9. Radon and tectonics

9.1 INFLUENCE OF TECTONICS IN THE CRYSTALLINE AND PROTEROZOIC BEDROCK

The main aim of the radon index mapping is to characterize the radon release from different lithological types of bedrock. Therefore for mapping purposes the test sites were preferably localized in the areas not affected by additive locally occurring factors like presence of tectonics or anthropogeneous influence (arable land, waste dumps, allochtonous building materials mixed with soil etc.). However the fault zones are part of the natural environment and due to the mineralogically and structurally altered fill of the fault planes the presence of faults can change the radon convective characteristics compared to unaltered rock. Many papers describe the active radon migration events along the active fault systems resulting in the anomalously increased radon concentration. On the other hand, the alterations of magmatic and crystalline rocks along the non-active faults increses the ratio of clay minerals which decrease the permeability. Generally, it can be said that according to geodynamic activity of particular faults the extremes (both high and low) of radon concentration can be detected (summary of recent research in Yang 2007).

For pilot study of the radon behaviour on the tectonically influenced crystalline and Proterozoic rocks 12 test localities were selected after the detailed geological maps at a scale 1 : 50 000 (Procházka et al. 1998). The localities were situated in the Moldanubian crystalline muscovite-biotitic para- and orthogneisses of Blanice furrow (Central Bohemia – localities Světlá, Smršťov Otradov, Sedlečko), in the Central Moldanubian granitoid Massif (Southern Bohemia – locality Hůrky), in the metavolcanites of Jílové zone (Central Bohemia – localities Psáry, Radlík, Kabáty), in orthogneisses and mica schists of the Kutná Hora crystalline complex (Eastern Bohemia – localities Krasoňov, Vernýřov, Kubíkovy Duby, Makolusky).

On each locality 3 test sites were measured – one situated directly at the tectonic structure and two of them 200–300 m apart in the tectonically unaffected rocks. The method of measurement was similar to that used for radon index mapping and building sites assessment (description in Chapter 6). The exact position of the fault zone was determined by geophysical Very Low Frequency method. The results of measurements are presented in Tab. 9-1 and Fig. 9-1.

9.2 SOIL GAS RADON AND DISTANCE FROM THE FAULTS

Increasing number of test sites in the radon database enabled to study the influence of the fault structures in a regional scale (Barnet 2005). 9300 test sites from the radon database of the Czech Geological Survey were georeferenced to database of vectorised tectonic structures, which is part of the database of vectorised geological maps at a scale 1 : 50 000 using ArcGIS 9.2. programme. The tectonic database comprises 119264 tectonic structures and 33131 of them is classified as detected faults. The selection database of detected faults served as an input for studying the radon behaviour on tectonic structures. The test sites were divided according the distance from detected faults into three groups: < 50, 50 – 100, >100 – 150 meters from the detected fault. Numbers of test sites within the particular distance ranges are given in Tab. 9-2.

The basic statistic characteristics were calculated for mean and maximum values in the geographically selected datasets. The substantial differencies in radon concentrations between distance ranges were observed only for test

Tab. 9-1. Mean, maximum and 3rd quartile of soil gas radon concentration over the selected tectonic faults

Locality	Geology	Rn mean (kBq.m^{-3})			Rn median (kBq.m^{-3})			Rn max (kBq.m^{-3})			Permeability			Rn index		
tectonic structure + yes, – no		–	+	–	–	+	–	–	+	–	–	+	–	–	+	–
Světlá	gneisses	14.9	15.7	21.8	14.4	15.7	25.6	24.5	31.0	29.3	1	2	2	2	2	2
Smršťov	gneisses	4.3	28.9	5.1	4.9	30.4	5.0	5.9	53.9	9.7	2	2	2	1	2	1
Sedlečko	gneisses	20.9	60.8	5.4	17.4	59.4	3.2	41.4	99.7	14.8	3	3	3	2	3	1
Otradov	gneisses	3.9	16.2	–	3.1	14.0	–	7.9	25.9	–	3	3	–	1	2	–
Hůrky	granites	140.7	352.7	194.2	117.8	150.3	54.4	284.6	531.4	452.1	3	3	3	3	3	3
Psáry	keratophyre	2.2	4.1	3.8	–	3.6	2.3	4.1	6.0	7.9	3	3	3	1	1	1
Radlík	keratophyre, tufite	1.6	6.3	3.5	1.3	3.4	2.4	2.2	15.6	7.7	3	3	2	1	1	1
Kabáty	granodiorites	22.5	8.8	11.3	13.1	6.2	6.5	47.3	19.0	22.8	1	2	3	2	1	2
Krasoňov	orthogneisses, mica schists	19.9	60.2	31.9	16.7	56.4	28.3	36.9	111.4	62.9	3	3	3	2	3	2
Vernýřov	orthogneisses, mica schists	19.9	42.2	18.3	22.1	41.9	14.3	39.5	70.6	51.5	2	3	3	2	3	2
Kubíkovy Duby	migmatites	10.7	15.8	14.6	4.1	10.1	16.9	16.1	45.1	24.1	3	3	3	2	2	2
Makolusky	orthogneisses	14.3	33.3	5.1	12.9	20.1	2.3	37.6	106.4	16.1	2	2	2	2	3	1

Permeability and Rn index: 1 – low, 2 – medium, 3 – high

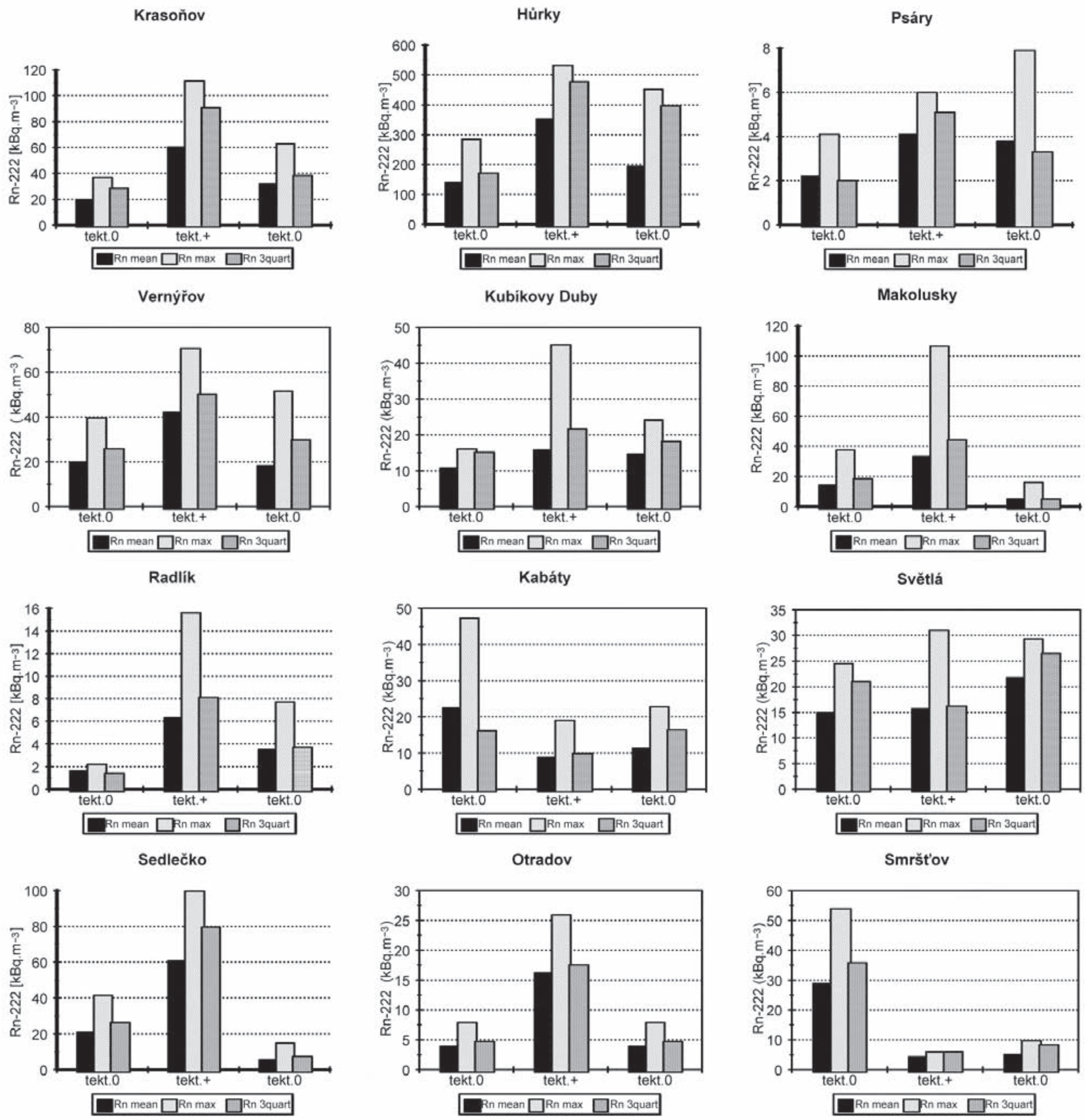

Fig. 9-1. Mean, maximum and 3rd quartile of datasets measured on the fault zones in crystalline and Proterozoic bedrock. The middle columns are situated directly on the fault zone. A substantial increase of mean and namely maximum soil gas Rn concentrations on the test sites situated on the fault zone compared to values in the tectonically unaffected rocks was found in most localities. It must be emphasized that the faults in crystalline and Proterozic rocks of the Bohemian Massif cannot be considered as recently tectonically active faults, however the occurence of remote maximum Rn concentrations at the fault course is clearly visible.

sites classified by high radon index and calculated from maximum detected values. The results of maximum Rn concentrations' statistics are given in Tab. 9-3 (grey marked cells indicate the high radon index test sites).

For each test site the permeability was also determined in three levels: 1 – low, 2 – medium and 3 – high (for details see Chapter 5). The differences in mean permeability were checked in three distance categories using the ratio of test sites with high+medium/low permeability (Tab. 9-4). Numbers of input test sites are the same as in Tab. 9-2. Calculated ratio indicates the level of radon release from bedrock according to the distance from faults. It can be observed that increased permeability at the faults supports the radon migration resulting in the occurrence of extreme (maximum Rn) test sites with high radon index (absolute maximum values and wider range of values – see Fig. 9-2.

Numbers of the test sites in distance ranges from detected faults			
Radon index	< 50 m	50–100 m	>100–150 m
1 low	21	17	27
2 medium	33	51	33
3 high	12	8	13

Tab. 9-2. Numbers of test sites within distance ranges from detected faults

Maximum soil gas Rn (kBq . m^{-3}) and distance from detected faults			
Radon index	< 50 m	50–100 m	>100–150 m
1 low			
mean	21.9	20.3	17.2
median	18	21.6	18.2
minimum	1.8	2,6	3.9
maximum	50	38.6	47.2
2 medium			
mean	48	51.7	58.4
median	38.7	50.4	52.5
minimum	15.1	16.3	17.1
maximum	129.8	134	143.4
3 high			
mean	210.5	179.8	144.4
median	166.3	163.3	122
minimum	87	92	80
maximum	556.7	347	269

Tab. 9-3. Basic statistics of maximum radon concentrations in distance ranges from detected faults

Tab. 9-4. Permeability mean levels at the distance ranges from faults

Distance from detected faults	Ratio of the test sites with permeability high + medium / low
< 50 m	6.37
50–100 m	5.2

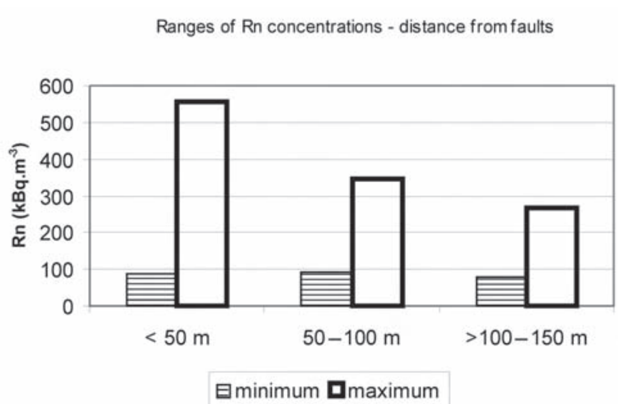

Fig. 9-2. The ranges of soil gas Rn concentrations according to distance from faults.

9.3. INDOOR RADON AND TECTONICS IN LOW RADON INDEX AREAS

One of the present studies was oriented to detect the dwellings with indoor radon concentrations exceeding the action level 400 Bq . m^{-3} which are situated on low radon index bedrock (Barnet et al. – in print). The indoor radon mea–surements (database of the National Radiation Protection Institute) was georeferenced to areas with predicted low risk from bedrock in ArcGIS 9.2. programme. From total 92 276 measurements with coordinates 11 360 dwellings are situated on the low risk and from this selection dataset only 7.3 % exceed the action level. Most of these above-level houses are situated in the contact rim of the Central Bohemian Plutonic Complex (in hornfelse bedrock and islet zone formed by Palaeozoic metabasalts and basaltic andesites), some of them were detected in the Cretaceous sediments in eastern Bohemia underlayed by granitoids of Železné hory pluton.

The most frequent area of occurrence the above-level houses is situated in the Western Carpathian nappes of E-S Moravia. The bedrock is formed mostly by Tertiary Flysch sediments (sandstones, greywackes and conglomerates) with soil gas radon concentrations in the range of 15–25 kBq . m^{-3}, classified by low radon index. Overlaying the positions of above-level houses on the tectonic scheme

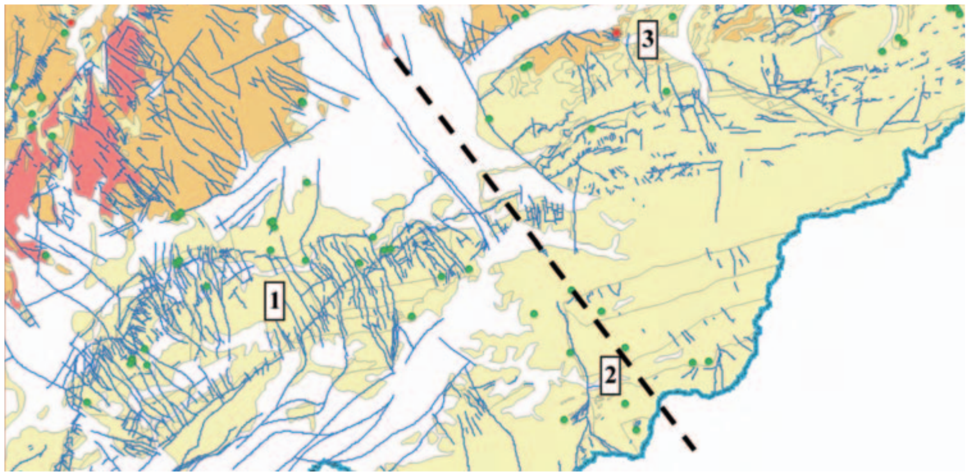

Fig. 9-3. The situation of the houses exceeding the action level 400 Bq . m^{-3} in the area of Carpathian nappes. Explanation: 1 – front planes of the Carpathian Flysch, 2 – area of influence of the deep seated fault Haná, 3 – hydrothermal activity at Teplice nad Bečvou spa.

show the areal linkage on the tectonically disturbed areas of the front part of Outer Carpathian nappes (number 1 in Fig. 9-3). The indoor radon concentrations usually do not exceed 550 Bq . m^{-3}. The outlier (number 3) with indoor Rn concentration 4358 Bq . m^{-3} was found in Teplice spa complex close to Gallas spring (CO_2 mineralised waters). The connection of above-level houses with deep seated tectonics can be discussed in the area marked with number 2 in Fig. 9-3. This area lies directly along the prolongation of the deep-seated fault of Haná, which can be detected by discontinuities in the radiometric field as well as by discontinuities of the deep bedrock lithology confirmed by prospecting deep drilling in the depth of kilometers. This tectonically weakened zone is about 20–30 km wide, coming from the Bohemian Massif into Outer Carpatian nappes. Recent – to present geodynamic activity is also evidenced by small Neogene trachyandesitic and andesitic outcrops and by presence of mineralised CO_2 rich mineral waters. The maximum indoor radon concentration reaches 774 Bq . m^{-3} in this area.

In 93 % of cases the low radon index bedrock causes under-action level indoor radon concentrations. The rest 7 % of houses on low radon index bedrock and exceeding the action level is situated in the areas influenced by tectonic disturbances and untypical development of underlying rocks. From the position of the houses it can be deduced that even deeper radon potential basement covered by rocks with low soil gas radon concentrations can increase the indoor radon levels in dwellings. For detecting the above-action level houses also the effect of contact metamorphosis connected with thermal and pressure restructuring of low radon index rocks in the rims of granitoid intrusions plays an important role. Therefore even in the non-active tectonically influenced areas the anomalous soil gas and indoor radon concentrations must be expected and targeted indoor radon surveys should comprise these areas.

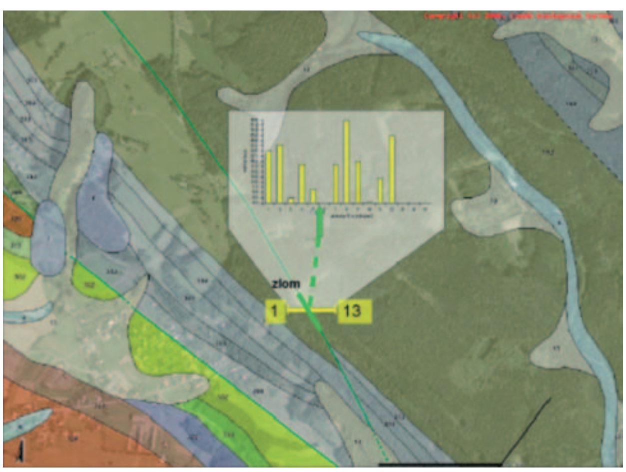

Fig. 9-4. The profile acroos the Hronov-Poříčí fault west of Náchod in Carboniferous sediments (locality Bohdašín). Reprinted by courtesy of Helebrandt (2007).

9.4. RADON AND TECTONICS IN THE SE PART OF THE BOHEMIAN MASSIF

One of the tectonically oriented studies cover the SE part of the Bohemian Massif formed by Permo-Carboniferous sediments (Helebrandt 2007). The seismo-tectonic activity has been observed in this area since 1883 (Laube 1883), in 1901 (Gränzer 1901, Woldřich 1902 – earthquake with magnitudo 7° MSK), the later earthquake swarms were observed also in 1905, 1984, and 2004–2005 (Špaček et al. 2006). 11 profiles across the thrust fault of Hronov-Poříčí were measured. The detailed course of the thrust plane was detected using the vectorised geological maps and ortophoto images, as the general orientation of the thrust fault did not enable using the geophysical Very Low Frequency method (Fig. 9-4). The distance between measuring points was variable (3–5 m) to cover the thrust plane together with the overlap into tectonically non-disturbed rocks. In spite of the expected soil gas radon anomalies situated in the center of the thrust plane, the altered clayey fill of the thrust plane nearly in all measured profiles decreases the radon concentration in the centerline of the thrust and increased radon concentration is observed only in the non-altered rock.

Another manifestation of the role of tectonics was observed in Culm low metamorphosed Carboniferous

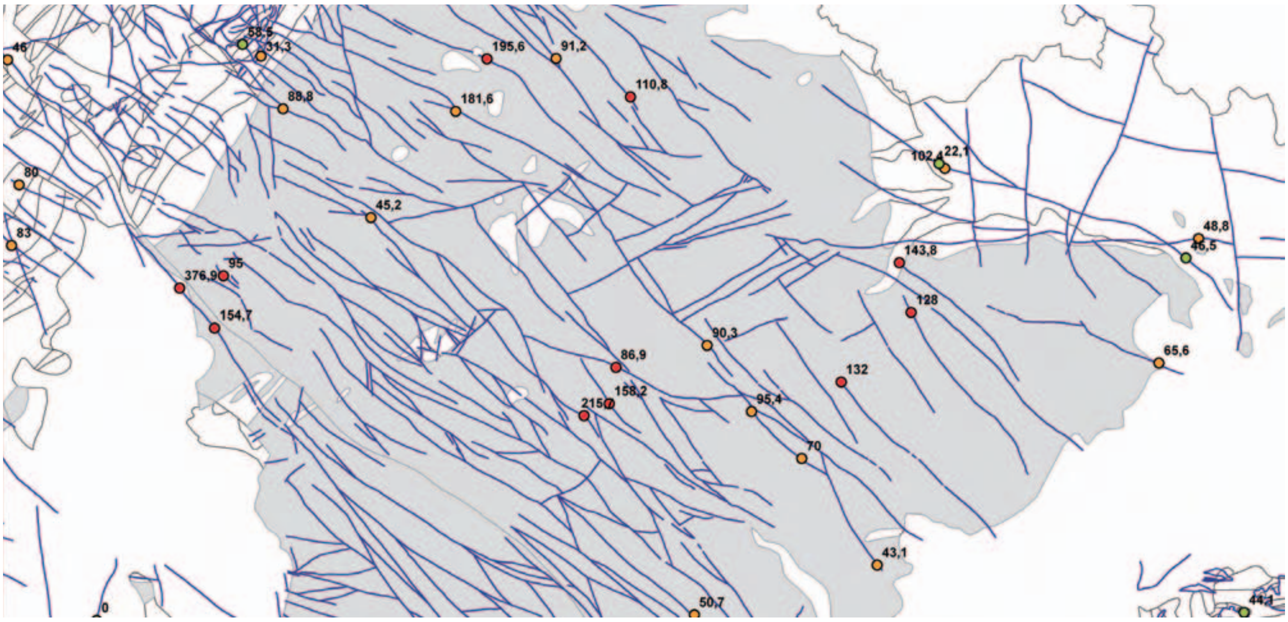

Fig. 9-5. The maximum soil gas radon concentrations on the test sites bound to tectonic structures in Culm metasediments of Northern Moravia. • high radon index, • medium radon index, • low radon index.

metasediments of Northern Moravia. Culm flysch metasediments are formed mostly by shales, greywackes, sandstones and conglomerates and from the radiometric point of view they are relatively monotonous. The Culm flysch formation is generally classified by medium radon index (mean soil gas radon concentration is 41 kBq . m^{-3}). The soil gas radon measurements were performed during the radon mapping programme at a scale 1 : 50 000. The selected test sites (shown in Fig. 9-5) are situated in the distance to 100 m from the faults oriented NW-SE. In most cases the maximum soil gas radon concentration (from 15 measurements at each test sites) exceeds 90 kBq . m^{-3} and the test sites are classified by high or medium radon index. Compared to mean radon concentration 41 kBq . m^{-3} the extreme outliers on the tectonically influenced test sites are obvious. From the geodynamic point of view the whole area reflects the stress processes in the Carpathian belt, which is evidenced also by recent microseismic activity (Havíř 2002) and by vectors of GPS monitored movements (Schenk et al. 2002)

Even in the areas of low geodynamic activity (Bohemian Massif) the tectonic structures of all orders play an important role in radon migration from deeper basement. The evidences of soil gas radon anomalies on the tectonic structures are pronounced mainly in general scales and are partly reflected also in the enhanced indoor radon concentrations. Resulting from the above mentioned studies, the radon migration on the tectonic structures is dependent on the structure type and namely on the fill of structure. Most of tectonic structures formed in granitoid and crystalline basement underwent the mineralogical alteration of the structure fill and the presence of clayey minerals directly in the structure plane decreses the radon release from bedrock. On the other hand, the ways for radon transport are shifted to marginal parts of structure in the contact with tectonically unaffected rocks. Therefore in detailed scale the increasing of radon concentration range must be expected and the presence of outlier concentrations is an frequent phenomenon. Thus the areas influenced by tectonics must be considered as radon active areas.

10. Geostatistical methods for radon risk evaluation

Supposing that radon coming from the geological basement is the major source of radon in houses (and radon from building materials and water originates also from rock material and surrounding rocks) the soil gas radon research brings the basic information for targeted indoor radon studies. The rock material is very inhomogeneous even in a small scale of several tens of meters, therefore the statistical approach is necessary to characterize particular rock types. Sufficient number of soil gas sampling points (probes) is the basic demand for determining the radon concentration ranges in particular lithological types.

The basic difference between rock types can be found in the petrogenesis of lithotype – magmatic, metamorphic and sedimentary. The source element for radon origin is uranium ^{238}U and generally it can be said that the mean uranium concentration decreases with the above mentioned sequence of the genetic rock types. However the magmatic and metamorphic processes give rise to new rock types and redistribution of the parent element uranium in the newly formed rocks is commonplace. Therefore some geological units with generally lower uranium concentration can contain the uranium enriched areas resulting also