GEOLOGICA CARPATHICA, 51, 6, BRATISLAVA, DECEMBER 2000
407–412

GEOLOGICAL CONDITIONS AND ROCK RADIOACTIVITY IN THE SPELEOTHERAPY MEDICAL FACILITY IN THE ZLATÉ HORY ORE DISTRICT (THE CZECH REPUBLIC)

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(Manuscript received February 25, 2000; accepted in revised form October 17, 2000)

Abstract: An abandoned mine located in the Zlaté Hory ore district is now used for speleotherapy. A detailed petrographical study along with extensive gamma-ray spectrometry measuring concentrations of naturally occurring radioactive elements (K, U and Th) was conducted in the mine in order to analyze the interrelationship between modal composition and radioactivity of the rocks. Authors warn of a potentially higher concentrations of ^{222}Rn in the subsurface atmosphere of the speleotherapeutic medical facility.

Key words: Zlaté Hory ore district, speleotherapy, petrography, natural radioactive elements.

Introduction

The children's speleotherapy medical facility in Zlaté Hory is located in one of the abandoned mines of the Zlaté Hory ore district. It is the Czech Republic's only speleotherapy medical facility apart from those situated in natural karst caves shaped in carbonate rocks or adits excavated in such rocks. Whereas carbonate rocks generally register low radioactivity (e.g. Solecki 1997), non-carbonate rocks in abandoned mines may contain an increased amount of naturally occurring radioactive elements. In these cases, their increased radioactivity represents a potentially significant health risk both to the staff and to the patients, which inevitably reduces time spent in the mine. Due to this possible health hazard, Zlaté Hory's medical facility was evaluated for potentially harmful levels of radioactivity.

Short characteristics of the Zlaté Hory ore district

The Zlaté Hory ore district is situated in the northern part of the Jeseníky Mts., close to the Czech-Polish border. From the geological point of view, the ore district is situated in the NE part of the Bohemian Massif, within the Vrbno Group — a volcanic-sedimentary formation of Devonian age that was epizonally to mesozonally metamorphosed during the Variscan orogeny (e.g. Souček 1978). Individual orebodies of the Zlaté Hory ore district are situated predominantly in quartzites and/or quartz keratophyres (paleorhyolites and their tuffs) or near the contact of such rocks with underlying or overlying pelitic schists. The ore minerals (mainly pyrite, chalcopyrite, sphalerite, galena and pyrrhotite) form either parallel streaks and bands within stratiform orebodies, generally parallel with schistosity of the host-rock, or form disseminated to locally massive accumulations. The ore which is composed mainly of chalcopyrite and pyrrhotite has been partially remobilized from stratiform layers to form veiny orebodies. In the western part of the Zlaté Hory ore district the sulphide ore contains a considerably high concentration of gold.

Apart from panning for gold in the alluvial deposits as well as mining of gold of hydrothermal and also cementary origin since the 13th century (lumps of gold weighing up to 1.7 kg were found in placers north of the primary deposits in the 16th century), sulphides were also occasionally dug in the 19th century.

From 1965 till 1993, the ores were intensively mined at the deposits of Zlaté Hory-South (Cu-ores), Zlaté Hory-Kozlín (Cu-ores), Zlaté Hory-Hornické skály (Cu-ores), Zlaté Hory-East (Pb, Zn-ores) and Zlaté Hory-West (Zn, Au-ores).

More details on the geology, petrography, ores and mining history of the Zlaté Hory ore district can be found in papers by Bernard (1991), Constantinides & Pertold (1974), Čabla et al. (1979), Fediuk et al. (1974), Fišera & Souček (1974), Kalenda & Grygar (1993), Patočka (1987a), Patočka & Vrba (1989). The natural conditions of the Zlaté Hory speleotherapy medical institution were described by Sas et al. (1998), Štelcl & Zimák (1998), Zimák & Štelcl (1999).

Though the Zlaté Hory ore district has been studied thoroughly with respect to its economic importance, only a little data on Th and U concentrations in the local rocks is available. From 69 samples of the Zlaté Hory pelitic schists (muscovite, biotite and quartzose schists) taken from a single deep borehole, the average contents of Th and U were 7.2 ppm and 1.7 ppm respectively (see Patočka 1987b, 1988). In the aforesaid papers the concentrations of both elements were determined by INAA located in the Central Laboratories of the Czechoslovak Uranium Industry in Stráž pod Ralskem.

Petrography and rock radioactivity of the speleotherapy institution

The Zlaté Hory speleotherapy medical facility is situated in an adapted part of the 2nd level of the Zlaté Hory-South ore deposit, which is accessible through an adit 700 m long. The speleotherapy medical facility is divided into eight sectors marked with Roman letters from A to H (see Fig. 1a, only the terminal part of the entrance adit is figured) as follows: A = active part (reserved for active physical training of patients); B = classroom and nurses' quarters; C = bedroom ward; D, E, F and G = corridors; H = entrance adit. The patients enter the speleotherapy institution through the entrance adit (sector H) and then move around the sectors A, B, C, E and F. (Patients are billeted in sectors A, B and C.)

Two major rock groups can be discerned within the speleotherapy facility: (1) quartzites (so-called "massive quartzites"), in places passing gradually into muscovite quartzites and chlorite quartzites, (2) chlorite-muscovite schists and muscovite schists (often quartzose or rich in carbonate), that appear below and above the quartzite horizon on the 2nd level of the Zlaté Hory-South ore deposit (see Fig. 1b).

The light-grey coloured quartzites have microscopically indistinct foliation planes. The quartzites have granoblastic texture; only locally those parts with a higher proportion of sheet silicates pass gradually into lepidogranoblastic texture. The sheet silicates comprise mainly muscovite, in places together with chlorite (see Table 1). Acid plagioclase and barium feldspar (celsian?) are present in accessory proportion. Typical accessory minerals include rutile and leucoxene (which, in some cases evidently originated from ilmenite alteration). Zircon is scarce. Opaque constituents comprise sulphides (mainly pyrrhotite and pyrite) and rarely also ilmenite.

Most often the schists are grey to green-grey, dark-grey to almost black in colour. The schists have a distinct planar-parallel fabric. Locally, especially the dark-grey to black (graphitic) schists are highly disaggregated (which was the reason for lagging of large sections of the entrance adit).

The schists have lepidogranoblastic or lepidoblastic texture. They are distinctly banded: light coloured bands with predominance of quartz alternate with darker bands with a considerable proportion of sheet silicates comprising especially muscovite and in some parts also chlorite which may infrequently predominate over the muscovite (see Table 1). Carbonate is present in variable proportions in the schists, causing the schists to pass gradually into marbles rich in noncarbonate minerals (sample 307). The schists contain small amount of acid plagioclase (probably albite). Rutile is present in particular in the muscovite-rich bands. Opaque constituents comprise mainly pyrite and pyrrhotite. Graphitic substance has been found in some samples. Whereas in samples 210 and 212 the percentage of graphitic substance varies between 1 and 3, it reaches an anomalous value in sample 232 (up to about 10 vol. %). With increasing percentage of quartz the schists pass into quartzose schists and in places even to quartzites that create up to several dm thick layers within the schists.

Concentrations of natural radioactive elements (potassium, uranium and thorium) were measured in the subsurface of the

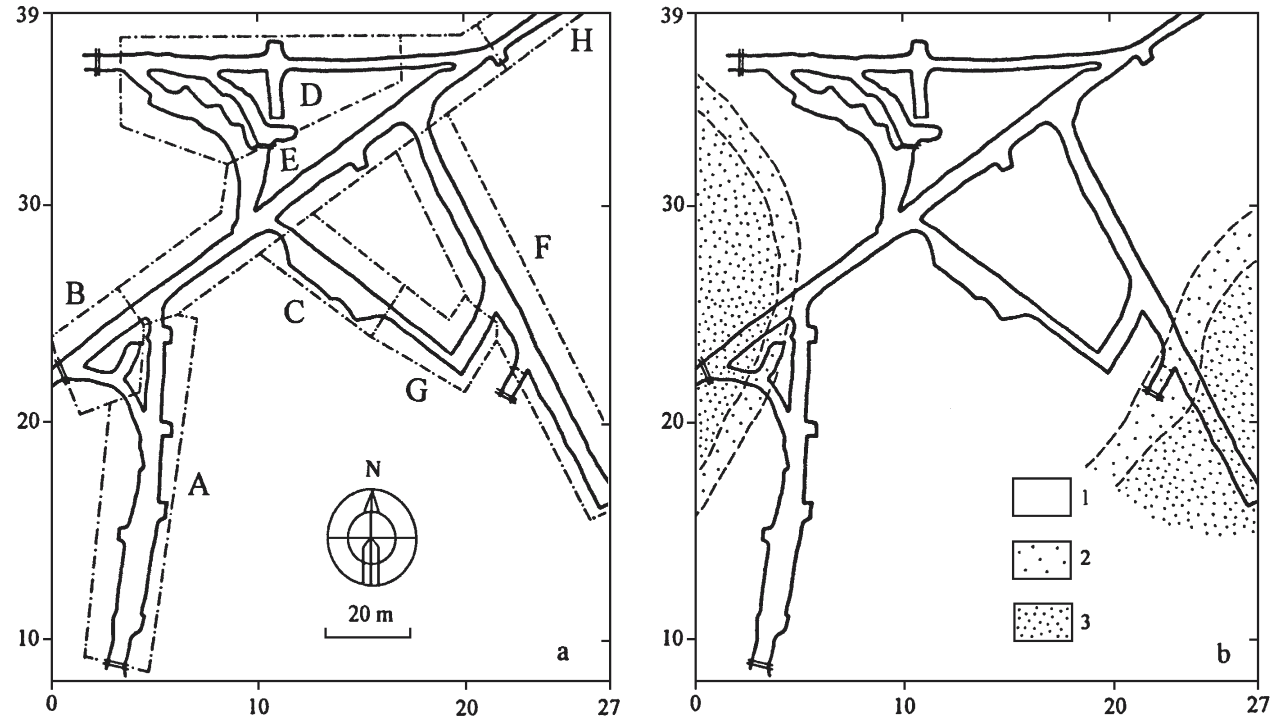


Fig. 1. a — Ground plan of the speleotherapy medical institution. **b** — Schematic geological map of the 2nd level of the Zlaté Hory-South ore deposit including the area of the speleotherapy medical institution (after Janák & Augusta 1969 and Janák 1970). **1** — quartzites with very small contents of muscovite and/or chlorite ("massive quartzites"), **2** — quartzites rich in muscovite and/or chlorite, **3** — chlorite-muscovite schists and muscovite schists (mainly quartzose).

Table 1: Modal compositions of rocks (in vol. %) in the sectors B (Samples Nos. 78, 82, 83, 302, 303 and 307) and H (Samples Nos. 201, 204, 210, 212, 232, 238, 254, 257 and 261) 78, 302, 254 and 257 — quartzites; 261 — muscovite quartzite; 303 — muscovite schist; 82, 201 and 210 — carbonate-muscovite schists; 83 — quartzose muscovite schist; 232 — graphite-muscovite schist; 212 — graphite-carbonate-muscovite quartzose schist; 204 — carbonate-chlorite-muscovite schist; 238 — muscovite-chlorite schist; 307 — marble rich in quartz and muscovite.

Sample No.	78	302	254	257	261	303	82	201	210	83	232	212	204	238	307
Quartz	86.75	77.60	84.35	94.15	85.40	25.65	27.00	37.75	45.10	55.40	15.35	56.60	23.80	44.60	37.50
Muscovite	1.60	2.65	5.20	5.25	13.20	56.45	36.60	17.95	26.25	31.60	72.15	13.60	45.70	17.05	6.40
Chlorite	6.65	-	0.50	-	-	2.80	-	1.00	-	8.20	2.95	-	11.45	30.20	-
Carbonate	0.05	1.75	0.15	-	-	0.25	28.20	41.05	25.05	2.05	0.50	9.05	13.10	0.15	55.65
Acid plg.	-	-	-	-	0.20	-	-	1.15	-	-	-	-	-	-	-
Ba-feldspar	-	-	0.30	-	-	-	-	-	-	-	-	-	-	-	-
Opaque	4.60	18.00	8.75	0.45	0.85	14.10	6.25	0.45	3.35	1.40	7.35	17.05	2.85	5.60	0.40
Rutile	0.35	-	0.75	0.15	0.35	0.75	1.95	0.65	0.25	1.35	1.70	0.05	3.10	2.40	0.05
Limonite	-	-	-	-	-	-	-	-	-	-	-	3.65	-	-	-

speleotherapy medical facility proper and in the entrance adit. A field gamma-ray spectrometer GS-256 manufactured by Geofyzika Brno, Czech Republic was used. Measurements totalling 264 points are summarized in Table 2.

Since various natural elements contribute in various proportions to the total gamma-ray activity of rocks (besides the sum of their concentrations a mutual ratio of particular concentrations is of essential importance, too) the K, U and Th concentrations were converted to mass activity of ^{226}Ra equivalent (a_m) in order to present the gamma-ray activity of the locality in question — see Table 2 and Fig. 2. Conversion coefficients commensurate with the UNSCEAR recommendation from 1996 were used to calculate the a_m value (the radium equivalent mass activity):

1 % K in rock = 313.00 Bq . kg^{-1} ^{40}K
1 ppm U in rock = 12.35 Bq . kg^{-1} ^{226}Ra
1 ppm Th in rock = 4.06 Bq . kg^{-1} ^{232}Th

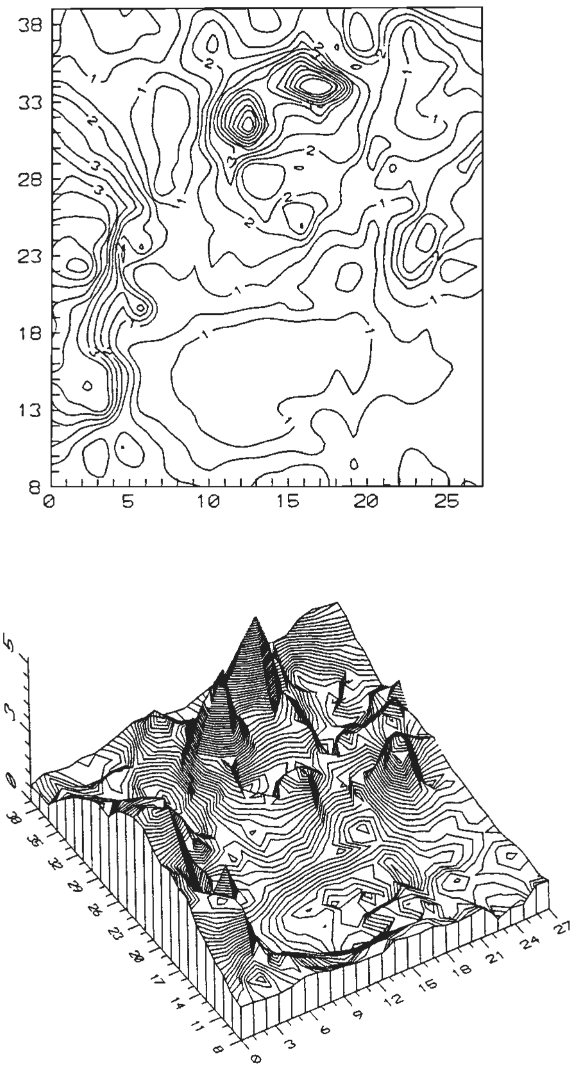
Radium equivalent mass activity was calculated using the following formula (U and Th contents are indicated in ppm, K content is indicated in wt. %):

$$a_m = 12.35U + (1.43 \times 4.06Th) + (0.077 \times 313K).$$

Radium equivalent mass activity allows the evaluation of potential risks of a given environment with respect to rock radioactivity in a more objective way. Average values a_m for the individual sectors vary between 80 and 222 Bq.kg^{-1}. Our measurements suggest that values of about 200 Bq.kg^{-1} can be considered as anomalous (in the studied area). Such values have been measured mainly in sectors B and H, therefore, detailed petrographie evaluations were done only there (see above). Evidently, the elevated concentrations of natural radioactive elements (and, consequently, relatively high values of a_m) are spatially related to those rocks containing a high proportion of sheet silicates, as evidenced in parts of sector B. Locally elevated concentrations of the monitored elements in quartzites may be connected with hydrothermal alteration (higher contents of U and Th were noted in places with frequent occurrence of quartz veins, but not always).

The distribution of K, U and Th contents and radium equivalent mass activity (a_m) in the area of the speleotherapy medi-

Fig. 2. Distribution of potassium contents in rocks of the speleotherapy institution (in wt. %).



cal facility is represented on Figs. 2, 3 and 4 (the area shown in all of the six partial figures is the same as that of Fig. 1a,b).

A 122 m long section, located in the northern wall of the entrance adit, has been investigated in detail (distance between

Table 2: Naturally radioactive elements contents in rocks of the individual sectors and the calculated radium equivalent mass activity.

Sector	Potassium (wt. %)		Uranium (ppm)		Thorium (ppm)		a_m (Bq.kg^{-1})	
	range	avg.	range	avg.	range	avg.	range	avg.
A	0.9-3.5	1.6	1.0-3.5	2.1	2.8-12.7	5.5	50-201	97
B	1.6-5.1	3.6	1.6-6.1	4.1	5.0-13.8	10.0	99-278	200
C	1.1-3.2	2.0	1.2-3.2	2.1	3.8-9.4	5.8	63-171	103
D	0.9-2.8	1.5	1.3-2.9	2.0	4.0-8.4	5.5	65-125	91
E	0.8-6.9	2.7	1.2-6.4	2.8	3.4-19.0	9.0	54-356	152
F	0.9-3.4	1.8	1.3-5.5	2.8	3.5-12.2	7.2	58-221	120
G	0.7-2.4	1.3	1.2-3.1	1.7	3.0-7.3	4.6	49-139	80
H	1.3-6.7	3.6	1.9-15.8	6.1	4.5-24.7	13.1	81-479	222

the points of measurement is approximately 2 m). The section can be divided in two parts, each with different petrography. The section between points 254 and 262 is composed of quartzites. The section between points 201 and 253 is dominated by various kinds of schists passing gradually to quartzites. The results from gamma-ray spectrometry measurements and calculated values of a_m are shown in Fig. 5. Whereas in the quartzites the contents of Th and U are very low (a_m under 200 Bq.kg^{-1}) the same contents are moderately elevated in the schists (calculated a_m values in individual section points reached the limit value of 370 Bq.kg^{-1}). As the results indicate, the highest contents of thorium (and probably also uranium) are related to occurrence of graphitic schists.

Fig. 3. Distribution of uranium contents in rocks of the speleotherapy institution (in ppm).

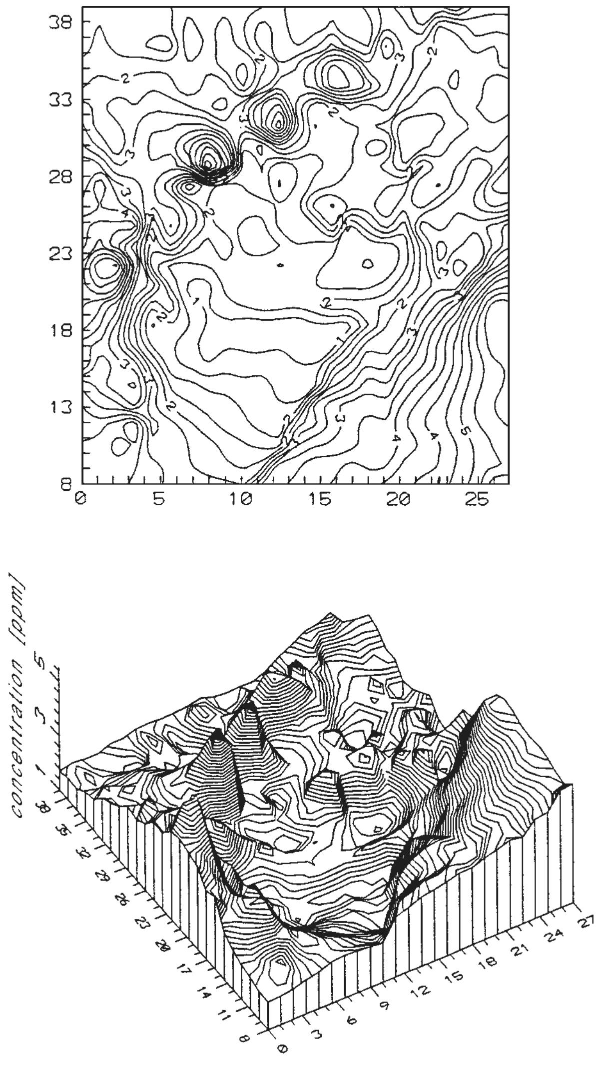
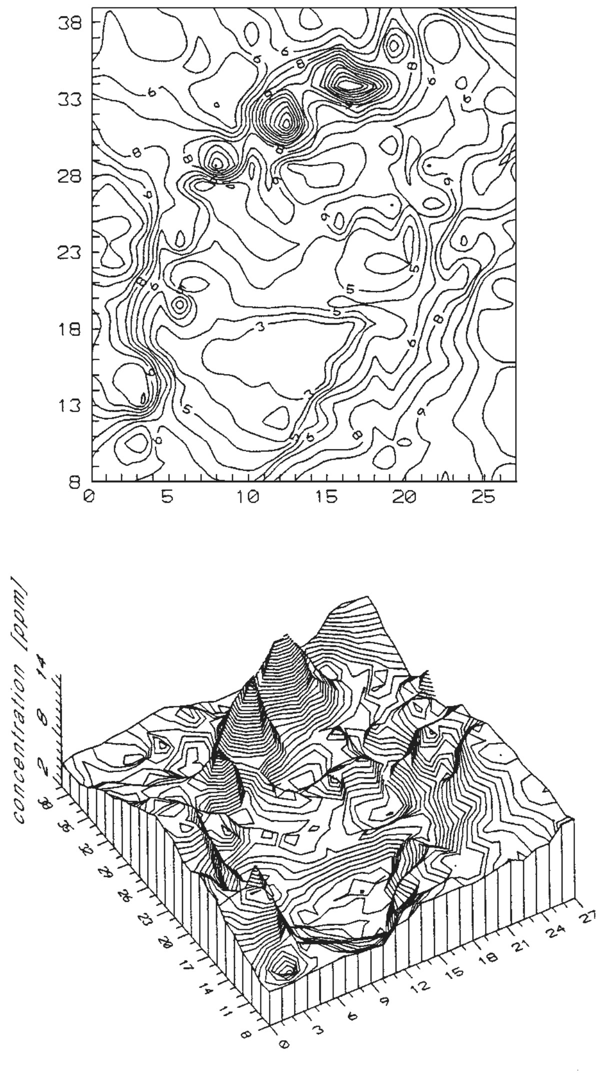


Fig. 4. Distribution of thorium contents in rocks of the speleotherapy institution (in ppm).



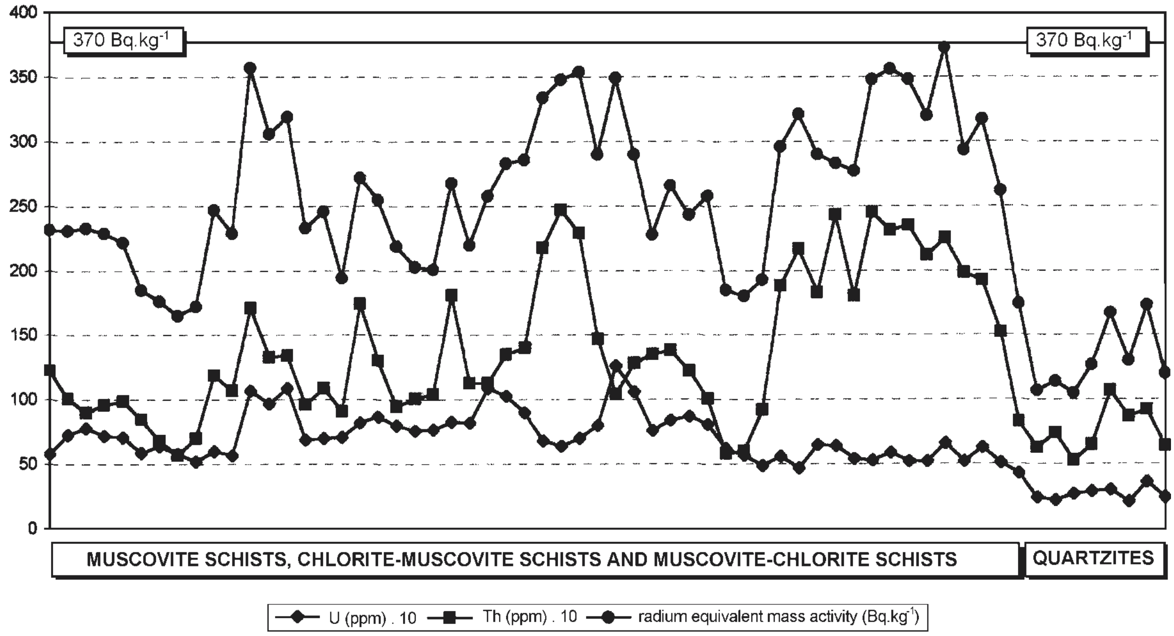


Fig. 5. Results from detailed gamma-ray spectrometry measurement of natural radioactive element contents in the section situated in the northern wall of the entrance adit (U and Th values on the vertical axis are indicated in tens of ppm, a_m values are indicated in $Bq.kg^{-1}$).

Conclusions

The gamma-ray spectrometry measurements showed slightly increased concentrations of naturally occurring radioactive elements when compared to their occurrence in natural caves and mine drifts excavated in carbonate rocks (e.g. in the Moravian Karst and Javoříčko Karst, the Czech Republic). However, the U and Th concentrations may still be considered relatively low. The average values of radium equivalent mass activity in separate parts of the speleotherapy medical facility fall within the prescribed state standards of 370 $Bq.kg^{-1}$. Whereas U and Th concentrations in the exposed quartzite in the former mine areas used for speleotherapy are relatively low, the concentrations of U and Th are highly variable and often moderately increased in the pelitic schists and even higher in the exposed graphitic rocks in the entrance adit. On the basis of our gamma-ray spectrometry measurements, it is our opinion that even long-term stays at the speleotherapy medical facility in Zlaté Hory should not pose any health risk to either patients or the staff.

The relatively higher contents of uranium in the exposed rocks in the entrance adit (chlorite-muscovite schists and muscovite schists, often graphitic) and strong tectonic deformation of such rocks may result in elevated concentrations of ^{222}Rn in the ambient atmosphere. Relatively higher concentrations of uranium can be expected in the schists lying below the quartzite horizon in which the speleotherapy medical facility is located, together with consequent generation of radon that can migrate upwards to diffuse into the subsurface atmosphere of the medical facility. Consequently, we consider radon monitoring in the speleotherapy medical facility imperative.

References

Bernard J.H. 1991: Empirical types of ore mineralizations in the Bohemian massif. *ÚÚG Praha 1991.*

Constantinides D. & Pertold Z. 1974: Geological position of the Zlaté Hory-South deposit. *Acta Univ. Carol., Geol.,* 145–154 (in Czech).

Čabla V., Hettler J. & Tomšík J. 1979: Deposits of the Zlaté Hory ore district from the point of view so called Global tectonics theory. *Sbor. GPO* 20, 5–69 (in Czech).

Fediuk F., Pouba Z., René M. & Tomšík J. 1974: Quartzites, metasilexites and metakeratophyres of the Zlaté Hory ore district. *Acta Univ. Carol., Geol.,* 185–202 (in Czech).

Fišera M. & Souček J. 1974: Metamorphic rocks of the Vrbno Beds of the Zlaté Hory area (Devonian, NW Moravia, Czechoslovakia). *Acta Univ. Carol., Geol.,* 231–257 (in Czech).

Janák J. 1970: Geological settings of the Zlaté Hory-South deposit. *MS. PřF UJEP Brno* (in Czech).

Janák J. & Augusta L. 1969: New opinions on development and evaluation of the Zlaté Hory-South ore deposit. *Geol. Průzk.* 11, 35–40 (in Czech).

Kalenda F. & Grygar R. 1993: Genetic aspects of the stratigraphic and structural control of the mineralization of the Zlaté Hory ore district, northern Moravia, Czechoslovakia. In: *Procceedings Eight IAGOD Symposium, Ottawa, Canada, August 12–18, 1990,* 513–522.

Patočka F. 1987a: The geochemistry of mafic metavolcanics: implications for the origin of the Devonian massive sulfide deposits at Zlaté Hory, Czechoslovakia. *Mineral. Deposita* 22, 144–150.

Patočka F. 1987b: Geochemistry of trace elements in metapelites of Zlaté Hory ore district. *Čas. Slez. Muz., Vědy Přír*. 36, 149–158 (in Czech).

Patočka F. 1988: Minor element geochemistry of pelitic schists of the Zlaté Hory ore district, the Jeseníky Mts.: Devonin tectonic setting of the primary sediment provenance. In: Proceedings of the 1st Int. Conf. on Bohemian Massif. *Prague, Sept. 26–Oct. 3, 1988*, 218–221 (in Czech).

Patočka F. & Vrba J. 1989: The comparison of strata-bound massive sulfide deposits using the fuzzy-linguistic diagnosis of the Zlaté Hory deposits, Czechoslovakia, as an example. *Mineral. Deposita* 24, 192–198.

Sas D., Navrátil O., Sládek P., Surý J., Štelcl J. & Zimák J. 1998: Geological and microclimatologica characteristics of speleotherapy medical facility of the 2nd level of the Zlaté Hory-South ore deposit. *Scripta Fac. Sci. Nat. Univ. Masaryk. Brun.*, *Geology* 25, 37–46 (in Czech).

Solecki A.T. 1997: Radioaktywność środowiska geologicznego. Acta Universitatis Wratislaviensis 1937, 7–69 (in Polish).

Souček J. 1978: Metamorphic zones of the Vrbno and Rejvíz series, the Hrubý Jeseník Mountains, Czechoslovakia. *Tschermaks Mineral. Petrogr. Mitt*. 25, 195–217.

Štelcl J. & Zimák J. 1998: Evaluation of content and distribution of natural radioactive elements in the speleotherapy medical facility of the 2nd level of the Zlaté Hory-South ore deposit. *Geol. Výzk. Mor. Slez. v r. 1997,* 109–112 (in Czech).

Zimák J. & Štelcl J. 1999: Results of detail petrographical and gammaspectrometric investigation of selected parts in the speleotherapy medical facility of the 2nd level of the Zlaté Hory-South ore deposit. *Geol. Výzk. Mor. Slez. v r. 1998,* 162–164 (in Czech).