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# MINERAL WATER SPRINGS AND THE SEISMIC ACTIVITY WITHIN THE WESTERN BOHEMIAN AREA

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ABSTRACT. Springs of natural mineral waters within the Western Bohemia area represent the meaning natural phenomenon as regard their varied composition and wide occurrence. The regimen of these waters has been influenced both a nam–made activity and seismic activity that is known for long time. In this paper possibilities and conditions are appraised concerning a correlation of seismic phenomena with changes of several parameters of mineral water springs. The most suitable indicators for an observation of changes, induced by natural processes, are radon and carbon dioxide in the gaseous phase of the mineral water outflow. The radon is sensitive on shocks with the low energy.

## 1. INTRODUCTION

The diversified composition and the broad occurrence of mineral waters within the spring area in Western Bohemia represent a significant natural phenomenon. The quantity and quality of mineral water of this region are affected by technogenic activities, such as drawing of waters, contamination of both surface and groundwaters, inadequate interventions in surroundings of springs and in infiltration territories, by mining of raw materials, etc. Mineral water springs reflect also natural processes taking place within the Earth's crust. One manifestation of these processes is the seismic activity, which has been known and recorded in greater detail during the last decades. The observation of changes in several mineral water springs confirms connections between them and the manifestations of seismic activities (Heinicke, Koch and Martinelli, 1993; Koch and Heinicke, 1994; Kaempf et al., 1989; Novotný et al., 1987). Anomalies observed in the spring regime are, in some cases, significant as seismic activity precursors (Heinicke, Koch and Martinelli, 1995). Possibilities of practical utilization of monitoring of seismic activities for the study of mineral waters are looked for.

The territory spring area in Western Bohemia is delimited, towards N and W, by the state border, the southern limit being formed by the connecting line Tachov–Stříbro. The eastern border is formed by Úterský potok (creek), Podkova hill (749 m) in Doupov Mts., river Ohře and surroundings of Jáchymov Spa. The western part of Bohemian Massif ranges among most geologically and hydrogeologically complicated and complex regions of the Czech republic. Extensive possibilities of landscape utilization (mining of mineral raw materials, spa resorts, agriculture, etc.) create clashes of interests, which mostly result in negative environmental impacts.

## 2. Geological Characteristics of the Territory

Geologically, the West–Bohemian region involves the boundary block contact territory, within which the deep faults are crossed (Fig. 1). The tectonical development was in substance terminated by the Hercynian orogenic. The ensuing phase of the platform development has been completed by the Saxonian tectogenesis of fault character with manifestations felt till present time. The Moldanubian region, as the oldest complex of the Bohemian Massif basement, is partially represented by the Moldanubicum of the Český Les Mts. at the SW border of the territory. The West–Bohemian fault zone, forming the Mariánské Lázně and Tachov faults, the Bohemian Quartz Lode, is considered the boundary contact territory between Moldanubicum and Bohemicum (Dudek, 1987, in Mísař, 1983). The Krušné hory Mts. form the SE part of Saxothuringicum, which is separated from the Bohemicum by the Litoměřice deep fault. The Slavkov crystallinics, as a part of the Krušné hory region, represents the connection between this and the central Bohemian region. Characteristical features are here numerous intrusions of Hercynian granitoids (Žandov massif etc.). An extensive shallow basin in a morphologically characteristic graben in SW–NE direction was formed as a consequence of subsidence within the broader neighbourhood of the Litoměřice fault. During the period from Eocene to Oligocene, this basin decomposed into three partial basins, but the Pliocenic sedimentation took place only in the Cheb basin. The direction of this basin is NNW–SSE, which is attributed to the synsedimentary and postsedimentary effects of the Tachov graben faults (Koudelková, 1995). The continuation of the Mariánské Lázně fault is markedly restricted by the eastern edge of the Cheb basin, other borders being mostly transgressive. The morphology of the basin's basement induced the formation of three separate basins, Odravian on S, Františkovy Lázně basin on W and Oldřichov – Pochlovice basin towards N and NE. Incoherent occurrence formations at the E edge of Mariánské Lázně fault are ranged to the Tertiary of SW Bohemia.

Neovolcanites are represented by the extensive stratovolcano of Doupovské hory Mts., which was created on the crossing of faults in the SW–NE direction with the deep fault of Jáchymov. Typical is the frequent occurrence of minor volcanic bodies within the crystalline rock territory of Krušné hory Mts., Slavkovský les Mts., Smrčiny Mts. and the youngest volcanoes in the Cheb basin – Komorní Hůrka and Železná Hůrka. Among Quaternary sediments, most important are those of elevated terraces. Within the Cheb basin, proluvial–fluvial sands with thickness of several tens metres have been developed along the eastern edge fault.

## 3. Tectonical Characteristics

Fault systems of the first order have directions of NE–SW to ENE–WSW and further NW–SE to WNW–ESE, accompanied with parallel faults of minor significance. Less frequent faults of the strikes N–S to NNE–SSE are encountered. The

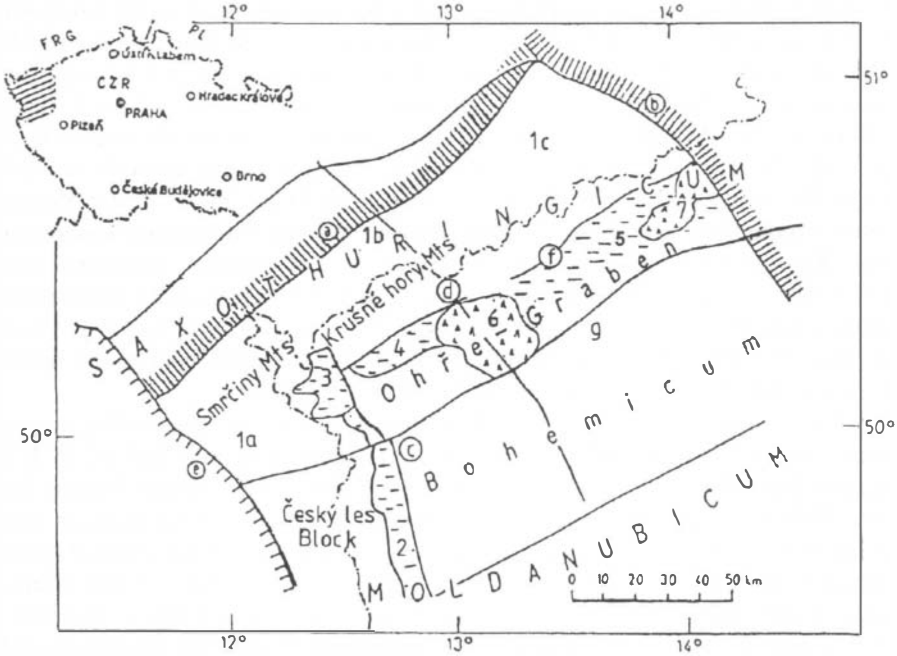


FIG. 1. Principal tectonic and geological units (adapted after Kossmat, 1927; Grünthal et al., 1990). Geological units: 1a – Smrčiny Mts. anticlinorium, 1b – transverse zone of southern Vogtland and western Krušné hory Mts., 1c – Krušné hory Mts. anticlinorium; 2 – Tachov–Domažlice Graben; Tertiary: 3 – Cheb Basin, 4 – Sokolov Basin, 5 – Northern Bohemia Basin; Neovolcanites: 6 – Doupovské vrchy, 7 – České Středohoří; a – Central Saxonian Lineament, b – Labe Lineament, c – Mariánské Lázně fault zone, d – Jáchymov deep fault, e – Franconian fault zone, f – Krušné hory Mts. fault, g – Litoměřice deep fault

formation age these faults comes to the Cadomian folding of the end of the upper Proterozoic and partially to the Variscan folding of the end of Palaeozic. More recent periods witnessed only revived movements on older structures and the faults in the basement manifested themselves in the platform cover up to the Quaternary sediments. The Variscan folding is also characterized by granitic magmatism during the Krušné hory phase period.

The neoidic tectogenesis was the deciding period for the formation of favorable conditions of creation and occurrence of mineral waters with gaseous carbon dioxide within the West–Bohemian spring area. In the Krušné hory Mts., this cycle made itself felt most during the formation of foothill basins of Krušné hory with linear tectonics and manifestations of recent volcanism. The foothill basins of Krušné hory exhibit geological and geophysical features of a continental rift (Kopecký, 1979; Zeman, 1988). The Ohárian rift, which reaches from Cheb up to Hrádek nad Nisou, was formed on an ancient mobile zone between the Saxothuringicum and Bohemicum. The rift is delimited by two antithetic faults – that of Krušné hory fault on the NW side and the Litoměřice fault on SE side of the central faults (Figs. 1, 2). The rift development was accompanied by intensive volcanic activities from the Tertiary till Quaternary. Main subsidences began in the lower Miocene and were accompanied by sedimentation between the first and second neovolcanic phases. The third phase asserted itself only in the Cheb basin. Geomorphologically, the rift has been formed probably already since Pliocene and its development continues even at present time. Manifestation of recent endogenic activity, mostly the seismic one, point the attention to the fact that the development of the Krušné hory region will continue also in the future (Zeman, 1988).

The Tachov graben (Planá hollow – Hynie, 1963) is another outstanding tectonic element, elongated in the NNW–SSE direction. This graben is limited to E by Mariánské Lázně fault and to W by the Aš cleft, further to SE by the Tachov fault and the Bohemian Quartz Lode (Fig. 1). Three phases of tectonic motions made themselves felt during Tertiary sedimentation. A system of horsts and ditches has been formed in the Cheb basin, from which an up to 300 m thick filling is situated at the eastern edge fault. The third phase of movements found its place in the formation of actual relief including the hydrographic network, and divided the sedimentation space into a system of partial fault blocks (Koudelková, 1995).

Among the displacements of the NNW–SSE direction, most outstanding is the Mariánské Lázně fault. Together with the Tachov fault, it forms a part of the West–Bohemian fault zone.

This zone is crossed, in the north, by the weakened zone of Krušné hory and predisponed the foundation of the Cheb basin. Both marginal faults indicate the presence, within the deep structure, of a ditch with basic volcanism. The intrusion of the Kynžvart granite suggests the fact that the Mariánské Lázně fault was limited, to N, by the Krušné hory zone already since the upper Palaeozic. The height of the throw is a result of Tertiary motions.

## 4. Hydrogeological Characteristics

The prevailing type of the environment is a hydrogeological massif formed by crystalline rocks. After–effects of active volcanic activity are displayed by regional occurrences of carbon dioxide which, depending on the geological structure, form numerous springs of waters with gas and the accumulations in basal sediments of the basins. Hydrogeological massifs are characterized by near–surface aquifer, for that is typical the higher permeability as a result of rocks loosening and weathering. The rock permeability of fundament depends on an extent and conductivity fault and fissure zones, which take both conductive and storage functions.

The territory basins are characterized by prevalence of structures with confined groundwater bodies located also in bedrocks. Groundwaters range among hydrodynamical zones of both active and decelerated flow. The reach of the active flow

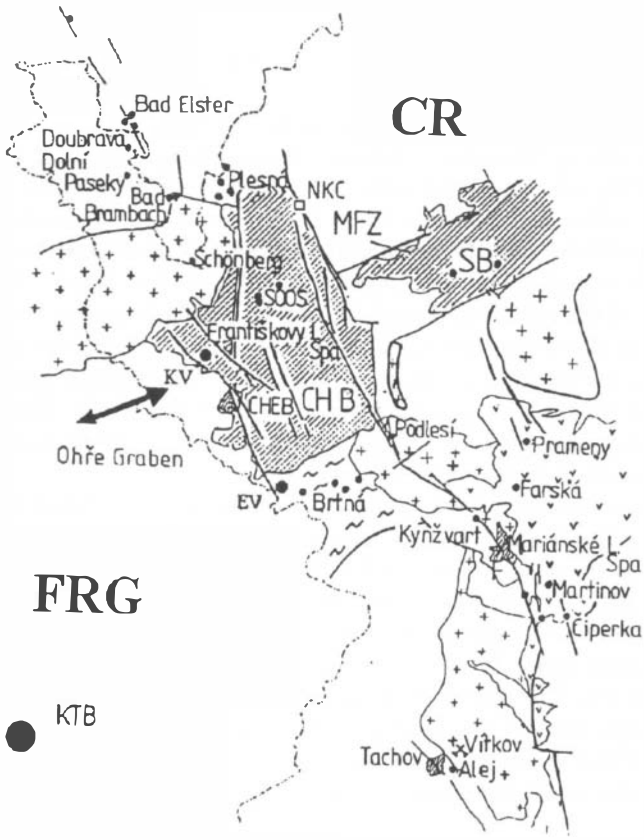


FIG. 2. Scheme of the geological settings of the W–Bohemian region and Vogtland (adapted after Heinicke and Hanzlík, 1996). CHB, SB – Cheb and Sokolov tertiary basins; MFZ – Mariánské Lázně fault zone; KV, EV – Komorní hůrka and Železná hůrka volcanoes. Geological legend: + granite, ᵛᵥᵛ amphibolite, ≈ mica schipt, □ phyllite; • mineral water springs with $CO_2$ content; NKC – Nový Kostel seismic station

does not exceed 200 m. The upper limit of the zone of decelerated flow is limited, in basins, by the lower part of the Cypressian strata series (Kolářová et al., 1986). According to the analogy of the mine Vítkov II near Tachov and results of the deep well KTB, the zone of the decelerated water flow attains 1500 to 2500 m. Natural drainage of groundwaters within the Cheb basin depends on the level of the erosion basis of the Ohře river. In the Sokolov basin, the flow of underground and gassed thermal waters from the basin's bedrock is basically changed by considerable drawdown of water head by intensive pumping of thermal waters on the open–pit mine Jiří.

## 5. Gassed Mineral Waters

Mineral water of western Bohemia form a part of the European province of carbonic waters, which continues, from France, across the Eifel mountains on central Rhine, Smrčiny Mts. (Fichtelgebirge) along Krušné hory Mts. to northern Bohemia and across northern Moravia to Silesia. Main outflow centers of mineral thermal waters and $CO_2$ are connected with a crossing of rift structures with weakened zones. In the spring region of Mariánské Lázně Spa, it is the direction of the Tachov graben, in the Cheb basin the submeridional line, and in the territory of Doupovské hory Hills the crossing of the Jáchymov and Litoměřice faults. The neotectonic development of the territory, namely the subrecent Quaternary dynamics, had the main effect on the hydrodynamical regime of groundwaters and the formation of infiltration and drainage parts of spring structures. The relation of the occurrence of gas–saturated waters to main structural zones is schematically illustrated in Fig.2. Carbonic waters do not occur in geologically ancient territories of Moldanubicum and crystalline rock formations of Domažlice.

The region of cold carbonic waters reaches from the Krušné hory graben far towards NW, S and SE. Carbonic waters are formed in the environment of crystalline rocks in the area of Smrčiny Mts., Slavkovský Les Mts., Teplá platform and Krušné hory Mts. The richest region with recurrence of carbonic waters within the Bohemian Massif is the spring area of Mariánské Lázně reaching as far as to Konstantinovy Lázně Spa. The elevation and recent lifting of the crystalline formation of Slavkovský Les Mts. help in degassing of $CO_2$ and concentration of outflows of gas–saturated waters. Outflows of mineral waters and carbon dioxide into sediments of the Cheb basin are mostly connected with the contact area of the Smrčiny granite with the crystalline mantle (Šantrůček, 1986).

## 6. Geodynamic Characteristics of the Territory

The actual tectonic activity within the studied territory can be demonstrated by the elevation of Doupovské Hory hills and the central part of Krušné hory Mts. (2–3 mm/year) as well as by the ascertained lifting of the eastern peripheral block of the Cheb basin (Vyskočil and Kopecký, 1974 in Dudek, 1987). These informations lead to the assumption that the Mariánské Lázně fault is still active. Long–term seismic observations support the opinion on the activity of young faults. Tectonical motions during individual periods are activated on different faults, either in the direction of the Tachov graben (more frequent) or, infrequently, in the direction of the Ohár rift (Dudek, 1987). Shearing deformations in the seismically active area of the Cheb basin occur in the approximate direction of the Mariánské Lázně fault (Vyskočil, 1987). The changes of the groundwater level are also affected by the tide forces, in the Cheb basin at Křižovatky and in the territory of Jehličná of the Sokolov basin (Špičák, personal communication).

The territory of western Bohemia is characterized also by the occurrence of earthquake swarms. Seismic activities have been observed in the regions of Aš, Adorf (FRG), Kraslice and Skalná already since year 1198. More important swarms were observed in 1522, 1701, 1771, 01–02/1824, 1850, 10–11/1897, 05–06/1901, 02–


FIG. 3. WEBNET (Western Bohemian Network) – positions of seismic stations: △ – stations of the Geophysical Institute AS CZR and Institute of Rock Structure and Mechanics AS CZR; ▲ stations of the Institute of Earth Physics, Masaryk University Brno; • earthquake foci (1–6 areas, Horálek et al., 1996); MFZ – Mariánské Lázně fault zone

05/1903, 10–11/1908, 1911, 05/1929, 1936, 08–10/1962, 03/1973, 11/1985–02/1986, 03–05/1992, 12/1994 (Brož and Buben, 1993; Schenková, 1996; Buben and Rudajev, 1963). The last considerable swarm was observed in January 1997 (Horálek, personal communication). During the last 5 years, the network of recording seismic stations WEBNET (Western Bohemian Network) has been established (Fig. 3).

Systematic precise measurements and observations of seismic phenomena prove the stability of distribution of sites where earthquake events occur; these are concentrated into six main regions (Horálek et al., 1996). The region 1 is seismically most active and it adjoints most closely the northern part of the Mariánské Lázně fault (Figs. 2, 3).

## 7. Relation of Seismic Phenomena to Gas–Saturated Mineral Waters

The seismic activity in western Bohemia is determined by the crossing of tectonically weakened zones. The changes of gaseous and chemical composition and regime of a mineral water spring, connected with seismic activities, are a consequence of preseismic, postseismic or coseismic events resp. These are most frequently reflected by anomalies of some mineral water parameters. While the preparation of an earthquake is a long–term process, the stress redistribution after occurrence of a focus is a short–time process. Changes in the regime of mineral water springs are the seismic manifestations differ by the character of their data. Changes of the mineral water parameters create more or less continuous series and, unlike that, the seismic events have a discrete character. However, the determination of a relation between these time series depends on the acquisition of input data at a comparable standard of instrumentation (automation of records of the changing spectrum of mineral water parameters). As a feedback, the study of correlations of seismic, hydrogeological, and geomechanical data series may improve the prediction precision of seismic events within the given territory (Heinicke and Hanzlík, 1996; Muir-Wood et al., 1993; Roeloffs, 1988; Kissin et al., 1988; Mogro-Campero et al., 1980; Shapiro et al., 1980).

The connection between seismic events and their manifestations within the hydrogeological massif or within the platform cover are sufficiently known. Brož and Buben (1993) quote examples from the Tashkent geodynamical polygon in Central Asia: reduction of water yield in a borehole at the distance of 100 km from epicentrum (Daghestan 05/1970), tenfold change of the helium content in the borehole water prior to the earthquake in Tashkent 1966, anomalous changes of concentrations of $CO_2$, H, N, F, B, Cl, He prior to a strong earthquake in Central Asia, these changes having a jump character. E.A.Roeloffs (1988) quotes from the years 1964 till 1983, a review of hydrogeological changes (drop or rise of water level in boreholes, overflows of water and crude oil), induced with the time advance of hours, days, months, and years prior to actual earthquakes. The observed water level fluctuations in China, USA, Japan, USSR, and Turkey (increase of the spring water yield at the fault) varied within the order of $10^{-2}$ m. Hydrological changes were mostly observed at deeper boreholes, tens and hundreds kilometers distant from epicentres and lasting a longer time. In the active territory of Sicily, a sudden and strong release of $CO_2$ connected with the earthquake in December 1990 has been established (Aglio et al., 1995). After the earthquake, a continuous decrease of the $CO_2$ content in groundwater along the marginal fault Augusta Graben has been observed at the epicenter. R.Muir-Wood (1993) describes the considerable increase of water flow in rivers and water yield of a spring several days after the earthquake Hebgen Lake (19–08–1959) and Boran Peak (28–10–1983), which continued for 2–12 months. Total volumes of water, releases by the normal fault earthquakes, amounted to 0.5 cb.km and 0.3 cb.km. The author eliminated the effect of precipitation water. E.A.Roeloffs et al. (1989) describe water level changes in the borehole in the proximity of San Andreas fault, induced by a fault creep in 1987. Water level changes were observed in two collectors with different depths (85 and 250 m). Changes of the level in the deeper collector lasted for 2 months, compared with 1 day in the other one. From the active area of the same fault, changes of water pressure in the borehole (152 m) induced in 1971 and 1972 by the fault creep are described (Johnson et al., 1974).

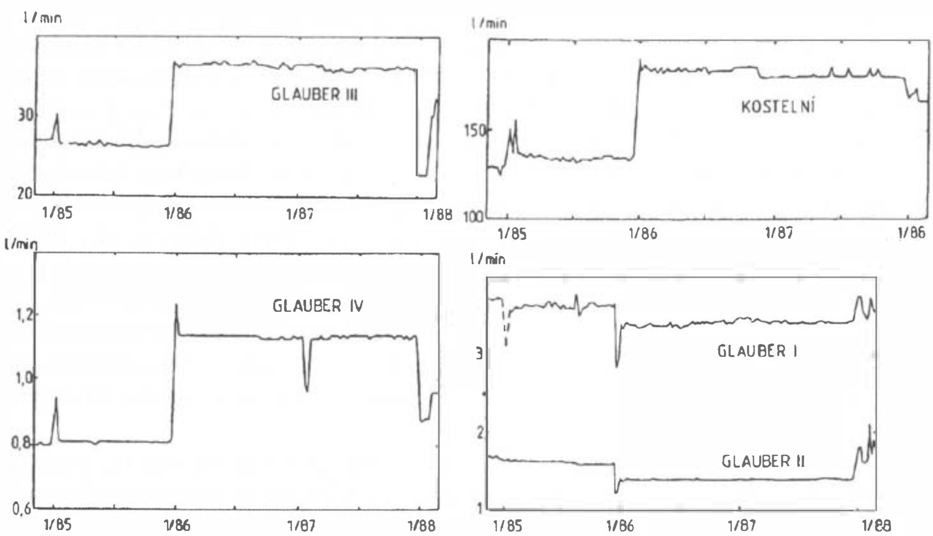


FIG. 4. Changes of the discharge (l/min) of corresponding Františkovy Lázně Spa mineral water springs during and after the period of the increased seismic activity in Dec.1985–Feb.1986 (after Novotný et al., 1988)

The seismic activity in western Bohemia has been known since several centuries. A deeper study of these phenomena has been developing during the last 20–30 years. Within the time interval from 1961 to 1994, earthquake swarms have been recorded, among which the most significant took place at the turn of years 1985–1986, with macroseismic effects and an earthquake shock on 21–12–1985 ($M = 4.6$). In the course of this swarm, an increase resp. decrease of the water yield was observed on some springs in Františkovy Lázně Spa (Novotný et al.,1987; 1988). The increased mineral water yield was measured on springs Glauber I and III, Kostelní. The water yield of spring Glauber I and II was somewhat lower (Fig. 4). The course of yield changes of the spring Glauber III shows that the flow increased already 11 days before shock. The induced water yield changes for the spring Glauber III (38 %), Glauber IV (40 %) and Kostelní (37 %) at the beginning of 1986, compared with November 1985, were recorded during the years 1986–1987 without significant changes (Fig. 4). At the turn of the years 1987–1988, a considerable decrease was recorded for springs Glauber II and IV, followed by a slight increase above the level prior to the seismic event. The Kostelní spring exhibited only a slight yield decrease, but its discharge was still higher that prior to December 1985. Springs Glauber I and II increased their water yield to the original value. Both groups of affected springs are situated in the Františkovy Lázně graben, which is linked up with the Krušné hory graben towards W and along the massif of Smrčiny granite. Springs with increased water yield are found in close neighbourhood in the centre of main spa springs. Springs Glauber I and II are situated at 400 m distance from each other and are located in NW part of the spa centrum, 630 and 830 m distant from the first spring group. Springs Glauber III and IV are intercepted by boreholes in the depth of 53.5 and 86 m, compared with other springs, where the drill depth practically does not exceed 30 m. The described changes point to changes of flow paths due to strains in the massif, induced by redistribution of stress. Reactions to seismic events in the hydrological regime are more expressive in springs intercepted at deeper levels close to basement than at those intercepted at shallower levels, which corresponds also to other fields (Roeloffs et al., 1989; Aglio et al., 1995). The study by O.Novotný (1985) deals with the application of some groundwater parameters as earthquake precursors. Main attention is paid to hydrogen released from crust during geodynamic processes. Measurements of changes of temperature, electrical conductivity, concentrations of radon, helium, argon, carbon dioxide, and pH are recommended. The accumulated information concerns mostly territories with seismic activities of higher energy.

It should be stated that relations between seismic phenomena and the mineral water regime are mostly not quoted in hydrogeological literature of western Bohemia (Kolářová, Hrkal et al., 1986; Klír, 1982; Hynie, 1963). A certain exception is presented by the report by J.Knett (1898), who proved that there does not exist any connection between thermal springs of Karlovy Vary Spa and three recorded shocks during the earthquake swarm between 24.10. and 25.11.1897. He states as well as that earthquake events in 1885 did not affect the regime of thermal springs. However, the big earthquake, which took place in Lisabon on 1.11.1755, induced a certain "turbidity" of thermal springs in Karlovy Vary Spa.

The West–Bohemian seismic region is linked up with the region of Vogtland (FRG). Kaempf et al. (1989) evaluated the measurement result on the spring Marie I in Bad Elster in relation to the earthquake swarm in 1985–86. His remarkable report describes measurements of a set of parameters, consisting of the observation of hydrologic and climatic data, determination of elements (Na, S, Ca, Mg, K, Ba, Sr, Fe, Mn) and deuterium, measurement of specific conductivity. All measurements were made daily from September 1985 to February 1986 as a continuation of observations started already in 1983. The measurement system included also the spring Radon–Quelle in Bad Brambach and the thermal spring in the fluorite mine Schoenbrunn with a weekly measurement frequency. A correlation of changes in connection with the earthquake swarm has been established. The authors make it clear that the reliability of results is determined by their frequency and daily measurements are considered adequate for the given conditions. J.Heinicke et al. (1993; 1995) observed, on the territory of Vogtland, concentration changes of radon and $CO_2$ in gaseous phases on springs Radon–Quelle and Eisen–Quelle in Bad Brambach, as well as the electric conductivity of water. Measurements involved the period from 11/1989 to 12/1992, i.e. during the occurrence of low–energy earthquake shocks. The authors confirmed the correlation of radon and $CO_2$ anomalies with earthquakes in the eastern part of Smrčiny Mts. (Fig. 5). Shocks located in the the E direction close to the Mariánské Lázně fault outside the structure of Smrčiny have their hypocentrum at the depth of 5–9 km. Thus, the observation of concentration changes of spring gases proved their significance as earthquake shocks precursors (Fig. 5). The main reason is the bigger mobility of gases on their conducting paths from the crust or mantle, higher sensibility and quicker reaction to deformations within the stress field. Changes of hydrological parameters of springs, induced by seismic events, have mostly a conservative course, conditioned by formation of new flowpath ways. In January 1997, an important earthquake swarm was recorded in the Cheb basin – region 1 (Fig. 3). This swarm was indicated by the radon anomaly in Bad Brambach with the advance of 10 days (U.Koch, J.Horálek, personal communication 1997).

The study of U.Koch and J.Heinicke (1994) analyzes the effect, on concentration changes of radon and $CO_2$ in springs in Bad Brambach, of a distant earthquake in Roermond, Netherlands. A.Mogro-Campero et al. (1980) recommend the radon concentration measurements as possible earthquake shocks precursors. Basing on the week–long measurements of radon in the soil air at the depth of 0.6 m at Blue Mountain Lake territory (New York), they establish the effect of a seismic event ($M = 3.9$) 14 km distant. During the subsequent three years, the radon concentration dropped with decreasing seismic activity. The author points out that, due to "sensibility" of the observation site, the radon measurements must not necessarily have the character of an earthquake shocks precursor. The similar opinion is expressed by Ta-Liang Teng (1980), who suggests laboratory measurements of the radon content with weekly sampling frequency. Shapiro et al. (1980) quote results of radon monitoring in southern California at earthquake manifestations ($M = 2$–$2.5$). A change of the stress field is a condition for anomalous radon contents in water or air. W.Irwin and I.Barnes (1980) describe the relation of the occurrence of $CO_2$ to tectonic structures and earthquakes. They point, at the same time, to the usefulness of monitoring the radioactive elements with short half–life for prediction of seismic events. F.H.Weinlich et al. (1993) emphasize, on the example from the Ohár rift, the importance of measurement of $^3He/^4He$, $^{15}N_2$ in gaseous phase of mineral waters, for the evaluation of their origin. The actual observation standard of changing parameters of mineral waters does not enable the detailed correlation of measurement results with seismic events to be carried out. Automatic independent measurements of selected mineral water parameters are a precondition for a reliable correlation with geodynamic events. As far as the stability of mineral water springs is concerned, measurements of seismic activities may contribute to the evaluation of changes of spring regime, for example, in connection with distant and near earthquakes or artificially induced tremors.

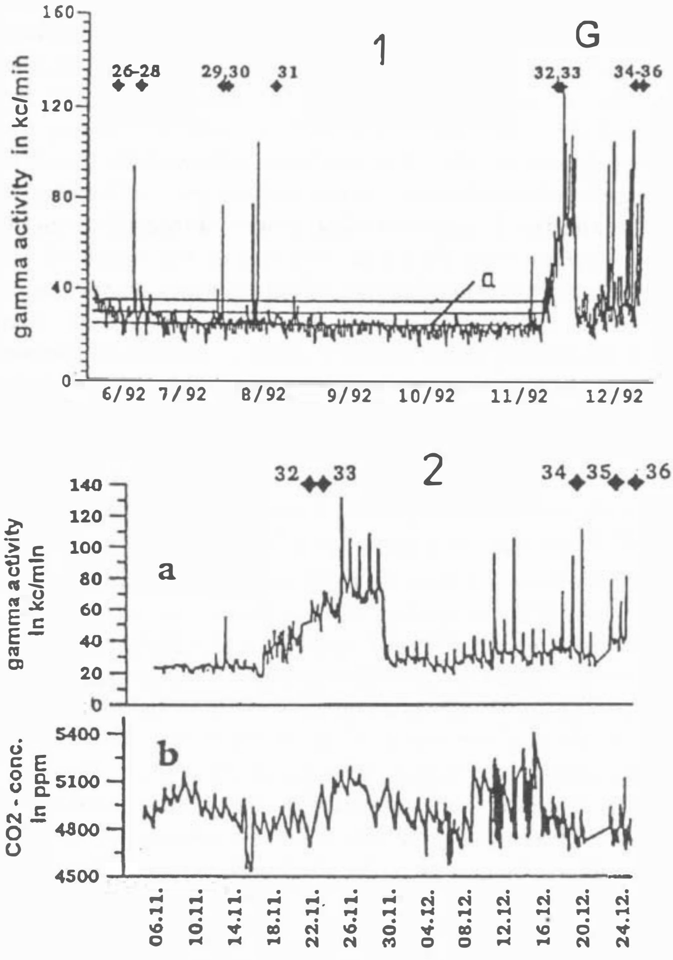


FIG. 5. 1 – Gamma activity recorded at the "Radon–Quelle" in Bad Brambach (FRG) for period G (observations were started in Nov.1989) and earthquake occurrence in the Vogtland area (squares); a – average activity of the period G. 2 – Gamma activity (a) in the water as well as $CO_2$ content (b) in the spring gas of the Radon–Quelle together with the earthquakes fro Nov. to Dec.1992 of the period G (adapted after Heinicke et al., 1995)

The observation of seismic events can also contribute to the study of mobility of the territory's tectonical structure. A good example is the synthesis of structural–geological information, earthquake measurements 1985-86, remote Earth sensing, etc., quoted in the study by Grünthal et al. (1990). This report confirm the

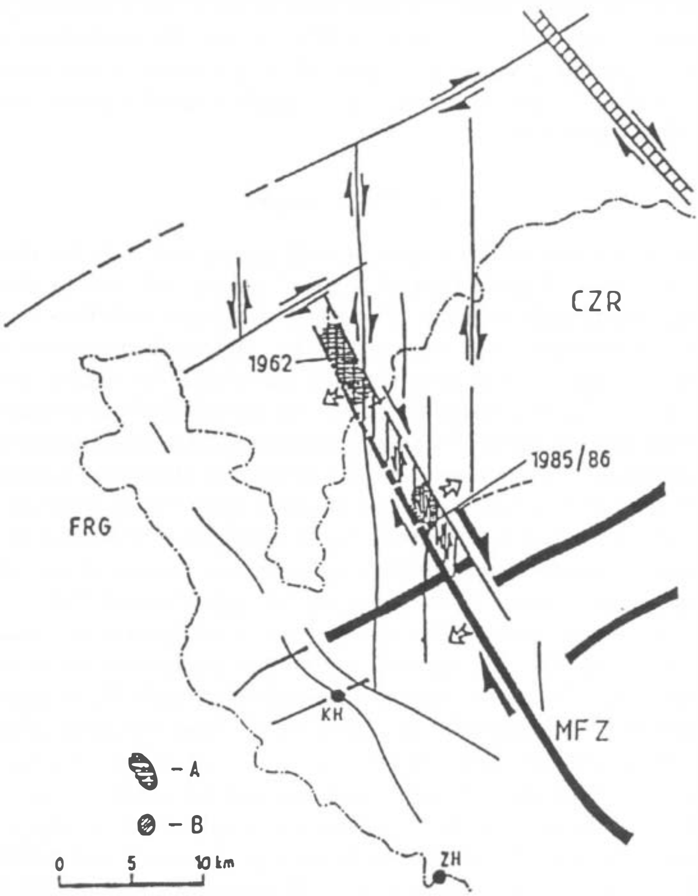


FIG. 6. Seismotectonic scheme for the focal zone in Vogtland/Western Bohemia (Grünthal et al., 1990). A – epicentral zone of swarms. B – youngest volcanoes, active $0.85 \pm 0.1$ Ma B.P. (Kh – Komorní hůrka, ZH – Železná hůrka). The tendency of the tectonic blocks for horizontal movements is given. Hatched parts depict epicentral areas of swarms sited within the Mariánské Lázně fault zone (MFZ). Dextral creep is observed in the N–S fault elements intersecting the Mariánské Lázně fault zone, where as sinistral elastic rebound occurs during the local process of swarms

significance of the Mariánské Lázně fault zone, it delimits partly its mobile part including the territory without significant seismic activity SE of the Krušné hory foothill graben (Fig. 6). Important is the evaluation of the effect of N–S structures, which disrupt the course of the Mariánské Lázně fault. Similar complex evaluation of information may significantly complete data required for a rational protection of mineral water springs. With the view of this purpose, the protection zones should be aimed at structural elements and their effect on formation and yield of mineral waters also outside the proper spring region. Such a trend depends also on several changes in the property law.

## 8. Conclusions

The West–Bohemian spring region is well–known not only by the abundance of a broad spectrum of gas–saturated mineral waters, but also by the occurrence of low–energy earthquake swarms. The effect of seismic activities on the mineral water regime is selective, but beyond dispute. Although numerous and detailed measurements of seismic actions are carried out within the region, possibilities of their application to hydrogeological evaluations are still limited, because sufficiently compatible observation series of changing parameters of mineral waters are still lacking. This shortage is particularly evident along the Mariánské Lázně fault zone. Measurements of concentration changes of radon and $CO_2$ on selected mineral water springs are important contributions to the evaluation of seismic events. Radon is an adequate indicator for territories with the occurrence of low–energy earthquake shocks. Observations of the changing concentrations of $CO_2$, whose sources are situated at deeper crust levels, are rendered more precise by measurements of radon, which are adequately completed by isotopic measurements of helium, nitrogen, deuterium, etc. Actually, concentrations of radon and $CO_2$ in gaseous phase of mineral water are experimentally measured on the Soos structure (Fig. 2; U.Koch, personal communication). Quite realistic is the use of seismic observations for the assessment of mobility of structural elements and for construction of a complex seismotectonic model in relation to mineral water springs. It is suggested to correlate the volume activity of radon in hydrogeological massifs and platform cover in the territory of significant structural lines. Measurement sets should be evaluated with the aim of rational protection of mineral water sources.

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