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Geochemical Atlas of Slovak Republic Part Rocks

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Abstract. As a part "Rocks" of the project "Geochemical Atlas of Slovak Republic" 64 main rock types of the Slovak territory (49 036 km^2) were defined during 1991 - 1995 (Marsina et al., 1995). The main rock types are presented through: **unique database** containing 3 839 samples placed in 7 main groups, **Brief text explanations** describing each rock type (geologic-tectonic setting, petrography, modal composition, anomalous element distribution, etc). Basic statistical parameters (mean, standard deviation, median, geometric mean, minimum, maximum, number of values below detection limit, count) were counted for each rock type and **Map of lithogeochemical types of Slovakia at a scale of 1 : 500 000** was constructed.

These data represent an information of the element distribution in the primary lithology. Thereby it is possible to distinguish primary lithogeochemical background and/or anomalies from the anomalies caused by metallogenic processes and anthropogenic impacts.

Key words: Geochemical atlas, rocks, main rock types, lithogeochemical database, lithological parameters, statistical parameters.

Introduction

Main aim of the Geochemical Atlas of the Slovak Republic - part Rocks - was to create the Lithogeochemical database on the distribution of all major and 26 minor elements and on other data, in the main rock types of Slovakia. The obtained geochemical data (Marsina et al, 1995) were needed for the complex characterization of the primary element distribution in all Slovakian main rock types. This knowledge was used as foundation for the distinctions between primary - lithological element distribution and secondary - metallogenicaly or anthropogenicaly caused distribution of the studied elements in other researched media (water, soil, biomass and stream sediments).

About 50 geologists and geochemists contributed to the research in various ways. Besides the Dionýz Štúr Institute of Geology (since January 1, 1996, a part of the Geological Survey of the Slovak Republic) other organizations participated; mainly the Faculty of Natural Sciences of Comenius University and Geological Institute of the Slovak Academy of Science.

During the first stage, all the accesible older rock analyses were collected.

During the second stage, new rock samples were taken on an irregular grid and were analysed to get suffi cient information about each lithotype present on the Geological Map of Slovakia at a scale of 1 : 500 000.

Inasmuch at all the achievements of the subproject "Rocks" will be published during 1998 as the "Catalogue of the Main Rock Types of Slovakia", this paper gives only the basic information dealing with methodology and brief text explanations of 64 main lithotypes including a table with some statistical data.

A brief review of the geological structure of Slovakia

(Hók, Kováč after Biely et al. (1992), in Maňkovská, in press)

Geologically, most of the Slovak territory is covered by the Western Carpathians (fig. 1).

As far as the age of tectonic individualisation of their geological units is concerned the Western Carpathians can be divided into outer and inner parts.

The Outer Western Carpathians are represented by the flysch belt units (the Magura and Krosno flysch), which were thrust over the margin of the European platform during the Tertiary period. Sandstones, mudstones and conglomerates are the predominant lithotypes.

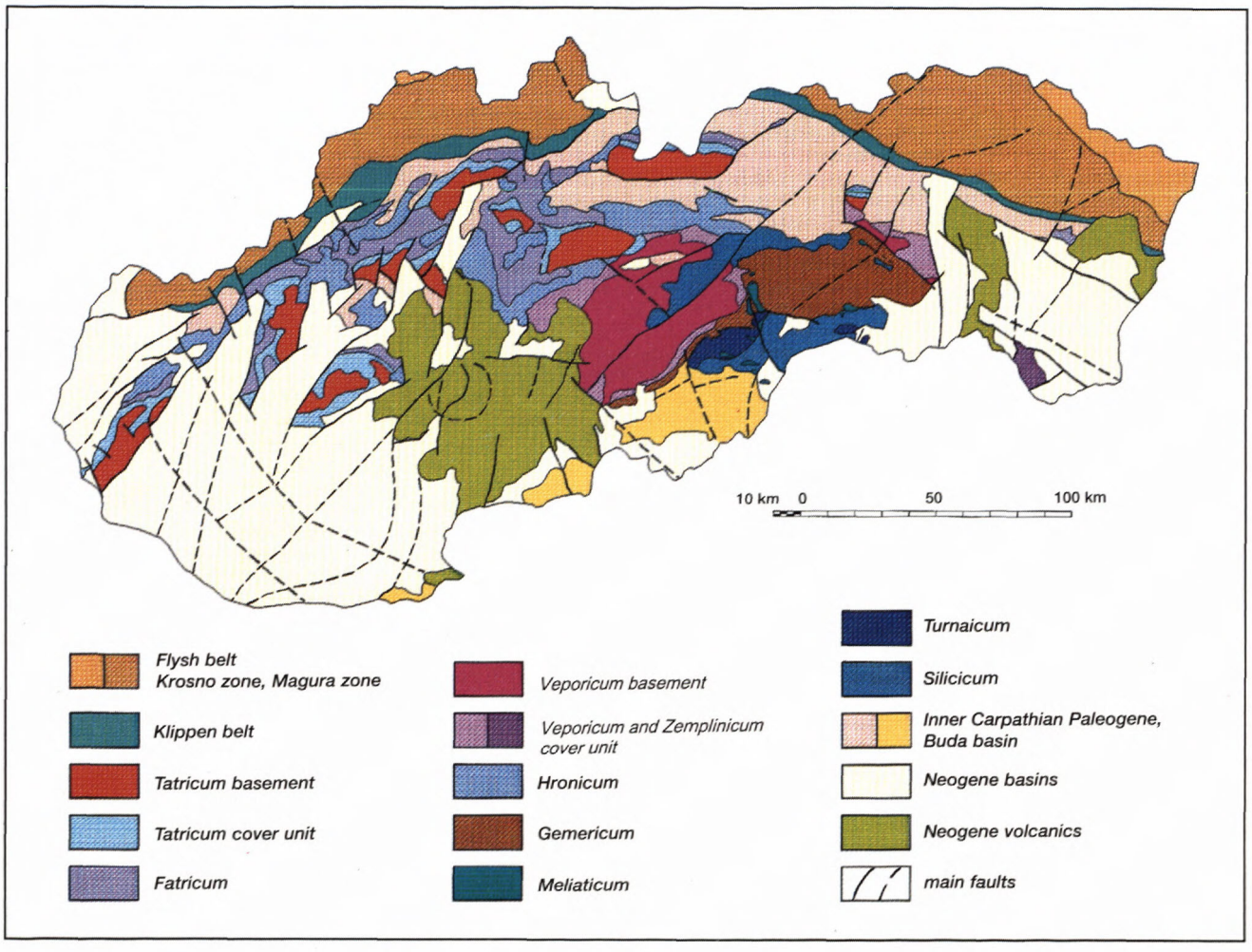

Fig. 1: Geologic-tectonic sketch of the Slovak part of Western Carpathians

The Klippen belt is an independent tectonic unit situated between Outer and Inner Western Carpathians. It comprises two basic units, the Čorštýn Unit, composed of the shallow water carbonate facies and a deep water Kysuce-Pieniny Unit. Both units were involved in several stages of folding, which occurred to some degree in the Inner Western Carpathians, or more intensely, with the Outer Western Carpathians.

Tectonic individualisation of the Inner Western Carpathians took place during the Middle Cretaceous Period. The principal tectonic units of the Outer Western Carpathians are divided, from north to south, into the Core mountain belt, the Veporicum belt and the Gemericum belt.

The Core mountain belt is made of the Tatricum Unit, composed of crystalline rocks, which are mostly granitoids, and of autochthonous cover units. In rising sequence there include Upper Paleozoic rocks, (only locally present) a Lower Triassic clastic arkosic to siliceous quartzite formation, Middle Triassic limestones and dolomites and Upper Triassic and Lower Cretaceous limestones, dolomites, marlstones, shales and sandstones. The Fatricum nappe (composed predominantly of the Krížna nappe) and the Hronicum Unit (made of the Choč nappe) are characterised by thin bedding.

The Veporicum belt comprises crystalline rocks (granitoids and crystalline schists) and a considerably reduced Mesozoic cover (siliceous sandstones, shales, limestones and dolomites), making together the Veporicum Unit. This unit is thrust northwards over the Tatricum Unit. The Veporicum Unit is overlain by the Hronicum and Silicicum (Silica nappe) nappes, represented mainly by Triassic limestones and dolomites.

The Gemericum belt is the southernmost unit of the Western Carpathians. Composed of low metamorphosed Early Paleozoic rocks of the flysch character and of Late Paleozoic cover with a strongly reduced Mesozoic development, this rock complex represents, in fact, the Gemericum Unit, thrusted northward over the Veporicum Unit. The Gemericum Unit, as well as the area south of it, are overlain by the Meliaticum, Turnaicum and Silicicum nappes, all composed predominantly of the carbonate rocks.

The Inner Carpathian Paleogene (conglomerates, sandstones, shales) with the relics of Upper Cretaceous

sediments and with the Neogene sedimentary basins (conglomerates, sandstones, mudstones, limy mudstones and rare carbonates and coal) represent a tectonic molasse. The Neogene volcanics and volcani-clastic rocks (Miocene) are products of back-arc volcanism, in which the andesites are the predominant lithology.

Methodology

1. Sampling

All new samples were taken predominantly from outcrops (some of them also from boreholes and adits) In general only fresh - unweathered and unaltered samples were taken. The grid sampling was irregular. The weight of samples depended on grain size, as follows: above 30 mm - 5 kg, 10 to 30 mm - 2 kg, below 10 mm - 1 kg. Thin sections were made of all samples, with the exceptions of carbonates, clays and claystones.

2. Analytical procedures

Together, 3 839 samples of three kinds were used for this study: a) archive analysed samples (not all minor elements determined), b) archive samples reanalysed for missing minor elements and c) new samples analysed for all major and 26 minor elements in the Geoanalytical Laboratories of Geological Survey of Slovak Republic at Spišská Nová Ves, with following analytical techniques and detection limits (in brackets, for major elements in %, for minor elements in ppm) :

major elements - SiO_2 - ICP OES (inductively coupled plasma optical emission spectrometry, 0.01), TiO_2 - ICP OES (0.001), Al_2O_3, Fe_2O_3, FeO - ICP OES (0.01), MnO, MgO, CaO - ICP OES (0.001), Na_2O, K_2O, P_2O_5, S_{Total} - ICP OES (0.01), H_2O^+ (350°C) - gravimetry (0.01), CO_2 - coulometry (0.01).

minor elements: Ag - GAAS (atomic absorption spectrophotometry, electrothermal atomization, 0.04), As - HGAAS (atomic absorption spectrophotometry, 0.1), B - ICP OES (3.0), Ba - XRF (x-ray fluorescence spectrometry, 30.0), Be - ICP OES (0.1), Ce - ICP OES (10.0), Cd - GAAS (0.1), Co - ICP OES (1.0), Cr - ICP OES (5.0), Cu - ICP OES (1.0), F - ISE (ionselective methods, 50), Ga - XRF (5.0), Hg - AAS - TMA (trace mercury analyser 0.01), La - ICP OES (1.0), Li - AAS (1.0), Ni - ICP OES (1.0), Pb - GAAS (1.0), Rb - XRF (5.0), Sb - HGAAS (0.1), Se - GAAS (0.05), Sn - GAAS (1.0), Sr - XRF (5.0), V - ICP OES (5.0), Y - XRF (1.0), Zn - ICP OES (1.0), Zr - XRF (1.0).

3. Statistical sets representing rock types

Statistical sets were created in two steps. In the first step, 100 sets - rock types were defined according to lithological, regional geologic and stratigraphic criteria. Several of the sets had shown either small representativity or geochemical similarity with other sets after counting all the basic statistical parameters (see bellow). Therefore, the second stage resulted in joining of several sets and creating of the final 64 sets - rock types. The main criteria used were lithology and the difference in element distribution.

4. Statistics

For each statistical set - rock type the following basic statistical parameters were counted: mean, standard deviation, median, geometric mean, minimum, maximum, number of values below detection limit and count (see example on table 1). Means / counts for each rock type - statistical set is present on table 2.

Mean and geometric mean were not counted in those cases in which more than 40 % values of an element content were below the detection limit. In other cases, half of the value below detection limit was included in the calculation. Extreme values = mean ± 3 standard deviations were exluded from the calculations.

138 samples representing "exotic", transitional or mixed rock types were excluded from the calculations and they were not included in any of the 64 statistical sets - rock types:

Granitoids (Crystalline)	770 samples	6 sets (Gt - 1 to Gt - 6)
Metamorfites (Crystalline)	225 samples	7 sets (Mt - 1 to Mt - 7)
Paleozoic (remaining)	457 samples	15 sets (Pz-1 to Pz -15)
Mesozoic	395 samples	12 sets (Mz - 1 to Mz -12)
Paleogene	258 samples	8 sets (Pg - 1 to Pg - 8)
Sedimentary neogene	237 samples	6 sets (Ne - 1 to Ne - 6)
Neovolcanics	1 359 samples	10 sets (Nv - 1 to Nv - 10)
Together:	3 701 samples	64 sets

64 main rock types of Slovakia - brief description

(after Marsina et al., 1995)

1. Granitoids

1a. Tatricum and Veporicum

Gt - 1 consists of amphibole-biotite diorites which generaly constitute fairly small bodies several metres and/or tens of metres in size. They are found mainly in the Malé Karpaty, Nízke Tatry, Vysoké Tatry, Strážovská hornatina, Čierna hora, Žiar and Malá Fatra Mts. Principal rock forming minerals (range in volume %): quartz 3.2 - 26, plagioclase 19 - 62, potassium feldspar 0 - 4, amphibole 9 - 66, biotite 5 - 20, accessory minerals 1.5-7 (apatite, titanite, zircon, diopside, magnetite, allanite, pyrite ± ilmenite).

Table 1: Granitic rocks of the Tatric and Veporic Units

	SiO_2 (%)	TiO_2 (%)	Al_2O_3 %)	Fe_2O_3 (%)	FeO (%)	MnO (%)	MgO (%)	CaO (%)
Mean	70.59	0.43	14.97	1.09	1.42	0.042	0.93	1.90
Standard Deviation	2.13	0.24	1.05	0.53	0.64	0.015	0.36	0.70
Median	70.62	0.38	14.85	1.00	1.40	0.040	0.85	1.95
Geometric Mean	70.56	0.37	14.94	0.96	1.23	0.039	0.86	1.74
Minimum	61.94	0.06	12.09	0.18	0.10	0.010	0.05	0.14
Maximum	75.75	1.50	19.32	3.03	3.23	0.100	2.25	3.52
Detection limit (d.l.)	0.01	0.001	0.01	0.01	0.01	0.001	0.001	0.001
Number of values below d. l.	0	0	0	0	0	0	0	0
Count	378	374	377	360	359	370	343	378

	Na_2O (%)	K_2O (%)	P_2O_5 (%)	CO_2 (%)	S_t. (%)	Ag (ppm)	As (ppm)	B (ppm)
Mean	3.89	3.27	0.19	0.54	0.05		1.6	11.7
Standard Deviation	0.58	0.65	0.09	0.26	0.03		1.4	6.2
Median	3.86	3.25	0.18	0.56	0.04		1.2	10.6
Geometric Mean	3.82	3.21	0.17	0.46	0.04		1.0	9.9
Minimum	0.21	1.32	0.01	0.11	0.005	0.02	0.1	1.7
Maximum	5.63	5.00	0.58	1.23	0.18	2.40	6.2	37.0
Detection limit (d.l.)	0.01	0.01	0.01	0.01	0.010	0.04	0.1	3.0
Number of values below d. l.	0	0	0	0	2	70	15	0
Count	356	328	332	111	107	99	116	258

	Ba (ppm)	Be (ppm)	Ce (ppm)	Cd (ppm)	Co (ppm)	Cr (ppm)	Cu (ppm)	F (ppm)
Mean	941	2.36	61.0		4.6	21.2	10.2	227
Standard Deviation	335	0.79	19.2		3.5	12.6	14.1	132
Median	910	2.30	58.0		3.8	20.0	5.0	200
Geometric Mean	880	2.23	58.0		3.4	16.8	5.5	185
Minimum	242	0.50	21.0	0.05	0.5	1.0	0.5	25
Maximum	2140	6.20	128.0	1.00	20.0	60.0	87.0	700
Detection limit (d.l.)	30	0.10	10.0	0.10	1.0	5.0	1.0	50
Number of values below d. l.	0	0	0	66	25	0	8	8
Count	347	277	215	124	299	343	319	120

	Ga (ppm)	Hg (ppm)	La (ppm)	Li (ppm)	Ni (ppm)	Pb (ppm)	Rb (ppm)	Sb (ppm)
Mean	16.1	0.08	33.2	31.8	6.8	20.5	91.6	0.76
Standard Deviation	5.7	0.10	12.2	17.6	3.7	10.6	30.0	0.99
Median	17.0	0.04	32.0	26.0	6.0	20.0	92.0	0.49
Geometric Mean	14.9	0.04	30.9	27.6	5.9	17.2	86.3	0.40
Minimum	2.5	0.01	9.4	6.0	1.5	1.0	30.0	0.05
Maximum	40.0	0.47	74.0	88.0	21.0	52.0	161.0	5.30
Detection limit (d.l.)	5.0	0.01	1.0	1.0	1.0	1.0	5.0	0.10
Number of values below d. l.	3	10	0	0	0	0	0	14
Count	205	75	214	268	341	309	305	175

	Se (ppm)	Sn (ppm)	Sr (ppm)	V (ppm)	Y (ppm)	Zn (ppm)	Zr (ppm)
Mean		2.9	373.8	33.5	13.2	53.9	134.8
Standard Deviation		2.3	168.8	16.5	6.3	17.6	44.7
Median		2.0	357.0	32.0	12.0	55.0	138.0
Geometric Mean		2.0	333.6	28.1	11.8	50.9	125.6
Minimum	0.03	0.5	39.0	1.5	1.0	18.0	10.0
Maximum	0.50	11.0	980.0	93.0	51.0	107.0	263.0
Detection limit (d.l.)	0.05	1.0	5.0	5.0	1.0	1.0	1.0
Number of values below d. l.	80	35	0	0	0	0	0
Count	98	249	347	346	339	270	346

Gt - 3 GRANODIORITES to GRANITES (378 samples)

Due to strong Alpine tectonic and metamorphic overprinting in the whole Veporic unit, the granitoids of Tatric unit are separated into Gt-2 to Gt-4 sets of the granitoids of the Veporic unit.

Gt - 2 includes Tatric biotite tonalites, hybrid biotite tonalites and Veporic Sihla-type granodiorites to biotite tonalites, as well as hybrid biotite tonalites to granodiorites.

a) Tatric unit: biotite tonalites occur in all core mountains except for the Žiar. Small quantities of hybrid biotite tonalites are present in the Čierna hora, Nízke Tatry, Malá Fatra, Malá Magura and Žiar. The principal rock forming minerals (range in volume %): quartz 20 - 40, plagioclase 30 - 60, potassium feldspar 0 - 16, biotite 3 - 21, amphibole 0 - 10, muscovite 0 - 5, accessory minerals 1 - 4 (apatite, zircon, magnetite, sillimanite, garnet ± titanomagnetite ± allanite ± ilmenite ± monazite ± titanite).

b) Veporic unit: Sihla-type granodiorites to biotite tonalites, present mainly in the western sector of the Vepor Massif. On the contrary hybrid biotite tonalites to granodiorites are found on the southeastern edge of the central granitoid body and in the Kohút zone. Principal rock forming minerals (range in volume %): quartz 19 - 35, plagioclase 40 - 60, potassium feldspar 0.5 - 27, biotite 4 - 13, amphibole 0 - 8, muscovite 0.5 - 4, accessory minerals 1 - 3.5.

Gt - 3 are Tatric and Veporic granodiorites to granites composed of four major rock types.

a) Tatric unit: Biotite and two-mica granodiorites, as well as two-mica granites, are present in all core mountains. Principal rock forming minerals (range in volume %): quartz 22 - 42, plagioclase 27 - 49, potassium feldspar 10 - 36, biotite 2.5 - 12, muscovite 0.5 - 7.7, sillimanite 1 - 4, accessory minerals 0.5 - 3.5 (apatite, zircon, ilmenite, ± monazite, ± garnet ± magnetite, ± allanite, ± titanomagnetite ± hematite ± xenotime ± tourmaline).

b) Veporic unit: Vepor-type porphyritic granodiorites to granites dominate in the Vepor pluton (Kohút and Stolica Massifs). Massive tonalites-granodiorites occur in the southernmost Veporicum from Krokava, through Lubeník Dam, as far as Hladomorná. Principal rock forming minerals (range in volume %): quartz 30 - 45, plagioclase 32 - 48, potassium feldspar 4 - 18, biotite 3 - 9, muscovite 0.4 - 3, accessory minerals 0.6 - 2.5.

Gt - 4 comprises Tatric and Veporic leucogranites, which in turn include 3 main rock types.

a) Tatric unit: leucogranitoids widespread in all core mountains.

b) Veporic unit: Leucogranitoids in southern Veporicum (Kohút zone) intrude mildly metamorphosed Paleozoic rocks. Hrončok-type granites are found in the Kamenistá dolina Valley and Hrončok Valley and recently also in the Čierny Balog area.

Principal rock forming minerals (range in volume %) of tatric and veporic leucogranites: quartz 28-40, plagioclase 20-46, potassium feldspar 10-36, biotite 1-8, muscovite 2 - 12, accessory minerals 0.6 - 2.5 (garnet, apatite, zircon, ilmenite, ± monazite, ± tourmaline, ± titanite.

Gt - 5 comprises Tatric pegmatites and aplites. These rocks are present in all core mountains. They form relatively thin veins (several metres to tens of meters) of various len. They occur in the granitoids, as well as in the surrounding metamorphic rocks. Principal rock forming minerals (range in volume %): quartz 30 - 43, plagioclase 20 - 37, potassium feldspar 19 - 42, biotite 0.5 - 12, muscovite 2.5 - 15, accessory minerals 1 - 2.5 (garnet, beryl, pyrochlore, gahnite, columbite - tantalite, fersmite, microlite).

1b. Gemericum

Gt - 6 consists of Gemeric granitoids. They are medium- to coarse-grained, but also slightly porphyritic rocks of pinkish-gray colour. Principal rock forming minerals (range in volume %): quartz 27 - 46, plagioclase 15 - 30, potassium feldspar 25 - 40, biotite 0 - 7, muscovite 2.5 - 10, accessory minerals 0.8 - 2.5 (tourmaline, zircon, apatite, garnet, ±magnetite).

2. Metamorphic rocks

Mt - 1 - Metapelites: low-grade metapelites (chlorite, muscovite and biotite-bearing schists and phyllites) are abundant in the Malé Karpaty crystalline, notably on the edge of the Bratislava Massif and between Pernek and Pezinok. In the Veporicum, they occur in the Paleozoic metasedimentary sequences in the southeastern part at the boundary with Gemericum. Medium-grade mica schists with staurolite, garnet and Al_2SiO_5 polymorphs (andalusite, sillimanite, kyanite) are present in the core mountains of Tatricum (Západné Tatry and Považský Inovec). In the Veporicum, they occur in several "mica schists complexes" (e.g.Hron and Ostrá complex).

Mt - 2 - Metapelites: high-grade paragneisses and migmatites rich in sillimanite and garnet occur in almost all Tatric core mountains (e.g. Západné and Nízke Tatry Tatry, Malá Fatra, Strážovské vrchy), as well as in the Veporicum (Kraľova hoľa complex).

Mt - 3 - Metapsammites: low-grade metasediments (quartz-rich schists and metaquartzites) are most widespread in the Malé Karpaty, they also occur in the SE Veporicum.

Mt - 4 - Metapsammites: quartz-rich gneisses to metaquartzites are common in several core mountains of Tatricum (e.g. Západné Tatry, Nízke Tatry) and they represent higher-grade-metamorphosed equivalents of the psammitic sediments.

Mt - 5 - Metabasites: green schists and amphibolites correspond to various types of metamorphosed basic rocks. They occur in the Tatric core mountains (Malé Karpaty, Západné Tatry, Nízke Tatry, Malá Fatra, Tribeč) as well as Veporicum (Hron and Ľubietová complex).

Mt - 6 - Metavolcanics - acid to intermediate (metarhyolites, metadacites) are represented by samples from the Jánov Grúň complex in the Veporicum.

Mt - 7 - Metagranitoids (orthogneisses, mylonites) represent intensely sheared and metamorphosed rocks of magmatic origin. They are common in high-grade, migmatitized complexes of the Tatricum (Ďumbierske Tatry, Západné Tatry, Malá Fatra) and Veporicum.

3. Paleozoic

3a. Early Paleozoic of the Gemericum

Pz - 1 - Psammites - Early Paleozoic sandstones comprise quartzose and lithic metagraywackes (Vozárová, 1993). Dominant rock forming minerals are (range in volume %): Quartz - 60-95 %; plagioclase - 2-16 %; rock fragments (volcanites - 8-17 %; sediments - 2-3 %), heavy minerals - 0,5 -1 % (zircon, edisonite, tourmaline, titanite, magnetite, ilmenite, anatase, apatite). The grade of metamorphism corresponds with the low-pressure greenschist facies.

Pz - 2 - Pelites, siltstones with variable content of semigraphite. Sericite and chlorite-sericite metapelites are most widespread. Critical metamorphic mineral associations are: muscovite + albite; muscovite + paragonite + albite; quartz + chlorite + muscovite with minor content of epidote, edisonite and graphite. Origin of biotite is linked to the metapelites with high Fe/Mg ratio and higher content of K. Geobarometric estimations ($d_{0,60,\ 311}$ parametres of muscovites) proved P = 2-3 kbar, T= 350 - 370 °C (Sassi, Vozárová, 1987).

Pz - 3 - Acid volcanics and volcanoclastics dominated by rhyolite volcanoclastics. Their composition corresponds with rhyolite and dacite tuffs, tuffites and rarely to quartzose andesite volcanoclastics. They are of calc-alkaline affinity (mainly the Gelnica Group). The only exception are rare layers of subalkaline intermediate and acid volcanics in the basal part of the Rakovec Group. The Gelnica Group calc-alkaline volcanism was related to an active continental margin.

Pz - 4 - Intermediate and basic volcanics and volcanoclastics - occur mainly in the Rakovec Group. The bulk composition and contents of REE of the Rakovec Group metabasalts suggests E-MORB / OIT and partly island arc tholeiites (Bajaník, 1981, Ivan, 1994). Rare fragments of tholeiitic basalts with CAB, E - and N-MORB affinity are associated with thick volcanogenic flysch sequences of the Gelnica Group.

Pz - 5 - Lydites - form thin-bedded bodies along with black phyllites and carbonates. Accumulation of rare earth elements is strongly related to the content of former clayey and organic matter.

3b. Late Paleozoic of the Gemericum

Pz - 6 - Psammites - are widely distributed in Carboniferous and Permian formations. The grade varies of metamorphism from anchizone to low - temperature greenschist facies. Dominant rock forming mineral in Lower Carboniferous metapsammites is quartz (70-80 %, in some cases even more) accompanied by plagioclase, micas and fragments of schists, lydites, volcanites, gneisses and rare granitoids. Westphalian metapsammites contain mainly rock fragments (50 %) together with feldspars (13 %), quartz (36 %) and micas (2 %). The only exception is the Upper Westphalian metapsammites of Hámor Formation, containing predominantly quartz grains (80 %) with minor feldspars (5 %) and rock fragments (15 %) (Vozárová, Vozár, 1988).

Permian metapsammites of the northern and southern Gemeric Units are distinctly different. The north-Gemeric psammites are relatively richer in feldspars (19 %) and rock fragments (20 %) with less content of quartz (50-60 %). Dominant rock forming mineral in the south Gemeric psammites is quartz (in average 90 %) accompanied by feldspars (3-8 %), micas (1-2 %) and rare fragments of acid volcanics.

Pz - 7 - Pelites, siltstones - Carboniferous pelites contain a detrital admixture dominated by quartz and clastic micas. Permian sediments contain, in addition to quartz and micas, also fragments of various rocks. As a consequence of different sedimentary and climatic conditions the Carboniferous metapelites contain organic admixture and Permian shales iron oxides.

Pz - 8 - Acid volcanics and volcanoclastics - are most widespread in Permian sequences of the northern and southern Gemericum and in the Bôrka Nappe. Their chemistry shows calc-alkaline affinity. Felsitic varieties with minor content of quartz, K - feldspar and plagioclase phenocrysts dominate. In general, different types of volcanoclastics prevail.

Pz - 9 - Intermediate and basic volcanics and volcanoclastics - are most widely distributed in Carboniferous sequences of the northern Gemeric zone, in minor quantities also in the Permian of the same zone. Their magmatic affinity is completely different. Carboniferous volcanics are of tholeiitic type with an E-MORB trend and Permian andesite/basalts have calc-alkaline affinity.

Pz - 10 - Limestones - In the Late Paleozoic Gemeric units they occur in the Lower Carboniferous Ochtiná Formation and Črmeľ Group, and in the Upper Carbonif-

erous Zlatník Formation. Among carbonate minerals, calcite is common and dolomite rare. Their chemical composition was influenced by detritic admixture (clayey material, quartz grains).

Pz - 11 - Dolomites and magnesites - These carbonates are associated with limestones. Magnesites occur primarily in the Lower Carboniferous. Principal carbonate minerals comprise dolomite and magnesite. Also talc + quartz, as a part of critical metamorphic mineral association are present.

3c. Late Paleozoic of the Tatricum, Veporicum, Zemplinicum and Hronicum

Pz - 12 - consists of two rock subgroups:

a) Psammites of the Lower Paleozoic in the Tatricum, Zemplinicum and Veporicum. Their composition corresponds to arkoses, arkosic graywackes and lithic graywackes. Content of main rock forming minerals vary in a wide range (in volume %): Quartz (20-65 %), feldspars (18-34 %), micas (8-20 %), rock fragments including synsedimentary volcanites (9-27 %). Metamorphic mineral assemblages indicated anchizone to low - temperature greenschist PT-conditions.

b) Psammites of the Hronic Late Paleozoic.

Sandstones are the most widespread lithotype here. They occur in both Carboniferous and Permian sequences. Quartz (54-66 %); feldspars (20 %), micas (6-4 %) and rock fragments (14-26 %) are their principal constituents (range in volume %).

Psammites of the Hronic Late Paleozoic are mostly unmetamorphosed. Their alteration reached PT conditions of diagenesis or the low - temperature part of anchizone (Plašienka et al., 1989, Šucha, Eberl, 1992).

Pz - 13 - Pelites and siltstones. These include Late Paleozoic pelites and siltstones in the Tatricum, Veporicum and Zemplinicum, as well as Late Paleozoic siltstones in the Hronicum. Their composition, as well as grade of metamorphism, reflects close association with psammite equivalents. In general, the pelites of the Veporicum, Tatricum, Zemplinicum show a low degree of maturity, with the admixture of course detritic material. Pelites and siltstones of the Hronicum are relatively more mature. Carboniferous sediments contain a variable admixture of organic matter. Permian fine grained sediments contain iron oxides or dolomitic concretions.

Pz -14 - Acid volcanics and volcanoclastics of the Veporicum, Zemplinicum and Tatricum. Rhyolite-dacite volcanoclastics and ignimbrites prevail over effusive varieties.

Their chemical composition shows calc - alkaline affinity. The characteristic feature of the volcanics is mainly the felsitic matrix and sparse phenocrysts (mainly 5-10 %, rarely 30 %).

Pz - 15 - Intermediate and basic volcanics of the Hronic Late Paleozoic are part of the Permian sequence. Characteristic is the manifold repeating of lava-flows, intraeffusive volcanoclastics or brecciated lavas in layers. Their bulk chemical composition and distribution of immobile elements indicate their continental tholeiitic affinity (WPB, Vozár, 1977).

4. Mesozoic

Mz - 1 - Limestones are fairly pure rocks of various lithostratigraphic and tectonic units, widespread across Slovakia: calcarenite limestones, reef limestones, lagoonal limestones, crinoidal limestones, nodular limestones, mud limestones and crystalline limestones.

Mz - 2 - Clayey limestones of Triassic to Lower Cretaceous age, mostly Cretaceous limestones in the Veporicum with less abundant Triassic limestones of the higher subtatric nappes.

Mz - 3 - Marlstones of Cretaceous and Paleogene age, accompanied by spotted limestones and minor nodular limestones of the Klippen Belt.

Mz - 4 - Sandy limestones - Jurassic limestones of the Tatricum, assigned to the Orešany, Tribeč and Donovaly Groups and limestones of the Krížna nappe.

Mz - 5 - Siliceous limestones to silicites - a group of Dogger - Malm siliceous limestones and radiolarites in the Veporicum, and cherty limestones of Triassic age in the Hronicum or of Cretaceous age in the Tatricum.

Mz - 6 - Dolomites of Middle to Upper Triassic age in the Tatricum, Veporicum, Hronicum and, less frequently, in the Silicicum. The dolomites are very pure.

Mz - 7 - Dolomites of Carpathian Keuper form layers of primary chemogenic dolomites in the variegated Carpathian Keuper formation. The dolomites are enriched in silica and alumina.

Mz - 8 - Claystones, sandy claystones of Triassic and Jurassic age - Lower Triassic claystones largely in the Tatricum and Silicicum, claystones in the Carpathian Keuper of the Tatricum and Veporicum, and claystones of the Lunz Member in the Hronicum. All these claystones are fairly sandy.

Mz - 9 - Claystones, sandy claystones of Cretaceous to Paleogene age. Unlike Triassic claystones of the Inner Carpathians (Mz-8), these claystones are less sandy, but richer in carbonate admixture.

Mz - 10 - Sandstones, quartzose sandstones to quartzites of Triassic and Jurassic age. This variegated group consists of sandstones and quartzites of the Tatricum, Veporicum and Silicicum, Upper Triassic quartzites of the Tatricum, Upper Triassic sandstones of the Veporicum and Hronicum, and Cretaceous sandstones of the Tatricum. The rocks are rich in silica and poor in CaO.

Mz - 11 - Carbonatic sandstones and conglomerates of Cretaceous and Paleogene age are carbonatic sandstones and conglomerates of Jurassic to Paleogene flysch sequences in the Klippen and Near-Klippen Belt.

Mz - 12 - Metabasalts of the Bôrka nappe include glaucophanites and greenschists.

5. Paleogene

5a. Inner-Carpathian Paleogene

Pg - 1 - Sandstones (except in the Biely Potok Formation). This set comprises sandstones with a variable content of carbonate material, mainly of the Zuberec and Huty formations, less the Borové Formations, in which sandstones are relatively not so abudant.

Pg - 2 - Claystones - This group includes primarily claystones of the Huty and Zuberec Formations which have variable carbonate content.

Pg - 3 - Breccias, conglomerates and carbonates - Mainly in the Borové Formation.

Pg - 4 - Sandstones of the Biely Potok Formation are sandstones with a carbonate admixture. These sandstones are richer in silica and lower in carbonates in comparison with the set Pg - 1.

5b. Outer Carpathian Paleogene

Pg - 5 - Dukla unit sandstones - The set embodies more or less carbonatic sandstones. Most samples come from the Menilite and Submenilite Members, the Lupkov, Čergov and Zboj Members are represented by fewer samples.

Pg - 6 - Dukla unit claystones - These claystones are represented mainly by the samples from Menilite, Submenilite and Čergov Members, sparcer are the samples from the Variegated Submenilite, Lupkov and Zboj Members.

Pg - 7 - Magura unit sandstones - In comparison with the Dukla unit sandstones (Pg - 5), these sandstones contain more quartz and less carbonate. Most samples come from the Zlín and Strihov Members, and less from the Bystrica, Racibor, Lupkov, Vychylovka and some other Members.

Pg - 8 - Magura unit claystones - These rocks are represented mainly by the Zlín Member and to a lesser extent also by the Bystrica, Strihov, Beloveža,Vychylovka and some other Members.

6. Sedimentary Neogene

Ne - 1 - Clays, claystones are widespread across Slovakia, but they occur in Inner Carpathian basins and the Miocene of the Eastern Slovakia Basin. Unlike the Ne - 2 group, these rocks have little or no carbonate admixture.

Ne - 2 - Calcareous claystones, marlstones - A variegated set of rocks occur in all Slovakia's Neogene basins, but mainly in the Miocene of the Eastern Slovakia Basin, Inner-Carpathian basins and in the Miocene of the Danube Basin.

Ne - 3 - Sands, sandstones, silts, siltstones - These occur in the Southern Slovakia Basin, Danube Basin and Inner-Carpathian basins. Unlike the Ne - 4 group, these rocks are mostly devoid of carbonate admixture.

Ne - 4 - Calcareous sandstones and siltstones make up a variegated set of rocks widespread throughout Slovakia, mainly in the Oligocene and Miocene of the Southern Slovakia Basin, and in smaller amounts also in the Miocene and Pliocene of the Danube Basin, in the Miocene of the Eastern Slovakia Basin and in the Vienna Basin.

Ne - 5 - Sandy limestones and limestones - These are present in the Upper Oligocene and Miocene of the Southern Slovakia Basin, Inner-Carpathian basins and the Vienna Basin.

Ne - 6 - Tuffaceous sediments - These comprise tuffaceous claystones, siltstones and sandstones in basins adjacent to Neogene volcanics in central and eastern Slovakia (Southern Slovakia, Upper Nitra, Žiar, Zvolen, Košice and other basins).

7. Neogene volcanics

Nv - 1 - Basalts and basaltic andesites are porphyritic rocks with phenocrysts of basic plagioclase, augite, olivine or hypersthene and titanomagnetite in a groundmass of plagioclase, pyroxene and magnetite. They occur in the form of massive lava, scoraceous breccias, agglomerates and tuffs, mostly as a part of large stratovolcanoes.

Nv - 2 - Pyroxene and hornblende-pyroxene andesites are porphyritic rocks with phenocrysts of plagioclase. augite and/or hypersthene, magnetite and rare olivine or biotite, in a groundmass of plagioclase, pyroxene, magnetite and comonly also altered glass. Rocks of this category dominate in structure of andesite stratovolcanoes in the central and eastern Slovakia alike.

Nv - 3 - Pyroxene-hornblende, hornblende and biotite-hornblende andesites and dacites are porphyritic rocks with phenocrysts of plagioclase, hornblende, biotite and rare hypersthene, augite, olivine, quartz in groundmass of acid plagioclase, sanidine, quartz, pyroxene, magnetite and usually also glass. They mostly form effusive complexes and extrusive domes associated with large stratovolcanoes, and they are associated with pyroclastic breccias, pumice tuffs and epiclastic breccias.

Nv - 4 - Rhyodacites and rhyolites are mostly porphyritic rocks with phenocrysts of acid plagioclase and/or sanidine, quartz, biotite and rare hornblende or hypersthene in a groundmass of sanidine, quartz and glass. They occur in the form of extrusive domes and dome

flows associated with tuffs, pumice tuffs and epiclastic volcanic breccias and sandstones.

Nv - 5 - Propylitized andesites and andesite porphyries. This group includes mostly pyroxene and hornblende-pyroxene andesites and andesite porphyry affected by propylitic alterations in surroundings of intrusive stocks and hydrothermal systems in central zones of large andesite stratovolcanoes.

Nv - 6 - Diorites and diorite porphyry are equigranular or porphyritic holocrystalline rocks composed of basic plagioclase, pyroxene, hornblende and rare magnetite, quartz, biotite. They occur as stocks in central zones of andesite stratovolcanoes and are affected by propylitic alteration.

Nv - 7 - Granodiorite is a coarse grained rock composed of intermediate plagioclase, biotite, hornblende, quartz, orthoclase and accessory magnetite, apatite and zircon. It crops out only in the Hodruša sector of the Štiavnica stratovolcano central zone.

Nv - 8 - Granodiorite porphyries are composed of plagioclase, hornblende, biotite and quartz phenocrysts, in a groundmass of quartz and orthoclase. They occur next to Pukanec and in the Štiavnica stratovolcano central zone, variably affected by silicification, sericitization and pyritization.

Nv - 9 - Quartz-diorite porphyries are composed of plagioclase, hornblende, biotite and quartz phenocrysts, in a groundmass of acid plagioclase, quartz and orthoclase. They form dykes and sills in the ćtiavnica stratovolcano central zone.

Nv - 10 - Alkali basalts and basanites are almost aphanitic rocks with sparce phenocrysts of plagioclase, augite, olivine and rare kersutitic hornblende, in a prevailing groundmass of acid plagioclase, pyroxene, magnetite and nepheline. They occur as lava flows, cinder/spatter cones, maars and diatremes in the Cerová Vrchovina Highlands and Lučenec Basin, and rarely also in the Central Slovakia volcanic field.

Lithogeochemical database

For each of the 3 839 samples - records, following information is available in the database: name of the sample, author, year, regional and local geologic setting, x and y coordinates, lithostratigraphy, petrographic data, chemical analyses for all major and 26 minor elements and some other data). dBase IV (dbf format) was used for the lithogeochemical database.

Map of lithogeochemical types of Slovakia at a scale 1 : 500 000

This map will appear as a part of the "Catalogue of the Main Rock Types of Slovakia" in 1998.

All geochemically defined lithotypes / lithofacies are shown on the map either as simple lithotypes or as a set of lithotypes due to their tight bedding. The legend of the map contains 54 items, from which about a half represent two and more lithotypes because of the complicated geological structure of Slovak territory. The map of the lithogeochemical types of Slovakia has a close relation to the Geological map of Slovakia 1 : 500 000 (Biely et al., 1992), from which it takes the majority of contours.

Simple lithotypes are distinguished on the map by numeric indexes and colour. Associated lithotypes are shown by a striped raster, with different colours according to the proportion of the individual component lithotypes.

The colour designation of lithotypes was chosen on the basis of four principal minerals groups, as follows:

carbonates - blue colour
mafic silicates - green colour
feldspars and micas - red colour
silica - yellow colour

Transitional lithotypes are coloured by transitional colours and with different intensity. The colour scale was chosen for the case by which one can distinguish carbonate and mafic rocks with their high buffering capacity (blue and green colours - favourable for the environment) from more acid rocks (red and orange colours) with their low buffering capacity and siliceous rocks (yellow colours - not favourable for the environment).

This map is considered to be a basic body of information on lithology for further regional geochemical mapping.

Summary and Conclusions

The above work, as a part of the Geochemical Atlas of Slovak Republic, presents the results of geochemical mapping of the main rock types on the Slovak territory.

64 main rock types were distinguished mainly according to lithological and geochemical-statistical criteria. The results reflect the very complicated geological structure of Slovakia with its large variety of rock types. The geochemical variability of these rocks is documented by the distribution of all major and 26 minor elements in them. Since the sampling was focused mainly on unaltered and unmineralized rocks, the results reflect the primary lithology.

These new and complex basic statistical data on element distribution of all main rock types represent an information which can be used in various ways:

- for setting the lithological background values for the whole territory of the Slovak Republic

- for distinguishing between geochemical anomalies caused by primary lithology and anomalies caused by metallogenic processes and anthropogenic impacts in

rocks and other researched media (soils, water, stream sediments, biomass)

- as a contribution for other projects dealing with the research of geological factors of environment at regional and local scales

- it provides the data sets, needed for comparison with the data in other countries.

All the primary data are in the Lithogeochemical database (dBase IV format) comprising 3 839 samples - records with chemical analytical data and other information (including geologic setting, x and y co-ordinates, litostratigraphy etc).

As an important part of this work, the Map of Lithogeochemical Types of Slovakia at a scale of 1 : 500 000 was compiled. The colour designation of lithotypes was chosen on the base of four principal minerals groups for rapid distinguishing between rocks favourable (carbonatic and mafic rocks) and not favourable (siliceous rocks) for the environment.

All the achievements of the subproject "Rocks" will be published in more detail during 1998 as "Catalogue of the Main Rock Types of Slovakia".

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