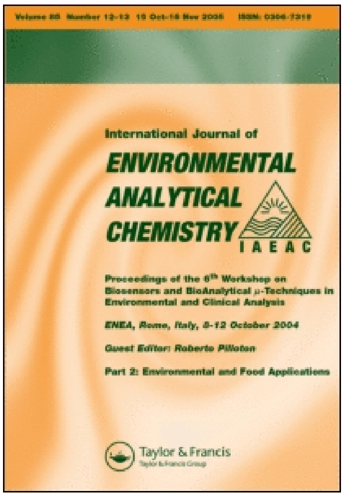

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Pollution of Lakes in a Former Mining and Smeltering Area: Evidence from Successive Extraction and Pollen Analysis of Lake Sediments
Part 2. Lake Dammsjön

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A sediment core from Lake Dammsjön in a previous mining and smeltering area at Nyberget, Central Sweden, was investigated for heavy metal pollution. Successive extraction and dissolution kinetics techniques were used. Environmental events in the area were assessed by means of pollen analysis and distribution of charcoal dust in the sediment.

The lake is situated upstream from the former smeltering site. Secondary pollution of sediments by Pb and Zn was discovered. The pollution was evidently due to release of the metals from the smelter and their subsequent redistribution by field and soil erosion. The input of eroded carbonate-bearing matter obviously neutralized natural acidity of the lake sediments.

The results of pollen analysis and charcoal dust distribution agree well with the chemical evidence reflecting environmental history in the lake area.

KEY WORDS: Lake sediments, mining and smeltering, heavy metal pollution, successive extraction, pollen analysis, anthropogenic indication.

INTRODUCTION

The site of Lake Dammsjön at the village of Nyberget in Central Sweden and the agricultural, mining and smeltering activities are described in Vuorinen *et al.*[1]

MATERIAL AND METHODS

A sediment core was taken from Lake Dammsjön using the smaller Russian peat sampler. The stratigraphy of the core consists of gyttja; in the upmost part (0–8 cm) of clay gyttja. The top of the core stays beyond the present sediment surface. Subsamples (2 cm's interval) were subjected to the analytical procedure presented in Fig. 1. The analytical methods are presented in detail in Vuorinen *et al.*[1] The acidity of the subsamples was determined by measuring pH of the NH_4Ac extractant of initial pH 7.3, and by reading the acidity value corresponding to mM of H_2SO_4 from an experimental diagram (Fig. 2), obtained by adding 0–125 mM of H_2SO_4 to the NH_4Ac.

PALAEOEVENTS IN THE SURROUNDINGS OF LAKE DAMMSJÖN

Due to the sampling techniques the sediments of Lake Dammsjön do

LAKE DAMMSJÖN

FRESH SAMPLE

I	II	III	IV	V
3 g	3 g	2 g	1 g	n g
↓ NH_4Ac, pH 7.3, 48 h	↓ HXl-HAc	↓ ACETONE	↓ DRY WEIGHT (110°C)	↓ POLLEN ANALYSIS
↓ NH_4Ac, pH 4.8	10, 20,80 and 300 min	CHLOROPHYLL	↓ LOSS-ON-IGNITION	↓ MICROSCOPIC
5,20,80 and 320 min	↓ 3 h, 80°C	(670.3 nm)		CHARCOAL PARTICLE COUNTS

NH_4Ac: 1 M ammonium acetate

HXl-HAc: 1 M hydroxylammonium chloride plus 2 M acetic acid

Fe, Mn, Pb, Zn, Na, K, Ca and Mg were analyzed by flame-AAS methods.

For more details see Vuorinen et al.[9,10]

Figure 1 Analytical procedures.

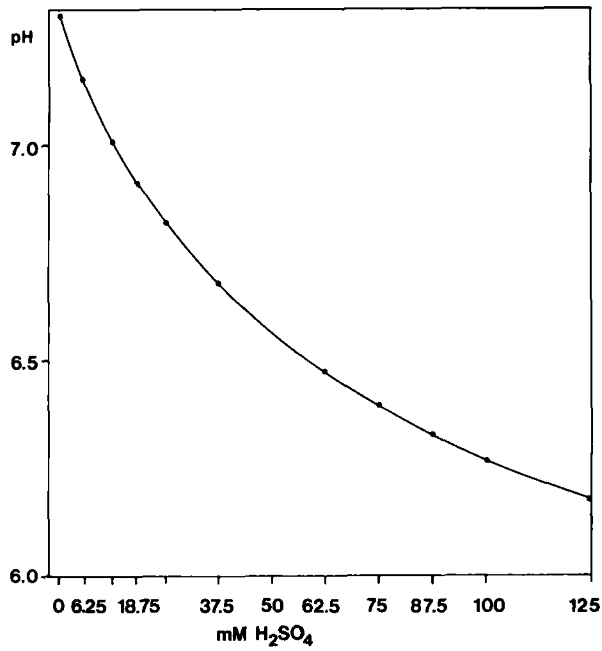

Figure 2 The change of pH of the 1 M NH_4Ac (initial pH 7.3) by adding H_2SO_4.

not represent the most recent centuries. Instead they cover the early agricultural period and the preceding few centuries. According to the historical data (cf. Vuorinen *et al.* in this volume)[1] the age of the boundary of these two phases found at the 45 cm level can be dated approximately to 15th century.

The pre-agrarian phase (64–35 cm)

The arboreal pollen data (AP) and especially that of *Picea*[2,3] show that the lowest part of the diagram belongs to the Sub-Atlantic chronozone.[4] The conifers seem to have dominated in the area during the period represented here while the QM pollen data (broad-leaved deciduous trees) were affected both by natural climatic deterioration, by invasion of *Picea* and by human impact (Fig. 3). When compared with the corresponding pollen frequencies in the diagram of Lake Lissjön it

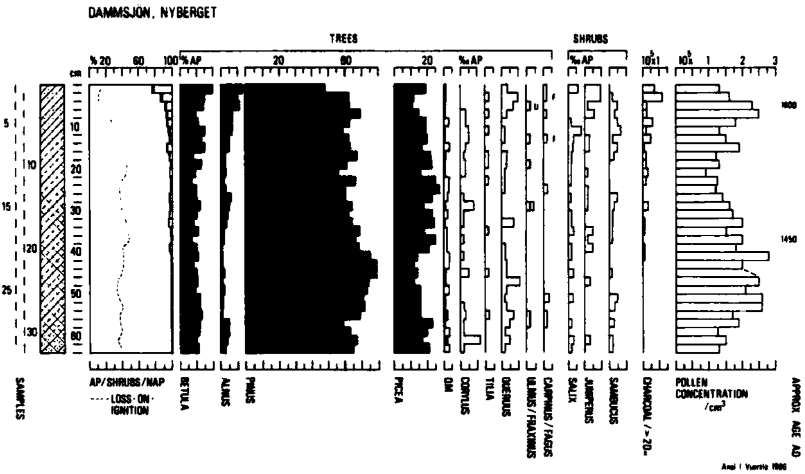

Figure 3 The data of tree and shrub pollen, total pollen concentrations and charcoal dust distribution in the sediment core.

seems evident that these two profiles enter almost the same level of vegetational history Dammsjön being slightly above the Pc+ level and Lissjön entering the start of the invasion of *Picea*.

Human impact may be reflected in the slightly decreasing *Picea* frequencies and in the relatively abrupt changes in the *Alunus* frequencies followed by fluctuations in the loss-on-ignition values. The very modest herb pollen data not to speak about the anthropogenic indicators during the pre-agrarian part of the profile, however, indicate that human activity was of relatively extensive kind, probably grazing or occasional settlement.

This is accompanied by mobilization of Fe and Mn from the lake surroundings and their subsequent deposition in lake sediments in loosely bound (NH_4Ac soluble) form, and by an increase in the relative chlorophyll and exchangeable and loosely bound Na contents, supposedly by their migration into lake—Na is preferentially bound by coniferous forest humus[5] (Figs 6, 7).

Slight but clear evidence of more intensive land occupation starts at the 45 cm level by a decrease in the QM pollen data accompanied by spores of *Pteridium* and pollen of *Epilobium* and *Rumex* (Fig. 4). At this

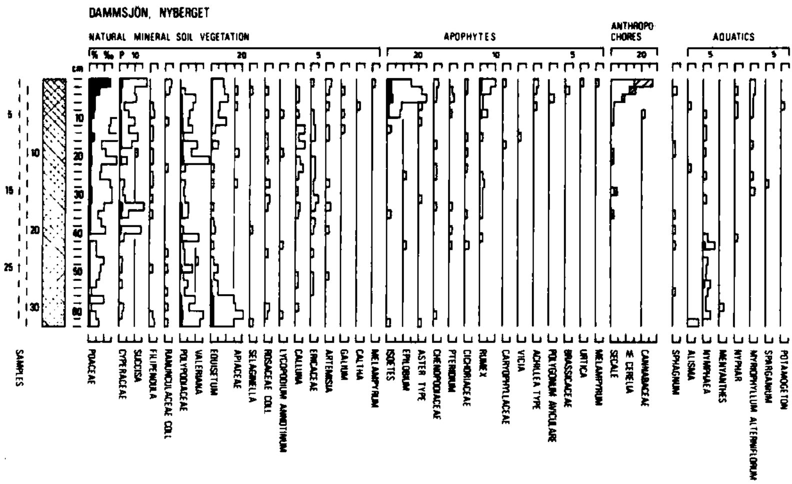

Figure 4 The pollen data of natural mineral soil vegetation, apophytes, anthropochores and aquatics in the sediment core.

level total herb pollen sum increases which confirms the interpretation of partial deforestation also reflected in the charcoal dust values.

The deforestation is accompanied by appearance of Fe and Mn oxides in sediments at the depth of 45 cm and upwards, and the increase in Pb content at the depth of 37 cm and upwards (Figs 6 and 8). These metals are considered mainly to have been migrated into the lake associated with suspended aluminosilicate matter from soils in the lake surroundings. Similar association of Pb in soil B horizons with amorphous hydroxides and mineral matter is reported by Glazovskoj[6] in contaminated areas—in "living soils" the heavy metals were mainly present in sorbed and organically bound forms.

Agrarian phase (35–0 cm)

The earliest evidence of agriculture—Cerealia pollen and spores of *Isoetes* occur at the 35 cm level in which connection both loss-on-ignition and pollen concentration values also indicate increasing field erosion (Figs 3 and 4).

Pollen evidence of man's activity stays, however, sporadical up to the 20 cm level and especially to the 10 cm level where great changes occur

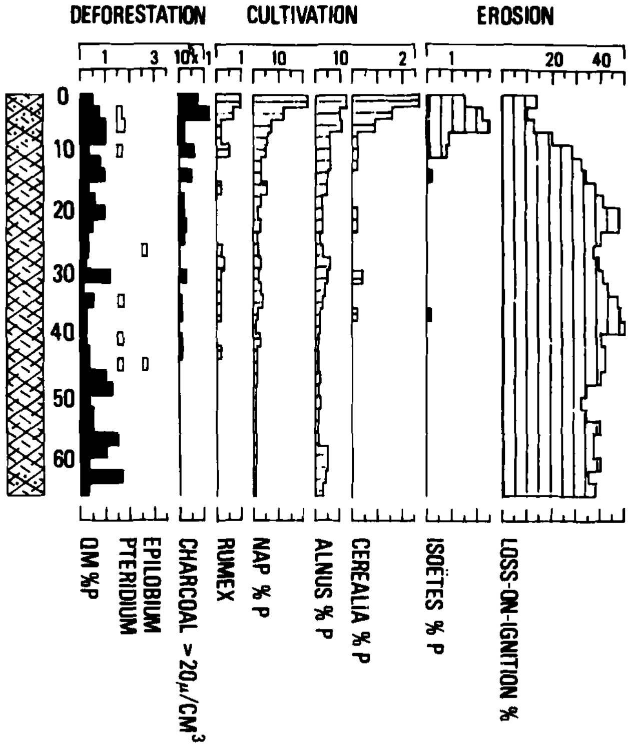

Figure 5 Deforestation, cultivation and erosion in the area of Lake Dammsjön as reflected by loss-on-ignition values, charcoal dust distribution and selected pollen data.

both in the pollen frequencies and in the indicators of erosion and sedimentation.

Among the tree pollen data it is especially *Alnus* and *Picea* that reflect clearing of nutrient rich soils in the vicinity of the sample site while increased values of herb and *Juniperus* pollen indicate opening landscape (Fig. 5). The charcoal dust concentration values which follow the pollen evidence of human activity are due to both mining activities and forest clearance. In a more open landscape the distribution of this indicator type was more effective than it had been until the fields existed between the sample site and the sites of human activity.

Among the natural mineral soil vegetation it was mainly Poaceae, Cyperaceae and *Equisetum* which profited from this kind of activity while among the hemerophiles Cerealia and *Rumex* indicate enlargening agricultural activities and spores of *Isoëtes* correspondingly increasing field erosion. In addition to grain cultivation the pollen find of *Cannabis* type in sample No 5 may indicate cultivation of this fiber plant in the area.

A distinct difference can be seen between the reflection of human activity in Dammsjön compared with that in the neighbouring Lake Lissjön.[1] While in the latter lake all the indicators were simultaneously represented in considerable frequencies, they only appear sporadically in most of the period represented in the diagram of Dammsjön.
The solution of this contradiction most evidently lies in the means if transportation of the eroded material including pollen from cultivated and settled areas.[8,9] In Lissjön this transportation mainly took place by water of the rivers passing through the area of mining and agricultural practices (Fig. 1), while in Dammsjön this was dependent on wind transportation through forested areas only until the shores of the lake were cleared for agricultural purposes. In the first decade of 17th century the water level of Lake Dammsjön was artificially risen by construction works. In connection with the rise of the water level by 3 m strong erosional processes must have taken place. The distinct palynological and sedimentological changes at the 10 cm level of the diagrams may reflect these events (Figs 3–5).

At the depth of 9 cm an acute increase in exchangeable and loosely bound Na, K, Ca and Mg and the Fe and Mn oxide maxima (Figs 6, 7 and 9) suggest redistribution of these cations and elements (the Fe and Mn oxides were associated with the mineral matter) as a consequence of hydrological construction works adjacent to the lake and rise of the lake water level by 3 m in the first decade of 17th century.

At the depths of 7–3 cm the exchangeable and loosely bound Na, K, Mg and Ca have minimal contents which suggests the leached character of the carbonate-bearing aluminosilicate impact material (i.e., eroded and transported into the lake from surrounding topsoil). This is accompanied by rapid sedimentation and maximal pollen concentration (300 000/cm^3) in the sediments (Fig. 3). At the depths of 5–0 cm the reducible loosely bound Pb and Zn contents (Fig. 8) show maximal contents (up to 200 mg Pb/kg) which is considered to represent a secondary pollution of the lake sediments by the pre-existing primitive iron smeltery nearby.

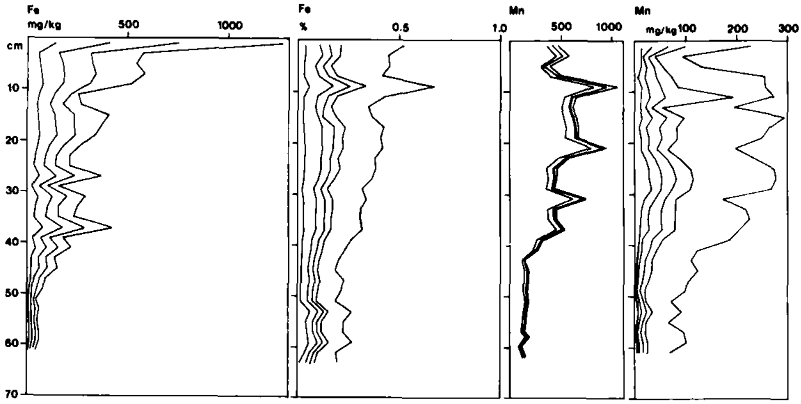

Figure 6 Distribution of NH_4Ac- (on the left hand) and HXl-HAc-soluble Fe and Mn (on the right hand) in the sediment core.

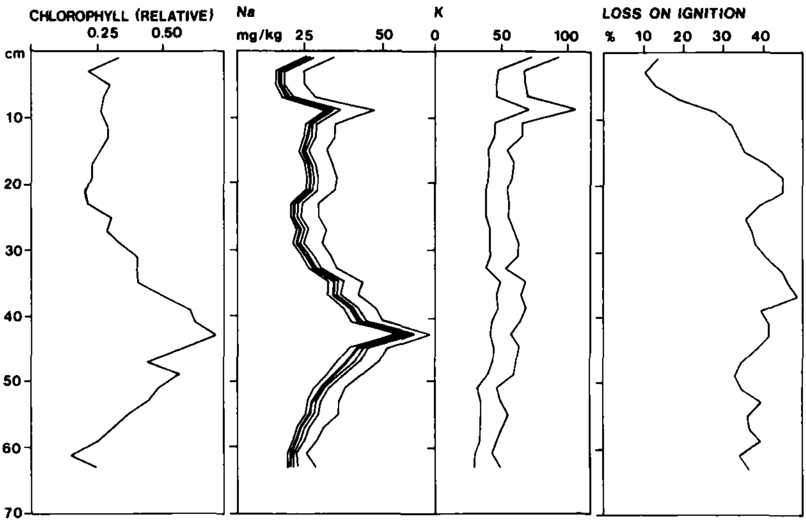

Figure 7 The relative chlorophyll content (optical density of acetone extractant at 670.3 nm per 1 g of dry sample), distribution of NH_4Ac- and HXl-HAc-soluble Na and K and the loss-on-ignition values in the sediment core.

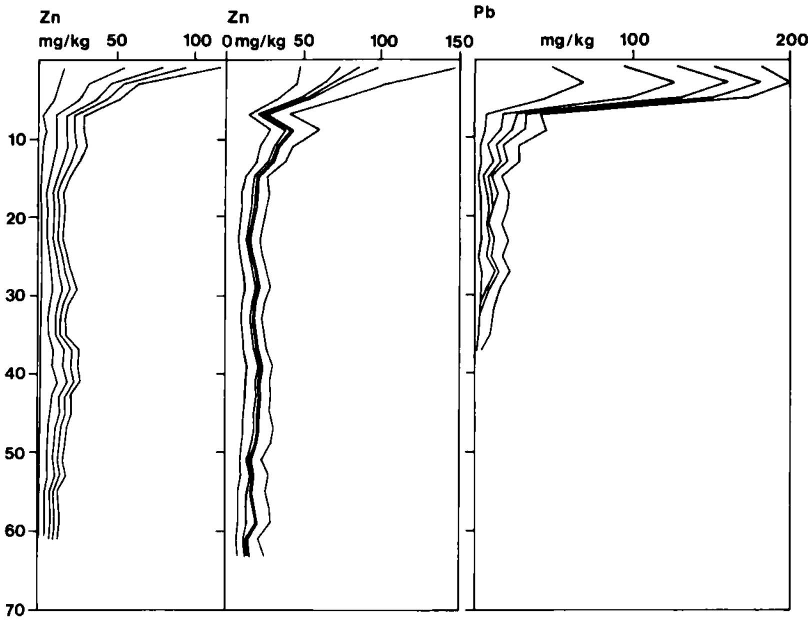

Figure 8 Distribution of NH_4- (on the left) and HXl-HAc-soluble Zn (in the middle) and HXl-HAc-soluble Pb (on the right) in the sediment core.

The loss-on-ignition values, the sample acidity (Figs 7 and 9) and exchangeable and loosely bound Ca (carbonate content) are in accordance in Lake Dammsjön column indicating neutralization of natural acidity by the carbonate-bearing aluminosilicate impact material.

CONCLUSIONS

The onset of settlement seems to be reflected in herb pollen data of the sediments of Lake Dammsjön and in appearance of Mn and Fe oxides. Oxide contents are highest in the upper part of the sediment core, as are the contents of exchangeable and loosely bound Na, K, Mg and Ca, suggesting intensified land use. An impact of leached aluminosilicate matter obviously caused by field and soil erosion is observed in the upmost part of the core. A rise in anthropogenic pollen frequencies in

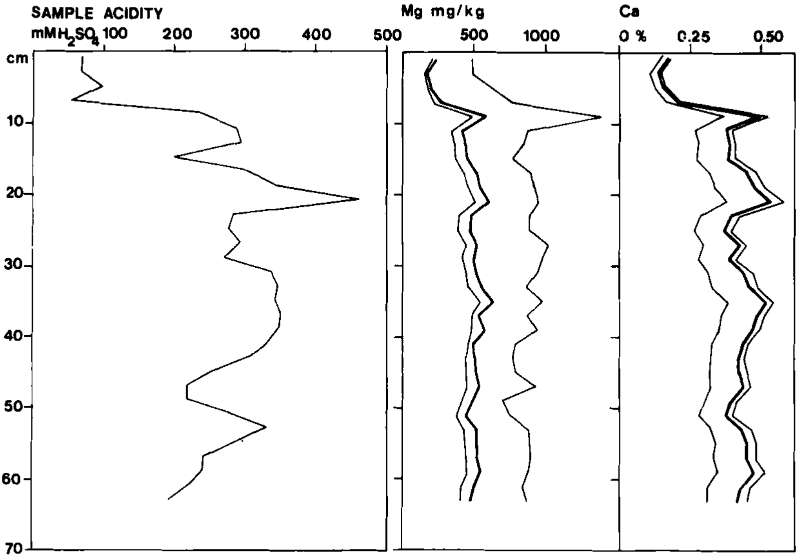

Figure 9 Sample acidity (corresponding mM H_2SO_4) and NH_4Ac- and HXl-HAc-soluble Mg and Ca in the sediment core.

the uppermost core suggests intensified agriculture. Increased amounts of Pb and Zn (max. 200.0 and 163.2 mg/kg, respectively) in loosely bound forms are associated with the mineral matter impact suggesting secondary pollution of the sediments. The pollution is evidently due to release of the metals from the pre-existing smelter and their subsequent redistribution. The natural acidity of the sediments seems to have been neutralized by the carbonate-bearing matter impact on the lake.

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