

Earthquake precursors observed from long-term radon measurements in eastern Taiwan

geochemist

seismologist



M.-C. T. Kuo¹ and H. Kuo-Chen²

1. National Cheng Kung University, Taiwan
2. National Central University, Taiwan



Outline

- Introduction of Radon-222 monitoring
- Case study (Antung well, eastern Taiwan)
- Mechanism for Radon anomaly
 - Dilatancy and Radon volatilization models
- Applications for earthquake early warning

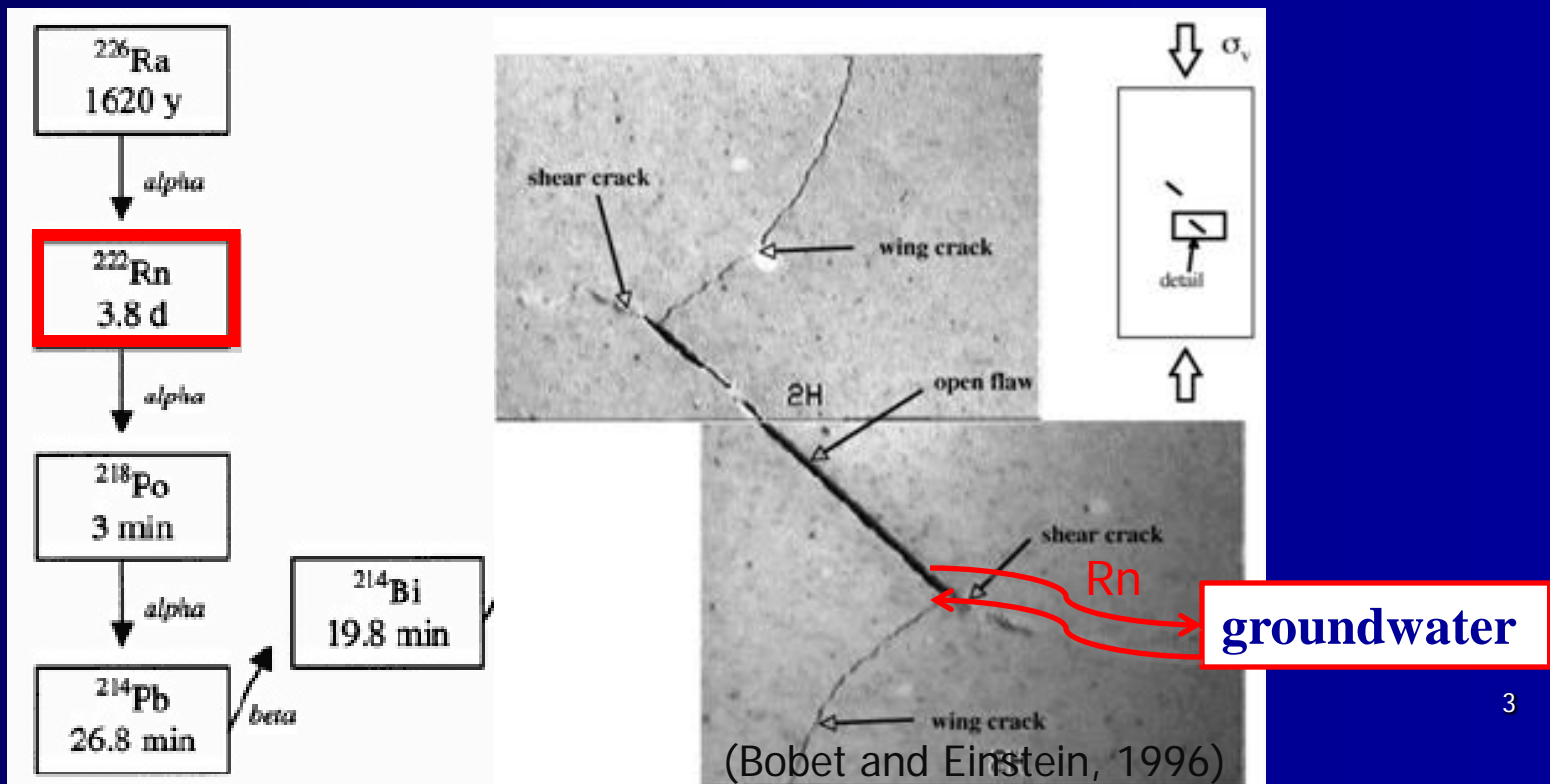
Radon-222 half life and its daughters

Regional stress increases

→ microcracks develop

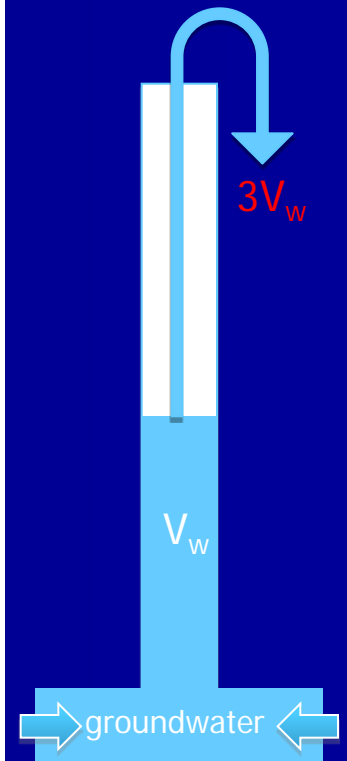
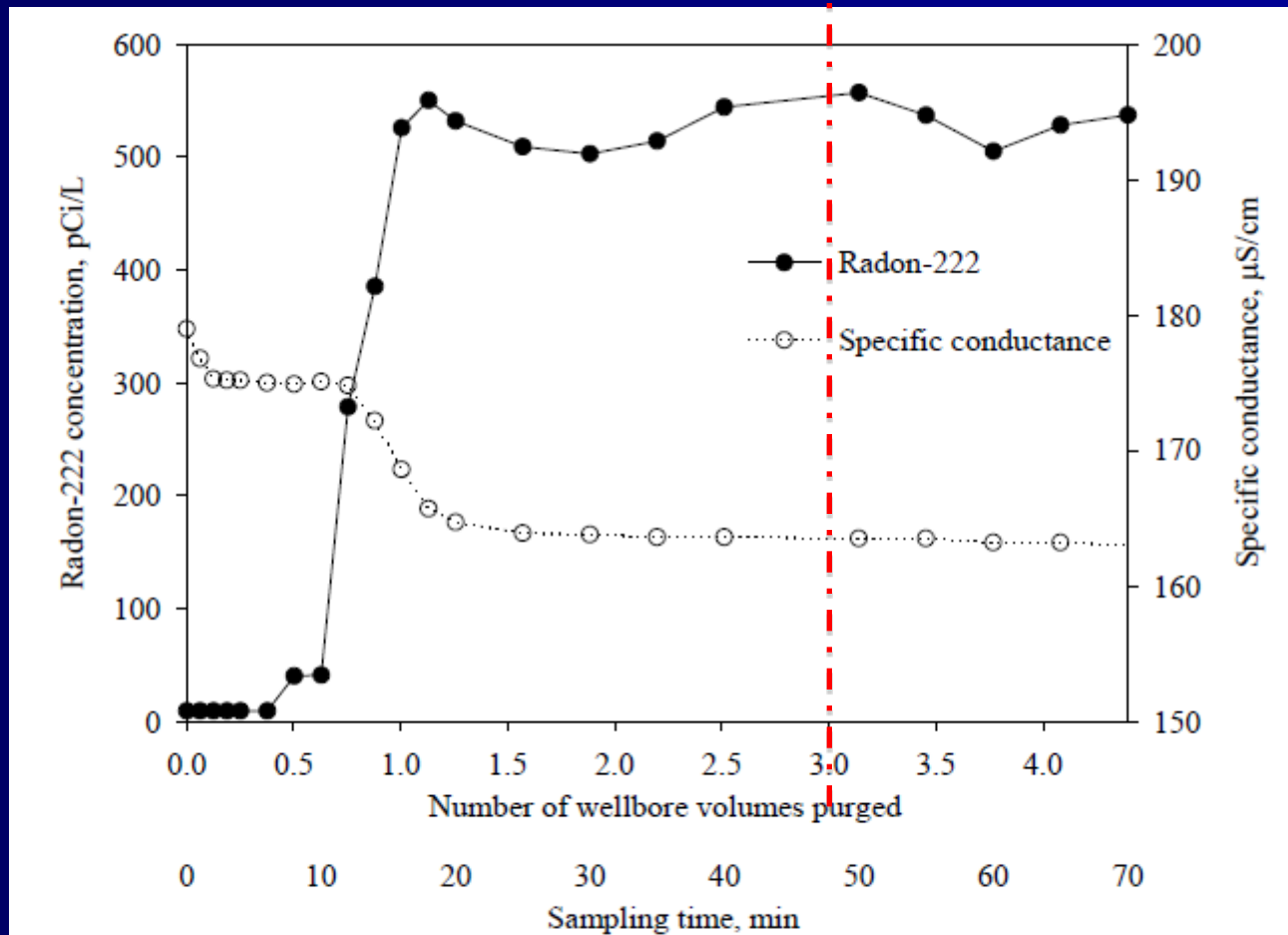
→ Concentration of Rn changes in groundwater

(e.g. Scholz et al., 1973; Wakita et al., 1980; Hauksson et al., 1981)



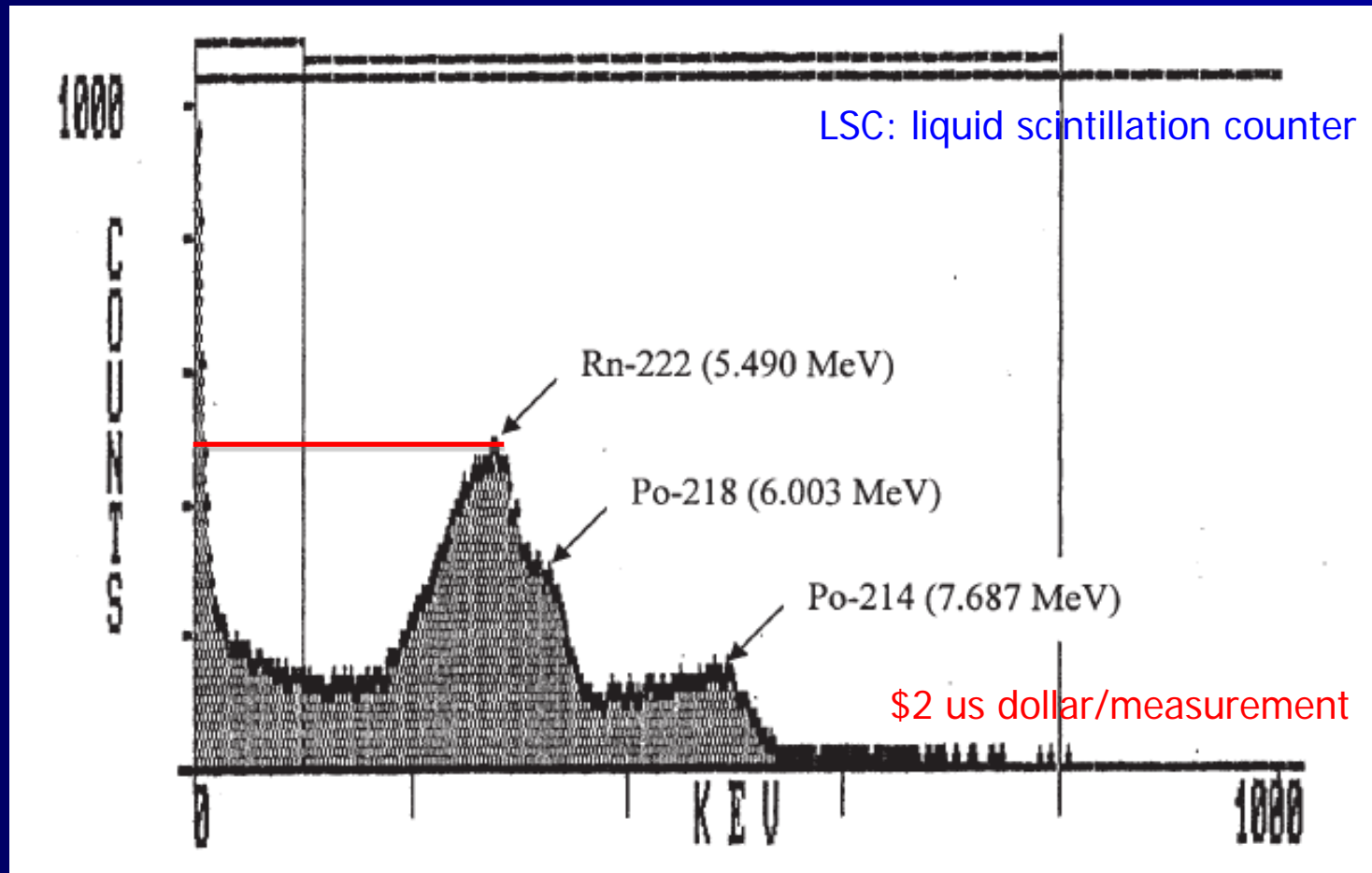
Radon concentration during well purging

Start to take samples (fresh groundwater)



(Han et al., 2006)

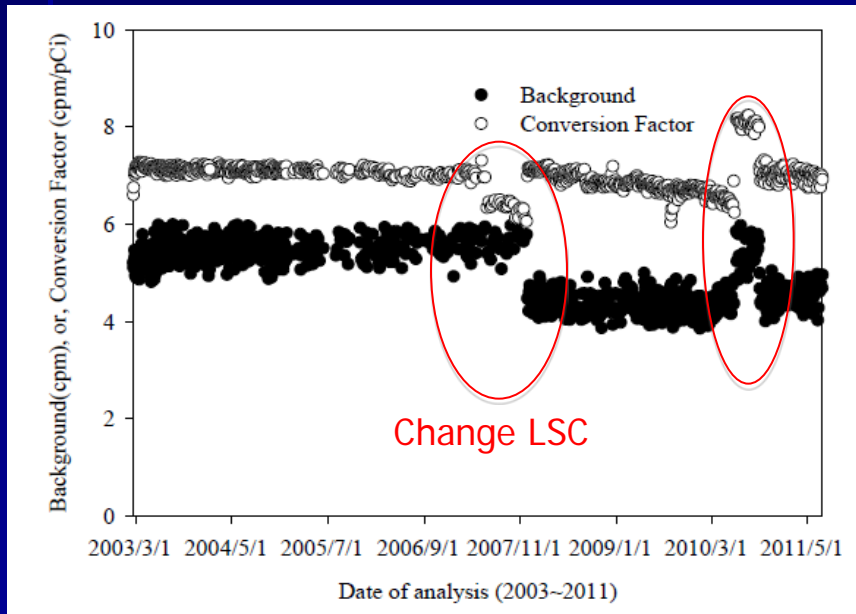
Measurements of Radon concentration (cpm: counts/minute)



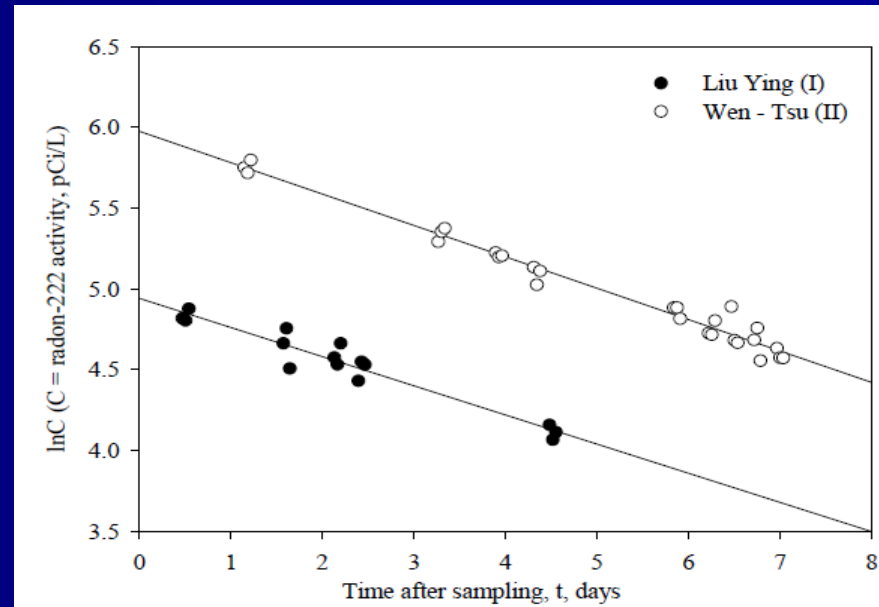
Alpha spectrum

(Kuo, 2012)

Radon QA/QC



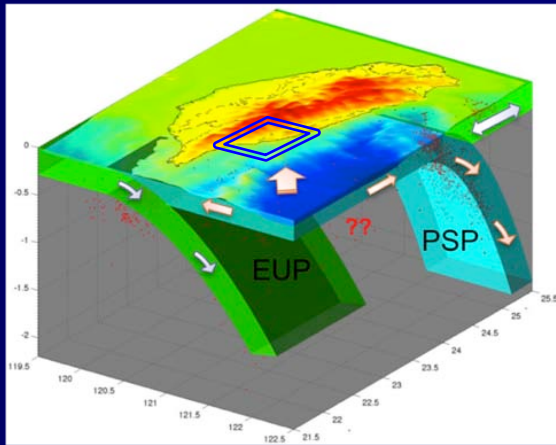
(Kuo, 2012)



(Han et al., 2006)

Tectonic setting

Waterwell near the suture zone

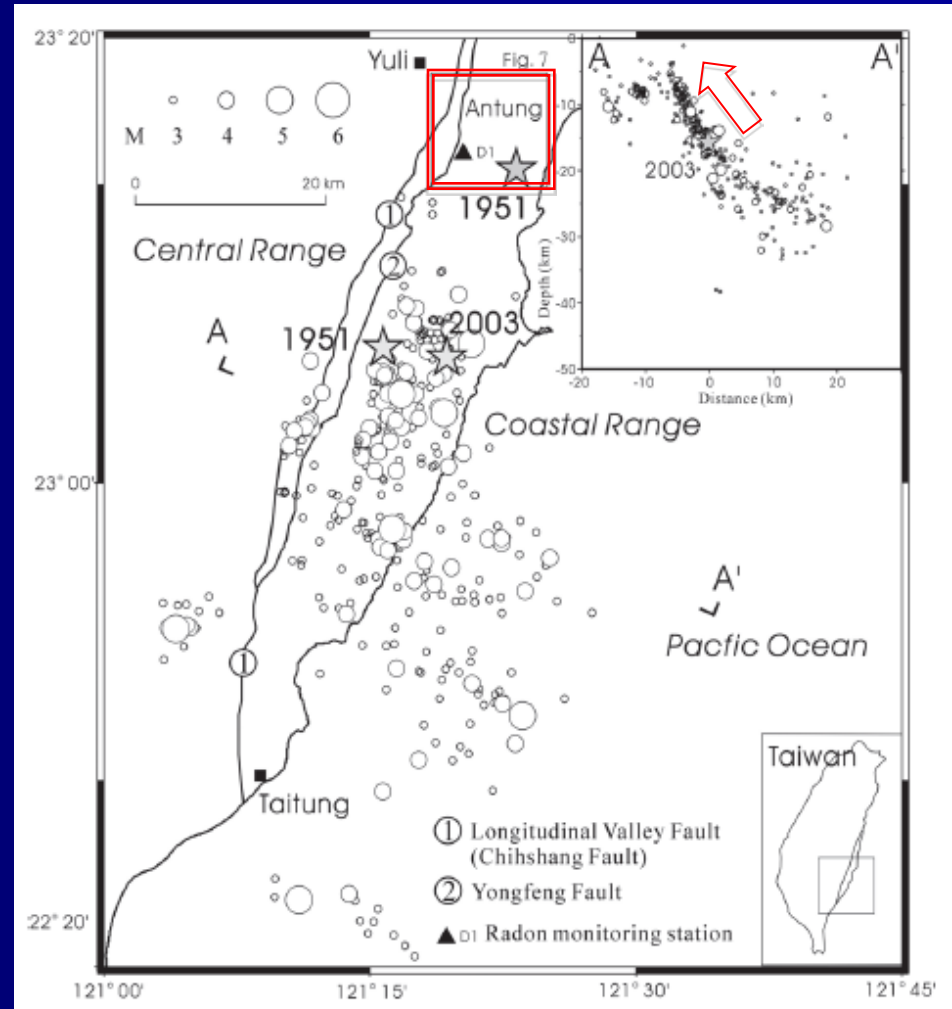


Historical damage earthquakes:

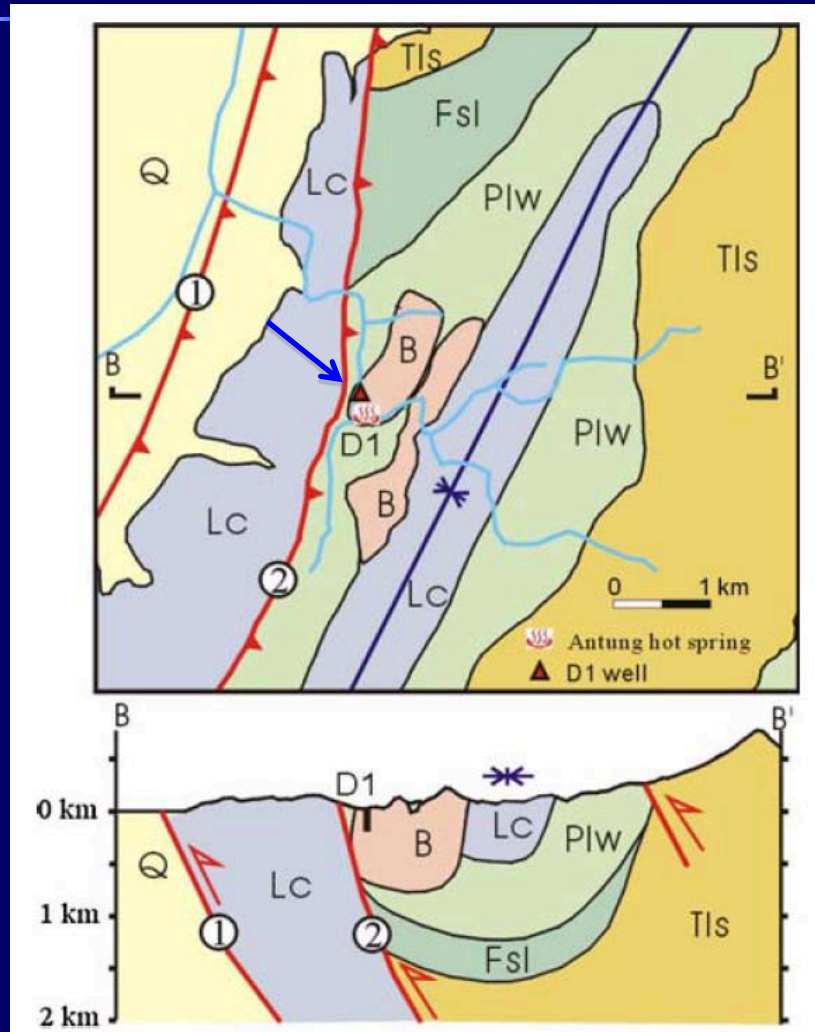
*1951 M_L 7.1 and 6.8

*2003 M_w 6.8

(Kuo et al., 2006)



Geological background of the monitoring well



Q: Holocene deposits

Lc: Lichi mélange

Plw: Paliwan Formation

Fsl: Fanshuliao Formation

Tls: Tuluanshan Formation

Bl: tuffaceous fault block
(low porosity)

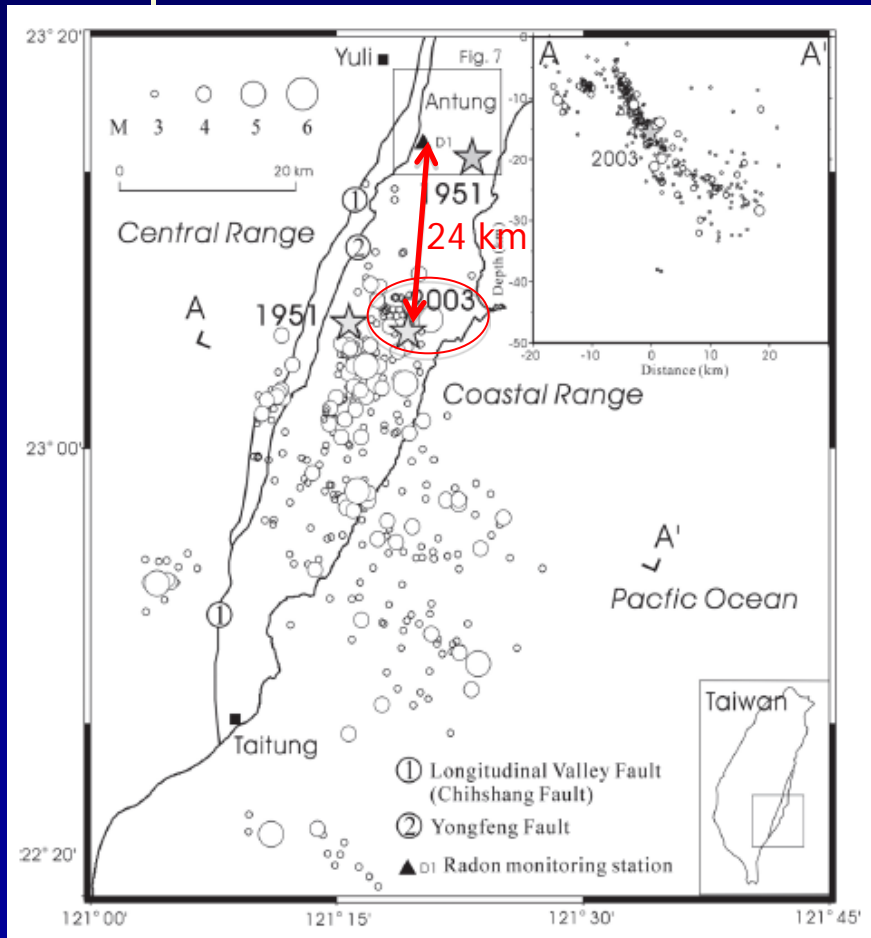
D1: radon monitoring well
(167~187m)

1. Longitudinal Valley Fault

2. Yongfeng Fault

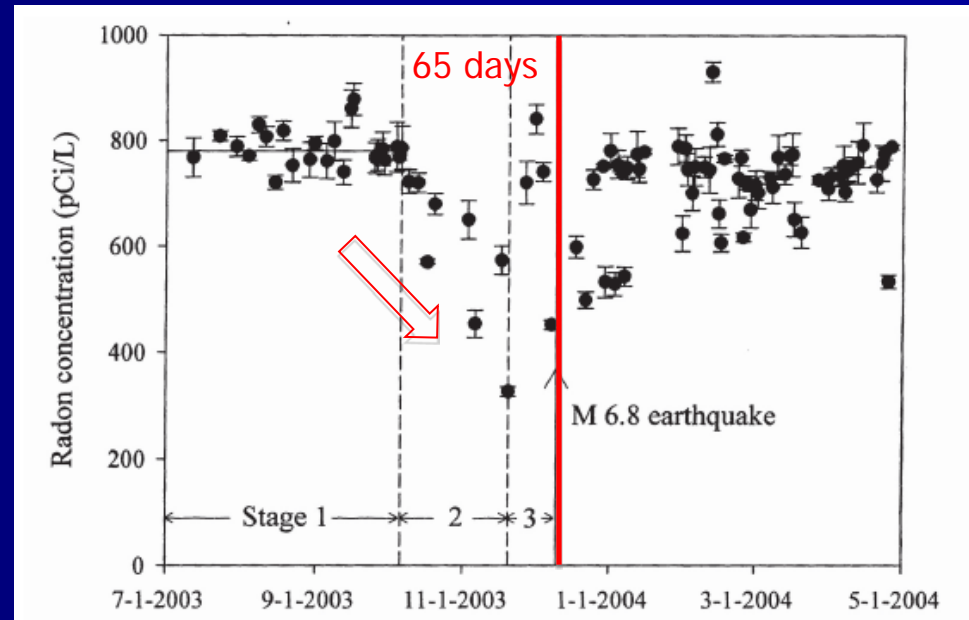
(Kuo et al., 2006)

Radon anomaly (Mw 6.8)

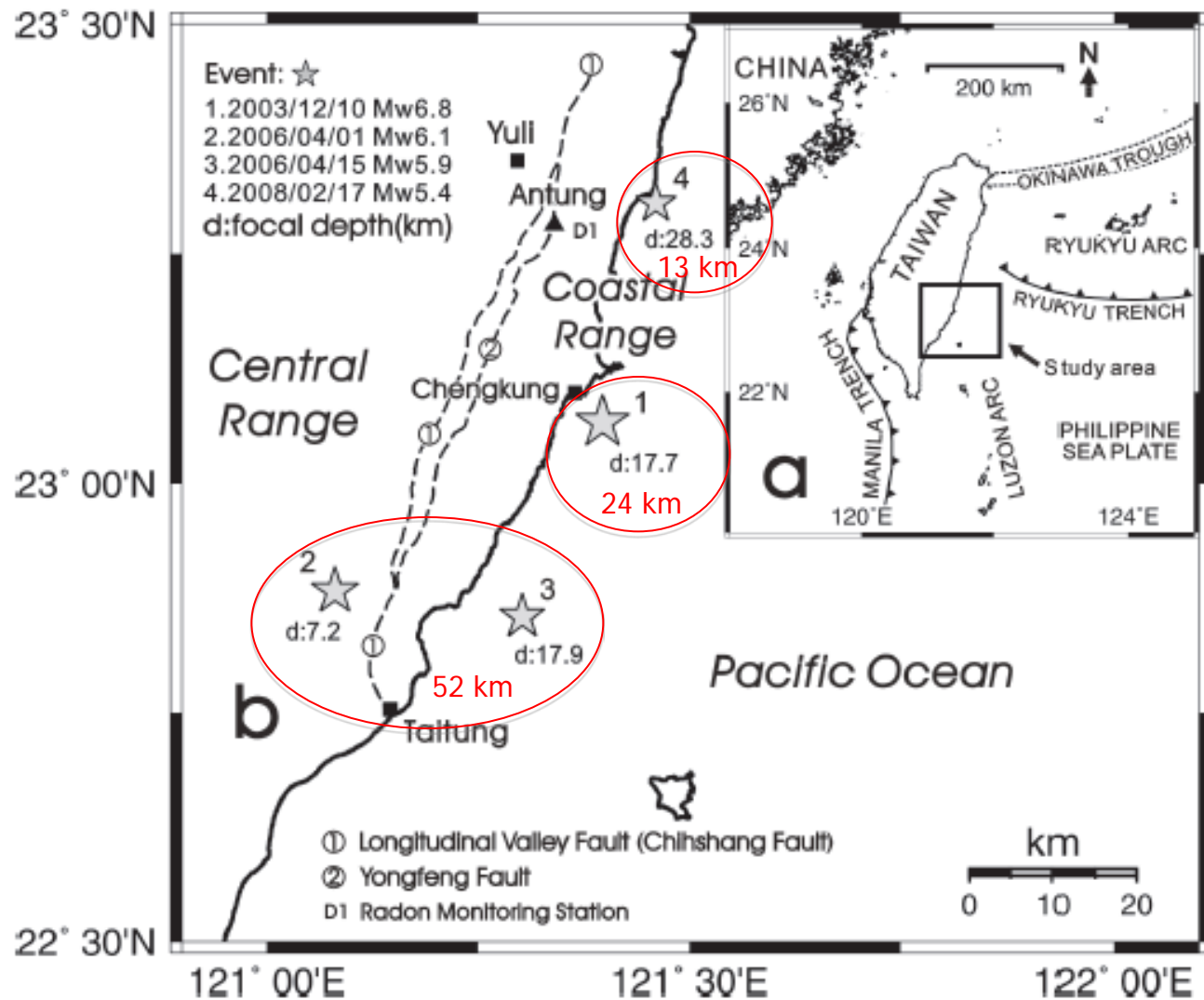


Concentration of Radon decreased
before earthquake occurred

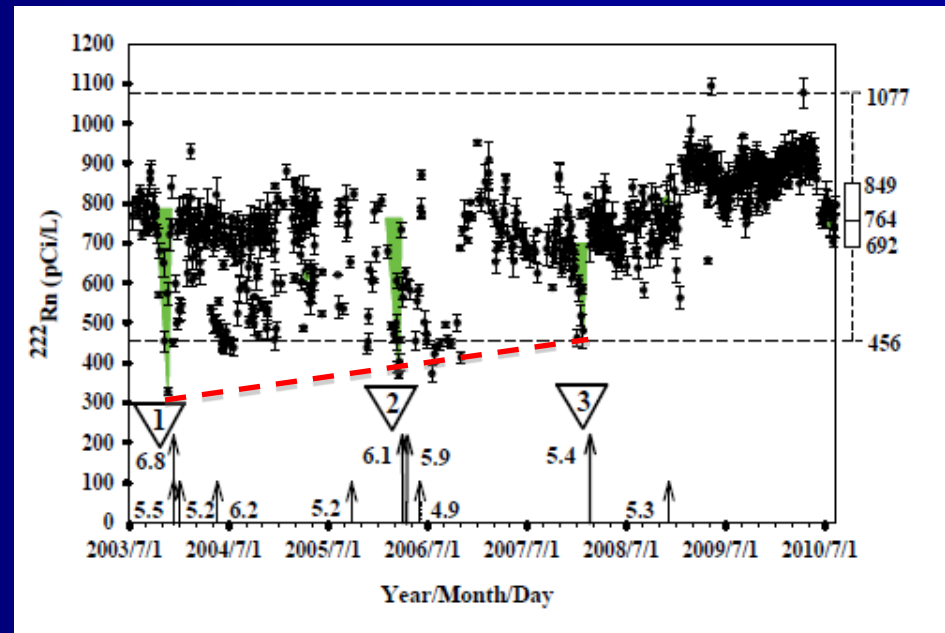
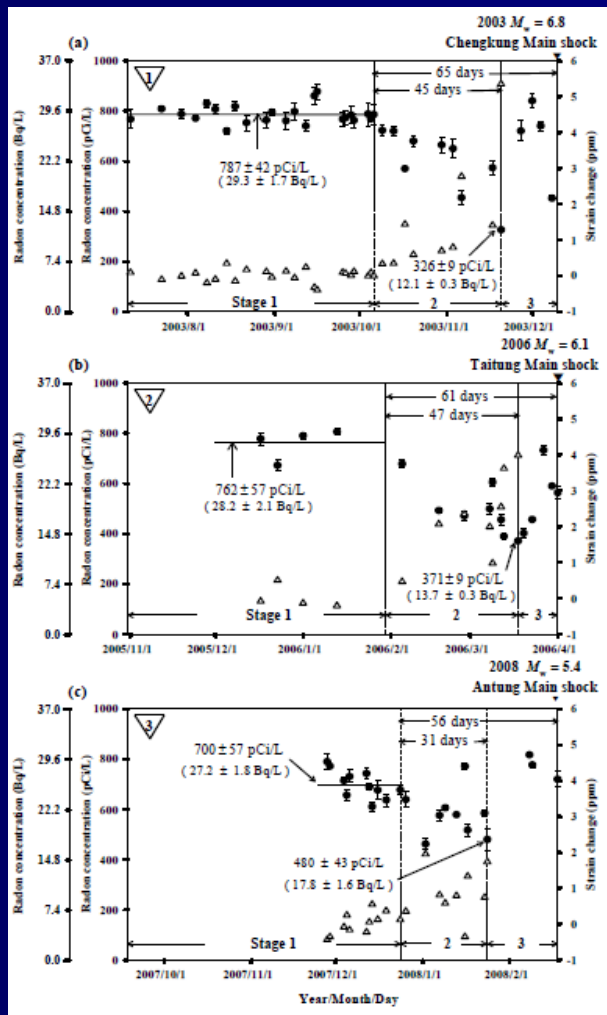
(Kuo et al., 2006)



Historical damage earthquakes:
1951 M7.1 and 6.8

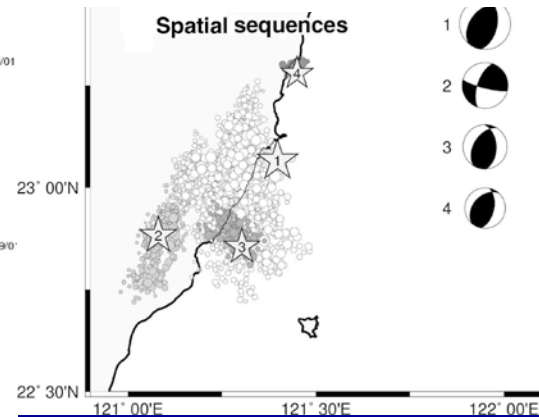
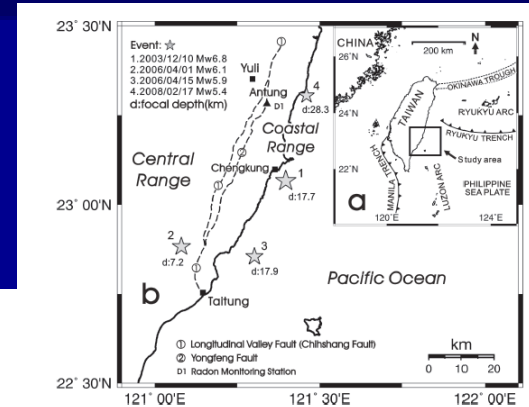
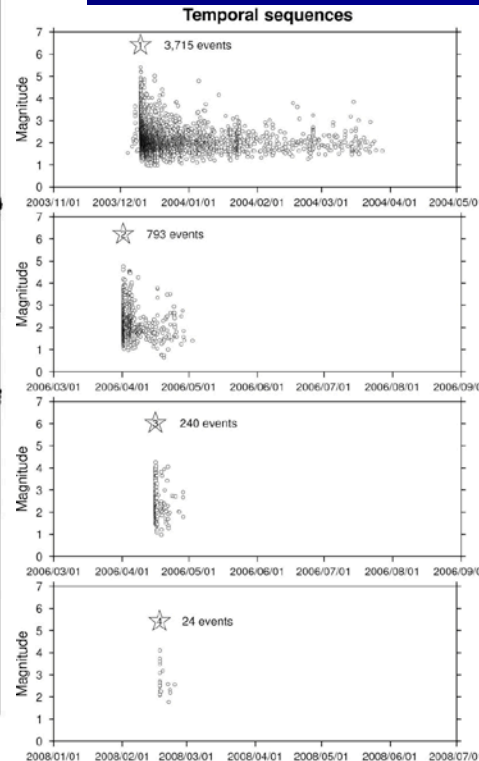
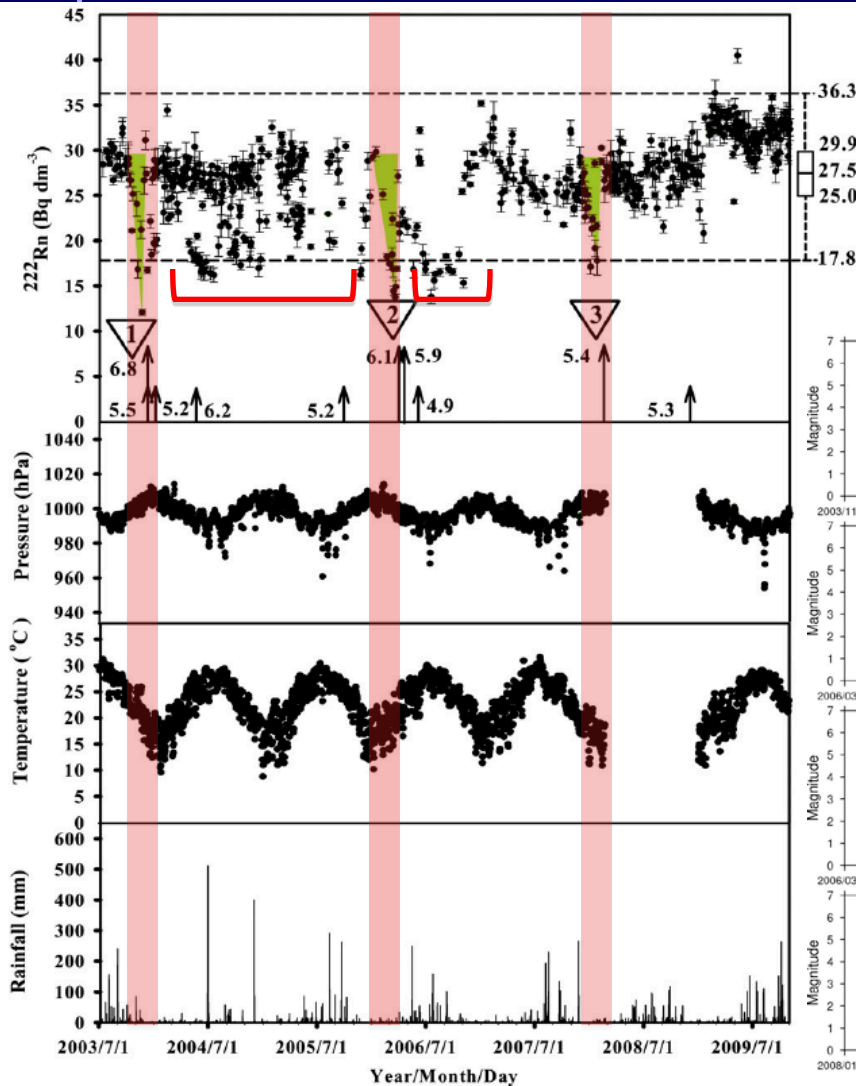


Radon monitoring at Antung well D1 (twice per week: 2003~ present)



(Kuo et al., 2010)

Checking for meteorological effects

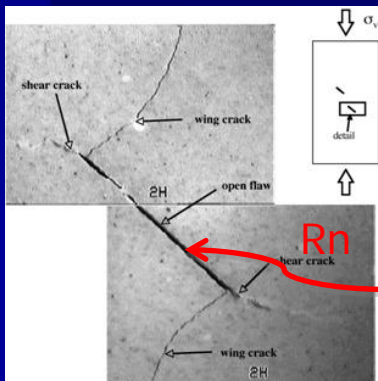
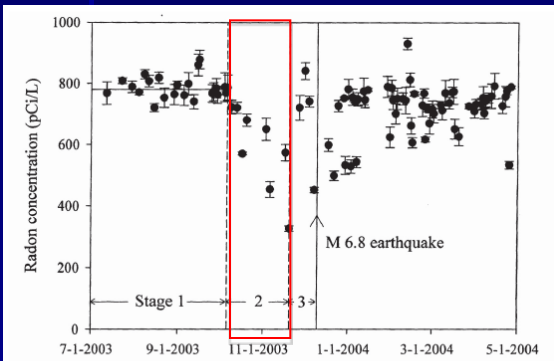


(Kuo et al., 2010; 2013)

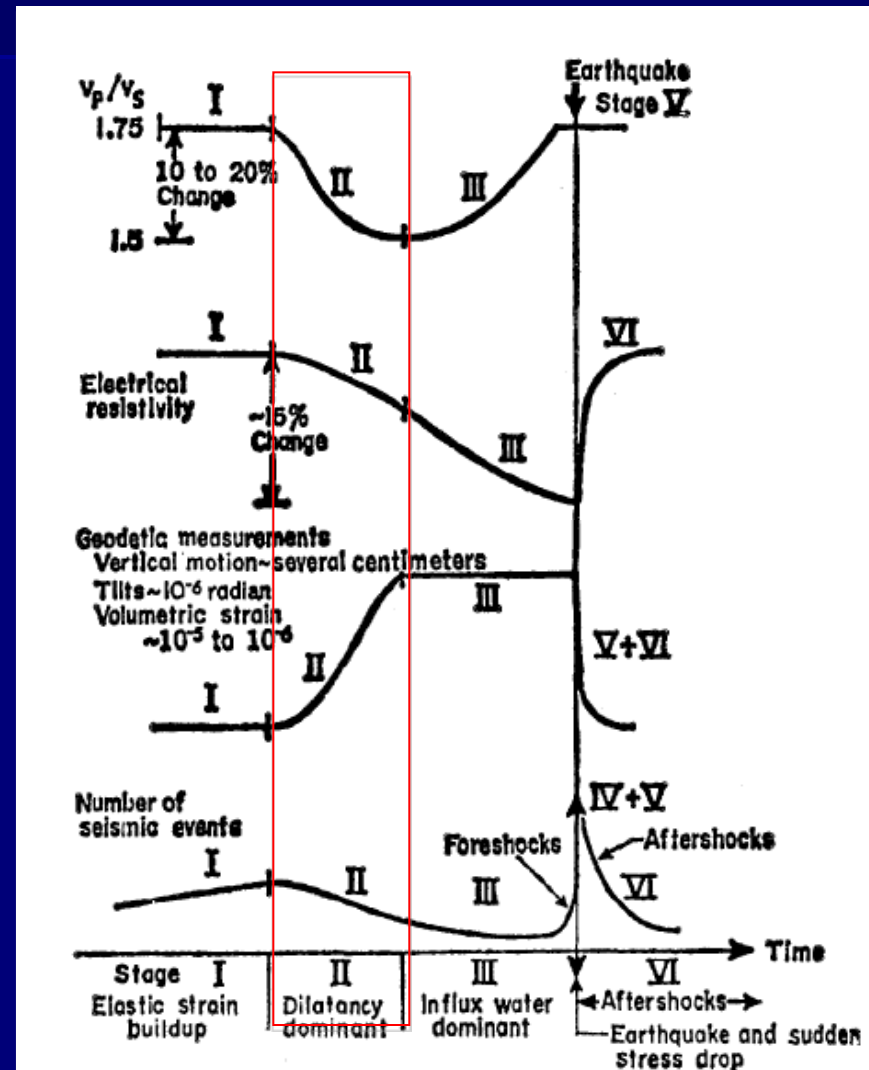
Rock dilatancy model

(Scholz et al., 1973)

Stage 1: Buildup of elastic strain.
Stage 2: Development of cracks.
Stage 3: Influx of ground water.



groundwater



Radon volatilation model

--Radon phase behavior (Lab experiment)

Radon favors in gas phase

$$C_o = C_w (H \times S_g + 1)$$

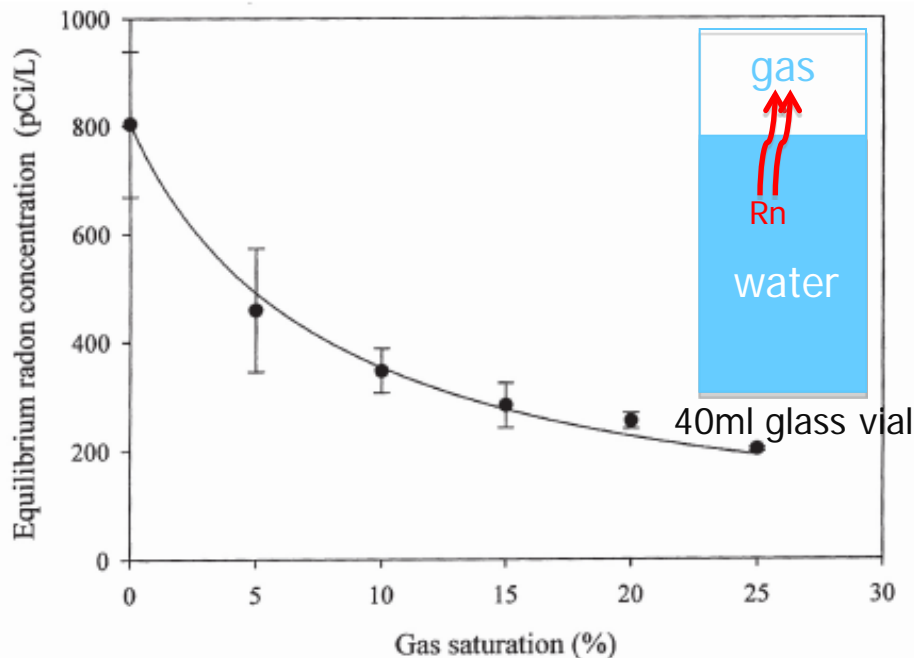
Where C_o is initial radon concentration

C_w is the radon minimum

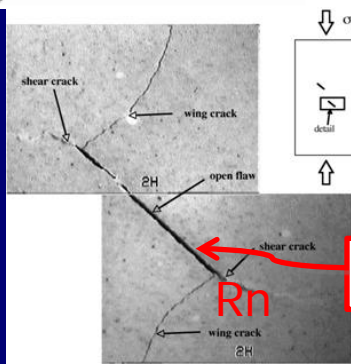
H is Henry's coefficient

S_g is gas saturation

groundwater



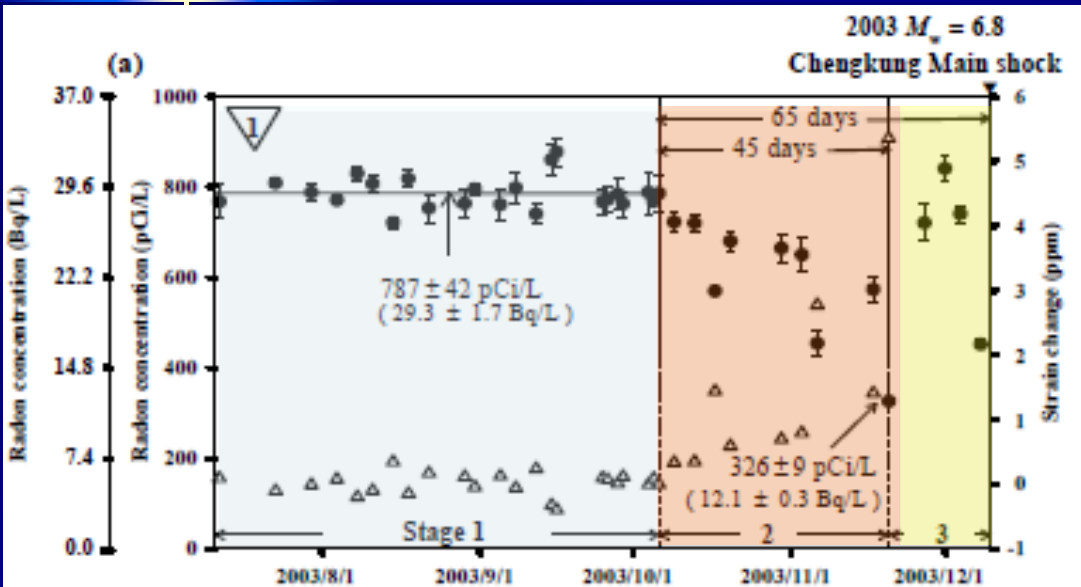
(Kuo et al., 2006)



2003 Mw 6.8

(Kuo et al., 2010)

Radon ↓
strain ↑



Stage 1: Buildup of elastic strain.

Stage 2: Development of cracks.

Stage 3: Influx of ground water.

$$d\varepsilon \cong \frac{\varphi}{H} \left(\frac{C_o}{C_w} - 1 \right)$$

C_w is the radon minimum

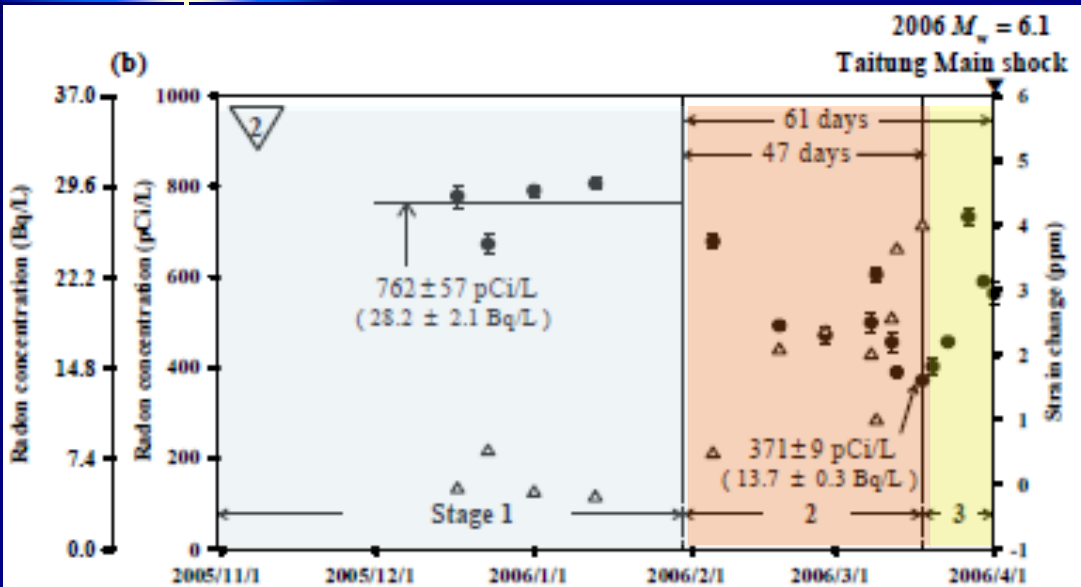
$d\varepsilon$ is volumetric strain

φ is fracture porosity

2006 Mw 6.1

(Kuo et al., 2010)

Radon ↓
strain ↑



Stage 1: Buildup of elastic strain.

Stage 2: Development of cracks.

Stage 3: Influx of ground water.

$$d\varepsilon \cong \frac{\varphi}{H} \left(\frac{C_o}{C_w} - 1 \right)$$

C_w is the radon minimum

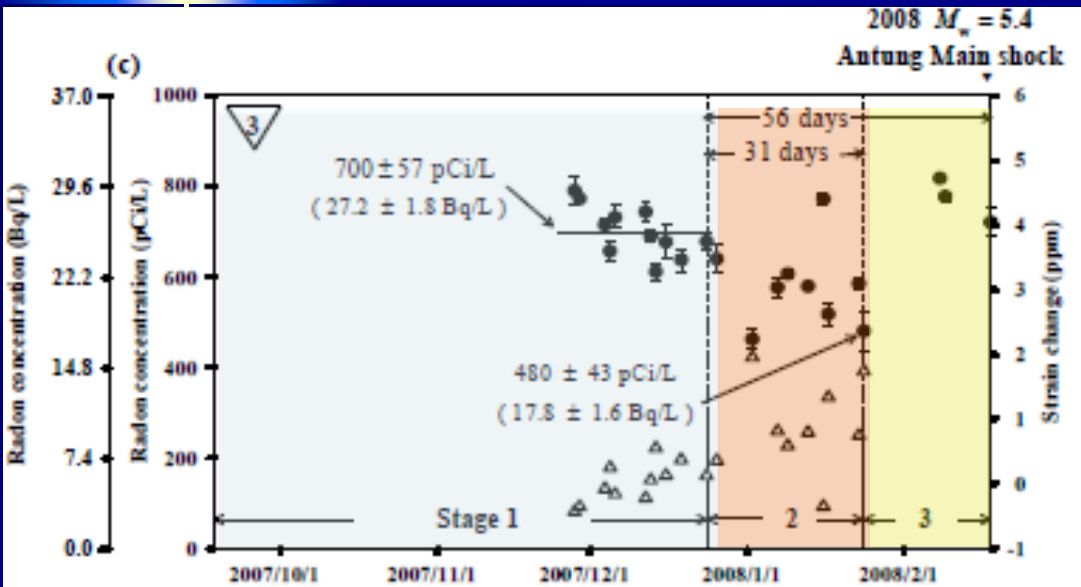
$d\varepsilon$ is volumetric strain

φ is fracture porosity

2008 Mw 5.4

(Kuo et al., 2010)

Radon ↓
strain ↑



Stage 1: Buildup of elastic strain.

Stage 2: Development of cracks.

Stage 3: Influx of ground water.

C_w is the radon minimum

$d\varepsilon$ is volumetric strain

ψ is fracture porosity

$$d\varepsilon \cong \frac{\varphi}{H} \left(\frac{C_o}{C_w} - 1 \right)$$

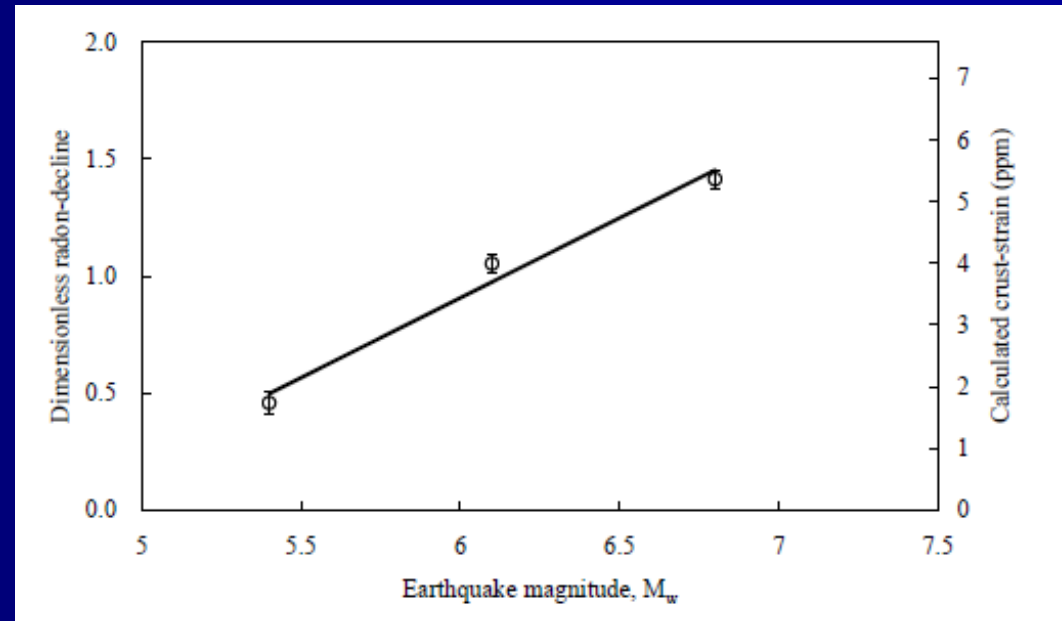
Calculations of strain and magnitude

Empirical equation:

$$C_w = 1063 - 110 M_w$$

$$d\varepsilon = 2.5893 M_w - 12.0948$$

$$\left(\frac{C_o}{C_w} - 1 \right) = 0.6827 M_w - 3.189$$



Where C_o is initial radon concentration

C_w is the radon minimum

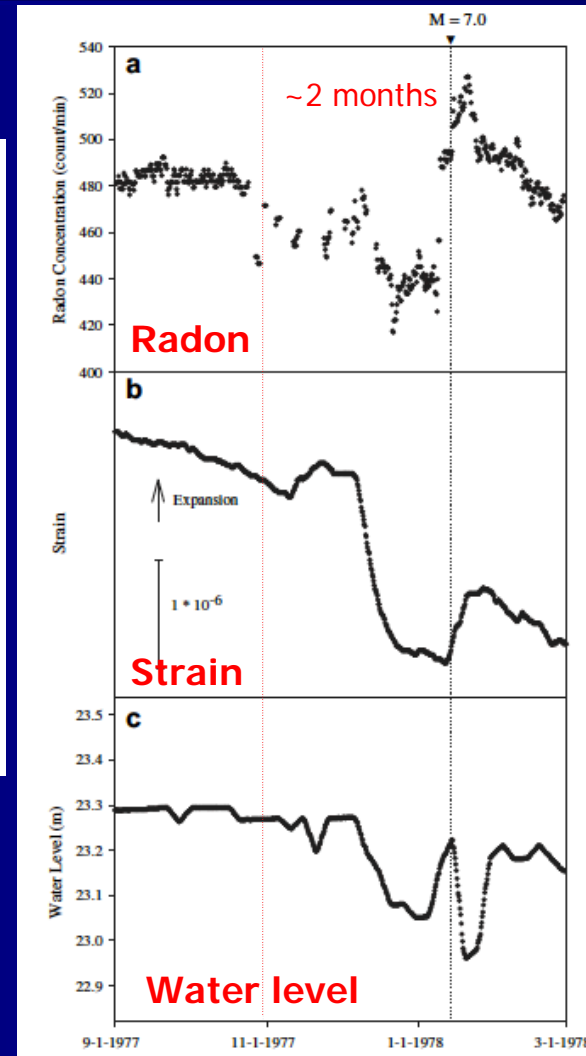
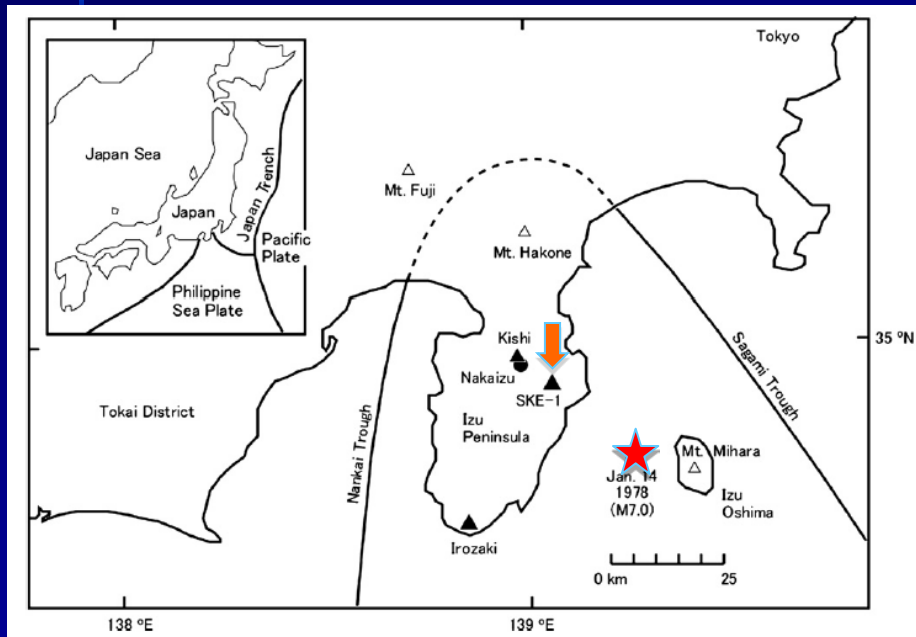
M_w is the earthquake magnitude

$d\varepsilon$ is volumetric strain

(Kuo et al., 2010)

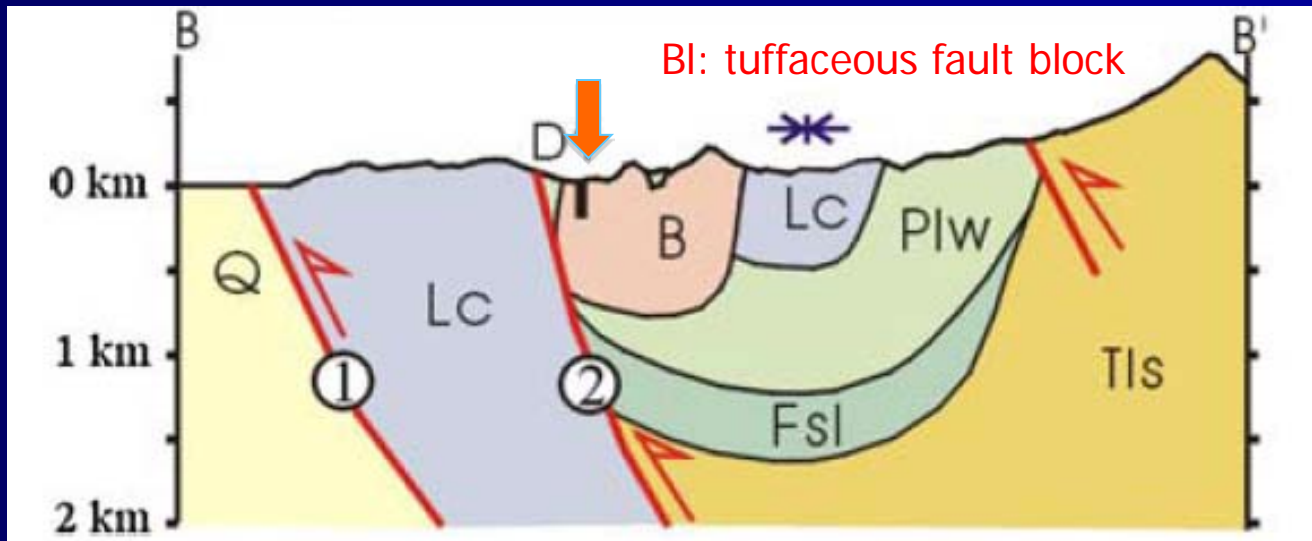
Another case: 1978 M7.0 Izu-Oshima-Kinkai earthquake in Japan

(Tsunomori and Kuo, 2010)



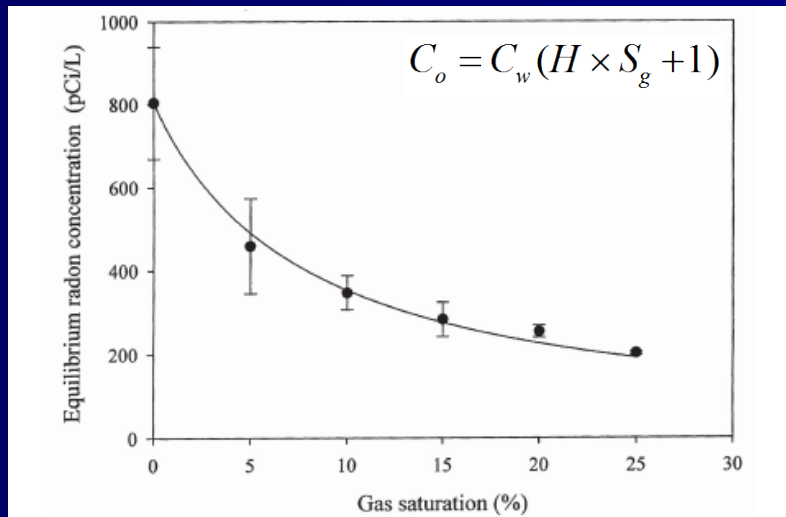
Conclusions

1. "A low-porosity fractured aquifer in a seismotectonic environment" is a suitable geological site to consistently catch precursory declines in groundwater radon.

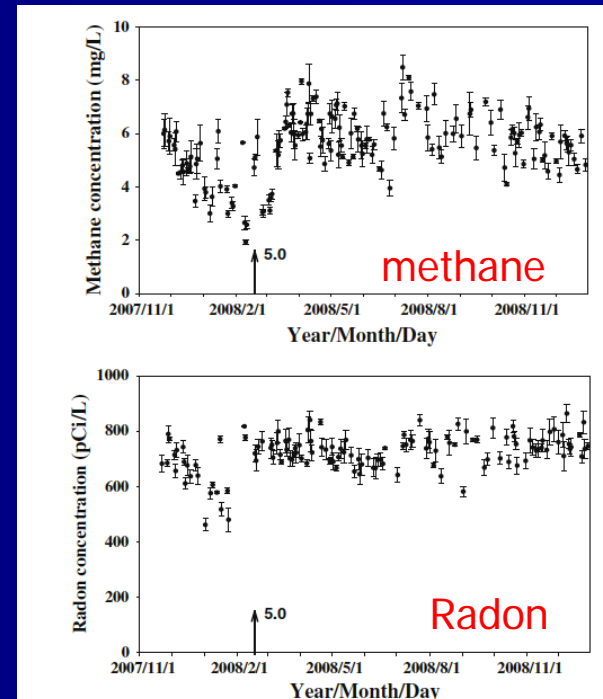


Conclusions

2. Radon partitioning into the gas phase may explain the radon anomalous declines in groundwater recorded prior to local large and moderate earthquakes

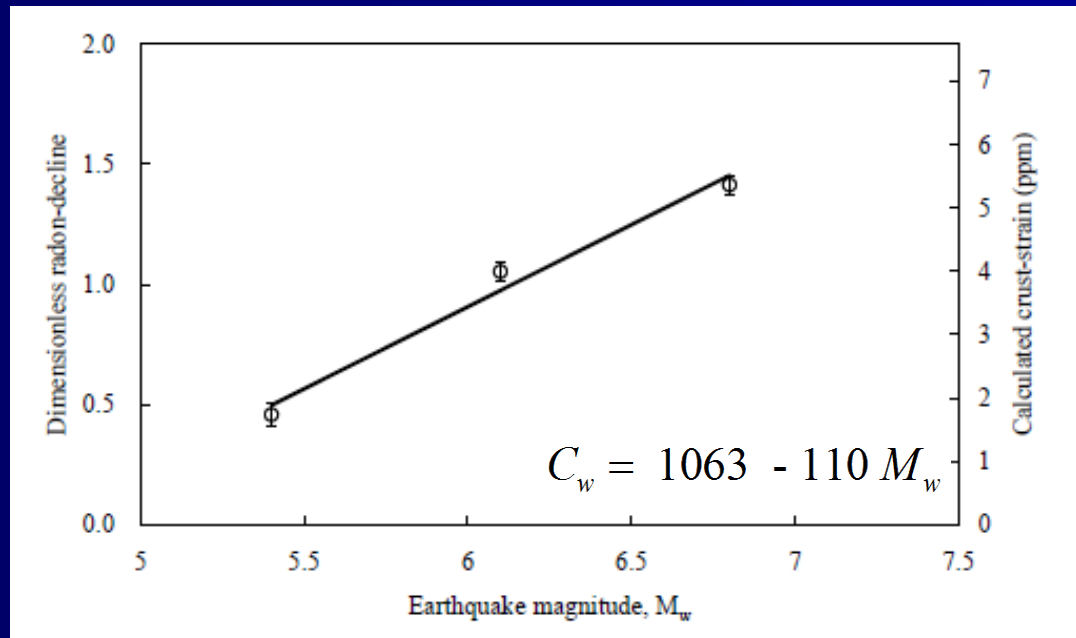


(Kuo et al., 2010)



Conclusions

3. The observed precursory minimum in radon concentration decreases as the earthquake magnitude increases. The observed relationship between radon minima and earthquake magnitude provides a possible means of early warning local disastrous earthquakes.



References

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2. Kuo, T.*, Lin, C., Chang, G., Fan, K., Cheng, W. and Lewis, C., 2010a, "Estimation of aseismic crustal-strain using radon Repetitive radon precursors of the 2003 M 6.8, 2006 M 6.1, and 2008 M 5.0 earthquakes in eastern Taiwan", *Natural Hazards*, vol. 53, pp. 219-228. (SCI)
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9. Han, Y.L., Kuo, M.C.Tom*, Fan, K.C., Chiang, C.J. and Lee, Y.P., 2006, "Radon Distribution in Groundwater of Taiwan", *Hydrogeology Journal*, vol. 14, pp.173-179. (SCI)
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11. Kuo, T.*, Fan, K., Kuochen, H., Han, Y., Chu, H. and Lee, Y., 2006b, "Anomalous Decrease in Groundwater Radon before the Taiwan M6.8 Chengkung Earthquake", *Journal of Environmental Radioactivity*, vol. 88, no.1, pp.101-106. (SCI)