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This is a reconnaissance study to establish whether economically viable young uranium deposits in peat could be found in Finland. From previous knowledge of their radioactivity or uranium contents, mires and springs in six areas in eastern and northern parts of the country were chosen for testing methods and equipment for exploration.

The mires were sampled with a Hiller or Russian-type sampler; at Matari, eastern Finland, bulk density samples were taken with a piston sampler.The samples were dried and ashed, and their uranium contents were determined from ash using both delayed neutron activation analysis and low energy gamma spectrometry. The contents of Co, Cu, Mn, Pb, Mo and Fe were also determined from the ashed samples with atomic absorption spectrometry.

Uranium contents of up to 1% were found in the peat ash from mires, but as high as 5% in that from springs. The most important factors in the deposition of uranium seemed to be the composition of the peat layers, the permeability of the peat deposits, and the location of feeders pouring minerogenic waters into the peat system. The samples showed radioactive disequilibrium to varying degrees. About 50% of the samples contained predominantly young uranium, but 10% contained only daughters. Copper and cobalt were enriched with uranium at some of the sites.

The results suggest the implementation of stepwise exploration for young uranium, the first step being the selection of target areas on the basis of background data. The second step would be follow-up sampling and, in the case of a discovery, the next steps would be detailed geological and technical assessment of the uraniferous peat resources.

An exploration target should be a suitable bedrock area with anomalous but not necessarily high uranium contents in groundwater and one or more drainage basins containing organic deposits capable of binding uranium.

Key words (GeoRef Thesaurus, AGI): uranium ores, bogs, springs, peat, ash content, heavy metals, uranium, mineral exploration, Holocene, Finland

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INTRODUCTION

A subgroup of surficial uranium deposits, young uranium deposits, is defined (Culbert et al. 1984; Culbert and Leighton 1988) as post-glacial, being formed at or near the surface in unconsolidated, organic-rich materials by the interaction of uraniferous ground or surface waters and sediments. The uranium is loosely held and easily remobilized. Because of its recent deposition, the uranium has not built up gamma-emitting daughter products, and the deposits are usually not detectable with radiometric methods.

Uraniferous waters in wells and springs found in southern and eastern Finland in the early years of this century (e.g. Aartovaara 1915) were the first signs of anomalous uranium concentrations in Finnish terrain. Since the late 1950s, exploration for uranium has revealed numerous radioactive and/or uraniferous springs and mires, the majority in eastern and northern parts of the country.

The bedrock of Finland consists of Archaean and Lower to Middle Proterozoic crystalline rocks, extensively covered with surficial deposits of Pleistocene glacial drift and Holocene sediments. Large volumes of the bedrock are composed of granitic rocks, often with uranium contents in excess of 4 ppm. Peatlands cover one third of the 337,000 km^2 total area of the country (Okko 1967; Shotyk 1988).

Commercial use of peat for fuel and other purposes is an important and growing industrial activity in Finland. The uranium contained in the fuel peat has been considered both as a potential source of additional energy (Yliruokanen 1980) and as a pollutant (Lehtovaara et al. 1989). Prospects for the recovery of uranium from fuel peat ash do not look good. Further, the enrichments of uranium in peat in Sweden and in Finland are of limited tonnages and, hence, are raked as non-economic deposits (Wilson 1984).

Research in Canada (Culbert and Leighton 1981, 1988), the findings of the IAEA Working Group (Otton 1984b), and the discovery of uranium at Flodelle Creek in Washington, U.S.A. (Johnson et al. 1987;Zielinski et al. 1987; Zielinski and Meier 1988; Otton et al. 1989) show that young uranium deposits could become economically viable although not in the present market situation. Even the "larger" deposits of this type (50 to 500 tonnes of contained uranium; Otton 1984a) cannot be compared with conventional deposits, and a cluster of deposits would be needed to support milling operations.

In 1983-84, studies of uranium in peat were included in an exploration project on the unconformity-related (Lower Proterozoic/Archaean) Riutta prospect in eastern Finland. Subsequently, the Geological Survey of Finland (GSF) implemented an orientation study to establish whether viable young uranium deposits in peat could be found in Finland.

MATERIALS AND METHODS

Test areas

Nine mires in northern and central Finland were chosen as targets for the orientation study (Yli-Kyyny 1987). All the targets had been found during previous uranium exploration. Included in the study was an enrichment of uranium in peat at Kontiolahti, near the Riutta uranium occurrence (Fig. 1).

(1) Keitele.

At Lemmetty, Keitele, non-economic uraninite mineralisations occur in pegmatite dykes cutting felsic and intermediate Proterozoic gneisses. The area is situated at the margin of the extensive granitoid area of Middle Finland; a set of northwest-trending faults and fractures cuts the bedrock. The mineralised pegmatites are related to the faults.

(2) Kontiolahti.

Matarinsuo, a mire at Kontiolahti, eastern Finland, belongs to the Koli-Kaltimo uranium province, where Lower Proterozoic sandstone type and unconformity-related deposits are known in quartzites and in the palaeoregolith at the Proterozoic/Archaean interface (Äikäs & Sarikkola 1987). An occurrence of the latter type, Riutta, is located near Matarinsuo (Fig. 2).

Archaean granitoid gneisses are exposed as hills in the area, but Proterozoic quartzites occur in the

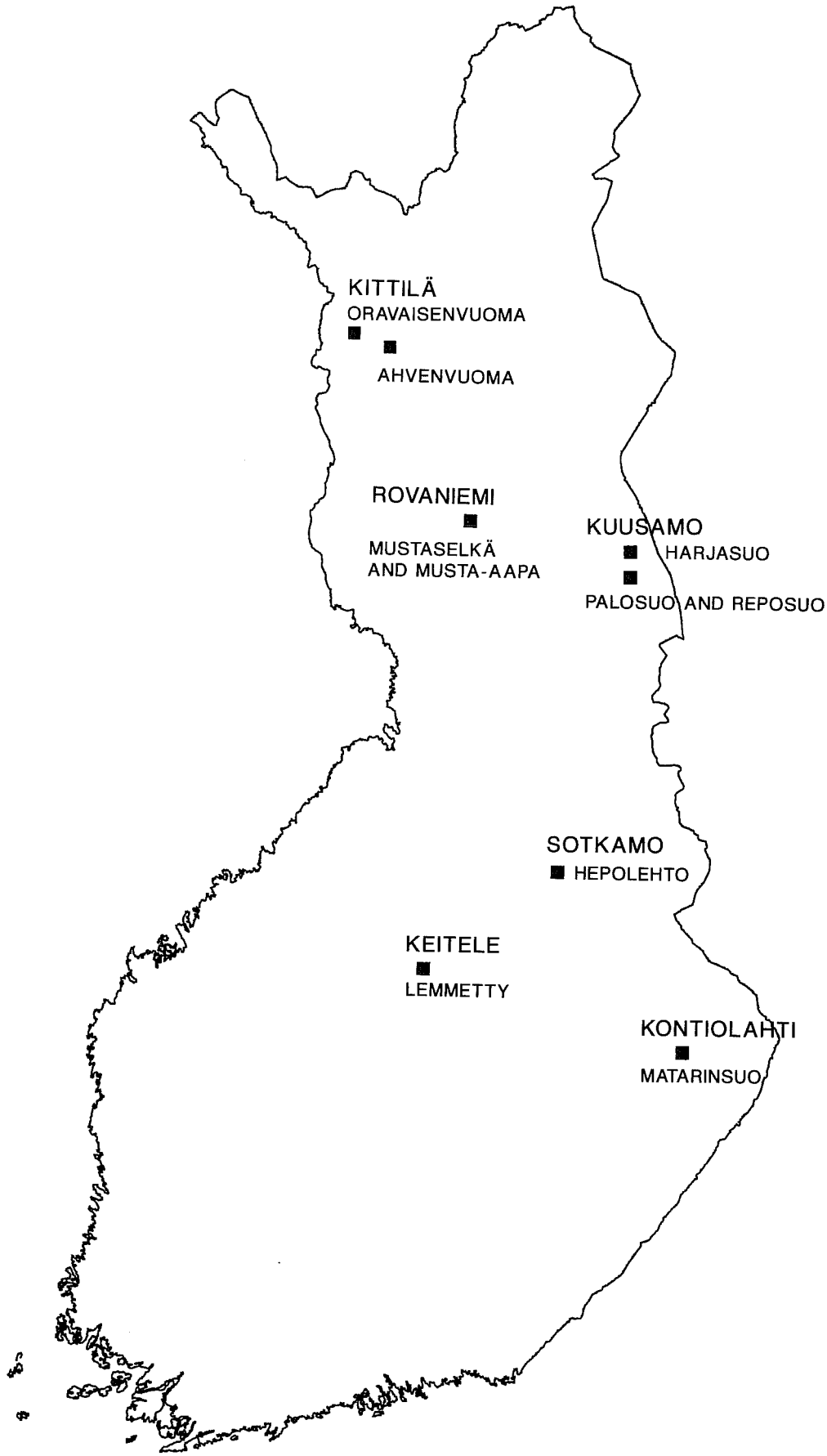


Fig. 1. Location of test sites.

Kuusoja valley, where the mire is located. An uplifted body of Archaean gneisses with a maximum diameter of 14 km partly feeds the Matarinsuo basin through a creek and springs. The drainage area extends onto the Proterozoic metasediments along the unconformity, a zone regionally considered as a host for uranium. The mire has developed on a glaciogenic outwash plain of sand, gravel and till more than 20 m thick. A ridge of end moraine deposited on the plain defines the Matarinsuo basin in the east (Fig. 3).

A radioactive spring is located some 350 m west-southwest of Matari farm. In 1981, concentrations of 2 to 480 ppm U (in ash) were found in organic stream sediment samples from the brook that runs through Matarinsuo into the river Kuusoja. A sample from Matari spring showed 2060 ppm U. The concentrations are higher than elsewhere in the Kuusoja valley, even near the pitchblende mineralisations of Riutta. Separate basins in the Archaean block west of Matari showed values as high as 950 ppm U.

(3) Sotkamo.

Hepolehto, a test site at Sotkamo, is a narrow mire at the foot of the western slope of a northward striking range of Proterozoic quartzites. The depression forming the basin is at the lithological margin between the quartzite and a mica schist. No granites are exposed in the area, and no significant uranium occurrences are known in the quartzite. Anomalous radioactivity occurs in the mire at an upwelling spring.

(4) Kuusamo.

The first test site is Reposuo, a mire where the checking of airborne radiometrics revealed radioactivity in peat around springs. The bedrock of the drainage area is composed of Proterozoic metasediments and mafic volcanics.

Another site, Palosuo, is a wet, spring-fed fen between a range of Proterozoic quartzites and a small lake. No radioactive spots were found in this mire.

Harjasuo, the third target, is a shallow mire on a gently sloping hill of similar lithology to the two other sites. The bedrock is not exposed, and the mire is surrounded by moraine hummocks. This target, too, was found by airborne radiometrics.

(5) Rovaniemi.

Radioactive springs and peat were found during the checking of airborne radiometrics at Mustaselkä, 35 km east of the town of Rovaniemi. The bedrock in the area is a sligthly radioactive granite. The samples were taken from radioactive peat at Mustaselkä and from non-radioactive peat 1 km to the east, where a creek from Mustaselkä flows into a vast fen called Mustaaapa.

(6) Kittilä.

The northernmost two targets are situated west of Kittilä, in an area where granitic lithology predominates over Proterozoic metasediments. The first site is the swampy slope of a hill near the mire Oravaisenvuoma. On this slope there is an area of 20 m by 100 m that contains a thin layer of radioactive peat discovered

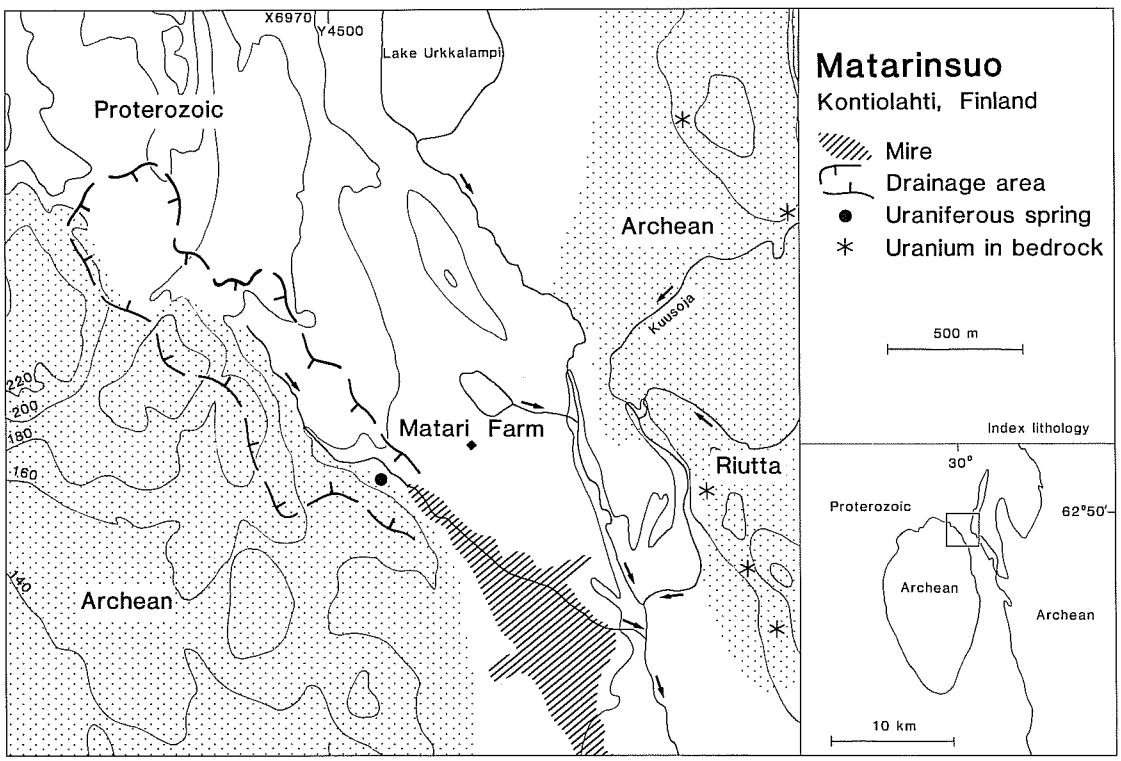


Fig. 2. Location of the mire Matarinsuo, Matari spring and their drainage area near the former Matari farm, Kontiolahti, eastern Finland. The topographic contours are in metres above sea level.

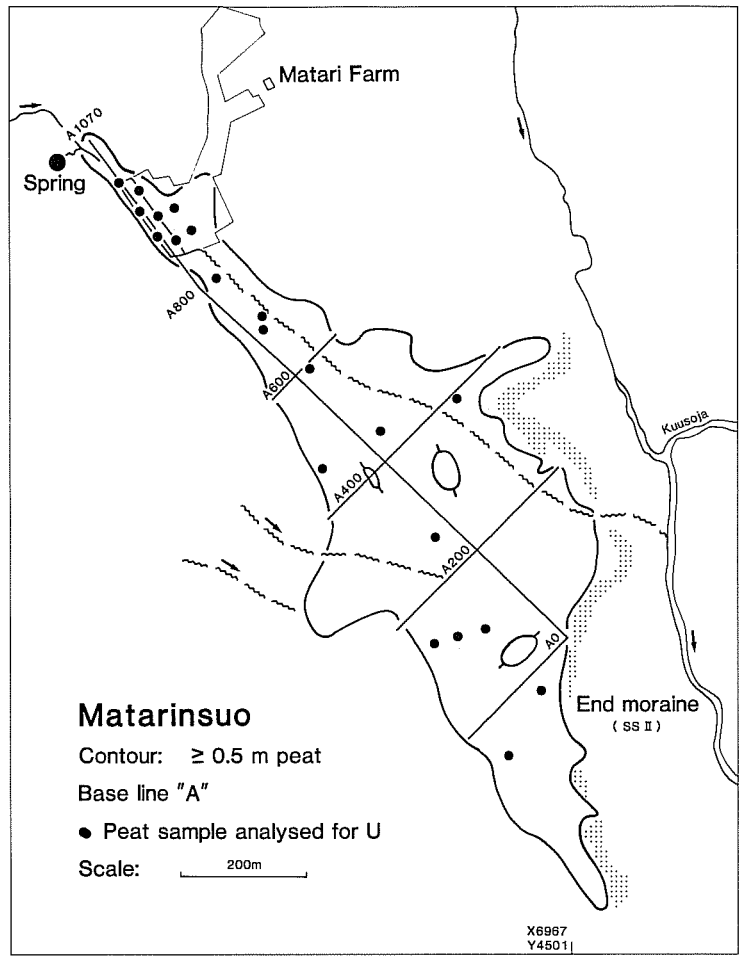


Fig. 3. Matari spring and the basin of the mire Matarinsuo, blocked by a ridge of Salpausselkä II end moraine. The network of lines depicted was used for the assessment of the peat deposit.

through airborne radiometry. The radioactive peat occurs in the oxbows of brooks running down the slope.

The other target, Ahvenvuoma, was chosen because of the anomalous radioactivity of the granite in the drainage area and the geometry of the drainage basin. Ahvenvuoma is a non-radioactive fen.

Sampling and analysing of peat

The mires were sampled with a Hiller sampler and a Russian-type sampler. At Matari, bulk density samples were taken with a piston sampler, and Matarinsuo was studied using methods developed by the GSF for peatland evaluation (Lappalainen 1979).

At all test sites gamma radiation was measured with the scintillometers (Scintrex BGS-3; energy threshold 50 keV) and portable spectrometers (EDA GRS-500; total count windows above 80 and 400 keV) used by the GSF for conventional uranium exploration. The samples were oven-dried at 110°C and combusted at 500°C. The ash was analysed for Co, Cu, Mn, Pb, Mo and Fe at the GFS using atomic absorption spectrometry (AAS; samples were decomposed by HCl). Uranium was determined from the ash at the Technical Research Centre of Finland using delayed neutron activation analysis (DNAA).

Low energy gamma spectrometry (LEGS)

The multichannel analysing system of the GSF features a lead-shielded NaI(Tl) detector, two amplifiers and a pulse-height analyser. The detector is a centre-well type, 4 inch (10 cm) crystal, with a 6 cm thick lead shield. Signals from the crystal's photomultiplier tube are fed through a preamplifier and

a second amplifier to the pulseheight analyser with 2048 channels. The system is controlled by microcomputer.

To calibrate the system, two sets of standards were used: (1) uranium and thorium standards purchased from the IAEA, and (2) standards of pure uranium oxide mixed with quartz sand at the GSF. The IAEA standards are in good equilibrium and the uranium oxide has practically no daughters.

The analyses were made using the method of Culbert and Leighton (1981). In general, the results of the two methods, DNAA and LEGS, correlate well (Fig. 4).

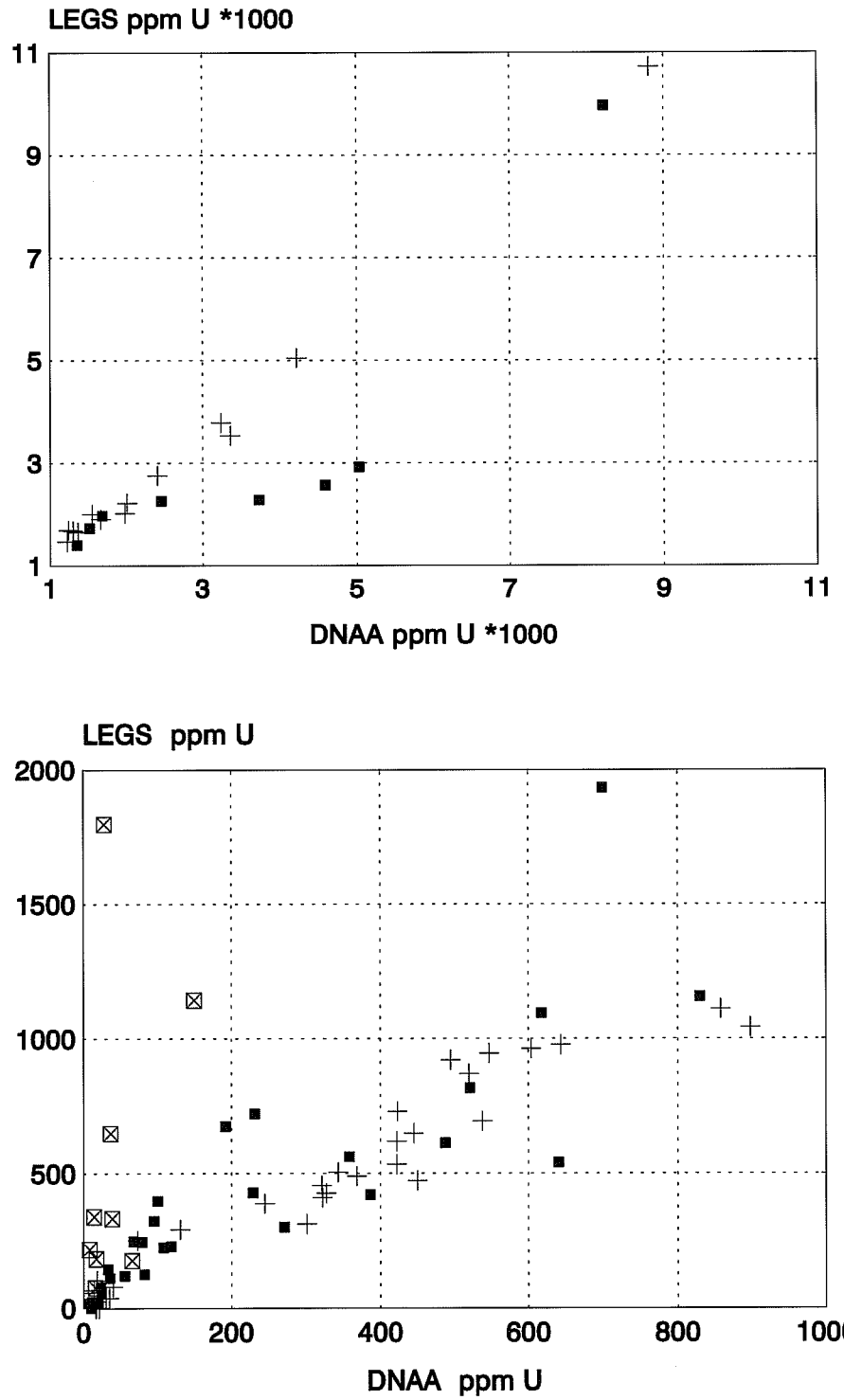


Fig. 4. Comparison between DNAA and LEGS analyses. ⊠ = samples mainly with daughters; + = samples mainly with young uranium; ■ = samples with both daughters and young uranium; (a) U_{DNAA} > 1000 ppm; (b) U_{DNAA} < 1000 ppm.

The greatest differences are in samples that contain mainly daughters. LEGS gives systematically slightly higher results, probably owing to a small inaccuracy in the uranium oxide standards. Another reason for the differences is the size of the sample: less than one gram of ash was used for the DNAA but from 5 to 25 grams for the LEGS.

RESULTS

The Matari Case

Stratigraphy

The peat deposit of Matarinsuo occurs in three separate basins. The southern part of the mire is shallow with only a narrow deeper basin in the southwest fed by two brooks flowing from the west (Fig. 3). With the exception of the uppermost layer, about 0.5 thick, of Sphagnum peat, the deposit consists mainly of Carex peat.

From A400 to A800, there is a 3–4 m deep basin southwest of the bed of the present brook. In this middle basin, Carex peat has deposited on a layer of ooze.

In the northwestern part of the mire there is a 2–7 m deep basin separated from the middle basin by a bank of sand and till. At the bottom of the northwest basin there is a layer of ooze overlain by mucky peat. The mucky peat consists of peat, ooze, wood remains and mineral soil. The topmost layer is Carex peat with abundant wood remains. Significant differences occur in the ash contents of the two units of peat (Table 1).

Separate from the mire in an area of 600 m^2 around the pool of Matari spring, there is woody Bryales-Carex peat with an average depth of one metre.

The evolution of the mire Matarinsuo started after the ponds in the three depressions of the area were filled in. The mire has been fed by minerogenic waters, with periods of greater inflow of surface waters than in the present channel. The northwest basin of the mire has been subjected to successive flooding events resulting in co-deposition of the mineral soil and organic matter now forming the unit of mucky peat.

Table 1. Uranium concentrations in peat ash and on a dry-weight basis in a sample column, A900, in Matarinsuo (see Fig. 6).

depth dm	sample	H	pH	ash %	U ppm in ash	U ppm dry-weight
5 –20		6	4.5	16.3	870	141
–40	Carex	4	4.5	7.0	1370	96
–60	peat	4	4.7	5.0	1950	97
- 80		4	4.9	7.5	1560	117
-100		4	5.1	7.4	1630	121
-120		7	5.0	52.0	360	187
-140	Mucky	8	5.0	73.6	240	177
-160	peat	8	5.1	62.8	560	351
155-175		7	5.1	59.8	250	150
180-190		6	5.0	47.1	410	193

H - humification on a scale 1–10 (cf. Lappalainen 1979), ash - percentage of ash in the dried sample

Distribution of uranium

The reconnaissance samples of peat collected in 1983 contained up to 0.2% uranium (in ash) in Matarinsuo, and 0.9 to 5.9% in samples from near Matari spring. The spring water contained <12 ppm U and 1230 Bq/l Rn. Spectrophotometric tests (O. Lehto, GSF, pers. comm.) of water samples collected in 1986 from the spring and the creek (both upstream and downstream of the spring outlet) showed 0.32 to 0.34 ppm U. This indicates that uranium is also carried by the creek from the upper parts of the drainage area. The initial water squeezed from the peat near Matari spring contained 0.96 ppm U.

High counts of total gamma radiation were recorded near the spring but the counts decreased rapidly away from the spring and down the outlet. Excluding the effect of mineral soil at the threshold of A800, the gamma radiation shows a weak anomaly in peat above the northwest basin and part of the middle basin (Fig. 5). As expected (cf. Culbert and Leighton 1981), conventional gamma radiometry could not be used for this kind of uranium exploration. The anomalies found are weak, and may also be caused by mobilised daughters.

Uranium concentrations in samples from the southern basin of Matarinsuo are low, 2–270 ppm in ash. In a peat column of 1.5 m near the spring, values of 140 to 22600 ppm U were recorded in ash (Fig. 6); on a dry-weight basis, the column averages 1000 ppm U.

In the northwest and middle basins, uranium concentrations of 1000 to 2000 ppm in ash occur in the surface layers at a depth of 0.5–1.5 m. This layer extends from the northwest basin to the middle basin as a narrow body following an old trough of the waterways. Concentrations of up to 2800 ppm U in ash were also found in the deeper parts of the sections. However, as calculated to the dry basis, the contents re main in the range <100–1000 ppm U. The uranium in the dry peat shows an inverse vertical distribution to that of the uranium in ash (Table 1).

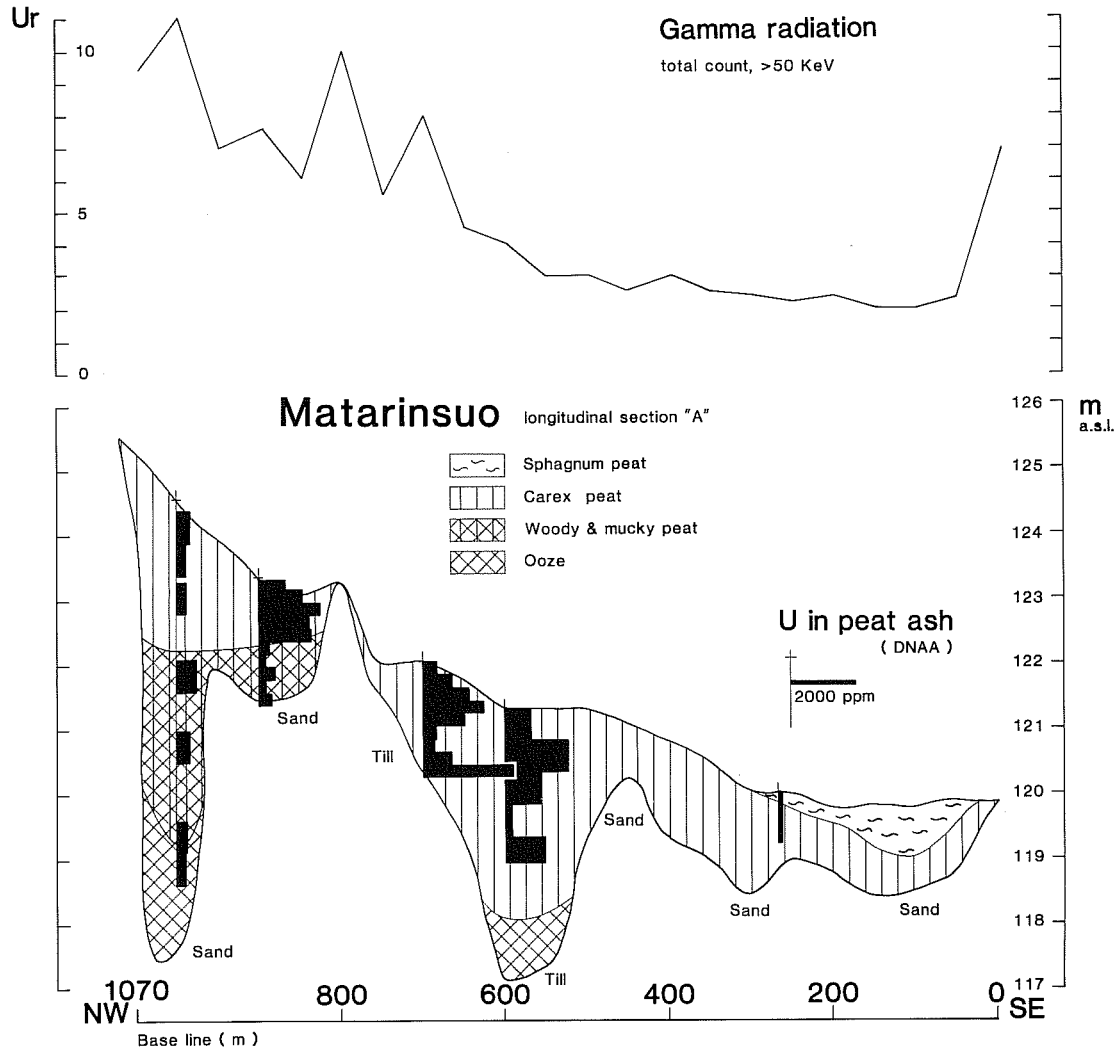


Fig. 5. Section of Matarinsuo, showing the main stratigraphic units of the mire, the distribution of uranium (ppm in peat ash) in some of the samples, and the total gamma radiation (Ur) measured on the surface of the mire.

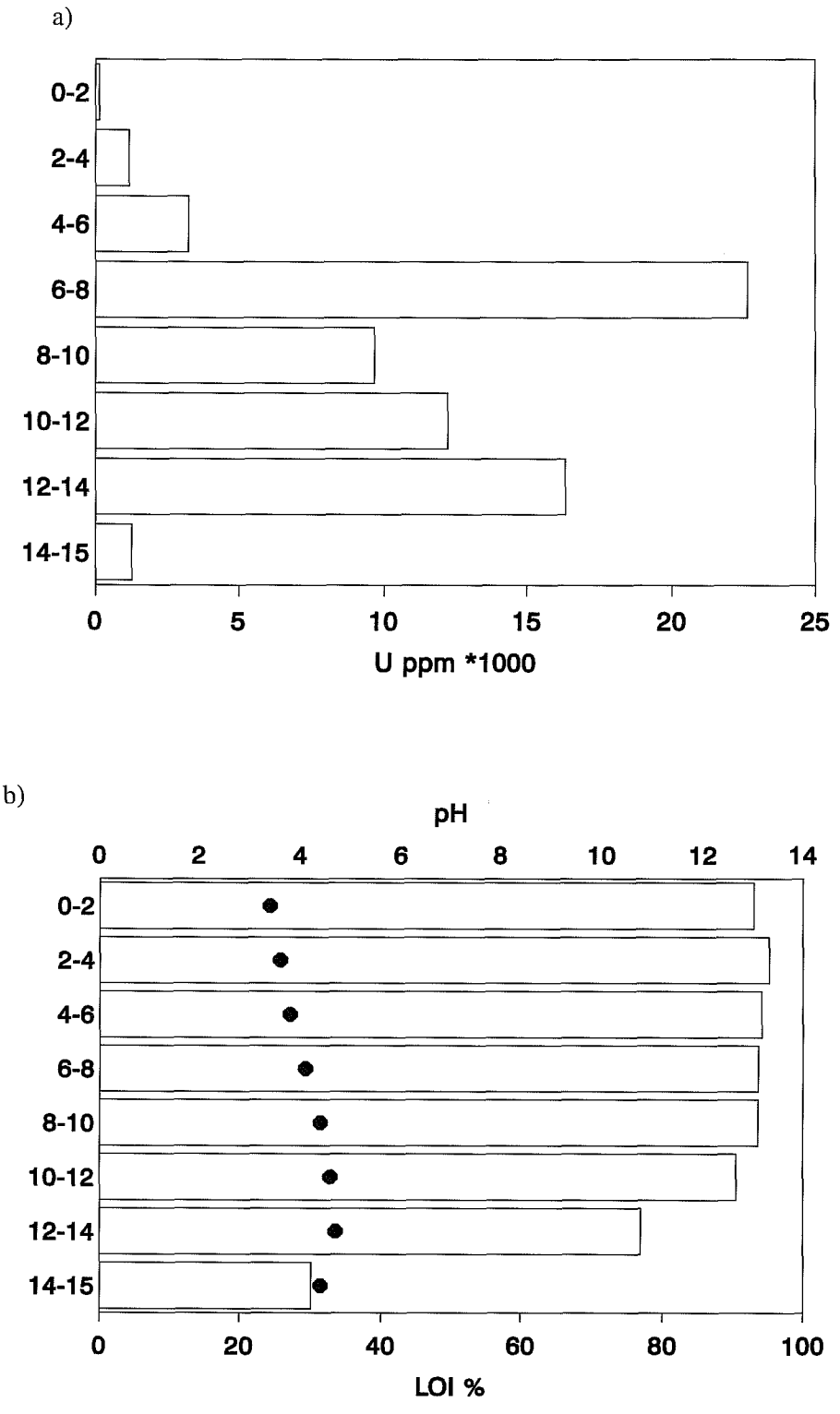
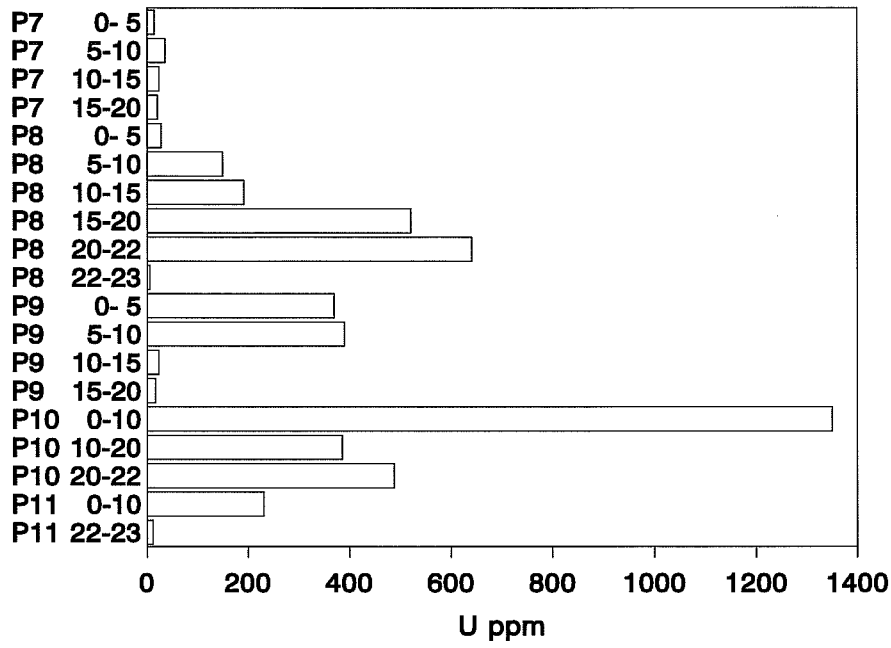


Fig. 6. Uranium content of a peat profile near Matari spring: (a) ppm U in peat ash; (b) loss on ignition (LOI) % (bars) and pH (points). Y-axis: sample depth in dm.

Uranium resources

Because of insufficient number of peat samples analysed the uranium resources in Matari could only be roughly assessed. The northwest and middle basins of Matarinsuo and Matari spring total 363,800 m^3 in-situ peat, with 8.3 tonnes U. The southern basin was estimated to contain less than 0.15 tonnes U in 223,600 m^3 of peat.

a)



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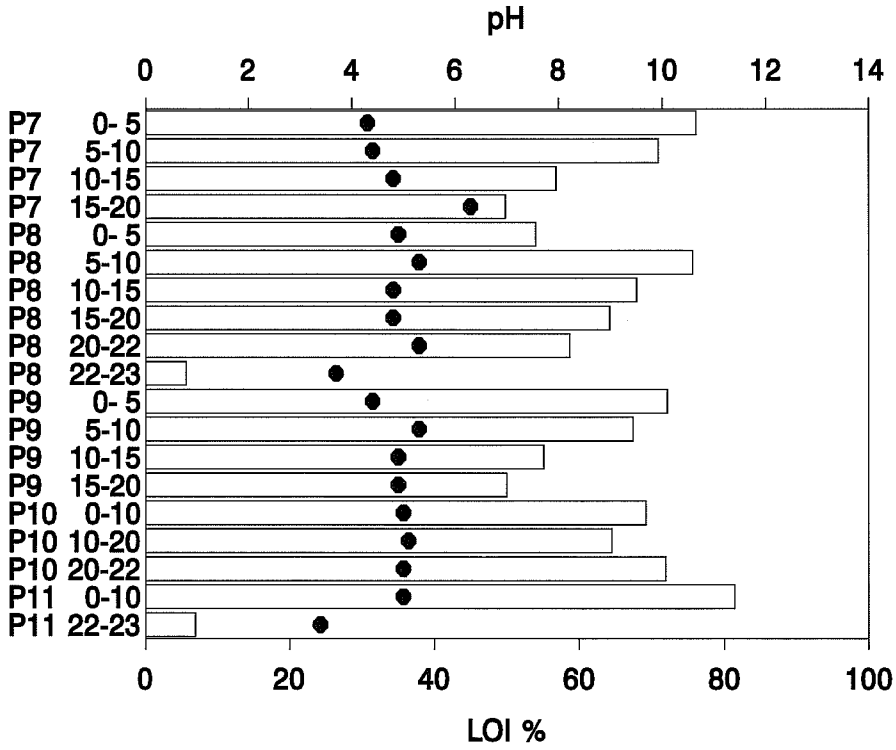

Fig. 7. Uranium content of peat samples from the mire Hepolehto, Sotkamo: (a) ppm U in peat ash; (b) LOI % (bars) and pH (points). Y-axis: sample site number and sample depth in dm.

Results from the other test sites

Keitele. Despite the uranium mineralisations in bedrock at Lemmetty, the peat samples contain only from 20 to 200 ppm uranium in ash, which means less than 10 ppm by dry weight.

Sotkamo. The mire Hepolehto can be divided into two parts, radioactive and non-radioactive. The peat from the radioactive areas, sample sites P8 and P10, contains up to 1300 ppm U in ash, and that from non-active areas under 50 ppm in ash (Fig. 7). On a dry-weight basis, the maximum uranium content is about 400 ppm.

Kuusamo. The samples of the mire Palosuo are practically devoid of uranium, which amounts to less than 10 ppm by dry weight.

In its radioactive parts, the mire Reposuo contains 100 to 600 ppm U by dry weight, whereas the samples the from non-active parts contain only 10 to 20 ppm U.

Harjasuo, the third test site at Kuusamo, contains radioactive peat. The uranium contents of the peat samples vary from 200 ppm to 1 % in ash (Fig. 8), which means from 20 ppm to 2000 ppm U by dry weight.

Rovaniemi. One sample from the radioactive peat area at Mustaselkä contains 3700 ppm U in ash, that is, about 600 ppm U by dry weight. The uranium content of all the other samples from Mustaselkä and Musta-aapa is less than 20 ppm by dry weight.

Kittilä. The samples from the mire Oravaisen-vuoma all derive from radioactive peat areas. The uranium contents in ash vary from 100 ppm to 0.5% (Fig. 9), equalling from 20 to 500 ppm U by dry weight.

Although the granite around the other test area, the mire Ahvenvuoma, was known to be anomalously radioactive, no uranium was found in the peat samples: the maximum content of uranium is only 2 ppm by dry weight.

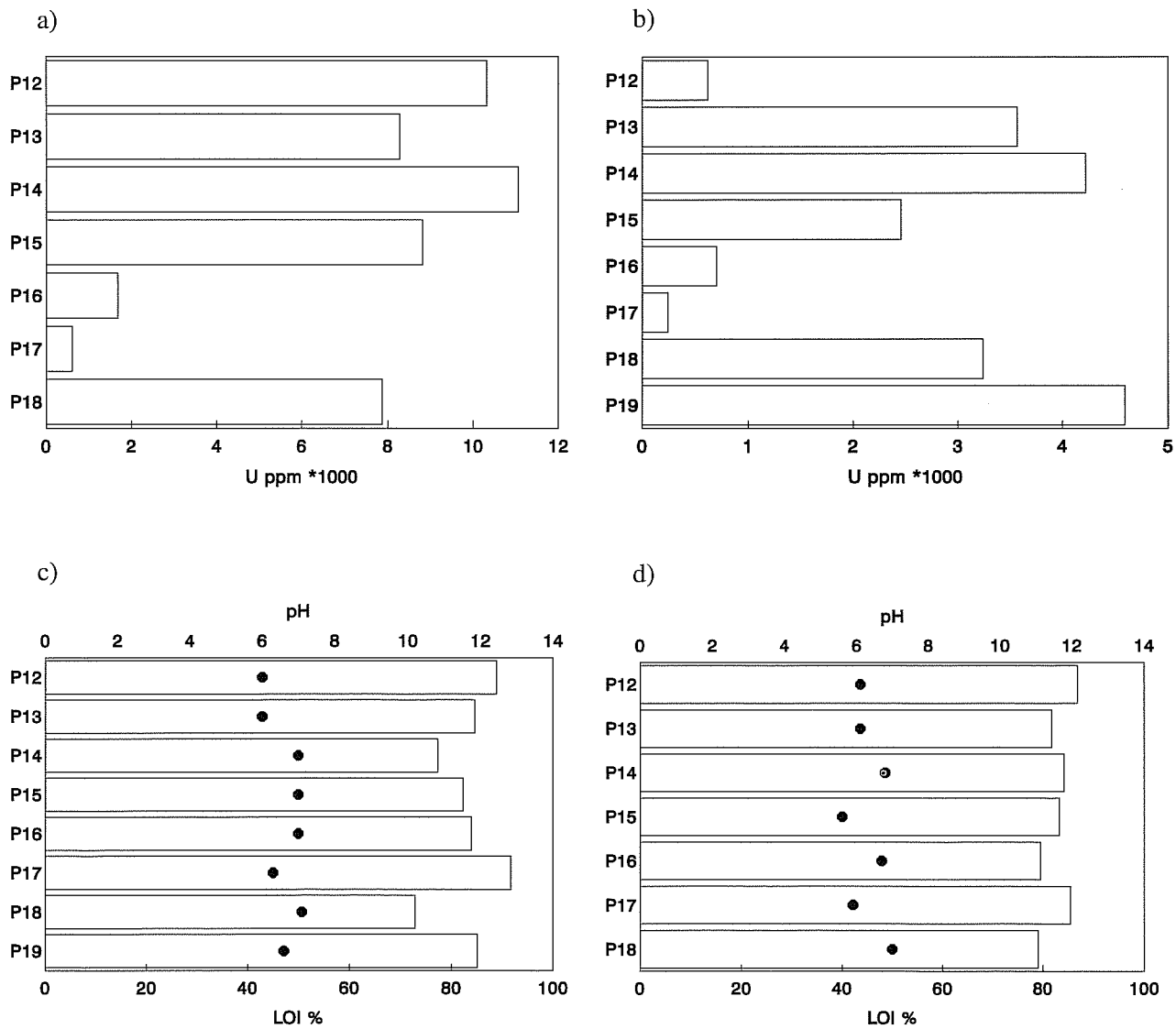

Fig. 8. Uranium content of peat samples from the mire Harjasuo, Kuusamo: (a) surface samples (0-5 dm) ppm U in peat ash; (b) basal samples (5–10 dm) ppm U in peat ash; (c) surface samples LOI % (bars) and pH (points); (d) basal samples LOI % (bars) and pH (points). Y-axis: sample site number.

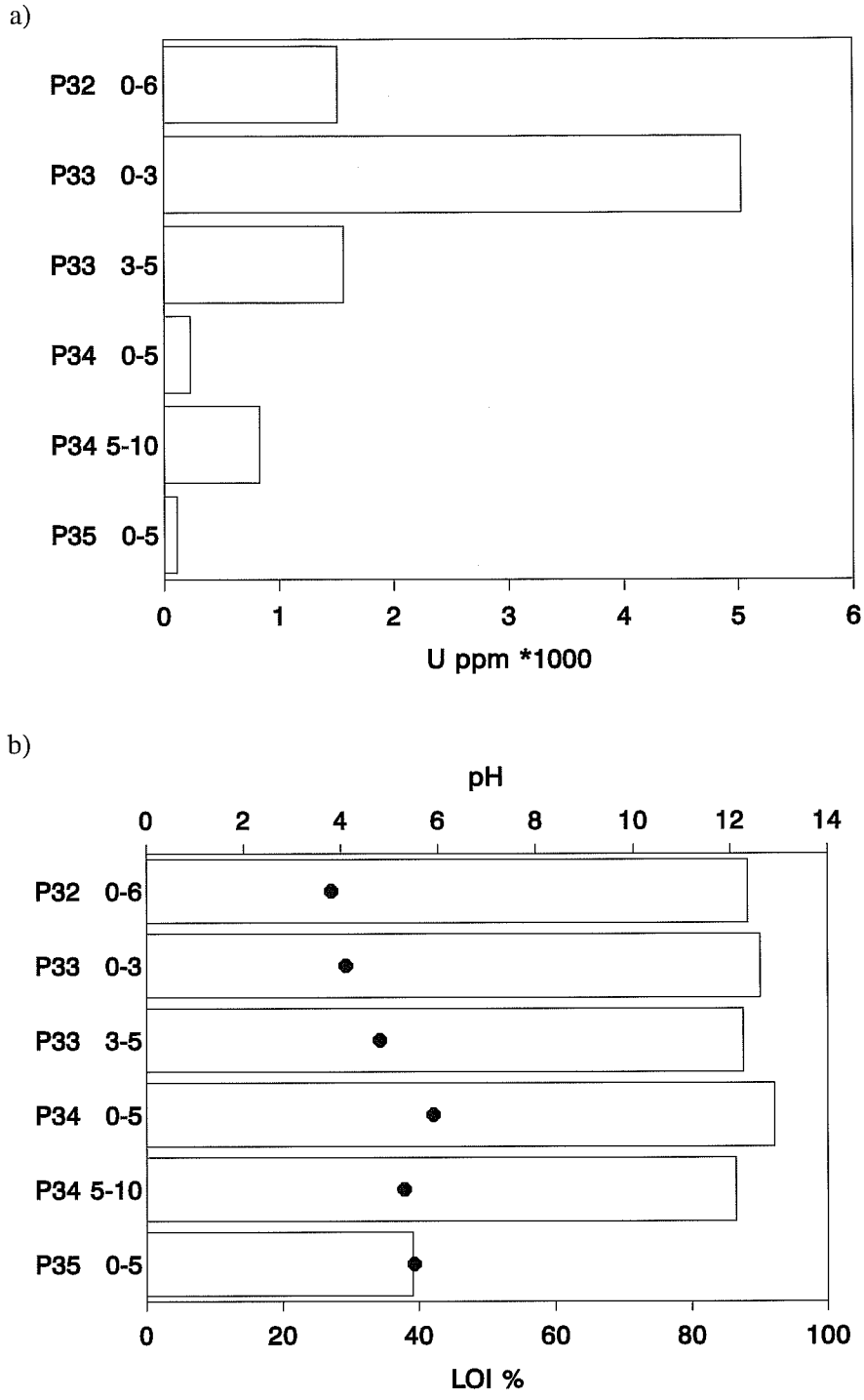

Fig. 9. Uranium content of peat samples from the mire Oravaisenvuoma, Kittilä: (a) ppm U in peat ash; (b) LOI % (bars) and pH (points). Y-axis: sample site number and sample depth in dm.

Young uranium: disequilibrium in samples

One hundred ashed peat samples were measured with the conventional gamma-ray method, and the equivalent uranium (eU) content was calculated using the gamma peaks of ^{214}Bi. The disequilibrium of the samp les was determined by comparing these data with those of the DNAA (U). The disequilibrium is also evident in the gamma-ray spectrum of a sample if no daughter products are present (Fig. 10).

About 50% of the samples contained predominantly young uranium, the ratio of eU/U being less than 0.25, but 10% of the samples contained only daughters with a ratio of eU/U exceeding 5. The extreme examples of the two types were: 36 ppm eU/ 2400 ppm U and 2500 ppm eU/28 ppm U. The results show that conventional gamma ray methods are unreliable for determining young uranium.

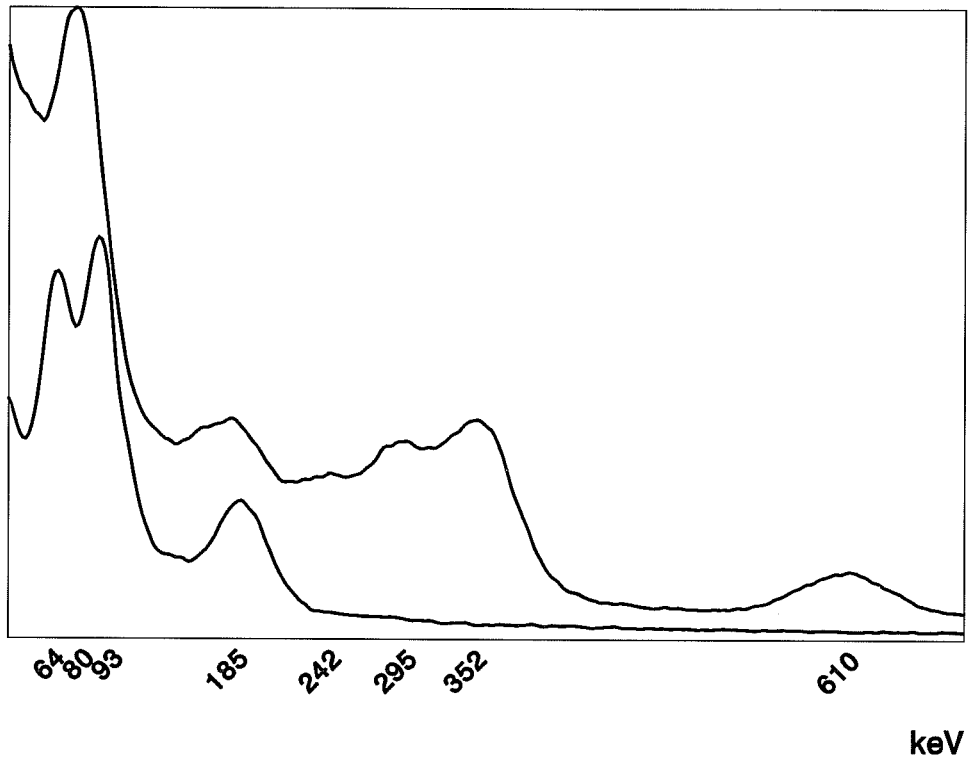

Fig. 10. Sample spectrum in disequilibrium (lower) and in equilibrium (upper). X-axis: γ-ray energy, Y-axis: relative counting rate.

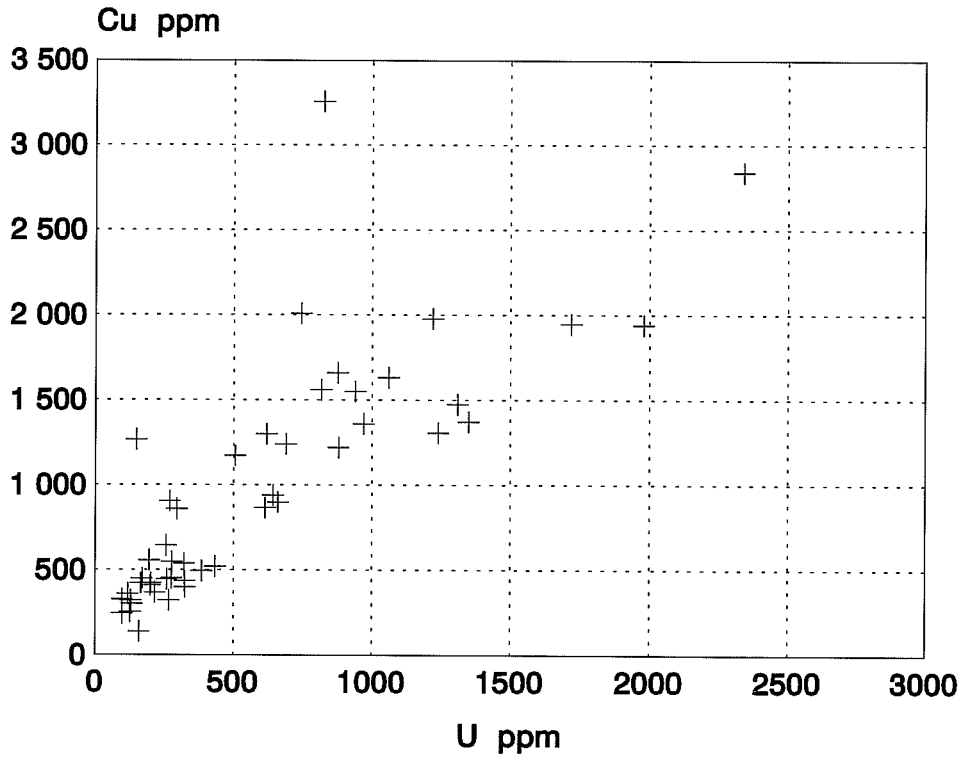

Fig. 11. Correlation between uranium and copper in peat ash in Matarinsuo (43 samples).

Table 2. Metal contents (dry-weight basis), LOI and pH of the mires.

Mire	U ppm			LOI %			pH		
	mean	min	max	mean	min	max	mean	min	max
1.	3.1	0.8	11	95.5	89.4	97.1	4.5	3.6	4.9
2.	400	9.7	3800	79.5	26.4	96.5	4.7	3.4	5.1
3.	73	3.4	420	58.8	5.6	81.4	4.8	3.4	6.3
4.	870	21	1800	83.1	72.8	91.7	6.5	5.6	7.1
5.	8.4	5.5	15	56.5	41.8	66.7	6.1	5.8	6.5
6.	170	8.1	550	51.9	20.2	86.9	6.2	4.5	6.9
7.	10	4.3	18	93.9	89.6	96.1	5.0	4.6	5.3
8.	120	1.3	620	78.0	22.3	96.0	5.1	4.6	5.9
9.	0.8	0.1	1.9	96.1	94.0	97.1	5.0	4.7	5.3
10.	180	18	500	80.6	39.1	92.2	4.9	3.8	5.9
	Co ppm			Cu ppm			Pb ppm		
	mean	min	max	mean	min	max	mean	min	max
1.	1.5	0.9	2.4	8.2	4.7	18	4.4	1.8	9.8
2.	4.2	1.3	18	110	11	470	12	1.3	35
3.	190	28	590	36	9.2	61	15	7.4	22
4.	15	1.7	110	12	0.1	38	6.8	4.5	11
5.	4.7	2.9	6.2	32	18	55	4.6	2.9	9.9
6.	9.6	1.8	41	15	5.9	23	6.4	3.0	8.4
7.	4.3	2.5	8.5	14	4.6	30	6.0	1.8	22
8.	5.0	2.4	8.3	15	6.4	25	9.7	2.5	15
9.	2.3	0.9	3.8	5.3	2.3	15	1.9	1.3	2.7
10.	8.1	2.3	21	7.8	4.7	12	6.2	4.4	12
	Mn ppm			Mo ppm			Fe %		
	mean	min	max	mean	min	max	mean	min	max
1.	19	7.4	33	0.7	0.4	1.3	0.2	0.1	0.5
2.	41	3.1	230	15	0.7	81	0.3	0.1	1.6
3.	12000	540	44000	49	1.6	200	7.7	2.7	23
4.	18000	1800	120000	130	43	300	1.5	0.3	3.0
5.	150	59	280	2.6	1.4	4.4	0.8	0.3	1.3
6.	410	180	1100	42	4.3	91	1.8	0.3	3.5
7.	100	32	270	5.0	4.1	6.9	0.9	0.3	1.8
8.	220	58	620	17	0.8	52	1.1	0.4	3.1
9.	25	9.3	43	1.2	0.7	2.6	0.6	0.2	1.9
10.	340	66	1200	11	2.3	21	2.3	0.6	5.5

Mire / number of samples:
1. Lemmetty (Keitele) / 19
2. Matarinsuo (Kontiolahti) / 27
3. Hepolehto (Sotkamo) / 19
4. Harjasuo (Kuusamo) / 16
5. Palosuo (Kuusamo) / 9
6. Reposuo (Kuusamo) / 9
7. Musta-aapa (Rovaniemi) / 6
8. Mustaselkä (Rovaniemi) / 6
9. Ahvenvuoma (Kittilä) / 7
10. Oravaisenvuoma (Kittilä) / 6

Abundance and distribution of other metals

Since the number of samples was small in each case (Table 2), correlation between uranium and other metals could only be roughly estimated. However, the correlation between uranium and copper is high in Matarinsuo (Fig. 11), and there are some positive correlations between uranium and cobalt in Hepolehto, and between uranium and molybdenum in Reposuo.

The metal abundances in Hepolehto and Harjasuo are high, the cobalt content of the peat from Hepolehto ranging from 28 to 590 ppm on a dry-weight basis, with a mean of 190 ppm. Averaging 110 ppm Cu, the copper content of the Matarinsuo peat is higher than that in the other test areas.

Of the seven metals analysed, copper is enriched in the bottom layersof the mires: in 25 columns out of 29 the highest contents are in the basal samples. The contents of the other metals are also usually higher in the bottom layers than in the surface layers. There are exceptions however: in Hepolehto, Harjasuo and Reposuo, which are the mires with the highest manganese contents in peat,the highest values of manganese are found in the surface samples. Lead contents,too, tend to be highest in the surface layers of the mires, possibly due to atmospheric deposition.

DISCUSSION

Bias in test site selection

The test sites were chosen on the basis of their radioactivity observed during conventional uranium exploration conducted earlier. In this sense, the material for the reconnaissance study is biased, because young uranium deposits are expected to emit only low energy gamma radiation and cannot be discovered by scintillometers or spectrometers except in cases of extreme enrichment or if daughter products are present (Culbert and Leighton 1988).

Economic aspects of young uranium deposits

Despite the existence of bedrock suitable for the occurrence of uranium, Finland's known uranium resources are low, only 1500 tonnes uranium in the cost category US$ 80–130 /kg U (OECD, in press). Four nuclear power plants with a total capacity of 2300 MWe are currently in operation; this equals an annual demand of about 500 tonnes of natural uranium.

Although the uranium deposits studied are small and thus not economically viable, they show that young uranium has been, and still is, accumulating from groundwater into peat deposits. Taking into account the exceptional economic aspects of young uranium deposits (Culbert and Leighton 1988), the crucial question now is to find accumulations big enough for exploitation. In the U.S.A., "larger" deposits of thistype contain 50 to 500 tonnes of uranium (Otton 1984a), and depositsof this size may occur in Finland as well. A cluster of such deposits in an area measuring 10 km by 10 km might support small-scale milling. No major deposits and thus no major uranium production are to be expected, but, as a possible domestic source of nuclear fuel, the young uranium deposits are worth further studies. Relevant to today's society is the fact that they provide an alternative means of uranium production without the problem of mining the daughter elements and storing radioactive tailings (Culbert and Leighton 1988). An experimental study of the young uranium deposit at Flodelle Creek, U.S.A.,indicates that sulphuric acid solutions are the most suitable agents for commercial leaching of uraniferous peat (Zielinski and Meier1988).

Fuel peat and young uranium deposits

A recent energy review by the Ministry of Trade and Industry shows that consumption of fuel peat increased from 39,000 toe (ton of oil equivalent) in 1973 to one million toe in 1988, representing 3–4% of present total energy consumption in Finland. The increased use of fuel peat has contributed to the concern about the harmful heavy metals contained in the peat. However, a recent study of 30 mires producing fuel peat in eastern and central Finland revealed reasonably low uranium contents, ranging from 0.6 to 76 ppm (dry-weight basis), with a mean of 2.6 ppm (Lehtovaara et al. 1989). In fuel peat research, uranium should be analysed systematically, because unexpectedly high values of uranium can occur (cf. Fredriksson 1987).

Geochemistry of peat samples

The chemistry of mires is a complex system involving the geochemistry of peatland waters and the geochemistry of peats and their mineral matter (e.g. Shotyk 1988). The deposition and mode of occurrence of uranium in mires, peat, peatland waters and organic stream and lakesediments have been studied and discussed in many contexts (Szalay1964; Kochenov et al. 1965; Armands 1967; Lestinen 1976a, 1976b; Tenhola 1979; Dunn et al. 1985; Van der Weijden and Van der Leeuwen1985; Doyle and Morse 1987). This orientation study did not attempt to investigate the mode of deposition of uranium in peat. Nevertheless some comments can be made.

Our findings indicate that the degree of humification of peat does not significantly affect the content of uranium in the peat. Averaging from 4.5 to 6.5, the pH of the peat samples seems to have little impact on the variation in uranium content. In most cases, the pH range coincides with the range favourable for the adsorption of uranium onto peat (Van der Weijden and Van der Leeuwen 1985). The most important factors in the deposition of uranium seem to be thecomposition of the peat layers, as shown by the ash contents of the peat, the permeability of the

peat deposits, and the location of feeders pouring minerogenic waters into the peat system.

The results show that copper tends to be enriched together with uranium in some of the deposits. In Canada, concentrations of copper from 2 to 6% have been reported from a swamp with 300 tons of copper contained (Boyle 1977). The mechanism of deposition is largely the same as that concentrating uranium or any other heavy metal known to be enriched in peat. The mires Hepolehto and Harjasuo show higher metal contents than do the examples given in the literature (Salmi 1950, 1956, 1967; Sillanpää 1973; Metso et al. 1976; Yliruokanen 1981). The cobalt content of Hepolehto is exceptional, up to 1920 ppm (in ash). The highest cobalt content in ash reported by Salmi (1950) is 200 ppm. In a recent study of the heavy metal content of 30 mires used for fuel peat production, the cobalt values ranged from 0.26 ppm to 5.0 ppm by dry weight (Lehtovaara et al. 1989).

The disequilibrium between uranium and its main gamma-emitting daughter, ^{214}Bi, is clear in the mires studied. The ratio eU/U is between 0.8 and 1.2 only in 6 % of the samples. This is due to the differences in the chemical and physical properties between ^{238}U and some of its daughters with long half-lives: ^{234}U, ^{230}Th, ^{226}Ra and ^{222}Rn (Hambleton-Jones 1978; Levinson and Coetzee 1978; Culbert and Leighton 1981; Levinson et al. 1984; Zielinski et al. 1986). Because of the disequilibrium, it is impossible to measure the uranium contentof the peat in the field using conventional gamma-ray spectrometry. However, reliable results can be obtained in the laboratory with LEGS, from either dried or ashed peat samples. Only if the activityof the daughters in the samples measured is high should the result be checked with some other method, for instance, DNAA.

Suggested exploration methods

The GSF continues to augment the coverage of regional surveys. Regional data, including petrological and soil maps, low-altitude airborne geophysical maps, and hydrogeochemical and geochemical maps, are already available from large areas of the country. Combined with more detailed research on peatlands and with the explorational data bases, the regional data form an excellent source for the search for young uranium.

The advanced methods used in Finland for peatland research could easily be applied to exploration for young uranium in peat. Similarly, groundwater research could support exploration for young uranium. Any exploration project on young uranium deposits in peat demands expertise in peatland assessment, groundwater research and uranium geology.

A stepwise procedure is suggested for carrying out exploration for young uranium deposits. The first stage is the selection of target areas. An exploration target should comprise (1) an area with granitic or other promising lithology, (2) an anomalous but not necessarily high uranium content in groundwater, and (3) drainage areas with rugged topography collecting the waters into (4) basins of appropriate geometry. The basins should be filled with minerotrophic peat. The second step includes analyses of groundwaters and surfacewaters and follow-up sampling of peat in the depositional basins. Once discovered, a young uranium deposit should be submitted to a detailed peatland inventory. Positive results would then lead to feasibility studies.

CONCLUSIONS

In an orientation study conducted by the Geological Survey of Finland in 1983–86, several mires at six test sites were sampled and the contents of uranium and some other heavy metals in peat determined. The results indicate widespread accumulations of young uranium in mires, with uranium values up to several thousands parts per million in dry peat. Marked radioactive disequilibrium was found in the samples: about 50% of the analysed samples contained mostly young uranium, but 10% showed gamma-emitting daughters only. Further studies are needed, however, to confirm whether economically viable deposits are to befound in Finland. Background geological data are increasingly available for such a project, which it is suggested should be run bya team with expertise in peatland evaluation, groundwater research and uranium geology.

Although the fuel peat industry monitors the radioelements in the rawmaterial, at least to some extent, the presence of rich accumulations of young uranium in peat calls for more comprehensive radioelement studies in planned production areas, eastern and northern Finland inparticular. As stated by Culbert and Leighton (1988), other environmental aspects of accumulations of young uranium in organic sediments involve agriculture and develop-

ment: young uranium is loosely held in its deposits and, in a changing environment, may be remobilised posing a danger to water reservoirs downstream. Observations on young uranium in peat may also lead to discoveries of anomalous radioelement values in groundwater, which may present a health risk when occurring in inhabited areas.

Research in Canada and the U.S.A. has shown that the concentrations of young uranium in organic sediments can be considered as exploitable resources of uranium. Although the deposits are likely to be small and, in the present market situation, non-economic, they have the environmental advantage that they lack radioactive daughterelements, and, hence, produce non-radioactive tailings.

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