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Engineering Geology in land-use planning and environmental protection in Slovakia

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Abstract: The actual task of engineering geology is to take responsibility for rational use of the geoenvironment and environmental protection against geological hazards. This role calls for new methods of engineering geological maps compilation and for evaluating methods of man's impact on geoenvironment and landscape, as well. To deal with these problems requires an effective monitoring system of environmental geofactors and elaborating of the effective methods of geoenvironment protection against stability failure and pollution.

Key words: geofactor, environment, groundwater, relief, geodynamic phenomena

Introduction

The Slovak engineering geology has fully accepted the International Association of the Engineering Geology (IAEG) declaration to take responsibility for the protection and rational use of the geological environment as well as the environmental protection against geological hazards, approved by the general assembly during the International Geological Congress held in Moscow in the 1980. Results are recorded by series of projects aimed to the geological hazard impact mitigation, geological input data for land-use planning and waste disposal site selection, as well as by numerous papers of Slovak engineering geologists in professional periodicals, proceedings of the IAEG international congresses held in Buenos Aires (1986), Amsterdam (1990), Lisboa (1994), and others.

Terminology and definitions

The trends mentioned above have been followed by a rapid development of the conceptual construction and terminology. It was reflected by the Slovak Geological Society by appointing of terminological commissions. The work of the engineering geological commission resulted issuing the Engineering Geological Terminological Dictionary (ANNON, 1992).

From the point of view of engineering geological projects undertaken in Slovakia, it is useful to explain some important concepts which have started to be used frequently, however, without distinctive definition, or using different definitions.

Geological environment (geoenvironment) is a term we use for the upper part of the lithosphere conditioning the existence and the development of the human society and which, in return, is exploited and changed by man. The geological environment, as a complex dynamic natural system, consists of the following basic components:

1. Rocks (rock environment) - create substancionally as well as structurally the basic constituent of any particular part of the Earth´s crust;

2. Ground water - represents the conjunction of the hydrosphere with lithosphere and creates a favourable condition for the existence of the biota, man included;

3. Topography (relief) - a division between lithosphere and outer Earth´s spheres (atmosphere, hydrosphere, biosphere, etc.) as a result of endogenous, exogenous and antropogeneous geological processes;

4. Soil - the uppermost part of the lithosphere resulting from its conjunction and interaction with atmosphere, hydrosphere and biosphere and conditioning substance and energy exchange between abiotic and biotic part of the nature.

5. Mineral deposits - solid and liquid mineral raw materials accumulated in the lithosphere in an exploitable quantity.

6. Geodynamic phenomena - recent natural and antropogeneous geological processes as well as resulting changes in the geological environment and its relief.

As geofactors (geological factors) we call the properties of the geological environment components facilitating, limiting or affecting the land-use. Factors which, through their character and quality, facilitate or in positive way affect the exploitation of an area in some way (mineral resources, aquifers, foundation ground of high quality, etc.) are called geopotencials (geological potentials). Geological factors which limit or affect in negative way the land-use (landslides, karst phenomena, seismicity of a high intensity, unsuitable foundation ground, etc.) are called geobarriers (geological barriers).

The most common geobarriers are hazardous geological processes, the probability of which within a particular area and time interval are expressed by the term of geological hazards (VARNES, 1984).

Development of engineering geology for land-use in Slovakia

Engineering geological project development for complex engineering designs resulted in the experience that understanding of geological structure and processes on regional background enables to make the design more effective. It generated a systematic study of engineering geological condition in regional aspects. In this aim Slovak engineering geology utilised results of numerous excellent geologists who worked in Slovakia, first of all results of D. Andrusov and his followers, as well as the methodology of the Russian school of regional engineering geology founded by V. I. Popov. The study results were presented in a monograph of the Regional Engineering Geology of Slovakia by M. MATULA (1969) which was presented at XXIII. International Geological Congress held in Prague in 1968.

Following the regionally oriented research the multipurpose engineering geological maps at a scale of 1:25 000 have been prepared covering the most important Slovak industrial and urban centres. Subsequently, general engineering geological map of Slovakia, at a scale of 1:200 000, was compiled (MATULA, HRAŠNA, ONDRÁŠIK, 1989) creating unified "skeleton" for mosaic of maps at a scale of 1:25 000 and binding urban areas mapped in detail together with their background. It resulted in the comprehensive information system of engineering geological conditions of the whole Slovak territory with more detailed data for economically significant regions. The map involves the data on geofactors affecting in zoning units the environment, as well.

Parallel to the systematic regional engineering geological research in the 60-ties a systematic research of hazardous geological phenomena (landslides, suffusion, erosion, sagging of loesses, etc.) has developed. The landslide disaster in Handlová at the turn of the years 1960-1961 triggered a systematic landslide inventory on the whole territory of previous Czecho-Slovakia. During the years 1962-1963 there were registered 123 594 slope deformations in Slovakia, with the total extent of 11 615 km^2, representing 3,3 % of the total state territory. However, slope deformations locally represent 20 up to 30 % of the area. Slope deformations maps of various types and scales have been systematically prepared for the exposed portions of the country (MALGOT & BALIAK, 1993). Subsequently, some landslides endangering engineering structures or urban areas have been reclaimed.

Recent state and trends in engineering geological research in Slovakia

While multipurpose maps of engineering geological conditions and zoning compilation prevailed in the last decade, special purpose maps of engineering geological valorization compilation predominate in Slovakia recently (HRAŠNA & VLČKO, 1994). These may be prepared as suitability maps, as optimization maps compiled on the base of multicriterial analysis or in the form of prognostic maps expressing the expected changes in geological environment due to man interferences.

The more extensive project of this type was to prepare the suitability maps for the waste disposal sitting compiled for the whole territory of the Slovakia, at a scale of 1:200 000 at the beginning (1990-1991) followed (1992-1993) by maps at a scale of 1:50 000 (HRAŠNA, 1993). The degree of the danger of ground water pollution and geodynamic phenomena impact are the main criteria from geological suitability aspects in these maps. Apart of them, protected areas of various kinds (including protected areas of mineral resources and aquifers) and other important phenomena (floodlands, protective forests, etc.) affecting the intended land-use were presented in the maps.

Optimization maps are compiled for land-use planning aimed to choose the most suitable land-use of various parts of the particular area (MATULA, HRAŠNA, VLČKO, 1986) or with the aim to select the most suitable site for particular investment decision. The last ones are compiled especially for the sitting of complex or ecologically dangerous development (HRAŠNA & SZABO, 1994, HRAŠNA, 1995). A specific program for waste disposal deals with the selection of suitable geological structures for toxic and radioactive wastes, as well as suitable waste disposal sites for some urban agglomerations.

The compilation of prognostic maps calls for the elaboration of classification systems both the character and intensity of man interferences, and the expected changes of the geoenvironment due to man's interference, as well. The example of such a map was introduced by HRAŠNA & VLČKO (1986).

The other significant program is the monitoring of environmental geofactors, realised on the request of Geological Section of the Ministry of Environment of the Slovak Republic, similarly as the above mentioned maps. The program involves monitoring of the following phenomena: landslides, erosion, weathering, subsidence of undermined areas, antropogeneous deposits and seismotectonic activity of the Slovak territory.

At present, the State Geological Service in cooperation with the Department of Engineering Geology of the Faculty of Natural Sciences elaborate the draft of recommendation for the geological investigation and compilation of special purpose maps for urban development in accordance with the new urbanization program of the Slovak Republic and expected innovation of the law on land-use planning.

Slovak engineering geology and hydrogeology have also played a significant role in environmental protection in accordance with recently (1994) adopted law for environmental impact assessment (EIA). The law specifies all kinds of environmental interferences at which the EIA method is to be accepted and gives a succession of particular steps to be done. Related and acute task of geology is to specify methods of geoenvironment assessment from the point of view of its stability failure or pollution and to quantify the extent of possible deterioration and the cost needed for the prevention, as well.

Conclusion

While the engineering geological research and investigation were concentrated on the close construction site surroundings and endeavour for the most economically effective structure realisation and safe utilization predominated in the past, modern engineering geology is characterised by the extent regional background and an endeavour for optimal sitting of engineering designs in the geoenvironment and landscape as well as with respect to the environmental protection. The stress is laid upon a rational use of the geological environment based on a complex assessment of a terrain potentials and relations in the system: engineering structure - geoenvironment - landscape.

To accomplish the above mentioned tasks the development of the assessment methods of the whole system and particular components of engineering geological conditions is required, and the assessment methods of engineering interferences with geoenvironment, as well. In relation to it, an improvement of rock mass and territorial units typology, as well as the methodology of special purpose maps compilation for various kinds of land-use is required. At the same time, there is a necessity to be directed in a larger scale at compilation of optimization and prognostic maps of geoenvironment changes due to man`s interferences.

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Monitoring of collapsible soils in Slovakia

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Abstract: Collapse is an important factor in assessing the economy of construction foundation and security. Collapsible soils affect unfavourably the foundation of constructions and the environment, since the process of collapse causes significant volume changes as well as changes in the properties of soils. Collapse monitoring in foundation soil consists of several subsequent stages. In the beginning stages, collapsing sediment occurrences are identified. In the territorial units studied monitoring of unfavourable results of collapse is carried out, consisting of inventory and documentation of damaged objects. Based on a set of obtained data and information, areas with soils susceptible to collapse may be distinguished, determining their engineering geological properties, degree of susceptibility to collapse, as well distinguishing regions and sub-regions with same susceptibility to collapse.

Key words: collapse, collapsible soils, susceptibility to collapse, monitoring, damages to objects.

Introduction

Monitoring of collapsible soil is one of the subsystems of the "Partial monitoring system of geological factors" (KLUKANOVÁ, 1993), which is a part of "Environmental Monitoring of the Slovak Republic". The aims of geofactor monitoring are to investigate and evaluate the mechanism of origin and evolution of processes in natural environment, to foresee their evolution trends in time and space and to suggest measures to reduce negative effects of these processes.

Under the term "collapse", used predominantly in geotechnical literature and referring mainly to aeolian sediments,. we understand a sudden reduction of volume due to moisture and load. Soil collapse leads in many cases to a failure of foundations and damage to buildings due to uneven or excessive subsidence. Therefore, collapsible soils belong to unreliable foundation soils.

The large number of failures and break-downs in buildings caused by soil collapse in our country as well as abroad points to the fact that geotechnical problems of collapsible soils have not been paid due attention. On the other hand, in many cases foundations are designed with excessive security, or inadequately, although modern and expensive technologies are being applied. The choice of inadequate design may be affected by various circumstances. Meagre knowledge of physical and mechanical properties of foundation soils is one of the most serious causes. Other factors to mention are: unexpected presence of water, insufficient knowledge of the load of the building, or wrong use of technology.

The problems of collapse are in Slovakia even more aggravating due to the fact that aeolian sediments occur on an area of almost 7000 km^2 (ŠAJGALÍK, 1985), which is approx. 14% of the surface of the Slovak Republic (Fig. 1). From the above it follows that it is important to investigate and evaluate the mechanism of soil collapse, surface collapse manifestations, changes in the geological environment, to foresee their temporal and spatial effects and to take measures which would minimize these effects to an acceptable level.

Conditions and mechanism of soil collapse

A number of Slovak as well as foreign authors have studied the conditions and mechanism of soil collapse. According to STN (Slovak Technical Standard) 73 1001 "Foundation of structures. Subsoil under shallow foundations", collapse may occur if any of the following conditions has been identified:

- the soil is of aeolian genesis,
- the content of the silt component is more than 60 % of dry soil weight,
- the content of the clayey component is less than 15 % of dry soil weight,
- the saturation degree is less than 60 % and liquid limit is less than 32 %.

Among other conditions of collapse the above standard mentions porosity exceeding 40 % and simultaneous natural moisture below 13 %. As collapsible soils are classified those in which the collapse coefficient (I_{mp}) exceeds 1 %.

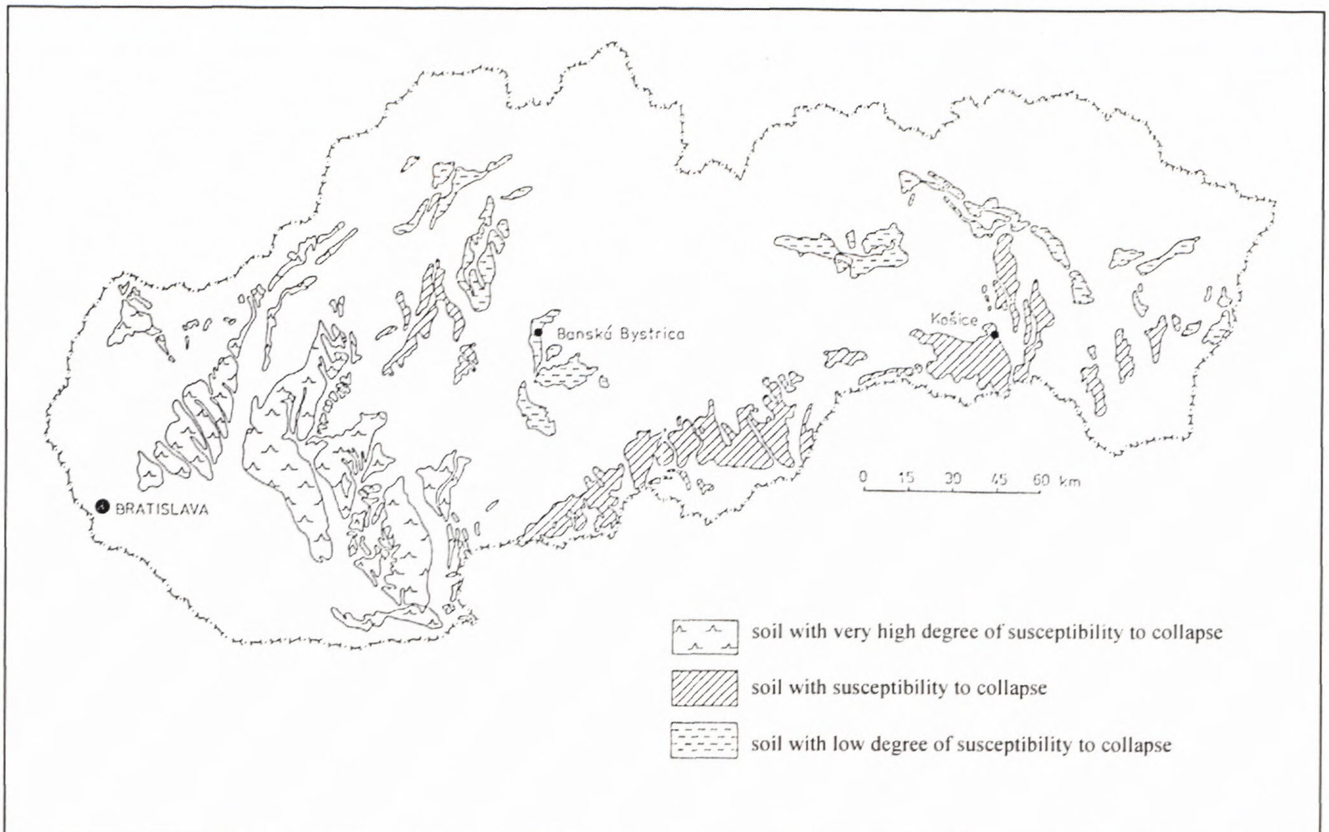


Fig. 1 Extend of collapsible soils in Slovakia. Map was compiled on the basis the work of J. ŠAJGALÍK, I. MODLITBA and A. KLUKANOVÁ

The causes of soil collapse are various. They are controlled by the genesis of soil, post-genetic processes, compactness of soil, hydrogeologic conditions, mineral composition etc. On the basis of microstructural analysis (KLUKANOVÁ, 1988) and the results of the work of ŠAJGALÍK and MODLITBA (1983), collapse may be divided into three phases, which, however, take place simultaneously.

In the first phase, the original microstructure is destroyed, due to increased moisture under external pressure. The increase of saturation degree in soil causes loss of capillary adhesion force and to a considerable extent it decreases the strength of clay bridges. The destruction leads also to damage of clay films covering sand or silt quartz grains, or other clastic minerals. Aggregates and micro-aggregates disintegrate as well. The intensity of carbonate dissolution and their migration in the soil increase.

In the second phase, the microstructure is disintegrating, which is reflected in the displacement of damaged clay films. Water, which causes also subsurface erosion, along with external stress affect, the transport of particles. Other important effects are: decrease of carbonate content, compressing of other fabric elements, decrease of the total volume of soil.

In the third phase, new micro-structure is formed after collapse. The soil acquires a heterogeneous structure, in contrast to the former homogeneous one, the basic structural units of the soil having disintegrated, i.e. individual grains are not perfectly covered by clay films any more and they are not connected by clay bridges. The per-cent content of individual pore-size fractions changes. The collapsed soils have lower percentage of pores with the size of up to 0.005 mm. The content of pores with a size of 0.005 to 0.01 is significantly higher. From the above facts it follows that the translocation of disintegrated clay films and bridges has a principal role in the soil collapse process (KLUKANOVÁ, 1988).

Characterisation of collapsible soils

There are several groups of collapsible soils. The two most important are:

- soils with a high degree of susceptibility to collapse. The collapse coefficient is higher than 3%. Among these soils are typical and sandy loess.

- soils susceptible to collapse. Their collapse coefficient ranges from 1 to 3%. Into this group belong aeolian sandy, clayey loess and a part of loess-like sediments described later.

Available results show that collapse depends above all on the fabric. Collapsible soil is composed of silt and sand grains covered by clay films, connected by clay bridges and clay buttresses. We assume that most susceptible to collapse is a soil having an exactly balanced ratio between the quantity of clay minerals and sand or silt grains, so that these grains are covered by clay minerals and connected by clay bridges. Clay minerals are not present in such fabric in any other form. Any variation from the balanced ratio between the two fractions (other form of clay mineral occurrence in the fabric) results in collapse. Any soil having above described fabric is collapsible at increased moisture and/or increased strain in the foundation soil. The degree of collapse is affected also by porosity (especially by pores with a diameter of about 0.01 mm), the contents of carbonates, oxides, hydroxides of metals (above all iron and manganese) and soluble salts. From the above it follows that the collapse process is very complex, depending on many factors, which are to a great extent variable.

From the viewpoint of geotechnical properties, collapsible soils have high strength under conditions of onstant natural moisture. After saturation with water, their strength rapidly decreases. The properties of these soils change significantly after collapse. Collapsible soils put higher requirements on geotechnical investigations than other foundation soils. Their characteristics, determined according to the results tests, are set out by the standard STN 73 1001.

Extensive investigations of the properties of collapsible sediments in previous years (Klukanová et al. 1989, 1992, Klukanová, 1988) allow us to characterize basic physical-mechanical properties of their various types and their variations.

Soils with a high degree of susceptibility to collapse

Among soils with a high degree of susceptibility to collapse are typical loess and sandy loess.

Typical loess is characterized by being non-bedded, primarily calcareous, having capillary porosity. It is generally dry, of yellow to dark-yellow colour with visibly predominant grain-size composition varying in the range of 20 - 63 μm, which corresponds to coarse-grained silt to very fine-grained sand.

The fabric consists exclusively of skeletal microstructure. The soil is very homogeneous and isotropic. Fig. 2 shows a micrograph of the fabric of a typical loess. The silt fraction is predominant. According to grain-size analysis, it is characterized by a high content of the silt fraction (65-72 %) and low content of the clay (7-17 %) and sand fractions (15-20%). The water content depends on the content of clay particles, which, due to their properties and the size of specific surface bind the predominant part of

Fig. 2 The micrograph of the fabric of a typical loess. Locality Mnešice brick-plant near Nové Mesto nad Váhom

water in the soil. The liquid limit, as a sensitive indicator of clay mineral content, is low as well. According to the liquid limit value and consistency index, we classify typical loess as low- to medium-plastic, with strong to hard consistency. The physical properties of loess sediments are listed in Tab. 1. The value of the collapse coefficient in relation to load is in Fig 3.

Tab.1 Physical properties of typical loess

Soil properties	Units	Average	Minimum	Maximum	Variance
Moisture content	%	9,955	5,391	14,900	3,119
Grain-size fraction < 0,002 mm	%	10,720	6,750	17,010	3,686
Grain-size fraction 0,002-0,06 mm	%	68,226	65,020	72,130	2,469
Bulk density of moisture soil	kgm^{-3}	14,564	1,399	15,070	2,514
Bulk density of dry soil	kgm^{-3}	13,788	1,337	14,207	2,137
Specific density	kgm^{-3}	26,956	26,570	27,329	1,324
Plasticity limit	%	24,044	22,300	24,906	0,509
Liquid limit	%	30,833	29,900	31,517	0,499
Pore content	%	46,900	44,500	50,850	2,286
Saturation degree	%	24,039	10,095	40,830	5,920
Carbonate content	%	13,828	6,750	19,790	1,827
Organic mater content	%	1,637	1,268	2,004	0,187

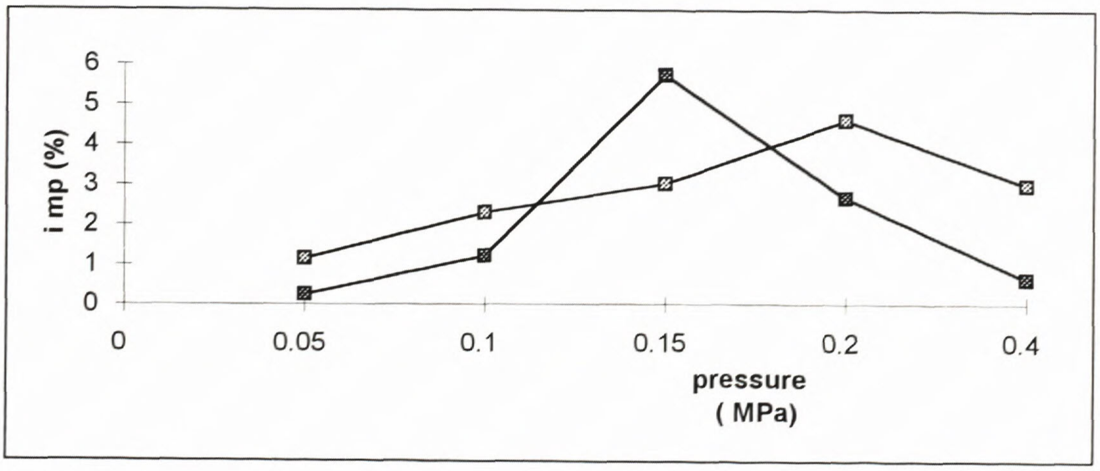


Fig. 3 Relationship between the collapse coeficient i_{mp} and load pressure for soils with high degree of susceptibility to collapse.

Sandy loess is mostly non-bedded, or there is fine bedding. Usually they are slightly calcareous, less porous than typical loess, having similar colour. This type of loess is characterized by a mixture of grains with sizes of 2 - 60 μm and 200 - 500 μm, which corresponds to fine-grained to medium-grained sand. The fabric is very similar to typical loess. The soil formed by aeolian transport, but the source areas had different rock composition than those of typical loess. Fig. 4 shows a micrograph of the fabric of sandy loess. Grain-size analysis revealed clay fraction contents of 7.38 to 9.43 %, silt of 35.34 to 40.00 % and sand fraction contents of 52.4 to 54.7 %. The higher content of sandy fraction to the detriment of clay results in lower moisture, lower plasticity limit values etc. Moisture at liquid limit varies from 23.8 to 24.71 %, at plasticity limit from 20.68 to 21.26 %. According to liquid limit and consistency index, we classify the soil as low-plastic, with hard consistency. The content of carbonates has been determined as 5.58 to 11.57 %. Physical properties of sandy loess are listed in Tab. 2.

Collapsible soils

Among collapsible soils we classify aeolian sands containing clay fraction, some clay loess and loess-like sediments. The value of the collapse coefficient I_{mp} for collapsible soils in relation to the size of load is shown on Fig. 5.

Aeolian sands are medium-grained, with typical good sorting and rounding of quartz grains, sometimes also of carbonates. The fabric is character

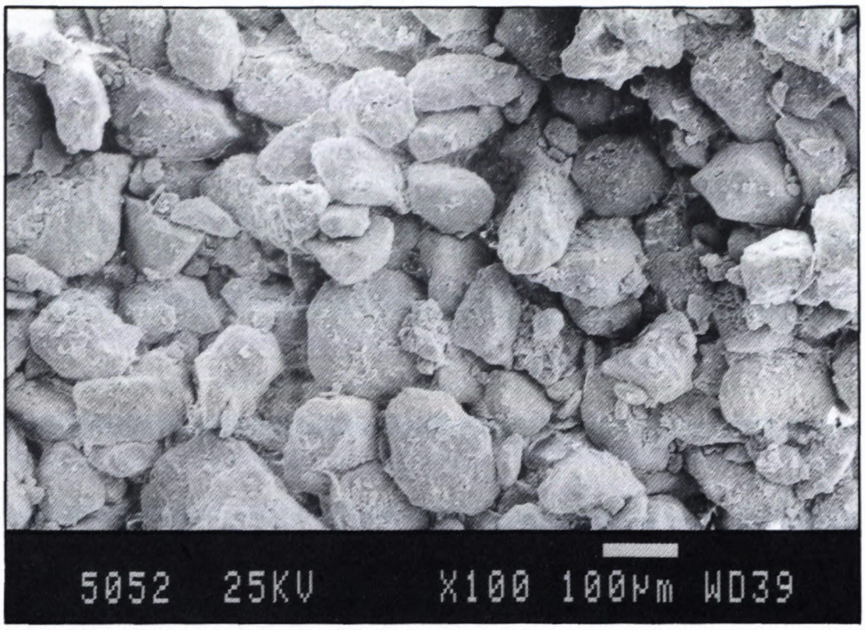


Fig. 4 The micrograph of the fabric of a sandy loess. Locality brick plant Hajnačka

Tab. 2 Physical properties of sandy loess

Soil properties	Units	Average	Minimum	Maximum	Variance
Moisture content	%	4,404	3,350	5,170	0,696
Grain-size fraction < 0,002 mm	%	6,453	7,380	9,430	2,195
Grain-size fraction 0,002-0,06 mm	%	37,730	35,340	40,000	2,001
Specific density	kgm^{-3}	27,295	27,270	27,410	7,263
Plasticity limit	%	21,032	20,680	21,260	0,214
Liquid limit	%	24,196	23,800	24,710	0,347
Pore content	%	37,700	31,120	39,210	2,786
Carbonate content	%	9,081	5,580	11,570	2,505

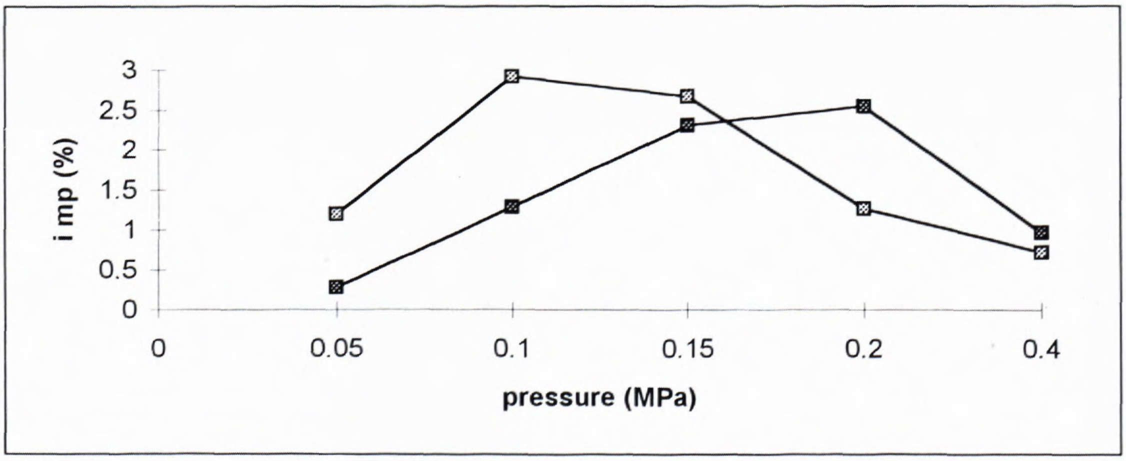


Fig. 5 Relationship between the collapse coefficient i_{mp} and load pressure for collapsible soils

ized by exclusively skeletal type of microstructure. Natural moisture of these soils is relatively low, it attains an average of 8.08%. According to grain-size analyses the clay fraction forms 4.02 to 9.57%, silt fraction 24.32 to 28.38% and sand 65.9 to 77.83%. The moisture at liquid limit varies from 24.2 to 24.7 %. Fig. 6 shows a micrograph of aeolian sand fabric. Their physical properties are listed in Tab. 3.

Clayey loess is non-bedded, low-porous. Its content of carbonates and its colour are similar to typical loess. The greatest percentage display silt particles of a grain-size ranging from 20 to 60 μm, and the clay faction is in the range of 25 to 30%, with a grain-size of 2 μm. Clayey loess has a matrix, skeletal-matrix to matrix-laminar microstructure. Collapsible are however only soils having skeletal-

Tab.3 Physical properties of eolian sand

Soil properties	Units	Average	Maximum	Minimum	Variance
Moisture content	%	8,078	6,770	9,570	1,019
Grain-size fraction < 0,002 mm	%	4,910	4,020	6,230	0,865
Grain-size fraction 0,002-0,06 mm	%	26,010	24,350	28,380	1,698
Bulk density of moisture soil	kgm^{-3}	18,070	16,800	19,500	0,111
Bulk density of dry soil	kgm^{-3}	16,270	15,400	16,800	0,062
Specific density	kgm^{-3}	26,925	26,900	27,000	0,004
Plasticity limit	%	19,900	19,200	20,600	0,700
Liquid limit	%	24,700	24,200	25,200	0,500
Pore content	%	39,573	37,780	42,751	2,342
Saturation degree	%	33,210	27,596	37,608	4,998
Carbonate content	%	4,000	1,010	7,030	2,898

Tab. 4 Physical properties of clayey loess

Soil properties	Units	Average	Maximum	Minimum	Variance
Grain-size fraction < 0,002 mm	%	32,660	25,010	37,600	4,246
Grain-size fraction 0,002-0,06 mm	%	50,386	48,800	51,300	0,824
Specific density	kgm^{-3}	27,410	27,390	27,440	1,915
Plasticity limit	%	25,448	22,360	30,130	2,573
Liquid limit	%	42,541	39,710	55,720	5,404
Pore content	%	35,875	34,100	37,250	1,403
Carbonate content	%	1,000	0,700	1,120	0,156

Tab. 5 Physical properties of loess-like sediments

Soil properties	Units	Average	Maximum	Minimum	Variance
Grain-size fraction < 0,002 mm	%	16,010	10,230	17,123	4,819
Grain-size fraction 0,002-0,06 mm	%	62,090	55,680	63,234	2,111
Specific density	kgm^{-3}	26,450	26,350	26,740	0,125
Plasticity limit	%	16,100	15,890	20,600	1,205
Liquid limit	%	27,400	24,870	33,300	2,229
Pore content	%	31,300	30,320	40,810	4,300
Carbonate content	%	1,944	0,897	2,520	0,511

matrix type of microstructure. Fig. 7 shows a micrograph of the fabric of a clayey loess.

According to grain-size analysis, the soil contains 38 % of clay, 51 % of silt and 11 % of sand fraction. The liquid limit according to Attenberg is 56 %, plasticity limit is 30 %. According to liquid limit and consistency index I_c = 1.7, we classify the soil as highly plastic, with solid consistency. The carbonate content is 1.1 % and the content of organic matter 4 %. Physical properties of these soils are listed in Tab. 4.

Loess-like sediments are represented by a large group of soils with different mineral and grain-size composition. Some physical properties are listed in Tab. 5. It is aeolian material, resedimented due to various secondary processes (allochtonous loess-

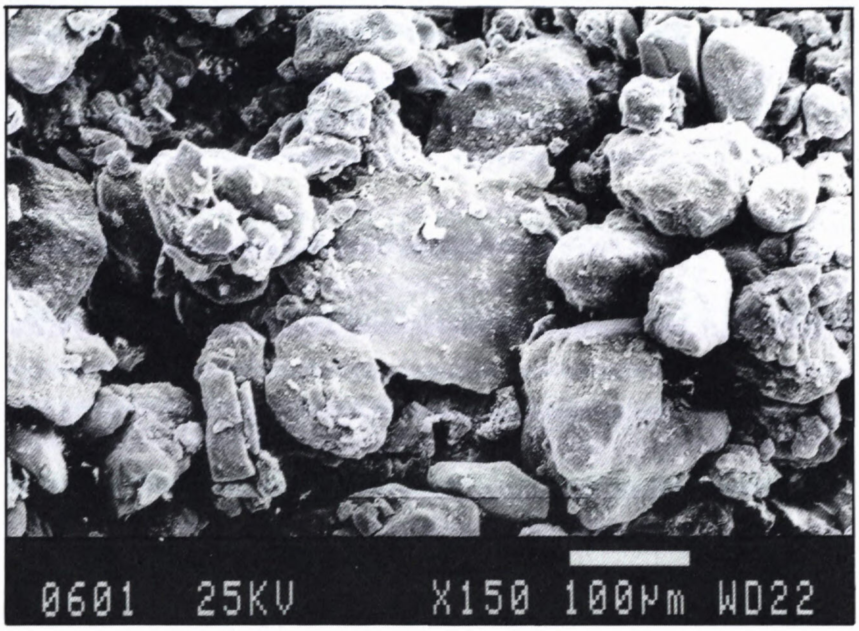


Fig. 6 The micrograph of the fabric of a aeolian sands containing clay fraction. Locality Bajč.

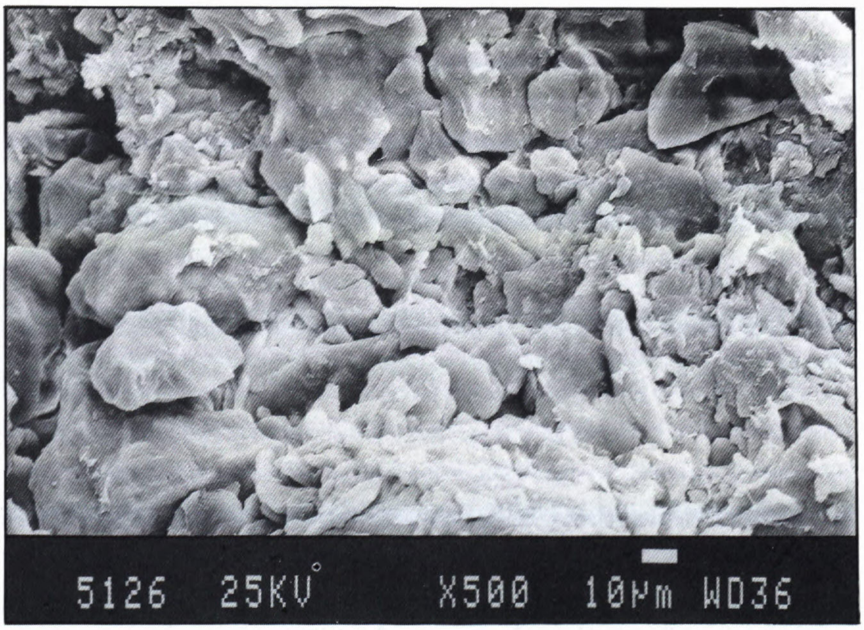


Fig. 7 The micrograph of the fabric of a clayey loess. Locality Jesenské.

like sediments) or changed in situ (autochtonous loess-like sediments), or it is non-aeolian material, in which the process of loessification took place. In place of loessification there is often loamification or gleyfication. The most important secondary processes taking place during resedimentation are:
- deluvial, colluvial processes and solifluction, due to which slope, deluvial and solifluction loess is formed,
- fluvial and proluvial processes - fluvial and proluvial loess,
- changes caused by cryoturbation - cryoturbational loess,
- eluvial and pedogenetic processes - give the origin to loess.

Loess-like sediments may have formed either from typical, sandy or clayey loess. Their porosity is lower than in the original material. A great change is observable, concerning the contents of carbonates. Some of these soils are totally without carbonates. They differ also in colour. Loess-like sediments may be characterized on the micro-scale only with difficulty, since they are strongly heterogeneous having anisotropic fabric. Heterogeneity is enhanced also by the occurrence of several basic microstructure types (matrix, skeletal, laminar as well as honeycomb etc.). Prone to collapse are however only those which have skeletal and skeletal-matrix type of microstructure. Fig. 8 shows a micrograph of the fabric of a loess-like soil.

Monitoring of collapsible soils

Among best ways of characterizing regional occurrence of collapsible soils is monitoring of their unfavourable results, i.e. damage to objects. An inventory of damaged objects was started to be taken on the territory of East Slovak Lowlands, Búčske Terraces, lower flow of the river Hron. We shall proceed towards the Southern Slovak Basin, Trnava and Nitra Hills. Failures are recorded in a specially designed inventory form (Fig. 9). The documentation of specific failures is aimed at most damaged construction parts, there are characterized the failures, the age of the object, the depth of foundations, type material used for the construction of the building, factors affecting the extent of damages, or repair work.

The investigation of the extent of damages to buildings is carried out on selected objects, in regular intervals - twice in a year - especially as far as the state, number and width of failures on objects are concerned, determined by indirect measurement of failure openness. The number and size of failures are then evaluated in time and space.

Engineering geological properties of soils are determined on undisturbed soil samples taken from boreholes, pits and outcrops near the object. The samples are tested in the engineering geology laboratory at the Doinýz Štúr Institute of Geology in Bratislava. First of all there are investigated moisture, plasticity, grain-size composition, bulk and specific density, saturation degree, contents of carbonates and organic matter. Besides this, mineral and chemical composition, as well as the fabric of soils, especially its changes caused by collapse, are studied as well, using an scanning electron microscope. The susceptibility to collapse of these soils is monitored as well using collapse test not only in oedometer, but also in a triaxial chamber.

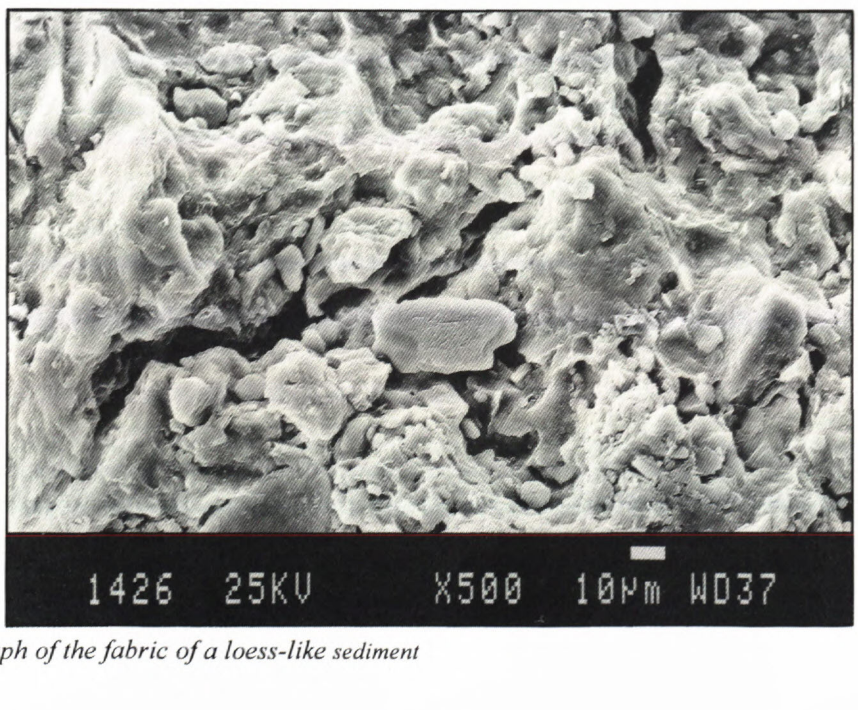
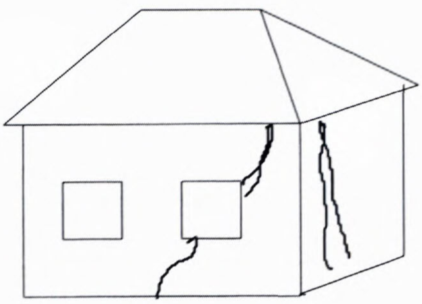


Fig. 8 The micrograph of the fabric of a loess-like sediment

Geomorphological unit: Podunajská pahorkatina - hilly land

District	Municipal	Street	Number	Type of object
NZ	Pohronský Ruskov	Pri kostole	8	family house

Outline-photo 3/21, 22 D1/12



Description of failure

Damaged pipe led to an intense penetrating of surficial water into the subgrade. Joints (cracks) are wide locally up to 10 cm.

Groundwater level

assumed – 2.0 m

bored:
stabilised:

Profile of foundation soil

0.0 -0.5m soil horizon
0.5 - loess sediments

Type of foundations

flat foundations, no cellar

Depth of foundations: 0.60 m

Characteristics of failure

Date	Type of change	Side of object	dip	Width	Length	Cause of failure	Environmental impact
		side	75	10 cm	3 m	sudden increase of moisture (w)	no
		front	45	10 cm	2 m	sudden increase of w	

Fig. 9 Inventory of failure of building

The output is a data bank, containing data on the degree and character of damages to an object, their development in time, about conditions at foundation of the object and causes of the collapse process etc. The inventory is complemented by a map on the scale 1 : 10 000, or 1 : 50 000, showing the extent and intensity of collapse processes on the territory studied, as well as an evaluation of the time course of the monitoring, with an interpretation of the measured data. The data bank with data on the occurrence and intensity of collapse processes will be adjusted for data input into a partial information system.

Causes of damages to objects

Among principal factors causing damages to objects are increased load and moisture, due to water infiltration into foundation soil. The source may be: damaged water piping, sewers, drain pipes or excessive precipitation. Moisture increase causes deterioration of geotechnical properties of foundation soil, decrease of its loading capacity, large deformations of constructions due to irregular or excessive subsidence of foundations. The occurrence of failures in buildings, foundations as well as supporting upper parts of building may be caused also by incorrect calculation of foundations of the building itself, or by a change of loading (e.g. by load concentration transferred from the neighbouring object, dynamic effects from a road or railway with high transport intensity).

Map of the susceptibility of soils to collapse

One of the most important outputs is the construction of maps of the susceptibility of soils to collapse. It is compiled by the method of engineering geological zoning. Zones and sub-zones are distinguished having the same susceptibility to collapse. The method applied in the compilation of the map corresponds to the proposed manual for the compilation of engineering geological maps of geofactors of the environment (KLUKANOVÁ et al., 1995). By the traffic-light method we mark homogeneous territorial units - zones and sub-zones with the same susceptibility. Green represents territories not susceptible to collapse, orange are territories susceptible to collapse and red are territories with very high susceptibility to collapse. Criteria for distinguishing the zones have been described in the above manual.

Fig. 10 shows the map of the susceptibility of soils to collapse on the scale 1 : 50 000 from the area of Búčske Terraces.

Conclusion

The aim of monitoring is to investigate changes in the observed characteristics, an analysis of relationships between these changes, a prognosis of the development of these processes, the verification of the reliability of prognoses in practice as well as a generalization of information in relation to territories with the same geological structure and other conditions of natural environment.

The paper refers to two groups of soils with different susceptibility to collapse: soils with a high degree of susceptibility to collapse and soils susceptible to collapse. In the first group there are typical loess and sandy loess. To soils susceptible to collapse belong aeolian sands, clayey loess and loess-like sediments with skeletal and skeletal-matrix microstructure. The character of their fabric affects the engineering geological properties and their changes due to environmental changes.

Monitoring of collapsible soils belongs to the most accurate ways of characterizing the results of collapsible soil occurrences. The aim of monitoring is to follow and evaluate the mechanism of soil collapse, its surface manifestations and negative changes in the geological environment, its destruction, to foresee the effects of these changes in time and space and to bring about measures which would reduce unfavourable effects of collapse to an acceptable level. The result should be input data used for finding solutions to the problems of environmental protection and optimisation of exploitation of the geopotential in the country.

Within the first stage of monitoring, an inventory of damaged objects is taken in the form of an evaluation of the unfavourable results of soil collapse. When documenting specific damages, the most damaged constructional parts are registered, the damages are characterized, as well as the age of the object, depth of foundations, type material used for the construction, factors affecting the extent of damages, or repair work. Further work will lay in permanent observation of changes of damages on selected objects, as well as of changes in soil properties.

A special kind of generalization of the results of the partial monitoring system is the evaluation of susceptibility of the territory to soil collapse, expressed in cartographic form as a map of the susceptibility to soil collapse, in which there are evaluated pre-defined geological regional units. The map is constructed by the method of engineering-geological zoning. Zones and sub-zones are distinguished, having the same susceptibility to collapse, i.e. the zone of territory not susceptible to collapse, the zone susceptible to collapse and zone of territory with very high susceptibility to collapse.

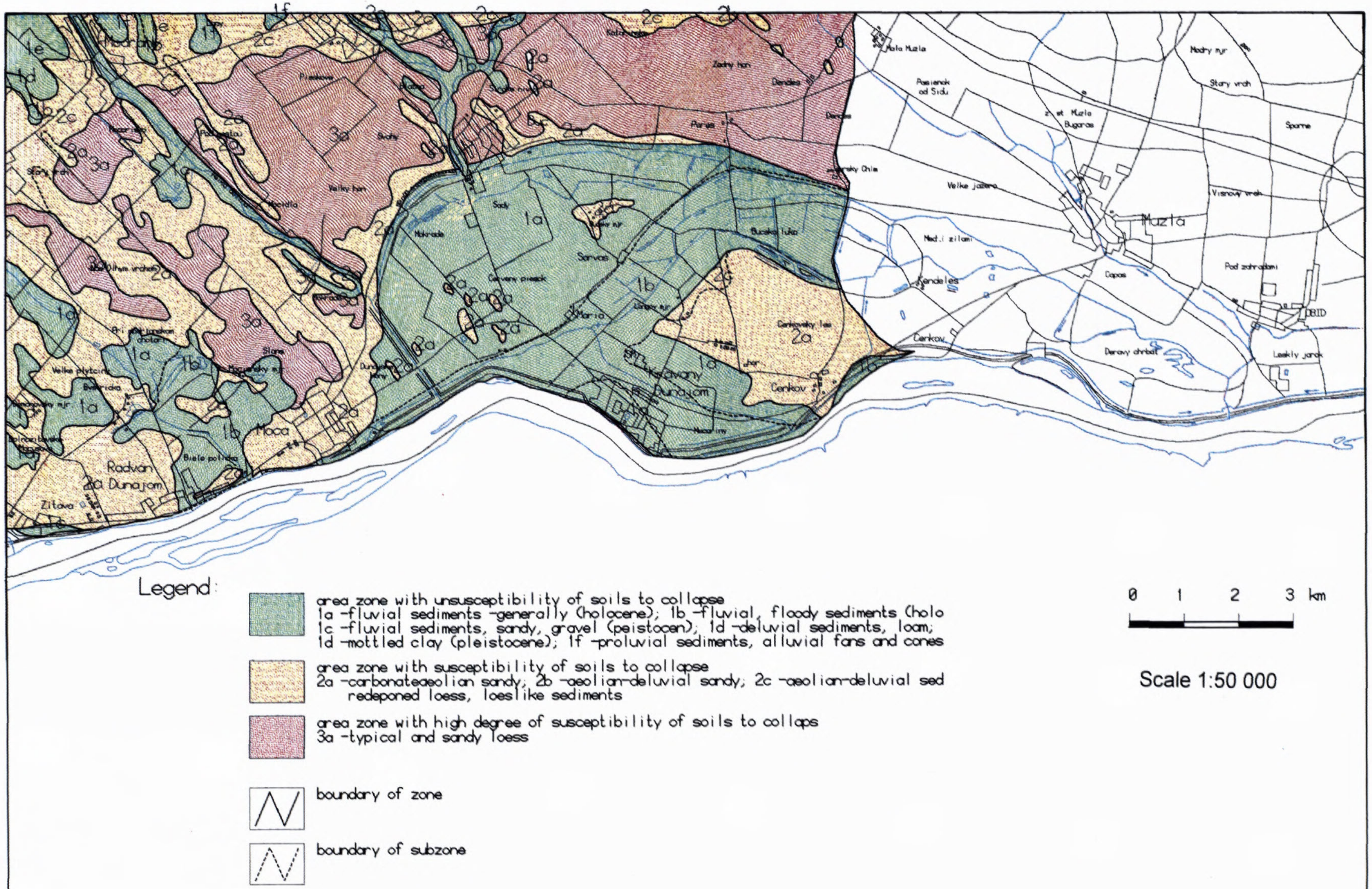


Fig. 10 Map of susceptibility of soil to collapse

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STN 73 1001: Foundation of structures. Subsoil under shallow foundations.

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Site selection methodology for deep repository of radioactive waste and prospective sites in Slovakia

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Abstract: The project of assessment of the territory of Slovak Republic from geological viewpoint of suitability for the construction of deep repositories for high-level radioactivity waste and spent fuel in the geological environment of the Western Carpathians started in the year 1993. The paper describes theoretical background of the problem, methodology of the investigation, criteria for the selection of suitable geological environment. 9 areas were selected in Slovakia for further investigation. They include areas covered by igneous rocks (granit, granodiorit, tonalit), metamorphic rocks (phyllit, metavolcanic rocks) and by sedimentary rocks (Paleogene claystone, Neogene carbonate clay).

Key words: radioactive wastes, deep repository, criteria for selection, Western Carpathians

Introduction

All countries, including Slovakia, which use nuclear energy to produce electricity in nuclear power plants, face the problem of spent fuel from reactor and high-level radioactive waste. During the last decade, the problem was solved by transferring this material to the former USSR. This temporary solution was abandoned several years ago. An attitude common to waste disposal in all world is to dispose it to a deep repository. Suitable geological formations and engineering barriers must prevent wastes from entering deep-circulating groundwater and limit the transfer of radionuclides into the biosphere for a very long time (ten to hundred thousand years). Because the whole problem is extremely complex, no country in the world has at present a final repository in operation. It is estimated that the first final repositories in the world could be completed in the second decade of 21st century. Slovakia has a great delay in solving of this problem. On the other hand, countries like ours can use theoretical and practical knowledge of countries which are much more ahead in this matter. At present, the problem of waste produced by 4 reactors in Jaslovské Bohunice (the only Slovak nuclear power plant in operation) is temporarily solved by an interim storage located directly in the power plant.

Methodology of the investigation and criteria for the selection of suitable sites

The problems of final repository for high-level radioactive waste and spent fuel was in the former Czecho-Slovakia solved by the Institute of Nuclear Research in Praha-Řež (NACHMILNER, 1993). A continuation of this work is the project "Repositories of radioactive and dangerous waste in geological environment" financed by the Ministry of the Environment of the Slovak Republic and realised by the Dionýz Štúr Institute of Geology, in co-operation with the Comenius University in Bratislava.

Existing experience from the world shows that there are no unambiguous criteria for the selection of the most suitable geological environment and no rock type may be unanimously declared as the most favourable. Various geological environments provide by their character and structure favourable as well as unfavourable conditions for the construction of a repository. If natural geological barriers are suitably complemented by engineering (technical) barriers and by adjusting the construction and technology of repository construction, the required security level can be reached in most geological environments, guaranteeing long-term security.

Fundamental terms

Schematic illustration of a deep-seated repository in geological environment formed by rocks is in Fig. 1.

Explanations of abbreviations used in paper:

DR - *deep-seated repository*

HGE - *host geological environment*

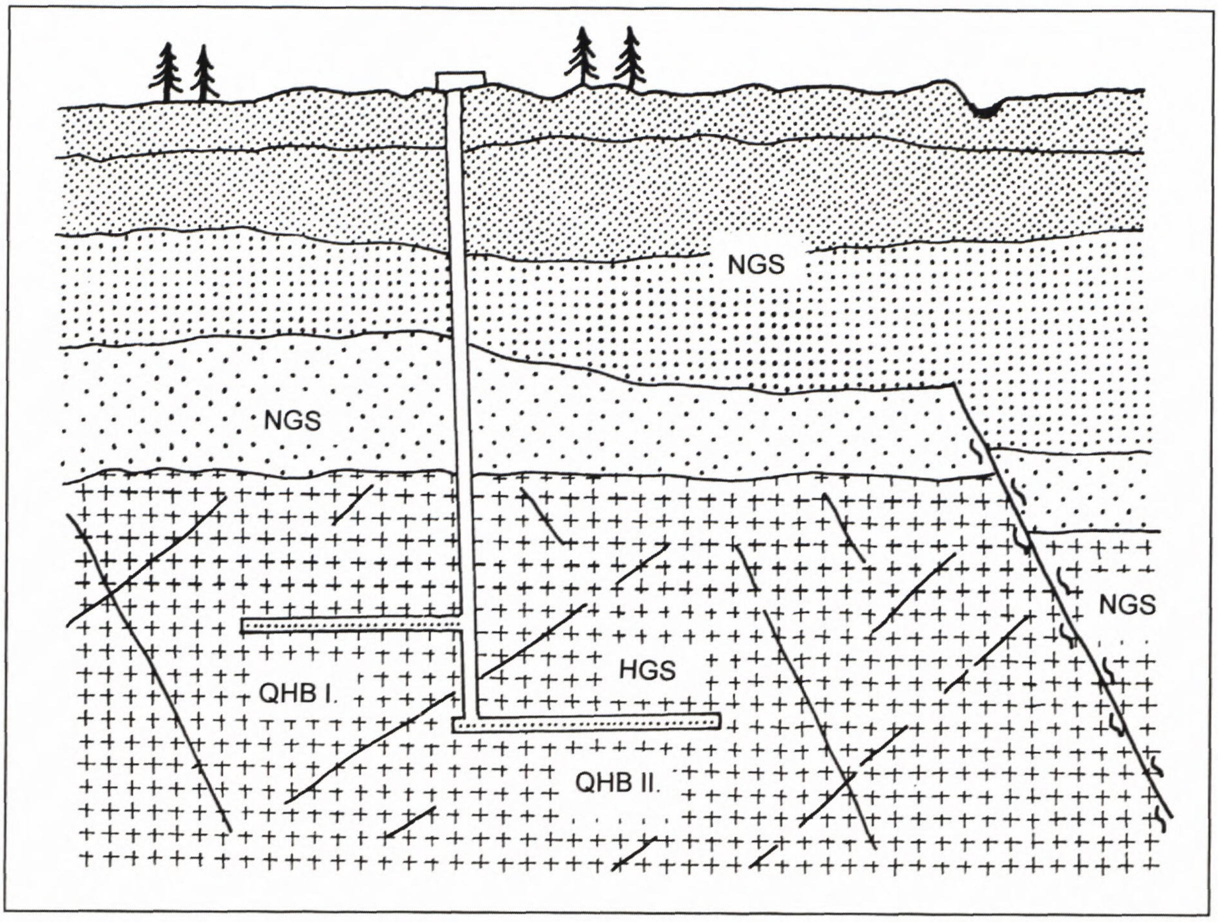

Fig. 1 Deep-seated repository in host environment formed by hard rocks

HGS - *host geological structure*
NGS - *neighbouring geological structure*
QHB - *quasi-homogeneous block*

Deep-seated repository (DR) of high-level radioactive waste and spent fuel is an underground structure, located usually in a depth exceeding 300-500 m below the surface. Part of the repository is a communication shaft and a system of galleries and tunnels, in which the radioactive waste is deposited. Host geologic environment (HGE) is a part of geological environment in which there are favourable conditions for waste deposition. It consists of two separate units: host geologic structure and neighbouring geological structures.

Host geologic structure (HGS) is a part of HGE formed by rocks in their natural state, including fissures and their filling. It is restricted by a geological or tectonic boundary. HGS is composed of several quasi-homogeneous blocks.

Quasi-homogeneous block (QHB) is a part of HGS. It is usually a tectonically restricted body, a layer, lens, or their various combinations. It is formed of rocks in their natural position, including fissures and their filling. It is characterised by high homogeneity of properties and it is separated from HGS by geological elements (faults, limit-exceeding concentration of thermolabile minerals, organic matter etc.), the presence of which is due to their character acceptable in HGS, but not in QHB. HGS may contain several QHBs. In QHB there will be located repository spaces of the deep repository (DR). Underground approach and other (technological) space may be constructed also outside the QHB, but within HGS.

Neighbouring geological structure (NGS) is a part of the rock environment in the surroundings of HGS, formed by rocks in their natural position, including fissures and their filling. NGS due to its character does not fulfil the criteria for HGS, but being in immediate neighbourhood, it affects the conditions in HGS (especially hydrogeology) and it is (will be) affected by HGS and DR. It is separated from HGS by a geologic or tectonic boundary, or by a tectonically (hydrogeologically) important boundary, which, due to its extent and character, cannot occur in HGS. Outer boundary of NGS shall be determined only on the basis of results of further investigations (except the upper boundary, formed by earth surface), the aim of which will be to determine the source and environment of transport ways of groundwater (PV) to HGS, or the environment of escape ways of by radionuclides contaminated PV.

Criteria for the evaluation of geological environment

General characterisation of criteria for the evaluation of geological environment

Evaluation criteria are, in view of the level reached by developed countries in prospecting and assessment of geological environment suitable for deep repositories (DR), on a sufficiently high theoretical as well as practical level. Criteria of geological character are only one of the groups of criteria, decisive for the final situation of a deep repository in geological environment.

According to the recommendations of the International Atomic Energy Agency (IAEA Vienna, 1981, 1982, 1983), criteria for the assessment of geological environment may be divided into exclusive and limiting ones, while:

- exclusive criteria are those which, if not fulfilled, exclude the assessed area, or geological environment, from further investigations. For the exclusion of an area it is sufficient when any of the exclusive criteria is not complied with.
- limiting criteria are those, which limit (restrict) the use of HGE, but they do not exclude it from further investigations. Processes and phenomena defined as limiting criteria have to be identified to determine further geological survey and investigations. Their aim shall be the determination of limiting values of these criteria and to investigate, if the evaluated HGE fall beyond these limits.

Exclusive criteria

Spatial conditions

HGS must have sufficient dimensions to accommodate a deep repository. The extent of the buffer zone (space in immediate surrounding of DR up to the next fault or other unfavourable geological boundary) depends on the character and properties of HGS (sorption capacity, permeability, faulting etc.). Security requirements determine the necessary dimensions of HGS. In plastic rocks it is usually smaller than in solid rocks. According to estimates based on permissible density of waste deposition (distance of containers) and requirements on insulation properties of HGE, HGS has a surface of 8-10 km^2 and a thickness of minimum 200 m (plastic rocks), or 500 m (solid rocks). Minimum depth of DR emplacement in HGE from the surface should vary between 300 and 500 m. A more accurate determination of emplacement depth for a deep repository is based on insulation properties of HGE and the results of a study of geomorphologic evolution of the territory. Maximum depth is limited by natural temperature of HGS, engineering-geological properties of HGS rocks, technologic and economic conditions. With increased depth, the costs increase disproportionally, due to more complicated technology of underground tunnelling.

Hydrogeological conditions

Hydrogeological conditions are principal criteria for the evaluation of HGS suitability. Groundwater is the principal transport medium for chemicals corroding the containers with waste and later on the transport medium for released radionuclides. The direction and rate of groundwater flow across HGE, sorption properties of HGE together with dimensions and depth of HGS must prevent first radionuclides from appearing in the biosphere earlier than in 100 000 years. Their principal activity will be then on sufficiently low level. An environment suitable for the construction of a repository must have a very low permeability and low hydraulic gradient. The value of hydraulic conductivity limit k_f of HGS has been presented by various authors in the range of 1×10^{-9} ms^{-1} to 1×10^{-11} ms^{-1}. Its permissible value depends on the hydraulic gradient, dimensions of HGS and insulation properties of NGS. The value of hydraulic gradient cannot be determined generally. It is related to concrete geological environment.

Tectonic conditions

Severely tectonically affected HGS and the presence of active tectonic fault in HGE are further exclusive criteria.

Tectonic effects in HGS are different in rigid solid rocks (granites, migmatites, limestones etc.) and in plastic rocks (rock salt, clays, claystones etc.). In solid rocks it results in fissures allowing groundwater circulation, in plastic rocks it causes inhomogeneity and irregularity of the dimensions of a geological body.

In brittle rocks of the Western Carpathians, tectonic processes (germanotype and, above all, alpinotype tectonics) resulted in a thick network of discontinuities (faults and fissures). Fissures, up to a depth of approx. 100 m, provide good conditions for groundwater flow. Deeper on they are usually gravitationally closed and water circulation is low.

Along faults, groundwater flow exists even in substantially greater depth. Soluble rocks are characterised by karst permeability, increasing thus the overall permeability of rock environment.

Plastic rocks, after the formation of various discontinuities, are capable of self-sealing, so that greater groundwater flow along discontinuities is usually exceptional. Fissures are closed already in a depth of several tens of meters (approx. 30 m).

Geomorphologic evolution of the relief

Vertical movements of Earth crust, along with denudation processes, affect in a decisive way the depth of emplacement of a deep repository.

Continuous denudation processes predominating over accumulation lead to gradual change of the relief and uncovering of Earth surface. The denudation process, intensified by vertical movements of Earth crust, may after longer time cause undesirable eroding of the overlier of a deep repository and, in an extreme case, even "emergence" of DR to the surface. To asses possible development of the relief, geomorphologic models are prepared, predicting future relief for a period of possible negative effects on the repository (10^4 up to 10^5 years).

Other criteria

Among other exclusive criteria are security, economic and ecological interests of man. From the viewpoint of the necessity of undisturbed (in the past, at present and in the future) HGE, the presence of old mining works, present mining activities, protection zones of mining areas and future prognostic mineral raw material deposits, which are assumed to be exploited in the future, are taken into consideration. The repository should be situated in a HGS, where survey drilling or other future human interference is excluded.

The presence of groundwater in HGS and below, occurrence of geothermal (prognostic as well) and mineral water in HGE, by legislation protected water-economy territories are further exclusive criteria for the selection of HGE. A legislative restriction is also the existence of protected areas (e.g. national parks, protected land etc.).

Limiting criteria

Hydrogeological conditions in the overlier of host geological environment

The existence of infiltration, transport and accumulation area of groundwater in the overlier of HGS is a limiting factor, which must be given increased attention in following stages of survey. When designing a repository, it is necessary to prevent underground spaces from being flooded due to accidental penetration through access shafts tunnelled across aquifers. Such conditions may be assumed to exist in Inner Carpathian Neogene basins.

Seismic conditions

Internationally accepted limit of seismic tremors is 8°MCS, the majority of Slovak territory complying with this value. Since seismic activity of the Western Carpathians is at present being re-evaluated, it is at this stage of assessment ranked with limiting criteria.

The majority of seismic tremors is usually dangerous only for engineering works situated on Earth's surface. In case of an earthquake in HGE, upper parts of access and ventilation shafts may be damaged, as well as equipment on the surface, while underground parts of the repository are relatively safe. In case that the access shaft is tunnelled across an aquifer, the repository can be flooded.

Direct endangerment of underground parts of the repository may occur only at strike-slip movement of HGS rock along a newly-formed fault. The probability of such phenomenon is however very low, even from long-range viewpoint.

Structural-geological conditions

Unfavourable mode of deposition (steep dip of beds and discontinuity planes, irregular shape of HGS body) allow to assume complex tectonic processes in the past, which disturbed the integrity of the rock massif (brittle rocks) and geometric shape of the body (plastic rocks). Unfavourable structural conditions substantially affect the engineering-geological properties of HGS, which influences the technology of underground tunnelling and security provisions.

Engineering-geological conditions

A deep repository is a large underground work in a considerable depth (approx. 300 - 1500 m), which remains open during construction and operation. After filling and closing of a repository, the rock becomes an environment, where all short- and long-time effects and processes, caused by the presence of deposited waste, are manifested. The values of physical-mechanical characteristics of the rock environment must comply with required conditions.

Rock homogeneity of host geological environment

From the viewpoint of DR security, high homogeneity of HGS rock composition is necessary, and thus also homogeneity of physical-mechanical properties of the rocks. Inhomogeneity of HGS results in lower precision of theoretical analysis of DR security. However, certain signs of inhomogeneity of rock composition or of their properties are to a limited extent acceptable.

Geochemical properties

Geochemical properties of rocks play an important role in long-range security of a repository. Sorption properties of rocks, aggresivity of groundwater, high solubility of rocks etc. influence the selection of suitable location for a DR. Chemical reactions may cause changes of the properties of engineering barriers and thus affect their retention effects on released radionuclides.

Thermal properties of rocks

Spent fuel in an interim repository (before its final deposition) cools down to a technologically acceptable temperature (60 to 140 °C) Deposited waste increases the natural temperature of DR environment. Therefore a HGS with low natural temperature, built of rocks and minerals with high thermal conductivity, is more advantageous. Thermal instability of minerals may result in their alteration and thus secondary change of mechanical properties of the environment.

Mineral deposits

Mineral deposits are acceptable in the overlier of NGS. From the viewpoint of security of a repository it is necessary to determine a limit for the depth or distance from occurrences of mineral raw material from HGS. This distance may be determined only for a concrete HGE.

The application of criteria to assessment of area suitability is to a certain extent problematic due to the fact that it requires detailed characterisation of rock environment. This is (in view of the degree to which Western Carpathian territory has been subjected to geological investigations) at various levels.

With increasing level of geological information it will be possible to apply the criteria on qualitatively quite different level. This, at the same time, assumes a process of continuous updating, complementing and precisifying of selection criteria in the following stages of this project.

The above geological criteria are only a part of criteria, which are decisive for the situation of DR. The distance of DR from inhabited areas, protected natural territories etc. is subject to public discussion or political decision-making.

Method of selection

The assessment of the territory of Slovak Republic was based on the application of internationally determined and applied criteria. The criteria were adjusted according to the required density (scale) of investigation, financial conditions and professional potential of the evaluating institute.

In the first stage, basic evaluation of the territory was carried out by regional geologists - specialists for various regional-tectonic units. Their task was to distinguish a prospective area, where it will be possible to find, with a great probability, a sufficiently large rock massif, in sufficient depth, tectonically unaffected and without active tectonic faults, adequately lithologically homogeneous.

The conclusions of regional geologists were followed by the evaluation of a hydrogeologist - specialist. Selected units were critically assessed especially from the viewpoint of their permeability. From the evaluation it follows that sufficient quantity of basic hydrogeological characteristics are necessary for the required depth level, which are at present not available.

The assessment of the hydrogeologist was decisive for the selection of prospective territories, while the conclusions of geophysical evaluation were taken into consideration as well (Šefara, 1994).

In the second stage, prospective territories shall be subjected to evaluation from the viewpoint of:
- protected mineral deposit territories and prognostic deposits
- protected water-resources management territories
- protected natural areas (national parks, protected land areas etc.)

and others, in the sense of above described criteria.

Further exclusive and limiting criteria will be applied to distinguished territories in next stages of investigation. The following text presents the results of the assessment of the Slovak territory after the first stage of investigation.

Prospective areas of the Western Carpathians for the construction of high-level radioactive waste repository

The aim of the evaluation of the whole territory of Slovakia is to distinguish and characterise those areas in Slovakia where the occurrence of HGE is probable, and to locate in them HGS with an accuracy corresponding to the level of present knowledge.

A great disadvantage of Slovakia from the viewpoint of possible DR construction is the small area of the country (49 013 km^2). Extremely high requirements for such a construction make necessary the evaluation of the territory according to many criteria, while geological criteria are only one group of them.

On the basis of geological and hydrogeological criteria, several prospective host geological environments (Fig.1) were distinguished on the territory of the Western Carpathians. Their brief characterisation is presented below.

1. Tribeč Mts.
2. Žiar Mts.
3. Rochovce
4. Territory between Čierny Balog and Sihla
5. Territory between Lom nad Rimavicou, Kokava nad Rimavicou, Málinec and Detvianska Huta
6. Nižná Slaná
7. Territory between Smolník, Mníšek nad Hnilcom, Prakovce and Poproč
8. Nízke Beskydy Mts. - area of Zborov
9. Juhoslovenská panva Basin (area of Lučenec Basin, SW part of the Rimavská Basin and Cerová vrchovina Hills)

Crystalline complexes

On the basis of the evaluation of Core Mountains belt and the Veporicum (BEZÁK - LUKÁČIK, 1994, KOHÚT, 1995), prospective host geological environment was located in the following areas: granitoid massif of the Tribeč and Žiar Mts., Rochovce granite, central part of the Vepor belt and the territory of metamorphic rocks of the Krakľová zone of the Veporicum (Fig. 2)

Tatricum

Tribeč Mts.

As a prospective territory has been selected an area built of granitoid rocks of the southern, Tribeč-Zobor block. The Zobor Massif, one of the largest in the Western Carpathians, is formed of granitoids characterised by monotoneity, little variable composition, corresponding to massive medium-grained tonalites.

The structure of crystalline complexes in the Tribeč Mts. is affected by the important transversal Skýcov Fault and other accompanying faults of NW-SE direction. Besides cross-wise faults, the granitoid core was to a considerable extent divided by faults of NE-SW direction. Important role was played by strike-slip faults and marginal faults on the contact of granitoids and younger units. The strike-slip faults are not assumed to reach a depth of over 500-700 m from the surface. Below this level, a relatively stabilised granitoid massif is assumed in the Zobor part. Especially in the area between Javorový vrch Hill and Veľký Tribeč, at present there are not known any limiting structural-tectonic phenomena in the present relief of the uncovered plutonic body. Besides this, no indications of ore mineral concentrations are know here. This were the reasons for the selection of this territory for further investigations.

Žiar Mts.

As prospective from the viewpoint of finding a HGS are considered granitoids of these core mountains. They form the predominant part of the crystalline complex and they are represented mostly by varieties with porphyric K-feldspars. Leucocratic aplite-pegmatite granites occur mostly in marginal upper parts of the granitoid body. Two-mica granitoids occur in the central part. Oriented and schistose types, affected by mylonitization, are spatially related to fault zones.

Predominant are faults of NNE-SSW direction, as well as parallel faults partly of SW-NE direction, participating in the segmentation of the crystalline core. Important are marginal faults of NE-SW direction.

At first sight it appears that the crystalline core of the Žiar Mts. is strongly tectonically affected. In reality this granitoid core is the most eroded one among core mountains of the Central Western Carpathians. During the Paleogene and Neogene, the upper, strongly alpinotype-affected (1000 to 1300 m in vertical cross-section) granitoid horizon was eroded away. In this way, the deepest plutonic levels have been exposed, in which protomagmatic structures may be identified. The granitoid core of the Žiar Mts. has on radar images the character of a territory affected only by germanotype tectonics, which makes it an exception in the Western Carpathians (KOHÚT, 1995). The prospects of finding economically exploitable mineral resources in the Žiar Mts. are low.

Veporicum

Rochovce

From available knowledge obtained from the investigation of crystalline complexes, as relatively prospective may be regarded young (Cretaceous) granitoids, which were not affected by tectonic

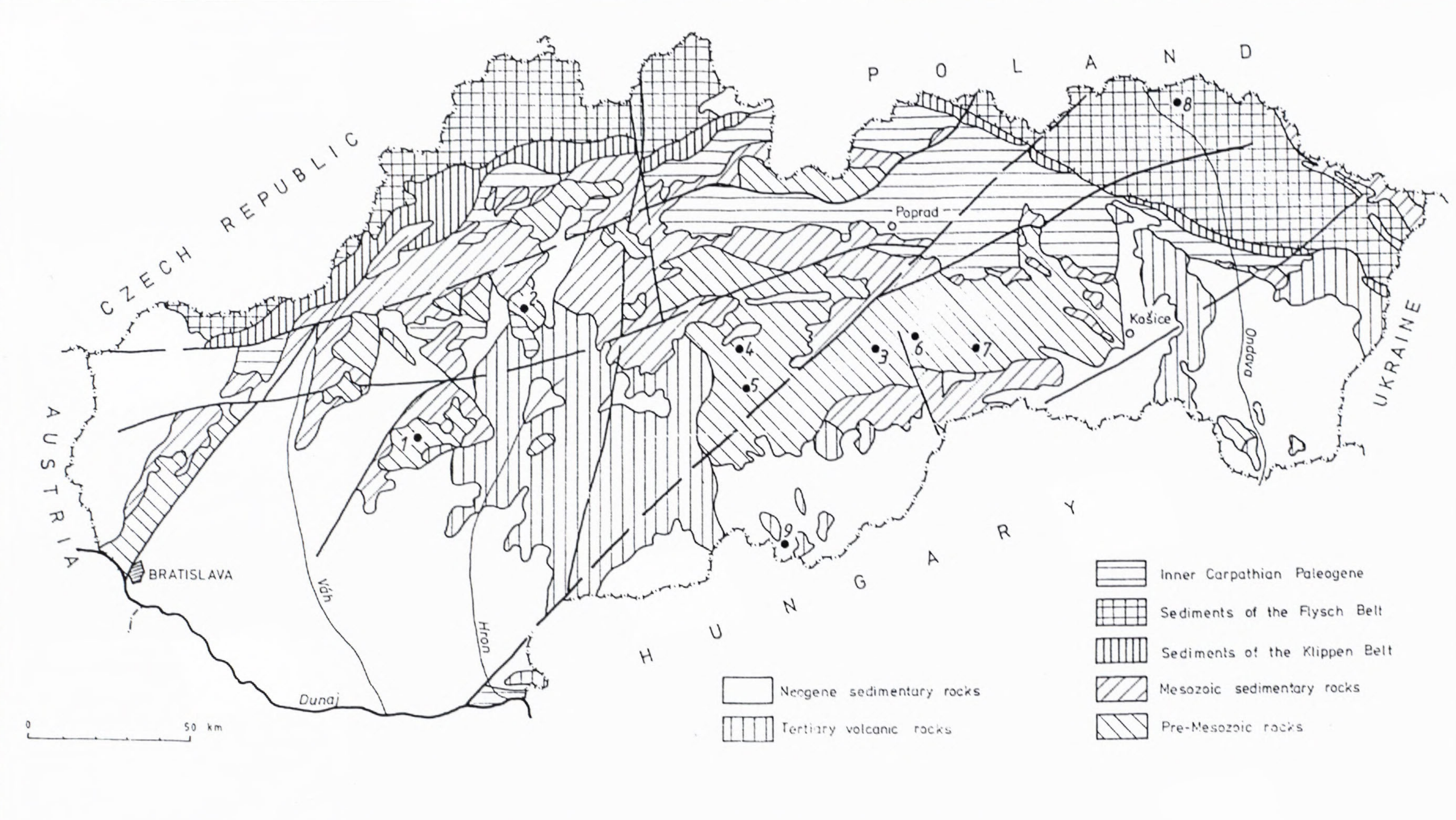

Fig. 2 Prospective areas for the final repository of high-level radioactive waste and spent fuel in the Slovak Republic

processes during the Alpine orogeny. Rheologic disturbance of these bodies may be assumed to be far lower than deformation of older bodies, to which they were subjected in main stages of both orogenies. Such body appears to be the Rochovce granite, identified for the first time by drilling survey (KLINEC et al., 1980).

It is a massive porphyric granite body, little faulted, with isotropic internal structure. It occurs at a depth of about 400 m below the surface and its great depth extent is assumed. Stratigraphically, its formation is dated as Upper Cretaceous (HRAŠKO, 1993). Past investigations of this body were aimed at intrusions accompanying the Mo-W mineralization. Their presence may be an unfavourable factor from the viewpoint of HGE selection.

The most important tectonic lineament of the area is the Ľubeník-Margecany line. The body is on north-east and east submerged along the Štítnik fault system, while in the north it is restricted by the Rochovce fault. The overall tectonic effects on the body are not known.

Territory between Čierny Balog and Sihla

The most frequent petrographic type of the Čierny Balog metamorphic rock are biotite plagioclase paragneisses, in some places with signs of partial anatexis. Characteristic of them are the same metamorphic conditions in all complex, without more significant signs of young recent tectonics, which is the main reason for their being included into further investigations.

The territory between Lom nad Rimavicou, Kokava nad Rimavicou, Málinec and Detvianska Huta

The Vepor pluton is built in another prospective area absolutely predominantly of deformed porphyric granitoids, with several cm large K-feldspar phenocrysts. A smaller area is occupied by biotite granodiorites to tonalites of Sihla type and by a belt of hybrid granitoids in the southern part. In all varieties typical are small bodies or veins of leucocratic granites, aplites and pegmatites.

The Vepor granitoid pluton is the largest one in the Western Carpathians (approx. 60 km in lengthwise direction). Even though it is a complex pluton, consisting of several granitoid rocks and Alpine deformation (recrystallization) has here regional character, due to its size it has been recommended for further investigation with prospects of finding a suitable HGE.

Hydrogeological properties of the rocks of Western Carpathian crystalline complexes in greater depths are so far little known . They may be estimated only from analogies with other territories. From the viewpoint of radioactive waste deposition their main deficiency is their relatively considerable petrophysical heterogeneity, resulting from tectonic effects and in some areas also relatively varied petrographic composition, with frequent alternation of bodies with different petrographic characteristics. An unfavourable result of tectonic disturbance is besides manifestations of disjunctive tectonics, connected with local increase of permeability, also frequent occurrence of mylonitized zones, which may represent in some sections an environment with increased permeability even in greater depths (JETEL, 1994).

To be able to asses reliably the suitability from hydrogeological viewpoint it is however necessary to determine hydraulic parameter values of rocks in the considered depths and their anisotropy. Only on the basis of such data it would be possible to evaluate more strictly the suitability from the viewpoint of hydrogeological and other criteria.

The Paleozoic of the Spišsko-gemerské rudohorie Mts.

On the basis of a study of literature concerning the Paleozoic of the Western Carpathians (VOZÁR, 1994), several prospective host geological environments have been distinguished here (Fig. 2).

Area of Nižná Slaná and territory between Smolník, Mníšek n. Hnilcom, Prakovce and Poproč

From geological viewpoint as potential ones may be assessed selected horizons of the Gelnica Group (Cambrian-Silurian) formed of graphite phyllites and phyllites with intercalations of lydites and carbonates. The above rocks attain thicknesses of several hundreds of meters. They are a part of the Drnovo Formation (Silurian-Devonian).

Experience from mining in Nižná Slaná shows that horizons 450-650 m thick are without groundwater circulation. A disadvantage is however the disturbance of hydraulic continuity and sealing of the environment by mining works, from which the older ones may have not accurately known position. The rocks of the Gelnica Group in the area Smolník-Mníšek nad Hnilcom - Prakovce - Poproč may be basically considered suitable, systematic information on permeability and possible privileged hydraulic communications related to fault tectonics is however lacking. In the near-surface zone of this area, the dependence of concentrated groundwater circulation on the direction of fault lines has been unambiguously proved. Information on the depth extent of this relationship is lacking.

Flysch Belt

Although the Paleogene flysch formations cover a considerable part of the Slovak territory, in view of their lithologic content, mostly carbonate underlying rocks and complex tectonic conditions it is difficult to distinguish in this environment a prospective territory. The only conditionally suitable site, recommended for further investigation, are the Nízke Beskydy Mts. (Fig.2).

Nízke Beskydy Mts.

From hydrogeological viewpoint the principal unfavourable factor for radioactive waste deposition in the Flysch Belt territory is the small thickness of hydraulically homogeneous rock bodies, which could function as strictly defined hydrogeological insulators and serve as a suitable host environment for radioactive waste deposition.

Intergranular permeability of sandstone members of the flysch complex is at present state of diagenetic lithification usually insignificant, so that decisive for groundwater movement is fissure permeability. At the same time, on the basis of the results of a study of spatial distribution of hydraulic parameters in flysch rocks (JETEL, a, b. JETEL et al., 1990), it may be stated that the flysch rock massif displays a high degree of homogenisation, especially in the western section of the Flysch Belt. These facts resulted in greater or smaller suppression of differences in primary permeability and hydrogeologic function of different lithologic type of flysch rocks.

The permeability of flysch rocks in the Western Carpathians is in the first place determined by their present depth, tectonic effects and age of the rocks, while the influence of lithologic differences is not in all parts of the Flysch Belt the same and unambiguous (JETEL, 1991).

As a suitable host environment in the Flysch Belt of the Western Carpathians could be from this viewpoint considered those sections of the Biela Več Formation of the Magura unit in the eastern part of the Flysch Belt which are in sufficiently thick and deposited in necessary depth.

The value of the hydraulic conductivity k = 10-11 to 10-12 m/s in depths of 300-500 m and more may be considered in this environment - outside the reach of tectonically related fissure zones - to be real.

Selected parts of the Biela Veža Formation would in these depths comply also with other hydrogeological criteria (insignificant groundwater flow velocity, non-existence of exploitable groundwater resources). The possibility of waste deposition in the upper part of the Biela Veža Formation may be however doubted by the problem of prospective carbohydrate deposit occurrence in this territory, or by the probability of survey in more distant future.

On the basis of lithologic content, required depth and thickness of HGE, as well as hydrogeological conditions, as a prospective area has been distinguished the area of Eastern Beskydy Mts., near Zborov.

Inner Carpathian basins

On the basis of geological evaluation of Inner Carpathian basins (VASS-ELEČKO, 1994), prospective environment has been localised in a part of the Juhoslovenská panva Basin (Fig. 2).

Lučenec Basin, SW part of the Rimavská Basin and Cerová vrchovina Hills

The prospective area belongs geomorphologically into the SE part of the Lučenec Basin, SW part of the Rimavská Basin and Cerová vrchovina Hills.

From lithological, structural and spatial viewpoint the most prospective HGS for the localisation of a repository appear to be two lithostratigraphic units? the Séčen schlier of the Lučenec Formation (Egerian) and Lenártovce Beds of the Číž Formation (Kiscellian).

The above lithostratigraphic units form the principal mass of the basin filling. The predominant lighologic type in both formations are siltstones and claystones. Maximum thickness of the Číž Formation in the Lučenec and Rimavská Basins attains over 300 m, in the underlier of the Cerová vrchovina Hills more than 400 m. Maximum thickness of the Lučenec Formation in the Lučenec Basin and Cerová vrchovina Hills is 1200 m, in the Rimavská Basin 1100 m. The thicknesses of both formations increase from the northern margin toward the south (VASS et al., 1989, VASS - ELEČKO et al., 1992). Cumulative thickness of both formations varies between 1400 and 1600 m.

From the viewpoint of hydraulic permeability it is necessary to investigate the HGS in greater detail, especially as far as possible permeability of the Séčen schlier siltstones and permeability along the faults (acidulous water springs) are concerned. In some parts of the HGS there are also sandstone lenses of not very great thickness and extent, which are saturated by fossil marine water.

On the majority of the territory under consideration the overlier of the Lučenec Formation are directly Qarternary sediments of insignificant thickness.

Conclusion

Distinguishing suitable geological structures for the construction of final repository of high-level radioactive waste and spent fuel is a long-lasting process, with the participation of many factors. Geologic conditions are only one of the criteria for final selection.

The aim of our investigation was to distinguish several areas, where detailed investigation and survey would be applied successively, while other relevant characteristics (geologic-tectonic, hydrogeological, geochemical, thermomechanical and thermochemical, geotechnical, seismic, hydrological) would be determined as well as a prognosis of geological and morphologic development within a time range of 10^4 to 10^5 years.

The briefly described potential HGE are a partial result of the at present carried out investigations. Final suggestions of HGE for further investigations may be in part different. The reason for this is the fact that when evaluating geological structure of Slovakia, only some selected criteria were considered. The application of other criteria is the subject of following study.

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Assessment of the territory of the Slovak Republic for waste disposal - Maps of the suitability the area for waste disposal, inventory of waste dumping grounds

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Abstract: Maps of the suitability of areas for waste disposal on the scale 1 : 50 000 have been constructed for the whole territory of Slovakia during the period 1992-1994. Simultaneously with the completion of the maps, field inventory of waste disposal sites has been made on the scale 1 : 10 00. The presented paper describes the methods of map construction and results of the waste dumping ground inventory. The total mapped area was 48 545.059 km^2. From this, 7094.993 km^2 (14.6%) was evaluated as area suitable for waste disposal, 17 933.862 km^2 (36.94%) as conditionally suitable and 23 516.204 km^2 (48.44%) as area unsuitable for the dumping of wastes. The total number of registered waste disposals is 8389 items.

Key words: waste disposal, field inventory, inventory sheet, maps of suitability, criteria of suitability

1. Introduction

Until basic legislation (laws and executive notices) has been passed, the situation in waste dumping grounds was unorganised and chaotic. Active policies concerning environmental protection aimed at minimising negative effects of waste disposal were absent.

The year 1989 was a turning point in problems of waste disposal. Initiated by local institutions as a reaction to the new approach to waste disposal, maps of area suitability for waste disposal have been constructed for different territorial units, with various accuracy and using different approaches for their elaboration. Similarly, there were different registration methods for existing waste dumping grounds - from questionnaires to very detailed records of present state.

The necessity of unification of approaches to both problems led to the project of construction of area suitability for waste disposal maps for the whole territory of the Slovak Republic, along with registration of waste dumping grounds. The project was initiated by Geological Factors Department of the Ministry of Environmental Protection of the Slovak Republic in the year 1992, and it ended in the first quarter of 1994.

The aim of the project was to construct the basic material for decision-making concerning the situation of new waste dumping grounds of home and similar waste.

Participants of the project in the various districts of the Slovak Republic were selected by competition, while, in view of the character of the task, renowned organisations were selected, specialising in geological and hydrogeological survey.

Maps of the area suitability for waste disposal

The construction of map of area suitability for waste disposal maps was preceded by the elaboration of instructions for its construction (Instructions for the construction of maps of area suitability for waste disposal, 1993). The starting point for the evaluation of area suitability is the presence of selected relevant factors (Tab. 1). The selection of the factors, having mostly the character of geofactors, depended on the scale of the map, availability of information, coverage of the territory of Slovak Republic as well as the necessity to attain uniform coverage density for the whole evaluated territory (or, in view of existing legislation), various limitations for making new dumping grounds.

Exclusive factors exclude by their presence the whole territory, or require special approach for acquiring a licence for waste disposal. Their presence makes the establishing of new waste dumping grounds considerably more complicated and increases the costs.

Limiting factors have a lower degree of restriction. Similarly as for exclusive factors, their complicate the establishing of new waste dumping grounds and make them more expensive.

In the maps, besides factors presented in Tab. 1, phenomena and processes have been presented,

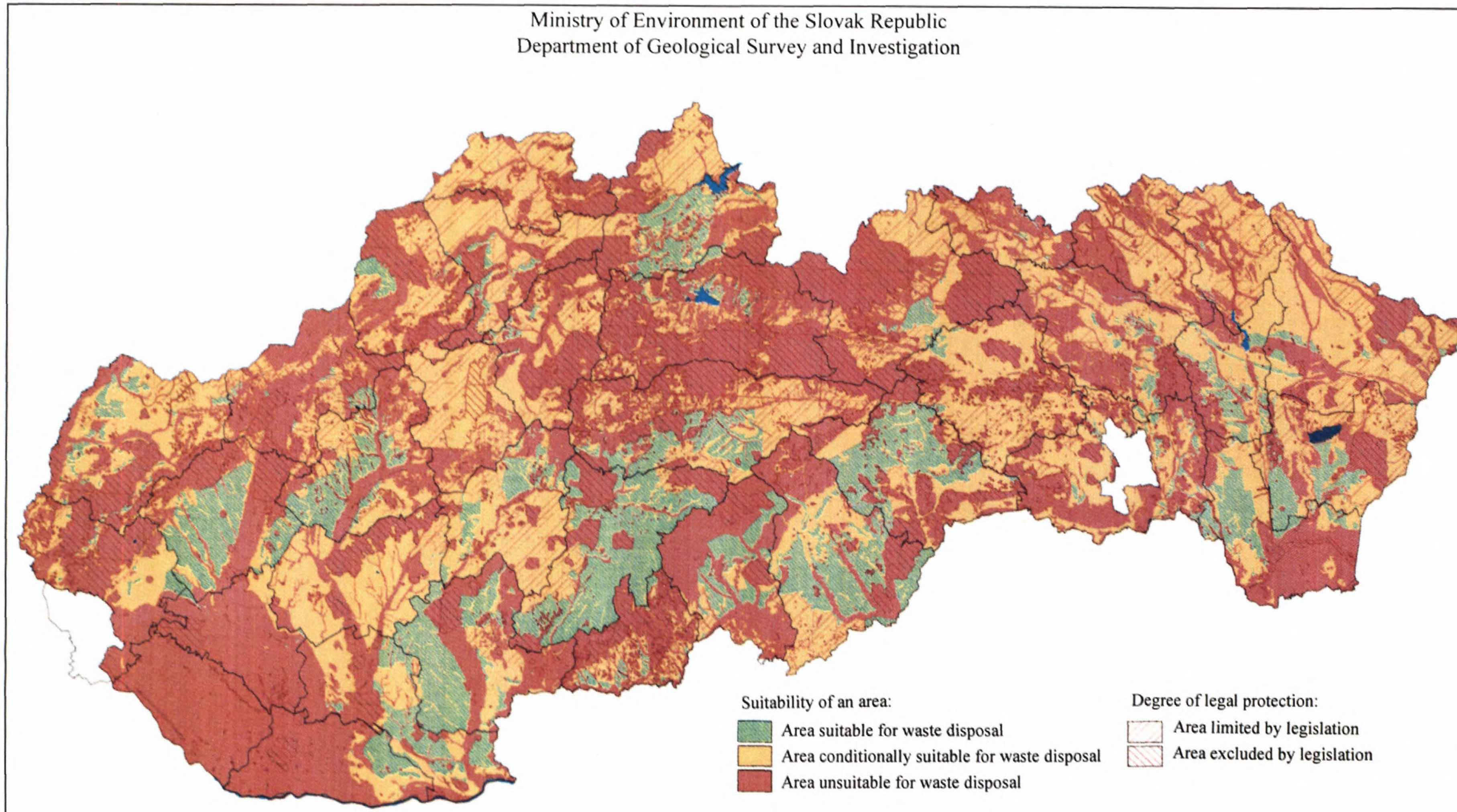

Fig. 1 Map of the suitability of the area for waste disposals (1:1 757 000)

having only informative character. They are e.g. seismicity of the territory, groundwater level depth, important geodynamic phenomena (landslides, sinking), active tectonics etc. By accepting their real importance in concrete conditions it was possible to re-classify some informative factors as limiting or exclusive.

Selected factors were evaluated and presented on the scale 1 : 50 000, in two documentation maps and resulting map evaluating the territory.

Documentation map I presents using marks, hatching and colour, by legislation determined factors for the situation of waste dumping grounds, which are protected deposit areas, protected forests, protected natural areas and protected water-management areas. For more details see Tab. 1.

Documentation map II presents other geofactors (Tab. 1), which are mineral deposits, hydrogeological phenomena, geodynamic phenomena and endangerment of groundwater. Endangerment of groundwater is a characteristic established for this special purpose, taking into consideration the position and thickness (depth) of aquiclude, the aquifer transmissivity value and the permeability type of rock environment. The method of estimating the grade of groundwater endangerment is shown in Tab. 2.

The map evaluating the territory by "traffic light" method shows the suitability, while an area suitable for making a waste dumping ground is free of exclusive and limiting factors, an area conditionally suitable is characterised by the presence of limiting factors and an unsuitable area is characterised by the presence of exclusive factors. Besides this, a coloured pattern (yellow or red) represents the presence of legislative factors (limiting or exclusive ones), not distinguished by type.

In the map there are also registered waste dumping grounds marked accordingly to show suggested procedures for their further existence.

Maps constructed by the above method were made for all districts of the Slovak Republic, with the exception of the cities Bratislava and Košice, where, before the construction of the above described maps, maps of suitability for wasted dumping grounds had been made on the scale 1:25 000, with extended contents.

All information collected according to the Instructions for different districts were digitised and printed by a uniform method for all districts of the Slovak Republic. The responsibility for data processing and map printing was delegated to Geofond Bratislava.

Maps of area suitability for waste dumping grounds were constructed for 36 districts of the Slovak Republic. The costs varied in the range of 300-500 thousand Sk, according to the size of the district. The price includes also costs of waste dumping ground registration and map printing.

An overview map of area suitability for waste disposal of all Slovak territory is presented in Fig. 1.

Tab. 3 shows the proportion of areas suitable, conditionally suitable and unsuitable for waste disposal in different districts of the Slovak Republic in km^2 as well as per cent.

The situation on the whole Slovak territory is the following:

Total evaluated area	48 545.059 km^2
Area suitable	7 094.993 km^2
i.e. 14.62%	
conditionally suitable	17 933.862 km^2
i.e. 36.94%	
unsuitable for waste disposal	23 516.204 km^2
i.e. 48.44%.	

From the above overview it follows that almost the half of the evaluated territory is unsuitable for waste disposal.

Territory suitable for waste disposal constitutes the smallest proportion of the total territory evaluated, while the number of districts with:

0 - 1 % of suitable areas is 6, i.e. 16.67%,
1 - 10 % of suitable areas is 15, i.e. 41.67 %,
10 - 20 % of suitable areas is 5, i.e. 13.89 %,
20 - 30 % of suitable areas is 5, i.e. 13.89 %,
30 - 40 % of suitable areas is 4, i.e. 11.11 %
40 - 50 % of suitable areas is 0,
50 - 60 % of suitable areas is 0,
60 - 70 % of suitable areas is 1, i.e. 2.78 %.

Of 36 districts, a proportion of areas suitable for waste disposal sites up to 40 % have 35 districts. Of these, as much as 17 % have a proportion of suitable areas up to 1 % and approximately 43 % of them a proportion of suitable areas of 1 to 10 %. This indicated unfavourable situation in making new waste dumping grounds. Reality will force people responsible for decision making to enter less favourable conditions, which will cause more confrontations of interests and increased costs of new waste dumping grounds.

Territory conditionally suitable for waste disposal forms approximately the third of the total territory evaluated, while the number of districts with:

0 - 1 % conditionally suitable areas is 1, i.e. 2. 78 %
1 - 10 % conditionally suitable areas is 1, i.e. 2.78%
10 - 20 % conditionally suitable areas is 6, i.e. 16.67 %
20 - 30 % conditionally suitable areas is 5, i.e. 13.89 %
30 - 40 % conditionally suitable areas is 9, i.e. 25.00 %
40 - 50 % conditionally suitable areas is 5. i.e. 13.89 %
50 - 60 % conditionally suitable areas is 2, i.e. 5.56 %

Tab. 1 Classification of factors controlling the suitability of an area for waste disposal

Type		Category	
		Exclusive	Limiting
Determined by legislation	Water - resources management- protected areas	- sources of mineral and thermal water and their protection zones of degree I and II - sources of drinking surface- and groundwater and their zones of hygienic protection of degree I and II - flooding area of dams under construction	- protection zones of mineral and thermal water - zones of hygienic protection of degree III of surface and grounwater sources - drainage area of a water-resource-management related waterflow - protected water-resources-management area - protected areas with groundwater resources
	Protected areas of nature	- National Park - State Nature Reserve - protected occurrence - protected work of nature and monument - protected park and garden - protected study area	- protection zone of a national perk - protected land area - protection zone of a protected land area - protection zone of a protected occurrence
	Protected forest	- special purpose forestts - preotection forests	
	Protected mineral deposit areas	- mining area of an important surface deposit - protected deposit area of an important surface deposit	- mining area of an important underground deposit - protected deposit area of an important underground deposit - survey area of a deposit
Other	Groundwater endangerment*	- high and very high	- medium
	Geodynamic phenomena	- area with manifestations of undermining on the surface	- areas with the occurrence of slope deformations** - areas affected by scouring erosion**
	Hydrogeologic phenomena	- wetlands - inundation areas	- areas with important groundwater resources
	Mineral deposits		- mined surface deposits of less important minerals

Symbol	Degree of groundwater endangement and costs of remedial measures	Structure of the rock environment remedial measures
A	very high	1A4
B	high	1A3 2A3 2A4 1N3 1B4
C	medium	1A2 2A2 3A3 3A4 1B2 2B2 2B3 2B4 1C3 1C4 2C3 2C4
D	low	1A1 4A4 1B1 3B3 3B4 1C2 2C2 3C3 3C4 1D3 1D4 2D3 2D4
E	very low	4B4 1C1 4C4 1D1 1D2 2D2 3D3 3D4 4D4 E

Transmissivity of aquifers:

$A \geq 10^{-3}\ m^{-2}\ s^{-1}$
$B \equiv 10^{-4}\ m^{-2}\ s^{-1}$
$C \equiv 10^{-5}\ m^{-2}\ s^{-1}$
$D \equiv 10^{-6}\ m^{-2}\ s^{-1}$
$E < 10^{-6}\ m^{-2}\ s^{-1}$

Thickness (depth of the surface) of aquicludes:

1 – 0– 2 m
2 – 2– 5 m
3 – 5–10 m
4 – > 10 m
izolátor – $k_f \leq 10^{-7}$ m . s^{-1}

Structure of the rock environment:

2A3 – Depth of the surface of underlying aquiclude
– aquifer characterised by transmissivity
– thickness of surface aquiclude

Types of rock environment permeability

I – pore
II – fracture-pore
III – fracture
IV – karst-fracture
V – karst

Examples of complex symbols of the rock environment

2AIV4	1BI3	CII3
2´IV4	1BI3	3CII
inhomogeneous aquiclude	insufficient data on the thickness of the aquiclude	unclear position of the aquiclude

Tab. 3 Assessment of the district of the Slovak Republic according to their suitability for waste disposal

Organization engaged	District	Abbre-viation	Areas assessed as:					
			suitable		conditionally suitable		unsuitable	
			km²	%	km²	%	km²	%
GP, š. p., Sp. N. Ves	Banská Bystrica	BB	373,164	17,99	819,751	39,53	881,066	42,48
GEOCONSULT, a. s., Košice	Bardejov	BV	4,889	0,48	550,690	54,33	458,097	45,19
GP, š. p., Sp. N. Ves	Bratislava vidiek	BH	44,367	3,57	387,609	31,25	808,186	65,18
INGEO, a. s., Žilina	Čadca	CA	0,366	0,04	630,853	67,45	304,111	32,51
INGEO, a. s., Žilina	Dolný Kubín	DK	315,512	19,59	644,726	40,03	650,300	43,48
GÚDŠ Bratislava	Dunajská Streda	DS	-	-	-	-	1 078,475	100,00
GEOS, a. s., Bratislava	Galanta	GA	15,239	1,55	75,936	7,70	894,788	90,75
GP, š. p., Sp. N. Ves	Humenné	HN	65,690	3,45	1 169,094	61,23	673,221	35,32
GEOS, a. s., Bratislava	Komárno	KN	114,413	10,42	129,626	11,80	853,969	77,78
GÚDŠ, Bratislava	Košice-vidiek	KS	95,772	5,39	670,497	37,74	1 010,491	56,88
Hydropol, Bratislava	Levice	LV	600,264	38,68	266,636	17,18	685,103	44,14
INGEO, a. s., Žilina	Lipt. Sv. Mikuláš	LM	96,531	4,90	352,105	17,86	1 522,476	77,24
GEOS, a. s., Bratislava	Lučenec	LN	275,101	21,15	150,154	11,55	875,147	67,30
INGEO, a. s., Žilina	Martin	MT	38,009	3,37	480,696	42,58	610,183	54,05
GP, š. p., Sp. N. Ves	Michalovce	MI	257,078	19,63	636,295	48,60	416,062	31,77
GEOHYCO, a. s., Bratislava	Nitra	NR	5,794	0,40	948,795	65,67	490,226	33,93
GEOHYCO, a. s., Bratislava	Nové Zámky	NZ	317,610	23,68	436,377	32,53	587,356	43,79
INGEO, a. s., Žilina	Poprad	PP	80,776	4,12	572,887	29,18	1 309,114	66,70
INGEO, a. s., Žilina	Považská Bystrica	PX	72,057	6,02	494,522	41,31	630,612	52,67
GÚDŠ, Bratislava	Prešov	PO	88,230	6,23	588,482	41,53	740,182	52,24
Lab. IG-PFUK, Bratislava	Prievidza	PD	2,459	0,26	730,322	76,16	226,186	23,58
GP, š. p., Sp. N. Ves	Rimavská Sobota	RS	600,874	32,94	557,700	30,58	665,504	36,48
GP, š.p., Sp. N. Ves	Rožňava	RO	570,948	35,30	441,583	27,30	604,753	37,40
GEOHYCO, a. s., Bratislava	Senica	SE	156,358	9,23	787,500	46,49	750,195	44,28
GP, š. p., Sp. N. Ves	Spiš. N. Ves	SV	39,857	2,61	971,602	63,68	514,395	33,71
GEOCONZULT, a. s., Košice	Stará Ľubovňa	SL	10,638	1,71	275,938	44,39	335,084	53,90
GEOCONZULT, a. s., Košice	Svidník	SD	8,552	1,00	587,639	68,58	260,640	34,42
GEOFAK., Bratislava	Topoľčany	TO	363,045	26,67	470,745	34,60	527,147	38,73
GEOCONZULT, a. s., Košice	Trebišov	TR	306,608	23,19	349,684	26,44	666,039	50,37
GEOS, a. s., Bratislava	Trenčín	TM	54,984	4,21	336,496	25,77	914,384	70,02
Lab. IG-PFUK, Bratislava	Trnava	TT	536,883	38,71	209,646	15,12	604,262	43,57
GEOS, a. s., Bratislava	Veľký Krtíš	VK	57,865	6,75	215,929	25,22	581,932	68,00
GEOKONZULT, a. s., Košice	Vranov n. Topľou	VR	206,887	24,73	397,947	47,58	231,621	27,69
GP, š. p., Sp. N. Ves	Zvolen	ZV	1 033,810	60,39	236,978	13,84	441,223	25,77
GEOS, a. s., Bratislava	Žiar n. Hronom	ZH	203,254	16,10	768,634	60,91	290,020	22,49
INGEO, a. s., Žilina	Žilina	ZA	81,159	7,40	591,779	53,97	423,654	38,63
Spolu			7 094,993	14,62	17 933,862	36,94	23 516,204	48,44

Tab. 4 Proposal of further management of the waste disposal site in the distrincts of the Slovak Republik

District	Abbre-viation	Proposal of further management of the waste disposal site:												
		L	LR	LM	LMR	R	MR	D	DR	DM	DMR	M	Z	Total
Banská Bystrica	BB	38				42		5				10		95
Bardejov	BV	159				50	6	7						222
Bratislava-vidiek	BH	23				64		9					9	105
Čadca	CA	192				47	39			7		1		286
Dolný Kubín	DK	199				24				13		14		250
Dunajská Streda	DS	65				87	1	2				28		183
Galanta	GA	108	23	74	1	103	34	1	1	1		136	1	483
Humenné	HN	147	23	3	8	75	15	3		1				275
Komárno	KN	50	1	20		103	2	3				188	264	631
Košice-vidiek	KS	115				92	42	18		7		1		275
Levice	LV	26				153	6	36		17				238
Lipt. Sv. Mikuláš	LM	66				127	26	11		7		2		239
Lučenec	LN		45		20	1	1			10				77
Martin	MT	190	14	2		67	5	13	15	5	3	3		317
Michalovce	MI	95	1	3		2		1		1	1	1		105
Nitra	NR	155				187	1	4	114		2			463
Nové Zámky	NZ	68	3	9	6	21	27	1		8	1	36		180
Poprad	PP	153	66			155	8			2	1	2		387
Považská Bystrica	PX	2	96		2	47	6			6	1	6		166
Prešov	PV	77				115	29			15		1		237
Prievidza	PD	95	1			53		19		6		3	2	179
Rimavská Sobota	RS	56	1	2		71	7	13		2		1		153
Rožňava	RO	60			1	99	14	4		4				182
Senica	SE	103	1			94	2	26		6		6		238
Sp. N. Ves	SV	137	1	2	1	16	4					9	1	171
Stará Ľubovňa	SL	64				17	4	1		5				91
Svidník	SD	138				65	31	21						255
Topoľčany	TO	142	9	1		53	1	5		3				214
Trebišov	TR	139	1	1		77	27	6		45		2		298
Trenčín	TN	63				27						16		106
Trnava	TT	83	28	2	1	108	8	24	3	3				260
Veľký Krtíš	VK	227				54	1	1		18				301
Vranov n. Topľou	VR	90				33	3	2		15				143
Zvolen	ZV	28	42			91	3	4		1		27		196
Žiar n. Hronom	ZH	74	2			20	4			13		5	1	119
Žilina	ZN	106	6			99	7	21		8		22		269
Total		3 533	364	119	40	2 539	364	261	133	229	9	520	278	8 389

Explanations: L - liquidation, R - recultivation, D - further use, M - monitoring, Z - liquidated

60 - 70 % conditionally suitable areas is 6, i.e. 16.67 %
70 - 80 % conditionally suitable areas is 1, i.e. 2.78 %

The above overview shows the relatively favourable situation in the distribution of per cent proportions of areas assessed as conditionally suitable. None of the districts (except for Dunajská Streda) is without conditionally suitable areas.

Favourable is also the number of districts with low proportion of suitable areas (up to 10%) in relation to conditionally suitable areas. From the twenty districts which have only 0-10 % of suitable areas there is:

1 district with 0 - 10 % of conditionally suitable areas, i.e. 5 %,

1 district with 10 - 20 % of conditionally suitable areas, i.e.5 %,

3 districts with 20 - 30 % of conditionally suitable areas, i.e.15 %,

3 districts with 30 - 40 % of conditionally suitable areas, i.e. 15 %,

4 districts with 40 - 50 % of conditionally suitable areas, i.e. 20 %,

3 districts with 50 - 60 % of conditionally suitable areas, i.e. 15 %,

4 districts with 60 - 70 % of conditionally suitable areas, i.e. 20 %,

1 district with 70 - 80 % of conditionally suitable areas, i.e. 5 %.

Only two districts (Dunajská Streda and Galanta) have a low proportion of suitable as well as areas conditionally suitable for waste disposal. Other districts have the low proportion of suitable areas compensated with a higher proportion of conditionally suitable areas.

Inventory of waste dumping grounds

Similarly as before constructing maps of area suitability for waste disposal, before taking the inventory of waste dumping grounds, a registration form had to be filled for each of them. The selection of information required has been made with the aim to obtain basic characteristics of a dumping ground and the waste, data on geological and hydrogeological conditions of its underlier, aimed at proposing its further existence.

The characteristics (items) are listed in Fig. 2.

The mode of data input into the registration form was adjusted to the requirements of simplicity, intelligibility, the possibility of their digital processing and further complementation of data. An important requirement was the effort to present with each item the way of data acquisition, which would be indicative of their accuracy and reliability.

Registered waste dumping grounds, in contrast to suitability maps, were marked into 1 : 10 000 maps. This scale allows accurate presentation of the waste dumping ground area. Separate instructions were given for marking dumping grounds of line or, on the other hand, spot character.

8 389 waste dumping grounds were registered on the territory evaluated (Tab. 4).
The number of dumping grounds in the districts, as shown in Tab. 4, varies considerably. The lowest number is found in the district of Lučenec - 77, the highest number of waste dumping grounds is in the district of Komárno - 631. This situation may have been caused by several factors. An important role plays the economic potential of the district. In districts with developed industrial and agricultural production we can expect higher number of waste dumping grounds. The number is considerably affected by the approach of management and controlling bodies (state administration) to environmental problems. With a benevolent approach, there is no effort to liquidate "wild" (unlicensed) dumping grounds, which reflects in their total number. Anyway, it is not possible to exclude subjective approach of different registration evaluators. In spite of having been given instructions before starting to work on the registration, local pollution, which cannot be considered a dumping ground, was sometimes included into the evidence. On the other hand, benevolent approach to waste dumping ground registration cannot be excluded as well.

Total number of waste dumping grounds, especially in relation to all environmental components, is not very favourable. An exact evaluation of this situation was not the aim of the registration. This situation is indicated indirectly by an analysis of data on further existence of waste dumping grounds. The workers evaluating this should have proposed, on the basis of data obtained in waste dumping ground registration, four possibilities (or their combination): liquidation of the dumping ground, its recultivation, its further use or monitoring. Some workers distinguished, on their own judgement, dumping grounds which have been already liquidated.
The results of the proposals for different districts are shown in Tab. 4.

4056 waste dumping grounds, i.e. 48.35 % from the total number of dumping grounds, are suggested for liquidation or liquidation combined with recultivation, or monitoring of the dumping grounds. This number indirectly indicates assumed bad conditions of the dumping grounds, without further specification of these conditions. We assume that this assessment results from the complex evalua-

1. Current registration number of phenomenon
2. Archive number
3. District
4. Land-register area
5. Map sheet 1 : 10 000
6. Number of
7. Co-ordinate X
8. Co-ordinate Y
9. Operator of waste dumping ground (IČO)
10. Area (m^2)
11. Co-ordinate Z, method of determination
12. Average thickness (m), method of determination
13. Maximum thickness (m), method of determination
14. Volume of waste in m3
15. Year of foundation and method of its determination
16. Year of termination of waste disposal and method of determination
17. Distance from habitation (m)
18. The dumping ground has basement protection (insulation), functionality
19. The dumping ground has drainage system of seepage water
20. The dumping ground has surface insulation (cover), functionality
21. The dumping ground has indication-control system, observation frequency
22. The dumping ground has evidence of waste type
23. The dumping ground has interlayers
24. The dumping ground is sprayed
25. Relief of dumping ground surface
26. Position of dumping grounded material in relation to surroundings
27. Contact of dumped material with groundwater
28. Extent of contact
29. Relation of deposited material to air
30. Technological security in the area of dumping ground
31. Technological security in the surroundings of dumping ground
32. Other influences on environment
33. Type of water source
34. Distance from water source
35. Geology of basement, method of determination
36. Permeability of rock environment (in basement of dumping ground)
37. Method of estimation of hydraulic conductivity
38. Evaluated by
39. Organisation
40. Date of documentation
41. Composition of waste and method of determination

Figure 2 Registration form of solid waste dumping grounds tion of the material on the dumping ground, its technical equipment, technology of waste disposal, lithologic composition of its underlier, hydrogeological and hydrological conditions on the site.

The necessity to improve the unfavourable conditions of dumping grounds is reflected in the relatively high number of proposals for recultivation, monitoring or recultivation as well as monitoring.

520 waste dumping grounds have been suggested for monitoring alone, which is 6.2 %. We assume that this way of further management of the dumping grounds has been selected for those where only the results of monitoring would allow to make a decision on their further destiny.

The last group of dumping grounds - liquidated ones (278 waste dumping grounds, i.e. 3.3 %) were not evaluated on the basis of any criteria. The conditions on the dumping grounds, in relation to ground and surface water, soil (or rock environment) and air cannot be determined on the basis of an evaluation of registration results alone. This was not its aim anyway. The results of the registration may indicate the priorities of further action. It is essential to submit a great number of dumping grounds to an evaluation under Instructions S-1 (1993), and only on the basis of this to make decisions on subsequent actions concerning the conditions on the dumping grounds.

Conclusion

Maps of the suitability of the area for waste disposal are used for basic orientation at decision making concerning the situation of waste dumping grounds, while the selection of a locality is subject to a number of further evaluations. They allow to avoid sites which from the viewpoint of legislation or presence of important geological phenomena and processes are not suitable for a waste dumping ground. In areas assessed as conditionally suitable it is necessary to respect the presence of factors limiting the setting up of waste dumping grounds. They may be a reason for negative reaction of bodies and organisations involved in licensing the construction of waste dumping grounds. In areas assessed as suitable for waste dumping grounds maps cannot substitute geological survey of sites designed for waste disposal, however, they may be a starting point for this survey.

Maps of the suitability of the area for waste disposal together with existing registration of waste dumping grounds provide important information about the relation of a waste dumping ground to factors evaluated in the suitability maps. Environmental offices may base on this their decision making concerning further operation or liquidation of a waste dumping ground. Basic information about dumping grounds and their environment is provided by registration forms of waste dumping grounds.

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Selection of suitable surface geological structures for permanent disposal of hazardous waste and other solid low- to medium-active wastes

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Abstract: One of the ways to dispose hazardous wastes is to deposit them in natural rock structures. The principal aim of this task was to distinguish surface geological structures with the highest potential for the disposal of hazardous waste on regional level. To solve these problems in an optimum way, it was necessary to formulate a complex methodology for the selection of the localities and to define and classify criteria important for the selection process. Absolute priority was given to geological and hydrogeological criteria. The use of the method of gradual elimination of "negative" areas was the basic feature of regional assessment of Slovakia. The result of this assessment is presented in two maps: the map of evaluation of geological and hydrogeological factors and the map of important legislative, hydrological and socio-economic factors of hazardous waste disposal.

Key words: waste, hazardous waste, disposal of hazardous waste, site selection criteria, regional assessment, geological and hydrogeological factors

Introduction

Much attention is currently given to hazardous wastes. The total quantity of wastes is increasing with alarming speed, thus increasing every day the danger of environmental contamination and long-range negative effects on human health. The principal task in the process of site location and selection is to assure that the depositories shall be situated at such sites which, due to their natural characteristics and present land use, will provide a high level of protection of human health and the environment. To fulfil this task, it is necessary to define the suitable geological environment and to analyse all factors entering the process of site location and selection.

To ensure long-range security of the depository, the multi-barrier principle is applied. It is based on creating several independent barriers above each other, which will be able to prevent hazardous substances from escaping from the depository. In the case of failure of one of the barriers, its function is taken over by the next one. Since rocks forming the immediate underlier of the depository are the last barrier, it is necessary for them to possess the following functions:

- stability of basic depository conditions and its construction elements,
- insulation in case of failure of technical barriers,
- retention to capture products of leachate and dangerous substances.

Basic requirements for the quality of the immediate geological barrier may be expressed as follows:

- sufficient dimensions and thickness:	
	minimum area 1 km^2
	minimum thickness 5 m
- stability of foundation environment:	
	low compressibility
	high plasticity
	low solubility
- low permeability:	filtration coefficient $< 1x10^{-9}$ $m.s^{-1}$
- high retention capacity:	contents of clay minerals with adsorptive properties > 10 mass. %
- tectonic and seismic stability:	
	outside active fault lines and intensely tectonically failured areas

The geological barrier must provide long-range protection of human health and of the environment. Therefore, the quality of the geological environment should be given absolute priority in the process of the selection of sites for hazardous waste disposal.

Methodology of finding and selection of sites suitable for the disposal of hazardous waste

Several alternative methods of input data synthesis and analysis may be used for the selection of hazardous waste depositories (WOODSIDE, 1993). They are for example:

- intuitive method - the specialist evaluates all input data as a whole and on the basis of experience he decides, which locality is suitable. The main argument in favour of this method is the fact that there is close functional dependence between the characteristics of a locality and therefore they must be evaluated as a whole.
- gradual elimination method - each factor is evaluated individually. Limiting values of acceptability of the factor (i.e. criteria) are determined and they are applied in elimination, i.e. exclusion of certain territories from further evaluation. Evaluated are environmental, technical, social, economic and political factors. In the evaluation process, all components of input factors are analysed in succession and "unacceptable" territories are gradually identified and eliminated.
- method of significance (weight) analysis - the importance of individual factors entering the process of site selection is expressed by a numerical value. For instance permeability in the underlier of the locality is one of the most important factors in the site selection process. The presence of clays is an indicator of low permeability, and so places with a 3 m thick clay layer in the underlier may be classified with the highest grade, say 10. Another locality, with sandy schlieren, may have a value of 3. Similar values may be assigned also to other factors. Relative significance of the factors is determined by calculating the total of the values and the most suitable locality is considered to be the one with the best score.
- method of criteria combination - is based on the selection and various combinations of input criteria. In its application we may use the method of gradual elimination or the method of significance analysis. A combination of certain criteria is used for the identification of suitable, or unsuitable territories. Later on, the process is repeated and the combination of criteria is always different. For instance, one combination gives priority to the thickness of underlying clays and population density is less stressed. Another combination may emphasize the situation of the locality in relation to the distance from producers of waste and regards seismicity as a less important factor. The result of the application of this method is the selection of several localities representing different aspects.

Each of the above methods has its good points, but also its shortcomings. The intuitive method is the only one which makes allowances for mutual interconnections between the factors, however, it includes the subjective opinion of the specialist. It is hardly applicable in regional evaluation. The method of gradual elimination is best applied on regional scale, but due to the application of initial (e.g. legislative) criteria, territories with high potential for disposal of dangerous waste are often excluded. The method of significance analysis may be best used at low number of localities with significantly different characteristics. However, its application can lead to great variations in the evaluation, since it does not take into account the mutual relationship between factors under consideration. The method of criteria combination takes into consideration interrelationships between the factors and it is usefull in public relations. However, when using this method, we do not get localities ordered according to suitability and its application is very complicated with greater number of localities.

Criteria for site location and selection and input factor analysis

An important task in the process of location and selection of sites for hazardous waste disposal is to determine unambiguous criteria. These criteria, used to evaluate the whole territory such as Slovakia, can best be defended in discussions with the public.

Working criteria are usually derived from factors which must be considered in the process of site location and selection. When assessing a territory from the viewpoint of hazardous waste disposal, the factors can be divided into two groups:

1. primary factors
2. secondary factors.

Primary factors represent qualitative characteristics of a natural geological barrier and factors of groundwater vulnerability. They include geological, hydrogeological, hydrological and geomorphologic factors.

Secondary factors represent conflicting interests from the environmental viewpoint. Among the most significant are legislative factors, mining activities, present land use, infrastructure of the country and other socio-economic factors.

Functional criteria for site location and selection

In the majority of methods used for location and selection of localities for hazardous waste depositories involve criteria of site selection. The determination of the criteria is a multi-stage process, beginning with the determination of general criteria, i.e. determination of basic requirements on the evaluated system. They are only descriptive and they are not associated with a concrete locality. General criteria must be gradually made more specific, taking into account the required host environment and the factors affecting this environment. The result are so-called functional criteria, which may be of semi-quantitative character. The process continues with a detailed analysis of input factors and operational or executive criteria are quantified subsequently. They are defined as the limit (boundary) value of a factor.

The most important criteria for the selection of sites for the disposal of hazardous waste involve: geological, hydrogeological and geomorphologic criteria.

Other criteria, i.e. legislative, hydrologic and socio-economic ones are not subjected to special evaluation. In the process of location and selection of sites for hazardous waste disposal, the criterion is basically their presence or absence on the territory under consideration (national parks, deposits, protected hydroeconomic areas etc.). Sometimes, the distance from a potential depository is evaluated as well, e.g. the distance from surface flows and water reservoirs > 300 m, distance from the nearest drinking water source > 500 m etc.

Hierarchy and degree to which the criteria are obligatory

After the analysis of factors entering the process of location and selection of sites for hazardous waste disposal and after the determination of the functional criteria, it is necessary to determine the hierarchy of the criteria and degree to which they are obligatory.

The degree, to which the criteria are obligatory, depends on the stage of the process of location and selection of a site. For example, in the stage of regional assessment of the territory the criterion of hydraulic conductivity is regarded as obligatory. Other hydrogeological parameters may considered to be important, or necessary. They will be regarded as obligatory at the evaluation of potential areas or specific localities. However, in each stage of the process of location and selection of localities, absolute priority is given to the criteria of geological barrier quality and groundwater vulnerability.

According to the degree of restriction, we propose to divide the criteria into three groups in the following way:

1. Exclusive criteria
2. Limiting (evaluating)criteria
3. Additional (accessory) criteria.

Exclusive criteria

Exclusive criteria are used to eliminate territories which do not fulfil the pre-condition of required geological barrier quality and groundwater vulnerability. Excluded are also the areas the protection of which is decreed by law, residential areas, and areas of major infrastructures. Excluded territories are not any more the object of survey and selection and their elimination, especially in the stage of regional assessment, saves considerably time and costs.

1. *Hydrology and groundwater protection*

- protection zones of natural curative water resources, degrees I, II and III.
- temporary protection zones of curative water resources
- hygienic protection zones of degrees I, II and III of ground- and surface drinking water resources
- protected area of natural groundwater accumulation
- protected water management area
- drainage area of an exploited water flow
- exploited water reservoir and flooding area of a water reservoir under construction
- territory with important groundwater resources
- important recharge areas
- floodlands (flooded by centennial waters)
- moist areas

2. *Areas of protected nature*

- national parks and their protection zones
- protected land areas and their protection zones
- state natural reserves
- local natural reserves
- natural monuments

3. *Mineral deposits*

- mining area of strategic deposits (surface and underground)
- protected deposit area
- proven reserves of strategic deposits
- mined deposits of non-strategic minerals
- mined out mineral deposits
- potential deposits of strategic importance (sensu SLAVKAY - PETRO, 1995)

4. *Residential areas and infrastructure*

- municipalities and their surroundings
- industrial areas
- large construction works (airports etc.)
- holiday resorts and others.

5. *Geological and hydrogeological parameters*

- presence of rocks with filtration coefficient k_f > $1x10^{-6}$ $m.s^{-1}$ to the depth of 90-100 m
- presence of gravel and sand formations to a great depth
- presence of lithologically inhomogeneous rock complexes

6. *Limiting factor values*

- filtration coefficient of immediate geological barrier k_f > $1x10^{-9}$ $m.s^{-1}$

- groundwater table depth < 3 m
- highest 100-year groundwater level reaching higher than 1.5 m from the bottom of depository
- immediate barrier thickness < 5 m
- specific yield > 7 $l.s^{-1}.\ km^{-2}$
- slope inclination > 6°
- areas prone to landslides
- areas sensitive to erosion
- areas near active faults and significant fault zones
- collapsible materials
- clay mineral contents < 30%
- adsorption clay contents < 10%
- organic matter contents > 5 %
- low plasticity - plasticity index < 15%
- high compressibility
- presence of soluble minerals
- pH < 5.5
- cation exchange capacity < 5 mg/100 g
- salt and alkali contents > 0.65 %

Limiting (evaluating) criteria

Factors regarded as limiting ones entering the process of location and selection of sites, determine (limit) the utilisation of a territory for the storage of hazardous waste with graded importance. It may be possible to establish and operate a depository in such area only under the pre-condition of technical measures eliminating the effects of the unfavourable factors. When these factors reach certain limiting values, they become exclusive and this leads to the elimination of these territories from further consideration.

1. *Geomorphologic*
- slope inclination
- intensity of geomorphologic processes

2. *Geological*
- landslide
- erosion
- weathering
- tectonic and seismic stability
- thickness and composition of natural geological barrier
- homogeneity of rock environment
- properties of rock environment

3. *Hydrogeological*
- hydraulic parameters
- groundwater quality
- distance from surface water flows and drinking water reservoirs and resources

Additional (accessory) criteria

Additional criteria are considered at the final decision-making regarding a site. When finally ordering the localities according to their potential, a situation may occur when two or more sites will have very similar characteristics, the most important consideration then becomes:

- distance from waste producers
- accessibility of construction material
- density of road and railway network
- climate
- land-use plans etc.

The procedure of location and selection of sites for hazardous waste disposal in Slovakia

After the evaluation of merits and shortcomings of the above mentioned methods, we propose to use for the location and selection of sites with high potential for the disposal of hazardous wastes in Slovak conditions the method of gradual elimination. The process of site location and selection should be carried out in three stages, according to clearly defined criteria. In final decision-making it is possible to use also the method of significance analysis, or use accessory criteria and the method of gradual elimination.

The stages of finding and selection of potential dangerous waste depositories may be characterised as follows:

- regional assessment - evaluation of the Slovak territory using exclusive criteria. The result of this evaluation is define potential areas.
- assessment of potential areas - consists of three stages:

1. distinguishing of prospective sites using exclusive and limiting criteria. The result of this phase is the selection of 3-5 prospective sites.

2. ordering of the prospective sites according to their suitability. At localities with very similar characteristics, additional criteria will be used in final decision-making.

- preliminary survey of sites with the highest potential for the construction of hazardous waste depositories. The result of this stage is the evaluation of basic requirements for the siting of a hazardous waste depository and proposal of geological surveys for the further stage of the investigation. In some cases this stage may exlude the site from being considered further.

Regional assessment

Basic feature of this proposal is the use of the method of gradual elimination of "negative" areas. The elimination is done using basic geological and hydrogeological, hydrologic and legislative criteria regarded as exclusive. It allows to site a depository in areas with the greatest probability of success. The obtained data serve for:

- outlining areas where the depository will have minimal potential of surface and groundwater resource contamination.
- preliminary determination of the characteristics of spatial variability of geological environment in the outlined areas.
- characterisation of basic hydrogeological parameters.
- locating areas with occurrences of non-renewable mineral resources, protected areas of nature, protected water management areas and densely populated areas.

Geological, hydrogeological, legislative and socio-economic factors are evaluated simultaneously. The result of regional assessment of the Slovak territory will be presented in two maps:

- map of evaluation of geological and hydrogeological factors from the viewpoint of hazardous waste disposal
- map of important legislative, hydrological and socio-economic factors of hazardous waste disposal.

At the end of this stage of the selection process, the transparency maps outlining the "negative" areas can be overlaid to show the areas where storage of waste will have minimum environmental impact.

Geological and hydrogeological factors evaluation map

The map of evaluation of geological and hydrogeological factors is a special analytical map (Fig.1). It is based on an analysis of existing geological and hydrogeological maps of much larger scale than usually used in regional assessment (1 : 25 000, 1 : 50 000 and 1 : 200 000). The obtained information on geological and hydrogeological conditions was evaluated on the basis of:

- transmissivity coefficient
- the presence of gravel and sand formations
- spatial variability of the geological environment.

Values of hydraulic parameters are determinative for the definition of hydrogeological aquifers and aquicludes. Their identification on the map allowed the exclusion of all areas with transmissivity coefficient exceeding $1x10^{-4}$ $m.s^{-1}$. In the following phase, the attention was aimed at formations classified on the map by low transmissivity, but with the presence of gravel and sand layers at various depths. In view of the generally high permeability of sands and gravels, and thus the enormous potential for the dissemination of contaminating substances, the areas with significant layers of these sediments were excluded from further survey and selection process. The criterion of spatial variability of the geological environment was used in rock complexes with low transmissivity, where very marked lithologic inhomogeneity of rocks complexes had been proved. Usually they are formations of rhythmic flysch, flysch complexes with predominant sandstones and other formations of flyschoid character. These were eliminated and they are not the object of further selection.

Areas remaining as suitable have the highest potential for the deposition of hazardous waste. They should be given greatest attention in further phases of the process of location and selection of sites.

Map of significant legislative, hydrologic and socio-economic factors

The map of significant legislative, hydrologic and socio-economic factors is a special synthetic map (Fig. 2a, 2b, 2c). Using a set of exclusive criteria, which can be applied on the scale 1 : 500 000, areas protected by legislation, areas with important socio-economic activities and some areas unsuitable from the hydrologic viewpoint were eliminated.

Protected nature areas :

The following protected nature areas were eliminated in the regional assessment:

- national parks and their protection zones
- protected land areas and their protection zones
- state nature reserves.

It was not possible to distinguish other small-scale protected nature areas on the scale 1 : 500 000. They will be the object of evaluation in next phases. On the map they are marked by a green contour and green hatching (except state nature reserves).

This category of factors is subject to Law No. 278/1994 Dig. on the protection of nature and environment.

Water-management protected areas:

Water-management protected areas may be regarded as the most important category of protected areas. The following areas were eliminated in the regional assessment:

- protection zones of natural curative water resources, degrees I, II and III.
- temporary protection zones of curative water resources
- hygienic protection zones of degrees I, II and III of ground- and surface drinking water resources
- protected area of natural groundwater accumulation
- protected water management area

- drainage area of an exploited water flow
- exploited water reservoir and flooding area of a water reservoir under construction
- territory with important groundwater resources.

These areas are marked in the map by a blue contour and blue hatching.

The following laws apply to water management protected areas:

Law No. 138/1973 Dig. on water (Water Act)
Law No. 238/1993 Dig. - amendment and complementation of the law No. 138/1973 Dig. on water
Governmental Regulation No. 13/1987 Dig. on some protected areas of natural water accumulation
Notice of the Ministry of Health No. 15/1972 Dig. and No. 17/1983 Dig. on the protection and development of natural curative resources.

Protected forests:

The category of protected forests includes protective forests and special purpose forests. Since they are usually small areas, their inclusion into this map is more or less informative only. They must be given greater attention in a more detailed evaluation of the territories. They are marked in the map by a green contour.

The applicable low to forests is Law No. 61/1977 Dig. on forests and Note 14/1978 on the categorisation, exploitation and economic adjustment of forest.

Mineral resources and mining activities:

The presence of mineral deposits and areas with mining activities is marked in the maps by black colour. On the map there are marked:

- mining areas of strategic surface and underground deposits
- protected deposit areas of surface and underground deposits
- proved reserve of strategic deposit
- mined deposits of non-strategic minerals
- mined out mineral deposits
- potential deposits of the strategic minerals.

Data on mineral deposits and mining activities were processes on the basis of data from the data base of Geofond. Data on potential solid mineral resources in Slovakia were taken from the Map of Prognostic Resources, prepared by SLAVKAY and PETRO (1995) for the purposes of radioactive waste disposal.

Hydrologic criteria:

From hydrologic data, only the presence of floodlands and more extensive wetlands was evaluated in this phase. Their inclusion in the maps is for the information of specialists involved in the next stages of survey. On the map they are marked by a blue contour.

Other criteria:

The only other exclusive criteria we used in the regional assessment was the criterion of population density. Population density was obtained according to the Atlas of SSR (1980). Areas with a density exceeding 150 inhabitants per km^2 were selected. We consider this factor to be only informative. It was not possible to apply other factors due to the scale of the map. It will be however necessary to consider them in next stages of location and selection of sites.

The maps of the evaluation of geological and hydrogeological factors and the maps of significant legislative, hydrologic and socio-economic factors are constructed to allow them to be overlayed to allow extraction of maximum quantity of data. This facilitates the identity of "positive" areas, i.e. areas with the highest potential for hazardous waste deposition. Areas so determinated as suitable are the object of the next phase of the survey process.

Evaluation of potential areas

The evaluation of potential areas includes collecting data on geological, hydrogeological and geomorphologic conditions of territorial units outlined in the previous phase. The following elements are stressed:

- slope and topography of the area
- geological structure of the area on the scale 1 : 50 000, to the depth of 100 m. It is necessary to identify the depth, extent and thickness of all significant* aquifers, or highly-permeable materials.
- well survey (determination of basic hydrogeological parameters)
- tectonic features
- slope stability
- sensitivity to erosion
- presence of strongly weathered materials
- local karst forms
- engineering-geological properties of rocks
- mineral deposits
- mining activities, identification of mined out ground.

The analysis of obtained data using exclusive and limiting criteria allows the identity of such geological, hydrogeological and geomorphologic elements, which, due to their dimensions, could not be evaluated on regional scale. Their presence may seriously limit the suitability of a site, or even exclude the site from further evaluation.

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* As significant are regarded gravel and sand formations with a thickness exceeding 1.5 m, sandstones exceeding 3 m and faulted limestones and dolomites of a thickness of at least 4.5 m, with a surface exceeding 1km^2

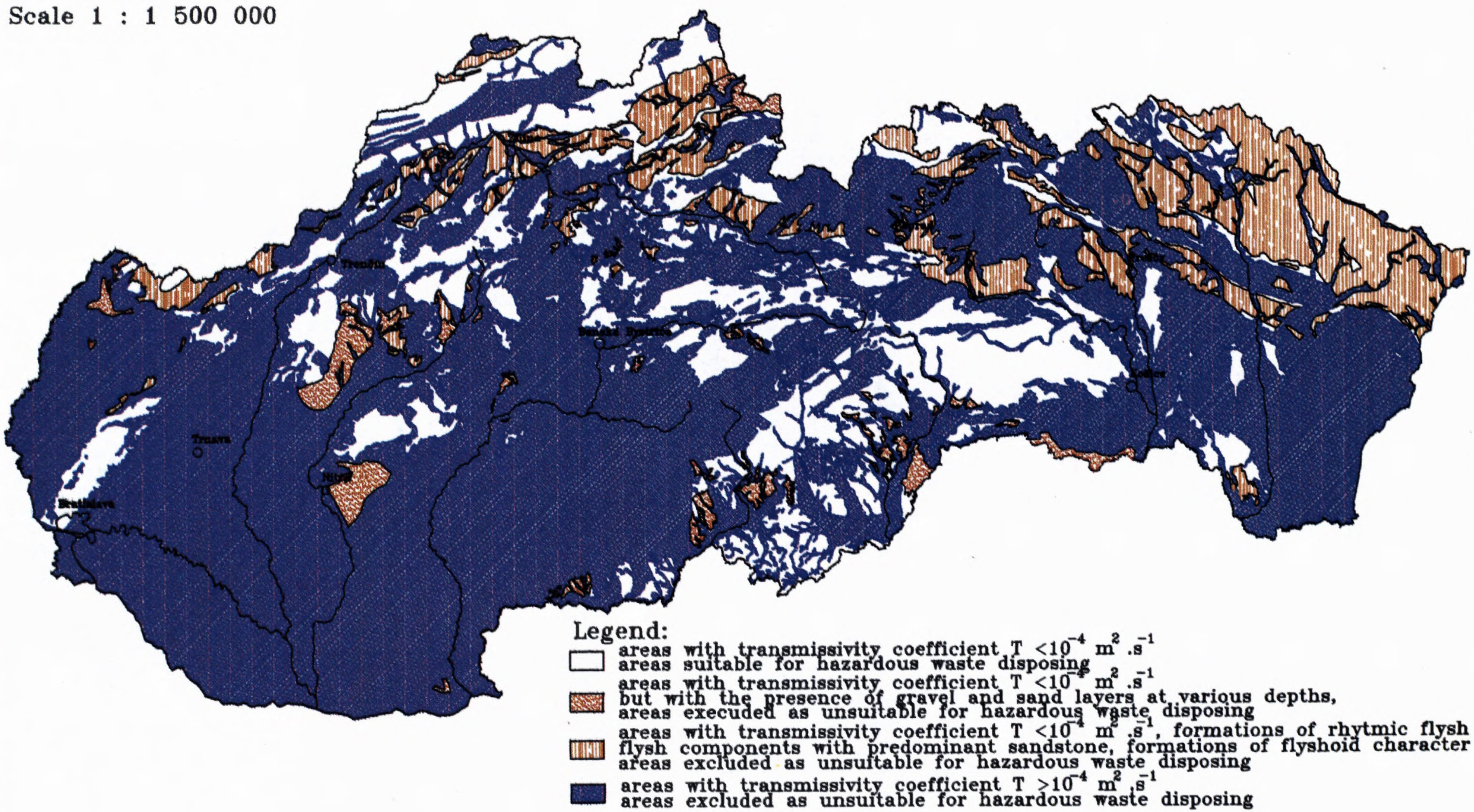

Fig. 1 Map of evaluation of geological and hydrogeological factors from the viewpoint of hazardous waste disposal

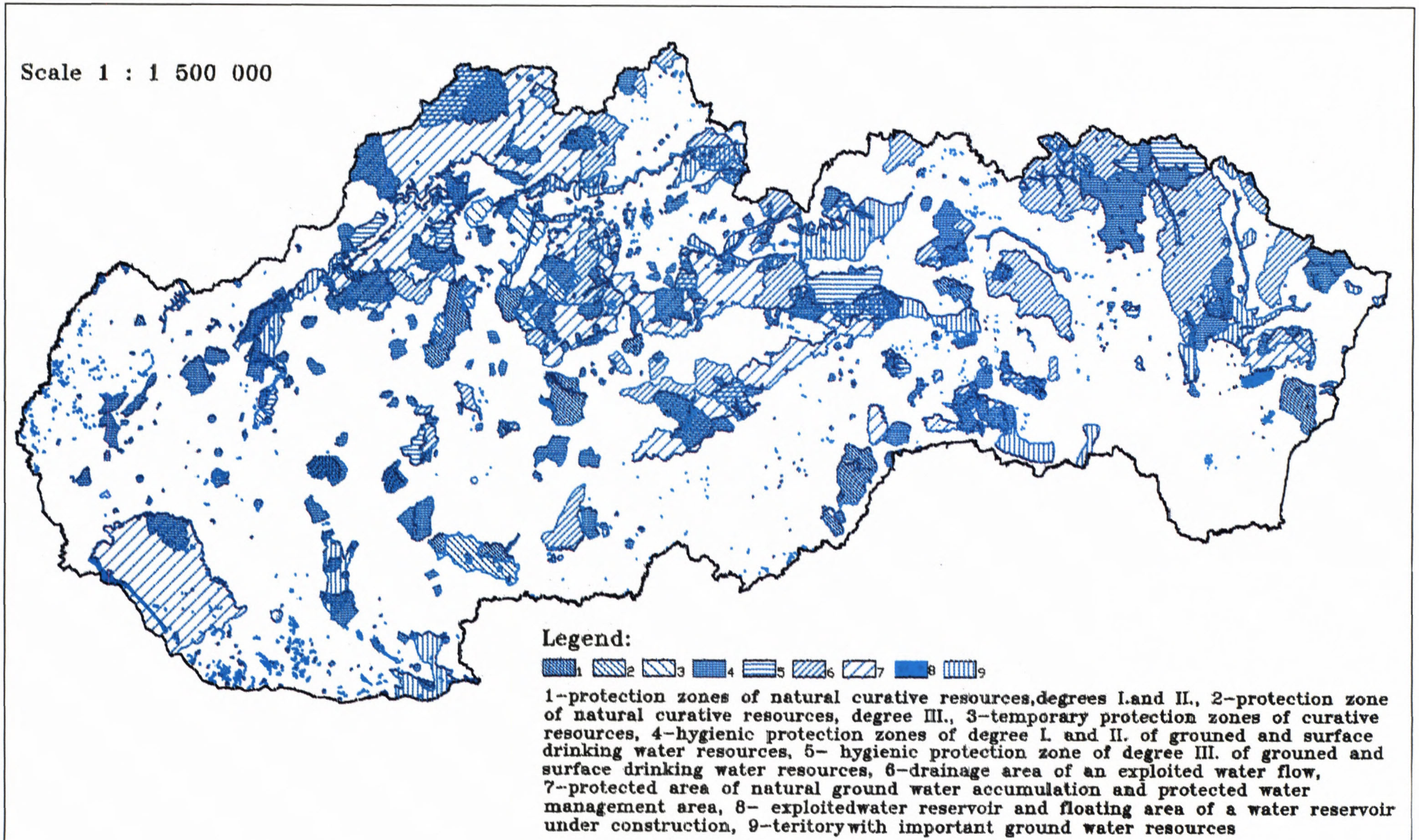

Fig. 2a Map of important legislative, hydrological and socio-economic factors of hazardous waste disposal – part I

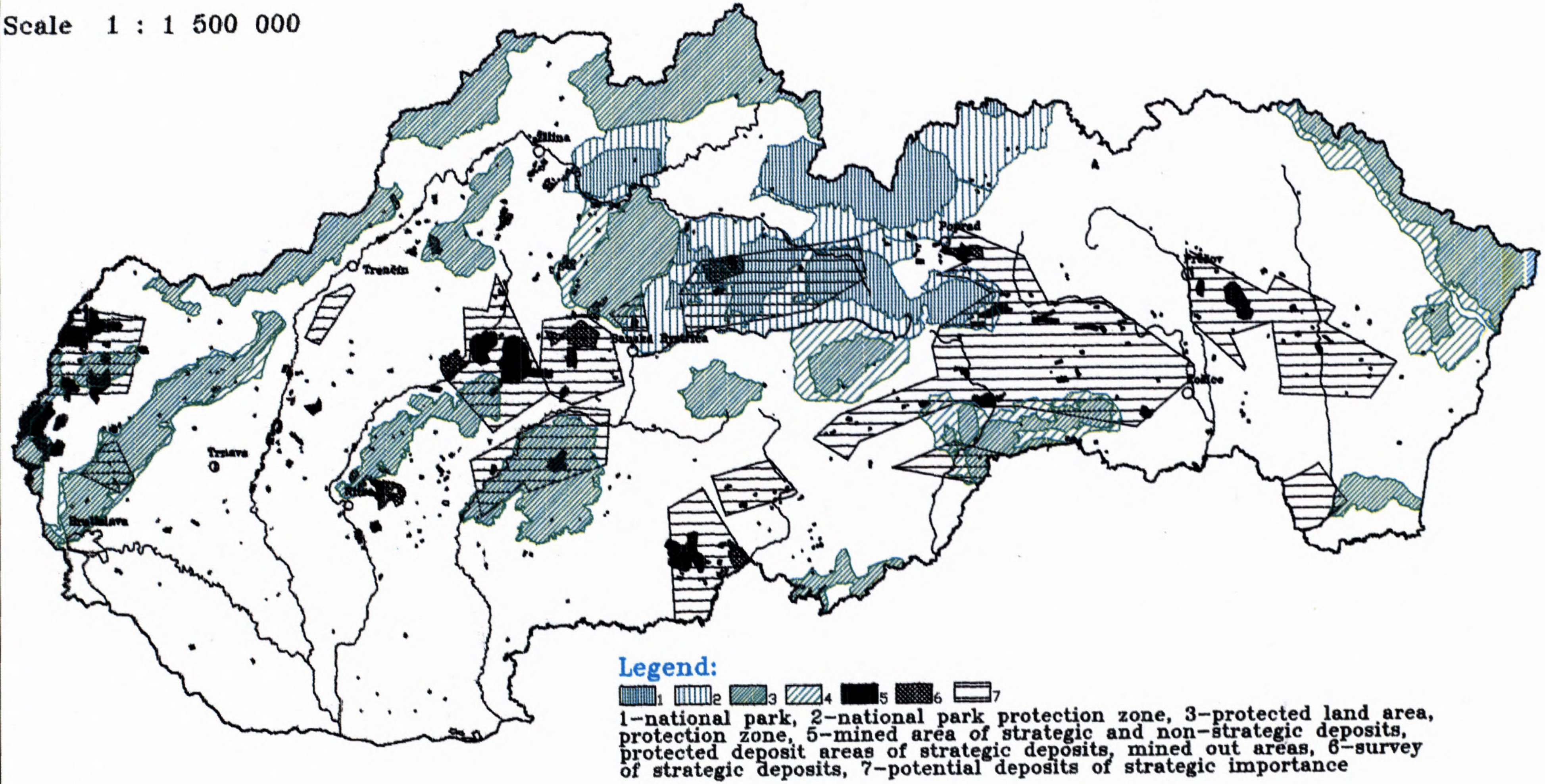

Fig. 2b Map of important legislative, hydrological and socio-economic factors of hazardous waste disposal – part II

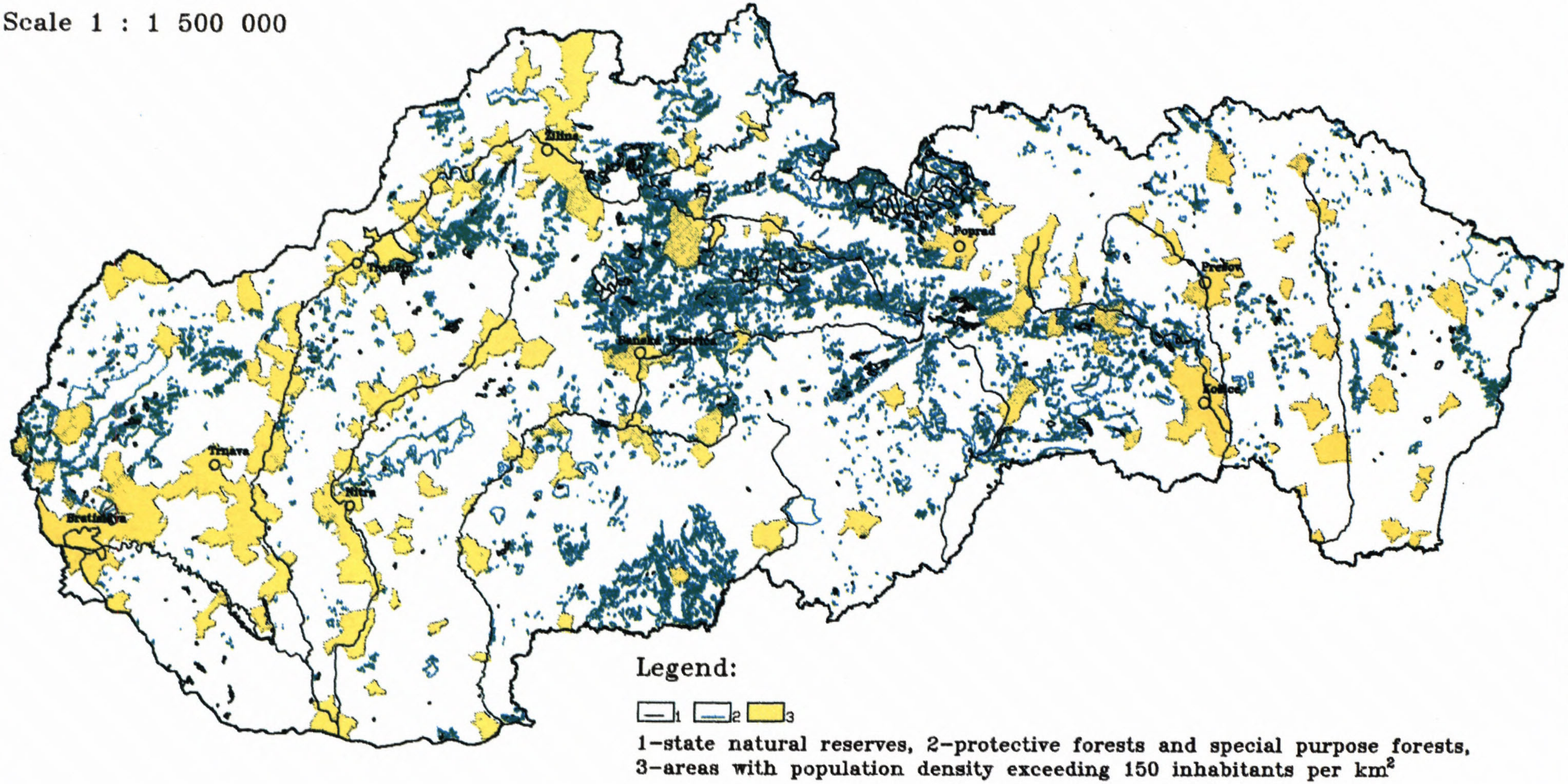

Fig. 2c Map of important legislative, hydrological and socio-economic factors of hazardous waste disposal – part III

It is also necessary to identify areas protected by legislation, which, due to their small extent, could not be eliminated in the stage of regional evaluation (e.g. protected parks, gardens etc.).

The result of the second stage of the process of location and selection of sites is the determination of sites (3-5) with the highest potential for the storage of hazardous waste. It is possible to order the sites according to their suitability using comparative analysis or accessory criteria.

Preliminary survey of the sites

Preliminary survey of the sites is carried out with the aim to define such geological, hydrogeological, geomorphologic, engineering-geological and geotechnical characteristics, which could affect negatively the long-term stability of the depository.

The object of the survey is the site (or two sites), which was identified as the most suitable in the previous evaluation. A territory of approx. 1 km^2 is investigated to a depth of 100 to 150 m.

In view of the specific character of the problem of hazardous waste, the principal task of the survey will be the determination of the following parameters:

a) geomorphologic stability and speed of geomorphologic processes
b) lithologic composition of rocks, stratigraphy, degree of deformation, spatial variability
c) structural-tectonic conditions on the site and in the wider surroundings
d) mineralogical-petrologic composition of rocks
e) geochemistry of the rocks
f) contents, type and micro-structural analysis of clay minerals
g) hydrogeological characteristics - local hydrogeology, hydraulic parameters (filtration coefficient, transmissivity, specific yield etc.)
h) physical-mechanical properties
i) geomechanic properties.

The stage ends by recommendation of the site for further survey or its refusal.

Conclusion

The problems of regional geological evaluation of surface geological structures for hazardous waste deposition have not been solved so far in Slovakia. The result of the proposed study will be two maps, the cartographic interconnection of which will clearly identify areas with the highest potential for the storage of hazardous wastes. The proposed methods and functional criteria may be used also in the selection of sites for a depository of low- and medium-radioactive waste, or for the siting of depositories of solid municipal or other waste.

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SLOVAK GEOLOGICAL MAGAZINE

Engineering geological maps of geofactors of the environment of the Košická kotlina Basin and Slanské vrchy Mts. (Eastern Slovakia)

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Abstract: The Košická kotlina Basin and Slanské vrchy Mts. region (1500 km^2) has been recently intensively studied from them viewpoint of relevant factors of the environment (geofactors), i.e. factors affecting significantly the environment. The result of their evaluation is a set of engineering geological maps on the scale 1 : 50 000. The set consist of a engineering geological zoning map, map of relative susceptibility of the area to landsliding and map of significant geofactors. The contribution briefly presents the methodology for their construction and main results of the mapping. The maps should serve as an aid in rational land use planning.

Key words: Košická kotlina Basin and Slanské vrchy Mts., geological factors, set of engineering geological maps.

1. Introduction

Intense development of the town agglomerations Košice and Prešov in the last 15 years brought about the necessity of compilation of suitable geological base materials. At the beginning of the 90-ties, in the framework of the science-technology project "ZP-547-008 - Investigation of Geological Factors of the Environment, co-ordinated by the Dionýz Štúr Institute of Geology (GÚDŠ) in Bratislava, a systematic compilation of a set of geofactor maps started on the scale 1 : 50 000 in 6 regions of Slovakia. It included the design of a methodology for different map types. The set consisted of a geological map, map of deposits and raw material prognosis, hydrogeological, pedological, groundwater quality map, map of geochemical reactivity of rocks, geochemical-environmental map, map of natural rock radioactivity and an engineering geological map. The aim of the investigation was to provide basic idea on relevant geological factors of the environment, i.e. on its abiotic component. They affect in a significant way, positively or negatively, the development of all spheres of the society. The maps should serve as one of basic materials in land use planning and rational use of the territory.

The Košice Basin and Slanské vrchy Mts. (Eastern Slovakia, Fig. 1) are one of the above mentioned regions of Slovakia, where the maps of geofactors were compiled in the years 1992 - 1993. In the presented contribution we are dealing with the mapping of geofactors important from the viewpoint of engineering geology, as well as with the methodology of engineering geological map compilation. It consists of a set of three maps - map of zoning, map of relative susceptibility of the area to landsliding and map of significant geological factors. The compilation of the above maps was based on suitable existing maps from the whole territory (geological map 1 : 25 000 and 1 : 50 000, map of suitability of the area for solid municipal waste disposal 1 : 50 000), of its part (engineering geological map 1 : 10 000) or other map types compiled within the above mentioned project.

2. Geomorphologic-geological setting

The Košická kotlina Basin has a generally hilly relief with an altitude above sea level of 250 - 400 m.

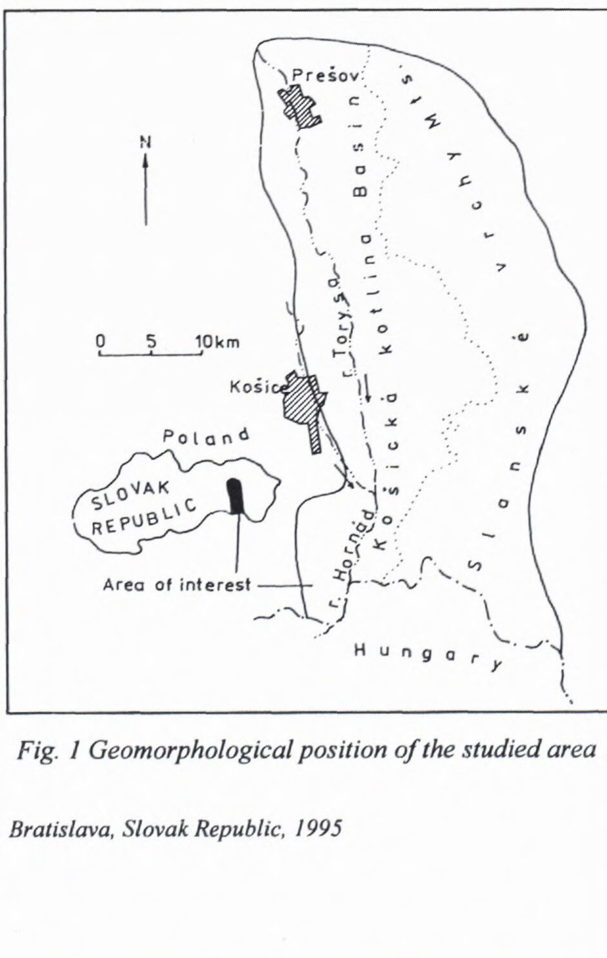

Fig. 1 Geomorphological position of the studied area

Average slope angle is 6° - 14°, less often 14°-24°. The relief is strong, relative altitude differences reaching as much as 550 m. Average annual precipitation in the basin is 600 - 700 mm.

The area under study is situated in the western part of the Eastern Slovak Neogene Basin, which formed due to the pull-apart process (VASS et al., 1988). The filling of the basin consists above all of molasse Neogene sediments of the Main Molasse (Egenburgian-Sarmatian) and partly also sediments of the Pannonian Late Molasse (VASS, 1982). From lithological viewpoint, Neogene sediments are represented by pelitic facies (claystones, clays, siltstones) as well as detritic facies (sandstones, conglomerates, gravels).

An organic part of the Eastern Slovak Neogene Basin are Neogene volcanic rocks (Egenburgian-Pannonian), which are, on one hand, a component of sedimentary formations (layers, lenses as well as extensive horizons of redeposited tuffs), but, on the other hand, they form morphologically conspicuous volcanic structures - andesite stratovolcanos of the Slanské vrchy Mts. (KALIČIAK et al., 1991 and in press). They are composed predominantly of effusive (lava flows) and volcanoclastic facies. To a lesser extent there are tumefaction and dome-shaped forms of extrusive and intrusive andesite and diorite porhyry bodies.

Quaternary rocks are represented significantly on the territory under consideration. This applies to their extent as well as thickness. Areally of greatest extent are fluvial, proluvial, deluvial and eolian-deluvial sediments. Their thickness is in some places reaching 20-25 m.

The oldest tectonic features on the territory, which affected significantly the pre-Tertiary underlier, are faults of NW-SE direction. Younger appear to be NE-SW faults. Faults of N-S direction created in the Neogene and reactivated during the Quaternary are the youngest as far as activity is concerned and the most important ones from the viewpoint of macro-relief formation (JANOČKO, 1989 and 1990). These tectonic faults are responsible for the origin of some landslides. In view of the considerable number (over 400) and area, landslides are an important geomorphologic element of the area under study (PETRO - SPIŠÁK, 1994).

3. Maps of geological factors of the environment

We started to compile maps of geological factors of the area studied from the viewpoint of engineering geology following a request of the Ministry of the Environment of the Slovak Republic in 1992. We used the methodology elaborated by specialists from the Department of Engineering Geology of the Dionýz Štúr Institute of Geology in Bratislava in 1991. At present, a modified version is prepared in the form of an obligatory regulation for the whole territory of Slovakia.

The basic philosophy for the compilation of the engineering geological zoning map, maps of relative susceptibility of the area to landslides and of significant geological factors was the use of all accessible geological, hydrogeological, engineering geological and pedological materials, especially maps. They were complemented by existing data bases of relevant geofactors, by aerial photographs and field mapping. Accessory were drilling and laboratory works.

3.1 Engineering geological zoning map

The map may be characterised as synthetic and multi-purpose. It shows geological environment to the depth of 10 m. Typologic zoning (MATULA - HRAŠNA, 1976) on the level of zone and sub-zone has been applied. Zones are territorial units distinguished on the basis of homogeneity or similarity of one of the principal geological factors - rocks. In this respect, the genetic-lithologic classification of rocks valid on the territory of Slovakia is used (MATULA - PAŠEK, 1986). This means that each zone represents a different genetic-lithologic rock complex. A change in the lithology within the same genetic complex, or a change of thickness of the Quaternary layer is expressed as a sub-zone. Besides rocks and soil, the map shows further significant geofactors, such as hydrogeological phenomena (groundwater level depth, its flow direction, aggresivity of groundwater, springs etc.), geodynamic phenomena (erosion gullies, landslides, block failures, neotectonic failures etc.) and raw material deposits.

The map includes text explanations with a detailed evaluation of physical-mechanical properties of rocks and soils within the distinguished zones (33) and sub-zones (166). The results of laboratory tests of soils, including archived ones (7575) were statistically processed. For the purpose of map compilation, 508 exposures were documented in the field, 44 boreholes were made (689 m) to the depth of maximally 20 m, 18 monoliths were collected (approx. 40x40x40 cm) from solid and semi-solid rocks as well as 16 samples of groundwater. Potential suitability of the zones for shallow foundations, for the construction of transport communications and earth dams was evaluated in the sense of standards valid on the whole territory of Slovakia. The breaking characteristic of rocks was evaluated in a similar way. The obtained results are summarised in a brief characterisation of the distinguished zones in a table.

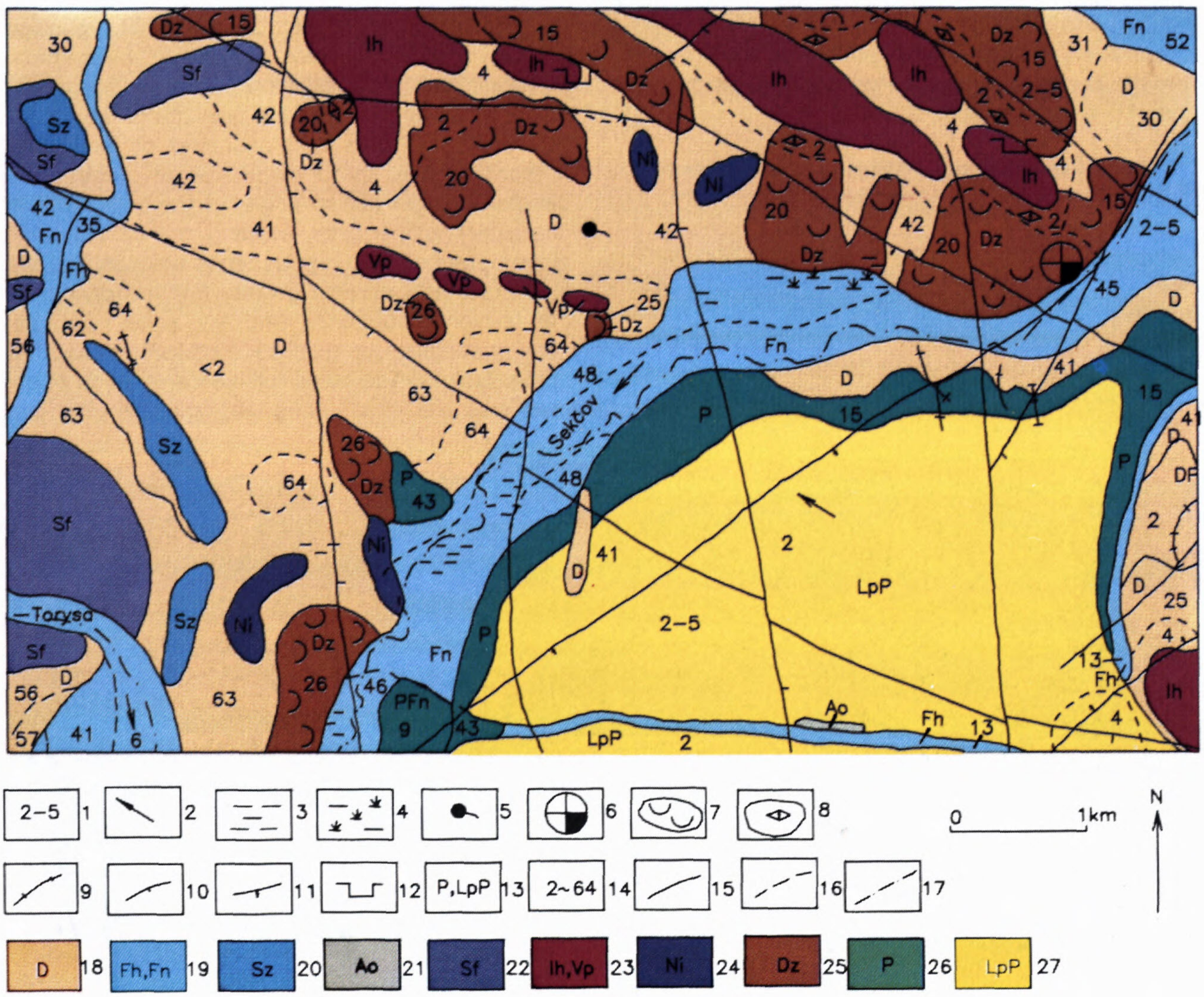

Fig. 2 Engineering geological zoning map (north of Prešov, northern part of the Košická kotlina Basin and Slanské vrchy Mts. region). Hydrogeological symbols: *1 – groundwater-level depth, 2 – groundwater flow direction, 3 – moist area, 4 – swamp, 5 – significant spring, 6 – corrosivity of groundwater (ph, hardness, content of SO_4^{2-} and CO_2.* Geodynamic phenomena symbols: *7 – landslide area, 8 – block deformations, 9 – erosion gully, 10 – fault active before the Quaternary, 11 – fault active during the Quaternary.* Documentation symbols: *12 – abandoned quarry, 13 – symbols of zones and combined zones, 14 – code number of subzone, 15 – zone contour, 16 – subzone contour, 17 – watch stream*

Zone types: *18 D – zone of deluvial sediments (clayey and clayey-gravelly soils), 19 Fn – zone of lowland stream sediments (gravels with clayey cover), Fh – zone of mountain stream sediments (sandy-clayey gravels), 20 Sz – zone of sandstone-conglomerate rocks (conglomerates with sandstone intercalations), 21 Ao – zone of waste filling, 22 Sf – zone of flysch rocks (sandstones, siltstones and claystones), 23 Ih – zone of intrusive rocks (andesites, diorite porphyres), Vp – zone of pyroclastic rocks (andesites and rhyolite breccias), 24 Ni – zone of clayey-silty sediments (claystones, siltstones), 25 Dz – zone of deluvial sediments of landslides (clayey-gravelly soils), 26 P – zone of alluvial fans (proluvial) sediments (clayey-sandy gravels, sandy clays), 27 Lp – zone of eolian-deluvial sediments (clays).*

From the map it is evident that in the Košice Basin, on the surface there are usually Quaternary rocks. In the Slanské vrchy Mts. predominant are volcanic and volcano-sedimentary rocks, covered in the foothills and in depression mostly by deluvial sediments. Neogene sediments emerge on the surface less frequently, they have usually the character of soils and they are characterised by considerable variability of physical-mechanical properties. This applies especially to lithologically varied formations in which there are alternating fine and coarse soils. High lithologic variability reflected in marked changes of properties is typical also for some types of Quaternary rocks (e.g. deluvial, proluvial and terrace fluvial sediments). An example of a simplified engineering geological zoning map from the northern part of the territory (the surroundings of Prešov) is on Fig. 2.

3.2 Map of relative susceptibility of the area to landslides

The map has the character of a special, multipurpose map. The "traffic-light" method indicates territorial units of zone and sub-zone type in which we assume the same or very similar conditions for the origin and development of landslides. Green colour represents stabile areas, orange conditionally stabile and red unstable areas. The principal factors of zoning were the rock environment (lithologic and sedimentation conditions, degree of failure and weathering of the pre-Quaternary underlier rocks, thickness and character of the rocks), hydrogeological (groundwater level depth) and geomorphologic (slope angle of the relief and its character) in the area, existing manifestations of slope deformations (various types of landslides and block failures), erosion gullies. For the division of the territory into zones and sub-zones we used semi-quantitative or qualitative classification of the above factors. The basis for the compilation of this map was the engineering geological zoning map

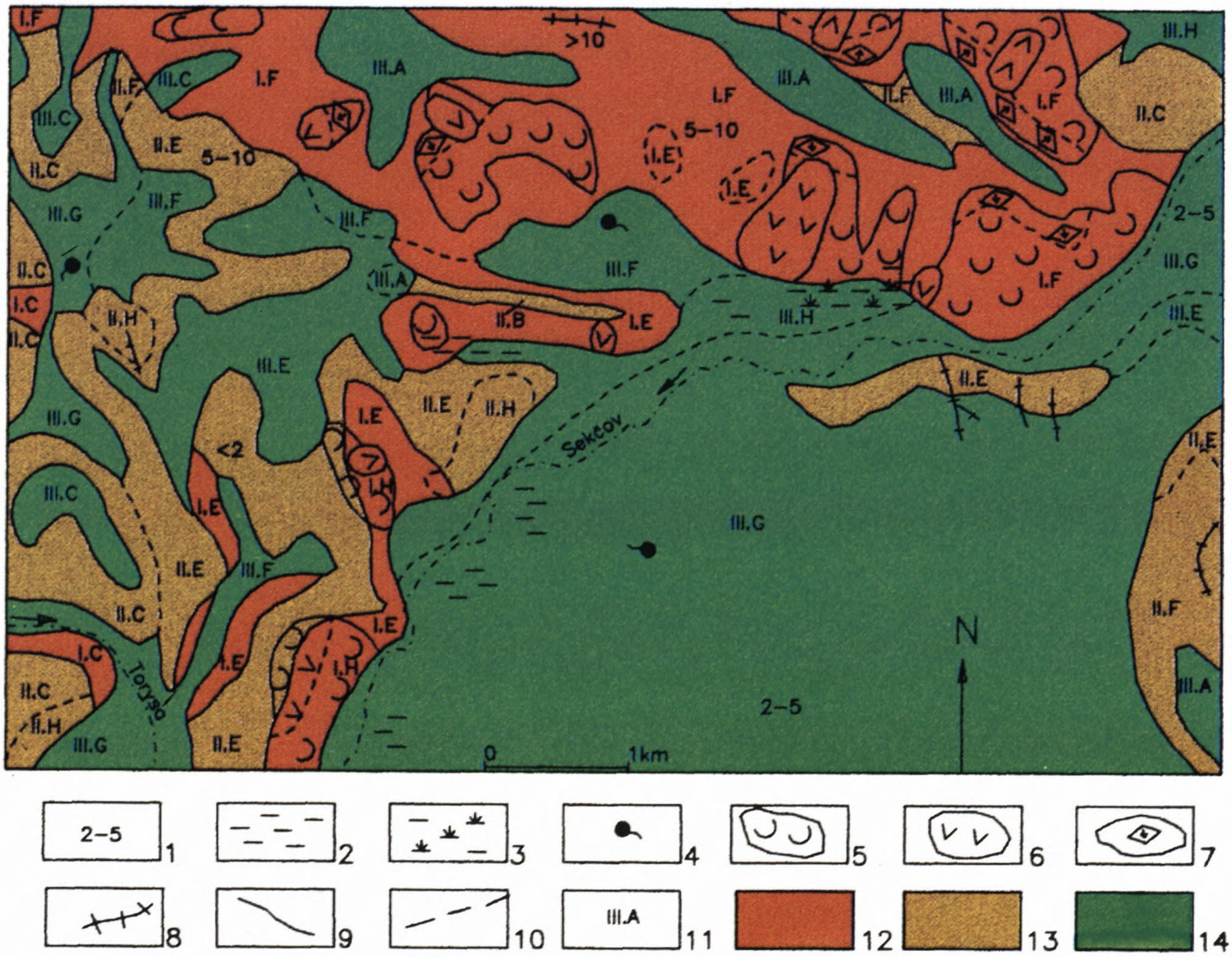

Fig. 3 Map of relatively susceptibility of the area to landsliding (north of Prešov, northern part of the Košická kotlina Basin and Slanské vrchy Mts. region)

Hydrogeological symbols: *1- groundwater-level depth, 2 - moist area, 3 - swamp, 4 - significant spring.* Geodynamic phenomena symbols: *5 - area of dormant or stabilized landslide occurrence, 6 - area of active landslide occurrence, 7 - area of block deformation occurrence, 8 - erosion gully.* Documentation symbols: *9 - zone contour, 10 - subzone contour, 11 - symbols of zone and subzone,* Zone symbols: *12 - Zone of unstable areas: I., subzones - I.C solid and semisolid rocks, I.E fine sediments, I.F debris, I.H fine soils; 13 - Zone of relatively stable areas: II., subzones - II.B and II.C solid and semisolid rocks (volcanic, flysh, II.E fine sediments, II.F debris, II.H fine soils; 14 - Zone of stable areas: III., subzones - III.A solid rocks, III.C solid and semisolid rocks, III.E fine sediments, III.F debris, III.G gravelly-sandy soils, III.H fine soils*

(3.1). Besides zones and sub-zones it contains also basic data on slope deformations (surface extent and activity) and hydrogeological condition (moist areas and swamps, springs and groundwater level depth). The map is complemented by a brief explanatory text and a brief table characterising the distinguished sub-zones in each zone, including a typical schematic cross-section.

We distinguished totally 23 sub-zones in the territory under study. The results of the mapping show evidently that unstable areas are concentrated in the Košická kotlina Basin as well as in the Slanské vrchy Mts. They are especially slopes with occurrences of active and potential landslides, block failures, or with favourable geological structure and high probability for destabilisation. The principal cause of the origin of slope deformations are excessive precipitation, slope angle change, its loading or moistening, weathering of the rocks and groundwater buoyancy. From anthropogenic causes predominant are deforestation, undercutting or loading of the slope, or undermining. An example of a map of relative susceptibility of the area to landslides, from the northern part of the territory (the surroundings of Prešov) is in Fig. 3.

3.3 Map of significant geological factors

This synthetic and multi-purpose map provides in a concentrated form a complex picture of relevant geological factors of the environment from the viewpoint of engineering geology. The geofactors have predominantly the character of geobarriers, i.e. they prevent or limit human activities. Only some of the shown geofactors have the character of geopotentials (e.g. mineral deposits or high-quality agricultural soil). It has to be mentioned that the character of a geofactor in relation to various activities of man is variable. This means that one and the same geofactor may have the form of a geopotential (e.g. deposit as a source of raw material), or geobarrier (deposit as a hindrance to construction).

The map of significant geological factors has been compiled with the use of both previously mentioned maps as well as some others (e.g. map of water management, deposits and prognoses of mineral resources, pedologic or seismic maps). It shows, with the help of coloured areal, linear and point indicators the following geofactors - mineral deposits (including groundwater resources), the suitability of the geological underlier for the construction of solid municipal waste depositories (areas suitable for waste disposal), agricultural soil (occurrences of highest-quality soil types), slope stability (by occurrences of landslides), low bearing capacity soils, gully erosion, seismicity (isoseists and seismic focuses), inundation (boundaries of maximum flooding), undermining and neotectonic failures (faults with activity range from the Upper Pliocene).

Dominant among the most frequent geobarriers are especially slope deformations of landslide and block failure types, neotectonic failures of normal fault type, inundation areas and low bearing capacity soils. Among the most important geopotentials of the area under study are fertile soils and groundwater resources. A list of mineral deposits and of most fertile soil types is attached in the explanatory text to the map. Fig. 4 shows an example of a map of significant geological factors, in non-coloured form, from the northern part of the territory (the surroundings of Prešov).

4. Conclusions

1. On the basis of geological, hydrogeological maps, maps of mineral deposits and pedologic maps, as well as complementary survey and mapping, an engineering geological map has been compiled, consisting of : zoning map, map of relative susceptibility of the area to landsliding and map of significant geological factors, on the scale 1 : 50 000.

2. The maps are multi-purpose and, using zones and sub-zones, they indicate or evaluate geological factors of the area under study from the viewpoint of engineering geology. Their legibility also for non-geologists is supported by tabular form of evaluation of the results applicable in practice.

3. In spite of the scale - 1 : 50 000 - the maps are a suitable basis for urban and land-use planners, as well as Bureaux of Environmental Protection, in land use planning and environmental impact assessment. Their application in practice may prevent unsuitable interventions into the geological component of the environment as well as help to eliminate existing negative impacts of such interference in Nature.

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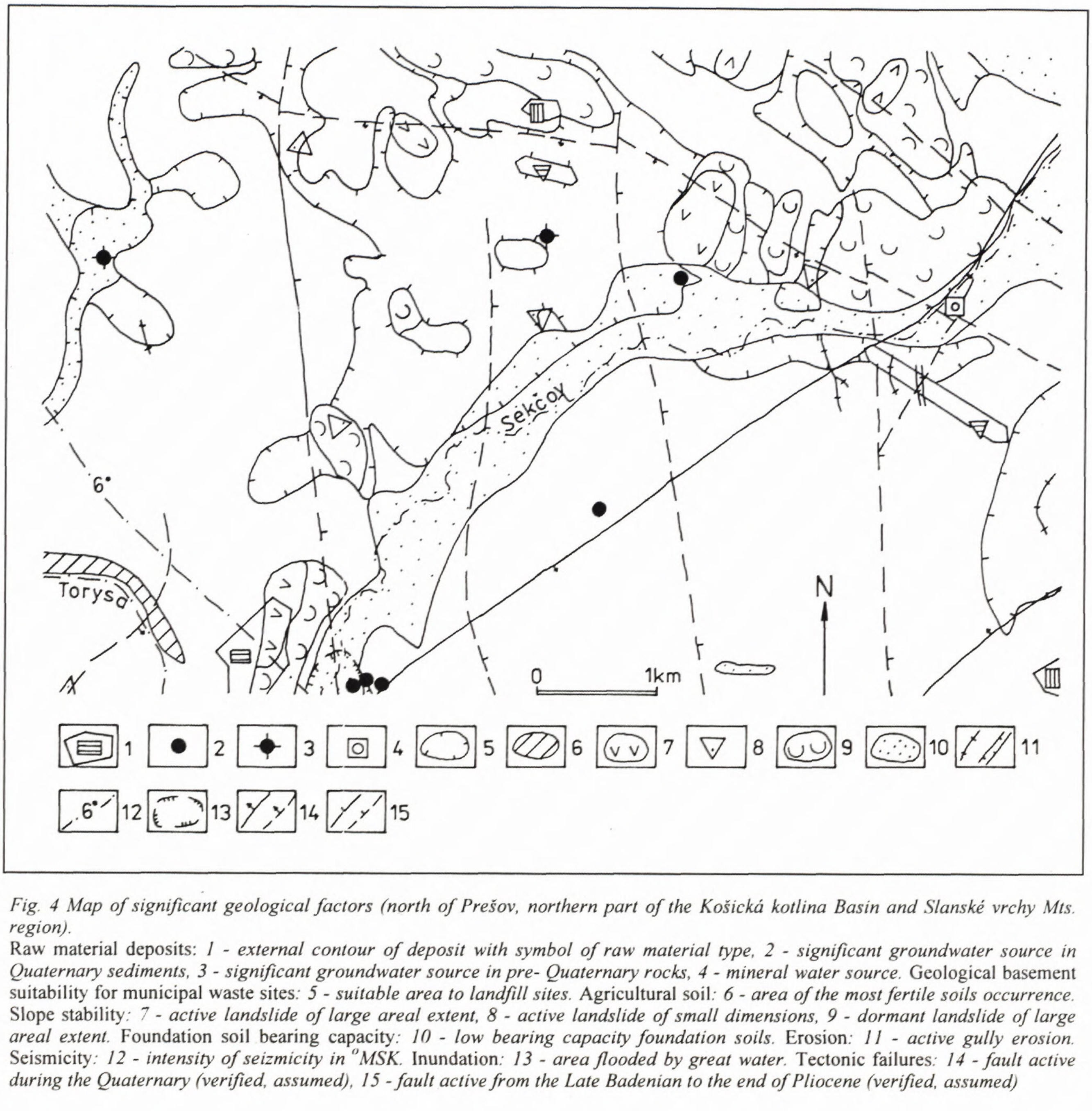

Fig. 4 Map of significant geological factors (north of Prešov, northern part of the Košická kotlina Basin and Slanské vrchy Mts. region).

Raw material deposits: *1 - external contour of deposit with symbol of raw material type, 2 - significant groundwater source in Quaternary sediments, 3 - significant groundwater source in pre- Quaternary rocks, 4 - mineral water source.* Geological basement suitability for municipal waste sites: *5 - suitable area to landfill sites.* Agricultural soil: *6 - area of the most fertile soils occurrence.* Slope stability: *7 - active landslide of large areal extent, 8 - active landslide of small dimensions, 9 - dormant landslide of large areal extent.* Foundation soil bearing capacity: *10 - low bearing capacity foundation soils.* Erosion: *11 - active gully erosion.* Seismicity: *12 - intensity of seizmicity in °MSK.* Inundation: *13 - area flooded by great water.* Tectonic failures: *14 - fault active during the Quaternary (verified, assumed), 15 - fault active from the Late Badenian to the end of Pliocene (verified, assumed)*

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Geodynamic Development of the Pokoradzská tabuľa Plateau

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Abstract: The character of the recent relief of the Pokoradzská tabuľa Plateau was determined close after the deposition of the volcanoclastic Pokoradz formation in the late Miocene. The most intense evolution of block rifts and fields as well as landslides occurred in the Early and Middle-Pleistocene, mainly due to relative uplift of the area and subsequent lateral erosion by the streams. The youngest landslides originated in Holocene and some older landslides revived are active even at present, and, both with the gully erosion they are the most remarkable geodynamic phenomena of the area. A part of them represent the older landslides which were reactivated due to improper construction and agricultural impacts.

Key words: landslides, gully erosion, karst, tectonic activity

Introduction

The Pokoradzská tabuľa Plateau situated in the middle part of southern Slovakia represents a transitive type of the area between the Revúcka vrchovina Upland and the Rimavská kotlina Basin. The major part of the plateau consists of volcanoclastic Pokoradz Formation which overlies the molasse sediments of the basin, or, in the northernmost part of the area where the volcanoclastics overlie the Paleozoic and Mesozoic rocks of the Slovenské rudohorie mountains. In the tiny part of the area, on its N and NE margin, this basement rise up to the surface.

The relief of the area has the character of a gently dissected plateau elongated only in its central part in the N-S direction. On its south margin and in the vicinity of the main valleys of Rimava and Blh rivers the area is more intensively dissected by tributary valleys and by slope failures and by gully erosion. Karst phenomena are present in the NE part where carbonate rocks occur.

The geologic-tectonic development and the structure of the area have been described in detail in the publication of VASS et al. (1986). A more precise research was carried out for the purposes of the investigation of the geodynamic development of the area (mainly of slope gravitational failures) (DEMJÁN et al.,1990). In the scope of this work the authors of this paper studied the area of the Pokoradzská tabuľa Plateau.

Pre-Quaternary development of the area

The oldest rocks of the area studied are Devonian lydites and graphitic phyllites (with layers of meta-rhyolite tuffs) of the Gelnica group occurring in the northern part of the area (Fig.1). Here they are overthrust above the phyllites and graphitic phyllites with layers of metamorphosed sandstones and conglomerates of the Carbonian Dobšiná group. Permian rocks have not been preserved. Triassic rocks are represented by sandy-clayey shales with layers of evaporites and marlstones and to a lesser extent by marly shales or limestones. These were (Silica nappe) overthrust over the Upper-Triassic limestones (locally hornfelsic), which, in the NE part of the area, are present in the form of a nappe inlier. The Jurassic rocks have not been preserved. Intense tectonic movements were active in the Cretaceous and the above mentioned nappe structure was formed.

During the Paleogene - up to the Kiscelian - the tectonic uplift of the area continued and weathering as well as karst process took place. The major part of the Rimavská kotlina Basin was flooded by sea in the Kiscelian. The thickness of Kiscelian sea sediments reaches from several meters up to tens of meters, but in the area studied they are covered by younger Tertiary sequences. At the end of the Kiscelian period the sea in the N part of the basin retreated and denudation and weathering took place. A new subsidence and transgression occurred in the Egerian. In that time the sediments of the Lučenec Formation were deposited. The formation is composed mainly of calcareous silts and siltstones

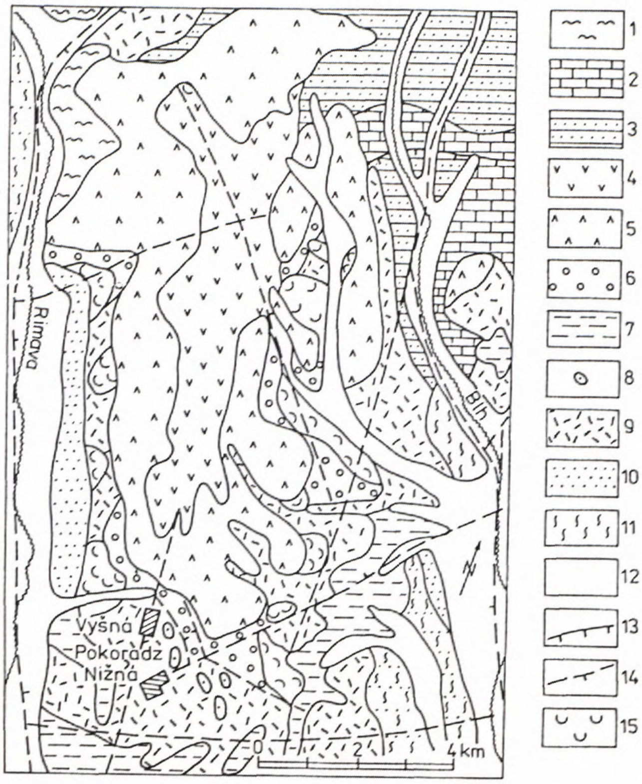

Fig.1 Geological map of the Pokoradzská tabuľa Plateau. 1 - phyllites, 2 - limestones, 3 - shales and sandstones, 4 - block rifts - plateau, 5 - dissected block rifts, 6 - block fields, 7 - clayey-silty sediments, 8 - rests of volcanoclastics on the hill tops, 9 - slope debris, 10 - terrace sediments, 11 - loess, 12 - flood plain deposits, 13 - overthrusts lines, 14 - faults, 15 - landslides

with layers of clays and sands. The thickness of the formation reaches several hundreds of meters. Towards the end of the Egerian regression took place and sedimentation continued only in the southern part of the basin. The next subsidence occurred in the Middle Miocene (Badenian, Sarmatian), connected with the deposition of partly lacustrine, partly terrestrial sediments of the volcanoclastic Pokoradz Formation, with a total thickness of 100 to 150 meters. The formation is composed of epiclastic volcanic sandstones, conglomerates and of volcanic breccias, which build the uppermost part of the formation. There followed the denudation of the volcanoclastic formation resulting in the reduction of the extent of the volcanoclastics.

The Tertiary sediments are tectonically dissected into blocks by two dominant perpendicular fault systems of NE-SW and NW-SE direction. Faults of N-S and E-W direction are to a lesser extent also present. The system of NE-SW direction is the older one and it dissects syngenetically the majority of Kiscelian and Egerian sediments. The NW-SE direction fault system was formed during the Badenian (VASS et al., 1986). Differential movements along the majority of faults occurred up to the end of the Neogene, some of them were active also in the Quaternary. During this time two periods of calm subtropical conditions resulted in the grading of the terrain. In the Pannonian a midmountain erosion level was formed. Its relicts are found in the altitudes of 470 to 530 m. In the Upper Pliocene, so called "riverain" plain developed - its very rare relicts are found in the altitudes of 330 to 350 m.

Excluding the exception of two smaller faults, other faults dissecting the Pokoradz Formation have been mentioned in publications. In the scope of our research several such faults have been found, based on the study of relicts of the midmountain erosion level and of the shifted basement of volcanoclastics, both from direct field observations and from structural boreholes.

Geologic and geomorphologic development during the Quaternary

In the Quaternary a revival of tectonic movements occurred. The upheaval in the entire area followed, but with a more intense process in the northern part. As a result of this uplift, together with climatic changes in the Pleistocene, there were alternating phases of river erosion and accumulation. In a more extended area 7 or 8 terrace benches have been formed (Donau-Würm) differing from the present flood plain altitude from 1 up to 105 m (PRISTAŠ in VASS et al., 1986). In the area studied, 3 terrace benches corresponding to the Mindel-Würm, with the base maximum 30 m above the flood plain level, have been found. Lithologically, sandy gravel sediments prevail.

The origin of proluvial deposits is closely connected with the above mentioned development. They are of similar composition as the terrace sediments. The youngest Holocene proluvial cones are prevailingly loamy or loamy-sandy, like the alluvial plain sediments. The terrace sediments are mostly covered by loess and loess loams with the thickness from 2 to 8 m (as a rule, greater thickness is developed on the older terraces).

Slope sediments have varied lithologic composition and thickness depending on the character of substratum, morphologic position and geodynamic development. On the slopes built by volcanoclastics and within the bodies of block fields loamy-stony, rarely stony debris are common. Considerable thicknesses (10 to 15 m) are frequent mainly in block fields, at the bases of slopes and in some sliding areas. Similar debris, however not so thick, overburdens the slopes built by Paleozoic and Mesozoic rocks. Loamy debris overlies the Egerian fine-grained sediments or Mesozoic shales.

Recent geodynamic phenomena

The geologic, geomorphologic, climatic and other natural conditions together with human impacts create the conditions and factors for the genesis and development of various geodynamic phenomena. The most important among them are slope gravitational phenomena, gully erosion, recent neotectonic activity of the area and karst.

Slope gravitational phenomena

In the area studied this type of the geodynamic factors is represented mainly by block rifts, block fields and landslides of various types, age and activity. Surficial creep of debris or falling of fragments and blocks of rocks are developed to a lesser extent.

Block rifts are developed in the whole range of the area, were the volcanoclastic Pokoradz Formation overlies the relatively softer plastic sediments of Lučenec Formation. In the northern part of the area with volcanoclastic rocks overlying the pre-Tertiary semisolid rocks, this type of slope failures is rather rare.

The orientation of single blocks is derived from the two main tectonic systems - NW-SE and NE-SW. Deviations converging to W-E and N-S occur from place to place, corresponding to the regional tectonics of the area. The dimensions of single blocks range between tens and hundreds of meters. The difference in the base level of blocks does not exceed 20 m, in majority of cases it is 10 to 15 m, and does not exceed 10% of their thickness.

The landscape of the block rifts depends on the geomorphologic position of their individual parts. The marginal parts of the plateau are characterized by steep and well dissected slopes, even with stony walls and pillars based on main tectonic faults of the area. The majority of these morphological forms represents the settled walls of single blocks which, at present, actively affect the foreland of block rifts. The central parts of the block rifts are prevailingly smaller plateaus and gentle slopes with thin debris cover.

The relatively extensive development of block fields was based on the tectonic and gravitational dissection of the Pokoradz Formation during the tectonic uplift of the whole geological structure and on the vertical river erosion. Generally in the tectonically predisposed valleys of NW-SE direction the erosion level reached more than 100 m deeper than the volcanoclastic base present. During the geomorphologic development this base was undercut by other streams. Thus conditions were created not only for vertical movements of blocks, but also for their horizontal slips and the formation of block fields.

Typical and rather extensive block fields were formed mainly in areas with sufficient height difference between the volcanoclastic base and local erosional base, where the length of slopes was sufficient. Generally, the complete succession of slope failure, e.g. block rifts - block fields - landslides (Fig.2 and 3) occurs under these conditions. From place to place, the dimensions of blocks range from a few meters up to 100 m. Blocks with dimensions reaching some hundreds of meters are rare. The maximum length of block field 1 km eastwards from Vyšná Pokoradz is approximately 1500 m.

Some morphologically active blocks on slopes consist of solid rocks and are covered by a thin layer of debris, or in some places they even emerge in natural outcrops. The majority of blocks is composed of intensively deteriorated and weathered volcanic rocks.

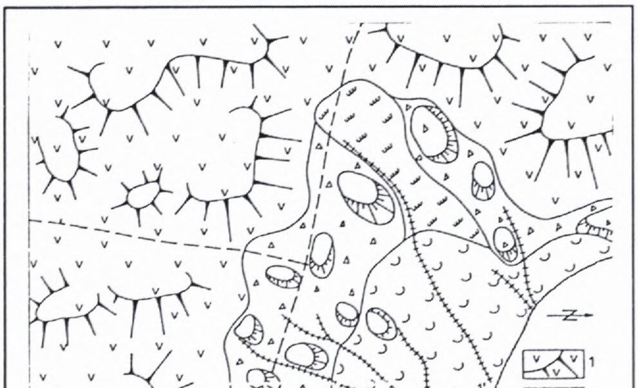

Fig.2 Landslide area on the right slope of the Faráš valley. 1 - block rifts, 2 - block fields, 3 - blocks of volcanoclastics in landslides, 4 - active landslides, 5 - potential landslides, 6 - stabilized landslides, 7 - erosional gullies, 8 - springs, 9 - faults, 10 - line of the cross-section.

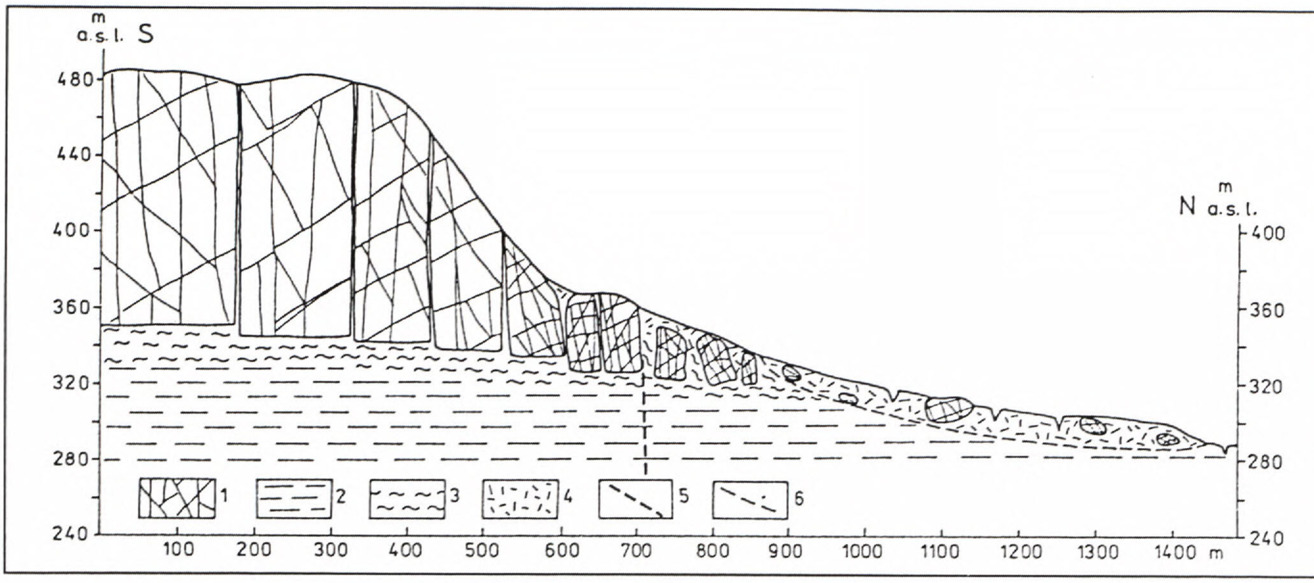

Fig. 3 The cross-section of the gravitationally disturbed slope near the Horné Záhorany village
1 - blocks of volcanoclastic rocks, 2 - clayey-silty sediments, 3 - clayey-silty sediments disturbed by squeezing, 4 - slope debris, 5 - fault, 6 - slip surface

Such blocks do not usually have active geomorphological features.

Block fields developed in an area of about 12,8 km^2 (approximately 10 % of the total area) are partly covered by forest, partly by meadows and grazeland. They do not represent any danger for engineering structures or to the environment. Nevertheless their loosen structure enables the infiltration of surficial waters and groundwaters waters into greater depths. This fact is important for activation of landslides in their foreland.

Landslides cover nearly 4 km^2 of the area, among which the active ones represent 1 km^2. Areal landslides are the most common type, the frontal ones are less frequent. Stream-like landslides, or earthflows are very rare. Depending on local conditions the total area of individual landslides reaches from several m^2 up to several thousands of m^2. The largest sliding area (nearly 1,5 km^2) is developed on the right bank of the stream Faráš, NW from the Horné Záhorany village (fig.2).

Landslides occur mostly on the periphery of block fields, some of them are in block fields or on the margin of block rifts. In both cases the sliding masses are composed of loamy-stony or stony-loamy debris usually containing isolated blocks of volcanic rocks. The underlying stratum is composed mainly of clayey-silty Lučenec Formation layers. They are practically impermeable and this feature together with their physico-mechanical properties enables the movement of sliding masses down the slopes.

Landslides developed in the area built by block rifts are less frequent. In this case shearing planes are developed either in the Quaternary sediments or on the boundary plane between Quaternary sediments and volcanoclastic rocks.

The thickness of landslides ranges from 5 to 15 m, occasionally it reaches up to 20 m. Greater thicknesses are typical for slides situated on the margins of block fields, mainly when the sliding masses comprise blocks of volcanoclastics.

Sliding of debris on Triassic and Paleozoic schists or of loamy debris overlying Lučenec Formation is very rare. Their thickness is up to 7 m.

Stream-like landslides or earthflows occur mostly within the active landslides, sometimes within the potential landslides. Several earthflows were formed in local terrain depressions with greater thickness of saturated slope debris.

Surficial creep of loamy debris is typical on relatively steeper slopes (6 to 12) formed by the sediments of the Lučenec Formation. Typical forms are characterized by gently undulating relief and several scars. This type of slope failure is caused by weathering of the clayey-silty Egerian sediments, which have comparatively higher shear strength than the weathered cover of loamy character and are able to keep steeper slopes better than the loamy debris.

The impact of landslides on the environment of the Pokoradz Plateau is negative. Frequently they damage meadows and pastures, forests and agricultural soils are less affected. Several failures endanger roads, mostly in the vicinity of Lukovištia and Ostrany villages.

Falling of fragments and rockfalls

This type of gravitational slope movement occurs mainly on steep slopes with frequent rock pillars and rock walls. This phenomenon is less common in the area of Mesozoic carbonate rocks.

The most frequent is falling of fragments with subsequent development of stony debris and talus. Toppling and falling of single blocks or walls resulting in rockfalls occurs rarely.

These phenomena can be seen mostly on the slopes built by volcanoclastic rocks, less frequently on slopes with Triassic carbonate rocks.

The development of slope gravitational phenomena

Based on the analysis of the geologic and the geomorphologic conditions we may conclude that the initial disintegration of rock masses formed by volcanoclastic rocks began very soon after their formation. At that time the clayey beds of the Lučenec Formation were insufficiently consolidated and thus they were very easy to deform under the load of volcanoclastic. The old networks of faults were copied due to these gravitational movements. Further excessive development of block rifts and locally block fields followed due to the erosional dissection of the midmountain paleoplain and mainly riverain level when the base of the Pokoradz Formation had been undercut. The most intense development of block fields and the creation of recent block rifts structure followed in the Late Pliocene and in the Early Pleistocene, when the vertical erosion reached the basement of volcanoclastics in the tributary valleys.

Landslides developed subsequently to the formation of the block fields. The oldest generation was formed in the Pliocene above the riverain level. Important development of landslides occurred in the Early Pleistocene during the intense tectonic upheaval of the area when extensive vertical erosion of streams took place. Most of the landslides of this age are recently stabilized.

Younger landslides are connected with the incision of the erosional level during the Interglacial Mindel/Riss. They are at present mostly stabilized or they are potential at present. The youngest landslides are related to the last phase of the incision of streams - from Riss to Würm. In several lateral valleys some new landslides have been formed during the Holocene period. Some of them are active up to now. However, in the scope of the geomorphologic development during Younger Pleistocene and Holocene, several older landslides have been activated. In most of the cases this activation took place close to the contact of the volcanoclastics in the block rifts or block fields with the underlying sediments of the Lučenec Formation. The triggering factor were the abrupt changes in climatic and/or hydrogeologic conditions. The precipitation waters penetrating the volcanic rock masses are drained by springs on the top of impermeable beds of the Lučenec Formation, or they are dewatered through the debris in their foreland. In the case of extreme precipitation, old landslides can be activated. An example of such failure can be seen NE from Horné Záhorany, in the valley of the stream Papča (Faráš, Fig.2). The activation of the older landslides or the initiation of the new ones occur also due to human impact. This was observed mainly in the case of undercutting of slopes in road cuts or by improper agricultural practices of the area.

Gully erosion

The most important occurrences of gully erosion are related to the tectonically deteriorated and weathered Triassic shales, at the lithological contact of the pre-Quaternary rocks with different sensitivity to erosion, and to the slope sediments failed by slope movements.

The erosion of the pre-Quaternary rocks is well developed in the northernmost part of the Pokoradzská tabuľa Plateau, within the area formed by Lower-Triassic shales. The undisturbed shales are relatively resistant to weathering. But, in the tectonically failured parts of the rock masses, their resistance is reduced. Weathering penetrates very deep into the mass and enables an intense development of gully erosion.

The average depth of gullies formed on shales ranges from 10 to 12 m. From their V-shape and the extensive lack of the vegetation cover it is evident, that the process of gully erosion is active at present. The orientation of gullies conforms to the main tectonic directions NE-SW and E-W. The greater gullies with a length of 700 to 800m are often drained by small streams and lateral erosion creates conditions for the initiation of small failures of slope sediments.

The rocks with different sensitivity to erosion create another possibility for gully erosion. Some smaller gullies occur at the contact of volcanoclastic rocks and carbonates or at the contact of volcanoclastics with slope debris.

Gully erosion occurs in the Quaternary deposits mainly within the landslide bodies. The gullies in active landslides are relatively shallower and shorter than others. The presence of gullies influences the stability regime of the landslides. In active landslides, the shallow fresh gullies enable the supply and penetration of surficial waters into their bodies leading to a decrease of passive forces and increase of active forces resulting in mass movements. The gullies within potential landslides have gentle slopes with a vegetation cover and are rather deeper then those within active ones. Usually, they are able to drain sufficiently landslide bodies, so that activation of potential landslides takes place only in the event of extreme precipitation.

Karst phenomena

The karst is developed only in the NE and northernmost margin of the area studied. The NE margin of the Pokoradzská tabuľa Plateau is confined by 4 km long allochthonous Blh river canyon -shaped valley. Westwards from Blh river there is a narrow strip of carbonate rocks with occurrences of a lot of karrens and several karst pits is developed. The karst phenomena are formed on the chemically pure biogenic and Wetterstein limestones. The diameters of karst depressions reach up to 150 m. Their occurrence together with karrens is related to tectonic jointing and to the subsequent dissolution of rocks.

Fluviokarst forms are represented by so called "dry valleys", for instance the Maruškin jarok Brook on the right side of the Blh River. The valleys begin in the Triassic shales or in volcanoclastics, and at the contact with carbonate rocks, surficial waters sink into the ground. An inactive cave with a length of 35,7m was created in the mouth of the Maruškin jarok Brook valley.

Tectonic activity and seismicity of the area

According to precise geodetic measurements, the intensity of recent vertical movements does not exceed 0.5 mm per year (MARČÁK in VASS et al.,1986). Positive anomalies are related to the northernmost part of the area, negative ones to the southern margin of the area studied.

Obviously, similar activity took place during the whole Quaternary period, during the prevailing uplift of the area. Deducing from the depth of the Quaternary incision of the valleys, the average value of the uplift was approximately 0.1 mm per year. The uplift was not uniform. During the formation of terrace deposits, the value of uplift could reach up to 3 mm per year.

The differential Quaternary movements along fault planes occurred mainly on the N, NW and S margin of the Rimavská kotlina Basin. Within the Rimavská kotlina Basin the movements along the NW-SE and N-S directed faults were the most frequent ones, for instant in the valley of the Rimava or Blh rivers (Fig.1). It is supported by the asymmetric distribution of the river terraces, which occur exclusively on the sunken blocks (PRISTAŠ in VASS et al.,1986).

The seismic activity of the area is rather low. According to various sources 5 earthquakes with intensity of 4° MSK were observed during the last hundred years. The most intense one was the earthquake near Dulovo (Blh river valley) in 1956 with an intensity reaching 5° MSK.

According to the current seismic activity and Quaternary vertical movements we can expect movements (in spite of not very convincing results of geodetic measurements) along the faults of mainly NW-SE direction and/or along the boundaries of the Pokoradzská tabuľa Plateau with adjacent geomorphologic units.

Conclusions

Relatively intense tectonic movements are typical for the geodynamic evolution of the Pokoradzská tabuľa Plateau from the Paleozoic up to the present, together with extensive gravitational deformations which took place from the Late-Miocene up to now. The whole volcanoclastic Pokoradz Formation is gravitationally deteriorated into blocks of various dimensions sunken deep into the underlying relatively plastic layers of the Lučenec Formation. These clayey-silty sediments are squeezed to the foreland of block rifts, moving some blocks of volcanoclastic rocks down the slope. Due to this mechanism, vast block fields have developed. Along the margins of some block rifts, but mainly block fields, numerous landslides of various dimensions and shape occurred. They damage and/or jeopardize the environment, mainly meadows and pastures, locally marginal parts of municipalities. In addition to extreme precipitation anomalies and gully erosion improper interference with the landuse, mainly grazing of pastures by cattle or undercutting of slopes, can be a triggering factor for development of slope deformation. Experience with surficial and deep dewatering (horizontal boreholes) proved that these remedial measures provide very good results in decreasing or stopping of the sliding activity.

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Some engineering geological problems encountered during the construction of the rock-fill dam Turček

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Abstract: The geological structure of Central Slovak Neovolcanites is very complicated. In spite of the similarity of petrographic composition of here occurring rocks, a characteristic feature of the geological structure is a considerable heterogeneity of physical conditions in rock massifs, caused by their petrogenetic and tectonic evolution. Due to this fact, all engineering activities in the above mentioned environment are connected with a number of problems and complications (different bearing value, permeability and rock material quality of various parts of rock massif). The heterogeneity of the rock environment affects especially adversely the prospects of finding a sufficient quantity of ballast, with a quality corresponding to requirements on material for rock-fill dams. The paper presents some results from geological-petrographical and, subsequently, engineering geological investigations of the andesite rock mass aimed at choice of suitable quality and quantity of the rock material for the dam of the water reservoir Turček.

Key words: andesites, physical and mechanical properties, ballast for dam, loosing of massif, discontinuity

Introduction

Any technical activity in an exceptionally heterogeneous rock environment of an autometamorphically altered andesite massif brings about a number of engineering geological problems. The range of this problems is extended and their gravity increased proportionally with the complexity of the designed technical work. Hydrotechnical constructions, consisting of a series of objects of different type and with different requirements, belong generally to the most complex technical works, having high demands on the quality of rock mass in which they should be realised, as well as on the quality of rock material, used in their construction.

The above facts were to a great extent manifested also during the investigation and the construction of the dam Turček, situated into a rock massif of autometamorphically altered andesites. Engineering geological investigation showed several controversial problems connected with the construction of the 59 m high and on the crest 285 m long-fill dam, (problems of loading capacity and impermeability of the dam underlier, problems of obtaining the required quality and quantity of rock material for the dam body etc.), as well as with the creation and operation of the reservoir itself (problems of impermeability of the bottom and slopes of the reservoir, problems of changes of reservoir banks in the selected regime of operation, prognosis of its siltation etc.). Several problems originated or were aggravated only during the construction of the water reservoir. From the indicated wide range of engineering geological problems, we shall deal with two selected groups of problems, in the solution of which the authors of the contribution were involved. They are the evaluation of quality of rock material used for the earth dam body and problems of obtaining the necessary quantity of material based on a study of massif loosening in the area of the material quarry.

Solving of the above problems was based on the results of petrographic study of the rocks, followed by their engineering geological evaluation.

Geological and engineering geological characterisation of the rock mass

The water reservoir Turček is located in Central Slovakia, east of the village Dolný Turček in Kremnické vrchy Mts. (Fig. 1). Geographically the territory belongs to the region of neovolcanites, the area of volcanic highlands.

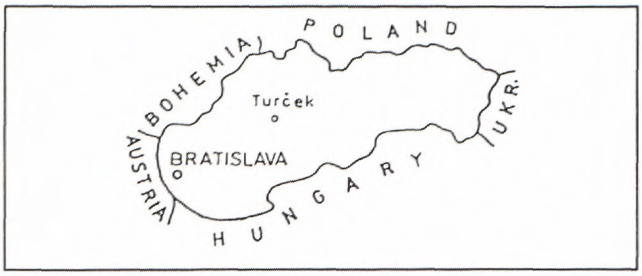

Fig. 1 Location map

The area of interest, a quarry for ballast used for the dam, occurs NE of the dam profile, partly in the area of the future reservoir. It is formed of an andesite body in the area of the elevation point Špicatá (898 m a.s.l.).

This is a considerably inhomogeneous rock environment, due to the formation mechanism of extrusive bodies, accompanying alterations of the material and tectonic activity. Simultaneously with the formation of the rock body, autometamorphic processes took place in some of its parts, especially basal ones, which, along with other factors, caused deterioration of the rock material quality. In some places there are even layers of extrusive breccias.

Detailed mapping aimed at determination of geological structure of the andesite body and distinguishing the most favourable lithologic type for use in the dam, complemented by sample collection for mineralogical, petrographic as well as engineering geologic analyses, was carried out on about 4 km^2 on the scale 1 : 2 500 (STOLÁR et al., 1994, Fig.2).

Geological-tectonic structure of the territory

Geological structure of the territory is formed of the Kremnické vrchy Mts. volcanic rock complex. The territory is built of three volcanic formations. The formations are covered by Quaternary fluvial and debris sediments.

The majority of the territory studied is built of the Kremnický štít Formation. From its underlier emerges the Turček Formation, covered by the Vlčí vrch Formation.

The Turček Formation is represented by denuded relics of a stratovolcano with pyroxene and basaltoid andesites, developed in the environment of the Kremnica graben. The Kremnický štít Formation, represented by amphibole-pyroxene andesites, formed successively above the previous one. The Turček and the Kremnický štít Formations are both severely tectonically affected.

The youngest volcanic formation on the territory under study is the Vlčí vrch Formation. The formation represents relics of a small basaltoid andesite stratovolcano, covering a rugged relief, formed on older rocks of the above formations. The formation is considerably eroded. The age of the described rock units is Badenian-Pannonian.

Above the volcanic formations, recent and subrecent sediments have been formed during the Quaternary, especially slope debris and alluvial ones. They are represented by bouldery sandy gravels, loamy-stony sediments and bouldery debris.

Lithologic characterisation of volcanic formations

Turček Formation

The formation occurs on the surface in a narrow belt at the elev. p. 720 m a.s.l. (Fig. 2). It is a lava flow of basaltoid andesite and pyroclastic rocks. The lava flow has a thickness of about three meters. The flow consists of bedded or irregularly cracked massive andesite, dark-grey to black in colour. The andesite is glassy. In the upper part, the flow passes into lava breccia. Pyroclastic rocks consist of dark, glassy andesite with fragment size of 5 to 50 cm (the proportion of which in the rock is 30 to 60 %). The fragments and blocks in the breccia have angular form. Between them, there is a groundmass consisting of a tuff-pumice substance.

Kremnický štít Formation

The formation occurs in the studied territory above all in the surroundings of the elev. p. 898 m a.s.l. Špicatá and elev. p. 855 m a.s.l., as well as on both sides of the brook Turiec (Fig. 2). Geological mapping revealed that the formation is represented by an extrusive body of dome flow type. This means that the extrusion passes in the upper part into a thick lava flow, tilting over towards the east and the west. The body displays tabular, sheet or block jointing. During the formation of the body, its different parts developed irregularly. This caused the formation of different structural and textural characteristics and lithologic phenomena.

Vlčí vrch Formation

The formation is represented by lava flows in the area of Šajba (Fig. 2). The lava flows are formed of massive lava in central parts and lava breccia in the basal and upper part. Their thickness reaches about 20 to 30 m. Jointing of the rock is tabular or blockwise. Lava breccias are characterised by caked porous to slaggy fragments 5 to 50 cm in size. The colour of the breccias is red to black. Groundmass of the breccia is detritic or it is completely missing.

Lava flows are formed of dark basaltoid andesite. From petrographic viewpoint the rock is ba-

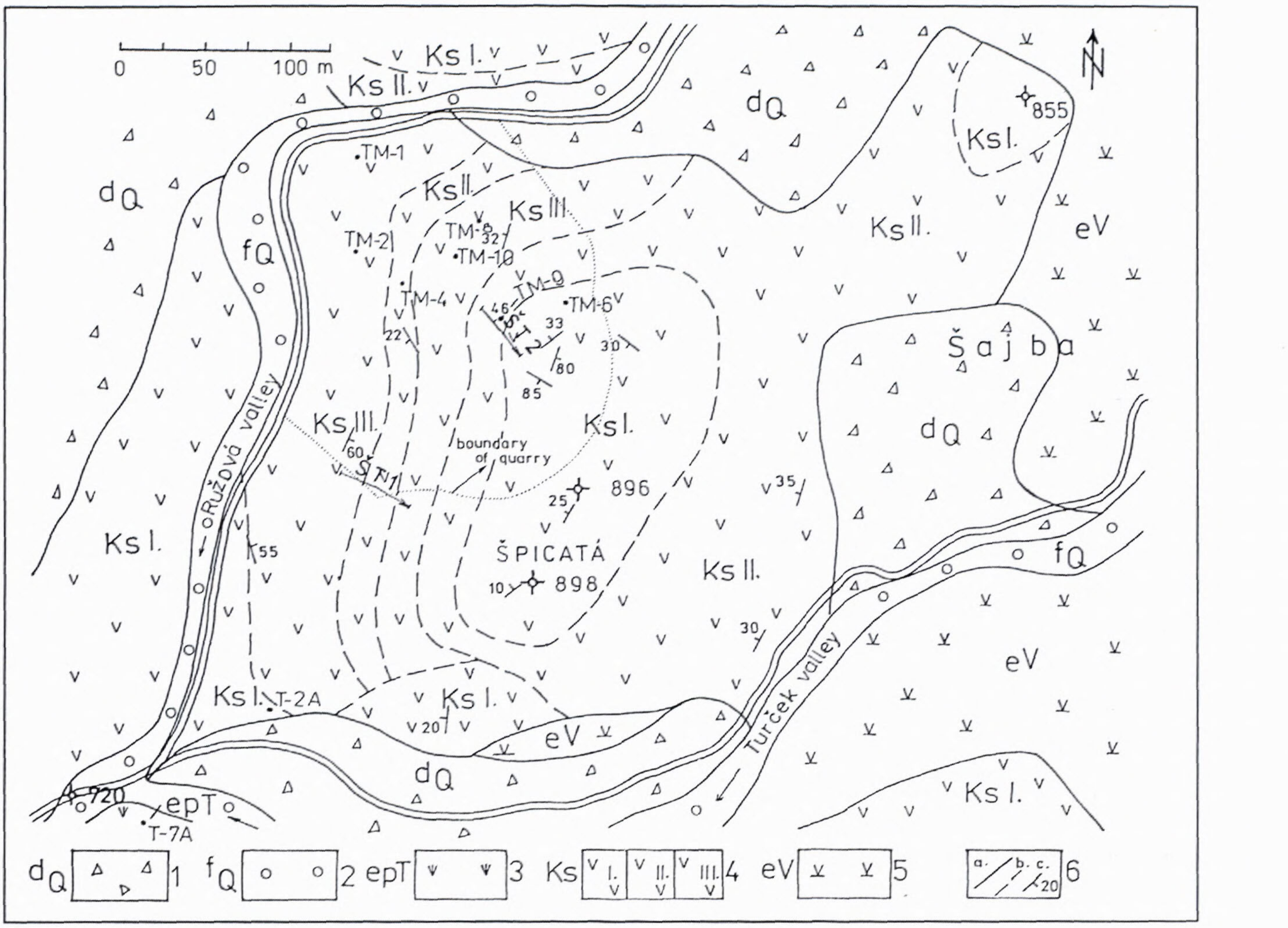

Fig.2 Geological map of the wider surroundings of the quarry of material for the dam Turček
1-deluvial loamy-stony debris, 2 - alluvial, predominantly gravelly sediments, 3 - the Turček Formation - lava flows and basaltoid andesite pyroclastics, 4 - the Kremnický štít Formation - amphibole-pyroxene andesite extrusive body: I, II, III - distinguished technologic types, 5- the Vlčí vrch Formation - lava flows of basaltoid andesites, 6 - others: a-geological boundaries, b - boundaries of distinguished technologic types, c - mode of deposition..

saltoid andesite with phenocrysts of hyperstene, augite and plagioclases. The groundmass is hyaline, composed of plagioclases and pyroxenes.

Engineering geologic characterisation of the rocks

Material quarry occurs in the rock environment of the Kremnický štít Formation (Fig. 2).

From petrographic viewpoint the volcanic body of the Kremnický štít is built of amphibole-pyroxene andesite with sporadic occurrence of biotite. Within this petrographically quasi-homogeneous rock massif we distinguished on the basis of a detailed mapping and petrographic analyses three rock types, differing significantly in their properties. Their areal extent is shown in the geological map (Fig. 2).

They are the following rock types:
Type I - fresh, unaltered andesite
Type II - transitional
Type III - porous.

Type I is represented by massive, dark-grey amphibole-pyroxene andesite, fresh, partly altered. The andesite is composed of plagioclases, pyroxenes, amphiboles and biotites. The groundmass is hyalopilitic - pilotaxic with sporadic presence of felsitic matrix (samples TM-1, TM-6, TM-9, Tab. 1). Dark minerals are relatively fresh. Amphiboles have opaquised margins.

Tab. 1 Modal composition of samples (%).

	TM - 1	TM - 2	TM - 4	TM - 6	TM - 8	TM - 9	TM - 10	T - 2A	T - 7A
plag.	25.00	18.33	20.52	25.98	15.15	21.56	21.73	18.57	32.97
px-hy	0.88		1.30	0.69	0.39	0.86	2.34	1.52	0.72
amph	5.59	2.87	8.86	8.63	2.52	12.02	5.85	7.36	1.62
bt	0.78							0.47	
dk.min.	0.49	2.18			3.69				1.26
aggr.	0.79			0.98		1.81	0.49		
mt-type1	66.47	18.84	50.40	56.67	43.10	56.40	20.37	66.82	40.00
mt-type2		57.78	18.92	7.05	35.15	7.35	41.13	5.26	23.43
pores							8.09		
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Explanations :
plag. = plagioclase,
px - hy = pyroxene - hypersthene,
amph = amphibole,
bt = biotite,
dk. min. = dark minerals,
aggr. = aggregates,
mt-type1 = groundmass hyalopilitic-pilotaxic,
mt-type2 = groundmass felsitic

Tab. 2: Principal distinguishing petrographic characteristics of the andesite types at the locality Turček

	Groundmass	Porosity	Colour	Opacitisation
type I	hyalopilitic-pilotaxitic	-	dark grey	margins
type II	hyalopilitic-pilotaxic felsitic	low	grey brown light brown	margins + sporadically areal
type III	felsitic hyalopilitic-pilotaxic	high	light, light-pinkish	margins and areally

Type II is represented by slightly porous, greyish-brown to light-brown amphibole-pyroxene andesite, slightly altered. The andesite is composed of plagioclases, pyroxenes and amphiboles. The groundmass is variable: hyalopilitic-pilotaxic and felsitic, hyalopilitic-pilotaxic predominating over the felsitic (see Tab. 1, samples TM-4 and TM-8).

Type III is represented by porous, light-coloured and light-pink amphibole-pyroxene andesite, strongly altered. It is composed of plagioclases, pyroxenes and amphiboles. The groundmass is felsitic and hyalopilitic-pilotaxic, felsitic groundmass being predominant (see modal composition in samples TM-2 and TM-10, Tab. 1). Dark minerals are areally strongly opaquised (Tab. 2).

The above distinguishing of three basic rock types conforms to engineering geological assessment of the rocks used as material for the dam. From engineering geological viewpoint, the type I rocks have high strength, rocks of the type II high to medium and the rock type III is classified among rocks with medium to low strength.

When describing the rock massif from engineering geological viewpoint, type I andesite may be characterised by tabular, less frequently banket bedding, which, together with irregular, vertical discontinuities, causes tabular jointing and blockiness of the rock, the blocks being of medium size. The blocks and fragments are characterised by sharp edges.

The massif with occurrences of type II and III rocks is usually characterised by irregular discontinuities, without significant ordering into systems, resulting in predominantly polyhedral blockiness, with blocks of small to medium size.

Engineering geological assessment of the rock material and massif in the area of material quarry

As already mentioned in the introduction, from the wide range of engineering geological problems connected with the construction of the water reservoir Turček, we aimed our attention at specific problems of assessing the quality of rock material for the dam and evaluating of massif loosening in the quarry. We base this on the conclusions of basic geologic mapping and petrographic analyses.

Assessment of the quality of rock material used in the rock-fill dam body

The considerably variable character of the amphibole-pyroxene andesite corresponding to various grades of its autometamorphic alteration is reflected quantitatively also in the values of characteristics describing physical state of the rock. They are above all the values of some physical and mechanical rock material properties (above all density, porosity, absorption capacity, uniaxial compressive strength and several others). Marked differences in these properties in different rock types have been pointed out already by authors of previous engineering geological investigations in the area of designed water reservoir, when analysing the possibilities of using the rock ballast as construction material. Jadroň (1971) distinguished in the wider area of the water reservoir three andesite types (I - pyroxene-biotite-amphibole andesite, medium to high-metamorphosed, II - pyroxene-biotite-amphibole andesite, low-metamorphosed, and III - andesite agglomerate) and he presented the ranges of selected rock material properties from the viewpoint of its use as construction rock ballast. Domanický (1988), on the basis of investigations of the territory with material for the rock-fill dam Turček, distinguished three types of construction ballast (I - dark grey amphibole-pyroxene andesite, unaltered, II - pinkish-red autometamorphically altered amphibole-pyroxene andesite, and III - tuff-breccia) characterised by selected physical and mechanical properties.

Assumptions of strong heterogeneity of the massif in the area of construction ballast deposit were confirmed after the opening of the quarry in the year 1993. In the highest part of the massif (below the elevation points Špicatá and 896 m a.s.l.), in the area of benches 1 and 2, partly also 3, there was relatively fresh, dark-grey andesite . Starting with bench 3, the character of rock material significantly deteriorated - in the area of benches 4, 5 and 6 predominated andesite of various alteration grade, porous, predominantly grey-brown in colour. From bench 5 and, above all, at bench 6, layers of porous, light-pink andesite, frequently totally disintegrated, of sandy character, occur significantly. At the foot of the slope, at bench 7, a body of relatively fresh, dark-grey andesite was exposed. The alternation of different andesite types from level 3 to the foot of the slope is very irregular.

The character of rock material in the quarry has been evaluated from the viewpoint of possible use as construction material for the rock-fill dam body independently by workers of the Dionýz Štúr Institute of Geology Bratislava (GÚDŠ) and Faculty of Natural Sciences, Comenius University (PriF UK), Bratislava. On the basis of field inspection and mapping of the exposed quarry area they came in both cases to the same conclusion regarding the classification of rock material in 3 basic technologic types, differing significantly in their physical state. Each of the distinguished types has been characterised by physical and mechanical properties, important from the viewpoint of its use as material for the rock-fill dam. The determined values of properties of basic three technologic andesite types occurring in the area of material quarry are summarised in Tab. 3.

From the comparison of the results of petrographic analyses (Tab. 1, 2) and physical parameter values (Tab. 3), a relationship between the mineral composition and properties of the distinguished three rock types may be inferred. Absorption capacity belonging to basic characteristics of physical state of rock material was determined (results of GÚDŠ) under specific conditions by permanent boiling of the samples during 3 hours, determining thus the active porosity values. The determined values (Tab. 3) correlate well with values of porosity, indicating good communication of the

Tab.3 Physical and mechanical properties of the three technologic types of andesite

Authors	Dionýz Štúr Instute of Geology			Faculty of Natural Sciences		
Properties	I	II	III	I	II	III
specific density ρ_s [kg.m^{-3}]	2664 (3)	2663 (2)	2633 (2)	2680-2700 2690 (3)	2670-2680 2670 (3)	2660-2680 2670 (3)
bulk density ρd[kg.m^{-3}]	2381 (3)	2228 (2)	2003 (2)	2450-2580 2518 (11)	2080-2490 2397 (27)	1900-2370 2195 (26)
porosity n [%]	10,63 (3)	16,28 (2)	23,93 (2)	6,4	10,3	17,8
saturation N [%]	4,01 (3)	6,46 (2)	11,22 (2)	0,85-1,59 1,19 (11)	0,86-6,76 2,56 (26)	1,67-12,4 5,48 (26)
Na_2SO_4 [%] 10 cycles				0,9-2,75 1,57 (5)	16,77-100,0 86,53 (20)	19,63-100,0 86,76 (18)
point load $Is_{(50)}$ MPa				1,64-6,31 3,98 (23)	0,8-5,48 2,64 (37)	0,65-2,51 1,53 (37)

Explanations
$x_{min,} - x_{max},$
x_{aver} *(frequency)*

Tab.4: Required properties of rock material for rock-fill dams

Authors	Properties of rock material			
	ρ_d [kg.m^{-3}]	N [%]	Na_2SO_4 [%]*	σ_c[MPa]
ESMIOL (1968)	2750		5	
Rip-rap comm. USBR (1970)	2500		10	
ONDRÁŠIK (1976)	> 2500	> 1,8	5 - 10	
MENCL (1966)				70

**The test with 5 cycles*

pores. In the case of gradual frost penetration into type I andesite, we may expect equalisation of pressure due to ice crystallisation. Andesites of the type I are fresh, or only partly altered, porosity of the above rocks is syngenetic. Andesites of the types II and III are also characterised by predominantly syngenetic porosity, however, reaching considerably higher values. At the same time it is important to know that autometamorphic alteration processes did not lead to the formation of a significant proportion of clayey minerals (up to 1%). According to ČABALOVÁ (1978) and other authors, the presence of clayey minerals has negative effects on the resistance of altered volcanic rocks to weathering.

When comparing the rock material characteristics with criteria required by various authors for rock dams (Tab. 4), we come to the conclusion that material of the types II and III is for this use unsuitable. Subsequently to these findings, the project of dam body construction has been adjusted. The surface of the more requiring water-front side is constructed of imported granitoid rocks. The surface parts of the crest of dam as well as its air-exposed side are built of highest-quality technologic andesite (type I). The dam body itself is zoned, with various per cent proportion of technologic andesite of the types II and III in the zones. The qualitatively most unsuit-

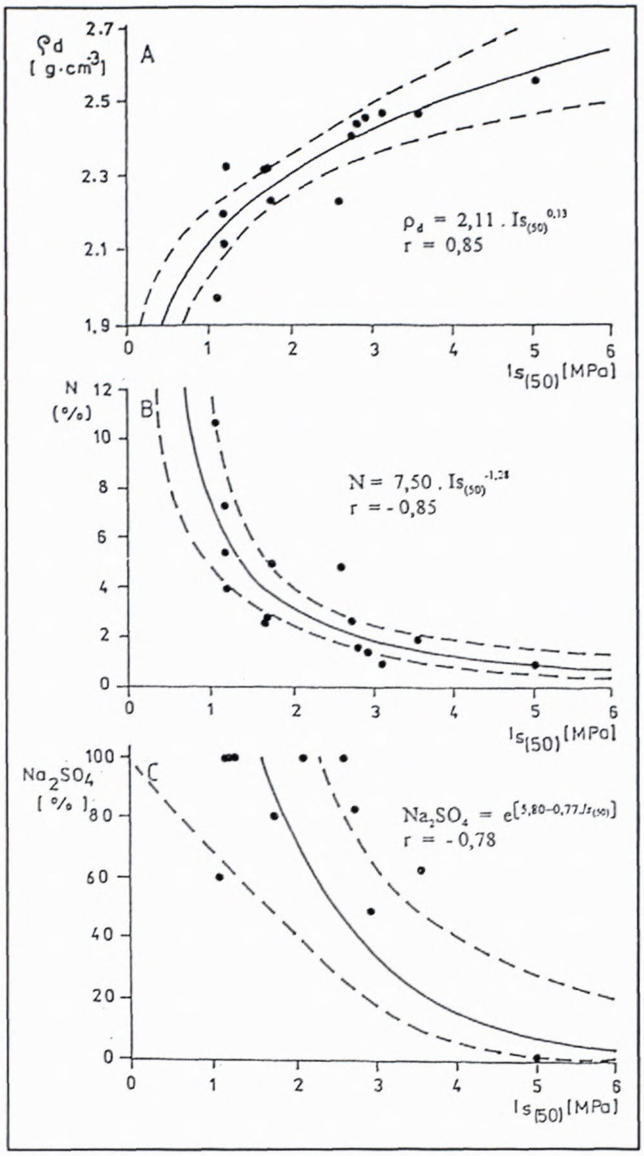

Fig. 3 Correlation between the strength index at point load $I_{s(50)}$ and bulk density ρ_d (A), absorption capacity N(B) and resistance to weathering in Na_2SO_4 solution (C). Dashed lines are restricting a reliability zone along the regression line with the probability of 95% (after HYÁNKOVÁ, SZABO, WAGNER, 1994). Each correlation is provided with a relationship corresponding to the highest value of the correlation coefficient r.

able material (andesite II : III ratio 5 : 5 to 3 : 7) occurs in the core of the dam body.

At mining of the rock ballast it is unavoidable to asses the qualitative classification of different charges (blasted rock) according to distinguished technologic types and to place them according to this into corresponding zones of the dam body. Physical state of the rocks is most accurately characterised by physical properties (density, porosity, absorption capacity), or by the results of special technologic tests (e.g. resistance against weathering tested by sodium sulphate). Their determination is however time-consuming and during mining practically not applicable. Therefore, such properties of rocks have been looked for, the determination of which is rapid and easy and the results of which are well correlable with the values of properties characterising the physical state of rocks.

The in such cases frequently used determination of rebound hardness using Schmidt´s hammer did not prove to be applicable in the very heterogeneous environment of altered andesites. Considerably more reliable results have been obtained by point load test. The test was carried out on samples of various technologic types of andesite, on which there were simultaneously determined physical properties. The obtained results show high correlation between point load strength, bulk density, absorption capacity and partly also resistance against weathering (saturation with sodium sulphate solution, Fig. 3). The figure shows only average values from the set of determinations, as well as point load tests. From thus deduced relationships, we can determine limit values of strength at point load, corresponding to required criteria of rock material physical properties. For example, if, for rocks used into surface parts of dam crest and its air-exposed side, we require volume bulk density of minimum 2500 kgm^{-3}, absorption capacity of approx. 1.3 % and sufficient weathering resistance, then these parameters are secured by strength at point load of above 4 MPa. Point load test may be carried out on irregular, unprepared samples (rock fragments, lumps), quickly, in great quantity, directly in the quarry. Its use makes the decisions on classification of mined parts of the quarry into required technologic rocks groups more objective and, at the same time, the test may be used also as a controlling and verifying method for the assessment of the quality of mined ballast, as well as of rock ballast incorporated into the dam body.

Calculation of rock massif loosening

Another separate problem which we attempted to solve was the assessment of rock massif loosening in the area of the exploited quarry. This problem has a practical meaning in connection with correct determination of the necessary quantity (volume) of material for the dam. High loosening of the rock massif requires mining of considerably larger quantity of material from the quarry, leading at volumes of matter necessary for the earth dam to serious economic effects.

The evaluation of the loosening of the massif is based on detailed documentation of joint parameters (above all orientation, mutual distances, width and filling). In the case of the evaluation of rock massif loosening in the area of material quarry for the dam of the water reservoir Turček, this was based on detailed documentation of discontinuities in survey galleries ŠT-1 and ŠT-2 (Fig.2). Only open discontinuities were taken into consideration. Their parameters were evaluated in accordance with the methodical manual (ONDRÁŠIK et al., 1983). In all, 296 discontinuities were selected in the gallery ŠT-1 and 95 discontinuities in ŠT-2, i.e. totally 391 discontinuities. For the calculation of loosing we used the software "PUKLINA" of the Department of Engineering Geology, Comenius University, Bratislava.

Adit ŠT - 1

The length of the gallery ŠT-1 is 90 m. The adit was in its whole length tunnelled through pink, red-brown, autometamorphically altered amphibole-pyroxene andesite (DOMANICKÝ, 1988) of the type II.

For the calculation of loosening, from available data, 296 discontinuities were taken into consideration. On the basis of evaluation of their spatial position, 9 fracture systems were distinguished.

The software PUKLINA is using the formula for the calculation of rock massif loosening (I_{rm}) according to ONDRÁŠIK et al., (1983):

$$I_{rm} = \sum I_{rmi} = \sum_{i=1}^{n} \frac{\delta a_i}{a_i + \delta a_i} .100\% \qquad (1)$$

where δa_i - is average discontinuity width in the system i,

a_i - is average distance between discontinuities of the system i,

n - is the number of discontinuity systems in a given massif volume.

For andesite of the type II in the gallery ŠT-1, the value of loosening index I_{rm} = 9.8 %.

Gallery ŠT-2

The gallery ŠT-2 had a total length of 58.8 m. According to DOMANICKÝ (1988), it cut across two andesite types:

1 - amphibole-pyroxene, dark-grey unaltered andesite (type I)

2 - pink, red-brown, autometamorphically altered amphibole-pyroxene andesite (type II)

Both types are alternating along the gallery, forming separate sections - three sections with a total length of 30.6 m (sections A, B, C) in the rock type I and two sections with a total length of 24.8 m (sections D and E) in the rock type II. The adit mouth section has not been evaluated.

The following values of loosening index I_{rm} (%) have been calculated according to the formula (1) for different sections:

A 1.9 , B 3.6, C 5.9, D 17.3, E 7.6

Average values of I_{rm} for different andesite types in the gallery ŠT-2 and general I_{rm} of the rock massif along the course of the gallery has been calculated according to the formula for the calculation of weighted arithmetic mean:

$$I_{rm} = \frac{\sum_{i=1}^{k} I_{rmi}.n_i}{\sum_{i=1}^{k} n_i} \qquad (2)$$

where I_{rmi} - is loosening index for section i of the gallery,

n - is the number of discontinuities in the section i of the gallery,

k - is the number of sections in the gallery.

For andesite of the type I, average value of the loosening index I_{rm} = 3.78 %.

For andesite of the type II in the gallery ŠT-2, average derived loosening index value I_{rm} = 12.2 %.

For andesite of the type II in both galleries, average value of loosening index calculated using the formula (2) is I_{rm} = 10.2%.

The above relatively very high values of massif loosening may be partly reduced if we take into consideration the average per cent filling of discontinuities.

Conclusion

On the basis of petrographic and engineering geologic analyses and evaluation it may be stated that the andesite body from which rock ballast for the construction of the water reservoir dam Turček is mined is characterised by marked inhomogeneity. The formation of the body by extrusion with gradual pushing of the material from the vent led to the formation of zones and layers of andesite, which differ considerably in their petrographic composition and above all development of groundmass. The variability of petrographic composition is reflected also in the variability of quality indicators of rock ballast. The qualitatively different zones are however not sharply restricted and transitions between them may be characterised as gradual, or the petrographic types are mutually mixing and alternating. The transition of the extrusive body into a "dome flow" body type in the upper part of the extrusion, with north- and south-dipping lava flows caused the formation of another rock type, with different petrographic development and thus different, more favourable quality parameters. To the contrary, the result of autometamorphic processes in the lower part of the extrusive body is alteration of minerals, causing unfavourable quality parameters of the rocks. Tectonic activity led to the formation of disintegration structures in the body.

From the viewpoint of the use of the rock ballast in the rock-fill dam of the water reservoir, as favourable may be regarded only the minimum occurrence of clayey minerals, representing the products of alteration processes. Petrographic analysis did not reveal propylitisation of the rocks. The relatively low values of absorption capacity and active porosity allow to assume considerable resistance of type I amphibole-pyroxene andesite to weathering factors. These indicators, as well as higher alteration grade are unfavourable at andesites of the type II and III. A practical result of these findings is the fact that the above technologic rock types are to be used only in those parts of the dam body where they shall not be exposed to weathering.

Calculations have shown also relatively high loosening of the rock massif in the area of the material quarry. The loosening values are significantly hogher in andesites of the technologic types II and III.

The investigations have shown the usefulness of mutually connected petrographic and engineering geological methods of rock environment evaluation, allowing to design optimum methods for solving practical problems of the construction large technical works.

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Radon in the geological medium

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Abstract: During last 6 years, the distribution of radioactive gas Rn-222 in soil air of the subsurface layer is among important objectives of the environmental projects in city agglomerations of Slovakia. The largest ones, covered by radon survey, are Bratislava and Košice regions.

On the radon survey results, a radon risk maps on 1:25 000 and 1:50 000 scales have been compiled in Bratislava region, while on 1:10 000 scale in Košice region.

The paper presented deals with main results of radon survey in a/m areas.

Key words: radon in soil air, radon risk maps

Introduction

The distribution of Rn-222 in the sub-surface layer of the geological medium is the current task of environmental projects in regions of city agglomerations in Slovakia.

The compilation of a radon risk map is, for example, among the sub-projects within the framework of the projects Bratislava - abiotic component of the environment (1990-1993) and Košice - abiotic component of the environment (1994-1999?).

The presented paper deals with the behaviour of radon in the geological medium and with some results of the radon survey in the Bratislava and Košice regions.

General informations

Rn-222 penetrates very easily through permeable rock complexes and active faults to a distance of a few kilometres from the source. The content of radon in soil air depends on the Ra-226 content in the rocks, the emanation ability of minerals and rocks, the permeability of rock formations in respect to water and gas.

Radon spreads in rocks and neotectonic zones by diffusion and convection. The diffusion movement is affected by physical properties of the geological medium, while convection flow is a consequence of changes in the physical properties, mainly temperature and pressure. Radon is transported by convection in greater quantities than by diffusion.

The distribution of radon and the values of its volume activity (a_v) in the sub-surface layer are influenced by climatic changes. The amount of radon rising up from the soil air to the surface increases with increased air temperature and decreases with high air pressure, humidity of the atmosphere and precipitation. The a_v values are low in a dry period and vice versa.

The risk of radon penetrating from the sub-surface layer to houses depends on the a_v value in the soil air and on structural-mechanical properties of the foundation soils.

The assessment of the radon risk in Bratislava and Košice regions is based on the methodology applied in the Czech Republic and on the Notice of the Ministry of Health of the Slovak Republic No. 406/92. The assessment of the soil gas permeability is in accordance with the former Czechoslovak standard No. 73 1001 (see table below).

Radon risk category	Volume radon activity ($kBq.m^{-3}$)		
	soil permeability		
	low	medium	good
low – I	< 30	< 20	< 10
medium – II	30 – 100	20 – 70	10 – 30
high – III	> 100	> 70	> 30

Radon risk maps

1. Bratislava region

The a_v was determined in 0.80 m deep holes. The density of observations was 3 reference areas (each representing 20 stations) per km^2. The radon risk maps have been compiled on the scales 1 : 25 000 and 1 : 50 000. 56.8 % of the area under study is lying in the low radon risk area, 37.6 % in the medium radon risk area and 5.6 % in the high radon risk area (see Fig. 1). Follow-up monitoring of the equivalent volume radon activity (EVRA) in apartments located in areas with high radon risk in the surface layer has shown

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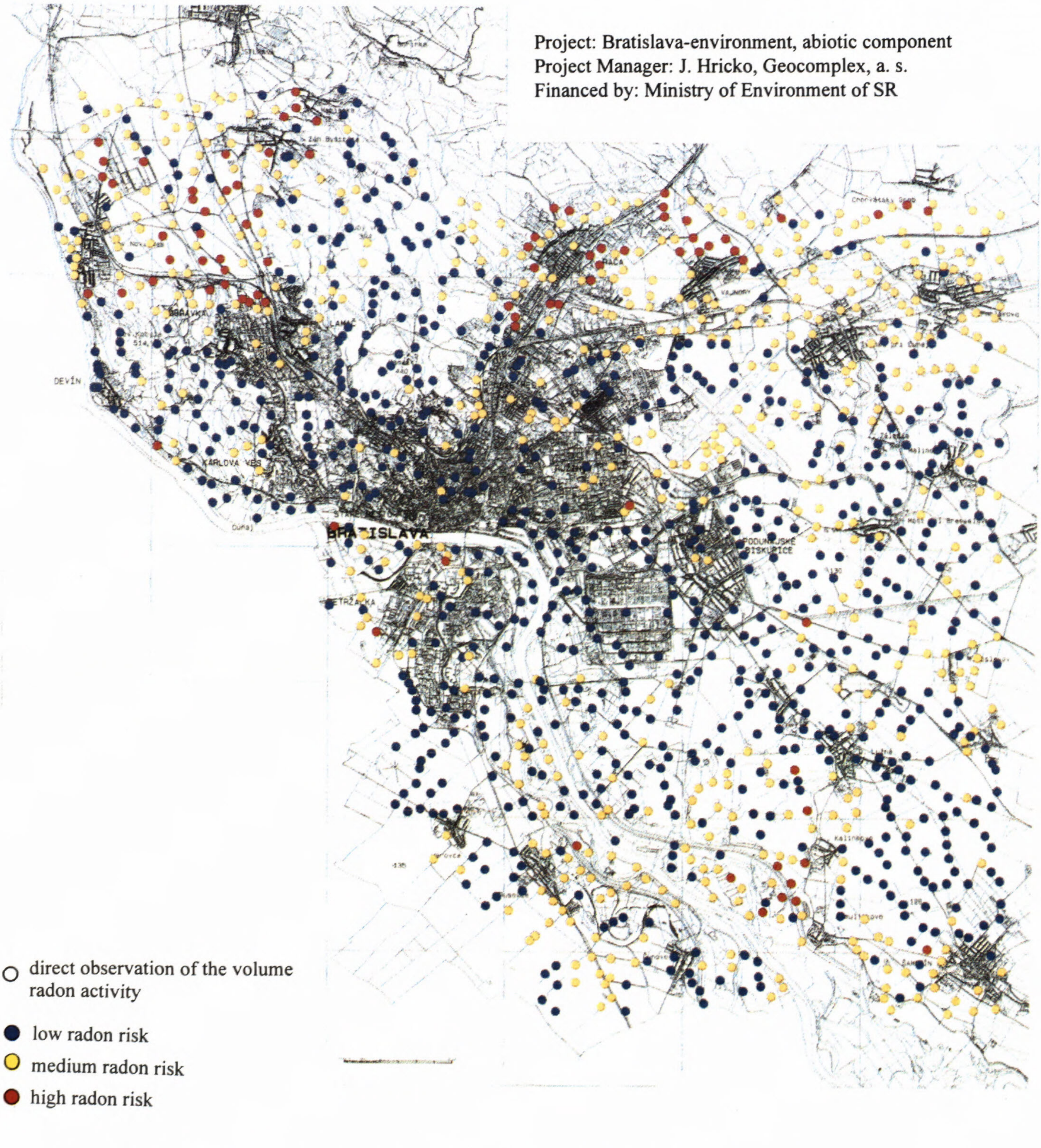

Fig. 1 Radon risk map of the Great Bratislava region (by ČÍŽEK, SMOLÁROVÁ 1992, HRICKO, 1993)

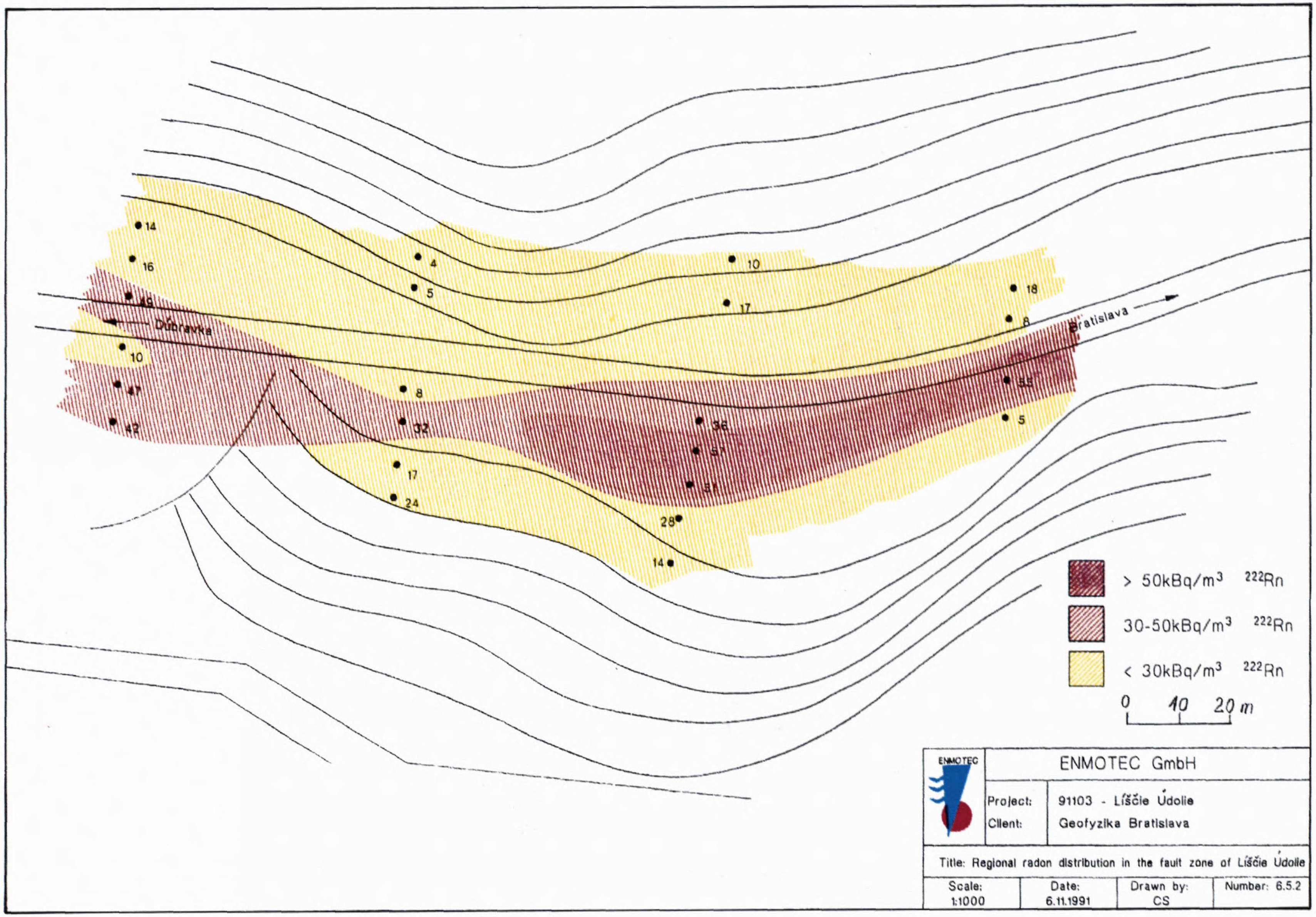

Fig. 2 Regional radon distribution in the fault zone of Líščie údolie valley (Bratislava-Karlova Ves)

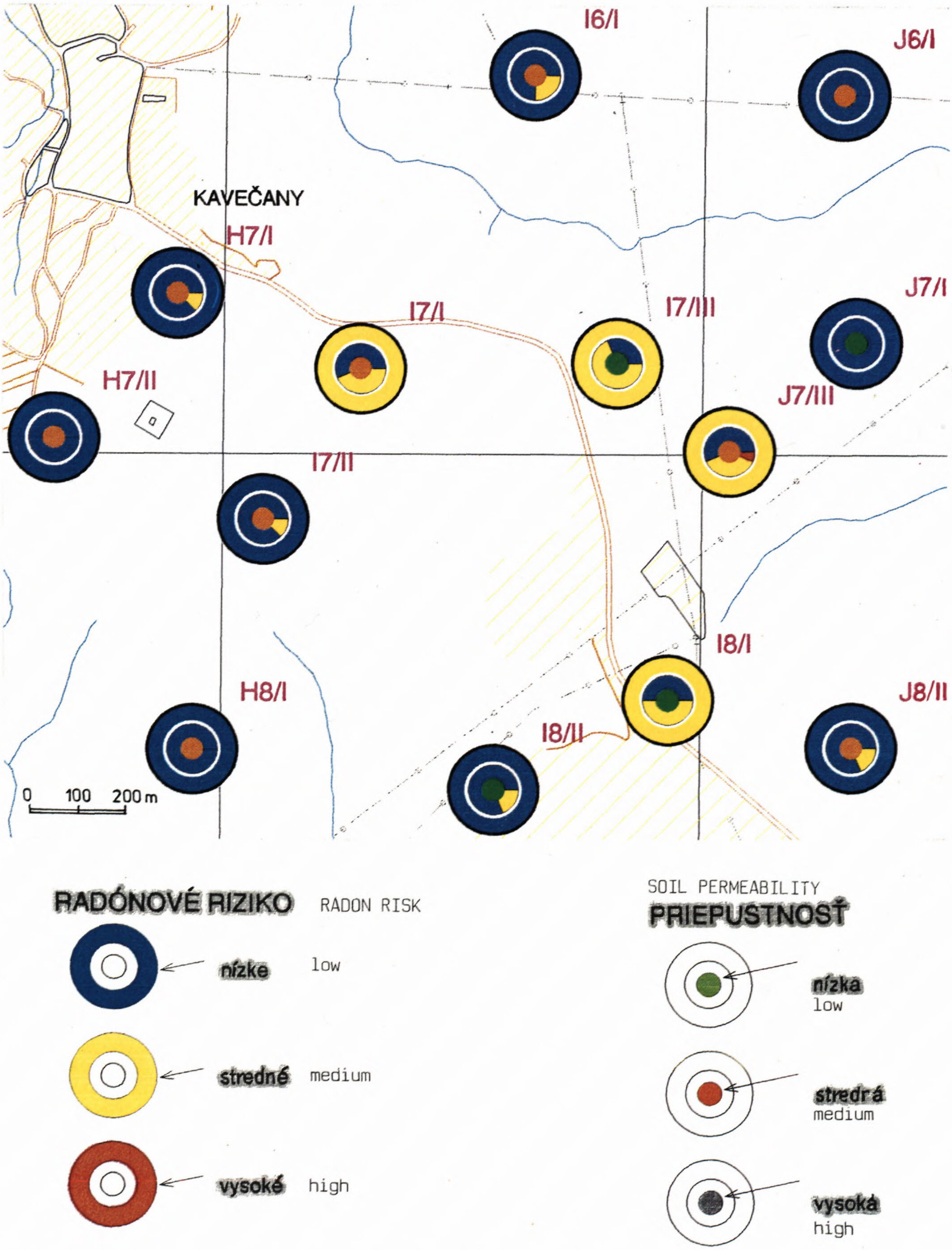

Fig. 3 Radon risk map from northern part of Košice region (by SUCHÝ, DANIEL, 1995)

values several times exceeding the Slovak limits (Marianka, Rača, Vajnory).

Evidence of neotectonic features being an excellent medium for radon emanation rising up to the subsurface layer is shown in Fig. 2. The tectonic zone of Líščie údolie valley in the Bratislava-Karlova Ves area has been clearly detected by the radon profile survey.

2. Košice region

At present, the northern half of the area in question has been covered by the radon survey. Low and medium radon risks have been observed here, while localities with a high radon risk are small in extent.

A part of the radon risk and soil permeability map from the northern Košice area is shown in Fig. 3.

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♦ ***Business activities:***

1. Current engineering geological projects
2. Co-operation with other institutions in business activities throughout Slovakia

♦ ***Realized projects:***

1. Compilation of various purpose engineering geological maps at scales ranging from 1:10 000 to 1:50 000 for instance:
   - slope deformation (landslides, block faults) at a scale 1:10 000 and entry of the data into database (Geofond Bratislava);
   - engineering geological maps (regional zoning and condition);
   - engineering geological maps of the environmental geofactors (e.g. map of regional zoning, relative tendency to landslides, important geologic factors etc.) at a scale 1:50 000;
   - waste disposal suitability maps;
   - engineering geological maps for planning and urban development.

♦♦♦

2. Investigation and registration of geodynamic phenomena, mainly slope deformations, predicting the slope failures, stability calculations, design and performance of remedial measures

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3. Monitoring of geological factors of the environment in Slovakia. The subjects of monitoring are:
   - Landslides and other slope deformations
   - Erosional processes
   - Weathering processes
   - Soil collapse
   - Impact of mining activity upon the environment
   - Changes in anthropogenic sediments (dumps and tailings)
   - Stability of rock massif underlying the historical objects
   - Covered anthropogenic sediments
   - Neotectonic activity
   - Seismic activity
   - Monitoring of snow cap quality

♦♦♦

4. Co-operation in setting up the methodologic regulations for construction of various types of engineering geological maps

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5. Study of physical an mechanical properties of rocks using modern devices and new methods.
Searching for natural building materials for earth dams, embankments, sealings of waste deposits etc.

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6. Engineering geological research for rational exploitation and protection of geological environment (anthropogenic deposits, suitability for waste disposal).

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7. Advisory activity in the field of environmental protection.

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8. Consulting and advisory activities for users of engineering geological maps with no geologic background.

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9. Evaluation of territories from the point of possible storing of all types of waste materials (radioactive, hazardous, municipal etc.).

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10. Laboratory tests of rocks and soils - physical and mechanical properties.