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Deposit modeling and mining–induced environmental risks

ENVIRONMENTAL SIGNATURES OF MINERAL DEPOSITS AND AREAS OF REGIONAL HYDROTHERMAL ALTERATION IN NORTHEASTERN HUNGARY

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ABSTRACT

Mineral deposits of northeastern Hungary are classified according to the well-known models of COX and SINGER (1986). These deposits and prospects in three mountainous regions (Zemplén, Mátra and Börzsöny Mts.) are all associated with Miocene andesitic volcanism. These regions have been mined intermittently since the Middle Ages. Environmental effects of old and recent mining activities are investigated through an examination of the minor element compositions of flood-plain and stream sediment deposits. Geochemical signatures of ore deposits are used and compared to the element associations observed in reconnaissance stream-sediment surveys. Stream-sediment geochemical data are used to outline areas with elevated concentrations of potentially toxic elements derived from the ore deposits and associated hydrothermal alteration using additive geochemical indices. These indices are derived from a statistical analysis of regional geochemical data. The suites and concentrations of elements typical of the environmental signatures or surface features of the known deposits and mineralized regions was also determined. Geoenvironmental mineral deposit models also were used to evaluate possible environmental behavior of ore deposits in Hungary. The actual environmental effects of development of the studied mineral deposits can be used to infer the potential impact of development of mines in the future. The list of elements analysed during our geochemical survey was limited compared to the list of elements given by the models. Prediction of the possible future appearance of a few elements in the environment was done this way. One mining site with a polluted flood plain below a base metal deposit was investigated in detail and the main results are summarized.

1. INTRODUCTION

Among the objectives of Joint Fund Project No. 415 ("Deposit Modeling, Assessment of Mineral Resources, and Mining Induced Environmental Risks."), the major aim was to exchange information on deposit types, methodology of mineral resources and environmental risk assessments between Hungarian and US scientists. Some results related to the 3rd component of this project (Mining Induced Environmental Risks) will be shown here.

Broad geological and geochemical investigations of ore deposits related to Miocene andesitic volcanism in north-eastern Hungary have been carried out in the last few decades. These studies permit comparisons to the Hungarian deposits so that the deposits can be classified in a developing scheme of geoenvironmental deposit modeling. These generalizations use geological information to anticipate possible environmental effects of development of new mines. With the accumulated knowledge of the geology and metallogeny of Hungary and through the use of geochemical data, potentially toxic element enrichments of natural and anthropogenic origin will be outlined.

Based mainly on US deposit modeling and assessment studies (COX and SINGER 1986, MCCAMMON et al. 1995, DREW 1997, BERGER et al. 1999) and new developments in environmental modeling (DU BRAY E. A. 1995, WANTY et al. 1999) a survey of mineral deposit types found in northern Hungary and related to Miocene volcanism can be conducted. The environmental signatures or behaviour of these mineral deposit types relate, in turn, to expected natural background and mining-related contributions in certain regions. The geology and geochemistry of these deposits (ÓDOR et al. 1992) can be interpreted in the context of the results of a low-density geochemical survey based on flood-plain sediments to characterise the actual regional natural background. In addition, surface geochemical anomalies can be attributed to economic and non-economic mineralizations or to regional rock alteration processes. This paper describes the use of a conventional stream sediment survey to find possible geochemical anomalies indicating ore mineralization and intensive alteration processes; to delineate areas with elevated geochemical baselines, to give additional data to the assessment method, and to summarize the main environmental concerns related to geology, that is, to outline areas in which high background concentrations may be related to geologic factors. Using this approach, an attempt also can be made to resolve pre-mining baseline conditions from mining related drainage signatures.

2. GENERAL DEFINITIONS

"Geoenvironmental models" (DU BRAY 1995, PLUMLEE and NASH 1995, WANTY et al. 1999) have been developed to complement mineral deposit models (COX and SINGER 1986, BLISS 1992). For a given deposit type the geoenvironmental model is: "A compilation of geologic, geochemical, geophysical, hydrologic, and engineering information pertaining to the environmental behavior of geologically similar mineral deposits (a) prior to mining, and (b) resulting from mining, mineral processing, and smelting." Starting from the ore-deposit models established for the deposits of the Mátra and Börzsöny Mountains (VETŐ–ÁKOS 1999) some aspects of these geoenvironmental models, especially those related to the "environmental signatures" of mineralizations, will be dealt with below. The term: "environmental signatures" (PLUMLEE and NASH 1995) is defined as: "the suites, concentrations, residences, and availabilities of chemical elements in soil, sediment, airborne particulates, and water at a site that result from the natural weathering of mineral deposits and from mining, mineral processing, and smelting." These terms will be used here in a larger sense, as not only mineral deposits, but surface geochemical anomalies will be included in the study. For lack of the necessary data only certain aspects of the environmental signatures of these Hungarian deposits will be dealt with in detail.

3. METHODS AND AREA DESCRIPTION

Achievements in deposit modeling in Hungary will be considered, emphasising geoenvironmental aspects of the existing data. Former investigations will be re-evaluated and deposit types of COX and SINGER (1986) will be assigned to the deposits in Hungary. Geochemical data for this work will be provided by two surveys.

1. Low-density survey based on flood-plain deposits. This survey was carried out in 1991–1995 in Hungary. In regions with well-developed drainage systems 196 catchment basins of approx. 400 km^2 were delineated and flood-plain deposits were sampled at their outlets. The samples were taken from 0–10 cm and from 50–60 cm depths. The Geochemical Atlas of Hungary is in preparation and it will show the distribution of 25 elements in the two sampled layers. Maps for the deeper layer are thought to represent regional geochemical baseline values, prior to significant anthropogenic influence.
2. Conventional stream sediment survey with 1 sample/4 km^2 sampling density. Hidden ore mineralizations and potentially toxic enrichments of natural origin may be expected on hilly and mountainous areas in Hungary. The aims of the stream sediment survey were twofold: to prospect for precious metal deposits and to evaluate the environmental state of the surface. The analytical data is available for the Zemplén, Mátra and Börzsöny Mts. and it is possible now to evaluate the geochemical data of these three volcanic terranes. Aqua regia dissolution was applied and ICP-OES, ICP hydride and AAS techniques were used for the analysis. The elements (and components) analysed included: Mo, Cr, Zn, Pb, Co, Cd, Ni, Ba, Mn, Cu, Sr, Li, K_2O, Hg, As, Sb, Au and Ag.

Geological setting and location of known mineral deposits are shown by Fig. 1.

4. GEOCHEMICAL BACKGROUND BASED ON A LOW-DENSITY SURVEY

The geochemical database containing the results of the low-density survey (ÓDOR et al. 1996, 1997c) for the 196 catchment basins has been an important contribution to the establishment of guidance values for soils in Hungary. Using the database, safe concentration levels were established for As, Cd, Cr, Cu, Hg, Pb and Zn. This kind of survey has the advantage of providing regional surface background geochemical data for more than 20 elements and for the whole country. Because of regional geologic differences, the northern part of Hungary can be treated separately; baseline values and other parameters are given below for the northern part of Hungary (Table 1), based on 38 catchment basins in this region.

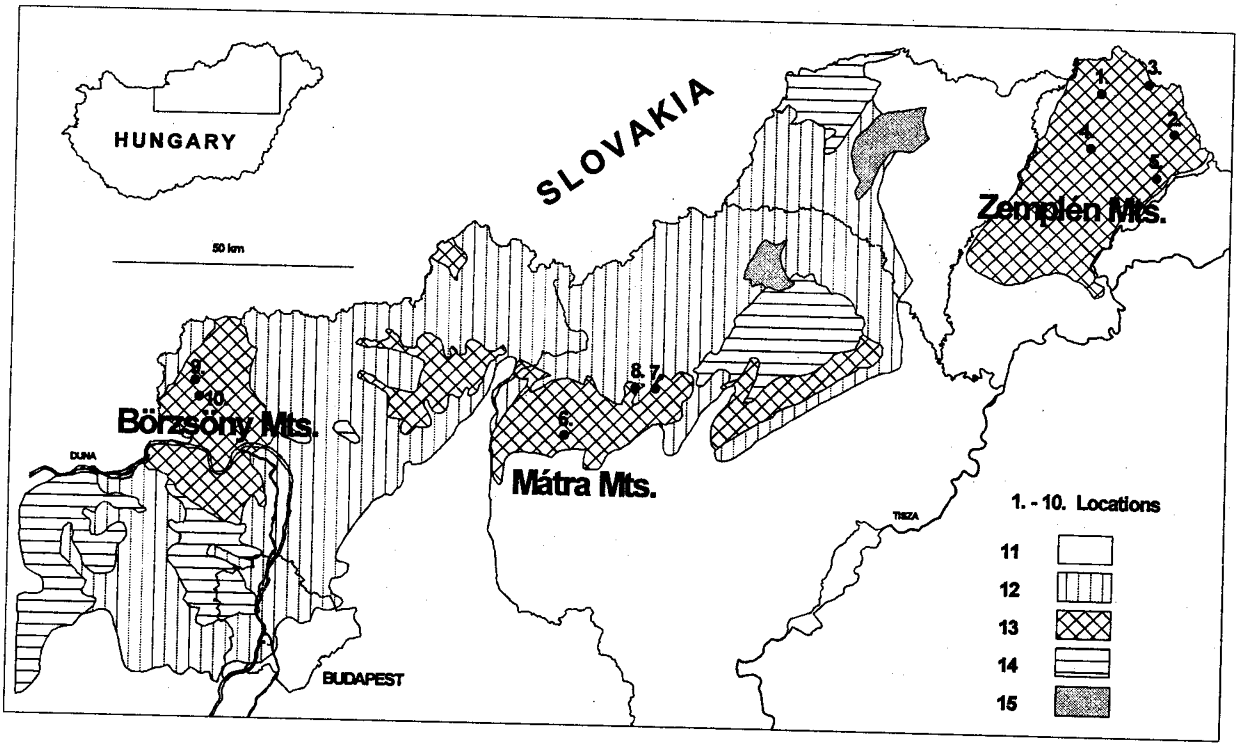

Fig. 1: Geological setting of the area
Location of mineral deposits and prospects: Zemplén Mountains: 1. Telkibánya, 2. Rudabányácska, 3. Füzérradvány, 4. Regéc, 5. Sárospatak; Mátra Mountains: 6. Gyöngyösoroszi, 7. Lahóca, 8. Recsk; Börzsöny Mountains: 9. Nagybörzsöny, 10. Nagyirtáspuszta. Geology: 11. Holocene and Pleistocene sediments, 12. Miocene–Palaeogene sediments, 13. Tertiary volcanic rocks, 14. Mesozoic sedimentary rocks, 15. Paleozoic sedimentary rocks

Table 1

Geochemical background values for northern Hungary based on flood-plain sediments (g/t, unless otherwise noted, N = 38)

Element	Upper layer (0–10 cm)				Lower layer (50–60 cm)			
	Background			Anomalous values	Background			Anomalous values
	minimum	median	maximum		minimum.	median	maximum	
As	< 2.5	7.3	27	58	< 2.5	5.5	18	140
Ba	39	107.5	209		39	111.5	184	
Cd	< 0.5	< 0.5	1.5	12.8; 4.0	< 0.5	< 0.5	1	6.8; 3.5
Cr	10	17.5	40	470	10	18.6	31	310; 47
Cu	11	15.8	31	400; 100; 66; 42	6.5	14.2	30	216; 52; 39
Hg (mg/t)	40	80	140	430; 340; 330; 230; 200; 200; 200	<20	80	260	400
Pb	10	17.3	28	80; 66; 49; 44	< 5	13.5	24	48; 47; 46
Zn	44	57.7	100	1260; 205; 190; 166	28	52.2	105	701; 176

The low-density survey has its limitations, but it helps to outline areas of possible surface contamination or anomalies (Based on the results of factor analysis, element associations have been distinguished: Ag-Au-Cd-Hg-Pb-(Cu-Zn) was found to be very characteristic, showing the elements of low to medium temperature hydrothermal ore processes. The samples collected from the flood-plains of the north-eastern rivers contain both traces of ore material coming from Slovakia and the pollution products of heavy industry from within the region.)

5. ENVIRONMENTAL SIGNATURES OF MINERAL DEPOSITS USING STREAM SEDIMENT SURVEYS FOR NORTHERN HUNGARY

Results are presented below for each region, from the Zemplén Mts. through the Mátra Mts. to the Börzsöny Mts. in order. Results of prospecting and mining activities carried out earlier and related to the characterization of deposits are our starting point. The next step is to use the established international and existing domestic models. A survey of the deposit models and their geochemical characterization will follow which correspond to the deposit types found in northeastern Hungary (Table 2).

Deposits will be surveyed on the basis of COX and SINGER (1986) and generalized geochemical features will be given. From the above approach the assignment of deposit types and classification numbers to our deposits in the three regions will result. Then the data of our stream sediment survey will be processed, element associations established and the results will be compared to those of the models. Finally delineation of additive geochemical anomalies based on the stream sediment survey and determination of the suites and concentrations of elements typical of the environmental signatures or surface features of these actual deposits and mineralized regions will be done. The actual and possible environmental effects of the studied mineral deposits, of potential future mines will also be given.

5.1. Zemplén Mountains

5.1.1. Polymetallic veins, hot-spring precious metal and Hg mineralizations

Geological setting, results of earlier investigations

The main volcanic sequences in the Zemplén Mountains are characterised by rhyodacite tuffs, welded rhyolite tuffs, redeposited rhyolite tuffs, rhyolites and pyroxene-hornblende dacites of Miocene age. Clayey and sandy shales appear in the lower part of the sequence, whereas pyroxene andesites cover extensive areas in the upper part.

A summary is given below of the main results of the geologic and geochemical investigations (VETŐ 1971, GYARMATI 1981, HARTIKAINEN et al. 1992, 1993, HORVÁTH et al. 1993, ÓDOR et al. 1997a,b). In the rhyolitic tuffs, quartzites and andesites, common ore minerals include pyrite, marcasite, native gold, native silver, chalcopyrite, galena, sphalerite, antimonite, argentite, cinnabar and barite. At Telkibánya (ZELENKA 1997a,b), in addition to vein type mineralization, the ore is also found in brecciated silicified and argillised bodies. In this environment, the predominant ore minerals are: pyrite, sphalerite, galena, chalcopyrite, argentite, tetrahedrite, pirargirite, native gold and antimonite. The characteristic gangue minerals are: chlorite, adularia, sericite, quartz, siderite, ankerite, dolomite, calcite, gypsum, alunite, illite, kaolinite and montmorillonite. Gold is associated with pyrite. The epithermal Au-Ag mineralization is related to alteration of the andesitic-rhyolitic succession of the Late Miocene, resulting in assemblages including quartz, alunite, kaolinite, montmorillonite, illite, adularia, carbonate propylitic types.

Deposit models

The models given by COX and SINGER (1986) and the studies of BERGER (1985), CSONGRÁDI and ZELENKA (1995), ZELENKA and CSONGRÁDI (1995), ZELENKA (1997b), MOLNÁR (1997) indicate that the polymetallic vein ("22c"), the hot-spring Au-Ag model ("25a") and the hot-spring Hg model ("27a") describe the ore mineralization processes taking place in the Zemplén Mountains (Table 2).

In ZELENKA and CSONGRÁDI (1995), a summary is given for three occurrences in the Zemplén Mts.: the Telkibánya vein type, the Mád epithermal and hot-spring type and the Füzérradvány-Koromhegy hot-spring type Au-Ag mineralizations. The generalized model (COX and SINGER 1986) is characterized by the following mineralogy: native gold + pyrite + stibnite + realgar; or arsenopyrite ± sphalerite ± chalcopyrite ± fluorite; or native gold + Ag-selenides or tellurides + pyrite. At deeper levels (more than 1 km below the present-day land surface) the sulfide minerals of Cu, Pb and Zn can also appear. The geochemical signature is given by the following elements:

Table 2

Geochemical signatures of deposit types (and occurrences) based on COX and SINGER (1986)

Deposits and prospects in northeastern Hungary			Corresponding deposit models of COX and SINGER (1986)		Geochemical signatures derived from the deposit models
Locality	**Category**	**Commodities resources**	**Descriptive deposit models**	**Model No.**	
Zemplén Mountains					
Telkibánya (1)*, Rudabányácska (2)	Deposit	Au, Ag	Polymetallic veins	22c	Zn, Cu, Pb, As, Au, Ag, Mn, Ba
Füzérradvány,-Füzérkajata (3)	Deposit	Au, Ag	Hot-spring Au-Ag	25a	Au, As, Sb, Hg, (Tl) higher in system, increasing Ag with depth; locally (W)
Regéc (4), Sárospatak (5)	Prospect	Hg	Hot-spring Hg	27a	Hg, As, Sb±Au
Mátra Mountains					
Gyöngyösoroszi (6)	Deposit	Zn, Pb, Cu, Ag, Au	Polymetallic veins	22c	Zn, Cu, Pb, As, Au, Ag, Mn, Ba
Lahóca (Recsk) (7)	Deposit	Cu, Au, Ag	Volcanic-hosted Cu-As-Sb	22a	As, Sb, Cu, Zn, Ag, Au, (Sn, W)
Recsk (deep level) (8)	Deposit	Cu, Mo	Porphyry Cu	17	Cu+Mo+Au+Ag+(W)+(B)+Sr (center); Pb, Zn, Au, As, Co, Ba, (Se, Te, Rb) (outer zone), locally (Bi, Sn)
Recsk (deep level) (8)	Deposit	Cu, Zn	Cu skarn	18b	Cu+Au+Ag (inner zone), Pb-Zn-Ag (outer zone); no Co, As, Sb, (Bi) anomalies
Recsk (deep level) (8)	Deposit	Zn, Pb	Zn-Pb skarn	18c	Zn, Pb, Cu, Co, Au, Ag, As, Mn, (W, Sn, F), possibly (Be)
Börzsöny Mountains					
Nagybörzsöny (Kuruc-patak, Bányapuszta, Rózsa-hegy) (9)	Prospect	Cu, Zn, Pb	Polymetallic veins	22c	Zn, Cu, Pb, As, Au, Ag, Mn, Ba
Nagyirtáspuszta (10)	Prospect	Pb, Zn	Polymetallic replacement	19a	Cu, Pb, Ag, Zn, Mn; locally Au, As, Sb (Bi); high Ba in jasperoids

Remarks: (1)* = see localities on Fig. 1; Elements in parentheses were not analysed during the geochemical surveys.

higher in the system Au + As + Sb + Hg + Tl, increasing Ag and decreasing As + Sb + Tl + Hg with depth (BERGER 1985). The hot-spring Hg mineralization ("27a") is associated with these types of deposits. In the Zemplén Mts. this deposit type is represented by the presence of cinnabar, pyrite and marcasite and by the element association Hg + As + Sb + Au. All the hydrothermal systems of the Zemplén Mts. belong to the low sulfidation types (MOLNÁR 1997).

5.1.2. Stream sediment survey of the Zemplén Mountains

The survey was conducted between 1989 and 1991. At that time the majority of elements was determined by semiquantitative OES (Optical Emission Spectometry). Only a few elements (Au, As, Sb and Hg) were analysed by quantitative AAS and ICP techniques. That is why this survey has its limitations in outlining characteristic suites of elements and establishing geochemical signatures of the ore mineralizations and alterations occurring in the Zemplén Mountains. On the other hand, four different geologic media were simultaneously sampled at that time (heavy mineral concentrate and fine fraction of stream sediment, composite soil and composite rock fragments) and their results helped to more reliably outline distribution patterns of elements.

The geochemical anomalies (Fig. 3) occurring in the Zemplén Mts. are characterized by Au, Ag, As, Sb and Hg (HARTIKAINEN et al. 1992). Anomalies and shows of Hg occur throughout the area (about 30 sites are known). Mercury is one of the elements giving the geochemical signature of one type of deposit (independent mercury mineralization) found in the Zemplén Mts. as shown by the fact that according to stream sediment data, gold has good and significant correlations only with As, Sb and Ag, but not with Hg. Elements having good correlations with each other are used to calculate additive anomalies. Anomaly scores are plotted to get a reliable distribution pattern.

A few words about the procedure follow. The underlying principle of the method lies in the observation that the frequency distributions of ore forming elements and their followers are never normal. From a background characterized by low concentrations of non correlating elements in certain areas, groups of elements can be found with high concentrations and good correlation. On the frequency distribution of elements enriched during ore forming processes there are distinct maxima. So certain concentration ranges can be attributed to certain frequency peaks and these peaks can be numbered. The boundaries of these ranges were chosen to be at frequency minima or at their apparent breaking places (Fig. 2; compare with data in Tables 3, 6 and 8). The additive index is then the sum of the numbers characterising given concentration ranges of different elements. Elements belonging to an association and having significant, positive correlation can only be used for the calculation of this index. It is not always the target element of a mineralization which has the highest score in this index, pathfinder elements like Ag and As are sometimes more useful to outline dispersion areas. In the Börzsöny Mts. +2 was added to the additive index of an element having more weight in the element association when its concentration was above the background range. This way it was possible to include those elements (Mn and Hg) with less weight into the additive index which were left out in the other two regions (Zemplén and Mátra Mts.), either because their role in the ore forming processes was insignificant (Mn) or because they also participated in the formation of other types of ores (Hg). There are of course many other ways to generate an additive index (different units can be used depending on the communality within the factor and in cases of element distributions close to lognormal geometric progressions can also be used).

In order to characterise the overall geochemical signatures, parameters of gold and its pathfinder elements are given in Table 3 for the fine fraction of stream sediments, together with how to calculate additive indices for the Zemplén Mts.

Figure 3 shows the distribution of additive indices and of anomalies for the four elements shown in Table 3. Favorability of a catchment area for mineralization will be evaluated on the basis of additive indices of elements. Spatial zonality of minor elements characterising these deposits (upper level and outside: Ba, Hg; below these: Sb, Au and Ag; then Pb and Zn; with downwardly increasing Cu) did not become visible here because of the scale of the survey.

5.1.3. Environmental considerations

It appears that sub-areas on Fig. 3 outline places of alterations and mineralizations with high concentrations of potentially toxic elements like As and Sb. Parts of these additive anomalies belong to known mineralizations (Telkibánya and Rudabányácska), giving evidence of the usefulness of our approach, while others suggest new targets for exploration around Füzérkajata–Füzérradvány and at the southern rim of the region (in the vicinity of Mád and Tállya. See Fig 3 for localities.). Füzérradvány can now be considered the site of possible future exploitation.

Environmental effects

On areas indicated by the anomaly maps, element associations characteristic for the deposit types can always be found. For As, Sb and Hg, the concentrations are much higher than guideline values for soil contaminants. These values are not due to pollution but to natural variation. They indicate that some local damage to certain species of plants or animals might be expected in limited areas with high toxic element content. In other areas, centuries old mining has left many dumps at the surface, especially at the upper courses of creeks in the Telkibánya region. These, in certain cases, have an influence on the geochemical signatures of the catchment basins, because the anomalies are not entirely generated by the natural outcrops of the ore mineralizations (see for example the anomalous area of cell No. 23 in Table 4).

On Fig.1 locations of mineral deposits and mining activities are shown for the Zemplén Mts. Drainage basins of the reconnaissance and stream sediment surveys including the area of these deposits were selected to show their possible environmental effects. Table 4 shows the data for several elements in the upper (0–10 cm) and lower (50–60 cm) sampling levels of these flood-plain sediments. Also shown in Table 4 are the relevant stream sediments' catchment areas lying within the larger flood-plain drainage basins and including sites of old mines.

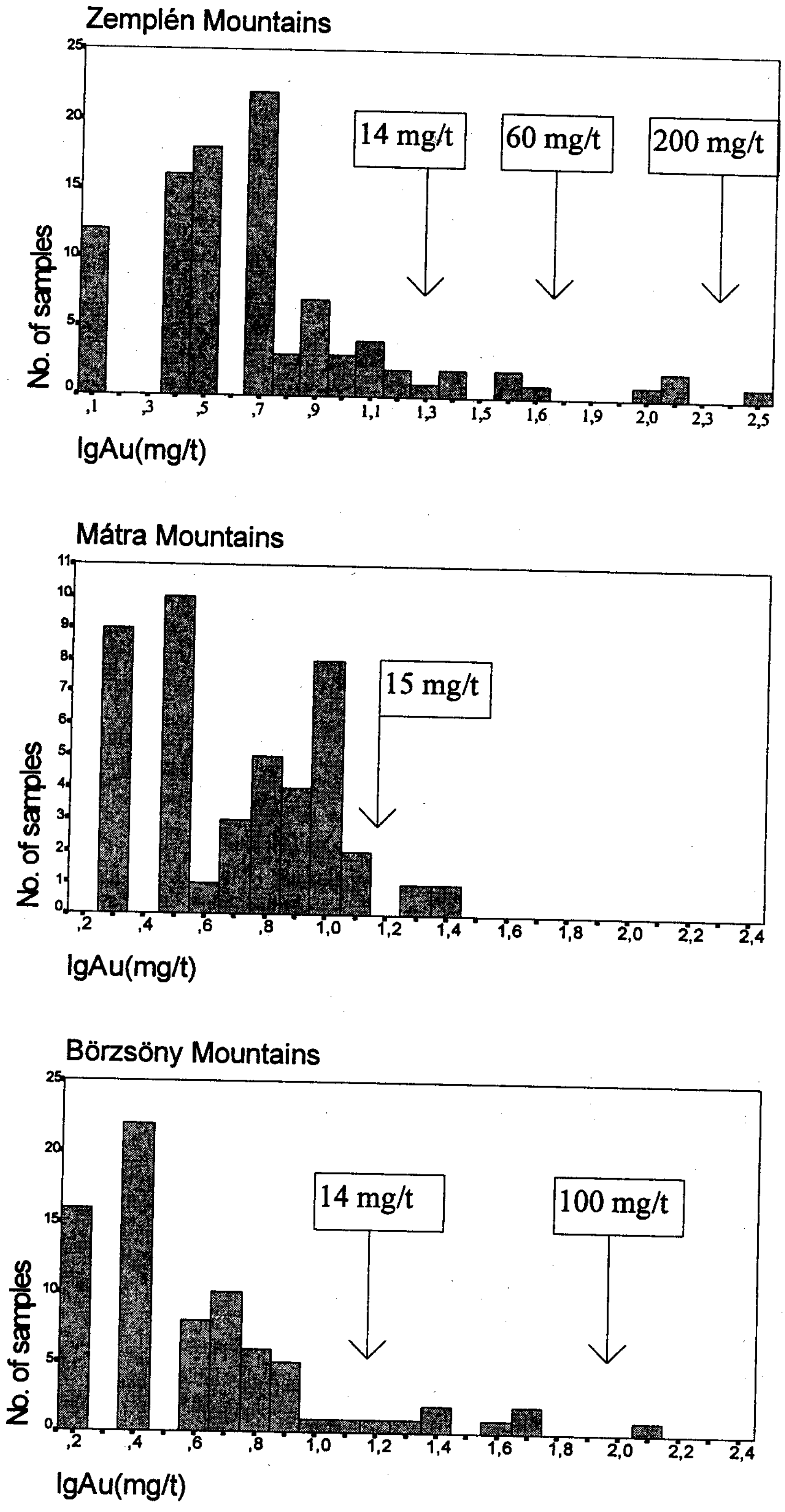

Fig. 2: Calculation of additive indices using frequency distributions of elements: Example of gold (See also Tables 3, 6 and 8 for concentration intervals and corresponding additive indices.)

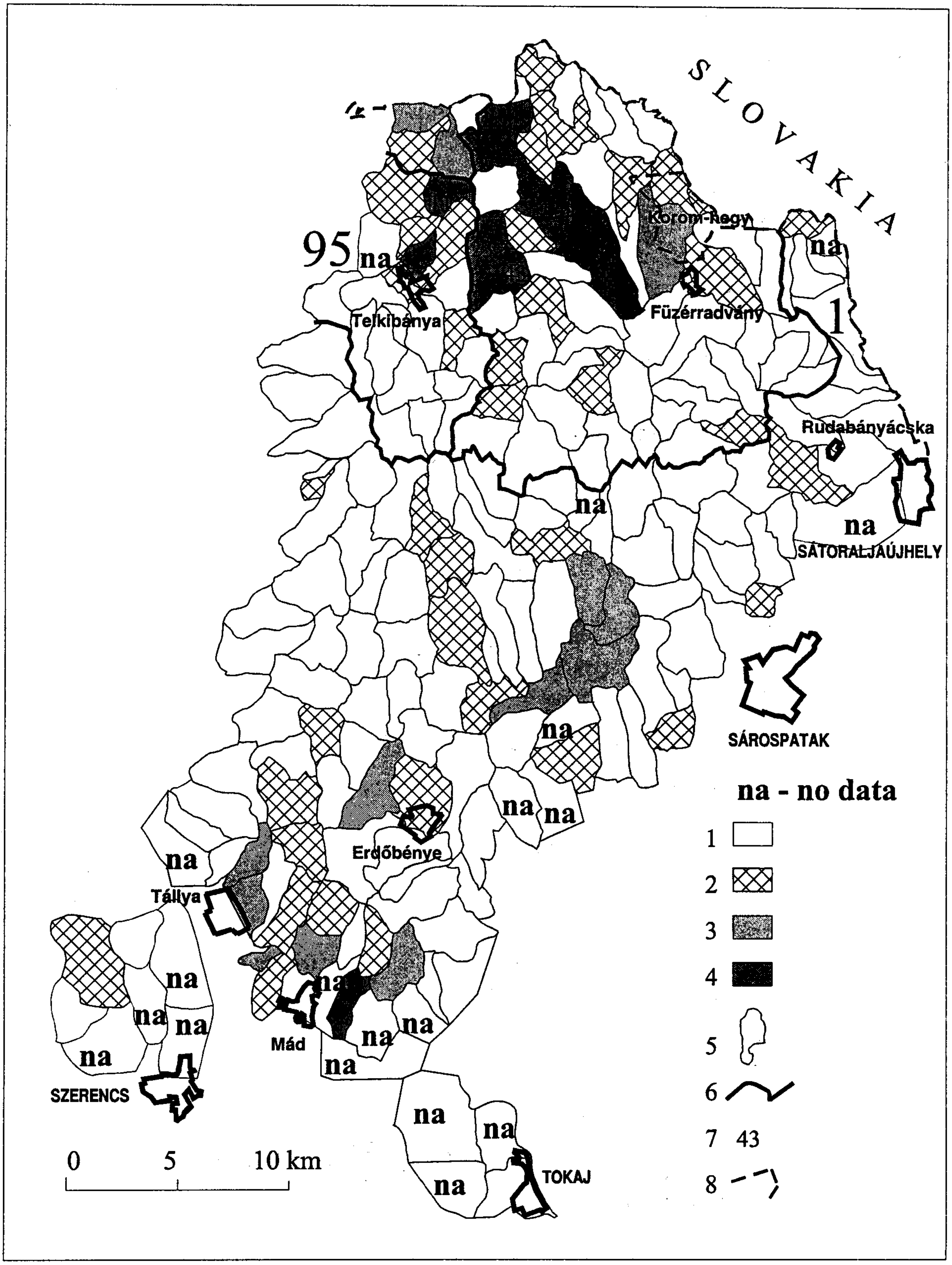

Fig. 3: Aggregated anomaly map of the Zemplén Mts. based on the stream sediment survey
Values of the additive indices: 1: 0–1; 2: 2–3; 3: 4–5; 4: 6–14; 5: Sampled catchment areas; 6: Drainage basins (Nos. 1. and 95) of the low-density survey (floodplain sampling) comprising old mining sites; 7. Catchment areas of the stream sediment survey comprising old mining sites (No. of cells), 8: Location of the follow-up soil survey near Füzérradvány

Table 3

**Geochemical parameters of elements in the fine fraction of stream sediments.
Calculation of additive indices. Zemplén Mts.
(g/t, unless otherwise noted, N=187)**

Element	Geochemical parameters				To calculate additive indices			
	Min.	Median	Threshold of anomaly	Max.	Index value +1	Index value +2	Index value +3	Index value +4
Au mg/t	< 1	1	50	257	10–13	15–45	100–160	257
Ag	< 0.4	< 0.4	15	46	0.4–8		46	
As	< 1	5	60	311	10–20	20–50	70–150	>280
Sb	< 1	< 1	12	22	1–7	8–10	14–15	18–22
Hg	<0.05	0.28	1.1	1.34	*			
Ba	160	1,000	-	1,600	*			
Cr	10	60	-	160	*			
Pb	< 6	40	-	250	*			
Zn	< 100	< 100	150	250	*			

Remark: * = elements not used for the calculation of additive anomalies.

Table 4

**Composition of the flood-plain deposits of large drainage basins
(low density survey) and that of the stream sediments within them covering
areas of known mineral deposits and mining sites in the Zemplén Mts. (g/t)**

Region	Zemplén Mountains, flood-plain deposits				Zemplén Mountains, stream sediments		
Cell	No. 1*		No. 95*		23*	43*	11*
Level	upper	lower	upper	lower	–	–	–
Ag	< 0.2	0.5	0.3	< 0.2	34	12	2.5
As	12.0	7.2	9.2	5.1	253	101	147
Ba	154	128	88	70	112	180	102
Cd	<0.5	<0.5	<0.5	<0.5	8	1	1
Cu	31	13	14	9	51	36	27
Hg	0.04	0.1	0.09	0.05	0.26	0.10	0.23
Pb	20	15	16	12	296	119	45
Zn	74	45	51	34	276	142	134

* = See position of the cells on Fig. 3.

The large flood-plain drainage basins show small concentrations for the above elements compared to the medians of the background (see Table 1). This might mean that the environmental effects of these deposits are insignificant either because of their distances from the sources of pollution or because many centuries had passed after the medieval mining activities. As to the stream sediments' catchment areas in the immediate surroundings of these old deposits, the difference in the concentrations of all the elements analysed is striking.

In the evaluation of environmental effects we have to consider the following facts. In the Zemplén Mts. Telkibánya was a significant mining region for gold and silver in medieval times. Quartz veins were mined in surface pits then in underground drifts. Ore crushers were in use from the 15th century on. Contamination of the environment became more and more intense after the 17th century, because of the new technology introduced into the mining industry. In the Telkibánya area water reservoirs and crushers were built in the valleys and waste dumps of the processed ore had also been deposited there. The dams erected in the Middle Ages, the crusher stones and the waste dumps can be still recognized at the site (ZELENKA 1997a). Geochemical signatures prior to mining would be important to be given, but the only suitable medium to sample would be the deep level horizon of flood-plain deposits, close to the site. Stream sediment signatures after the development of mining are shown on Tables 3 and 4.

Investigations conducted on the anomalies of the reconnaissance stream sediment survey (Fig. 3), revealed significant concentrations in the soil around Füzérradvány, an area with no prior mining activities. Consequently the stream sediments contained only the natural weathering products of the outcropping rocks. A follow-up soil survey using a 200 m x 40 m grid helped to outline areas of high heavy metal contents in soils originated by natural weathering processes (Fig. 4). These concentrations are compared with the concentration ranges of stream sediments transported from the same area and with tolerable values in soils (Table 5).

Concentrations of one or more heavy metals are much higher for the major part of the detailed soil survey (Fig. 4B) than tolerable values in soils. On the other hand catchment areas having the same or higher additive indices than these Füzérradvány cells, cover large surface areas on the aggregated anomaly map (Fig. 3) of the Zemplén Mts. So one can infer from this fact, that natural environmental loads of the extent of many km^2 can be taken for granted in the whole Zemplén Mountains for the heavy metals and associated elements.

Potential environmental considerations

The activities of foreign companies interested in ore exploration in Hungary have recently been intensified. In some concession areas detailed investigations are going on and production will probably start in the near future. The most important effects to be expected of possible future mining are the following: 1. Modern open-pit mining

Environmental loads revealed by the follow-up soil survey in a mineralized area in the Zemplén Mountains. (g/t) *Table 5*

Element	As	Sb	Pb	Hg
Concentration range in the stream ediments *	16–94	2–22	10–40	0.11–0.58
Background (median) for the area of the follow-up soil survey	10	3.6	57	0.16
Max. concentration in the soil	2,810	395	160	29.4
Tolerable values in soils **	30	--	100	1

* = Based on catchment areas Nos. 19, 27, 29, and 199, which include the area of the follow-up survey.

** = Values taken from the environmental quality criteria prepared by the Ministry of the Environment in 1995, as a draft of a new law. The values are limits for very sensitive areas.

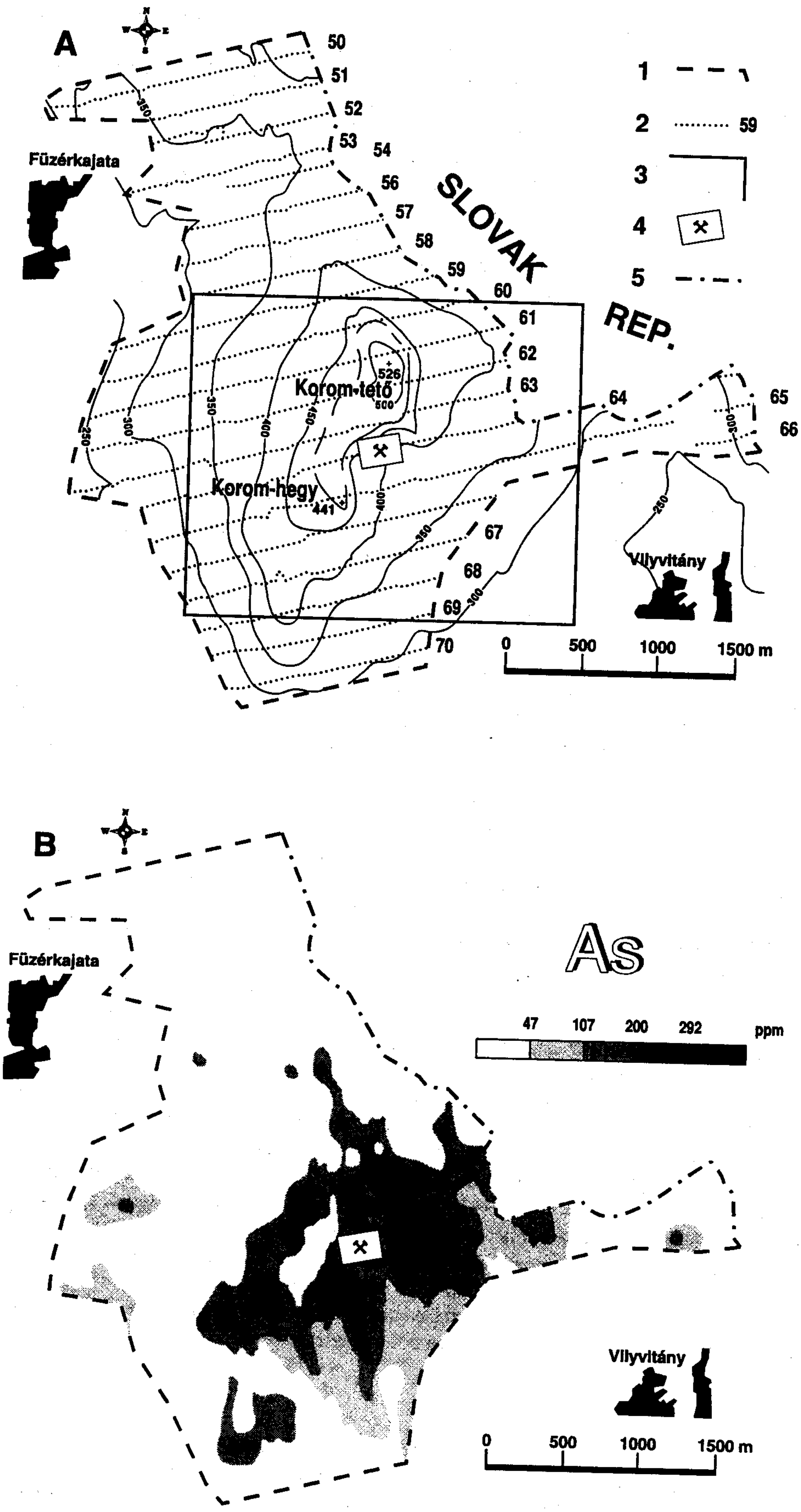

Fig. 4: A. Sampling sites of the follow-up soil survey near Füzérradvány (Korom-hegy), Zemplén Mts.

1. The area of the follow-up survey. 2. Soil sampling sites and No. of profile, 3. Area of detailed geophysical investigations, 4. Illite mine, 5. State boundary.

B. Distribution of As in the soil

methods are to be expected. These produce great volumes of untreated waste rock. Increased traffic, noise and dust generation is also expected. This poses quality of life problems. 2. Disposal of tailings by erosion processes will cause sedimentation problems in stream valleys. 3. The possible future mine (or mines) will probably produce gold from low-grade ore, using cyanide heap-leach techniques. The cyanide used for gold extraction will be a potential additional contaminant in waste water discharge downstream in the valleys if mining operations are not carefully constructed. 4. The sulfide minerals (pyrite, marcasite, chalcopyrite, galena, sphalerite etc.) contained in the mine tailings will be oxidised and potentially hazardous components (As, Sb, Cd, Hg, methylated species, etc.) may be released and carried into the water in moderate amounts. 5. Acid mine drainage will not cause serious problems, because of the low sulfide and high carbonate contents of this type of ore.

According to environmental deposit models, in addition to the elements analysed the appearance of Tl is also to be expected in the ores of Füzérradvány, in the alteration zones and erosion products of the hot-spring type Au-Ag mineralization.

5.2. Mátra Mountains

5.2.1. Polymetallic veins, volcanic-hosted Cu, porphyry copper and Cu-Zn-Pb skarn mineralizations

Geological setting, main results of earlier investigations

The rocks of the andesitic stratovolcanic sequence of Middle Miocene age comprise the bulk of the Mátra Mts. Andesitic volcanism of Eocene age is restricted to an area of a few km^2 in the Recsk–Parádfürdő area. In a clastic sedimentary sequence with diversified composition deposited in the Oligocene to Lower Miocene there are many intercalations of dacitic tuffs. Mesozoic sedimentary formations are observed only in boreholes and adits of the Recsk deposit.

The history of mining in the Mátra Mts. (NAGY B. 1997a) probably goes back to the Middle Ages. The Lahóca copper mine was discovered in 1852. The base metal mining at Gyöngyösoroszi was in its prime from 1950–1970. In the 1960's the important deep-level copper-zinc deposit of Recsk was discovered.

All known ore occurrences are the products of postvolcanic geologic activities. At Recsk, copper porphyry ores can be found in the upper part of diorite porphyry bodies lying below Eocene andesites. Cu-Zn skarns are found in the contact zone between the diorite and Mesozoic carbonate rocks, while in the upper part of the sedimentary sequence and in the stratovolcanic series metasomatic mineralizations are characteristic (these are all related to the Recsk deep level mineralization). At and around the centers of geyser and hot-spring activities gray copper ores with precious metals were mined at Lahóca. In the Miocene andesites of the Mátra Mountains polymetallic vein-type mineralization is found. Our stream sediment survey did not cover the area near Lahóca, so the only area that can be analysed in detail is the surface geochemical features of the Gyöngyösoroszi polymetallic mineralization. These results will be applied to understanding possible environmental effects of the ores, as well as for other types of mineralization, which are developed in this region. (An epi-telethermal Hg-Sb indication has been known in the region of Asztagkő, (CSONGRÁDI 1984).

Deposit models

At the Gyöngyösoroszi deposit, the ore mineralization is of polymetallic vein type, locally in stockwork form; there are 15 to 20 veins of ore. Carbonate alteration is the strongest and youngest process but siliceous, sericitic and chloritic alteration is also frequent along the veins and in the host rocks. (VETŐ É. 1988, VETŐ–ÁKOS 1994, VETŐNÉ ÁKOS É. 1996, NAGY 1997a and VETŐ–ÁKOS 1999). This alteration assemblage corresponds to model "22c" of COX and SINGER (1986). According to this model the ore mineralization can be geochemically characterized by the element association: Zn, Cu, Pb, As, Au, Ag, Mn, Ba (Table 2). The epithermal gold-Cu mineralization of Eocene age at Lahóca (FÖLDESSY 1997, GATTER 1997) is associated with intrusion, tectonic, hydrothermal and explosion breccias. The ore bearing breccia contains a considerable amount of sulfides (mainly pyrite, less enargite, luzonite and tetrahedrite). The gold is concentrated in the sulfides. On the basis of COX and SINGER (1986) this corresponds to volcanic hosted Cu-As-Sb ("22a") deposits. Model Nos. "17", "18b" and "18c" can be assigned to the deep level deposits at Recsk (see Table 2). The stream sediment geochemical survey did not cover the Lahóca region, so the geochemical signatures of this deposit are not considered in this survey.

5.2.2. Stream sediment survey of the Mátra Mountains

The surface geochemical features in the Mátra Mountains are basically determined by the characteristics of the known ore mineralization at Gyöngyösoroszi. In the fine fraction of the stream sediments gold, in accordance with the polymetallic nature of the mineralization, shows positive significant correlation with Ag, As, Cu, Pb and

Zn (ÓDOR et al. 1997b). These elements have been used for the calculation of additive anomalies for the Mátra Mts. The statistical parameters and the calculation of additive indices used to outline additive anomalies are summarised in Table 6.

The additive indices are plotted on Fig. 5. The mineralization situated in the Western Mátra Mts. has been known and mined for a long time. It gives elevated values towards northwest and strong anomalies towards Gyöngyösoroszi in the distribution pattern. Another area, south of Parádsasvár, is also well outlined: this is the Middle Mátra region, also formerly mined. The dispersion fans can be traced for long distances along the creeks. There are two other additive geochemical anomalies in the eastern part of the mountains partly known from previous investigations. Among the elements in Table 6 not used for the calculation of additive anomalies Hg and Ba are enriched in and around a mercury mineralization of lesser importance.

5.2.3. Environmental considerations

On Fig. 1 locations of mineral deposits and mining activities are shown for the Mátra Mts. Environmental considerations are mainly based on COX et al. 1995; KING, 1995; PLUMLEE and NASH 1995, PLUMLEE et al. 1993, 1995a,b,c., WANTY et al. 1999.

Environmental effects

Drainage basins which include these deposit sites were selected to show their possible environmental effects in the composition of flood-plain deposits and stream sediments. Table 7 shows the data for several elements in the upper (0–10 cm) and lower (50–60 cm) sampling levels of these flood-plain sediments together with the minor element composition of the stream sediments covering areas of known mineralization.

Fig. 5: Aggregated anomaly map of the Mátra Mts. based on the stream sediment survey
Values of the additive indices: 1: 0–1; 2: 2–3; 3: 4–5; 4: 6–11; 5: Sampled catchment areas; 6: Drainage basins (Nos. 18. and 20.) of the low-density survey (floodplain sampling) comprising old and recent mining sites; 7. Catchment areas of the stream sediment survey comprising old mining sites (No. of cells), 8. Sampling sites upstream and downstream of Recsk, 9: The Gyöngyösoroszi base metal mine and polluted flood-plain below

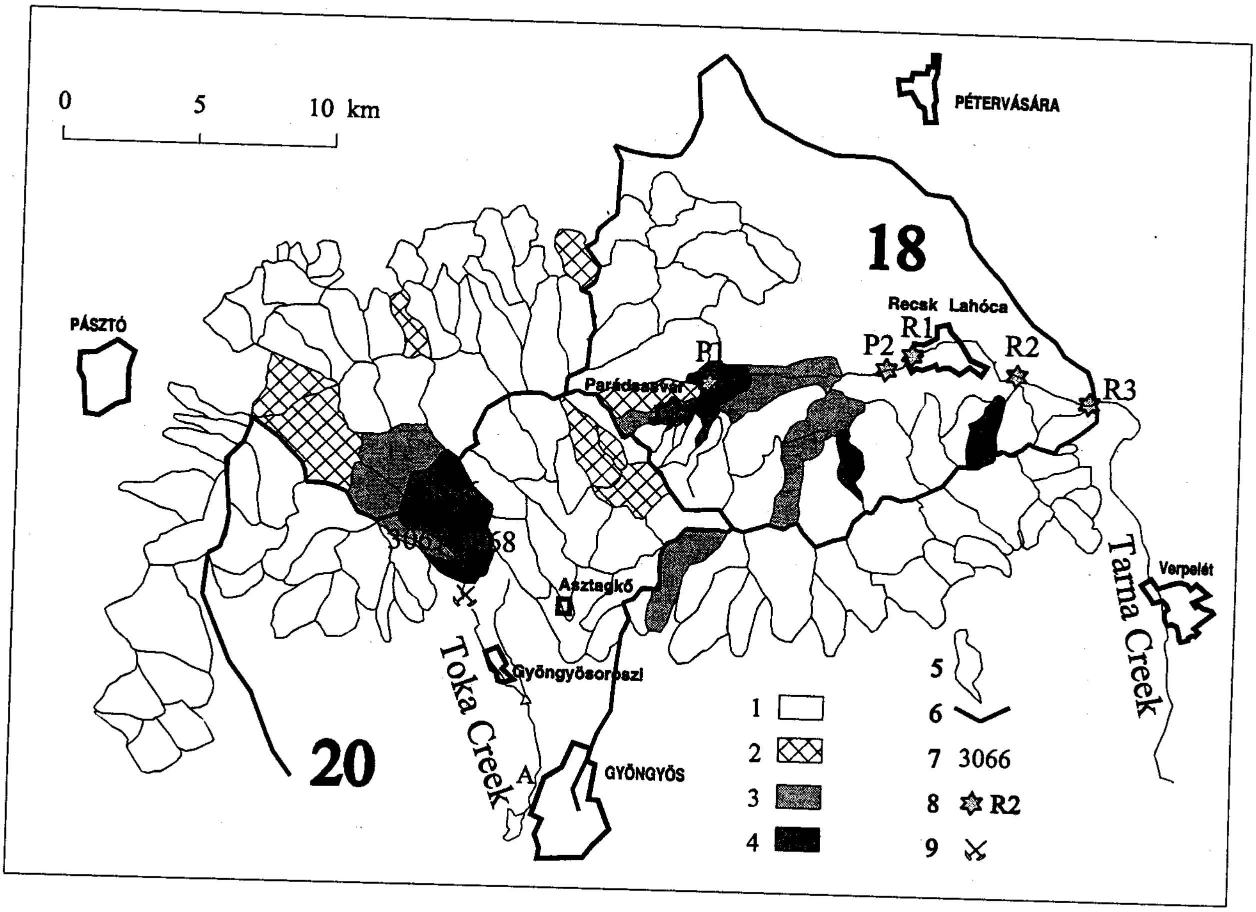

Table 6

Geochemical parameters of elements in the fine fraction of stream sediments. Calculation of additive indices. Mátra Mountains (g/t, unless otherwise noted, N = 104)

Element	Geochemical parameters				To calculate additive indices			
	Min.	Median	Threshold of anomaly	Max.	Index value + 1	Index value + 2	Index value + 3	Index value + 4
Au mg/t	< 2	< 2	16	24	6.5–12	> 20		
Ag	< 0.4	< 0.4	—	0.4	=> 0.2			
As	1.7	5.7	50	163	12–22	39–44	> 60	
Cu	2	14	50	153	30–45	> 100		
Pb	7	18.5	50	288	40–45	55–110	> 190	
Zn	34	65	280	12 200	100–250	300–700	900–2,000	> 10,000
Ba	41	123	280	320	*			
Cd	< 1	< 1	4	47	*			
Cr	3	11	-	23	*			
Hg mg/t	< 20	140	600	2560	*			

Remark: * = elements not used for the calculation of additive anomalies.

Table 7

Composition of the flood-plain deposits of large drainage basins (low density survey) and that of the stream sediments within them covering areas of known mineral deposits and mining sites in the Mátra Mts. (g/t)

Region	Mátra Mountains, flood-plain deposits				Mátra Mts., stream sediments		
Cell	No. 18*		No. 20*		3066*	3067*	3068*
Level	upper	lower	upper	lower	–	–	–
Ag	0.4	0.2	0.3	0.2	0.3	0.2	0.3
As	54.8	7.3	14.6	16.2	18.1	17.7	163
Ba	158	118	177	184	41	85	73
Cd	1.47	<0.5	0.68	0.68	2.6	1	47
Cu	100	30	42	30	41	29	153
Hg	0.3	0.2	0.33	0.4	0.5	1.28	0.44
Pb	21	17	49	47	95	59	241
Zn	71	77	191	176	382	185	12 200

* = see position of the cells on Fig. 5

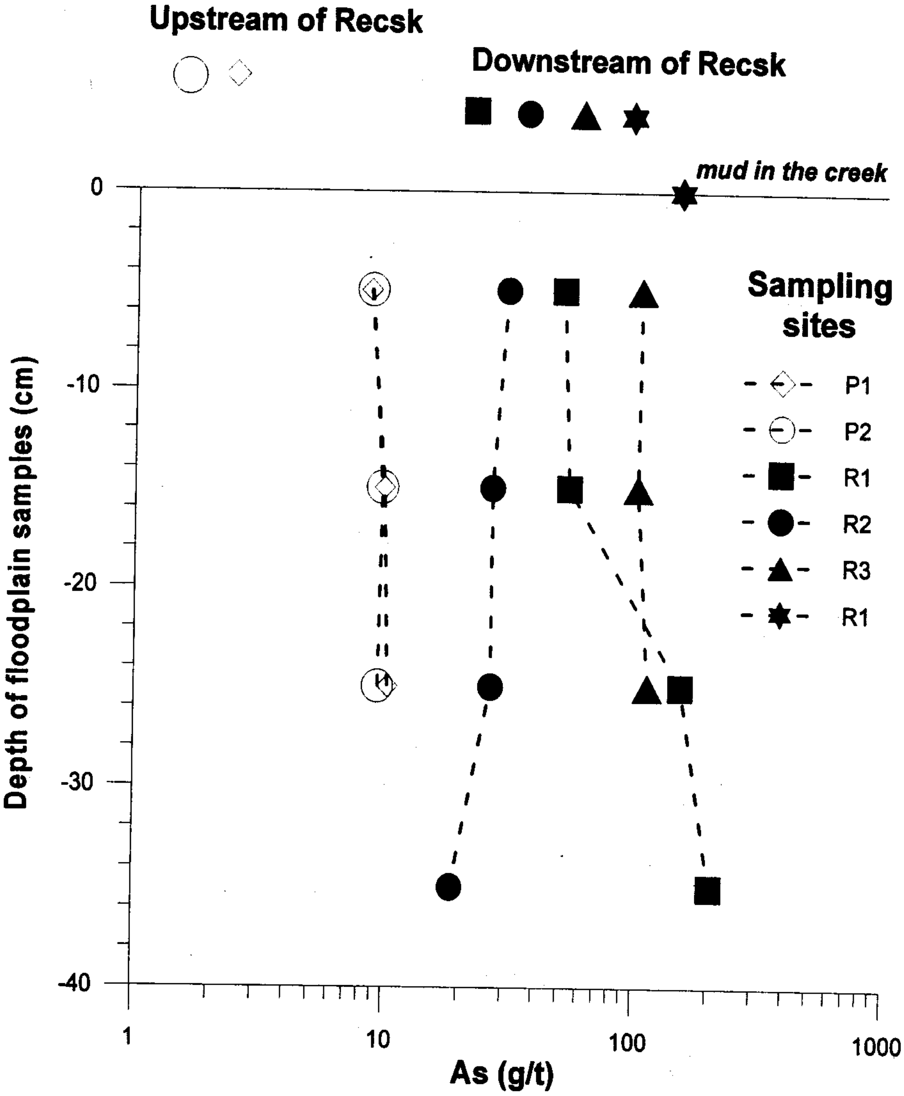

Fig. 6: Arsenic contents of the floodplain deposits upstream and downstream of Recsk (For sampling sites see Fig. 5.) Description of the sampled profiles: at P1, P2, R1 = predominantly silt with small pebbles; at R2, R3 = clayey fine sand; R1 mud = mud in the creek collected at site R1

Elevated concentrations of a few elements are observed in cell No. 18 of the low-density survey (see on Fig. 5), which covers part of the Mátra Mountains, the other drainage basin shows small concentrations for the above elements compared to the medians of the background (see in Table 1). This might mean that the environmental effects of the near-surface deposits are insignificant in such distances from the mineralized centers. (Cell No. 18 might show the recent contaminating effects of the ore and waste material originating from the Lahóca deposit. A new sampling was conducted in 1997 upstream and downstream of the Recsk (and Lahóca) mining sites (Fig. 6) to show the effects on the environment of the ore and waste dumps being eroded. Floodplain (overbank) sediments were sampled from 0 to 40 cm at 5 sites and analysed for 18 elements. Differences in the element contents of Ba, Cu, Sr, Hg, As, Sb and Au of the floodplain sediments in the valley above and below Recsk are significant and can be illustrated by the distribution of arsenic (Fig. 6). The arsenic contents of floodplain sediments downstream of Recsk (Lahóca deposit) are increased by an order of magnitude compared to the unpolluted sediments higher up in the valley of the Tarna Creek above Recsk. This contamination of the floodplain sediments was probably caused by the Lahóca deposit (WANTY et al. 1999) and related mining activities.

The deep level Recsk deposit will probably be mined in the future. The main commodities will be: Zn, Cu, Ag (Au). The geochemical investigation of the skarn mineralization of this deposit was carried out by U. FÜGEDI at the Geochemistry Department in 1985–90 using OES semiquantitative data. It can be assumed that the concentration of Zn, Cu and Cd will be much higher in the flotation waste after the processing of ore than the allowable limits for soil. So these elements will be the main contaminants to be released to the environment if the dumps are eroded. Lead will not be an important factor in this respect.

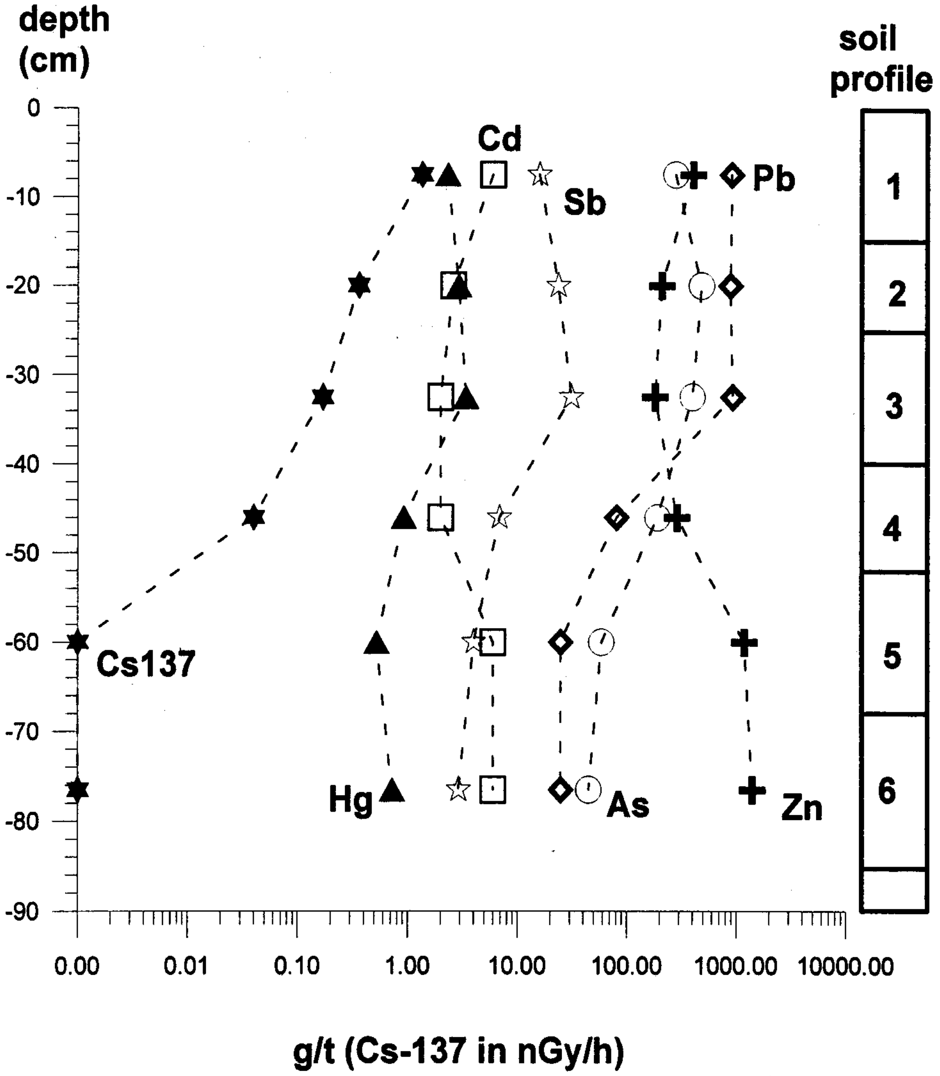

Fig. 7: Gyöngyösoroszi: Geochemical profile at site A on the flood-plain (see location on Fig. 5.)
Description of the profile: 1. Brown silty sand, 2. Greyish yellow clayey sand, 3. Yellow clayey sand, 4. Dark brown sand, 5. and 6. Brown clayey sand

In the stream sediment catchment areas near the Gyöngyösoroszi deposit, concentrations of As, Cd, Hg, Pb and especially Zn are high and anomalous. The environmental effects of the Gyöngyösoroszi mine were studied in detail and their description is based mainly on Ódor et al. (1997d). The waste material of the Gyöngyösoroszi base metal mine, the mine water, the ore-dressing, the washed away concentrate and the flotation waste dump (cleaner tailings) are all sources of contamination along Toka Creek and its flood sediments (for location see Fig. 5). During floods the mud of high metal content which had accumulated in the reservoirs was also carried away and spread out. The sand fraction was deposited near the bed as long and narrow sand bars ("yellow sand") and the finer fractions accumulated elsewhere on the flood-plain. By studying the petrologic composition, toxic element and Cs–137 contents of soil profiles on the flood-plain, thickness of recent sediments deposited in the last 40–50 years can be established. The majority of the sedimentary material comprising this recent upper layer (30–50 cm thick) is composed of the flotation waste (Fig. 7). So mining has contributed a huge quantity of fine-grained material of anthropogenic origin to the natural processes. The extent of the contamination on the surface and at depth has roughly been delineated. The area of the land used for agriculture and affected by floods is marked or indicated. Detailed studies on the toxic element content of different plants and vegetables were also conducted in the Toka Creek valley (unpublished data of Peter Marth, Soil Information Monitoring System at the Budapest Plant Health and Soil Protection Station, Hungary). These results can be compared to uptake ratios of elements by plants established by John and Leventhal (1995) and suggestions can be made for the most appropriate edible garden plants which can be safely grown on these contaminated soils.

The main problem to be solved in this area is not caused by the polluted mine water. Attenuation of metals in stream water is taking place within a relatively short distance. The most important problem is the presence of polluted soils on the flood-plain. Floods had carried and will probably carry the flotation material to great distances (> 10 km) from its source and there is no significant attenuation of metal contents of this material downstream (ÓDOR et al. 1997d).

Potential environmental considerations

Toxic elements enriched in the upper layers of soils situated on the flood-plain in the Gyöngyösoroszi area are the main sources of future pollution. The flotation waste is a long-term source of metals and acid, and is impossible to remediate. Both the material deposited in the reservoirs along the Creek and the so called "yellow sand" and their toxic metal content can be continuously remobilised, horizontally and vertically by new floods and under hypergene conditions, respectively. According to geoenvironmental deposit models, the elements analysed and shown on Table 2 are the ones to be expected in the flood-plain and stream sediment deposits below the Gyöngyösoroszi base metal mine.

The environmental effects enumerated above for possible mining in the Zemplén Mts. apply as well to the Lahóca area. The elements indicated by the geoenvironmental deposit models for the deep level Recsk deposit should also be taken into consideration in case of future mining when evaluating potential effects of the ores. The porphyry copper and the skarn deposits, in addition to the elements analysed by our Laboratory, would give the following elements as possible future contaminants: Se, Te, Bi, Be.

5.3. Börzsöny Mountains

5.3.1. Polymetallic veins and replacement mineralizations

Geological setting, main results of earlier investigations

Two volcanic units have been delineated in the Börzsöny Mts. In the lower unit products of explosive-extrusive activities are mainly found, resulting in the accumulation of a thick stratovolcanic complex of andesites and dacites. Both lavas and pyroclastics are characterized by great mineralogical variations (CSILLAGNÉ–TEPLÁNSZKY et al. 1983, KORPÁS and LANG 1991). In the upper volcanic event a large stratovolcanic structure was formed. The maximum thickness of this andesitic stratovolcanic complex is 450 m. This late complex shows no signs of hyd-rothermal alteration.

The main features of the mineralization developed in the central part of the Börzsöny Mountains are based on CSILLAGNÉ–TEPLÁNSZKY et al. (1983), KORPÁS and LANG (1993), NAGY B. (1983, 1990, 1997b). The mineralization (and alteration) took place at the end of the first phase of the Börzsöny volcanic activity. Clear zonation can be seen at the different occurrences. Copper mineralization is associated with a central biotitic zone, which is surrounded by either barren or polymetallic zones. Three main zones with typical hydrothermal mineral assemblages can be distinguished vertically. In the upper zone the argillite-carbonate-pyrite facies is accompanied by polymetallic mine-ralization which comprises the following mineralogy: pyrite, marcasite, pyrrhotite, sphalerite, galena, chalcopyrite, argentite, Bi- and Ag minerals, quartz, calcite, siderite and clay minerals. In the middle or transitional zone the facies described above is accompanied by a biotite-bearing chalcopyrite ore mineralization in its center and by a polymetallic mineralization at the margins. In the lower zone the biotite-bearing chalcopyrite facies is found with a copper ore mineralization: pyrite, pyrrhotite, magnetite, chalcopyrite, sphalerite, phlogopite, chlorite, and quartz.

Deposit models

Genetic models of the Börzsöny mineralizations were described by CSILLAGNÉ–TEPLÁNSZKY et al. 1983, VETŐNÉ–ÁKOS 1996 and VETŐ–ÁKOS 1999). In the central part of the mountain there are three well-defined base metal mineral occurrences: 1. The environs of Kuruc–patak; 2. Bányapuszta and 3. Rózsa–hegy (Table 2). Near the surface there are vein type, epithermal precious and base metal occurrences (COX and SINGER: type "22c"), at deeper level metasomatic type Pb-Zn (Ag, Au) ore mineralization is known (NAGY B. 1990, 1997). This corresponds to model "19a", which, at places, can be found near the surface too. The weak and unimportant porphyry copper mineralization had originally been formed below the metasomatic type of mineralization (according to recent views this type of mineralization does not exist in the region, see VETŐ–ÁKOS 1999). Thus the near-surface precious and base metal mineralizations are characterised by the appearence of Zn, Cu, Pb, As, Au, Ag, Mn, and Ba; these elements are found also in the Mátra Mts. The copper enriched central part of the metasomatic mineralizations at deeper level is surrounded by a broad, Pb-Ag enriched zone, while Zn and Mn are enriched at the fringes. The mineralization in the central part is characterised by Cu + Mo + Ag (± W±B±Sr), while Pb, Zn, Au, As, Sb, Co, and Ba are found in the outer zone.

5.3.2. Stream sediment survey of the Börzsöny Mountains

In the Börzsöny Mts. the correlations of the gold contents of the fine fraction of stream sediment are more extensive and include more elements than in the other two regions studied (ÓDOR et al. 1997b, 1998). The reason for that might be that there is only one ore-generating event in the Börzsöny Mts. Geochemical parameters of gold and pathfinder elements, as well as the calculation of additive indices are shown in Table 8.

On the favorability map of the Börzsöny Mts. (Fig. 8) the Middle Börzsöny is spectacularly highlighted by the aggregated anomalies giving the area of old mining activities and recent prospecting. This anomaly is surrounded by a broad dispersion halo. There are two other anomalous regions worth mentioning. 1. The anomalous cell, situated northwest of Szokolya lies at the northern edge of a collapsed caldera, there are hematite and limonite indications here. 2. North of Szob the anomalies outline the center of a stratovolcano. These two isolated anomalies are not significant with respect to economic ore mineralization.

5.3.3. Environmental considerations

Environmental effects

On Fig. 1 locations of mineral deposits and mining activities are shown for the Börzsöny Mts. Drainage basins which include the area of these deposits were selected to show their possible environmental effects (Fig. 8). Table 9 shows the data for several elements in the upper (0–10 cm) and lower (50–60 cm) sampling levels of the floodplain sediments.

The drainage basin of the low-density survey incorporating the old mines and mining-related activities of a few decades ago shows only small concentrations for the above elements compared to the medians of the background (see in Table 1). This might mean that the environmental effects of these deposits are insignificant in such distances from the mines. In the small catchment areas in the immediate surroundings of these deposits, the concentrations of the following elements are high in the fine fraction of stream sediments: Ag, As, Pb and Zn.

Geochemical parameters of elements in the fine fraction of stream sediments. Calculation of additive indices. Börzsöny Mountains (g/t, unless otherwise noted, N = 91)

Table 8

Element	Geochemical parameters				To calculate additive indices				
—	Min.	Median	Threshold of anomaly	Max.	Index value + 1	Index Value + 2	Index value + 3	Index value + 4	Index value + 5
Au mg/t	< 2	< 2	15	123			2–13	15-100	> 100
Ag	< 0.3	0.4	—	1.6			0.8–1	1–1.5	>1.5
As	0.5	2.6	10	22.5	> 10				
Cu	3	6.6	25	64		12–21	30	64	
Hg mg/t	< 20	< 20	100	284	40–45	50–80	> 284		
Mn	170	640	1,600	3,194	1,600-2,000	3,194			
Pb	4	9.5	20	187			30–50	60–110	187
Zn	19	44.5	100	583			54–120	250–400	583
Ba	38	93	170	2,468	*				
Cr	5	13.3	40	73	*				
Sb	< 0.2	< 0.2	1	1.2	*				

Remark: * = elements not used for the calculation of additive anomalies.

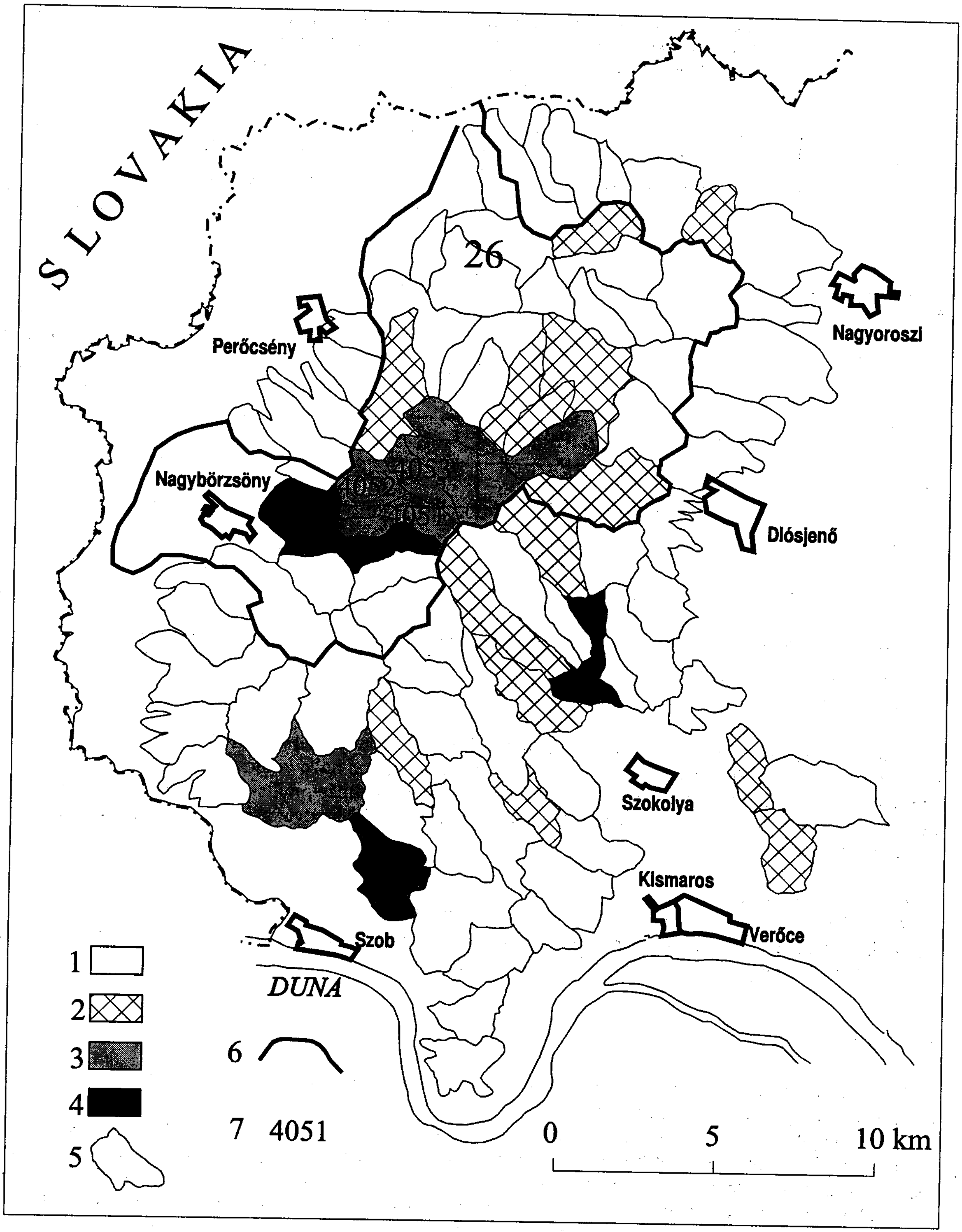

Fig. 8: Aggregated anomaly map of the Börzsöny Mts. based on the stream sediment survey
Values of the additive indices: 1: 0–3; 2: 4–7; 3: 9–11; 4: 14–19; 5: Sampled catchment areas; 6: Drainage basin (No. 26) of the low-density survey (floodplain sampling) comprising old mining sites; 7: Catchment areas of the stream sediment survey comprising old mining sites (No. of cells)

Composition of the flood-plain deposits of large drainage basins (low density survey) and that of the stream sediments within them covering areas of known mineral deposits and mining sites in the Börzsöny Mts. (g/t values)

Table 9

Region	Börzsöny Mts., flood-plain deposits		Börzsöny Mts., stream sediments		
Cell	No. 26*		4051*	4052*	4053*
Level	upper	lower	–	–	–
Ag	0.2	0.2	0.7	0.9	0.7
As	<2.5	<2.5	22.5	3.8	3.2
Ba	98	85	82	96	90
Cd	<0.5	<0.5	< 1	< 1	< 1
Cu	13	12	21	30	15
Hg	0.05	0.04	0.05	0.06	0.029
Pb	24	24	107	32	30
Zn	76	61	376	103	92

* = see position of the cells on Fig. 8

Mining at Nagybörzsöny goes back to the middle of the 13th century (BENKE 1994). It flourished in the 15th century, when at least 100 miners worked here (there are old adits and hollows along the veins over a length of approximately 1 km). The second boom was in the 18th century (crushers, mills and furnaces had been built). Mining activities in the 1950's (an adit of 1800 m long had been made) brought great quantities of ore and waste material to the surface.

Potential environmental considerations

According to the deposit models (COX and SINGER 1986, COX et al. 1995), in addition to the elements analysed, the appearance of minor elements like Se, Te and Bi is also to be expected in the ores, in the alteration zones and weathering products of mineralized rocks in the Börzsöny Mountains.

6. CONCLUSIONS

The lithogeochemical zonality derived from the deposit models cannot be revealed with certainty by the use of a sampling density of 4–5 km^2/catchment area.

Comparing the geochemical features of the volcanic regions in northern Hungary, based on the stream sediment survey, it can be stated that the background values of andesitic areas are very similar for most of the elements analyzed. Arsenic is the only element accompanying the gold-silver couple which can be used for geochemical purposes in every mountain unit. Comparing the medians of the elements for the three different mountain regions, Hg and Ba have significantly higher values in the Zemplén Mts. than in the other regions. These units are characterized, one by one, by the following element associations: Zemplén Mts.: Au, Ag, As, Sb and an independent Hg, (Ba) suite; Mátra Mts.: Au, Ag, As, Cu, Pb, Zn and independent Hg; Börzsöny Mts.: Au, Ag, As, Cu, Hg, Pb and Zn. The dispersion haloes are toxic heavy metal anomalies of natural origin, as far as environmental aspects are concerned. Follow-up soil investigations have only been carried out in a small anomalous area in the Zemplén Mts. Exact data for the environmental loads of heavy metals in soils in a mineralized area can only be given for this location. For the major part of the Zemplén Mts. and for the two other regions (Mátra and Börzsöny Mts.) detailed soil data are not available and only the patterns derived from the additive geochemical anomalies of the stream sediment survey refer to the existence of actual environmental loads in the soils.

An important remark must be made here. We have to consider the list of minor elements analysed in the Laboratory of GIH, and compare them to the list given by the generalized deposit type and geoenvironmental mineral deposit models. There will be quite a few elements not yet detected in these three volcanic regions of Hungary. So geochemical signatures of the Hungarian deposits can only be predicted on the basis of international models but cannot be completely covered or established by the use of our analytical data. Improved analytical data may be obtained in the future, but the current data set provides a useful synthesis of the environmental conditions in the mineralized areas of northern Hungary.

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