Geofísica Internacional (2002), Vol. 41, Num. 4, pp. 507-511

Automated radon monitoring of seismicity in a fault zone

L. L. Chyi[1], C. Y. Chou[2], F. T. Yang[2] and C. H. Chen[2]
[1] *Dept. of Geology, Univ. of Akron, Akron, USA*
[2] *Dept. of Geosciences, National Taiwan University, Taiwan*

Received: September 2, 2001; accepted: May 22, 2002

RESUMEN

Se utilizó un detector con un fotodiodo de silicio y un «data logger» para medir radón en el suelo en la zona de falla de Chuko en el centro-sur de Taiwan. La variación temporal del radón muestra un ciclo de preparación del sismo con un aumento rápido de radón seguido de un nivel elevado sostenido, una anomalía en forma de pico y por último un decrecimiento mayor hasta alcanzar casi el nivel del fondo antes del inicio del sismo. La aproximación integrada de las medidas de radón del suelo indica que las anomalías en forma de pico son mejores precursoras y pueden utilizarse para determinar el lugar y la fecha de un sismo. Sin embargo, la geología local es un factor crítico para determinar la fecha y la localización del sismo.

PALABRAS CLAVE: Radón, sismicidad, Taiwan, zona de falla.

ABSTRACT

Silicon photodiode detector and data logger are employed in soil gas radon measurement in Chuko fault zone in south central Taiwan. Time variation of radon shows that there is a radon earthquake preparation cycle with a fast radon build-up, then a sustaining high level, a spike-like anomaly, and then a faster decrease to near background level before the onset of an earthquake.

The new integrated approach in soil gas radon monitoring reveals that the spike-like anomalies are superior precursors and could be used to delineate time and place of an earthquake. However, basement geology is a critical factor in determining time and place of earthquake. When multiple units of this system are emplaced at different locations, it is possible that the time, place, and magnitude of earthquakes could all be predicted.

KEY WORDS: radon, seismicity, Taiwan, fault zone.

INTRODUCTION

Radon anomalies, either in groundwater or as soil gas, have been used as earthquake precursors since Ulomov and Mavashev (1967). Chyi *et al.*(2001) reviewed the historical efforts in using radon anomaly as earthquake precursor. However, in actual prediction of earthquakes the precursor is not always effective. It is obvious that the techniques of radon gas sampling and detection could be improved. Above all, the signal to background ratio must be improved by placing the detector within a fracture zone of an active fault with upwelling gases. Secondly, the environmental factors affecting radon variation must be reduced, by housing of the detector. Thirdly, the data recording must be continuous and retrievable at a remote site.

Taiwan has certain advantages in evaluating radon anomalies as earthquake precursors. The island is subjected to a compressive force coming from the southeast. The Philippine Sea Plate is moving N55°W against the Eurasia plate at 7±4 cm/year (Kao *et al*., 1998). In addition, at least in southern Taiwan, the sedimentation rate during the Pleistocene and Holocene time has been extremely fast with a total thickness exceeded 10 000 m. The contemporaneous compaction and rapid compression have resulted in quick soil gas release as witnessed by the number of springs, mud volcanoes, and diapers. These features are usually found along fractured anticlines or fault zones. The tropic of cancer passes through central south Taiwan. The ambient temperature could only affect the top 0.5 m of soil profile and soil temperature is about 12°C year round.Thus, the ambient temperature is always higher than soil temperature. There is no down soil gas flux as experienced in temperate zone. Earthquakes with M_L>4 occur at least one a day. There are numerous seismic stations and the reporting is fast. It is, therefore, possible to evaluate whether the anomalies are due to seismic or nonseismic events.

METHODS

To make sure that there is a favorable signal to background ratio, a site located within a facture zone in south central Taiwan is chosen (Figure 1). This site has numerous springs and soil gas releases. Yang *et al*. (2001) reported that the $^3He/^4He$ in this area are 4.0-5.9 R_A and indicate significant mantle gas contributions. Moreover, they found that this

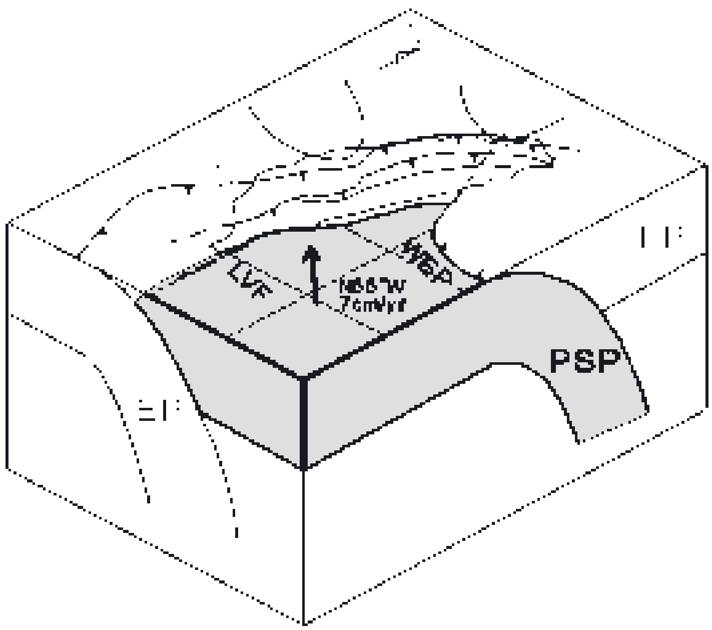

Fig. 1. Geomechanical framework of Taiwan showing direction of stress and distribution of major faults. EP denotes Eurasia plate. WEP the western edge of Eurasia plate. PSP Philippine Sea plate. FT frontal thrust. CCF Chuchih-Chaochou fault. LVF longitudinal valley fault.

ratio is reduced to 3.7 to 0.7 R_A just before the earthquake and suggested that the gas conduits are sensitive to stress changes.

To further rectify the soil gas radon releases, a ditch 3 m long 0.6 m wide, and 1.5 m deep is prepared. The bottom of the ditch is lined with 30 cm gravel and covered with a 0.8 mm thick plastic sheet before back filling. A PVC pipe is used to house the radon detecting system and the pipe is anchored in the middle part of the ditch (Figure 2). In addition, the site is on a gravelly sandy river terrace deposit high above the groundwater table.

Housing the detecting system inside a PVC pipe and retrieving the data electronically without removing the PVC pipe cap reduced the influence of environmental factors dramatically. The radon detecting system consists of a silicon photodiode detector, an interface, and a data logger. The system is capable of recording radon flux changes with less than minute duration. By connecting the data logger to a modem and telephone line, the data could be retrieved at a remote site at any time (Chyi *et al*., 2001).

RESULTS

The recorded radon spectrum is presented as Figure 3 with all spike-like anomalies identified. The timing of the spike-like anomalies and the onset of earthquakes, and other pertinent parameters are listed in Table 1. Figure 4 shows the locations of these earthquakes. These fifteen earthquakes represent all the M_L>4 earthquakes occurred between the end of October 2000 and the end of February 2001. All observable earthquakes are found to be within a 100x30 km radii ellipse with the present station as the center. Precursory intervals are between 0.49 and 7.40 days.

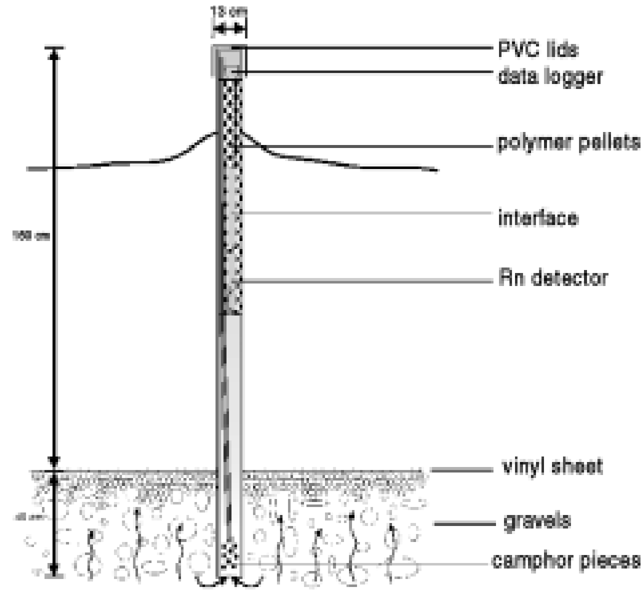

Fig. 2. Schematic diagram of the detector assembly and the monitoring station.

Other earthquakes occurred during this period are simply missed because of services of detector. Earthquake I has 3 or 4 poorly defined preceding anomalies. Earthquake II and III may be too far away and too weak for the detection. Earthquake IV and V may have produced anomalies but were masked by the closer earthquake 2. Earthquakes VI may have produced anomalies but they are intermingled with two other M_L=3.9 earthquakes nearby. Earthquake VII and VIII occurred when the detector was in service. The anomaly from earthquake IX was probably masked by the stronger anomaly from earthquakes13a and b. Earthquakes X may have small anomaly but definitive identifications could not be made.

Earthquakes 1, 3, 4, and 14 show a complete earthquake cycle development (Figure 3). The cycle consists of a quick radon build up, sustaining at high level, the spike-like anomalies, and the decay of the anomalies before the onset of an earthquake.

DISCUSSION

The immediate cause of earthquake is believed to be the result of elastic rebound. The explanation has been confirmed over the years (Bolt, 1999). If the rock formations are low in modulus of elasticity, then the maximum deformation is realized before rebound rather than after. Following the discussion of Keller (1996), during initial energy accumulation stage, there is no change in soil gas radon level. However, radon level starts to increase when stress exceeded one half of the rock strength. Small spike-like anomalies start to appear as a result of micro-fracture of rock formation and the formation of micro seep when groundwater level is increasing at the same time. At this point, the volume of rock starts to increase responding to the development of microfracturing and the flow of groundwater into these fractures (Rahn, 1996). As the microfractures are interconnected, added amount of groundwater will flow into these spaces and result in lowering of groundwater level. The drastic lowering of groundwater level in conjunction with the maximum deformation before rebound produces spike-like radon anomaly of short duration. Further interconnecting of the fractures will result in sliding along fault and the rebound. For a stack of mudstone dominant sedimentary rocks, the rebound

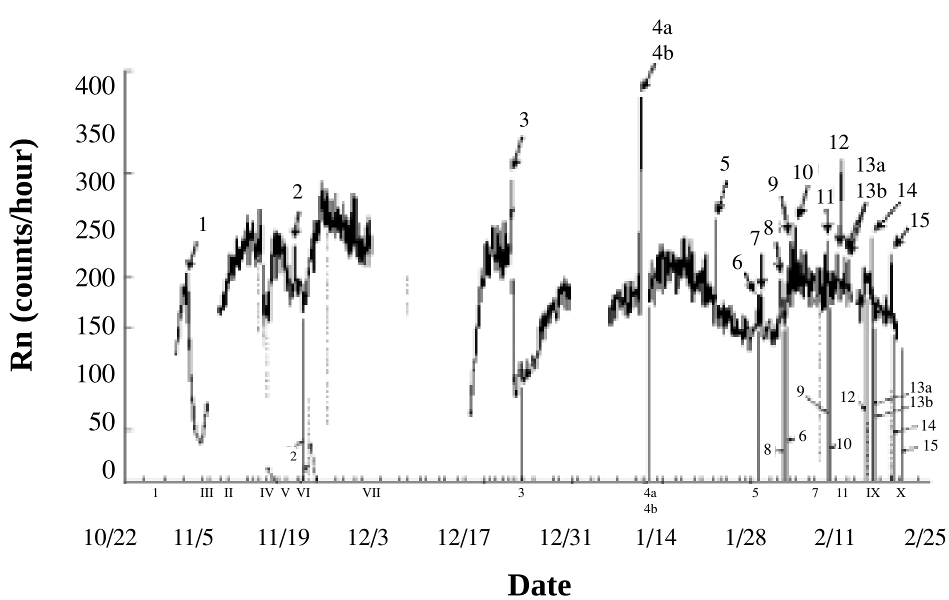

Fig. 3. Continuous radon spectrum recorded from the end of October 2000, to the end of February. Counting rate is calculated for every 384 counts. Numbers denote earthquakes (M_L>4) precursors recorded and dotted lines indicate the onset of earthquakes corresponding to the precursor numbers.

Table 1

Radon spectrum and earthquake characteristics

No.	Precursor	Earthquake	Interval(day)	Distance(km)	Depth(km)	Magnitude
1	10/31 14:13	11/01 17:08	1.12	8.5	11.9	4.1
I		11/11 16:41		16.0	12.1	4.0
II		11/12 21:27		81.0	13.4	4.0
III		11/13 01:32		73.0	7.1	4.1
2	11/17 12:30	11/18 18:21	1.16	4.8	15.7	4.1
IV		11/19 19:46		61.0	23.3	4.4
V		11/19 19:48		74.8	24.5	4.0
VI		11/22 17:00		74.1	8.1	4.6
VII		12/04 22:20		66.4	14.7	4.0
3	12/21 09:34	12/22 19:22	1.41	93.0	3.0	4.7
4a	01/10 14:56	01/11 16:37	1.08	85.0	24.6	5.2
4b	01/10 14:56	01/11 17:09	1.10	85.0	25.0	5.0
5	01/22 12:35	01/28 21:08	6.36	15.7	6.3	4.5
6	01/29 02:00	02/02 06:05	4.16	17.6	2.1	4.3
7	01/29 11:16	02/05 20:49	7.40	59.7	22.5	4.2
8	02/01 13:29	02/02 01:12	0.49	22.6	11.8	3.7
VIII		02/07 16:54		67.7	22.1	4.2
9	02/03 11:47	02/09 01:34	5.59	9.1	7.0	4.9
10	02/03 19:27	02/09 02:17	5.37	8.1	11.8	4.2
11	02/08 18:20	02/11 20:43	3.10	61.6	13.9	4.7
12	02/10 09:19	02/14 21:17	4.50	27.4	18.2	4.5
IX		02/15 17:02		75.8	11.5	4.1
13a	02/1116:43	02/15 06:25	3.57	27.3	17.7	4.7
13b	02/12 04:49	02/15 22:51	3.75	27.3	18.1	4.3
X		02/18 18:32		17.0	6.8	4.3
14	02/15 18:22	02/19 04:25	3.41	27.3	18.4	5.2
15	02/18 18:34	02/20 09:41	1.64	27.4	18.9	4.8

is small compared with the maximum deformation. After this fast radon release, radon flux starts to decrease while groundwater level is gradually rising responding to the continuing increase of stress after all the fracture spaces are filled. Sometime at this point, the slide along fault occurs and it is the onset of earthquake. The radon release pattern before the onset of an earthquake implies that there must be a degas phase because radon with a molecular weight of 222 is the heaviest natural occurring gas.

Earthquake events at M_L=4 and 5 range outside this perimeter are not visible to the monitoring station. It is possible that larger magnitude earthquakes may be detectable outside this ellipse. This assumption appears to be justified when reviewing the list in Table 1. Closer earthquake is detectable with an M_L=3.7 but farther earthquakes are not detectable until the M_L reaches 5.0. The trending appears to reflect the direction of the stress coming from the southeast trending N55°W and the old structure trend of Taiwan trending lengthwise along the island. Time intervals between anomaly precursor and the onset of earthquake vary from 0.49 to 7.40 days. The intervals may have related to the responsive time at the monitoring station to that earthquake event and modified by the local lithology and the structure of the fault. Higher percentage of mudstone or gauge along the fault zone would mean a slow migration of gases and the nature and shape of fracture zone would undoubtedly affect the upward migration of gases. Quantitative analyses of these factors are yet to be made.

CONCLUSIONS

Preselection of monitoring site is important in detecting quality precursor signals and hot springs and mud volcanoes with $^3He/^4He$ >1.0R_A in the gas phase. The site should also be permanently above groundwater table and should be

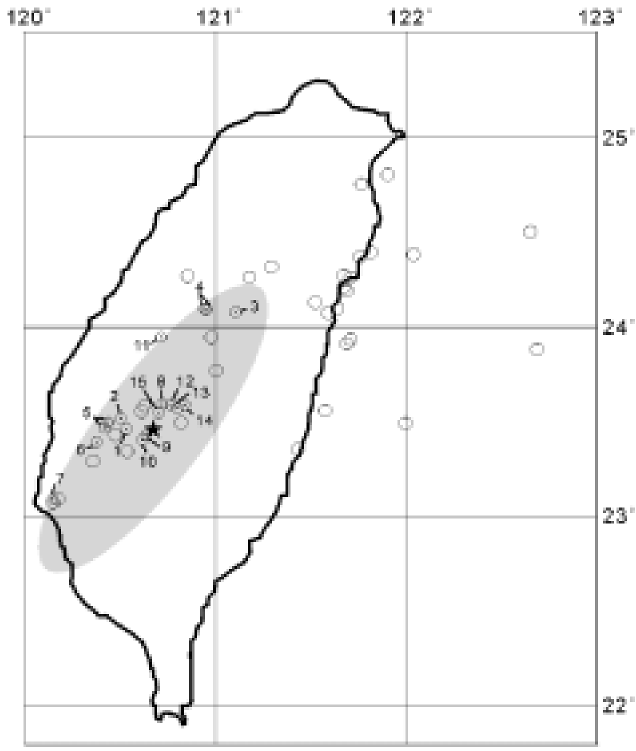

Fig. 4. Earthquakes (M_L>4) occurred between the end of October, 2000 to the end of February. Numbers next to dotted circles denote those detected by the radon detector assembly at the monitoring station (the star symbol) and those in open circles are not detected.

well drained. A ditch covered with polyvinyl sheet with the detector assembly housing placed in the middle may facilitate the collection of soil gas radon. The housing is capable of protecting the detector assembly from environmental influence.

Silicon photodiode detector is desirable because it could function under high humidity conditions and is capable of recording the data continuously with very little energy consumption. The recorded data could also be retrieved remotely.

This integrated geological, physical and engineering design is effective in detecting radon signal variations. The continuous radon spectrum contains signals related to earthquake cycle and, therefore, effective in predicting earthquakes. Multiple units functioning at strategic sites could provide new hope in even shorter earthquake prediction and may lead to understanding the duration of precursory time.

BIBLIOGRAPHY

BOLT, B. A., 1999. Earthquakes, 4th ed., 366 p., W. H. Freeman and Co.

CHYI, L. L., T. Y. CHOU, F. T. YANG and C. H. CHEN, 2001. Continuous radon measurements in faults and earthquake precursor pattern recognition. *Western Pacific Earth Sci., 1, 2,* 227-246.

KAO, H., S. J. SHEN and K. F. MA, 1998. Transition from oblique subduction to collision: earthquakes in the southwestern most Ryukyu arc-Taiwan region. *J. Geophys. Res. 103,* 7211-7229.

KELLER, E. A., 2002. Introduction to environmental geology, 2nd ed., Prentice Hall, Upper Saddle River, N. J, 564 pp.

RAHN, P. H., 1996. Engineering geology: an environmental approach, 2nd ed., Prentice Hall, NJ, 657 pp.

ULOMOV, V. I. and B. Z. MAVASHEV, 1967. O predvesnike sil'nogo tecktonicheskogozemietryarsenia (A precursor of a strong tectonic earthquake). *Dokl. Earth Sci. Sect., 176,* 9-11.

YANG, T. E. , P. S. HSIEH and C. H. CHEN, 2001. Gas variations associated with 1999 Chi-Chi Taiwan earthquake and its aftershocks, 6th International Conference on Rare Gas Geochemistry, Abstract with Programs.

L.L. Chyi[1], C.Y. Chou[2], F. T. Yang[2] and C.H. Chen[2]
[1] Dept. of Geology, Univ. of Akron, Akron,
OH 44325-4101, USA
Email: Lynn Chyi <lchyi@uakron.edu>
[2] Dept. of Geosciences, National Taiwan University,
245 Chosan Rd., Taipei 106, Taiwan