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Post-glacial Vegetation History of the Aishihik Basin and Its Vicinity, Southwest Yukon Territory, Canada: A Palynological Perspective

by

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To my parents and my wife

Abstract

Nine pollen profiles were obtained along a broad latitudinal transect extending from the Upper Nisling Valley to the Ittlemit Lake and Bear Lakes areas in the southwest Yukon Territory. Radiocarbon dated fossil pollen records from these profiles provided evidence for the reconstruction of post-glacial environmental history of the area. Surficial samples combined to aid the interpretation of the fossil data.

Records of these sequences suggest that the post-glacial vegetation in the area exhibited a successional development. Immediately after the deglaciation, the area was covered by a sparse herb dominated tundra assemblage. Betula glandulosa invaded the area at about 10,000 yr BP, which initiated the replacement of herbaceous tundra by a dwarf birch shrub-tundra. Picea glauca invaded the Upper Nisling Valley in the northern part of the study area and the Ittlemit Lake Basin in the south at least around 9,000 yr BP, while 8,600 yr BP in the central Aishihik Basin, marked the establishment of forest-tundra environment in the area. Significant rise of Picea pollen at 7,500-8,000 yr BP in the north-central part of the study area indicate the establishment of a modern boreal forest, which is approximately 1,500-2,000 years earlier than that indicated by the Antifreeze Pond pollen diagram from the Snag area of the southwest Yukon. It is notable that the pollen spectra of two

lacustrine sediments suggest a phase change of lakes into marsh occurring around 5,000-6,000 yr BP in the area, and change of bog conditions has also been recorded at almost the same time in the area. These events occurred simultaneously in the area and probably reflect the change of climatic conditions, which might have led to the development of permafrost in the region.

The development of early post-glacial vegetation in the area exhibited an unstable pattern. This instability was primarily related to the sequential invasion and migration of taxa from late-glacial refugia. Stable vegetation associations were established in the area as a result of migrators reaching their limit of climatic tolerance during the middle Holocene.

Post-glacial vegetation history in the Ittlemit Lake Basin area seems to have exhibited a different pattern. Spruce invaded the area at about 9,000 yr BP, and since then the regional forest-tundra vegetation has undergone little change. Variation of the pollen spectra during the last 9,000 years in this area has been interpreted as responses to the modification of local environmental conditions. Fossil pollen records from this area and the Middle Mackintosh Creek area support the interpretation deduced from analysis of modern surficial pollen records that changes of pollen spectra are not exclusively related to the variation of climatic conditions or upland vegetation succession, but also can be caused by the development of geomorphological processes or the modification of local environmental conditions.

Alnus pollen records in this study indicate that Aishihik Basin has never been favorable for the expansion of *Alnus* during the middle and/or late Holocene, although the rise of *Alnus* pollen to more than 20% was a common phenomenon in the northern pollen records. This discripency is primarily due to very low precipitation in the area. Exotic *Pinus* pollen records, however, reveal a frequent shift of atmospheric circulation system during the late Holocene, which is consistent with the extension of glaciers in the St. Elias Mountains during the Little Ice Age.

Résumé

Neuf profils polliniques ont été obtenus le long d'un transect latitudinal s'étendant de la vallée de la rivière Nisling jusqu'au Lac Ittlemit et jusqu'à la région du Bear lakes au sud ouest du Territoire du Yukon. Les échantillons polliniques datés au radiocarbone fournissent les éléments pour reconstituer l'histoire postglaciaire de l'environnement de cette région. L'analyse des echantillons polliniques de surface a facilité l'interprétation des données fossiles.

L'exemple de ces séquences montre des successions dans le développement de la végétation. Immédiatement après la déglaciation, la région a été couverte par une toundra herbacée. Betula glandulosa qui a envahi la région a environ 10,000 BP a initié le developpement de la toundra arbustive. Picea glauca qui colonise le bassin supérieur de la vallée de la rivière Nisling dans la partie nord de la région étudiée et le bassin du lac Ittlemit au sud, a environ 9,000 BP, et vers 8600 au centre du bassin d'Aishihik, marque l'installation de la toundra forestière. L'augmentation significative de Picea a 7,500 - 8,000 BP dans la partie centre nord de la region étudiée indique le passage à la forêt boréale moderne, soit approximativement 1,500 à 2,000 ans plus tot que dans le diagramme d'Antifreeze Pond au sud de Snag. La transformation des lacs en marais à 5,000 - 6,000 Bp reflète probablement un changement climatique qui suggère le développement du permafrost.

L'histoire postglaciaire de la végétation dans le bassin du lac Ittlemit semble aussi avoir été differente. La région a été envahie par Picea à environ 9,000 BP et depuis la toundra forestière régionale n'a guère changé. Les variations dans les spectres polliniques ont été interprétés en terme de réponse au modification des conditions environnementales locales. Le profil pollinique de cette région et celui de Mackintosh Creek moyen étaye l'hypothèse déduite de l'analyse des spectres contemporains, à savoir que les changements dans les spectres polliniques ne sont pas nécessairement reliés aux variations climatiques ou aux successions de végétation, mais peuvent aussi être causé par le développement de processus géomorphologiques ou de modification des conditions environnementales.

Le pollen d'Alnus n'ést jamais abondant dans nos diagrammes ce qui indique que le bassin d'Aishihik n'a jamais été favorable a son extension durant le milieu ou la fin de l'Holocène bien qu'il atteigne communément une fréquence de 20% dans les diagrammes polliniques nordiques. Cette différence est due au precipitation tres basse dans notre region. Par ailleurs les pourcentages polliniques de Pinus révèlent un changement fréquent du systeme de circulation atmosphérique durant la derniére partie de l'Holocène, qui est consistant avec l'éxtension des glaciers dans les Montagnes St. Elias durant la Petit Age Glaciaire (s.s.).

内容提要 (Abstract)

本文提供了艾什克盆地 (Aishihik Basin) 及其相邻地区九条剖面的孢粉资料. 这些剖面北起尼斯林河谷 (Nisling Valley), 南到依特尔米特湖 (Ittlemit Lake) 及贝尔湖 (Bear Lakes) 地区, 大致呈经向分布. 化石孢粉资料佐以碳同位素测年资料, 为重建该区冰后期环境演替历史提供了可靠证据. 同时, 区内现代地表孢粉学的研究结果为化石孢粉资料的解释提供了参考.

这些剖面的孢粉记录表明, 研究区内冰后期的植被发育过程呈现序列性. 末次冰期后, 区内发育了草本植物为主的稀疏苔原植被. 大约 10,000 年前 (yr BP), <u>Betula glandulosa</u> 侵入该区, 从而导致了一次植被更替—— 以丛桦为主的灌木苔原取代了以前的草本苔原. 黑云杉 (<u>Picea glauca</u>) 至少在 9,000 年前分别侵入研究区北部的尼斯林谷地和南部的依特尔米特湖区, 而抵达艾什克盆地中部的时间则为 8,600 年前. 区内北部及中部剖面中的黑云杉花粉含量 (百分比及花粉聚集速率) 显著增加, 标志着现代北方针叶林在区内的出现. 这一事件至少比邻区斯奈格 (Snag) 的孢粉记录所指示的年代早 1,500 - 2,000 年. 值的注意的是, 本项研究中有两个钻孔的孢粉谱表明, 约在 5,000 - 6,000 年前, 这两个湖塘涸化成为泥炭沼泽. 与此同时, 其余几个泥炭沼泽的生态条件也发生了变化. 这些几乎同时发生的事件可能标志着气候条件的变化及区域性多年冻土的发育.

该区早冰后期的植被极不稳定，这种不稳定性主要与来自末次冰期避难所的植物属种呈序列性迁移和侵入有关．到全新世中期，迁移者到达了其气候适应界限，因此，稳定的植被面貌在该区建立了起来．在依特尔米特湖区，冰后期的植被发育历史呈现不同的格局．黑云杉至少已在 9,000 年前侵入该区，从此以后，区域性森林苔原植被面貌未发生大的变化，孢粉谱的变化主要受局部环境条件变化的影响．该区及马肯它什谷地中游的孢粉资料的解释与现代地表孢粉学研究的结论一致：孢粉谱的变化并非毫无例外的都是由气候变化或植被演替所致，地貌发育过程所诱发的局部环境条件变化同样可以导致孢粉谱的变化．

虽然 Alnus 花粉在亚极地全新世中晚期孢粉谱中一般都超过 20%，但本项研究表明，由于受到艾什克盆地环境条件的限制，Alnus 未能在该区广泛分布．这一差异主要由于该区的干旱气候所造成．

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Chapter 1

Introduction

1.1 Introduction

Pollen analysis has been widely used throughout the world as a tool for the reconstruction of Quaternary vegetational history and climatic changes. During the last few decades, palynological investigations in northwestern Canada have been one of the important targets for Quaternary research because of the geographic position. Most of Canada experienced several periods of massive glaciation during Pleistocene while most of Alaska and the far northwest of Canada escaped the last glaciation, and therefore formed an important refugium during late Pleistocene for the plants and animals (Hultén, 1937). The consequent approach of post-glacial environmental history in this region also exhibits great interest for Quaternary scientists since the high latitude sites are sensitive to global change of environmental conditions, which is of great importance to human society. A working knowledge of the history of variation of post-glacial environments is essential for a better understanding of the inter-relationships between the Earth's ecosystem and climatic conditions upon which human beings depend.

Attempts to reconstruct past environments through pollen analysis are based upon the collection and appropriate interpretation of modern and fossil pollen records. The Aishihik Basin and its adjacent areas (Fig. 1.1) have been chosen for such an effort in order to trace the environmental

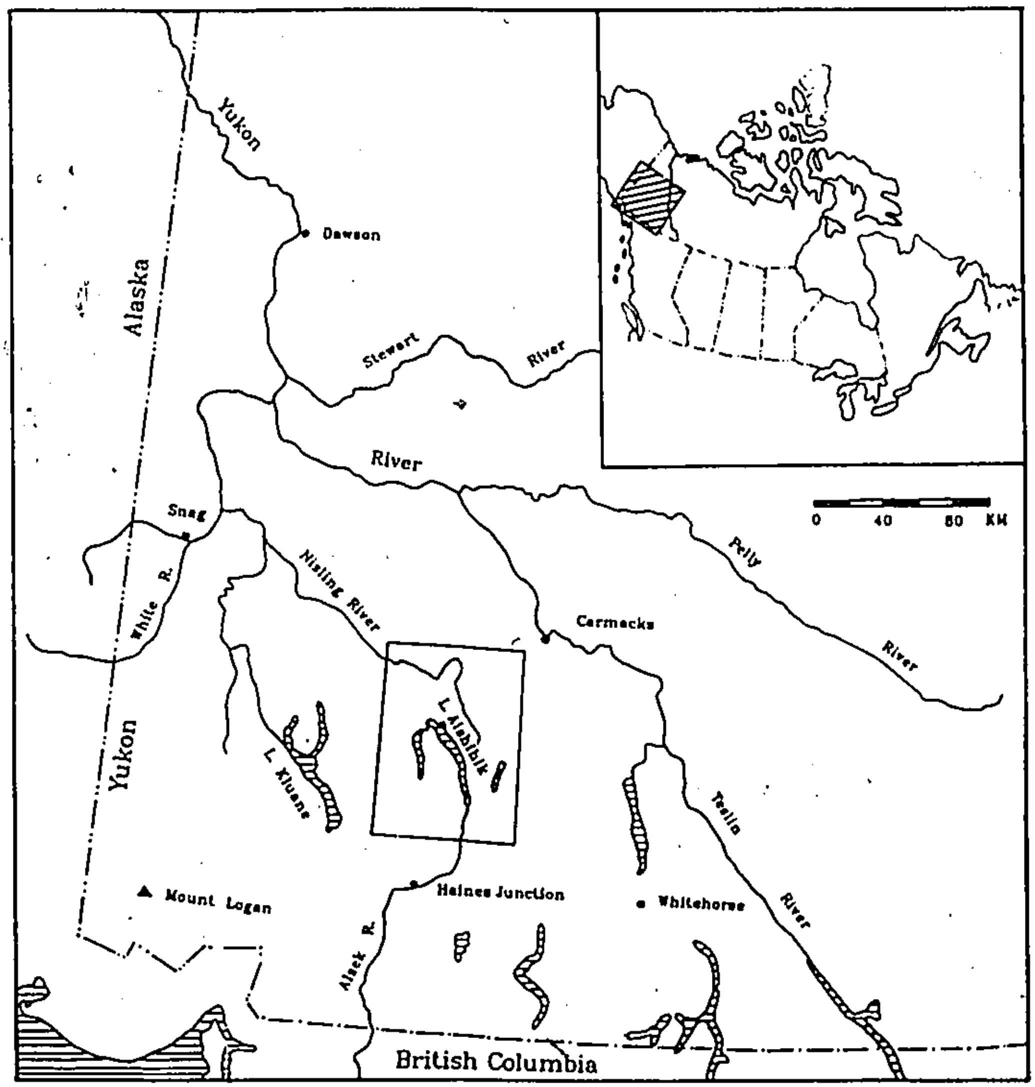

Figure 1.1 Location of the study area

history. Although it is close to the east end of Beringia, this region has not been fully investigated for pollen records and therefore remains a large gap in the paleogeography of northwestern Canada.

1.2 Previous Palynological Investigations in the Southwest Yukon Territory and adjacent Areas

Previous palynological investigations of late Quaternary environment history in northwest Canada and adjacent Alaska have been summarized before (Terasmae, 1961; 1967a; 1973; Ritchie, 1976; 1984a; 1985; Ritchie and Hare, 1971; Liu, 1980; Wright, 1971; Nichols, 1974; 1975; Colinvaux, 1967b; Hills and Sangster, 1980; Ager, 1983; Ager and Brubaker, 1985; Heusser, 1983; MacDonald, 1984). During the last few decades, a number of paleoecological investigations of the late Quaternary history of vegetation and climatic variation in Yukon Territory, Alaska, and Northwest Territories have been carried out (e.g. Terasmae, 1959; Terasmae and Hughes, 1966; Ritchie, 1982; Ritchie et al., 1982; Lichti-Federovich, 1973; 1974; Ovenden, 1982; Cwynar, 1982; Rampton, 1971; Hansen, 1953; Ritchie, 1972; Ritchie and Hare, 1971; Spear, 1983; Hyvärinen and Ritchie, 1975; Mackay and Terasmae, 1963; Ritchie, 1984a; 1984b; MacDonald, 1983; Slater, 1978; Matthews, 1974; 1975; 1980; Nichols, 1972; 1974; 1975; Bourgeois et Geurts, 1983; Geurts, 1985; Beaudet, 1986; Campbell, 1987; de Bastiani, 1988; Wang, 1988a; Ager, 1975; 1983; Ager and Sims, 1981; 1984;

Schweger, 1981; 1982; Brubaker et al., 1983; Livingstone, 1955; 1957; Hopkins et al., 1981; 1982). Among these numerous publications, most pollen profiles concerning the history of paleoenvironment are concentrated in Alaska, northern Yukon, and adjacent Northwest Territories. These areas were not glaciated during the repeated glaciations of the Quaternary and form the eastern end of an ice-free refugium named Beringia by Hultén (1937). As an area that provided the late Cenozoic terrestrial link between the eastern and western hemispheres (Matthews, 1979), Beringia has drawn much attention, and its vegetation history during the Quaternary still remains in dispute (Matthews, 1982). The debate is concentrated on whether late Pleistocene vegetation was an extinct ancient "Arctic-steppe biome" (Matthews, 1976; Guthrie, 1982) or a sparse, discontinuous herbaceous tundra on upland sites and local sedge-grass meadows on lowlands (Cwynar and Ritchie, 1980; Cwynar, 1982; Ritchie and Cwynar, 1982). Consequently, pollen sites which cover the vegetation history of post-glacial time in Beringia provide a much larger record than sites in the glaciated southwestern Yukon and its adjacent areas. This section summarizes most of the published pollen profiles in the southwest Yukon Territory and its adjacent area. Several important profiles from the east end of Beringia will be mentioned also. Table 1.1 and figure 1.2 illustrate the frequently mentioned pollen sites in the area.

Table 1.1 A summary of fossil pollen sites frequently referred in the text. Site numbers appear on figure 1.3 and in the text.

Site #	Author (s)	Site Name	Co-ordinates	Sediment
1	Beaudet (1986)	Mackintosh Creek	61°45'08" 137°12'43"	lac
2	Hansen (1953)	Alaska Highway	52°–65° 113°–148°	bog
3	Stuart et al (1988)	Jenny Lake	Not available	lac
4	de Bastiani (1988)	Williscroft Creek	61°00' 138°33'	bog
5	Bourgeois et Geurts (1983)	Grizzly Creek	61°07' 139°02'	bog
6	Birks (1980a)	Klutlan Glacier	61°35'–37' 140°30'–35'	bog
7	Campbell (1987)	Shaky Hand Creek	61°33' 138°21'	min
8	Rampton (1971)	Antifreeze Pond	61°21' 140°50'	lac
9	Ager (1975)	Lake George	63°47' 144°30'	lac
10	Ager (1975)	Birch Lake	64°19' 146°40'	lac
11	Matthews (1974)	Isabella Basin	Not available	clv
12	Terasmae and Hughes (1966)	Chapman Lake	64°55' 138°23'	bog
13	Ritchie (1982)	Lateral Pond	65°57' 135°31'	lac
14	Aderson et al. (1988)	Tiinkdhual Lake	66°34'46" 143°09'13"	lac

Notes: lac = lake, min = mineral, clv = colluvial

Table 1.1 continued

Site #	Author (s)	Site Name	Co-ordinates	Sediment
15	Anderson et al. (1988)	McFarlane Lake	68°21'27" 143°32'56"	lac
16	Edwards and Brubaker (1986)	Ped Lake	67°12' 142°05'	lac
17	Ovenden (1982)	Polybog	67°48' 139°48'	bog
18	Cwynar (1982)	Hanging Lake	68°23' 138°23'	lac
19	Hyvärinen and Ritchie (1975)	Eskimo Lakes	69°24' 131°40'	lac
20	Ritchie and Hare (1971)	Tuktoyaktuk 5	69°03' 133°27'	lac
21	Ritchie (1972)	Tuktoyaktuk 6	69°06' 133°25'	lac
22	Spear (1983)	Sleet Lake	69°17' 133°35'	lac
23	Ritchie (84a)	Twin Tamarack	68°09' 133°29'	lac
24	Ritchie (1977)	Maria Lake	68°06' 133°28'	lac
25	Ritchie (1984b)	SW Lake	67°38' 132°00'	lac
26	MacDonald (1984)	Ra Lake	65°14' 126°25'	lac
27	MacDonald (1984)	Lac Meleze	65°13' 126°07'	lac
28	MacDonald (1983)	Natla River	63°00' 129°05'	bog

Notes: lac = lake, min = mineral, clv = colluvial

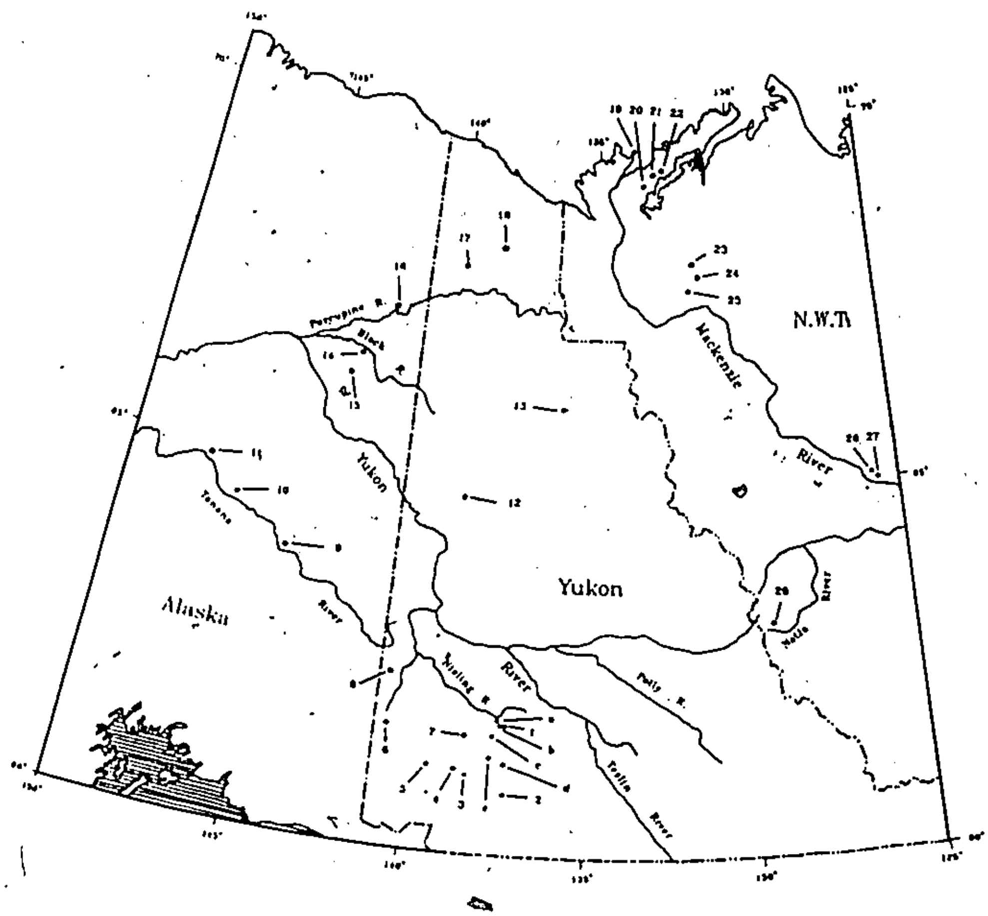

Figure 1.2 Location of selected fossil pollen sites frequently referred in the text. Specifications see table 1.1

Hansen (1953) was probably the first palynological investigation in the area (site 2 on fig. 1.2), reporting 75 peat sections and 40 pollen diagrams along the Alaska Highway. More recently, Rampton (1971, site 8) reported a 6.4 m sequence from Antifreeze Pond in the Snag - Klutlan area (62°21' N, 140°50' W), which provided the first long records of detailed pollen analysis for the entire region, covering an interval from about 31,000 yr BP to the present. The original percentage diagram was divided into 6 pollen zones. Rampton (1971) concluded that pollen zone 1 represents a sedge-moss or fell-field vegetation stage, and Zone 2 a shrub tundra vegetation in the area under slightly less severe climatic conditions. Sedge-moss tundra with a cold summer climate prevailed in the area during zone 3 time, from 27,000 to 9,980 yr BP. The post-glacial environment history is represented by pollen zones 4 to 6, which indicate a transition from shrub tundra via *Picea* woodland to mature *Picea* forest. Zone 4 represents a time interval from 9,980 yr BP to 8,710 yr BP during which the area was covered by a shrub tundra similar to zone 2 but characterized by increased precipitation. Spruce invaded the area about 8,710 yr BP at the beginning of zone 5, and a spruce forest or woodland vegetation was interpreted from pollen records. A sharp rise of *Alnus* pollen at 5,700 yr BP marks the end of zone 5 and the beginning of zone 6. The vegetation and climate in the area during this period have been interpreted as similar to those at present. It is also suggested by macrofossil evidence that the treeline was higher than at present at least three times since 5,700 yr BP, however such a regime was not registered in pollen records.

Four short profiles from Gull Lake and Triangle Lake at the Klutlan Glacier area in the southwest Yukon were reported by Birks (1980a, site 6). These profiles represent the vegetation history of the last 1,230 years. Pollen records on the upland at Gull Lake suggest an initial species-rich treeless vegetation after the White River eruption (at about 1,230 yr BP, see chapter 2). This vegetation cover was replaced by birch-alder-willow shrub tundra which was replaced by an open spruce forest similar to the present vegetation around the lake. Profile Triangle Lake provided pollen records of a vegetation succession from a Salix-Shepherdia canadensis stage via open spruce woodland to a dense spruce forest. These profiles however, are lacking in ^{14}C date control although the presence of the White River ash layer does provide a reliable date of 1,230 yr BP (Denton and Karlén, 1977).

Bourgeois and Geurts (1983) reported three pollen sections from the Grizzly Creek basin in the southwest Yukon Territory. Three pollen zones were interpreted from these profiles presenting evidence for vegetation evolution in the area during the last 2,000 years (site 5). The oldest zone has been interpreted as representing a vegetation which is comparable to that of the present and a climate similar to or slightly colder than today. The subsequent zone represents a drier and warmer climate than before causing a strong decrease of <u>Picea</u> in the pollen spectra (a break of pollen production). Zone 3 represents vegetation and climate conditions similar to those of zone 1 thus marking the return of zone 1 environmental conditions to the area.

A 3.05 meter lacustrine sediment core analyzed by Beaudet (1986) at Upper Mackintosh Creek is the first pollen profile obtained in the Aishihik Basin (site 1), and was classified into three local pollen zones. Interpretation of the pollen records in this profile suggests that the area was covered by a herb tundra followed by a birch-dominated shrub tundra at about 9,900 yr BP. Spruce arrived in the area at about 8,900 yr BP. The modern forest tundra vegetation developed at about 8,000 yr BP and has remained stable since then. However, the conclusion that the pollen records of this profile indirectly support the spruce refugium hypothesis in unglaciated southwestern Yukon and/or Alaska lacks hard data.

Campbell (1987, site 7) analyzed a 2.34 meter section from Shaky Hand Creek in the central Ruby Range near the Aishihik Basin. The pollen profile was divided into 7 local pollen zones which represent a small-scale, short-duration, climatic oscillation regime over the past 4,500 years. Two different states of the oscillation have been proposed which includes a present cold and semi-arid condition and a warmer and drier climate. However, due to severe problems with ^{14}C date determination, the absolute chronology of these events is uncertain.

Pollen records from a 26 cm section in the Bear Lakes area (Wang and Geurts, 1987a; Wang, 1988a; site e) represent a history of vegetational and climatic variation during the last 1,230 years. The area was covered by spruce forest tundra after the deposition of the White River ash, which is supported by both pollen and macrofossil evidence. Natural fire was interpreted as being responsible for an abrupt decline of spruce pollen. Reforestation in the area occurred quickly after the fire as a result of the strong reforestation potential of the prefire vegetation. An abrupt increase of spruce pollen in the uppermost part of the section, and the periodic occurrence of *Pinus* pollen peaks, have been interpreted as an indication of the occurrence of colder and moister climatic conditions and a periodic shift of atmospheric circulation systems in the area. This interpretation is consistent with the evidence of glacier advance in the St. Elias Mountains during the Little Ice Age.

More recently, Stuart et al. (1988, site 3) reported a 1.73 m sequence at Jenny Lake located about 55 km northwest of Haines Junction in the southwest Yukon. The sequence is divided into 5 pollen zones which cover the period from 12,500 yr BP to the present. Zone 1 is interpreted as a shrub-tundra assemblage which ranges from about 12,500 to 9,500 yr BP. Zone 2 from 9,500 to 8,500 yr BP is dominated by Alnus therefore representing an Alnus shrub-tundra. Zone 3 represents an interval of Picea forest in the area, from 8,500 to 4,500 yr BP. Zone 4 is characterized by an increase of Alnus from 15% to about 25%, and a decrease of Picea. A Picea-Alnus woodland is reconstructed from about 4,500 to 2,000 yr BP. Zone 5 covers an interval from about 2,000 yr BP to the present, characterized by a return of Picea dominance in the area. The authors have concluded that pollen records of this sequence do not support the belief that the southwest Yukon supported an extensive grassland vegetation during much of Holocene (Johnson and Raup, 1964; Workman, 1978), and therefore argued for a re-evaluation of the hypothesis that early prehistoric hunters and gatherers in the area were adapted to grasslands.

A 2.75 m pollen section at Williscroft Creek in the Kluane Lake area (de Bastiani et Geurts, 1987; de Bastiani, 1988; site 4) represents a time interval from 5,480 yr BP to present during which a dense spruce forest covered the landscape in the area. It has been concluded that "the low altitude forest was not affected by Neoglacial climatic fluctuations such as observed at high altitude sites" (de Bastiani, 1988, p. i). Such a conclusion is consistent with that of Stuart et al. (1988).

Besides the above mentioned pollen sequences in the southwest Yukon, some pollen profiles from the central to north Yukon, the adjacent Northwest Territories and Alaska provided interesting data pertinent to this study due to their detailed and distinctive pollen records of postglacial time. Terasmae and Hughes (1966, site 12) reported a pollen sequence from a 4.2 m frozen peat core at Chapman Lake in the Ogilvie Mountains which represents a vegetational history for the past 13,870 years. Cyperaceae and Gramineae dominated pollen zone 1 while zone 2 was characterized by an abrupt rise of Betula. Zone 3 represented a Picea-Alnus assemblage. Although the second site at Gill Lake investigated by Terasmae and Hughes (1966) lacked the herbaceous zone of the Chapman Lake profile, the basic pattern of these two profiles has been repeatedly recognized at many sites in the northwest (Ritchie, 1985).

The pollen profile of Lateral Pond in the Richardson Mountains in northern Yukon (Ritchie, 1982, site 13) has been repeatedly cited as a representative example of late Quaternary pollen records in this area. The area supported a sparse, unproductive herb tundra on the lower montane slopes and a sedge-grass marsh complex in poorly drained sites before 16,000 yr BP. By 12,500 yr BP the entire region was covered by a treeless community, while a rapid spread of dwarf shrubs occurred at 12,000 yr BP. The modern spruce woodland had established at about 7,500 yr BP, and changed slightly with the expansion of <u>Alnus</u> and tree birch to their modern status around 6,000 yr BP.

Further north in the Old Crow Flats area, a 4.03 m pollen sequence was reported by Cwynar (1982, site 18), who provided a very detailed and thorough analysis with numerous ^{14}C dates, large pollen sums, and detailed pollen identifications. The sequence was divided into 5 pollen zones which represent a vegetation history covering the past 25,000 or 33,000 years. Pollen zone 1, from 33,000 to 18,450 yr BP, was dominated by herbaceous pollen with a low pollen accumulation rate. Interpretation of this herb zone as a sparse, discontinuous vegetation of herbaceous tundra on upland and local sedge-grass meadows on lowlands, challenges the traditional arctic-steppe or grassland concept of late Pleistocene paleovegetation in the unglaciated northern Yukon (Cwynar and Ritchie, 1980; Cwynar, 1982; Ritchie and Cwynar, 1982). Zone 2 suggests the development of snowbed and willow scrub communities in sheltered areas between 18,450 and 14,600 yr BP. Zone 3 indicates the spread of dwarf birches into the area between 14,600 and 11,000 yr BP. Variations of the pollen spectra of zone 4 represent a warmer and wetter climate from 11,000 to 8,900 yr BP and provide evidence for a late Pleistocene to early Holocene warm interval (Cwynar, 1982; Ritchie et al., 1983). The last pollen zone represents the regional expansion of Alnus crispa into the area from 8,900 yr BP and the pollen spectra remain unchanged until the present.

Matthews (1980) reported a pollen sequence from John Klondike Bog in the southwest District of Mackenzie in the Northwest Territories, which consisted of a 4.7 m peat and gyttja core. Three regional pollen zones were recognized from this profile, which represent a history of paleoecological evolution for the last 9,600 years. Macrofossils including mollusca, insects, as well as fruits and seeds of higher plants were also recovered from this sequence. Interpretation of the pollen and macrofossil records indicates that spruce forest conditions have prevailed in the area for most of the last 9,500 years. Pinus moved into the area at about 6,700 yr BP and have never been much less or more abundant than now during the last 6,700 years. Alnus were absent or rare in the area prior to 8,700 yr BP. This sequence, however, in general is largely a record of local environmental change during the last 9,600 years.

In the southwestern Northwest Territories, MacDonald (1983) reported a 2.3 m peat sequence in the Upper Natla River area (site 28). This profile fills a large geographic gap of palynological investigation in the entire region, and represents a vegetation history covering the past 8,640 years. Two pollen zones were recognized and interpretations were facilitated by a set of 15 surface pollen samples and analyzed with principal component analysis. Interpretation of the records suggests that a dwarf birch tundra was widespread in the entire valley from 8,640 to 7,000 yr BP, and *Picea* expanded into the area at about 7,700 yr BP, remaining at its greatest dominance in the landscape until 5,000 yr BP. During this period, as MacDonald suggested, the treeline was probably higher than its present position as a result of middle Holocene climate amelioration.

More recently, MacDonald (1984; 1987) analyzed nine pollen profiles along a broad latitudinal transect extending from central Alberta to the Middle Mackenzie River valley, Northwest Territories, of which two profiles from the middle Mackenzie River valley are illustrated on figure 1.2 and table 1.1 (sites 26 and 27; other profiles are out of the mapped area). The Middle Mackenzie River valley supported a herb and shrub dominated vegetation during the interval of 12,000 to 11,000 yr BP. From 10,500 to 8,500 yr BP the region was dominated by a *Betula glandulosa* shrubland. *Picea glauca* arrived in the region shortly after 9,000 yr BP, and *Alnus crispa* achieved its late Holocene and modern representation in the region by 5,000 yr

BP. MacDonald has concluded that the early Holocene was a period of vegetation instability and rapid change, and regional vegetation of this period lacks a modern analogue in the area. Modern boreal forest has been established in the area since 5,000 yr BP and has remained stable since then.

A number of pollen profiles have been reported from the Mackenzie River valley and Tuktoyaktuk peninsula which provide detailed palynological records of late- and post-glacial vegetation history (Ritchie, 1972; 1977; 1984a; 1984b; Ritchie and Hare, 1971; Spear, 1983; Hyvärinen and Ritchie, 1975; Mackay and Terasmae, 1963. Site 19-25). Late Quaternary vegetation history could be summarized in this area from these publications. Following the last deglaciation, the area was probably covered by a dense shrub tundra on upland sites, a Salix community with grass-sedges on poorly drained lowlands, and an open sedge-herb-grass community on ridge summits and kame-like mounds. Spruce migrated into the Tuktoyaktuk peninsula at about 10,000 yr BP and a continuous spruce forest occupied the landscape from 9,000 to 5,000 yr BP. The modern forest-tundra ecotone reached its modern position at about 4,500 yr BP as the result of retreat of northern limit of boreal forest (Ritchie, 1984a). In the lower Mackenzie River Basin at the Travaillant Lake area (Ritchie, 1984b), the earliest vegetation cover from 10,500 to 9,000 yr BP in this area was a Betula glandulosa-Salix shrub-tundra as the chief community. _Picea glauca_ invaded the area at about 9,000 yr BP followed by a rapid expansion of the spruce forest onto upland sites. _Picea mariana_ spread into the area between about 8,500 and 5,000 yr BP. _Alnus crispa_ and _Alnus incana_ arrived at about 6,000-5,000 yr BP. Modern spruce-dominated vegetation has been stable since 5,000 yr BP.

In adjacent Alaska at Brooks Range and Umiat, Livingstone (1955; 1957) recognized three distinctive pollen assemblage zones. The first zone (herbaceous zone) represents a herbaceous tundra vegetation. The second zone (birch zone) represents a shrub tundra environment with dwarf birch predominating. The youngest zone (_Picea_-_Alnus_ zone) is characterized by high percentages of _Alnus_ and _Picea_. This three-zone sequence was soon realized to be applicable over an extensive area in central-north Alaska and north Yukon (Heusser, 1963; Colinvaux, 1964; 1967b).

Pollen records from lakes at Tanana Valley in the interior of Alaska (Ager, 1975; 1983; Ager and Brubaker, 1985) provided detailed continuous records of late Pleistocene and Holocene vegetation history (site 9 and 10). The herb zone of these lake sequences suggests that the full glacial vegetation in the Tanana Valley area was a herbaceous tundra community, which was replaced at about 14,000 yr BP by a shrub-tundra vegetation represented by a birch zone. From 11,500 to 9,500 yr BP the area probably supported an open *Populus* woodland and birch shrub tundra, as suggested by the *Populus*-*Salix* zone. *Picea* invaded the area at approximately 9,500 yr BP and the area supported a spruce-birch forest-tundra vegetation. It has been widely suspected that spruce spread into the southwest Yukon Territory from the Tanana Valley shortly after the invasion at 9,500 yr BP. The *Picea*-*Betula*-*Alnus* zone from these lake sequences suggests that the lowland boreal forest vegetation similar to that at present was established at about 8,400 yr BP, while at higher elevations *Picea* and *Alnus* occurred simultaneously at about 7,500 yr BP.

Investigations in the Ped Pond area in the Porcupine valley (Edwards and Brubaker, 1986, site 16) suggested that shrub birch and willow probably occurred locally in a sparse herb-dominated landscape during late-glacial period and early Holocene. *Picea glauca* first arrived near Ped Pond about 8,500 years ago, which has been considered as an indication of rapid expansion of spruce across far-eastern Beringia 8,000-9,000 years ago. Other boreal forest taxa became established between 7,000 and 8,000 yr BP. *Alnus* rose at about 7,500 yr BP, which has been interpreted as reflecting an eastward movement of alder.

More recent investigation in the Black River region (Anderson *et al.*, 1988) suggests that Livingstone's three-zone sequence is recognizable in this area (site 14 and 15). Tundra grew in the area between 19,800 and 15,000 yr BP, while a birch zone occurred between 15,000 and 7,500 yr BP. Spread of *Populus* (probably *Populus balsamifera*), *Betula nana-glandulosa*, and *Salix* between 9,700 and 7,500 yr BP resulted in a vegetation of shrub-tundra and *Populus* forest mosaic. *Picea glauca* migrated into the area at about 7,500 yr BP and *Picea mariana* about 1,500 years later. *Alnus* invaded the area at about 7,200 yr BP. Spruce arrived in the Black River region at 7,500 yr BP, and that in the central Porcupine Valley at the Ped Pond area (Edwards and Brubaker, 1986) around 8,500 yr BP. This was as much as 1,000 years after its first appearance in the Tanana Valley at 9,500 yr BP, and therefore questions the previous suggestion of spruce invasion from northwestern Canada via the Porcupine and Yukon River into central Alaska (Hopkins *et al.*, 1981; Ager, 1983), and indicates that this area probably was not an early Holocene migration route for *Picea*.

1.3 Objectives

The objectives of this thesis are to collect and interpret data concerning the post-glacial paleoecology, the local and regional environmental history, the development and stability of paleovegetation, and the variation of post-glacial climatic conditions of the Aishihik Basin and adjacent areas, and to undertake an assessment of palynological investigations in permafrost regions.

1.3.1 Paleoecological Data

Detailed paleoecological data for the east end of Beringia and adjacent areas are available from the literature as stated in the previous section. However there are few palynological records available from the southwest Yukon, especially in the Aishihik Basin and its adjacent areas. This study fills a large geographic gap in the palynological investigation in northwest Canada, which is essential for a better understanding of the post-glacial environmental history of the area.

1.3.2 Local Vegetation-Landform Relations and Environment History

Most pollen sequences from northern environments are recovered from lacustrine sediments, i.e. gyttja, which register the change of paleovegetation on a regional scale. Peat bog sequences on the other hand can provide detailed evidence of variations of local paleoenvironmental conditions without the common problem of the disturbance of sediments in lacustrine environment (Birks and Birks, 1980). Determination of local environment and the relationship between pollen spectra and local landscape have been previously practiced (eg. Savoie et Gangloff, 1980; Geurts, 1983; etc.). For this purpose, several peat sequences were recovered from the study area.

1.3.3 Vegetation Development and its Stability

Post-glacial vegetation development and vegetation stability will be considered and major factors controlling the vegetation stability will be discussed.

1.3.4 Paleoclimatic Inference

Paleoecological data will be used to reconstruct the variations of post-glacial climatic conditions. Such an effort will be facilitated with information regarding the relationship between modern surficial palynology and modern climatic conditions.

1.3.5 Problems of Pollen Analysis in Permafrost Regions

Efforts will be made to assess the problems of pollen analysis in permafrost sequences related to the influence of ice lensing and frost heaving on the determination of pollen accumulation rates in peat sediments.

1.3.6 Summary

Achievement of these objectives was attempted using palynological evidence collected from the Aishihik Basin and its adjacent areas. Nine pollen sequences, of which 2 were limnic sediments, were recovered (Fig. 1.3, Tab. 1.2). Interpretation of the results was supplemented by the

Table 1.2 A summary of fossil pollen sites in this study. Site numbers appear on figure 1.3 (Abbreviation: lac = lake)

Site #	Site Name	Lantitude	Longitude	Sediment
a	Upper Nisling Valley (XW-1)	61°51 13"	137°21 43"	bog
	Middle Mackintosh Creek (XW-2)	61°49 00"	137°15 09"	bog
b	Upper Mackintosh Creek (XW-3)	61°45 53"	137°14 40"	bog
	Polecat Lake (XW-4)	61°40 45"	137°27 12"	lac
	Aishihik Kettle (XW-5)	61°36 23"	137°32 48"	bog
c	Moose Depression (XW-6)	61°35 26"	137°30 57"	lac
d	Ittlemit Lake (XW-7)	61°14 07"	137°11 47"	bog
e	High Bog (XW-8)	61°16 47"	137°41 07"	bog
	Bear Lakes (XW-13)	61°16 05"	137°36 07"	bog

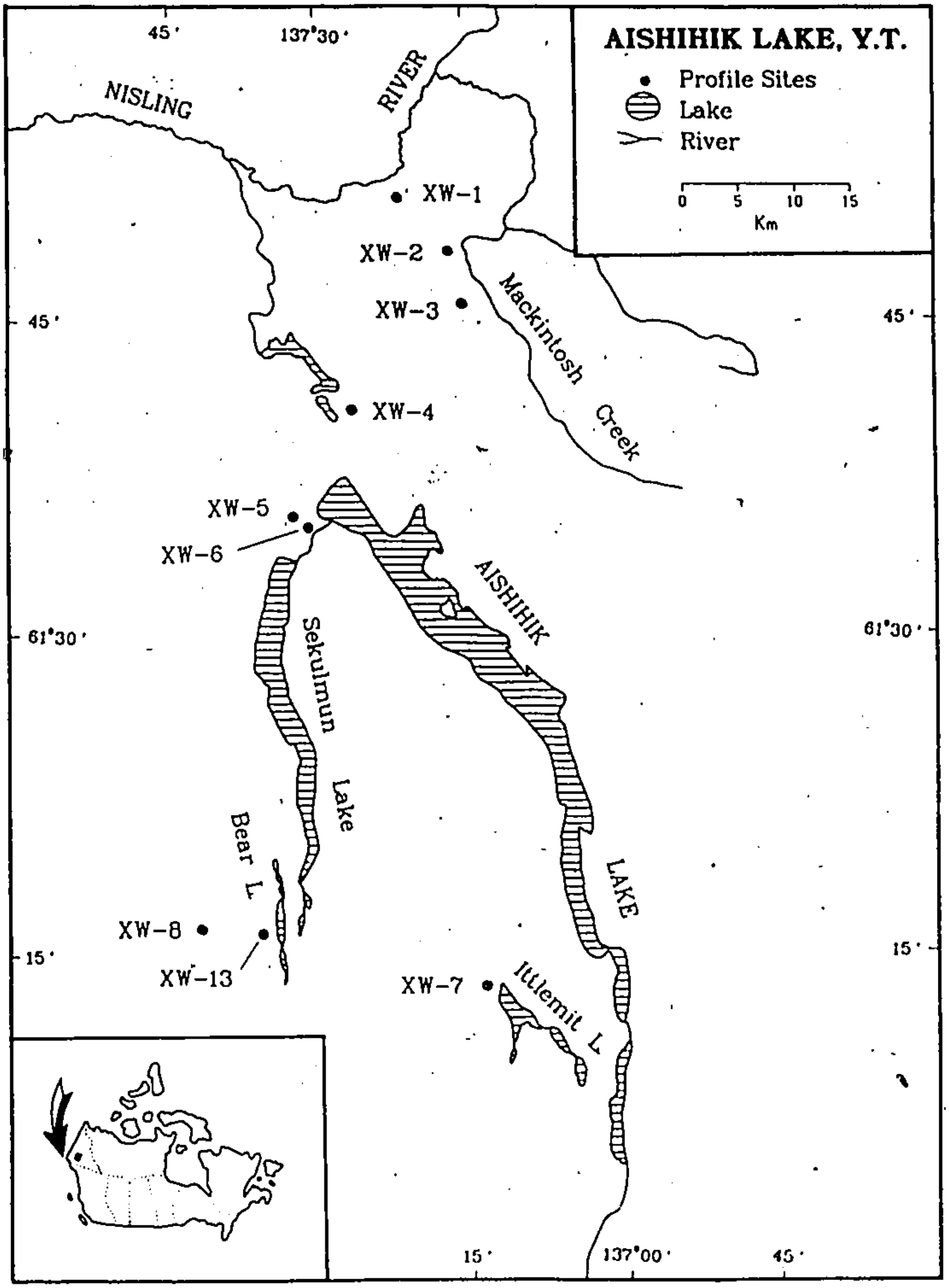

Figure 1.3 Location map of fossil pollen sites of this study

previously published palynological data in the area. Surficial pollen data were also obtained to compare the modern and fossil pollen spectra.

The thesis is broadly divided into three parts. The first part, chapters 1 to 3, contains introductory and background material. The second part, chapters 4 to 8, contains the modern and post-glacial pollen records in the different parts of the study area. The last part, chapters 9 and 10, is a synthesis and concluding discussion of all related topics.

Chapter 2

Physical Setting of the Study Area

2.1 Physiography

The physiography of the southwest Yukon Territory has been fully described and various subdivisions have been named by Bostock (1948, 1952). The basic classification and unit names are followed here (Fig. 2.1).

Bostock divided the Canadian Cordillera into three systems, Western, Interior and Eastern. The Western system comprises a lofty barrier between the interior Yukon and the Pacific Ocean. The St. Elias Mountains, the highest mountains of Canada and the largest group of great peaks in North America (Bostock, 1948), are an important physiographic component in the southwest Yukon because of their influence on climatic conditions and impact on aeropalynology of the study area.

The Interior system is made up of several major and minor mountain and plateau areas. Of these units, the Western Yukon Plateau, in Bostock's classification hierarchy, comprises Kluane Plateau, Klondike Plateau, and Shakwak Valley. Klondike Plateau is uniform in character. Kluane Plateau, however, with a general elevation of 1,524 m, is variable and also divisible into several subunits. Of these subunits, Ruby Range is the highest part of the plateau, reaching elevations up to 2,438 m (Bostock, 1952). North of Ruby Range, a few peaks of Nisling Range reach 2,130 m. Southeast of Nisling Range and east of Ruby Range, a subunit was identified by Bostock as Aishihik

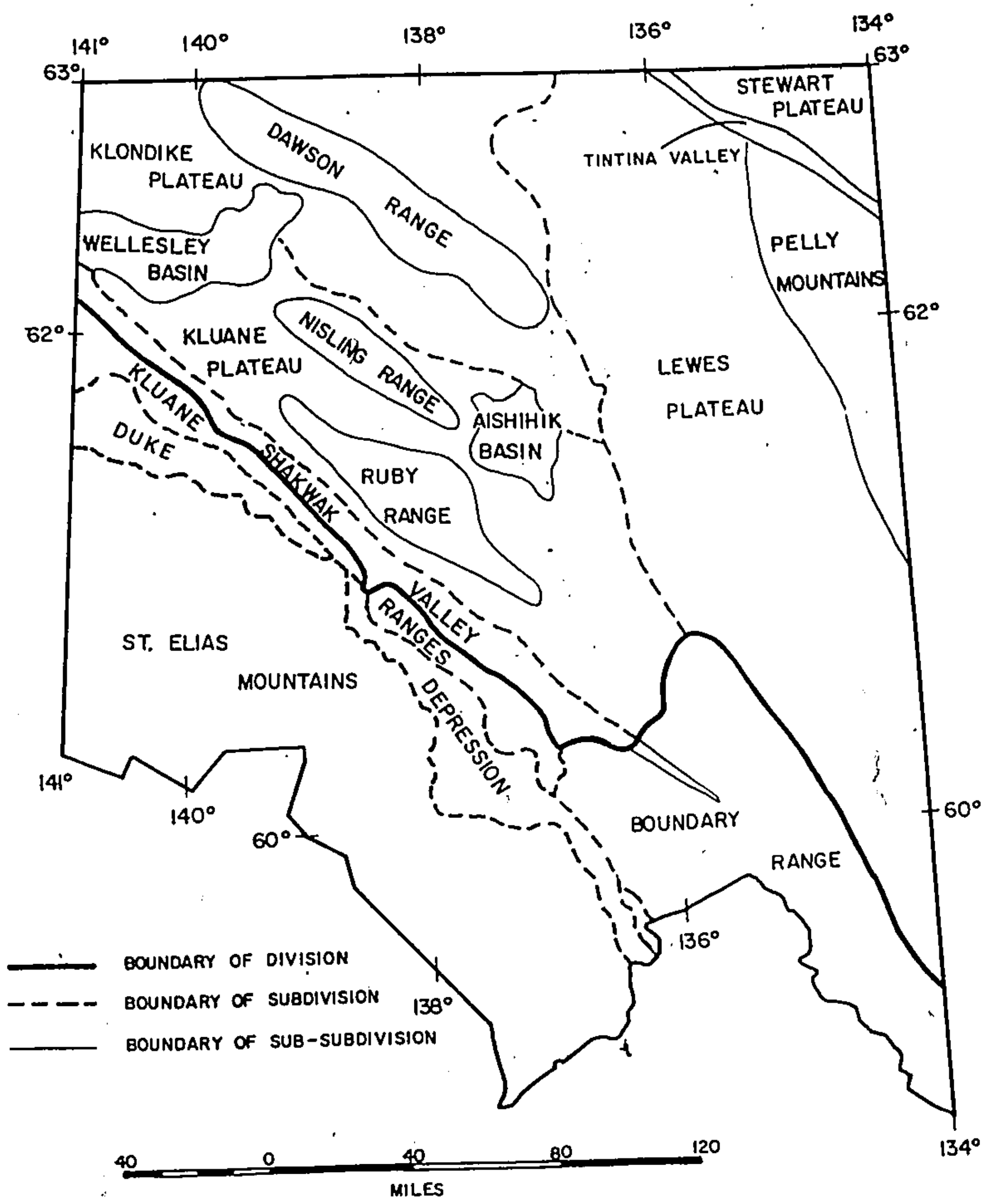

Figure 2.1 Physiographic subdivision of southwest Yukon Territory (after Bostock, 1948)

Basin, which includes Aishihik Lake and the area to the southeast. Most of the palynological investigations in this work are undertaken within this basin and its adjacent areas. Bostock (1948) described the physiographic features of this basin as follows:

> "Aishihik Basin is a broad, rolling depression lying for the most part between 4,000 and 5,000 feet above sea-level, and has a general slope northeast to Lews Plateau and Nisling River. Except for a number of rather widely separated valleys, whose floors are about 3,000 feet high, its dissection is not marked, and between Sekulmun and Aishihik Lakes and east of the latter broad stretches of rather smooth rolling plateau have a relief of about 1,000 feet without distinctly entrenched valleys. A few isolated mountains and mountain groups, with elevations in excess of 6,000 feet, stand upon it. Pleistocene ice reached to a height of about 5,000 feet above sea-level in the southern part of the basin, and moved northwestward along Aishihik Lake to near Nisling River. The ice also overflowed northeastward through gaps in the divide between Aishihik Lake and Nordenskiold River. A great part of the basin is drift covered." (p. 72).

The last subunit of Kluane Plateau is Wellesley Basin, which is located to the northwest in Kluane Plateau and has an elevation of about 610 m.

The Eastern System is made up of three units. Of these the Arctic Mountain and Mackenzie Mountain areas have built up a barrier between the interior Yukon and the Arctic Ocean, which has influenced the climatic conditions of the study area.

The environment described above makes up the physiographic framework of the study area and its adjacent territory. All environmental factors, such as vegetation distribution, evolution and climatic conditions, are controlled or influenced by this physiographic pattern.

2.2 Present Vegetation

Regional aspects of the vegetation in southwest Yukon Territory have been well documented (Oswald and Senyk, 1977; Rowe, 1972; Orloci and Stanek, 1979; Douglas, 1974; Johnson and Raup, 1964; Parent, 1988). However, no detailed investigations of either the present flora or vegetation have been carried out in the Aishihik Basin. This section, therefore, contains only a sketch of the present vegetation in the study area based upon airphoto interpretation and limited field observations. Further information about modern vegetation can be found under descriptions of physiographic setting for each pollen profile.

The study area falls in the central Yukon boreal forest region (Fig. 2.2; Rowe, 1972). Local tree line on the adjacent Ruby Range occurs at 1,158 m (Price, 1971). Within this general context, present vegetation cover exhibits great variety due to the complexity of landform, and can be classified into different vegetation-landform units. The diversity of these units is one of the most striking features of the area. The Nisling Valley area is covered by spruce forest with variations in vegetation-landform units. The North end of Aishihik and Sekulmun Lakes area also supports dense spruce forest. A broad region between these two forest areas, namely from north of Stevens Lake to an area near Nisling Valley, is covered by forest-tundra with different tree density. The forest spreads southward to the edge of the study area. As the result of its hilly and undulating topography, the area also exhibits altitudinal variation of vegetation cover. This variation is most conspicuous in the east and south-east parts of the area adjacent to the mountain ranges.

The differentiation of vegetation is controlled not only by altitudinal and ecological succession but also by landforms and surficial material. Picea glauca (white spruce) forest or woodland often occupy the hills or southerly slopes of gullies which are well-drained, mesic to moderately dry, and often covered by glacial till. Populus spp. groves are occasionally

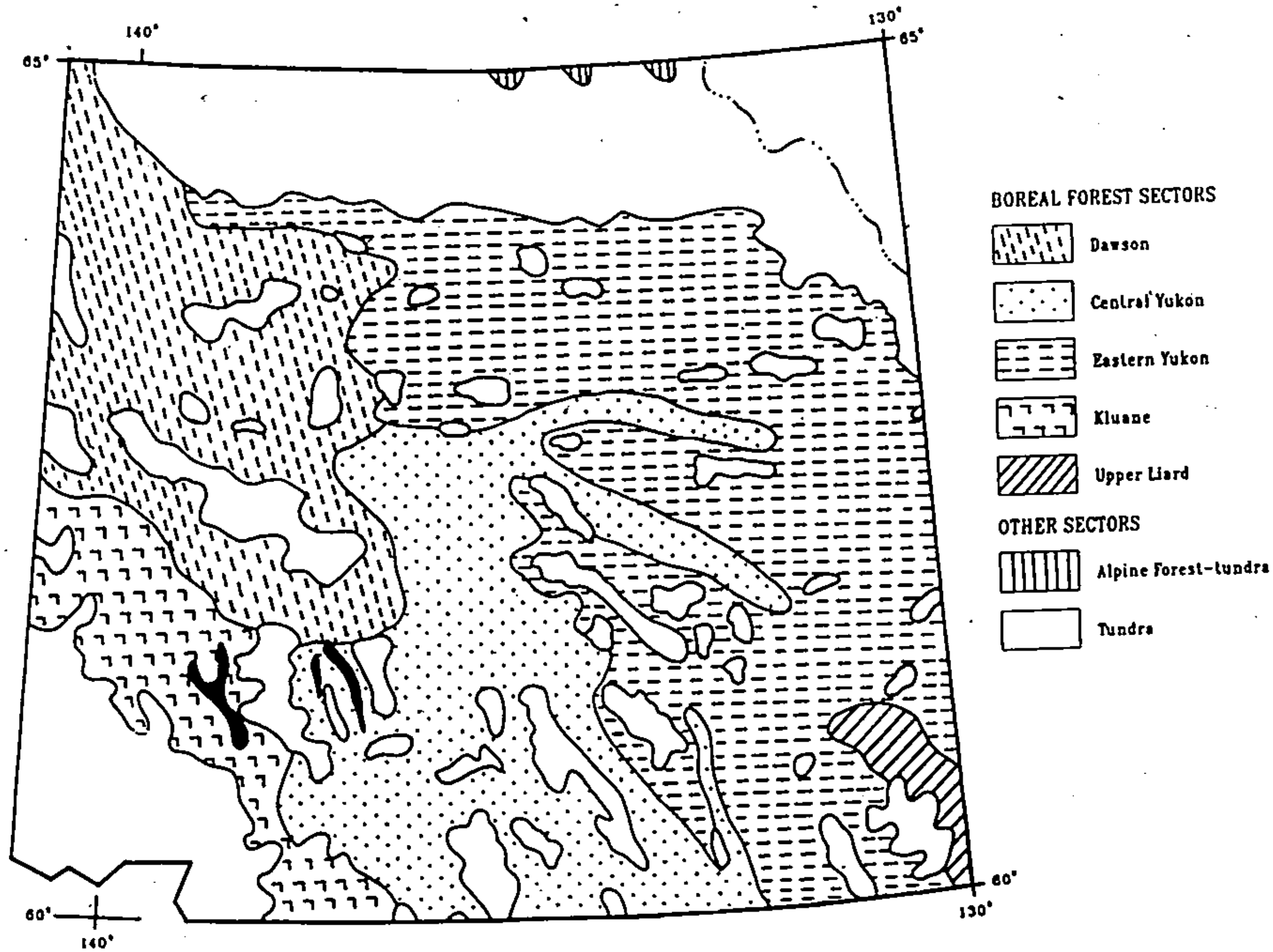

Figure 2.2 The major vegetation zones of south-central Yukon Territory (after Rowe, 1972)

found at the tops or upper slopes of moraine ridges in the Bear Lakes and Aishihik area. Betula glandulosa-dominated shrub communities are usually restricted to poorly to moderately drained depressions on glacial till parent material, and Salix glauca-dominated shrub communities are common on mesic to dry, moderately drained to well-drained glacial till. Cyperaceae-dominated herbaceous communities, however, occur on most poorly drained lowlands or in depressions such as wet meadow or wet tundra on organic peat deposits of various thickness usually underlain by glacial drift or glacial-fluvial deposits. This wet community is spread all over the area upon the landform variation.

2.3 Modern Climate

The study area is on the southern edge of the "Central Interior" climatic division of the Yukon Territory (Kendrew and Kerr, 1955). Climatic records (Environment Canada, 1982) from the abandoned Aishihik climatic station, which was located at the centre of the study area, show that there are seven months in which the mean daily temperature is lower than the freezing point, and similar records have also been discovered in the climatic stations of Snag, Kluane, and Carmacks (Tab. 2.1). Mean annual temperature in Aishihik is -4.4°C. The ombrothermic diagram is shown in figure 2.3.

Table 2.1 Temperature (°C) and precipitation (mm) in four stations in southwest Yukon

Month	Aishihik		Carmacks		Snag		Kluane	
	T	P	T	P	T	P	T	P
Jan	-23.6	11.7	-28.2	18.4	-30.4	17.2	-20.5	7.2
Feb	-16.9	9.1	-19.4	12.5	-22.0	16.0	-15.4	5.9
Mar	-12.2	10.1	-11.6	10.6	-14.1	12.4	-10.9	5.2
Apr	-3.7	8.3	-0.1	7.2	-2.2	17.9	-1.8	7.9
May	4.2	22.4	7.1	15.5	6.4	28.9	5.4	22.1
Jun	9.8	41.1	12.5	37.4	12.0	58.3	10.3	32.3
Jul	12.1	48.5	14.5	42.3	14.0	61.1	12.6	47.0
Aug	10.3	40.5	12.4	34.1	11.5	39.0	11.2	34.1
Sep	5.1	24.5	6.7	25.1	5.2	29.0	6.3	17.2
Oct	-2.6	16.0	-2.0	17.7	-6.1	21.0	-1.6	16.3
Nov	-13.6	12.4	-13.8	18.6	-19.3	18.8	-9.7	17.7
Dec	-21.9	11.7	-24.0	14.9	-28.2	18.9	-18.5	11.0
Year	-4.4	256.3	-3.8	254.3	-6.1	338.5	-2.7	223.9

Note: Data from Environment Canada (1982)

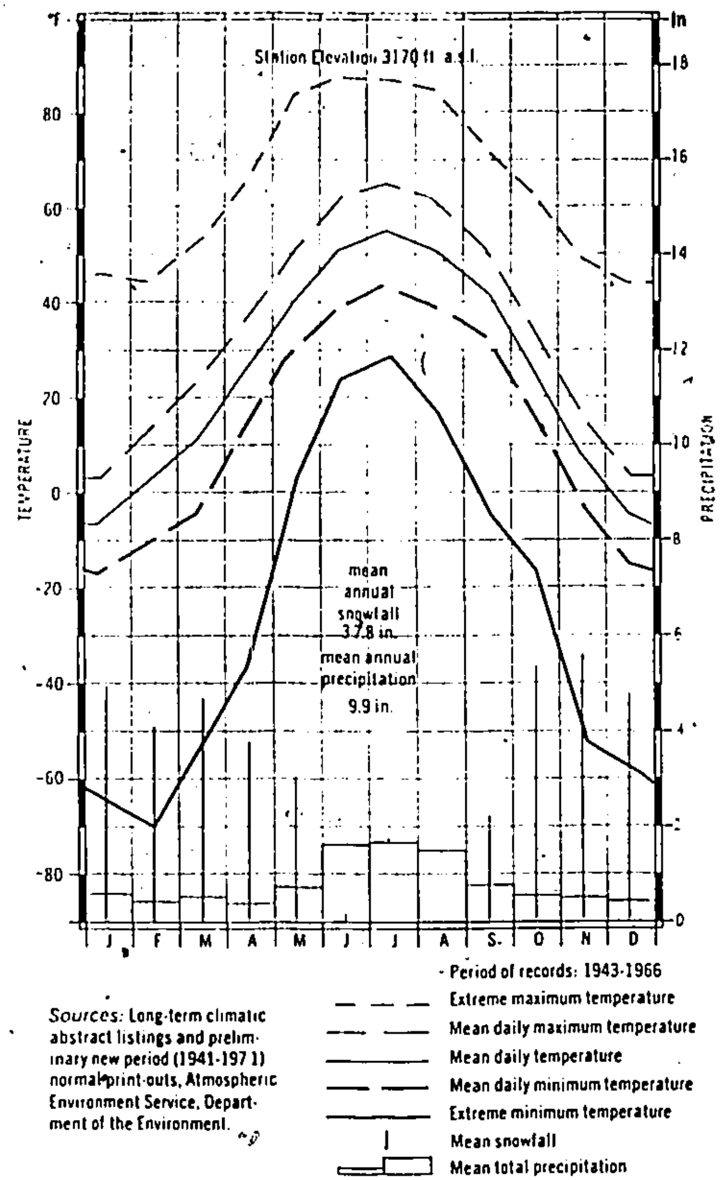

Figure 2.3 Climatic characteristics of the Aishihik area, southwest Yukon Territory (after map of Land Use Information Series, 1973, 115h.).

This area receives an average of 256.3 mm precipitation per year, with 63.2% of that being rainfall. 79.1% of annual rainfall and 50% of annual total precipitation occurs in June, July and August (Tab. 2.1). This precipitation regime makes the region one of the driest in Canada.

Summer in the area is very short. An average of 16 years of records shows 47 frost-free days. The last day of frost occurs on June 23, and the first day of frost on August 10. The shortest frost-free record was only 25 days.

It is remarkable that the wind normals in the area exhibit strongly seasonal variations (Tab. 2.2; Tab. 2.3). The dominant wind directions are S and SE throughout the year except in the winter, during which northerlies are more important (Fig. 2.4). In terms of mean wind speed, the winds in the area are among the strongest recorded at Yukon climatic stations. The mean is about 12.9 km per hour in spring and fall, and 8 km per hour in winter. Kendrew and Kerr (1955) described the wind regime in Aishihik as below:

> "SE and S winds are by far the strongest all the year and also among the most frequent; N winds which are the most frequent in winter have only half the speed of the southerlies; ......"(p.165).

Table 2.2 Percentage frequency of wind directions in Aishihik, Yukon Territory (period: 1955-1980)

Month	N	NE	E	SE	S	SW	W	NW	Calm
Jan	9.7	8.6	1.1	2.0	12.8	8.3	2.0	1.4	32.9
Feb	13.8	10.1	1.0	1.9	14.1	9.2	1.5	2.2	20.7
Mar	13.9	9.3	1.5	2.7	16.2	9.5	2.2	2.4	19.7
Apr	7.3	4.8	1.7	3.9	24.2	12.3	2.3	4.4	12.4
May	6.4	5.1	1.6	5.0	27.4	9.7	2.7	3.0	6.5
Jun	7.6	5.1	1.8	5.9	23.5	10.6	3.2	3.0	6.6
Jul	8.0	5.4	1.9	5.3	23.0	11.2	3.7	2.8	8.6
Aug	7.3	5.2	1.7	7.0	22.4	10.8	4.3	2.9	10.4
Sep	11.3	6.7	1.6	3.7	18.9	9.3	4.1	2.7	12.5
Oct	14.2	10.6	1.3	2.7	14.4	8.7	3.9	2.3	10.9
Nov	12.3	12.1	1.4	1.8	11.0	6.7	3.5	1.2	20.1
Dec	10.5	9.2	1.3	1.4	10.8	8.9	2.7	2.0	30.6
Year	10.2	7.7	1.5	3.6	18.2	9.6	3.0	2.5	16.0

Note: Data from Environment Canada (1982)

Table 2.3 Mean wind speed (Kilometres per Hour) at Aishihik (period: 1955-1980)

Mean Monthly		Wind Directions							
		N	NE	E	SE	S	SW	W	NW
Jan	5.8	8.2	7.6	5.2	12.6	9.9	7.2	4.6	6.6
Feb	8.3	10.0	7.7	6.0	9.8	11.9	8.9	5.2	13.3
Mar	8.9	11.2	9.2	6.4	12.2	13.0	8.4	5.7	9.6
Apr	10.9	10.9	9.9	7.0	12.3	14.2	9.9	6.6	13.5
May	14.0	11.9	10.9	7.4	15.4	16.6	11.1	8.8	13.2
Jun	12.1	11.7	9.5	8.3	13.2	14.6	10.3	8.5	10.9
Jul	11.4	11.6	9.0	6.6	11.8	14.8	9.9	7.8	12.4
Aug	10.8	10.4	8.1	6.9	13.3	15.2	9.0	6.9	9.9
Sep	10.6	9.4	7.9	5.7	12.8	16.6	9.8	6.0	8.4
Oct	11.1	9.0	7.3	6.7	14.9	19.3	12.9	7.3	8.2
Nov	8.6	7.6	7.3	7.0	14.4	14.8	10.6	6.3	5.4
Dec	6.8	8.1	7.7	6.4	11.2	12.8	8.6	5.9	10.3
Year	9.9	10.0	8.5	6.6	12.8	14.5	9.7	6.6	10.1

Note: Data from Environment Canada (1982).

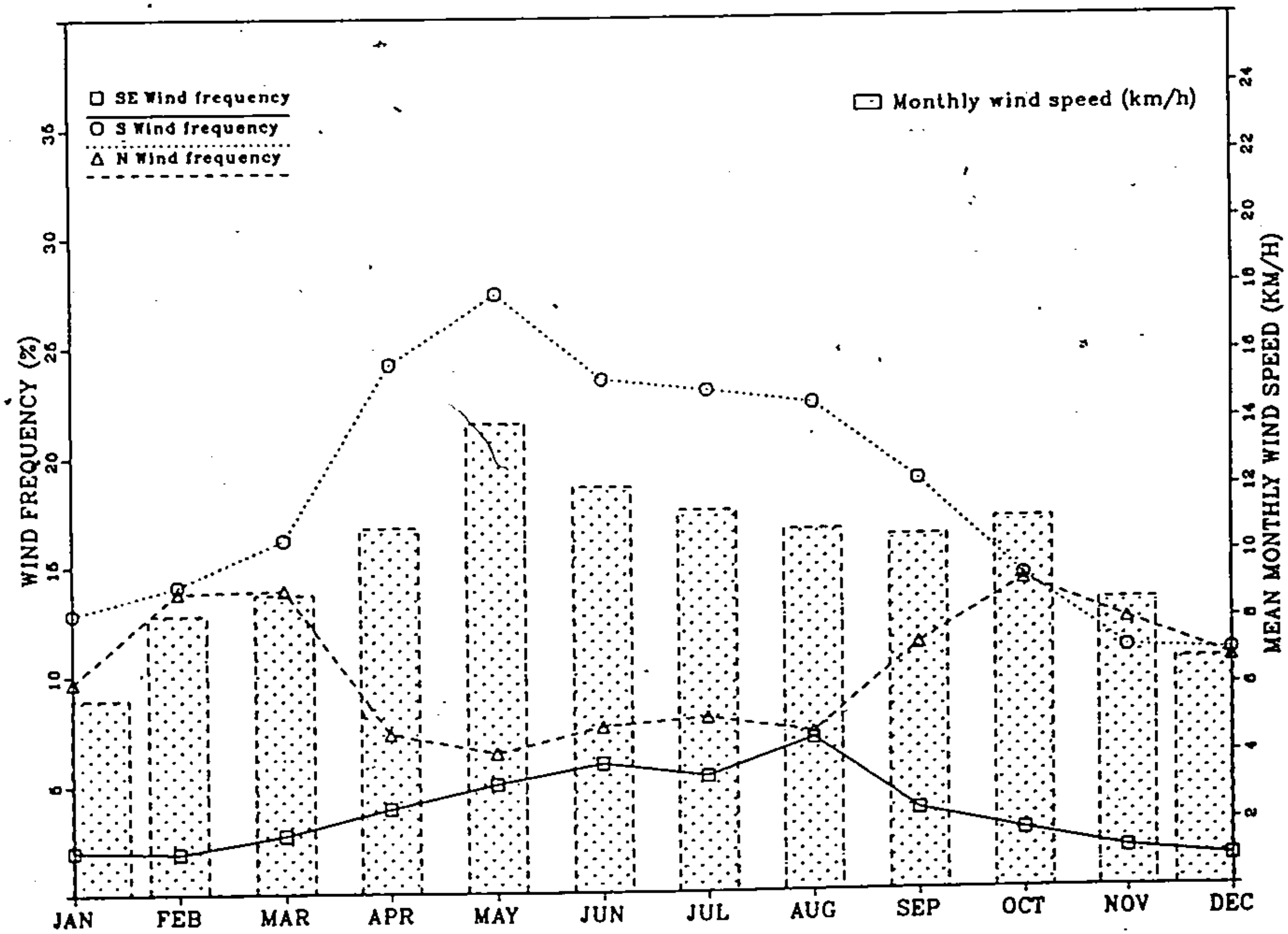

Figure 2.4 Distribution of wind percentages (modified from Wang, 1988a; data from Environment Canada, 1982)

This wind regime has considerable impact on the pollen dispersal patterns. The pollination periods of most plants in northwestern North America are from May to August, during which interval strong and frequent southerly winds may transport pollen grains from far south to the study area. It is absolutely necessary therefore, for palynologists to consider the influence of wind direction and speed in pollen dispersal in such an area, and proceed with caution when interpreting pollen spectra of exotic pollen. Also, because pollen production at high latitude is much reduced, the representation of exotic pollen becomes even more exaggerated.

In conclusion, therefore, the study area exhibits a severe continental climate, even though it is quite close to the oceans. The St. Elias Mountains form a remarkably effective barrier against the influence of Pacific airmass circulation to the area. The Mackenzie Mountains (Ogilvie Mountains along the Yukon-Northwest Territory border) provide a barrier against cold polar airmasses. The broad and long valley of Aishihik and Sekulmun lakes enables southerly winds to dominate throughout the year, and a fairly open passage from the Nisling River valley provides a route for northerly winds during the winter. The basic climatic conditions of the study area are controlled by all of these physical environmental factors.

2.4 Periglacial Features

Periglacial phenomena existing in the area are seasonal and perennial frozen ground, cryoturbation, solifluction (Price, 1971), thermokarst, pingo (Hughes, 1969; Geurts et Dewez, 1985), patterned ground, etc. The features resulted from the effects of climate on Quaternary surficial deposits and formed by periodic freeze-thaw action. Perennially and seasonally frozen ground are the most striking periglacial phenomena in the area. Perennially frozen ground, or permafrost, is a layer of frozen ground that does not completely thaw during the summer (French, 1976, P. 45). The study area is located within the discontinuous permafrost zone (Hughes, 1969) which is characterized by the simultaneous existence of frozen and unfrozen bodies. In practice, the boundary between continuous and discontinuous permafrost zones coincides with the general position of the -6 to -8 °C mean annual air temperature isotherm which relates to the -5 °C isotherm of mean annual ground temperature measured just below the zone of annual variation (French, 1976, P. 52). This boundary, however, is quite differently placed. Kendrew and Kerr (1955) supplied a map of this boundary on which this study area is located near the border of continuous permafrost zone, but the map supplied by Brown and Péwé (1973) placed this boundary further to the north.

The thickness of the seasonally frozen layer, namely the active layer, varies according to the thermal properties of the surficial material, the vegetation cover, the slope and aspect, and the soil moisture conditions (Ritchie, 1984a; Price, 1971). Its thickness in the study area varies from 12 cm to 58 cm.

The quantity of segregated ice lenses varies considerably from place to place and from depth to depth. Any serious distortion of sediment depth, namely frost heaving, results in the miscalculation of sedimentation rates. This effect creates problems for the determination of absolute pollen accumulation rate. Calibration of this effect, therefore, is essential for absolute pollen studies in a periglacial environment. Procedures and detailed considerations will be discussed in chapter 3.

Other periglacial phenomena or processes, such as solifluction, thermokarst, cryoturbation, etc., result in the disturbance of the sediment sequence and create difficulties for pollen analysis. These problems, however, are avoidable by careful selection of sampling sites and cautious examination and description of the sediment sequence in the field.

2.5 Glacial History

Detailed studies of glacial features and glacial history in the study area and its vicinity have been made by Hughes

(1967; 1968; Hughes et al., 1969). Several glacial maps which cover the study area have been published (Bostock, 1966; Hughes et al., 1969).

Bostock (1966) found evidence in central Yukon for four glacial advances: Nansen (oldest), Klaza, Reid, and McConnell (youngest). No confirmed evidence of Nansen and Klaza advances has been reported in the study area (Hughes, manuscript). Figure 2.5 illustrates the generalized glacial limits and flow patterns in the study area and its vicinity. The Reid limit, to which ice-marginal features are not continuously traceable, marks the digitate margin of the main Cordilleran ice sheet during that advance. The McConnell limit, however, is marked by remarkably continuous and well preserved ice-marginal features in the study area.

A date from Stewart River indicates retreat of the Cordilleran ice sheet from the area more than 42,000 years ago (GSC-524), thus the Reid is older than the classical Wisconsin of midwestern United States, but not necessarily as old as Illinoian (Hughes et al., 1969). In the study area, several radiocarbon dates from organic deposits above McConnell drifts reveal that deglaciation of the study area was considerably before 10,000 years ago (Fig. 2.6). Two very close dates from a relatively wide area between Mackintosh Creek (10,300 +/- 150 yr BP, UQ-1373) and south of Aishihik Village (9,790 +/- 130 yr

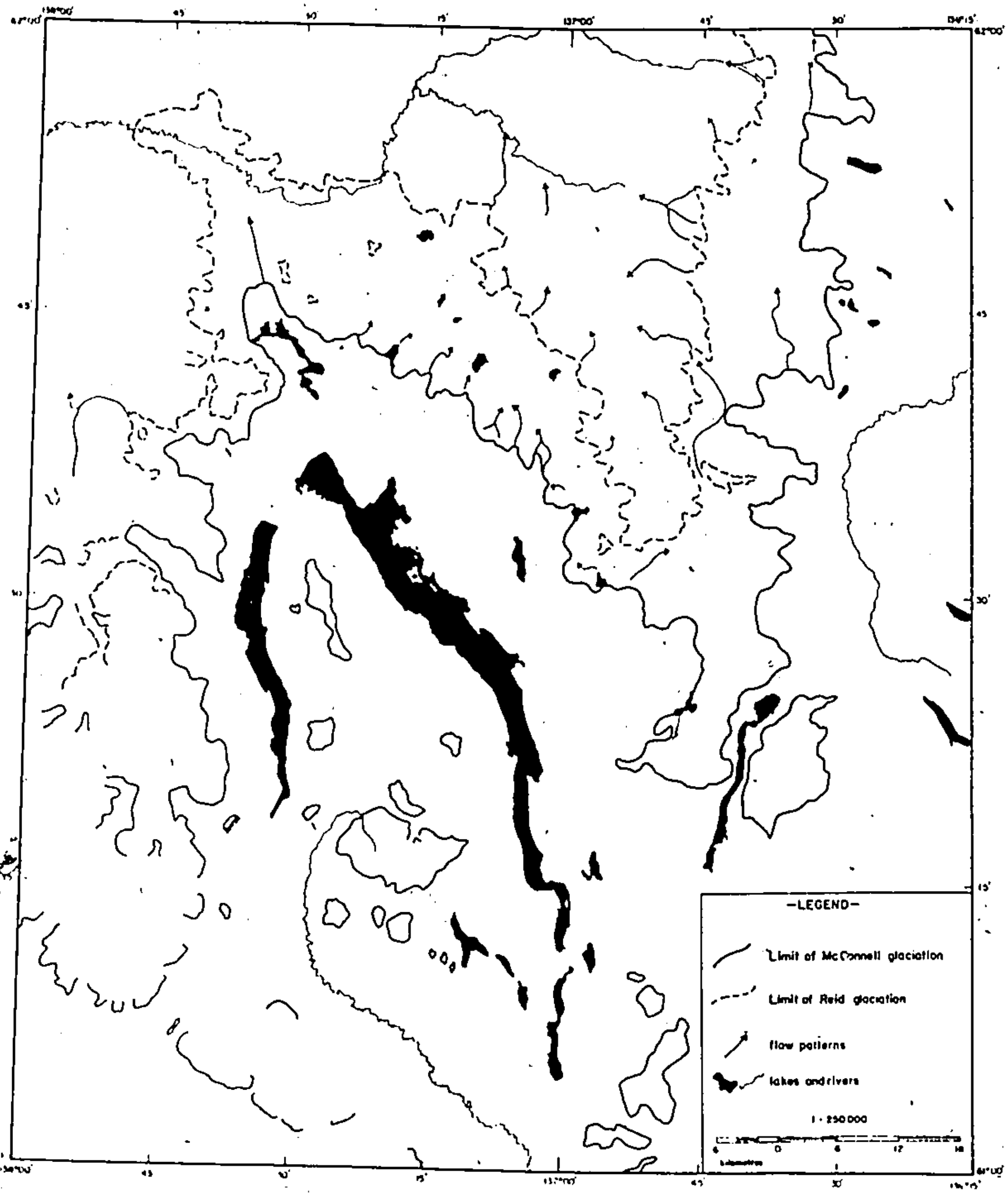

Figure 2.5 Limits of glaciations in the study area (after Hughes, manuscript)

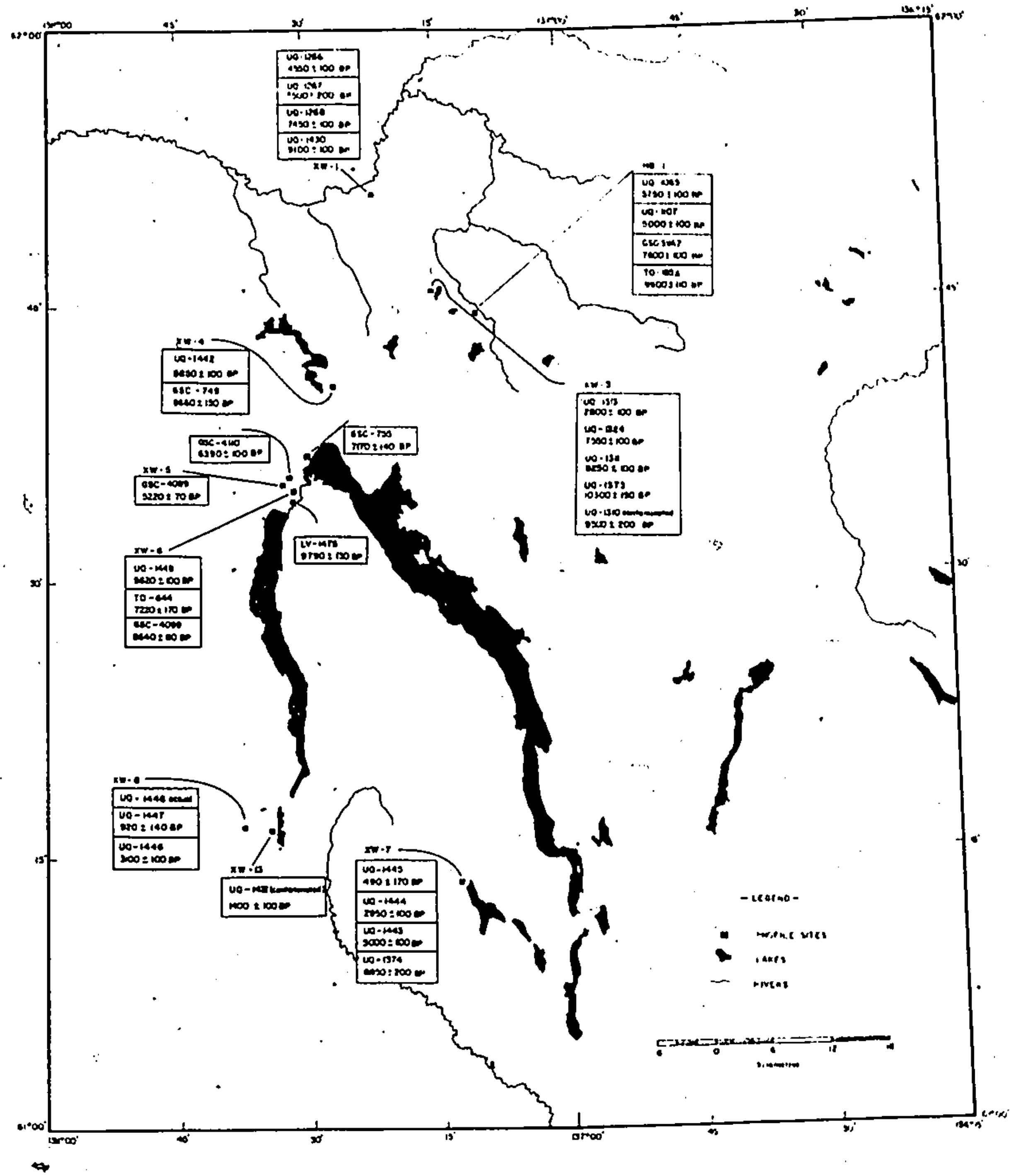

Figure 2.6 Location of ^{14}C dates in the study area

BP, LV-1475, Geurts et al., 1985) imply that deglaciation of the study area was not a gradual retreat but a very rapid disintegration (Dewez, 1988). As the result of deglaciation, the drainage pattern in the study area changed around 10,000 yr BP (Geurts et al., 1987). The most extensive drainage change in the study area was reversal of the formerly northward drainage of Aishihik Lake via Nisling, White and Yukon Rivers to Bering Sea, to its present southward drainage via Dezadeash and Alsek Rivers to Pacific Ocean (Hughes, manuscript).

2.6 Bedrock Geology

The investigation of the bedrock geology of the study area was initially undertaken by Cockfield (1927), which included the south part of Aishihik map-area. A more detailed investigation, was reported in 1974 (Tempelman-Kluit, 1974). As summarized by those investigators, the rocks of the area include both metamorphic and igneous types, and the igneous types include both volcanics and intrusives (Fig. 2.7). Much of the study area is underlain by Precambrian and/or Paleozoic metamorphic rocks, namely, the Yukon Group or Yukon Metamorphic Complex. This complex consists of biotite schist, hornfelsed schist, amphibolite, and marbles. Hornfelsed schists occur at the southwestern corner of the study area and build up the steep topography there. The biotite schists are exposed on ridgetops near Aishihik and Sekulmun Lakes.

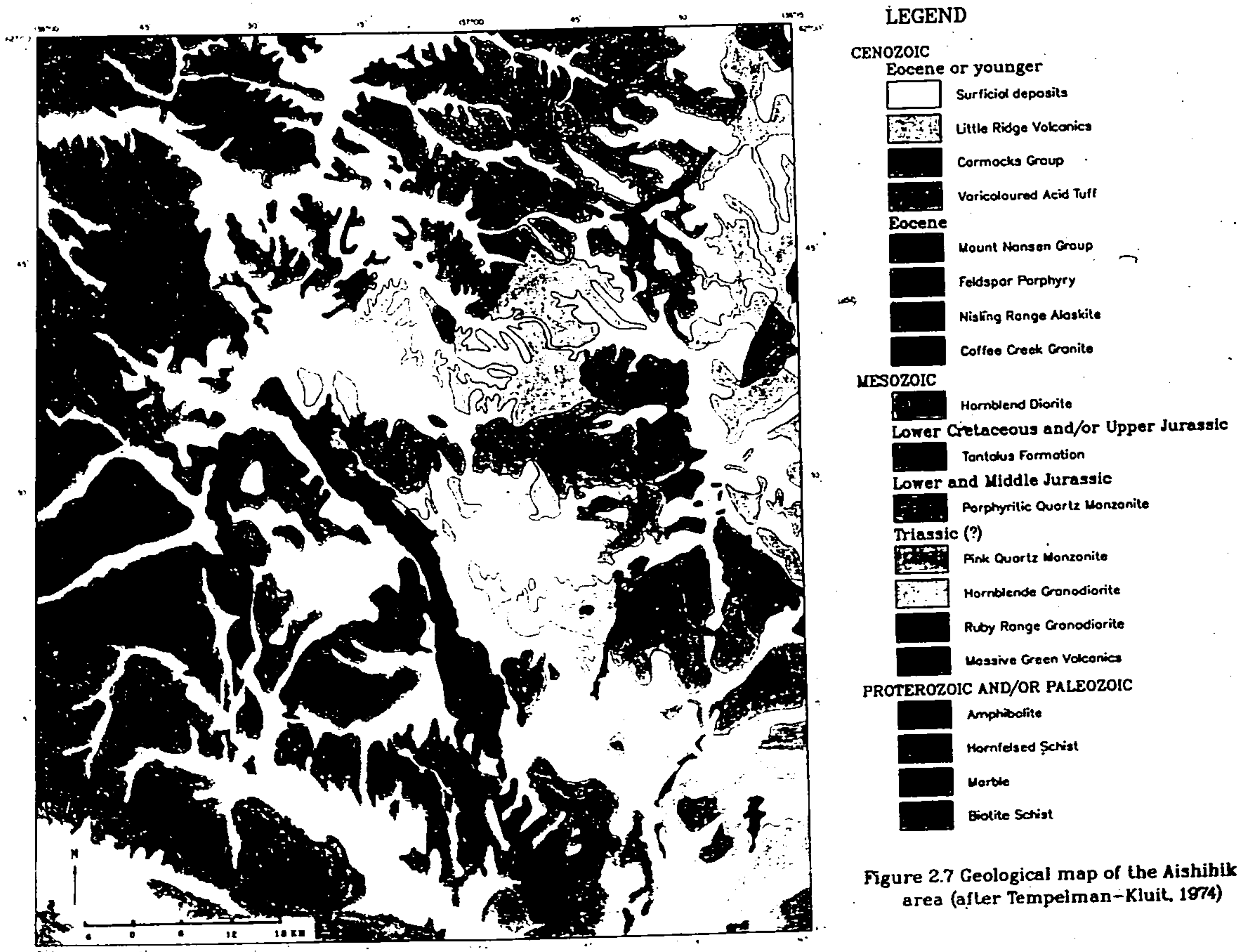

Figure 2.7 Geological map of the Aishihik area (after Tempelman-Kluit, 1974)

The intrusives include Ruby Range granodiorite, hornblende diorite, Coffee Creek granite, Nisling Range alaskite, and porphyritic biotite quartz monzonite. Of these rocks, Ruby Range granodiorite and hornblende granodiorite and pink quartz monzonite have the widest distributions. Ruby Range granodiorite, exposed along a northwestward belt in the Canyon Lake, Ittlemit Lake and Bear Lakes areas, has an age of Triassic or older, and comprises the Three Guardsmen and other high peaks (above 1,830 m) in the southwest of study area. The hornblende granodiorite, also with a tentative age of Triassic or older, is mainly distributed in the Mackintosh and Tahte Creeks. Pink quartz monzonite occurs extensively on the mountains east of Long Lake and north of Mount Cooper.

The volcanic rocks in the area include feldspar porphyry, which has the widest distribution among the volcanics, Mount Nansen Group, and varicolored acid tuff. All these rocks are early Tertiary in age. The northwest part of the area has wide and extensive dike swarms of feldspar porphyry, which build up the high relief of Nisling Range. Mount Nansen Group and varicolored acid tuff, however, are scattered in the central to northern part of the study area.

Within the valleys and lowlands, thick accumulations of surficial deposits including glacial drifts, gravel, sand, clay, silt, soil, rock talus, and volcanic ash, are found.

Considering the distribution of different rock types and the topography of the study area, Mesozoic intrusive and Tertiary volcanic activity played an important role in the formation of major topographic features. Muller (1967) and Tempelman-Kluit (1974) believed that Pleistocene glaciation developed the topography and drainage pattern of the southwestern Yukon. In the Aishihik Basin, the most spectacular impact of Pleistocene glaciation is the extensive topography of glacial-lacustrine and dead ice environments (Dewez, 1988).

2.7 White River Ash

White River Ash is a bi-lobate tephra deposit covering the southern half of Yukon Territory and easternmost Alaska. These deposits were recognized by Dawson (1889) and Schwaika (1885). A later survey by Bostock (1952) revealed the bi-lobate form with a dominant east lobe and a less extensive north lobe. As presently mapped, White River Ash covers an area of about 300,000 km^2, and the east lobe extends at least 724 km from the source (see Lerbekmo and Campbell, 1969; Lerbekmo et al., 1975; Workman, 1978; Dewez et al., 1984).

Available radiometric dates suggest that the north lobe of the White River ash is approximately 1,980 yr BP old based on seven ^{14}C dates in White River Valley (Denton and Karlén, 1977). Fernald (1962) has published dates of 1,520 +/- 100 and 1,750 +/- 110 yr BP in Tanana Valley, and another date of 1,990 +/- 130 yr BP has also been obtained from a wood sample just below the ash collected by Hughes (Lerbekmo and Campbell, 1969).

The younger eastern lobe has been considered as old as 1,230 yr BP (Denton and Karlén, 1977). A date of 1,250 yr BP has also been used in literature (such as MacDonald and Cwynar, 1985). Three ^{14}C dates, 1,260 +/- 90, 1,175 +/- 90, and 1,255 +/- 90 yr BP which conclude a date of 1,230 yr BP (Denton and Karlén, 1977), have been reported from spruce wood and muskeg samples in White River Valley. Earlier reported dates include 1,460 +/- 70 yr BP and 1,390 +/- 70 yr BP (Stuiver et al., 1964), 1,200 +/- 140 yr BP (Lowdon and Blake, 1968).

The study area in this monograph falls into the extensive eastern lobe of the White River ash. Mineralogical investigation of this ash layer has been completed previously (Lerbekmo et al., 1975). Dewez (1988) identified the ash layer in this study area through mineralogical analysis of hornblende. Field observations indicate that most of the area preserves a conspicuous layer with sandy to silty facies, generally around several centimetres thick. The ash layer is usually buried by peat a few to 25 cm thick.

The ash layer serves as a key bed for dating purpose. Since it is widespread and in most cases well preserved, it is a key horizon which facilitates the correlation of stratigraphic sequences.

The impact of the ashfall on vegetation and therefore on the pollen records has been investigated in the southwest Yukon Territory (i.e. Dewez et al., 1984). Further consideration of this aspect will be made during the interpretation of pollen diagrams later.

Chapter 3 Methodology

3.1 Field Methods

The aim of the field work was to collect uncontaminated samples of the deposits, to define as exactly as possible the conditions under which the samples were taken, to determine the types of sediment, and to explain the stratigraphy (Faegri and Iversen, 1975). During the 1984, 1985, and 1986 summer field seasons, surface samples and pollen-bearing stratigraphic samples were collected from the Aishihik Basin and its vicinity. The evidence for the reconstruction of environmental history was extracted from the palynological analysis of these samples.

3.1.1 Surface Samples

Surface samples, collected from moss polsters, surficial lake sediments, the top layer of peat, bog and fen surfaces, conifer swamps, fruticose lichens, surface plant detritus and soil, have been widely used throughout the world, especially in North America (Terasmae, 1967b; Adam and Mehringer, 1975; Farley-Gill, 1980; Jacobs et al, 1985). In this study, moss polster samples were collected for surficial palynological analysis during three successive field seasons.

Moss polster samples were collected by hand from selected communities, or in some cases along line transects throughout vegetation zones. At every coring site for stratigraphic sections, at least one moss polster sample was also collected.

The sampling procedure followed the description of Heim (1970). A 10 m^2 quadrat was chosen and 8 to 10 subsamples were collected evenly throughout the quadrat, and then thoroughly mixed together to make one single sample, in order to prevent statistical instability. The collected polster samples were sealed in plastic bags and stored moist until preparation in the laboratory. At each site where the samples were collected, great care was taken to identify and record every plant taxon, and estimate its distribution and relative density.

3.1.2 Palynostratigraphic Samples

Sampling sites were selected according to several parameters. The first was latitudinal and altitudinal gradients in the basin along which pollen profiles were located. The second was the geomorphological framework which controlled the deposition of organic matter. One of the objectives of this study was to reconstruct the local environmental history and therefore the influences of geomorphological processes on the pollen spectra were important. Other considerations included the possibility of sampling and accessibility. In this study, all profiles were collected either from peat bogs or dry lakes. Most profiles were collected from sites which were accessible by truck or canoe. Some of the profile sites were reached by helicopter. Organic sediments were chosen for sampling as they are the most favorable medium for pollen preservation.

In very well exposed profiles, the samples were collected in plastic bags at about 2.5 cm intervals (i.e. XW-2). In some cases plastic trays, 38 cm X 5 cm X 4 cm in dimension, were employed to collect whole sections (i.e. XW-8, XW-13). In both cases the cross section was cleaned back until coarse sediment or permafrost was encountered. Great care was taken to prevent contamination since no method can compensate for contamination of samples (Faegri and Iversen, 1975).

Most long profiles, however, consisted of permafrost (i.e. XW-1, XW-3, XW-4, XW-5, XW-6, XW-7). The seasonal unfrozen top layer, usually peat containing the White River ash layer, was cleaned carefully back to the permafrost table, and collected using the same procedure as exposed sections. The frozen part of the section below was cored by means of a modified CRREL Ice-Coring Auger (Veillette and Nixon, 1980), which is a motor-driven hollow drill with an inner diameter of 5 cm. The core was raised in 5 to 35 cm long segments, each of which was scraped clean of possible contamination, photographed, cut into 2.5 cm segments and sealed in labeled plastic bags or bottles. A survey of the geomorphology and modern vegetation around each core site was undertaken. In the laboratory, the samples were stored in a refrigerator until the subsampling and chemical treatment phase.

3.2 Laboratory Methods

Both surface samples and section samples underwent several stages of analysis in the laboratory. This section describes the procedures used for subsampling, chemical preparation, pollen identification and counting, determination of organic content, and measurement of the water content.

3.2.1 Subsampling Methods

Samples to be analyzed were removed from the refrigerator individually. Sediments were described, including the type of sediments, colour, texture and structure if applicable, macrofossils (if any), and moisture condition. After completing the description, the samples were subsampled for pollen analysis. Material was removed using a stainless steel laboratory spatula, then placed into a graduated cylinder, followed by a liquid replacement procedure to measure the precise volume of the subsample. About 2 cm^3 peat or 4 to 5 cm^3 of organic silt or clay were essential for the purpose of pollen analysis. The spatula was carefully washed after each subsampling to prevent contamination. Additional material was also removed for the determination of organic content and for radiocarbon dating. The procedure for determining the organic content will be discussed later.

Pollen data were used whenever possible to guide the selection of section position for radiocarbon dating.

Significant changes of vegetation reflected in a pollen diagram made it possible to pinpoint the section interval which could date these events. The sediments with high water content (ice lenses) were avoided because of the deficiency of datable material. The samples for dating were dried at 75 °C for 12 hours, sealed in labeled plastic bags, then forwarded to the radiocarbon dating laboratory.

3.2.2 Measurement of Water Content

After the volume measurements were taken (section 3.2.1.), all samples were transferred into labeled beakers and dried for 12 hours at 75 °C. A METTLER (Mode H4) balance was employed to weigh the samples and beakers, which provided an accuracy of 1.0×10^{-3} grams. The following relationship was established to determine the water content, and required weights were measured when necessary:

$$\text{Water Content } (cm^3 cm^{-3}) = \frac{BW_i - BD_i}{VW_i \times D}$$

where:

- BW_i ---- Wet weight of the ith sample with beaker (g)
- BD_i ---- Dry weight of the ith sample with beaker (g)
- VW_i ---- Volume of the ith wet sample (cm^3)
- D ------ Density of water, equal to 1.0 ($g\ cm^{-3}$)

The results of these analyses were used to modify the calculated sedimentation rate which is essential for the determination of pollen accumulation rates (see section 3.4).

3.2.3 Preparation Procedure

Preparation procedures involved several chemical and physical treatments. The objective of sample preparation was to concentrate any pollen and spore grains present in the material and render them as visible as possible. Since sample condition varied, different procedures were employed.

The classical acetolysis method, originally introduced by Erdtman in 1934 (cf. Erdtman, 1960), was used to treat the surficial moss polster samples. This method involved treatment with 10% NaOH to remove the pollen from the fiber and other material. Subsequently an acetolysis was used to dissolve the cellulose and organic debris, and make the pollen grains transparent, thus facilitating identification (detail of the procedure is listed in appendix A). Most samples, however, consisted of peat, organic silt, clay, and a few contained fine sand. These samples required additional treatments with 10% HCL to dissolve the calcareous material, treatment with hot concentrated HF (48 %) to dissolve silicate minerals, then followed by an acetolysis procedure (Appendix B). For the samples which consisted mainly of silt or clay, a sieving method (Cwynar et al., 1979) was employed after the acetolysis procedure to concentrate the pollen grains. The pollen-bearing residue of the preparation was preserved in diluted glycerol (2/3 of glycerine jam and 1/3 of distilled water) until subsequent microscopic identification tasks.

3.2.4 Counting and Pollen Identification

After chemical concentration, a 10 µl drop of pollen-bearing residue was mixed with 10 µl of glycerinated water to make a working slide, using an Eppendorf micro-pipette. The analyzed residue was weighed prior to mounting for the calculation of the absolute pollen frequency or the pollen accumulation rates. Pollen-bearing residue was examined with an Olympus CH or BH biological microscope at magnifications of 200 X or 400 X for routine counts. The microscope slides were examined in parallel swaths. Each pollen grain encountered was identified. The total number of pollen grains counted for each sample was based on the criteria established by Bastin (1971), and at least 150 pollen grains, usually more than 200, were counted in each sample. Those pollen grains that remain unidentified but had definite morphological characteristics, were tabulated as "indeterminate" type. This group also included a few unknown types. The only spores counted were Dryopteris, Lycopodium, Sphagnum, and Equisetum.

The pollen identification was aided by about 500 reference slides of pollen, most of which were collected from the southwest Yukon Territory and stored in the Palynology Laboratory of the University of Ottawa. Several well-illustrated publications of pollen taxonomy were referred to when necessary (Bassett et al., 1978; McAndrews et al., 1973; Kapp, 1969; Moore and Webb, 1978).

3.2.5 Organic Content Determination

All samples of the Moose Depression profile (XW-6) were treated with loss-on-ignition to determine the organic content (Appendix C). The result derived from the procedure could be over-estimated because of the loss of "irreducible" water in clay minerals and CO_2 in carbonates. However, the over-estimation should be limited since the samples lacked carbonates evidenced by no reaction to concentrated HCL and the paucity of clay observed in the stratigraphy of the profile.

3.2.6 Sediment Analysis

Grain size analysis was carried out for all samples of profile XW-6, which involved a wet sieving procedure and the operation of a COULTER COUNTER (model TAII). Since the samples consisted mainly of silt-sized particles, 250 mesh (63 µm) and 60 mesh (250 µm) sieves were used. The latter was the maximum allowable particle size for the COULTER COUNTER. To ensure statistical stability, at least 45,000 particles were counted for each sample (Appendix D).

3.3 Presentation of the Results

The results of an analysis are better illustrated by diagrams or charts than tabulation in most cases. A pollen diagram is a conventional aid, and its usefulness is directly proportional to the universality of the convention (Faegri and Iversen, 1975). The clarity of a diagram and its comparability with others are the most important factors guiding the construction of pollen diagrams. This principle was borne in mind through the construction of pollen diagrams in this study. Two kinds of pollen diagrams were constructed, i.e. the relative pollen frequency (RPF) diagram, and the pollen accumulation rate (PAR) diagram.

3.3.1 Relative Pollen Frequency

It is a practical convention to illustrate the pollen data by means of a relative pollen frequency (pollen percentage) diagram. This presents the proportion between pollen of a particular taxon and a certain pollen sum. The pollen sum used in calculating percentages is determined in different ways by different authors and for different purposes. For the basic diagrams in this monograph, the pollen sum, including the calculation of the total pollen concentration or total pollen accumulation rate, is the total number of pollen grains encountered during microscopic counting excluding all aquatics, spores, and indeterminate palynomorphs. The proportion of the latter components in the sample, however, was also presented as a percentage of the sum and illustrated at the right side of the pollen diagrams. Special pollen sums were also applied whenever necessary and specified when encountered.

3.3.2 Absolute Pollen Frequency and Pollen Accumulation Rate

Since the very beginnings of pollen analysis in this century, the consideration of absolute pollen frequency or absolute pollen grain numbers in the sediment sample of known volume or weight has been noted. Hesselman (1916) first suggested the measurement of the numbers of pollen grains per unit weight or volume of sediment. As Davis (1965) has indicated, however, since von Post, the pioneer of pollen analysis, felt that such measurements would be meaningless for comparison and correlation because the pollen number as a function of weight or volume would be strongly influenced by fluctuation of sedimentation rate, relative pollen frequency (pollen percentage) has been used for long time (Davis, 1963; 1965; von Post, 1916). The attempts to determine absolute pollen frequency, however, have never been abandoned. As the result of the development of radiometric dating techniques, it has become practical to determine precise sedimentation rates, which greatly facilitates the determination of the absolute pollen concentration. The consideration of pollen grains per unit area per year (pollen accumulation rate, pollen deposition rate, pollen influx, termed by various analysts) initially introduced by Davis (1963) has improved the theory of pollen analysis from the era of von Post. Pollen accumulation rate or pollen influx has been defined as the pollen grains deposited per square centimetre per year, and can be calculated by multiplying the pollen concentration in a known volume of wet sediments with the sedimentation rate. During this decade, numerous publications have involved the determination of pollen accumulation rate or pollen influx around the world. The pollen concentration per unit volume or weight is still used either in palynostratigraphy or surficial palynology.

Pollen concentration could be obtained through several methods. Erdtman (1943) used a hemacytometer to count pollen grains. Muller (1959) proposed a method using aliquot slides prepared from standard drops taken from glycerine-alcohol suspension of pollen samples. Davis (1965, 1966) developed a method to measure the volume of aliquot so that absolute pollen frequency could be determined. This method suspended the pollen-bearing residue prepared from a wet sediment sample of a known volume or weight in some standard volume of tertiary butyl alcohol. The total pollen number in the original sample can be calculated by the pollen number which is counted from all aliquots, times the dilution factor during preparation of aliquots, divided by the number of aliquots. On the other hand, an exotic pollen method was initially proposed for the same purpose by Benninghoff (1962), developed by Matthews (1969), and fully described and discussed by Bonny (1972) and Maher

(1972). For the same purpose, pollen-sized polystyrene spheres rather than exotic pollen grains were also employed by some analysts (Craig, 1972). This methodology used exotic grains as markers. The measured volume of mixture with a known number of exotic markers or marker-bearing tablets (Stockmarr, 1971) was introduced into the original sediment sample before the ordinary laboratory preparation. A weight method instead of suspension or tabular method was also proposed recently (Salgado-Labouriau and Rull, 1986). Under this category, the total indigenous pollen number can be calculated from the number of indigenous pollen grains counted times the ratio of exotic markers introduced to that counted during slide counting, and then divided by the volume of the sediment sample.

In contrast with the pollen concentration per unit volume of sediment sample, Jørgensen (1967) had established a procedure to determine the pollen concentration per unit weight of sediment samples. This technique involved several measurements of centrifuge tubes and samples and so on, and resulted in fixed slides which took more time during preparation.

Since both sample volumes and wet and dry weights were measured before chemical preparation, the procedures used in this monograph allowed the author to calculate pollen concentrations either by volume or by weight. In most cases, pollen concentration and pollen accumulation rate were determined using the standard exotic mark method described by Maher (1972). Eucalyptus globulus was chosen as a marker during this study. Since a hemacytometer was not available, the determination of marker numbers in a known volume suspension (NaOH as medium) was aided by a time-consuming counting procedure. A prepared suspension was agitated by a magnetic agitator for 15 minutes, and then 5 subsamples of 50 µl suspension were extracted by an Eppendorf micro-pipette (0.001 % precision). These subsamples were then diluted by a factor of 50 with the same medium, and 10 slides, 10 µl for each, of each subsample were counted under the microscope. The total number of markers per unit volume of concentrated suspension was subsequently calculated.

Samples of profile XW-1 on the other hand, had been prepared in the laboratory before the acquisition of a suitable marker. A volume-weight method therefore was developed to perform the role of determining pollen concentration and pollen accumulation rate by volume in the profile XW-1 samples. This procedure involved the basic measurement of the weight of the pollen-bearing residue of the preparation (WP) and that analyzed under microscope (WA). The pollen concentration in a known volume of sediment sample is determined by the following relationship:

$$APFV_{ij} = \frac{WP_i}{WA_i} \cdot N_{ij} \cdot \frac{1}{V_i} \quad (i = 1,k, \quad j = 1,l) \qquad (1)$$

where $APFV_{ij}$ is the pollen concentration of the jth taxon per unit volume of the ith wet sample. N_{ij} is the number of pollen grains of the jth taxon encountered in the ith sample during counting. V_i is the volume of the ith sediment sample. The total pollen concentration is the sum of $APFV_{ij}$ for each taxon in the ith sample, i.e., $\Sigma APFV_{ij}$. Based upon this calculation, the pollen accumulation rate is determined by the following equation:

$$PAR_{ij} = APFV_{ij} \cdot R_i$$

$$= \frac{WP_i}{WA_i} \cdot N_{ij} \cdot \frac{R_i}{V_i} \quad (i = 1,K; \quad j = 1,L) \qquad (2)$$

where PAR_{ij} is the pollen accumulation rate of the jth taxon in the ith sample, and R_i is the sedimentation rate determined by radiometric dates. Similarly, the total pollen accumulation rate for a sample is the sum of PAR_{ij} for each taxon in the ith sample, i.e., ΣPAR_{ij}.

3.4 Modification of Absolute Pollen Accumulation Rate

It is common for permafrost cores to contain numerous segregated ice lenses, which result in severe vertical displacement throughout sediment depth. It is a well known fact that during the freezing of soils the moisture in the soil will be redistributed along a temperature or heat gradient, or in other words a water potential (Smith, 1985). The impact of such vertical displacement on the determination of pollen accumulation rates has not yet been fully assessed (Wang and Geurts, 1987b).

In an ideal closed system, the volume of water will be expanded 9% upon freezing. For a 1 cm layer of sediments containing 0.4 cm^3cm^{-3} of water, freezing of this layer would result in a 0.36 mm increase in the layer thickness. However, the natural environment is far from an ideal closed system. Migration of moisture along the direction of the temperature gradient might cause a significant accumulation of excess water during the formation of permafrost (French, 1976), therefore causing greater problems than pore water. Field investigations at Inuvik in the Northwest Territories revealed that ice segregation could account for up to 90% of the total heave, while the freezing of pore water accounted for as little as about 10% (Smith, 1985). The same study also indicated that a 31 mm heave was recorded in a 40 cm layer between October 5 and November 16 of 1983, which implies that the vertical increase of the sediment thickness was up to approximately 7.7%.

The absolute pollen accumulation rate is a function of multiple variables including the sedimentation rate and sample volume, therefore possible impact of permafrost configuration on the determination of the pollen accumulation rate is twofold. Firstly, vertical displacement of the permafrost core would lead to an incorrect determination of sedimentation rates since the sedimentation rate is a function of depth and age intervals expressed as:

$$\text{Sedimentation rate (cm/yr)} = \frac{\text{Depth interval (cm)}}{\text{Age interval (yr)}}$$

The increase in sediment depth as a result of frost heaving causes an increase of calculated sedimentation rate, therefore exaggerating the pollen accumulation rate. Secondly, ice lensing and frost heaving would cause a sharp increase in the actual volume of samples therefore leading to an artificial decrease of the absolute pollen accumulation rate. Ager (1975) interpreted a decrease of the pollen accumulation rate, in the pollen zone 3B of Birch Lake profile in the middle Tanana Valley, as being due to the high water content in the samples thus decreasing the actual sample volume. In permafrost cores, the effect is much greater than in fresh lake cores, especially if there is excess water in the permafrost samples.

Since sample volume was measured in the laboratory after the melting of all enclosed water (section 3.2.1), the effect of the 9% volumetric expansion of pore and excess water was therefore eliminated. However, this elimination did not apply to the determination of sedimentation rates since the profile depth (including the vertical position of each core segment) was measured in the field under frozen conditions. To deal with the samples which apparently had excess water, a 24 hour water saturation was carried out. Core segments containing apparent excess water were stirred using a stainless laboratory spatula and then transferred into a graduated cylinder with a laboratory spoon. For the liquid replacement measurement, subsamples were left in the cylinder for 24 hours after recording the raw sample volume, then the water saturated volume was recorded. Excess water was subsequently estimated by subtracting the water saturated volume from the raw volume of the subsample.

Modification of the pollen accumulation rate required two steps. Firstly the depth of the palynological samples and dated segments had to be modified in order to estimate the sedimentation rate and extrapolate or approximate the chronology of each sample. If we defined the depth increase by the 9% volumetric expansion of water upon freezing between two neighboring samples as D_{1i}, then

$$D_{1i} = \frac{V_{Hi-1} + V_{Hi}}{2} \times 0.09 \times (D_i - D_{i-1})$$

where V_{Hi} is the measured water content of the ith sample at level D_i cm, and heave caused by excess water as D_{2i}, then

$$D_{2i} = \frac{V_{Ei-1} + V_{Ei}}{2} \times (D_i - D_{i-1})$$

where V_E is the content of excess water per unit volume of wet sample. The total heave or depth increment between a given depth interval D' can be estimated by the following relationship:

$$\begin{aligned} D\delta_i &= D_{1i} + D_{2i} \\ &= (D_i - D_{i-1}) \times 0.045 \times (V_{Hi} + V_{Hi-1}) \\ &\quad + (D_i - D_{i-1}) \times 0.5 \times (V_{Ei} + V_{Ei-1})) \\ &= D' \times (0.045 \times (V_{Hi} + V_{Hi-1}) + 0.5 \times (V_{Ei} + V_{Ei-1})) \end{aligned}$$

Therefore, the depth of an entire sequence could be modified by

$$D_i = D_{Oi} - \sum_{i=j}^{n} D\delta_i$$

where D_i is the modified new depth for the ith sample in the sequence, D_{oi} is the original position, and j is the position number of the sample in the sequence which is just below the permafrost table. The position of the dated core segments or samples could be extrapolated by this new depth system. Sedimentation rates and sample chronology determined from this modified depth system were no longer affected by frost heave.

The second step was to modify the sample volume. Since the 9% volumetric expansion of sample volume was automatically eliminated, the modified volume could be determined through the subtraction of excess water from the raw volume.

To evaluate the significance of these modifications, the data set of profile XW-1 from the Upper Nisling Valley was used to investigate the relationship between several variables. A full description and palynological interpretation of this data set, however, is reserved for chapter 5. The following relationships were used to estimate the variation of pollen accumulation rates deduced before and after the modification:

$$PAR_{p\delta} = (PAR_{pm} - PAR_{pu})$$

and

$$PAR_{p\delta} (\%) = \frac{(PAR_{pm} - PAR_{pu})}{PAR_{pm}} \times 100$$

where PAR_{pm} is the modified pollen accumulation rate of _Picea_, and PAR_{pu} is the _Picea_ pollen accumulation rate without modification. $PAR_{p\delta}$ is therefore the difference between the two. Similar definitions are also employed for the sample volume and the sedimentation rate.

As illustrated in figure 3.1a, the general pattern of modified _Picea_ pollen accumulation rates is similar to that of the unmodified rates. However, the differentiation becomes more significant with the existence of excess water (Fig. 3.1b). The registered variation percentage of the _Picea_ pollen accumulation rates ($PAR_{p\delta}$ (%)) is between -25.3% and 62.9%, which implies that the modification was necessary.

The variation of the _Picea_ pollen accumulation rate ($PAR_{p\delta}$) was very well correlated to the distribution of water content in the sequence and the change of sample volume V_δ. Furthermore the variation of the sedimentation rate (R_δ) was very well correlated to $PAR_{p\delta}$ when the water content was low (Fig. 3.2). Further investigation of the relationship among these variables indicated that the percentage of $PAR_{p\delta}$ was strongly related to the distribution pattern of the excess water variation ($V_{w\delta}$). The variation of 9% volumetric expansion of water upon freezing was mainly related to the fluctuation of

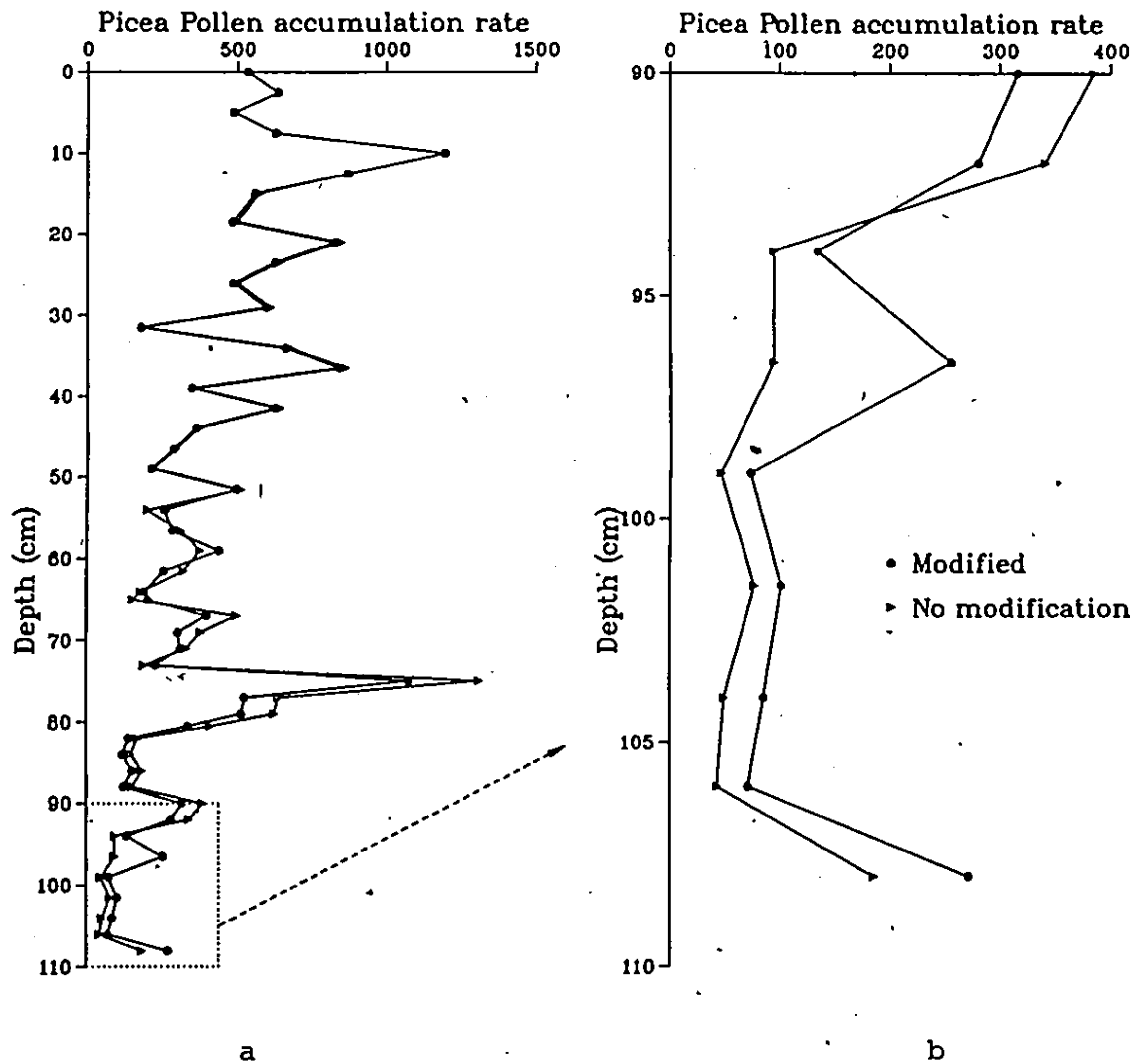

Figure 3.1 Differentiation of spruce pollen accumulation rate. See text for descriptions

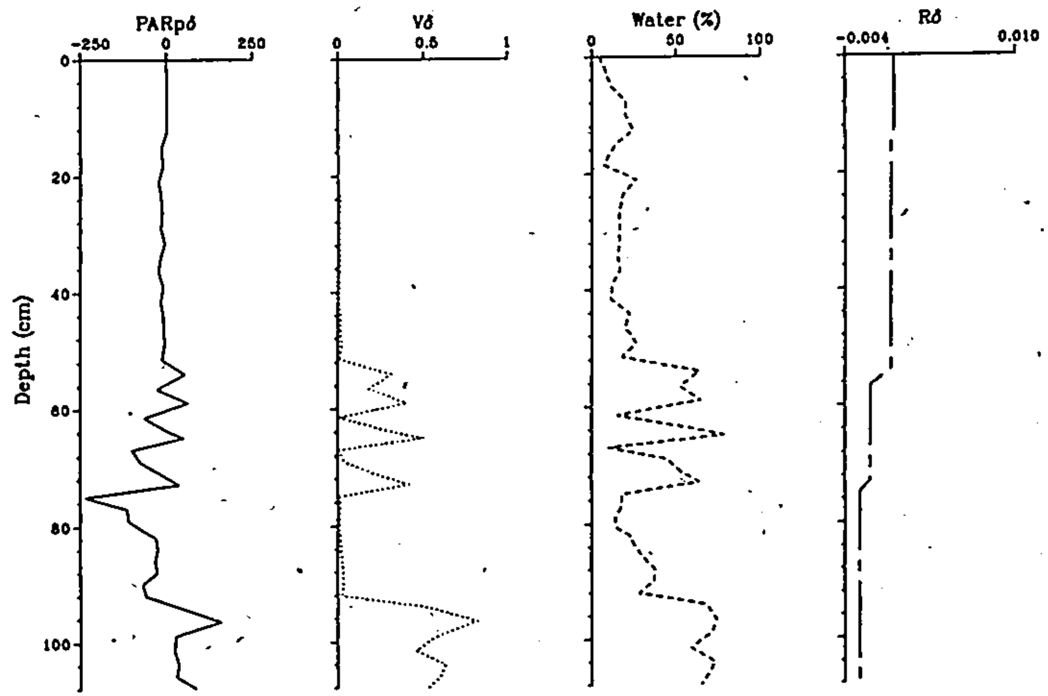

Figure 3.2 Relationships between water content and variations of <u>Picea</u> pollen accumulation rates ($PAR_{p\delta}$), sample volumes (V_δ), and sedimentation rates (R_δ). See text for more explanation

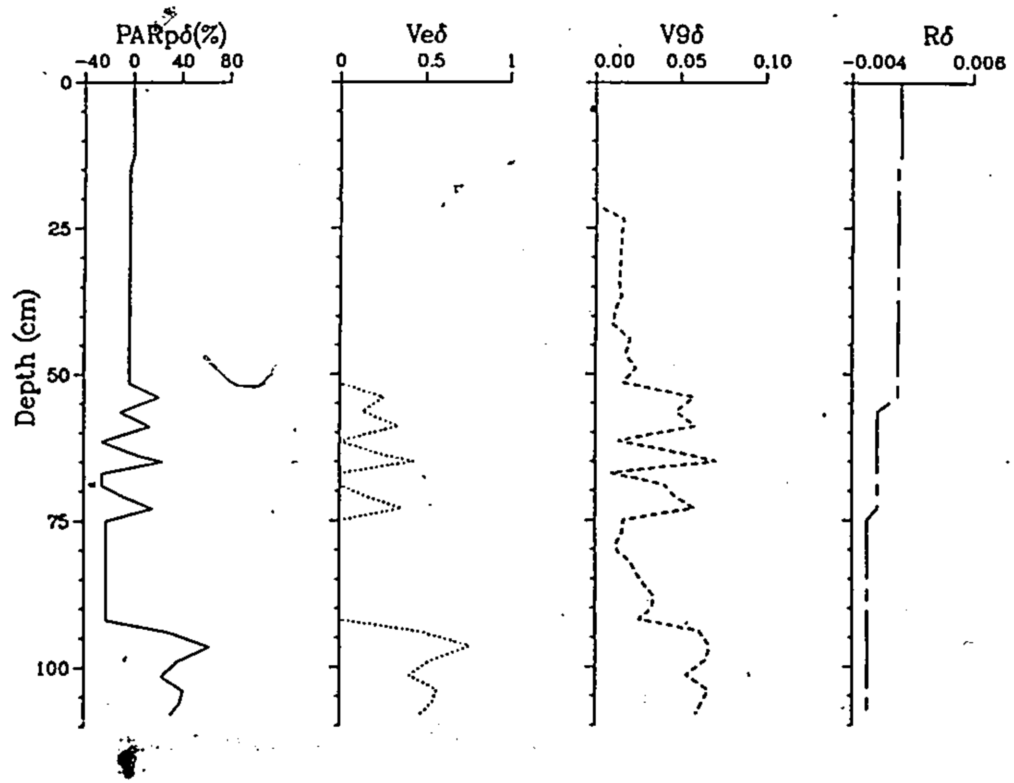

Figure 3.3 Relationships between the percentages of variation of <u>Picea</u> pollen Accumulation Rates ($PAR_{p\delta}$ (%)) and the variations of excess water volume ($Ve\delta$), expansion of pore water volume ($V9\delta$) and sedimentation rates ($R\delta$). See text for more explanation

R6 (Fig. 3.3). These results suggest that excess water is the major element which strongly impacts on the determination of the pollen accumulation rate. The principal mechanism of this impact was an expansion of actual volume of palynological samples. A change in the sedimentation rate resulting from a 9% volumetric expansion of pore water did not strongly influence the determination of the pollen accumulation rate, while the influence of excess water was more important. In conclusion, the determination of the absolute pollen accumulation rates in a permafrost area should be accompanied by the above proposed modifications if samples contain a high water content or if excess water exists in the sediments.

3.5 Computation and Numerical Procedures

This section describes the numerical methods and computation procedures which will be utilized later in this monograph.

3.5.1 Numerical Analysis

The results or the data of Quaternary pollen analysis, either palynostratigraphic or non-stratigraphic, are nothing more than a multivariate matrix consisting of a number of observations and variables (Birks and Gordon, 1985). A number of numerical techniques such as Discriminant Analysis (DA), CLuster Analysis (CLA), Principal Component Analysis (PCA), Principal Coordinate Analyses (PCoA) and Principal Component

Biplot (PCB), etc. have already been successfully employed in palynology to manipulate data. A concise review of the applications and ordination procedures of multivariate analysis on Quaternary palynological data has been carried out by Birks and Gordon (1985) and Prentice (1980).

Numerical methods are useful for detecting, summarizing, and displaying major patterns of variation within modern pollen data sets, and are also powerful for comparing contemporary pollen data with the vegetation types from which the surface samples were collected, and thus assist in characterizing the modern vegetation types in terms of contemporary pollen assemblages (Birks and Gordon, 1985, p.143). CLuster analysis (CLA) and Q-mode Principal Component Analysis (PCA) were employed in this monograph to classify the surface samples solely by their pollen contents and to compare the results with present vegetation-landform units from which the samples were collected. Application of the methods and detailed discussions are reserved for chapter 4.

In palynostratigraphy, numerical methods also play important roles for zoning the pollen sequence, displaying the inter-structure of the data set, and comparing events among several sequences. Q-mode PCA (Davis, 1973, program PCA) was applied in this monograph to facilitate the interpretation of palynostratigraphic data. As Prentice (1980) indicated, most palynologists use PCA with a standardization of the data with the exception of a few users such as O'Sullivan and Riley (1974) and Adam (1970, 1974) and Heusser and Balsam (1977). This standardization was applied to both palynostratigraphic and surficial pollen data.

In this study, PCB and Correspondence Analysis (CA) were also used in the interpretation of pollen data. Ordination procedures of these two techniques have been fully described by Gordon (1982) and the computer program BIPLOT and CORRAN were provided by Dr. Gordon to the author. Gordon (1982) proposed that both CA and PCB should be used simultaneously because "if broadly similar results are obtained, one can have a greater measure of confidence that these are faithfully reflecting the nature of the data" rather than being a mathematical artifact of one particular method (Gordon, 1982, p.117). Therefore, it was important to use several methods to assess the consistency of the results (Birks, 1987a).

Both CA and PCB were closely related to PCA, except that they involved more complex scaling of the axes and distance measurements between samples and variables (Gabriel, 1971; Hill, 1974). It was of primary interest to the author that PCB and CA simultaneously display the geometrical relationships of both samples and variables on the same axes, thus permitting direct interpretation of observed patterns between samples in terms of relationships within and between samples, and *vice versa* (Birks, 1985).

Selected pollen taxa were used in numerical analyses to avoid statistical noise from the rarely present taxa. Therefore only those taxa which appeared fairly consistently and reached values of 5% in one or more samples were included in the data set (Gordon and Birks, 1972). The same taxa from modern surficial samples were combined with the stratigraphic samples for direct comparisons. Samples which had similar pollen contents should cluster together, providing possible modern analogues to the fossil spectra. The application of combined matrices ordination techniques to Quaternary palynological data has been discussed by Prentice (1980) and combined data sets of modern and fossil pollen spectra have been previously used with great success by MacDonald (1983, 1984).

3.5.2 Zonation of Pollen Diagrams

Pollen sequences were often subdivided into smaller units in order to be more easily described, interpreted, compared, and correlated. The most popularly used subunit is a pollen zone. However, "although pollen analysts have been delimiting and, in some cases, defining pollen zones for over 50 years, there are very few definition of guidelines about what a pollen zone is or should be " (Birks and Gordon, 1985, P. 48). Upon the various considerations, the term "pollen zone" as used in this thesis refers to a local pollen assemblage zone which by definition follows standards set out in the "International Guide to Stratigraphic Classification, Terminology, and Usage" (Hedberg, 1976). The determination of a pollen zone or pollen assemblage zone is only based upon the observed pollen and spore content without considering sediment lithology, inferred climate, past vegetation, or presumed time-equivalence (Janssen, 1980).

It is a convention to zone a pollen diagram only by visual inspection of the diagnostic features of the sequence. Quantitative or numerical approaches, however, have also been employed to achieve the same end during the last decade. Birks and Gordon (1985) have already given an historical review of the different zonation approaches, and an interested reader may refer to them. Up to the present, the most widely applied numerical zonation procedures for palynological data have been those of Gordon and Birks (1972), containing three different methods; i.e. CONSLINK, SPLITINF, SPLITLSQ. Birks (1979) has published a FORTRAN IV computer program to provide these procedures. More recently a new program named CONISS has been published to zone a palynological data matrix using stratigraphically constrained criteria (Grimm, 1987).

Comparing these different procedures, CONSLINK uses a single linkage criterion for merging clusters, and employs two different dissimilarity coefficients. The first dissimilarity coefficient used by CONSLINK is the Manhattan or city-block metric. The second is the Canberra metric. Procedure SPLITINF uses information statistics, and procedure SPLITLSQ uses a sum of squares measure of within-cluster variability. Program CONISS, however, performs a stratigraphically constrained cluster analysis using the incremental sum of squares method, which is operated on a dissimilarity matrix of squared Euclidian distances. The sum of squares method is an intense clustering criterion that minimizes chaining, but tends to produce compact, "spherical shaped" groups of samples, often of roughly similar size (Birks, 1987b, p.112).

At the early stages of this study, however, only ZONATION procedures had been published, and program CONISS was not available until mid-1987. The application of program ZONATION to 8 data sets revealed that none of these procedures could properly zone all of the data sets. A FORTRAN 77 program named CONZONE was therefore developed by the author to fulfill the zonation process (Wang, 1988b).

Program CONZONE, consisting of two procedures: CONCLINK and CONUPGMA, carried out stratigraphically constrained cluster analysis similar to CONSLINK but employing different linkage methods and different variation measurements. Multiple options enabled the user to choose from three different variation measurements (appendix E), *i.e.* cosine theta coefficient, Pearson's correlation coefficient, and the average Euclidian distance. The first two measurements exhibit the similarity between samples, therefore the samples which have largest similarity coefficients will be clustered first. The average Euclidian distance is a dissimilarity coefficient measuring the dissimilarity between the samples, and the samples which have smallest dissimilarity coefficient should be clustered together first. To perform the stratigraphically constrained clustering, only those coefficients between stratigraphically neighboring samples will be considered and compared. The smallest dissimilarity coefficient or the largest similarity coefficient is then assigned to the dissimilarity level as an accumulative squared distance measurement, as illustrated below:

$$C_i = \sum_{i=1}^{n} (1-r_i)^2 \qquad \text{(for correlation coefficient)}$$

$$C_i = \sum_{i=1}^{n} (1-\text{Cos } O_i)^2 \qquad \text{(for Cosin theta coefficient)}$$

$$C_i = \sum_{i=1}^{n} D_i^2 \qquad \text{(for Euclidian distance)}$$

Procedure CONCLINK used a complete linkage clustering method to merge the coefficient matrix.

The differences between program CONSLINK and CONCLINK are twofold. Firstly different resemblance matrices are employed between these two methods. Secondly and fundamentally, the linkage methods are different. CONSLINK, as a single linkage clustering method, has to assign the minimum value between two coefficients to a new cluster for merging the resemblance matrix. Although an excellent example of the application of this method has been published (i.e. Birks and Berglund, 1979), "the single linkage criterion of CONSLINK can lead to severe chaining, especially in pollen sequences where analysts usually place samples closer together in zones of rapid change." (Grimm, 1987). The procedure CONCLINK, however, uses a different linkage clustering method to merge the resemblance matrix. Instead of choosing the minimum value for a new coefficient as in CONSLINK, the maximum value is assigned to the merged coefficient for CONCLINK. This selection would avoid the severe chaining since the clusters will be grouped together by their minimum dissimilarity.

In comparison with CONSLINK and CONCLINK, program CONUPGMA is midway between these two procedures. The basic difference is that CONUPGMA uses an unweighted pair-group method using arithmetic averages, which is the one most widely used method in cluster analysis. Instead of choosing the largest or the smallest value to assign a new coefficient, CONUPGMA averages the grouped coefficients to merge the data and form a new resemblance matrix.

Examples of the application of CONCLINK and CONUPGMA and the detailed comparison of various numerical zonation procedures will be discussed and graphically illustrated later with the pollen data of the study areas. A computer program list and related documents are presented in Appendix F.

Pollen spectra derived from lake sediments represent regional pollen rain (Ritchie, 1974), whereas spectra from peat deposits are subject to fluctuations caused by variations in local environmental factors. Numerical zonation procedures such as ZONATION and CONISS may work well with lacustrine profiles, but may also present problems when applied to peat profiles owing to fluctuations between samples. The conclusion here is not to reject numerical zonation procedures but to apply multiple procedures and synthesize the results. Therefore, the definition of the zone boundary in this monograph, unless specified, will be a combination of the CONZONE, CONISS, and ZONATION procedures.

3.5.3 Computing Procedure

As the result of the rapid development of high speed electronic computers and fast graphic plotters, several computer programs have been developed in the past 20 years for the storage, retrieval, and manipulation of palynological data and the plotting of the pollen diagrams (such as Squires, 1970; Birks and Huntley, 1978; Cushing, 1979). Among these programs POLLDATA.MK5 developed by Birks and Huntley in 1978 seems to be the most powerful one. However, as indicated by Birks and Gordon (1985, P. 25), all these programs are heavily dependent on the local installation of hardware systems. At the time when this study began, none of these programs was conveniently available, therefore, a FORTRAN 77 computer program named PALYDP (PALYnological Data Processor) was developed by the author. The main characteristics of this system included the storage and manipulation of the pollen and spore data. The system facilitates the calculation of pollen percentage upon an user-defined pollen sum, the calculation of pollen ratios between some user-selected taxa, the calculation, extrapolation and modification of sedimentation rate using a number of radiocarbon dates, the calculation of absolute pollen concentrations and pollen accumulation rates, and the calculation of species richness using three different indices and Shannon-Weaver diversity (Appendix E, <u>sensu</u> Odum, 1971, p.144). All the above functions are hardware and software installation independent. Unfortunately, the portion of the program utilized for plotting the diagrams are hardware and software dependent. Pollen diagrams of the relative pollen frequency, pollen concentration, and pollen accumulation rates can be plotted using a Calcomp plotter which produces a reducible publish-ready pollen diagram with an option for including sediment symbols. Meanwhile, a series of programs were prepared using DISSPLA subroutines (Integrated Software Systems Corporation, 1986) to plot charts for pollen ratios, species diversity and richness, ^{14}C dates _vs_ depth relations, and so on. A user's guide-book for the program PALYDP and program source codes are listed in Appendix G.

Chapter 4

Contemporary Pollen Records of the Aishihik Basin and its Vicinity

4.1 Introduction

The relationship between contemporary pollen spectra and present vegetation from which the pollen spectra derive has been conventionally a useful parameter for the interpretation of palynostratigraphic data. It is especially useful to use surficial pollen data in a new area of investigation, where little is known of the pattern of the pollen sequence (Wright, 1967). During the last few decades, great quantities of surficial pollen data have been published, and isopoll maps have been produced for much of North America (Delcourt *et al*. 1984). Some investigations of contemporary pollen and vegetation/climate relationships have been carried out in southwestern Yukon Territory. In the Aishihik Basin and its vicinity, however, the records still remain fragmentary.

As discussed previously (see Chapter 2), the study area exhibits complex topography and landforms with extremely variable vegetation covers. Surficial palynological investigations in the adjacent areas show that the pollen records are strongly influenced by environmental conditions in addition to the present vegetation. Geurts (1983) has found that the modern pollen assemblage in Coppermine valley has a close relationship with landforms and concluded that the variations in the pollen spectra do not exclusively reflect climatic variations or ecologic successions. Campbell (1987) reported the over-representation of *Picea* by more than 60% in

Ruby Range, and de Bastiani (1988) also demonstrated strong over-representation of Picea in all alpine vegetation zones in Williscroft Creek in the Kluane Lake area. These studies suggested strong modification by topography of the pollen records. Meanwhile, studies on the relationship between airborne pollen records and climatic data in the Ruby Range revealed that the contemporary pollen records are also influenced by the variation of atmospheric circulation system (Lagarec et Geurts, 1984). It is, therefore, essential that the interpretation of the fossil pollen records in this area be facilitated by a surficial palynological investigation.

Field and laboratory methods are described in Chapter 3. Modern vegetation and other environmental parameters are discussed in Chapter 2. The numerical approaches involve a pair-weighted cluster analysis and principal component analysis. The results of these analyses will be discussed in section 4.3.

4.2 Contemporary Surface Pollen Analyses

In comparison with surface lake sediments, moss polsters generally yield a greater representation of locally derived pollen, which can be valuable for evaluation of local environmental changes (Short et al., 1986). Twenty polster samples were collected from four different vegetation-landform units (Fig 4.1) in order to determine whether a polster could

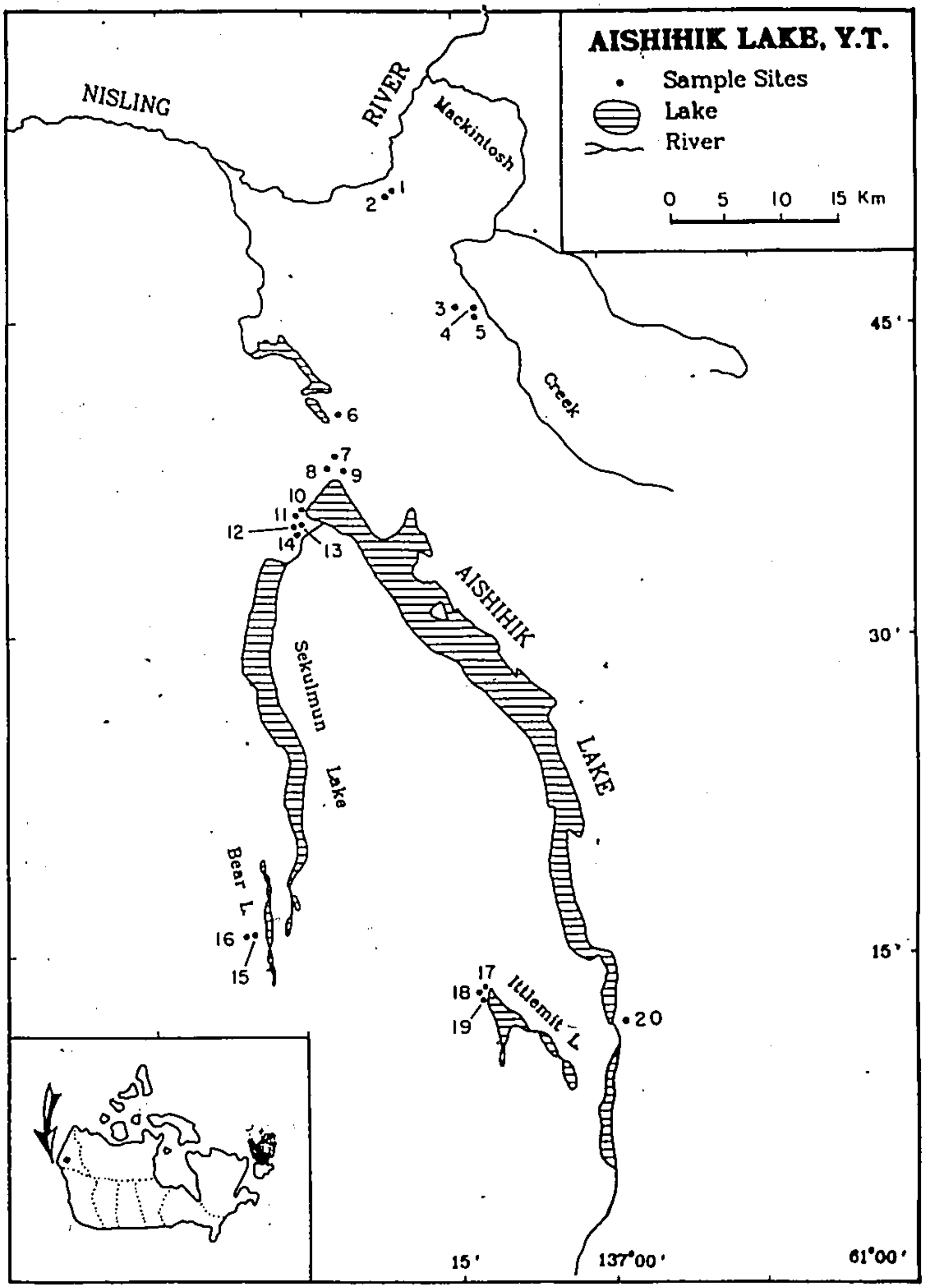

Figure 4.1 Location of surficial pollen samples in this study

produce a pollen spectrum which could reflect the original vegetation.

4.2.1 <u>Results</u>

The results of the pollen analysis are illustrated in a relative pollen frequency diagram (Fig. 4.2). The samples are grouped according to the local vegetation-landform units from which the samples were collected. The following discussion will follow this classification.

Nineteen pollen types (excluding unknowns) were distinguished and arranged in the order of trees-shrubs-herbs-pteridophytes. The preservation of pollen and spores was very good in all samples.

SPRUCE FOREST: The samples collected from spruce forest yield pollen spectra dominated by high <u>Picea</u> percentage (50-78%). <u>Pinus</u> is also well represented (0-11%). <u>Betula</u> percentage is relatively low, varying from 4% to 14% except in one sample which has 26%. <u>Salix</u> varies from absent to 15%. Percentages of herbaceous taxa, including Cyperaceae and Gramineae, are generally low.

FOREST-TUNDRA: The pollen spectra from the forest-tundra vegetation-landform unit have 34-55% of <u>Picea</u>. The next dominant taxon is <u>Betula</u> which varies from 22% to 38%. <u>Salix</u> is around 3-5%. <u>Pinus</u> is present in all samples with values of 3-8%. <u>Alnus</u> varies from 1% to 9%. Ericaceae is moderately

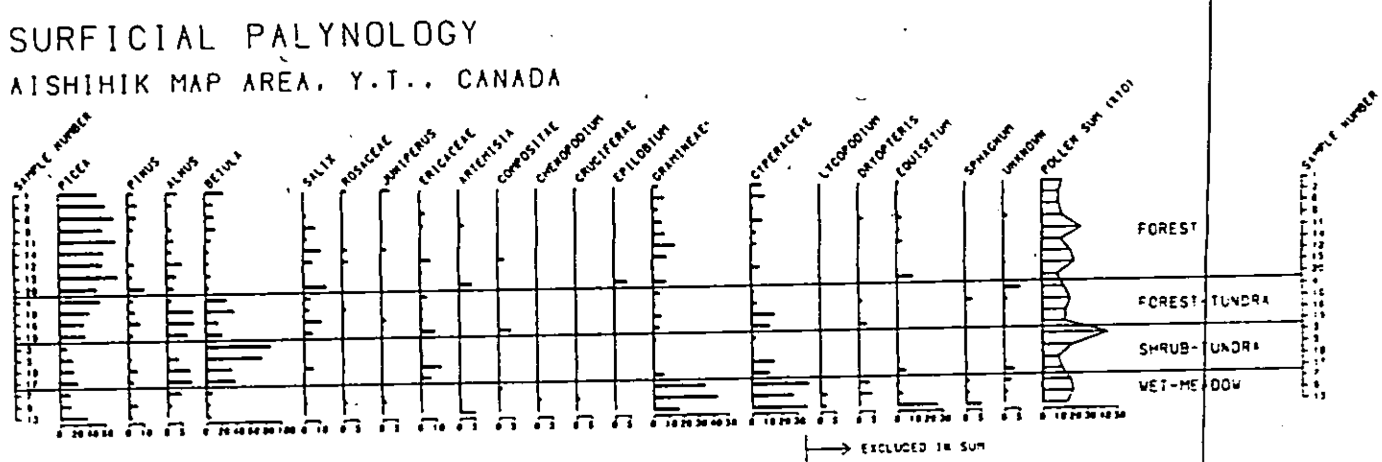

Figure 4.2 Pollen percentage diagram of surficial samples

represented in all samples at 1-9%. Herbaceous percentages are generally low.

SHRUB-TUNDRA: The dominant pollen taxa from the shrub-tundra vegetation-landform unit is *Betula*, which varies from 34% to as high as 87%. *Picea* percentages are comparatively low (9-25%). *Pinus* varies from 0.2% to 6%, *Alnus* from 0.2% to 0.8%, and Ericaceae from 0 to 13%. Herbaceous percentages are also low.

WET-MEADOW: The high percentages of Cyperaceae and Gramineae mark the pollen spectra derived from the wet-meadow vegetation-landform unit. Cyperaceae percentages are approximately 36-38%. Gramineae varies from 17% to 43%. The spores are well represented in contrast with those in the other pollen spectra: *Sphagnum* varies from 1% to 5%, *Equisetum* from 1% to 26%, *Dryopteris* from absent to 4%, and *Lycopodium* from 0-2%. Trees and shrubs, however, are obviously less well represented than in the other units: *Picea* varies from 13% to 36%, *Pinus* from 1% to 5%, *Betula* from 4-8%, and *Alnus* from absent to 4%.

4.2.2 Summary of the Basic Features

The following features are distinguishable from the present percentage diagram:

(a) Samples from the spruce forest vegetation-landform unit are distinct from the others by high *Picea* percentages and low *Betula* representation.

(b) Samples from the forest-tundra vegetation-landform unit are not easy to distinguish from those of the spruce forest because of the high values of *Picea*, but they have relatively higher *Betula* and *Alnus* percentages.

(c) Samples from the shrub-tundra vegetation-landform unit are characterized by high percentages of *Betula* and simultaneous low representation of *Picea*.

(d) Samples from the wet-meadow vegetation-landform unit are distinct from the others by dominant percentages of Cyperaceae and Gramineae pollen and low values of tree and shrub pollen.

4.3 Statistical Analyses

Statistical methods have been employed for summarizing and displaying the pattern of modern Pollen data, and a number of successful approaches have been undertaken (Birks and Gordon, 1985). The methods employed in this study are pair-weighted cluster analysis and principal component analysis (Davis, 1973, program CLUST and PCA). The initial aim in employing these analyses was the classification of pollen samples. If numerical classification corresponds with the classification of vegetation-landform units, it can be concluded that different vegetation-landform units produce distinctive pollen spectra which can be used to facilitate the interpretation of palynostratigraphic data with high confidence. The second purpose was to extract some information for interpreting the inter-structure of pollen data. Taxa included in the data set are Picea, Pinus, Alnus, Betula, Salix, Ericaceae, Gramineae, and Cyperaceae because these taxa reach 5% in at least one sample and have relatively consistent occurrence. This selection is based upon the consideration of statistical 'noise' derived from rarely represented taxa (Prentice, 1980).

4.3.1 Cluster Analysis

As one of most conventional numerical classification methods, cluster analysis was carried out to group the samples into clusters without an priori grouping but purely based on their pollen content. The samples were used as objects and the pollen types as variables. Pearson's product-moment correlation coefficient was calculated (Appendix E), and the weighted-pair group method was employed for the clustering. The result is illustrated in figure 4.3.

The similarity between clusters decreases rapidly after 0.6 where an arbitrary cut divides the dendrogram into 3 groups, i.e. A, B, and C (Fig.4.3). Ignoring the portion below

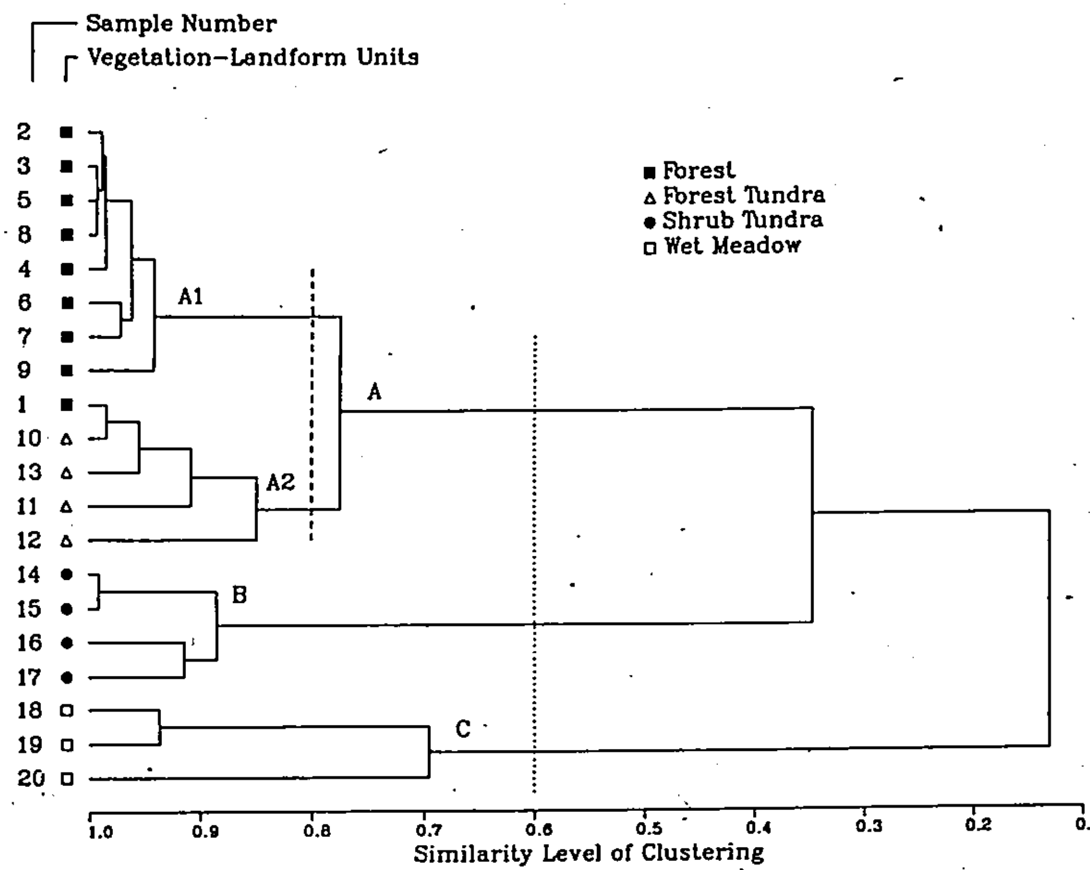

Figure 4.3 Dendrogram of Cluster Analysis

0.6, the remained part contains 89.5% of the clusters. In comparison with initial classification based on vegetation-landform units, group A contains the samples collected from spruce forest and forest-tundra. This group can be further divided into sub-groups A1 and A2, which contain the forest and forest-tundra samples, respectively. This result implies that pollen spectra from the spruce forest are not easy to distinguish from those of forest-tundra samples. This interpretation is also consistent with the classical interpretation of pollen diagrams. However, spruce forest and forest-tundra may yield highly similar pollen spectra within the group. Group B contains the samples collected from shrub-tundra which also corresponds with the vegetation-landform unit classification. The last group (C) only contains samples collected from the wet-meadow environment. These results, in conclusion, suggest that shrub-tundra and wet-meadow pollen spectra can be easily distinguished from the others, while forest and forest-tundra spectra have higher similarity.

4.3.2 Principal Component Analysis

Principal component analysis is powerful in displaying the structure of a large number of interrelated variables in terms of a smaller and simpler set of new uncorrelated variables or principal components (Birks et al., 1975). It is useful for summarizing and extracting interpretable information from a data matrix.

The results of principal component analysis are represented in figure 4.4a and 4.4b. As illustrated in figure 4.4a, herbaceous taxa have high positive loadings on the first PCA axis, while tree and shrub taxa all have negative loadings. These results indicate that pollen spectra from herbaceous vegetation are statistically distinctive from others. *Picea* has relatively high positive loading on the second PCA axis, while *Betula* has high negative loading. This differentiates, statistically, the spectra of the spruce-dominated community from those of the birch-dominated community and suggests a negative correlation between these two taxa or a compensating relation. The other axes are relatively noisy and are not easy to interpret.

The plotting of component scores along the first two principal component axes (Fig. 4.4b) accounts for about 54% of total data covariance. It is interesting to note that the wet-meadow samples are distinctively separated from all other samples with high positive scores on the first PCA axis and moderate scores on the second. Shrub-tundra samples are also distinctive from others with moderate scores on the first axis and high negative scores on the second. All forest samples have moderate to high negative scores on the first axis and positive scores on the second axis. The forest-tundra samples have intermediate negative scores on the first axis and moderate

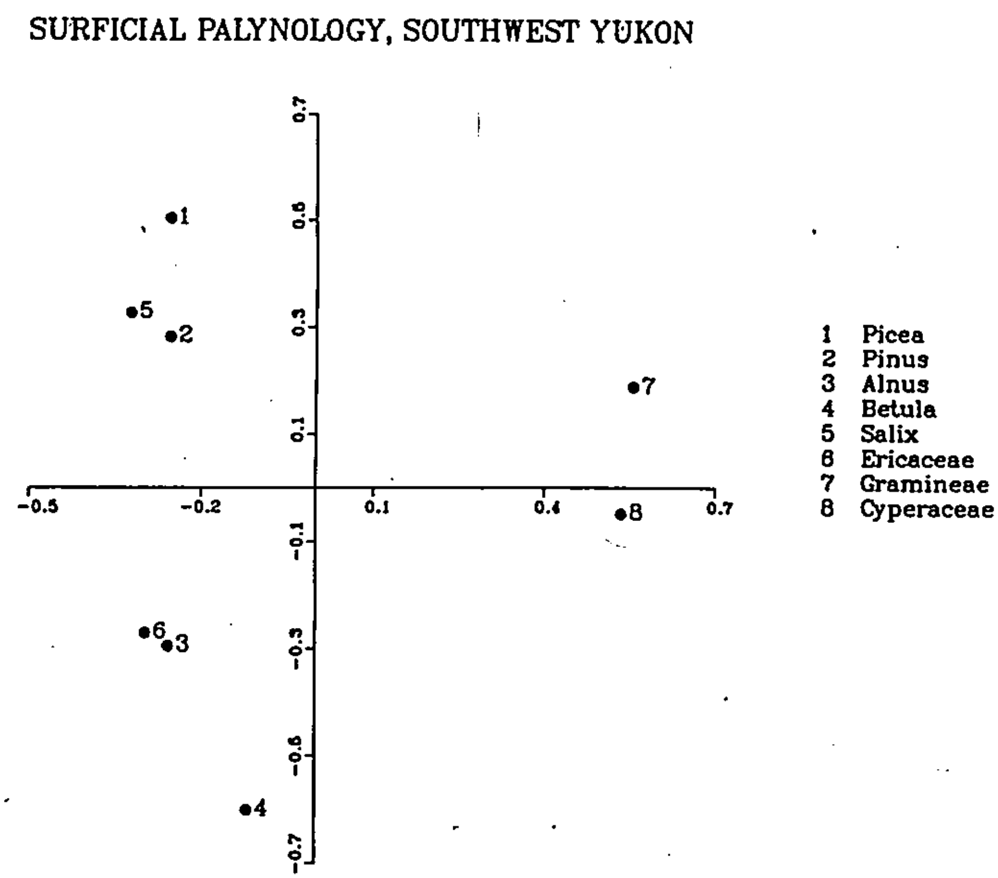

Figure 4.4a Principal component loadings of selected taxa on the first (horizontal) and second (vertical) PCA axes, surficial pollen samples, Aishihik Basin and its vicinity

SURFICIAL PALYNOLOGY, SOUTHWEST YUKON

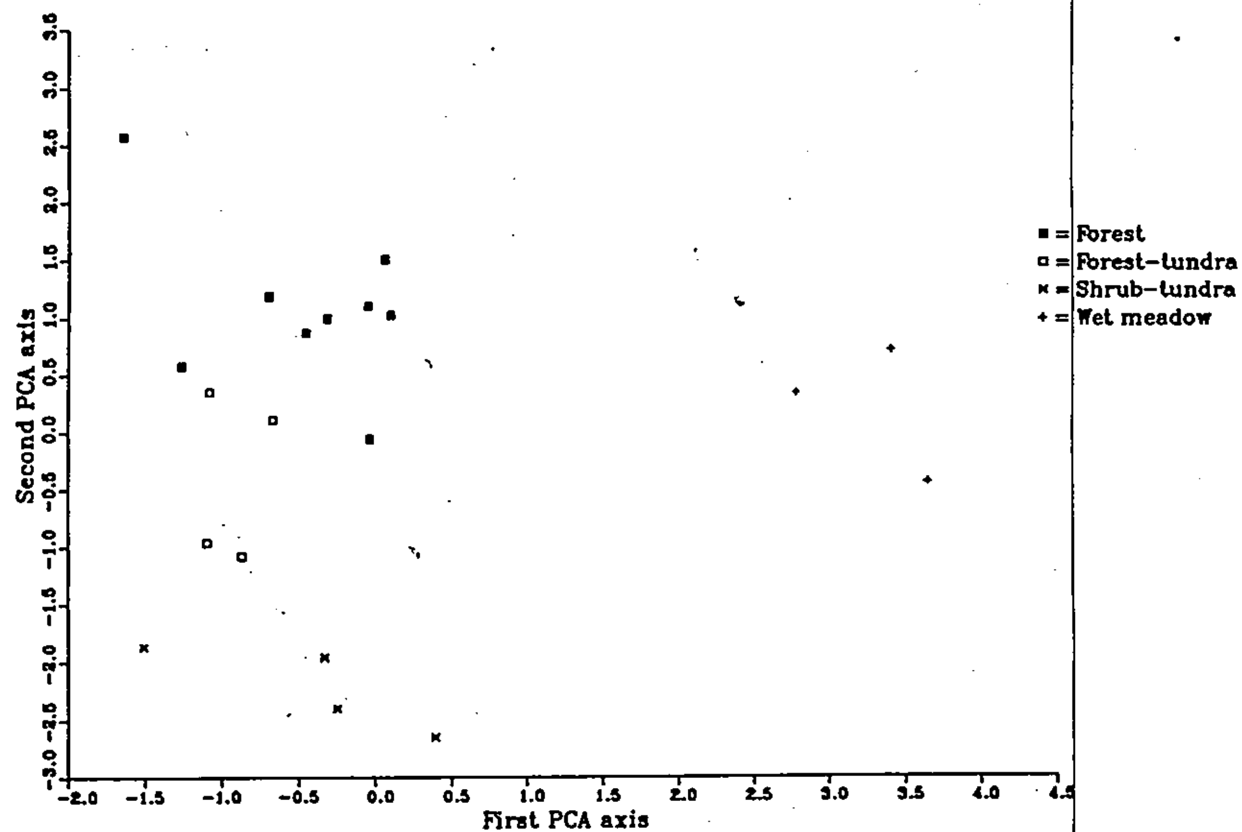

Figure 4.4b Principal component scores of surficial pollen samples, Aishihik Basin and its vicinity, southwest Yukon

scores on the second axis. The highly similar pattern of scores for forest and forest-tundra samples is consistent with the results of the cluster analysis.

4.3.3 Summary of the Results

The quantitative analysis of the modern pollen spectra indicates a high degree of correspondence between palynological data and vegetation-landform unit classification. Cluster analysis provides the fundamentals for comparison between the numerical classification of samples based only on their pollen contents and that based on vegetation-landform units from which the samples were collected (Tab. 4.1). Group A1 consists of 8 samples all collected from the forest unit, which includes 88.9% of the total samples from that unit. All forest-tundra and shrub-tundra samples have been grouped together respectively. Only one forest sample is not adequately grouped together with other samples from the same unit.

The distinctive principal component scores on the first two principal component axes confirm the classification of samples by cluster analysis. Principal component analysis also provides a numerical synthesis of information on the importance of a particular pollen taxon in the different vegetation-landform units, as well as the relationships between pollen taxa.

Table 4.1 Comparison of sample classification suggested by cluster analysis and by the vegetation–landformunits from which the samples were collected

Cluster Group	Vegetation–landform units			
	Forest	Forest–tundra	Shrub–tundra	Wet meadow
A1	8	–	–	–
A2	1	4	–	–
B	–	–	4	–
C	–	–	–	3
Total Samples for each unit	9	4	4	3

In conclusion, different vegetation-landform units can yield numerically distinguishable pollen spectra which reflect contemporary vegetation with high confidence. Therefore the pollen spectra of modern moss polsters can be used as references for the interpretation of fossil pollen records in the study area.

4.4 Discussion and Conclusion

The values of 8 major pollen taxa in the 20 moss polster samples from four vegetation-landform units are summarized in table 4.2. The ratio of *Picea*/*Betula* and the second principal component scores are plotted in figure 4.5. The *Picea* pollen percentages are also presented in the figure. All curves were smoothed by the third order parametric polynomial interpolation method. It is notable that all samples from the spruce forest have more than 50% *Picea* pollen with a mean of 62.9%. The high pollen ratio of *Picea*/*Betula* reflects the importance and dominance of *Picea* in this vegetation-landform unit. The high second principal component scores also give the same information since *Picea* has highest positive loading on this axis. The high representation of *Picea* pollen presented here is consistent with previous studies in the area (*i*.*e*. Rampton, 1971; de Bastiani, 1988). Pollen percentages of surficial moss polsters from Williscroft Creek in Kluane National Park of southwest Yukon Territory vary from 78% to 83%. The different *Picea* percentages in these two areas presumably reflect

Table 4.2 Summary of selected pollen percentages in surficial samples.
Upper figures are ranges of percentages, lower figures are mean
Pollen sums exclude aquatics and spores

Pollen Taxa	Vegetation–landform units			
	Forest	Forest–tundra	Shrub–tundra	Wet meadow
Picea	50.0–75.4 62.9	32.1–54.5 39.9	8.9–24.6 17.1	13.3–35.5 20.9
Pinus	0.0–10.9 3.8	2.7–7.7 4.3	0.2–5.7 2.7	1.1–5.3 2.7
Alnus	0.0–5.2 2.4	1.4–9.0 6.5	0.2–8.2 4.9	0.0–4.4 1.8
Betula	4.3–25.5 10.1	16.7–38.0 26.0	34.3–86.8 58.7	4.3–7.8 5.7
Salix	0.0–15.2 5.0	3.3–11.5 6.1	0.2–5.7 1.6	0.0–1.0 0.4
Ericaceae	0.0–7.3 1.6	1.1–9.5 4.0	0.0–13.3 5.2	0.0–0.0 0.0
Gramineae	0.8–15.0 7.0	1.1–5.1 3.6	0.0–6.6 2.1	16.5–42.6 31.2
Cyperaceae	0.0–9.7 4.3	1.4–15.4 8.0	1.0–15.2 7.6	27.7–37.8 33.9

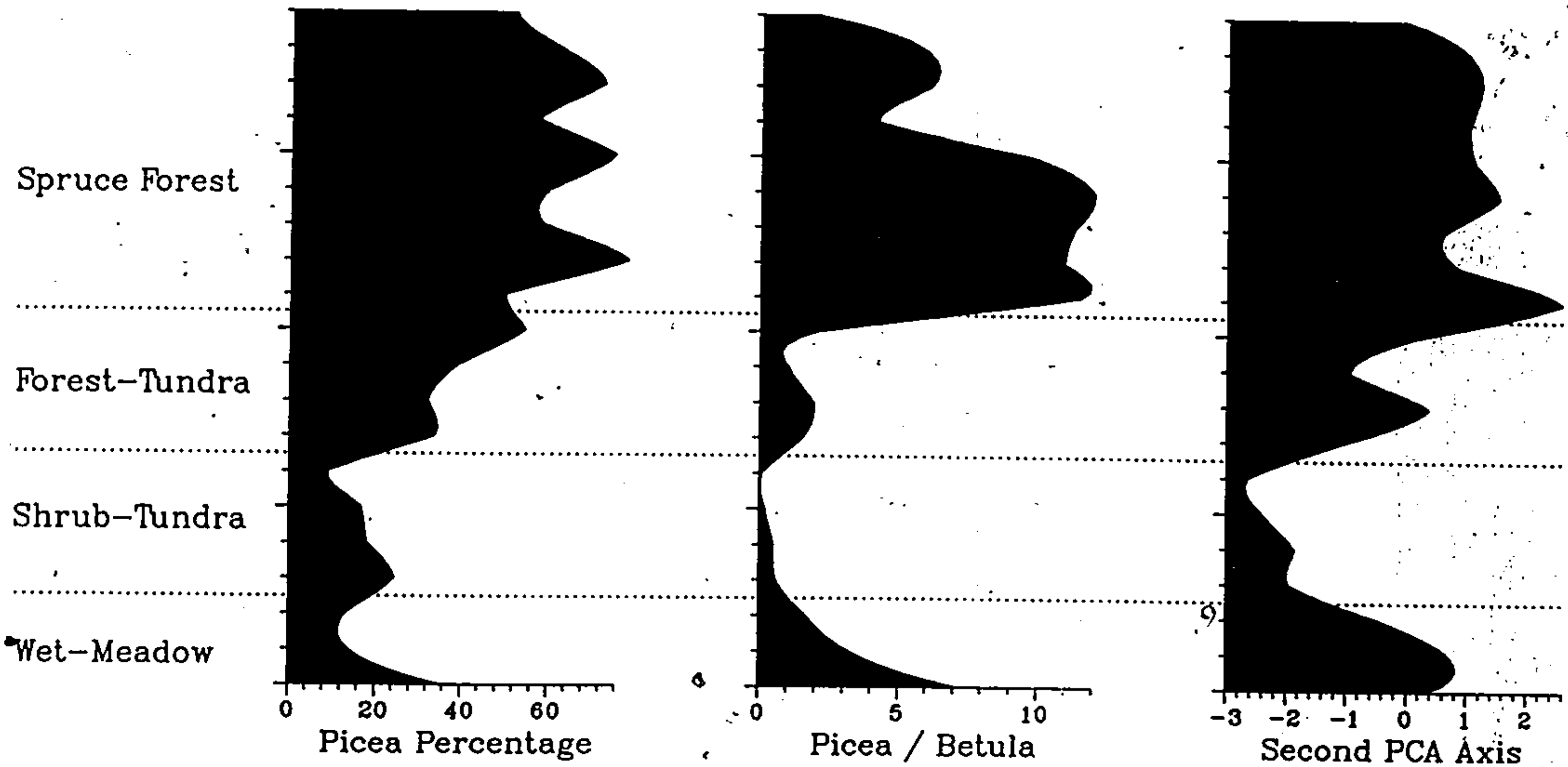

Figure 4.5 Smoothed curves for <u>Picea</u> percentage, ratio of <u>Picea</u> / <u>Betula</u>, and the second PCA axis scores for the surficial samples in the study area

differences of both landform and forest density. Samples of Williscroft Creek (de Bastiani, 1988) were collected within a *Picea glauca* forest which occupied a steep slope and faced the relatively broad valley of Kluane Lake. The area reported on in this study, however, has various micro-topography in a broad area with undulating and hilly topography. This difference would result in differences in pollen dispersion. Geurts (1983) reported another similar example of *Picea* percentage related to topography from Coppermine Valley in the Northwest Territories, and concluded "Une dominance du pollen de *Picea* correspond aux plateaux forestiers sur des versants en pente de +/- 12°" (Geurts, 1983, p.586). A similar result was also reported from the Natla River area in the Northwest Territories (MacDonald, 1983). MacDonald and Ritchie (1986) also reported corresponding values of *Picea* from the western interior. Unfortunately, Rampton's data (1971) are less valuable since only one sample was collected from the white spruce forest, although the result is comparable to the present study. In the St. Elias Mountains, however, *Picea* pollen percentages from forest samples are quite different (Birks, 1977), varying from 5% to 43%. The sample sites were adjacent to Klutlan Glacier where down-glacier wind produces a different pollen transport system. Ritchie (1974) reported that forest site spectra from the Mackenzie Delta in the Northwest Territories consisted of over 50% arboreal types (*Picea*, 25-30%; *Betula*, 30%). The taxa which compensate the low *Picea* values were *Betula* and *Alnus*. In comparison with this study, the differences of forest composition and local environmental components between two areas supply one of the reason for the dissimilarity of pollen data. High values of Alnus and birch tree pollen in the Mackenzie Delta area indicated that these plants have denser distribution in that area. Conversely, in this study area, Alnus has a very sparse distribution and tree birch is not present according to the three year field observations.

The pollen spectra of forest-tundra samples are generally distinguishable from the others except for the high similarity to those of forest samples. High correlation coefficients between spectra of forest and forest-tundra samples in the cluster analysis (Fig. 4.3) and the close relation of their principal component scores on the first two axes (Fig. 4.4b) reveal the affinity between those two groups. This may suggest that the pollen spectra of forest-tundra samples could be confused with those of forest samples, especially if the forest is in an open phase. Similar phenomena have been found in the Upper Natla River area in the Northwest Territories (MacDonald, 1983), and comparable pollen spectra have also been reported from the western interior (MacDonald and Ritchie, 1986). However, a great decrease of the Picea/Betula pollen ratio in comparison with that of forest samples and obvious decrease of the second principal component scores (Fig 4.5) still suggest that forest-tundra and forest pollen spectra can be distinguashed despite their similar Picea percentages. In conclusion, these two groups are distinguishable based upon their pollen spectra, numerical approaches, and pollen ratios.

The shrub-tundra sites are typified by high shrub pollen percentages, especially that of Betula, and low frequencies of tree pollen (Tab. 4.2). Both pollen spectra and numerical analysis indicate that shrub-tundra sites can yield obviously different pollen spectra in comparison with other vegetation-landform units. Betula-dominated spectra have also been observed in the birch tundra samples from the Upper Natla River area (MacDonald, 1983) where the general aspects of shrub-tundra pollen spectra are quite similar to those ih the present study. Very low Picea/Betula pollen ratio and the second principal component scores (Fig 4.5) strongly suggest the low influence of Picea pollen in the spectra. In comparison with the pollen spectra from other units, low Picea percentages from shrub-tundra samples are consistent with those in other studies. However, since the general area in which these four samples were collected is a forest-tundra environment and near a spruce forest, Picea percentages from these tree-less units are higher than the 10% threshold defined by Ritchie (1984a).

It is not surprising that Cyperaceae and Gramineae dominate the pollen spectra of wet-meadow samples (Tab. 4.2). High percentages of Cyperaceae and Gramineae have been frequently observed from the surficial pollen diagrams (Jacobs *et al.*, 1985; Short *et al.*, 1986) and also palynostratigraphic diagrams (*e.g.* Kay, 1979; Ritchie, 1982) derived from the north. In this study, well represented *Sphagnum*, *Equisetum*, Cyperaceae, as well as the low frequency of *Betula* strongly suggest the wet condition. Large areas of wet ground are frequently scattered in the lowland of the study site, representing a distinct ecosystem. However, the high percentages of Gramineae and Cyperaceae are not necessarily related to a tree-less vegetation since the general study area is forested. This result is consistent with previous studies (Ritchie, 1976; 1977).

In conclusion, contemporary pollen spectra from moss polsters can provide a base for the interpretation of palynostratigraphic data in the study area where the vegetation-landform units show great complexity. Both the classical interpretation of the pollen diagram and the numerical analysis of the pollen data verify that different vegetation-landform units in the area can yield distinguishable pollen spectra except for a high similarity between forest and forest-tundra groups. However, the small number of samples in the wet-meadow unit may raise statistical instability in the result for that group.

Chapter 5

Post-glacial Pollen Records in the Northern Aishihik Basin

5.1 Introduction

The northern Aishihik Basin and adjacent Klondike Plateau (Fig. 2.1) exhibit a complex Quaternary environmental history. In fact, the extent of the last glaciation still remains in dispute (Hughes, manuscript; Prest, 1984; Beaudet, 1986). Records of Holocene vegetation history in this area are extremely fragmentary and rare. Only one pollen profile has been reported from this area (Beaudet, 1986, summary diagram presented here in figure 5.1) , which is a part of a regional investigation of late-Quaternary history in the southwest Yukon conducted by a research group from the University of Ottawa. Initial interpretation of this pollen profile suggests that spruce arrived in the Mackintosh Creek area approximately 8,900 yr BP, and that the modern forest-tundra environment has been stable since about 8,000 yr BP. The initial vegetation in the area was a herb tundra followed by a birch-dominated shrub tundra at about 9,900 yr BP (Beaudet, 1986).

It is essential to conduct a series of paleoecological investigations so that the regional environmental history can be reconstructed for an area, such as northern Aishihik Basin and its vicinity, which has a complex topography and Pleistocene history. In this chapter, two Holocene pollen profiles, one between the Reid and McConnell glaciation limits (XW-1), and one between the McConnell limit and an uncorrelated moraine system (XW-3), and one late-Holocene pollen profile, were examined to trace the paleoenvironmental evolution (Fig. 1.3; Fig. 5.2). The influence of landform development processes on the pollen records was also assessed.

5.2 Upper Nisling Valley (XW-1)

5.2.1 Site Description and Present Vegetation

Profile XW-1 was cored in a peat bog in the Upper Nisling Valley area at 61°51'13" N Lat., 137°21'43" W Long., 975 m a.s.l. (Fig. 5.2, Fig 1.3). The elongated bog depression is about 600 m long in NE direction and *ca*. 200 m wide in NW direction. This area is near the edge of the Reid moraine as identified by Hughes (manuscript). The depression is currently surrounded by white spruce (*Picea glauca*) forest. *Salix glauca* and *Betula glandulosa* are two shrub taxa in the community. *Potentilla fruticosa*, *Arctostaphylos* sp., *Ledum tetragonum*, *Equisetum* sp., and Gramineae are also present. At the core site, however, Cyperaceae cover about 50% of ground surface compared with Gramineae at about 20%. *Salix glauca* and *Betula glandulosa* cover about 15% and 10%, respectively. *Potentilla fruticosa* and *Chenopodium* sp. are present.

5.2.2 Sediment Stratigraphy

The lithology of this profile is relatively simple. Organic peat with rootlets occurs in the top 15 cm. White River

MACKINTOSH CREEK-HB1, YUKON TERRITORY

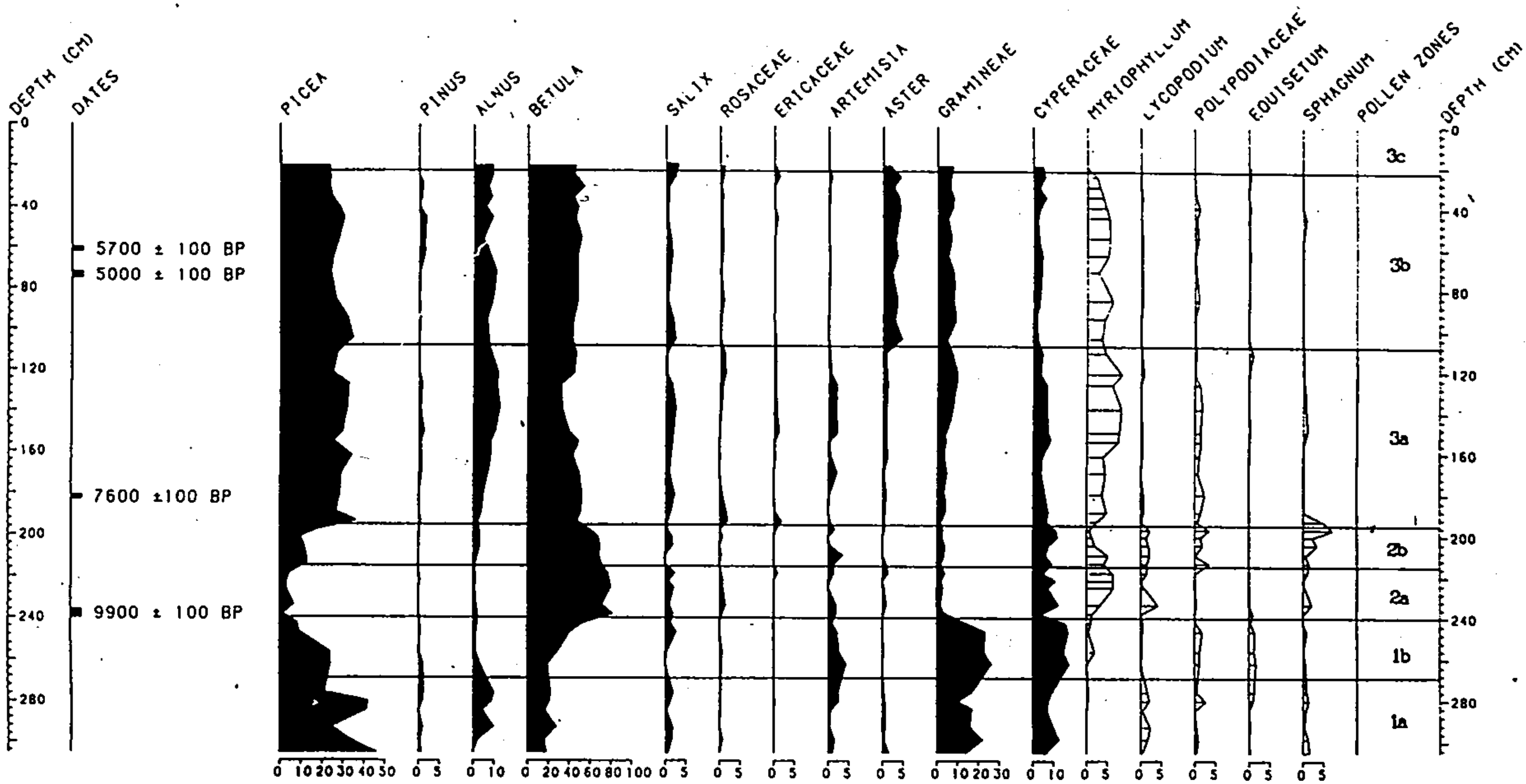

Figure 5.1 A sumaary pollen percentage diagram of profile Mackintosh Creek-HB1 (data from Beaudet, 1986)

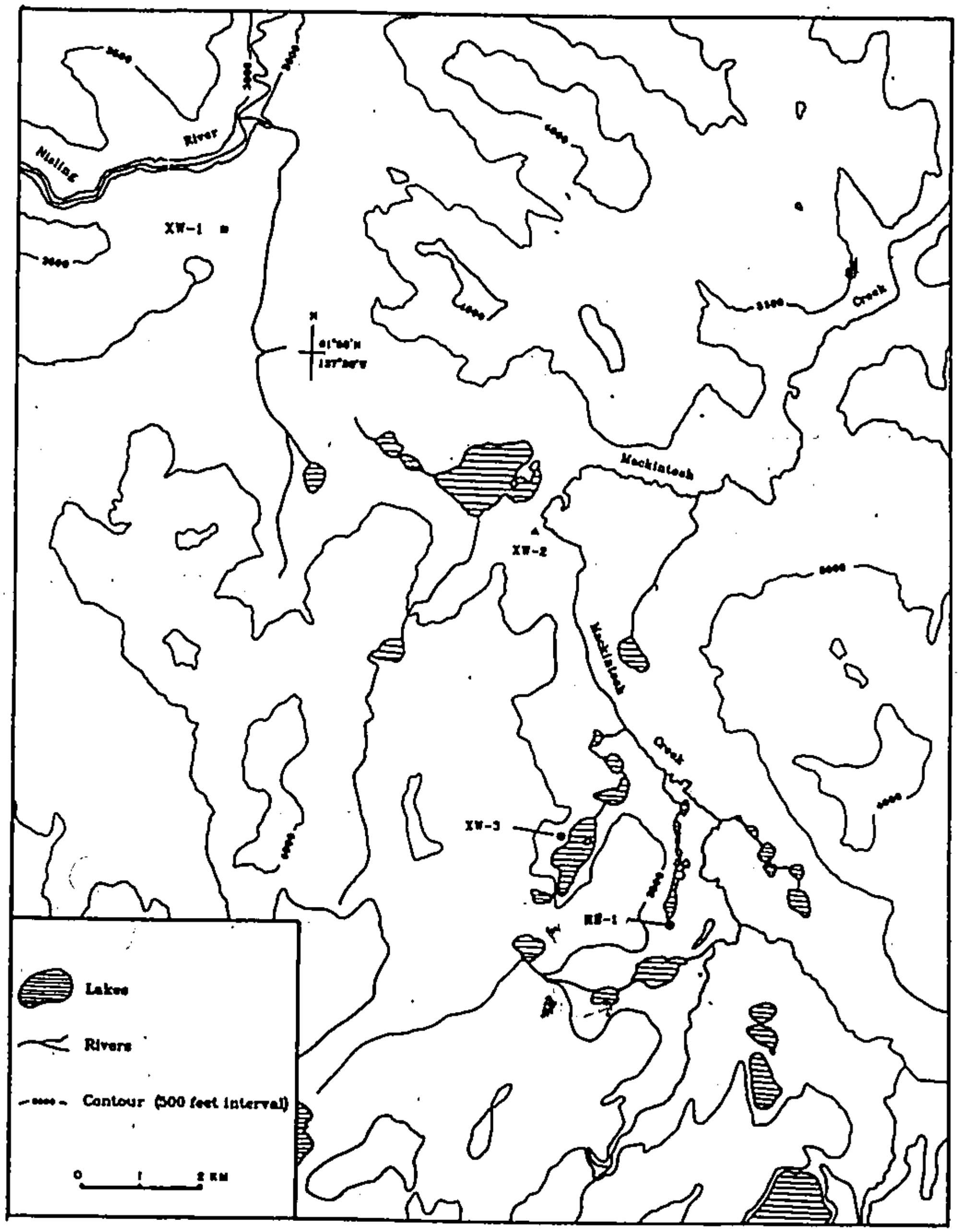

Figure 5.2 Map of northern Aishihik Basin showing fossil pollen sites and topography

ash which is found between 15 and 18 cm depth, overlies more peat which extends to the bottom of the profile at 104 cm. Frozen ground was encountered at 26 cm on July 17 of 1985. The drilling was terminated when rocks were encountered. Ice lenses are common in the sediments, especially at 97.5 cm and 104 cm depth.

5.2.3 RadioCarbon Dates and Chronology

Four core segments were submitted for ^{14}C dates and the results are listed in table 5.1. All these dates were obtained from the same section as the pollen spectra.

The distortion of sediment depth by frost heave was estimated following the method described in chapter 3. Four ^{14}C dates and the White River ash layer (*ca*. 1,230 yr BP) were used to determine the sedimentation rates after the calibration of sediment depth. A polynomial regression technique (Davis, 1973, program POLYD) was employed to fit the ^{14}C dates *vs* depth relation (Fig. 5.3), and the second order polynomial equation, which gives a multiple R^2 of 0.9727 for the goodness of fit, was used to calculate the age of samples and determine the sedimentation rate (in centimetres per year). Such a technique has been employed elsewhere (*e.g.* Cwynar and Ritchie, 1980; Cwynar, 1982; MacDonald, 1983).

Table 5.1 ^{14}C dates of Profile XW-1

Lab Number	Depth Interval	^{14}C date	Material
	12.0-18.0 cm	1230 yr BP	ash
UQ-1266 *	25.0-35.0 cm	4550 +/- 100 yr BP	peat
UQ-1267	50.0-60.0 cm	5500 +/- 200 yr BP	peat
UQ-1268	71.0-76.5 cm	7450 +/- 100 yr BP	peat
UQ-1430	95.0-104.0 cm	9100 +/- 100 yr BP	peat

* Not used for calculating sedimentation rates

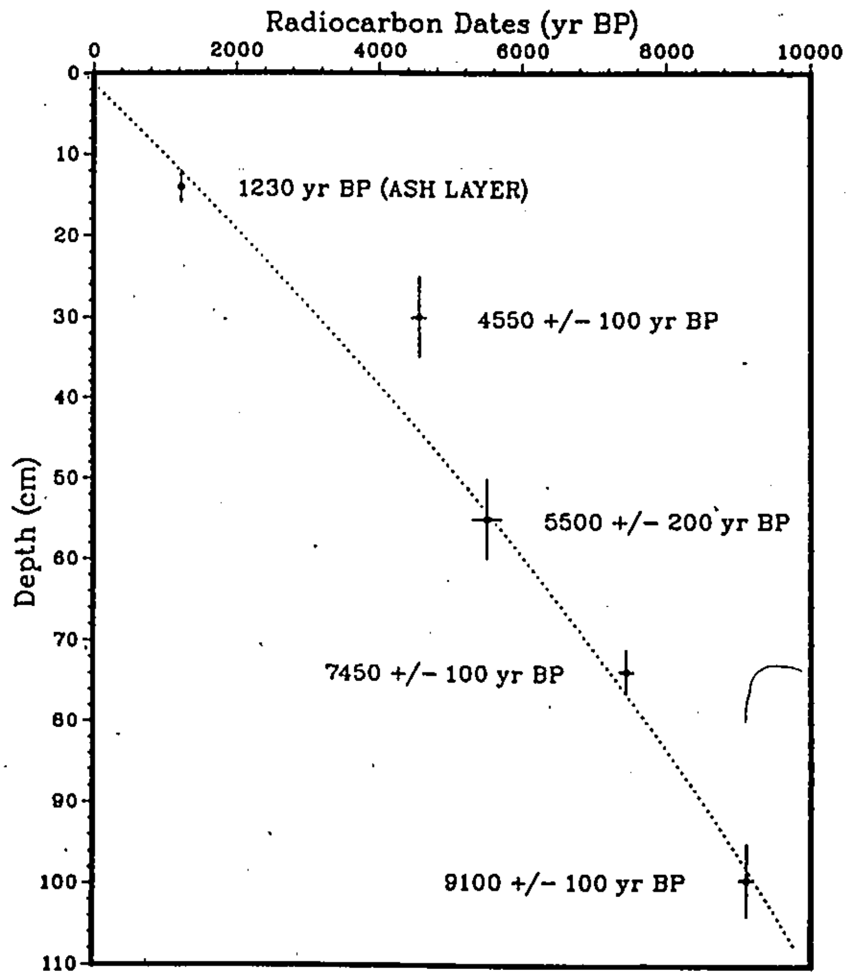

Figure 5.3 ^{14}C dates vs depth relation of profile XW-1, Upper Nisling Valley

5.2.4 Relative Pollen Frequency

The results of pollen analysis are shown as a relative pollen frequency diagram (Fig.5.4) and an absolute pollen accumulation rate diagram (Fig.5.5). As suggested earlier (chapter 3), the large fluctuation of pollen spectra between peat samples causes real practical difficulties for numerical zonation approaches, and therefore, quantitatively defined zones of a peat profile are better examined by more than one procedure to ensure reliability. Hence, numerical zonation procedures employed here to zone the relative pollen frequency diagram are programs of CONZONE, ZONATION, and CONISS. Dendrograms of different procedures are illustrated in figure 5.6. The relative pollen frequency diagram was classified by these numerical procedures into three local pollen zones. To avoid statistical noise of rare taxa, only those taxa which have relatively frequent occurrence and considerable values were included in the entrance data set. These are *Picea*, *Alnus*, *Betula*, *Salix*, Rosaceae, *Juniperus*, Ericaceae, *Shepherdia*, Gramineae, Cyperaceae, *Lycopodium*, *Dryopteris*, *Equisetum*, and *Sphagnum*.

ZONE 1 (80.0 cm - 108.0 cm): Zone 1 is characterized by high values for herbs (27.7% to 50%) and shrubs (13% to 32%). *Picea* values are also quite high (23% to 43%, mean 36%). *Betula* is the most dominant shrub in this zone (9% to 27%, mean 16.8%). *Shepherdia* and Rosaceae are consistently represented

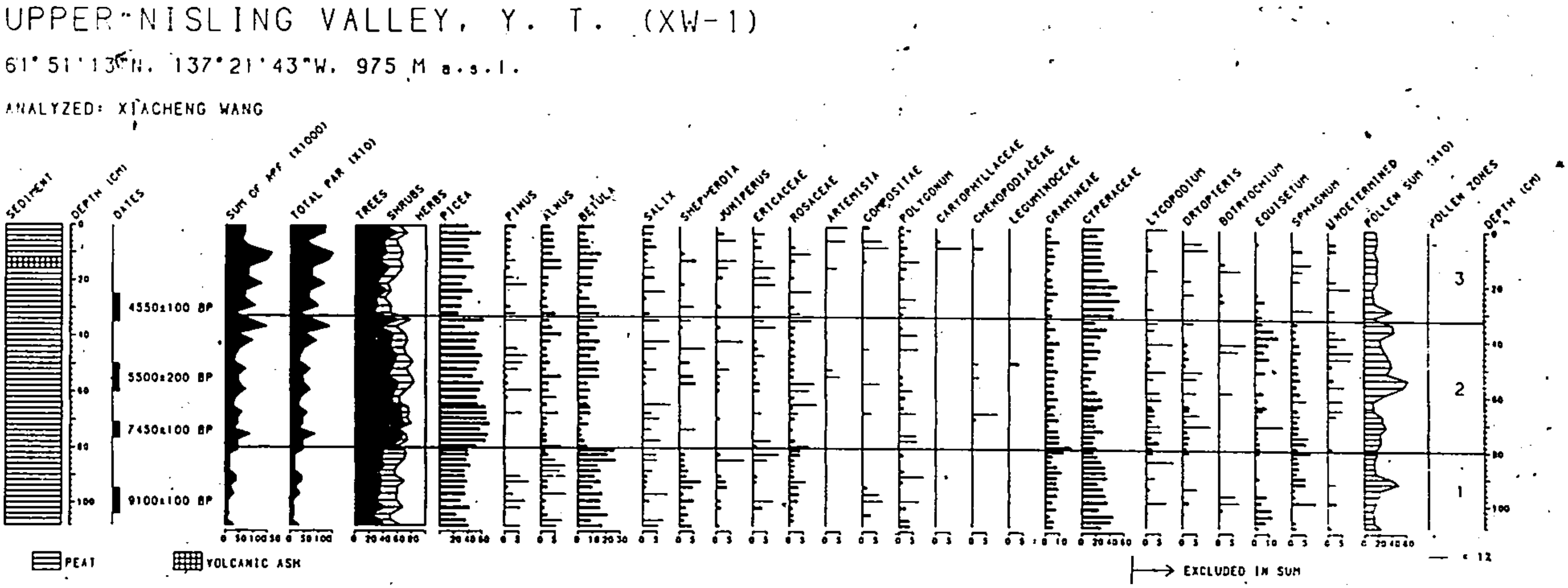

Figure 5.4 Pollen percentage diagram of profile XW-1, Upper Nisling Valley

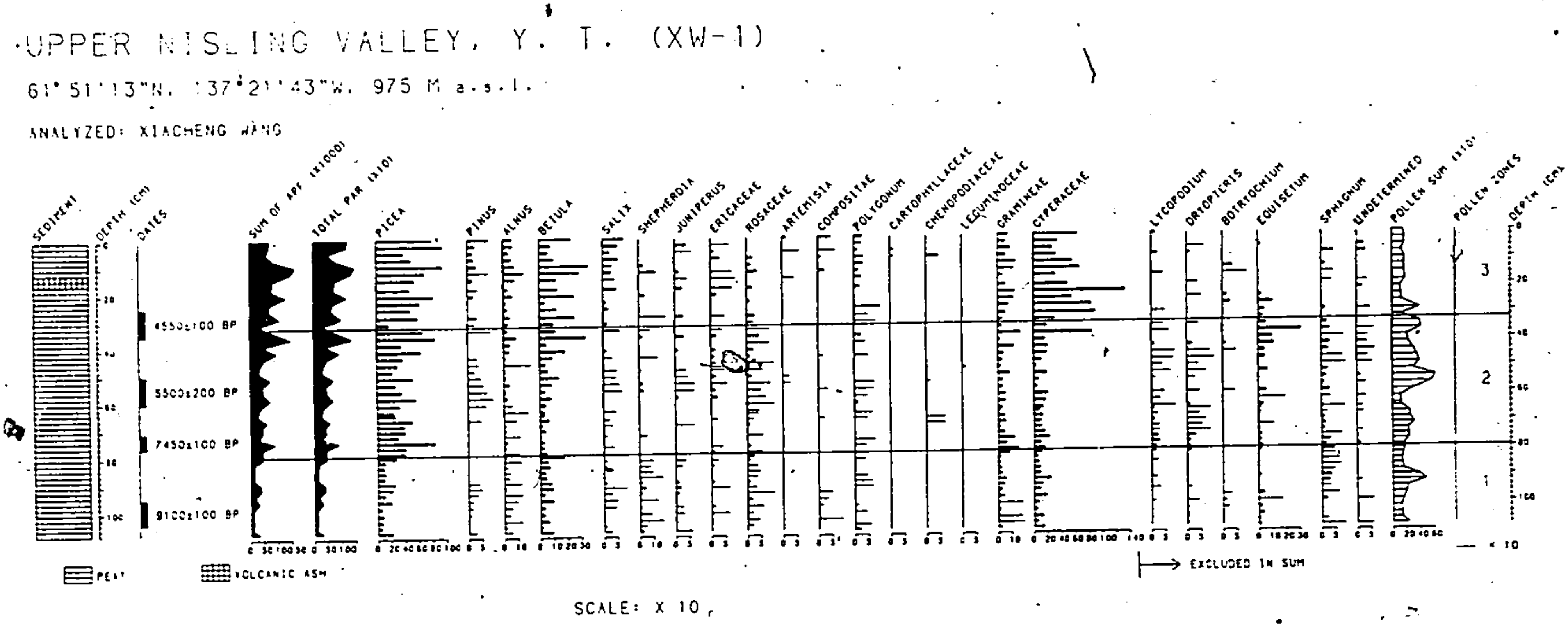

Figure 5.5 Absolute pollen accumulation rate diagram of profile XW-1, Upper Nisling Valley

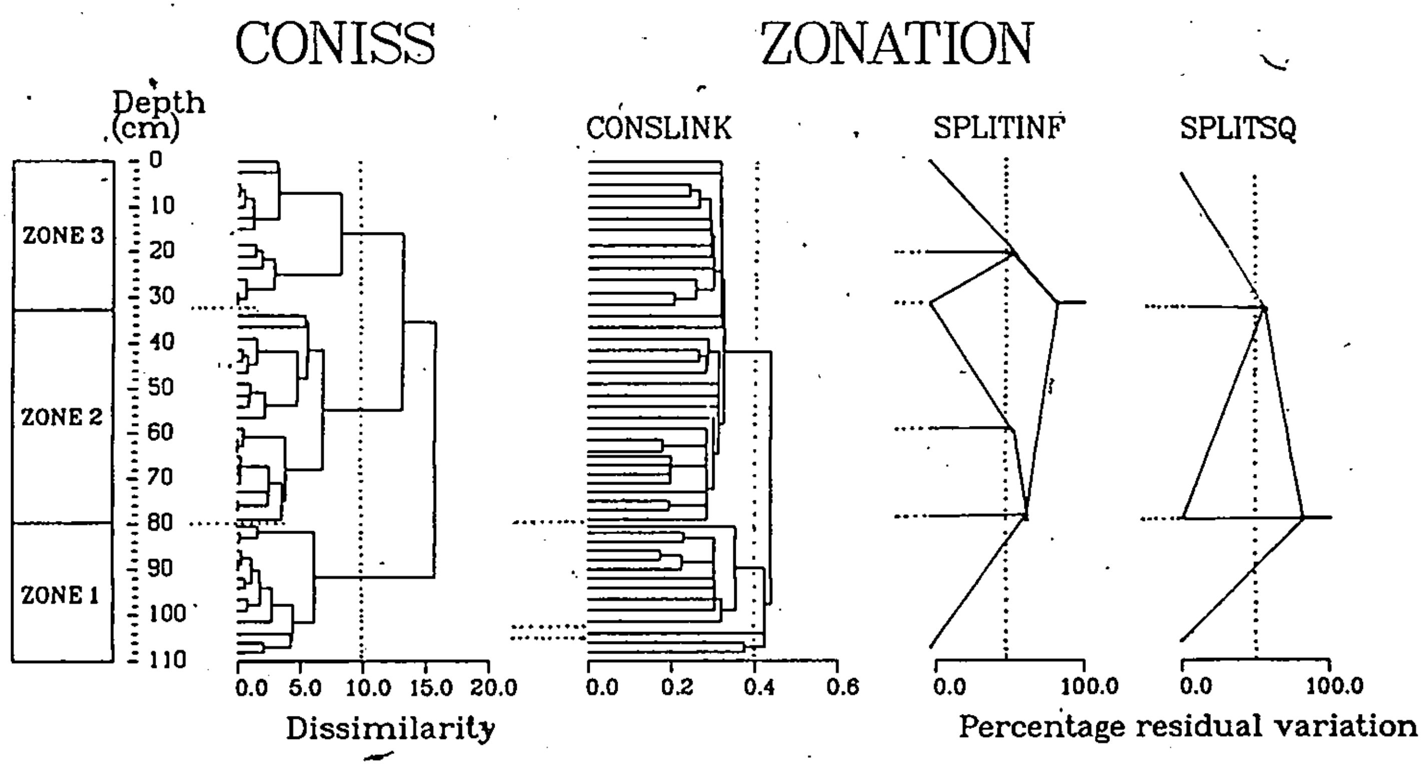

Figure 5.6 Dendrogram of zonation procedures of profile XW-1

(Three pages)

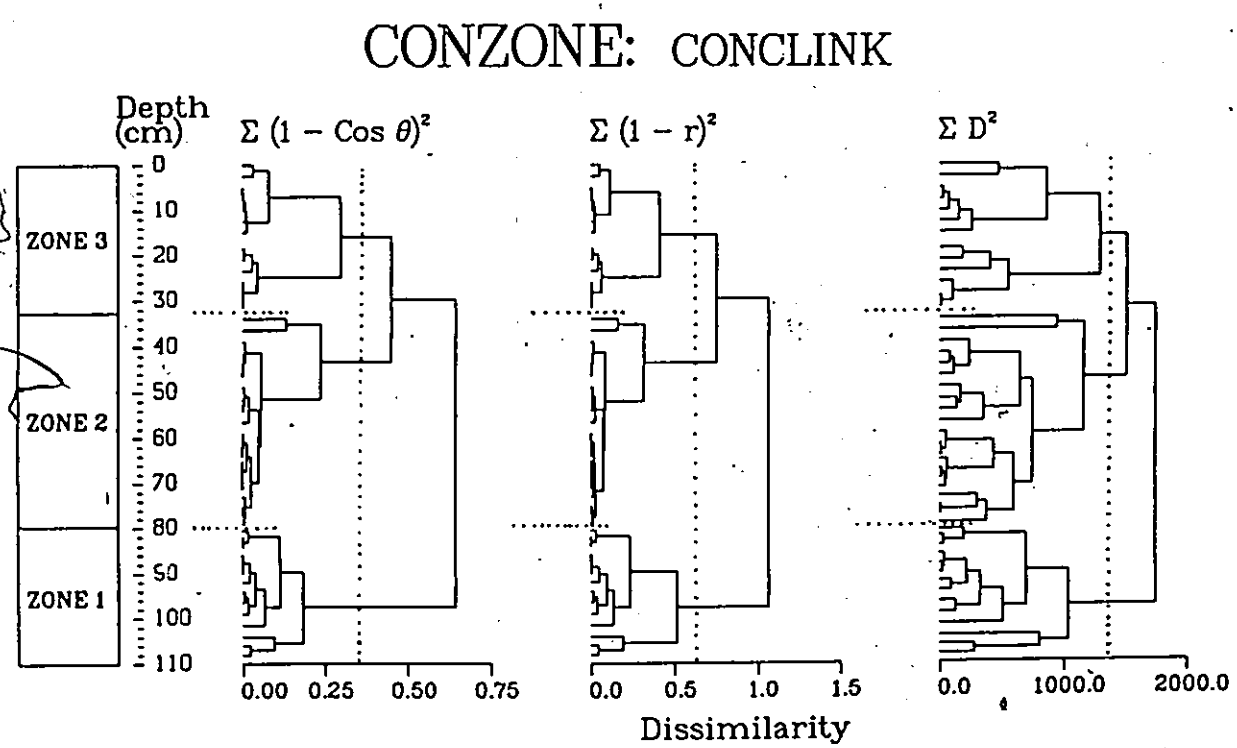

Figure 5.6 (Continued)

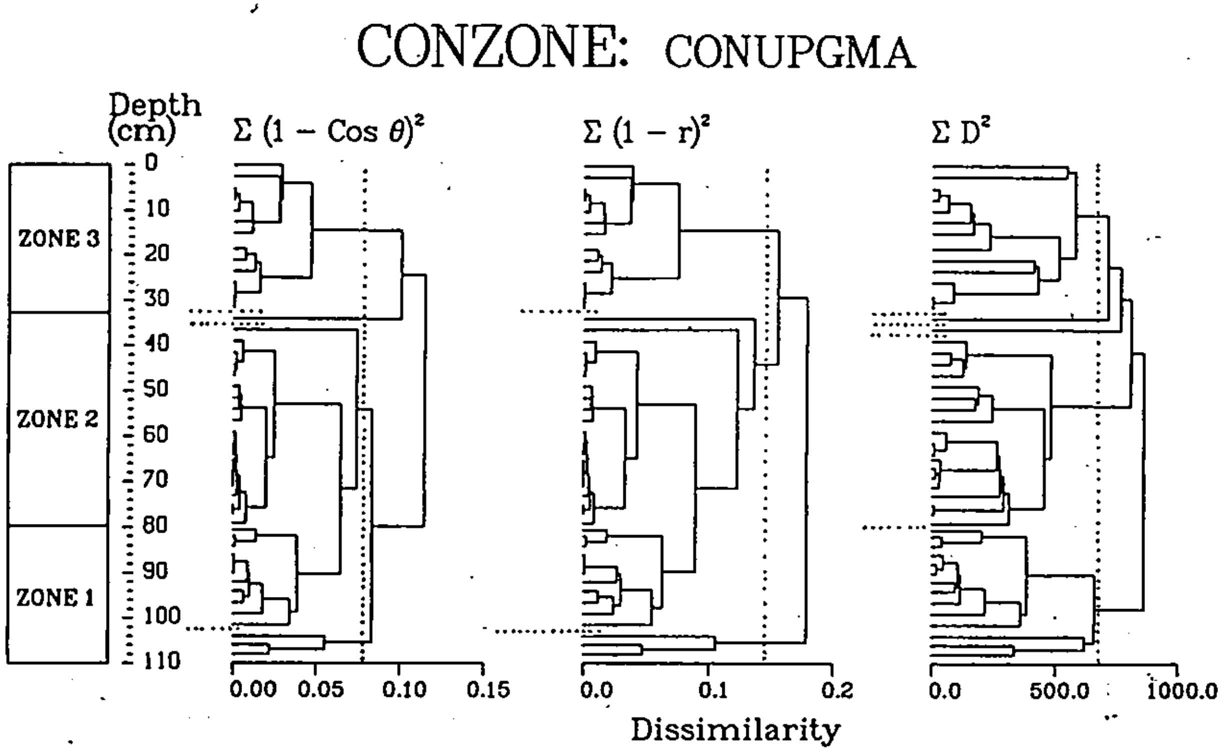

Figure 5.6 (Continued)

(1% to 5%), and *Juniperus*, *Alnus*, and *Salix* are less frequent (<4%). Cyperaceae are the most important herbaceous taxa in this zone (16.5% to 44.3%, mean 30%). Gramineae percentages range from 3% to 13% with a mean of 7%. *Equisetum* is well represented in the lower part of the zone (3% to 13%), and occasionally occurs in the upper part of the zone. *Sphagnum* is absent from two samples and ranges from 1% to 8.6% in the other samples. Other taxa are not significantly represented.

ZONE 2 (33.0 cm - 80.0 cm): Zone 2 is characterized by an obvious increase of *Picea* pollen percentage and significant decrease of *Betula* values. *Picea* ranges from 35% in one sample to 75% as maximum, with a mean of 57%. *Alnus* pollen is more consistently represented than before with values from 2-3% generally. *Betula* values have decreased to 2-15% with a mean of 8.7%. Rosaceae are still consistently represented with a value of less than 2%. Other shrubs are less important than before. Cyperaceae values are slightly lower as well, ranging from 8% to 35% with a mean of 20%. Gramineae are similar to before at 7%. However, both *Lycopodium* and *Dryopteris* are well represented in this zone especially in the lower part with values around 1-3%. *Equisetum* is now more consistently represented, varying from absent in few samples to 16% although generally around 5-6%. *Sphagnum* is also consistent with values around 2-3%. Other taxa are not well represented.

ZONE 3 (0.0 cm - 33.0 cm): The most distinctive feature of zone 3 is the decrease of *Picea* values with a compensating increase of Cyperaceae. *Picea* percentages vary from 26% to 57% with a mean of 38%. *Pinus* pollen is consistently represented in the upper part of the zone (*ca*. 2%). *Alnus* values in the lower part of the zone are similar to before, although a better representation is found in the upper part (about 3-7%). *Betula* percentage is similar to before (from 3% to 15%, mean 10%). *Salix* has its best representation in the profile (from absent in a few samples to 4.4%, mean 2%). Cyperaceae show an obvious increase, varying from 21% to 53% (mean 35.6%). Gramineae, however, show no significant change. *Polygonum* values are approximate 2% in the upper part of the zone, and rise simultaneously with *Salix*. All other taxa, including *Lycopodium*, *Dryopteris*, *Equisetum*, and *Sphagnum*, which are significantly represented in zone 2, show no significant occurrence in this zone.

5.2.5 Pollen Accumulation Rate

The pollen accumulation rate diagram (Fig. 5.5) was zoned according to the zonation definition of the pollen percentage diagram. Determination of the pollen accumulation rate was carried out after modification of sediment depth and extrapolation of sedimentation rate using the second polynomial regression equation, as stated earlier.

ZONE 1: Total pollen accumulation in zone 1 is relatively low, ranging from 100 grains/cm^2/yr to 420 grains/cm^2/yr with a low pollen concentration of about 7.5-41.0 X 10^3 grains/cm^3 sediment. Picea values are about 100-250 grains/cm^2/yr. Betula values range from 20 grains/cm^2/yr to 100 grains/cm^2/yr (mean 60 grains/cm^2/yr). Shepherdia varies from a few grains to about 40 grains/cm^2/yr, though values around 10 grains are most common. Cyperaceae range from 50 grains/cm^2/yr to about 250 grains/cm^2/yr, around 100 grains/cm^2/yr on average. The rate of Gramineae accumulation is less than 50 grains/cm^2/yr in most cases. Equisetum, at about 30 grains/cm^2/yr is found in the lower part of the zone. Other taxa are usually represented by just a few grains when present.

ZONE 2: Total pollen concentration of zone 2 is about 3-15 X 10^4 grains/cm^3, and the total pollen accumulation rate is from 300 grains/cm^2/yr to 1400 grains/cm^2/yr with a mean of about 750 grains/cm^2/yr. Picea values are obviously higher than before, varying between 250 grains/cm^2/yr in one sample and 1700 grains/cm^2/yr, with 600 grains/cm^2/yr being the most common rate. Alnus pollen is better represented with rates ranging from a few grains to about 40-50 grains/cm^2/yr. Betula values fluctuate widely, varying from about 20 grains/cm^2/yr to about 200 grains/cm^2/yr. Cyperaceae values are similar to those in zone 1, at 200 grains/cm^2/yr with the exception of one extreme value (850 grains/cm^2/yr) at the 36.5 cm level.

Gramineae increase slightly to about 50 grains/cm^2/yr on average. Equisetum values range from 20 grains/cm^2/yr to 320 grain/cm^2/yr when present, but are usually less than 50 grains/cm^2/yr. Other taxa are not significantly represented.

ZONE 3: The total pollen accumulation of zone 3 is about 330-1300 grains/cm^2/yr, and the total pollen concentration in this zone is between 4 X 10^4 grains/cm^3 and about 17 X 10^4 grains/cm^3, which is similar to concentrations in zone 2. Picea values are still around 500-600 grains/cm^2/yr. Pinus pollen however, is better represented in the upper part of the zone, varying from a few grains to 40 grains/cm^2/yr. Alnus values increase slightly, ranging from 15 grains/cm^2/yr to 70 grains/cm^2/yr, except for an extreme value (130 grains/cm^2/yr) at the 12.5 cm level. Betula values still fluctuate considerably with a general increase, ranging from 35 grains/cm^2/yr to 310 grains/cm^2/yr. Salix values in the upper part of zone are consistently around 30-50 grains/cm^2/yr. Along with the increase of Salix, Polygonum values also increase to about 10-30 grains/cm^2/yr. The most notable feature is that Cyperaceae values are much higher in this zone, but show a general pattern of decrease from 900 grains/cm^2/yr at the bottom to about 200 grains/cm^2/yr at top of the zone. Gramineae values, however, are similar to those in zone 2. No significant occurrence of other taxa were found.

5.2.6 Numerical Analysis

Results of Q-mode PCA (Fig. 5.7a and 5.7b) indicate that *Picea*, *Lycopodium*, and *Dryopteris* have high positive loadings on the first axis, which account for 24% of the total covariance of the data set. This reflects the fact that these taxa are best represented in zone 2 and explains the high positive principal component scores of zone 2 samples. Cyperaceae have the highest negative loading on this axis, which accounts for the negative scores of zone 1 and zone 3 samples. *Sphagnum* and most shrubs (*e.g.* *Betula*, Rosaceae, *Juniperus*, *Shepherdia*), have high negative loadings on the second principal axis but no taxa have significant positive values. The second PCA axis accounts for about 17.8% of total data covariance. The negative scores of zone 1 samples reflect the fact that those shrub taxa are most important in the pollen spectra. The low negative or moderate positive scores of zone 2 and zone 3 samples may be explained as the result of insignificant representation of those shrubs. The third axis, which accounts for about 13.3% of total information, is not easy to interpret. *Picea*, *Alnus*, *Salix*, *Juniperus*, and Ericaceae have considerable negative loadings on this axis, while Cyperaceae and *Equisetum* have relatively high positive loadings. Highly fluctuating sample scores on this axis may reflect the complex relationship between these taxa. High negative scores at the upper part of zone 3 probably reflect the increase of *Alnus* and *Salix* percentages in the pollen

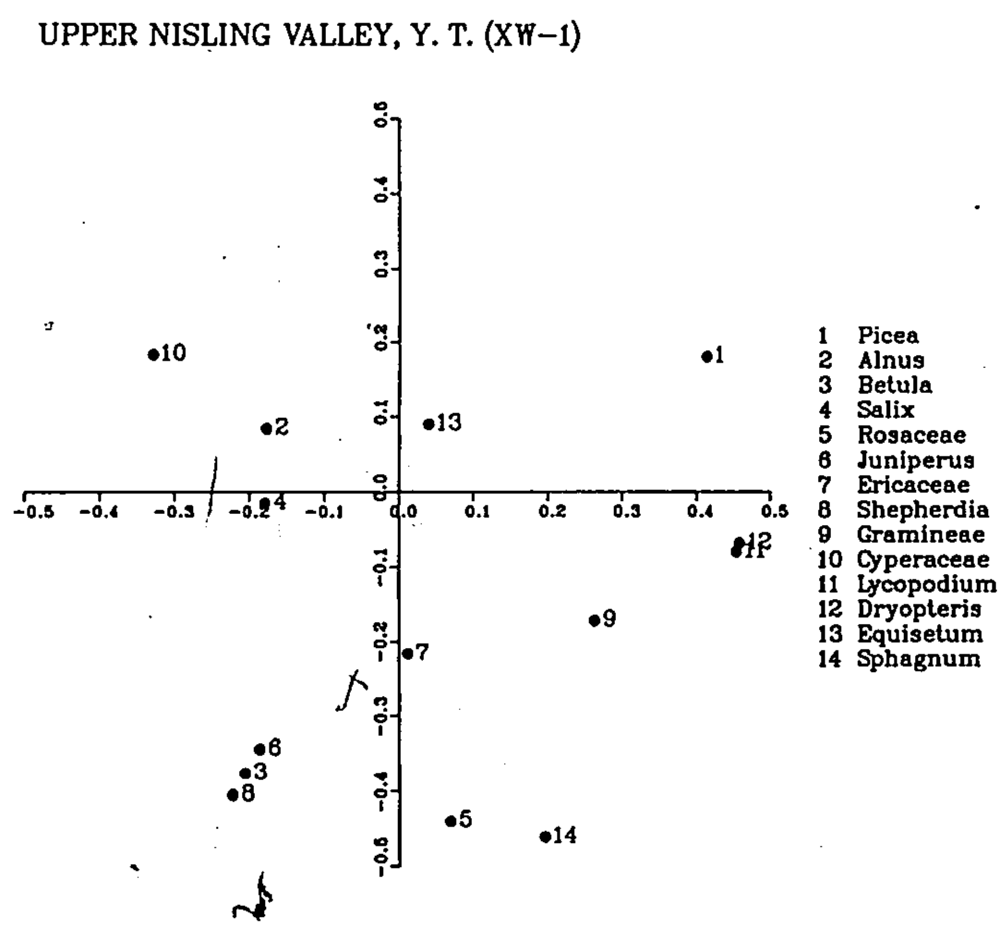

Figure 5.7a Principal component loadings of selected taxa on the first (horizontal) and second (vertical) PCA axes, profile XW-1, Upper Nisling Valley

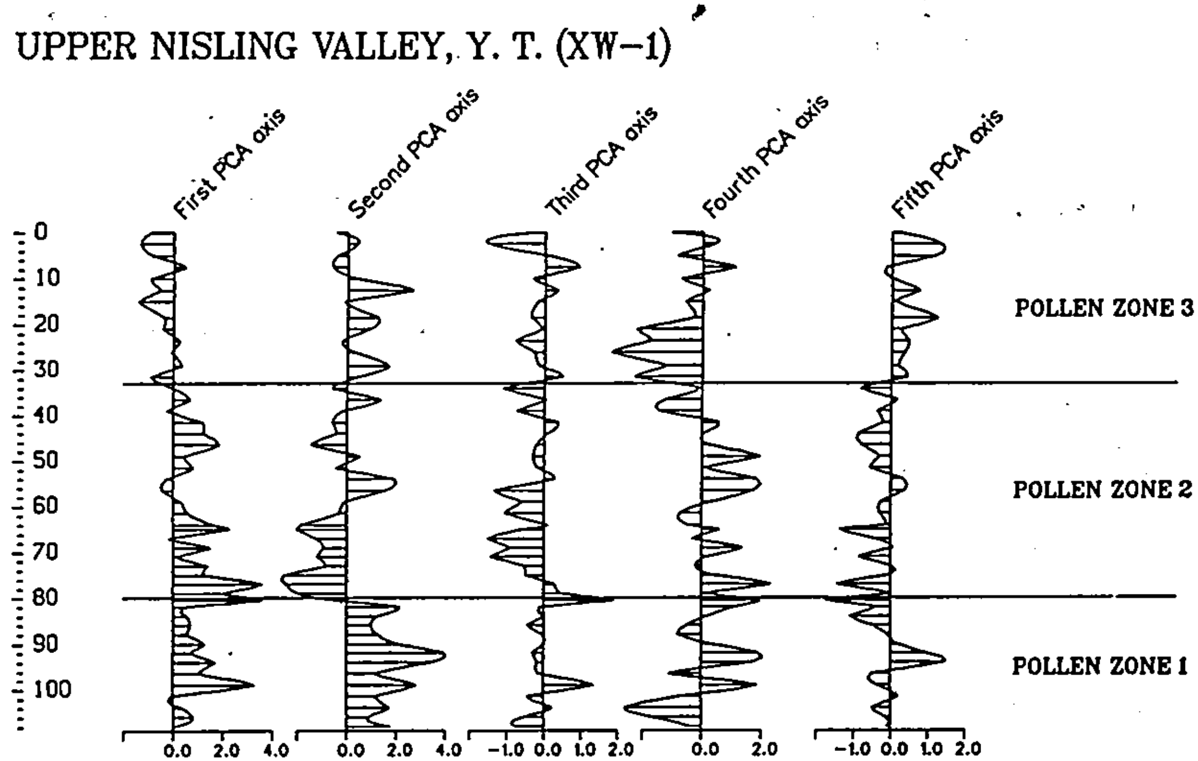

Figure 5.7b Principal component scores of profile XW-1 samples, Upper Nisling Valley

spectra. The fourth axis accounts for about 8.8% of total covariance. Equisetum, Ericaceae, and Alnus have high positive loadings on this axis, while Salix has a considerable negative value. High positive scores of samples in the upper part of zone 2 may reflect the considerable representation of Equisetum and Ericaceae in this part of the profile. The fifth axis accounts for about 8.0% of total covariance. Both Alnus and Salix have high positive loadings on this axis while Picea, Cyperaceae, and Gramineae have relatively high negative values. Considerable positive sample scores in the upper part of the profile probably indicate that Alnus or Salix are better represented here. These five axes account for about 72% of the total covariance of the data set. Discarding the other axes will not significantly reduce the information.

The results of PCB are presented in figure 5.8 which shows the plane of the first and second PCB axes. This plane accounts for about 83.8% of total information as measured by criterion C_2 (Appendix E; Gordon, 1982). In the entire data set, Picea, Betula, and Cyperaceae are the most important taxa, as indicated by the high values of their corresponding vectors (Fig. 5.8). These three taxa, as suggested by the orientation of their vectors, are complementary to each other; that is, an increase or decrease of any one of these taxa will cause the reverse change in the other two. All other taxa are much less important. By the clustering of samples of different zones, it

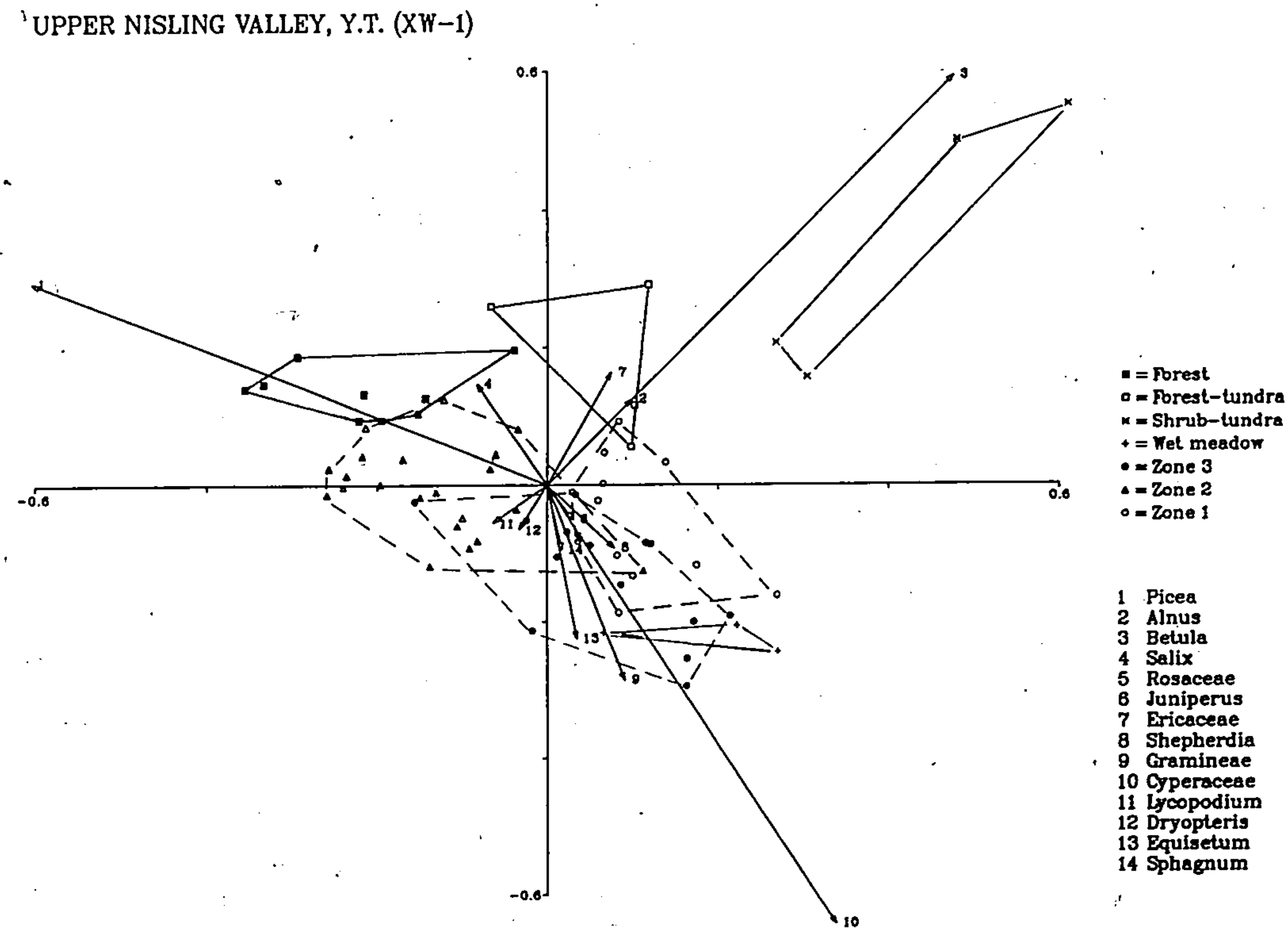

Figure 5.8 Ordination of combined data matrix of modern and fossil pollen samples on the first (horizontal) and second (vertical) PCB axes, profile XW-1, Upper Nisling Valley.

is clear that zone 1 samples are similar to modern forest-tundra samples, and zone 2 samples are close to those of the modern forest vegetation-landform unit. The cluster of zone 3 samples, however, is elongated in the direction of the Cyperaceae vector and overlaps with zone 1 and 2 clusters as well as modern wet-meadow vegetation-landform unit samples. This indicates the importance of Cyperaceae pollen in zone 3.

In comparison with PCB, results of CA illustrate the broadly similar pattern of sample ordination (Fig. 5.9). The first and second CA axes capture about 49.0% of the total information. Sample clusters of zone 2 and zone 3 overlap, which indicates the similarity of pollen content in those samples. The zone 1 cluster is relatively separated from the others. The high similarity between the results of different numerical analysis methods provides high confidence for the conclusion extracted.

5.2.7 Reconstruction of Paleoenvironment

Pollen profile XW-1 provides palynological evidence of local environmental history after the last deglaciation in the Upper Nisling Valley area. It can be divided into three stages, as represented by three local pollen zones.

ZONE 1: Pollen zone 1 represents a time during which the study area was covered by a spruce forest-tundra. High *Picea*

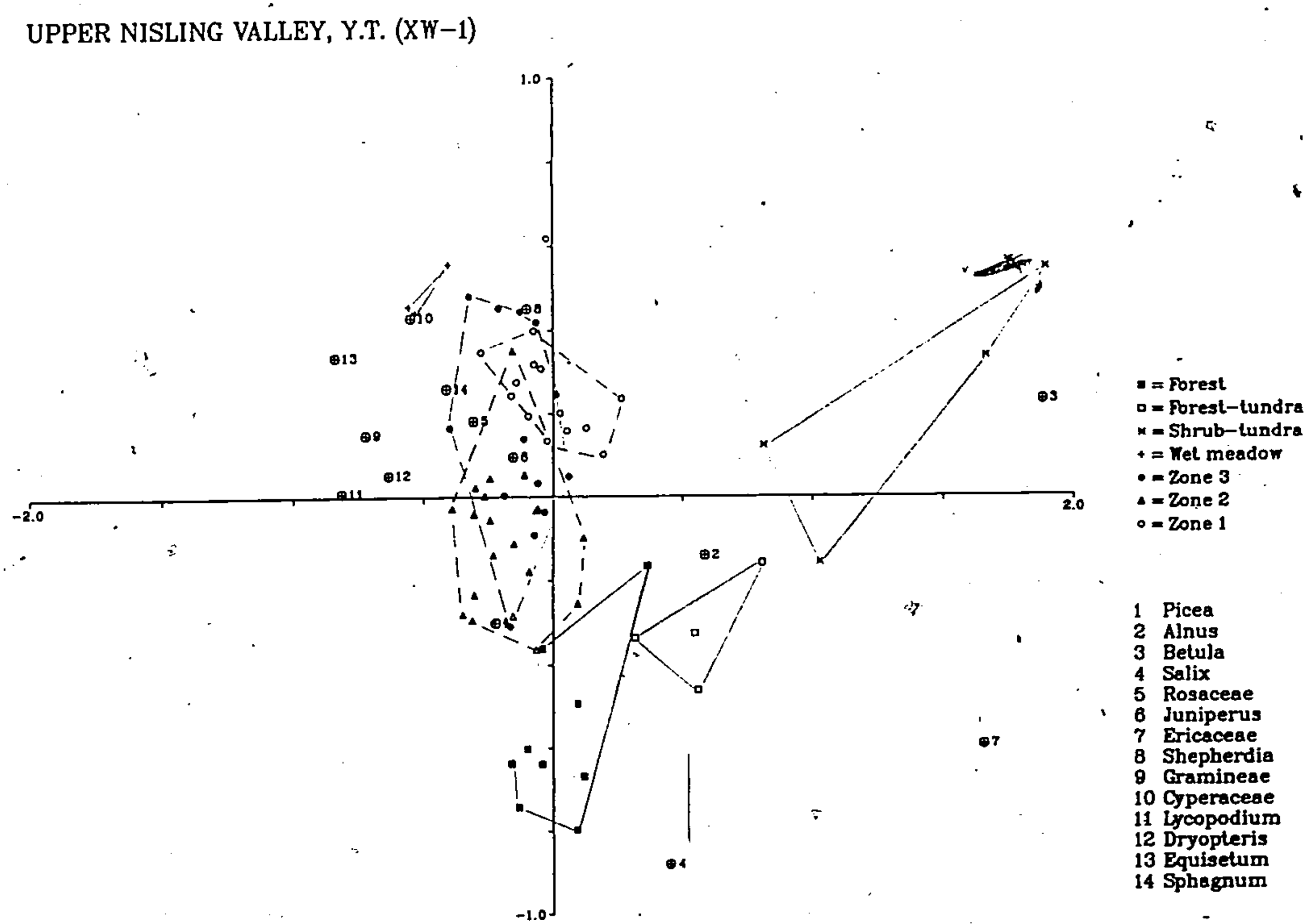

Figure 5.9 Ordination of combined data matrix of modern and fossil pollen samples on the first (horizontal) and second (vertical) CA axes, profile XW-1, Upper Nisling Valley

percentages and considerable accumulation rates during this interval suggest that spruce arrived in the Upper Nisling Valley at least 9,000 yr BP. Although the Picea percentage is around 40% in this zone, vegetation during this period could not be interpreted as a forest environment since the spruce pollen accumulation rate at 100-380 grains/cm²/yr is too low to support such an interpretation. The Picea pollen accumulation rate of about 500-1,000 grains/cm²/yr has been interpreted as spruce woodland or forest from the northern Yukon (Ritchie, 1982) and lower Mackenzie River Basin (Ritchie, 1984b). A similar value has also been reported from the Upper Natla River area in the Northwest Territories (MacDonald, 1983). In the middle Tanana River area of Alaska, a maximum 5,000 grains/cm²/yr pollen accumulation rate of Picea for boreal forest has been recorded (Ager, 1975). It must be kept in mind, however, that pollen accumulation rates in lacustrine sediments, such as in gyttja, might be quite different from those in peat bog deposits. A high proportion of shrub pollen in the pollen spectra indicates that these taxa were important elements in the past vegetation. Considerable percentages of Shepherdia, Rosaceae, and Juniperus suggest an open habitat existed during this time interval since these taxa are unable to survive in a shaded environment (Ritchie, 1984b). High percentages of Cyperaceae, Gramineae, and Sphagnum are only local components which by themselves cannot indicate regional vegetation cover, and probably indicate wet or moist conditions during this time. Therefore, it is reasonable to interpret the paleovegetation of zone 1 time interval as a *Picea*-*Betula*-*Shepherdia* forest-tundra, which is in agreement with the conclusion derived from PCB and CA results. This forest-tundra event probably lasted until 7,900 yr BP.

ZONE 2: During the zone 2 time interval the area was probably covered by a spruce forest. High *Picea* percentages and accumulation rates and *Picea* *vs* *Betula* and *Picea* *vs* Cyperaceae ratios (Fig. 5.10) indicate that spruce was the dominant element in the vegetation during this time interval. Both percentages and accumulation rates suggest that *Betula* was still common in the area. Other shrubs such as *Shepherdia*, *Juniperus*, and Rosaceae were obviously less abundant due to the competition of spruce. Frequent occurrence of *Lycopodium* and *Dryopteris* in the lower part of the zone probably suggests moist conditions. *Equisetum* and *Sphagnum* as local bog-forming components suggest wet environmental conditions in the vicinity of the core site. This vegetation pattern was probably stable until about 4,000 yr BP (extrapolated), which is a few hundred years younger than the ^{14}C date obtained at the zone boundary level (4,550 +/- 100 yr BP, UQ-1266). By a linear extrapolation of sedimentation rate between each date, the rate between 27.5 cm and 55.0 cm seems rather high and that between the White River ash layer and 27.5 cm is quite low. Although sedimentation rates in peat sediments vary, dates UQ-1266 and

UPPER NISLING VALLEY, Y. T. (XW–1)

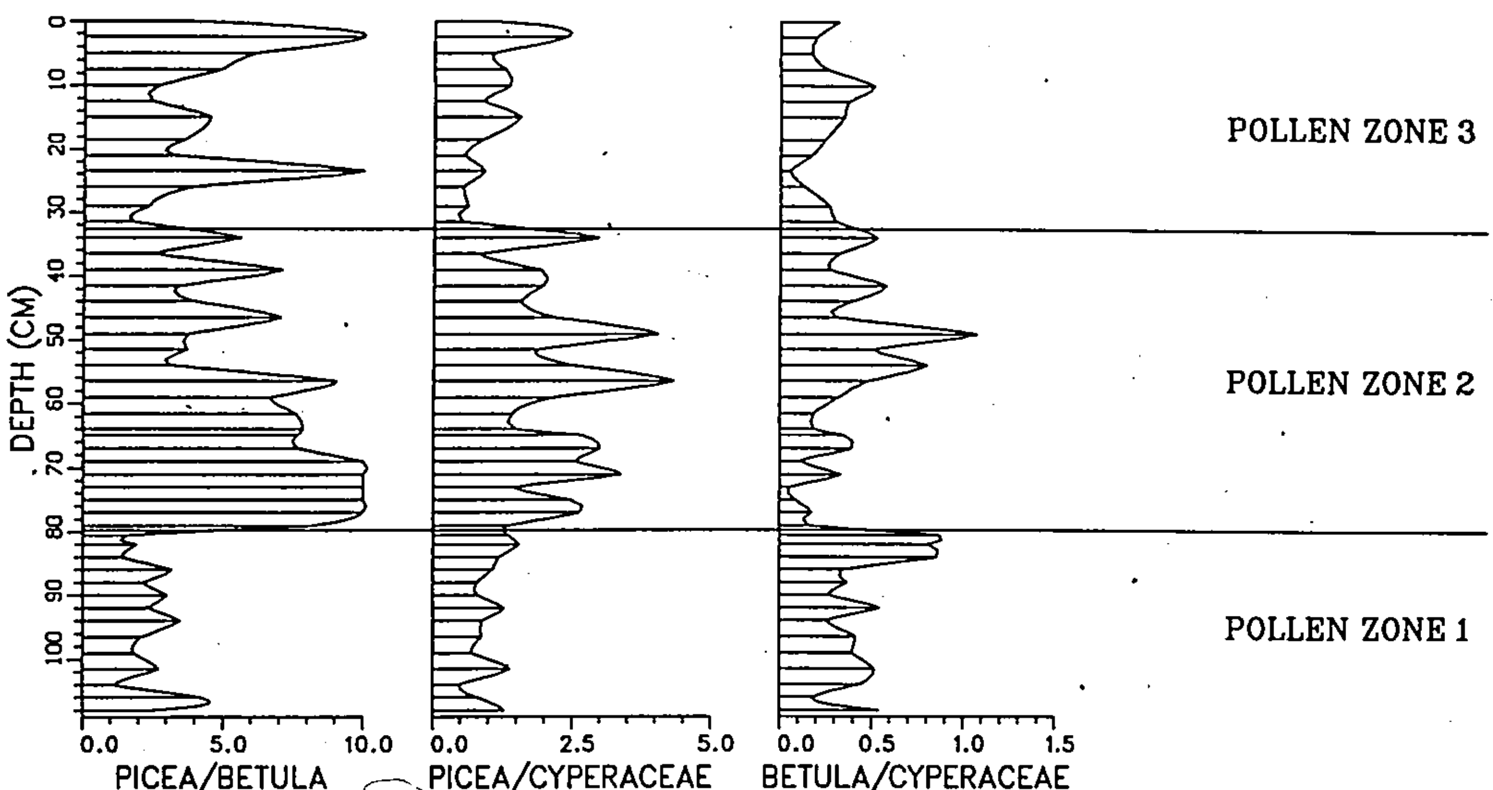

Figure 5.10 Selected pollen ratios of profile XW-1, Upper Nisling Valley

UQ-1267 present a problem. Geurts (1985) modified the extrapolation of the ^{14}C vs depth relationship using palynological evidence, implying that the significant change in sedimentation rate might cause a change in the pollen spectra. Such palynological evidence, however, is not found at the 55.0 cm level. The significant change of Cyperaceae and Sphagnum pollen percentages at the 27.5 cm level might suggest a change of growth rate of the peat bog. This suggests that either UQ-1266 or UQ-1267 is a spurious date. There is no evidence that field or laboratory contamination caused the problem since great care was given during the collection, transportation, and subsampling of all samples in the field and in the laboratory. Both samples have a limited inorganic carbon content. Therefore it is difficult to determine which date is more reasonable. Pollen spectra in this case suggest that UQ-1266 is probably misleading since an increase of growth rate of the peat bog might lead to an increase of absolute pollen value of bog-forming taxa such as Cyperaceae. To deal with such a ^{14}C array, a second order polynomial regression was employed to determine the best fitting curve between these dates, as stated in the section 5.2.3.

ZONE 3: Zone 3 represents a time interval during which the area was still covered by spruce forest, although a minor change of local environmental conditions had occurred. Although the *Picea* percentages are obviously lower than before and do not favour a forest interpretation, the discrepancy between percentages and accumulation rates suggests that the decrease of *Picea* percentages is misleading due to the great increase of one local component, *i.e.* Cyperaceae. The obvious increase of Cyperaceae percentages as well as their accumulation rates suggests an increase in the growth rate of the peat bog, which suppressed the *Picea* pollen percentages. This result is also shown by the selected pollen ratios (Fig. 5.10). To support such an hypothesis, an arboreal pollen percentage diagram was created (Fig. 5.11) to examine the relationship between *Picea* and Cyperaceae pollen. The result shows that the *Picea* percentage in zone 3 is similar to that in zone 2, which implies that the decrease of *Picea* value in this zone is mainly caused by overwhelming representation of the local element. Results of PCB and CA indicate the great resemblance between zone 2 and zone 3 samples which implies an affinity of paleoenvironmental nature. A simultaneous decrease of *Sphagnum* with the increase of Cyperaceae suggests a change in the bog condition which was probably more minerotrophic than before. *Pinus* pollen in this zone is still the result of long distance transportation but its frequent occurrence in the upper part of the zone reflects, 1) the migration of pine into the southwestern Yukon and, 2) frequent changes of the atmospheric circulation system (Lagarec et Geurts, 1984). *Alnus* pollen is probably a regional element via long distance transport because of its low value. The increase of *Salix* pollen in the upper

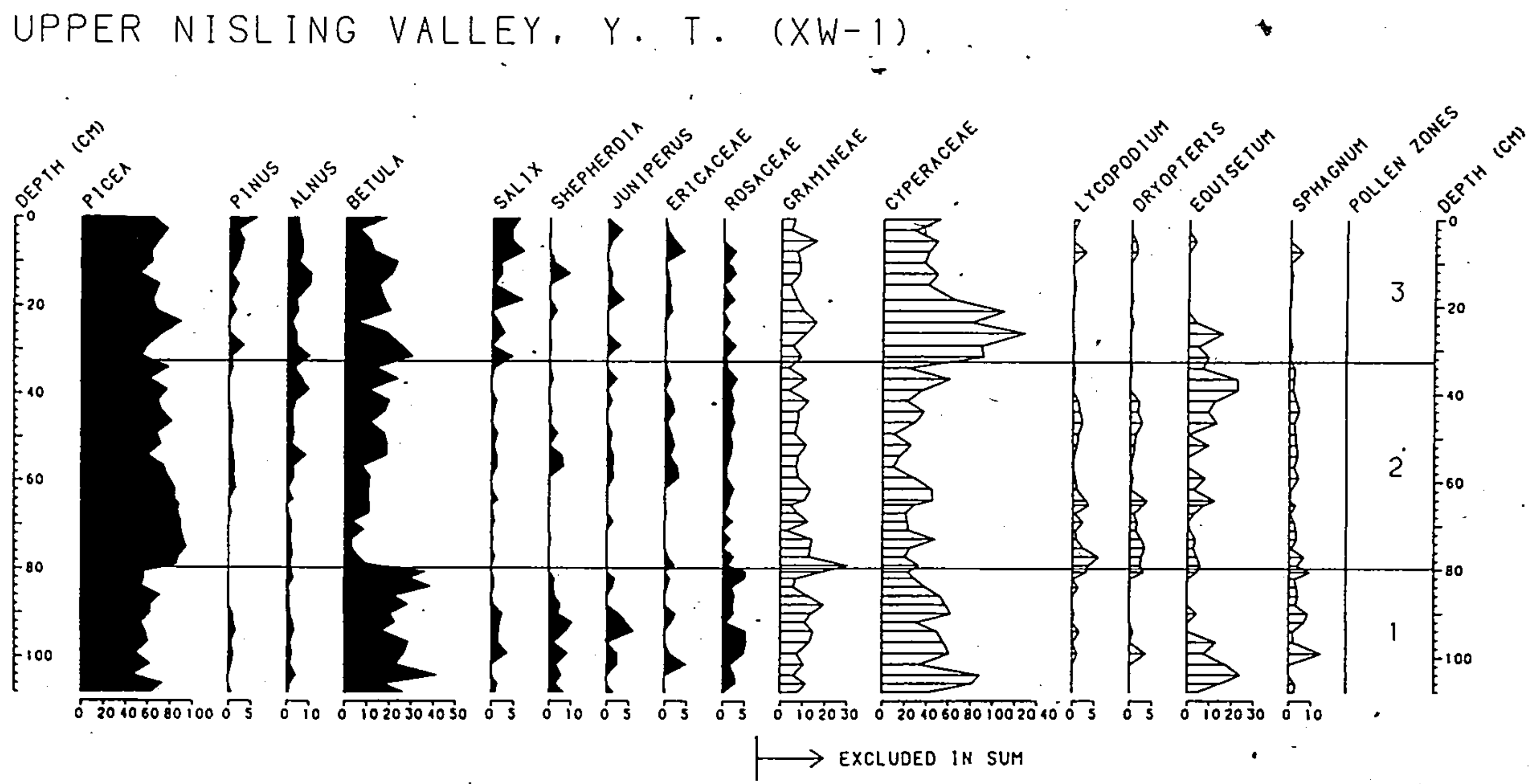

Figure 5.11 A summary pollen percentage diagram of profile XW-1 using a sum of tree and shrub pollen

part of the zone indicates a small rise of willow in the vegetation cover which could grow at the edge of or on the bog since its poor dispersal ability does not favour long distance transportation. This vegetation pattern in the area has probably been stable from about 4,000 yr BP to the present.

5.2.8 Summary and Conclusion

Pollen profile XW-1 from the Upper Nisling Valley area provides the first comprehensive paleoenvironmental record for this area. Numerical analysis and interpretation of pollen data indicate that from at least 9,000 yr BP to about 7,900 yr BP, the area was covered by *Picea*-*Betula*-*Shepherdia* forest-tundra vegetation. High *Picea* percentage accompanied with low pollen accumulation rates indicate the influence of local bog-forming taxa such as Cyperaceae on the determination of pollen percentages. During this interval the condition of the bog was probably very wet as suggested by high percentages of Cyperaceae, *Sphagnum*, and *Equisetum*. During the period from 7,900 yr BP to about 4,000 yr BP, the landscape around the depression was probably covered by spruce forest with ferns and other pteridophyte taxa as strongly suggested by percentage and pollen accumulation rate values, selected pollen ratios, and also numerical analysis. The bog condition was still wet as suggested by high values of *Sphagnum* spores in the pollen spectra. During the last stage, from about 4,000 yr BP to the present, a spruce forest remained though local elements changed somewhat. These include the small rise in the percentage of willows in the vicinity of the core site, and the decrease in moisture conditions at the bog reflected in the reduction of Sphagnum and increase of Cyperaceae. The low value of Sphagnum in the profile suggests that this depression has never been in a full ombrotrophic condition, rather it is a minerotrophic peat bog with slight modification of the condition.

5.3 Middle Mackintosh Creek (XW-2)

5.3.1 Introduction

A 32 cm profile was collected in a palsa field near the bank of middle Mackintosh Creek at 61°49'00" N Lat., 137°15'09" W Long., and approximately 1,001 m a.s.l. (Fig. 5.2). Here the creek becomes wider and flatter. The present vegetation at the sampling site is *Betula glandulosa*-dominated community in a forest-tundra environment. *Picea glauca* stands are scattered throughout the general area.

The sediment stratigraphy of this short profile is relatively simple. White River ash is found between 28 cm and 29 cm depth. Above and beneath the ash layer, is organic peat. Between the surface and 17 cm, the peat contains more silt than elsewhere. Nine samples were collected in sampling bags at intervals of about 5 cm to the base of the active layer (about

32 cm). White River ash is the only parameter available for estimating the chronology of this short profile..

5.3.2 Result of Pollen Analysis

The relative pollen frequency of this profile, based upon a sum excluding spores, is presented in figure 5.12. Numerical procedures suggest a zone boundary at 17 cm which divides the profile into two zones (Fig. 5.13). The taxa used in this approach are _Picea_, _Alnus_, _Betula_, _Salix_, Rosaceae, _Juniperus_, Ericaceae, Gramineae, and Cyperaceae because of their relatively frequent occurrence. From the profile base to 17 cm, the _Picea_ value varies from 27.1% to 38.8%. _Pinus_ pollen occasionally occurs in the two bottom samples with values of 0.6% and 2.8%. _Populus_ values range from 0.8 to 1.4%. _Alnus_ pollen frequencies vary between 4.5% and 8.1%. _Betula_ percentages are consistently around 11-16%. Salix pollen percentages range between 0.3% and 2.8%. Rosaceae range from 0.0 to 1.9%. _Juniperus_ varies from absent to 1.9%. Gramineae range from 0.8% to 8.3%. Cyperaceae values are consistently higher than 30%, varying from 31% to 41.7%. Other taxa are less important with percentages less than or around 1% when present.

From the level of 17 cm to the surface, the relative pollen spectra show a different pattern. _Picea_ percentages are lower than before, varying from 16.4% to 21.4%. _Pinus_ pollen occurs again after an absence in four samples and varies in

MIDDLE MACKINTOSH CREEK, Y. T. (XW-2)

61° 49'00"N. 137° 15'09"W. 1001 m a.s.l.

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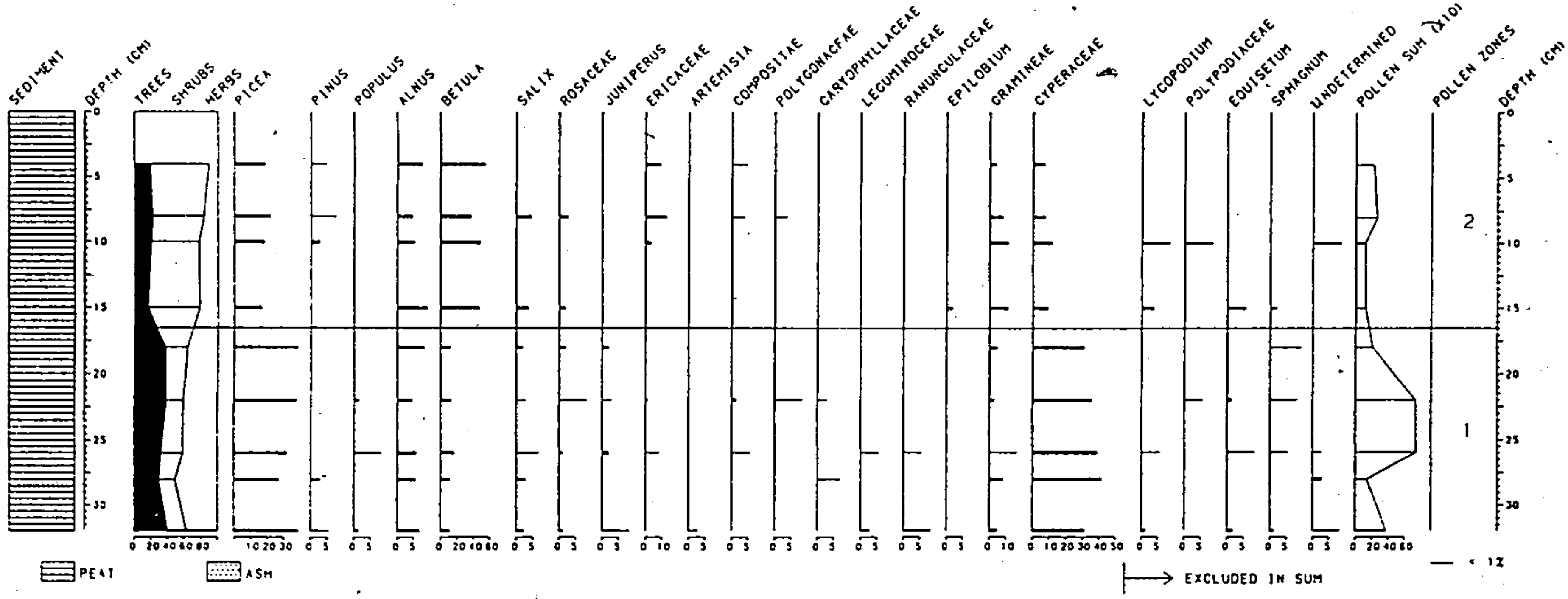


Figure 5.12 Pollen percentage diagram of profile XW-2, Middle Mackintosh Creek

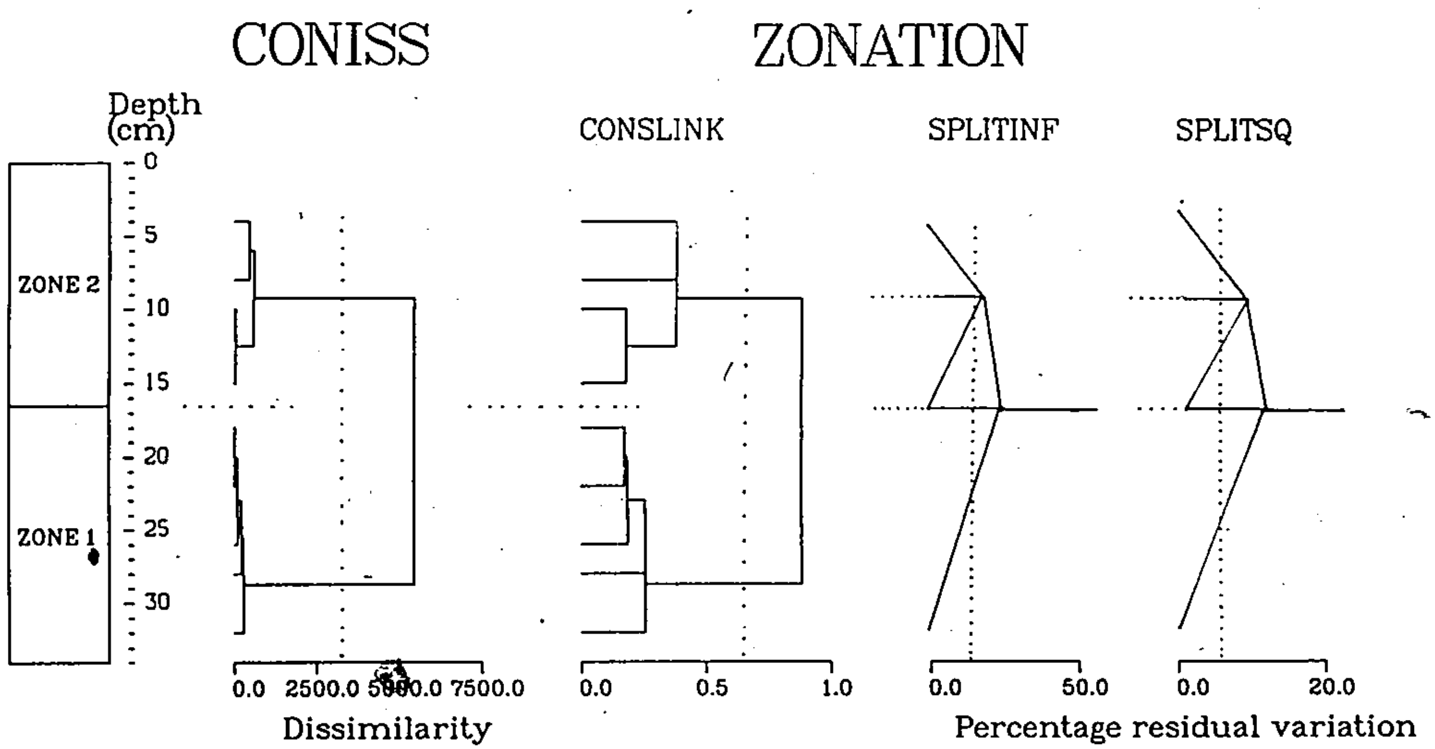


Figure 5.13 Dendrograms of zonation procedures of profile XW-2
(Three pages)

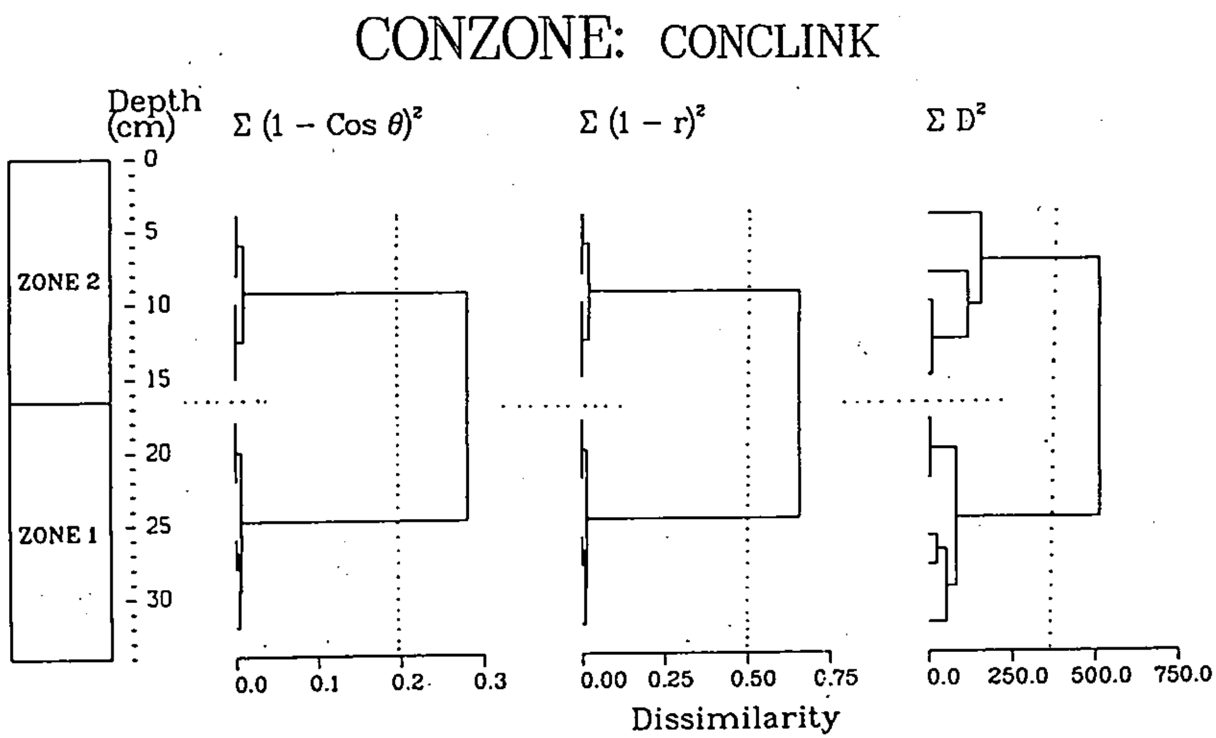


Figure 5.13 (Continued)

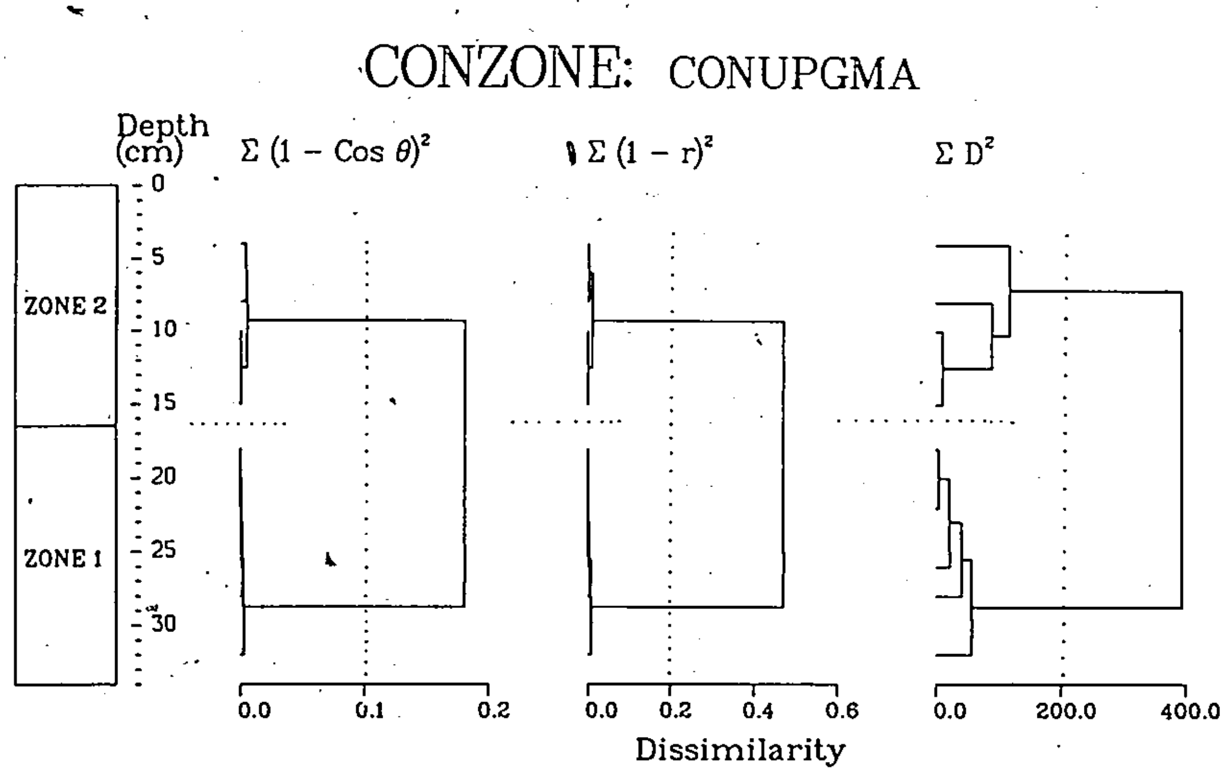


Figure 5.13 (Continued)

value between 0.5% to 2.6%. Populus disappears completely from the diagram. Alnus changes very little, varying from 4.6% to 9.1%. Betula values are significantly increased, from 37% to 53.7%. Ericaceae range between from 3.5% to 12.6%, except at the 16 cm level where it is absent. Gramineae are very well represented in the two bottom samples with values around 11%. At higher levels, the percentage drops to 4-8%. Cyperaceae compensate for the increased Betula values by decreasing to 7.6-11.2%. Other taxa are not well represented.

5.3.3 Numerical Analysis

Analysis of the same data set as used in numerical zonation procedures combined with modern surficial samples with PCA (Fig. 5.14a and 5.14b) shows that Betula and Ericaceae have high negative loadings on the first PCA axis which accounts for 24.4% of the total variation, while Gramineae and Juniperus have relatively high positive loadings. The second axis, which accounts for 21.4% of the total variation, is highly loaded negatively by Picea and Salix and positively by Cyperaceae and Alnus. The third axis, accounting for about 17.4% of the total covariance, has high negative loadings for Rosaceae, Juniperus, and Alnus. These three axes account for more than 63% of total information. Interpretation of principal component scores of all samples on these three axes will cover most of the information available from the data set. Sample scores on the first axis are very distinctive. All samples from zone 1 have

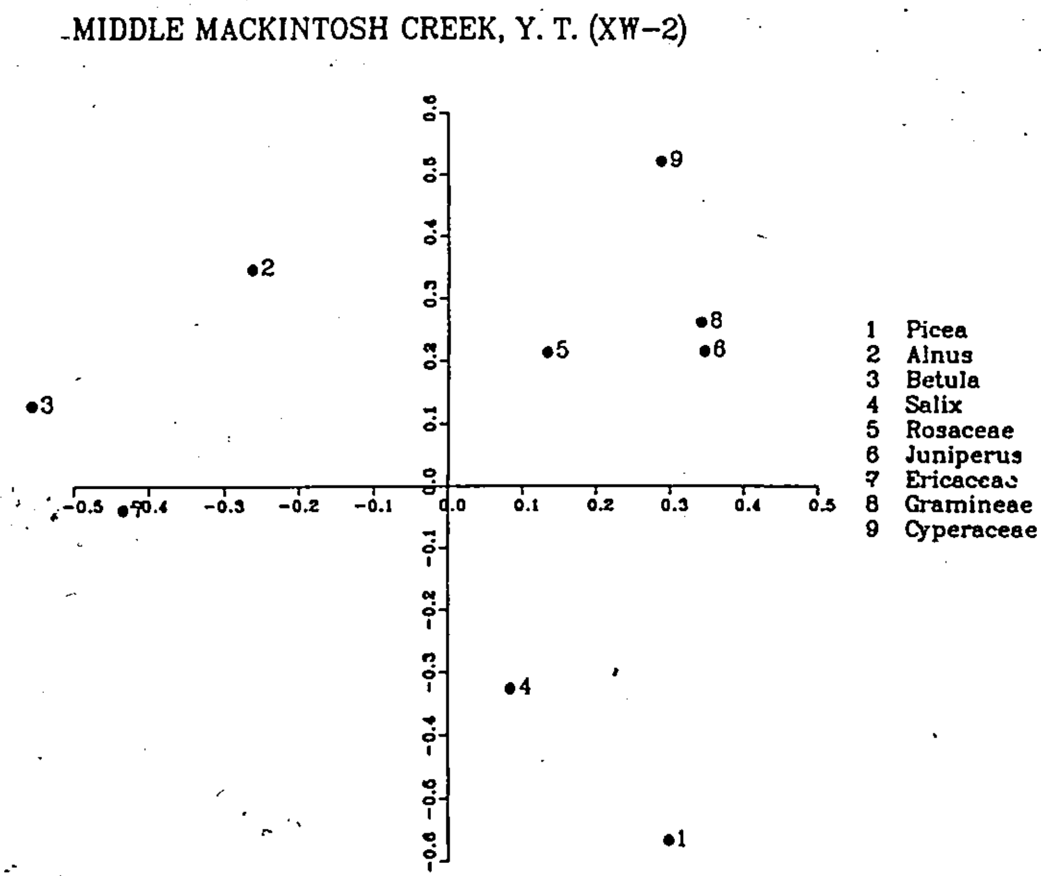


Figure 5.14a Principal component loadings of selected taxa on the first (horizontal) and second (verticla) PCA axes, profile XW-2, Middle Mackintosh Creek

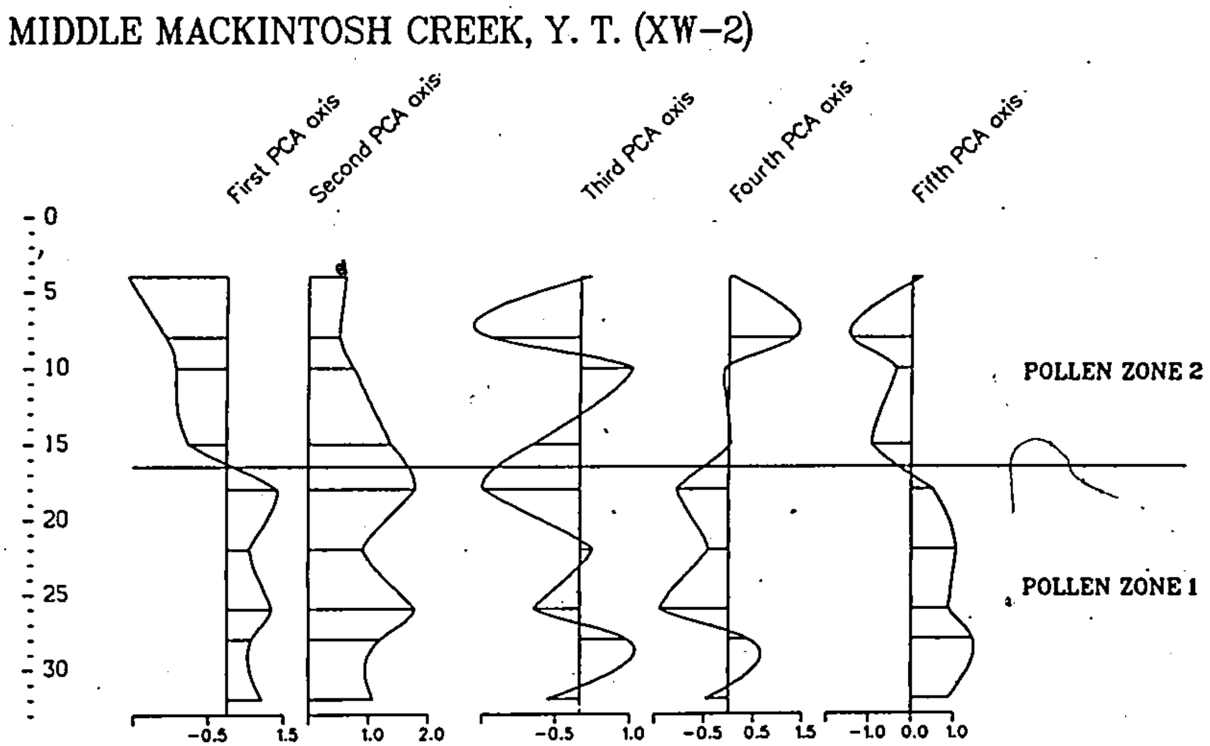


Figure 5.14b Principal component scores of profile XW-2 samples on the first five PCA axes, Middle Mackintosh Creek

positive scores while all those from zone 2 have negative scores. This pattern is probably related to the high negative loadings of Betula and Ericaceae, which are most abundant in zone 2. Samples on the second axis only have positive scores (samples from a modern forest vegetation-landform unit have negative scores in this application), which is related to the high percentage of Cyperaceae in zone 1 and low percentage of Picea in zone 2. The third axis is difficult to interpret due to fluctuating sample scores which may suggest a complex relationship between these taxa.

Simultaneous representation of both taxa vectors and sample vectors on the first and second PCB axes plane (Fig. 5.15) illustrates the relationship between taxa and samples more directly. This plane extracts about 88.7% of the variation in the data set measured by criterion C_2 (see appendix E) as defined by Gordon (1982). It is clear that Picea, Betula, Cyperaceae, and Gramineae are the four most important taxa in the data set, as suggested by the length of their vectors respectively. Alnus, Ericaceae, and Salix are the second group having relatively important representation. The relationships between each pair of taxa also show some patterns. Gramineae has a positive correlation with Cyperaceae, and Picea has a positive correlation with Salix. Betula and Juniperus are also positively correlated. These three pairs, however, are negatively correlated to each other, thus, are complementary. The pattern of sample vectors is also distinctive. All samples

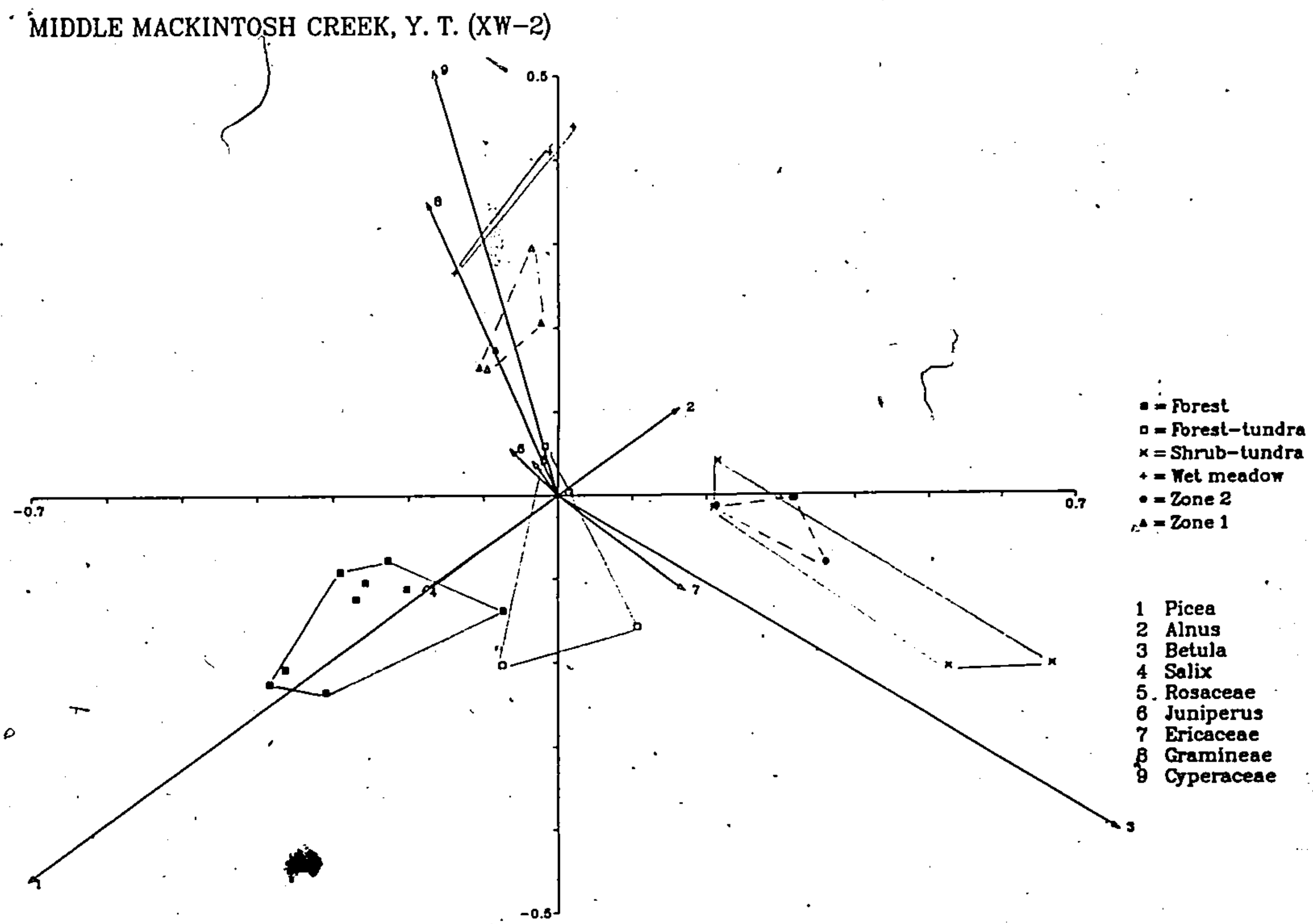


Figure 5.15 Ordination of combined data matrix of modern and fossil pollen samples on the first (horizontal) and second (vertical) PCB axes, profile XW-2, Middle MacKintosh Creek

from zone 1 are similar to those from a modern wet-meadow vegetation-landform unit, which explains the high percentages of Cyperaceae in the pollen spectrum. Samples from zone 2 overlap those from a modern shrub-tundra vegetation-landform unit. This is due to the high percentages of _Betula_ and Ericaceae in the data set.

Results of CA illustrate a broadly similar pattern to those from PCB (Fig. 5.16). The first and second CA axes account for about 68.1% of total variation in the data set. Samples of zone 1 are more closely located in this multidimensional space to Rosaceae and _Juniperus_, which is a reflection of the more frequent occurrence of these two taxa in zone 1. Other features are the same as those given by PCB. By a 45° rotation of the axes, the first axis seems to represent the density of the vegetation cover and the second axis represents the moisture condition of the local area in terms of the behaviour of this taxa in surficial samples (Fig. 5.17). Similar rotation can also be carried out for PCB and the result shows a similar pattern. Interpretation of this rotation for the first and second axes in CA will be discussed in the next section.

5.3.4 _Interpretation of Paleoenvironment_

Pollen records of this short peat profile provide evidence of local environmental variation during the last 1,230 years.

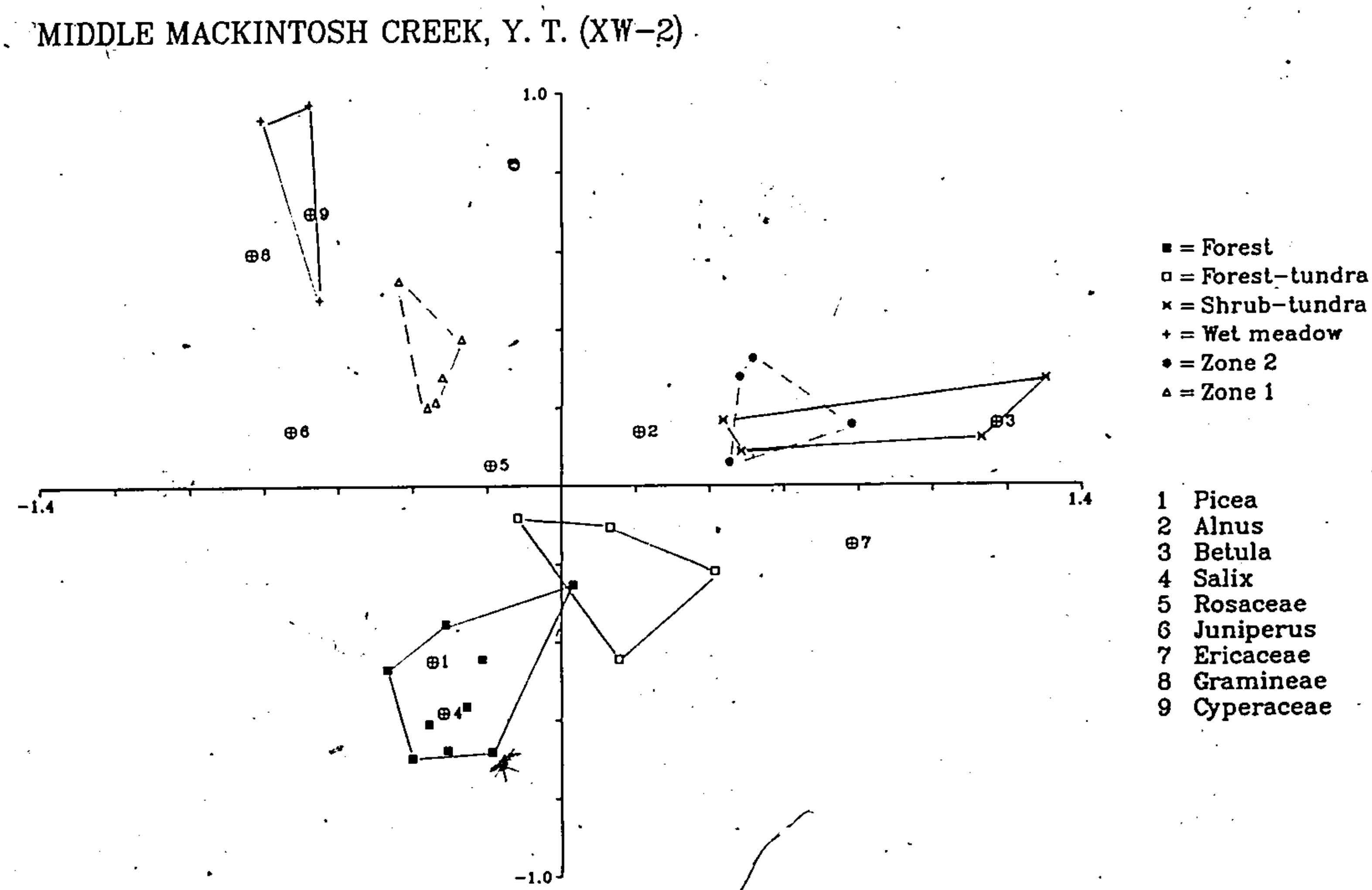


Figure 5.16 Ordination of combined data matrix of modern and fossil pollen samples on the first (horizontal) and second (vertical) CA axes, profile XW-2, Middle Mackintosh Creek

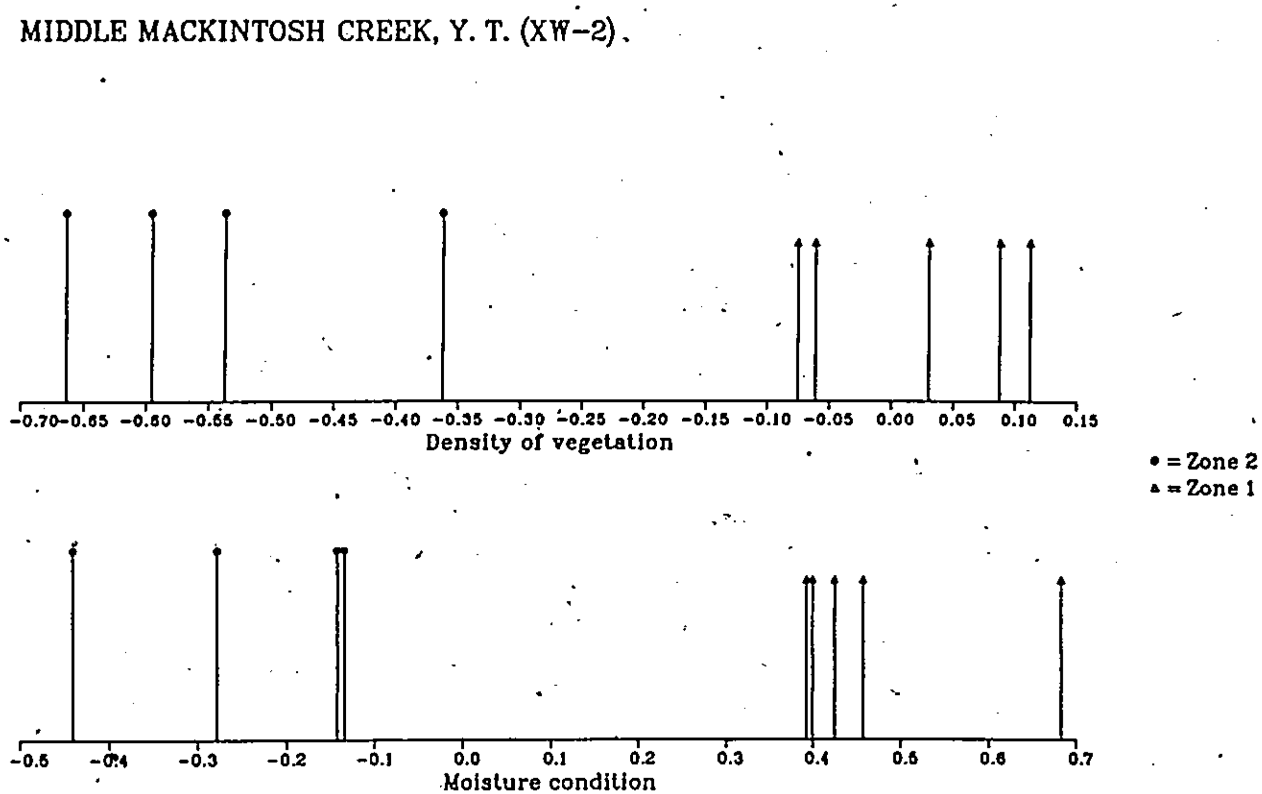


Figure 5.17 Projection of sample ordination on the first and second CA axes with a 45^0 rotation, profile XW-2, Middle Mackintosh Creek

At the early stage of landform and vegetation evolution, as represented by site-pollen-zone 1, the section site and vicinity were probably mesic or very poorly drained wetland on which a wet community was developed (as indicated by very high Cyperaceae percentage). Similarity of the ordination between zone 1 samples and those from a modern wet-meadow vegetation-landform unit in PCB and CA support this interpretation (Fig. 5.15 and 5.16). Projection of the ordination of zone 1 samples on the second rotated CA axis also indicates the wet nature of the area during the zone 1 time interval (Fig. 5.17). High percentage of Cyperaceae pollen was often observed in northern environments and such pollen spectra can be obtained from modern wet meadow samples (refer to chapter 4). A high percentage of spruce pollen (up to 38.8%) indicates that spruce trees were common in the area. As Picea is a prolific pollen producer, even a sparse distribution of Picea in a fairly open environment may cause a very high percentage in the pollen spectra, especially if local taxa can only produce a small quantity of pollen. Although Betula is usually overrepresented in pollen spectra, it can also be proportionally representative (Ritchie, 1974) where abundant local types existed (e.g. Cyperaceae or Salix). Considerable percentages of Betula in the zone (around 10-20%), doubtless indicate the presence of birch in the vicinity. However, high percentages of Cyperaceae suggest mesic or poor drainage conditions existed in the low land area such as the section site, which were possibly too wet for the shrub birch to colonize. Low percentages of Salix, Rosaceae, and Juniperus pollen reflect the fact that these shrubby taxa only occasionally occurred in this stage in the area. Therefore, during this stage a wet meadow or wet tundra community existed on the section site and lowland area in the valley within a sparse forest-tundra environment in general. Shrubs dominated by birch covered the moderately drained ground surface.

A possible change of environmental or drainage conditions around the section site is suggested by the pollen spectra at the beginning of zone 2. Since then, environmental conditions at the site have remained stable. A considerable decrease of Picea pollen to about 20-25% and a gradual decrease of Cyperaceae values are compensated for by a sharp increase of Betula and Ericaceae pollen. This pattern of pollen zone 2 can be interpreted by two controversial hypotheses: 1) Zone 2 represents a time interval during which spruce trees were dramatically reduced and the vegetation opened up from the beginning of the zone; 2) There was a change in the drainage or moisture conditions at the section site and vicinity while the spruce distribution in the general area varied little. Under the first hypothesis, the decrease of spruce pollen production is the most important factor dominating the general pattern of the pollen spectra. Possible reasons for a low productivity of Picea pollen include the reduction of spruce trees in the vegetation cover and/or ecologically unfavorable conditions for pollination. Fire, for example, can destroy the tall canopy of spruce and cause a dramatic decrease of spruce pollen percentage in the pollen spectra. A considerable percentage of Epilobium occurred in the bottom sample of the zone corresponding with the decrease of spruce pollen percentage. Although Epilobium is often considered a pioneer after fires (White, 1974), it is not likely that the decrease of spruce pollen percentage was caused by fire since no charcoal has been observed in the sediments or in the field. Picea values in zone 2 are quite consistent and provide no evidence of reforestation which often happens after fires (Payette and Gagnon, 1985). On the other hand, unfavorable climatic conditions may cause a change of Picea pollen production without obviously changing spruce tree distribution in the vegetation (Wang and Geurts, 1987a; Wang, 1988a). Under the severe continental climatic condition of the southwest Yukon Territory, warmer and drier climate may suppress the pollen productivity of Picea glauca. If this is the case, the warm and dry climate has lasted in the region since the beginning of zone 2. This interpretation, however, is in conflict with the regional study for the Little Ice Age (Denton and Karlén, 1973; Wang and Geurts, 1987a).

Under the second hypothesis, geomorphological processes during landform development are the primary agents for building the pollen sequence of zone 2. The present palsa field could have been developed at the beginning of zone 2 possibly during the Little Ice Age. Growth of the palsa field changed the drainage pattern at the section site which is now favorable for *Betula*. Alternatively, the drainage pattern at the section area could have been modified somewhat by the accumulation of zone 1 sediments. Both PCB and CA results show a perfect overlap of zone 2 samples with those of a modern *Betula*-dominated shrub-tundra vegetation-landform unit (Fig. 5.15 and 5.16), which suggests a shrub-tundra vegetation cover occurred during the zone 2 time interval. Projection of samples on the second rotated CA axis clearly indicates a change of moisture condition during zone 2 time interval. *Betula* groves spread out over the area where conditions were previously too wet for the growth of birch. Since *Betula* is a prolific pollen producer, substitution of *Betula* for Cyperaceae in a relatively flat low altitude area could seriously change the structure of local pollen rain. Up to 60% of consistent representation of *Betula* in the pollen spectra of zone 2 with an increment of about 35-40% from the zone 1 spectra reflects this change. The simultaneous decreases of the Cyperaceae portion in the pollen spectra favors this interpretation. The decrease of *Picea* pollen percentage in this zone can be, at least, partly caused by the extensive representation of *Betula* pollen in the pollen sum which would suppress the *Picea* pollen percentages.

The extensive occurrence of Ericaceae in the top three samples could be an indication of the disturbance of the area which is a common process in north environments. The *Alnus* pollen representation in this short section remains consistent from the bottom to the top. It is expected here that alder has probably been stable, though very sparsely distributed, in the area at least since the beginning of this sequence (*i. e.* around 1,230 yr BP). Selected pollen ratios, as illustrated in figure 5.18, indicate the relationship between tree, major shrub and herbaceous pollen. High *Picea* *vs* *Betula* and low *Betula* *vs* herbs ratios as well as the moderate value of the *Picea* *vs* herbs ratio in zone 1 indicate that *Betula* was not a major component in the vegetation during the first stage. Herbaceous taxa, mainly Cyperaceae, were major components of past vegetation at the section site and vicinity. Considering the high pollen production of *Picea*, the value of *Picea* *vs* herbs ratio around 1.0 corresponds with pollen percentage diagrams suggesting a forest-tundra environment in the area during the first stage. A completely different pattern of certain ratios in zone 2 reveals the change of vegetation structure during the second stage. The very low *Picea* *vs* *Betula* ratio (<1.0) and the very high *Betula* *vs* herbs ratio indicate the extensive rise of *Betula* in the local vegetation. In contrast, the *Picea* *vs* herbs ratio shows little difference. This pattern suggests that the pollen composition at this site was strongly influenced by *Betula* pollen production, which is

MIDDLE MACKINTOSH CREEK, Y. T. (XW–2)

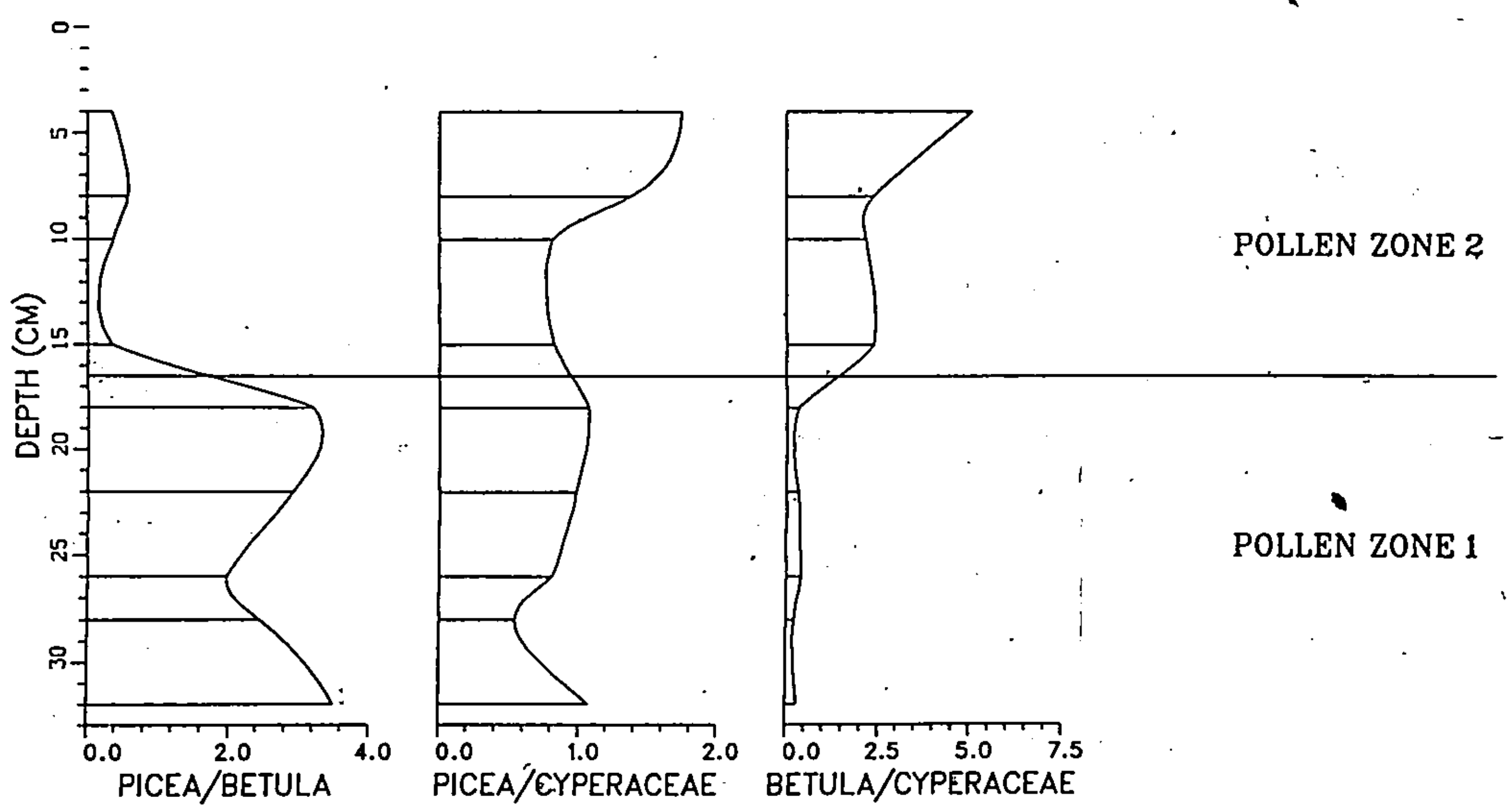


Figure 5.18 Selected pollen ratios of profile XW-2, Middle Mackintosh Creek

controlled by local development of drainage condition and landform evolution related to the growth of a palsa field in the area. Previous investigation in Northwest Territories (Savoie et Gangloff, 1980) indicates that the growth of palsas can be accompanied by an increase in Gramineae and some shrubs, such as Betula and Salix, compensating for the decrease in Cyperaceae. The present interpretation of the zone 2 pollen spectra is in agreement with this postulation. The simultaneous increases of Picea vs Cyperaceae and Betula vs Cyperaceae ratios and decrease of Picea vs Betula ratio in the top two samples is a reflection of the low representation of Cyperaceae pollen which compensates for the rise of Ericaceae pollen in these two samples.

5.3.5 Summary and Conclusion

Pollen records of profile XW-2 from the middle of Mackintosh Creek represent two developmental stages of paleovegetation and environmental conditions during the last 1,230 years. During the first stage, as represented by pollen zone 1, the section site and vicinity were mesic or poorly drained, which is an unfavorable habitat for Betula, while wet meadow or wet tundra developed in the lowland area within a background forest-tundra environment. During the second stage, represented by pollen zone 2, the drainage condition was improved by the process of landform evolution related to the growth of a palsa field. This improvement provided a favorable habitat for shrub Betula. Dense Betula shrub-tundra was developed around the section site and vicinity with a forest-tundra background. High production of Betula pollen suppressed the representation of Picea pollen which accounts for the decrease of spruce in the pollen spectra. These results are in agreement with modern pollen records from the Coppermine Valley, Northwest Territory (Geurts, 1983) and surficial palynological investigations in the study area (Chapter 4; Wang, 1988c), which suggests that the variation of pollen spectra is not exclusively related to climatic change or vegetation succession but also, to the process of landform evolution.

5.4 Upper Mackintosh Creek (XW-3)

5.4.1 Site Description

The study area lies in the northeastern corner of Aishihik Basin (Bostock, 1948) termed the Aishihik Lowland by Hughes (manuscript). The core site (61°45'53" N Lat., 137°14'40" W Long.) is in the basin of a short tributary of Mackintosh Creek near a kettle lake in a low lying area between the lake and a hill to the west (Fig. 5.2). The tributary drains northward about 3 km to join the main Mackintosh Creek, which also drains northward at present. The profile was cored from the flat bottom of the tributary at 1,060 m.a.s.l. At the east side of the kettle lake, a bedrock hill separates the tributary from the main Mackintosh Creek. The surficial deposits in the area are glacial drift. The bedrock around the area was recognized as Precambrian and/or Paleozoic amphibolite (Tempelman-Kluit, 1974).

5.4.2 Present Vegetation

The wet meadow vegetation at the core site is dominated by Cyperaceae, which constitutes as much as 85% of ground cover. Potentilla fruticosa and Betula glandulosa each make up about 5% respectively. Salix glauca, Arctostaphylos sp., and Compositae are present but less important. Within this vegetation cover, Betula glandulosa and Salix glauca stands are scattered over the flat area. Northward from the core site, the vegetation changes into a Salix glauca-dominated community, while southward it becomes a Betula glandulosa-dominated community. About 500 m westward, a spruce forest tundra occupies a southeast- facing slope. Approximately the same distance eastward, across the kettle lake, a small hill is also occupied by spruce forest tundra.

5.4.3 Stratigraphy and Methods

The profile of Upper Mackintosh Creek core (XW-3) has a depth of 107 cm with a relatively homogeneous sediment content. Peat is found from the surface to 7.5 cm while from 7.5 to 15 cm depth a conspicuous layer of the White River ash occurs. Peat underlies the ash to 93 cm. From 93 to 102 cm the sediments are lacustrine gyttja. At 102 cm the gyttja is underlain by fine sands.

5.4.4 ^{14}C Dates and Chronology

Five samples were submitted for radiocarbon dating in order to establish the chronological sequence of the profile. The results are listed in table 5.2. All samples were collected from the same core on which the pollen diagrams were based. The dates listed here were not previously cited, except for UQ-1373 which was referred to before (Geurts et al., 1987).

One or both of the last two dates at lower part of the sequence may be spurious and need to be considered carefully. It may be assumed that either: 1), UQ-1310 (9,500 +/- 200 yr BP) is a reasonable date and UQ-1373 (10,300 +/- 150 yr BP) is the result of redeposition; or; 2), UQ-1373 is reasonable and UQ-1310 is spurious, or; 3), both dates are not acceptable. Sample UQ-1310 has a wider correction range (+/- 200 year) which implies that this date has less precision than the other dates. However, if we adopt this date, the sedimentation rate between interval 63.5 and 89.7 cm will be unnaturally high. These facts together could lead to the rejection of assumption 1. On the other hand, a date of 9,900 +/- 110 yr BP (TO-185) from lacustrine gyttja in an area very close to the XW-3 core site has been reported and interpreted as the first organic sedimentation in the area after the last deglaciation (Beaudet, 1986). This date is comparable to both UQ-1373 and UQ-1310, implying that at least one of these two dates is acceptable and making assumption 3 unlikely. In comparison of the nature of these two problematic samples and in consideration of area correlation, assumption 2 seems most acceptable.

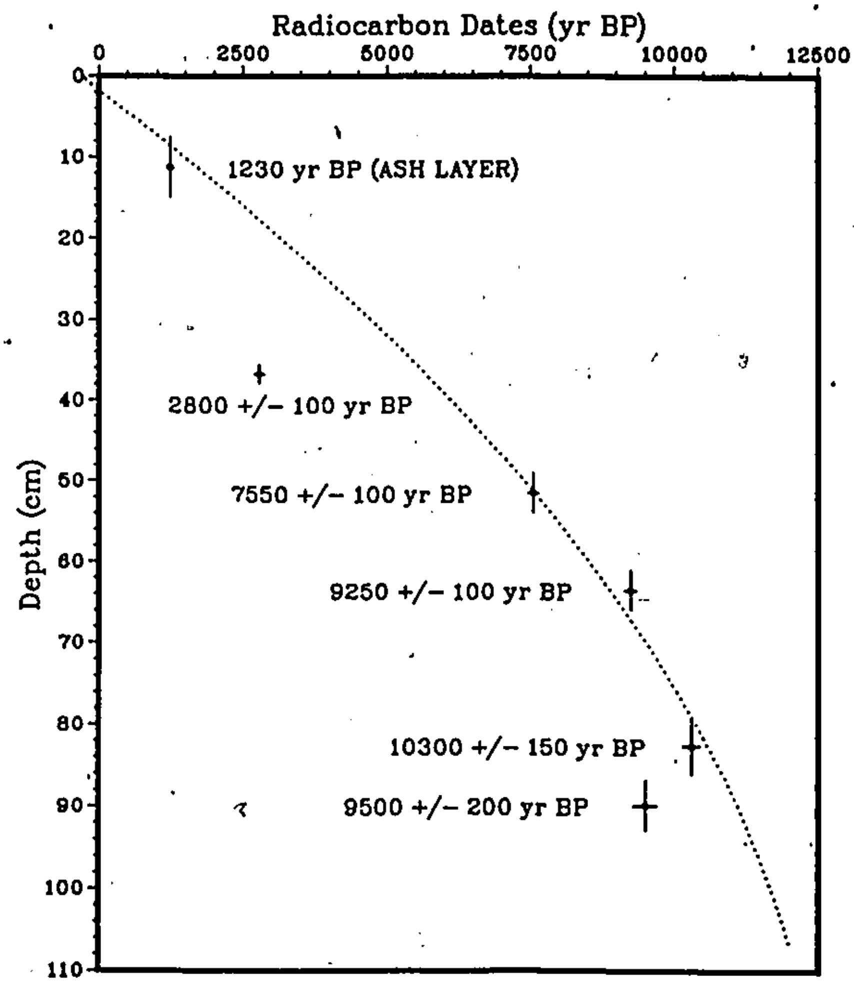
The interpretation of such a sequence thus excludes the redeposition of old sediments. It is unlikely that the reversion is caused by sample contamination during the sample collection, transportation, storage, and pretreatment in the laboratory since great care was taken. Although the sediments are fairly decomposed and humified, and obvious evidence of younger roots was found, the possibility of root system contamination cannot be eliminated. On the other hand, spurious dates in a core from St. Paul in the Pribilof Islands (Colinvaux, 1967a) were explained by groundwater contamination. Although the perennially frozen condition of the samples would restrict modern groundwater contamination, the very high permeability of peat in the profile leaves the possibility of contamination before permafrost was formed in the area.

It is also noted that date UQ-1313 is probably too young to be acceptable since by linear extrapolation between this date and the White River ash the sedimentation rate in this interval would be unnaturally high leading to an extraordinary increase in the pollen accumulation rate. However, in the Upper Nisling Valley, the pollen accumulation rate of profile XW-1

Table 5.2 ^{14}C dates of profile XW-3

Lab Number	Depth Interval	^{14}C Date	Material
	7.5-15.0 cm	1230 yr BP	ash
UQ-1313 *	35.5-38.0 cm	2800 +/- 100 yr BP	peat
UQ-1324	49.0-54.0 cm	7550 +/- 100 yr BP	peat
UQ-1311	61.0-66.0 cm	9250 +/- 100 yr BP	peat
UQ-1373	79.0-86.5 cm	10300 +/- 150 yr BP	peat
UQ-1310 *	86.5-93.0 cm	9500 +/- 200 yr BP	peat

* Not used for calculating sedimentation rates



Figue 5.19 ^{14}C dates vs depth relation of profile XW-3, Upper Mackintosh Creek

would be extremely low in a similar time interval if date UQ-1266 were adopted. Such a conflict of ^{14}C dates in this relatively small area makes it difficult to apply the absolute pollen accumulation rate. A second order polynomial regression technique was adopted to produce a best fitting curve with a data set excluding dates UQ-1324 and UQ-1310. White River ash was considered as a date control (1,230 yr BP) and the assumption that the top of the profile equals 0 yr BP was adopted. Such an analysis produces a multiple R^2 of 0.9781 for the goodness of fit. The age of samples and the sedimentation rates were extrapolated or calculated using the regression equation, which was used to determine the pollen accumulation rates (Fig. 5.19).

5.4.5 Relative Pollen Frequency

The results of pollen analysis for 39 samples in this profile are represented as a relative pollen frequency diagram (Fig. 5.20) and an absolute pollen accumulation rate diagram (Fig. 5.21). Numerical zonation procedures employed here to zone the relative pollen frequency diagram are programs of CONZONE, ZONATION, and CONISS. Dendrograms of different procedures are illustrated in figure 5.22. Taxa in the entrance data set include *Picea*, *Alnus*, *Betula*, *Salix*, Rosaceae, *Juniperus*, Ericaceae, Gramineae, Cyperaceae, *Myriophyllum*, *Lycopodium*, *Dryopteris*, and *Equisetum*. Final definition of zone

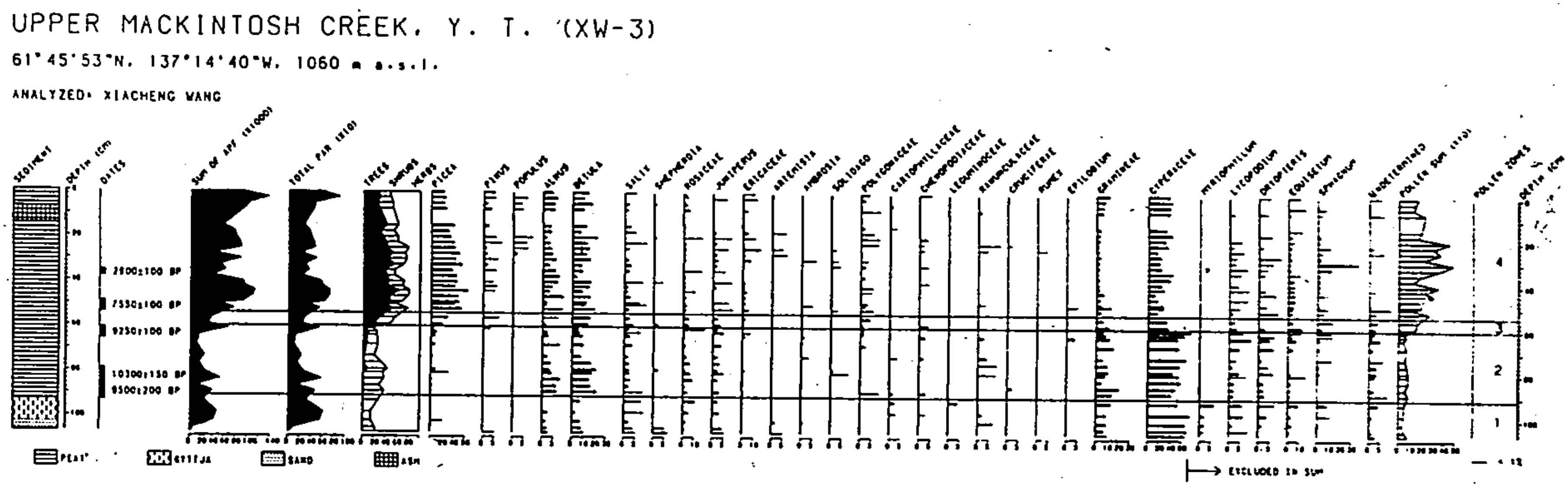


Figure 5.20 Pollen percentage diagram of profile XW-3, Upper Mackintosh Creek

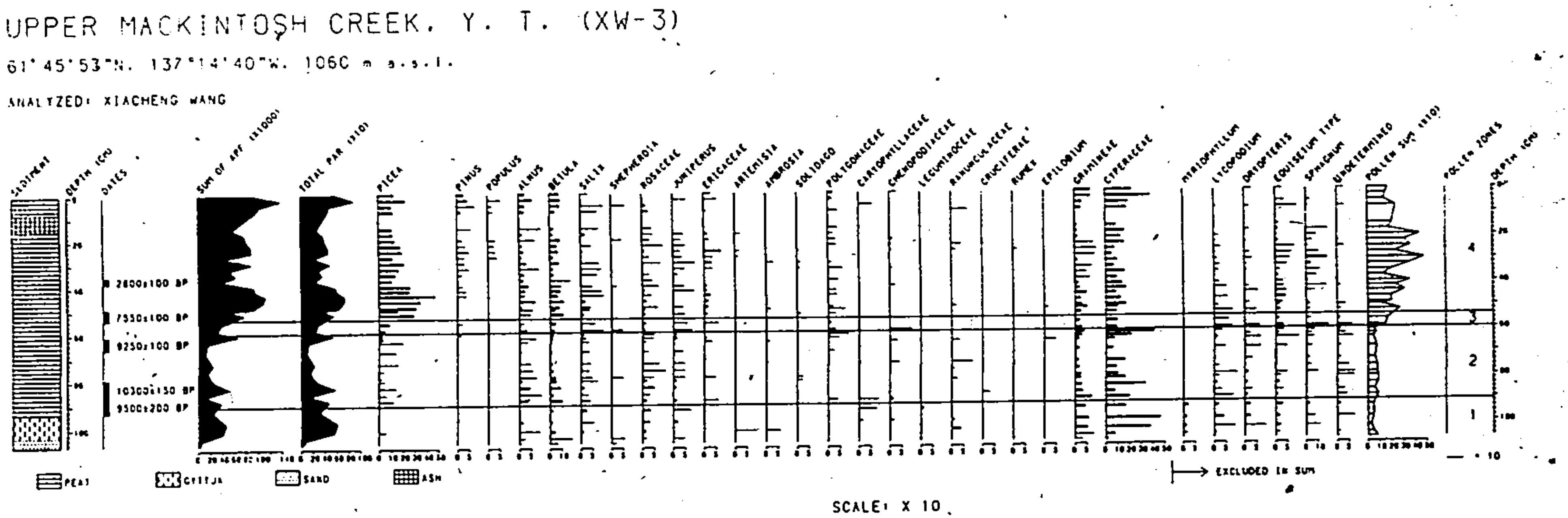


Figure 5.21 Absolute pollen accumulation rate diagram of profile XW-3, Upper Mackintosh Creek

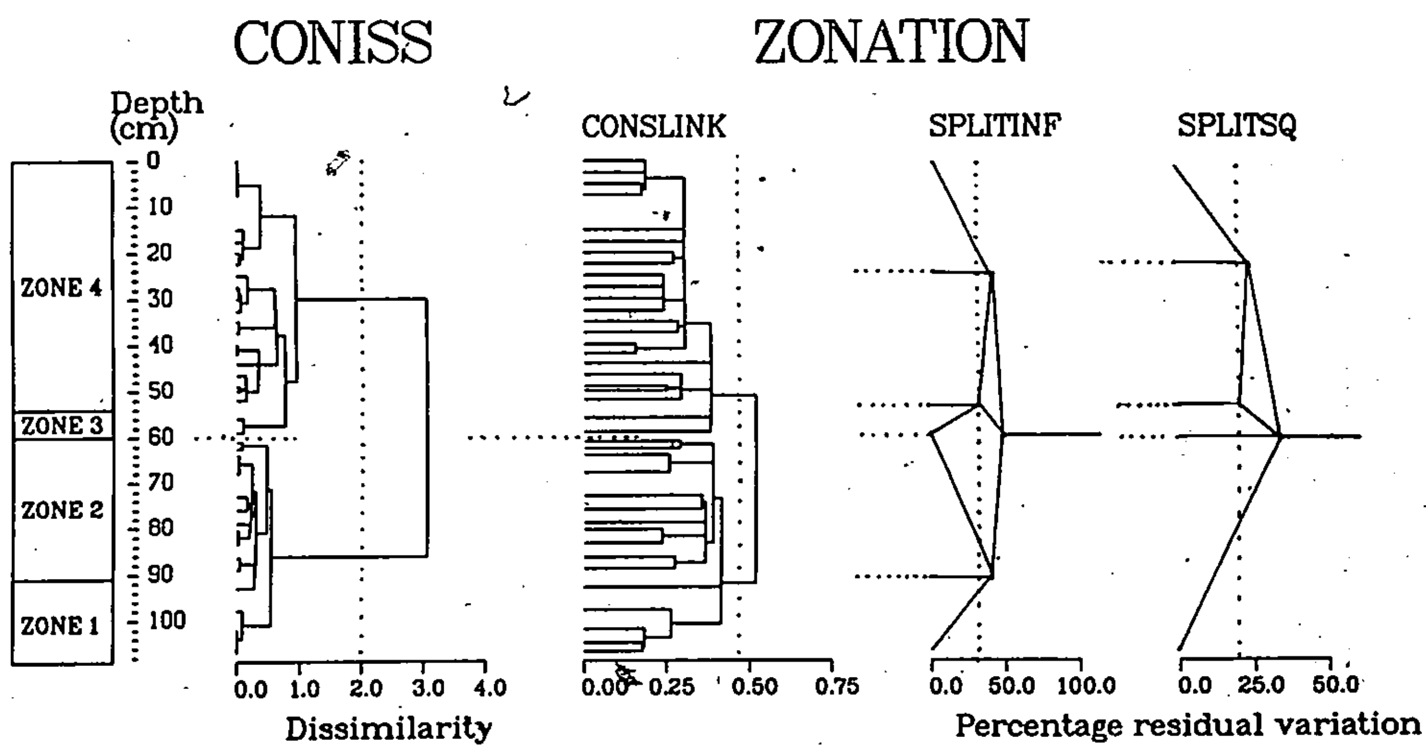


Figure 5.22 Dendrogram of zonation procedures of profile XW-3

(Three pages)

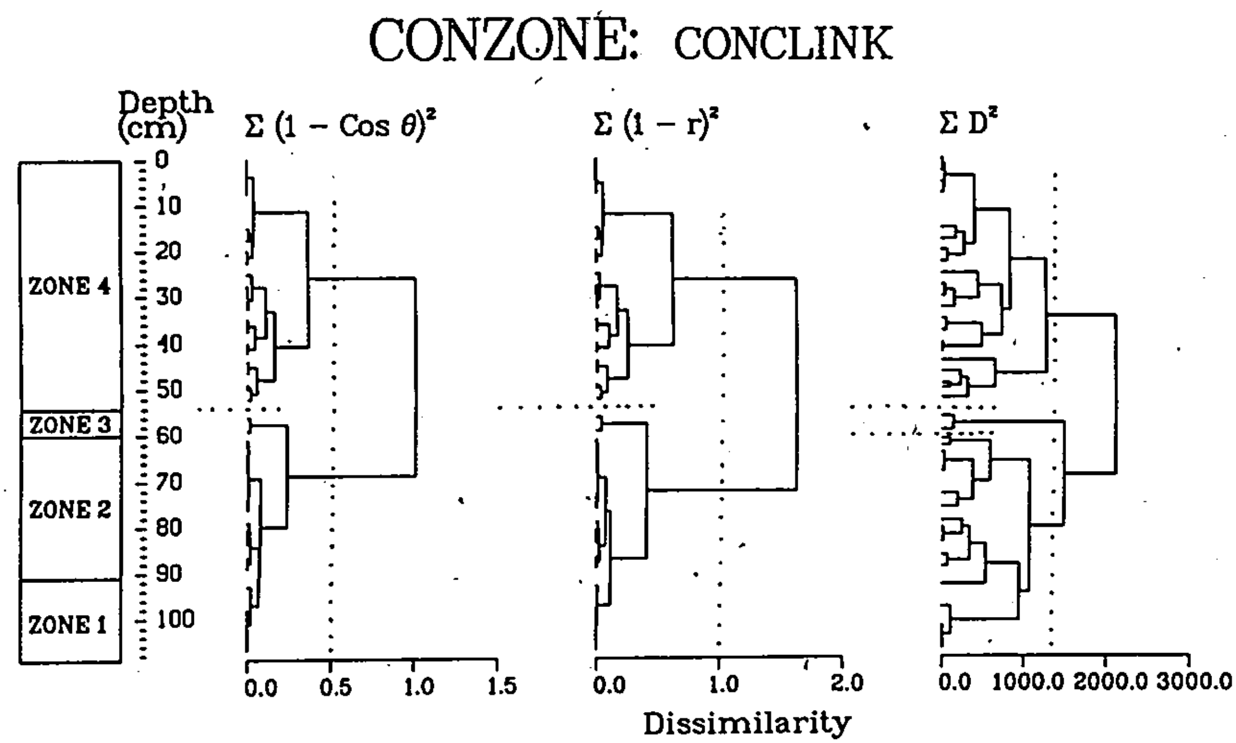


Figure 5.22 (Continued)

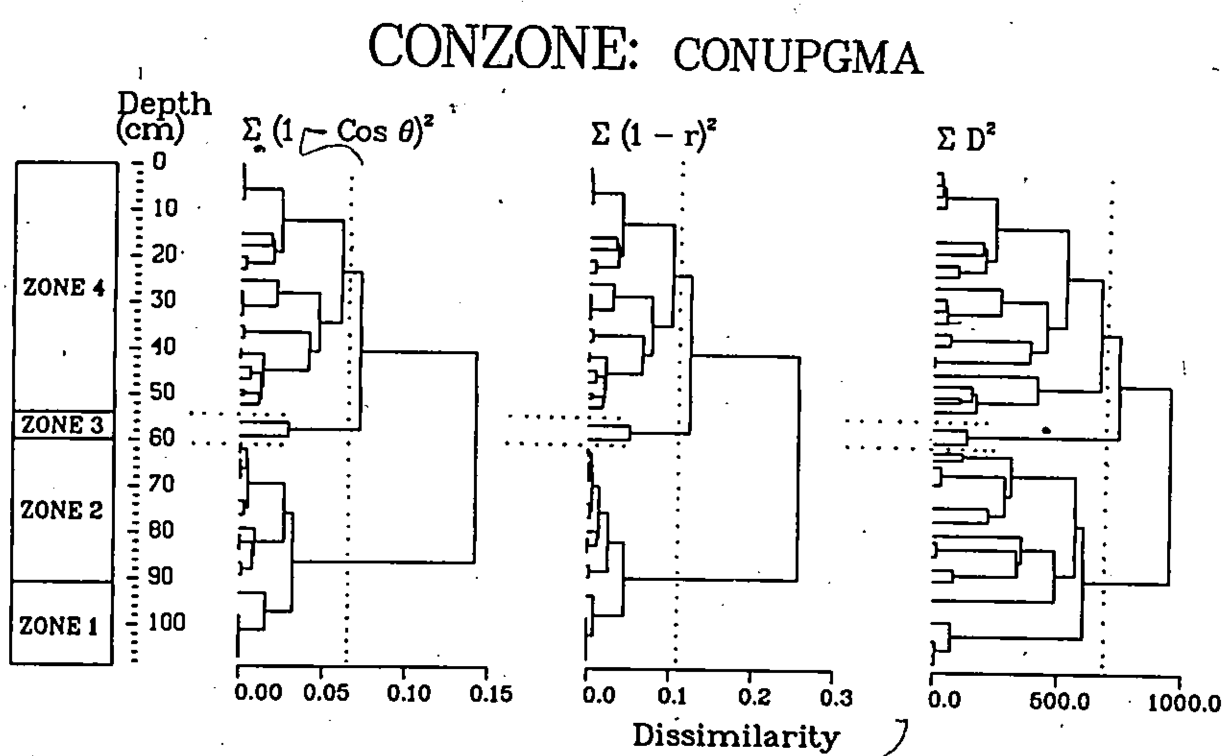


Figure 5.22 (Continued)

boundaries are determined empirically, aided by the results of numerical analysis.

POLLEN ZONE 1 (91.0 - 107.0 cm): Pollen zone 1 is dominated by herbaceous taxa, which is generally more than 72% of the total pollen. Cyperaceae predominates with values ranging from 52.9% to 74.3%, around 70% in most cases. Gramineae percentages vary from 7.3% to 13.4%. Other important taxa occurring with values more than 1% are _Myriophyllum_, _Lycopodium_, _Dryopteris_, and _Equisetum_. Shrub percentages are less than 27%, around 20% on average. _Betula_ is the most important shrub within this zone with values between 3.2% and 10.6%, 7.4% on average. Rosaceae is another element which produces a continuous percentage curve, with values between 1% and 4.7% except for 10% in one sample. _Alnus_ percentages are from zero to 2.7%, around 2% in most cases. Tree pollen is almost absent from this zone.

POLLEN ZONE 2 (60.0 - 91.0 cm): In comparison with pollen zone 1, Cyperaceae is still a dominant element in the pollen spectra with values varying from 42% to 76%. Gramineae values vary from 4.7% to 20%. _Myriophyllum_ is absent. _Lycopodium_, _Dryopteris_, and _Equisetum_ percentages fluctuate with low values around 2%. Total herbaceous taxa make up about 70% on average. Arboreal pollen increased in comparison with that in zone 1. _Betula_ is the most significant shrub component with values between 6% and 22%, 13.4% on average. *Alnus*, *Salix*, Rosaceae and *Juniperus* show continuous curves with values around 2% to 5% respectively. In total, shrub pollen varies from 11% to 37%, 26% on average. Trees start to have their pollen records in this zone. *Picea* pollen values vary from 0.8% to 9.5%.

POLLEN ZONE 3 (54.0 - 60.0 cm): Pollen records of this zone are transitional. *Picea* values are 19% and 29%. *Pinus* has one occurrence in two samples of this zone with a value less than 1%. *Betula* percentages have an obvious increase from less than 10% in several immediately neighboring samples to 14% and 16%. *Salix* and *Juniperus* values are around 3%, and Rosaceae have values about 4.5%. Cyperaceae percentages have obviously decreased, from more than 50% in upper zone 2 to 36% and 33% in this zone. Gramineae percentages are 11% and 6%. *Lycopodium*, *Dryopteris*, and *Sphagnum* values are about 2% where present. *Equisetum* values fluctuate widely, from 12.7% to 4%. Other taxa are not significantly present. In summary, tree pollen values in this zone are about 24%, shrub pollen values about 28%, and herbaceous pollen values 48%.

POLLEN ZONE 4 (0.0 - 54.0 cm): The lower boundary of zone 4 is defined by the occurrence of a climax of tree and shrub pollen percentages, and this zone is characterized by the constant domination of tree pollen, with values of 26% to 64.5%, 42% on average. *Picea* has relatively constant values around 40%, varying from 31% to 64%, decreasing above the ash layer to 22-26.5%. *Pinus* does not form a significant continuous curve, and only a few small peaks with values of about 1% occur within the lower part of the zone. *Pinus*, however, occurs continuously at 1.6% to 5% from 17.5 cm to the top of the section. Shrubs have similar proportions to those in zone 3 and upper zone 2 with values of 12.4% to 36.9%. The dominant shrub is still *Betula*, which varies from 3.6% to 21.7%, more than 12% in most cases. *Alnus* shows an increase at the base of the zone and varies from 0.4% to 9%. Other relatively abundant shrubs are *Salix*, Rosaceae, *Juniperus*, and Ericaceae, varying around 1-2% where present. Ericaceae, having its most significant occurrence in this part of the whole profile, varies from absent up to 15%. Herbaceous taxa contribute much less to the pollen spectra. Cyperaceae have decreased to values between 11.7% and 43.8%. Gramineae have also decreased notably, varying from 1.3% to 13% though around 3-5% in most cases. *Equisetum* and *Sphagnum* have more significant contributions in the spectra with values of 3% and 1.5%.

5.4.6 Absolute Pollen Accumulation Rate

The absolute pollen accumulation rate was determined using the standard exotic marker method (Maher, 1972) and the diagram is zoned using the relative pollen frequency diagram. It is a common feature that pollen accumulation rate and pollen concentration obtained from peat deposits in the study area are less than those obtained from lacustrine gyttja in the study area. An hypothesis to explain this phenomenon is that the lacustrine environment has a larger accumulation area and receives pollen from the air and rainfall runoff. However, peat bogs mainly receive pollen from the air and bog-forming taxa *in situ*. This hypothesis will be re-examined later with the comparison of pollen records from lacustrine sediments.

ZONE 1: The total pollen concentration of zone 1 varies from 0.2 X 10^4 to 7.8 X 10^4 grains /cm^3. The total pollen accumulation rate varies from 0.3-6.2 X 10^2 grains/cm^2/yr, mainly Cyperaceae (21 to 465 grains/cm^2/yr, 220 grains/cm^2/yr on average) and Gramineae (3 to 57 grains/cm^2/yr, 32 grains/cm^2/yr on average), which tend to increase from the bottom to the top of the zone. *Myriophyllum* varies from absent at the bottom to 20 grains/cm^2/yr at the top (9 grains/cm^2/yr on average). *Betula* is the best represented shrub ranging from 3 to 41 grains/cm^2/yr. Rosaceae values range from absent to 34 grains/cm^2/yr. Other taxa are much less important, generally represented by a few grains when present.

ZONE 2: Both total pollen concentration and accumulation rates are moderately larger than values in zone 1. The total pollen concentration varies from 1.2 X 10^4 to 6.7 X 10^4 grains/cm^3. The total pollen accumulation rate is between 1.1 X

10^2 and 5.8 X 10^2 grains/cm^2/yr. The most important taxa in this zone are still Cyperaceae (77 to 413 grains/cm^2/yr) and Gramineae (16 to 70 grains/cm^2/yr). Other herbaceous taxa are still not well represented. Shrub taxa show an obvious increase in pollen accumulation rate in general except for an unexpected decrease in the topmost part of the zone. Alnus values vary from absent to 45 grains/cm^2/yr. Betula is the best represented shrub in this zone and varies from 11 to 104 grains/cm^2/yr; 40 grains/cm^2/yr on average. Salix values are very low in most samples, usually a few grains. Rosaceae values are about 20 grains on average in the lower part of the zone but decrease to about 5 grains in the upper part. Picea is first registered at the bottom of the zone with about 3 grain/cm^2/yr, and gradually increases upward to ca. 32 grains/cm^2/yr. Other taxa, however, are far from significantly represented.

ZONE 3: Total pollen concentration in zone 3 is about 3.2-3.9 X 10^4 grains/cm^3, and total pollen accumulation rate is 250-290 grains/cm^2/yr. Picea values are 47 to 85 grains/cm^2/yr, and Betula values are 35-46 grains/cm^2/yr. Only a few grains of Salix, Rosaceae, Juniperus, and Ericaceae are present. Cyperaceae values are approximately 90-97 grains/cm^2/yr, while Gramineae values are 18-28 grains/cm^2/yr.

ZONE 4: The most dominant taxa in zone 4 are Picea and Cyperaceae. Picea values vary from 110 to 474 grains/cm^2/yr, *ca*. 200 grains/cm²/yr on average. *Betula* is still a dominant shrub in this zone with values from 10 to 110 grains/cm²/yr, *ca*. 80 grains/cm²/yr on average. *Alnus* is better represented than before with values between 5 and 66 grains/cm²/yr. Cyperaceae values vary from 53 to 384 grains/cm²/yr, *ca*. 160 grains/cm²/yr on average. Gramineae values range from 5 to 70 grains/cm²/yr, *ca*. 15-30 grains/cm²/yr in most cases. Other taxa are much less significantly represented (only a few grains where present). The total pollen concentration values range from 4 X 10^4 to 14 X 10^4 grains/cm³. The total pollen accumulation rates vary from 240 to 900 grains/cm²/yr.

5.4.7 Numerical Analysis

The results of PCA (Fig. 5.23a and 23b) show that the first principal component axis, accounting for 32% of the total covariance of the data set, is loaded by Cyperaceae, *Lycopodium*, *Dryopteris*, Rosaceae, *Juniperus*, and *Myriophyllum* with a negative value near to or less than -0.3. On its positive side, however, only *Picea* loading is greater than 0.3. This pattern is reflected quite well by the principal component scores of samples on this axis. Samples from zones 1 to 3 all have negative scores while those from zone 4 have positive values. This feature indicates the dominance of low shrubs, herbs, and pteridophytes in zones 1 to 3 and the high percentage of *Picea* in zone 4. Component loadings of taxa on the second axis, which account for 13% of the total covariance,

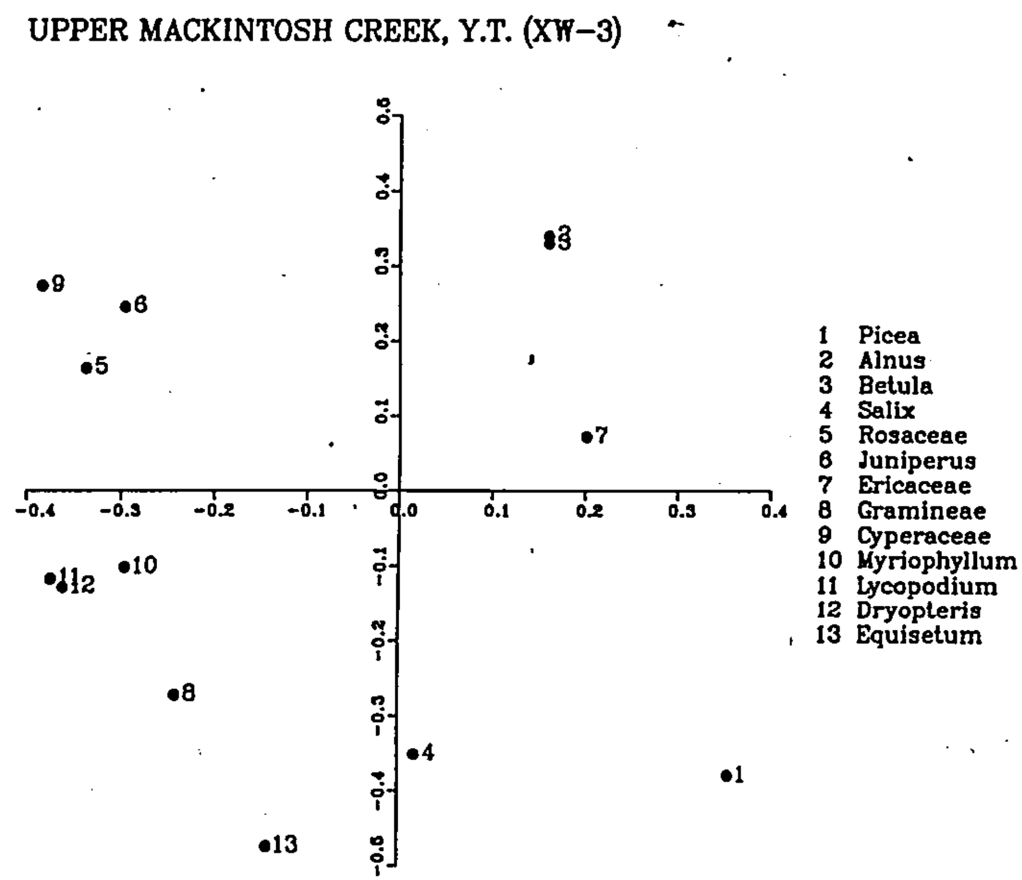


Figure 5.23a Principal component loadings of selected taxa on the first (horizontal) and second (vertical) PCA axes, profile XW-3, Upper Mackintosh Creek

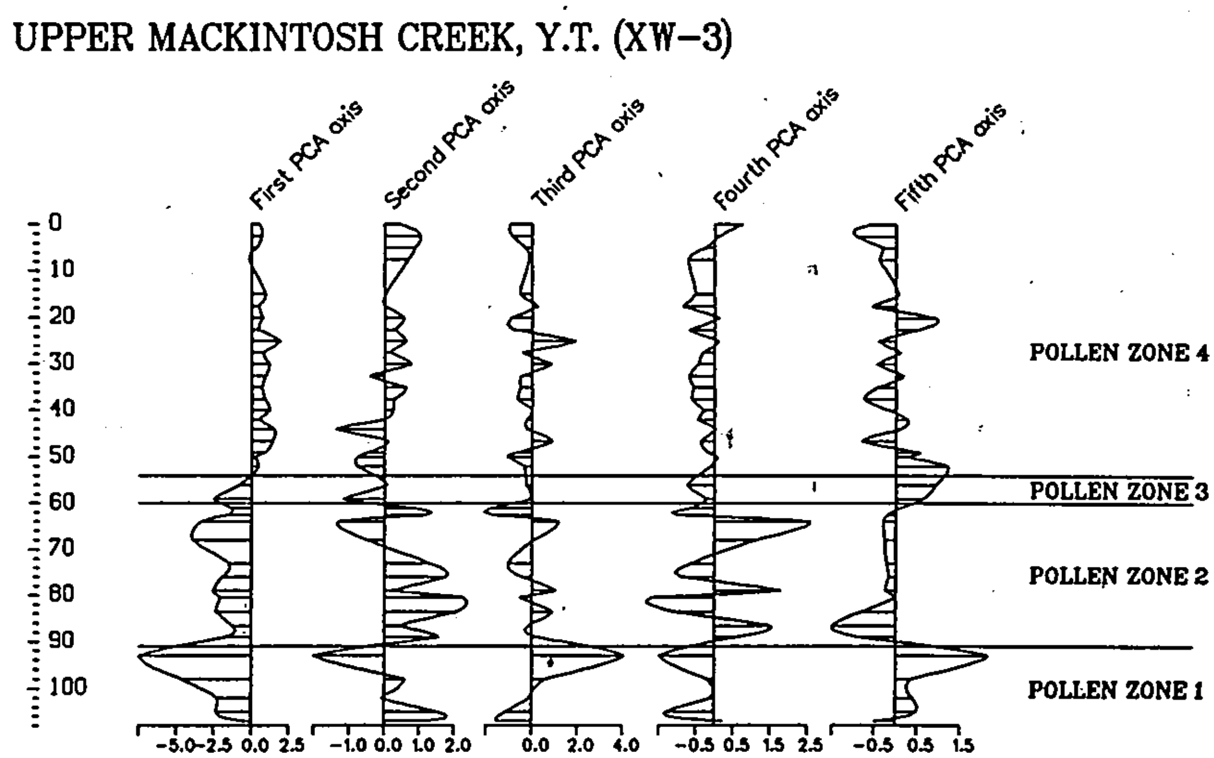


Figure 5.23b Principal component scores of profile XW-3 samples on the first five PCA axes, Upper Mackintosh Creek

are shared by high positive values of Alnus and Betula and high negative values of Picea, Equisetum, and Salix. This loading pattern explains the high positive scores of samples in the lower part of zone 2 which refer to a peak of Betula and Alnus percentages. Moderate scores of samples in zone 1 reflect the complex relationship between those taxa. In comparison with the first two axes, the third principal component axis, which accounts for 10.6% of the total variation of the data, is more difficult to interpret. Salix and Ericaceae have high positive loadings on this axis, while Gramineae and Cyperaceae have high negative values. The fluctuation of sample scores on this axis mirrors the variation of the relation between these four taxa. The fourth axis accounts for 8.9% of the total information in the data set. Taxa with high positive loadings are Betula and Gramineae, while Salix, Rosaceae, and Juniperus have high negative loadings. Samples from zones 3 and 4 produce negative principal component scores which are related to the low percentages of Gramineae in these samples. Fluctuating scores of samples in the lower part of the profile vary in accordance to the variation of the percentage values of Salix and Gramineae. The fifth axis, accounting for 7.8% of the total covariance, shows the relationships between Alnus and Gramineae (which have high negative loadings) and Betula and Myriophyllum (which have high positive loadings). High positive component scores of the samples in zone 1 reflect the consistent occurrence of Myriophyllum in the pollen spectra. The negative scores of zone 2 samples, however, are related to the high percentage of Gramineae and Alnus. Positive scores of samples from zone 3 and the base of zone 4 are more likely related to the Betula values. These five axes contain more than 72.2% of the total variation of the data set, and little information will be lost in discarding the other axes.

Results of PCB are summarized by the first and second axes plane in figure 5.24. This presentation accounts for 90.3% of the total variation of the data set, measured by criterion C_2 (Appendix E) as defined by Gordon (1982). Clearly, Picea, Betula, and Cyperaceae are three major taxa in the data set as reflected by the lengths of their respective vectors. The relations between these three taxa are complementary, or in another words are in negative correlation. Gramineae, Equisetum, and Ericaceae are the second group which have high vector values. In terms of the sample ordinations, samples of zone 1 and zone 2 all plot on the positive side of the first PCB axis with a small area of overlap. This distribution accounts for the high values of Cyperaceae, Gramineae, and low shrubs. Samples of zone 3 and zone 4 overlap significantly, and approach sample clusters of modern forest, forest-tundra, and wet-meadow. This feature is basically related to the moderate values of shrubs and the high value of Picea in the pollen spectra.

UPPER MACKINTOSH CREEK, Y.T. (XW-3)

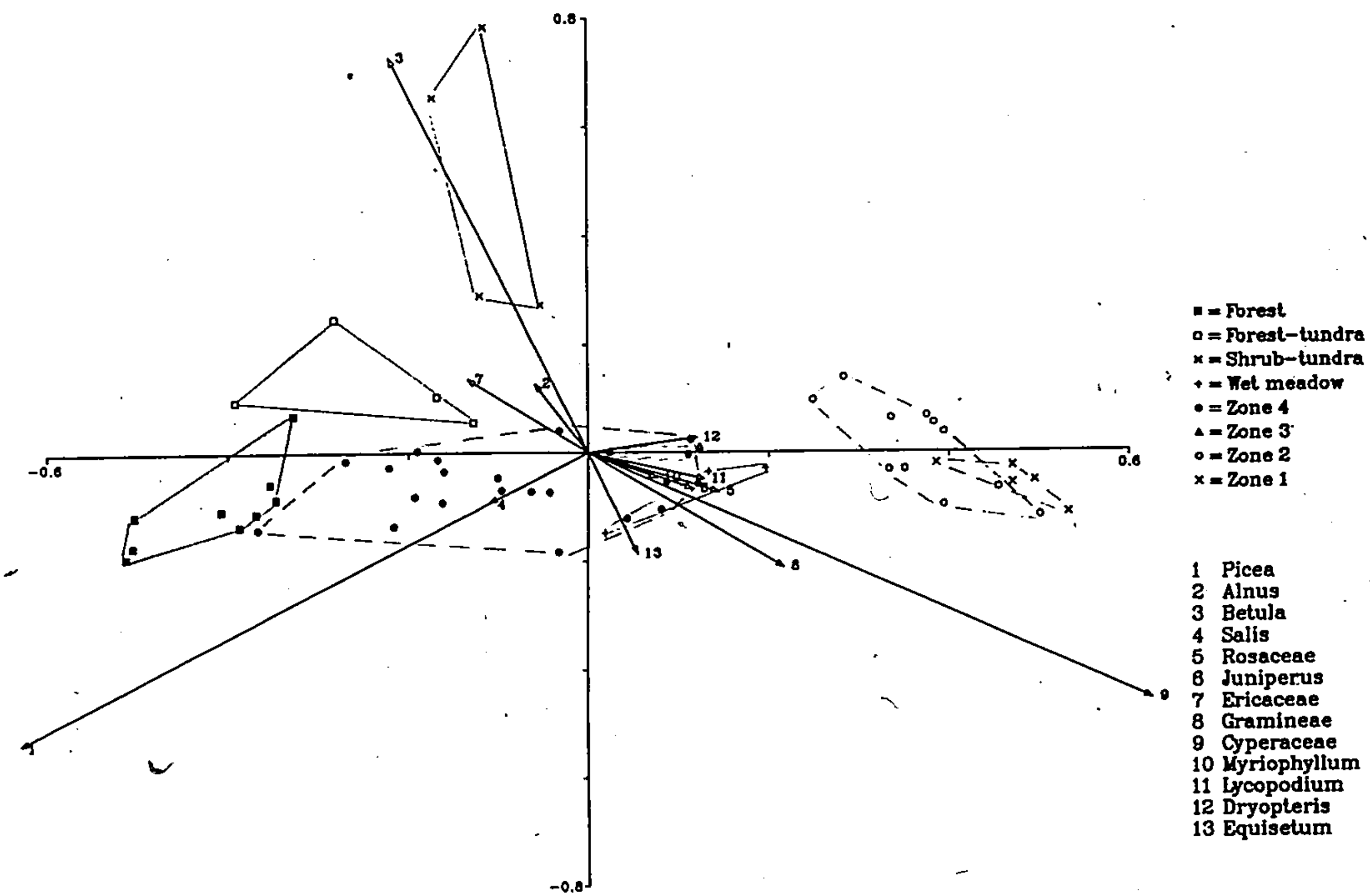


Figure 5.24 Ordination of combined data matrix of modern and fossil pollen samples on the first (horizontal) and second (vertical) PCB axes, profile XW-3, Upper Mackintosh Creek

As illustrated in figure 5.25, presentation of the first two CA axes accounts for 61.5% of the total information. It is better illustrated by CA than PCB that the cluster of zone 1 samples is mainly related to the *Myriophyllum* vector. Zone 2 samples are primarily related to Cyperaceae, Rosaceae, *Juniperus*, *Lycopodium*, and *Dryopteris*. These taxa all have their best representation in zone 1 and zone 2. The relationship between zone 3-4 samples and *Picea*-*Salix*-*Alnus* are also better illustrated. The overlap of some zone 4 samples with those of modern forest and forest-tundra vegetation-landform units suggests the great resemblance between vegetation in modern forest to forest-tundra environment and that during zone 4 time interval. Other interesting information may be extracted by a 45° rotation of the first two axes. The new axes may represent the vegetation density and moisture gradient, respectively (Fig.5.26).

5.4.8 Reconstruction of Paleoenvironment

The reconstruction of paleovegetation and paleoclimate requires interpretation of the pollen diagrams (Fig. 5.20, 5.21), selected pollen ratios (Fig. 5.27), and the information deduced from the numerical analysis. Contemporary pollen-vegetation relations in the area (see chapter 4) provide modern analogues for the interpretation. The chronology of the events is based upon the interpretation of radio-carbon dates *vs.* sediment depth with certain modifications (section 5.4.3).

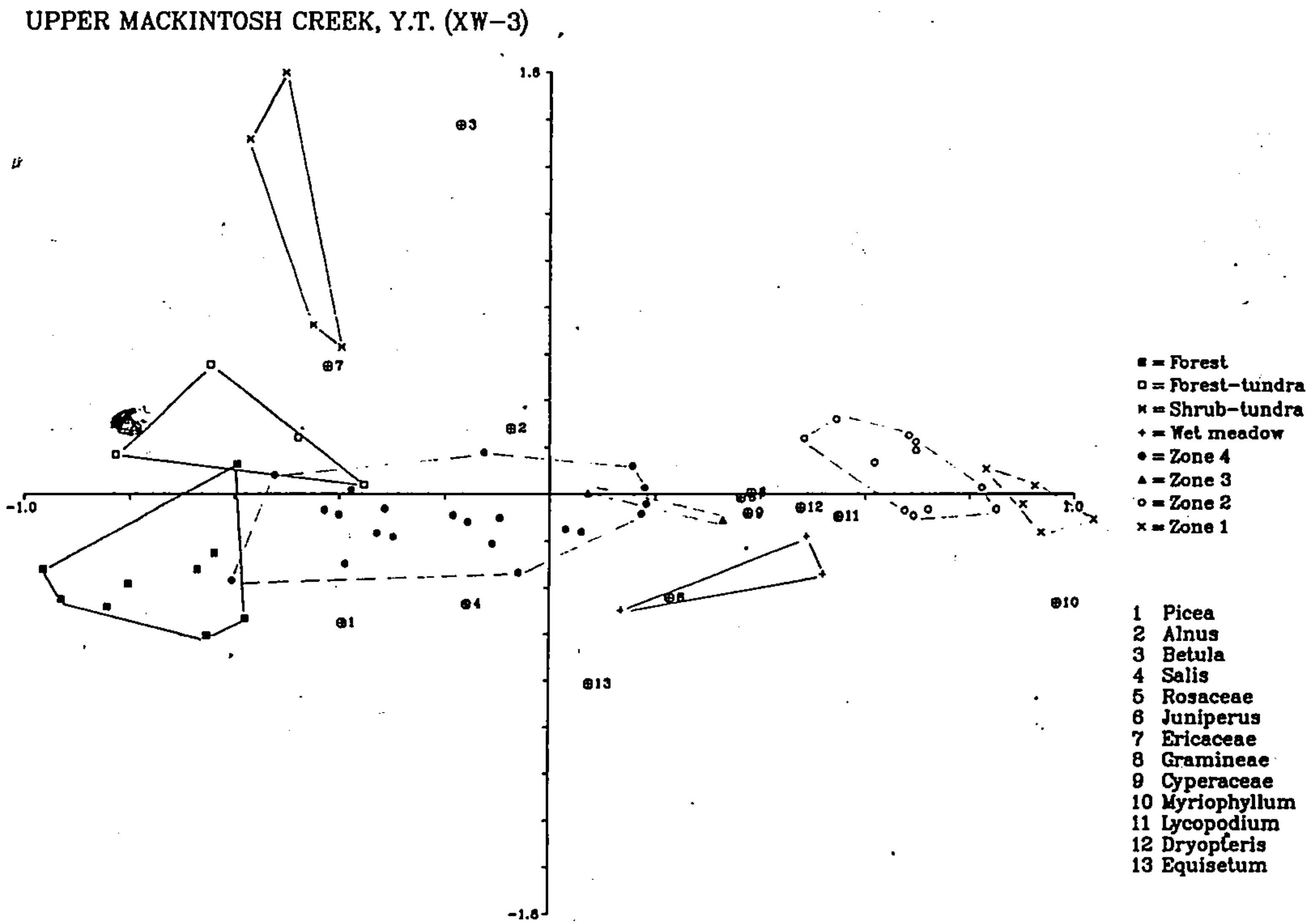


Figure 5.25 Ordination of combined data matrix of modern and fossil pollen samples on the first (horizontal) and second (vertical) CA axes, profile XW-3, Upper Mackintosh Creek

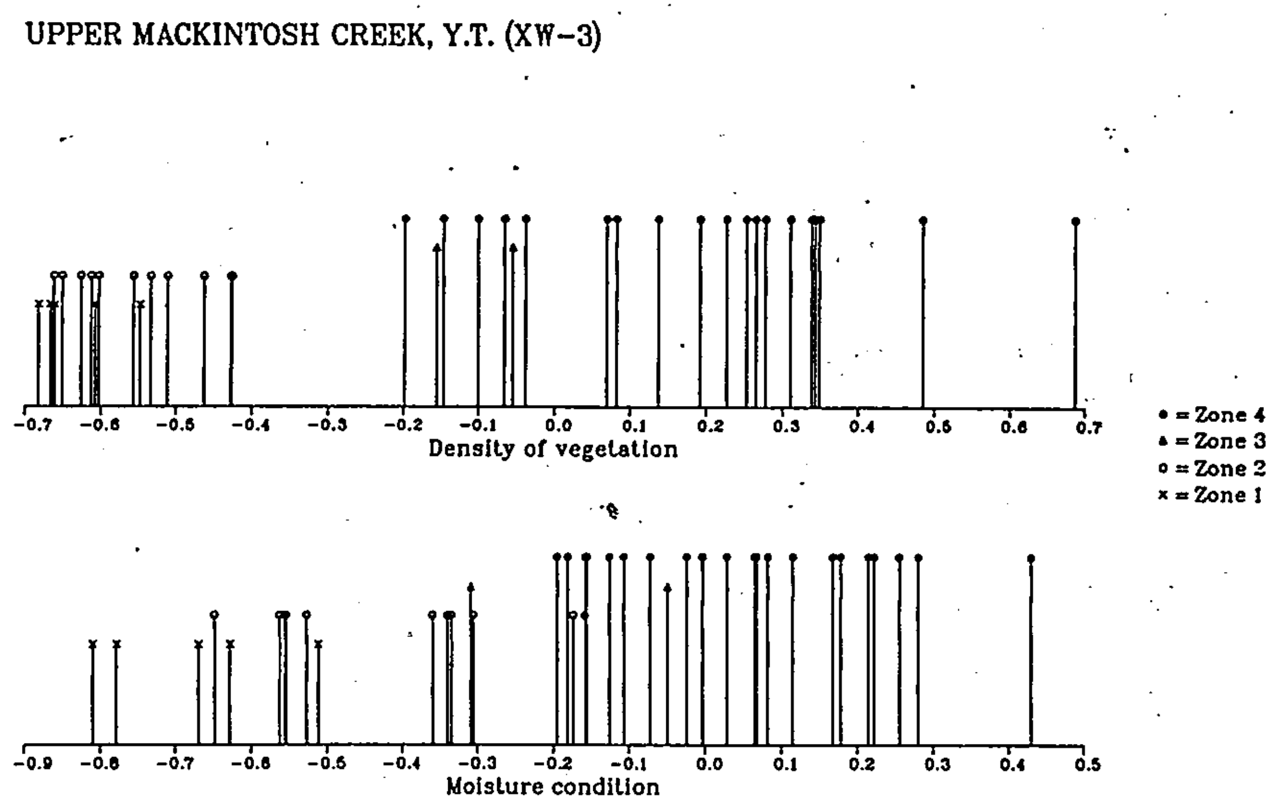


Figure 5.26 Projection of sample ordination on the first and second CA axes with a 45^0 rotation, profile XW-3, Upper Mackintosh Creek

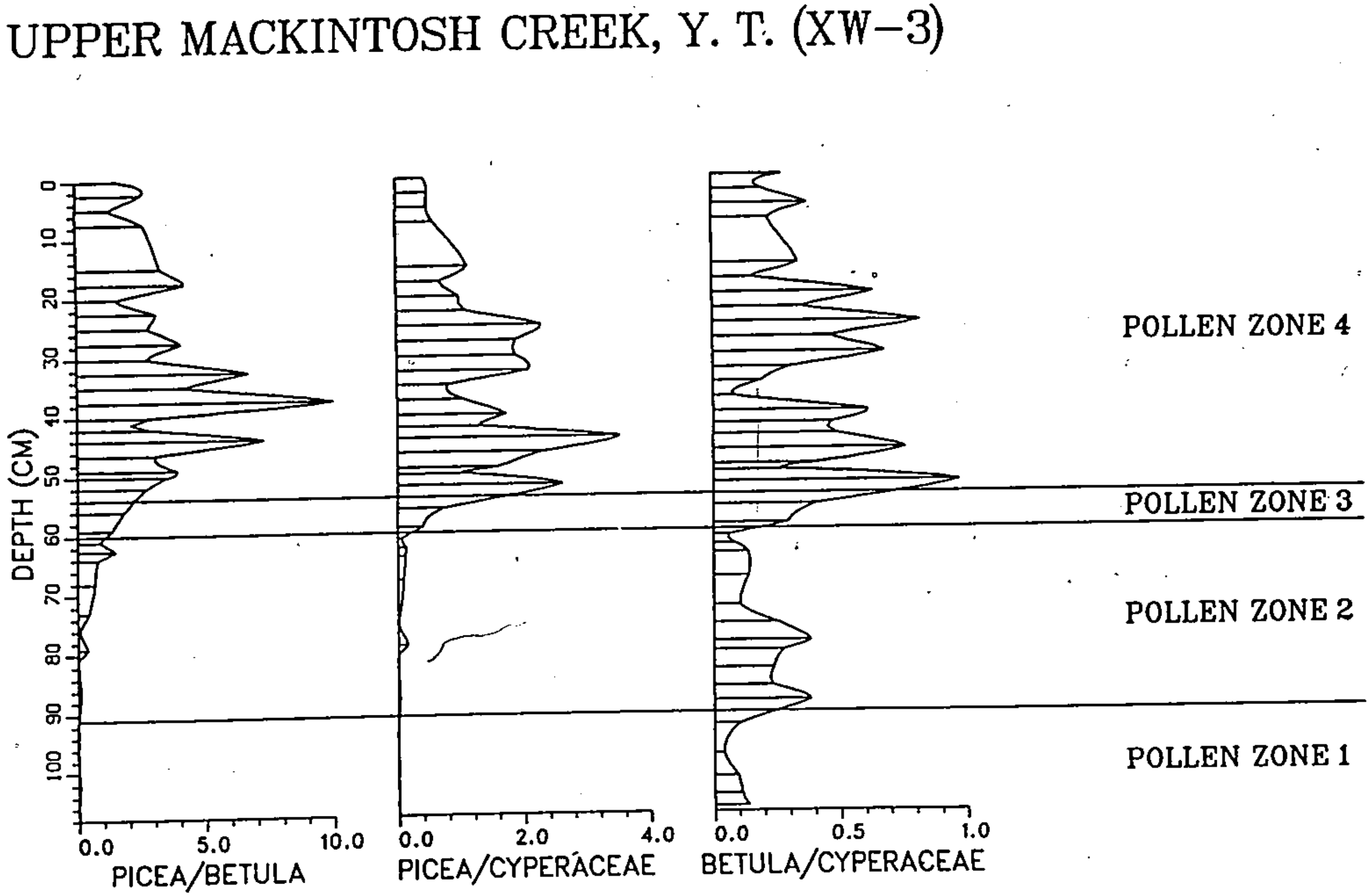


Figure 5.27 Selected pollen ratios of profile XW-3, Upper Mackintosh Creek

POLLEN ZONE 1 (91.0 - 107.0 cm): Both relative frequency and absolute accumulation rate diagrams suggest that pollen zone 1 represents a time interval during which the landscape around the core site was probably occupied by a sedge-moss tundra or fell-field. Davis (1969) has discovered that pollen influx values are extremely low in tundra regions. Extremely low total pollen influx values of the two bottom samples thus reflect very sparse vegetation cover following the last local deglaciation. The high Betula percentage in the last sample is artificial because of the discrepancy with influx value. Zone one in the spectrum is basically similar to well known surface pollen spectra from alpine, subarctic, and arctic regions that have a dominant representation of Gramineae and Cyperaceae (Rampton, 1971; Ritchie and Lichti-Federovich, 1967; Andrews et al., 1979; Jacobs et al., 1985). The fossil vegetation, however, can never be matched exactly by modern examples (Livingstone, 1955). Palynostratigraphic records of herbaceous zones characterized by an abundance of Gramineae and Cyperaceae have been reported in the Yukon (Ritchie, 1982; Rampton, 1971) and Alaska (Livingstone, 1955). Livingstone (1955) has interpreted his sedge-dominated herbaceous zone as a reflection of herbaceous vegetation in arctic Alaska and suggested that "they indicate conditions under which much fresh ground was available for colonization by herbaceous plants, presumably because of a severe climate with extensive frost-scarring of the ground" (p.594). Sedge- and grass-dominated pollen zones in the Dall Creek area, north Yukon, have been interpreted as indicators of a landscape occupied by tundra vegetation (Ritchie, 1982). In southwest Yukon, a sedge-moss tundra has also been reconstructed from herbaceous pollen zones (Rampton, 1971). Selected pollen ratios in this zone are consistent with the above interpretation. Extremely low ratios (near zero) of Picea/Betula and Picea/Cyperaceae reflect the absence of spruce trees in the area. Since Betula is the best represented shrub taxon, very low values of the Betula/Cyperaceae ratio may indicate the herbaceous taxa-dominant nature of local vegetation during this interval.

Consistently represented Myriophyllum pollen in this zone suggests a shallow water environment existed since this taxon is restricted to such an environment (Hulten, 1968). This suggestion is confirmed by lacustrine gyttja in the sediment log. The diminishing of this aquatic taxon and the transformation of gyttja into humified peat mark the end of this phase at no later than about 10,000 yr BP. The presence of gyttja deposits below the zone boundary implies that the first accumulation of organic material in the area occurred at least before 10,000 yr BP which is somewhat earlier than that in the main Mackintosh Creek (Beaudet, 1986). This discrepancy could be the result of local environmental influence. The main Mackintosh Creek is a wider and flatter valley with two chains of kettle lakes scattered along the valley floor, and the elevation at the Mackintosh Creek-HB1 pollen core site is 20 m lower than that of the XW-3 core site. Also, since profile HB1 was cored above the bank of an old kettle lake, the sediments were lifted for a few meters by frost heaving and ice lensing, which means the deposition level of the first organic deposits was lower than that measured today. Those features make it probable that the main valley of Mackintosh Creek had a thicker ice cover during the last glaciation than in the XW-3 core tributary. The rapid local disintegration of ice (Geurts *et al.*, 1987) during the last deglaciation provided numerous blocks of abandoned ice (dead ice) in both locations. It is believed that these ice bodies melted out earlier in the XW-3 tributary.

The pollen spectra of this zone are somewhat similar to the surficial pollen spectra from the wet-meadow vegetation-landform unit in the area (see chapter 4 and figure 4.2). The major differences are pollen percentages of *Picea* and *Myriophyllum*. High percentages of *Picea* pollen in the surficial pollen spectra diagram (Fig. 4.2) reflect a forest and forest-tundra vegetation environment in the general region. In the diagram of profile XW-3 however, such a regional vegetation background did not exist during the deposition of this zone. Meanwhile, high values of *Myriophyllum* percentage provide evidence of a lacustrine environment which is lacking a surficial analogue in the present investigation. Both PCB and CA, moreover, indicate that zone 1 pollen spectra are not comparable with any modern surficial spectra.

POLLEN ZONE 2 (60.0-91.0 cm): The obvious increases in shrub pollen abundance and pollen accumulation rates suggest an increased density of vegetation from the sparse sedge-moss tundra or fellfield of zone 1. High representation of *Betula*, especially in the lower part of the zone, Rosaceae, *Juniperus*, and *Salix* indicate that the sample site and vicinity were probably occupied by a *Betula*-*Salix* shrub tundra during zone 2 time. Since *Salix* pollen is often underrepresented in the pollen spectra, its consistent occurrence at about 3% might be considered significant representation, and indicates wide distribution throughout the area. The consistent occurrence of Rosaceae and *Juniperus* pollen with values around 5% suggests that these two groups of shrubs were common in the area at this time in a generally treeless open habitat. On the other hand, *Alnus* was probably absent from the area although its value is about 5%. Contemporary pollen records from the study area (see chapter 4 and Wang, 1988c) exhibit strong over-representation of *Alnus* pollen in the area. High values of sedge and grass pollen reflect the local vegetation pattern immediately around the core site, which probably was a mesic to wet community. High values and consistent occurrence of *Lycopodium*, *Dryopteris*, and *Equisetum* spores also indicate a locally wet to mesic environment. *Picea* pollen, however, was apparently recorded as exotic in the pollen spectra due to long distance transportation from its source area. This vegetation pattern probably lasted in the area until about 8,800 yr BP. Both PCB and CA indicate that the pollen spectra of zone 2 are not directly comparable to any modern surficial samples in the area, implying there are no modern analogues for the paleovegetation during the zone 2 time interval in the area.

POLLEN ZONE 3 (54.0-60.0 cm): This zone exhibits strong transitional features which mark the beginning of spruce colonization in the area and change of the vegetation cover. A dramatic rise of spruce pollen percentage and decrease of sedges at the base of the zone clearly indicate the change of vegetation. Although a threshold value of 10% spruce pollen percentage in lacustrine gyttja sediment may not be applicable to peat sediments, especially in such a complex landform environment, more than 25% spruce pollen in this zone undoubtedly indicates the arrival of spruce in the area around 8,700-8,800 yr B.P. (extrapolated). This result is in agreement with that obtained from the Mackintosh Creek-HB1 pollen profile (Beaudet, 1986). The similarity of these results from two separate studies suggests that this event can be documented not only in lacustrine sediments but also in peaty environments, implying that peat sediments are as good as lacustrine sediments for palynostratigraphic purposes. Pollen records from

Alaska and southwest Yukon show that <u>Picea</u> invaded the middle Tanana Valley at about 9,500 yr BP (Ager, 1975; 1983), and quickly spread from there eastward into southwest Yukon Territory to the Snag area (Ager, 1975, Rampton, 1971). A dramatic rise in <u>Picea</u> pollen percentages in the Snag area by 8,700 yr BP (from nearly absent to more than 20%) has been interpreted as the first occurrence of spruce forest or woodland in the area (Rampton, 1971). The arrival of spruce in this area has been extrapolated to about 9,000 or 9,500 yr BP (Ritchie, 1984a, discrepancy in Tab. 10 and Fig. 27, PP. 126-127). Pollen records from the Upper Mackintosh Creek area show that the spruce arrival time at both Snag and Mackintosh Creek was about the same. In summary, during this very short interval, and resulting from the arrival of spruce, sparse <u>Picea</u>-<u>Betula</u> forest-tundra began its occupation of the area at about 8,700-8,800 yr BP after the last deglaciation. As a transitional period, this vegetation pattern was replaced by a dense forest-tundra ecotone at the end of the zone 3 time which dates to about 7,700 yr BP.

POLLEN ZONE 4 (0.0-54.0 cm): Pollen zone 4 represents an interval from about 7,700 yr BP to the present, during which the vegetation pattern in the Upper Mackintosh Creek area stabilized. The <u>Picea</u> values at the bottom of the zone indicate the beginning of a dense spruce forest-tundra vegetation environment near the core site, probably covering the local slopes and moderately drained kame deposits. A consistent representation of *Picea* and most taxa in the zone reflect the stability of vegetation cover during this interval. High values of *Betula* and fluctuating though low values of *Salix* reveal that *Betula* remained the dominant shrub during this interval as before. Decreased values of *Juniperus* and Rosaceae in the pollen spectra are the result of competition from *Picea*. *Juniperus* and Rosaceae require an open habitat while the high stature and canopy of spruce create an unfavorable shaded environment. A gradual increase of *Alnus* values at the bottom of the zone might reflect the regional rise of *Alnus* at 6,000 to 5,000 yr BP in northern environments (Rampton, 1971; Cwynar, 1982; Ritchie, 1984a; 1984b; Ager, 1975). However, its low value in this study cannot be compared with the high values of alder found in the other locations. Frequent occurrence of Ericaceae, Polygonaceae, and *Equisetum* might indicate a moist soil condition at or near the core site though this may be related less to a wet climate, than to the effect of local topography or landform. The flat and channel-like nature of the site might encourage moist soil conditions even while the climate is generally dry.

5.4.9 Summary and Conclusion

In summary, pollen profile XW-3 represents the late Quaternary paleoenvironmental history of the Upper Mackintosh Creek area. As represented by local pollen zone 1, the vegetation of the area after the last deglaciation to at least 10,000 yr BP was probably a sparse fellfield. Spruce was absent from the area and its vicinity. The core site was still a shallow pond as the significant occurrence of Myriophyllum pollen would suggest. Extremely low pollen ratios of Picea vs Betula and Picea vs Cyperaceae (Fig 5.27) reflect the absence of Picea pollen in the vegetation. Low values of Betula vs Cyperaceae reflect the herbaceous taxa-dominant nature of the vegetation in the area. The frequent occurrence of Lycopodium, Dryopteris, and Equisetum suggests that a mesic condition existed in the flat valley bottom near the pond. High values of Cyperaceae also indicate the presence of wet ground conditions in the area. This vegetation and climatic regime was soon replaced by shrub-tundra and warmer, moister conditions at ca. 10,000 yr BP. The significant rise in Betula percentage and accumulation rate in the lower part of zone 2 and the abundant occurrence of Salix pollen reflect this change. High values of Cyperaceae and frequent occurrence of Lycopodium and Dryopteris indicate the moist nature of the soil. A minor decrease of Betula values in the upper part of zone 2 might reflect a small climatic oscillation between 8,700-9,800 yr BP. Slightly increased pollen ratios of Picea vs Betula and Picea vs Cyperaceae in zone 2 reflect the occurrence of exotic Picea pollen in the profile, and the minor decrease of Betula in the upper part of the zone. As the climate warmed again by ca. 8,700-8,800 yr BP, spruce invaded the area (when Betula pollen values were back to about 20%). This sparse forest-tundra condition lasted for about 1,000 years. By about 7700 yr BP the vegetation in the area became stable to the present day with a dense forest-tundra condition. High values of the *Picea vs* Cyperaceae ratio reflect the arrival and dominance of spruce in the area in the time interval of zones 3 and 4.

5.5 Post-glacial Paleoenvironmental History: Correlation and Conclusion

Palynological investigation in the northern Aishihik Basin reveals broadly comparable pollen records within this area. These records are also broadly comparable to other parts of the Yukon Territory, adjacent eastern and central Alaska, and the Northwest Territories. Some distinctive differences are believed to be due to the differences of local environmental conditions. Great similarity between pollen profiles in this area makes correlation relatively simple (Fig. 5.28). After the last deglaciation, the area was covered by a sedge-moss tundra (XW-3) or herbaceous tundra (HB1) followed by a short-lived *Betula*-*Salix* shrub tundra at about 10,000 yr BP. Spruce arrived in the Upper Nisling Valley (XW-1) at least 9,000 yr BP, reaching the Upper Mackintosh Creek area at about 8,800 yr BP (XW-3) or 8,900 yr BP (HB1). After a short transitional period, spruce forest developed in the Upper Nisling Valley (XW-7) area about 7,900 yr BP, while simultaneously, a dense spruce forest tundra took its place in the Upper Mackintosh Creek area

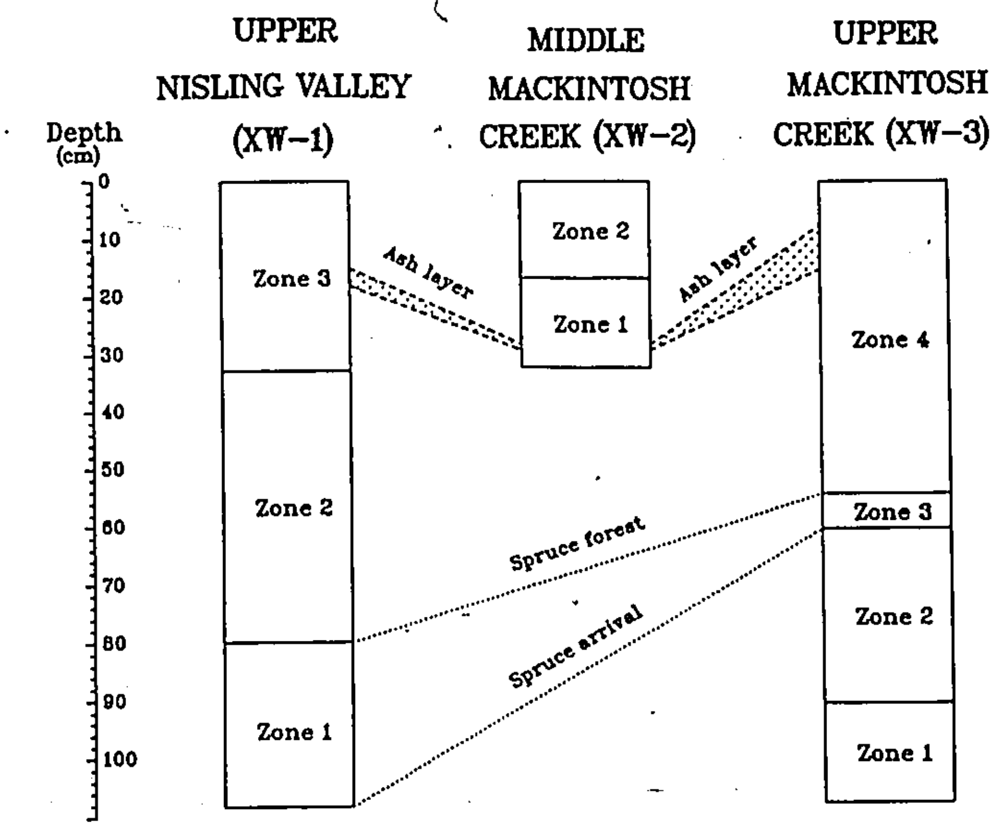


Figure 5.28 Correlation of pollen sequences in the northern Ashibik Basin

(around 7,700-8,000 yr BP). In the Antifreeze Pond area (Fig. 1.2), the Holocene pollen records reveal that a shrub tundra vegetation was developed in the area between 10,000 yr BP and 8,710 yr BP and spruce arrived in the area at 8,700 yr BP. As it has been concluded that ^{14}C age errors between gyttja and peat are likely larger than any differences due to time-transgressive events (Ritchie, 1982), spruce invaded these two areas almost at the same time. It is interesting to note that the rise of Picea pollen occurred somewhat later in Antifreeze pond than in other areas. In the Upper Nisling Valley, the obvious increase of Picea pollen occurred about 7,900 yr BP. This is similar to the date of Picea increase (7,700-8,000 yr BP) in the Upper Mackintosh Creek area. In the Upper Natla River area, this event is controlled by a ^{14}C date of 7,700 yr BP (MacDonald, 1983). However, spruce forest established in the Antifreeze Pond area around 5,700 yr BP (Rampton, 1971), which is more than 2,000 years later than in the other sites. In central Alaska, pollen records of Tanana Valley show that Picea invaded the Tanana Valley from the northern Yukon at about 9,500 yr BP and spread rapidly into the adjacent southwestern Yukon Territory (Ager, 1975; 1983). The present study indicates that spruce arrived in the southwestern Yukon Territory at least 9,000 yr BP in the Upper Nisling Valley, and about 8,700-8,900 yr BP in both Antifreeze Pond and Upper Mackintosh Creek areas, probably via different migration route.

A detailed comparison of these sequences suggests that local environmental impacts on the pollen records are important. By about 4,000 yr BP an obvious decrease of *Picea* pollen percentage in the Upper Nisling Valley is not recorded in the other parts of the study area. This event was due to the great representation of bog-forming taxa at the core site in the Upper Nisling Valley resulting from changing local environmental conditions. Interpretation of such a pollen record, therefore, must involve careful consideration of the complex relationships between regional and local pollen taxa, especially if only percentage data are available.

Chapter 6

Post-glacial Pollen Records in the Central Aishihik Basin

6.1 Introduction

The central Aishihik Basin was glaciated during the late Pleistocene. Widespread organic deposits above glacial drifts in the area enable the palynological investigation of post-glacial environmental history to be carried out. Previous investigation of pollen records is scarce. Only one pollen diagram has been reported during the investigation of a pingo from the area, but has no ^{14}C date control (Geurts et Dewez, 1985). The vegetational and environmental history of the area after the last deglaciation still remains fragmentary.

Three pollen profiles were raised from this area to obtain palynological evidence for post-glacial paleoenvironmental history (Fig. 6.1).

6.2 Polecat Lake Area (XW-4)

6.2.1 Site Description

Lacustrine clay and other sediments overlain by organic peat were cored at the northwest corner of an unnamed pond near Polecat Lake and the road to radio towers in the abandoned Aishihik Village area. The core site is located at 61°40'45" N Lat. and 137°27'12" W Long. with an altitude of 935 m a.s.l. Present vegetation is spruce forest, and the core site is located within a dense stand of *Picea glauca*. Wetlands and

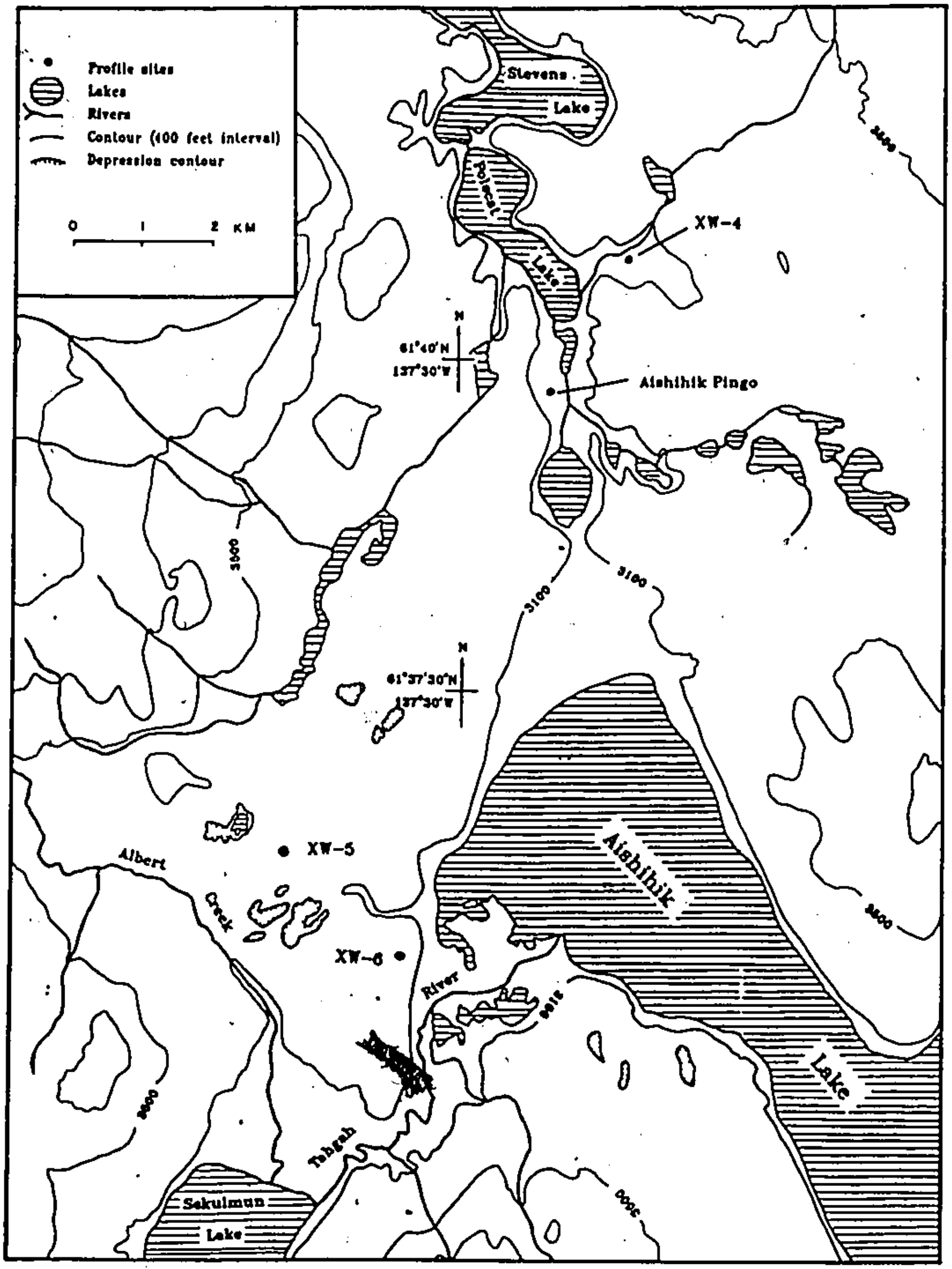


Figure 6.1 Location map of fossil pollen sites in the central Aishihik Basin

shrub-dominated communities are scattered throughout the area in accordance with drainage condition.

6.2.2 Sediment Stratigraphy and Chronology

The upper part of this profile, consisting of organic peat underlain successively by White River ash, fine sand, and organic peat again, is obviously cryoturbated by periglacial processes, which is confirmed by the observation of White River ash dispersion and sandy layer ejection within the peat deposits. Evidence of cryoturbation disappears at 80 cm depth (sampling started from 90 cm).

Peat accumulation from 90 cm to 107 cm is underlain by silty clay with abundant mollusc shells to 338 cm. Fine sands occur at level 338 cm with increased organic content.

About 2 m away from the core hole on the bank of the pond, a cross section was examined and its stratigraphy is the same as that described by Hughes (Lowdon and Blake, 1970) on which a ^{14}C date of 9,660 +/- 150 yr BP (GSC-749) was obtained at the basal organic lens in sands. However, since the cross section is badly penetrated by modern root systems, no palynological sampling was carried out. Correlation of the cross section and cored profile cannot be matched by depth since the numerous ice lenses in the cored profile increased its depth (frost heave). However, the stratigraphy of these two sections are well matched in sediment properties. The date of 9,660 +/- 150 yr BP (GSC-749) could be considered as a reference date for the interpretation of the pollen spectra. Additionally, a ^{14}C date of 5,850 +/- 100 yr BP (UQ-1442) was obtained at the base of the top organic peat layer.

6.2.3 Relative Pollen Frequency Diagram

Relative pollen frequency (pollen percentage), calculated on the sum excluding pteridophytes and aquatics, is presented in figure 6.2. Numerical zonation procedures, using a data set of selected taxa including *Picea*, *Alnus*, *Betula*, *Salix*, Rosaceae, *Juniperus*, Ericaceae, Gramineae, Cyperaceae, *Sparganium*, and *Equisetum*, suggest three zone boundaries at 111.0, 201.0, and 292.0 cm levels respectively (Fig. 6.3). This section describes the basic features of the relative pollen frequency diagram.

ZONE 1 (292.0 cm - 329.0 cm): The most striking feature of zone 1 is the dominance of shrub pollen which varies from 57.5% to 74.0%. *Betula* is the taxon responsible and it ranges between 54.0% and 66.0%. *Juniperus* varies from absent in one sample to 4.4%. Others have fairly low percentages and are only occasionally represented. Herbaceous pollen is the second most abundant group and ranges between 24.3% and 38.5%. Gramineae percentages vary from 13.05 to 25.0%. Cyperaceae percentages are 4-25% with high values in the two bottom samples. Other

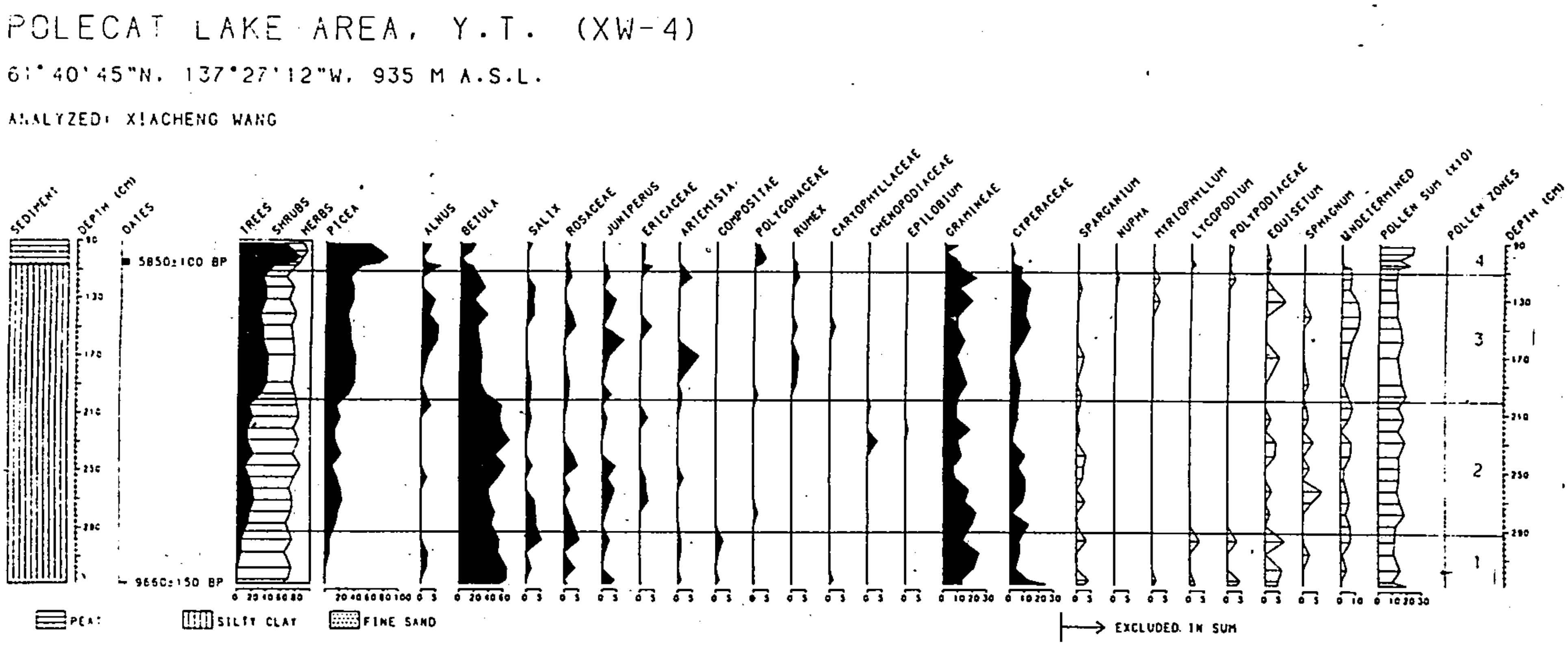


Figure 6.2 Pollen percentage diagram of profile XW#4

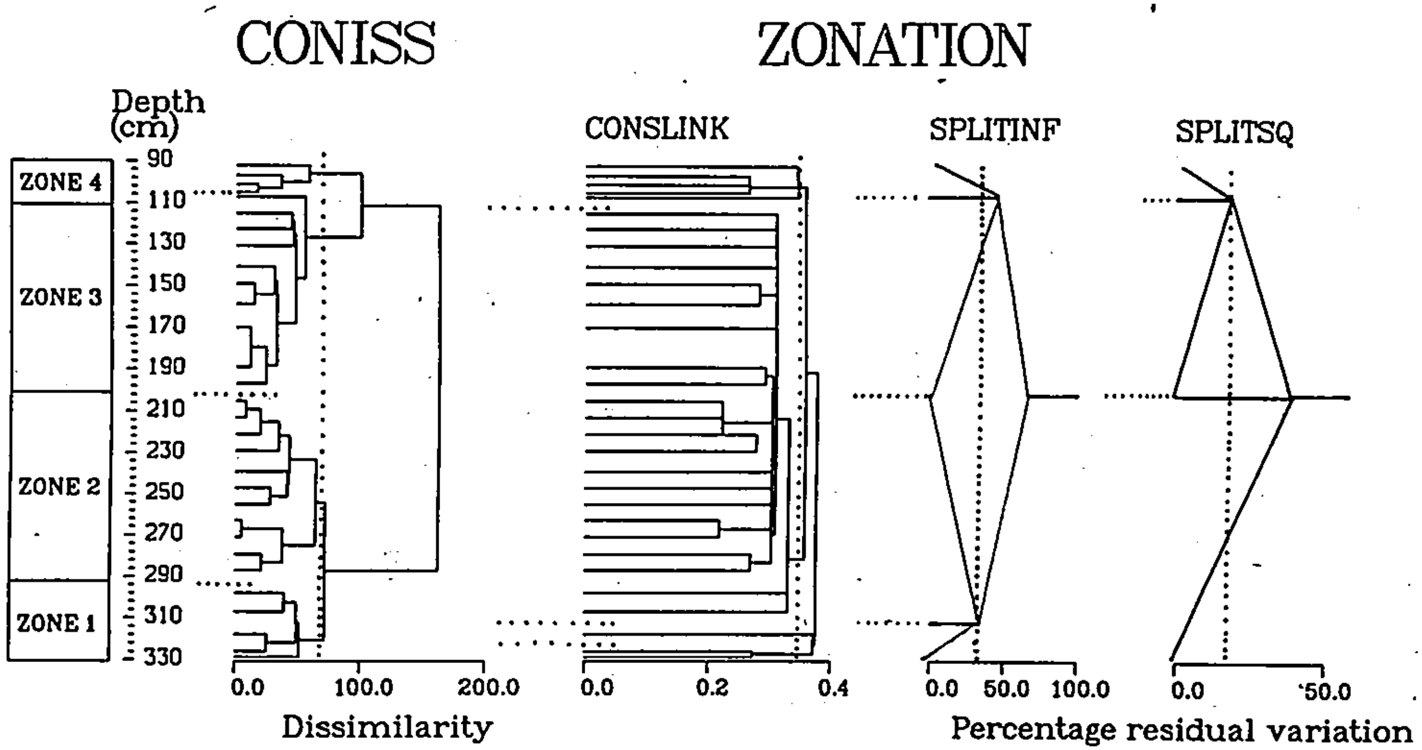


Figure 6.3 Dendrograms of zonation procedures of profile XW-4

(Three pages)

CONZONE: CONCLINK

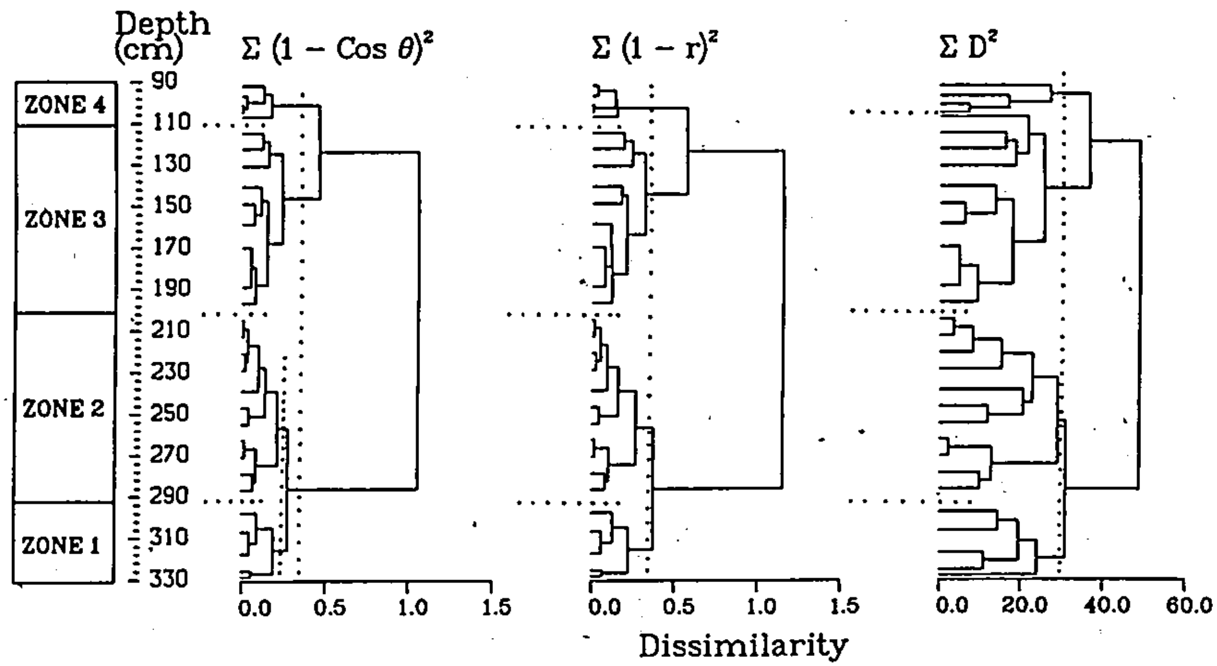


Figure 6.3 (Continued)

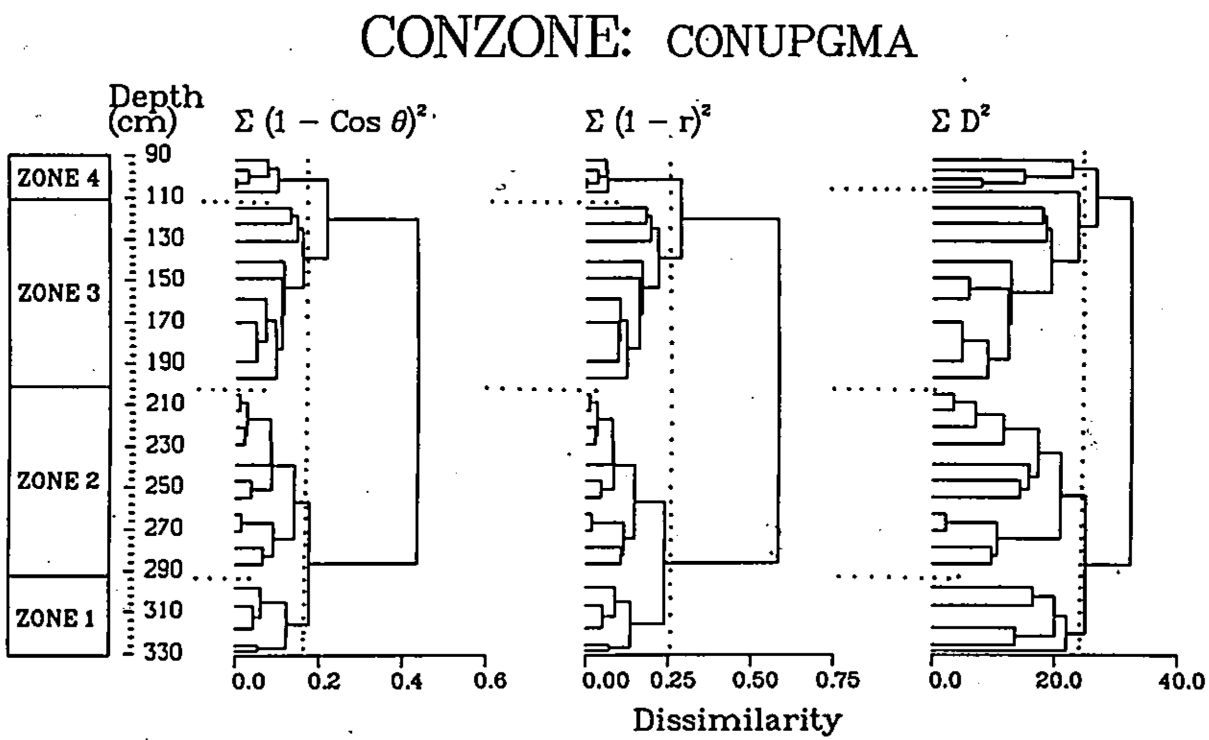


Figure 6.3 (Continued)

herbs are limited. _Picea_ pollen is less than 10%, ranging between absent and 8.0%. _Equisetum_, not included in the sum, has a percentage around 5.0%.

ZONE 2 (201.0 cm - 292.0 cm): Zone 2 is characterized by the rise of _Picea_ pollen percentage which is higher than 10%, and varies from 10.3% to 24.2%. Shrub pollen, however, is still the major constituent in the pollen spectra, with percentages varying from 49.0% to 84.0%. _Betula_ still has the highest values, varying from 40.0% to 71.6%. _Salix_, Rosaceae, _Juniperus_, and Ericaceae are all less than 5% where present. Herbaceous taxa values are lower than before, varying from 5% in one sample to 35% and usually higher than 20%. Gramineae percentages range from 5% to 23%, usually higher than 10%. Cyperaceae vary from absent in one sample to 14%, usually 5-10%. _Sparganium_ values are between absent and 3%. _Equisetum_ and _Sphagnum_ are less than or around 5% where present.

ZONE 3 (111.0 cm - 201.0 cm): The rise of _Picea_ and decline of shrub percentages are the basic features of zone 3. _Picea_ values range between 31% and 42%, with an increment of about 10-20% over zone 2 values. The shrub pollen, however, decreases to about 31-41%. _Betula_ is responsible for this decease with a range of 20% to 38.5%. _Alnus_, however, is better represented than before, varying between absent in a few samples and a maximum of 6%. Herbaceous taxa values are not greatly changed from zone 2 except for a peak of Cyperaceae in upper zone 3 with values steadily around 10-13% in contrast with the consistent low values of 3-9% in the lower part of the zone.

ZONE 4 (92.0 cm - 111.0 cm): Zone 4 is characterized by a large increase of _Picea_ pollen which varies from 49% to 84% and compensates for a decrease in shrub and herbaceous taxa abundances. All aquatic taxa disappear in this zone. _Alnus_ is 0-6%. _Betula_ is down to 3-21%. Ericaceae and _Polygonum_, however, are more abundant than before but with low values. Gramineae decrease to 1-11%. Cyperaceae are down to 0-7%. The sum of shrub pollens account for 4-30% of the total, and herb pollens are about 6-21%.

6.2.4 Numerical Analysis

Results of PCA (Fig. 6.4) show that on the first principal component axis, which accounts for about 27.1% of total data covariance, _Picea_, _Alnus_, and Ericaceae have relatively high positive loadings while _Betula_, _Sparganium_, _Juniperus_, and Gramineae have relatively high negative loadings. High values of zone 4 sample scores in contrast with those in other zones reflect the sharp increase of _Picea_ percentage of zone 4, and also the importance of _Betula_ in the other zones. The second axis accounts for 16.4% of total information. Gramineae, Cyperaceae, and _Equisetum_ have high positive loadings, and

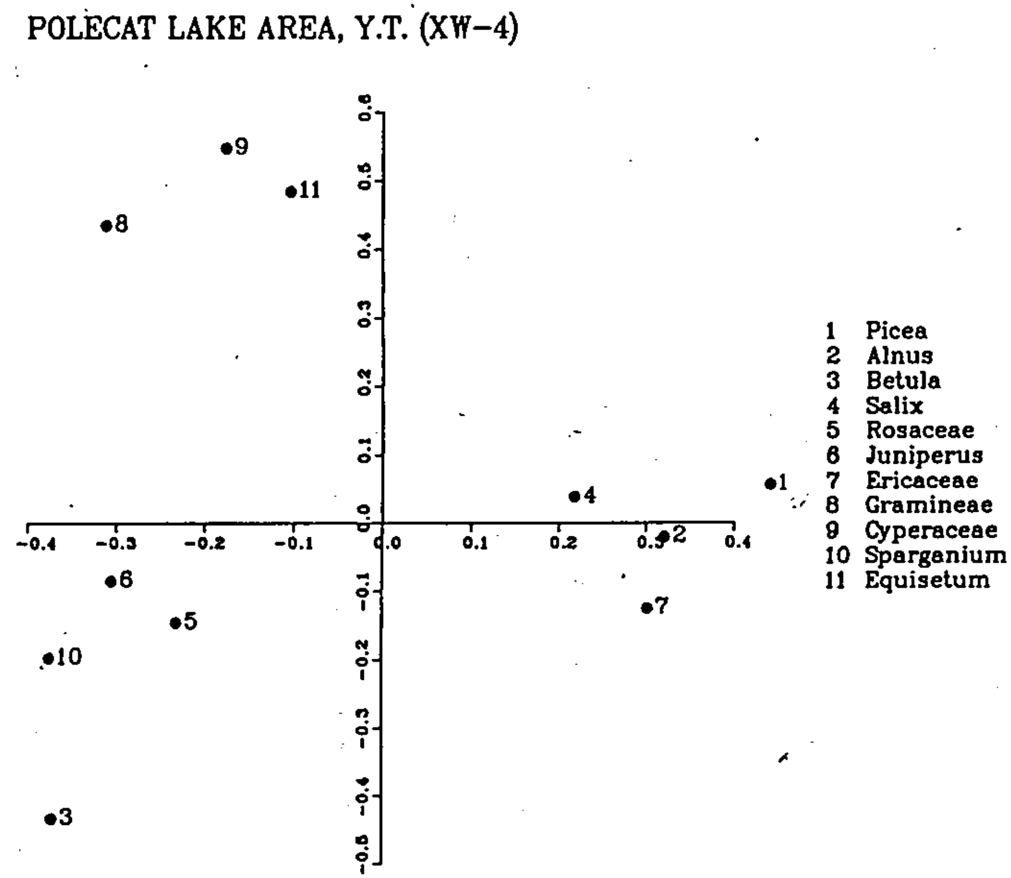


Figure 6.4a Principal component loadings of selected taxa on the first (horizontal) and second (vertical) PCA axes, profile XW-4, Polecat Lake area

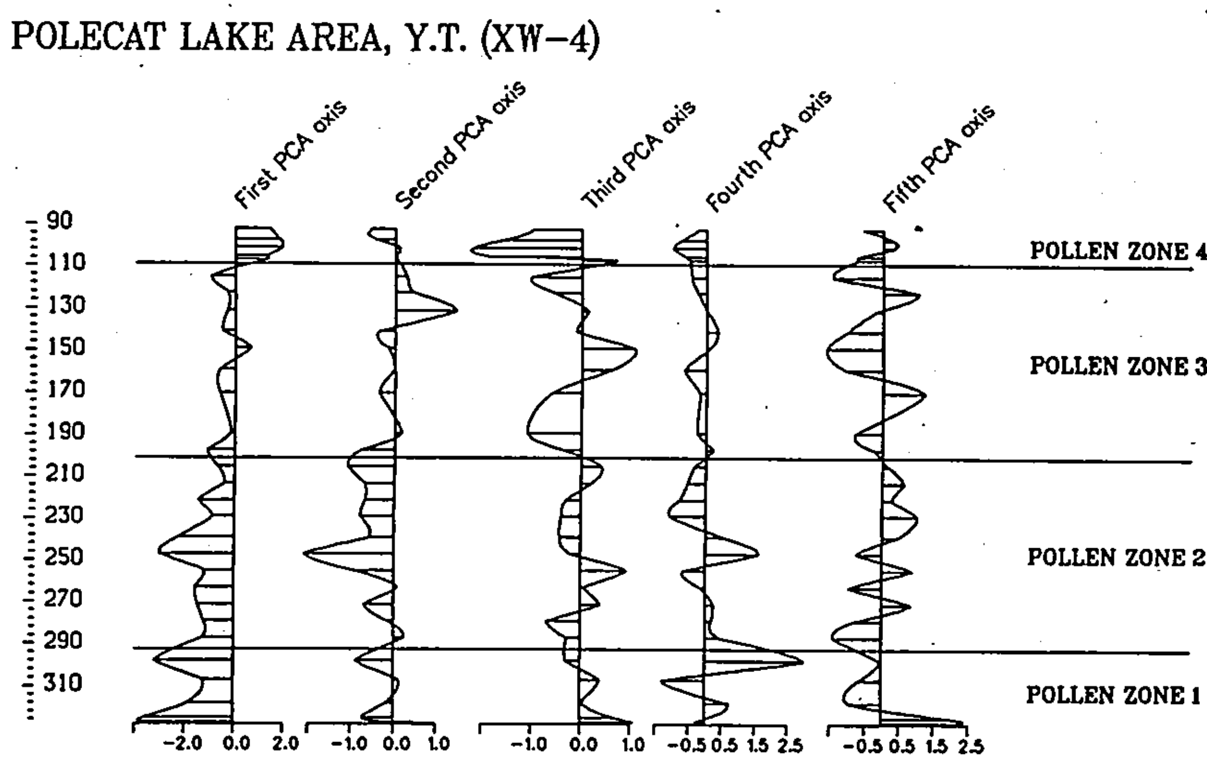


Figure 6.4b Principal component scores of profile XW-4 samples on the first five PCA axes, Polecat Lake area

Betula loading is highly negative. Negative sample scores in most of the profile indicate the importance of birch pollen in the pollen spectra which indicates that birch was one of the most important elements of paleovegetation. Positive scores of upper zone 3 samples probably reflect a slight increase of Gramineae pollen in those samples. The third axis, as in other pollen profiles, is difficult to interpret. This axis accounts for about 13.1% of total covariance. *Picea* has the highest negative loading on this axis, and *Alnus*, Ericaceae, and Cyperaceae have high positive loadings. Notable negative scores of zone 4 samples reflect the importance of *Picea* pollen in this zone, and the fluctuation of sample scores in the other zones is probably related to the complex relationships among these taxa. The fourth axis accounts for about 9.7% of total covariance, which represents *Salix* and Rosaceae since only these two taxa have significant positive loadings on this axis while no taxa have considerable negative values. The sample scores on this axis mirror the percentage variation of *Salix* and Rosaceae. The fifth axis represents the complex relationships among *Sparganium*, *Equisetum*, Rosaceae, and Ericaceae. This axis accounts for about 8.8% of total data covariance. The first five PCA axes in total account for more than 75% of total data covariance, and the discarding of other axes will not lose much information.

Although 23 taxa were identified in this profile, only 4 of them are important, in terms of their percentage values, as suggested by the result of PCB. As illustrated in figure 6.5, <u>Picea</u> and <u>Betula</u> vectors have highest values on the first and second PCB axes plane which accounts for about 92.2% of total data variation. Gramineae and Cyperaceae have a similar value, and are positively correlated as indicated by the orientation of these two vectors. The relations between <u>Picea</u>, <u>Betula</u>, and the herbs (Cyperaceae and Gramineae), however, are complementary or in negative correlation. Considering the sample ordination, zone 1 samples are clustered together and placed at the positive end of the first PCB axis, which has no direct connection with other groups. Zone 2 cluster, however, overlaps with the cluster of samples from the modern shrub-tundra vegetation-landform unit, and is distributed along the direction of <u>Betula</u> vector. This result is obviously caused by the good representation of birch pollen in the zone 2 samples. Samples of zone 3 are well correlated with those of the modern forest-tundra vegetation-landform unit as suggested by the overlap of these two groups, and are located at the centre of this plane which probably reflects an even representation of the four major pollen types. Zone 4 sample cluster perfectly overlaps that of the modern forest vegetation-landform unit, and distributed along the direction of the <u>Picea</u> vector. This feature indicates that <u>Picea</u> was the most important taxon in the past vegetation during zone 4 time which is comparable with the modern spruce forest in the area.

As illustrated in figure 6.6, the first and second CA axes plane, which accounts for about 60.7% of the total data variation, indicates results broadly similar to those of PCB. It is notable that the overlap between clusters of zone 2 samples and modern shrub-tundra samples is not as good as that in PCB. The samples of zone 3, are closer to those of the shrub-tundra with two samples overlapped. However, the discrepancy between the results of PCB and CA is minor, and is not large enough to contradict either interpretation.

6.2.5 Reconstruction of Paleoenvironment

Pollen profile XW-4 represents palynological records of paleovegetation and paleoenvironmental variation history in the central Aishihik Basin area, and may be divided into four stages as represented by four local pollen zones.

Pollen zone 1 represents a time interval during which the area was covered by a *Betula*-dominated shrub-tundra. This stage lasted from 9,600 to about 9,000 yr BP. *Betula* is the most abundant arboreal taxon, reaching about 60% in the pollen spectra. Although this taxon is a prolific pollen producer, such a high value evidently indicates that birch was widespread in the area at this time. *Picea* was obviously absent during

POLECAT LAKE AREA, Y.T. (XW-4)

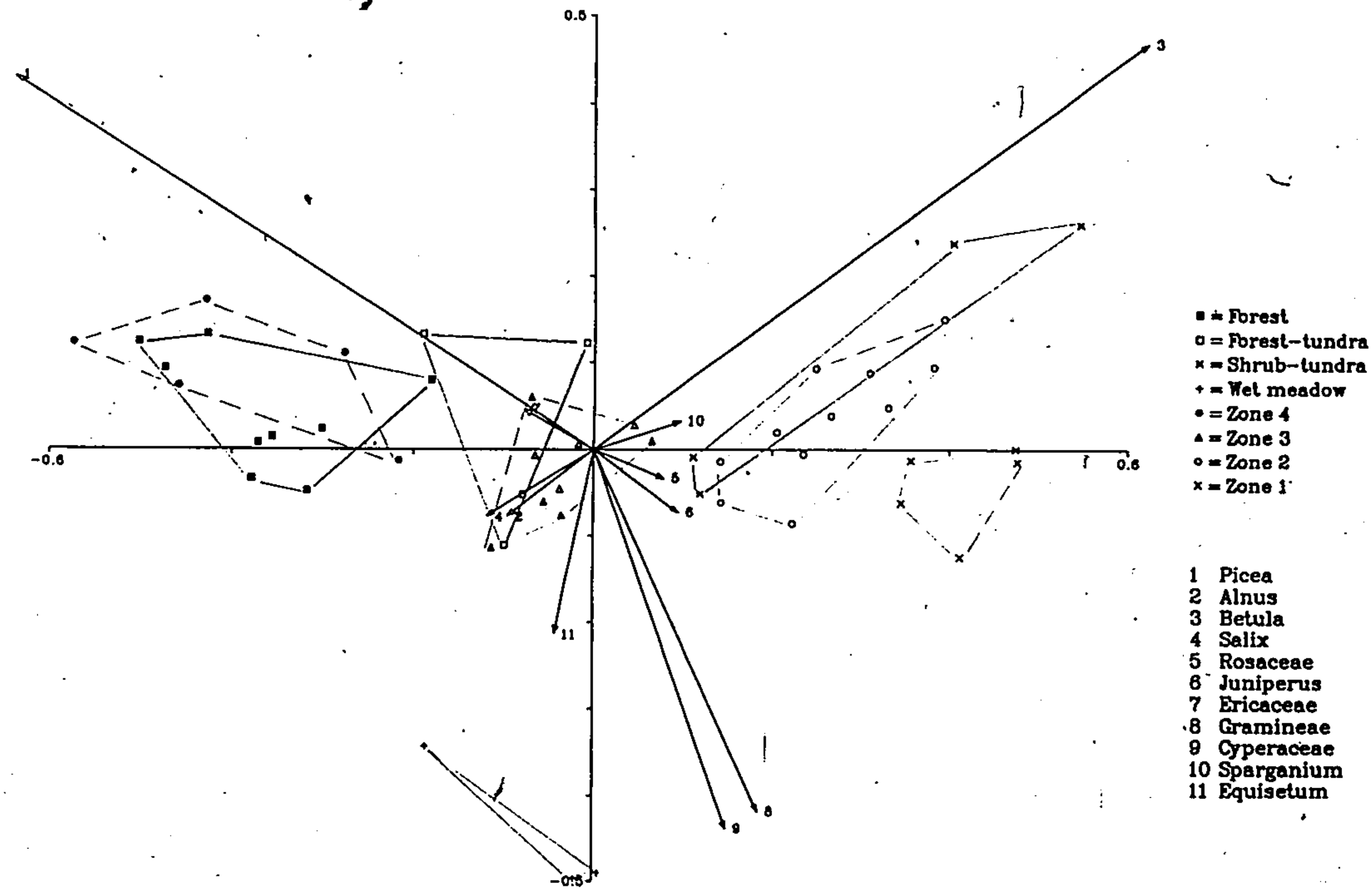


Figure 6.5 Ordination of combined data matrix of modern and fossil pollen samples on the first (horizontal) and second (vertical) PCB axes, profile XW-4, Polecat Lake area.

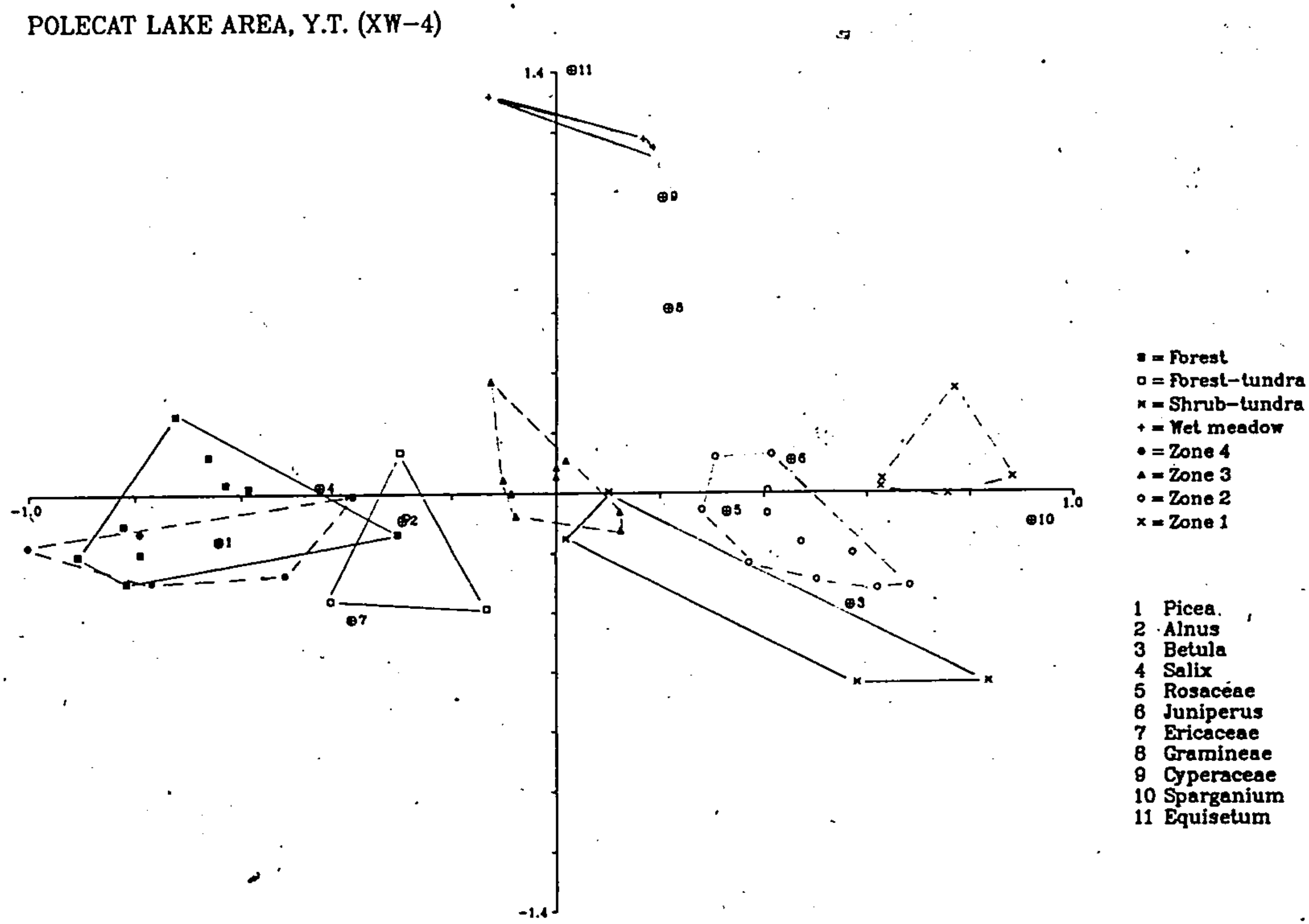


Figure 6.6 Ordination of combined data matrix of modern and fossil pollen samples on the first (horizontal) and second (vertical) CA axes, profile XW-4, Polecat Lake area

this interval, as indicated by very low *Picea* pollen percentages. Gramineae was another important taxon in the paleovegetation as suggested by relatively high values. Cyperaceae were also important, especially at the beginning of this time interval as suggested by their high values in the two bottom samples.

Zone 2 represents a time interval from 9,000 to about 7,500 yr BP. During this time interval the area was probably covered by a sparse forest-tundra vegetation. *Picea* invaded the area at about 9,000 yr BP, as suggested by percentages consistently higher than 15%. Previous studies in the northern Yukon indicate that a *Picea* pollen percentage of 10% in lacustrine sediments may be considered as a threshold to indicate the presence of spruce in the area (Ritchie, 1984a). Palynological investigations in northern Aishihik Basin indicate that spruce arrived in that area at about 8,700-9,000 yr BP, which is in agreement with the interpretation of pollen zone 2. *Betula* was still a dominant element in the paleovegetation, as suggested by its high percentages. Other taxa show little changes from zone 1, implying that basic features of the vegetation in this interval were similar to those preceding, with the exception of an invasion of spruce in the area. In pollen profile XW-1 and XW-3, forest-tundra spectra are characterized by high values of *Picea*, *Betula* and other shrubs, notably Cyperaceae. However, pollen profile HB1 and XW-4 have no extensive representation of Cyperaceae pollen. This indicates the influence of local environment on the pollen records. High values of peat-forming taxa such as Cyperaceae in the pollen spectra from peat bogs is expected, and pollen records from lacustrine sediments such as profile XW-4 and HB1 show small representation of Cyperaceae due to differences in local depositional environments.

Pollen zone 3 represents a time interval from approximately 7,500 to about 5,900 yr BP during which the area was covered by open spruce forest or spruce woodland. High _Picea_ pollen percentages around 40% indicate the dense cover of spruce in the area, although they are lower than those of the forest spectra from the Upper Nisling Valley profile (XW-1) and modern surficial forest vegetation-landform unit samples. The Polecat Lake area in central Aishihik Basin is an open and flat area of generally low altitude. The core site was a pond during deposition of pollen zones 1 to 3, as suggested by widespread mollusc shells in sediments and by aquatic taxa, _e.g._ _Sparganium_ and _Myriophyllum_ in the pollen spectra. The large airsac of _Picea_ pollen enables it to float on the water surface during the pollination season, and winds tend to blow the floating pollen to the edges of ponds or lakes (Birks and Birks, 1980). Therefore, pollen records from the central lake sediments may have lower coniferous pollen percentages than those from other parts. Decrease of _Betula_ pollen in the pollen spectra may indicate competition from spruce. However, the results of numerical analysis are not consistent with such a forest interpretation. Broad similarity of sample ordinations between zone 3 and modern forest-tundra samples suggest a forest-tundra environment during the zone 3 time interval, while the results of CA indicate a broad similarity between zone 3 and modern shrub-tundra samples. Explanation of this discrepancy between the numerical results and classical interpretation requires an understanding of the nature of the data set. In this monograph, modern moss polster samples are employed in the comparison between modern and fossil pollen spectra. In modern forest pollen spectra, _Picea_ values are usually higher than 50%, while only about 40% spruce pollen was recorded in the zone 3 samples. This discrepancy is mainly caused by differences in the nature of the samples. Although pollen spectra from different types of sediments may not be compared directly, numerical analysis still can provide some interpretable information if differences of pollen spectra from different sediments are fully understood.

A change of the sedimentary environment at the core site from pond to marsh occurred at about 5,900 yr BP, which marks the beginning of the zone 4 time interval. The regional vegetation in the area after this local environment change likely was still a spruce forest, as suggested by high _Picea_ percentage in the pollen spectra. However, the tremendous increase of Picea values in this zone is mainly due to the change of sedimentary environment rather than the change of paleovegetation. A low income of local pollen grains can cause an exaggeration of regional elements, which was probably the case during the zone 4 time interval. Due to lack of information, the environmental history since zone 4 time remains unknown at this site.

6.2.6 Summary and Conclusion

A typical birch zone pollen spectra in the Polecat Lake area indicates widespread birch-dominated shrub-tundra in the area, which was replaced by a spruce forest-tundra at about 9,000 yr BP. Spruce invaded the area at approximately 9,000 yr BP, in agreement with the pollen records in northern Aishihik Basin. Spruce forest has occupied the area since 7,500 yr BP, and a sedimentary phase change from a pond to marsh took place at about 5,900 yr BP. Comparison of pollen records from this profile with other studies in northern Aishihik Basin indicates that the local environment may have had strong influence on the pollen records under similar regional vegetation and other environmental background. Therefore, the interpretation of fossil pollen records must be accompanied by a full understanding of the structure of pollen data and the relation of regional and local pollen taxa.

6.3 Aishihik Kettle (XW-5)

6.3.1 Site Description

Peat and silt deposits were cored from a elongated dead-ice kettle near the northwest end of Aishihik Lake. The core site is located at 61°36'23" N Lat., 137°32'48" W Long., with an altitude of 954 m a.s.l. (Fig. 6.1). This area is characterized by its remarkable dead-ice features such as dead-ice kettles, eskers or kame deposits, etc. The core site is at the north edge of a dense spruce forest around the Aishihik village. At the core site, Cyperaceae and Gramineae are dominant taxa in the present plant community, about 40% and 30%, respectively. Betula glandulosa and Salix glauca-dominated communities surround the site as rings in accordance with the drainage conditions. Picea glauca stands occur about 30 m away from the core site. Potentilla fruticosa, Artemisia sp., Epilobium angustifolia, Shepherdia canadensis, and Ledum groenlandicum, are common taxa in the area. At the foot of the southwest-facing slope of the kettle, Populus balsamifera groves are present.

6.3.2 Stratigraphy and Chronology

The profile is 143 cm in depth. Organic peat from the surface down to 14 cm is underlain by a 9 cm thick deposit of

White River ash. A 59.5 cm thick organic peat deposit with various silt content beneath the ash layer is underlain by a 63 cm thick silt deposit. The contact between organic peat and silt is fairly abrupt, and separated by a 7.5 cm thick ice layer from 82.5 cm to 90.0 cm. The permafrost table occurred at a depth of 40 cm on August 6, 1984.

The White River ash layer provides a reference date for the estimation of a time sequence for this profile. One ^{14}C date was determined for the interval between 75.0 and 77.5 cm, which is 5,200 +/- 70 BP (GSC-4089).

6.3.3 Relative Pollen Frequency

The result of pollen analysis of this profile is represented as a relative pollen frequency diagram (Fig. 6.7). Selected taxa, *e.g.* *Picea*, *Alnus*, *Betula*, *Salix*, Rosaceae, *Juniperus*, *Artemisia*, Gramineae, Cyperaceae, *Sparganium*, *Lycopodium*, *Dryopteris*, and *Equisetum*, were employed to carry out the numerical zonation procedures. All the procedures used in this monograph, *i.e.*, CONZONE, ZONATION, CONISS, exclusively indicate a zone boundary at about 80-90 cm (Fig. 6.8). This result implies a dramatic change of the inner structure of the relative pollen frequency data matrix.

ZONE 1 (143 - 90 cm): This zone is characterized by high percentages of herbaceous pollen. Gramineae values are 20.5-

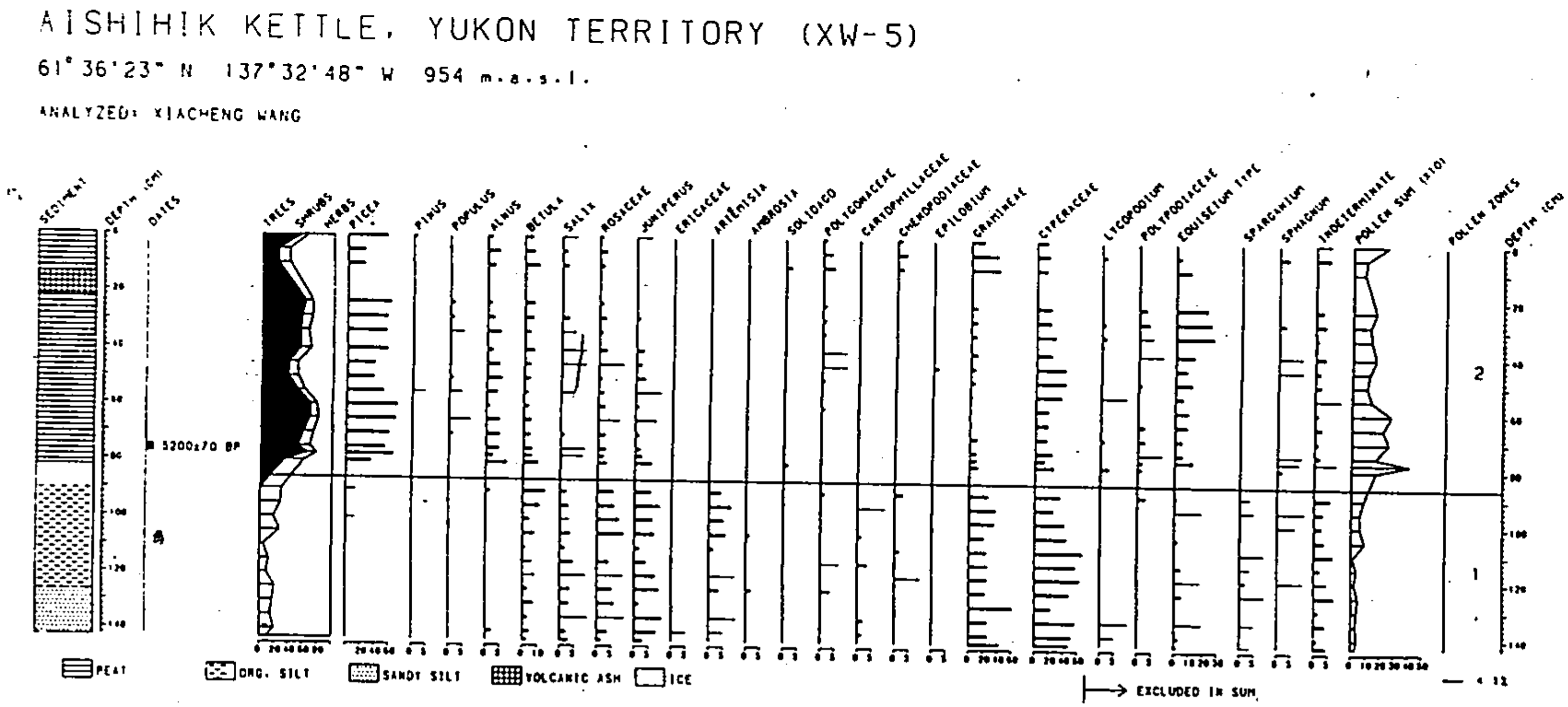


Figure 6.7 Pollen percentage diagram of profile Aishihik Kettle (XW-5)

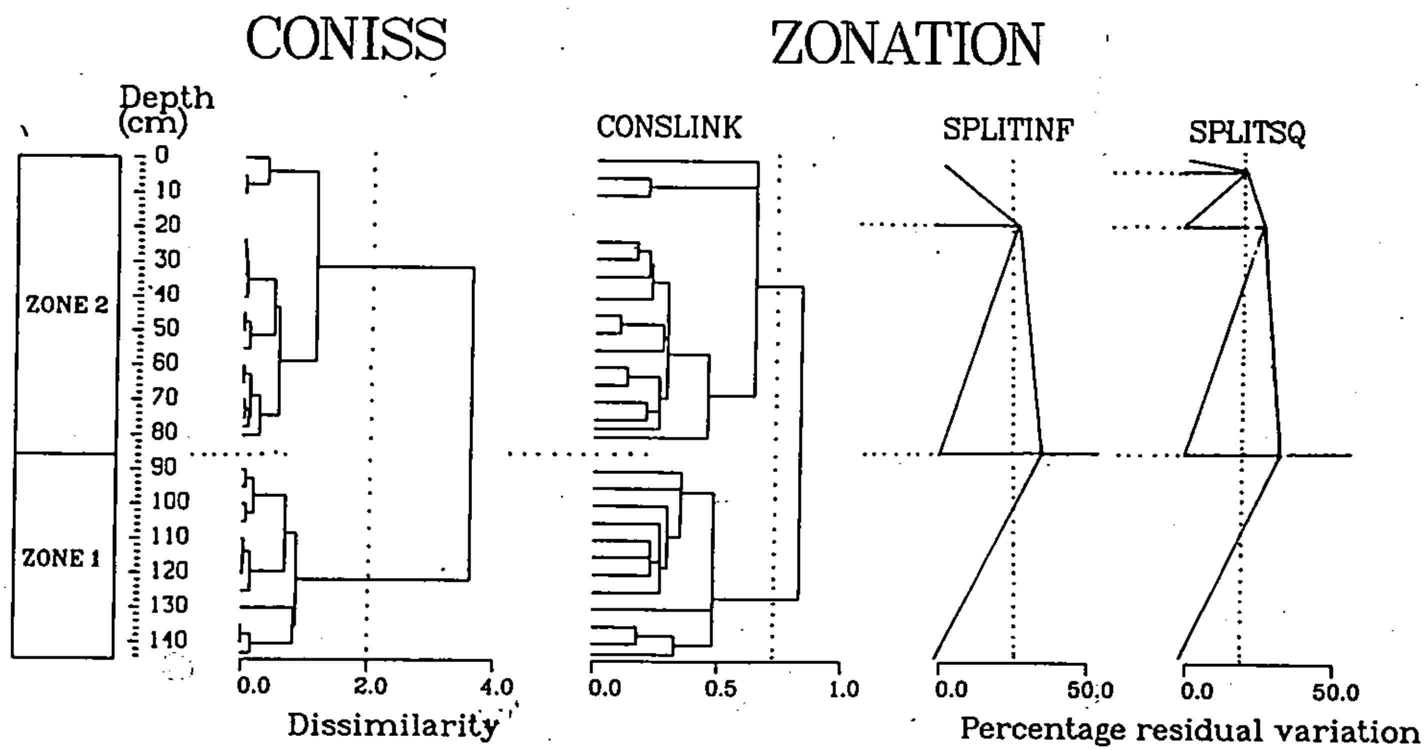


Figure 6.8 Dendrograms of zonation procedures of profile XW-5
(Three pages)

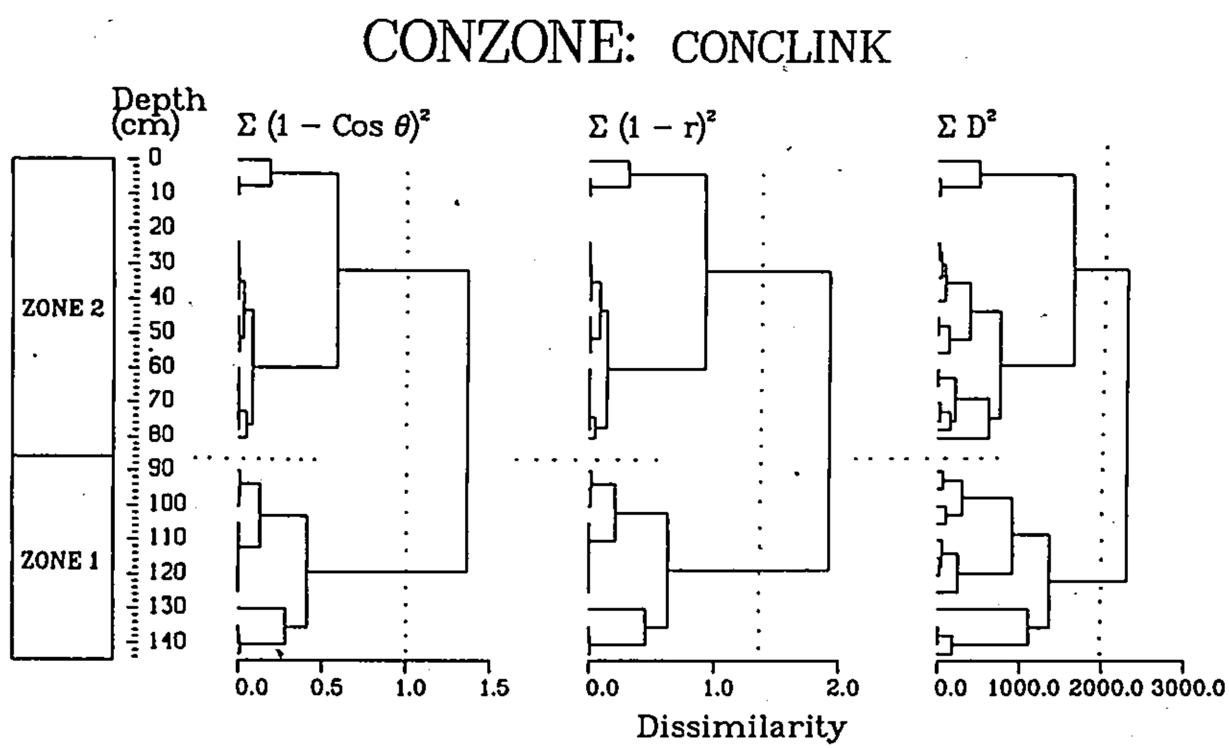


Figure 6.8 (Continued)

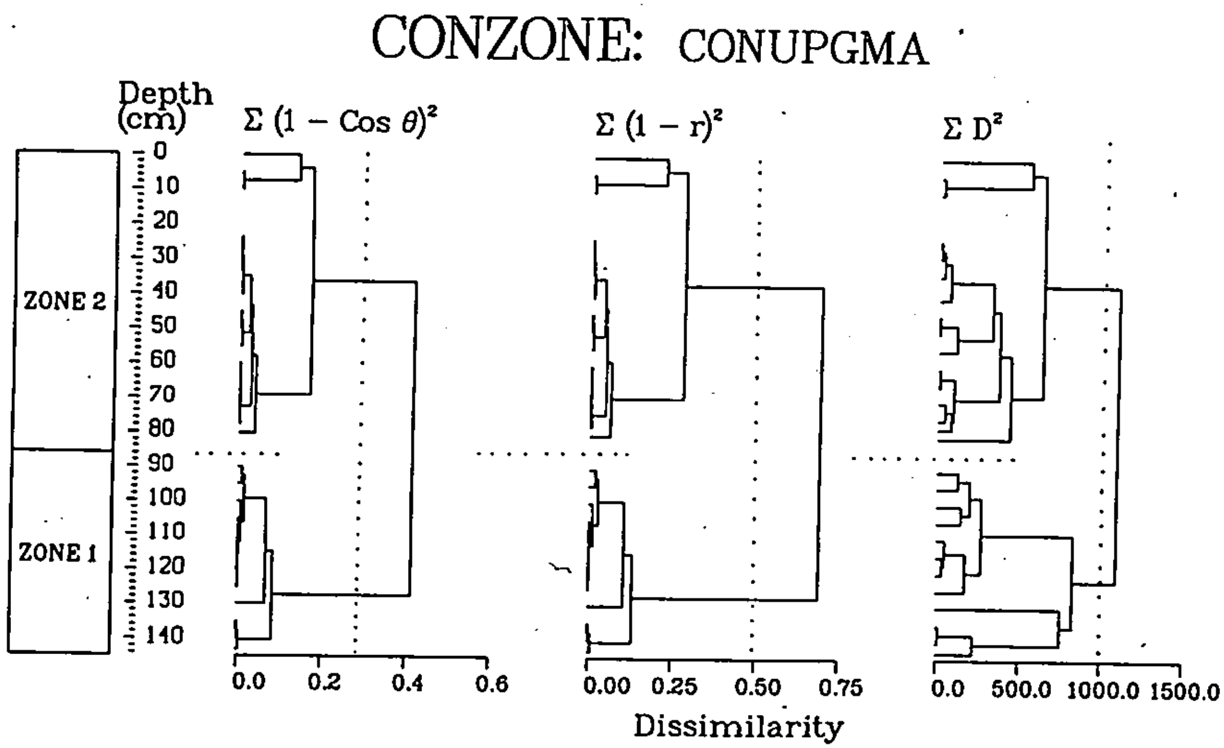


Figure 6.8 (Continued)

60.3%, mostly around 25-35%. Cyperaceae values vary from 22% to 67%, mostly around 40-55%. *Artemisia* values are relatively high, varying from absent in a few samples to 7.7%. Shrub pollen is moderately represented. *Betula* values are between 0.3% and 15%, usually around 3-4%. *Salix* pollen percentages are 0.3% to 4.7%. Rosaceae are absent from one sample and vary from 0.9-9% in others. *Juniperus* values are 1.6% to 9.6%. *Picea* pollen, basically absent from the pollen spectra, only occurred twice around 1%. *Equisetum* spores vary from absent to 5%. Other taxa are much less important and occurred only occasionally.

ZONE 2 (surface to 80 cm): High *Picea* pollen percentages from 34.8% to 70.6% are the most remarkable feature of this zone. *Alnus* pollen starts to register in the top sample of zone 1, and varies from absent in two samples to 7.3%. *Betula* is the most well represented shrub with values between 2.7% and 10%, usually around 5%. *Salix*, Rosaceae, and *Juniperus* are less well represented than before. Values of herbaceous pollen drop in this zone. *Artemisia* pollen disappears completely, and Gramineae percentages decrease to around 7%, varying from 2% to 39%. Cyperaceae percentages are between 13% to 41%. However, *Equisetum* spores have higher values than before, varying from absent in two samples to 26%, with a peak occurring between samples 4 and 7. Other taxa are only occasionally represented.

6.3.4 Numerical Analysis

The results of PCA are shown in figure 6.9. The first five PCA axes account for 73.9% of the total information. On the first PCA axis, which accounts for 33.2% of the total information, Picea and Alnus have significant loading which is more than 0.2, while low shrubs and herbs (Juniperus, Cyperaceae, Gramineae, Rosaceae, Artemisia, and Sparganium) have high negative loadings (less than -0.3). On the second PCA axis, which accounts for about 14.3% of total covariance, Betula and Salix have high positive loadings (great than 0.3), while pteridophytes have high negative loadings (less than-0.4). The other axes, however, do not provide much interpretable information. Samples which have high negative principal component scores on the first PCA axis have high scores on the second PCA axis. These samples are all from zone 1, which indicates that local vegetation was dominated by shrubs and herbs during the zone 1 time interval. All samples from zone 2 have positive scores on the first axis but negative scores on the second axis. This pattern indicates the significant presence of Picea, Alnus, and pteridophytes in the local vegetation during the zone 2 time interval.

The first PCB axis accounts for 61.6% of total information and the second axis accounts for 25.1%. The results indicate that Picea, Betula, Cyperaceae, and Gramineae are the most important taxa in the data set (Fig. 6.10). Gramineae show

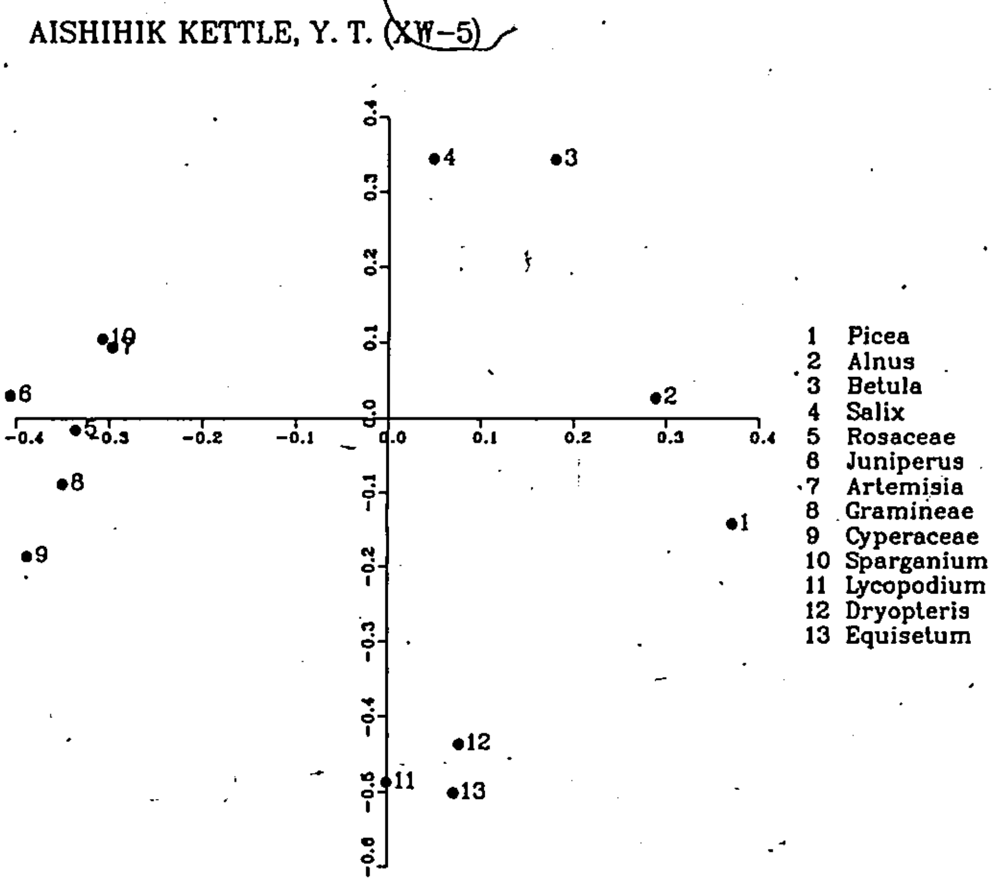


Figure 6.9a Principal component loadings of selected taxa on the first (horizontal) and second (vertical) PCA axes, profile Aishihik Kettle (XW-5)

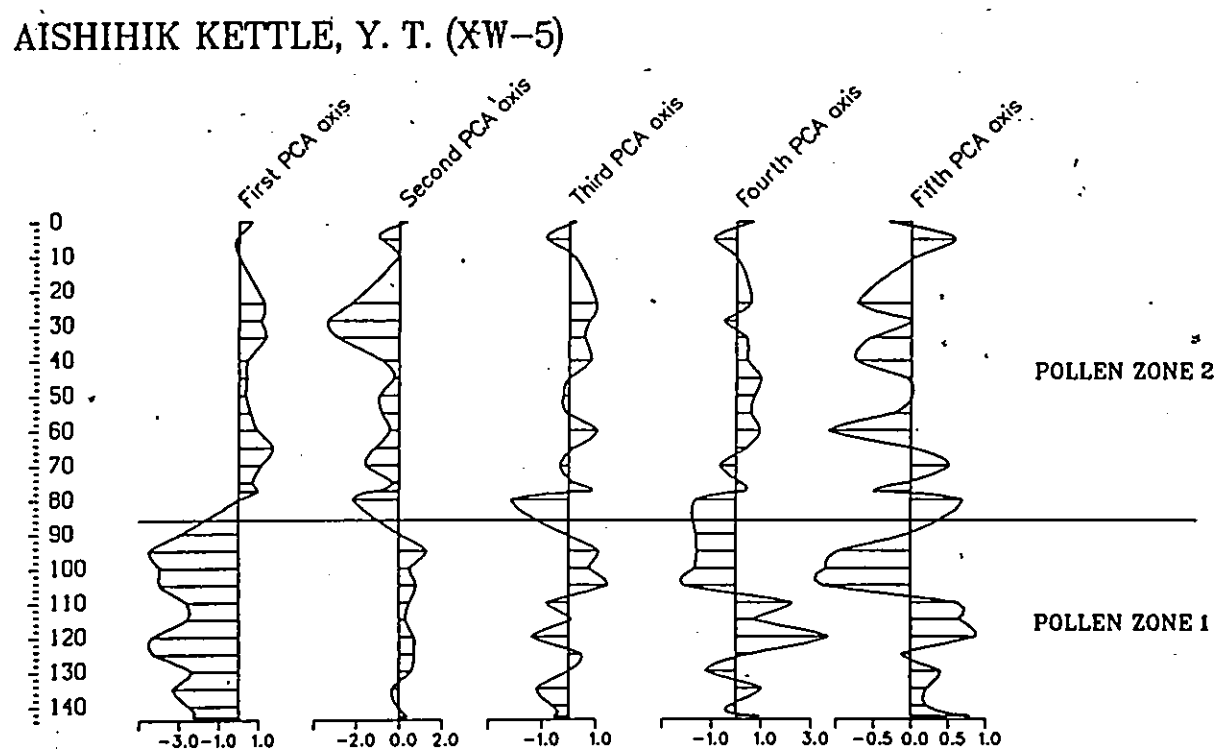


Figure 6.9b Principal component scores of profile Aishihik Kettle (XW-5) samples on the first five PCA axes

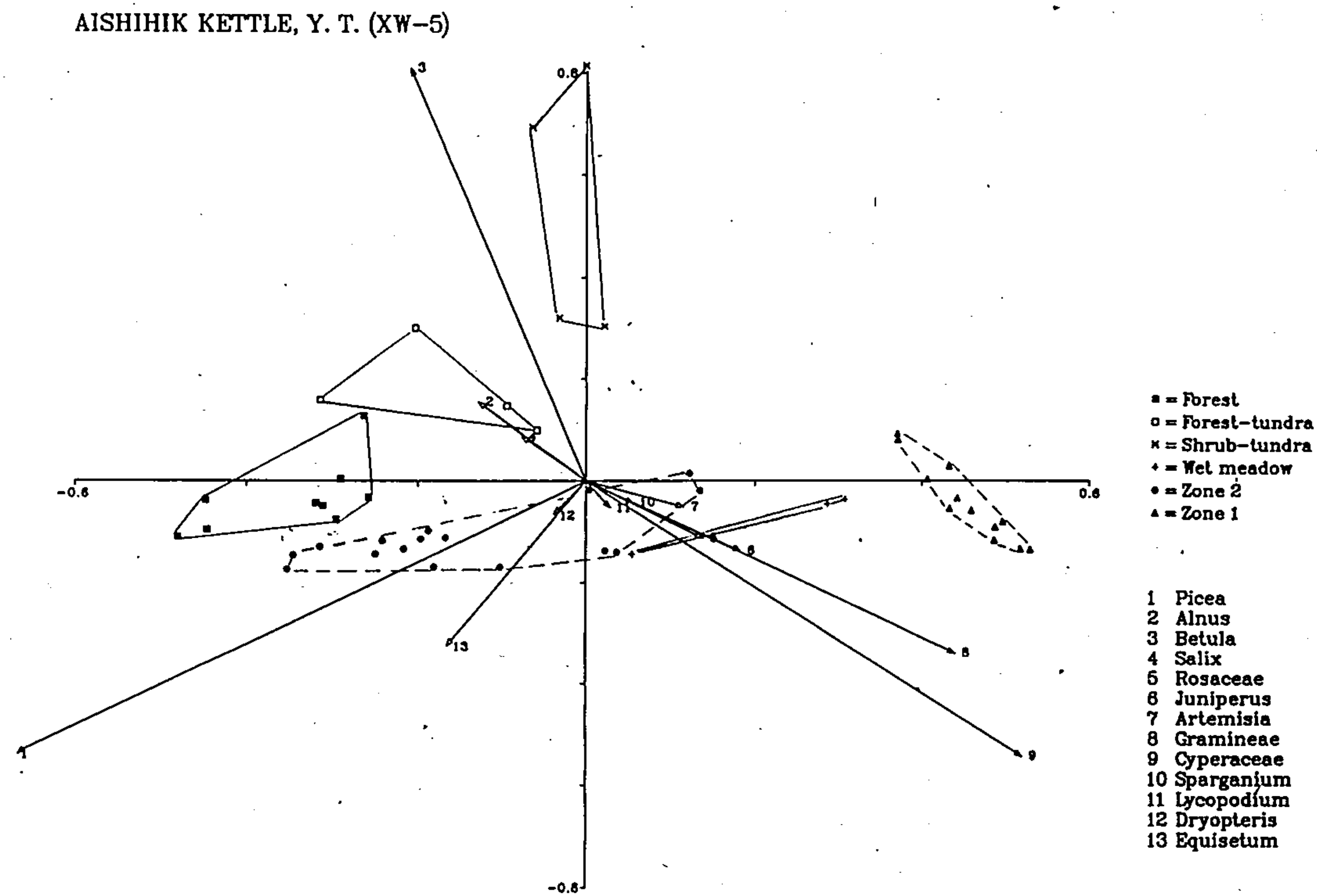


Figure 6.10 Ordination of combined data matrix of modern and fossil pollen samples on the first (horizontal) and second (vertical) PCB axes, profile Aishihik Kettle (XW-5)

positive correlation with Cyperaceae as suggested by the orientation of these two vectors, while Betula and Picea show negative correlation with respect to each other and also to Gramineae - Cyperaceae. Equisetum is the fifth taxon which has significant representation in the data set, and is positively correlated with Picea. As the result of this pattern, all samples from zone 1 cluster at the positive end of the first axis, which is related to Cyperaceae, Gramineae, and low shrubs. Samples from zone 2 are separated from the zone 1 cluster, and most samples are very close to the samples from the modern forest vegetation-landform unit (Fig. 6.10). However, the zone 1 cluster has no modern analogue in terms of its scores on the first and second PCB axes plane.

Similar results can be obtained from the first and second CA axes (Fig. 6.11), which account for 69.0% of total variation of the data set. It is more clearly indicated on this plane that the cluster of zone 1 samples is closely related to Artemisia and Juniperus which are important taxa in the zone 1 pollen spectra. By a 45° rotation of the axes, the first axis may represent the density of the vegetation, and the second axis may represent the moisture condition of the local area as suggested by the modern surficial samples (Fig. 6.12). This rotation is useful for facilitating reconstruction of environmental history.

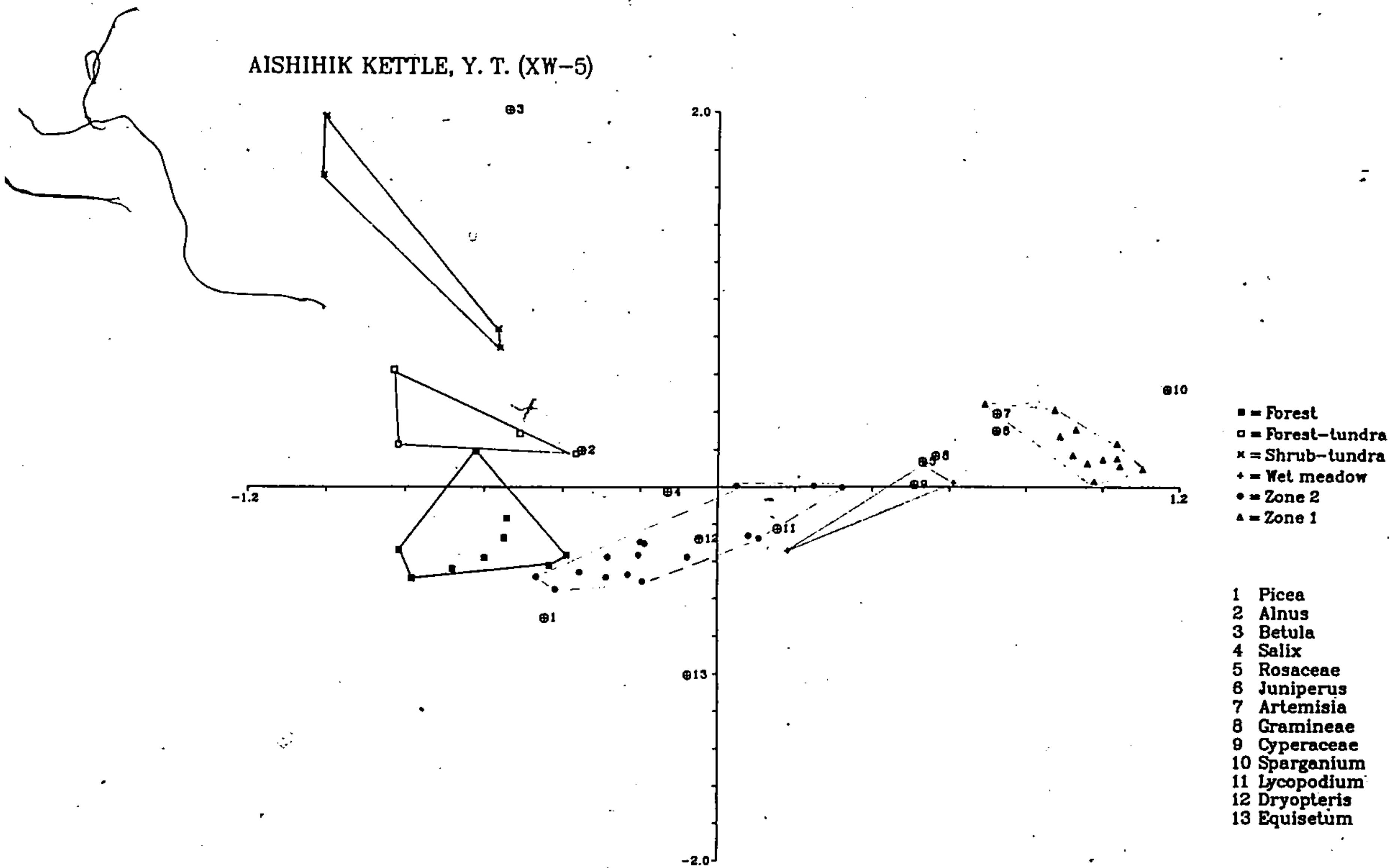


Figure 6.11 Ordination of combined data matrix of modern and fossil pollen samples on the first (horizontal) and second (vertical) CA axes, profile Aishihik Kettle (XW-5)

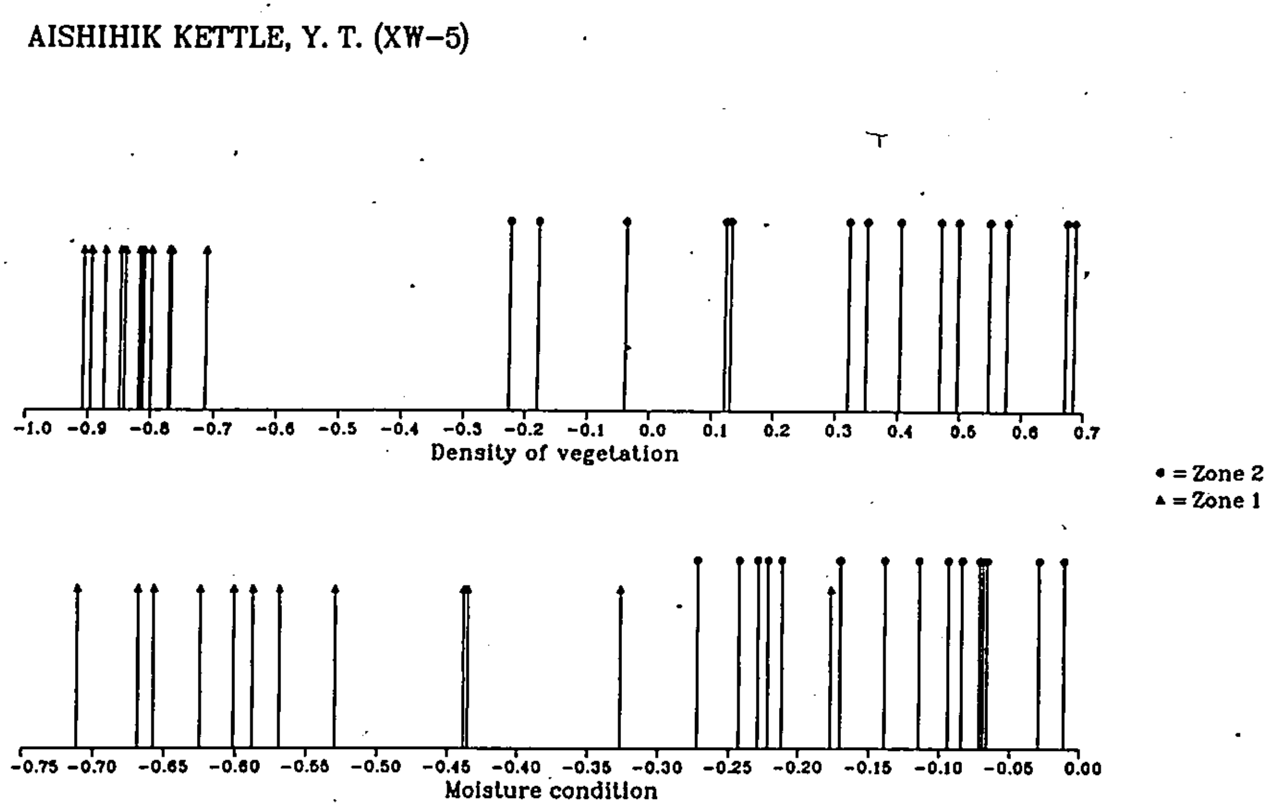


Figure 6.12 Projection of sample ordination on the first and second CA axes with a 45^0 rotation, profile Aishihik Kettle (XW-5)

6.3.5 Reconstruction of Paleoenvironment

The lower part of the pollen diagram (Fig. 6.7), namely site pollen zone 1, represents a time interval during which the kettle was probably filled by water as a shallow pond as suggested by the frequent occurrence of Sparganium spores. Unfortunately there is no absolute chronological control on this event due to a lack of datable material.

The occurrence of a 7.5 cm thick ice layer between the 82.5 and 90.0 cm levels and the change of sediment lithology beneath and above the ice layer made it impossible to extrapolate the approximate age of zone 1 sediment. Both PCB and CA suggest that there is no modern analogue of the vegetation which the zone 1 pollen spectra represent. The general pattern of the pollen spectra in this zone is similar to Livingstone's herbaceous zone (Livingstone, 1955), which was dominated by high Cyperaceae percentages with frequent occurrences and reasonable values of Salix, Betula, Gramineae, and Artemisia. Moderate occurrences of Caryophyllaceae and Chenopodiaceae are also in agreement with basic features of the herbaceous zone (Livingstone, 1955). However, high values and the consistent occurrence of Rosaceae and Juniperus in zone 1 of this study lead the author to consider the role of shrub taxa in the actual vegetation during this interval. At present, there are three species of Rosaceae in the area according to field observation. _Potentilla fruticosa_ is the most common one observed in the area today, and _Potentilla diversifolia_ is less common. _Rosa woodsii_ was only observed on the poorly vegetated slopes of moraine ridges or kame deposits. _Juniperus_ requires an open habitat to survive. _Salix_ is often under-represented in the pollen spectra and 5% value can be considered as a significant representation, especially when local types such as Cyperaceae are abundantly present in the spectra. Shrub pollen account for about 20-30% in the total spectra, suggesting a _Salix_-dominated sparse shrub-tundra existed in the area after the last deglaciation.

ZONE 2 represents a time interval during which spruce forest covered the area and the kettle was water free. Sudden rise of spruce pollen to a value of about 40% without any transition implies an apparent gap of sedimentation in the kettle between two zones, which coincides with the occurrence of a thick ice layer and abrupt change of sediment lithology. This unconformity of sedimentation might be caused by catastrophic opening of the kettle at its northwest end leaving the core site exposed for a duration, and creating a sudden sedimentary facies change. As a result of this hiatus between zones, there is no evidence to predict the arrival time of spruce in the area and the beginning of spruce forest in the area. The ^{14}C data in this profile (GSC-4089), however, provide a basis for estimation of the restarting time for sedimentation in the kettle and information for regional comparison of pollen events.

Significant decrease of shrub and herbaceous pollen percentages compensates for the rise of spruce in zone 2, supporting the interpretation of a spruce forest vegetation in the area. Modern surficial samples from the study area (see Chapter 4) and Coppermine valley (Geurts, 1983) all suggest that samples from spruce forest usually have more than 40% spruce pollen (Geurts, 1983) or even 50% (this study, Chapter 4). It is evident that the forest in the area was stable at least during the interval of 5,200 yr BP to 1,230 yr BP, the former marked by a ^{14}C date (GSC-4089) and the latter by the occurrence of the White River ash. After the ash fall spruce pollen decreased to a minimum of about 20%, and back to about 60% in the top sample. Selected pollen ratios also show this pattern (Fig. 6.13). In compensation with this change, a significant reversal occurs among Gramineae, Chenopodiaceae, and Polygonaceae. These changes could represent a climatic oscillation or fluctuation during the last 1,230 years or disturbance caused by ashfall. The density of the forest, however, was not necessarily very different from before. This conclusion is based on consideration of the landscape at the core site. Increasing precipitation or changing the permafrost table could create wetter conditions on the slope of the kettle where the profile was cored, enough to support these wet to

AISHIHIK KETTLE, YUKON TERRITORY (XW–5)

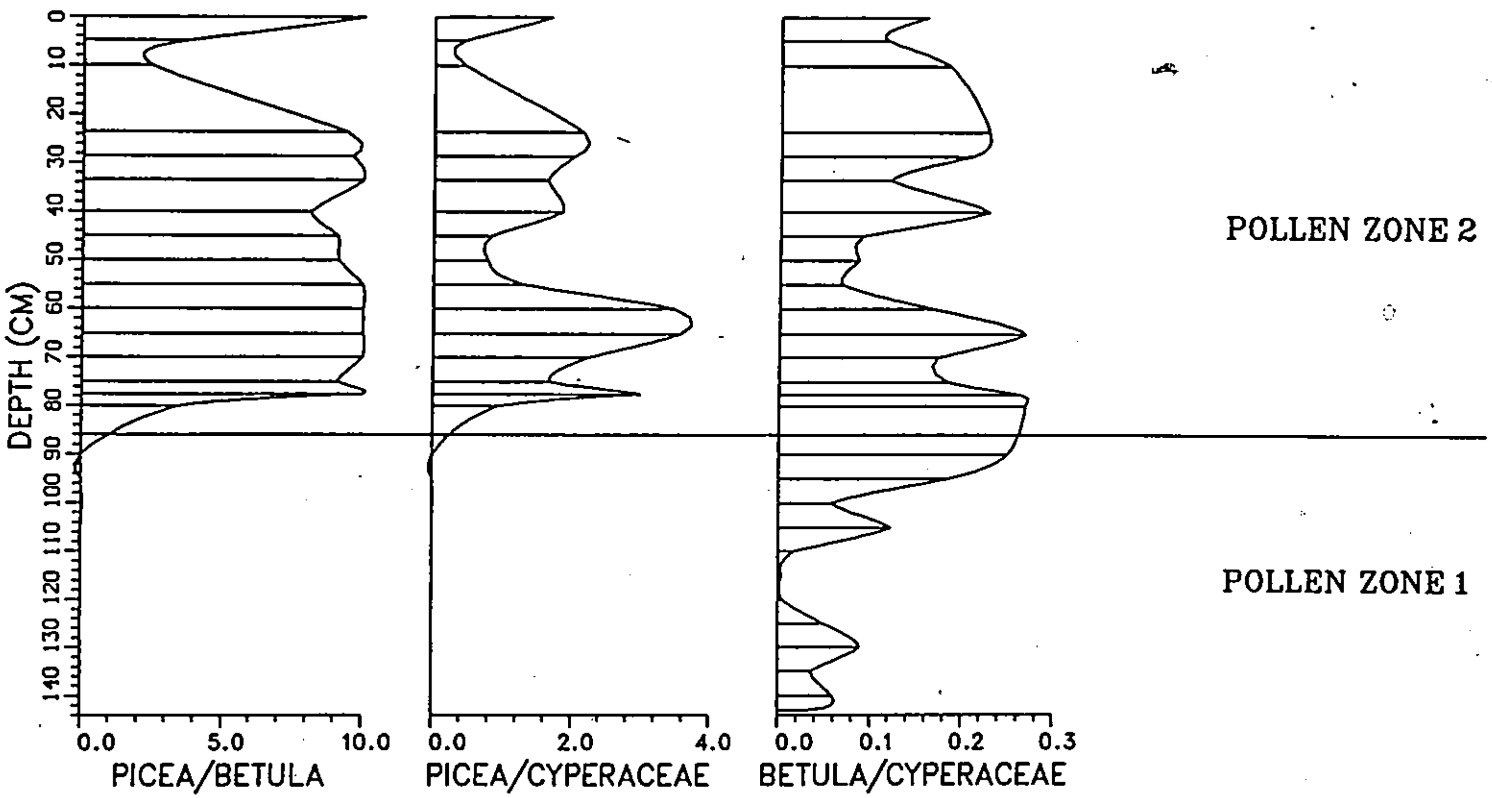


Figure 6.13 Selected pollen ratios of profile Aishihik Kettle (XW-5)

mesic taxa. As the result of the herbaceous pollen increase, the representation of spruce pollen is suppressed.

6.3.6 Summary and Conclusion

Pollen records of profile XW-5 suggest that the central Aishihik Basin area was covered by a sparse shrub-tundra vegetation after the last deglaciation. However, since there is a hiatus in the sediment records, there is no absolute time control for such an event. Dense spruce forest developed in the area at least before 5,200 yr BP. Since then, vegetation in the area has remained stable.

6.4 Moose Depression (XW-6)

6.4.1 Site Description

Moose Depression is located at the northwest corner of Aishihik Lake near the abandoned Aishihik Village (61°35'26" N Lat., 135°30'57" W Long., 953 m.a.s.l) where a terrace of glacial lake Aishihik was developed during the last deglaciation (Fig. 6.1). The core site is at the northeastern part of this 1,000 m x 350 m elongated depression. During the last deglaciation when glacial ice occupied the present position of Aishihik and Sekulmun Lakes, a proglacial lake surrounded the northern end of Aishihik Lake between the ice body and the extensive kame deposits. This proglacial lake left about 8 to 9 m of lacustrine silt deposits (Geurts et al., 1985; 1987). The cored depression is on the southwestern end of this silt terrace between Aishihik and Sekulmun lakes, about 500 m northwest of the present Tahgah river (Fig. 6.14). A ^{14}C data of 9,790 +/- 130 BP (LV-1475, Geurts et al., 1985; 1987) from a peat layer which is an old channel filling deposit at the bank of Tahgah River and now is about 15 m lower than the surface of the silt terrace, provides an estimation of minimum age of the glacial-lacustrine episode and the minimum age of the last deglaciation. Further to the west and northwest the topography turns mountainous with a local relief of about 400 m above the surface of the flat kame deposits (Fig. 6.1)

6.4.2 Present Vegetation

Present vegetation around the abandoned Aishihik Village and between Aishihik and Sekulmun Lake is dense white spruce forest. Other types of vegetation, however, occur in accordance with change of landform and geomorphic context. The following is a brief description of main plant communities observed during the field investigation in this area.

Picea glauca community: This is one of the major plant communities between the two lakes, and is developed on the moderately drained kame or glacial-fluvial deposits. Plants commonly occurring in this community are: *Picea glauca*, *Salix glauca*, *Arctostaphylos uva-ursi*, *Betula glandulosa*, *Epilobium*

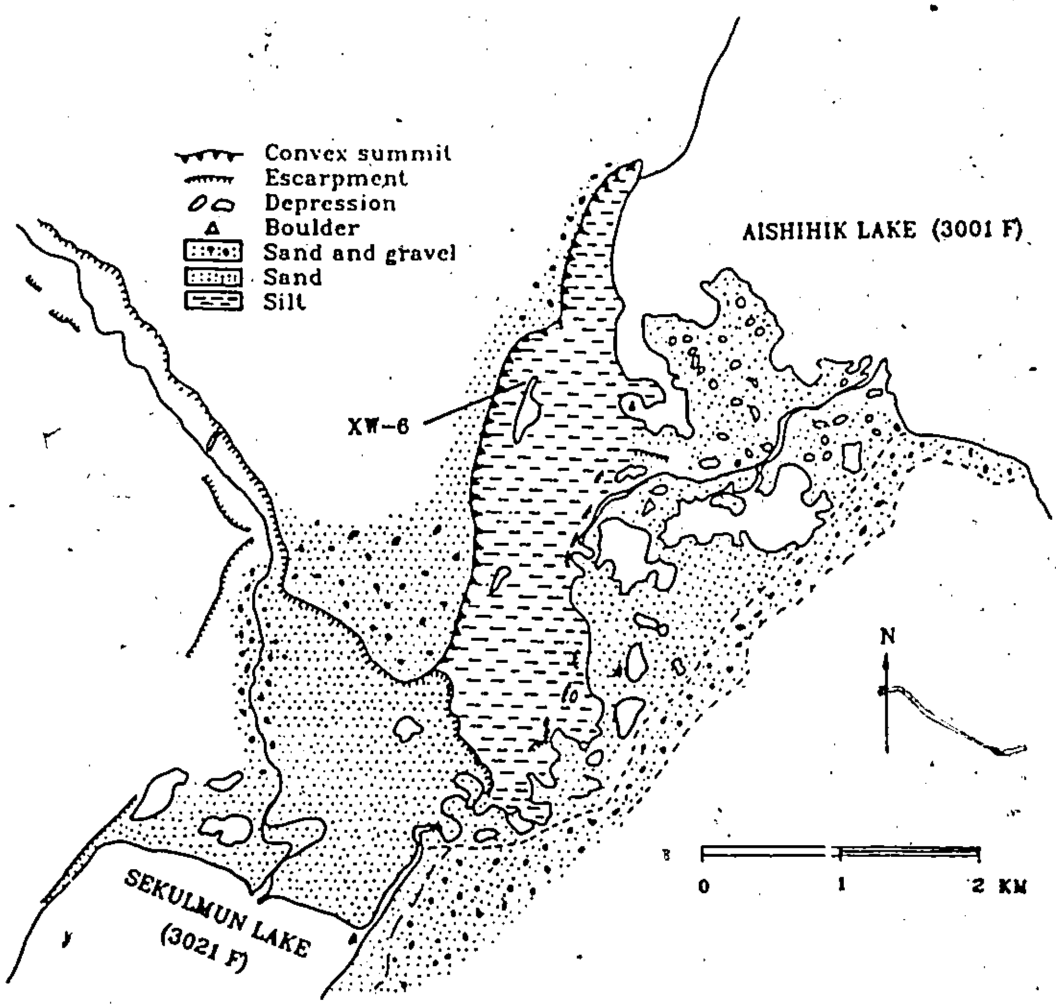


Figure 6.14 Sediment types between Aishihik and Sekulmun Lakes (after Geurts et al., 1985)

angustifolium, Lupinus arcticus, Castilleja sp., Empetrum nigrum, Linnaea borealis, Rosa acicularis. Sometimes Populus tremuloides (Aspen) is found in the more open locations in the forest canopy. The Moose Depression is surrounded by this community, especially on its west side.

Salix glauca community: This willow-dominated community is typically developed on the flat marginal parts of the depression, as well as on other parts of the silty glacial-lacustrine terrace. Common taxa in this community are: Salix glauca, Potentilla fruticosa, Castilleja sp., Achillea sp., some Ericaceae, Leguminosa, and Gramineae.

Cyperaceae Community: This community is commonly developed in the study area on fine-grained mineral soil of lowland flats or in the organic accumulating depressions. The central part of Moose Depression is covered by this community. Eriophorum sp. or Carex aquatilis are the most predominant plants in the community. The Eriophorum sp.-dominated community occurs in the mesic to poorly drained lowland area, and the Carex aquatilis-dominated community occurs in the extremely wet area which often merges with shallow water when the active layer above the permafrost table melts during the summer.

Betula glandulosa community: This is a common plant community in the Aishihik map area, but it has restricted distribution in the area between Aishihik and Sekulmun Lakes. It is recognized by an often patchy but heavy cover of *Betula glandulosa* and a dense understory of grasses and sedges. Other taxa commonly occurring are *Salix glauca*, *Potentilla fruticosa*, Gramineae, Ericaceae, and *Equisetum arvense*.

6.4.3 Sediment Stratigraphy

Peat deposits from the surface to 35 cm are interbedded with a conspicuous 7 cm thick ash layer from 11 cm to 18 cm. Then the sediments progressively change into organic silt with some mollusc shells between 35 cm and 145 cm. Grey silts occur at the bottom of the profile from 145 cm to 157 cm. Lacustrine organic silt occurs from 35 cm to 145 cm with progressively changing organic content. Results of loss on ignition indicate that organic contents in the top three peat samples are from 49.7% to 73.8%. Samples immediately above and beneath the ash layer have lower organic content (41% and 26.2%, respectively) due to the influence of the ash layer. From 31 cm to 105 cm the organic content decreases gradually from 28% to 13.2% with small fluctuations. In most cases it is around 15-16%. From 105 cm to 131 cm the organic content has a small abrupt increase, to 20%, and then decreases again between 131 cm and 145 cm from 17.8% to 13.7%. Organic content abruptly decreases from 145 cm to the bottom of the profile with very low values from 9.5% to 6.2%. The pattern of organic content variation in the profile is graphically illustrated in figure 6.15. The curve is

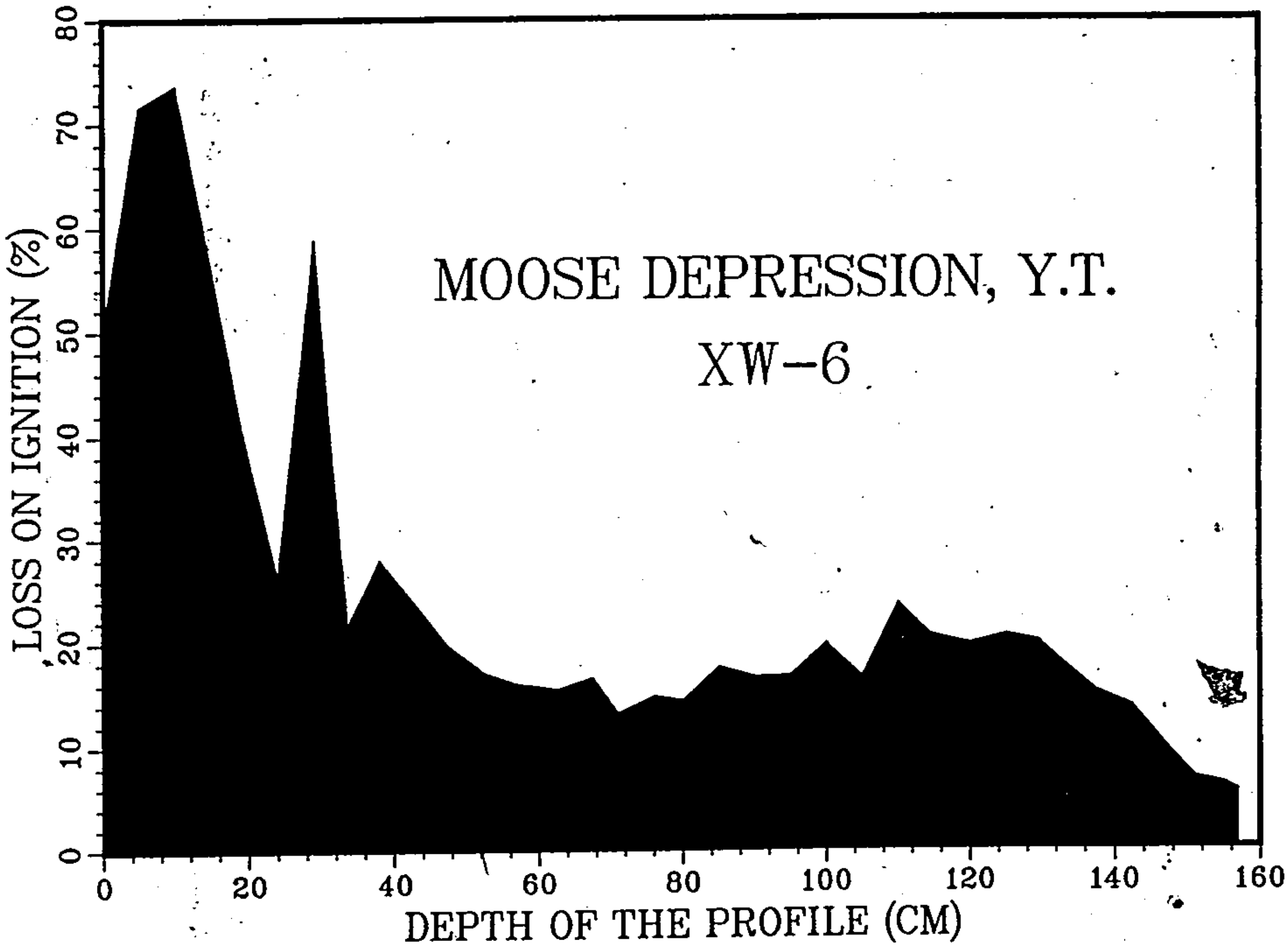


Figure 6.15 Organic content of Moose Depression sediments

smoothed using the third order parametric polynomial technique supplied by DISSPLA graphics software (Integrated Software Systems Corporation, 1986).

The technique of grain size analysis, described previously in chapter 3, was employed to evaluate the sedimentological properties of these samples. Figure 6.16 illustrates the percentage frequency of particles of different size, calculated on total dry weight after the removal of organic material. The organic contents are also shown in the right column of the figure. The predominant particles in all samples are silt. Medium silt (5-6 phi or 31.25-15.6 microns in size) is the most important group. The sand portion, however, has a relatively obvious distribution trend. More sand was deposited in the peat layers. Further analysis of the data reveals that the mean grain size is all around 4.1-5.15 phi (Tab. 6.1). The sorting and skewness indices, however, vary through the profile. The sorting index, determined following Folk and Ward (1957), is 0.7-0.8 in the lower part of the profile which means the sediments are moderately sorted, and 1.2-1.3 in the top part which indicates poor sorting. Relatively high positive skewness indices (>1.0) at the lower part of the profile imply that the sediments in this part of the section have a large fine tail, and low values in the topmost section (<1.0) indicate that the sediments are coarser particles. This result is in agreement with the frequency distribution analysis (Fig. 6.16). Other

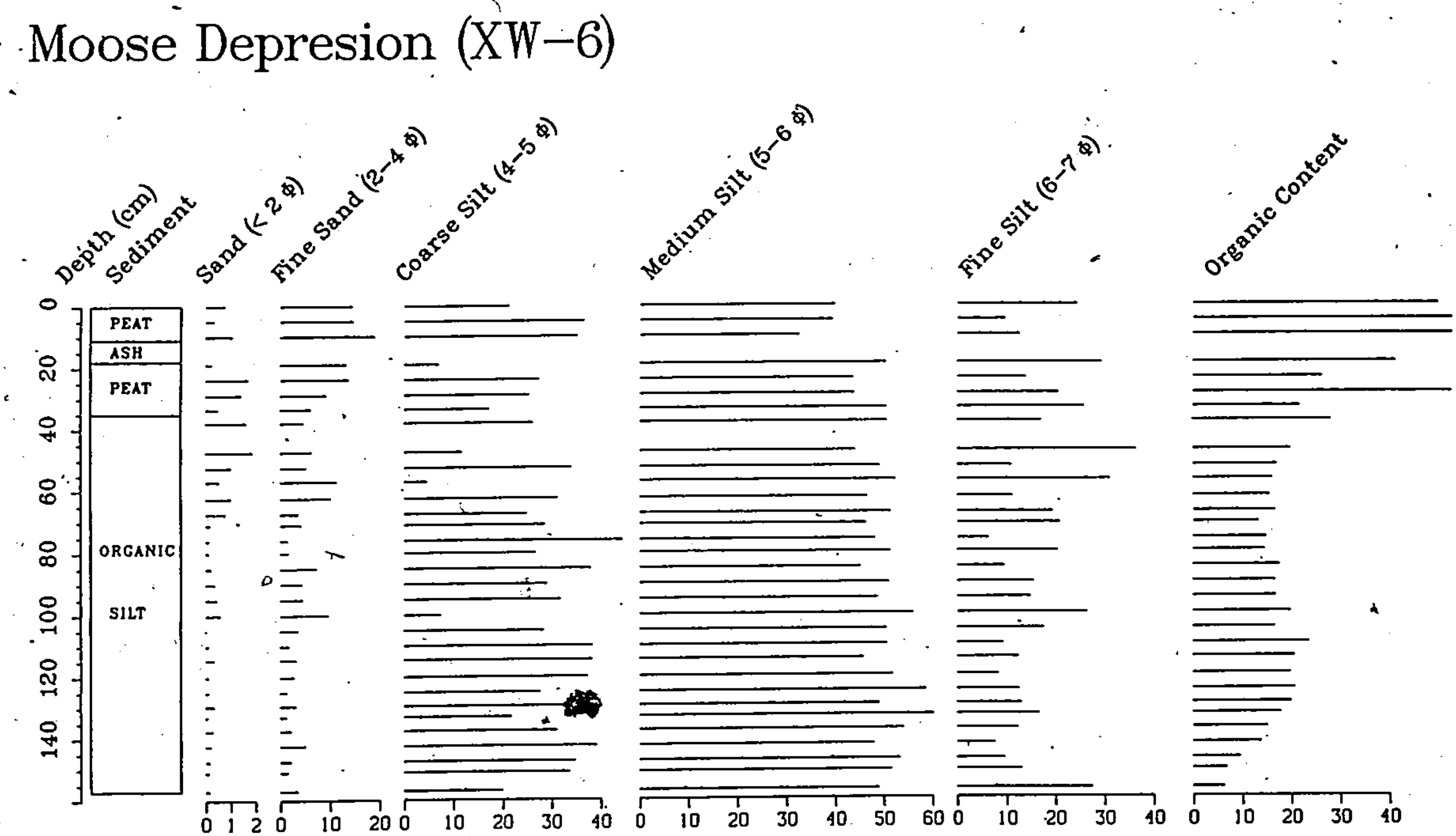


Figure 6.16 Percentage frequency of particles with different grain size group. Result of loss on ignition also presented at the right column

Table 6.1 Results of grain size analyses from profile of Moose Depression (XW-6) sediments

	Median (Φ)	Mean (Φ)	Sorting	Skewness	Kurtosis
1	4.8200	4.5967	1.3386	0.5903	1.0439
2	4.3800	4.2800	1.1432	0.7790	1.0111
3	4.2000	4.1000	1.3212	0.6233	0.8844
4	5.0800	5.0433	1.0792	1.2788	1.6246
5	4.5500	4.2600	1.1933	0.6496	1.1284
6	4.7200	4.6067	1.1515	0.8557	1.1622
7	5.0000	4.9600	0.9761	1.2848	1.3674
8	4.7800	4.7267	0.9445	1.1849	1.2185
9	5.1200	5.0900	1.0837	1.1595	1.3443
10	4.6000	4.5433	0.8845	1.1894	1.0795
11	5.1500	5.1533	1.0416	1.4506	1.6507
12	4.6200	4.5000	1.0564	0.8913	1.1160
13	4.9000	4.8700	0.8214	1.4954	1.2640
14	4.8500	4.8067	0.8690	1.3259	1.1414
15	4.7500	4.5733	0.7310	1.2269	0.8728
16	4.9000	4.8733	0.7533	1.5948	1.0580
17	4.5500	4.4733	0.8895	1.1102	1.0160
18	4.8000	4.7500	0.8223	1.3902	1.1532
19	4.7800	4.6933	0.8364	1.3014	1.1031
20	5.1000	5.0967	0.9820	1.6974	2.0350
21	4.8200	4.7867	0.7947	1.5065	1.1584
22	4.6800	4.6167	0.7281	1.4474	0.9470
23	4.6400	4.5800	0.8386	1.2550	0.9814
24	4.6800	4.6033	0.7181	1.4425	0.9953
25	4.8500	4.8033	0.6091	1.8890	1.0196
26	4.7200	4.6567	0.7875	1.3780	1.0608
27	4.9000	4.9067	0.5980	2.0847	0.9996
28	4.8000	4.7400	0.7141	1.5276	1.0444
29	4.6000	4.5000	0.7970	1.2254	0.9762
30	4.6800	4.6500	0.7090	1.5101	0.9904
31	4.7500	4.7000	0.7261	1.5237	1.0354
32	5.0000	5.0000	0.7886	1.6245	1.0656

indices such as median and kurtosis show no obvious trends (Tab. 6.1).

In summary, abrupt change of organic content, sorting and skewness indices, and increase of sand percentage in the sediments seem to indicate a sedimentary facies change at about 35 cm. Below 35 cm the sedimentary environment was a shallow pond. Occurrences of mollusc shells below 35 cm provide strong evidence for such an interpretation. Above 35 cm this pond was drained and became a marsh or wet peat bog.

6.4.4 Radiocarbon Dates and Sedimentation Rates

Three core segments from profile Moose Depression (XW-6) were submitted for radiocarbon dating (Tab. 6.2). Samples were selected to confine special events or close to zone boundaries. The White River ash layer was considered to be 1,230 yr BP for the calculation of sedimentation rates. Since the ash layer is an event deposit accumulated in a relatively short time span, its thickness was eliminated as in other profiles in this monograph to minimize the deviation of the calculated ages of the samples. As in other profiles, calibration of sediment depth for eliminating the influence of frost heaving on the calculation of sedimentation rates and pollen accumulation rates were carried out. Sedimentation rates used here for calculating the pollen accumulation rates were determined by linear extrapolation of the age-depth relation (Fig. 6.17) and the result is listed in the table 6.3.

6.4.5 Relative Pollen Frequency

Results of pollen analysis from the Moose Depression profile (XW-6, Fig. 6.1) are represented in a relative pollen frequency diagram (Fig 6.18) and a pollen accumulation rate diagram (Fig. 6.19).

Zonation procedures of CONZONE, CONISS, and ZONATION were applied to zone the relative pollen frequency diagram. Taxa used for the zonation purpose include *Picea*, *Alnus*, *Betula*, *Salix*, Rosaceae, *Juniperus*, *Artemisia*, Compositae, Gramineae, Cyperaceae, *Myriophyllum*, *Sparganium*, *Lycopodium*, *Dryopteris*, and *Equisetum*. The dendrograms are illustrated in figure 6.20. The numerical and empirical results of zonation are illustrated on the pollen percentage diagram.

ZONE 1 (154.0 - 157.0 cm): Pollen zone 1 consists of 1 sample which is characterized by high percentages of Gramineae and Cyperaceae, a low percentage of *Betula*, and an absence of *Picea*. *Betula* percentage is 20.6% which is only one third the value of the samples above. Cyperaceae percentage is 31% and Gramineae value is 32.5%, which are the maximum values of these taxa in the profile. Other taxa are less important.

Table 6.2 ^{14}C dates of profile Moose Depression (XW-6)

Lab Number	Core interval (cm)	^{14}C date (yr BP)	Material used
	11.0 - 18.0	1,230	ash layer
UQ-1449	32.0 - 35.0	5,620 +/- 100	peat
TO- 644	33.5 - 70.2	7,220 +/- 170	organic silt
GSC-4099	70.2 - 111.3	8,640 +/- 80	organic silt

Table. 6.3 Sedimentation rates of profile Moose Depression (XW-6)

Core interval (cm)	Time interval (yr BP)	Mean sedimentation rate (cm/yr)
0.0 - 11.0	0 - 1,230	0.00894
11.0 - 18.0	ash layer	
18.0 - 33.5	1230 - 5620	0.00353
33.5 - 70.2	5620 - 7220	0.02206
70.2 - 111.3	7220 - 8640	0.02754
111.3 - 157.0	8640 - 10230 *	0.02754

* Extrapolated

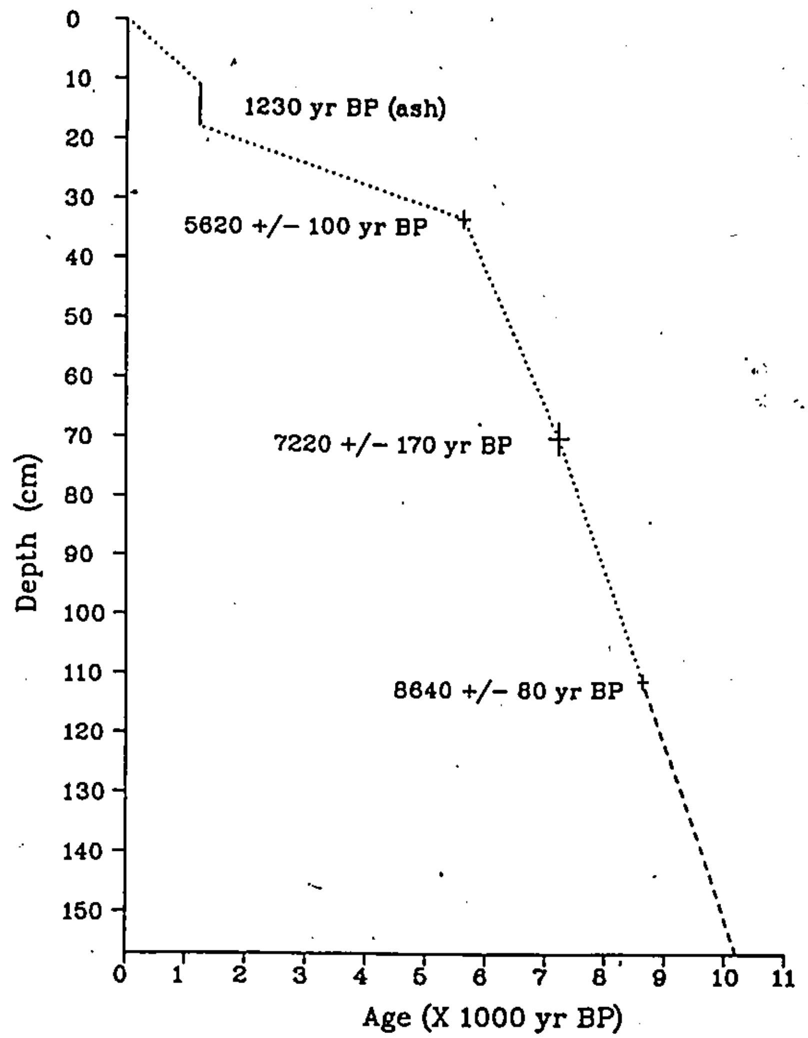


Figure 6.17 ^{14}C dates vs depth relation of profile Moose Depression (XW-6)

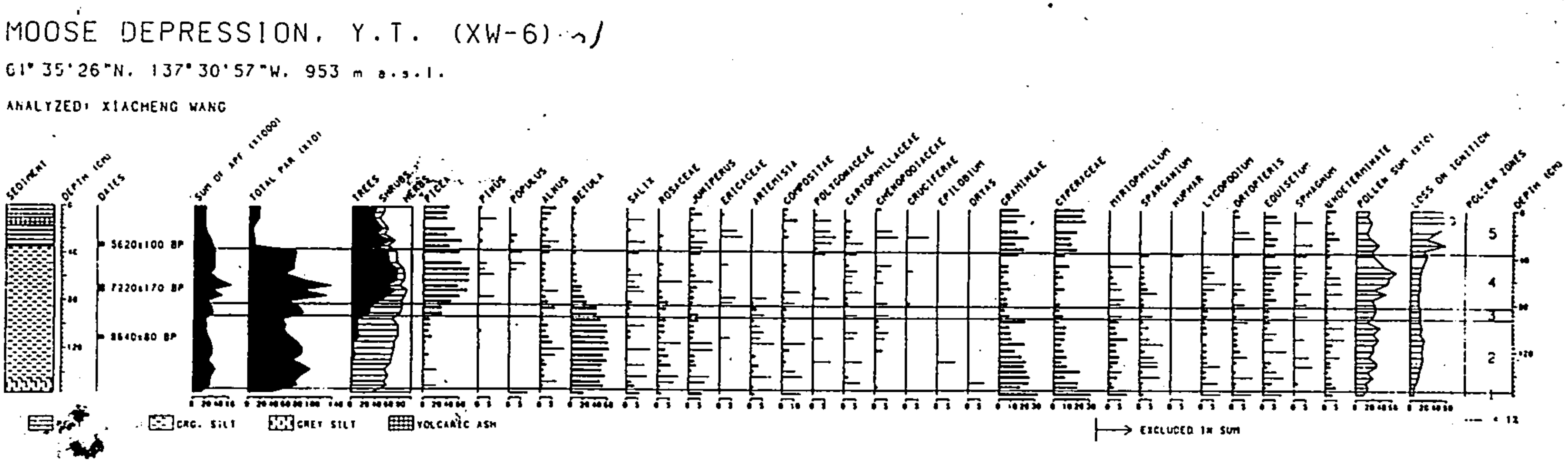


Figure 6.18 Pollen percentage diagram of profile Moose Depression (XW-6)

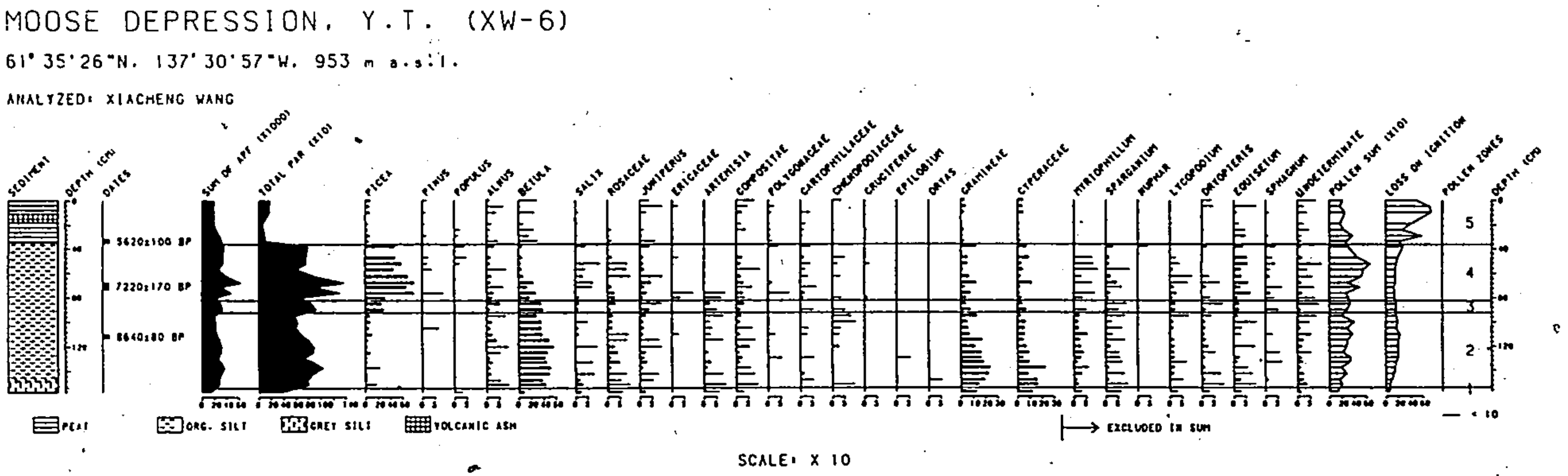


Figure 6.19 Absolute pollen accumulation rate diagram of profile Moose Depression (XW-6)

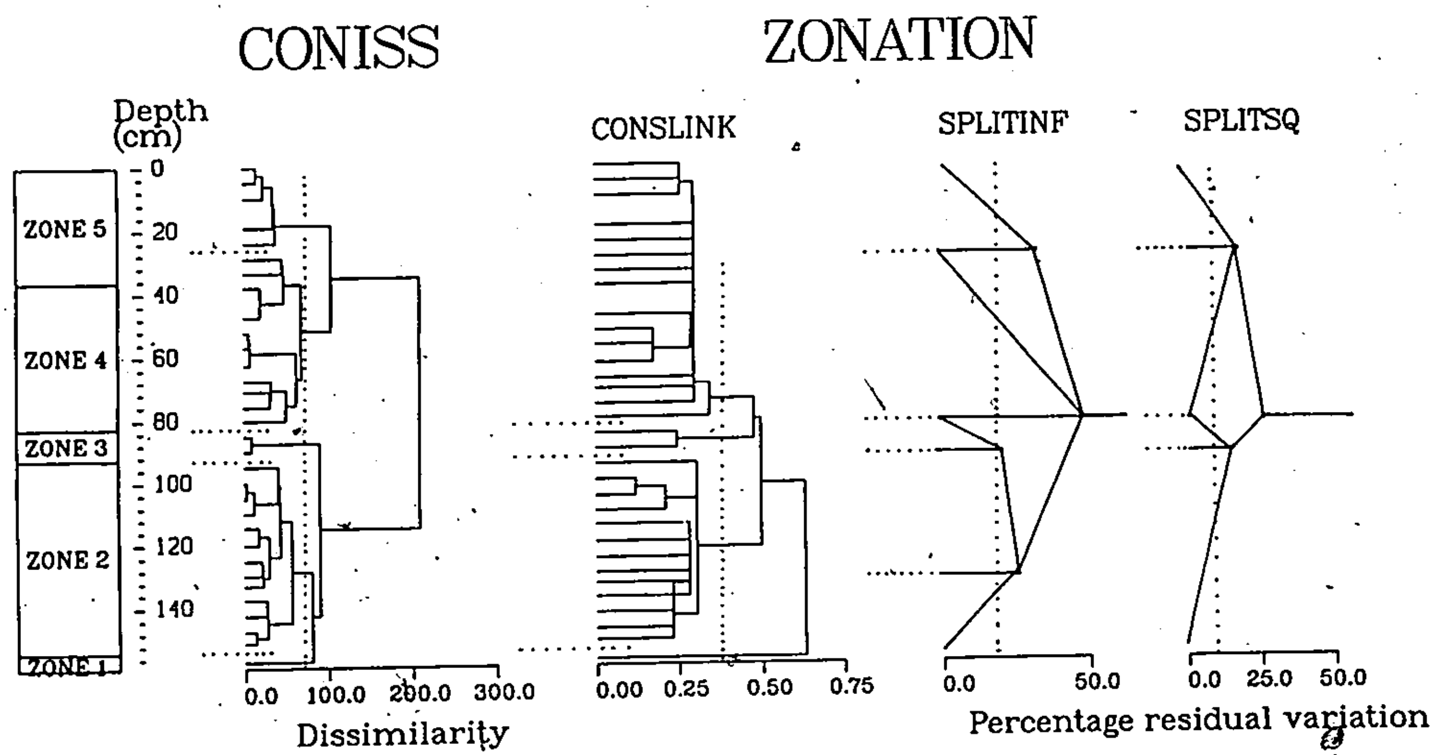


Figure 6.20 Dendrograms of zonation procedures of profile Moose Depression

Three pages)

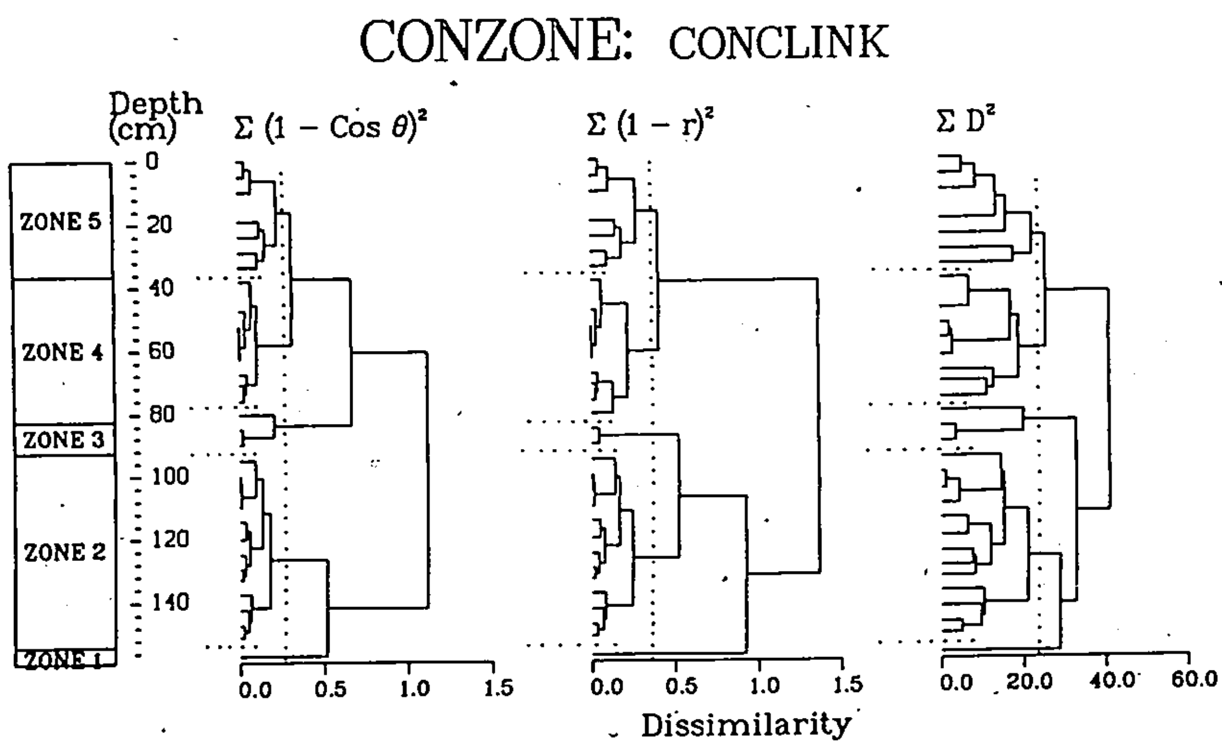


Figure 6.20 (Continued)

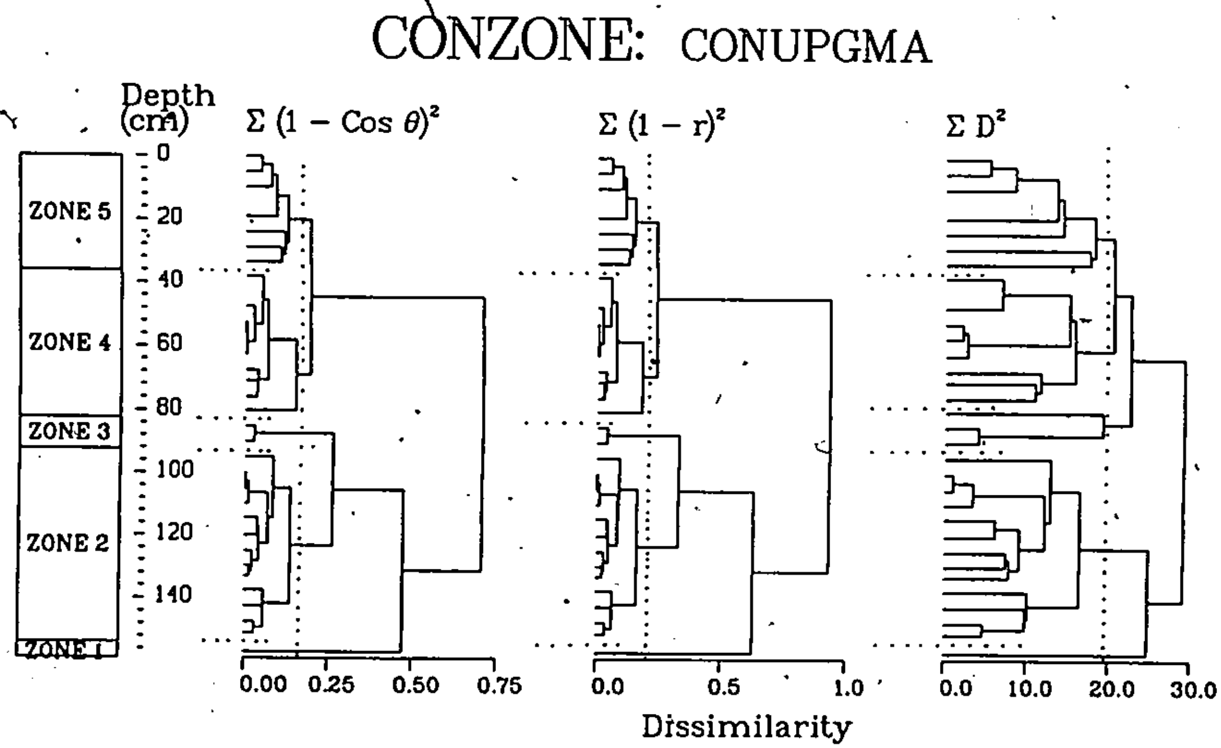


Figure 6.20 (Continued).

ZONE 2 (92.5 - 154.0 cm): Pollen zone 2 is characterized by very high percentages of *Betula* pollen which vary from 48% at the bottom of the zone to 62% in the middle. *Alnus* pollen values fluctuate around 2%. *Salix* values vary from absent to 3%. Rosaceae and *Juniperus* percentages range from less than 1% to 5%. *Picea* pollen values slowly increase from 0.6% at the bottom to around 10% at top of the zone. In herbaceous taxa, Gramineae have the highest values, varying from 8% to 24.6%, and more than 20% in most cases. Cyperaceae values fluctuate between 4% and 21.7%. *Artemisia* occurrences are relatively continuous with values around 1%. Compositae is another group which produces a continuous curve with values between less than 1% and 5.9%. Aquatic taxa are relatively abundant. *Myriophyllum* is continuous and its values vary from 0.6% to 4%. *Sparganium* percentages are also continuously observed with values from 0.4 to 2%. In the pteridophyte group, *Lycopodium* values vary from absent to 2.3%, about 2% in most cases. *Dryopteris* percentages are between absent and 3% with 2% in most cases. *Equisetum* is similar in occurrence to *Dryopteris*. *Sphagnum* only occurs occasionally. Total tree pollen percentages gradually increase from 0.6% at the bottom to 10% at the top of the zone. Shrub pollen percentages vary from 52% To 68%. Herbaceous pollen percentages gradually decrease from 46% at the bottom to 27% at the top of the zone.

ZONE 3 (82.5 - 92.5 cm): As illustrated in the pollen diagram, pollen spectra of zone 3, consisting of only 2 samples, exhibit transitional features. _Picea_ pollen percentages are about 30%. _Betula_ values are 42%. _Alnus_ values vary from 1% to 6%. _Salix_ percentages are about 1%. Rosaceae and _Juniperus_ vary from 1% to 3%. In herbaceous taxa, both Gramineae and Cyperaceae have values between 5% and 8%. _Artemisia_ percentages are 0.6% and 2.5%. Compositae are also around 1-3%. Aquatics are less than or around 1%. Pteridophytes are all around 2-3%. In summary, both shrub and herbaceous pollen percentages show a moderate decrease in this zone, and tree pollen has an obvious increase.

ZONE 4 (35.5 - 82.5 cm): Pollen zone 4 exhibits different pollen spectra from any previous zones in this profile. _Picea_ pollen reaches maximum values, varying from 46% at the base of the zone to 76%. _Alnus_ values are between 0.7% and 3.5% showing little difference from before. _Betula_ percentages, however, decrease progressively from the top of zone 2, and drop from 25.5% at the bottom to 6.5% at the top of zone 4. _Salix_ percentages are usually less than 1%. Other shrubs, _i.e._ Rosaceae and _Juniperus_, are all less than 5% where present. Herbaceous taxa have their minimum representation in this zone. Gramineae are less important than before with values from 2.9% to 9.6% except in the top sample which is up to 15%. Cyperaceae fluctuate from 1.3% to 12%, less than 10% in most cases. Other herbs have no significant occurrence. Aquatic taxa have a different distribution pattern than before. *Myriophyllum* percentages have dramatically decreased, and *Sparganium* values take their place, usually around 2%. In pteridophyte taxa, *Equisetum* has higher values than that before, varying from 3% to 7%. Others have no large difference. In summary, tree pollen percentages dominate this zone with values from 46.4% to 76.6%. Shrub pollens have decreased, varying from 9.5% to 37%. Herbaceous pollen values are down to 8-25%.

ZONE 5 (0 - 35.5 cm): Pollen zone 5 is characterized by the disappearance of aquatic taxa and abrupt increase of grass-sedge proportion. Gramineae values are up to 13-24%. Cyperaceae percentages are consistently higher than 13%, varying from 13% to 25.6%. Compositae also have higher values. In shrub taxa, *Betula* values show little change. *Alnus* percentages are slightly increased, varying from 0.8% to 6%, usually more than 2%. Tree pollen, however, has decreased. *Picea* percentages vary from 37% to 62.6%, usually less than 50%, dropping about 20% from before. *Pinus* and *Populus* have more frequent occurrence than before without continuous curves. In summary, tree pollen in this zone varies from 37% to 65.5%. Shrubs are from 6% to 17%. Herbaceous taxa have obviously increased, varying from 29% to 54%, usually more than 40%.

6.4.6 Absolute Pollen Accumulation Rate (PAR)

Absolute pollen accumulation rates were determined using the classical exotic marker methods described in chapter 3. The pollen diagram is zoned following the relative pollen frequency diagram.

ZONE 1 (154 - 157 cm): Total pollen concentration in this zone is about 1.5×10^4 grains/cm³. Total pollen accumulation rate was ca. 380 grains/cm²/yr, mainly consisting of Cyperaceae and Gramineae (each ca. 120 grains/cm²/yr). The *Betula* rate was ca. 80 grains/cm²/yr. The *Salix* rate was about 20 grains/cm²/yr. Other taxa have very low values. *Picea* pollen is absent.

ZONE 2 (9.25 - 154 cm): The total pollen concentrations of zone 2 vary from $2.9\text{-}5.8 \times 10^4$ grains/cm³ except in one sample at the 100 cm level which has a concentration up to 8.0×10^4 grains/cm³. Total pollen accumulation rates vary from $0.74\text{-}2.0 \times 10^3$ grains/cm²/yr. *Picea* values steadily increase from a few grains at the bottom to ca. 220 grains/cm²/yr at the top with a large jump at 110 cm above which the values are three-fold larger in magnitude than before. *Alnus* values vary from a few grains to 70 grains/cm²/yr. *Betula* is the most dominant taxon in this zone with values of $0.4\text{-}1.2 \times 10^3$ grains/cm²/yr. *Salix* values fluctuate from absent to 30 grains/cm²/yr. Rosaceae vary from a few grains to 50 grains/cm²/yr. *Juniperus* values are less than 50 grains/cm^2/yr. *Artemisia* is well represented with values from absent in a few samples to 28 grains/cm^2/yr. Compositae values vary from absent to 50 grains/cm^2/yr. Gramineae are consistently greater than 150 grains/cm^2/yr. Cyperaceae fluctuate between 45 and 240 grains/cm^2/yr. *Myriophyllum* is well represented with values between *ca*. 10 to 100 grains/cm^2/yr, mainly around 20-40 grains/cm^2/yr. *Sparganium* values vary from a few grains to 15 grains/cm^2/yr. *Lycopodium*, *Dryopteris*, and *Equisetum*-type values fluctuate from absent to less than 40 grains/cm^2/yr represented.

ZONE 3 (82.5 - 92.5 cm): Total pollen concentration values in this zone are about 3.4-6.6 x 10^4 grains/cm^3, and total pollen accumulation rates are about 0.9-1.7 x 10^3 grains/cm^2/yr, dominated by *Picea* and *Betula* pollen. *Picea* values are around 270-520 grains/cm^2/yr. *Betula* values are from 360 to 720 grains/cm^2/yr. *Alnus* values have large fluctuation between these two samples, from 10 to 100 grains/cm^2/yr. *Salix*, Rosaceae, and *Juniperus* values are all less than 50 grains/cm^2/yr. *Artemisia* and Compositae values are between a few grains and 50 grains/cm^2/yr, respectively. Gramineae and Cyperaceae values are all around 70 grains/cm^2/yr. *Myriophyllum* values dramatically decrease to less than 5 grains/cm^2/yr, and *Sparganium* exhibits an increasing trend. *Dryopteris* values are around 15 grains/cm^2/yr. *Lycopodium* and *Equisetum*-type are both between 20 and 42 grains/cm²/yr. Other taxa are not continuously or significantly represented.

ZONE 4 (35.5 - 82.5 cm): Total pollen concentrations in this zone vary from 2.8×10^4 grains/cm³ to 6.2×10^4 grains/cm³. Total pollen accumulation rates are from 0.62×10^3 to 1.7×10^3 grains/cm²/yr. Picea pollen has its highest value in this zone, and varies from 462 grains/cm²/yr to 986 grains/cm²/yr, more than 600 grains/cm²/yr in most cases. Alnus varies from a few grains to 55 grains/cm²/yr. Betula values have decreased, varying from 30 to 450 grains/cm²/yr. Salix and Rosaceae are less important than before. Juniperus values vary from 10 to 44 grains/cm²/yr. Artemisia disappears with the exception of a few grains in the two bottom samples. Compositae fluctuate between a few grains and 45 grains/cm²/yr. Gramineae values are between 20 and 240 grains/cm²/yr, with large fluctuation. Cyperaceae values are from 15 to 190 grains/cm²/yr, less than 100 grains in most cases. Myriophyllum is less important than before, with only a few grains/cm²/yr in most cases. However, Sparganium has better representation than before, varying from a few grains to 55 grains/cm²/yr, and more than 20 grains in most cases. Lycopodium is less represented than before, varying from absent to 25 grains/cm²/yr. Dryopteris values fluctuate from a few grains to 40 grains/cm²/yr where present. Equisetum-type has a better representation than before, varying from 30 to 72 grains/cm²/yr except one sample with a value of about 100 grains/cm²/yr. Sphagnum also has better representation with values from absent in one sample to 16 grains/cm²/yr, about 6 in most cases. Other taxa are not well represented.

ZONE 5 (0 - 35.5 cm): Total pollen concentration values in zone 5 have obviously decreased and are consistently around 2×10^4 grains/cm³, varying from 2×10^4 to 2.9×10^4 grains/cm³ with the exception of the bottom sample. Total pollen accumulation rates have also dramatically decreased, varying from about 70 grains/cm²/yr to 350 grains/cm²/yr, which are only 10-20% of those in the zone 4. Picea is still a dominant taxon with values from 30 to 150 grains/cm²/yr, around 65 grains/cm²/yr in most cases. Pinus pollen occurs occasionally with a few grains. Alnus has also decreased to less than 10 grains/cm²/yr in most cases. Betula and Juniperus values markedly drop to a few grains/cm²/yr. Gramineae and Cyperaceae decrease to 10-70 grains/cm²/yr. All aquatic taxa disappear from the pollen spectra. Other taxa are only a few grains where present.

6.4.7 Numerical Analysis

The combined data set using selected pollen taxa provides the basis for numerical analysis. The results of PCA as illustrated in figure 6.21 indicate that the first PCA axis accounts for about 24.4% of the total data covariance. Picea

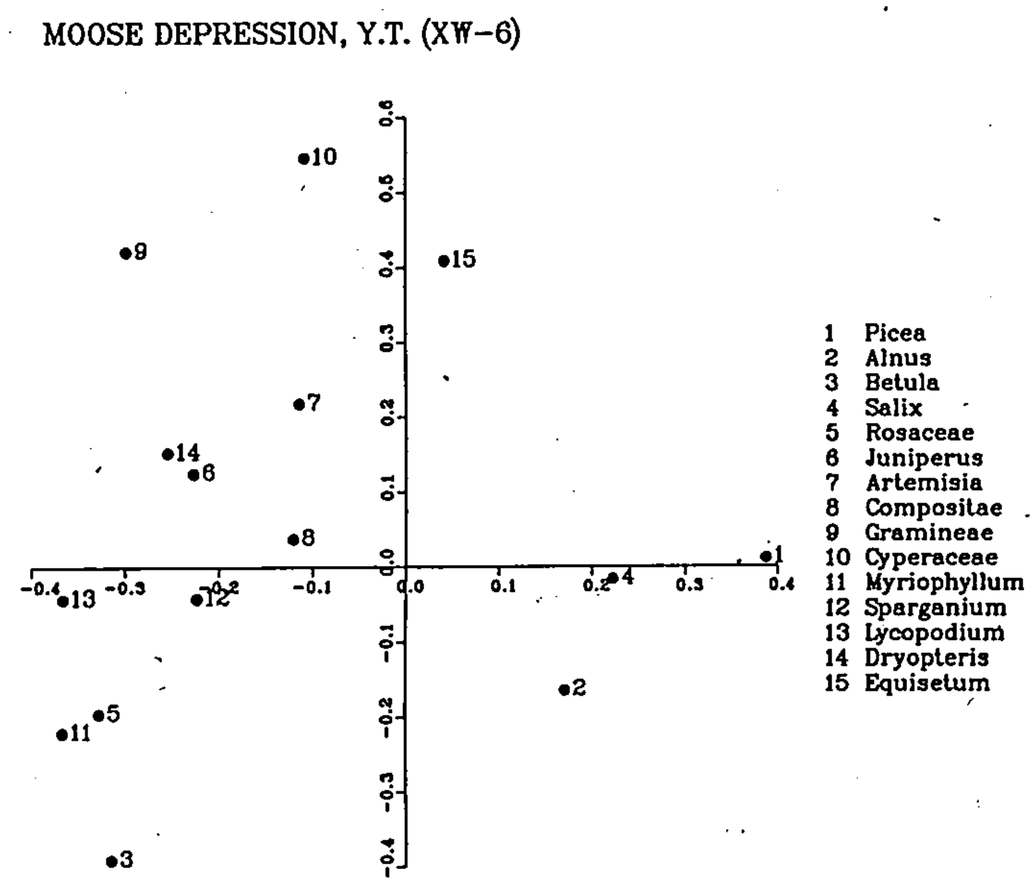


Figure 6.21a Principal component loadings of selected taxa on the first (horizontal) and second (vertical) PCA axes, Profile Moose Depression (XW-6)

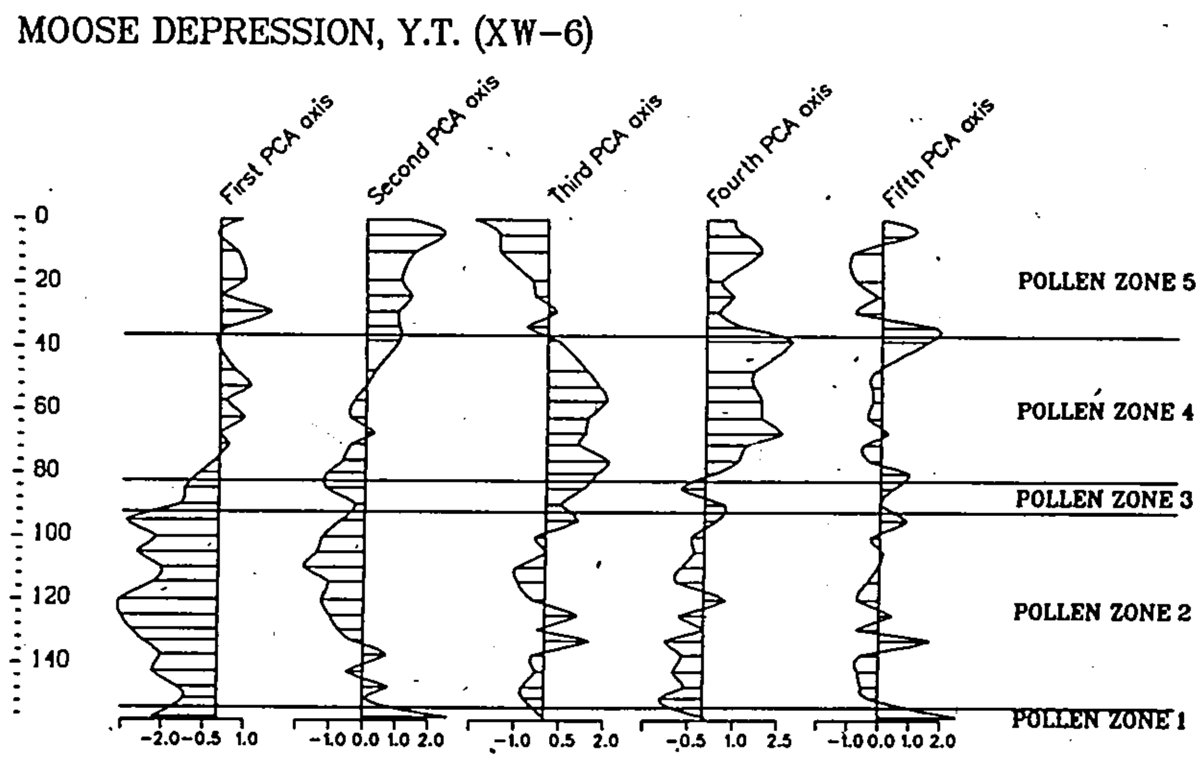


Figure 6.21b Principal component scores of profile Moose Depression (XW-6) samples on the first five PCA axes

has the highest positive loading on this axis, while Betula, Rosaceae, Myriophyllum, and Lycopodium have high negative loadings. This result reflects the relationship among these taxa, where low Picea values are accompanied by high values of others. Considerable negative scores of zones 1 to 3 samples and moderate positive scores of zones 4 and 5 samples on the first axis quantitatively define this complementary relation. The second PCA axis accounts for about 14.5% of the total covariance. Betula has the highest negative loading, while Gramineae, Cyperaceae, and Equisetum have high positive loadings on this axis. This loading regime accounts for the sample scores on this axis. The high positive score of the zone 1 sample indicates the great representation of Cyperaceae and Gramineae and less importance of Betula. Fluctuating scores of samples from the lower part of zone 2 reflect the balance of considerable values of Betula, Cyperaceae, and Gramineae in these samples. Negative scores in the central part of the profile broadly mirror the variation of Betula values, and positive scores of zone 5 samples reflect the rise of Cyperaceae, Gramineae, and Equisetum. The third axis accounts for about 13.1% of the total information. Alnus and Dryopteris have considerable negative loadings on this axis, and Artemisia and Equisetum have positive loadings. Sample scores on this axis basically reflect the complex relation among these taxa. Considerable positive scores of zone 4 samples indicate the importance of Equisetum pollen in the spectra. On the fourth axis, which accounts for about 11.3% of the total data covariance, *Picea*, *Juniperus*, and *Sparganium* have high positive loadings, while *Salix* and *Artemisia* loadings are negative. High positive scores of zone 4 samples show that *Sparganium* has its best representation in this zone. Sample scores on the fifth axis which account for about only 6.7% of the total information, are extremely variable. This result reflects the relationship among the *Alnus*, *Salix*, Rosaceae, *Juniperus*, and *Equisetum* pollen representation in the spectra. The first five axes in total account for more than 70% of the total data covariance, and the discard of other axes will not lose much of the information.

As indicated by the lengths of variable vectors in the result of the first and second PCB axes (Fig. 6.22) which accounts for about 94% of the total variability of the data set, *Picea*, *Betula*, Cyperaceae, and Gramineae are the four most important taxa in the data set. This result is in common with other profiles. Among these four major taxa in the data set, Cyperaceae and Gramineae are most alike since the orientations of the two groups are similar. However, the relation between this herbaceous group and *Picea* and *Betula*, is largely complementary, *i.e.* in negative correlation. It is interesting to note that the zone 1 sample is isolated from all other samples, and exhibits a distinctive feature closely related to Cyperaceae and Gramineae vectors, indicating the importance of

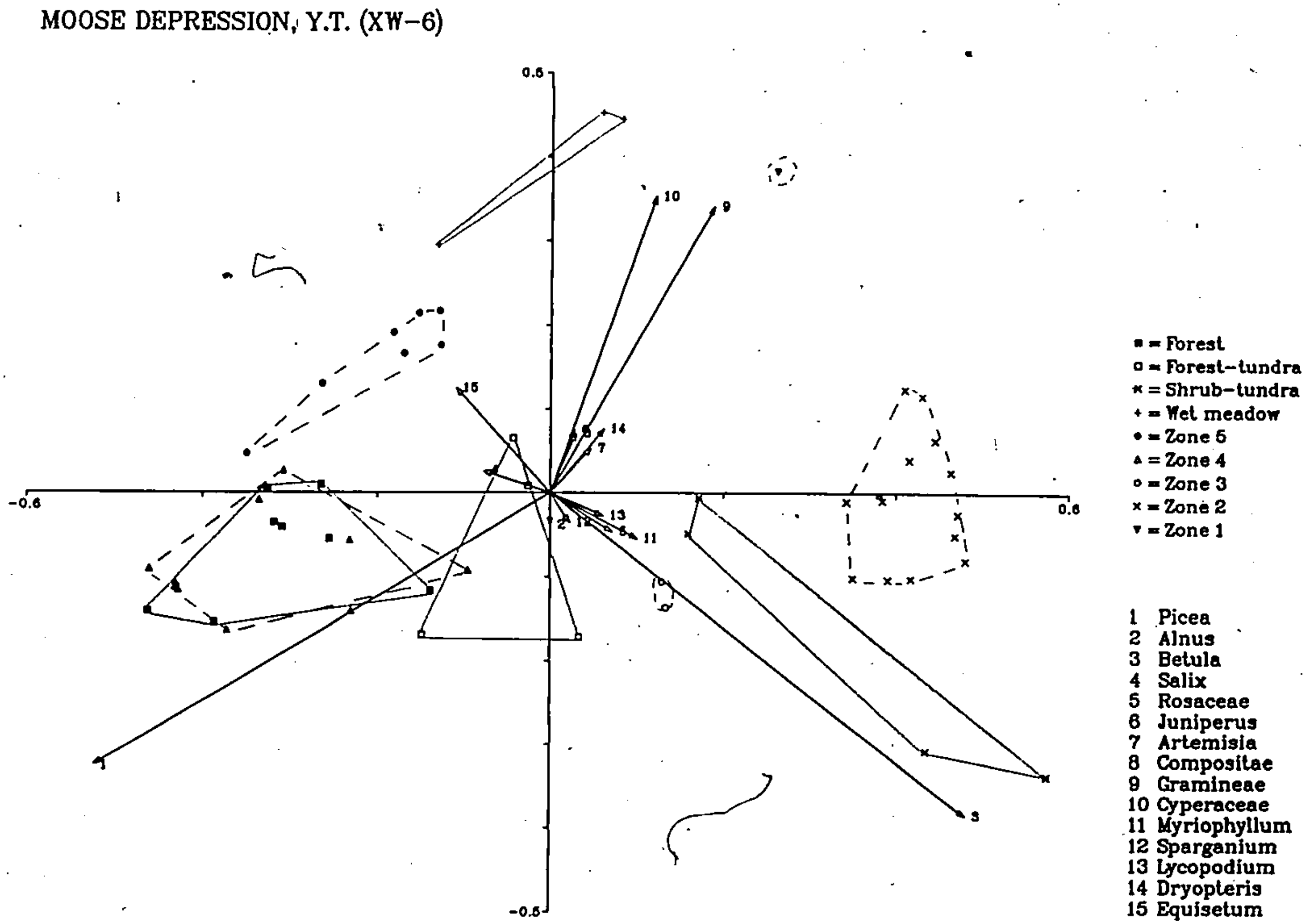


Figure 6.22 Ordination of combined data matrix of modern and fossil pollen samples on the first (horizontal) and second (vertical) PCB axes, profile Moose Depression (XW-6)

herbaceous taxa in the pollen spectra. Zone 2 samples are also distinctive from other samples and closely related to modern shrub-tundra samples. Zone 3 samples are between those of modern shrub-tundra and forest-tundra spectra, due to their high Betula and Picea contents. Zone 4 samples largely overlap the modern spruce forest cluster, which indicates that during the zone 4 time interval the vegetation in the area was similar to that of a modern spruce forest. Departure of zone 5 samples from the modern forest sample cluster is along the direction of Cyperaceae and Gramineae vectors, which indicates that the differentiation of zone 4 and 5 samples is basically caused by the change of herbaceous values in the data set.

The result of CA as illustrated in figure 6.23 shows great similarity to that of PCB. The first and second CA axes account for about 66.2% of the total variability of the data set. All samples from different zones are perfectly grouped and distinguishable from the others. This similarity indicates the high confidence of the results (Gordon, 1982), and high stability of the relations among the pollen taxa. Picea and Salix are closely related to forest spectra, while Betula, Lycopodium, and Rosaceae are better represented during the zone 2 time interval, or in the modern shrub-tundra environment. Equisetum is closer to zone 5 samples.

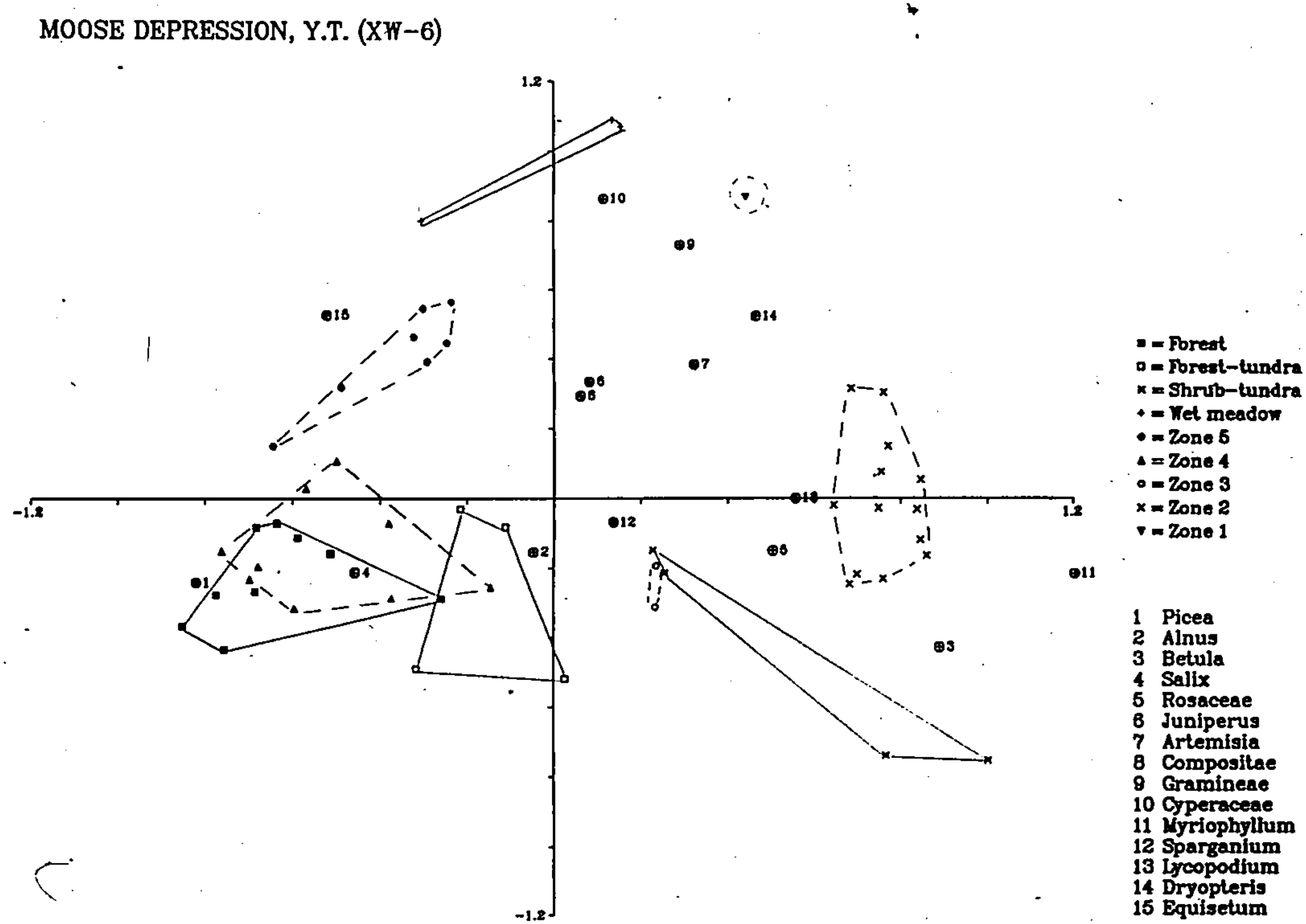


Figure 6.23 Ordination of combined data matrix of modern and fossil pollen samples on the first (horizontal) and second (vertical) CA axes, profile Moose Depression (XW-6)

6.4.8 Reconstruction of Paleoenvironment

Zone 1 pollen spectra resemble those of modern herbaceous-tundra samples (Livingstone, 1955; Ritchie, 1974; Ritchie and Lichti-Federovich, 1967) and fossil herbaceous zone spectra (Ager, 1975; 1982; Ritchie, 1982). High values of Cyperaceae and Gramineae pollen in the spectra and low values of selected pollen ratios (Fig. 6.24) indicate that herbs were the most important elements in the vegetation during this time interval. Analysis of the dated peat sample at the bank of Tahgah River (LV-1470, Geurts, 1986a) produced a similar herb-dominated pollen spectrum, which suggests that herbaceous tundra prevailed in the area prior to 9,700-10,000 yr BP. Although the Betula percentage is high enough to indicate a wide spread of birch in the area, its relatively low pollen accumulation rate suggests that birch was not an important element in the vegetation. Salix and Juniperus values suggest that these two taxa were widely present in the paleovegetation.

Pollen zone 2 represents a time interval during which the area was covered by dwarf birch shrub-tundra from an extrapolated date of 10,000 yr BP to about 8,000 yr BP. Pollen spectra of this zone greatly resemble the birch zone pollen spectra in the northern and southwestern Yukon (Ritchie, 1982; Cwynar, 1982; Rampton, 1971), Northwest Territories (Ritchie and Hare, 1971; Ritchie, 1977), Alaska (Livingstone, 1957; Ager, 1975; 1982) and modern pollen spectra from shrub-tundra

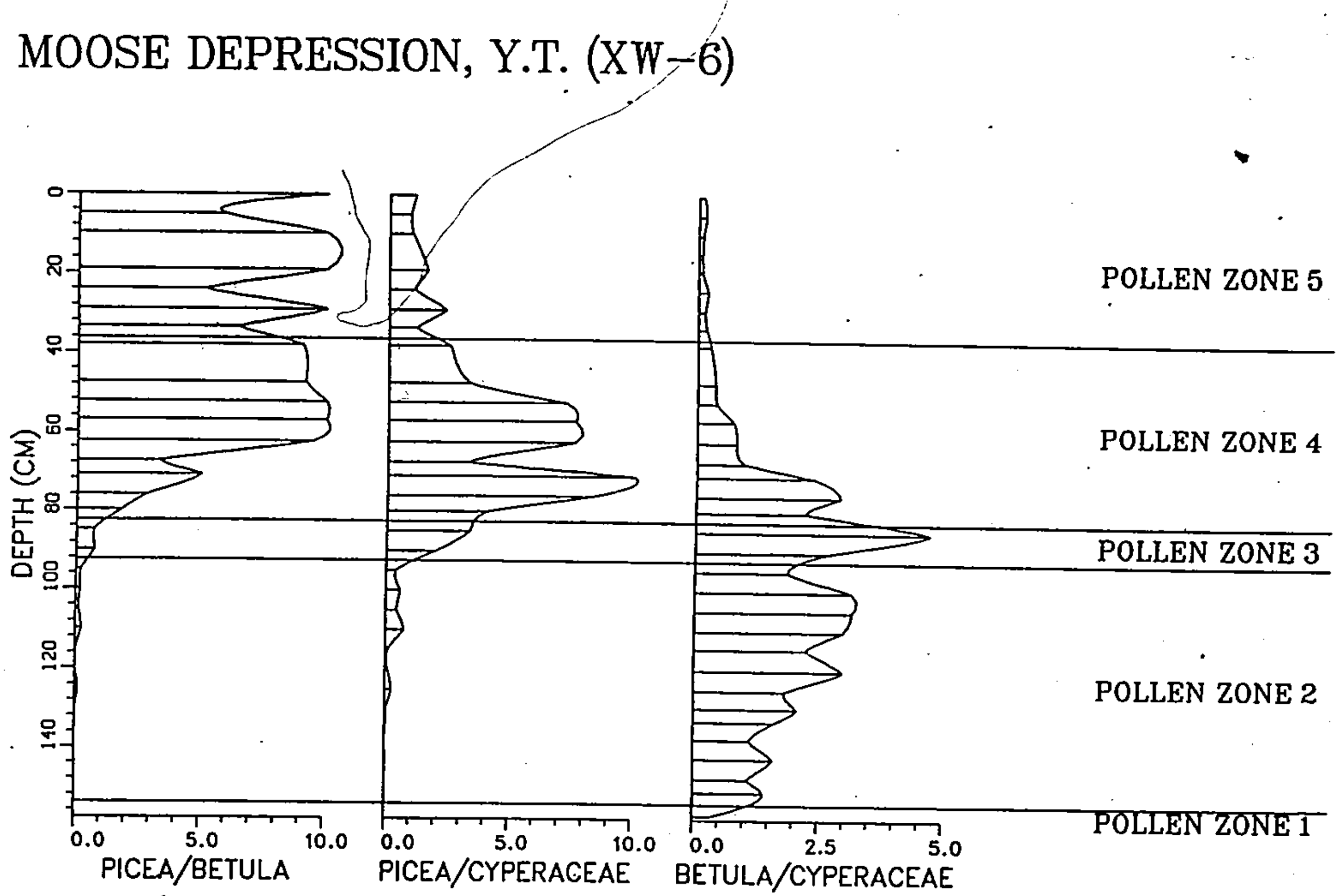


Figure 6.24 Selected pollen ratios of profile Moose Depression (XW-6)

areas of Alaska and northwestern Canada (Colinvaux, 1964; Ritchie, 1974; Birks, 1973). Both percentages and accumulation rates indicate that dwarf birch was the most important element in the paleovegetation during this interval. High values of Gramineae and Cyperaceae in the lower part of the zone, however, suggest that herbs were wide spread near the depression. Moderate values of _Juniperus_ and Rosaceae, common elements of modern shrub-tundra vegetation-landform unit in the area, indicate that those two taxa were common in the area. Increasing values of the _Betula_ _vs_ Cyperaceae ratio (Fig. 6.24) indicate the change in relative importance between shrubs and herbs along with the development of landform and vegetation. Consistent and moderate values of _Myriophyllum_ in this zone suggest that the water level of this pond during the zone 2 time interval was relatively stable. Most modern shrub-tundra spectra have considerable _Picea_ pollen due to long distance transportation. Extremely low values of spruce pollen in the lower part of the zone suggest that spruce was absent from the area until 8,600 yr BP. The first significant representation of _Picea_ pollen higher than 10% at 8,600 yr BP suggests the invasion of spruce into the area. This conclusion is consistent with the pollen records from other profiles in the area. Pollen zone 2 was deposited during approximately the same time interval as pollen zone 4 in the Antifreeze Pond area. The pollen spectra of these two profiles in this interval greatly resemble each other, which suggests that a similar vegetation pattern existed over a relatively large area.

Pollen zone 3 represents a short-lived interval during which spruce forest-tundra occupied the area. Abrupt rise of spruce pollen to more than 30% indicates the wide distribution of spruce in the area. Betula was still an important element of the paleovegetation as suggested by its significant value. The basic features of the vegetation during this period are similar to those preceding except for the increase of spruce density and decrease of herbs in the area.

Pollen zone 4 represents a time interval during which the central Aishihik Basin was covered by a dense spruce forest. This interval ranges from about 7,600 yr BP to 5,700 yr BP. Gradual decrease of Betula and increase of Picea indicate the replacement of the vegetation cover in the early stage of this interval. High Picea percentages and accumulation rates suggest that spruce was the most dominant element in the paleovegetation. It is well shown by the results of PCB and CA that the sample cluster of zone 4 perfectly overlaps that of the modern forest vegetation-landform unit, which indicates the great resemblance between these two groups. This interval is approximately the same age as the upper pollen zone 5 of the Antifreeze Pond profile, but the pollen spectra of these two sites have distinct differences. The Antifreeze Pond area was covered by a spruce woodland with a high value of *Betula* pollen. Records from Moose Depression have no such a high representation of birch pollen, which in fact decreases quickly at the beginning of this interval. Meanwhile, *Picea* pollen values in the Moose Depression profile are twice as high as those from Antifreeze Pond. These differences probably indicate that the vegetation during this time interval was somewhat different in these two localities even though they are only 180 km from each other. The vegetation or the forest density was higher in the central Aishihik Basin area than in the Antifreeze Pond area. It is notable that *Juniperus*, Rosaceae, and *Equisetum* have considerable representation in this zone. Usually the presence of these taxa in pollen records represents an open habitat, therefore the forest interpretation may not be relevant. However, these taxa may also represent a nearshore community, as exists today in the area. The replacement of *Sparganium* for *Myriophyllum* probably reflects the change of water table of the pond which may suggest a shallowing trend.

Pollen zone 5 represents a time interval from 5,700 yr BP to present during which the regional vegetation shows little change from before. It is notable that *Picea* pollen values decrease about 20%, accompanied by a dramatic decrease of absolute pollen accumulation rates. Visual inspection and empirical analysis of the pollen spectra of this zone indicate that the decrease of spruce pollen is mainly caused by the increase of Gramineae and Cyperaceae which are local elements. Meanwhile, all aquatic taxa lose their pollen representation in this zone, which suggests a sedimentary facies change by pure palynological evidence. Results of sediment analysis and organic content determination suggest that the organic silt is replaced by organic peat at 35 cm, which indicates a facies change also. Therefore it is clear that the decrease of spruce pollen is due to the change of local community without variation of regional vegetation cover. As a result of overrepresentation of bog-forming elements, i.e. Cyperaceae and Gramineae, *Picea* percentage was strongly suppressed. It is possible to test this hypothesis by constructing an AP pollen percentage diagram (Fig. 6.25), on which several non-arboreal taxa are also represented, as the percentage of a pollen sum only includes arboreal types (Faegri and Iversen, 1975). On this diagram *Picea* percentage shows no obvious change from before, indicating that local elements may have a strong influence on the representation of regional pollen rain. Therefore great caution must be taken when interpretation of such a pollen sequence is attempted. Comparing the pollen accumulation rate and pollen concentration data, it seems that the decrease of pollen accumulation rate is related to the decrease of sedimentation rate. If the general input of pollen grains to the sedimentary basin does not change, a decrease of sedimentation rate should be accompanied by an increase of pollen concentration rate. However, this is not the case in the

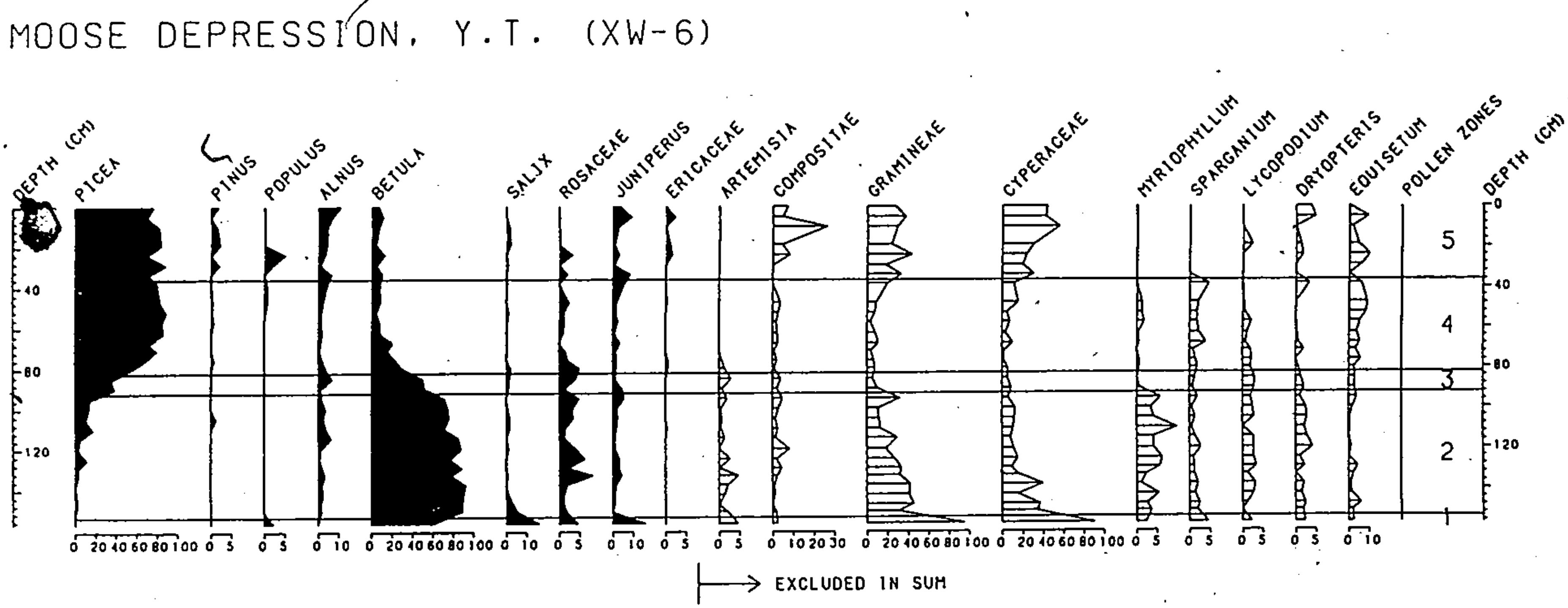


Figure 6.25 A summary pollen percentage diagram of profile Moose Depression (XW-6) using a sum of tree and shrub pollen

Moose Depression profile. This result leads to the conclusion that pollen accumulation rates in peat bog sediments may not be directly comparable to those in lacustrine sediments. As proposed in the previous chapter, lacustrine environments may have larger accumulation areas than peat bogs, which directly influence the accumulation rates of pollen grains to the sediments.

6.4.9 Summary and Conclusion

In summary, pollen profile XW-6 from Moose Depression in the central Aishihik Basin provides palynological evidence for the environmental evolution of the area during the post-glacial period. After the last deglaciation, a stagnant dead ice pond on the former proglacial Aishihik Lake terrace was surrounded by herbaceous tundra vegetation. This vegetation cover was soon replaced by a dwarf birch-dominated shrub-tundra at approximately 10,000 yr BP, as happened in other localities in northern environments. Spruce invaded the area at about 8,600 yr BP, and had its first dramatic rise at about 8,000 yr BP, which indicates a forest-tundra environment existed in the area. The second jump of Picea pollen values at about 7,600 yr BP marks the establishment of a spruce forest environment in the area, which has been stable until the present. A sedimentary facies change at about 5,700 yr BP has been documented by pollen records as well as sediment analysis.

Since then the cored depression has been a marsh to peat bog environment.

It is well documented by the pollen records in zone 4 and zone 5 that local vegetation elements can strongly suppress the representation of regional pollen rain if the sedimentary environment is favorable for such local and ultralocal elements. Change of pollen content can be caused, therefore, not only by the variation of climate or development of vegetation succession, but also by the development or variation of local environments such as the closing of lakes or ponds and developing of peat bogs. It is also concluded that pollen accumulation rates determined from different sedimentary environments such as peat and lacustrine sediments may not be directly comparable.

6.5 Postglacial Paleoenvironmental History: Correlation and Conclusion

Pollen records from the central Aishihik Basin area document a broadly similar environmental history to that of the northern basin and its vicinity. The great similarity of pollen records between the sequences makes the correlation relatively simple (Fig. 6.26). The initial vegetation cover in the central basin was a typical herbaceous tundra which ended at about 10,000 yr BP and was followed by a birch-dominated shrub-tundra. Spruce invaded the area between about 9,000 yr BP (XW-

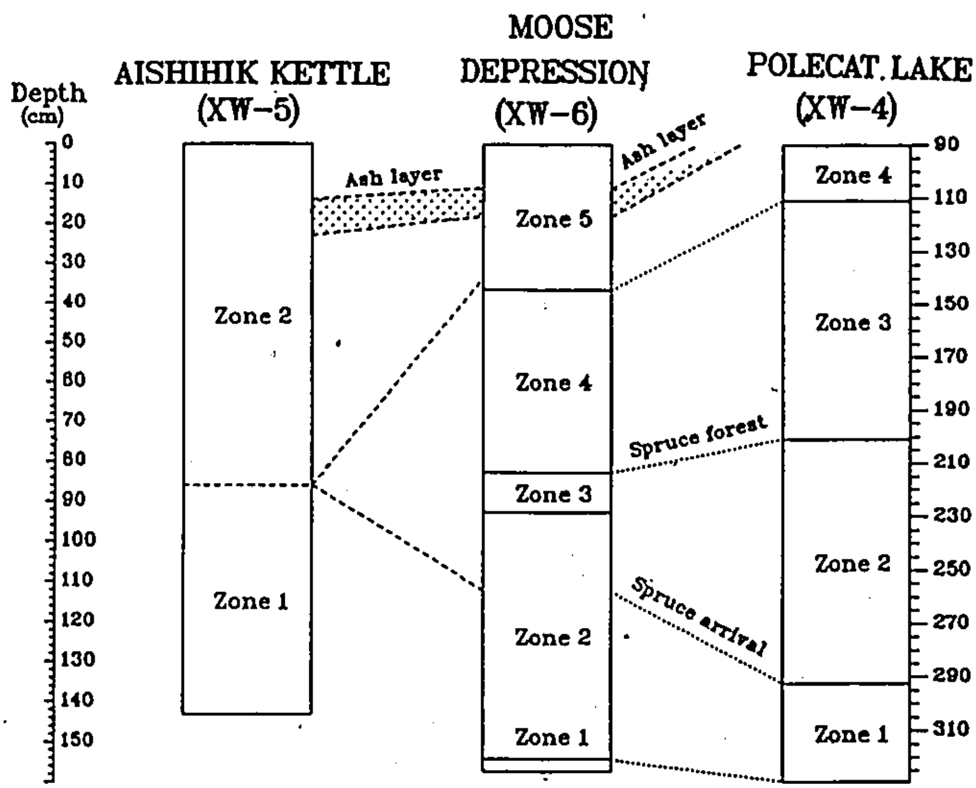


Figure 6.26 Correlation of pollen sequences in the central Aishihik Basin

4) and about 8,600 yr BP (XW-6), which is approximately the same as suggested by other pollen sequences. The different spruce arrival times in the area seem to be caused by extrapolation or estimation of the dates. The error of extrapolated dates could be larger than the time transgressive event.

By about 7,500-7,600 yr BP the area was covered by a dense spruce forest. This conclusion is consistent with results from the northern part of the basin, where an obvious spruce rise was documented around 7,700-8,000 yr BP. As discussed in the previous chapter, this event was somewhat earlier than that in the Antifreeze Pond area. At about 5,900 yr BP the local depositional environment changed from a pond to peat bog or marsh in the Polecat Lake area, and shortly after or even at the same time at about 5,700 yr BP the pond of Moose Depression was closed also. Previous study (Geurts et Dewez, 1985) suggested that the Aishihik Pingo was uplifted after the establishment of central Aishihik forest in the area. Disturbance of sediments around 5,700 yr BP and spurious ^{14}C dates have been recorded from the Upper Mackintosh Creek area (Beaudet, 1986), and change of sediment texture around 5,400 yr BP has also been visible from the pollen profile at Williscroft Creek (de Bastiani, 1988). These almost simultaneous events in such a small area may not necessarily be a coincidence, but are probably related to climatic change or other environment factors.

General environmental conditions in the area seem to have been stable after 5,700 yr BP as suggested by the pollen records of XW-5 and XW-6. However, such a suggestion is not possible in the Polecat Lake area due to the lack of pollen records. Rampton (1971) has reported that the tree line advanced in the Antifreeze Pond area at least three times during the last 5,700 yr BP according to the macrofossil records. Such a variation in vegetation cover, however, is not documented in the pollen records from the central Aishihik Basin, which is the same situation as in Antifreeze Pond area.

Chapter 7

Post-glacial Pollen Records in the Ittlemit Lake Basin

7.1 Introduction

Ittlemit Lake area is between the Aishihik Basin and Ruby Range. Palynostratigraphic study of this area has two purposes: 1) to fill a large gap in the geographic coverage of pollen records within the general study area, and 2) to search for the relationship between pollen records and local environmental conditions since the site is situated in a small basin at a relatively high elevation. Vegetation in such an environment relies not only upon climatic conditions but also upon geomorphological processes and landform.

The specific problems examined in this study include the nature of vegetational changes over time and the relationship between pollen records and environmental conditions.

7.2 Site Description and Present Vegetation

Samples of profile XW-7 were collected from a wet peatland near the northwest end of Ittlemit Lake at 61°13'35" N Lat., 137°12'53" W Long., at an elevation of 1180 m.a.s.l. (Fig. 3.1, 7.1). The core site is located at the southwest end of a flat lowland near the north end of Ittlemit Lake. A series of moraine ridges are scattered in the lowland area and in adjacent gullies. On the southeast-facing slope of northern bedrock peaks, extensive old channels and other lateral structures of glacial activities are present.

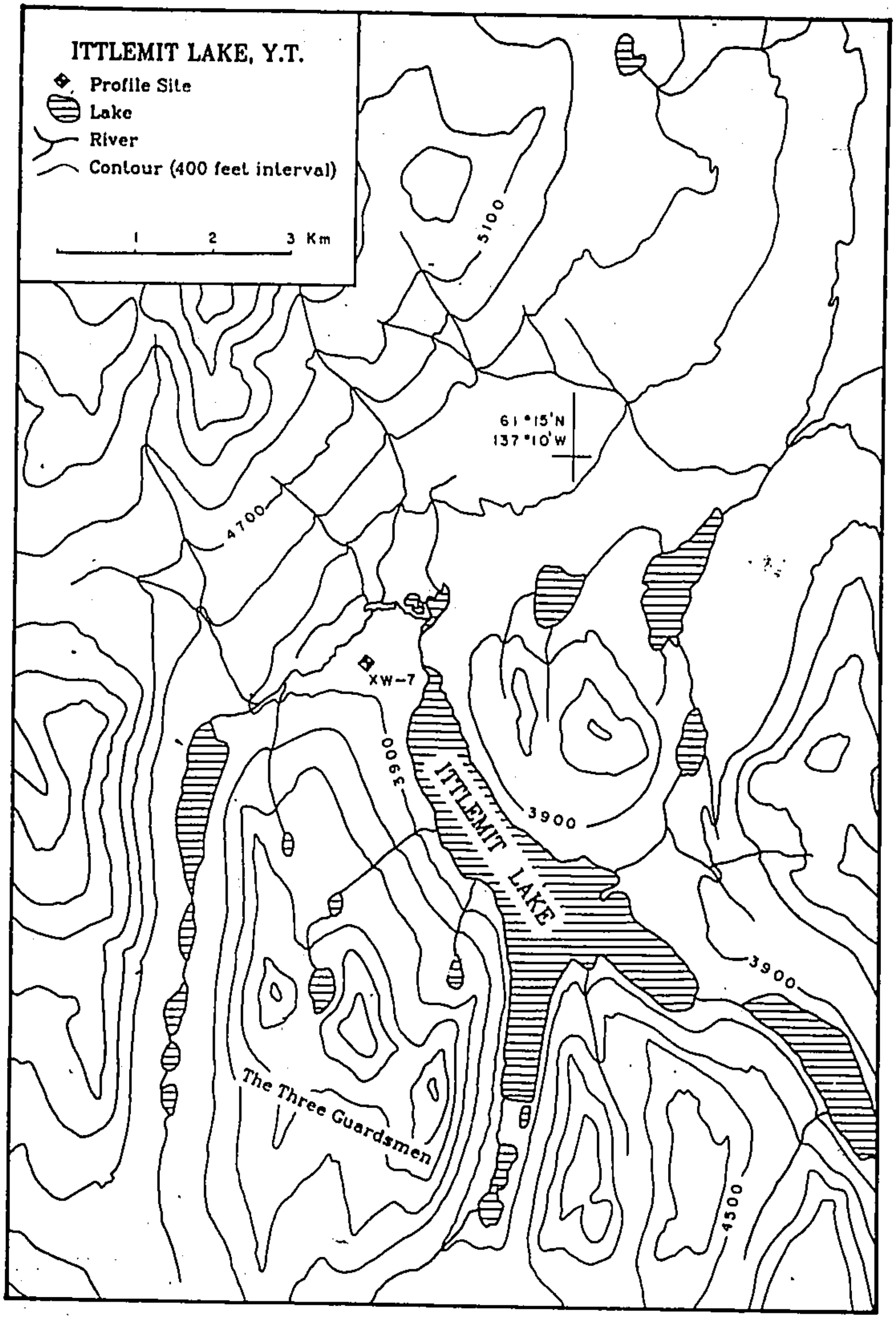


Figure 7.1 Map of Ittlemit Lake Basin showing fossil pollen site and topography

The present vegetation in the area is classified as a sparse white spruce (Picea glauca) forest-tundra environment. An obvious vertical zonation of vegetation cover on the northeast-facing slopes was observed. Forest-tundra on the foot of slopes consists of 5% Picea glauca, 15-70% Betula glandulosa, 5-10% Salix glauca, and 15-60% Ericaceae. With increased altitude, forest-tundra is replaced at about 1,220 m by high shrub-tundra which consists of about 60% Betula glandulosa, 20% Salix glauca, and 15% Ledum groenlandicum. Low shrub-tundra occurs at about 1,370 m and consists of approximately 40% Betula glandulosa, 40% Salix glauca, and 15% Vaccinium sp. The shrubs in this zone are less than 0.5 m high. Dryas tundra occurs above ca. 1460 m and consists of 60% Dryas hookeriana and 30% bare ground. Compositae, Saxifraga sp., Betula sp. and Salix sp. are also present. In the lowland area, spruce forest-tundra covers the well-drained glacial deposits, while an Eriophorum sp. wet community occupies all wet ground. Betula glandulosa or Salix glauca patches occupy all moderately drained areas. At the core site, Eriophorum sp. covers about 80% of the ground. Betula glandulosa patches exist only a few metres away from the core site. Salix glauca and Potentilla fruticosa are also present in the vicinity.

7.3 Sediment Stratigraphy

The sediments in this profile consist basically of organic peat with variable lithic content and humification. White River ash grains are scattered above and below the 20 cm horizon. Extensive ice lenses occur between 40 and 43 cm. At the 63 cm and 83 cm horizons, the peat becomes very unhumified or woody with long fibers.

Beneath 131 cm, lithic material starts to increase. From 154.5 cm to 206.5 cm, the sediments change to an organic silt with extensive ice lenses between 177 and 180 cm and fine sands between 182 and 185.5 cm. Fibric peat occurs from 206.5 cm down to an occurrence of coarse sand with organic material at 222 to 226 cm. Organic silt with ice lenses occurs between 226 and 234 cm, and fibric peat occurs between 234 and 238 cm. At the bottom of the profile, organic fibers with sand occur from 238 to 240 cm. The detailed stratigraphy of this profile is sketched on the pollen diagram.

7.4 Radiocarbon Dates and Sedimentation Rates

Four segments of the core were submitted for ^{14}C dates to establish the absolute chronology of the pollen sequence. The stratigraphic positions of dated samples are approximately similar to the changes of pollen spectra so that the chronology of events reflecting environmental

Table 7.1 ^{14}C dates of profile XW-7

Lab number	Sediment Interval	^{14}C dates	Material
UQ-1445	5.0-13.0 cm	490 +/- 170 yr BP	peat
UQ-1444	68.0-74.0 cm	2950 +/- 100 yr BP	peat
UQ-1443	149.0-154.5 cm	5000 +/- 100 yr BP	peat
UQ-1374	232.0-240.0 cm	8850 +/- 200 yr BP	peat

Table. 7.2 Sedimentation rates of profile XW-7

Core interval (cm)	Time interval (yr BP)	Mean sedimentation rate (cm/yr)
0.0 - 9.0	0 - 490	0.01837
9.0 - 71.0	490 - 2950	0.02443
71.0 - 153.0	2950 - 5000	0.03829
153.0 - 236.0	5000 - 8850	0.02088
236.0 - 240.0	8850 - 9031 *	0.02088

* Extrapolated

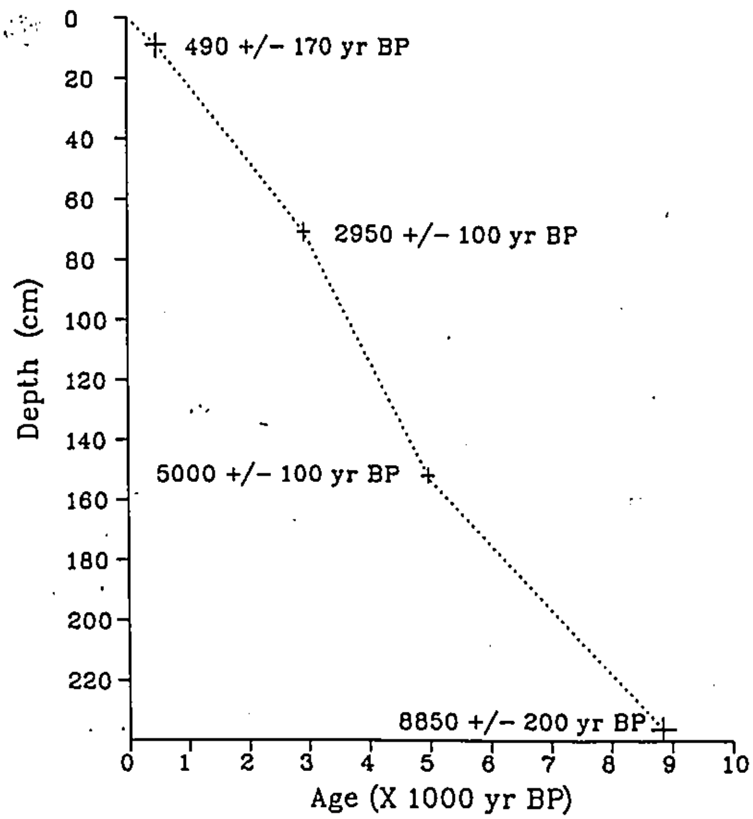


Figure 7.2 Relation of ^{14}C dates vs depth for profile XW-7, Ittlemit Lake area

variation can be estimated more accurately. The results of the dating are listed in table 7.1.

Sedimentation rates were determined using the relation of the four ^{14}C dates with depth (Fig.7.2). The results (Tab. 7.2) are used to determine absolute pollen accumulation rates. White River ash however, was not used in this profile because of its poor preservation.

Ice lenses in this profile are extensive and its contents vary throughout the section. Therefore, a modification of the sedimentation rates was applied following the method described in chapter 3.

7.5 Relative Pollen Frequency Diagram

The results of pollen analysis are represented in a relative pollen frequency (pollen percentage) diagram (Fig. 7.3). Numerical procedures, *i.e.* CONZONE, CONISS, and ZONATION, were employed to zone the pollen diagram with a data matrix of pollen percentages including *Picea*, *Alnus*, *Betula*, *Salix*, Rosaceae, *Juniperus*, Ericaceae, Gramineae, Cyperaceae, *Lycopodium*, *Dryopteris*, and *Equisetum*, because of their relatively abundant occurrence. Four major site-pollen-zones were recognized with zone boundaries at 40.0 cm, 76.5 cm, and 157.0 cm (Fig. 7.3 and Fig. 7.4).

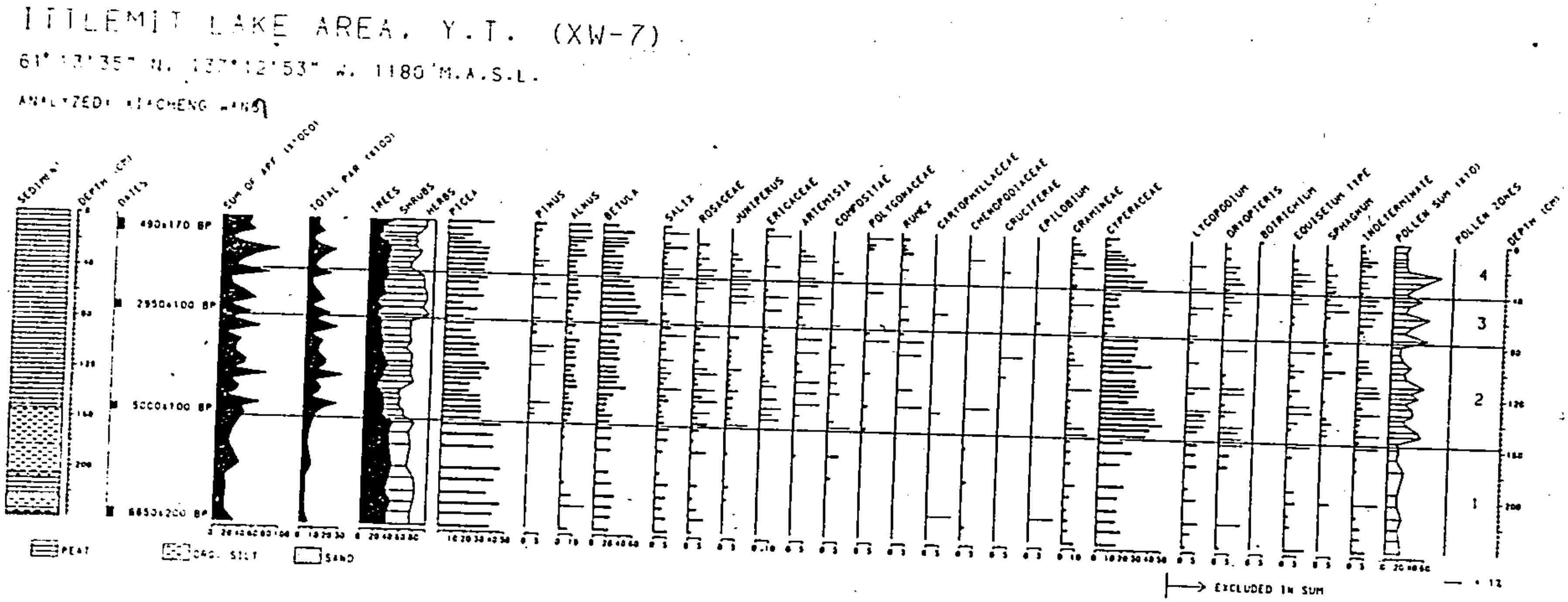


Figure 7.3 Pollen percentage diagram of profile XW-7 at the Ittlemit Lake area

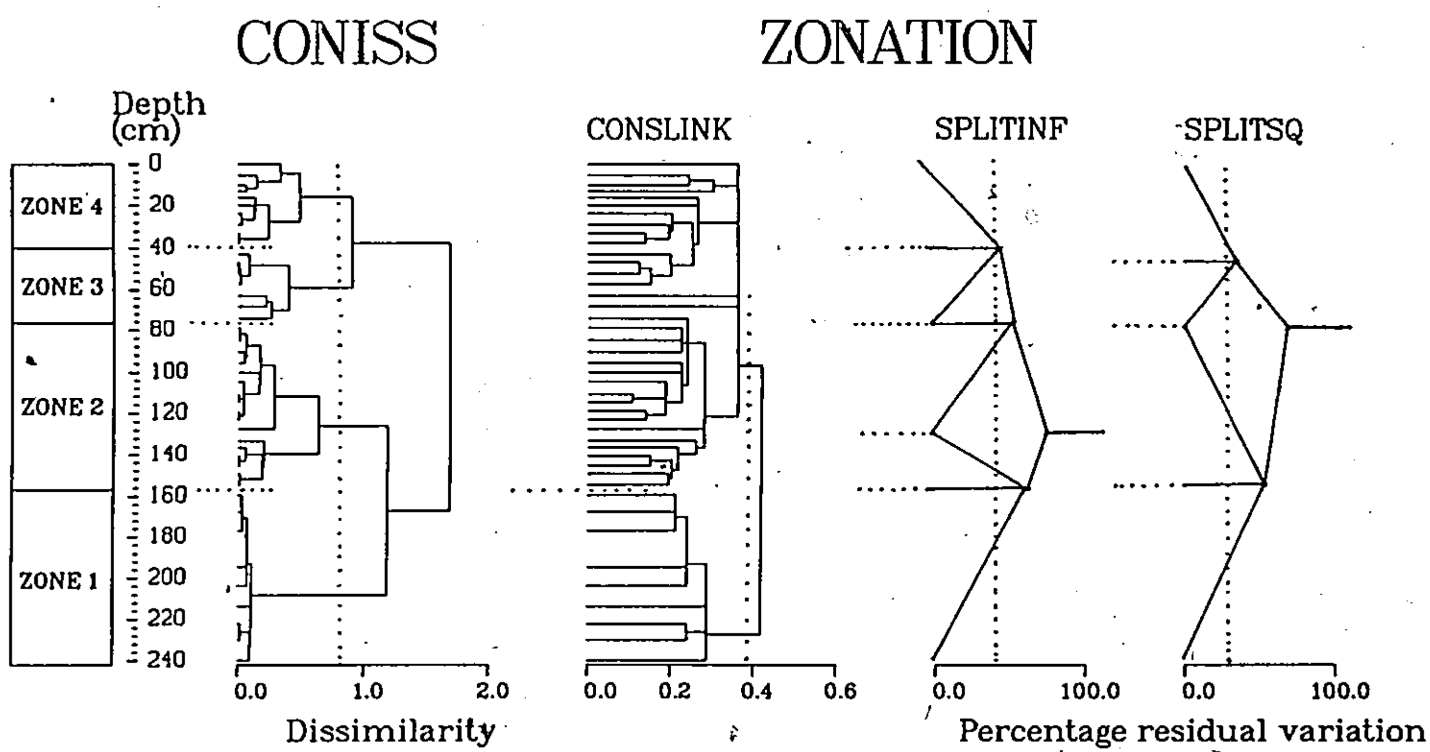


Figure 7.4 Dendrograms of zonation procedures of profile XVI-7

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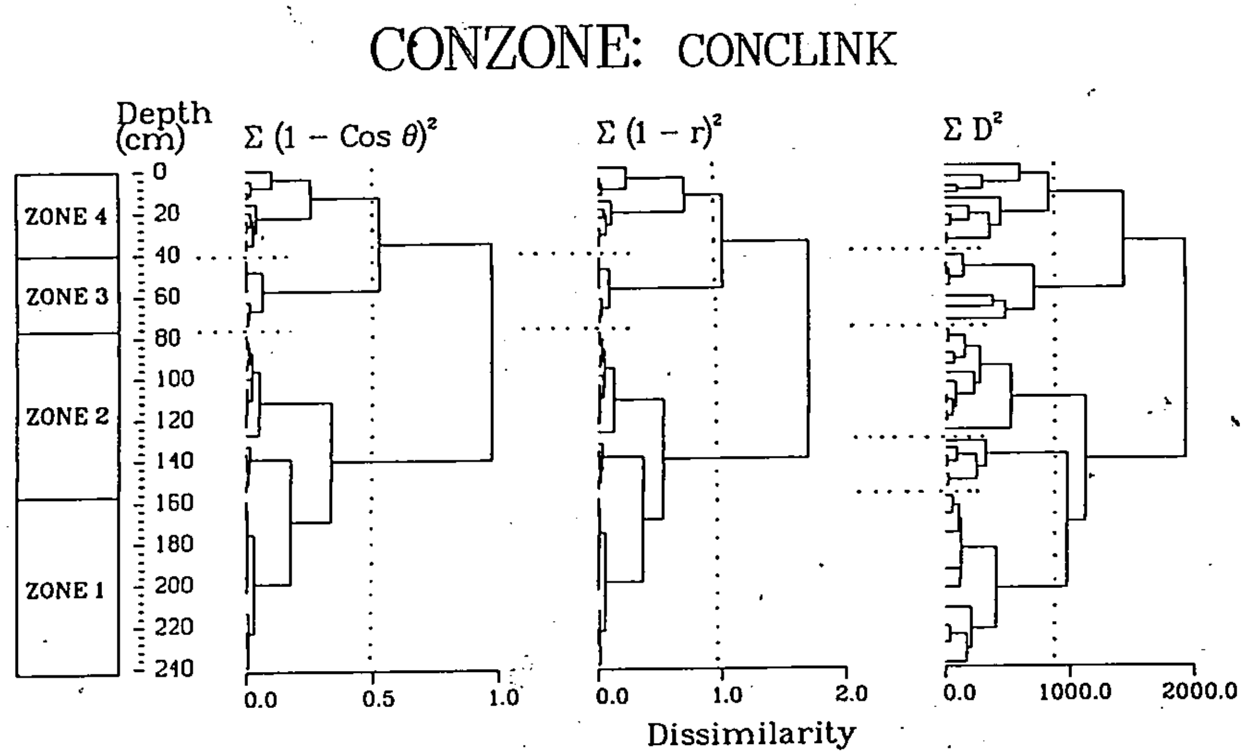

Figure 7.4 (Continued)

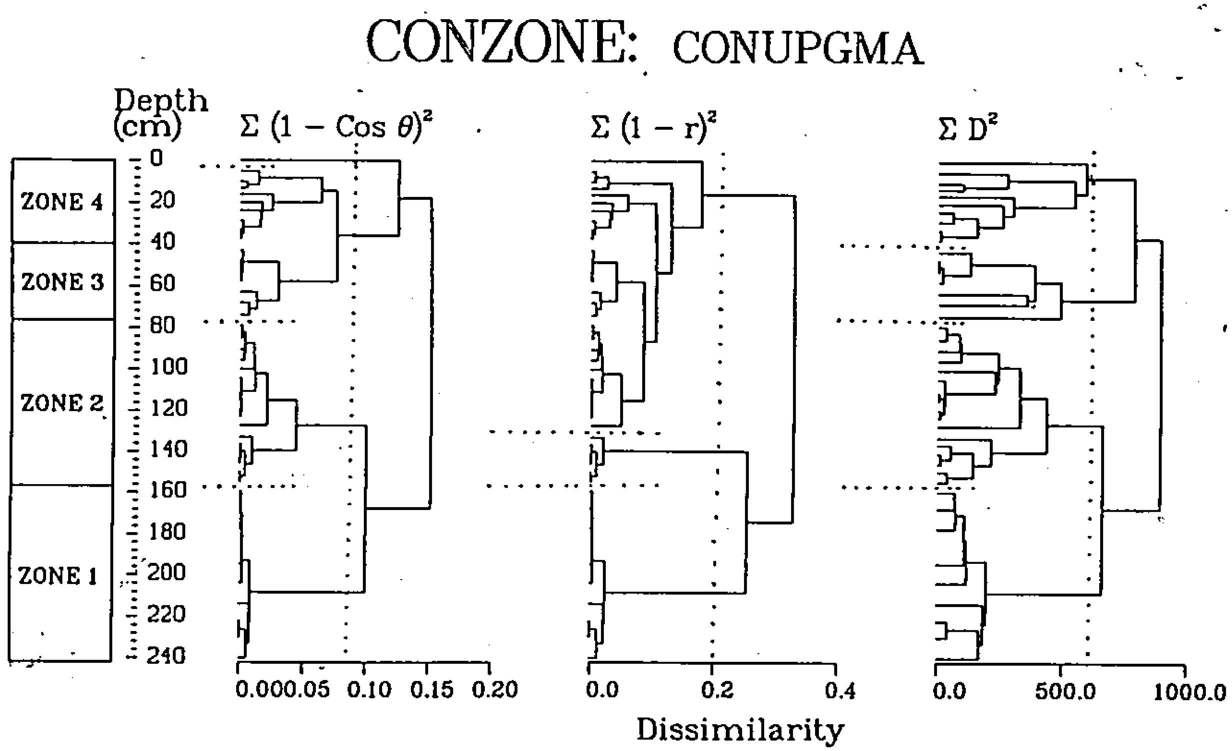

Figure 7.4 (Continued)

ZONE 1 (157.0 cm - 240.0 cm): ZONE 1 is characterized by high Picea and shrub pollen which are about 36-46% and 22-46% of the total respectively. Betula is the most dominant shrub in the pollen spectra with values around 20-30%. Salix values are consistently around 2-5%, its highest occurrence in the profile. Rosaceae percentages range from zero in one sample to 6%, ca. 2% in most cases. Alnus is only occasionally observed. Herbaceous pollen accounts for about 18-32% of the total pollen percentages with a mean of 24.5%. Cyperaceae are the most abundant herbs with percentages ranging from 14.4% to 25.6% and 17.9% on average. Gramineae percentages are consistently around 5%. Other taxa are not significantly present. In the pteridophyte group, Lycopodium has its best occurrence here in the profile with values around 4%. Equisetum also has its best occurrence here with values between zero and 7.8%.

ZONE 2 (76.5 cm - 157.0 cm): The most striking feature of zone 2 is the rise of Alnus pollen percentage and high values of Cyperaceae. Tree pollen, namely Picea, is lower in percentage than before, varying from 19.4% to 34.4% with a mean of 26.3%. Shrub pollen varies from 21.7% to 54.0% of the total pollen percentage with a mean of 37.7%. Alnus pollen percentages rise from 1% at the top of zone 1 to 10.6% in zone 2 with a mean of 6.8%. Juniperus has its best occurrence in this zone with values from zero in a few samples to about

1-2% in most samples. Rosaceae decrease somewhat with values around 1.5%. The performance of other taxa, might suggest further subdividing of the zone into lower and upper parts bounded at 130.3 cm (Fig. 7.3, Fig. 7.4). Although the values of Salix and Gramineae decrease and Cyperaceae and Ericaceae increase in comparison with those in zone 1, Salix and Cyperaceae percentages are higher in the lower part of zone 2 than in the upper part, while Betula, Ericaceae, and Gramineae values are higher in the upper part of the zone. Betula values vary from 11.4% to 23.2% in the lower part and from 26.6% to 42.0% in the upper part with means of 17.3% and 29.5%, respectively. Salix values range from 0.24% to 3.9% with a mean of 2.0% in the lower part and from about 0 to 3.6% with a mean of 1.2% in the upper part of the zone. Ericaceae values are less than 1% in the lower part while consistently around 2% in the upper part. Cyperaceae are the dominant taxon in this zone with very high values of ca. 27.0% in the upper part of the zone.

ZONE 3 (40.0 cm - 76.5 cm): Picea values in zone 3 vary from 13% to 31% with a mean of 22.5%. Alnus percentage is similar to before, ranging from 4% to 10% with a 7% mean. Betula is more important in this zone with values between 42% and 75% (54% mean). Cyperaceae percentages are very low, ranging from 3.4% to 13% with a mean of 8.7%. All other taxa are not significantly represented in this zone and values are very low.

Zone 4 (0 cm - 40.0 cm): Zone 4 is characterized by a rise of Cyperaceae and _Salix_ percentages and a decrease of _Betula_ values. Cyperaceae vary from 10% to 32.5%, except for one sample at 3.3%. The mean is about 20%. Gramineae values are higher than before, especially in the top part of the zone, where values range up to 11%. The mean is around 4.3%. _Rumex_ occurs extensively in the top few samples with values around 2.5%. _Salix_ values increase in this zone, from zero in one sample to 8.8% as maximum, about a 2.3% mean. _Betula_ is much less important, ranging from 18.4% to 46.9%, with a mean of 31.5%. _Alnus_ experiences a large increase in values in the upper part of the zone, ranging consistently from 12-18%. _Pinus_ occurs irregularly in this zone, ranging from 0.4% to 1.8% in the first peak and from 1.55 to 4.4% in a second peak. _Picea_ values, however, are similar to before.

7.6 Absolute Pollen Accumulation Rates

The exotic marker method was employed to estimate the absolute pollen accumulation rates (PAR) and the results are illustrated in figure 7.5. The accumulation rate diagram is divided into site-zones following the percentage diagram.

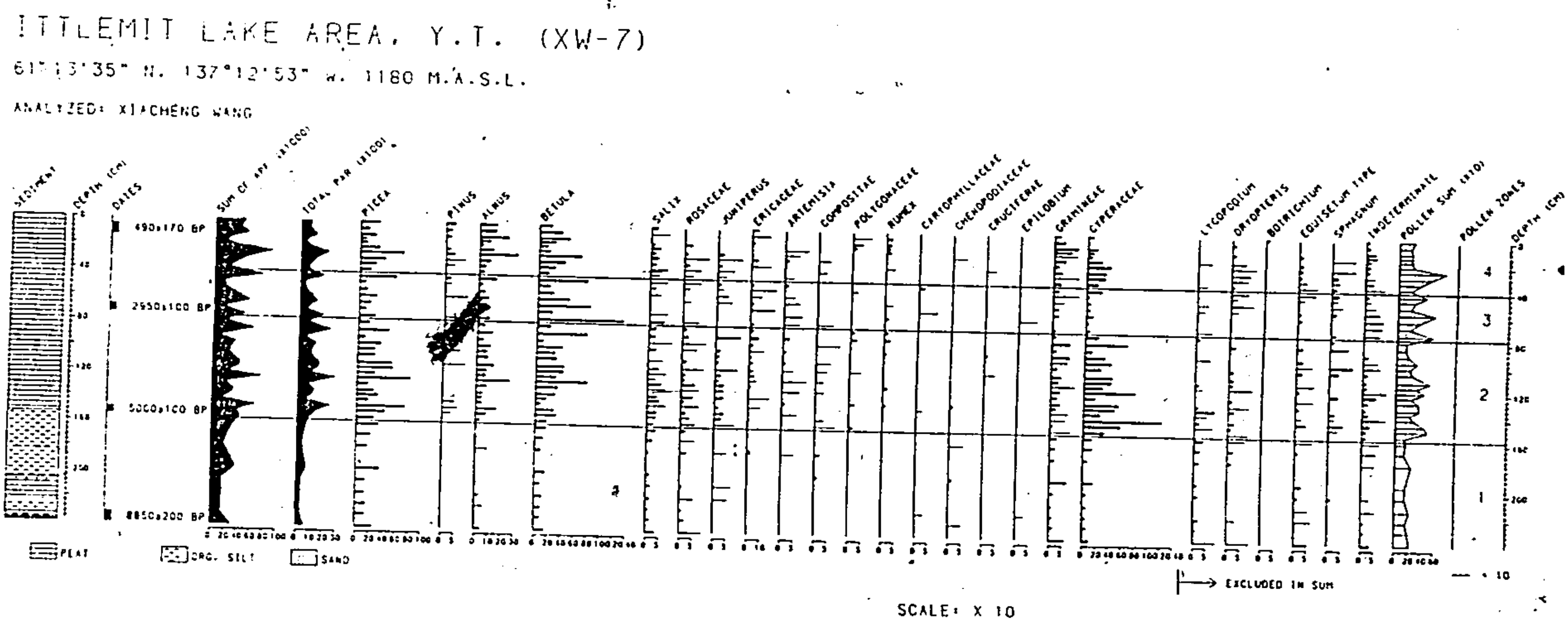

Figure 7.5 Absolute pollen accumulation rate diagram of Profile XW-7 at the Ittlemit Lake area

ZONE 1: The total pollen accumulation rate of zone 1 varies from 360 to 800 grains/cm²/yr, with a mean of about 520 grains/cm²/yr, while the concentration value is 17 - 38 x 10^3 grains/cm³. *Picea* pollen accumulation rates are 143 - 366 grains/cm²/yr with a mean of about 220 grains/cm²/yr. *Alnus* values vary from zero to 45 grains/cm²/yr, and the *Betula* values are between 90 and 175 grains/cm²/yr with a mean of 125 grains/cm²/yr. *Salix* values range from 10 to 36 grains/cm² with a mean of about 20 grains/cm²/yr. The Rosaceae values vary from zero as in the percentage diagram to 56 grains/cm²/yr with an average of about 18 grains/cm²/yr. Gramineae average about 29 grains/cm²/yr, while Cyperaceae fluctuate from 52 to 163 grains/cm²/yr, with a mean of 96 grains/cm²/yr. *Equisetum* values vary from 0 to 54 grains/cm²/yr, averaging 14 grains/cm²/yr. Other taxa have no significant occurrence or representation.

ZONE 2: The total pollen accumulation rate is around 1300 grain/cm²/yr, varying from 590 to 2500 grains/cm²/yr, which is about 2 to 3 times that in zone 1. Total pollen concentration also increases but not as much as the pollen accumulation rate, varying from 11 X 10^3 grains/cm³ to 75 X 10^3 grains/cm³ with a mean value of 36 X 10^3 grains/cm³. The pollen accumulation rates for most taxa vary little except for *Salix*, Gramineae, and *Lycopodium* which show relatively obvious differences in the upper and lower parts of the zone.

In the lower part of the zone, <u>Salix</u> values range from 4 to 44 grains/cm²/yr with a mean of 25 grains/cm²/yr. Gramineae vary from 6 to 37 grains/cm²/yr with a mean of 15 grains/cm²/yr. <u>Lycopodium</u> values are between absent in one sample and 78 grains/cm²/yr with a mean of 20 grains/cm²/yr. In the upper part of the zone however, <u>Salix</u> and <u>Lycopodium</u> values are much reduced. Values of willow vary from zero (one sample) to 52 grains/cm²/yr with a mean value of about 15 grains/cm2/yr. <u>Lycopodium</u> only occurs occasionally. Gramineae values are higher in the upper part of the zone than in the lower part, fluctuating from 6 to 70 grains/cm²/yr with a mean of 30 grains/cm²/yr, which is approximately twice as much as found in the lower part of the zone. <u>Picea</u> values vary from 164 grains/cm²/yr to 820 grains/cm²/yr through the zone with a mean of about 360 grains/cm²/yr. <u>Alnus</u> values range from a few grains at the top of zone 1 to about 258 grains/cm²/yr with a mean of about 90 grains/cm²/yr. <u>Betula</u> values range from about 80 to 790 grains/cm²/yr with a mean of 335 grains/cm²/yr. There is no obvious difference in <u>Betula</u> values between the upper and lower parts of the zone which provides a discrepancy with the relative pollen frequency. Other shrubs, namely Rosaceae, <u>Juniperus</u>, and Ericaceae, range from a few grains to several tens of grains/cm²/yr. Cyperaceae values, like <u>Betula</u>, also show no difference between the lower and upper parts of the zone. Values range between 110 and 792 grains/cm²/yr with an exception of 1,213 grains/cm^2/yr at the 145.5 cm level. The mean value of Cyperaceae is about 436 grains/cm^2/yr. The values of other taxa range from a few to several tens of grains/cm^2/yr where present.

Zone 3: Total pollen concentration in this zone varies between 9 X 10^3 grains/cm^3 and 74 X 10^3 grains/cm^3. The total pollen accumulation rate varies from 250 to 2100 grains/cm^2/yr. Picea values are lower in this zone, ranging from 120 to 650 grains/cm^2/yr. Alnus values vary between 20 and 160 grains/cm^2/yr. Betula values are extremely high, ranging from 270 to 1326 grains/cm^2/yr. Both Gramineae and Cyperaceae values are low in comparison with their values in zone 2. Other taxa are not significantly represented.

Zone 4: Total pollen accumulation rate in zone 4 is about 250 - 2500 grains/cm^2/yr, averaging 930 grains/cm^2/yr. Total pollen concentration is around 1.7 - 8.8 X 10^4 grains/cm^3. Picea values show little difference from before. Pinus values vary from a few grains to 40 grains/cm^2/yr where present. Alnus values are as high as 350 grains/cm^2/yr. Betula values are significantly lower than before, varying from 82 to 466 grains/cm^2/yr. Salix values are up to 33 grains/cm^2/yr. Gramineae values increase in this zone to about 30 grains/cm^2.yr. Cyperaceae have higher values in the lower part of zone, varying from 135 to 430 grains/cm2/yr, but lower values in the upper part of the zone (about 50 grains/cm²/yr). Other taxa are less important than those stated here.

7.7 Numerical Analysis

The results of Q-mode PCA (Fig. 7.6) provide useful information. The first five principal component axes account for more than 71% of total covariance of the data set. On the first PCA axis, which accounts for about 22% of total covariance, Betula has the largest negative value reflecting the dominant nature of birch pollen in zone 3 and relatively high values in zone 4 and the upper part of zone 2 (Fig. 7.4). It also explains the negative values of principal component scores of samples from these parts of the profile in the first PCA axis. This pattern is also the reflection of the consistent occurrence of Alnus pollen from the base of zone 2 where values quickly rose and stabilized. Alnus is the second taxon which has a high negative value on the first PCA axis. On the other hand, none of these 12 taxa has a comparable positive loading (>0.4) on this axis which makes interpretation difficult. However, moderate positive loadings of Lycopodium, Rosaceae, Picea, Gramineae, and Cyperaceae explain the positive sample scores of zone 1 on this axis, and explain the consistent occurrence and relatively high percentage of those taxa (except Cyperaceae which have relatively low values here compared with other zones). In

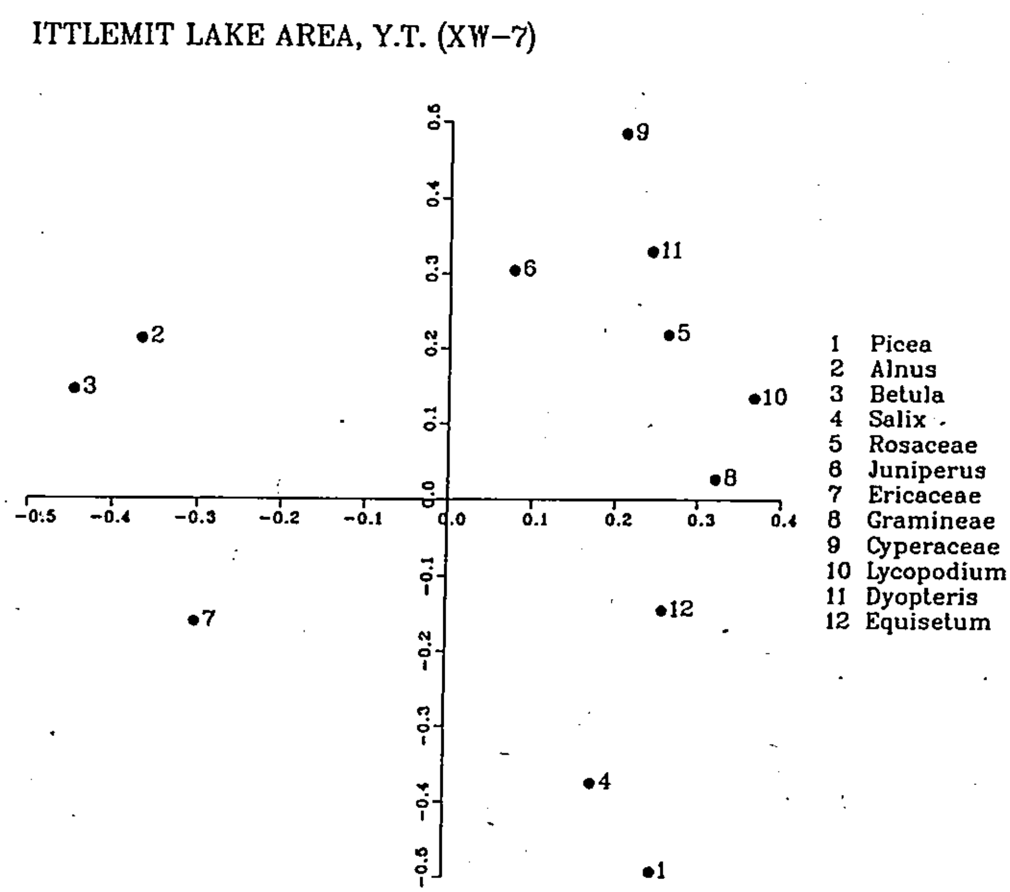

Figure 7.6a Principal component loadings of selected taxa on the first (horizontal) and second (vertical) PCA axes, profile XW-7, Ittlemit Lake area

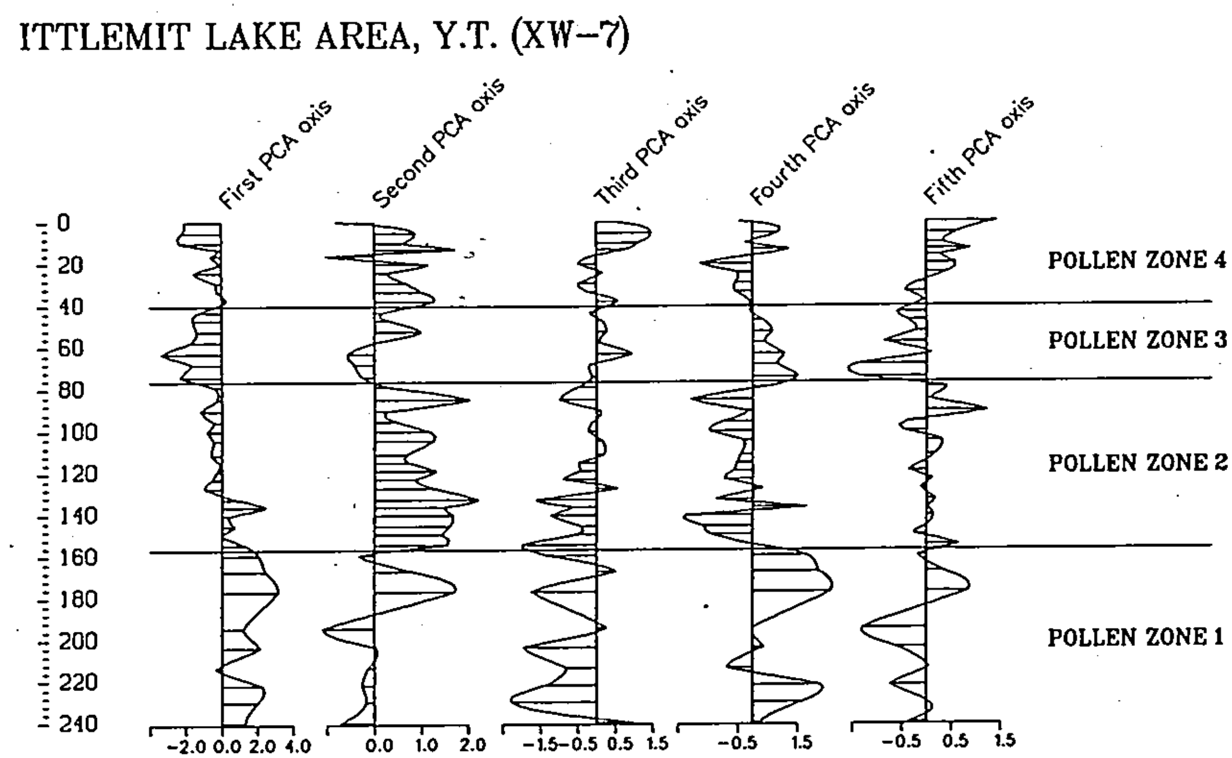

Figure 7.6b Principal component scores of profile XW-7 samples on the first five PCA axes, Ittlemit Lake area

contrast with the first axis, Picea has the highest negative loading and Cyperaceae have highest positive loading on the second PCA axis. This axis accounts for about 17.8% of total variation. Salix is the second taxon which has a high negative value, while Dryopteris and Juniperus loadings are also higher than 0.3. The results seem to suggest that high Cyperaceae pollen percentages are associated with low Picea pollen or vice versa. High positive scores of samples in zone 2 and zone 4 reflect the high Cyperaceae pollen percentages. It is worth noting that the consistent occurrence of Juniperus pollen in zone 2 is clearly reflected in its relatively high positive loading on the second PCA axis where samples in this zone all have high positive scores. The third PCA axis, accounting for about 12% of total covariance, has a high negative loading (-o.43) for Rosaceae and a high positive loading (0.58) for Gramineae. As a matter of fact, these two taxa have little significance in the total pollen percentage data, and thus, sample scores on the third PCA axis provide no significant pattern. Fluctuating negative scores may reflect the fluctuation of Rosaceae pollen percentages, and high positive scores for the top four samples in zone 4 reflect the high value of Gramineae in these samples. Although it only accounts for about 10.8% of total covariance, the fourth PCA axis provides interesting information. Consistent occurrence of Juniperus pollen in zone 2 is responsible for the very high negative loading of this taxon on the fourth axis, and explains the extensive occurrence of negative scores of samples from this zone. Lycopodium has the highest positive loading (0.45) which explains the positive scores of samples in the zone 1. Betula also has a high positive loading (0.38) and is probably more responsible for the positive scores of samples from zone 3 than Lycopodium. These four PCA axes account for about 63% of total covariance in the data set. The fifth axis, which only accounts for about 8.3% of total covariance, is not easy to interpret since it shows the combined results of Ericaceae, Salix, Alnus with positive loadings and Equisetum, Betula with negative loadings. Positive sample scores in zone 4 are probably due to Alnus and Salix, and negative scores in zone 1 related to Lycopodium. Low scores in zone 2 are more or less related to the fluctuation and low value of Ericaceae in the zone.

In summary, two conclusions can be drawn from the above discussion and the PCA results. Firstly, PCA is a powerful tool, as demonstrated here and in other sections of this monograph, that can be used to illustrate the variation in relationships between pollen taxa, and is sensitive to even minor variation of some low frequency taxa. This is typically illustrated in this study by the sample scores on the fourth PCA axis which reflect the consistent occurrence of Juniperus pollen in zone 2 even if this taxon has only a very low frequency in relation to the whole pollen data set. Other multivariate analysis techniques are not sensitive enough to show such a variation. In terms of the behaviour of different taxa on different axes, the first four PCA axes in this study might be named as 1) the Betula - Alnus axis, 2) the Picea-Cyperaceae axis, 3) the Rosaceae - Gramineae axis, and 4) the Juniperus axis.

Secondly, the PCA results (as illustrated in figure 7.6b), coincided quite well with the results of numerical zonation procedures. In other words, the zone boundaries defined in this study coincide well with the variation of sample scores on the first five PCA axes which account for most of the information in the data set. This confirms the zoning schedule in this study.

In comparison with PCA, PCB produces some different information beyond the points obtained from PCA. The results of PCB are shown in figure 7.7 which accounts for 78.3% of the total information, as measured by criterion C_2 (appendix E) as defined in Gordon (1982). The first axis of the ordination accounts for 50.3% of the data variation, and the second accounts for about 28.0%. It is clear that the most important taxa in this data set (in terms of pollen percentages) are Picea, Betula, and Cyperaceae as shown by the lengths of the vectors. The orientation of these three

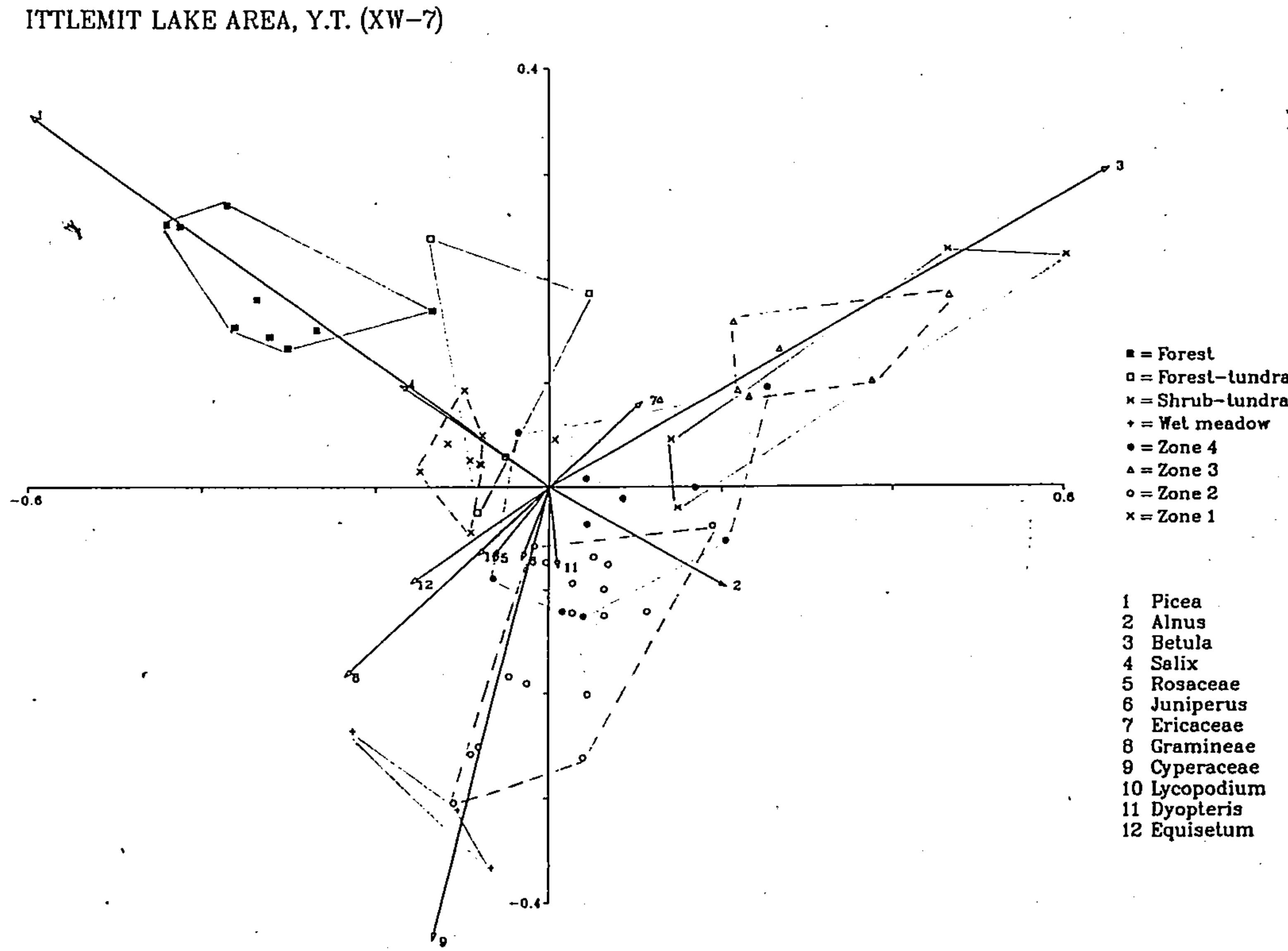

Figure 7.7 Ordination of combined data matrix of modern and fossil pollen samples on the first (horizontal) and second (vertical) PCB axes, profile XW-7, Ittlemit Lake area

vectors creates an interesting pattern, which suggest that these three taxa are essentially complementary to each other, or have negative correlation. An increase of any one will cause the decrease of the other two taxa. Gramineae, though much less important, behave similarly to Cyperaceae, and are complementary to Betula but have almost no relationship with Picea as suggested by the nearly orthogonal vectors. Salix, though having a low value, behaves similarly to spruce as demonstrated by the same orientation of these two vectors. Alnus, however, is complementary to Picea as suggested by its vector orientation which is opposite to the Picea vector. Comparing the results of PCB (Fig. 7.7) with the pollen percentage diagram (Fig. 7.3) shows that the PCB results are in agreement with the distribution pattern of these taxa. All samples in zone 1 form a cluster close to the forest-tundra cluster of surficial samples (Fig. 7.7). The most important taxa associated with this cluster are Picea and Salix. The second cluster or group of the samples is from zone 2, and is loosely distributed in the direction of Cyperaceae vector. This reflects the minor change of Cyperaceae pollen percentage in the zone. Another taxon associated with this cluster is Alnus. Two clusters of modern samples may be associated with this elongated cluster: wet-meadow samples at one end, and shrub-tundra samples at the other. It is clear that the sample cluster of zone 3 is spatially close to that of the modern shrub-tundra landform-vegetation unit. The taxon which is most responsible for this resemblance is *Betula*. *Alnus* also contributes and may be seen by projecting the samples on this vector. Zone 4 seems to present a type intermediate to the three previous zones. A few samples overlap the ranges of the other three zones. The most similar modern samples are those of shrub-tundra and forest-tundra vegetation-landform units. *Betula*, Cyperaceae, and *Alnus* are three important vectors related to this pattern. *Picea* and *Salix* are of secondary importance.

The results of CA, as illustrated in figure 7.8, provide a broadly similar pattern to that of PCB. The first axis of the ordination accounts for 61.9% of the data information, and the second axis accounts for 11.5%. The presentation of the ordination results on the first two axes will gather most information of the data set (up to 73.4%), and discarding of other axes will not lose much information. The similarity of PCB and CA results confirms the usefulness of both methods, thus providing greater confidence in the numerical results. However, a few minor differences do exist. Firstly, samples from different zones or vegetation-landform units are grouped more closely in the CA results, which better displays the similarity within each group. Secondly, samples from the wet-meadow vegetation-landform unit are placed far away from the other groups. The taxa responsible for this phenomenon in this combined data set are Gramineae and *Equisetum*. This

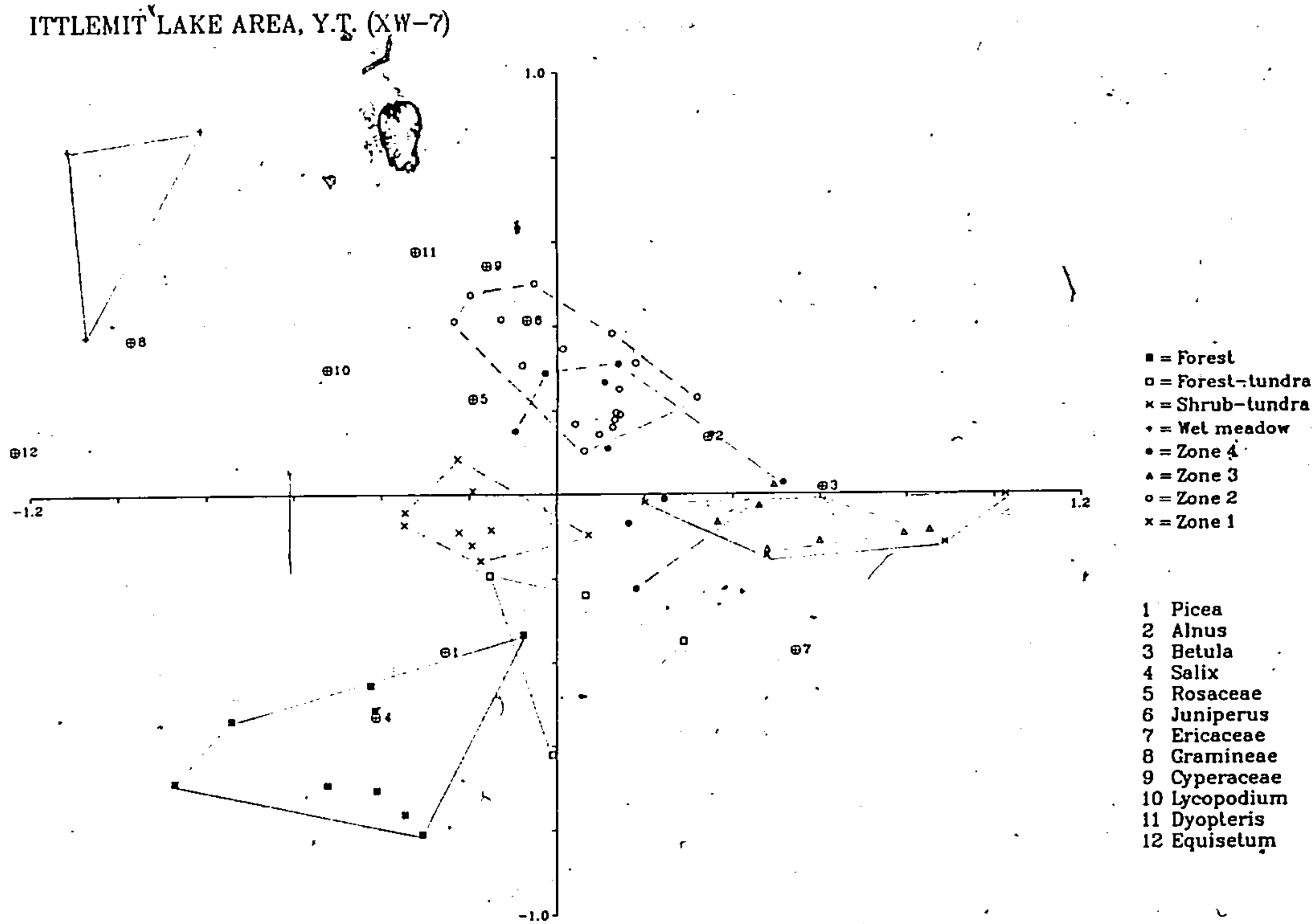

Figure 7.8 Ordination of combined data matrix of modern and fossil pollen samples on the first (horizontal) and second (vertical) CA axes, profile XW-7, Ittlemit Lake area

suggests that these two taxa are poorly represented in the data set except in the samples of the wet-meadow vegetation-landform unit. A comparison of figures 7.4 and 4.2 demonstrates that this interpretation is fully supported by the behaviour of these two taxa. Thirdly, as illustrated in figure 7.8, Juniperus correlates quite well with the sample cluster of zone 2, which indicates that this taxon is better represented in the pollen spectra of zone 2. This feature is not shown by PCB.

In conclusion, three different numerical analyses are used in this study, namely PCA, PCB, and CA, each of which provides quantitatively interpretable information with different emphasis based updn their own mathematical principles. This information is essential to the recognition and differentiation of the diagnostic characteristics of each local or site pollen assemblage zone. Thus such information forms the basis for understanding environmental history in this study.

7.8 Reconstruction of Paleoenvironment

The evolutionary history of the environment in the Ittlemit Lake basin during the last 9,000 radio-carbon years is preserved within pollen records of profile XW-7. This history may be divided into four stages, represented by four local or site pollen zones.

Zone 1 (ca. 9,000 BP - ca. 5,000 BP): During this time interval the Ittlemit Lake area supported a forest-tundra vegetation in which *Salix*, *Betula*, and Rosaceae were important components. High *Picea* percentage in this zone seems to suggest that spruce arrived in the area at least by 9,000 yr BP which was the beginning of this sequence. As an alternative to this forest - tundra interpretation, high *Picea* percentage in zone 1 may also suggest an open spruce forest existed in the area during this time interval. *Picea* vs *Betula* and *Picea* vs Cyperaceae ratios which are consistently higher than 1.0, favour the open forest interpretation (Fig. 7.9). However, *Picea* pollen accumulation rates in this zone are too low to support this suggestion. The results of PCB and CA simultaneously suggest that pollen zone 1 is somewhat similar to modern forest-tundra spectra. It is interesting to note the discrepancy of *Picea* values between the pollen percentage diagram and pollen accumulation rate diagram. This may suggest that *Picea* pollen is mis-represented on the percentage diagram. In this zone, *Picea* is the only tree taxon, and high tree pollen percentages compensate the low value of shrubs and herbs. In shrub taxa, the *Betula* values are consistently around 20%. As previous studies have indicated, dwarf birch is a prolific pollen producer, and in north Yukon and N.W.T., 2-3% dwarf birch ground cover may cause 13-28% of *Betula* pollen in adjacent

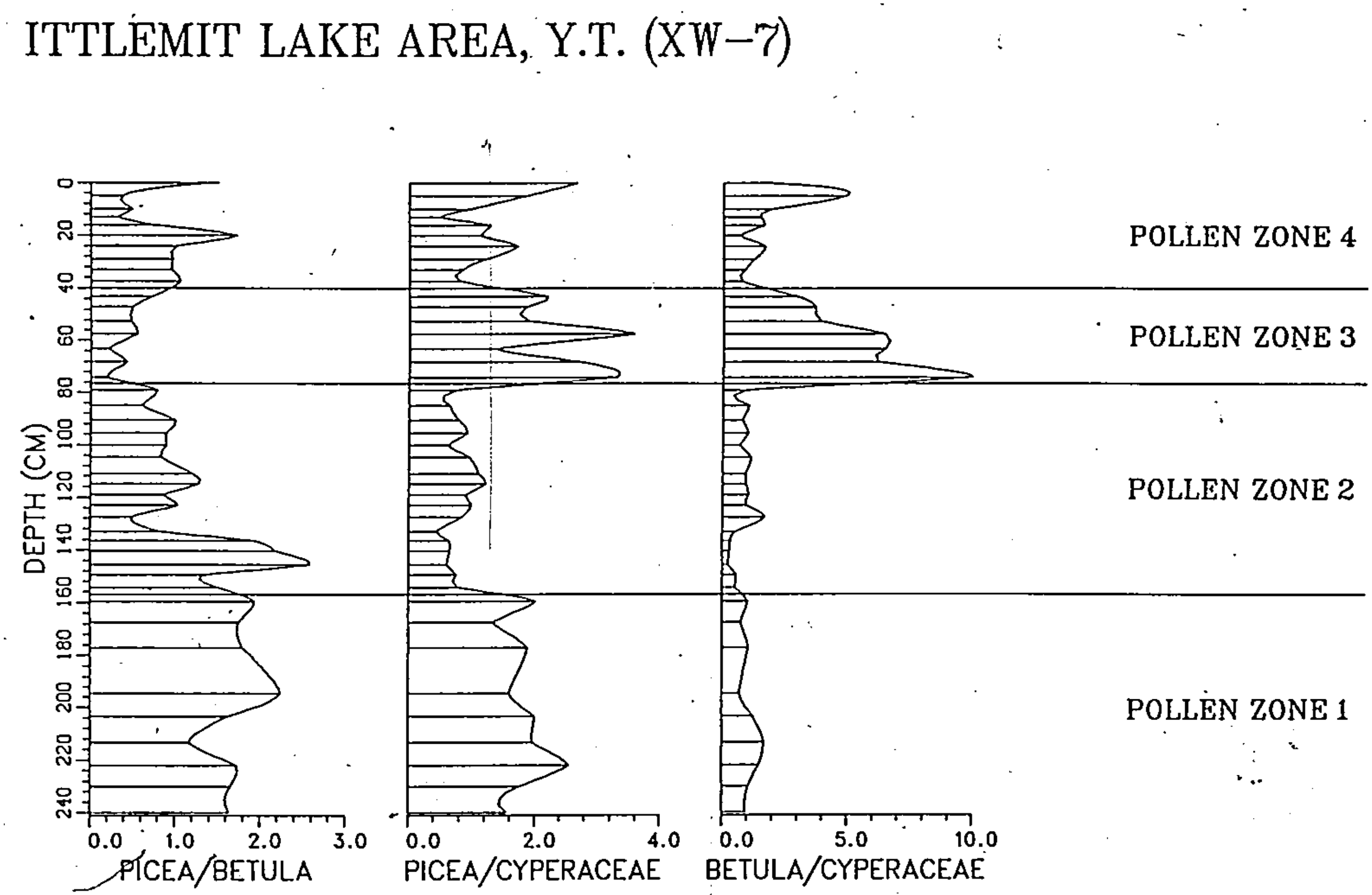

Figure 7.9 Selected pollen ratios of profile XW-7, Ittlemit Lake area

lake sediments (Ritchie, 1977, Table 6; 1982, Table 1; 1984a, P. 135). Although the pollen records recovered from lake sediments and peat may not be directly comparable (Ritchie, 1974; Birks, 1977; Kay and Andrews, 1983), these figures may give a rough estimation of the *Betula* pollen representation factor in general. The value of *Betula* percentage in this zone suggests a moderate ground cover of dwarf birch in the area from about 9,000 yr BP to about 5,000 yr BP. In contrast to the overrepresentation of *Betula* pollen, *Salix* is usually underrepresented regionally (Farley-Gill, 1980). Three to four percent willow pollen in the pollen spectra has been considered as evidence of the presence of this shrub at the sampling site (Janssen, 1966). Thus, the consistent occurrence of *Salix* pollen with a value around 5% is a significant representation of this zoogamous taxon, and indicates that willow occurred widely in the area during the zone 1 time interval. Rosaceae, requiring an open habitat, is another taxon with significant representation in the pollen spectra. As the result of low pollen production within the shrub and herbaceous community, consisting of taxa such as *Salix* and Rosaceae, *Picea* pollen may be strongly overrepresented. This may explain the discrepancy between *Picea* pollen percentage and pollen accumulation rate. Therefore, an interpretation of open phase forest vegetation for pollen zone 1 is misleading due to the strong overrepresentation of *Picea* pollen percentages, while a forest-tundra reconstruction is relevant.

Zone 2 (5,000 yr BP - 3,000 yr BP): A discrepancy again appears in the pollen curves of *Picea* percentages and accumulation rates. A decrease of the *Picea* percentages in zone 2 from zone 1 contrasts with an increasing pollen accumulation rate. Meanwhile, an increase of the *Betula* pollen accumulation rate occurs while its percentages remain the same. Also, the rise of *Alnus* and Cyperaceae pollen percentages are simultaneously accompanied by the increase of pollen accumulation rate. As the result of most taxa increasing their accumulation rates, total pollen accumulation rate increases 2 to 3 times higher than before. The most striking feature in this zone is the great increase in the Cyperaceae percentages and the rise of *Alnus* and *Juniperus*. Selected pollen ratios (Fig. 7.9) also show this increase of Cyperaceae. Although Zone 2 falls into the same time range as pollen zone 6 at Antifreeze Pond about 210 km northwest of the Ittlemit Lake (Rampton, 1971), the pollen spectra in those two sequences are not very similar. Clearly, pollen records in lake deposits may be quite different from those in peat. However, both sites have comparable *Picea*, *Betula*, and Gramineae percentages. The prime difference relates to the Cyperaceae curves, *i.e.*, there is much higher representation of Cyperaceae in the Ittlemit Lake area. The increase in *Alnus* percentages occurred at Antifreeze pond about 5,700 yr BP, about 700 years earlier than at Ittlemit Lake. Although the values at Antifreeze Pond are much higher than that at Ittlemit Lake. Other differences include greater representation of shrubs such as *Juniperus* and Ericaceae in the Ittlemit Lake area. Although zone 6 at Antifreeze Pond was described as a spruce forest, this interpretation is not applicable to the Ittlemit Lake area. The consistent representation of *Juniperus* pollen in this zone indicates that an open habitat existed in this area since this taxon is unable to persist in shaded environments (Ritchie, 1984b).

Surficial pollen investigation in southwestern Yukon (see chapter 4) and Coppermine Valley (Geurts, 1983) indicate that *Picea* pollen in forest samples should be higher than 40-50% in moss polsters. It is relevant to interpret the pollen spectra of zone 2 as a forest-tundra vegetation with shrub components differing from those in zone 1. *Salix*, Rosaceae and Gramineae were apparently less important than before. A limited population of *Alnus* probably invaded the general area about 5,000 yr BP. At first, *Juniperus*, then later, Ericaceae became important components of the vegetation. Although a slight decrease of spruce pollen percentage was recorded, *Picea* might have a larger population or more efficient pollen production than before as suggested by the increase of spruce pollen accumulation rate in this zone. However, this change in regional vegetation components was probably of limited extent. Within a general background of regional (Picea) and local (shrubs) components, peat-forming taxa, mainly Cyperaceae, changed significantly. The increase of Cyperaceae by about 20% indicates a deterioration of local drainage conditions or an increase in soil moisture at the sampling site and vicinity. This explains the similarity of zone 2 samples to wet-meadow samples on PCB results.

Zone 3 (3,000 yr BP - 1,900 yr BP): Pollen spectra of zone 3 are very similar to those of zone 2 except for the remarkable decrease of Cyperaceae and associated increase of Betula with a value of about 30% in magnitude. Changes in pollen accumulation rate follow the change in percentage. This resemblance between percentage and accumulation rate data implies a real change of pollen rain composition. Decreased Picea vs Betula ratio and increased Picea vs Cyperaceae and Betula vs Cyperaceae ratios directly illustrate this change (Fig. 7.9). Since Picea values show no obvious difference from before, it is concluded that the regional vegetation component did not change significantly. The only variation occurred in zone 2 when changes in local vegetation components probably reflected the modification of drainage or moist conditions at the sampling site and its vicinity. The area was still under a forest-tundra environment as before. Similar pollen spectra have also been found in zone 3b at Mackintosh Creek-HB1 diagram (Beaudet, 1986) and upper zone 3b of Birch Lake Core II (Ager, 1975). The former has been interpreted as a forest-tundra environment, and the latter a part of Middle Tanana Valley forest. However, it must be kept in mind that the birch pollen in Middle Tanana Valley was considered to be from tree _Betula_ compared with the dwarf birch of the Mackintosh Creek and Ittlemit Lake areas. It is not surprising that pollen spectra of zone 3 are similar to those of modern shrub-tundra samples as suggested by the results of PCB and CA, if the vegetation patterns in the investigated area are kept in mind. With the general spruce forest to forest-tundra vegetational environment in southwest Yukon, _Picea_ pollen from a modern _Betula_-dominated shrub-tundra vegetation-landform unit is strongly overrepresented. However, due to the lack of such an overrepresentation of spruce pollen at zone 3 time, strongly represented _Betula_ pollen overwhelms the other taxa and is responsible for the resemblance between the zone 3 samples and those of modern shrub-tundra on the PCB and CA results. Therefore, the analog approach when comparing modern and fossil pollen spectra must be used with great caution, especially when numerical analysis is undertaken.

Zone 4 (1,900 yr BP - present): Pollen zone 4 is characterized by an abrupt rise of Cyperaceae followed by a smooth decline and simultaneous decrease of Betula. However, this decline of Betula is basically caused by the abrupt rise of Cyperaceae. In general, vegetation in the area was similar to before and typical of a forest-tundra environment. The components of this vegetation, however, have undergone a modification by slight replacement of certain local taxa. Increased Cyperaceae in the lower part and Rumex and Polygonaceae in the top part of the zone reflect the changes in local moisture conditions, and that wet ground at the sampling site existed from approximately 1,900 yr BP. Salix scrubs increased in distribution shortly after the beginning of this wet episode. Both percentage and accumulation rates of Alnus increased after about 800 yr. BP, indicating either an increase in distribution density of this taxon in the area, or more efficient pollen production reflecting favorable climatic or ecological conditions. The discontinuous occurrence of Pinus pollen in the profile is apparently exotic as suggested by low values. However, this discontinuous representation following the deposition of White River ash is a common feature in the area and is especially interesting. This feature and associated implications will be discussed in a specific section in chapter 9 with reference to regional correlations.

7.9 Summary and Conclusion

The pollen records provided above present a clear picture of changing local environmental conditions in the Ittlemit Lake area over the last 9,000 radiocarbon years.

The pollen sequence suggests that spruce arrived in this area at least 9,000 yr BP. This suggestion is supported by both percentage and accumulation rate data. During the interval between 9,000 and 5,000 yr BP, the area was covered by a sparse _Picea_ - _Salix_ - _Betula_ - _Gramineae_ forest-tundra vegetation. Low production and preservation of _Salix_ and herbs pollen caused a severe exaggeration of _Picea_ pollen percentage in the records and therefore created a discrepancy between percentage and accumulation rate data. By 5,000 yr BP, local environmental change created a different habitat for this forest-tundra vegetation cover which primarily affected the local taxa. The importance of _Salix_, Rosaceae, and Gramineae in the vegetation decreased. Cyperaceae, _Juniperus_, and Ericaceae became more important. Increased accumulation rate values for many taxa suggest an amelioration of the pollination environment for most plants in the area. _Alnus_ invaded the general area shortly after 5,000 yr BP. Rise of _Alnus_ pollen in both percentage and accumulation rate data in the middle Holocene is a common feature of many pollen sequences in northwest North America (Ritchie, 1984a; 1984b; Rampton, 1971; Ager, 1975; Matthews, 1974; Macdonald, 1984; etc.) However, this event occurred about 1,000 to 2,000 years later in the Ittlemit Lake area than the other places. Beginning around 3,000 yr BP, a Betula-dominated local community replaced the previous Cyperaceae-dominated one, causing a change of shrub constituents in the vegetation. This Betula-dominated forest-tundra phase lasted for about 1,100 years and was replaced by the Cyperaceae-dominated community again around 1,900 yr BP. Associated with the increase of Cyperaceae, Salix became more important than that before. Gramineae and Rumex also increased somewhat about 800 yr BP. A further increase of Alnus, associated with an increase of Pinus pollen, occurred at about 500 yr BP, which corresponds to the advance of glaciers in the St. Elias mountains. However, the regional forest-tundra environment has not changed significantly during the last 1,900 radiocarbon years.

In terms of the climatic implications of the information extracted from this sequence and related data, it is essential to realize the complexity of the relationship and interaction between climate and vegetation. A change in vegetation can result from any one of a number of climatic and other environmental variables, and it is difficult to determine which parameters produce what change (Ager, 1975, p. 48). Moreover, this difficulty is complicated by the complex relationship between actual vegetation and pollen records. The climatic interpretation of pollen spectra therefore relies highly upon present-day knowledge of the ecological requirements and pollination behaviour of the plants involved. Previous studies (Walter, 1973; Budyko, 1974) indicate that the amount of soil moisture is more critical than the amount of precipitation which falls. This is particularly important in the permafrost regions overlain by a thin active layer (Ager, 1975) as occurs at the Ittlemit Lake area. The diagonal line in the second and fourth quadrants in the first and second PCB and CA axes plane (Fig. 7.7 and 7.8) shows a gradient of moisture conditions of the ground while the line crossing the first and third quadrants indicates a gradient of vegetation density referring to modern surficial samples. By a 45° rotation of the first and second CA axis, all stratigraphic samples can be projected on these two diagonal lines or new axes which represent the density of vegetation cover and the moisture condition respectively (Fig. 7.10). It must be kept in mind that the values obtained by this rotation are only the rotated coordinates, not a direct measurement or index. The positions of samples from zone 1 on the vegetation density axis, however, give a false impression due to overrepresentation of Picea pollen in the percentage data set. In general, zone 1 is a time interval over which a moderately low moisture condition existed at the sampling site. This interpretation is consistent with the early Holocene warm model developed in north Yukon (Ritchie, et al., 1983). From 5,000 yr BP to

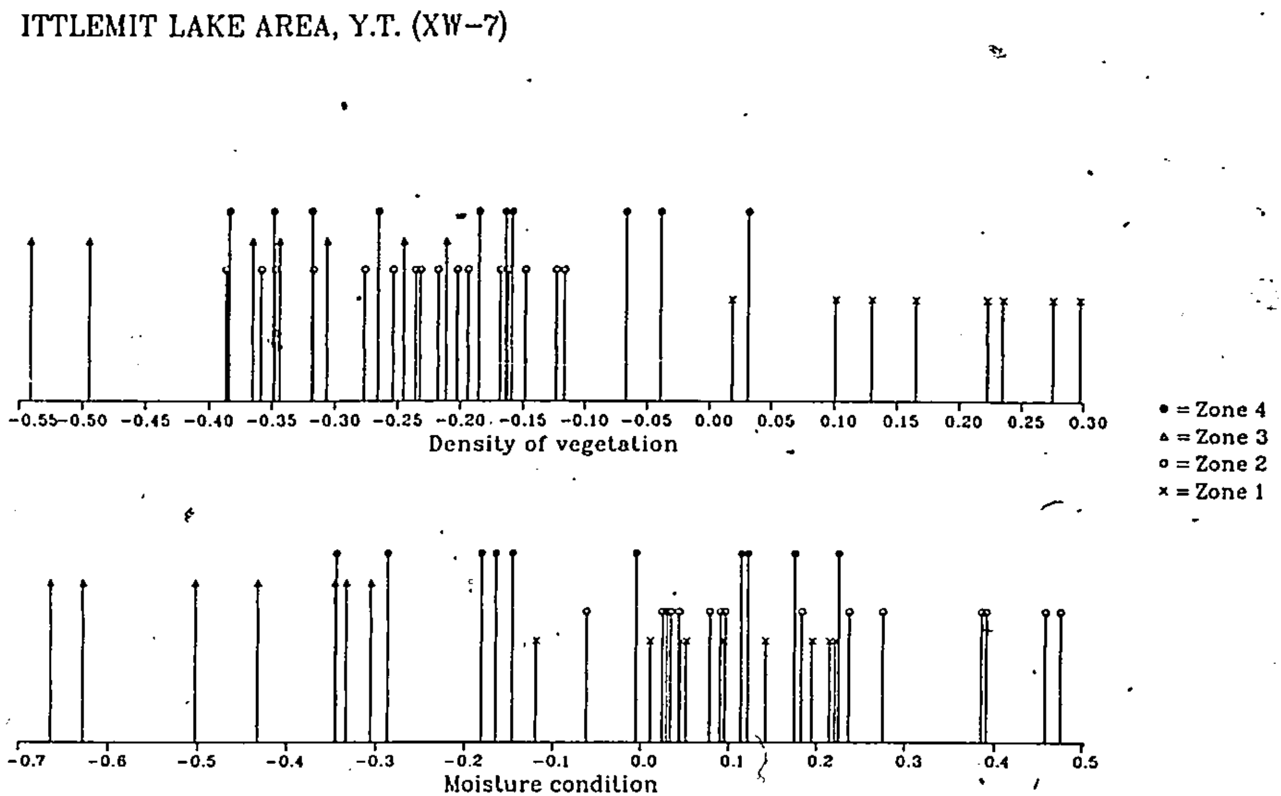

Figure 7.10 Projection of sample ordination on the first and second CA axes with a 45^0 rotation, profile XW-7, Ittlemit Lake area

3,000 yr BP, very wet conditions developed with a vegetation density similar to present. The increasing pollen accumulation rate of *Picea* suggests a relatively cooler thermal condition developed. This may have raised the permafrost table leading to a lifting of the groundwater table. Zone 3 was a time interval characterized by a very low vegetation density in a very dry local environment, while the next episode, zone 4, was a moderate to wet period with a slight denser vegetation cover.

In conclusion, pollen records from a relatively high elevated peatland environment can be used to reconstruct past vegetation and other environmental conditions such as paleoclimate in the area. However, the impact of local enriched taxa on the total pollen spectra must be considered when interpretation is carried out. Pollen spectra from peatland are sensitive to variations in local components which may be caused not only by variations in climate and succession of vegetation, but also by changes in other environmental factors such as local drainage or soil moisture conditions. Therefore, this kind of data can provide important information for the reconstruction of the evolutionary history of local environmental conditions.

Chapter 8

Post-glacial Pollen Records in the Bear Lakes Area

8.1 Introduction

The Bear Lakes area is located at the eastern border of Ruby Range (Fig. 2.1). Palynological investigation in this area fills a large geographic gap since no such an effort has been carried out previously to this study.

Organic deposits above the glacial drift are normally very shallow in the Bear Lakes area, therefore a narrow sampling interval is required to obtain detailed information concerning the paleoenvironment. In Quaternary pollen analysis, narrow sampling interval has been employed previously for detailed study of paleoenvironmental history, and "fine-resolution pollen analysis, referring to studies in which the time represented by the interval between adjacent sediment samples is significantly less than traditionally used, has been attained in several studies" (Green, 1984). Garbett <u>et al</u>. (1984) reported a technique utilizing 1 mm sampling intervals, constituting a true "fine-resolution analysis". Several larger sampling interval approaches have also been reported. For instance, Nichols <u>et al</u>. (1978) proposed a 1 cm sampling interval to trace the palynological evidence of paleowinds. In this study a sampling interval of 1 cm was chosen to extract as detailed information as possible.

8.2 High Bog, Bear Lakes Area (XW-8)

8.2.1 Site Description and Present vegetation

The profile XW-8 was collected as a monolith, using a plastic tray, from a peat bog at the eastern edge of Ruby Range (Fig. 1.3, 8.1). The section site is located at 61°16'47" N Lat. 137°41'07" W Long. with an altitude of 1615 m.a.s.l. The sampled peat bog is developed in a flat area on the northeast-facing slope of an unnamed creek which drains eastward into Sekulmun Lake.

The present vegetation of the area is a *Betula glandulosa*-dominated shrub-tundra with abundant *Eriophorum* sp. and Ericaceae. *Potentilla fruticosa* is present in the area. A few spruce in krummholts status without cone productivity exist in the area also. No trees were observed during one summer field investigation in the vicinity of the bog.

8.2.2 Sediment Stratigraphy

From the surface to 21.0 cm is organic peat, with White River ash grains scattered between 8.5 cm and 10.5 cm. From 21.0 cm to 24.0 cm the sediments are organic peat with a small proportion of sand and gravel. Light brown silt occurs from 24.0 cm to 26.0 cm. The samples were collected in a plastic tray as a monolith which was terminated at 26 cm

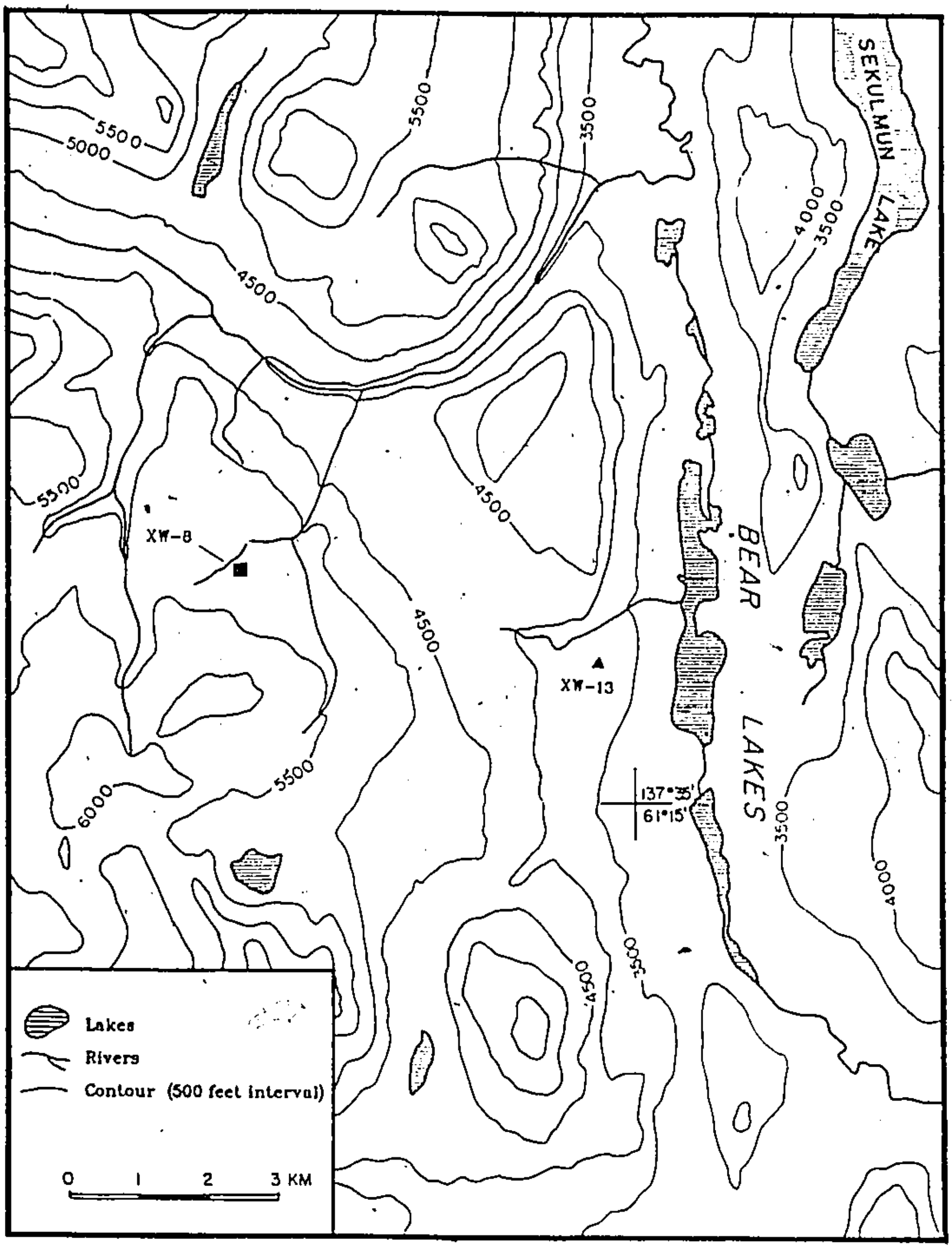

Figure 8.1 Map of the Bear Lakes area showing fossil pollen sites and topography

Table 8.1 ^{14}C dates of the Profile XW-8

Lab Number	Sample Interval	^{14}C date	
UQ-1448 *	2.5 - 5.5 cm	Actual	peat
UQ-1447	6.0 - 8.0 cm	920 +/- 140 yr BP	peat
	8.5 - 10.5 cm	1230 yr BP	ash
UQ-1446	19.0 - 20.0 cm	3900 +/- 100 yr BP	peat

Table 8.2 Sedimentation rate of profile XW-8

Sediment interval (cm)	Time interval (yr BP)	Mean sedimentation rate (cm/yr)
0.0 - 7.0	0 - 920	0.00761
7.0 - 9.5	920 - 1230	0.00806
9.5 - 19.5	1230 - 3900	0.00375
19.5 - 26.0	> 3900	0.00375 *

* Extrapolated

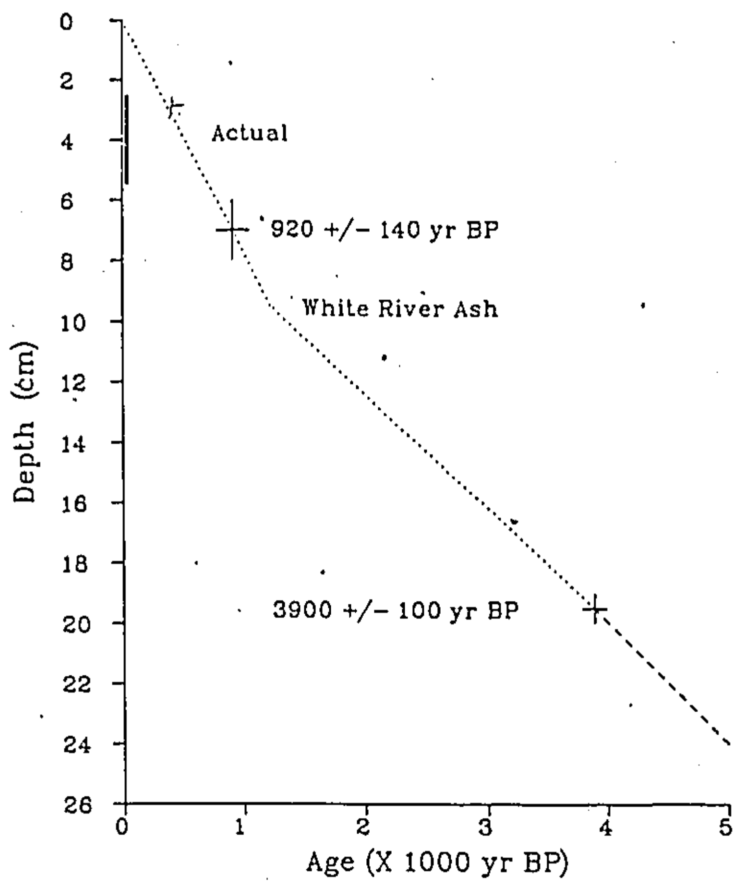

Figure 8.2 Relation of ^{14}C dates vs depth for profile High Bog (XW-8)

level due to the occurrence of big blocks. The monolith was subsampled in the laboratory in 1 cm intervals and 26 samples were obtained and analyzed .

8.2.3 ^{14}C Dates

Three segments of the monolith were submitted for ^{14}C dates. The stratigraphic positions of the dated samples were chosen to approximate the occurrence of special phenomena in the pollen spectra. The results are listed in table 8.1.

Among these three dates, UQ-1448 (actual) seems to be misdetermined. Because this sample is near the surface, it is considered that ground water movement may have contaminated the sample. Therefore, only two ^{14}C dates, i.e. UQ-1447 and UQ-1446, and White River ash were used to calculate the sedimentation rates (Tab 8.2) according to the relation of ^{14}C dates versus depth (Fig. 8.2).

8.2.4 Relative Pollen Frequency Diagram

The results of pollen analysis are represented in a relative pollen frequency diagram (Fig. 8.3) and a pollen accumulation rate diagram (Fig. 8.4). Following the method of the previous chapters, the pollen percentages of 11 taxa are included in the data matrix for the numerical zonation procedures: *Picea*, *Pinus*, *Alnus*, *Betula*, *Salix*, Gramineae, Cyperaceae, *Lycopodium*, *Dryopteris*, *Equisetum*, and *Sphagnum*.

HIGH BOG, BEAR LAKES AREA, Y.T. (XW-8)

61°16'47" N. 137°41'07" W. 1615 M.A.S.L.

ANALYZED: XIACHENG WANG

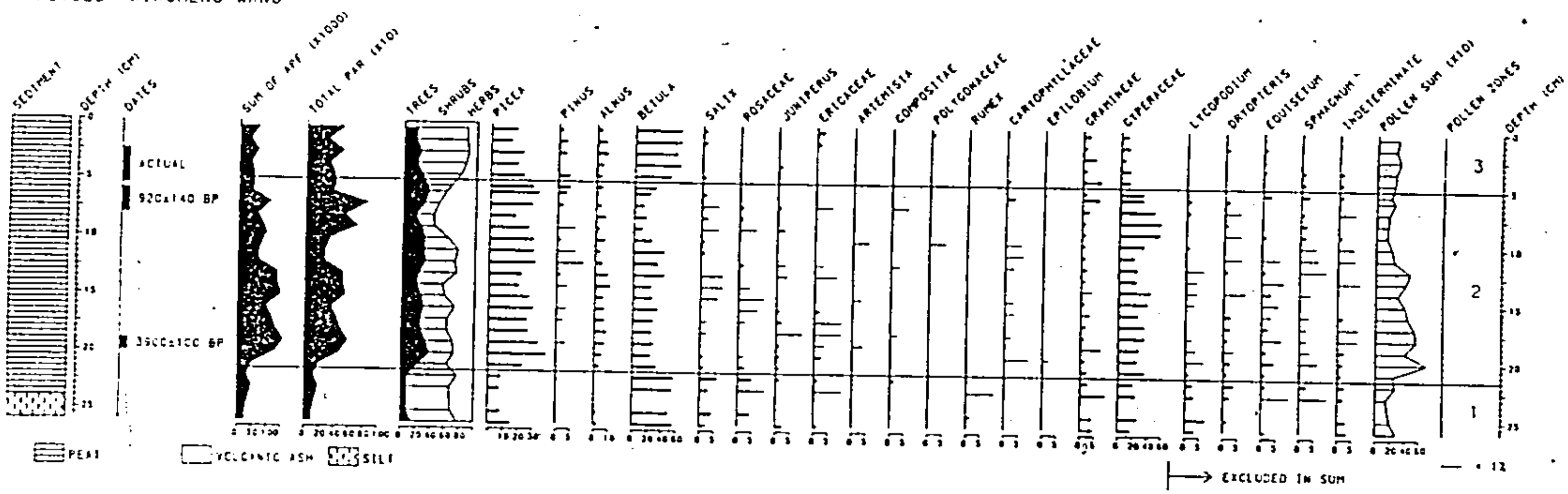

Figure 8.3 Pollen percentage diagram of profile High Bog (XW-13)

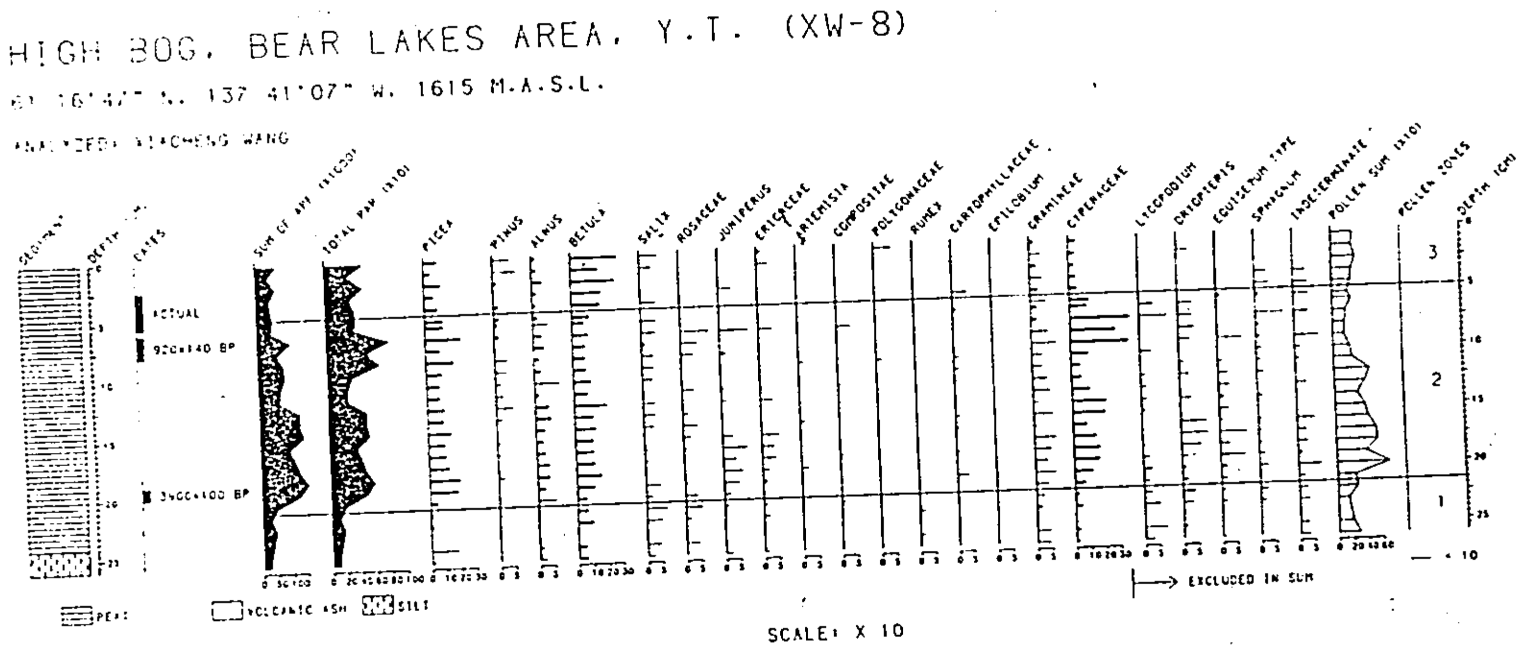

Figure 8.4 Absolute pollen accumulation rate diagram of profile High Bog (XW-8)

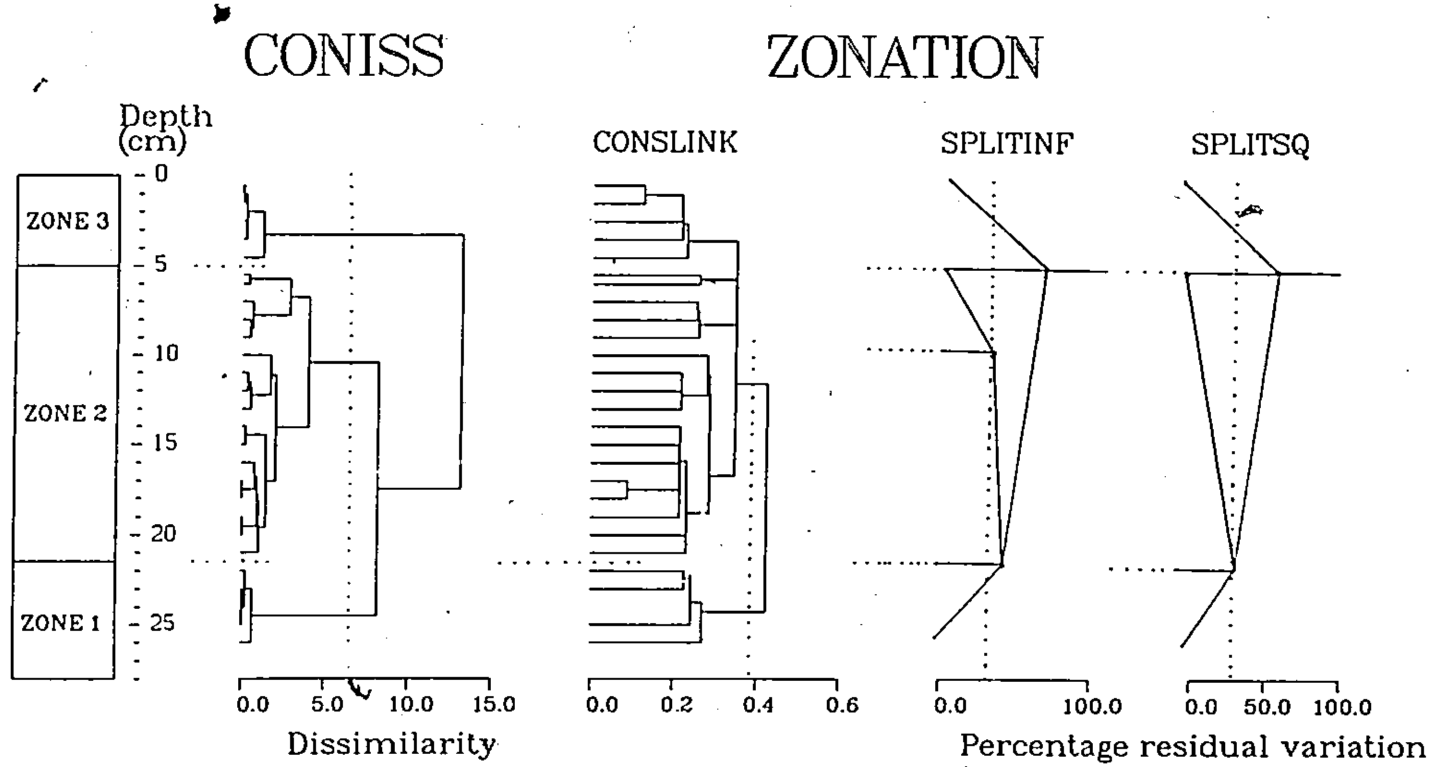

Figure 8.5 Dendrograms of zonation procedures of profile High Bog (Three pages)

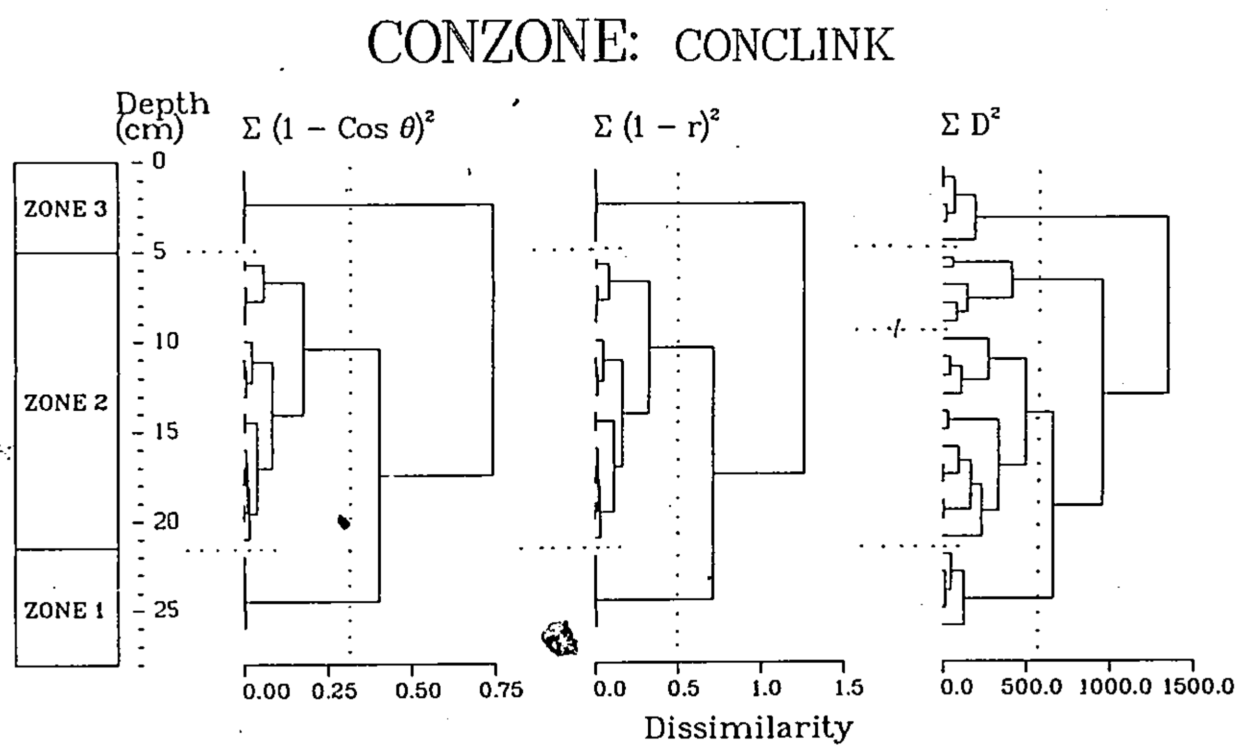

Figure 8.5 (Continued)

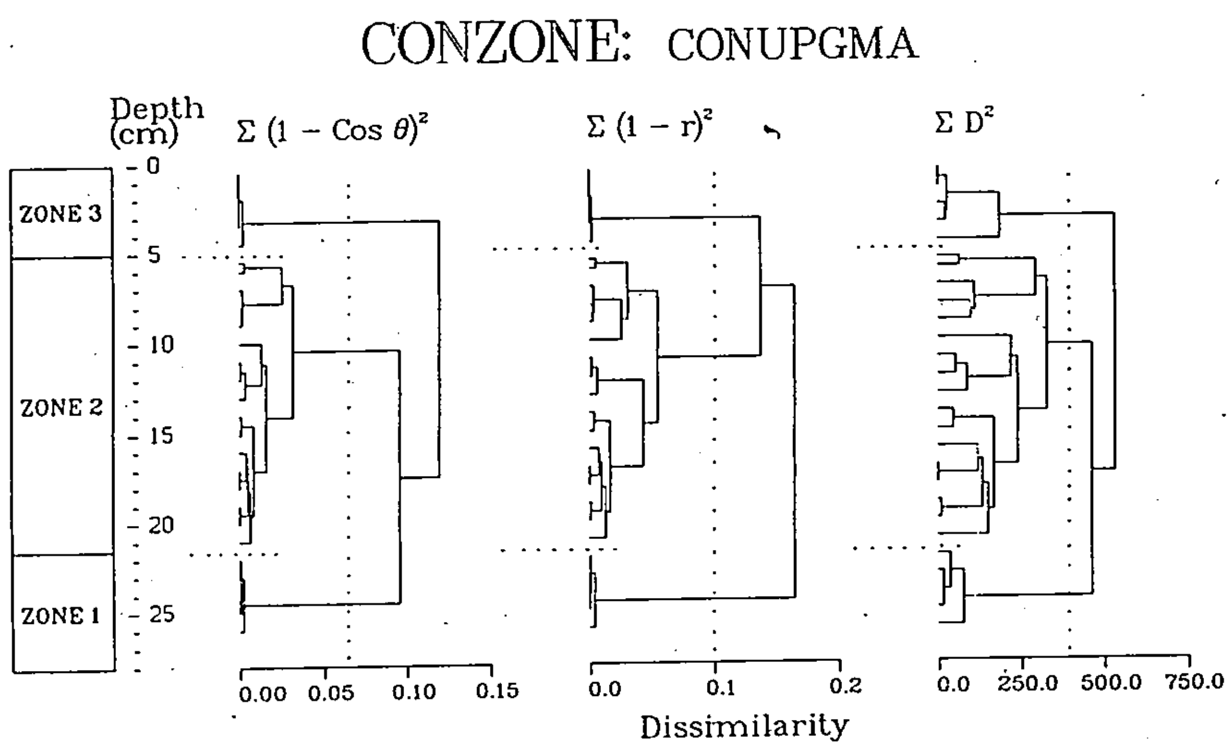

Figure 8.5 (Continued)

All procedures, CONZONE, ZONATION, and CONISS, suggest three site-pollen zones (Fig 8.5), bounded at 5.0 cm and 21.5 cm.

ZONE 1 (21.5 cm - 26.0 cm): This zone is characterized by the high percentages of <u>Betula</u> which consistently vary from 50.0% to 55.5%. <u>Salix</u> percentages are between 2.2% and 5.8%. Other shrubs are not consistently represented, and all are less than 5% when present. <u>Picea</u> pollen percentages vary around 8% except for one occurrence of 15% in the bottom sample. In the herbaceous and pteridophyte group, Cyperaceae are the most abundant group, and vary from 17% to 26%. Gramineae values range from zero in the bottom sample to 3.5% at the top of the zone. Other taxa are not consistently represented. The total tree pollen percentages are 7.6-15% and herbaceous are 22-33%, while shrubs account for 59-68% of the total.

ZONE 2 (5.0 cm - 21.5 cm): Tree pollen has an obvious increase, ranging from 17% to 42%, and is mostly <u>Picea</u>. <u>Pinus</u> occurs sporadically with a small peak at the top of the zone varying from 2% to 4%. Total shrub pollen percentages decreased considerably, ranging from 17% to 52%, mainly due to the decrease of <u>Betula</u> pollen which varies from 12.6% to 42%. <u>Alnus</u> values, however, have a well-marked increase at the bottom of the zone and range from 0 in the bottom sample to 10%, higher than 4% in most cases. Other shrubs have no significant representation. Herbaceous pollen values are moderately higher than in zone 1, ranging from 23% to 57%. Cyperaceae are the most important herbaceous taxa, ranging from 21% to 56%. Gramineae do not have much importance in the zone, only around 1%. Other herbs are all less than or around 1% when present. Pteridophytes are also not significantly represented.

ZONE 3 (0 cm - 5.0 cm): The most striking feature of this zone is the increase of *Betula* percentages and decrease of Cyperaceae values. *Betula* values range from 49% in the bottom sample to about 62% in the others, which bring the total shrub pollen values up to 52-70%. *Alnus* values show no significant variation since the first rise at the base of the zone 2. Other shrubs are not significantly represented. Cyperaceae values range from more than 30% in the upper part of zone 2 down to 6.7-13% in zone 3, resulting in a decrease in total herbaceous pollen values of 11-20.7%. Gramineae vary from about 1% to 6%, more than 2% in most cases. Total tree pollen values decrease to 16.6-26.5%, mainly due to the decrease of *Picea* values which range from 14% to 22.6%. *Pinus* pollen is well represented beginning in upper zone 2 at the 7 cm level with values varying from 1.7% to 4%, is absent at 3.5 cm, then reappears with proportions around 1.2-27%.

8.2.5 Absolute Pollen Accumulation Rate

Absolute pollen accumulation rate was determined using the exotic marker method (chapter 3) and the results are presented in figure 8.4. The diagram is subdivided into three zones following the zone definition of the relative pollen frequency diagram.

Pollen accumulation rates in zone 1 have a distribution pattern similar to the percentages. *Betula* is still the dominant taxon in the pollen diagram with values around 55-100 grains/cm^2/yr. *Salix* values are only a few grains per square centimetre per year. Cyperaceae values are around 17-44 grains/cm^2/yr. Other taxa are not significant.

Pollen accumulation rates in zone 2, however, have a different pattern from that of the percentage diagram. Even with a 20-30% decrease in the percentage values, the pollen accumulation rates of *Betula* are still considerably higher than those in zone 1, and are more than 110 grains/cm^2/yr in most samples. *Picea* values are consistently over 80 grains/cm^2/yr and greater than 100 grains/ cm^2/yr in most cases. *Alnus* values are consistently greater than 20 grains/cm^2/yr in most cases, with a maximum of 50 grains/cm^2/yr. Cyperaceae were the other major pollen producer along with *Picea* and *Betula* with values more than 100 grains/cm^2/yr in most case. Other taxa are not significantly represented. The total pollen accumulation rate values are 190-700 grains /cm²/yr.

ZONE 3 has similar patterns of pollen accumulation rate and percentage. Betula values are significantly increased to 180-310 grains/cm²/yr. Alnus maintains the values of zone 2. Picea values, however, decrease considerably to 40-110 grains/cm²/yr. Cyperaceae values decrease to 33-50 grains/cm₂/yr. Pinus values, as in the percentage diagram, have better representation from upper zone 2 to zone 3 with a gap at 3.5 cm. The first significant peak occurs between 7.0 cm and 4.0 cm with values around 10-20 grains/cm²/yr, and the second peak from 3.0 cm to the surface with values around 6-11 grains/cm²/yr.

8.2.6 Numerical Analysis

Analysis of a combined data set of selected taxa indicates that on the first PCA axis (Fig.8.6), accounting for 21.7% of the total covariance, Picea has high positive loading while Rosaceae, Cyperaceae, Lycopodium, and Dryopteris have high negative loadings. As the result of this loading pattern, zone 1 samples have high negative PCA scores which indicates that spruce pollen was not important in comparison with the others until the beginning of zone 2. The second PCA axis accounts for 17.7% of the total covariance. Picea, Gramineae, and Equisetum have high positive loadings,

HIGH BOG, BEAR LAKES AREA, Y.T. (XW-8)

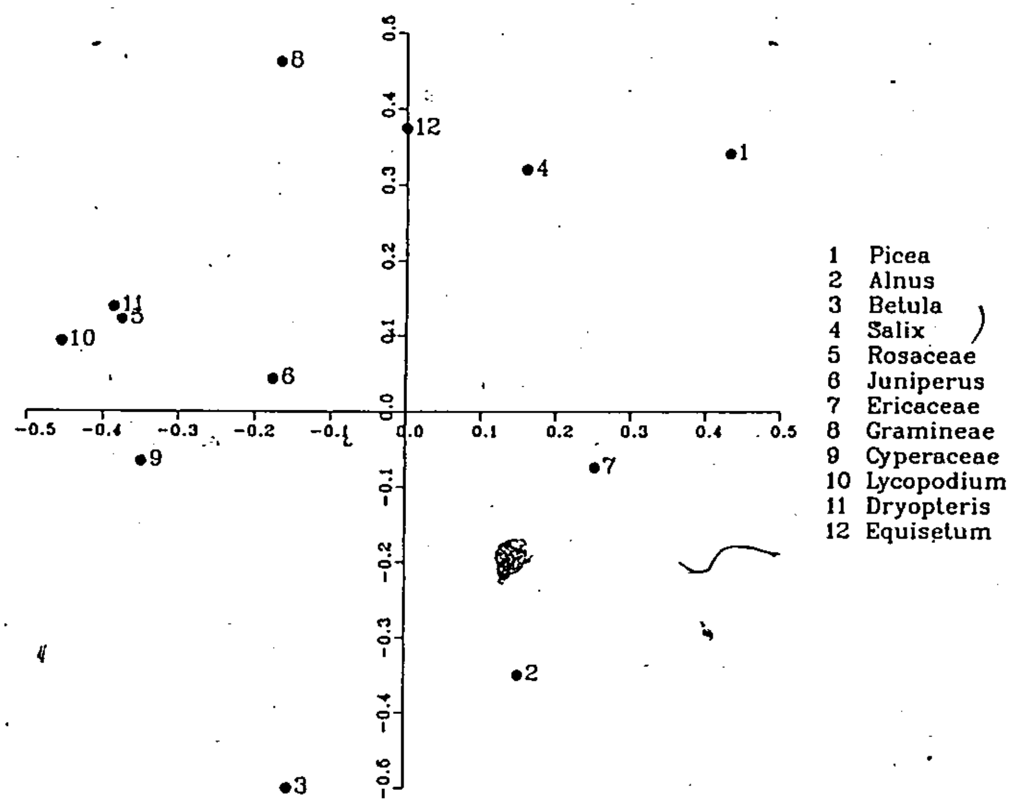

Figure 8.6a Principal component loadings of selected taxa on the first (horizontal) and second (vertical) PCA axes, profile High Bog (XW-8)

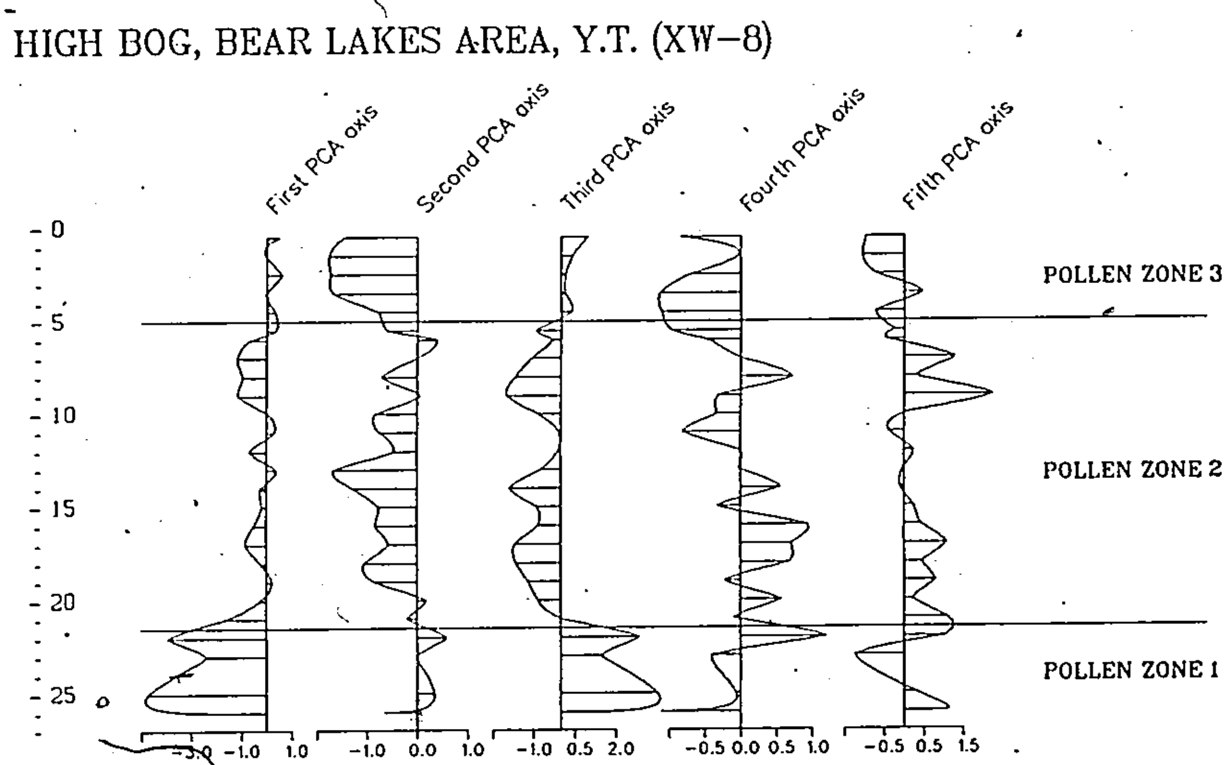

Figure 8.6b Principal component scores of profile High Bog (XW-8) samples on the first five PCA axes

while Alnus and Betula have high negative loadings. Positive scores of zone 1 samples seem to be related to the best representation of Salix, Gramineae, and the poorest representation of Alnus. Scores of zone 2 and 3 samples primarily reflect the rise of Alnus at the beginning of zone 2 and the high values of Betula in zone 3. The third axis captures 13.4% of the total data variation. Betula, Salix, Rosaceae, and Lycopodium have high positive loadings which explains the positive scores of zone 1 and 3 samples. Cyperaceae and Alnus have high negative loadings which account for the negative sample scores of zone 2. Other axes are difficult to interpret due to the fluctuation of sample scores.

Results of PCB and CA are illustrated in figure 8.7 and 8.8, which accounts for 87.6% and 54.5% of the total variation of the data set, respectively. It is notable that the results of these two methods show good agreement on the first and second axes. As indicated by the length of variable vectors in PCB, Picea, Betula, and Cyperaceae are the three most important taxa in the data set. The relations among these three taxa are complementary or negatively correlated. Samples of different zones are well grouped without overlap, which implies that these local zones are numerically distinctive. Zone 3 samples are close to modern shrub-tundra samples, indicating their similarity. However, zones 1 and 2

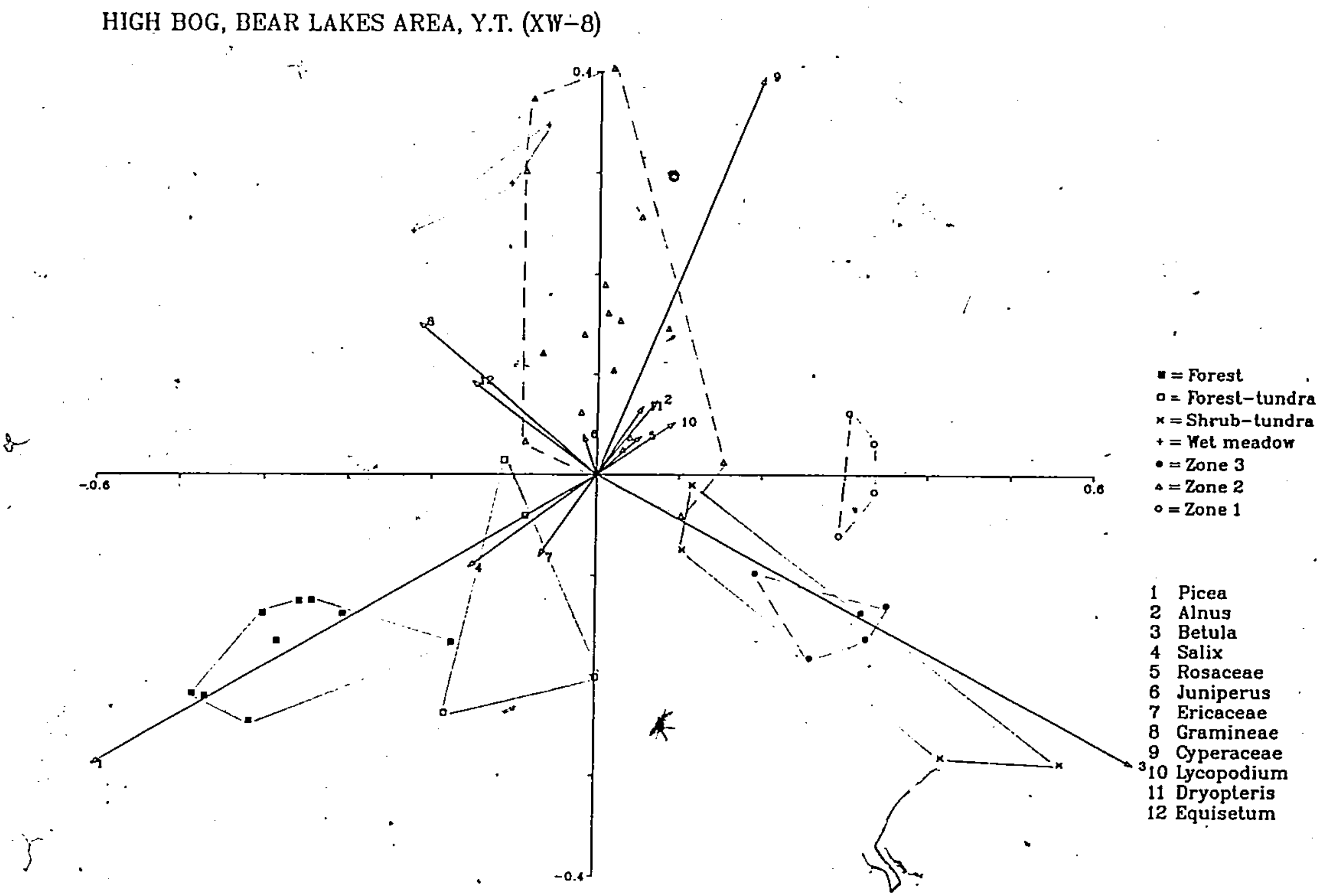

Figure 8.7 Ordination of combined data matrix of modern and fossil pollen samples on the first (horizontal) and second (vertical) PCB axes, profile High Bog (XW-8)

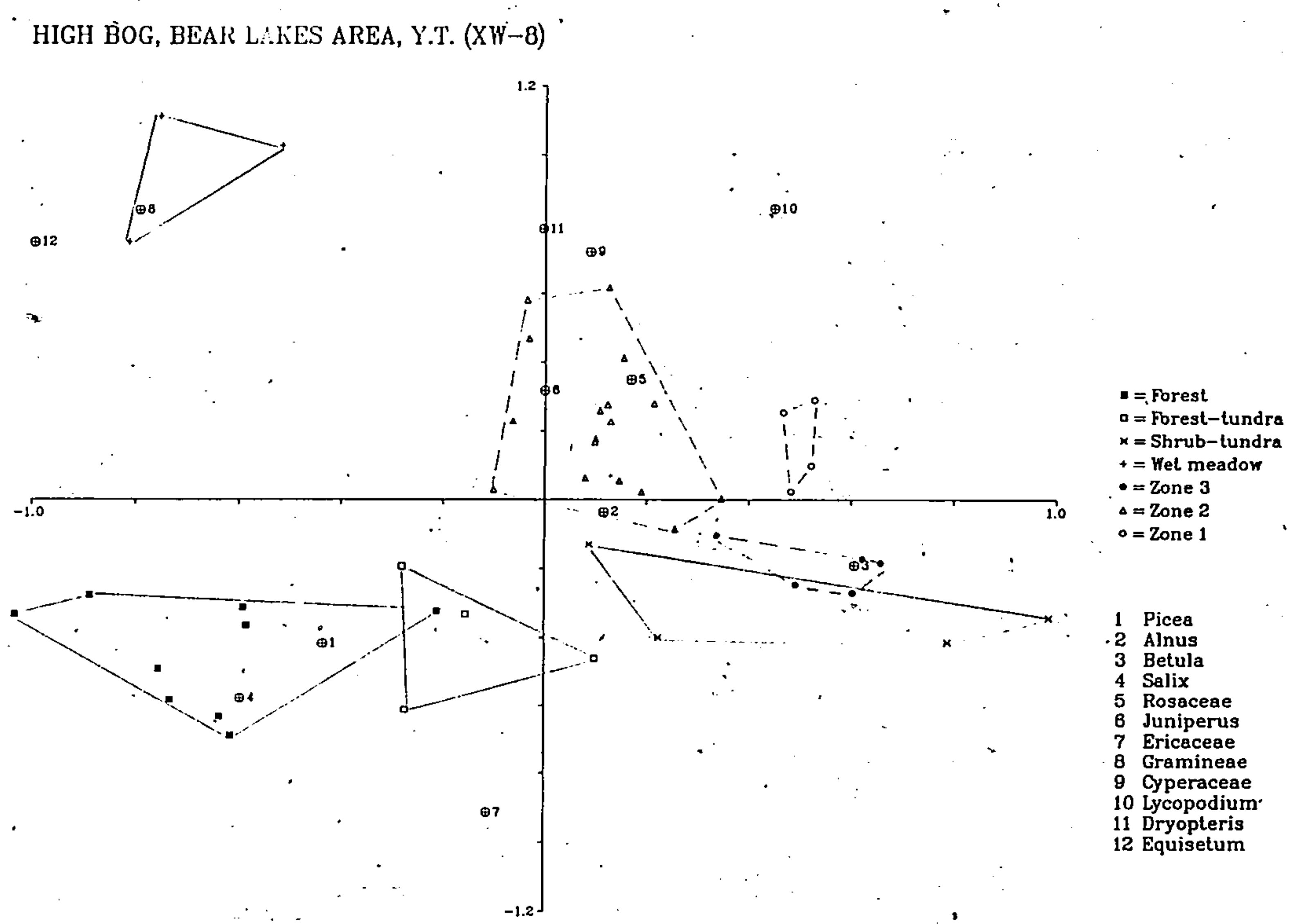

Figure 8.8 Ordination of combined data matrix of modern and fossil pollen samples on the first (horizontal) and second (vertical) CA axes, profile High Bog (XW-8)

samples have no directly comparable modern analogue in the present data set.

8.2.7 Interpretation

This area is important for palynological investigation because of its high altitude. It seems that before 4,000 yr BP this area was covered by a very sparse shrub-tundra or sedge-tundra. Picea pollen is apparently exotic as suggested by its low value. The discrepancy between the percentages and accumulation rates of Betula indicates that dwarf birch was not the major element in the paleovegetation in the area. From 4,000 yr BP to approximately 650 yr BP the sampling site was covered by a wet meadow or mesic community dominated by Cyperaceae. High values of both percentage and accumulation rate of Cyperaceae favour such an interpretation. Although the percentage value is decreased, increased accumulation rate of Betula indicates that dwarf birch became widespread in the area. Low percentage values of birch in pollen zone 2 is the result of suppression by Cyperaceae pollen. It is interesting to note the Alnus pollen rise at 4,000 yr BP which is apparently exotic in nature. Although the percentage value of Picea is relatively high, its low accumulation rate suggests that spruce has never been there, and the pollen records of Picea in the area are exotic. However, the rise of Picea pollen at 4,000 yr BP reflects the regional development of spruce forest in the lower altitudes of the region.

The first comprehensive occurrence of _Pinus_ pollen at about 1,000 yr BP and the second peak at 400 yr BP are consistent with the regional pollen records. This pattern is related to the migration of _Pinus contorta_ into the southwest Yukon Territory (MacDonald and Cwynar, 1985) and climatic variation (Wang and Geurts, 1987a).

Since about 650 yr BP the sampling site has been covered by a dwarf birch-dominated shrub community. The replacement of Cyperaceae by _Betula_ may indicate the change of drainage environment or ground moisture conditions at the site. This modification, however, may not be related necessarily to change in precipitation but instead probably to the development of landscape.

8.3 Bear Lakes Peat (XW-13)

8.3.1 Site Description

The section was collected in an about 800 m^2 depression between two morainic ridges near the Bear Lakes (61°16'05"N Lat., 137°37'49"W Long.) at 1143 m a.s.l.. The glacial history of the area is not known in great detail. Ice contact features and linear morainic sediments are widespread throughout the area. The surrounding topography is a complex of linear morainic sediments and bedrock, with local relief of approximately 300 m (Fig. 8.1). Between and surrounding the morainic ridges, organic peat may be found varying in depth from 10 to 40 cm, underlain by glacial deposits. The section site was located in one of these small depressions.

8.3.2 Present Vegetation

Spruce forests occupy the lowland area. Low shrubs and herbs with a few spruce trees commonly cover the depressions. At the top of several high morainic ridges, a few *Populus tremuloides* groves were found. Altitudinal zonation of the present vegetation is obvious. With increase in altitude, the vegetation turns into sparse forest tundra and then tundra. *Betula glandulosa* is a very common shrub, but tree birch has not been found in the area for the past three field seasons.

8.3.3 Stratigraphy and Chronology

The stratigraphy of this 26 cm profile is very simple. A conspicuous layer of White River ash, in sandy facies, occurs from 26 cm to 24.5 cm (the bottom of the section). Above the ash layer, from 24.5 cm to the surface, peat deposits contain gradational humification. Charcoal was identified in the interval from 19 cm to 16 cm. Beneath the ash layer the sediments turn into organic peat again. The permafrost table occurred at 26 cm on 11 July 1986.

One peat sample from the interval between 8 cm and 9.5 cm was dated. However, the result is unacceptable since the date obtained (UQ-1431, 1,400 +/- 100 yr BP) is older than the bottom of the section marked by the 1,230 year old White River ash layer. This spurious date could be the result of contamination caused by old charcoal blown from adjacent slopes, or contamination with old carbon caused by the rise of the groundwater table which may have transported humic acid upward. Another possibility associated with the concept of upward transportation of humic acid is the "cryosuccion" (term used by Pissart, 1983) mechanism related to formation of ice lenses, considered to be a problem for radiometric dating in periglacial environments. No carbonate material was determined to be present in the sample since the sample did not react with concentrated HCl. No palynological and sedimentological evidence indicates redeposition. As the result of the rejection of this older date, it is assumed only that the surface of the section represents contemporary deposition, since the site is apparently still a depositional environment. However, since the accumulation rate of peat may vary, it is not safe to calculate pollen influx without having other confident dates.

8.3.4 Relative Pollen Frequency

The result of pollen analysis is presented in a relative pollen frequency diagram (Fig. 8.9). Four local pollen zones

BEAR LAKES AREA, YUKON TERRITORY (XW-13)

61°15'05"N, 137°37'49"W, 1143 m a.s.l.

ANALYZED BY: XIACHENG WANG

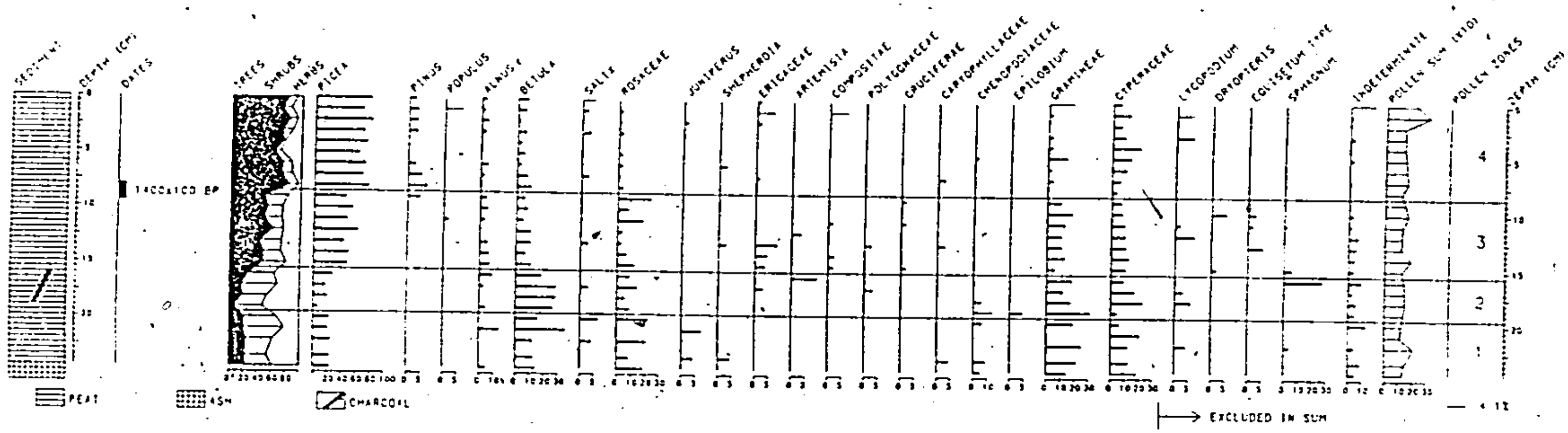

Figure 8.9 Pollen percentage diagram of profile XW-13

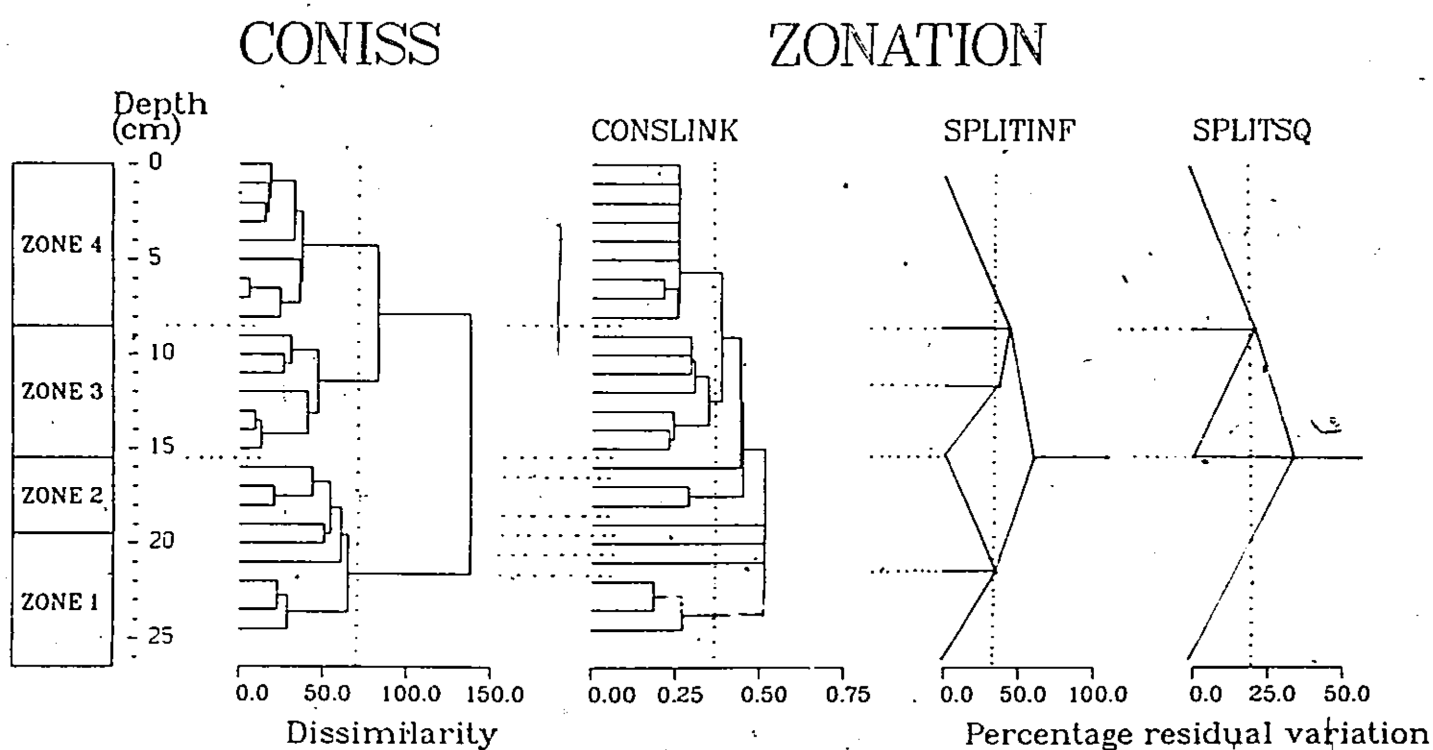

Figure 8.10 Dendrograms of zonation procedures of profile XW-13
(Three pages)

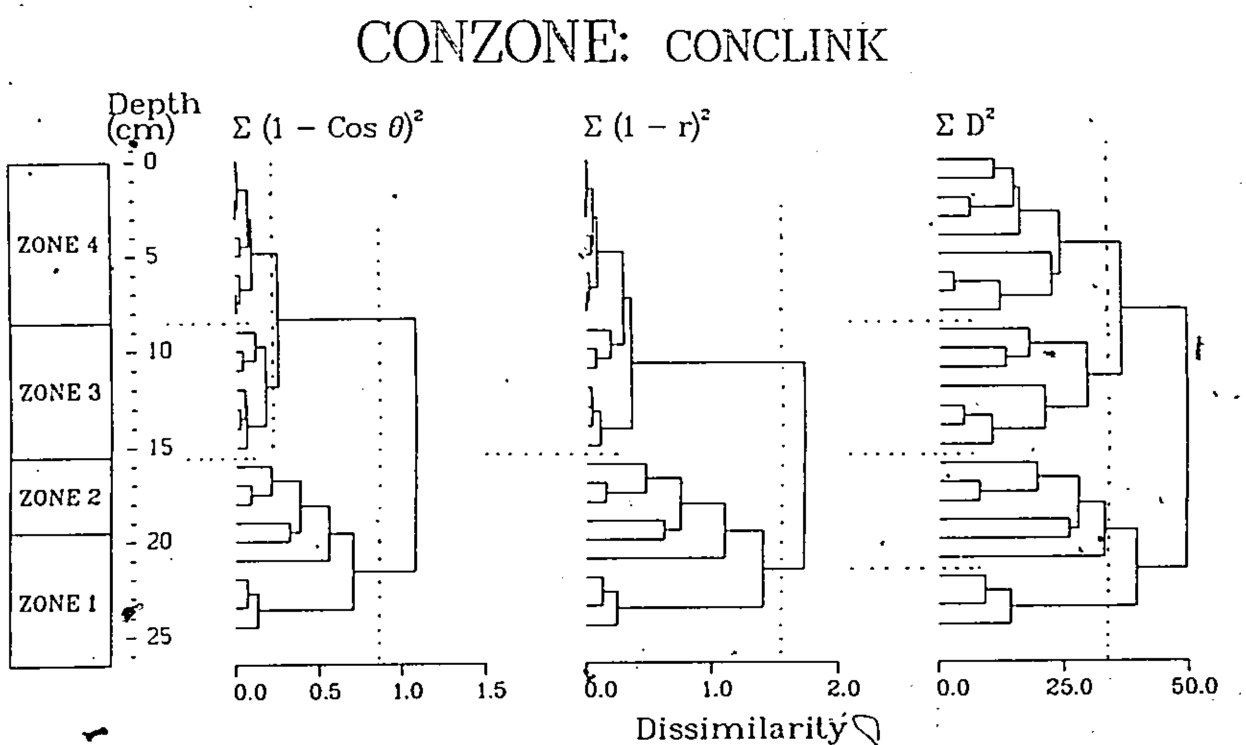

Figure ε.10 (Continued).

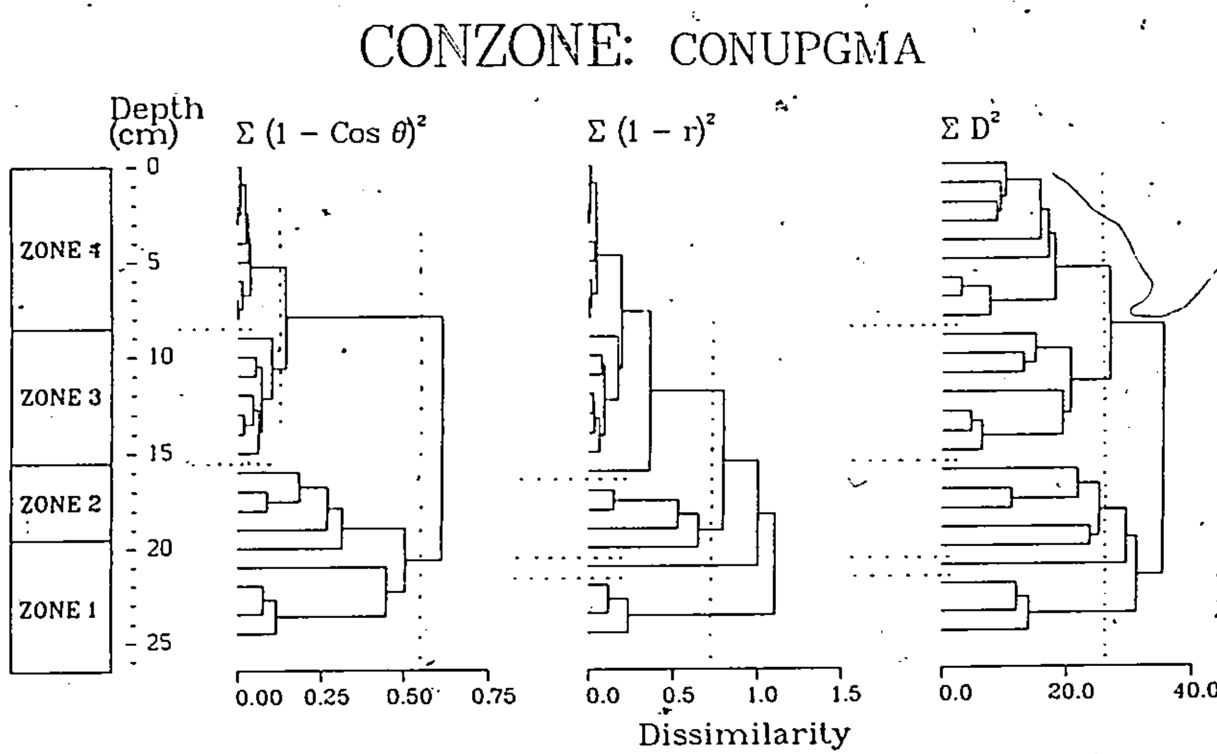

Figure 8.10 (Continued)

can be recognized upon visual inspection aided by numerical examination of the variation of pollen spectra (Fig. 8.10), likely representing local vegetation change.

ZONE 1 (24.5 cm - 19 cm): The predominant taxon in this zone is Picea, which is consistently higher than 21%. Betula is generally around 13%, with one sample at the 21 cm level at 35.7%. Rosaceae values vary from 0 to 22.6% and other shrubs occur occasionally. Cyperaceae (6-21%) and Gramineae (0-25%) are the most significant herbs.

ZONE 2 (19 cm - 15 cm): A minimum of 7% at base and gradational increase to 26% of Picea pollen, as well as the occurrence of macro-charcoal debris in the sediments characterize zone 2. Betula abundance is significantly increased in comparison with zone 1, and constantly around 28%. Rosaceae is better represented than before, and varies from 6% to 14%. Gramineae percentages vary from 11% to 31%. Cyperaceae percentages fluctuate more than before, varying from 4% to 23%.

ZONE 3 (15 cm - 8 cm): Picea has an overwhelming abundance in zone 3, varying from 42% to 53%. Shrub pollen shows a conspicuous decrease. The Betula abundance has an obvious decrease, varying from 4% to 10%. Rosaceae is still a significant component in the pollen spectra, with percentages varying from 3% to 24%. *Alnus* has more representation than before. Ericaceae is well represented in the lower part of the zone, increasing from 4% to 8%. Gramineae and Cyperaceae both are constant but less important than before.

ZONE 4 (8 cm - 0 cm): Two isolated peaks of *Pinus* and high *Picea* abundance characterize zone 4. *Picea* percentage jumps from about 44% in the top sample of zone 3 to 76% in the bottom sample of zone 4, and varies from 62% to 79% in the zone. Two small peaks of *Pinus* abundance are evident at the bottom (3 - 7%) and top (2 - 3%) of the zone. Rosaceae experience the most obvious decrease in the profile, from 24% in the top sample of zone 3 to 3% in the bottom sample of zone 4, and constantly less than 3% thereafter. *Betula* are still low in abundance, varying from 2% to 10%. Herbaceous species also show a decrease in abundance, especially for Gramineae. Cyperaceae, however, experience an increase in abundance, particularly in the lower part of the zone.

8.3.5 Numerical Analysis

The result of PCA is illustrated in figure 8.11. The first axis accounts for 29.7% of the total data variation. *Picea* and *Pinus* have high positive loadings on this axis, while Rosaceae, Gramineae, and Cyperaceae have high negative loadings. Sample scores on this axis demonstrate a distinctive pattern which mirrors the variation of these

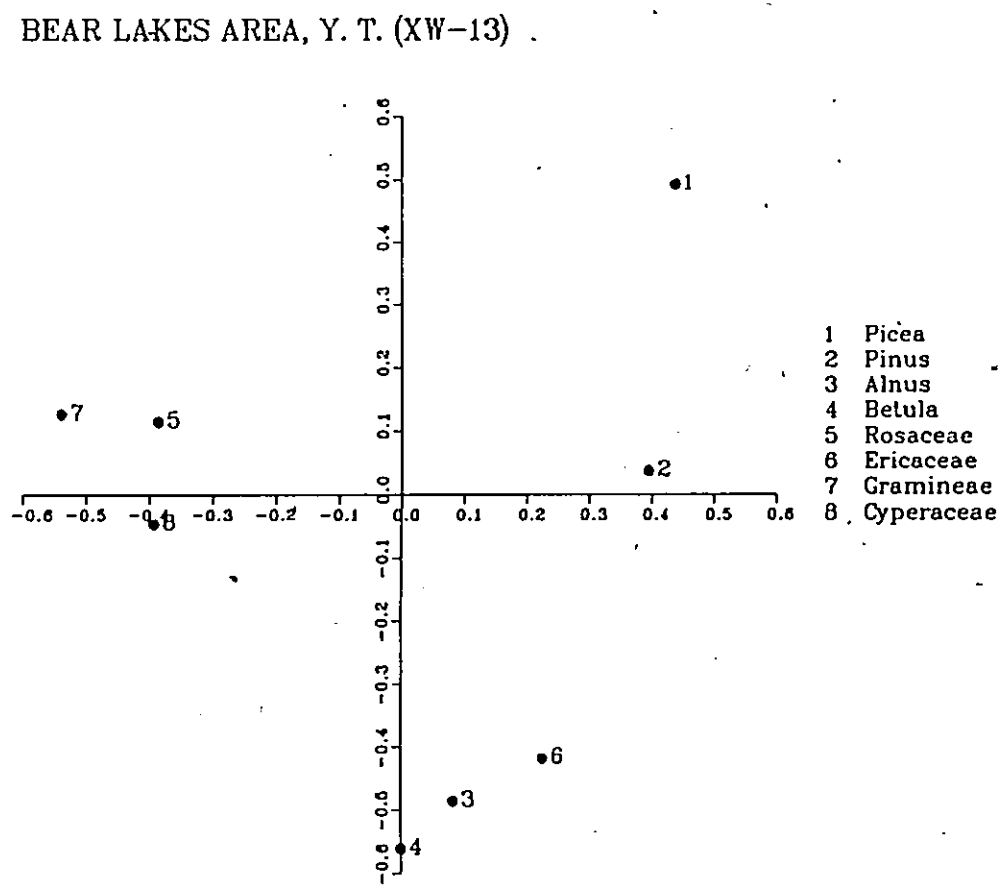

Figure 8.11a Principal component loadings of selected taxa on the first (horizontal) and second (vertical) PCA axes, profile XW-13, Bear Lakes area

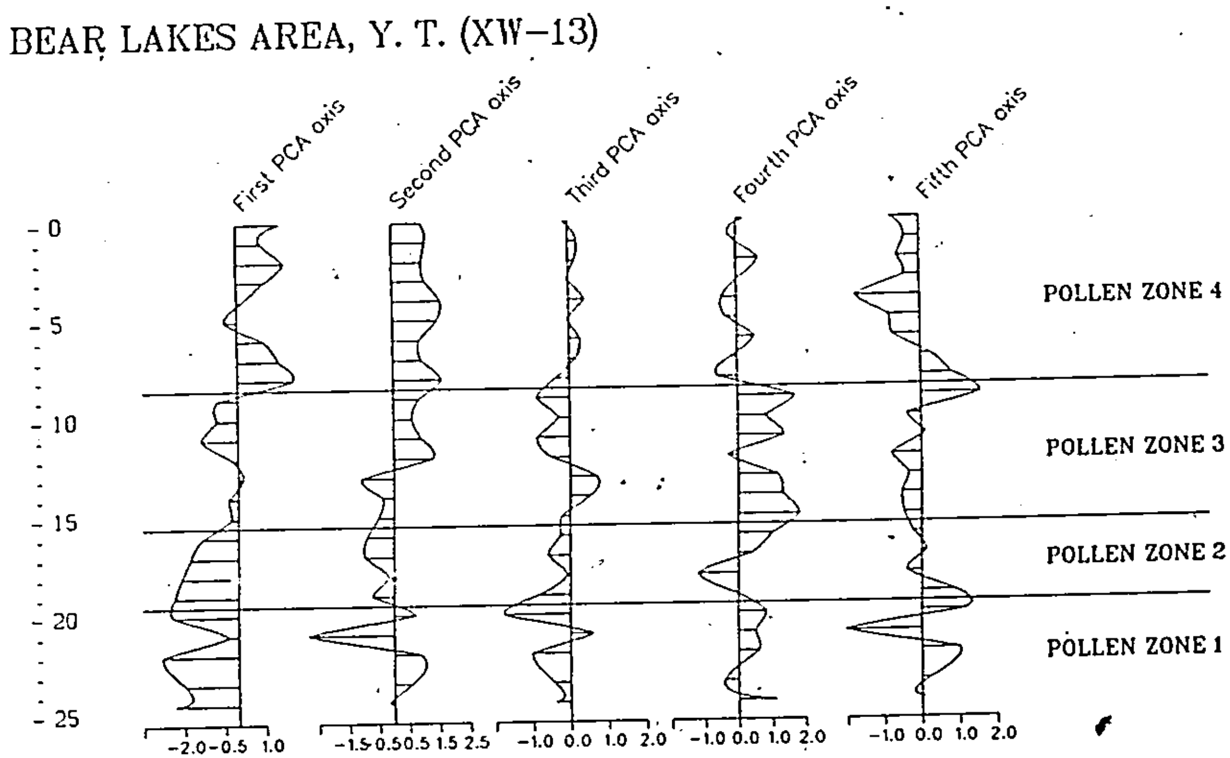

Figure 8.11b Principal component scores of profile XW-13 samples on the first five PCA axes, Bear Lakes area

taxa. Negative scores of zones 1 to 3 samples indicate that Gramineae, Cyperaceae, and Rosaceae have important representation, while the score pattern of zone 4 samples precisely reflects the variation of _Pinus_ values. The second axis accounts for 22.9% of the total data covariance. _Picea_ has high positive loading, while _Alnus_, _Betula_, and Ericaceae have high negative loadings. As the result of this loading pattern, samples of zones 1 and 2 all have low scores, and positive scores of zones 3 and 4 samples reflect the increasing importance of _Picea_ and decrease of _Betula_. Ericaceae are responsible for the negative sample scores in the lower part of zone 3. The third axis, representing 14.5% of the total data variation, reflects the complex relation among Cyperaceae, Rosaceae, and _Betula_. Dominant negative scores of zones 1 to 3 samples account for the significant representation of _Betula_ and Rosaceae in these zones, while the low positive scores of zone 4 samples indicate the increased importance of Cyperaceae in comparison with _Betula_ and Rosaceae. These first three axes account for more than 67% of the total data covariance. Other axes such as the fourth and fifth, are not as important as the first three.

Results of PCB and CA are broadly similar (Fig. 8.12 and 8.13). The first and second axes of PCB and CA capture 88.1% and 85.6% of the total data variability. It is clearly indicated by the result of PCB that _Picea_, _Betula_, Gramineae,

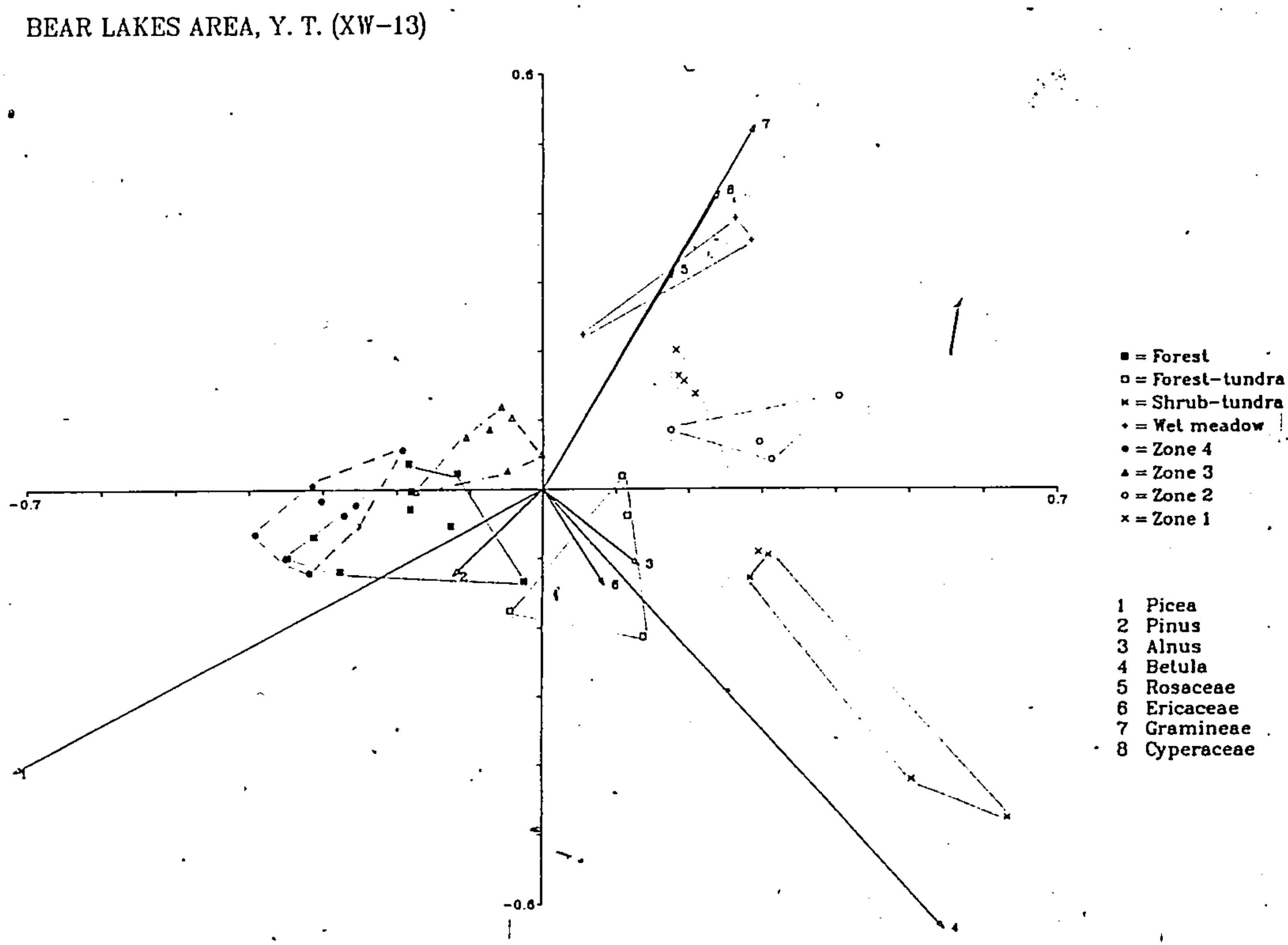

Figure 8.12 Ordination of combined data matrix of modern and fossil pollen samples on the first (horizontal) and second (vertical) PCB axes, profile XW-13

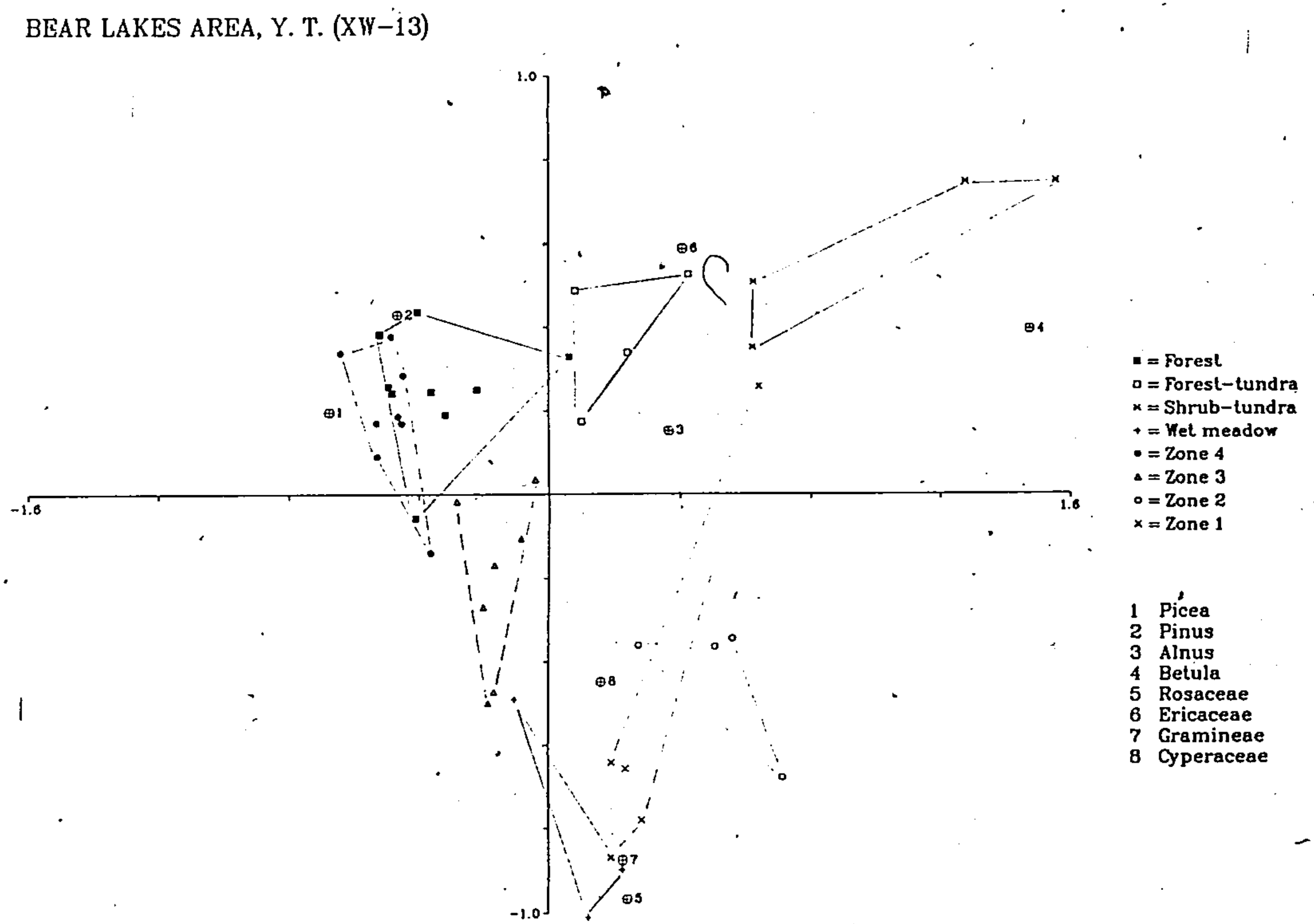

Figure 8.13 Ordination of combined data matrix of modern and fossil pollen samples on the first (horizontal) and second (vertical) CA axes, profile XW-13

Cyperaceae, and Rosaceae are the five most important taxa in the data set. The relations among these dominant taxa exhibit an interesting pattern. The orientations of Gramineae, Cyperaceae, and Rosaceae vectors are exactly same which indicate that these taxa are positively correlated. However, negative correlation exists among Picea, Betula, and this Gramineae-Cyperaceae-Rosaceae group. The overlap of the zone 4 sample cluster with the modern forest sample cluster indicates the great similarity between these two groups. It is notable that one of the zone 1 samples is far away from the cluster of zone 1 samples and is more closely related to modern shrub-tundra samples. This feature is due to the high Betula pollen percentage in this sample which might be an anomaly of preservation. Other samples or clusters are all numerically distinctive from each other.

8.3.6 Reconstruction of Paleovegetation

A broad reconstruction of paleovegetation in the Bear Lakes area has been provided in earlier studies (Wang, 1988a; Wang and Geurts, 1987a). Ages of events are assumed on the basis of a depth vs. age relationship using White River ash, but are not controlled by radiocarbon dates.

ZONE 1: Surficial pollen spectra from the Mackenzie Delta region have shown a relative abundance of > 20% to about 10% spruce in the forest-tundra vegetation zone

(Ritchie, 1974). Ten percent spruce pollen is considered as an "appropriate threshold value to indicate spruce presence " (Ritchie, 1984a, p. 125). This value was determined from lacustrine sediments. In the case of peat bog sediments, however, the overrepresentation of local components in comparison with lacustrine environments might dilute the regional and extra-regional components, therefore the percentage of regional taxa, namely Picea here, is considerably under-estimated. In the Bear Lakes area, spruce percentage is consistently around 21 to 25% in this zone, implying the presence of spruce in the area. Moreover, a spruce log (identified by R. J. Mott) preserved just above the Ash layer also confirms the presence of spruce in the area. On the other hand, comparable Picea percentages (5-20%) have been interpreted as a result of long distance transport (MacDonald, 1983) in the Upper Natla River area. This interpretation, however, is probably not applicable to the Bear Lakes area since the spruce value here is higher and much more consistent than that in the Upper Natla River area, and also conflicts with the presence of the macrofossil.

High abundances of shrub and herbaceous pollen indicate that these components were also important during this period. Rosaceae was often seen in open habitats during the last three field seasons. Juniperus, occurring in two of five samples, is also an indicator of open habitats.

Investigations of modern pollen dispersion in the northern Yukon Territory suggest that dwarf birch is a prolific pollen producer (Ritchie, 1977; 1982; 1984a). It can be assumed that birch was not a major component in the vegetational community (with a value of about 14%) but it was present in the area during this period. As a feature of peat bog sediments, local taxa are often very well represented in pollen spectra. High percentages of Gramineae and Cyperaceae in zone 1 are a reflection of this feature, indicating those taxa were widespread in the vicinity of the core site during this period. Considering all of the above information, the initial vegetation following the deposition of White River ash was a forest-shrub-tundra on the basis of pollen assemblages.

ZONE 2: Minimal *Picea* value and the occurrence of charcoal at horizon 19 cm indicate a fire around 950 yr BP. This minimal percentage suggests that the fire destroyed the spruce trees in the area. The occurrence of *Epilobium*, a pioneer after fires (White, 1974), indicates the presence of an open habitat after the fire. The high percentages of *Betula* and Rosaceae are also an indication of open habitat, and the lack of competition with a high canopy of trees, since the fire likely destroyed the tall stands of spruce and created a favorable habitat for these shrubs. Moreover, the presence of very well preserved charcoal in the sediments between 19 cm to 15 cm in the profile confirm the occurrence of fire. The extent and origin of this fire, however, are not clear based on only one profile.

The gradual increase of Picea percentage from 7% at the bottom of zone 2 to 47% at the bottom of zone 3 indicates the reforestation process in the area. Birks (1980b) has reported that after the White River volcanic eruption, a pioneer phase of herb-dominated assemblages persisted in the Klutlan Glacier area for about 200 years, a shrub-tundra phase for about 200 years, and then a Picea glauca forest developed about 800 years ago. This implies that the forestation process took about 400 years to complete in the area. In Bear Lakes area the reforestation process probably took about 200 years to complete, which is much less than that in the Klutlan Glacier area. However, the reforestation process in the Bear Lakes area was following a fire, and "the importance of post-fire tree regeneration depended on the regeneration potential of the pre-fire communities, ... and on the timing between a fire occurrence and the onset of cold or mild climatic conditions" (Payette and Gagnon, 1985, p.571). If spruce in a pre-fire community was mature and produced seeds constantly, those seeds would have had a high potential for reforestation. If one of the above mentioned factors were met, it would have been possible for a reforestation process in the Bear Lakes area to be completed within 200 years rather than 400 years as in the Klutlan Glacier area.

ZONE 3: Zone 3 represents a time during which an open spruce forest or at least very dense forest tundra existed in the area. Comparable spruce values of surficial samples from spruce forests were reported from the Klutlan Glacier area (Birks, 1980b), the Mackenzie Delta area (Ritchie, 1974), and also from boreal forest samples in Alaska (Short et al., 1986). The apparent decrease of shrub and herbaceous abundance also support this reconstruction of the paleovegetation in the area. Meanwhile, most taxa which require open habitat are more poorly represented than before, indicating the increasing density of vegetation cover on the landscape. The small peak of Ericaceae at the base of the zone could be interpreted either as an indication of a disturbance of the environment or the existence of moist soil conditions.

ZONE 4: An abrupt increase of spruce abundance (about 20%) and the occurrence of two *Pinus* peaks characterize this zone. Rosaceae has distinctly smaller representation than before, and *Betula* shows little change. In herbaceous taxa, Gramineae has decreased, but Cyperaceae has increased somewhat. Three hypotheses concerning the reconstruction of vegetation during this interval could be advanced: A)

Increasing density of the forest; B) No change of the vegetation cover but more efficient pollen production by spruce; C) A combination of hypotheses A and B.

An increase of more than 10% spruce pollen has often been interpreted as an indication of increasing density of vegetation cover or an advance of tree line. This classical interpretation is supported here by the more than 20% increase in spruce pollen abundance and obvious decrease of Rosaceae and Gramineae. However, it is hard to explain why Betula does not exhibit a simultaneous decrease in response to the increasing density of vegetation. In conclusion, it is difficult to interpret such a pollen assemblage purely on the premise of a closing-up of forest. This could potentially eliminate hypothesis A.

Considering hypothesis B, the vegetation cover during this interval was probably similar to that which existed before. In this case, the productivity of spruce could have improved during the interval of zone 4 by either climatic or ecological factors or a combination of both. This interpretation is supported by the obvious decrease of Rosaceae pollen abundance and simultaneous increase of Cyperaceae. The decrease of Rosaceae could be the result of climatic influences since Rosaceae is less tolerant of wet conditions than spruce, and the increase of Cyperaceae indicates an increase of soil moisture. Wet conditions in a relatively dry area are favorable for spruce pollen production. However, this interpretation does not correspond with the obvious decrease of Gramineae abundance. In conclusion, hypothesis B on its own could not account for such an assemblage.

Considering hypothesis C, the wet conditions evidenced by the Rosaceae versus Cyperaceae relationship improved the pollen production of spruce, and a slightly higher density of forest partly caused the increased spruce percentage and also accounted for the decrease in Gramineae. A suitable interpretation of pollen zone 4 therefore, includes a more efficient pollen production of spruce and a slightly increasing density of forest in the area, as suggested by hypothesis C.

8.3.7 Climatic Inference

The high percentages of Cyperaceae from 1,230 yr BP to approximately 1,000 yr BP suggest a relatively moist climate during this period. By 1,000 to 950 yr BP, lower Cyperaceae as well as higher Rosaceae percentages reflect a drier summer climate condition, under which fire may be triggered easily. The period of 950 to 750 yr BP probably experienced high precipitation as suggested by high percentages of Cyperaceae and *Betula*. These conditions were favorable for the rapid reforestation by spruce. At Port Radium in the Great Bear Lake area, N. W. T., Nichols (1975) reported a short-lived warm and wet episode between 950 yr BP and about 750 yr BP with a more successful development of spruce forest. After the event of reforestation in the Bear Lakes area, the records of pollen zone 3 suggest a relatively dry period which probably moderated the pollination of spruce until the end of zone 3 (about 400 yr BP). Well represented Rosaceae and lower Cyperaceae percentages support this suggestion. Similar records have been reported from Port Radium in the Great Bear Lake area, N. W. T. (Nichols, 1975). Considering the similarity of records from the Bear Lakes area and those from Port Radium in the Great Bear Lake area, Northwest Territories, which is about 820 km away, the coincidence of pollen content as well as the time sequence established in both areas, may suggest a climatic shift from a wet condition between 950 and 750 yr BP to a drier condition between 750 and 400 yr BP over a broad area. By the beginning of zone 4 (about 400 yr BP) the pollen records started to register more wet events. A gradual rise of Cyperaceae and a rapid reduction of Rosaceae and Gramineae strongly suggest a wet condition and higher precipitation rate than before. The flourishing of spruce as indicated by the 20% increase in spruce percentage (Fig. 8.9), possibly derived from more efficient pollen productivity as well as slight increasing density of the forest in the area, is a reflection of this wet and cooler climatic condition. Bourgeois and Geurts (1983) reported cooler and higher moisture conditions for the interval 1,363 to 1,230 yr BP evidenced by an increase in spruce pollen percentages in a forest area in Grizzly Creek, southwestern Yukon Territory. Ager and Sims (1981) gave a similar interpretation for a spruce flourishing after 3,500 yr BP in the Tangle Lake area of Alaska. This climatic interpretation is also consistent with glacier advances in the St. Elias Mountains during the Little Ice Age, which occurred from 473 yr BP to 53 yr BP (Denton and Karlén, 1973). Moreover, the contemporary record of annual precipitation at Aishihik (256.5 mm) is very close to the documented 250 mm threshold of dryness tolerance for the sexual reproduction of black spruce (Black and Bliss, 1980), and *Picea glauca* has a similar climatic tolerance range to black spruce (Beaudet, 1986). Therefore improvement of moisture conditions in such a dry area is favorable for an increase in spruce pollination.

8.3.8 Summary and Conclusion

The environmental history in the Bear Lakes area during the last 1,230 yr BP, as revealed by pollen records of profile XW-13, can be divided into four different developing stages. Forest-shrub-tundra occupied the area from 1,230 to 950 yr BP, characterized by moist climatic conditions. A short-lived dry event around 1,000 to 950 yr BP was a fire prone period, and pollen records as well as the presence of charcoal in the sediments reveal the evidence of a fire at the beginning of zone 2. After the fire, the vegetation in the area was typical shrub-tundra for a while, then the area was gradually reforested. This process took about 200 years to complete. By the beginning of zone 3 at ca. 750 yr BP, high spruce abundance recorded the history of an open phase spruce forest with relatively drier climatic conditions than before. This probably moderated the pollen production of spruce during the period. A sharp increase of tree pollen, mainly spruce, at the beginning of zone 4 (ca. 400 yr BP) indicates a change in the environmental condition of the area. More efficient pollen production, caused by the increase of precipitation, combined with a slightly increased density of forest in the area, accounted for a 20% increase of spruce percentage.

8.4 Summary Remarks

Narrow sampling of two short peat sections in the Bear Lakes area produced a pollen record of post-glacial environmental history in this area, especially the profile XW-13 which provides detailed information about the environmental variation during the last 1,230 years.

At the High Bog site, which is far above the modern tree line, pollen records indicate that the site was occupied by a

Cyperaceae-dominated mesic community from 4,000 yr BP until 650 yr BP. A modern dwarf birch-dominated community at the site has been stable since 650 yr BP as the result of landform development. *Picea*, *Pinus*, and *Alnus* have significant representation in the pollen spectra as exotic pollen, which indicates that the low pollen production of tundra can strongly exaggerate the representation of long distance transported taxa.

Pollen records of profile XW-13, which is below the modern tree line, are not directly comparable with that of XW-8 due to the difference in time scale. However, this profile provides the information for short term variation or oscillation of environmental conditions in this area.

Chapter 9

Reconstruction of Paleoenvironment: A Synthesis

9.1 Introduction

The five previous chapters presented the modern and post-glacial pollen records of different parts of the Aishihik Basin and the adjacent area, and the reconstruction of local environmental history at each of the fossil sites. It is now appropriate to discuss the history of post-glacial environmental variation in a regional context. This chapter therefore, presents a synthesis of the post-glacial history of regional vegetation and climatic variation over the study area. The post-glacial vegetation development and stability will also be considered. Some problems regarding the determination of pollen accumulation rate in peat and permafrost regions as stated in the objective section of chapter 1, will be briefly discussed.

9.2 Post-glacial Vegetation History: Spatial and Temporal Patterns

A comparison of the pollen records of southwest Yukon and other parts of northwest North America demonstrates that the post-glacial vegetation history of the Aishihik Basin and the adjacent area is similar and comparable to that in the other localities (Tab. 9.1). It must be kept in mind, however, that the differences in radiocarbon age of a single event between adjacent sites may not exclusively reflect the migration of taxa but can be due to error or variation of the radiocarbon date itself. As Birks and Birks (1980, p. 15) have indicated,

Table 9.1 Late Quaternary vegetation history from selected localities in northwestern North America

Age yr BP	Alaska				North Yukon	N.W.T.	
	Tanana Valley Ager (1975)	Black River Anderson et al (1988)	Brooks Range Livingstone (1955,1957)	Issabella Basin Matthews (1974)	Hanging Lake Cwynar (1982)	Natla River MacDonald (1983)	Mackenzie River Ritchie (1984b)
1000							
2000	Picea-Betula -Alnus Zone						
3000	(Boreal forest)						Picea-Betula -Alnus Zone
4000		Alnus-Picea Zone	Alnus-Betula Zone	Picea-Betula -Alnus Zone		Picea-Betula Zone	
5000					Alnus crispa Zone		
6000							
7000	(Picea decline)		Birch Zone				Picea-Betula Zone
8000			????	????		Betula Tundra	
9000	Picea-Betula Zone (Gallery forest)						
10000	Populus-Salix Zone (Deciduous Scrub-forest)		Herb Zone	Betula-herb Zone	Ericales Zone		Betula-Populus -Juniper Zone
11000		Betula Zone		????			
12000							
13000	Betula Zone Shrub-tundra				Betula Zone		
14000				Herb-Betula Zone			
15000	Herbaceous Tundra	Herb Zone			Salix-Cyperaceae Zone		

Table 9.1 continued

Age yr BP	Southwest Yukon							
	Antifreeze Pond Rampton (1971)	Jenny Lake Stuart et al (1988)	Nisling Valley This study	Mackintosh Creek Beaudet (1986)	Mackintosh Creek This study	Polecat Lake This study	Moose Depression This study	Ittlamit Lake This study
1000		Picea forest						Picea-Salix -Cyperaceae
2000			Picea-Cyperaceae Zone (Forest)					Picea-Betula -Alnus
3000	Spruce forest	Picea-Alnus Woodland					Picea forest (Cyperaceae)	
4000				Dense spruce forest tundra	Dense spruce forest tundra			Picea-Alnus -Juniperus -Cyperaceae
5000						Marsh		
6000		Picea forest	Picea-Betula Zone (Forest)			Picea forest	Picea forest	Picea-Salix -Gramineae
7000	Spruce woodland							
8000			Picea Forest tundra	Sparse Forest-tundra	Sparse Forest-tundra	Picea-Betula Forest tundra	Picea Forest tundra	
9000	Shrub-tundra	Alnus Shrub tundra		Shrub tundra	Shrub tundra	Betula Tundra	Betula Shrub tundra	
10000					Herbaceous Tundra		Herb tundra	
11000		Birch tundra		Herbaceous Tundra ? ? ?				
12000								
13000	Sedge-moss Tundra							
14000								
15000								

radiocarbon ages of a paleoecological event provide only an approximate measure of simultaneity at different sites because many sources of error and discrepancy exist in the method.

During early post-glacial time, Aishihik Basin and its adjacent area supported a herb-dominated tundra vegetation as suggested by pollen records from Upper Mackintosh Creek (Beaudet, 1986; XW-3, this study) and central Aishihik Basin (XW-6, this study). This was a short-lived event in the area. The herb zone has been reported from the north in many localities from late glacial to early post-glacial time. The basic characteristics of the herb zone of this study resemble those from north Alaska (Livingstone, 1955; 1957) but are somewhat different from those of the Hanging Lake area (Cwynar, 1982). This is due to the lack of great representation of *Artemisia*, which is probably due to the moisture of the soil in the lowland area where the above pollen sequences were recovered. Therefore the herb zone from Aishihik Basin and the adjacent area represents a lowland sedge-grass-dominated community.

By approximately 10,000 yr BP, the vegetation of Aishihik Basin and the adjacent area was replaced by a birch-dominated shrub tundra whose pollen content resembles that from northern and interior Alaska (Livingstone, 1955; 1957; Ager, 1975; Matthews, 1974). A similar vegetation replacement at 10,000 yr

BP has also been reported from Antifreeze Pond in southwest Yukon (Rampton, 1971), which suggests that such a change in vegetation cover was a regional rather than a local phenomenon in the southwest Yukon. It is unique that the pollen records of Jenny Lake (Stuart et al., 1988) suggest a short-lived Alnus shrub tundra phase following the birch zone between 9,500 and 8,500 yr BP. Such records have not been found from the other localities in the area. However, this finding seems to support the hypothesis that Alnus migrated from south to north along the British Columbia and Alaska coast (MacDonald, 1984, p. 174).

Following the shrub-tundra phase, spruce arrived at least 9,000 yr BP in the Upper Nisling Valley (XW-1, this study), 8,900 to 9,000 yr BP in the Upper Mackintosh Creek (Beaudet, 1986; XW-3, this study), and 8,600 yr BP in the central Aishihik Basin (XW-6, this study). Pollen records from Ittlemit Lake Basin show that the arrival of spruce in the basin occurred at about 9,000 yr BP (XW-7, this study). Such events marked the beginning of a short-lived spruce forest-tundra environment in the area. A significant rise of spruce occurred at 7,900 yr BP in the Upper Nisling Valley, which reflects a spruce forest vegetation cover in the area; at 8,000 yr BP and 7,700 yr BP in the Upper Mackintosh Creek area at low altitude (975 m a.s.l.) and high altitude (1,060 m a.s.l.) sites, respectively, which suggests a dense spruce forest-tundra environment; and at 7,500 to 7,600 yr BP in the central Aishihik Basin area, which marks the beginning of dense spruce forest vegetation in the region. This vegetation change, however, is not recorded in the pollen sequence from Ittlemit Lake Basin (XW-7), probably due to local environmental conditions. The Ittlemit Lake area is a small basin at a higher altitude (1,180 m a.s.l.) than the other sites and is surrounded by a rolling and mountainous topography which isolates the area from central and northern Aishihik Basin except by a pass to the east (Fig. 7.1). Climatic stress due to high altitude seems to have suppressed the normal ecological succession in this case.

It is notable that the vegetation changes around 9,000 yr BP and 8,000 yr BP have been recorded across the North. In the lower Mackenzie River basin a Picea-Betula zone replaced a Betula-Populus-Juniperus zone at 9,000 yr BP which marks the first occurrence of spruce in the area (Ritchie, 1984b). At Hanging Lake in northern Yukon, Cwynar (1982) reported a substitution of an Alnus crispa zone for the previous Ericaceae zone at 8,900 yr BP. Pollen records of the Upper Natla River area (MacDonald, 1983) suggest that spruce invaded the area at 8,640 yr BP and subsequently rose at 7,700 yr BP. In central Alaska, Matthews (1974) reported a replacement by Picea-Betula-Alnus zone of a Betula-herb zone at about 8,000 yr BP. A decline of Picea, which represents a warm and dry event, has been documented from Tanana Valley between 8,400 and 6,000 yr BP (Ager, 1975). The replacement of the herb zone by the birch zone (Livingstone, 1955; 1957) was also around 8,000 yr BP. In southwest Yukon, spruce woodland replaced a shrub-tundra phase at 8,700 yr BP at the Antifreeze Pond area (Rampton, 1971), while spruce forest established at 8,500 yr BP at the Jenny Lake area (Stuart et al., 1988). It is concluded, therefore, that the vegetation changes during early post-glacial time as suggested by pollen records from this study in the Aishihik Basin and its adjacent area are related to the climatic variation and reflect synchronous modification of environmental conditions across the North.

After the establishment of forest and forest-tundra vegetation in the northern and central study area at 7,500-8,000 yr BP, the area vegetation pattern remained relatively stable. However, it is worthwhile to note the change of pollen composition around 6,000 yr BP. In central Aishihik Basin, the pond of XW-4 was closed at approximately 5,900 yr BP and became a marsh or peat bog environment. Moose Depression (XW-6) was changed from a shallow pond to the present peat bog at 5,700 yr BP. In northern Alaska, *Alnus*-*Betula* shrub-tundra replaced previous *Betula*-Ericaceae shrub-tundra at 6,000 yr BP (Livingstone, 1955; 1957), while in Tanana Valley spruce recovered and modern boreal forest was established at 6,000 yr BP (Ager, 1975). In the southwest Yukon, Rampton suggested an establishment of modern boreal forest accompanied by intensive rise of Alnus at 5,700 yr BP (Rampton, 1971). In the southern part of the study area, pollen records of Ittlemit Lake basin (XW-7) suggest a slightly later event at 5,000 yr BP when a rise of Alnus and Cyperaceae was documented. A change of pollen spectra with a tremendous increase of Alnus has also been recorded in the Lower Mackenzie River Basin at 5,100 yr BP (Ritchie, 1984b). In conclusion, these facts suggest a change of environmental conditions around 6,000 yr BP documented by the pollen records of this study. This is consistent with the records across a wide area and therefore reflects the regional rather than local modification of the environment.

It is significant that the vegetation pattern has been stable since 5,000-6,000 yr BP, although it has been suggested that the tree line advanced three times during this interval (Rampton, 1971). Most of the pollen sites in this study are 60-250 m below the modern tree line and minor climatic oscillations which could cause fluctuation of the tree line would probably not strongly influence pollen rain within the forest. Pollen profile XW-8 at High Bog is above modern tree line and therefore might provide some information. An increase of Picea pollen percentage and accumulation rate at about 4,000 yr BP might suggest a slight tree line advance. This change, however, could be very limited since in this region a cooler and moister climatic condition could cause the increase of spruce pollen production which might change the composition of the regional pollen rain. Such a result is consistent with previous studies in southwest Yukon (Bourgeois et Geurts, 1983; Campbell, 1985). The succession of vegetation development in the Bear Lakes area during the last 1,230 years, as reconstructed from profile XW-13, is probably a local rather than regional variation due to fire and reforestation processes. However, the variation of pollen spectra during the last few hundred years in that area has more regional significance, which reflects the changes of environmental conditions during the Little Ice Age.

9.3 Special Considerations of Selected Taxa

9.3.1 *Picea*

The only *Picea* species existing in the study area is *Picea glauca* according to the three years field observations, although *Picea glauca* and *Picea mariana* have broadly similar distribution ranges in the North. The following discussion will therefore focus on *Picea glauca*.

The origin and post-glacial migration routes of *Picea* in the North have been repeatedly discussed before (*e.g.* Ritchie, 1984a; MacDonald, 1984). Hopkins (1972) and Matthews (1976) initially proposed that spruce survived in Beringia during full-glacial time, but this idea was later abandoned (Hopkins et al., 1981). However, current studies cannot reject or prove this proposition (MacDonald, 1984). Beaudet (1986) found a high spruce percentage peak prior to 10,000 yr BP in Upper Mackintosh Creek and interpreted his result as a possible support of the Alaska and/or Yukon spruce refugium hypothesis. However, this interpretation probably needs to be re-evaluated due to the extremely low pollen concentration and high portion of corroded spruce pollen grains, which might suggest redeposition.

Ritchie (1984a) and MacDonald (1984) have proposed a popular hypothesis which postulates that spruce migrated from a southern refugium, northward into south-central Manitoba, and from there moved to the Mackenzie Delta region. It has also been proposed that spruce migrated from the northern Yukon via the Porcupine Valley to central Alaska and arrived at Tanana Valley at 9,500 yr BP. From there, spruce expanded rapidly southward into southwest Yukon (Ager, 1975; 1983). However, a recent study suggests that spruce arrived at Ped Pond area in the middle of Porcupine Valley (site 16, Fig. 1.2) at 8,500 yr BP and at the Black River region, which is between northern Yukon and Tanana Valley, at 7,500 yr BP. This result suggests that this region was not the route of *Picea* migration (Anderson *et al.*, 1988).

It has also been proposed that *Picea* could enter the Yukon from northern British Columbia via the Liard River Plain and subsequently migrate northward along the Tintina Trench (MacDonald, 1984). It is worthy to note that spruce arrival dates deduced from this study suggest a southward migration (Fig. 9.1). *Picea* invaded the Upper Nisling Valley at least 9,000 yr BP (XW-1, this study), arrived in the Upper Mackintosh Creek area at 8,900-8,800 yr BP (Beaudet, 1986; XW-3, this study), and in the central Aishihik Basin at 8,600 yr BP (XW-6). However, evidence of this southward migration is not observed in the southern part of the study area. Solid data from the Ittlemit Lake Basin suggest that spruce arrived in this area at least 8,900-9,000 yr BP which is approximately 300-400 years earlier than that at the central Aishihik Basin. These results seem to suggest that spruce invaded the study area via different migration routes, supporting the hypothesis that spruce invaded the Yukon via Liard River Plain (MacDonald, 1984). In this case, it is possible that spruce migrated from Tintina Trench via the uppermost Yukon River plain, southwestward into the study area. This hypothesis, however, could be artificial, resulting from the error or deviation of ^{14}C dates and therefore requires further investigation in the uppermost Yukon River plain area. Future investigation in the lower Nisling Valley may also be helpful.

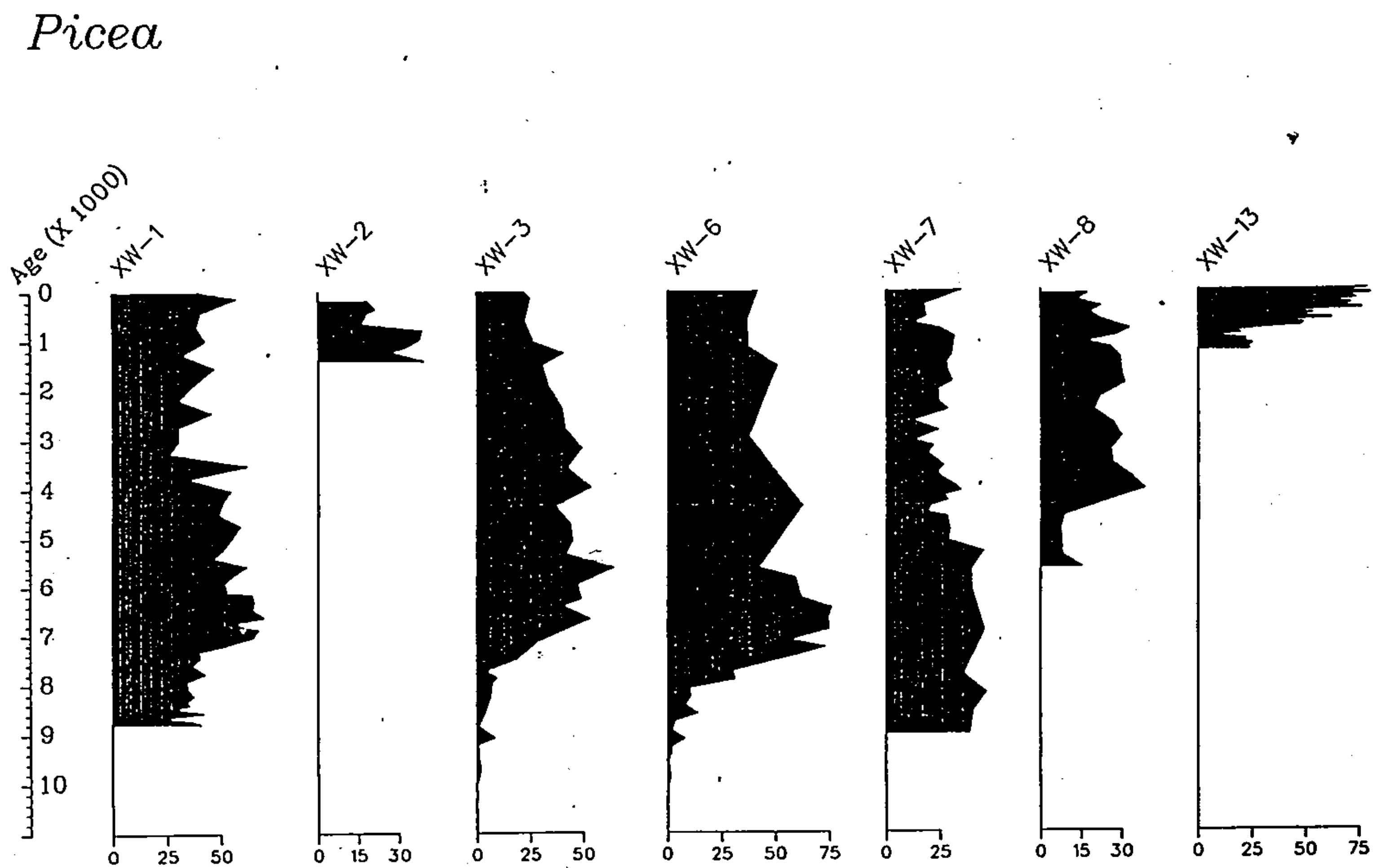

Figure 9.1 A summary diagram of Picea pollen percentage in the study area

9.3.2 Pinus

The post-glacial migration of lodgepole pine (*Pinus contorta*) has been previously reported (MacDonald, 1984; MacDonald and Cwynar, 1985). The present study area is beyond the distribution range of *Pinus contorta* (Geurts, 1986b), and pollen records from this study suggest that *Pinus contorta* has never colonized the area during post-glacial time. However, the low percentages of exotic *Pinus* pollen, from different sites in this study, illustrate an interesting pattern. Although *Pinus* pollen has been traceable from 9,000 yr BP in the area, considerable values (>1%) were only registered in the pollen spectra after the deposition of White River ash in most sites. This phenomenon reflects the migration of *Pinus* into the southwest Yukon during late Holocene (MacDonald, 1984; MacDonald and Cwynar, 1985). Moreover, the *Pinus* pollen percentages from this study (Fig. 9.2) show a close relation with the density of vegetation cover. High *Pinus* percentage is recorded from Upper Mackintosh Creek (XW-3), Ittlemit Lake Basin (XW-7), and the Bear Lakes region (XW-8, XW-13). All these localities supported a sparse vegetation of forest-tundra or shrub-tundra (XW-8). This result may suggest that sparse vegetation cover has less effect on the filtration of regional pollen rain. Another interesting phenomenon is that sites at higher altitudes have a better representation of *Pinus* pollen, which is strongly overrepresented.

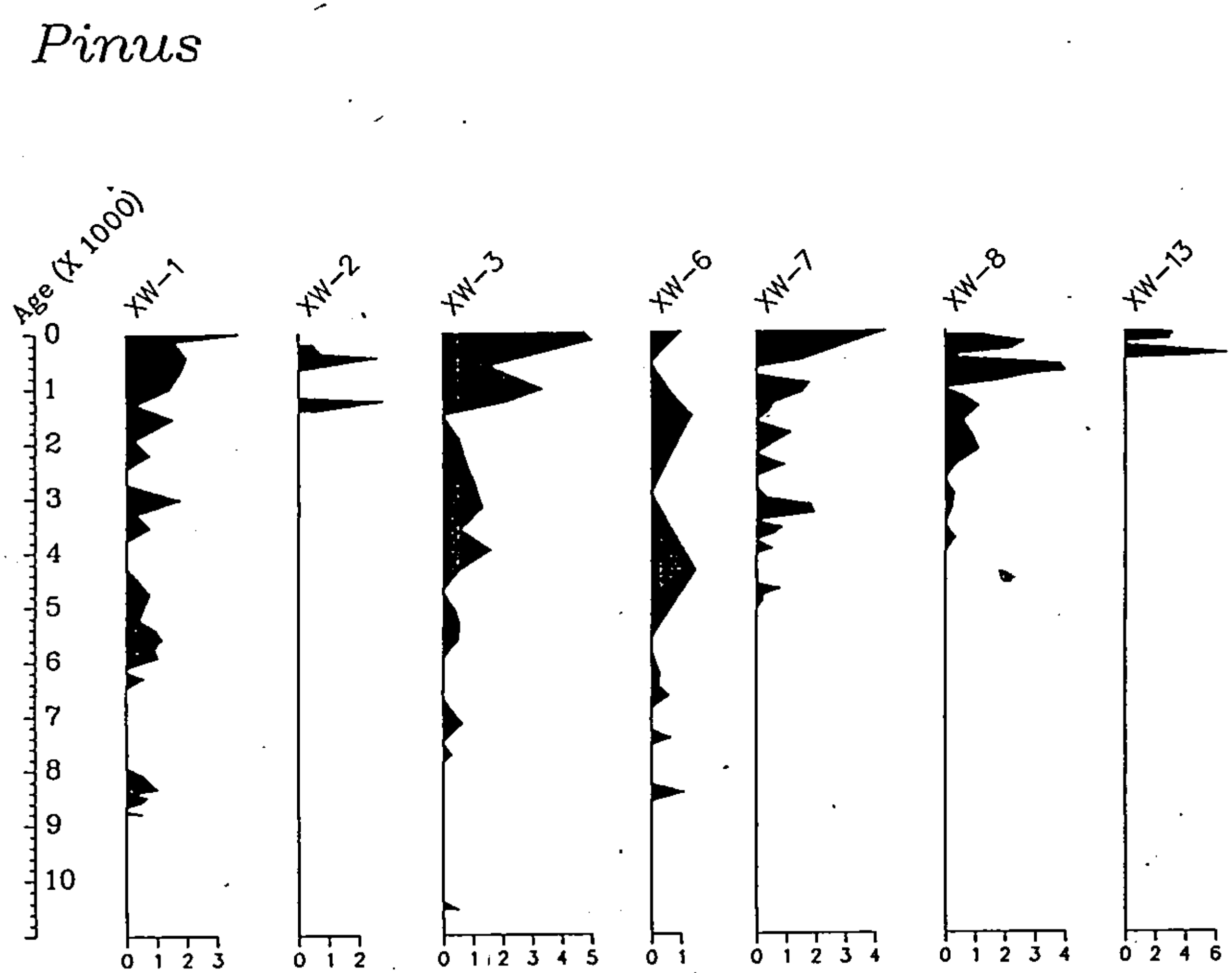

Figure 9.2 A summary diagram of Pinus pollen percentage in the study area

It is worthwhile to note that the *Pinus* pollen percentage exhibits a discontinuous representation and several peaks have been recorded (Fig. 9.2). Isolated peaks of *Pinus* pollen percentages, despite low values, were registered in Upper Nisling Valley and Upper Mackintosh Creek as early as prior to 8,000 yr BP, and such a phenomenon was repeated several times in the records during the Holocene, especially during the last 1,230 years when the values reached 1% or more. Although the chronology of these events can not be confidently correlated due to the difficulty of radiocarbon dating, at least one isolated peak was recorded at Ittlemit Lake Basin around 500 yr BP which is firmly controlled by a ^{14}C date. Similar spectra have also been observed from the Bear Lakes area (XW-13) and High Bog site (XW-8) at approximately the same time, based on linear extrapolation. Apparently, it is difficult to interpret the fluctuation of pine pollen with the normal migration model (MacDonald and Cwynar, 1985). The analysis of climatic data from the abandoned Aishihik Climatic Station (Environment Canada, 1982) reveals that the dominant directions of wind are S and SE throughout the year except in winter, when the dominant winds are northerlies. Moreover, the mean monthly wind speeds from spring to fall are higher than those during winter and two maxima occur in May and September (Fig. 2.11, Wang, 1988a). During the pollination period of *Pinus contorta* in May and June (Bassett *et al*. 1978), high mean monthly wind speeds and dominant SE and S winds might bring the pine pollen to the study area and form these peaks. Airborne pollen records from the Gladstone Creek area, southwest Yukon Territory (Lagarec et Geurts, 1984) reveal that low pressure on Ruby Range and meridional circulation of air masses are favorable conditions for the transport of airborne pollen to the study area. This is consistent with the prevailing wind direction during the summer in the area. These isolated Pinus peaks in the fine resolution diagram, moreover, may reveal a frequent shift of this low pressure and meridional circulation system. Exotic pollen peaks have been interpreted as evidence of paleowind directions as reported from Baffin Island (Nichols et al., 1978). The fine resolution of records with narrow sampling intervals and isolated exotic pollen peaks in the Bear Lakes and Ittlemit Lake area provides a confirmation of the theoretical approach.

On the other hand, favorable pollen formation conditions for Pinus consist of low radiation, cloudy conditions, and high humidity during late summer and fall (Lejoly-Gabriel, 1978). Isolated peaks of Pinus pollen around 500 yr BP indicate a wetter climate during the pollen formation period in late summer and fall and an increase of southeast wind frequency during the flowering period in the following year. This interpretation is consistent with the previous conceptual approach of Geurts (1988; Géurt et Lagarec, 1987), and with the extension of glaciers in the St. Elias Mountains during the Little Ice Age.

9.3.3 *Alnus*

The obvious rise of *Alnus* pollen, to higher than 20% around 8,000-6,000 yr BP following the expansion of spruce, has been reported from most pollen sites in northern and central Yukon (such as Ovenden, 1982; Çwynar, 1982; Ritchie, 1982), the Northwest Territories (such as Ritchie and Hare, 1971; Ritchie, 1977; 1984b), the Snag area and Jenny Lake area in southwestern Yukon (Rampton, 1971; Stuart *et al*., 1988), and eastern Alaska (Ager, 1975; 1983; Edwards and Brubaker, 1986; Anderson *et al*., 1988). However, such a rise is not registered in the pollen records from the Aishihik Basin and its adjacent area. The percentage of *Alnus* in most localities of this study (Fig. 9.3) rarely exceeds 10%, and remains *ca*. 5% in most sections described in this monograph. Although a rise of *Alnus* pollen has been recorded from the Ittlemit Lake Basin and High Bog site in the Bear Lakes area, its value is still not comparable with those at other sites in the North. Pollen spectra in this study illustrate that *Alnus* pollen is better represented at sites with higher altitude (profile XW-7, XW-8, and XW13), which suggests a strong overrepresentation from regional or extraregional sources. This interpretation is consistent with the previous conclusion that alder pollen is usually overrepresented in the pollen spectra from high altitude sites (Bourgeois et Geurts, 1983; Campbell, 1985; 1987). Other anomalies of *Alnus* pollen representation have also been found

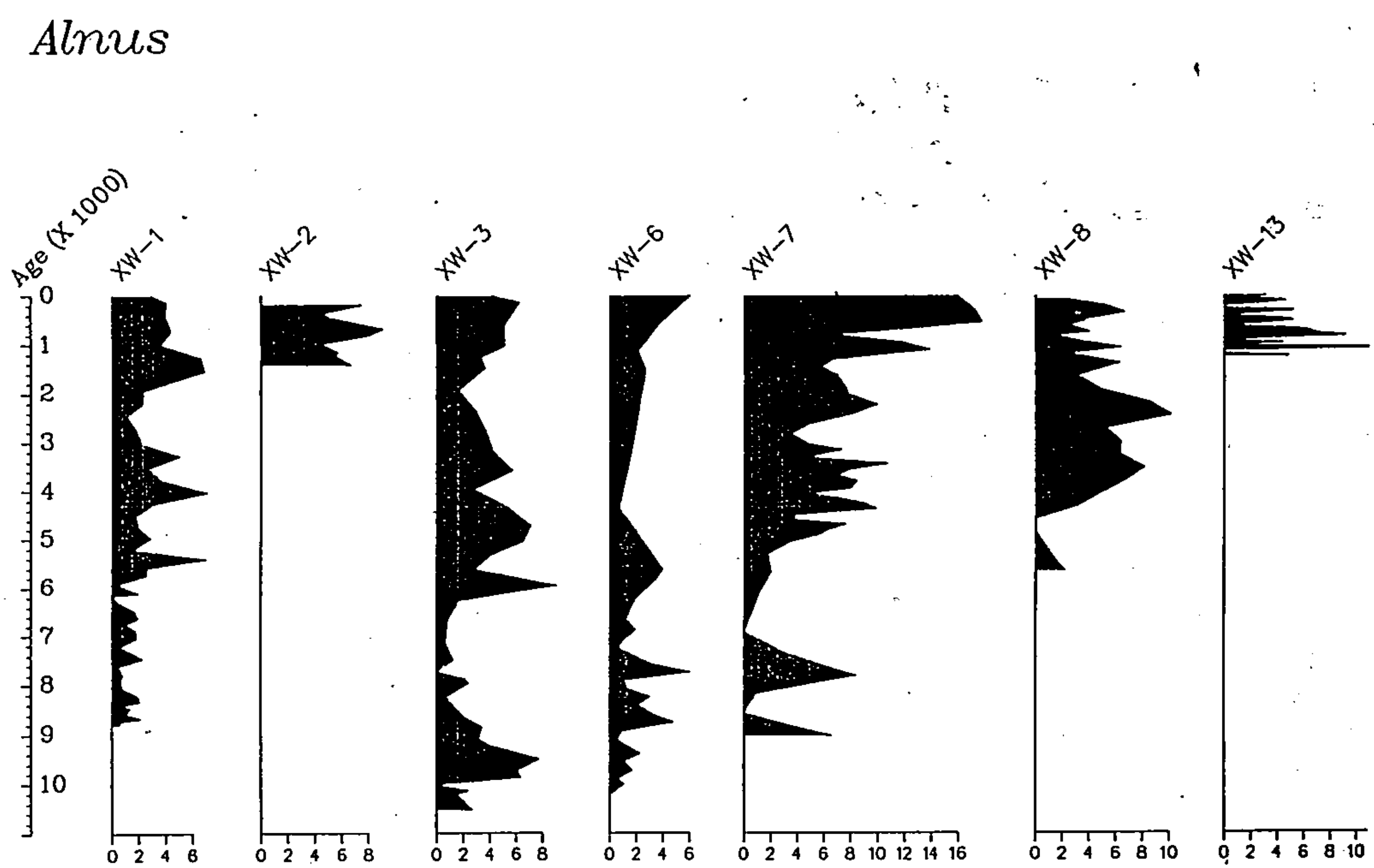

Figure 9.3 A summary diagram of Alnus pollen percentage in the study area

from the south-central Yukon at Two Horsemen and Kettlehole sites (Cwynar, unpublished data, see Cwynar *et al.*, 1987), where *Alnus* expanded simultaneously with *Betula* before the rise of *Picea*. The occurrence of alder in the modern vegetation of the study area is very sparse according to the three summer field observations from 1984 to 1986. The interesting question is why was the spread of *Alnus* to the north retarded, and to the Aishihik Basin suppressed? The possible answer includes the regime of precipitation during the Holocene. Previous studies indicate that *Alnus crispa* requires a relatively moist substrate, and development of organic soils with higher water-holding capacities in the continental interior might have allowed the species to expand in the mid-Holocene (MacDonald, 1984). Severe climatic conditions with very low precipitation in the Aishihik Basin and the adjacent area might account for the extremely low representation of *Alnus* in the vegetation and thereby the low value of *Alnus* pollen spectra.

Previous study in the Jenny Lake area indicated that an *Alnus* shrub-tundra developed between 9,500 and 8,500 yr BP, and a *Picea*-*Alnus* woodland between 4,500 and 2,000 yr BP (Stuart *et al.*, 1988). However, field investigation in the Kluane Lake area indicates that *Alnus* has a low representation in the modern vegetation in the area. Only one individual was observed in the Cultus Creek and some small stands of *Alnus* in the steep Williscroft Creek canyon (M.-A. Geurts, personal communication, 1988). It is very interesting to note that moss samples in a shrub-tundra, where Alnus is present in the vegetation, yield 10-20% Alnus pollen (de Bastiani et Geurts, 1987; de Bastiani, 1988). Comparing the records in these areas and those from the Aishihik Basin, it can be presumed that Aishihik Basin has never been favorable for the expansion of Alnus during the middle and/or late Holocene.

It has been noted from previous studies in northwestern Canada and adjacent Alaska that Alnus is strongly overrepresented as a minor component of vegetation (<10%), contributing up to 50% of the regional pollen spectra (Ritchie, 1984a; Macdonald, 1984). However, modern pollen records from central and western Alberta indicate that Alnus with similar density often produces less than 10% of regional spectra (MacDonald, 1984). This fact might suggest the differential pollen production between southern and northern localities, or higher production of other taxa at southern sites. However, this hypothesis can not be properly evaluated without pollen accumulation rate or pollen concentration data.

9.4 Post-glacial Vegetation Development and Stability

The present study supports the proposal that significant vegetation development and plant community instability occurred during the late Pleistocene and early Holocene (MacDonald, 1984). Pollen records suggest that there was a short-lived phase of herbaceous tundra in the study area immediately after deglaciation. This vegetation cover was soon replaced by the invasion of Betula-dominated shrub communities at about 10,000 yr BP. A significant change of vegetation pattern in the area occurred at 9,000-8,600 yr BP when spruce invaded the area. After the establishment of the spruce forest at 7,600-8,000 yr BP in the area, there is little evidence that any fluctuation or major change of vegetation composition has happened in the area. Such a rapid replacement of vegetation in late-glacial and early post-glacial time is related primarily to the migration of invasion taxa. Survivors of Beringia communities first invaded the area upon the retreat of ice due to close geographical proximity. Taxa such as Picea from a southern refugium invaded the area several thousand years later due to long distance migration. It is likely that vegetation instability during the early Holocene was primarily related to the migration of the invader, and the expansion of plant populations probably ceased when its range limit of climatic tolerance was reached.

It is inevitable that invasion of a species to an existing community should lead to competition if there is a significant overlap of niches. Successful competition of the invader should initiate the change of vegetation pattern and therefore cause instability (MacDonald, 1984). Early post-glacial vegetation instability represented by the rapid change of vegetation patterns is likely the result of such competition. The invasion of shrubs around 10,000 yr BP caused the decline of herbaceous pollen in the pollen spectra, which might reflect a successful competition for light by Betula and other tall taxa. Occurrence of Picea in the area around 9,000-8,600 yr BP initiated another rapid change of vegetation. The tall stature, longevity and developed root system of spruce enable it to have a great advantage in the competition for light, soil moisture, and nutrients. After the establishment of spruce forest or forest-tundra in the study area, the basic vegetation pattern remained stable during the middle and late Holocene. This was probably due to the cessation of plant migration as the result of reaching their climatic range limits, and also due to the competitive advantage of spruce which might make other invaders unsuccessful.

In summary, the early post-glacial instability of vegetation documented in this study is comparable to that at other localities (MacDonald, 1984; Ager, 1975). This instability appears to be primarily the result of plant invasion with differential migration. Successful competition of invaders caused the replacement and change of vegetation patterns in the area and therefore initiated the vegetational instability. Most taxa attained their climatic range limits in the middle Holocene, creating a stabilization of vegetation during the middle and late Holocene. The great competitive advantage of spruce might be also important for such a change.

9.5 Post-glacial Climatic Variation

Climatic interpretation of pollen data requires knowledge of the interaction between the plant communities and their ecological environments, the present-day relationship between pollen records and the vegetation they represent, and the precision of paleovegetational reconstruction from fossil pollen records. Unfortunately, our understanding of the precise mechanisms controlling the relationship between vegetation and climate is still poor (Ager, 1975), which makes the climatic interpretation more difficult and possibly misleading.

The major environmental and vegetational changes represented by the pollen records from Aishihik Basin and the adjacent area provide some information concerning the broad climatic conditions in the region during the past 10,000 years. This section is a brief interpretation of this information.

Pollen records from the northern Yukon have suggested an early Holocene Milankovitch thermal maximum (Ritchie *et al.*, 1983). Interpretation of the deglaciation model in the study area (Dewez, 1988) indirectly supports such an thermal model. Pollen records from sites such as Moose Depression with high pollen accumulation rates indicate a warm but dry period from

10,000 yr BP to about 7,600 yr BP. This interpretation is supported by the frequently occurring Artemisia pollen in the central Aishihik Basin (XW-5, XW-6) and Rosaceae in most sections from the study area during this interval. The interval between 7,600 and about 5,700 yr BP was characterized by the significant increase of Picea percentage and accumulation rates in most sections, which probably reflects the middle Holocene climatic amelioration with an increasing precipitation. Decrease of Rosaceae and increase of Equisetum in most profiles support this interpretation. Significant changes of environmental conditions around 5,000-6,000 yr BP have been recorded in most profiles. Although eutrophication of lakes is a common evolutionary phenomenon (M.-A. Geurts, personal communication, 1988), it cannot be ignored that Moose Depression (XW-6) and a pond in the Polecat Lake area turned into a marsh or peat bog almost simultaneously. This fact is difficult to interpret as being due to eutrophication and was likely a response to climatic change. Such a consideration is also consistent with a previous study of an ice-cored pingo in the area, which was formed approximately at 6,000 yr BP (Geurts et Dewez, 1985). The increase of Equisetum and Cyperaceae along with the great representation of Picea in most profiles, and slight rise of Ericaceae pollen in some sections indicates the beginning of a cold and wet event, which probably indicates that the development of regional permafrost initiated the formation of existing frozen, elevated bogs in the area.

There is little information concerning the climatic conditions after 5,700 yr BP in the area, despite the proposal that the tree line has advanced three times according to macrofossil evidence from southwest Yukon (Rampton, 1971). The rise of Cyperaceae and Polygonum in some profiles after the deposition of the White River ash suggests an increase of ground moisture which is probably related to the Little Ice Age. The increase of Picea pollen in some localities (XW-13) can be interpreted as the result of such an increase of precipitation and decrease of temperature in the area, and such an interpretation is consistent with glacier extension in the St. Elias Mountains (Denton and Karlén, 1977).

9.6 Pollen Accumulation Rate of Peat in Permafrost Regions

Problems with the determination of pollen accumulation rates in peat sediments have been noted in the northern Yukon, and it has been suggested that variations in microtopography at Polybog over the past 10,000 years are likely to have caused significant differences in total pollen accumulation rates irrespective of the regional vegetation (Ovenden, 1982). Although frequent fluctuations of calculated pollen accumulation rates have been observed, this study suggests that the principles and methodologies for the determination of pollen accumulation rates still remain valid in peat sections since the general trend of variation of pollen accumulation rates coincides with the change of percentage data in most cases. However, comparison of accumulation rates from different sediments (e.g. peat and gyttja) is difficult because of their different properties for pollen accumulation. It has been proposed in an earlier chapter that pollen accumulation rates determined from lacustrine sediments are higher than those from peat. Data from Moose Depression (XW-6, chapter 6) provide a good example of this proposal. A significant decrease of pollen accumulation rate at 34.0 cm coincides with the change of sediments from organic silt to peat. Such a decrease has been interpreted as the result of a changing sedimentation environment rather than vegetation change since there is no indication of significant change of relative pollen frequency of major taxa. Lower pollen accumulation rates in peat sediments are probably related to the fact that peat bogs receive pollen grains from the bog-forming taxa and from wind or suspended grains, while lakes or ponds can also receive pollen grains from runoff or streams. Another possibility is that lacustrine sediments such as silt or gyttja consist of fine-grained autochthonous material accumulated from a large area and therefore might have a higher density, while peat sediments are more fibrous material with less density and are accumulated *in situ*. Therefore, the calculated pollen accumulation rates from lacustrine sediments might be higher.

Other problems concerning the determination of pollen accumulation rates in peat from cold regions include the distortion of sedimentation rates and sample volume determination caused by frost heave during the formation of permafrost, which has been fully discussed in chapter 3. Cryoturbation, solifluction, and other periglacial phenomena might cause severe problems for pollen analysis in cold regions due to the disturbance of the sediment sequence, which must be carefully avoided in the field.

A further problem is the determination of radiocarbon dates in the northern environment. It has been observed that there are severe reversions of dates from the Shaky Hand Creek sequence in the Ruby Range (Campbell, 1987), and several spurious dates have also been reported in this study. One possible interpretation of such inversions is a change of the permafrost table which could cause a change of ground water activity and therefore cause the contamination, described as "cryosuccion" (see chapter 8, term used by Pissart, 1983). However, the mechanisms of this problem are still not fully understand.

Chapter 10

Summary

The objectives of this study as stated in chapter 1 were to obtain information regarding the paleoenvironmental history during post-glacial time in the Aishihik Basin and adjacent areas. This chapter provides a very brief review of the basic approaches and results of this study.

10.1 <u>Basic Approaches</u>

1. Nine pollen-bearing sediment cores and/or monoliths were collected along a north-south transect from the Upper Nisling Valley in the north to Ittlemit-Bear Lakes area in the south. Detailed fossil pollen analyses were carried out on these cores and/or monoliths.

2. Modern pollen surface samples were obtained from 20 sites in four different vegetation-landform units to evaluate the relationship between modern pollen rain and its mother vegetation-landform environment.

3. Radiocarbon dates were obtained from the palynostratigraphic sequences to approximate the chronology of interesting events. The results suggest that this study provides a paleoecological record for the last 10,000-11,000 years.

4. Numerical methods were used to aid in the empirical zonation of pollen assemblages. These procedures include ZONATION, CONISS, and CONZONE.

5. Principle Component Biplot (PCB) and Correspondence Analysis (CA) were used to compare the fossil and modern pollen records obtained from this study. A combined data set of modern and fossil pollen spectra was used during these analyses.

6. Principle Component Analysis (PCA) and CLuster Analysis (CLA) were employed to investigate the relationship between the modern pollen spectra and the vegetation-landform units from which the surficial samples were collected.

7. The absolute pollen accumulation rates were analyzed from four of these nine sections to aid in the interpretation of the pollen percentage data.

8. Loss on ignition and grain size analysis were carried out for the Moose Depression section (XW-6) to aid the analysis of sediments and achieve a better understanding of the paleoenvironment.

10.2 Principal Results

1. This study fills a large geographic gap in the post-glacial pollen records for the southwest Yukon, and provides information on post-glacial environmental variation.

2. The initial vegetation of the study area was a herb-dominated tundra followed by the replacement of dwarf birch-dominated shrub-tundra at about 10,000 yr BP. Spruce invaded the area at 9,000-8,600 yr BP, and spruce forest and/or dense forest-tundra were established at about 7,500-7,900 yr BP. A modification of the local environment was recorded around 5,000-6,000 yr BP, including the closing of lakes or ponds, changes of bog conditions, etc. Modern regional vegetation patterns were established about 6,500 yr BP and have been stable since. The basic features of vegetational variations deduced from this study are comparable to the other studies in the North.

3. Spruce invaded the area at 9,000-8,600 yr BP and exhibit a southward migration in the area from Middle Nisling Valley to the central Aishihik Basin. However, records from the southern part of the study area, e.g. Ittlemit Lake Basin, show that spruce arrival time was earlier than that at central Aishihik Basin, which suggests different or multiple migration routes. Results of this study support the hypothesis that spruce might have invaded the Yukon via the Liard River plain and migrated through the Tintina Trench.

4. Dense spruce forest was established at about 7,600 yr BP in the area. The expansion of spruce in the area was much earlier than that at Antifreeze Pond in southwest Yukon.

5. The records of *Pinus* pollen in this study show that *Pinus* was never in the area during post-glacial time. The fluctuating pattern of *Pinus* pollen cannot be simply interpreted by the previously proposed migration model (MacDonald and Cwynar, 1985). However, the fossil records support the model deduced from modern airborne pollen records in the area (Lagarec et Geurts, 1984; Geurts et Lagarec, 1987) that such fluctuations of *Pinus* pollen in southwest Yukon are related to changes in the atmospheric circulation system. Low pressure and high humidity are favorable conditions for the transport of *Pinus* pollen to the area. Repeated peaks of *Pinus* pollen frequency in the fossil records suggest a periodic shift of such climatic conditions.

6. Records of *Alnus* pollen in this study are different from other investigations in northwestern Canada and adjacent Alaska. *Alnus* pollen percentages in this study rarely exceed 10%, while in other localities they are often 20-50%. Such a difference might be related to low precipitation in the study area since *Alnus crispa* requires moist strata. However, it is evident from this study that *Alnus* is strongly overrepresented in the pollen spectra, and better registered in the sites at higher altitude (Fig. 9.3).

7. The early post-glacial vegetation exhibited a high instability, basically related to sequential migration and invasion of taxa from late-glacial refugia. The vegetation pattern became stable when most taxa reached their range limit in the middle Holocene.

8. Fossil pollen records from peat sediments suggest that a change of pollen spectra does not exclusively reflect a variation of climate or development of vegetation succession. The evolution of landform or a change of sedimentation environments or even microtopography might also cause a significant modification of the pollen spectra. Such fossil records are consistent with the suggestion deduced from modern surficial pollen records (Geurts, 1983).

9. Absolute pollen accumulation rates from different sediments, e.g. peat and gyttja or lacustrine silts, are not directly comparable. Low values are expected in peat due to its small pollen accumulation area and low density.

10. The data from this study demonstrate that pollen accumulation rates can be strongly influenced by the exaggeration of sample volume and distortion of sedimentation rates due to ice lensing and frost heaving in a permafrost environment. This fact should be considered in future palynological investigations in permafrost regions.

Modification of such influences on the determination of pollen accumulation rates is also discussed in this monograph.

10.3 Supplementary Results

1. Numerical zonation of pollen spectra from peat sediments is better carried out with a comparison of the results from several different procedures due to the fluctuation of pollen content between samples. Program CONZONE was carried out by the author for such a purpose.

2. Quick development of computer technology enables palynologists to deal with large data sets easily. Program PALYDP (PALYnology Data Processor), created by the author, is one of the newly developed systems, which can carry out the data storage, retrieval, calculations, and diagram construction.

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Appendix A

Preparation Procedure for Moss Polster Samples

1. Place ca. 1 cubic cm sample in the beaker.
2. Add 50 ml NaOH (10%) and boil for 10 minutes.
3. Filter into a centrifuge tube by a metal filter with ca. 200 µ mesh, centrifuge for 10 minutes, decant and wash.
4. Add 5 ml acetic acid glacial (99.5%), stir, centrifuge for 10 minutes and decant.
5. Add 5 ml Erdtman acetolysis mixture (9 parts of acetic anhydride, 1 part of concentrated sulphuric acid), stir while heating in steam bath until 100 °C, cool for 30 minutes, centrifuge and decant.
6. Add 5 ml acetic acid glacial, stir, centrifuge, decant and wash.
7. Dilute the final residue of centrifuge with mixture of glycerine and water (2/3 : 1/3), transfer into a small bottle.

Appendix B

Preparation Procedure for Sediment Samples

1. Place ca. 2 cubic cm sample in the beaker.
2. Add 50 ml NaOH (10%) and boil for 10 minutes.
3. Filter into a centrifuge tube by a metal filter (200 µ mesh), centrifuge for 10 minutes, decant and wash.
4. Add 5 ml HCL (10%), stir, centrifuge and decant.
5. Add 5 ml HF (48%), stir, boil for 10 minutes in steam bath, or lay down overnight, centrifuge, decant and wash. Repeat this treatment if sample is very mineral-rich.
6. Add 5 ml NaOH (10%), stir, boil 10 minutes in steam bath, centrifuge, decant and wash.
7. Add 5 ml acetic acid glacial (99.5%), stir, centrifuge and decant.
8. Add 5 ml Erdtman acetolysis mixture (9 parts of acetic anhydride, 1 part of concentrated sulphuric acid), stir when heating in steam bath until 100 °C, cool for 30 minutes, centrifuge and decant.
9. Add 5 ml acetic acid glacial, stir, centrifuge, decant and wash.
10. If original sample has much clay or silt, sieve with a magnetic sieve (7 µ mesh), 10 % NaOH as medium and wash.
11. Dilute the pollen-bearing residue with diluted glycerol (66%), transfer to small bottle.

Appendix C

Loss on Ignition Procedure

1. Dry samples at 105 °C for 12 hours.
2. Desiccate crucibles with burner for 15 minutes, cool in desiccation chamber, without manipulating crucibles with fingers, and weigh when extremely cool (BE).
3. Place approximately 2 g dry sample in the crucible, weight (BD).
4. Heat the crucible, which contains the sample, on a gas burner for at least 15 minutes until there are no sparks when stirring and sample turns into extremely loose powder. Cool in desictation chamber, and weigh when extremely cool (BR).
5. Calculation:

$$\text{Loss on Ignition (\%)} = \frac{BD-BR}{BD-BE} \times 100$$

Appendix D

Grain Size Analysis Procedure

1. Dry the sample at 105 °C for 12 hours, weigh when cool.
2. Soak the samples in a solution of hexametaphosphate for at least 12 hours to disaggregate particles.
3. Add hydrogen peroxide to burn organic material for at least 12 hours, repeat until reaction ceases.
5. Place the sample into the 60 mesh sieve and lay the 250 mesh sieve below, run water through the sample. Agitate the sample with fingers. The 250 mesh separation is complete when the water running through is clear.
6. Wash the material from the 250 and 60 mesh sieves back into small dishes. Dry at 105 °C for 12 hours, and weigh when cool.
7. Stir the suspension of fines and pour it into bottles.
8. Add several drops of the fine suspension into a beaker containing acetone solution, counted by a COULTER COUNTER model TAII until reaching the sum of 45000 particles.
9. Tabulate, calculate, then present the final result in histograms.

Appendix E

Statistical Formulas Used in this Study

1. Pearson's product-moment correlation coefficient.

$$r_{ij} = \frac{\Sigma_{i=1}^{n} X_{ij} X_{ik} - \frac{1}{n}\Sigma_{i=1}^{n} X_{ij} \Sigma_{i=1}^{n} X_{ik}}{\sqrt{\left[\Sigma_{i=1}^{n} X_{ij}^2 - \frac{1}{n}\left(\Sigma_{i=1}^{n} X_{ij}\right)^2\right]\left[\Sigma_{i=1}^{n} X_{ik}^2 - \frac{1}{n}\left(\Sigma_{i=k}^{n} X_{ik}\right)^2\right]}}$$

2. Cosine theta coefficient.

$$\cos\theta = \frac{\Sigma_{i=1}^{n} X_{ij} X_{ik}}{\sqrt{\Sigma_{i=1}^{n} X_{ij}^2 \Sigma_{i=1}^{n} X_{ik}^2}}$$

3. Average Euclidian distance.

$$d_{ij} = \sqrt{\frac{\Sigma_{k=1}^{m}\left(X_{ik} - X_{jk}\right)^2}{m}}$$

4. The goodness-of-fit criterion.

$$C_t = \frac{\Sigma_{j=1}^{t} \theta_{jj}^2}{\Sigma_{j=1}^{r} \theta_{jj}^2}$$

5. Three species richness or variety indices (d).

$$d_1 = \frac{S-1}{\ln N}$$

$$d_2 = \frac{S}{\sqrt{N}}$$

$$d_3 = S \; per \; 1000 \; individual$$

where S=number of species, N=number of individuals,etc.

6. Shannon–Weaver information measurement.

$$\overline{H} = -\Sigma \frac{n_i}{N} \ln \left(\frac{n_i}{N} \right)$$

$$= -\Sigma p_i \ln p_i$$

where p_i = importance probability for each species.

Appendix F

CONZONE: A FORTRAN-77 Computer Program
for the Numerical Zonation
of Pollen Data

- A User's Guide and Program Listing

Version 1.1

July 26, 1988

F.1 Introduction

CONZONE is a program which partitions a palynological or biostratigraphic data set into stratigraphically constrained zones. The program has been designed for the users who know the fundamentals of the operating system. A working knowledge of FORTRAN 77 is useful but not required. The interactive feature of the program allow the user to communicate with the computer and choose from different actions. Statistical principles of the program have been described previously in chapter 3.

F.2 Program Listing

The program is written in standard FORTRAN 77. It has been compiled and run successfully on an AMDAHL 470 computer with VS FORTRAN and WATFOR-77 compilers under CMS operating system, and it will run on IBM PC family micro-computers also, with the exception of dendrogram plotting. The program listing is given here in table F.1, and a brief description of each subprograms has been supplied at the beginning of the program. Line numbers at the leftmost side in table F.1 are not a part of the program.

F.3 Files:

The program requires two disk files for input and output. The data are read from a file connected to unit 5, and the results are written to unit 6. Unit 0 is assigned to the terminal (key board and screen) for interactive communication between the user and computer. These units or files must be preconnected with system commands. Microcomputer users however, will be prompted to enter a file name. Caution must be given for these users that the extension of data file on micros (.DAT) should not be specified when a file name is entered. The program will add the extension for you automatically. It is necessary to take the following line (line 97) off when the program is run on a microcomputer:

```
OPEN(IREAD,FILE='STATDA',STATUS='OLD')
```

In addition, delete the letter "C" from the first column of the following statements:

```
C      WRITE(0,'(A)')' File name:'
C      READ(0,'(A8)')FN
C      FNIN=FN//'.DAT'
C      FNOUT=FN//'.RST'
C      OPEN(IREAD,FILE=FNIN,STATUS='OLD')
C      OPEN(IPRINT,FILE=FNOUT,STATUS='UNKNOWN')
```

F.4 Format of Input data file

The input data file should have a name as "name.DAT" on the microcomputer, and any name on the mainframe, provided the name is predefined for a character string "FNAMEI". For example, users of CMS systems can preconnect the data file by entering a command as

```
FILEDEF FNAMEI DISK fn DATA A
```

This command will define your file FN DATA from your A disk to the program unit 5.

The ideal input data file can be built during the execution of program PALYDP (see appendix G in this monograph) by a selection option. However, data file can also be created using system editor following the format described here.

The input file format is basically controlled by a data file IDentifier (abbreviated as ID hereafter) system. All data must be preceded with some program reserved ID. The following is a brief description and list of these ID distinguishable by the program. All ID must be in upper case, and started at column 1 in the data file. Example of an input data file is listed in table F.2.

LOCATION	(Required for plotting dendrogram. A character string of 40 characters must start at column 25 on the same line)
NUMBER OF SAMPLES	(Required. An integer must begins at column 25 on the same line)
NUMBER OF TAXA	(Required. An integer must begins at column 25 on the same line)
LIST OF TAXA	(Optional. If present a list of taxa must start on the next line. An order

number starts at column 5, and a taxa name consisting of 20 characters as maximum starts at column 10. Each line contains only one taxa)

DATA — (Required. Input data follow this ID on the next line. Each line contains data for one sample. The first input on each line is an order number for the sample, and data entered in a free format, i.e. leave at least one space between two data)

DEPTH LEVEL OF SAMPLES — (Required for plotting the dendrogram. An array of sample depth levels follow this ID on the next line in a free format)

END OF FILE — (Required. This ID must be placed at the bottom of the data file, otherwise all input after this ID will be ignored, or an error message will be prompted and the program will be terminated if this ID is missed in the data file)

F.5 Output File

The results of clustering is represented in a resulting file through unit 6. The first part of the result file contains the input data, including the title or location of the data set (required), a list of taxa used (optional) and table of input data (optional). The second part of the output file is the results of clustering. The information measurement and clustering method are specified before writing the results. Clustering results are written in sequential order of merging data. The original input order of the first sample in a cluster is assigned to the number of clusters. For example, if a cluster contains sample 4,5,6,and 7, therefore the cluster is referred to as cluster 4 for the next merging of data. The first two columns of output are the cluster numbers merged at each stage. The third column indicates the result of dissimilarity measurements for each merge, to be subsequently used for dendrogram construction. If there are N samples, there will be only N-1 cluster merge stages. Table F.3 represents an example of output file.

F.6 Dendrogram Plot

As a convention of zonation procedures, the results are usually represented as a dendrogram. Program CONZONE provides four subroutines (YDNPLT, YDDPLT, YORDER, YSCALE) to furnish the plotting job. These subroutines use the DISSPLA graphics package (Version 10.0, Integrated Software Systems Corporation, 1986), and are therefore installation dependent. As a basic feature of the DISSPLA package, graphical display of an image is device independent therefore "does not rely upon features particular to any type of graphical device" (Integrated Software Systems Corporation, 1986). However, the CALL ANYDEV statement at line 316 in subroutine CZONES of program CONZONE must be supplied by the user's computer centre to integrate the program with an available interface or device for the display of plotting results. Where the DISSPLA graphics package is not available users can delete the plotting subroutines and line 302-317 and 431-440 in subroutine CZONES. Subroutine YORDER converts the plotting data into xy coordinates for each cluster and can therefore be adapted for plotting dendrograms on other plotting packages. A sample of a dendrogram plotted by the program is represented in figure F.1.

F.7 Error Messages

Some possible problems in the input data file have been predicted in the program, therefore a number of error message can be displayed on screen when necessary. The following is a list of these possible messages.

"Too many samples -- program terminated"

This message indicates that the sample numbers in the data file exceed the allowable maximum of 150 as present specified.

To expand the allowable maximum of sample, change KD=150 on line 74 (PARAMETER statement) to a larger number)

"Too many taxa -- program terminated"

This message provides similar information to the previous error message. Change LD=30 on line 74 (PARAMETER statement) to expand the allowable maximum of taxa.

"The first few line in data file in not understood"

This message indicates that a data file ID is not correctly placed or spelled. Check the input ID with table F.2. The program will be terminated automatically if this message is displayed on the screen.

"Data file ID not recognized"

Similar to above, this message indicates that an ID in the input data file is misspelled. the program will automatically terminate if this message is displayed on the screen.

Other error messages could be written to unit 6 or the screen by the system compiler if an error encountered. Check the user's manual of operating system to find out what the problem is.

Table F.1 Listing of computer program CONZONE. Note the line numbers at the left side of the table is not the part of the program

```
         1         2         3         4         5         6
....,....+....,....+....,....+....,....+....,....+....,....+..

************************************************************
*                                                          *
*                    CONZONE  (FORTRAN)                    *
*                                                          *
*      CONSTRAINED ZONATION PROCEDURE FOR POLLEN DATA      *
*                                                          *
*                           BY                             *
*                     XIA-CHENG WANG                       *
*                  DEPARTMENT  OF GEOLOGY                  *
*                  UNIVERSITY OF OTTAWA                    *
*                                                          *
*                      VERSION  1.1                        *
*                       07-26-1988                         *
*                                                          *
************************************************************
*
*
*
*
*                  INDEX OF SUBPROGRAMS
*                  --------------------
*..........................................................
*  #     NAME  FUNCTION                                    :
*.........................................................:
*  1  CONZON  MAIN PROGRAM                                 :
*  2  COEFFS  SUBROUTINE TO CALCULATE THE CORRELATION      :
*             COEFFICIENT                                  :
*  3  COLINK  SUBROUTINE TO MERGE INFORMATION MATRIX BY    :
*             COMPLETE CLUSTERING METHOD                   :
*  4  COSETA  SUBROUTINE TO CALCULATE THE COSIN THETA      :
*             COEFFICIENT                                  :
*  5  CZONES  MAJOR SUBROUTINE TO CARRY OUT CLUSTERING     :
*  6  DATAIN  SUBROUTINE TO READ INPUT DATA MATRIX         :
*  7  EUCDST  SUBROUTINE TO CALCULATE EUCLIDIAN DISTANCE   :
*  8  UWPGMA  SUBROUTINE TO MERGE INFORMATION MATRIX BY    :
*             UNWEIGHTED PAIR GROUP CLUSTERRING METHOD     :
*  9  WRITER  SUBROUTINE TO PRINT A MATRIX                 :
*                                                          :
*      SUBROUTINE FOR GRAPHICAL DISPLAY OF DENDROGRAM      :
* 10  YDDPLT  SUBROUTINE TO PLOT THE DEPTH COLUMN ON       :
*             DENDROGRAM                                   :
* 11  YDNPLT  MAJOR SUBROUTINE TO PLOT DENDROGRAM          :
* 12  YORDER  SUBROUTINE TO ORDER THE CLUSTERS             :
* 13  YSCALE  SUBROUTINE TO SCALE Y AXIS (DEPTH)           :
*.........................................................:
```

```
*
*
*
*                                    LIST OF FILES
*                                    -------------
*..........................................................................
* UNIT #    UNIT NAME         DESCRIPTION                                 :
*.........................................................................:
*   50      SCREEN            SCREEN AND KEY BOARD                        :
*   4       IREAD             INPUT DATA FILE                             :
*                             (*.DAT ON PC)                               :
*   6       IPRINT            OUTPUT FILE                                 :
*                             (*.RST)                                     :
*..........................................................................
*
*
*
C
C                =====================================
C
C                          PROGRAM CONZON
C
C                =====================================
C
C      SUBROUTINE REQUIRED: DATAIN,CZONES
C
       PROGRAM   CONZON
C
       PARAMETER (KD=150,LD=30)
       INTEGER   SCREEN
       CHARACTER LOCATE*40,FN*8,FNIN*12,FNOUT*12,CARDS*80
       DIMENSION VAR(KD*LD*5),IVAR(KD*LD),CHAR(LD)
       COMMON    /IO/SCREEN
C
C.... OPEN DATA FILES
C
       SCREEN=50
       IREAD =4
       IPRINT=6
C
C.... FOR USERS ON MAIN FRAME, TAKE THIS PARAGRAPH OFF
C
C      WRITE(SCREEN,'(A)')' File name:'
C      READ(SCREEN,'(A8)')FN
C      FNIN=FN//'.DAT'
C      FNOUT=FN//'.RST'
C      OPEN(IREAD,FILE=FNIN,STATUS='OLD')
C      OPEN(IPRINT,FILE=FNOUT,STATUS='UNKNOWN')
C
C.... PC USERS TAKE THIS STATEMENT OFF
C
       OPEN(IREAD,FILE='STATDA',STATUS='OLD')
```

```
C
C.... READ CONTROL CARD
C
 100  READ(IREAD,'(A)')CARDS
      IF(CARDS(1:8).EQ.'LOCATION') THEN
        READ(CARDS(25:64),'(A40)')LOCATE
      ELSEIF(CARDS(1:17).EQ.'NUMBER OF SAMPLES') THEN
        READ(CARDS(25:34),'(BN,I10)')K
        IF(K.GT.KD) THEN
          WRITE(SCREEN,'(A)')' Too many samples -- program terminated'
          STOP
        ENDIF
      ELSEIF(CARDS(1:14).EQ.'NUMBER OF TAXA') THEN
        READ(CARDS(25:34),'(BN,I10)')L
        IF(L.GT.LD) THEN
          WRITE(SCREEN,'(A)')' Too many taxa -- program terminated'
          STOP
        ENDIF
        GOTO 200
      ELSE
        WRITE(SCREEN,'(2A)')'The first few lines in data file',
     1                      ' is not understood'
      ENDIF
      GOTO 100
 200  CONTINUE
      REWIND IREAD
      WRITE(IPRINT,'(//60A)')('*',I=1,60)
      WRITE(IPRINT,'(//T18,A)')'OUTPUT OF PROGRAM CONZONE'
      WRITE(IPRINT,'(//60A)')('*',I=1,60)
C
C.... READ SAMPLE DATA MATRIX
C
      CALL DATAIN(K,L,VAR(1),VAR(1+K),IVAR(1),CHAR(1),IREAD,
     1            IPRINT)
C
C.... STRATIGRAPHICALLY CONSTRAINED CLUSTERING ANALYSIS
C
      CALL CZONES(K,L,VAR(1),VAR(1+K),VAR(1+K+K*L),
     1            VAR(1+K*(1+L+K)),VAR(1+K*(2+L+K)),
     2            VAR(1+K*(3+L+K)),VAR(1+K*(4+L+K)),
     3            IVAR(1+L),IVAR(1+L+K),IVAR(1+L+2*K),
     4            IPRINT)
C
      CLOSE (IREAD)
      END
C
C         ====================================
C
C                   SUBROUTINE COEFFS
C
C         ====================================
C
```

```
      SUBROUTINE COEFFS(N,M,X,A)
C
C     SUBROUTINE TO CALCULATE THE MATRIX OF CORRELATIONS
C     BETWEEN COLUMNS OF DATA MATRIX X
C
      DIMENSION X(N,M),A(N,N)
      AN=M
C
C.... CALCULATE CORRELATION COEFFICIENT BETWEEN COLUMNS I AND J
C
      DO 1 I=1,N
      DO 1 J=I,N
C
C.... ZERO SUMS
C
        SX1=0.0
        SX2=0.0
        SX1X1=0.0
        SX2X2=0.0
        SX1X2=0.0
C
C.... CALCULATE SUMS, SUMS OF SQUARES AND SUM OF CROSS-PRODUCT
C     OF COLUMNS I AND J
C
        DO 2 II=1,M
          SX1=SX1+X(I,II)
          SX2=SX2+X(J,II)
          SX1X1=SX1X1+X(I,II)**2
          SX2X2=SX2X2+X(J,II)**2
          SX1X2=SX1X2+X(I,II)*X(J,II)
    2   CONTINUE
C
C.... CALCULATE CORRELATION COEFFICIENT AND STORE IN MATRIX A
C
        R=(SX1X2-SX1*SX2/AN)/
     1   SQRT((SX1X1-SX1*SX1/AN)*(SX2X2-SX2*SX2/AN))
        A(I,J)=R
        A(J,I)=R
    1 CONTINUE
      RETURN
      END
C
C             ====================================
C
C                        SUBROUTINE COLINK
C
C             ====================================
C
      SUBROUTINE COLINK(KN,K,M,N,X)
C
      CHARACTER  DISP*1
      DIMENSION  X(KN,KN)
```

```
      COMMON     /COM1/DISP
C
      DO 1 J=1,K
        IF(DISP.EQ.'C') THEN
          IF(X(M,J).LT.X(N,J)) THEN
            X(M,J)=X(M,J)
          ELSE
            X(M,J)=X(N,J)
          ENDIF
        ELSE
          IF(X(M,J).GT.X(N,J)) THEN
            X(M,J)=X(M,J)
          ELSE
            X(M,J)=X(N,J)
          ENDIF
        ENDIF
      DO 1 I=N,K
        X(I,J)=X(I+1,J)
    1 CONTINUE
      DO 2 I=1,K
        IF(DISP.EQ.'C') THEN
          IF(X(I,M).LT.X(I,N)) THEN
            X(I,M)=X(I,M)
          ELSE
            X(I,M)=X(I,N)
          ENDIF
        ELSE
          IF(X(I,M).GT.X(I,N)) THEN
            X(I,M)=X(I,M)
          ELSE
            X(I,M)=X(I,N)
          ENDIF
        ENDIF
      DO 2 J=N,K
        X(I,J)=X(I,J+1)
    2 CONTINUE
  999 RETURN
      END
C
C          ====================================
C
C                    SUBROUTINE COSETA
C
C          ====================================
C
      SUBROUTINE COSETA(N,M,X,C)
C
C.... SUBROUTINE TO CALCULATE THE COSINE COEFFICIENT C
C
      DIMENSION  X(N,M),C(N,N)
C
      DO 1 J=1,N
```

```
      DO 1 K=J,N
        XIJK=0.0
        XXK=0.0
        XXJ=0.0
C
        DO 11 I=1,M
          XIJK=XIJK+X(J,I)*X(K,I)
  11    CONTINUE
        DO 12 I=1,M
          XXK=XXK+X(K,I)**2
          XXJ=XXJ+X(J,I)**2
  12    CONTINUE
          XXJ=SQRT(XXJ)
          XXK=SQRT(XXK)
C
        A=XXJ*XXK
        B=XIJK/A
        C(K,J)=B
        C(J,K)=B
   1  CONTINUE
      RETURN
      END
C
C              ====================================
C
C                        SUBROUTINE CZONES
C
C              ====================================
C
C     SUBROUTINE REQUIRED: COEFFS,COSETA,EUCDST,COLINK,UWPGMA
C
      SUBROUTINE CZONES(K,L,DEPTH,X,Y,DEND,X1,YD,XE,
     1                 MARK,IAA,IBB,IPRINT)
C
      INTEGER    SCREEN,A,B
      CHARACTER  DISP*1,PLT*1
      DIMENSION  X(K,L),Y(K,K),DEND(K),IAA(K),IBB(K),MARK(K),
     1           DEPTH(K),X1(K),YD(K),XE(K,4)
      COMMON     /IO/SCREEN/COM1/DISP
C
C.... DETERMINE INFORMATION MEASUREMENT
C
      WRITE(SCREEN,'(/A)')'Please chose a measurement:'
      WRITE(SCREEN,'(/A)')'    1    COSIN THETA COEFFICIENT'
      WRITE(SCREEN,'(A)')'    2    CORRELATION COEFFICIENT'
      WRITE(SCREEN,'(A)')'    3    EUCLIDEAN DISSIMILARITY'
      WRITE(SCREEN,'(A)')'    4    ALL ABOVE RESPECTIVELY'
      READ(SCREEN,*)ITEM
C
C.... PREPARATION OF PLOTTING DENDROGRAM
C
      WRITE(SCREEN,'(A)')' Plot dendrogram (Y/N)?'
```

```
      READ(SCREEN,'(A1)')PLT
      IF(PLT.EQ.'Y'.OR.PLT.EQ.'y') THEN
        DELTA=2.0
        YMAX=DEPTH(K)+DELTA
        DO 1 I=1,K
          DEPTH(I)=DEPTH(K)-DEPTH(I)+DELTA
  1     CONTINUE
C
C.... THIS STATEMENT IS INSTALLATION DEPENDENT
C
        CALL ANYDEV
      ENDIF
C
C.... CLASSIFICATION START
C
      WRITE(IPRINT,'(//2A)')' *********** RESULT OF ZONATION ',
     1                      '************'
C
      IF(ITEM.EQ.4) THEN
        IT=1
      ELSE
        IT=ITEM
      ENDIF
   40 DO 3 LINK=1,2
C
C.... INITIALIZE
C
        K1=K-1
        K2=K-1
        DO 4 I=1,K
          MARK(I)=I
  4     CONTINUE
C
C.... CALCULATE THE COEFFICIENT OR DISTANCE
C
        GO TO(10,20,30) IT
   10   CALL COSETA(K,L,X,Y)
          DISP='C'
          GOTO 60
   20   CALL COEFFS(K,L,X,Y)
          DISP='C'
          GOTO 60
   30   CALL EUCDST(K,L,X,Y)
          DISP='D'
   60   CONTINUE
C
C.... START THE CLUSTERING
C
        IC=0
        DO 6 IC1=1,K1
          IC=IC+1
```

```
C
C.... SORT THE COEFFICIENT
C
          IF(IT.LE.2) THEN
            CLUST=0.1E-8
          ELSE
            CLUST=0.1E+10
          ENDIF
C
          DO 7 J=1,K2
            I=J+1
            IF(DISP.EQ.'C') THEN
              IF(Y(I,J).GT.CLUST) THEN
                CLUST=Y(I,J)
                A=J
                B=I
              ENDIF
            ELSE
              IF(Y(I,J).LT.CLUST) THEN
                CLUST=Y(I,J)
                A=J
                B=I
              ENDIF
            ENDIF
    7     CONTINUE
C
  110     IA=MARK(A)
          IB=MARK(B)
          IAA(IC)=IA
          IBB(IC)=IB
          IF(DISP.EQ.'C') THEN
            DTEMP=(1.0-CLUST)*(1.0-CLUST)
          ELSE
            DTEMP=CLUST*CLUST
          ENDIF
          IF(IC.GT.1) THEN
            DEND(IC)=DEND(IC-1)+DTEMP
          ELSE
            DEND(IC)=DTEMP
          ENDIF
C
C.... UPDATE THE DATA
C
          IF(LINK.EQ.1) CALL COLINK(K,K2,A,B,Y)
          IF(LINK.EQ.2) CALL UWPGMA(K,K2,A,B,Y)
          DO 8 I=B,K2
            MARK(I)=MARK(I+1)
    8     CONTINUE
C
          K2=K2-1
    6   CONTINUE
```

```
C
C.... PRINT THE RESULTS
C
          IF(IT.EQ.1) THEN
            WRITE(IPRINT,'(/A)')' COSINE THETA COEFFICIENT USED'
          ELSEIF(IT.EQ.2) THEN
            WRITE(IPRINT,'(/A)')' CORRELATION COEFFICIENT USED'
          ELSE
            WRITE(IPRINT,'(/A)')' EUCLIDIAN DISTANCE USED'
          ENDIF
          IF(LINK.EQ.1) THEN
            WRITE(IPRINT,'(/A)')' CONCLINK METHOD'
          ELSE
            WRITE(IPRINT,'(/A)')' CONUPGMA METHOD'
          ENDIF
          WRITE(IPRINT,'(/T26,A,/T10,A,T24,A)')
     1       'CUMULATIVE','GROUP','DISSIMILARITY'
C
          DO 11 I=1,K-1
            WRITE(IPRINT,'(3X,2I6,8X,F10.4)')IAA(I),IBB(I),DEND(I)
   11     CONTINUE
C
C.... PLOT THE DENFROGRAMS
C
          IF(PLT.EQ.'Y'.OR.PLT.EQ.'y') THEN
            DO 12 I=1,K
              YD(I)=DEPTH(I)
   12       CONTINUE
            CALL YDNPLT(K,L,IAA,IBB,DEND,YD,YMAX,XE,Y,X1,LINK,
     1                  IT,ITEM)
          ENDIF
    3 CONTINUE
      IT=IT+1
      IF(ITEM.EQ.4.AND.IT.LT.4) GOTO 40
  999 RETURN
      END
C
C           ====================================
C
C                    SUBROUTINE DATAIN
C
C           ====================================
C
C     SUBROUTINE REQUIRED: WRITER
C
      SUBROUTINE DATAIN(K,L,DEPTH,STATD,J2,SPECIS,IREAD,IPRINT)

      INTEGER    SCREEN
      CHARACTER  SPECIS(L)*20,WRT*1,CARDS*80,LOCATE*40
      DIMENSION  STATD(K,L),J2(L),DEPTH(K)
      COMMON     /IO/SCREEN
```

```
C
C.... READ INPUT DATA
C
  300 READ(IREAD,'(A)',END=400) CARDS
      IF(CARDS(1:8).EQ.'LOCATION') THEN
        READ(CARDS(25:64),'(A40)') LOCATE
        WRITE(IPRINT,'(///A,A40)')'LOCATION: ',LOCATE
      ELSEIF(CARDS(1:17).EQ.'NUMBER OF SAMPLES') THEN
        WRITE(IPRINT,'(/A,T25,I3)')'NUMBER OF SAMPLES IS ',K
      ELSEIF(CARDS(1:14).EQ.'NUMBER OF TAXA') THEN
        WRITE(IPRINT,'(/A,T25,I3)')'NUMBER OF TAXA IS ',L
      ELSEIF(CARDS(1:12).EQ.'LIST OF TAXA') THEN
        DO 1 I=1,L
          READ(IREAD,'(T5,BN,I3,T10,A20)')J,SPECIS(I)
    1   CONTINUE
      ELSEIF(CARDS(1:17).EQ.'DATA') THEN
        DO 3 I=1,K
          READ(IREAD,*)J,(STATD(I,J),J=1,L)
    3   CONTINUE
      ELSEIF(CARDS(1:22).EQ.'DEPTH LEVEL OF SAMPLES') THEN
        READ(IREAD,*)(DEPTH(I),I=1,K)
      ELSEIF(CARDS(1:11).EQ.'END OF FILE') THEN
        GOTO 400
      ELSE
        WRITE(SCREEN,'(A)')' Data file ID not recognized'
        STOP
      ENDIF
      GOTO 300
  400 CONTINUE
C
C.... PRINT THE INPUT DATA (OPTIONAL)
C
      WRITE(SCREEN,'(A)')' Print the taxa used (Y/N)?'
      READ(SCREEN,'(1A)')WRT
      IF(WRT.EQ.'Y'.OR.WRT.EQ.'y') THEN
        WRITE(IPRINT,'(/A)')' TAXA USED'
        DO 2 J=1,L,2
          J1=J+1
          IF(J1.LE.L) THEN
            WRITE(IPRINT,'(2(5X,I3,2X,A20))')J,SPECIS(J),
     1                                        J1,SPECIS(J1)
          ELSE
            WRITE(IPRINT,'(5X,I3,2X,A20)')J,SPECIS(J)
          ENDIF
    2   CONTINUE
      ENDIF
      WRT='N'
      WRITE(SCREEN,'(A)')' Print the input data Y/N)?'
      READ(SCREEN,'(1A)')WRT
      IF(WRT.EQ.'Y'.OR.WRT.EQ.'y') THEN
        WRITE(IPRINT,'(/A)')' INPUT DATA MATRIX:'
        WRITE(IPRINT,'(/A)')' ROW    = SAMPLE'
```

```
            WRITE(IPRINT,'(A)')' COLUMN = TAXA'
            CALL WRITER(K,L,STATD,IPRINT)
          ENDIF
C
          END
C
C                  ====================================
C
C                             SUBROUTINE EUCDST
C
C                  ====================================
C
          SUBROUTINE EUCDST(N,M,X,A)
          DIMENSION  X(N,M),A(N,N)
          AN=M
C
C         CALCULATE DISTANCE COEFFICIENT BETWEEN COLUMNS I AND J
C
          DO 1 I=1,N
          DO 1 J=I,N
C
C         ZERO SUM AND CALCULATE DISTANCE
C
            DISTX=0.0
            DO 2 K=1,M
              DISTX=DISTX+(X(I,K)-X(J,K))**2
     2      CONTINUE
C
C         CALCULATE DISTANCE COEFFICIENT AND STORE IN MATRIX A
C
            A(I,J)=SQRT(DISTX/AN)
            A(J,I)=A(I,J)
     1    CONTINUE
          RETURN
          END
C
C                  ====================================
C
C                            SUBROUTINE UWPGMA
C
C                  ====================================
C
          SUBROUTINE UWPGMA(KN,K,M,N,X)
C
          DIMENSION  X(KN,KN)
C
          DO 1 J=1,K
            X(M,J)=(X(M,J)+X(N,J))*0.5
          DO 1 I=N,K
            X(I,J)=X(I+1,J)
     1    CONTINUE
          DO 2 I=1,K
```

```
      X(I,M)=(X(I,M)+X(I,N))*0.5
    DO 2 J=N,K
      X(I,J)=X(I,J+1)
  2 CONTINUE
999 RETURN
    END
C
C           ====================================
C
C                    SUBROUTINE WRITER
C
C           ====================================
C
    SUBROUTINE WRITER(N,M,A,IPRINT)
C
C... SUBROUTINE TO PRINT A MATRIX HAVING N ROWS AND M COLUMNS
C
    DIMENSION  A(N,M)
C
C.... PRINT MATRIX OUT IN STRIPS OF 5 COLUMNS
C
    DO 1 IB=1,M,5
      IE=IB+4
      IF(IE-M) 20,20,10
 10   IE=M
C
C.... PRINT HEADING
C
 20   WRITE(IPRINT,'(/6X,5(8X,I4))')(I,I=IB,IE)
C
C.... PRINT ROW OF MATRIX
C
      DO 2 J=1,N
        WRITE(IPRINT,'(1X,I5,5F12.4)')J,(A(J,K),K=IB,IE)
  2   CONTINUE
  1 CONTINUE
999 RETURN
    END
C
C           ====================================
C
C                    SUBROUTINE YDNPLT
C
C           ====================================
C
C.... THIS SUBROUTINE CONTAINS SOFTWARE DEPENDENT CALLS FROM
C.... DISSPLA GRAPHICS PACKAGE
C
C.... SUBROUTINE REQUIRED: YDDPLT,YORDER
C
    SUBROUTINE YDNPLT(K1,L,IA,IB,DEND,YD,YMAX,XE,YE,X1,
   1              LINK,IM,ITEM)
```

```
C
      INTEGER     SCREEN
      DIMENSION   XE(K1,4),YE(K1,K1),IA(K1),IB(K1),DEND(K1),
     1            X1(K1),YD(K1),Y1(4)
      COMMON      /IO/SCREEN
C
      K=K1-1
      XMAX=0.0
      DO 1 I=1,K
        DEND(I)=SQRT(DEND(I))
        IF(XMAX.LT.DEND(I)) XMAX=DEND(I)
    1 CONTINUE
C
      CALL SETDEV(SCREEN,SCREEN)
      IF(LINK.EQ.1) THEN
        PAGEX=32.0
        PAGEY=25.0
        XAX=21.5
        YAX=15.0
        YAXIS=10.0
        XL=4.5
        YL=8.0
  100   CALL RESET('ALL')
        CALL UNITS('CM')
        CALL SETCLR('MAGENTA')
        CALL NOBRDR
        CALL PAGE(PAGEX,PAGEY)
        CALL PHYSOR(XL,YL)
        CALL AREA2D(XAX,YAX)
        CALL SCMPLX
        CALL HEIGHT(0.6)
        YPOS=YAXIS+1.0
        CALL MESSAG('CONCLINK$',100,3.0,YPOS)
        CALL MESSAG('CONUPGMA$',100,14.0,YPOS)
        CALL HEIGHT(0.4)
        CALL MESSAG('(cm) $',100,0.0,YPOS)
        YPOS=YPOS+0.5
        CALL MESSAG('Depth$',100,0.0,YPOS)
        CALL HEIGHT(0.8)
        YPOS=YPOS+1.0
        CALL MESSAG('CONZONE$',100,8.0,YPOS)
        CALL HEIGHT(0.4)
        CALL MESSAG('Dissimilarity$',100,10.0,-1.5)
        CALL ENDGR(0)
        CALL YSCALE(YMAX,YSTEP)
        CALL YDDPLT(5.0,YL,YSTEP,YMAX,YAXIS,0.3)
        XL=XL+2.0
      ELSE
        XL=XL+11.0
      ENDIF
C
      CALL YORDER(K1,L,IA,IB,DEND,YD,XE,YE,X1)
```

```
C
      XAXIS=10.0
  110 CALL RESET('ALL')
      CALL UNITS('CM')
      CALL PHYSOR(XL,YL)
      CALL AREA2D(XAXIS,YAXIS)
      CALL HEIGHT(0.4)
      CALL COMPLX
      CALL XTICKS(1)
      CALL YTICKS(0)
      CALL YNONUM
      CALL YNAME(' ',1)
      CALL XNAME(' ',1)
      CALL GRAF(0.0,'SCALE',XMAX,0.0,YSTEP,YMAX)
      DO 3 I=1,4
        Y1(I)=0.0
    3 CONTINUE
      DO 11 I=1,K
      DO 12 J=1,4
        X1(J)=XE(I,J)
        Y1(J)=YE(I,J)
   12 CONTINUE
        CALL CURVE(X1,Y1,4,0)
   11 CONTINUE
      CALL ENDGR(0)
      IF(LINK.EQ.2) CALL ENDPL(0)
      IF(ITEM.NE.4.AND.LINK.EQ.2) THEN
        GOTO 888
      ELSEIF(IM.EQ.3.AND.LINK.EQ.2) THEN
        GOTO 888
      ELSE
        GOTO 999
      ENDIF
  888 CALL DONEPL
C
  999 RETURN
      END
C
C             ====================================
C
C                      SUBROUTINE YDDPLT
C
C             ====================================
C
C.... THIS SUBROUTINE CONTAINS SOFTWARE DEPENDENT CALLS FROM
C.... DISSPLA GRAPHICS PACKAGE
C
      SUBROUTINE YDDPLT(XL,YL,YSTEP,YMAX,YAX,HY)
C
      DIMENSION  XT(2),YT(2),XT1(2),YT1(2),XT2(2),YT2(2)
C
      XT(1)=0.0
```

```
      XT(2)=-0.2
      XT1(1)=0.0
      XT1(2)=-0.1
      XT2(1)=0.0
      XT2(2)=0.0
      YT2(1)=0.0
      YT2(2)=YMAX
      CALL PHYSOR(XL,YL)
      CALL AREA2D(0.5,YAX)
      CALL RESET('ALL')
      CALL XNAME(' ',1)
      CALL YNAME(' ',1)
      CALL YNONUM
      CALL XNONUM
      CALL XTICKS(0)
      CALL YTICKS(0)
      CALL GRAF(0.0,0.1,0.5,0.0,YSTEP,YMAX)
      N=0
      M=0
      YT(1)=YMAX+YSTEP
  101 YT(1)=YT(1)-YSTEP
      YT(2)=YT(1)
      DO 11 J=1,5
      YT1(1)=YT(1)-YSTEP/5.0*J
      YT1(2)=YT1(1)
      IF(YT1(1).GE.0.0) CALL CURVE(XT1,YT1,2,0)
   11 CONTINUE
      CALL HEIGHT(HY)
      IF(YT(1).GE.0.0) THEN
        CALL CURVE(XT,YT,2,0)
        Y=YT(1)
        Y=YPOSN(0.5,Y)-0.1
        CALL INTNO(N,0.2,Y)
        M=M+1
        N=INT(YSTEP)*M
      ELSE
        GOTO 102
      END IF
      GOTO 101
  102 CONTINUE
      CALL ENDGR(0)
      RETURN
      END
C
C             ====================================
C
C                       SUBROUTINE YORDER
C
C             ====================================
C
      SUBROUTINE YORDER(K,L,IA,IB,DEND,Y1,X,Y,X1)
C
```

```
      DIMENSION  IA(K),IB(K),Y1(K),DEND(K),X1(K),X(K,4),Y(K,K)
C
      DO 1 I=1,K-1
        X1(I)=0.0
    1 CONTINUE
      DO 2 I=1,K-1
        IAA=IA(I)
        IBB=IB(I)
        X(I,1)=X1(IAA)
        X1(IAA)=DEND(I)
        X(I,4)=X1(IBB)
        Y(I,1)=Y1(IAA)
        Y(I,4)=Y1(IBB)
        YTMP=Y1(IAA)
        Y1(IAA)=(YTMP+Y1(IBB))*0.5
        X(I,2)=DEND(I)
        X(I,3)=DEND(I)
        Y(I,2)=Y(I,1)
        Y(I,3)=Y(I,4)
C       WRITE(6,*)(X(I,J),J=1,4)
C       WRITE(6,*)(Y(I,J),J=1,4)
    2 CONTINUE
      RETURN
      END
C
C             ====================================
C
C                         SUBROUTINE YSCALE
C
C             ====================================
C
      SUBROUTINE YSCALE(YMAX,YSTEP)
C
      IF(YMAX.GE.250.0)                           YSTEP=50.0
      IF(YMAX.GE.150.0.AND.YMAX.LT.250.0) YSTEP=20.0
      IF(YMAX.LT.150.0.AND.YMAX.GE.50.0)  YSTEP=10.0
      IF(YMAX.LT.50.0.AND.YMAX.GE.20)     YSTEP=5.0
      IF(YMAX.LT.20.0)                     YSTEP=1.0
      RETURN
      END
```

Table F.2 An example of input data file for program CONZONE. Note the line numbers at the left side of the table is not the part of the file.

```
         1         2         3         4         5         6
....,....+....,....+....,....+....,....+....,....+....,....+..

LOCATION                MIDDLE MACKINTOSH CREEK, Y. T. (XW-2)
NUMBER OF SAMPLES       9
NUMBER OF TAXA          9
LIST OF TAXA
      1  PICEA
      2  ALNUS
      3  BETULA
      4  SALIX
      5  ROSACEAE
      6  JUNIPERUS
      7  ERICACEAE
      8  GRAMINEAE
      9  CYPERACEAE
DATA
  1      18.52      7.41     53.70      0.00      0.00
          0.00      8.80      3.70      6.94
  2      21.37      4.58     37.02      4.58      2.67
          0.00     12.60      8.02      7.63
  3      17.80      5.08     47.46      0.00      0.00
          0.00      3.39     11.02     11.02
  4      14.75      8.20     42.62      3.28      1.64
          0.00      0.00      9.84      8.20
  5      37.91      8.06     11.85      1.90      1.90
          1.90      0.00      4.74     30.81
  6      36.51      4.36     12.53      0.27      0.82
          0.27      1.36      2.72     34.60
  7      31.25      5.57     15.90      0.68      1.09
          1.90      0.41      0.82     38.04
  8      27.08      5.56     11.11      2.78      0.00
          0.00      0.00      8.33     41.67
  9      37.33      6.40     10.67      2.13      1.07
          0.80      0.00      4.53     30.13
DEPTH LEVEL OF SAMPLES
   4.0       8.0       10.       15.       18.
   22.       26.       28.       32.
END OF FILE
```

Table F.3 An example of output file for program CONZONE. Note the line numbers at the left side of the table is not the part of the file.

```
         1         2         3         4         5         6
....,....+....,....+....,....+....,....+....,....+....,....+..


************************************************************


                 OUTPUT OF PROGRAM CONZONE


************************************************************



LOCATION: MIDDLE MACKINTOSH CREEK, Y. T. (XW-2)

NUMBER OF SAMPLES IS       9

NUMBER OF TAXA IS          9

 TAXA USED
       1  PICEA                        2  ALNUS
       3  BETULA                       4  SALIX
       5  ROSACEAE                     6  JUNIPERUS
       7  ERICACEAE                    8  GRAMINEAE
       9  CYPERACEAE


 *********** RESULT OF ZONATION ***********

 CORRELATION COEFFICIENT USED

 CONCLINK METHOD


                            CUMULATIVE
        GROUP             DISSIMILARITY
       5     6               0.0001
       3     4               0.0003
       7     8               0.0015
       1     2               0.0029
       7     9               0.0092
       5     7               0.0157
       1     3               0.0238
       1     5               0.6616

CORRELATION COEFFICIENT USED

```

CONUPGMA METHOD

GROUP		CUMULATIVE DISSIMILARITY
5	6	0.0001
3	4	0.0003
5	7	0.0011
1	2	0.0025
5	8	0.0051
5	9	0.0078
1	3	0.0106
1	5	0.4722

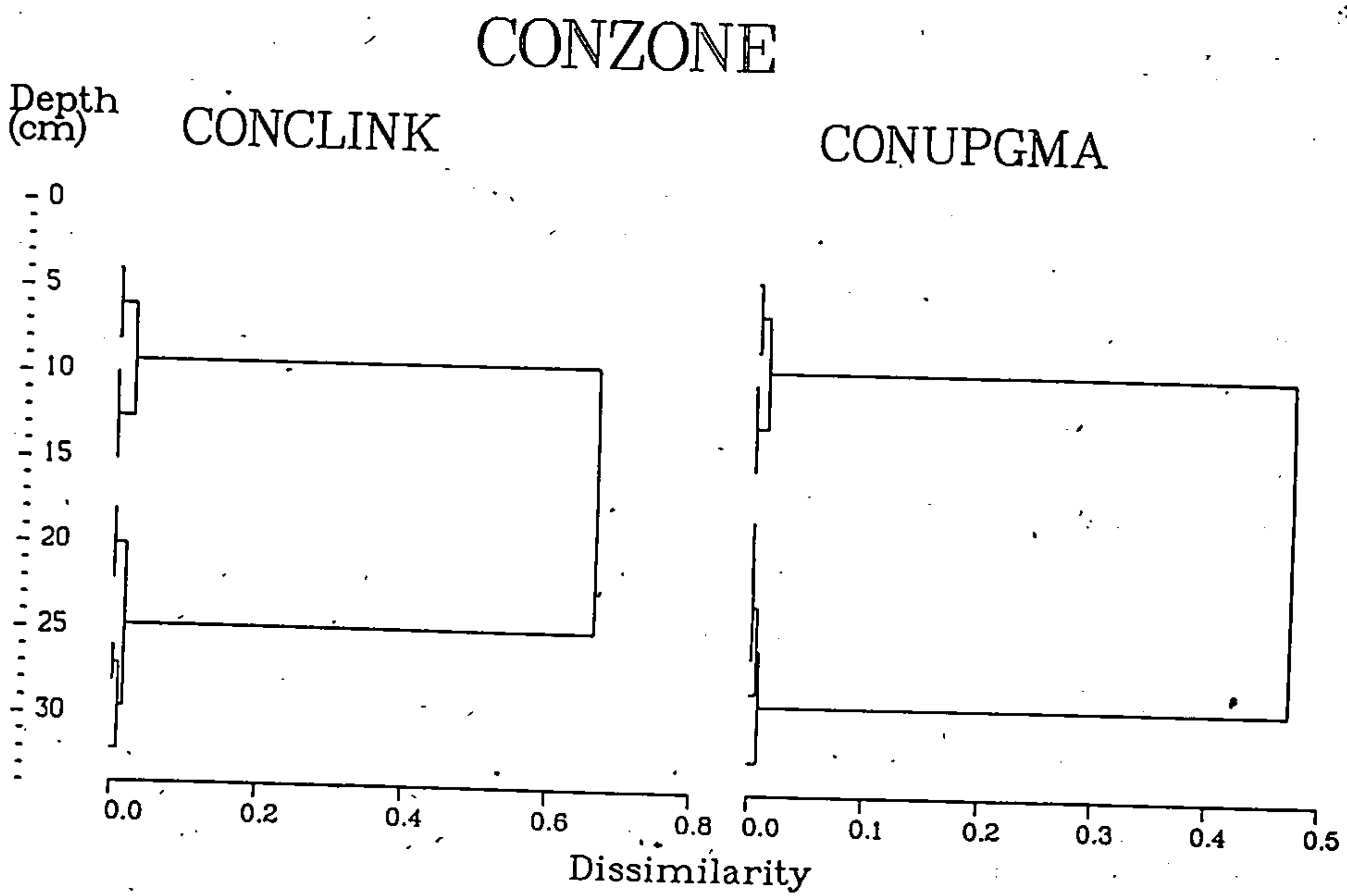

Figure F.1 Dendrogram plotted by program CONZONE

Appendix G

```
PPPPPPP     A        LL      YY    YY DDDDDDDD   PPPPPPP
PP    PP   AAA       LL       YY  YY   DD     DD PP     PP
PPPPPPP  AA AA       LL        YYYY    DD     DD PPPPPPP
PP      AA   AA      LL         YY     DD     DD PP
PP     AA AAA AA     LL         YY     DD     DD PP
PP    AA       AA   LLLLLLLL    YY    DDDDDDDD   PP
```

(PALYnological Data Processor)

A FORTRAN-77 Program for Processing

Palynological Data

- A User's Guide and Program Listing

Version 1.2

August 10, 1988

G.1 Introduction

PALYDP (PALYnology Data Processor) is a computer program which can handle the storage, retrieval, manipulation, and plot diagrams of palynological data with high user's flexibility. The basic functions of the program are summarized as follows:

1). The program can handle large numbers of both samples and species. It is presently specified to 150 samples and 30 taxa. But these parameters can easily be changed by the user.

2). Pollen percentages can be calculated upon a user defined pollen sum, which provides a high degree of freedom to the user.

3). Pollen concentration can be determined through three different preparation methods, including the standard exotic marker method (Maher, 1972), the weight method (Jorgenson, 1967), and the method described in this monograph (Weight-Volume method).

4). Pollen accumulation rates for all taxa can be calculated by the program on the basis of ^{14}C dates with two preparation methods, e.g. exotic marker method and Weight-Volume method. Total pollen accumulation rates for each sample will also be produced.

5). To calculate pollen accumulation rates, sedimentation rates can be determined using ^{14}C dates either by a linear extrapolation and intérpolation or using a polynomial regression equation provided the coefficients for the equation is supplied by the user. The coefficient for the regression equation can be determined using program POLYD (J.C. Davis, 1973).

6). The program provides techniques for calibrating the influence of frost heave and ice lensing on the determination of pollen concentration and/or pollen accumulation rates provided suitable data are supplied. Principles concerning this calibration have been described and discussed in chapter 3.

7). The program can calculate three different species richnesses and Shannon-Weaver's diversity upon the user's wish. The statistics of the indices are listed in appendix F.

8). Pollen ratios between any user selected species can be calculated through a screen-menu-driven feature of the program, which provides users with the high degree of freedom to choose as many ratios as one wishes.

9). The program allows users to select from input species lists for building a new data file for statistical analysis. The computing results of either pollen percentage or concentration or accumulation rates can be used with the user's option by just pressing one key to respond to the screen prompt.

10). Pollen percentage, pollen concentration, or pollen accumulation rates diagrams can be plotted on a Calcomp plotter in a reducible publish-ready format according to the user's option. Two different styles of diagram, *i.e.* bar diagram or saw-tooth curve diagram, can be produced.

11). The sediment column and its legend can be plotted on the pollen diagram with eight different symbols (Fig. G.1) according to the user's requirement and desire.

12). It is the user's option to plot the ^{14}C dates, total pollen concentration, total pollen accumulation rate, and results of loss on ignition if the data available, on the pollen diagram.

13). Users can select from input species lists to build a new data file for plotting a summary pollen diagram. Either pollen percentage or pollen concentration or pollen accumulation rate can be used.

The program has been designed for the users who have a working knowledge of a computer operating system. A working knowledge of FORTRAN 77 will provide a better understanding of the internal structure of the program, but it is not necessary for using the program. The program has been used by the author for the past four years, and is operated upon a very simple data format classified by a list of required identifiers, which will be listed later in section G.3.

G.2 Program List

The program has been written in standard FORTRAN 77. It has been compiled and run successfully on a AMDAHL 470 computer with a VS FORTRAN compiler under the CMS operating system. It can also be used on an IBM Personal Computer (PC) or a compatible micro-computer with a Microsoft FORTRAN Compiler version 4.0 or later. However, the plot of pollen diagrams cannot be carried out on micros because this part of the program is software and installation dependent. The program listing is given here in table G.1, and a brief description of the basic function for each subroutines used in the main program is provided at the beginning of the program.

G.3 Files

Several files are required to run the program which allows the program to communicate with the user or computer disks. Unit 0 has presently been assigned to the terminal (key board and screen). Control cards are read from a file connected to unit 1, and data are read from a file connected to unit 5.

Results of laboratory preparation are read from a file connected to unit 3 should the pollen concentration or pollen accumulation rate need to be determined, or should the sedimentation rates need to be calculated. These files must been created before executing the program using the operating system editor. The output results are written to a file connected to unit 6. Results of selected data for numerical analysis are written to unit 4, and those for plotting a summary diagram are written to unit 2. All these files must be preconnected with system commands.

G.3.1 Control Card File

A file contains instructions (Control Card Identifier) for controlling the program actions must be preconnected in order to calculate the pollen concentration or pollen accumulation rate. If only the pollen percentage will be calculated, the control cards file does not necessary need to be created. Each identifier in the control card file begins in column 1. All identifiers are optional. The following identifier can be placed in any order except the last one.

CONCENTRATION BY WEIGHT

CONCENTRATION BY WEIGHT-VOLUME

CONCENTRATION BY EXOTIC MARKER

DETERMINE SPECIES DIVERSITY

SEDIMENTATION RATE	(If this identifier is ommitted, a linear extrapolation between dates will be carried out. If this identifier is given, the phrase REGRESSION must be given at column 25, and the following line must supply the order number (an integer) of polynomial regression, followed by the coefficients (real numbers) for the regression equation (Age=A + B * Depth + C * Depth^2 + D * Depth^3....) in a free format, *i.e.* leave a space between two data)
MODIFICATION OF ICE LENSES	(If this identifier is specified, the stratigraphic positions where the modification will start and end must be supplied following the identifier in a free format on the same line)
END OF FILE	(Required. Must be placed at the end of the file)

G.3.2 Basic Data File

The basic data file connected to unit 5 contains the data of species list, a tabulation of pollen counting, ^{14}C dates, and other related data. A set of identifiers is required to allow the program identifying the data to proceed. Some of these identifiers are optional, and some are required. All identifiers begin at column 1, and related data start at column 25 unless a free format is specified. The following required identifiers must be placed in the first five lines.

LOCATION	(A title or location of data up to 40 characters should begin at column 25 on the same line)
COORDINATES	(Coordinates specify the latitude, longitude, and altitude of the data sequence up to 40 characters start at 25 columns on the same line)
ANALYZER	(Analyzer's name up to 40 characters starts at 25 column on the same line)

The above three identifiers will be important for plotting pollen diagrams. If the plotting job will not be carried out, these data may be omitted.

NUMBER OF SAMPLES	(Required, and a integer must begin at column 25 on the same line)
NUMBER OF TAXA	(Required, an integer must begin at or after column 25 on the same line)

The following identifier can be placed in any order.

NUMBER OF TREE TAXA	(Required, an integer must begin at or after column 25 on the same line)
NUMBER OF SHRUB TAXA	(Required, an integer must start after or at column 25 on the same line)
TAXA INCLUDED IN SUM	(Required, an integer must begin at or after 25 column)
LIST OF TAXA	(Required, a list of taxa identified must follow the identifier on the next line. Each line contains only one taxa with an up to three digit number beginning at column 5, and the species name up to 20 characters beginning at column 10)
TABLE OF-COUNTING	(Required. Counting table must be supplied starting from the next line. The first value on the data line should be an integer specifying the sample number. Counting results entered in a free format for each sample. Leave at least one space between two data. More than one line can be used for one sample if necessary)

EXOTIC MARKER INPUT	(Optional. If present, data should be started from the next line with free format)
EXOTIC MARKER COUNTED	(Optional. If present, data should follow on the next line with free format)
WEIGHT OF RESIDUE	(Optional. If present, weight of residue used for pollen identification should follow on the next line with free format)
DEPTH LEVEL OF SAMPLES	(Required if plotting will be carried out, otherwise optional. If present, data should follow on the next line)
RADIOCARBON DATES	(Optional. If present, number of dates used for calculating sedimentation rates followed by number of dates will appear on the pollen diagram should begin at column 25. Pinpoint of depth position of the date and date itself should follow on the next line. Each line contains one date. Dates which will appear on the pollen diagram should follow the data block for calculation in a sequence of start and end positions of the dated segments, dates with deviations on each line.)

ORGANIC CONTENT (Optional. If present, result of loss on ignition or other measurement of oganic content should be suplied on the next line with a free format. This information will be plotted on the pollen diagram)

ZONES (Optional. If present, number of pollen zones should follow at column 25 on the same line, and depth position of zone boundaries (zone number manus 1) should follow on the next line in a free format.)

END OF FILE (Required. This identifier must be the last one in the data file.)

G.3.3 Preparation Data File

Several data are required either in order to determine pollen concentration and pollen accumulation or to calibrate the influence of frost heave and ice lensing on the determination of pollen concentration and accumulation rates. These data are contained in a file connected to unit 3. The following are the identifiers and data format in the file.

WEIGHT OF RESIDUE (Optional. If present, weight of preparation residue should follow on the next line in a free format)

WEIGHT OF DRY SAMPLE	(Optional. If present, data should follow on the next line in a free format)
VOLUME OF SAMPLE	(Optional. If present, data should follow on the next line in a free format)
WATER CONTENT	(Required if calibration of ice lensing will be carried out, otherwise optional. Data (cm^3cm^{-3}) should follow on the next line in a free format)
CONTENT OF EXCESS WATER	(Optional. If present, data should follow on the next line in a free format. This item should be the last one in the file if present)
END OF FILE	(Required. This identifier must be the last one in the data file.)

G.3.4 Output File

The results are written to a program output file connected to unit 6 in a easy to read format. All results are preceded with a certain index to indicate what is the output and what method used if appropriate. This file can be printed out as a hard copy using the operating system print command. Example of the output file will be given in section G.12.

G.4 Pollen Percentage, Concentration, and Accumulation Rate

The first step is to calculate pollen percentage after the reading of input data and control cards from disk files. If the control file exists, then the program will automatically calculate pollen concentration and pollen accumulation rates using the instructions in the control card file. If the control card file does not exist, only pollen percentage will be calculated. All results will be written to the output file connected to unit 6.

G.5 Species Richness and Diversity

Each time the program is executed, three different species richness and Shannon-Weaver's diversity indices will be automatically determined. The formula of these indices are presented in the appendix E. Results are written to the output file through unit 6.

G.6 Selection Menu

It is the user's choice to determine if a selection session should be carried out by positive or negative response to the screen prompt. In the present version of the program, the user can select as many taxa as one wishes to build a new disk data file for statistical analysis, or for plotting of a summary diagram. It is possible also that the selected file can be used for other purposes. In fact, this feature of the program provides the user with a flexible choice to choose some variables from a matrix, which could be pollen percentage, pollen concentration, or the pollen accumulation rate.

To deal with a selection menu, the program will prompt the following message on the screen every time when program is executed.

Select taxa for a special purpose (Y/N) ?

At this point an user should respond a Y for yes or a N for no through the key board. If a Y is entered, the following message will be prompted.

1 For Statistical Analysis
2 For Summary Diagram Plot

Enter Your Choice

If 1 or 2 is entered, the third prompt will be a list of data sets from which the user will make his/her selection.

1	Original Counting	2	Pollen Percentage
3	Concentration (Weight)	4	Concentration (W-V)
5	Concentration (Marker)	6	PAR (W-V)
7	PAR (Marker)	8	No Selection

At this point the user still can change his/her mind to decide if he/she will like to cancel the selection. If 8 is entered, no selection will be carried out. If any other data set is chosen, and such a data set is present, *i.e.* the preparation method in brackets was used, the program will ask how many taxa the user would like to include in the new data set.

How Many Taxa Do You Wish To Use ?

An appropriate answer should be an integer less than or equal to the total number of taxa counted. Following the user's response, the program will hold on and wait for the user to clear the screen

Please Clear the Screen and Press RETURN key to continue

Now the user should find and press the clear screen key on his/her key board, and then press the RETURN key to tell the program to continue (On some key board, a RETURN key is the same as the ENTER key). Then a list of taxa will appear on the screen.

```
1  Taxa 1          2  Taxa 2
3  Taxa 3          4  Taxa 4
.
.
.
```

Which Taxa Do You Need ?

The taxa list will show all taxa names in your data set on the screen, and the user should enter the appropriate numbers for his/her selection. At least one space should be left between each number. For example,

    1 2 3 5 8   (Followed by pressing RETURN key)

This action tells the program that taxa 1, taxa 2, taxa 3, taxa 5, taxa 8 should be chosen from the above selected data set to build the new data file. After completing this step, the selection session is finished.

G.7 Selected Pollen Ratios

After the selection session, the program will prompt the following message.

    Calculate Pollen Ratios (Y/N) ?

A positive response will lead to the following prompt.

    How Many Ratios to be Determined ?

Following the entry of an integer, a taxa list like that in the selection session will be prompted, and the program will ask

    Which Pair of Taxa ?

The answer should be two integers representing two taxa in the taxa list, with at least one space between each other, and followed by pressing RETURN key. The pollen percentage of the first selected taxa will be divided by the second taxa to determine the first pollen ratio. This prompt and process will continue until the number of ratios selected at the beginning of the session is encountered. Result are written to the output file through unit 6. Taxa names of a ratio will be printed ahead of the ratio.

G.8 Plotting of Pollen Diagram

Plotting of pollen diagrams is carried out in the program by subprogram CALPLT and its associated subroutines using Calcomp Plotter Software routines, and is therefore installation and device dependent. IBM PC family computer users and those without the installation of Calcomp Plotter Software can easily delete subroutine CALPLT and its related routines (subroutine 13 to 34 as listed at the beginning of the main program). The following paragraph in subprogram PALYDP should also be deleted.

```
C
C.... PLOT POLLEN DIAGRAMS
C
      WRITE(SCREEN,'(A)')'Plot pollen diagram (Y/N) ?'
      READ(SCREEN,'(A1)')PLT
      IF(PLT.EQ.'Y'.OR.PLT.EQ.'y') THEN
        CALL CALPLT(K,L,..........
        .
        .
        .
      ENDIF
```

A plotting job can be easily furnished by communication between the program and the user on the screen and key board. It is user's option to decide either to plot ^{14}C dates, total pollen concentration, total pollen accumulation rates, and sediment symbols each time he/she runs the program. The plotting results as a feature of Calcomp Plotter Software will be written to a disk file known as FILE PLOTTER on user's "A" disk (CMS operating system). Hard copy of the plotted diagram can be obtained by entering the following commands.

For a draft copy using ball pens

```
PLOT FILE (FORM 0001
```

For a final copy using ink pens

```
PLOT FILE (FORM 0111
```

The program can plot up to ten different symbols for different sediment types. Information for plotting sediment columns is contained in a program created file connected to unit 7. An arbitrary allocation of sediment type to a certain symbol has been assigned by the program, which however can always be easily changed by the user utilizing the operating system editor in the related data file referred to unit 7. The program will prompt to inquire if data for sediment symbols has been entered previously or not. If the user responds with a 'Y' for 'Yes', the program will open and read the data from a disk file. Otherwise if the users's response is 'N' for 'No', the program will create a file and prompt to ask the user to enter appropriate data. Available symbols for sediment types and legends are presented if figure G.1

The program will plot the result of loss on ignition at the wight side of pollen diagram if the user wishes. Data should be placed in the basic data file with an identifier ORGANIC CONTENT.

G.9 Error Message

The program has its build-in error handling routines which will terminate the program and prompt on the screen a message to indicate what the problem is. The following are the messages which may be prompted during the execution of the program.

1. Input data file not found (This message indicates that the basic data file is not created or not connected to unit 5. Use your system editor to create the required data file, and re-run the program again.)

2. The first few lines in data file is not recognized

(The first few identifiers in the data file are not correctly specified.)

3. Control card ID not recognized (An identifier in the control card file, connected to unit 1, is not correctly specified.)

4. Data file ID not recognized (An identifier in basic data file, connected to unit 5, is not correctly specified.)

5. Preparation result not available (The data file containing results of preparations for determining the pollen concentration and pollen accumulation rates was not created while such a job is requested.)

6. Preparation result not understood (An identifier in the preparation data file, connected to unit 3, is not correctly specified.)

The above messages will be prompted on the screen and the program will be terminated immediately when one of these errors is encountered. Various error messages may also be written to the output file connected to unit 6 by the compiler.

G.10 Plotting of a Summary Pollen Diagram

Program PALYDP itself can not plot summary diagrams. However, subroutines in the plotting part of the program can be used to carry out the job. A supplementary program known as SUMPLT has been written using several subroutines of program PALYDP to plot a summary diagram. The program SUMPLT is listed in table G.2. The subroutines called from program PALYDP are not repeatedly provided here. Example of a summary diagram plotted by program SUMPLT can be found in this monograph (*e.g.*, Fig. 5.1).

G.11 Statistical Analysis

Although a data file for statistical analysis can be created by the program during a selection session, program PALYDP is not designed to contain statistical procedures. However, the selection session provides the user with an opportunity to build an appropriate data set for statistical analysis. If a suitable data import procedure can be found, the data file created by program PALYDP can be directly used for other statistical programs. A minor change of data reading procedure in a statistical program will allow the user to establish the connections between program PALYDP and a statistical procedure.

G.12 Execution of the Program: An Example Session

This section provides an example of the execution of the program on a AMDAHL 470 computer under CMS operating system. Different operating systems may require different procedures to carry out the compiling and execution of the program. A VS FORTRAN compiler is used to compile the program first. The following are the execution steps.

1. Using the operating system editor (here is CMS editor, for example) to create a data file (here as TEST DATA A, Tab. G.3), a control card file (here as TEST CARD A, Tab. G.4), and a preparation data file (here as TEST PREPD A, Tab. G.5).

2. Use system editor to create an EXEC file containing all your execution commands. This EXEC file will save typing time during the execution of the program. The following is a list of such a file named arbitrarily "R EXEC A".

```
GLOBAL TXTLIB VLNKMLIB VFORTLIB VPLOTLIB
FILEDEF 0       TERM
FILEDEF FNCONT  DISK &1 CARD        A
FILEDEF SUMMARY DISK &1 SUMMARY     A
FILEDEF FNPREP  DISK &1 PREPD       A
FILEDEF STATD   DISK &1 STATDATA    A
FILEDEF FNAMEI  DISK &1 DATA        A
FILEDEF 6       DISK &1 RESULT      A
FILEDEF SEDS    DISK &1 SEDS        A
LOAD    &2 &3   (NOMAP
START
```

The first line in this file specifies text library and load libraries from which routines are loaded during execution. The second line defines unit 0 as the terminal (key board and screen). The third to ninth lines define and/or connect the files and their input or output devices. The LOAD command places the PALYDP TEXT or SUMPLT TEXT file into computer storage and establishes the linkages for execution. The last command begins execution of the loaded file.

3. Compile program PALYDP with VS FORTRAN compiler.

```
FORTVS PALYDP
```

This compilation will produce two new files on your A disk. One is the PALYDP LISTING A which gives the user the compilation information and can be erased. Another is PALYDP TEXT A which is the executable program and should be conserved.

4. Execute the program using the following command.

```
R TEST PALYDP
```

where R is the EXEC file name previously created, which contains a series CMS command (Step 2), and TEST is the data file name (see step 1). Now the content of R EXEC A file will be prompted on the screen. Note the symbol &1 in file R EXEC A has been replaced by TEST automatically by the system.

5. When the following prompt occurs on the screen, it means the program has successfully calculate the pollen percentage, pollen concentration, pollen accumulation rate, species richness and species diversity.

Select Taxa for a Special Purpose (Y/N) ?

Since the selection session have been fully described before, and for now enter N to escape the selection session.

6. Then take the following action to the prompt.

```
PROMPT:   Calculate Pollen Ratios (Y/N) ?
ENTER:    Y
PROMPT:   How Many Ratios to be Determined ?
ENTER:    3
PROMPT:     1  Picea                  2  Pinus
            3  Alnus                  4  Betula
            5  Cyperaceae             6  Gramineae
            7  Lycopodium
          Which Pair of Taxa ?
ENTER:    1   4
PROMPT:   Which Pair of Taxa ?
ENTER:    1   5
PROMPT:   Which Pair of Taxa ?
ENTER:    4   5
```

7. After the determination of pollen ratios, the plotting session will start with the following prompt.

Plot Pollen Diagram (Y/N) ?

8. If a Y is entered, the following prompt will occur.

Please Clear Screen and Hit RETURN to Continue

An appropriate reaction will lead to the following prompt.

```
1   Percentage
2   Accumulation Rate (Marker)
3   Accumulation Rate (WV)
4   Concentration (Marker)
5   Concentration (WV)
6   Concentration (Weight)
```

Which Diagram do You Want to Plot ?

9. For the example session, enter 1 to plot the pollen percentage diagram, and it will lead to the following prompt.

```
1   Histogram
2   Saw-tooth Curves
```

What Kind of Diagram do You Want to Plot ?

10. Enter 2 for a saw-tooth curve diagram. And then the program will prompt to request for a length of paper. A pollen percentage diagram with 20 taxa will require approximately 80 cm of paper. For the test data set, enter 40 for the following prompt.

Enter Paper Length (cm):

11. The following prompts and reactions will be:

```
PROMPT:   Plot Total APF on Diagram (Y/N) ?
ENTER:    Y
PROMPT:   Plot Total Par on Diagram (Y/N) ?
ENTER:    Y
PROMPT:   Draw Dates on Diagram (Y/N) ?
ENTER:    Y
PROMPT:   Draw Sediment symbol (Y/N) ?
ENTER:    Y
```

12. At this point, suppose that the program and the data set have been run once before, and the data file containing information of the sediment types has been created by the program, the program will plot a pollen percentage diagram in a file known as FILE PLOTTER A. Then, the following message will be prompted, which marks the normal end of the program, and will finish the session.

Normal End of Plotting

13. If you need a hard copy of the diagram on a piece of paper, enter the following system commands.

For a draft copy using ball pens

PLOT FILE (FORM 0001

For a final copy using ink pens

PLOT FILE (FORM 0111

This command will send a plotting job to the Calcomp plotter.

15. The output results are written to file named TEST RESULTS A, containing all of the results of calculations. This file can be opened by a system editor, or hard copies can be obtained using the operating system's print command to send a print job to a print.

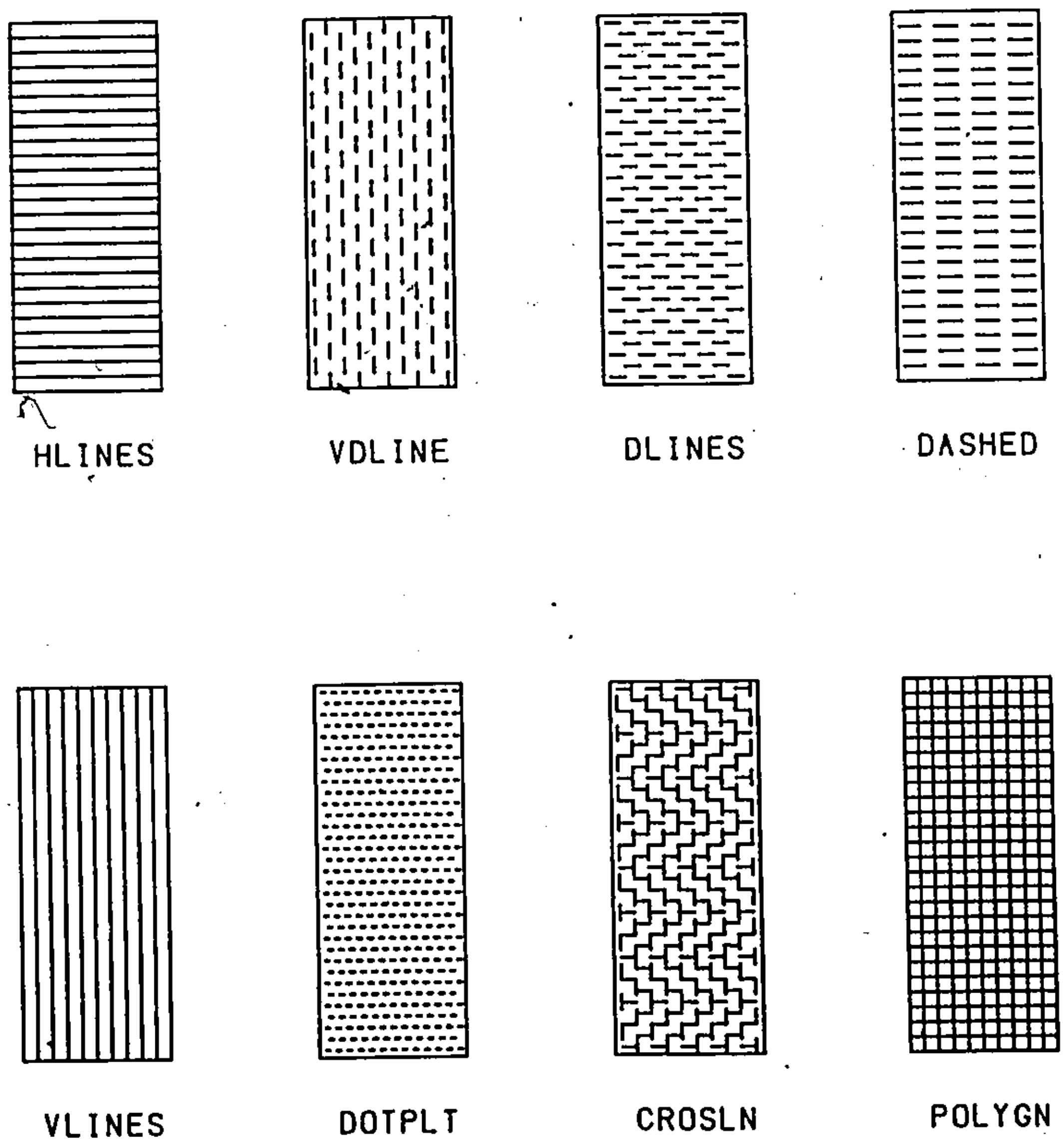

Figure G.1 Examples of sediment symbols plotted by program PALYDP.

Table G.1 The listing of pogram PALYDP. Note the line numbers at the left side of the table are not the part of the program.

```
         1         2         3         4         5         6
....,....+....,....+....,....+....,....+....,....+....,....+....,
************************************************************
*                                                          *
*                    PALYDP   (FORTRAN)                    *
*                                                          *
*              PALYNOLOGICAL DATA PROCESSOR                *
*                                                          *
*                          BY                              *
*                   XIA-CHENG WANG                         *
*                DEPARTMENT  OF GEOLOGY                    *
*                 UNIVERSITY OF OTTAWA                     *
*                                                          *
*                     VERSION  1.2                         *
*                      07-26-1988                          *
*                                                          *
************************************************************
*
*
*                      DESCRIPTION
*                      -----------
*...........................................................
*                                                          :
*   THIS PROGRAM CAN                                       :
*                                                          :
*        1)  DETERMINE POLLEN PERCENTAGE BY A USER DEFINED :
*            POLLEN SUM                                    :
*        2)  DETERMINE ABSOLUTE POLLEN CONCENTRATION.THREE :
*            PREPARATION METHODS ARE ACCEPTABLE            :
*        3)  DETERMINE POLLEN ACCUMULATION RATE WITH TWO   :
*            PREPARATION METHODS                           :
*        4)  MODIFY THE INFLUENCE OF ICE LENSES ON POLLEN  :
*            ACCUMULATION RATES                            :
*        5)  CALCULATE  SEDIMENTATION  RATES EITHER WITH   :
*            LINEAR EXTRAPOLATION OR A USER SUPLIED POLY-  :
*            NOMIAL REGRESSION EQUATION                    :
*        6)  CHOOCE FROM INPUT POLLEN TAXA TO BUILD A NEW  :
*            DATA FILE FOR STANTISTICAL ANALYSIS           :
*        7)  CHOOCE FROM COMPUTING RESULTS TO BUILD A NEW  :
*            DATA FILE FOR PLOTTING A SUMMARY DIAGRAM      :
*        8)  DETERMINE POLLEN RATIOS UPON USER SELECTED    :
*            PAIR OF TAXA                                  :
*        9)  DETERMINE SPECIES RICHNESS IN THREE WAYS, AND :
*            CALCULATE SHANNON-WEAVER DIVERSITY INDEX      :
*        10) PLOT POLLEN DIAGRAM UPON USER'S SELECTION OF  :
*            SIX DIFFERENT COMPOSITION AND TWO DIFFERENT   :
```

```
*              DIAGRAM STYLES                                    :
*          11) PLOT SEDIMENTS SYMBOL, RADIOCARBON DATES,         :
*              TOTAL POLLEN CONCENTRATION AND / OR POLLEN        :
*              ACCUMULATION RATE, RESULT OF LOSS ON IGNITION     :
*              ON EACH DIAGRAM UPON USER'S OPTION                :
*                                                                :
*.................................................................
*
*
*                          INDEX OF SUBPROGRAMS
*                          --------------------
*................................................................:
*  #   NAME    FUNCTION                                          :
*................................................................:
*  1   STARTS  START THE PROGRAM                                 :
*  2   PALYDP  MAIN SUBPROGRAM                                   :
*  3   APFCSS  SUBROUTINE TO DETERMINE ABSOLUTE POLLEN           :
*              CONCENTRATION                                     :
*  4   DEPCAL  SUBROUTINE TO MODIFY THE INFLUENCE OF ICE         :
*              LENSES ON POLLEN ACCUMULATION RATE                :
*  5   DIVSTS  SUBROUTINE TO DETERMINE SPECEIS RICHNESS          :
*              AND DIVERSITY                                     :
*  6   PARSSS  SUBROUTINE TO DETERMINE POLLEN ACCUMULATION       :
*              RATES                                             :
*  7   PRINTS  SUBROUTINE TO PRINT A MATRIX WITH SPECEIS         :
*              HEADING                                           :
*  8   RATESS  SUBROUTINE TO CALCULATE SEDIMENTATION RATE        :
*  9   RATIOS  SUBROUTINE TO DETERMINE SELECTED POLLEN           :
*              RATIOS                                            :
*  10  RPFSSS  SUBROUTINE TO DETERMINE POLLEN PERCENTAGE         :
*  11  SUMUPS  SUBROUTINE TO CALCULATE THE SUM OF AN ARRAY       :
*  12  WRITER  SUBROUTINE TO PRINT A MATRIX                      :
*                                                                :
*          SUBPROGRAM FOR PLOTTING DIAGRAMS                      :
*          ---------- --- -------- --------                      :
*          (INSTALLATION DEPENDENT ROUTINES)                     :
*                                                                :
*  13  CALPLT  SUBROUTINE TO START THE PLOTTING                  :
*  14  POLPLT  MAIN SUBPROGRAM FOR PLOTTING                      :
*  15  APFPSS  SUBROUTINE TO PLOT AN ARRAY IN TIME SERIES        :
*  16  DEPPLT  SUBROUTINE TO PLOT DEPTH COLUMNS                  :
*  17  GENUSS  SUBROUTINE TO WRITE SPECIES NAME ON DIAGRAM       :
*  18  PRIMES  SUBROUTINE TO PLOT PRELIMINARY ITEMS              :
*  19  SCALES  SUBROUTINE TO PLOT SCALE ON DIAGRAM               :
*  20  SPECT1  SUBROUTINE TO PLOT A HISTOGRAM SPECTRA            :
*  21  SPECT2  SUBROUTINE TO PLOT A SAW-TOOTH SPECTRA            :
*  22  STANDD  SUBROUTINE TO SCALE DATA FOR PLOTTING             :
*  23  TRIPSS  SUBROUTINE TO PLOT TREE-SHRUB-HERB COLUMN         :
*  24  TITLES  SUBROUTINE TO PLOT TITTLE OF DIAGRAM              :
*  25  SEDPLT  SUBROUTINE TO START PLOTTING OF SEDIMENT          :
*              SYMBOLS                                           :
*  26  CROSLN  SUBROUTINE TO PLOT CROSS LINES SYMBOL             :
```

```
*   27  DASHED  SUBROUTINE TO PLOT CONDENCED DASH LINE       :
*   28  DLINES  SUBROUTINE TO PLOT DASH LINE SYMBOL          :
*   29  DOTPLT  SUBROUTINE TO PLOT DOTTED SYMBOLS            :
*   30  HLINES  SUBROUTINE TO PLOT HORIZONTAL LINE SYMBOL    :
*   31  POLYGN  SUBROUTINE TO PLOT POLYGON SYBOL             :
*   32  VDLINE  SUBROUTINE TO PLOT VERTICAL DASH LINES       :
*   33  VLINES  SUBROUTINE TO PLOT VERTICAL LINES            :
*   34  ZONESS  SUBROUTINE TO PLOT ZONE BOUNDARIES           :
*                                                            :
*............................................................:
*
*
*                         LIST OF FILES
*                         -------------
*.............................................................
* UNIT #  UNIT NAME    DESCRIPTION                           :
*............................................................:
*   0     SCREEN       SCREEN                                :
*   1     IREADC       INPUT FILE FOR CONTROL CARDS          :
*   3     IREADP       INPUT FILE FOR PREPARATION DATA       :
*   5     IREADD       INPUT DATA FILE                       :
*   7     ISEDSS       INPUT FILE FOR SEDIMENT TYPES         :
*   2     ISUMRY       OUTPUT FILE FOR SUMARY DIAGRAM        :
*   4     ISTATD       OUTPUT FILE FOR STATISTICAL DATA      :
*   6     IPRINT       OUTPUT FILE FOR RESULTS               :
*.............................................................
*
*
*
*
*              ====================================
*
*                        PROGRAM STARTS
*
*              ====================================
*
*      SUBROUTINE REQUIRED: PALYDP
*
       PROGRAM     STARTS
       PARAMETER   (KD=150,LD=30)
       INTEGER     SCREEN
       CHARACTER   LOCATE*40,PLACE*40,NAME*40,CARDS*80,
      1            CHAR(LD*2)*20
       DIMENSION   VAR(KD*LD*30),IVAR(LD)
       COMMON      /IO/SCREEN
C
       SCREEN=0
       IREADD=5
C
C.... READ INPUT DATA
C
  100  READ(IREADD,'(A)',END=300) CARDS
```

```
      IF(CARDS(1:8).EQ.'LOCATION') THEN
        READ(CARDS(25:64),'(A40)') LOCATE
      ELSEIF(CARDS(1:11).EQ.'COORDINATES') THEN
        READ(CARDS(25:64),'(A)') PLACE
      ELSEIF(CARDS(1:8).EQ.'ANALYZER') THEN
        READ(CARDS(25:64),'(A)') NAME
      ELSEIF(CARDS(1:17).EQ.'NUMBER OF SAMPLES') THEN
        READ(CARDS(25:44),'(BN,I20)') K
      ELSEIF(CARDS(1:14).EQ.'NUMBER OF TAXA') THEN
        READ(CARDS(25:44),'(BN,I20)') L
        GOTO 200
      ELSE
        WRITE(SCREEN,'(2A)')' The first few lines in ',
     1         ' data file is not recognized'
        STOP
      ENDIF
      GOTO 100
  300 WRITE(SCREEN,'(A)')' Input data file not found'
      STOP
  200 CONTINUE
      REWIND IREADD
C
C.... START THE PROGRAM
C
      CALL PALYDP(K,L,VAR(1),VAR(1+K),VAR(1+2*K),VAR(1+3*K),
     1     VAR(1+4*K),VAR(1+5*K),VAR(1+6*K),VAR(1+7*K),
     2     VAR(1+8*K),VAR(1+9*K),VAR(1+10*K),VAR(1+11*K),
     3     VAR(1+12*K),VAR(1+13*K),VAR(1+14*K),VAR(1+15*K),
     4     VAR(1+16*K),VAR(1+17*K),VAR(1+18*K),VAR(1+19*K),
     5     VAR(1+20*K),VAR(1+21*K),VAR(1+22*K),VAR(1+23*K),
     6     VAR(3+24*K),VAR(5+25*K),VAR(5+K*(25+L)),
     1     VAR(5+K*(25+2*L)),VAR(5+K*(25+3*L)),
     2     VAR(5+K*(25+4*L)),VAR(5+K*(25+5*L)),
     3     VAR(5+K*(25+6*L)),VAR(5+K*(25+7*L)),
     4     VAR(5+K*(25+8*L)),
     1     VAR(5+K*(25+8*L)+L),VAR(5+K*(25+8*L)+2*L),
     2     VAR(5+K*(25+8*L)+3*L),VAR(5+K*(25+8*L)+4*L),
     1     IVAR(1),CHAR(1),CHAR(1+L),IREADD)
      END
C
C             ===================================
C
C                        SUBROUTINE PALYDP
C
C             ===================================
C
C.... SUBROUTINE REQUIRED: DEPCAL,SUMUPS,RPFSSS,APFCSS,RATESS,
C                          PARSSS,DIVIST,SELECT,RATIOS,CALPLT
C
      SUBROUTINE PALYDP(K,L,WA,WP,WD,WC,VE,VW,SUM,SUMV,SUME,
     1          QSUMV,QSUME,SUMW,HERB,SHRUB,TREE,WATER,AGE,
     2          DEPTH,TDEPTH,EXOTP,EXOTC,R,ORG,YD,B,POL,APFV,
```

```
     3              RPF,APFE,APFW,PARV,PARE,X,DATE,DSTART,DEND,
     4              DDEP,ZONE,J2,SPECIS,DATES,IREADD)
C
      INTEGER       SCREEN
      CHARACTER     CARDS*80,STYPE*10,SPECIS(L)*20,DATES(L)*20,
     1              STAT*1,IRAT*1,LOCATE*40,PLACE*40,NAME*40
      LOGICAL       WEIGHT,WV,MARKER,MODIF,DIVERS,EXW,IGP
      DIMENSION     BB(5),WA(K),WP(K),WD(K),WC(K),VE(K),VW(K),
     1              SUM(K),SUMV(K),SUME(K),QSUMV(K),QSUME(K),
     2              SUMW(K),HERB(K),SHRUB(K),TREE(K),YD(K+2),
     3              B(K+2),DEPTH(K),TDEPTH(K),EXOTP(K),EXOTC(K),
     4              R(K),AGE(K),WATER(K),ORG(K),J2(K)
      DIMENSION     POL(K,L),RPF(K,L),APFV(K,L),APFW(K,L),
     1              APFE(K,L),PARV(K,L),PARE(K,L),X(K,L)
      DIMENSION     DATE(L),DSTART(L),DEND(L),DDEP(L),ZONE(L)
      DATA          MODIF,DIVERS,EXW,IGP/4*.FALSE./
      COMMON        /IO/SCREEN/CONT/MARKER,WV,WEIGHT
C
C.... DEFINE I/O
C
      IREADC=1
      IREADP=3
      ISUMRY=2
      ISTATD=4
      IPRINT=6
C
C.... INITIALIZE THE CONTROL CARDS
C
      MARKER=.FALSE.
      WEIGHT=.FALSE.
      WV=.FALSE.
C
C.... READ CONTROL CARD
C
 100  READ(IREADC,'(A)',END=200) CARDS
        IF(CARDS(1:23).EQ.'CONCENTRATION BY WEIGHT') THEN
           WEIGHT=.TRUE.
        ELSEIF(CARDS(1:30).EQ.'CONCENTRATION BY EXOTIC MARKER')THEN

           MARKER=.TRUE.
        ELSEIF(CARDS(1:30).EQ.'CONCENTRATION BY WEIGHT-VOLUME')THEN
           WV=.TRUE.
        ELSEIF(CARDS(1:27).EQ.'DETERMINE SPECIES DIVERSITY') THEN
           DIVERS=.TRUE.
        ELSEIF(CARDS(1:18).EQ.'SEDIMENTATION RATE') THEN
           READ(CARDS(25:35),'(A)') STYPE
           IF(STYPE.EQ.'REGRESSION') THEN
             READ(IREADC,*)IORDER,A,(BB(I),I=1,IORDER)
           ENDIF
        ELSEIF(CARDS(1:26).EQ.'MODIFICATION OF ICE LENSES') THEN
           READ(CARDS(27:80),'(BN,2F10.3)') TSTART,TEND
           MODIF=.TRUE.
```

```
      ELSEIF(CARDS(1:11).EQ.'END OF FILE') THEN
         GOTO 200
      ELSE
         WRITE(SCREEN,'(A)')' Control card ID not recognized'
         STOP
      ENDIF
      GOTO 100
  200 CONTINUE
C
C.... READ INPUT DATA
C
      WRITE(IPRINT,'(///60A)')('*',I=1,60)
      WRITE(IPRINT,'(//T23,A)')'RESULT OF PALYDP'
      WRITE(IPRINT,'(//60A)')('*',I=1,60)
  300 READ(IREADD,'(A)',END=400) CARDS
      IF(CARDS(1:8).EQ.'LOCATION') THEN
        READ(CARDS(25:64),'(A40)') LOCATE
        WRITE(IPRINT,'(///A40)') LOCATE
      ELSEIF(CARDS(1:11).EQ.'COORDINATES') THEN
        READ(CARDS(25:64),'(A)') PLACE
        WRITE(IPRINT,'(/A40)') PLACE
      ELSEIF(CARDS(1:8).EQ.'ANALYZER') THEN
        READ(CARDS(25:64),'(A)') NAME
        WRITE(IPRINT,'(/A40)') NAME
      ELSEIF(CARDS(1:17).EQ.'NUMBER OF SAMPLES') THEN
        WRITE(IPRINT,'(/A,I4)')'NUMBER OF SAMPLES IS ',K
      ELSEIF(CARDS(1:14).EQ.'NUMBER OF TAXA') THEN
        WRITE(IPRINT,'(/A,I4)')'NUMBER OF TAXA IS ',L
      ELSEIF(CARDS(1:19).EQ.'NUMBER OF TREE TAXA') THEN
        READ(CARDS(20:40),'(BN,I20)') ITREE
      ELSEIF(CARDS(1:20).EQ.'NUMBER OF SHRUB TAXA') THEN
        READ(CARDS(21:40),'(BN,I20)') ISHRUB
      ELSEIF(CARDS(1:20).EQ.'TAXA INCLUDED IN SUM') THEN
        READ(CARDS(21:40),'(BN,I20)') LS
        WRITE(IPRINT,'(/A,I4)')'TAXA INCLUDED IN SUM IS',LS
      ELSEIF(CARDS(1:12).EQ.'LIST OF TAXA') THEN
        WRITE(IPRINT,'(/A)')'TAXA IDENTIFIED'
        DO 1 I=1,L
          READ(IREADD,'(T5,BN,I3,T10,A20)')J,SPECIS(I)
          WRITE(IPRINT,'(T5,I3,T10,A20)')I,SPECIS(I)
    1   CONTINUE
      ELSEIF(CARDS(1:17).EQ.'TABLE OF COUNTING') THEN
        DO 3 I=1,K
          READ(IREADD,*)J,(POL(I,J),J=1,L)
    3   CONTINUE
      ELSEIF(CARDS(1:19).EQ.'EXOTIC MARKER INPUT') THEN
        READ(IREADD,*)(EXOTP(I),I=1,K)
      ELSEIF(CARDS(1:21).EQ.'EXOTIC MARKER COUNTED') THEN
        READ(IREADD,*)(EXOTC(I),I=1,K)
      ELSEIF(CARDS(1:17).EQ.'WEIGHT OF RESIDUE') THEN
        READ(IREADD,*)(WA(I),I=1,K)
      ELSEIF(CARDS(1:22).EQ.'DEPTH LEVEL OF SAMPLES') THEN
```

```
            READ(IREADD,*)(DEPTH(I),I=1,K)
          ELSEIF(CARDS(1:17).EQ.'RADIOCARBON DATES') THEN
            READ(CARDS(18:38),'(BN,I5,BN,I5)') ID,IDP
            DO 4 I=1,ID
              READ(IREADD,*)DDEP(I),DATE(I)
    4       CONTINUE
            WRITE(IPRINT,'(/A)')'RADIOCARBON DATES:'
            WRITE(IPRINT,'(T10,A,T25,A)')'Depth Interval','Dates'
            DO 5 I=1,IDP
              READ(IREADD,'(T5,BN,F5.2,T15,BN,F5.2,T25,A20)')
     1            DSTART(I),DEND(I),DATES(I)
              WRITE(IPRINT,'(T5,F5.2,T15,F5.2,T25,A20)')
     1            DSTART(I),DEND(I),DATES(I)
    5       CONTINUE
          ELSEIF(CARDS(1:15).EQ.'ORGANIC CONTENT') THEN
            IGP=.TRUE.
            READ(IREADD,*)(ORG(I),I=1,K)
          ELSEIF(CARDS(1:5).EQ.'ZONES') THEN
            READ(CARDS(6:35),'(BN,I30)') IZONE
            READ(IREADD,*)(ZONE(I),I=1,IZONE-1)
          ELSEIF(CARDS(1:11).EQ.'END OF FILE') THEN
            GOTO 400
          ELSE
            WRITE(SCREEN,'(A)')' Data file ID not recognized'
            STOP
          ENDIF
          GOTO 300
  400     CONTINUE
C
C.... READ PREPARATION RESULTS
C
          IF(WEIGHT.OR.WV.OR.MARKER.OR.MODIF) THEN
  500       READ(IREADP,'(A)',END=600) CARDS
              IF(CARDS(1:17).EQ.'WEIGHT OF RESIDUE') THEN
                READ(IREADP,*)(WP(I),I=1,K)
              ELSEIF(CARDS(1:20).EQ.'WEIGHT OF DRY SAMPLE') THEN
                READ(IREADP,*)(WD(I),I=1,K)
              ELSEIF(CARDS(1:18).EQ.'VOLUME OF SAMPLE') THEN
                READ(IREADP,*)(VW(I),I=1,K)
              ELSEIF(CARDS(1:13).EQ.'WATER CONTENT') THEN
                READ(IREADP,*)(WATER(I),I=1,K)
              ELSEIF(CARDS(1:23).EQ.'CONTENT OF EXCESS WATER') THEN
                EXW=.TRUE.
                READ(IREADP,*)(VE(I),I=1,K)
              ELSEIF(CARDS(1:11).EQ.'END OF FILE') THEN
                GOTO 700
              ELSE
                WRITE(SCREEN,'(A)')'Preparation result not understood'

                STOP
              ENDIF
              GOTO 500
```

```
 600    WRITE(SCREEN,'(2A)')'Result of preparation not ',
     1                       'available'
          STOP
 700    CONTINUE
      ENDIF
C
C.... MODIFICATION OF DEPTH
C
      IF(MODIF) CALL DEPCAL (K,VW,WATER,VE,DEPTH,TDEPTH,
     1          TSTART,TEND,EXW,IPRINT)
C
C.... SUM UP
C
      CALL SUMUPS(K,L,1,ITREE,POL,TREE)
      ISTART=1+ITREE
      IEND=ITREE+ISHRUB
      CALL SUMUPS(K,L,ISTART,IEND,POL,SHRUB)
      CALL SUMUPS(K,L,1,LS,POL,SUM)
C
C.... DETERMINE POLLEN PERCENTAGE
C
      WRITE(IPRINT,'(/A)')'RESULT OF POLLEN PERCENTAGE'
      CALL RPFSSS(K,L,POL,SUM,TREE,SHRUB,HERB,RPF,SPECIS,IPRINT)
C
C.... DETERMINE POLLEN CONCENTRATION
C
      IF(WEIGHT) THEN
        WRITE(IPRINT,'(/A)')'POLLEN CONCENTRATION: WEIGHT METHOD'
        CALL APFCSS(K,L,POL,SUM,WP,WA,WD,SUMW,WC,APFW,
     1             SPECIS,IPRINT)
      ENDIF
C
      IF(WV) THEN
        WRITE(IPRINT,'(/A,A)')'POLLEN CONCENTRATION: ',
     1       'WEIGHT-VOLUME METHOD'
        CALL APFCSS(K,L,POL,SUM,WP,WA,VW,SUMV,WC,APFV,
     1             SPECIS,IPRINT)
      ENDIF
      IF(MARKER) THEN
        WRITE(IPRINT,'(/A,A)')'POLLEN CONCENTRATION: ',
     1       'EXOTIC MARKER METHOD'
        CALL APFCSS(K,L,POL,SUM,EXOTP,EXOTC,VW,SUME,WC,APFE,
     1             SPECIS,IPRINT)
      ENDIF
C
C.... DETERMINE POLLEN ACCUMULATION RATE
C
      IF(ID.GE.1) THEN
        IF(WV.OR.MARKER) THEN
          CALL RATESS(K,L,DEPTH,TDEPTH,DDEP,DATE,R,AGE,RATE,
     1                MODIF,STYPE,BB,ID)
          IF(WV) THEN
```

```
          WRITE(IPRINT,'(/A)')'POLLEN ACCUMULATION RATES:'
          WRITE(IPRINT,'(T5,A)')'WEIGHT-VOLUME METHOD'
          CALL PARSSS(K,L,APFV,SUMV,R,PARV,QSUMV,SPECIS,IPRINT)
        ENDIF
        IF(MARKER) THEN
          WRITE(IPRINT,'(/A)')'POLLEN ACCUMULATION RATES:'
          WRITE(IPRINT,'(T5,A)')'EXOTIC MARKER METHOD'
          CALL PARSSS(K,L,APFE,SUME,R,PARE,QSUME,SPECIS,IPRINT)
        ENDIF
      ENDIF
    ENDIF
C
C...  DETERMINATION OF DIVERSITY
C
      IF(DIVERS) CALL DIVSTS(K,L,POL,SUM,IPRINT)
C
C.... SELECTION OF TAXA FOR STATISTICAL ANALYSIS OR SUMMARY
C
      WRITE(SCREEN,'(//A,A)')' Select Taxa for a Special ',
     1                        'Purpose (Y/N)?'
      READ(SCREEN,'(A1)')STAT
      IF(STAT.EQ.'Y') THEN
 800    WRITE(SCREEN,'(2A)')' Please clear screen and press ',
     1                       'RETURN to continue......'
        PAUSE
        WRITE(SCREEN,'(8(/A),//A)')
     1       '1   Original Counting',
     2       '2   Pollen Percentage',
     3       '3   Accumulation Rate (Marker)',
     4       '4   Accumulation Rate (WV)',
     5       '5   Concentration (Marker)',
     6       '6   Concentration (WV)',
     7       '7   Concentration (Weight)',
     8       '8   No selection',
     9       'ENTER YOUR CHOICE:'
        READ(SCREEN,*) ISELT
        IF(ISELT.EQ.1) THEN
          DO 11 I=1,K
          DO 11 J=1,L
            X(I,J)=POL(I,J)
  11      CONTINUE
        ELSEIF(ISELT.EQ.2) THEN
          DO 12 I=1,K
          DO 12 J=1,L
            X(I,J)=RPF(I,J)
  12      CONTINUE
        ELSEIF(ISELT.EQ.3) THEN
          IF(MARKER) THEN
            DO 13 I=1,K
            DO 13 J=1,L
              X(I,J)=PARE(I,J)
  13        CONTINUE
```

```
        ELSE
          WRITE(SCREEN,'(A)')'Exotic Marker Method not used'
          GOTO 800
        ENDIF
      ELSEIF(ISELT.EQ.4) THEN
        IF(WV) THEN
          DO 14 I=1,K
          DO 14 J=1,L
            X(I,J)=PARV(I,J)
14        CONTINUE
        ELSE
          WRITE(SCREEN,'(A)')'Weight-volume Method not used'
          GOTO 800
        ENDIF
      ELSEIF(ISELT.EQ.5) THEN
        IF(MARKER) THEN
          DO 15 I=1,K
          DO 15 J=1,L
            X(I,J)=APFE(I,J)
15        CONTINUE
        ELSE
          WRITE(SCREEN,'(A)')'Exotic Marker Method not used'
          GOTO 800
        ENDIF
      ELSEIF(ISELT.EQ.6) THEN
        IF(WV) THEN
          DO 16 I=1,K
          DO 16 J=1,L
            X(I,J)=APFV(I,J)
16        CONTINUE
        ELSE
          WRITE(SCREEN,'(A)')'Weight-Volume Method not used'
          GOTO 800
        ENDIF
      ELSEIF(ISELT.EQ.7) THEN
        IF(WEIGHT) THEN
          DO 17 I=1,K
          DO 17 J=1,L
            X(I,J)=APFW(I,J)
17        CONTINUE
        ELSE
          WRITE(SCREEN,'(A)')'Weight Method not used'
          GOTO 800
        ENDIF
      ELSEIF(ISELT.EQ.8) THEN
        GOTO 900
      ENDIF
      WRITE(SCREEN,'(/A)')'      1    For Statistical Analysis'
      WRITE(SCREEN,'(A)')'      2    For Summary diagram Plot'
      WRITE(SCREEN,'(/A)')'     ENTER YOUR CHOICE '
      READ(SCREEN,*) ISELT
      IF(ISELT.EQ.1) THEN
```

```
            CALL SELECT(K,L,X,X,J2,LOCATE,SPECIS,ISTATD)
            WRITE(ISTATD,'(A)')'DEPTH LEVEL OF SAMPLES'
            WRITE(ISTATD,'(5G10.2/(5G10.2))')(DEPTH(I),I=1,K)
            WRITE(ISTATD,'(A)')'END OF FILE'
          ELSEIF(ISELT.EQ.2) THEN
            CALL SELECT(K,L,X,X,J2,LOCATE,SPECIS,ISUMRY)
            WRITE(ISUMRY,'(A)')'DEPTH LEVEL OF SAMPLES'
            WRITE(ISUMRY,'(5G10.2/(5G10.2))')(DEPTH(I),I=1,K)
            IF(IDP.GE.1) THEN
              WRITE(ISUMRY,'(A,T25,I3)')'RADIOCARBON DATES',IDP
              DO 18 I=1,IDP
                WRITE(ISUMRY,'(T5,BN,F5.2,T15,BN,F5.2,T25,A20)')
     1          DSTART(I),DEND(I),DATES(I)
   18         CONTINUE
            ENDIF
            IF(IZONE.GT.1) THEN
              WRITE(ISUMRY,'(A,T25,I3)')'ZONES',IZONE
              WRITE(ISUMRY,*)(ZONE(I),I=1,IZONE-1)
            ENDIF
            WRITE(ISUMRY,'(A)')'END OF FILE'
          ENDIF
        ENDIF
C
C.... DETERMINE POLLEN RATIOS
C
  900   WRITE(SCREEN,'(A)')' Calculate Pollen Ratios (Y/N)?'
        READ(SCREEN,'(A1)')IRAT
        IF(IRAT.EQ.'Y') THEN
          CALL RATIOS(K,L,RPF,SPECIS,X,J2,IPRINT)
        ENDIF
C
C.... PLOT POLLEN DIAGRAMS
C
        STAT='N'
        WRITE(SCREEN,'(A)')'Plot pollen diagram (Y/N) ?'
        READ(SCREEN,'(A1)')STAT
        IF(STAT.EQ.'Y'.OR.STAT.EQ.'y')  THEN
          CALL CALPLT(K,L,LS,LOCATE,PLACE,NAME,SPECIS,DEPTH,
     1         IZONE,ZONE,TREE,SHRUB,SUM,RPF,SUME,APFE,QSUME,
     3         PARE,SUMV,APFV,QSUMV,PARV,SUMW,APFW,DSTART,
     4         DEND,DATES,IDP,IGP,ORG,X,YD,B,WC)
        ENDIF
        CLOSE(IREADD)
        CLOSE(IREADC)
        CLOSE(IREADP)
  999   END
C
C              ====================================
C
C                          SUBROUTINE APFCSS
C
C              ====================================
```

```
C
      SUBROUTINE APFCSS(K,L,X,SUM,WP,WA,WD,SUMC,WC,APF,SPECIS,
     1                IPRINT)
C
C.... SUBROUTINE REQUIRED: PRINTS
C
      CHARACTER*20 SPECIS(L)
      DIMENSION SUM(K),SUMC(K),APF(K,L),X(K,L),WP(K),WA(K),
     1          WD(K),WC(K)
C
      DO 1 I=1,K
        WC(I)=WP(I)/(WD(I)*WA(I))
        SUMC(I)=SUM(I)*WC(I)
      DO 1 J=1,L
        APF(I,J)=WC(I)*X(I,J)
    1 CONTINUE
      CALL PRINTS(K,L,APF,SPECIS,IPRINT)
      WRITE(IPRINT,'(/2(3X,A))')'#','Total Pollen Concentration'
      DO 11 I=1,K,5
        I2=I+4
        IF(I2.GT.K) I2=K
        WRITE(IPRINT,'(I4,3X,5F9.0)')I,(SUMC(J),J=I,I2)
   11 CONTINUE
      END
C
C            ====================================
C
C                     SUBROUTINE DEPCAL
C
C            ====================================
C
      SUBROUTINE DEPCAL (K,V,H2OV,VE,DEPTH,TDEPTH,TSTART,
     1           TEND,EXW,IPRINT)
C
      LOGICAL EXW
      DIMENSION V(K),H2OV(K),DEPTH(K),TDEPTH(K),VE(K)
C
C.... MODIFICATION OF 9% EXPANSION OF ICE
C
      DELTA=0.0
      DO 5 I=1,K
        I1=I-1
        IF(DEPTH(I).LE.TSTART) TDEPTH(I)=DEPTH(I)
        IF(DEPTH(I).GT.TSTART.AND.DEPTH(I).LE.TEND) THEN
          A1=(H2OV(I)+H2OV(I1))*0.045
          DELTA=DELTA+A1*(DEPTH(I)-DEPTH(I1))
        ENDIF
        TDEPTH(I)=DEPTH(I)-DELTA
    5 CONTINUE
C
C.... MODIFY EXCESS WATER
C
```

```
      IF(EXW) THEN
        DELTA=0.0
        DO 13 I=2,K
          I1=I-1
          IF(DEPTH(I1).GE.TSTART) THEN
            A1=(VE(I)+VE(I1))*0.5
            DELTA=DELTA+A1*(DEPTH(I)-DEPTH(I1))
            TDEPTH(I)=TDEPTH(I)-DELTA
            V(I)=V(I)*(1.0-VE(I))
          ELSE
            V(I)=V(I)
            TDEPTH(I)=TDEPTH(I)
          ENDIF
   13   CONTINUE
      ELSE
        WRITE(IPRINT,'(/T5,2A)')'Excess water not measured,',
     1       'only 9% volume expansion caliberated'
      ENDIF
C
      END
C
C             ====================================
C
C                          SUBROUTINE DIVSTS
C
C             ====================================
C
      SUBROUTINE DIVSTS(K,L,RPF,SUM,IP)
C
      DIMENSION RPF(K,L),SUM(K)
C
      WRITE(IP,'(/A)')'SPECIES RICHNESS AND DIVERSITY'
      WRITE(IP,'(T5,A,T15,A,T25,A,T35,A)')
     1     'R1','R2','R3','Diversity'
      DO 1 I=1,K
        SPN=0.0
        SHW=0.0
        DO 2 J=1,L-1
          IT=IFIX(RPF(I,J))
          IF(IT.GT.0) SPN=SPN+1.0
          RPF(I,J)=RPF(I,J)/SUM(I)
          IF(RPF(I,J).GT.0.0) THEN
            SHW=SHW+RPF(I,J)*ALOG(RPF(I,J))
          ELSE
            SHW=SHW
          END IF
    2   CONTINUE
        R1=SPN
        R2=SPN/SQRT(SUM(I))
        R3=(SPN-1.0)/ALOG(SUM(I))
        SHW=-SHW
        WRITE(IP,'(4F10.4)')R1,R2,R3,SHW
```

```
      1 CONTINUE
        END
C
C            =====================================
C
C                        SUBROUTINE PARSSS
C
C            =====================================
C
        SUBROUTINE PARSSS(K,L,APF,SUMC,R,Y,QSUM,SPECIS,IPRINT)
C
C.... SUBROUTINE REQUIRED: PRINTS
C
        DIMENSION  APF(K,L),Y(K,L),R(K),SUMC(K),QSUM(K)
        CHARACTER*20 SPECIS(50)
C
C.... CALCULATE THE POLLEN INFLUX
C
        DO 1 I=1,K
          QSUM(I)=SUMC(I)*R(I)
        DO 1 J=1,L
          Y(I,J)=APF(I,J)*R(I)
      1 CONTINUE
C
C.... PRINT OUT THE RESULTS
C
        CALL PRINTS(K,L,Y,SPECIS,IPRINT)
        WRITE(IPRINT,'(/T8,A)')'Total Pollen Accumulation Rate:'
        DO 2 I=1,K,5
          I2=I+4
          IF(I2.GT.K) I2=K
          WRITE(IPRINT,'(I4,3X,5G7.0)')I,(QSUM(J),J=I,I2)
      2 CONTINUE
        END
C
C            =====================================
C
C                        SUBROUTINE PRINTS
C
C            =====================================
C
        SUBROUTINE PRINTS(N,M,A,SPECIS,IPRINT)
C
C...   SUBROUTINE TO PRINT A MATRIX HAVING N ROWS AND M COLUMNS
C
        CHARACTER SPECIS(M)*20
        DIMENSION A(N,M)
C
C.... PRINT MATRIX OUT IN STRIPS OF 5 COLUMNS
C
        DO 1 I=1,M,5
        I1=I+4
```

```
      IF(I1-M) 20,20,10
   10 I1=M
C
C.... PRINT HEADING
C
   20 WRITE(IPRINT,'(/6X,5(8X,A4))')(SPECIS(J),J=I,I1)
      DO 2 J=1,N
C
C.... PRINT ROW OF MATRIX
C
      WRITE(IPRINT,'(1X,I5,5F12.2)')J,(A(J,K),K=I,I1)
    2 CONTINUE
    1 CONTINUE
      END
C
C             ====================================
C
C                            SUBROUTINE RATESS
C
C             ====================================
C
      SUBROUTINE RATESS(K,L,DEPTH,TDEPTH,DDEP,DATE,R,AGE,
     1                   RATE,MODIF,STYPE,B,ID)
C
      CHARACTER  STYPE*10
      LOGICAL    MODIF
      DIMENSION  DEPTH(K),TDEPTH(K),R(K),AGE(K),DATE(L),
     1           RATE(L),DDEP(L),B(5)
C
      DELTA=0.0
      IF(MODIF) THEN
        DO 75 J=1,ID
        DO 76 I=2,K
          I1=I-1
          IF(DDEP(J).EQ.DEPTH(I))  DDEP(J)=TDEPTH(I)
          IF(DDEP(J).LT.DEPTH(I).AND.DDEP(J).GT.DEPTH(I1)) THEN
            Y1=DDEP(J)-DEPTH(I1)
            Y2=DEPTH(I)-DEPTH(I1)
            YY2=TDEPTH(I)-TDEPTH(I1)
            YY1=Y1*YY2/Y2
            DDEP(J)=YY1+TDEPTH(I1)
          END IF
   76   CONTINUE
   75   CONTINUE
C
        RATE(1)=DDEP(1)/DATE(1)
        DO 45 I=2,ID
          I1=I-1
          IF(DATE(I).EQ.DATE(I1)) RATE(I)=100.0
          IF(DATE(I).GT.DATE(I1))
     1      RATE(I)=(DDEP(I)-DDEP(I1))/(DATE(I)-DATE(I1))
          IF(DATE(I).LT.DATE(I1)) RATE(I)=RATE(I1)
```

```
         IF(RATE(I).GT.1.0) DELTA=DDEP(I)-DDEP(I1)
         IF(RATE(I).GT.1.0) ADEP=DDEP(I)
  45   CONTINUE
       II=ID+1
       IF(DDEP(ID).LT.TDEPTH(K)) RATE(II)=RATE(ID)
       IF(DDEP(ID).LT.TDEPTH(K)) DDEP(II)=TDEPTH(K)
       IF(STYPE.EQ.'REGRESSION') THEN
         DO 46 I=1,K
           IF(TDEPTH(I).LT.ADEP) TDEPTH(I)=TDEPTH(I)
           IF(TDEPTH(I).GE.ADEP) TDEPTH(I)=TDEPTH(I)-DELTA
           AGE(I)=A+B(1)*TDEPTH(I)+B(2)*TDEPTH(I)*TDEPTH(I)
     1       +B(3)*TDEPTH(I)**3.0+B(4)*TDEPTH(I)**4.0
           IF(AGE(I).LT.0.0) AGE(I)=0.0
  46     CONTINUE
         DO 780 I=2,K
           I1=I-1
           IF(AGE(I).EQ.AGE(I1)) THEN
             R(I)=R(I1)
           ELSE
             R(I)=(TDEPTH(I)-TDEPTH(I1))/(AGE(I)-AGE(I1))
           ENDIF
           IF(R(I).EQ.0.0) R(I)=R(I1)
 780     CONTINUE
         R(1)=R(2)
       ELSE
         DO 48 I=1,K
           IF(TDEPTH(I).LT.ADEP) TDEPTH(I)=TDEPTH(I)
           IF(TDEPTH(I).GE.ADEP) TDEPTH(I)=TDEPTH(I)-DELTA
           IF(TDEPTH(I).LE.DDEP(1)) R(I)=RATE(1)
         DO 48 J=2,II
           IF(TDEPTH(I).LE.DDEP(J).AND.TDEPTH(I).GT.DDEP(J-1))
     1       R(I)=RATE(J)
  48     CONTINUE
         DO 139 J=1,II
           IF(DDEP(J).GE.ADEP) THEN
             DDEP(J)=DDEP(J)-DELTA
           ELSE
             DDEP(J)=DDEP(J)
           ENDIF
 139     CONTINUE
         AGE(1)=TDEPTH(1)/R(1)
         DO 47 I=2,K
           I1=I-1
           IF(R(I).GT.1.0) R(I)=R(I+1)
           IF(R(I).NE.R(I1)) THEN
             DO 138 J=1,II
               IF(TDEPTH(I).GT.DDEP(J).AND.TDEPTH(I1).LE.
     1           DDEP(J)) THEN
                 C=DDEP(J)
                 NC=0
               ENDIF
               IF(TDEPTH(I).EQ.DDEP(J)) NC=1
```

```
138          CONTINUE
             IF(NC.EQ.0) THEN
               A1=(C-TDEPTH(I-1))/R(I1)
               A2=(TDEPTH(I)-C)/R(I)
               AGE(I)=A1+A2+AGE(I1)
             ELSE
               AGE(I)=(TDEPTH(I)-TDEPTH(I1))/R(I)+AGE(I1)
             ENDIF
             NC=0
           ELSE
             AGE(I)=(TDEPTH(I)-TDEPTH(I1))/R(I)+AGE(I1)
           END IF
 47      CONTINUE
       ENDIF
      ELSEIF(.NOT.MODIF) THEN
       RATE(1)=DDEP(1)/DATE(1)
       DO 98 I=2,ID
         I1=I-1
         IF(DATE(I).EQ.DATE(I1)) RATE(I)=100.0
         IF(DATE(I).GT.DATE(I1))
    1      RATE(I)=(DDEP(I)-DDEP(I1))/(DATE(I)-DATE(I1))
         IF(DATE(I).LT.DATE(I1)) RATE(I)=RATE(I1)
         IF(RATE(I).GT.1.0) DELTA=DDEP(I)-DDEP(I1)
         IF(RATE(I).GT.1.0) ADEP=DDEP(I)
 98    CONTINUE
       II=ID+1
       IF(DDEP(ID).LT.DEPTH(K)) RATE(II)=RATE(ID)
       IF(DDEP(ID).LT.DEPTH(K)) DDEP(II)=DEPTH(K)
       IF(STYPE.EQ.'REGRESSION') THEN
         DO 789 I=1,K
           IF(DEPTH(I).LT.ADEP) TDEPTH(I)=DEPTH(I)
           IF(DEPTH(I).GE.ADEP) TDEPTH(I)=DEPTH(I)-DELTA
           AGE(I)=A+B(1)*TDEPTH(I)+B(2)*TDEPTH(I)*TDEPTH(I)
    1           +B(3)*TDEPTH(I)**3.0+B(4)*TDEPTH(I)**4.0
           IF(AGE(I).LT.0.0) AGE(I)=0.0
789      CONTINUE
         DO 790 I=2,K
           I1=I-1
           IF(AGE(I).EQ.AGE(I1)) THEN
             R(I)=R(I1)
           ELSE
             R(I)=(TDEPTH(I)-TDEPTH(I1))/(AGE(I)-AGE(I1))
           ENDIF
           IF(R(I).EQ.0.0) R(I)=R(I1)
790      CONTINUE
         R(1)=R(2)
       ELSE
         DO 49 I=1,K
           IF(DEPTH(I).LT.ADEP) TDEPTH(I)=DEPTH(I)
           IF(DEPTH(I).GE.ADEP) TDEPTH(I)=DEPTH(I)-DELTA
         DO 49 J=2,II
           IF(DEPTH(I).LE.DDEP(1)) R(I)=RATE(1)
```

```
            IF(DEPTH(I).LE.DDEP(J).AND.DEPTH(I).GT.DDEP(J-1))
     1        R(I)=RATE(J)
   49       CONTINUE
            DO 148 J=1,II
              IF(DDEP(J).GE.ADEP) THEN
                DDEP(J)=DDEP(J)-DELTA
              ELSE
                DDEP(J)=DDEP(J)
              ENDIF
  148       CONTINUE
            AGE(1)=TDEPTH(1)/R(1)
            DO 40 I=2,K
              I1=I-1
              IF(R(I).GT.1.0) R(I)=R(I+1)
              IF(R(I).NE.R(I1)) THEN
                DO 149 J=1,II
                  IF(DEPTH(I).GT.DDEP(J).AND.DEPTH(I1).LE.DDEP(J))
     1              THEN
                    C=DDEP(J)
                    NC=0
                  ENDIF
                  IF(DEPTH(I).EQ.DDEP(J)) NC=1
  149           CONTINUE
                IF(NC.EQ.0) THEN
                  A1=(C-TDEPTH(I1))/R(I1)
                  A2=(TDEPTH(I)-C)/R(I)
                  AGE(I)=A1+A2+AGE(I1)
                ELSE
                  AGE(I)=(TDEPTH(I)-TDEPTH(I1))/R(I)+AGE(I1)
                ENDIF
              ELSE
                AGE(I)=(TDEPTH(I)-TDEPTH(I1))/R(I)+AGE(I1)
              END IF
   40       CONTINUE
          ENDIF
        ENDIF
  999   END
C
C               ====================================
C
C                        SUBROUTINE RATIOS
C
C               ====================================
C
        SUBROUTINE RATIOS(K,L,RPF,SPECIS,RATIO,J2,IP)
C
        INTEGER   SCREEN
        CHARACTER SPECIS(L)*20
        DIMENSION RPF(K,L),RATIO(K,L),J2(K)
        COMMON    /IO/SCREEN
C
        WRITE(SCREEN,'(A)')'How many ratios to be determined ?'
```

```
      READ(SCREEN,*)IR
      L1=L-1
      DO 21 JJ=1,L1,2
        J1=JJ+1
        IF(J1.LE.L1) THEN
          WRITE(SCREEN,'(2(I3,2X,A20))')JJ,SPECIS(JJ),J1,
     1          SPECIS(J1)
        ELSE
          WRITE(SCREEN,'(I3,2X,A20)')JJ,SPECIS(JJ)
        ENDIF
   21 CONTINUE
      DO 1 J=1,IR
        JB=J*2
        JA=JB-1
        WRITE(SCREEN,'(A)')'Which pair of taxa ?'
        READ(SCREEN,*)J2(JA),J2(JB)
        DO 2 I=1,K
          JC=J2(JA)
          JD=J2(JB)
          IF(RPF(I,JD).GT.0.0) THEN
            RATIO(I,J)=RPF(I,JC)/RPF(I,JD)
          ELSE
            RATIO(I,J)=RATIO(I-1,J)
          END IF
    2   CONTINUE
    1 CONTINUE
C
      WRITE(IP,'(/A)')'SELECTED POLLEN RATIOS'
      DO 5 J=1,IR
        JB=J*2
        JA=JB-1
        JA=J2(JA)
        JB=J2(JB)
        WRITE(IP,'(/T5,BN,3A)')SPECIS(JA),' vs ',SPECIS(JB)
        WRITE(IP,'(4X,5F10.4/(4X,5F10.4))')(RATIO(I,J),I=1,K)
    5 CONTINUE
      END
C
C              ====================================
C
C                         SUBROUTINE READIN
C
C              ====================================
C
      SUBROUTINE READIN(N,M,FVAR,IREAD)
C
C.... SUBROUTINE TO READ A MATRIX WITH N BY M DIMENSION
C
      DIMENSION FVAR(N,M)
      CHARACTER*4 A
```

```
      C
      C.... READ MATRIX IN STRIPS OF 5 COLUMNS
      C
            DO 1 I=1,M,5
              I1=I+4
              IF(I1-M) 20,20,10
        10    I1=M
      C
      C.... READ HEADING
      C
        20    READ(IREAD,'(/6X,5(8X,A4))')A,T
      C
      C.... READ ROW OF MATRIX
      C
              DO 2 J=1,N
                READ(IREAD,'(1X,I5,5F12.2)')JJ,(FVAR(J,K),K=I,I1)
         2    CONTINUE
         1  CONTINUE
       999  RETURN
            END
      C
      C             ====================================
      C
      C                        SUBROUTINE RPFSSS
      C
      C             ====================================
      C
            SUBROUTINE RPFSSS(K,L,X,SUM,TREE,SHRUB,HERB,RPF,SPECIS,
           1          IPRINT)
      C
      C.... SUBROUTINE REQUIRED: PRINTS
      C
            CHARACTER  SPECIS(L)*20
            DIMENSION  X(K,L),SUM(K),RPF(K,L),TREE(K),SHRUB(K),
           1           HERB(K)
      C
            DO 1 I=1,K
              HERB(I)=SUM(I)-TREE(I)-SHRUB(I)
              TEMP=100.0/SUM(I)
              TREE(I)=TREE(I)*TEMP
              SHRUB(I)=SHRUB(I)*TEMP
              HERB(I)=HERB(I)*TEMP
            DO 1 J=1,L
              RPF(I,J)=X(I,J)*TEMP
         1  CONTINUE
            CALL PRINTS(K,L,RPF,SPECIS,IPRINT)
            WRITE(IPRINT,'(/T16,A,T30,A,T46,A)')'Tree','Shrub','Herb'
            DO 2 I=1,K
              WRITE(IPRINT,'(T10,F10.1,T25,F10.1,T40,F10.1)')
           1         TREE(I),SHRUB(I),HERB(I)
         2  CONTINUE
            END
```

```
C
C               ====================================
C
C                        SUBROUTINE SELECT
C
C               ====================================
C
      SUBROUTINE  SELECT(K,L,X,Y,J2,LOCATE,SPECIS,ISLT)
C
C.... SUBROUTINE REQUIRED: WRITER
C
      INTEGER       SCREEN
      CHARACTER     LOCATE*40,SPECIS(L)*20
      DIMENSION     X(K,L),J2(K),Y(K,L)
      COMMON        /IO/SCREEN
C
      WRITE(ISLT,'(A,T25,A)')'LOCATION',LOCATE
      WRITE(SCREEN,'(A)')' How many taxa do you wish to use ?'
      READ(SCREEN,*)II
      WRITE(ISLT,'(A,T25,I4)')'NUMBER OF SAMPLES',K
      WRITE(ISLT,'(A,T25,I4)')'NUMBER OF TAXA',II
      WRITE(SCREEN,'(2A)')' Please clear screen and press ',
     1                    'RETURN to continue......'
      PAUSE
      L1=L-1
      DO 1 JJ=1,L1,2
        J1=JJ+1
        IF(J1.LE.L1) THEN
          WRITE(SCREEN,'(2(I3,2X,A20))')JJ,SPECIS(JJ),J1,
     1         SPECIS(J1)
        ELSE
          WRITE(SCREEN,'(I3,2X,A20)')JJ,SPECIS(JJ)
        ENDIF
    1 CONTINUE
      WRITE(SCREEN,'(A)')' Which taxa do you need ?'
      READ(SCREEN,*)(J2(I),I=1,II)
      WRITE(ISLT,'(A)')'LIST OF TAXA'
      DO 2 J=1,II
        JS=J2(J)
        WRITE(ISLT,'(T5,I3,T10,A20)')J,SPECIS(JS)
    2 CONTINUE
      DO 3 J=1,II
        J1=J2(J)
        DO 4 I=1,K
          Y(I,J)=X(I,J1)
    4   CONTINUE
    3 CONTINUE
      WRITE(ISLT,'(A)')'DATA'
      DO 6 I=1,K
        WRITE(ISLT,'(I3,1X,5F10.2/(4X,5F10.2))')I,(Y(I,J),J=1,II)
    6 CONTINUE
      END
```

```
C
C             ====================================
C
C                        SUBROUTINE SUMUPS
C
C             ====================================
C
      SUBROUTINE SUMUPS(K,L,ISTART,IEND,X,Y)
C
      DIMENSION  X(K,L),Y(K)
C
      DO 1 I=1,K
        Y(I)=0.0
        DO 1 J=ISTART,IEND
          Y(I)=Y(I)+X(I,J)
    1 CONTINUE
      END
C
C             ====================================
C
C                        SUBROUTINE WRITER
C
C             ====================================
C
      SUBROUTINE WRITER(N,M,A,IPRINT)
C
      DIMENSION  A(N,M)
C
C.... PRINT MATRIX OUT IN STRIPS OF 5 COLUMNS
C
      DO 1 I=1,M,5
        I1=I+4
        IF(I1-M) 20,20,10
   10   I1=M
C
C.... PRINT HEADING
C
   20   WRITE(IPRINT,'(/6X,5(8X,I4))')(J,J=I,I1)
C
C.... PRINT ROW OF MATRIX
C
        DO 2 J=1,N
          WRITE(IPRINT,'(1X,I5,5F12.4)')J,(A(J,K),K=I,I1)
    2   CONTINUE
    1 CONTINUE
  999 RETURN
      END
C
C             ====================================
C
C                        SUBROUTINE CALPLT
C
```

```
C             =====================================
C
C
C.... SUBPROGRAM CALPLT AND ITS RELATED SUBROUTINES ARE
C.... DESIGNED FOR PLOTTIN PALYNOLOGICAL DATA AND OTHER
C.... CHARTS USING CALCOMP PLOTTER SOFTWARE PACKAGE
C
C.... SUBROUTINE REQUIRED: POLPLT
C
      SUBROUTINE CALPLT(K,L,LS,LOCATE,PLACE,NAME,SPECIS,DEPTH,
     1           IZ,BY,TREE,SHRUB,SUM,RPF,SUME,APFE,QSUME,
     3           PARE,SUMV,APFV,QSUMV,PARV,SUMW,APFW,DSTART,
     4           DEND,DATES,ID,IGP,ORG,RPFR,YD,B,AMAX)
C
C.... SUBROUTINE REQUIRED: POLPLT
C
      INTEGER    SCREEN
      CHARACTER  CHART*43,LOCATE*40,NAME*40,PLACE*40,
     1           SPECIS(L)*20,DATES(L)*20
      LOGICAL    MARKER,WV,WEIGHT,IGP
      DIMENSION  TREE(K),SHRUB(K),SUM(K),BY(L),SUMV(K),
     1           SUMW(K),SUME(K),QSUME(K),QSUMV(K),B(K+2),
     2           RPF(K,L),APFV(K,L),APFE(K,L),APFW(K,L),
     3           PARE(K,L),PARV(K,L),DEPTH(K),YD(K+2),
     4           DSTART(L),DEND(L),AMAX(K),ORG(K)
      COMMON     /COM1/NGR,NN/IO/SCREEN/CONT/MARKER,WV,WEIGHT
C
      WRITE(SCREEN,'(2A)')'Please clear screen and hit ',
     1                    'RETURN to continue'
      PAUSE
      WRITE(SCREEN,910)
  910 FORMAT('      1   Percentage',/
     1       '      2   Accumulation Rate (MARKER)',/
     2       '      3   Accumulation Rate (WV)',/
     3       '      4   Concentration (MARKER)',/
     4       '      5   Concentration (WV)',/
     5       '      6   Concentration (WEIGHT)',//
     6       'Which diagram do you want to plot ?')
      READ(SCREEN,*)NN
C
      IF(NN.EQ.1) THEN
        CHART='POLLEN PERCENTAGE DIAGRAM                  '
      ELSEIF(NN.EQ.2) THEN
        CHART='POLLEN ACCUMULATION RATE: MARKER METHOD    '
      ELSEIF(NN.EQ.3) THEN
        CHART='POLLEN ACCUMULATION RATE: V-W METHOD       '
      ELSEIF(NN.EQ.4) THEN
        CHART='POLLEN CONCENTRATION: MARKER METHOD        '
      ELSEIF(NN.EQ.5) THEN
        CHART='POLLEN CONCENTRATION: VOLUME-WEIGHT METHOD '
      ELSEIF(NN.EQ.6) THEN
        CHART='POLLEN CONCENTRATION: WEIGHT METHOD        '
```

```
      ENDIF
C
      WRITE(SCREEN,'(2(A/)/A)')
     1 '    1   Histogram','    2   saw-tooth curves',
     2 'What kind of diagram do you want to plot ?'
      READ(SCREEN,*)NGR
      WRITE(SCREEN,'(A)')'Enter paper length (cm):'
      READ(SCREEN,*)PAPER
C
      CALL PLOTS(PAPER,27.5)
      CALL PLOT(5.0,5.0,-3)
C
      IF(NN.EQ.1) THEN
        IF(MARKER) THEN
          CALL POLPLT(K,L,DEPTH,SUME,QSUME,TREE,SHRUB,RPF,LS,
     1            LOCATE,PLACE,NAME,SPECIS,DSTART,DEND,DATES,ID,
     2            IZ,BY,CHART,SUM,YD,B,AMAX,RPFR,APFW,IGP,ORG)
        ELSEIF(WV) THEN
          CALL POLPLT(K,L,DEPTH,SUMV,QSUMV,TREE,SHRUB,RPF,LS,
     1            LOCATE,PLACE,NAME,SPECIS,DSTART,DEND,DATES,ID,
     2            IZ,BY,CHART,SUM,YD,B,AMAX,RPFR,APFW,IGP,ORG)
        ELSEIF(WEIGHT) THEN
          CALL POLPLT(K,L,DEPTH,SUMW,QSUMW,TREE,SHRUB,RPF,LS,
     1            LOCATE,PLACE,NAME,SPECIS,DSTART,DEND,DATES,ID,
     2            IZ,BY,CHART,SUM,YD,B,AMAX,RPFR,APFW,IGP,ORG)
        ELSE
          CALL POLPLT(K,L,DEPTH,WC,WC,TREE,SHRUB,RPF,LS,
     1            LOCATE,PLACE,NAME,SPECIS,DSTART,DEND,DATES,ID,
     2            IZ,BY,CHART,SUM,YD,B,AMAX,RPFR,APFW,IGP,ORG)
        END IF
      ELSEIF(NN.EQ.2) THEN
        IF(MARKER) THEN
          CALL POLPLT(K,L,DEPTH,SUME,QSUME,TREE,SHRUB,PARE,LS,
     1            LOCATE,PLACE,NAME,SPECIS,DSTART,DEND,DATES,ID,
     2            IZ,BY,CHART,SUM,YD,B,AMAX,RPFR,APFW,IGP,ORG)
        ELSE
          WRITE(SCREEN,'(A)')'Exotic marker method not used'
          STOP
        ENDIF
      ELSEIF(NN.EQ.3) THEN
        IF(WV) THEN
          CALL POLPLT(K,L,DEPTH,SUMV,QSUMV,TREE,SHRUB,PARV,LS,
     1            LOCATE,PLACE,NAME,SPECIS,DSTART,DEND,DATES,ID,
     2            IZ,BY,CHART,SUM,YD,B,AMAX,RPFR,APFW,IGP,ORG)
        ELSE
          WRITE(SCREEN,'(A)')'Weight-Volume method not used'
          STOP
        ENDIF
      ELSEIF(NN.EQ.4) THEN
        IF(MARKER) THEN
          CALL POLPLT(K,L,DEPTH,SUME,QSUME,TREE,SHRUB,APFE,LS,
     1            LOCATE,PLACE,NAME,SPECIS,DSTART,DEND,DATES,ID,
```

```
     2           IZ,BY,CHART,SUM,YD,B,AMAX,RPFR,APFW,IGP,ORG)
        ELSE
          WRITE(SCREEN,'(A)')'Exotic marker method not used'
          STOP
        ENDIF
      ELSEIF(NN.EQ.5) THEN
        IF(WV) THEN
          CALL POLPLT(K,L,DEPTH,SUMV,QSUMV,TREE,SHRUB,APFV,LS,
     1           LOCATE,PLACE,NAME,SPECIS,DSTART,DEND,DATES,ID,
     2           IZ,BY,CHART,SUM,YD,B,AMAX,RPFR,APFW,IGP,ORG)
        ELSE
          WRITE(SCREEN,'(A)')'Weight-Volume method not used'
          STOP
        ENDIF
      ELSEIF(NN.EQ.6) THEN
        IF(WEIGHT) THEN
          CALL POLPLT(K,L,DEPTH,SUMW,TREE,TREE,SHRUB,APFW,LS,
     1           LOCATE,PLACE,NAME,SPECIS,DSTART,DEND,DATES,ID,
     2           IZ,BY,CHART,SUM,YD,B,AMAX,RPFR,APFE,IGP,ORG)
        ELSE
          WRITE(SCREEN,'(A)')'Weight method not used'
          STOP
        ENDIF
      END IF
      CALL PLOT(0.0,0.0,999)
C
      WRITE(SCREEN,'(A)')'Normal end of plotting'
      END
C
C           ====================================
C
C                     SUBROUTINE POLPLT
C
C           ====================================
C
      SUBROUTINE POLPLT(K,L,DEPTH,APF,QSUM,RAP,RSHRUB,RPF,LSS,
     1           LOCATE,PLACE,NAME,SPECIS,DSTART,DEND,DATES,
     2           ID,IZ,BY,CHART,SUM,YD,B,AMAX,RPFR,APFT,IGP,ORG)
C
C.... SUBROUTINE REQUIRED: PRIMES,TRIPSS,STANDD,SCALES,SPECT1,
C                          SPECT2,GENUSS,APFPSS,ZONESS,DEPPLT,
C                          TITLES
C
      INTEGER    SCREEN
      LOGICAL    IGP,MARKER,WV,WEIGHT
      CHARACTER  CHART*43,LOCATE*40,PLACE*40,NAME*40,
     1           SPECIS(L)*20,DATES(L)*20
      DIMENSION  DEPTH(K),YD(K+2),DSTART(L),DEND(L),BY(L),
     2           RAP(K),RPFR(K,L),RSHRUB(K),AMAX(K),B(K+2),
     3           RPF(K,L),APF(K),QSUM(K),SUM(K),APFT(K,L),ORG(K)
      COMMON     /COM1/NGR,NN/IO/SCREEN/CONT/MARKER,WV,WEIGHT
C
```

```
      IF(DEPTH(K).GE.300.0) A=0.025
      IF(DEPTH(K).GE.150.0.AND.DEPTH(K).LT.300.0) A=0.05
      IF(DEPTH(K).LT.150.0.AND.DEPTH(K).GT.50.0) A=0.1
      IF(DEPTH(K).LE.50.0) A=0.4
      DEPTHP=DEPTH(K)*A
      DX=DEPTHP+0.2
      CALL PRIMES(K,L,A,PLACE,LOCATE,NAME,DX,DEPTH,YD,DATES,
     1   ID,DSTART,DEND,APF,QSUM,XL,LSS,XT,B,APFT,AMAX,RPFR)
C
      IF(NN.EQ.1) THEN
         CALL TRIPSS(K,DX,RAP,RSHRUB,YD,B,X)
         XL=XL+X
      ENDIF
C
C.... PLOT OF MAIN DIAGRAM
C
      CALL STANDD(K,L,RPF,RPFR,AMAX,IS)
      CALL SCALES(K,L,RPF,AMAX,XX,LSS)
      IF(NGR.EQ.1) THEN
        CALL SPECT1 (K,L,RPF,RPFR,YD,DEPTHP)
      ELSEIF(NGR.EQ.2) THEN
        CALL SPECT2 (K,L,RPF,YD,B,DEPTHP)
      ENDIF
      CALL GENUSS(K,L,SPECIS,RPF,DX,XX)
      XL=XL+XX
C
C.... PLOT OF POLLEN SUM
C
      CALL PLOT(0.0,0.0,3)
      CALL PLOT(0.0,DEPTHP,2)
      IM=0
      CALL APFPSS(K,1,SUM,RPF,YD,IM,B,AMAX,RPFR,XX,LSS,
     1           DEPTHP)
      C=0.2-XX
      IF(IM.EQ.1) THEN
        CALL SYMBOL(C,DX,0.28,'POLLEN SUM (X10)',45.0,16)
      ELSEIF(IM.EQ.2) THEN
        CALL SYMBOL(C,DX,0.28,'POLLEN SUM (X100)',45.0,17)
      ELSEIF(IM.EQ.3) THEN
        CALL SYMBOL(C,DX,0.28,'POLLEN SUM (X1000)',45.0,18)
      ELSEIF(IM.EQ.4) THEN
        CALL SYMBOL(C,DX,0.28,'POLLEN SUM (X10000)',45.0,19)
      ELSEIF(IM.EQ.5) THEN
        CALL SYMBOL(C,DX,0.28,'POLLEN SUM (X100000)',45.0,20)
      ENDIF
      CALL PLOT(0.0,0.0,3)
      XL=XL+XX
C
C.... PLOT LOSS ON IGNITION
C
      IF(IGP) THEN
        CALL PLOT(0.0,0.0,3)
```

```
            CALL PLOT(0.0,DEPTHP,2)
            CALL APFPSS(K,1,ORG,APFT,YD,IM,B,AMAX,RPFR,XX,LSS,
     1          DEPTHP)
            C=0.2-XX
            CALL SYMBOL(C,DX,0.28,'ORGANIC CONTENT',45.0,16)
            CALL PLOT(0.0,0.0,3)
            XL=XL+XX
          ENDIF
C
C.... DRAW THE BOUNDARY OF ZONES
C
          IF(IZ.GT.1) CALL ZONESS(L,IZ,BY,DEPTHP,XL,A)
C
C.... PRINT DEPTH OF THE PROFILE AT RIGHT SIDE OF DIAGRAM
C
          CALL DEPPLT(DX,A)
C
C.... PRINT THE TITTLE OF PLOTED DIAGRAM
C
          CALL TITLES(CHART,XL,IS,XT)
          CALL PLOT (5.0,0.0,-3)
          END
C
C               ====================================
C
C                         SUBROUTINE APFPSS
C
C               ====================================
C
          SUBROUTINE APFPSS(K,L,APF,APFT,YD,IM,B,AMAX,RPFR,XX,
     1                LSS,DEPTHP)
C
C.... SUBROUTINE REQUIRED: STANDD,SCALES,SPECT2
C
          DIMENSION  APF(K),APFT(K,L),YD(K+2),B(K+2),AMAX(L),
     1                RPFR(K,L)
C
          DO 1 I=1,K
            APFT(I,1)=APF(I)
    1     CONTINUE
          CALL STANDD(K,L,APFT,RPFR,AMAX,IM)
          CALL SCALES(K,L,APFT,AMAX,XX,LSS)
          CALL SPECT2(K,L,APFT,YD,B,DEPTHP)
          END
C
C               ====================================
C
C                         SUBROUTINE DEPPLT
C
C               ====================================
C
          SUBROUTINE DEPPLT(DX,A)
```

```
C
      DEPTHP=DX-0.2
      CALL PLOT(0.0,0.0,3)
      CALL PLOT(0.0,DEPTHP,2)
      CALL SYMBOL(0.2,DX,0.28,10HDEPTH (CM),45.0,10)
      CALL PLOT(0.0,DEPTHP,3)
      S=DEPTHP
  550 CALL PLOT(0.0,S,3)
      CALL PLOT(0.2,S,2)
      SS=S-0.2
      I=1
  555 CALL PLOT(0.0,SS,3)
      CALL PLOT(0.1,SS,2)
      SS=SS-0.2
      IF(SS.LT.0.0) GOTO 560
      IF(I.EQ.4) GOTO 556
      I=I+1
      GOTO 555
  556 S=S-1.0
      IF(S.LT.0.0) GOTO 560
      GOTO 550
  560 P=0.0
      S=DEPTHP-0.1
  570 CALL PLOT(0.0,S,3)
      CALL NUMBER(0.3,S,0.21,P,0.0,-1)
      IF(A.EQ.0.4) P=P+5.0
      IF(A.EQ.0.1) P=P+20.0
      IF(A.EQ.0.05) P=P+40.0
      S=S-2.0
      IF(S.LT.0.0) GOTO 580
      GOTO 570
  580 CALL PLOT(1.5,0.0,-3)
      END
C
C             ====================================
C
C                        SUBROUTINE GENUSS
C
C             ====================================
C
      SUBROUTINE GENUSS(K,L,SPECIS,RPF,DX,XX)
C
      CHARACTER SPECIS(L)*20
      DIMENSION RPF(K,L)
C
      CALL PLOT(-XX,0.0,-3)
      X=0.0
      DO 1 J=1,L
        CALL PLOT(X,0.0,-3)
        CALL SYMBOL(0.2,DX,0.28,SPECIS(J),45.0,20)
        RMAX=0.0
        DO 2 I=1,K
```

```
            IF(RMAX.LT.RPF(I,J)) RMAX=RPF(I,J)
    2     CONTINUE
          MAX=IFIX(RMAX)*2+1
          X=FLOAT(MAX)*0.5+0.8
    1   CONTINUE
        CALL PLOT(-X,0.0,-3)
        END
C
C              ====================================
C
C                         SUBROUTINE PRIMES
C
C              ====================================
C
        SUBROUTINE PRIMES(K,L,A,PLACE,LOCATE,NAME,DX,DEPTH,YD,
     1           DATES,ID,DSTART,DEND,APF,QSUM,XL,LSS,XT,B,
     2           APFT,AMAX,RPFR)
C
C.... SUBROUTINE REQUIRED: SEDPLT,DEPPLT,APFPSS
C
        INTEGER     SCREEN
        LOGICAL     MARKER,WV,WEIGHT
        CHARACTER   DATEP*1,APFP*1,PARP*1,DATES(L)*20,LOCATE*40,
     1              PLACE*40,NAME*40
        DIMENSION   DEPTH(K),YD(K+2),DSTART(L),DEND(L),APF(K),
     1              QSUM(K),APFT(K,L),B(K+2),AMAX(K),RPFR(K,L)
        COMMON      /COM1/NGR,NN/IO/SCREEN/CONT/MARKER,WV,WEIGHT
C
        DEPTHP=DX-0.2
        DDX=DX+0.25
        TITLE=DEPTHP+7.0
        TITL=TITLE-1.3
        AUTHOR=TITL-1.3
        XL=0.0
C
C.... CONVERSION OF DEPTH FOR PLOTTING
C
        DO 1 I=1,K
          YD(I)=(DEPTH(K)-DEPTH(I))*A
    1   CONTINUE
        IF(MARKER.OR.WV.OR.WEIGHT) THEN
          WRITE(SCREEN,'(A)')'Plot total APF on diagram (Y/N)?'
          READ(SCREEN,'(A1)')APFP
        ENDIF
        IF(MARKER.OR.WV) THEN
          IF(ID.GT.0) THEN
            WRITE(SCREEN,'(A)')'Plot total PAR on diagram (Y/N) ?'
            READ(SCREEN,'(A1)')PARP
          ENDIF
        ENDIF
        IF(ID.GT.0) THEN
          WRITE(SCREEN,'(A)')'Draw dates on diagram (Y/N) ?'
```

```
          READ(SCREEN,'(A1)')DATEP
        END IF
C
C.... DRAW LEGENDS AND SEDIMENTS SECTION
C
        CALL SEDPLT(DEPTHP,A,XT,Q)
C
C.... DRAW TNE LOCATION OF STUDY AREA ON DIAGRAM
C
        CALL SYMBOL(Q,TITLE,0.8,LOCATE,0.0,40)
        CALL SYMBOL(Q,TITL,0.5,PLACE,0.0,40)
        CALL SYMBOL(Q,AUTHOR,0.4,NAME,0.0,40)
C
C.... PRINT DEPTH OF THE PROFILE AT LEFT SIDE OF DIAGRAM
C
        CALL DEPPLT(DX,A)
        DEPTHP=DEPTH(K)*A
C
C.... PLOT OF RADIOMETRIC DATES
C
        IF(ID.GT.0) THEN
         IF(DATEP.EQ.'Y') THEN
          CALL PLOT(0.0,DEPTHP,2)
          CALL SYMBOL(0.2,DX,0.28,5HDATES,45.0,5)
          DO 2 I=1,ID
            CD=(DEND(I)+DSTART(I))*0.5
            CD=(DEPTH(K)-CD)*A-0.14
            CALL SYMBOL(0.6,CD,0.28,DATES(I),0.0,20)
            DSTART(I)=(DEPTH(K)-DSTART(I))*A
            DEND(I)=(DEPTH(K)-DEND(I))*A
            T=0.0
            DO 4 J=2,10
              T=T+0.03
              IF(DSTART(I).NE.DEND(I)) THEN
                CALL PLOT(T,DSTART(I),3)
                CALL PLOT(T,DEND(I),2)
              END IF
    4       CONTINUE
    2     CONTINUE
          CALL PLOT(4.0,0.0,-3)
         END IF
        END IF
C
C.... PLOT OF TOTAL ABSOLUTE POLLEN FREQUENCY
C
        IF(APFP.EQ.'Y') THEN
          CALL PLOT(0.0,0.0,3)
          CALL PLOT(0.0,DEPTHP,2)
          CALL APFPSS(K,1,APF,APFT,YD,IM,B,AMAX,RPFR,XX,LSS,
     1        DEPTHP)
          C=0.2-XX
          IF(IM.EQ.1) THEN
```

```
          CALL SYMBOL(C,DX,0.28,'SUM OF APF (X10)',45.0,16)
        ELSEIF(IM.EQ.2) THEN
          CALL SYMBOL(C,DX,0.28,'SUM QF APF (X100)',45.0,17)
        ELSEIF(IM.EQ.3) THEN
          CALL SYMBOL(C,DX,0.28,'SUM OF APF (X1000)',45.0,18)
        ELSEIF(IM.EQ.4) THEN
          CALL SYMBOL(C,DX,0.28,'SUM OF APF (X10000)',45.0,19)
        ELSEIF(IM.EQ.5) THEN
          CALL SYMBOL(C,DX,0.28,'SUM OF APF (X100000)',45.0,20)
        ENDIF
        XL=XL+XX
      END IF
C
C.... PLOT OF TOTAL POLLEN ACCUMULATION RATE
C
      IF(ID.GT.1) THEN
        IF(PARP.EQ.'Y') THEN
          CALL PLOT(0.0,0.0,3)
          CALL APFPSS(K,1,QSUM,APFT,YD,IM,B,AMAX,RPFR,XX,LSS,
     1         DEPTHP)
          C=0.2-XX
          IF(IM.EQ.1) THEN
            CALL SYMBOL(C,DX,0.28,'TOTAL PAR (X10)',45.0,15)
          ELSE IF(IM.EQ.2) THEN
            CALL SYMBOL(C,DX,0.28,'TOTAL PAR (X100)',45.0,16)
          ELSE IF(IM.EQ.3) THEN
            CALL SYMBOL(C,DX,0.28,'TOTAL PAR (X1000)',45.0,17)
          ELSE IF(IM.EQ.4) THEN
            CALL SYMBOL(C,DX,0.28,'TOTAL PAR (X10000)',45.0,18)
          ELSE IF(IM.EQ.5) THEN
            CALL SYMBOL(C,DX,0.28,'TOTAL PAR (X100000)',45.0,19)
          ENDIF
          XL=XL+XX
        END IF
       END IF
      END
C
C          ====================================
C
C                      SUBROUTINE SCALES
C
C          ====================================
C
      SUBROUTINE SCALES(K,L,RPF,FMAX,XX,LSS)
C
      DIMENSION RPF(K,L),FMAX(L)
C
      X=0.0
      XX=0.0
      SU=0.0
      DO 1 J=1,L
        RMAX=0.0
```

```
      DO 2 I=1,K
      IF(RMAX.LT.RPF(I,J)) RMAX=RPF(I,J)
    2 CONTINUE
      MAX=IFIX(RMAX)*2+1
      CALL PLOT(X,0.0,-3)
      S=-0.5
      DO 3 I=1,MAX
        S=S+0.5
        SS=S+0.5
        CALL PLOT(S,-0.3,3)
        CALL PLOT(S,-0.2,2)
        CALL PLOT(SS,-0.2,2)
        CALL PLOT(SS,-0.3,2)
    3 CONTINUE
C
      KMAX=MAX+1
      S=-0.6
      IF(FMAX(J).GE.150.0) P=-50.0
      IF((FMAX(J).GE.10.0).AND.(FMAX(J).LT.50.0))  P=-10.0
      IF(FMAX(J).LE.10.0) P=-5.0
      IF(FMAX(J).GE.50.0.AND.FMAX(J).LT.150.0) P=-20.0
C
      DO 4 I=1,KMAX
        S=S+0.5
        IF((FMAX(J).GE.10.0).AND.(FMAX(J).LT.50.0))  P=P+10.0
        IF(FMAX(J).LT.10.0) P=P+5.0
        IF(FMAX(J).GE.50.0.AND.FMAX(J).LT.150.0) P=P+20.0
        IF(FMAX(J).GE.150.0) P=P+50.0
        CALL NUMBER(S,-0.6,0.21,P,0.0,-1)
    4 CONTINUE
      X=FLOAT(MAX)*0.5+0.8
      IF(J.GT.LSS) SU=SU+X
      XX=XX+X
    1 CONTINUE
    IF(LSS.EQ.0) GOTO 100
    SU=SU-0.8
    SUX=SU-1.5
    SUX1=SUX+0.3
    SUX2=SUX-0.4
    IF(L.GT.LSS) THEN
      CALL PLOT(-SU,-1.0,3)
      CALL PLOT(-SU,-2.0,2)
      CALL PLOT(-SU,-1.5,3)
      CALL PLOT(-SUX,-1.5,2)
      CALL PLOT(-SUX1,-1.3,2)
      CALL PLOT(-SUX,-1.5,3)
      CALL PLOT(-SUX1,-1.7,2)
      CALL SYMBOL(-SUX2,-1.64,0.28,'EXCLUDED IN SUM',0.0,15)
    END IF
100 CONTINUE
    C=XX-X
    CALL PLOT(-C,0.0,-3)
```

```
      END
C
C          =====================================
C
C                   SUBROUTINE SPECT1
C
C          =====================================
C
      SUBROUTINE SPECT1(K,L,APFT,RPFR,YD,DEPTHP)
C
      DIMENSION APFT(K,L),RPFR(K,L),YD(K+2)
C
      X=0.0
      DO 1 J=1,L
        CALL PLOT(X,0.0,-3)
        CALL PLOT(0.0,DEPTHP,2)
        RMAX=0.0
        DO 2 I=1,K
          IF(RMAX.LT.APFT(I,J)) RMAX=APFT(I,J)
          YD1=YD(I)-0.03
          YD2=YD(I)+0.03
          CALL PLOT(0.0,YD(I),3)
          CALL PLOT(APFT(I,J),YD(I),2)
          CALL PLOT(0.0,YD1,3)
          CALL PLOT(RPFR(I,J),YD1,2)
          CALL PLOT(0.0,YD2,3)
          CALL PLOT(RPFR(I,J),YD2,2)
    2   CONTINUE
        MAX=IFIX(RMAX)*2+1
        X=FLOAT(MAX)*0.5+0.8
    1 CONTINUE
      CALL PLOT(X,0.0,-3)
      END
C
C          =====================================
C
C                   SUBROUTINE SPECT2
C
C          =====================================
C
      SUBROUTINE SPECT2(K,L,APFT,YD,B,DEPTHP)
C
      DIMENSION APFT(K,L),YD(K+2),B(K+2)
C
C     DEPTHP=YD(1)
      X=0.0
      DO 2 J=1,L
        CALL PLOT(X,0.0,-3)
        CALL PLOT(0.0,DEPTHP,2)
        RMAX=0.0
        DO 3 I=1,K
          B(I)=APFT(I,J)
```

```
          CALL PLOT(0.0,YD(I),3)
          CALL PLOT(B(I),YD(I),2)
          IF(RMAX.LT.B(I)) RMAX=B(I)
    3   CONTINUE
        B(K+1)=0.0
        B(K+2)=1.0
        YD(K+1)=0.0
        YD(K+2)=1.0
        CALL LINE(B,YD,K,1,0,0)
        MAX=IFIX(RMAX)*2+1
        X=FLOAT(MAX)*0.5+0.8
    2 CONTINUE
      CALL PLOT(X,0.0,-3)
      END
C
C             ======================================
C
C                        SUBROUTINE STANDD
C
C             ======================================
C
      SUBROUTINE STANDD(K,L,APF,RPFR,AMAX,IM)
C
C.... SUBROUTINE TO STANDIZE THE DATA FOR PLOT
C
      DIMENSION APF(K,L),AMAX(L),RPFR(K,L)
C
      COMMON /COM1/NGR,NN
      E=0.0
      DO 1 J=1,L
        AMAX(J)=0.0
      DO 1 I=1,K
        IF(APF(I,J).GT.AMAX(J)) AMAX(J)=APF(I,J)
        IF(AMAX(J).GT.E) E=AMAX(J)
    1 CONTINUE
      IM=0
      IF(E.LT.200.0) GOTO 201
  202 E=E/10.0
      IM=IM+1
      DO 2 J=1,L
        AMAX(J)=AMAX(J)/10.0
      DO 2 I=1,K
        APF(I,J)=APF(I,J)/10.0
    2 CONTINUE
      IF(E.GT.200.0) GOTO 202
  201 CONTINUE
C
      IF(NGR.EQ.1) THEN
        DO 3 I=1,K
        DO 3 J=1,L
          RPFR(I,J)=APF(I,J)
          IF(AMAX(J).LT.10.0) THEN
```

```
              IF(APF(I,J).GE.1.0) RPFR(I,J)=APF(I,J)*0.1
              APF(I,J)=APF(I,J)*0.1
            ELSEIF(AMAX(J).GE.10.0.AND.AMAX(J).LT.50.0) THEN
              IF(APF(I,J).GE.1.0) RPFR(I,J)=APF(I,J)*0.05
              APF(I,J)=APF(I,J)*0.05
            ELSEIF(AMAX(J).GE.50.0.AND.AMAX(J).LT.150.0) THEN
              IF(APF(I,J).GE.1.0) RPFR(I,J)=APF(I,J)*0.025
              APF(I,J)=APF(I,J)*0.025
            ELSEIF(AMAX(J).GE.150.0) THEN
              IF(APF(I,J).GE.1.0) RPFR(I,J)=APF(I,J)*0.01
              APF(I,J)=APF(I,J)*0.01
            ENDIF
    3     CONTINUE
        ELSEIF(NGR.EQ.2) THEN
          DO 4 I=1,K
          DO 4 J=1,L
            IF(AMAX(J).LT.10.0) THEN
              APF(I,J)=APF(I,J)*0.1
            ELSEIF(AMAX(J).GE.10.0.AND.AMAX(J).LT.50.0) THEN
              APF(I,J)=APF(I,J)*0.05
            ELSEIF(AMAX(J).GE.50.0.AND.AMAX(J).LT.150.0) THEN
              APF(I,J)=APF(I,J)*0.025
            ELSEIF(AMAX(J).GE.150.0) THEN
              APF(I,J)=APF(I,J)*0.01
            ENDIF
    4     CONTINUE
        ENDIF
        END
C
C               ====================================
C
C                          SUBROUTINE TRIPSS
C
C               ====================================
C
        SUBROUTINE TRIPSS(K,DX,RAP,RSHRUB,YD,B,X)
C
C.... PLOT OF TREE AND SHRUB AND HERB PORTION
C
        DIMENSION RAP(K),B(K+2),RSHRUB(K),YD(K+2)
C
        DEPTHP=DX-0.2
        RMIN=500.0
        DO 1 I=1,K
          RSHRUB(I)=RAP(I)+RSHRUB(I)
          IF(RSHRUB(I).LT.RMIN) RMIN=RSHRUB(I)
    1   CONTINUE
        RMIN=RMIN+0.5
        CALL PLOT(0.0,0.0,3)
        CALL PLOT(0.0,DEPTHP,2)
        CALL PLOT(2.5,DEPTHP,2)
        CALL PLOT(2.5,0.0,2)
```

```
      CALL PLOT(0.0,0.0,2)
      CALL SYMBOL(0.2,DX,0.28,5HTREES,45.0,5)
      IF(RMIN.GE.100.0) THEN
        CALL SYMBOL(2.3,DX,0.28,'SHRUBS',45.0,6)
      ELSE
        CALL SYMBOL(1.3,DX,0.28,6HSHRUBS,45.0,6)
        CALL SYMBOL(2.3,DX,0.28,5HHERBS,45.0,5)
      END IF
C
      B(K+1)=0.0
      B(K+2)=1.0
      YD(K+1)=0.0
      YD(K+2)=1.0
      DO 2 I=1,K
        B(I)=RAP(I)/40.0
        RSHRUB(I)=RSHRUB(I)/40.0
        CALL PLOT(0.0,YD(I),3)
        CALL PLOT(RSHRUB(I),YD(I),2)
    2 CONTINUE
C
      CALL PLOT(0.0,0.0,3)
      CALL LINE(B,YD,K,1,0,0)
      DO 3 I=1,K
        B(I)=RSHRUB(I)
    3 CONTINUE
      CALL LINE(B,YD,K,1,0,0)
C
      S=-0.5
      DO 4 J=1,5
        S=S+0.5
        SS=S+0.5
        CALL PLOT(S,-0.3,3)
        CALL PLOT(S,-0.2,2)
        CALL PLOT(SS,-0.2,2)
        CALL PLOT(SS,-0.3,2)
    4 CONTINUE
      S=-0.6
      P=-20.0
      DO 5 J=1,6
        S=S+0.5
        P=P+20.0
        CALL NUMBER(S,-0.6,0.21,P,0.0,-1)
    5 CONTINUE
      X=3.0
      CALL PLOT(3.0,0.0,-3)
      END
C
C              ====================================
C
C                      SUBROUTINE TITLES
C
C              ====================================
```

```
C
      SUBROUTINE TITLES(CHART,XL,IM,XT)
C
      CHARACTER  CHART*43
      COMMON     /COM1/NGR,NN
C
      A=XT-XL
      B=-3.0
C     CALL SYMBOL(A,B,0.42,CHART,0.0,43)
C     C=A+18.5
      C=A
      IF(IM.EQ.0) GOTO 105
      IF(IM.EQ.1)
     1     CALL SYMBOL(C,B,0.42,'SCALE: X 10     ',0.0,15)
      IF(IM.EQ.2)
     1     CALL SYMBOL(C,B,0.42,'SCALE: X 100    ',0.0,15)
      IF(IM.EQ.3)
     1     CALL SYMBOL(C,B,0.42,'SCALE: X 1000   ',0.0,15)
      IF(IM.EQ.4)
     1     CALL SYMBOL(C,B,0.42,'SCALE: X 10000  ',0.0,15)
      IF(IM.EQ.5)
     1     CALL SYMBOL(C,B,0.42,'SCALE: X 100000',0.0,15)
  105 CONTINUE
      D=-3.5
      CC=-2.8
      IF(NGR.EQ.1) THEN
           CALL PLOT(D,-1.0,3)
           CALL PLOT(CC,-1.0,2)
      END IF
      D=-2.3
      IF(NN.LE.2.AND.NGR.EQ.1) THEN
           CALL SYMBOL(D,-1.1,0.28,4H< 1%,0.0,4)
      END IF
      IF(NN.LT.2.AND.NGR.NE.1) GOTO 106
           IF(IM.EQ.0) GOTO 106
           IF(IM.EQ.1)
     1         CALL SYMBOL(D,-1.1,0.28,'< 10',0.0,4)
           IF(IM.EQ.2)
     1         CALL SYMBOL(D,-1.1,0.28,'< 100',0.0,5)
           IF(IM.EQ.3)
     1         CALL SYMBOL(D,-1.1,0.28,'< 1000',0.0,6)
           IF(IM.EQ.4)
     1         CALL SYMBOL(D,-1.1,0.28,'< 1000',0.0,7)
           IF(IM.EQ.5)
     1         CALL SYMBOL(D,-1.1,0.28,'< 10000',0.0,8)
  106 CONTINUE
      CALL PLOT(0.0,0.0,3)
      END
C
C              ====================================
C
C                          SUBROUTINE SEDPLT
```

```
C
C                   ======================================
C
      SUBROUTINE SEDPLT(DEPTHP,A,XT,XQ)
C
C.... SUBROUTINE REQUIRED: HLINES,VDLINE,DLINES,DASHED,VLINES,
C                          DOTPLT,CROSLN,POLYGN
      PARAMETER  (KX=20)
      INTEGER    SCREEN
      LOGICAL    EXT
      CHARACTER  SED*1,SEDD*1,SEDSL(KX)*15
      DIMENSION  XLED1(KX),XLED2(KX),SLEDX(KX),SEDS(KX),ILED(KX),
     1           SSTART(KX),SEND(KX),ICODE(KX)
      COMMON     /IO/SCREEN
C
C.... PRINT THE COLUMN FOR SEDIMENT SECTION
C
      ISEDSS=7
      WRITE(SCREEN,'(A)')'Draw sediment symbol (Y/N) ?'
      READ(SCREEN,'(A1)')SED
      IF(SED.EQ.'Y') THEN
        XQ=-2.3
        WRITE(SCREEN,'(A)')'Enter data before (Y/N) ?'
        READ(SCREEN,'(A1)')SEDD
        IF(SEDD.EQ.'Y'.OR.SEDD.EQ.'y') THEN
          READ(ISEDSS,*,END=100)K
          DO 3 I=1,K
            READ(ISEDSS,*)SSTART(I),SEND(I),ICODE(I)
    3     CONTINUE
          READ(ISEDSS,*)LED
          DO 4 I=1,LED
            READ(ISEDSS,'(I5,5X,A15)')ILED(I),SEDSL(I)
    4     CONTINUE
        ELSEIF(SEDD.EQ.'N'.OR.SEDD.EQ.'n') THEN
          WRITE(SCREEN,'(A)')'How many segments of seds ?'
          READ(SCREEN,*)K
          WRITE(ISEDSS,'(I4)')K
          DO 1 I=1,K
            WRITE(SCREEN,'(A)')'Top of the seds (cm) ?'
            READ(SCREEN,*)SSTART(I)
            WRITE(SCREEN,'(A)')'End of the seds (cm) ?'
            READ(SCREEN,*)SEND(I)
            WRITE(SCREEN,'(/4(/T5,A),/A)')
     1        '1  PEAT              2  GYTTJA        3  ORG ISLT',
     2        '4  SILT              5  CLAY          6  SAND    ',
     3        '7  GRAV & SAND       8  ASH           9  CHACOAL ',
     4        '10 ICE LENSES',
     5        'PLEASE ENTER A CODE :'
            READ(SCREEN,*)ICODE(I)
            WRITE(ISEDSS,'(1X,2F6.1,I3)')SSTART(I),SEND(I),
     1        ICODE(I)
```

```
    1      CONTINUE
C
C.... ENTER THE INFORMATION OF LEGENDS
C
           WRITE(SCREEN,'(A)')'How many types of seds ?'
           READ(SCREEN,*)LED
           WRITE(ISEDSS,*)LED
           DO 2 I=1,LED
             WRITE(SCREEN,'(A,I3,A)')
     1          'What is the',I,'th type of seds ?'
             READ(SCREEN,*)ILED(I)
             IF(ILED(I).EQ.1) SEDSL(I)='PEAT           '
             IF(ILED(I).EQ.2) SEDSL(I)='GYTTJA         '
             IF(ILED(I).EQ.3) SEDSL(I)='ORG. SILT      '
             IF(ILED(I).EQ.4) SEDSL(I)='SILT           '
             IF(ILED(I).EQ.5) SEDSL(I)='CLAY           '
             IF(ILED(I).EQ.6) SEDSL(I)='SAND           '
             IF(ILED(I).EQ.7) SEDSL(I)='GRAVE & SAND   '
             IF(ILED(I).EQ.8) SEDSL(I)='VOLCANIC ASH   '
             IF(ILED(I).EQ.9) SEDSL(I)='CHACOAL        '
             IF(ILED(I).EQ.10) SEDSL(I)='ICE LENSES     '
             WRITE(ISEDSS,'(I5,5X,A15)')ILED(I),SEDSL(I)
    2      CONTINUE
         ENDIF
         GOTO 200
  100    WRITE(SCREEN,'(2A)')'Can not plot seds column:',
     1                        ' No data file'
         RETURN
C
C.... PLOT THE SEDS SECTION
C
  200    DX=DEPTHP+0.2
         CALL PLOT(0.0,0.0,-3)
         CALL PLOT(0.0,DEPTHP,2)
         CALL SYMBOL(0.2,DX,0.28,8HSEDIMENT,45.0,8)
         CALL PLOT(0.0,DEPTHP,3)
         CALL PLOT(2.0,DEPTHP,2)
         CALL PLOT(2.0,0.0,2)
         CALL PLOT(0.0,0.0,2)
         DO 8 I=1,K
           U=DEPTHP-SSTART(I)*A
           V=DEPTHP-SEND(I)*A
           IF(ICODE(I).EQ.1) THEN
             CALL HLINES(U,V,0.0,2.0)
           ELSEIF(ICODE(I).EQ.2) THEN
             CALL VDLINE(U,V,0.0,2.0)
           ELSEIF(ICODE(I).EQ.3) THEN
             CALL DLINES(U,V,0.0,2.0)
           ELSEIF(ICODE(I).EQ.4) THEN
             CALL DASHED(U,V,0.0,2.0)
           ELSEIF(ICODE(I).EQ.5) THEN
             CALL VLINES(U,V,0.0,2.0)
```

```
          ELSEIF(ICODE(I).EQ.6) THEN
            CALL DOTPLT(U,V,0.0,2.0)
          ELSEIF(ICODE(I).EQ.7) THEN
            CALL CROSLN(U,V,0.0,2.0)
          ELSEIF(ICODE(I).EQ.8) THEN
            CALL POLYGN(U,V,0.0,2.0)
          ENDIF
    8   CONTINUE
C
C.... PRINT THE LEGEND OF SEDIMENTS
C
        XLED1(1)=1.0
        XLED2(1)=XLED1(1)+1.0
        YLED1=-1.0
        YLED2=YLED1-0.6
        SLEDX(1)=XLED1(1)+1.2
        SLEDY=YLED1-0.5
        DO 11 I=2,LED
          XLED1(I)=XLED1(I-1)+5.0
          XLED2(I)=XLED1(I)+1.0
          SLEDX(I)=XLED2(I)+0.2
   11   CONTINUE
        XT=SLEDX(LED)+3.0
        CALL PLOT(0.0,0.0,3)
        DO 12 I=1,LED
          CALL PLOT(XLED1(I),YLED1,3)
          CALL PLOT(XLED2(I),YLED1,2)
          CALL PLOT(XLED2(I),YLED2,2)
          CALL PLOT(XLED1(I),YLED2,2)
          CALL PLOT(XLED1(I),YLED1,2)
          U=YLED1
          V=YLED2
          S1=XLED1(I)
          S2=XLED2(I)
          IF(ILED(I).EQ.1) THEN
            CALL HLINES(U,V,S1,S2)
            CALL SYMBOL(SLEDX(I),SLEDY,0.28,SEDSL(I),0.0,15)
          ELSEIF(ILED(I).EQ.2) THEN
            CALL VDLINE(U,V,S1,S2)
            CALL SYMBOL(SLEDX(I),SLEDY,0.28,SEDSL(I),0.0,15)
          ELSEIF(ILED(I).EQ.3) THEN
            CALL DLINES(U,V,S1,S2)
            CALL SYMBOL(SLEDX(I),SLEDY,0.28,SEDSL(I),0.0,15)
          ELSEIF(ILED(I).EQ.4) THEN
            CALL DASHED(U,V,S1,S2)
            CALL SYMBOL(SLEDX(I),SLEDY,0.28,SEDSL(I),0.0,15)
          ELSEIF(ILED(I).EQ.5) THEN
            CALL VLINES(U,V,S1,S2)
            CALL SYMBOL(SLEDX(I),SLEDY,0.28,SEDSL(I),0.0,15)
          ELSEIF(ILED(I).EQ.6) THEN
            CALL DOTPLT(U,V,S1,S2)
            CALL SYMBOL(SLEDX(I),SLEDY,0.28,SEDSL(I),0.0,15)
```

```
          ELSEIF(ILED(I).EQ.7) THEN
            CALL CROSLN(U,V,S1,S2)
            CALL SYMBOL(SLEDX(I),SLEDY,0.28,SEDSL(I),0.0,15)
          ELSEIF(ILED(I).EQ.8) THEN
            CALL POLYGN(U,V,S1,S2)
            CALL SYMBOL(SLEDX(I),SLEDY,0.28,SEDSL(I),0.0,15)
          ELSEIF(ILED(I).EQ.9) THEN
            CALL SYMBOL(SLEDX(I),SLEDY,0.28,SEDSL(I),0.0,15)
          ELSEIF(ILED(I).EQ.10) THEN
            CALL SYMBOL(SLEDX(I),SLEDY,0.28,SEDSL(I),0.0,15)
          END IF
 12     CONTINUE
          CALL PLOT(2.3,0.0,-3)
      ELSE
        XQ=0.0
      END IF
      END
C
C             ====================================
C
C                         SUBROUTINE CROSLN
C
C             ====================================
C
      SUBROUTINE CROSLN (Y1,Y2,T1,T2)
C
C.... SUBROUTINE REQUIRED: VDLINE,DLINES
C
C
C.... SUBROUTINE TO PLOT SMALL CROSS
C
      CALL DLINES(Y1,Y2,T1,T2)
      CALL VDLINE(Y1,Y2,T1,T2)
      END
C
C             ====================================
C
C                         SUBROUTINE DASHED
C
C             ====================================
C
      SUBROUTINE DASHED(S1,S2,T1,T2)
C
C.... SUBROUTINE TO PLOT SILT
C
      DIMENSION X1(5),X2(5)
C
      Y1=S1
      Y2=S2
      Y1=Y1-0.2
      X1(1)=0.1+T1
      X2(1)=0.4+T1
```

```
      A=(T2-T1)/0.5
      N=INT(A)
      DO 1 I=2,N
      X1(I)=X1(I-1)+0.5
      X2(I)=X2(I-1)+0.5
    1 CONTINUE
   10 DO 2 I=1,N
      CALL PLOT(X1(I),Y1,3)
      CALL PLOT(X2(I),Y1,2)
    2 CONTINUE
      Y1=Y1-0.2
      IF(Y1.LE.Y2) GOTO 999
      GOTO 10
  999 END
C
C               ======================================
C
C                         SUBROUTINE DLINES
C
C               ======================================
C
      SUBROUTINE DLINES (Y1,Y2,T1,T2)
C
C.... SUBROUTINE TO PLOT DASH LINES
C
      DIMENSION X1(5),X2(5),X3(5),X4(5)
C
      X1(1)=0.1+T1
      X2(1)=0.3+T1
      X3(1)=0.3+T1
      X4(1)=0.5+T1
      A=(T2-T1)/0.4
      N=INT(A)
      DO 1 I=2,N
      X1(I)=X1(I-1)+0.4
      X2(I)=X2(I-1)+0.4
      X3(I)=X3(I-1)+0.4
      X4(I)=X4(I-1)+0.4
    1 CONTINUE
      Y3=Y1-0.1
      YD=Y2+0.1
   10 DO 2 I=1,N
      CALL PLOT(X1(I),Y3,3)
      CALL PLOT(X2(I),Y3,2)
    2 CONTINUE
      IF(Y3.LE.YD) GOTO 20
      Y3=Y3-0.3
      GOTO 10
   20 Y4=Y1-0.25
   30 DO 3 I=1,N-1
      CALL PLOT(X3(I),Y4,3)
      CALL PLOT(X4(I),Y4,2)
```

```
    3 CONTINUE
      Y4=Y4-0.3
      IF(Y4.LE.YD) GOTO 999
      GOTO 30
  999 END
C
C           =====================================
C
C                      SUBROUTINE DOTPLT
C
C           =====================================
C
      SUBROUTINE DOTPLT(Y1,Y2,T1,T2)
C
C.... SUBROUTINE TO PLOT SAND ON POLLEN DIAGRAM
C
      DIMENSION X1(15),X2(15),X3(15),X4(15)
C
      X1(1)=0.1+T1
      X2(1)=0.15+T1
      X3(1)=0.15+T1
      X4(1)=0.2+T1
      Y3=Y1-0.1
      Y4=Y1-0.25
      YD=Y2+0.1
      A=(T2-T1)/0.15
      N=INT(A)
      DO 1 I=2,N
      X1(I)=X1(I-1)+0.15
      X2(I)=X2(I-1)+0.15
      X3(I)=X3(I-1)+0.15
      X4(I)=X4(I-1)+0.15
    1 CONTINUE
   10 DO 2 I=1,N
      K=I
      CALL PLOT(X1(I),Y3,3)
      CALL PLOT(X2(I),Y3,2)
      IF(Y3.LE.YD) GOTO 2
      IF(K.EQ.13) GOTO 2
      CALL PLOT(X3(I),Y4,3)
      CALL PLOT(X4(I),Y4,2)
    2 CONTINUE
      IF(Y3.LE.YD.OR.Y4.LE.YD) GOTO 999
      Y3=Y3-0.3
      Y4=Y4-0.3
      GOTO 10
  999 END
C
C           =====================================
C
C                      SUBROUTINE HLINES
C
```

```
C          ====================================
C
      SUBROUTINE HLINES(S1,S2,T1,T2)
C
C.... SUBROUTINE TO PLOT SYMBOL OF HORIZONTAL LINE
C
      Y1=S1
      Y2=S2
      A=(Y1-Y2)/0.2
      N=INT(A)+1
      DO 1 I=1,N
      CALL PLOT(T1,Y1,3)
      CALL PLOT(T2,Y1,2)
      Y1=Y1-0.2
    1 CONTINUE
      CALL PLOT(T1,Y2,3)
      CALL PLOT(T2,Y2,2)
      END
C
C          ====================================
C
C                   SUBROUTINE POLYGN
C
C          ====================================
C
      SUBROUTINE POLYGN(Y1,Y2,T1,T2)
C
C.... SUBROUTINE REQUIRED: HLINES,VLINES
C
C
C.... SUBROUTINE TO PLOT SYMBOL OF POLYGON
C
      S=Y1
      T=Y2
      CALL HLINES(S,T,T1,T2)
      CALL VLINES(Y1,Y2,T1,T2)
      END
C
C          ====================================
C
C                   SUBROUTINE VDLINE
C
C          ====================================
C
      SUBROUTINE VDLINE (Y1,Y2,T1,T2)
C
C.... SUBROUTINE TO PLOT VERTICAL DASH LINES ON DIAGRAM
C
      DIMENSION X1(5),X2(5),X3(5),X4(5)
C
      X1(1)=0.3+T1
      X2(1)=0.1+T1
```

```
      A=(T2-T1)/0.4+1.0
      N=INT(A)
      DO 1 I=2,N
      X1(I)=X1(I-1)+0.4
      X2(I)=X2(I-1)+0.4
      IF(X1(I).GT.T2) X1(I)=T2
      IF(X2(I).GT.T2) X2(I)=T2
    1 CONTINUE
      Y3=Y1
      Y4=Y1-0.2
      Y5=Y4-0.2
      YD=Y2
   10 DO 2 I=1,N
      CALL PLOT(X1(I),Y3,3)
      CALL PLOT(X1(I),Y4,2)
      IF(Y4.LE.YD) GOTO 2
      CALL PLOT(X2(I),Y4,3)
      CALL PLOT(X2(I),Y5,2)
    2 CONTINUE
      IF(Y4.LE.YD.OR.Y5.LE.YD) GOTO 999
      Y3=Y3-0.4
      Y4=Y4-0.4
      Y5=Y5-0.4
      GOTO 10
  999 END
C
C               ======================================
C
C                              SUBROUTINE VLINES
C
C               ======================================
C
      SUBROUTINE VLINES(Y1,Y2,T1,T2)
C
C.... SUBROUTINE TO PLOT SYMBOL OF VERTICAL LINES
C
      DIMENSION X(10)
C
      A=(T2-T1)/0.2
      N=INT(A)+1
      X(1)=T1
      DO 2 I=2,N
      X(I)=X(I-1)+0.20
    2 CONTINUE
      DO 3 I=1,N
      CALL PLOT(X(I),Y1,3)
      CALL PLOT(X(I),Y2,2)
    3 CONTINUE
      END
C
C               ======================================
C
```

```
C                            SUBROUTINE ZONESS
C
C                  ====================================
C
      SUBROUTINE ZONESS(L,IZ,BY,DEPTHP,XL,A)
C
      DIMENSION  BY(L)
C
      DX=DEPTHP+0.2
      IZ1=IZ-1
      IF(IZ.LE.2) THEN
        BY(1)=DEPTHP-BY(1)*A
      ELSEIF(IZ.GT.2) THEN
        DO 1 I=1,IZ1
          BY(I)=DEPTHP-BY(I)*A
    1   CONTINUE
      ENDIF
      ZY=BY(IZ1)*0.5-0.21
      CALL NUMBER(1.0,ZY,0.42,1.0,0.0,-1)
      IF(IZ.GT.2) THEN
        DO 2 I=2,IZ1
          IZ2=IZ-I
          ZY=(BY(IZ2)+BY(IZ2+1))*0.5-0.21
          ZONE=FLOAT(I)
          CALL NUMBER(1.0,ZY,0.42,ZONE,0.0,-1)
    2   CONTINUE
      ENDIF
      ZY=(DEPTHP+BY(1))*0.5-0.21
      ZONE=FLOAT(IZ)
      CALL NUMBER(1.0,ZY,0.42,ZONE,0.0,-1)
C
      CALL PLOT(0.0,0.0,3)
      CALL PLOT(0.0,DEPTHP,2)
      CALL SYMBOL(0.2,DX,0.28,'POLLEN ZONES',45.0,12)
      CALL PLOT(2.0,0.0,-3)
      XL=XL+2.0
      IF(IZ.LE.2) THEN
        CALL PLOT(-XL,BY(1),3)
        CALL PLOT(0.0,BY(1),2)
      ELSEIF(IZ.GT.2) THEN
        DO 4 I=1,IZ1
          CALL PLOT(-XL,BY(I),3)
          CALL PLOT(0.0,BY(I),2)
    4   CONTINUE
      ENDIF
      CALL PLOT(0.0,0.0,3)
      END
```

Table G.2 Listing of computer program SUMPLT FORTRAN. Note the line numbers at the left side of the table is not the part of the program

```
         1         2         3         4         5         6
....,....+....,....+....,....+....,....+....,....+....,....+..

************************************************************
*                                                          *
*                    SUMPLT   (FORTRAN)                    *
*                                                          *
*         PROGRAM TO PLOT A SUMMARY POLLEN DIAGRAM         *
*                                                          *
*            (SUPPLIMENTARY PROGRAM TO PALYDP)             *
*                                                          *
*                        07-26-1988                        *
*                                                          *
************************************************************
*
*
*                   INDEX OF SUBPROGRAMS
*                   --------------------
*..........................................................
*  #     NAME  FUNCTION                                    :
*..........................................................:
*  1   STARTS  INITIATE THE PROGRAM                        :
*  2   SUMPLT  MAIN SUBROUTINE TO PLOT THE SUMMARY DIAGRAM :
*  3   DEPPLT  SUBROUTINE TO PLOT DEPTH COLUMNS            :
*  4   GENUSS  SUBROUTINE TO WRITE SPECIES NAME ON DIAGRAM :
*  5   SCALES  SUBROUTINE TO PLOT SCALE ON DIAGRAM         :
*  6   SPECT1  SUBROUTINE TO PLOT A HISTOGRAM SPECTRA      :
*  7   SPECT2  SUBROUTINE TO PLOT A SAW-TOOTH SPECTRA      :
*  8   STANDD  SUBROUTINE TO SCALE DATA FOR PLOTTING       :
*  9   TITLES  SUBROUTINE TO PLOT TITTLE OF DIAGRAM        :
*  10  ZONESS  SUBROUTINE TO PLOT ZONE BOUNDARIES          :
*..........................................................:
*
*
*                       LIST OF FILES
*                       -------------
*..........................................................
* UNIT #  UNIT NAME    DESCRIPTION                         :
*..........................................................:
*   0     SCREEN       SCREEN                              :
*   2     ISUMRY       OUTPUT FILE FOR SUMARY DIAGRAM      :
*..........................................................
*
*
*
C
C            ====================================
C
```

```
C                             PROGRAM STARTS
C
C                 ====================================
C
C      SUBROUTINE REQUIRED: SUMPLT
C
       PROGRAM  STARTS
C
       PARAMETER (KD=150,LD=30)
       INTEGER   SCREEN
       CHARACTER LOCATE*40,CHAR(2*LD)*20,CARDS*80
       DIMENSION VAR(KD*LD*3)
       COMMON    /IO/SCREEN
C
       SCREEN=0
       IREADD=2
C
C.... READ INPUT DATA
C
  100  READ(IREADD,'(A)',END=300) CARDS
         IF(CARDS(1:8).EQ.'LOCATION') THEN
           READ(CARDS(25:64),'(A40)') LOCATE
         ELSEIF(CARDS(1:17).EQ.'NUMBER OF SAMPLES') THEN
           READ(CARDS(25:44),'(BN,I20)') K
         ELSEIF(CARDS(1:14).EQ.'NUMBER OF TAXA') THEN
           READ(CARDS(25:44),'(BN,I20)') L
           GOTO 200
         ELSE
           WRITE(SCREEN,'(2A)')' The first few lines in ',
     1            ' data file is not recognized'
           STOP
         ENDIF
         GOTO 100
  300  WRITE(SCREEN,'(A)')' Input data file not found'
       STOP
  200  CONTINUE
       REWIND IREADD
C
C.... START THE PROGRAM
C
       CALL SUMPLT(K,L,VAR(1),VAR(1+L),VAR(1+2*L),VAR(1+3*L),
     1      VAR(1+4*L),VAR(3+4*L+K),VAR(5+4*L+2*K),
     2      VAR(5+4*L+3*K),VAR(5+4*L+K*(3+L)),CHAR(1),CHAR(1+L),
     3      IREADD)
       END
C
C                 ====================================
C
C                        SUBROUTINE SUMPLT
C
C                 ====================================
C
```

```
      SUBROUTINE SUMPLT(K,L,ZONE,DSTART,DEND,AMAX,B,YD,DEPTH,
     1                X,X1,SPECIS,DATES,IREADD)
C
C.... SUBROUTINE REQUIRED: STANDD,SCALES,GENUSS,SPECT1,SPECT2
C                         DEPPLT,TITLES,ZONESS
C
      INTEGER    SCREEN
      CHARACTER  LOCATE*40,SPECIS(L)*20,CARDS*80,DATES(L)*20
      DIMENSION  X(K,L),X1(K,L),DEPTH(K),YD(K+2),B(K+2),
     1           DSTART(L),DEND(L),AMAX(L),ZONE(L)
      COMMON     /IO/SCREEN/COM1/NGR,NN
C
C.... INITIALIZE
C
      IDP=0
      IZONE=0
C
C.... READ INPUT DATA
C
  300 READ(IREADD,'(A)',END=400) CARDS
      IF(CARDS(1:8).EQ.'LOCATION') THEN
        READ(CARDS(25:64),'(A40)') LOCATE
      ELSEIF(CARDS(1:17).EQ.'NUMBER OF SAMPLES') THEN
        GOTO 300
      ELSEIF(CARDS(1:14).EQ.'NUMBER OF TAXA') THEN
        GOTO 300
      ELSEIF(CARDS(1:12).EQ.'LIST OF TAXA') THEN
        DO 1 I=1,L
          READ(IREADD,'(T5,BN,I3,T10,A20)')J,SPECIS(I)
    1   CONTINUE
      ELSEIF(CARDS(1:17).EQ.'DATA') THEN
        DO 3 I=1,K
          READ(IREADD,*)J,(X(I,J),J=1,L)
    3   CONTINUE
      ELSEIF(CARDS(1:22).EQ.'DEPTH LEVEL OF SAMPLES') THEN
        READ(IREADD,*)(DEPTH(I),I=1,K)
      ELSEIF(CARDS(1:17).EQ.'RADIOCARBON DATES') THEN
        READ(CARDS(18:38),'(BN,I20)') IDP
        DO 5 I=1,IDP
          READ(IREADD,'(T5,BN,F5.2,T15,BN,F5.2,T25,A20)')
     1          DSTART(I),DEND(I),DATES(I)
    5   CONTINUE
      ELSEIF(CARDS(1:5).EQ.'ZONES') THEN
        READ(CARDS(6:35),'(BN,I30)') IZONE
        READ(IREADD,*)(ZONE(I),I=1,IZONE-1)
      ELSEIF(CARDS(1:11).EQ.'END OF FILE') THEN
        GOTO 400
      ELSE
        WRITE(SCREEN,'(A)')' Data file ID not recognized'
        STOP
      ENDIF
      GOTO 300
```

```
  400 CONTINUE
C
C.... START PLOT
C
      WRITE(SCREEN,'(A)')'Enter the length of paper (cm)'
      READ(SCREEN,*)PAPER
      WRITE(SCREEN,'(3(/A))')'    1    Histogram',
     1     '    2    Curve fitting','Enter your choice'
      READ(SCREEN,*)NGR
C
      CALL PLOTS(PAPER,27.5)
      CALL PLOT(5.0,5.0,-3)
C
      IF(DEPTH(K).GE.150.0) A=0.05
      IF(DEPTH(K).LT.150.0.AND.DEPTH(K).GT.50.0) A=0.1
      IF(DEPTH(K).LE.50.0) A=0.4
      DEPTHP=DEPTH(K)*A
      DX=DEPTHP+0.2
      DDX=DX+0.25
      TITLE=DEPTHP+4.0
      XL=0.0
C
C.... CONVERSION OF DEPTH FOR PLOTTING
C
      DO 7 I=1,K
        YD(I)=(DEPTH(K)-DEPTH(I))*A
    7 CONTINUE
C
C.... DRAW TNE LOCATION OF STUDY AREA ON DIAGRAM
C
      CALL SYMBOL(0.0,TITLE,0.6,LOCATE,0.0,40)
C
C.... PRINT DEPTH OF THE PROFILE AT LEFT SIDE OF DIAGRAM
C
      CALL DEPPLT(DX,A)
C
C.... PLOT OF RADIOMETRIC DATES
C
      IF(IDP.GT.0) THEN
        CALL PLOT(0.0,DEPTHP,2)
        CALL SYMBOL(0.2,DX,0.28,5HDATES,45.0,5)
        DO 8 I=1,IDP
          CD=(DEND(I)+DSTART(I))*0.5
          CD=(DEPTH(K)-CD)*A-0.14
          CALL SYMBOL(0.6,CD,0.28,DATES(I),0.0,20)
          DSTART(I)=(DEPTH(K)-DSTART(I))*A
          DEND(I)=(DEPTH(K)-DEND(I))*A
          T=0.0
          DO 9 J=2,10
            T=T+0.03
            IF(DSTART(I).NE.DEND(I)) THEN
              CALL PLOT(T,DSTART(I),3)
```

```
              CALL PLOT(T,DEND(I),2)
            END IF
    9     CONTINUE
    8   CONTINUE
        CALL PLOT(4.0,0.0,-3)
      END IF
C
C.... PLOT OF MAIN PART OF DIAGRAM
C
      CALL STANDD(K,L,X,X1,AMAX,IS)
      CALL SCALES(K,L,X,AMAX,XX,0)
      IF(NGR.EQ.1)
     1     CALL SPECT1(K,L,X,X1,YD,DEPTHP)
      IF(NGR.EQ.2)
     1     CALL SPECT2(K,L,X,YD,B,DEPTHP)
      CALL GENUSS(K,L,SPECIS,X,DX,XX)
      XL=XL+XX
C
C.... DRAW THE BOUNDARY OF ZONES
C
      IF(IZONE.GT.1) CALL ZONESS(L,IZONE,ZONE,DEPTHP,XL,A)
C
C.... PRINT DEPTH OF THE PROFILE AT RIGHT SIDE OF DIAGRAM
C
      CALL DEPPLT(DX,A)
C
C.... PRINT THE TITTLE OF PLOTED DIAGRAM
C
      CALL TITLES (CHART,XL,IS,0.0)
      CALL PLOT (5.0,0.0,-3)
      CALL PLOT(0.0,0.0,999)
      END
```

Table G.3 An example of input data file for program PALYDP FORTRAN. Note the line numbers at the left side of the table is not the part of the file

```
          1         2         3         4         5         6
....,....+....,....+....,....+....,....+....,....+....,....+..

LOCATION                MIDDLE MACKINTOSH CREEK, Y. T. (XW-2)
COORDINATES             61 49'00"N, 137 15'09"W, 1001 m a.s.l.
ANALYZER                ANALYZED: XIACHENG WANG
NUMBER OF SAMPLES          9
NUMBER OF TAXA            23
NUMBER OF TREE TAXA        3
NUMBER OF SHRUB TAXA       9
TAXA INCLUDED IN SUM      22
LIST OF TAXA
      1  PICEA
      2  PINUS
      3  POPULUS
      4  ALNUS
      5  BETULA
      6  SALIX
      7  ROSACEAE
      8  JUNIPERUS
      9  ERICACEAE
     10  ARTEMISIA
     11  COMPOSITAE
     12  POLYGONACEAE
     13  CARYOPHYLLACEAE
     14  LEGUMINOCEAE
     15  RANUNCULACEAE
     16  EPILOBIUM
     17  GRAMINEAE
     18  CYPERACEAE
     19  LYCOPODIUM
     20  POLYPODIACEAE
     21  EQUISETUM
     22  SPHAGNUM
     23  INDETERMINED
TABLE OF COUNTING
   1  40   1   0  16 116   0   0   0  19   0   1   0   0   0   0
       0   8  15   0   0   0   0   0
   2  56   2   0  12  97  12   7   0  33   0   1   1   0   0   0
       0  21  20   0   0   0   0   0
   3  21   3   0   6  56   0   0   0   4   0   0   0   0   0   0
       0  13  13   1   1   0   0   1
   4  18   0   0  10  52   4   2   0   0   0   0   0   0   0   0
       2  12  10   4   0   6   2   0
   5  80   0   0  17  25   4   4   4   0   0   0   0   0   0   0
       0  10  65   0   0   0   2   0
   6 268   0  10  32  92   2   6   2  10   0  10   6   2   0   0
```

```
        0  20 254   0   4  10   6   0
   7 230   0   6  41 117   5   8  14   3   0   4   0   0   4   4
        0   6 280   4   0   6   4   2
   8  39   4   0   8  16   4   0   0   0   0   0   0   1   0   0
        0  12  60   0   0   0   0   4
   9 140   2   5  24  40   8   4   3   0   1   0   0   0   1   3
        0  17 113   4   0   6   4   3
WEIGHT OF RESIDUE
    0.020 0.020 0.019 0.009 0.009 0.010 0.008 0.036 0.018
DEPTH LEVEL OF SAMPLES
      4.0   8.0  10.0  15.0  18.0  22.0  26.0  28.0  32.0
ZONES                     2
  16.50
```

Table G.4 An example of control card file for program PALYDP FORTRAN. Note the line numbers at the left side of the table is not the part of the file

```
         1         2         3         4         5         6
....,....+....,....+....,....+....,....+....,....+....,....+..

CONCENTRATION BY WEIGHT
DETERMINE SPECIES DIVERSITY
END OF FILE
```

Table G.5 An example of preparation result file (input) for program PALYDP FORTRAN. Note the line numbers at the left side of the table is not the part of the file

```
         1         2         3         4         5         6
....,....+....,....+....,....+....,....+....,....+....,....+..

WEIGHT OF RESIDUE
       3.001  2.440  2.773  4.972  3.987  3.109  3.389  2.130
       3.568
WEIGHT OF DRY SAMPLE
       0.555  0.408  0.588  1.219  1.484  1.747  1.452  2.412
       1.633
END OF FILE
```