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MONITORING OF EARTHQUAKES AND HYDRO–PARAMETERS OF HEALING SPRINGS IN THE WEST BOHEMIA SPA REGION

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ABSTRACT. Seismological observations in the area of the West Bohemian spas are associated with the study of a seismic and tectonical active part of the Bohemian Massif. The experience so far suggests an uneven activity of curing springs, fluctuation of their yields and changes of their parameters (mineral compound contents, pressure, temperature).

The primary purpose of the study is to investigate the relationships between some hydrodynamic and hydrochemical parameter changes of the mineral springs, and seismic phenomena. The complex processing of the seismic events, of the balneo–technical observations and meteorological data will make it possible to evaluate their correlations.

KEYWORDS: seismological observations; mineral waters, monitoring measurement processing

1. INTRODUCTION

The area of the West Bohemian spas is of great interest for geologists, hydrogeologists, geophysicists and balneologists. The theories and the experiments carried out to explain the hot–spring phenomenon and earthquake swarms occurring in this area from time to time, are dated as back as to the early modern era. Tens of papers have been devoted to the genesis of the healing springs and to their characteristic and extraordinary properties. In these works, however, there have not been studied the correlations between mineral spring parameters and seismic activity, the latter representing a marked, worldwide unique nature phenomenon in this part of the Bohemian Massif.

To study the effect of the seismic events on the hydrogeological structure of mineral, gaseous and hot springs, there has been established a net of seismographic stations in this area. The occurrence of seismic events is monitored simultaneously with hydrogeological, meteorological and hydrochemical parameters of natural mineral waters and hot-springs.

The purpose of these works is to extend our knowledge on possible mutual linkage between the natural or even artificially induced seismic phenomena, and proved variability of some mineral springs, chemical composition, temperature, quantity of gas content and its origin, and other parameters, together with some intuitive human perceptions not yet observed in this connection.

The attention has also been paid to the historically justified hypotheses which, basing on empirical observations, described the regime changes and anomalous behaviour of some springs, structurally linked to a deeper structure, prior to the occurrence of local earthquakes.

It is evident from the collected records that these phenomena were recorded only after the earthquake, or at best during it, because previous changes and anomalies had been considered as random events and there was not performed any systematic observation before their fortuitous occurrence. This is the reason why there has not been any objective classification of the predictable factors, which were recorded in some cases.

There are literature references, both from abroad and from our country, on the correlation of seismic phenomena with ground water regime. There have been observed sudden changes in regimes, in particular of mineral springs with hydrogeologic structure anchored in the tectonic systems of a deep range, even during very remote earthquakes of 6 – 7° MSK 64.

The possibilities of observation of seismic events simultaneously with natural curing spring regimes have been influenced by the specific local conditions of individual outflows, which extensively vary in West Bohemia. From the point of view of the seismological observations, it would be most convenient to install a seismograph very close to the outflowing part of the spring structure [Jíra, Brož 1992]. However, this has faced the problem of the high level of a technical noise, overlapping the signals of natural seismic phenomena by its intensity in a wide frequency range. From the viewpoint of physical and chemical parameters, it is behind the currently available technical and especially economical means to obtain continuous series of balneo–technical data of a large number (more than 200) of springs situated in this area.

2. The Review of Geological Structure

The region of the West Bohemian spas is located in the significant territory exposed to tectonic activity (Fig.1).

The formation and circulation of mineral thermal waters saturated with gases is associated with the abyssolithic structure, in which the separate hot-spring structures and their dismembered structures are influenced by a young and recent endogenous dynamics. According to [Kopecký, 1986] the primary abyssolithic rift faults are manifested by a specific manner of evolution of the Ohar rift. In addition to this general event, the rift is dismembered internally, by combination with thwart abyssal fractures, to a set of blocks, characterized by differentiated movements and a different nature of volcanism. The most significant vertical movements occurred along the Ore Mountain governing abyssal fracture, where the relative upheaval of side crust of the Ore Mountain is estimated to be more than 1500 m in its central part. The thickness of the crushed zone, which was in the fracture structure verified by geological boreholes, reaches up to several hundreds meters [Marek, 1983].

Due to a considerable complexity, the tectonics of the area cannot be studied only based on the determination and distribution of discontinuities. The more

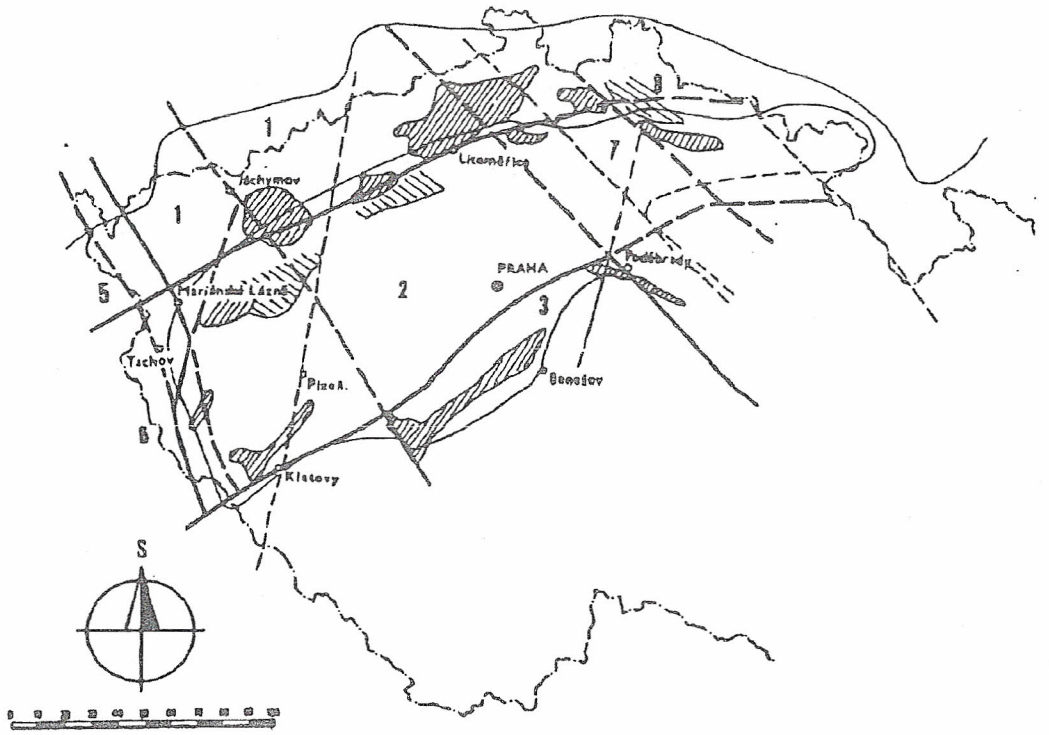

FIG.1. Scheme of block structure of the Bohemian Massif [Pokorný, Polanský and Štovičková, 1984], Evidence of the deep segmented structure of Bohemian Massif based on geophysical data.

complex view is provided by the results of geophysical observations together with the knowledge of the deep structure of the Earth's crust in the area and its environs. The recent manifestations of active tectonics in Ore Mountains – the Thuringen area, are also necessary to be involved into this analysis, or even together with some knowledge acquired by analogous hydrogeologic structures.

The external manifestation of these extensive tectonic activities consists in the occurrence of mineral springs, and in seismic activity that is displayed in a form of repeated swarms. Even though it may seem that this concerns apparently non-related natural phenomena, it is necessary to consider the fact that their foci are located by experts to a depth of the order of several to ten kilometers under Earth's surface.

With respect to the variety of geological structures, it is necessary to evaluate separately also the individual source areas and to take into account the different prerequisites for genesis of mineral springs in a different linkage to abyssal tectonics. Together with this, however, it is also necessary to consider the fact that it concerns relatively limited fragment of a spatial structure of supraregional significance.

The localities of mineral outflows as well as hypocenters of seismic swards are to be considered as certain collision points of discontinuity, which obtained the significance of privileged fault indicators by their spatial incorporation. It is possible

to assume that they have certain prediction properties with respect to their mutual contact both with the outer environ and with the assumed abyssal endogenous linkage. Some of their properties affect the final formation.

The whole area can be locally divided into basic autonomous areas with separate hydrogeological regimes as follows:

The Cheb Basin,
The Mariánské Lázně region,
The Karlovy Vary thermal zone,
Radioactive thermal outflow in Jáchymov.

In the Cheb Basin, there is the highest concentration of mineral water and carbon dioxide outflows of all area under the Ore Mountains. A larger part of acidulous water and CO_2 outflows is bounded to the territory with crystalline basement with open fissures.

Into the larger Mariánské Lázně region, the following localities are incorporated: Mariánské Lázně, Kynžvart, Prameny and Nová Ves (along the geophysically indicated Litoměřice deep fault). There are 39 springs in this area.

The Karlovy Vary thermal spring structure belongs to the area of crust thinning in the Bohemian Massif, which is less than 30 km thick there [Beránek and Zátopek, 1981]. The Karlovy Vary thermal spring outflows on tectonically contingent centered outflow path in granite massif. Its natural influx leads to the river Teplá valley in Karlovy Vary.

The total yield of the spring structure is much larger than the outflow yield of a hot-spring. In the river Teplá valley there are small Karlovy Vary springs and other not caught up wild springs.

The radioactive thermal outflow in Jáchymov was discovered in 1864 on mine "Svornost" sinking. Since 1924 it has been used for spa purposes due to its high radioactivity. In addition to it also springs "Behounek" and "Curie" are utilized.

3. Seismological Evaluation of the Area

The earthquakes in the western part of the Bohemian Massif are evidenced by historical records dating back 12^{th} century, and are included in works describing the seismicity in Central Europe. These events can be classified among shallow earthquakes at depths of 5–12 km, which are bound to the upper pert of the Earth's crust. Genesis of the earthquakes is probably associated with tectonic movements on fault boundaries between the individual geological blocks.

According to [Schenk et al., 1986], the earthquakes shocks are bound by zones of the NNW–SSE direction, which are fairly well correlated with the direction of Mariánské Lázně fault. According to [Kárník et al., 1981], the Karlovy Vary area is part of an area of increased recent seismic activities, where the earthquakes foci of an intensity of 5–6° (MSK–64) belong to a general line W–E. The map of the earthquake zones of Czechoslovakia describes this focal area by a degree of 6–7° MSK 64 (Fig.2).

The available historical information on the earthquake swarms in Western Bo-

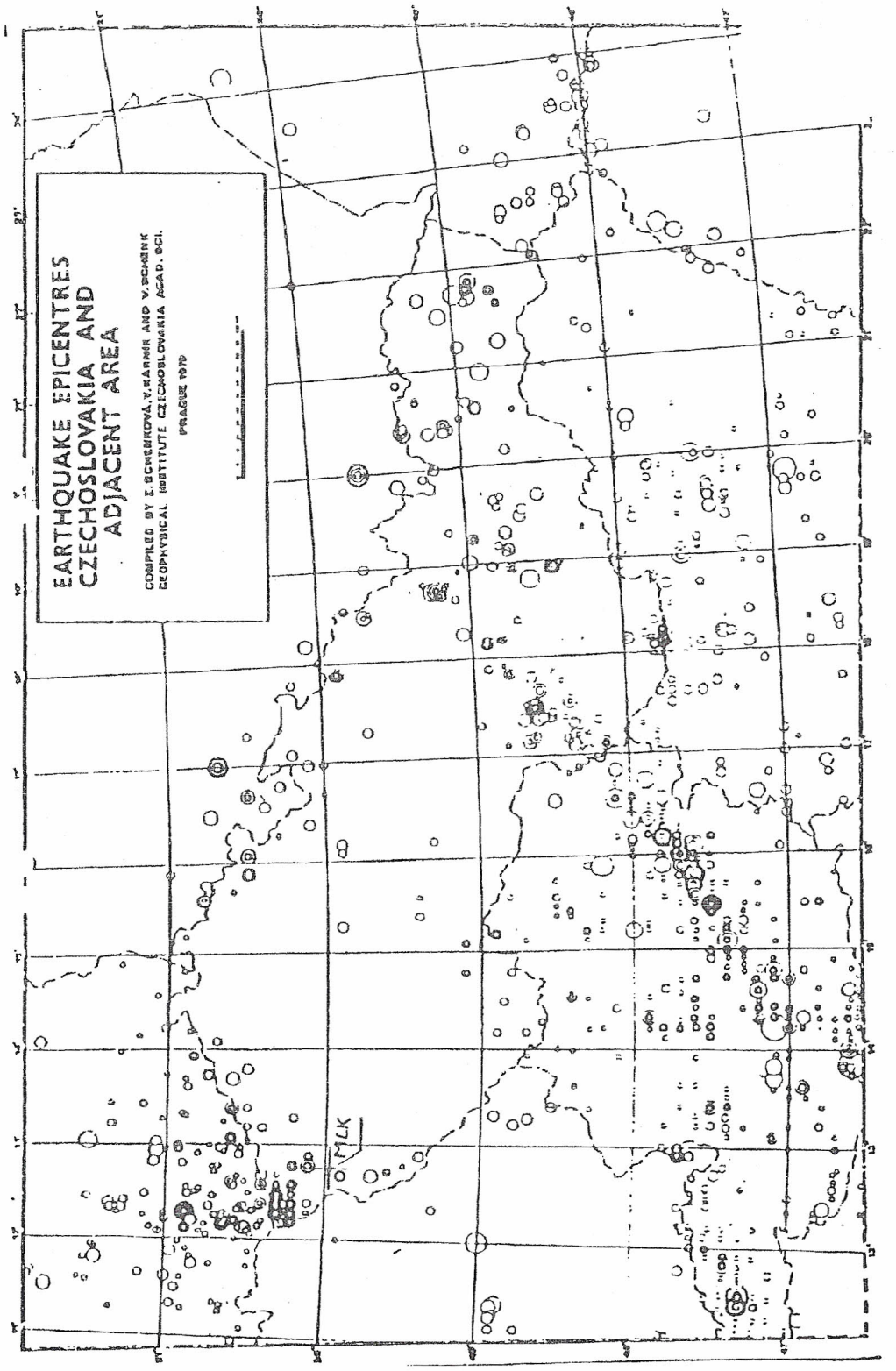

FIG.2. Earthquake epicenters in Czechoslovakia and adjacent area

hemia and its study in the individual localities and times of occurrence are published in [Procházková, 1987]. The evaluation of the seismological data recorded during the last, and up to now the most intense earthquake swarm in 1985–1986, is particularly in detail described there. In the region there occurred only several slight seismic events with a maximum value of magnitude $M = 2$ during the following six years.

In nearly 1991 slight earthquake swarms were recorded ($M = 2$–3), however, which faded away within ten days.

4. The Connections between Earthquakes and Curing Springs

The manifestations are described in the literature of ground waters connected with the earthquake activity. For example, in Japanese earthquake area in the Izu peninsula, the observing network has been constructed based on monitoring of water level in drills and wells for an earthquake prediction [Sigero Kodaka, Tomio Hirano, 1976]. The results made possible a successful prediction of an earthquake several hours in advance.

The cases of sudden decrease or increase of mineral spring yields were, e.g., recorded also in the Mariánské Lázně fault region. The observation of a natural outflow in the village Prameny can be considered as significant, when during the earthquake swarm in 1985–86 a demonstrable effect on the yield occurred, followed by a loss of usual amount in the Obecní (Municipal) springs.

Theoretically, it is possible to start from the opinion that the water level change, or mineral springs yield change suggest a certain movement in the Earth's crust, which may indicate a precursor of an earthquake. According to the dilatation–diffusion theory developed in the USA for an earthquake mechanism. The theory assumes that the system of an earthquake preparation proceeds in stages of accumulation of mechanical stress, opening of microfractures accompanied by volume dilatation, leaking of water into the pores thus formed, and a subsequent drop of mechanical strength, which cause the earthquake. Thus, the rapid release of stress occurs in the entire area.

Practical knowledge arising out of this theory, however, does not suggest unambiguousness of the precursors, which should indicate an approaching earthquake. This is why also other factors are investigated, which could be connected with the earthquake preparation. They are, e.g., the chemical parameter changes in ground waters, water temperature, or amounts of released gases. The particularly promising parameter seems to be the analysis of trace elements performed with a high accuracy using the atomic absorption spectrophotometry. This method has produced encouraging results at trial evaluation of the Karlovy Vary thermal spring [Kašák, Rudajev, Buben, 1985].

Contrary to the dilatation–diffusion theory, for example, substantial increases of mineral water production occurred, instead of drop of yield of springs during earthquake swarm in 1985–86 in Františkovy Lázně area. In some cases, some of the springs even renewed their activity after several years of inactivity. This can be explained by certain, e.g., shear movements of tectonic blocks, which cause increase

of the outflow yield.

Another possible hypothesis of correlation between mineral waters and an earthquake has been suggested by [Novotný, Čadek and Zahradník, 1986] on evaluating the effect of gases, especially post-volcanic CO_2 on the earthquake genesis.

Because the predispositions to accurence of the earthquakes are assigned to the post-volcanic activities, a real symbiosis of these two features occurs in West Bohemian area, and it is possible to explain by this hypothesis the earthquake genesis. The contact of the volcanic activity are directly in the Cheb Basin represented by three volcanic formations (Komorní Hůrka, Železná Hůrka, and yet nameless volcanic outcrop).These may be connected by so far unknown way with the Quaternary volcanos in the Doupovské hory Mountains and the Tepelské vrchy Hills regions.

For the actual understanding of correlations of the earthquake activity in this region with the regime of ground waters and gases, it is also possible to have certain ideas and intuitions, however, only the concrete results obtained from the representative instrumental data will make it possible to define the real interrelating linkage. Only then it will be possible to confirm or change the contemporary concepts of the classical theory attributing only genesis to these earthquakes in West Bohemia.

5. METHODS OF OBSERVATION AND EQUIPMENT

We have to choose a certain compromise for regime observation of physical and chemical properties of mineral springs and seismic phenomena, enabling us to process extensive data files with available means. In the regime measurement, a number of data is limited by the existing equipment of the balneo-technical service, which makes it possible to observe the principal spring parameters of only 20 outflows throughout the whole West Bohemian spa area. Those are in particular the yield, pressure, temperature, gas occurrence, radon concentration, and chemical analysis. These measurements are carried out with a varying periodicity and with various types of measuring devices. A partial advantage of these observations is the fact that they are performed backwards several years or even tens of years so that it is possible to trace and evaluate easier the importance of measured deviation from a long-term standard.

The measurement devices used are described in technical reports of individual balneo-technical services in spas.

As an example of evaluation there is given a measurement processing of 4 selected springs in Františkovy Lázně in the period preceding the earthquake swarm in 1985–86. Fig.3 shows the average CO_2 content in 1985–87 on the following springs: Glauber III, Kostelní, Adler and Železnatý. No unambiguous conclusions on the earthquake effect can be mode from these graphs, it is evident, however, that a significant drop in relative amount of CO_2 occurred in the end of 1985.

The measuring devices recording the amplitude values of oscillation frequency are used for seismic measurements. In relation to the earthquake swarm occurrence, the expedition seismic measurements have been carried out in this region with various device types. Only since the end 1985 the digital seismic devices have been used

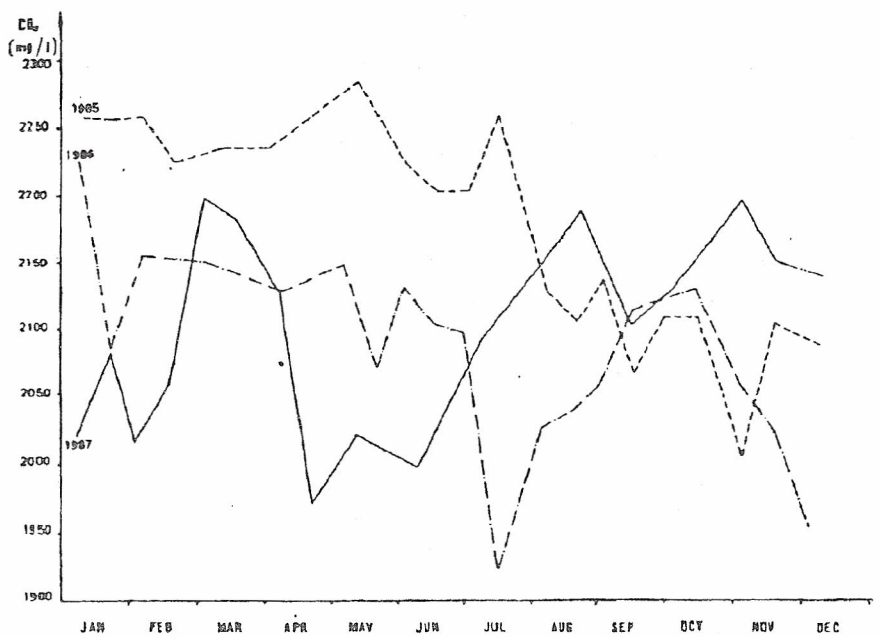

FIG.3. The average CO_2 content in 1985–1987 in the following springs: Glauber III, Kostelní, Adler, Železnatý

making possible the comprehensive representative processing of all recorded events.

To obtain a more complex view on seismicity of the whole area with a purpose of parallel observation of mineral springs, financial means and equipment have been given for building up a seismic network. Simultaneously, a seismic network in focal area was put into operation and controlled by the Geofyzika Brno.

The Spa Seismic Network (LASES) consists of five separated seismographic stations of the MARS 88 type, and of one digital station of a PCM 5800 type. The instruments are obtained from the Lennartz company (FRG) and the synchronization is secured by a common reception of time signals of the DCF 77 emitter. The station locations are close to the spa centers: Karlovy Vary [KVM], Jáchymov [JAS], Mariánské Lázně [MLK], and Františkovy Lázně [KHU]. The fifth station is located in the focal swarm area in the village Sněžná [SNE]. The station PCM 5800 is in Hora Svaté Kateřiny [HSK] village (Fig.4).

It is possible to state from the short, several months' recording that ann increase in seismic noise during the day hours in all stations has been systematically manifested. The level of this technical–industrial noise is less then ca 0.1 μm. The maxima in these monitoring blocks are usually attributed to the heavy lorries and are of a value up to 0.3 μm. The frequency spectrum of these events is in the range 5–20 Hz.

Another type of recorded phenomena are the seismic events induced by blasting in nearby quarries and coal open pits. It usually concerns the records of oscillations induced by large extent charges, i.e., of a total amount of up to 9000 kg of explosives, which is fired by a millisecond priming with partial charges 500–100 kg.

The recorded maximum amplitudes of oscillation frequency is up to 50 μm/s with

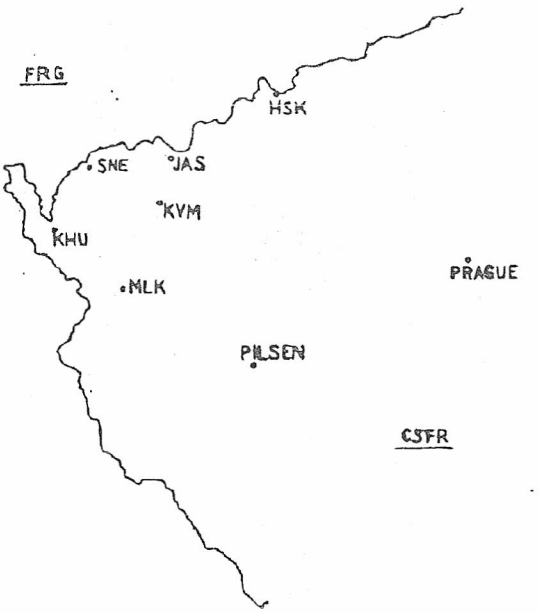

FIG.4. The locations seismographic stations in the area of the West Bohemian spas
KVM – Karlovy Vary – Muzeum
JAS – Jáchymov – Svornost
MLK – Mariánské Lázně – Kamzík
KHU – Komorní Hůrka
SNE – Sněžná
HSK – Hora Svaté Kateřiny

prevailing maximum frequency of the main wave phase of 1–3 Hz. By subtracting the differences of start of the P and S phases, i.e. the difference of start (ts – tp) – 5 s, we obtain a fictitious velocity (ts – tp)/R = 6 km/s. If we perform the determination of magnitude according to the relation which is used for calculation of local magnitude (M_1), we obtain the value of $M_1 = 3.2$, which corresponds to a very slight earthquake without any consequences to impairing construction objects.

$$M_1 = \log \frac{2800.D}{0{,}63} + 0.1 + 1.4 \log R$$

cohere D is the amplitude in μm, R is the distance in km.

At present we start up from the empiric assumption that seismic phenomena, the oscillation frequency amplitude of which is of the order of tens of μm/s, may adversely influence the underground mineral outflows.The seismic events of such an activity form a substantial group of recorded phenomena and they are in most of the cases identified by methods of type analysis, location programs, and last but not least, also by the subsequent records of these operations.

Fig.5 shows an example of an record of seismic waves from recorded blast in the coal open pit "Jiří" near Karlovy Vary.

The other category of seismic phenomena is formed by natural seismic events representing remote earthquakes and local earthquakes from the swarm focal. There

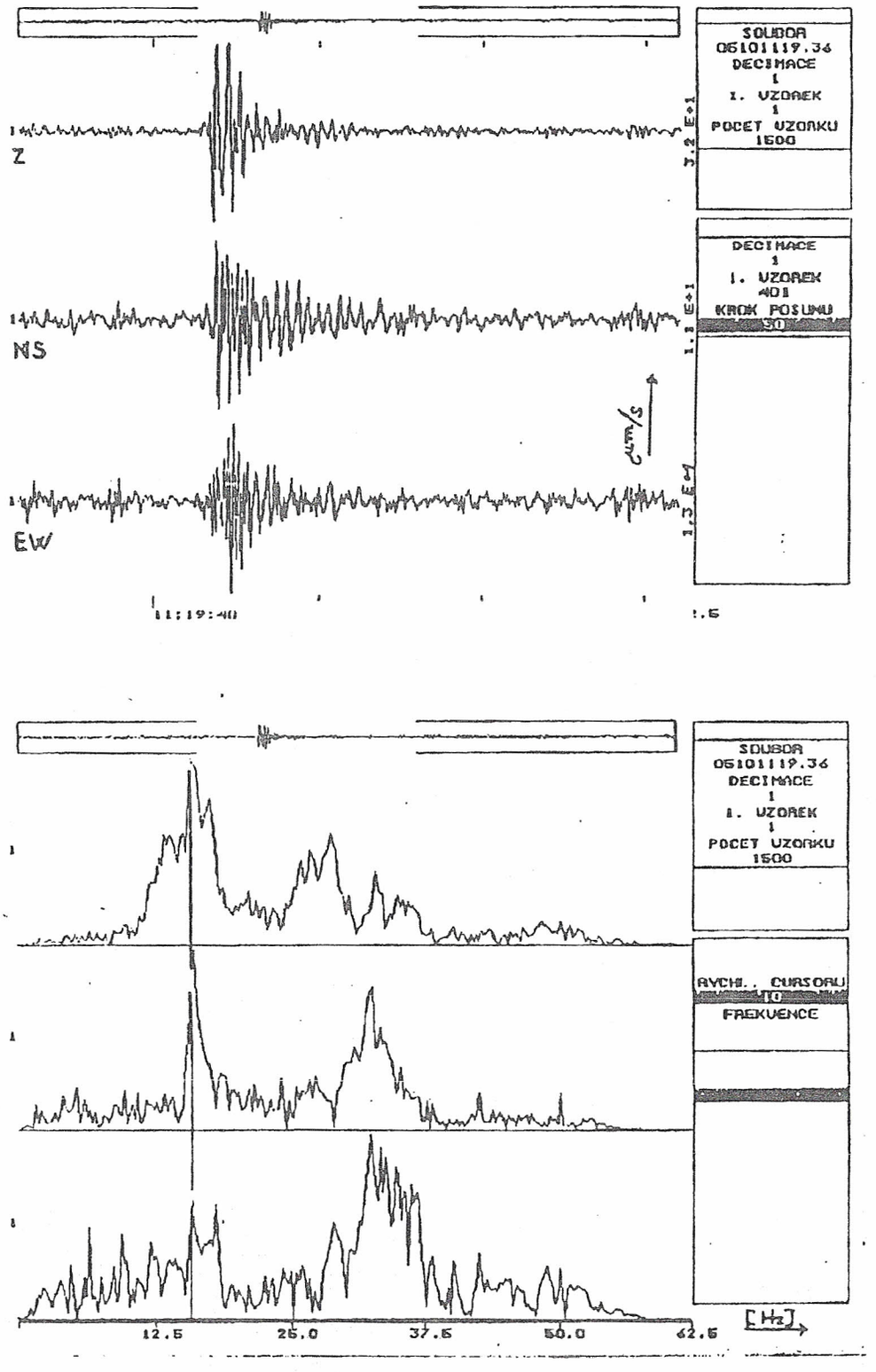

FIG.5. The example of an record of seismic waves from blasting in the coal open pit "Jiří" near Karlovy Vary

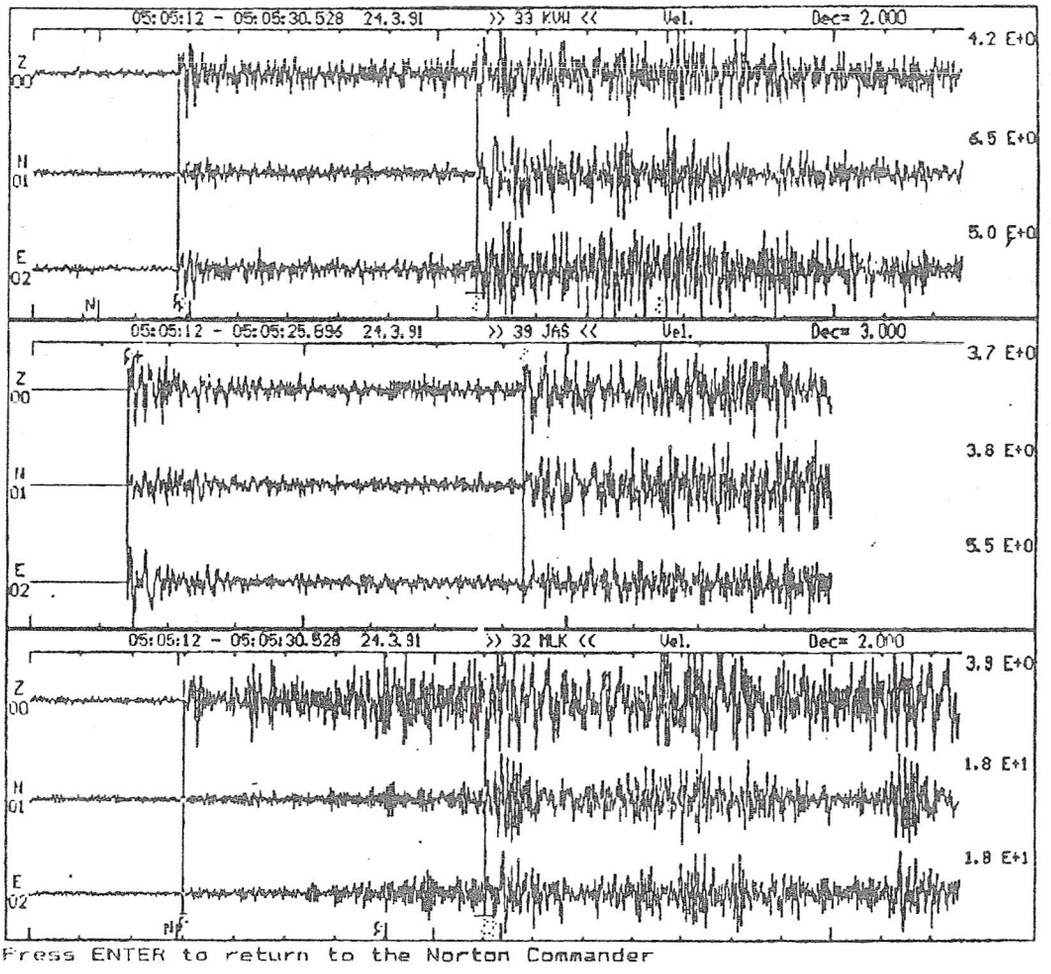

FIG.6. The record of seismic events from the Kraslice region (March 24.1991)

are recorded both the Alpine earthquakes of magnitude of 3–3.5 calculated from the surface waves, and macroplate earthquakes (e.g., Turkey, China, Tadjikistan) of magnitude $M = 5$–6.5 surface wave magnitude. These earthquakes exhibit no macroseismic demonstration in the whole territory of the CZR, however, they may to a certain degree influence the parameters of mineral springs and gas containing springs. Their observation is therefore needed.

The most consequential types of seismic phenomena are the local earthquakes occurring from time to time in the West Bohemia. During the swarm activity (e.g., in 1985–1986) they can reach a magnitude of $M = 5$ and they manifest themselves macroseismically in the focal area. In the periods between the heavy earthquake swarms there are recorded either individual tremors or smaller earthquake swarms lasting only several days. The magnitudes of these events have been usually of a value of $M_1 = 2$–3.

As an example of this type, an event recorded during a short seismic swarm in

March 1991 (Fig.6) can be named, which ranked to heavier events occurring within 10 days.

The local seismic activity is historically supported by records on macroseismic events sensed by the local population [Procházková, 1987].

6. Conclusion

During the investigation of thermal mineral springs in Karlovy Vary, the fluctuation of some trace element concentrations have been recorded, which appeared in various periods and no acceptable natural explanation has been found for them so far.

One of the most acceptable hypotheses is linkage of these periodical changes to hydrogeological phenomena in the region of mineral water formation zone, which is hypothetically located at a depth of several to ten km under the Earth's surface. This hypothesis is supported by the localization of the focal depths of the swarm earthquakes, which are located into similar depths. This concerns the instability zones, which a could be better described by the methods of multielement correlation, for which a sufficient information database will be created within the project of observation of seismological and balneo-technical data.

The purpose of this paper is to implement new views into the investigation of a deeper structure of the Ore Mountain (Krušné hory) area of the Bohemian Massif.

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MONITOROVÁNÍ ZEMĚTŘESENÍ HYDROLOGICKÝCH PARAMETRŮ LÉČIVÝCH PRAMENŮ V LÁZEŇSKÉ OBLASTI ZÁPADNÍCH ČECH

Pro studium možných souvislostí mezi přirozenou seismickou činností a fyzikálními parametry podzemních minerálních zdrojů v oblasti západních Čech jsou prováděna instrumentální pozorování. Tyto mají objektivně posoudit vzájemné vazby těchto přírodních jevů. Věrohodnost těchto pozorování je dána kvalitou datových souborů a jejich přesnou časovou identifikací. V uvedeném příspěvku je uveden popis oblastí z hlediska studia seismicity a parametrů minerálních zdrojů a přiloženy příklady monitorování těchto parametrů.