Introduction

The Arctic Coastal Plain of northern Alaska is dominated by ice-wedge polygons and successional thaw lakes. The geomorphic process by which a thaw lake forms and drains is called the "thaw-lake cycle." Much of the Arctic Coastal Plain, and large portions of the Arctic Foothills and Seward Peninsula, are covered by thaw lakes developed in ice-rich permafrost. Nearly all of the remaining landscape is scarred by drained thaw-lake basins, which subsequently become sites for peat accumulation. Research in Canada (Mackay, 1992), Alaska (Hopkins, 1949) and eastern Siberia (Czudek and Demek, 1970; Sher, 1992) suggests that the widespread formation of thaw lakes is linked to changes in climate.

This pilot study analyzed the pollen and microfossils deposited on the surface of drained thaw-lake basins in order to interpret long-term patterns of vegetation succession associated with the thaw-lake cycle. Fourteen basins were sampled and classified as old, intermediate, and young stages based on present-day vegetation and geomorphology. Pollen grains (produced by seed plants) and spores (produced by non-seed plants, algae, and fungi) found in the modern surface mosses and plant litter of the thaw-lake basin should be representative of the current vegetation in the basin. As a first step in a larger project, modern pollen and microfossils (the term microfossil refers specifically to spores from fungi and algae) were compared to surface vegetation to verify that palynological data represent the vegetation patterns currently found in thaw-lake basins. Our findings can be applied to future analysis and radiocarbon dating of peat and sediment cores from thaw-lake basins in order to refine the concept of the "thaw-lake cycle" as it applies to the Arctic Coastal Plain of Alaska.
Re-vegetation and peat accumulation begin and ice-wedge growth is usually re-activated as permafrost aggrades into the substrate below the basin. Ice-wedge growth yields low-centered polygons with ponds forming preferentially over the resulting troughs. In this way, the cycle begins again. Successional processes are very slow in the tundra region, resulting in a mosaic of plant communities within the thaw-lake basins. The entire “thaw-lake cycle” is estimated to be 2000-3000 years long (Britton 1967; Sellman et al., 1975; Billings and Peterson, 1980), but this hypothesis requires further testing.

Although forming today, many thaw lakes came into existence during the early Holocene warming, around 10,000 14C yr B.P. (Ritchie et al. 1983; Hopkins and Kidd, 1988; Rampton, 1988); their formation apparently associated with a deepening of the active layer in an ice-rich substrate (Burn, 1997). Lake drainage probably occurred preferentially in the colder late Holocene, beginning around 4500 14C yr B.P. In northwestern Canada, this period is associated with peat accumulation in drained lake basins, and reactivation of ice-wedge cracking and growth (Mackay, 1992).

Thaw lakes are widespread in Arctic lowland periglacial environments (Northeast Siberia and Arctic Canada), although the model of cyclic formation and drainage may not apply in these regions. In northern Canada, they appear to be in equilibrium and thus are permanent landscape features. Thaw lake development may occur in response to site-specific conditions such as disturbance which are not necessarily related to regional geomorphic or climate change, as noted by Burn and Smith (1990).

The young lake basins sampled for this project are characterized by well-dispersed, early colonizing vegetation and standing water. The development of ice wedges, low-centered polygons, and prominent polygon ridges becomes progressively more pronounced in the intermediate and old stages (Brown and Krieg, 1983; Bliss and Peterson, 1992). The different phases of the thaw-lake cycle are accompanied by changes in the surface hydrology of the basin and by changes in plant composition. An important successional pattern is the shift from dominance by Dupontia fisheri (grass) in the younger basins to Carex aquatilis (sedge) in the older basins. Thus, the age of the basin since drainage can be determined according to the floristic assemblages.

**Methods**

Surface samples were collected from near the center of 14 drained thaw-lake basins around Barrow, Alaska, in June 1996. We characterized all the basins as young (recently drained), intermediate (medium) and old based on the vegetation communities and degree of ice-wedge polygon development within the basin. These are relative categories since, as discussed above, the time span of the complete cycle of thaw-lake development and drainage is not known. Lake basins were selected to provide adequate spatial coverage (approxi-
approximately 60 km²) and to ensure that basins of all ages were sampled.

Subsamples were prepared for pollen analysis by standard procedures including treatment with hydrofluoric acid and acetolysis (Berglund and Ralska-Jasiewiczowa, 1986). A known amount of *Lycopodium clavatum* spores was added in tablet form to each sample to determine pollen concentrations and as a processing control. Samples were mounted in silicon oil and identified at 400x magnification. Algal and fungal remains were identified based on the work Van Geel and others (i.e., Van Geel, 1978; 1986; Van Geel et al., 1989) using an extensive collection of photographs and reference material of the University of Amsterdam's Hugo de Vries Laboratory.

**Results**

The percentage diagram of the pollen and microfossils in surface samples is displayed in Figure 1. One of the 14 samples analyzed had insufficient pollen to be included in the diagram. The remaining samples are arranged vertically from old to young basins. The pollen and spores from each basin-specific surface sample are presented as a percentage of the sum of all pollen in that sample. The other data presented include spores of *Equisetum* (horsetail), *Sphagnum* (true mosses), and fungi, algae, and zoological remains (e.g., Types 28 and 352). These are also presented as percentages of the pollen sum. Table 1 provides ecological information on some of the more significant microfossils found in the samples, as well as listing those fungi and algae which have been identified and described but, as yet, cannot be further classified.

We identified certain notable patterns of change in the modern accumulation of pollen and spores which appear to be related to the vegetation patterns of drained thaw lakes. Some taxa are clearly stronger indicators of basin age than others. An overview of the general patterns is depicted in Figure 2 and discussed below.

Young thaw-lake basins display characteristic pollen and microfossil assemblages, as compared to drained basins of intermediate age which, in turn, have a distinctive signature compared to old basins. In particular, *Ericaceae* (heath family) and *Cyperaceae* (sedge family) appear to be characteristic of young basins. The appearance of the *Cyperaceae* may be correlated with the abundantly flowering sedge *Eriophorum scheuchzeri* characteristic of young basins. High percentages of sedge (presumably *Carex*) are also found in the old basins and this is discussed further below. *Sphagnum* spp. is also present in relatively high amounts. This is the reverse of the expected trend and is difficult to interpret. The presence of *Sphagnum* in the vegetation of

![Figure 2. Schematic summary of drained thaw-lake stages and characteristic pollen and microfossils.](image-url)
the basins is one of the best indicators of the later stages of succession, and it is essentially absent in the vegetation of young basins. It may be that these spores were transported to the basin through hydrologic processes, since the particular basin in which they were most abundant, Footprint Lake (FP), is characterized by a significant amount of water flow around the time of melt. Future investigation will track the presence of not only spores but of leaf and stems remains (macrofossils) of *Sphagnum*, which are identifiable to species level. Of the microfossils, *Pediastrum spp.* (green algae) is an important indicator, as are the algae Type 314 (*Zygnema*) and Type 229 (unidentified algal spore), both of which are indicative of sandy pools (Table 1).

In basins of intermediate age, *Gramineae* (grass) pollen is much more dominant than in either young or old basins, and there is a greater variety of herb vegetation (*Caryophyllaceae*, Composites, *Rubus chamaemorus*). Basins of intermediate age display elements of both the young and old lakes, as expected in a transitional category. Consequently, heath pollen, *Sphagnum*, and *Pediastrum* are also found in these basins, and *Artemisia spp.* (sage) and *Equisitum spp.* (horsetail) appear in low amounts. Figure 2 illustrates the overlap of pollen and microfossils across the basin categories. Type 83, which appeared solely within basins of intermediate age, is a fungal spore which has been found in peat sediments in The Netherlands, but its ecological significance is as yet unknown (Van Geel, 1978).

The oldest drained lake basins have a superficial similarity to the young basins because of high *Cyperaceae* percentages. The *Salix spp.* (willow) component is high, as are horsetail and sage. Especially noteworthy is the fungal type 126, *Gaumannomyces*. This fungus is found in European deposits in association with local *Carex spp.* stands, and has been found in sediments still attached to *Carex epithelmis* (Van Geel et al., 1989; Pals et al., 1980). It does not occur in the younger basins, and likely indicates the presence of a different species of *Cyperaleae*. Fungal amounts, in general, are much greater in the old drained basins (Figure 2). The high amounts of fungal threads or *hyphae* (Type 79) are significant, since these develop as part of soil-forming processes (Anderson, 1984).

An important consideration in our interpretation is our inability to differentiate species through the use of pollen analysis. *Cyperaceae* and *Gramineae* pollen cannot be identified to species level, a serious drawback when analyzing plant succession change where the transition is from *Eriophorum scheuchzeri* (and to a lesser extent *Eriophorum angustifolium*) in young basins to *Carex aquatilis* in old basins. In this case, the identification and presence of the fungi *Gaumannomyces* allows us to reduce the possible species of *Cyperaceae* represented in these assemblages and gives us a much stronger diagnostic tool.

**Concluding remarks**

A pattern emerges of re-vegetation in the initially wet drained thaw-lake basins, which is indicated by the presence of sedges, green algae, and other algae which thrive in shallow or sandy pools. The drier conditions associated with enhanced drainage in the basins of intermediate age are suggested by greater herb species diversity, a sharp decrease in green algae, and high grass percentages. *Carex* communities, indicated by the association of fungal type 126, are most dominant in the strongly polygonized older basins, and high levels of fungal hyphae suggest increased dryness and soil development.

---

**Table 1. Selected diagnostic microfossils from the Barrow thaw-lake sediments.**

<table>
<thead>
<tr>
<th>Type</th>
<th>Name</th>
<th>Environmental Significance/Host/Association</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 - fungal ascospore</td>
<td><em>Gelasinospora</em> spec.</td>
<td>dry conditions</td>
</tr>
<tr>
<td>3 - fungal ascospore</td>
<td><em>Pleospora</em> spec.</td>
<td>dry, nutrient poor peat</td>
</tr>
<tr>
<td>28 - zoological remain</td>
<td><em>Spermatophore of Copepoda</em></td>
<td>(temporary) open water</td>
</tr>
<tr>
<td>55A - fungal-ascospore</td>
<td>cf. <em>Sordaria</em></td>
<td>eu- to mesotrophic peat (animal dung)</td>
</tr>
<tr>
<td>79 - fungal hyphae (threads)</td>
<td>includes many different taxa</td>
<td>biotic activity-soil formation</td>
</tr>
<tr>
<td>83 - fungal spore</td>
<td>not known</td>
<td>not known</td>
</tr>
<tr>
<td>126 - fungus-hyphopodia</td>
<td><em>Gaumannomyces</em></td>
<td>local <em>Carex</em> stands</td>
</tr>
<tr>
<td>229 - algal spore</td>
<td>not known</td>
<td>sandy pools?</td>
</tr>
<tr>
<td>314 - algal spores</td>
<td><em>Zygnema</em> type</td>
<td>shallow pools?</td>
</tr>
<tr>
<td>352 - Rhizopod</td>
<td><em>Arcella</em></td>
<td>nutrient poor</td>
</tr>
</tbody>
</table>

---

*The 7th International Permafrost Conference*
Certain biases are inherent in palynological analysis. Although every attempt is made to collect representative surface samples, there is often considerable variation in surface drainage, soil moisture, and vegetation patterns even within one thaw-lake basin. Also, different basins will entrap and preserve pollen and other fossil material to a greater or lesser extent, and this may vary according to the morphology and surface moisture of the basin. Furthermore, the categories of young, intermediate, and old basins are discrete, whereas basins exhibit vegetation and geomorphic variation across a spectrum. Finally, the dominant pollen taxa of the Arctic tundra are rarely identifiable to species, and this has limited our capacity to infer vegetation changes in the stratigraphic record. Fungal and algal remains, however, are ubiquitous in standard pollen preparations and can provide a remarkable range of ecological information on hydrology and nutrient levels through time, thus augmenting the limitations of conventional pollen analysis.

The first step in understanding the past vegetation history of the thaw lakes has been to identify modern pollen and microfossil patterns within the basins. The modern pollen does change across the age categories and a signal, based on vegetation succession and relative age, is clearly discernible. The variation from recent to old drained thaw-lake basin surfaces is, in effect, the spatial expression of a temporal pattern which we can expect to see preserved as a pollen and microfossil sequence in a drained thaw-lake organic sediment core. Our next step will be to analyze deep cores from within these basins, identifying similar changes in pollen and microfossil assemblages reflecting successional patterns over the last few millennia.

Acknowledgments

This research was supported by the U.S. National Science Foundation’s Visiting Professorship for Women Award GER 9550382 and Arctic System Science Program grant ATM 9416858 to WRE. The authors would like to thank Ms. Katie Turner for her invaluable field assistance, Dr. Bas van Geel for his assistance in identifying the microfossils, and anonymous reviewers for their suggestions. This is PALE Contribution No. 107.

References


