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Anomalous change of groundwater radon concentration monitored at Nakaizu well in 2011

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HIGHLIGHTS

- A counter-flow extractor is useful for continuous radon observation.
- Groundwater radon anomalies were recorded before the 2011 Tohoku earthquake.
- A modified volatilization can interpret radon concentration anomalies.

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ABSTRACT

An anomalous increase in radon concentration was measured at the Nakaizu observatory on the Izu Peninsula prior to the 2011 Tohoku earthquake using a custom-made radon counter. Since the increase was more than three times the standard deviation of radon concentration variations over 35 years of recorded data, it is considered likely that it is a precursor to the earthquake. Following the earthquake, the radon concentration decreased exponentially to the background level. The anomalous increase is explained using a modified volatilization model containing three important aquifer parameters: the groundwater saturation ratio, the fracture surface area per unit volume, and the porosity. The modified model can also explain the radon concentration behavior prior to the 1978 Izu-Oshima-Kinkai earthquake.

1. Introduction

Monitoring of groundwater radon concentration to predict the onset of earthquakes has been conducted since the 1970s. It is thought that there may be a relationship between anomalous changes in radon concentration and the initial stages of earthquakes, because more than two hundred anomalous radon concentration changes have been reported as precursory indicators of earthquakes.

The work conducted by Ulomov and Mavashav (1971) has strongly influenced other geochemical studies of anomalous preseismic variations in groundwater radon concentration (e.g., Noguchi and Wakita, 1977; Wakita et al., 1980; Yamauchi et al., 1988; Igarashi et al., 1995; Yang et al., 2005; Kuo et al., 2006). There have been two significant reports of radon anomalies. The first focused on the 1978 Izu-Oshima-Kinkai earthquake (Wakita et al., 1980), and the second on the 1995 Kobe earthquake (Igarashi et al., 1995). The former anomaly was considered a remarkable precursor because the change in radon concentration coincided qualitatively with similar changes in groundwater level, groundwater temperature, and volumetric strain measured on the Izu Peninsula (Wakita, 1996). The latter anomaly is believed to have been a precursor because a similar change was observed in the chloride ion concentration in groundwater that was bottled near the radon observatory (Tsunogai and Wakita, 1995). Although there are many examples of anomalous changes in groundwater radon concentration prior to earthquakes, the physical mechanism involved remains hypothetical.

Kuo et al. (2006, 2009, 2010, 2011) conducted studies on anomalous radon concentration changes using a volatilization model. Observed decreases in radon concentration prior to earthquakes near the eastern coast of Taiwan in 2003, 2006, and 2008 were attributed to the generation of a headspace in an aquifer. Kuo's volatilization model implicitly supposes that (1) there is no headspace during aseismic periods, (2) a change in crustal strain generates a headspace that extracts radon from groundwater in an aquifer, resulting in a decrease in groundwater radon concentration. This model was established to describe situations in which the radon concentration declines from its normal level, which

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correspond to approximately 20% of all reported radon concentration anomalies. Therefore, to account for the much larger number of cases in with the radon concentration increased, Kuo's model should be coupled with a model that can explain such increases.

The objective of the present study is to modify the volatilization model to describe anomalous groundwater radon concentration records from the Nakaizu (SKE) observatory. The model must be able to explain both the negative change in radon concentration in 1978 and the positive change in 2011.

2. Observation

2.1. Observation well

The Izu Peninsula is an allochthonous continental block that collided with Honshu Island in Japan due to the northern movement of the Philippine Sea plate. The eastern side of the Izu Peninsula has many active polygenetic volcanoes and a group of active monogenetic volcanoes. Therefore, the geological structure of the Izu Peninsula is complicated.

The SKE observatory is located in the central area of the Izu Peninsula (Lat. = N34.93°, Lon. = E139.04°, Alt. = 276 m; Fig. 1). In April 1976, an observation well was drilled into an aquifer contained in either the Shirahama group, which is primarily composed of tuffaceous sandstone, or the Atami group, which is composed of volcanic rocks. The screen depth of this well is approximately 350 m, and its groundwater discharge rate is approximately 200 L/min. Unfortunately, more detailed information regarding this well is unavailable.

2.2. Counter-flow type gas extractor

We manufactured a counter-flow radon extractor for semi-continuous monitoring. A schematic diagram of the extractor is shown in Fig. 2. The gray-shaded area is the extraction chamber, which is constructed from polyvinylchloride pipes. Balls fabricated by folding a stainless steel plate are packed into the chamber to enlarge its internal surface area. Groundwater is pumped directly from the well by a vortex-flow turbine pump (Pw in Fig. 2). The temperature and pumping rate are measured just after the groundwater passes through the pump. The groundwater is introduced into the chamber through an inlet (A in Fig. 2), then flows downward and exits the chamber through an outlet (B in Fig. 2). Ambient air is used as radon-free gas (hereafter referred to as zero gas) because the radon concentration in the atmosphere is very low compared to that in groundwater. The zero gas is blown into the chamber through an inlet (C in Fig. 2), flows upward and then exits the chamber through an outlet (D in Fig. 2). This counter-flow of the zero gas and groundwater effectively accelerates the gas–liquid equilibrium of radon in the chamber. Radon dissolved in the groundwater migrates into the gas phase in the chamber, in an amount determined by the distribution coefficient. The radon in the gas phase is then drawn out by the zero gas, which functions as a carrier. The sample gas containing radon is dried using an electric gas cooler (ED in Fig. 2). After flow rate measurement (Fa in Fig. 2) and filtration of

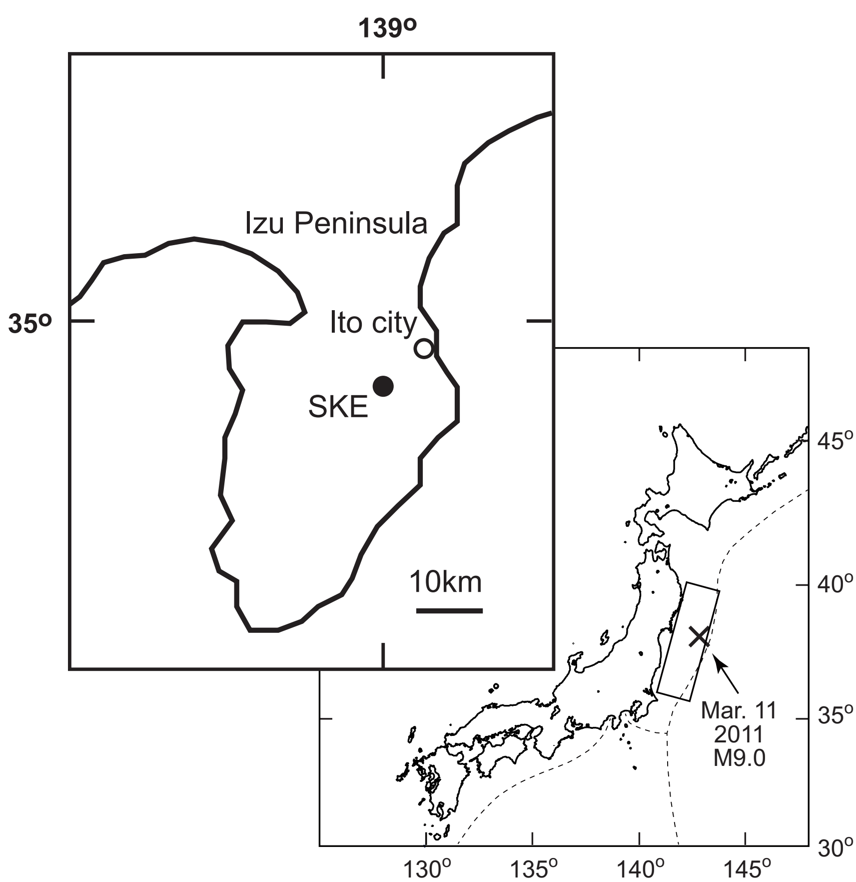

Fig. 1. Location of SKE observatory (filled circle) on Izu Peninsula; epicenter of 2011 Tohoku earthquake mainshock (×); epicentral distribution of aftershocks (rectangle); and oceanic trenches (dashed lines).