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CO_2 and Radon measurements in the Vogtland area (Germany) - a contribution to earthquake prediction research

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Abstract. The interpretation of long term radon measure-ments in a spring located in Vogtland shows a significant relationship to the seismicity of a region close to the sampling point. A statistical check was performed in order to identify the anomaly-generating area. The cause for this relation is emission of mantle originated gases (including CO_2) influenced by tectonic processes in the crust.

Introduction

Geochemical investigations are widely carried out in earthquake prediction researches. The basic idea is that the concentrations of fluids are influenced by the stress/ strain field and/or by pore pressure variations before an earthquake occurs. Interesting results of this phenomenon were published for example by King (1978), Wakita et al. (1988) and Virk & Singh (1994). Besides these radon measurements the observation of other gases such as Helium (Wakita et al., 1978) or CO_2 (Shapiro et al., 1982; Sugisaki et al., 1983), were also discussed. Irwin & Barnes (1980) showed the correlation between active seismic regions and CO_2 degassing from the mantle. King (1986) reported about the state-of-the-art of gas geo-chemistry for earthquake prediction research.

Our long-term basic study for the investigation of geochemical precursor effects was started in 1989 in the seismically active region of Vogtland (SE Germany). Besides continuous radon measurements at the Bad Brambach mineral spring "Radon-Quelle", several other hydrological as well as meteorological data were recorded with the purpose to find any possible relations between the fluid variations detected at the spring and the seismicity of the Vogtland area.

Geological and geophysical situation

The Saxon State Spa of Bad Brambach (12.298E, 50.239N) is located on the E-W directed boundary between the Fichtelgebirge granite (S) and the mica slate (N). These geological units are segments of the Central Saxonian Lineament (NE-SW). This great tectonic structure is subdivided into different blocks by fault zones in NW-SE direction (block juncture zones). The S Vogtland area is limited by the Tachov-As-Hainichen fault zone to the SW and by the Marianske Lazne fault zone (MFZ) to the NE (Fig. 1). Old tectonic elements in N-S direction lead to a segmentation of the MFZ. According to Bormann (1989) only intersections of the disturbed MFZ are seismically active. Quaternary volcanism (Eger basin), mofettes, mineral- and geothermal springs as well as strong gas emissions (CO_2, N_2) are the main evidence of subrecent volcanism. Recent neotectonic processes are observable in regional seismicity and dislocations due to the regional stress field with main components in NW-SE direction. This region is characterized by a typical seismicity of microearthquakes (M<4). A distinction has to be made between the Vogtland swarm quakes (shallow hypocenter 3-12 km and typical frequency) and single earthquakes with hypocenters in the depth range of 8-20 km (Neunhöfer & Güth, 1988). The seismicity of the Vogtland/ West Bohemia region has been monitored by 6 local networks with 34 stations since 1962 (e.g. Neunhöfer, 1993).

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Isotope hydrology

In the Vogtland/NW-Bohemia region the spring fluids were well investigated (Polyak et al., 1985; Heinicke et al., 1992; Weinlich et al., 1993). According to $^3H(T)$, $^2H(D)$ and ^{18}O measurements, the springs in Bad Brambach are characterized by a mixture of fresh and old meteoric water and by a high content of CO_2 gas. The helium R/R_a ratio shows a mantle contribution of up to 20 %. The CO_2 may be characterized as a mantle-derived gas because of the absence of ^{14}C and a range of $\delta^{13}C$ of -3 to -6 ‰.

The mineral springs in the Vogtland region have a relatively high natural radioactivity (e.g. 1-2 kBq/l ^{222}Rn) due to the granitic host rocks. In particular the "Radon-Quelle" spring shows an average radon activity of 25 kBq/l, caused by a local radium accumulation at a depth of <100 m.

Measuring technique

A gamma scintillation counter (NaI) with a reading interval of 40 min was set up in the spring water of the Radon-Quelle in 1989 to continuously monitor the radon concentration. Gamma counting of the short-lived radon daughter products was used instead of alpha counting because of the extremely high radon concentration (approximately 100 kc/min).

In addition to radon measurement, several meteorological as well as hydrological parameters were recorded at this site. The daily discharge was disturbed periodically (2-3 hours per day, longer on weekends) by filling water containers for therapeutic purposes. Specifically, the radon activity decreased during these

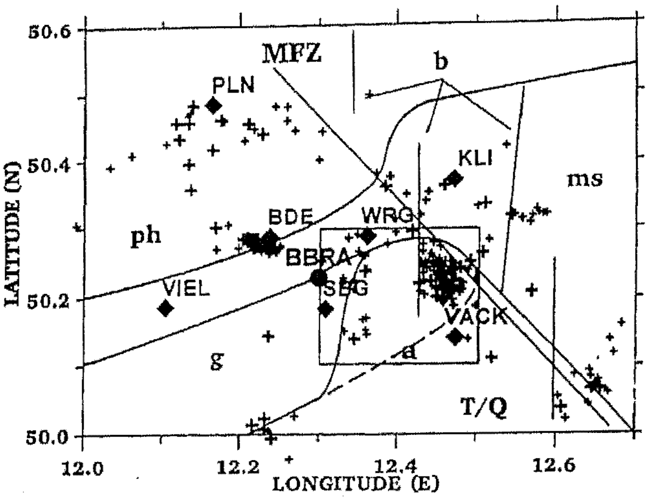

Figure 1. Distribution of the earthquakes in the Vogtland area during 11/1989 - 12/1992. + earthquakes with local magnitude <1, + earthquakes with local magnitude >1, BBRA(•)= Bad Brambach, squares-seismological stations: BDE= Bad Elster, KLI= Klingenthal, PLN= Plauen, SBG= Schönberg, VACK= Vackovec, VIEL= Vielitz, WRG= Wernitzgrün, g= granite, ph= phyllite, ms= mica slate, T/Q= Tertiary/Quaternary sediments, MFZ= Marianske Lazne fault zone, a= area of Fig. 3, b= N-S fault elements intersecting the MFZ.

exploitation intervals. By the end of 1992, these measurements has been supplemented by continuous observation of other parameters (CO_2 and Rn concentration of the spring gas, water temperature, electric conductivity).

Results and discussion

The presented interpretation is based on data recorded during 11/1989 to 12/1992 and on the latest published earthquake data (Neunhöfer, 1993). 294 earthquakes of the Vogtland/NW-Bohemia region have been included. They are classified with respect to local magnitude, epicenter and focal depth. Fig. 1 shows the spatial distribution of these earthquakes. The fluctuation of the radon concentration during this time is presented in Fig. 2A-G. Time intervals (A-G) with different levels of radon variations caused both naturally and by the above-mentioned artificial water-utilization process were identified. The standard deviation of each data group was calculated without correcting for the disturbance by the spring management (therefore, the σ values are artificially increased). We define the values exceeding 2σ from the mean value as radon anomalies.

The statistical method for "random spatial points fields" (Stoyan et al., 1987) was applied to find out possible correlations between the anomalies in Bad Brambach and the earthquakes in this region (Fig. 1). The method calculates cross-correlation of the time series of the radon data at our measuring

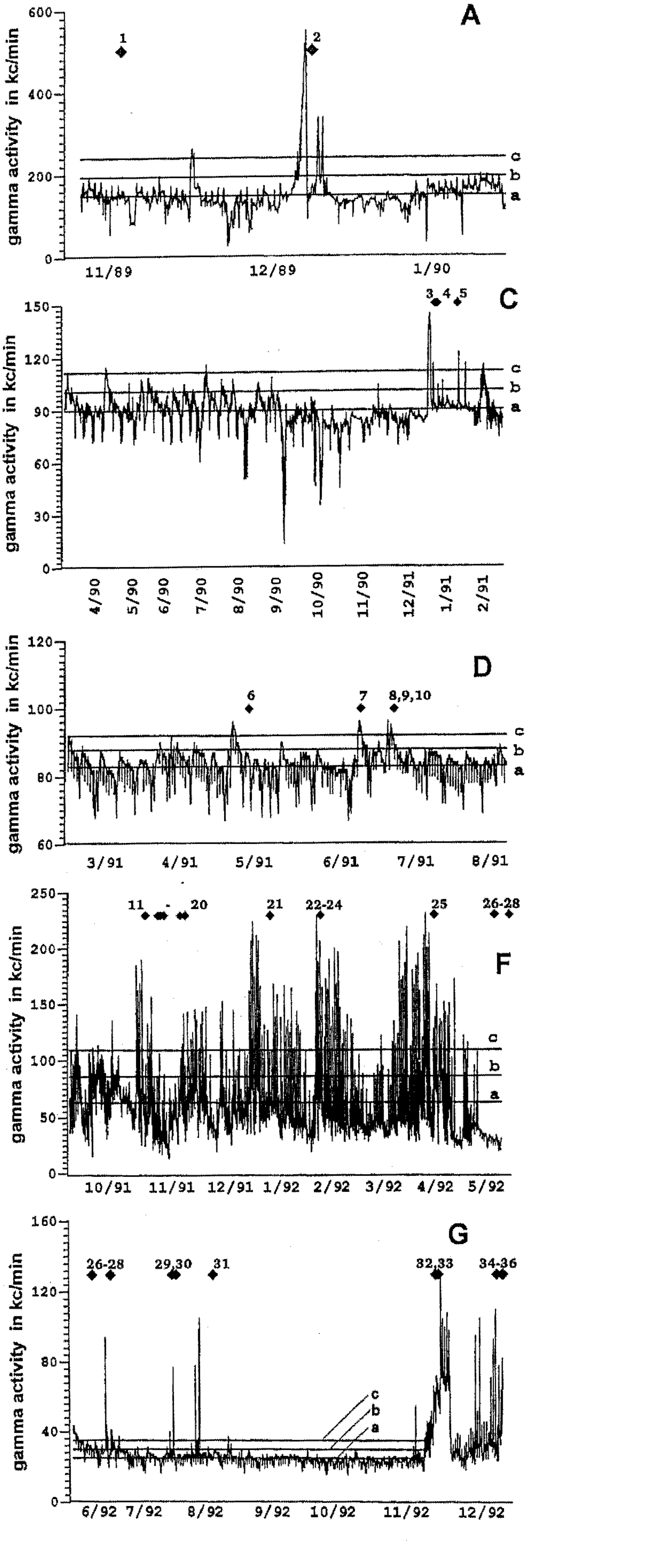

Figure 2A-G. Earthquake occurrence (squares with numbers of earthquakes) in the selected area and gamma activity recorded for different periods A-G, a = average activity of the period, $b=a+\sigma$, $c=a+2\sigma$. The periods B and E are lacking because of damages and changes of the measuring probe.

site with the time series of the seismic events at arbitrary areas (areas which are separated by circles with a randomly chosen middle point in the area of Fig. 1). The cross-correlations yield an increased coefficient for a region in the east of Bad Brambach situated about 8 km from the spring (see also polygon in Fig. 3). We found a significant correlation between the earthquakes in this region and the recorded radon anomalies. Further analysis showed that 75 % of the radon anomalies were followed by earthquakes within the region. Fig. 2A-G show the results during different periods. However not all of the seismic events can be related to radon anomalies and vice versa. For example, radon anomalies were recorded before and after the earthquake at the end of December 1989 (Fig. 2A). No relations between the radon anomalies and their delay time to the events and the magnitudes were found. We have no definite explanation for the slow decrease of the radon concentration level between periods C-G. On the other hand long term geochemical variations possibly connected with geodynamic processes cannot be excluded (see also Sultankhodzhayev, 1984).

The correlation between the radon anomalies and the earthquakes in the identified area is remarkable. Fig. 3 shows a detailed plot of the selected area within Fig. 1. The earthquakes marked by "+" are those which are illustrated in Fig. 2A-G. The geochemical sensitivity of the identified region can be related to the local geological structure. The shape of the Fichtelgebirge granite is shown in Fig. 3. Probably, the fluids stream through and around this part of the granite massif before they reach the Bad Brambach location. During this migration they are influenced by the active seismo-tectonic processes. In the center of the considered region all earthquakes are accompanied by a radon anomaly. It is found that a particular relation-ship between the foci and the recorded radon fluctuations exists. While the quakes in the NE region have focal depths of 5-9 km, the quakes in the region F between 12.32-12.37E and 50.12-50.27N show a significantly deeper hypocenter range (8-13 km). These relatively deep earthquakes occurred in particular during the F time interval which is characterized by the highest daily radon fluctuations (see Fig. 2F and Fig. 3 field F). These strong radon fluctuations disappeared with decreasing seismic activity in this region (last events in the beginning of period G, Fig. 2G). Thus, a significant influence on the fluids due to local seismo-tectonics of the region F can be assumed. Also the relatively short epicentral distances could be a reason for the stronger radon fluctuations during this period.

In a deep fault system like the MFZ the majority of the gases ascent to the surface by a two-phase system (Emmermann et al., 1993). Also the tectonic behaviour of the rock matrix before an earthquake involves opening and closing of cracks and stress drops (Scholz, 1990) and lead to changes in the p-V-T regime (Nicholson, 1993). These pressure changes may be transferred by pressure pulses which are the reason of our geochemical anomalies. The preliminary evaluation of pressure conductivity (a) allows us to estimate a transmission time (t) of only a few days for a migration distance of x from the hypocenter to the surface given by $dx=2\sqrt{a\,dt}$.

Since October 1992, the CO_2 concentration of the spring gas of Radon-Quelle test site has been measured continuously in order to study possible relationship between deeply generated CO_2 and radon anomalies (see Fig. 4). The different shapes of the anomalies can be explained by differences in transport mechanisms of radon in the water or in gas bubbles. The records show a significant correlation between CO_2 and radon in the gaseous phase. On the way up to the earth's surface, the CO_2 bubbles brought up more radon gas. It turns out that CO_2 fluctuations appear to be also related with locally defined seismic events. These processes may be similar to those of anomalous helium and CO_2 degassing in connection with earthquake swarms and shallow magmatic intrusions observed in Japan (Wakita et al., 1978).

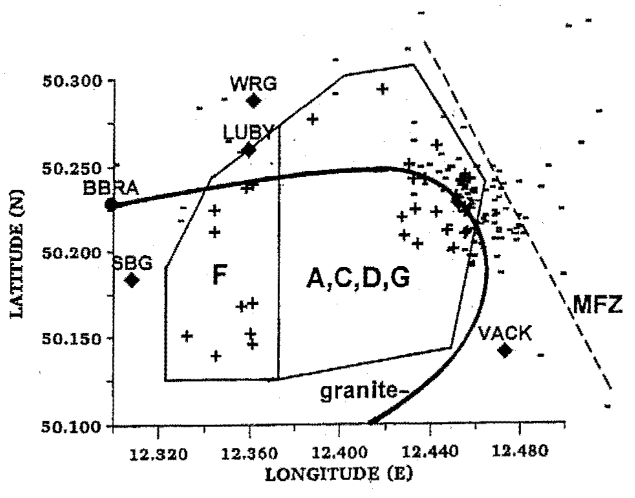

Figure 3. Section of Fig. 1 with the epicenters of the region (-) and with the epicenters within the polygon (+) which are correlated with the radon anomalies in Fig. 2A-G. Note the clustering of the seismic events in the time interval F (interval with high radon fluctuation) and also the shape of the granite pluton (within the curve).

Conclusions

Data recorded at the spring water of the Bad Brambach Radon-Quelle over a 3-year period suggests a significant, but not a one-to-one, correlation with the local seismicity. The radon

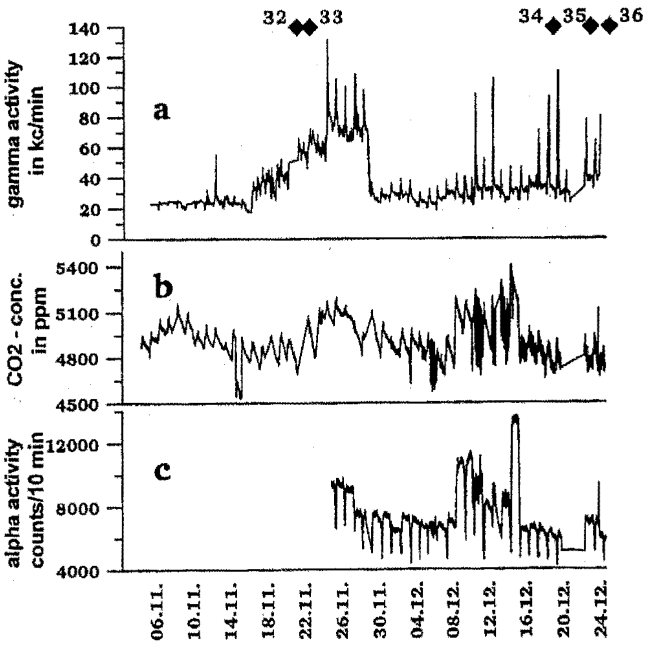

Figure 4. Gamma activity in the water (a) as well as CO_2 (b) and alpha activity (c) in the spring gas of the Radon-Quelle together with the respective earthquakes from period G.

anomalies may be related to a large number of quakes located in a statistically defined area on the eastern edge of the Fichtelgebirge granite.

The results suggests that CO_2 gas transport from the mantle is influenced prior to earthquakes by the stress/ strain processes within the geodynamically active part of the fault system. The opening and closing of joint systems leads to changes in the transport process. The consequence is a seismically modified outgassing behaviour.

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