

Soil-Gas Radon as a Possible Earthquake Precursor: A Case Study from the Khlong Marui Fault Zone, Southern Thailand

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ABSTRACT

This study was initiated to measure the radon concentration in soil over time and then to analyze possible variations of the radon data with respect to potential earthquake precursors for the Khlong Marui fault zone (KMFZ) and related faults in Southern Thailand. An automatic soil gas radon monitoring system (12 Feb-2 May 2007) and a short-period seismometer (14 Jan-21 Apr 2007) were installed in Thap Put district, Phang Nga province in the KMFZ. Two significant positive radon anomalies were observed during the short period of study, on 18 Feb and 1 Mar 2007, and an increase in local and regional earthquake activity was observed several days after each radon anomaly. It was concluded that there was a possibility of using the radon monitoring in soil gas as a possible method for providing earthquake warnings in the study area.

Keywords: radon in soil gas, fault, earthquake precursor, Khlong Marui Fault Zone, Southern Thailand

INTRODUCTION

A devastating Mw 9.3 Sumatra-Andaman Earthquake occurred on 26 December 2004 at 00:58:53 UTC (07:58:53 Thai time, Universal Coordinate Time, UTC+7 hrs = Thai Time, all time data here in UTC) off the west coast of Northern Sumatra, Indonesia, in the Sunda subduction zone (USGS, 2005) (Figure 1). The tsunami triggered by the earthquake had devastating effects on the coastlines of the Indian Ocean, including Thailand's west coast, and caused huge losses of life and widespread destruction of near-shore structures. The crustal movements related to the earthquake on 26 December 2004 resulted in the seismic reactivation of the Khlong Marui fault zone (KMFZ) and the Ranong fault zone (RFZ) and an increased number

of reported sinkholes in Southern Thailand (DMR, 2005; Dürrast *et al.*, 2007). Data from a global positioning system network have shown that the station in Phuket, southern Thailand, moved 26 cm to the WSW during the earthquake, the largest movement measured in comparison to stations in Thailand, Malaysia, and Indonesia (Hashimoto *et al.*, 2006). This movement resulted in crustal extension and subsequent mechanical instability of roofs covering subsurface holes, leading then to the increased development of the reported sinkholes.

For many decades, changes in radon concentrations in the air, groundwater and soil have been measured and applied subsequently as possible precursors of large tectonic earthquakes (e.g. Ulomo and Mavashev, 1967; Chyi *et al.*, 2001). However, no radon study has been carried

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out in Southern Thailand before the 26 December 2004 Earthquake. Although past research has shown that the use of soil-gas variation as an earthquake precursor is not always effective, it still can be used as an additional tool, as shown by a recent example (Ghosh *et al.*, 2007). Over the years, the techniques of radon gas sampling and detection have been improved and still are undergoing further developments, as was reported at the biennial International Conference on Nuclear Tracks in Solids (Fernández *et al.*, 2005; Guo *et al.*, 2008). One aspect of the ongoing research is to reduce the signal to background ratio. Chyi *et al.* (2002) improved the ratio by placing a detector within a fracture zone of an active fault with upwelling gases located in the Chuko fault zone in south central Taiwan.

The variations of soil-gas radon with meteorological parameters have been studied by many authors (Stranden *et al.*, 1984; Wattanikorn *et al.*, 1998; Ghosh *et al.*, 2007). For example, Wattanikorn *et al.* (1998) reported that the radon in soil gas measured at 100 cm depth below the ground surface was not influenced by meteorological parameters, mainly air temperature and pressure. As the meteorological effects are reduced, the signal to noise ratio of radon concentrations in soil-gas measurements might be increased significantly, so that anomalies related to tectonic movements of the Earth's crust can be identified. For the current study, the main objective was to investigate possible variations of radon concentration in soil gas along the KMFZ as local earthquakes were observed at the KMFZ during earlier study (Dürrast *et al.*, 2007), and based on that to investigate whether the variations of radon in soil gas could be used as a possible tool for an earthquake warning system in the study area.

Regional geology

Thailand is part of a geological entity extending from the Chinese province of Yunnan and the Shan state of Myanmar to the Malay

Peninsula in the south. There are two major fault zones in the South of Thailand, both aligned NE-SW, known as the Ranong fault zone (RFZ) and the Khlong Marui fault zones (KMFZ), respectively (Bunopas, 1981) (Figure 1). It is presumed that they both converge in the Gulf of Thailand and the Andaman Sea, as seen in petroleum seismic sections that were covered later under a thick load of late Tertiary sediments (Garson and Mitchell, 1970). The RFZ is a strike-slip fault, constituted by a series of faults parallel

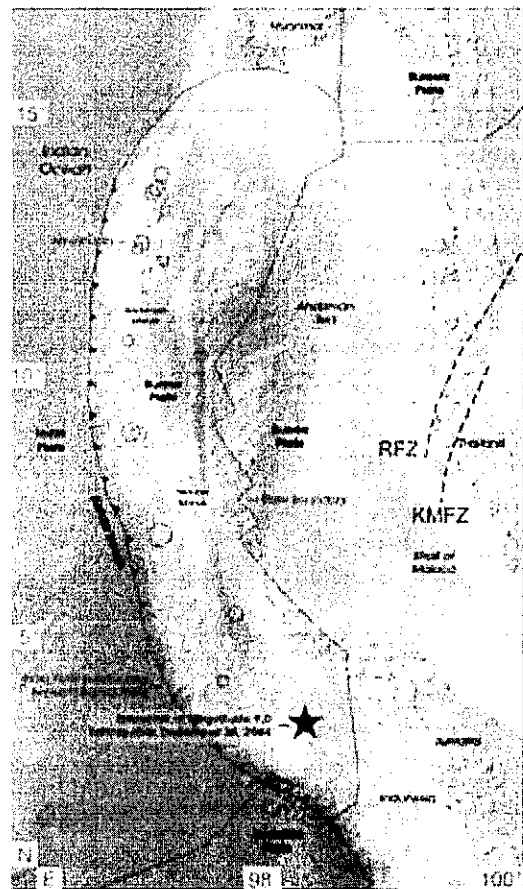


Figure 1 Generalized map of Andaman Sea area with the main tectonic features and location of the 26 December 2004 Earthquake. RFZ = Ranong Fault Zone, KMFZ = Khlong Marui Fault Zone (Courtesy of NASA Earth Observatory, 2010).

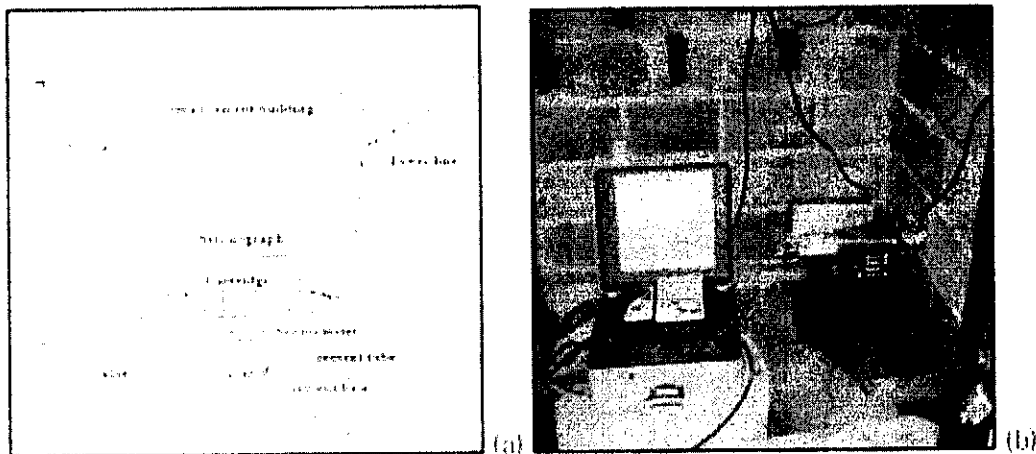


Figure 2 (a) Schematic diagram of the seismic station with the seismometer covered by a concrete tube, all inside a shelter made out of cement bricks and wood. (b) Photo inside, showing the seismograph sitting on the cover of the cement tube and continuous radon monitoring system, RPM-256, inside the small hut.

along a NE-SW orientation from the Andaman Sea to the northeastern part of the Gulf of Thailand in Prachuap Khiri Khan and Chumphon provinces. Onshore, the fault lies in the channel of the Kra-Buri River, and has a length of about 270 km. The Carboniferous-Permian rocks in the area (Kang-Kra-Chan group) have been affected by these faults (Garson and Mitchell, 1970). The KMFZ is a transcurrent fault system, aligned parallel to the RFZ. Initially, it moved 150 km in a sinistral sense, and then right-laterally at the transition from the Jurassic to the Cretaceous period. In the middle of the Tertiary period, the fault was similar to the RFZ (Tapponnier *et al.*, 1986).

MATERIALS AND METHODS

The location of the radon and earthquake monitoring site was within the KMFZ at 8°33'N and 98°39'E, in Thap Put district, about 20 km ESE from the Phang Nga municipality, Southern Thailand. The radon concentrations in soil gas were measured automatically with the RPM-256 system (UGF, Czech Republic) for 10 min counting time after every 3 h, from 12 Feb to 2

May 2007. The system was connected to a PVC tube (length 1.5 m long and diameter 5 cm), which was placed in the ground at a depth of 1 m. The tube was open at the bottom and airtight at the surface (Figures 2 and 3) and was covered with thin polyethylene film to filter ^{220}Rn (Thoron) emission and humidity at the bottom. The soil gases, including radon, were drawn through the tube by a built-in air pump at the rate of 1 L/min.

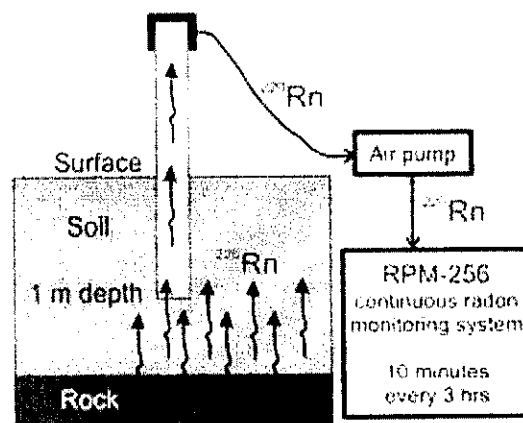


Figure 3 Schematic diagram of the radon emission and the radon detector system at the monitoring station.

The alpha rays emitted from radon and its progeny were counted in the counting chamber of the RPM system, using a silicon barrier semiconductor detector.

The seismic recording system consisted of a Mark L-4-3D seismometer with 1 Hz natural frequency, containing three geophones in three perpendicular directions, namely, an N-component (N-S), E-component (E-W) and Z-component. The seismometer was connected via a data cable to an Orion datalogger (Nanometrics, Canada). The datalogger contained a hard disk for data storage as the system was set up to be stand-alone, with no real-time communication. Therefore, during the measurement period of the earthquakes, between 14 Jan and 21 Apr 2007, the data from the datalogger had to be transferred to a computer about every 2 w. The data processing, analysis and interpretation of the seismic events was carried out using Seisan software (Havskov and Ottemöller, 2005). A seismogram of a local earthquake is shown in Figure 4.

For the analysis of a seismic event, the

primary (P) wave arrival was marked (see Figure 4), which was usually quite clearly identifiable, but the secondary (S) wave that arrived later was more difficult to identify. After the phase identification, the time between the S- and P-wave arrival was determined (delta time). With this information and the travel timetables given by Jeffreys and Bullen (1967), the distance of the earthquake from the seismic station could be determined. Distance was used as the criterion for the separation of the regional (more than 500 km) and local (less than 500 km) events. The local earthquakes were then separated from man-made seismic events (mainly resulting from blasting) and seismic noise.

For local earthquakes, the local magnitude (M_L , or Richter scale) was determined; whereas the body-wave magnitude (m_b) was determined for the regional earthquakes (Dangmuan, 2008). The epicenter of each earthquake was located using the distance to the seismic station and the back azimuth, based on the first P-wave arrival in all three components.

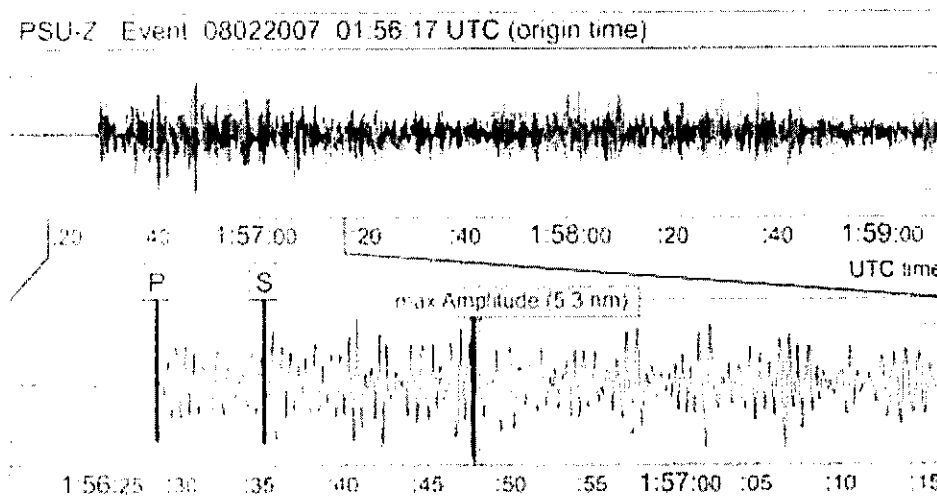


Figure 4 Full seismogram (upper window) and details (lower window, filtered as a Wood-Anderson equivalent) showing the Z-component of the 8 Feb 2007 (UTC time 01:56:17 origin time) for a local earthquake recorded at Thap Put Station. P= arrival of P-wave; S = S-wave arrival. x-axis = UTC time; y-axis = amplitude in counts; Maximum (max) amplitude used for local magnitude (M_L) determination.

The depths for the local and regional earthquakes were set at 0 and 30 km, respectively. For more details of the earthquake analysis procedure, see the work of Dangmuan (2008).

RESULTS

Earthquakes

From 14 January to 21 April 2007, the short period seismic station in Thap Put detected 135 local earthquakes, with a magnitude M_l range from -1.6 to 3.1. Additionally, 31 man-made events were determined, probably from blasting in rock quarries. Figure 5 shows the distribution of the local earthquakes determined from this study in relation to the magnitude.

The regional earthquake data were obtained from the United States Geological Survey (USGS) database (USGS, 2008). In the period between 14 January 2007 and 4 May 2007, 198 regional earthquakes were recorded in the region

between 3° S and 15° N and between 90° E and 105° E (Figure 6). These earthquakes were related to either the Sunda subduction zone (SSZ) or the adjacent fracture zones (FracZ).

Radon concentration at the time of measurements

The 3-hourly radon concentrations were reported in count/10 min for the period 12 February 2007 to 29 April 2007 (Figure 7). The longest continuous measuring period was between 12 February and 23 March 2007. Two clear radon peaks could be determined during this period; the first peak (A) occurred on 18 February 2007 at 15:48:53 UTC (54 count/10 min) and the second one (B) on 1 March 2007 at 14:34:35 UTC (91 count/10 min). Daily averaged radon concentrations were calculated and are shown as the thick dark line in Figure 7. Five radon peaks were observed and registered as peak-1 to peak-5 (Figures 8, 9 and 10). The peak-1 anomaly (23.75

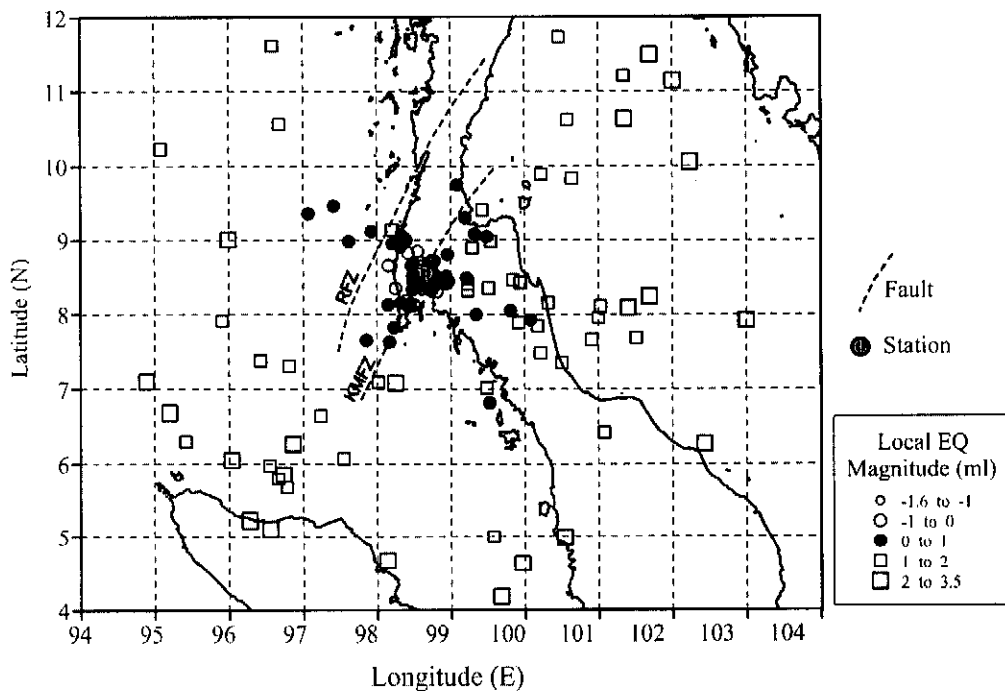


Figure 5 Locations of local earthquakes in Southern Thailand in relation to their magnitude, based on data in the present study from 14 Jan to 21 Apr 2007.

count/10 min on 18 February) was an isolated peak, with a peak width of 3-4 d rising and falling to a mean value (20.74 count/10 min), whereas peak-2 (30.25 count/10 min on 1 March, corresponding to peak B in Figure 7), peak-3 (29.0 count/10 min on 4 March) and peak-4 (27.37 count/10 min. on 6-7 March) could be combined into a single, wide peak with a peak width of 8-9 d (or 11-12 d if peak-5 were included).

Effect of meteorological parameters on soil-gas radon concentrations

Daily average air pressure (P) and temperature (T) provided by the Thai Meteorological Department were plotted with the daily average radon concentration values for the period 12 February–23 March 2007, which was the longest measuring period (Figure 8). It should

be noted that the P and T measurements were taken at the same time every 3 h, whereas the radon measurements were taken every 3 h, but 50 min after the P and T measurements.

Analysis of the meteorological parameters of air pressure and temperature indicated a general trend showing an inverse proportionality between soil-gas radon and air pressure (Figure 8b), while a linear relation was observed for soil-gas radon and air temperature (Figure 8c). However, very small linear correlation coefficients ($R^2=0.134$ and 0.068) were obtained between radon and air pressure (Figure 8b), and radon and air temperature (Figure 8c), respectively. This indicates a non-significant influence of the meteorological factors on the measured soil-gas radon data. This was most likely because the soil gas was taken from a hole in the ground at a depth

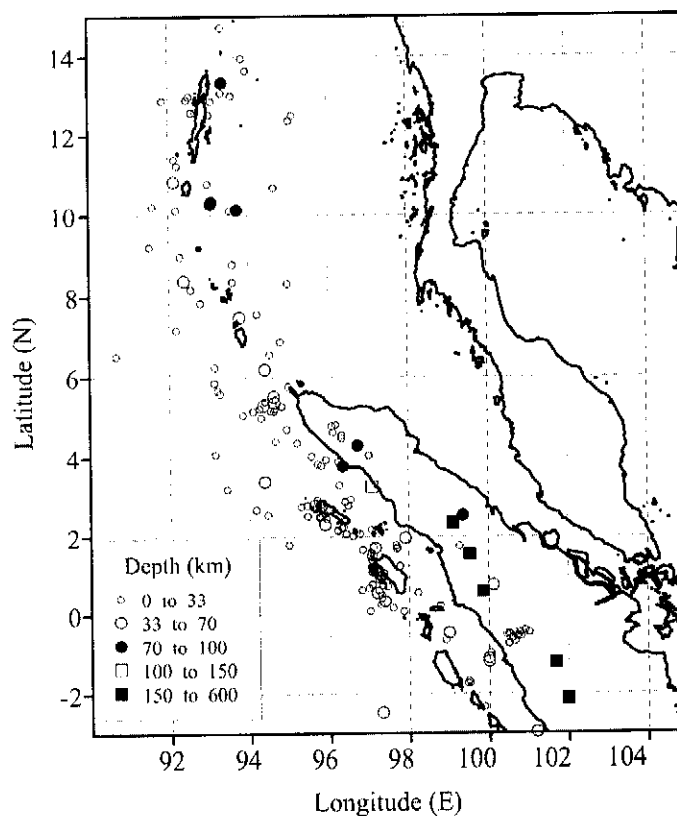


Figure 6 Locations of regional earthquakes in relation to their depth, based on data from 14 Jan to 21 Apr 2007 (USGS, 2008).

of more than 1 m, which was the recommended depth suggested by Wattananikorn *et al.* (1998). Since no obvious correlations between radon anomalies and the meteorological parameters, P and T, were observed, further investigation was undertaken into the possibility that the radon anomalies were related to seismic activity.

Soil-gas radon and the earthquake occurrences

The daily average soil-gas radon concentration data over the period between 12 February and 23 March 2007 (UTC date), as shown in Figure 8, together with the occurrence time and magnitude of the local and regional earthquakes are presented in Figures 9 and 10.

There were five radon peak anomalies observed in the period of measurement (Figures 9 and 10) that were registered as peak-1 to peak-5. The radon concentrations at all peaks were higher than the mean value plus 0.5σ , whereas the radon concentrations at peak-2, peak-3 and peak-4 were

higher than the mean plus 1.0σ . The highest concentration was observed at peak-2, corresponding to Peak B in Figure 7. The local earthquake occurrences were observed to be more frequent after the radon peaks, especially after the highest concentration (peak-2). There were only four local earthquakes with magnitude $M_L < 0.5$ that occurred between peak-1 and peak-2. During this time, the radon concentration dropped from peak-1 down to a value less than the mean concentration. After peak-2 (the highest concentration of the data presented here), it took 11 d for the radon concentration to drop down through peak-3, peak-4 and peak-5 to a concentration below the mean value. There were 12 local earthquakes in this 11-day period, with nine of them having a magnitude $M_L > 1.0$, whereas the remainder had $M_L < 1.0$. After this 11-day period, there were an additional 15 local earthquakes, whereas the radon concentration varied to less than the mean value without any

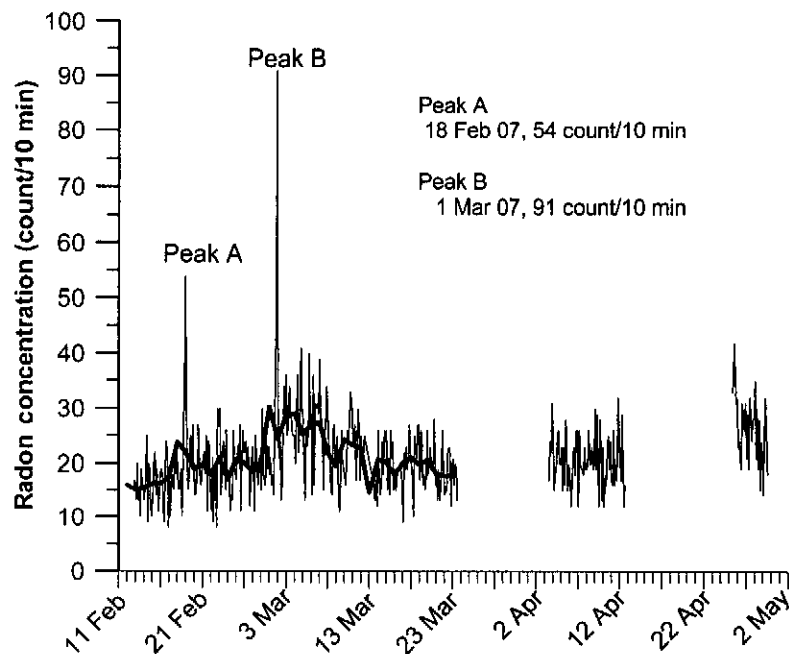


Figure 7 Radon concentrations in soil gas (count/10 minutes) between 12 February 2007 and 2 May 2007 (UTC date), showing 3-hourly (thin line) and daily averaged (thick line) radon concentrations.

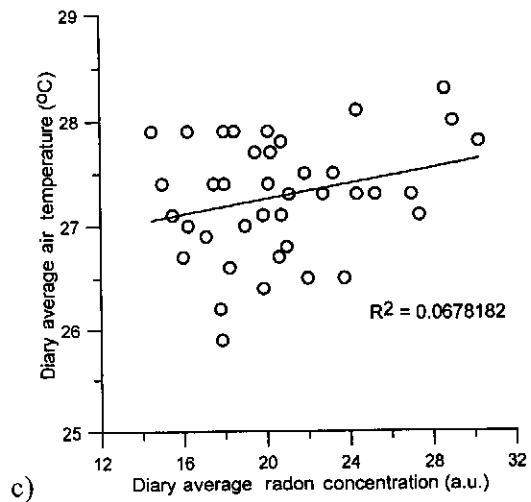
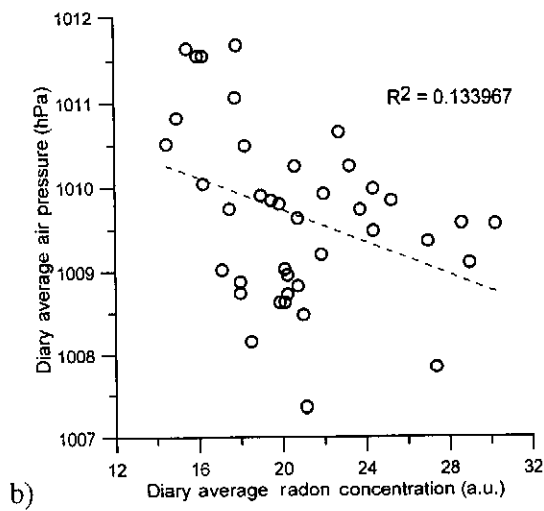
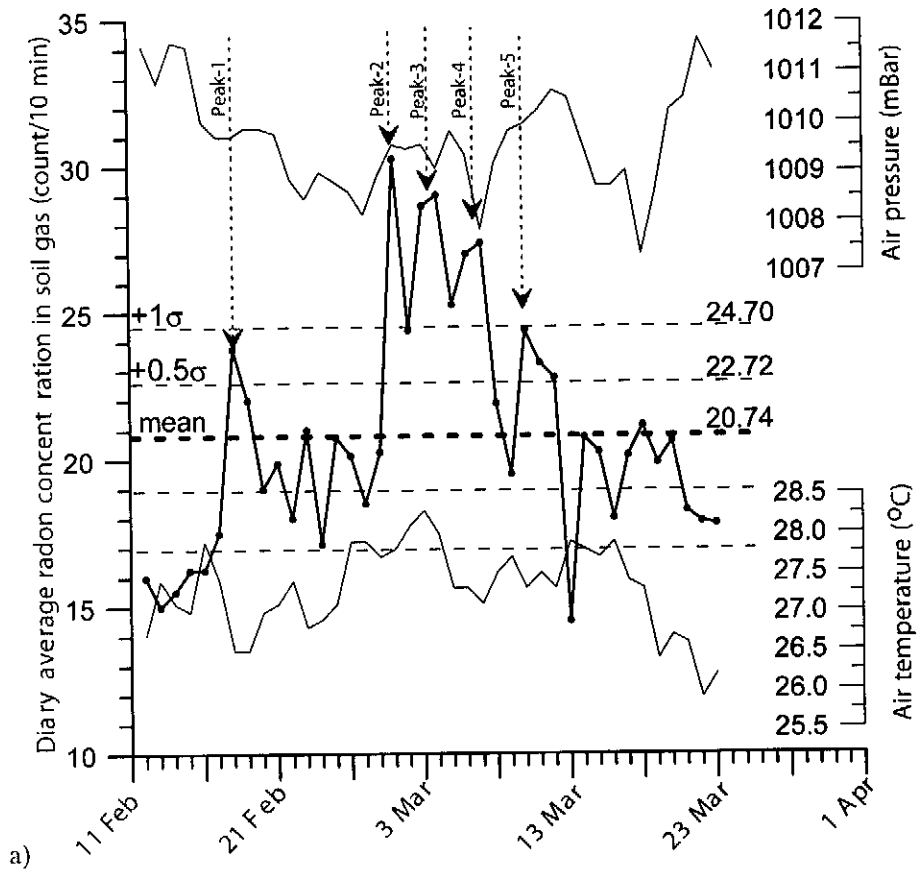


Figure 8 Meteorological effects on the radon in soil gas: (a) daily average radon concentration, air pressure, and air temperature over the period 12 February–23 March 2007; (b) air pressure; and (c) air temperature.

radon peak. These additional local earthquakes were probably the consequences of the wide and high radon peak (peak-2 + peak-3 + peak-4).

The regional earthquakes occurred more frequently after the radon peaks, especially after the highest concentration (peak-2). There were 15 regional earthquakes with magnitude $m_b > 4.0$ in between peak-1 and peak-2. During this period, the radon concentration dropped down to less than the mean value. There were 20 regional earthquakes ($m_b > 4.0$) in this 11-day period; four of them had magnitude $m_b > 5.0$ whereas one large one had $m_b = 6.5$. After this 11-day period, there were an additional seven regional earthquakes ($m_b > 4.0$). These additional regional earthquakes were considered to be as a consequence of the wide and high radon peak from peak-2 to peak 5.

DISCUSSION

Any further analysis could apply an empirical relationship to quantify a possible correlation between the radon concentration and earthquakes using correlation coefficients between the amplitude of a radon anomaly, the distance to the epicenter from the radon station and the earthquake magnitude, for example as in Hauksson (1981) and Walia *et al.* (2003). This approach could not be applied here, as not enough data were available for a statistical evaluation. Therefore, a more qualitative analysis had to be applied.

As shown in Figure 1, the main tectonic structure causing earthquakes in the study area is the Sunda subduction zone and related faults

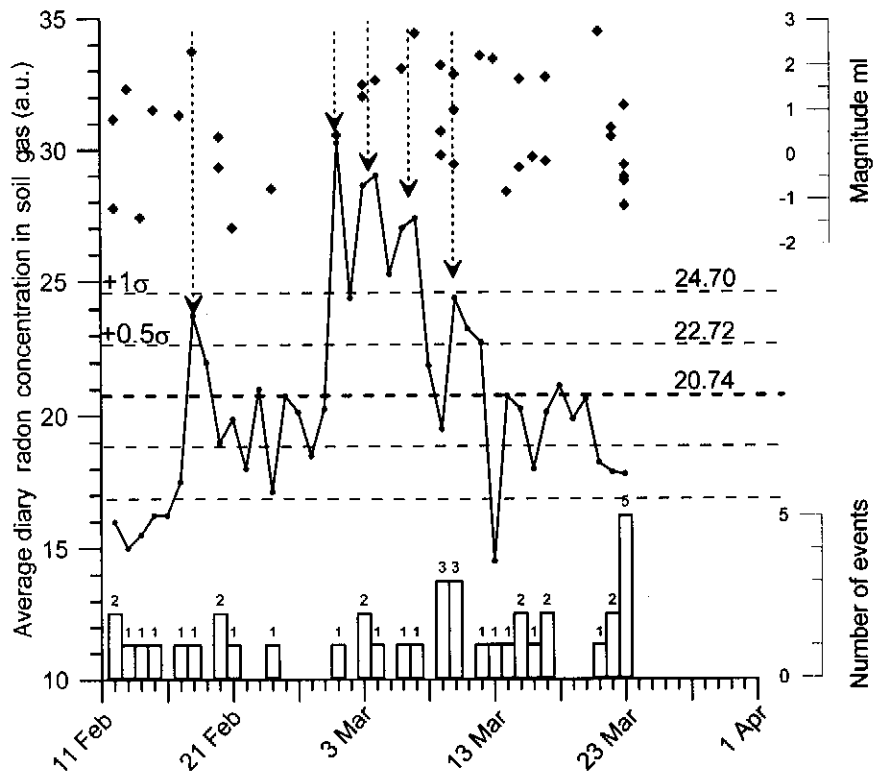


Figure 9 Soil-gas radon concentration (count/10 min) between 12 February 2007 and 23 March 2007 (UTC date), with the mean (thick dashed line) and standard deviation levels (thin dashed lines). Filled diamond symbols represent the local earthquakes with magnitude MI; bar chart represents the frequency of the events.

(regional earthquakes) and fault zones in Southern Thailand (local earthquakes). The radon monitoring station was located in the southern fault zone, the KMFZ (Figure 11), and therefore, reacted to stress changes in this fault zone. After the second radon peak (peak-2) on 1 March, the number of local earthquakes increased steadily with increasing magnitudes. About 8 d after the Rn-anomaly, the number of local earthquakes increased but with lower magnitudes (Table 1). Most of these local earthquakes were located along the KMFZ (Figure 11). Therefore, it might be possible that the precursor time between the Rn-anomaly and the following local earthquakes is relatively short, as it can be seen as a local stress change. However, the effect of the regional

earthquakes along the Sunda subduction zone on the radon concentration anomalies was not clear and should be subjected to further investigation, such as whether the Rn-anomaly should be seen as a precursor for the sharp increase in regional earthquakes starting about 4 d after the anomaly occurred (Table 1). By determining this, it may be possible to address whether and how the main tectonic structures, the subduction zone and fault zone, are physically connected.

CONCLUSIONS AND SUGGESTIONS

1. This study presented the first measurements of radon concentration in soil gas in the active fault zones of Southern Thailand, in

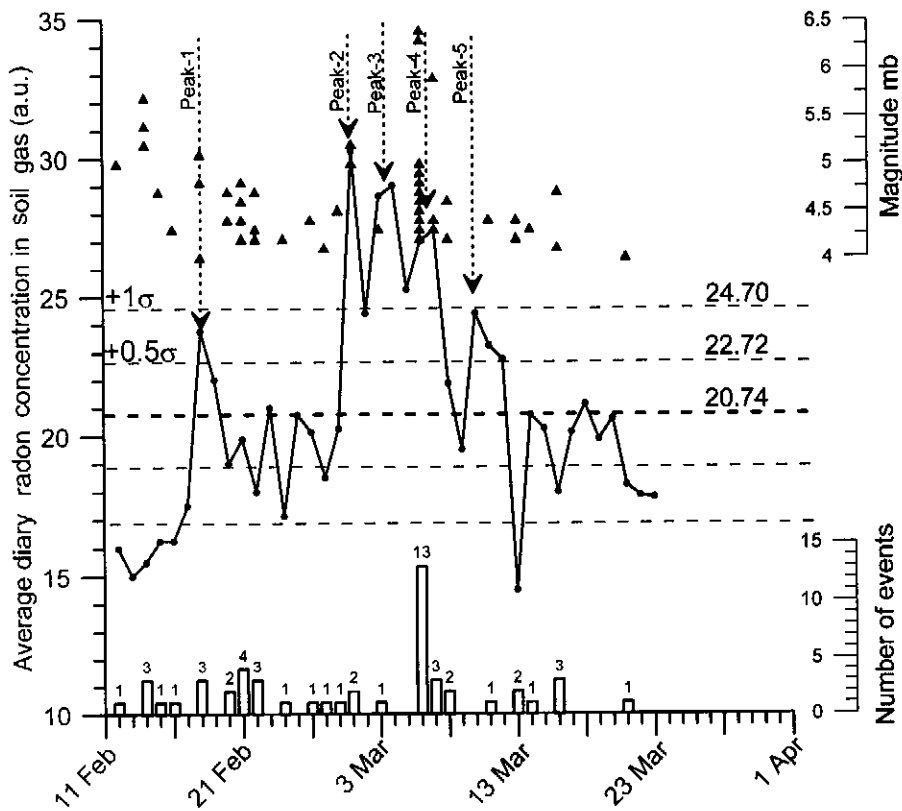


Figure 10 Daily averaged radon concentration in soil gas (count/10 min) between 12 February 2007 (UTC date) and 23 March 2007 (UTC date), with the mean (thick dashed line) and standard deviation levels (thin dashed lines). Filled triangle symbols represent the regional earthquake with magnitude mb (after USGS, 2008); bar chart represents the frequency of the events.

this case in the Khlong Marui Fault Zone.

2. There was clearly no effect of air pressure and temperature on the concentration changes of the soil-gas radon, most likely because the radon emission was measured at a depth of 1 m below the surface. This is important for further similar studies.

3. Two clear radon anomalies (A and B in Figure 7) could be identified in the unprocessed data during a relatively short continuous measurement period.

4. The calculated daily average of the radon data revealed more anomalies. (5 different peaks in total) and this might provide a more

promising way to analyze the 3-hourly measured radon values. Peak-1 (equal to peak A) was separated from the others in time. The regional earthquakes showed an increase in frequency after peak-1 and also after peak-2 (equivalent to peak B) and peak-3. However, the local earthquakes showed an increase after peak-2.

5. The second main radon anomaly (B or peak-2) on 1 Mar 2007 might have been a possible precursor for the sharp increase in regional earthquake activity about 4.53 to 5.85 d later and around 11.40 to 14.99 d later (Table 1). There was a build up in the number of local earthquakes, culminating with an $M_l=2.7$

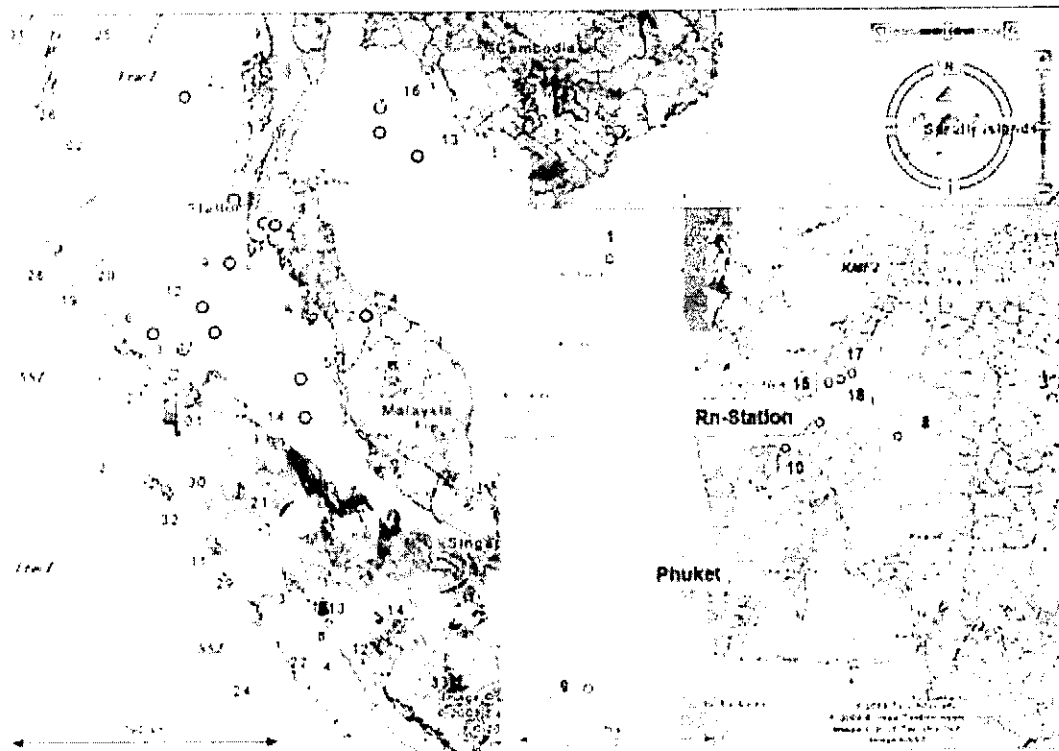


Figure 11 Locations of local and regional earthquakes shortly before and after the second radon anomaly (B) on 1 March 2007, 21:34 UTC. Unshaded squares = regional events numbered 01 and 02 before the Rn-anomaly and 1 to 33 after the Rn-anomaly. Unshaded circles = local events numbered 1-18 after the Rn-anomaly. Event details are provided in Table 1. Rn-Station = radon measurement station, SSZ = Sunda subduction zone, FracZ = fracture zone, KMFZ = Khlong Marui Fault Zone. Right lower box shows magnification of the area around the station (Courtesy of and copyright by Google™ Earth 2008).

Table 1 Details of earthquake activities (EQ) after the second radon anomaly (B) on 1 March 2007 21:34 UTC. See also map in Figure 11 for locations.

| Date of occurrence of radon anomaly | Earthquake occurrence | | Map | Magnitude (M) | Epicenter distance from radon station (km) | Radon anomaly (count) | Radon anomaly from average value σ | Delta time between Rn anomaly and EQ (Precursor time, days) |
|-------------------------------------|-----------------------|----------------------|-----|---------------|--|-----------------------|---|---|
| | Local EQ (M) | Regional EQ (mb) | | | | | | |
| 1/3/2007 14:34:35.00 UTC date | | 01/03/07 02:01:07.00 | 01 | 5.6 | 590 | 91 | $> 2\sigma$ | -12.56 h |
| | 01/03/07 15:20:05.00 | 01/03/07 05:08:20.74 | 02 | 5 | 651 | | | -9.44 h |
| | 03/03/07 00:07:31.50 | 03/03/07 07:39:32.03 | 1 | 1.6 | 410 | | | 0.76 hr |
| | | 03/03/07 10:09:19.65 | 2 | 4.3 | 822 | | | 1.40 |
| | 03/03/07 22:05:26.57 | | 3 | 1.3 | 382 | | | 2.31 |
| | 04/03/07 21:26:05.59 | | 4 | 1.7 | 358 | | | 3.29 |
| | | 05/03/07 04:22:50.97 | 3 | - | 1002 | | | 3.58 |
| | | 06/03/07 03:23:15.13 | 4 | 4.7 | 1069 | | | 4.53 |
| | | 06/03/07 03:49:38.90 | 5 | 6.4 | 1025 | | | 4.55 |
| | | 06/03/07 04:28:35.79 | 6 | - | 1052 | | | 4.58 |
| | | 06/03/07 05:49:25.43 | 7 | 6.3 | 1026 | | | 4.64 |
| | | 06/03/07 06:18:09.35 | 8 | - | 1025 | | | 4.66 |
| | | 06/03/07 08:13:39.51 | 9 | 4.6 | 1027 | | | 4.74 |
| | | 06/03/07 08:49:50.38 | 10 | 4.9 | 1035 | | | 4.76 |
| | | 06/03/07 09:34:03.12 | 11 | 4.8 | 814 | | | 4.79 |
| | | 06/03/07 10:08:53.58 | 12 | 4.4 | 1038 | | | 4.82 |
| | | 06/03/07 12:53:06.86 | 13 | 5.1 | 1025 | | | 4.93 |
| | | 06/03/07 15:22:17.67 | 14 | 4.5 | 1033 | | | 5.03 |
| | | 06/03/07 16:02:13.99 | 15 | 4.2 | 1027 | | | 5.06 |
| | | 06/03/07 16:23:52.93 | 16 | 4.9 | 1037 | | | 5.08 |
| | | 06/03/07 17:37:21.30 | 17 | 4.3 | 1037 | | | 5.13 |
| | 06/03/07 18:21:06.10 | | 5 | 1.9 | 408 | | | 5.16 |
| | | 06/03/07 20:14:50.33 | 18 | 4.6 | 1048 | | | 5.24 |
| | | 07/03/07 01:14:10.69 | 19 | 4.3 | 511 | | | 5.44 |
| | | 07/03/07 01:24:37.55 | 20 | 4.4 | 469 | | | 5.45 |

Table 1 (cont.)

| Date of occurrence of radon anomaly | Earthquake occurrence | | Magnitude (Ml) (mb) | Epicenter distance from radon station (km) | Radon anomaly (count) | Radon anomaly from average value σ | Delta time between Rn anomaly and EQ (Precursor time, days) |
|-------------------------------------|-----------------------|----------------------|---------------------|--|-----------------------|---|---|
| | Local EQ (Ml) | Regional EQ (mb) | | | | | |
| 1/3/2007 14:34:35.00 UTC date | 6 | 07/03/07 01:24:46.75 | 2.7 | 403 | 91 | $> 2\sigma$ | 5.45 |
| | 21 | 07/03/07 10:53:37.59 | 5.9 | 737 | | | 5.85 |
| | 22 | 08/03/07 22:36:12.57 | 4.6 | 1083 | | | 7.33 |
| | 23 | 08/03/07 22:39:45.02 | 4.2 | 1050 | | | 7.34 |
| | 24 | 08/03/07 23:51:51.58 | - | 1232 | | | 7.39 |
| | 7 | 09/03/07 03:29:30.70 | 2.0 | 377 | | | 7.54 |
| | 8 | 09/03/07 07:55:46.58 | 0.0 | 31 | | | 7.72 |
| | 9 | 09/03/07 17:48:43.81 | 0.5 | 135 | | | 8.13 |
| | 10 | 10/03/07 09:57:54.70 | -0.2 | 17 | | | 8.81 |
| | 11 | 10/03/07 17:15:05.08 | 1.0 | 303 | | | 9.11 |
| | 12 | 10/03/07 21:23:12.98 | 1.8 | 265 | | | 9.28 |
| | 13 | 12/03/07 06:15:07.67 | 2.2 | 430 | | | 10.65 |
| | 25 | 11/03/07 06:09:00.33 | 4.4 | 749 | | | 9.65 |
| | 26 | 13/03/07 00:12:16.41 | 4.4 | 676 | | | 11.40 |
| | 27 | 13/03/07 03:22:43.73 | - | 609 | | | 11.53 |
| | 14 | 13/03/07 03:22:53.42 | 2.2 | 498 | | | 11.53 |
| | 28 | 13/03/07 20:42:49.41 | 4.2 | 736 | | | 12.26 |
| | 29 | 14/03/07 00:54:43.16 | 4.3 | 957 | | | 12.43 |
| | 15 | 14/03/07 10:40:30.00 | -0.8 | 15 | | | 12.84 |
| | 30 | 14/03/07 20:52:38.31 | - | 731 | | | 13.26 |
| | 16 | 15/03/07 06:13:31.00 | 1.7 | 419 | | | 13.65 |
| | 17 | 15/03/07 10:38:10.00 | -0.3 | 21 | | | 13.84 |
| | 31 | 16/03/07 07:19:42.83 | 4.7 | 895 | | | 14.70 |
| | 32 | 16/03/07 10:07:15.52 | 4.1 | 796 | | | 14.81 |
| | 18 | 16/03/07 10:09:30.00 | 0.0 | 17 | | | 14.82 |
| | 33 | 16/03/07 14:15:47.48 | 4.1 | 1243 | | | 14.99 |

earthquake that occurred 5.45 d after the radon anomaly and between 7.54 to 9.28 d later, with two M1 2.2 earthquakes after this period, occurring 10.65 d and 11.53 d later, respectively (Table 1).

6. The earthquake and radon data indicated that there might be a relationship between the local and regional earthquakes, suggesting a possible (stress/strain) relationship between the Sunda subduction zone and the fault zones in Southern Thailand. This is under further investigation and will be important for any seismic hazard assessment in Southern Thailand.

7. Longer-term measurements of earthquake activities and radon emissions would be preferable over several years, as these ground related processes occur over a longer time scale.

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