UNIVERSITY OF ALBERTA

STRATIGRAPHIC, MICROCLIMATIC AND THAWING ATTRIBUTES ASSOCIATED WITH PALSAS LOCATED IN THE ALPINE TUNDRA ENVIRONMENT OF THE MACMILLAN PASS-TSICHU RIVER REGION, N.W.T., CANADA

BY

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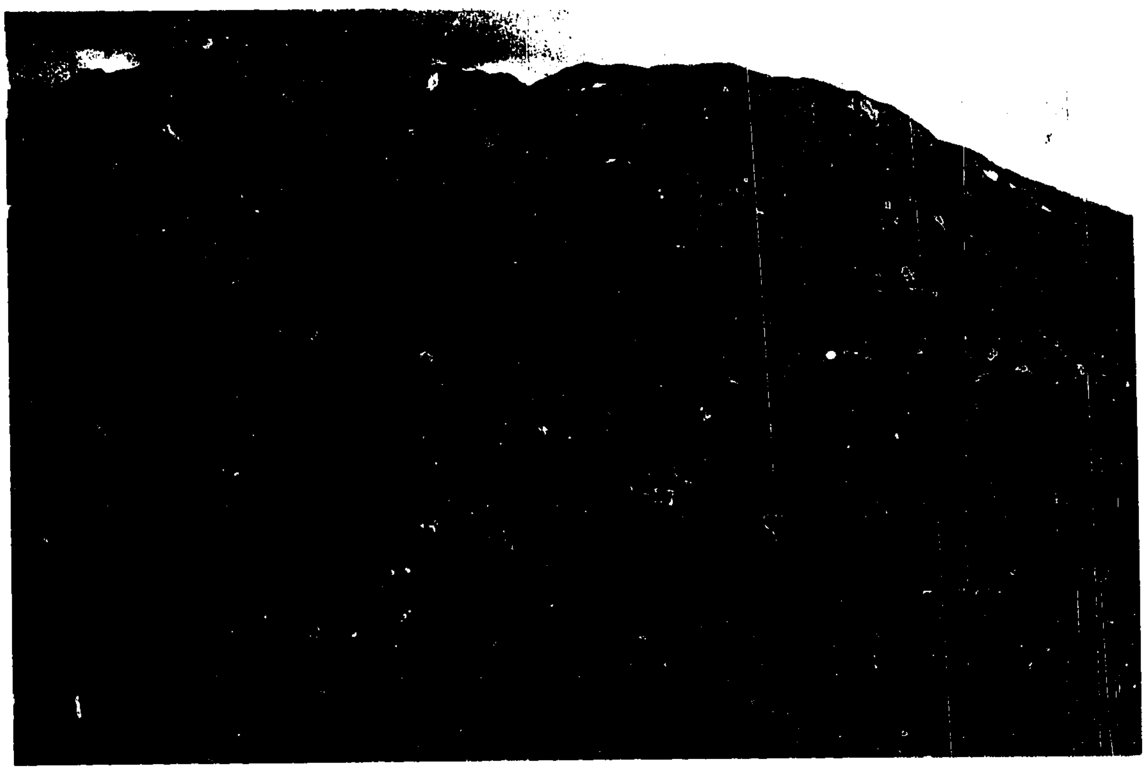

UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled Stratigraphic, Microclimatic and Thawing Attributes Associated with Palsas Located in the Alpine Tundra Environment of the Macmillan Pass-Tsichu River Region, N.W.T., Canada submitted by Kevin D. Skaret in partial fulfillment for the degree of Master of Science.

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28 September, 1994

ABSTRACT

Five palsas located at four different sites in the Macmillan Pass-Tsichu River region, N.W.T. (63°15'N, 130°02'W) were monitored during 1990-1991. As a result of these field investigations the thermal and stratigraphic conditions associated with palsa fields, as well as a conceptual model pertaining to palsa evolution are described. The study features occur within an alpine tundra environment and are situated along a 410 m altitudinal gradient. The relief of study features ranges from 2.2 to 4.9 m above the surrounding wetland and their diameters vary from 37 to 90 ... ominant plants associated with palsas are moss, lichen, grass, low shrub, whereas the predomina ... of the adjacent wetlands are sedge, mixed shrub, and moss.

In all ... atures, peat was covering an underlying silty substratum, and these soil components contained rhythm ... lenses interspaced with unconsolidated mineral sediment of diverse origin containing pore ice. The highest moisture contents were often associated with ice lenses or other regions that inhibited water movement such as the permafrost table or peat/mineral interface. Each feature contained a stratigraphic marker horizon (White River volcanic ash, 1250 years BP [Lerbekmo *et al.* 1975]) that was used to calculate approximate peat accumulation rates. The drier conditions of the palsa surfaces inhibited peat accumulation, yet accelerated plant decomposition, hence, palsas had lower rates (0.96-2.0 cm/100 years) of peat accumulation than the surrounding wetlands (1.5-2.28 cm/100 years). Aquatic peat and/or pond sediments were found above the tephra layer in four palsas, implying that these features were heaved above the wetland sometime after the White River volcanic eruption. One feature, however, had the xerophilous/hydrophilous peat transition zone below the volcanic ash, which may suggest that this feature was elevated above the wetland prior to tephra deposition.

Within this mountainous study area, the altitudinal differences among the sites had a significant effect upon air temperatures at the different palsa study sites. A positive regional environmental lapse-rate occurred during summer, hence the mean temperature of the upper-elevation site was 2.66 C° cooler than the lowest valley site. In winter, however, cold air drainage events kept the lower-elevation sites cooler by a maximum mean temperature of 2.04 C°. On a local basis, the thermal regime was influenced by specific site-conditions associated with the internal boundary layer. Thus, ground temperatures were warmer on those features that had a protective cover such as a thick snowpack in winter and/or well developed plant canopy in summer. Ground temperatures fluctuated annually, however, attenuation in the temperature wave occurred as it propagated downwards, therefore, temperature amplitudes decreased with increasing depths.

On palsas, the active layer began to develop in early May and continued to deepen until late August, however, unfrozen conditions between the permafrost table and surface still persisted until late September/early October. On a regional scale, the upper plateau site had a more moderate climate that ultimately resulted in greater thaw depths. However, cold air drainage events kept the mean winter surface temperature of the lower-elevation valley sites 4 C° colder and mean annual core temperature (150 cm) at least 1 C° cooler than the upper-elevation palsa. Thus, cooler permafrost conditions coupled with the insulative properties of a dry peat cover inhibited thaw. Hence, minimum mean thaw depths were associated with the lower-elevation features.

Local variation in thaw was common to each palsa and this was attributed to differences in vegetation cover, microclimate, aspect, slope angle, and proximity to water. The greatest mean rates and depth of thaw mainly occurred on the south-facing palsa edge locations, with maximum thaw occurring on the lower slope angles adjacent to bodies of water. Thus, thaw characteristics varied with the specific site-conditions associated with each palsa.

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I am also indebted to the following individuals for contributing to the success of the field component of the Palsa Evolution in Alpine Tundra (PEAT) Project: Brent Ambrose, Linda, Eric and Geoffrey Kershaw, Dave ... lton, Craig Olsen, Elaine Seier, and Kim Winnicky. Sam ... er and later Norm Barichello and George Calef of Old Squaw Lodge allowed us the use of their trailer at Camp 222 and helped with equipment lifts onto the Barrens whenever they could. I would also like to express my appreciation to Steve Zoltai for letting us use his Permafrost and Macauley corers, as well as our neighbours Jim and Sammy Hickling who provided 4X4 lifts, fresh food, card games, and a phone. I also thank David Chesterman and G. Lestor for their laboratory and drafting expertise.

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1.0 Introduction

1.1 Permafrost

Permafrost is a ground thermal condition, affecting approximately 22-25% of the earth's total land surface (French 1976). Extensive permafrost regions are located throughout the northern hemisphere of Canada, Alaska, Russia, the Peoples Republic of China, Greenland, and Scandinavia (Briggs *et al.* 1993). In Canada, permafrost covers approximately 50% of the land surface, and occurs in continuous, discontinuous, alpine, and sub-sea zones (French and Slaymaker 1993).

Permafrost is a dynamic condition, and its origin and existence is closely linked to various geophysical processes such as: surface radiation, atmospheric convection, moisture flow, phase change, geothermal heat transfer, and the conduction/convection of energy within near-surface boundary layers (Lunardini 1981). The geophysical conditions that affect the spatial distribution, thickness, and composition of permafrost are: physical location, height above sea level, relief, vegetation, snow cover, cloud cover, surface water, soil properties, and ground water (Lunardini 1981). Generally, the existence of permafrost depends upon the interactions between atmospheric climate and ground surface, or microclimatic conditions, yet, it is not entirely linked to geographic locations (Williams and Smith 1989). Permafrost, therefore, is sensitive to the local site-conditions that affect the surface energy regime (Smith 1993). For example, peat can influence the thermal regime of the ground on a seasonal basis, and generally, mean annual ground temperatures tend to be cooler beneath an organic cover (Williams and Smith 1989). Hence, perennially frozen ground in marginal areas is often associated with a peat cover. In Canada, peatlands constitute 12% of the land area, and approximately 30% of the land surface in the Subarctic (Zoltai *et al.* 1988).

Palsas are unique periglacial features that are closely associated with Subarctic peatlands. Within many regions of the discontinuous permafrost zone, palsas are the only examples of permafrost landforms and their existence is associated with the physical attributes of peat. This study focuses upon the thermal and stratigraphic conditions associated with palsas.

1.1.1 Terminological Interpretation

1.1.1.1 Palsa

Since the term "palsa" was first introduced into the periglacial geomorphological nomenclature (Fries and Bergström 1910), there have been numerous discussions as to the precise definition of the word (e.g. Lundqvist 1969; Nelson *et al.* 1991; Outcalt *et al.* 1884; 1986; Pissart 1985; Seppälä 1972, 1988; Washburn 1983; Worsley 1986). Seppälä (1988) maintains that "real palsas, [are] updomed by ice segregation" and these aggradational forms occur only in the discontinuous permafrost zone. Pollard's (1988) classification system is similar and this definition is generally supported by Brown (1980), Kershaw (1976), Kershaw and Gill (1979), Zoltai (1972), Zoltai and Tarnocai (1971; 1975), and Zoltai *et al.* 1988 as a result of their work across western Canada; while Allard and Seguin (1987), Allard *et al.* (1987), Cummings and Pollard (1989; 1990), Dionne (1978; 1984), and Seguin and Crépault (1979) adhere to a corresponding formation theory and have reported on palsas east of Hudson Bay.

Washburn (1983) suggests that the term "palsa" is useful in a general context, and could be modified adjectivally based on: morphology, occurrence (discontinuous or continuous permafrost), constitution (peat and/or mineral soil), ice type (injection and/or segregation), and origin (aggradation or degradation). Generally, Outcalt *et al.* (1984; 1986) and Nelson *et al.* (1991) concur with Washburn's definition, however, they maintain that the term "palsa" should be used in a morphological context only, and be modified with adjunct terminology representing its genesis. Nelson *et al.* (1991) uses the term "palsa-scale frost mounds" to describe all morphologically similar frozen mounds, and claim that there are four likely mechanisms of "palsa-scale frost mound" genesis: hydraulic pressure, hydrostatic pressure, ice segregation, and buoyancy.

For this study the term "palsa" is applied in the same manner as: Lundqvist (1969), Seppälä (1972; 1986; 1988), and several Canadian researchers and publications (e.g. Brown 1977; Dionne 1978; French 1976; Kershaw and Gill 1979; Permafrost Subcommittee 1988; Williams and Smith 1989; Zoltai 1972; Zoltai and Tarnocai 1971; 1975; Zoltai *et al.* 1988). The author believes that a general definition based on morphology alone tends to neglect the genetically unique geomorphological processes involved in the development of many similaraly-shaped periglacial frost mounds. Although, numerous frost mounds are morphologically analogous (e.g. earth hummocks, frost blisters/hydrolaccoliths, ice blister, palsas, pingos etc.), their modes of origin are distinct, and therefore, they should be classified as separate features. The Permafrost Subcommittee (1988) presented a similar view, and recommend that the term "frost mound" be used to define morphologically similar, yet, genetically distinct features that occur within permafrost environments.

1.1.1.2 Peat Plateaus

Peat plateaus are perennially frozen peatlands that are elevated approximately 1 m above the surrounding wetland (Zoltai and Tarnocai 1975). Genetically, these features are similar to palsas, however, peat plateaus are lower in relief and are usually flat with little surface irregularities (Zoltai and Tarnocai 1975). Peat plateaus also cover a larger aerial extend (several square kilometres, Zoltai and Tarnocai 1975) than palsas (few square metres to 0.5 square kilometres, Seppälä 1988).

The lower relief of the peat plateaus is thought to be the result of insitu-freezing with limited water migration (Zoltai 1972). In palsas, however, the mineral component allows water to be drawn from the wetland towards the freezing front through pores in the sediment. Hence, increasing the accumulation of segregated ice within the mineral soil, thereby increasing the vertical displacement of the feature. With peat plateaus, however, the wetlands can be tens to thousands of meters from the core of the feature, thus these areas are isolated from water sources that might contribute to further height increases.

Zoltai (1972) has stated that in the southernmost permafrost regions the permafrost core associated with peat plateaus occurs predominately within the peat. However, in more northern latitudes the permafrost in peat plateaus can extend into the mineral soil (Zoltai and Tarnocai 1975). Peat plateaus and palsas are elevated above the contiguous wetland by freezing conditions that initiate volume changes within the peat/mineral soil. In both features, the formation and maintenance of permafrost relies upon the insulating attributes of peat (Zoltai *et al.* 1988; Zoltai 1993).

1.1.2 Palsa Delineation

Palsas are a widespread periglacial phenomena that occur in wetland environments (fens or bogs) located throughout the discontinuous circumpolar permafrost zone. These features are commonly associated with peatlands (wetlands with a peat layer greater than 40 cm, Tarnocai 1980; Zoltai *et al.* 1988), however, palsas can also develop in waterlogged soils with less than a 40 cm organic cover (e.g. Seppälä 1980). Hence, "wetland" (Zoltai *et al.* 1988) is used throughout the thesis as a general term for regions where palsa evolution occurs. In Canada, the recorded distribution of palsas range from British Columbia to Labrador and include both Territories (Dionne 1984). They have also been reported to occur in Fennoscandia, Iceland, Siberia and the United States (Seppälä 1986).

The word "palsa" was originally used by Lappish and Finnish cultures to describe a frozen-cored hummock rising from a bog (Seppälä 1972). These features are meso-scale permafrost mounds that include a surface cover of peat (Figure 1.1). Generally, palsas rise 1 to 7 m from the surrounding permafrost-free wetland and have maximum diameters that are usually less than 100 m (Zoltai and Tarnocai 1975), although, their relief has been measured up to 15 m above the adjacent wetland (Kershaw pers. comm. 1990). Morphologically, palsas vary from hemispherical-shaped features to elongated ridge-like forms that occur individually or in complex groups (Åhman 1976, 1977; Seppälä 1988). Both aggradational and degradational forms can exist in the same wetland (Zoltai *et al.* 1988) or on the same feature. Internally, the features are composed of a frozen core of non-cryoturbated peat and/or mineral soil (predominantly silty in texture), pore ice and segregation ice. The dynamic processes of ice segregation and pore ice freezing result in frost heaving mechanisms that are responsible for the formation of palsas. Hence, palsa formation and maintenance is closely linked to cold climates and site conditions that promote and preserve permafrost.

1.2 Objectives

Site-conditions influence microclimatic characteristics (Williams and Smith 1989), and together, they play

Figure 1.1. Hemispherical-shaped palsa from the Macmillan Pass-Tsichu River region, N.W.T.

an integral role in the formation, maintenance, and degradation of palsas. Hence, a more comprehensive account on how the two are interrelated can further our understanding on the evolutionary processes affiliated with palsas. A number of climatological studies have extrapolated palsa field temperatures from regional stations (e.g. Åhman 1977; Brown 1967; Dionne 1984; Lagarec and Dewez 1990; Priesnitz and Schunke 1978), and some have included internal temperatures over short periods (Cummings and Pollard 1990; Kershaw and Gill 1979; Seguin and Allard 1984), however, only a few studies have monitored climatic and microclimatic conditions for even a year (e.g. Lindqvist and Mattsson 1965 for palsas; Allard and Forier 1990 for peat plateaus). Furthermore, only a few researchers have focused on these features in mountainous environments (Brown 1980; Kershaw and Gill 1979; Seppälä 1980), yet, a paucity of data pertaining to the annual microclimatic conditions still exist; especially in regard to the influence that elevation differences impose upon microclimate and its subsequent effect upon the physical characteristics of palsas. Therefore, this study was designed to achieve a better understanding of the thermal regime associated with palsas situated within an alpine tundra environment. The major aim of this project was to monitor the seasonal thaw characteristics of palsas located at various elevations along an altitudinal gradient, and evaluate the influence that elevation differences and site conditions impose upon microclimate. The objectives of the study were the following:

A. To examine the thermal and physical characteristics of palsas at various elevations.
B. To evaluate the role of microclimatic characteristics on palsas at various elevations.
C. To construct a non-numerical conceptual model that relates to the development and degradation of palsas.

1.3 Study Area

This research was conducted in the Macmillan Pass-Tsichu River-Mackenzie Mountain Barrens area of the Northwest Territories, Canada, and lies within the transition zone between the Selwyn (Interior Cordillera) and Mackenzie Mountains (Eastern Cordillera) (Figure 1.2). Macmillan Pass is 1350 m asl and straddles the Yukon-Northwest Territories border in the discontinuous permafrost zone. Elevations along the Continental Divide (the border between the two territories) are 2060-2430 m asl and the main drainage course in the study region is the Tsichu River, a headwater tributary of the Keele River.

1.3.1 Geology

The study area occurs within the Selwyn Basin (Eisbacher 1981; Morrow 1991) of the Mackenzie Mountain region (Kent 1982). The Selwyn mountains are underlain by Proterozoic to Permian miogeosynclinal sedimentary rocks that have been folded along a northwest-trending axis and separated by northwest and east trending faults (Gill 1976). The Mackenzie Mountains are a component of the Foreland Fold-Thrust Belt of the Mesozoic-Paleogene Cordilleran Orogeny (Eisbacher 1981). This is a northwesterly to westerly trending mountain range that contains marine carbonates and clastics from the Proterozoic to Paleogene; the Proterozoic is composed of two significant sedimentary successions: Mackenzie Mountains Supergroup and the Windermere Supergroup (Eisbacher 1981).

1.3.2 Climate

A meteorological station was operated by AMAX in conjunction with Atmospheric Environment Service at Tsichu River (old road mile post 222 on the Canol Road) from October 1974 to August 1982. This area has a Continental climate that is influenced by mountains, and has a mean annual air temperature of -7.7°C and an average precipitation of 490 mm (Kershaw and Kershaw 1983). The average annual snowfall was 294 cm and during mid-winter the snowpack varied from discontinuous on windswept sites, to greater than 2 m in areas that encountered drifting snow (Kershaw and Kershaw 1983). Within the study area, meteorological records from 1974 to 1982 indicate that the mean annual air temperature increased by 3.5 C° (Liang and Kershaw 1994, in press). Ambient temperature increases were also observed at other meteorological stations within the area (e.g. increases of 3.6° at Ross River (1968-1992); 1.8° at Tungsten (1966-1990); and approximately 0.9° at Norman Wells (1943-1992) (Liang and Kershaw 1994, in press). Within the study area, the thermal season (mean daily temperatures above 0°C) occurred from late May to mid-September.

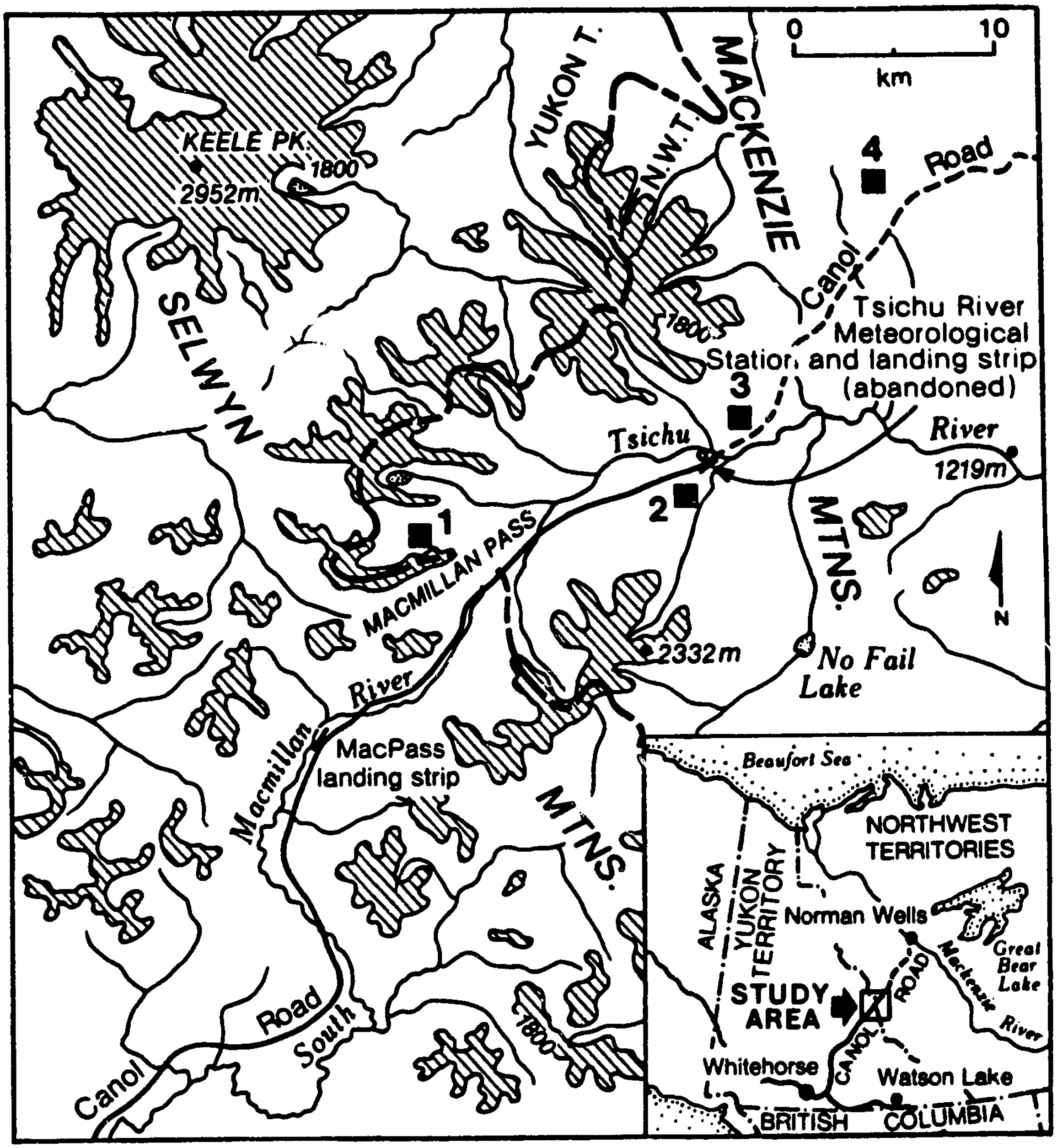


Figure 1.2. The study area is just east of the Yukon border in the Northwest Territories; the transition area between the Selwyn and Mackenzie Mountains. Palsas are found in valley bottom locations and in wetlands on the plateau of the Mackenzie Mountain Barrens (shading denotes > 1800 m asl). Intensive study sites: **1.** Dale Creek; **2.** Beaver Pond; **3.** Hare Foot; **4.** Goose Flats.

1.3.3 Geomorphological Features

The study area has been classified as a high energy environment because of its high elevation, great relief, and plentiful moisture (Gill 1976). Relief varies from relatively flat valley bottoms with rolling hills to plateaus and steep mountain cliffs. Elevations range from approximately 1200 to 2300 m asl with numerous geomorphological landforms occurring throughout the study area. These geomorphological features have been categorized as glacial, fluvioglacial, periglacial, fluvial, masswasting and organic (Kershaw and Kershaw 1983).

Glacial landforms include glacierets, mammillated surfaces, ice-molded features and moraines. Glaciers also occur on nearby mountains. The fluvioglacial landforms include outwash channels, kames, eskers and outwash plains. The periglacial features in the study area include rock glaciers, debris slopes, palsas and peat plateaus, blockslopes, gelifluction slopes and patterned ground. Some of these landforms are currently active.

Landforms produced by mass-wasting occur throughout the study area and are especially common in the western section of the study region (Kershaw and Kershaw 1983). The fluvial landforms associated with the study region are mudflows, floodplains and alluvial fans. Organic deposits occur at lower elevation sites where there is impeded drainage, and tend to be associated with palsa and/or peat plateau fields.

1.3.4 Plant Community Complexes

In the study area the vegetation varies considerably depending upon the elevation, drainage and substrate. The study region occurs above treeline and is classified as alpine tundra. In the study area, twelve plant community complexes (physiognomically-defined) have been described and mapped (Kershaw and Kershaw 1983). The plant community complexes identified in the tundra were: Epilithic Lichen Tundra, Cushion Plant Tundra, Alpine Meadow, Alpine Lichen Grass, Lichen-Heath, Birch-Lichen, Birch-Moss, Willow-Forb, Riparian Willow, Meadows, and Lowland Lichen-Grass.

On the palsas, the plant communities were classified as: Birch-Lichen, Birch-Lichen-Moss, *Sphagnum* Tussocks, Lichen-Moss, Moss-Organic, Sedge-Moss, Sedge-Moss-Lichen, Grass, Willow-Grass, Moss, *Eriophorum*-Lichen, Raised Tussock-Lichen, Grass-Moss, Palsa depression, Palsa pond, Organic, and Organic-Soil Lichen (Kershaw *et al.*, unpublished data). In the wetlands that surrounded the palsas, the plant community complexes were classified as the following: Sedge, Sedge-Water, Sedge-Willow, Sedge-Meadow, Raised Sedge-Meadow, Grass, Low Sedge, Sedge-Shrub, Lowland Birch, and Upland community (Kershaw *et al.*, unpublished data). The nomenclature of scientific names used for vascular and non-vascular plants follows Porsild and Cody (1980) and Vitt *et al.* (1988) respectively.

1.4 Study Features

During July and August 1990, five palsas located at four different sites within an alpine tundra environment were selected for the study. The features chosen for the research project were located approximately 5 km northwest to 32 km east of Macmillan Pass, and were selected to be along a 410 m altitudinal gradient (1250 to 1660 m asl). All study features were situated within the fen wetland class and are classified as palsa fens. These features were named Dale Creek 2, Dale Creek 6, Beaver Pond, Hare Foot and Goose Flats (Table 1.1). Common to all of the landforms were bodies of water (palsa laggs) that partially surrounded the palsas.

1.4.1 Dale Creek 2

Dale Creek 2 was located in a valley bottom approximately 5 km northwest of Macmillan Pass (Figure 1.3). The dominant plant communities on the palsa were Lichen-Moss (*Cetraria nivalis, Polytrichum commune*, miscellaneous mosses, organic-soil lichen); Moss-Organic (organic-soil lichen, *Polytrichum commune*); Sedge-Moss (*Carex aquatilis*, organic-soil lichen, *Polytrichum commune*, miscellaneous mosses, *Cladonia* spp., *Deschampsia brevifolia*); Sedge-Lichen-Moss (*Carex aquatilis, Polytrichum commune*, miscellaneous mosses, *Cladina mitis, C. rangiferina, C. stellaris, C. sp., Cladonia spp*, organic-soil lichens, *Cetraria nivalis*). The main plant communities associated with the wetlands were Willow-Sedge (*Salix planifolia, Carex aquatilis, Polemonium acutiflorum, Senecio triangularis, Salix barrattiana, Pohlia nutans, Aulacomnium palustre*); Sedge-Meadow (*Carex aquatilis*, miscellaneous mosses, organic-soil lichen); Upland Community (*Carex aquatilis*, dead grasses, *Aulacomnium palustre, Salix planifolia, S. reticulata*, miscellaneous mosses, *Polytrichum commune*,

Palsa Name	Elevation (m asl)	Height Above Wetland (m)	Diameter (m)	Mean Peat Thickness (m)	Dominant Plant Type
Goose Flats	1660	2.2	59.0	0.90	g/m/l
Dale Creek 2	1480	3.7	45.0	1.58	l/m
Dale Creek 6	1480	4.2	37.0	1.86	ms/g
Beaver Pond	1270	4.0	90.0	3.02	ls/l/m
Hare Foot	1250	4.9	54.0	2.48	ls/l/m

g=grass; m=moss; l=lichen; ms=mixed shrub; ls=low shrub

Table 1.1. Site characteristics of palsas in the Macmillan Pass-Tsichu River study area.

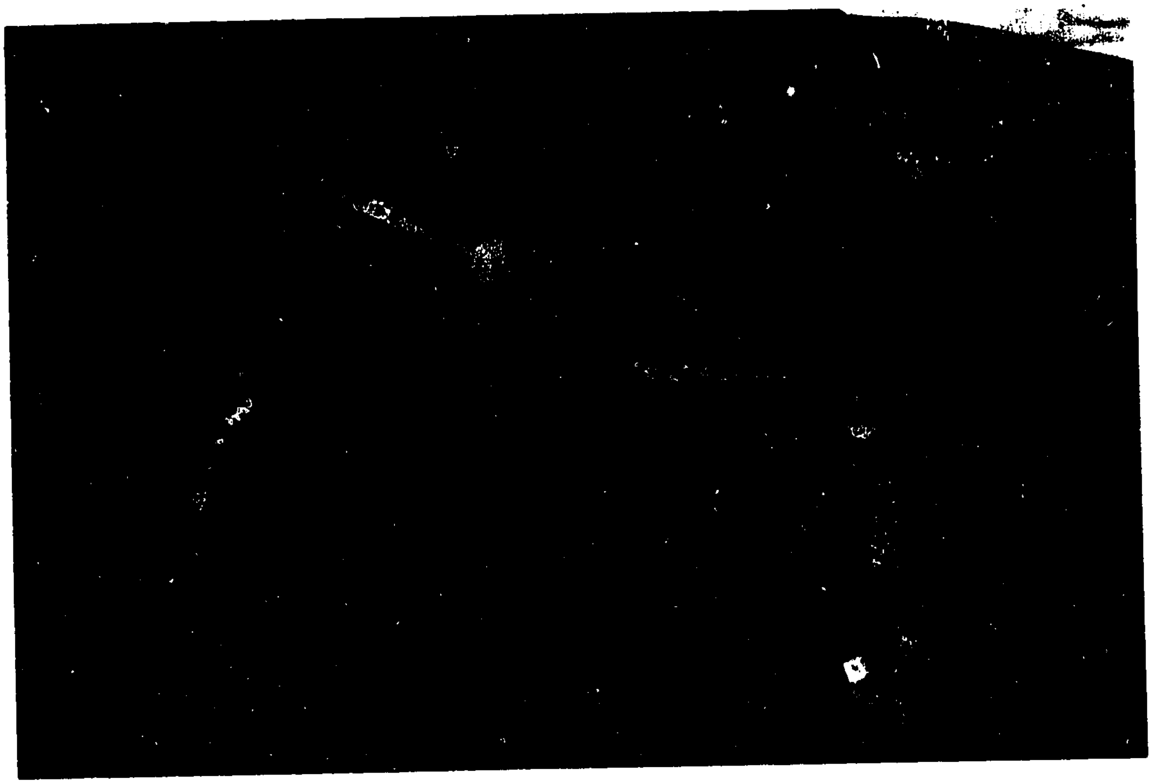


Figure 1.3. Dale Creek 2 is the palsa on the right, and it is located in a valley bottom approximately 5 km northwest of Macmillan Pass. This feature is dominated by lichen and mosses with *Carex aquatitilis* on the western portion of the feature.

Tomenthypnum nitens, Deschampsia brevifolia, Epilobium angustifolium) (Kershaw *et al.*, unpublished data).

1.4.2 Dale Creek 6

Dale Creek 6 (Figure 1.4) was situated approximately 125 m east of Dale Creek 2 and the dominant plant communities on the palsa were Grass (dead grasses, *Calamagrostis inexpansa, Cladina mitis, Polytrichum commune, Pleurozium schreberi, Cladina rangiferina*, organic); Willow-Grass (*Salix planifolia*, dead grass, *Polytrichum commune, Pleurozium schreberi*, organic, *Cetraria cucullata*); Moss (*Polytrichum commune*, dead grass, *Calamagrostis inexpansa, Cladina mitis*, organic). The predominant plant communities associated with the Dale Creek 6 wetland were Raised Sedge-Meadow (*Carex aquatilis*, water, organic, miscellaneous mosses); Sedge-Meadow (*Carex aquatilis*, water, miscellaneous mosses); Upland community (*Carex aquatilis*, miscellaneous mosses, *Salix planifolia*, organic, *Calamagrostis inexpansa, Aulacomnium palustre*) (Kershaw *et al.*, unpublished data).

1.4.3 Beaver Pond

Beaver Pond was located in the bottom of a 5 km wide valley and was situated adjacent to an active beaver pond (Figure 1.5). The main plant communities on the palsa were Birch-Lichen (*Cetraria nivalis, Cladina stellaris, C. mitis, C. rangiferina, Betula glandulosa, Cetraria cucullata*, miscellaneous mosses, organic); *Sphagnum* tussocks (*Sphagnum sp., Rubus Chamaemorus, Cladina rangiferina, C. mitis, C. stellaris, Cetraria nivalis, C. cucullata, Empetrum nigrum, Betula glandulosa, Ledum groenlandicum, Cladonia* spp.); Palsa depression (*Polytrichum commune*, miscellaneous mosses, organic, *Cladonia* spp., *Carex aquatilis, Betula glandulosa, Rubus Chamaemorus, Sphagnum* spp.); Palsa pond (water, miscellaneous moss, *Carex aquatilis, Sphagnum* spp.). The dominant plant communities associated with the wetland were Sedge (*Carex aquatilis, Polytrichum commune*, organic, miscellaneous mosses); Sedge-Water (water, *Carex aquatilis*, miscellaneous mosses); Sedge-Willow (*Carex aquatilis, Salix planifolia*, miscellaneous mosses, organic, water, *Scirpus caespitosus*) (Kershaw *et al.*, unpublished data).

1.4.4 Hare Foot

Hare Foot was located in the same valley bottom as Beaver Pond and was situated between two small lakes (Figure 1.6). The dominate plant community associated with the palsa was Birch-Lichen-Moss (*Betula glandulosa, Cladina rangiferina, C. stellaris*, organic, miscellaneous mosses, *Ledum decumbens, Cladina mitis, C. arbuscula, Cetraria cucullata*). The main plant communities found in the wetland were Sedge-Meadow (*Carex aquatilis*, water, organic, *Polytrichum commune, Aulacomnium palustre*, miscellaneous mosses) Sedge-Shrub (*Carex aquatilis, Betula glandulosa, Sphagnum sp.*, miscellaneous mosses, *Salix planifolia*, organic, water); Lowland-Birch (*Betula glandulosa, Sphagnum sp., Hylocomium splendens*, miscellaneous mosses, Salix planifolia, organic, *Carex aquatilis, Petasites frigidus, Tomenthypnum nitens*) (Kershaw *et al.*, unpublished data).

1.4.5 Goose Flats

Goose Flats was located on the Mackenzie Mountain Barrens (Figure 1.7) and the primary plant communities associated with the palsa were *Eriophorum*-Lichen (*Eriophorum vaginatum, Cetraria nivalis*, miscellaneous mosses, organic, *Polytrichum commune, Cetraria cucullata, Cladonia* spp.); Raised Tussock-Lichen (*Polytrichum commune, Deschampsia caespitosa*, soil lichen, *Vaccinium uliginosum*, organic, *Cladonia* spp., *Calamagrostis inexpansa*); Grass-Moss (*Polytrichum commune, Deschampsia caespitosa*, organic, soil lichen, *Artemisia arctica, Cladonia* spp.). The main plant communities of the wetlands were Grass (*Calamagrostis inexpansa, Polytrichum commune*, organic, *Cladina mitis, Cladonia spp.*, soil Lichen, miscellaneous moss); Low Sedge (*Carex aquatilis, Eriophorum angustifolium*, organic, miscellaneous moss, water); Thaw Zone (water, organic, miscellaneous moss); Raised Sedge Meadow (*Carex aquatilis, Polemonium acutiflorum, Deschampsia caespitosa, Petasites frigidus, Aulacomnium palustre, Polytrichum commune*) (Kershaw *et al.*, unpublished data).

Figure 1.4. Dale Creek 6 is situated 125 m east of Dale Creek 2 and has a *Salix planifolia* shrub cover with graminoids dominating the understorey.

Figure 1.5. The Beaver Pond palsa is located in the bottom of a 5-km-wide valley. The top of the feature has a sparse *Betula glandulosa* shrub cover with a thick moss/lichen mat. This palsa is situated adjacent to an active beaver pond that inundated portions of the palsa edge as well as the shrubs in the foreground.

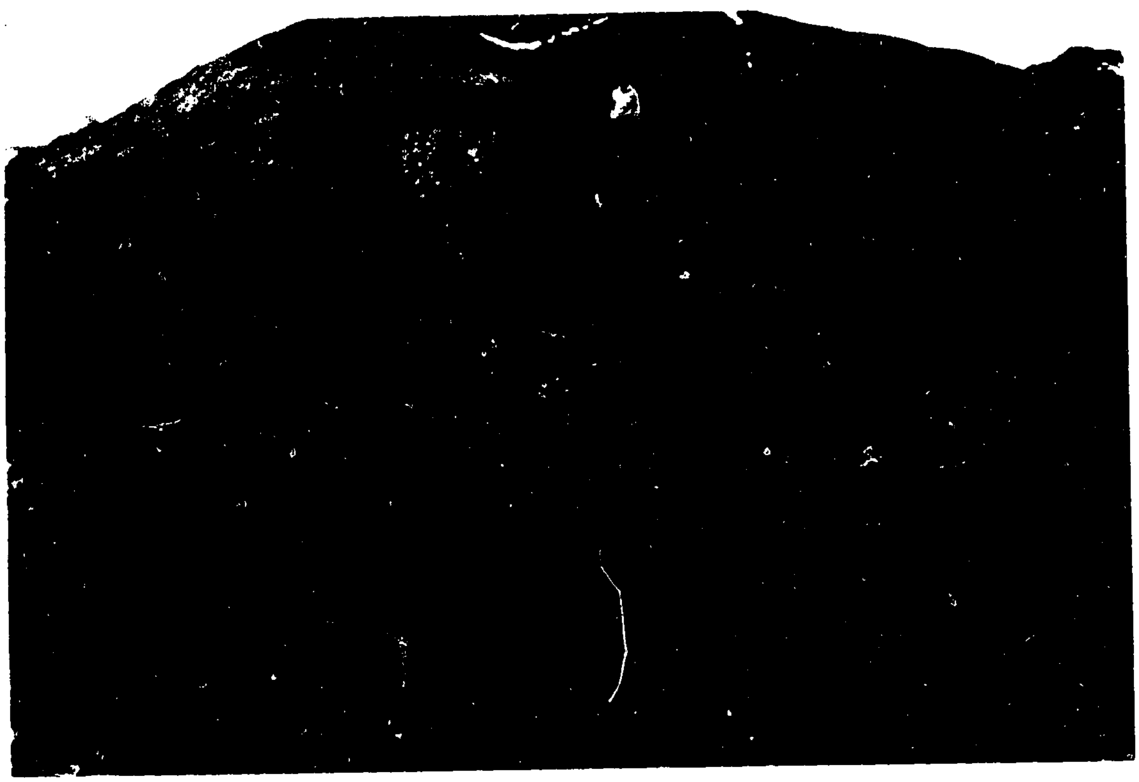


Figure 1.6. Hare Foot is located in the same valley bottom as Beaver Pond, between two small lakes. The palsa has a relatively dense *Betula glandulosa* shrub cover with an ericaceous shrub and lichen/moss understorey.

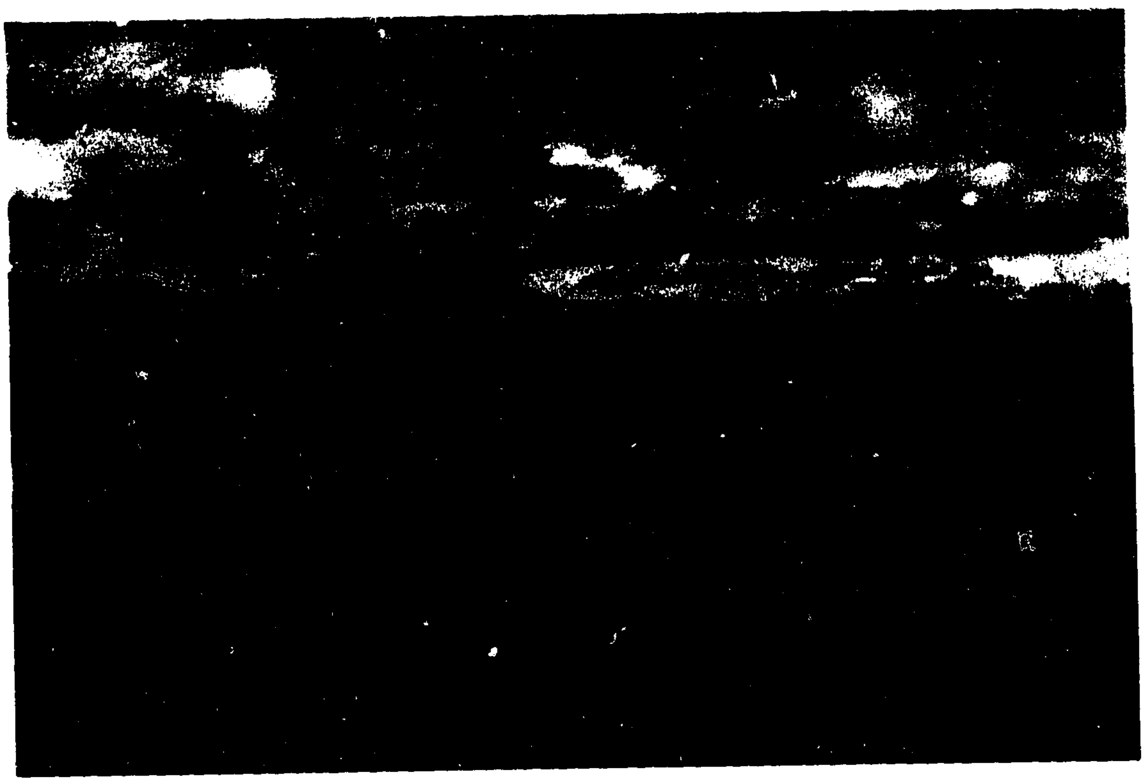


Figure 1.7. Goose Flats is located in a sedge-tundra environment on the Mackenzie Mountain Barrens. The palsa is dominated by a graminoid plant cover.

1.5 References

Åhman, R. 1976. The structure and morphology of minerogenic palsas in northern Norway. *Biuletyn Peryglacjalny*, 26:25-31.

Åhman, R. 1977. Palsar i Nordnorge. *Meddelanden från Lunds Universitets, Geografiska Institution, Avhandlingar LXXVIII*, 165p.

Allard, M., Fortier, R. 1990. The thermal regime of a permafrost body at Mont du Lac des Cygnes, Québec. *Canadian Journal of Earth Sciences*, 27: 694-697.

Allard, M. and Seguin, M.K. 1987. The Holocene evolution of permafrost near the tree line, on the eastern coast of Hudson Bay (Northern Quebec). *Canadian Journal of Earth Sciences*, 24:2206-2222.

Allard, M., Seguin, M.K. and Lévesque R. 1987. Palsas and mineral permafrost mounds in northern Québec. In V. Gardiner (ed.) *International Geomorphology, Part II.* John Wiley and Sons, Chichester, pp. 285-309.

Associate Committee on Geotechnical Research. 1988. *Glossary of Permafrost and Related Ground-Ice Terms*. National Research Council Canada, Ottawa, Technical Memorandum 142.

Briggs, D., Smithson, P., Ball, T., Johnson, P., Kershaw, P., and Lewkowicz, A. 1993. *Fundamentals of Physical Geography*. Copp Clark Pitman Ltd. Toronto. 692p.

Brown, G. 1980.Palsa and other permafrost features in the lower Rock Creek Valley, west central Alberta. *Arctic and Alpine Research, 12: 31-40.*

Brown, R.J.E. 1967. Permafrost Investigations in British Columbia and Yukon Territory. *Technical Paper No. 253*, National Research Council of Canada, Division of Building Research.

Brown, R.J.E. 1977. Muskeg and Permafrost. In N.W. Radforth and C.O. Brawner (eds.). *Muskeg and the Northern Environment*, University of Toronto Press, pp. 148-163.

Cummings, C.E. and Pollard, W.H. 1989. An investigation of palsas in the Schefferville area, Quebec. *The Musk-Ox*, 37:8-18.

Cummings, C.E. and Pollard, W.H. 1990. Cryogenetic categorization of peat and mineralcored palsas in the Schefferville area, Quebec. Fifth Canadian Permafrost Conference, *Collection Nordicana*, 54:95-102.

Dionne, J.C. 1978. Formes et phénomènes périglaciaires en Jamésie, Québec subarctque. *Géographie physique et Quaternaire*, 32: 187-247.

Dionne, J.C. 1984. Palses et limites méridionales du pergélisol dans l'hémisphère nord: le cas de Blanc-Sablon, Québec. *Géographie physique et Quaternaire*, 38:165-184.

Eisbacher, G.H. 1981. Sedimentary tectonics and glacial record in the Windermere Supergroup, Mackenzie Mountains,Northwestern Canada. Geological Survey Paper 80-27. Minister of Supply and Services Canada, Ottawa, 40 p.

French, H.M. 1976. *The Periglacial Environment*. Longmans, London, 309 p.

French, H.M. and Slaymaker, O. 1993. Canada's cold land mass. In H.M. French and O. Slaymaker (eds.), *Canada's Cold Environment*, McGill-Queen's University Press, Montréal, pp. 3-27.

Fries, T. and Bergström, E. 1910. Några iakttagelser öfver palsar och deras förekomst i nordligaste Sverige. *Geol. Fören. Förhandl.* 32(1).

Gill, D. 1976. Environmental report on the Macmillan Tungsten property. AMAX Inc. Environmental Services Group, Denver, 235p.

Kent, T.D. 1982. Mackenzie Mountains region bibliography. Environment Canada, Ottawa, 71 p.

Kershaw, G.P. 1976. The periglacial environments and its limitations to development. The Mactung Case Study, Northwest Territories-Yukon Territory, M.Sc. Thesis, Department of Geography, University of Waterloo, 298 p.

Kershaw, G.P. 1990. Personal communications. University of Alberta, Department of Geography.

Kershaw, G.P. and Gill, D. 1979. Growth and decay of palsas and peat plateaus in the Macmillan Pass-Tsichu River area, Northwest Territories, Canada. *Canadian Journal of Earth Sciences*, 16(7):1362-1374.

Kershaw, G.P. and Kershaw, L.J. 1983. *Geomorphology and Vegetation of the MacTung Study Area, Yukon/NWT*. Report prepared for AMAX Northwest Mining Co. Ltd., Vancouver.

Kershaw, G.P. and Skaret, K.D. 1993. Microclimatic characteristics of palsas along an altitudinal gradient, Mackenzie Mountains, NWT, Canada. In *Proceedings Sixth International Permafrost Conference*, National Academy Press, Washington DC, pp. 338-343.

Kershaw, L.J., Winnicky, K. and Kershaw, G.P. 1991. Unpublished vegetation survey data from palsas in the Upper-Tsichu River Valley.

Lagarec, D. and Dewez, V. 1990. Dynamique du pergélisol discontinu et changements globaux dans le nord du Québec. Fifth Canadian Permafrost Conference, *Collection Nordicana*, 54: 215-222.

Liang, L. and Kershaw, G.P. 1994. Climate change in the Mackenzie Mountains, N.W.T., in press.

Lindqvist, S. and Mattsson, J.O. 1965. Studies on the thermal structure of a pals. *Svensk Geographisk Årsbok* 41:38-49.

Lunardini, V. 1981. *Heat Transfer in cold climates*. New York, Van Nostrand Reinhold. 731 p.

Lundqvist, J. 1969. Earth and ice mounds: a terminological discussion, In T.L. Péwé (ed.), *The Periglacial Environment: Past and Present*, McGill-Queen's University Press, Montreal, pp. 203-215.

Morrow, D.H. 1991. The Silurian-Devonian sequence in the northern part of the Mackenzie Shelf, Northwest Territories. Minister of Supply and Services Canada, Ottawa, 121 p.

Nelson, F.E., Hinkel, K.M. and Outcalt, S.I. 1991. Palsa-scale frost mounds. In J.D. Dixon and A.D. Abrahams (eds), *Periglacial Geomorphology, Proceedings of the 22nd Annual Binghmton Symposium in Geomorphology*, John Wiley and Sons, Chichester, pp. 305-325.

Outcalt, S.I. and Nelson, F. 1984. Computer simulation of bouyancy and snow-cover effects in palsa dynamics. *Arctic and Alpine Research*, 16(2): 259-263.

Outcalt, S.I., Nelson, F., Hinkel, K.M. and Martin, G.D. 1986. Hydrostatic-system palsas at Telex Lake, Alaska; field observations and simulations. *Earth Surfaces Processes and Landforms*, 11(1): 70-94.

Permafrost Subcommittee, 1988. *Glossary of Permafrost and Related Ground-Ic Terms*, National Research Council of Canada Technical Memorandum 142, Ottawa, 156 p.

Pissart, A. 1985. Pingos and palsas: a review of the present state of knowledge. *Polar Geography and Geology*, 9(3): 171-195.

Pollard, W.H. 1988. Seasonal frost mounds. In M.J. Clark (ed.) *Advances in Periglacial Geomorphology*, John Wiley and Sons Ltd., pp. 201-229.

Porsild, A.E. and Cody, W.J. 1980. *Vascular Plants of Continental Northwest Territories, Canada*, National Museums of Canada, 667p

Priesnitz, K. and Schunke, E. 1978. An approach to the ecology of permafrost in Central Iceland. In *Proceedings of the Third International Conference on Permafrost*, National Research Council of Canada, Ottawa, Vol. 1, pp. 474-479.

Railton, J.B. and Sparling, J.H. 1973. Preliminary studies on the ecology of palsa mounds in northern Ontario. *Canadian Journal of Botany*, 51: 1037-1044.

Seguin, M.K. and Crépault, J. 1979. Étude géophysique d'un champ de palses à Poste-de-la-Baleine, Nouveau-Québec. *Géographie physique et Quaternaire*, 33:327-337.

Seguin, M.K. and Allard, M. 1984. Le pergélisol et les processus thermokarstiques de la région de la Rivière Nastapoca, Nouveau-Québec. *Géographie physique et Quaternaire*, 38: 11-25.

Seppälä, M. 1972. The term 'palsa'. *Zeitschrift für Geomorphologie*, 16:463.

Seppälä, M. 1986. Origin of palsas. *Geografiska Annaler*, 68A(3), pp. 141-147.

Seppälä, M. 1988. Palsas and related forms. In M.J. Clark (ed.), *Periglacial Geomorphology*. John Wiley and Sons, Chichester, pp. 247-278.

Smith, M.W. 1993. Climatic change and permafrost. In *Canada's Cold Environments*, McGill-Queen's University Press, Montréal, pp. 291-311.

Tarnocai, C. 1980. Canadian wetland registry. In C.D.A. Rubec and F.C. Polletti (eds.) *Proceedings, Workshop on Canadian Wetlands*. Lands Directorate, Environment Canada. Ecologiocal Land Classification Series No 12. Ottawa, Ontario. pp. 9-39.

Vitt, D.H., Marsh, J.E. and Bovey, R.B. 1988. *Mosses Lichens and Ferns of Northwest North America*. Lone Pine Publishing, Edmonton, 296p.

Washburn, A.L. 1983. Palsas and continuous permafrost. In *Proceedings Fourth International Permafrost Conference*, National Academy Press, Washington DC, pp.1372-1377.

Williams, P.J. and Smith, M.W. 1989. *The Frozen Earth*. Cambridge University Press, New York, 306 p.

Worsley,P. 1986. Periglacial environments. *Progress in Physical Geography*, 10: 265-274.

Zoltai, S.C. 1972. Palsas and peat plateaus in Central Manitoba and Saskatchewan. *Canadian Journal of Forest Research*, 2:291-302.

Zoltai, S.C. 1993. Cyclic development of permafrost in the peatlands of Northwestern Alberta, Canada. *Arctic and Alpine Research*, 25(3): 240-246.

Zoltai, S.C. and Tarnocai, C. 1971. Properties of a wooded palsa in northern Manitoba. *Arctic and Alpine Research*, 3:115-129.

Zoltai, S.C. and Tarnocai, C. 1975. Perennially frozen peatlands in the western Arctic and Subarctic of Canada. *Canadian Journal of Earth Sciences*, 12:28-43.

Zoltai, S.C., Tarnocai, C., Mills, G.F., Veldhuis, H. 1988. *Wetlands of Canada*. Ecological Land Classification Series, No 24, Sustainable Development Branch, Environment Canada, Ottawa, Ontario and Polyscience Publication Inc., Montreal Quebec. pp. 55-96.

2.0 Internal Characteristics of Palsas

2.1 Introduction

Palsas are periglacial landforms that are characterized by ice accumulations and are predominantly associated with wetland environments located throughout the discontinuous circumpolar permafrost zone (Dionne 1984; Seppälä 1986; Williams and Smith 1989; Zoltai *et al.* 1988). These features are primarily composed of a surface cover of peat underlain by mineral soil coupled with interstitial ice (e.g. Åhman 1976, 1977; Dionne 1984; Seppälä 1980, 1988; Zoltai 1972; Zoltai *et al.* 1988; Zoltai and Tarnocai 1971, 1975 (Figure 1.1). The formation and subsequent maintenance of palsas are closely linked to local site-conditions. Hence, palsa development is the product of interacting microclimatic variables (e.g. cold temperatures and thin snow covers) coupled with the physical characteristics of peat, and the availability of water (Seppälä 1982, 1988; Zoltai 1972; Zoltai *et al.* 1988).

The soil within palsas is not deformed by cryotubation, implying that frost has penetrated from the surface downwards, as a direct result of freezing air temperatures (Seppälä 1980; Zoltai *et al.* 1988). During successive winters (given opportune conditions), the frost layer aggrades in both a downward and lateral direction, subsequently, freezing the water within the peat. This phase change results in approximately a 9% volume increase which elevates the surface above the unfrozen wetland, thereby creating drier conditions (Zoltai 1972; Zoltai *et al.* 1988). With progressive heave, wind becomes more effective at keeping the surface relatively snow-free in winter and rather dry in summer (Seppälä 1988; Zoltai 1972). This allows for the relatively efficient removal of heat during winter, thereby increasing ground cooling, and when dry, provides greater thermal insulation (Williams and Smith 1989). Hence, temperatures within the permafrost-cored palsas are considerably cooler than those within the adjacent permafrost-free wetlands (Kershaw and Skaret 1993). Thus, under freezing conditions, thermodynamic potentials draw water from the unfrozen wetland towards the freezing zone where it changes phase and subsequently heaves the surface above the wetland (Zoltai and Tarnocai 1975).

Under optimal conditions, the frost may aggrade and penetrate into the underlying silty soil (Åhman 1977; Seppälä 1986, 1988; Zoltai 1972). These frost susceptible soils are even more effective at inducing capillary water, and when given enough time ultimately develop thicker ice lenses, subsequently, elevating the surface even further above the surrounding wetland (Williams and Smith 1989). Eventually, these features experience degradational phases that modify the original form, and ultimately thaw the permafrost core (Seppälä 1988).

Palsa degradation is the result of a disrupted microclimatic balance that propels the feature into a disequilibrium phase, ultimately initiating a positive heat budget. Degradation is mainly brought about by changes in regional climate and/or microclimate, surface conditions, and rates of water infiltration. The thermo-erosional agents that thaw the permafrost core eventually leave behind water-filled or plant-devoid depressions.

2.1.1 Peat Layer

In Subarctic Canada, the thickness of the peat cover ranges from 7 cm (Seppälä 1980) to over 500 cm (Kershaw and Gill 1979). Generally, the peat within palsas consists of a basal hydrophilous zone overlain by a xerophilous layer (Vorren 1972, 1975). Initiation of the upper xerophilous peat occurs once the hydrophilous surface is heaved above the surrounding minerotrophic wetland (Seppälä 1988). These better-drained raised positions create ombrotrophic conditions that terminate the growth of hydrophilous plants (Seppälä 1988; Zoltai *et al.* 1988). Lichens (*Cladina. sp., Cetraria sp.*), dwarf shrubs (*Ledum groenlandicum, L. decumbens, Rubus Chamaemorus, Vaccinium vitis-idaea*), taller shrubs (*Betula glandulosa, Salix planifolia*) and sometimes open stands of stunted trees (*Picea mariana*) come to dominate the elevated surfaces of palsas in Western Canada (Kershaw and Gill 1979; Seppälä 1980; Zoltai 1972; Zoltai and Tarnocai 1971, 1975; Zoltai *et al.* 1988). Lee *et al.* (1982) described the plant cover of 3 peat plateaus in Caribou Mountains, Alberta, and found the dominant plant cover consists of *Drepanocladus revolvens, Carex limosa, Sphagnum warnstorfii, Andromeda polifolia, Cladina rangiferina, Sphagnum angustifolium, Picea mariana, Ledum groenlandicum* and *Rubus Chamaemorus*. A detailed vegetation description of palsas has been presented for Eastern Canada (e.g. Railton and Sparling 1973;), Europe (e.g. Seppälä 1990; Vorren 1972, 1979; Vorren and Vorren 1975).

The near-surface peat at palsa summit positions tends to consist of a thin layer of humified sylvic peat underlain by *Sphagnum* peat followed by mesic brown moss peat with sedge (*Carex* sp.) and woody shrub remains

(Zoltai and Tarnocai 1975; Zoltai *et al.* 1988). The upper peat constitutes part of the active layer and thus contains seasonal frost, however, pore ice and thin ice lenses (<10 cm) tend to comprise the zone immediately below the permafrost table. Conversely, basal peat tends to be an ice-rich zone that contains alternating 5-10 cm (Salmi 1970) and less than 35 cm (Zoltai and Tarnocai 1975) thick ice lenses. Within the active layer, the moisture contents were found to increase rapidly below the surface and peak towards the permafrost table (Zoltai 1972); high volumetric moisture contents have also been measured near the basal peat-mineral interface (Zoltai *et al.* 1988).

2.1.2 Mineral Layer

The substratum beneath the peat layer has been reported to be predominately composed of a silty to clayey soil matrix embedded with pebbles (Åhman 1976, 1977; Seppälä 1988; Zoltai 1972; Zoltai and Tarnocai 1975; Zoltai *et al.* 1988). As the frost penetrates further into the ground it may eventually reach the peat/mineral soil contact zone. Pure ice has often been found at this boundary with thick (>1 m) ice lenses developing in the upper-mineral zone (Brown and Péwé 1973; Zoltai and Tarnocai 1975), resulting in relatively high moisture contents (Zoltai *et al.* 1988). Generally, descriptions of the frozen mineral soil indicate that there is a progressive development of rhythmic ice lenses (Williams and Smith 1989), and the magnitude of vertical displacement tends to equal the thickness of the segregated ice coupled with the expansion associated with pore ice (Anderson *et al.* 1984; Seppälä 1988).

2.2 Objectives

Numerous studies have contained stratigraphic descriptions of palsas (e.g. Åhman 1976, 1977; Allard *et. al* 1987; Cummings and Pollard 1989; Forsgren 1968; Salmi 1968; Seguin and Crépault 1979; Svensson 1964; Vorren 1972, 1979; Vorren and Vorren 1975; Wramner 1973; Zoltai 1972; Zoltai and Tarnocai 1971, 1975; Zoltai *et al.* 1988), however, only a few studies have described the internal characteristics of these features in the mountainous regions of Western Canada (Brown 1980; Kershaw and Gill 1979; Seppälä 1980). Furthermore, stratigraphic analysis of palsas in mountainous regions has only been based on brief descriptions of usually 1 to 2 corehole logs (Brown 1980; Seppälä 1980; Kershaw and Gill 1979). This lack of stratigraphic information from palsas in alpine environments, especially with reference to moisture contents, peat decomposition status, and corehole logs (palsa and wetland) provided the impetus for this portion of the research. Hence, the primary intent is to conduct replicate coring from peat-covered frozen mounds and adjacent wetlands and to describe their internal composition in order to classify the form. This study was intended to provide a considerable expansion of the sampling area and stratigraphic detail reported by Kershaw and Gill (1979).

2.3 Study Area

The study area was located in the alpine tundra environments of the Macmillan Pass-Tsichu River-Mackenzie Mountain Barrens region of the Northwest Territories, Canada (Figure 1.2). This area occurs within the discontinuous permafrost zone of the Rocky Mountain Wetland region (National Wetland Working Group 1988). Regional climate is influenced by the mountains that form the Continental Divide (2060-2430 m asl). The mean annual temperature and precipitation values for the 1974-82 period were -7.7°C and 490 mm respectively (Kershaw and Kershaw 1983).

Palsas within the study area were first described by Porsild (1945), and later, Kershaw and Gill (1979) conducted more detailed investigations upon these features, as well as other palsas and peat plateaus within the area. This paper is a result of recent investigations that cover a similar yet larger area than that examined by Kershaw and Gill (1979). During July, August 1990 five palsas located at four different sites were selected for the research project after air photo analysis and site reconnaissance.

There were several different phases of the palsa cycle present within each palsa field. For example, each palsa field had features that varied in relief, diameter, plant type and cover, therefore, those chosen as study features were subjectively selected as being representative of the range of features present in the study area. These sites were situated over a 410 m altitudinal gradient (1250-1660 m asl) and were located approximately 5 km northwest to 32 km east of Macmillan Pass, the border of the two Territories.

2.4 Methods

From 19 July to 26 August 1990, 30 soil cores to a maximum depth of 5 m were taken from palsas and the adjacent wetlands, for the determination of moisture content, bulk density, peat decomposition using a modified von Post humification scale (Okruszko 1976), pH, and Munsell colours. In the palsa, core locations were based upon a height gradient; 1 core taken at the apex with 1 to 4 lower sites randomly chosen. The wetland cores were randomly selected from positions surrounding the palsa.

Out of the 30 cores, 19 were located on 5 different palsas, and 11 were located in the wetlands associated with the palsas. In palsas, the frozen cores were obtained by using two different hand-driven permafrost corers, having an inside diameter of 2.2 and 3.86 cm respectively; non-frozen samples collected in the wetlands were obtained with a Macauley corer (McKeague 1978). The permafrost core samples were taken at approximately 10 cm intervals whereas the wetland cores were separated and bagged at points of distinct change within the soil profile. It should be noted that peat thicknesses are only a minimum estimate; some of the coreholes were abandoned before the mineral soil was reached, therefore, exact thicknesses remain unknown. In addition, coreholes that were supersaturated within 1 m of the surface were dropped from peat thickness calculations. Wet weights were calculated in the field with a triple beam balance and air-dried at room temperature prior to oven-drying in the laboratory.

Classification of the mineral soil was based upon the manual methods of describing soils in the field (Expert Committee on Soil Survey 1983) and subsequently checked in the laboratory (McKeague 1978). Thus, particle-size analysis was calculated for 18 samples; determination of the coarse soil was achieved by sieving whereas the finer material (<300μm) was analyzed with a sedigraph (Micromeritics 1991).

2.4.1 Moisture Content

Moisture contents were determined by oven-drying the soil samples at 105±5°C for 24 hours (McKeague 1978; Kalra and Maynard 1991). Soil samples that had high organic contents were dried at 60°C to prevent oxidation of the peat (Head 1980). Moisture contents were expressed on dry weight, wet weight (total moisture), and volumetric basis. The latter was calculated by converting the volume of water to ice by using a factor of 0.917 g cm^{-3} for the density of the ice (Pounder 1965); bulk densities were also calculated (McKeague 1978).

$$\textit{Water Content (weight \%)} = \frac{\textit{Moist wt. - Oven-dry wt.}}{\textit{Oven-dry wt.}} \times 100 \quad (1)$$

$$\textit{Total Moisture (\%)} = \frac{\textit{Moist wt. - Oven-dry wt.}}{\textit{Moist wt.}} \times 100 \quad (2)$$

$$\textit{Volume of Water (\%)} = \left(\frac{\textit{Weight of Water}}{\textit{Weight of Dry Soil}}\right)\left(\frac{\textit{Bulk Density}}{\textit{Density of Water}}\right) \times 100 \quad (3)$$

$$Volume\ of\ Ice\ (\%) = \left(\frac{Weight\ of\ Water}{Weight\ of\ Dry\ Soil}\right)\left(\frac{Bulk\ Density}{Density\ of\ Ice}\right) \times 100 \quad (4)$$

$$Bulk\ Density = \frac{Soil\ Mass}{Soil\ Volume} \quad (5)$$

It should be noted that the permafrost corer did not allow for the extraction of undisturbed samples, subsequently, it was not consistently possible to remove a known volume of soil (Kershaw pers. comm. 1994). For example, the exact depth of the core may have been influenced by wall slumping or material lost from the core barrel under supersaturated conditions. Hence, some volumetric moisture calculations exceeded 100%; these were then reduced to 100% for analysis purposes.

2.5 Results

Palsa surfaces are primarily dominated by lichens and moss with some features supporting shrubs, sedges, and grasses. Sedges and moss were the dominant plant species in the surrounding wetland, however, most wetlands also contained shrubs. A more detailed description of the plant species associated with palsas and wetlands is given in Chapter 1. All palsas and adjacent wetlands contain a peat cover underlain by mineral soil, with mineral inclusions (predominately silt) and small wood fragments occurring throughout the peat layer (Figures 2.1 to 2.8).

2.5.1 Peat Layer

The thickness of the peat within palsas varied from 59.5 (Goose Flats) to at least 387 cm (Beaver Pond); the mean thickness of the peat in palsas was 191.9 cm. In the surrounding wetlands the peat thickness ranged from 44 (Goose Flats) to 248.2 cm (Hare Foot); the mean thickness of the peat in the wetlands was 141.8 cm.

In all palsas, the peat near the surface was classified as H1 (Table 2.1), and generally, the degree of peat decomposition increased with progressive depths to a maximum scale grade of H8 (Table 2.1) at 99.5 cm (Beaver Pond-1) and 240 cm (Beaver Pond-4) (Appendix A). Within the wetlands, the surface peat was predominately classified as H1 (all wetlands), except two coreholes at Goose Flats had scale grades of H4 and H6. The maximum degree of peat decomposition within the wetlands was classified as H10, and this occurred at 248.2 cm (Hare Foot) (Appendix A).

Within the palsas, the pH of the peat was usually between 4.1 to 5.3, however, samples were measured as low as 3.5 (Goose Flats) and as high as 5.6 (Dale Creek 6) (Appendix A); the pH of the mineral soil within palsas commonly ranged from 4.7 to 5.3, however, some samples were as high as 5.9 (Beaver Pond) and as low as 3.5 (Goose Flats) (Appendix A). The pH within the wetlands varied from 4.4 to 5.9 for both peat and mineral samples (Appendix A).

2.5.2 Ice Lenses

All palsas contained alternating ice lenses that ranged from <1 cm to approximately 12 cm within the upper peat zones; ice lenses became progressively thicker with depth (Figures 2.1-2.5). The basal peat layers contained an ice lens that was 45 cm thick (Figure 2.1, Hare Foot-2), however, a 53 cm lens was encountered within a mineral-rich zone at the peat/mineral interface (Figure 2.1, Hare Foot-1).

Ice lenses within the mineral soil ranged from <1 cm to >50 cm, and occurred in alternating lens and lens-free layers (Figures 2.1-2.5). The total volume of ice lenses within a single core ranged from 0% (2 cores at Beaver Pond; 2 cores at Goose Flats) to 33.4% (1 core at Hare Foot) (Table 2.2). The total cumulative percentage of ice lenses within each palsa corehole ranged from 1.8% (Goose Flats) to 25% (Hare Foot). Generally, the upper mineral zone contained the thickest ice lenses, with most containing trace amounts of mineral particles.

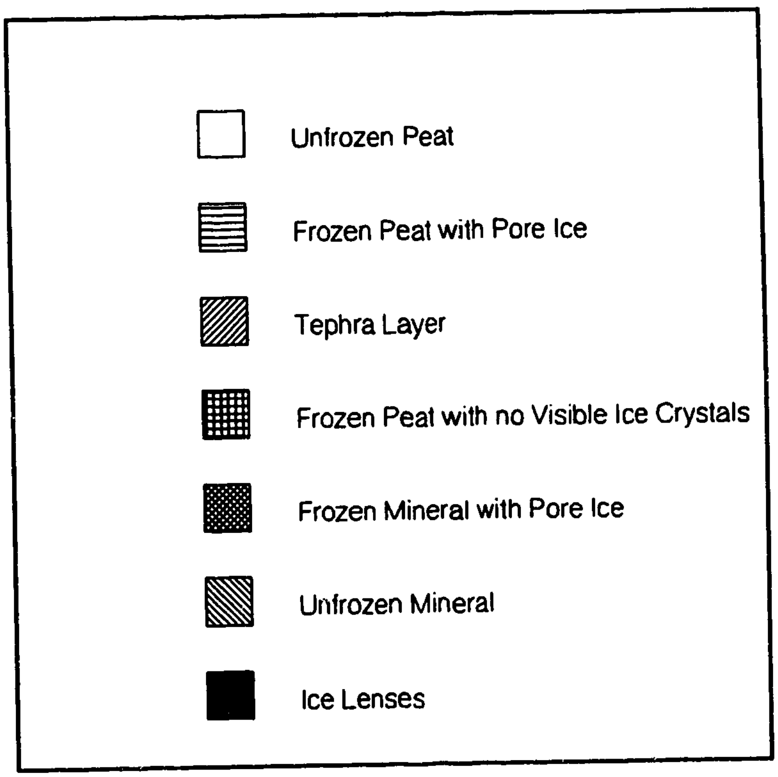


Figure 2.0. Legend for stratigraphic logs (Figures 2.1-2.8, 5.2-5.6).

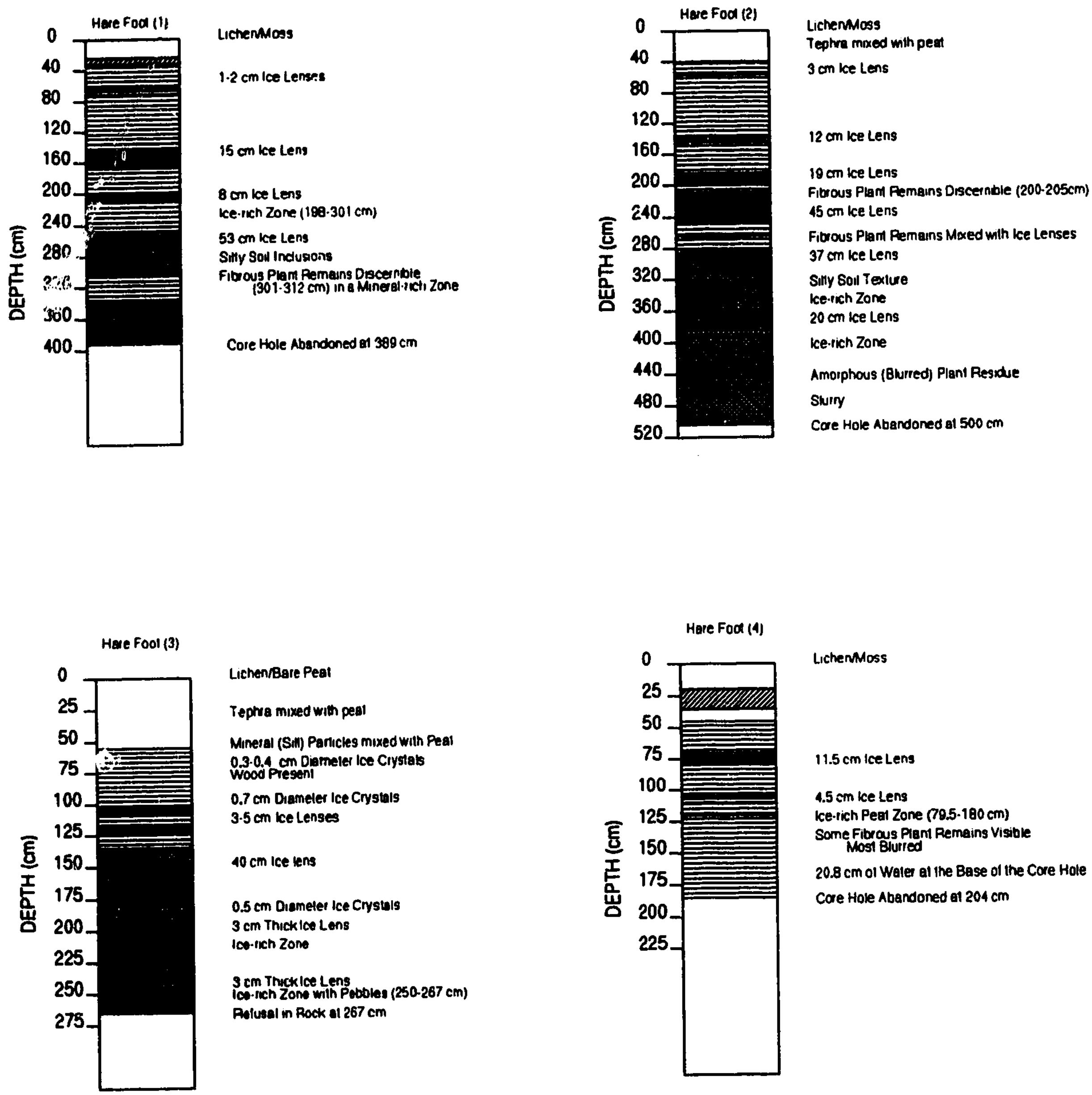


Figure 2.1. Stratigraphic logs of the Hare Foot palsa, 28 July to 18 August 1990.

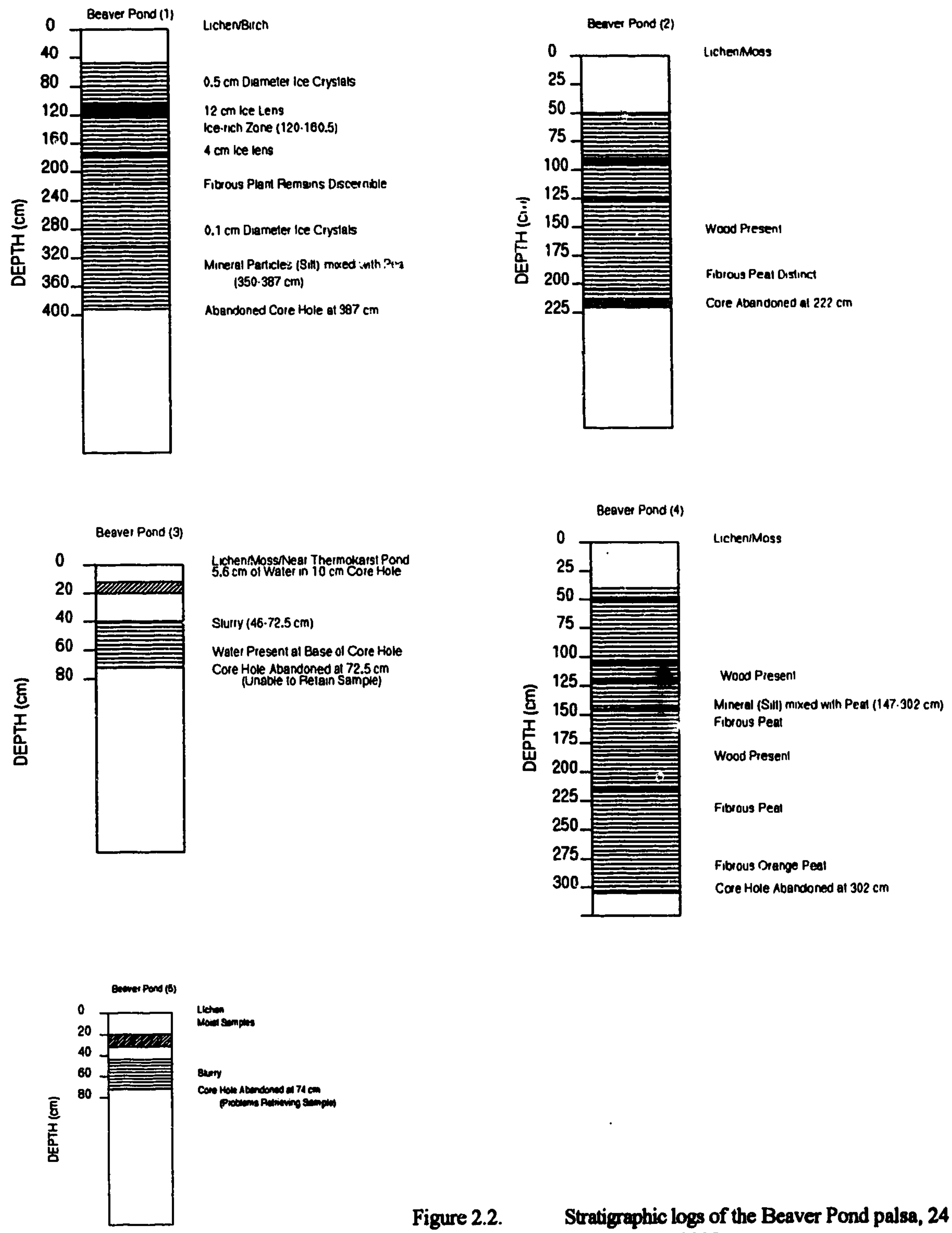


Figure 2.2. **Stratigraphic logs of the Beaver Pond palsa, 24 July to 25 August 1990.**

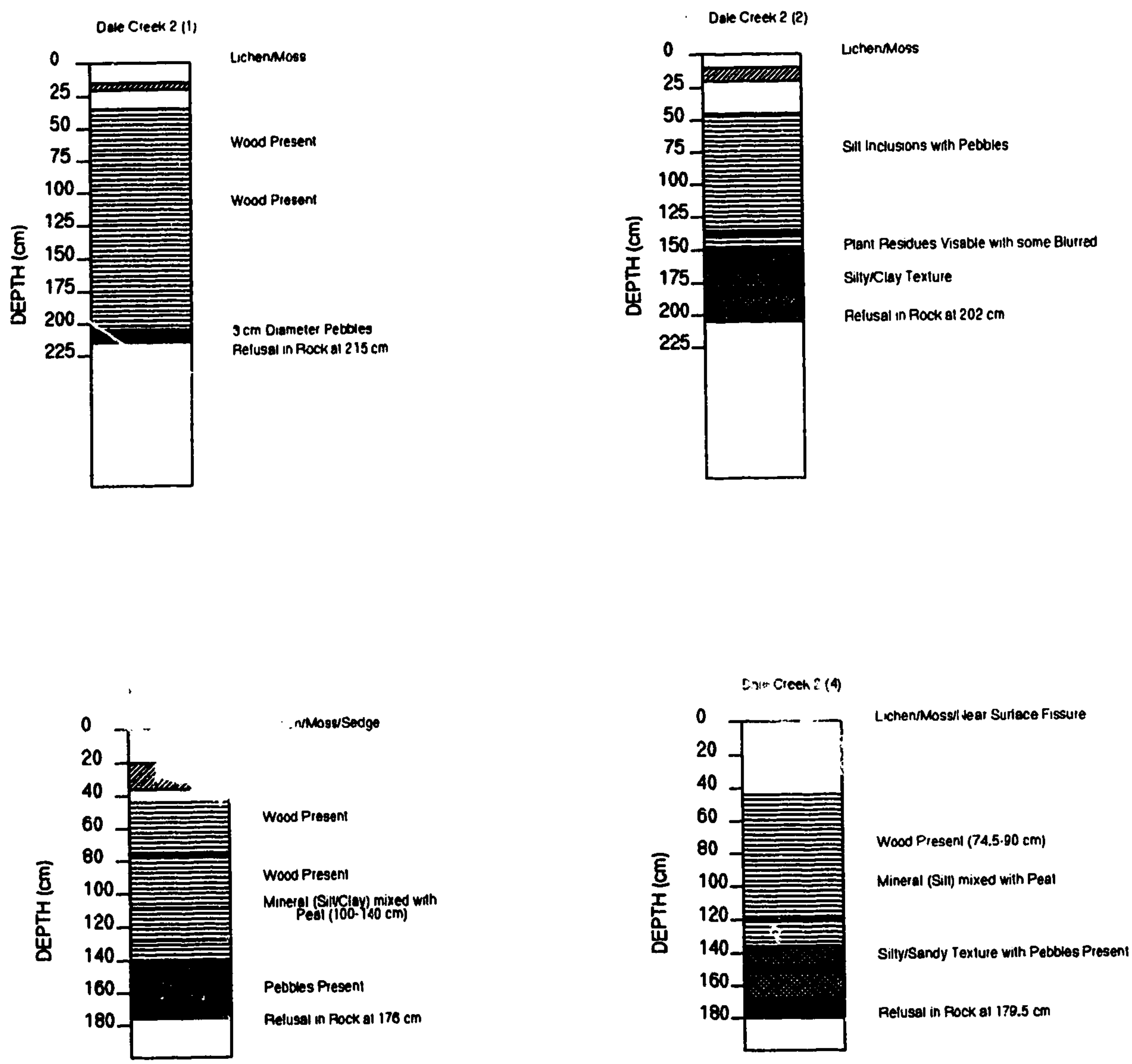


Figure 2.3. **Stratigraphic logs of the Dale Creek 2 palsa, 19 July to 23 August 1990.**

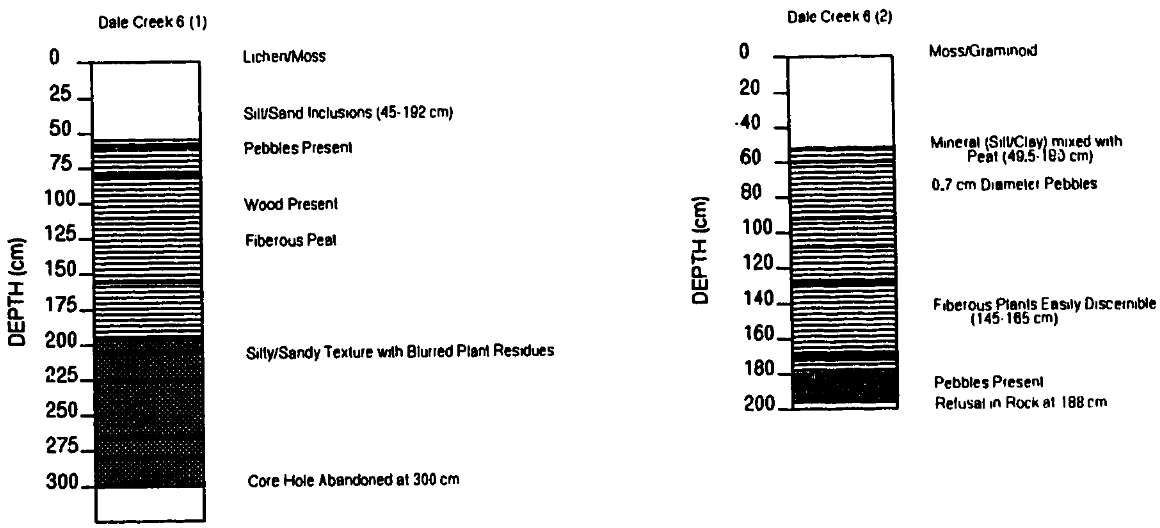


Figure 2.4. Stratigraphic logs of the Dale Creek 6 palsa, 24-26 August 1990.

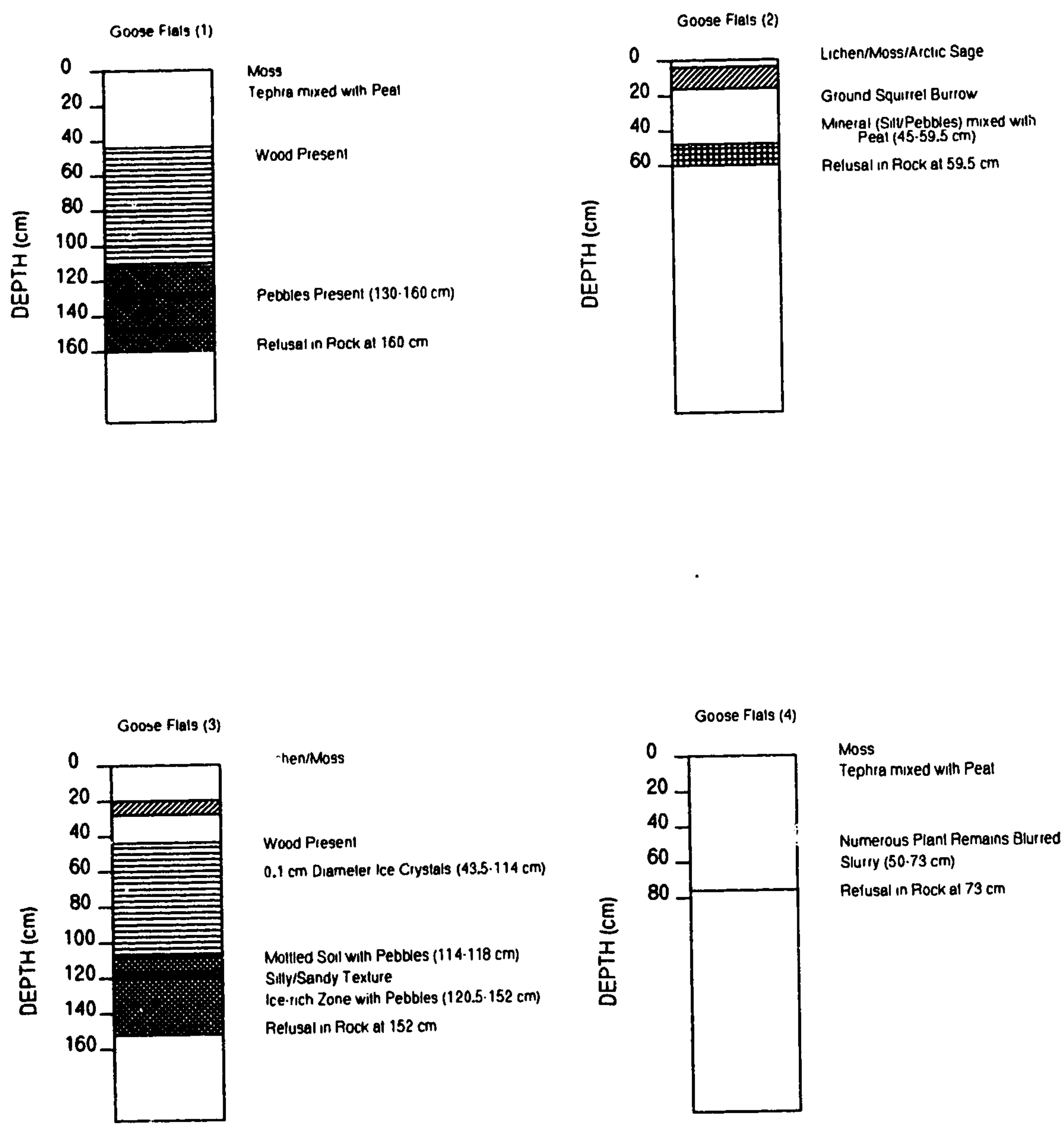


Figure 2.5. **Stratigraphic logs of the Goose Flats palsa, 1-19 August 1990.**

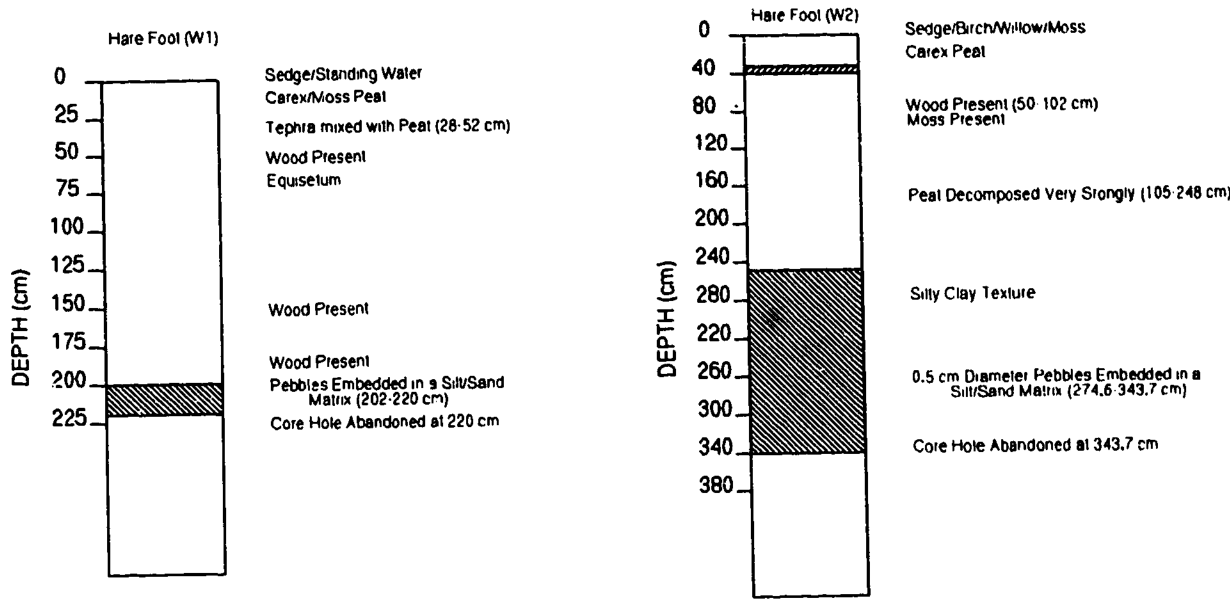


Figure 2.6a. Stratigraphic logs of the Hare Foot wetland, 18 August 1990.

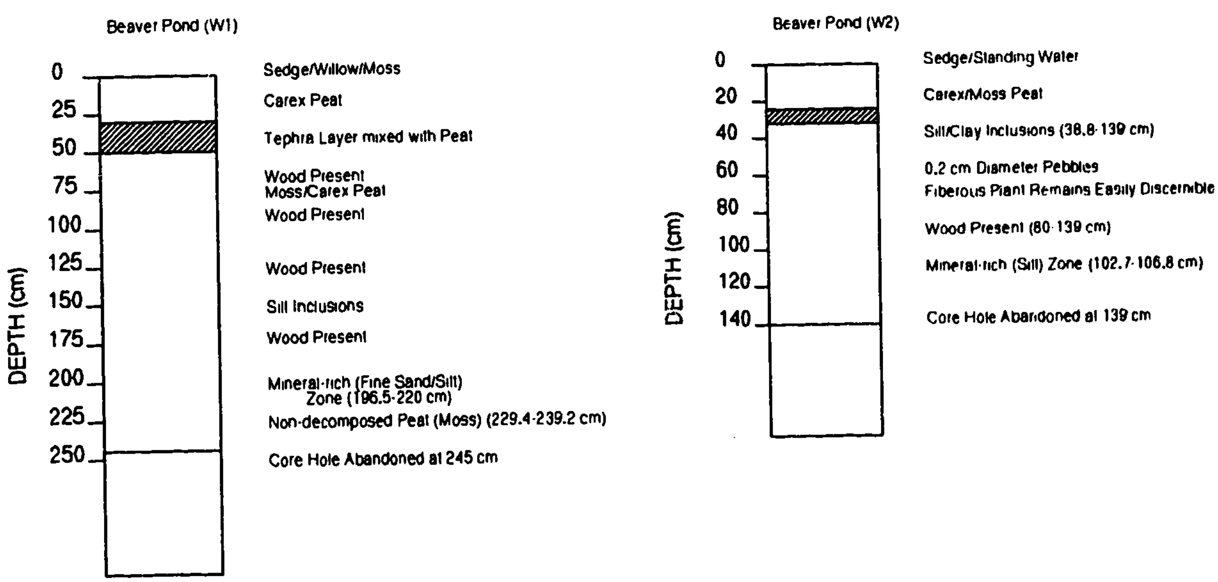


Figure 2.6b. Stratigraphic logs of the Beaver Pond wetland, 21-24 August 1990.

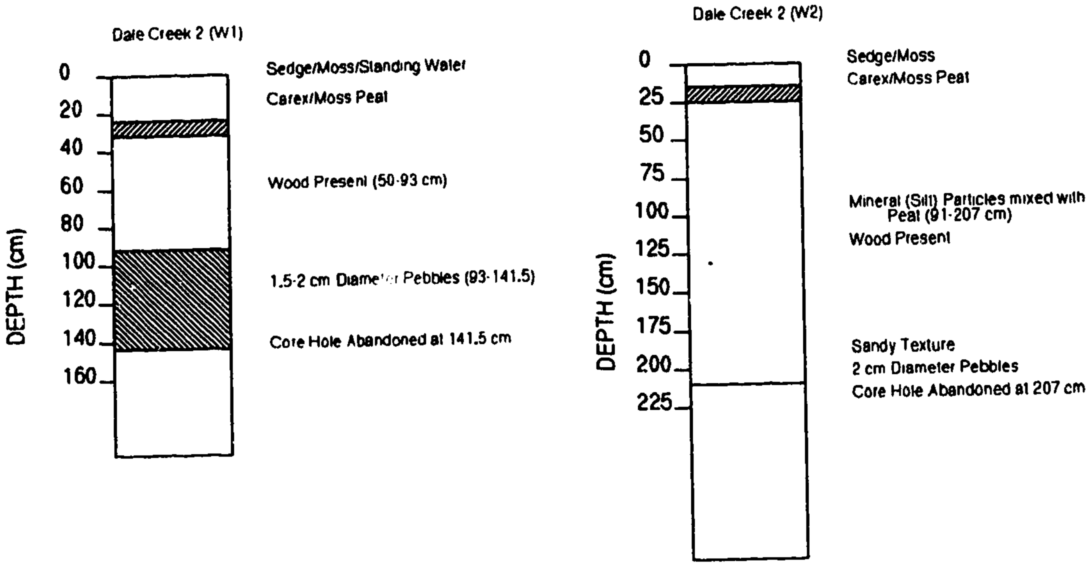


Figure 2.7a. Stratigraphic logs of the Dale Creek 2 wetland, 22 August 1990.

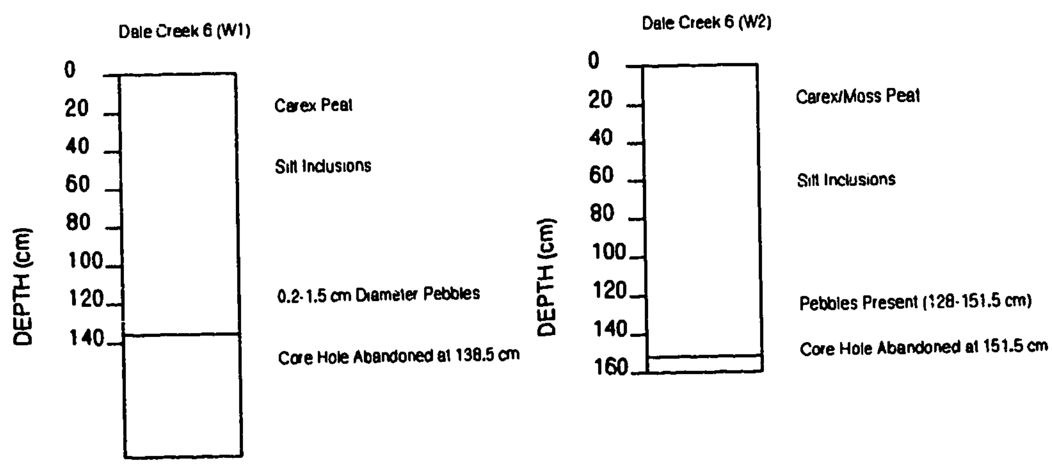


Figure 2.7b. Stratigraphic logs of the Dale Creek 6 wetland, 24-25 August 1990.

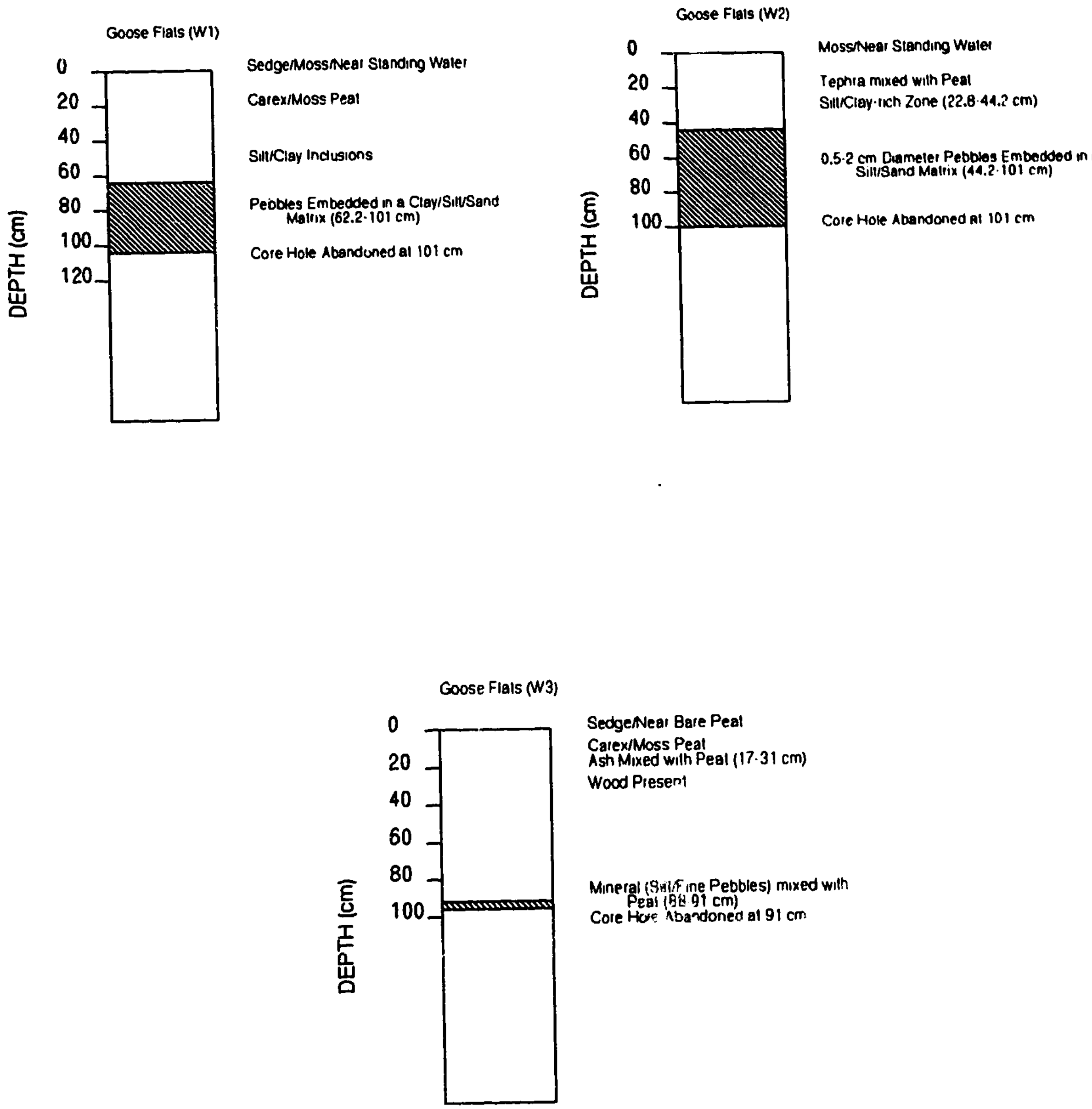


Figure 2.8. **Stratigraphic logs of the Goose Flats wetland, 19 August 1990.**

SCALE GRADE	GENERAL DESCRIPTION OF PEAT	PEAT DECOMPOSITION DEGREE (%)
H1	Non-decomposed or almost non-decomposed peat, without humus, plant residues distinctly visible	10
H2	Peat slightly decomposed, humus weakly discernible, plant residues distinctly visible	20
H3	Peat decomposed rather distinctly, humus weakly discernible, visible plant residues	30
H4	Peat decomposed distinctly, humus clearly visible, easily discernible plant residues	40
H5	Peat decomposed, humus visible quite clearly, numerous plant residues blurred	50
H6	Peat decomposed rather strongly, with a predominance of humus; greater plant residues discernible clearly and smaller ones less clearly	60
H7	Peat strongly decomposed, with a distinct predominance of humus; greater plant residues discernible clearly and smaller ones less clearly	70
H8	Peat decomposed very strongly, with a very high humus content, greater plant residues still clearly visible	80
H9	Peat almost fully decomposed, almost exclusively humus, few greater plant residues are discernible	90
H10	Peat fully decomposed, exclusively humus, few greater plant residues are discernible	100

Table 2.1. Field methods for the degree of peat decomposition based on a modified von Post scale. *Source*: Okruszko (1976).

PALSA CORE	DEPTH OF CORE (cm)	CUMULATIVE ICE LENS THICKNESS (cm)	% OF ICE LENSES
Hare Foot (1)	389	125	33.4
Hare Foot (2)	500	138	27.6
Hare Foot (3)	267	56	21.0
Hare Foot (4)	204	21	10.3
Beaver Pond (1)	387	26	6.7
Beaver Pond (2)	222	12	5.4
Beaver Pond (3)	72.5	0	0
Beaver Pond (4)	302	10	3.3
Beaver Pond (5)	74	0	0
Dale Creek 2 (1)	215	6	2.8
Dale Creek 2 (2)	202	10	5.0
Dale Creek 2 (3)	176	8	5.0
Dale Creek 2 (4)	179.5	16	8.9
Dale Creek 6 (1)	300	13	4.3
Dale Creek 6 (2)	188	7	3.7
Goose Flats (1)	160	5	3.1
Goose Flats (2)	59.5	0	0
Goose Flats (3)	152	3	2
Goose Flats (4)	73	0	0

Table 2.2. Percentage of ice lenses present within the coreholes, as indicated by the total cumulative ice lens thickness.

2.5.3 Particle-size

Mineral soil was present in at least one corehole from every site (palsa and wetland), and analysis was based on field methods that were subsequently checked in the laboratory. Within the field, the mineral particles were classified as being predominately fine textured; falling into the silt to clayey classes with smaller quantities of sand present in all the palsas and surrounding wetlands (Figures 2.1-2.8). Laboratory SediGraph analysis confirmed the field results with the palsas being classified as having a silt loam (Dale Creek 2 and Dale Creek 6), silty clay loam (Hare Foot), and silt (Beaver Pond) textures (Figure 2.9). Laboratory analysis for the Goose Flats palsa excluded the use of the SediGraph, however, sieving methods for 2 samples confirmed the palsa as having a silt loam texture. The mean percentage of sand, silt and clay within all the palsas was 16%, 68%, and 16% respectively. Within the palsas, the silt particles varied from 41.1% to 88.4%; clay particles had a range of 0.01% to 37.5%, whereas the sand particles had minimum and maximum values of 0.4% and 44.65% respectively. Within all palsas, the peat layer was in contact with the mineral soil substratum. The underlying mineral soil was elevated from a mean height of 129.6 cm (Goose Flats) to 234.0 cm (Dale Creek 2) above the adjacent wetland.

2.5.4 Moisture Contents and Bulk Density

Generally, moisture contents within palsas increased rapidly below the surface and peaked near the permafrost table or in the vicinity of ice lenses. Volumetric moisture contents ranged from 10% near the surface to 100% deeper in the palsa (Figures 2.10-2.14). Moisture contents within the perennially frozen material commonly ranged between 60% and 100%, however, at a depth of 450 cm (Figure 2.10, Hare Foot-2), the moisture content dropped to 13%. Moisture contents in the wetlands were measured on a total weight percentage basis, and were generally the inverse of palsas (Figures 2.15-2.19). Consequently, higher moisture contents were found near the surface with progressively lower percentages occurring deeper within the wetland. The maximum moisture content near the wetland surface was 95% (Figure 2.15), whereas, the minimum moisture content was 16.5%, and this occurred at the bottom of a corehole in the Goose Flats wetland (Figure 2.19). However, a relatively high moisture content (91.5%, Hare Foot) was measured at almost 200 cm (Figure 2.16).

Dry bulk density is an expression of the ratio of the mass of dried soil to its total volume (Hillel 1971). Within palsas, the bulk densities were the lowest in the peat and generally higher in the underlying mineral soil (Figures 2.10-2.14). For example, the minimum mean bulk density was 0.31 g cm^{-3} and it occurred at Beaver Pond (Figure 2.10), whereas the maximum mean bulk density was 2.04 g cm^{-3} and this occurred at Goose Flats (Figure 2.14).

2.5.5 White-River Volcanic Ash

The White-River volcanic ash (1250 years BP, Lerbekmo *et al.* 1975) was present in all palsas and adjacent wetlands except in the Dale Creek 6 palsa. In some palsas and wetlands, however, the tephra was mixed with the organic or visually absent from coreholes. It was not possible to assess tephra layer thickness when the deposit was mixed or discontinuous, and these zones were noted in the core logs (Figures 2.1-2.8) but not used to calculate deposit thickness. In palsas, the mean depth of the tephra from 9 coreholes was 19.1 cm with a range of 3 (Goose Flats) to 28 cm (Hare Foot); the average thickness of the tephra layer was 4.62 cm (Table 2.3). In the surrounding wetland the mean depth of the tephra layer from 6 coreholes was 25.2 cm and the minimum and maximum depths were 15 (Dale Creek 2) and 34.9 cm respectively; the mean tephra thickness was 7.35 cm (Table 2.4).

2.6 Discussion

There are many morphologically-similar periglacial features that contain ice accumulations (e.g. earth hummock, frost blister/hydrolaccolith, ice blister, palsa, pingo etc.), yet, each can be classified as a distinct landform based upon their unique modes of origin. Therefore, accurate identification of these similarly-shaped geomorphological features requires both external and internal information.

The stratigraphic profiles of the study features indicate that these landforms were similar to the palsas described by numerous researchers (e.g. Åhman 1977; Allard and Seguin 1987; Allard *et al.* 1987; Dionne 1984; Kershaw and Gill 1979; Lundqvist 1969; Seppälä 1980; 1986, 1988; Vorren 1972; Zoltai 1972; Zoltai and

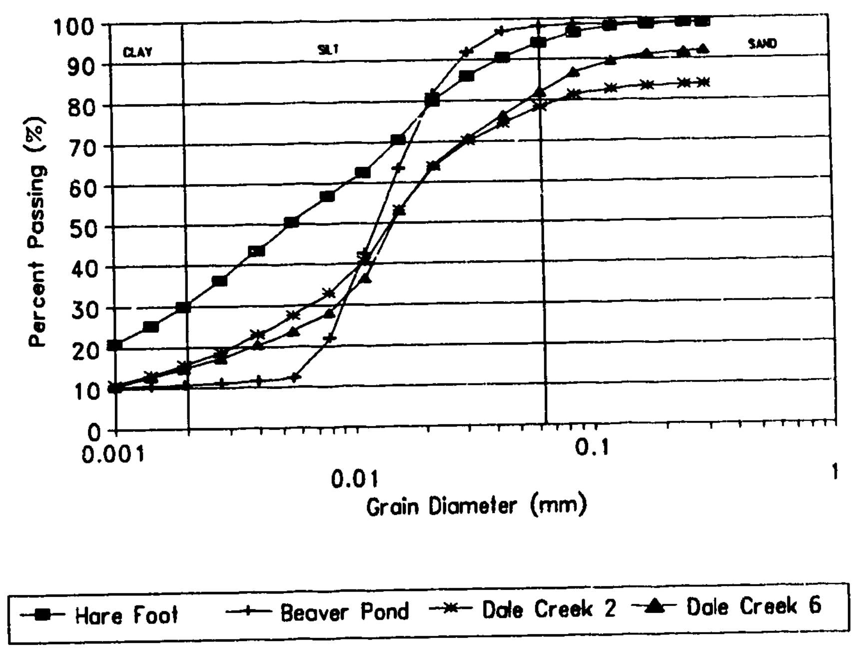
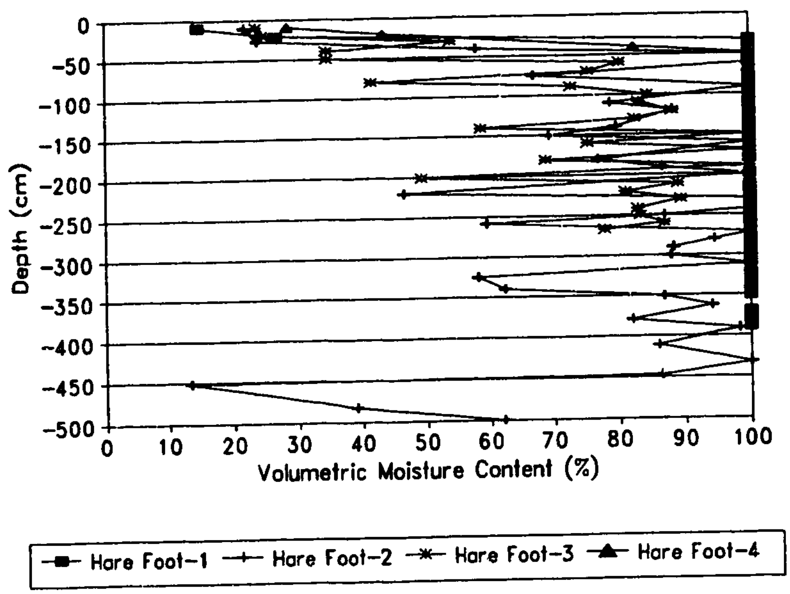


Figure 2.9. Sedigraph particle size analysis of the frozen mineral material within representative palsas, Macmillan Pass-Tsichu River area N.W.T.



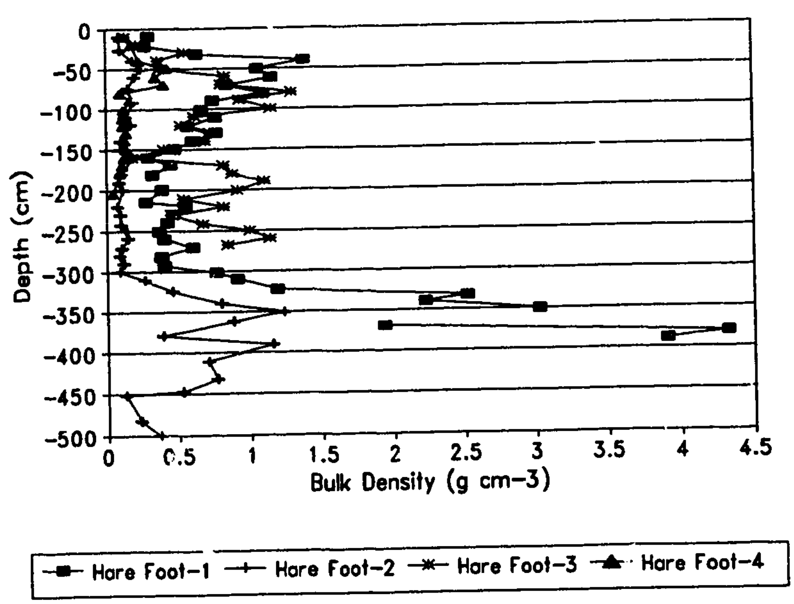


Figure 2.10. Mean volumetric moisture content (%) and mean bulk density (g cm^{-3}) vs. depth for the Hare Foot palsa.

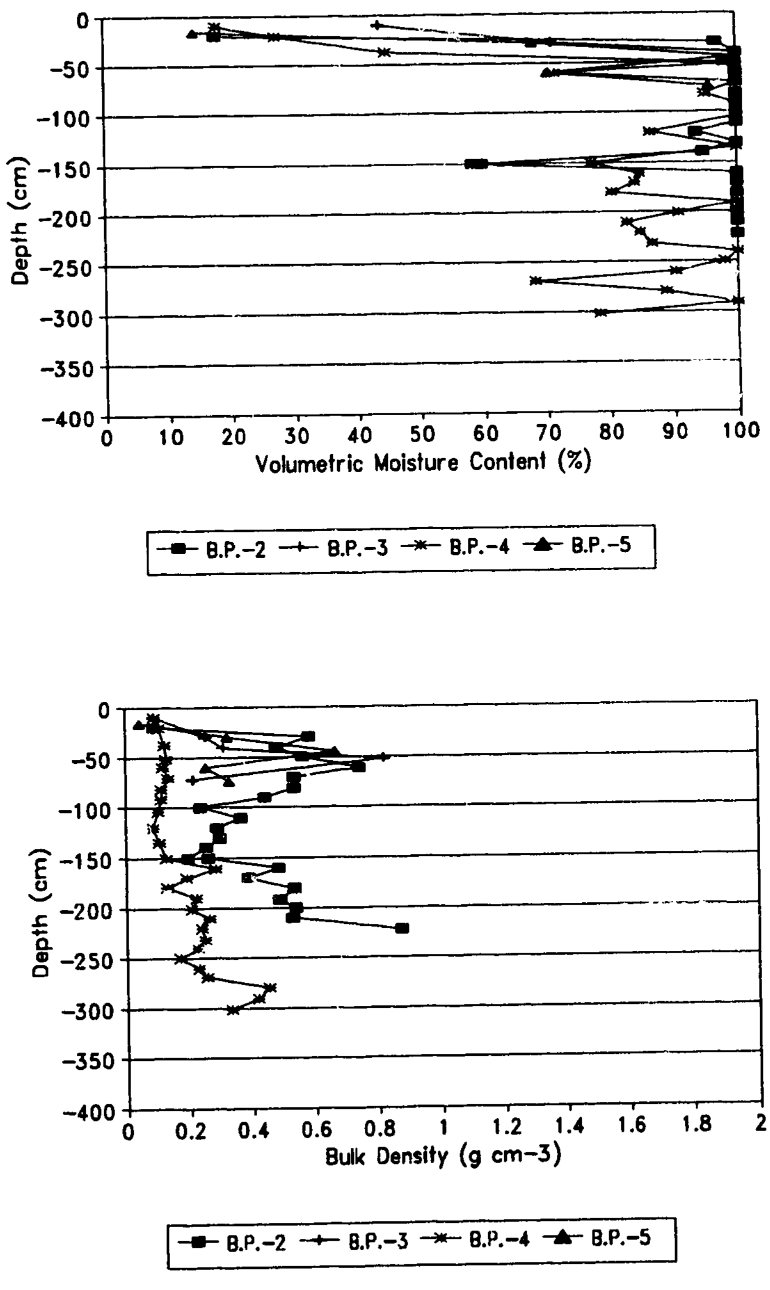
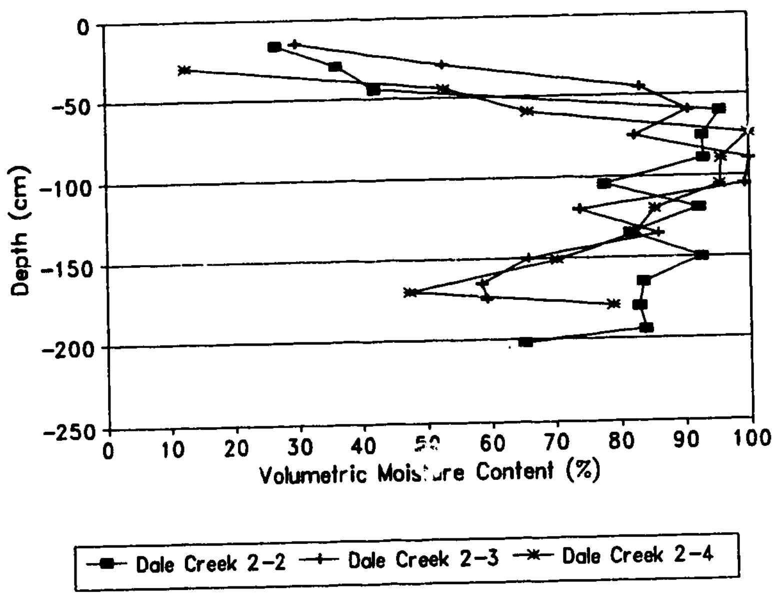


Figure 2.11. Volumetric moisture content (%) and bulk density (g cm^{-3}) vs. depth for the Beaver Pond palsas.



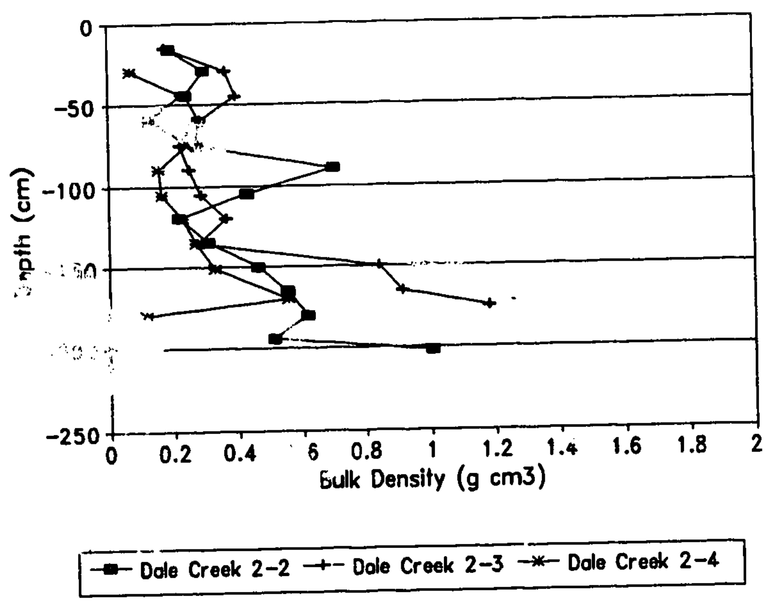


Figure 2.12. Mean volumetric moisture content (%) and mean bulk density (g cm^{-3}) vs. depth for the Dale Creek 2 palsa.

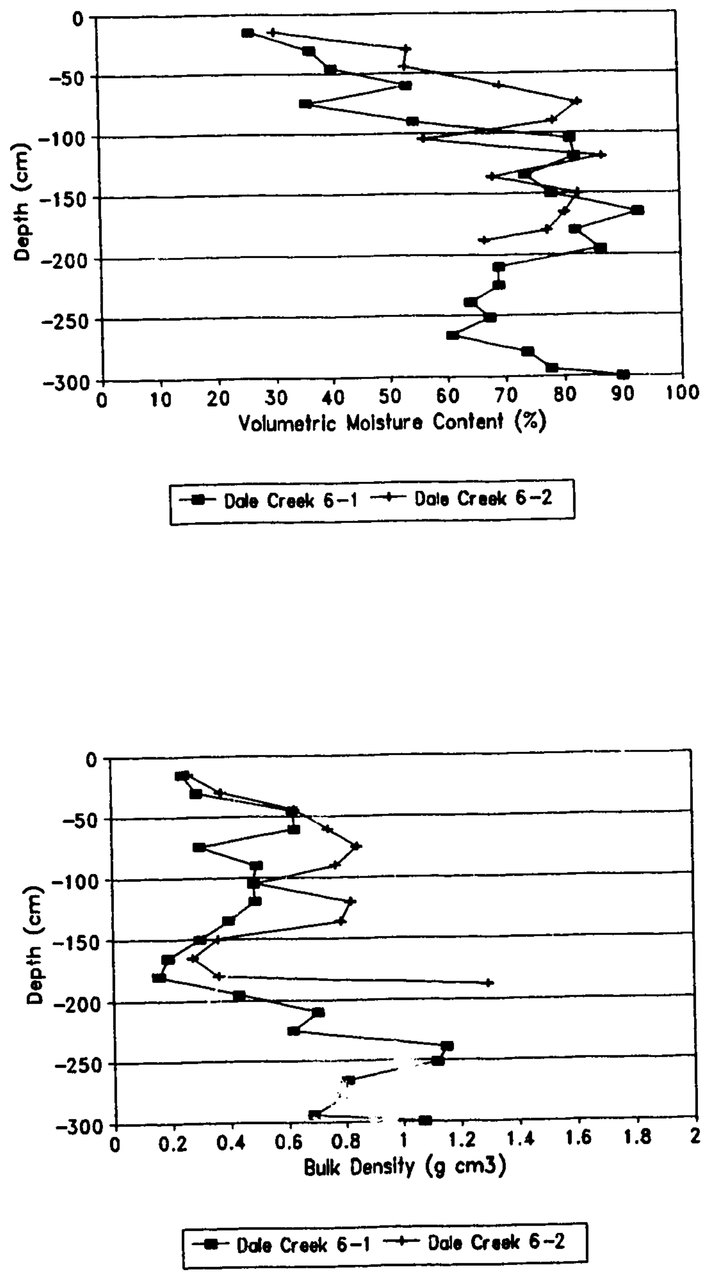
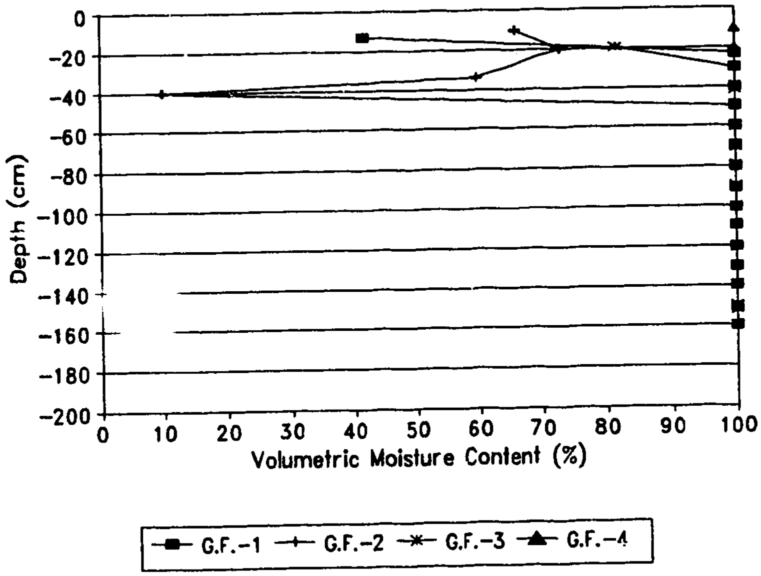


Figure 2.13. Mean volumetric moisture content (%) and mean bulk density (g cm^{-3}) vs. depth for the Dale Creek 6 palsa.



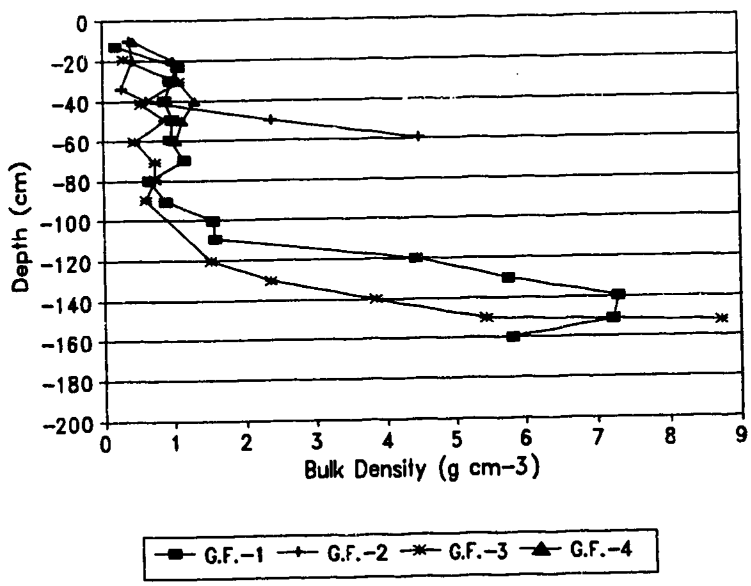


Figure 2.14. Volumetric moisture content (%) and bulk density (g cm^{-3}) vs. depth for the Goose Flats palsas.

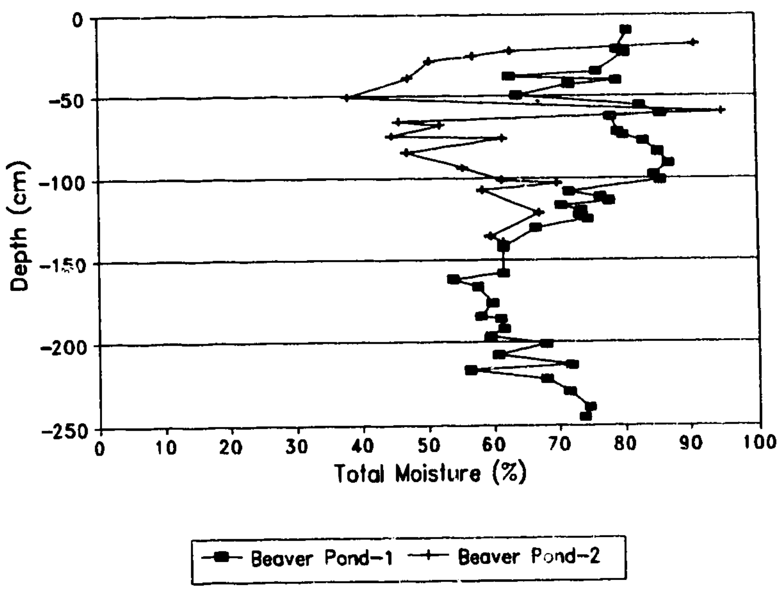


Figure 2.15. Mean total moisture content (%) vs. depth for the Beaver Pond wetland.

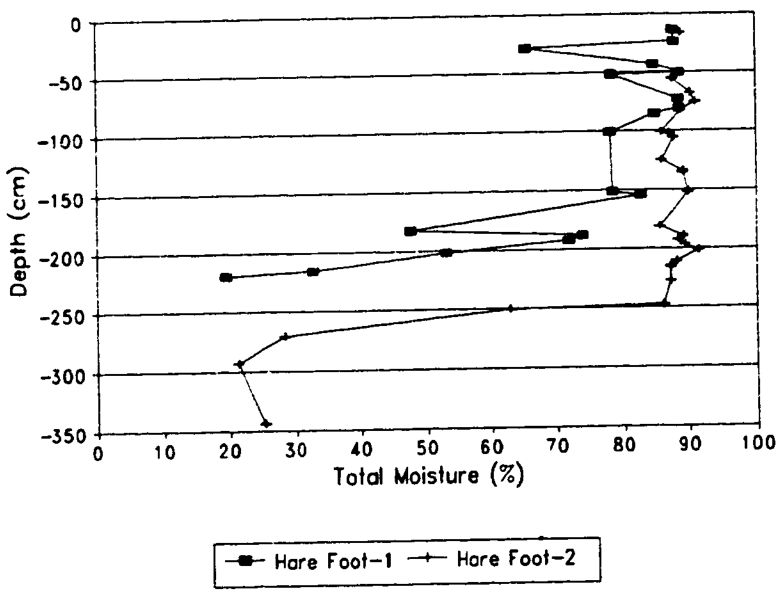


Figure 2.16. Mean total moisture content (%) vs. depth for the Hare Foot wetland.

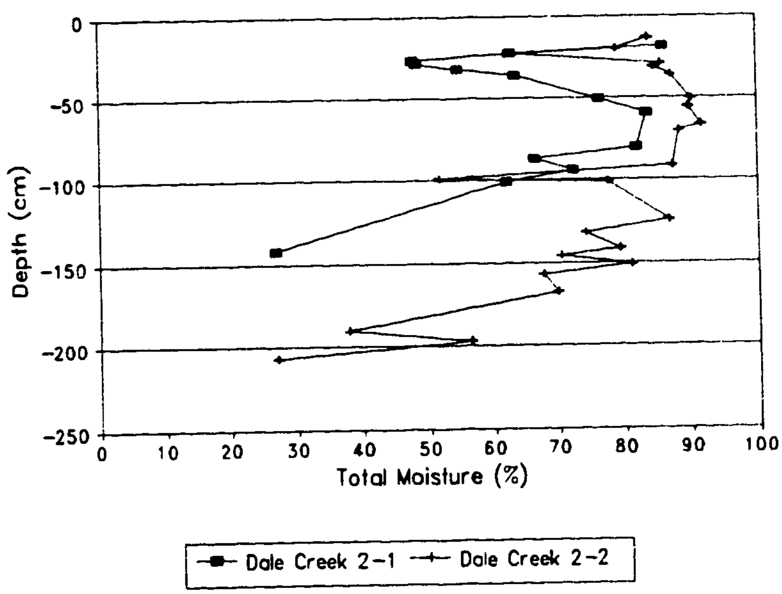


Figure 2.17. Mean total moisture content (%) vs. depth for the Dale Creek 2 wetland.

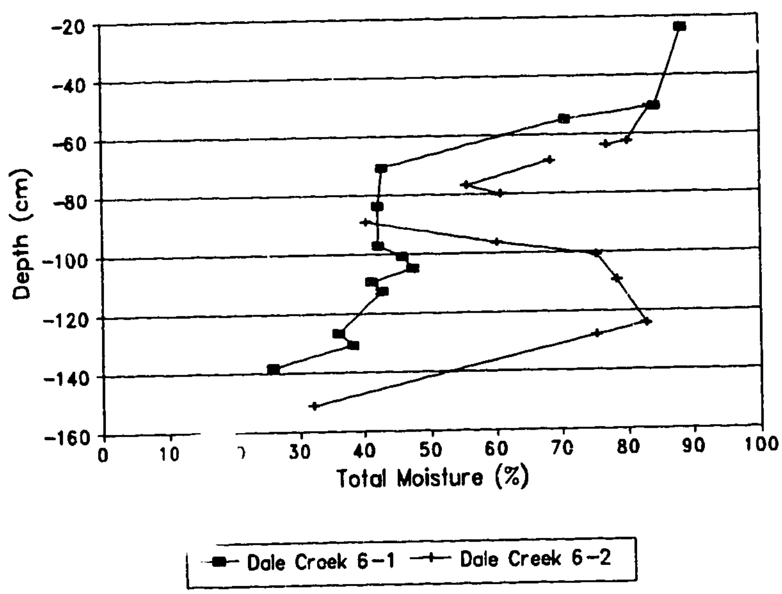


Figure 2.18. Mean total moisture content (%) vs. depth for the Dale Creek 6 wetland.

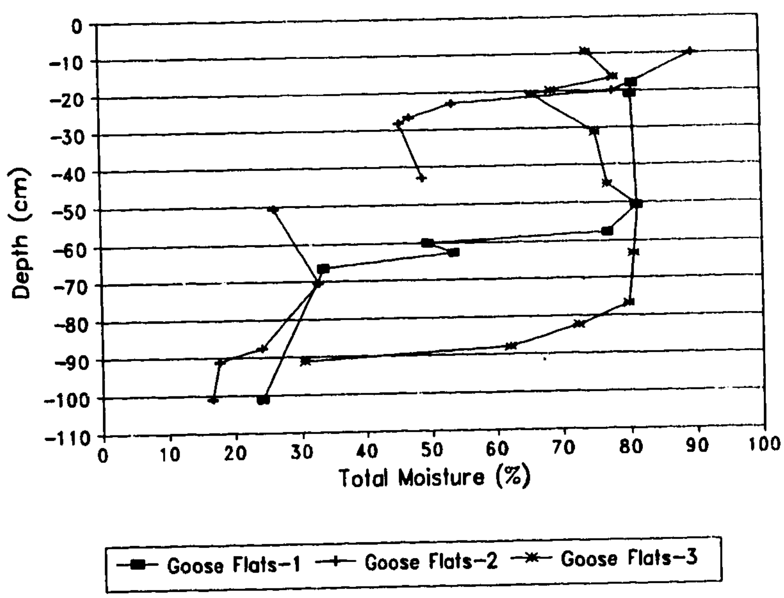


Figure 2.19. Mean total moisture content (%) vs. depth for the Goose Flats wetland.

PALSA	NO. OF SITES WITH TEPHRA	TEPHRA RANGE (cm)	MEAN DEPTH (cm)	ACCUMULATION (cm/100 yrs)
Hare Foot	2	22-28	25	2.00
Beaver Pond	2	20-28	24	1.92
Dale Creek 2	3	13-20	15	1.20
Dale Creek 6	NA	-	-	2.00
Goose Flats	2	3-21	12	0.96

NA: no tephra was visible in the Dale Creek 6 palsa cores

Table 2.3. Peat accumulation in palsas, as indicated by peat thickness above the White River tephra.

WETLAND	NO. OF SITES WITH TEPHRA	TEPHRA RANGE (cm)	MEAN DEPTH (cm)	ACCUMULATION (cm/100 yrs)
Hare Foot	2	23-34	28.5	2.28
Beaver Pond	2	22-34.9	28.5	2.28
Dale Creek 2	2	15-22.3	18.7	1.50
Dale Creek 6	NA	-	-	-
Goose Flats	NA	-	-	-

NA: no tephra was distinctly visible

Table 2.4. Peat accumulation in wetlands, as indicated by peat thickness above the White River tephra.

Tarnocai 1975; Zoltai *et al.* 1988). For example, each feature contained ice accumulations within a perennially frozen core of peat underlain by mineral soil. These two contrasting media did not exhibit cryoturbated soils, therefore, normal methods of palsa formation (e.g. where frost penetrates from the surface downwards) were thought to have prevailed at each site. Thus, ambient freezing conditions were thought to have initiated frost development at the surface, and ultimately, similar circumstances allowed the frost to aggrade into the underlying mineral soil. In all palsas, the peat layer was anchored to the mineral soil substratum, and the pore/segregation ice that occurred throughout the frozen sections were thought to be responsible for elevating the surface above the adjacent wetlands. These ice accretions were also thought to be responsible for elevating the top of the mineral soil a maximum of 2.34 m (Dale Creek 6) above the surrounding wetland. The peat in palsas was thicker than that within the surrounding wetlands, however, these greater thicknesses were related to the additional volume occupied by ice rather than thicker peat layers. Hence, stratigraphic analysis of the study features confirmed the integral role that segregation ice imparted upon the heaving processes.

Based upon information derived from the study features, and terminology used by the National Wetlands Working Group (1988), the study sites were classified within three different hierarchical levels: (1) class; (2) form; (3) type. All features occurred within the fen wetland class, and were categorized as palsa fen forms. The study area fen wetland types were predominately sedge/mixed shrub/moss. Palsas, however, were well defined meso-scale permafrost features that were distinct from the surrounding wetland (as defined by morphology, surface cover, and stratigraphy) and classified as: lichen/moss (Dale Creek 2); mixed shrub/grass (Dale Creek 6); low shrub/lichen/moss (Beaver Pond and Hare Foot); and grass/moss/lichen (Goose Flats) (Table 1.1).

2.6.1 Ice Lenses

Ice accumulations in the form of pore ice and segregated ice lenses were thought to account for approximately 80 to 90% of the volume of a palsa (Seppälä 1988). Within the study features, the stratigraphic logs indicate that ice lenses only account for approximately 1.8 to 25% of the total cumulative corehole length. Most of the coreholes, however, had to be abandoned before the maximum permafrost depth was reached, and furthermore these values neglected to include the volume occupied by pore ice. Hence, these values are an underestimate of the total percentage of ice lenses present within the palsa. Therefore, it is speculated that a greater abundance of ice lenses occur below the maximum penetration of the coring. Nevertheless, these coreholes still contained progressively thicker ice lenses with increasing depths.

The thickness of the ice lenses were thought to be directly related to freezing conditions. For example, upon freezing, the rate of heat removal from the ground is relatively high, subsequently, near-surface hydraulic conductivities decrease with increasing frost development (Williams and Smith 1989). This limits the amount of water that could migrate at a rate sufficient enough to form large planar ice lenses. Thus, ice lenses near the surface were restricted by insufficient amounts of water migrating towards the freezing zone, thereby limiting growth. Consequently, the near surface frozen peat was predominantly comprised of pore ice and very thin ice lenses. Thicker ice lenses, however, were found at greater depths, and are thought to be associated with the slower rates of freezing that occur as the freezing front penetrates deeper into the ground (Williams and Smith 1989). Generally, with increasing depth, the temperature gradient and flow of heat decrease, thereby, slowing the rate of freezing. These slower rates of freezing, however, allow enough water to migrate towards the freezing zone, where it can accumulate to form larger ice lenses. Hence, the basal peat and underlying mineral soil were capable of inducing a relatively steady influx of capillary water. Thus, with increasing depths, larger ice lenses were often found and were directly related to the slower rates of freezing and the capillary-like forces generated within the soil.

As the freezing front penetrates further into the ground, lenses will continue to grow so long as there is a balance in the rate of heat removal and migration of soil water (Anderson *et al.* 1984). However, when the heat and moisture fluxes become "sufficiently unequal", new lenses start to form beneath the older site, wherever, a "favourable balance" occurs between these interacting fluxes (Anderson *et al.* 1984). Generally, the thickness and distance between the ice lenses are the result of heat flow rate, moisture flow and soil characteristics (Lunardini 1981). In the study features, new lenses formed anywhere from 5 cm (Beaver Pond) to 82 cm (Hare Foot) below the previous lens (Figures 2.1-2.5).

2.6.2 Moisture Contents

High moisture contents were associated with zones proximal to the frost table, peat/mineral interface, and spaces containing ice lenses. The high moisture contents near the frost table were related to meteoric water infiltrating downwards and accumulating at this relatively impermeable contact. A similar situation occurred at the peat/mineral interface, where the lower hydraulic conductivity of the mineral soil produced a slower rate of water infiltration, subsequently, allowing more to accumulate at the discontinuity. The frozen core, however, created a thermal gradient that induced water movement and ultimately enabled water to freeze onto existing ice crystals and aggrade to form laminar ice lenses, hence, moisture contents were relatively high wherever ice accumulated.

The moisture contents within the frozen lens-free zones were considerably lower than those associated with ice lenses (Figures 2.1-2.5); falling moisture contents beneath these ice lenses were related to zones of insufficient water flow caused by thermal imbalances coupled with consolidation (Williams and Smith 1989). The lowest moisture contents, however, occurred within the thawed zones of the active layer, where insolation and evapotranspirative processes dried the upper peat layers, subsequently, decreasing the moisture contents.

2.6.3 Soil Texture

The texture of the soil is another element that affects frost development, and the most frost susceptible soil component is silt (Linnell and Kaplar 1959; Chamberlain 1981). Silt has intermediate qualities of motive force and permeability (Beskow 1935), that allow it to draw and hold more moisture than either sand or clay. Thus, silt-dominated landforms become more susceptible to frost heaving processes, and frost heave (other circumstances being equal) is greatest in moist to wet regions (Williams and Smith 1989). This explains why palsas are located in wetland environments, and why silt is usually the principal component within the mineral portion of these features (Åhman 1977; Seppälä 1980, 1988). The palsas within the study area were no exception and were classified as silt, silt-loam, and silty clay loam features. Hence, silt played an important role in inducing and retaining water for heaving processes in all the study features. It should be noted, that not all palsas are composed primarily of silt, for example, Zoltai (1972) reported clay contents as high as 66% in a 210 cm high palsa. Nevertheless, heaving processes within palsas require mineral inclusions that allow segregated ice to form (Williams and Smith 1989), however, the physical characteristics of a silty soil render it to be the most common mineral component within palsas (Seppälä 1988).

2.6.4 White River Volcanic Ash and Rates of Peat Accumulation

The White River volcanic ash was deposited approximately 1250 years BP by a volcanic eruption west of the study area (Lerbekmo *et al.* 1975). This tephra provides an important stratigraphic marker that allows the peat to be dated (Kershaw and Gill 1979). Thus, near surface peat accumulation rates can be estimated by measuring the thickness of the peat layer above the tephra (Tarnocai 1973; Zoltai *et al.* 1988). Within the Mackenzie Valley, the rate of peat accumulation in palsas and peat plateaus was 0.29 cm/100 years, whereas, *Carex* fen peat accumulated at 2.66 cm/100 years (Tarnocai 1973; Zoltai *et al.* 1988). In the study area, Kershaw and Gill (1979) determined that the peat in palsas accumulated at a mean rate of 1.68 cm/100 years. However, upon further sampling within a similar yet larger area than that investigated by Kershaw and Gill (1979), the mean rate of peat accumulation was found to be 1.55 cm/100 years in palsas, and 3.35 cm/100 years in the *Carex* dominated wetlands. This dissimilarity in peat accumulation is ascribed to the influence that morphological position exerts upon organic matter production. For example, the rate of plant production generally decreases as these landforms are heaved above the surrounding wetland, however, plant decomposition rates can increase. Hence, the drier surface conditions associated with these elevated features allow less peat deposition and more plant decomposition, especially with regard to the lichen-dominated palsas (Zoltai *et al.* 1988). Therefore, the diminished rate of phytomass productivity on the raised surfaces coupled with greater rates of organic matter decomposition ultimately resulted in lower rates of peat accumulation on palsas than in the adjacent wetlands.

In the study area, the lower-elevation shrub-dominated palsas experienced slightly greater rates of peat accumulation compared to the lichen-rich shrub-less features. This can be attributed to the amount of plant remains that were deposited; lichens contain no fibres and only leave trace amounts of residue, subsequently diminishing the amount of peat accumulated (Zoltai *et al.* 1988). Conversely, phytomass productivity on the shrub-dominated palsas can be slightly higher, and less prone to decomposition relative to the lichen-dominated features. Consequently, increased deposition rates coupled with less decomposition, ultimately induce higher rates of peat accumulation on the shrub-dominated palsas. Furthermore, in palsas, there was a progressive decrease in the rates of peat build-up with increased elevations. This may be linked to the positive lapse rates that occur during summer (Skaret and Kershaw 1994, in review), hence, the warmer lower-elevation sites may have been more conducive to peat accumulation.

Within the study area, aquatic peat and/or pond sediments were found above the tephra layer, implying that the formation of palsas at various sites (e.g. Dale Creek; Goose Flats; Beaver Pond; Porsild's Field as cited by Kershaw and Gill 1979) were thought to have commenced some time after the White River volcanic eruption. However, the stratigraphic profile at Hare Foot's apex indicates that the surface began to rise above the wetland approximately 335 years prior to the White River volcanic eruption. It should be noted that this formation date is only a rough estimate based upon the rate of peat accumulation between the xerophilous/hydrophilous peat contact zone and the bottom of the tephra layer at Hare Foot. Furthermore, this formation date excludes the impact that exogenous and endogenous variables can inflict upon peat thickness, thereby, influencing such a date. Ideally, a macrofossil radiocarbon date from the hydrophilous/xerophilous transition area would provide a more accurate datum to calculate accumulation rates.

2.7 Conclusion

All study features within this alpine tundra environment of Northwestern Canada were well defined as meso-scale permafrost landforms that were distinct from other features in morphology, surface cover, and internal composition. These features contained a peat cover that was affixed to the underlying silty soil. No evidence of cryoturbation was found in the cores and the frozen sections contained segregated ice, hence, stratigraphic analysis confirmed that these ice-rich periglacial features were palsas.

All sites contained a stratigraphic marker horizon (White River volcanic ash, 1250 years BP) that allowed peat accumulation rates to be calculated. The raised palsas had lower rates of peat accumulation than the surrounding wetlands. This was attributed to the drier conditions of the elevated surface which permitted higher levels of decomposition than peat deposition. Consequently, palsa surfaces were less conducive to peat formation than the surrounding wetlands. Aquatic peat occurred above the tephra layer, implying that most of these features began to develop within the last 1250 years, however, stratigraphic information suggests that one palsa initiated development approximately 300 years prior to the White River volcanic eruption.

In palsas, the magnitude of vertical displacement is directly related to the volume of frozen water, and it is speculated that the majority of ice lenses occurred below the depth of coring. The highest moisture contents were often associated with ice lenses or zones that inhibited water movement (permafrost table, peat/mineral interface). The thickest ice lenses developed in the basal peat and upper mineral zones and were related to the specific site conditions that drew capillary water towards the freezing zone. The rates of freezing were thought to decline with increased depth, therefore, water at depth had enough time to migrate towards the freezing zone, subsequently allowing the ice lens to grow. Conversely, the thinner ice lenses of the upper peat zones were associated with the higher rates of freezing that decreased the hydraulic conductivity, subsequently limiting lens growth. Hence, the majority of ice occurred lower in the feature and was linked to the greater cumulative heave associated with these soils. Thus conditions that dominated deeper within the palsas were primarily responsible for elevating the surface above the surrounding wetland.

2.8 References

Åhman, R. 1976. The structure and morphology of minerogenic palsas in northern Norway. *Biuletyn Peryglacjalny*, 26:25-31.

Åhman, R. 1977. Palsar i Nordnorge. *Meddelanden från Lunds Universitets, Geografiska Institution, Avhandlingar LXXVIII*, 165p.

Allard, M. and Seguin, M.K. 1987. The Holocene evolution of permafrost near the tree line, on the eastern coast of Hudson Bay (Northern Quebec). *Canadian Journal of Earth Sciences*, 24:2206-2222.

Allard, M., Seguin, M.K. and Lévesque R. 1987. Palsas and mineral permafrost mounds in northern Québec. In V. Gardiner (ed.) *International Geomorphology, Part II*. John Wiley and Sons, Chichester, pp. 285-309.

Anderson, D.M., Williams, P.J., Guymon, G.L. and Kane, D.L. 1984. Principles of soil freezing and frost heaving. In R.L. Berg and E.A. Wright (eds.), *Frost Action and its Control*. American Society of Civil Engineers, New York, pp. 1-21.

Beskow, G. 1935. *Tjälbildningen och tjällyftningen med särskild hänsyn til vägar och järnvägar*. Stockholm, 242 pp. Statens väginstitut, Stockholm, Meddelande 48. (Also published as Sveriges geologiska undersökning. *Avh. och Uppsats. Ser. C*, 375, and translated into English: Tech. Inst. Northwestern University, Evanston, Ill. November 1947.)

Brown, G. 1980. Palsa and other permafrost features in the lower Rock Creek Valley, west central Alberta. *Arctic and Alpine Research*, 12: 31-40.

Brown, R.J.E. and Péwé, T.L. 1973. Distribution of permafrost in North America and its relationship to the environment: a review, 1963-1973. *Proceedings of the Second International Conference on Permafrost, Yakutsk, USSR, North American Contribution*, Washington D.C., National Academy of Science, pp.71-100.

Chamberlain, E.J. 1981. *Frost susceptibility of soil and review of index texts. United States Army Cold Regions Research and Engineering Laboratory. Hanover, New Hampshire, Monogr. 81-82: 110 p.*

Cummings, C.E. and Pollard, W.H. 1989. An investigation of palsas in the Schefferville area, Quebec. *The Musk-Ox*, 37:8-18.

Dionne, J.C. 1984. Palses et limites méridionales du pergélisol dans l'hémisphère nord: le cas de Blanc-Sablon, Québec. *Géographie physique et Quaternaire*, 38:165-184.

Expert Committee on Soil Survey, 1983. The Canadian Soil Information System (CanSIS), Manual for describing soils in the field, 1982 Revised. Research Branch, Agriculture Canada, Ottawa.

Forsgren, B. 1968. Studies on palsas in Finland, Norway and Sweden, 1964-1966. *Biuletyn Periglacjalny*, 17: 117-123.

Head, K.H. 1980. Manual of Soil Laboratory Testing. Volume One: Soil Classification and Compaction Tests. Pentech Press, London. 339 p.

Kalra, Y.P. and Maynard, D.G. 1991. Methods Manual for Forest Soil and Plant Analysis. Forestry Canada, Edmonton, Alberta. Information Report NOR-X-319, 116p.

Kershaw, G.P. 1994. Personal Communications. University of Alberta, Department of Geography.

Kershaw, G.P. and Gill, D. 1979. Growth and decay of palsas and peat plateaus in the Macmillan Pass-Tsichu River area, Northwest Territories, Canada. *Canadian Journal of Earth Sciences*, 16(7):1362-1374.

Kershaw, G.P. and Kershaw, L.J. 1983. *Geomorphology and Vegetation of the MacTung Study Area, Yukon/NWT*. Report prepared for AMAX Northwest Mining Co. Ltd., Vancouver.

Kershaw, G.P. and Skaret, K.D. 1993. Microclimatic characteristics of palsas along an altitudinal gradient, Mackenzie Mountains, NWT, Canada. In *Proceedings Sixth International Permafrost Conference*, National Academy Press, Washington DC, pp. 338-343.

Lee, P.G., Ellis, R.A., and Achuff, P.E. 1982. Vegetation and flora of the Caribou Mountains, Alberta. *The Canadian Field-Naturalist*, 96(4): 389-408.

Lerbekmo, J.F., Westgate, J.A., Smith, D.G.W., and Denton. 1975. New data on the character and history of the White River volcanic eruption, Alaska. In R.P. Suggate and M.M. Cresswell (eds.) *Quaternary Studies. Royal Society of New Zealand*. pp. 203-209.

Linell, K.A. and Kaplar, C.W. 1959. *The factor of soil and material type in highway pavement design in frost areas: a symposium - Part 1, Basic Considerations*. Highway Res. Board Bulletin 225, 131 p.

Lunardini, V. 1981. *Heat Transfer in cold climates*. New York, Van Nostrand Reinhold. 731 p.

Lundqvist, J. 1969. Earth and ice mounds: a terminological discussion, In T.L. Péwé (ed.), *ThePeriglacialEnvironment: Past and Present*, McGill-Queen's University Press, Montreal, pp. 203-215.

Micromeritics 1991. SediGraph 5100 Particle Size Analysis System, Operator's Manual V3.01, Part No. 510-42801-01.

McKeague, J.A. (ed) 1978. Manual on Soil Sampling and Methods of Analysis. Second Edition, Canada Soil Survey Committee, Subcommittee on Methods and Analysis, Canadian Society of Soil Science, Ottawa, 212p.

Okruszko, H. 1976. Field methods of the peat decomposition degree determination in the three- and ten-grade scale. In Polish National Committee of International Peat Society, Commission I of IPS, Poland, pp. 27-30

Porsild, A.E. 1945. The alpine flora of the east slope of Mackenzie Mountains, Northwest Territories, *National Museums of Canada, Bulletin 101 (Biological Series, No. 30)*, Edmond Cloutier, Printer, Ottawa.

Pounder, E.R. 1965. *The Physics of Ice*. Pergamon Press, Oxford, New York, 151 p.

Railton, J.B. and Sparling, J.H. 1973. Preliminary studies on the ecology of palsa mounds in northern Ontario. *Canadian Journal of Botany*, 51: 1037-1044.

Salmi, M. 1968. Development of palsas in Finnish Lapland. In *Proceedings of the Third International Peat Congress, Ottawa*, National Research Council of Canada, pp. 182-189.

Salmi, M. 1970. Investigations on palsas in Lapland Finnish. In *Ecology of Subarctic Regions Proceedings of the Helsinki Symposium 1966*, UNESCO, Paris, pp. 143-153.

Seguin, M.K. and Crépault, J. 1979. Étude géophysique d'un champ de palses à Poste-de-la-Baleine, Nouveau-Québec. *Géographie physique et Quaternaire*, 33:327-337.

Seppälä, M. 1980. Stratigraphy of a silt-cored palsa, Atlin Region, British Columbia, Canada, *Arctic*, 33 (2): 357-365.

Seppälä, M. 1982. An experimental study on the formation of palsas. In *Proceedings of the Fourth Canadian Permafrost Conference*, National Research Council of Canada, Ottawa, pp. 36-42.

Seppälä, M. 1986. Origin of palsas. *Geografiska Annaler*, 68A(3), pp. 141-147.

Seppälä, M. 1988. Palsas and related forms. In M.J. Clark (ed.), *Periglacial Geomorphology*. John Wiley and Sons, Chichester, pp. 247-278.

Seppälä, M. 1990. Depth of snow and frost on a palsa mire, Finnish Lapland. *Geografiska Annaler*, 72A: 191-201.

Skaret, K.D. and Kershaw, G.P. 1994. Thaw characteristics on palsas in the Macmillan Pass-Tsichu River, N.W.T., Canada, in review.

Svensson, H. 1964. Structural observation in the minerogenic core of a pals. *Geogafisk Krönika*, 40:138-142.

Tarnocai, C. 1973. Soils of the Mackenzie River area. Environmental-Social Committee, Northern Pipelines. Task Force on Northern Oil Development. Report No. 73-26. 136p.

Vorren, K.D. 1972. Stratigraphical investigation of a palsa bog in Northern Norway. *Astarte*, 5: 39-71.

Vorren, K.D. 1979. *Vegetation investigation of a palsa bog in Northern Norway*. (Tromsø Museum's Report Series), Naturritenska. Nr. 5, 182 p.

Vorren, K.D. and Vorren, B. 1975. The problems of dating a palsa. Two attempts involving pollen diagrams, determination of moss subfossils, and C^{14}-datings. *Astarte*, 8: 73-81.

Williams, P.J. and Smith, M.W. 1989. *The Frozen Earth*. Cambridge University Press, New York, 306 p.

Wramner, P. 1973. *Palsmyrar i Taavavuoma, Lappland*. (Summary: Palsa bogs in Taavavuoma, Swedish Lapland). Göteborgs Universitets Naturgeografiskn Institutionen, Rapport, 3, 140 p.

Zoltai, S.C. 1972. Palsas and peat plateaus in Central Manitoba and Saskatchewan. *Canadian Journal of Forest Research*, 2:291-302.

Zoltai, S.C. and Tarnocai, C. 1971. Properties of a wooded palsa in northern Manitoba. ***Arctic and Alpine Research***, 3:115-129.

Zoltai, S.C. and Tarnocai, C. 1975. Perennially frozen peatlands in the western Arctic and Subarctic of Canada. ***Canadian Journal of Earth Sciences***, 12:28-43.

Zoltai, S.C., Tarnocai, C., Mills, G.F. and Veldhuis, H. 1988. Wetlands of subarctic Canada. In ***Wetlands of Canada. Ecological Land Classification Series, No. 24***, Sustainable Development Branch, Environment Canada, Ottawa, Ontario and Polyscience Publication Inc., Montreal Quebec. pp. 55-96.

3.0 Microclimatic Characteristics Associated with Palsas in an Alpine Tundra Environment, Macmillan Pass-Tsichu River Region, N.W.T., Canada *

3.1 Introduction

Palsas are a widespread periglacial phenomena that develop throughout wetlands such as fens or bogs of the discontinuous circumpolar permafrost zone. These features are meso-scale permafrost mounds that typically rise 1 to 7 m above the surrounding permafrost-free wetland, and generally, their maximum diameters are less than 100 m (Zoltai and Tarnocai 1975). However, palsas as high as 15 m have also been observed (Kershaw pers comm, 1990). Internally, palsas are composed of frozen non-cryoturbated peat and/or mineral soil (predominantly silty in texture), pore ice and segregation ice (Seppälä 1972). The critical factors that have been postulated to be responsible for the formation of these features are: cool climates, thin snow cover, surface peat cover and the availability of a water source (Forsgren 1968, Seppälä 1986, 1988, Zoltai 1972). The dynamic processes of ice segregation and pore ice freezing result in frost heaving events that elevate the surface above the wetland. These heaving processes and the associated effects they impose upon site-specific factors are responsible for creating these distinct landforms (as defined by morphology, surface cover and internal composition). Eventually, these features are destroyed, and degradation is the result of a disrupted microclimatic balance, brought about by changes in the vegetation cover, rates of water infiltration, snow cover thickness, and regional climates (Kershaw and Gill 1979). Hence, microclimate and the interacting influences it imposes upon site-specific factors can lead to the formation, maintenance, and degradation of palsas.

3.2 Regional Climates and Microclimates Associated with Palsas

The distribution of palsas has been correlated with various climatic parameters such as mean annual temperature and precipitation. The upper temperature limit for the formation of these features was thought to correspond to the 0°C mean annual isotherm (Åhman 1977, Brown 1970, Harris 1982, Seppälä 1988). The annual precipitation values associated with palsa environments vary with location. For example, the mean total precipitation differs from less than 400 mm year^{-1} in Finnish Lappland (Salmi 1968,1970) and Northern Norway (Åhman 1977), to approximately 700 mm year^{-1} in central Iceland (Schunke 1973) and up to 800 mm year^{-1} along the Labrador coast (Roberts and Robertson 1980).

The extent of palsas has also been estimated by using freezing and thawing indices. Harris (1982) suggested that palsas occur within the 1000 to 7500 freezing-degree-day total (Fddt) range and the 300 to 2300 thawing-degree-day total (Tddt) range. Seppälä (1988), however, proposed that the range for more representative values of "normal palsa regions" are 1000-4000 Fddt and 1000-2300 Tddt. It should be noted that the majority of Seppälä's work has been in Finland where there can be a significant maritime influence to the climate, whereas, Harris's paper dealt with North American climatic normals.

There have been numerous studies that have extrapolated palsa field temperatures from local weather stations (e.g. Åhman 1977, Brown 1967, Dionne 1984, Lagarec and Dewez 1990, Priesnitz and Schunke 1978), and a number of papers that have dealt with short-term core temperatures (e.g. Cummings and Pollard 1989, 1990, Kershaw and Gill 1979, Nelson et al. 1985, Seguin and Allard 1984). However, only a few studies have measured the actual climatic and/or microclimatic parameters of palsas or similar permafrost features on an annual basis (e.g. Allard and Fortier 1990 for peat plateaus, Lindqvist and Mattsson 1965 for palsas); moreover, very few investigations have focused on the annual microclimatic characteristics of palsas in alpine environments (e.g. Kershaw and Skaret 1993). Consequently, the lack of research on palsas in mountainous environments; especially with respect to their microclimatic characteristics and the influence they impose upon palsa site conditions proved to be the partial motive for the study. The objective of this study was to quantify various annual microclimatic attributes associated with palsas in alpine environments. In addition, the differences in microclimatic

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characteristics that are associated with palsa along altitudinal gradient will be discussed.

3.3 Study Area

The study area is located in the Macmillan Pass-Tsichu River-Mackenzie Mountain Barrens region of the Northwest Territories, Canada (Figure 1.2). Macmillan Pass is 1350 m asl and straddles the Yukon-Northwest Territories border in the discontinuous permafrost zone. This area has a Continental climate that is influence by mountains. Climate in the study area has been described, based on 8 years of data as having a mean annual temperature of -7.7°C and an average precipitation of 490 mm (Kershaw and Kershaw 1983). The average annual snowfall is 294 cm and during mid-winter the snowpack varied from discontinuous on windswept sites, to greater than 2.0 m in areas that collected drifting snow (Kershaw and Kershaw 1983).

Palsas were first described in the vicinity of the study area by Porsild (1945) while he was conducting botanical studies. Later, Kershaw and Gill (1979) conducted more detailed investigations at the same site described by Porsild (1945), in addition to a number of other palsa fields located throughout the study area. Kershaw and Gill (1979) determined that, possibly due to an amelioration of the regional climate, palsas had experienced degradational processes and were reduced in their overall area by 34 to 100%, over a 30 year period that ended in 1974.

The study area chosen for this project encompassed that investigated by Kershaw and Gill (1979). However, the four palsa fields selected for this investigation, occur over a larger area than those examined by Kershaw and Gill (1979). These palsa fields were selected during early July 1990 and were located approximately 5 km northwest to 32 km east of Macmillan Pass, and occur over a 410 m altitudinal gradient. The sites were named Goose Flats, Dale Creek, Beaver Pond, and Hare Foot (Figures 1.3-1.7).

3.4 Methods

Analysis of microclimate data was based on one 365-day period beginning 1 August 1990 and ending 31 July 1991. Automated dataloggers (Campbell Scientific CR10) were installed at each site and used to monitor ground and ambient temperatures, wind speed, radiation, and rain. Thermocouples were installed at the apex of each palsa to measure air, surface and core temperatures. These sensors were positioned on the palsa at +150 cm, 0.0 cm, and in the feature at 2.5 cm, 5 cm, 150 cm and in the wetland at 5 cm and 150 cm for each site; in addition, palsa core temperatures were also recorded at 160 cm (Goose Flats), 215 cm (Dale Creek, Hare Foot), and 385 cm (Hare Foot). Temperatures were also recorded for the dominant surface cover, and these measurements were taken near the top of each palsa at a depth of 5 cm, as well as three other positions (bare peat always, tussock base, tussock top, thin snowpack slope as determined by the shrub leader kill zone, moss polster, lichen mat). At every sensor position the mean daily values were determined each day (288 readings at 5 minute scan intervals).

Rain gauges and pyranometers were installed at every site except Hare Foot. Only the 24 h summary data are presented here. The annual thawing and freezing-degree-day totals were calculated by summing all > and < 0°C temperature values during the one year period. Gaps in the data were left as blank spaces on the illustration, and the length of these gaps were noted in Table 3.1.

3.5 Results

The Beaver Pond station was damaged shortly after leaving the study area during the 1990 field season. Data were lost when an animal cut the cable connecting the solar cell to the power supply, and as a result of this action the Beaver Pond site was dropped from all microclimatic analysis. At the Hare Foot site an animal tore out the sensors from the wetland during mid-April, and during mid-June a grizzly bear knocked down the anemometer mast at Dale Creek. At Goose Flats an animal ripped out the wetland sensors during late July and, furthermore, rain was not recorded between 3 July and 5 August 1991.

3.5.1 Air Temperature

The mean annual air temperatures were similar at all three palsa sites and the difference in these temperatures was only 0.7 C°. The minimum mean annual air temperature was -7.4°C and it occurred at both the lowest (Hare Foot) and highest (Goose Flats) elevation sites, whereas, the maximum mean temperature was -6.7°C and it occurred at the mid-elevation site (Dale Creek) (Table 3.1). Both the extreme maximum (15.8°C) and minimum (-44.6°C) air temperatures occurred on the lowest elevation feature. There was only minor variation in

	Annual Temperature								
	Air on Palsa Top	Palsa Top with Plants		Bare Peat	Palsa Core	Fen		Wind (m·s⁻¹)	Total Rain (mm)
	+150 cm	Surface	-5.0 cm	-5.0 cm	-150 cm	-5.0 cm	-150 cm	+150 cm	
Goose Flats (1660 m)									
Mean	-7.37	-3.43	-3.31	-4.01	-1.55	1.37	0.87	2.69	142.24
Maximum	13.6	12.4	10.9	12.95	0.5	13.2	3.7	7.3	
Minimum	-34.5	-20.9	-19.4	-23.5	-3.7	-1.1	-1.1	NA	
Days of record	365	364	365	365	365	365	356	357	
Thawing- degree-days	695.3	747.2	654.9	781.4	7.9	556.2	343.6		
Thawing days	123	133	136	134	38	197	263		
Freezing-degree-days	3385.2	1996.7	1862.9	2243.4	572.2	69.4	32.3		
Freezing days	242	231	229	231	327	159	94		
Dale Creek (1480 m)									
Mean	-6.69	-3.18	-3.1	1.14	-2.85	1.83	1.98	2.35	113.03
Maximum	15.4	13.6	11.8	15.4	-0.7	13.1	3.1	10.2	
Minimum	-42.7	-22.2	-20.8	-6.8	-6.5	-1.0	0.0	NA	
Days of record	365	365	365	365	365	365	365	345	
Thawing-degree-days	906.8	797.6	715.2	946.0	0.0	753.3	720.1		
Thawing days	139	131	132	142	0	154	364		
Freezing-degree-days	3354.8	1963.7	1853.4	537.6	1038.4	96.6	0.0		
Freezing days	226	234	233	223	365	210	0		
Hare Foot (1250 m)									
Mean	-7.37	-4.25	-3.43	-2.73	-2.52	0.97	1.49	2.39	NA
Maximum	15.8	18.6	13.9	14.95	-0.6	14.3	3.5	11.1	
Minimum	-44.6	-30.9	-22.0	-12.6	-6.5	-1.9	0.1	0	
Days of record	365	365	365	287	365	287	287	365	
Thawing-degree-days	1041.5	1176.0	917.1	351.2	0.0	500.0	428.8		
Thawing days	146	147	148	56	0	71	287		
Freezing-degree-days	3731.6	2728.3	2162.7	1134.8	920.8	221.8	0.0		
Freezimg days	219	218	217	231	365	216	0		

Table 3.1. Summary of several microclimatic parameters measured on three palsas over the 1 August 1990 to 31 July 1991 period in the Macmillan Pass-Tsichu River region, N.W.T.

the maximum air temperatures (2.1°C), however, a 10.1 C° difference was recorded between the minimum temperatures (Table 3.1). The warmest minimum temperature occurred on the highest elevation site, whereas the coolest minimum temperature was recorded at the lowest elevation location (Table 3.1). Seasonal temperatures were differentiated by thawing (summer) and freezing (winter) temperatures. Winter temperatures were defined as the consecutively negative mean daily values that began in the Fall (1990) and concluded with the first positive temperatures of Spring (1991); summer temperatures were defined as the continuously positive values that began in Spring (1991) and lasted until Julian Day 238 (26 August 1991). During the thaw season, the lowest elevation valley site was on average 2.66 C° warmer than the upper plateau location (Table 3.2a). However, during winter, the lowest-elevation palsa field was on average 2.04 C° cooler than the upper plateau site (Table 3.2a).

The fall freeze-back period commenced on or shortly after 26 September 1990 at all three palsa sites. During the following spring, the switch from positive to negative air temperatures was relatively rapid at the lowest elevation site, however, at the upper plateau site this temperature change was stretched out for approximately one month (Figure 3.1).

3.5.2 Palsa Surface and Near-surface Temperatures

At the apex of each feature, the mean annual surface (0 cm) and near-surface temperatures were 3.12° to 3.94 C° warmer than their respective air temperatures (Table 3.1). Variations during the winter period, however, were even larger, and the range in minimum near-surface ground temperatures were from 15.2° (Goose Flats at 5 cm) to 22.6 C° (Hare Foot at 5 cm) warmer than their respective minimum air temperatures (Table 3.1). The minimum mean annual surface temperature was -4.25°C and it occurred at the lowest elevation palsa; whereas, the maximum average surface temperature was -3.18°C and was recorded at the mid-elevation palsa. The extreme maximum and minimum surface temperatures both occurred at the lowest elevation site (Hare Foot), and these values were 2.87° (maximum) and 13.67°C (minimum) warmer than their respective air temperatures (Table 3.1).

During the winter season the mean minimum surface temperature was -12.76°C and it occurred at the lowest elevation valley site, whereas the warmest average surface temperature was -8.76°C and it occurred at the upper plateau site (Table 3.2a) The greatest variation between the mean winter surface and air temperatures was 6.5 C° (Goose Flats and Dale Creek 2), whereas the minimum difference was 4.5 C° (Hare Foot) (Table 3.2a). During the thaw season the average maximum surface temperature was 8.92°C and was recorded at the Hare Foot site; whereas the coolest summer surface temperature was 6.07°C and it occurred at Goose Flats (Table 3.2a). All palsa surfaces had greater mean summer temperatures compared to their respective ambient temperatures, and the largest variation between these values was 1.09 C° (Hare Foot), whereas the minimum difference was only 0.03 C° (Dale Creek 2) (Table 3.2a).

The difference in the mean annual near surface temperatures were minor. At a depth of 2.5 cm there was only a 0.37 C° difference between sites, whereas, the variation in temperature at 5.0 cm was 0.33 C° (Table 3.1). During the winter period the minimum mean 2.5 and 5.0 cm temperatures occurred at the lowest elevation feature. However, during the thaw season the minimum mean temperatures at 2.5 and 5.0 cm occurred at the highest elevation site (Table 3.2a). The minimum mean annual and extreme minimum bare peat temperatures were -4.01° and -23.5° respectively, and both these values occurred at the highest elevation palsa (Goose Flats) (Table 3.1). During winter, the upper-elevation bare peat sensor was subjected to minimum temperatures that were up to 16.7 C° cooler (Table 3.1) and mean temperatures that were 4.95° (Hare Foot) to 7.43 C° (Dale Creek 2) cooler than those encountered at the lower-elevation palsas (Table 3.2a). During the thawing season the maximum mean bare peat temperature was 8.98° (Goose Flats), and this was 3.3° warmer than its respective apex value (Table 3.2a).

3.5.3 Core Temperatures

The internal portions of a palsa that are perennially frozen are referred to as the core, and the phrase *core temperatures* is considered to be synonymous with "ground or soil temperatures". The maximum mean annual core temperature was -1.55°C (150 cm) and this occurred at the highest elevation site (Table 3.1). The minimum mean annual core temperature at 150 cm was -2.85°C, and it was recorded at the mid-elevation palsa field. The maximum variation in the mean annual core temperatures (150 cm) for an individual palsa occurred at the lowest elevation site, and the temperature range was 5.94 C° (Table 3.1).

The extreme minimum core temperature was -6.54°C and this occurred at 150 cm in the lowest elevation valley palsa, whereas the extreme maximum core temperature was 0.49°C and it was recorded at 150 cm in the upper plateau palsa. The maximum difference between the winter and summer mean core temperatures in an individual palsa was 1.88 C° (Dale Creek), whereas the minimum variation was 0.44 C° (Goose Flats) (Table 3.2a). The deepest sensor was located in the lowest elevation feature (Hare Foot) at a depth of 385 cm. The mean

Mean Temperatures (°C) at

PALSA

	Sensor Depth (cm)								
Palsa	+150	0.0	-2.5	-5.0	-150	-160	-215	-385	-BP-5
Goose Flats (1660 m)									
Winter	-15.29	-8.76	-8.22	-8.10	-1.77	-1.67	NS	NS	-9.88
Summer	5.17	6.07	5.52	5.68	-1.33	-1.34	NS	NS	8.98
Dale Creek 2 (1480 m)									
Winter	-15.29	-8.80	-8.29	-8.02	-3.62	NS	-2.96	NS	-2.45
Summer	6.77	6.80	6.92	6.22	1.74	NS	-2.10	NS	6.73
Hare Foot (1250 m)									
Winter	-17.33	-12.76	-10.76	-9.97	-3.37	NS	-2.81	-1.85	-4.93
Summer	7.83	8.92	6.85	6.85	-1.54	NS	-1.72	-1.71	SD

NS= No Sensor, SD= Sensors down, BP= Bare Peat

Table 3.2a. Mean winter (Fall 1990 to Spring 1991) and summer (first thaw temperatures from Spring 1991 to Julian Day 238) temperatures on palsas in the Macmillan Pass-Tsichu River region N.W.T.

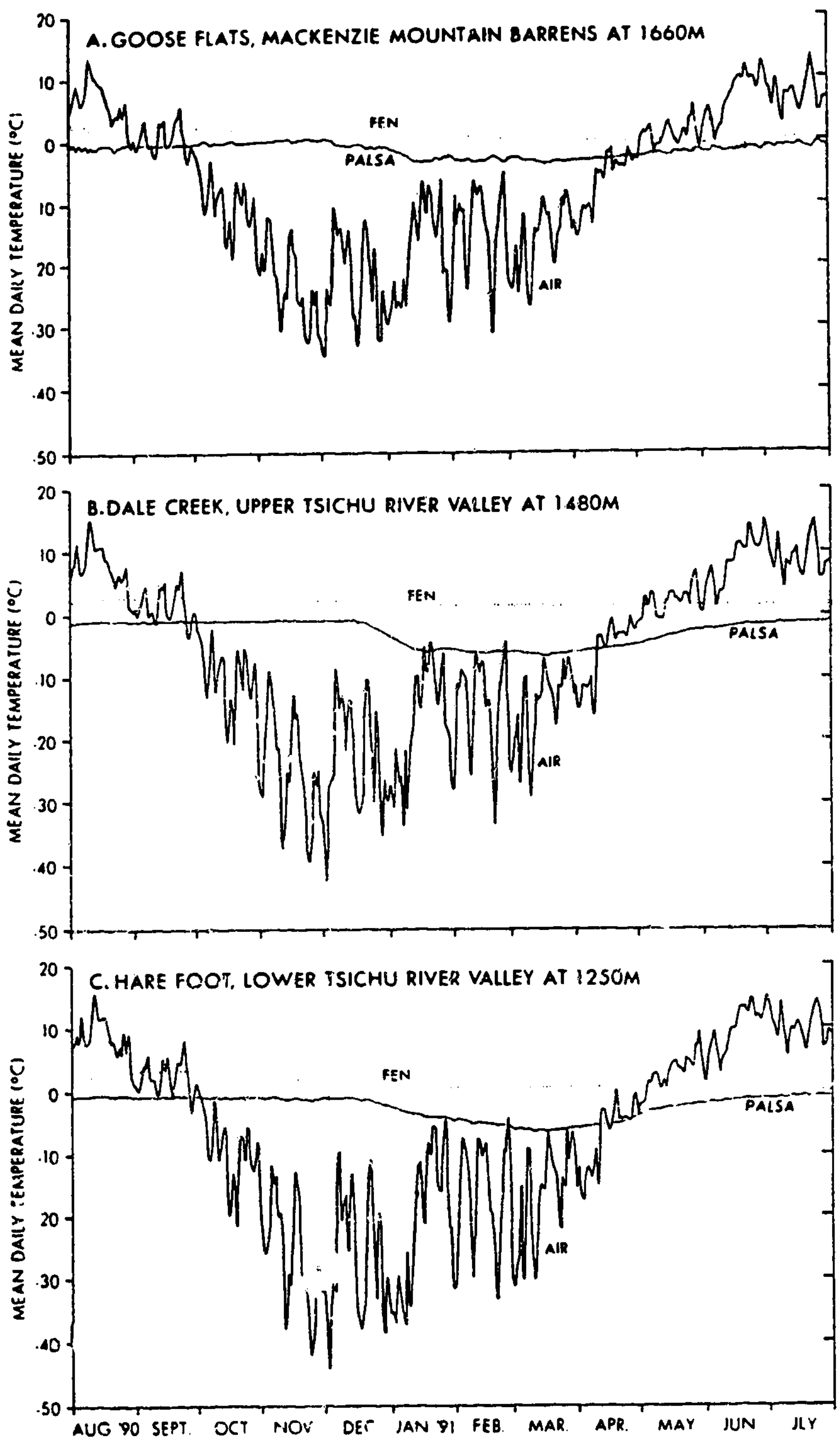

Figure 3.1. Air, wetland and palsa temperature data for 3 palsa study sites in the Macmillan Pass-Tsichu River region, N.W.T.

winter temperature at this position was 1.52 C° and 0.86 C° warmer than the core sensors located at 150 cm and 215 cm respectively, however, the differences in the summer core temperatures (385 cm) were much closer; core temperatures were only 0.01° cooler at the 215 cm sensor and 0.17° warmer at the 150 cm position (Table 3.2a). There was a 3.6 C° difference in the minimum core temperatures between the 150 cm and 385 cm sensor positions. The maximum core temperature at 385 cm was 0.37 C° cooler than that recorded at 150 cm. The variation between the mean summer and winter core temperatures at 385 cm was only 0.14 C°, whereas these differences at 150 cm and 215 cm were 1.83 C° and 1.09 C° respectively (Table 3.2a).

The annual temperature range within the core fluctuated much less than the above ground temperature oscillations. The maximum annual ambient air temperature range was 60.33°, whereas those at the surface, 5.0 cm and 150 cm were 49.53°, 35.87° and 5.94° respectively; moreover, all these maximum temperature ranges occurred at the lower-elevation palsa. However, all the minimum annual temperature ranges were experienced at the upper-elevation feature (Table 3.1 and Figure 3.2)

The minimum temperature time lag between the surface and the core (150 cm) was 10 days (Hare Foot), whereas, the lag interval between these positions in the upper elevation palsas was 69 at Dale Creek 2 and 70 days at Goose Flats. It should be noted the relatively short duration (10 days) in the surface to core minimum temperature lag may be a misinterpretation of the actual temperature wave effect. Although, the minimum surface temperature was -30.91° on 1 March 1991; a surface temperature of -30.02° occurred on 28 December 1990. The latter temperature may be more representative of the actual temperature lag, subsequently, the minimum temperature lag (surface to core) would then be 73 days. The maximum temperature influence at 150 cm within the palsa was experienced in late September for the lower-elevation feature, but not until mid to late November at the upper-elevation features (Table 3.3a).

3.5.4 Wetland Temperatures

Both the maximum mean annual 5 and 150 cm wetland temperatures occurred at the mid elevation Dale Creek palsa field, and there was only a 0.15 C° difference between these two depths (Table 3.1). The minimum mean annual wetland temperatures at 5 and 150 cm were 0.97°C (Hare Foot) and 0.87°C (Goose Flats) respectively. The maximum and minimum 5 cm wetland temperatures both occurred at the lowest elevation site, and their respective temperatures were 14.3° and -1.9°C (Table 3.1). However, the maximum and minimum 150 cm wetland temperatures both occurred at the highest elevation site (Goose Flats), and this was the only wetland that experienced freezing temperatures at this depth (Table 3.1). The duration of negative temperatures in the wetland (150 cm) adjacent to Goose Flat persisted from mid-May to early July.

During the winter season, the mean 5 cm temperatures were at least 7.6 C° warmer than their respective palsa apex values, and 1.3 C° warmer during the thaw period (Table 3.2a, 3.2b). It should be noted that the Hare Foot sensors were out of commission for approximately 85 days during the thaw season; therefore these values were excluded from analysis. The minimum near-surface (5 cm) annual temperature fluctuations were 16 C° less in the wetlands compared to those encountered at palsa apex positions. The mean wetland temperatures at 150 cm were still warmer than the palsas, however, the palsa and wetland temperature fluctuation rates were closer, and only varied by a maximum value of 3.79 C° (Table 3.2a, 3.2b).

3.5.5 Thawing and Freezing Indices

The accumulated thawing-degree-day totals (Tddt) were the greatest for the air (+150 cm) and surface (0.0 cm) sensor positions. The maximum Tddt at +150 cm and 0.0 cm both occurred at the lowest elevation site and these values were 1041.5° and 1176.0° respectively; whereas, both the minimum air and surface Tddt occurred at the highest elevation site and were 346.2° (at +150 cm) and 428.8° (at 0.0 cm) cooler than the lowest elevation palsa (Table 3.1). Generally, sensors that were located deeper in the feature had lower Tddt (Figure 3.3). However, the near surface bare peat sensors (5 cm) that recorded an entire year of data (Goose Flats and Dale Creek 2) had a higher number of thawing-degree-days than the near surface (0.0 and 5 cm) sensors beneath a plant cover (Table 3.1). The upper plateau palsa (Goose Flats) was the only feature that had positive core temperatures. However, the accumulated number of thawing-degree-days was only 8.10° at the 160 cm sensor; positive values occurred over a 37-day-period commencing 4 October 1990.

The trend in freezing-degree-day totals (Fddt) was for the higher accumulated values to occur at the air (+150 cm) and surface (0.0 cm) sensor positions (Figure 3.3). The highest Fddt were recorded at the +150 cm sensors; the maximum total was 3731.6° and this occurred at the lowest elevation site, whereas the minimum value was 3354.8° and was recorded at the mid-elevation site (Table 3.1). Generally, the lower-elevation site had the highest Fddt except at the 5 cm bare peat (Goose Flats) and 150 cm (Dale Creek 2) sensors (Table 3.1). The Fddt

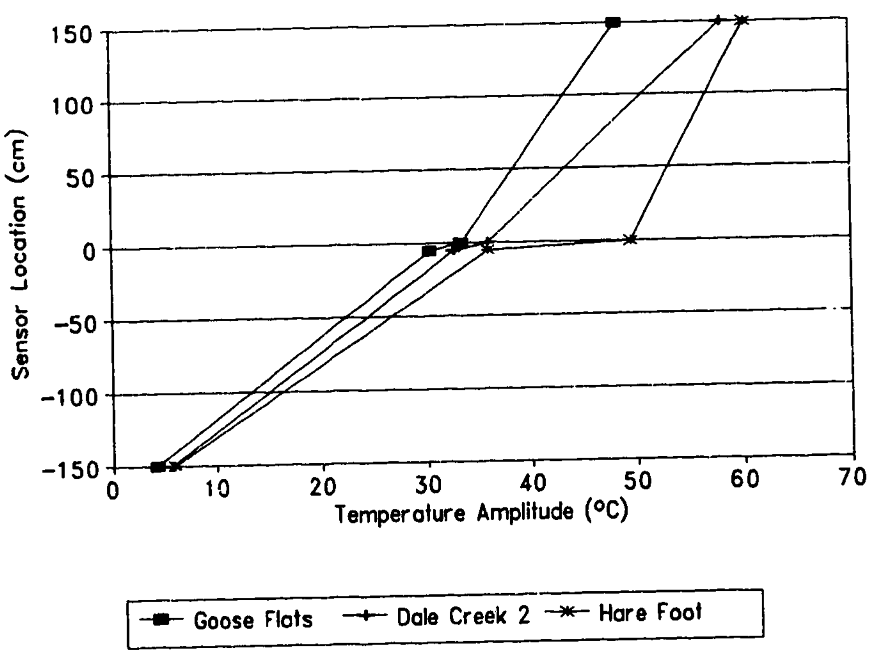

Figure 3.2. Annual temperature amplitudes at various heights and depths for 3 palsas in the Macmillan Pass-Tsichu River region, N.W.T.

Mean Tempertures (°C) at WETLAND		
	Sensor Depth (cm) -5.0	-150
Goose Flats (1660 m)		
Winter	-0.52	-0.30
Summer	7.19	3.38
Dale Creek 2 (1480 m)		
Winter	-0.40	1.76
Summer	7.59	1.93
Hare Foot (1250 m)		
Winter	-1.03	1.00
Summer	SD	SD

SD= Sensor Down

Table 3.2b. Mean winter (Fall 1990 to Spring 1991) and summer (first thaw temperatures from Spring 1991 to Julian Day 238) temperatures associated with wetlands in the Macmillan Pass-Tsichu River region N.W.T.

Maximum/Minimum Temperatures Associated with Julian Day

	Palsa Sensor Depth (cm)		
	0.0	-5.0	-150
Goose Flats (1660 m)			
Maximum Temperature	181	223	328
Minimum Temperature	7*	7*	77*
Dale Creek 2 (1480 m)			
Maximum Temperature	182	182	314
Minimum Temperature	7*	7*	76*
Hare Foot (1250 m)			
Maximum Temperature	181	182	265
Minimum Temperature	60*	60*	70*

*= 1991 dates

Table 3.3a. Temperature lags associated with palsas in the Macmillan Pass-Tsichu River region N.W.T.

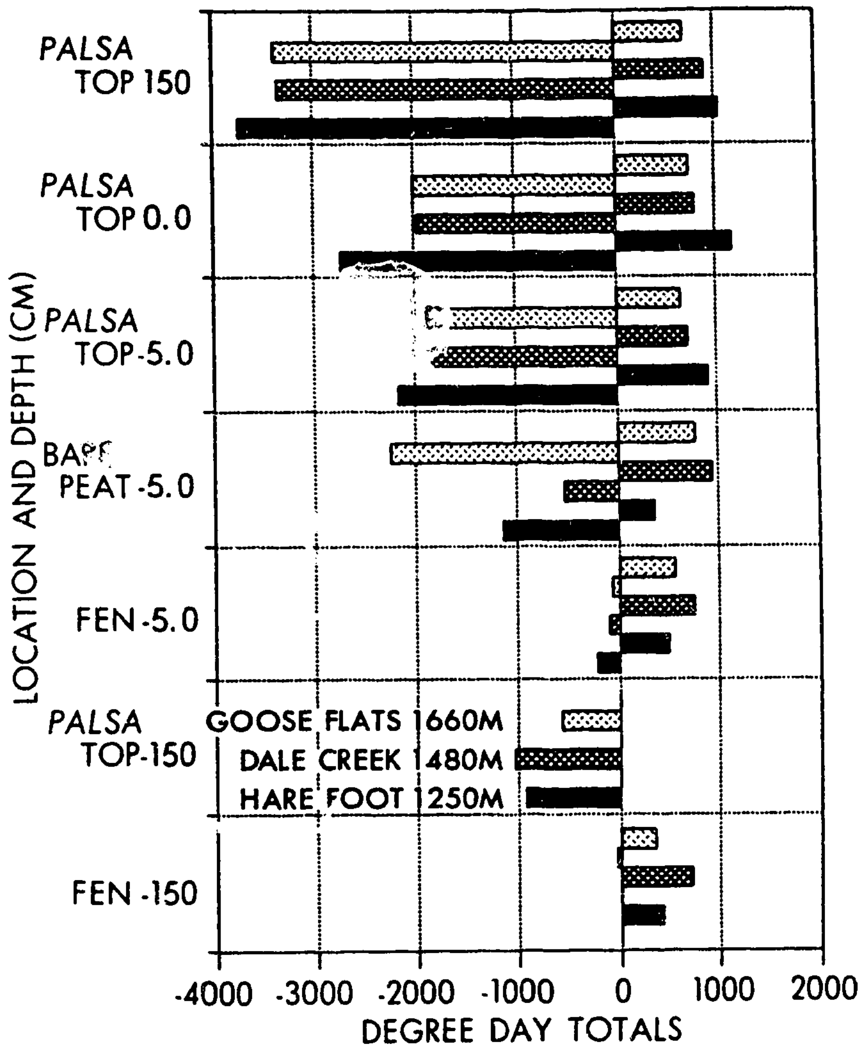

Figure 3.3. Thawing and freezing indices at various heights and depths for 3 palsas and adjacent wetlands in the Macmillan Pass-Tsichu River region, N.W.T.

accumulated values decreased with increasing sensor depth, with the exception of the 5 cm bare peat sensors at upper-elevation palsa and mid-elevation sites (Figure 3.3). Within the mid-elevation palsa the 150 cm Fddt were 466.2° higher than the upper site and 117.6° greater than the lowest-elevation palsa; the 215 cm Fddt were 113.3° higher than Hare Foot's.

The freezing indices in the wetland were substantially lower than those in the palsa (Figure 3.3). In the fen, the Fddt for the near surface (5 cm) sensors were the highest at the lower-elevation site, and lowest at the upper-elevation location (Table 3.1). There were no freezing-degree-days recorded at the 150 cm sensor in both the Hare Foot and Dale Creek wetlands, however, temperatures in the wetland at the upper plateau site were below freezing for 94 days.

3.5.6 Wind Speed

The mean annual wind velocities were similar at all three palsa sites, and there was only a 0.33 $m \cdot s^{-1}$ difference between the mean maximum and minimum wind speeds (Table 3.1). The mean annual wind speeds were highest at the upper-elevation site, yet, the maximum value at this site was 4 $m \cdot s^{-1}$ slower than that recorded at the lowest elevation palsa (Table 3.1). The valley sites experienced the extreme maximum wind velocities on the same day (26 January 1991), however, the lowest elevation sites had slightly higher values (Table 3.1). The seasonal wind characteristics were similar at each site, however, the mid-elevation location experienced mean wind velocities that were approximately 1 $m \cdot s^{-1}$ faster during the winter than in the summer (Table 3.4).

During winter, both Goose Flats and Hare Foot had periods of relatively calm wind conditions. At the upper plateau site the wind speeds were relatively calm between mid-December and mid-January; whereas Hare Foot experienced three separate periods of reduced wind (20-28 November, 1990; 15-20 December 1990; and 28 December 1990 to 11 January 1991) (Table 3.4).

3.5.7 Rain

It should be noted that one month of data was missing from the upper plateau site (Goose Flats), consequently, there was an underestimate in the actual rainfall for this station. However, even with one month of rainfall data missing, the upper-elevation site had 29.21 mm more rain than the Dale Creek site (Table 3.1).

3.6 Discussion

Wetland environments that are conducive to the development and maintenance of palsas tend to exhibit similar characteristics (e.g. cold climates, thin snow cover, peat cover, access to a water source). These general traits, however, engender different responses depending upon the various site-specific factors dominating the geomorphic processes (e.g. snow cover thickness and density, albedo, slope angle, aspect, soil moisture conditions, plant cover type and density, peat thickness, water quantity, relief, temperature, precipitation, wind, insolation, soil texture etc.). The intensity and duration of the aforementioned variables are highly dependent upon the season and status of the palsa (e.g. incipient, disequilibrium aggradational, dynamic-equilibrium, disequilibrium degradational), yet, microclimatic characteristics can influence all phases of the evolutionary process. Furthermore, each stage has unique microclimatic attributes that play key roles in the geomorphic evolution of a palsa.

Microclimatic parameters associated with palsas in the alpine tundra environments of the Selwyn and Mackenzie Mountains have been described on both a short-term (Kershaw and Gill 1979) and annual basis (Kershaw and Skaret 1993). From 1974 to 1982, the regional climate within the study area warmed by 3.5 C°, and temperatures at Ross River from 1968 to 1992 increased by 3.6 C° (Liang and Kershaw 1994, in press). This warming trend was thought to be partially responsible for the degradation of various palsas within the study area (Kershaw and Gill 1979). However, the geomorphic evolution of palsas is highly dependent upon the site-specific factors associated with each feature, therefore, the thermal characteristics of palsas may be influenced on both a regional and local basis. Consequently, each palsa can exhibit unique microclimatic traits, and therefore, in a region, the status of the features will not necessarily be identical.

3.6.1 Air Temperature

The elevation difference between the lower and upper sites (410 m) should have accounted for a cooling of approximately 2.62 C°, based on an adiabatic cooling rate of 0.64 C° 100 m^{-1}, nevertheless, the measured mean annual air temperatures at these locations were identical. However, substantial differences between the upper- and lower-elevation air temperatures did occur when these annual values were split into seasonal periods (summer thawing vs. winter freezing) (Table 3.2a). It should be noted that the distance between the lower valley site and the upper plateau location (<15 km) was not sufficient cause for differences in the synoptic weather system, yet, seasonal temperature variations between these sites were common. During summer, adiabatic cooling processes kept the upper-elevation site cooler, therefore this location had fewer thawing-degree-days. Hence, the mean summer air temperature at the upper-elevation site was 2.66 C° cooler than the lowest-elevation location. Therefore, the higher-elevation site had a mean positive regional environmental lapse-rate of 0.65 C° 100 m^{-1}, which is extremely close to the normal environmental lapse-rate.

In contrast to the mean atmospheric temperatures of summer, those of the winter season were almost the exact opposite, with the lower-elevation site experiencing cooler temperatures. Therefore, in winter there was a negative mean regional environmental lapse-rate. The cooler temperatures associated with the valley sites were a direct result of the cold air drainage processes that occurred throughout winter, hence, pronounced cooling episodes in the valleys led to a greater number of freezing-degree-days (Kershaw and Skaret 1993). These events resulted in the lower-elevation palsa being cooler on both a seasonal and annual basis, with the mean winter air temperature being 2.04 C° cooler than the upper-elevation palsa. Additionally, winter cooling events led to a maximum ambient difference of 10.1 C° between the upper- and lower-elevation sites. These temperature inversions were a common winter phenomena that ultimately influenced regional atmospheric temperatures. Thus, air density stratification in alpine areas played an important role on influencing the microclimate of palsa-sites.

3.6.2 Palsa Surface and Near-surface Temperatures

Generally, seasonal surface and near-surface temperatures were warmer than ambient air values, however, the atmosphere to surface temperature amplitudes were much larger during the winter (Table 3.2a). These differences were attributed to near-surface energy exchanges, and reflect the influence that the boundary layer imposes upon the ground thermal regime (Luthin and Guymon 1974).

During winter, the snow acts as a buffer layer that is interposed between the surface and the atmosphere (Luthin and Guymon 1974). This buffer layer isolates the ground from daily ambient temperature fluctuations and acts as a barrier to heat loss, subsequently, ground temperatures tend to be warmer underneath a snowpack in comparison to those values above the snow layer (Gold 1963; Steppuhn 1981; Willams and Smith 1989). Similar conditions prevailed at all the instrumented palsa sites, hence, warmer ground temperatures were recorded relative to their respective atmospheric values (Table 3.2a, 3.2b). These warmer ground temperatures were thought to be the result of the damping effect that a snow layer imposes upon the heat flux. It should be noted that snow depths were not measured, there were however, observations made during a site visit in May 1992, which revealed that each palsa top had a snow cover, and moreover, the leeward side of Dale Creek 2 and Hare Foot experienced relatively deep (approximately 3 to 4 m) snow drifts (Kershaw pers. comm. 1992) (Figure 3.4). These snow drift sites imparted a significant influence upon the near-surface thermal regime. For example, sensors (5.0 cm bare peat at both Dale Creek 2 and Hare Foot) located beneath the drift sites experienced mean winter temperatures that were approximately 5 C° warmer than their respective apex values (Table 3.2a). At the apex of each feature, the snow cover was thought to be relatively thin compared to the drift sites. Consequently, the heat flux from the palsa top would have been more efficient than from the drift sites, thus, greater apex heat loss rates resulted in cooler near-surface temperatures. Goose Flats had a more moderate climate compared to the two lower sites (Kershaw and Skaret 1993), however, its bare peat sensor was subjected to cooler winter temperatures. This may have been the result of sensor position, since, the bare peat sensor at Goose Flats was located in close proximity to the apex of the feature where thinner snow covers may have developed. Hence, apex heat loss would have been greater than that experienced beneath the relatively deep snow drifts on the two lower sites. This difference confirms the importance of site-specific factors and their influence upon the near-surface thermal regime. Thus, the buffering qualities of the near-surface boundary layer were found to profoundly moderate winter ground temperatures.

The extreme differences between atmospheric and surface temperatures in winter contrast with their relative similarity during the summer (Table 3.2a). In summer, the buffering effect of the plant canopy can keep surface temperatures warmer than atmospheric values (Cernusca and Seeber 1981). This was found to be the case within the study area, hence, slightly warmer surface conditions prevailed at all the palsa sites, and this was most pronounced on the shrub dominated feature (Hare Foot) (Table 3.2a). The dense shrub cover coupled with a thick lichen/moss mat may have prevented rapid radiative losses by reemitting and holding longwave radiation within the canopy (internal boundary layer). This trapped energy may have reduced the heat loss rates and maintained warmer surface temperatures during the summer (Table 3.2a). Therefore, near-surface buffering mediums protected the surface from extreme ambient temperature fluctuations and imposed a moderating influence upon surface temperatures, thus daily surface maximums were lowered and night-time minimums were raised. Dale Creek 2, however, had a thin surface plant cover that permitted a more direct linkage between the atmosphere and surface temperatures, subsequently, this palsa lost heat more efficiently, and thus, experienced surface temperatures

Figure 3.4. A 3-4 m snow drift on the leeward side of the Hare Foot palsa. This snow drift covered the bare peat and wetland sensors. *Photo:* G.P. Kershaw

that were closer to its ambient air values.

During summer, however, the direct effect that vegetation imposed upon the ground thermal regime was not as important as the role it played in trapping snow during winter (Annersten 1964; Smith 1975; Rouse 1984). Consequently, the ratio between air and surface temperatures was larger during winter, especially in regions that had a relatively thick snow cover (e.g. palsa edge locations and wetlands). Nevertheless, seasonal boundary layers had a significant effect upon the local ground thermal regime, however, atmospheric conditions (cold air drainage and adiabatic cooling) also had an important role in affecting ground temperatures on a regional scale.

3.6.3 Palsa Core Temperatures

The temperatures within the ground fluctuated on an annual basis much like those above the surface, however, the amplitude of this oscillation decreased with depth. Steep temperature gradients occurred at all the near-surface locations with a relatively sharp inflection occurring somewhere between 5.0 and 150 cm, at which point the annual temperature fluctuations became closer (Figure 3.2). Fluctuation rates beyond 150 cm were even closer, and at 385 cm (Hare Foot) the annual temperature amplitude was <2 C°.

The significant decrease in the annual temperature range with increasing depth, is the result of the temperature wave effect (Williams and Smith 1989). Generally, as the temperature wave propagates downward from the palsa surface into the core of the feature, the intensity of the wave tends to diminish with increasing depth, hence, core temperatures are influenced accordingly. Furthermore, the influence of the temperature wave is delayed with increased depths, thus positions located deeper in the ground experienced a longer lag (Sellers 1965; Williams and Smith 1989) (Table 3.3a, 3.3b). Duration of the lag, however, is dependent upon the various site-specific factors that govern ground thermal regimes (e.g boundary layer effects, thermal diffusivity, etc.). For example, the damping effect of snow helps to decrease the efficiency of the heat flux, subsequently, the temperature wave propagates at a diminished intensity, thus, lengthening the time lag.

During winter, the lower-elevation sites (Dale Creek 2 and Hare Foot) accumulated cool air through cold air drainage events (Kershaw and Skaret 1993), thus winter temperatures tended to be cooler at the valley locations (Table 3.2a). From late December to late February, the core temperatures at the two valley sites decreased by 4 C° (from -2° to -6°). During this period, the mean surface temperature at the lowest elevation palsa was approximately 12° warmer than that experienced at Dale Creek 2 (Table 3.3c). These warmer surface conditions were thought to be the result of enhanced surface insulation induced by the dense shrub cover on Hare Foot. This shrub cover may have increased the features snow trapping ability, thus allowing a relatively thick blanket of snow to remain on top of the feature, thereby, decreasing the efficiency of the heat flux from the palsa. Consequently, attenuation of the temperature wave with depth escalated the lag, hence, Hare Foot required 18 additional days for the core temperatures to drop 4° (Table 3.3c).

In contrast, the low plant cover on Dale Creek 2 would not have facilitated snow trapping, therefore, a thinner snowpack was thought to have existed near the apex of the feature. A relatively thin snow cover on the top of the palsa would have allowed heat to escape in a more efficient manner. Additionally, the lack of a sufficient buffer layer permitted surface temperatures to be more responsive to ambient conditions, therefore, the surface temperatures during mid- winter at Dale Creek 2 were closer to its atmospheric values than those at Hare Foot (Table 3.3c). Thus, Dale Creek 2 had a more direct linkage between the atmospheric and surface temperatures, subsequently, the temperature wave was allowed to disperse at a more efficient and intense rate, thereby, shortening the lag interval. Nevertheless, extreme cooling events at both of the lower-elevation features, led to winter heat loss rates that exceeded the gains during the thaw season to such an extend, that the mean core temperatures (150 cm) at the lower sites were cooler on an annual basis relative to the upper-elevation palsa.

The highest elevation feature had the least variation in annual core (150 cm) temperatures, in addition to experiencing the warmest mean annual and maximum temperatures (Table 3.1). The warmer thermal characteristics exhibited by this feature may be the result of the moderating effect of local weather conditions coupled with its topographic position. For example, Goose Flats had considerably less relief than the other features, hence, it may have been less prone to winter wind erosion.

Wind associated with shrubless palsas can impose a twofold effect upon snow by decreasing the snow depth through erosional processes (Seppälä 1988), and by increasing snow density through wind packing (Marchand 1987). Consequently, these processes act in conjunction with each other to decrease the insulative value of the snow cover. Therefore, those features that are less susceptible to the influence of wind may develop (given adequate conditions) deeper, lower density snowpacks that enhance insulation of the palsa core. These processes retard heat loss and ultimately keep core temperatures warmer, hence, warmer permafrost becomes more

Maximum/Minimum Temperatures Associated with Julian Day

	Wetland Sensor Depth (cm)	
	-5.0	-150
Goose Flats (1660 m)		
Maximum Temperature	223	241
Minimum Temperature	171	174
Dale Creek 2 (1480 m)		
Maximum Temperature	223	260
Minimum Temperature	7*	100*
Hare Foot (1250 m)		
Maximum Temperature	224	258
Minimum Temperature	329	61*

*= 1991 dates

Table 3.3b. Temperature lags associated with wetlands in the Macmillan Pass-Tsichu River region N.W.T

		TEMPERATURE (°C)		
Palsa Name	Lag Interval at Core (-150 cm)	Surface (0.0 cm)	Air (+150 cm)	Julian Day (1990-1991)
Dale Creek 2	-2.0 to -6.0	-16.23	-20.85	359-40
(1485 m)	-6.0 to -6.5	-12.10	-16.07	40-76
Hare Foot	-2.0 to -6.0	-4.52	-15.30	361-60
(1250 m)	-6.0 to -6.5	-6.74	-19.63.	60-70

Table 3.3c. Minimum temperature lag intervals between -2.0° to -6.0° associated with core temperatures at the valley bottom palsas.

Wind Velocity ($m \cdot s^{-1}$)	
Goose Flats (1660 m)	
Winter	2.45
Summer	2.57
Dale Creek 2 (1480 m)	
Winter	2.62
Summer	1.68
Hare Foot (1250 m)	
Winter	2.14
Summer	2.34

Table 3.4. Seasonal wind speeds associated with palsas in the Macmillan Pass-Tsichu River region N.W.T.

susceptible to thawing and subsequently would thaws first (Williams and Smith 1989).

The warmer core temperatures at the upper-elevation palsa may also be linked to the status of its geomorphic evolution. Various geomorphological and microclimatic characteristics indicate that Goose Flats is in a disequilibrium degradation phase, and the evidence that supports this is as follows: a rampart partially surrounds the feature (Figure 3.5), the palsa has low relief with a depressed mid-portion (Figure 4.5), it has a relatively moderate microclimate, with the lowest annual temperature amplitude (Figure 3.2) and it was the only palsa to have evidence of positive core temperatures (Table 3.1). Thus, Goose Flats may have been retaining more heat on an annual basis compared to the other instrumented features, therefore, conditions seem to be more susceptible to degradation.

3.6.4 Wetland Temperatures

The temperatures in the wetlands were considerably warmer and more stable than in the adjacent palsas. These warmer conditions were an indirect result of morphological position and a direct result of its internal characteristics. Since palsas are elevated above the contiguous wetland, they tend to experience thinner snow covers (Figure 3.4), whereas, in the summer the elevated portion dry through evaporative processes (Seppälä 1986; Zoltai and Tarnocai 1971). Seasonal heat fluxes, therefore, are influenced by the changing thermal conductivities of the peat associated with the palsas and the adjacent wetlands. During winter, the insulative characteristics of a thicker wetland snow cover help reduce ground heat loss and ultimately keep ground temperatures warmer than the palsas (Seppälä 1990). In summer, however, the relatively dry peat covers associated with palsas act as an insulator that help keep palsa core temperatures cooler than the moist wetlands (Brown 1966). Thus, the unfrozen wetlands tend to remain warmer on an annual basis relative to the permafrost-cored palsas.

The variation in thermal characteristics between wetlands may be the result of numerous interacting variables that were not measured (e.g. water depth and through flow, peat volume, snow depth and other physical characteristics). The warmest wetland was that adjoining Dale Creek 2, and it was the only wetland that experienced channelized and overland flow. This fen may have been fed by groundwater that helped keep temperatures slightly warmer than the other sites (Kershaw and Skaret 1993).

3.6.5 Thawing and Freezing Indices

Thawing and freezing indices are dictated by temperature, and therefore correspond to much of the temperature data and boundary layer effects discussed above. Generally, in palsas, these variables decreased with depth, and this was associated with the diminished intensity of the temperature wave as it propagated downwards. However, the bare peat sites that recorded an entire year of data were the exception. Hence, the darker surfaces of the bare peat had a lower albedo, thereby decreasing the amount of radiation that was reflected from the surface (Williams and Smith 1989). Thus, greater amounts of energy were absorbed at the palsa surface, and this enhanced heat penetration promoted warmer bare peat conditions (Table 3.2a). Conversely, during winter, exposed peat sites (Goose Flats) lost heat more efficiently than those beneath known drift sites, and subsequently experienced a higher number of freezing-degree-days (Table 3.1). Consequently, temperature variations between the microsites were the result of cover differences.

The thawing and freezing indices in the wetlands were significantly different from those encountered on the palsas. The wetlands experienced relatively deep snowpacks in winter and moist conditions during summer, therefore, these combined effects ultimately allowed the wetlands to stay warmer and with less temperature fluctuation. Thus, wetlands at 150 cm experienced fewer freezing-degree-days during the winter, yet a higher number of thawing-degree-days during the summer.

3.6.6 Wind Speed

Seasonal wind speeds were similar among the instrumented palsa sites, therefore, wind was not directly responsible for variations in snowpack characteristics, evaporative heat losses, and boundary layer thicknesses (Kershaw and Skaret 1993). Near-surface wind, however, was indirectly affected by site-specific factors unique to each palsa (e.g. plant cover type and density, morphological position, surface roughness, altitude, relief, etc.), thus location and slight physical differences among the sites led to minor variations in wind characteristics. For example, the valley sites experienced wind speeds that were at least 3 ms^{-1} greater than those encountered at the upper-elevation palsa. In addition, these higher velocity winds coincided with sudden temperature change; air temperatures increased as the relatively warm, high velocity, chinook-like winds developed on the leeward side of the Selwyn Mountains and moved downslope past Dale Creek 2 and Hare Foot. Within 1 day after the maximum wind speeds passed through the valleys, the temperatures cooled by 12° (Hare Foot) and wind velocities decreased by approximately 6 ms^{-1}. After 5 days, the temperatures dropped by 22° (Dale Creek 2) and 27° (Hare Foot), and

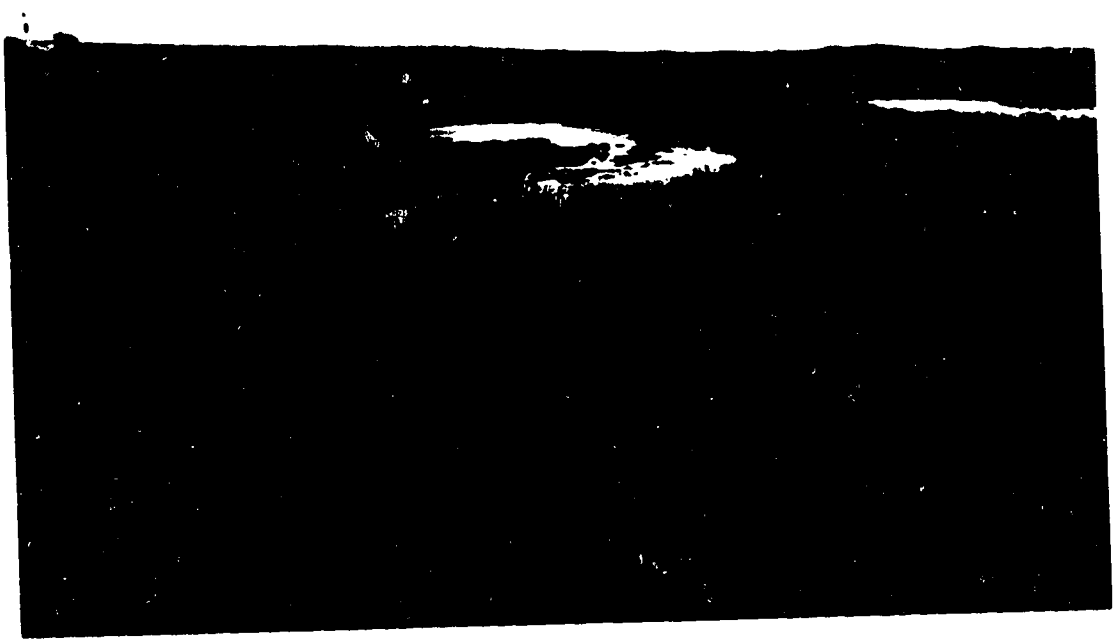

Figure 3.5. The rampart in the foreground of the Goose Flats palsa may suggest that this feature is in a disequilibrium degradational phase.

wind speeds decreased by approximately 10 ms^{-1} (Dale Creek 2 and Hare Foot. Similar warming events occurred numerous times throughout winter (7 major warming events at Dale Creek 2 and 9 at Hare Foot), and most episodes were associated with accelerated wind velocities. The most significant warming event was when temperatures increased by 21° and wind speeds increased by 3.21 ms^{-1} in less than 24 hours (Hare Foot). During early-March, another warming event resulted in temperatures increasing by 12° and wind velocities by approximately 7 ms^{-1} within 24 hours. In addition, numerous warming events were associated with frontal activity and these were associated with significant atmospheric pressure change.

Throughout the study area there were numerous periods of relatively light wind. The calm conditions at Goose Flats commenced during late-November and persisted for 50 consecutive days; during this period the mean wind speed was 0.471 ms^{-1}. Within this time interval (late-November to mid-January), Hare Foot also experienced periods of light wind, however, the calm conditions were split into three distinct events. Each episode lasted from a minimum of 5 days to a maximum of 14; mean wind speed for the three episodes was 0.682 ms^{-1}. This calm period may reflect an actual lack of wind, or anemometer problems during periods of kanik accumulation (rimming) on the cups (Kershaw and Skai... 1993), however, without any observation during this period it is difficult to tell. The wind sensors at Goose Flats did not recommence recording velocities greater than 0.447 ms^{-1} until 17 January 1991, at which time air temperatures warmed considerably, subsequently, these warmer temperatures may have unlocked the mechanism.

The calm air period at Hare Foot may be the result of ground-based temperature inversions that trapped cold air in the valley bottoms, consequently, providing a stable layer that suppressed air movement. Cold air entrapment produced extremely cool temperatures at Hare Foot (mean temperature -33°), thereby influencing the rate at which heat may have been lost from the palsa. Nevertheless, calm conditions at Goose Flats, Hare Foot and to a lesser extent at Dale Creek 2, suggest that the study area was experiencing extended periods of light wind throughout winter.

3.6.7 Rain

Rain gauges were installed at only two sites and with one month of data missing from Goose Flats it was difficult to compare the results. Despite the missing month of data, the upper-elevation site still had higher rainfall. Annual precipitation records collected from 1974 to 1981 indicate that summer is the period that receives the greatest amount of precipitation (Kershaw and Kershaw 1983).

3.7 Conclusion

The thermal characteristics of palsas located in the alpine tundra environments of the study area were influenced by the microclimatic attributes associated with each feature. Within this mountainous study area, the altitudinal variations among the sites had a significant effect upon the regional air temperatures. During summer, a positive regional environmental lapse rate was found to exist between the lower- and upper-elevation palsas, with the upper-elevation site being cooler by 2.67 C°. During winter, however, temperature inversions developed as a result of cold air drainage events. Consequently, the lowest palsa experienced the coldest temperatures coupled with periods of relatively calm wind velocities.

On a regional scale, the near-surface thermal regimes were influenced by the ambient conditions dictated by synoptic-scale weather systems, however, local differences in the thermal characteristics were predominately influenced by site-specific factors associated with the internal boundary layer. Thus, ground temperatures were warmer on palsas that had a protective cover (e.g. tall shrubs, thick snowpack) that isolated the surface from daily ambient temperature fluctuations; buffer layers dampened the heat flux and acted as barriers to heat loss. The warmest ground temperatures were commonly associated with features that had a relatively thick snow cover in winter and/or a well-developed plant canopy in summer, however, the moderating effect of the buffer zone was most pronounced in winter.

Temperatures within the ground fluctuated annually, however, the influence exerted by the temperature wave lessened with increasing depth, therefore, points located deeper in the features experienced longer temperature lags and smaller annual temperature amplitudes. The duration of the lag was affected by site-specific conditions, thus palsas that maintained an insulative snow layer experienced a diminished intensity in wave propagation and thus greater lag intervals. In contrast, palsas that had a minimal buffering effect ultimately encountered a more direct linkage between the atmosphere and the surface, thus temperature waves were able to disperse at a more efficient rate, subsequently, shortening the lag interval. Generally, the microclimates associated with each palsa acted in a similar manner and were reciprocally related, however, the intensity and duration of these effects were highly dependent upon the influence that site-specific factors exerted at each location.

3.8 References

Åhman, R. 1977. Palsar i Nordnorge. *Meddelanden från Lunds Universitets, Geografiska Institution, Avhandlingar LXXVIII*, 165p.

Allard, M. and Fortier, R. 1990. The thermal regime of a permafrost body at Mont du Lac des Cygnes, Québec. *Canadian Journal of Earth Sciences*, 27: 694-697.

Annersten, L.J. 1964. Investigation of permafrost in the vicinity of Knob Lake, 1961-1962. *McGill Sub-Arctic Research Papers*, 161: 51-137.

Brown, R.J.E. 1966. Influence of vegetation on permafrost. In Proceedings, 1st International Permafrost Conference. National Academy of Science-National Research Council. Publication No. 1287. Washington, DC. pp. 20-25.

Brown, R.J.E. 1967. Permafrost Investigations in British Columbia and Yukon Territory. *Technical Paper No. 253*, National Research Council of Canada, Division of Building Research.

Brown, R.J.E. 1970. Occurrence of permafrost in Canadian peatlands. In Proceedings, 3rd International Peat Congress. National Research Council of Canada. pp. 174-181.

Cernusca, A. and Seeber, M.C. 1981. Canopy structure, microclimate and the energy budget in different alpine communities. In J. Grace, E.D. Ford and P.G. Jarvis (eds.) *Plants and their Atmospheric Environment, 21st. Symposium of the British Ecological Society*. Blackwell Scientific Publications, Oxford, pp. 75-81.

Cummings, C.E. and Pollard, W.H. 1989. An investigation of palsas in the Schefferville area, Quebec. *The Musk-Ox*, 37:8-18.

Cummings, C.E. and Pollard, W.H. 1990. Cryogenetic categorization of peat and mineralcored palsas in the Scefferville area, Québec. Fifth Canadian Permafrost Conference, *Collection Nordicana*, 54: 95-102.

Dionne, J.C. 1984. Palses et limites méridionales du pergélisol dans l'hémisphère nord: le cas de Blanc-Sablon, Québec. *Géographie physique et Quaternaire*, 38:165-184.

Forsgren, B. 1968. Studies on palsas in Finland, Norway and Sweden, 1964-1966. *Biuletyn Periglacjalny*, 17: 117-123.

Gold, L.W. 1963. Influence of snow cover on the average annual ground temperature at Ottawa, Canada. *International Association Scientific Hydrology, Publication*, 61: 82-91.

Harris, S.A. 1982. Identification of permafrost zones using selected permafrost landforms. In *Proceedings of the Fourth Canadian Permafrost Conference*, National Research Council of Canada, Ottawa, pp. 49-58.

Kershaw, G.P. 1992. Personal communication. Department of Geography, University of Alberta, Edmonton, Alberta, Canada.

Kershaw, G.P. and Gill, D. 1979. Growth and decay of palsas and peat plateaus in the Macmillan Pass-Tsichu River area, Northwest Territories, Canada. *Canadian Journal of Earth Sciences*, 16(7):1362-1374.

Kershaw, G.P. and Kershaw, L.J. 1983. *Geomorphology and Vegetation of the MacTung Study Area, Yukon/NWT*. Report prepared for AMAX Northwest Mining Co. Ltd., Vancouver.

Kershaw, G.P. and Skaret, K.D. 1993. Microclimatic characteristics of palsas along an altitudinal gradient, Mackenzie Mountains, NWT, Canada. *In Proceedings Sixth International Permafrost Conference*, National Academy Press, Washington DC, pp. 338-343.

Lagarec, D. and Dewez, V. 1990. Dynamidue du pergélisol discontinu et changements globaux dans le nord du Québec. Fifth Canadian Permafrost Conference, *Collection Nordicana*, 54: 215-222.

Liang, L. and Kershaw, G.P. 1994. Climate change in the Mackenzie Mountains, N.W.T., in press.

Lindqvist, S. and Mattsson, J.O. 1965. Studies on the thermal structure of a pals. *Svensk Geographisk Årsbok* 41:38-49.

Luthin, J.N and Guymon, G.L. 1974. Soil moisture-vegetation-temperature relationships in central Alaska. *Journal of Hydrology*, 23:233-246.

Marchand, P.J. 1987. *Life in the Cold*. University Press of New England, Hanover, 176p.

Nelson, F.E., Outcalt, S.I., Goodwin, C.W. and Hinkel, K.M. 1985. Diurnal thermal regime in a peat-covered palsa, Telex Lake, Alaska. *Arctic*, 38(4): 310-315.

Pavlov, A.V. 1973. Heat exchange in the active layer. *Proceedings of the Second International Conference on Permafrost, Yakutsk, USSR, USSR Contribution*, Washington, D.C., National Academy of Science, pp. 25-30.

Porsild, A.E. 1945. The alpine flora of the east slope of Mackenzie Mountains, Northwest Territories, *National Museums of Canada, Bulletin 101 (Biological Series, No. 30)*, Edmond Cloutier, Printer, Ottawa.

Priesnitz, K. and Schunke, E. 1978. An approach to the ecology of permafrost in Central Iceland. In *Proceedings of the Third International Conference on Permafrost*, National Research Council of Canada, Ottawa, Vol. 1, pp. 474-479.

Roberts, B.A. and Robertson, A.W. 1980. Palsa bogs, sand dunes and salt marshes, environmentally sensitive habitats in the coastal region Southeastern Labrador. In *Workshops on Research in the Labrador Coastal and Offshore Region*, pp. 245-260.

Rouse, W.R. 1984. Microclimate of the Arctic tree line. 2: Soil microclimate of tundra and forest. *Water Resources Research*, 20, 1: 67-73.

Salmi, M. 1968. Development of palsas in Finnish Lapland. In *Proceedings of the Third International Peat Congress, Ottawa*, National Research Council of Canada, pp. 182-189.

Salmi, M. 1970. Investigations on palsas in Lapland Finnish. In *Ecology of Subarctic Regions Proceedings of the Helsinki Symposium 1966*, UNESCO, Paris, pp. 143-153.

Schunke, E. 1973. Palsen und kryokarst in Zentral-Island. Nachr. Akad. *Wissenschaften in Gottingen, II Mathematisch-Physikalische Klasse*, H.4:65-102.

Seguin, M.K. and Allard, M. 1984. Le pergélisol et les processus thermokarstiques de la région de la Rivière Nastapoca, Nouveau-Québec. *Géographie Physique et Quaternaire*, 38: 11-25.

Sellers, W.D. 1965. *Physical Climatology*. Chicago, University of Chicago Press. 272p.

Seppälä, M. 1972. The term 'palsa'. *Zeitschrift für Geomorphologie*, 16:463.

Seppälä, M. 1986. Origin of palsas. *Geografiska Annaler*, 68A(3), pp. 141-147.

Seppälä, M. 1988. Palsas and related forms. In M.J. Clark (ed.), *Periglacial Geomorphology*. John Wiley and Sons, Chichester, pp. 247-278.

Seppälä, M. 1990. Depth of snow and frost on a palsa mire, Finnish Lapland. *Geografiska Annaler*, 72A: 191-201.

Smith, M.W. 1975. Microclimatic influences on ground temperatures and permafrost distribution, Mackenzie Delta, Northwest Territories. *Canadian Journal of Earth Sciences*, 12: 1421-1438.

Steppuhn, H. 1981. Snow and Agriculture. In D.M. Gary and D.H. Male (eds.) *Handbook of Snow: Principle, Processes, Management and Use*. Pergamon Press, Toronto, pp. 60-125.

Williams, P.J. and Smith, M.W. 1989. *The Frozen Earth*. Cambridge University Press, New York, 306 p.

Zoltai, S.C. 1972. Palsas and peat plateaus in Central Manitoba and Saskatchewan. *Canadian Journal of Forest Research*, 2:291-302.

Zoltai, S.C. and Tarnocai, C. 1971. Properties of a wooded palsa in Northern Manitoba. *Arctic and Alpine*, 3(2): 115-129.

Zoltai, S.C. and Tarnocai, C. 1975. Perennially frozen peatlands in the western Arctic and Subarctic of Canada. *Canadian Journal of Earth Sciences*, 12:28-43.

4.0 Thaw Characteristics Associated with Palsas in an Alpine Tundra Environment Macmillan Pass-Tsichu River Region, N.W.T., Canada**

4.1 Introduction

Palsas are widespread periglacial phenomena that occur in wetland environments (fens or bogs) located throughout the discontinuous circumpolar permafrost zone. In Canada, the recorded distribution of palsas range from British Columbia to Labrador and include both Territories (Dionne 1984). They have also been reported to occur in Fennoscandia, Iceland, Siberia and Alaska (Seppälä 1986).

The word "palsa" was originally used by Lappish and Finnish cultures to describe a frozen-cored hummock rising from a bog (Seppälä 1972). These features are meso-scale permafrost mounds that include a surface cover of peat. They rise 1 to 15 m from the surrounding permafrost-free wetland, and generally have maximum diameters of less than 100 m (Zoltai and Tarnocai 1975).

Morphologically, palsas vary from hemispherical-shaped features to elongated ridge-like forms that occur individually or in complex groups (Åhman 1976, 1977; Seppälä 1988). Both aggradational and degradational forms can exist in the same wetland (Zoltai 1988) or on the same feature. Internally, the features are composed of frozen non-cryoturbated peat and/or mineral soil (predominantly silty in texture), pore ice and segregation ice. The dynamic processes of ice segregation and pore ice freezing result in frost heaving mechanisms that are responsible for the formation of palsas.

4.2 Thaw Depths

Palsa morphology and structure have been assessed by a number of researchers and these studies frequently included thaw depths (e.g. Åhman 1977; Dionne 1984; Kershaw and Gill 1979; Lagerback and Rodhe 1986; Nicholson 1979; Salmi 1968, 1972; Schunke 1973; Seguin and Crépault 1979; Seppälä 1976; 1983; Zoltai and Tarnocai 1971,1975). Depth of thaw may vary on both a regional (Table 4.1) and local basis relative to specific site conditions. For example, local variations in thaw depth commonly occur on individual palsas and may be attributed to differences in slope, aspect, microclimate, vegetation cover and proximity to water. Few studies have focused on these landforms in mountainous environments (Brown 1980; Collins et al. 1984; Kershaw and Gill 1979) and it was the paucity of research in alpine areas that was a partial motive for the study. Specifically, few researchers have studied thaw and microclimatic characteristics on palsas at various elevations within one region. Consequently, the objective of the study was to compare the rate and depth of thaw on palsas at various elevations in an alpine tundra environment, with respect to any microclimatic variations between features.

4.3 Study Area

The study area is located in the Macmillan Pass-Tsichu River-Mackenzie Mountain Barrens area of the Northwest Territories, Canada, and occurs within the transition zone between the Selwyn (Interior Cordillera) and Mackenzie Mountains (Eastern Cordillera) (Figure 1.2). Macmillan Pass is 1350 m asl and straddles the Yukon-Northwest Territories border in the discontinuous permafrost zone. Elevations along the Continental Divide (the border between the two territories) are 2060 - 2430 m asl and the main drainage course in the study region is the Tsichu River, a tributary of the Keele River. This area has a Continental climate influenced by mountains with a mean annual temperature of -7.7°C and an average precipitation of 490 mm (Kershaw and Kershaw 1983). The average annual snowfall was 294 cm and during mid-winter the snowpack varied from discontinuous on windswept sites, to greater than 2 m in areas that encountered drifting snow (Kershaw and Kershaw 1983).

Palsas within the study area were first described by Porsild (1945) while conducting botanical studies along the Canol Road. Later, Kershaw and Gill (1979) conducted more detailed investigations at the same site described by Porsild (1945), in addition to a number of other palsas and peat plateaus located throughout this region. This paper is a product of recent investigations that cover a similar yet larger area than that investigated by Kershaw and Gill (1979).

During July and August 1990 five palsas located at four different sites were chosen for the research project. These sites were situated over a 410 m altitudinal gradient (1250 to 1660 m asl) and were located approximately 5 km northwest to 32 km east of Macmillan Pass. The study features were named Goose Flats, Dale Creek 2, Dale Creek 6, Beaver Pond, and Hare Foot (Figures 1.3-1.7 and Table 1.1).

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LOCATION	THAW DEPTH (cm)	MEAN ANNUAL AIR TEMPERATURE (°C)	SOURCE
CANADA			
Northern Québec	35-45 (peat) 100-125 (silt)	-2.0 to -5.8°	Allard et al. 1987
Mount du Lac des Cygnes, Québec	65	-1.3°	Allard and Fortier 1990
Rock Valley Creek, Alberta	30-35	-0°	Brown 1980
Blanc-Sablon, Québec	30	0.6°	Dionne 1984
Newfoundland	33-54 50-64	-4.9°	Doolittle, Hardisty and Black 1992
Macmillan Pass-Tsichu River, N.W.T.	48.6 44.8 45.0 64.6	(Jan) -19.4° (July) 6.7°	Kershaw and Gill 1979
Southeastern Labrador	40-50	0 to 2.5°	Roberts and Robertson 1980
Poste-de-la-Baleine, Nouveau Québec	70	ND	Seguin and Crépault 1979
Atlin, British Columbia	30-75	ND	Tallman 1973
Resolute Area Cornwallis Island	20	-16.6°	Washburn 1983
Cranberry Portage, Manitoba	43-127 60	-1.2°	Zoltai and Tarnocai 1971
C.I.S.			
Chernychevsky, Yakutia	85-105 90-100	ND	Åkerman 1982
Western Siberia	50	ND	Novikov and Usova 1979
FINLAND			
Enontekio Utsjoki	40-60 40-80	<-1°	Salmi 1968
Enontekio	50-80	<-1°	Salmi 1970
Enontekio	10-105	-1°	Seppälä 1976
Finnish Lappland	55-70	ND	Seppälä 1983
Utsjoki	57-74	-2°	Seppälä 1990
ICELAND			
Central Region	60-95 45-55	-1.2° to -1.9	Friedman et al. 1971
Central Region	30-60	-1.6	Schunke 1973
NORWAY			
Northern Norway	65-100	0 to -1	Åhman 1977
Haugtjörnin, Dovrefjell	35-45	-0.5°	Sollid and Sørbel 1974
Varangerfjord	60-115	ND	Svensson 1964
Fardesmyra	67.5	-1.1°	Vorren 1979
SWEDEN			
Koresuando	60	ND	Forsgren 1966
Lake Arasjaure	40-50	ND	Lagerback and Rodhe 1986
Northern Sweden	70	-2.0°	Rapp and Annersten 1969
UNITED STATES			
Beartooth Mountains, Wyoming	38-46	ND	Collins, Lichvar and Evert 1984
Toolik Lake, Alaska	30	-10.0°	Hinkel, Nelson and Outcalt 1987

a = mean annual surface temperature, ND = no data

Table 4.1. Regional thaw differences on palsas and palsa-like mounds.

4.4 Methods

Frost probe sampling grids were established on each palsa as reference points for measuring thaw depth. The depth of the frost table was determined by inserting a graduated rod through the thawed peat layer down to the frost table. The metal rod used in 1990 was 2.25 m long and had a diameter of 0.95 cm, whereas, the probe used in 1991 was 3.0 m long. Due to the icy nature of the sediments and the constitution of the frozen material composing palsas (peat and/or silt) the point of rejection coincided closely with the depth of thaw. The reliability of this method was tested with a YSI probe of approximately half the diameter, and similar thaw depths were generated by the temperature method. Furthermore, the probe method was quicker and more practical, since it was not necessary to wait for the sensor to equilibrate. On each palsa, measurements were conducted on the top and sides. The top sections of each palsa were distinguished from the sides by the main change in slope, thus tops were considered to be the relatively level portion of the feature. The field season defined the period of thaw layer monitoring: 36 days in 1990 (22 July - 26 August) and 32 days in 1991 (26 July - 26 August).

The interval between sample points varied depending on the size of each feature. The minimum interval between probe positions along a transect was 0.25 m (all features) whereas the maximum interval was 10.0 m (Beaver Pond). The minimum distance between transects was 4.5 m (Dale Creek 6) whereas the maximum distance was 10.0 m (Beaver Pond). Where possible, the probe transects extended 10 m out into the fen. Altogether, there are 568 sample points with the number of probe sites ranging from 76 to 174 points on each feature. During the 1990 and 1991 thaw season there were a number of surveys for a combined total of 3,501 thaw measurements. The last thaw depth measurements were taken on 25, 26 August 1990 and 26 August 1991.

Microclimatic stations were installed at each site to monitor subsurface and ambient air temperature, wind speed, radiation and rain. However, the power supply for the data logger at Beaver Pond was damaged; thus, microclimate data were not collected at this site (Kershaw and Skaret 1993). All palsas were surveyed and the results digitized.

4.5 Results

4.5.1 Thaw Depth

During both seasons, the greatest thaw occurred near the perimeter of each palsa, whereas minimum thaw depths generally occurred on the top portions of each feature (Figure 4.1-4.5). The minimum mean top and side thaw depths were 50.1 and 108.8 cm respectively, and both of these values occurred during the 1990 season at the lowest elevation site (Hare Foot) (Table 4.2). The maximum mean thaw on the top (87.4 cm) and sides (221.5 cm) occurred on Dale Creek 6 during 1991. However, Dale Creek 2 was located within the same fen as Dale Creek 6 (approximately 125 m east) yet had 27.8 (1990) and 26.3 cm (1991) less thaw than Dale Creek 6 (Table 4.2).

Maximum thaw in the adjacent wetlands was greater than the probe length (300 cm) and was associated with water bodies such as the palsa laggs. The maximum thaw on Goose Flats was 279 cm and it also occurred adjacent to a palsa lagg. Goose Flats (Figure 4.5) was unique in that its central portion had lower relief and slightly greater thaw relative to the other features. The maximum variation in thaw between consecutive years at a single probe site was 218 cm (Beaver Pond); whereas, the minimum difference was 0 cm (Beaver Pond, Dale Creek 2, Goose Flats and Hare Foot).

The greatest single thaw point on the top portion of the palsas was measured adjacent to a thermokarst pond (Beaver Pond). Depths of thaw near this body of water were up to 115 cm greater than those recorded a few metres away. The least seasonal thaw was 25 cm and it occurred on the top of Beaver Pond amongst 1 m tall *Betula glandulosa* shrubs. On most palsas, greater mean thaw occurred on the south-facing side, with the difference in thaw between North/South aspects ranging from 2.9 (Dale Creek 2, 1991) to 36.4 cm (Beaver Pond, 1990) (Table 4.3). However, during the 1991 thaw season the north-facing side on Beaver Pond experienced a greater mean thaw of 9.4 cm.

4.5.2 Rate of Thaw

The 1990 rates of thaw were calculated over the summer field season and the maximum mean rate of thaw on the palsa proper was approximately 20 mm day^{-1} (Hare Foot) with a minimum of 7 mm day^{-1} (Beaver Pond) (Table 4.2). The lowest rates of thaw were observed on the top section of each feature with values ranging from 5 mm day^{-1} at Beaver Pond and Dale Creek 2 to 10 mm day^{-1} at Dale Creek 6 (Table 4.2). Rates of thaw on the sides varied from 8 mm day^{-1} on Beaver Pond to 47 mm day^{-1} on the palsa with the steepest slopes (Hare Foot). Dale Creek 2 was located in the same wetland as Dale Creek 6 yet it experienced considerably lower rates of thaw

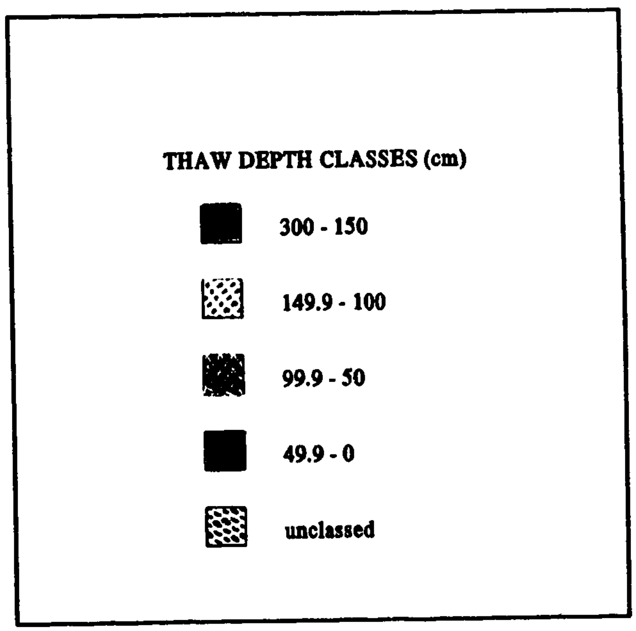


Figure 4.0. Legend for thaw classes (Figures 4.1-4.5).

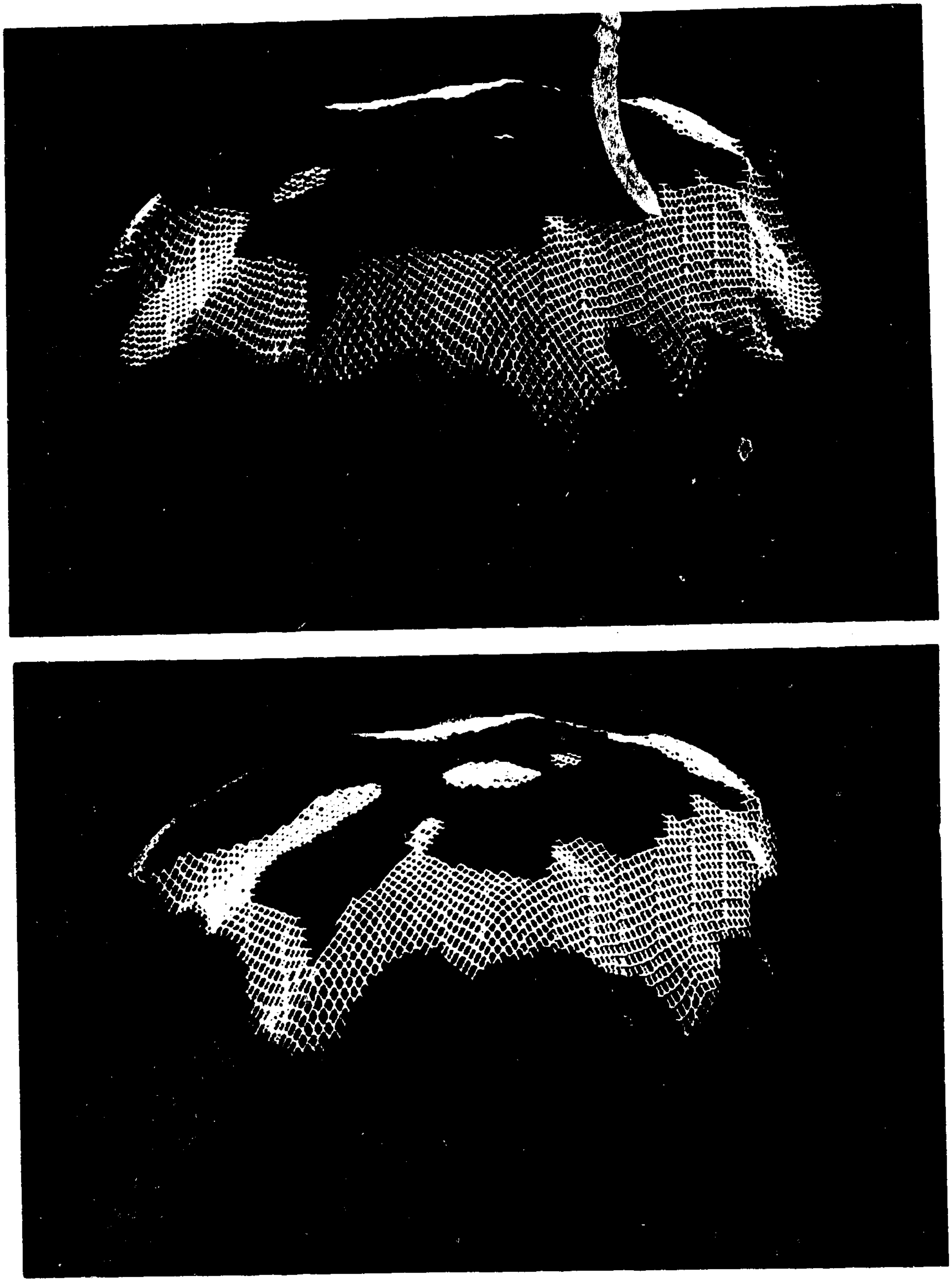
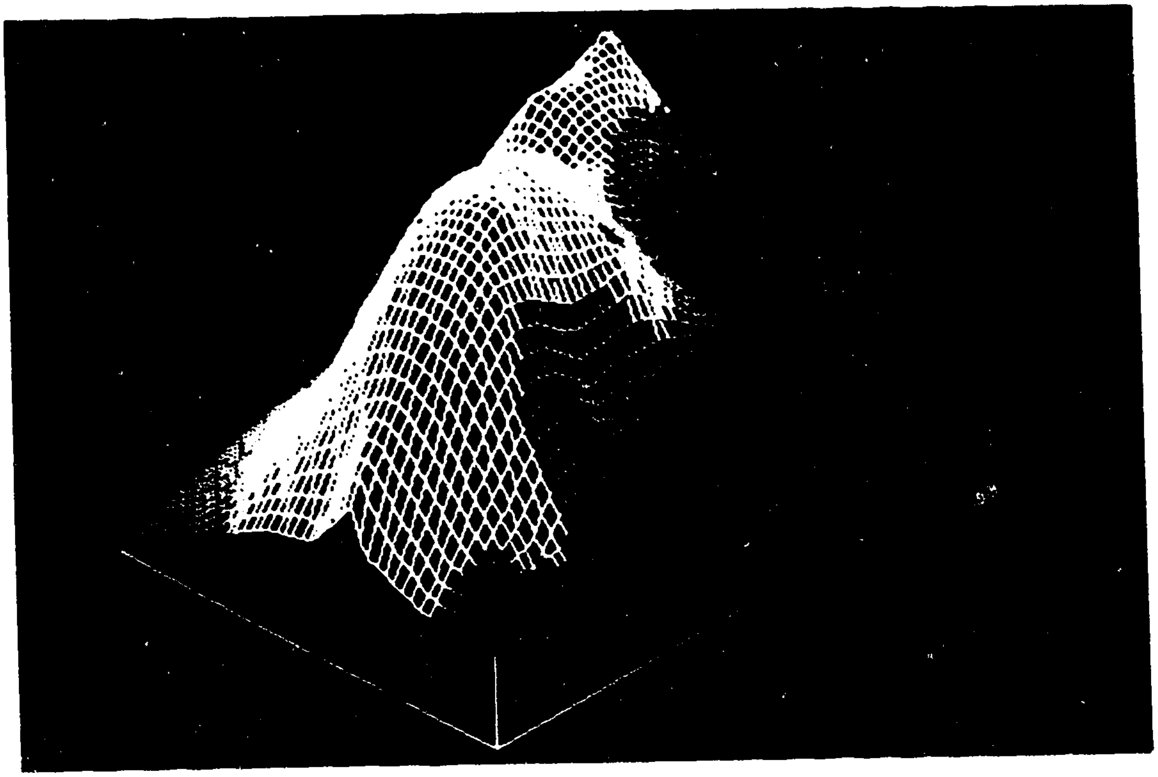


Figure 4.1. The maximum mean thaw on the Dale Creek 2 palsa for the 1990 (top) and 1991 (bottom) thaw season. General site characteristics for this feature are given in Table 1.1.



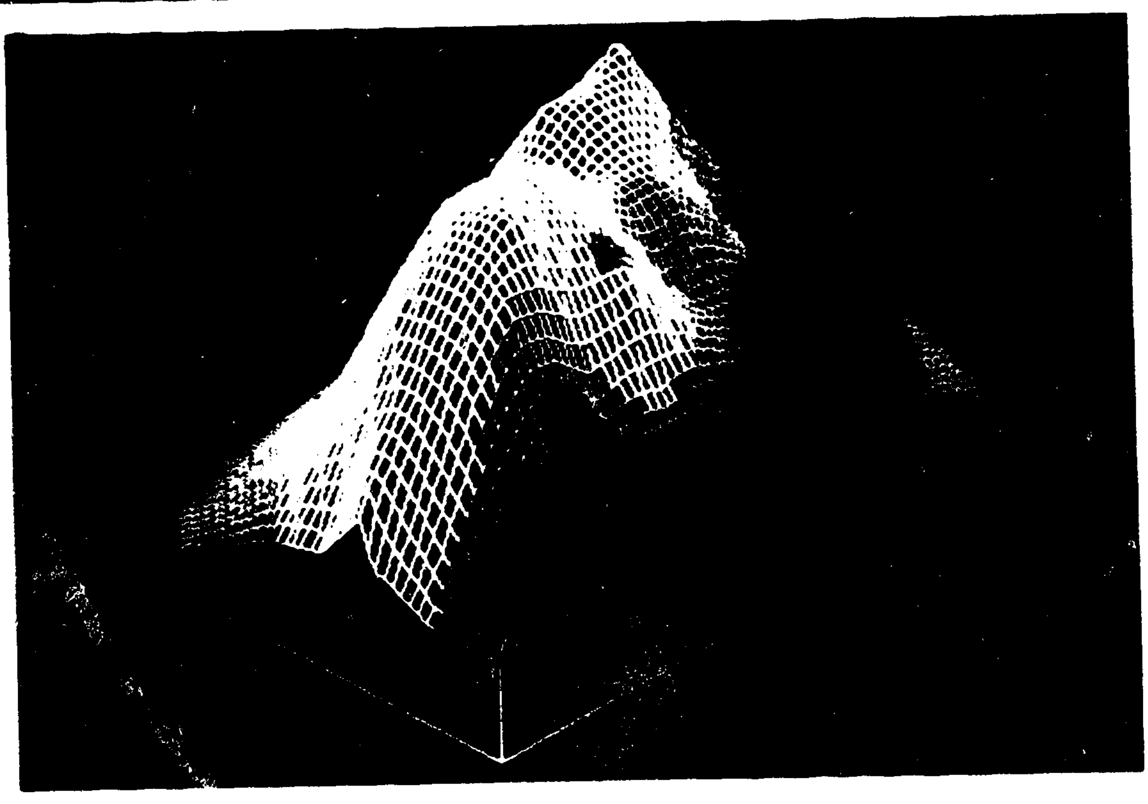


Figure 4.2. The maximum mean thaw on the Dale Creek 6 palsa for the 1990 (top) and 1991 (bottom) thaw season. General site characteristics for this feature are given in Table 1.1.

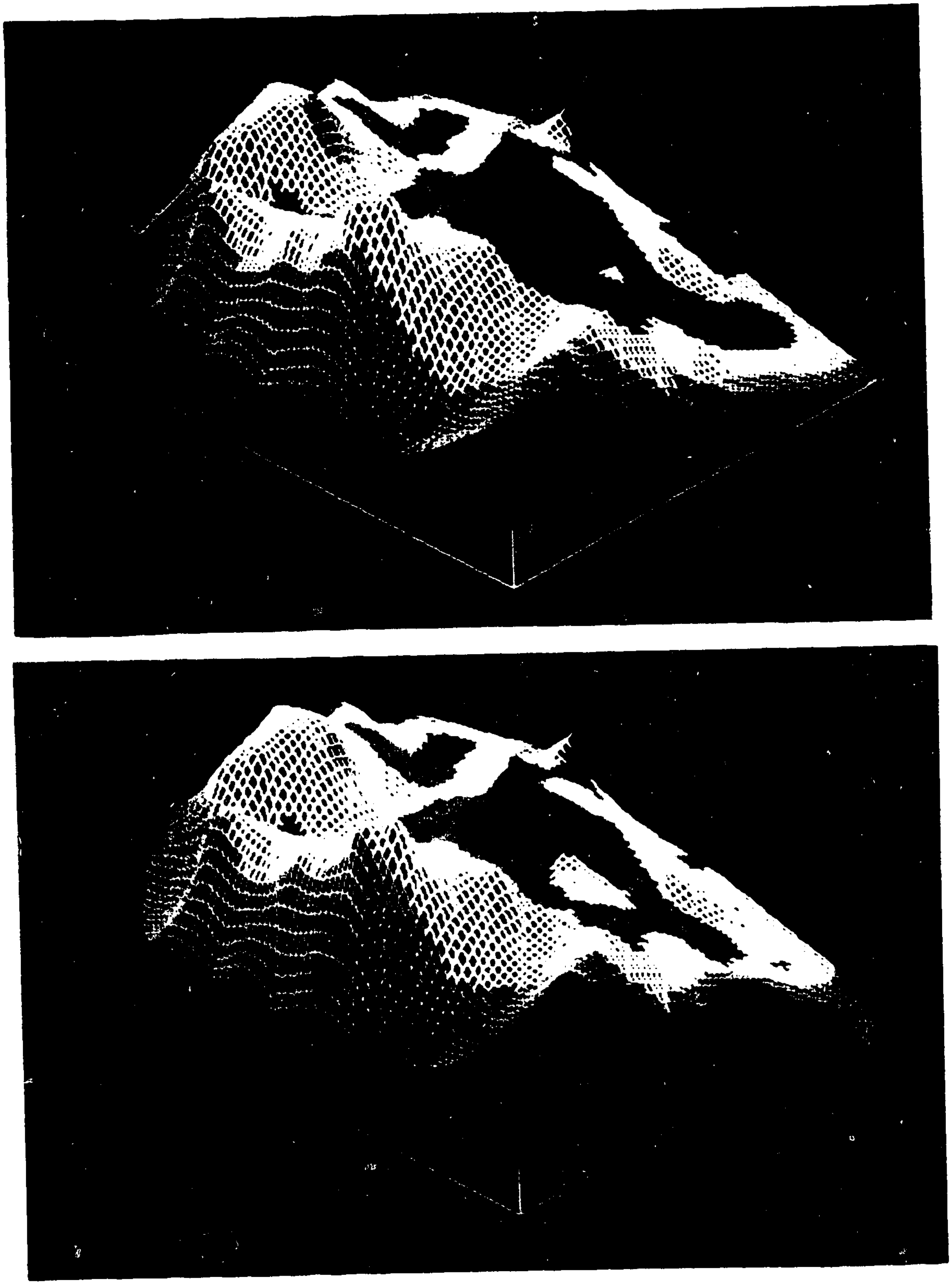


Figure 4.3. The maximum mean thaw on the Beaver Pond palsa for the 1990 (top) and 1991 (bottom) thaw season. General site characteristics for this feature are given in Table 1.1.

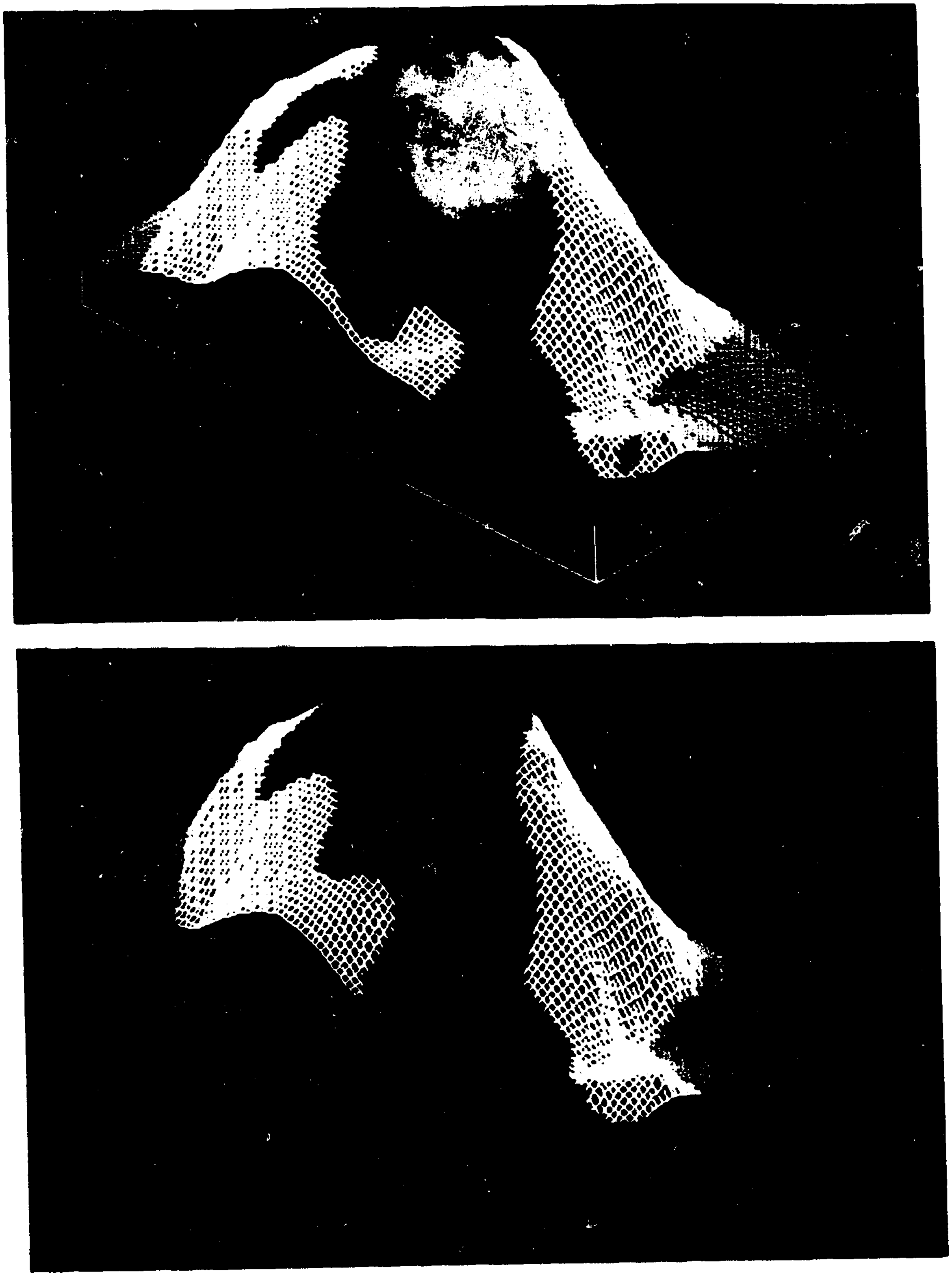


Figure 4.4. The maximum mean thaw on the Hare Foot palsa for the 1990 (top) and 1991 (bottom) thaw season. General site characteristics for this feature are given in Table 1.1.

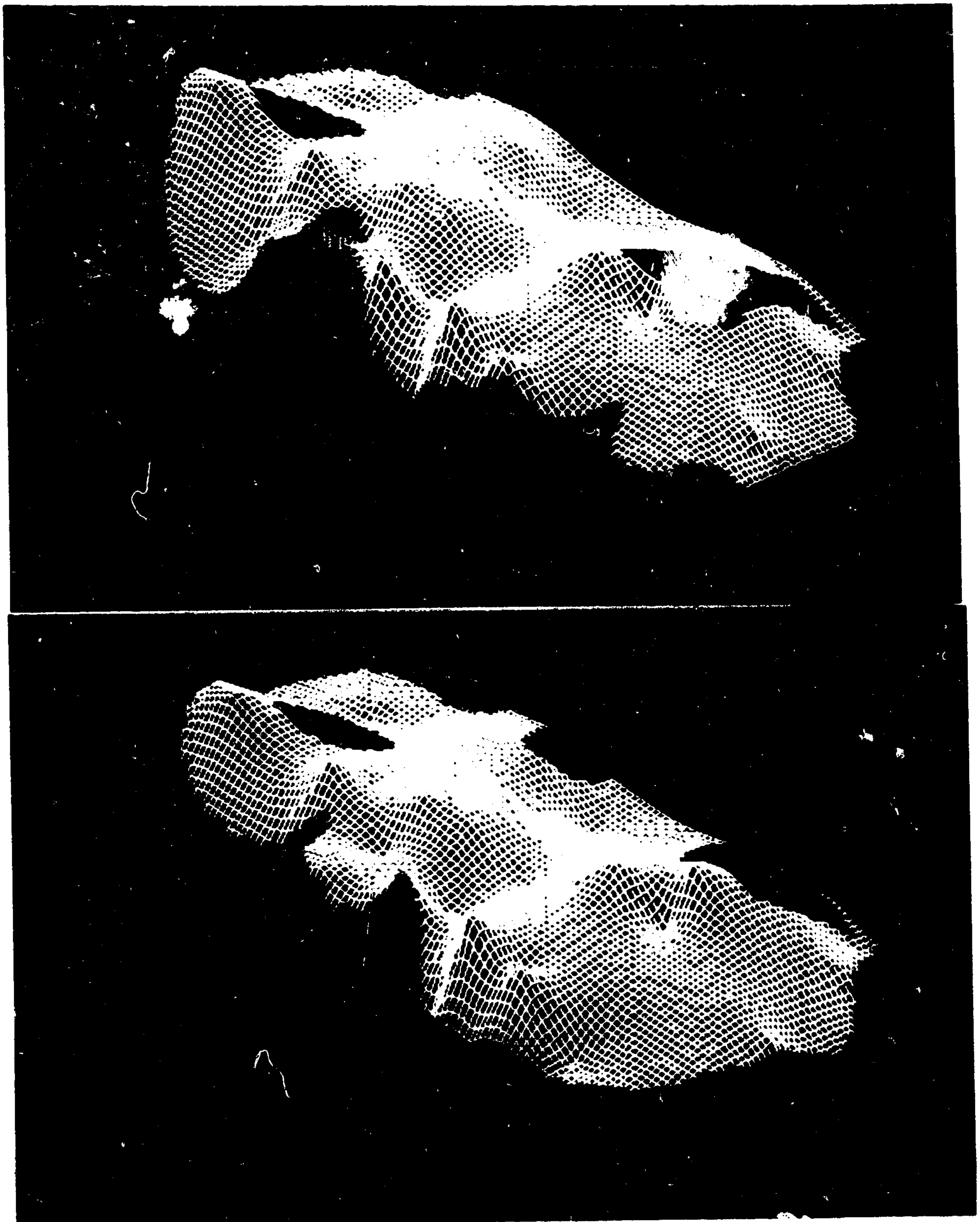


Figure 4.5. The maximum mean thaw on the Goose Flats palsa for the 1990 and 1991 thaw season. General site characteristics for this feature are given in Table 1.1.

	THAW DEPTH (cm)				RATE OF THAW (mm day^{-1})			
	1990 TOP	1991 TOP	1990 SIDE	1991 SIDE	1990 TOP	1991 TOP	1990 SIDE	1991 SIDE
HARE FOOT (1250m)								
Mean	50.1*	50.4*	108.8*	117.0*	.9	4.7	47.2	11.5
Std	11.8	12.9	49.7	82	0.8	0.1	6.1	0.7
BEAVER POND (1270m)								
Mean	53.2	53.0	132.8	148.7	4.7	NC	8.3	NC
Std	25.8	21.4	64.2	78.9	0.8		1.2	
DALE CREEK 2 (1480m)								
Mean	55.6**	62.4**	145.4	191.8	4.8	7.0	18.3	24.0
Std	20.9	37.1	35.2	85.2	0.5	0.5	2.8	1.0
DALE CREEK 6 (1480m)								
Mean	8[illegible]	88.7	183.4**	221.5**	9.7	NC	33.2	NC
Std	33.[illegible]	36.5	37.4	120.2	1.4		4.0	
GOOSE FLATS (1660m)								
Mean	57.4	62.3	137.2	129.2	8.7	6.0	28.4	13.8
Std	18.2	18.[illegible]	38.6	47.6	0.6	0.2	3.0	0.6

Statistical Test: Student's t
Top vs Side: significant difference in thaw depths at (p>0.001) unless otherwise specified * = (p>0.01)

Top vs Top and Side vs Side:
no significant difference in thaw depths at (p>0.001) unless otherwise specified ** = (p>0.2)

Table 4.2. Mean annual thaw depth and rate of thaw on palsas in the Macmillan Pass-Tsichu River region NWT.

	THAW DEPTH (cm)				RATE OF THAW (mm day^{-1})			
	1990 N-facing	1990 S-facing	1991 N-facing	1991 S-facing	1990 N-facing	1990 S-facing	1991 N-facing	1991 S-facing
HARE FOOT (1250m)								
Mean	59.3	84.5	66.6	85.8	8	32	4.8	6.1
Std	52.1	23.7	53.6	66.9	1	5.5	0.2	0.3
BEAVER POND (1270m)								
Mean	76.4	112.8	109.5	100.1	8	8.4	NC	NC
Std	49.3	70.5	90.2	57.6	1	1.2		
DALE CREEK 2 (1480m)								
Mean	83.6	86.5	102.7	105.5	9	12	9.8	9.9
Std	40	57	71.7	89.[illegible]	1.3	2.3	0.8	1.0
DALE CREEK 6 (1480m)								
Mean	120.2	124.0	135.3	162.0	21	17	NC	NC
Std	55.6	64.6	89.7	103.6	3	2.7		
GOOSE FLATS (1660m)								
Mean	94.6	103.5	84.2	101.4	18	19	7.0	7.2
Std	39.8	50.5	38.7	55.3	2.3	2.3	0.4	0.2

NC = Not calculated

Table 4.3. Mean annual rate and depth of thaw in relation to aspect on palsa proper in the Macmillan Pass-Tsichu River region NWT.

on the top and sides (Table 4.2). The 1991 rates of thaw were calculated from the initiation of surface thaw and since this could only be determined from the microclimate data, the rates of thaw were only calculated for those sites that had functioning microclimate stations. The mean rate of thaw on the palsa proper ranged from 7 mm day^{-1} (Hare Foot) to 13 mm day^{-1} (Dale Creek 2), whereas the mean rates of thaw on the top portion of the palsas ranged from 5 mm day^{-1} (Hare Foot) to 7 mm day^{-1} (Dale Creek 2). The rates of thaw on the side varied from 12 mm day^{-1} (Hare Foot) to 24 mm day^{-1} (Dale Creek 2) (Table 4.2). During both years, all features except Dale Creek 6 had the greatest mean rates of thaw on the southern aspects and the difference in rates of thaw between exposures varied from 0.1 to 24.0 mm day^{-1}.

4.5.3 Microclimate

Analysis of microclimate data was based on one 365-day period beginning 1 August 1990 and ending 31 July 1991. The annual thawing and freezing-degree-day totals were calculated by summing all positive and negative temperature values respectively, during the one year period. The highest surface freezing-degree-day total (Fddt) was 2728.3 and it occurred at the lowest elevation site (Hare Foot), whereas on Dale Creek 2 and Goose Flats the respective values were 1963.7 and 1996.7 (Table 3.1). The respective surface thawing-degree-day totals (Tddt) on Hare Foot, Dale Creek 2 and Goose Flats were 1176.0, 797.6 and 747.2 respectively.

Both the minimum mean annual air (-7.37°C) and surface (-4.25°C) temperatures occurred on the lowest elevation site. This location also experienced the extreme minimum air (-44.6°C) and surface (-30.9°C) temperatures as well as the maximum air (15.8°C) and surface (18.6°C) temperatures (Table 3.1). The warmest mean annual core temperature at 150 cm was -1.55°C and it occurred on the highest elevation Goose Flats palsa. This palsa also experienced the highest maximum core (150 cm) temperature, and it was the only feature to have core temperatures greater than 0°C (Table 3.1). The minimum core (150 cm) temperature was -6.5°C and it occurred at the two lower valley sites (Dale Creek 2 and Hare Foot) (Table 3.1).

The seasonal temperatures were differentiated by freezing (winter) and thawing (summer) periods. Winter temperatures were defined as the consecutively negative mean daily values that began in the Fall (1990) and concluded with the first positive temperatures of Spring (1991); summer temperatures were defined as the continuously positive values that began in Spring (1991) and lasted until Julian day 238 (26 August 1991). During winter, the lowest elevation palsa experienced a mean surface temperature that was 4° cooler than the upper-elevation feature (Table 3.2). During summer, however, the mean surface temperatures at the lowest elevation palsa were at least 2° warmer than the highest elevation site (Table 3.2). Freeze-back as defined by either air temperature or surface temperatures occurred on or shortly after 26 September 1990 at all three palsas sites (Table 4.4). In the adjacent fens, however, freeze-back initiation was delayed by 12 to 21 days at the two lower-elevation valley sites, but by 162 days at the higher-elevation Goose Flats site. Thaw condition air temperatures were first experienced during early May at all the sites; moreover, they all occurred within one day of each other (Table 4.4). At Hare Foot, however, surface thaw commenced 3 days prior to the initiation of positive air temperatures, and 11 days earlier than the upper two sites (Table 4.4). The fen at the highest elevation Goose Flats site began thawing approximately 40 days after it was initiated at the 2 lower sites.

4.6 Discussion

The formation and subsequent maintenance of palsas rely upon microclimatic characteristics. The factors required for the development of these features are cold temperatures, thin snow cover, surface peat cover and availability of water (Seppälä 1982; Zoltai 1972). Any alterations in these variables may directly or indirectly influence thaw characteristics. The critical factors influencing rate and depth of thaw are slope, proximity to water, plant cover, microclimatic characteristics and aspect.

4.6.1 Thaw Characteristics

In this mountainous region of Northwestern Canada seasonal thaw on palsas varied from 25 to greater than 300 cm with mean thaw on the top and sides ranging from approximately 50 to 89 cm and 109 to 221 cm respectively. Greater depths of thaw on sides during the 1991 thaw season (Table 4.2), may have been due to a longer probe, and the extended depths it was able to penetrate. The greater rate and depth of thaw on the southern slopes can be explained by the higher angle of solar incidence that subsequently enhanced solar energy absorption. However, on low slope angles near the edge, other factors may also contribute to the enhanced thaw. For example, heat imported along the thermal gradient from the surrounding water bodies (e.g. beaver pond, palsa lagg, thermokarst pond) or wetland may have contributed to deeper thaw. In support of this, is the situation at Goose Flats where thaw in the fen persisted into March. Although thaw initiation in the fen lagged behind the other

	Julian Day of Freeze-back Period Initiation 1990				Julian Day of Thaw Period Initiation 1991			
Sensor location	+150	0.0	P-5	F-5	+150	0.0	P-5	F-5
	(cm)				(cm)			
Goose Flats (1660 m)	269	269	270	66*	124	132	135	174
Dale Creek 2 (1480 m)	269	269	270	290	123	132	135	134
Hare Foot (1250 m)	274	274	270	286	124	121	122	>135

P = palsa, F = fen, * = 1991 data

Table 4.4 Initiation of freezing and thawing periods on palsas in the Macmillan Pass-Tsichu River region N.W.T.

instrumented palsas by 40 days, the prolonged period of winter thaw would help moderate the adjacent palsa temperatures during winter. Thus, warmer palsa temperatures would reduce the heat flux necessary to develop the active layer. Additionally, snow trapping on the leeward side of the palsas may alter the energy exchanges between the atmosphere and palsa core. This results in warmer peripheral temperatures (Lindqvist and Mattsson 1965; Kershaw and Skaret 1993) and ultimately greater thaw. Due to time restrictions the last th[illegible]aw measurements were taken near the end of August. The possibility that the recorded thaw measurements w[illegible]re not at their absolute maximum depth does exist. The data, however, indicate that thaw depths were stabilizing, and in numerous instances actually declining by the end of the field seasons. For example, the last thaw measurements during the 1990 field season indicate that 77% of the probe sites had begun to freeze-back or stabilize, since these depths were shallower or [illegible] as the previous measurements. Similar calculations were not done for the following season due to fewe[illegible]tervals, however, surface temperatures in the last week of the 1991 field season ranged from 1.8 to 4.5 C[illegible]han the same period during the previous season. Consequently, thaw depths for 1991 may have also b[illegible]ng by late August. Thus, our results indicate that the maximum thaw or active layer on palsas tends [illegible] by late August and moreover, these results closely correspond with those found by Zo[illegible] and Tar[illegible]). These authors state that maximum thaw depths in the Western Arctic and Subarctic regions of Can[illegible]ght to occur by mid-August. In Eastern Canada, however, the maximum thaw on one palsa was found to occ[illegible]s early as late July (Allard et al. 1987). Nevertheless, it is important to note that thaw conditions near the surface still persisted long after the date of maximum thaw. For example, surface and near surface freeze-back was not initiated until late September/early October; thus, a condition of thaw would have still existed prior to this period. Furthermore, thawed material should have still been present between the surface and permafrost table well after early October, however, the magnitude of the heat flux would not be sufficient enough to allow deeper thaw.

4.6.2 Plant Cover

The relatively large differences in rate and depth of thaw between the two Dale Creek palsas may be attributed to the difference in the vegetation, which indirectly influences the energy budget properties at the ground surface (Luthin and Guymon 1974; Rouse 1982). For example, Dale Creek 6 had a rather dense shrub cover of *Salix planifolia* (mean height of 0.7 m) that enhanced its snow trapping ability, therefore, a thicker snow cover would help insulate the ground and reduce palsa core heat loss. This barrier to heat loss would keep ground temperatures warmer than the snow-free surfaces common to palsas (Seppälä 1982), thus contributing to greater depths and rates of thaw. In contrast, Dale Creek 2 lacked a shrub cover and was thought to have a thinner snow cover, hence, heat would be lost more efficiently on Dale Creek 2 resulting in cooler core temperatures, subsequently, leading to lower rates and depths of thaw.

4.6.3 Microclimate

The elevation difference between the lower and upper sites (410 m) should have accounted for a cooling of approximately 2.62 C° based on an adiabatic cooling rate of 0.64 C° 100 m^{-1}, nevertheless, the measured mean annual air temperatures at these locations were identical. However, substantial differences between the upper- and lower-elevation air temperatures did occur when these annual values were split into seasonal periods (e.g. summer thawing vs. winter freezing) (Table 3.2).

During the thaw season the lowest elevation feature experienced the greatest number of Tddt, whereas the highest elevation site had the least. Consequently, the lowest elevation site experienced a mean air temperature that was 2.66 C° warmer than the upper site (Table 3.2). This was calculated to be a positive regional environmental lapse rate of 0.65 C° 100 m^{-1}, which in turn is extremely close to the actual rate that air temperatures decrease with increasing altitudes, based on the normal environmental lapse rate. However, summer warming episodes at the lowest site were not so substantial as to offset the insulative properties of the dry peat cover coupled with cooler core temperatures.

During the winter period the valley sites experienced pronounced cooling events that led to a higher Fddt, subsequently the lowest valley site experienced mean air temperatures that were 2.04 C° cooler than the upper plateau site (Table 3.2). This inversion is the reverse of the summer environmental lapse rate. In addition, the mean winter surface temperatures at the lowest elevation site were 4.0 C° cooler than the plateau site. These winter cooling events led to a maximum ambient difference of 10.1 C° between the upper plateau site and the lower-elevation valley palsa. Winter cooling episodes in the valleys also contributed to mean annual core temperatures that were at least 1 C° cooler than that experienced at the plateau site, and this may have been an essential factor in influencing thaw characterist[illegible]se events confirm the importance that air density stratification can impart upon the microclimatic charac[illegible]es of palsas.

It should also be noted that the distance between the upper and lower sites (<15 km) was not so substantial as to significantly alter the synoptic weather systems of this alpine study area. However, seasonal temperature variations commonly occurred between the upper- and lower-elevation sites. Consequently, different site conditions led to variable palsa microclimates that ultimately resulted in distinct thawing characteristics. For example, the higher elevation sites experienced a more moderate climate (Kershaw and Skaret 1993) and consequently greater thaw, whereas the cooler lower elevation features had less thaw and colder core temperatures. Thus, we suggest that cold air drainage plays an integral role on the temperature regime and thaw characteristics of palsas in mountainous environments (Kershaw and Skaret 1993).

4.6.4 Aspect

During summer, the south-facing slopes within the study area (approximately 63°15'N 130° 02'W) tend to receive the highest amounts of solar radiation. Thus, southern aspects are generally warmer (Williams and Smith 1989), subsequently resulting in greater mean rates and depths of thaw (Table 4.3). Higher rates of insolation coupled with the deeper snow drifts that commonly form along the sides of palsas (Seppälä 1990), tend to keep these edge locations warmer on an annual basis (Kershaw and Skaret 1993), therefore, southern aspects are more likely to develop palsa laggs. These water bodies constitute a heat source that ultimately raise adjacent ground temperatures (Williams and Smith 1989). Thus, heat imported from these bodies of water can enhance peripheral thaw.

This aspect difference may be offset by water ponding; a similar situation may explain why greater thaw occurred on Beaver Pond's north-facing slopes during 1991. The input of water, however, was a direct result of an active beaver dam and not from a palsa lagg. Flooded probe sites experienced up to 218 cm deeper thaw after being inundated with a mean water depth of 22 cm. Consequently, heat importation from the pond was responsible for the deeper thaw on Beaver Pond's north-facing edge.

4.7 Conclusion

Thaw characteristics on palsas located in the alpine tundra environments of northwestern Canada were influenced by microclimate and the associated effects that these characteristics impart upon palsa energy regimes. Active layers began to develop in early May and continued to deepen until late August. However, a thawed state near the palsa surface persisted well after the date of maximum thaw, and this zone did not start to freeze-back until late September/early October.

On a regional scale, cold air drainage events were found to have influenced the rate and depth of thaw on palsas, consequently, the cooler lower elevation valley sites experienced the least thaw. The upper plateau site, however, had a more moderate climate that ultimately resulted in greater thaw depths.

Local thaw variation was common to each feature and this was attributed to the differences in vegetation cover, microclimate, aspect, slope angle and proximity to water. The greatest mean rates and depth of thaw mainly occurred on south-facing palsa edges, with maximum thaw occurring on lower slope angles adjacent to bodies of water. The relatively high discrepancy in thaw characteristics between two features located within the same fen was ascribed to the difference in vegetation cover and its subsequent influence on the thermal regime of palsas. Thus, intrinsic thawing properties were indicative of the site-specific factors associated with each palsa.

4.8 References

Åhman, R. 1976. The structure and morphology of minerogenic palsas in northern Norway. *Biuletyn Peryglacjalny*, 26:25-31.

Åhman, R. 1977. Palsar i Nordnorge. *Meddelanden från Lunds Universitets, Geografiska Institution, Avhandlingar LXXVIII*, 165p.

Åkerman, H.J. 1982. Observations of palsas within the continuous permafrost zone in Eastern Siberia and in Svalbard. In *Nordiskt Symposium I Frostmarksmorfologi, Copenhagen, September 7-10, 1982.* Geografisk Tidsskrift, 82:45-51.

Allard, M., Seguin, M.K. and Lévesque R. 1987. Palsas and mineral permafrost mounds in northern Québec. In: V. Gardiner (ed.) *International Geomorphology, Part II.* John Wiley and Sons, Chichester, pp. 285-309.

Allard, M. and Fortier, R. 19‥ . The thermal regime of a permafrost body at Mont du Lac des C‥nes, Québec. *Canadian Journal of Earth Sciences*, 27: 694-697.

Brown, G. 198‥. Palsas and other permafrost features in the lower Rock Creek Valley, West Central Alberta. *Arctic and Alpine Research*, 12(1):31-40.

Collins, E.I., Lichvar, R.W. and Evert, E.F. 1984. Descriptions of the only known fen palsa in the contiguous United States. *Arctic and Alpine Research*, 16(2):255-258.

Dionne, J.C. 1984. Palses et limites méridionales du pergélisol dans l'hémisphère nord: le cas de Blanc-Sablon, Québec. *Géographie physique et Quaternaire*, 38:165-184.

Doolittle, J.A., Hardisty, M.A. and Black, S. 1992. A ground-penetrating radar study of Goodream palsas, Newfoundland, Canada. *Arctic and Alpine Research*, 24:173-178.

Forsgren, B. 1966. Tritium determinations in the study of palsas. *Geografiska Annaler*, 46: 343-344.

Friedman, J.D., Johansson, C.E., Oskarsson, N., Svensson, H., Thorarinsson, S. and Williams, R.S. Jr. 1971. Observations on Icelandic polygon surfaces and palsa areas. *Geografiska Annaler*, 53A:115-145.

Hinkle, K.M., Nelson, F.E. and Outcalt, S.I. 1987. Frost mounds at Telex Lake, Alaska. *Physical Geography*, 8:148-159.

Kershaw, G.P. and Gill, D. 1979. Growth and decay of palsas and peat plateaus in the Macmillan Pass-Tsichu River area, Northwest Territories, Canada. *Canadian Journal of Earth Sciences*, 16(7):1362-1374.

Kershaw, G.P. and Kershaw, L.J. 1983. *Geomorphology and Vegetation of the MacTung Study Area, Yukon/NWT*. Report prepared for AMAX Northwest Mining Co. Ltd., Vancouver.

Kershaw, G.P. and Skaret, K.D. 1993. Microclimatic characteristics of palsas along an altitudinal gradient, Mackenzie Mountains, NWT, Canada. *In Proceedings Sixth International Permafrost Conference*, National Academy Press, Washington DC, pp. 338-343.

Lagerback and Rodhe, L. 1986. Pingos and palsas in northern-most Sweden-Preliminary notes on recent investigations. *Geografiska Annaler*, 68A(3):149-154.

Lindqvist, S. and Mattsson, J.O. 1965. Studies on the thermal structure of a pals. *Svensk Geographisk Årsbok* 41:38-49.

Luthin, J.N. and Guymon, G.L. 1974. Soil moisture-vegetation-temperature relationships in central Alaska. *Journal of Hydrology*, 23:233-246.

Nicholson, F.H. 1979. Permafrost spatial and temporal variations near Schefferville, Nouveau-Québec. *Geographie physique et Quaternaire*, 33:265-277.

Novikov, S.M. and Usova, L.I. 1979. Nature and Classification of palsa bogs. *Soviet Hydrology*, 18(2): 109-113.

Porsild, A.E. 1945. The alpine flora of the east slope of Mackenzie Mountains, Northwest Territories, *National Museums of Canada, Bulletin 101 (Biological Series, No. 30)*, Edmond Cloutier, Printer, Ottawa.

Rapp, A. and Annersten, L. 1969. Permafrost and Tundra polygons in Northern Sweden. In T.L. Péw‥ (ed), *The Periglacial Environments*. McGill-Queen's University Press, Montréal, pp. 65-91.

Roberts, B.A. and Robertson, A.W. 1980. Palsa bogs, sand dunes and salt marshes, environmentally sensitive habitats in the coastal region Southeastern Labrador. In *Workshops on Research in the Labrador Coastal and Offshore Region*, pp. 245-260.

Rouse, W.R. 1982. Microclimate of low arctic tundra at Churchill, Manitoba, *Proceedings of the 4th Canadian Permafrost Conference*, National Research Council of Canada, pp.68-80.

Salmi, M. 1968. Development of palsas in Finnish Lapland. In *Proceedings of the Third International Peat Congress, Ottawa*, National Research Council of Canada, pp. 182-189.

Salmi, M. 1970. Investigations on palsas in Lapland Finnish. In *Ecology of Subarctic Regions Proceedings of the Helsinki Symposium 1966*, UNESCO, Paris, pp. 143-153.

Salmi, M. 1972. Present developmental stages of palsas in Finland. In *Proceedings of the 4th International Peat Congress, Helsinki*, 1:121-141.

Schunke, E. 1973. Palsen und kryokarst in Zentral-Island. Nachr. Akad. *Wissenschaften in Gottingen, II Mathematisch-Physikalische Klasse*, H.4:65-102.

Seguin, M.K. and Crépault, J. 1979. Étude géophysique d'un champ de palses à Poste-de-la-Baleine, Nouveau-Québec. *Géographie physique et Quaternaire*, 33:327-337.

Seppälä, M. 1972. The term 'palsa'. *Zeitschrift für Geomorphologie*, 16:463.

Seppälä, M. 1976. Seasonal thawing of a palsa at Enontekiö, Finnish Lapland, in 1974. *Biuletyn Peryglacjalny*, 26:17-24.

Seppälä, M. 1982. An experimental study on the formation of palsas. <u>In</u> *Proceedings of the Fourth Canadian Permafrost Conference*, National Research Council of Canada, Ottawa, pp. 36-42.

Seppälä, M. 1983. Seasonal thawing of palsas in Finnish Lapland. <u>In</u> *Fourth International Conference on Permafrost, Fairbanks*, pp. 1127-1132.

Seppälä, M. 1986. Origin of palsas. *Geografiska Annaler*, 68A(3), pp. 141-147.

Seppälä, M. 1988. Palsas and related forms. <u>In</u> M.J. Clark (ed.), *Periglacial Geomorphology* [illegible] and Sons, Chichester, pp. 247-278.

Seppälä, M. 1990. Depth of snow and frost on a palsa mire, Finnish Lapland. *Geografiska Annaler* [illegible] 91-201.

Sollid, J.L. and Sørbel, L. 1974. Palsa bogs at Haugtjørnin, Dovrefjell, South Norway. [illegible] *Tidskr.*, 28:271-283.

Svensson, H. 1964. Structural observation in the minerogenic core of a pals. *Geografisk* [illegible]

Tallman, A.M. 1973. Resistivity methodology for permafrost delineation. <u>In</u> B.D. [illegible] and [illegible] D. Thompson (eds.), *Research in Polar and Alpine Geomorphology*. Department of Geography, University of Guelph. Geographical Publication 3, pp. 73-83.

Vorren, K.D. 1979. *Vegetation investigation of a palsa bog in Northern Norway*. (Tromsø Museum's Report Series), Naturritenska. Nr. 5, 182 p.

Washburn, A.L. 1983. Palsas and continuous permafrost. <u>In</u> *Proceedings Fourth International* [illegible] *mafrost Conference*, National Academy Press, Washington DC, pp. 1372-1377.

Williams, P.J. and Smith, M.W. 1989. *The Frozen Earth*. Cambridge University Press, New York, 306 p

Zoltai, S.C. 1972. Palsas and peat plateaus in Central Manitoba and Saskatchewan. *Canadian Journal of Forest Research*, 2:291-302.

Zoltai, S.C. and Tarnocai, C. 1971. Properties of a wooded palsa in northern Manitoba. *Arctic and Alpine Research*, 3:115-129.

Zoltai, S.C. and Tarnocai, C. 1975. Perennially frozen peatlands in the western Arctic and Subarctic of Canada. *Canadian Journal of Earth Sciences*, 12:28-43.

Zoltai, S.C. Tarnocai, C., Mills, G.F. and Veldhuis, H. 1988. Wetlands of subarctic Canada. <u>In</u> *Wetlands of Canada. Ecological Land Classification Series, No. 24*, Sustainable Development Branch, Environment Canada, Ottawa, Ontario and Polyscience Publication Inc., Montreal Quebec. pp. 55-96.

5.0 Conceptual Model of Palsa Development and Degradation

5.1 Introduction

Palsas are a widespread periglacial phenomena that occur in wetland environments located throughout the discontinuous circumpolar permafrost zone. The constituent elements that have been postulated to promote the formation of palsas are relatively cool climates, thin snow cover, a surface peat cover, and the availability of water (e.g. Forsgren 1968, Zoltai 1972). These general characteristics, however, can engender various responses depending upon the influence exerted by site conditions (e.g. snow cover thickness and density, albedo, slope angle, soil moisture conditions, plant cover type and density, peat type and thickness, water quantity, relief, temperature, precipitation, wind, insolation, soil texture, surface roughness etc.). Hence, palsas are influenced by a variety of biotic and abiotic components acting within exogenous and endogenous spatial environments (Figure 5.1). Alterations to any of these variables may directly or indirectly influence the thermal regime of palsas and ultimately their future existence.

Palsas encompass both aggradational and degradational phases; terms, such as Incipient, Disequilibrium aggradational, Dynamic equilibrium, and Disequilibrium degradational are used to denote various stages of palsa evolution without implying an absolute time frame. Each phase depicts the dominant processes that are influencing the palsas, however, it should be noted that some features may not be subjected to all phases within this progressive sequence. For example, palsas that undergo an early deterioration phase do not experience many of the intermediary stages. Nevertheless, each feature is influenced by specific site-conditions, therefore, the geomorphic evolution of individual palsas is not identical. These features were also thought to undergo cyclic evolution following a renewed phase of peat development coupled with favourable site conditions that promote permafrost aggradation (Seppälä 1979; 1986; 1988; Zoltai 1993; Zoltai and Tarnocai 1975).

5.2 Model Components Derived from the Database

A number of site characteristics regarding the morphology, microclimate and stratigraphy of palsas have been presented in previous chapters, and this data can be viewed within the context of a conceptual model of palsa evolution. However, much remains to be investigated and gaps in the data prevent a comprehensive testing of the model, yet, it is useful to place the data previously presented within the model framework. It should be noted, that many other factors and parameters affect these features, however, they were not the focus of this study. Furthermore, some of the factors included in the sketches (Figures 5.2-5.6, 5.12 Ker...aw and Skaret 1993a) were derived from literature sources, and supported for the study area through casual observations.

5.2.1 Temperature

It has been established that palsas occur within a zone having certain common temperature characteristics. For example, the upper temperature limit for the formation of these features was thought to correspond to the 0°C mean annual isotherm (Åhman 1977; Brown 1970; Harris 1982; Seppälä 1988), yet, these permafrost features occur more frequently under cooler climatic conditions (Zoltai 1993). The extent of palsas has been estimated by using freezing and thawing indices. Harris (1982) suggested that palsas occur within the 1000 to 7500 freezing-degree-day total range and the 300 to 2300 thawing-degree-day totals range. Seppälä (1988), however, proposed that the range for more representative values of "normal palsa regions" are 1000-4000 freezing-degree-day totals and 1000-2300 thawing-degree-day totals. It should be noted that Seppälä's work has been in Finland where there can be a significant maritime influence to the climate, whereas, Harris's paper dealt with North American climatic normals predominantly from interior continental locations.

5.2.1.1 Air Temperature

The Macmillan Pass-Tsichu River study area has a Continental climate influenced by mountains and a mean annual air temperature that ranged from -6.69° to -7.37°C (1 August 1990 to 31 July 199... ...e cumulative degree days that were above and below 0°C for 1 year commencing August 1990 ranged f... ...- 1041.5 and 3354.8-3731.6 respectively (Table 3.1). These annual temperatures were slightly war... ...e

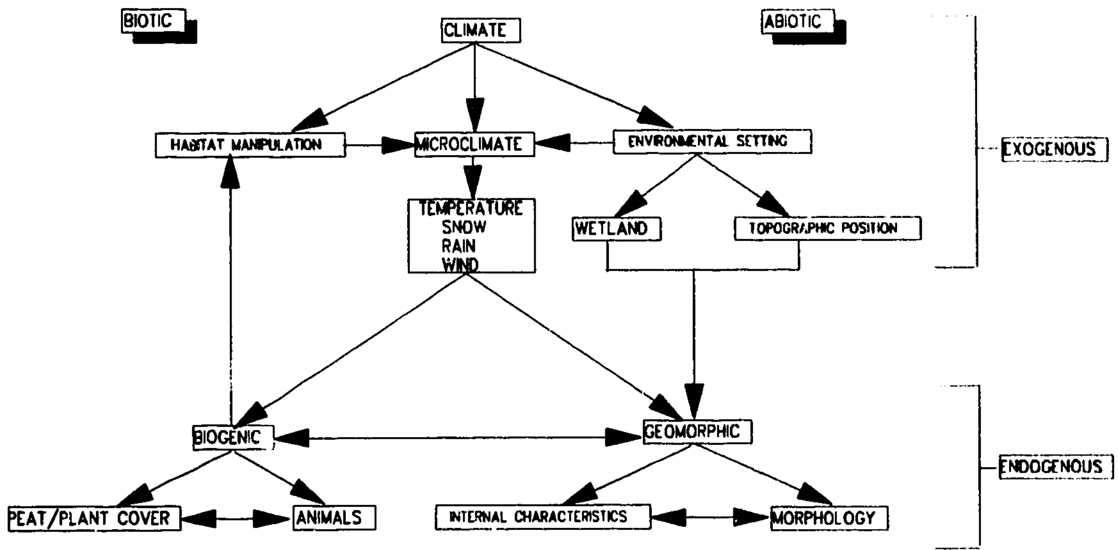


Figure 5.1. A generalized flow diagram illustrating the dominate biotic and abiotic variables acting within the exogenous and endogenous spatial environments of palsas.

mean from 1974 to 1982 for a similar location (-7.7 °C as cited by Kershaw and Kershaw 1983), and furthermore, air temperatures during this 8 year period warmed by 3.5 C° (Liang and Kershaw 1994, in press). More specifically, altitudinal differences between study sites were found to influence seasonal temperatures (winter/summer). For example, during summer, adiabatic cooling kept the mean temperature at the upper-elevation site (1660 m asl) 2.67 C° cooler than the lowest-elevation site (1250 m asl) (Table 3.2a). During winter, however, a negative mean environmental lapse-rate kept valley sites up to 10°, or a mean of 2.04° cooler than the upper-elevation site. Hence, cold air drainage events were a common winter phenomena that ultimately had a strong influence upon regional temperatures.

Temperature data from the study area fall within Harris's (1982) classification, and the negative heat budget suggests that conditions might be conducive to permafrost formation and maintenance. However, all of the investigated palsas display evidence of relatively recent or active degradational processes (e.g. surface fissure development, peat block calving, thermokarst depressions and surface subsidence). Kershaw and Gill (1979) came to a similar conclusion for the Macmillan Pass-Tsichu River region and stated that no new palsas or peat plateaus had formed between 1944-1978, and furthermore, some features had degraded by 34 to 100% over the 34 year period. A site reconnaissance within a similar but larger area than that investigated by Kershaw and Gill (1979) did not locate any examples of palsa classes as being representatives of the incipient phase. Thus, within the study area, thermal conditions appear to be more conducive to permafrost degradation/maintenance rather than formation. Consequently, all study features were classified within the Disequilibrium degradational evolutionary phase (Figures 5.2-5.6).

5.2.1.2 Palsa Surface, Near-Surface and Core Temperatures

In the Macmillan Pass-Tsichu River region, near-surface temperatures were influenced by ambient conditions that were dictated by the regional climate. However, local differences in temperature were common at each site, and were the result of various site-specific factors associated with the buffer zone. Generally, seasonal (summer/winter) ground temperatures were warmer than ambient values, however, the temperature amplitudes were much larger in the winter (Table 3.2a). More specifically, ground temperatures were warmer at locations that had a relatively thick snow cover in winter or well-developed plant canopy in summer (Table 3.2a, 3.2b). These results support the literature (e.g. Luthin and Guymon 1974; Cernusca and Seeber 1981; Williams and Smith 1989) and were attributed to the influence that buffer layer imparts upon the ground. For example, buffer zones isolate the ground from ambient temperature fluctuations by acting as a barrier to heat loss, thereby keeping the ground warmer on an annual basis. Within the investigated palsas, core temperatures fluctuated annually, however, the amplitude decreased with increasing depths (Table 3.2). Also, the influence of the temperature wave lessened with increasing depths, thereby creating temperature lags. The greatest lag intervals occurred at sites that had an insulative snow layer that ultimately diminished wave propagation. However, sites that had a more direct linkage between the atmosphere and the palsa surface experienced a more efficient wave dispersal, and subsequently, shorter temperature lags (Table 3.3c).

5.2.2 Stratigraphic Characteristics

All the study palsas in the Macmillan Pass-Tsichu River region have a surface cover of peat underlain by mineral soil (Figures 5.2-5.6). Pore and segregated ice lenses occur throughout the features and are partially responsible for anchoring the organic layer to the underlying mineral sediment. In all palsas, the mineral soil is heaved to a height that surpasses the surrounding wetland, and the top of the mineral soil in one feature is approximately 2.34 m above the surrounding fen. Within this study area, however, it should be noted that Kershaw and Gill (1979) described degrading features that were comprised of a detached organic/mineral soil substratum. They determined that the peat-portion of the palsas were "floating" in the fen. Since these palsas were already degrading, the buoyant organic portion may have been disconnected from a stable substratum as part of the degradation process, and not the result of aggrading features as proposed by Outcalt *et al.* (1984; 1986) and Nelson *et al.* 1991. Nevertheless, soil within all study features has not been distorted by cryoturbation, implying that frost

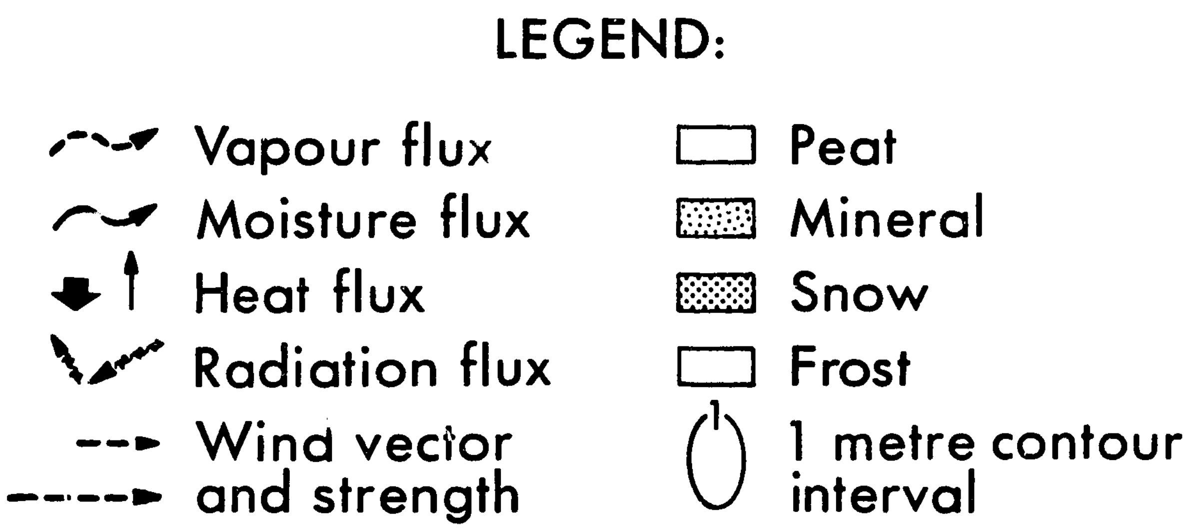


Figure 5.2a. Legend for the conceptual diagrams of palsa evolution (Figures 5.2-5.6, 5.12).

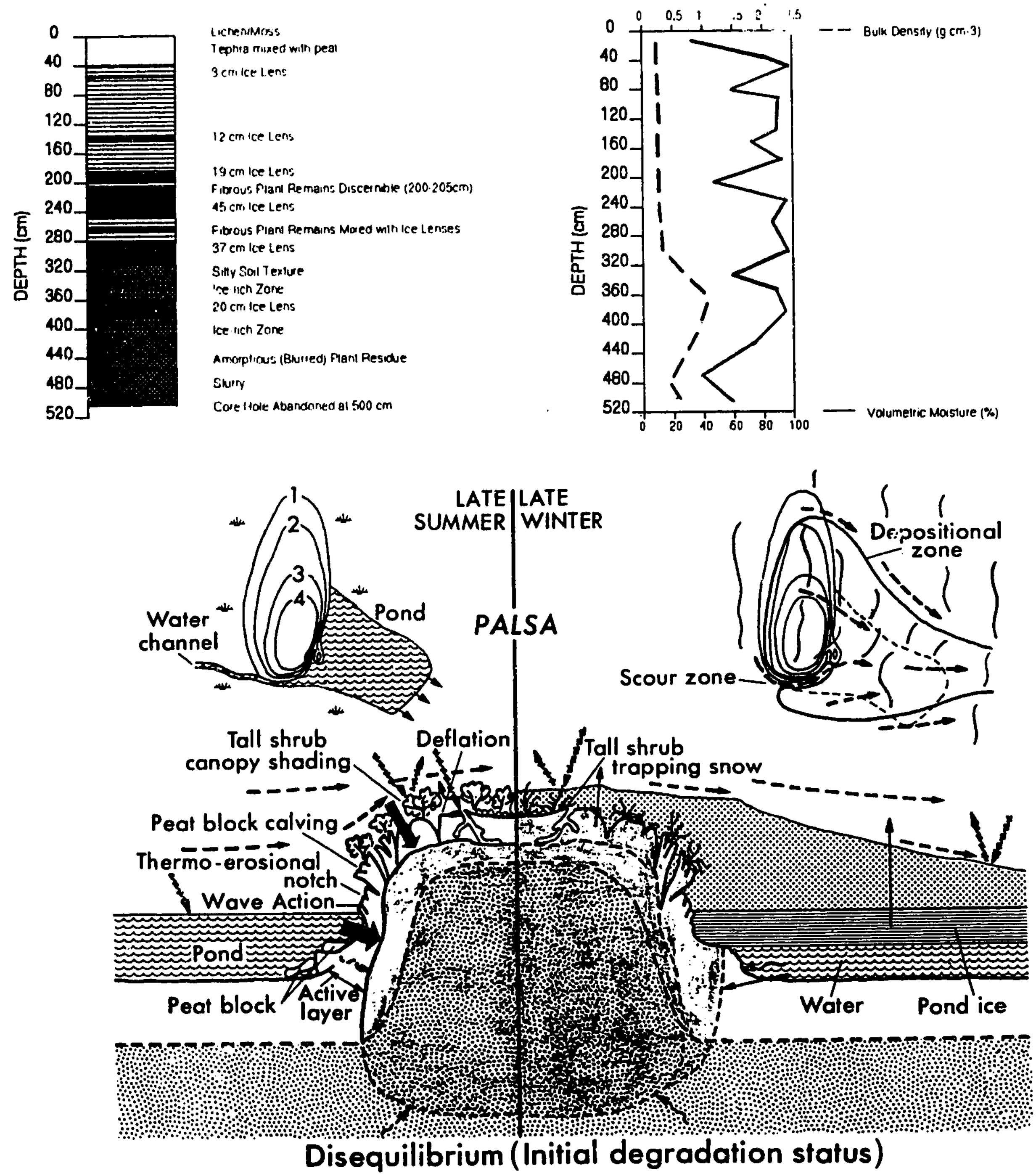


Figure 5.2. Representative diagrams depicting stratigraphy, bulk density, volumetric moisture contents and evolutionary status of Hare Foot. This palsa is thought to be in an initial disequilibrium degradational phase (bottom diagram is part of the conceptual model).

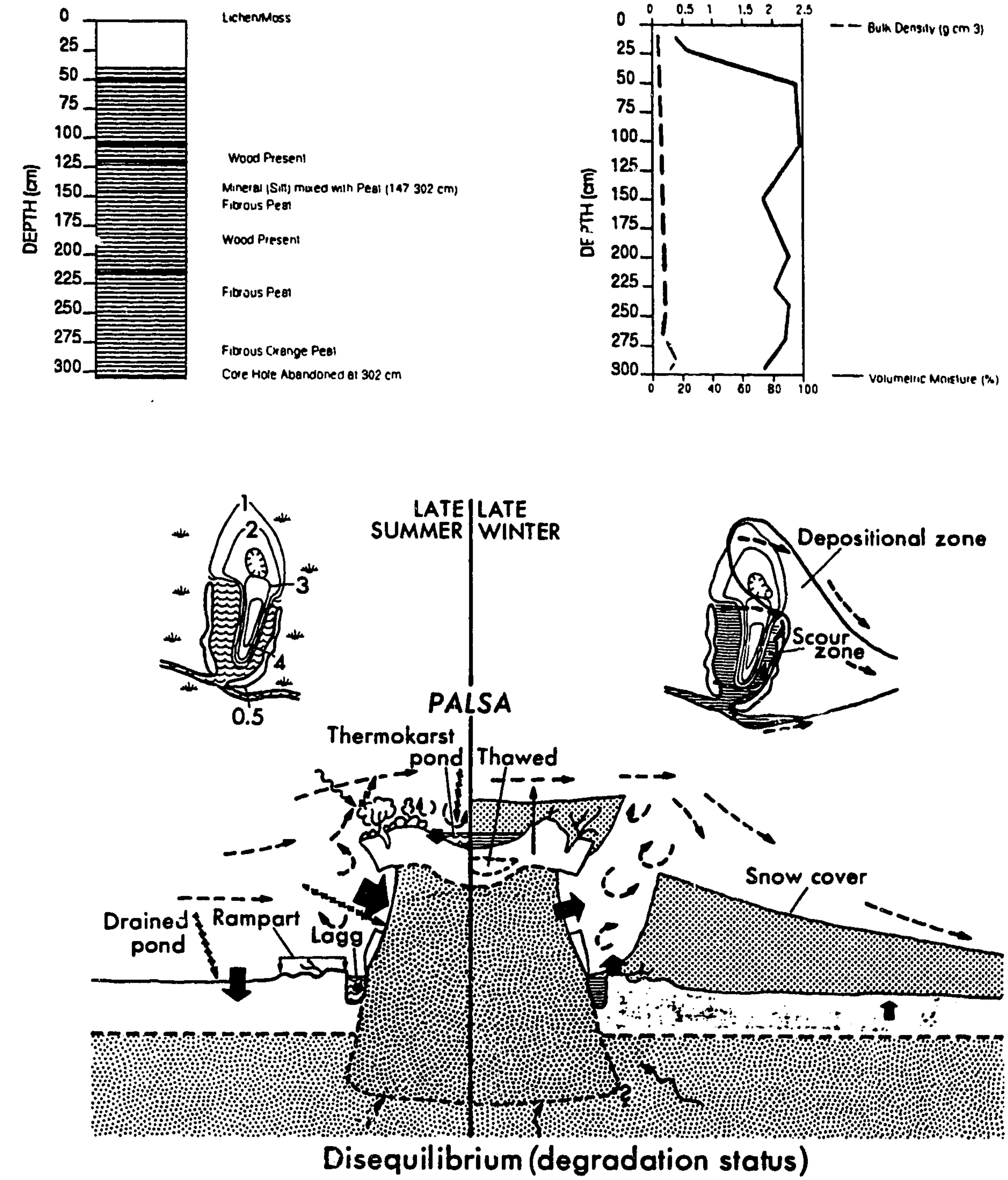


Figure 5.3. Representative diagrams depicting stratigraphy, bulk density, volumetric moisture contents and evolutionary status of Beaver Pond. This palsa is thought to be in a disequilibrium degradation phase (bottom diagram is part of the conceptual model).

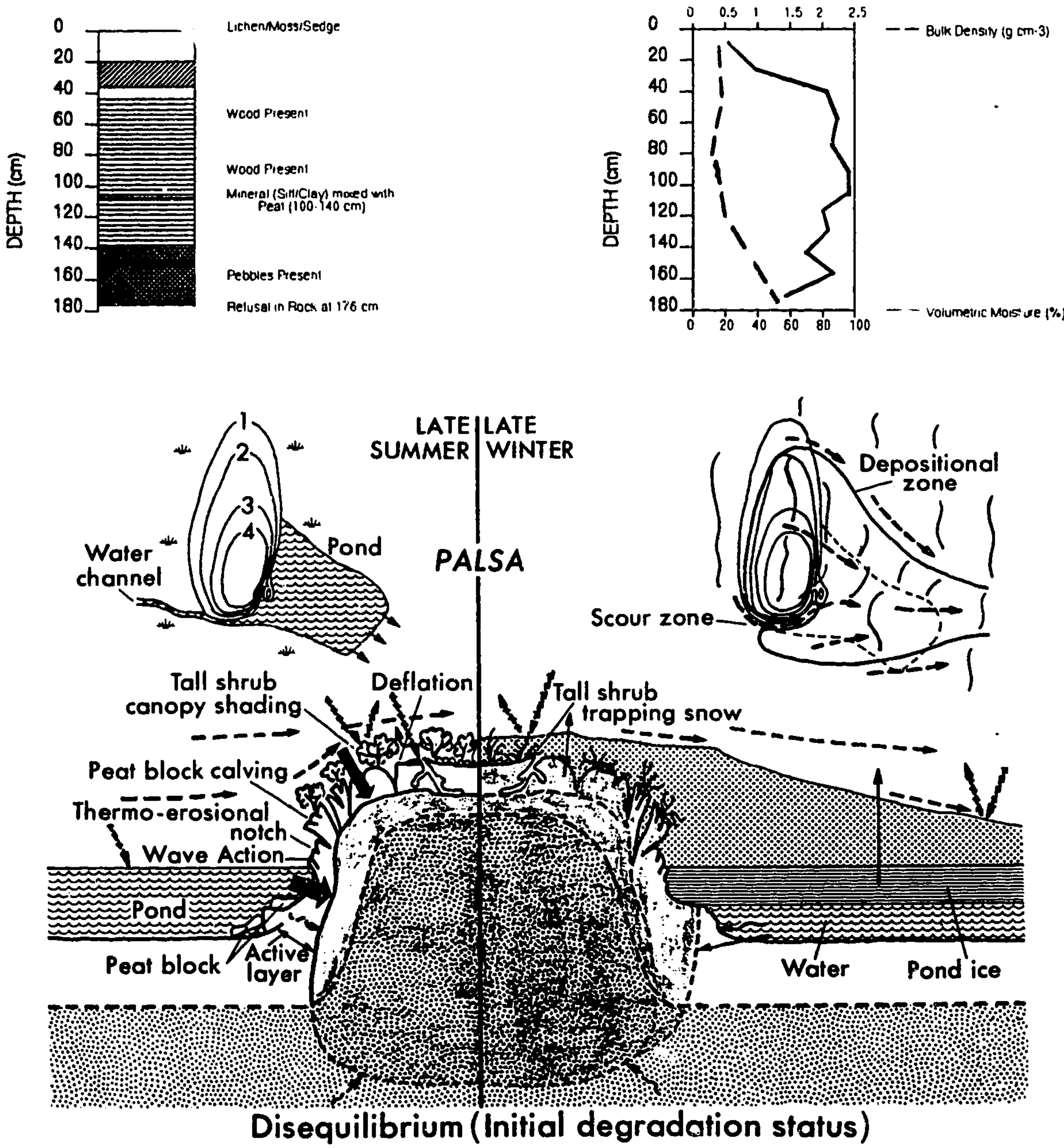


Figure 5.4. Representative diagrams depicting stratigraphy, bulk density, volumetric moisture contents and evolutionary status of Dale Creek 2. This palsa is thought to be in an initial disequilibrium degradational phase (bottom diagram is part of the conceptual model).

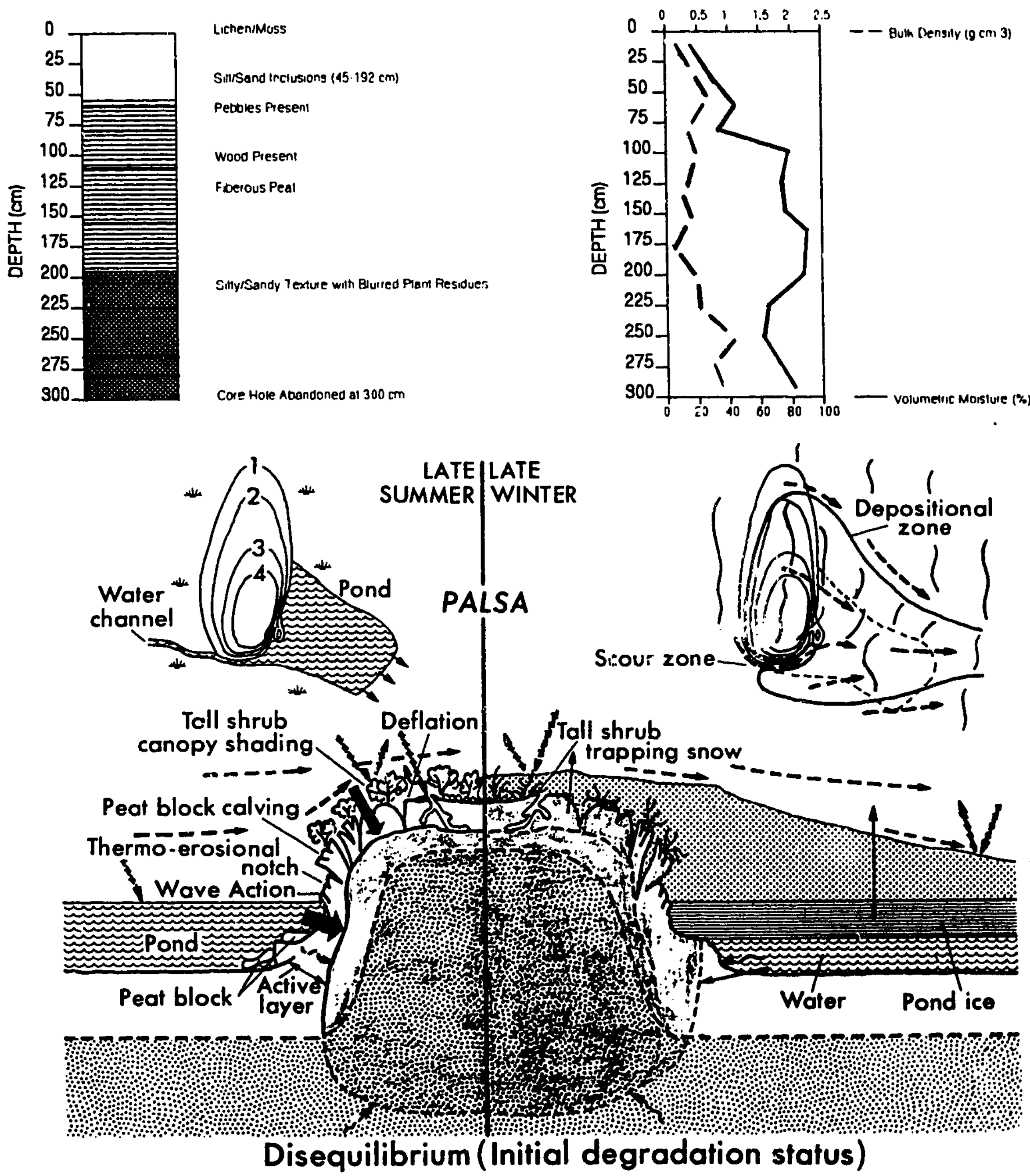


Figure 5.5. Representative diagrams depicting stratigraphy, bulk density, volumetric moisture contents and evolutionary status of Dale Creek 6. This palsa is thought to be in an initial disequilibrium degradational phase (bottom diagram is part of the conceptual model).

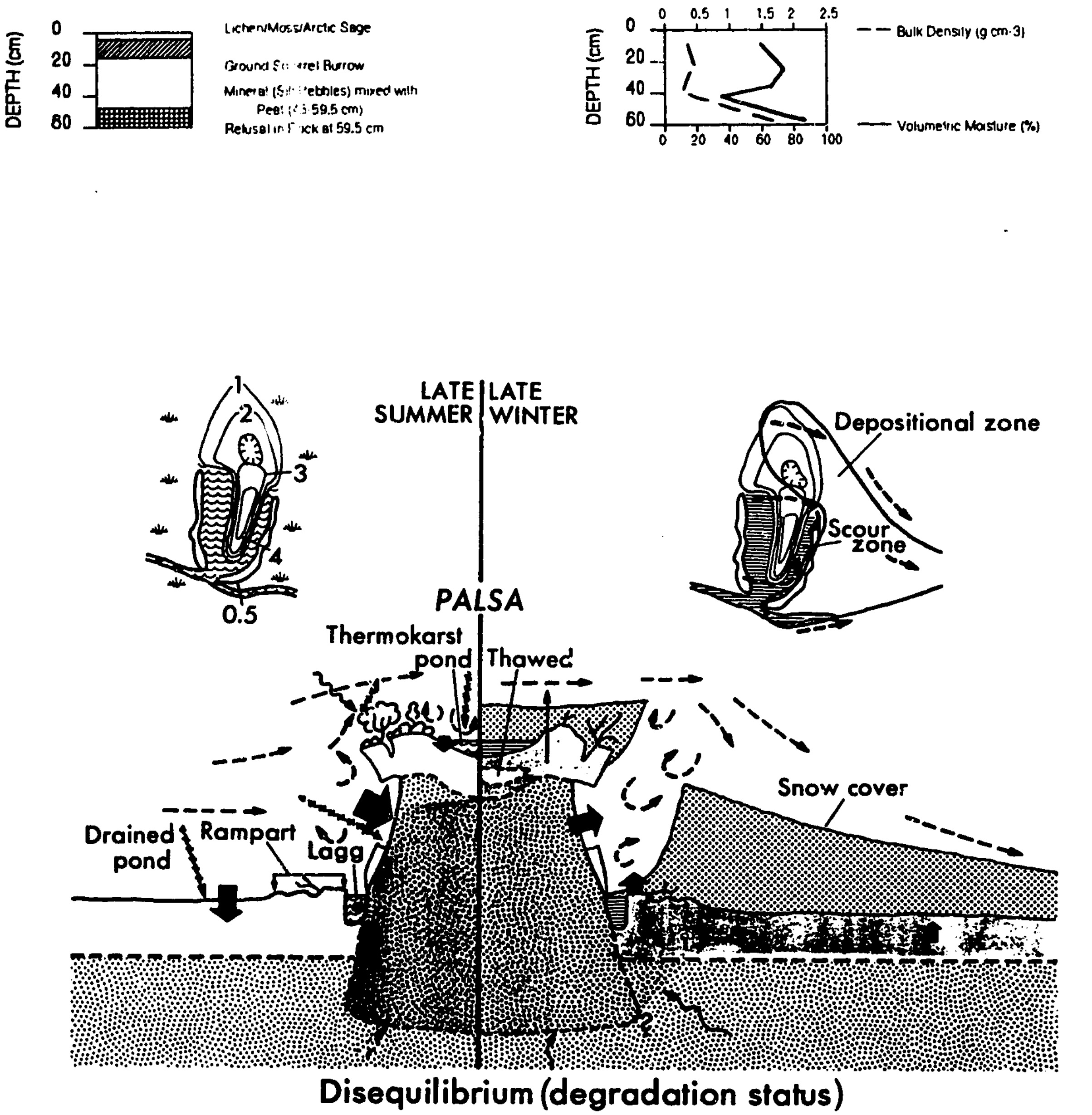


Figure 5.6. Representative diagrams depicting stratigraphy, bulk density, volumetric moisture contents and evolutionary status of Goose Flats. This palsa is thought to be in a disequilibrium degradation phase (bottom diagram is part of the conceptual model).

has penetrated downwards from the surface.

5.2.2.1 Peat

In the Macmillan Pass-Tsichu River region the mean thickness of the peat in the wetlands ranges from approximately 1-3 m (Table 1.1), therefore, according to Zoltai *et al.* (1988) these sites can be classed as peatlands. The thickness of the peat required for the development and maintenance of palsas may depend upon local climatic conditions, whereby warmer regions command thicker peat layers (Seppälä 1988). Cooler regions, however, may require less summer insulation and thus thinner peat layers. Nevertheless, it is suggested in much of the literature that the persistence of the seasonal frost layer depends upon the presence of peat (e.g. Brown 1977; French 1976; Seppälä 1986; 1988; Zoltai and Tarnocai 1971; 1975). Thus, peat plays an important role in influencing the thermal properties of the ground year round (e.g. Luthin and Guymon 1974; Nakano and Brown 1972; Nelson *et al.* 1985; Seppälä 1988; Zoltai and Tarnocai 1971; 1975). Hence, the conductivity of the organic layer varies in conjunction with its changing physical status, which is subsequently linked to the seasons (Williams and Smith 1989).

During summer, the surface peat dries out through evaporative processes, thereby, decreasing near-surface moisture contents to as low as 10% (Figures 5.2-5.6). In a dry unfrozen state the thermal conductivity of the peat is relatively low (e.g. Washburn 1979), consequently, ground warming is inhibited. Within the study area, mean temperatures within the ground (e.g. 5 cm and below, Table 3.2a) were cooler than surface temperatures. During fall, however, the ambient temperature and evaporation rates decrease, and eventually the surface peat becomes moist, and with time freezes. In 1990-91, the initiation of surface and near-surface freeze-back occurred in late September/early October (Table 4.4). These changes increase the conductivity of the peat and allow the ground to cool rapidly (Williams and Smith 1989; Zoltai and Tarnocai 1971; 1975). The conductivity of frozen saturated peat approaches that of ice, hence, ground temperatures tend to be cooler beneath peat (Smith 1975), and the existence of permafrost in "marginal areas" is often related to its presence (Williams and Smith 1989).

By analyzing and dating peat profiles, it is possible to determine the approximate age of palsas (e.g. Vorren 1972; Seppälä 1988). The best indication of when these peat surfaces were heaved above the wetland is by obtaining radiocarbon dates from apex position between the transition layer of hydrophilous and xerophilous peat (Vorren 1972). Also, tephra layers can provide an important stratigraphic marker that can be used as a reference point for dating palsas (Friedman *et al.* 1971; Kershaw and Gill 1979). Within the study area, White River volcanic ash was deposited approximately 1250 years BP (Lerbekmo *et al.* 1975). This volcanic ash was present at each site, and four of the investigated palsas had aquatic peat and/or pond sediments lying above the tephra layer, thereby implying that surface heave occurred after the White River volcanic eruption. The surface of one feature, however, had the hydrophilous/xerophilous peat transition region located below the volcanic ash, hence, this feature was thought to have been heaved above the surrounding wetland prior to tephra deposition.

On palsas, the rate of peat accumulation was found to be less than in the wetlands (Tables 2.3-2.4). Similar results have been reported in the literature, and have been ascribed to morphological position and the influence this exerts upon organic matter production (e.g. Zoltai *et al.* 1988). For example, the elevated surfaces within a wetland tend to be drier, and therefore experience more plant decomposition and less peat deposition (Zoltai *et al.* 1988). Thus, raised surfaces (e.g. palsas) experience lower peat accumulation rates (e.g. Zoltai *et al.* 1988).

5.2.2.2 Soil Texture and Ice Lenses

Soil texture can influence the influx of water, and consequently, the volume of segregated ice, therefore, soil texture is an important attribute in frost heaving processes. Both the motive force (that which causes water migration) and the permeability of the soil system are highly dependent upon the texture of the soil. The soil's permeability and its ability to produce a motive force tend to be inversely proportional to each other (Lunardini 1981). Hence, silts which have intermediate qualities of motive force and permeability tend to be the most susceptible to the development of heaving processes and ice lens formation (e.g. Beskow 1935; Linnell and Kaplar

1959; Lunardini 1981). Generally, these particles are small enough to be readily rejected from expanding ice crystals, however, their hydraulic conductivity is high enough to maintain a constant influx of water (under good supply conditions) (Anderson *et al.* 1984). Fine textured soils, however, tend to contain less segregated ice and are not as prone to frost heaving (Williams and Smith 1989). Their lower rates of hydraulic conductivity impede water migration towards the freezing zone in both the saturated and unsaturated conditions. Conversely, coarse textured soils are not able to efficiently hold or draw water to the freezing front, and subsequently, contain fewer ice lenses (Lunardini 1981). Hence, palsas tend to achieve the majority of their height from frost heaving events that occur within silty soil (e.g. Allard *et al.* 1987; Sollid and Sørbel 1974).

Stratigraphic analysis confirmed that the principle mineral component of the investigated palsas is silt, and furthermore, all features contained rhythmic ice lenses that resulted in alternating layers of frozen soil containing pore ice and ice lenses (Figures 5.2-5.6). Generally, the upper peat layer contained relatively thin ice lenses that ranged from less than 1 cm to approximately 12 cm (Figures 5.2-5.6). Ice lenses, however, became progressively thicker with depth, and near the basal peat/mineral interface the ice lenses were up to 50 cm thick. These thicker ice lenses were thought to be the result of the gradual decrease in freezing rates with increasing depths (Williams and Smith 1989). The literature suggests that smaller temperature gradients at depth may slow the rate of freezing, thereby allowing enough time for water to migrate to the freezing front where larger lenses can develop (e.g. Williams and Smith 1989). Sensors within the investigated palsas confirmed that the temperature gradient decreased with increasing depths (Figure 5.7). Also, the literature suggests that as an ice lens continues to thicken, the soil beneath the lens can experience a "falling moisture content" (Williams and Smith 1989). Analysis of samples from the study area confirmed that moisture contents actually declined below ice lenses (Figures 5.2-5.6), and this was thought to be related to zones of insufficient water flow caused by thermal imbalances coupled with consolidation. Hence, variations in the hydraulic and thermal attributes of the soil, coupled with the differences in accessible soil moisture, result in differing frost depths and subsequent heave. The magnitude of vertical displacement tends to equal the thickness of the segregated ice within the feature (Brown 1977), however, the height of palsas ultimately depends upon the availability of water during the freezing period; absence of water during freezing tends to limit palsa growth (Seppälä 1988).

5.2.3 Plant Cover

Within the study area, the dominant plant cover on palsas varies from lichen/moss to a relatively dense shrub cover with a lichen/moss understorey (Table 1.1). Generally, the plant cover acts as a buffer zone that reduces the amount of solar radiation reaching the surface (Luthin and Guymon 1974). However, the plant cover can also trap and reemit radiation back towards the surface, subsequently, keeping the ground warmer on an annual basis (Figure 3.2a). Nevertheless, the most important aspect of a plant cover in relation to its influence upon the thermal characteristics of the ground, is the indirect effect that it has as a snow collector (Annersten 1964; Smith 1975; Rouse 1984).

The type of plant cover and its variable effects on snow depth and duration, can drastically influence near-surface thermal conditions (Rouse 1982). For example, palsas with a relatively dense yet erect shrub cover (Hare Foot, Beaver Pond, Dale Creek 6) are more effective at trapping snow than features covered by predominantly low-lying plant species (e.g. sedges, graminoids, lichens, moss, decumbent shrubs, etc.) (Kershaw and Gill 1979). Consequently, thicker snow covers help insulate the ground and reduce the heat flux (heat loss) exiting the feature, therefore, palsa surfaces blanketed with snow tend to be warmer than the snow-free surfaces commonly associated with apex positions (Kershaw and Skaret 1993b). For example, sensors beneath drift sites had mean winter temperatures that were approximately 5 C° warmer than their respective apex values (Table 2a) Furthermore, warmer ground conditions beneath the snowpack made these areas more susceptible to thawing (Smith 1975), hence, warmer seasonal frost or permafrost is predisposed to earlier and longer thawing conditions (Williams and Smith 1989).

Within the study area, cold air drainage events influenced the regional climate and ultimately kept the

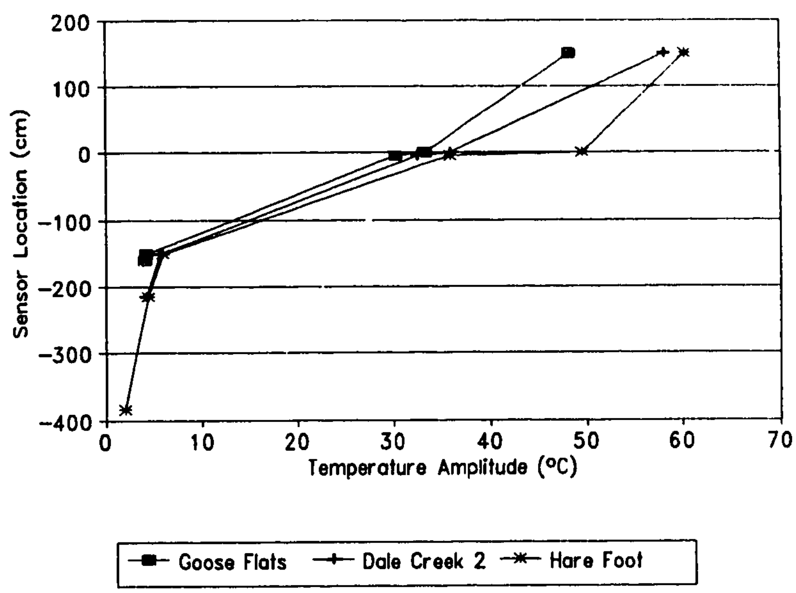


Figure 5.7. The annual temperature amplitudes above the surface and within the ground for 3 palsas in the Macmillan Pass-Tsichu River region, N.W.T.

lower-elevation locations cooler, consequently, these sites had less thaw. Local variations in thaw were common to each palsa and this was attributed to the differences in site-characteristics. For example, the greatest rates and depth of thaw mainly occurred on the south-facing edges with the greatest depths of thaw occurring on the lower slope angles adjacent to bodies of water. Additionally, if thawing permafrost contains excessive ice, it can lead to surface subsidence (Williams and Smith 1989). Since the interior of palsas include pore and segregated ice, these features become thaw susceptible, therefore, thermokarst processes can enhance surface subsidence and/or deflation.

In the Macmillan Pass-Tsichu River region there are numerous examples of thermokarst features on top of palsas, and on many features thermokarst development may have aided in degradational processes (Figure 5.8). For example, an upper portion of Beaver Pond has subsided by 1.59 m and the active layer was up to 1.15 m deeper near this water body compared to probe sites less than 3 m away. Water in these ponds acts as a heat sink and a heat source that can lead to the development of thaw zones and taliks below the base of the water (Figure 5.3), thus producing further degradation. Surface subsidence can also be enhanced as thermokarst ponds expand at the expense of the features. Expansion of these water bodies occurs as wind-generated waves lap against the palsa edge, and mechanically remove the surface peat and/or undercut peat blocks that facilitate calving processes, thereby, promoting further thaw. In addition, these depressional areas may also act as snow traps that encourage further ground warming and subsequent thawing processes (Williams and Smith 1989).

On palsas, the surface organic cover has a low tolerance to disturbances and is rather susceptible to damage (Roberts and Robertson 1980), therefore, any depressional areas that pond water, or regions that have their plant cover removed or killed can accelerate the degradational processes (Zoltai 1993). Mass wasting and/or allogenic (e.g. disease, fire) processes that aid in the removal of the living plant cover and its insulative characteristics, tend to promote further wind and water erosion (Allard *et al.* 1987). Also, fire can destroy some of the drier peat within the active layer, thereby enhancing the degradational process (Zoltai 1993). Eventually, most of the organic material may be removed from the sides of the palsa, subsequently, exposing the mineral soil that often lies beneath the peat cover (Figure 5.3). This newly exposed mineral soil has a higher thermal conductivity than peat (Williams and Smith 1989). Consequently, more heat is transferred towards the permafrost core, and this coupled with the higher solar energy absorption rates that occur on slopes, leads to greater thaw depths (Table 4.2).

5.2.4 Animal Activities

The activities of animals can alter the surface cover of palsas (e.g. Roberts and Robertson 1980; Zoltai 1972). Some of these effects have been observed in the mountainous regions of Northwestern Canada and verify the deleterious role that animals inflict upon these features, subsequently, amplifying degradational processes (Kershaw 1976). For example, birds and small mammals use the habitats provided by these features to feed and burrow, and in turn disrupt the surface organic cover (Figure 5.9). These disturbances are furthered when larger predators such as *Ursus arctos* and medium-sized mammals such as *Gulo gulo, Canis lupus Vulpes vulpes* attempt to excavate smaller mammals such as *Spermophilus parryii* from their burrows (Figure 5.10). Such activities create large openings in the surface organic cover and allow water and/or sunshine to enter the core of the palsa, subsequently, accelerating the degradation process. In addition, these excavation procedures leave a dark peat and/or mineral cover on the surface. This lowers the albedo and decreases the amount of radiation that is reflected, thus increasing surface temperatures, thereby initiating a positive feedback loop that may ultimately lead to the development of thermokarst features (Williams and Smith 1989). Temperature data from the investigated palsas confirm that bare peat sites have a higher mean summer temperature compared to adjacent sites with a plant cover (Table 3.2a).

The activities of *Castor canadensis* are another example of an outside influence that contribute to the degradation of palsas. These animals can both directly and indirectly alter the thawing processes by either burrowing into the sides of palsas and exposing the frozen core to water or by building dams that eventually

Figure 5.8. Degradational processes has created a thermokarst pond on the top of the Beaver Pond palsa. The excess ice in the permafrost has thawed, subsequently leading to ground subsidence.

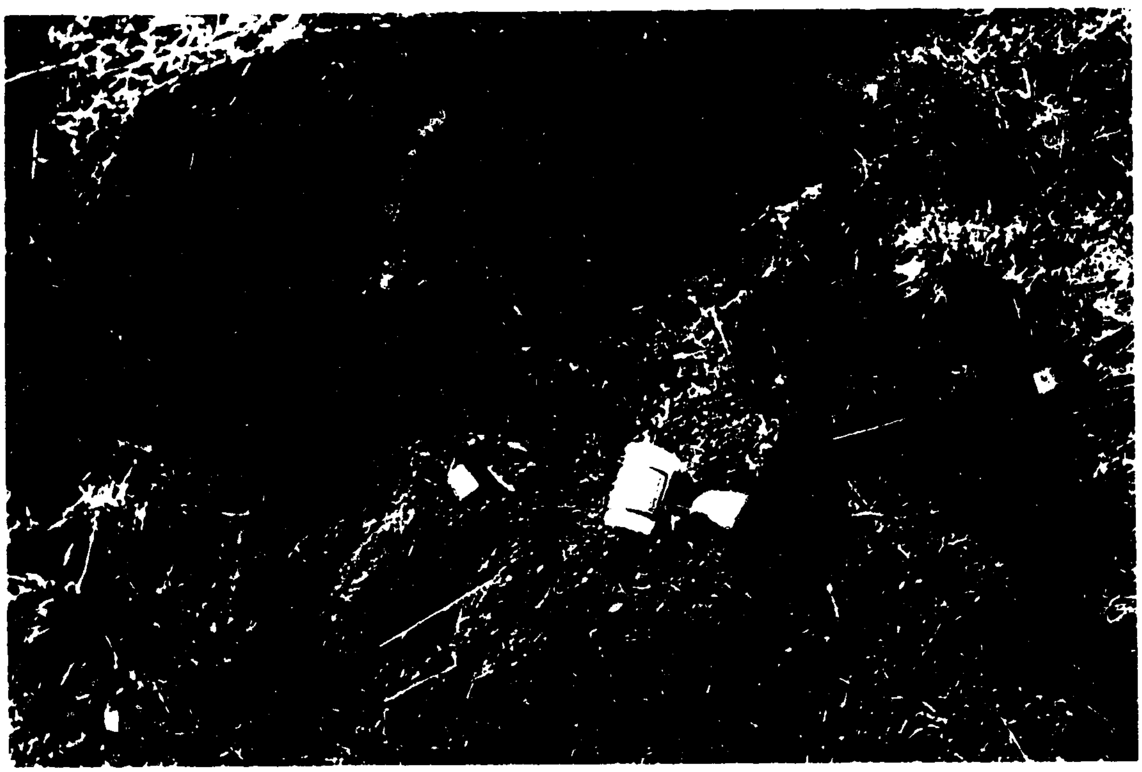


Figure 5.9. A ground squirrel burrow on the side of the Dale Creek 2 palsa. Note the mineral soil and pebbles overlying the peat.

Figure 5.10. The surface of a palsa has been disrupted by a grizzly bear after it dug for ground squirrels in the Mackenzie Mountain Barren region, N.W.T. These excavation procedures created large openings in the surface organic cover that could ultimately accelerate degradational processes.

inundate portions of the palsas' periphery (Zoltai 1972) (Figure 5.11). Furthermore, the burrowing activities of beavers can oversteepen the sides of the palsa and accelerate mass wasting.

5.3 Model Components Derived from Analysis of the Literature

In the context of the thesis, data have been presented on the morphology, microclimate and stratigraphy of palsas, however, gaps in the study prevent a comprehensive explanation of the evolutionary history of palsas. Thus, information from various literature sources are used to help fill in and expand upon the research data. Model components derived from the literature are grouped in a progressive sequence using terminological phases such as: Incipient status, Disequilibrium aggradational status, Dynamic equilibrium status, Disequilibrium degradation status, and Disequilibrium advanced degradation status (Figure 5.12). It should be noted that site-conditions influence each palsa environment in a distinctive manner. Hence, the geomorphic evolution of individual features/sites can differ, therefore, palsas may not necessarily experience each aggradational/degradational phase. Furthermore, site-conditions can also be conducive to concurrent aggradational/degradational processes (Zoltai 1993). Nevertheless, the dominant components controlling palsa evolution are thought to be due to the insulating attributes of peat, cold climates, water, and a relatively thin snow cover (e.g. Forsgren 1968; Zoltai 1972).

5.3.1 Incipient Palsas

Incipient palsas (Figure 5.12) represent the earliest developmental phase, and exhibit only slight vertical displacement initiated by freezing temperatures. In addition to cool air temperatures, the literature suggests that palsa genesis also requires a thin snow cover. The thin snow cover theory was first proposed by Fries and Bergström (1910) and eventually experimentally tested by Seppälä (1982). Generally, thinner snow covers encourage ground cooling and subsequent frost development (e.g. Seppälä 1982; 1986; 1988). A thicker snow cover, however, can act as a barrier to heat loss, and ultimately keep ground temperature warmer than snow-free surfaces (Williams and Smith 1989). Consequently, palsas tend to develop in wetland areas that have a sparse snow cover; such as, those found in wind scour zones (Allard *et al.* 1987; Seppälä 1982; 1986), tussock fields, beneath dense stands of trees (Zoltai 1972), or possibly regions that experience methane doming (Kershaw and Gill 1979; Washburn 1973, 1979).

A thin snow cover coupled with the relatively high thermal conductivity of frozen peat allow rapid and deep cooling (Seppälä 1888). These cooling episodes are commonly associated with phase changes that ultimately displace soil masses (Lunardini 1981). Upon freezing, the rate of frost penetration tends to be relatively high, and any available pore water freezes in situ (Williams and Smith 1989). Although, the initial heaving rate may be high, the overall heave tends to be rather small (Williams and Smith 1989); heat escaping from the ground allows rapid cooling, hence, near-surface hydraulic conductivities decrease with increasing frost development. This reduces the water's ability to migrate towards the freezing front at a rate that would allow for the development of large ice lenses, consequently limiting the cumulative heave (Williams and Smith 1989). However, if site conditions are conducive to further permafrost aggradation, palsas can enter a disequilibrium aggradational phase that elevates these features even further above the contiguous wetland.

5.3.2 Disequilibrium (Aggradation Status)

Palsas within a disequilibrium aggradational phase (Figure 5.12) experience further frost penetration, and thus greater heave (e.g. Seppälä 1986; 1988). Progressive heave is a result of a thermal gradient (Lock and Kay 1978) acting within a medium that is capable of inducing a steady influx of capillary water (cryosuction) (Anderson *et al.* 1984). The migration of water in frozen soil occurs in all three phases as a response to potential gradients associated with freezing temperatures, and tends to be in the direction of heat conduction; from a warmer region (e.g. unfrozen wetland) to a cooler zone (e.g. freezing front) (Anderson *et al.* 1984; Williams and Smith 1989). As additional water is drawn towards the frozen zone it freezes and coalesces into hair-like lenses (Miller 1978). These ice lenses continue to grow so long as the temperatures remain below freezing and the rate of "evolution and dissipation of latent heat of freezing does not exceed" the flow of water (Anderson *et al.* 1984). Consequently, soil

Figure 5.11. A beaver dam has allowed water to inundate part of the Beaver Pond palsa (left) as well as adjacent shrubs and sedges.

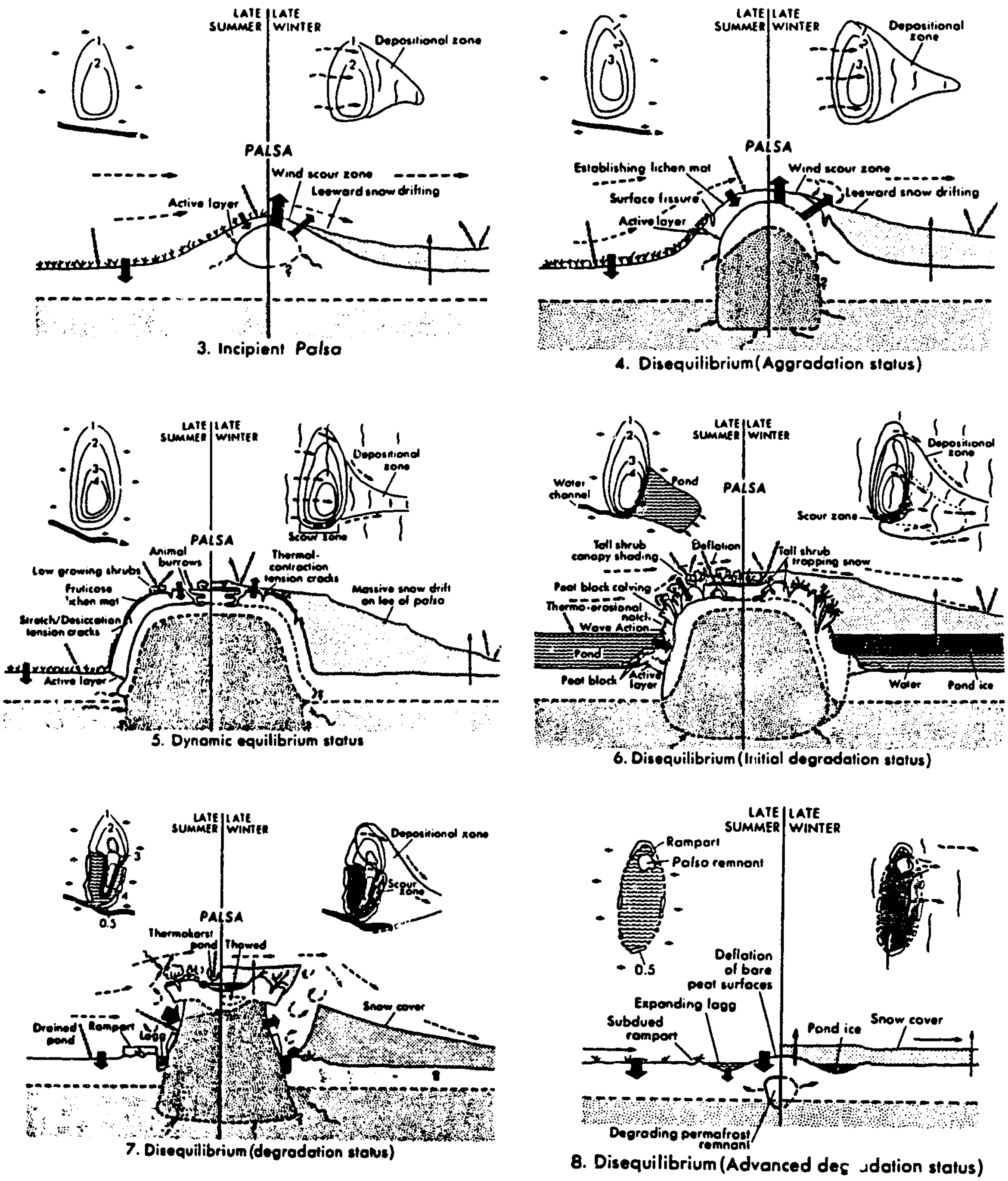


Figure 5.12. A generalized conceptual model of the evolutionary history of palsas. These features develop in wetland environments where cold climates coupled with a thin snow cover, a surface peat cover and a water source are thought to be the principal parameters required for the formation and maintenance of these permafrost features. Palsa degradation is thought to be the result of a disrupted microclimatic balance brought about by changes in site-conditions (e.g. regional climate, water infiltration, plant cover, snow characteristics, animal and anthropogenic activity) (Kershaw and Skaret 1993a).

above the freezing interface is displaced in order to accommodate the newly formed ice lens. The growth of ice lenses and ensuing heave perpetuates as long as there are mutually favourable conditions among the nature of the soil matrix, rate of heat removal, influx of soil water, and confining pressures (Anderson *et al.* 1984). As the balances between these relationships are interfered with, lens formation ceases but can reestablish where new equalization levels exist; usually, behind the descending 0°C isotherm (Anderson et al. 1984). The magnitude of displacement depends upon the volume of ice present coupled with the overburden pressure exerted within the soil mass (Lunardini 1981). These displaced surfaces become more susceptible to wind erosion, and tend to have thinner snowpacks during winter and be relatively dry in summer (Seppälä 1986; 1988), thus, winter aggradational and summer insulative processes are enhanced. As frost penetrates further into the ground it may eventually reach the organic/mineral soil boundary, at which point the peat layer can become anchored to a stable substratum (Figure 5.12).

5.3.3 Dynamic Equilibrium Status

The dynamic equilibrium status (Figure 5.12) is one phase in the life history of a palsa cycle where it has reached a relatively stable state. Consequently, there tends to be a balance in the summer and winter heat fluxes and little morphological or surface cover changes. Thus, palsas in this stage have reached a point where they neither exhibit further aggradational or significant degradational signs. However, this developmental stage is not exactly in true balance and depending upon a number of different interacting variables there are still numerous changes that occur. For example, changes in the microclimate can affect parameters such as: active layer, plant cover, surface fissure development and subsequent calving processes. Thus, slight changes in these variables can alter various site-specific factors, thereby, propelling the feature into an imbalanced or disequilibrium status.

5.3.4 Disequilibrium (Degradation Status)

Palsa degradation is the result of a disrupted microclimatic balance, brought about by changes in, regional climate, hydrology, plant cover, snow characteristics, animal and anthropogenic activity. Modifications to these variables may directly or indirectly alter such a balance, and subsequently initiate a deterioration phase.

While water is a critical component in the development of palsas, it is conversely the most effective method of degradation. The high heating capacity of water enables heat to be transferred towards the permafrost core via surface fissures (Åhman 1977; Zoltai 1988) and/or animal burrows (Figure 5.12). This relatively warm water (e.g. snow meltwater, precipitation) entering the palsa may initiate a deterioration phase, that may eventually create a positive heat budget (Åhman 1977; Friedman *et al.* 1971). Water can also affect the edge of palsas as pools of water commonly develop in these peripheral positions as a result of the formation of palsa laggs, beaver dams, or from channelized flow, sheetflow, and throughflow within the wetland.

In addition to acting as a conduit for water importation, cracks adjacent to the periphery may develop into blocks and slide off the feature. These blocks are transported downslope by gravity and/or water and are deposited at the base of the palsa, subsequently removing the protective plant cover and a layer of peat (Figure 5.12). This exposed surface is now susceptible to the coupling effects of wind and water erosion, that may ultimately propel the feature into an advanced degradational phase.

5.3.5 Disequilibrium (Advanced Degradation Status)

This stage is characterized by further deflation and erosional events that result in a net positive heat budget that melts much of the frozen core, subsequently, expanding the palsa laggs and reducing the relief of the feature. Palsas in this advanced degradation status tend to be scarred by pits and rarely stand more than 2.0 m above the surrounding wetland (Seppälä 1988). Ultimately, there will be a total collapse of the palsa and all that will remain are subdued ramparts, post palsa ponds (thermokarst ponds) or slightly raised surfaces that are devoid of plants (Figure 5.12). This depicts the end stage of the degradation cycle and is mainly accomplished through the combined effects of peat block calving, wind and water erosion, fauna activity and any microclimatic changes that alter the thermal regime of these features. Palsas, however, can also be degraded from climate amelioration, thus, regional climatic warming trends can initiate thermal erosion of the frozen core from the surface, and sides

(Kershaw and Gill 1979; Sollid and Sørbel 1974). Hence, palsa degradation is brought about by numerous interacting variables acting in unison to create complex feedback systems (Figure 5.13). It should be noted that palsas may not necessarily experience strictly aggradational or degradational processes, but depending upon the microsites and the site-specific factors associated with them, an individual palsa may encounter concurrent aggradational and degradational processes. Post palsa ponds would normally be the last stage of the cycle, however, with a renewed phase of peat accumulation and favourable site conditions, palsas were thought to recommence the aggradational phase at the same location (Seppälä 1979; 1986; 1988; Zoltai 1993; Zoltai and Tarnocai 1975). Thus, palsas may follow cyclic aggradational/degradational stages (Figure 5.13), and the duration of each sequence is entirely dependent upon specific site-conditions.

5.3 Conclusion

Palsas are closely linked to specific site-conditions that promote and preserve permafrost. Research on palsas has suggested that cold climates coupled with a thin snow cover, surface peat cover, and a water source are the principle parameters required for the formation and maintenance of these permafrost features. Much of the data from the Macmillan Pass-Tsichu River region supports the literature. Within this study area, conditions affecting the thermal regime of palsas are found to act in a similar manner and are reciprocally related. However, the intensity and duration of these effects are highly dependent upon the site-specific factors influencing each location. Hence, geophysical processes affiliated with each site ultimately create unique thermodynamic conditions, thereby producing distinctive stratigraphic, microclimatic and thawing characteristics.

All study features are elevated above the surrounding wetland and are composed of a surface peat layer that is affixed to the underlying silty soil. Surface heave was thought to be directly related to insitu-freezing of nonmotive pore water coupled with ice accretion caused by thermodynamic potentials that induced an influx of water towards the freezing front. In palsas, these ice accumulations were rhythmic and repetitive, subsequently resulting in alternating layers of laminar ice lenses and frozen soil containing pore ice. The thickness and spacing between the ice lenses were thought to be the product of heat/moisture flow rates and soil properties.

All study sites contain a stratigraphic marker horizon (White River tephra 1250 years BP, as cited by Lerbekmo 1975) that was used to estimate peat accumulation rates and formation dates. Palsas had lower rates of peat accumulation than the contiguous wetlands, and this was attributed to the drier conditions of the elevated surfaces. These drier conditions were more conducive to greater levels of peat decomposition than deposition, especially on the lichen dominated features. Thus, palsas accumulated peat at a slower rate than the adjacent wetlands.

Aquatic peat and/or silty clay pond sediments were situated above the tephra layer in 4 palsas, implying that the surface of these feature were submerged in water at the time of the White River volcanic eruption. Consequently, these features were thought to have been formed within the last 1250 years. Stratigraphic information from one feature, however, showed a distinct change from hydrophilous to xerophilous peat below the tephra layer. Therefore, at least 1 palsa within the study area was thought to have formed prior to the White River volcanic eruption. Nevertheless, the surface of these features were originally quasi-parallel to the wetland, and only those changes in microclimate and site-conditions conducive to ice accumulation were responsible for heaving the surface above the wetland.

In the study area, the interactions between the atmosphere and the ground were responsible for creating a negative heat budget, hence, ambient conditions were conducive to frost development. However, morphological evidence (e.g. surface fissures, peat block calving, thermokarst features, surface subsidence) suggests that these features experienced relatively recent degradational processes. Thus, all study features were classified as belonging to a disequilibrium degradational phase. The relatively cool climate, however, was still regarded as being important in maintaining or slowing down degradation of the permafrost core.

Altitudinal differences between the study sites had a significant impact upon seasonal air temperatures.

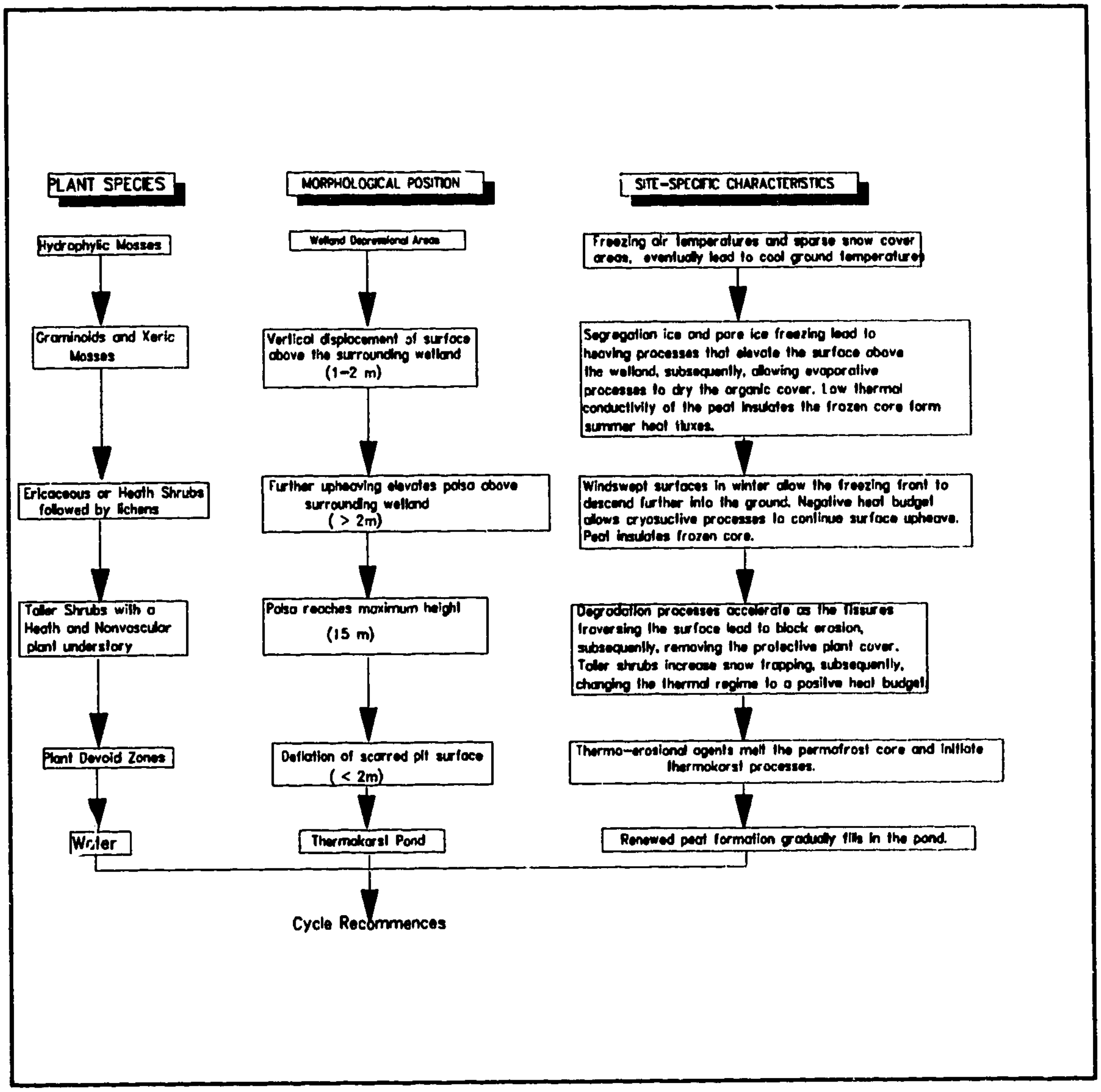


Figure 5.13. A generalized flow diagram illustrating some of the processes involved in the cyclic developmental/degradational phases associated with palsas. This model is not complete but does outline some of the more important aspects influencing palsa formation and degradation.

In summer, a positive regional environmental lapse-rate kept the upper-elevation site cooler, however, during winter, temperature inversions developed as a result of cold air drainage events, therefore, lower-elevation sites were colder. Thus, altitudinal differences influenced ambient temperatures on a regional basis, whereas, local thermal conditions were dictated by site-specific factors connected to the internal boundary layer. For example, features that had a protective cover (e.g. tall shrubs, thick snow cover) could isolate the ground from daily ambient temperature fluctuations and reduce palsa core heat loss. Consequently, ground temperatures were warmer at sites that had a well developed buffer zone relative to those features that had a more direct linkage between the atmosphere and the surface. Temperatures within the ground fluctuated annually, however, the amplitude decreased with increasing depth.

Regional differences in air temperatures also influenced thawing characteristics, thus, the cooler valley sites experienced less thaw, whereas, the upper plateau location had a more moderate climate that ultimately resulted in greater thaw depths. Thawing characteristics were also influenced on a local basis, and this was ascribed to differences in vegetation cover, microclimate, aspect, slope angle and proximity to water. The greatest melt rates and depth of thaw mainly occurred at the south-facing palsa edge, and the maximum thaw depths were located on the lower slope angles adjacent to bodies of water. Ultimately, warmer ground became more susceptible to thawing and subsequently amplified various degradational processes.

Generally, palsa degradation occurs as a result of a disrupted microclimatic balance brought about by changes in: vegetation cover, water infiltration, snow cover and regional climate. These alterations can initiate a positive heat budget that enhances permafrost degradation. Eventually, the entire permafrost core melts, subsequently leaving behind a post palsa pond (thermokarst pond). Palsa initiation, however, may occur after a renewed phase of peat formation coupled with favourable site conditions.

5.4 References

Åhman, R. 1977. Palsar i Nordnorge. *Meddelanden från Lunds Universitets, Geografiska Institution, Avhandlingar LXXVIII*, 165p.

Allard, M., Seguin, M.K. and Lévesque R. 1987. Palsas and mineral permafrost mounds in northern Québec. In V. Gardiner (ed.) *International Geomorphology, Part II.* John Wiley and Sons, Chichester, pp. 285-309.

Anderson, D.M., Williams, P.J., Guymon, G.L. and Kane, D.L. 1984. Principles of soil freezing and frost heaving. In R.L. Berg and E.A. Wright (eds.), *Frost Action and its Control.* American Society of Civil Engineers, New York, pp. 1-21.

Annersten, L.J. 1964. Investigations of permafrost in the vicinity of Knob Lake, 1961-1962. *McGill Sub-Arctic Research Papers*, 161: 51-137.

Beskow, G. 1935. *Tjälbildningen och tjällyftningen med särskild hänsyn til vägar och 48 järnvägar.* Stockholm, 242 pp. Statens väginstitut, Stockholm, Meddelande 48. (Also published as Sveriges geologiska undersökning. *Avh. och Uppsats. Ser. C*, 375, and translated into English: Tech. Inst. Northwestern University, Evanston, Ill. November 1947.)

Brown, R.J.E. 1970. *Permafrost in Canada Its Influence on Northern Development.* University of Toronto Press, Toronto, 234 p.

Brown, R.J.E. 1977. Muskeg and Permafrost. In N.W. Radforth and C.O. Brawner (eds.). *Muskeg and the Northern Environment*, University of Toronto Press, pp. 148-163.

Çernusca, A. and Seeber, M.C. 1981. Canopy structure, microclimate and the energy budget in different alpine communities. In J. Grace, E.D. Ford and P.G. Jarvis (eds.) *Plants and their Atmospheric Environment, 21st. Symposium of the British Ecological Society.* Blackwell Scientific Publications, Oxford, pp. 75-81.

Forsgren, B. 1968. Studies on palsas in Finland, Norway and Sweden, 1964-1966. *Biuletyn Peryglacjalny*, 17: 177-123.

French, H.M. 1976. *The Periglacial Environment.* Longmans, London, 309 pp.

Friedman, J.D., Johansson, C.E., Oskarsson, N., Svensson, H., Thorarinsson, S. and Williams, R.S. Jr. 1971. Observations on Icelandic polygon surfaces and palsa areas. *Geografiska Annaler*, 53A:115-145.

Fries, T. and Bergström, E. 1910. Några iakttagelser öfver palsar och deras förekomst i nordligaste Sverige. *Geol. Fören. Förhandl.* 32(1).

Harris, S.A. 1982. Distribution of zonal permafrost landforms with freezing and thawing indices, *Biuletyn Peryglacjalny*, 29: 163-182.

Kershaw, G.P. 1976. The Periglacial environments and its limitations to development. The Mactung Case Study, Northwest Territories-Yukon Territory, M.Sc. Thesis, Department of Geography, University of Waterloo, 298 p.

Kershaw, G.P. and Gill, D. 1979. Growth and decay of palsas and peat plateaus in the Macmillan Pass-Tsichu River area, Northwest Territories, Canada. *Canadian Journal of Earth Sciences*, 16(7):1362-1374.

Kershaw, G.P. and Kershaw, L.J. 1983. *Geomorphology and Vegetation of the MacTung Study Area, Yukon/NWT*. Report prepared for AMAX Northwest Mining Co. Ltd., Vancouver.

Kershaw, G.P. and Skaret, K.D. 1993a. Mechanisms of palsa degradation in the Mackenzie Mountains, N.W.T. Canada. *Third International Geomorphology Conference*, McMaster University, Hamilton, Ontario: 169 (Manuscript presentation).

Kershaw, G.P. and Skaret, K.D. 1993b. Microclimatic characteristics of palsas along an altitudinal gradient, Mackenzie Mountains, NWT, Canada. In *Proceedings Sixth International Permafrost Conference*, National Academy Press, Washington DC, pp. 338-343.

Lerbekmo, J.F., Westgate, J.A., Smith, D.G.W., and Denton. 1975. New data on the character and history of the White River volcanic eruption, Alaska. In R.P. Suggate and M.M. Cresswell (eds.) *Quaternary Studies. Royal Society of New Zealand.* pp. 203-209.

Liang, L. and Kershaw, G.P. 1994. Climate change in the Mackenzie Mountains, N.W.T., in press

Linell, K.A. and Kaplar, C.W. 1959. *The factor of soil and material type in highway pavement design in frost areas: a symposium - Part 1, Basic Considerations*. Highway Res. Board Bulletin 225, 131 p.

Loch, J.P.G. and Kay, B.D. 1978. Water distribution in partially frozen saturated silt under several temperature gradients and overburden loads. *Soil Science Society of America Journal*, 42(3): 400-406.

Lunardini, V. 1981. *Heat Transfer in cold climates*. New York, Van Nostrand Reinhold. 731 p.

Luthin, J.N. and Guymon, G.L. 1974. Soil moisture-vegetation-temperature relationships in central Alaska. *Journal of Hydrology*, 23:233-246.

Miller, R.D. 1978. Frost heaving in non-colloidal soils. *Proceedings of the Third International Conference on Permafrost*, Edmonton, Canada. vol. 1, National Research Council of Canada, Ottawa, pp. 708-713.

Nakano, Y. and Brown, J. 1972. Mathematical modelling and validation of the thermal regimes in tundra soils, Barrow, Alaska. *Arctic and Alpine Research*, 4(1): 19-38.

Nelson, F.E., Outcalt, S.I.,Goodwin, C.W. and Hinkel, K.W. 1985. Diurnal thermal regime in a peat-covered palsa, Toolik Lake, Alaska. *Arctic*, 38(4): 310-315.

Nelson, F.E., Hinkel, K.M. and Outcalt, S.I. 1991. Palsa-scale frost mounds. In *Periglacial Geomorphology, Proceedings of the 22nd Annual Bingahmton Symposium in Geomorphology*. J.D. Dixon and A.D. Abrahams (eds.), John Wiley and Sons, Chichester, pp. 305-325.

Outcalt, S.I. and Nelson, F. 1984. Computer simulation of buoyancy and snow-cover effects in palsa dynamics. *Arctic and Alpine Research*, 16(2): 259-263.

Outcalt, S.I., Nelson, F.Hinkel, K.M. and Martin, G.D. 1986. Hydrostatic-system palsas at Toolik Lake, Alaska; field observations and simulations. *Earth Surfaces Processes and Landforms*, 11(1): 70-94.

Roberts, B.A. and Robertson, A.W. 1980. Palsa bogs, sand dunes and salt marshes, environmentally sensitive habitats in the coastal region Southeastern Labrador. In *Workshops on Research in the Labrador Coastal and Offshore Region*, pp. 245-260.

Rouse, W.R. 1982. Microclimate of low Arctic tundra and forest at Churchill, Manitoba. *Proceedings of the Fourth Canadian Permafrost Conference, Calgary Alberta*. N.R.C.C., Ottawa, pp. 68-80.

Rouse, W.R. 1984. Microclimate of Arctic tree line. 2: Soil microclimate of tundra and forest. *Water Resources Research*, 20(1): 67-7

Seppälä, M. 1979. Recent palsa studies in Finland, *Acta Universitatis Ouluensis*, Ser.A 82: 81-87.

Seppälä, M. 1982. An experimental study on the formation of palsas. In *Proceedings of the Fourth Canadian Permafrost Conference*, National Research Council of Canada, Ottawa, pp. 36-42.

Seppälä, M. 1986. Origin of palsas. *Geografiska Annaler*, 68A(3), pp. 141-147.

Seppälä, M. 1988. Palsas and related forms. In M.J. Clark (ed.), *Periglacial Geomorphology*. John Wiley and Sons, Chichester, pp. 247-278.

Smith, M.W. 1975. Microclimatic influences on the ground temperatures and permafrost distribution, Mackenzie Delta, Northwest Territories. *Canadian Journal of Earth Sciences*, 12: 1421-1438.

Sollid, J.L. and Sørbel, L. 1974. Palsa bogs at Haugtjørnin, Dovrefjell, South Norway, *Norsk. Geogr.Tidskr.*, 28:271-283.

Vorren, K.D. 1972. Stratigraphic investigations of a palsa bog in northern Norway. *Astarte*, 5:39-71.

Washburn, A.L. 1973. *Periglacial Processes and Environments*. Edward Arnold, London, 320 p.

Washburn, A.L. 1979. *Geocryology A Survey of Periglacial Processes and Environments*. Edward Arnold, London, 406p.

Williams, P.J. and Smith, M.W. 1989. *The Frozen Earth*. Cambridge University Press, New York, 306 p.

Zoltai, S.C. 1972. Palsas and peat plateaus in central Manitoba and Saskatchewan. *Canadian Journal of Forest Research*, 2:291-302.

Zoltai, S.C. 1993. Cyclic development of permafrost in the peatlands of Northwestern Alberta, Canada. *Arctic and Alpine Research*, 25(3): 240-246.

Zoltai, S.C. and Tarnocai, C. 1971. Properties of a wooded palsa in northern Manitoba. *Arctic and Alpine Research*, 3:115-129.

Zoltai, S.C. and Tarnocai, C. 1975. Perennially frozen peatlands in the western Arctic and Subarctic of Canada. *Canadian Journal of Earth Sciences*, 12:28-43.

Zoltai, S.C., Tarnocai, C., Mills, G.F. and Veldhuis, H. 1988. Wetlands of subarctic Canada. In *Wetlands of Canada. Ecological Land Classification Series, No. 24*, Sustainable Development Branch, Environment Canada, Ottawa, Ontario and Polyscience Publication Inc., Montreal Quebec, pp. 55-96.

APPENDIX A:

STRATIGRAPHIC DATA: PALSA

DALE CREEK 2-2

Depth (cm)	Differ-ence (cm)	Core Voulme (cm^3)	Wet Weight (g)	Dry Weight (g)	%Dry	%Wet	Bulk Density ($g\ cm^{-3}$)	Volmetric Moisture (%)	pH	vonPost	Munsell Colour
-16.00	16.00	249.84	115.20	48.07	139.65	58.27	0.19	26.87	4.4-4.7	H1	
-29.50	13.50	210.80	139.20	62.36	123.21	55.20	0.30	36.45	4.4-4.7	H2,H3	
-44.50	15.00	234.22	155.10	55.87	177.60	63.98	0.24	42.36	4.4-4.7	H2,H3	
-60.50	16.00	249.84	289.90	70.60	310.62	75.65	0.28	95.72	4.4-4.7	H3,H4	
-75.50	15.00	234.22	264.20	64.50	309.61	75.59	0.28	92.98	4.4-4.7	H4,H5	
-89.50	14.00	218.61	340.20	153.45	121.70	54.89	0.70	93.16	5.0	H6	
-104.50	15.00	234.22	267.70	100.69	165.87	62.39	0.43	77.76	5.0-5.3	H4,H5	
-119.50	15.00	234.22	249.50	51.15	387.76	79.50	0.22	92.35	5.0-5.3	H4,H5	
-134.50	15.00	234.22	247.10	71.73	244.49	70.97	0.31	81.65	5.0	H4,H5	
-150.00	15.50	242.03	317.80	112.07	183.57	64.74	0.46	92.70	4.7-5.0	H5,H6	
-165.00	15.00	234.22	309.80	130.27	137.81	57.95	0.56	83.59	5.0-5.3		10YR2/1
-180.00	15.00	234.22	322.40	144.36	123.33	55.22	0.62	82.89	5.0-5.3		10YR2/1
-194.50	14.50	226.42	290.00	115.81	150.41	60.07	0.51	83.90	5.0-5.3		10YR2/1
-202.00	7.50	117.11	187.90	117.89	59.39	37.26	1.01	65.19	5.0-5.3		2.5Y2/0
DALE CREEK 2-3											
-15.00	15.00	234.22	112.30	41.95	167.73	62.65	0.18	30.04	4.4-4.7	H1,H2	
-30.00	15.00	234.22	209.20	85.30	145.25	59.23	0.36	52.90	4.4-4.7	H1,H2	
-45.00	15.50	242.03	298.30	96.46	209.25	67.66	0.40	83.39	4.4	H2,H3	
-60.00	14.00	218.61	243.80	61.72	295.01	74.68	0.28	90.83	4.4-4.7	H3,H4	
-75.00	15.00	234.22	229.50	52.49	337.24	77.13	0.22	82.41	4.4-4.7	H3,H4	
-90.00	16.50	257.65	308.30	64.26	379.77	79.16	0.25	100.00	4.7-5.0	H3,H4	
-105.00	14.00	218.61	261.50	62.24	320.15	76.20	0.28	99.40	4.7	H4,H5	
-120.00	15.00	234.22	244.00	85.49	185.41	64.96	0.36	73.80	5.0-5.3	H4,H5	
-135.00	15.00	234.22	249.30	64.50	286.51	74.13	0.28	86.04	4.7-5.0	H4,H5	
-150.00	15.00	234.22	338.20	196.93	71.74	41.77	0.84	65.77	4.7-5.0		2.5Y2/0
-165.00	15.00	234.22	339.80	214.12	58.70	36.99	0.91	58.51	4.7-5.0		2.5Y2/0
-175.00	11.00	171.76	296.20	202.67	46.15	31.58	1.18	59.38	5.0		2.5Y2/0
DALE CREEK 2-4											
-30.00	30.00	468.45	92.10	32.98	179.23	64.19	0.07	12.62	4.4-4.7	H1,H2	
-44.50	14.50	226.42	171.70	51.66	232.37	69.91	0.23	53.02	4.4-4.7	H1,H2	
-60.00	15.60	243.59	179.30	31.86	462.74	82.23	0.13	66.00	4.7-5.0	H2,H3	
-74.50	14.50	226.42	326.50	56.96	473.21	82.55	0.25	100.00	4.7-5.0	H3,H4	
-90.00	15.50	242.03	250.70	37.93	560.94	84.87	0.16	95.87	5.0-5.3	H4,H5	
-105.00	15.00	234.22	244.00	38.56	532.78	84.20	0.16	95.65	5.0-5.3	H4,H5	
-15.00	15.00	234.22	237.20	53.74	341.41	77.35	0.23	85.42	5.0	H4,H5	
-135.00	15.00	234.22	239.90	63.22	279.47	73.65	0.27	82.26	5.0	H5	
-151.00	16.00	249.84	243.20	81.98	196.66	66.29	0.33	70.37	4.7-5.0		2.5Y2/0
-170.00	19.00	296.68	295.10	165.82	77.96	43.81	0.56	47.52	4.7		2.5Y2/0
-179.50	9.50	148.34	124.40	17.06	629.11	86.28	0.12	78.91	4.7-5.0		2.5Y2/0

*not enough peat

DALE CREEK 6-1

Depth (cm)	Differ-ence (cm)	Core Voulme (cm^3)	Wet Weight (g)	Dry Weight (g)	%Dry	%Wet	Bulk Density ($g\ cm^{-3}$)	Volmetric Moisture (%)	pH	vonPost	Munsell Colour
-15	15	234.2	118.6	57.41	106.6	51.6	0.245	26.13	4.4-4.7	H1,H2	
-30.5	15.5	242	160	71.07	125.1	55.58	0.294	36.74	4.4-4.7	H2,H3	
-45	14.5	226.4	233.1	141.8	64.34	39.15	0.626	40.31	4.7-5.0	H3,H4	
-60	15	234.2	263.2	148.2	77.62	43.7	0.633	53.55	5.0-5.3	H4-H5	
-74.5	14.5	226.4	143.2	68.61	108.7	52.09	0.303	35.93	5.0-5.3		10YR7/1
-90	15.5	242	241.9	120.6	100.6	50.14	0.498	54.65	5.0-5.3		2.5Y2/0
-105	15	234.2	289.5	114.5	152.8	60.45	0.489	81.48	5.0-5.3		2.5Y2/0
-119.5	14.5	226.4	282.5	112.1	152.1	60.33	0.495	82.09	5.0-5.3		2.5Y2/0
-135	15.5	242	260.4	96.88	168.8	62.8	0.4	73.68	5.0-5.3		2.5Y2/0
-150	15	234.2	238.2	70.68	237	70.33	0.302	77.99	5.0-5.3	H4,H5	2.5Y2/0
-165	15	234.2	244	44.18	452.2	81.89	0.189	93.03	5.0-5.3	H4,H5	
-180	15	234.2	212.8	36.44	484	82.88	0.156	82.11	5.3-5.6	H5,H6	
-195	15	234.2	287.2	101.5	183	64.67	0.433	86.47	5.0-5.3	H5,H6	2.5Y2/0
-210	15	234.2	313.2	165.3	89.47	47.22	0.706	68.86	5.0		2.5Y2/0
-225	15	234.2	293	145.2	101.8	50.45	0.62	68.83	5.0-5.3		2.5Y2/0
-239.5	14.5	226.4	394.2	261.2	50.93	33.74	1.154	64.07	5.0		2.5Y2/0
-251.5	12	187.4	325.7	210.2	54.98	35.48	1.122	67.25	5.0-5.3		2.5Y2/0
-266	14.5	226.4	308.7	182.4	69.22	40.91	0.806	60.82	5.0		2.5Y2/0
-280	14	218.6	319.2	171.8	85.81	46.18	0.786	73.53	5.0		2.5Y2/0
-294	14	218.6	305.8	150.3	103.4	50.84	0.688	77.55	5.0		2.5Y2/0
-300	6	93.69	177.6	100.4	76.96	43.49	1.071	89.90	5.0		2.5Y2/0

DALE CREEK 6-2

Depth (cm)	Differ-ence (cm)	Core Voulme (cm^3)	Wet Weight (g)	Dry Weight (g)	%Dry	%Wet	Bulk Density ($g\ cm^{-3}$)	Volmetric Moisture (%)	pH	vonPost	Munsell Colour
-15	15	234.2	133.6	62.3	114.4	53.37	0.266	30.44	4.4-4.7	H1,H2	
-29.5	14.5	226.4	206.6	85	143.1	58.86	0.375	53.71	4.4-4.7	H2,H3	
-44.5	15	234.2	273.5	148.4	84.3	45.74	0.634	53.41	4.4-4.7	H3,H4	
-60	15.5	242	335.2	181	85.2	46.01	0.748	69.48	4.7-5.0	H4,H5	
-75	15	234.2	376.4	198.5	89.62	47.26	0.847	82.83	5.0		10YR7/1
-90	15	234.2	349.3	180.9	93.08	48.21	0.772	78.40	5.0-5.3		10YR7/1
-104.5	14.5	226.4	229.5	112.3	104.4	51.07	0.496	56.45	5.0-5.3		2.5Y2/0
-120	15.5	242	392.1	199.4	96.6	49.14	0.824	86.81	5.0		2.5Y2/0
-136	16	249.8	353.1	197.2	79.1	44.17	0.789	68.07	5.0-5.3		2.5Y2/0
-150	14	218.6	244.3	78.66	210.6	67.8	0.36	82.63	5.0-5.3	H4	2.5Y2/0
-165	15	234.2	236.8	64.5	267.1	72.76	0.275	80.22	5.0-5.3	H4,H5	
-180	15	234.2	250.3	84.66	195.7	66.18	0.361	77.12	5.0-5.3	H5,H6	
-188	8	124.9	237.9	161.8	47.08	32.01	1.295	66.48	5.0-5.3	*	2.5Y2/0

BEAVER POND-2

Depth (cm)	Differ-ence (cm)	Core Voulme (cm^3)	Wet Weight (g)	Dry Weight (g)	%Dry	%Wet	Bulk Density ($g\ cm^{-3}$)	Volmetric Moisture (%)	pH	vonPost	Munsell Colour
-20	20	192.3	51.4	17.65	191.2	65.66	0.092	17.55	4.1-4.4	H1,H2	
-30	10	96.16	149.6	56.27	165.9	62.39	0.585	97.05	4.1-4.4	H1,H2	
-40	10	96.16	143.2	46.51	207.9	67.52	0.484	100.00	4.4	H3	
-49.5	9.5	91.35	149.2	51.42	190.2	65.54	0.563	98.15	4.4-4.7	H4,H5	
-60.5	11	105.8	237.4	78.62	202	66.88	0.743	100.00	4.7	H5,H6	
-70	9.5	91.35	208.5	49.15	324.2	76.43	0.538	100.00	4.7	H5,H6	
-81	11	105.8	237.3	56.79	317.8	76.07	0.537	100.00	4.7	H6,H7	
-90	9	86.55	154.7	38.31	303.8	75.24	0.443	100.00	4.7-5.0	H6,H7	
-99.5	9.5	91.35	122.2	21.6	465.7	82.32	0.236	100.00	5.0	H7,H8	

BEAVER POND-2 (continued)

Depth (cm)	Differ-ence (cm)	Core Voulme (cm^3)	Wet Weight (g)	Dry Weight (g)	%Dry	%Wet	Bulk Density ($g\ cm^{-3}$)	Volmetric Moisture (%)	pH	vonPost	Munsell Colour
-110	10.5	101	196.3	37	430.6	81.15	0.366	100.00	5.0	H6,H7	
-120	10	96.16	126.3	27.95	351.9	77.87	0.291	93.79	5.0	H6,H7	
-130.5	10.5	101	156.2	30.25	416.4	80.63	0.3	100.00	5.0	H6,H7	
-140	9.5	91.35	117.9	23.4	403.8	80.15	0.256	94.86	5.0	H6	
-150	10	96.16	81.5	18.8	333.6	76.94	0.195	59.79	5.0	H6	
-150	10	96.16	86.1	25.03	244	70.93	0.26	58.24	5.0	H6	
-160	10	96.16	193.5	46.81	313.4	75.81	0.487	100.00	5.3	H6,H7	
-170	10	96.16	156.9	37.38	319.8	76.18	0.389	100.00	5.0-5.3	H6,H7	
-180.5	10.5	101	210.1	53.85	290.2	74.37	0.533	100.00	5.3	H6,H7	
-191.5	11	105.8	180.5	51.76	248.7	71.32	0.489	100.00	5.3	H6,H7	
-200	8.5	81.74	144	44.18	225.9	69.32	0.541	100.00	5.3	H5,H6	
-210	10	96.16	175.7	50.91	245.1	71.03	0.529	100.00	5.3	H5,H6	
-222	12	115.4	312.1	101	209.1	67.64	0.875	100.00	5.9		10YR6/3

BEAVER POND-3

Depth (cm)	Differ-ence (cm)	Core Voulme (cm^3)	Wet Weight (g)	Dry Weight (g)	%Dry	%Wet	Bulk Density ($g\ cm^{-3}$)	Volmetric Moisture (%)	pH	vonPost	Munsell Colour
-10	10	156.1	82.8	14.49	471.6	82.51	0.093	43.75	4.1-4.4	H1,H2	
-30	20	312.3	301.3	79.68	278.1	73.55	0.255	70.96	4.4	H2,H3	
-40.5	10.5	164	236.6	50.97	364.2	78.46	0.311	100.00	4.4-4.7	H4	
-52	11.5	179.6	800.3	147.2	443.8	81.61	0.82	100.00	4.7	H4,H5	
-72.5	20.5	320.1	405.1	68.12	494.7	83.18	0.213	100.00	4.7	H6	

BEAVER POND-4

Depth (cm)	Differ-ence (cm)	Core Voulme (cm^3)	Wet Weight (g)	Dry Weight (g)	%Dry	%Wet	Bulk Density ($g\ cm^{-3}$)	Volmetric Moisture (%)	pH	vonPost	Munsell Colour
-10.5	10.5	164	44.7	15.57	187.2	65.18	0.095	17.77	3.8-4.1	H1	
-20.5	10	156.1	59.5	16.98	250.5	71.47	0.109	27.23	3.8-4.1	H2,H3	
-38	17.5	273.3	157.2	34.98	349.4	77.75	0.128	44.73	4.1-4.4	H3	
-52	14	218.6	236.2	29.03	713.7	87.71	0.133	100.00	4.7	H4	
-60	8	124.9	97.2	15.19	540	84.38	0.122	71.60	4.4-4.7	H4,H5	
-70.5	10.5	164	[illegible]	22.67	796.3	88.84	0.138	100.00	4.4	H4,H5	
-81.5	11	171.8	[illegible]	19.91	753.7	88.29	0.116	95.29	4.7	H4,H5	
-91.5	10	156.1	170.9	18.1	844.3	89.41	0.116	100.00	4.7	H4,H5	
-104	12.5	195.2	199.5	20.5	873.5	89.73	0.105	100.06	4.7	H4,H5	
-120.5	16.5	257.6	227.9	22.98	891.6	89.92	0.089	86.73	4.7	H4,H5	
-135	14.5	226.4	[illegible]	[illegible]	949.1	90.47	0.107	100.00	4.7	H4,H5	
-150	15	234.2	196.2	30.42	544.9	84.49	0.13	77.18	4.7-5.0	H4,H5	
-160.5	10.5	164	174.4	46.74	273.1	73.2	0.285	84.91	4.7-5.0	H6	
-170	9.5	148.3	142.8	28.3	404.5	80.18	0.191	84.17	4.7-5.0	H4,H5	
-180	10	156.1	155.6	[illegible]	560.3	84.86	0.132	80.36	5.0	H4,H5	
-190	10	156.1	[illegible]	35.09	[illegible]	81.13	0.225	100.00	5.0-5.3	H5,H6	
-200.5	10.5	164	[illegible]	34.07	[illegible]	80.06	0.208	91.01	5.0-5.3	H4,H5	
-210.5	10	156.1	[illegible]	[illegible]	288.7	74.27	0.263	82.84	4.7-5.0	H4,H5	
-220	9.5	148.3	150.9	35.36	326.7	76.57	0.238	84.94	5.0	H8,H9	
-232	12	187.4	196.2	47.1	[illegible]	75.99	0.251	86.77	5.0-5.3	H8,H9	
-240	8	124.9	240	28.36	[illegible]	88.18	0.227	100.00	5.0	H8,H9	
-249.5	9.5	148.3	158.7	25.38	[illegible]	84.01	0.171	98.01	5.0	H4,H5	
-260	10.5	164	173.7	37.71	360.6	78.29	0.23	90.45	5.0	H4,H5	
-269.5	9.5	148.3	130.9	38.05	244	70.93	0.256	68.26	5.3-5.6		
-280	10.5	164	208.1	74.38	179.8	64.26	0.454	88.94	5.9		

BEAVER POND-4 (continued)

Depth (cm)	Differ-ence (cm)	Core Voulme (cm³)	Wet Weight (g)	Dry Weight (g)	%Dry	%Wet	Bulk Density (g cm⁻³)	Volmetric Moisture (%)	pH	vonPost	Munsell Colour
-291.5	11.5	179.6	240	75.18	219.2	68.68	0.419	100.09	5.3		
-302	10.5	164	172.5	54.74	215.1	68.26	0.334	78.32	5.6-5.9		
BEAVER POND-5											
-16	16	2?9.8	46.7	11.4	309.6	75.59	0.046	14.13	4.7	H1,H2	
-30	14	218.6	219.9	71	209.7	67.71	0.325	68.11	4.7	H2,H3	
-44.5	14.5	226.4	467.9	151.1	209.7	67.71	0.667	100.00	4.7	H3	
-60	15.5	242	218	62	251.6	71.56	0.256	70.29	4,7	H4,H5	
-74	[illegible]	218.6	264.5	72.31	265.8	72.66	0.331	95.87	4.7	H5	
HARE FOOT-1											
-10	10	38	17	11.45	48.47	32.65	0.301	14.61	4.1	H1	
-22	12	45.6	24.9	12.65	96.87	49.2	0.277	26.87	4.1-4.4	H1	
-32	12	45.6	79.2	29.36	169.7	62.93	0.644	100	4.1	H1,H2	
-40.5	8.5	32.3	151.7	44.91	237.8	70.4	1.39	100	4.4-4.7	H2	
-50	9.5	36.1	180	38.36	369.3	78.69	1.063	100	4.7	H2,H3	
-61.5	11.5	43.7	275.3	50.77	442.3	81.56	1.162	100	4.7	H4	
-70.5	9	34.2	122.1	29	321	76.25	0.848	100	4.7	H4,H5	
-81	10.5	39.9	204.1	43.89	365	78.49	1.1	100	4.7	H5	
-90	9	34.2	134	25.64	422.6	80.86	0.75	100	4.7	H5,H6	
-101	11	41.8	164.7	28.15	485	82.91	0.674	100	4.7-5.0	H6	
-110	9	34.2	132.7	26.34	403.9	80.15	0.77	100	4.7-5.0	H6	
-121.5	11.5	43.7	155.7	25.14	519.2	83.85	0.575	100	5.0	H6	
-130	8.5	32.3	130.9	24.93	425	80.95	0.772	100	5.0	H6	
-140	10	38	122.4	23.21	427.5	81.04	0.611	100	5.0-5.3	H6	
-150	10	38	126.4	18.3	590.7	85.52	0.482	100	4.7-5.0	H6	
-160	10	38	108.5	11.35	855.9	89.54	0.299	100	4.7-5.0	*	
-169.5	9.5	36.1	146.5	16.47	789.6	88.76	0.456	100	4.7-5.0	*	
-182	12.5	47.5	153.8	15.72	878.6	89.78	0.331	100	4,7-5.0	*	
-200.5	10	38	195.5	15.05	1199	92.3	0.396	100	5.0-5.3	*	
-214	13.5	51.3	229.5	14.24	1512	93.79	0.278	100	4.7-5.0	*	
-220	6	22.8	74.5	12.65	488.7	83.01	0.555	100	4.7-5.0	*	
-229.5	9.5	36.1	120.5	17.02	608.2	85.88	0.471	100	4.7-5.0	*	
-240	10.5	39.9	145.6	17.22	745.6	88.17	0.432	100	4.7-5.0	*	
-251	11	41.8	165.4	15.54	964.6	90.61	0.372	100	4.7-5.0	*	
-260	9	34.2	119	13.94	753.9	88.29	0.407	100	4.7	*	
-270	10	38	132.2	23.12	471.9	82.51	0.608	100	4.7-5.0	*	
-282	12	45.6	168.3	17.81	844.8	89.42	0.391	100	4.7	*	
-293	11	41.8	157.3	17.04	823.3	89.17	0.408	100	4.7	*	
-301	8	30.4	118.1	23.35	405.8	80.23	0.768	100	4.7-5.0	*	
-309.5	8.5	32.3	111.5	29.4	279.3	73.63	0.91	100	4.7-5.0	*	
-322.5	13	49.4	227	58.73	286.5	74.13	1.189	100	4.7-5.0	*	
-332	9.5	36.1	178.7	90.97	96.44	49.09	2.52	100	4.7-5.0	*	
-339.5	7.5	28.5	141.7	63.38	123.6	55.27	2.224	100	4.7-5.0	*	
-350	10.5	39.9	233	120.7	92.98	48.18	3.026	100	5.0-5.3		2.5Y3/0
-369.5	6.5	24.7	112.3	47.89	134.5	57.36	1.939	100	5.0-5.3		2.5Y3/0
-380	10.5	39.9	268.7	172.4	55.86	35.84	4.321	100	5.0-5.3		2.5Y3/0

HARE FOOT-1 (continued)

Depth (cm)	Differ-ence (cm)	Core Voulme (cm^3)	Wet Weight (g)	Dry Weight (g)	%Dry	%Wet	Bulk Density ($g\ cm^{-3}$)	Volumetric Moisture (%)	pH	vonPost	Munsell Colour
-389	9	34.2	234.3	133.6	75.44	43	3.905	100	5.0-5.3		2.5Y3/0
				HARE FOOT-2							
-10.5	10.5	164	52.5	16.51	218	68.56	0.10	21.95	4.4	H1	
-26.5	16	249.8	86.4	26.81	222.3	68.97	0.11	23.85	4.4-4.7	H1-H2	
-40	13.5	210.8	163.8	41.37	295.9	74.74	0.20	58.08	4.4-4.7	H2,H3	
-50	10	156.1	227.4	37.89	500.1	83.34	0.24	100.00	4.7-5.0	H3,H4	
-61	11	171.8	270.4	35.58	659.9	86.84	0.21	100.00	4.7-5.0	H4	
-75	14	218.6	169	34.56	389	79.55	0.16	67.06	4.7-5.0	H5,H6	
-91.5	16.5	257.6	290	50.02	479.8	82.75	0.19	100.00	4.7-5.0	H6	
-110	18.5	288.9	249.4	40.84	510.7	83.63	0.14	78.73	5.0	H6	
-120	10	156.1	153.9	27.54	458.8	82.1	0.18	88.25	5.0	H6	
-140	20	312.3	263.8	35.44	644.4	86.57	0.11	79.74	5.0	H6	
-150	10	156.1	117	17.68	561.8	84.89	0.11	69.36	5.0	H6	
-160	10	156.1	196.2	29.27	570.3	85.08	0.19	100.00	5.0	H6	
-181	21	327.9	267	35.6	650	86.67	0.11	76.95	5.0-5.3	H6	
-191	10	156.1	138.8	14.7	844.3	89.41	0.09	86.67	4.7-5.0	H6	
-200	9	140.5	146.5	16.3	798.8	88.87	0.12	100.00	4.7-5.0	H6	
-220	20	312.3	159.1	25.79	516.8	83.79	0.08	46.55	5.0-5.3	H6	
-230.5	10.5	164	187.3	16.5	1035	91.19	0.10	100.00	4.7-5.0	H6	
-243	12.5	195.2	199.9	20.01	898.9	89.99	0.10	100.50	5.0	H6	
-250	7	109.3	102.6	15.49	562.4	84.9	0.14	86.91	4.7-5.3	H6	
-259.5	9.5	148.3	104.1	23.07	351.2	77.84	0.16	59.57	5.0	H6	
-271	11.5	179.6	187.8	20.07	835.7	89.31	0.11	100.00	5.0-5.3	H6	
-281	10	156.1	149.8	14.37	942.6	90.41	0.09	94.58	5.0-5.3	H6	
-290	9	140.5	130.9	17.17	662.4	86.88	0.12	88.25	4.7-5.0i	H6	
-299.5	9.5	148.3	133.7	14.22	840.2	89.36	0.10	87.83	4.7-5.0	H6	
-310.5	11	171.8	273.8	46.41	490	83.05	0.2[illegible]	100.00	4.7-5.3	H6	
-324	13.5	210.8	209.8	97.32	115.6	53.61	0.46	58.19	5.0-5.3	*	
-339.5	15.5	242	331.5	193.1	71.66	41.75	0.80	62.35	5.0-5.3	*	
-351	11.5	179.6	364.2	221.2	64.62	39.25	1.23	86.82	5.0-5.3	*	
-362	11	171.8	300	151.6	97.89	49.47	0.88	94.22	5.0-5.3	*	
-379.5	17.5	273.3	312.9	107.5	191.1	65.65	0.39	81.97	4.7-5.3		
-391	11.5	179.6	368.6	206.8	78.21	43.89	1.15	98.24	5.0-5.3	*	
-411	20	312.3	467.1	220.9	111.5	52.72	0.71	85.99	5.0-5.3	*	
-432	21	327.9	564.5	251.3	124.7	55.49	0.77	100.00	5.0-5.3	*	
-447.5	15.5	242	319	127.1	150.9	60.15	0.53	86.45	5.0-5.3	*	
-452	4.5	70.27	17.7	9.157	93.29	48.27	0.13	13.26	5.0-5.3	*	
-483	31	484.1	286.1	112.7	153.8	60.6	0.23	59.06	5.0-5.3	*	
-500	17	265.5	248.9	97.94	154.1	60.65	0.37	62.02	5.0-5.3	*	
				HARE FOOT-3							
-10	10	156.1	58.9	21.75	170.8	63.07	0.14	23.79	4.1-4.4	H1	
-20	10	156.1	72.6	34	113.5	53.17	0.22	24.72	4.1-4.4	H2	
-30	10	156.1	171.2	86.8	97.24	49.3	0.56	54.05	4.4	H3,H4	
-40	10	156.1	111.9	57.7	93.93	48.44	0.37	34.71	4.4-4.7	H4-H5	
-50	10	156.1	113.7	59.5	91.09	47.67	0.38	34.71	4.4-4.7	H4,H5	

HARE FOOT-3 (continued)

Depth (cm)	Difference (cm)	Core Volume (cm³)	Wet Weight (g)	Dry Weight (g)	%Dry	%Wet	Bulk Density (g cm⁻³)	Volumetric Moisture (%)	pH	vonPost	Munsell Colour
-60	10	156.1	245.2	130.3	88.18	46.86	0.83	80.24	4.4-4.7	H4,H5	
-69.5	9.5	148.3	222.5	119.9	85.52	46.1	0.81	75.40	4.4-4.7	H5	
-80	10.5	164	275.4	212.7	29.48	22.77	1.30	41.70	4.1-4.4	H5,H6	
-89.5	9.5	148.3	237.9	139	71.19	41.58	0.94	72.73	4.1-4.4	H5,H6	
-100	10.5	164	316	188.8	67.34	40.24	1.15	84.58	4.1	H5,H6	
-109.5	9.5	148.3	205.8	92.69	122	54.96	0.62	83.15	4.7-5.0	H5	
-121	11.5	179.6	[illegible]	95.65	152	60.31	0.53	88.27	4.4-4.7	H5,H6	
-130	9	140.5	[illegible]	[illegible]	103.4	50.85	0.73	82.58	4.7-5.0	H5,H6	
-140	10	156.1	[illegible]	[illegible]	[illegible]	43.69	0.69	58.73	4.7	*	
-150.5	10.5	164	[illegible]	[illegible]	[illegible]	71.19	0.42	100.00	4.7	*	
-160	9.5	148.3	[illegible]	[illegible]	[illegible]	78.77	0.19	75.28	4.7	*	
-170.5	10.5	164	324.2	[illegible]	[illegible]	58.48	0.82	100.00	4.7	*	
-180.5	10	156.1	236.2	[illegible]	71.59	41.72	0.88	68.83	4.7	*	
-189.5	9	140.5	284.3	155	83.42	45.48	1.10	100.00	4.7	*	
-201.5	12	187.4	257.2	172.4	49.19	32.97	0.92	49.35	4.7	*	
-211.5	10	156.1	212.2	84.7	150.5	60.08	0.54	89.04	4.7	*	
-221	9.5	148.3	232.6	122.4	90.03	47.38	0.83	81.01	4.7	*	
-231	10	156.1	200.6	72.4	177.1	63.91	0.46	89.53	4.7	*	
-242	11	171.8	247.5	116.9	111.8	52.78	0.68	82.93	4.7	*	
-250	8	124.9	220.6	125.1	76.34	43.29	1.00	83.37	4.7	*	
-260	10	156.1	302.8	178.3	69.83	41.12	1.14	86.95	4.7	*	
-267	7	109.3	170.4	92.4	84.42	45.77	0.85	77.82	4.7	*	

HARE FOOT-4

Depth (cm)	Difference (cm)	Core Volume (cm³)	Wet Weight (g)	Dry Weight (g)	%Dry	%Wet	Bulk Density (g cm⁻³)	Volumetric Moisture (%)	pH	vonPost	Munsell Colour
-10	10	156.1	62.5	17.8	251.1	71.52	0.11	28.63	4.7	H1,H2	
-20	10	156.1	97.9	29.87	227.8	69.49	0.19	43.57	4.4-4.7	H2	
-40	10.5	164	174.4	39.12	345.8	77.57	0.24	82.51	4.7	H2,H3	
-49.5	9.5	148.3	313.4	64.5	385.9	79.42	0.43	100.00	4.7	H4,H5	
-60.5	11	171.8	232.9	60.23	286.7	74.14	0.35	100.00	4.7	H5	
-70	9.5	148.3	254.7	60.9	318.2	76.09	0.41	100.00	4.7	H5	
-79.5	9.5	148.3	175	15.52	1028	91.13	0.10	100.00	4.7	H5,H6	
-89.5	10	156.1	194.9	28	596.1	85.63	0.18	100.00	4.7-5.0	H6	
-101	11.5	179.6	199	23.74	738.2	88.07	0.13	100.00	4.7-5.0	H6	
-111.5	10.5	164	183	20.7	784.1	88.69	0.13	100.00	4.7	H6	
-121	9.5	148.3	175.5	18.59	844.1	89.41	0.13	100.00	4.7	H6	
-130	9	140.5	150.5	20.4	637.7	86.45	0.15	100.00	4.7	H6,H7	
-139.5	9.5	148.3	160.2	20.25	691.1	87.36	0.14	100.00	4.7	H6	
-150.5	11	171.8	194.8	25.27	670.9	87.03	0.15	100.00	4.7	H6	
-161	10.5	164	226.8	20.95	982.6	90.76	0.13	100.00	4.7-5.0	H6	
-171	10	156.1	243.5	18	1253	92.61	0.12	100.00	4.0-4.7	H6,H7	
-180	9	140.5	163.7	13.71	1094	91.62	0.10	100.00	4.7	H6	
-204	24	374.8	163.4	18.62	777.6	88.6	0.05	100.00	5,0	H6,H7	

Depth (cm)	Differ-ence (cm)	Core Voulme (cm³)	Wet Weight (g)	Dry Weight (g)	%Dry	%Wet	Bulk Density (g cm⁻³)	Volmetric Moisture (%)	pH	vonPost	Munsell Colour
GOOSE FLATS-1											
-13	13	49.4	30.3	9.7	212.4	67.99	0.20	41.70	4.1-4.4	H1	
-23	10	38	106.2	41.5	155.9	60.92	1.09	100.00	4.1	H2,H3	
-30	7	26.6	66.8	26	156.9	61.08	0.98	100.00	4.1-4.4	H3	
-40	10	38	98	33.9	189.1	65.41	0.89	100.00	4.1-4.4	H3,H4	
-49.5	9.5	36.1	111.6	36.5	205.8	67.29	1.01	100.00	4.4-4.7	H3,H4	
-59.5	10	38	161.4	36.7	339.8	77.26	0.97	100.00	4.7-5.0	H3,H4	
-70	10.5	39.9	210	46.4	352.6	77.9	1.16	100.00	4.7-5.0	H4,H5	
-80	10	38	135.9	25.6	430.9	81.16	0.67	100.00	4.7-5.0	H5,H6	
-90.5	10.5	39.9	158.4	35.8	342.5	77.4	0.90	100.00	5.0	H6	
-100.5	10	38	198	59.1	235	70.15	1.56	100.00	5.0-5.3	H6	
-109.5	9	34.2	136.6	54.1	152.5	60.4	1.58	100.00	5.0	H6,H7	
-120	10.5	39.9	284.7	177.2	60.67	37.76	4.44	100.00	5.0	H7	2.5Y4/0
-130	10	38	319.9	219.2	45.94	31.48	5.77	100.00	5.0		2.5Y4/0
-139.5	9.5	36.1	336.6	263.4	27.79	21.75	7.30	100.00	5.0		2.5Y4/0
-151	11.5	43.7	399.3	315.7	26.48	20.94	7.22	100.00	5.0		2.5Y4/0
-160	9	34.2	256.4	199.4	28.59	22.23	5.83	100.00	5.0		2.5Y4/0
GOOSE FLATS-2											
-10.5	10.5	39.9	42.6	16.3	161.3	61.74	0.41	65.91	4.4-4.7	H1	
-20	9.5	36.1	42	15.7	167.5	62.62	0.43	72.85	4.7	H2,H3	
-34	14	53.2	46.7	14.9	213.4	68.09	0.28	59.77	4.7	H3	
-40	6	22.8	44.5	14.3	211.2	67.87	0.63	10.00	4.7	H3,H4	
-50	10	38	223.3	90.9	145.7	59.29	2.39	100.00	4.4-4.7	H3,H4	
-59.5	9.5	36.1	339.2	162.6	108.6	52.06	4.50	100.00	4.7	H4,H5	10YR3/1
GOOSE FLATS-3											
-19.5	19.5	74.1	83.9	23.4	258.5	72.11	0.32	81.65	3.8-4.1	H1	
-30.5	11	41.8	120.8	45.9	163.2	62	1.10	100.00	4.4	H1,H2	
-41.5	11	41.8	72.8	23.5	209.8	67.72	0.56	100.00	4.7	H2,H3	
-49.5	8	30.4	130	27.3	376.2	79	0.90	100.00	4.7	H3,H4	
-60.5	11	41.8	124.8	19.5	540	84.38	0.47	100.00	4.7	H4-H5	
-70.5	10	38	156.8	28.7	446.3	81.7	0.76	100.00	4.7	H5	
-79.5	9	34.2	137.3	25.7	434.2	81.28	0.75	100.00	4.4-4.7	H5	
-90	10.5	39.9	116.8	24.7	372.9	78.85	0.62	100.00	<3.5	H5,H6	
-120.5	30.5	115.9	316.2	177.1	78.54	43.99	1.53	100.00	3.5-3.8	H6	10YR3/1
-130	9.5	36.1	153.1	85.6	78.86	44.09	2.37	100.00	4.4-4.7		10YR3/1
-140	10	38	229.4	146.8	56.27	36.01	3.86	100.00	4.1-4.4		10YR3/1
-150	10	38	323	206.5	56.42	36.07	5.43	100.00	4.1-4.4		2.5Y4/0ii
-152	2	7.6	100.8	66.3	52.04	34.23	8.72	100.00	4.4		2.5Y4/0ii
GOOSE FLATS-4											
-10.5	10.5	39.9	63.1	18	250.6	71.47	0.45	100.00	4.4	H1	
-20	9.5	36.1	117	36.8	217.9	68.55	1.02	100.00	4.4-4.7	H2-H3	
-30	10	38	132.2	41.2	220.9	68.84	1.08	100.00	4.1-4.4	H3,H4	
-40	10	38	163.8	50.2	226.3	69.35	1.32	100.00	4.1-4.4	H3,H4	
-50	10	38	171	43.4	294	74.62	1.14	100.00	3.8-4.1	H4,H5	
-60	10	38	194.6	40	386.5	79.45	1.05	100.00	3.8	H5	

STRATIGRAPHIC DATA: WETLAND

HARE FOOT-1

Depth (cm)	Wet weight (g)	Minus Bag (g)	Dry Weight (g)	Minus Bag (g)	%Moisture Dry	%Moisture Wet	pH	von Post
-13.50	27.40	25.78	4.81	3.18	710.03	87.65	4.7	H1,H2
-23.50	22.10	20.48	4.13	2.51	716.39	87.75	5.0	H4
-28.40	17.40	15.78	7.06	5.44	190.09	65.	5.0	*
-43.50	70.50	68.88	12.13	10.51	555.58	84.75	5.0	H6
-50.50	28.00	26.38	4.64	3.01	776.25	88.59	5.0	H4
-52.00	8.30	6.68	3.07	1.45	361.94	78.35	5.0	*
-73.00	54.00	52.38	7.68	6.05	765.27	88.44	4.7	H4
-80.70	23.60	21.98	4.14	2.52	773.41	88.55	4.7	H3
-85.80	25.50	23.88	5.23	3.60	562.83	84.91	4.7	H5
-101.00	81.60	79.98	19.19	17.57	355.31	78.04	4.7	H7
-151.50	285.20	283.58	62.80	61.18	363.55	78.43	4.7	H7
-154.30	14.90	13.28	3.91	2.28	481.98	82.82	4.7	H7
-182.80	75.30	73.68	40.21	38.58	90.97	47.63	4.7	H7
-188.30	38.40	36.78	11.24	9.62	282.40	73.85	4.7	H8
-192.60	25.30	23.68	8.32	6.69	253.78	71.73	4.7	H8
-202.00	58.70	57.08	28.42	26.79	113.03	53.06	4.7	*
-216.00	131.40	129.78	88.92	87.30	48.66	32.73	4.7	*
-220.00	34.50	32.88	28.13	26.51	24.03	19.37	4.7	*

HARE FOOT-2

Depth (cm)	Wet weight (g)	Minus Bag (g)	Dry Weight (g)	Minus Bag (g)	%Moisture Dry	%Moisture Wet	pH	von Post
-16.00	28.50	26.88	4.64	3.01	792.56	88.80	4.7	H2
n/a	n/a	n/a	n/a		n/a		n/a	n/a
n/a	n/a	n/a	n/a		n/a		n/a	n/a
-55.40	17.30	15.68	3.58	1.96	701.38	87.52	4.7	H3
-68.30	44.70	43.08	5.82	4.19	927.06	90.26	4.7	H3
-76.00	46.70	45.08	5.64	4.02	1022.11	91.09	4.7	H3
-82.50	39.20	37.58	5.86	4.23	787.67	88.73	4.7	H4
-101.00	107.40	105.78	16.65	15.03	603.81	85.79	4.7	H6
-102.80	11.30	9.68	2.88	1.26	670.92	87.03	4.7	H6
-105.50	15.50	13.88	3.33	1.71	712.35	87.69	4.7	H6
-125.20	106.80	105.18	16.54	14.92	605.07	85.82	4.4	H8
-134.10	58.40	56.78	7.87	6.24	809.71	89.01	4.4	H8
-135.40	9.00	7.38	2.43	0.80	819.58	89.13	4.4	H9
-151.50	88.60	86.98	10.43	8.80	888.13	89.88	4.4	H9
-181.00	160.30	158.68	24.62	22.99	590.13	85.51	4.7	H9
-190.00	54.10	52.48	7.34	5.72	818.20	89.11	4.7	H9
-192.50	14.90	13.28	3.18	1.56	751.51	88.26	4.7	H9
-196.60	22.20	20.58	3.81	2.18	842.51	89.39	4.7	H9
-201.50	25.60	23.98	3.67	2.05	1071.23	91.46	4.7	H9
-211.10	52.30	50.68	7.69	6.06	735.95	88.04	4.7	H9
-215.50	25.90	24.28	4.74	3.12	678.79	87.16	4.7	H9
-227.60	75.90	74.28	11.22	9.60	673.78	87.08	4.7	H9

HARE FOOT-2 (continued)

Depth (cm)	Wet weight (g)	Minus Bag (g)	Dry Weight (g)	Minus Bag (g)	%Moisture Dry	%Moisture Wet	pH	von Post
-248.20	136.60	134.98	20.51	18.88	614.76	86.01	4.7	H10
-251.20	17.50	15.88	7.51	5.88	169.85	62.94	4.7	*
-271.60	208.50	206.88	149.92	148.30	39.50	28.32	4.7	*
-293.20	172.10	170.48	135.89	134.27	26.97	21.24	4.7	*
-343.70	486.10	484.48	363.51	361.89	33.88	25.30	4.7	*
BEAVER POND-1								
-10.00	26.20	24.58	6.33	4.71	422.09	80.85	4.7	H2
-21.20	17.80	16.18	4.97	3.35	382.98	79.30	4.7	H3
-23.30	8.70	7.08	3.01	1.38	411.94	80.47	4.7	H3
-34.90	49.60	47.98	13.09	11.47	318.30	76.09	4.7	H3
-37.80	14.60	12.98	6.46	4.84	168.19	62.71	4.7	*
-40.40	11.10	9.48	3.61	1.98	378.29	79.09	4.7	H3
-42.80	11.40	9.78	4.39	2.76	253.78	71.73	4.7	H3
-49.30	31.00	29.38	12.28	10.65	175.82	63.74	4.7	*
-55.60	29.80	28.18	6.51	4.88	477.00	82.67	4.4	H4
-60.50	22.20	20.58	4.54	2.91	606.56	85.85	4.7	H4
-62.80	14.40	12.78	4.41	2.79	358.38	78.18	4.7	H4
-71.80	49.30	47.68	11.50	9.88	382.64	79.28	4.7	H4
-73.70	11.80	10.18	3.66	2.03	400.74	80.03	4.7	H4
-77.00	21.00	19.38	4.89	3.27	492.87	83.13	4.4	H4
-84.00	39.90	38.28	7.19	5.57	587.78	85.46	4.7	H3
-90.80	38.00	36.38	6.38	4.75	665.63	86.94	4.7	H3
-97.90	49.50	47.88	8.92	7.30	555.91	84.75	4.7	H3
-100.70	18.90	17.28	4.09	2.47	600.81	85.73	4.7	H2
-108.00	50.30	48.68	15.41	13.79	253.00	71.67	4.7	H4
-111.00	18.10	16.48	5.49	3.86	326.37	76.55	4.7	H4
-113.60	16.20	14.58	4.86	3.24	349.98	77.78	4.7	H4
-116.20	16.80	15.18	6.11	4.48	238.43	70.45	4.7	H4
-119.40	20.00	18.38	6.50	4.88	276.61	73.45	4.7	H4
-121.90	17.20	15.58	5.80	4.17	273.50	73.23	4.7	H4
-124.40	17.40	15.78	5.65	4.02	292.02	74.49	4.7	H4
-129.90	40.30	38.68	14.55	12.92	199.27	66.59	4.7	H4
-142.20	97.10	95.48	38.28	36.66	160.46	61.61	4.7	H5
-158.30	111.80	110.18	43.97	42.35	160.18	61.56	4.7	H6
-161.50	22.60	20.98	11.29	9.67	117.00	53.92	4.7-5.0	*
-166.00	35.10	33.48	15.78	14.16	136.42	57.70	5.0	*
-176.50	90.00	88.38	37.06	35.44	149.39	59.90	5.0	H2
-184.20	70.30	68.68	30.41	28.78	138.61	58.09	5.9	H2
-185.80	11.30	9.68	5.40	3.77	156.63	61.03	5.9	H2
-192.00	48.80	47.18	19.74	18.11	160.43	61.60	5.6	H2
-196.50	29.40	27.78	12.89	11.26	146.58	59.45	5.6	H2
-200.90	30.50	28.88	10.86	9.24	212.64	68.01	5.9	H2
-207.50	46.90	45.28	19.43	17.80	154.34	60.68	5.9	H2
-213.50	31.00	29.38	9.90	8.28	254.86	71.82	5.9	H2

BEAVER POND-1 (continued)

Depth (cm)	Wet weight (g)	Minus Bag (g)	Dry Weight (g)	Minus Bag (g)	%Moisture Dry	%Moisture Wet	pH	von Post
-216.50	22.40	20.78	10.70	9.07	128.95	56.32	5.9	*
-222.00	38.10	36.48	13.30	11.67	212.50	68.00	5.9	*
-229.40	51.50	49.88	15.87	14.24	250.17	71.44	5.9	*
-239.20	62.70	61.08	17.21	15.59	291.81	74.48	5.6	H1
-245.00	32.20	30.58	9.63	8.01	281.76	73.81	5.3	H3
				BEAVER POND-2				
-18.30	27.50	25.88	3.94	2.31	1019.16	91.06	4.7	H1
-22.50	11.30	9.68	5.22	3.59	169.20	62.85	5.0	*
-25.20	6.70	5.08	3.80	2.18	133.33	57.14	5.0	*
-28.30	15.90	14.28	8.68	7.05	102.37	50.58	5.0	*
-38.80	53.50	51.88	29.01	27.39	89.42	47.21	5.3	*
-50.50	78.70	77.08	49.40	47.77	61.34	38.02	5.3	*
-59.50	76.80	75.18	5.43	3.80	1877.25	94.94	5.3	*
-65.40	50.20	48.58	27.95	26.32	84.53	45.81	5.3	*
-67.70	18.60	16.98	9.77	8.14	108.49	52.04	5.0	*
-74.00	67.00	65.38	37.81	36.18	80.68	44.65	5.0	*
-75.90	15.50	13.88	6.96	5.34	159.93	61.53	4.7	H2
-84.40	81.80	80.18	44.23	42.61	88.18	46.86	5.0	*
-93.30	74.10	72.48	33.88	32.26	124.69	55.49	5.0	*
-101.00	50.20	48.58	20.32	18.70	159.80	61.51	5.0	*
-102.70	11.60	9.98	4.64	3.01	231.07	69.79	5.0	*
-106.80	30.90	29.28	13.80	12.18	140.43	58.41	5.0	*
-121.00	120.00	118.38	40.56	38.93	204.05	67.11	5.0	*
-135.40	107.50	105.88	44.36	42.74	147.74	59.64	5.0	*
-139.00	22.70	21.08	9.73	8.11	159.96	61.53	5.3	*
				DALE CREEK 2-1				
-18.30	28.20	26.58	5.34	3.71	615.92	86.03	5.0	H1
-22.30	16.60	14.98	7.21	5.59	168.13	62.70	5.3	H6
-26.40	22.00	20.38	12.23	10.60	92.16	47.96	5.3	*
-28.50	13.40	11.78	7.69	6.06	94.21	48.51	5.0	*
-31.80	19.70	18.08	9.80	8.18	121.05	54.76	5.3	*
-36.10	24.50	22.88	9.96	8.34	174.45	63.56	5.3	H7
-50.50	75.50	73.88	19.10	17.48	322.72	76.34	5.3	H4
-59.30	46.70	45.08	9.00	7.38	510.86	83.63	5.0	H5
-80.20	123.70	122.08	23.62	22.00	454.99	81.98	5.3	H5
-86.70	47.10	43.85	17.95	14.70	198.40	66.49	5.3	H5
-93.80	45.40	43.78	13.74	12.11	261.48	72.34	5.3	H5
-101.00	43.40	41.78	17.46	15.84	163.78	62.09	5.3	H5
-141.50	162.00	160.38	119.02	117.40	36.61	26.80	5.3	*
				DALE CREEK 2-2				
-13.40	30.20	28.58	6.25	4.62	518.51	83.83	5.0	H2
-20.00	24.10	22.48	6.32	4.69	379.21	79.13	5.3	H3
-22.50	12.60	10.98	5.63	4.00	174.10	63.52	5.3	*
-28.80	31.20	29.58	5.88	4.26	594.90	85.61	5.6	H3

DALE CREEK 2-2 (continued)

Depth (cm)	Wet weight (g)	Minus Bag (g)	Dry Weight (g)	Minus Bag (g)	%Moisture Dry	%Moisture Wet	pH	von Post
-31.00	12.20	10.58	3.25	1.63	550.77	84.63	4.7	H2
-35.90	31.00	29.38	5.37	3.75	684.17	87.25	4.7	H4
-50.50	69.00	67.38	8.17	6.55	928.78	90.28	5.0	H4
-55.70	23.10	21.48	3.79	2.17	891.92	89.92	5.3	H5
-66.60	64.80	63.18	6.91	5.28	1096.50	91.64	5.6	H5
-70.40	24.10	22.48	4.24	2.61	760.12	88.37	5.6	H5
-91.20	125.50	123.88	17.23	15.61	693.82	87.40	5.6	H5
-98.60	54.80	53.18	27.27	25.65	107.32	51.76	5.3	H5
-101.00	12.90	11.28	4.14	2.52	348.31	77.69	5.6	H5
-124.00	129.50	127.88	18.57	16.94	654.78	86.75	5.6	H5
-131.50	40.20	38.58	11.57	9.95	287.73	74.21	5.6	H5
-141.20	59.10	57.48	13.51	11.88	383.76	79.33	5.3	H5
-145.70	33.80	32.18	11.16	9.53	237.48	70.37	5.3	H5
-150.90	35.40	33.78	8.01	6.39	428.89	81.09	5.3	H5
-156.50	40.60	38.98	14.26	12.63	208.57	67.59	5.3	H5
-167.50	63.20	61.58	20.18	18.56	231.82	69.86	5.3	H5
-190.20	98.70	95.45	62.56	59.31	60.93	37.86	5.3	*
-196.80	40.70	37.45	19.56	16.31	129.56	56.44	5.3	H5
-207.00	74.90	71.65	55.51	52.26	37.10	27.06	5.3	*
				DALE CREEK 6-1				
-24.00	29.20	27.58	4.82	3.20	762.53	88.41	5.3	H3
-50.50	102.10	100.48	17.50	15.87	533.11	84.21	5.3	H3
-54.90	28.10	26.48	9.42	7.80	239.60	70.55	5.0	H3
-70.90	119.70	118.08	69.01	67.39	75.22	42.93	5.3	*
-83.80	109.70	108.08	64.10	62.48	72.99	42.19	5.3	*
-97.30	116.40	114.78	67.94	66.32	73.08	42.22	5.0	*
-101.00	26.00	24.38	14.81	13.19	84.84	45.90	5.3	*
-104.80	27.20	25.58	15.07	13.45	90.22	47.43	5.6	*
-109.50	34.00	32.38	20.66	19.04	70.05	41.19	5.3	*
-112.40	23.10	21.48	13.91	12.29	74.76	42.78	5.6	*
-126.80	106.90	105.28	68.99	67.37	56.28	36.01	5.0	*
-130.80	34.90	33.28	22.18	20.56	61.87	38.22	5.3	*
-138.50	62.30	59.05	47.01	43.76	34.93	25.89	5.3	*
				DALE CREEK 6-2				
-50.50	30.17	28.55	6.37	4.75	501.58	83.38	5.0	H1
-62.50	56.12	54.50	12.52	10.90	400.00	80.00	5.3	H3
-63.80	9.44	7.82	3.44	1.81	331.29	76.81	5.3	H3
-68.90	11.35	9.73	4.71	3.08	215.34	68.29	5.3	H3
-77.00	59.54	57.92	27.27	25.65	125.80	55.71	5.3	H3
-80.20	23.88	22.26	10.36	8.73	154.84	60.76	5.6	H2
-89.20	48.49	46.87	29.57	27.95	67.70	40.37	5.6	*
-96.40	51.73	50.11	21.62	20.00	150.54	60.09	5.3	H4

DALE CREEK 6-2 (continued)

Depth (cm)	Wet weight (g)	Minus Bag (g)	Dry Weight (g)	Minus Bag (g)	%Moisture Dry	%Moisture Wet	pH	von Post
-101.00	27.90	26.28	8.16	6.53	302.37	75.15	5.0	H2
-109.40	54.60	52.98	13.09	11.47	362.06	78.36	5.3	H2
-124.50	92.36	90.74	17.20	15.58	482.46	82.83	5.3	H3
-128.20	26.66	25.04	7.83	6.20	303.66	75.23	5.3	H5
-151.50	209.87	206.62	143.60	140.35	47.22	32.07	5.3	*
GOOSE FLATS-1								
-18.00	36.80	35.18	8.38	6.76	420.49	80.79	4.4	H4
-20.90	14.10	12.48	4.05	2.42	415.50	80.60	4.4	H5
-50.50	158.20	156.58	30.97	29.35	433.55	81.26	4.4	H5
-57.70	39.20	37.58	10.31	8.68	332.79	76.89	4.4	*
-60.00	14.90	13.28	8.31	6.68	98.61	49.65	4.7	H7
-62.70	16.00	14.38	8.28	6.66	115.87	53.68	4.7	*
-66.60	35.40	33.78	24.06	22.43	50.57	33.58	4.7	*
-101.00	303.80	302.18	231.29	229.67	31.57	24.00	4.7	*
GOOSE FLATS-2								
-10.00	27.90	26.28	4.31	2.68	878.95	89.78	4.4	H5
-20.00	65.60	63.98	15.74	14.12	353.14	77.93	4.4	H5
-22.80	18.20	16.58	9.29	7.67	116.13	53.73	4.4	*
-26.60	25.60	23.98	14.30	12.67	89.21	47.15	4.4	*
-28.20	12.40	10.78	7.49	5.87	83.72	45.57	4.4	*
-42.80	95.80	94.18	49.68	48.05	95.98	48.97	4.7	*
-50.50	50.30	48.68	37.60	35.98	35.30	26.09	4.7	*
-70.60	65.40	63.78	44.51	42.89	48.70	32.75	4.7	*
-87.60	145.20	143.58	110.67	109.05	31.67	24.05	4.7	*
-91.00	32.90	31.28	27.41	25.79	21.28	17.54	4.7	*
-101.00	104.40	102.78	87.46	85.84	19.74	16.48	4.7	*
GOOSE FLATS-3								
-7.50	29.30	27.68	7.11	5.49	404.19	80.17	4.7	H6
-9.50	7.50	5.88	3.15	1.53	284.74	74.01	4.7	H4
-16.40	33.50	31.88	8.59	6.96	357.97	78.16	4.4	H4
-19.70	18.70	17.08	6.95	5.32	220.84	68.83	4.4	H4
-20.70	8.00	6.38	3.81	2.18	192.43	65.80	4.4	*
-31.20	61.20	59.58	16.44	14.81	302.15	75.13	4.4	H4
-44.80	80.50	78.88	19.78	18.15	334.57	76.99	4.4	H5
-50.50	31.90	30.28	7.28	5.65	435.65	81.33	4.4	H5
-63.30	148.90	147.28	30.05	28.43	418.06	80.70	4.4	H5
-77.00	98.10	96.48	21.06	19.43	396.45	79.86	4.4	H4
-82.40	42.50	40.88	12.94	11.32	261.18	72.31	4.4	H5
-88.00	40.90	39.28	16.49	14.87	164.18	62.15	4.4	H5
-91.00	26.40	24.78	18.83	17.20	44.01	30.56	4.4	*

APPENDIX B:

MICROCLIMATE DATA: HARE FOOT

TEMPERATURE (°C)

		PALSA (cm)							FEN (cm)	
Year	Julian Day	150	0	-2.5	-5	-150	-215	-385	-5	-150
1990	212	9.65	9.23	9.29	8.95	-0.705	-0.862	-1.112	12.77	1.839
1990	213	7.52	9.56	9.2	8.5	-0.743	-0.896	-1.145	12.17	1.878
1990	214	7.88	9.37	9.33	8.76	-0.735	-0.881	-1.139	12.18	1.934
1990	215	9.2	8.57	8.73	8.2	-0.743	-0.898	-1.151	12.32	1.986
1990	216	7.58	7.35	7.21	6.839	-0.801	-0.955	-1.19	10.76	2.028
1990	217	12.06	11.78	11.34	10.24	-0.697	-0.863	-1.106	12.02	2.112
1990	218	8.53	8.6	8.54	8.21	-0.751	-0.892	-1.131	11.32	2.192
1990	219	7.4	7.77	8	7.87	-0.758	-0.912	-1.151	10.93	2.261
1990	220	7.43	8.06	7.84	7.29	-0.795	-0.962	-1.205	9.69	2.214
1990	221	8.47	8.32	8.2	7.72	-0.745	-0.894	-1.128	10.21	2.369
1990	222	12.26	11.8	11.29	10.16	-0.674	-0.847	-1.082	11.77	2.445
1990	223	15.75	15.78	13.7	12.64	-0.599	-0.775	-1.025	13.38	2.493
1990	224	14.04	14.35	12.39	11.97	-0.634	-0.779	-1.027	14.31	2.592
1990	225	11.59	13.84	10.79	10.37	-0.623	-0.79	-1.071	12.45	2.56
1990	226	11.56	15.31	12.46	11.05	-0.622	-0.779	-1.042	12.43	2.648
1990	227	11.83	15.07	12.79	10.87	-0.611	-0.769	-1.027	12.76	2.705
1990	228	12.02	11.6	11.54	10.77	-0.624	-0.766	-1.006	12.87	2.79
1990	229	10.81	10.04	10.04	9.59	-0.637	-0.799	-1.041	12.79	2.837
1990	230	9.65	9.55	9.5	9.09	-0.676	-0.813	-1.046	12.15	2.881
1990	231	7.83	7.31	7.33	7.17	-0.714	-0.867	-1.091	10.46	2.881
1990	232	8.14	7.51	7.22	7.16	-0.676	-0.805	-1.072	10.87	2.948
1990	233	6.893	6.126	5.858	5.778	-0.716	-0.872	-1.11	10.48	2.945
1990	234	5.706	4.817	4.275	4.421	-0.711	-0.876	-1.124	9.88	2.953
1990	235	7.28	5.603	4.53	4.549	-0.679	-0.849	-1.1	9.8	2.992
1990	236	5.842	5.685	4.449	4.401	-0.747	-0.885	-1.122	8.99	3.023
1990	237	9.65	10.44	7.46	6.471	-0.613	-0.741	-0.986	9.55	3.218
1990	238	6.096	5.78	5.14	4.623	-0.718	-0.87	-1.091	8.34	3.137
1990	239	9.36	8.6	7.51	6.696	-0.654	-0.818	-1.046	9.37	3.223
1990	240	7.4	6.97	6.639	6.381	-0.643	-0.794	-1.033	10.19	3.28
1990	241	2.683	3.207	3.658	3.825	-0.755	-0.901	-1.156	8.7	3.194
1990	242	0.979	1.24	1.543	1.885	-0.809	-0.974	-1.229	7.1	3.142
1990	243	1.028	2.656	2.224	2.134	-0.791	-0.963	-1.208	6.612	3.179
1990	244	0.357	-0.16	0.266	0.657	-0.904	-1.041	-1.274	5.876	3.179
1990	245	0.172	-0.266	0.134	0.38	-0.862	-1.025	-1.266	5.379	3.198
1990	246	2.359	1.968	1.439	1.254	-0.84	-0.995	-1.222	5.522	3.256
1990	247	4.222	5.019	4.454	3.919	-0.746	-0.894	-1.124	6.518	3.379
1990	248	3.844	3.644	3.328	3.102	-0.765	-0.92	-1.144	6.598	3.361

1990	249	6.057	5.346	5.058	4.741	-0.703	-0.848	-1.075	7.26	3.466
1990	250	2.087	0.663	1.497	1.802	-0.793	-0.953	-1.19	6.088	3.336
1990	251	2.104	1.082	0.713	0.85	-0.747	-0.921	-1.158	5.45	3.358
1990	252	1.973	2.217	1.814	1.578	-0.802	-0.954	-1.176	5.309	3.367
1990	253	-0.41	-0.197	0.298	0.537	-0.866	-0.985	-1.209	4.235	3.352
1990	254	-0.41	-0.349	-0.109	0.002	-0.917	-1.042	-1.264	3.045	3.301
1990	255	1.511	-0.216	-0.076	-0.03	-0.862	-0.991	-1.212	3.312	3.37
1990	256	5.39	4.412	3.304	2.691	-0.683	-0.839	-1.077	5.068	3.473
1990	257	3.659	2.18	1.964	1.907	-0.79	-0.934	-1.155	5.295	3.405
1990	258	5.771	4.851	4.627	4.304	-0.683	-0.827	-1.047	5.555	3.512
1990	259	2.685	1.838	2.098	2.15	-0.746	-0.881	-1.119	5.375	3.408
1990	260	1.206	0.948	1.563	1.599	-0.692	-0.854	-1.082	5.32	3.414
1990	261	-0.518	0.228	0.293	0.37	-0.882	-1.013	-1.236	4.617	3.308
1990	262	3.141	2.404	1.946	1.706	-0.74	-0.899	-1.127	4.813	3.375
1990	263	4.592	3.624	3.288	3.046	-0.645	-0.788	-1.017	5.618	3.446
1990	264	4.536	3.168	2.833	2.641	-0.729	-0.867	-1.1	5.279	3.367
1990	265	4.493	3.889	3.36	3.018	-0.75	-0.897	-1.106	4.782	3.354
1990	266	8.25	6.602	5.872	5.557	-0.598	-0.741	-0.962	5.99	3.498
1990	267	4.594	3.655	3.334	3.399	-0.694	-0.832	-1.055	5.77	3.394
1990	268	2.322	1.848	2.319	2.408	-0.759	-0.89	-1.117	5.42	3.309
1990	269	-0.668	-1.383	-0.1	0.248	-0.798	-0.945	-1.185	4.617	3.236
1990	270	-3.501	-3.789	-1.46	-0.659	-0.907	-1.054	-1.287	3.604	3.159
1990	271	0.238	-0.613	-0.524	-0.49	-0.871	-1.019	-1.238	2.62	3.139
1990	272	1.367	0.335	-0.292	-0.363	-0.805	-0.948	-1.167	2.159	3.183
1990	273	0.494	0.03	-0.265	-0.375	-0.806	-0.944	-1.165	2.566	3.174
1990	274	-0.755	-0.816	-0.402	-0.424	-0.837	-0.989	-1.205	2.88	3.151
1990	275	-1.009	-1.235	-0.507	-0.444	-0.853	-0.99	-1.203	2.793	3.131
1990	276	-3.119	-0.901	-0.505	-0.514	-0.921	-1.048	-1.269	2.467	3.07
1990	277	-4.776	-2.191	-0.766	-0.557	-0.941	-1.073	-1.296	2.082	3.053
1990	278	-10.2	-4.55	-1.927	-1.139	-0.994	-1.115	-1.341	1.753	3.035
1990	279	-11.28	-5.072	-2.501	-1.777	-1.013	-1.116	-1.352	1.041	3.009
1990	280	-8.71	-4.661	-2.676	-2.093	-1.018	-1.147	-1.363	0.497	2.959
1990	281	-1.211	-1.527	-1.262	-1.16	-0.91	-1.052	-1.267	0.327	2.987
1990	282	-3.315	-1.331	-0.869	-0.828	-0.905	-1.031	-1.251	0.209	2.99
1990	283	-11.04	-2.934	-1.529	-1.259	-0.976	-1.121	-1.359	0.043	2.928
1990	284	-9.83	-3.966	-2.368	-1.948	-1.012	-1.177	-1.402	-0.041	2.878
1990	285	-7.16	-3.561	-2.378	-2.025	-1.002	-1.159	-1.382	-0.081	2.857
1990	286	-5.321	-2.662	-1.911	-1.702	-0.975	-1.117	-1.33	-0.101	2.858
1990	287	-7.38	-3.351	-2.026	-1.741	-0.971	-1.099	-1.323	-0.131	2.859
1990	288	-17.61	-5.644	-3.404	-2.816	-1.011	-1.111	-1.349	-0.209	2.841
1990	289	-19.91	-7.14	-4.576	-3.82	-1.058	-1.192	-1.432	-0.309	2.762
1990	290	-13.07	-6.076	-4.091	-3.522	-1.024	-1.2	-1.427	-0.344	2.716
1990	291	-15.3	-6.782	-4.295	-3.644	-0.999	-1.124	-1.362	-0.333	2.752
1990	292	-21.45	-9.11	-6.01	-5.106	-1.071	-1.182	-1.422	-0.437	2.682
1990	293	-11.27	-6.13	-4.425	-3.931	-1.029	-1.187	-1.409	-0.444	2.637
1990	294	-6.91	-4.374	-3.254	-2.936	-0.984	-1.123	-1.341	-0.412	2.652
1990	295	-7.32	-5.368	-3.298	-2.86	-0.973	-1.091	-1.317	-0.418	2.643
1990	296	-10.85	-5.978	-4.069	-3.515	-0.987	-1.129	-1.354	-0.465	2.587
1990	297	-5.536	-3.661	-2.879	-2.616	-0.972	-1.11	-1.325	-0.449	2.561
1990	298	-6.186	-5.278	-3.578	-3.131	-0.935	-1.039	-1.262	-0.409	2.584
1990	299	-10.81	-5.453	-3.613	-3.183	-0.962	-1.064	-1.289	-0.449	2.535

1990	300	-12.99	-6.883	-4.433	-3.794	-0.978	-1.08	-1.304	-0.463	2.505
1990	301	-10.86	-4.557	-3.311	-2.962	-0.966	-1.094	-1.31	-0.492	2.439
1990	302	-7.75	-3.663	-2.595	-2.334	-0.938	-1.072	-1.283	-0.474	2.424
1990	303	-10.29	-3.73	-2.646	-2.346	-0.932	-1.087	-1.304	-0.504	2.375
1990	304	-20.7	-5.928	-3.785	-3.225	-0.98	-1.103	-1.322	-0.536	2.315
1990	305	-24.72	-6.971	-4.532	-3.943	-0.982	-1.106	-1.327	-0.552	2.291
1990	306	-25.93	-7.52	-5.124	-4.444	-0.993	-1.143	-1.364	-0.596	2.246
1990	307	-24.02	-8.12	-5.418	-4.703	-0.961	-1.055	-1.283	-0.537	2.304
1990	308	-21.48	-7.64	-5.438	-4.773	-0.99	-1.074	-1.3	-0.555	2.261
1990	309	-11.72	-6.891	-4.59	-4.089	-0.985	-1.093	-1.309	-0.58	2.202
1990	310	-14.72	-8.05	-5.573	-4.867	-0.979	-1.13	-1.343	-0.642	2.132
1990	311	-13.3	-9.59	-6.362	-5.429	-0.968	-1.151	-1.373	-0.662	2.072
1990	312	-19.85	-13.14	-8.22	-6.984	-0.984	-1.138	-1.356	-0.669	2.068
1990	313	-19.44	-12.41	-8.62	-7.39	-1.011	-1.219	-1.453	-0.725	1.974
1990	314	-26.39	-13.48	-8.97	-7.56	-1.068	-1.302	-1.567	-0.821	1.885
1990	315	-38.15	-16.79	-11.18	-9.52	-1.337	-1.636	-1.923	-1.141	1.607
1990	316	-36.89	-17.8	-12.39	-10.73	-1.387	-1.65	-1.922	-1.202	1.572
1990	317	-29.13	-12.81	-9.49	-8.42	-1.138	-1.366	-1.622	-0.965	1.79
1990	318	-30.84	-13.35	-9.66	-8.51	-1.148	-1.389	-1.649	-1.021	1.745
1990	319	-20.72	-10.91	-8.44	-7.63	-1.084	-1.263	-1.493	-0.98	1.803
1990	320	-12.8	-9.17	-6.667	-6.042	-0.977	-1.114	-1.33	-0.801	1.87
1990	321	-14.79	-12.51	-8.78	-7.97	-0.95	-1.027	-1.246	-0.73	1.928
1990	322	-16.82	-12.72	-9.55	-8.61	-1.012	-1.121	-1.34	-0.812	1.811
1990	323	-29.14	-20.02	-14.69	-12.87	-1.189	-1.252	-1.467	-1.032	1.676
1990	324	-29.19	-19.19	-14.88	-13.34	-1.144	-1.335	-1.549	-1.184	1.597
1990	325	-30.32	-19.86	-15.55	-13.99	-1.159	-1.337	-1.548	-1.22	1.57
1990	326	-30.45	-19.71	-15.52	-14.03	-1.178	-1.325	-1.537	-1.236	1.553
1990	327	-39.49	-23.7	-18.35	-16.42	-1.34	-1.416	-1.623	-1.441	1.442
1990	328	-42.07	-26.5	-20.83	-18.78	-1.463	-1.524	-1.726	-1.714	1.323
1990	329	-40.04	-26.33	-21.25	-19.37	-1.462	-1.591	-1.8	-1.885	1.258
1990	330	-28.27	-19.77	-17.1	-16.07	-1.144	-1.381	-1.592	-1.627	1.416
1990	331	-30.69	-20.09	-16.74	-15.5	-1.148	-1.322	-1.526	-1.479	1.443
1990	332	-25.42	-16.15	-14.11	-13.33	-1.037	-1.238	-1.446	-1.37	1.484
1990	333	-31.76	-17.91	-14.68	-13.49	-1.05	-1.192	-1.398	-1.292	1.503
1990	334	-31.92	-18.89	-15.67	-14.34	-1.067	-1.192	-1.39	-1.317	1.488
1990	335	-38.47	-17.59	-14.74	-13.67	-1.072	-1.258	-1.46	-1.443	1.409
1990	336	-44.58	-20.03	-16.37	-15.04	-1.15	-1.343	-1.556	-1.751	1.308
1990	337	-33.77	-17.81	-15.36	-14.43	-1.083	-1.284	-1.486	-1.884	1.339
1990	338	-30.01	-15.61	-13.49	-12.78	-1.028	-1.204	-1.405	-1.646	1.386
1990	339	-32.31	-15.7	-13.55	-12.74	-1.125	-1.201	-1.433	-1.555	1.406
1990	340	-11.54	-11.15	-10.49	-10.22	-0.995	-1.147	-1.341	-1.468	1.393
1990	341	-9.44	-9.61	-8.99	-8.79	-0.949	-1.061	-1.253	-1.181	1.434
1990	342	-20.75	-15.01	-11.99	-10.92	-1	-1.103	-1.3	-1.126	1.361
1990	343	-17.07	-13.9	-12.15	-11.44	-1.015	-1.163	-1.354	-1.099	1.315
1990	344	-16.44	-12.38	-10.46	-9.89	-0.982	-1.087	-1.282	-1.048	1.35
1990	345	-25.58	-16.82	-13.7	-12.61	-1.02	-1.128	-1.307	-1.094	1.294
1990	346	-16.56	-13.8	-12.17	-11.6	-1.025	-1.142	-1.33	-1.142	1.272
1990	347	-12.94	-10.84	-10.02	-9.68	-1.009	-1.091	-1.27	-1.112	1.298
1990	348	-19.64	-13.04	-10.79	-9.98	-1.05	-1.082	-1.258	-1.07	1.284
1990	349	-34.84	-20.07	-15.4	-13.82	-1.163	-1.218	-1.39	-1.178	1.168
1990	350	-36.1	-21.91	-17.42	-15.8	-1.226	-1.294	-1.46	-1.352	1.094

1990	351	-38.04	-23.03	-18.53	-16.83	-1.367	-1.271	-1.419	-1.511	1.11
1990	352	-36.42	-23.3	-19.32	-17.76	-1.45	-1.327	-1.465	-1.708	1.055
1990	353	-33.45	-21.83	-18.11	-16.76	-1.407	-1.316	-1.434	-1.787	1.077
1990	354	-21.11	-16.76	-15.14	-14.53	-1.403	-1.259	-1.361	-1.703	1.121
1990	355	-12.82	-11.9	-11.49	-11.3	-1.425	-1.21	-1.292	-1.551	1.146
1990	356	-10.82	-10.97	-10.48	-10.25	-1.48	-1.186	-1.244	-1.364	1.163
1990	357	-17.55	-12.98	-10.93	-10.23	-1.551	-1.179	-1.215	-1.216	1.165
1990	358	-33.1	-20.97	-16.63	-15.08	-1.756	-1.318	-1.325	-1.254	1.073
1990	359	-19.17	-15.59	-13.72	-13	-1.77	-1.345	-1.32	-1.277	1.067
1990	360	-20.12	-18.62	-15.76	-14.52	-1.852	-1.34	-1.283	-1.323	1.086
1990	361	-33.03	-27.72	-22.18	-20.14	-2.069	-1.476	-1.373	-1.388	0.985
1990	362	-38.72	-30.02	-23.86	-21.71	-2.238	-1.602	-1.461	-1.446	0.897
1990	363	-29.63	-21.79	-19.04	-18.05	-2.189	-1.623	-1.448	-1.424	0.914
1990	364	-32.41	-23.47	-19.45	-18.08	-2.29	-1.609	-1.391	-1.433	0.942
1990	365	-35.67	-25.29	-20.69	-19.09	-2.467	-1.706	-1.435	-1.524	0.876
1991	1	-35.13	-24.48	-20.24	-18.77	-2.572	-1.754	-1.436	-1.574	0.861
1991	2	-37.16	-26.01	-21.4	-19.74	-2.71	-1.814	-1.443	-1.637	0.849
1991	3	-29.45	-22.89	-19.74	-18.56	-2.766	-1.888	-1.46	-1.697	0.828
1991	4	-31.15	-23.8	-19.83	-18.43	-2.866	-1.897	-1.412	-1.691	0.853
1991	5	-33.28	-23.6	-20.12	-18.83	-3.022	-2.006	-1.452	-1.746	0.802
1991	6	-34.6	-24.33	-20.34	-18.86	-3.155	-2.073	-1.457	-1.773	0.788
1991	7	-37.43	-25.9	-21.75	-20.13	-3.351	-2.195	-1.512	-1.849	0.733
1991	8	-25.83	-19.68	-17.93	-17.23	-3.323	-2.197	-1.451	-1.803	0.786
1991	9	-34.52	-21.76	-18.64	-17.5	-3.445	-2.239	-1.413	-1.813	0.8
1991	10	-28.51	-19.58	-17.43	-16.63	-3.525	-2.317	-1.422	-1.797	0.782
1991	11	-22.12	-16.58	-15.25	-14.81	-3.595	-2.341	-1.365	-1.723	0.81
1991	12	-18.29	-14.52	-13.68	-13.36	-3.665	-2.368	-1.316	-1.624	0.839
1991	13	-12.06	-12.41	-12.07	-11.92	-3.758	-2.428	-1.299	-1.531	0.84
1991	14	-11.21	-11.11	-10.75	-10.63	-3.827	-2.474	-1.275	-1.401	0.852
1991	15	-16.07	-14.38	-12.55	-11.93	-3.92	-2.551	-1.285	-1.312	0.846
1991	16	-21.04	-15.36	-13.75	-13.12	-3.994	-2.68	-1.351	-1.263	0.795
1991	17	-9.94	-9.73	-10.39	-10.5	-4.008	-2.703	-1.313	-1.185	0.808
1991	18	-8.13	-8.71	-8.3	-8.26	-3.991	-2.697	-1.253	-1.107	0.841
1991	19	-10.17	-11.03	-10.14	-9.83	-4.045	-2.778	-1.299	-1.085	0.818
1991	20	-5.357	-7.32	-8.2	-8.41	-4.073	-2.83	-1.303	-1.019	0.797
1991	21	-5.845	-6.755	-6.667	-6.725	-4.047	-2.841	-1.284	-0.97	0.808
1991	22	-14.67	-13.09	-10.9	-10.1	-4.083	-2.91	-1.338	-0.987	0.789
1991	23	-15.8	-14.74	-12.88	-12.06	-4.136	-3.02	-1.427	-1.011	0.734
1991	24	-16.21	-15.55	-13.46	-12.65	-4.133	-3.046	-1.433	-0.991	0.725
1991	25	-9.12	-10.16	-10.28	-10.31	-4.101	-3.041	-1.412	-0.914	0.74
1991	26	-4.025	-5.221	-6.196	-6.611	-4.094	-3.024	-1.375	-0.882	0.742
1991	27	-16.35	-17.9	-14.28	-12.5	-4.174	-3.091	-1.459	-0.946	0.731
1991	28	-21.77	-21.34	-17.9	-16.42	-4.299	-3.284	-1.635	-1.059	0.606
1991	29	-21.79	-20.58	-17.4	-16.04	-4.326	-3.317	-1.66	-1.06	0.598
1991	30	-31.57	-28.25	-22.49	-20.03	-4.605	-3.532	-1.855	-1.26	0.425
1991	31	-31.31	-26.62	-22.69	-20.92	-4.67	-3.636	-1.946	-1.28	0.369
1991	32	-22.99	-17.65	-16.64	-16.14	-4.461	-3.411	-1.717	-1.028	0.578
1991	33	-17.79	-14.34	-13.95	-13.78	-4.476	-3.361	-1.632	-0.961	0.634
1991	34	-11.48	-12.78	-12.22	-12.05	-4.551	-3.357	-1.593	-0.941	0.668
1991	35	-7.4	-9.08	-9.46	-9.67	-4.618	-3.361	-1.561	-0.923	0.684
1991	36	-9.74	-10.44	-9.69	-9.47	-4.687	-3.416	-1.572	-0.961	0.678

1991	37	-11.45	-11.58	-10.87	-10.58	-4.769	-3.512	-1.635	-1.011	0.652
1991	38	-15.96	-16.55	-13.7	-12.56	-4.825	-3.573	-1.666	-1.058	0.633
1991	39	-23.19	-23.79	-18.99	-16.86	-4.975	-3.713	-1.777	-1.187	0.557
1991	40	-30.02	-28.52	-23.2	-20.94	-5.237	-4.069	-2.098	-1.449	0.309
1991	41	-18.05	-18.02	-17.12	-16.67	-5.062	-3.891	-1.898	-1.214	0.486
1991	42	-7.55	-9.27	-10.39	-10.93	-4.948	-3.702	-1.688	-1.019	0.643
1991	43	-7.82	-8.93	-8.98	-9.12	-5.008	-3.73	-1.697	-1.035	0.633
1991	44	-10.52	-10.6	-10.14	-9.99	-5.096	-3.801	-1.749	-1.058	0.617
1991	45	-8.45	-8.73	-8.89	-8.98	-5.132	-3.838	-1.755	-1.039	0.617
1991	46	-8.26	-8.27	-8.18	-8.19	-5.144	-3.877	-1.766	-1.034	0.611
1991	47	-15.49	-12.44	-11	-10.25	-5.163	-3.943	-1.821	-1.069	0.585
1991	48	-19.33	-16.81	-14.16	-12.9	-5.181	-3.991	-1.869	-1.09	0.579
1991	49	-19.3	-17.22	-14.94	-13.99	-5.226	-4.093	-1.959	-1.136	0.527
1991	50	-24.94	-21.81	-18.36	-16.85	-5.267	-4.126	-2.011	-1.174	0.513
1991	51	-33.01	-22.6	-19.54	-18.2	-5.54	-4.454	-2.336	-1.452	0.253
1991	52	-33.34	-22.98	-20.12	-18.87	-5.62	-4.582	-2.461	-1.508	0.172
1991	53	-22.33	-18.07	-16.85	-16.29	-5.418	-4.338	-2.231	-1.252	0.381
1991	54	-16.36	-15.67	-14.84	-14.5	-5.409	-4.226	-2.11	-1.133	0.478
1991	55	-9.32	-11.25	-10.93	-11.09	-5.399	-4.16	-2.021	-1.042	0.541
1991	56	-9.53	-10.28	-10.55	-10.72	-5.478	-4.18	-2.012	-1.02	0.55
1991	57	-4.183	-6.563	-7.53	-8.05	-5.489	-4.184	-1.993	-0.984	0.557
1991	58	-11.02	-13.22	-11.15	-10.26	-5.567	-4.261	-2.065	-1.039	0.536
1991	59	-29.86	-29.96	-22.77	-19.88	-5.931	-4.633	-2.408	-1.35	0.292
1991	60	-31.27	-30.91	-24.56	-22.01	-6.087	-4.857	-2.616	-1.481	0.139
1991	61	-27.9	-30	-24.14	-21.88	-6.083	-4.889	-2.643	-1.471	0.136
1991	62	-26.29	-25.36	-21.89	-20.48	-6.022	-4.815	-2.558	-1.363	0.215
1991	63	-14.93	-15.85	-15.38	-15.2	-5.805	-4.552	-2.295	-1.099	0.44
1991	64	-30.13	-29.95	-23.15	-20.76	-6.152	-4.845	-2.579	-1.381	0.218
1991	65	-20.49	-19.48	-18.19	-17.62	-6.094	-4.778	-2.49	-1.23	0.312
1991	66	-8.85	-10.69	-11.35	-11.79	-5.977	-4.596	-2.267	-1.033	0.478
1991	67	-9.36	-10.59	-10.32	-10.37	-6.013	-4.606	-2.259	-1.027	0.499
1991	68	-20.1	-21.33	-16.72	-15.19	-6.152	-4.735	-2.37	-1.13	0.442
1991	69	-30.5	-29.89	-22.87	-20.5	-6.49	-5.085	-2.684	-1.403	0.201
1991	70	-27.97	-26.98	-22.2	-20.48	-6.543	-5.188	-2.772	-1.431	0.151
1991	71	-18.13	-19.05	-17.66	-17.02	-6.313	-4.966	-2.534	-1.184	0.367
1991	72	-15.63	-15.12	-14.74	-14.65	-6.289	-4.896	-2.447	-1.11	0.429
1991	73	-14.91	-14.86	-13.68	-13.24	-6.296	-4.919	-2.453	-1.113	0.431
1991	74	-15.69	-15.33	-13.75	-13.28	-6.371	-4.982	-2.501	-1.137	0.412
1991	75	-11.52	-12.06	-11.97	-11.99	-6.409	-5	-2.504	-1.114	0.423
1991	76	-6.391	-7.28	-7.94	-8.46	-6.379	-4.978	-2.461	-1.058	0.453
1991	77	-8.93	-8.92	-8.44	-8.5	-6.372	-5.005	-2.478	-1.079	0.451
1991	78	-11.17	-10.23	-9.8	-9.67	-6.382	-5.057	-2.527	-1.091	0.436
1991	79	-12.41	-9.64	-9.29	-9.2	-6.351	-5.074	-2.551	-1.095	0.435
1991	80	-13.75	-9.83	-9.37	-9.24	-6.3	-5.088	-2.569	-1.085	0.442
1991	81	-20.65	-11.56	-10.51	-10.17	-6.29	-5.112	-2.619	-1.119	0.418
1991	82	-22.13	-13.82	-12.12	-11.53	-6.278	-5.146	-2.671	-1.137	0.401
1991	83	-13.66	-12.18	-11.36	-11.09	-6.23	-5.15	-2.704	-1.131	0.388
1991	84	-15.44	-11.74	-11.01	-10.79	-6.189	-5.126	-2.714	-1.111	0.394
1991	85	-6.028	-6.508	-6.727	-7.1	-6.081	-5.025	-2.645	-1.038	0.422
1991	86	-11.15	-9.05	-8.61	-8.49	-6.061	-5.028	-2.68	-1.046	0.426
1991	87	-7.66	-6.677	-6.989	-7.17	-6.013	-5.004	-2.692	-1.038	0.412

1991	88	-6.507	-6.301	-6.366	-6.537	-5.941	-4.966	-2.676	-1.018	0.429
1991	89	-10.17	-11.61	-8.83	-8.19	-5.905	-4.945	-2.689	-1.01	0.448
1991	90	-15.54	-14.19	-11.87	-11.02	-5.922	-4.992	-2.752	-1.026	0.427
1991	91	-12.06	-9.51	-8.85	-8.67	-5.832	-4.959	-2.77	-1.024	0.407
1991	92	-16.92	-11.06	-9.86	-9.41	-5.803	-4.95	-2.792	-1.032	0.411
1991	93	-17.35	-11.69	-10.3	-9.78	-5.774	-4.934	-2.81	-1.026	0.409
1991	94	-13.45	-10.41	-9.57	-9.33	-5.724	-4.887	-2.806	-0.992	0.414
1991	95	-12.02	-9.99	-9.14	-8.98	-5.692	-4.855	-2.81	-0.975	0.421
1991	96	-12.5	-9.65	-8.67	-8.47	-5.664	-4.825	[illegible]	-0.968	0.425
1991	97	-13.92	-10.45	-9.47	-9.1	-5.65	-4.811	-2.823	-0.961	0.42
1991	98	-11.57	-9.46	-9.01	-8.82	-5.625	-4.809	-2.843	-0.958	0.404
1991	99	-9.35	-7.47	-7.41	-7.49	-5.567	-4.765	-2.819	-0.919	0.413
1991	100	-15.14	-8.75	-8.13	-7.91	-5.57	-4.762	-2.847	-0.933	0.428
1991	101	-8.57	-7.77	-7.57	-7.56	-5.54	-4.747	-2.858	-0.927	0.402
1991	102	-2.995	-4.934	-5.587	-5.915	-5.461	-4.713	-2.872	-0.934	0.38
1991	103	-3.068	-3.375	-3.675	-3.749	-5.421	-4.677	-2.867	-0.929	0.38
1991	104	-4.905	-3.467	-3.32	-3.497	-5.402	-4.706	-2.895	-0.945	0.366
1991	105	-5.99	-4.733	-4.663	-4.811	-5.39	-4.714	-2.926	-0.959	0.349
1991	106	-6.485	-4.855	-4.652	-4.821	-5.349	-4.709	-2.943	-0.959	0.34
1991	107	-4.048	-4.164	-4.183	-4.349	-5.292	-4.667	-2.924	-0.936	0.35
1991	108	-1.936	-2.748	-2.787	-2.958	-5.21	-4.612	-2.896	-0.911	0.363
1991	109	0.122	-0.569	-0.898	-1.065	[illegible]	-4.523	-2.818	-0.871	0.381
1991	110	-4.525	-2.325	-1.38	-1.358	-5.076	-4.543	-2.898	-0.913	0.349
1991	111	-4.266	-1.832	-1.994	-1.973	-5.035	-4.544	-2.931	-0.918	0.34
1991	112	-4.58	[illegible]	-1.92	-1.881	-4.943	-4.504	-2.923	-0.907	0.338
1991	113	-4.069	-1.749	[illegible]	[illegible]	-4.841	-4.461	-2.932	-0.904	0.331
1991	114	-4.309	-2.23	[illegible]	[illegible]	-4.75	-4.422	-2.939	-0.897	0.327
1991	115	-4.702	-2.23	[illegible]	[illegible]	-4.649	-4.372	-2.943	-0.891	0.319
1991	116	-4.855	-2.247	[illegible]	[illegible]	-4.533	-4.314	-2.931	-0.877	0.314
1991	117	-0.988	-0.048	[illegible]	-0.763	-4.374	-4.205	-2.895	-0.815	0.329
1991	118	-0.526	1.893	0.846	-0.548	-4.232	[illegible]	-2.81	-0.731	0.395
1991	119	-1.639	0.934	1.192	-0.46	-4.086	-3.967	-2.752	-0.672	0.454
1991	120	-3.785	-1.284	1.123	-0.348	-3.949	-3.828	-2.672	-0.571	0.544
1991	121	-1.982	0.433	1.457	-0.108	-3.775	-3.694	-2.615	-0.507	0.573
1991	122	-1.945	0.727	2.509	0.341	-3.581	-3.609	-2.596	-0.457	0.542
1991	123	-1.354	1.077	3.086	0.574	-3.447	-3.504	-2.549	-0.358	0.568
1991	124	0.96	2.944	4.596	1.344	-3.303	-3.395	-2.491	-0.291	0.585
1991	125	1.419	3.103	5.065	1.845	-3.208	-3.328	-2.484	-0.279	0.586
1991	126	1.24	2.724	3.502	1.373	-3.143	-3.286	-2.516	-0.302	0.559
1991	127	2.598	5.137	6.365	2.642	-3.038	-3.203	-2.455	-0.27	0.575
1991	128	2.933	5.122	6.398	2.941	-3.001	-3.114	-2.413	-0.22	0.626
1991	129	2.175	4.652	5.655	2.748	-2.901	-3.076	-2.418	-0.243	0.599
1991	130	0.461	1.118	1.567	0.841	-2.968	-3.061	-2.479	-0.258	0.596
1991	131	0.429	2.854	3.001	1.855	-2.907	-3.046	-2.491	-0.275	0.547
1991	132	1.978	5.151	5.563	3.868	-2.693	-2.901	-2.395	-0.236	0.559
1991	133	0.41	1.874	1.831	1.178	-2.821	-2.955	-2.476	-0.284	0.565
1991	134	2.599	4.418	3.734	2.557	-2.663	-2.831	-2.387	-0.217	0.607
1991	135	3.396	6.072	5.635	3.95	-2.65	-2.867		-2.419	
1991	136	4.235	9.43	8.33	5.029	-2.64	-2.798		-2.375	
1991	137	4.581	7.54	6.737	4.328	-2.546	-2.71		-2.32	
1991	138	4.85	8.44	7.63	4.675	-2.515	-2.667		-2.302	

1991	139	3.753	5.493	4.41	2.772	-2.423	-2.662	-2.355
1991	140	3.593	5.337	3.856	2.432	-2.433	-2.633	-2.332
1991	141	3.507	6.253	4.381	2.468	-2.358	-2.624	-2.351
1991	142	2.645	4.803	3.735	2.185	-2.384	-2.55	-2.304
1991	143	5.208	8.72	6.871	4.402	-2.256	-2.483	-2.25
1991	144	4.957	6.226	4.718	3.063	-2.209	-2.446	-2.255
1991	145	4.515	4.959	3.712	2.684	-2.191	-2.398	-2.215
1991	146	3.523	4.492	3.022	2.379	-2.194	-2.397	-2.245
1991	147	7.09	8.41	5.742	3.915	-2.084	-2.312	-2.158
1991	148	7.09	8.35	6.386	4.332	-2.039	-2.277	-2.158
1991	149	9.21	12.93	10.93	7.24	-2	-2.238	-2.109
1991	150	6.669	8.36	7.71	5.99	-2.006	-2.168	-2.065
1991	151	2.484	2.867	1.849	1.944	-2.058	-2.261	-2.196
1991	152	1.384	1.501	0.866	0.775	-2.077	-2.296	-2.236
1991	153	4.228	6.388	3.887	2.929	-1.956	-2.186	-2.132
1991	154	6.69	8.41	6.913	5.251	-1.894	-2.055	-1.997
1991	155	8.1	10.59	9.24	6.13	-1.821	-2.032	-1.979
1991	156	9.41	11.42	10.02	6.695	-1.797	-1.986	-1.929
1991	157	8.36	9.63	8.52	6.151	-1.79	-1.967	-1.954
1991	158	4.73	4.306	4.374	4.115	-1.793	-2.033	-2.051
1991	159	2.722	3.276	3.119	2.708	-1.832	-2.03	-2.051
1991	160	5.149	5.886	3.419	2.72	-1.747	-1.965	-1.974
1991	161	5.639	7.08	5.698	4.636	-1.713	-1.879	-1.913
1991	162	6.489	8.11	5.465	4.432	-1.655	-1.913	-1.944
1991	163	8.32	11.19	9.27	6.486	-1.668	-1.845	-1.858
1991	164	9.57	11.34	11.13	7.93	-1.611	-1.78	-1.801
1991	165	9.68	12.06	12.14	8.75	-1.553	-1.747	-1.779
1991	166	9.72	10.27	9.13	7.41	-1.573	-1.745	-1.784
1991	167	10.63	12.34	10.21	8.21	-1.521	-1.653	-1.694
1991	168	11.97	14.13	13.41	9.74	-1.488	-1.654	-1.703
1991	169	13	14.96	13.97	10.56	-1.453	-1.603	-1.67
1991	170	12.97	14.87	14.44	11.03	-1.441	-1.578	-1.64
1991	171	13.13	15.52	16.03	12.31	-1.417	-1.576	-1.637
1991	172	12.75	14.68	13.65	12.19	-1.398	-1.565	-1.637
1991	173	12.08	13.86	13.33	11.07	-1.378	-1.545	-1.624
1991	174	14.72	17.55	18.18	13.86	-1.313	-1.505	-1.565
1991	175	14.17	14.35	14.02	12.14	-1.329	-1.448	-1.544
1991	176	11.52	13.1	12.43	11.49	-1.293	-1.455	-1.548
1991	177	12.13	12.24	11.98	10.96	-1.325	-1.443	-1.546
1991	178	11.61	12.04	11.16	10.17	-1.318	-1.445	-1.542
1991	179	10.99	13.19	11.77	10.46	-1.306	-1.459	-1.58
1991	180	12.95	18.29	17.21	12.65	-1.236	-1.433	-1.533
1991	181	15.01	18.62	17.88	13.54	-1.184	-1.349	-1.455
1991	182	14.38	15.61	15.02	12.49	-1.197	-1.364	-1.5
1991	183	13.15	15.64	16.7	13.1	-1.199	-1.384	-1.513
1991	184	11.78	12.41	13.27	11.89	-1.176	-1.309	-1.194
1991	185	10.23	10.62	9.84	9.42	-1.167	-1.359	-1.513
1991	186	8.38	8.84	8.69	8.38	-1.229	-1.379	-1.529
1991	187	8.83	10.07	8.3	7.02	-1.25	-1.428	-1.55
1991	188	13.9	15.48	13.18	10.07	-1.118	-1.312	-1.458
1991	189	10	10.32	9.9	8.3	-1.152	-1.309	-1.466

1991	190	8.49	10.72	9.38	8.25	-1.144	-1.351		-1.512	
1991	191	5.607	6.131	6.818	6.449	-1.175	-1.342		-1.527	
1991	192	8.69	10.93	10.04	8.89	-1.151	-1.334		-1.492	
1991	193	9.82	10.74	10.64	9.65	-1.073	-1.253		-1.427	
1991	194	9.31	9.35	9.43	9.0'	-0.907	-1.114		-1.415	
1991	195	10.59	11.08	10.67	9.8-	-1.056	-1.222		-1.404	
1991	196	10.75	10.97	10.48	9.84	-1.041	-1.203		-1.377	
1991	197	10.35	10.92	9.91	9.33	-1.078	-1.212		-1.385	
1991	198	9.3	10.16	8.14	7.62	-1.052	-1.225		-1.404	
1991	199	6.345	6.67	6.689	6.299	-0.953	-1.182		-1.453	
1991	200	6.623	7.45	7.34	6.875	-0.809	-1.119		-1.442	
1991	201	8.5	10.18	10.13	9.32	-0.99	-1.169		-1.374	
1991	202	10.08	11.34	10.66	9.77	-0.985	-1.189		-1.384	
1991	203	12.22	12.8	9.75	8.76	-0.967	-1.187		-1.366	
1991	204	13.76	14.5	12.34	10.04	-0.911	-1.139		-1.338	
1991	205	14.42	15.74	13.9	10.93	-0.941	-1.139		-1.326	
1991	206	13.17	14.15	13.17	11.71	-0.868	-1.051		-1.276	
1991	207	10.4	11.45	11.36	10.72	-0.897	-1.072		-1.283	
1991	208	6.94	6.955	7.46	7.64	-0.957	-1.145		-1.366	
1991	209	7.37	7.09	7.4	7.16	-0.955	-1.145		-1.353	
1991	210	9.77	11.02	9.98	9.09	-0.874	-1.089		-1.275	
1991	211	9.31	9.84	9.31	8.42	-0.884	-1.078		-1.287	
1991	212	9.18	10.21	9.98	8.63	-0.874	-1.039		-1.249	
1991	213	7.6	8.04	8.32	7.26	-0.892	-1.049		-1.263	
1991	214	8.64	8.48	8.33	7.57	-0.873	-1.068		-1.282	
1991	215	8.55	8.2	8.07	7.49	-0.881	-1.038		-1.254	
1991	216	5.7	4.636	4.14	4.545	-0.957	-1.125		-1.347	
1991	217	5.357	5.593	5.364	4.714	-0.937	-1.115		-1.331	
1991	218	7	7.34	7.31	5.874	-0.846	-1.054		-1.27	
1991	219	13.32	13.68	14.13	11.2	-0.81	-0.767		-1.057	
1991	220	10.96	10.9	10.56	9.41	-0.741	-0.91	-1.155	10.83	
1991	221	9.66	9.08	8.69	8.17	-0.764	-0.95	-1.185	10.9	2.791
1991	222	9.15	8.54	7.67	7.34	-0.764	-0.966	-1.199	10.93	2.812
1991	223	9.39	9.58	8.21	7.43	-0.744	-0.944	-1.175	11.12	2.873
1991	224	10.03	10.52	10	8.68	-0.721	-0.929	-1.158	11.74	2.931
1991	225	13.89	15	14.01	11.9	-0.636	-0.91	-1.125	13.59	2.921
1991	226	12.48	12.42	11.96	10.49	-0.67	-0.871	-1.107	13.78	3.044
1991	227	12.14	11.45	10.62	9.27	-0.658	-0.934	-1.162	13.13	3.015
1991	228	13.33	13.47	12.34	10.18	-0.636	-0.881	-1.118	13.89	3.082
1991	229	13.05	13.18	12.44	10.58	-0.665	-0.875	-1.105	13.57	3.144
1991	230	9.78	8.8	8.37	8.04	-0.675	-0.862	-1.104	12.55	3.218
1991	231	5.119	6.556	6.449	5.928	-0.793	-0.963	-1.21	10.4	3.162
1991	232	4.062	6.107	6.393	6.021	-0.792	-1.019	-1.256	9.78	3.09
1991	233	4.75	6.463	6.362	5.176	-0.756	-1.048	-1.279	8.68	3.122
1991	234	5.727	6.133	5.629	4.701	-0.73	-0.981	-1.221	8.23	3.212
1991	235	5.805	6.294	5.498	4.511	-0.736	-0.96	-1.204	7.91	3.263
1991	236	3.251	3.002	3.562	3.627	-0.838	-1.008	-1.26	7.82	3.296
1991	237	-3.406	-0.421	0.169	0.788	-1.065	-1.199	-1.452	4.592	3.143
1991	238	-3.832	-0.883	-0.411	0.007	-1.091	-1.228	-1.478	2.815	3.156

MICROCLIMATE DATA: DALE CREEK 2

TEMPERATURE (°C)

Year	Julian Day	150	Surface	PALSA (cm) -2.5	PALSA (cm) -5	PALSA (cm) -150	PALSA (cm) -215	FEN (cm) -5	FEN (cm) -150
1990	202	14.72	12.55	13.02	10.47	-2.06	-2.47	12.61	1.24
1990	203	13.08	12.51	12.31	9.28	-1.78	-2.16	12.71	1.57
1990	204	12.46	10.96	11.65	9.00	-1.57	-1.93	12.13	1.77
1990	205	10.17	8.97	9.37	7.94	-1.44	-1.80	10.95	1.86
1990	206	7.33	6.98	6.87	6.33	-1.39	-1.75	9.65	1.87
1990	207	7.19	6.73	6.64	6.36	-1.35	-1.72	9.41	1.94
1990	208	10.20	8.96	8.49	7.73	-1.35	-1.68	10.90	2.03
1990	209	11.28	9.21	9.66	8.88	-1.25	-1.63	10.79	2.04
1990	210	8.34	8.22	8.03	7.57	-1.27	-1.60	9.52	2.11
1990	211	7.17	6.30	6.26	6.31	-1.21	-1.59	9.47	2.16
1990	212	5.80	6.84	6.31	5.92	-1.25	-1.58	8.58	2.21
1990	213	6.48	6.41	6.34	6.30	-1.20	-1.51	9.66	2.27
1990	214	8.06	6.53	6.47	6.36	-1.11	-1.42	9.23	2.38
1990	215	8.37	6.47	6.48	6.44	-1.15	-1.40	8.17	2.19
1990	216	11.65	9.55	8.90	8.02	-1.12	-1.38	8.94	2.36
1990	217	8.72	7.70	7.40	7.05	-1.08	-1.36	9.62	2.55
1990	218	6.58	7.10	7.04	6.88	-1.03	-1.36	8.83	2.56
1990	219	6.97	7.11	6.80	6.36	-1.05	-1.36	8.31	2.64
1990	220	8.20	7.95	7.69	7.19	-1.01	-1.32	8.99	2.70
1990	221	12.13	10.05	10.10	9.39	-1.00	-1.31	10.10	2.70
1990	222	15.45	12.03	11.89	10.88	-0.98	-1.28	12.43	2.80
1990	223	13.18	11.76	11.31	10.81	-0.97	-1.25	13.10	2.81
1990	224	10.76	10.50	9.87	9.57	-0.97	-1.25	11.55	2.85
1990	225	10.81	10.31	9.80	9.36	-0.97	-1.26	11.00	2.80
1990	226	10.73	9.07	8.93	8.53	-0.96	-1.25	11.16	2.79
1990	227	10.92	9.45	9.34	8.83	-0.94	-1.23	11.18	2.77
1990	228	10.97	8.78	9.16	8.65	-0.94	-1.23	10.67	2.71
1990	229	8.86	8.07	8.07	7.78	-0.96	-1.25	9.96	2.74
1990	230	8.86	8.07	8.07	7.79	-0.96	-1.24	9.96	2.74
1990	231	7.88	6.60	6.66	6.55	-0.97	-1.27	8.26	2.73
1990	232	6.89	6.04	6.03	6.05	-0.97	-1.27	8.22	2.75
1990	233	6.21	5.41	5.53	5.47	-0.98	-1.27	7.91	2.83
1990	234	4.33	4.68	4.55	4.62	-0.97	-1.25	8.60	2.88
1990	235	6.49	4.31	4.18	4.39	-0.94	-1.22	7.90	2.91
1990	236	6.55	4.08	3.92	4.00	-0.94	-1.22	7.19	2.90
1990	237	5.44	3.19	3.58	3.43	-0.95	-1.23	6.72	2.86
1990	238	6.47	5.04	5.30	4.73	-0.92	-1.22	7.33	2.83
1990	239	7.88	6.63	6.79	6.23	-0.92	-1.21	7.76	2.87
1990	240	5.31	5.12	5.14	5.06	-0.94	-1.22	6.56	2.87
1990	241	1.13	2.54	2.35	2.68	-0.99	-1.28	4.54	2.82
1990	242	0.78	1.87	2.03	2.20	-0.98	-1.25	4.18	2.87

1990	243	0.60	0.99	1.18	1.32	-0.98	-1.26	3.48	2.93
1990	244	1.21	0.65	0.72	0.86	-1.00	-1.27	2.40	2.80
1990	245	-0.35	0.20	0.29	0.44	-1.01	-1.29	2.34	2.78
1990	246	1.33	0.48	0.46	0.47	-0.99	-1.27	2.60	2.80
1990	247	2.85	3.52	3.21	2.81	-0.95	-1.21	4.13	2.90
1990	248	3.98	2.87	3.09	2.76	-0.95	-1.21	4.45	2.92
1990	249	4.84	3.72	3.79	3.59	-0.92	-1.19	4.69	2.97
1990	250	0.11	0.01	-0.22	0.24	-1.00	-1.26	4.10	2.89
1990	251	0.21	-0.22	-0.42	0.07	-0.99	-1.25	2.81	2.92
1990	252	0.89	-0.16	-0.18	-0.12	-0.97	-1.23	2.42	2.94
1990	253	-0.75	-0.05	-0.03	0.08	-0.97	-1.23	2.01	2.91
1990	254	-1.40	-0.11	-0.07	-0.01	-0.97	-1.23	1.71	2.91
1990	255	2.22	-0.16	-0.15	-0.10	-0.95	-1.21	1.56	2.92
1990	256	4.74	1.98	2.24	1.64	-0.89	-1.14	2.81	3.05
1990	257	4.28	2.23	2.55	2.22	-0.90	-1.15	3.42	3.05
1990	258	5.45	4.17	4.02	3.72	-0.86	-1.11	4.05	3.10
1990	259	0.19	1.24	1.21	1.31	-0.92	-1.18	3.26	2.99
1990	260	-0.30	0.86	0.96	0.99	-0.89	-1.15	3.51	3.14
1990	261	-0.60	-0.33	-0.10	0.13	-0.95	-1.20	3.10	2.98
1990	262	1.71	0.68	0.79	0.66	-0.91	-1.16	3.24	3.01
1990	263	3.54	1.99	2.16	1.84	-0.87	-1.11	3.83	3.07
1990	264	5.17	3.54	3.69	3.54	-0.85	-1.10	4.02	3.07
1990	265	4.18	3.06	3.02	2.75	-0.87	-1.11	3.56	3.04
1990	266	7.40	5.13	5.19	4.96	-0.80	-1.05	4.59	3.13
1990	267	3.34	2.15	2.11	2.23	-0.86	-1.10	4.04	3.04
1990	268	1.15	1.43	1.37	1.62	-0.89	-1.14	3.65	2.95
1990	269	-2.89	-0.32	-0.23	0.32	-0.92	-1.18	2.64	2.94
1990	270	-3.74	-2.20	-1.55	-0.71	-0.95	-1.19	2.05	2.95
1990	271	-0.15	-0.51	-0.41	-0.33	-0.90	-1.14	1.62	2.93
1990	272	0.63	-0.18	-0.17	-0.18	-0.89	-1.14	1.23	2.93
1990	273	0.29	-0.19	-0.17	-0.18	-0.90	-1.13	.84	2.92
1990	274	-2.29	-0.22	-0.20	-0.20	-0.90	-1.13	.97	2.94
1990	275	-2.87	-0.26	-0.22	-0.22	-0.90	-1.14	.90	2.90
1990	276	-4.41	-0.31	-0.24	-0.23	-0.89	-1.13	.81	2.87
1990	277	-7.29	-0.44	-0.36	-0.28	-0.92	-1.15	.73	2.84
1990	278	-11.91	-0.96	-0.70	-0.46	-0.89	-1.13	.67	2.90
1990	279	-13.37	-1.63	-1.24	-0.88	-0.87	-1.12	.38	2.89
1990	280	-8.87	-1.67	-1.32	-1.00	-0.92	-1.15	.13	2.81
1990	281	-1.94	-0.81	-0.69	-0.59	-0.91	-1.14	.24	2.79
1990	282	-4.98	-0.50	-0.45	-0.39	-0.88	-1.12	.37	2.80
1990	283	-12.26	-1.09	-0.86	-0.66	-0.88	-1.12	.41	2.87
1990	284	-9.41	-1.40	-1.15	-0.91	-0.92	-1.15	.36	2.78
1990	285	-7.87	-1.15	-0.96	-0.78	-0.92	-1.15	.33	2.77
1990	286	-6.21	-1.00	-0.84	-0.69	-0.91	-1.13	.33	2.77
1990	287	-7.05	-0.88	-0.74	-0.62	-0.90	-1.12	.33	2.77
1990	288	-17.73	-1.69	-1.36	-1.04	-0.85	-1.09	.27	2.78
1990	289	-20.37	-2.60	-2.12	-1.65	-0.87	-1.11	.10	2.75
1990	290	-13.22	-2.16	-1.81	-1.48	-0.92	-1.15	-.03	2.70
1990	291	-14.89	-1.88	-1.58	-1.29	-0.89	-1.11	-.04	2.73

1990	292	-20.64	-2.75	-2.27	-1.81	-0.84	-1.07	-.09	2.75
1990	293	-10.57	-2.36	-2.02	-1.70	-0.93	-1.15	-.14	2.66
1990	294	-5.36	-1.43	-1.25	-1.09	-0.92	-1.12	-.11	2.67
1990	295	-8.31	-1.15	-1.02	-0.88	-0.90	-1.11	-.10	2.67
1990	296	-11.93	-1.81	-1.53	-1.26	-0.88	-1.10	-.12	2.69
1990	297	-5.11	-1.35	-1.19	-1.04	-0.90	-1.11	-.12	2.63
1990	298	-6.38	-1.38	-1.22	-1.03	-0.90	-1.11	-.13	2.64
1990	299	-10.82	-1.66	-1.43	-1.22	-0.89	-1.11	-.13	2.63
1990	300	-13.36	-1.92	-1.66	-1.41	-0.92	-1.14	-.16	2.59
1990	301	-10.74	-1.45	-1.29	-1.13	-0.91	-1.13	-.13	2.58
1990	302	-7.35	-1.04	-0.95	-0.85	-0.87	-1.08	-.11	2.58
1990	303	-12.15	-1.03	-0.93	-0.84	-0.89	-1.07	-.10	2.58
1990	304	-26.46	-2.13	-1.79	-1.47	-0.89	-1.11	-.12	2.61
1990	305	-29.09	-2.98	-2.53	-2.11	-0.90	-1.12	-.14	2.60
1990	306	-23.21	-3.11	-2.68	-2.28	-0.91	-1.13	-.18	2.57
1990	307	-19.10	-2.74	-2.44	-2.06	-0.92	-1.15	-.23	2.49
1990	308	-15.77	-3.88	-3.42	-2.82	-0.96	-1.21	-.29	2.45
1990	309	-8.51	-3.66	-3.24	-2.74	-0.90	-1.12	-.26	2.48
1990	310	-12.24	-2.92	-2.58	-2.23	-0.86	-1.08	-.22	2.55
1990	311	-15.06	-2.56	-2.28	-1.99	-0.91	-1.13	-.25	2.47
1990	312	-21.50	-4.61	-4.01	-3.32	-0.82	-1.03	-.24	2.60
1990	313	-21.11	-4.53	-3.95	-3.42	-0.82	-1.03	-.28	2.51
1990	314	-29.22	-5.56	-4.81	-4.07	-0.74	-0.95	-.30	2.54
1990	315	-37.27	-7.91	-6.89	-5.88	-0.76	-0.99	-.36	2.54
1990	316	-31.37	-8.06	-7.11	-6.20	-0.80	-1.02	-.38	2.49
1990	317	-25.00	-6.37	-5.71	-4.96	-0.88	-1.09	-.35	2.49
1990	318	-26.70	-8.01	-7.20	-6.27	-0.85	-1.07	-.35	2.58
1990	319	-16.66	-6.15	-5.64	-5.13	-0.92	-1.13	-.43	2.34
1990	320	-12.63	-4.12	-3.78	-3.38	-0.89	-1.10	-.39	2.38
1990	321	-16.38	-6.15	-5.52	-4.85	-0.83	-1.04	-.40	2.44
1990	322	-15.73	-5.66	-5.18	-4.69	-0.85	-1.06	-.38	2.44
1990	323	-21.69	-7.15	-6.51	-5.83	-0.79	-1.00	-.39	2.46
1990	324	-25.46	-7.91	-7.21	-6.55	-0.80	-1.02	-.39	2.48
1990	325	-27.92	-9.57	-8.71	-7.95	-0.80	-1.02	-.44	2.45
1990	326	-30.28	-10.30	-9.46	-8.71	-0.82	-1.03	-.46	2.43
1990	327	-38.28	-12.34	-11.35	-10.45	-0.88	-1.10	-.59	2.35
1990	328	-39.65	-14.37	-13.33	-12.40	-0.98	-1.20	-.73	2.24
1990	329	-35.20	-14.78	-13.89	-13.09	-0.96	-1.18	-.71	2.22
1990	330	-25.00	-12.89	-12.36	-11.86	-0.94	-1.15	-.53	2.36
1990	331	-27.24	-13.21	-12.58	-11.96	-0.86	-1.07	-.53	2.37
1990	332	-24.71	-11.91	-11.46	-11.06	-0.90	-1.10	-.50	2.34
1990	333	-31.92	-12.13	-11.57	-11.07	-0.85	-1.05	-.52	2.33
1990	334	-33.02	-11.99	-11.46	-11.00	-0.85	-1.05	-.51	2.35
1990	335	-38.38	-12.88	-12.25	-11.67	-0.84	-1.04	-.57	2.31
1990	336	-42.72	-14.47	-13.72	-13.02	-0.89	-1.10	-.67	2.24
1990	337	-27.46	-13.51	-13.07	-12.63	-0.95	-1.15	-.71	2.12
1990	338	-26.46	-13.33	-12.85	-12.26	-0.89	-1.09	-.68	2.21
1990	339	-25.39	-14.72	-14.14	-13.56	-0.93	-1.13	-.75	2.13
1990	340	-8.37	-10.41	-10.34	-10.31	-0.89	-1.07	-.57	2.18

1990	341	-9.85	-9.01	-8.89	-8.78	-0.89	-1.07	-.55	2.16
1990	342	-14.78	-9.71	-9.35	-9.04	-0.83	-1.02	-.49	2.27
1990	343	-12.82	-9.47	-9.23	-9.01	-0.88	-1.06	-.53	2.14
1990	344	-14.54	-9.00	-8.74	-8.46	-0.86	-1.04	-.48	2.20
1990	345	-21.86	-11.06	-10.50	-10.00	-0.79	-0.99	-.47	2.25
1990	346	-14.51	-10.38	-10.11	-9.83	-0.87	-1.06	-.52	2.11
1990	347	-13.31	-9.01	-8.85	-8.70	-0.88	-1.07	-.51	2.08
1990	348	-17.65	-9.40	-9.08	-8.68	-0.84	-1.03	-.48	2.17
1990	349	-27.42	-12.54	-11.89	-11.20	-0.82	-1.01	-.54	2.21
1990	350	-30.55	-15.69	-14.88	-14.13	-0.99	-1.17	-.70	2.05
1990	351	-31.52	-17.94	-17.14	-16.11	-1.05	-1.20	-.70	2.06
1990	352	-31.39	-19.43	-18.72	-17.90	-1.11	-1.24	-.82	1.91
1990	353	-28.68	-18.23	-17.63	-17.11	-1.11	-1.17	-.80	1.90
1990	354	-15.65	-15.24	-15.06	-14.93	-1.17	-1.10	-.62	1.97
1990	355	-10.24	-11.50	-11.52	-11.56	-1.32	-1.06	-.51	2.05
1990	356	-10.63	-10.76	-10.67	-10.58	-1.54	-1.07	-.53	2.03
1990	357	-18.04	-9.97	-9.83	-9.72	-1.77	-1.11	-.51	2.03
1990	358	-30.18	-12.14	-11.68	-11.26	-1.93	-1.14	-.52	2.04
1990	359	-15.19	-11.80	-11.53	-11.22	-2.14	-1.24	-.54	1.99
1990	360	-19.44	-11.74	-11.39	-11.08	-2.24	-1.27	-.52	2.03
1990	361	-30.43	-16.49	-15.70	-14.80	44	-1.43	-.70	1.94
1990	362	-35.52	-18.68	-17.84	-17.09	76	-1.70	-.87	1.81
1990	363	-26.31	-17.22	-16.80	-16.37	.84	-1.72	-.72	1.85
1990	364	-29.66	-18.76	-18.11	-17.51	3.03	-1.84	-.77	1.89
1990	365	-29.76	-20.48	-19.80	-19.04	-3.25	-1.96	-.83	1.81
1991	1	-27.36	-20.39	-19.83	-19.15	-3.35	-1.97	-.83	1.78
1991	2	-31.07	-21.33	-20.63	-20.00	-3.65	-2.16	-1.01	1.66
1991	3	-21.06	-19.48	-19.18	-18.83	-3.76	-2.16	-.84	1.69
1991	4	-24.22	-19.30	-18.84	-18.33	-3.91	-2.20	-.80	1.79
1991	5	-26.82	-19.99	-19.48	-18.99	-4.20	-2.39	-.92	1.69
1991	6	-25.86	-19.95	-19.44	-18.90	-4.37	-2.47	-.85	1.75
1991	7	-33.91	-22.21	-21.45	-20.78	-4.70	-2.74	-1.08	1.58
1991	8	-21.62	-19.29	-19.07	-18.86	-4.75	-2.71	-.85	1.66
1991	9	-31.17	-20.84	-20.24	-19.70	-5.01	-2.91	-.99	1.63
1991	10	-24.37	-19.51	-19.20	-18.92	-5.16	-2.98	-.88	1.65
1991	11	-19.31	-17.44	-17.28	-17.14	-5.22	-2.99	-.76	1.74
1991	12	-16.26	-15.86	-15.77	-15.70	-5.34	-3.07	-.71	1.76
1991	13	-9.69	-13.89	-13.90	-13.96	-5.45	-3.14	-.63	1.81
1991	14	-9.61	-12.09	-12.12	-12.19	-5.55	-3.24	-.59	1.84
1991	15	-14.17	-12.83	-12.66	-12.49	-5.62	-3.35	-.60	1.84
1991	16	-14.96	-12.67	-12.56	-12.45	-5.69	-3.48	-.60	1.78
1991	17	-4.92	-10.29	-10.43	-10.65	-5.71	-3.56	-.53	1.81
1991	18	-8.79	-9.46	-9.47	-9.51	-5.70	-3.62	-.52	1.82
1991	19	-9.01	-10.39	-10.28	-10.18	-5.69	-3.69	-.54	1.80
1991	20	-3.99	-8.33	-8.50	-8.73	-5.69	-3.76	-.49	1.79
1991	21	-6.83	-7.80	-7.84	-7.90	-5.64	-3.81	-.49	1.78
1991	22	-10.26	-9.68	-9.49	-9.30	-5.57	-3.82	-.50	1.80
1991	23	-11.84	-10.34	-10.14	-9.94	-5.53	-3.87	-.50	1.78
1991	24	-14.34	-11.62	-11.31	-11.00	-5.47	-3.90	-.51	1.77

1991	25	-11.22	-11.11	-11.00	-10.89	-5.45	-3.93	-.51	1.71
1991	26	-5.86	-8.17	-8.34	-8.55	-5.46	-3.96	-.44	1.74
1991	27	-17.22	-11.09	-10.65	-10.23	-5.38	-3.93	-.49	1.79
1991	28	-18.27	-13.66	-13.17	-12.68	-5.43	-4.00	-.58	1.67
1991	29	-19.25	-13.80	-13.41	-13.02	-5.41	-4.01	-.55	1.70
1991	30	-26.29	-15.82	-15.24	-14.65	-5.47	-4.08	-.69	1.63
1991	31	-28.02	-17.34	-16.80	-16.30	-5.62	-4.23	-.80	1.47
1991	32	-22.26	-14.99	-14.84	-14.69	-5.56	-4.12	-.63	1.54
1991	33	-10.77	-13.43	-13.35	-13.29	-5.59	-4.10	-.56	1.60
1991	34	-11.67	-12.43	-12.36	-12.30	-5.66	-4.11	-.51	1.65
1991	35	-8.52	-10.71	-10.75	-10.84	-5.73	-4.13	-.47	1.68
1991	36	-9.67	-10.41	-10.38	-10.35	-5.79	-4.18	-.48	1.67
1991	37	-9.72	-10.26	-10.22	-10.22	-5.82	-4.22	-.49	1.66
1991	38	-16.13	-11.63	-11.34	-11.05	-5.82	-4.25	-.51	1.68
1991	39	-23.15	-14.63	-14.04	-13.42	-5.87	-4.36	-.61	1.65
1991	40	-25.58	-17.25	-16.62	-16.04	-6.02	-4.55	-.80	1.45
1991	41	-13.58	-14.74	-14.60	-14.51	-5.92	-4.43	-.60	1.55
1991	42	-5.55	-11.16	-11.31	-11.50	-5.91	-4.39	-.47	1.63
1991	43	-7.34	-9.77	-9.84	-9.93	-5.95	-4.40	-.45	1.65
1991	44	-9.29	-10.30	-10.23	-10.21	-6.01	-4.45	-.49	1.61
1991	45	-7.29	-9.45	-9.47	-9.53	-6.04	-4.49	-.48	1.59
1991	46	-7.81	-8.68	-8.72	-8.77	-6.04	-4.53	-.48	1.58
1991	47	-14.85	-8.70	-8.67	-8.65	-6.03	-4.56	-.48	1.57
1991	48	-13.27	-9.65	-9.48	-9.30	-5.98	-4.58	-.50	1.56
1991	49	-14.22	-10.03	-9.91	-9.75	-5.95	-4.60	-.50	1.55
1991	50	-25.66	-10.55	-10.32	-10.09	-5.92	-4.62	-.51	1.56
1991	51	-33.39	-12.12	-11.72	-11.35	-5.88	-4.63	-.52	1.57
1991	52	-28.07	-13.12	-12.74	-12.38	-5.89	-4.66	-.58	1.50
1991	53	-15.83	-12.08	-11.92	-11.78	-5.88	-4.66	-.55	1.47
1991	54	-13.55	-11.63	-11.49	-11.35	-5.86	-4.63	-.50	1.52
1991	55	-7.84	-9.77	-9.81	-9.89	-5.89	-4.63	-.46	1.53
1991	56	-6.38	-9.39	-9.41	-9.47	-5.91	-4.64	-.45	1.53
1991	57	-4.04	-7.92	-8.04	-8.18	-5.91	-4.66	-.43	1.52
1991	58	-11.51	-8.13	-8.05	-8.00	-5.88	-4.66	-.45	1.54
1991	59	-25.22	-12.28	-11.72	-11.19	-5.83	-4.63	-.53	1.55
1991	60	-24.99	-14.44	-13.88	-13.30	-5.88	-4.71	-.60	1.46
1991	61	-20.65	-15.55	-15.05	-14.46	-5.91	-4.79	-.60	1.42
1991	62	-18.85	-14.85	-14.53	-14.17	-5.92	-4.79	-.60	1.39
1991	63	-15.95	-13.68	-13.48	-13.27	-5.92	-4.74	-.54	1.44
1991	64	-26.96	-15.26	-14.75	-14.27	-5.99	-4.75	-.61	1.44
1991	65	-13.87	-13.57	-13.47	-13.36	-6.07	-4.78	-.55	1.41
1991	66	-9.75	-11.43	-11.46	-11.51	-6.11	-4.79	-.48	1.46
1991	67	-9.60	-10.33	-10.35	-10.40	-6.17	-4.81	-.46	1.47
1991	68	-21.57	-11.59	-11.34	-11.10	-6.17	-4.80	-.49	1.49
1991	69	-29.09	-14.19	-13.67	-13.21	-6.22	-4.87	-.59	1.43
1991	70	-23.16	-14.57	-14.20	-13.81	-6.28	-4.94	-.59	1.40
1991	71	-18.36	-14.75	-14.40	-14.03	-6.31	-4.98	-.59	1.38
1991	72	-12.56	-12.63	-12.59	-12.57	-6.33	-4.97	-.52	1.41
1991	73	-13.72	-11.62	-11.55	-11.49	-6.35	-4.98	-.49	1.45

1991	74	-12.75	-11.16	-11.07	-11.02	-6.40	-5.01	-.49	1.43
1991	75	-10.05	-10.53	-10.49	-10.50	-6.44	-5.04	-.50	1.42
1991	76	-6.52	-8.89	-8.98	-9.13	-6.46	-5.08	-.47	1.42
1991	77	-8.79	-8.56	-8.57	-8.60	-6.44	-5.09	-.46	1.43
1991	78	-10.93	-9.26	-9.16	-9.11	-6.43	-5.11	-.48	1.42
1991	79	-11.42	-8.55	-8.55	-8.56	-6.41	-5.15	-.49	1.39
1991	80	-13.73	-8.56	-8.51	-8.48	-6.38	-5.16	-.49	1.38
1991	81	-17.86	-8.96	-8.83	-8.73	-6.32	-5.15	-.48	1.40
1991	82	-15.83	-9.75	-9.56	-9.38	-6.28	-5.17	-.51	1.36
1991	83	-11.39	-9.54	-9.46	-9.37	-6.24	-5.15	-.49	1.38
1991	84	-11.69	-9.51	-9.38	-9.30	-6.19	-5.14	-.48	1.39
1991	85	-7.09	-7.45	-7.58	-7.71	-6.16	-5.13	-.45	1.37
1991	86	-10.68	-7.99	-7.93	-7.92	-6.13	-5.12	-.46	1.37
1991	87	-6.85	-7.17	-7.21	-7.28	-6.10	-5.12	-.46	1.35
1991	88	-6.78	-7.07	-7.07	-7.08	-6.06	-5.12	-.46	1.34
1991	89	-9.01	-7.34	-7.26	-7.20	-6.01	-5.08	-.45	1.36
1991	90	-12.80	-8.69	-8.45	-8.27	-5.93	-5.06	-.45	1.38
1991	91	-11.26	-7.62	-7.60	-7.57	-5.93	-5.10	-.47	1.33
1991	92	-15.22	-8.10	-7.96	-7.86	-5.88	-5.06	-.46	1.34
1991	93	-14.62	-8.41	-8.26	-8.14	-5.82	-5.02	-.45	1.35
1991	94	-11.45	-8.00	-7.91	-7.88	-5.79	-5.01	-.43	1.35
1991	95	-11.19	-8.04	-7.91	-7.83	-5.76	-4.99	-.43	1.35
1991	96	-11.54	-8.04	-7.90	-7.79	-5.75	-4.98	-.43	1.34
1991	97	-11.77	-8.50	-8.30	-8.13	-5.73	-4.98	-.45	1.32
1991	98	-9.72	-7.74	-7.66	-7.62	-5.71	-4.97	-.45	1.30
1991	99	-13.82	-7.19	-7.17	-7.17	-5.71	-4.98	-.47	1.27
1991	100	-16.27	-7.79	-7.69	-7.59	-5.71	-5.01	-.52	1.21
1991	101	-6.71	-6.79	-6.81	-6.88	-5.62	-4.90	-.42	1.30
1991	102	-3.43	-6.25	-6.28	-6.34	-5.57	-4.86	-.41	1.30
1991	103	-3.10	-5.72	-5.75	-5.86	-5.53	-4.84	-.38	1.32
1991	104	-3.86	-5.70	-5.72	-5.78	-5.51	-4.83	-.39	1.30
1991	105	-5.30	-5.76	-5.76	-5.79	-5.48	-4.82	-.41	1.28
1991	106	-5.39	-5.76	-5.75	-5.77	-5.43	-4.80	-.40	1.28
1991	107	-2.40	-5.54	-5.56	-5.62	-5.38	-4.78	-.38	1.29
1991	108	-0.81	-3.64	-3.61	-3.78	-5.34	-4.75	-.36	1.29
1991	109	-0.62	-1.94	-2.14	-2.49	-5.28	-4.71	-.32	1.32
1991	110	-4.11	-4.37	-4.36	-4.42	-5.23	-4.70	-.34	1.31
1991	111	-2.82	-4.30	-4.27	-4.43	-5.18	-4.67	-.35	1.30
1991	112	-3.10	-3.40	-3.37	-3.58	-5.14	-4.65	-.34	1.29
1991	113	-2.85	-2.77	-2.85	-2.96	-5.09	-4.63	-.34	1.29
1991	114	-2.65	-2.24	-2.37	-2.47	-5.04	-4.60	-.33	1.30
1991	115	-3.22	-1.85	-1.98	-2.07	-4.99	-4.57	-.32	1.29
1991	116	-3.70	-2.37	-2.43	-2.48	-4.94	-4.55	-.33	1.28
1991	117	-0.11	-2.57	-2.61	-2.70	-4.90	-4.52	-.31	1.28
1991	118	-1.18	-2.62	-2.66	-2.74	-4.84	-4.48	-.26	1.29
1991	119	-2.07	-2.59	-2.62	-2.70	-4.80	-4.45	-.27	1.28
1991	120	-2.24	-2.68	-2.69	-2.76	-4.76	-4.43	-.30	1.26
1991	121	-1.20	-2.33	-2.38	-2.47	-4.71	-4.41	-.28	1.25
1991	122	-0.85	-1.81	-1.91	-2.02	-4.63	-4.35	-.23	1.30

1991	123	0.22	-1.46	-1.52	-1.61	-4.57	-4.31	-.21	1.31
1991	124	2.65	-0.84	-0.89	-0.98	-4.49	-4.25	-.15	1.35
1991	125	2.91	-0.51	-0.52	-0.58	-4.39	-4.17	-.07	1.43
1991	126	1.31	-0.52	-0.49	-0.52	-4.32	-4.12	-.05	1.45
1991	127	3.51	-0.15	-0.13	-0.19	-4.21	-4.04	.09	1.54
1991	128	3.29	-0.09	-0.06	-0.10	-4.14	-4.01	.08	1.53
1991	129	2.32	-0.01	-0.08	-0.11	-4.07	-4.00	.05	1.48
1991	130	-0.52	-0.14	-0.16	-0.20	-4.05	-4.04	-.09	1.32
1991	131	-0.49	-0.12	-0.14	-0.18	-3.92	-3.96	-.04	1.39
1991	132	-0.56	0.88	-0.04	-0.06	-3.73	-3.81	.14	1.59
1991	133	-0.11	0.39	-0.08	-0.12	-3.70	-3.84	-.02	1.42
1991	134	2.05	1.35	0.21	-0.02	-3.58	-3.76	.04	1.44
1991	135	2.08	2.82	1.30	0.07	-3.43	-3.63	.18	1.59
1991	136	3.26	3.89	2.39	0.45	-3.32	-3.56	.21	1.62
1991	137	3.61	3.75	2.67	1.25	-3.25	-3.52	.17	1.57
1991	138	3.81	4.44	3.26	1.98	-3.18	-3.47	.16	1.54
1991	139	2.55	2.55	2.55	1.78	-3.10	-3.43	.10	1.48
1991	140	2.58	3.23	2.66	1.79	-3.04	-3.37	.11	1.48
1991	141	1.97	3.14	3.07	2.65	-2.94	-3.27	.16	1.53
1991	142	1.95	2.68	2.19	1.60	-2.92	-3.27	.10	1.44
1991	143	3.25	3.86	3.23	2.32	-2.83	-3.20	.13	1.46
1991	144	3.44	1.88	1.95	1.59	-2.81	-3.20	.02	1.36
1991	145	3.26	2.33	2.32	1.92	-2.77	-3.17	.00	1.32
1991	146	1.69	1.96	1.93	1.57	-2.73	-3.14	-.03	1.31
1991	147	5.50	4.36	4.26	3.1[illegible]	-2.62	-3.00	.14	1.45
1991	148	6.35	4.34	4.38	3.63	-2.56	-2.94	.14	1.48
1991	149	7.22	6.76	5.85	4.52	-2.49	-2.87	.24	1.57
1991	150	5.71	4.76	4.47	3.89	-2.48	-2.87	.16	1.50
1991	151	0.68	1.24	1.22	1.14	-2.51	-2.93	-.06	1.31
1991	152	0.21	1.16	1.08	0.89	-2.49	-2.91	-.05	1.28
1991	153	2.26	3.36	3.22	2.61	-2.39	-2.79	.07	1.39
1991	154	5.08	5.36	5.03	4.11	-2.30	-2.68	.21	1.52
1991	155	5.87	5.59	5.08	4.18	-2.26	-2.65	.24	1.56
1991	156	7.59	5.18	4.85	4.02	-2.24	-2.63	.20	1.51
1991	157	6.53	5.85	5.50	4.62	-2.19	-2.58	.19	1.51
1991	158	2.77	3.24	3.30	3.27	-2.23	-2.64	-.02	1.34
1991	159	1.18	2.03	2.04	1.87	-2.24	-2.65	-.04	1.32
1991	160	3.59	2.65	2.62	2.25	-2.17	-2.56	.06	1.37
1991	161	3.53	4.04	3.72	3.12	-2.12	-2.51	.07	1.39
1991	162	4.36	4.24	4.28	3.87	-2.05	-2.44	.13	1.43
1991	163	7.21	6.40	5.66	4.80	-2.01	-2.39	.21	1.49
1991	164	8.38	6.29	5.87	5.01	-1.95	-2.35	.25	1.52
1991	165	8.09	6.25	6.15	5.34	-1.93	-2.33	.28	1.51
1991	166	8.45	6.43	6.76	5.51	-1.91	-2.31	.84	1.47
1991	167	8.34	6.37	6.64	5.50	-1.88	-2.30	1.46	1.45
1991	168	10.09	7.94	8.66	6.62	-1.85	-2.25	2.42	1.46
1991	169	11.07	8.95	9.93	7.46	-1.80	-2.20	3.53	1.47
1991	170	11.42	8.90	9.74	7.46	-1.79	-2.20	4.21	1.44
1991	171	10.78	9.31	9.46	7.73	-1.77	-2.17	4.[illegible]	1.44

1991	172	10.16	10.15	9.75	8.39	-1.75	-2.14	5.67	1.43
1991	173	10.52	10.03	10.23	8.90	-1.73	-2.14	6.25	1.40
1991	174	13.99	12.71	13.33	10.91	-1.72	-2.11	7.01	1.44
1991	175	13.94	12.28	12.75	10.48	-1.67	-2.07	8.32	1.43
1991	176	11.81	10.97	11.22	10.13	-1.67	-2.06	7.95	1.41
1991	177	11.26	10.28	10.67	9.49	-1.64	-2.03	7.89	1.40
1991	178	10.65	8.63	8.81	8.23	-1.64	-2.04	7.69	1.39
1991	179	10.52	9.89	10.21	9.18	-1.60	-1.97	7.97	1.40
1991	180	11.98	11.01	11.49	10.18	-1.61	-1.99	8.95	1.46
1991	181	15.18	13.18	14.01	11.71	-1.57	-1.94	9.89	1.50
1991	182	14.14	13.65	14.52	11.77	-1.54	-1.92	10.92	1.48
1991	183	13.05	12.43	13.10	10.94	-1.53	-1.91	10.89	1.51
1991	184	10.03	9.58	9.81	9.18	-1.51	-1.89	9.95	1.50
1991	185	8.68	8.65	8.85	8.33	-1.51	-1.91	9.12	1.46
1991	186	7.00	7.50	7.62	7.40	-1.48	-1.85	9.16	1.54
1991	187	8.76	7.61	7.78	7.23	-1.49	-1.87	9.03	1.62
1991	188	12.81	10.52	11.00	9.47	-1.43	-1.79	11.27	1.70
1991	189	9.38	8.15	8.43	7.71	-1.43	-1.82	11.45	1.69
1991	190	6.90	7.11	7.51	6.87	-1.43	-1.81	9.90	1.70
1991	191	3.96	5.51	5.66	5.47	-1.45	-1.83	8.52	1.69
1991	192	8.72	8.76	9.08	8.21	-1.39	-1.76	10.70	1.81
1991	193	8.18	8.29	8.49	7.95	-1.38	-1.75	9.35	1.78
1991	194	7.63	7.86	8.01	7.62	-1.37	-1.76	8.63	1.80
1991	195	9.64	9.52	9.79	9.02	-1.33	-1.70	8.90	1.91
1991	196	9.55	9.54	9.82	9.05	-1.31	-1.68	9.27	1.96
1991	197	10.65	9.95	10.23	9.41	-1.29	-1.64	10.63	2.04
1991	198	8.00	7.84	8.04	7.65	-1.27	-1.66	9.83	2.04
1991	199	6.16	6.00	6.10	5.90	-1.32	-1.70	8.25	1.97
1991	200	5.51	6.17	6.35	5.92	-1.31	-1.68	7.87	1.99
1991	201	7.96	9.05	9.34	8.42	-1.25	-1.61	8.53	2.13
1991	202	9.54	9.36	9.66	8.75	-1.21	-1.57	8.96	2.22
1991	203	12.77	9.49	9.72	9.04	-1.19	-1.55	10.67	2.27
1991	204	14.16	10.91	11.21	9.99	-1.17	-1.53	10.91	2.30
1991	205	15.15	11.55	11.85	10.32	-1.16	-1.51	11.49	2.33
1991	206	11.36	10.98	11.28	10.33	-1.15	-1.52	11.69	2.29
1991	207	9.70	9.88	10.09	9.51	-1.15	-1.51	11.20	2.29
1991	208	5.75	6.40	6.44	6.50	-1.19	-1.57	9.38	2.21
1991	209	6.21	6.61	6.79	6.43	-1.18	-1.55	8.29	2.29
1991	210	8.15	6.78	6.98	6.45	-1.15	-1.52	10.01	2.38
1991	211	8.06	7.39	7.47	7.25	-1.12	-1.48	9.39	2.35
1991	212	8.46	8.39	8.56	8.16	-1.09	-1.45		
1991	213	6.84	6.68	7.10	6.67	-1.12	-1.49		
1991	214	8.10	7.88	7.86	7.20	-1.10	-1.46	9.14	2.35
1991	215	7.48	6.28	6.26	6.31	-1.11	-1.46	8.56	2.3[illegible]
1991	216	5.10	3.28	3.54	4.47	-1.13	-1.49	5.82	2.34
1991	217	5.49	6.24	6.00	5.50	-1.09	-1.45	7.39	2.41
1991	218	5.52	5.31	5.28	5.23	-1.09	-1.44	7.03	2.41
1991	219	8.38	8.95	8.05	6.85	-1.05	-1.39	8.37	2.51
1991	220	8.12	7.35	6.94	6.42	-1.05	-1.39	8.41	2.50

1991	221	8.44	8.59	8.44	7.80	-1.04	-1.39	9.49	2.49
1991	222	8.65	7.71	7.85	7.56	-1.02	-1.37	9.06	2.54
1991	223	8.89	8.23	8.00	7.35	-1.00	-1.34	9.05	2.55
1991	224	9.50	9.63	9.29	8.17	-0.99	-1.33	9.99	2.56
1991	225	13.51	13.14	12.52	10.62	-0.96	-1.29	12.24	2.64
1991	226	12.56	10.97	10.82	10.06	-0.95	-1.29	11.98	2.64
1991	227	11.86	10.74	10.47	9.45	-0.94	-1.27	11.22	2.67
1991	228	12.20	10.57	10.05	9.32	-0.94	-1.26	11.58	2.68
1991	229	12.56	10.58	9.80	8.95	-0.93	-1.26	12.61	2.68
1991	230	7.89	6.79	6.88	7.69	-0.94	-1.28	10.11	2.63
1991	231	3.22	4.55	4.98	5.42	-1.01	-1.34	7.48	2.56
1991	232	5.07	7.23	7.66	7.64	-0.94	-1.27	8.95	2.67
1991	233	4.06	4.34	4.46	4.57	-0.99	-1.32	5.98	2.64
1991	234	5.40	4.70	4.51	4.55	-0.96	-1.28	6.70	2.69
1991	236	0.92	2.17	2.53	3.03	-1.01	-1.33	4.53	2.58
1991	237	-4.72	0.21	0.52	1.14	-1.10	-1.40	2.07	2.47
1991	238	-5.04	-1.78	-1.39	-0.29	-1.13	-1.44	1.73	2.48
1991	239	-2.69	-0.73	-0.72	-0.35	-1.10	-1.41	1.86	2.55

MICROCLIMATE DATA: GOOSE FLATS

TEMPERATURE (°C)

Year	Julian Day	150	Surface	PALSA (cm) -2.5	PALSA (cm) -5	PALSA (cm) -150	PALSA (cm) -160	FEN (cm) -5	FEN (cm) -150
1990	213	5.15	7.17	6.92	6.89	-0.33	-0.42	8.26	2.78
1990	214	6.34		6.31	6.23	-0.86	-0.66	8.79	2.34
1990	215	7.44	6.96	6.75	6.71	0.01	-0.75	9.46	3.29
1990	216	9.15	8.06	7.45	7.23	-1.33	-0.81	9.15	1.94
1990	217	7.57	7.94	7.82	7.75	-0.64	-0.85	10.74	2.66
1990	218	5.77	7.15	7.02	6.99	-0.26	-0.88	8.93	3.02
1990	219	6.02	6.28	5.86	5.75	-1.20	-0.93	7.22	2.10
1990	220	7.30	6.66	6.40	6.30	-0.79	-0.98	7.88	2.53
1990	221	10.65	9.80	9.03	8.72	-0.51	-1.04	9.13	2.83
1990	222	13.52	11.06	9.96	9.56	-1.48	-1.08	10.99	1.98
1990	223	11.49	11.96	11.15	10.92	-0.60	-1.10	13.15	2.88
1990	224	10.12	10.13	9.67	9.47	-1.28	-1.07	10.75	2.29
1990	225	10.32	10.73	10.15	9.96	-0.99	-1.00	10.67	2.56
1990	226	9.74	9.39	9.16	9.01	-1.36	-0.89	9.21	2.24
1990	227	9.35	9.35	9.02	8.92	-0.80	-0.77	9.03	2.81
1990	228	9.05	9.15	8.82	8.71	-0.82	-0.65	9.23	2.87
1990	229	7.94	8.37	8.19	8.15	-0.52	-0.65	9.18	3.17
1990	230	7.11	6.72	6.80	6.80	-0.54	-0.64	8.57	3.22
1990	231	5.65	7.03	6.80	6.77	-0.57	-0.64	8.01	3.25
1990	232	4.85	5.99	5.95	5.94	-0.53	-0.64	7.82	3.36
1990	233	2.65	3.97	4.21	4.31	-0.69	-0.63	7.01	3.29
1990	234	3.84	4.46	4.31	4.24	-1.44	-0.63	6.12	2.62
1990	235	4.28	4.90	4.74	4.68	-1.01	-1.02	6.56	3.06
1990	236	3.78	3.50	3.80	3.87	-0.73	-0.74	6.37	3.32
1990	237	5.80	5.95	5.05	4.84	-0.76	-0.77	6.24	3.27
1990	238	3.88	2.85	2.92	2.93	-0.60	-0.61	5.18	3.38
1990	239	6.46	5.76	5.11	4.95	-0.68	-0.70	5.89	3.28
1990	240	4.75	5.19	4.96	4.91	-0.48	-0.50	6.38	3.47
1990	241	0.29	1.35	1.91	2.08	-0.30	-0.30	5.40	3.70
1990	242	-1.00	0.04	0.53	0.70	-0.51	-0.51	3.95	3.43
1990	243	0.51	0.13	0.35	0.41	-0.67	-0.68	3.19	3.38
1990	244	-0.22	-0.06	0.18	0.28	-0.49	-0.49	2.95	3.40
1990	245	-1.54	0.10	0.12	0.20	-0.52	-0.53	2.71	3.35
1990	246	-0.31	0.04	0.08	0.11	-0.59	-0.60	2.39	3.24
1990	247	1.64	2.34	1.90	1.82	-0.58	-0.58	3.05	3.14
1990	248	2.21	2.53	2.16	2.09	-0.59	-0.60	3.51	3.06
1990	249	3.62	3.42	3.13	3.04	-0.50	-0.51	4.12	3.10
1990	250	-0.50	0.93	1.13	1.21	-0.46	-0.47	3.33	3.12
1990	251	-0.86	0.41	0.57	0.61	-0.60	-0.61	2.71	3.04
1990	252	-0.51	0.08	0.16	0.22	-0.50	-0.52	2.21	2.93

1990	253	-2.40	0.19	0.25	0.28	-0.39	-0.40	2.21	3.01
1990	254	-2.66	0.07	0.12	0.16	-0.49	-0.49	1.72	2.89
1990	255	-0.50	-0.02	0.03	0.06	-0.50	-0.50	1.49	2.83
1990	256	3.18	1.24	0.94	0.84	-0.80	-0.78	1.52	2.50
1990	257	2.88	1.29	1.21	1.18	-0.53	-0.54	2.20	2.68
1990	258	3.76	3.28	3.06	2.97	-0.43	-0.44	2.91	2.72
1990	259	-0.55	0.48	0.74	0.83	-0.36	-0.36	2.62	2.75
1990	260	-0.64	0.38	0.37	0.39	-0.69	-0.70	1.86	2.48
1990	261	-0.52	-0.33	-0.07	0.01	-0.55	-0.56	1.56	2.44
1990	262	0.41	0.14	0.02	0.06	-0.56	-0.56	1.65	2.38
1990	263	2.01	1.53	1.22	1.15	-0.66	-0.67	2.05	2.28
1990	264	3.46	1.79	1.68	1.63	-0.49	-0.50	2.28	2.36
1990	265	3.75	2.02	1.89	1.80	-0.50	-0.51	2.25	2.28
1990	266	5.62	4.71	4.36	4.26	-0.49	-0.50	3.33	2.28
1990	267	1.76	1.99	2.07	2.12	-0.46	-0.46	3.25	2.28
1990	268	0.01	0.99	1.16	1.23	-0.41	-0.42	2.78	2.27
1990	269	-2.54	-0.19	0.27	0.38	-0.35	-0.35	2.14	2 45
1990	270	-3.536	-1.818	-0.894	-0.598	-0.565	-0.565	0.681	2.142
1990	271	-0.806	-0.614	-0.445	-0.378	-0.504	-0.512	0.51	2.101
1990	272	-1.015	-0.199	-0.134	-0.109	-0.401	-0.41	0.564	2.168
1990	273	-1.47	-0.254	-0.191	-0.167	-0.444	-0.449	0.555	2.099
1990	274	-2.568	-0.125	-0.073	-0.041	-0.347	-0.35	0.691	2.201
1990	275	-3.525	-0.354	-0.214	-0.147	-0.394	-0.397	0.577	2.092
1990	276	-5.641	-0.262	-0.102	-0.018	-0.221	-0.223	0.76	2.26
1990	277	-7.93	-0.073	0.144	0.249	0.073	0.071	1.068	2.555
1990	278	-11.71	-0.929	-0.317	-0.084	0.116	0.124	0.974	2.517
1990	279	-11.3	-1.573	-0.801	-0.509	0.073	0.088	0.815	2.416
1990	280	-8.4	-1.863	-1.131	-0.882	-0.19	-0.188	0.481	2.07
1990	281	-2.922	-1.224	-0.893	-0.8	-0.565	-0.57	0.046	1.593
1990	282	-6.127	-0.458	-0.301	-0.237	-0.256	-0.259	0.41	1.91
1990	283	-12.16	-1.436	-0.9	-0.722	-0.189	-0.181	0.475	1.954
1990	284	-9.5	-1.919	-1.285	-1.086	-0.207	-0.203	0.371	1.827
1990	285	-8.34	-1.553	-1.095	-0.947	-0.251	-0.252	0.317	1.739
1990	286	-6.868	-1.192	-0.905	-0.794	-0.306	-0.307	0.277	1.66
1990	287	-8.5	-1.293	-0.926	-0.81	-0.274	-0.274	0.289	1.639
1990	288	-16.01	-2.495	-1.775	-1.542	-0.094	-0.081	0.454	1.812
1990	289	-17.09	-3.24	-2.41	-2.133	-0.055	-0.033	0.469	1.818
1990	290	-12.51	-2.781	-2.117	-1.897	-0.052	-0.04	0.445	1.771
1990	291	-16.43	-2.487	-1.936	-1.733	0.083	0.092	0.647	1.944
1990	292	-19.08	-4.229	-3.217	-2.922	0.068	0.092	0.58	1.878
1990	293	-8.97	-3.407	-2.727	-2.531	-0.142	-0.134	0.336	1.603
1990	294	-6.306	[illegible]	-1.771	-1.662	-0.291	-0.292	0.161	1.389
1990	295	-9.01	[illegible]	-1.379	-1.297	-0.261	-0.267	0.196	1.38
[illegible]	296	-10.2	[illegible]	-1.92	-1.77	-0.072	-0.069	0.419	1.548
1990	297	-6.377	[illegible]	-2.068	-1.951	-0.292	-0.295	0.191	1.287
1990	298	-7.5	-2.592	-2.066	-1.947	-0.195	-0.206	0.275	1.328
1990	299	-12.42	-2.762	-2.211	-2.071	-0.105	-0.103	0.41	1.414
1990	300	-13.67	-3.818	-3.106	-2.92	-0.127	-0.118	0.393	1.387
1990	301	-11.05	-2.945	-2.442	-2.324	-0.137	-0.139	0.304	1.305

1990	302	-8.68	-2.716	-2.29	-2.2	-0.234	-0.239	0.267	1.172
1990	303	-13.15	-2.578	-2.185	-2.092	-0.174	-0.177	0.331	1.221
1990	304	-19.63	-4.325	-3.51	-3.323	-0.035	-0.028	0.472	1.362
1990	305	-21.39	-5.119	-4.272	-4.069	0.06	0.07	0.57	1.446
1990	306	-17.74	-5.527	-4.61	-4.412	0.086	0.098	0.547	1.452
1990	307	-20.87	-5.129	-4.536	-4.376	0.054	0.065	0.495	1.416
1990	308	-20.05	-5.275	-4.682	-4.531	0.05	0.057	0.442	1.375
1990	309	-11.93	-5.136	-4.514	-4.387	-0.046	-0.049	0.285	1.216
1990	310	-12.66	-4.923	-4.294	-4.156	0.109	0.114	0.453	1.402
1990	311	-14.97	-5.405	-4.67	-4.51	0.116	0.131	0.471	1.414
1990	312	-21.12	-6.451	-5.485	-5.316	0.013	0.011	0.326	1.246
1990	313	-21.57	-7.89	-6.816	-6.646	0.284	0.298	0.639	1.549
1990	314	-27.33	-9.4	-8.09	-7.86	0.249	0.263	0.609	1.514
1990	315	-30.63	-11.58	-10.08	-9.82	0.339	0.346	0.648	1.537
1990	316	-26.25	-12.13	-10.82	-10.62	0.363	0.356	0.609	1.478
1990	317	-24.25	-10.41	-9.52	-9.37	0.251	0.247	0.476	1.352
1990	318	-25.3	-10.68	-9.7	-9.53	0.432	0.43	0.656	1.532
1990	319	-14.94	-9.18	-8.64	-8.53	0.22	0.221	0.463	1.341
1990	320	-13.9	-7.91	-7.42	-7.35	-0.16	-0.168	0.058	0.92
1990	321	-18.06	-9.14	-8.32	-8.2	0.011	0.002	0.205	1.054
1990	322	-18.44	-9.09	-8.44	-8.34	-0.034	-0.043	0.177	1.008
1990	323	-25.54	-11.66	-10.44	-10.26	0.269	0.264	0.521	1.343
1990	324	-26.38	-13.41	-12.09	-11.89	0.353	0.347	0.575	1.398
1990	325	-24.83	-13.84	-12.65	-12.48	0.225	0.213	0.427	1.245
1990	326	-27.39	-14.32	-13.01	-12.84	0.245	0.244	0.485	1.317
1990	327	-31.9	-15.58	-14.11	-13.92	0.395	0.396	0.594	1.433
1990	328	-32.7	-16.79	-15.27	-15.07	0.491	0.489	0.647	1.487
1990	329	-31.62	-17.68	-16.12	-15.94	0.487	0.486	0.632	1.482
1990	330	-23.79	-15.67	-14.82	-14.71	0.203	0.202	0.302	1.17
1990	331	-26.37	-15.93	-14.75	-14.61	0.244	0.237	0.326	1.195
1990	332	-23.8	-14.32	-13.6	-13.51	0.113	0.11	0.194	1.072
1990	333	-31.46	-15.9	-14.55	-14.39	0.202	0.193	0.28	1.137
1990	334	-31.89	-17.3	-15.77	-15.58	0.282	0.291	0.402	1.274
1990	335	-34.37	-17.79	-16.33	-16.14	0.333	0.334	0.422	1.281
1990	336	-34.55	-19.15	-17.47	-17.26	0.459	0.479	0.578	1.447
1990	337	-23.66	-17.38	-16.43	-16.31	0.205	0.236	0.327	1.207
1990	338	-26.73	-16.67	-15.68	-15.56	0.136	0.176	0.264	1.142
1990	339	-23.37	-17.09	-16.06	-15.94	0.171	0.231	0.365	1.245
1990	340	-10.39	-12.87	-12.73	-12.72	-0.335	-0.259	-0.085	0.787
1990	341	-11.98	-11.38	-11.19	-11.17	-0.486	-0.392	-0.156	0.698
1990	342	-15.22	-11.49	-10.97	-10.91	-0.488	-0.368	-0.057	0.77
1990	343	-13.79	-11.16	-10.71	-10.66	-0.605	-0.486	-0.07	0.728
1990	344	-16.44	-10.31	-9.9	-9.84	-0.74	-0.607	-0.111	0.674
1990	345	-19.78	-11.11	-10.4	-10.31	-0.683	-0.561	0.025	0.771
1990	346	-15.93	-11.17	-10.53	-10.47	-0.804	-0.678	-0.041	0.696
1990	347	-14	-10.23	-9.79	-9.74	-0.867	-0.742	-0.06	0.663
1990	348	-19.19	-9.75	-9.28	-9.2	-0.852	-0.722	0.009	0.719
1990	349	-28.62	-10.69	-9.94	-9.83	-0.585	-0.453	0.331	1.043
1990	350	-28.01	-12.42	-11.47	-11.29	-0.386	-0.245	0.581	1.295

1990	351	-32.81	-16.17	-14.52	-14.19	-0.469	-0.334	0.533	1.251
1990	352	-31.72	-16.22	-15.08	-14.86	-0.52	-0.388	0.462	1.196
1990	353	-23.88	-13.97	-13.29	-13.18	-0.648	-0.506	0.332	1.079
1990	354	-15.62	-12.63	-12.25	-12.19	-0.836	-0.702	0.149	0.911
1990	355	-12.41	-11.27	-10.99	-10.94	-1.092	-0.953	-0.068	0.703
1990	356	-13.46	-10.73	-10.37	-10.32	-1.171	-1.038	-0.099	0.667
1990	357	-19.07	-10.87	-10.25	-10.14	-1.197	-1.052	-0.064	0.694
1990	358	-26.03	-14.04	-12.76	-12.54	-0.784	-0.623	0.432	1.188
1990	359	-17.16	-12.21	-11.69	-11.61	-1.121	-0.974	0.095	0.829
1990	360	-21.15	-12.35	-11.61	-11.49	-1.148	-0.999	0.101	0.859
1990	361	-32.09	-17.73	-15.95	-15.61	-0.804	-0.647	0.564	1.316
1990	362	-32.19	-19.4	-17.64	-17.35	-0.824	-0.654	0.59	1.357
1990	363	-24.04	-17.54	-16.6	-16.43	-1.131	-0.962	0.27	1.048
1990	364	-28.15	-19.26	-17.76	-17.5	-0.948	-0.777	0.534	1.34
1990	365	-29.9	-20.8	-19.26	-18.97	-1	-0.814	0.545	1.374
1991	1	-28.23	-20.22	-18.88	-18.65	-1.204	-1.014	0.362	1.209
1991	2	-26.01	-20.6	-19.24	-19.01	-1.329	-1.122	0.317	1.188
1991	3	-22.52	-19.15	-18.28	-18.15	-1.584	-1.37	0.103	1.001
1991	4	-26.99	-19.55	-18.28	-18.07	-1.583	-1.356	0.247	1.172
1991	5	-25.58	-19.72	-18.68	-18.51	-1.75	-1.509	0.142	1.078
1991	6	-26.31	-19.76	-18.53	-18.34	-1.85	-1.605	0.157	1.11
1991	7	-27.04	-20.95	-19.57	-19.36	-1.899	-1.65	0.177	1.15
1991	8	-22.24	-18.26	-17.72	-17.64	-2.316	-2.065	-0.199	0.806
1991	9	-26.84	-19.46	-18.3	-18.13	-2.228	-1.963	0.016	1.048
1991	10	-22.92	-18.18	-17.4	-17.29	-2.455	-2.192	-0.16	0.885
1991	11	-17.28	-16.07	-15.74	-15.69	-2.753	-2.488	-0.388	0.672
1991	12	-13.59	-14.28	-14.14	-14.12	-2.953	-2.686	-0.496	0.563
1991	13	-9.54	-11.93	-12.09	-12.11	-3.201	-2.935	-0.65	0.387
1991	14	-12.22	-11.79	-11.54	-11.5	-3.219	-2.954	-0.562	0.428
1991	15	-16.05	-12.09	-11.64	-11.59	-3.131	-2.876	-0.385	0.538
1991	16	-12.62	-11.69	-11.44	-11.39	-3.112	-2.873	-0.327	0.571
1991	17	-6.149	-9.23	-9.48	-9.5	-3.414	-3.188	-0.624	0.247
1991	18	-10.39	-9.05	-8.93	-8.91	-3.367	-3.153	-0.563	0.277
1991	19	-11.73	-10.1	-9.69	-9.64	-3.154	-2.954	-0.342	0.451
1991	20	-6.937	-8.99	-8.98	-8.96	-3.226	-3.033	-0.399	0.343
1991	21	-8.36	-8.14	-8.06	-8.05	-3.277	-3.1	-0.457	0.248
1991	22	-13.35	-9.48	-8.98	-8.9	-2.954	-2.78	-0.146	0.538
1991	23	-13.89	-9.84	-9.42	-9.34	-2.874	-2.703	-0.087	0.568
1991	24	-15.6	-10.69	-10.06	-9.96	-2.769	-2.604	-0.009	0.626
1991	25	-11.43	-9.94	-9.68	-9.62	-2.845	-2.682	-0.099	0.518
1991	26	-6.036	-8.34	-8.4	-8.4	-3.097	-2.943	-0.373	0.241
1991	27	-21.46	-9.29	-8.8	-8.72	-2.774	-2.621	-0.057	0.552
1991	28	-20.84	-12.15	-11.19	-11.04	-2.479	-2.335	0.22	0.824
1991	29	-21.01	-12.04	-11.37	-11.27	-2.529	-2.38	0.165	0.746
1991	30	-29.21	-15.22	-13.7	-13.48	-2.249	-2.095	0.457	1.045
1991	31	-25.56	-16.11	-14.98	-14.81	-2.306	-2.15	0.408	0.999
1991	32	-15.95	-13.16	-12.9	-12.85	-2.767	-2.611	-0.041	0.554
1991	33	-8.68	-11.38	-11.32	-11.31	-2.964	-2.797	[illegible]	0.406
1991	34	-13.51	-10.77	-10.53	-10.5	-3.082	-2.907	-0.[illegible]	0.353

1991	35	-9.84	-9.92	-9.82	-9.8	-3.148	-2.973	-0.324	0.319
1991	36	-11.57	-9.59	-9.35	-9.32	-3.207	-3.034	-0.361	0.285
1991	37	-11.1	-9.88	-9.58	-9.54	-3.103	-2.924	-0.249	0.4
1991	38	-18.43	-10.69	-10.02	-9.94	-3.104	-2.939	-0.25	0.387
1991	39	-24.09	-12.71	-11.67	-11.54	-2.95	-2.792	-0.103	0.532
1991	40	-20.43	-14.32	-13.26	-13.11	-2.71	-2.553	0.143	0.776
1991	41	-11.25	-12.22	-11.91	-11.87	-2.935	-2.78	-0.091	0.527
1991	42	-6.085	-9.27	-9.49	-9.52	-3.275	-3.115	-0.409	0.199
1991	43	-6.936	-8.29	-8.35	-8.36	-3.364	-3.197	-0.465	0.136
1991	44	-8.9	-8.4	-8.26	-8.23	-3.267	-3.107	-0.359	0.233
1991	45	-7.24	-7.73	-7.72	-7.71	-3.3	-3.152	-0.401	0.191
1991	46	-8.13	-7.12	-7.11	-7.1	-3.339	-3.194	-0.451	0.139
1991	47	-11.78	-7.42	-7.23	-7.2	-3.241	-3.096	-0.373	0.216
1991	48	-13.19	-7.9	-7.57	-7.51	-3.111	-2.981	-0.269	0.31
1991	49	-15.01	-8.84	8.34	-8.26	-2.987	-2.854	-0.166	0.391
1991	50	-26.06	-11.01	-9.91	-9.75	-2.746	-2.619	0.052	0.603
1991	51	-31.14	-13	-11.75	-11.56	-2.488	-2.365	0.3	0.845
1991	52	-24.49	-13.95	-12.87	-12.7	-2.423	-2.299	0.352	0.889
1991	53	-16.17	-12.52	-12.02	-11.94	-2.706	-2.579	0.075	0.596
1991	54	-13.62	-12.06	-11.6	-11.53	-2.752	-2.621	0.05	0.571
1991	55	-9.93	-10.58	-10.4	-10.37	-2.998	-2.852	-0.167	0.364
1991	56	-7.27	-9.5	-9.46	-9.46	-3.12	-2.969	-0.251	0.282
1991	57	-5.028	-8.04	-8.19	-8.2	-3.327	-3.178	-0.432	0.105
1991	58	-13.52	-7.4	-7.43	-7.42	-3.348	-3.201	-0.443	0.102
1991	59	-21.95	-9.47	-8.85	-8.72	-2.869	-2.723	0.048	0.593
1991	60	-23.07	-11.38	-10.49	-10.32	-2.68	-2.54	0.228	0.768
1991	61	-23.78	-11.49	-10.88	-10.75	-2.709	-2.573	0.189	0.727
1991	62	-20.78	-12.35	-11.57	-11.44	-2.736	-2.599	0.155	0.688
1991	63	-16.97	-11.17	-10.82	-10.75	-2.915	-2.775	-0.016	0.52
1991	64	-24.77	-12.73	-11.82	-11.66	-2.769	-2.626	0.159	0.694
1991	65	-17.56	-12.83	-12.18	-12.06	-2.836	-2.684	0.102	0.651
1991	66	-11.92	-11.19	-10.96	-10.92	-3.083	-2.93	-0.126	0.428
1991	67	-11.76	-10.27	-10.12	-10.08	-3.213	-3.059	-0.235	0.324
1991	68	-22.24	-11.08	-10.51	-10.43	-3.231	-3.072	-0.231	0.333
1991	69	-26.87	-13.86	-12.59	-12.41	-3.054	-2.902	-0.047	0.54
1991	70	-24.42	-14.11	-13.08	-12.93	-3.053	-2.896	-0.032	0.56
1991	71	-20.34	-13.89	-13.13	-13.02	-3.126	-2.974	-0.104	0.481
1991	72	-14.15	-12.29	-11.95	-11.89	-3.217	-3.061	-0.18	0.414
1991	73	-14.76	-11.12	-10.89	-10.84	-3.387	-3.221	-0.324	0.285
1991	74	-13.6	-10.88	-10.59	-10.54	-3.439	-3.274	-0.344	0.273
1991	75	-11.47	-10.11	-9.93	-9.89	-3.495	-3.328	-0.399	0.228
1991	76	-8.83	-8.92	-8.92	-8.91	-3.607	-3.444	-0.507	0.125
1991	77	-10.93	-8.23	-8.24	-8.24	-3.728	-3.575	-0.627	0.019
1991	78	-12.14	-8.34	-8.17	-8.14	-3.638	-3.482	-0.542	0.099
1991	79	-11.57	-7.82	-7.72	-7.7	-3.621	-3.481	-0.551	0.087
1991	80	-16.22	-7.72	-7.57	-7.54	-3.605	-3.464	-0.546	0.084
1991	81	-19.65	-8.25	-7.9	-7.85	-3.495	-3.353	-0.464	0.171
1991	82	-19.61	-8.64	-8.26	-8.2	-3.435	-3.301	-0.427	0.197
1991	83	-14.66	-8.26	-8.05	-8.01	-3.429	-3.298	-0.44	0.171

1991	84	-13.88	-8.28	-8	-7.96	-3.374	-3.254	-0.417	0.185
1991	85	-9.37	-7.4	-7.4	-7.39	-3.436	-3.314	-0.498	0.091
1991	86	-10.55	-7.14	-7.05	-7.03	-3.449	-3.324	-0.525	0.064
1991	87	-8.05	-6.522	-6.549	-6.543	-3.451	-3.342	-0.558	0.02
1991	88	-9.19	-6.192	-6.217	-6.217	-3.494	-3.383	-0.621	-0.041
1991	89	-11.45	-6.143	-6.098	-6.089	-3.464	-3.354	-0.627	-0.05
1991	90	-14.44	-7.05	-6.701	-6.651	-3.36	-3.25	-0.523	0.04
1991	91	-13	-6.445	-6.34	-6.323	-3.324	-3.212	-0.518	0.04
1991	92	-15.67	-6.537	-6.357	-6.324	-3.299	-3.196	-0.513	0.034
1991	93	-14.52	-6.686	-6.487	-6.458	-3.253	-3.147	-0.487	0.049
1991	94	-11.73	-6.487	-6.345	-6.32	-3.221	-3.12	-0.481	0.048
1991	95	-10.6	-6.335	-6.217	-6.198	-3.21	-3.116	-0.515	0.014
1991	96	-10.7	-6.057	-6.001	-5.986	-3.213	-3.113	-0.541	-0.019
1991	97	-11.1	-6.088	-5.966	-5.945	-3.156	-3.066	-0.507	0.005
1991	98	-10.06	-5.893	-5.796	-5.778	-3.114	-3.022	-0.467	0.036
1991	99	-11.14	-5.469	-5.468	-5.461	-3.107	-3.031	-0.507	-0.007
1991	100	-13.61	-5.733	-5.595	-5.58	-3.105	-3.016	-0.52	-0.017
1991	101	-8.35	-5.727	-5.622	-5.605	-3.064	-2.976	-0.508	-0.011
1991	102	-4.757	-5.178	-5.199	-5.2	-3.054	-2.976	-0.527	-0.04
1991	103	-5.493	-4.669	-4.766	-4.78	-3.065	-2.986	-0.571	-0.09
1991	104	-4.78	-4.506	-4.573	-4.583	-3.037	-2.948	-0.578	-0.097
1991	105	-5.602	-4.391	-4.451	-4.458	-3.033	-2.954	-0.592	-0.115
1991	106	-6.526	-4.315	-4.37	-4.374	-3.011	-2.929	-0.586	-0.117
1991	107	-1.905	-3.929	-3.982	-3.979	-2.988	-2.908	-0.589	-0.128
1991	108	-2.001	-3.284	-3.447	-3.459	-2.956	-2.882	-0.581	-0.13
1991	109	-1.168	-3.131	-3.355	-3.384	-2.966	-2.896	-0.617	-0.172
1991	110	-5.155	-3.309	-3.413	-3.428	-2.944	-2.873	-0.596	-0.177
1991	111	-3.569	-3.59	-3.629	-3.628	-2.877	-2.807	-0.543	-0.138
1991	112	-3.278	-3.554	-3.595	-3.602	-2.845	-2.776	-0.529	-0.136
1991	113	-4.225	-3.583	-3.616	-3.615	-2.799	-2.733	-0.502	-0.123
1991	114	-3.869	-3.594	-3.631	-3.638	-2.778	-2.71	-0.494	-0.135
1991	115	-4.247	-3.52	-3.578	-3.589	-2.738	-2.675	-0.465	-0.124
1991	116	-4.335	-3.559	-3.585	-3.584	-2.706	-2.645	-0.468	-0.124
1991	117	-1.136	-2.946	-3.118	-3.141	-2.661	-2.604	-0.486	-0.122
1991	118	-2.082	-2.454	-2.713	-2.748	-2.722	-2.663	-0.54	-0.182
1991	119	-3.409	-2.424	-2.627	-2.648	-2.72	-2.656	-0.538	-0.19
1991	120	-3.68	-2.62	-2.728	-2.739	-2.659	-2.602	-0.493	-0.157
1991	121	-2.675	-2.756	-2.827	-2.826	-2.634	-2.577	-0.498	-0.163
1991	122	-3.132	-2.175	-2.385	-2.416	-2.626	-2.571	-0.51	-0.181
1991	123	-1.372	-2.077	-2.269	-2.292	-2.593	-2.534	-0.489	-0.167
1991	124	0.902	-1.376	-1.637	-1.688	-2.597	-2.542	-0.511	-0.191
1991	125	1.475	-0.525	-0.645	-0.678	-2.56	-2.51	-0.498	-0.181
1991	126	0.759	-0.251	-0.35	-0.393	-2.49	-2.442	-0.382	-0.143
1991	127	1.574	-0.231	-0.296	-0.311	-2.447	-2.401	-0.337	-0.131
1991	128	2.205	-0.224	-0.291	-0.301	-2.419	-2.373	-0.337	-0.14
1991	129	0.468	-0.105	-0.284	-0.288	-2.381	-2.34	-0.324	-0.127
1991	130	-2.205	-0.155	-0.207	-0.208	-2.257	-2.216	-0.234	-0.045
1991	131	-1.028	-0.059	-0.093	-0.089	-2.08	-2.053	-0.113	0.061
1991	132	-0.842	0.028	-0.218	-0.218	-2.177	-2.146	-0.242	-0.057

1991	133	-0.518	0.359	-0.086	-0.082	-1.985	-1.962	-0.11	0.072
1991	134	0.38	2.047	0.049	-0.222	-2.255	-2.239	-0.41	-0.224
1991	135	1.011	2.598	0.821	0.468	-2.319	-2.297	-0.485	-0.293
1991	136	2.424	2.843	1.22	0.903	-2.445	-2.427	-0.638	-0.447
1991	137	2.796	3.508	1.861	1.503	-2.515	-2.5	-0.76	-0.575
1991	138	2.003	3.674	2.096	1.764	-2.475	-2.465	-0.795	-0.618
1991	139	0.749	3.692	2.153	1.874	-2.417	-2.414	-0.842	-0.666
1991	140	0.043	2.612	1.815	1.669	-1.806	-1.806	-0.184	-0.008
1991	141	-0.687	1.767	1.273	1.178	-1.862	-1.86	-0.249	-0.07
1991	142	-0.729	0.694	0.261	0.209	-1.911	-1.914	-0.413	-0.243
1991	143	0.524	3.328	2.54	2.324	-1.89	-1.893	-0.31	-0.139
1991	144	1.42	3.401	2.411	2.158	-1.918	-1.923	-0.427	-0.262
1991	145	1.445	3.451	2.401	2.128	-1.913	-1.928	-0.523	-0.364
1991	146	0.17	3.233	2.284	2.084	-1.919	-1.927	-0.583	-0.422
1991	147	3.473	5.422	3.868	3.439	-2.396	-2.406	-1.008	-0.846
1991	148	3.579	3.704	2.605	2.288	-2.054	-2.064	-0.84	-0.683
1991	149	5.647	5.211	3.975	3.547	-2.226	-2.238	-1.013	-0.857
1991	150	3.556	3.568	2.722	2.489	-1.719	-1.73	-0.5	-0.347
1991	151	-0.247	2.283	1.595	1.442	-1.531	-1.542	-0.335	-0.198
1991	152	-1.401	2.027	1.307	1.148	-1.526	-1.538	-0.384	-0.249
1991	153	0.427	4.103	2.984	2.689	-1.792	-1.804	-0.645	-0.513
1991	154	2.477	5.566	4.231	3.884	-1.995	-2.006	-0.864	-0.729
1991	155	4.134	5.322	4.167	3.805	-2.012	-2.023	-0.807	-0.671
1991	156	5.181	5.879	4.608	4.218	-1.986	-1.998	-0.812	-0.675
1991	157	4.169	5.552	4.363	4.023	-1.892	-1.904	-0.877	-0.742
1991	158	1.799	2.525	2.208	2.156	-1.234	-1.245	-0.202	-0.065
1991	159	-0.51	2.076	1.74	1.657	-1.42	-1.43	-0.34	-0.214
1991	160	0.989	2.486	1.863	1.705	-1.571	-1.587	-0.573	-0.447
1991	161	2.158	3.537	2.659	2.455	-1.637	-1.645	-0.668	-0.536
1991	162	2.158	4.588	3.78	3.555	-1.509	-1.519	-0.455	-0.323
1991	163	4.263	6.733	5.343	4.916	-1.973	-1.982	-0.889	-0.756
1991	164	5.595	7.72	6.311	5.887	-2.057	-2.069	-1.015	-0.879
1991	165	6.169	7.64	6.514	6.162	-1.776	-1.789	-0.746	-0.611
1991	166	7.03	7.59	6.478	6.12	-1.798	-1.806	-0.816	-0.682
1991	167	7.27	7.16	6.17	5.836	-1.626	-1.634	-0.717	-0.591
1991	168	8.11	7.69	6.541	6.144	-1.68	-1.697	-0.738	-0.61
1991	169	9.13	8.15	6.854	6.448	-1.927	-1.944	-1.055	-0.931
1991	170	9.75	8.09	6.988	6.646	-1.474	-1.487	-0.548	-0.424
1991	171	10.16	10.25	8.64	8.11	-2.011	-2.029	-1.143	-1.021
1991	172	9.86	9.49	8.54	8.19	-1.492	-1.505	-0.677	-0.55
1991	173	9.45	8.25	7.44	7.11	-1.349	-1.364	-0.517	-0.408
1991	174	11.83	10.97	10.52	8.94	-2.097	-2.116	0.066	-1.144
1991	175	10.75	8.03	8.47	7.28	-1.382	-1.396	2.099	-0.425
1991	176	9.64	10	8.14	8.68	-1.221	-1.237	2.948	-0.28
1991	177	9.86	10.32	8.8	9.04	-1.429	-1.447	3.807	-0.527
1991	178	9.66	9.08	8.14	8.15	-1.298	-1.317	4.238	-0.381
1991	179	8	8.67	6.747	7.66	-1.154	-1.167	4.702	-0.3
1991	180	9.63	10.54	9.48	8.72	-2.008	-2.022	4.908	-1.096
1991	181	12.55	12.37	12.04	10.45	-1.98	-1.993	8.75	-1.074

1991	182	11.75	11.35	10.6	10.11	-1.324	-1.339	10.96	-0.46
1991	183	10.56	11.01	9.38	9.67	-1.41	-1.423	10.01	-0.527
1991	184	8.53	9.55	7.74	8.88	-1.01	-1.024	8.37	-0.103
1991	185	7.75	9.21	6.915	8.42	-0.995	-1.011	7.35	-0.116
1991	186	5.031	7.21	4.623	6.782	-1.076	-1.088	6.871	-0.191
1991	187	6.2	6.703	5.589	5.857	-1.563	-1.578	6.252	-0.651
1991	188	9.92	9.18	7.86	7.76	-1.523	-1.537	8.06	-0.563
1991	189	7.83	7.69	6.57	7.05	-0.939	-0.952	8.59	0.044
1991	190	4.474	7.48	5.006	6.729	-1.117	-1.129	7.79	-0.106
1991	191	2.823	3.161	2.064	3.396	-1.034	-1.041	5.469	-0.004
1991	192	6.048	7.71	5.416	6.462	-1.288	-1.301	6.457	-0.256
1991	193	7.38	7.72	5.594	7.1	-0.93	-0.945	7.61	0.14
1991	194	7.14	8.43	5.871	7.87	-0.818	-0.834	7.6	0.352
1991	195	7.77	8.6	5.989	7.83	-0.928	-0.945	7.15	0.282
1991	196	8.06	8.53	6.529	7.73	-1.043	-1.061	7.49	0.202
1991	197	7.9	8.05	6.301	7.39	-1.106	-1.123	7.85	0.198
1991	198	7.15	7.6	6.187	6.967	-1.058	-1.075	8.23	0.363
1991	199	5.005	6.219	3.914	6.001	-0.68	-0.694	8.25	0.88
1991	200	4.234	4.952	2.387	4.49	-0.786	-0.798	7.06	0.834
1991	201	6.094	8.11	5.295	7.17	-0.989	-1.006	6.85	0.666
1991	202	7.45	8.75	6.438	7.89	-1.154	-1.172	7.37	0.607
1991	203	9.89	8.11	7.61	7.38	-1.351	-1.371	7.89	0.504
1991	204	11.36	9.46	8.51	8.44	-1.281	-1.298		0.662
1991	205	13.65	10.35	11.35	9.14	-1.616	-1.625		
1991	206	10.18	11.16	10.43	10.05	-1.03	-1.04		
1991	207	8.32	9.78	8.21	9.32	-0.564	-0.573		
1991	208	4.568	5.912	4.321	6.298	-0.363	-0.374		
1991	209	4.625	5.615	3.869	5.502	-0.625	-0.64		
1991	210	6.573	6.546	5.94	5.922	-1.063	-1.074		
1991	211	6.493	7.07	5.87	6.613	-0.719	-0.731		
1991	212	6.684	8.44	7.21	7.59	-1.079	-1.089		
1991	213	5.552	6.281	5.316	6.176	-0.672	-0.684		
1991	214	6.245	7.36	6.557	6.545	-1.029	-1.038		
1991	215	6.322	6.156	6.084	6.036	-0.672	-0.684		
1991	216	7.06	7.04	6.808	6.39	-0.732	-0.608	10.65	4.734
1991	217	4.289	3.592	4.713	4.622	-0.724	-0.698	6.843	4.641
1991	218	7.27	6.234	6.511	6.19	-0.732	-0.63	7.99	4.619
1991	219	8.16	5.796	6.321	6.169	-0.651	-0.637	8.63	4.613
1991	220	7.48	6.394	7.54	7.34	-0.636	-0.629	9.54	4.608
1991	221	7.1	5.84	7.06	6.885	-0.66	-0.633	8.57	4.66
1991	222	7.18	6.167	7.04	6.814	-0.649	-0.606	8.67	4.729
1991	223	8.44	7.31	7.95	7.63	-0.614	-0.58	9.53	4.824
1991	224	11.66	11.17	11.26	10.65	-0.617	-0.51	12.01	4.905
1991	226	9.45	8.59	9.57	9.68	-0.462	-0.512	12.86	5.071
1991	227	10.39	9.71	10.3	9.97	-0.621	-0.554	10.79	5.044
1991	228	10.86	9.67	10.35	10.03	-0.513	-0.536	11.1	5.23
1991	229	11.51	8.92	9.73	9.44	-0.542	-0.561	10.89	5.319
1991	230	6.671	5.018	7.38	7.41	-0.607	-0.611	8.66	5.398
1991	231	1.804	1.912	4.931	5.043	-0.685	-0.716	6.152	5.35

1991	232	1.813	2.534	5.381	5.407	-0.643	-0.703	6.348	5.364
1991	233	3.573	3.664	5.446	5.34	-0.616	-0.625	6.306	5.358
1991	234	3.976	3.523	4.902	4.813	-0.601	-0.612	6.046	5.263
1991	235	2.852	1.013	3.095	3.143	-0.658	-0.674	4.558	5.123
1991	236	0.193	-0.501	2.36	2.458	-0.729	-0.744	3.829	4.938
1991	237	-5.783	-4.41	0.089	0.476	-0.837	-0.916	1.496	4.729
1991	238	-6.545	-5.324	-0.719	-0.371	-0.834	-0.911	1.224	4.559

APPENDIX C:

MAXIMUM THAW DATA: DALE CREEK 2

THAW DEPTH (cm)

TRANSECT: DC2-T0			TRANSECT: DC2-TW1			TRANSECT: DC2-TW2			TRANSECT: TE1			TRANSECT: T2E		
SITE	1990	1991	SITE	1990	1991	SITE	1990	1991	SITE	1990	1991	SITE	1990	1991
0	-125	-125	0	-134	-128	0	-119	-300	0	-101	-146	0	-95	-170
0.25	-166	-131	0.25	-123	-106	0.25	-127	-160	0.25	-120	-300	0.3	-106	-165
0.5	-42.5	-176	0.5	-134	-100	0.5	-127	-300	0.5	-114	-300	0.5	-106	-108
1	-44.5	-51	1	-167	-104	1	-132	-300	1	-130	-285	1	-127	-128
2	-41	-53	2	-115	-115	2	-136	-168	2	-143	-165	2	-72	-88
4	-53	-58	4	-48.5	-51	4	-144	-146	4	-50.5	-62	4	-81	-152
6	-53	-61	6	-54.5	-59	6	-210	-262	6	-47	-52	6	-102	-121
8	-49	-54	8	-59.5	-63	8	-51.5	-45	8	-41	-46	8	-109	-103
10	-49.5	-50	10	-48	-55	10	-58.5	-46	10	-50.5	-58	10	-83	-74
12	-47	-48	12	-51	-53	12	-46.5	-42	12	-43	-46	12	-100	-98
14	-50.5	-53	14	-43	-48	14	-46.5	-40	14	-50.5	-51	14	-164	-165
16	-43.5	-49	16	-45.5	-50	16	-48.5	-43	16	-42	-45	16	-147	-117
18	-44	-49	18	-47.5	-50	18	-48.5	-44	18	-41.5	-44	18	-83	-90
20	-53	-54	20	-46	-49	20	-48.5	-44	20	-38.5	-42	20	-84	-300
22	-46	-55	22	-46.5	-49	22	-45.5	-39	22	-49.5	-53	22	-148	-300
26	-43	-47	24	-45	-49	24	-47	-40	24	-55.5	-58	22	-120	-300
28	-45.5	-49	26	-45	-50	26	-49.5	-43	26	-52	-54	22	-125	-142
30	-52.5	-52	28	-54	-55	28	-57	-39	28	-46	-48	23	-86	-126
32	-48	-50	30	-50.5	-52	29	-55	-38	30	-53.5	-56			
34	-45.5	-49	32	-49.5	-56	30	-193	-200	32	-56	-60			
36	-49	-50	34	-48	-50	30.3	-148	-198	34	-81	-80			
38	-51	-57	36	-49	-53	30.5	-122	-201	36	-52	-71			
40	-48	-53	38	-53	-55				40	-190	-300			
42	-47	-52	40	-52.5	-55				40.9	-210	-300			
44	-125	-50	42	-47	-50				41.2	-178	-295			
44.7	-210	-53	43	-210	-275				41.4	-196	-300			
44.9	-210	-300	43.5	-183	-177									
45.2	-185	-158	43.8	-143	-163									
			44	-128	-134									

MAXIMUM THAW DATA: DALE CREEK 6

THAW DEPTH (cm)

TRANSECT: DC6-T0

SITE	1990	1991
0	-175	-300
0.25	-210	-300
0.5	-210	-300
1	-125	-300
2	-98.5	103
4	-102	-108
6	-62	-60
8	-52.5	-56
10	-64.5	-70
12	-56	-58
14	-63	-67
16	-57	-72
18	-56.5	-74
20	-78.5	-72
22	-55.5	-60
24	-60.5	-68
26	-53.5	-72
28	-56.5	-71
30	-65.5	-65
32	-76.5	-82
34	-70	-89
36	-210	-300
36.5	-210	-300
36.8	-210	-300
37	-125	-300

TRANSECT: DC6-T1W

SITE	1990	1991
0	-162	-164
0.25	-136	-138
0.5	-139	-124
1	-155	-75
2	-210	-74
4	-72	-80
6	-106	-107
8	-83	-90
10	-82	-77
12	-57.5	-64
14	-63.5	-71
16	-59.5	-64
18	-66.5	-73
20	-71	-80
22	-71	-79
24	-86	-90
26	-65	-71
28	-77	-76
29.3	-58.5	-90
29.8	-210	-300
30.1	-210	
30.3	-210	

TRANSECT: DC6-T1E

SITE	1990	1991
0	-210	-300
0.25	-210	-300
0.5	-210	-300
1	-210	-300
2	-130	-141
4	-120	-125
6	-136	-141
8	-161	-57
10	-148	-117
12	-125	-128
14	-131	-130
16	-47.5	-49
18	-53.5	-50
20	-130	-56
22	-115	-120
24	-160	-180
26	-136	-150
28	-46.5	-224
30	-177	-300
30.5	-198	-300
31	-210	-300
31.3	-210	-300
31.5	-210	-300

MAXIMUM THAW DATA: BEAVER POND

THAW DEPTH (cm)

TRANSECT: BP-T0			TRANSECT: BP-T1W			TRANSECT: BP-T2W			TRANSECT: BP-T3W			TRANSECT: BP-T1E		
SITE	1990	1991	SITE	1990	1991	SITE	1990	1991	SITE	1990	1991	SITE	1990	1991
0	-141	-195	0	-133	-156	0	-27	-30	0	-60	-99	0	-210	-300
0.25	-205	-282	0.25	-108	-280	0.25	-38	-35	0.25	-76	-103	0.3	-125	-300
0.5	-192	-175	0.5	-95	-300	0.5	-55	-56	0.5	-40	-49	0.5	-92	-120
1	-102	-106	1	-82	-300	1	-21	-68	1	-33	-61	1	-89	-106
10	-56	-66	10	-36	-25	10	-54	-56	10	-39.5	-42	10	-36	-40
20	-53.5	-56	20	-32	-35	20	-70.5	-72	20	-57.5	-62	20	-49	-51
30	-41	-57	30	-38	-29	30	-66	-65	30	-44	-43	30	-38	-39
40	-39.5	-40	40	-45.5	-51	40	-44.5	-46	40	-141	-135	40	-50	-50
50	-46	-50	50	-42	-40	50	-105	-70	50	-37.5	-41	50	-44	-44
60	-34	-40	60	-48.5	-52	60	-38	-40	60	-57.5	-56	60	-44	-50
71	-150	-124	70	-39	-36	70	-55	-55	62.1	-147	-125	70	-42	-44
80	-57	-58	80	-46.5	-49	79.5	-210	-170	63.6	-165		74	-90	-97
89.5	-210	-161	87.5	-135	-185	80	-201	-212	62.8	-185	-161	74	-95	-83
90	-210	-162	88	-210	-165	80.3	-181	-180	63.1	-177	-160	74	-85	-77
90.3	-210	-160	88.3	-210	-178	80.5	-190	-168				75	-59	-65
90.5	-210	-148	88.5	-210	-170									

MAXIMUM THAW DATA: HARE FOOT

THAW DEPTH (cm)

TRANSECT: HF-T0

SITE	1990	1991
0.0	-130	-300
0.25	-62.5	-77
0.5	-43.5	-44
1	-50	-55
5	-43.5	-45
10	-50.5	-42
15	-46.5	-32
20	-46	-43
25	-42	-45
30	-56.5	-63
35	-58.5	-64
40	-90	-95
40.5	-180	-107
41	-160	-110
41.3	-140	-186
41.5	-139	-109

TRANSECT: HF-T1S

SITE	1990	1991
0	-39	-47
0.25	-38	-42
0.5	-31.5	-35
1	-39	-40
5	-57.5	-60
10	-56	-56
15	-52	-46
20	-46.5	-42
25	-27	-31
30	-44	-47
35	-38	-38
40	-51	-53
45	-46	-49
50	-69	-67
53	-130	-100
53.5	-85	-69
53.8	-108	-108
54	-130	-66

TRANSECT: HF-T2S

SITE	1990	1991
0.0	-210	-300
0.25	-210	-300
0.5	-45	-53
1	-59	-65
5	-67	-67
10	-42	-46
15	-65.5	-63
20	-44	-45
25	-48.5	-58
27.7	-41.5	-41
28.2	-47.5	-50
28.4	-49	-48
28.7	-67	-48

TRANSECT: HF-T1N

SITE	1990
0.0	-76
0.3	-77
0.5	-67
1	-37
5	-50
10	-71
15	-53
20	-88
25	-62
30	-68
0.0 E	-130

MAXIMUM THAW DATA: GOOSE FLATS

THAW DEPTH (cm)

TRANSECT: GF-T0

SITE	1990	1991
0.0	-88.5	-200
0.25	-154	-100
0.5	-122	-75
1	-88.5	-81
5	-56.5	-57
10	-50	-51
15	-50.5	-61
20	-44	-56
25	-58	-61
30	-69	-61
35	-53.5	-58
40	-86	-64
45	-47	-46
50	-37	-33
55	-44	-43

TRANSECT: GF-T1W

SITE	1990	1991
0	-135	-120
0.25	-156	-110
0.5	-158	-107
1	-185	-178
5	-48	-50
10	-52	-48
15	-72	-44
20	-61	-54
25	-91	-89
30	-81	-43
35	-64	-47
39.5	-81	-108
40	-134	-130
40.3	-122	-123
40.5	-119	-121

TRANSECT: GF-T1E

SITE	1990	1991
0.0	-98	-104
0.25	-135	-100
0.5	-108	-78
1	-125	-120
5	-74.5	-77
10	-104	-79
15	-80	-69
20	-83	[illegible]
25	-70	-97
30	-94	-94
35	-99	-71
38.7	-128	-80
39.2	-130	-108
39.5	-139	-155
39.7	-64	-279