MINERAL ELEMENT COMPOSITION OF SPHAGNUM FUSCUM PEATS COLLECTED FROM MINNESOTA, MANITOBA AND ONTARIO

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ABSTRACT

Surface moss and peat analyses are presented from five North American ombrotrophic bogs: three sites in northern Minnesota, one in central Manitoba, and one in NE Ontario. All these sites have a well-developed, fibric surface peat layer with Sphagnum fuscum as a dominant, and as a typical feature of continental bogs, black spruce (Picea mariana) forms a continuous, although locally sparse tree canopy.

In addition to nitrogen and sulfur analyses, data are presented for several major and minor elements based on ICP atomic emission spectrometry: P, K, Ca, Mg, Na, Fe, Al, Mn, Zn, Cu, and Pb. Significant vertical and regional differences were found in the elemental concentrations. The possibilities of estimating the accumulation rates of chemical elements in the surface peat layers are discussed using examples from Finland and Ontario.

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Introduction

Nutrient-poor ombrotrophic *Sphagnum* bogs occur over a wide geographical range in North America: from coastal areas to the interior of the continent (Osvald, 1970; Heinselman, 1970; Damman, 1977; Bannatyne, 1980; Kivinen and Pakarinen, 1981), and from the cool temperate zone in the south to the northern boreal and subarctic regions in the north (Sjörs, 1963; Pakarinen and Talbot, 1976; Malterer *et al.*, 1979; Glaser *et al.*, 1981). Such bogs are nourished wholly or largely by precipitation (atmospheric deposition) rather than by inflowing surface or ground water from adjacent mineral soils. Although some peat and moss chemical results from North American ombrotrophic bogs have appeared in the literature (e.g., Pollett, 1972; Glooschenko and Capobianco, 1978; Gorham and Tilton, 1978; Lévesque *et al.*, 1980), very little research has been done until recent years on the chemical ecology and nutrient dynamics of bog ecosystems in the U.S. or Canada. In 1980 a research team at the University of Minnesota and four other institutions initiated a 5-year project on "Ecology and biogeochemistry of *Sphagnum* bogs in North America" (Gorham, 1979). Since then a large number of sites has been investigated from the maritime northeast (Newfoundland; New Brunswick; Novia Scotia; Maine) to the continental midwest U.S.A. (Minnesota) and a prairie province of Canada (Manitoba).

In this paper we examine some results from the continental end of the transect, from sites in Minnesota, Manitoba and Ontario. The vertical variability of elemental concentrations in the surface peat was studied in detail by comparing the live moss layer with the underlying peat, composed mainly of the same moss species (*Sphagnum fuscum*), at two different depths. Furthermore, regional comparisons were made among the five bogs studied, with a particular reference to corresponding analyses from the European literature. Finally, the possibilities of dating different layers of surface peat and estimating the chemical accumulation rates are discussed, with an example from one site in Ontario.

Sites studied

After a preliminary reconnaissance in Minnesota in 1980, the sampling along the continental-oceanic transect was carried out in 1981 and 1982. Chemical aspects of the following five sites are discussed in this paper:

(1) Toivola Bog, 16 km NNE of Floodwood, St. Louis Co., NE Minnesota (47°04'N, 92°52'W),

(2) Arlberg Bog, 20 km E of Floodwood, St. Louis Co., NE Minnesota (46°56'N, 92°40'W),

(3) Red Lake Peatland, N of Upper Red Lake, Beltrami Co., N Minnesota (48°15'N, 92°37'W, crested bog, 1982),

(4) Beaver Point Bog, 50 km N of Riverton, Washow Bay area, central Manitoba Canada (51°25'N, 96°52'W),

(5) Iroquis (Diamond) Bog, 11 km NNE of Iroquois Falls, NE Ontario, Canada (49°52'N, 80°36'W).

Peat surveys carried out in sites 1, 2, and 4 indicate that the total peat depths vary generally between 3 and 6 m, and the uppermost fibric layer of *Sphagnum* peat is well developed (Malterer *et al*., 1979; Olson *et al*., 1979; Bannatyne, 1980). The study sites have vegetational features which are considered as typical of continental ombrotrophic bogs: on the ground, hummocks with *Sphagnum fuscum* and several ericaceous low shrubs (*Ledum groenlandicum*, *Chamaedaphne calyculata*, *Kalmia polifolia*) predominate, and black spruce (*Picea mariana*) forms a more or less continuous, although often sparse and semi-open tree canopy. Feather mosses (mainly *Pleurozium schreberi*) are found locally under the trees, but terricolous lichens appear to have an insignificant role in the study area. Such vegetation corresponds with the 'low shrub bogs' or 'treed bogs' of Jeglum *et al*. (1974).

Methods

In each site, 2-3 representative *Sphagnum fuscum* hummocks, located in canopy openings, were selected for peat coring which was carried out with a stainless steel cylinder (diameter 15 cm). 'Short cores' included the top 50 or 60 cm of peat, capped with a living moss layer (on average 2 cm thick). Peat, starting from the base of live moss, was sectioned in the field into 2.5-cm vertical segments which were later oven-dried in the laboratory at 60°C and weighed for bulk density. Chemical analyses from homogenized samples were performed at the Research Analytical Laboratory of the Soil Science Dept., University of Minnesota (St. Paul) under the supervision of Prof. R.C. Munter. Total N was determined by the semi-micro Kjeldahl method, total S with the Leco SC-132 sulfur analyzer, and the other elements (P, K, Ca, Mg, Na, Fe, Al, Mn, Zn, Cu, Pb) with the new multielement technique, inductively coupled plasma (ICP) emission spectrometry (see Munter and Grande, 1980). Before this, the ground samples were dry-ashed at 485°C, and the ash was treated with boiling 2N hydrochloric acid.

Results

Bulk density and ash contents

In the uppermost parts of the peat profiles studied, dead *Sphagnum fuscum* moss is still uncompressed and only slightly decomposed (H1-2, von Post scale) and consequently the bulk densities for the 0-10 cm layer are extremely low, about 20 g/dm^3 (Table 1). The volume weights increase with depth (Figure 1), the values for the 45-50 cm layer varying from 35-90 g/dm^3. The corresponding degree of humification ranged from H2 to H5. Thus, the deeper samples represented mostly fibric, in some cases hemic sphagnum peats. (Farnham *et al*., 1975; Olson *et al*., 1979).

The lowest ash concentrations (less than 3%) were found in the two Canadian profiles, while in the Minnesota sites slightly higher values were recorded, mostly between 3 and 6% (Table 1). In the Red Lake profile, exceptionally high ash percentages (9-14%) were determined for a subsurface layer between 30 and 45 cm.

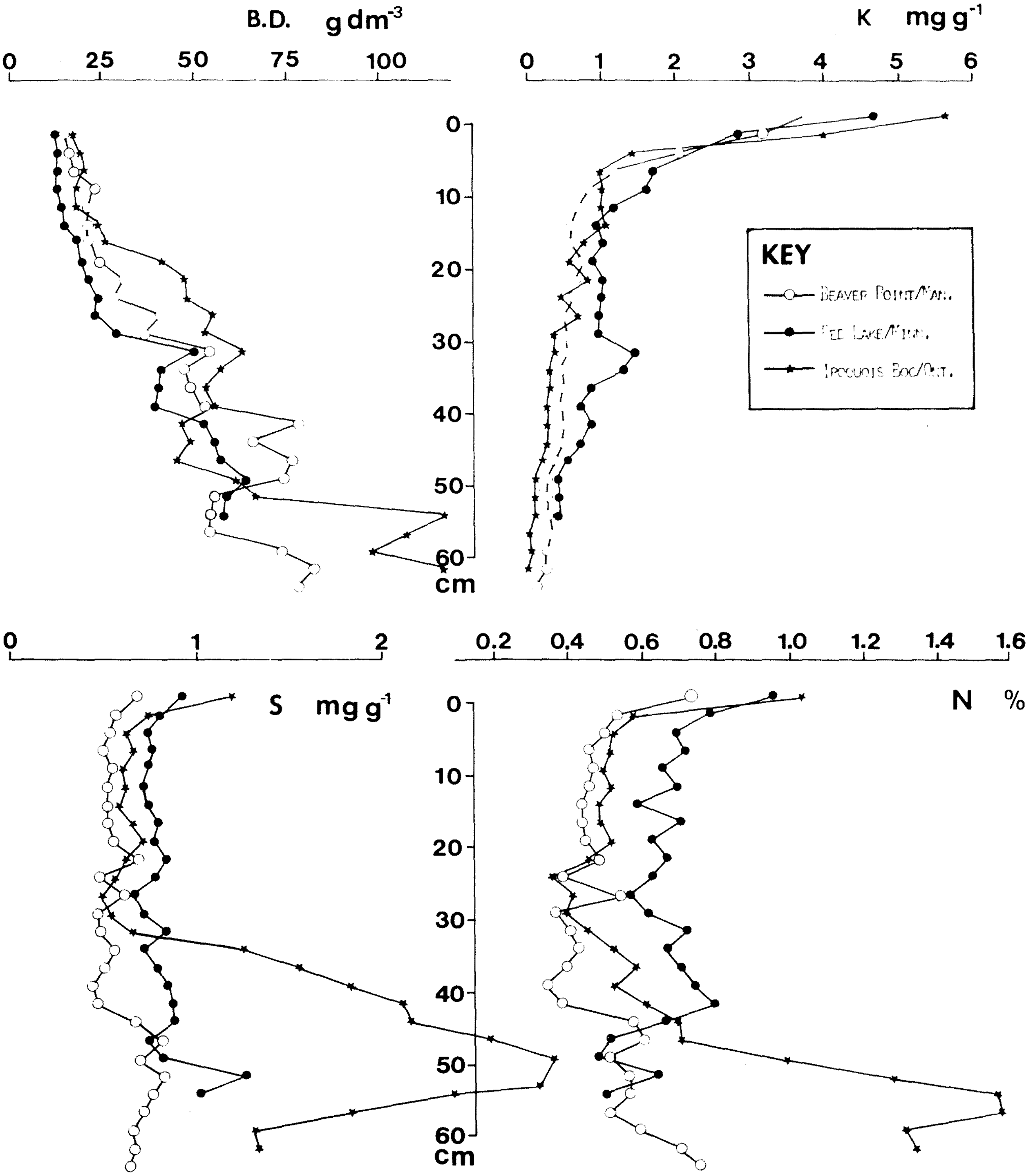

Figure 1. Vertical profiles of bulk density (B.D.) and total K, S, and N for Sphagnum fuscum hummocks in three bogs: Beaver point (Manitoba), Red Lake (Minnesota), and Iroquois bog (Ontario).

Table 1. Total ash content and concentrations of mineral elements in *Sphagnum fuscum* surface moss and peat in five continental bogs studied. B.D. = bulk density.

Site and layer sampled	Ash %	N %	S mg/g	P ppm	K ppm	Ca ppm	Mg ppm	Na ppm	Fe ppm	Al ppm	Mn ppm	Zn ppm	Cu ppm	Pb ppm	B.D. g/dm^3
MINNESOTA/TOIVOLA															
- Live moss 2 cm	3.43	0.75	1.14	351	4448	2355	737	118	1325	810	496	18.8	5.0	12.6	15.3
- Peat 0-10 cm	4.01	0.48	0.70	246	1326	1964	724	70	2056	1321	194	26.0	4.2	29.7	21.1
- Peat 45-50 cm	4.74	1.36	2.05	651	281	2649	500	19	1273	1871	8	11.2	2.2	3.6	89.7
MINNESOTA/ARLBERG															
- Live moss 2 cm	3.60	0.78	0.83	405	4570	1985	637	128	1098	819	369	16.8	3.8	8.3	18.9
- Peat 0-10 cm	3.06	0.45	0.58	289	1877	1633	502	121	1371	898	230	16.5	3.6	14.0	23.7
- Peat 45-50 cm	6.03	0.51	0.57	273	789	1607	639	75	2561	2205	69	39.9	3.3	24.7	34.6
MINNESOTA/REDLAKE															
- Live moss 2 cm	3.66	0.96	0.89	579	5049	3294	865	124	521	567	591	22.6	3.5	5.9	14.4
- Peat 0-10 cm	4.43	0.72	0.76	448	2103	3873	708	57	879	956	541	25.3	3.0	8.1	20.5
- Peat 45-50 cm	6.72	0.50	0.77	327	418	1740	798	31	2084	2495	34	20.2	1.1	10.8	59.8
MANITOBA/BEAVER															
- Live moss 2 cm	2.81	0.62	0.60	397	3787	2420	827	82	487	580	177	12.2	2.5	4.0	12.1
- Peat 0-10 cm	2.69	0.50	0.54	318	1847	2132	734	59	674	769	117	15.7	2.5	6.0	17.8
- Peat 45-50 cm	2.92	0.56	0.74	259	313	1194	662	41	1265	1193	9	11.0	0.6	5.5	75.2
ONTARIO/IROQUOIS															
- Live moss 2 cm	2.41	0.87	1.02	571	5484	1661	684	105	279	294	265	27.6	6.5	6.7	11.4
- Peat 0-10 cm	2.17	0.53	0.66	336	1882	1705	528	74	501	477	229	35.1	6.1	16.1	18.1
- Peat 45-50 cm	1.80	0.86	2.91	339	242	1963	356	31	486	648	14	28.4	2.7	17.1	53.4

Vertical variation in elemental concentrations

The concentrations of 13 elements in different vertical layers of the study sites are given in Tables 1 and 2. The possible enrichment of elements into the moss layer was evaluated by calculating the concentration ratio 'live moss/surface peat' (Table 2). The results indicate that K, N, Na, Mn, P, S, and probably also Mg, are enriched by the living *Sphagnum* layer, while on the other hand particularly Pb, Fe, and Al show consistently lower levels in moss than in the underlying peat. Only Ca and Cu show relatively small changes on average from live to dead *Sphagnum fuscum*.

Another vertical comparison was made between the aerobic surface peat (0-10 cm) and the deeper usually anaerobic peat (45-50 cm layer). Based on deep/surface peat ratio (C/B, Table 2) the following ranking was obtained:

S,Al>N,Fe>P>Zn,Mg>Pb,Ca>Na,Cu>K>Mn

While some elements, especially K and Mn, appear to be remarkably depleted from deeper peat layers (Figure 1), several other elements (S, N, Al, Fe) show increasing concentrations with depth. A closer look at the continuous chemical profiles (Figures 1 and 2) reveals that increases in N and S are positively related to the bulk density (and humification degree) of peat, while Fe, Al and Pb may show more or less distinct enrichment in the intermediate layers, near or above the zone of water table fluctuation (Damman, 1978; Pakarinen *et al*., 1981).

Regional comparisons

A few notable inter-site differences in the chemical composition of surface peat (and moss) were observed in the study material (Table 1). The lowest levels of Pb, S and Cu were recorded in the relatively remote site (Beaver Pt.) in Manitoba. The lowest concentrations of Fe and Al were found in NE Ontario (Iroquois Bog), far from the prairies, while Cu levels were elevated in the same site, perhaps reflecting medium-long distance atmospheric transport from mining areas in Sudbury or Timmins. Fe levels were highest in NE Minnesota, near the Iron Range mining area. In the Red Lake profile, relatively near to cultivated prairies, the Ca concentrations of moss and surface peat were distinctly higher than in the other ombrotrophic sites.

Sphagnum fuscum is also a major peat former in northern Europe, and chemical analyses from corresponding ombrotrophic sites have been compiled into Table 2 for comparison. By and large, the current results from Minnesota, Manitoba, and Ontario fall well within the ranges observed in Finland, with the exception of phosphorus which may require intercalibration of methods. Potassium concentrations in the study material (0-10 cm layer) are relatively high, but sodium concentrations are generally lower than reported, e.g., from Sweden and Britain. In the latter area other *Sphagnum* species including *S. rubellum*, are dominant in raised bogs.

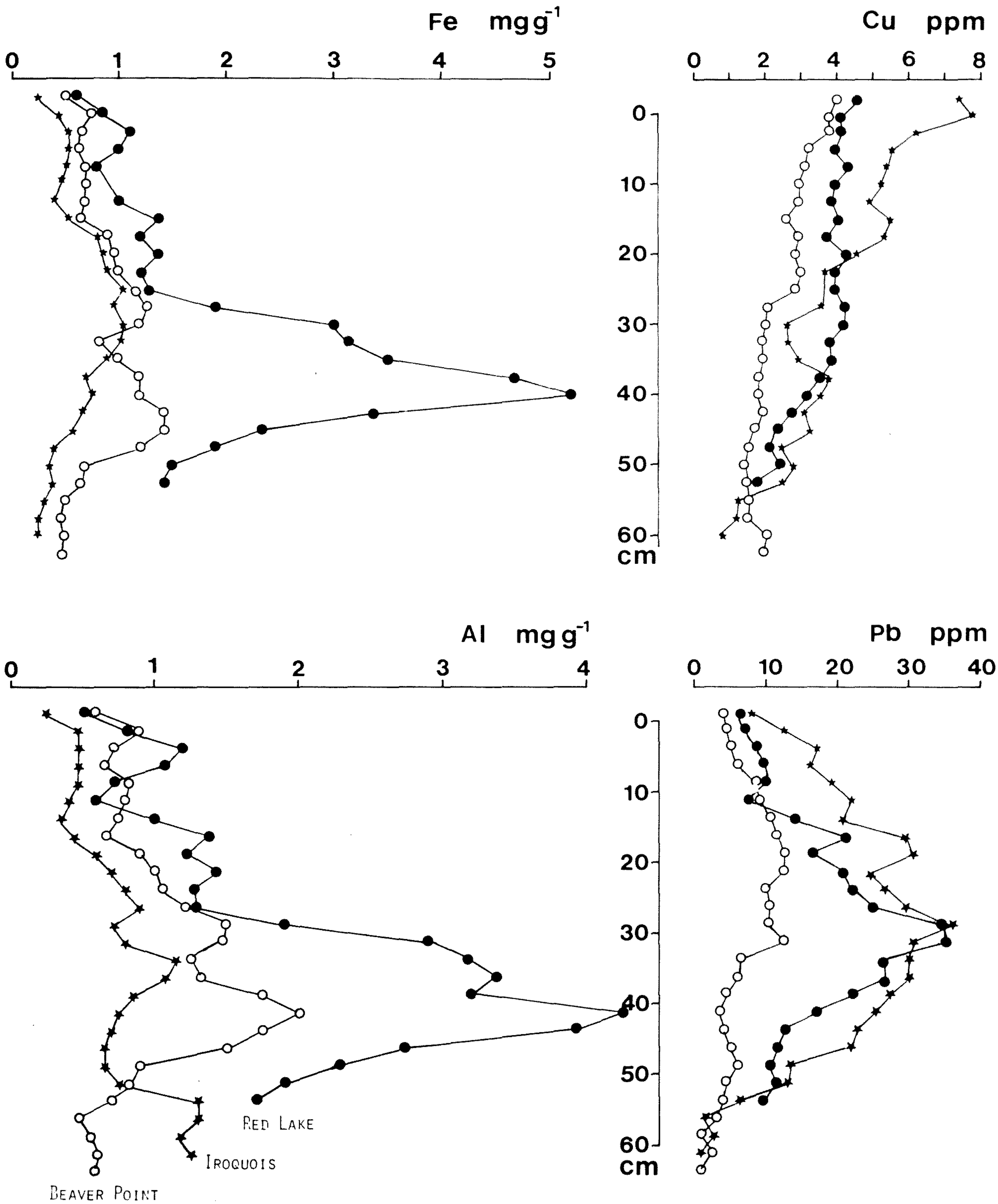

Figure 2. Vertical profiles of total Fe, Cu, Al, and Pb for Sphagnum fuscum hummocks in three continental bogs (symbols: see Figure 1).

Table 2. Mean concentrations and vertical concentration ratios of chemical elements in the study material (Table 1), together with comparable analyses from the literature.

Reference/ area	N %	S mg/g	P mg/g	K mg/g	Ca mg/g	Mg mg/g	Na ppm	Fe ppm	Al ppm	Mn ppm	Zn ppm	Cu ppm	Pb ppm
This study:													
A. Live moss, mean	0.80	0.90	0.46	4.67	2.34	0.75	112	742	614	380	20	4.3	7.5
B. Peat 0-10, mean	0.54	0.65	0.33	1.81	2.26	0.64	76	1096	884	262	24	3.9	14.8
C. Peat 45-50,mean	0.76	1.41	0.37	0.41	1.83	0.59	39	1534	1682	27	22	2.0	12.3
A/B (live moss/surface peat) ratio	1.48	1.38	1.41	2.58	1.04	1.17	1.47	0.68	0.69	1.45	.83	1.10	0.51
C/B (deep peat/surface peat) ratio	1.41	2.17	1.13	0.23	0.81	0.92	0.52	1.40	1.90	0.10	.93	0.51	0.83
Sphagnum mosses:													
-Finland (Pakarinen 1978a,1981b,1981c)	0.66-0.74	0.81-1.60	0.31-0.42	2.70-5.55	1.03-4.08	0.40-1.89	nd	95-1590	nd	53-653	17-60	2.6-12.2	3.8-64.6
-N Sweden (Malmer & Nihlgård 1980)	0.64	0.93	0.60	2.64	1.80	1.29	517	709	147	179	32	3.5	nd
-Minnesota (Gorham& Tilton 1978)	nd	nd	0.57-1.20	3.70-5.00	1.10-3.10	0.45-1.10	nd	nd	180-970	57-540	nd	nd	nd
Sphagnum peat:													
-Finland (0-10 cm, Pakarinen&al 1981)	nd	0.88	nd	nd	nd	nd	nd	532	nd	157	43	4.7	23.4
-N Sweden (0-10 cm, Sonesson 1973)	0.93	1.36	0.59	0.50	2.01	0.73	126	3611	nd	41	18	5.1	4.0
-Britain (5-15 cm, Pyatt & al. 1979)	1.53	nd	0.47	0.25	1.42	0.83	180	nd	nd	nd	nd	nd	nd
-Newfoundland (0-20 cm, Pollett 1972)	0.67	nd	0.34	0.58	1.24	1.17	nd	740	nd	60	31	nd	nd

Growth rates and accumulation rates

From volumes and bulk densities of samples, (Table 1) it is possible to calculate the amounts of elements per unit area of ground (to a specific depth). When the profile has been dated, one can estimate the accumulation rates of organic matter and various chemical elements. The growth increments of *Sphagnum spp*. are not very distinct, but can be defined in many places either by special morphological features, most reliably by perichaetia, or with the aid of intermixed *Polytrichum* mosses (Pakarinen, 1978a, Pakarinen and Rinne, 1979). The moss increment dating method has been applied to *Sphagnum fuscum* surface peats in southern Finland (Pakarinen *et al*., 1981, 1983), and an example from the current study material is presented in Table 3.

Table 3. Net accumulation rates of organic matter (OM, $g/m^2 \cdot y$) and trace metals ($mg/m^2 \cdot y$) in the surface layers of a *Sphagnum fuscum* hummock in Iroquois Bog, NE Ontario. The estimates are based on moss-increment dating as in the corresponding south Finnish material (Pakarinen, 1978b; Pakarinen *et al*., 1981). Comparison to the atmospheric input is provided by bulk deposition data from Muskoka-Haliburton area in central Ontario (Jeffries and Snyder, 1981).

	OM	Fe	Al	Mn	Zn	Pb	Cu
ONTARIO							
Iroquois Bog							
Live moss 2 cm (1982)	239	67	70	63	6.6	1.6	1.6
Peat 0-10 cm (1977-1981)	362	182	173	82	12.6	5.8	2.2
Peat 10-20 cm (1967-1976)	282	156	132	25	13.5	7.5	1.5
Muskoka-Haliburton Atmospheric deposition (1977-1978)	nd	85	59	8	15.7	10.2	2.1
SOUTH FINLAND							
Live moss (*S. fuscum* 1976)	195	113	nd	34	7.2	4.6	1.2
Peat 0-10 cm (12-19y)	235	125	nd	37	10	5.5	1.1

According to observations made in Minnesota bogs in 1980-1982, a typical range of the annual length growth of *Sphagnum fuscum* in undisturbed hummocks was from 20-29 mm/y, while in the sites studied in Manitoba and Ontario the corresponding range was 17-24 mm/y; these can be compared with the values reported from southern Finland (7-16 mm/y, Pakarinen, 1978a).

In Iroquois Bog (Ontario), the estimated age for the 0-10 cm peat layer was 5.0 yr and for the 10-20 cm layer 9.8 yr. Thus peat at 20 cm depth in this well-growing hummock was only 15 yr old, in contrast to the base of the 60 cm profile, which was more compacted and more decomposed and, according to an unpublished radiocarbon dating, over 1200 yr old. The annual accumulation rates of many trace metals (Fe, Al, Zn, Cu, Pb) are in reasonable agreement with the deposition measurements made in central Ontario (Jeffries and Snyder, 1981), and also quite comparable with the retention (accumulation) rates reported from southern Finnish raised bogs (Table 3).

Summary and conclusions

(1) A number of elements, most notably K and Mn, are enriched in the living moss layer. To make chemical peat samples comparable, it is recommended that the green moss layer (which may vary considerably in thickness in various sites) be separated from the surface peat. From the various depth limits used in site surveys, the range 5-15 cm (Pyatt *et al*., 1979) may be preferable. On the other hand, in moss chemical surveys, only the green part or consistently the top 3 cm (Pakarinen, 1981b,c) or 5 cm (Gorham and Tilton, 1978) should be used for analysis (Glooschenko and Capobianco, 1978).

(2) From information about vertical distribution patterns and vertical concentration ratios observed in this study (Figures 1 and 2, Table 2) as well as in some earlier, European studies (e.g., Damman, 1978; Pakarinen *et al*., 1978; Wandtner, 1981) it is evident that a few elements (K, Na, Mn at least) are retained in the uppermost part of the profile in undisturbed *Sphagnum* bogs and depleted from deeper, ombrotrophic peat (Pakarinen, 1981a). Other elements (Fe, Al, Pb, Zn) commonly display a gradual or even steep increase downwards, with peak concentrations usually between 10 and 50-60 cm below the surface, indicating partial mobility of these trace metals through acid, weakly decomposed *Sphagnum* peat. A third behavorial group (N, S, and possibly P) is to some extent recycled near the surface and also enriched into moderately or well humified deeper peat layers.

(3) As to the regional features, the elevated Fe and Al concentrations in Minnesota and Manitoba peats support the idea that wind-blown dust from cultivated or disturbed prairie soils affects the atmospheric deposition rates and chemistry of mid-western continental bogs (Finney and Farnham, 1970; Gorham and Tilton, 1978; Thornton and Eisenreich, 1982). On the other hand, the anthropogenic trace metals Pb and Cu seem to occur at very low concentrations in Manitoba.

(4) The use of moss-increment method for dating purposes and for estimating accumulation rates was demonstrated with one Canadian example (Table 3). Currently the continental *Sphagnum fuscum* bogs appear to be rapidly growing, and the net production estimate for a representative *S. fuscum* sample from the study site in Ontario (239 $g/m^2 \cdot y$, Table 3) is clearly

higher than previously reported for the same moss species from a bog in Manitoba (Reader and Stewart, 1972). The applicability of the moss-increment method is limited to the uppermost (usually the top 10-25 cm), weakly decomposed *Sphagnum* peat accumulated during the past few decades. The vascular plant below-ground component in this surface layer is an additional factor which needs further studies. While radiocarbon dating becomes reliable for organic samples older than 300-500 yr, there is a definite need for accurate dating methods for 50-300 yr old peat layers (Clymo, 1978; Aaby and Jacobsen, 1979).

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Discussion

In responding to Dr. Raymond, Dr. Pakarinen speculated that most of the mineral elements identified are present as organic complexes. Prof. Kadlec asked whether radio-cesium could be used to date peats. Dr. Pakarinen said it could be used, althouth the interpretation was complicated by active uptake of the cesium by living plants.