Recurrent radon minima and crustal-strain transients precursory to earthquakes in eastern Taiwan

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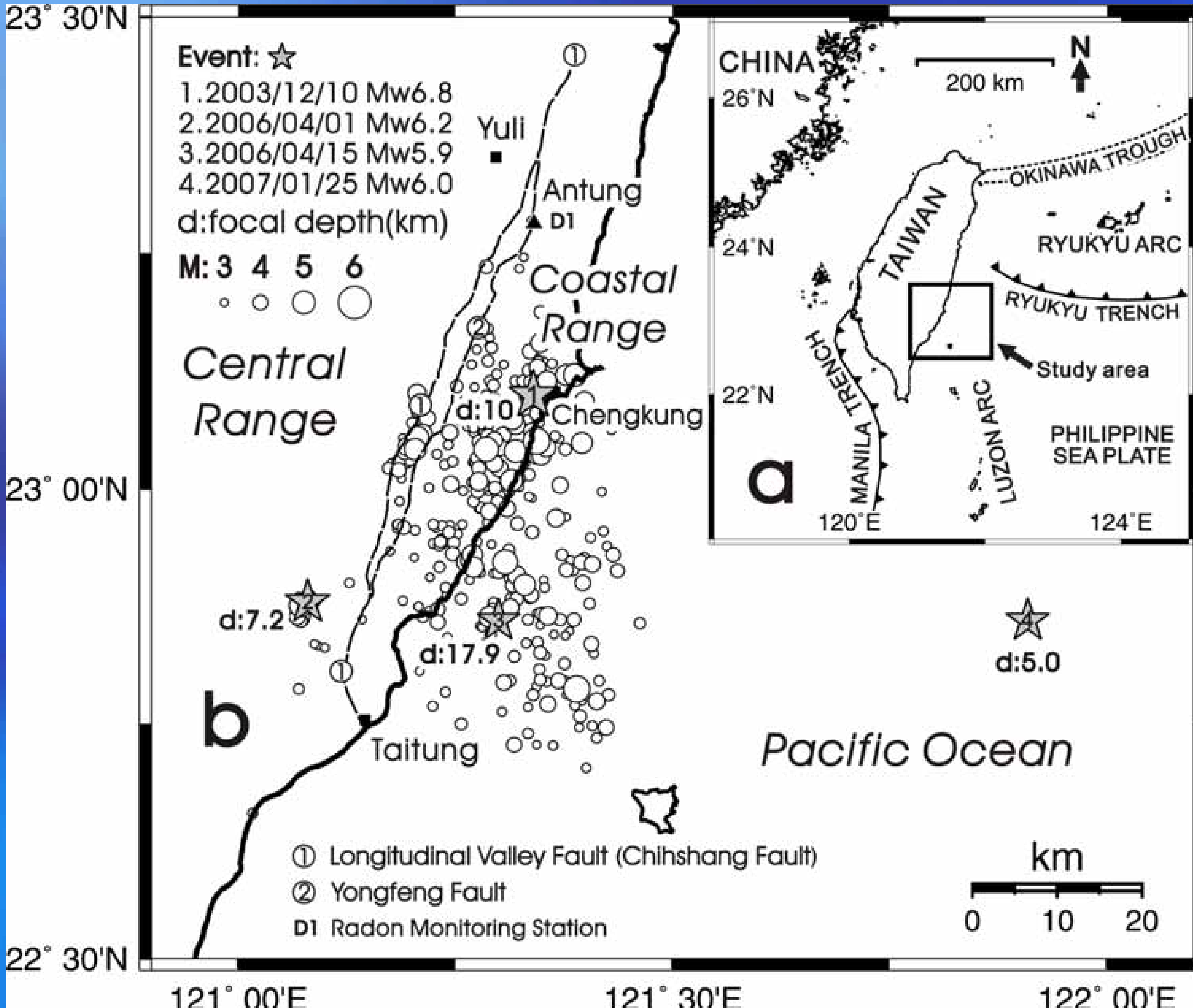
- Variations in radon (Rn-222) content in groundwater have been observed prior to some earthquakes.

- A sudden drop followed by an increase in the radon concentration occurred prior to the 1978 Izu-Oshima-kinkai earthquake of magnitude 7.0.

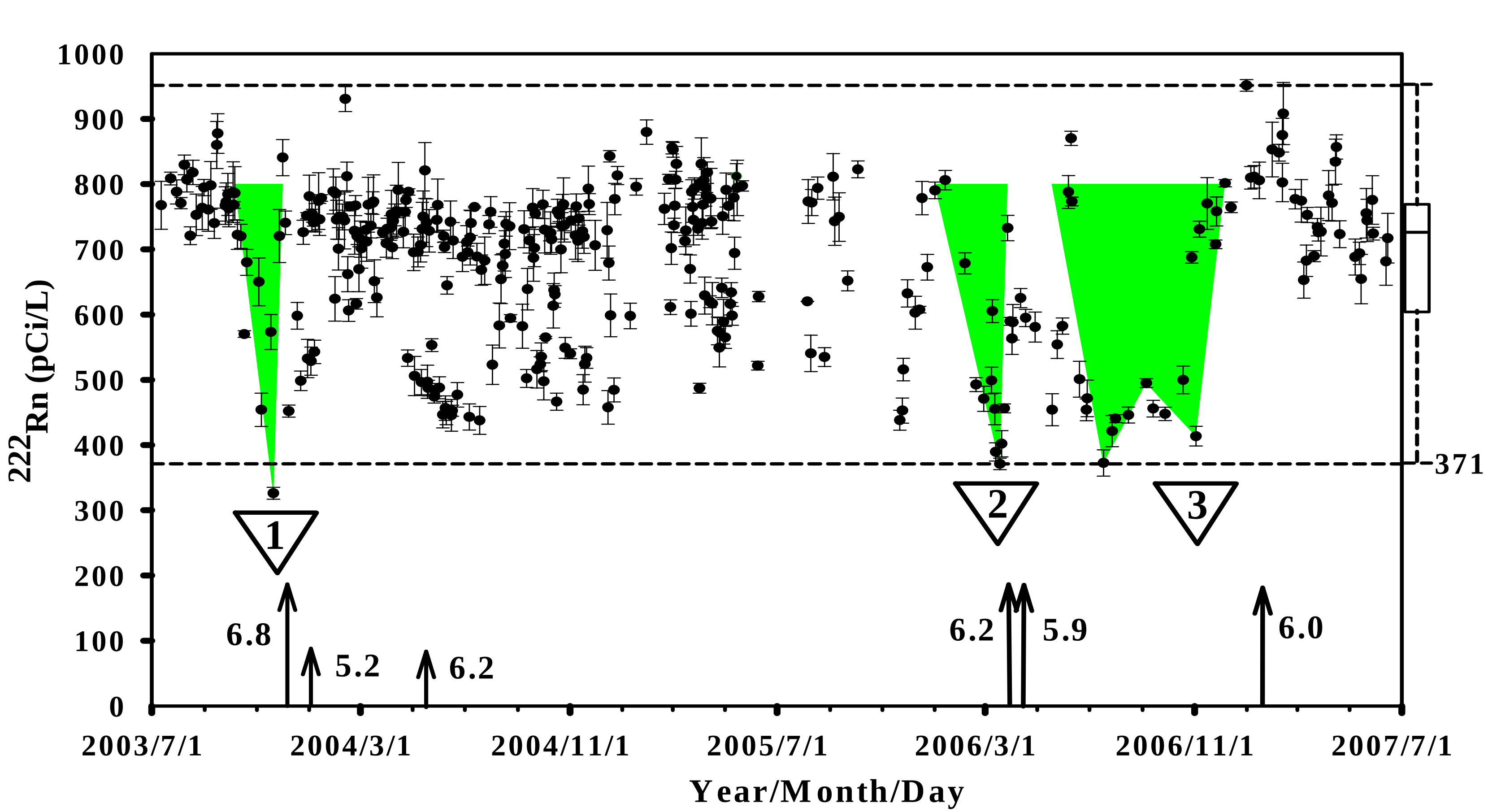
- For the first time, three anomalous decreases in radon concentration have been recorded prior to the large earthquakes within a 75 km radius from the Antung D1 monitoring well in eastern Taiwan.

- M_W 6.8, December 10, 2003.
- M_W 6.2 and M_W 5.9, April 1 and 15, 2006.
- M_W 6.0, January 25, 2007.

Map of the epicenters of the earthquakes that occurred near Chengkung.



Radon concentration data at the monitoring well (D1) in the Antung hot spring.



- The box-and-whisker plot shows the median (724 pCi/L).
- The whiskers (371 pCi/L and 952 pCi/L) cover all but the most extreme values in the data set.

Recurrent precursory radon minima observed at Antung.

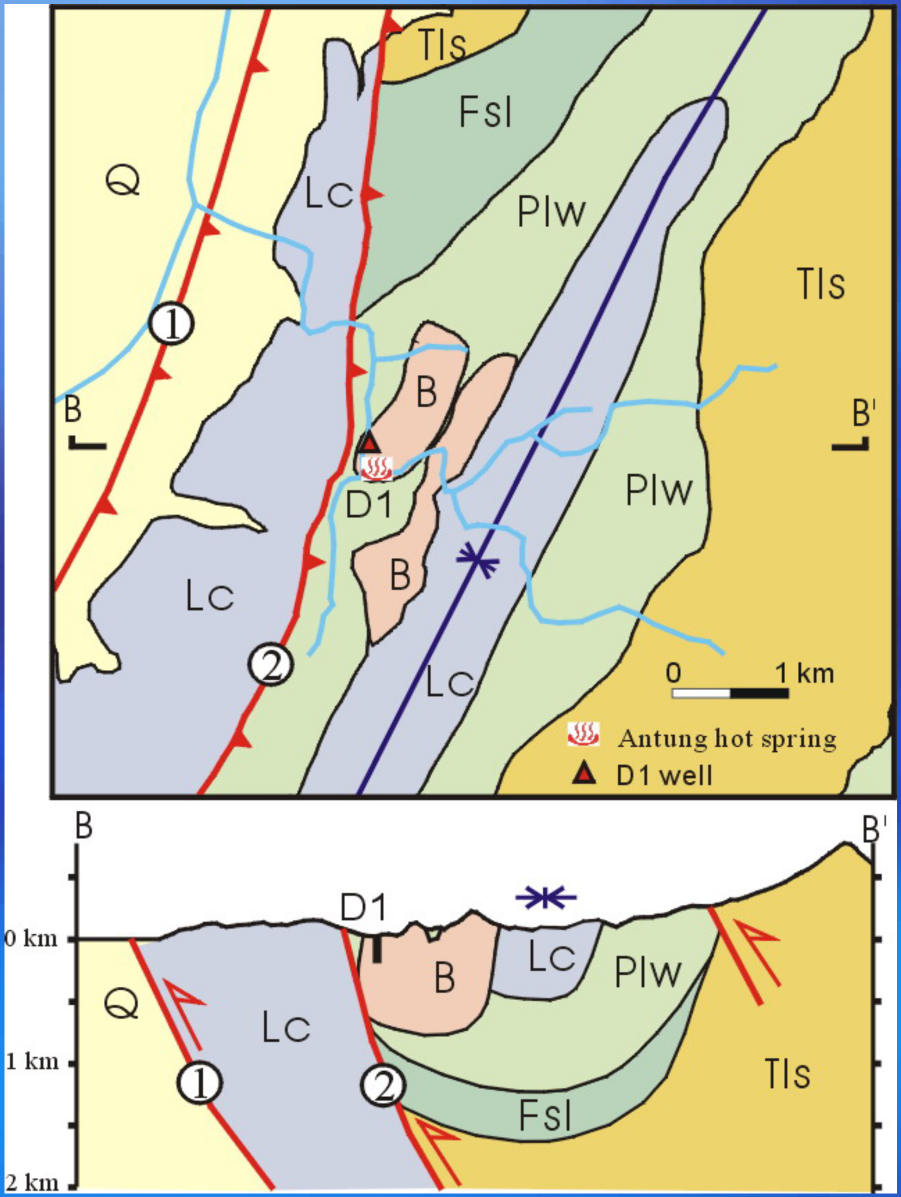
Concentration and date of radon-222 minimum, pCi/L	Magnitude and date of the associated earthquake, Mw	Distance between well D1 and hypocenter, km
326 ± 9 (November 20, 2003)	6.8 (December 10, 2003)	20
371 ± 9 (March 16, 2006)	6.2 (April 1, 2006)	52
414 ± 15 (November 2, 2006)	6.0 (January 25, 2007)	75

- The recurrent precursory minima in radon concentration observed at the Antung hot spring demonstrate that the radon minimum decreases as the earthquake magnitude increases and as the distance between the hypocenter and the Antung hot spring decreases.

- Reproducible observations at the Antung hot spring suggest that radon concentrations in ground water, under suitable geological conditions, can be a sensitive tracer of strain changes in the crust preceding an earthquake.

- The Antung hot spring is situated in a fractured block of tuffaceous-sandstone surrounded by ductile mudstone.

Geological map and cross section near the radon-monitoring well in the area of Antung hot spring.

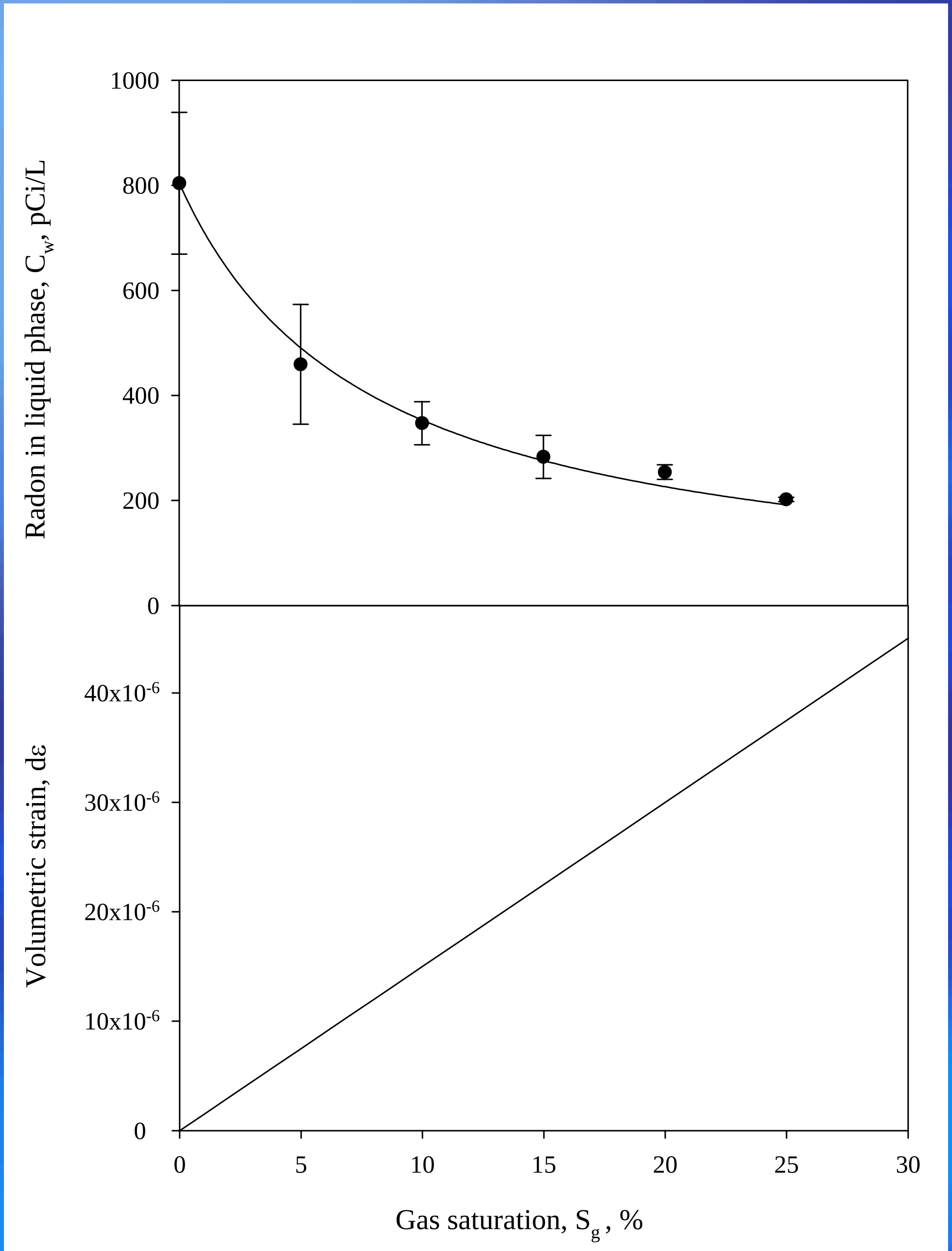


Q: Holocene deposits
Lc: Lichi mélange
Plw: Paliwan Formation
Fsl: Fanshuliao Formation
Tls: Tuluanshan Formation
Bl: tuffaceous fractured block
D1: radon-monitoring well
①: Chihshang, or,
Longitudinal Valley Fault
②: Yongfeng Fault

- Under these geological conditions, the dilation of brittle rock mass occurred at a rate faster than the recharge of pore water and gas saturation developed in newly created cracks preceding the above mentioned earthquakes.

- Radon partitioning into the gas phase can explain the anomalous decreases of radon precursory to the earthquakes.

- Ground-water radon can be employed as a quantitative tracer to calcalate strain changes associated with earthquake occurrences.

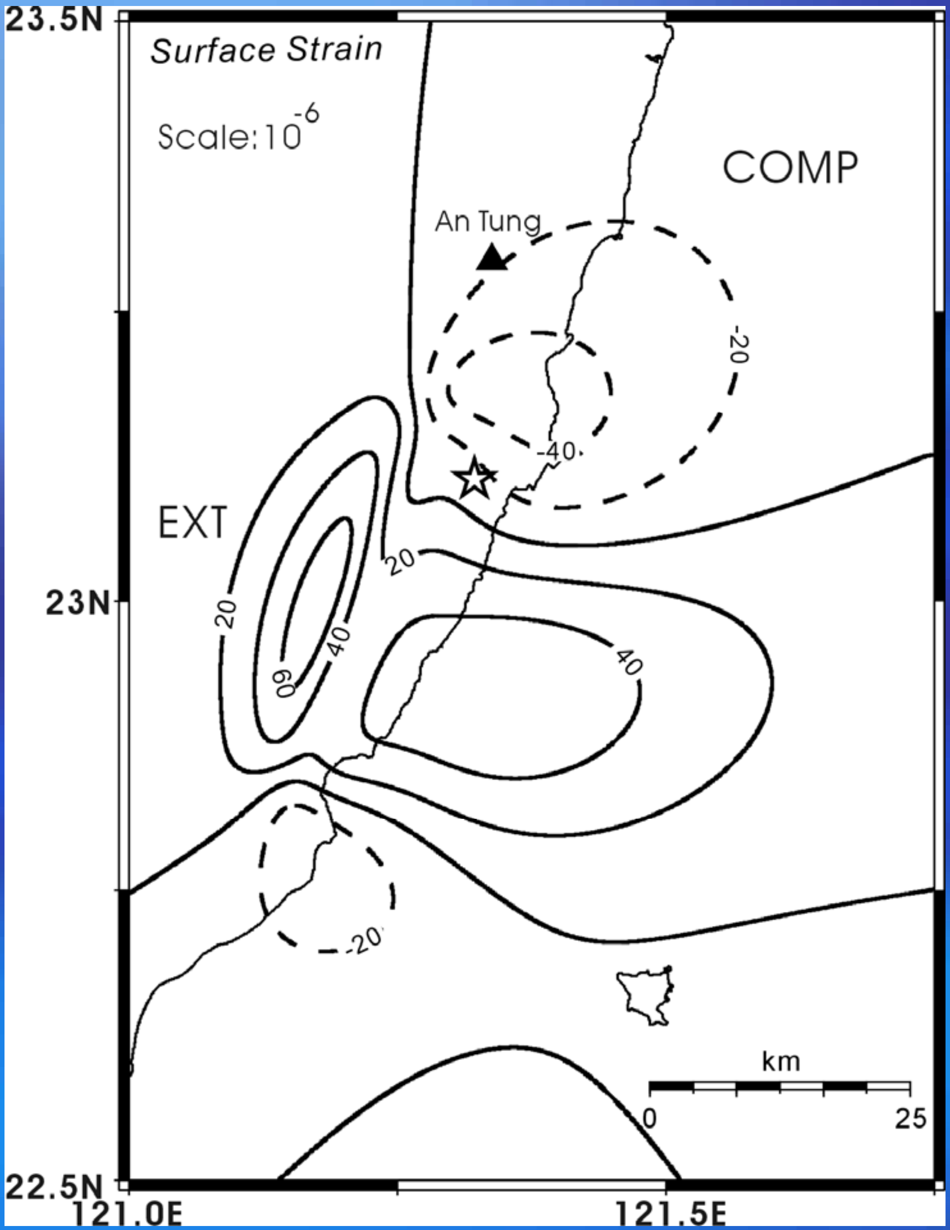


(Top) Variation of radon concentration remaining in ground water with gas saturation at 60°C using formation brine from the Antung hot spring.

(Bottom) Variation of volumetric strain change with gas saturation.

- We also calculated the coseismic strain distribution due to the 2003 Chengkung earthquake based on the dislocation fault model.

Distribution of coseismic surface strain (ppm) calculated based on the fault dislocation model.



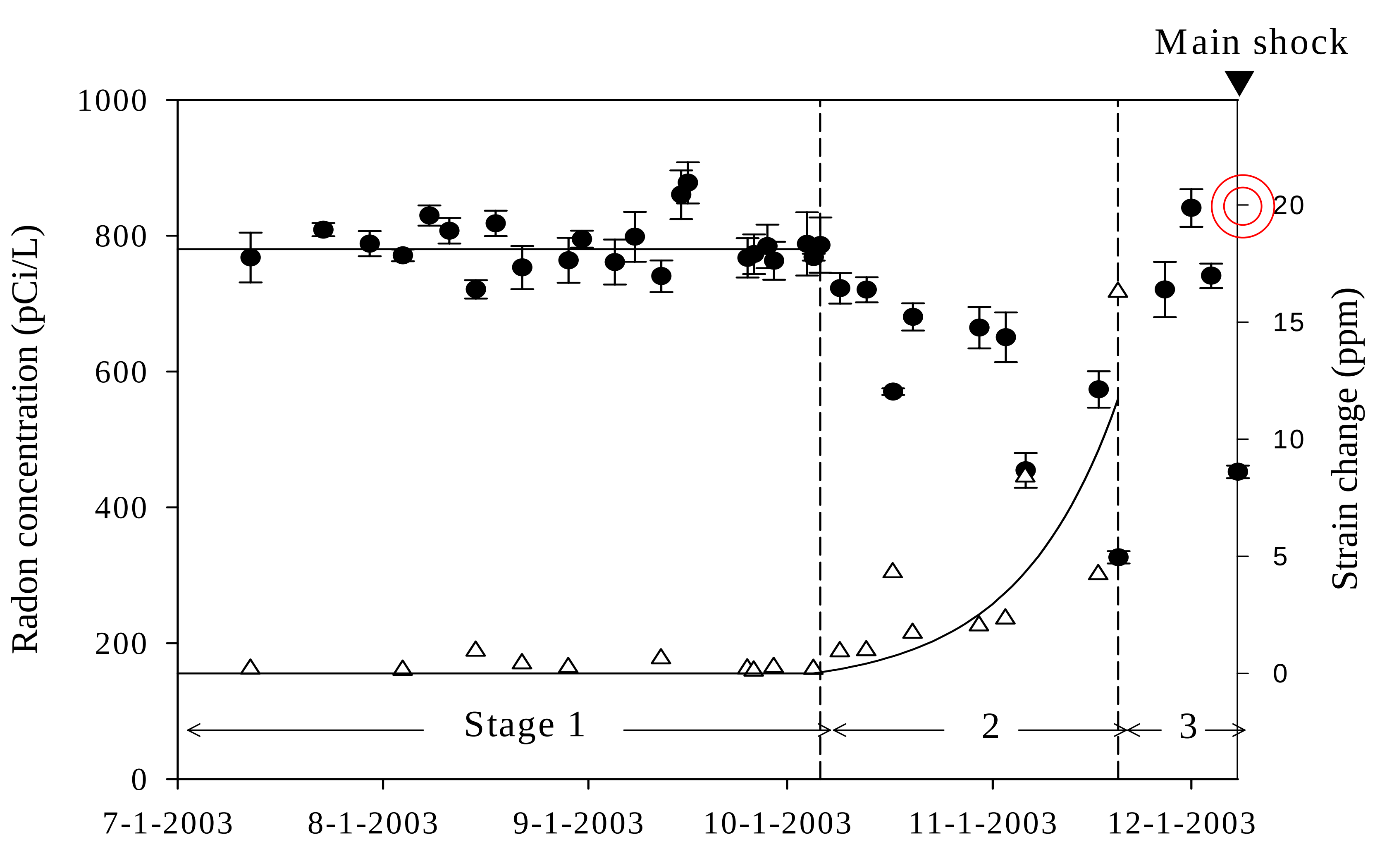
The open star denotes the 2003 mainshock.

The filled triangle denotes the radon-monitoring well (D1).

EXT and COMP denote dilatation and contraction, respectively.

- The calculated surface strain near the Antung hot spring area was about 20 ppm.

Radon and crustal-strain transients prior to the 2003 MW 6.8 Chengkung earthquake at the monitoring well (D1) in the Antung hot spring.



- Stage 1 is buildup of elastic strain.
- Stage 2 is dilatancy and development of cracks and gas saturation.
- Stage 3 is influx of ground water and diminishment of gas saturation.

- The aseismic transient crustal-strain signals prior to the 2003 M_W 6.8 Chengkung earthquake can be correlated reasonably with the coseismic strain change calculated based on the dislocation fault model using the data recorded by nearby strong-motion stations and a GPS network.

Periodic Table of Elements

IA	IIA	IIIB	IVB	VB	VIB	VIIB	VIIIB	VIIIB	VIIIB	IB	IIB	IIIA	IVA	VA	VIA	VIIA	
1 **H** 1.00797																	2 **He** 4.003
3 **Li** 6.939	4 **Be** 9.012											5 **B** 10.81	6 **C** 12.011	7 **N** 14.007	8 **O** 15.9994	9 **F** 19.00	10 **Ne** 20.183
11 **Na** 22.99	12 **Mg** 24.31											13 **Al** 26.98	14 **Si** 28.09	15 **P** 30.974	16 **S** 32.064	17 **Cl** 35.453	18 **Ar** 39.948
19 **K** 39.102	20 **Ca** 40.08	21 **Sc** 44.96	22 **Ti** 47.90	23 **V** 50.94	24 **Cr** 52.00	25 **Mn** 54.94	26 **Fe** 55.85	27 **Co** 58.93	28 **Ni** 58.71	29 **Cu** 63.54	30 **Zn** 65.37	31 **Ga** 69.72	32 **Ge** 72.59	33 **As** 74.92	34 **Se** 78.96	35 **Br** 79.909	36 **Kr** 83.80
37 **Rb** 85.47	38 **Sr** 87.62	39 **Y** 88.905	40 **Zr** 91.22	41 **Nb** 92.91	42 **Mo** 95.94	43 **Tc** 98	44 **Ru** 101.1	45 **Rh** 102.90	46 **Pd** 106.4	47 **Ag** 107.87	48 **Cd** 112.4	49 **In** 114.82	50 **Sn** 118.69	51 **Sb** 121.75	52 **Te** 127.60	53 **I** 126.90	54 **Xe** 131.30
55 **Cs** 132.905	56 **Ba** 137.34		72 **Hf** 178.49	73 **Ta** 180.95	74 **W** 183.85	75 **Re** 186.2	76 **Os** 190.2	77 **Ir** 192.2	78 **Pt** 195.09	79 **Au** 196.97	80 **Hg** 200.59	81 **Tl** 204.37	82 **Pb** 207.19	83 **Bi** 208.98	84 **Po** 210	85 **At** 210	86 **Rn** 222
87 **Fr** 223	88 **Ra** 226																

← Lanthanide series

← Actinide series

57 **La** 138.91	58 **Ce** 140.12	59 **Pr** 140.91	60 **Nd** 144.24	61 **Rm** 147	62 **Sm** 150.35	63 **Eu** 152	64 **Gd** 157.25	65 **Tb** 158.92	66 **Dy** 162.50	67 **Ho** 164.93	68 **Er** 167.26	69 **Tm** 168.93	70 **Yb** 173.04	71 **Lu** 174.97
89 **Ac** 227	90 **Th** 232.04	91 **Pa** 231	92 **U** 238.03	93 **Np** 237	94 **Pu** 242	95 **Am** 243	96 **Cm** 247	97 **Bk** 247	98 **Cf** 251	99 **Es** 254	100 **Fm** 253	101 **Md** 256	102 **No** 254	103 **Lw** 257

Future Plans

- Pumping tests
- Temperature measurements
- Helium measurements
- Mathematical models

Thanks

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