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PEAT AND COMPOST FILTERS FOR THE SEPARATION OF HAZARDOUS WASTES FROM WATER

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ANNUAL REPORT 1993-1994

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INTRODUCTION

The overall goal of this project is to develop an inexpensive, yet reliable filter made out of peat or related material, to adsorb and treat heavy metals and organic pollutants from industrial effluents. As outlined in our research proposal, such filter can find its niche in cases of small industries or remote isolated sources of pollution.

In order to achieve this overall goal we proposed to obtain the following specific objectives:

* To characterize the adsorption of heavy metals on the different organic substrates in order to enable prediction of adsorption capacity and intensity.
* To study metal desorption at different pH values in order to evaluate the possibility of desorption and reuse of the heavy metals.
* To evaluate the effect of additional electrolytes on adsorption and desorption.
* To study the effect of the different substrates on the biodegradation of organic pollutants.
* To plan and try small scale water treatment units.

The first year of our project was, unfortunately, affected by adverse administrative difficulties. The first payment addressed to the Polish Institution was some how lost. An investigation on the case took a long period. The problem was solved only a few weeks ago and the money was transferred. This delay in the payment caused real difficulties to our Polish group, as well as agony and mistrust. Till now, it was not clear if the project is active, or weather it is frozen till the administrative problems are solved. Unfortunately, the communication between the two principal investigators dealt with administrative problems, much more than in science. In addition, we were not able to arrange a meeting between the two investigators, to clear up technical approaches, to compare results, to discuss, compute and draw conclusions of experimental results or to plan future work.

The administrative problems have been solved. We plan to meet in mid-March and we do hope that the next stages of this project will go smoother.

The present report should accordingly, be considered as a preliminary presentation of results and not as a final presentation of a research phase.

SUMMARY

The first phase of work of the two groups was devoted to the collection of adsorbing substrates. The Polish group collected 26 samples of peat from different sites in Poland. The Israeli group have collected 2 samples of peat in the Hula Valley, purchased three batches of agricultural peat substrate, imported from Germany, Finland and the Netherlands. In addition they took samples of municipal solid waste compost (MSWC) and of sewage sludge.

The next stage was the characterization of the substrates. The main means of classification were pedological definition, X-ray structure analysis and IR spectroscopy and the determination of pH, bulk density, specific gravity and porosity, used by the Polish group, and the determination of organic carbon contents, heavy metal contents, acidity and specific surface area used by the Israeli team. This lack of coordination will be corrected in future work.

The bulk of the work done by the two groups was the measurement and evaluation of heavy metals adsorption. The technique used by the two groups was, regretfully different. The Israeli group developed a protocol under which, all samples had a constant pH. the rationale of this was that since pH is such an important factor determining heavy metals adsorption, a constant pH is essential for the comparison of results obtained in different substrates. The Polish group preferred to study adsorption at different pH values, as dictated by the different systems, since they assumed that the addition of buffers or the pre treatment of the substrates will change the nature of the adsorbent. The typical adsorption maxima found in Poland were usually an order of magnitude higher than those reported by the Israeli group. One possible reason for this discrepancy is the different pH system.
The effect of pH on the adsorption of heavy metals will be studied this year. This, and the agreement on comparable experimental protocols to be achieved in the coming soon meeting of the two principal investigators will probably lead to the calibration of results from the two groups.

The adsorption data were evaluated and interpreted, presently, separately by each group. The Israeli group interpreted the results according to the Langmuir adsorption theory and equations. Doing this, it was found that the results seemed to better suit a two compartments adsorption model. The Polish group followed a sequential extraction procedure and is proposing to define and describe the heavy metals adsorption as distributed among 7 pools, pore water held ions, exchangeable, carbonate, easily reducible, moderately reducible, organic/sulphidic and residual.

The two groups have tested a large number of substrates, proved effective adsorption properties and are ready to develop these findings toward a more elaborated work. The exact agreed upon work plan for the second year will be sent within a few weeks.

We anticipate that now, when the administrative problems are solved, a much more effective and coordinated work will follow.

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(our no. 150-708)

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1. Summary

First three months of project were devoted to selection and analysis of properties of adsorbing materials. Samples of compost, commercially sold North European peat, peat from the Hula valley Israel and sewage sludge were collected.

Dry matter content of the adsorbents was found to be in range 40 to 82% and that foilowed the order Sewage sludge > Composts > Peat Hula > Commercial Peats. All computations and reported data are given on a dry matter base. Organic matter content of the adsorbents was found to be in range 28 to 98.7% and that followed the order Commercial Peats > Peat Hula > Sludge > Composts. Compost Afula fraction 0 - 5 mm was determined to have the smallest specific surface area, 30.7 M^2/gr, while commercial peat # 1 the biggest specific surface, 204.5 M^2/gr. Quantitative analysis of heavy metals was also conducted; all samples contained more Zinc than Copper.

Acidity of the adsorbents varied in broad range. More than 12 mg of NaOH was required for each gram of the Hula peat to bring the pH of its aqueous suspension to 7.5. To get the same pH in suspension of commercial peat # 3. less than 0.01 mg of NaOH was needed. The acidity followed the order Hula Peat > Commercial Peats > Sludge > Composts. To minimize the effects of varying acidity and to establish reproducible base-line in adsorption experiments the same were conducted at constant pH.

Isothermal adsorption of Cu^{2+} and Zn^{2+} onto the adsorbents was also studied, the experiments were conducted in batch mode in agreement with procedure developed in this laboratory. Copper concentration was in range 0 to 5000 µgr Cu/L; zinc concentration was in range 0 to 11800 µgr Zn/L.

Average efficiency of Cu adsorption was, on all adsorbents tested, higher than 94.6 %. on both high and low concentrations. Peat and sludge were very good in removal of Zn from polluted waters, their average removal efficiency was higher than 92%. This was not the case with composts produced from municipal solid waste, there removal efficiency was in range 68 to 85%. At equivalent metal concentration all materials tested adsorbed more Cu than Zn.

Maximal adsorption capacity of Hula up peat for Copper, 6585 µgr Cu/gr peat, was some 1.90 times higher than the maximal adsorption capacity of commercial peat # 2 and almost five times as high as that of HCl leached compost "Naman". Maximal adsorption capacity of commercial peats was roughly equal for Cu and Zn. The ratio of maximal adsorption capacity for Copper to that of Zinc on various fractions of Hula peat was in range 1.06 to 2.30.

In practice for safe and reliable plant operation only a fraction of adsorbent's maximal capacity should be used. The fraction should not exceed 60 - 70% of the capacity. By doing so standards pertaining to heavy metal concentrations could be easily met.

A phenomenon similar to the inflection point on titration curves was detected on the Langmuir isotherms depicting Cu and Zn adsorption. Inflection points could have been due to the sequential saturation of different functional groups present throughout adsorbent matrix. The points could be used for the detection of concentration intervals of adsorption isotherm which had different free energy of adsorption. The concentration intervals exhibiting differences in free energy of adsorption were probably governed by separate adsorption mechanism

2. Introduction

There is a need for elimination of soil and water pollution by heavy metals and recalcitrant organic throughout the world. Present decontamination routines are inadequate and often costly The problem is that trace quantities of the substances contaminate immense amounts of water so the efficient decontamination requires huge reactor volumes which is especially pronounced when chemical precipitation, the most common treatment practice today, is used for removal of metals.

Our working hypothesis rely on fact that peat, compost and similar materials have a pronounced capacity for adsorption of heavy metals and organic. The capacity is due to adsorbent's high specific surface yet it's structure is porous enough to allow good hydraulic conductivity. In addition the materials are cheap and when saturated can either be disposed by incineration or treated biologically to degrade recalcitrant organic. If need be adsorbed metals can be reused after leaching with acids.

The general objective of the project is the development of inexpensive but reliable filtration - adsorption process for separation of heavy metals and/or recalcitrant organic from effluents and further treatment of the pollutants at elevated concentrations.

The specific objectives during the first year, 1993 - 1994, of research were:

a. to select and analyze few promising adsorbent

b. to study precipitation free adsorption of Cu and Zn at pH as close to neutral as possible.

c. to develop reproducible method for elucidation of adsorption isotherms on peat and materials alike.

d. to correlate physico-chemical characteristics of adsorbent with its adsorbing properties.

3. Experimental

3.1 Materials

3.1.1. Chemicals

Stock Solutions, having a metal concentration of 1000 mg/L, were prepared by dissolving separately 2.744 g $ZnSO_4*H_20$ and 3.929 g $CuSO_4*5H_20$ in 1000 mL H_20.

Working Solution were made from stock solution by diluting it to concentration 0 - 500 mg Me^{2+}/L.

Acetate Buffer was prepared by mixing 87.5 mL Na-acetate (2N) with 12.5 ml concentrated CH_3COOH and adding distilled H_20 up to 1000 mL.

3.1.2. Adsorbents

Peat from the Hula valley Israel, commercially sold North European Peats, compost from municipal waste and an aerobically digested sewage sludge were tested as Cu and Zn adsorbing materials. Analysis performed on the adsorbents are described in chapter 3.2.; results of analysis are given in chapter 4.

3.2. Methods

3.2.1. Instruments

Atomic adsorption spectrophotometer "Varian - Spectra 300 Plus", pH meter "Metrohm 654", Centrifuge, Conductivity meter, shaker were used during the work.

3.2.2. Sample Preparation

Adsorbents were tested at constant pH in either *status nascendi* or after washing with H_2O or HCl. In washing pre treatment Whatman # 1 or # 42 filter paper was placed into wide Buchner funnel to which one to three L of a material was added. The material was slowly leached with distilled H_20 or HCl, water to solid ratio (w/w) was 5 to 1. Leached sample was vacuum dried and kept in refrigerator at cca 5^oC.

Determination of buffer mixtures for constant pH: place 10 g of peat into suitable glass and add different amount (0 - 50 mL) of 0.5 N HCl. Make final volume of samples to 50 mL using acetate buffer. Put on shaker (100 RPM) and shake overnight. Measure pH in samples. An acid addition that yields desired pH is used in subsequent experiments.

3.2.3. Method for Elucidation of Adsorption Isotherm on Peat and Materials Alike.

Mixture of acetate buffer and HCl (50 mL) was added to 10 g of an adsorbing material. Suspension was pre-equilibrated for 16 h. Immediately thereafter 50 mL of either Cu or Zn working solution of known concentration C was added to suspension. The suspension was shaken for additional 20 hours and than filtered through Wathman # 1 or # 42. In case of slow filtration solid and liquid phases were separated by centrifugation.

Metal concentration, C_o = metal concentration at 0 time and C_{eq} = metal concentration in equilibrium after 20 hours adsorption, was determined by atomic adsorption.

3.2.4. Other Methods

All other analyses were performed in agreement with "Methods of Soil Analysis" (1982) except for determination of humic and fulvic acids (Stevenson 1965) and organic carbon (Raveh & Avnimelech 1972).

4. Research Activities and Discussion

Adsorption process is critically affected by several factors one of which is pH; at its low values adsorbent's weak acidic groups are slightly dissociated and marginally contribute to the process while on high pH metal precipitate and can be physically entrapped within adsorbent matrix. Metal solubility increases and its adsorption decreases with decreasing pH. At the present stage we chose to conduct the experiments at the highest pH range at which precipitation does not take place. Hula peat had to be acidified in order to maintain chosen pH.

First three months of the project, stage A - Chapter 4.1, were devoted to selection and analysis of properties of adsorbing materials. Results are given in Tables 1 and 2.

Isothermal adsorption of Cu and Zn on adsorbents selected was studied next (stage B - Chapter 4.2).

4.1. Stage A - Selection and Analysis of Adsorbents

Peat's matrix contains various amounts of immobilized humic acids (**HA**) and fulvic acids (**FA**). In the solution humic acids and metal ions form stable complexes which is attributed to functional groups like -COOH, phenolic, alcoholic, enolic -OH and -C=0 existing in **HA**'s. Fulvic acids also complex with metals but their total acidity (640 - 1420 meq/100 gr) is considerably higher than that of humic acids (560 - 890 meq/100 gr) because -OH and -COOH groups contribute more to the acidic nature of **FA**'s with -COOH being more important (Chen and Avnimelech 1986).

Hula valley peat is highly mineralized lowland peat which contains up to 61.4 % organic matter and has high surface area (Column 2 and 3 in Table 1) but its acidity is high. We found that more than 12 mg of NaOH was required for each gram of the peat to bring pH to 7.5 in its aqueous suspension. To get equivalent pH in suspension of commercial peat # 3 only traces of NaOH were needed (Column 4 in Table 1). Acidity of tested adsorbents varied in very broad range (column 4 in Table 1) but follows the order Hula Peat > Commercial Peats > Sludge > Composts.

To minimize the effects of varying acidity and to establish reproducible base-line in adsorption experiments (Chapter 4.2) we conducted them at constant pH. For this reason a number of buffers were tested and acetate buffer was found to give stable pH in all samples but in

samples of Hula peat. Buffering capacity of the peat suspension was so high that easily suppressed buffering capacity of acetate and other butters tested. We found that the pH in the peat suspension could be kept constant only if the peat is pretreated with acid. The procedure concerning pre treatment of the peat samples is described in chapter 3.2.2.1.

Analysis on adsorbents' dry matter content were also conducted. Minimal amount of dry matter, 40%, was found in commercial peat # 1 the amount of dry matter in sewage sludge was more than two time higher (82.2%). Dry matter content for the adsorbents followed the order Sewage Sludge > Composts > Peat Hula > Commercial Peats (Column 1 in Table 1). Computations and reported data are given on a dry matter base.

The adsorbents had organic matter content in range 28%, compost "Afula" fraction 0 - 8 mm, to 98.7% commercial peat # 3. Organic matter content followed the order Commercial Peats > Peat Hula > Sewage Sludge > Composts (Column 2 in Table 1).

Compost "Afula" fraction 0 - 5 mm was determined to have the smallest, 30.7 M^2/gr, while commercial peat # 1 the biggest, 204.5 M^2/gr, specific surface in the group (Table 1). Although organic matter content and dry matter content followed certain order it appeared that specific surface of the adsorbents varied randomly (Column 3 in Table 1). The question will be re-examined in near future.

Quantitative analysis of heavy metals was also conducted on the adsorbents, all were found to contain more Zn than Cu (Table 2).

Adsorbent	DM	OM	AM2	ACD	pH_o
Sludge(1)	82.2	47.4	68.8	0.2650	6.71
Commercial Peat(2):					
#1	40.4	98.5	204.5	0.7450	5.40
#2	50.0	94.4	77.9	0.1700	6.70
#3	43.5	98.7	151.3	1.1900	4.80
Compost "Afula" Fraction(3):					
0-5mm	74.9	45.3	30.7	0.1500	6.78
0-8mm	71.8	28.0	52.5	0.0002	7.44
8-18mm	75.9	32.3	82.0	0.0900	7.18
Compost "Naman"(4):					
(a)		43.9	108.1	0.1600	7.10
(b)	69.2	59.7	188.8	0.0400	7.37
Peat "Hula"(5):					
Up-Peat		51.1	125.3	3.1000	5.30
Bottom-Peat(b)		58.1	80.8	0.6400	6.50
Bottom-Peat(c)	68.8	61.4	127.8	0.5500	

Table 1. Adsorbents Used and Their Characteristics;

DM = Dry Matter %,
OM = Organic Matter %,
AM2 = Specific Surface M^2/gr (EGME),
ACD = Acidity as meq NaOH per 10g of adsorbent to bring pH to 7.5,
pH_o = suspension pH at time 0.

(a) = Not leached,
(b) = H_2O leached,
(c) = HCl leached.

(1) Dry sewage sludge, following sedimentation and anaerobic digestion in the Haifa sewage treatment plant.
(2) Peat sold as substrate, imported from the Germany, Finland, Germany, respectively.
(3) Municipal waste compost from the "Afula" plant.
(4) Municipal waste compost from the "Naman" plant.
(5) Peat of the Hula valley Israel; fraction up peat sampled at the soil surface, fraction bottom peat sampled 120 cm below the soil surface.

	M E T A L					
	Cu	Zn	Cd	Mn	Fe	Mg
			(μgr/gr)			
Sludge:						
avg	306.5	1943.5	10.70	200.7	17562	6330
std	28.7	24	0.74	41.9		
Commercial Peat:						
#1						
avg	1.40	19.0	0.44	6.1	923	998
std	0.04	2.06	0.11	0.2	74	95
#2						
avg	13.0	17.4	0.23	36.5	543	3078
std	0.2	0.26	0.03	0.8	19	8
#3						
avg	6.1	19.0	0.46	3.8	356	26184
std	0.1	1.14	0.17	0.0	68	25106
Compost "Afula" Fraction:						
0- 5mm						
avg	362.4	490.9	2.48	774.5	9568	7733
std	26.6	81.6	1.01	588.1	1539	959
0- 8mm						
avg	364.3	628.7	2.42	192.7	10402	13457
std	64.5	116.73	0.03	14.2	1101	
8-18mm						
std	336.4	469.1	13.03	216.2	15456	14980
avg	24.2	40.0	0.44	49.5	4027	8170
Compost "Naman":						
avg	132.0	646.3	9.10	126.9	5797	6751
std.	61.4	397.1	9.63	67.4	2578	5432
Peat "Hula":						
Up-Peat						
avg	13.7	36.8	0.25	69.1	23146	1609
std	7.6	11.6	0.07	4.4	1848	249
Bottom-Peat						
avg	10.5	27.5	0.36	86.0	15834	3440
std	2.8	8.0	0.27	13.4	2955	1134

Table 2. Total Heavy Metal Contents for Adsorbents Used; avg = average, std = standard deviation.

4.2. Stage B - Batch Adsorption Experiments

Various experimental approaches were used to determine the binding capacity of humic and fulvic acids for metal ions in solution. These include coagulation, proton release, dialysis, stripping voltametry and ion-selective electrode measurement. Studies on Cu^{2+} and Zn^{2+} adsorption on selected adsorbents were conducted in batch mode in agreement with procedure developed in our laboratory (chapter 3.2.3.).

4.2.1. Efficiency of Adsorption and Maximal Adsorption Capacity

Results of experiments to determine efficiency and maximal capacity of adsorption are presented in Figures 1 to 15 and Tables 3 to 5.

Chaney and Hundemann found peat to adsorb more than 99% of Cd^{2+} from solution whose initial concentration was 100 mg Cd^{2+}/L (1979). In chemical precipitation similar Cd removal is experienced at pH higher than 9 (Lanouette 1977). Adsorbents we tested were of similar efficiency in removal of Cu^{2+} ions on both high and low concentrations (Table 3, Figures 1 to 15). Peat of Hula valley, commercially sold peats and sewage sludge were also very good adsorbents for decontamination of Zn polluted waters but this was not the case with composts produced on municipal solid waste (Table 5 and Figures 1 to 15).

Equilibrium adsorption capacity for Cu^{2+} was determined from the amount of Cu in solution after period of contact with adsorbent. Copper solutions, over concentration range 0 to 5000 μgr Cu/L, were equilibrated for period of one day with a known amount of adsorbent. The efficiency of Cu adsorption was always higher than 94.6 % (Table 3 and Figures 1 to 15).

The equilibrium adsorption capacity for Zn was determined in the same manner as that of Cu except that Zn concentration was in range 0 to 11800 μgr/L. The efficiency of Zn removal was in range 68.19 to 97.99% (Table 3 and Figures 1 to 15).

Adsorbent	Average Removal Efficiency. % adsorbed and number of readings (nn)	
	Cu	Zn
Sludge	98.20 (25)	92.72 (39)
Commercial Peat:		
# 1.	99.37 (22)	97.95 (14)
# 2.	98.72 (23)	94.33 (12)
# 3.	99.38 (22)	96.87 (14)
Compost "Afula" Fraction (mm):		
0- 5	97.72 (25)	78.52 (22)
0- 8	97.90 (26)	68.19 (21)
8-18	94.66 (11)	
Compost "Naman"	96.95 (34)	85.08 (33)
Peat "Hula"		
Up-Peat	99.49 (23)	95.70 (42)
Bottom Peat	99.76 (54)	97.99 (12)

Table 3. Adsorption Efficiency

Linear regression analysis was performed on experimental data using rearranged form of Langmuir isotherm (equation 2); calculated values of maximum adsorption capacity (M), factor of free energy of adsorption (E) and square of regression coefficient (R^2)are given in Tables 5 and 6. The use of the Langmuir isotherm to Cu^{2+} and Zn^{2+} adsorption onto adsorbents tested is, on one side, justified by the rather homogenous surface of adsorbents and, on the other, by size and geometry of adsorbent's particles which yield significant adsorption surface (Table 1).

The Langmuir isotherm is expressed as:

$$Y = (a * b * X) / (1 + b * X) \qquad \text{eqv. 1.}$$

coefficients a and b were estimated from equation 2.

$$1/Y = 1/b + (1/(b*a)) * (1/X) \qquad \text{eqv. 2.}$$

where:

Y = the mass of metal adsorbed per mass of adsorbent at equilibrium = SAA (see below)

X = measured metal concentration in solution at equilibrium

a and b = constants

b = M = the maximal metal adsorption capacity of adsorbent
(b/a) = E = the factor related to free energy of adsorption $\approx e^{(-\partial G/RT)}$

The amount of metal adsorbed (AA) was calculated from:

$$AA = (C_O - C_{eq})/10 \qquad \text{eqv. 3.}$$

where:

C_O = Metal concentration at beginning of experiment.

C_{eq} = Metal concentration at the end of experiment.

Specific Amount Adsorbed (SAA) was calculated from:

$$SAA = AA/m = (A/10)*1000 \qquad \text{eqv. 4.}$$

Adsorbent	Leached	pH	M	E	R^2
Sludge:	Not	5.9	4223	0.0841	0.98
	H_2O	5.5	3434	0.0175	0.99
Commercial Peat:					
#-1	Not	5.8	3866	0.1090	0.99
#-1	H_2O	5.4	2999	0.2864	0.99
#-2	Not	5.5	3513	0.0584	0.99
#-2	H_2O	5.5	2208	0.2511	0.97
#-3	Not	5.6	4572	0.1180	0.99
#-3	H_2O	5.4	3346	0.1980	0.97
Up Peat "Hula"	Not	5.3	6585	0.0620	0.99
	H_2O	5.4	3610	0.1100	0.97
Bottom Peat	H_2O	5.5	4994	0.0681	0.94
	HCl	6.2	5091	0.0562	0.89
	HCl	5.4	3432	0.3400	0.90
	HCl	5.2	3233	0.1090	0.99
Compost "Afula" Fraction mm:					
0-5	H_2O	6.0	3382	0.0484	0.95
0-5	H_2O	5.5	4217	0.0165	0.96
0-8	Not	6.2	4294	0.0391	0.96
0-8	H_2O	5.6	3723	0.0226	0.96
8-18	H_2O	5.4	2116	0.0199	0.91
Compost "Naman"					
	H_2O	5.8	5557	0.0234	0.99
	HCl	5.4	1400	0.0402	0.98
	HCl	4.9	2124	0.0293	0.96

Table 4. Estimated Values of Maximal Adsorption Capacity (M) and Energy Factor (E) for adsorption of Cu on Adsorbent Tested; R^2 = regression coefficient.

Adsorbent	Leached	pH	M	E	R^2
Sludge:	H_2O	5.4	5076	0.0031	0.88
Commercial Peat:					
#-1	H_2O	5.4	3665	0.0300	0.99
#-2	H_2O	5.5	3060	0.0110	0.99
#-3	H_2O	5.3	3268	0.0204	0.99
Up Peat "Hula"	Not	5.3	2838	0.0198	0.99
	H_2O	5.5	3211	0.0098	0.99
	HCl	5.7	1803	0.0344	0.99
Bottom Peat "Hula"	H_2O	5.3	4752	0.0187	0.87
Compost "Afula" Fraction mm:					
0-5	H_2O	5.8	309	0.0239	0.52
0-8	Not	5.9	726	0.0067	0.54
8-18	H_2O	5.3	24579	0.0005	0.68
Compost "Naman"					
	H_2O	5.6	17863	0.0008	0.65
	HCl	5.5	1474	0.0082	0.67

Table 5. Estimated Values of Maximal Adsorption Capacity (M) and Energy Factor (E) for Adsorption of Zn on Adsorbent Tested; R^2 = regression coefficient.

In *status nascendi* Hula up peat exhibited highest maximal adsorption capacity, 6585 μgr Cu/gr peat. The peat maximal adsorption capacity for Cu was some 1.90 times higher than the maximal adsorption capacity of commercial peat # 2 and was almost five times as high as that of HCl leached compost Naman (column M in Table 4).

To gain better insight into the problematic selected adsorbents characteristics were examined in *status nascendi* and after pre treatment. The pre treatment consisted of leaching with either distilled H_20 or HCl (see chapter 3.2.3). We found Hula up peat to be the most sensitive to washing; commercial peats were less sensitive to washing; sewage sludge and compost Afula were the least sensitive to leaching with H_20. Naman Compost was found to have the highest maximal adsorption capacity after leaching with H_20 (column M in Table 4).

Washing the adsorbent, with either H_20 or HCl seems to reduce the maximal adsorption capacity. The reproducibility of this phenomenon has to be checked. Though the phenomenon has to be checked, it is possible that leachning washed out either mineral impurities (e.g. CaCO3, iron oxides, clay) or some active organic groups.

The reproducibility of this phenomenon will be further tested. If it will be found real, this may have important practical implication, such as the reduced capacity of regenerated adsorbent.

It is interesting to note that maximal adsorption capacity for Cu of majority of adsorbents after washing with H20 clustered in range 3000 to 4000 μgr Cu/gr adsorbent.

Maximal adsorption capacity was, as expected, found to decrease with decrease in pH at which adsorption was conducted (see columns pH and M in Tables 4 and 5). For example more than 5000 μgr of Cu was adsorbed per gram of Hula up peat when adsorption was conducted at pH 6.2. On pH 5.2 each gram of the peat adsorbs only 3233 μgr Cu (columns pH and M in Table 4).

The values of the maximal adsorption capacitiy M_{Cu}/M_{Zn} ratio (see column AD in Table 11) show that the fractions of Hula peat adsorbed on average 1.4 times more Cu than Zn. Calculated M values for Cu and Zn on commercial peats # 1 and # 2 were, on average, 18% higher in Zn adsorption. Commercial peat # 3 adsorbed almost equal amount of Cu and Zn while sewage sludge was found to adsorb less Cu than Zn (see M values in Tables 4 and 5). Apparently preferential adsorption changed from adsorbent to adsorbent and the values of adsorbent's M_{Cu}/M_{Zn} ratio were within interval 0.67 to 2.41. In contrast M_{Cu}/M_{Zn} ratio on composts produced from municipal solid waste varied in interval, from 0.09 to 10.95 (see M values in tables 4 and 5 and AD column in Table 11). In addition compost Afula fraction 0-5

mm maximal adsorption capacity (M) for Zn was found to be slightly higher than 300 μgr Zn per gram compost while compost Afula fraction 8-18 mm had M for Zn of more than 24000 ugr Zn per gram compost. When compost Naman was H_2O leached its maximal adsorption capacity for Zn was calculated to be almost 18000 ugr Zn per gram compost but when the compost was washed with HCl its maximal adsorption capacity for Zn decreased more than 90% (see Table 5). Such fluctuations in M values and M ratio were not observed with other adsorbents tested. In addition linear regression analysis for the composts and Zn adsorption yielded R^2 values smaller than 0.7 (column R^2 in Table 5). From the data presented in Figures 6 to 10 and Figure 15 and behavior of the composts in Cu adsorption we could see that the composts could be as efficient as other adsorbents tested. Limited sample size and, perhaps, aging of composts under storage conditions we employed are plausible explanation for the observed fluctuations. Fresh batches of the composts were sampled recently; zinc adsorption experiments will be repeated in near future.

Adsorbents physico-chemical characteristics (Tables 1 and 2) and their maximal adsorption capacities (see column M in Tables 4 and 5) were examined and correlated (Table 5A). Adsorbents' specific surface (AM2) and its maximal adsorption capacity (M) for either Cu or Zn were found to be weakly correlated; in all cases studied regression coefficient (R) was equal or smaller than 0.38 (AM2 column in Table 5A). High correlation was found when adsorbent organic carbon (OC) was related to its maximal adsorption capacity (M); regression coefficient (R) here was found to be 0.73 and 0.89 for Zn and Cu respectively (see M-correlation below). Weak correlation was found between hygroscopic water content (HW) and adsorbents' maximal adsorption capacity (M), (see M-correlation Table 5A).

Adsorbents physico-chemical characteristics (Tables 1 and 2) were also correlated with their free energy of adsorption factor (E in Tables 4 and 5). Best correlation was found when specific surface area (AM2) was related to copper's energy factor regression coefficient (R) here was found to be equal to 0.88. No other strong relationship were found (see Table 5B).

Adsorbents examined have, even after leaching with H_20 or HCl, high adsorption capacity for Cu and for Zn. They are cheap. Sewage sludge even has negative cost. In removal of heavy metals from effluent only a fraction of adsorbent's maximal capacity should be utilized. In practice for safe and reliable plant operation not more than 60 - 70% of the maximal adsorption capacity should be utilized. By doing so standards, like Water Quality Criteria EPA R3-73-033, concerning heavy metal concentrations could be easily met.

M-correlation :

$M_{Cu} = 3.35 * 10^1 * OC - 1.57 * 10^3$ R = 0.89 (a)
$M_{Zn} = 2.51 * 10^1 * OC - 6.82 * 10^2$ R = 0.73 (a)
$M_{Cu} = 7.27 * 10^0 * OC + 8.21 * 10^2$ R = 0.65 (b)
$M_{Zn} = 1.41 * 10^1 * OC + 3.91 * 10^3$ R = 0..11 (b)
$M_{Cu} = -8.56 * 10^0 * AM2 + 4.56 * 10^3$ R = 0.28
$M_{Zn} = -7.97 * 10^0 * AM2 + 4.40 * 10^3$ R = 0.38
$M_{Cu} = 7.18 * 10^1 * HW + 3.24 * 10^3$ R = 0.16
$M_{Zn} = -7.58 * 10^2 * HW + 9.16 * 10^3$ R = 0.29

Table 5A. Correlation - Physico Chemical Characteristics and Maximal Adsorption Capacity; (a) compost Afula fractions 0-5 and 0-8 mm Ms' were excluded, (b) all data included.

E-correlation :

$E_{Cu} = -4.1 * 10^{-5} * OC + 9.53 * 10^{-2}$ R = 0.32
$E_{Zn} = -9.8 * 10^{-6} * OC + 1.40 * 10^{-2}$ R = 0.14
$E_{Cu} = 3.39 * 10^{-2} * HW - 7.98 * 10^{-3}$ R = 0.52
$E_{Zn} = 9.99 * 10^{-4} * HW + 8.12 * 10^{-3}$ R = 0.30
$E_{Cu} = 1.54 * 10^{-3} * AM2 - 6.53 * 10^{-2}$ R = 0.88 (c)
$E_{Zn} = 8.36 * 10^{-5} * AM2 + 4.41 * 10^{-3}$ R = 0.41 (c)
$E_{Cu} = 1.22 * 10^{-3} * AM2 + 1.61 * 10^{-2}$ R = 0.34 (d)
$E_{Zn} = 5.48 * 10^{-5} * AM2 + 6.79 * 10^{-3}$ R = 0.34 (d)

Table 5B. Correlation Physico-Chemical Characteristics and Energy Factor; (c) compost Naman, Bottom peat Hula and commercial peat # 2 Es' were excluded, (d) all data included.

In Tables 5A and 5B:

OC = Organic Carbon (mg/gr)
AC = Acidity (meq NaOH/ 10 gr adsorbent)
AM2 = Specific Surface M^2/gr ,
HW = Hygroscopic water (%)

4.2.2. Inflection Points

Inspecting Figures 1 to 15 we observed a phenomenon similar to the Inflection Point (IP) on titration curves. The phenomenon was particularly pronounced for samples Cu-2 and Zn-2 Figure 1, Zn-3 Figure 2, Zn-1 Figure 3, Cu-2 and Zn-1 Figure 5, Cu-2 and Zn-1 Figure 6, Zn-1 Figure 10, Cu-1 Figure 14. The observed inflection points could be due to the sequential saturation of different functional groups present throughout adsorbent matrix. If so than inflection points on adsorption curves, within the concentration interval we used in tests, also indicate that the chemical interaction between Me^{2+} and adsorbents functional groups was important adsorption mechanism. This does not minimize importance of other (physical and pysico-chemical) adsorption mechanisms and weak interactions.

To check if detected IPs' are the real phenomenon and not the "calculation artifact" we first determined the position and than the number of IPs for each particular adsorbent. Calculation procedure used for detection of position of inflection point is outlined below; in short, crude adsorption data were first arranged as in Table 6. Than the first derivative, dCuA/dCuE, was calculated by dividing the difference between two adjacent CuA values by the difference between two adjacent CuE values. Second derivative, $d^2CuA/dCuE^2$, was computed by taking the difference between two adjacent dCuA/dCuE values. Than we normalized second derivative by deviding each $d^2CuA/dCuE^2$ value in the sample by maximum $d^2CuA/dCuE^2$ value for that sample.

CuE	CuA	dCuA/dCuE	$d^2CuA/dCuE^2$	NV
0.00	0.00		0	0.00
1.17	406	347	347	0.07
2.49	644	180	167	0.03
3.20	804	226	46	0.01
4.15	962	166	-60	0.01
5.60	1198	163	-3	0.00
6.31	1442	343	180	0.03
6.34	1609	5560	5217	0.99
8.00	2010	242	-5284	1.00
13.90	2369	61	-181	0.03
16.45	2762	154	93	0.02
23.60	3108	48	-106	0.02
28.15	3481	82	34	0.01
31.35	3867	121	39	0.01

Table 6. Adsorption Data For Inflection Point Determination for Cu Adsorption on Sewage Sludge; CuE = Copper concentration in equilibrium (μgr/L), CuA = Specific amount of Copper adsorbed (μgr Cu/gr sludge), NV = Normalized value of $d^2CuA/dCuE^2$.

Following this we plotted the normalized $d^2CuA/dCuE^2$ values versus the corresponding CuE values. The Inflection Point is located at that equilibrium concentration of metal at which the second derivative has zero value (see Figures 16 to 21).

After determining positions of individual inflection points the number of them was count for each sample from plotted graph (see Table 7). The following criterion were used to determine a significant inflection point:

1. asymmetric points were not counted.

2. symmetric points whose numerical value was smaller than 33 % of the maximum found were not taken into consideration.

On a number of adsorbents tested we found sharp, well defined IP but on others only ill defined IPs were detected. Examples for Cu and Zn adsorption cases of well and ill defined inflection points are illustrated in Figures 16 to 21.

Variation in number of IPs per sample and lack of IP are also evident from data presented in Table 7 and Figures 16 to 21. Still copper's inflection points clustered around mean equilibrium concentration of 21.0 mg Cu/L while zinc's inflection points clustered around mean equilibrium concentration of 48.8 mg Zn/L (see mens and 95% confidence in Table 7)

To check if the points are due to saturation of different functional groups co-existing within adsorbent matrix and not to the "calculation artifact" we divided original data into two subgroups; subgroup one data Before IP (BIP) and subgroup two data After Inflection Point (AIP). After this we calculated E values for each subgroup according to procedure described in chapter 4.2.1. For simplicity of calculation we assumed that not more than one IP was exhibited per sample. When this was not true, and that was in majority of cases, point of division was taken to coincide with metal concentration at which normalized value of $d^2MeA/dMeE^2$ reaches its maximum (see above). After this in each group and subgroup (i.e. group All Data (AD) and subgroups BIP and AIP) calculated E values for Cu were devided by corresponding E values for Zn. Calculated ratios of E_{Cu}/E_{Zn} for the group and the subgroups are given in Table 10.

In addition to the above ratios of M_{Cu}/M_{Zn} were calculated for the group and subgroups. Calculated M values, the values of maximal adsorption capacity, for Cu were devided by corresponding M values for Zn. The ratios of M_{Cu}/M_{Zn} for the group and the subgroups are given in Table 11. In Table 11 M_{Cu}/M_{Zn} ratio for subgroup "Corrected data after Inflection Point" is also given; M values in this subgroup are obtained by subtracting M values of BIP subgroup from M values of AIP subgroup. Data used for calculation of E_{Cu}/E_{Zn} and M_{Cu}/M_{Zn} ratios are given in Table 12. Values of maximum adsorption capaciy for Zn of water leached compost "Naman" (see column MAD in Table 12) and that of Hula Up-peat (see column MAIP in Table 12) were out of range for other adsorbents; Zn adsorption experiments on these adsorbents with will be repeated in near future.

It is clear that numerical values of E_{Cu}/E_{Zn} ratio for group and subgroups, given in Table 10 and presented graphically in Figures 22 to 25, differ very much. The same is true for the numerical values of M_{Cu}/M_{Zn} ratio (see Table 11). The smallest variation in the E ratio was experienced in data subgroup BIP (column BIP in Table 10 and Figure 23), smallest standard deviation was calculated for the same group (see Std.Dev. of column BIP in Table 10). Confidence Interval, 95% confidence, was also narrowest in the same group (see 95% Conf. of column BIP in Table 10).

On one side E_{Cu}/E_{Zn} values for AD group and AIP and AIP" subgroup spreads in broad intervals (see AD, AIP and AIP" columns in Table 10 and Figures 22, 24 and 25) but on the other E_{Cu}/E_{Zn} values for BIP subgroup are concentrated within narrow interval (Figure 23 and Table 10). All points in the Figure 23 were close, almost parellel, to line whose numerical value is equal to numerical value of $(K_{Cu:FA})/(K_{Zn:FA})$ ratio and the same is correct for data given in Figure 25. We should remember here that ionic radius of Copper ($0.72E^{-10}$ m) and Zinc ($0.74E^{-10}$ m), much like their charge densities, are almost identical (Parson 1959). But numerical values of stability constants for complexes which Cu forms in various chemical reactions are, generally, higher than that of the constants of corresponding Zn complexes (Dawson et al 1986). In addition working with purified humic (**HA**) and fulvic (**FA**) acids in solution Stevenson (1977), Schnitzer and Skinner (1966), Verloo and Cottenie (1972) showed that stability constants for $\mathbf{HA:Me^{2+}}$ and $\mathbf{FA:Me^{2+}}$ complexes vary with pH (Table 8) and that relative affinities for metal changes with pH also (Table 8). All our experiments were performed on constant pH; at the equivalent concentration of metal, but below the point of maximal adsorption capacity, each adsorbent adsorbed much higher amount of Cu than Zn (see Figures 1 to 15). In addition free energies of adsorption of Zn and of Cu and maximal adsorption capacities were also different(see E and M columns in Tables 4 and 5).

Adsorbent (treatment)	Copper			Zinc		
	NIP	$[mg/L]_{eq}$	IP	NIP	$[mg/L]_{eq}$	IP
Sludge:						
(NL)	1	13.80	DE			
(LH20)	1	23.50	CD	1	26.4	CD
Commercial Peat:						
#-1(LH20)	2	6.74	DE	2	28.7	DE
#-2(LH20)	2	17.9	DE	2	46.4	CD
#-3(LH20)	2	14.9	DE	2	36.2	CD
Compost "Afula" Fraction (mm):						
0-5(LH20)	2	21.0	CD	2	50.5	CD
0-8(NL)	2	27.7	CD	2	61.0	CD
0-8(LH20)	2	16.7	DE			
8-18(LH20)	2	26.3	DE	-	---	ND
Compost "Naman"						
(NL)	2	17.9	DE	2	65.5	CD
(LH20)	2	65.0	CD	2	73.4	CD
Peat "Hula":						
Up-Peat						
(NL)	-	--	ND	2	46.2	DE
(LH20)	2	17.8	DE	2	52.3	DE
Bottom-Peat						
(LH20)	2	4.5	DE	2	50.3	DE
Mean		21.0			48.8	
Std.Dev.		14.8			14.6	
95% Conf.		8.95			9.80	

Table 7. Inflection Points for Cu and Zn on Different Adsorbents;

Where: NIP = Number of Inflection Points
$[mg/L]_{eq}$ = Equilibrium Metal Concentration at which IP was detected
NL = Not Leached
LH_20 = Leached with H_20
IP = Comment :
CD = Clearly Defined IPs' (see Figure 16)
DE = Defined IPs' (see Figure 18)
ND = Not defined IPs' (see Figure 20)

pH	LogK for COMPLEX (1)		Ratio K_{Cu}/K_{Zn}	Log K for COMPLEX (2)		Ratio K_{Cu}/K_{Zn}
	HA:Cu	**HA:Zn**		**FA:Cu**	**FA:Zn**	
3.5				5.78	1.74	3.32
4.0	7.15	5.90	1.22			
5.0	7.25	6.15	1.18	8.67	2.34	3.70

Table 8. Stability Constants are pH Dependent.
Data after: 1 = Stevenson (1977), 2= Schnitzer and Skinner (1966).

Acid	pH	Relative Affinity	Reference
Fulvic	5.0	Cu > Pb > Zn	Schnitzer and Skinner (1966)
Humic	4.0	Zn > Cu > Pb	Verloo and Cottenie (1972)
Humic	4.0-6.0	Cu > Pb > Cd > Zn	Stevenson (1977)

Table 9. Relative Affinity of Heavy Metals for Fulvic and Humic Acids

In the light of the above the results in Tables 10 to 12 and Figures 23 to 25 show that

- within concentration range examined inflection point are real phenomenon;
- inflection points could be used for the detection of those parts of adsorption isotherm which have different free energies of adsorption (i.e. estimation of E values).
- concentration intervals on adsorption isotherm having different E values are quite probably governed by separate adsorption mechanism.

It is true that E values and E ratio do not provide information on the mechanism of *metal:adsorbent* interactions nor do they provide information on the chemical structure of bond formed but it is also clear that further polishing of experimental technique is needed for better resolution (detection!?) and utilization of the inflection point phenomenon. The phenomenon should be examined in series of kinetic studies on constant pH. Rigorous experiments intended on determination of stability and reproducibility and on detection of the concentration at which particular inflection point occur are also required.

Adsorbent (Treatment)	pH_{Cu}	pH_{Zn}	E_{Cu}/E_{Zn} AD	E_{Cu}/E_{Zn} BIP	E_{Cu}/E_{Zn} AIP
Sludge: (LH_20)	5.5	5.4	5.64	1.16	4.15
Commercial Peat #1: (LH_20)	5.4	5.4	9.55	3.83	5.76
Commercial Peat # 2: (LH_20)	5.5	5.5	22.8	5.24	2.86
Commercial Peat # 3: (LH_20)	5.4	5.3	9.71	4.21	7.27
Up Peat "Hula": (LH_20)	5.4	5.5	91.67	8.00	32.00
Bottom Peat "Hula": (LH_20)	5.5	5.3	36.41	2.55	15.80
Compost "Afula" Fraction 0 - 5 mm: (LH_20)	6.0	5.8	2.02	0.84	10.95
Compost "Afula" Fraction 0 - 8 mm: (NL)	6.2	5.9	5.84	1.36	9.80
Compost "Naman":					
(NL)	5.8	5.6	29.25	5.41	15.1
(LH_20)	5.4	5.5	4.90	1.89	6.12
Mean			21.76	3.25	10.98
Std.Dev.			27.17	2.22	8.57
95% Conf.			19.44	1.59	6.13

Table 10. Ratio of E Values for Cu and Zn on Different Adsorbents;
AD = group All Data,
BIP = subgroup Data Before Inflection Point,
AIP = subgroup Data After Inflection Point.
pH_{Cu} = average equilibrium pH during Cu adsorption
pH_{Zn} = average equilibrium pH during Zn adsorption

Adsorbent (Treatment)	pH_{Cu}	pH_{Zn}	M_{Cu}/M_{Zn}			
			AD	BIP	AIP	AIP"
Sludge:						
(H_20)	5.5	5.4	0.67	12.5	0.73	0.27
Commercial Peat #1:						
(H_20)	5.4	5.4	0.82	1.06	0.87	0.56
Commercial Peat # 2:						
(H_20)	5.5	5.5	0.72	1.40	1.30	1.10
Commercial Peat # 3:						
(H_20)	5.4	5.3	1.03	1.81	1.03	0.55
Up Peat "Hula":						
(H_20)	5.4	5.5	1.12	1.31	0.55	0.50
Bottom Peat "Hula":						
(H_20)	5.5	5.3	1.05	2.73	1.03	0.43
Compost "Afula" Fraction 0 - 5 mm:						
(H_20)	6.0	5.8	10.95	51.40	5.09	-5.16
Compost "Afula" Fraction 0 - 8 mm:						
(NL)	6.2	5.9	5.91	20.73	1.39	-0.30
Compost "Naman":						
(NL)	5.8	5.6	0.31	2.02	1.94	-2.81
(H_20)	5.4	5.5	0.95	21.8	0.94	0.52
Mean			2.35	11.67	1.49	-0.37
Std.Dev.			3.42	16.20	1.52	1.99
95% Conf.			2.45	11.58	0.95	1.43

Table 11. Ratio of M Values for Cu and Zn on Different Adsorbents;
AD = group All Data,
BIP = subgroup Data Before Inflection Point,
AIP = subgroup Data After Inflection Point.
AIP" = subgroup Corrected Data After Inflection Point (AIP" = AIP - BIP)
pH_{Cu} = average equilibrium pH during Cu adsorption
pH_{Zn} = average equilibrium pH during Zn adsorption

Adsorbent	MAD	MBIP	MAIP	EAD	EBIP	EAIP
Sludge:						
Cu	3434	2607	4105	0.0175	0.0236	0.0137
Zn	5067	165	5596	0.0031	0.0204	0.0033
Commercial Peat:						
#-1Cu	2999	3538	4694	0.2864	0.1200	0.0691
#-1Zn	3665	3319	5380	0.0300	0.0313	0.0120
#-2Cu	2208	3314	4791	0.2511	0.0592	0.0264
#-2Zn	3060	2363	3699	0.0110	0.0113	0.0092
#-3Cu	3346	3932	5927	0.1980	0.1400	0.0691
#-3Zn	3268	2175	5775	0.0204	0.0332	0.0095
Compost "Afula" Fraction (mm):						
0-5Cu	3382	6117	3343	0.0484	0.0093	0.0241
0-5Zn	309	119	657	0.0239	0.0110	0.0022
0-8Cu	4295	5888	4923	0.0391	0.0139	0.0098
0-8Zn	726	284	3551	0.0067	0.0102	0.0010
Compost "Naman"						
NLCu	5557	7619	4426	0.0234	0.0168	0.0302
NLZn	17836	3449	2279	0.0008	0.0031	0.0020
LH20Cu	1400	1356	2978	0.0402	0.0388	0.0196
LH20Zn	1474	64	3162	0.0082	0.0205	0.0032
Peat "Hula"						
Up-Peat						
H2OCu	3610	2741	7224	0.1100	0.1600	0.0320
H2OZn	3211	2087	11103	0.0012	0.0200	0.0010
Bottom Peat						
H2OCu	4994	2625	3779	0.6810	0.4600	0.4900
H2OZn	4752	960	3662	0.0187	0.1800	0.0310

Table 12. Data Used for Calculation of E_{Cu}/E_{Zn} and of M_{Cu}/M_{Zn} Ratios for Cu and Zn Adsorption on Different Adsorbents.

Where: MAD = Maximal adsorption capacity - All Data
MBIP = Maximal adsorption capacity - data Before Inflection Point
MAIP = Maximal adsorption capacity - data After Inflection Point
EAD = adsorption Energy factor - All Data
EBIP = adsorption Energy factor - data Before Inflection Point
EAIP = adsorption Energy factor - data After Inflection Point

5. Conclusions

At the end of the first research year preliminary results from batch adsorption experiments indicate that adsorbents selected could be very good alternative to the present technologies in elimination of heavy metal pollution. In decontamination Cu and Zn polluted waters only a fraction of maximal adsorbent capacity should be used. For stable and reliable plant operation not more than 60 - 70% of the capacity should be used. By doing so standards concerning heavy metal concentrations could be easily met.

Physical and chemical analysis were performed on adsorbents; method for elucidation of pollutant's adsorption isotherms was developed.

All adsorption experiments were conducted at constant pH. Acetate buffer was used. Equilibrium pH was in range 4.9 to 6.2 in Cu adsorption experiments. In Zn adsorption experiments equilibrium pH was in range 5.3 to 5.9.

Adsorbents organic carbon content and its maximal adsorption capacity were found to be well correlated ($R \leq 0.89$). Adsorbent specific surface correlated well with copper's energy of adsorption ($R \leq 0.88$).

The following are the main results of the first research year:

a. Copper adsorption on the adsorbents was studied in concentration range 0 to 5000 μgr/L, average adsorption efficiency was, in all cases, higher than 94.6 %.

b. In status nascendi Hula up peat adsorbs biggest amount of copper, 6585 μgr Cu/ gr peat.

c. Hula up peat maximal adsorption capacity for Cu is some 1.90 times higher than the maximal adsorption capacity of commercial peat # 2 and is almost five times as high as that of HCl leached compost Naman.

d. The adsorbents were tested on zinc removal in concentration range 0 to 11800 μgr Zn/L suspension, removal efficiency was within an interval 68 to 98%.

e. Maximal adsorption capacity of adsorbents changes after washing. Hula up peat is the most sensitive to washing; commercial peats are less while sewage sludge and compost Afula are the least sensitive on leaching with H_2O.

f. Maximal adsorption capacity of majority of adsorbents after washing with H_20 clustered in range 3000 to 4000 μgr Cu/gr adsorbent.

g. Maximal adsorption capacity decreases with decrease in pH at which adsorption is conducted. For example more than 5000 μgr of Cu was adsorbed per gram of Hula up peat when adsorption was conducted at pH 6.2. On pH 5.2 each gram of the peat adsorbs only 3233 μgr Cu.

h. A phenomenon similar to the Inflection Point on titration curves was detected on adsorption isotherms for both Cu and Zn.

i. within concentration range examined inflection points could be used for the detection of the concentration intervals on the adsorption isotherm which have different free energies of adsorption.

j. concentration intervals of adsorption isotherms having different adsorption energy values are probably governed by separate adsorption mechanism.

k. further polishing of experimental technique is needed for better resolution and utilization of inflection point phenomenon.

l. The phenomenon should be examined in series of kinetic studies on constant pH.

In addition to already submitted plan for the second research year we will conduct experiments aimed on determination of reproducibility and detection of the position at which particular inflection point occurs.

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Appendix 1. Figures

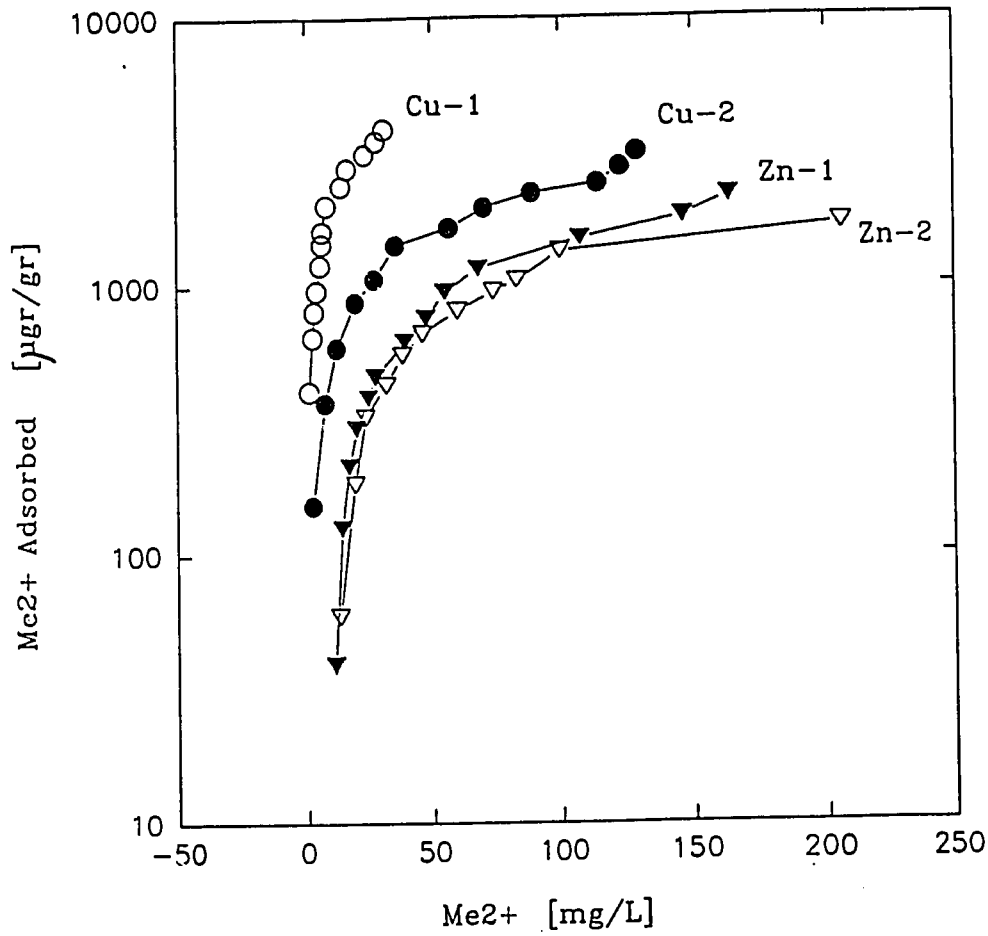


Figure 1. Equilibrium isotherm evaluated for Cu and Zn adsorption onto sewage sludge; Cu-1 pH = 5.94, Cu-2 pH = 5.50, Zn-1 pH = 5.62, Zn-2 pH = 5.73

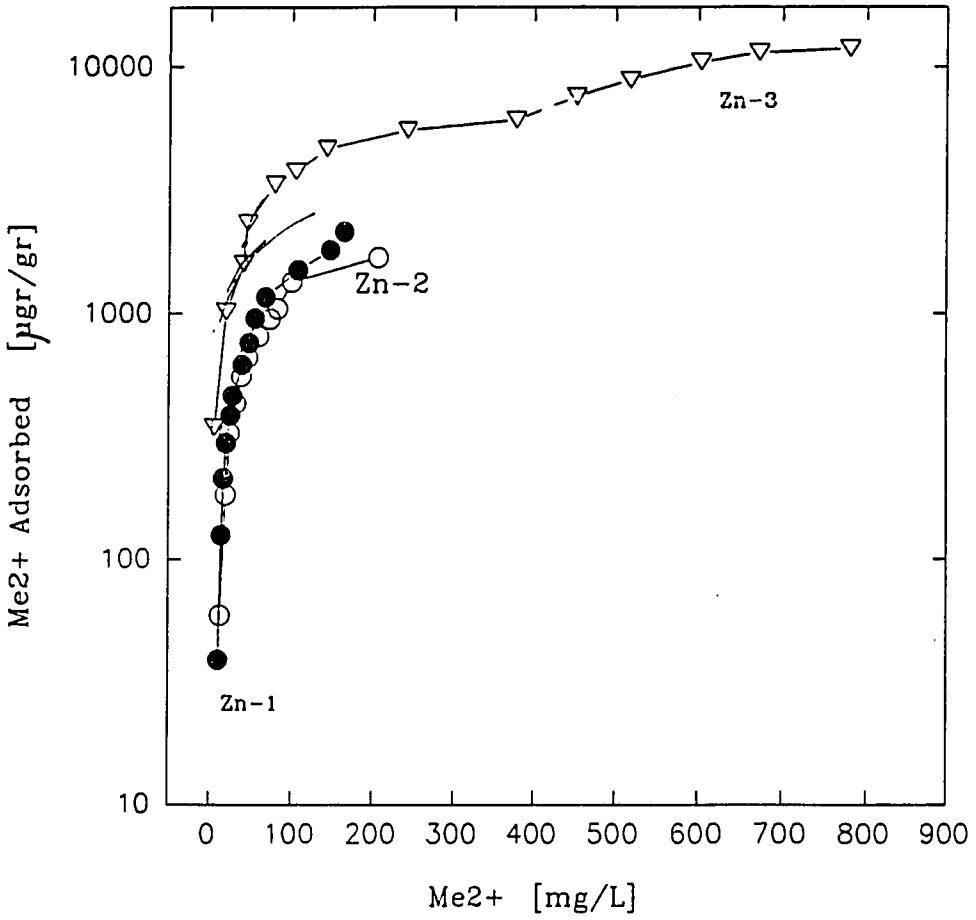


Figure 2. Equilibrium isotherm evaluated for Zn adsorption onto sludge; Zn-1 pH = 5.62, Zn-2 pH = 5.73, Zn-3 pH = 5.35

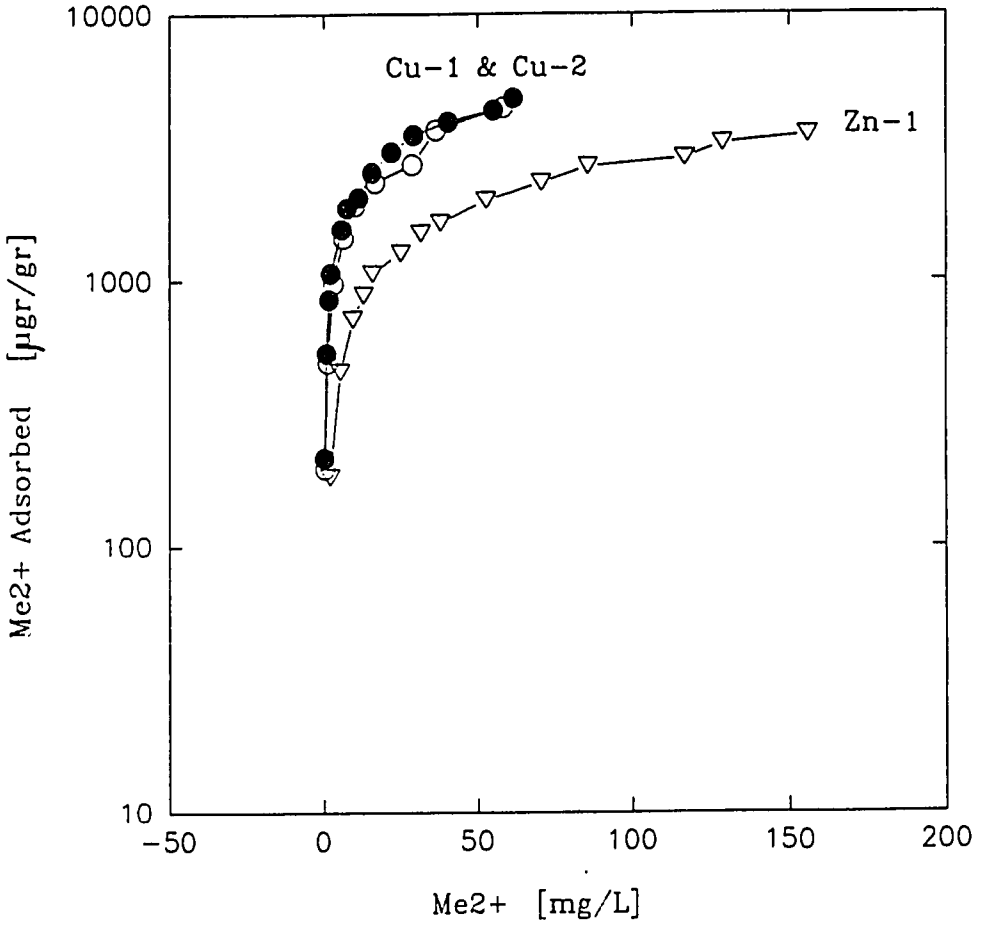


Figure 3. Equilibrium isotherm evaluated for Cu and Zn adsorption onto commercial peat # 1.; Cu-1 pH = 5.35, Cu-2 pH = 5.48, Zn-1 pH = 5.35.

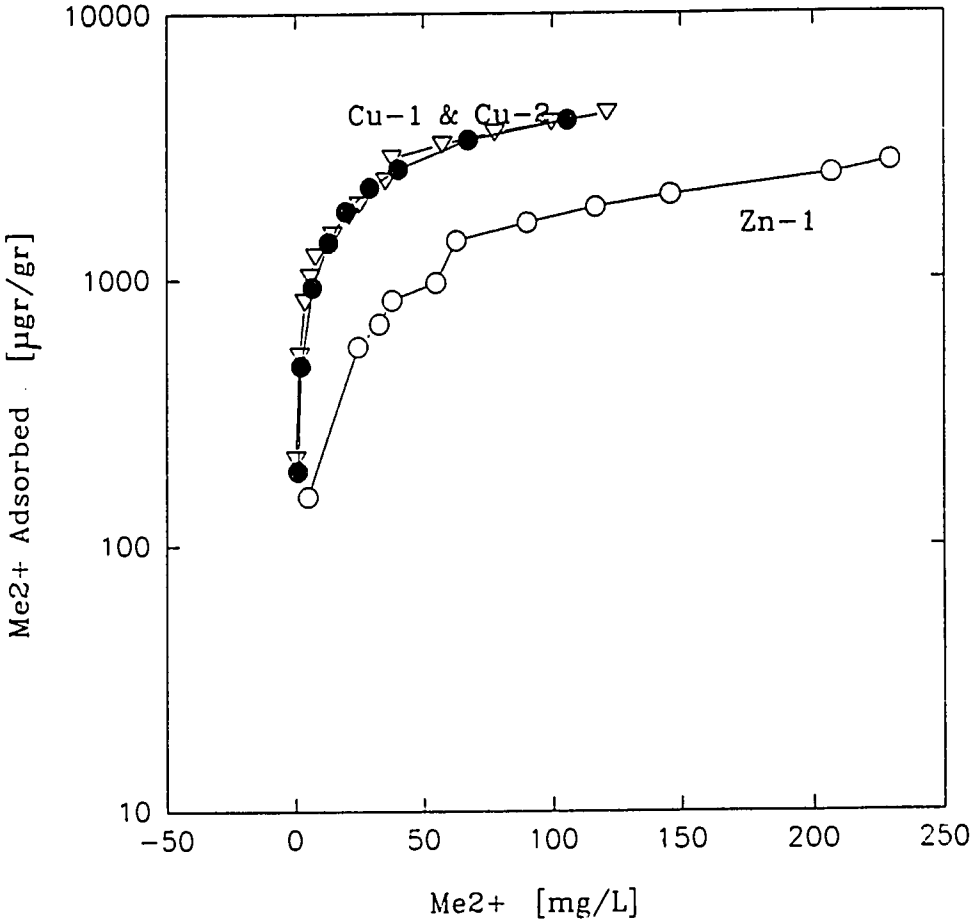


Figure 4. Equilibrium isotherm evaluated for Cu and Zn adsorption onto commercial peat # 2.; Cu-1 pH = 5.48, Cu-2 pH = 5.50, Zn-1 pH = 5.50

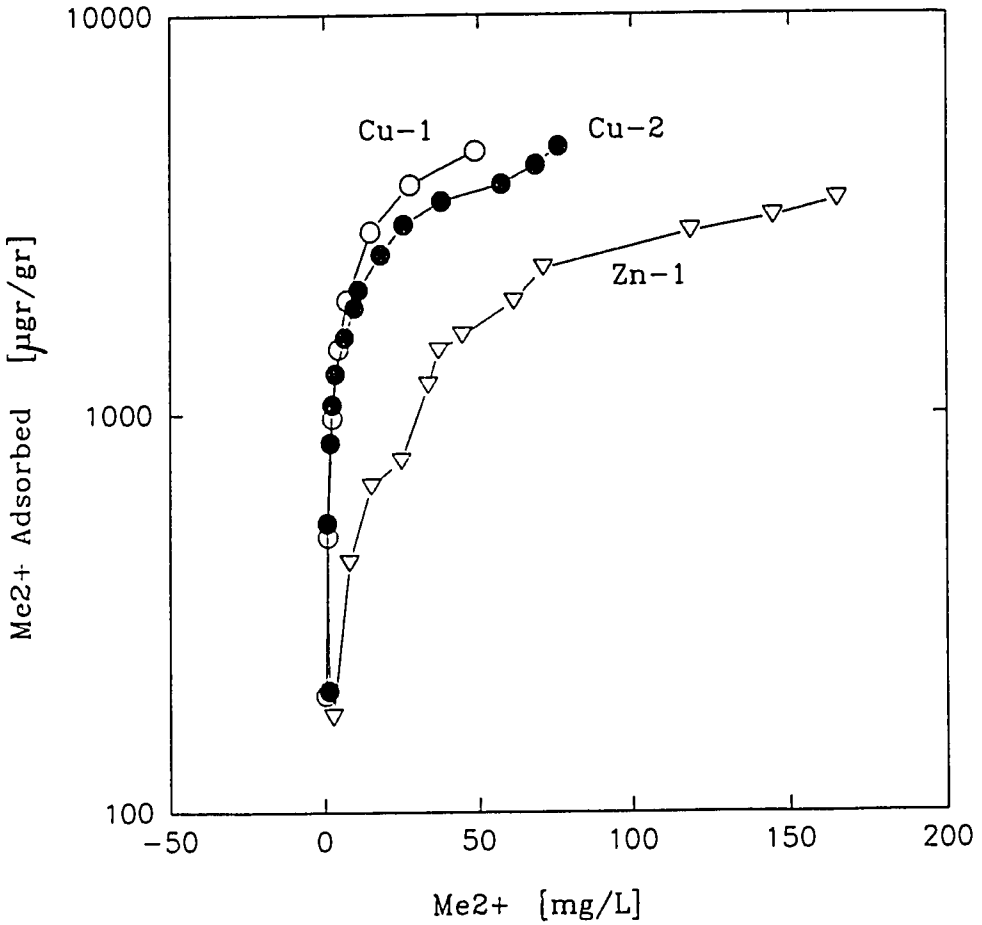


Figure 5. Equilibrium isotherm evaluated for Cu and Zn adsorption onto commercial peat # 3.; Cu-1 pH = 5.26, Cu-2 pH = 5.35, Zn-1 pH = 5.31.

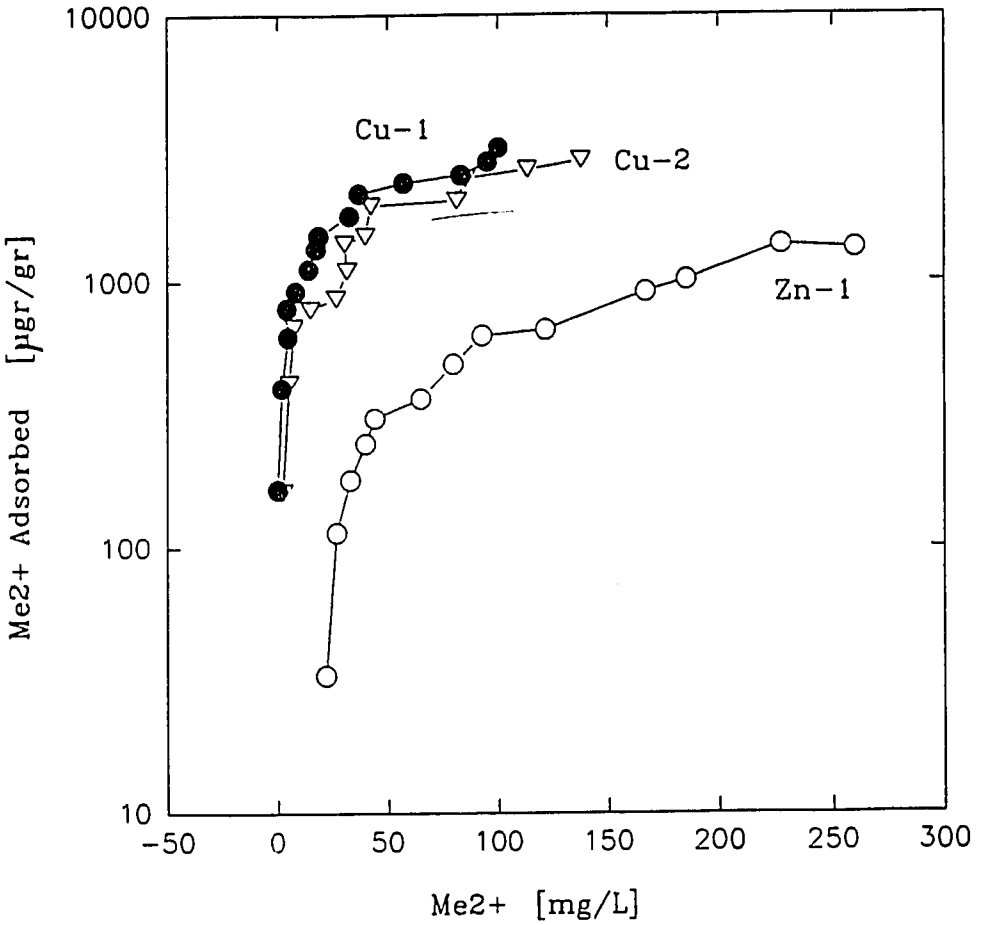


Figure 6. Equilibrium isotherm evaluated for Cu and Zn adsorption onto compost "Afula" fraction 0 - 5 mm; Cu-1 pH = 6.01, Cu-2 pH = 5.53, Zn-1 pH = 5.84.

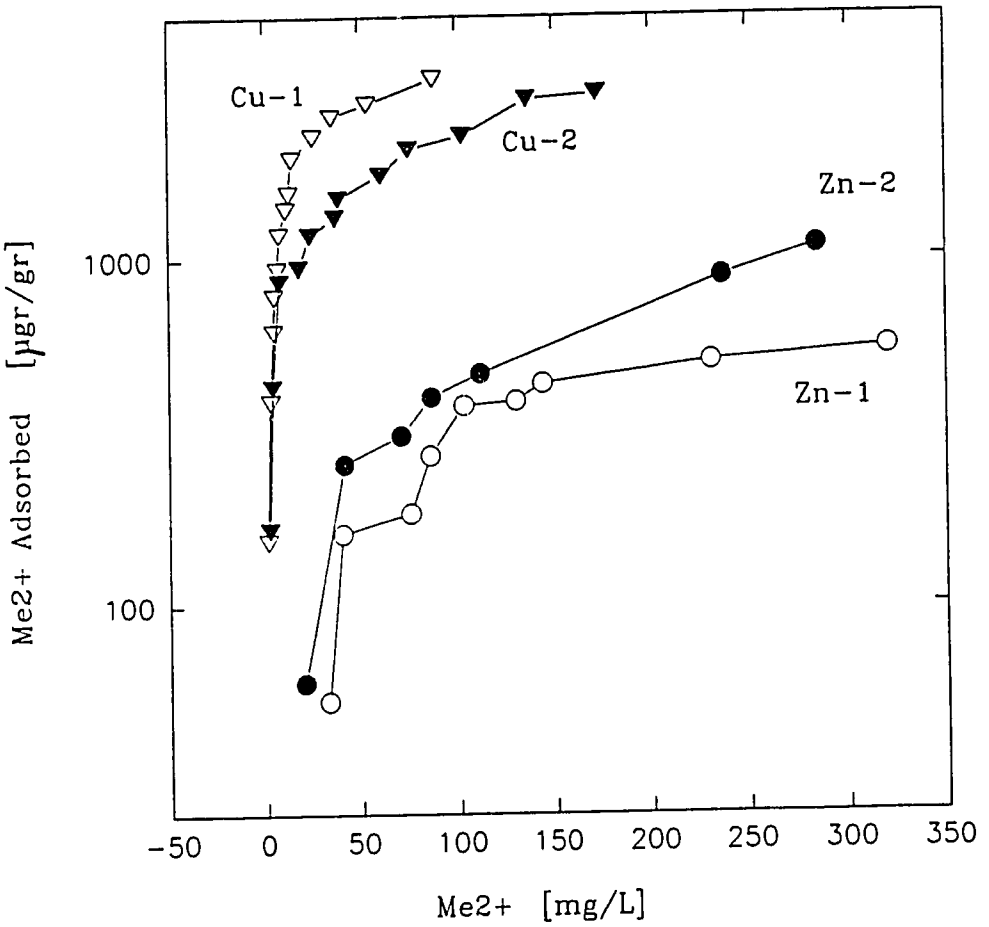


Figure 7. Equilibrium isotherm evaluated for Cu and Zn adsorption onto compost "Afula" fraction 0 - 8 mm; Cu-1 pH = 6.28, Cu-2 pH = 5.61, Zn-1 pH = 5.59, Zn-2 pH = 5.88

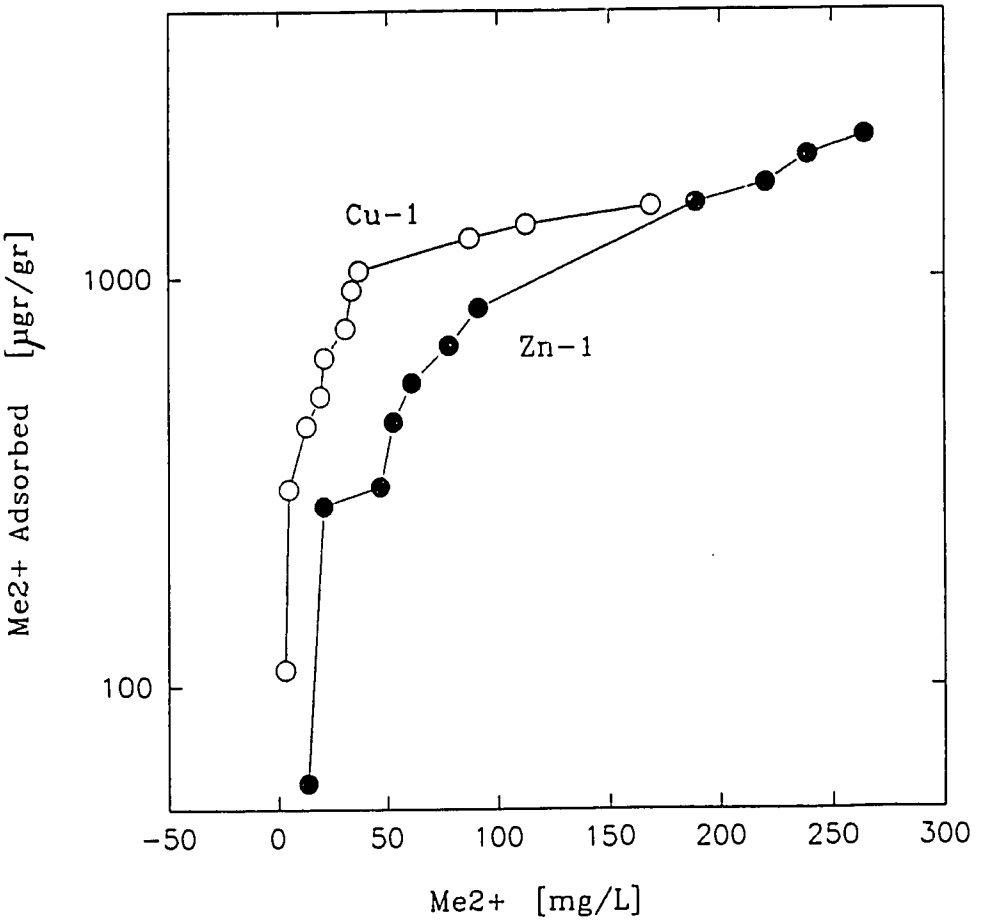


Figure 8. Equilibrium isotherm evaluated for Cu and Zn adsorption onto compost "Afula" fraction 8 - 18 mm; Cu-1 pH = 5.40, Zn-1 pH = 5.32.

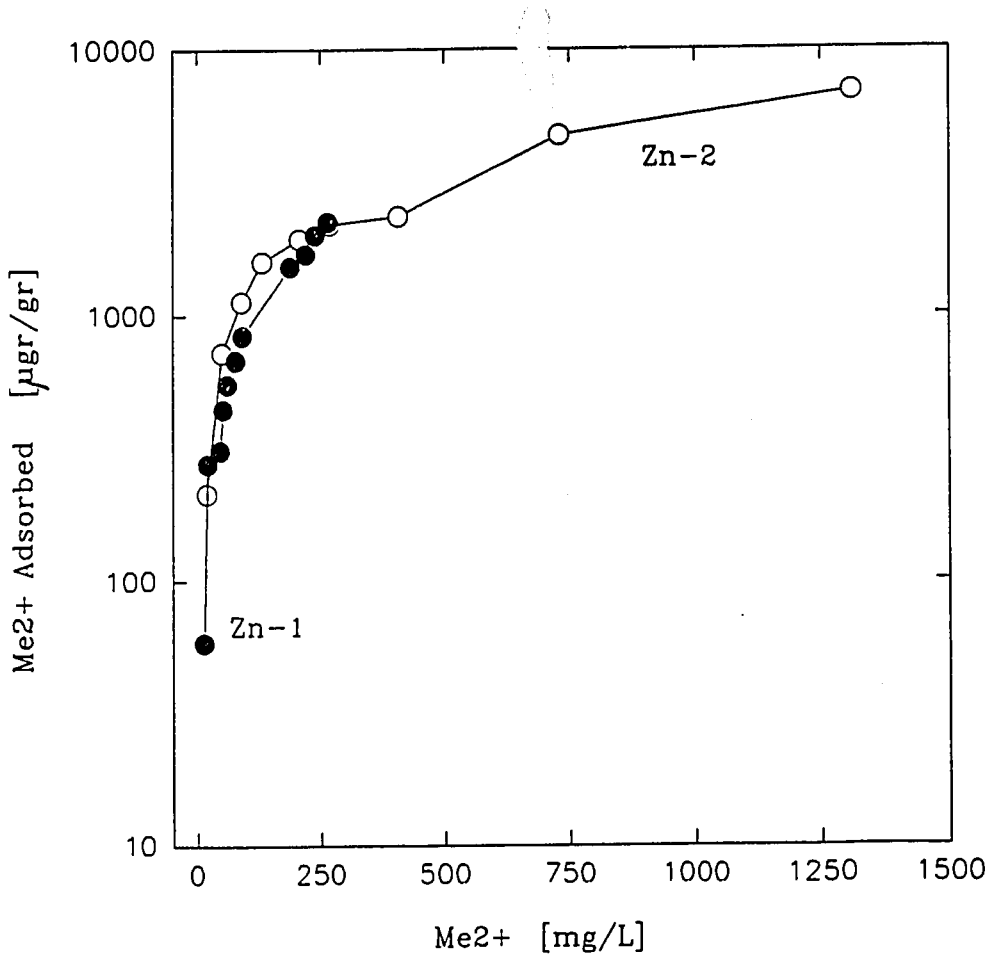


Figure 9. Equilibrium isotherm evaluated for Zn adsorption onto compost "Afula" fraction 8 - 18 mm; Zn-1 pH = 5.32, Zn-2 pH = 5.54.

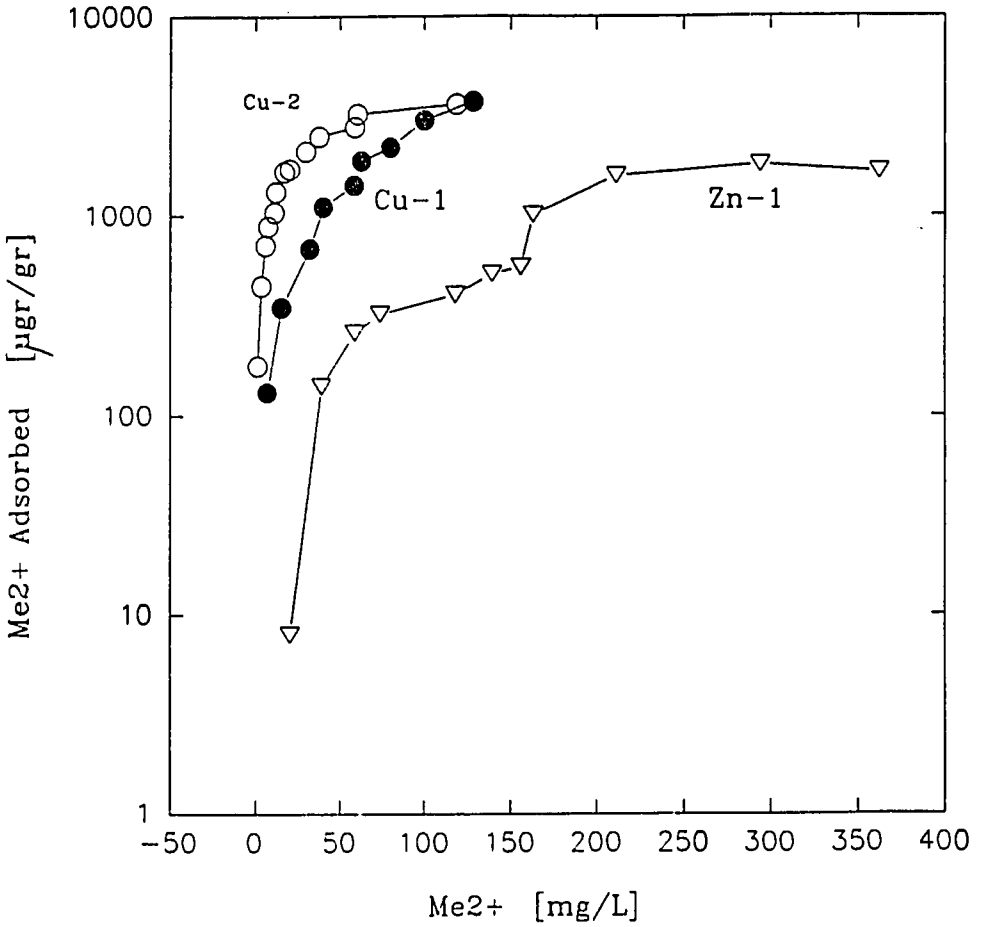


Figure 10. Equilibrium isotherm evaluated for Cu and Zn adsorption onto compost "Naman"; Cu-1 pH = 5.76, Cu-2 pH = 5.43, Zn-1 pH = 5.47.

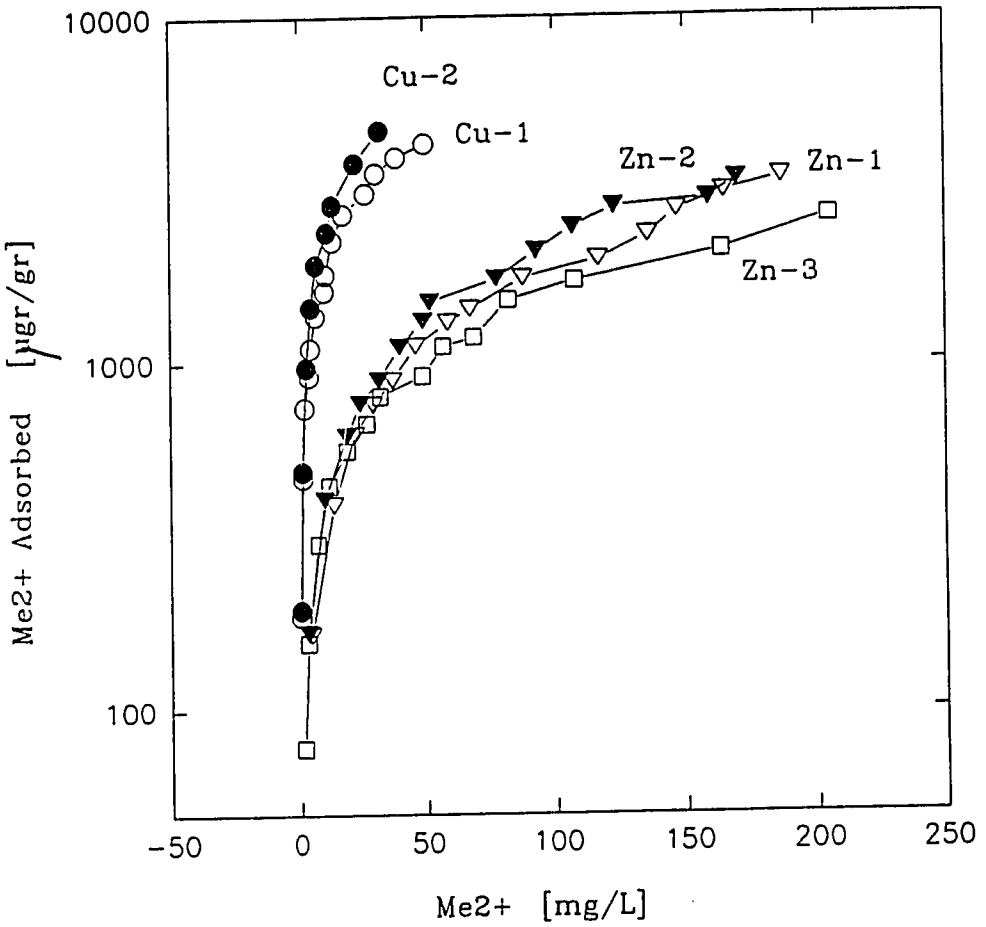
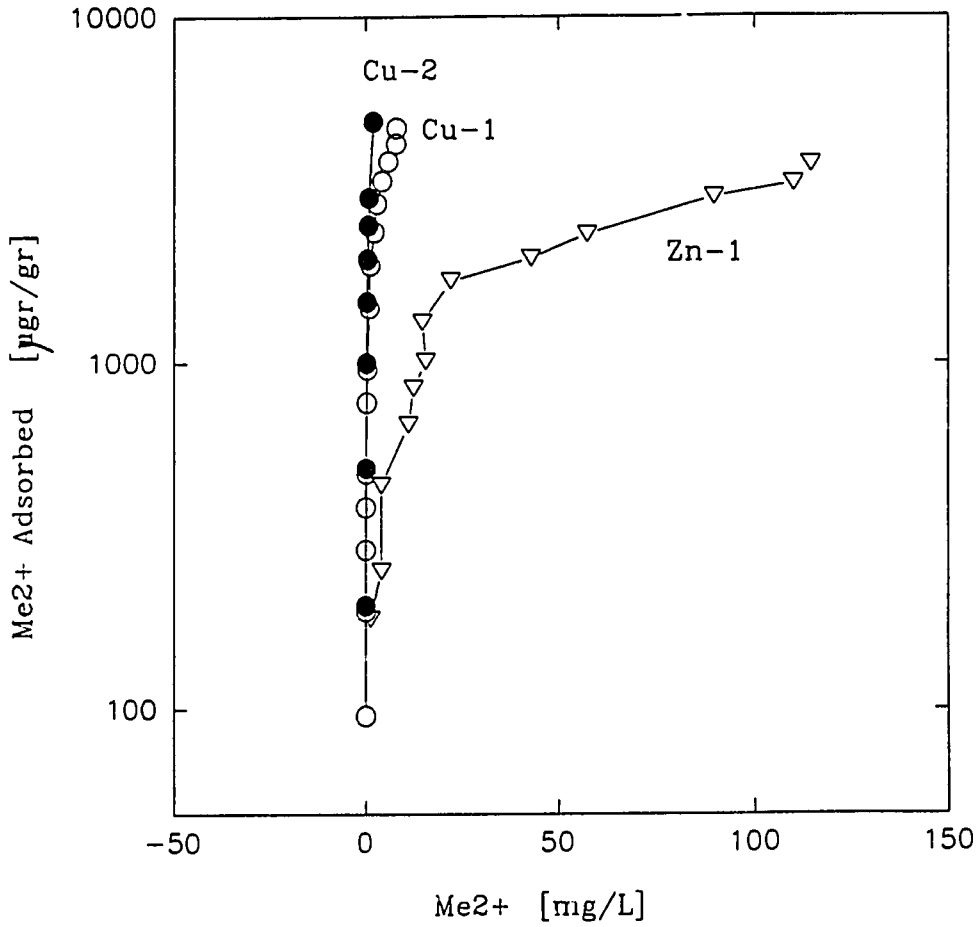


Figure 11. Equilibrium isotherm evaluated for Cu and Zn adsorption onto "Hula" Up-Peat; Cu-1 pH = 5.43, Cu-2 pH = 5.31, Zn-1 pH = 5.47, Zn-2 pH = 5.31, Zn-3 pH = 5.65



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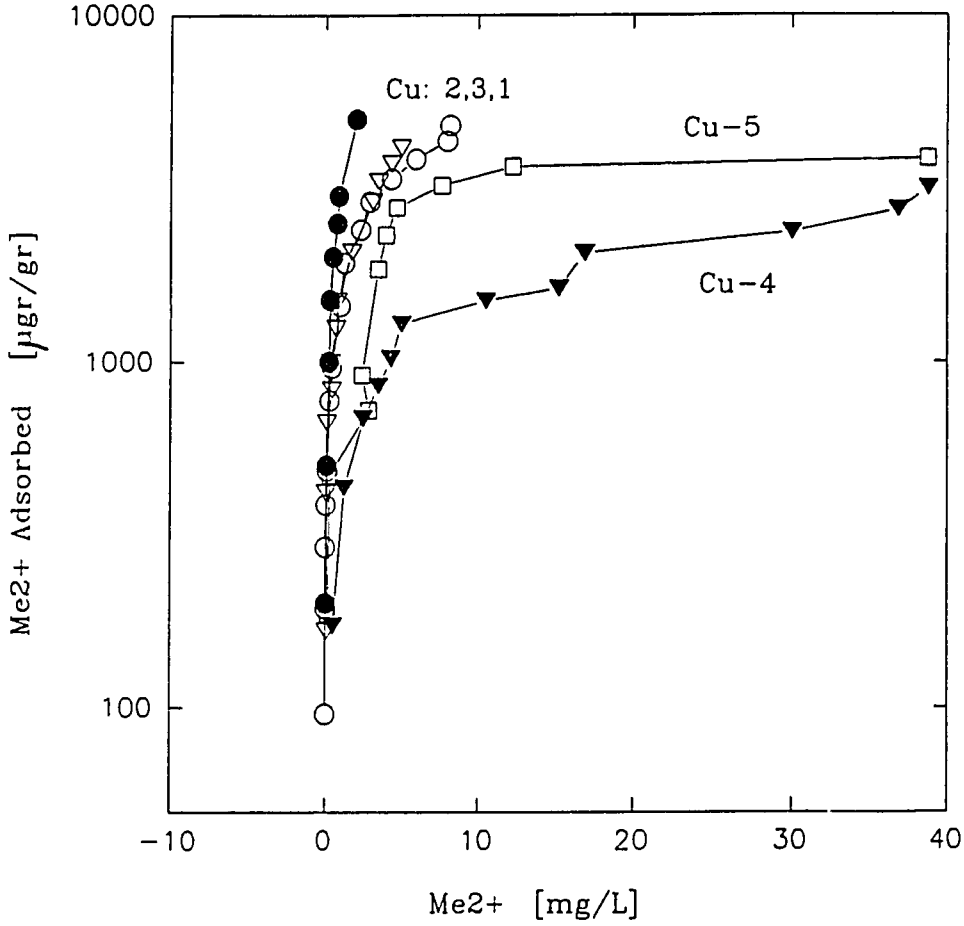

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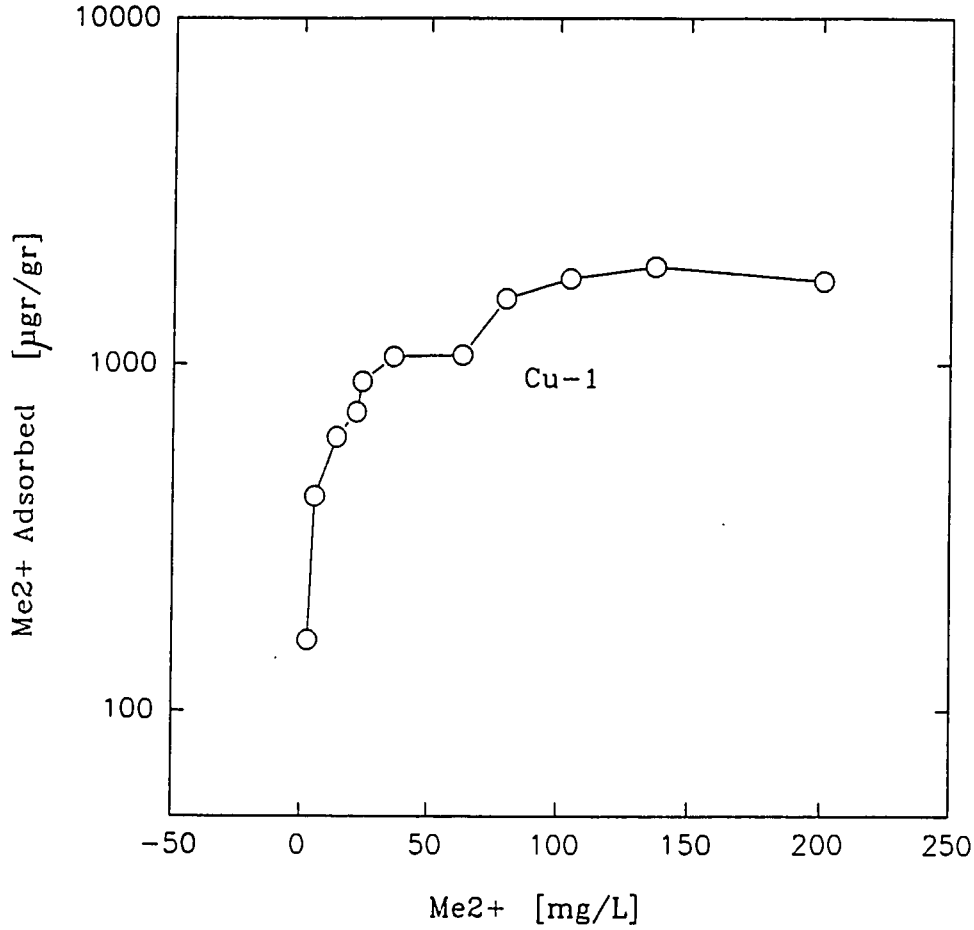


Figure 14. Equilibrium isotherm evaluated for Cu adsorption onto Compost "Naman"; Cu-1 pH = 4.88.

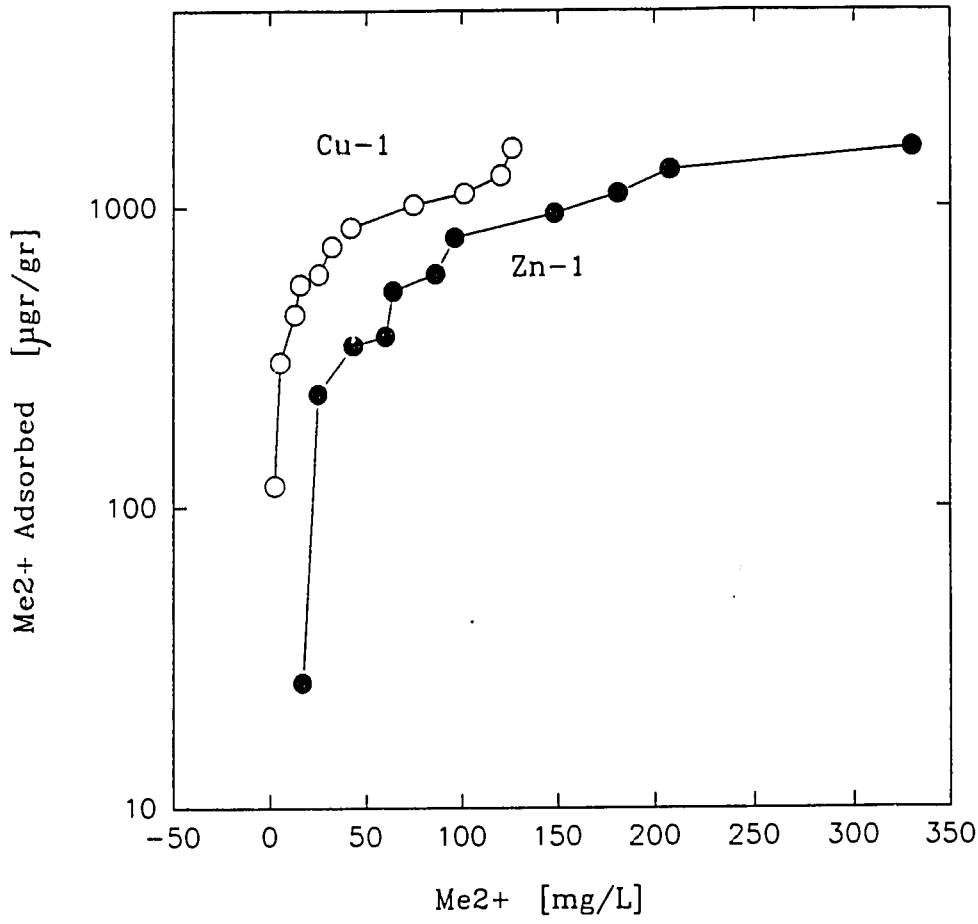


Figure 15. Equilibrium isotherm evaluated for Cu and Zn adsorption onto compost "Naman"; Cu-1 pH = 5.42, Zn-1 pH = 5.57

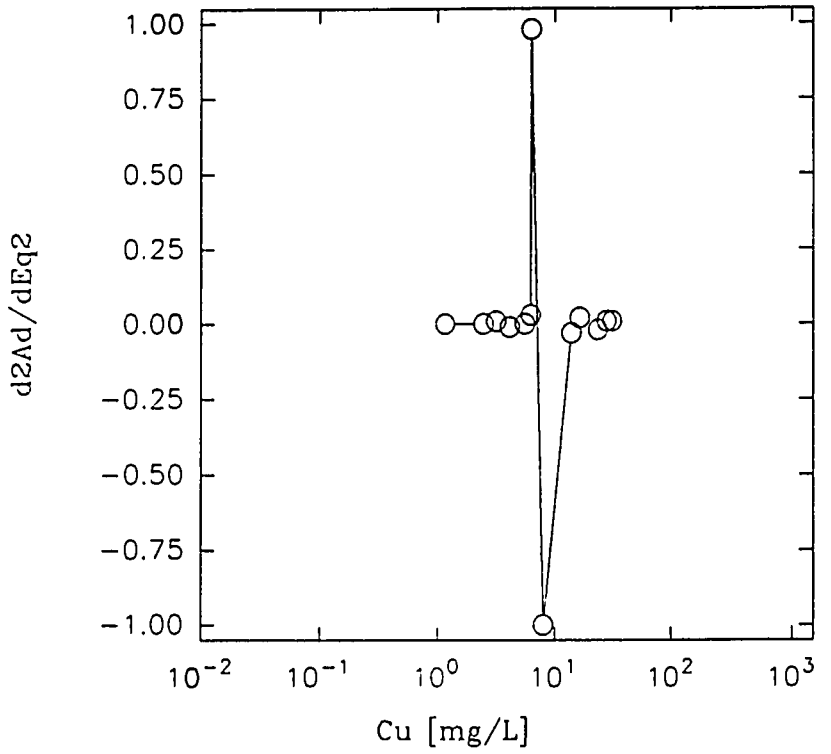


Figure 16. Inflection Point for Cu on Sludge

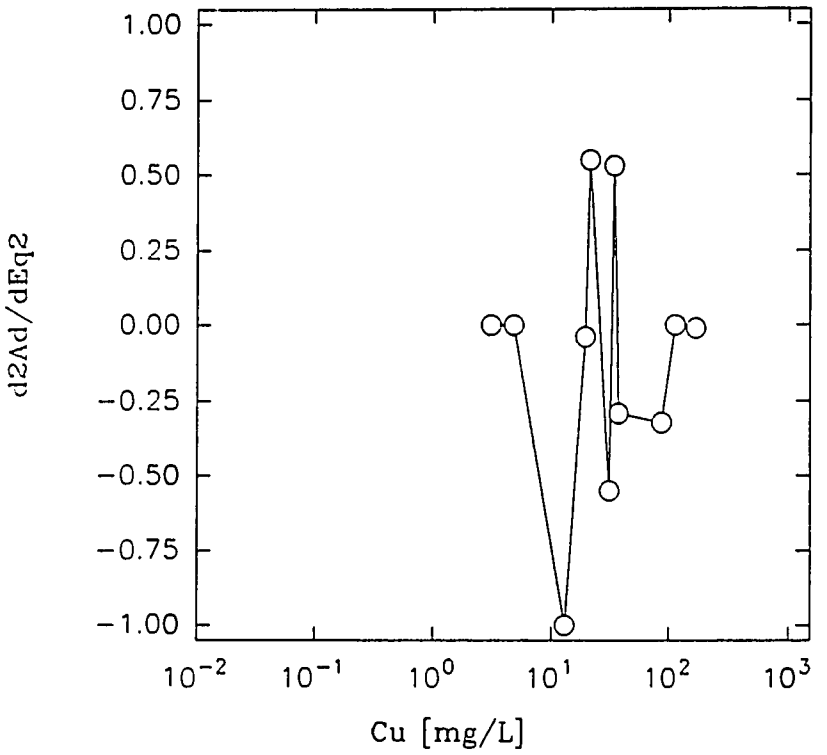
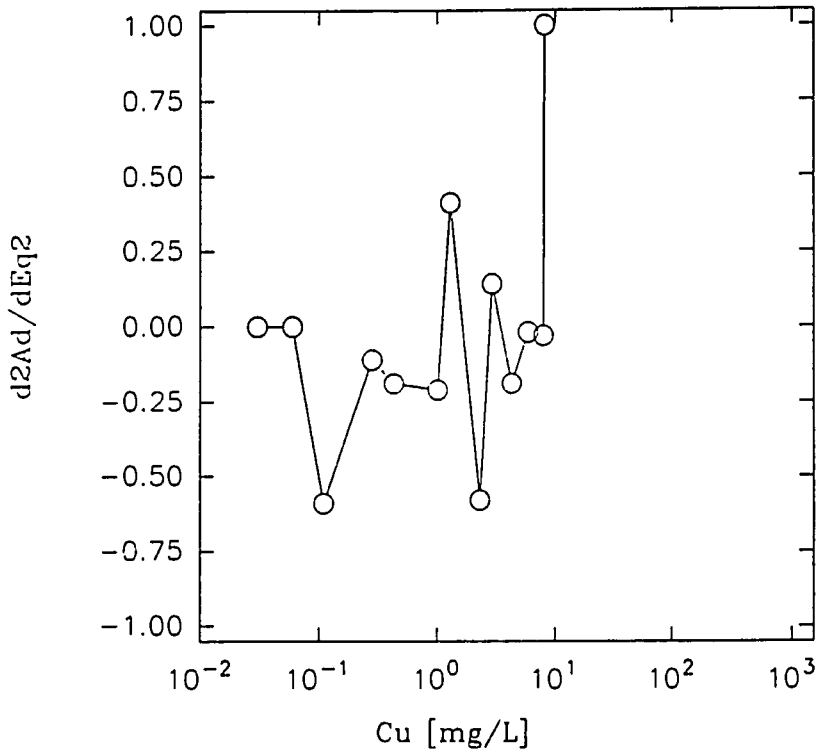


Figure 17. Inflection Point for Cu on "Afula" compost fraction 8 - 18 mm



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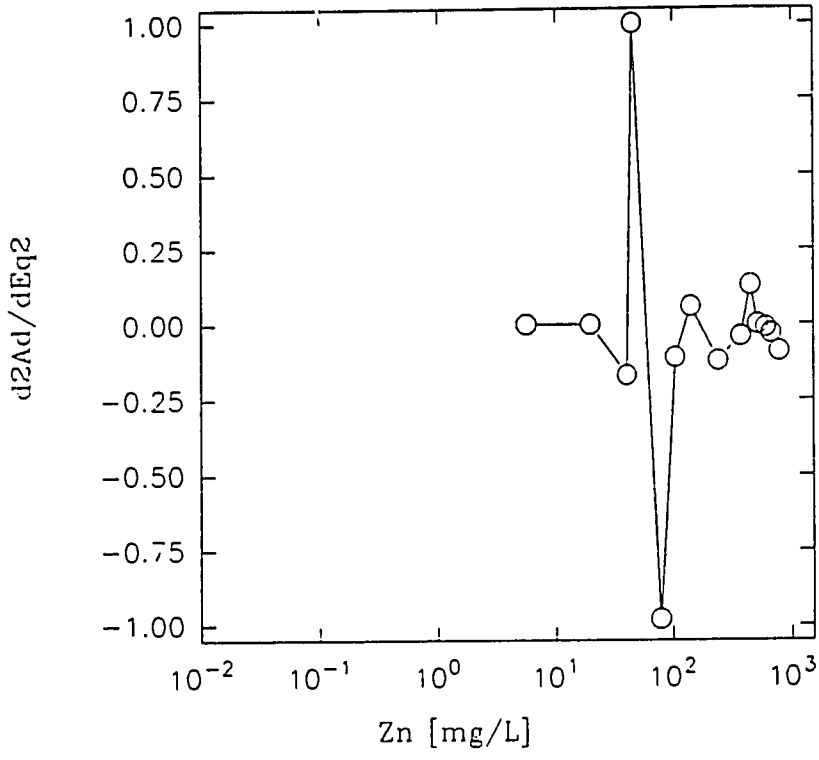
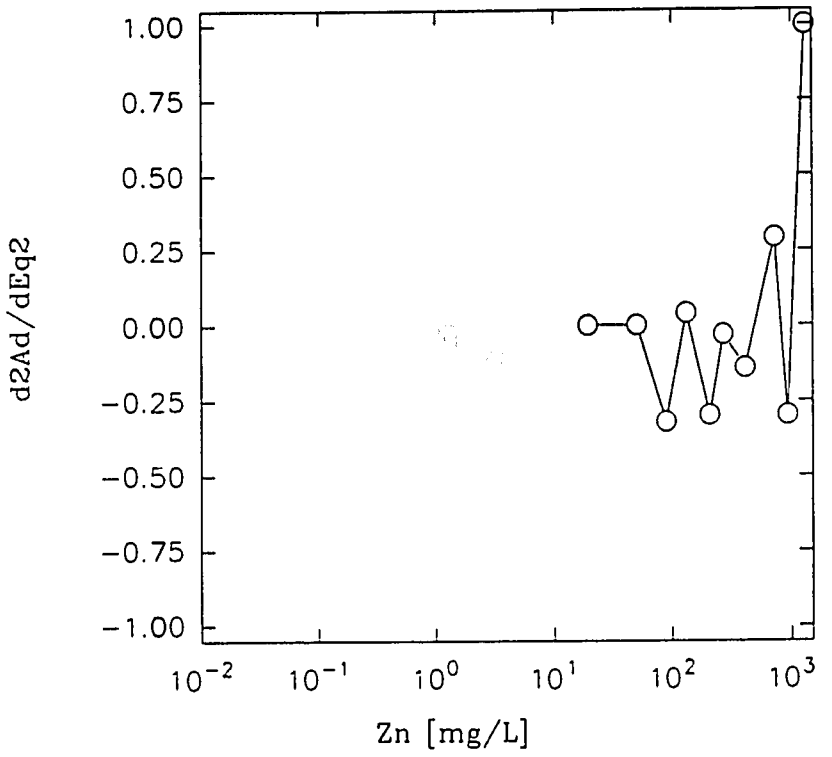


Figure 19. Inflection Point for Zn on Sludge



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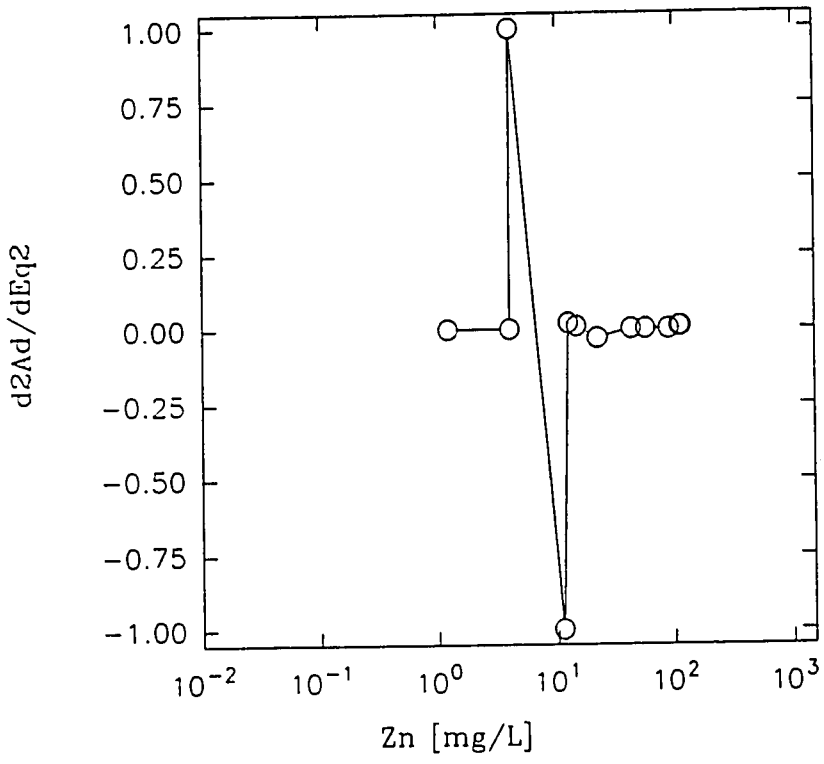

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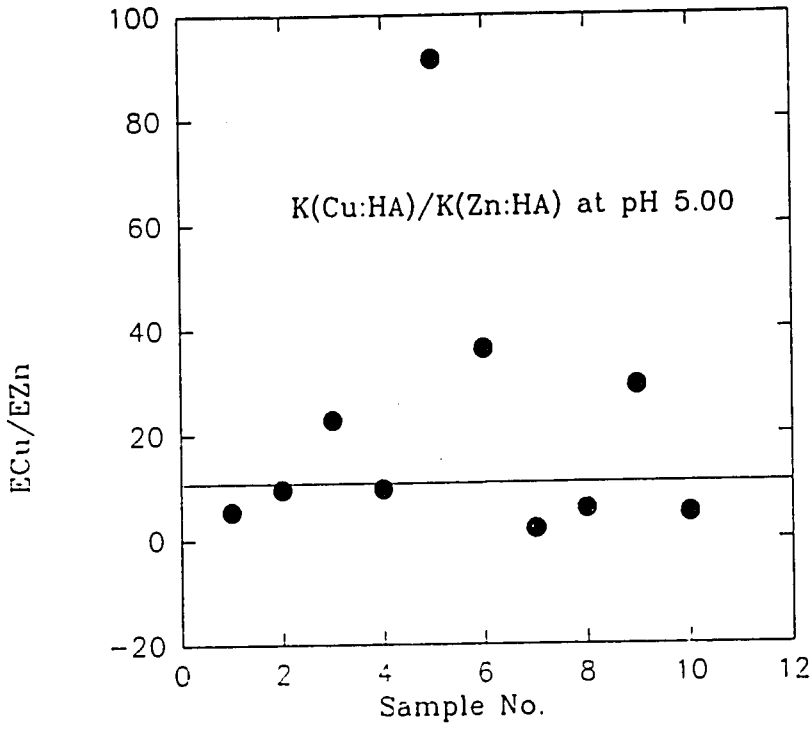
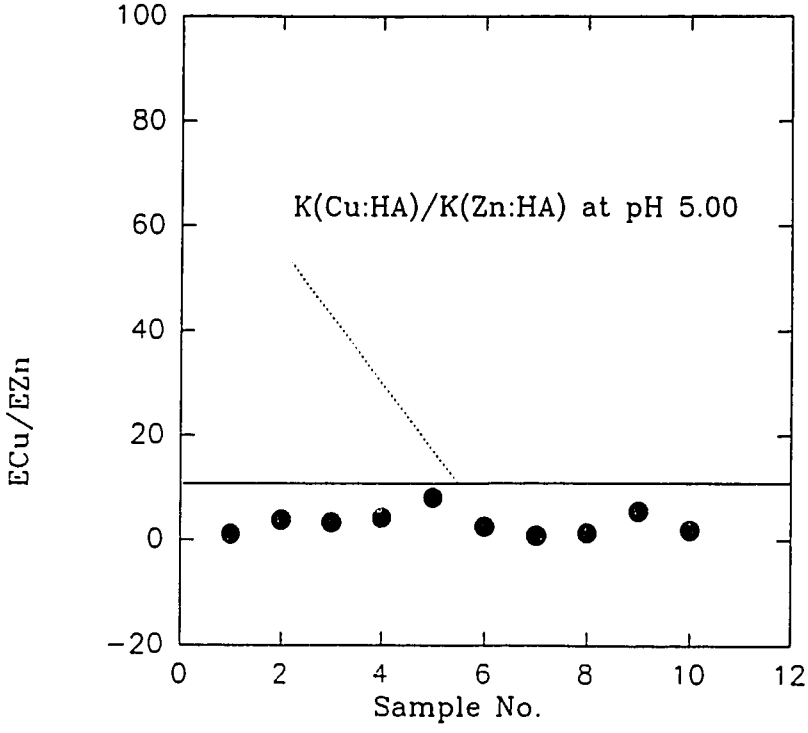


Figure 22. Ratio of ECu/EZn - group All Data (AD).



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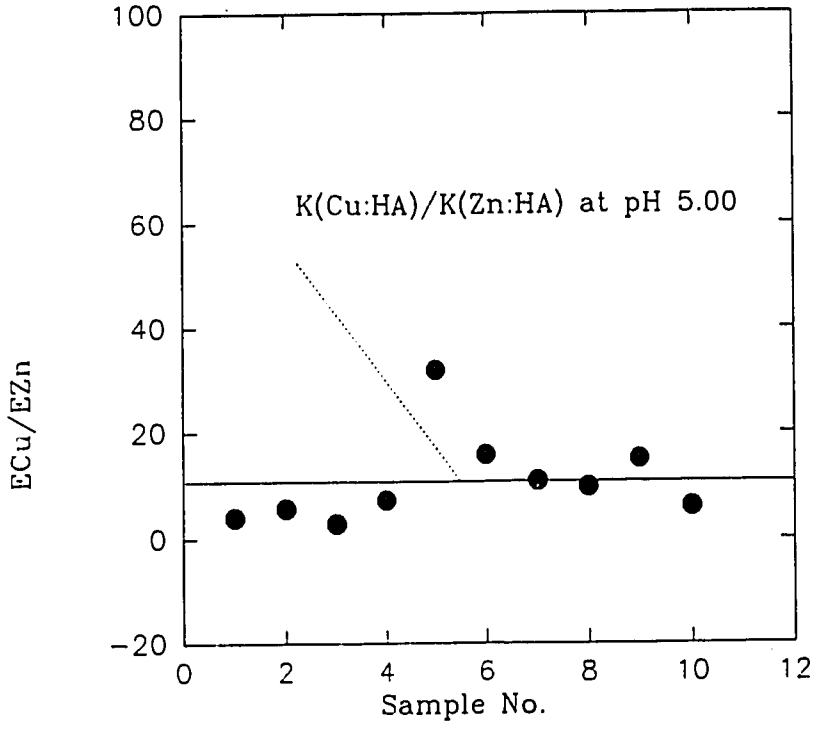

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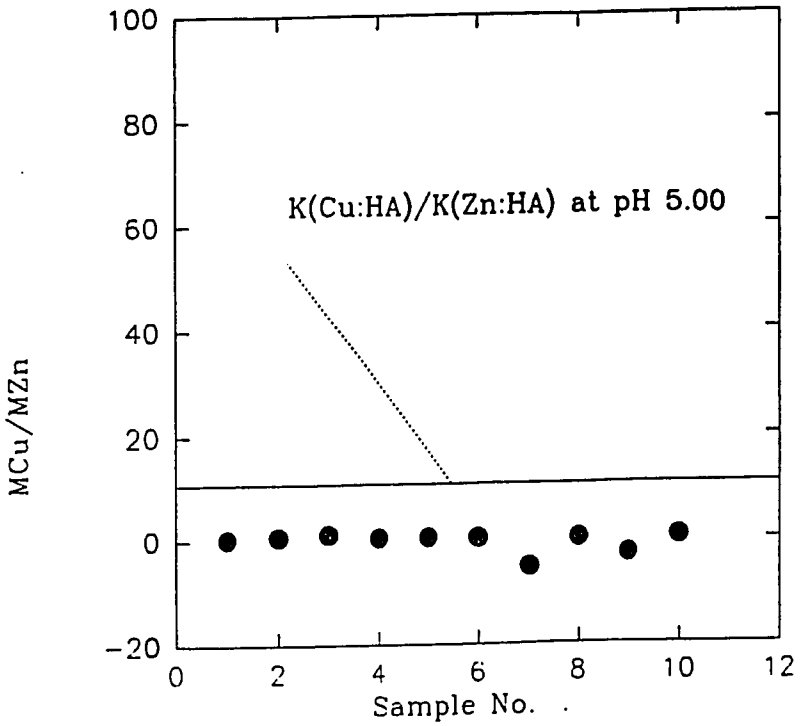

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PEAT AND COMPOST FILTERS FOR THE SEPARATION OF HAZARDOUS WASTES FROM WATER

CDR Grant No. TA-MOU-C12-050

ANNUAL REPORT
(for the period from August 10, 1993 to August 10, 1994)

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6 persons

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1.INTRODUCTION

This report covers the period from August 10, 1993 to August 10, 1994, i.e. the first year of the planned 3-years' duration of the project. Because of the administrative problems (difficulties in money transfer from US-Israel (CDR) Program), and climatic conditions during the winter and early spring 1993/1994 (low temperatures and deep snow cover in winter, quaggy peat bog surface caused by snow thawing and heavy rains in spring time), the research work in Poland was delayed until the end of April and then started despite lack of funding from the US-Israel (CDR) Program during the whole reporting period. The reported investigations could have been carried out partially due to obtaining Polish governmental matching funds and to a great extent due to crediting from other research programs being conducted by the principal investigator in Poland, that must be paid back.

1.1. Aim and objectives of the project

According to the project outline, the overall aim of the project is to develop an inexpensive filter made of peat, compost or related materials to adsorb and treat heavy metals and organic pollutants from industrial effluents.

The specific objectives of studies are:

- The adsorption of heavy metals to peat or similar substrate as a function of the substrate properties;

- The adsorption of organic pollutants on peat or related material. Relation of the adsorption capacity to the hydrophobicity of the organic adsorbent and the organic pollutant;

- The effect of peat as a biofilter to adsorb and degrade organic pollutants;

- The recovery of adsorbed metals by leaching with acids and possibly by incineration;

1.2. Work programme for the reporting period

The scientific programme for the first phase of the work was discussed during the visit of the principal investigator Prof. Yoram Avnimelech in the Institute of Environmental Engineering of the Polish Academy of Sciences on October 1-4, 1993.

It was agreed preliminary, that the first phase of the work would be devoted to sampling peat and compost and running adsorption isotherms of Zn and Cu on these samples. The goal was to characterize the different material in respect to the adsorption capacity and intensity. Subsequently, the adsorption properties would be related and correlated to different properties of the tested materials. The adsorption of Cr, Cd and As would be measured later.

The first phase would have been devoted also to laboratories quality control (2-3 samples, 2 kg each would have been exchanged by air mail among the two laboratories following sampling).

Time table for the first phase in Poland (IT), presented in the semi-annual report on the project, was as following:

- Sending information on the used adsorption research methods and techniques to Israel;
- Selection of a representative material, sampling the selected peats (10 samples in total);
- Running adsorption isotherms according to methods elaborated and tested by YA with Zn and Cu;
- Sending results to each other;
- Planning Phase II;

Despite of financial problems and late start of the research programme in Poland, it was substantially extended in comparison with the above timetable for the first phase due to the doubled effort and comprised:

- Selection of a representative material, sampling the selected peats (26 samples in total)
- Characteristics of physical properties and pH of peat samples;
- Chemical and mineralogical composition; identification of functional groups in organic fraction in selected peat samples;
- Batch experiments: adsorption isotherms for Cr(III), Cu, Cd, Zn (separately), input pH 4.0;
- Selection of peats showing the highest binding capacity;
- Determination of chemical fractionation of bound metals in a selected peat sample;

Experiments in progress:

- Batch experiments: desorption isotherms for Cr(III), Cu, Cd, Zn (separately), pH value of input metal solution 3.5);

2. MATERIAL

2.1. Site selection

From database at the Institute of Melioration and Grassland (IMG), comprising 50807 peat deposits in Poland, in this 8876 highmoor and transitory types and 41931 lowmoor deposits (number of peat-bogs registered in database enclosed, Fig. 1), 10 typical kinds of lowmoor-type peats from peat-bogs sited in the Pilica, Vistula, Pisa and Warta River basins and Niegocin Lake were preliminary selected for sampling (a list of the selected peats has been given in the semi-annual report). Shortly afterwards the list was revised with respect to site more convenient localization, that permitted to reduce the costs of sampling, while all the basic criteria of sample selection was taken into consideration. General assumptions at selection the sites for sampling were as follows:

- Sorption properties of peats depend on the type, kind, decomposition rate and composition of material, and not on the localization of a site in the area of the country;

- The number of samples to be taken is limited, and in no case would prove the differences, even though they would occur;

- Such peat properties as the type, kind, decomposition rate, extent of decay and pH are of the greatest effect on the sorption capacity of material .

- Sampling points should be placed in the known sites, of well identified kinds of peats, their physical properties and water balance; High decomposition rate (DR) that causes substantial increase of sorption properties, but at the sane time makes assessment of peat kind difficult, and in some cases impossible, particularly in field conditions.

Taking the above assumptions into consideration, three different peat-bogs sited in Northern East of Poland, in the area of Bialystok, Łomża and Suwalki districts were finally selected for sampling. The sites are situated in the distance of about 100 km from each other. All three of them are big peat-bogs, sited in the valleys of different rivers, reclaimed and natural, being an object of investigations of the Institute of Melioration and Grassland for many years. The selected sites are:

- The Wizna peat-bog;
- The Biebrza River valley;
- Zbójna site.

The sites and peats has been characterized according to the updated Polish Standards PN-70/G-02500, 1970, based on the genetic division of material, and also classified in accordance with ASTM D 2607-69, 1969, based on the genetic origin and fiber content. It should be mentioned, that Polish Standards use much more developed and detailed classification than ASTM D 2607-69, that specifies only five major types of peat, i.e. Sphagnum Moss Peat, Hypnum Moss Peat, Reed-Sedge Peat, Peat Humus and also Other Peats. Polish Standards' classification comprises **3 types** in accordance with three main types of peat deposits : lowmoor (N), transitory (P) and highmoor (W); Within this major types, **10 kinds** of peats are differentiated according to the peat-forming group of plants specific for a habitat and marked by symbols 1-5 for kinds specific for lowmoor type [1 - Alga Peat (Potamioni), 2 - Rush Peat (Limno-phragmitioni), 3 - Sedgeous Peat (Magnocaricioni), 4 - Hypnum Moss Peat(Bryalo-parvocaricioni) , 5 - Humus Peat (Alnioni)], by symbols 10-11 for kinds representing transitory type [10 - Transitory Sphagnum Moss Peat (Minero-sphagnioni), 11 - Birch Brushwood Peat (Betulioni)] and by symbols 20-22 for kinds representing the highmoor type [20 - Highmoor Sphagnum Moss Peat (Ambro-sphagnioni), Moor Peat (Ericioni), and Wood-Marshy Peat (Ledo-pinioni)]. The lowest systematic unit is **peat class** (24 classes), that differentiates peats with respect to the combination of dominating plant species. Peat classes are marked by triletter symbols. This enables short, but detailed classification notation by symbols [Appendix 1].

2.1.1. The Wizna peat-bog

The Wizna peat-bog sited in the drainage basins of the Narew and Biebrza Rivers covers 9000 hectares. Average peat deposit thickness is 3 m, max 7 m. Site was reclaimed 300 years ago. Intensive meadow cultivation is being conducted.

In this site, peats of four basic kinds of lowmoor type occur, i.e Hypnum Moss Peats (Brynieti), Rush Peat (Limno-phragmitioni), Sedgeous Peat (Magnacaricioni), Peat Humus (Alnioni) as well as different stratigraphic systems of mixed peats (Fig. 3)

2.1.2. The Biebrza River Valley

This site comprises three basins: upper, middle and lower one of a total area 116 577 hectares, while peat deposits occupy 88 530 ha. This is the only site in Poland where the biggest part of the valley retains in the natural state, and in the upper basin lands has never been meliorated. Great variety of peats and detrital gyttja at small depths is specific for this site. Stratigraphic systems of peat deposits of the Middle Biebrza River shows Fig. 4.

2.1.3. Zbójna Site

Zbójna site is localized in a trough separated from the Pisa and Narew Rivers by the mineral islands, while water is discharged by ditches with outlet to the Narew and Pisa Rivers. The site covers 1200 hectares, since five years is reclaimed (meliorated) and used as meadows and grassland for live-stock. Peat-bog occupies area of 700 hectares, the rest are mineral/organic soil. Here deep and medium peats of a high decomposition rate, typical for particular peat kinds occur (Fig. 5).

2.2. Sampling

In the each site, samples representing basic kinds of lowmoor peats, i.e. Rush Peat and Sedgeous Peat (both classified by ASTM as Reed-Sedge Peat), Peat Humus and also Hypnum Moss Peat, though the latter one usually occurs in a weakly decomposed form (DR=10-30%), that should considerably reduce its sorption capacity.
In total, 26 samples of peat in three sites were collected from 25 to 29th of April, 1994 and protected against loss of a natural moisture content.

2.2.1. Wizna Peat-bog: sampling points

In the Wizna Peat-bog, 11 samples were taken in 9 points, in this in point W9 three layers of peat were sampled along the vertical profile. Sampling points are presented in Fig 3 and described in the list below.

Sample symbol	Sampling depth, cm	Site characteristics
W1	below 28 cm	cultivable meadow, intensively fertilized; ground water-table below 35 cm

W2	15-50 cm	cultivable meadow, intensively fertilized
W3	below 27 cm	cultivable meadow
W4	below 20 cm	meadow formerly cultivated, now barren land
W5	17-50 cm	cultivable meadow
W6	below 35 cm	forest reservation, overgrown with birch trees
W7	below 35 cm	cultivable meadow, frequently flooded
W8	below 33 cm	cultivable meadow
Profile W9:		
W9a	6-20 cm	cultivable meadow (boggy soil)
W9b	20-60 cm	Humus peat
W9c	below 60 cm	Reed-Sedge peat

2.2.2. The Biebrza River Valley

In the Biebrza Site, 11 samples were taken in 9 points, in this in point B1 three layers of peat were sampled along the vertical profile. Sampling points are presented in Fig. 4a and described in the list below:

Sample symbol	Sampling depth, cm	Site characteristics
Profile B1:		
B1	20-30 cm	cultivable meadow, Hypnum Moss peat
B1a	30-50 cm	Sedgeous peat
B1b	50-130 cm	Brushwood Peat Humus
B2	35-45 cm	Alder-birch forest, no fertilization
B3	below 28 cm	experimental plot of IMG, meadow, fertilized by PK for 35 years
B4	30-80 cm	experimental plot of IMG, degraded sod, not fertilized for 35 years
B5	below 80 cm	cultivable meadow
B6	45-100 cm	meadow by the river

B7	36-60 cm	meadow partially fertilized
B8	20-40 cm	meadow
B9	below 90 cm	highmoor peat, swamp

2.2.3. Zbójna Site

In the Zbójna Site, 4 samples were taken in 3 points, in this in point Z2 two layers of peat were sampled along the vertical profile. Sampling points are presented in Fig. 5 and described in the list below:

Sample symbol	Sampling depth, cm	Site characteristics
Z1	25-100 cm	meadow fertilized for 5 years
Profile Z2:		meadow fertilized for 5 years
Z2a	45-90 cm	
Z2b	100-200 cm	
Z3	50-70 cm	degraded meadow, deficiency of K, excess of N

3. METHODS

3.1. Characterization of the sampled material

3.1.1. Characteristics of physical properties d pH of peat samples

Peat samples were classified according olish Standards (PN-70/G-02500 updated in 1973) and ASTM D 2607-69, l hysical properties of sampled peats was determined by standard methods, inclu

- decomposition rate (DR), %
- natural moisture content, %,
- bulk density, g/cm^3,
- specific gravity, g/cm^3,
- porosity, %,
- ash content, %.

In the next phase of experiments, also specific surface (calculated by BET equation), CEC (cation exchange capacity) and the initial composition of exchangeable cations in peat matrix will be also determined.

3.1.2. Phase composition of mineral fraction

Further investigations were carried out using air-dried samples powdered in beater laboratory mill. For estimation of phase composition of mineral fraction in peats, 11 representative samples of 26 were selected: W1, W2, W4, W5, W8, W9b, W9c, B1, B3, B5, Z2b.

Preparation of samples for analysis included:

1. Heating of sample for 2 hours at 350^0 C in electric furnace;
2. Separation of fraction enriched with mineral matter from water suspension after prior ultrasonic dispersion;
3. Separation of mineral matter by use of heavy liquid (*sym*-tetrabromoethane).

Obtained mineral concentrates were analyzed by use of X-ray diffractometer TUR with goniometer HZG4 (Germany). Radiation $Cu_{K\alpha}$ and counter rotation speed $1^0\theta$/min was applied.

3.1.3. Identification of functional groups in organic fraction in selected peat samples

Functional groups, presence of humic acids and forms of chemical combination of sulphur with organic matter was investigated by use of IR spectroscopy.
The selected samples W1, W2, W4, W5, W8, W9b, W9c, B1, B3, B5 and Z2b were analyzed directly; one sample (W1) was analyzed after ultrasonic separation of two fractions: $> 2\mu m$ and $< 2\ \mu m$.
Samples were analyzed in the form of pressed pellets of KBr, except the sample W1, fraction $< 0.2\ \mu m$, which was analyzed after evaporation on the plate of Germanium crystal.
Spectra were registered with use of Fourier Spectrometer BIO-RAD FTS 165.

3.2. Batch experiments on metal cation binding to peat

This phase is an initial stage of studies on metal cation binding to peat and comprises batch experiments accomplished to evaluate the binding of individual cations.

3.2.1. Experiments on the binding of individual cations

Prior to our experiments, a "Standard method to obtain an adsorption isotherm on peat" (Appendix 2) was elaborated by the Main Grantee YA and sent to IT research group. We, though, could not agree with the proposed method for several reasons, that was explained in the letter to YA of April 28, 1994 (Appendix 3). Briefly, our opinion on the points of disagreement were as follows:

1. Sample preparation should not too deeply interfere into a pore structure of the material, thus air drying instead of vacuum is preferable;

2. There is no reason for peat sample pre-treatment by leaching the substrate with distilled water. This procedure also interfere into peat properties: some mineral compounds and part of simple sugars, humic acids, alkaloids and pectines will be leached out.

3. There is no reason for adjusting pH of peat suspension. The pH value of input metal solution should be adjusted and kept constant, but not the resultant pH of peat suspension, that is one of parameters determining peat binding properties. By adjusting pH of peat suspension, one suppresses the effect of at least two binding fractions (i.e. exchangeable and carbonatic) and such important mechanisms as precipitation and co-precipitation.

4. The proposed pH value of the input metal solution is too high (pH 5.5), considering that usually industrial effluents of high metal content are strongly acidic. Therefore the input value pH 4.0 would be more suitable.

5. There is no reason for application of a variety of ions (sulphate stock solution, adjusting of pH by HCl, use of Na-acetate to get volume). Our studies on metal ion binding on different matrices (Janta-Koszuta and Twardowska, 1994) show considerable influence of the kind of anion in solution on sorption properties. Therefore, rather one kind of anion of high mobility e.g. Cl^- should be used. The lesser diversity of number and amount of "strange" ions (anions and cations) is applied, the easier is interpretation and comparison of results.

To summarize, there is no need in elaboration of a new standard method for evaluation of cation binding by batch method. The general protocol for a variety of matrices is being widely applied [e.g. Wieder 1990, Wieder et al. 1990,6,7], and differs only in details depending on the application target of the studies. This procedure described below has been applied also in reported batch experiments:

Studies on sorption of individual cations: Cd^{2+}, Cu^{2+}, Cr^{3+} and Zn^{2+} on 26 samples of peats have been carried out. To evaluate the binding of these cations, 2g replicate samples of air-dried peat were placed into 125 ml Erlenmeyer flasks. To each flask, 20 ml of a solution containing 1, 100, 1000, 2000, 3000, 4000, 5000 mg/dm^3 (input concentration c_0), all Cl^- salts adjusted to pH 4.0 with 0.1n HCl or 0.1n KOH, were added (for substrates of particularly high binding capacity, also solutions containing 7500 and 10000 mg/dm^3 of $Co2\underline{+}$, Cu_{2+} and Cr^{3+} will be applied). There were two replicate flasks for each solution. All flasks were shaken for 24 hrs and, after equilibration, filtered through 0.45μm Sartorius filter paper (I of two) or centrifuged (II of two replicates). In both different methods of separation, very good conformity of results was obtained. In the equilibrated filtrates, pH, conductivity and non-bound cation concentration (c_{eq}) were determined on a Perkin Elmer FAAS Mod. 1100 B . An air-acetylene flame was used for all determinations.

Specific amount of metal bound on peat was next calculated using the mean values of 3 replicates.

$$S = c_0 - c_{eq}$$

Metal cations bound on the particulates of peat were next desorbed, using the following procedure:
Peat samples with bound metals were separated from the solution and leached twice with distilled water. Next, the distilled water adjusted to the initial pH 3.5 with 0.1n HCl are being added, using the same general protocol described above, but without metal solution. Remobilized metal ions are being estimated in the equilibrated solution by FAAS method and their amount with respect to the unit of sample mass (D) are being calculated (experiment in progress).

3.2.2. Determination of chemical fractionation of bound metals in a selected peat sample

To determine phases where bound metal ions are retained, to the peat samples of one of the highest sorption capacity was selected [Peat Humus (Alder Peat) from the Wizna site, DR 70%, AC 12.55%, c_0 = 5000 mg M/dm^3]. To this substrate with bound individual cations of Cd^{2+}, Cu^{2+}, Cr^{3+} and Zn^{2+}, *sequential extraction* has been applied which is designed to differentiate between the exchangeable, carbonatic, easily reducible (hydrous Mn-oxides), moderately reducible (amorphous Fe-oxides), oxidizable (sulphides and organic phases) and residual fractions (Engler et al. 1977). In this study, Tessier and co-workers'(1979) scheme of sequential extraction modified by Kersten and Forstner, 1986 (in: Forstner and Kersten, 1988), comprising 7 steps, has been applied.

4. RESULTS AND DISCUSSION

4.1. Characterization of the sampled material

4.1.1. Physicochemical properties of peats

Classification and basic physicochemical properties of sampled peats are presented in Table 1.
Among investigated peats of lowmoor type, Peat Humus (*Alnioni*) originating from decomposed Alder trees, brushwood and forest wood (samples W1, Z1, W9b, B1b, B3, B4) represents the highest decomposition rate ranging from DR 55% to DR 80% and also the highest ash content ranging from AC 10.20 to 12.55 %.

Lower decomposition rate shows Rush Peat *(Limno-phragmicioni)* represented by Reed (samples W2,B6, B7) and Reed-Sedge Peat (sample W9c) for these samples. DR ranges from 50% to 65%, while AC ranges from 9.25% to 12.60%.

Sedgeous Peat *(Magnocaricioni)* that comprises Reed-Sedge and Sedge Peat (B1a and W4), displays large differentiation of the decomposition rate (DR 60% and 30%) while AC is as high as 8.00 and 9.80%, respectively).

The most abundant is Hypnum Moss Peat occurring as Sedge-Moss kind, sampled in 9 points in all three sites (W3, W5, W6, W7, B1, B2, B8, Z2a, Z3). Generally, these peats

are being decomposed to a considerably lesser extent than the previous kinds (DR 25-40%), though sometimes more strongly decomposed substrate can occur (e.g. samples B1 or Z3, DR 60 and 65%). Ash content is also lower in these matrices (AC = 7.20-9.80%). The sample of Hypnum Moss peat, Moss class (W8) shows the lowest decomposition rate (DR 18 %) and a low ash content (AC 7.20%)

Specific kinds of substrate are the entirely transformed peats such as Gyttja: Calcareous (B5) and Detrituous (Z2b), and Mellow Bog Soils (W9a).

Highmoor type of peat has been represented by only one sample B9 (*Sphagnum* Moss Peat), showing a very low extent of decomposition (DR 15%).

All peat samples of lowmoor type were slightly acidic (pH values in the range from 5.02 to 6.45) except Gyttja, that shows slightly alkaline reaction (pH 7.26-7.46). Lowmoor peat is positively acidic (pH 4.60).

Such parameters as porosity, moisture content and specific gravity does not show any regular correlation with the peat kind and range: porosity: 80.73-90.87%, specific gravity 1.432-1.627 g/cm^3 and moisture content 61.28-84.92%. Bulk density is generally the highest for Peat Humus, Rush and Sedgeous Peat and lower for *Hypnum* Moss Peat (Table 1).

4.1.2. Phase composition of mineral fraction

X-ray structure analysis of peat samples pre-heated at 350^{0}C, displayed occurrence of small quantities of calcite, quartz and presumably kaolinite (Fig. 6.1 - 6.9). These minerals were present in amounts somewhat higher than the detectable level, which shows that the total content of mineral fraction in the untreated (raw) sample does not exceed 1%, dry wt.

Only the composition of mineral fraction of Calcareous Gyttja (B5) distinctly differs from other samples (calcite comprisesalmost 100% dry wt.).

The attempts of separation of fraction enriched with mineral matter from water suspension failed because of its low content in the analyzed samples. Also separation of mineral matter with use of heavy liquid was unsuccessful due to small size of grains and difficulties of their separation from organic matter.

4.1.3. Identification of functional groups in organic fraction in selected peat samples

Spectra of samples analyzed by IR spectroscopy are presented in the Fig. 7.1 - 7.11. In the spectrum of samples W1, W2, W4, W5, W8, W9b, W9c, B1 and B3 representing all the basic peat kinds of a lowmoor type except Gyttja (Fig. 7.1 - 7.9), the following absorption bands can be distinguished:

- in the area 1600-1630, close to 1400 and to 1040 cm^{-1} issued from carboxylic groups of humic and fulvic acids;

- band with the maximum at about 3380 and 1620 cm^{-1}, coming from water;

- bands 2850 and 2920 cm^{-1} correspond with vibration of CH_2 and CH_3 groups;

- small bands at 1512 and 1266 cm^{-1} correspond with absorption of organic compounds containing nitrogen (amides);

Spectra of fractionated sample W1 (Fig. 7.1: a,b,c) does not differ considerably from each other.
Generally, spectrum pattern of all these samples is similar, some differences occur in the size of peaks.

Spectra of Gyttja samples B5 and Z2b (fig. 7.10 and 7.11) display:

- bands 876, 713 cm^{-1} , specific for calcite;

- bands from admixture of organic matter;

- weak band at 2511 cm^{-1} can originate from the occurrence of organic compounds of sulphur (thiol).

4.2. Metal cation binding to peat (batch experiments)

4.2.1. Binding of individual cations

The data depicting the binding of individual cations to investigated peat samples are shown in Fig. 8 - 33 and in Tables 2 - 27.

Generally, peats display substantial binding capacity with regard to studied metals, that, though, differs significantly, depending on:

- kind of metal ion;
- input concentration of bound metals;
- type and kind of peat.

Maximum binding capacities (in mass units) for the 4 metals to studied substrates followed the order:

$$Cr^{3+} > Cu^{2+} > Cd^{2+} > Zn^{2+}$$

This series is in agreement with a known order of increasing binding to soil organic matter of monovalent alkali metal cations < H_3O^+ < alkaline earth cations < transitional group monovalent cations < transitional group divalent cations (among them Cu^{2+} and Zn^{2+}) < trivalent cations (Cr^{3+}) (Taliburdeen, 1981). Also results obtained by Wieder, 1990, confirm this conclusion.
As have been expected, lowmoor peats of all kinds display better sorption properties than highmoor *Sphagnum* peat.

Increased concentrations of metal in input solution resulted in decrease of pH value of equilibrated solution, different for different metals, that suggested diversity of binding mechanisms. The extent of pH decrease, in general, followed the order:

$$Cr^{3+} < Cu^{2+} < Zn^{2+} \leq Cd^{2+}$$

This order was not, though, applicable to Gyttja, that showed considerably weaker and less differentiated decrease of pH, within the range of the lowest values up to pH 5.35 - 6.38.

The highest decrease of pH value occurred in chromium sorption series, when it fell from pH 6.95-7.65 at c_0 = 1 mg Cr^{3+}/dm^3 to pH 2.52-3.43 at c_0 = 5000 mg Cr^{3+}/dm^3. For peats showing decrease to pH<3 usually had have lower binding capacity than for peats displaying lesser acidification (pH>3). Gyttja (B5 and Z2b) was acidified to the smallest extent (pH = 5.95 and 5.67, respectively), while full applied load of chromium was bound to this substrate.
Maximum binding capacity for chromium within the applied range of input concentrations (from 1 to 5000 mg/dm³) varied from 35.92 g Cr^{3+}/kg to 50.0 g Cr^{3+}/kg for lowmoor peats and accounted for 23.50 g Cr^{3+}/kg for highmoor *Sphagnum* peat. The sorption rate for this metal is very high. For lower input concentrations (up to 2000-3000 mg Cr^{3+}/dm^3, almost full binding to peat occurred, while at maximum applied input concentration of 5000 mg Cr^{3+}/dm^3, the sorption rate ranged from 71.8 to 100 % for lowmoor peats and accounted for 48.5 % for highmoor peat B9.
With regard to maximum binding capacity of chromium within the applied range of input concentrations, the rank order for studied peats is:
Z2b ≈ B5 > W9c > W2 > B1b > W1 ≈ B1a ≈ W9b > Z1 > B7 > B3 ≈ B4 > W3 > B6 > W6 > W5 > B1 > W7 > Z3 > W9a ≈ B8 ≈ W4 > B2 > Z2a > W8 > B9. The kinds of peat followed the order: Gyttja > Rush Peat (Reed-Sedge Peat) ≈ Peat Humus > *Hypnum* Moss Peat and Boggy Soil > Highmoor *Sphagnum* Moss Peat. The bound amounts of chromium for these kinds were, respectively: 50.0 g/kg (100 %) > 49.38 - 45.23 g/kg (98.8 - 90.5 %) > 44.75 - 35.92 g/kg (89.5 -71.8 %) > 24.25 g/kg (48.5 %). At the higher concentrations of input Cr solution some changes of rank order and bigger differentiation between the peat samples can be expected. Probably, maximum binding capacity for individual Cr^{3+} cations to a number of peat samples will be considerably higher, that depict the binding curves of Gyttja, Rush Peat, Peat Humus and several Hypnum Moss samples. Only a pattern of binding curves for samples W4, B8, Z2a, W8, W9a and B9 displays binding capacity close to maximum or decreasing.

Sorption pattern and capacity for individual copper Cu^{2+} ions to peat is comparable with binding of Cr^{3+}, though some distinct differences can be easily observed. The increase of input concentrations also causes the decrease of pH, up to below the input value pH 4.0, though the extent of decrease is smaller: from pH 6.78 - 7.85 at c_0 = 1 mg Cu^{2+}/dm^3 to pH 3.03-4.44 (except Gyttja) at c_0 = 5000 mg Cu^{2+}/dm^3. For Gyttja, much weaker acidification occurred: up to pH 6.38 (B5) and pH 6.14 (Z2b). Sorption capacity for Cu^{2+} to peats is also high, but somewhat lower than for Cr^{3+}. With regard to maximum binding capacity for copper ions, peat kinds followed the same order: Gyttja > Peat Humus ≈ Rush Peat (Reed-Sedge Peat) > *Hypnum* Moss Peat (Sedge-Moss Peat) > Highmoor Sphagnum Moss Peat. The ranges of bound copper loads for these kinds were, respectively: 49.85-49.10 g/kg (99.7-98.1 %) > 47.39 - 42.26 g/kg (94.8 - 84.5 %) > 40.80 - 27.30 g/kg (81.6 - 54.6 %) > 23.5 g/kg (54.6 %). The highest differentiation of

binding capacity occurred thus in *Hypnum* Moss peat; no correlation of binding capacity with the decomposition rate or ash content in *Hypnum* Moss samples has been observed. Also decrease of pH has not showed regularity in the descending order of binding capacities, the lowest values ranging from pH 3.85 to 3.03. Studied peat rank order regarding the maximum obtained Cu-binding capacity is: B5 > Z2b > W9c ≈ W1 > B1b > Z1 > W9b > W2 ≈ B1a ≈ B7 > B3 ≈ W5 ≈ B4 > B6 > W7 ≈ B1 > W6 > W4 > W9a > B8 ≈ W3 ≈ Z2a > B2 > B2 > W8 > Z3 > B9. Similarly to chromium binding, most of sorption curves for Cu^{2+} ions suggest further increase of binding capacity with increase of input concentrations; several curves for the sample of Sedge peat W4 and Lowmoor Moss peats (W3, B2, B8, Z2a, Z3, W8) show decreasing trend. Close to maximum are the samples of Boggy Soil (W 9a) and Highmoor *Sphagnum* Moss Peat (B9).

Maximum binding capacity for **cadmium** varied from 11.3 to 37.5 g Cd^{2+}/kg for lowmoor peats and was as high as 18.15 g Cd^{2+}/kg for highmoor peat. Of all investigated peats, the lowest sorption of cadmium showed Detrituous Gyttja Z2b, while binding capacity of Calcareous Gyttja was within the range of *Hypnum* Moss Peat, that suggests a considerable role of carbonaceous fraction in cadmium binding. At maximum applied input concentration of 5000 mg Cd^{2+}/dm^3, sorption rate ranged from 22.6 % (Z2B, Detrituous Gyttja) to 75.0 % (Rush Peat, W9c). To Highmoor *Sphagnum* Moss Peat B9 was bound 36.3 % (B9) of applied load. Maximum binding capacities for cadmium to peats followed the order:
W9c > B1b > Z1 ≈ W1 > B7 ≈ W9B > B1a > W2 > B3 ≈ W7 > W5 > B1 > W4 ≈ B4 > W6 ≈ W9a > B5 > B8 > Z2a > Z3 ≈ B2 > W8 > B9 > Z2b. In general, with respect to binding capacity, an order for different kinds of peat is:
Peat Humus > Rush Peat (Reed and Reed-Sedge Peat) > Hypnum Moss Peat and Calcareous Gyttja > Highmoor *Sphagnum* Moss Peat > Detrituous Gyttja, that roughly corresponds also with decreasing decomposition rate and ash content (except Gyttja). Sorption capacity decreases within this order gradually and ranges, respectively.

Sorption capacity for individual **zinc** ions to peat is, in general, the lowest of the studied metals and comparable with binding of Cd^{2+}. Also sorption pattern resembles binding of Cd^{2+}, that suggests the similarity of binding mechanisms and phases, though some differences can be observed. The increase of input concentrations likewise causes the decrease of pH; the extent of decrease is somewhat deeper, than that for cadmium: from pH 6.06 - 7.72 at c_0 = 1 mg Zn^{2+}/dm^3 to pH 3.88-5.09 (except Gyttja) at c_0 = 5000 mg Zn^{2+}/dm^3. For Gyttja, similarly as at sorption of other individual cations, much weaker acidification occurred: up to pH 5.88 (B5) and pH 6.02 (Z2b). With regard to maximum binding capacity for zinc ions, peat kinds followed the same order as for cadmium: Peat Humus ≈ Rush Peat (Reed-Sedge Peat) > *Hypnum* Moss Peat (Sedge-Moss Peat) and Boggy Soil > *Sph*agnum Moss Peat > Gyttja, binding capacity to Calcareous Gyttja being more than twice higher than to Detrituous one. The ranges of maximum bound zinc loads for these kinds were, respectively: 33.70-25.50 g/kg (67.4-51.0 %) > 26.40 - 15.80 g/kg (52.8 - 31.6 %) > 15.20 g/kg (30.2 %) > 8.50 - 4.0 g/kg (17.0 - 8.0 %). Therefore, substantial differentiation of binding capacity occurred in Peat Humus, Rush Peat and *Hypnum* Moss peat; no strong correlation of binding capacity with the decomposition rate or ash content in peat samples was observed. Also decrease of pH did not show regularity in the descending order of binding capacities. Investigated peat samples' rank order regarding the maximum obtained Zn-binding capacity is: Z1 > B7 > W9c > B1a > B1b > W9b > W1 > B6 ≈ B3 > B4 > W5 ≈ W6 > W2 > W4 ≈ W7 ≈ B1 >

Z2a > Z3 > B2 > B8 > W9a > W8 > W3 > B9 > B5 > Z2b. Contrary to other studied metals, most of sorption curves for Zn^{2+} ions show decrease of binding capacity with increase of input concentrations above 2000 mg Zn^{2+}/dm^3; several curves, e.g. for the samples of Sedge Peat W4, Peat Humus (Z1, B3, B4), Rush Peat (B7) and Reed-Sedge Peat (B1a) show still increasing trend, though close to maximum.

In general, investigated samples display considerable diversity with regard to the rank order of maximum binding capacity of individual ions, that is apparently results from different prevailing mechanisms of binding and occurrence of different binding phases, therefore selection and ranking samples according the best sorption properties is rather difficult:
Nevertheless, among these samples several ones occupying top ten of the ranking list with respect to all four individual metal ions, i.e. Cr^{3+}, Cu^{2+}, Cd^{2+} and Zn^{2+} can be selected. With regard to sorption capacity for these ions, the approximate rank order for the most effective peat samples is, respectively:

Rush (Reed-Sedge) Peat W9c:	(2-2-3-1)
Peat Humus (Brushwood) Peat B1b:	(4-3-2-4)
Peat Humus (Alder Peat) W1:	(5-2'-3-6)
Sedgeous (Reed-Sedge) Peat B1a:	(5'-6'-7-3')
Peat Humus (Brushwood) Peat W9b:	(5"-5-5-5)
Peat Humus (Alder Peat) Z1:	(7-4-4-1)
Rush (Reed) Peat B7:	(8-6"-6-2)
Peat Humus (Forest Wood Peat)B3:	(9-7-10-7')

Gyttja shows the highest binding capacity with regard to Cr^{3+} and Cu^{2+}, but the lowest one with regard to Cd^{2+} and Zn^{2+}:

Calcareous Gyttja B5:	(1-1-20-20)
Detrituous Gyttja Z2b:	(1-1-26-21)

Highmoor *Sphagnum* Moss Peat B9 occupies the bottom of the ranking list:
(20-18-19'-25)
Also *Highmoor Hypnum* Moss Peat and Boggy Soil display distinctly lower sorption capacities than other kinds of highmoor peats, though, as have been mentioned, there is no
decidedly worse results than for the most effective peats.

4.2.2. Chemical fractionation of bound metals in a selected peat sample

Chemical fractionation of Cr^{3+}, Cu^{2+}, Cd^{2+} and Zn^{2+} in the sample of Peat Humus (Alder Peat) W1, belonging to the group of samples of the highest binding capacity, confirms the diversity of prevailing binding fractions for the studied metal ions (Fig. 34, Table 28).

No metal ions in the residual fraction was found.

Chromium has been stably bound mainly to the organic matter (59.5 %), forming presumably organometallic complexes. Much lesser amounts of Cr^{3+} -ions have occupied exchangeable sites F1 (18.9%) and moderately reducible phase F4 (amorphous Fe-oxides) (15.2%). Minor percentages of chromium have been bound in the carbonate F2 (4.0%) and

easily reducible Mn-oxide F3 fraction (0.4%). Some 2.0% has been retained in pore solution. Of other metals, chromium ions are positively dominating in the organic fraction F5, that has been observed in sorption studies involving other heterogenous substrates (Twardowska and Jarosinska, 1991). Considering occurrence of carboxylic O-containing functional groups of humic and fulvic acids in the peat samples (Fig 7/1 - 7/9), among them in the W1 sample (Fig. 7/1, 7/1a), it should be assumed that chromium preferentially forms complexes with these groups, that are particularly selective toward multivalent cations. It has long been recognized (Taliburdeen, 1981), that carboxylic sites show higher selectivity towards multivalent cations, when they are attached to adjacent carbon atoms on a ring structure than when they are widely spaced (thorough domination of chromium in the fraction F5 suggests a ring structure for the sample W1, though it should be confirmed by the detailed studies of the nature of binding sites). Strong acidification of equilibrated solution at individual Cr^{3+}-ions sorption experiments (Table 2-25) indicates displacement of H_3O^+ into solution by chromium ions from the carboxylic sites. The nature of chromium binding suggests, that no competition from other studied metals can be expected, unless some other multivalent cations are also present in the input solution.
Very strong chromium binding to Gyttja (B5 and Z2b samples) is of entirely different nature: dominating mechanism of binding is precipitation, while dominating binding phase is supposedly calcium carbonate F2 and to lesser extent sulphidic/organic F5 fraction (the IR spectra for these substrates depict bands characteristic for calcite and thiols: Fig. 7/10 - 7/11).

Copper is highly enriched in two fractions, that play almost equivalent role in Cu^{2+} ions binding to peat: exchangeable F1 (42.3 %) and moderately reducible amorphous Fe-oxide fraction F4 (37.1 %), while copper percentage in carbonatic fraction is also significant (16.2 %). In other fractions, excluding retention in pore solution (2.1 %), has been bound in total 2.3 % of Cu^{2+}.
Similarly to chromium, almost thorough binding of Cu^{2+} ions in Gyttja indicates precipitation as a prevailing mechanism, and calcium carbonate as a main binding fraction.

In relation to species distribution in the peat example W1, the inputs of **cadmium and zinc** have been similarly bound in more labile exchangeable F1 (50.4 and 55.2 %, respectively) and carbonatic F2 forms (25.9 and 24.1 %) and should be, therefore, more susceptible to remobilization due to changes of the chemical environment. Much lower decrease of pH in equilibrated solution indicates replacement by metal ions, besides H_3O^+, of exchangeable alkaline earth cations and probably also monovalent basic cations (mainly Na^+).
Other fractions are poorly enriched by cadmium and zinc. In a stable organic /sulphidic fraction is bound somewhat higher percentages of Cd^{2+} (10.2 %), while zinc is bound in similar percentages in moderately reducible amorphous Fe-oxide form F4 (11.5 %). In pore solution have been retained somewhat higher amounts of these ions (8.1 and 4.7 %), than it has been estimated for chromium and copper.
Sorption of cadmium and zinc ions to Gyttja B5 and Z2b (Table 19, 26) suggests carbonate being prevailing binding fraction in these substrates; binding capacity for these metals to Gyttja is low and comparable to those bound by carbonate fraction F2 in Peat Humus (W1) sample and is more than twice higher for Calcareous Gyttja B5 than for Detrituous one Z2b.

With respect to maximum metal enrichment in the peat sample W1 (mg/kg), the binding fractions followed the order:

F0 (Pore water):	Cd > Zn > Cu ≈ Cr
F1 (Exchangeable):	Cu > Cd > Zn >> Cr
F2 (Carbonatic):	Cd > Cu > Zn >> Cr
F3 (Easily reducible Mn-oxides)	Cd > Cu > Zn >> Cr
F4 (Moderately reducible amorphous Fe-oxides)	Cu >> Cr >> Zn >>> Cd
F5 (Organic/sulphidic)	Cr>>>>Cd >> Zn > Cu
F6 (Residual)	0

Of these fractions, easily reducible Mn-oxide fraction F3 plays a negligible role. Retention capacity of pore water F0 is also low, while metals in residual fraction do not occur in detectable amounts. The highest metal enrichment occurs in fractions F1 (Exchangeable), F2 (Carbonatic), F4 (moderately reducible amorphous Fe-oxide) and F5 (organic/sulphidic).

With respect to percentage of total sorption capacity for individual metal ions to peat example W1, binding fractions followed somewhat different order:

F0 (Pore water):	Cd > Zn > Cu ≈ Cr
F1 (Exchangeable):	**Zn > Cd > Cu >> Cr**
F2 (Carbonatic):	**Cd > Zn > Cu >> Cr**
F3 (Easily reducible Mn-oxides)	Cd > Zn > Cu >> Cr
F4 (Moderately reducible amorphous Fe-oxides)	Cu >> Cr > Zn >> Cd
F5 (Organic/sulphidic)	**Cr>>>>Cd >>> Zn > Cu**
F6 (Residual)	0

To understand binding mechanism, more detailed studies on the chemical nature of binding sites should be conducted, that is planned in the next stage of experiments. It is anticipated, that in the dynamic conditions, the binding capacity of peat will differ considerably from that estimated in batch experiments for individual ions.

5. CONCLUSIONS

1. Presented results comprising the first stage of experiments on binding heavy metals to Polish peats as individual ions, confirm generally high, but different sorption capacity and binding strength, as well as distinct diversity in binding mechanisms, phases and chemical nature of binding sites, depending on type and kind of peat, kind of metal ion and its input concentrations.

2. In general, all peats of lowmoor type show higher sorption capacity than highmoor *Sphagnum* Moss peat, as it has been anticipated.

3. With regard to maximum binding capacity for Cr^{3+}, Cu^{2+}, Cd^{2+} and Zn^{2+} to peats, substrate follows the order:
   Gyttja (Cr^{3+}, Cu^{2+}) > Rush (Reed-Sedge) Peat ≈ Peat Humus > *Hypnum* Moss Peat and Boggy Soil > Highmoor *Sphagnum* Moss Peat > Gyttja (Cd^{2+}, Zn^{2+}).
   No regular direct correlation of this order with the decomposition rate DR and ash content AC occurs, though generally decreasing trend for these parameters has been observed.

4. Maximum binding capacity for the 4 cations to peat follows the order:
   Cr^{3+} > Cu^{2+} > Cd^{2+} > Zn^{2+} and results in decrease of pH in the same order, due to displacement of H_3O^+ from the substrate by metal ions.

5. The highest metal enrichment occurs in binding fractions F1 (Exchangeable), F2 (Carbonatic), F4 (Moderately reducible amorphous Fe-oxide) and F5 (Organic/sulphidic).

6. In relation to the species distribution in peats, the prevailing part of inputs of Cr^{3+} is stably bound in Organic/sulphidic fraction F5, while Cu^{2+} is highly enriched in the Moderately reducible amorphous Fe-oxide fraction F4 and Exchangeable fraction F1; both these metals are also pliant to precipitation in calcareous material; Cd^{2+} and Zn^{2+} are predominantly bound in more labile Exchangeable F1 and Carbonatic F2 fractions.

7. Diversity of the predominant binding phases for studied metals suggests lack of strong competition for binding sites for chromium and copper; the strongest competition is anticipated for exchange sites of F1 fraction (the competition studies will be conducted in the next phase).

6. The presented batch experiments on the sorption of individual ions does not give enough information about the metal binding and remobilization mechanisms, as well as about binding capacity of peat for metals in the real conditions of metal-polluted water flow and its chemical composition. These studies are planned for the next phase of experiments.

6. WORK PLAN FOR THE PERIOD FROM AUGUST 30, 1994, TO AUGUST 30, 1995:

The proposed work plan for the next year's period (from August 30, 1994 to August 30, 1995) comprises:

1) Batch experiments:

- completion of adsorption-desorption studies for individual ions, including Cr(VI) and As, on selected peat samples (adsorption at pH 4.0, desorption at pH 3.5 of input solution).

- studies on ion competition for binding sites (adsorption-desorption studies on solution containing several cations, including simulation of a real typical composition of metal-polluted solution);

2) Dynamic (column) experiments for selected peat samples:

- adsorption-desorption studies for individual ions, on selected peat samples (adsorption at pH 4.0, desorption at pH 3.5 of input solution, water flow simulating real flow conditions).

- studies on ion competition for binding sites (adsorption-desorption studies on solution containing several cations, including simulation of a real typical composition of metal-polluted solution);

- adsorption-desorption studies with use of a a real metal-polluted solutions;

3) Studies on mechanism and phases of metal binding to peat:

- determination of chemical fractionation of bound metals in selected peat samples from batch and column experiments for individual and competing ions, prepared and real metal-containing input solution;

- studies on the characterization of chemical nature of the binding sites on selected peat samples and processes of binding;

4) Characterization of binding properties of peat samples

- Evaluation of binding capacities of peat for individual metal ions and in co-occurrence, in static and dynamic flow conditions, on prepared and real metal-containing input solutions (on the basis of the Langmuir equation and assessment of a maximum specific retention load for a given substrate and input concentrations of metals);

- Evaluation of desorption conditions for separation of bound metals from the matrices;

- Data-based cost/benefit analysis of peat application for treatment of metal-polluted effluents.

The details of the above work plan should be discussed by both Principal Investigators in Israel and Poland and accepted by the Main Grantee prof. Yoram Avnimelech. For this purpose, the meeting of the heads of both research groups in Israel and Poland is necessary. To rationalize the research work, we propose division of the research fields of both groups, in accordance with the experience and available equipment, as follows:

- IT group would conduct research on metal binding to substrates from Poland and Israel;
- YA group would conduct research on organic contaminants separation on substrates from Poland and Israel;

QA/QQ tests would be accomplished by both research groups.

The pre-requisite of successful realization of the work plan is setting in order the financial side of the project.

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Table 1
Physiochemical properties of investigated peats

Nr	Peat		Decomposition Rate (DR), (%)	pH (H_2O)	Natural moisture content (%)	Bulk density (g/cm^3)	Specific gravity (g/cm^3)	Porosity (%)	Ask content (AC), (%)
	Type	Kind							
	WIZNA SITE								
W1	Peat Humus	Alder Peat	70	6.45	73.60	0.310	1.609	80.73	12.55
W2	Rush Peat	Reed Peat	55	6.28	84.92	0.217	1.609	86.51	12.60
W3	Hypnum Moss Peat	Sedge-Moss Peat	35	6.03	81.27	0.182	1.576	88.45	9.80
W4	Sedgeous Peat	Sedge Peat	30	5.81	78.45	0.195	1.587	87.11	9.10
W5	Hypnum Moss Peat	Sedge-Moss Peat	25	6.08	83.51	0.157	1.557	89.92	8.20
W6	Hypnum Moss Peat	Sedge-Moss Peat	40	6.09	78.50	0.149	1.432	90.87	8.80
W7	Hypnum Moss Peat	Sedge-Moss Peat	30	6.19	76.27	0.188	1.552	87.89	7.80
W8	Hypnum Moss Peat	Moss Peat	18	5.76	92.80	0.156	1.551	89.94	7.20
W9a	Mellow Boggy Soil			6.11	73.31				
W9b	Peat Humus	Brushwood	55	6.32	79.67	0.295	1.587	81.88	10.40
W9c	Rush Peat	Reed-Sedge Peat	55	6.21	75.11	0.247	1.597	85.54	9.50
	BIEBRZA SITE								
B1	Hypnum Moss	Sedge-Moss Peat	60	6.21	68.81	0.281	1.541	81.84	7.40
B1a	Sedgeous Peat	Reed-Sedge Peat	60	6.54	74.11	0.278	1.554	82.11	8.00
B1b	Peat Humus	Brushwood Peat	65	6.18	75.21	0.232	1.598	83.12	10.20
B2	Hypnum Moss Peat	Sedge-Moss Peat	40	5.02	73.68	0.198	1.565	87.35	8.90
B3	Peat Humus	Forest Wood	80	5.81	70.00	0.248	1.599	84.49	11.70

Nr	Peat		Decomposition Rate (DR), (%)	pH (H_2O)	Natural moisture content (%)	Bulk density (g/cm^3)	Specific gravity (g/cm^3)	Porosity (%)	Ask content (AC), (%)
	Type	Kind							
B4	Peat Humus	Forest Wood	60	5.52	78.95	0.257	1.585	83.78	10.55
B5	Gyttja	Calcareous		7.46	61.28				
B6	Rush Peat	Reed Peat	50	6.46	83.45	0.189	1.569	87.95	9.25
B7	Rush Peat	Reed Peat	65	6.24	84.90	0.187	1.587	88.22	10.70
B8	Hypnum Moss Peat	Sedge-Moss Peat	40	6.05	69.32	0.151	1.468	80.12	7.10
B9	Highmoor Peat	Sphagnum Moss Peat	15	4.60	78.91				
ZBÓJNA SITE									
Z1	Peat Humus	Alder Peat	60	6.42	83.10	0.228	1.627	85.99	14.10
Z2a	Hypnum Moss Peat	Sedge-Moss Peat	40	6.30	89.60	0.137	1.549	91.16	7.55
Z2b	Gyttja	Detrituous		7.26	72.69	0.263			
Z3	Hypnum Moss Peat	Sedge-Moss Peat	65	5.82	80.10	0.146	1.582	92.12	7.90

Table 2
Heavy metal binding on Peat Humus (Alder Peat) from the Wizna peat bog, mg/kg (%)
Sampling point W1

Sample	Peat Humus (Alder Peat) - W1, (DR 70%)															
Metal	Cd				Cu				Cr				Zn			
C_o	pH	EC	C_{eq}	S	pH	EC	C_{eq}	S	pH	EC	C_{eq}	S	pH	EC	C_{eq}	S
1	7.95	180	0.00	10.0 (100)	7.78	316	0.00	10 (100)	6.95	211	0.00	10 (100)	7.50	301	0.03	9.7 (97.0)
100	7.61	340	0.61	994 (99.4)	7.29	650	0.26	997 (99.7)	7.57	705	0.06	999 (99.9)	7.63	611	1.49	985 (98.5)
1000	6.55	1250	11.4	9886 (98.7)	6.05	4330	1.78	9982 (99.8)	7.34	4630	0.22	9998 (99.9)	6.78	3680	110	8900 (89.0)
2000	6.16	2860	96.0	19040 (95.2)	5.05	6740	9.15	19908 (99.5)	6.24	7990	0.47	19995 (99.9)	6.25	5320	404	15960 (79.8)
3000	6.72	6010	338	26620 (88.7)	5.42	8540	39.0	29610 (98.7)	4.78	10550	1.16	29988 (99.9)	5.69	8250	730	22700 (75.7)
4000	6.11	7120	679	33210 (83.0)	4.76	10670	92.0	39080 (97.7)	3.91	12930	5.32	39947 (99.9)	5.59	10400	1210	27900 (69.7)
5000	6.01	7940	1490	35100 (70.2)	4.11	13360	285	47150 (94.3)	3.11	16030	260	47370 (94.7)	5.15	11300	2049	29510 (59.0)

Table 3
Heavy metal binding on Rush (Reed) Peat from the Wizna peat bog, mg/kg (%)
Sampling point W2

Sample	Rush (Reed) Peat - W2, (DR 55%)															
Metal	Cd				Cu				Cr				Zn			
C_o	pH	EC	C_{eq}	S	pH	EC	C_{eq}	S	pH	EC	C_{eq}	S	pH	EC	C_{eq}	S
1	7.10	190	0.00	10 (100)	7.26	237	0.00	10 (100)	7.07	177	0.00	10 (100)	7.22	297	0.02	9.8 (98.0)
100	6.52	367	0.53	995 (99.5)	7.40	663	0.13	999 (99.9)	7.49	549	0.05	999 (99.9)	7.32	560	0.28	997 (99.7)
1000	5.92	1354	21.8	9782 (97.8)	5.32	4140	3.75	9962 (99.6)	7.27	4700	0.17	9998 (99.9)	6.49	3710	165	8350 (83.5)
2000	6.16	2810	188	18115 (90.6)	5.32	6600	14.2	19857 (99.3)	6.24	7920	0.28	19997 (99.9)	6.01	5460	339	1661 (83.1)
3000	6.05	5870	494	25060 (83.5)	5.10	9140	62	29380 (97.9)	5.25	10058	0.40	29996 (99.9)	5.71	7920	986	20140 (67.1)
4000	5.59	6940	1019	29810 (74.5)	4.42	10450	86	39140 (97.8)	4.44	12870	1.66	39983 (99.9)	5.27	10740	1560	24400 (61.0)
5000	5.05	7710	1660	33400 (66.8)	3.80	13350	470	45300 (90.6)	3.43	16200	110	48900 (97.8)	5.22	11690	2420	25800 (51.6)

Table 4
Heavy metal binding on Hypnum Moss (Sedge-Moss) Peat from the Wizna peat bog, mg/kg (%)
Sampling point W3

Sample	Hypnum Moss (Sedge-Moss) Peat - W3, (DR 35%)															
Metal	Cd				Cu				Cr				Zn			
C_o	pH	EC	C_{eq}	S	pH	EC	C_{eq}	S	pH	EC	C_{eq}	S	pH	EC	C_{eq}	S
1	6.60	175	0.00	10 (100)	7.47	205	0.00	10 (100)	7.46	298	0.00	10 (100)	7.26	273	0.00	10 (100)
100	7.15	340	0.20	998 (99.8)	6.83	680	0.11	999 (99.9)	7.36	505	0.07	999 (99.9)	6.78	439	0.43	996 (99.6)
1000	5.06	1440	15.0	9850 (98.5)	5.90	4080	3.71	9963 (99.6)	7.22	4620	0.12	9999 (99.9)	6.58	3580	280	7200 (72.0)
2000	5.93	2810	142	1858 (92.9)	4.43	6620	38.5	19615 (98.1)	6.30	8050	0.18	19998 (99.9)	6.38	5410	835	1165 (58.2)
3000	5.76	5070	706	22940 (76.5)	4.08	8980	243	27570 (91.8)	5.35	10490	1.23	29988 (99.9)	5.23	8320	1400	16000 (53.3)
4000	5.02	6080	1138	28620 (71.5)	3.90	9540	472	35280 (88.2)	3.52	12660	48.6	39514 (98.8)	4.88	10010	2390	16100 (40.2)
5000	4.88	7310	2240	27600 (55.2)	3.48	12570	1660	33400 (66.8)	3.06	15120	525	44750 (89.5)	4.64	10890	3420	15800 (31.6)

Table 5
Heavy metal binding on Sedgeous (sedge) Peat from the Wizna peat bog, mg/kg (%)
Sampling point W4

Sample	Sedgeous (Sedge) Peat - W4, (DR 30%)															
Metal	Cd				Cu				Cr				Zn			
C_o	pH	EC	C_{eq}	S	pH	EC	C_{eq}	S	pH	EC	C_{eq}	S	pH	EC	C_{eq}	S
1	7.45	190	0.00	10 (100)	7.75	415	0.00	10 (100)	7.56	287	0.00	10 (100)	7.83	325	0.00	10 (100)
100	5.90	320	0.13	999 (99.9)	7.82	794	0.16	998 (99.8)	7.38	477	0.05	999 (99.9)	7.77	675	0.16	998 (99.8)
1000	5.63	1400	28.0	9720 (97.2)	6.06	4470	8.20	9918 (99.2)	7.17	4540	0.10	9999 (99.9)	6.62	2740	265	7350 (73.5)
2000	5.04	1450	266	17740 (88.7)	4.66	6370	92.0	19080 (95.4)	6.03	7800	0.62	19994 (99.9)	6.45	5420	744	12560 (62.8)
3000	5.73	5140	689	23110 (77.0)	4.02	8270	179	28210 (94.0)	3.87	9280	51.2	29488 (98.3)	5.62	7510	1340	16600 (55.3)
4000	5.00	6370	1226	27740 (69.3)	3.99	9500	384	36160 (90.4)	3.07	12530	348	36520 (91.3)	4.62	9800	1890	21100 (52.7)
5000	4.83	7440	2020	29800 (59.6)	3.78	12100	1230	37700 (75.4)	2.98	15120	1158	38420 (78.8)	4.62	11550	2450	25500 (51.0)

Table 6
Heavy metal binding on Hypnum Moss (Sedge-Moss) Peat from the Wizna peat bog, mg/kg (%)
Sampling point W5

Sample	Hypnum Moss (Sedge-Moss) Peat - W5, (DR 25%)															
Metal	Cd				Cu				Cr				Zn			
C_o	pH	EC	C_{eq}	S	pH	EC	C_{eq}	S	pH	EC	C_{eq}	S	pH	EC	C_{eq}	S
1	6.85	188	0.00	10 (100)	7.99	248	0.00	10 (100)	7.28	210	0.00	10 (100)	6.90	105	0.03	9.7 (97.0)
100	5.15	340	0.22	998 (99.8)	6.60	680	0.21	998 (99.8)	7.18	621	0.08	999 (99.9)	6.88	468	0.53	995 (99.5)
1000	4.87	1210	28.0	9720 (97.2)	5.87	4110	2.61	9974 (99.7)	7.08	4250	0.21	9998 (99.9)	6.30	3380	216	7840 (78.4)
2000	6.08	2230	186	18140 (90.7)	4.92	6170	18.5	19815 (99.1)	6.17	7870	0.33	19996 (99.9)	6.53	5390	627	13730 (68.6)
3000	5.99	5030	545	24550 (81.8)	4.28	8300	119	28810 (96.0)	4.47	10470	10.4	29896 (99.6)	4.60	7090	1150	18500 (61.7)
4000	4.97	6080	982	30180 (75.5)	4.15	9740	277	37230 (93.1)	3.23	12970	174	38260 (95.6)	4.78	9100	1790	22100 (55.2)
5000	4.87	7200	1920	30860 (61.6)	3.55	12420	720	42800 (85.6)	2.79	15160	632	43680 (87.4)	4.53	11100	2310	26900 (53.8)

Table 7
Heavy metal binding on Hypnum Moss (Sedge-Moss) Peat from the Wizna peat bog, mg/kg (%)
Sampling point W6

Sample	Hypnum Moss (Sedge-Moss) Peat - W6, (DR 40%)															
Metal	Cd				Cu				Cr				Zn			
C_o	pH	EC	C_{eq}	S	pH	EC	C_{eq}	S	pH	EC	C_{eq}	S	pH	EC	C_{eq}	S
1	7.20	195	0.00	10 (100)	7.44	251	0.00	10 (100)	7.11	224	0.00	10 (100)	7.15	271	0.01	9.9 (99.0)
100	5.67	375	0.38	996 (99.6)	7.03	643	0.29	997 (99.7)	7.10	387	0.20	998 (99.8)	7.09	527	0.41	996 (99.6)
1000	5.22	1422	33.8	9662 (96.6)	6.08	4130	3.04	9979 (99.7)	6.94	4470	0.53	9995 (99.9)	6.45	3700	236	7640 (76.4)
2000	5.17	2720	265	17350 (86.7)	4.78	6370	30.3	19697 (98.5)	6.18	7730	0.66	19993 (99.9)	6.50	5480	554	14400 (72.3)
3000	4.56	4920	695	23050 (76.8)	3.97	8210	222	27780 (92.6)	4.61	10490	5.80	29942 (99.8)	4.87	8100	1008	19920 (66.4)
4000	4.59	5600	1384	26160 (65.4)	3.95	10560	430	35700 (89.2)	3.29	13070	82.2	39178 (97.9)	4.83	10510	1620	23800 (59.5)
5000	4.16	6750	2220	27800 (55.6)	3.50	13170	1046	39540 (79.1)	2.83	15440	636	43640 (87.3)	4.54	11410	2360	26400 (52.8)

Table 8
Heavy metal binding on Hypnum (Sedge-Moss) Peat from the Wizna peat bog, mg/kg (%)
Sampling point W7

Sample	Hypnum Moss (Sedge-Moss) Peat - W7, (DR 30%)															
Metal	Cd				Cu				Cr				Zn			
C_o	pH	EC	C_{eq}	S	pH	EC	C_{eq}	S	pH	EC	C_{eq}	S	pH	EC	C_{eq}	S
1	7.24	185	0.00	10 (100)	6.97	217	0.00	10 (100)	7.21	345	0.00	10 (100)	7.16	360	0.00	10 (100)
100	5.41	365	0.30	997 (99.7)	6.50	648	0.15	999 (99.9)	7.14	704	0.03	999 (99.9)	6.93	486	0.33	997 (99.7)
1000	5.30	1410	27.8	9722 (97.2)	5.95	3870	2.59	9974 (99.7)	6.85	4650	0.16	9998 (99.9)	5.97	3730	223	7770 (77.7)
2000	5.20	2800	180	18200 (90.9)	5.19	6013	9.11	19909 (99.5)	6.17	8020	0.26	19997 (99.9)	5.91	5200	639	13610 (68.1)
3000	5.40	5140	572	24280 (80.9)	4.56	8330	125	28750 (95.8)	4.25	10350	10.2	29898 (99.7)	4.68	7250	1184	18160 (60.5)
4000	4.73	6230	960	30400 (76.0)	4.12	10310	284	37160 (92.9)	3.21	13130	195	38050 (95.1)	4.71	9800	1980	20200 (50.5)
5000	4.50	7440	1780	32200 (64.4)	3.53	12250	920	40800 (81.6)	2.72	15480	704	42960 (85.9)	4.52	11560	2490	25100 (50.2)

Table 9
Heavy metal binding on Hypnum Moss (Moss) Peat from the Wizna peat bog, mg/kg (%)
Sampling point W8

Sample	Hypnum Moss (Moss) Peat - W8, (DR 18%)															
Metal	Cd				Cu				Cr				Zn			
C_o	pH	EC	C_{eq}	S	pH	EC	C_{eq}	S	pH	EC	C_{eq}	S	pH	EC	C_{eq}	S
1	6.55	182	0.00	10 (100)	6.85	224	0.00	10 (100)	7.12	235	0.00	10 (100)	7.24	176	0.03	9.7 (97.0)
100	5.24	359	0.27	997 (99.7)	6.74	634	0.25	998 (99.8)	7.10	710	0.06	999 (99.9)	6.67	644	0.38	996 (99.6)
1000	5.18	1430	62.8	9372 (93.7)	6.02	3840	5.20	9948 (99.5)	6.74	4220	0.15	9998 (99.9)	6.60	3670	324	6760 (67.6)
2000	5.45	2780	375	16250 (81.2)	4.64	5200	51.5	19485 (97.4)	5.70	7480	3.94	19961 (99.8)	4.30	5210	1204	7960 (39.8)
3000	4.70	4900	1300	17000 (56.7)	3.93	7280	364	26360 (87.9)	3.34	9850	157	28430 (94.8)	4.43	7100	1942	10580 (35.3)
4000	4.90	6030	2070	19300 (48.7)	3.53	10120	788	32120 (80.3)	2.98	12340	607	33930 (84.8)	4.54	9200	2615	13850 (34.5)
5000	4.83	6900	2810	21900 (43.8)	3.36	11230	2130	28700 (57.4)	2.76	14310	1408	35920 (71.8)	4.41	11150	3340	16600 (33.2)

Table 10
Heavy metal binding on Mellow Boggy Soil from the Wizna peat bog, mg/kg (%)
Sampling point W9

Sample	Mellow Boggy Soil - W9a															
Metal	Cd				Cu				Cr				Zn			
C_o	pH	EC	C_{eq}	S	pH	EC	C_{eq}	S	pH	EC	C_{eq}	S	pH	EC	C_{eq}	S
1	7.40	198	0.00	10 (100)	7.36	211	0.00	10 (100)	7.45	234	0.00	10 (100)	7.27	214	0.05	9.5 (95.0)
100	6.33	384	1.12	999 (99.9)	7.10	590	0.58	994 (99.4)	7.35	658	0.30	997 (99.7)	6.83	477	1.22	988 (98.8)
1000	6.14	1375	25.8	9742 (97.4)	5.26	4090	8.20	9918 (99.2)	6.48	4480	0.87	9991 (99.9)	6.19	3600	326	6740 (67.4)
2000	5.98	2470	179	18210 (91.1)	4.16	6650	57.8	19422 (97.1)	5.77	7750	1.49	19985 (99.9)	5.94	6290	876	11240 (56.2)
3000	6.13	5610	765	22350 (74.5)	4.05	8980	230	27700 (92.3)	4.10	10520	22.4	29776 (99.2)	4.99	8001	1478	15220 (50.7)
4000	5.08	6050	1570	24300 (60.7)	3.91	10330	428	35720 (89.3)	3.24	12850	137	38630 (96.6)	4.86	10480	2400	16000 (40.0)
5000	4.80	7320	2240	27600 (55.2)	3.85	12990	1260	37400 (74.8)	2.93	15190	1055	39450 (78.9)	4.62	11880	3260	17400 (34.8)

Table 11
Heavy metal binding on Peat Humus (Brushwood) from the Wizna peat bog, mg/kg (%)
Sampling point W9

Sample	Peat Humus (Brushwood) - W9b, (DR 55%)															
Metal	Cd				Cu				Cr				Zn			
C_o	pH	EC	C_{eq}	S	pH	EC	C_{eq}	S	pH	EC	C_{eq}	S	pH	EC	C_{eq}	S
1	7.96	280	0.00	10 (100)	7.60	294	0.00	10 (100)	7.87	264	0.00	10 (100)	7.55	292	0.03	9.7 (97.0)
100	7.24	395	0.60	994 (99.4)	7.16	620	0.42	996 (99.6)	7.76	604	0.16	998 (99.8)	7.50	536	0.52	995 (99.5)
1000	6.80	1462	10.6	9894 (98.9)	4.96	3810	2.73	9973 (99.7)	6.53	4450	0.36	9996 (99.9)	6.42	3590	2.17	7830 (78.3)
2000	6.53	2880	106	18940 (94.7)	4.87	6690	16.6	19833 (99.2)	5.92	7810	0.72	19993 (99.9)	6.52	5500	448	15120 (75.6)
3000	6.50	5790	457	25430 (84.8)	4.66	9000	58.0	29420 (98.1)	5.47	10450	1.07	29990 (99.9)	5.35	8330	780	22200 (74.0)
4000	5.66	6480	900	31000 (77.5)	4.74	10620	166	38340 (95.8)	4.43	12870	6.40	39936 (99.8)	5.58	10850	1105	28950 (72.4)
5000	5.01	7820	1680	33200 (66.4)	3.77	13510	446	45540 (91.1)	3.18	13400	238	47620 (95.2)	5.15	12230	2010	29900 (59.8)

Table 12
Heavy metal binding on Rush (Reed-Sedge) Peat from the Wizna peat bog, mg/kg (%)
Sampling point W9

Sample	Rush (Reed-Sedge) Peat - W9c, (DR 55%)															
Metal	Cd				Cu				Cr				Zn			
C_o	pH	EC	C_{eq}	S	pH	EC	C_{eq}	S	pH	EC	C_{eq}	S	pH	EC	C_{eq}	S
1	7.42	195	0.00	10 (100)	7.54	290	0.00	10 (100)	7.65	365	0.00	10 (100)	7.72	289	0.00	10 (100)
100	6.10	365	0.25	997 (99.7)	7.29	665	0.28	997 (99.7)	7.53	706	0.08	999 (99.9)	7.42	551	0.30	997 (99.7)
1000	5.94	1510	12.6	9874 (98.4)	6.30	4060	2.80	9972 (99.7)	6.54	4620	0.29	9997 (99.9)	6.43	3650	116	8840 (88.4)
2000	5.98	2870	107	18925 (94.6)	4.94	6620	9.28	19907 (99.5)	6.00	7840	0.41	19996 (99.9)	6.20	5490	379	16210 (81.1)
3000	5.67	5640	301	26990 (90.0)	4.84	9070	32.0	29984 (99.9)	4.98	10560	0.80	29992 (99.9)	5.32	8330	750	22500 (75.0)
4000	5.35	6790	696	33040 (82.6)	4.67	10340	81.0	39190 (97.9)	4.56	12750	3.21	39968 (99.9)	5.65	10610	1280	27200 (68.0)
5000	5.30	7960	1248	37520 (75.0)	4.44	13300	261	47390 (94.8)	3.22	13640	62.0	49380 (98.8)	5.16	11900	1730	32700 (65.4)

Table 13
Heavy metal binding on Hypnum Moss (Sedge-Moss) Peat from the Biebrza River Valley, mg/kg (%)
Sampling point B1

Sample	Hypnum Moss (Sedge-Moss) Peat - B1, (DR 60%)															
Metal	Cd				Cu				Cr				Zn			
C_o	pH	EC	C_{eq}	S	pH	EC	C_{eq}	S	pH	EC	C_{eq}	S	pH	EC	C_{eq}	S
1	7.89	230	0.01	9.9 (99.0)	7.67	285	0.00	10 (100)	7.64	209	0.00	10 (100)	7.49	245	0.02	9.8 (98.0)
100	7.04	395	0.75	992 (99.2)	6.47	575	1.38	986 (98.6)	7.55	706	0.28	997 (99.7)	7.56	546	0.47	995 (99.5)
1000	6.68	1190	24.2	9758 (97.6)	5.01	4040	12.4	9876 (98.8)	6.51	4460	0.53	9995 (99.9)	6.44	3650	278	7220 (72.2)
2000	6.30	2780	177	18230 (91.1)	4.94	6420	28.6	19714 (98.6)	6.03	7750	0.86	19991 (99.9)	6.58	5410	654	13460 (67.3)
3000	6.01	5120	644	23560 (78.5)	4.21	8950	109	28910 (96.4)	4.88	10120	7.64	29924 (99.7)	5.60	8160	1286	17140 (57.1)
4000	5.50	6040	1110	28900 (72.2)	4.02	10480	330	36700 (91.7)	3.30	12810	135	38650 (96.6)	5.15	10450	1810	21900 (54.7)
5000	5.82	7180	1984	30160 (60.3)	3.80	12880	930	40700 (81.4)	2.81	12900	696	43040 (86.1)	5.06	11440	2520	24800 (49.6)

Table 14
Heavy metal binding on Sedgeous (Reed-Sedge) Peat from the Biebrza River Valley, mg/kg (%)
Sampling point B1

Sample	Sedgeous (Reed-Sedge) Peat - B1a, (DR 60%)															
Metal	Cd				Cu				Cr				Zn			
C_o	pH	EC	C_{eq}	S	pH	EC	C_{eq}	S	pH	EC	C_{eq}	S	pH	EC	C_{eq}	S
1	7.76	195	0.00	10 (100)	7.59	225	0.00	10 (100)	7.63	149	0.00	10 (100)	7.36	232	0.03	9.7 (97.0)
100	7.03	370	0.49	995 (99.5)	7.20	619	0.22	998 (99.8)	7.60	619	0.13	999 (99.9)	7.24	473	0.22	998)99.8)
1000	6.83	1440	18.0	9820 (98.2)	5.06	3990	4.40	9956 (99.6)	6.52	4420	0.34	9997 (99.9)	6.75	3640	215	7845 (78.5)
2000	6.66	2800	147	18525 (92.6)	4.81	6440	20.4	19796 (98.9)	6.15	7960	0.66	19993 (99.9)	6.39	5410	431	15690 (78.5)
3000	6.44	5460	462	25380 (84.6)	4.28	8800	68.0	29320 (97.7)	4.94	10040	2.18	29978 (99.9)	5.55	8230	806	21940 (73.1)
4000	5.78	6720	922	30780 (76.9)	4.33	10510	177	38230 (95.6)	3.77	12910	22.8	39772 (99.4)	5.15	10550	1140	28600 (71.5)
5000	5.32	6860	1600	34000 (68.0)	3.81	13300	474	45260 (90.5)	3.00	13550	211	47890 (95.8)	5.04	11750	1740	32600 (65.2)

Table 15
Heavy metal binding on Peat Humus (Brushwood) from the Biebrza River Valley, mg/kg (%)
Sampling point B1

Sample	Peat Hummus (Brushwood) - B1b, (DR 65%)															
Metal	Cd				Cu				Cr				Zn			
C_o	pH	EC	C_{eq}	S	pH	EC	C_{eq}	S	pH	EC	C_{eq}	S	pH	EC	C_{eq}	S
1	6.90	186	0.00	10 (100)	7.64	208	0.00	10 (100)	7.59	198	0.00	10 (100)	7.15	198	0.02	9.8 (98.0)
100	6.20	328	0.57	994 (99.4)	7.40	652	0.24	998 (99.8)	7.56	612	0.09	999 (99.9)	7.08	475	0.57	994 (99.4)
1000	6.13	1430	10.6	9894 (98.9)	5.18	4012	4.28	9957 (99.6)	6.52	4430	0.30	9997 (99.9)	6.50	3670	157	8425 (84.2)
2000	5.40	2880	110	18895 (94.5)	4.42	6670	35.8	19642 (98.2)	5.60	7800	0.65	19994 (99.9)	6.23	5500	401	15990 (79.9)
3000	5.40	5840	342	26580 (88.6)	4.38	8910	42.0	29580 (98.6)	4.50	10390	1.82	29982 (99.9)	5.20	8040	838	21620 (72.1)
4000	5.68	6900	698	33020 (82.5)	4.31	10540	97.0	39030 (97.6)	3.66	12800	18.0	39820 (99.6)	4.97	10640	1260	27400 (68.5)
5000	5.65	7910	1284	37160 (74.3)	3.87	13490	331	46690 (93.4)	3.02	13520	199	48010 (96.0)	4.87	11720	1860	31400 (62.8)

Table 16
Heavy metal binding on Hypnum Moss (Sedge-Moss) Peat from the Biebrza River Valley, mg/kg (%)
Sampling point B2

Sample	Hypnum Moss (Sedge-Moss) Peat - B2, (DR 40%)															
Metal	Cd				Cu				Cr				Zn			
C_o	pH	EC	C_{eq}	S	pH	EC	C_{eq}	S	pH	EC	C_{eq}	S	pH	EC	C_{eq}	S
1	5.80	180	0.00	19 (100)	6.88	278	0.00	10 (100)	6.98	267	0.00	10 (100)	6.63	210	0.04	9.6 (96.0)
100	4.96	320	1.64	984 (98.4)	6.56	707	.17	988 (98.8)	6.05	844	0.45	996 (99.6)	5.63	665	1.66	983 (98.3)
1000	4.56	1336	71.4	9286 (92.9	6.21	4140	9.60	9904 (99.0)	4.57	4433	1.20	9988 (99.9)	5.92	3210	460	5400 (54.0)
2000	4.36	2710	417	15830 (79.1)	4.11	6680	94.6	19054 (95.3)	3.81	7670	26.8	19732 (98.7)	5.86	5430	964	10360 (51.6)
3000	4.12	5270	940	20600 (68.7)	3.51	8320	287	27130 (90.4)	3.09	10930	188	28120 (93.7)	4.20	8000	1820	11800 (39.3)
4000	4.08	6900	1750	22500 (56.2)	3.22	10470	808	31920 (79.8)	2.80	12940	663	33370 (83.4)	4.04	9760	2510	14900 (37.2)
5000	4.07	6710	2480	25200 (50.4)	3.03	13070	1990	30100 (60.2)	2.52	13350	1080	39200 (78.4)	4.01	11250	3180	18200 (36.4)

Table 17
Heavy metal binding on Peat Humus (Forest Wood) from the Biebrza River Valley, mg/kg (%)
Sampling point B3

Sample	Peat Humus (Forest Wood) - B3, (DR 80%)															
Metal	Cd				Cu				Cr				Zn			
C_o	pH	EC	C_{eq}	S	pH	EC	C_{eq}	S	pH	EC	C_{eq}	S	pH	EC	C_{eq}	S
1	7.44	185	0.00	10 (100)	7.26	230	0.00	10 (100)	7.26	130	0.00	10 (100)	7.13	216	0.03	9.7 (97.0)
100	6.48	356	0.75	993 (99.3)	7.67	609	0.75	993 (99.3)	6.59	608	0.34	997 (99.7)	6.93	494	0.74	993 (99.3)
1000	5.59	1343	24.6	9754 (97.5)	5.22	4100	6.15	99385 (99.4)	5.37	4530	0.63	9994 (99.9)	6.15	3660	311	6890 (68.9)
2000	5.19	2710	185	18150 (90.8)	4.75	6430	21.6	19784 (98.9)	4.97	7950	1.61	19984 (99.9)	6.49	5460	688	13120 (65.6)
3000	5.36	5580	630	23700 (79.0)	3.96	9160	110	28900 (96.3)	4.15	10530	6.74	29933 (99.8)	5.05	8120	1122	18780 (62.6)
4000	5.13	6800	1144	28560 (71.4)	3.93	10520	27[illegible]	37280 (93.2)	3.25	12860	80.8	39192 (97.9)	4.69	10700	1670	23300 (58.2)
5000	5.10	7800	1680	33200 (66.4)	3.52	13540	722	42780 (85.6)	2.87	13360	487	45130 (90.3)	4.59	12100	2150	28500 (57.0)

Table 18
Heavy metal binding on Peat Humus (Forest Wood) from the Biebrza River Valley, mg/kg (%)
Sampling point B4

Sample	Peat Humus (Forest Wood) - B4, (DR 60%)															
Metal	Cd				Cu				Cr				Zn			
C_o	pH	EC	C_{eq}	S	pH	EC	C_{eq}	S	pH	EC	C_{eq}	S	pH	EC	C_{eq}	S
1	6.87	188	0.00	10 (100)	7.51	229	0.00	10 (100)	7.13	235	0.00	10 (100)	7.15	189	0.04	9.6 (96.0)
100	5.38	358	0.55	945 (94.5)	6.56	625	0.51	995 (99.5)	6.79	693	0.22	998 (99.8)	6.40	613	0.78	992 99.2)
1000	4.94	1380	29.4	9706 (97.1)	4.99	4180	6.65	9934 (99.3)	5.32	4460	0.51	9995 (99.9)	6.30	3660	317	6830 (68.3)
2000	4.82	2710	216	17840 (89.2)	4.78	6630	19.4	19806 (99.0)	5.20	8050	1.66	19983 (99.9)	6.17	5470	734	12660 (63.3)
3000	5.80	5870	648	23520 (78.1)	3.86	9190	118	28820 (96.1)	4.09	10530	12.6	29874 (99.6)	4.61	8490	1202	17980 (59.9)
4000	4.55	6930	1180	28200 (70.5)	3.64	10510	300	37000 (92.5)	3.22	13060	126	38740 (96.9)	4.46	10670	1720	22800 (57.0)
5000	4.40	7610	2070	29300 (58.6)	3.48	13350	744	42560 (85.1)	2.72	13450	477	45230 (90.5)	4.37	11650	2270	27300 (54.6)

Table 19
Heavy metal binding on Calcareous Gyttja from the Biebrza River Valley, mg/kg (%)
Sampling point B5

Sample	Calcareous Gyttja - B5															
Metal	Cd				Cu				Cr				Zn			
C_o	pH	EC	C_{eq}	S	pH	EC	C_{eq}	S	pH	EC	C_{eq}	S	pH	EC	C_{eq}	S
1	7.82	191	0.00	10 (100)	7.69	226	0.00	10 (100)	7.47	198	0.00	10 (100)	7.17	322	0.02	9.8 (98.0)
100	7.51	340	0.95	991 (99.1)	7.64	677	0.18	998 (99.8)	7.28	689	0.00	1000 (100)	7.60	496	0.12	999 (99.9)
1000	6.74	1462	59.8	9402 (94.0)	7.31	4020	1.53	9985 (99.8)	6.83	4390	0.05	9999 (99.9)	6.74	3570	640	3600 (36.0)
2000	6.11	2860	475	15250 (76.3)	6.68	6190	2.35	19976 (99.8)	6.83	8120	0.05	19999 (99.9)	6.44	5390	1338	6620 (33.1)
3000	6.22	5200	900	21000 (70.0)	7.00	7680	3.65	29964 (99.8)	6.08	10680	0.06	29999 (99.9)	5.79	8140	2350	6500 (21.7)
4000	6.14	6480	1720	22800 (57.0)	6.89	9170	6.85	39932 (99.8)	5.87	12820	0.07	39999 (99.9)	5.82	10350	3200	8000 (20.0)
5000	6.38	7650	2200	28000 (56.0)	6.38	11440	15.5	49845 (99.7)	5.95	15100	0.24	49998 (99.9)	5.88	11680	4150	8500 (17.0)

Table 20
Heavy metal binding on Rush (Reed) Peat from the Biebrza River Valley, mg/kg (%)
Sampling point B6

Sample	Rush (Reed) Peat - B6, (DR 50%)															
Metal	Cd				Cu				Cr				Zn			
C_o	pH	EC	C_{eq}	S	pH	EC	C_{eq}	S	pH	EC	C_{eq}	S	pH	EC	C_{eq}	S
1	7.18	196	0.00	10 (100)	7.33	214	0.00	10 (100)	7.33	177	0.00 (100)	10 (100)	6.96	204	0.04	9.6 (96.0)
100	5.91	350	0.37	996 (99.6)	6.88	740	0.37	996 (99.6)	5.25	603	0.18	998 (99.8)	6.77	458	0.34	997 (99.7)
1000	5.87	1430	17.6	9824 (98.2)	5.98	4070	3.01	9970 (99.7)	6.70	4530	0.25	9998 (99.9)	6.59	3680	252	7480 (94.7)
2000	5.59	2760	189	18105 (90.5)	4.80	6510	18.8	19811 (99.1)	6.37	7870	0.89	19991 (99.9)	6.44	5460	669	13310 (66.5)
3000	6.00	5760	558	24420 (81.4)	4.21	8850	117	28830 (96.1)	4.40	10600	8.38	29916 (99.7)	5.07	8190	880	21200 (70.7)
4000	5.15	6710	1088	29120 (72.8)	4.19	10130	292	37080 (92.7)	3.34	12710	150	38500 (96.2)	4.84	10230	1530	24700 (61.7)
5000	4.95	7200	1850	31500 (63.0)	3.67	12920	774	42260 (84.5)	3.68	13020	611	43890 (87.8)	5.29	11870	2170	28300 (56.6)

Table 21
Heavy metal binding on Rush (Reed) Peat from the Biebrza River Valley, mg/kg (%)
Sampling point B7

Sample	Rush (Reed) Peat - B7, (DR 65%)															
Metal	Cd				Cu				Cr				Zn			
C_o	pH	EC	C_{eq}	S	pH	EC	C_{eq}	S	pH	EC	C_{eq}	S	pH	EC	C_{eq}	S
1	7.67	188	0.00	10 (100)	7.43	188	0.00	10 (100)	7.34	156	0.00	10 (100)	7.11	176	0.04	9.6 (96.0)
100	6.66	362	0.25	998 (99.8)	7.01	680	0.20	998 (99.8)	7.16	647	0.19	998 (99.8)	6.88	645	0.20	998 (99.8)
1000	5.53	1417	21.4	9786 (97.9)	5.89	4050	2.69	9973 (99.7)	6.53	4480	0.29	9997 (99.9)	6.34	3230	214	7860 (78.6)
2000	5.80	2820	136	18635 (93.2)	4.97	6530	17.4	19826 (99.1)	6.80	7730	1.35	19986 (99.9)	6.11	5440	562	14380 (71.9)
3000	5.54	5680	485	25150 (83.8)	4.19	8810	70.0	29300 (97.7)	4.44	10540	8.24	29918 (99.7)	5.19	8190	720	22800 (76.0)
4000	5.35	6770	918	30820 (77.0)	4.00	10410	180	38200 (95.5)	3.42	12720	112	38880 (97.2)	5.10	9820	1030	29700 (74.2)
5000	5.46	7490	1280	37200 (74.4)	3.66	13270	500	45000 (90.0)	2.87	13440	447	45530 (91.1)	5.24	11830	1680	33200 (66.4)

Table 22
Heavy metal binding on Hypnum Moss (Sedge-Moss) Peat from the Biebrza River Valley, mg/kg (%)
Sampling point B8

Sample	Hypnum Moss (Sedge-Moss) Peat - B8, (DR 40%)															
Metal	Cd				Cu				Cr				Zn			
C_o	pH	EC	C_{eq}	S	pH	EC	C_{eq}	S	pH	EC	C_{eq}	S	pH	EC	C_{eq}	S
1	7.69	174	0.02	9.8 (98.0)	7.87	211	0.00	10 (100)	7.35	176	0.00	10 (100)	7.70	308	0.05	9.5 (95.0)
100	6.66	364	0.47	995 (99.5)	6.50	648	0.40	996 (99.6)	7.25	639	0.22	998 (99.8)	7.54	491	1.27	987 (98.7)
1000	6.82	1430	36.4	9636 (96.4)	5.75	4050	4.94	9951 (99.5)	6.28	4480	0.48	9995 (99.9)	6.26	3570	290	7100 (71.0)
2000	6.45	2890	291	17085 (85.4)	4.66	6300	42.8	19572 (97.9)	6.70	7810	1.23	19988 (99.9)	6.42	5400	744	12560 62.8)
3000	6.09	5110	757	22430 (74.8)	3.93	6900	223	27770 (92.6)	3.57	10480	41.5	29585 (98.6)	5.41	6950	1340	16600 (55.3)
4000	5.25	6060	1470	25300 (63.2)	3.86	10290	469	35310 (88.3)	3.07	12790	325	36750 (91.9)	5.20	8420	1920	20800 (52.0)
5000	5.72	7100	2980	20200 (40.4)	3.57	12600	1530	34700 (69.4)	2.73	12860	1054	39460 (78.9)	5.09	10100	3215	17850 (35.7)

Table 23
Heavy metal binding on Highmoor (Sphagnum Moss) Peat from the Biebrza River Valley, mg/kg (%)
Sampling point B9

Sample	Highmoor (Sphagnum Moss) Peat - B9, (DR 15%)															
Metal	Cd				Cu				Cr				Zn			
C_o	pH	EC	C_{eq}	S	pH	EC	C_{eq}	S	pH	EC	C_{eq}	S	pH	EC	C_{eq}	S
1	5.8	145	0.00	10 (100)	7.15	148	0.00	10 (100)	7.26	154	0.00	10 (100)	6.06	180	0.00	10 (100)
100	5.71	320	10.0	900 (90.0)	7.03	572	4.20	958 (95.8)	6.11	565	0.19	998 (99.8)	6.14	368	13.1	869 (86.9)
1000	4.91	1320	150	8500 (85.0)	5.03	3720	106	8940 (89.4)	5.01	4100	12.5	9875 (98.8)	6.15	3190	189	8110 (81.1)
2000	4.11	2610	718	12820 (64.1)	3.78	4900	578	14220 (71.1)	3.54	5400	72.4	19276 (96.4)	5.09	4280	784	12160 (60.8)
3000	3.78	5370	1392	16080 (53.6)	3.74	6200	1326	16740 (55.8)	3.31	8700	924	20760 (69.2)	4.11	5890	1398	16020 (53.4)
4000	3.68	6190	2072	19280 (48.2)	3.67	7890	1916	20840 (52.1)	3.11	10320	1485	25150 (62.9)	3.97	6430	2348	16520 (41.3)
5000	3.64	7230	3185	18150 (36.3)	3.50	8760	2650	23500 (47.0)	2.99	11430	2575	24250 (48.5)	3.88	7620	3480	15200 (30.2)

Table 24
Heavy metal binding on Peat Humus (Alder Peat) from the Zbojna peat bog, mg/kg (%)
Sampling point Z1

Sample	Peat Humus (Alder Peat) - Z1, (DR 60%)															
Metal	Cd				Cu				Cr				Zn			
C_o	pH	EC	C_{eq}	S	pH	EC	C_{eq}	S	pH	EC	C_{eq}	S	pH	EC	C_{eq}	S
1	7.41	182	0.00	10 (100)	7.07	244	0.00	10 (100)	6.65	143	0.00	10 (100)	7.03	240	0.03	9.7 (97.0)
100	5.87	384	0.17	998 (99.8)	6.44	667	0.20	998 (99.8)	6.80	438	0.00	1000 (100)	6.97	482	0.26	997 (99.7)
1000	5.83	1360	8.68	9913 (99.1)	6.21	4050	3.18	9968 (99.7)	6.08	5930	0.13	9998 (99.9)	6.77	3690	146	8540 (85.4)
2000	5.56	2630	110	18900 (94.5)	4.92	6660	25.8	19742 (98.7)	5.00	7080	0.32	19997 (99.9)	5.35	4290	435	15650 (78.2)
3000	5.26	4120	374	26260 (87.5)	4.63	8340	51.0	29490 (98.3)	6.49	9540	1.34	29987 (99.9)	5.13	7870	730	22700 (75.7)
4000	5.14	6720	789	32110 (80.3)	4.40	9820	120	38800 (97.0)	4.15	12540	12.8	39872 (99.7)	5.14	9860	1160	28400 (71.0)
5000	5.10	7700	1320	36800 (73.6)	4.06	12390	390	46100 (92.2)	3.10	15220	31.5	46850 (93.7)	4.80	11940	1630	33700 (67.4)

Table 25
Heavy metal binding on Hypnum Moss (Sedge-Moss) Peat from the Zbojna peat bog, mg/kg (%)
Sampling point Z2

Sample	Hypnum Moss (Sedge-Moss) Peat - Z2a, (DR 40%)															
Metal	Cd				Cu				Cr				Zn			
C_o	pH	EC	C_{eq}	S	pH	EC	C_{eq}	S	pH	EC	C_{eq}	S	pH	EC	C_{eq}	S
1	6.88	194	0.00	10 (100)	6.68	430	0.00	10 (100)	6.91	180	0.00	10 (100)	7.06	270	0.02	9.8 (98.0)
100	6.03	390	0.24	998 (99.8)	6.36	788	0.21	998 (99.8)	6.78	380	0.00	1000 (100)	6.78	581	0.27	997 (99.7)
1000	5.84	1400	52.2	9478 (94.8)	5.95	4070	5.15	9948 (99.5)	5.73	3790	0.12	9999 (99.9)	6.70	3490	225	7750 (77.5)
2000	5.50	2810	312	16875 (84.4)	4.65	6490	36.5	19635 (98.2)	4.36	7730	2.23	19978 (99.9)	6.38	4310	590	14100 (70.5)
3000	5.10	5080	838	21620 (72.1)	3.71	8560	272	27280 (90.9)	3.36	10070	203	27970 (93.2)	4.80	7870	959	20410 (68.0)
4000	4.56	6120	1520	24800 (62.0)	3.57	10120	516	34840 (87.1)	2.94	12520	572	34280 (85.7)	4.49	9390	1660	23400 (58.5)
5000	4.40	7160	2550	24500 (49.0)	3.41	12210	1520	34800 (69.6)	2.69	14760	1250	37500 (75.0)	4.34	11040	2675	23250 (46.5)

Table 26
Heavy metal binding on Detrituous Gyttja from the Zbojna peat bog, mg/kg (%)
Sampling point Z2

Sample	Detrituous Gyttja - Z2b															
Metal	Cd				Cu				Cr				Zn			
C_o	pH	EC	C_{eq}	S	pH	EC	C_{eq}	S	pH	EC	C_{eq}	S	pH	EC	C_{eq}	S
1	7.97	192	0.00	10 (100)	7.85	247	0.00	10 (100)	7.54	256	0.00	10 (100)	7.63	284	0.00	10 (100)
100	7.65	90	0.27	997 (99.7)	7.80	682	0.09	999 (99.9)	7.45	768	0.00	1000 (100)	7.49	541	0.00	1000 (100)
1000	6.16	1371	212	7880 (78.8)	7.04	4040	3.80	9962 (99.6)	7.50	4620	0.00	10000 (100)	6.60	3580	615	3850 (38.5)
2000	5.35	2310	330	16700 (83.5)	6.53	6060	5.80	19942 (99.7)	6.18	7940	0.05	19999 (99.9)	6.50	5310	1300	7000 (35.0)
3000	5.18	4670		15400 (51.3)	6.45	7720	8.0	29920 (99.7)	6.27	10430	0.11	29999 (99.9)	5.61	8180	2540	4600 (15.3)
4000	5.34	5590		14200 (35.5)	6.33	9110	14.0	39860 (99.6)	6.08	12380	0.12	39999 (99.9)	5.96	10340	3580	4200 (10.5)
5000	5.35	5950		11300 (22.6)	6.14	11290	90.0	49100 (98.1)	5.67	15210	0.14	49999 (99.9)	6.02	11600	4600	4000 (8.0)

Table 27
Heavy metal binding on Hypnum Moss (Sedge-Moss) Peat from the Zbojna peat bog, mg/kg (%)
Sampling point Z3

Sample	Hypnum Moss (Sedge-Moss) Peat - Z3, (DR 65%)															
Metal	Cd				Cu				Cr				Zn			
C_o	pH	EC	C_{eq}	S	pH	EC	C_{eq}	S	pH	EC	C_{eq}	S	pH	EC	C_{eq}	S
1	6.66	189	0.00	10 (100)	6.78	475	0.00	10 (100)	7.31	324	0.00	10 (100)	6.95	462	0.01	9.9 (99.0)
100	5.51	324	0.44	996 (99.6)	6.12	911	0.17	998 (99.8)	7.28	783	0.00	1000 (100)	6.27	770	0.58	994 (99.4)
1000	5.12	1553	65.6	9344 (93.4)	5.17	4260	7.85	9921 (99.2)	7.48	4740	0.08	9999 (99.9)	6.44	3950	403	5970 (59.7)
2000	4.67	2510	452	15480 (77.4)	4.04	6670	184	18160 (90.8)	4.06	7460	29.1	19710 (98.5)	6.16	5460	855	11450 (57.2)
3000	5.39	5220	1043	19570 (65.2)	3.89	9000	287	27130 (90.4)	3.99	10900	67.6	29324 (97.7)	5.20	8490	1270	17300 (57.7)
4000	4.67	6540	1416	25840 (64.6)	3.80	10700	384	36160 (90.4)	3.43	12730	408	35920 (89.8)	5.15	10620	1740	22600 (56.5)
5000	4.59	7160	2800	22000 (44.0)	3.47	13050	2270	27300 (54.6)	2.85	15670	694	43060 (86.1)	4.40	11290	2975	20250 (40.5)

Table 28
Chemical fractionation of Cadmium, copper, chromium and zinc in Peat Humus (Alder Peat) from the Wizna Peat Bog

SAMPLE: W1 (DR 70%), INPUT CONCENTRATION c_o = 5000 mg/dm³					
		Cd	Cu	Cr	Zn
SORPTION mg/kg		35100	47150	47370	29510
FRACTION mg/kg (%)					
Pore water	0	2856 (8.1)	990 (2.1)	956 (2.0)	1400 (4.7)
Exchangeable	I	17680 (50.4)	19960 (42.3)	8943 (18.9)	16280 (55.2)
Carbonatic	II	9100 (25.9)	7640 (16.2)	1900 (4.0)	7120 (24.1)
Easily reducible (Mn-oxides)	III	700 (2.0)	580 (1.2)	171 (0.4)	410 (1.4)
Moderately reducible (Amorphous Fe-oxides)	IV	1200 (3.4)	17500 (37.1)	7200 (15.2)	3390 (11.5)
Organic/sulphidic	V	3564 (10.2)	480 (1.1)	28200 (59.5)	910 (3.1)
Residual fraction	VI	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)

Card numbers in the square network of the Institute of Melioration and Grassland Database

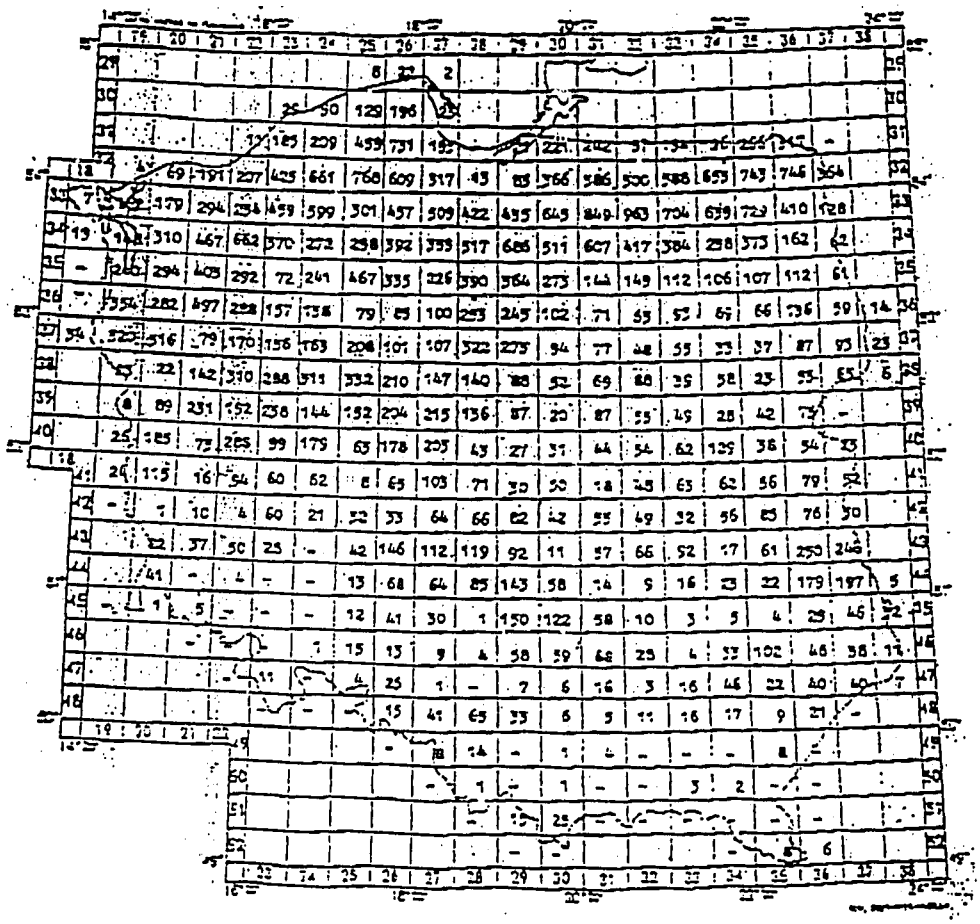

Fig.1 Peat-bogs in Poland

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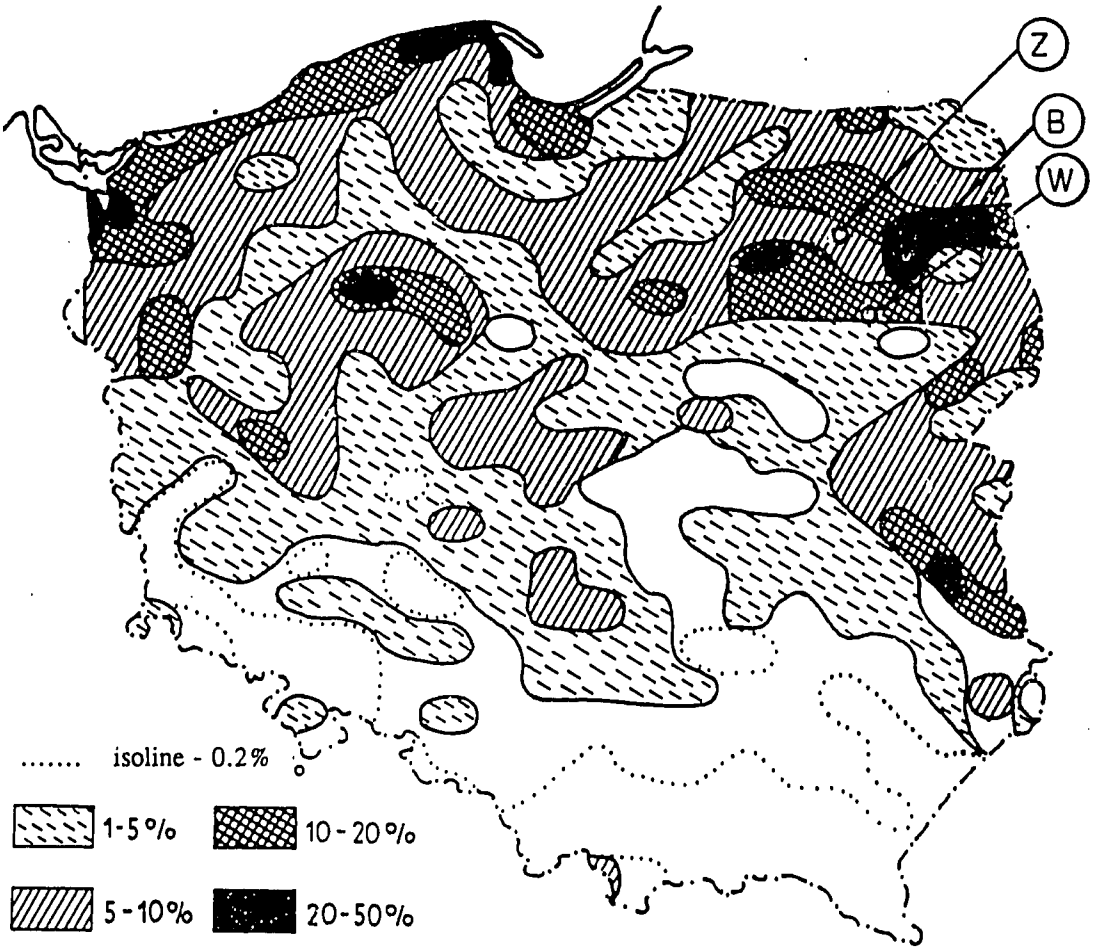

Fig.2 Location of the selected sites in the map of peat-bogs density in Poland

Scale: 1:73000

Stratigraphic systems:

a Sedgeous Peat
b Sedgeous Peat on Reed Peat
c Sedgeous Peat on Peat Humus
d Deep Moss - Turf Peat
e Moss-Turf Peat on Sedgeous Peat
f Moss-Turf Peat on Reed-Sedge Peat
g Wood Peat Humus
h Brushwood Peat Humus

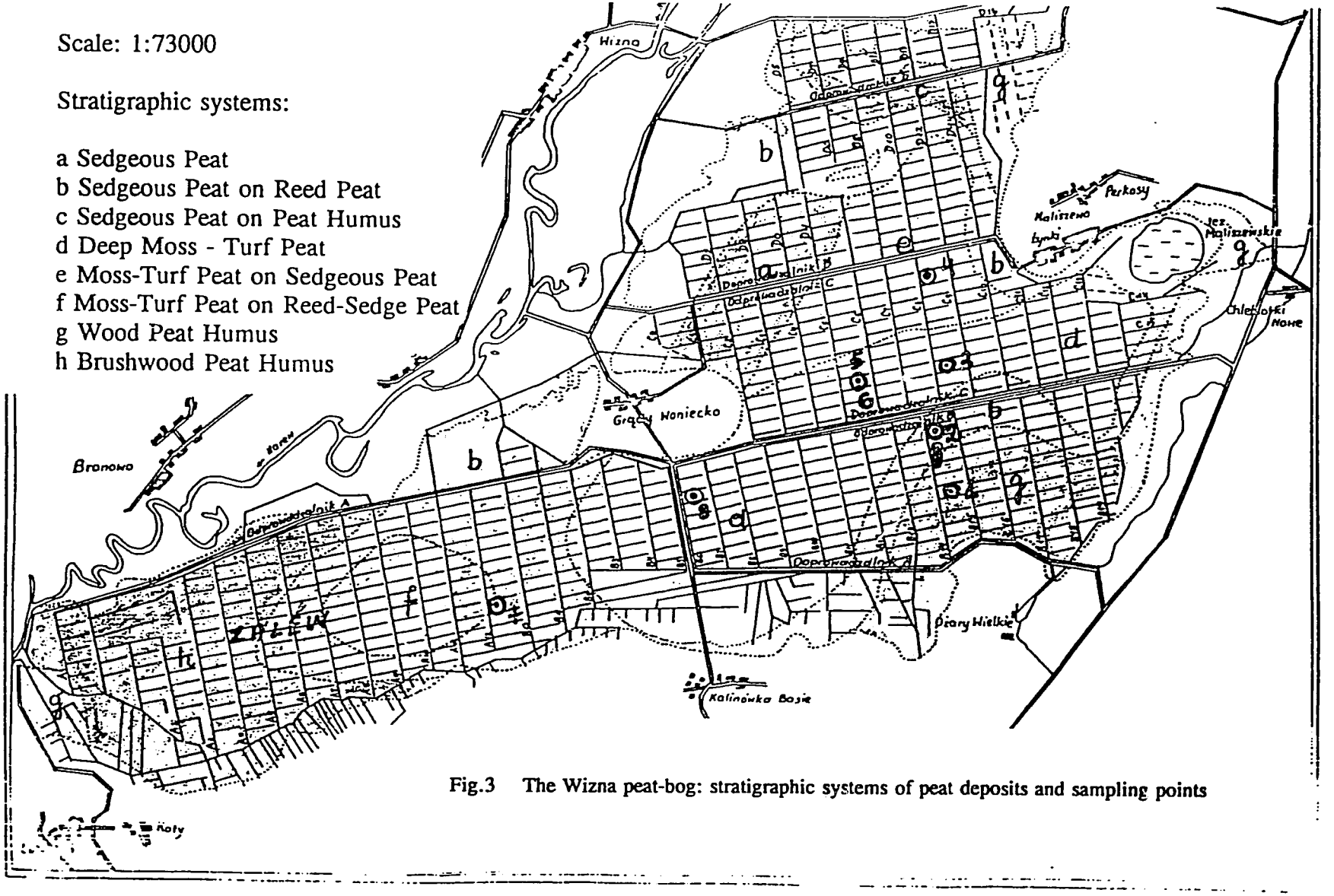

Fig.3 The Wizna peat-bog: stratigraphic systems of peat deposits and sampling points

a Sedgeous Peat
b Sedgeous Peat on Reed Peat
c Sedgeous Peat on Peat Humus
d Deep Moss - Turf Peat
e Moss-Turf Peat on Sedgeous Peat
f Moss-Turf Peat on Reed-Sedge Peat
g Wood Peat Humus
h Brushwood Peat Humus

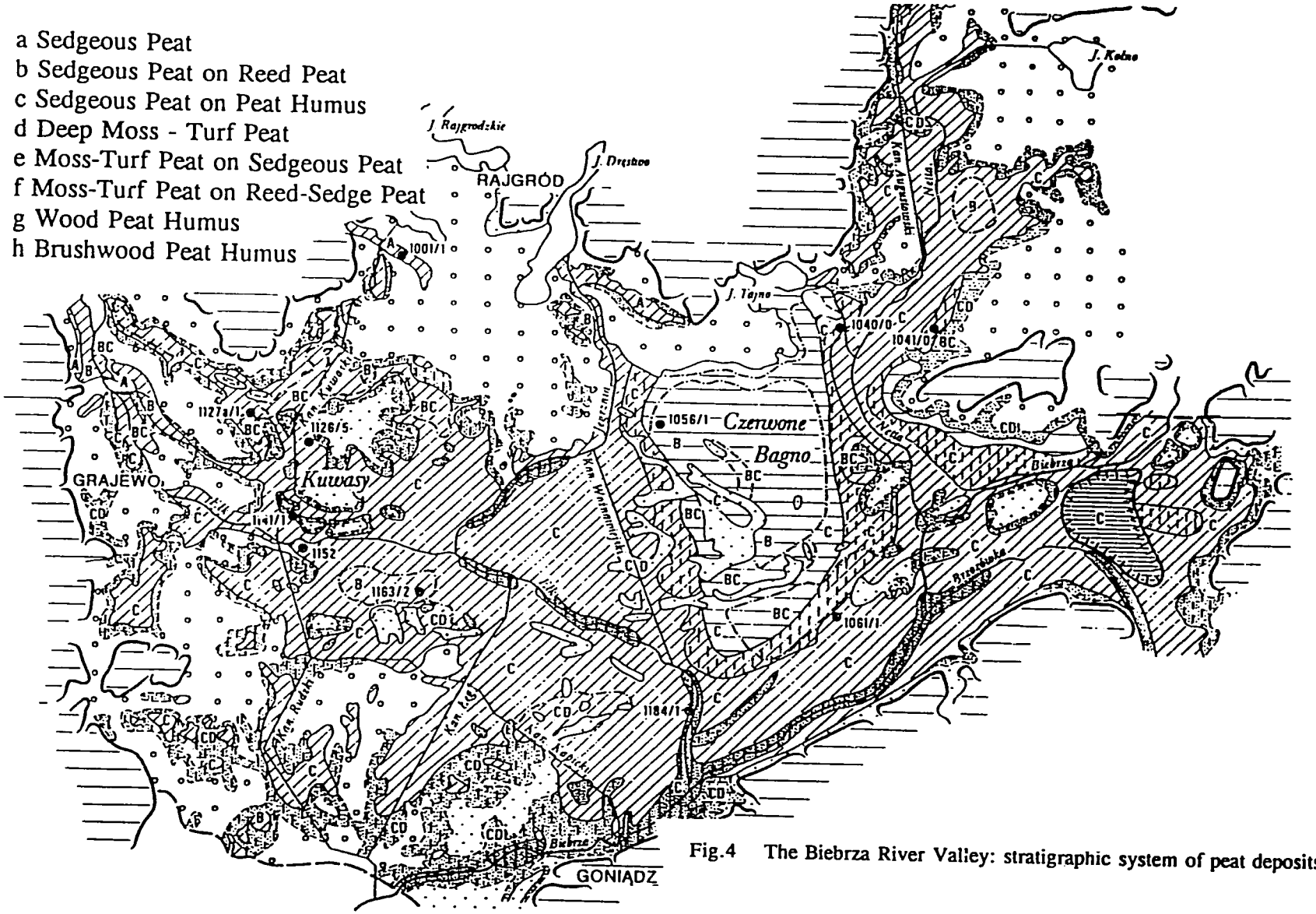

Fig.4 The Biebrza River Valley: stratigraphic system of peat deposits

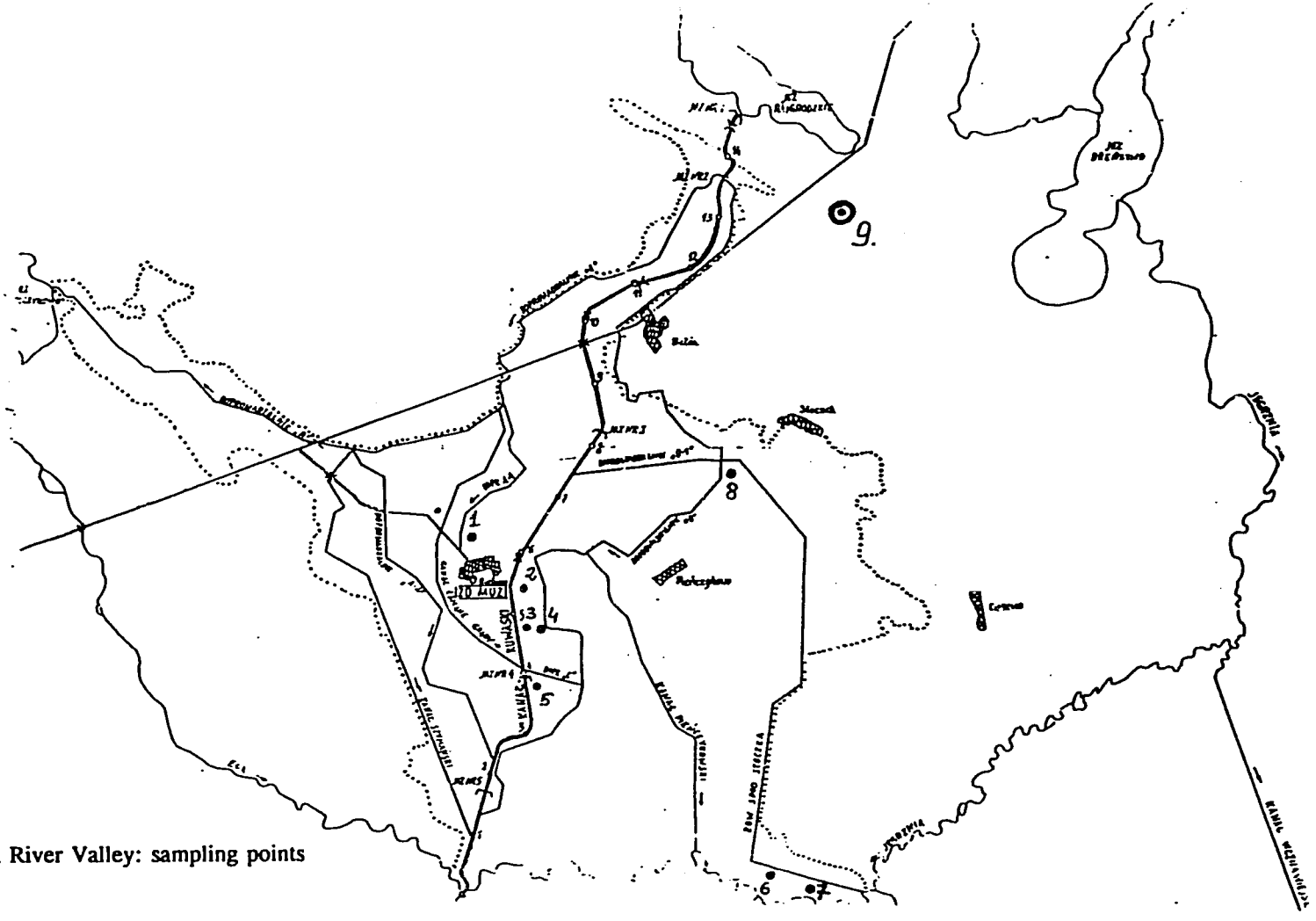

Fig.4a The Biebrza River Valley: sampling points

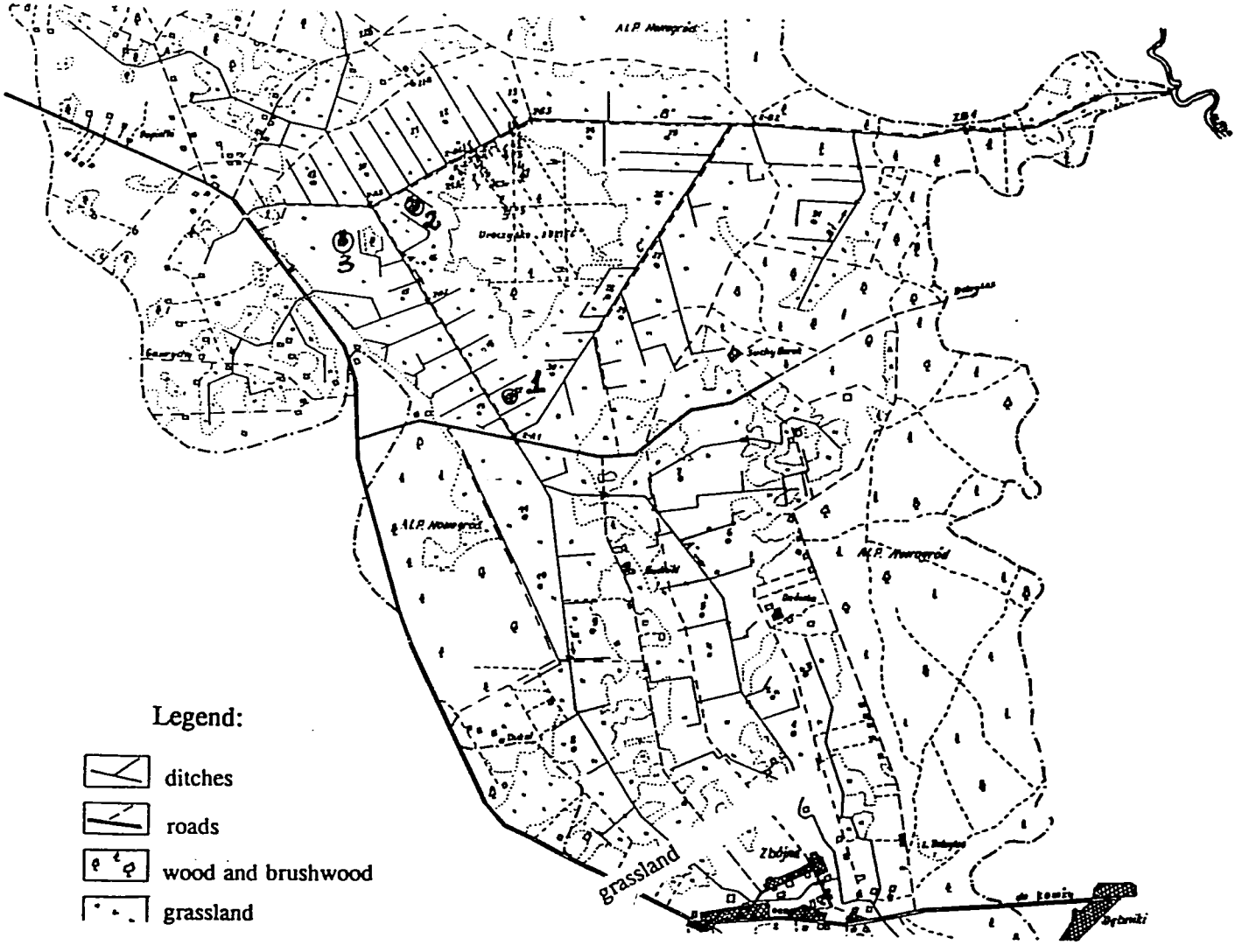

Fig.5 The Zbojna Site: sampling points

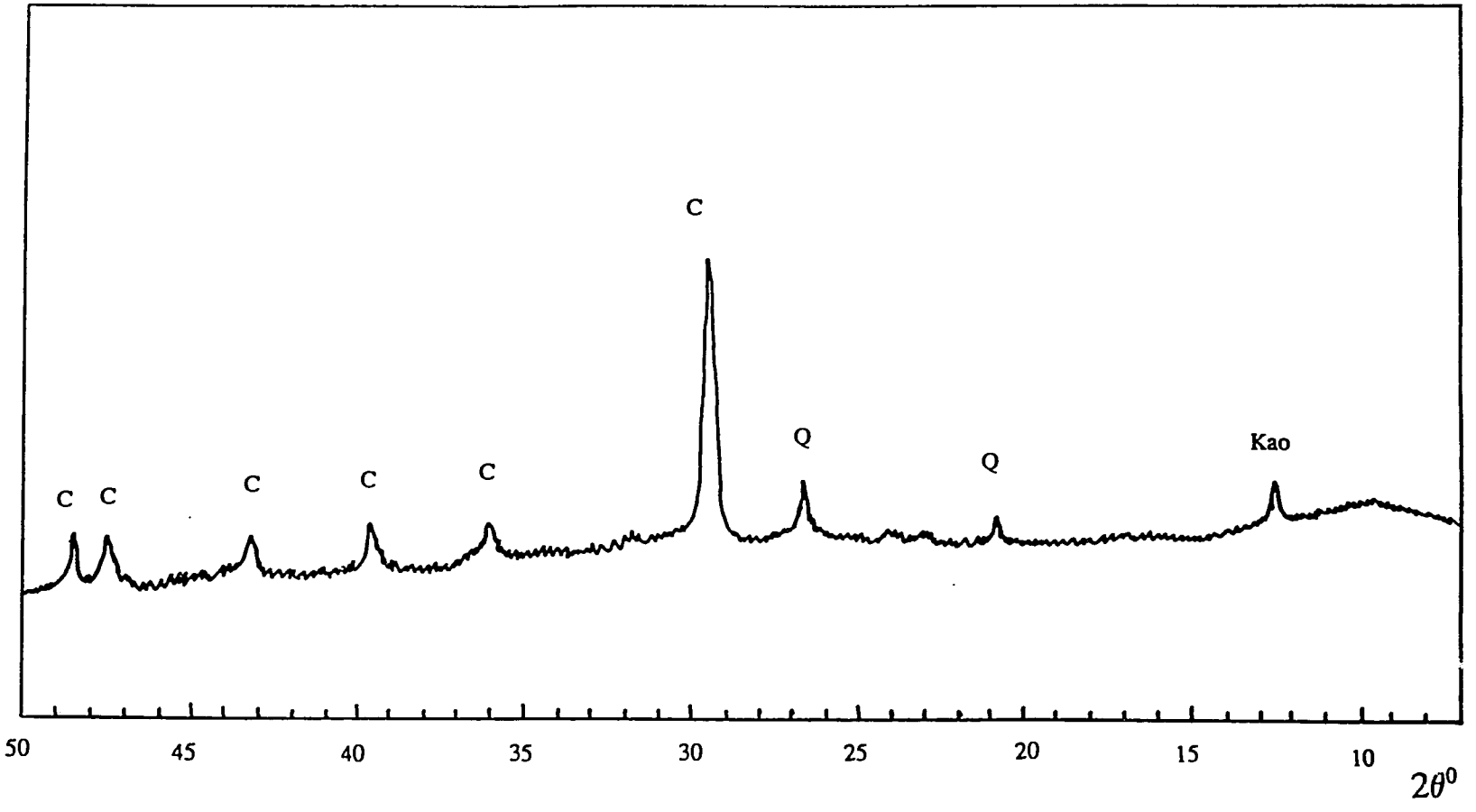

Fig.6/1 Phase composition of mineral fraction in W1 sample - Peat Humus (Alder Peat) (x-ray diffractograms)

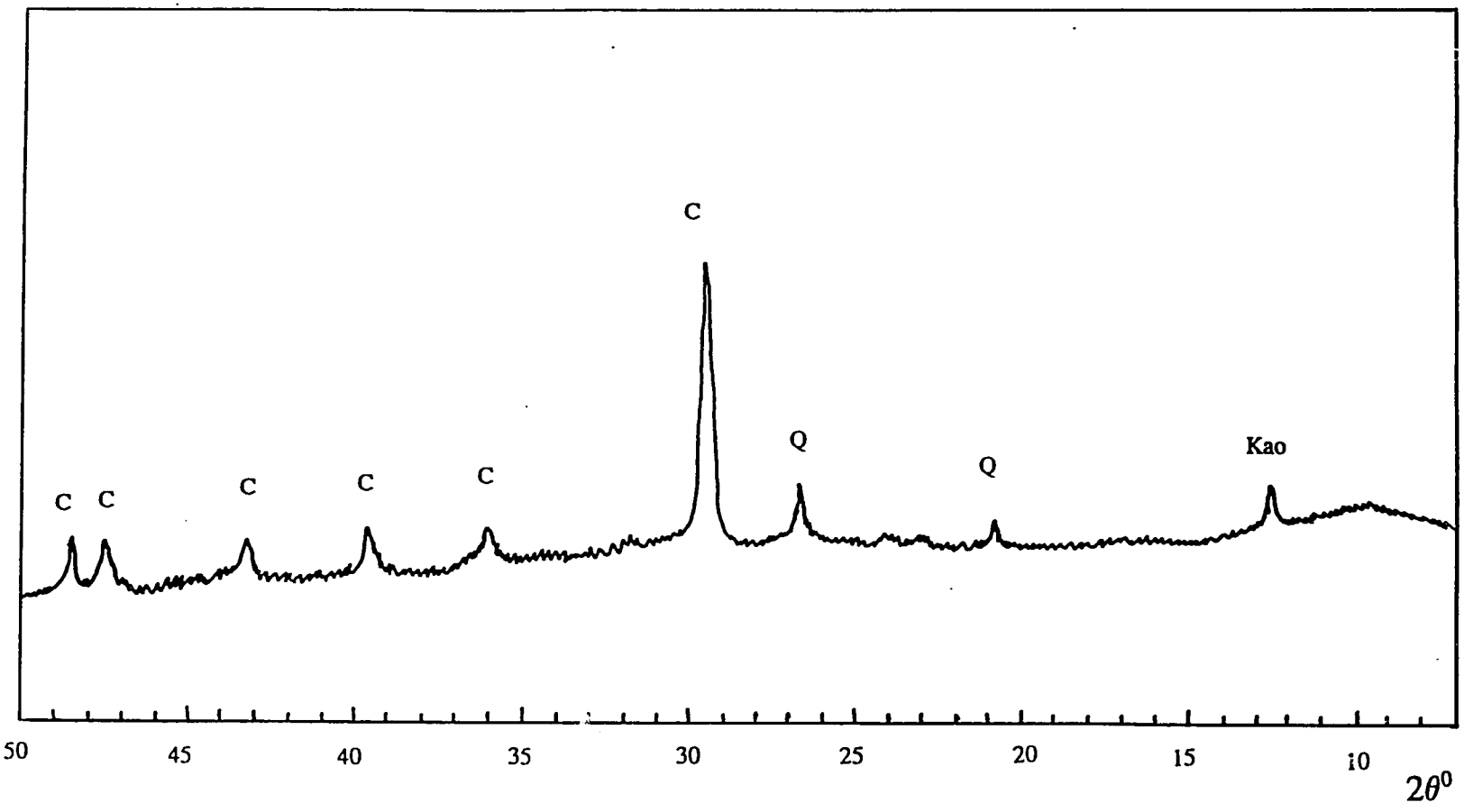

Fig.6/2 Phase composition of mineral fraction in W2 sample - Rush (Reed) Peat (x-ray diffractograms)

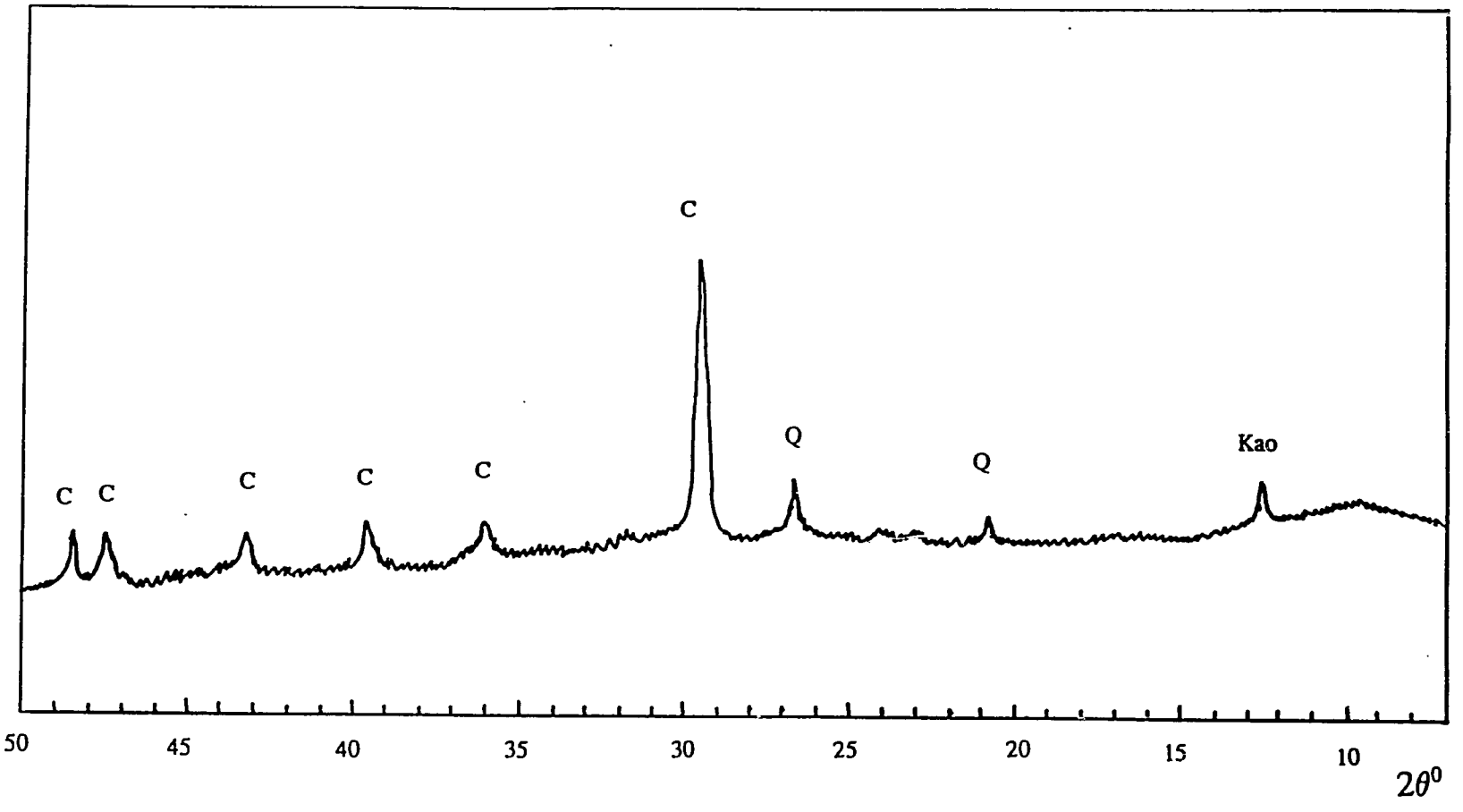

Fig.C3 Phase composition of mineral fraction in W4 sample - Sedgeous (Sedge) Peat (x-ray diffractograms)

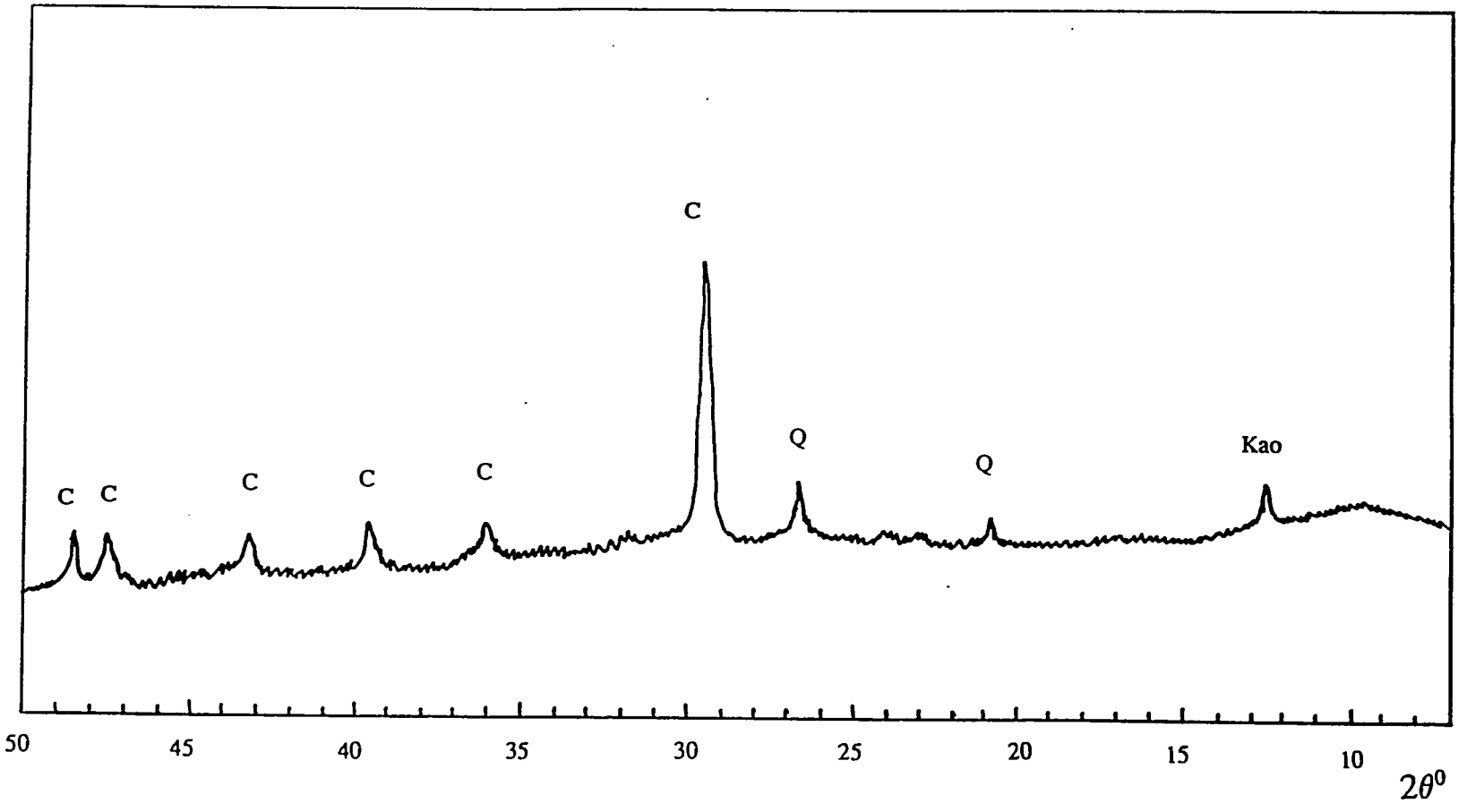

Fig.6/4 Phase composition of mineral fraction in W5 sample - Hypnum Moss (Sedge-Moss) Peat (x-ray diffractograms)

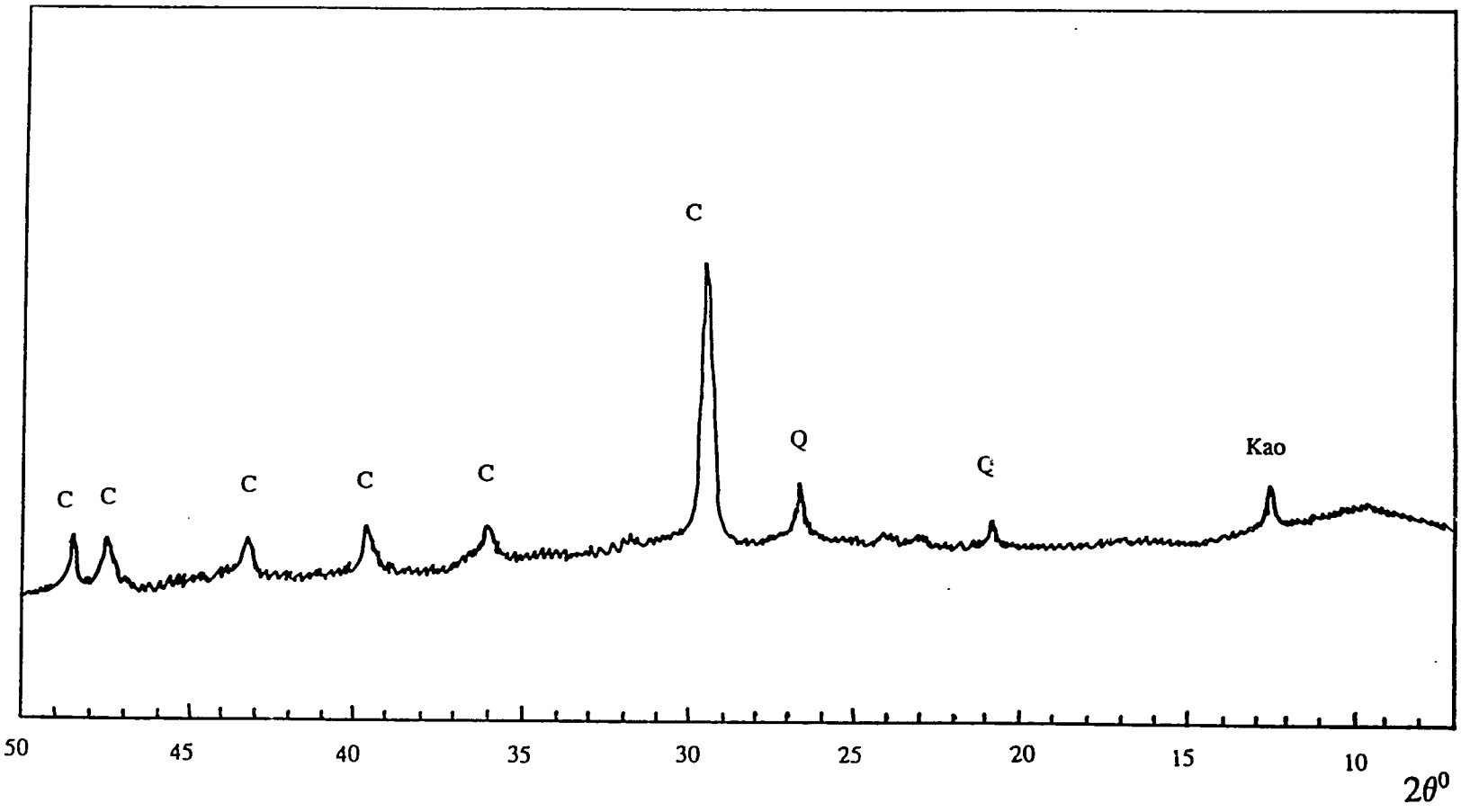

Fig.6/5 Phase composition of mineral fraction in W8 sample - Hypnum Moss (Moss) Peat (x-ray diffractograms)

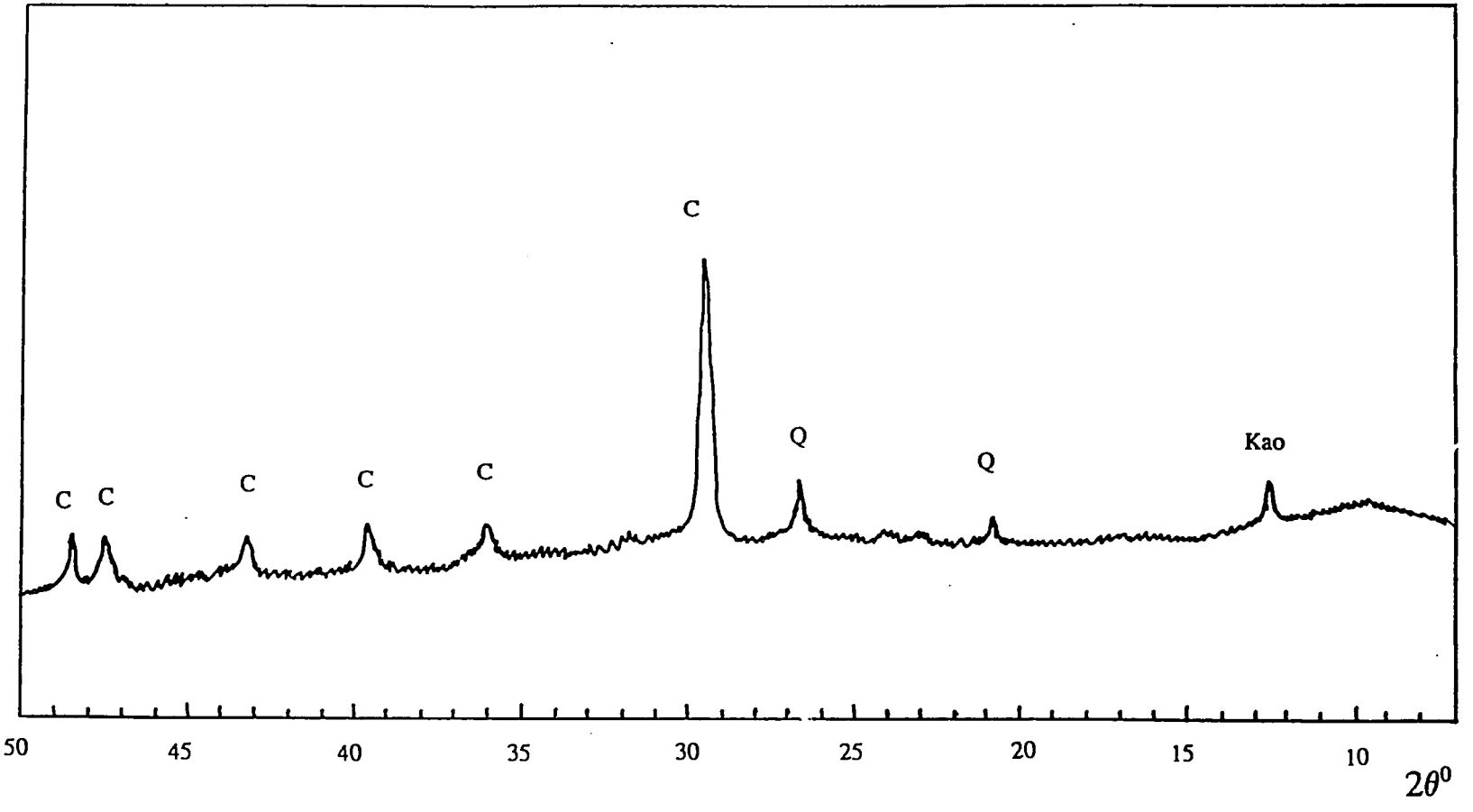

Fig.6/6 Phase composition of mineral fraction in W9b sample - Peat Humus (Brushwood Peat) (x-ray diffractograms)

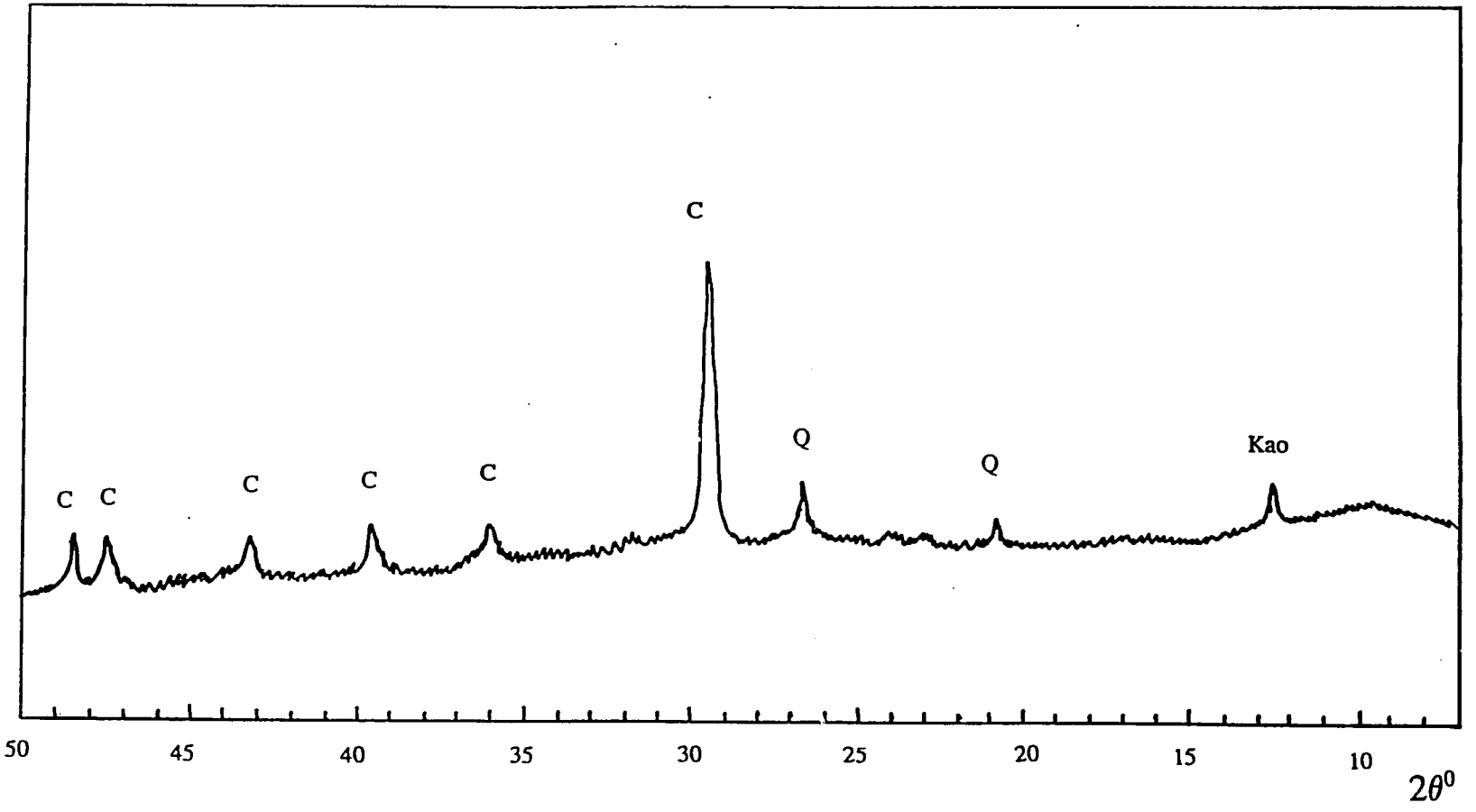

Fig.6/7 Phase composition of mineral fraction in W9c sample - Rush (Reed-Sedge) Peat (x-ray diffractograms)

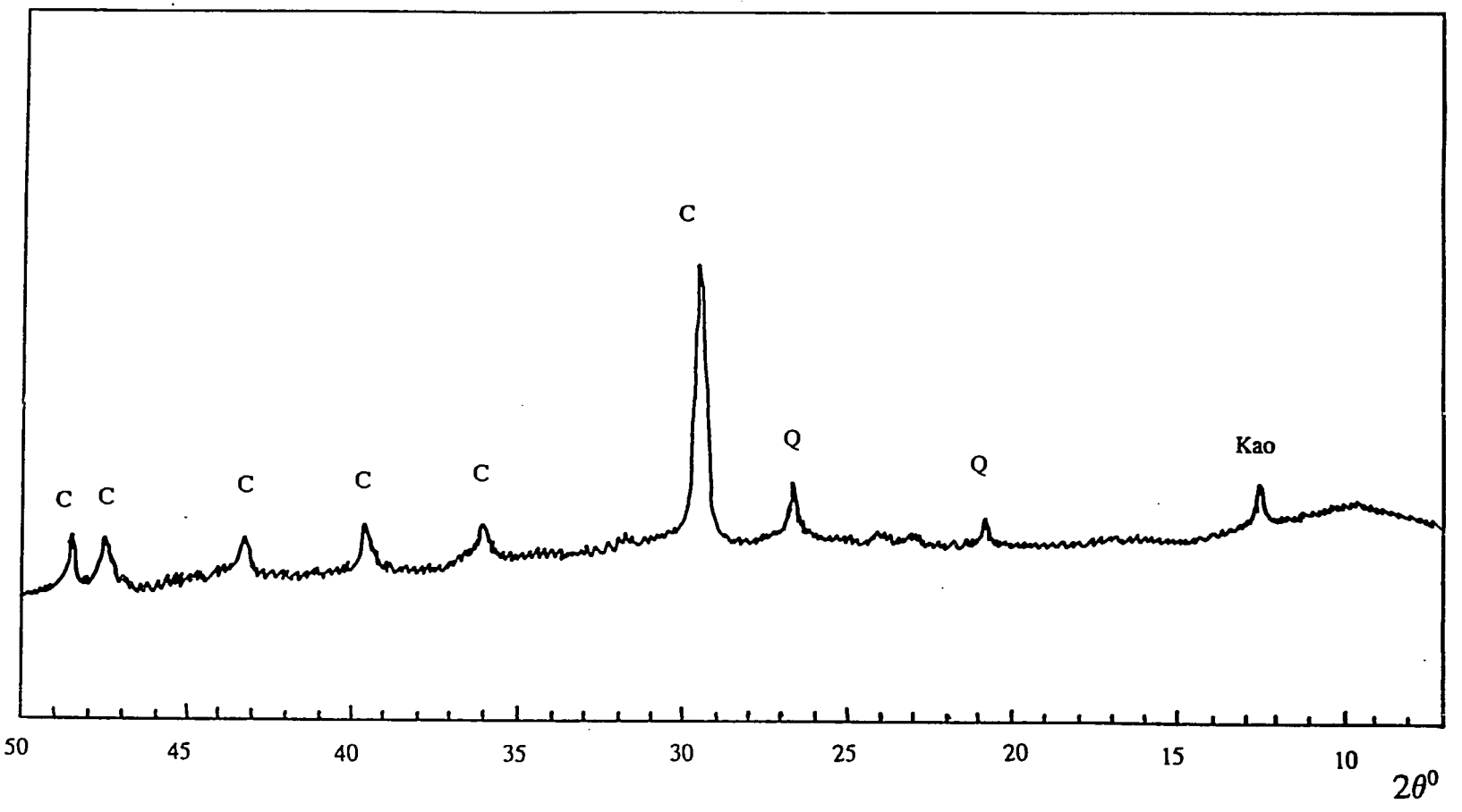

Fig.6/8 Phase composition of mineral fraction in B1 sample - Hypnum Moss (Sedge-Moss) Peat (x-ray diffractograms)

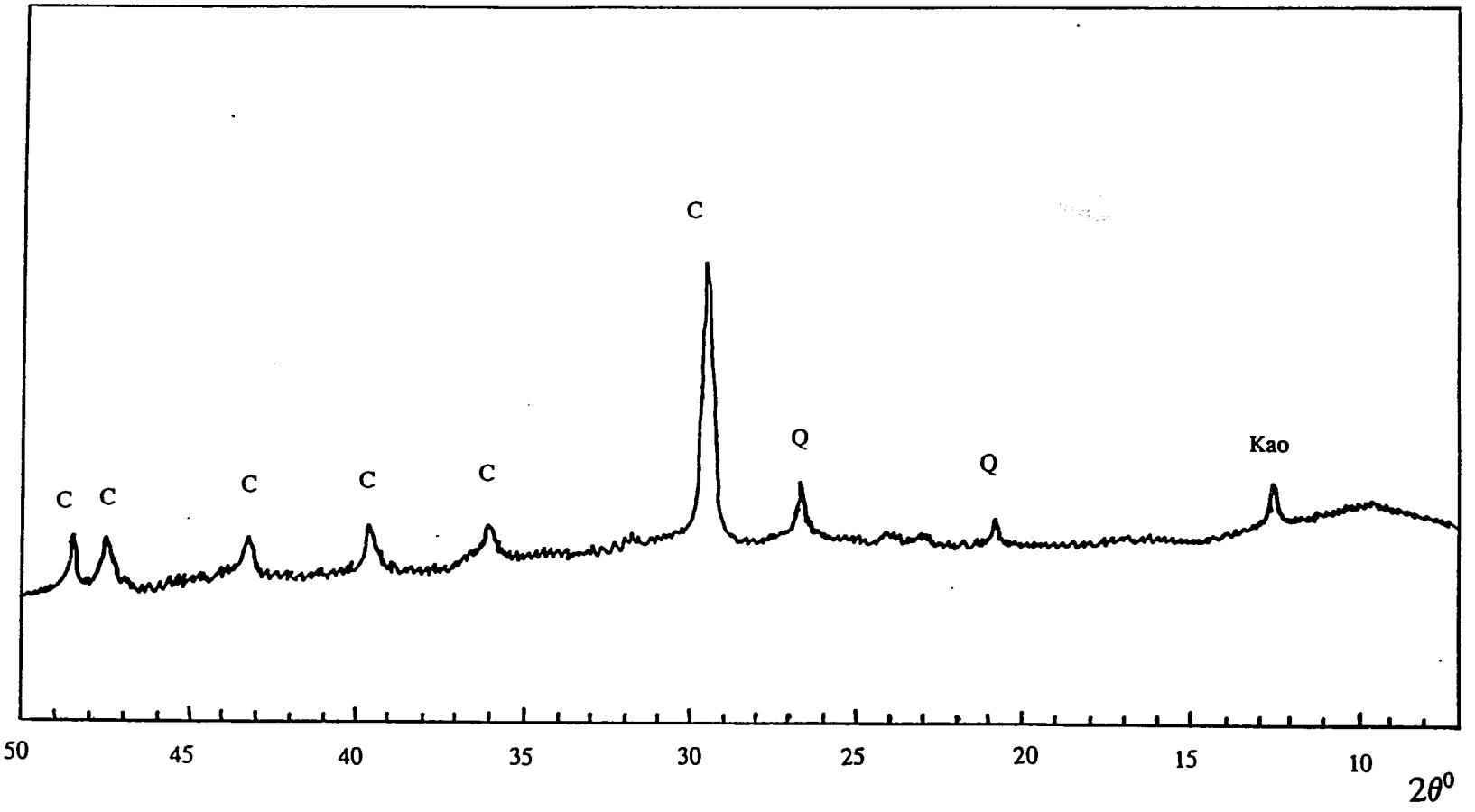

Fig.6/9 Phase composition of mineral fraction in B3 sample - Peat Hum.:s (Forest Wood Peat) (x-ray diffractograms)

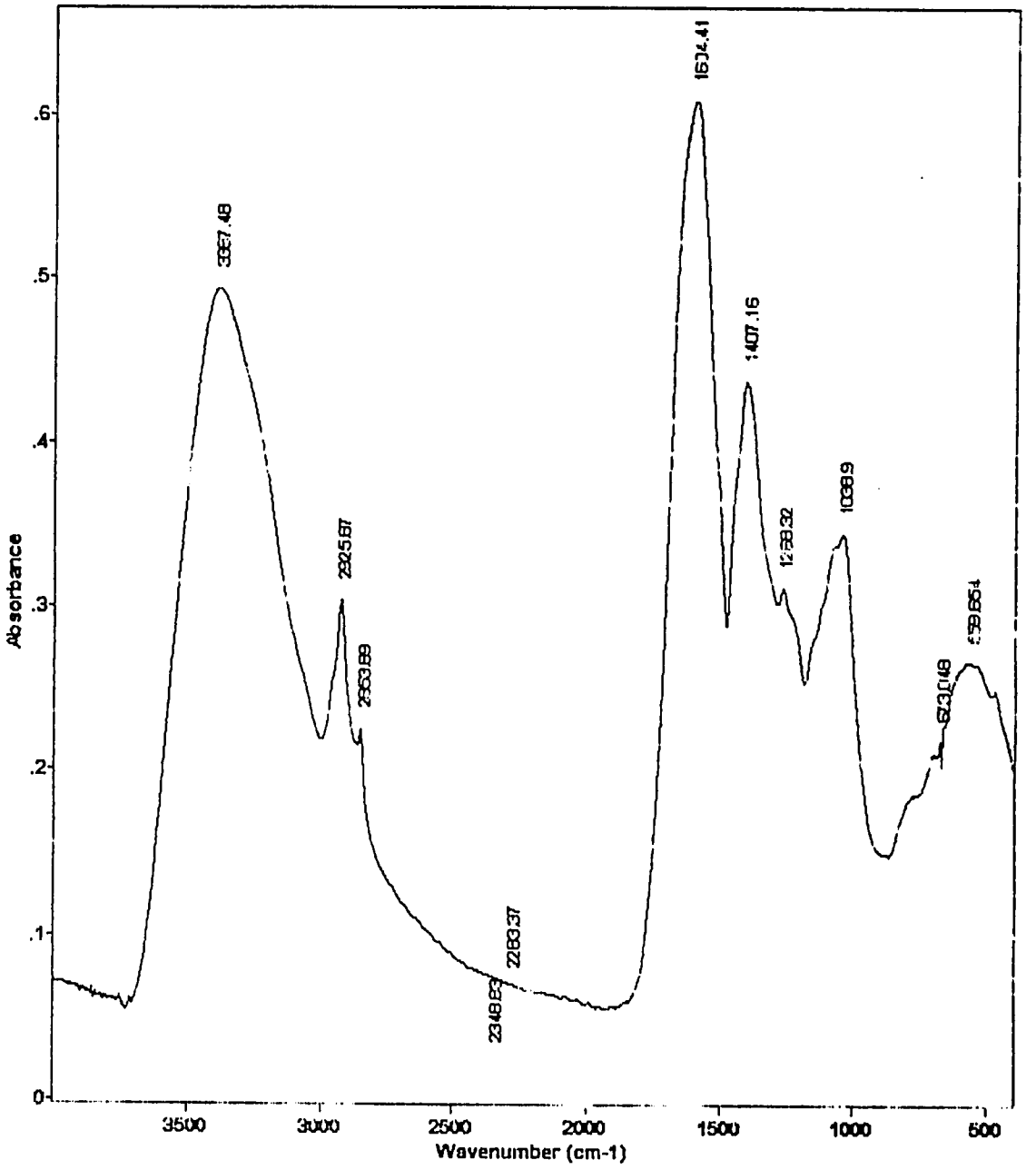

Fig.7/1 IR spectrum of W1 sample - Peat Humus (Alder Peat)

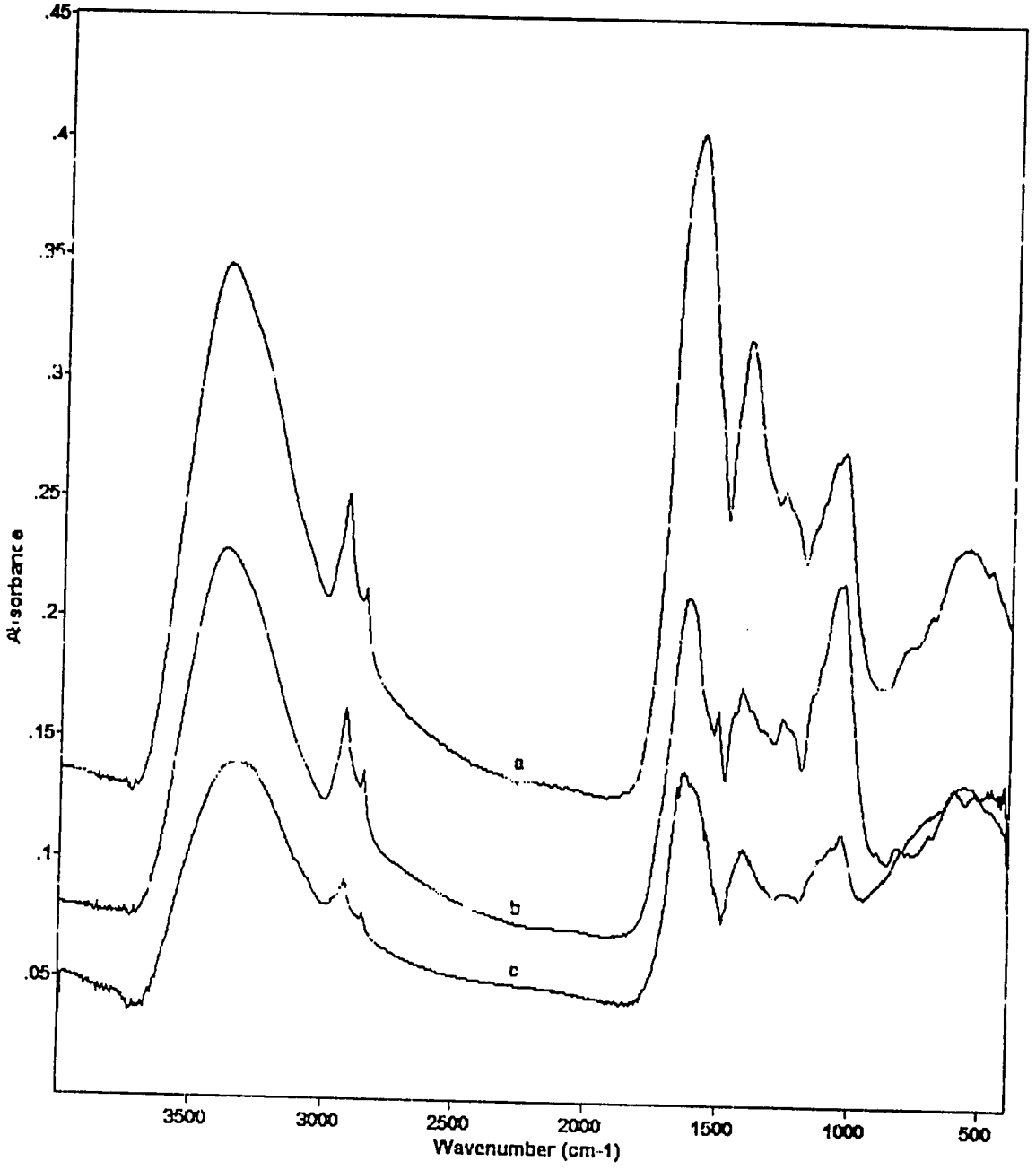

Fig.7/1a IR spectrum of W1 sample - Peat Humus (Alder Peat);
a - unfractionated sample, b - fraction > 0.2 μm, c - fraction < 0.2 μm

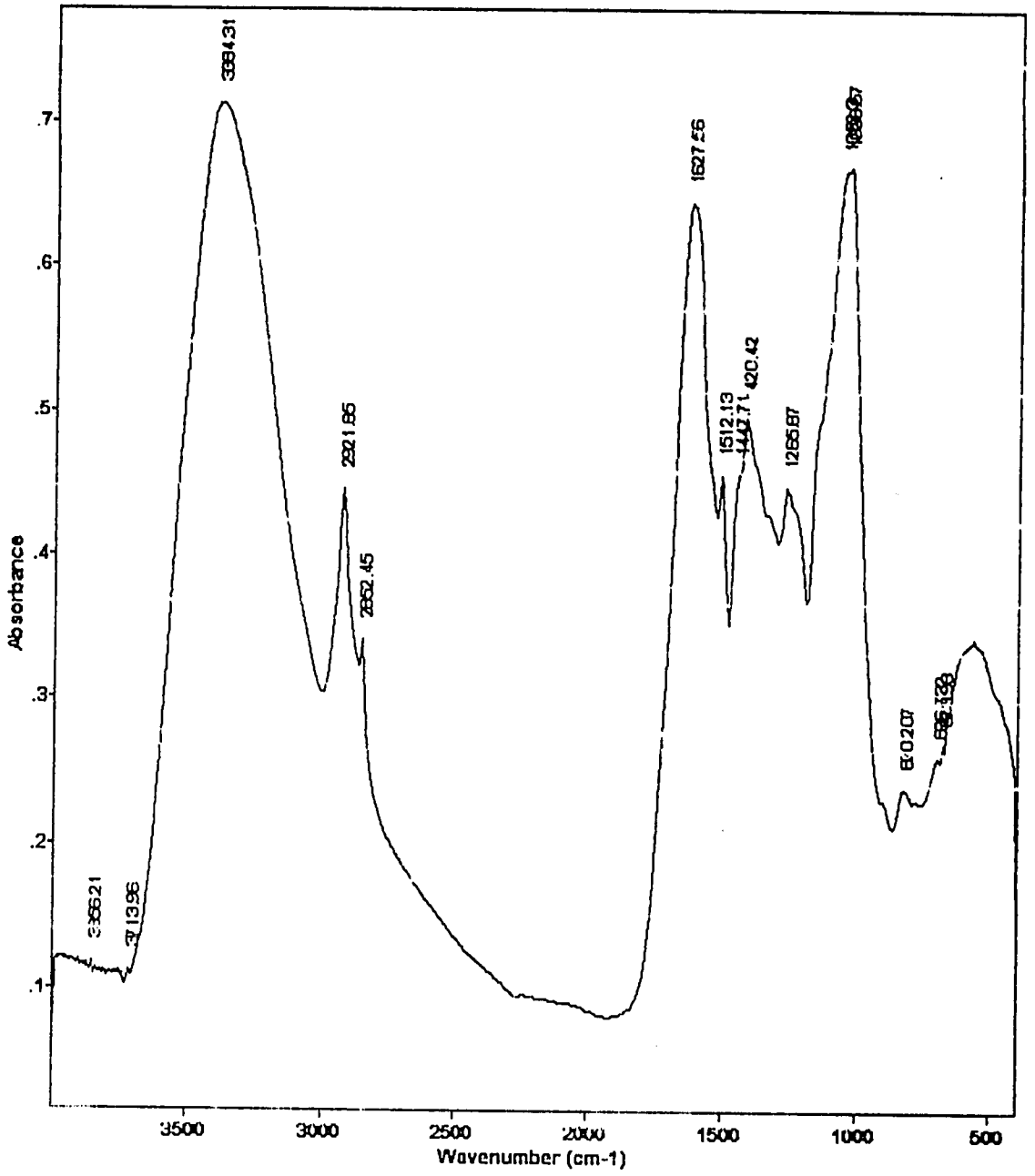

Fig.7/2 IR spectrum of W2 sample - Rush (Reed) Peat

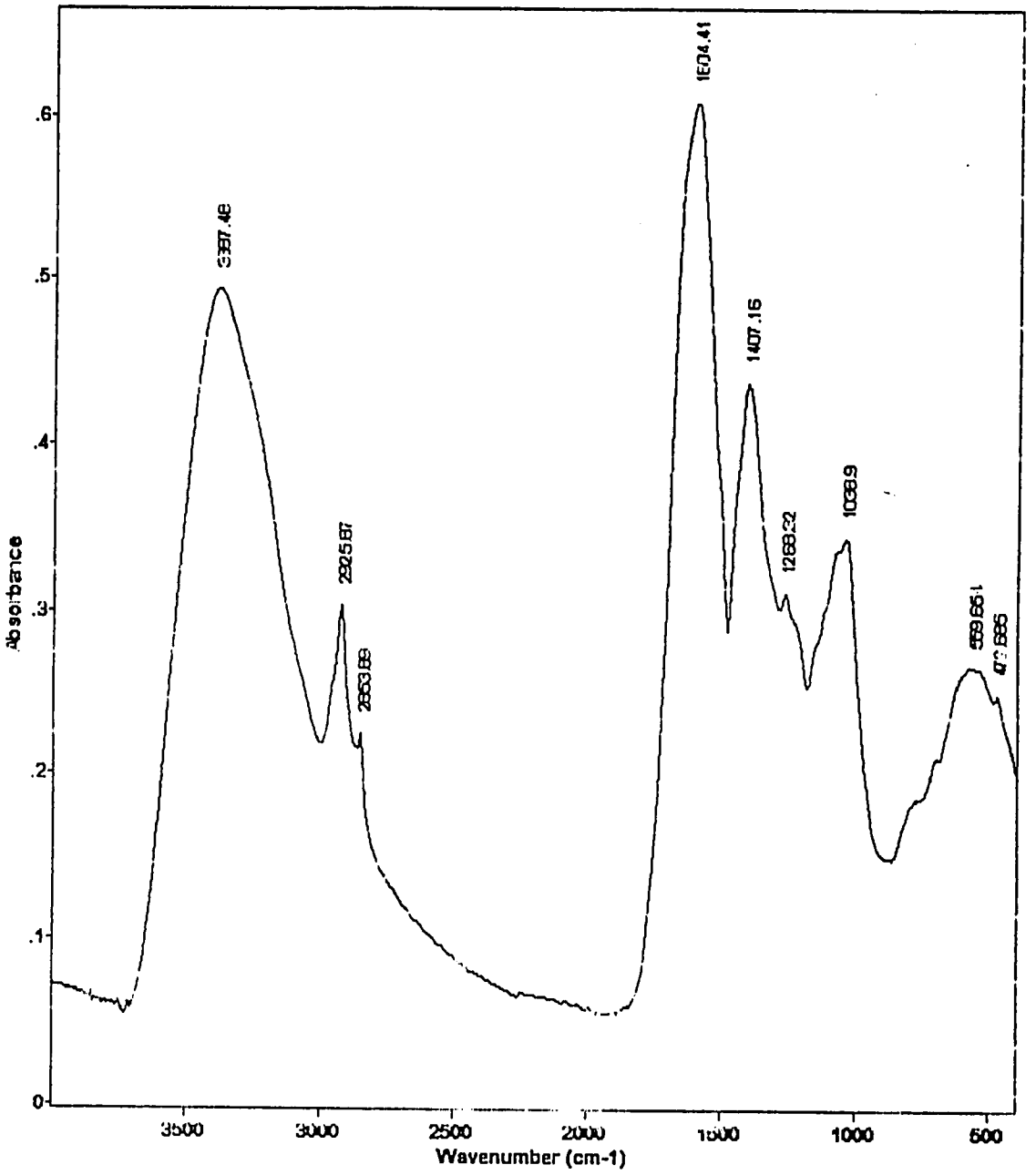

Fig.7/3 IR spectrum of W4 sample - Sedgeous (Sedge) Peat

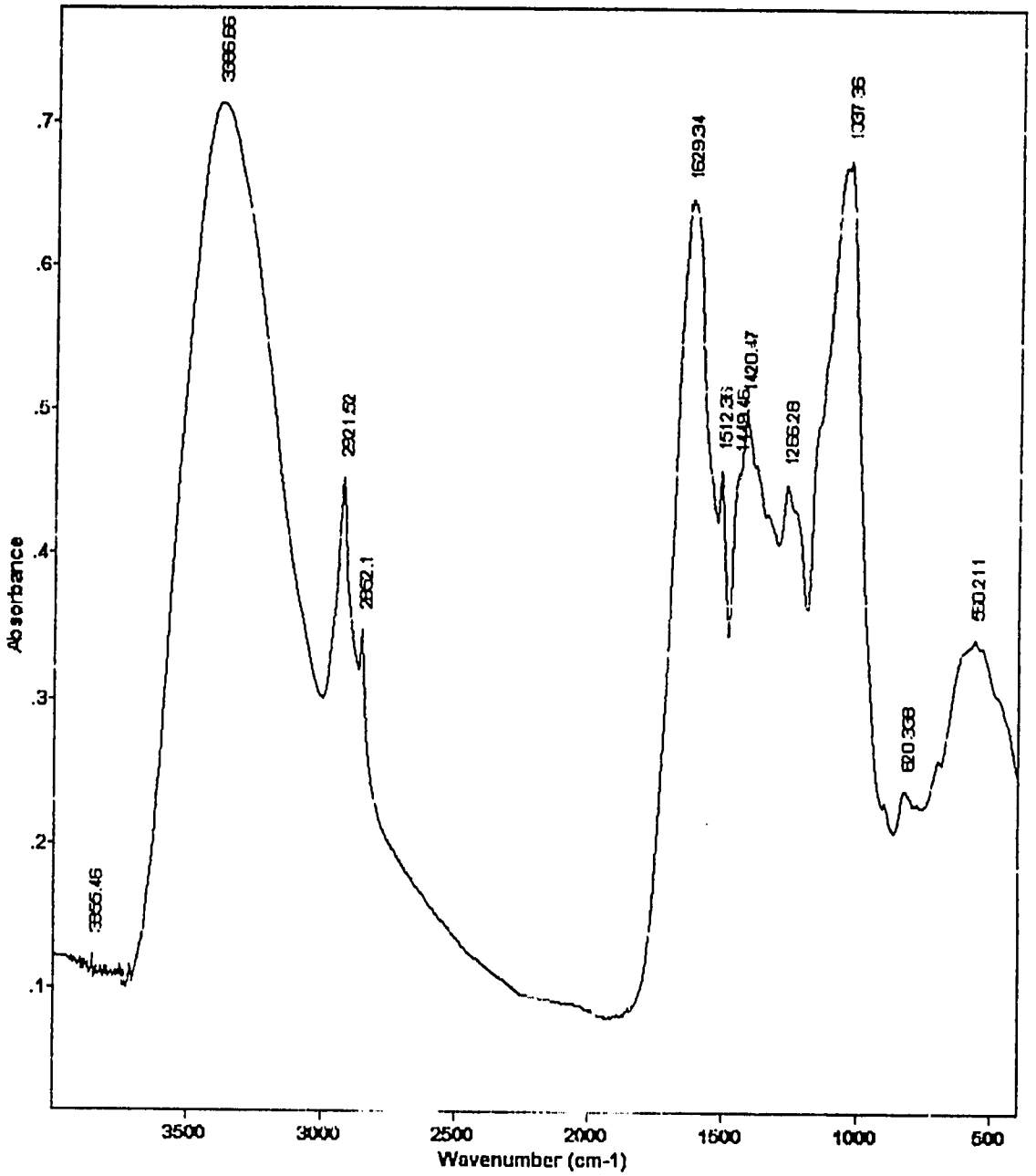

Fig.7/4 IR spectrum of W5 sample - Hypnum Moss (Sedge-Moss) Peat

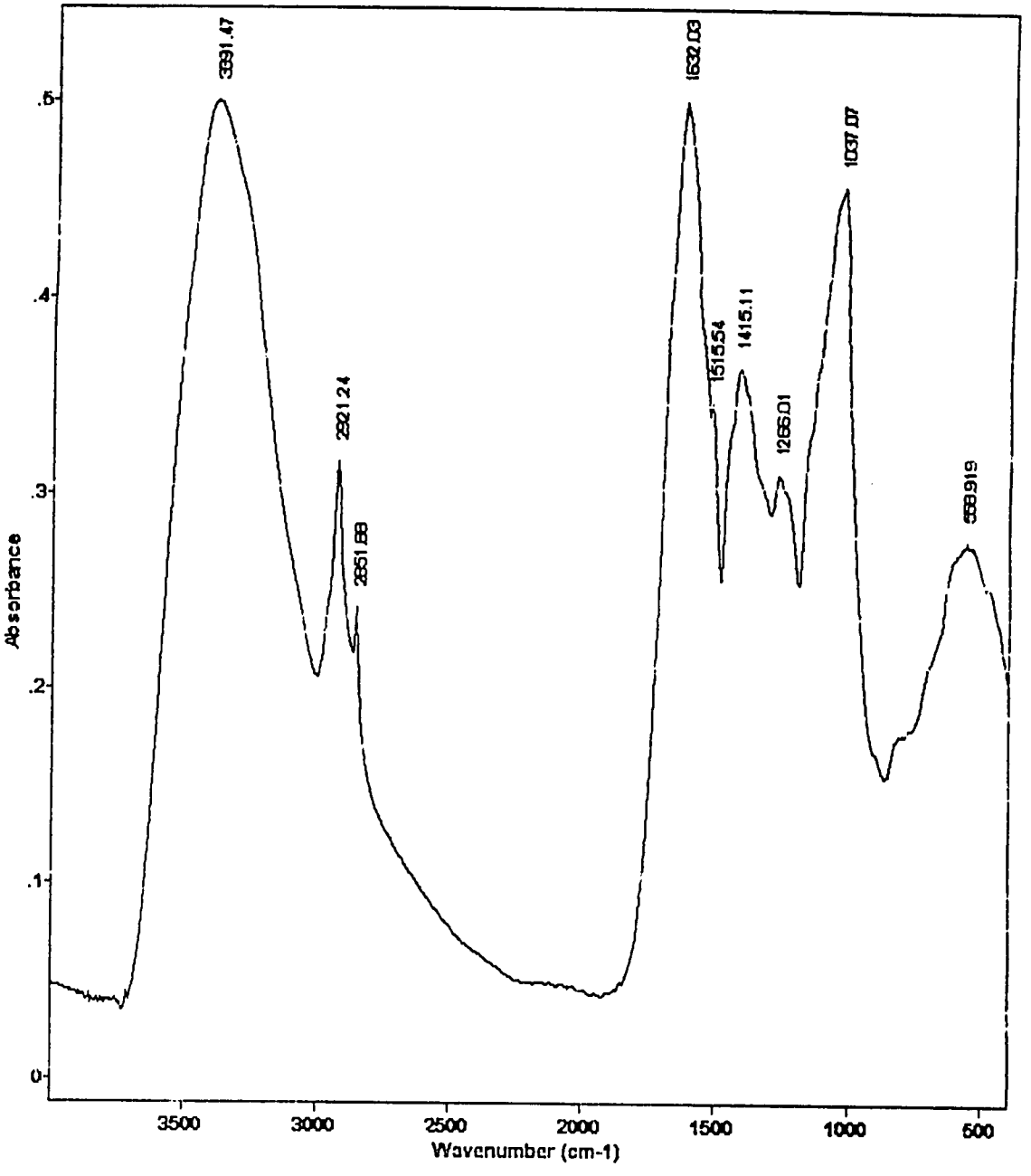

Fig.7/5 IR spectrum of W8 sample - Hypnum Moss (Moss) Peat

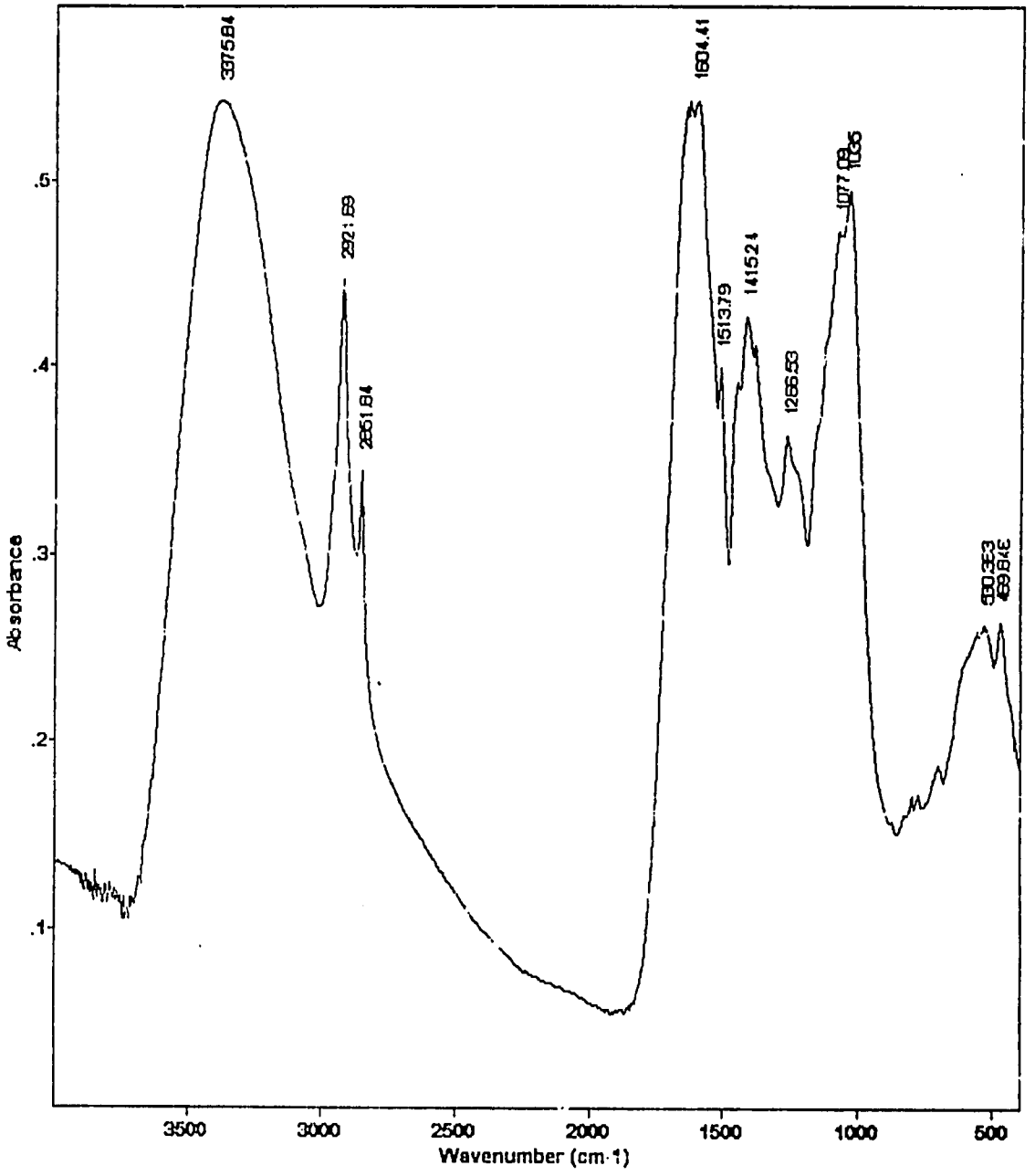

Fig.7/6 IR spectrum of W9b sample - Peat Humus (Brushwood Peat)

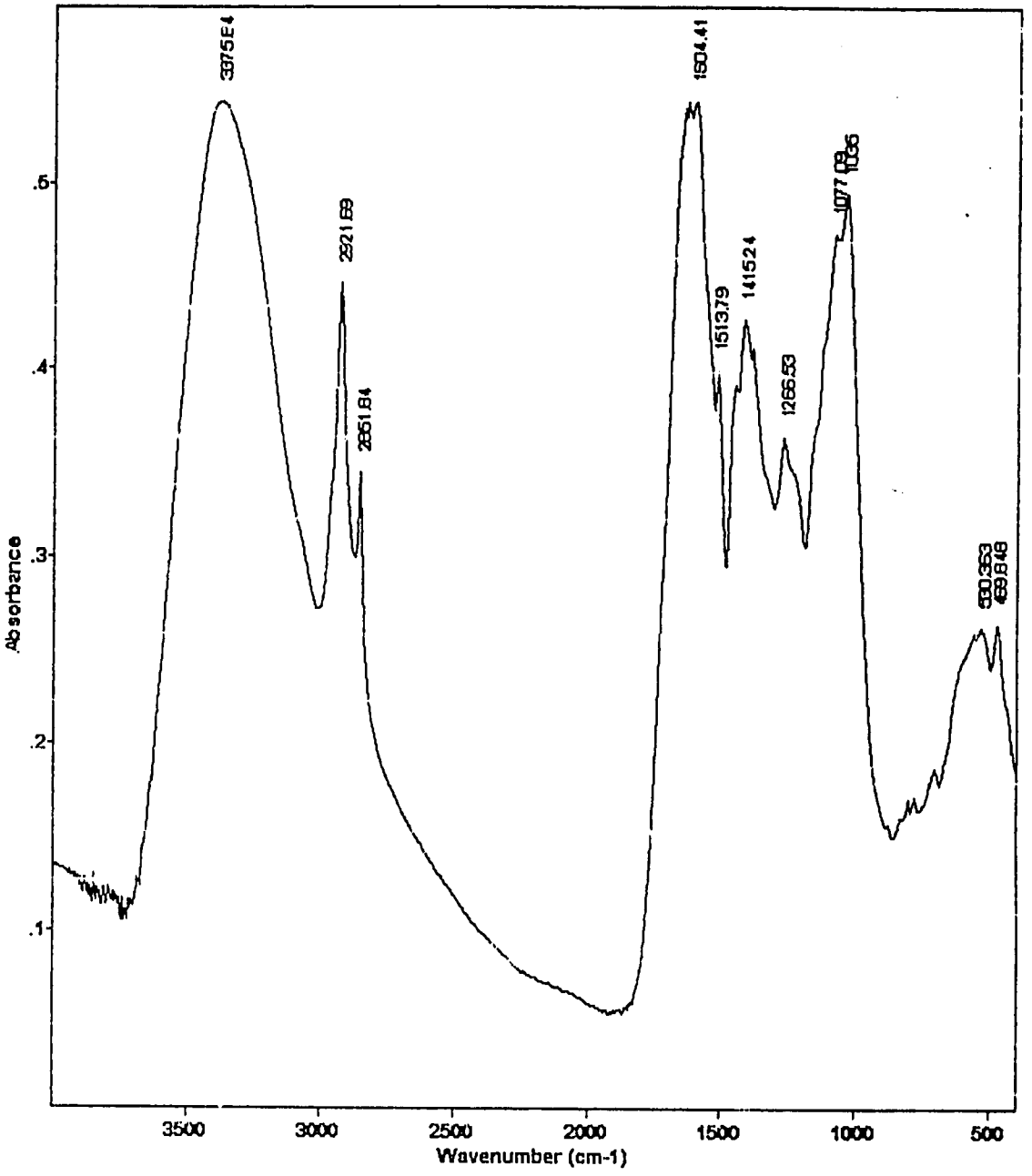

Fig.7/7 IR spectrum of W9c sample - Rush (Reed-Sedge) Peat

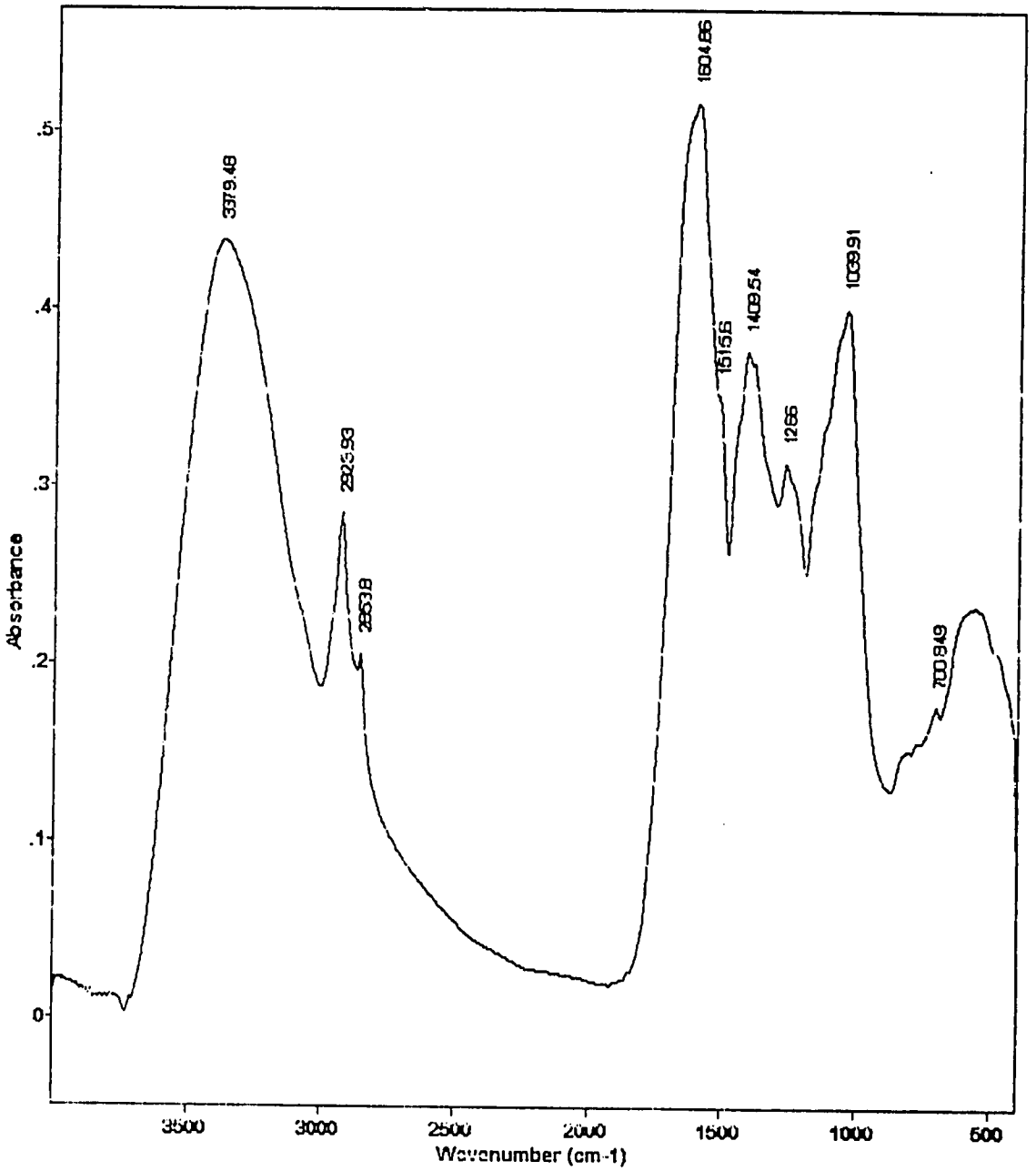

Fig.7/8 IR spectrum of B1 sample - Hypnum Moss (Sedge-Moss) Peat

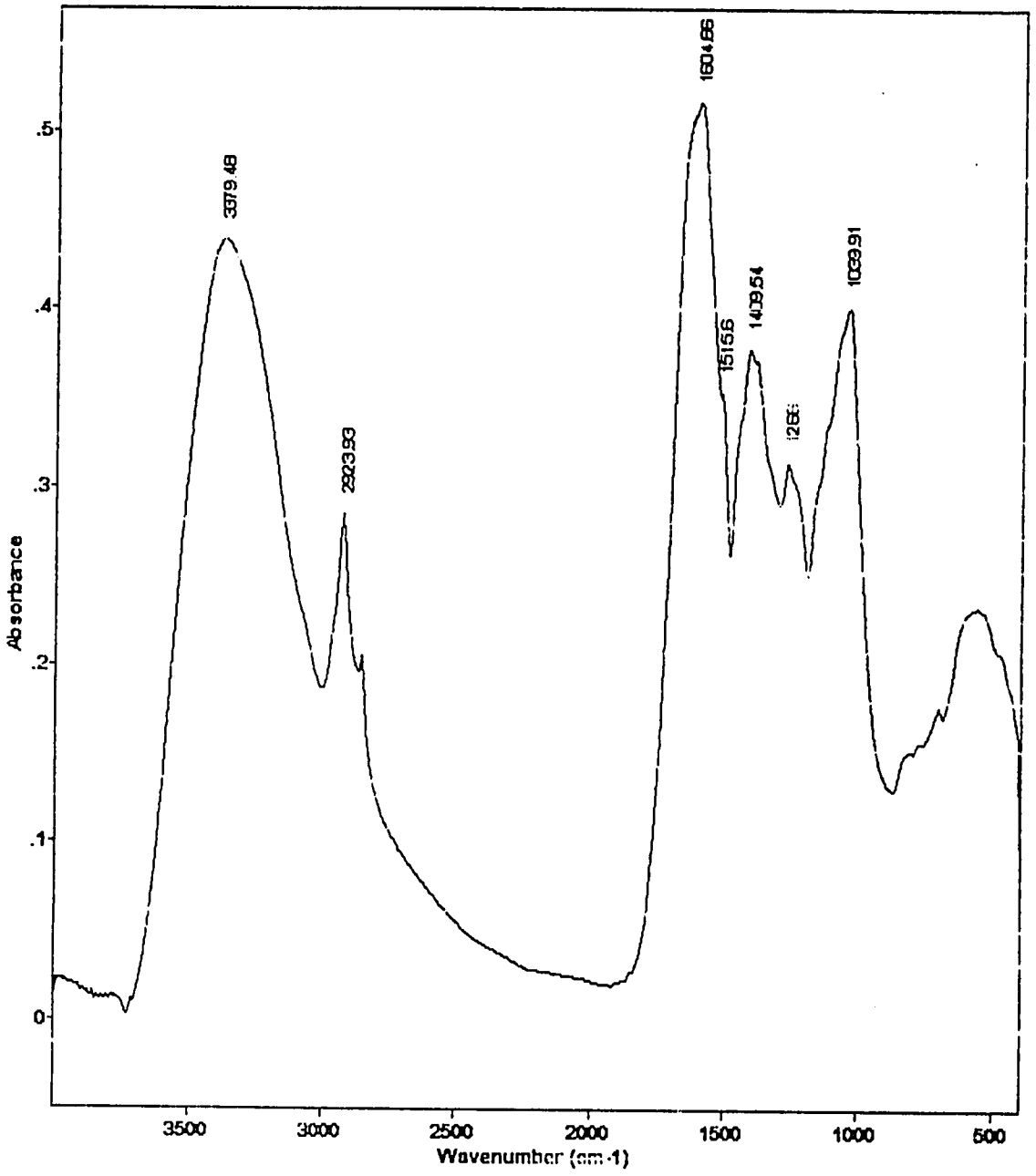

Fig.7/9 IR spectrum of B3 sample - Peat Humus (Forest Wood Peat)

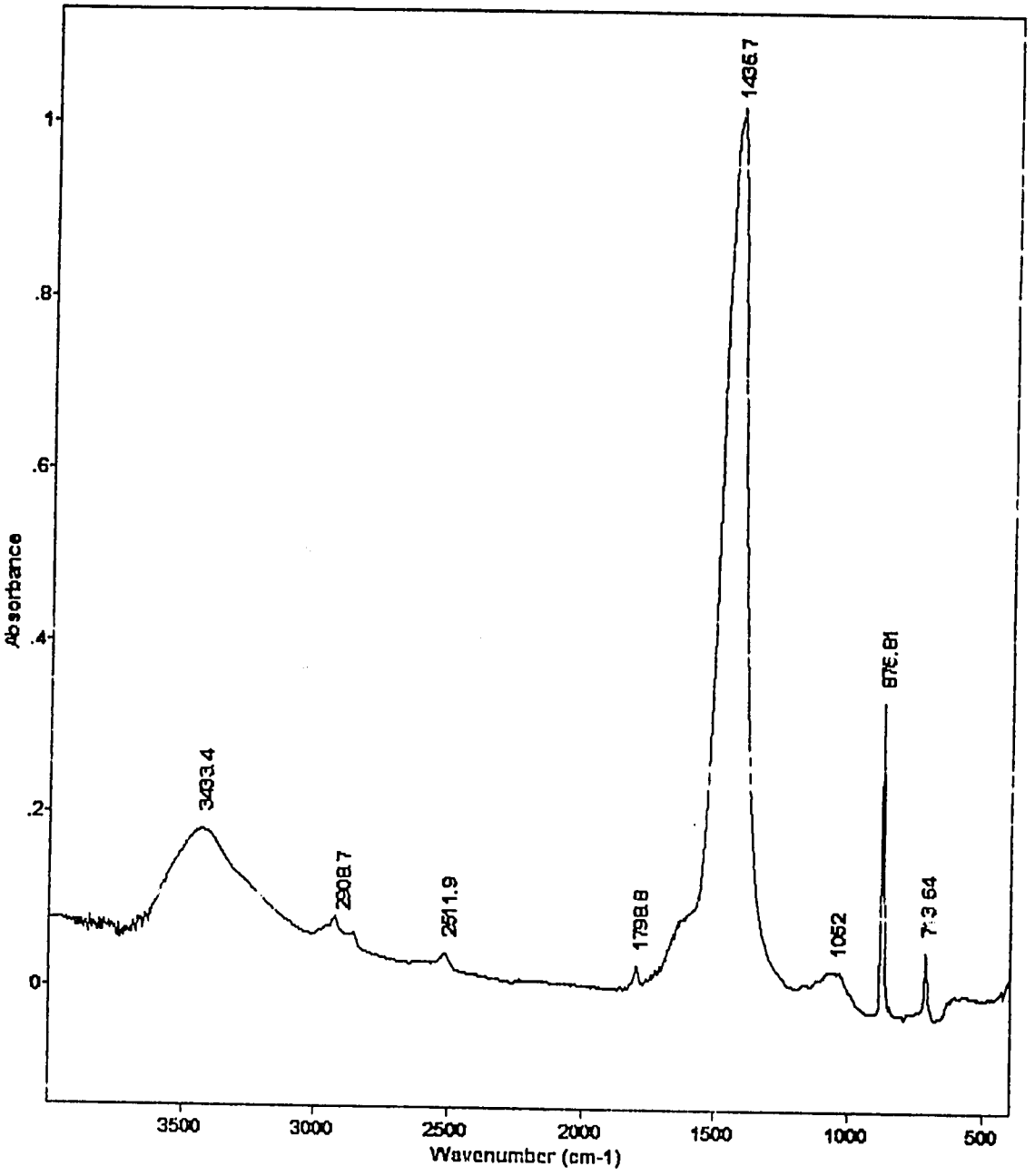

Fig.7/10 IR spectrum of B5 sample - Calcareous Gyttja

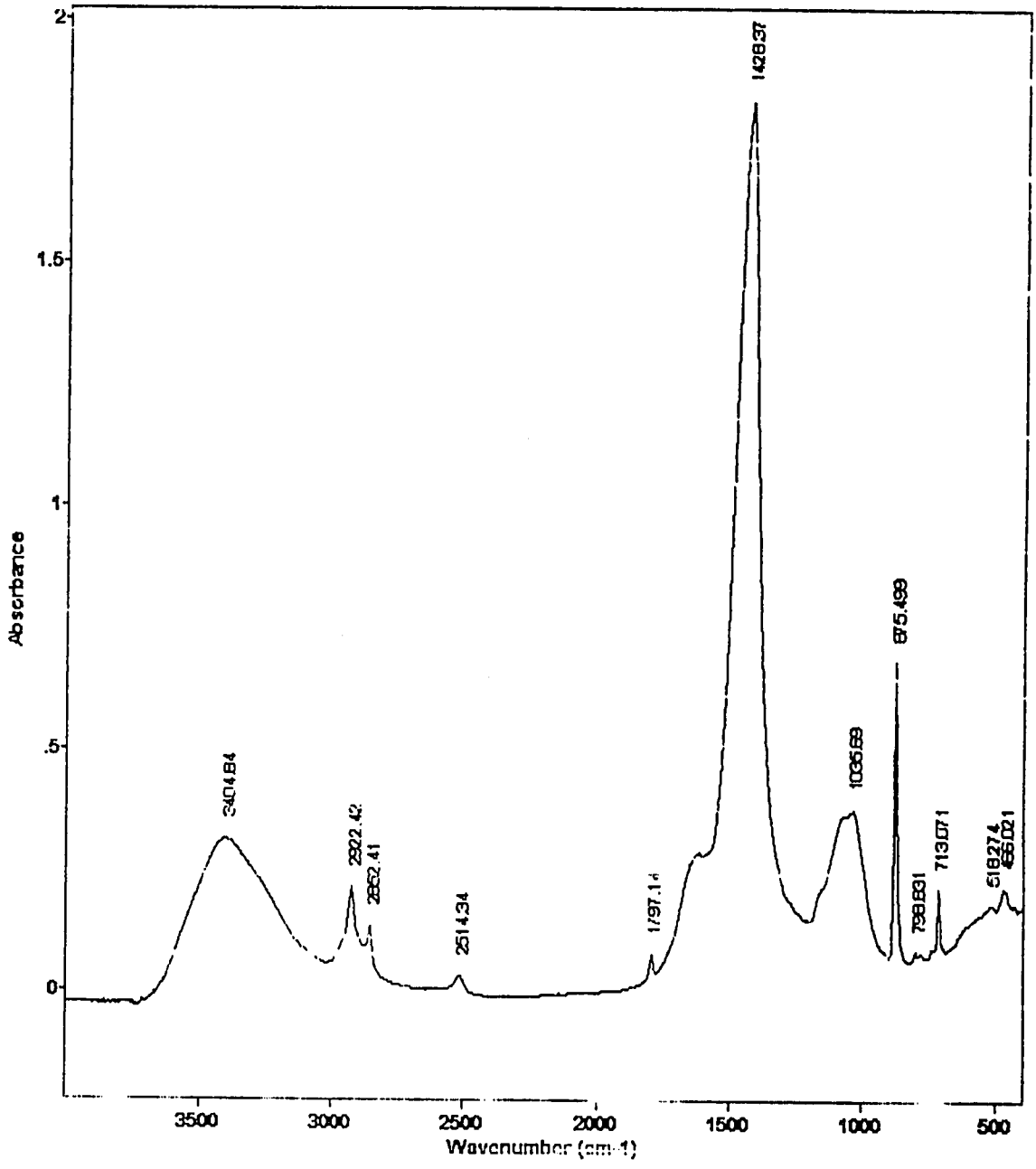

Fig.7/11 IR spectrum of Z2b sample - Detrituous Gyttja

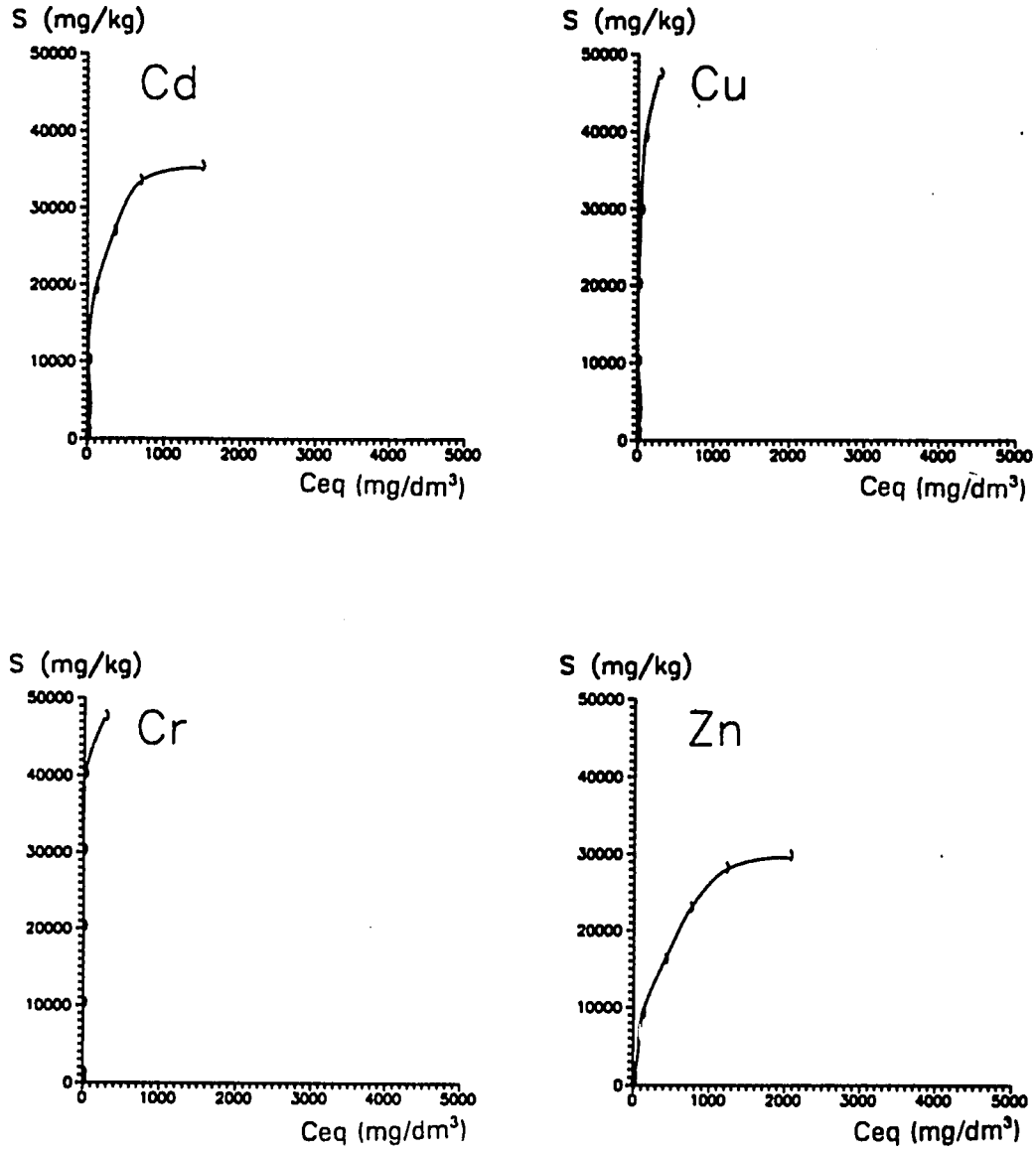

Fig.8
Sorption of heavy metals on Peat Humus (Alder Peat), DR=70%, AC=12.55%, Wizna Site

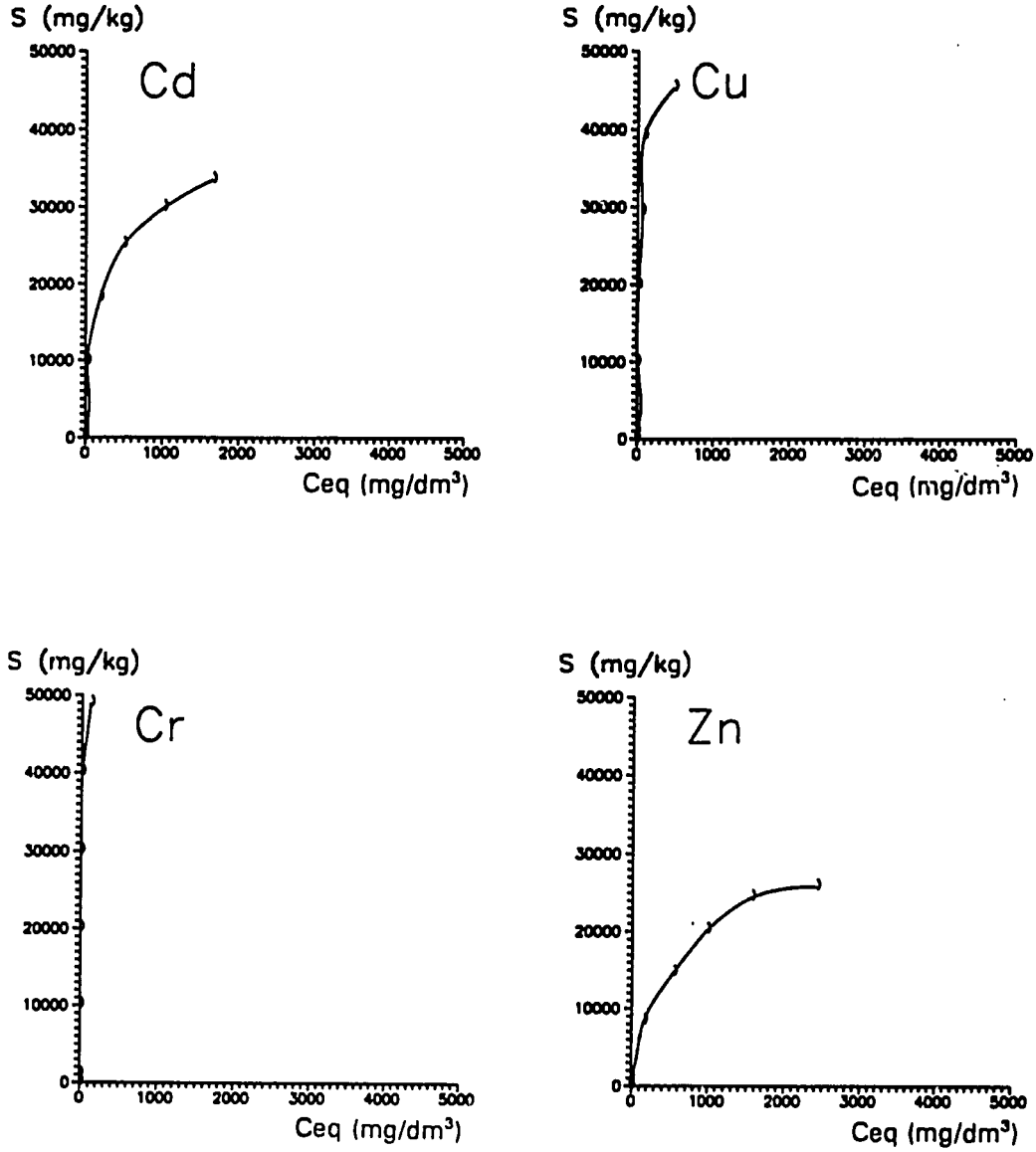

Fig.9
Sorption of heavy metals on Rush (Reed) Peat, DR=55%, AC=12.60%, Wizna Site

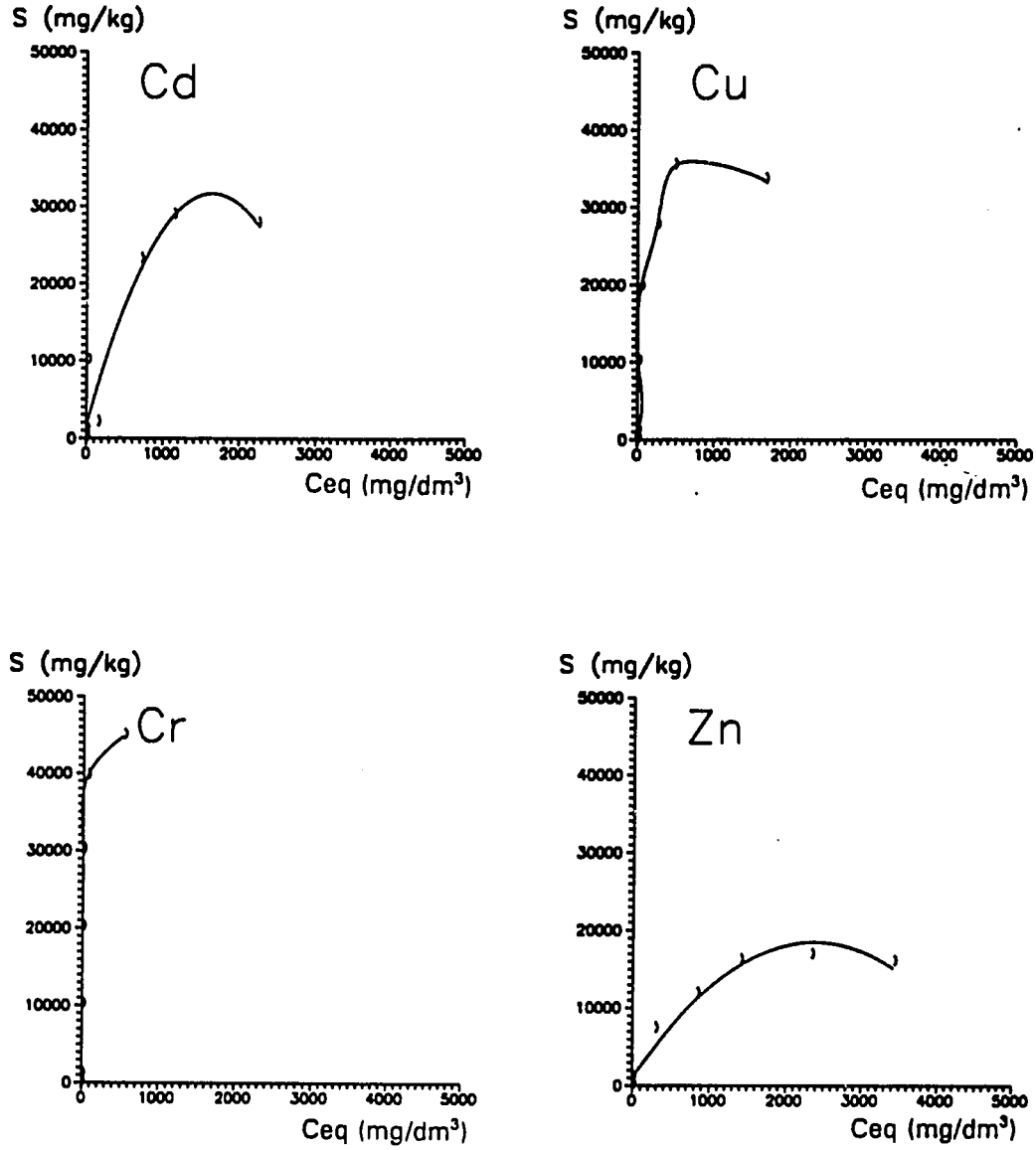

Fig.10
Sorption of heavy metals on Hypnum Moss (Sedge-Moss) Peat, DR=35%, AC=9.80%, Wizna Site

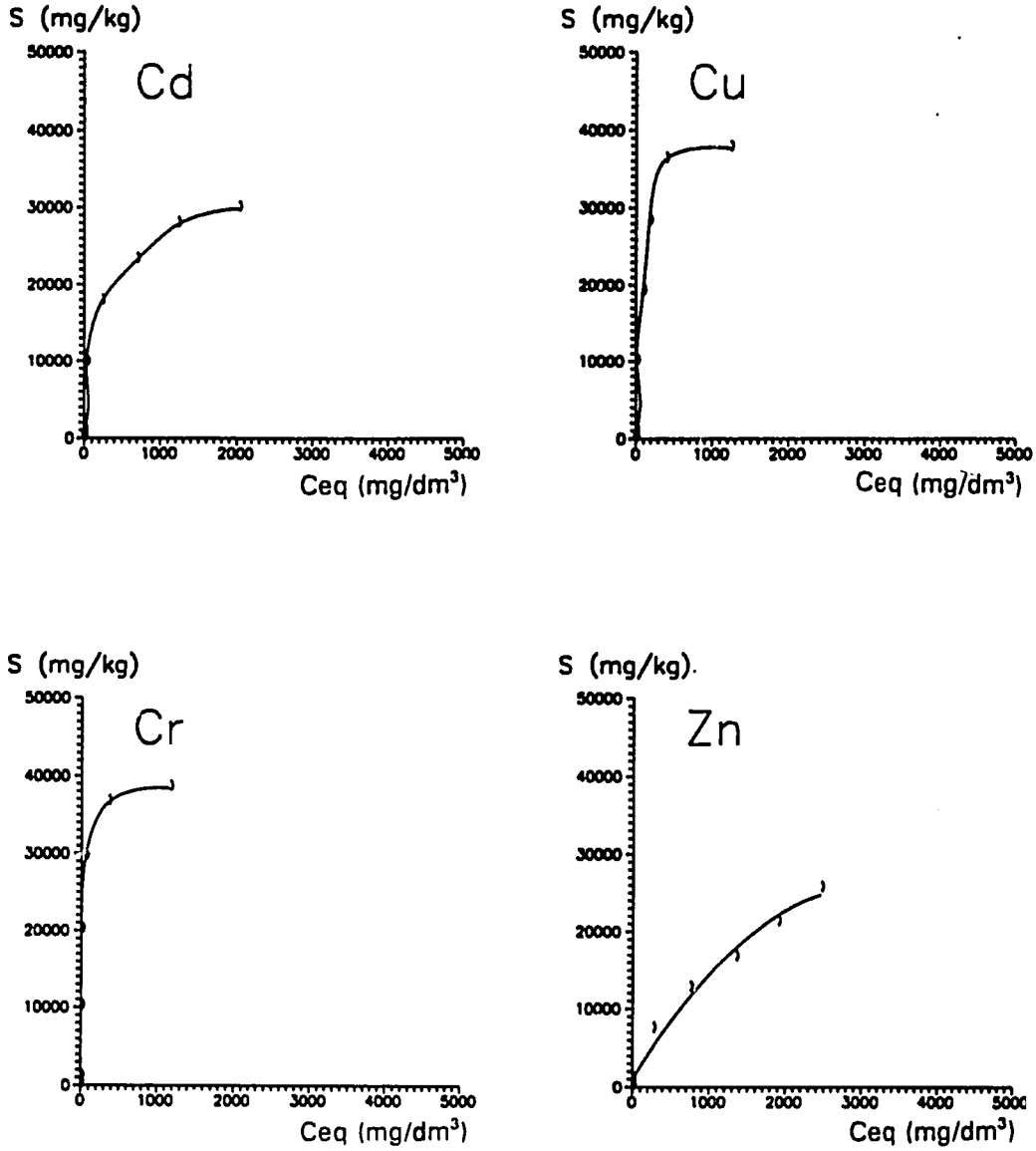

Fig.11
Sorption of heavy metals on Sedgeous (Sedge) Peat, DR=30%, AC=9.10%, Wizna Site

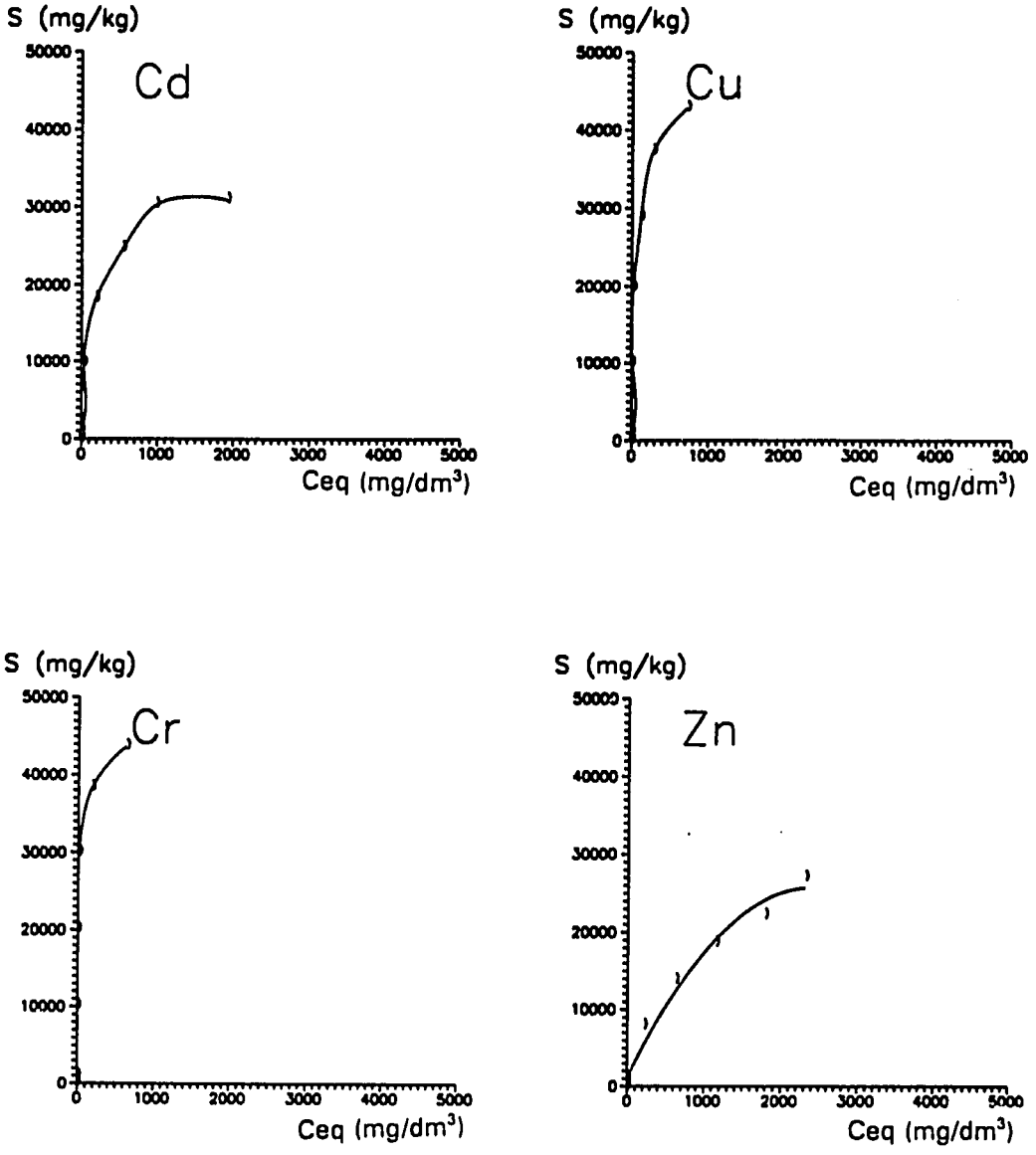

Fig. 12
Sorption of heavy metals on Hypnum Moss (Sedge-Moss) Peat, DR=25%, AC=8.20%, Wizna Site

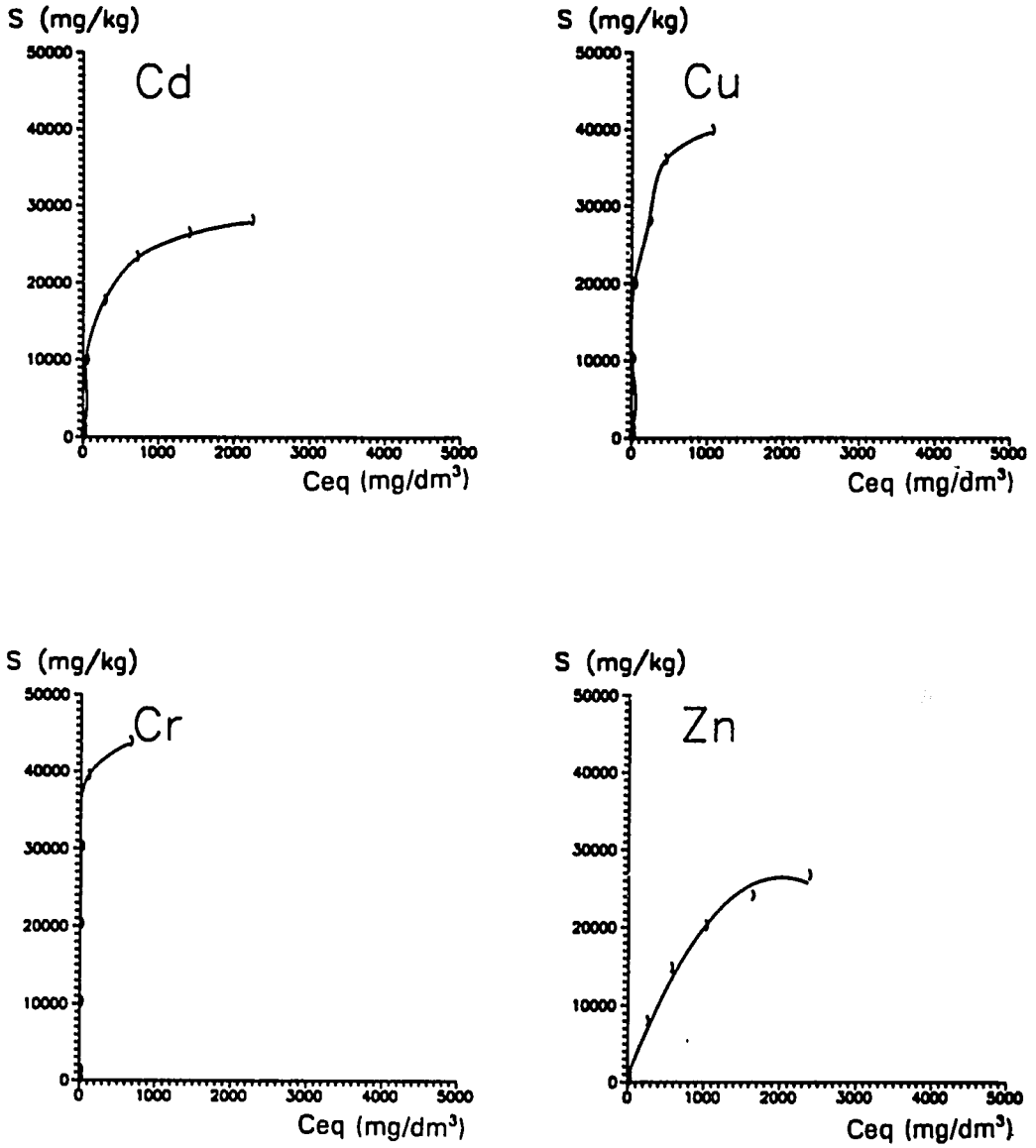

Fig.13
Sorption of heavy metals on Hypnum Moss (Sedge-Moss) Peat, DR=40%, AC=8.80%, Wizna Site

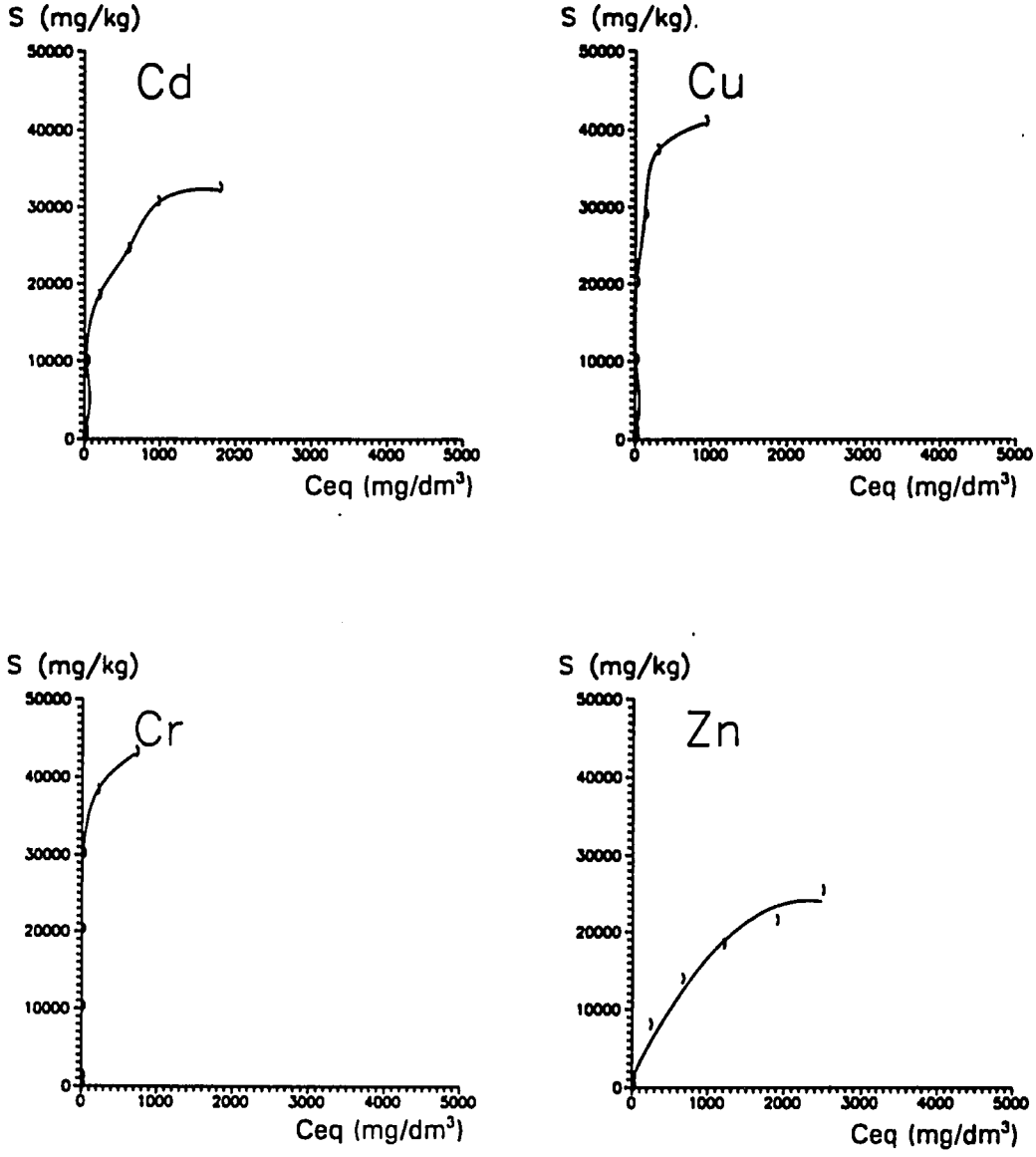

Fig.14
Sorption of heavy metals on Hypnum Moss (Sedge-Moss) Peat, DR=30%, AC=7.80%, Wizna Site

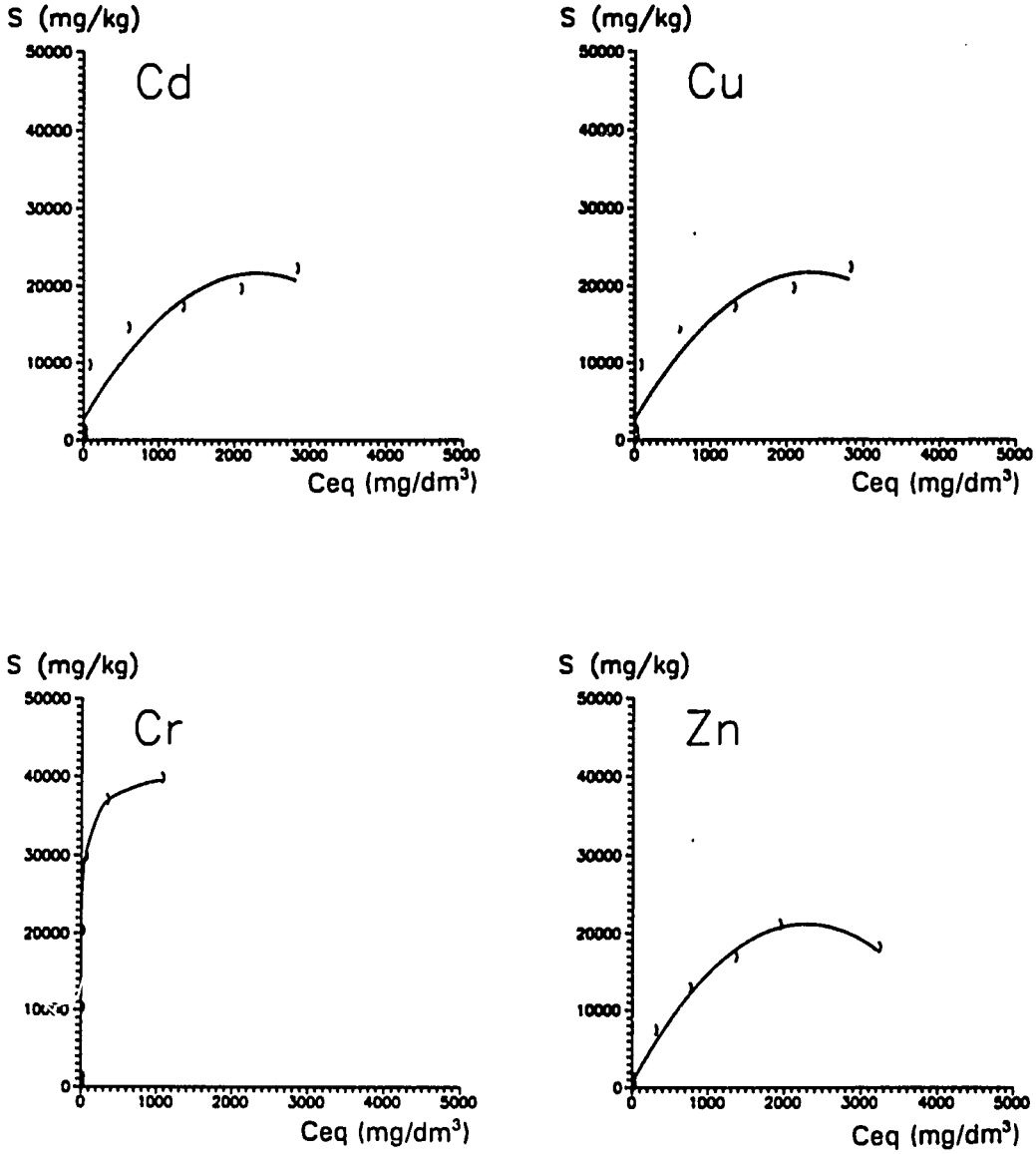

Fig.15
Sorption of heavy metals on Hypnum Moss (Moss) Peat, DR=18%, AC =7.20%, Wizna Site

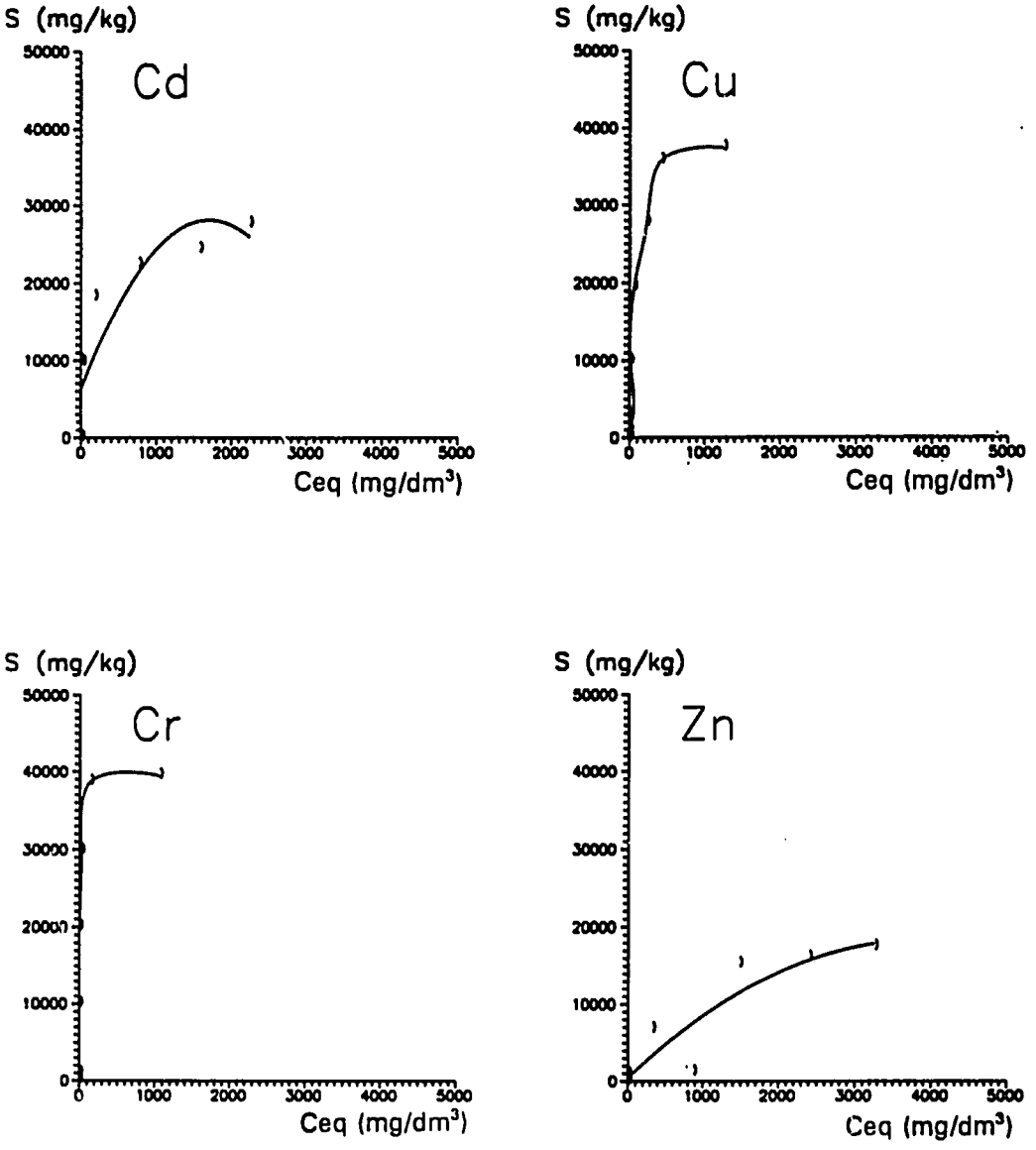

Fig.16
Sorption of heavy metals on Mellow Boggy Soil
Wizna Site

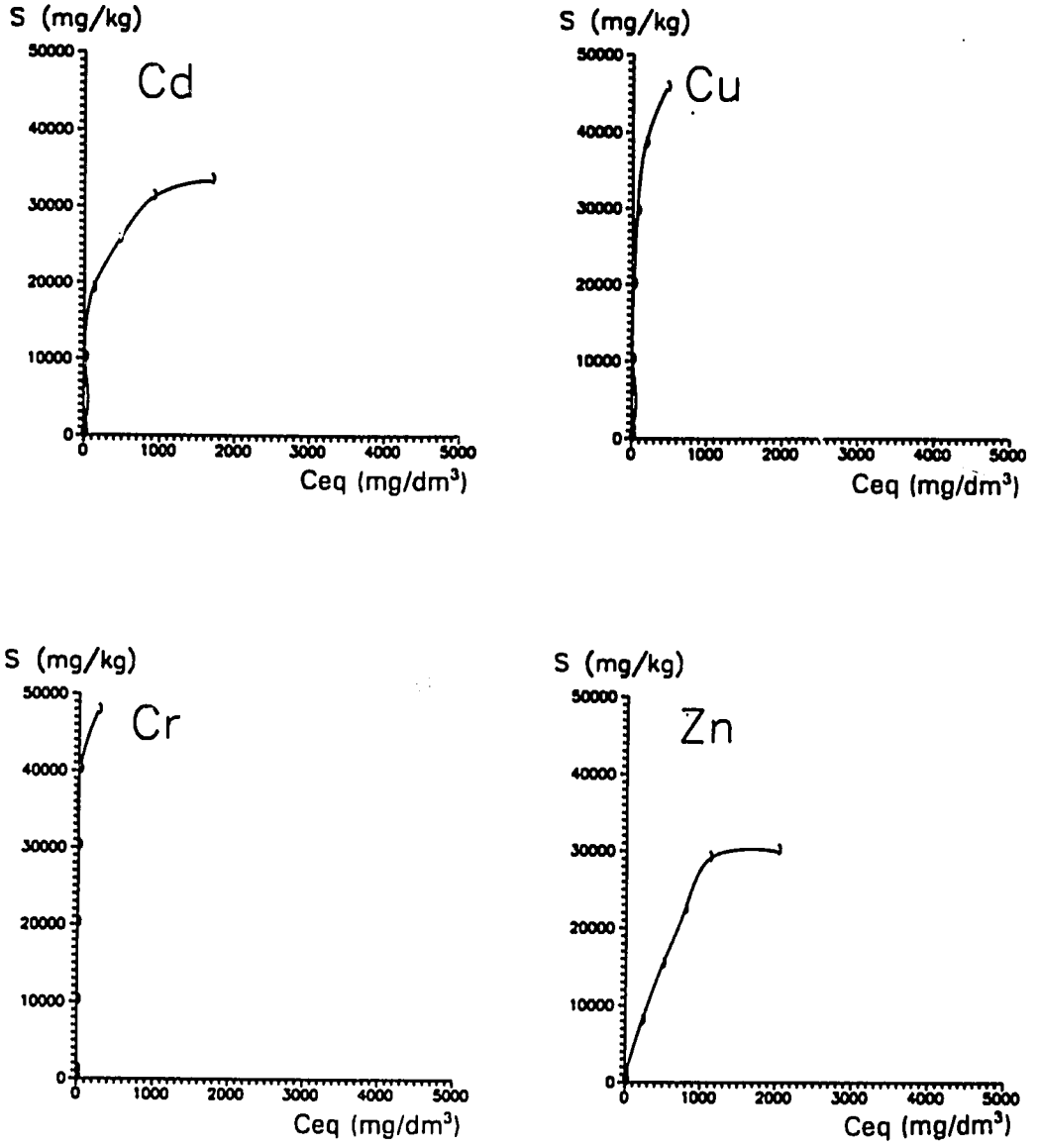

Fig.17
Sorption of heavy metals on Peat Humus (Brushwood Peat), DR=55%, AC=10.40%
Wizna Site

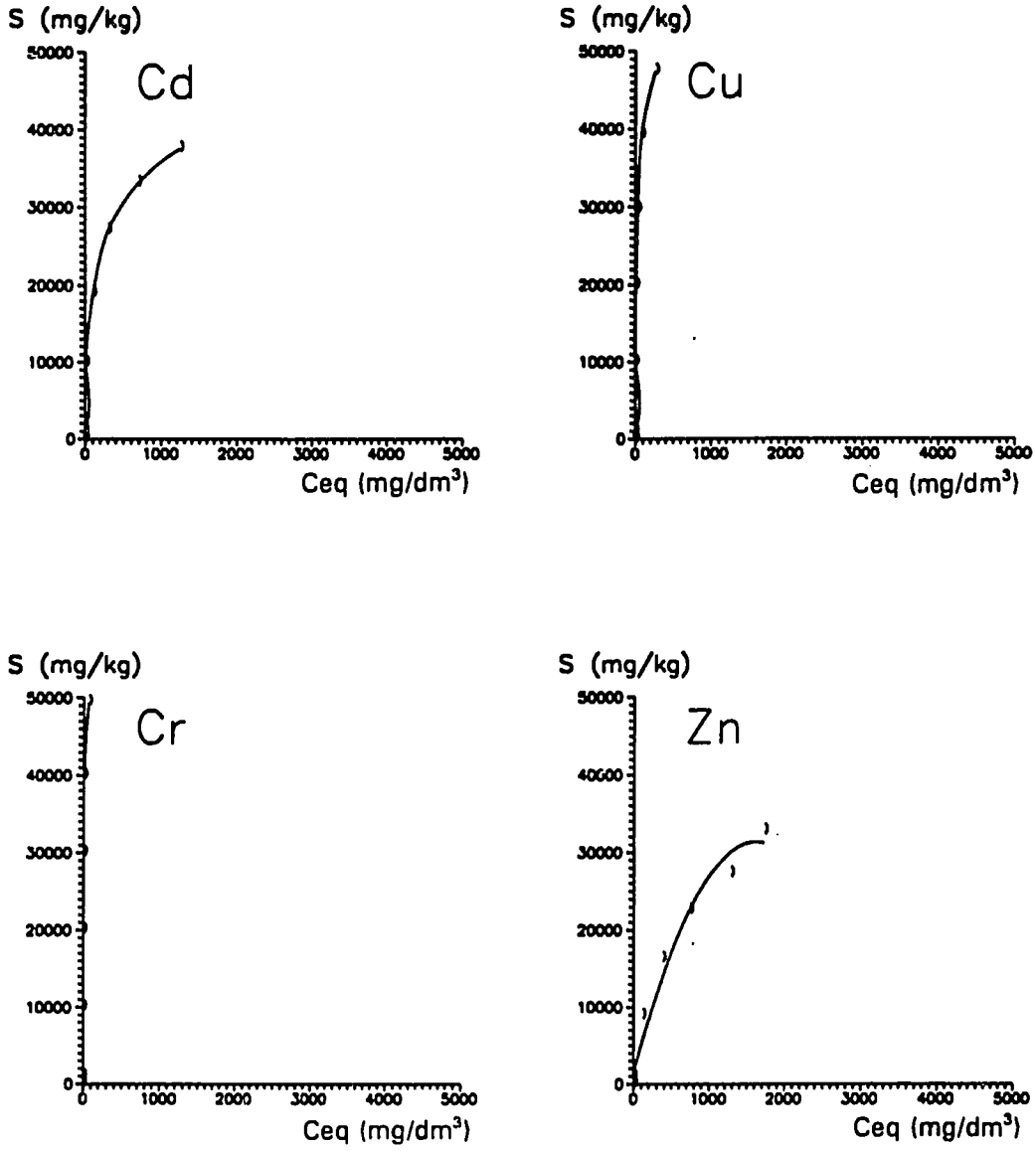

Fig.18
Sorption of heavy metals on Rush (Reed-Sedge) Peat, DR=55%, AC=9.50%
Wizna Site

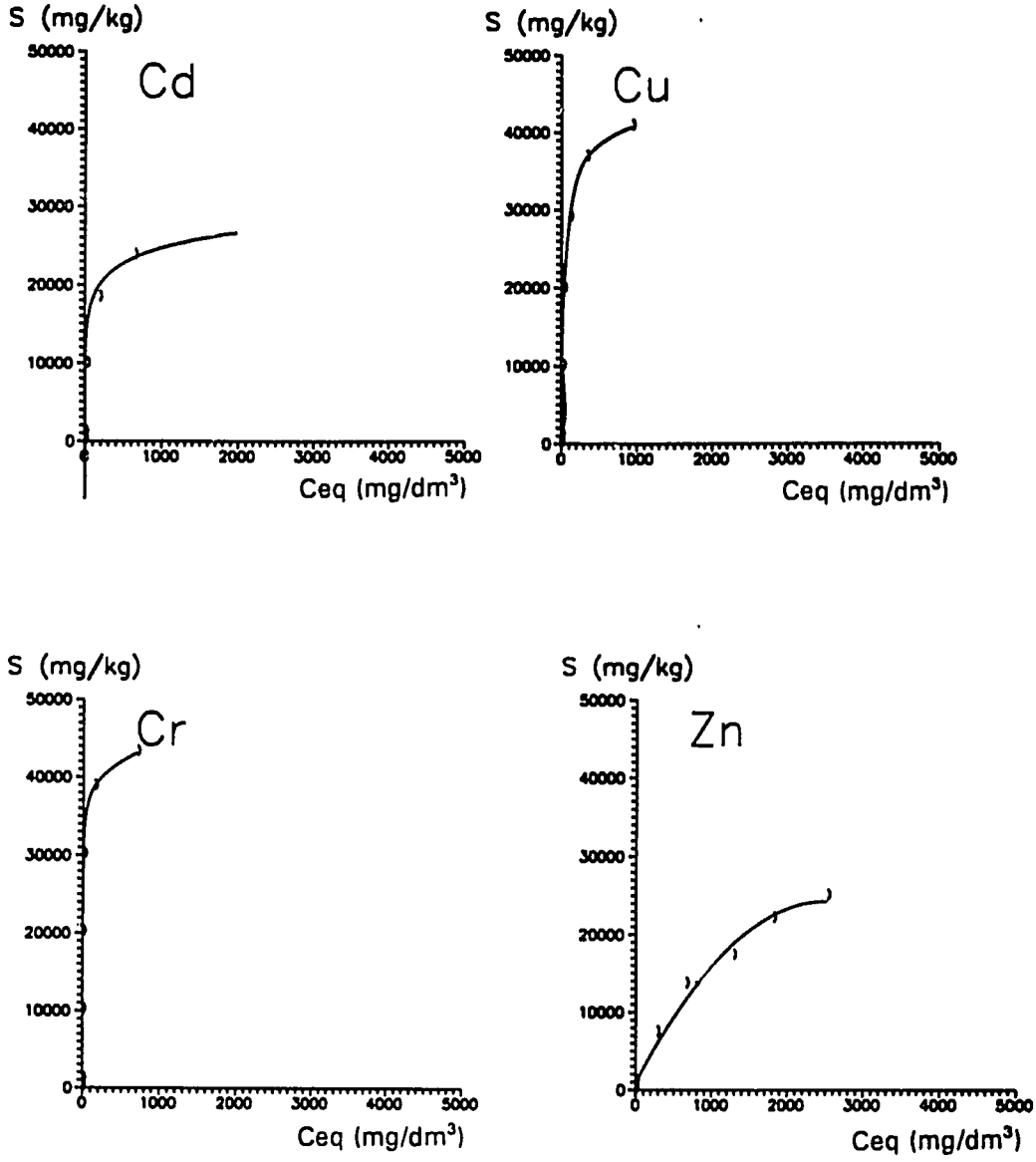

Fig.19
Sorption of heavy metals on Hypnum Moss (Sedge-Moss) Peat, DR=60%, AC=7.40%
Biebrza Site

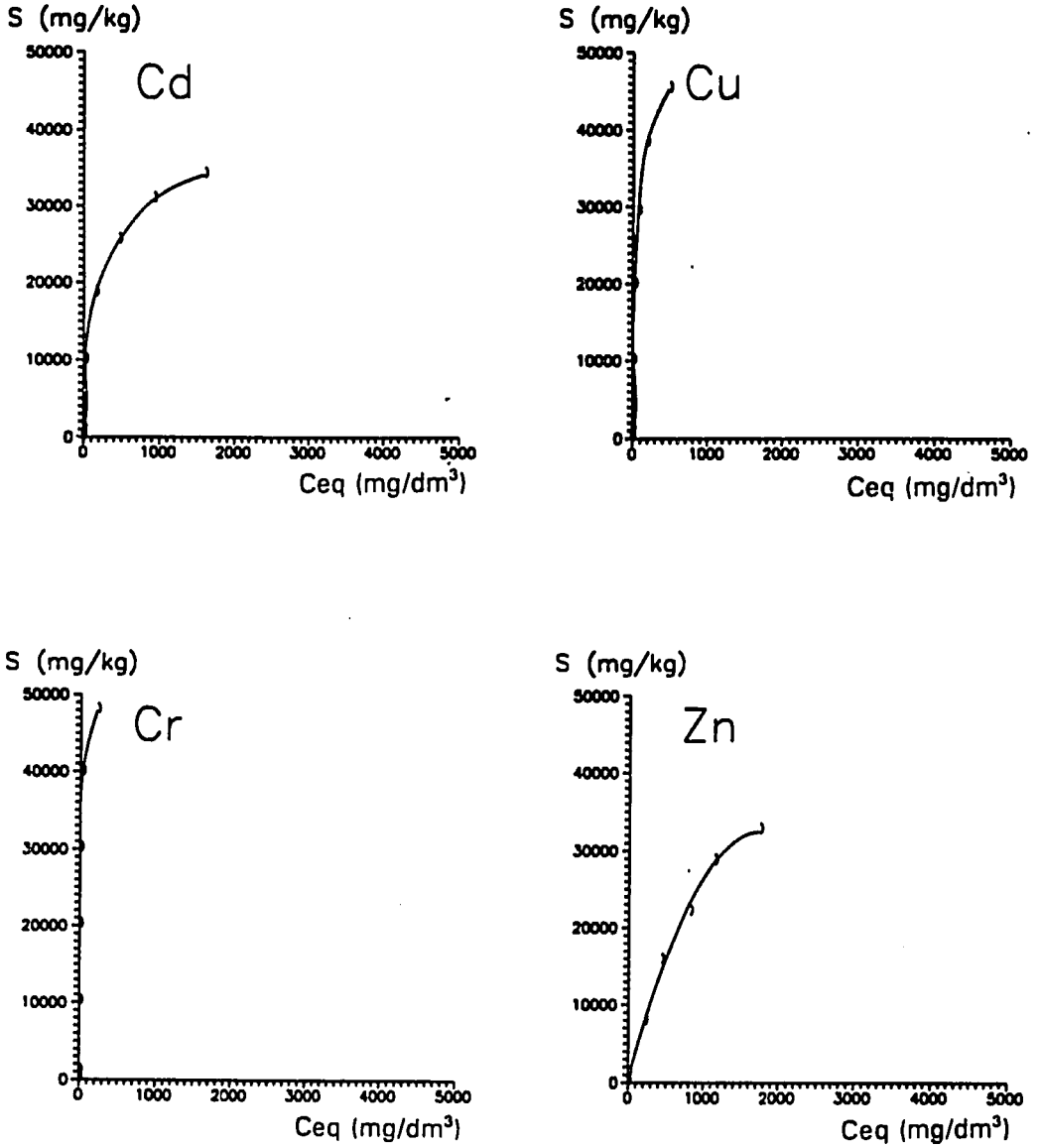

Fig.20
Sorption of heavy metals on Sedgeous (Reed-Sedge) Peat, DR=60%, AC=8.00%
Biebrza Site

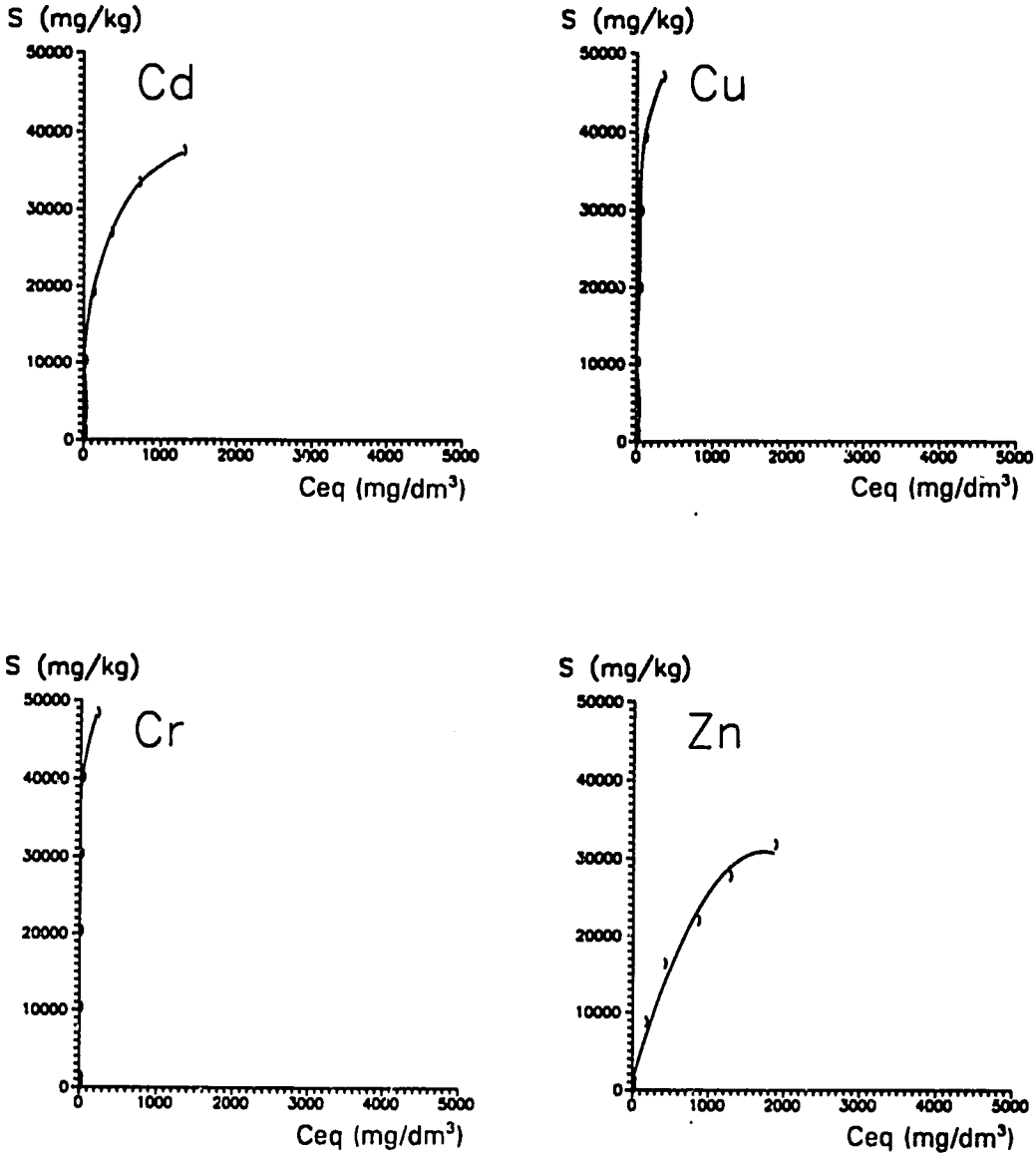

Fig.21
Sorption of heavy metals on Peat Humus (Brushwood) Peat, DR=65%, AC=10.20%
Biebrza Site

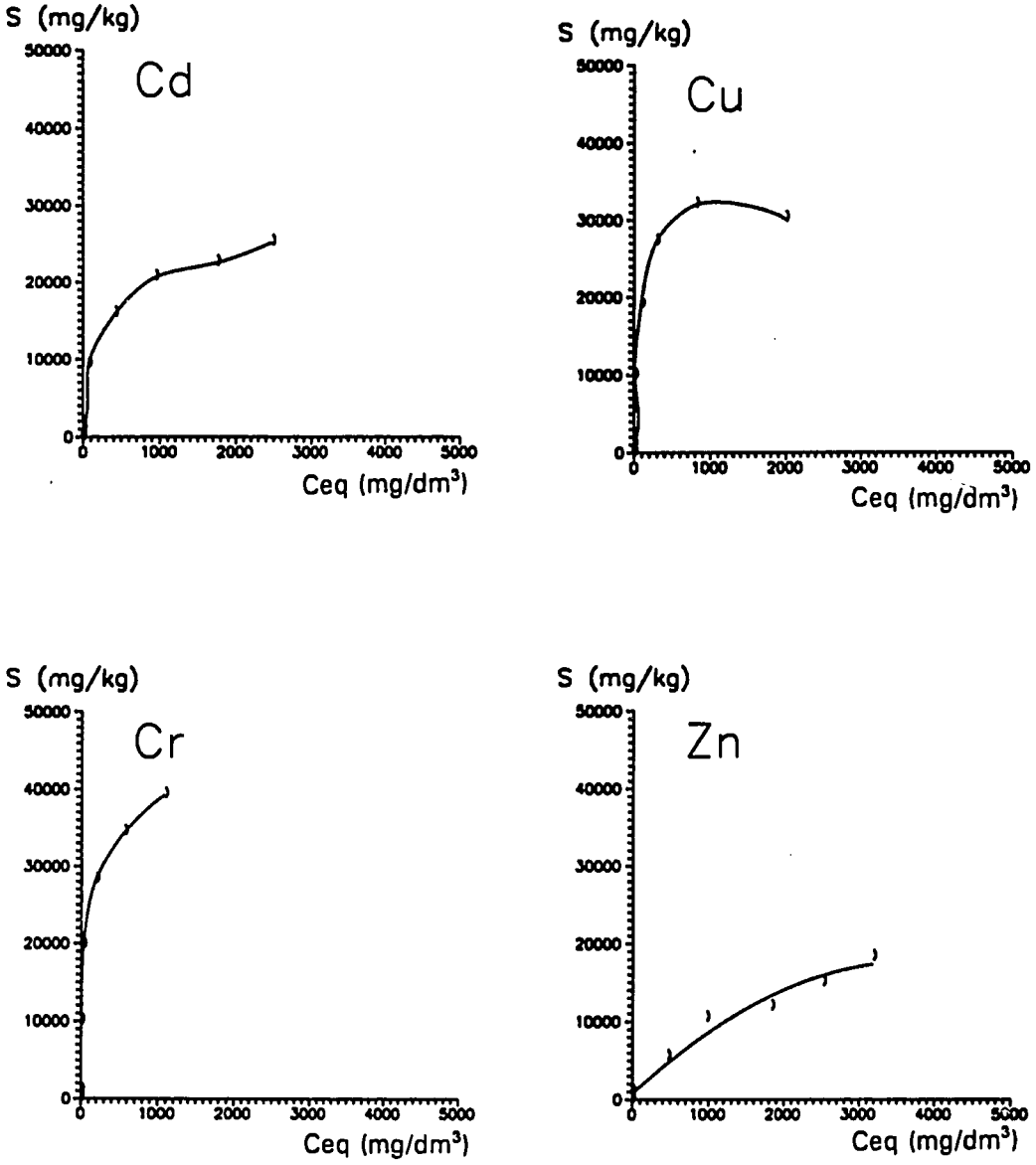

Fig.22
Sorption of heavy metals on Hypnum Moss (Sedge-Moss) Peat, DR=40%, AC=8.90%
Biebrza Site

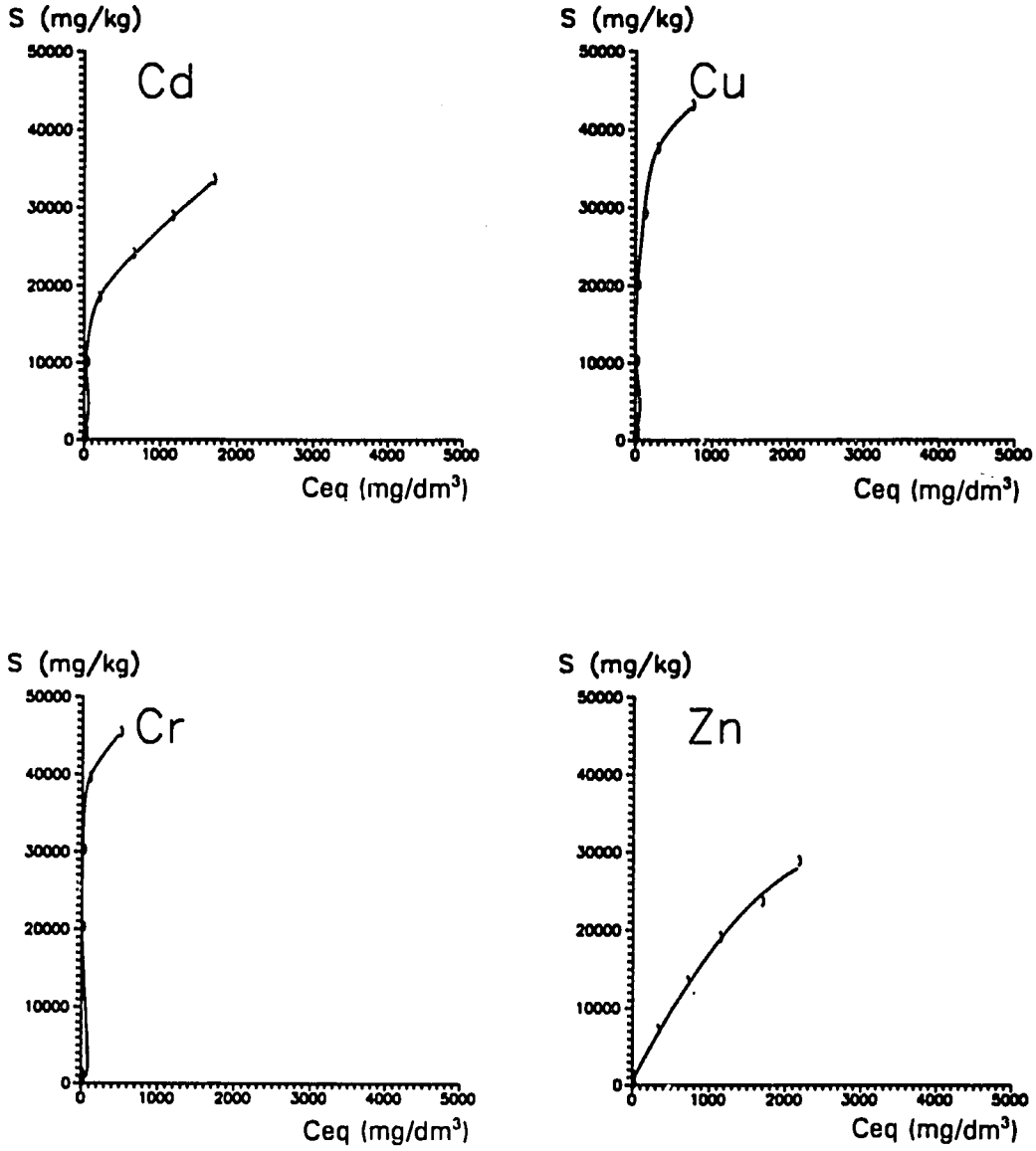

Fig.23
Sorption of heavy metals on Peat Humus (Forest Wood) Peat, DR=80%, AC=11.70%
Biebrza Site

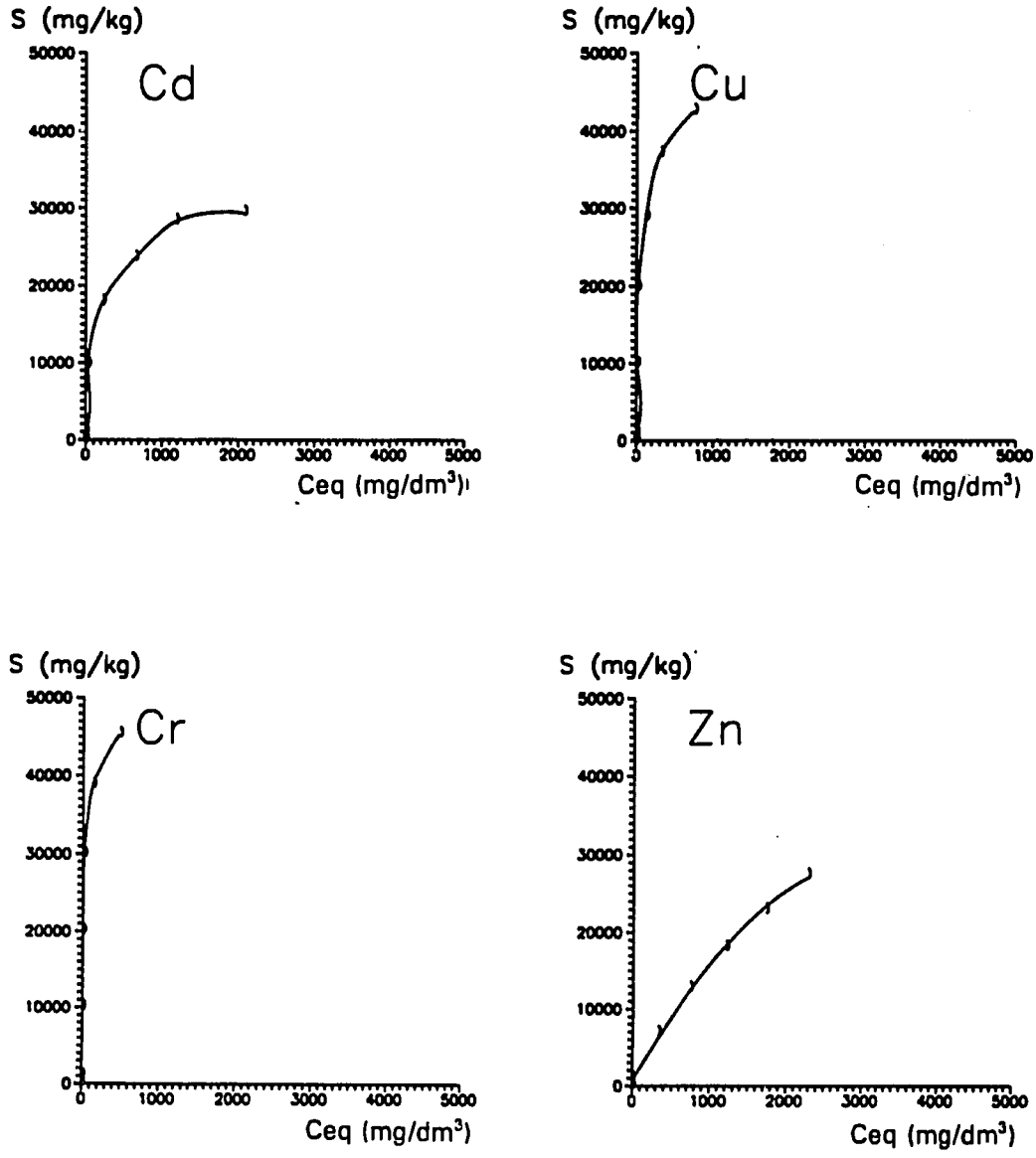

Fig.24
Sorption of heavy metals on Peat Humus (Forest Wood) Peat, DR=60%, AC=10.55%
Biebrza Site

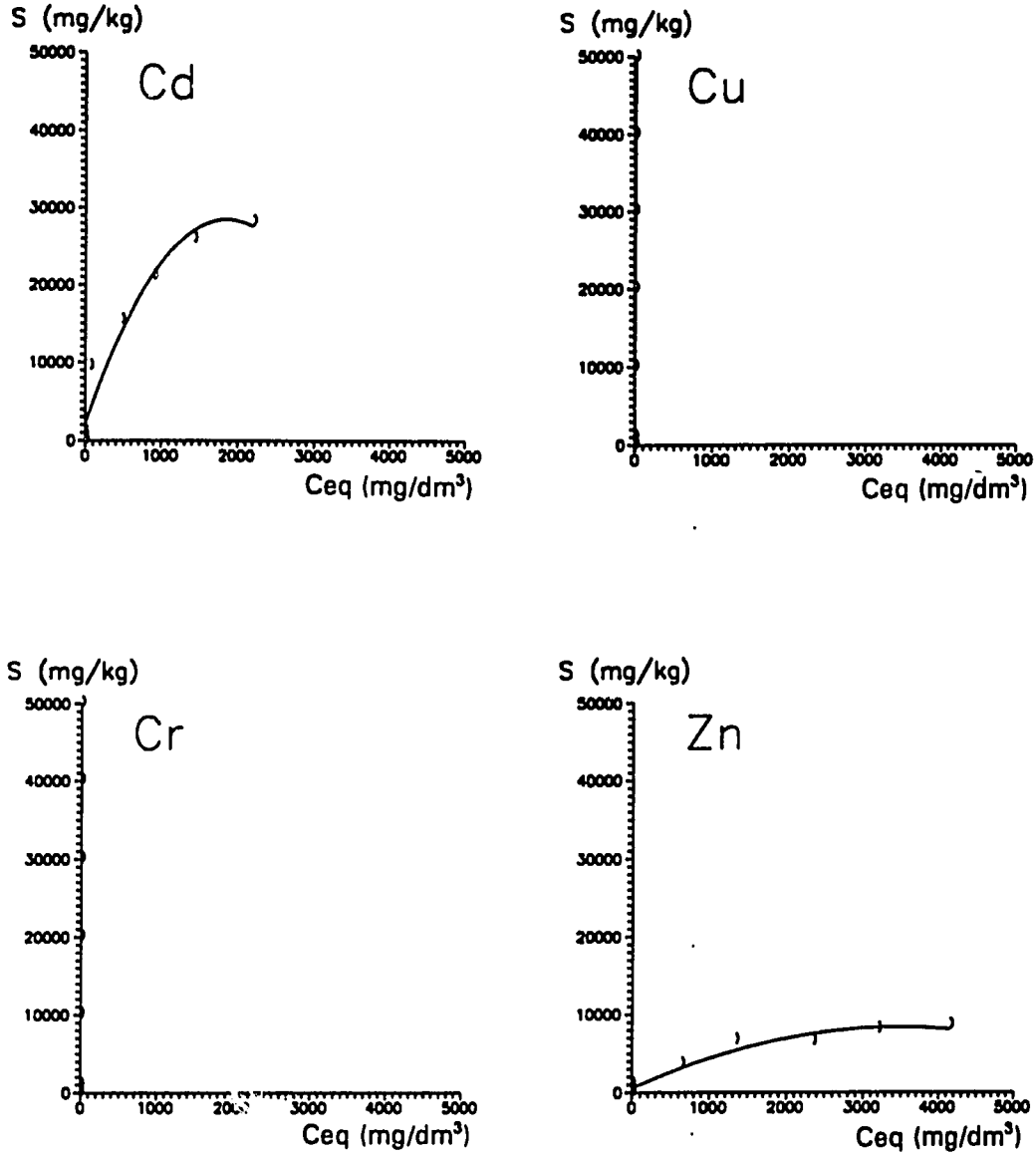

Fig.25
Sorption of heavy metals on Calcareous Gyttja
Biebrza Site

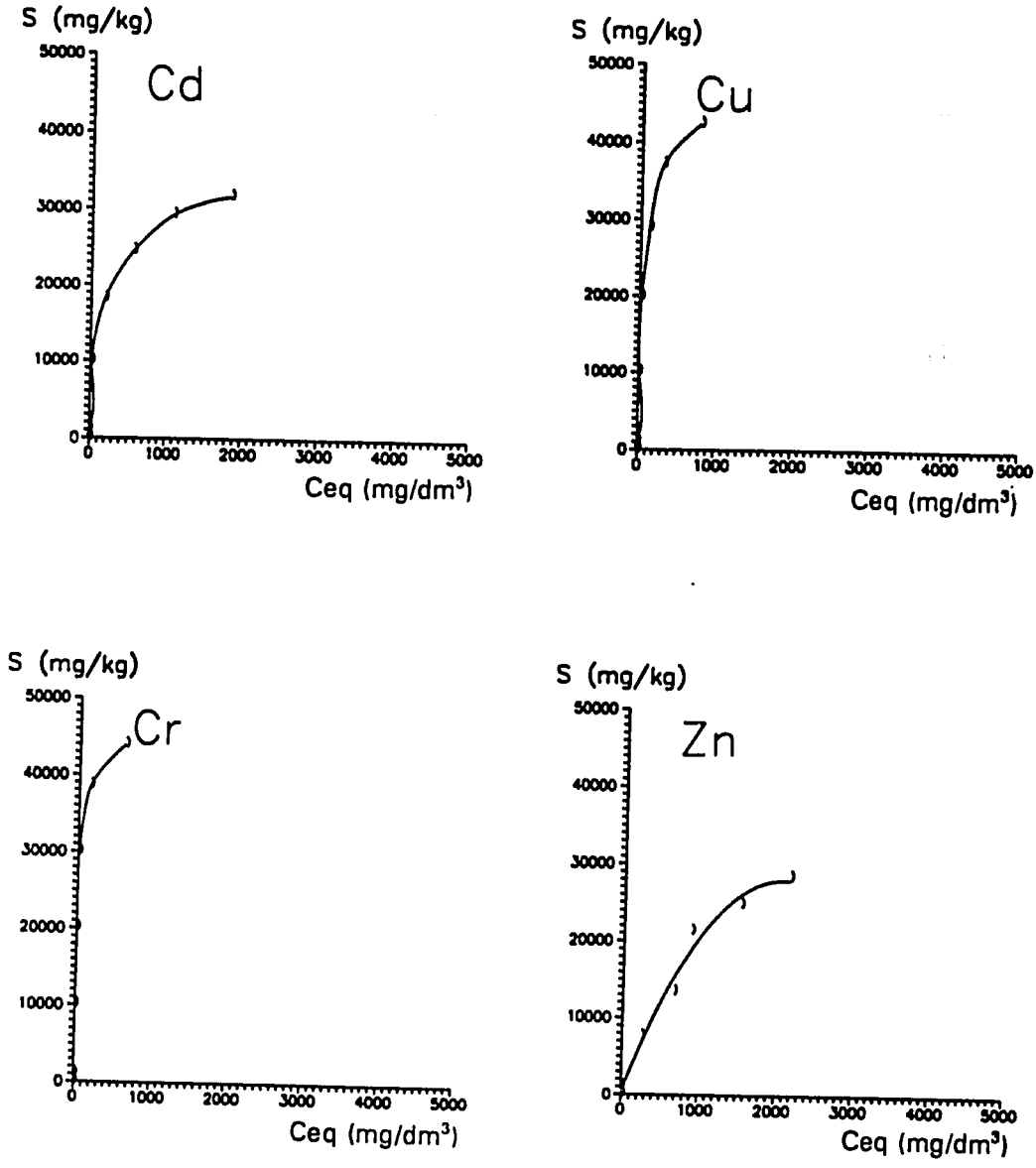

Fig.26
Sorption of heavy metals on Rush (Reed) Peat, DR=50%, AC=9.25%
Biebrza Site

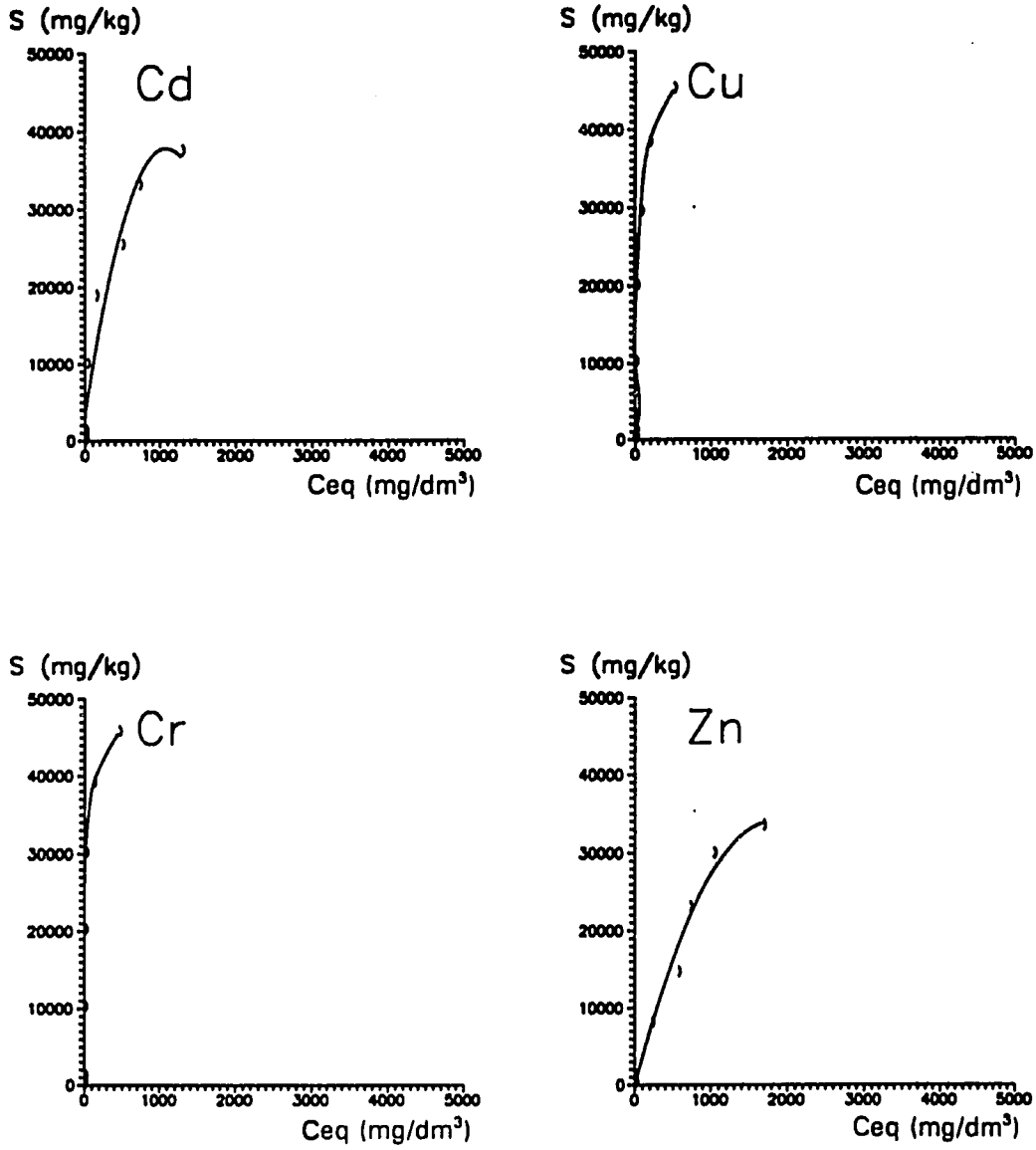

Fig.27
Sorption of heavy metals on Rush (Reed) Peat, DR=65%, AC=10.70%
Biebrza Site

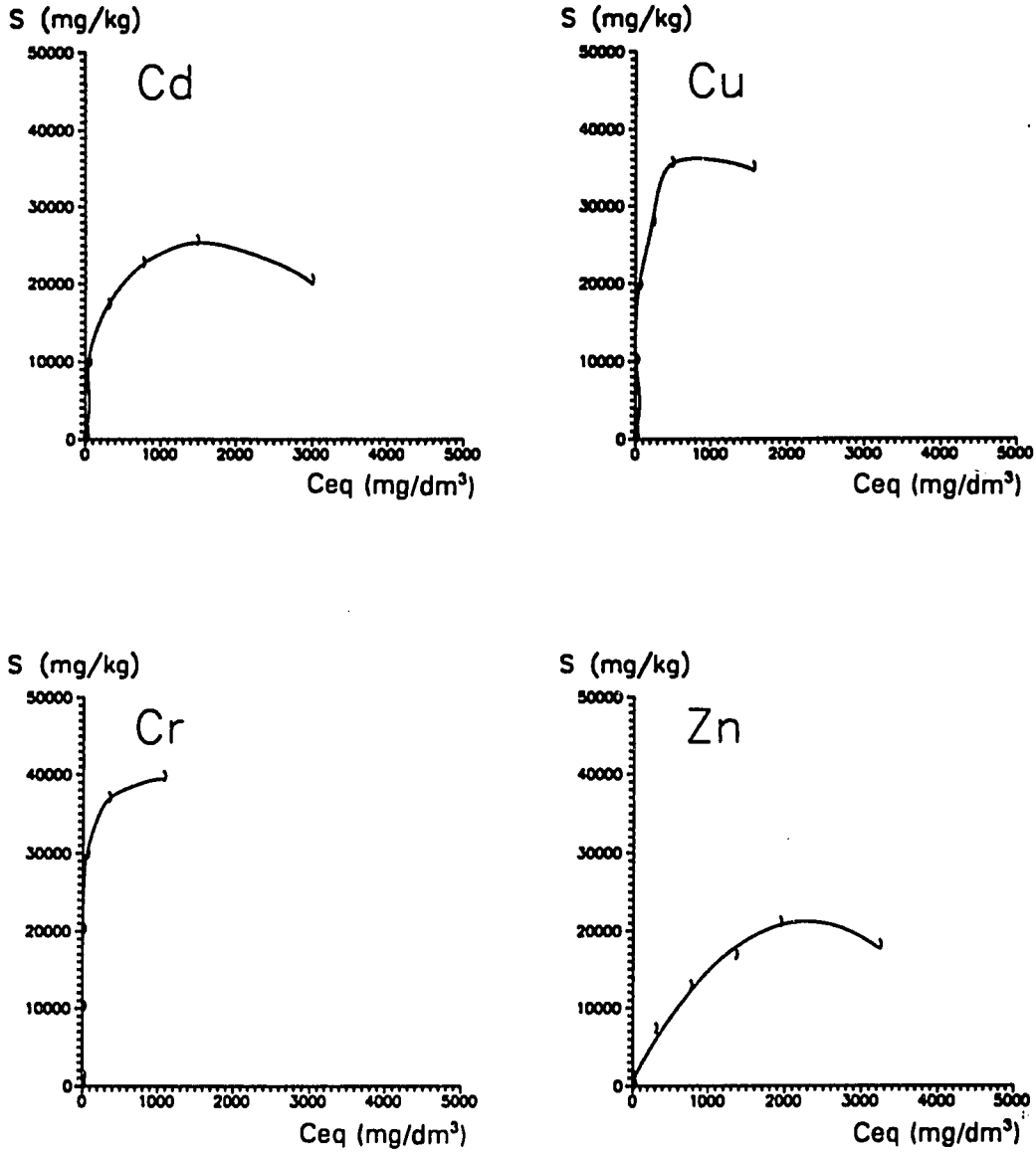

Fig.28
Sorption of heavy metals on Hypnum Moss (Sedge-Moss) Peat, DR=40%, AC=7.10%, Biebrza Site

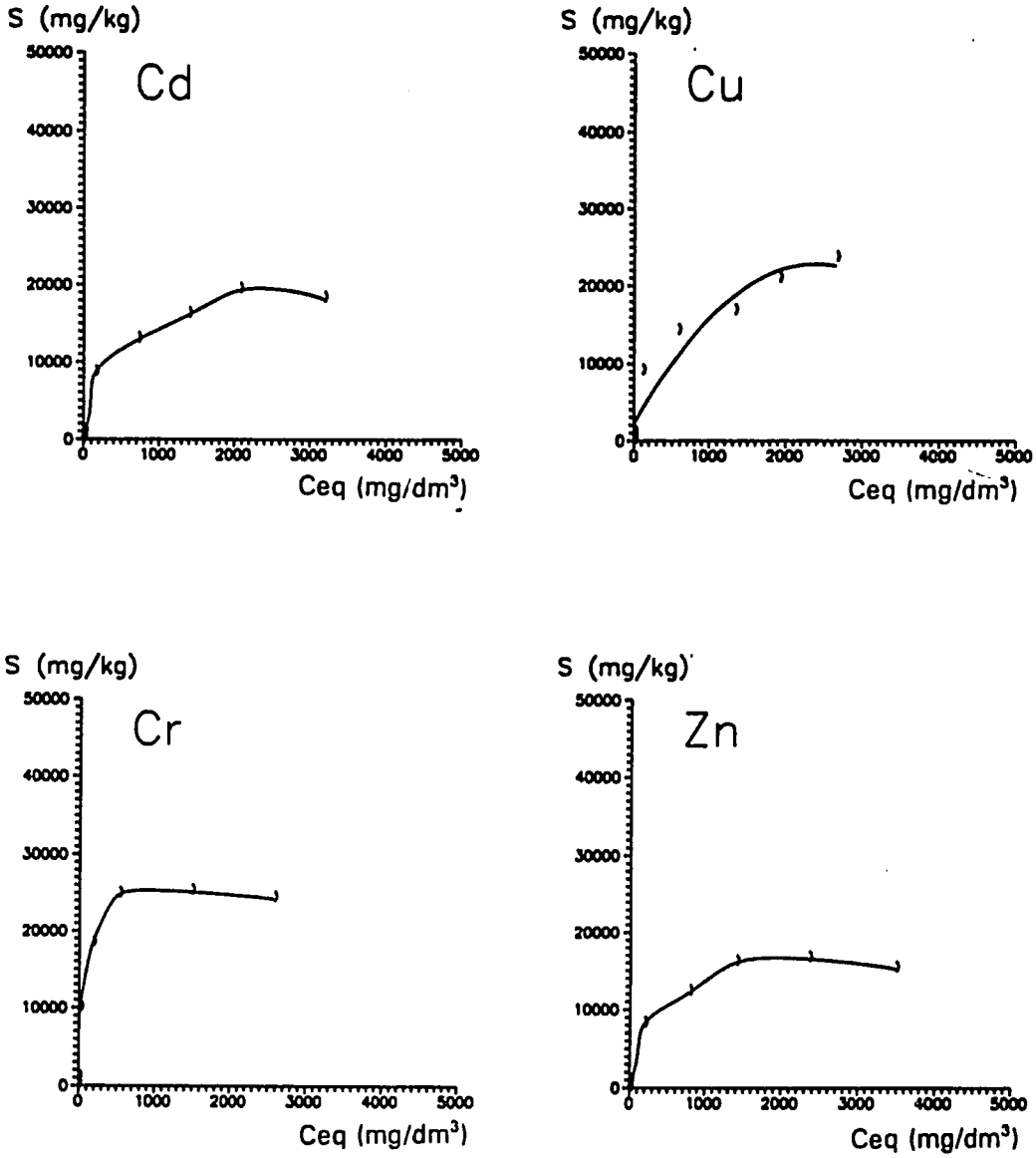

FIg.29
Sorption of heavy metals on Highmoor (Sphagnum Moss) Peat, DR=15%, Biebrza Site

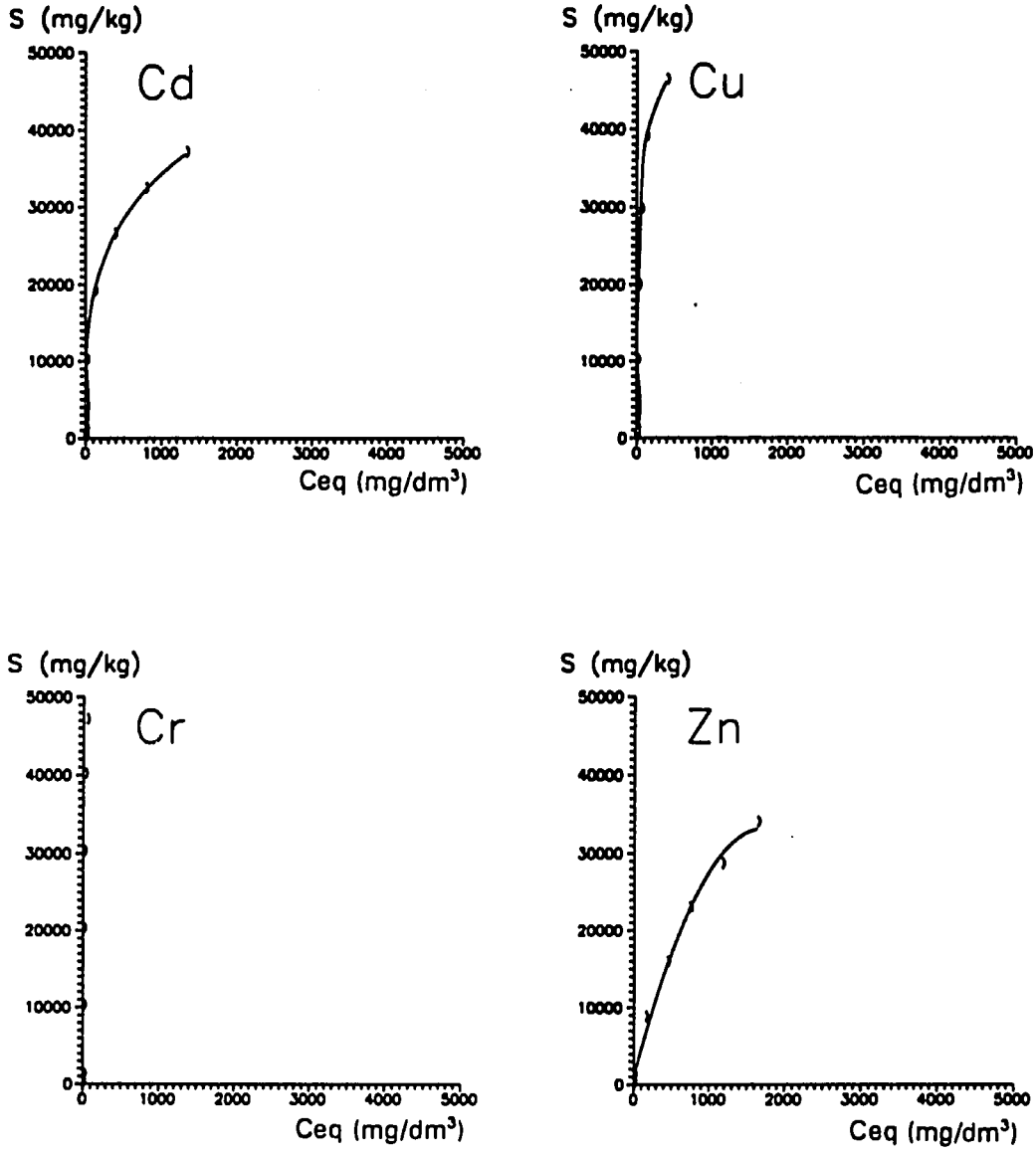

Fig.30
Sorption of heavy metals on Peat Humus (Alder Peat), DR=60%, AC=14.10, Zbojna Site

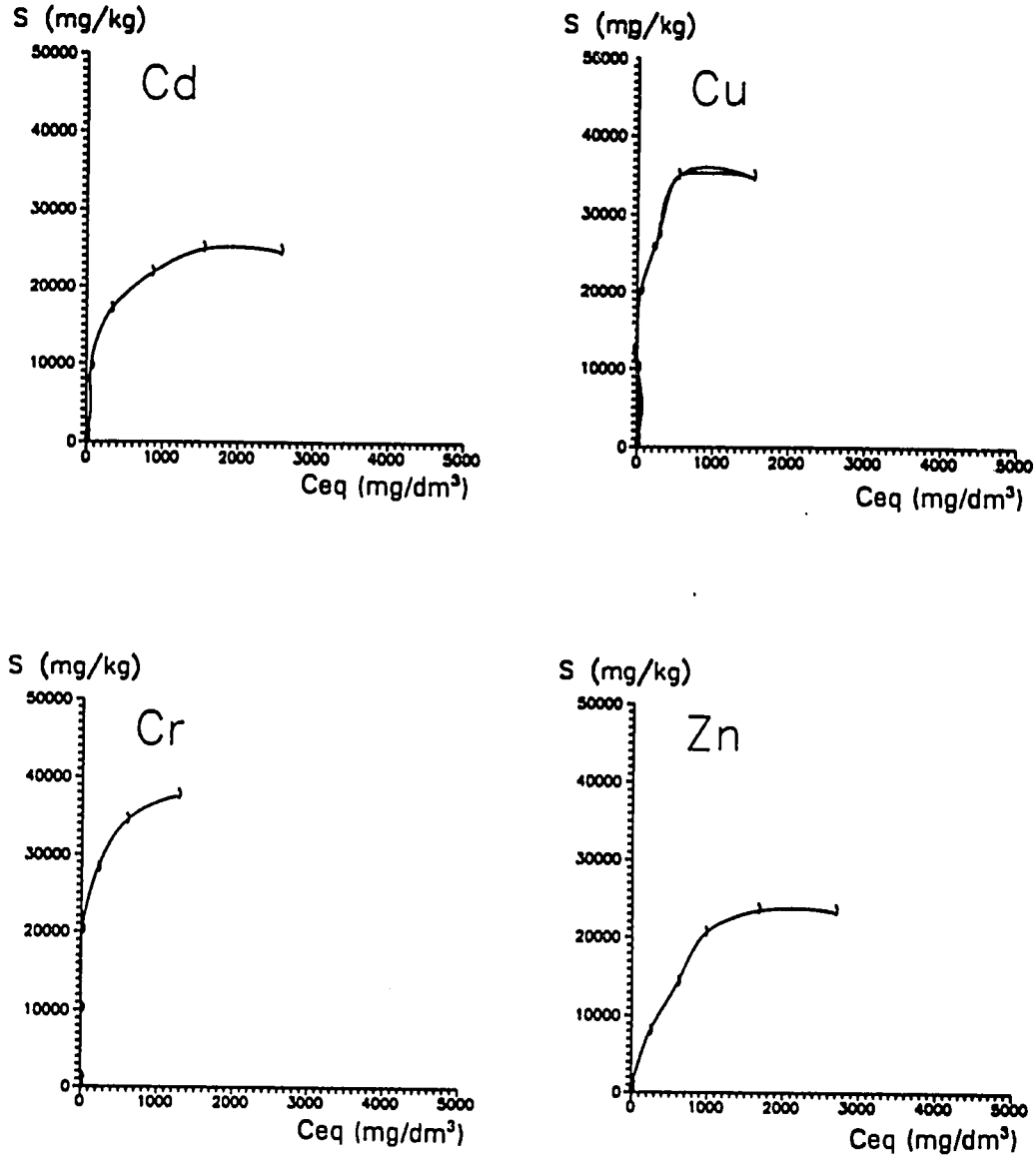

Fig.31
Sorption of heavy metals on Hypnum Moss (Sedge-Moss) Peat, DR=40%, AC=7.55, Zbojna Site

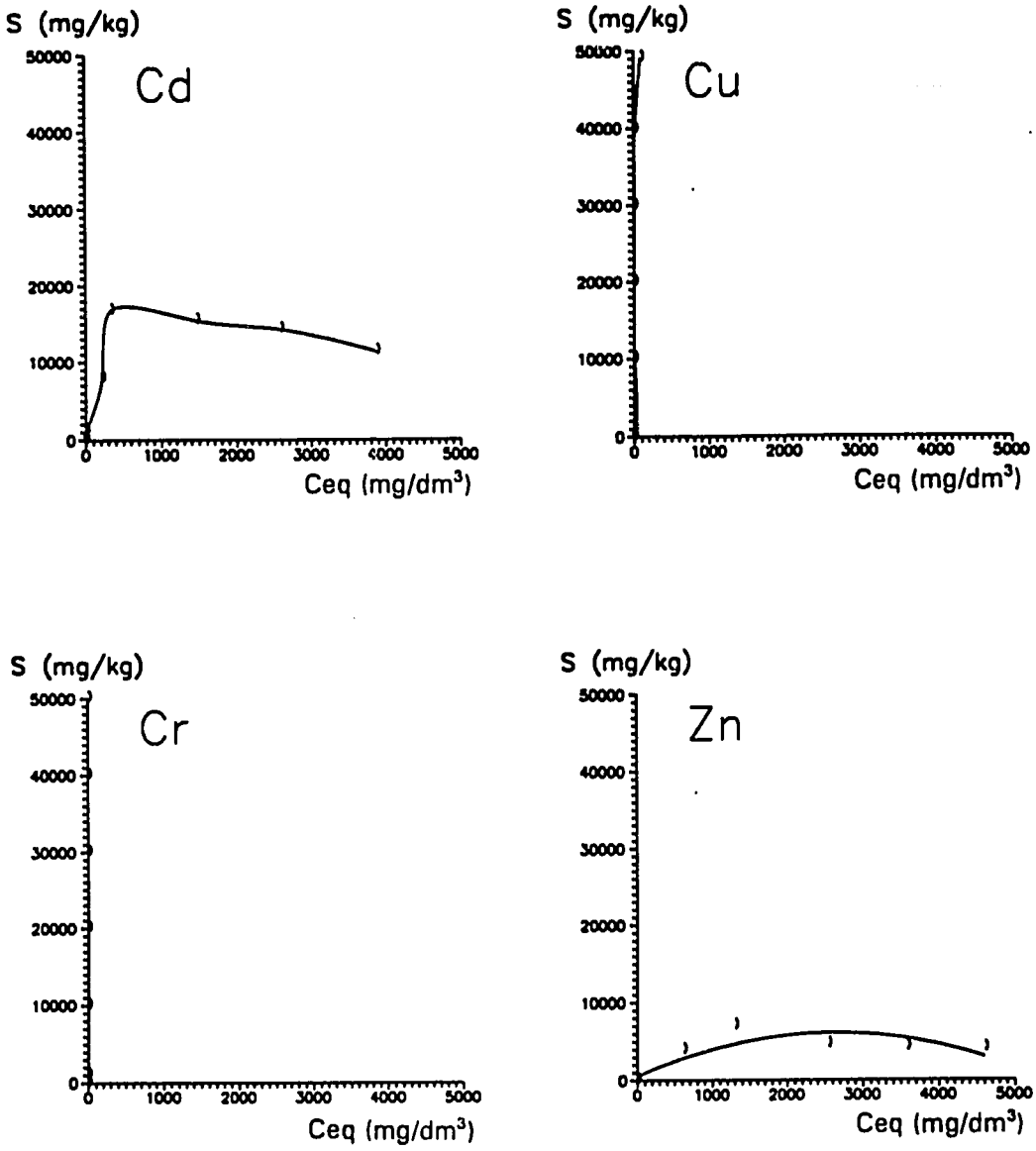

Fig.32
Sorption of heavy metals on Detrituous Gyttja,
Zbojna Site

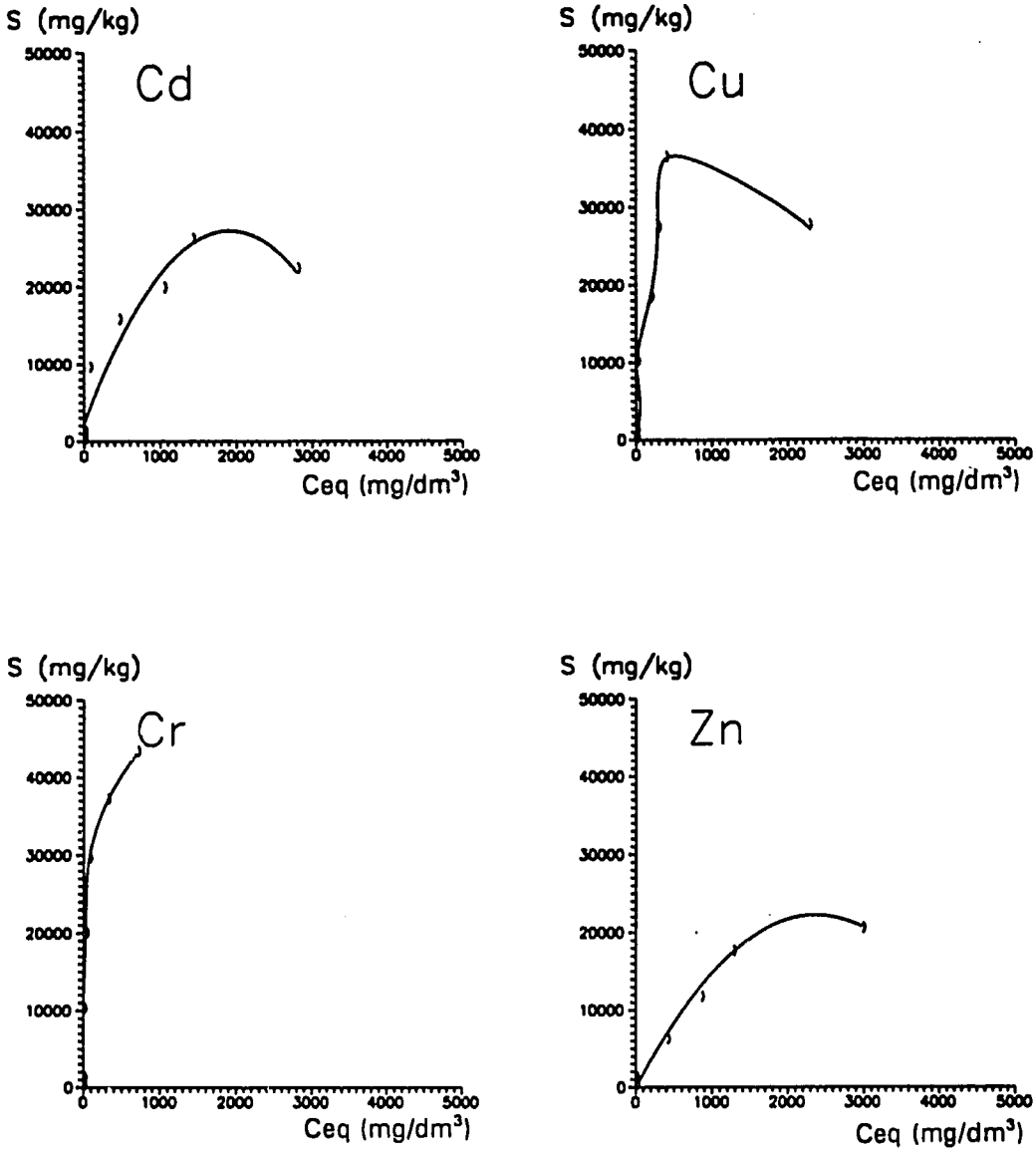

Fig.33
Sorption of heavy metals on Hypnum Moss (Sedge-Moss) Peat, DR=65%, AC=7.90, Zbojna Site

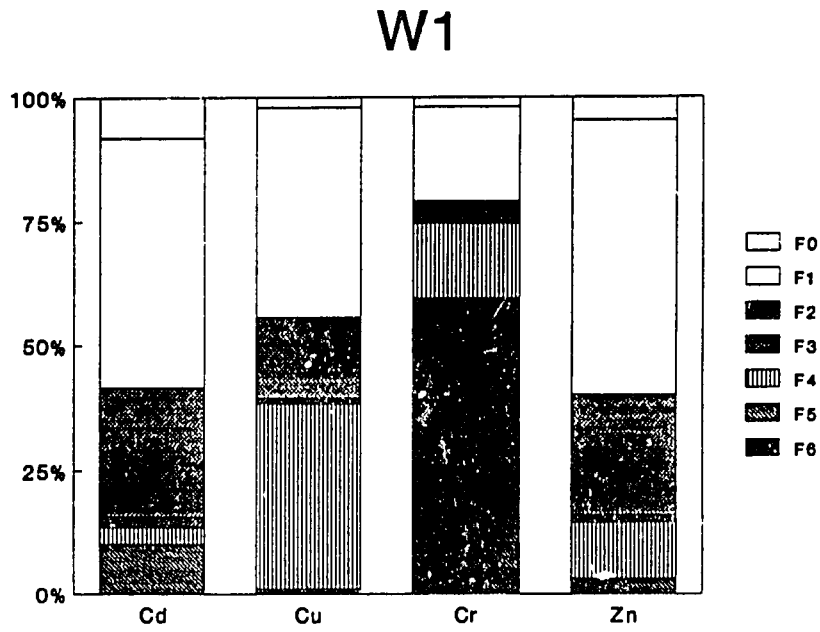

Fig.34 Chemical fractionation of cadmium, copper, chromium (III) and zinc in Peat Humus (Alder Peat) sample (W1)

Fractions:
F0 - pore solution
F1 - exchangeable
F2 - carbonatic
F3 - easily reducible (Mn-oxides)
F4 - moderately reducible (amorphous Fe-oxides)
F5 - sulphidic/organic (sulphides toogether with organic matter
F6 - residual (lithogenic crystallites)