

Late Quaternary Vegetation History of Sulphur Lake, Southwest Yukon Territory, Canada

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ABSTRACT. Paleocological studies based on the analysis of pollen in lake sediments offer the potential for high resolution and well-dated independent records of past vegetation and climate. A 5 m sediment core was raised from the deepest section of Sulphur Lake, located in the southwest Yukon (60°95'N, 137°95'W; 847 m a.s.l.). The pollen spectra indicate that before 11 250 yr BP, the vegetation was a herbaceous tundra marked by the presence of *Artemisia*. However, the date of the establishment of this initial vegetation cannot be secured because of problems with the basal radiocarbon date and the lack of a reliable chronology of regional deglaciation. A birch shrub tundra prevailed between 11 250 and 10 250 yr BP and was then replaced by a discontinuous poplar woodland. *Juniperus* populations expanded at 9500 yr BP, and by 8400 yr BP, *Picea* invaded the region. The white spruce forest that occupies the region today was established by approximately 8000 yr BP. *Alnus crispa* increased at 6000 yr BP, but the simultaneous increase in *Picea mariana* found at most sites in the Yukon was not present at Sulphur Lake. Black spruce was never a dominant component of the vegetation in the southwest Yukon, as it was in the south-central Yukon between 6100 and 4100 yr BP.

Key words: pollen analysis, Quaternary paleoecology, southwest Yukon, spruce migration, vegetation history

RÉSUMÉ. Les études paléocologiques fondées sur l'analyse de pollens de sédiments lacustres offrent la possibilité d'obtenir une chronologie de la paléovégétation et du paléoclimat à haute résolution et avec une datation précise. Une carotte de sédiment de 5 m a été prélevée dans la section la plus profonde de Sulphur Lake, situé au sud-ouest du Yukon (60°95'N., 137°95'0.; 847 m alt.). D'après les spectres polliniques, la végétation a été une toundra herbacée marquée par la présence d'*Artemisia* avant 11 250 ans B.P. Cependant, la date de colonisation de cette végétation ne peut être déterminée de façon définitive à cause des problèmes de datation du début de la séquence sédimentologique et l'absence d'une chronologie fiable de la déglaciation régionale. Une toundra arbustive à bouleau a prédominé entre 11 250 B.P. et 10 250 B.P., et a ensuite été remplacée par une région boisée de peuplier discontinu. Les populations de *Juniperus* ont augmenté vers 9500 ans B.P. et, vers 8400 ans B.P., *Picea* a colonisé la région. La forêt relativement fermée d'épinettes blanches qui occupe la région aujourd'hui s'est établie vers 8000 ans B.P. *Alnus crispa* s'est répandu il y a environ 6000 ans B.P. Alors qu'on retrouve une augmentation de *Picea mariana* à cette époque dans la plupart des sites dans le Territoire du Yukon, celle-ci n'a pas eu lieu à Sulphur Lake. L'épinette noire n'a jamais été une composante dominante de la végétation au sud-ouest du Yukon comme elle l'a été entre 6100 et 4100 ans B.P. au centre-sud du Yukon.

Mots clés: analyses polliniques, paléocologie quaternaire, sud-ouest du Yukon, migration de l'épinette, histoire de la végétation

INTRODUCTION

The southwest Yukon is a region that warrants detailed biogeographical and paleoenvironmental investigation. Many species characteristic of the North American boreal forest, including black spruce (*Picea mariana*), larch (*Larix laricina*), and paper birch (*Betula papyrifera*), are rare or absent in the southwest Yukon. Yet, with a large number of disjunct species and species endemic to Alaska and the Yukon (*Stellaria alaskana*, *Salix setchelliana*, *Androsace alaskana*, *Castilleja yukonis*, *Artemisia alaskana*, *Aster yukonensis*, and *Claytonia bostockii*) (Murray and Douglas, 1980), substantial ecological diversity remains.

Because of its high elevation and proximity to alpine glaciers, the southwest Yukon displays steep environmental gradients. Cold, dry arctic air masses influence the area, while the warm, moist Pacific air masses are modified in transit over the St. Elias Mountains. Lying at the boundary between these two major climate systems, the southwest Yukon is sensitive to even minor environmental changes.

Although a number of paleoecological studies have been undertaken in the southwest Yukon, unresolved questions remain. The direction of spruce migration in this region is still not fully understood. Cwynar (1982, 1988) and MacDonald (1984) suggested that spruce migrated from the upper Liard River to the Yukon River drainage

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system into the southwest Yukon, but both cautioned that more sites are required before a precise migration route can be determined. A second question concerns the early suggestion that extensive grasslands were present in the southwest Yukon for much of the Holocene (Johnson and Raup, 1964; Workman, 1978; Morlan and Workman, 1980). Cwynar (1988), Stuart et al. (1989), Wang and Geurts (1991b), and Keenan and Cwynar (1992) found no evidence in their study areas to support this suggestion, but more data are needed for a complete rejection of this hypothesis. Widespread increases in black spruce (*Picea mariana*) and green alder (*Alnus crispa*) occurred throughout most of the Yukon between 6500 and 6000 yr BP (Cwynar and Spear, 1995). These vegetational changes are less clear in the southwest Yukon and thus require further investigation.

These questions can be addressed with well-dated reconstructions of postglacial vegetation history in the southwest Yukon Territory. To this end, a paleoecological study at Sulphur Lake in the Kluane Lake region (Fig. 1) was conducted to further define the vegetation history of this region.

STUDY AREA

The modern vegetation of the southwest Yukon has been well studied (Johnson and Raup, 1964; Price, 1971; Rowe, 1972; Douglas, 1974; Hoefs et al., 1975; Birks, 1977; Oswald and Senyk, 1977; Orlóci and Stanek, 1979; Murray and Douglas, 1980; Parent, 1988). Closed-to-open boreal forests dominated by white spruce (*Picea glauca*) occupy valley bottoms. Black spruce (*P. mariana*), larch (*Larix laricina*), and white birch (*Betula papyifera*) are uncommon or absent in the southwest Yukon. Extensive stands of poplar (*Populus tremuloides* and *P. balsamifera*) are common, especially on warmer sites. Shrub willow (*Salix glauca*), dwarf birch (*Betula glandulosa*), and, to a lesser extent, *Shepherdia canadensis* are important constituents of the regional vegetation, while alder (*Alnus* spp.) is scarce, present only as scattered shrubs (Johnson and Raup, 1964). Lodgepole pine (*Pinus contorta*) and subalpine fir (*Abies lasiocarpa*) are absent from the region but become increasingly important to the east and south. *Artemisia*-dominated communities occur on dry, south-facing slopes, particularly surrounding Kluane Lake and in Kluane National Park. In the Shakwak Trench, the treeline varies between 1066 and 1220 m (Johnson and Raup, 1964), with alpine tundra at higher elevations.

Sulphur Lake (60°95'N, 137°9'W; 847 m a.s.l.) is located in the Shakwak Trench adjacent to the Alaska Highway, approximately 26 km southeast of Kluane Lake (Fig. 1). It is a large lake (~150 ha) with two main basins, a shallow (2 m) southwest basin and a much deeper (10 m) northeast basin, which are separated to some extent by a point that extends into the center of the lake (Fig. 2). Sulphur Lake is characterized by magnesium-rich

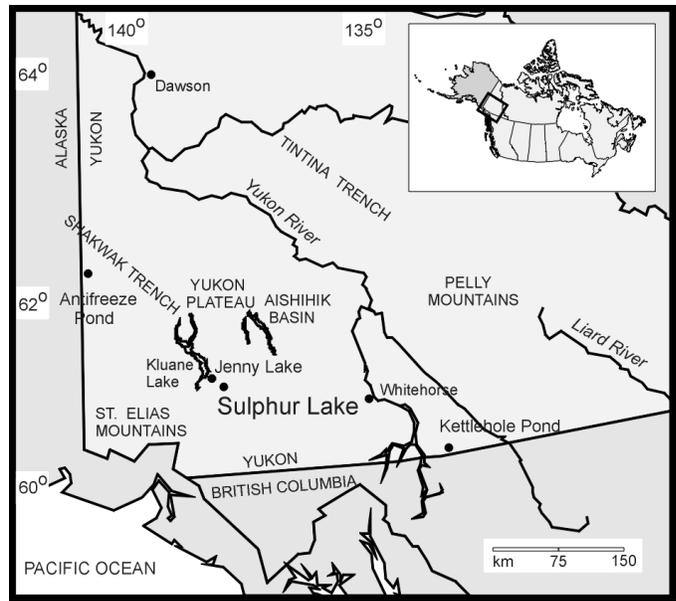


FIG. 1. Map of the southwest Yukon Territory, showing Sulphur Lake and other localities mentioned in the text.

bicarbonate waters, with low nutrient (0.1 µg/L TPU) and chlorophyll *a* (0.62 µg/L) levels.

METHODS

Three duplicate sediment cores, 5 cm in diameter, were recovered from the deepest basin of Sulphur Lake (Fig. 2) using a modified Livingstone piston sampler (Wright, 1967) operated from a raft anchored at three points. PVC casing was used to direct the corer. Lake bathymetry was determined through sonar measurements. Cores were extruded in the field and wrapped in plastic and aluminium foil to maintain the integrity of each core during transport. The uppermost unconsolidated sediment was extruded at 1 cm intervals using a portable extruding device (Glew, 1988). Whole core X-radiography and magnetic susceptibility served as nondestructive methods for correlating core segments and determining the depth of the White River Ash. Whole core magnetic susceptibility was measured at 1 cm intervals using a Bartington MS2C Core sensor (6 cm internal diameter).

A calibrated brass sampler was used to remove 1 cc subsamples at 5 cm intervals for pollen analysis. Pre-acetolyzed *Lycopodium* spores in tablet form were added to each subsample to determine pollen concentrations and accumulation rates (Benninghoff, 1962). Standard methods for pollen analysis were followed (Cwynar et al., 1979; Faegri and Iversen, 1989). A minimum sum of 500 grains was counted for each subsample. The differentiation of *Picea glauca* and *P. mariana* pollen grains was based upon morphological characteristics outlined by Hansen and Engstrom (1985). All undifferentiated *Picea* grains (an average of 10% of the grains) were assigned to either *P. glauca* or *P. mariana* according to the proportional

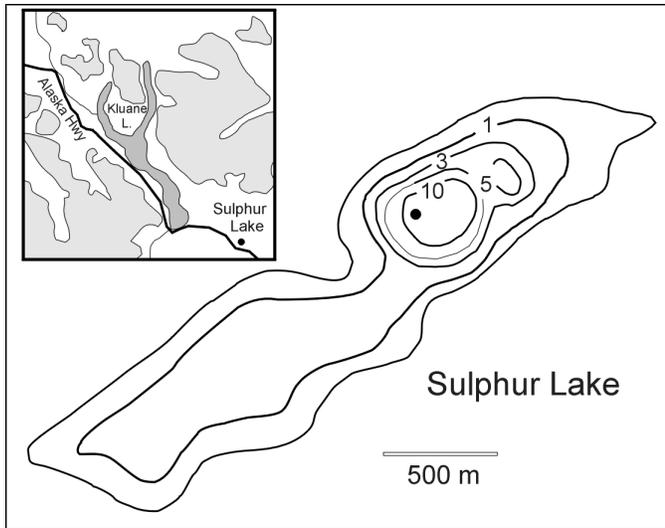


FIG. 2. Bathymetric map of Sulphur Lake showing the coring location (●). Light shading in the inset map indicates elevation over 1525 m.

TABLE 1. Radiocarbon dates from Sulphur Lake, southwest Yukon Territory, Canada.

Laboratory No.	Depth of sample (cm)	Radiocarbon age (BP \pm 1 SD)	Material
BETA-104734	87.5– 89.5	1960 \pm 50	bulk sediment
BETA-109436	131.0– 132.5	2700 \pm 70	<i>Picea</i> seed and Cyperaceae leaves
BETA-109437	320.3– 321.7	6240 \pm 50	shrub branch
BETA-109438	368.0– 370.0	8240 \pm 50	<i>Picea</i> seed and <i>Drepanocladus</i> sp.
BETA-104735	410.5– 412.5	9530 \pm 60	bulk sediment
BETA-104736	454.0– 457.0	10820 \pm 90	bulk sediment
BETA-104737	496.0– 499.0	17370 \pm 140	bulk sediment

distribution of the grains identified to species. *Alnus crispa* and *A. rugosa* were discriminated on the basis of morphological criteria described by Richard (1970). Plant macrofossils were recovered from the core and were identified where possible. Four bulk sediment samples and three plant macrofossils were submitted to Beta Analytic Radiocarbon Dating Laboratory for accelerator mass spectrometer (AMS) ^{14}C dating. Sediment cores were subsampled to estimate the portion of inorganic and organic materials through loss on ignition (Dean, 1974), and carbonate content was estimated by removing carbonate with 10% HCl.

RESULTS

Sediment Stratigraphy

A 5 m long sediment core from Sulphur Lake was analysed for the purpose of reconstructing the vegetation history. The uppermost 315 cm consist of homogeneous brown gyttja. The White River Ash (WRA) (Lerbekmo et al., 1975; Clague et al., 1995), identified based on geographic

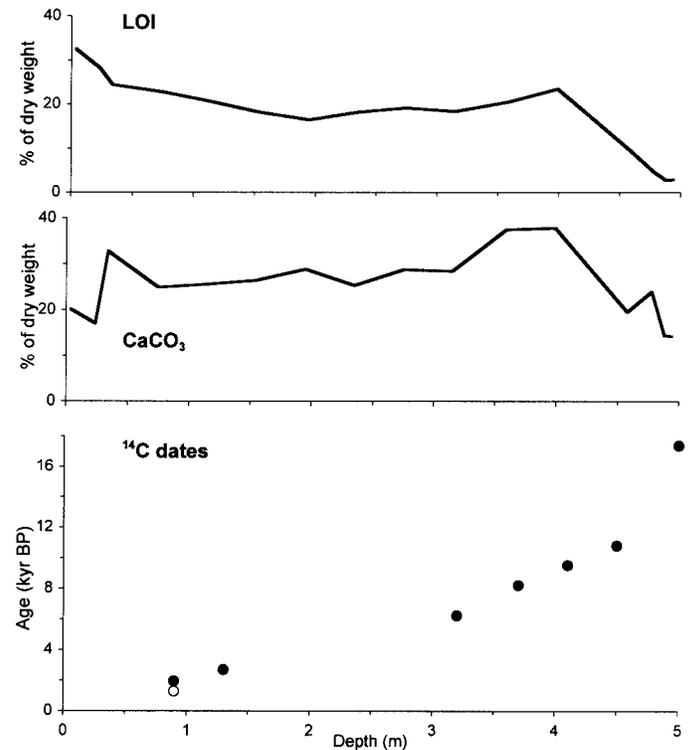


FIG. 3. Sulphur Lake radiocarbon dates, carbonate content (CaCO_3), and loss on ignition (LOI) versus sediment depth. The open circle represents the Clague et al. (1995) date of the White River Ash.

location, x-radiography, magnetic susceptibility and visual inspection, lies 88 cm below the water-sediment interface. Between 315 and 415 cm, the sediment is blackish brown silty gyttja intermittently laminated with fine-grained layers that are lighter in colour. The basal sediments, from 415 to 500 cm, are dark grey to black fine-grained sediments; their magnetic susceptibility increases with depth, indicating an increase in grain size and inorganic content towards the base of the sequence (Thompson et al., 1980).

Chronology

The seven radiocarbon dates (Table 1, Fig. 3) are in chronological order, irrespective of the type of material that was dated. There is a hard-water effect, as shown by our bulk sediment date of 1960 \pm 50 yr BP for sediment at the position of the White River Ash (BETA-104734). On the basis of four dates, Clague et al. (1995) assigned a weighted mean of 1147 cal yr BP (1300 \pm 90 yr BP) to the tephra. This suggests a hard-water error of 660 radiocarbon years for this portion of the core. When only the White River Ash and the one date (BETA-109437) based entirely on a terrestrial sample are used, the remaining dates all fall above a linear fit line, and the deviation from that line increases with depth. With only one estimate of the hard-water effect, the remaining radiocarbon dates were not adjusted, since it was not feasible to determine whether the offset was linear for the period of record. Therefore, the

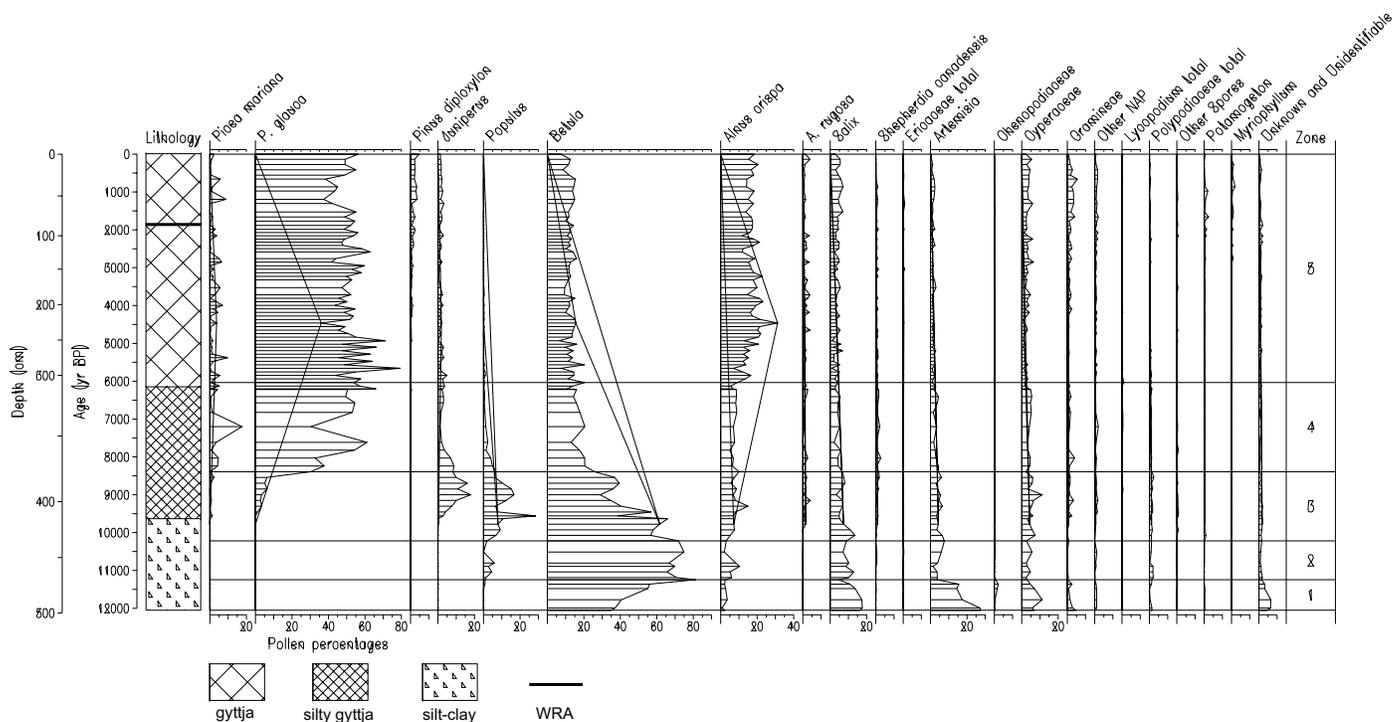


FIG. 4. Summary pollen percentage diagram from Sulphur Lake, Yukon Territory. White River Ash (WRA) lies at a depth of 88 cm.

uncorrected chronology was used. The potential offset was considered in the interpretation of the palynological record. Individual pollen spectra were dated through linear interpolation between radiocarbon dates.

The basal date of 17 370 yr BP (BETA-104737) appears to be too old, given the accepted date of 12 500 yr BP for clearance of ice from the Shakwak Trench (Denton and Stuiver, 1966, 1967). The accepted date was based on bulk sediment from nearby Jenny Lake (Fig. 1) that has a 70–80% carbonate content in basal sediments (P. Johnson, pers. comm. 1998). Bulk sediment dates are often problematic where carbonate content is high. The carbonate content of the basal sediments at Sulphur Lake is only 14% (Fig. 3), considerably lower than that of basal sediments at Jenny Lake. However, the loss on ignition indicates that the basal sediments of Sulphur Lake contain less than 5% organic matter (Fig. 3). For this reason, the basal date of 17 370 yr BP is not used in establishing the Sulphur Lake chronology.

For the pollen diagram, levels below 10 820 yr BP (BETA-104736) were dated through linear extrapolation, using the sedimentation rate of the section from 411.5 to 455.5 cm. This dating puts the base of the sequence at roughly 12 000 yr BP. This method was chosen because the upper six dates are all well aligned. The chronology of the basal sediments may need to be revised using the basal date of 17 370 yr BP if deglaciation was earlier than 12 500 yr BP. However, the high carbonate content of Jenny Lake basal sediments suggests that even Denton and Stuiver's (1966) date of 12 500 yr BP for clearance of ice from the Shakwak Trench may be too old. Perhaps the chronology

of deglaciation, and more specifically the clearance of ice from the Shakwak Trench, needs to be more firmly dated.

Palynological Record

The Sulphur Lake pollen percentage diagram (Fig. 4) is divided into 5 zones.

Zone 1 (*Betula* - *Artemisia* - *Salix*, >11 250 yr BP; 470–500 cm): This zone is dominated by high percentages of *Betula* (35–81%), *Artemisia* (4–27%), *Salix* (5–18%), and *Cyperaceae* (3–11%). *Artemisia*, *Salix*, *Chenopodiaceae* and *Cyperaceae* reach their maximum for the period of record in this zone.

Zone 2 (*Betula*, 11 250–10 250 yr BP; 470–435 cm): *Betula* reaches its maximum (81%) for the period of record in this zone. *Salix* is relatively abundant (5–13%). *Populus* pollen is present in this zone but remains less than 6% of the pollen sum. *Alnus crispa* rises in this zone, and total herb pollen decreases.

Zone 3 (*Populus* - *Juniperus*, 10 250–8400 yr BP; 435–374 cm): This zone is marked by a significant decline in *Betula* (26–66%) and an increase in *Populus* (6–29%). *Juniperus* arrives by 9500 yr BP and accounts for up to 18% of the pollen sum. *Picea* pollen is present in small amounts.

Zone 4 (*Picea glauca*, 8400–6000 yr BP; 374–310 cm): Zone 4 is characterized by the arrival of *Picea*, the majority of which is *P. glauca*. *Picea glauca* rises from 6% to 60% in a period of roughly 900 years. *Betula* remains more or less constant until the present. *Juniperus* and *Populus* pollen both decline to trace amounts. *Alnus crispa*, *Salix*,

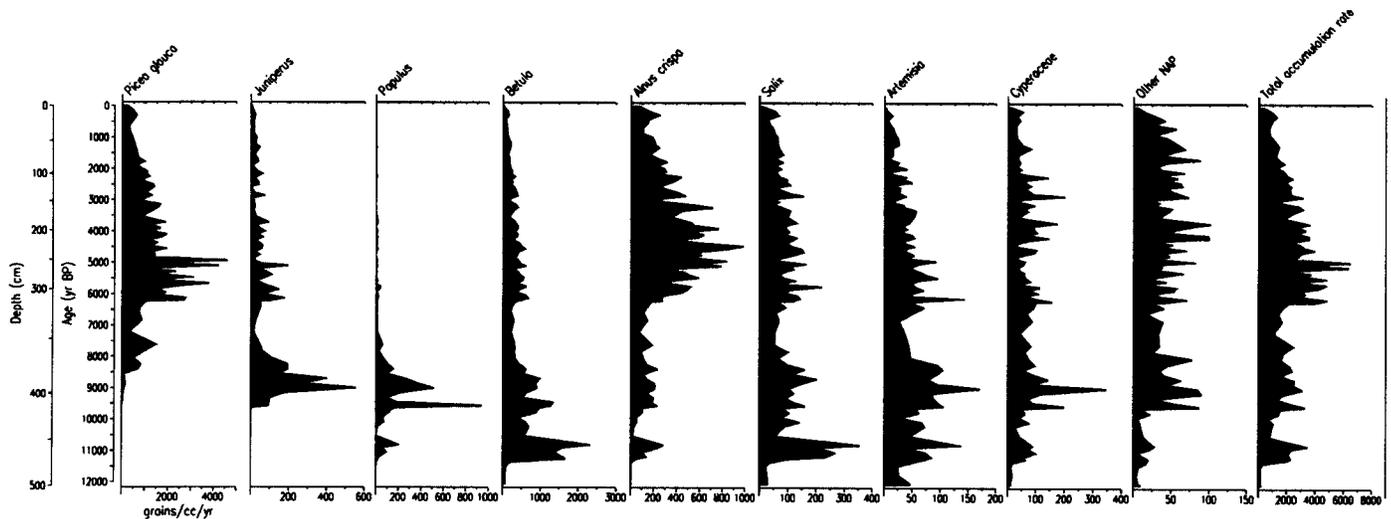


FIG. 5. Pollen accumulation rates for selected taxa from Sulphur Lake, Yukon Territory. Note changes in scale.

Artemisia and *Cyperaceae* remain constant at low levels.

Zone 5 (*Picea glauca* - *Alnus*, 6000 yr BP to present; 310 cm to surface): *Picea glauca* remains at high levels throughout this zone, with some variability including a marked decrease between roughly 1250 and 600 yr BP. *Alnus crispa* increases gradually from 6000 to 4500 yr BP, reaching values up to 30%. *Pinus* pollen is continuously present by 5000 yr BP and increases shortly after the deposition of the White River Ash. Gramineae, *Salix*, *Betula* and aquatic pollen (*Potamogeton* and *Myriophyllum*) increase around 1500 yr BP.

Total pollen accumulation rates (PARs) increase from the base of the record to a maximum between 5000 and 6000 yr BP (Fig. 5). This maximum is largely due to the increase in *Picea glauca* PARs at this time and corresponds to the maximum of *Picea glauca* and *Alnus crispa* in the pollen percentage diagram (Fig. 4). *Cyperaceae*, *Salix* and *Artemisia* PARs as well as other herb PARs are low in the basal sediments, whereas in the pollen percentage diagram (Fig. 4) these types are at a maximum. *Salix* PARs reach their maximum later during the birch shrub tundra stage, and maximum nonarboreal pollen (NAP) PARs occur around 9000 yr BP, during the *Populus*-*Juniperus* zone (Fig. 5). In the late Holocene, *Picea glauca*, *Alnus crispa*, and total PARs gradually decrease until the present. This decline in PARs may reflect reduced compaction or decreased sediment focusing or both. However, it may also reflect lower pollen production related to cooler climates.

DISCUSSION

Immediately following deglaciation, the pollen assemblages were dominated primarily by *Betula*, *Artemisia*, *Salix*, and *Cyperaceae*. This basal zone represents a shrub birch-herb tundra marked by relatively low amounts of *Betula*, high NAP (including *Chenopodiaceae*, *Asteraceae*, and *Rumex*) and an abundance of *Artemisia*. Climate during this time was drier and colder than at present. Total

pollen accumulation rates are low at this time (Fig. 5), suggesting that the vegetation was an open, tundra environment (Davis et al., 1984; Delcourt and Delcourt, 1991). High inorganic content in basal sediments also suggests sparse vegetative cover as well as significant loess input. Today, *Artemisia*-dominated communities in the southwest Yukon grow primarily in open, dry habitats on warm, south-facing slopes (Johnson and Raup, 1964; Douglas, 1974). The modern influx of *Artemisia* pollen is considerably lower than that in late glacial sediments. Given the relatively high influx of *Artemisia* pollen following deglaciation, *Artemisia* communities must have been more extensive in the late glacial era than they are today. However, these are not comparable habitats. The presence of *Betula*, *Salix*, and other NAP in the late glacial indicate a sparse tundra community, whereas today in the southwest Yukon *Artemisia* spp. are found in localized grass-forb communities. Hence, a sparse herbaceous tundra dominated by *Artemisia* probably occupied xeric upland sites, while birch and willow shrubs were common in lowlands.

By roughly 11 250 yr BP, this herbaceous tundra was replaced by a birch shrub tundra. Total PARs (Fig. 5) increased significantly with the establishment of a birch shrub tundra, indicating that a more continuous vegetative cover prevailed. This increase in *Betula* and total influx signals increased moisture and probably warmer summer temperatures. The first appearance of *Populus* coincides with the dominance of shrub birch at this time. *Populus* may have grown in some of the drier habitats. *Alnus crispa* began to rise slowly, but it is less than clear whether it was growing locally. Modern pollen assemblages indicate that *Alnus* is significantly overrepresented in the Shakwak Trench (Lacourse, 1998). Birks (1977, 1980) also documented the overrepresentation of *Alnus* pollen in the southwest Yukon.

By 10 250 yr BP, *Betula* began to decline, perhaps because of a lower tolerance of arid conditions, and the birch shrub tundra was gradually replaced by a poplar woodland with an understory of shrub birch. Both trembling

aspen (*Populus tremuloides*) and balsam poplar (*P. balsamifera*) are abundant in the Kluane Lake region today, but only trace amounts of *Populus* pollen are found in modern surface samples (Lacourse, 1998). This underrepresentation of *Populus* in surface sediments suggests that the peak in *Populus* between 10 250 and 8000 yr BP represents the establishment of a significant poplar community in the southwest Yukon, as opposed to merely gallery forests along rivers. A peak in *Populus* around 10 000 yr BP is a common feature of pollen diagrams from Alaska, Yukon Territory, and the adjacent Northwest Territories (Ritchie, 1984, 1987). In fact, this kind of zone is found in late glacial sediments throughout Canada (Mott, 1978).

Juniperus, the first conifer to colonize the area, arrived by 9500 yr BP. Its presence indicates openings in the woodland vegetation and well-drained, unshaded habitats (Ritchie, 1984, 1987). It probably grew in woodland gaps as well as on dry, open slopes that previously had been occupied by *Artemisia*. The addition of juniper shrubs to the landscape around 9500 yr BP corresponds with a change in the sediment stratigraphy at 415 cm (Fig. 4), suggesting widespread changes in edaphic parameters at this time. A decrease in loess production resulting from a more continuous vegetative cover might explain the increase in organic content.

Trace amounts of *Picea* pollen were present by roughly 9500 yr BP, and white spruce has dominated the landscape from 8400 yr BP until the present. A spruce seed dated at 8240 ± 50 yr BP (BETA-109438) confirms its local presence. The combination of white spruce, poplar, shrub birch, willow, and juniper indicates that a boreal forest, similar in structure and composition to the boreal forest present in the southwest Yukon today, had been established by approximately 8000 yr BP. This suggests an overall increase in effective moisture and temperature. Given the length of time required for spruce migration (Ritchie and MacDonald, 1986), it is probable that the arrival of spruce lagged behind the postglacial climatic change.

Too few sites have been studied in the southwest Yukon to draw concrete conclusions on the pattern of spruce migration. Cwynar (1982, 1988) and MacDonald (1984) proposed that spruce migrated from northern British Columbia through the upper Liard River to the Yukon River drainage system and then into the southern Yukon. Spruce arrived west of the Liard Plain at Kettlehole Pond at 9250 yr BP (Cwynar, 1988), and in the central Aishihik Basin by 8600 yr BP (Wang, 1989). It is therefore conceivable that spruce migrated from northern British Columbia to the Liard River and then into the Tintina Trench to continue further north. However, spruce migrated up the Mackenzie Valley, arriving in the Mackenzie Delta before 9000 yr BP (Ritchie, 1987). Wang and Geurts (1991a) suggested that spruce migrated southward from the Tintina Trench into the Aishihik Basin and its adjacent area via the Yukon River plain. In the central Yukon, just to the north of Dawson, there is clear macrofossil evidence of spruce at

9400 yr BP (Cwynar and Spear, 1991). There is also evidence of spruce in central Alaska by 9000 yr BP (Anderson and Brubaker, 1993). Spruce had arrived at Antifreeze Pond on the Alaska-Yukon border at 8700 yr BP (Rampton, 1971). From the Tintina Trench, spruce could have migrated south into the Kluane Lake region to arrive at Jenny Lake at 8500 yr BP (Stuart et al., 1989) and at Sulphur Lake at 8400 yr BP. However, as both Cwynar (1988) and Wang and Geurts (1991a) noted, we need additional sites, particularly to the east in the Pelly Mountains and along the Yukon River plain, to secure the pattern of spruce migration into the southwestern Yukon.

Alnus crispa increased significantly at 6000 yr BP, indicating cooler and moister conditions, as suggested by Cwynar and Spear (1995). Ritchie (1984) associates an increase in *Alnus* with increased paludification and permafrost development in the Northwest Territories. The increase in *Picea glauca* and *Alnus crispa* PARs (Fig. 5) at this time suggests that forest cover was more continuous. This change in vegetation and climate occurs simultaneously with a lithological change at Sulphur Lake (Fig. 4), which suggests that edaphic parameters that affected sediment deposition also changed at this time. For example, with moister conditions and increased forest cover, loess input to Sulphur Lake would have decreased (Nickling, 1978), explaining in part the transition from silty gyttja to homogenous brown gyttja at 315 cm. Throughout the Yukon, the increase in *Alnus crispa* in the mid-Holocene is usually accompanied by an increase in *Picea mariana* (Cwynar and Spear, 1995). The history of *Picea mariana* is less clear in the Shakwak Trench (Cwynar, 1988). At Sulphur Lake, black spruce was never a significant component of the vegetation, as it was to the southeast at Kettlehole Pond (Cwynar, 1988). Conditions may have been too dry at Sulphur Lake to support black spruce. However, this is the first diagram from the Shakwak Trench to differentiate white and black spruce pollen; with additional sites, the importance of black spruce could be better determined. Stuart et al. (1989) interpret the rise in *Alnus* at nearby Jenny Lake at 4500 yr BP to represent the establishment of a spruce-alder woodland. However, modern pollen assemblages indicate that *Alnus* is severely overrepresented in the southwest Yukon. Values of up to 30% were obtained at sites where alder was not growing locally (Lacourse, 1998). It is therefore possible that alder was not as important a constituent of the regional vegetation as the sequence suggests: rather, its pollen was merely transported long distances.

Only minor adjustments in the vegetation occurred following the rise in *Alnus crispa* at 6000 yr BP. At approximately 1500 yr BP, Gramineae, *Salix*, *Betula* and total NAP increased at the expense of *Picea glauca*. In view of the 660 year difference between the accepted date of the White River Ash (Clague et al., 1995) and the date obtained from Sulphur Lake, the decrease in white spruce may correspond to the Little Ice Age, during which it is known that glaciers advanced in the St. Elias Mountains

(Denton and Karlén, 1977). The increase in aquatics (*Potamogeton* and *Myriophyllum*) at this time is probably associated with local changes in the physical or chemical conditions of Sulphur Lake. For example, higher lake levels as a result of increased precipitation would have allowed aquatics to expand on the margins of Sulphur Lake. *Pinus* pollen increased shortly after the deposition of the White River Ash but has remained at low levels (< 5%). To the southeast, at Kettlehole Pond, Cwynar (1988) found *Pinus contorta* to be the dominant tree by 1900 yr BP. Given that pine has not reached Sulphur Lake, the increase in *Pinus* pollen is presumably a function of transport linked to the dramatic increase in growing populations of pine to the south.

Johnson and Raup (1964), Workman (1978), and Morlan and Workman (1980) have suggested that extensive grassland communities occupied the southwest Yukon following deglaciation until roughly 3000 yr BP. This largely speculative hypothesis was based on two elements. First, wood bison (*Bison bison athabasca*) fossils are present in early and middle Holocene sediments in the southwest Yukon. Second, early inhabitants (Little Arm and Gladstone cultural phases) were adapted to the hunting of grassland species, including muskox (*Ovibos moschatus*), caribou (*Rangifer tarandus*), and bison (*Bison* sp.) (MacNeish, 1964). However, the Sulphur Lake pollen diagram, as well as other nearby postglacial vegetation reconstructions (Rampton, 1971; Stuart et al., 1989), clearly indicate that a white spruce boreal forest has dominated the Shakwak Trench since at least 8000 yr BP. Extensive grasslands were not present in the southwest Yukon in the early Holocene or at any time, as previous archaeological histories have proposed. In fact, at Sulphur Lake, grasses account for less than 5% of the pollen sum for the period of record. As Stuart et al. (1989) and Keenan and Cwynar (1992) have indicated, regional archaeological reconstructions that suggest that early hunters and gatherers in the southern Yukon were adapted to widespread grassland environments (i.e., Johnson and Raup, 1964; Workman, 1978; Morlan and Workman, 1980) will have to be revised accordingly.

SUMMARY

At Sulphur Lake, a sparse shrub birch-herb tundra marked by the presence of *Artemisia* was present during the late-glacial and early Holocene. With a marked decrease in *Artemisia* and an increase in *Betula*, a birch shrub tundra prevailed between 11 250 and 10 250 yr BP. Between 10 250 and 8400 yr BP, a poplar woodland with an understory of juniper scrub and dwarf birch was supported. Spruce invaded the region at 8400 yr BP and the present white spruce boreal forest was established by about 8000 yr BP. *Alnus crispa* increased at 6000 yr BP at Sulphur Lake as it did throughout most of the Yukon, but *Picea mariana* did not increase.

There are problems with the Sulphur Lake basal radiocarbon date of 17 370 yr BP as well as Denton and Stuiver's (1966) 12 500 yr BP date from Jenny Lake. These difficulties and the lack of a reliable chronology for clearance of ice from the Shakwak Trench make it impossible to date the initial vegetation succession securely. If the regional deglaciation history is revised, the interpretation of the Sulphur Lake pollen diagram would need to be revisited.

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