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Natural radioactivity of water in Slovakia

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Abstract. This paper summarizes the results of radiohydrochemical mapping of Slovakia carried out between 1991 and 1997. The results are processed on the basis of natural radionuclide U_{nat}, ^{226}Ra and ^{222}Rn contents in 5 818 samples collected mainly from natural and mineral springs, from thermal boreholes, wells and surface streams.

The paper also describes an assessment of natural radioactivity in groundwater from the main tectonic units of Slovakia, natural radioactivity in 243 samples of mineral and natural water, interrelations of individual water types in terms of radionuclide contents, most common types of radon-bearing waters and statistic indicators of the assessed radionuclides in waters of Slovakia.

Key words: Mapping of natural radioactivity, natural radionuclides U_{nat}, ^{226}Ra and ^{222}Rn groundwaters, mineral and thermal waters

Introduction

Natural radioactivity of waters is caused by the content of dissolved solid and gaseous natural radioactive substances. Major natural radionuclides in ground and surface waters comprise ^{40}K, ^{238}U, ^{234}U, ^{232}Th, ^{226}Ra and ^{222}Rn, all of which pass into waters from a rock environment. Of these radionuclides, those of the uranium decay series (a mixture of ^{238}U and ^{234}U referred, to as U_{nat}, ^{226}Ra and ^{222}Rn) are most abundant in water.

Mapping of natural radioactivity of Slovakia's waters was compiled from some studies completed in 1991–1997. The first of these studies was aimed at producing the reportant map „Radiohydrochemical sampling of Slovakia" at a scale of 1:200,000. Second study was part of the geological factors of the environment map of Slovakia compiled on regional geological maps at a scale of 1:50,000. This study also included the compilation of radiohydrochemical maps in the areas of the Upper Nitra river, Malá Fatra Mts. and surrounding basins, Nízke Tatry Mts., Starohorské vrchy Mts., Hornád river Basin and the Eastern Slovak Ore Mts., Košice Basin and Slanské vrchy, (1991-1993), the Jelšava-Lubeník-Hnúšťa region (1994-1997), Tatry Mts. and the Liptov Basin (1996-1997).

Methods of Sampling and Radiochemical Analyses

Throughout the Slovak Republic 5818 water samples were collected from springs, mineral springs, fresh, mineral and thermal waters from artesian wells, from wells, water sources, pumped wells, mine effluent, streams, lakes and tailing dumps.

The sampling density at the survey scale of 1:200,000 averaged sample per 10 km^2 and in some areas (Upper Nitra river, Malá Fatra Mts. and surrounding basins, Nízke Tatry Mts., Starohorské vrchy Mts., Hornád river Basin and the Eastern Slovak Ore Mts., Košice Basin and Slanské vrchy, Jelšava-Lubeník-Hnúšťa region, Tatry Mts., Liptov Basin), surveyed at scale 1:50,000, one sample per 5 km^2.

U_{nat} contents, as well as ^{226}Ra and ^{222}Rn volume activities, were determined in laboratories. U_{nat} contents were measured through colorimetric method on instrument whose sensitivity range was 0.002 – 0.40 $mg.l^{-1}$. ^{226}Ra volume activity was determined on the instrument having sensitivity range is 0.002 – 400 $Bq.l^{-1}$. The apparatus with lucastype scintillation chambers measured ^{222}Rn volume activity with sensitivity range is 0.05 – 10 000 $Bq.l^{-1}$.

Natural radioactivity of groundwaters in major geological units of Slovakia

Paleogene

Flysch Belt

Groundwaters in the Flysch Belt of northwestern Slovakia have relatively stable values of uranium concentrations, as well as radium and radon volume activities. Average values of uranium concentrations are typical of flysch facies (0.003 $mg.l^{-1}$). An increased number of samples with increased uranium contents were noted only in the Javorníky Mts. The values of radium volume activities are also low (arithmetic mean „x" - 0.033 – 0.039 $Bq.l^{-1}$, geometric mean „GM" – 0.018 – 0.024 $Bq.l^{-1}$). The lowest values were found in the Javorníky Mts. (mostly below 0.03 $Bq.l^{-1}$). The values of radon volume activities are increased only locally. Uranium concentrations in waters of the eastern Slovakia Flysch Belt (mostly 0.002 – 0.003 $mg.l^{-1}$) reflect the variation of lithological types of underlying rocks. Radium and radon volume activities are increased only in waters having a deeper circulation.

Inner Carpathian Paleogene

Ground waters with increased radium concentrations occur in the rocks of the Inner Carpathian Paleogene. In many springs, mainly in the Hornád basin, the concentration of Ra is higher than 0.1 $Bq.l^{-1}$. The source of radium is probably in the underlying mesozoic carbonate rocks. Hypoallogene radon (from 20 to 30 $Bq.l^{-1}$) occurs in the spring waters with deeper circulation. The average concentration of uranium varies from 0.002 $mg.l^{-1}$ (in the Huty formation, mainly claystones) to 0.004 $mg.l^{-1}$ (in the sandstone-dominated Biely Potok formation).

Core Mountains

Malé Karpaty Mts.

In the southwestern part of the mountain range, crystalline complex rocks prevail, which is reflected by the presence of waters with increased concentrations of radioactive elements, mainly radon. These are the waters, mainly of shallow circulation, connected to the weathering zone of granites and granodiorites, where exist good conditions for the formation of hypergene radon in the waters. Uranium concentrations are slightly increased, values of radium volume activity are fairly high (x 0.070 $Bq.l^{-1}$, GM 0.053 $Bq.l^{-1}$) and the values of volume activity of radon are high (x 33.31 $Bq.l^{-1}$, GM 17.00 $Bq.l^{-1}$). The water from the spring „Zbojnícka studňa" near Rača (volume activity ^{222}Rn 303.69 $Bq.l^{-1}$) and from the spring near Kuchyňa (volume activity ^{222}Rn 261.48 $Bq.l^{-1}$) are classified as low-radon water (Lučivjanský, 1996).

Považský Inovec Mts.

In the crystalline complex of the eastern part of the mountain range, waters with increased uranium and radon concentrations are present. These waters occur for instance near Podhradie (U_{nat} 0.195 $mg.l^{-1}$, ^{226}Ra 0.447 $Bq.l^{-1}$) and Duchonka (^{222}Ra 315.79 $Bq.l^{-1}$). Water with increased concentrations of radionuclides flows from the uranium exploration adit no. 60 in Kálnica. Its uranium concentration is 0.063 $mg.l^{-1}$, the volume activity ^{226}Ra is 0.464 $Bq.l^{-1}$, and the volume activity of radon is 61.11 $Bq.l^{-1}$.

Strážovske vrchy Mts.

Slightly increased values of uranium concentrations (0.004 – 0.008 $mg.l^{-1}$) are present in waters from the Middle to Upper Triassic dolomites of the Choč nappe in the southern part of Strážovske vrchy. These waters are also slightly enriched in radon, probably from the underlying crystalline complex. Higher concentrations of radon are present in waters of the crystalline complex, which is underlain by banded migmatites and migmatitized paragneisses in the Kanianka area (the maximum value of radon volume activity is 173.36 $Bq.l^{-1}$).

Tríbeč Mts.

In the southwestern (Zobor) part of the mountain range, where the granitoids prevail over Mesozoic complexes, occur waters with increased concentrations of uranium (more than 0.004 $mg.l^{-1}$) and radon (more than 30 $Bq.l^{-1}$). In the northeastern (Razdiel) part, where crystalline complex rocks (migmatites, paragneisses) and Mesozoic (envelope as well as nappe types) are present fairly equally, no waters had increased radioactivity values.

Malá Fatra Mts.

Waters from the weathered zone of crust crystalline complex commonly contain increased concentrations of uranium and radon. In the Lúčanská Malá Fatra Mts. these waters are connected to two-micas and biotite paragneisses and in the Krivánska Malá Fatra Mts. to biotite quartz diorites to granodiorites. The water from the spring near Turčianske Kľačany is classified as radioactive – low-uranium water (uranium concentration is 0.035 $mg.l^{-1}$). In waters from dolomites of the Choč nappe of the Lúčanska Malá Fatra Mts., slightly increased uranium concentrations are present (more than 0.004 $mg.l^{-1}$).

Veľká Fatra Mts.

Slightly increased values of uranium concentrations (x 0.0041 $mg.l^{-1}$, GM 0.0033 $mg.l^{-1}$) are present in waters from Middle Triassic dolomites of the Choč nappe. Some samples have an increased volume activity ^{226}Ra. These are the waters draining Lower Triassic and Cretaceous pelitic rocks in the northern part of the Veľká Fatra Mts.

Tatry Mts.

Waters from the crystalline units of the Západné Tatry and Vysoké Tatry are isolated occurrences of increased values uranium, radium and radon. They are controlled by altitude and consequently by the speed and length of groundwater circulation. The summit sectors of the highest mountain ranges of Tatry are without springs. In the southern mountain ranges are waters having slightly increased values of radionuclids, mainly radon. These are the waters from the weathering zone of acid igneous rocks.

Nízke Tatry Mts. (part Ďumbierske Tatry)

Increased uranium concentrations occur mainly in waters of Choč nappe dolomites (average value of uranium is 0.004 $mg.l^{-1}$). Moderately increased uranium concentrations are also present from the crystalline complex, such at waters from leucocratic granites south Partizánska Ľupča and of waters from migmatites in the Jasenie and Dolná Lehota regions (max. 0.026 $mg.l^{-1}$). Radium volume activity is increased only rarely.

In this region, waters with increased values of radon volume activity are present. These increased values can be divided into two groups:

– Waters connected to the weathering zone of leucocratic granites and migmatites of the crystalline complex in the surroundings of Brusno (293.45 $Bq.l^{-1}$ – low-radon water, Pohronský Bukovec 108.53 $Bq.l^{-1}$, Jasenie 159.78 $Bq.l^{-1}$)

– Deeply circulated waters associated with tectonic faults, e. g. near the Partizánska Lupča (increased volume activities of radium are also typical).

Veporic Zone

Increased uranium concentrations are found mainly in waters from Permian sediments in the Kozie chrbty Mts. (average uranium content 0.004 mg.l^{-1}). The increased contents in Permian sediments are associated with the occurrences of U minerals in sandstones, for example a spring south of the village Východná in Chmelinec Valley, which was explored for uranium, the water containing 0.027 mg.l^{-1}. Further examples of such waters come from the Vikartovce, Kravany and Primovce areas. These waters have increased radon volume activity, too.

The average values of radon volume activity in waters in the crystalline units of the Veporské vrchy Mts. and Stolické vrchy Mts. rank among the highest in Slovakia (x 57.47 and 56.82 Bq.l^{-1}, GM 29.94 and 30.11 Bq.l^{-1}). As much as 40 % of the waters show values above 50 Bq.l^{-1}. These are waters of shallow circulation in the weathered zone of crystalline rocks of the Kráľova hoľa and Kohút unit, notably biotite granodiorites to quartz diorites and light-coloured granites. Major occurrences of such waters are situated in the area between Detvianska Huta, Sihla and Klenovec and northwest of Revúca in the Kohút and Stolica areas.

Gemeric zone

The average uranium concentrations in waters of the Volovské vrchy Mts. Paleozoic are not substantially different from those in groundwaters. In some areas (near Švedlár, Nálepkovo, Henclová and Smolník), the values are 0.004 – 0.008 mg.l^{-1}. These scattered anomalies are bound to minor occurrences of uranium or uranium-bearing minerals.

The area underlain by Paleozoic rocks is characterized by highly variable values of radon's volume activity values in groundwaters (5 – 500 Bq.l^{-1}). Increased values occur in shallow-circulation waters associated with Silurian metarhyolite tuffs of the Gelnica Group (in waters near Henclová, Stará Voda, Smolnícka píla, Prakovce) and to the Gemeric granites (near Poproč and Rudník). These values often exceed 200 Bq.l^{-1} and therefore the waters fall into the category of slightly radon waters. The maximum value was measured in water from a spring near Dobšiná (518.86 Bq.l^{-1}).

The abandoned uranium deposit Novoveská Huta lies in the northern sector of the Volovské vrchy. Of the several mine-water discharges, only that from adit No. 2 displays increased values of radionuclids. Average monitored values are U_{nat} 0.185 mg.l^{-1}, ^{226}Ra 0.185 Bq.l^{-1} and ^{222}Rn 205.00 Bq.l^{-1}. Slightly increased radon volume activities were noted in waters from the vicinity of uranium occurrences at Pelc near Dobšiná and at Jahodná near Košice.

Groundwaters in Mesozoic complexes of the Slovenský raj Mts., Slovak Karst Mts. and Galmus Mts. display increased values of radium volume activity. These waters are largely associated with to Lower Triassic shales interlayered with evaporites. Uranium concentrations are low. Radon volume activity is locally increased through emanations of hypoallogenic radon from the Paleozoic substratum.

Intramontane Basins

Danube Basin (Danube Lowland and Podunajská pahorkatina Upland)

Natural radioactivity of groundwaters in the Danube Lowland and that in the Podunajská pahorkatina Upland are almost identical, except for the radon volume activity. The average uranium concentration (0.0053 mg.l^{-1}) is among the highest in Slovakia. These concentrations are associated mostly with waters whose T.D.S. (Total Disolved Solids) is 750 – 1,000 mg.l^{-1} (Rapant et al., 1997). This agrees with Lisicin's (1975) data that waters with such T. D. S. in arid areas most intensively dissolve uranium from rocks. Radium volume activity is increased only in western sector (between Dunajská Streda and Bratislava) which, like the Záhorie Basin, is rich in waters whose T.D.S. is 500 – 750 mg.l^{-1}. More strongly mineralized waters mostly have a radium volume activity range from 6.55 Bq.l^{-1} in the Danube Lowland to 11.73 Bq.l^{-1} in the Podunajská pahorkatina Upland. Greatest activities in the Podunajská pahorkatina probably result from the presence of thickness of Tertiary sediments.

Southern Slovakia Basin

This region is characterized by increased uranium concentrations, notably in areas underlain by Neogene sediments (average 0.004 – 0.005 mg.l^{-1}). Concentrations between 0.002 – 0.003 mg.l^{-1} are typical of volcanoclastic rocks. Waters in the volcanic complexes of the Cerová vrchovina upland display slightly increased radon volume activities (x 28.38 Bq.l^{-1}, GM 22.72 Bq.l^{-1}).

Eastern Slovakia Basin (Košice Basin, Eastern Slovakia Lowland)

In the Košice Basin, uranium concentrations and radium volume activity do not exceed average values of Slovakia's groundwaters. Slightly increased values have been noted only in wells in Quaternary sediments in the vicinity of the Hornád River. These higher values, such as those at Haniska and Seňa, are presumably caused by fragments of Gemeric rocks of Paleozoic age in poorly consolidated Quaternary sediments. In places, increased values of radon volume activity (up to 50 Bq.l^{-1}) are associated with N or NE-trending tectonic lines.

Unlike waters in the Danube Lowland, those in Neogene sediments of the Eastern Slovakia Lowland are devoid of increased uranium concentrations (average U_{nat} content is 0.003 mg.l^{-1}). The latter have a T. D. S. above 1 000 mg.l^{-1} and therefore their ability to dissolve uranium from rocks is reduced (Lisicin, l. c.).

***Neovolcanic rocks** (Central Slovakia Neovolcanic Rocks, Slanské Vrchy Mts. and Vihorlatské vrchy Mts.)*

The groundwater radioactivity in neovolcanic mountain ranges is extremely low. Uranium concentrations in

groundwaters from the neovolcanic rocks are typical for the shallow groundwater circulation in disturbed upper parts of the volcanic rocks. Radium volume activity of waters in the Central Slovakia Neovolcanic Rocks differs from that in the Slanské vrchy Mts. and Vihorlatské vrchy Mts. neovolcanic rocks. Waters in acid rock varieties of the Central Slovakia Neovolcanic Rocks have very low radium values (x 0.031 Bq.l^{-1}, GM 0.017 Bq.l^{-1}) in comparison with more mafic neovolcanic rocks in the Slanské vrchy Mts. (x 0.052 Bq.l^{-1}, GM 0.049 Bq.l^{-1}) and Vihorlatské vrchy Mts. (x 0.047 Bq.l^{-1}, GM 0.039 Bq.l^{-1}). Radon volume activity is highest in the Central Slovakia Neovolcanic Rocks (x 15.32 Bq.l^{-1}, GM 9.10 Bq.l^{-1}) and lowest in the Slanské vrchy Mts. neovolcanic rocks (x 6.40 Bq.l^{-1}, GM 3.40 Bq.l^{-1}). The radon here is of hypallogenic origin associated with faults and hyperallogenic origin from upper parts of weathering crusts.

Radioactivity of Slovakia's Mineral and Thermal Waters

In comparison with fresh waters, cold mineral waters are enriched in some radionuclides, notably radium and radon. Radium volume activity of some thermal waters is 100 x high than that of fresh waters. These mineral and thermal waters fall into the category of low-radium or low-radon waters.

On the basis of natural radioactivity of 243 of Slovakia's sampled mineral water occurrences, they are divided into several types:

– mineral waters bound to Triassic carbonates, mostly in the Krížna and Choč nappes

Uranium concentrations in these waters are low, averaging 0.003 mg.l^{-1}. Radium volume activity usually is 0.2 to 0.9 Bq.l^{-1}. Such mineral water occurs at such as Bešeňová, Sivá Brada near Spišské Podhradie, Sobrance and Oravice. Many of them (e.g. the springs „Sv. Ondrej" and „Sv. Kríža" at Sivá Brada, and the spring „Očný prameň" at Sobrance) are classified as low-radium waters. Radon volume activities largely are 20 – 50 Bq.l^{-1}, but in some waters they are much higher. For example the spring „Sv. Ondrej" at Sivá Brada yields 170.5 Bq.l^{-1}. Vicinity of these springs is commonly covered with travertine. The highest radon volume activity occurs in water from spring „Uhličitý" at Oravice – 1,293.2 Bq.l^{-1}.

– mineral waters of the crystalline unit

These are mostly cold acidic water, with increased values of uranium and radium, but mainly of radon. The increased contents result from aggressive CO_2 affecting crystalline rocks and from the hypallochtonous origin of the radon. Such waters include those of the Nízke Tatry Mts. crystalline unit (near Bacúch, in Jasenie and near Braväcovo) and Veporské vrchy (springs near Čierny Balog, e.g. water from mineral spring „Zuzka" has a ^{222}Rn volume activity as much as 817.89 Bq.l^{-1}) and others. The group partly comprises also the mineral waters of the Tatry Mts. crystalline unit associated with the Subtatric fault (e.g. at Starý Smokovec). The mineral waters of the crystalline units have uranium contents of 0.005 – 0.015 mg.l^{-1}, ^{226}Ra volume activity mostly 0.1 – 0.5 Bq.l^{-1} and ^{222}Rn volume activity commonly greater than 200 Bq.l^{-1}, and consequently are classified as radon waters.

– mineral waters of the Flysch belt

These are sodium-bicarbonate waters with hydrogensulphide or acidulous water. The waters are linked to tectonic lines in all partial-flysch units. They are characterized by slightly increased uranium concentrations (0.004 – 0.005 mg.l^{-1}), average ^{226}Ra volume activity (0.02 – 0.08 Bq.l^{-1}, only rarely above 0.1 Bq.l^{-1}). The ^{222}Rn volume activity is 10 – 20 Bq.l^{-1}, and only in waters enriched in CO_2 is above 20 Bq.l^{-1}.

– mineral waters of the neovolcanic rocks

The are characterized mostly by low uranium (average 0.002 mg.l^{-1}) and radium contents (as much as 0.05 Bq.l^{-1}) and mildly increased ^{222}Rn volume activity (20-40 Bq.l^{-1}).

Slovakia's thermal waters are divided into two groups reflecting their associated rocks:

– thermal waters of pre-Tertiary units

Are characterized by a high ^{226}Ra volume activity. They comprise waters at Bešeňová – well ZGL-1 (^{226}Ra volume activity 9.7 Bq.l^{-1}), Piešťany (3.068 Bq.l^{-1}), Oravice – well OZ-2 (3.209 Bq.l^{-1}), Lúčka near Spišské Podhradie – well BŠ-1 (2.503 Bq.l^{-1}), Poprad - well PP-1 (1.733 Bq.l^{-1}), Kováčová – well K-1 (0.998 Bq.l^{-1}), Lúčky – well BJ-101 (0.985 Bq.l^{-1}), Trenčianske Teplice – well SBP-5 (0.784 Bq.l^{-1}) and elsewhere. These waters have temperatures between 30 and 60 °C, and Ca-Mg-Na-SO_4-HCO_3 (well OZ-1), Ca-Mg-HCO_3 (wells PP-1, BŠ-1), Ca-Mg-SO_4-HCO_3 (well BJ-101) chemistries. The waters are associated primarily with Triassic rocks of the Krížna and Choč nappes. Waters of the Choč nappe in Poprad and Lučka are enriched in uranium (e. g. in well BŠ-1 as much as 0.111 mg.l^{-1}).

– thermal waters of Tertiary units

These characterized by a low ^{226}Ra volume activity (as much as 0.1 Bq.l^{-1}). The group includes thermal waters from wells at Dunajský Klátov, Vlčany, Tvrdošovce, Sládkovičovo, Diakovce, Nové Zámky and Topoľníky.

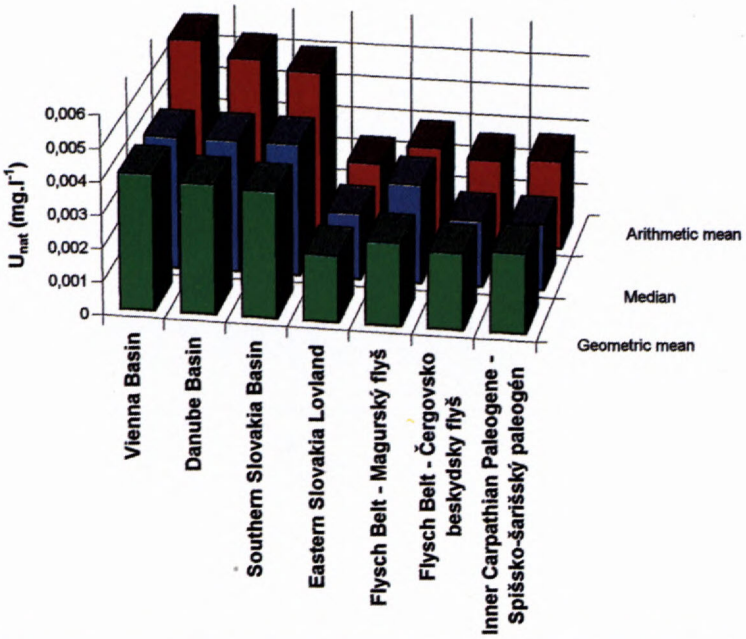
Conclusion

Uranium - U_{nat}

Uranium concentrations in groundwaters are increased in waters flowing from uranium mine workings (Novoveská Huta, Kálnica), in springs close to uranium occurrences, such as those near Vychodná and in some thermal waters (Oravice, Lúčka near Spišské Podhradie).

A locally increased uranium concentration also occur in waters of some core mountains composed of crystalline units, such as the Považský Inovec Mts., Malá Fatra Mts., Tríbeč Mts., and in waters of Choč nappe dolomites, e.g. in the Nízke Tatry Mts.

The largest area of slightly increased uranium content (averaging as much as 0.005 mg.l^{-1}) is in found the waters of the Danube Basin, Southern Slovakia Basin and



	Vienna Basin	Danube Basin	Southern Slovakia Basin	Eastern Slovakia Lovland	Flysch Belt - Magurský flyš	Flysch Belt - Čergovsko beskydsky flyš	Inner Carpathian Paleogene - Spišsko-šarišský paleogén
Geometric mean	0,0041	0,0039	0,0038	0,002	0,0025	0,0023	0,0024
Median	0,004	0,004	0,004	0,002	0,003	0,002	0,002
Arithmetic mean	0,0058	0,0053	0,005	0,0023	0,0029	0,0026	0,0027

Fig. 1 Concentration U_{nat} in groundwaters Tertiary and Quaternary sediments

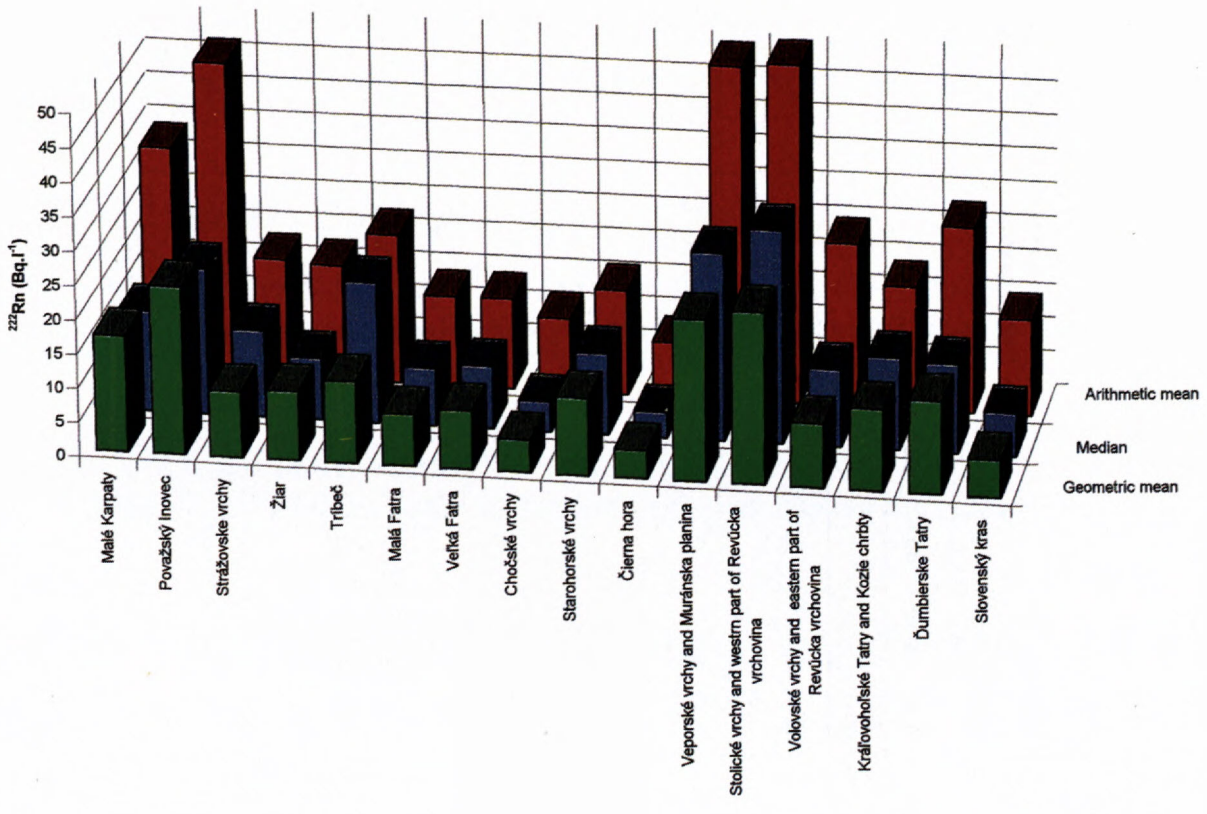


Fig. 2 Volume activity ^{222}Rn in groundwaters selected pre-Tertiary units

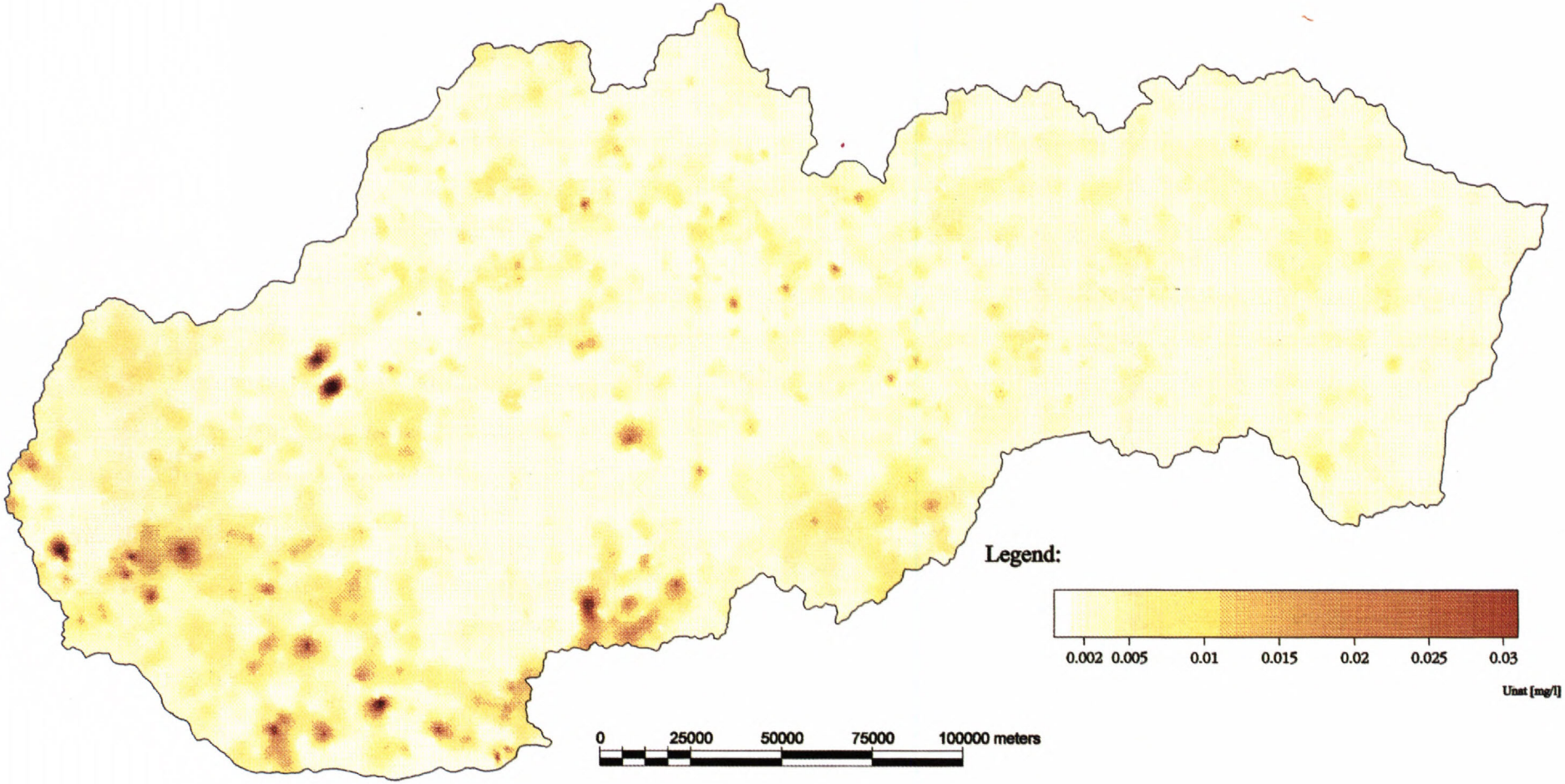


Fig.3 Map of Uranium Concentration (Unat) in Groundwaters

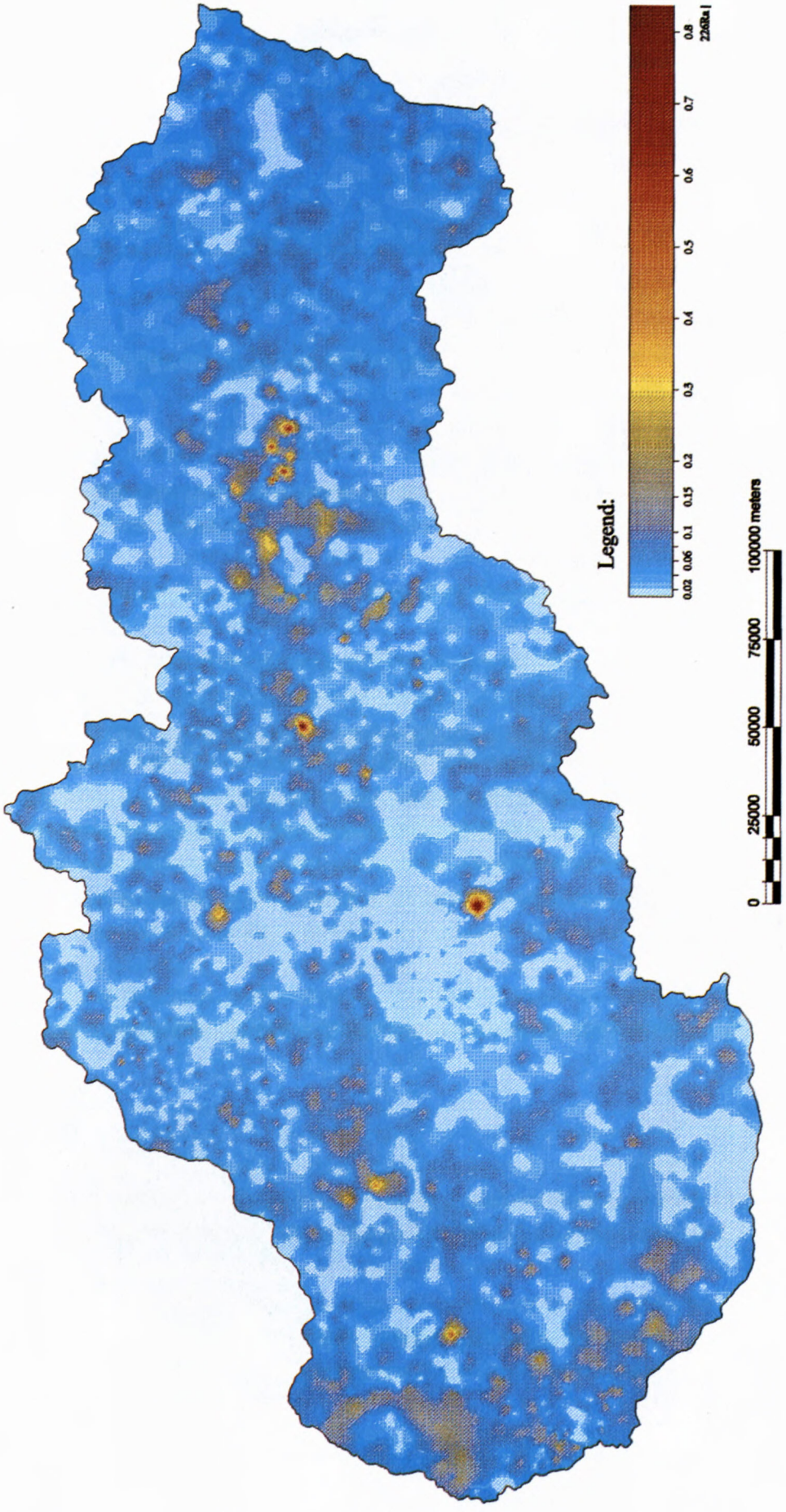


Fig.4 Map of Volume Activity of Radium (226Ra) in Groundwaters

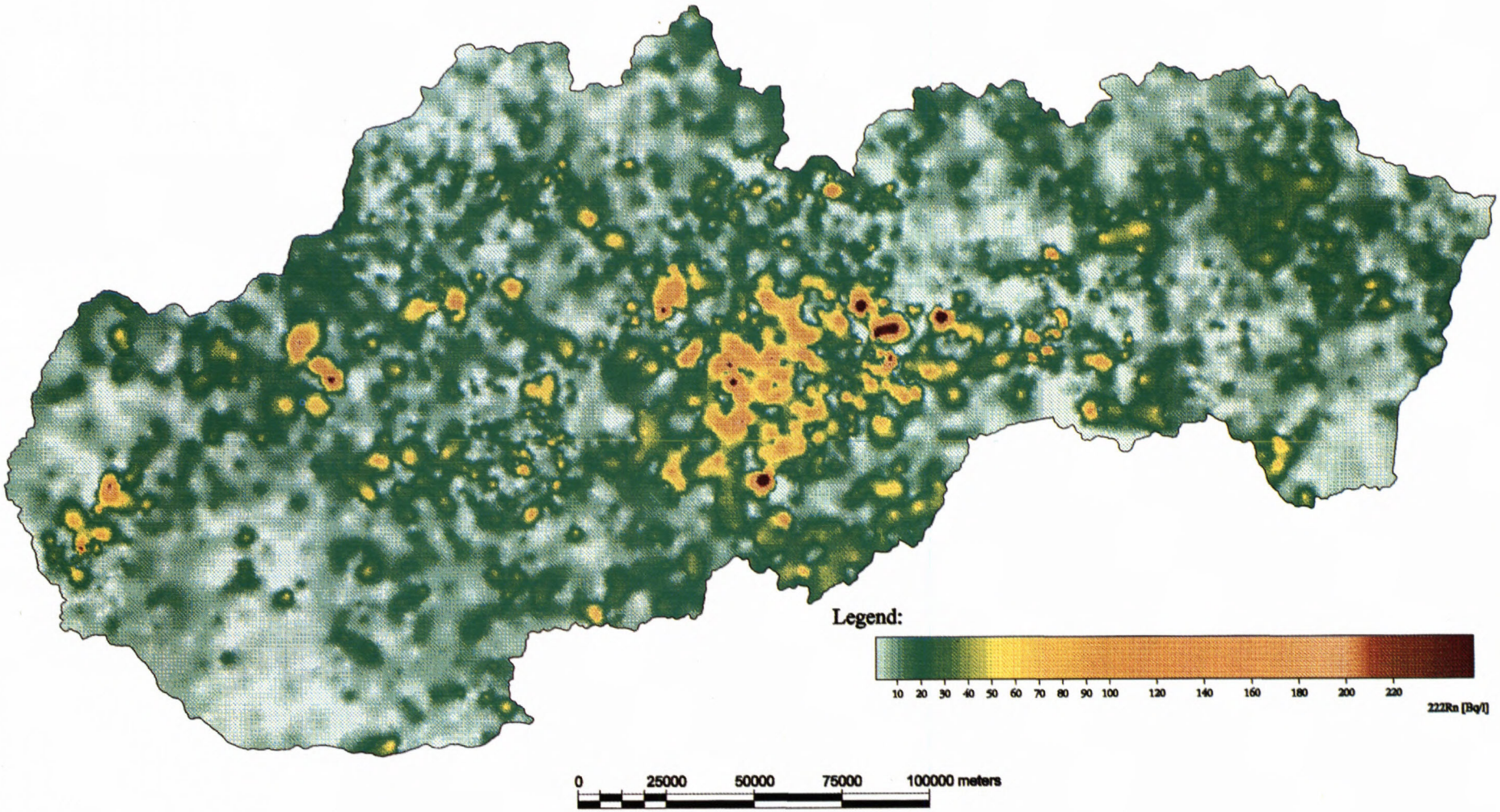


Fig.5 Map of Volume Activity of Radon (222Rn) in Groundwaters

Vienna Basin (Fig. 1, 3). In flysch areas, waters from sandstone formations (average uranium content 0.003 $mg.l^{-1}$) are a little different from those in claystone and claystone-sandstone formations (average uranium content 0.002 $mg.l^{-1}$). Waters in neovolcanic rocks typically have low uranium concentrations (0.002 $mg.l^{-1}$).

Radium – ^{226}Ra

The radium volume activity values are more widely dispersed than are the uranium concentrations (from less than 0.001 to 9.7 $Bq.l^{-1}$). The highest values are typical of mineral and thermal waters. Increased values also have been noted in fresh waters of the Záhorie Lowland and western part Danube Lowland, and in some core mountains (Malé Karpaty Mts., Považský Inovec Mts.), eastern sector of Nízke Tatry Mts., Hornád Basin, Poprad Basin, Galmus Mts. and western part Volovské vrchy Mts. (Fig. 4). From pre-Tertiary units, these waters are mostly associated with to Lower Triassic (Werfenian) rocks with gypsum and baryte occurrences. In Paleogene rocks, radium volume activity increases with the depth of groundwater circulation. Radium values in waters of the Central Slovakia Neovolcanics Rocks are half as large as those from the neovolcanic rocks of the Slanské vrchy Mts. and Vihorlat Mts., except for areas composed mostly of volcanic-sedimentary rocks, e.g. the Krupinská planina Plain.

Radon – ^{222}Rn

Radon volume activity values are from less than 0.05 – 1,293.20 $Bq.l^{-1}$. Radon occurrences in water depend on the presence of uranium minerals in rock, tectonic setting, mineralization and water temperature. The highest values of radon in groundwaters are from crystalline units of the Tatricum and Veporicum (Fig. 2, 5), also in some waters from acid neovolcanic rocks, in waters from the volcanic-sedimentary rocks of the Cerová vrchovina Upland, Zemplínske vrchy Mts.. The lowest values are from waters from sedimentary rocks of the Danube Basin, Southern Slovakia Basin, Vienna Basin, Eastern Slovakia Basin, and from waters of the Slovenský raj Mts., Slovak Karst Mts., northwestern part Flysch Belt (Magurský flyš) and the inner carpathian Paleogene rocks in the Levočské vrchy Mts..

Several kinds of radon waters are distinguished, according to Lange's (1969) classification:

1. Waters with increased to high radon volume activity occur from crystalline parts of core mountains (composed mostly of acid granitoids and migmatites). These waters are most common ***radon water of weathered zone of igneous rocks*** formed in the upper parts of fractured zones. Such waters are found in nearly all core mountains, notably the Malé Karpaty Mts., Považský Inovec Mts., Tríbeč Mts., Malá Fatra Mts. and Nízke Tatry Mts.. They are most widespread in the crystalline units of Veporské and Stolické vrchy Mts. Waters from some acid rocks in the Central Slovakia Neovolcanic Rocks and the Cerová vrchovina Upland are also included in this category.

2. The second type is made up of ***radon waters with increased radium values associated with clayey-travertine sediments***. This type comprises mineral waters at Sivá Brada and Bešeňová.

3. The third type consists of ***radon waters from along deep tectonic faults*** of high discharge and increased temperature. Such waters include the mineral spring „Uhličitý" at Oravice. This spring has the highest radon volume activity in Slovakia – 1,293.2 $Bq.l^{-1}$.

4. Fairly widely distributed types of radon waters are ***radon waters on tectonic faults***. These waters are mineralized to various degrees and they ascend from various depths along the faults. Many of them are enriched in radium and satured with CO_2. Radon here originated at depth or from radium precipitated on the walls of faults. These waters are found near the Subtatric faults, on tectonic lines in the Hornád Basin and Košice Basin and, to a lesser extent, also in the neovolcanics rocks and other intramontane depressions.

5. ***Radon waters of uranium deposits*** draining uranium deposits and present in springs near uranium occurrences. These waters are also characterized also by increased uranium concentrations and radium volume activity. Waters discharged from abandoned uranium deposits at Novoveská Huta and Kálnica best exemplify the type.

In following Tables 1 and 2 show statistical values of concentration U_{nat}, volume activities ^{226}Ra and ^{222}Rn.

Table 1 Statistical values of concentration U_{nat}, volume activities ^{226}Ra and ^{222}Rn in Slovakia's groundwaters (evaluated from 5299 samples)

	Concentration U_{nat} ($mg.l^{-1}$)	Volume activity ^{226}Ra ($Bq.l^{-1}$)	Volume activity ^{222}Ra ($Bq.l^{-1}$)
Arithmetic mean (x)	0.0034	0.048	15.51
Geometric mean (GM)	0.0027	0.035	9.61
Median	0.003	0.039	9.75

Table 2 Statistical values of concentration U_{nat}, volume activities ^{226}Ra and ^{222}Rn in Slovakia's mineral waters (evaluated from 243 samples)

	Concentration U_{nat} ($mg.l^{-1}$)	Volume activity ^{226}Ra ($Bq.l^{-1}$)	Volume activity ^{222}Ra ($Bq.l^{-1}$)
Arithmetic mean (x)	0.0045	0.196	29.13
Geometric mean (GM)	0.0027	0.063	9.89
Median	0.003	0.060	10.27

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