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**NUMBER 16**



**LATE QUATERNARY  
VEGETATION AND CLIMATES  
OF THE AMERICAN SOUTHWEST**

**Edited by**

**Bonnie F. Jacobs, Patricia L. Fall and Owen K. Davis**

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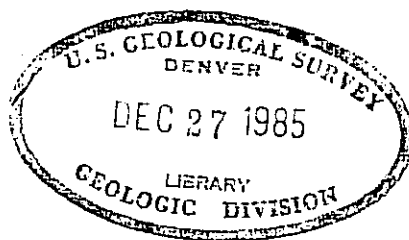
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# PALYNOLOGY OF HOLOCENE SEDIMENTS, COLORADO FRONT RANGE: VEGETATION AND TREELINE CHANGES IN THE SUBALPINE FOREST

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## Abstract

A paleoenvironmental chronology spanning the last 12,000 years for the central Colorado Front Range is provided based upon three dated pollen records from the subalpine forest. The data provide a record for changes in treeline which are in anti-phase with the published record from Redrock Lake. Broad similarities are found in the timing and direction of Holocene climatic changes based upon the fossil pollen and insect records from the region. Climatic conditions were generally warmer than present until at least 4500 yr B.P. and possibly until 3500 yr B.P. The maximum advance of treeline is tentatively dated after 6500 yr B.P. This period also represents the maximum pine pollen densities in the upper subalpine forest and the forest-tundra ecotone. The initiation of climatic cooling conditions and subsequent retreat of treeline began about 3500 yr B.P. in the pollen record or about 4500 yr B.P. based upon fossil insect data. There is evidence of increasingly severe conditions in the last 1000 years.

## INTRODUCTION

Few sites have been investigated that record the vegetation and climate of the Colorado Front Range in

post-glacial times (see review in Nichols, 1982). Although there are several sequences available from the Rocky Mountains (Maher, 1961; Bright, 1966; Andrews *et al.*, 1975; Baker, 1976; Petersen and Mehringer, 1976; Madsen and Currey, 1979; Markgraf and Scott, 1981; Carrara *et al.*, 1984), only three published studies provide palynological data for the Front Range. The pioneer work in the region done by Pennak (1963) covered four sites on the eastern slope of the Front Range. Maher (1972) reexamined one of Pennak's sites, Redrock Lake, extending the record back to 9500 yr B.P. An abbreviated record for the late Holocene was examined by Nelson *et al.* (1979) for the western slope of the Front Range.

The interpretation of Holocene climates that Maher (1972) offers is significantly different from climatic and glacial chronologies for the eastern and central United States and for the Rocky Mountains. He suggests that between 10,000 and 7600 yr B.P. the climate was cooler and wetter than present, with treeline about 150 m below Redrock Lake (3095 m) prior to 9490 yr B.P. The elevation of treeline was similar to that of the present from 7600 to 6700 yr B.P. Summer temperatures during the middle Holocene (from 6700 to 3000 yr

B.P.) were interpreted as cooler than those of the present. This cool episode was followed by warmer summer temperatures and higher treeline in the region. Thus, Maher's (1972) climatic history is in opposition to reconstructions for a middle Holocene warm period ("Altithermal" of Antevs, 1955; "Hypsithermal" of Deevey and Flint, 1957) followed by Neoglacial cooling. The present study aims to test Maher's climatic reconstruction and to provide additional data for reconstructing the ecological history of the Colorado Front Range alpine and subalpine vegetation zones.

### Study Area

The Front Range is a major range in the southern Rocky Mountain physiographic province. It extends over 300 km from the Arkansas River on the south and north to the Colorado-Wyoming state line. The mountains rise from 1600 m at their base on the plains to nearly 4350 m on the highest peaks. A broad band of forest vegetation is bordered both above (greater than ca. 3500 m) and below (less than 1700 m) by shrub and grassland vegetation.

The area is underlain almost entirely by Precambrian granites, gneisses, and schists. Till of the Pinedale Glaciation covers 90% of the glaciated area in the study area; deposits of the earlier Bull Lake Glaciation (145,000-105,000 yr B.P.) are rare. Pinedale glaciers advanced down to altitudes between 2400 and 2640 m. The tills are characterized by rugged topography, prominent moraines, many undrained depressions, and soils 30-75 cm thick.

Pinedale valley glaciers began to recede from their terminal positions about 14,000 to 13,000 yr B.P., and had disappeared, or were reduced to small remnants, by 8000 yr B.P.

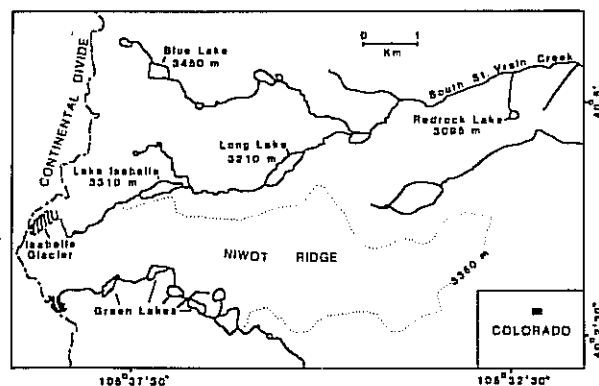
(Madole, 1976). During this late Pinedale recession, a period of glacial advance at about 10,000 yr B.P. has been identified in many valleys in the Front Range (Benedict, 1968; Meierding and Birkeland, 1980).

Holocene deposits in the region consist of small moraines, talus, and rock glaciers high in the valleys. The development of a Holocene chronology has been hindered by both the incompleteness of the stratigraphic record and the inaccuracy and ambiguity of dating methods. The paucity of radiometrically datable material within sequences (Benedict, 1973) has forced a heavy emphasis on less reliable relative age dating techniques (*e.g.*, rock weathering, soil development).

The mountainous relief of the Front Range along with topographic diversity produces complex climatic conditions. The east slope is in the lee of the prevailing westerly winds. Most of the precipitation is caused by convection and by upslope, easterly air flows produced by Gulf air masses during the spring, summer, and fall. Heavy winter snows are produced by Pacific air masses moving in from the west; within the sub-alpine zone, heavy forest cover ensures that the snow often stays late into the spring and summer.

Measurements at the highest climate station (D-1, 3740 m) on Niwot Ridge (Text-Figure 1) have characterized the alpine zone with low temperatures and high winds with gusts in excess of 48 m/sec (100 mph) nine months of the year. The mean annual air temperature is  $-3.8^{\circ}\text{C}$  at this site (Losleben, 1983).

The vegetation of the Front Range is described by Marr (1961) and only a brief summary is provided here (see also Komarkova and Weber, 1978; Peet, 1978, 1981). There are four vegeta-



Text-Figure 1. Map of the upper South St. Vrain Creek drainage and Niwot Ridge showing pollen study sites.

tion zones on the east slope of the Front Range: the grassland zone (below 1800 m), the montane zone (1800 to 2800 m), the subalpine zone (2800 to 3400 m), and the alpine zone (above 3400 m).

The grassland zone extends many kilometers east of the foothills. With the introduction of cattle grazing, it has become short-grass prairie; *Pinus ponderosa* (ponderosa pine) becomes more important as elevations increase.

The montane forest consists of two subzones. The lower montane forest is found between 1800 and 2350 m and is dominated by *Pinus ponderosa* and *Pseudotsuga menziesii* (Douglas fir), with abundant shrubs, herbs and grasses in the understory. The soils are poorly developed sandy loams, often lacking in moisture. Dry grasslands are common here. The lower montane zone is disturbed by grazing, mining, and lumbering. The upper montane zone is similar, but here ponderosa pine and Douglas fir form denser stands; *Pinus flexilis* (limber pine), *Pinus contorta* (lodgepole pine), and *Populus tremuloides*

(aspen) are also important forest trees in this subzone.

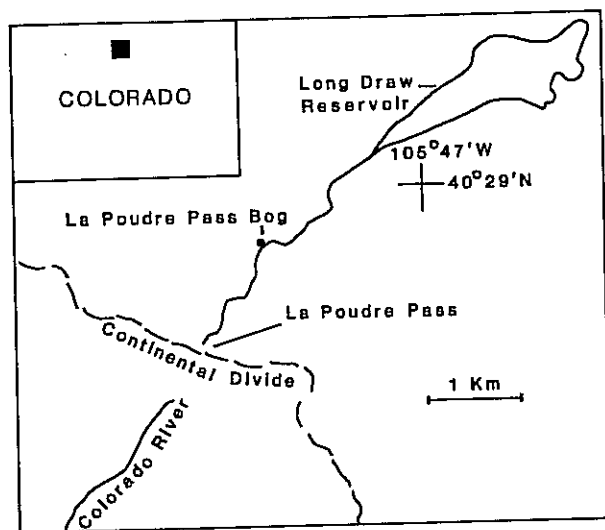
The pollen sites discussed in this study are all located in the subalpine zone which is dominated by dense stands of *Picea engelmanni* (Englemann spruce) and *Abies lasiocarpa* (subalpine fir). Burnt areas are indicated by aspen and lodgepole pine (Stahelin, 1943), and limber pine is found on exposed sites. *Juniperus communis* (dwarf juniper) occurs throughout this zone. Timberline occurs at about 3400 m; however, the band of krummholz vegetation (dwarfed trees) is broad in the Front Range and may extend up to 3600 m (Marr, 1961; Hansen-Bristow, 1981; Peet, 1981).

The alpine zone is one in which no arboreal forms occur. It has fewer species than the lower zones and is dominated by Gramineae (grass family) and Cyperaceae (sedge family) and several herb families (e.g., Saxifragaceae [saxifrage family], Caryophyllaceae [pink family], Rosaceae [rose family], and Polygonaceae [buckwheat family]).

## METHODS

### Field Procedures

Long Lake and Lake Isabelle form an altitudinal transect with Redrock Lake in the South St. Vrain Valley (Text-Figure 1). La Poudre Pass Bog is located on the northern boundary of Rocky Mountain National Park, approximately 35 km north of the other study sites (Text-Figure 2). Long Lake was cored with a modified Livingstone corer (5-cm diameter) from the ice in early spring. The core sections were later extruded in the INSTAAR Palynology Laboratories and split lengthwise into halves. One half was used for stratigraphic analyses and the other for pollen



Text-Figure 2. Map of the La Poudre Pass site, Rocky Mountain National Park.

samples. Peat sections from La Poudre Pass and Lake Isabelle bogs were sampled from exposed sections. Thus it was possible to recover large quantities of organic material for radiocarbon dating and paleo-insect studies.

#### Laboratory Procedures

The sediment cores and peat sections were sampled at 2-cm intervals for pollen analyses. Long Lake was analyzed at 4-cm intervals; both peat sections have been counted at 2-cm intervals. The samples were processed by techniques modified from Faegri and Iversen (1975) with successive treatments of 10% NaOH, 48% HF, and acetolysis solution.

Routine pollen identifications were made at 500 magnification. Three hundred pollen grains were counted for each sample. The percentage graphs were based on total pollen excluding unidentifiable grains for the lake core and on total

pollen excluding Cyperaceae and unidentifiable grains for the peat sections. Unidentifiable grains include those which could not be identified due to breakage or corrosion. Unknown grains could not be identified by reference to slide collections or published keys, but are included within the pollen sum. Over 60 pollen types have been identified in this study.

The pollen diagrams were produced by the CALCOMP plotter from programs derived at the INSTAAR laboratory for paleoecological data (Eccles *et al.*, 1979). The determination of the pollen concentration values follows Jørgensen (1967) in which the concentration values per gram dry weight is derived from relative counts. For each site, the values for the *Picea*:*Pinus* ratios and AP (arboreal pollen) percentages have also been plotted.

#### DESCRIPTION OF POLLEN DIAGRAMS

##### Modern Pollen Data

Twenty-one moss polsters from four sites in the Colorado Front Range have been analyzed to date. They include four from Long Lake, five from Lake Isabelle, seven from Green Lake 4 (3560 m), and five from Green Lake 5 (3620 m). The latter two sites are located 3 km to the south of my study sites (Text-Figure 1).

The Long Lake modern pollen spectrum is dominated by *Pinus* (44.8%), *Picea* (9.9%), *Artemisia* (sagebrush) (14.3%), Gramineae (5.9%), and Cyperaceae (7.8%). The *Picea*:*Pinus* mean is 0.22. This compares favorably with Maher's curve (1972, figure 6) which predicts a ratio of 0.18 for this elevation.

*Betula* (birch) is important in the Lake Isabelle polsters, with a mean

of 7.4% (range = 3 to 21%). This reflects the local habitat preference of this taxon for stream and bog margins in the subalpine zone (Weber, 1976). A mean of 3.3% for *Picea* and a mean of 40.7% for *Pinus* are recorded for this site. Lake Isabelle is windswept and relatively barren, and the *Picea:Pinus* mean value of 0.08 contrasts with the values estimated from Maher's curve (1972, figure 6) of 0.18.

### Fossil Pollen Data

#### La Poudre Pass Bog

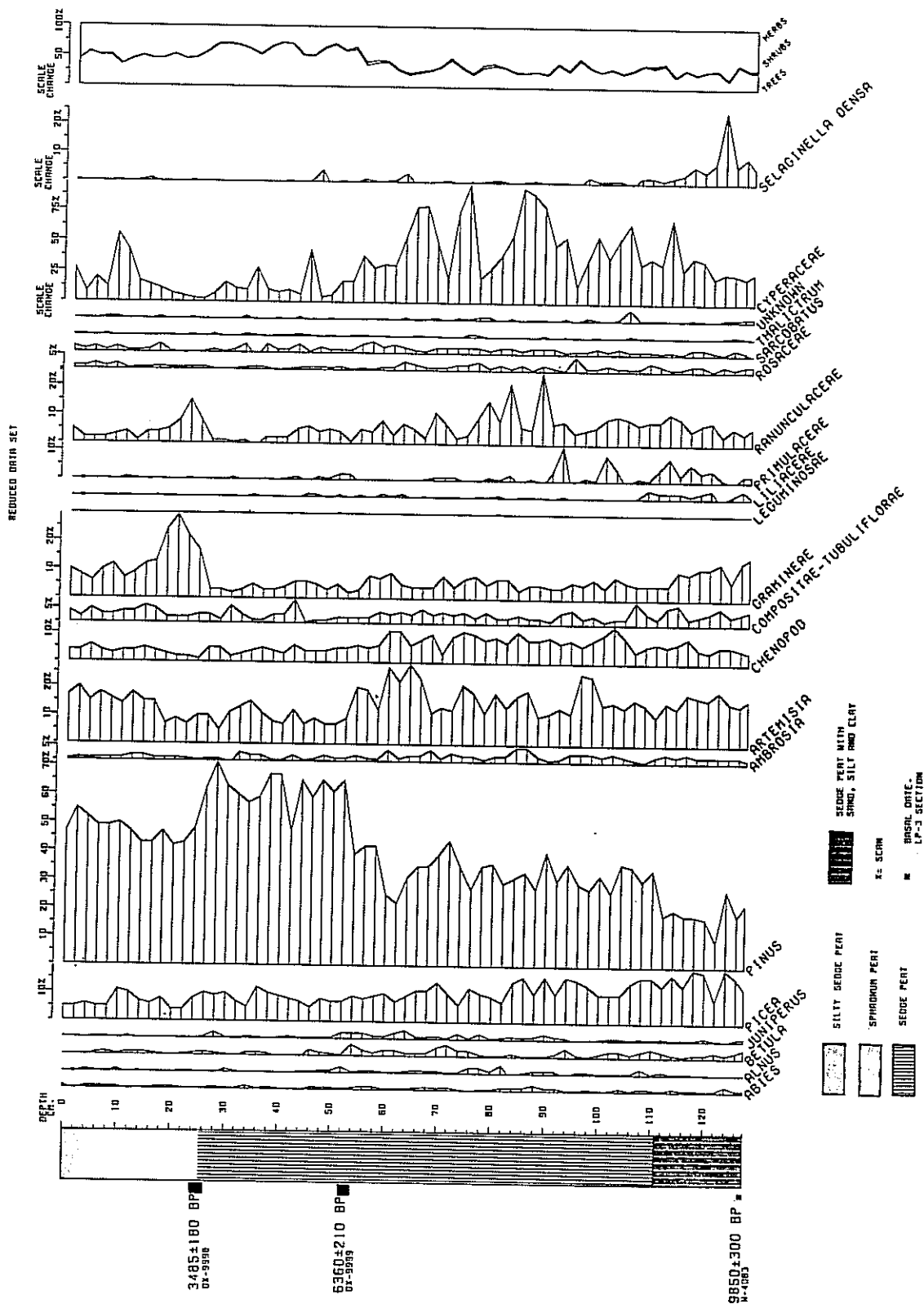
La Poudre Pass Bog (40°29'N, 105°47'W) is located at 3103 m in the subalpine spruce-fir forest on a col between the Colorado River and the La Poudre Pass Creek (Text-Figure 2). Local treeline appears depressed at this site, extending approximately 150 m above the bog (S.A. Elias, personal communication), due perhaps to strong winds funneling over the col. The site is approximately 35 km north of the main study area on the northern boundary of Rocky Mountain State Park. This bog has been studied stratigraphically by Madole (1980), for fossil insects by Elias (1983, 1985), and it was resampled by Elias and Nichols in 1983. Two radiocarbon dates have been received for this section; a basal date of 9850±300 yr B.P. from section 3 (Elias, 1983, 1985) has been used to extrapolate the age for the base of the section (4) reported here. Sedimentation was initially rapid at this site, 0.02 cm/yr, but subsequently slowed to ca. 0.009 cm/yr in the middle Holocene.

**Pollen Zones.** Pollen analysis and peat stratigraphy were used to divide the peat section into four pollen zones (Text-Figures 3 and 4). Zone I, 128 to 112 cm (9800 to 9100 yr

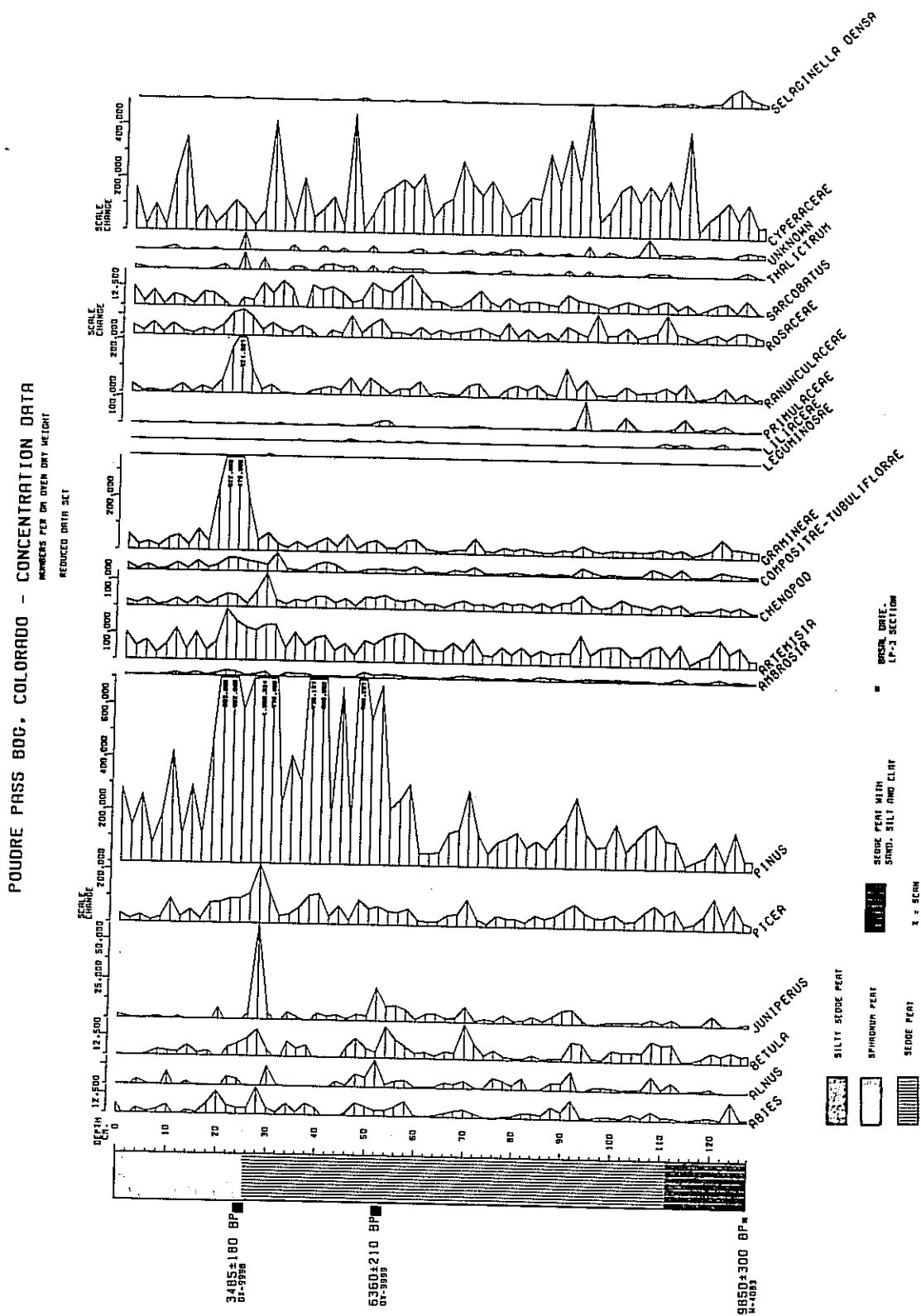
B.P.), is characterized by peak *Picea* pollen (ca. 15%) percentages and minimum *Pinus* pollen values (less than 30%); the mean *Picea:Pinus* ratio for this zone is 0.8 (Text-Figure 5). This basal zone is characterized by low pollen concentration values (ca. 100-200,000 grains/gm dry weight [g/gdw]) with a secondary maximum of *Picea* pollen (ca. 100,000 g/gdw). Maximum pollen percentages and secondary concentration maxima for non-arboreal pollen (NAP) also characterize this period, and important pollen types include *Artemisia* and Gramineae. Large peaks in *Selaginella densa* (rock selaginella) percentage and concentration curves (25% and 67,878 g/gdw at 122 cm) distinguish this zone.

It is difficult to pinpoint the timing of the Zone I/II boundary. There appears to have been compression during transport and storage of section 4, which measured 150 cm in the field (Nichols, field notes), but only 127.5 cm in the laboratory. However, a date of ca. 9100 yr B.P. has been estimated for the end of Zone I.

Zone II, 110 to 60 cm (9100 to 6800 yr B.P.), is characterized by rising *Pinus* pollen percentages (generally 30-40%), decreasing *Picea* pollen percentages (9-12%) and concentration, increasing *Artemisia* pollen percentages (greater than 20% in the upper part of the zone), and moderate to high Cyperaceae percentages (to greater than 75%) and concentration (greater than 400,000 g/gdw). The *Picea:Pinus* ratios have decreased from Zone I to a mean of 0.35. NAP percentages remain large in this zone and several pollen types -- Chenopod (Chenopodiaceae-*Amaranthus* group), Primulaceae (primrose family), Ranunculaceae (buttercup family) -- register maxima here. Total concentration values do not change significantly.

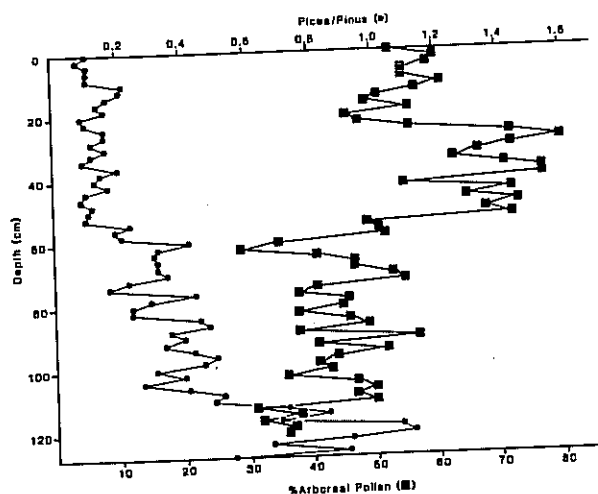


Text-Figure 3. Percentage pollen diagram, La Poudre Pass Bog. Pollen sum excludes Cyperaceae. Data set is reduced from 52 pollen types.



Text-Figure 4. Concentration pollen diagram, La Poudre Pass Bog. Numbers of pollen grains per gram oven dry weight. Data set is reduced from 52 pollen types.

Zone III, 60 to 24 cm (6800 to 3400 yr B.P.), is dominated by maximum *Pinus* pollen percentages (generally 50-70%). *Pinus* pollen concentration increases at the base of the zone, with very large values (greater than 300,000 and up to 1,800,624 g/gdw at 28 cm [3800 yr B.P.]) recorded throughout this zone and into the base of Zone IV. *Picea* pollen percentages decrease slightly (5-10%) from the previous zone, but concentration values increase to a diagram maximum of 220,831 g/gdw at 28 cm. Pollen concentration values for *Abies*, *Juniperus* and *Chenopod* also peak at 28 cm in the section. Maximum AP percentages characterize this zone, and the *Picea:Pinus* ratios average 0.14 (Text-Figure 5).



Text-Figure 5. Graph of percent arboreal pollen (*Abies*, *Picea*, *Pinus*, *Pseudotsuga*) percentages and *Picea:Pinus* ratios plotted against depth, La Poudre Pass Bog.

NAP percentages increase in Zone IV, 24 cm to the top of the section (3400 yr B.P. to the present), with increases in *Artemisia*, *Gramineae* (diagram maximum of 29% at 20 cm),

*Ranunculaceae*, and *Cyperaceae*. The base of the zone is marked by large concentration values of *Gramineae* (622,089 g/gdw at 20 cm) and *Ranunculaceae* (324,897 g/gdw); *Artemisia* pollen concentration also peaks here. *Pinus* pollen percentages decrease from Zone III although percentages remain high (ca. 40-50%); *Picea* pollen percentages decline in the upper 8 cm (1440 yr B.P.). *Picea* pollen concentration drops off to less than 100,000 g/gdw at the top of the section. At 18 cm below the surface (2600 yr B.P.), *Pinus* pollen concentration decreases along with *Artemisia*, *Gramineae*, and *Ranunculaceae*. *Picea:Pinus* ratios of 0.1 to 0.2 (mean = 0.13) and the AP percentages (40-50%) (Text-Figure 5) appear consistent with modern collections from similar elevations. The base of this zone coincides with a change in peat stratigraphy to *Sphagnum* moss.

**Interpretation of La Poudre Pass Bog.** During Zone I, 9800 to 9100 yr B.P., spruce woodland was probably at or very close to the site, but tundra elements were an important part of the vegetation, as indicated by the presence of selaginella, sagebrush, grasses and other herbs. Spruce needles were found in all intervals of section 3 from 1.44 m upward (S.A. Elias, personal communication, 1985).

Zone II, 9100 to 6800 yr B.P., is interpreted as a spruce-fir forest with some pine; however, treeline, at least the limit of pine, was probably still depressed relative to the present. The large NAP component suggests that the vegetation was still open, but that tundra areas were now well above the elevation of the site.

Zone III, 6800 to 3500 yr B.P., is dominated by pine percentages and very large pollen concentration values. Spruce values decrease only slightly, but non-arboreal pollen percentages are minimum. This period

represents the time of maximum warmth and expansion of pine into the lower subalpine forest. It is uncertain whether the upper elevational limit of spruce was significantly higher.

The last 3500 years, Zone IV, are characterized by decreased pine percentages and increased herb values. Although no modern polsters were collected from this site, the *Picea:Pinus* ratios and the arboreal pollen percentages appear consistent with modern collections from similar elevations. This period is interpreted as representing modern day conditions at La Poudre Pass; that is, the pollen spectrum suggests a cooling and lowering of pine treeline and/or a reduction in pine tree abundance in the late Holocene.

#### Long Lake

Long Lake (40°04'N, 105°36'W) is located in the Englemann spruce-subalpine fir forest at an elevation of 3210 m; it is the lowest elevation lake in the South St. Vrain transect and is situated 115 m higher than Redrock Lake. A core 290 cm long was recovered by H. Nichols and his students from the ice covered lake. The basal sediments provided a radiocarbon age of 11,800±450 yr B.P., the second oldest for Holocene sediments in the Front Range. Five additional radiocarbon samples were submitted for analysis. The upper two samples were erroneously combined in the lab; the date of 2880±150 yr B.P. shown in Text-Figure 6 is used as an estimate for the 40-42 cm level, but this is problematic. A third date, 1910±80 yr B.P. at 172 cm, is out of sequence, also due to laboratory problems. The final two dates of 4035±170 yr B.P. and 9855±300 yr B.P. are believed to be accurate dates. By eliminating the anomalous <sup>14</sup>C date, the following sedimentation

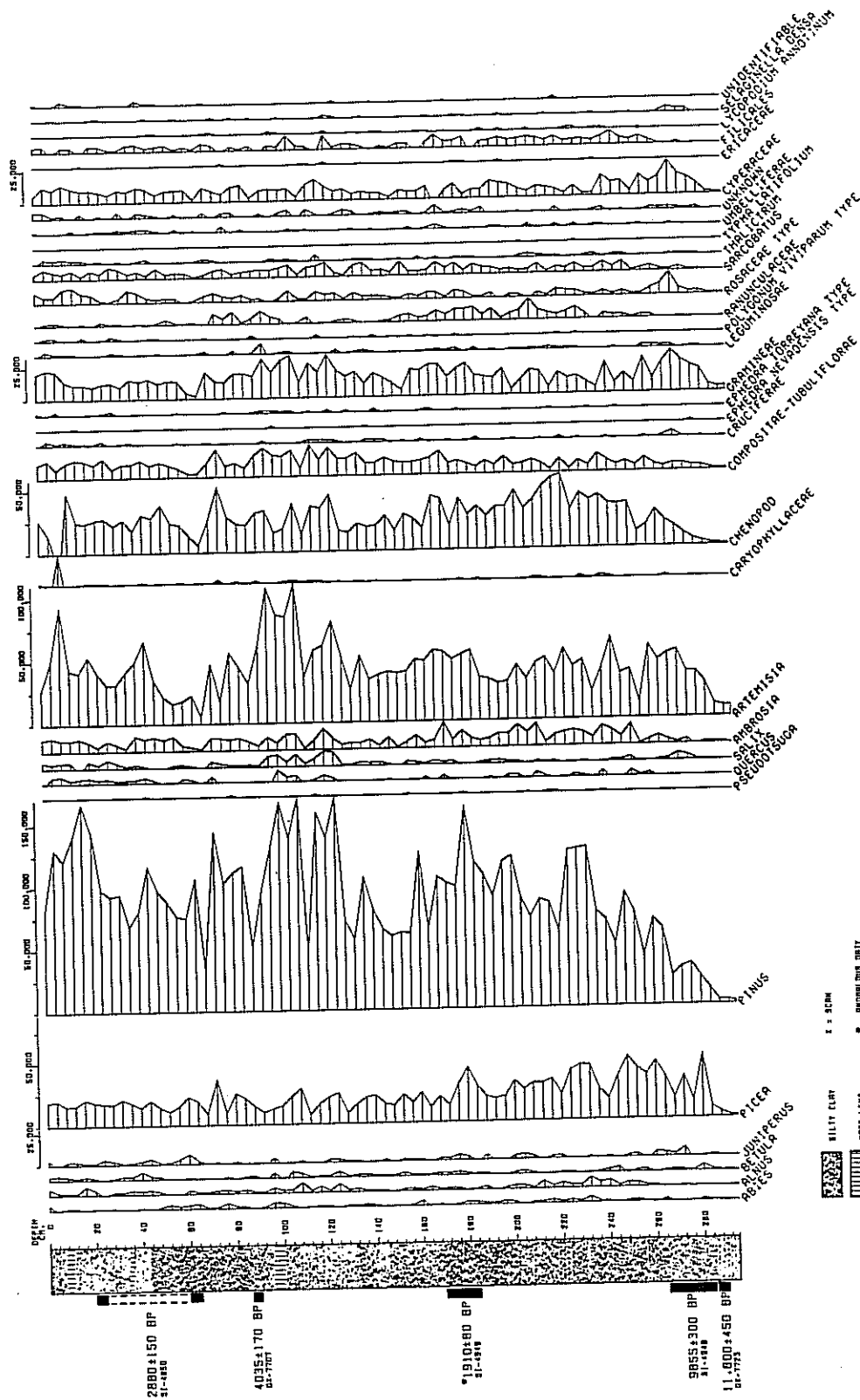
rates have been calculated: 0.006 cm/yr between 11,800 and 4000 yr B.P.; 0.03 cm/yr from 4000 to 3000 yr B.P.; and 0.014 cm/yr after 3000 yr B.P.

**Pollen Zones.** Five pollen zones have been identified for Long Lake based on pollen stratigraphy (Text-Figures 6 and 7). Zone I extends from the base of the section to 272 cm, approximately 12,000 to 9600 yr B.P. It is characterized by maximum NAP percentages and minimum AP values (generally less than 30%) (Text-Figure 8). *Picea* pollen percentages peak in this section with 15-25%, and minimum *Pinus* pollen percentages, generally less than 20%, are recorded. Maximum *Picea:Pinus* ratios are recorded in this zone, with a mean of 0.99 (Text-Figure 8). Important pollen types include *Artemisia* (25-40%), Gramineae (10-20%), Cyperaceae (up to 10%), Rosaceae type, and *Selaginella densa*.

Pollen concentration values (Text-Figure 7) in Zone I are the lowest for the Long Lake section, especially before 284 cm (30,000 g/gdw); *Artemisia* pollen values dominate this lowest part of the zone. Subsequently, concentration values increase for most curves but remain low; the most important pollen types are *Picea*, *Pinus*, *Artemisia*, and Gramineae. This increase in pollen concentration is estimated at ca. 10,500 yr B.P.

Zone II extends from 272 cm to 244 cm, approximately 9600 to 8850 yr B.P. It is characterized by decreasing percentages of most NAP types and by rising *Pinus* pollen percentages (20-30%). *Picea* pollen percentages continue to be important in this zone, and the *Picea:Pinus* ratio, although large, has decreased to between 0.5 and 0.8. Percentages of Filicales (fern) spores increase here.

LONG LAKE, BOULDER COUNTY, COLORADO - CONCENTRATION DATA  
NUMBERS PER GRAM DRY WEIGHT



Text-Figure 6. Percentage pollen diagram, Long Lake. Pollen sum excludes unidentifiable pollen grains.



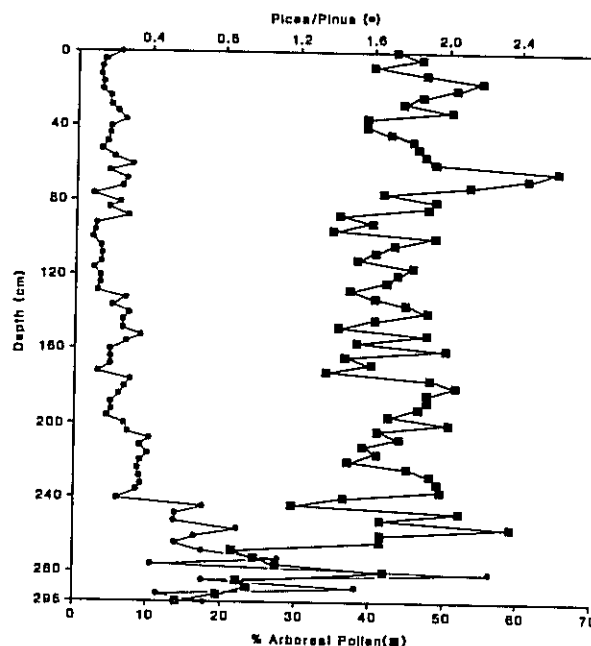
Maximum concentration values for *Picea* pollen (50,000 g/gdw) characterize this zone. The *Pinus* pollen curve is rising (50-75,000 g/gdw), and moderately large *Artemisia* and *Chenopod* pollen concentration values are recorded (ca. 60,000 and 30,000 g/gdw, respectively).

Zone III occupies a major portion of the pollen spectrum until ca. 3800 yr B.P. Large *Pinus* pollen percentages (30-40%) and concentration values (150-170,000 g/gdw after 132 cm) dominate this zone. Preliminary pine size studies suggest that an increased proportion of the pine pollen grains can be referred to *P. contorta*. *Picea* pollen percentages are moderate in the lower part of the record, but decrease in the upper part of this zone, especially after the 132 cm level (approximately 5600 yr B.P.); *Picea* concentration decreases to less than 25,000 g/gdw. The mean *Picea:Pinus* ratio is 0.23. *Artemisia* percentages remain moderately large in this zone, and Gramineae values are low. *Chenopod* pollen increases at the base of zone III with peak percentages recorded at 220 cm (25%). Many curves register maxima or secondary concentration maxima in the upper part of this zone between ca. 132 and 80 cm.

Zone IV, 3800-3200 yr B.P., is dominated by the AP percentages (Text-Figure 8), with peak *Pinus* percentages (greater than 50%) and a secondary peak in the *Picea* curve (10%). The *Picea:Pinus* mean of .22 is similar to the previous zone.

Large pollen concentration values occur in the base of Zone IV, but values decline during this zone in most curves; indeed, minima or generally low values are registered at 68 cm (ca. 3500 yr B.P.).

AP percentages decrease in Zone V, 3200 yr B.P. to the present. This is



Text-Figure 8. Graph of percent arboreal pollen (*Abies*, *Picea*, *Pinus*) percentages and *Picea:Pinus* ratios plotted against depth, Long Lake.

reflected by decreases in both the *Picea* and *Pinus* curves (less than 10% and 30-45%, respectively); the *Picea:Pinus* mean is 0.17 for this zone. Pine size studies indicate an increase in pine pollen grains referable to *P. flexilis*. *Artemisia* percentages rise in this zone (10-25%) and *Chenopod* values remain moderately large. Gramineae values rise in the upper 20 cm of the section.

This zone has moderately large to large pollen concentrations for most pollen types, with the exception of *Picea* pollen (approximately 25,000 g/gdw). Zone V is dominated by high *Pinus* and *Artemisia* pollen concentrations, but slightly decreased pollen percentages in the upper 15 to 20 cm.

**Interpretation of Long Lake.** The lower portion of Zone I is interpreted as a tundra vegetation. This

is supported by low pollen concentrations and the importance of many herb types, especially sagebrush, grasses and selaginella. Although the latter taxon occurs from the montane through the alpine tundra vegetation zones, it is most common on rock and bare ground substrates (Weber, 1976). In modern samples, this species is common only in samples at or above the present treeline (S.K. Short, unpublished data). Therefore, it appears to be a useful indicator of tundra or ecotone conditions in the Front Range.

The increase in spruce pollen percentages and concentration values ca. 10,500 yr B.P. is interpreted as indicating the arrival of spruce at this site. The continued importance of herb pollen, however, suggests that the forest was still very sparse and that the dominant vegetation continued to be tundra and shrub species. There is a discrepancy of a thousand years in the timing of the arrival of forest between Redrock Lake (ca. 9500 yr B.P.) (Maher, 1972) and Long Lake. This may be due to problems with the radiocarbon dates, changes in sedimentation type (Redrock Lake), and slow sedimentation rates (especially Long Lake). Thus, 10,500 yr B.P. is still only an estimate for the beginning of forest establishment following deglaciation.

Zone II represents a well established spruce-fir forest similar to the present at Long Lake between 9500 and 8850 yr B.P., although percentages of non-arboreal pollen indicates that open areas still remained. During Zone III rising *Pinus* percentages and concentration values register the rise in the lodgepole pine treeline to higher than present levels, certainly after ca. 5600 yr B.P. The climate is inferred to be warmer than present, at least in this upper section.

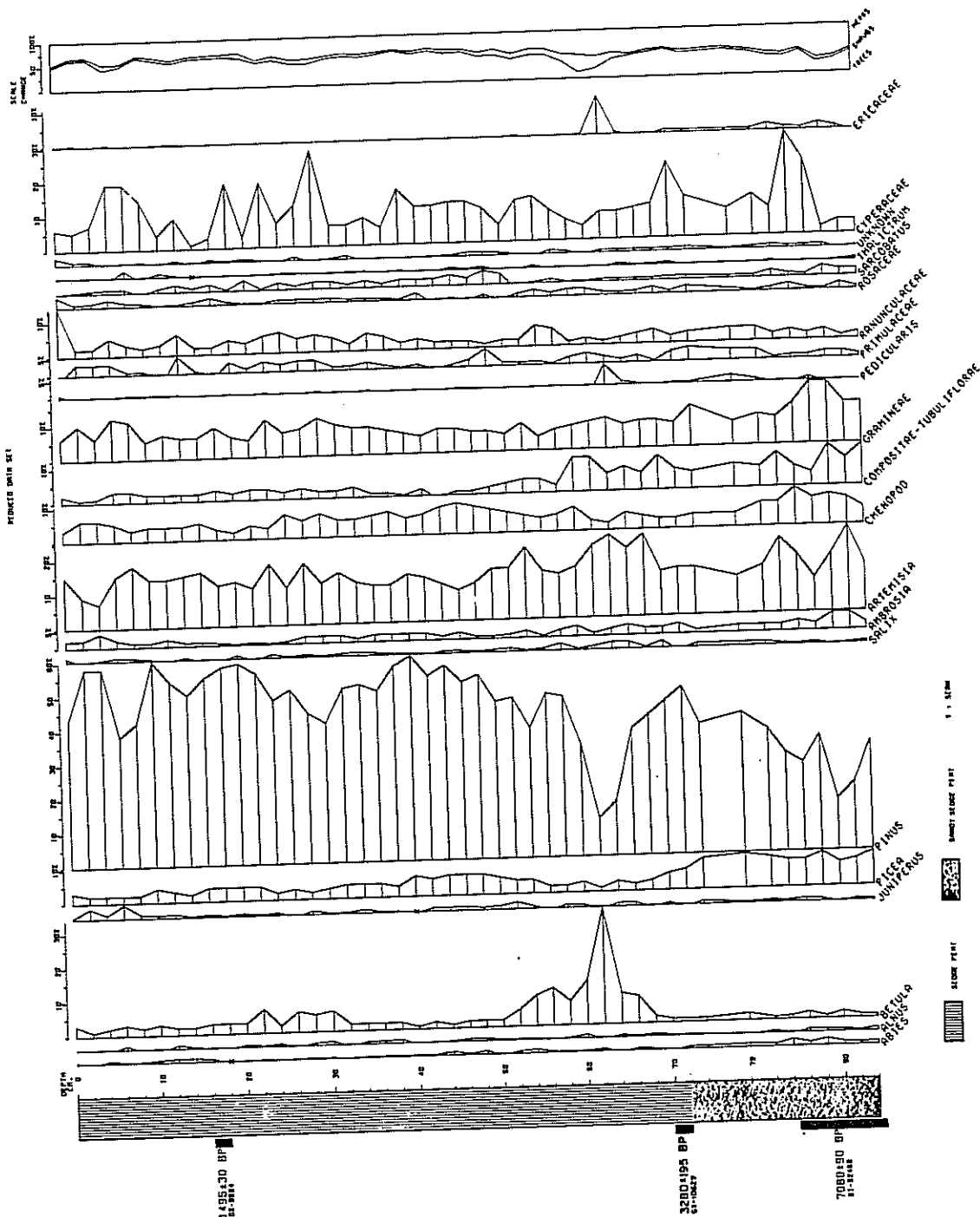
Zone IV is defined by peak arboreal pollen values with maximum pine percentages and a secondary source percentage peak, although pollen concentration values are generally low in this zone. This pollen spectrum may indicate a more closed forest with increased spruce representation, but it is not well understood at this time.

Zone V is interpreted as representing a thinning of the forest and the establishment of conditions like the present. Pine representation decreases at this time with preliminary data supporting a lowering of the lodgepole pine treeline.

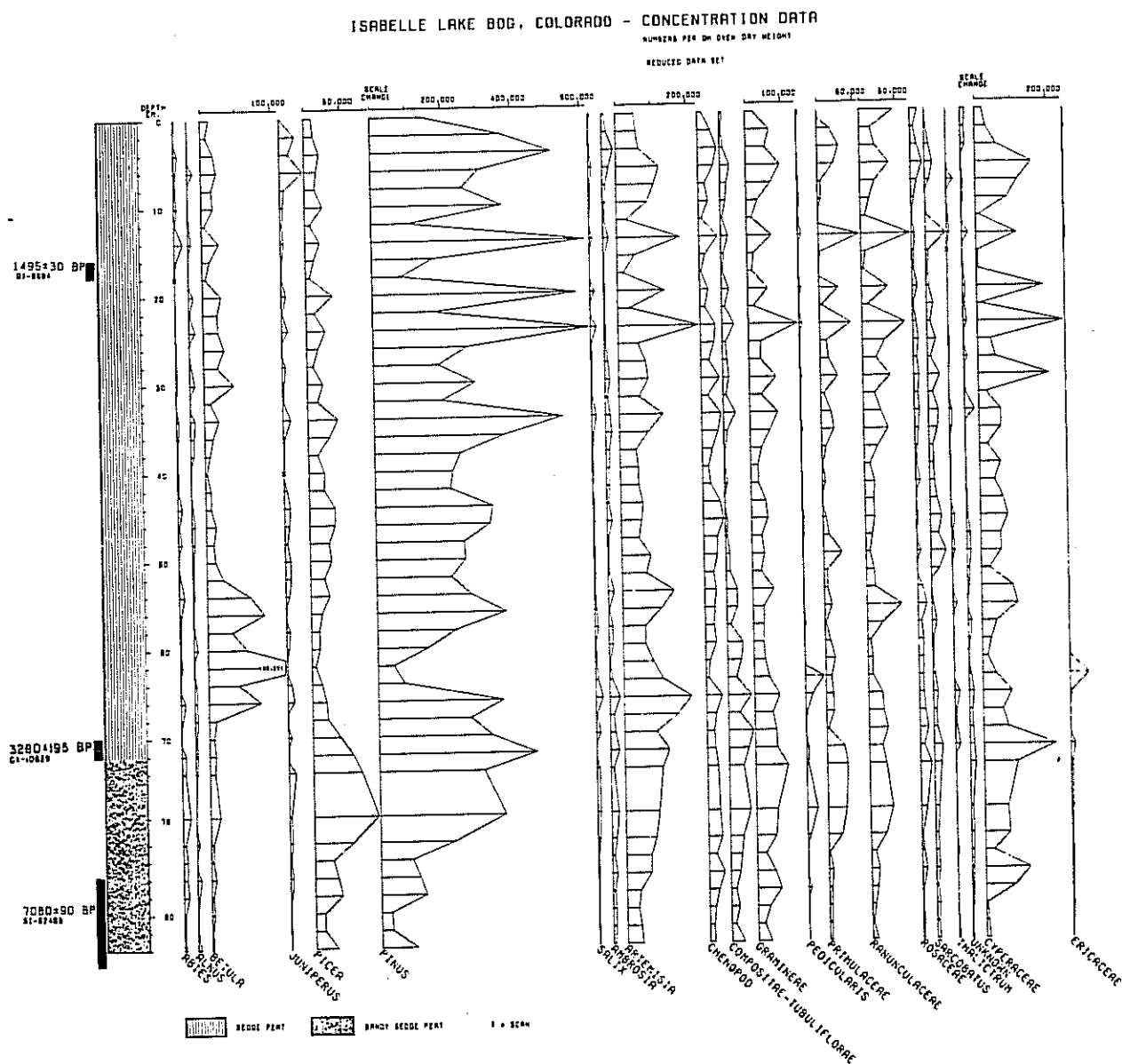
#### Lake Isabelle Bog

The bog (40°04'N, 105°37'W) is located at the western end of Lake Isabelle at 3310 m in the upper sub-alpine forest zone. The trees are sparse and dwarfed immediately around the lake because of strong, local winds. *Pinus flexilis* is important at this site, perhaps because this species is common on dry, windswept sites. A short peat section of 94 cm was collected in 1982. Three radiocarbon dates have been received for this site and the following sedimentation rates have been calculated: 0.005 cm/yr between 7400 and 3300 yr B.P.; 0.030 cm/yr from 3300 to 1500 yr B.P.; and 0.01 after 1500 yr B.P. The major change in sedimentation is correlated with a change from sandy sedge peat to sedge peat (Text-Figures 9 and 10).

**Pollen Zones.** The pollen diagrams (Text-Figures 9 and 10) have been divided into four zones based on pollen stratigraphy. Zone I, from 84 cm to 76 cm (7400 to 3900 yr B.P.), is characterized by maximum *Picea* and *Abies* pollen percentages (ca. 10% and 2%, respectively).



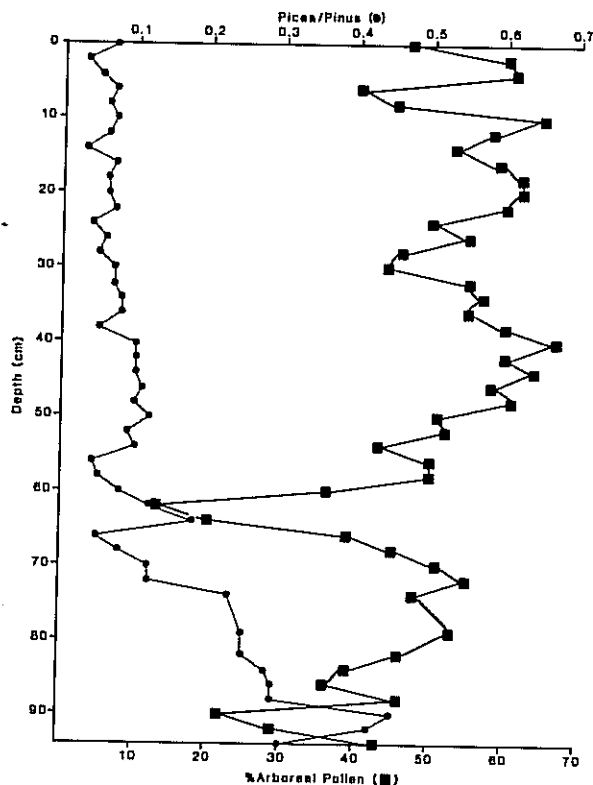
9. Percentage pollen diagram, Lake Isabelle Bog. Pollen sum excludes  
Text-Figure  
Cyperaceae. Data set is reduced from 44 pollen types.



Text-Figure 10. Concentration pollen diagram, Lake Isabelle Bog. Numbers of pollen grains per gram oven dry weight. Data set is reduced from 44 pollen types.

*Pinus* pollen percentages are generally less than 35%, but increase during this zone. Maximum *Picea:Pinus* ratios (mean = 0.3) (Text-Figure 11) also characterize this basal zone. NAP types are important and percentage maxima are recorded for Compos-

itae (sunflower family) (12%), Gramineae (18%), and Chenopod (11%); moderately large *Artemisia* percentages (10-20%) are also found in this lower zone. Pollen concentrations are low initially, but increase at the top of Zone I, especially *Picea*



Text-Figure 11. Graph of percent arboreal pollen (*Abies*, *Picea*, *Pinus*, *Pseudotsuga*, *Tsuga*) percentages and *Picea*:*Pinus* ratios plotted against depth, Lake Isabelle Bog.

(diagram maximum of 90,246 g/gdw) and *Pinus* (360,983 g/gdw).

Zone II is subdivided by an important local event, the "birch episode." The percentage pollen diagram (Text-Figure 9) was constructed with *Betula* and other shrub pollen types (*Salix* [willow], *Ericaceae* [heath family]) included in the pollen sum. A test diagram was subsequently constructed with *Betula* excluded from the pollen sum. The important characteristics of the following zones do not, however, significantly change (e.g., decreased *Picea* percentages in Zone II).

Subzone IIA, from 76 to 66 cm (3900 to 3110 yr B.P.), is characterized by increasing *Pinus* pollen percentages (40-50%), moderate *Picea* pollen (5-10%), and moderate NAP percentages. A mean *Picea*:*Pinus* ratio of 0.1 reflects the increased pine pollen.

Moderately large concentration values characterize Zone IIA; *Pinus* values dominate the spectrum, while *Picea* values are decreasing from maximum values. *Artemisia* values continue to be important in this zone as are several other NAP curves.

Zone IIB is designated the birch episode because both the percentage and concentration diagrams are dominated from 66 to 54 cm (3110 to 3650 yr B.P.) by moderate to large *Betula* values (generally 10 to 30+% and up to 136, 291 g/gdw at 62 cm). Low or minimum concentration values are recorded for most of the other pollen types. Other shrub pollen types — *Ericaceae*, *Salix* — and herb pollen types are also important in the percentage spectrum and AP percentages are very low (Text-Figure 11).

Zone III (2650 to 2250 yr BP) is dominated by peak AP (60%) percentages (Text-Figure 11) due to increasing *Pinus* pollen (40-60%) and moderate *Picea* percentages (6%). Small percentage decreases are registered by *Artemisia* and *Gramineae*. *Betula* concentration values decline rapidly here and most of the other pollen types have moderate concentration values.

Zone IV (2250 yr B.P. to the present) is dominated by *Pinus* pollen percentages (generally 45-60%). *Picea* pollen values are low (less than 4%), and low *Picea*:*Pinus* ratios (mean = 0.06) are recorded for this zone (similar to values recorded in modern polsters). AP percentages are

lower than in Zone III due to the reduced spruce percentages.

This zone is marked by increased pollen concentration of many types, especially *Pinus*, *Artemisia*, Gramineae, Cyperaceae, and other NAP. However, values fluctuate widely, with low as well as peak values in many curves. The fluctuations are simultaneous in the curves and suggest that they are related to changes in stratigraphy which were not observed in the field or laboratory. A short, secondary *Betula* episode (5-6% and ca. 20-40,000 g/gdw) is recorded between 30 and 20 cm (1900 to 1600 yr B.P.). Pollen concentration decreases in the upper 8 to 6 cm of the diagram from 700 to 500 yr B.P. to the present; however, both *Juniperus* and *Ambrosia*-type (ragweed) pollen are at their maxima at this time.

**Interpretation of Lake Isabelle Bog.** The basal date for this peat section is similar to several others in the subalpine forest region of the Brainard Lake valley (Madole, 1976; Elias, 1985) and suggests a regional climatic regime suitable for the initiation of peat growth and accumulation between 8000 and 7000 yr B.P. The pollen spectrum of Zone I, 7400 to 5900 yr B.P., indicates an open spruce-fir woodland with a large tundra component. During Zone IIA, it is believed that the pine tree limit was rising and also that the general density of spruce, fir and pine at the site was increasing from 5900 to 5200 yr BP. This is interpreted as a warm period at Lake Isabelle. The birch episode, which lasted approximately 500 years, is interpreted as a local event and is believed to represent an expansion of the bog and subsequent invasion by shrubs. The decrease in sedge concentration values may indicate drier conditions at this time.

Zone III, dominated by peak arbo-

real pollen values, is interpreted as the period of maximum warmth at Lake Isabelle, with increased representation of all tree taxa. Subsequently, the decrease in spruce and the low *Picea:Pinus* ratio (mean = 0.06) in Zone IV suggests that the maximum pine percentages are indicative of the overrepresentation of this productive genus. Therefore, this zone is believed to represent a thinning of conifer growth at Lake Isabelle. Because of the importance of limber pine at present at this site, pine size studies would add to the interpretation.

#### REGIONAL SUMMARY

The three sites presented here provide a transect across the upper subalpine zone, extending the pioneering study from Redrock Lake at 3100 m to 3300 m at Lake Isabelle Bog. Pollen analyses are in progress for a fourth site, Blue Lake, situated at the upper forest-alpine tundra ecotone at 3450 m (Text-Figure 1); preliminary data from this site will be presented to supplement the discussion.

Based on the pollen stratigraphy from Long Lake, the period from 12,000 to ca. 10,500 yr B.P. is interpreted as a tundra dominated by sagebrush and grasses with some birch and willow; the importance of rock selaginella at this time appears to serve as a tundra "marker."

Spruce and fir arrive by 10,500 yr B.P. at Long Lake, and are already present by 9800 yr B.P. when peat accumulation began at La Poudre Pass. At both sites, large herb values indicate that the forest was open until ca. 9000 yr B.P. at both sites. Rock selaginella values suggest large areas of tundra or open vegetation around both sites until approximately 9500 yr B.P.

From 9000 to approximately 6500 yr B.P., the vegetation is interpreted as a spruce-fir forest similar to the present subalpine zone of the Colorado Front Range; increasing pine values indicate that the pine species limit (probably lodgepole pine) was rising. Warmer temperatures characterize this period.

The period of maximum warmth and presumed maximum extent of treeline in the Colorado Front Range is dated between 6500 and 3500 yr B.P. During this period, pine achieves its maximum representation in the forest. The record from Blue Lake (7800 yr B.P.) dates the first arrival of pine at this high elevation site (3450 m) at around 6200 yr B.P.

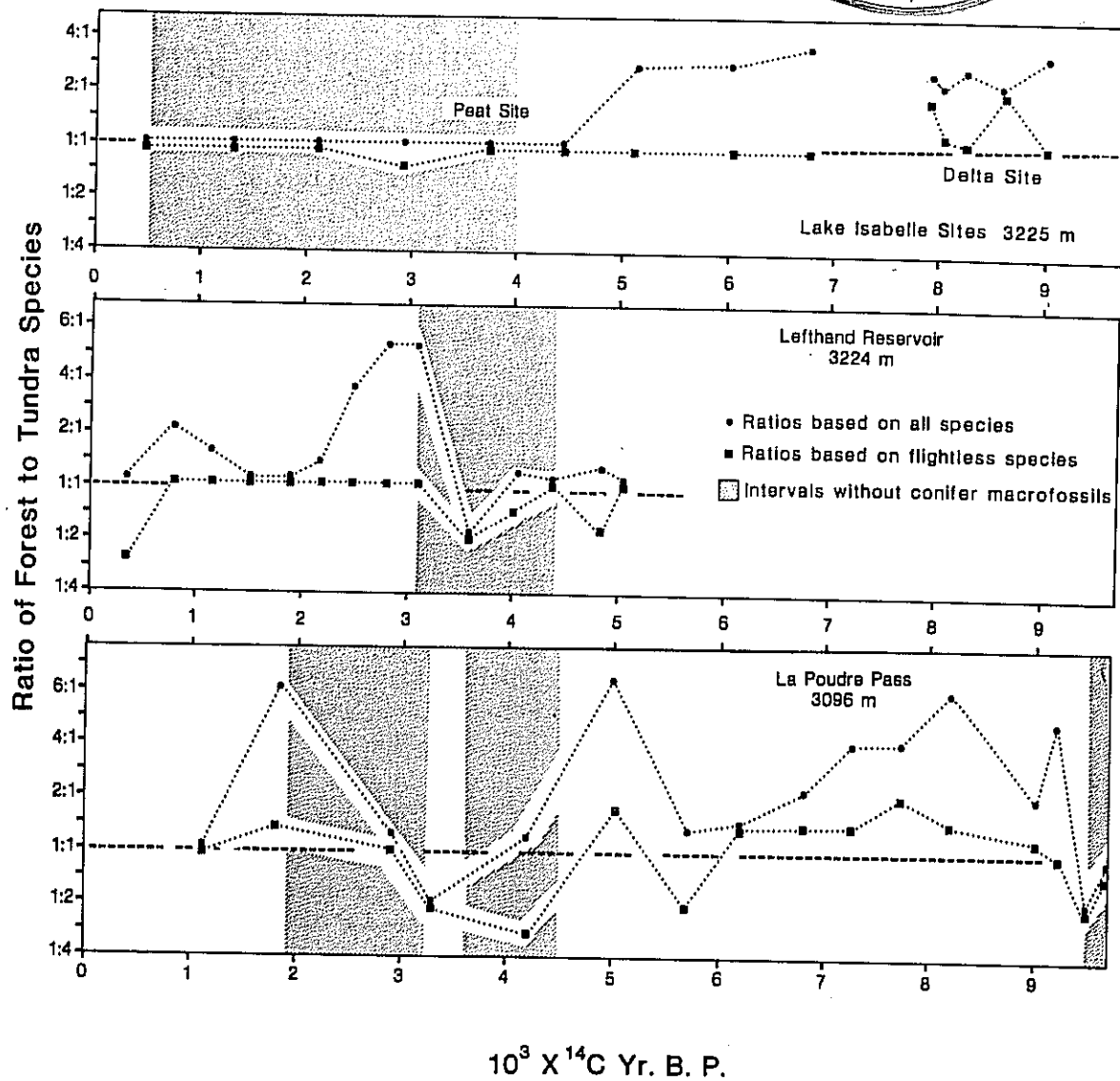
There is a decrease in arboreal pollen representation and an increase in herb pollen (especially sagebrush and grasses) after 3500 yr B.P. in the three sites discussed here; preliminary data from Blue Lake indicate that this change may have begun at ca. 4000 yr B.P. at the higher site. It is suggested that treeline either lowered slightly or perhaps thinned, with a decrease in the pine component due to a climatic cooling. This cooling may have intensified in the last several hundred years.

The vegetation and climatic history presented here is out of phase with Maher's interpretation of the Redrock Lake core (1972), but compares well with studies from southern Colorado (Andrews *et al.*, 1975; Petersen and Mehringer, 1976) as well as elsewhere in North America.

These interpretations based upon fossil pollen data correspond to studies by Elias on fossil beetles from the Front Range (1983, 1985). He has analyzed a series of four Holocene sites along an altitudinal transect from subalpine forest to

alpine tundra; two of his sites, La Poudre Pass and Lake Isabelle Bog, provide a complementary record for the pollen analyses. Insect fossil assemblages from these sites have been analyzed for paleoenvironmental changes, including shifts in upper treeline. The position of treeline has been inferred from the ratio of forest to tundra insect species in the fossil assemblages, supplemented by plant macrofossil data. Two sets of ratios were constructed, one of which excludes bark beetles (Scolytidae) and other flying taxa which may be caught up by convection wind currents and carried to high altitudes. Elias (1985) feels that the most reliable estimate of forest-tundra species ratios lies between the two sets. Text-Figure 12 illustrates the ratios from the Lake Isabelle, LaPoudre Pass, and Lefthand Reservoir sites; the latter is located at 3224 m, 2 km south of Long Lake.

Elias interprets the record as indicating that forest trees reached modern altitudinal limits between 9500 and 9000 yr B.P. and that climatic conditions were probably already as warm as today. A climatic optimum, based on maximal forest-tundra ratios and indicative of elevated treeline, occurred between 9000 and 7000 yr B.P. The fossil assemblages from deltaic deposits at Lake Isabelle indicate the nearby presence of trees at that site between 9000 and 8000 yr B.P. The more conservative set of ratios, which excludes bark beetles and other flying insect taxa, indicates at least one major treeline oscillation during this period. Higher treeline is inferred at La Poudre Pass from at least 8800 yr B.P. From 7000 to 4500 yr B.P., the insect data suggest the continued presence of conifers at the sites, as supported by the plant macrofossil evidence. From 4500 to 3100 yr B.P., forest:tundra insect



Text-Figure 12. Ratios of forest dwelling to alpine tundra dwelling beetle species from Lake Isabelle, Lefthand Reservoir and LaPoudre Pass site (reproduced with permission from Elias, 1985).

ratios decline; Elias believes this indicates a climatic deterioration leading to a decline in elevation of treeline in the region. A rapid climatic amelioration from 3000 to 2000 yr B.P. was subsequently followed by a gradual decline in the for-

est:tundra ratios after 2000 yr B.P., reaching 1:1 ratios at or before 1000 yr B.P. At Lake Isabelle Bog, a remarkably constant forest:tundra species ratio is found after 4500 yr B.P. This is interpreted as indicating that the sedge meadow above the

lake became very stable, or perhaps expanded, to the exclusion of the coniferous forest.

### CONCLUSIONS

The pollen analyses of three subalpine lake and peat sections in the Colorado Front Range, supported by fossil insect studies by Elias, provide a different paleoenvironmental reconstruction than the one proposed by Maher (1972).

Conditions were generally warming through at least 4500 yr B.P., until approximately 3500 yr B.P. Conifers were established at 3200 m by 10,500 yr B.P. (Long Lake), and there are minimum dates of 9000 yr B.P. at 3300 m (Elias, 1985) and 9500 yr B.P. at 3400 m (Benedict, 1981).

The maximum extent of elevation of upper treeline may postdate ca. 6500 yr B.P.; ongoing analyses at Blue Lake will help clarify this point. Both the fossil pollen and the fossil insect studies indicate that this period primarily reflects the maximum extent of pine in the subalpine forest and forest:tundra ecotone. Elias records maximal forest:tundra species ratios between 9000 and 7000 yr B.P., but the pollen record suggests that the density of the spruce-fir forest increased during that period. Subsequently, pine became more important.

There is a difference of approximately 1000 years between the fossil insect (4500 yr B.P.) and pollen (3500 yr B.P.) for dating the onset of cooler climatic conditions and the

retreat of treeline. This difference may be due to the lower elevation of the pollen records located in the upper subalpine forest. The preliminary data from Blue Lake correlate better with the insect record, placing the initiation of cooler temperatures at 4000 yr B.P. Further, this discrepancy may also be due to an overrepresentation of pine pollen in high altitude sites. This problem may be clarified by the analysis of modern pollen data from different elevations and by pine pollen size studies.

There is some evidence in the pollen spectra from Long Lake and La Poudre Pass Bog of colder conditions in the last approximately 1000 years. This is represented by further increases in several of the NAP types during this time period.

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