Environmental Geochemistry and Environmental - Geochemical Mapping of the Slovak Republic

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Abstract: Methodology and the results of the geochemical mapping of Slovak Republic territory (the Geochemical Atlases (scale 1 : 1 000 000) as well as environmental-geochemical maps (scale 1 : 50 000)) are presented in this article. Some theoretical problems of environmental-geochemical mapping are analysed, for instance environmentally important contents of elements and technique of their determination, principles and bases for creation of environmental-geochemical maps and others. Samples of individual parts of the Geochemical Atlases and environmental-geochemical maps are presented.

Key words: environmental geochemistry, geochemical maps, geochemical atlases, environment of Slovak Republic

Introduction

The distribution of elements in individual earth's zones is not random but controlled by the physical-chemical conditions and parameters, which were gradually recognised by the progressively developing scientific discipline – geochemistry. Broadly speaking the purpose of the geochemistry is to study elements and their isotope distribution in atmosphere, hydrosphere, earth's crust, mantle and core. With respect to biota and human beings, the surface component of the environment with the dominant importance is the technosphere. This has become the subject of intensive investigation as a response to the population explosion as well as to the socio-economic, economic and technical development and related problems with raw material processing and consequent environment contamination.

One of the most negative and probably the most dangerous impacts of human activities on geological components of the environment is the widespread contamination of natural waters, soils, recent sediments and rocks with inorganic and organic chemical compounds, that have a consequently negative impact on the character of a country, biosphere and man. A large-scale contamination of the environment with a local, regional and even global character invoked the necessity to study changes in cycles of environmentally important elements and thus conditioned the birth and development of a new scientific discipline – environmental geochemistry.

Definition and Role of the Environmental Geochemistry

The environmental geochemistry is the study of the distribution and mutual interactions of chemical elements in rocks, waters, soils, atmosphere and biosphere and their impact on man. Thus, it is dealing with a complex of interactions in the rock–soil-water–atmosphere-biosphere–life system, it investigates primary and secondary factors influencing sources, dispersion and distribution of elements in environment, as well as their role in food chain, including its key part – water and with water associated potential negative impact upon plants, animals and man. The so-called environmentally significant content (concentration) of an element is one of the key input data. This term means that such concentrations of elements, substances and components and in such forms, which indicates a pollution of the environment either by human or by geogenic origin and which can negatively influence the natural ecosystem. Their indicative values are given by environmental standards, norms, critical or maximal concentrations defined for individual abiotic agents of the environment and also they are determined by experimental studies (statistic analyses and modelling). Except for the monitoring of polluter concentrations in geologic environment, the role of environmental geochemistry is also the investigation and identification of their origin (geogenic or anthropogenic), conditions and forms of migration, forms of occurrences, toxicity levels, risk and conditions of their accumulation and the redistribution in various components of the geologic environment.

Rather than dealing with a broader spectrum of issues studied by other geosciences, environmental geochemistry closely cooperates with related and in some cases also with seemingly unrelated scientific disciplines. For example, concerning biological sciences, the interest of environmental geochemistry is not in organism and its associations, but in its living environment affected by natural and man-introduced processes.

The above mentioned concept suggests that environmental geochemistry is a multidisciplinary scientific branch expressly based upon national and international team co-operation of a wide range of specialists. Its current dynamic development and importance in practice can be documented by its development toward other disciplines such as medicine (geomedicine), hygiene (geohygiene), urban planning etc., it can be talked about applied environmental geochemistry.

The Environmentally Important Contents of Elements and Methods of their Determination

Concerning the distribution of elements, for various purposes geochemistry distinguishes positive and negative anomalies, prospective symptoms, criteria etc. One of the basic attributes of environmental geochemistry is to determine environmentally significant concentrations of elements/components as well as their background and critical values. In most cases there are determined maximal permissible concentrations that are obligatory and can be checked by legislative. On the other hand deficit environmental concentrations and criteria (various sums and ratios of elements) are important as well, for instance contents of the elements F, I, or that critical loads and their exceeding. In many cases these contents are very low, close to the detection limits of routinely used analytic techniques and methods. Analytical chemistry, development of analytical techniques and, last but not least, also a new approach to analytical procedures have considerably contributed to recognizing of forms of element occurrences, their biologically available concentrations (through sequential leachate and toxicity tests chiefly in soils, stream sediments, but also in other non-geological materials, such as emissions, sludges, waste of various kinds, etc.). All of the processes are preceded by the elaboration of specific sampling design and methods of sampling that are discussed, but often not respected in practice (for instance instructions for compilation of maps of geofactors of the environment etc.). It should be realized that mistakes done during sampling have usually greater influence on the total error than used analytic method.

With respect to determination of environmentally significant contents of elements/components for evaluation of pollution sources and their intensity, there are currently several approaches (or philosophies) in existence:

- legislative
- determination of a background pre-industrial (precivilisation) concentration
- application of statistic analysis
- combined
- geochemical

The **legislative** approach is based on comparison of observed concentrations of monitored parameters with limit values that are given in particular standards and defined for particular components of the geologic environment (for instance Slovak Technical Standard No. 75 7111,. *Drinking water* – for underground waters, Resolution of Ministry of Agriculture of the Slovak Republic No. 581/94-540 – for soils etc.). The contents above (or below) limit levels are regarded as environmentally significant. This approach is handicapped by the fact that the range of analytically monitored elements and components is often wider than the range in individual standards. Moreover, some standard values (mostly indirectly or experimentally derived from the daily dose per the average man's weight, lethal dose LD50, exposure time, or concentration causing death or deformations of plants and animals) are not always suitable for man-made pollution. The maximum permissible values of Zn (5 $mg.l^{-1}$) and chlorides (100 $mg.l^{-1}$) according to Slovak Technical Standard 75 7111, *Drinking Water* are good examples. Waters containing more than 5 $mg.l^{-1}$ zinc can hardly be found in Slovakia, whereas chloride concentrations over 10 $mg.l^{-1}$ always indicate secondary contamination except for waters circulating in Tertiary sediments at greater depths. It is worth mentioning that the legislative approach has more or less the character of a basic environmental information and does not deal with the biological availability of elements mentioned in the standards, which merits more detailed environmental geochemical research and evaluation.

The determination of ***background*** or ***pre-industrial contents*** of elements is an important step in environmental geochemical research as it provides a good basis for comparisons for follow-up investigations. These values can be identified by techniques that are summarised by Förstner – Wittman (1979) as follows:

- average composition of shales, applicable as a global standard value,
- fossil sediments laid down in a defined subaquatic environment, applying the conditions of autochthonous or allochthonous origin and regional-effect mechanisms,
- recent sediments from relatively uncontaminated regions,
- dated drillcores of sediments that provide a historical record of effects and changes in the investigated drainage basin and which left their imprints in the sediment.

Each of these four techniques has its advantages and disadvantages, and its application depends upon specific natural conditions of the investigated site and upon the research objectives. The resulting background values are often influenced by the predominance of a certain rock type, occurrence of ore and mineral assemblages, etc.

A number of ***statistical analyses*** are employed to determine background values (local or regional background) and also effect of natural environment on background concentration, i.e. partial distinguishing between geogenic and anthropogenic effects. The mathematical-statistical approach in modelling of environmental-geochemical significant contents and anomalies is similar to that applied in prospecting geochemistry. It determines the mean (modified mean) values and standard deviations. This approach is recommended mainly for elements and components which limits are not determined in standards (e.g. Sb in sediments and surface water) and for the evaluation of those components of the geological environment that are not dealt with in legislation (e.g. rocks, snow, etc.).

Statistical-analysis techniques most widely used to distinguish geogenic and man-made effects on background values are as follows:

- calculation of correlation coefficients, which indicates a common source of elements, e.g. if Zn, Pb, Cd and Hg display a correlation with organic carbon, they are probably of man-made origin. However, such correlation should be strictly reviewed, since, e.g. the above-mentioned correlation in black shales has a completely different meaning.
- cluster analysis,
- multivariant statistical methods, e.g. factor analysis, etc.

The ***combined*** approach is mostly based upon the legislative and statistical procedures that mathematically combine the limit values with the absolute concentrations of evaluated elements. One of these parameters is also a contamination index (Backman et al., 1997).

$$C_d = \sum_{f=1}^{n} C_{fi} \quad \text{where} \quad C_{fi} = \frac{C_{Ai}}{C_{Ni}} - 1$$

where C_d – level of sample contamination
C_{fi} – contamination factor for the i-th component
C_{Ai} – analytic value of the i-th component
C_{Ni} – normative value of the i-th component

The so-called geoaccumulation index represents another example of the combined approach that was implemented by Müller (1979) as the quantitative expression of the degree of contamination by heavy metals in stream sediments:

$$I_{geo} = \log_2 \frac{C_n}{1{,}5xB_n}$$

where C_n is an observed concentration of element n of argilliferous fraction of sediment (<2μm) and B_n is a value of geochemical background in argilliferous shale or observed background in argilliferous fraction of pre-civilisation sediments in evaluated region. Factor *1,5* is used because of possible background values variation due to lithogenetic effects. The values of geoaccumulation indexes are divided into 6 level scale of contamination by monitored heavy metals encountered in argilliferous fraction of the bottom stream sediments. In the case of combined approaches, we can already speak about the evaluation of the degree of contamination of the environment.

Another distinct method is the ***geochemical approach***. This technique assesses environmentally significant concentrations of elements of the investigated component of geological environment (waters, soils, sediments, etc.). It determines whether the contents of elements are adequate to the given natural conditions of their formation, i.e. whether they correspond to the natural geological processes forming chemistry in local conditions. This approach requires a detail analysis of geochemical processes taking place in the respective components of the geological environment with assumed quantitative effect of geochemical processes. It is particularly suitable for distinguishing of proportion of man-introduced concentrations of contaminants and it enables evaluate proportion of man-made contamination of geological environment. This approach is mainly applicable when contaminant concentrations are below limits defined by the legislation, but obviously exceed concentrations that can be expected in the local geological environment. It is often applied to distinguish the degree of influence of man on natural water.

Main Principles of Creation of Environmental-Geochemical Maps

As in other geoscience disciplines, so also in environmental geochemistry are maps the most effective and the most often used approach for evaluation of condition of the environment, in term of visualisation of environmentally important element concentrations. Similarly, it is with interpretation of results that the dominant element is the summary distinction of the degree of contamination and negative impact on the ecosystem.

The simplest and the most frequently used method of expression of environmental-geochemical anomalies are maps with appropriate quantification that is graphically expressed. The important decisions regarding compilation of environmental-geochemical maps are:

- the aims of a map
- the group of users the map is trying to reach
- the character and relevance of input data
- map scale
- cartographic readability of the map

The main aim of environmental-geochemical maps is presentation of the spot or superficial model of distribution of the investigated parameters. This data group is commonly mathematically or logically combined with the character of the environment (geologic structure, hydrogeological conditions etc.) or with other groups of information, such as the demographic, geographic distribution of mortality, health reproduction, land use etc. The choice and mainly the form of expression of environmental-geochemical information must be designed to reach a group of users. For instance, for the administrative purposes it is highly recommended to use bold criteria expressed by the so-called semaphore coloured scale that simplify a communication between specialists (map authors) and state administrators. From the above mentioned it is obvious that environmental-geochemical maps are specifically created and can have different design from case to case.

Reproducible databases of input data in text, numeric and graphic form are considerable bases for map creation. Their verification is conditioned by character of the data and it has its own rules and prescriptions, for instance chemical analyses are internally and externally verified, other data groups are verified by statistical tools, etc. Basically, it can be said that environmental geochemistry operates with multimedia input data, and with regard to this there is a problem arising from their related interpretation: what form and what environment should the information be processed from the beginning to definite graphic form.

One way is to process information with equal character separately and later transform them into integrated graphic form, for instance. That approach cannot be always accepted, in some cases the determining information is formulated in text as legislation, permissions, licences etc. Another way has become, for instance, hypermedia system called „Microcosm„ developed for the environment of MS Windows by Southampton University (Ashton – Simmons, 1994). This software is able to accept and transform multimedia data for subsequent mutual interpretation.

The information value of the map and its scale are conditioned by the number of information units – statistical density of the sampling grid. The number of units depends mainly upon complexity of natural conditions, map aims and sampled media. Map compilation and its scale plays an important role in solving of local, regional and global geochemical problems mainly in complicated interaction among society, hydrosphere, pedosphere and biosphere. At present maps are compiled with the help of a geographic information system (GIS). GIS in various forms represents a very useful tool for work with spatial data distribution, but in general it does not incorporate the fourth dimension – time, or evaluation of monitoring results, time anticipating models etc. This problem is being solved by a chronological succession of maps (principle of animation) or by the application of specially developed software.

As mentioned above for compilation of environment-geochemical maps it is necessary to maintain a simplicity of information expression, even if complicate simultaneously functioning factors are expressed, with respect to users and also with respect to cartographic readability of a map.

Environmental Geochemistry in the Slovak Republic

In the conditions of former Czechoslovakia and the present Slovakia the geochemistry was almost exclusively focused on activities regarding mineral deposits exploration e.g. prospective geochemistry and later on problems of hydrogeochemistry and groundwater protection.

Two main kinds of geochemical works mentioned above have given the methodological background of environmental geochemistry (design of sampling, sample adaptation, chemical analyses, and way of interpretation). The experts interested in environmental-geochemical problems were formed by the branches of geochemistry mentioned above. Geochemical-prospective works (mainly E. Mecháček, I. Čilík, J. Gubač, J. Václav and others) were the base for the delimitation of geochemical anomalies and the determination of occurrences of prospective and economically significant elements. Beside hydrogeochemical research (mainly Gazda) the main interaction processes were defined and classified (Gazda, 1974): water – rock, form of element transfer in liquid phase and conditions of phase equilibrium. Inasmuch as the water component of the environment is the most dynamic and at the same time the most vulnerable, it served as base for the elaboration of problems of environmental protection against pollution (for instance Goldberg – Gazda, 1984).

Later on, especially during the beginning of nineties, when widespread geochemical mapping has begun (Vrana, 1991), the reproducible database of chemical composition of natural water, streams, rocks, soils, natural radioactivity and forest biomass were created. By this mean the concept of geochemical background and elements/components distribution in sampled media was formed at a certain level. Later on it was purposely updated in a set of maps of geofactors of the environment through supplementary data gathered by an identical methodical process. The activities mentioned above were accompanied by forming methodology for interpretation of results and mainly for the compilation of particular maps (Rapant – Bodiš, 1994; Marsina – Lexa 1995; Čurlík – Šefčík – Šurina, 1995). These were oriented especially on the summarisation of anomalies and the distinction of their geogene, geogenic–anthropogene and anthropogene origin.

The orientation of environmental geochemistry in Slovakia is also focused on one of its current trends – medical geochemistry, which includes retrieval viewpoint (Khun, 1996) and applied one, for instance in Žiar basin region (Khun et al., 1997). Recently there are ongoing projects focused on influences of the geochemical environment on state of health of inhabitants, for instance in Spiš-Gemer Rudohorie region (Rapant et al., 1998).

The development of applied environmental geochemistry proceeds also towards projects focused on critical loads evaluation and their exceeding (Bodiš et al. 1995), chemical time bombs (Rapant – Bodiš, 1995) and monitoring of geochemical parameters within the frame of monitoring of geological factors of the environment of the Slovak Republic (Klukanová, 1998) etc.

One of the new tasks of environmental geochemistry for a close future, currently elaborated abroad and in the Slovak Republic as well is for instance the monitoring of total concentrations and form of occurrences of „classic" environmentally responsible elements as As, Cd, Hg and Pb, because of their high toxicity and the processes leading to the creation of metal-organic compounds frequently relevant in a food chain. It will be inevitable to study biochemical processes that influence the cycle and distribution of elements in nature such as acid deposition, eutrophication of natural water etc.

As the beginning of modern and systematic environmental – geochemical mapping of Slovak Republic is considered the project *„Investigation of geological factors of environment of Slovak Republic"* (Vrana, 1991). Within the frame of this project the first Geochemical atlases of Slovak Republic were compiled and the methodical principles of evaluation and expression of particular components of environment in maps were set in the form of regional environmental-geochemical maps.

Environmental-geochemical mapping of Slovakia is especially focused on the detection of primary and secondary concentrations of elements and substances in rocks, soils, streams and waters (underground and surface). Beside inorganic components organic substances also are

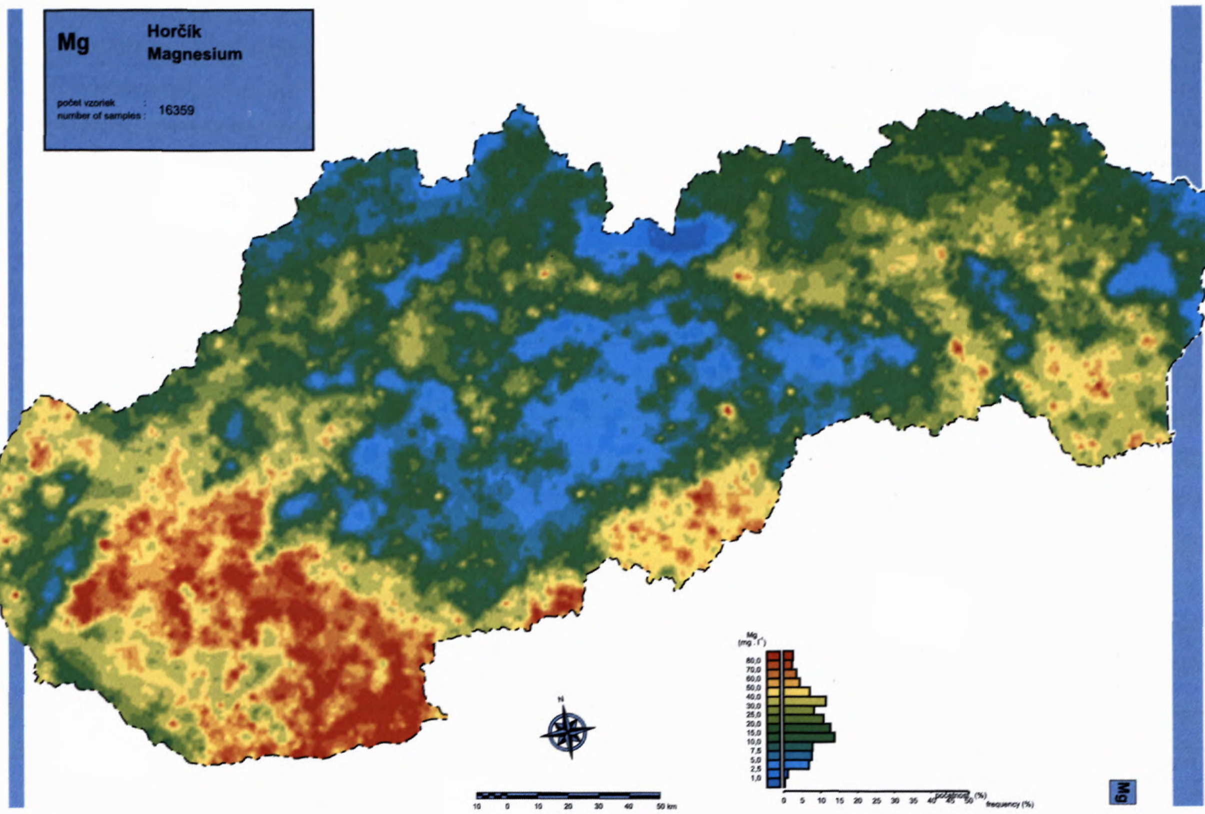

Fig. 1 Geochemical Atlas of Slovak Republic (1 : 1 000 000), Part I: Groundwater. Distribution of Magnesium.

monitored on a regional scale; however, in a smaller extent and as a group indicator of organic pollution.

From a regional viewpoint, the environmental-geochemical mapping of the Slovak Republic is done in two main levels. The first is represented by geochemical atlases of the Slovak Republic in a scale 1 : 1 000 000 and the second one by environment-geochemical maps of selected areas at a scale 1 : 50 000, or in case of urban areas a scale of 1 : 25 000.

Geochemical Atlases

The main aim of the Geochemical atlases was to compile one set of element maps at a scale of 1 : 1 000 000 showing a distribution of chemical elements and components in the groundwater (Fig. 1), soils, streams and forest biomass. The observed and derived components of natural radioactivity of rocks and water were similarly depicted in maps. Within the frame of the Geochemical atlas of rocks a Map of the litho-geochemical types at a scale of 1 : 500 000 was also compiled. The basic characteristics of individual Geochemical Atlases of the Slovak Republic is summarised on Tab.1. On Tab.2 there is an overview of the analysed elements and their limits of detection in particular volumes of Geochemical Atlases.

The elaboration of each part of the Geochemical Atlas of Slovakia is based on new sampling and new chemical analyses and measurements, except for the part „Rocks“ where about 30% of archive analytic data were used (mainly in principal elements).

The first three volumes of the Geochemical Atlases of Slovakia were issued in 1996 as monographs in a bilingual Slovak-English version: „Groundwater“ (Rapant et al., 1996), „Forest biomass“ (Maňkovská, 1996) and „Natural radioactivity“ (Daniel et al., 1996). In 1999 „Stream sediments“ (Bodiš – Rapant, 1999) and „Rocks“ (Marsina et al., 1999) were finished and issued as monographs. The volume of Atlas „Soils“ was finished in 1999 and the monograph will be issued in 2000.

The compilation of maps, interpretation, sampling and analyses were done according to methods within the frame of International Geologic Programme IGCP No. 360, Baseline Geochemical Mapping (Darnley et al., 1995).

Within the frame of particular parts of the Geochemical Atlases of the Slovak Republic there were created a new state of interactive geochemical databases of the most important components of the environment. Moreover, an overview of the degree of environmental contamination of Slovakia was acquired. These results were fully used in subsequent environmental–geochemical mapping at more detail scales and following environmental-geochemical and ecological works.

Environmental-Geochemical Maps at a Scale of 1 : 50 000

Concerning the results of geochemical data obtained during the project of Geochemical atlases of the Slovak Republic, there is currently ongoing environmental-geo-

Tab. 1 General characteristics of individual parts of the Geochemical Atlas of Slovak Republic

Sampling medium	Sampling density	Number of samples	Remark	Contractor
Groundwater	1 sample/3 km^2	16 359	springs, wells, drillholes, drainage	Geological Service of SR
Stream sediments	1 sample/2 km^2	24 422	Active stream sediments <0,125 mm	Geological Service of SR
Rocks	Irregular grid	3 839	„main rock type“	Geological Service of SR
Soils	1 profile/10 km^2	9 892	1 profile = 2 samples (A and C horizons)	Research Institute of Soil Fertility, Bratislava
Forest biomass	1 sample/16 km^2	3 063	Composite sample	Forest Research Institute, Zvolen
Radioactivity	1 point/10 km^2	4 900 (reference points)	– total natural radioactivity – individual components of natural radioactivity K, U, Th, Rn	URANPRES, ltd., Spišská Nová Ves

Tab. 2 Overview of analysed elements and their detection limits in individual parts of the Geochemical atlases

Groundwater		*Stream sediments*		*Forest biomass*		*Rocks*		*Soils*	
element	det. limit [$mg.l^{-1}$]	element	det. limit [$mg.kg^{-1}$]	element	det. limit [$mg.kg^{-1}$]	element	det. limit [$mg.kg^{-1}$]	element	det. limit [$mg.kg^{-1}$]
CO_2aggr.	2,2	**Al**	100	**Al**	4	**Ag**	0,04	**Al**	100
CO_2 free	2,2	**As**	0,1	**As**	0,01	**Al**	100	**As**	0,1
O_2	0,1	**B**	5,0	**Ba**	2	**As**	0,1	**B**	3
conduct.	1,0	**Ba**	30,0	**Be**	0,001	**B**	3	**Ba**	5
Al	0,01	**Be**	0,1	**Ca**	0,1	**Ba**	30	**Be**	0,2
As	0,001	**Bi**[b]	0,1	**Cd**	0,003	**Be, Bi**	0,1	**Bi**	0,1
Ba	0,01	**Ca**	100	**Co**	0,03	**Ca, Ce**	10	**Ca**	100
Ca	1	**Cd**	0,1	**Cr**	0,02	**Cd**	0,1	**Ce**	0,01
Cd	0,0005	**Ce**	10,0	**Cu**	0,1	**Co**	1	**Cd**	5
Cl	0,1	**Co**	1,0	**F**	2	**Cr**	5	**Co**	1
COD_{Mn}	0,08	**Cr**	5,0	**Fe**	0,3	**Cu**	1	**Cr**	5
Cr	0,0005	**Cu**	1,0	**Hg**	0,001	**F**	50	**Cs**	1
Cu	0,0005	**Fe**	100	**K**	0,05	**Fe^{2+},Fe^{3+}**	100	**Cu**	1
F	0,1	**Ga**	5,0	**Li**	0,1	**Ga**	5	**F**	300
Fe	0,01	**Hg**	0,03	**Mg**	0,05	**Hg**	0,01	**Fe**	100
HCO_3	0,1	**K**	100	**Mn**	0,1	**K**	100	**Ga**	2
Hg	0,0002	**Li**	1,0	**N**	100	**La, Li**	1	**Hg**	0,01
K	0,1	**Mg**	100	**Na**	0,05	**Mg**	10	**K**	100
Li	0,002	**Mn**	10	**Ni**	0,3	**Mn**	10	**La**	1
Mg	1	**Mo**	0,2	**Pb**	0,07	**Mo**	0,2	**Li**	1
Mn	0,005	**Na**	100	**Rb**	0,8	**Na**	100	**Mg**	100
Na	0,1	**Ni**	1,0	**S**	50	**Ni**	1	**Mn**	10
NH_4	0,05	**P**	100	**Se**	0,01	**P**	100	**Mo**	0,2
NO_3	0,5	**Pb**	5,0	**Sr**	0,8	**Pb**	1	**Na**	100
Pb	0,001	**Rb**	5,0	**V**	0,07	**Rb**	5	**Ni**	1,0
PO_4	0,05	**Sb**	0,1	**Zn**	0,1	**S**	100	**P**	100
Sb	0,0002	**Se**	0,1			**Sb**	0,1	**Pb**	2
Se	0,001	**Sn**	1,0			**Se**	0,05	**Rb**	1
SiO_2	0,5	**Sr**	5,0			**Si**	100	**Sb**	0,1
SO_4	0,3	**Ti**	0,001			**Sn**	1	**Se**	0,1
Sr	0,01	**Tl**	0,2			**Sr**	5	**Sn**	1
Zn	0,001	**V**	5,0			**Ti**	10	**Sr**	1
Data in $mg.l^{-1}$, except pH value and conductivity ($\mu S.cm^{-1}$)		**W**	5,0			**V, W**	5	**V**	3
		Zn	1,0			**Y, Zn, Zr**	1	**W**	1
		Zr	5,0			**CO_2**	100	**Y**	1
		Y	5,0			**H_2O^+, 350 °C**	100	**Zn**	1
		Data in $mg.kg^{-1}$.							

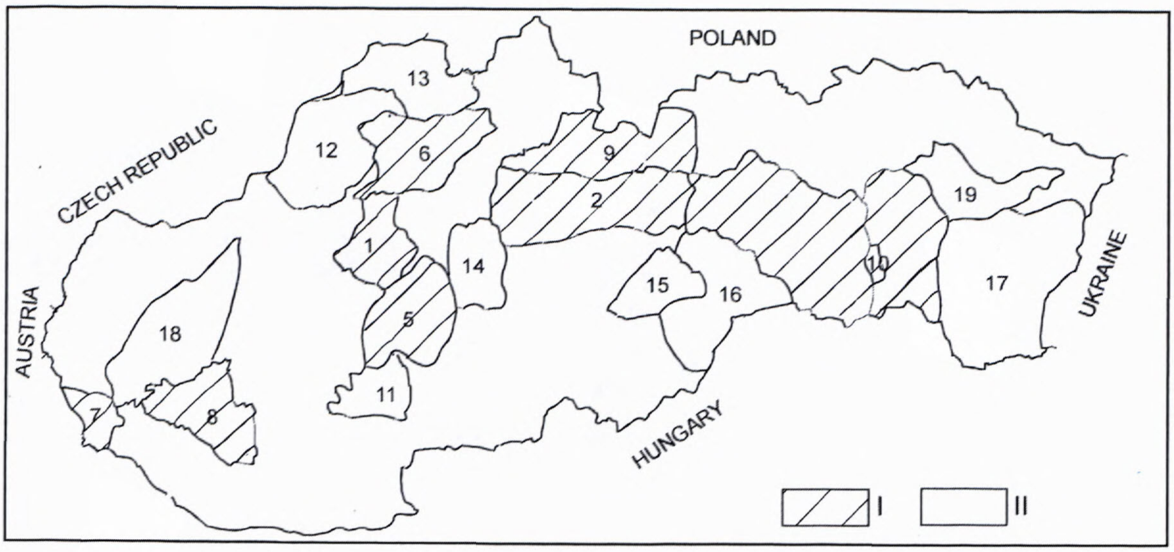

Fig. 2 Review of mapped regions (1 : 50 000): I = regions compiled 1991–1999: 1 = Horna Nitra, 2 = Nizke Tatry Mts., 3 = Hornádska kotlina basin and eastern part of Slovenské Rudohorie Mts., 4 = Košická kotlina basin and Slánske vrchy Mts., 5 = Žiarská kotlina basin and Banská Štiavnica area, 6 = Malá Fatra Mts. and some adjoining depressions, 7 = Veľká Bratislava urban area (1 : 25 000), 8 = Galanta district, 9 = Vysoké Tatry Mts. – Ružomberok – Liptovský Mikuláš, 10 = Košice urban area (1 : 25 000); II = regions under study: 11 = North-eastern part of Levice district, 12 = Central Považie, 13 = Kysuca drainage system, 14 = Banská Bystrica – Zvolen, 15 = Jelšava – Lubeník – Hnúšťa, 16 = Slaná drainage area, 17 = Tibreg, 18 = Trnavská pahorkatina, 19 = Vranov – Strážske –Humenné.

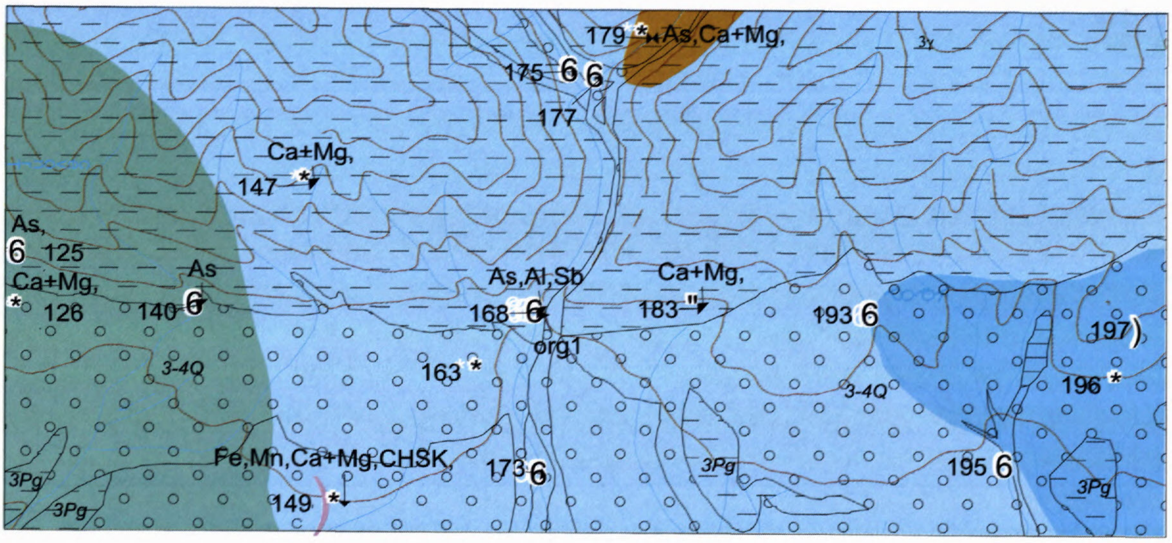

Fig. 3 Map of Natural Water Quality. A segment of the Vysoke Tatry Mts. Colours show qualitative properties of natural water. Traffic lights were used to show the water quality: blue represents the best water quality and red-most contaminated water. Raster represents the type of permeability. ?, □,? – type of sample collection sites with serial number, Al, As, Sb, ... – represent symbols of elements and components exceeding upper permissible limits.

chemical mapping of selected regions of Slovak Republic at a scale of 1 : 50 000 or a scale of 1 : 25 000 in urban areas (Fig. 2).

Environmental-geochemical maps, focused on sediments, soils, waters (ground, surface and meteoric) and rocks, represent a part of the basic set of maps of Geofactors of the environment. This set includes, except for geochemical maps also hydrogeological, engineering-geological, pedological maps, and maps of natural radioactivity. In order to unify and standardise the methodical process and compatibility of mapped regions there have been issued method instructions for the compilation of individual maps, which are obligatory for all works financed by the Ministry of Environment of the Slovak Republic.

The following maps are standard for all regions: a map of natural water quality, a map of stream sediment geochemistry, a map of geochemical rock types and a map of pedogeochemistry.

Taking into account specifics of regions the following special geochemical maps were created: a map of snow geochemistry (in urban areas), a map of chemical time

Slovak Geol. Mag., 6, 1(2000), 5–16

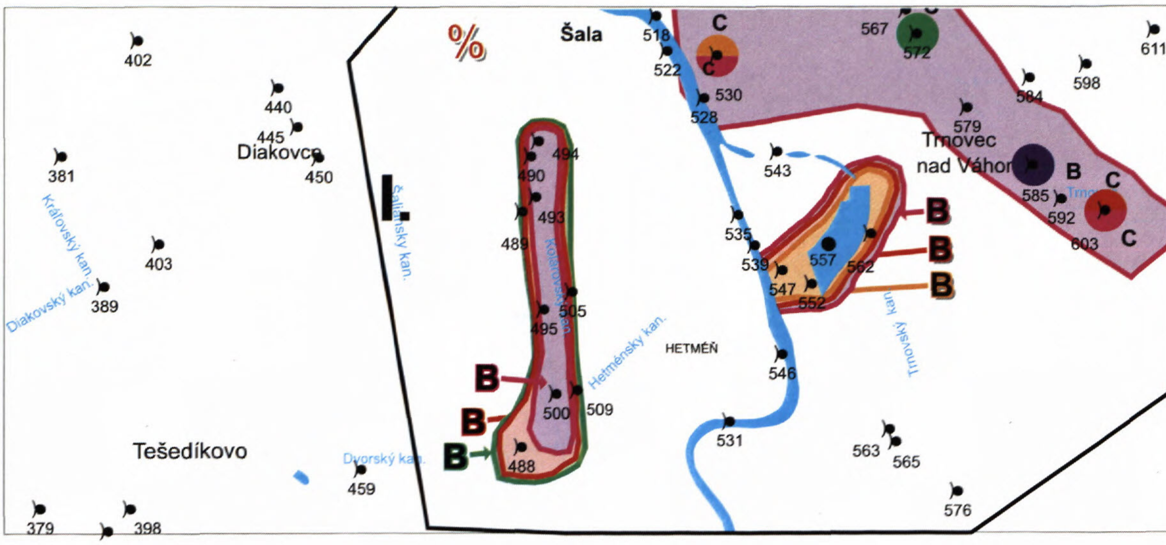

Fig. 4 Stream Sediments Geochemistry Map. A segment of the Galanta district. Multi-element map; colours – both surface and borders represent areas of exceeding contents of individual elements (green –Zn, violet – Hg, red – Cu, orange – As, ...). Circles represent the point anomalies. White represents non-contaminated areas. Points with serial number represent sampling collection sites. B, C – represent the level of exceeding values according to „Nederland letters". Contour borders with roman numbers allocate the areas recommended for detailed research.

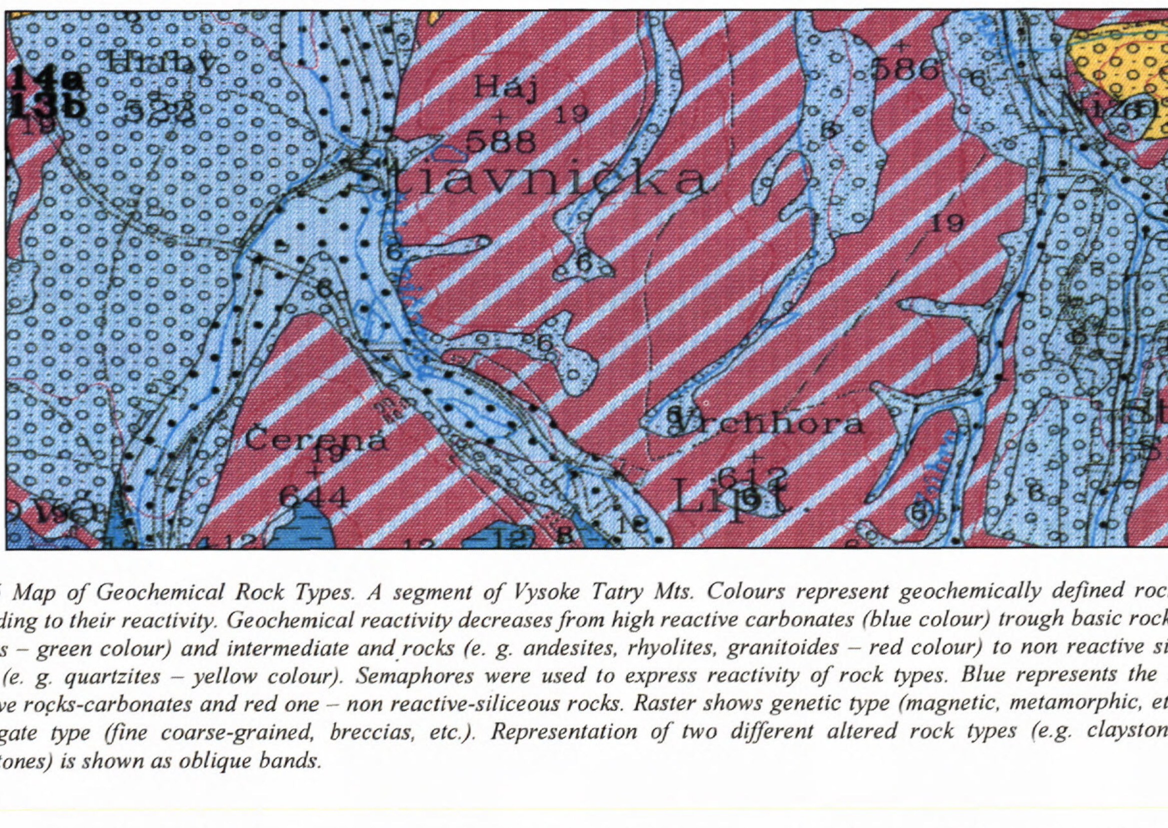

Fig. 5 Map of Geochemical Rock Types. A segment of Vysoke Tatry Mts. Colours represent geochemically defined rock types according to their reactivity. Geochemical reactivity decreases from high reactive carbonates (blue colour) trough basic rocks (e. g. basalts – green colour) and intermediate and rocks (e. g. andesites, rhyolites, granitoides – red colour) to non reactive siliceous rocks (e. g. quartzites – yellow colour). Semaphores were used to express reactivity of rock types. Blue represents the highest reactive rocks-carbonates and red one – non reactive-siliceous rocks. Raster shows genetic type (magnetic, metamorphic, etc.) and aggregate type (fine coarse-grained, breccias, etc.). Representation of two different altered rock types (e.g. claystones and sandstones) is shown as oblique bands.

bombs, a map of contamination degrees, a map of critical loads and their exceeding etc.

The analytic data and measurements gathered in the Geochemical atlases are used in the compilation of environmental-geochemical maps. The new sampling sites and new measurements are pointed predominantly in areas of geochemical anomalies found in the Geochemical Atlas, for the purpose of their verification and study in detail.

In environmental-geochemical maps the environmentally relevant anomalies (positive and negative) of elements/components that are of either human or geogenic origin are expressed in a synthetic way. As environmentally relevant elements and components we consider those that can negatively influence biota and man. The standard values (limit values from the Slovak Standards and standards valid for individual components of the environment) are the base for the determination of the environmentally important concentrations.

The number of monitored items for geochemical mapping usually ranges between 25–30 elements and compo-

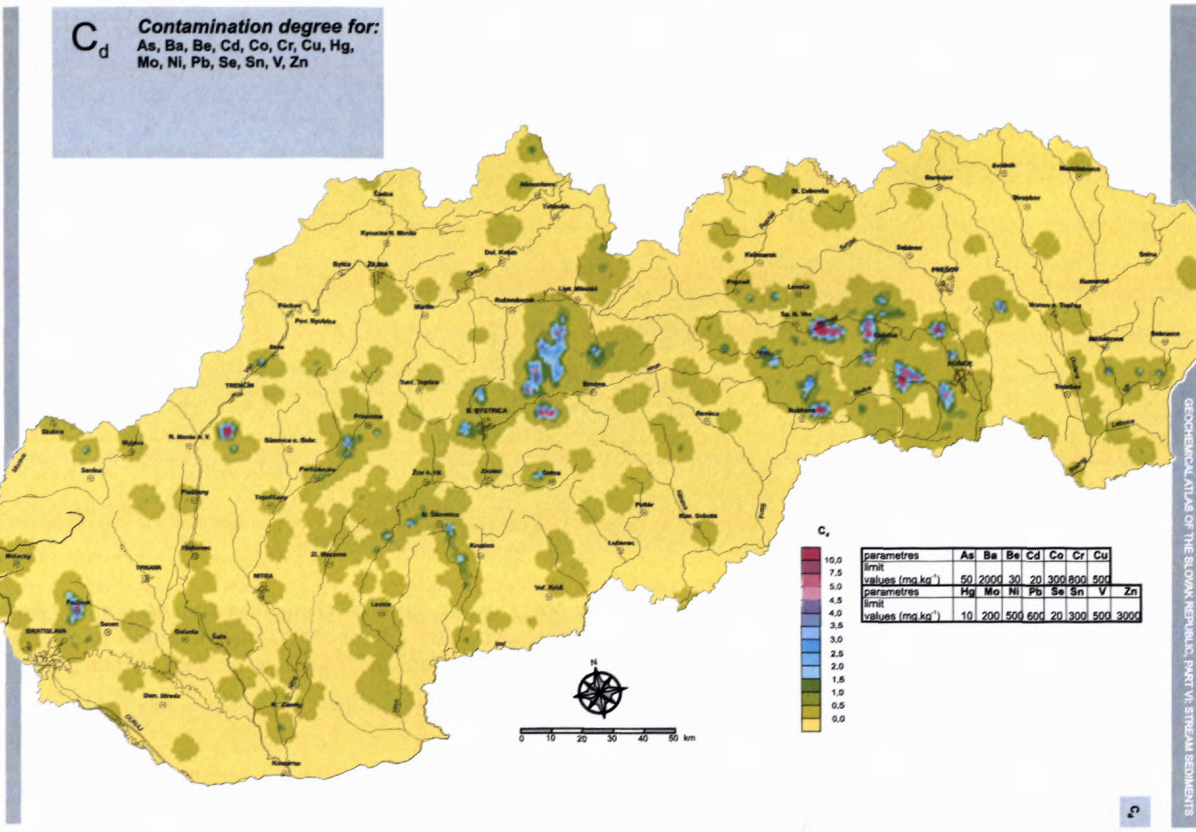

Fig. 6 Geochemical Atlas of Slovak Republic (1 : 1 000 000), Part VI: Stream Sediments. Map of Contamination Degree

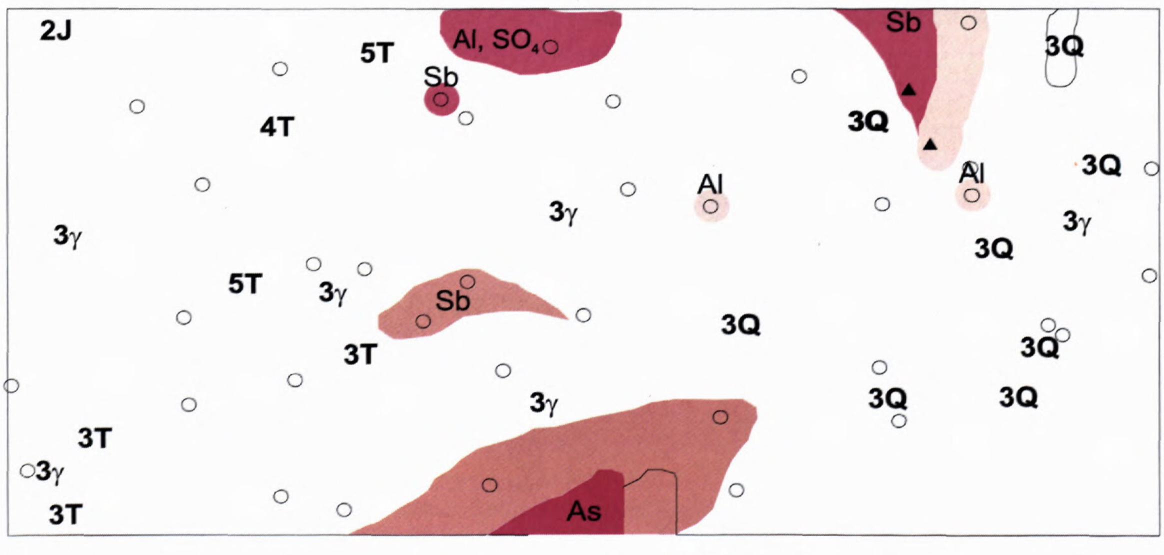

Fig. 7 Map of Areas with Contaminated Groundwater. A segment of the Nizke Tatry Mts. Al, Se ... symbols of elements exceeding limit values. Red colour, areas and point anomalies (local contamination) represent groundwater contamination. Red-most colour – higher contamination, white – represent non-contaminated areas. Geological age of aquifers is shown as a symbol (Pg – Paleogene, T – Triassic, ...). Raster represents type of aquifer permeability. Numbers show the degree of water bearings of aquifers (1-very high, 2-high .... 5 = area without aquifers).

nents (often even more). Modern computers enable to visualise the informative distribution of each monitored element in form of a model of monoelemental maps. However, the big set of maps hardly offers a full overview of the degree of contamination of the environment. On environmental-geochemical maps the monitored elements are joined into groups of elements according to their toxicity or their similar geochemical properties. In maps the determined groups of elements are plotted (Natural Water Quality Map – Fig. 3) or the anomaly concentrations are visualised with the use of method of intersection of subsets of monoelemental anomalies,

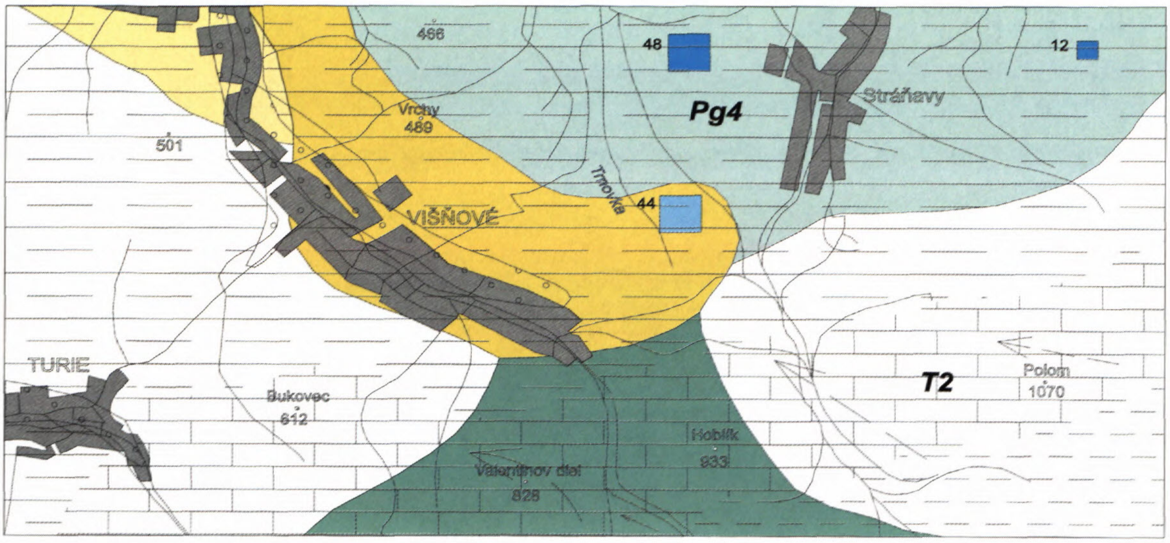

Fig. 8 Map of Chemical Time Bombs. A segment from the Mala Fatra Mts. Colours represent critical areas, plotted on the bases of potential CTB sources (contaminated groundwater, surface water, stream sediments). Square sizes show the degree of toxicity and intensity of blue colour shows the potentiality of spreading of CTB hot spots into the environment. Description of the rock environment as in Fig. 7.

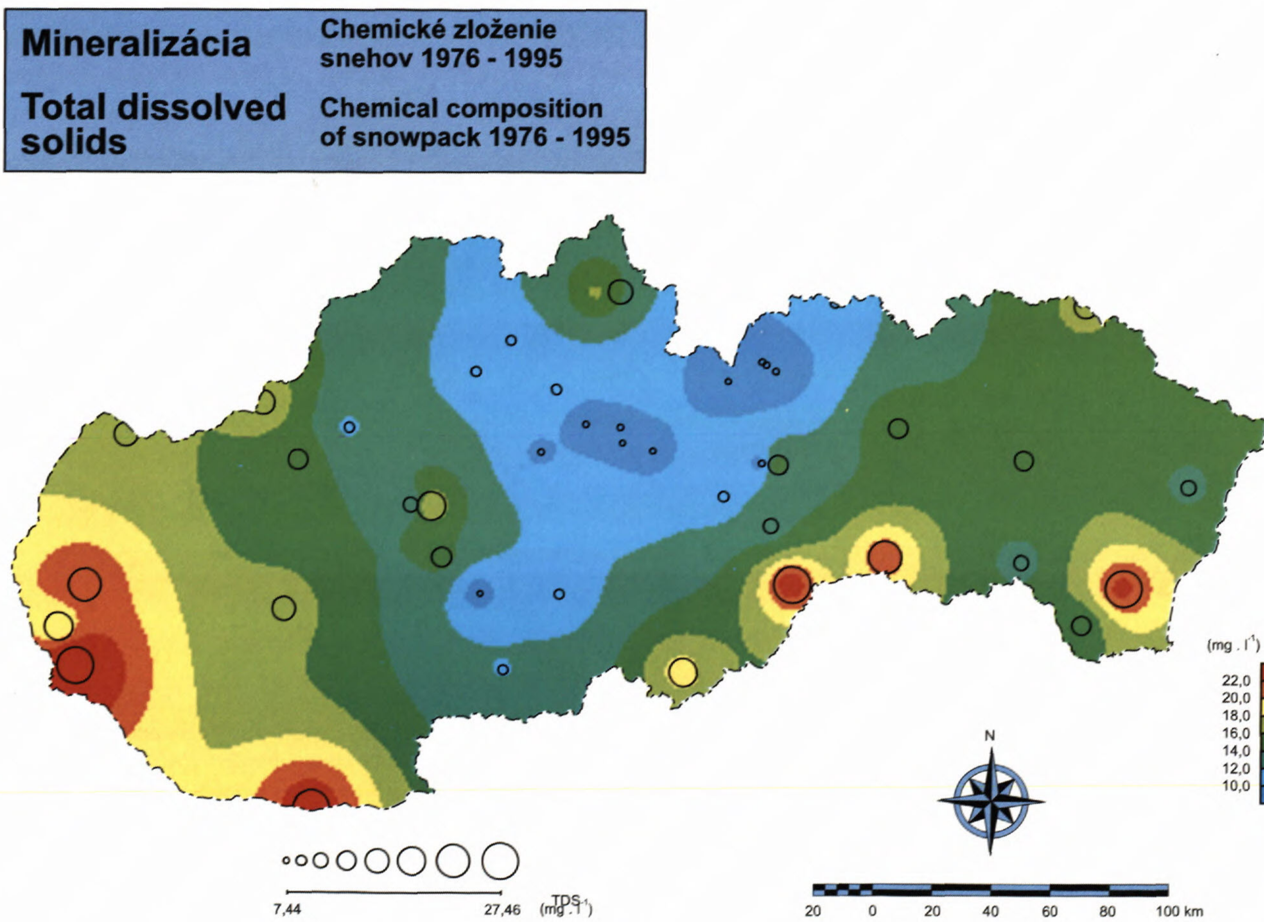

Fig. 9 Geochemical Atlas of the Slovak Republic, Part I: Groundwater. Distribution of TDS of snow-pack. Mean contains after 20 years of monitoring, 1997–1996.

which are expressed by colour of the first subset and in the intersection area by colour contour of the second subset (Stream Sediment Geochemistry Map - Fig. 4). In the case of the Map of Geochemical Rock types (Fig. 5), the distribution of chemical elements in rocks is expressed by mean concentrations of elements in rock bodies (complexes) that can be mapped in a field and outlined on a map. The complexes are outlined according to their geochemical (value of concentrations of monitored elements), as well as mineralogical (mineral content), and genetic criteria. A calculation of the contamination degree C_d that cumulates all excessive values of all monitored elements is another approach visualising and evaluating the analytic data from monitored analytic results.

The contamination level can be visualised in maps, the with help of mathematical interpolation, as well as with, the help of decorrugation (Fig. 6), or areas with equal degree of contamination can be joined into anomaly zones by the author of a map (Fig. 7). As an example of a map where various components of environment are evaluated, we can use the Map of Chemical Time Bombs (CTB – Fig. 8). In this map the anomalies in surface and underground waters and stream sediments are expressed together with point sources (waste disposals) (Rapant - Bodiš, 1995).

Mapping of critical loads/overloads was done in cooperation with the Norwegian Institute for Water Research (NIVA) according to the Henriksen et al. (1992) method. In the whole area of the Slovak Republic following receptors were monitored: surface and groundwater and forest soils (Bodiš et al. 1995, Babiaková et al. 1996).

A specific example of mapping of abiotic environmental component is mapping and monitoring of chemical composition of snow cover. This research was carried out since 1977 (Vrana et. al., 1989) a 44 selected sites around Slovakia (Fig. 9).

Conclusion

The applied geochemical research of environmental problems throughout the world dated since the end of fifties and intensively in sixties. In many countries there were established research teams that were focused on the application of geochemical background and its potential impact on agriculture, water management, land use, relation to biota and human health, etc. The first multi-disciplinary workshop has been organised in the USA at the beginning of 1972 (Thortnon, 1983) by the Sub-commission for Environmental Geochemistry in Relation to Health and Illnesses at National Academy of Science, and by the Association of Environmental Geochemistry.

The beginnings of environmental-geochemical research and survey of the Slovak Republic are dated since the second half of seventies. The task of protection of the environment and solving problems of the environment contamination has begun to be studied on the example of natural water because the water component of the environment is not only the most dynamic but also the most vulnerable.

The widespread geochemical mapping of Slovakia since the nineties is one of the bases for the geoscience disciplines for complex evaluation of the environment state of the Slovak Republic. The compiled geochemical databases and map outputs are integral part of the national environmental information system.

The methods used process for field and laboratory works, as well as the interpretations used in the Geochemical Atlases, were done with respect to well established methodology of similar foreign projects (IGCP 259, 360). The subsequent environmental-geochemical mapping with more detail scales has been done according to original methodical instructions that are based on the database and the results of the Geochemical Atlases and that respect the natural and socio-economic conditions in Slovak Republic.

On the one hand, the achieved results enable to evaluate and objectify environmental data of the Slovak Republic and determine the degree of its contamination, They form the base for the following environmental-geochemical works in regional and local scale and for study of rules of re-distribution and migration of elements in individual components of the environment and the mechanism of their influences and impacts on ecosystems and humans.

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