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Radon in Soils Overlaying Several Tectonic Zones of the South Bohemian Moldanubicum

By MILAN KREŠL, MILAN KLEČKA & VĚRA VAŇKOVÁ*)

With 10 Text-Figures and 2 Tables

Tschechische Republik
Böhmische Masse
Moldanubikum
Granit
Orthogneis
Störungszone
Radioaktivität
Radon

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Radon in Böden über einigen Störungszonen des südböhmischen Moldanubikums

Zusammenfassung

Die Radonintensität im Boden wurde mit der Alphakartenmethode in ausgewählten, geologisch gut beschriebenen Lokalitäten gemessen. Die Beziehungen der Radonkonzentration mit verschiedenen Gesteinsarten und Deformationsgraden unter Berücksichtigung verschiedener Parameter der Bodenbedeckung wurden untersucht.

Die folgenden geologischen und strukturellen Faktoren zeigten sich für die Radonintensität und Radonmigration als entscheidend: hohe Urananreicherung von unterlagernden Gesteinen, Art und Intensität spröder Gesteinsdeformation, Neigung von Scherungs- und Bruchzonen, Eigenschaften der Bruchfüllung und Charakter der Bodenbedeckung.

Abstract

The radon intensity in soil was measured (alpha cards method) in selected geologically well described localities, and the relations of radon concentration with various types and grades of rock deformation have been studied with respect to different parameters of the soil cover. The main geological and structural factors affecting the radon intensity and radon migration through the ground were found to be the following: high U-enrichment of underlying rocks, type and grade of brittle deformation, dip of shear or fault zones, type of fault filling and character of sedimentary and soil cover.

*) Authors' addresses: Ing. MILAN KREŠL, RNDr. VĚRA VAŇKOVÁ; CSc., Geophysical Institute, Academy of Science of the Czech Republic, Boční II, ČZ-14131 Praha 4; RNDr. MILAN KLEČKA, Geological Institute, Academy of Science of the Czech Republic, Rozvojová 135, ČZ-16500 Praha 6.

1. Introduction

Radon is a radioactive, odorless, colourless, noble gas that is chemically inert. Radon isotopes originate in the natural radioactive decay series, ^{222}Rn (further denoted as Rn) in the ^{238}U decay series, ^{220}Rn (thoron) in the ^{232}Th series and ^{219}Rn (actinon) in the ^{235}U series, all isotopes being alpha particle emitters. Their half-life is 3.82 days, 55.6 sec and 4.0 sec, respectively.

Various methods of measurement of the radium emanations were broadly used in the past, particularly as prospecting methods in the search for uranium deposits.

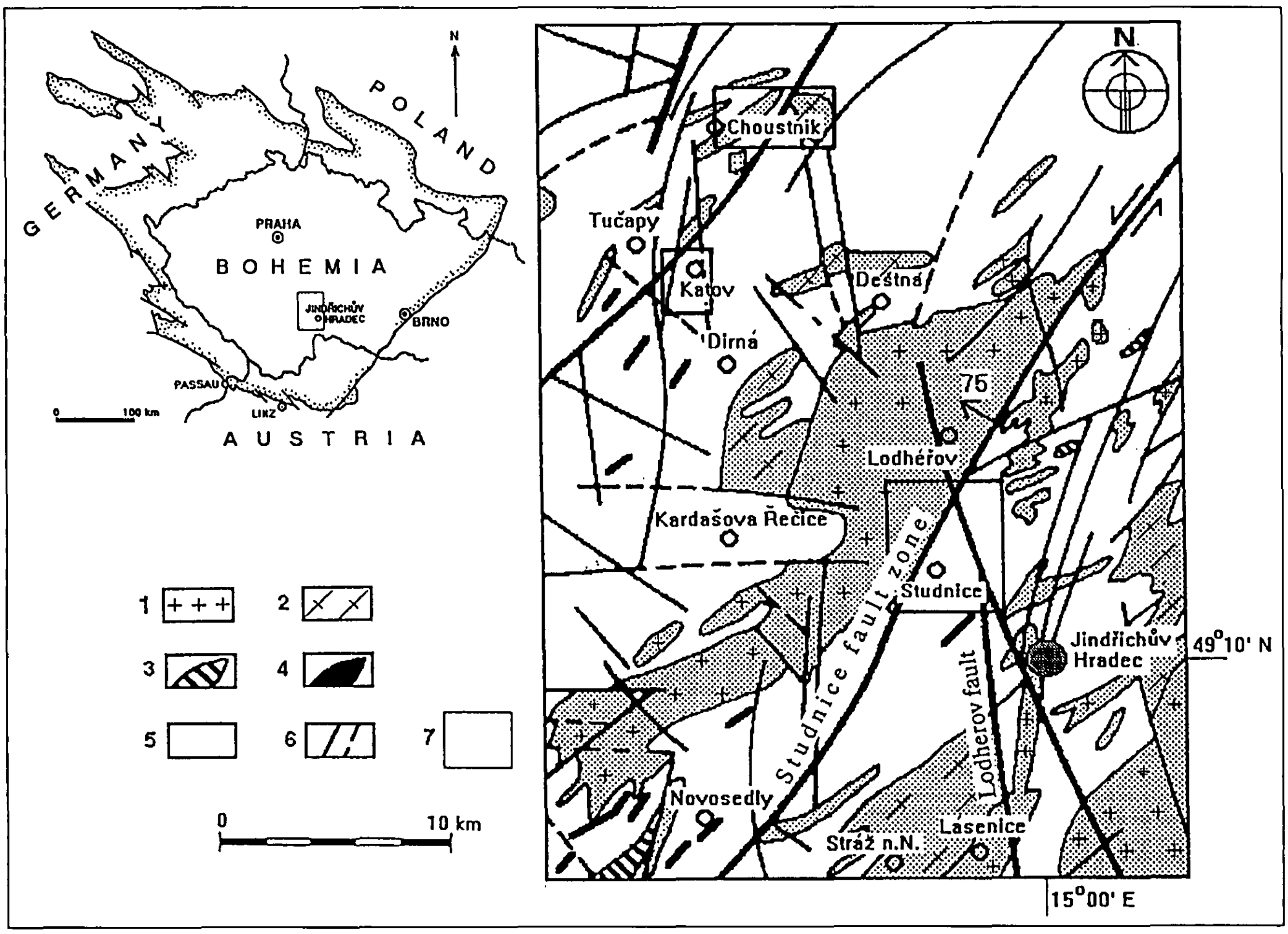
In the last tens of years the interest in Rn studies has increased, especially in connection with the effects of environmental radiation on humans. From this point of view, the problems of the indoor radioactivity are investigated, including besides the estimation of unsuitable building materials (from various types of cinder, fly ash, etc.) also the influence of radon from underlying rocks and earth materials around buildings (e.g. GRUNTORÁD & MATOLÍN, 1991; BARNET, 1990; BARNET et al., 1992a, 1992b).

The results of recent studies of radon migration in different environments bring many indications of various processes of Rn motion in the ground.

With several exceptions most studies incline to the opinion that the transport mechanism of Rn cannot be explained only by its diffusion but also by additional processes such as slow vertical upward flow, which allows Rn to move from larger distances under favourable conditions. Both transport mechanisms are extensively discussed by TANNER (1964, 1978). Numerous authors present results of measurements documenting the transport of Rn from larger distances over deep seated uranium mineralizations (MOGRO-CAMPERO & FLEISCHER, 1977; FLEISCHER & MOGRO-CAMPERO, 1979; FLEISCHER et al., 1980) as well as in localities without increased contents of uranium (KRISTIANSSON & MALMQVIST, 1982; MALMQVIST et al., 1986); in many cases the influence of disturbed zones of various kinds was stated.

The upward motion of Rn is often explained by the transportation by an upward flowing carrier gas (e.g., He, H, CO_2, CH_4, etc.) or by rising bubbles of the carrier gas to the surface. The suitable conditions for radon migration can represent geological settings with various types of rock deformations, mainly faults, contact zones of magmatic bodies, superposed rocks with high permeability.

In the present study, several geologically and structurally well investigated localities (Text-Fig. 1) with increased U contents and with different types of rock deformations were selected; the aim of the study is to obtain basic information on types of deformation suitable as possible ways for Rn migration, and to select localities for further more detailed studies.



Text-Fig. 1.
Sketch geological map of the studied area in the central part of the Bohemian Moldanubicum.
1 = Variscan granitoids, 2 = Pre-Variscan orthogneisses, 3 = granulites, 4 = amphibolites, 5 = paragneisses and migmatites, 6 = observed and supposed faults, 7 = investigated areas.

2. Geological Setting

As already mentioned, the favourable conditions for radon migration can be found in geological structures, in which tectonic zones of various kinds occur. In searching for such suitable "model" situations, the area in the central part of the Bohemian Moldanubicum appeared to be perspective. In this area many detailed geological and structural studies have been performed (HOUSKA, 1980; KLEČKA et al., 1986, 1989; ZIKMUND, 1983) and the types and locations of several shear and fault zones of different character have been well described. For the present studies, shear zones with ductile to brittle deformation and fault zones with various fillings were selected and investigated with respect to different types of sedimentary or soil cover (for their locations see Text-Fig. 1).

2.1. Localities No 1, 2, 3, 4

The localities were situated on several bodies of two-mica orthogneisses with tourmaline (denoted as Blaník type after ZIKMUND, 1983) which form the so-called Choustník orthogneiss. Orthogneiss bodies are concordantly bedded in paragneisses and have approximately flat platy shape with the thickness of 50–200 m (KLEČKA et al., 1989; RAJLICH et al., 1992).

According to their mineral and chemical properties, the orthogneiss bodies are relatively homogeneous. In the main body of the Choustník orthogneisses (Text-Fig. 2), two basic groups of rocks can be distinguished: the group of relict granitoids and the group of orthogneisses (KLEČKA et al., 1986); both can be further divided in several rock types.

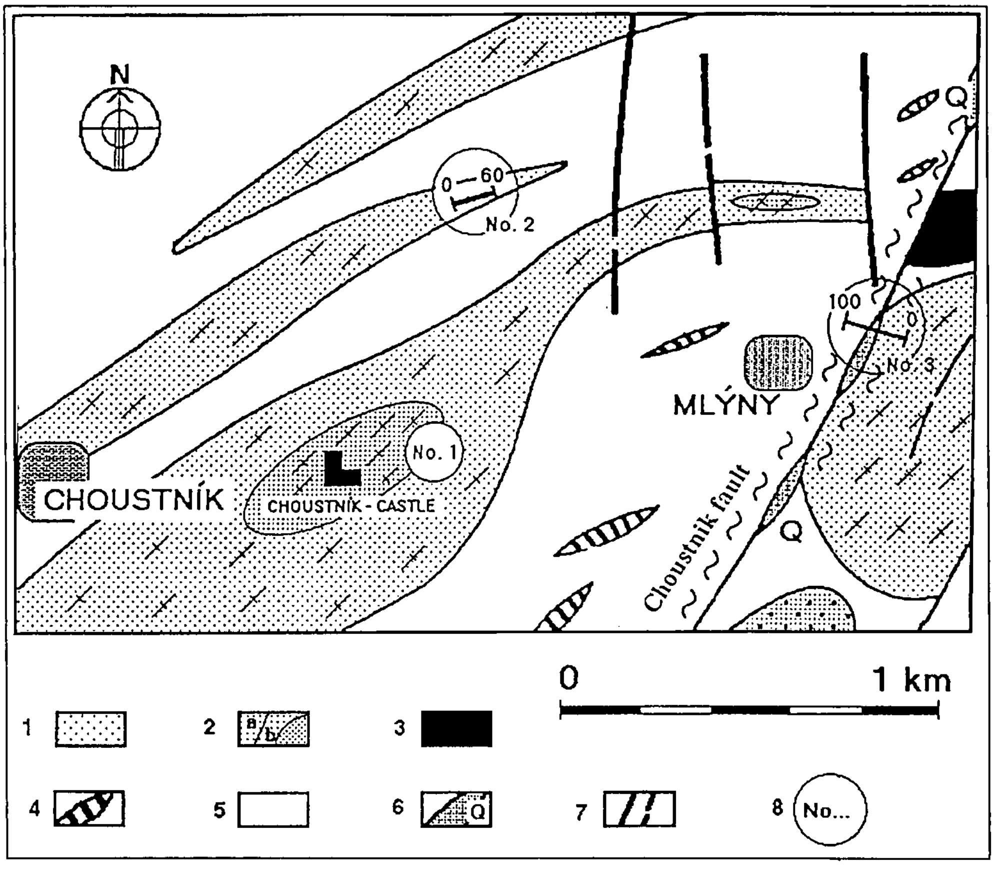
The relict alkali-feldspar metagranites comprise coarse grained porphyric to inexpressively porphyric biotite-muscovite granites and very coarse-grained granite porphyries.

The group of orthogneisses comprises two types: orthogneisses originated in dependence on ductile shear zones inside larger bodies of relict granites (A-type, locality No. 1), and orthogneisses originated as smaller bodies in the rim parts of larger bodies of relict granites (B-type, locality No. 2).

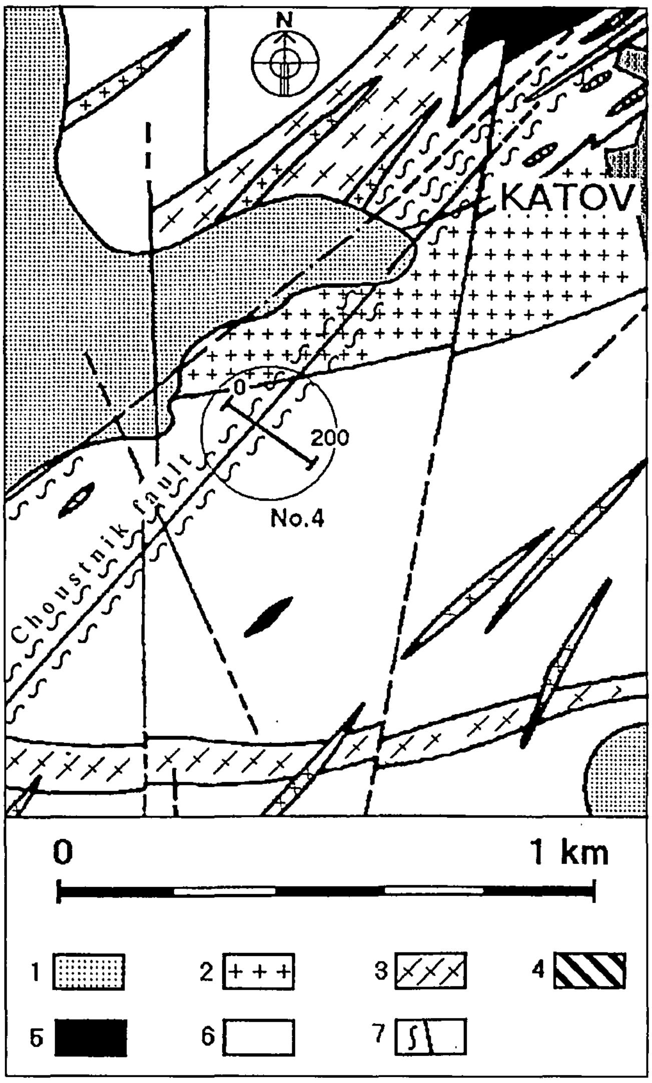
The process of the origin of A-type orthogneisses is isochemical, only texture rebuilding takes place. In the direction from the texturally undeformed granitoid towards the shear zone, i.e., with the increasing intensity of deformation, the building components of the rock are plastically deformed.

The B-type orthogneisses represent completely recrystallized metamorphites without any relict structures. In difference from central parts of larger bodies they represent contaminated material of surrounding paragneisses. Metamorphic allochemical processes and complicated migration of compounds between the granitoid and its surroundings participated in the origin of B-type orthogneisses.

In the main body of Choustník orthogneisses the following two types of shear zones occur: subhorizontal (dip 0–30°) and subvertical (dip 40–90°). The older, more ductile subhorizontal shear zones originated in scaled overthrust of larger dimensions (KLEČKA et al., 1986). The younger subvertical shear zones correspond to normal faults; after ductile motion with amplitude of about 30 m, the deformation of these zones continued as brittle-ductile. Postmetamorphic deformations have exclusively brittle character. In the studied region, the Choustník fault (Text-Fig. 1) represents the most important fault structure passing in the direction 30–40° with the variable dip around 80° to NW as well as to NE. Its thickness varies from 30 to 100 m, decreasing to 20 m W from Katov. The filling is formed by crushed and mylonitized rocks (Katov), sometimes by ultramylonites with frequent fault clays of the thickness up to one meter, in the northern parts also by dykes and lodes of hydrothermal quartz with the thickness up to 40 m (Mlýny). On this fault structure indications of U-mineralization are found in several places (e.g., Katov), as verified by test trenches, prospect pits and boreholes, provided by the Czechoslovak Uranium Industry.



Text-Fig. 2.
Sketch geological map of the sites No. 1, 2 and 3 (modified according to HOUSKA, 1980).
1 = Neogene sediments, 2 = Pre-Variscan orthogneisses (Blaník type), relict metagranites, 3 = eclogites, 4 = calc-silicate rocks, 5 = paragneisses and migmatites, 6 = quartz dyke, 7 = observed and supposed faults, 8 = localities under study.



Text-Fig. 3.
Sketch geological map of the site No. 4 (modified according to HOUSKA, 1980).
1 = Neogene sediments, 2 = medium-grained biotite-muscovite to two-mica granite, 3 = medium- to coarse-grained two-mica orthogneiss with tourmaline, 4 = amphibolitic gneiss, 5 = eclogites, 6 = paragneisses, localy migmatizated, 7 = mylonitization, faults observed and supposed.

Locality No. 1: Choustník

Measurements of Rn were performed directly on rock outcrops (Text-Fig. 2) containing orthogneisses with different types of deformation (undeformed, ductile, ductile-brittle and brittle deformed orthogneisses).

Locality No. 2: a small quarry near the road Choustník – Mlýny (Text-Fig. 2)

It is situated in partly weathered orthogneisses (B-type). The quarry is crossed by a zone of intensive breaking of the thickness of 1–1.5 m, characterized by a system of parallel subvertical joints, 5–10 cm mutually distant.

Locality No. 3: Mlýny (Text-Fig. 2)

The measured section intersects the Choustník fault near Mlýny in the part filled with quartz lode.

Locality No. 4: Katov (Text-Fig. 3)

The measured section intersects the Choustník fault near Katov in the part where intensive mylonitization of a small body of two-mica orthogneiss takes place. Mylonitization is here accompanied by partly hydrothermal alteration with scarce manifestations of U-mineralization on joints.

2.2. Localities No. 5 and 6

The localities are situated on two important fault structures of the Bohemian Moldanubicum (Lodhéřov fault and Studnice fault zone – Text-Fig. 4); in parts, where they disturb granites of the central massif of the Moldanubian Batholith, indications of U-mineralization can be observed.

Locality No. 5: Lodhéřov (Text-Fig. 4)

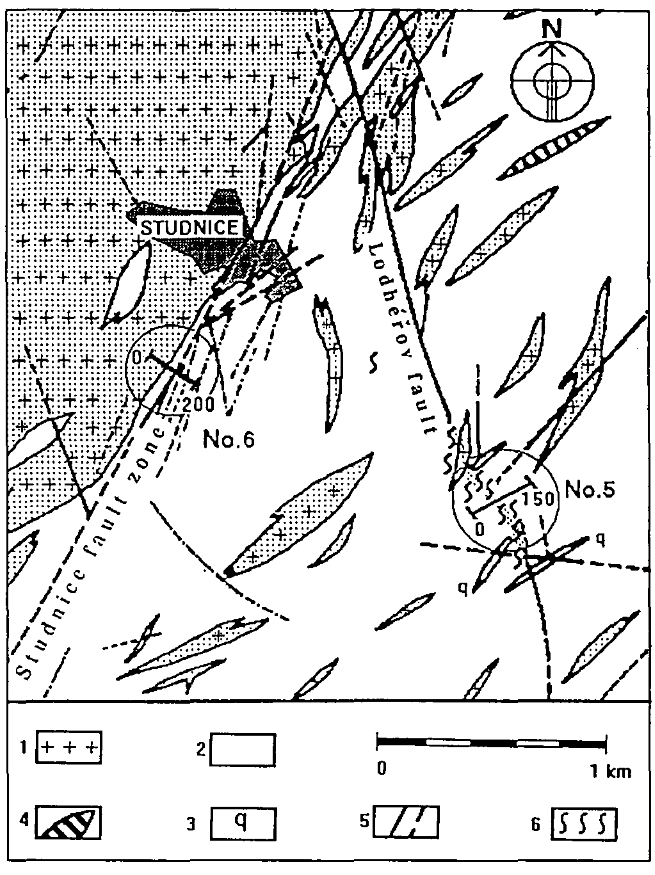
The measured section intersects the Lodhéřov fault in places where it disturbs the Moldanubian metamorphic rocks. The filling of the fault consists of altered and mylonitized biotite-sillimanite paragneisses with layers of tectonic clay. In the part under study the fault zone is covered by clay sediments.

Locality No. 6: Studnice (Text-Fig. 4)

The section intersects a distinct regional fault structure of NE–SW direction, the so-called Studnice fault zone, forming the tectonic contact of the Klenov Massif granites from the paragneisses of the Varied Group of the Moldanubicum.

3. Experimental Technique

Concentration of radon in soil, air and above rock outcrops was determined by measuring the amount of daughter products of radon decay on a detecting foil (the method of alpha-cards). The TAC-018 foil, protected by



Text-Fig. 4.
Sketch geological map of the sites No. 5 and 6 (according to Z. PLETÁNEK, unpublished data of Czech. Uran. Industry).
1 = Variscan two-mica granites, 2 = paragneisses and migmatites, 3 = quartzites, 4 = amphibolites, 5 = observed and supposed faults, 6 = zone of mylonitization.

a cylindrical plastic cup, was either placed vertically into a borehole 0.8 m deep, 80 mm in diameter, bottom of the cup facing upwards or it was air-proof stuck on the surface of an outcrop. The foil was exposed to radiation for 24 hours followed by 2 minutes counting of alpha products by means of a MP-103-D radiometer. All the measurements were carried out in warm, dry and windless weather.

At the same points where radon concentration measurements were taken, the content of Th, U, K by means of a portable gamma-spectrometer GS-256 was also determined. Spectrum was accumulated for 1 minute at each point. Field gamma-spectrometric measurements (further denoted as FGS) were checked by laboratory gamma-spectrometric measurements (further LGS) on rock samples in laboratory equipped by a 100 x 100 mm NaI(Tl) crystal, Silena-Cicero analyzer on line with a M-24 Olivetti computer, calibrated by IAEA gamma-ray spectrometry reference material. Counting time was 5000 sec.

An usual method of measuring volume and weighting dry and saturated specimens was applied for calculating density and porosity of rigid rocks. Granularity of soil samples was determined by using a standard set of screens.

4. Rock and Soil Properties

The results of measurements of Th, U and K contents by laboratory gamma spectrometry (LGS), of density, porosity and granularity of the collected samples of rocks and soils are given in Tab. 1.

In the whole Choustník locality 7 samples of metagranites (3 slightly deformed, 4 strongly deformed) and one sample of coarse-grained metagranitic porphyry were collected (Ra-11 to RA-17). The samples differ only in U-concentrations according to the place of sampling location: the samples from the central part of the body contain two-fold contents of U (around 10 ppm) in comparison with the samples from the rock defile. The differences in U-concentrations are not connected with the grade of deformation of metagranites. The Th and K contents of samples are the same for all in the limits of error. The values of densities also display a small variability. The porosity values vary in the ranges from 1.9 to 4.3 % and are not dependent on the grade of rock deformations.

Two samples from the quarry near the road Choustník – Mlýny, namely the silty-gravel sandy residuum (RA-1) and the weathered orthogneiss (RA-2) display almost identical contents of U and K, while the Th content of weathered orthogneiss is a little lower. The porosity of the weathered orthogneiss is 5.6 %.

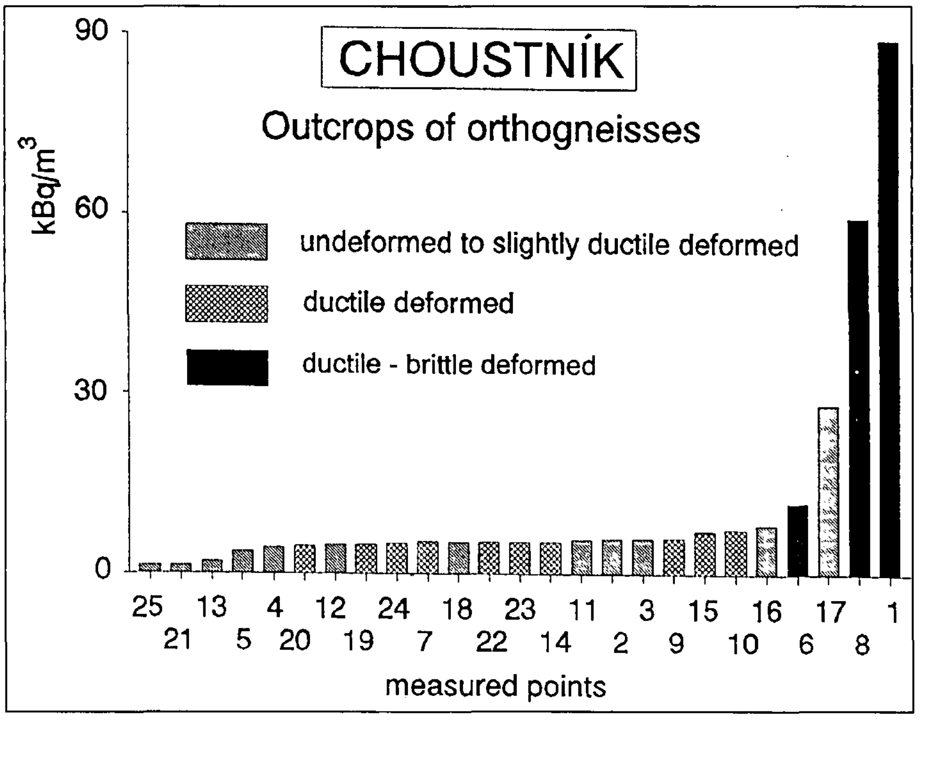
From the section No. 4a near Katov two samples of soil cover were collected; the sample RA-3 taken at 50 m of the section contains a greater share of sandy component while the sample RA-4 at 205 m of the section has a predominant clay component. The contents of Th, U and K (LGS) of the samples are different, the sample with a greater share of clay displaying a higher content of Th, almost a half content of U and K and two-fold Th/U ratio.

From the section No. 5 across the Lodhéřov fault two samples of soil cover at 20 and 80 m of the section were collected (RA-5, RA-6). The samples are not very different in the share of sandy and clay components, and their Th, U and K contents differ only in limits of error.

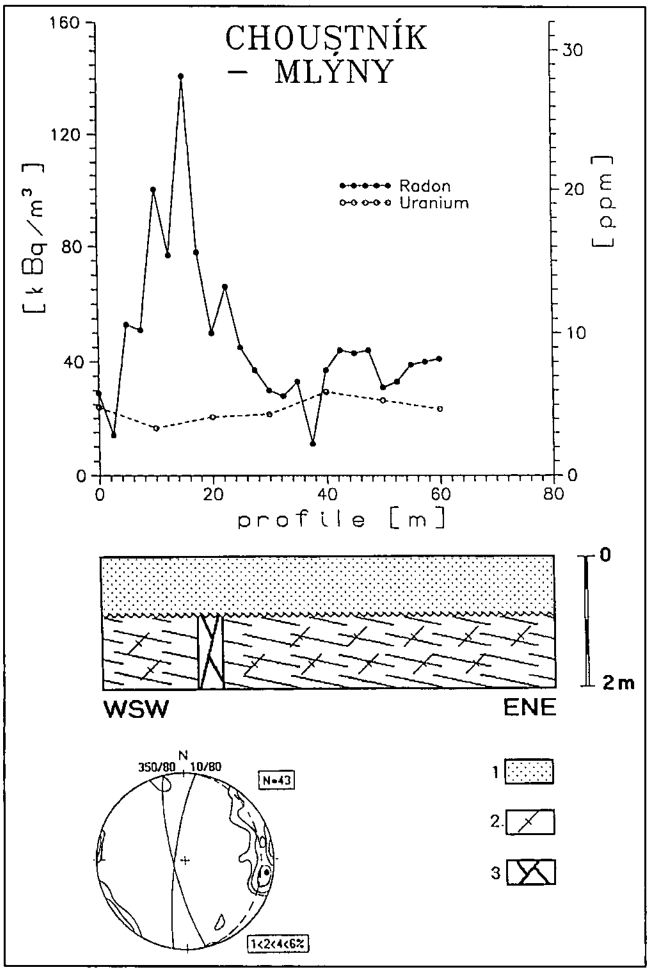
Two samples from the 5th and 65th m of the section No. 6 near Studnice (RA-7a,b) slightly differ in the share of clay components, which is higher for sample RA-7b. The contents of Th are very close, the contents of U and K are lower in sample RA-7b. The sample of biotite-muscovite granite RA-8 collected in the vicinity of the section has very low contents of Th and U.

5. Results of Radon and FGS Measurements

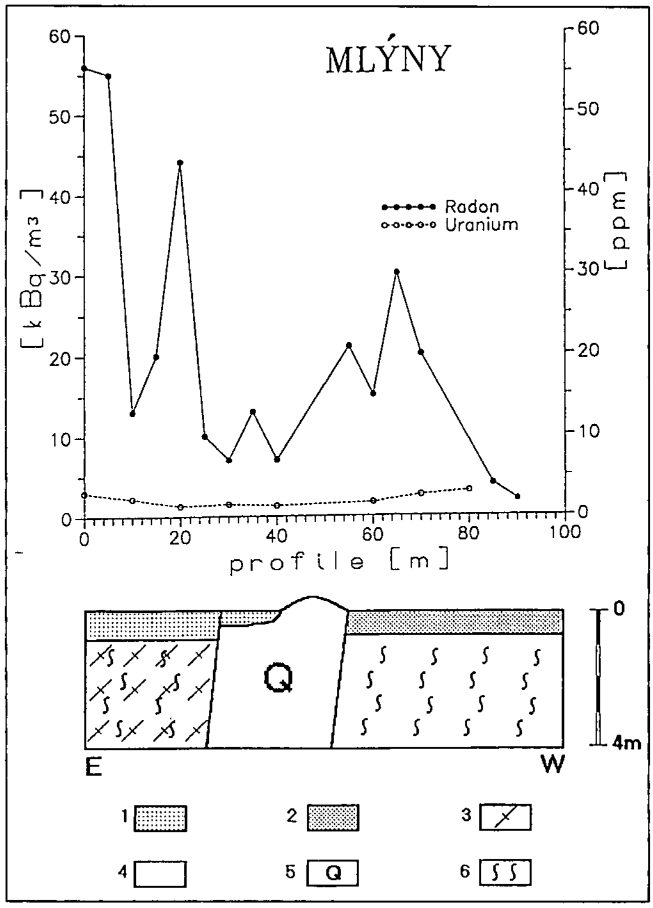
The results of measurements of Rn activity directly on orthogneiss outcrops with different grade of deformation (locality No. 1) are shown in Text-Fig. 5, where the values measured at individual points are arranged according to the increasing concentration of Rn, denoting the main three types of deformation by different symbols. In spite of the fact that the experimental arrangement of measuring directly on the rock outcrops needs many improvements, basic tendencies of the relation between the Rn concentration and the type of rock deformation can be observed. The influence of the ductile deformation imprinting a linear to planar texture to the rocks is negligible, the Rn values do not display greater differences in comparison with Rn values obtained on undeformed rocks. A pronounced increase of Rn values (Text-Fig. 5) can be observed with the increasing share of brittle deformation (ductile-brittle de-



Text-Fig. 5.
Relationship between radon concentration and character of deformation at the site No. 1 (Choustník).



Text-Fig. 6.
Radon concentration along the profile No. 2 (Choustník – Mlýny).
1 = sandy residuum, 2 = two-mica orthogneiss with tourmaline with distinguished foliation, 3 = joints.



Text-Fig. 7. ▲
Radon concentration along the profile No. 3 (Mlýny).
1 = sandy residuum, 2 = sandy-silty residuum, 3 = two-mica orthogneiss with tourmaline. 4 = two-mica paragneiss, 5 = quartz lode, 6 = mylonitization.

formation), during which partial granulation of rocks occurs and the origin of parallel systems of shear planes starts. Only in one case (point No. 17) a higher Rn concentration was obtained on undeformed rock; here, the increased concentration of Rn could be connected with the local enrichment of U in biotite-rich xenoliths, clusters of which were observed in the place of measurements.

The results of gamma-spectrometric measurements, FGS as well as LGS, do not show any relations between the U concentration and the grade of rock deformation. The FGS measurements give values in the ranges 11–13 ppm for Th, 8–20 ppm for U and 4–6 % for K in the case of slightly deformed rocks and comparable values of 10–15 ppm for Th, 11–19 ppm for U and 4–6 % for K in the case of strongly deformed rocks. Similar results were also obtained by LGS measurements on similarly deformed rock samples (see Tab. 1).

In section No. 2 (Choustník – Mlýny), passing across the zone of intensive breaking, the Rn concentration was measured in shallow holes in homogeneous silty-gravel

Text-Fig. 8. ▶
Radon concentration along the profile No. 4 (Katov).
1 = sandy residuum, 2 = sandy-silty residuum, 3 = two-mica orthogneiss with tourmaline, 4 = slightly migmatized biotite-sillimanite paragneiss with muscovite, 5 = zone of mylonitization, 6 = mylonitized hydrothermally altered orthogneiss with indications of U-mineralization on fissures.

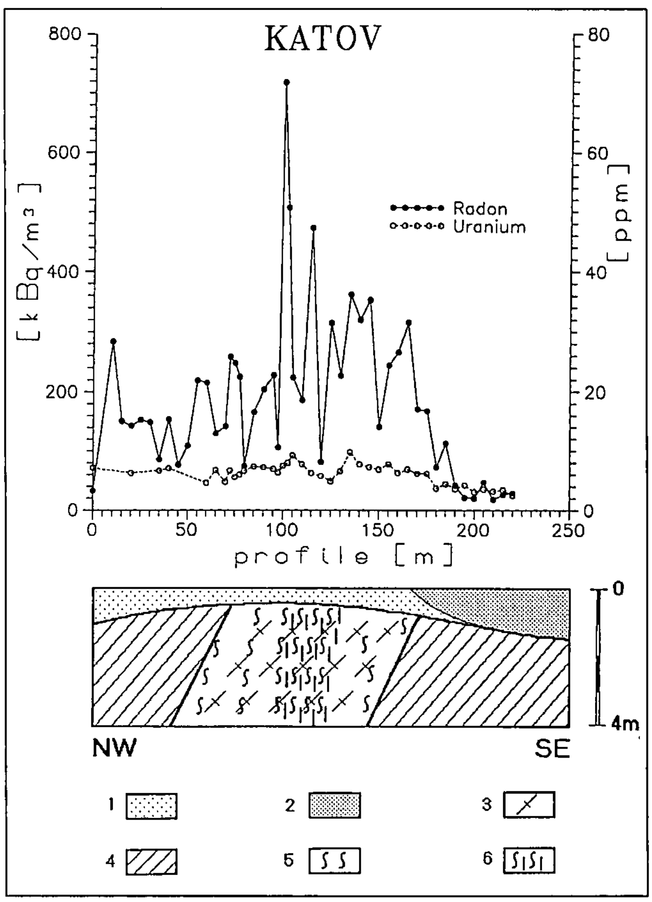


Table 1.
Main properties of the collected samples.

Sample	Rock/Locality	Radioactivity			Density	Porosity	Granularity		
		Th	U	K			>2	2–0.063	<2
		[ppm]	[ppm]	[%]	[g/cm³]	[%]	[mm]	[mm]	[mm]
RA- 1	Silty-gravel sandy residuum Quarry near road Choustník – Mlýny	3.60	4.38	3.90			22	64	14
RA- 2	Weathered orthogneiss Same locality as RA-1	2.95	4.39	4.08	2.50	5.6			
RA- 3	Silty-gravel sandy residuum Choustník fault, Katov (50th m of section)	7.24	6.70	4.00			23	55	22
RA- 4	Sandy-silty residuum Choustník fault, Katov (205th m of section)	10.14	3.67	2.49			4	33	63
RA- 5	Sandy-silty residuum Lodhéřov fault, Velký Ratmírov (20th m of section)	14.09	4.46	2.51			2.5	36.5	61
RA- 6	Sandy-silty residuum Same locality as RA-5 (80th m of section)	13.00	3.54	2.40			5	39	56
RA- 7a	Silty-gravel sandy residuum Fault system near Studnice, (5th m of section)	9.09	4.09	3.32			27	57	16
RA- 7b	Silty-sandy residuum Same locality as RA-7a (65th m of section)	8.78	2.53	2.01			6	58	36
RA- 8	Fine-grained muscovite-biotite granite Studnice	2.12	2.40	3.91	2.55	3			
RA-10	Strongly deforemd metagranite from shear zone Choustník	12.55	10.20	3.55	2.62	1.9			
RA-11	Slightly deformed metagranite Choustník, central part of the body	10.85	10.06	4.12	2.61	1.9			
RA-12	Slightly deformed metagranite with tourmaline Rock defile near Choustník	9.92	5.54	4.15	2.58	2.8			
RA-13	Strongly deformed metagranite from shear zone Same locality as RA-12	10.05	5.83	4.29	2.58	2.7			
RA-14	Strongly deformed metagranite from fine-grained shear zone Same locality as RA-12	9.92	4.73	3.98	2.55	4.0			
RA-15	Slightly deformed metagranite Choustník, central part of the body	10.23	10.24	4.29	2.62	1.6			
RA-16	Strongly deformed metagranite from fine-grained shear zone Same locality as RA-15	10.17	10.44	4.00	2.59	2.6			
RA-17	Coarse-grained metagranite porphyry Same locality as RA-15	10.25	8.04	4.26	2.55	4.3			

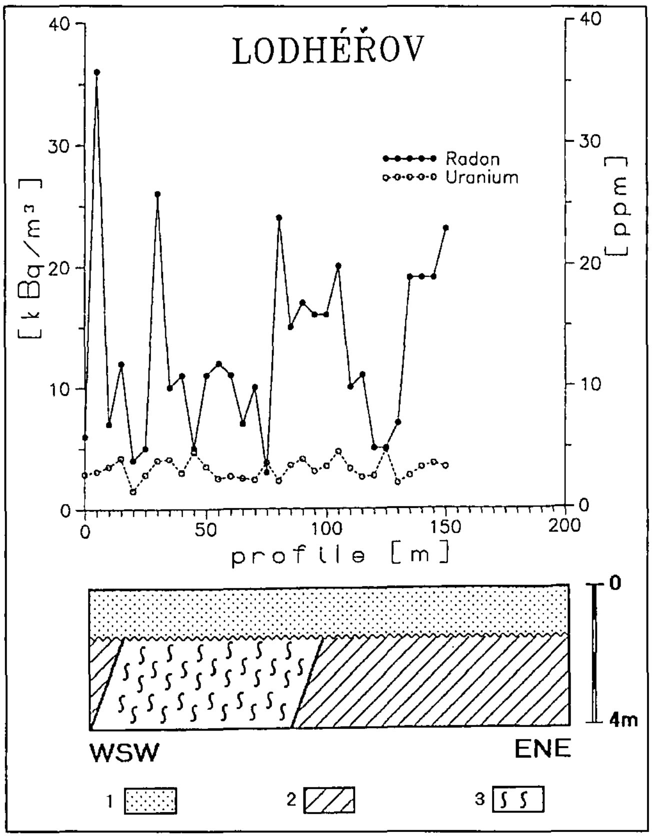
sandy residuum cover with high permeability (Tab. 1). As can be seen from Text-Fig. 6, at 15–20 m of the section, the weathered orthogneisses beneath this cover are disturbed by systems of parallel subvertical joints, the influence of which is reflected by expressively increased values of Rn concentration on the profile. In difference, the profile of U concentrations (FGS) in the same figure shows monotonous values and is not influenced by the presence of the zone of joints. The values of Th and K (not shown in the Fig.) follow a similar course as the U values.

The section No. 3 (Text-Fig. 7) crosses the Choustník fault in its northern part, the section No. 4 (Text-Fig. 8) in its southern part. The behaviour of Rn in both profiles is quite different, evidently due to different filling of the fault in both parts. The position of decreased values of Rn in the profile No. 3 agrees with the location of quartz lode forming the filling of the fault. The profile of U contents (FGS) show low values in the whole profile without any pronounced anomaly. The Th and K contents, in general, follow the behaviour of the U values.

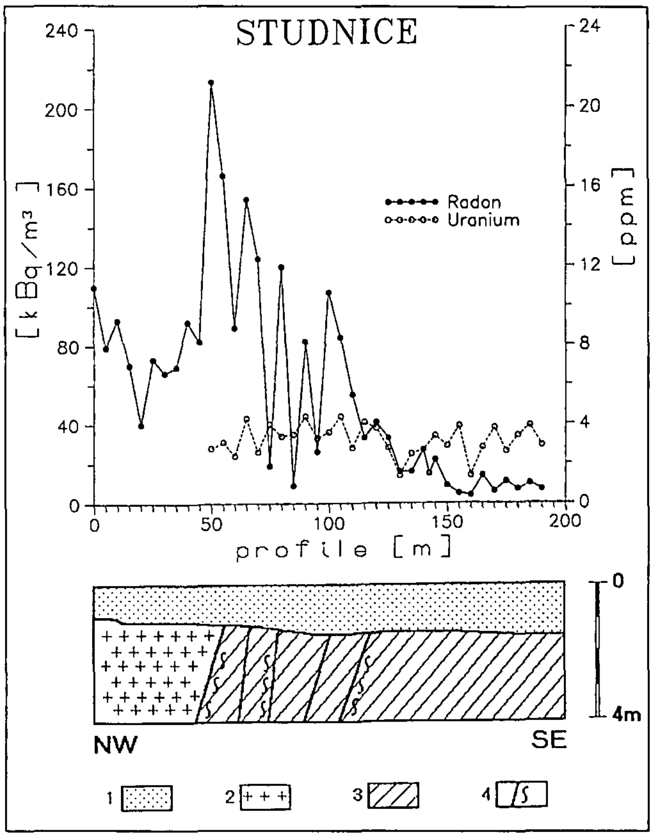
The results obtained in the other part of the same fault show a different pattern, the presence of the fault causing a pronounced increase of Rn values in the profile: high values are especially found over the mylonitized zone. The soil cover up to 180 m of the profile is formed by silty-gravel sandy residuum with a medium permeability (see Text-Fig. 8). Towards the end of the profile the values of

Table 2.
Mean concentrations of Th, U and K in ductile deformed metagranites to orthogneisses obtained by laboratory gamma spectrometry.
n = number of samples; standard error = $\Sigma(\epsilon^2/n)^{1/2}$.

Intensity of deformation	Type of Rock	n	Th [pm]	U [ppm]	K [%]
Undeformed to slightly deformed	Coarse-grained metagranites	4	10.32±0.33	8.90±1.95	4.06±0.23
	Relict coarse-grained quartz porphyry	2	10.23±0.02	7.95±0.09	4.07±0.19
Strongly deformed	Plano-linear orthogneiss	4	10.67±1.09	7.80±2.55	3.96±0.26



Text-Fig. 9.
Radon concentration along the profile No. 5 (Lodhéřov).
1 = sandy-silty residuum, 2 = paragneiss, 3 = zone of mylonitized paragneisses.



Text-Fig. 10.
Radon concentration along the profile No. 6 (Studnice).
1 = sandy-silty residuum, 2 = two-mica granite (Klenov Massif), 3 = sillimanite-biotite paragneiss, 4 = faults (with mylonitization).

Rn decrease, evidently due to a very low permeability of the soil cover, which is formed here by sandy-silty residuum.

The results of FGS measurements of U, Th and K show mainly the radioactivity of the soil cover: U and K values are higher in the part of the section up to 180 m and decrease towards the end of the profile, the behaviour of Th being reverse. These tendencies are in agreement with the LGS measurements of samples from both parts of the profile (Tab. 2).

The Th-enrichment in sedimentary cover can be explained by increased concentration of zircon grains in Neogene sediments. Several increased U values measured by FGS over the disturbed zone can be in connection with the U mineralization present in the zone.

The section No. 5 (Text-Fig. 9) intersecting the Lodhéřov fault shows large variations in Rn contents, which are in no connection with the position of the disturbed zone. The possible influence of the fault is here probably eliminated by soil cover with a low permeability. Neither the U values (FGS) show any expressive anomalies.

The section No. 6 (Text-Fig. 10) near Studnice intersects the fault structure in the boundary between two-mica granites (Klenov Massif) and sillimanite-biotite paragneisses. The influence of the fault structure can be seen in the profile by expressively increased values of Rn, especially over the contact with the granite.

The Rn values in the profile are variable and decrease considerably over paragneisses at the end of the profile. The permeability of the soil cover is high in the first part of the profile and medium to the end of the profile. The U values from FGS measurements do not show any anomaly.

6. Discussion

The results of measurements of the Rn intensity in different geologically well investigated areas in which the relations of Rn concentration with different types and grades of rock deformation has been studied with respect to different parameters of the soil cover, enabled us to specify several basic influences on the Rn migration through soils and rocks.

The simultaneous measurements of Rn and U in the studied localities did not show any correlation between these parameters (Text-Figs. 6–10), the anomalous values of Rn were not accompanied by increased or decreased contents of U obtained by FGS or by LGS. This fact supports the opinion that the content of Rn in the soil cannot be caused by its diffusion from local sources alone but that the Rn anomalies can be caused by migration of Rn from greater distances under suitable conditions.

The influence of ductile to brittle deformation on Rn concentration was observed during the Rn measurements on rock outcrops. It seems that the ductile rock deformation, which is engaged in the origin of anisotropic structure of the rock,does not influence the Rn intensity. The pronounced increase of Rn can be observed after the transition from the ductile to brittle stage, causing a network of discontinuities in the rock. Many authors (e.g., MOGRO-CAMPERO & FLEISCHER, 1977; KRISTIANSSON & MALMQVIST, 1982; MALMQVIST et al., 1986; KING, 1984/85; CHUNG, 1984/85; KRISTIANSSON & MALMQVIST, 1984) assume that Rn atoms are transported from greater distances together with carrier gases (N_2, CH_4, CO_2, He, H etc.) which slowly move upwards through the ground, especially through cracks and fissures. From this point of view, the anisotropic structures of the ductile stages of deformation are not very suitable for such a motion because only re-orientation of structural components takes place here. In the further stages of deformation (ductile-brittle), during which a partial granulation of rocks occurs along the parallel system of shear planes, small discontinuities can represent possible ways for the fluid migration. For such a transport various structures of brittle deformation with many open discontinuities of larger sizes (fault cleft zones, fault-slip cleavages, fault zones, etc.) can be yet more favourable. As an example, studies of gas contents in the superdeep borehole (KTB) can serve, where a positive correlation between the methan content and the number of clefts, and between the helium content and the number of clefts were observed (ZIMMER & ERZINGER, 1989; HEINSCHILD & WITTENBECHER, 1989). However, the capability of fluid migration along the fractures is probably influenced also by the contemporaneous pressure condition in the studied region.

Within the framework of one structure, the Rn intensity can considerably vary in dependence on the character of fault filling, as can be documented by the situation on the Choustník fault. In locality No. 3 over quartz lode filling the Rn intensity is very low while in the other part of the fault (locality No. 4) over the filling of mylonitized orthogneisses expressively increased Rn values were measured. It follows that the individual faults cannot be simply denoted as "Rn risky or safe" in their whole length, but that their detailed geological situation must be taken in account.

In all the studied cases the influence of the type of soil or sedimentary cover on the intensity of Rn is dominant. The rocks or soils with a high permeability (gravel and sandy sediments) are very suitable for Rn migration while clay sediments are almost impermeable.

From the point of view of radon risk classification as proposed in BARNET et al. (1992a), parts of profiles No. 2, 4 and 5 can be denoted as environment with high Rn risk. The highest values in locality No. 4 belong to the highest Rn values obtained in the Bohemian Massif (results of Czechoslovak Uranium Industry).

From the studied types of rock deformations the system of subvertical joints in a homogeneous environment (No. 2) and the fault structure with the filling of mylonitized paragneisses (No. 4) appeared to be most suitable for the Rn migration. Therefore, both localities will be subject of further studies.

7. Conclusions

The main factors influencing the radon intensity and its migration through the ground rocks, observed in the present study, can be summarized as follows:

❶ The high radioactivity of underlying rocks, above all the high contents of U. The highest radioactivity was measured in granitoids, namely durbachites, alkalic granites and their effusive equivalents and in several orthogneisses (MATOLÍN, 1970; FIALA et al., 1983; VAŇKOVÁ et al., 1979).

❷ The type and grade of brittle deformation. Brittle deformation appeared to be most favourable for Rn migration. Also the intensity of deformation expressed by the grade of cataclasis and by frequency of discontinuities is very important.

❸ The redistribution of radioactive elements. During brittle deformation a local loss (KLEČKA et al., 1987) or local enrichment (GATES & GUNDERSEN, 1989) of radioactive elements may occur.

❹ The dip of shear or fault zone. Higher Rn values can be more often observed over subvertical zones than over subhorizontal zones of overfault or normal-slip fault type.

❺ The type of fault filling. The intensively fractured zones, the zones of fault cleavage etc. are very favourable for Rn migration. The clay, quartz or carbonate fillings of faults restrain the Rn penetration in soils and rocks.

❻ The type of sedimentary and soil cover. The main parameters are permeability and porosity.

The greatest radon risk can appear in combination of the following geological factors: underlying rocks with U-enrichment + intensive brittle deformation in subvertical zones without quartz, carbonate or clay filling + gravel or sandy eluvium soil cover.

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