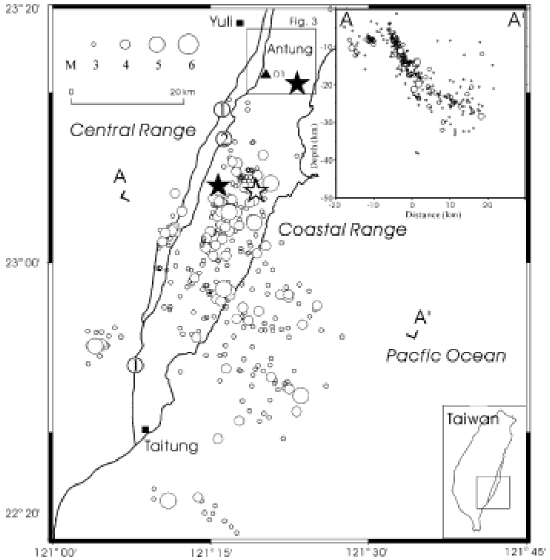
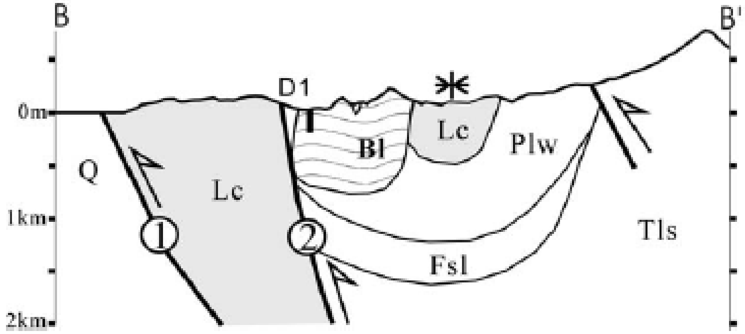
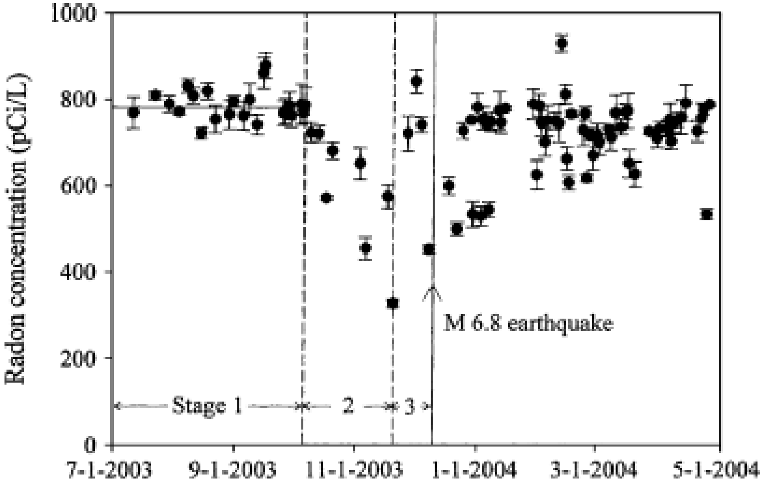
A Mechanism of Radon Concentration Decline Prior to 1978 Izu-Oshima-Kinkai Earthquake

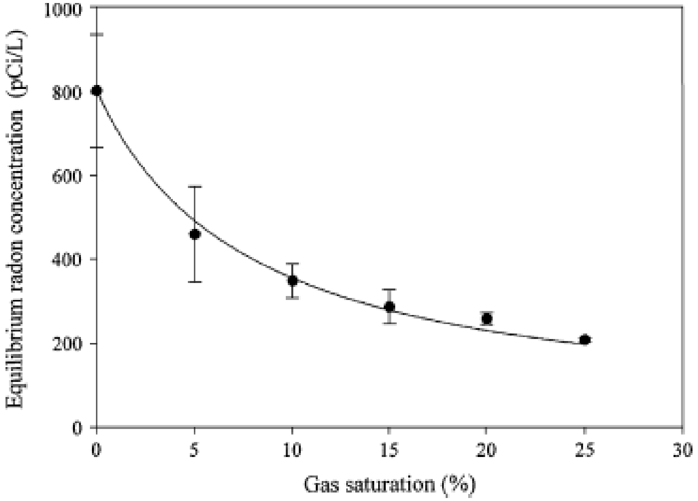
Tsunomori F. (UT) and Kuo M.C.T. (NCKU)

2003 Cheng Kung Earthquake







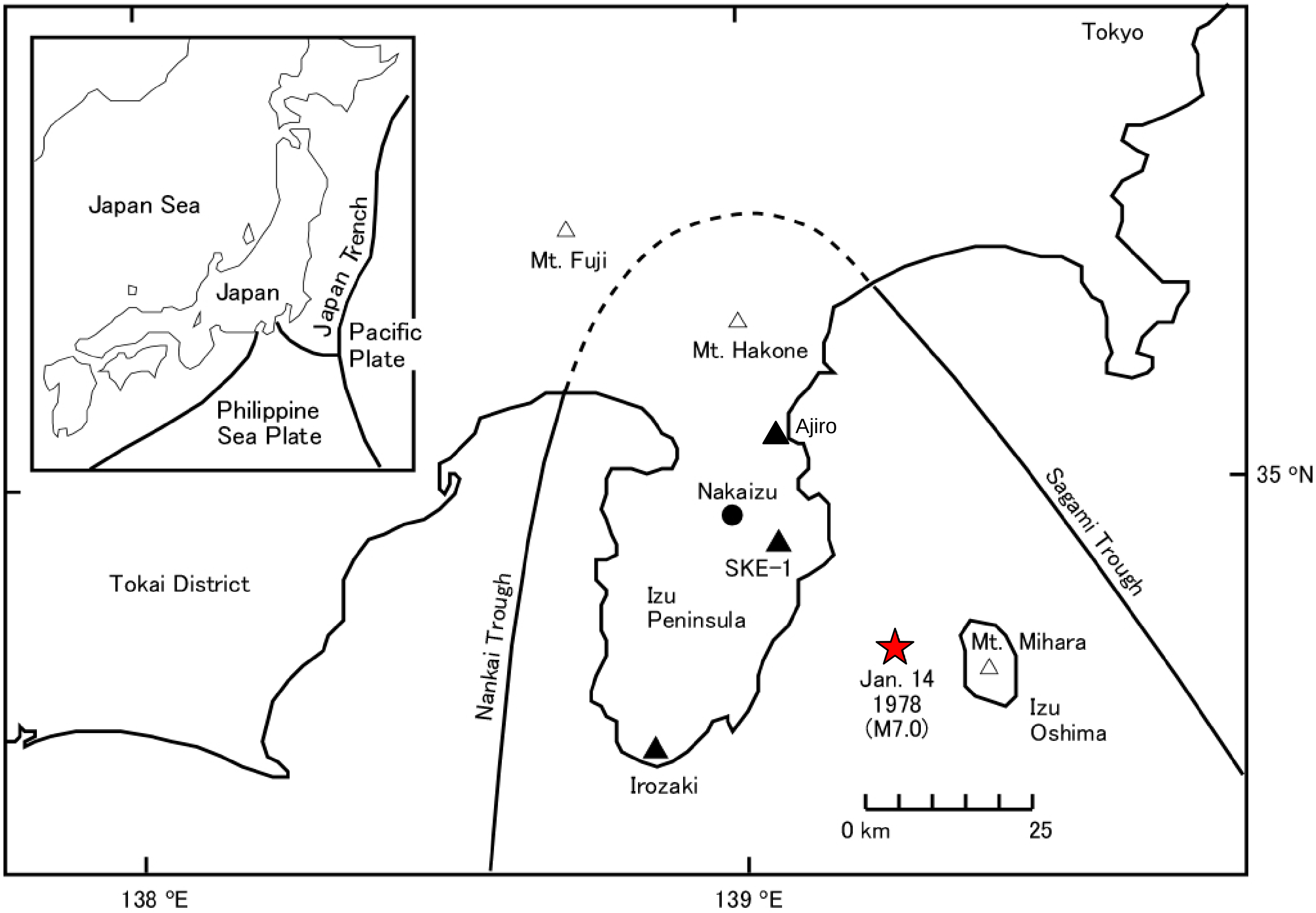


Kuo, 2006

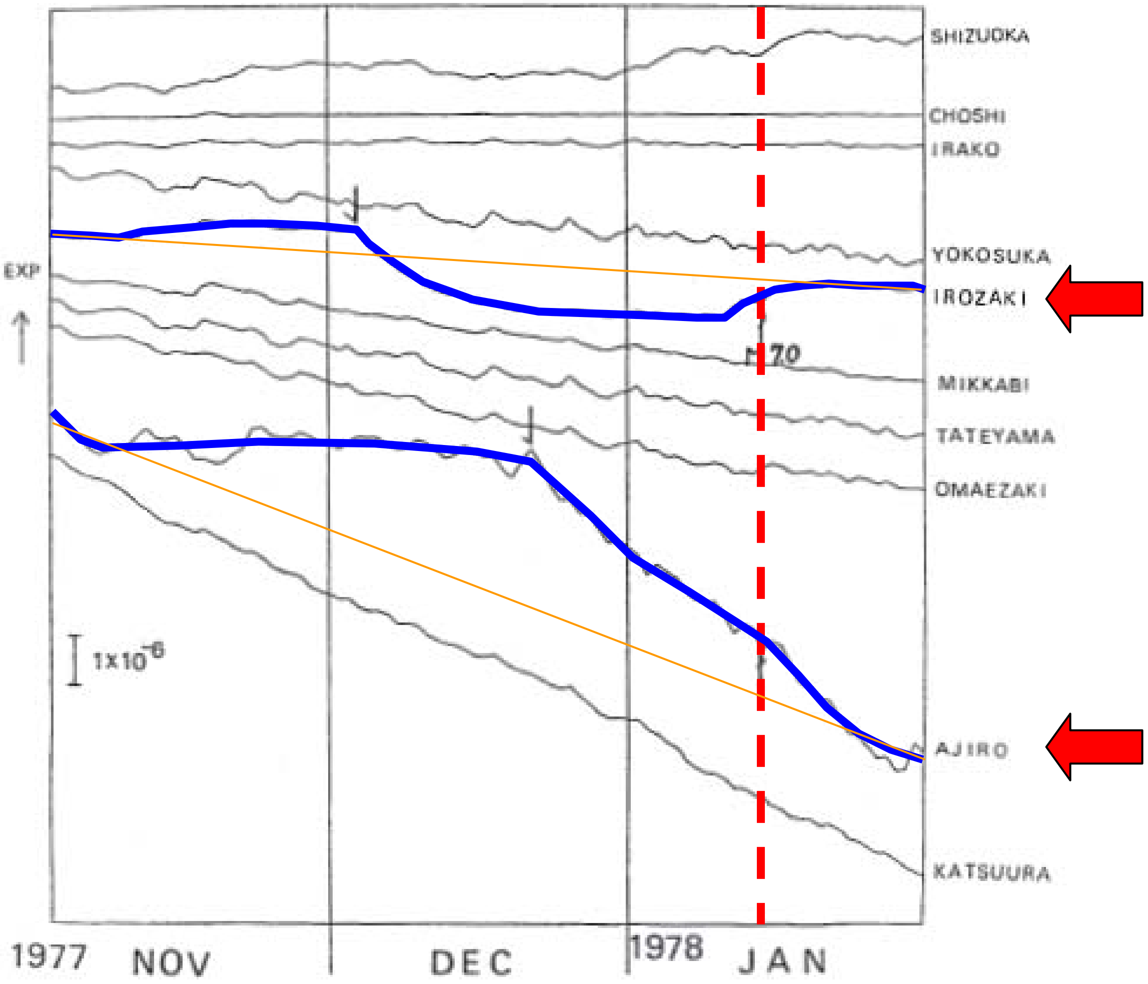
Objectives

- Possible scenarios of radon concentration change in groundwater are presented.
- Radon concentration decline mechanisms are discussed.
- In this talk, a gas partitioning model is focused for a possible mechanism to explain the 1978 Izu-Oshima-Kinkai Earthquake.

1978 Izu-Oshima-Kinkai Earthquake



Strain Records in Izu Peninsula

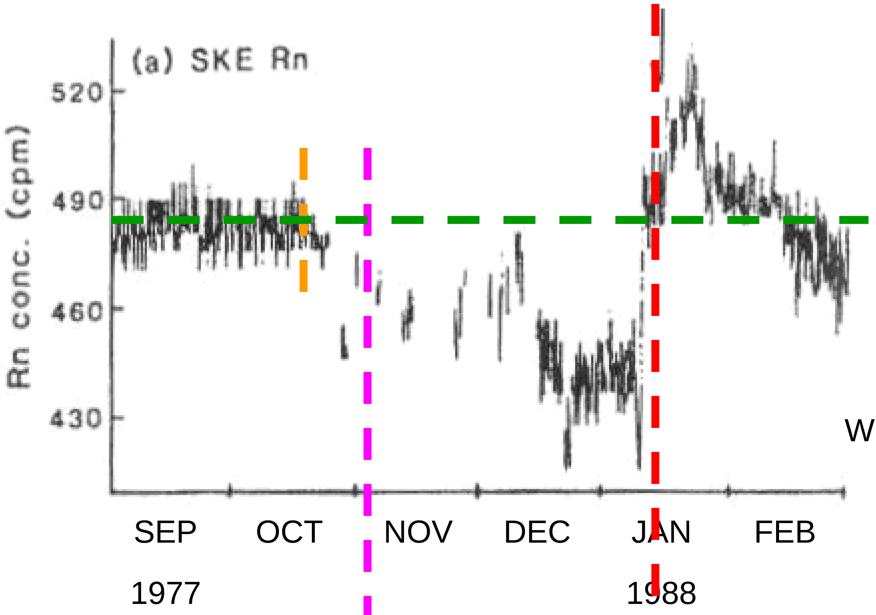


第1図　東海・関東地域の埋込型体積歪計の変化

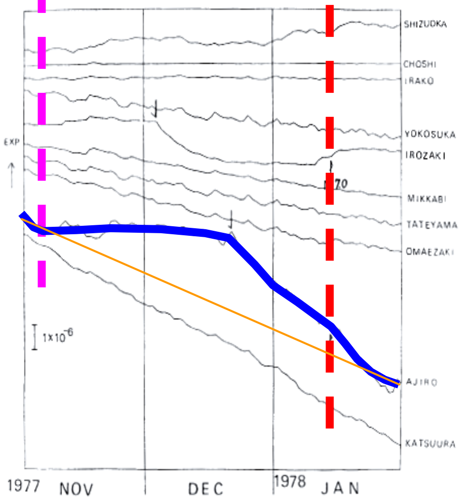
Fig. 1 Strain changes by the borehole strainmeters in the Tokai and Kanto districts.

CCEP, 1978

Radon Concentration Decline



Wakita et al., 1988

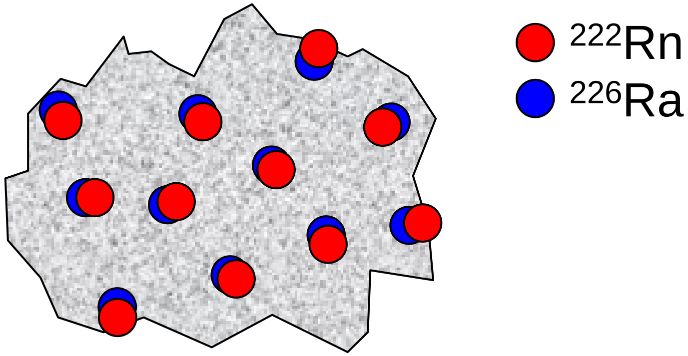


CCEP, 1978

1978 Izu-Oshima-Kinkai Earthquake

Radon from Rocks

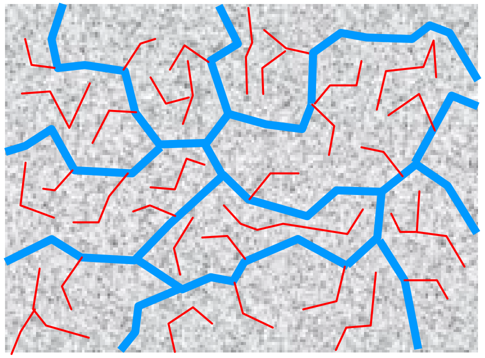
- ^{222}Rn is generated by α decay of ^{226}Ra existing in rock subsurface.



- Radon emanation power governing the amount of radon gas released from a rock is regarded as constant because the half-life of ^{226}Ra is 1600ys.
- The radon supply is proportional to surface area of a rock.

Radon in Aquifer

- Aquifer has many fractures retaining groundwater.



Effective Porosity

$$\phi_e = \frac{V_{p,all} - V_{p,stag}}{V_t} = \frac{V_{p,flow}}{V_t}$$

- Radon is supplied from fracture surfaces contacting with groundwater.
- The radon supply is proportional to surface area of cracks S.

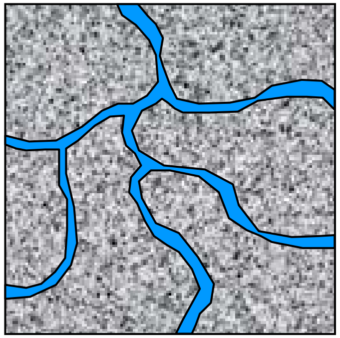
Radon Supply into Groundwater

- In a fractured aquifer
  - – Radon emanation power E is constant.
  - – Radon supply is proportional to surface area S.

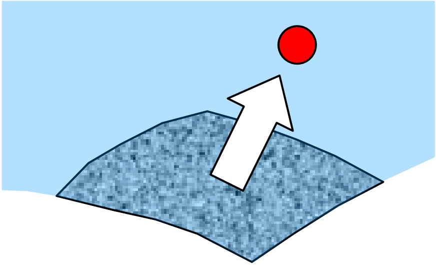
- Radon generation rate from crack surfaces into pore volume is written as,

$$R \propto ES$$

Radon Concentration



- ✓ Groundwater flow is stable.
- ✓ Rn diffusion coefficient is same as that in normal water.



Number of radon is written as,

$$\frac{d}{dt}N = R - \frac{1}{\tau}N \qquad (1)$$

R : Radon generation rate in pore space (Bq s^{-1})

τ : Decay time of radon (s)

$$N = D\exp\left(-\frac{t}{\tau}\right) + \tau R \qquad (2)$$

Under the steady state,

$$N_0 = \tau R \qquad (3)$$

$R \rightarrow R'$ at t=0,

$$N = (N_0 - \tau R')\exp\left(-\frac{t}{\tau}\right) + \tau R' \qquad (4)$$

Radon Decline

$$N = \tau R = \tau E S$$

$$C = \frac{N}{V_p} = \tau E \frac{S}{V_p}$$

τ : Decay time of radon (s)

R : Radon generation rate in pore space (Bq s^{-1})

E : Radon emanation power (Bq m^{-2} s^{-1})

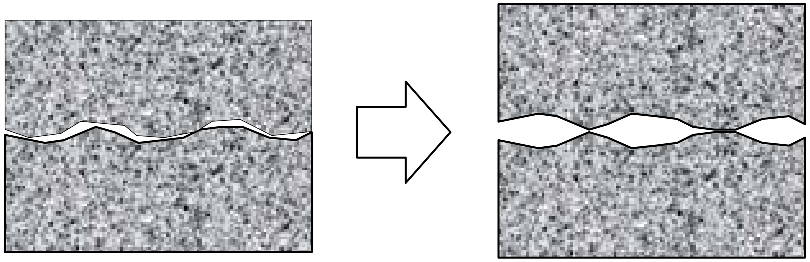
S : Effective surface area (m^2)

V_p : Effective pore volume (m^3)

Decrease of a radon concentration can be induced by S to be decreased, V_p to be increased, or S/V_p ratio to be decreased.

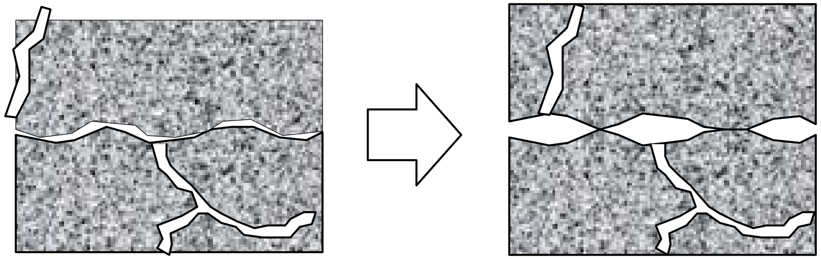
Scenarios for Pore Volume Change

- Without increase of surface area



No additional fracture is generated.

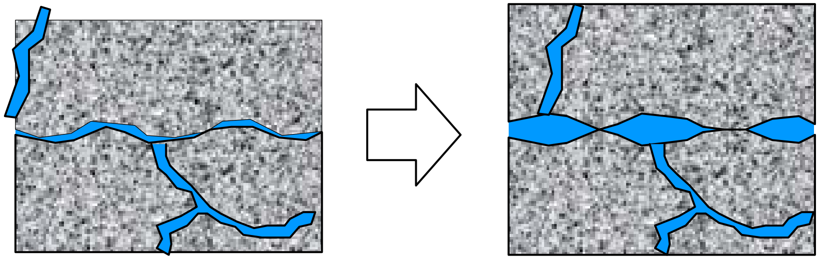
- With increase of surface area



New fractures are generated.

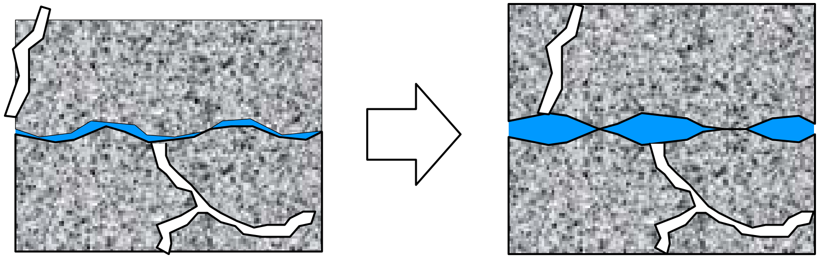
Possible Cases

- Dilation rate of rock mass ≤ Recharge rate



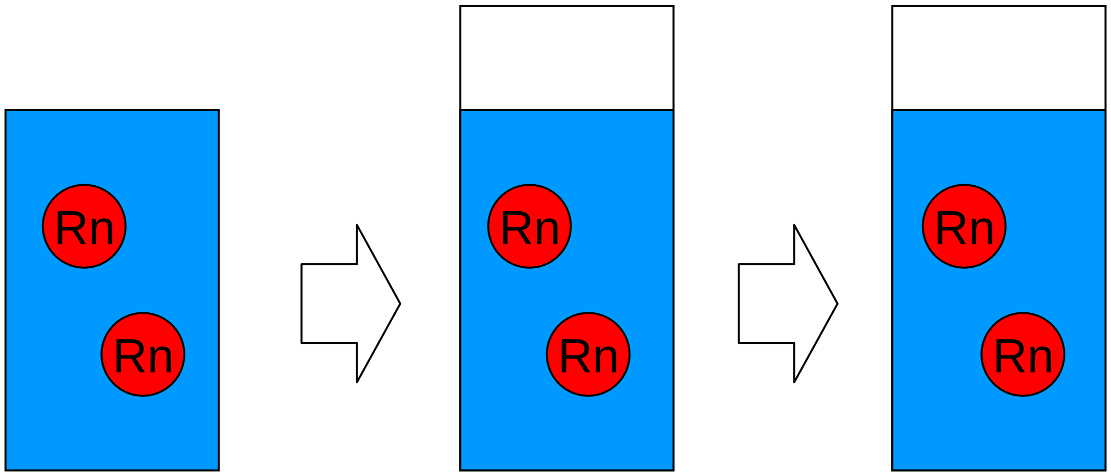
All cracks are filled with water.

- Dilation rate of rock mass > Recharge rate



Gas phase is produced in new cracks.

Gas-Liquid Partitioning Model



Rn concentration in groundwater declines

Gas phase is generated by pore volume increase because of new crack generation.

Radon gas must move to gas phase according to Henry’s law.

Gas Partitioning Experiment

- Henry’s coefficient depends on salinity and temperature.
- In order to get Henry’s coefficient of groundwater of the SKE well…
  - Groundwater was sampled at SKE in a glass vial with a Teflon-lined septum.
  - Five levels of head space volumes (0, 9, 17, 26 and 34 %) were investigated.
  - Radon concentration remaining in water was measured in scintillation counter with a mineral-oil based scintillation cocktail.

Groundwater Sampling

SKE

Well

Vial

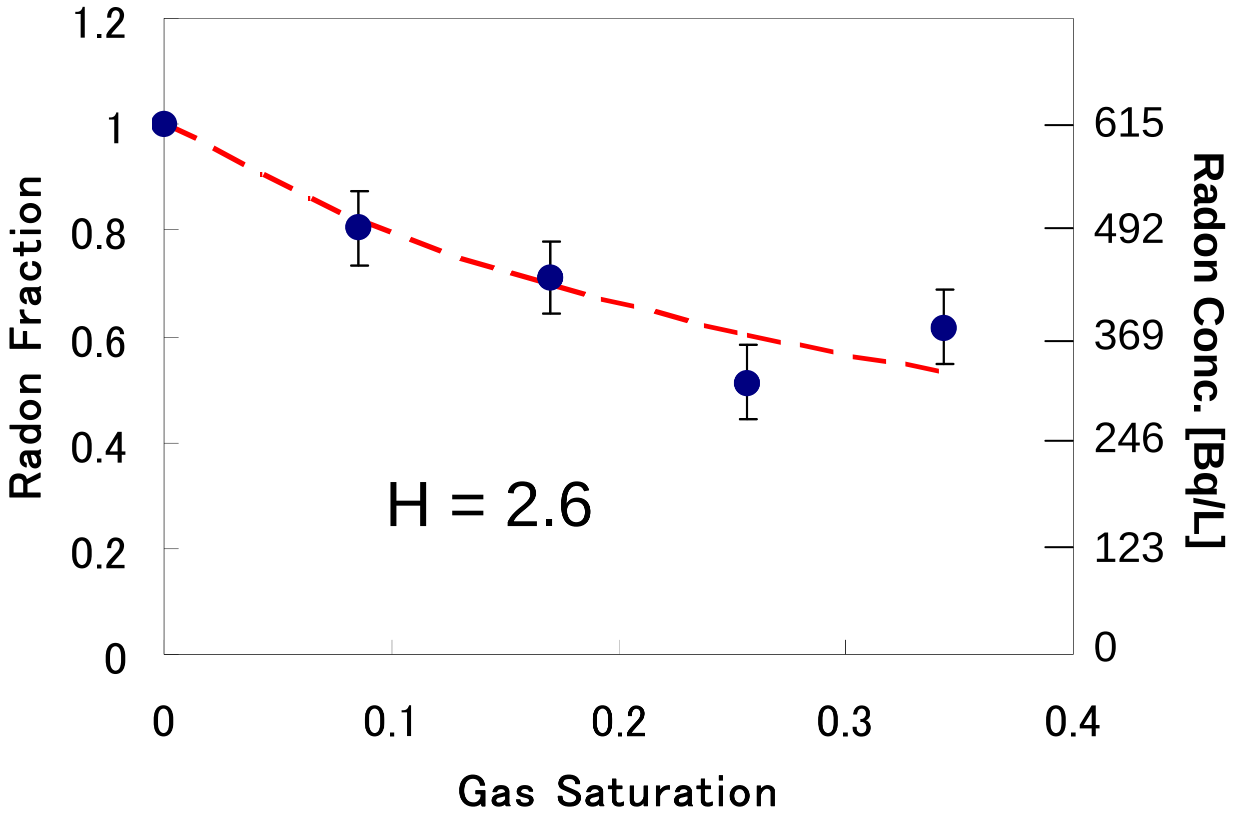
Samples

Scintillation Counter

- Perkin-Elmer Tri-Carb 2900TR

- Mineral-Oil Based Scintillation Cocktail
  - 6NE9571 (Wadach, J. B, 1985)

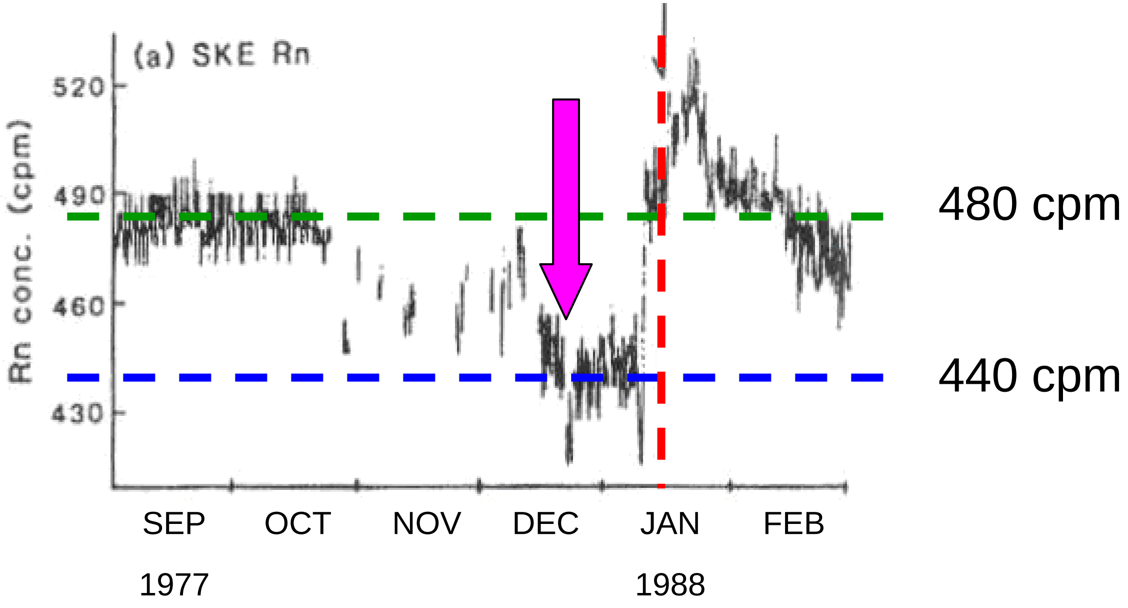
Results of Radon Partitioning



$$C_w = \frac{C_0}{HS_g + 1}$$

S_g	Cw	Fraction
0	615	1
0.085	495	0.804
0.170	437	0.711
0.256	315	0.512
0.342	379	0.617

Dilation Evaluated by Radon Anomaly



Wakita et al., 1988

$$C_w = \frac{C_0}{HS_g + 1}$$

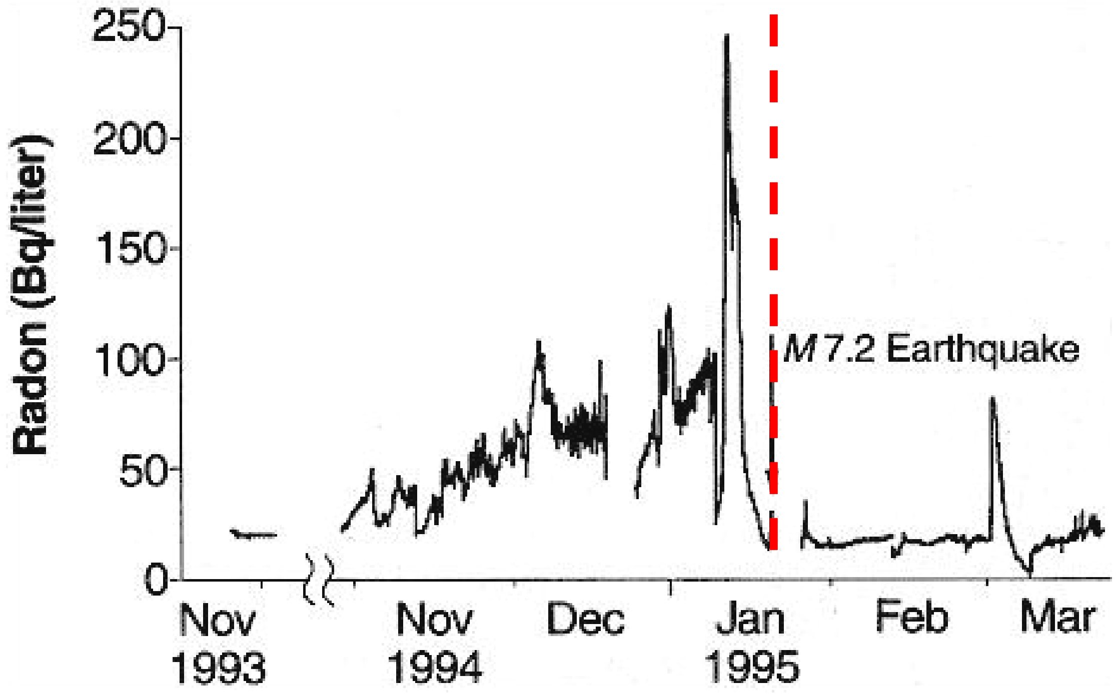
$S_g = 0.035$

The 3.5 % gas phase volume was induced in pore space by volumetric strain change before the earthquake.

Conclusions

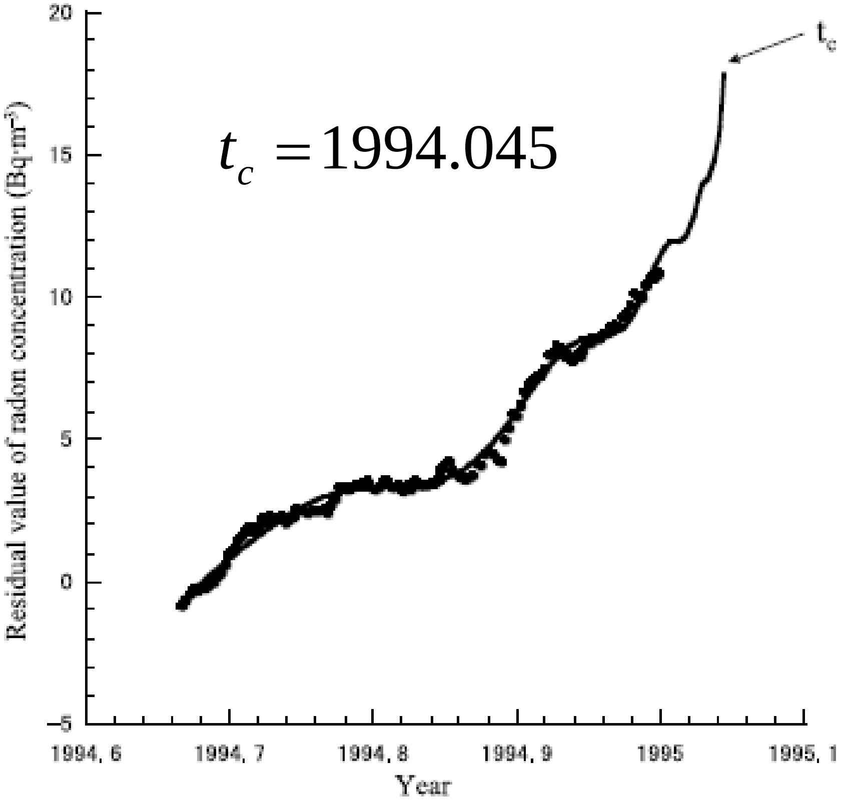
- Three possible scenarios have been presented as radon concentration decline mechanism. (1)simple dilation, (2)dilation with water-filled cracks and (3)dilation with gas-rich cracks. In this talk, the last model has been discussed.
- Henry’s coefficient of SKE groundwater is 2.6.
- A gas-liquid partitioning experiment has revealed that the radon concentration decline before the 1978 Izu-Oshima-Kinkai Earthquake can be explained by 3.5 % gas phase generation in pore volume.

1995 Kobe Earthquake



Igarashi et al., 1995

1995 Kobe Earthquake



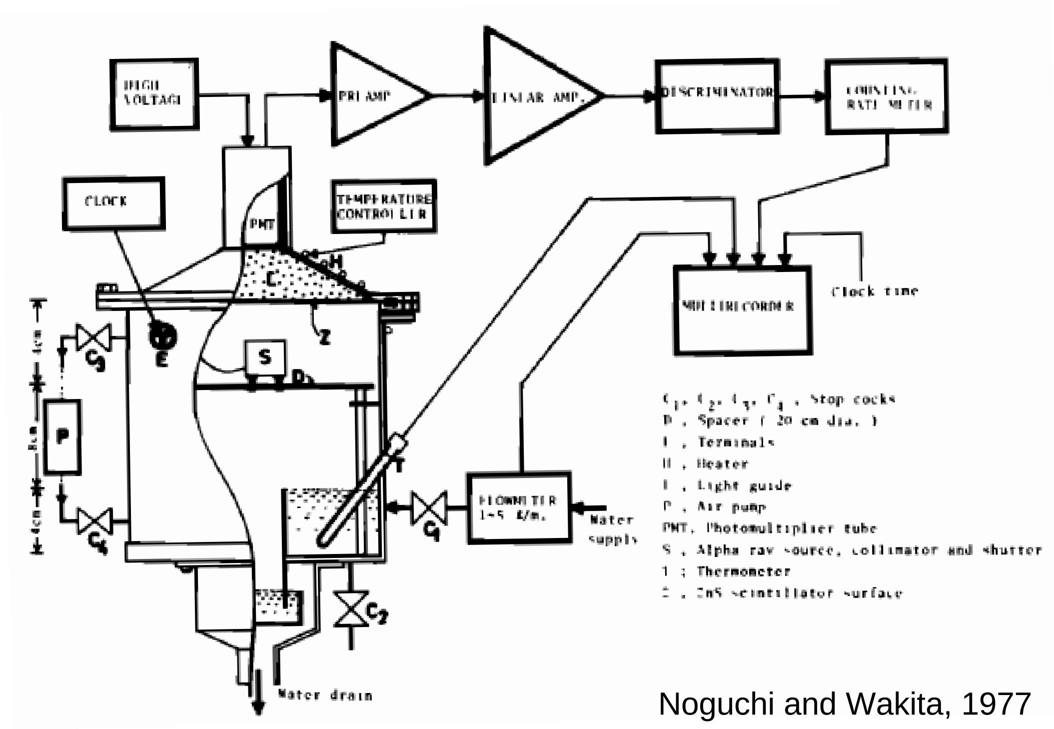
$$t_c = 1994.045$$

Yasuoka, 2006

$$f(t) \approx A + B(t_c - t)^z[1 + C\cos(\omega\log(t_c - t) + \psi)] \quad \omega = \frac{2\pi}{\log\lambda}$$

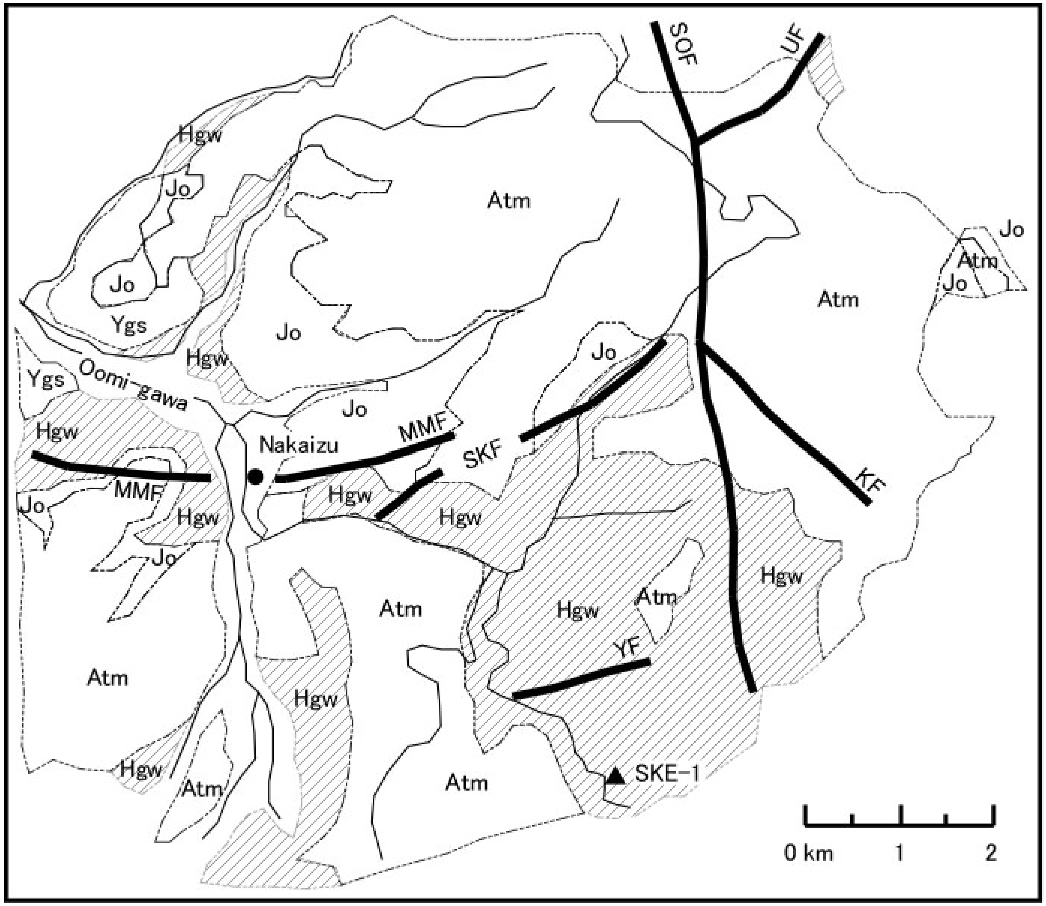
NW-101 Radon Counter

- ZnS(Ag) Scintillator
- Background noise is 20 Bq/m^3



Noguchi and Wakita, 1977

Geology around SKE



Koyama, 1982

Hiekawa Group (Hgw)

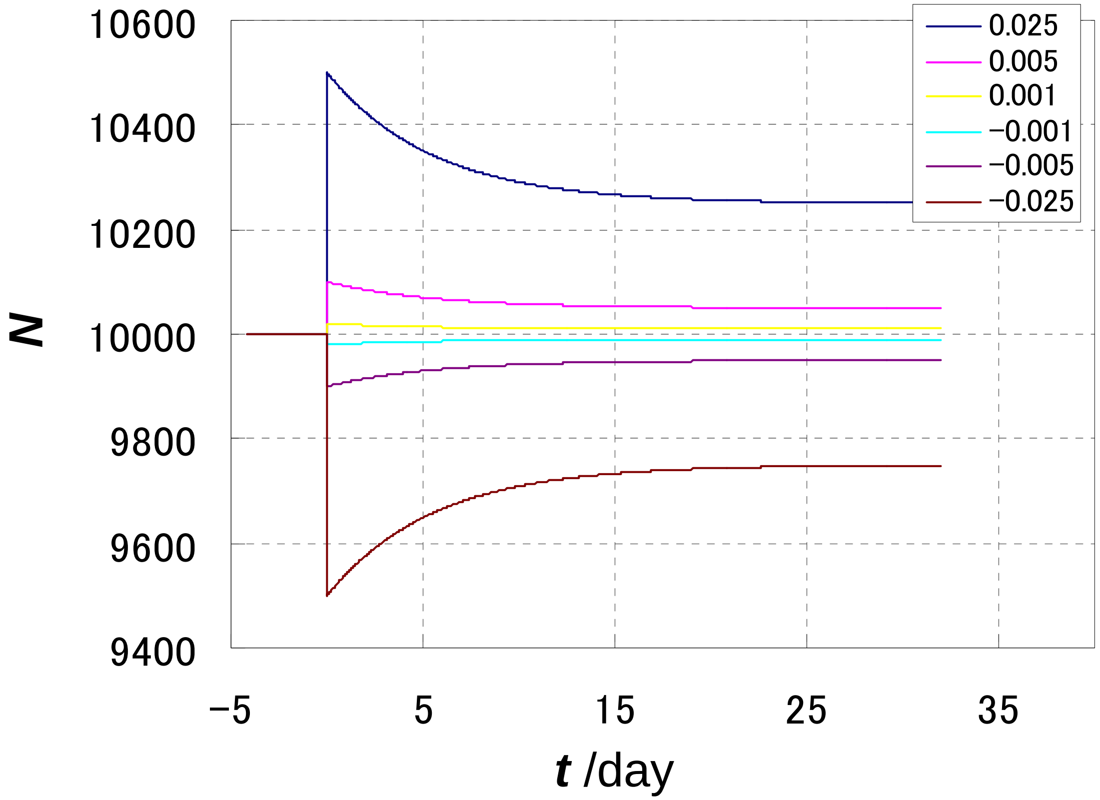
Pumice tuff

Uranium Decay Series

	Element	Decay	Half Life	Energy /MeV
1	^{238}U	α	4.468x10^{9} y	
2	^{234}Th	β^{-}	24.10 d	
3	^{234m}Pa	β^{-}	1.17 m	
4	^{234}U	α	2.455x10^{5} y	
5	^{230}Th	α	7.538x10^{4} y	
6	^{226}Ra	α	1.600x10^{3} y	
7	^{222}Rn	α	3.824 d	
8	^{218}Po (RaA)	α	3.10 m	
9	^{214}Pb (RaB)	β^{-}	26.8 m	
10	^{214}Bi (RaC)	β^{-}	19.9 m	
11	^{214}Po (RaC’)	α	1.643x10^{-4} s	
12	^{210}Pb (RaD)	β^{-}	22.3 y	
13	^{210}Bi (RaE)	β^{-}	5.013 d	
14	^{210}Po (RaF)	α	138.4 d	
15	^{206}Pb (RaG)		∞	

Radon Conc. and Generation Rate

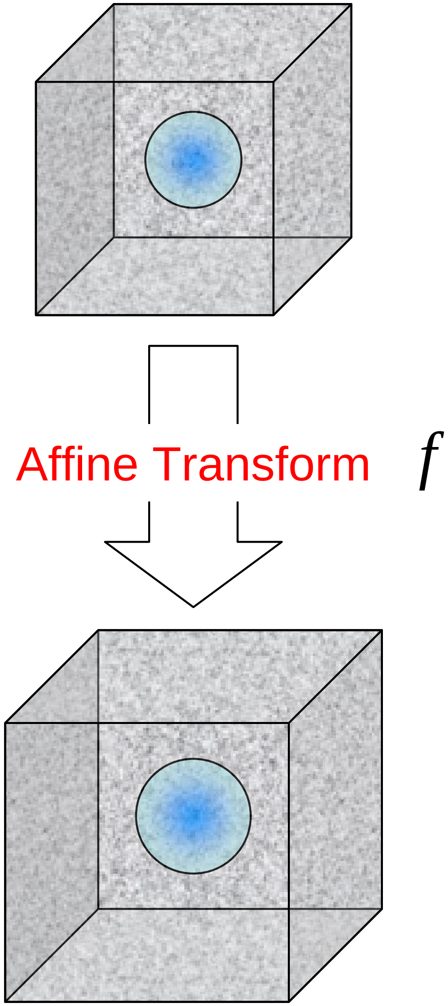
Without pore volume change



Generation Rate

τ : 4.77 x 10^5 (s) R : 2.10 x 10^{-2} (Bq s^{-1}) N_0 : 10000 (Bq)

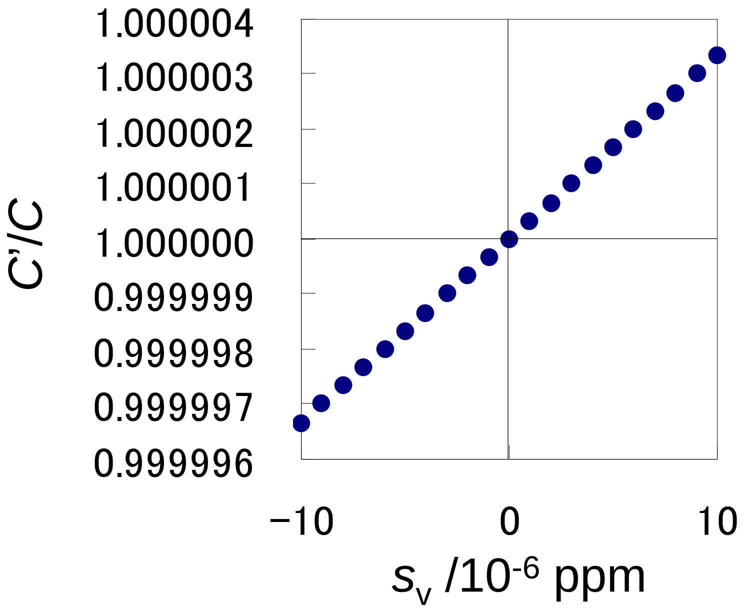
Radon Conc. and Volumetric Strain



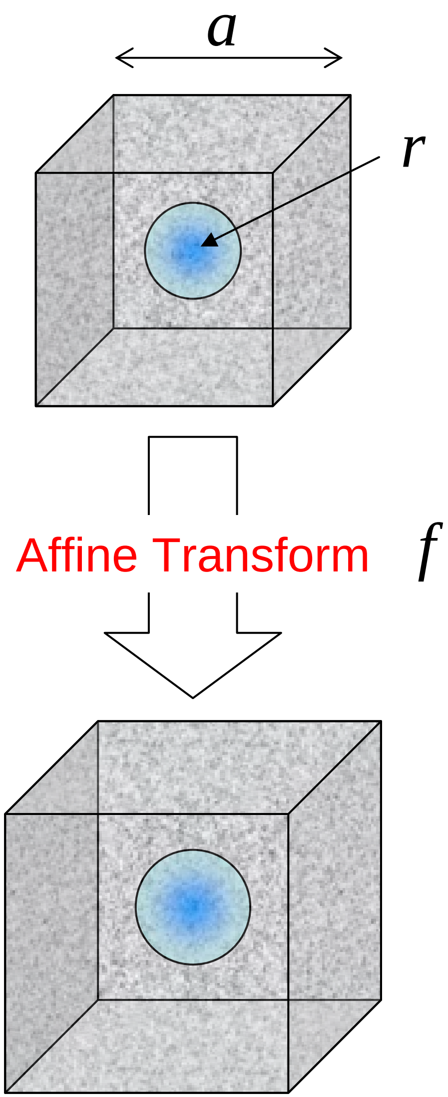
Radon concentration depends on pore volume.
If volumetric change is affine transform….

$s_v = 1 - f^3$: Volumetric Strain

$$C' = C\frac{1}{(1-s_v)^{1/3}}$$



Affine Transform



$$V_t = a^3 \qquad V_p = \frac{4}{3}\pi r^3 \qquad S_p = 4\pi r^2$$

$$C = \frac{ES_p}{V_p} = 3E\frac{1}{r}$$

$$s_v = \frac{V_t - V_t'}{V_t} \Rightarrow s_v = 1 - f^3$$

$$V_t' = f^3 a^3 \quad V_p' = f^3 \frac{4}{3}\pi r^3 \quad S_p' = f^2 4\pi r^2$$

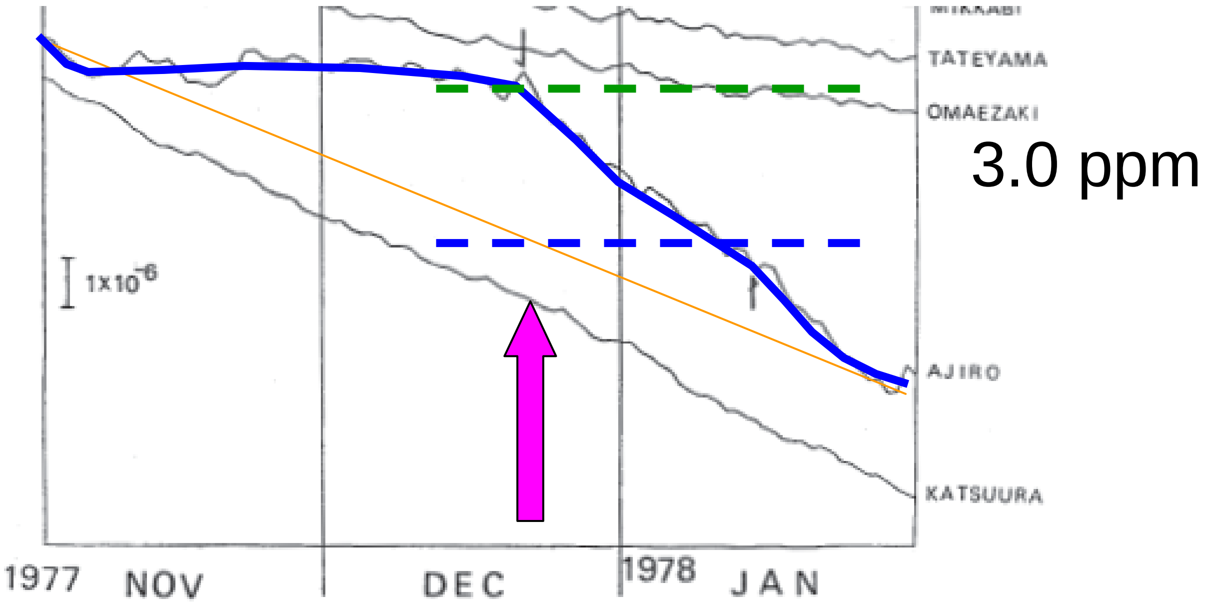
$$C' = \frac{ES_p'}{V_p'} = 3E\frac{1}{r}\frac{1}{f} = C\frac{1}{f}$$

Groundwater Flow

	Retention Time
Ocean	10^3 y
Glacier	$10^1 \sim 10^2$ y
Snow	2 ~ 6 m
Soil	1 ~ 2 m
Shallow Aquifer	10^2 y
Deep Aquifer	10^4 y
Lake, Pond	$10^1 \sim 10^2$ y
River	10^0 m
Air	10^1 d

	Size	Permeability [m/s]
Cray	< 1/256 mm	$10^{-13} \sim 10^{-11}$
Silt	< 1/16 mm	$10^{-11} \sim 10^{-7}$
Sand	< 2mm	$10^{-7} \sim 10^{-4}$
Gravel	> 2mm	$10^{-4} \sim 10^{-2}$

Volumetric Strain at Ajiro

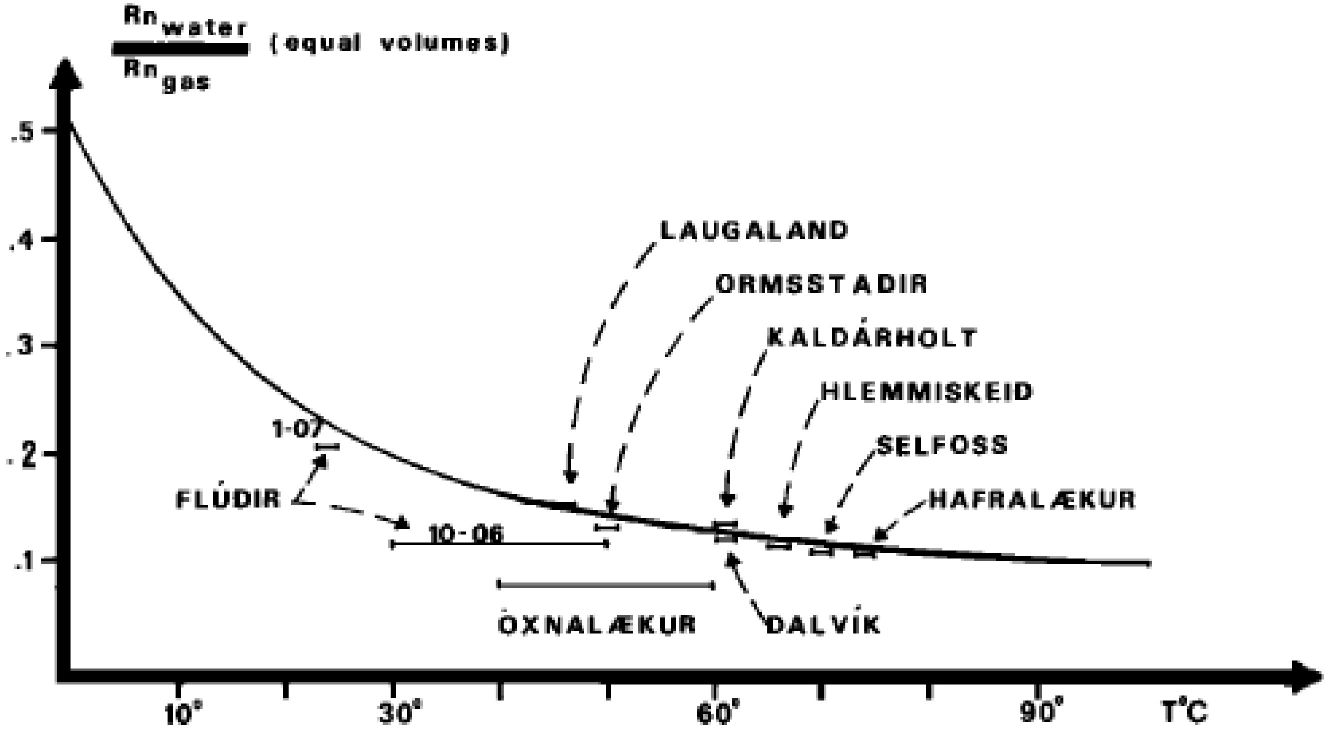


Maximum volumetric strain change recorded at Ajiro was about 3 ppm.

Parameters for Radon

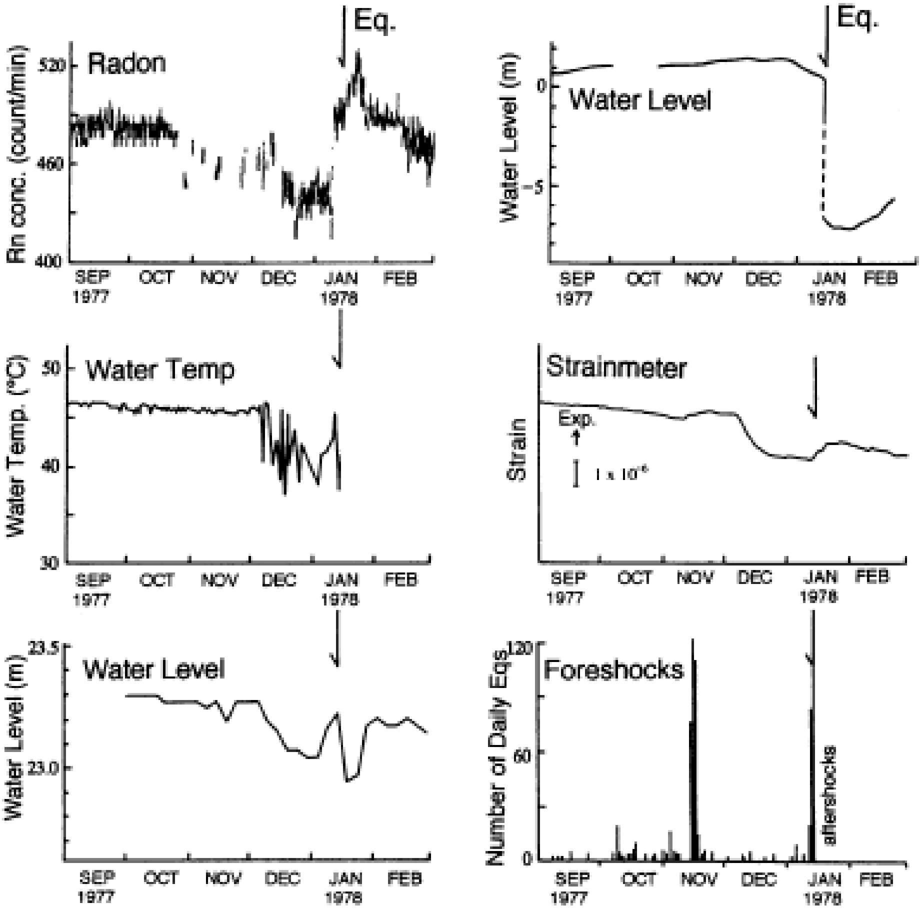
Production Rate of ^{222}Rn in Pore Space	1.14 x 10^{-5} $kBqm^{-3}s^{-1}$	
Henry's Constant	4.4	Wilhelm et al. (1977)
Solid–Water Partitioning Coefficient	1.4 x 10^{-5} m^3kg^{-1}	Nazaroff (1992)
Diffusion Coefficient	~ 10^9 m^2s^{-1}	
Half-life	3.3 x 10^5 s	
Boiling Temperature	211.3 K	
Melting Temperature	202 K	
Solubility	22 $cm^3/100gH_2O$	20ºC, 1atm
Recoil Length	20 ~ 70 nm	

Radon Distribution Coefficient



Hauksson, 1981

1978 Izu-Oshima-Kinkai Earthquake



Wakita, 1996

Upheaval Pattern

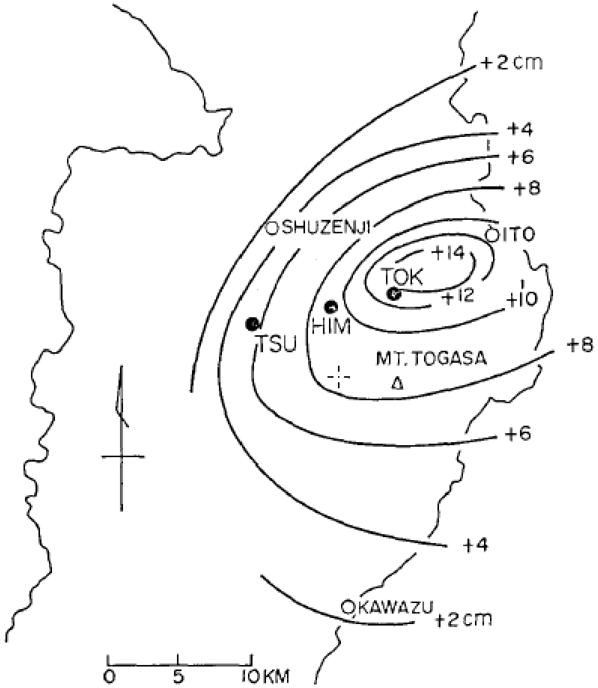
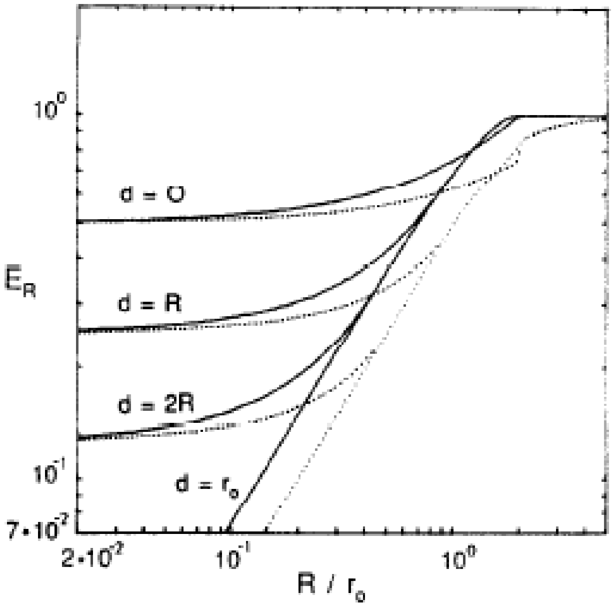


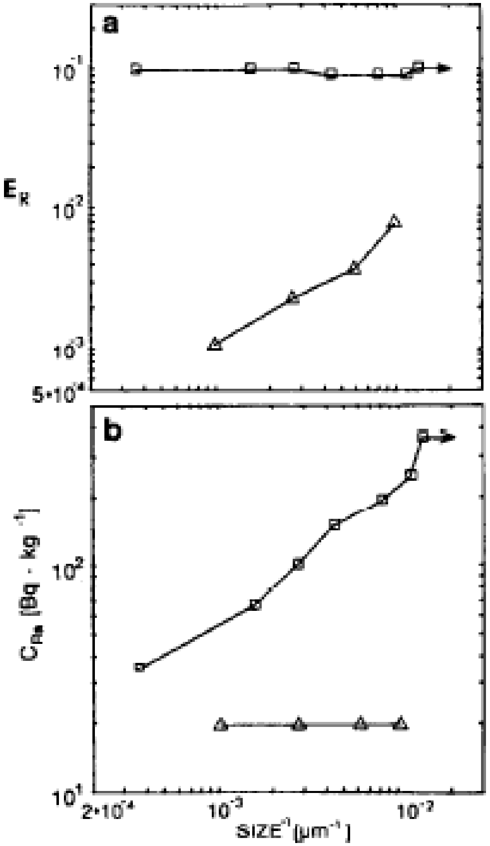
Fig. 1. Locality map. The upheaval pattern after the Geographical Survey Institute. Black circles denote locations of observation wells.
TOK: Tokunaga-minami,
HIM: Himenoyu,
TSU: Tsukigase.

Takahashi, 1977

Emanation Power and Grain Size



Semkow, 1990



Semkow, 1990;
Megumi, 1974;
Adams, 1973