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Estimation of fracture porosity using radon as a tracer

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ABSTRACT

In this paper, a quantitative method using the precursory radon decline as a tracer to estimate fracture porosity is presented with the help of a case study. In a fractured confined aquifer of limited recharge, the in-situ volatilization of dissolved radon could cause a decline of radon in groundwater precursory to an earthquake. Based on the mechanisms of in-situ radon volatilization and rock-dilatancy, a mathematical model has been developed to correlate the radon decline with fracture porosity and volumetric strain change in the aquifer rocks.

1. Introduction

Naturally fractured reservoirs hold large groundwater, geothermal, and hydrocarbon resources. Fracture porosity is an important formation parameter for evaluating the fluid in place in naturally fractured reservoirs. Whole core analysis (Kelton, 1950) and downhole cameras provide direct sources of information for evaluating fracture porosity. Snow (1968) developed a method to determine fracture porosity from permeability measurements in drill holes. Other indirect sources of information for evaluating fracture porosity and permeability include drilling history, log analysis (Aguilera, 1980), well testing (Jenkins and Prentice, 1982), inflatable packers (Anderson and Stahl, 1967), and production history. This paper presents a quantitative method to determine fracture porosity in a naturally fractured reservoir using radon as a tracer.

Geo-gases (carbon dioxide, methane, and nitrogen) sometimes may assume a role in transport of radon released from deep sources. Nevertheless, the radon concentration in ground water is mainly proportional to the uranium concentration in adjacent rocks. Andrews and Wood (1972) presented experimental results for sands, sandstone, and limestone to support the above mechanisms of radon release from minerals. The particle diameter ranged from 20 μm to 10,000 μm. Andrews and Wood (1972) showed that the radon release from secondary phases (cemented material or fracture) became independent of particle size when d exceeded 450 μm. Because of radon's short recoil length (3×10^{-8} cm), only atoms produced at the surface of rock grains are released to the surrounding ground water. Thus, the concentration of radon in ground water is largely dependent on the surface area of the rocks (Torgersen et al., 1990). Before the occurrence of an earthquake, regional stress increases causing formation of microcracks in the rock mass that could cause an increase in the surface area of the rocks. As a result, radon concentration increases (Igarashi et al., 1995; Teng, 1980). Possible mechanisms for interpreting anomalous decreases in radon prior to earthquakes have also been investigated in a limited-size fractured confined aquifer (Kuo et al., 2006). It is possible to quantify fracture porosity using the precursory radon decline as a tracer for a fractured confined aquifer of limited recharge.

Anomalous declines in the radon concentration of groundwater precursory to nearby earthquakes have been observed in fractured confined aquifers of limited recharge in both Japan and Taiwan. An anomalous radon decline from a background level of 483 ± 3 cpm to a minimum of 439 ± 7 cpm was observed at the SKE-1 well in the Izu Peninsula precursory to the 1978 M=7.0 Izu-Oshima-Kinkai earthquake in Japan (Wakita et al., 1980). An anomalous radon decline from a background level of 791 ± 46 pCi/L to a minimum of 326 ± 9 pCi/L was also observed at the D1 well in the Antung hot spring prior to the 2003 M_w=6.8 Chengkung earthquake in eastern Taiwan (Kuo et al., 2006). Both wells (SKE-1 and Antung D1) were completed in fractured confined aquifers of limited recharge. Under such geological conditions, the dilation of brittle rock mass and in-situ volatilization of radon could cause the anomalous declines of radon in groundwater precursory to nearby earthquakes (Kuo et al., 2006).

It is of practical interest to develop a mathematical model correlating the radon decline with the gas saturation, fracture porosity, and volumetric strain change in the aquifer rocks.

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We also illustrated the application of the model to estimate fracture porosity using the radon decline precursory to the 1978 M=7.0 Izu-Oshima-Kinkai earthquake as an example.

2. Radon and strain anomalies precursory to the 1978 Izu-Oshima-Kinkai earthquake

The M=7.0 Izu-Oshima-Kinkai earthquake occurred at 12:24 h (JST) on January 14 of 1978 to the east of the Izu Peninsula. The epicenter of the main shock was located at 34.8°N and 139.3°E (Fig. 1). The principal fault inferred from a seismological study (Shimazaki and Somerville, 1978) was an east-trending right-lateral strike-slip fault 17 km long that was situated beneath the sea between the Izu Peninsula and Izu-Oshima Island. On the east coast of the Izu Peninsula, the western edge of the fault, ground displacement occurred along a fault trending northwest–southeast with a length of 3 km (Tsuneishi et al., 1978). The maximum displacement of the fault was 1.3 m.

Figs. 2a, 2b, and 2c summarized precursory changes of radon, strain and water level for the 1978 M=7.0 Izu-Oshima-Kinkai earthquake, respectively (Wakita, 1996). Fig. 2a shows the radon record at the SKE-1 well. The SKE-1 is an artesian well with a depth of 350 m. A continuous measuring system was used to monitor radon concentration in groundwater at the SKE-1 well. The measuring system consists of a ZnS scintillation chamber for alpha counting and a separation chamber in which radon is emanated from groundwater to the gaseous phase. The radon concentration in the gaseous phase equilibrates with that in water according to the distribution coefficient. Alpha activities of radon and its daughters (^{218}Po and ^{214}Po) in the scintillation chamber are counted and recorded continuously (Noguchi and Wakita, 1977). The distance from the epicenter to the radon monitoring station (SKE-1) for the 1978 Izu-Oshima-Kinkai earthquake was about 25 km. In October 1977 the radon concentration at the SKE-1 monitoring well began to decrease from a background level of 483 ± 3 cpm about 80 days before the 1978 Izu-Oshima-Kinkai

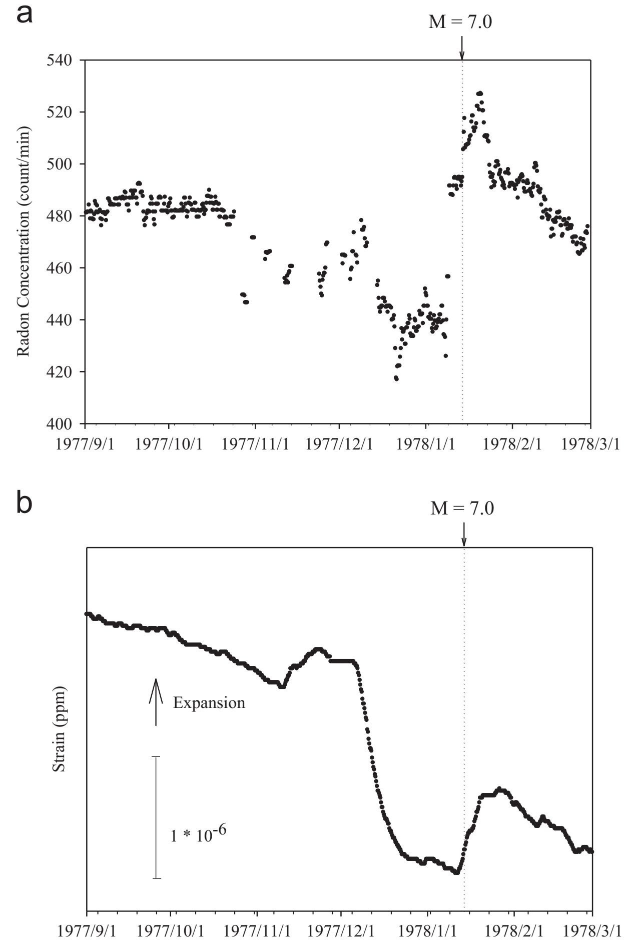

Fig. 2. Precursory changes of the 1978 Izu-Oshima-Kinkai earthquake (adapted from Wakita, 1996). (a) Radon concentration changes observed at the SKE-1 well (350 m deep) with a distance from the epicenter (D)=25 km. (b) Record of the volumetric strainmeter at Irozaki with D=50 km.

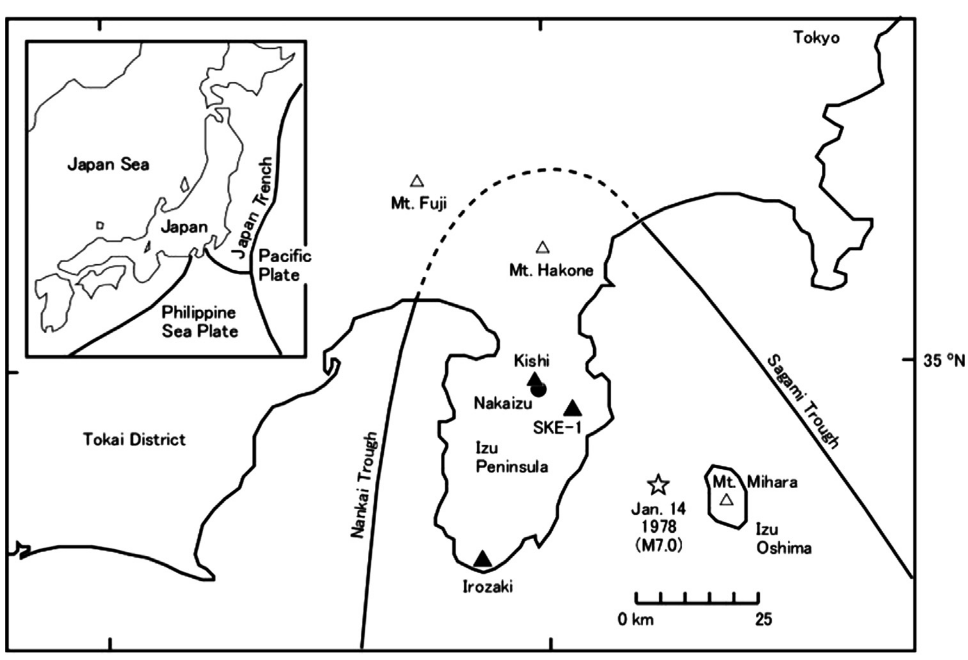

Fig. 1. Map of the Izu Peninsula and the surrounding area (open star: 1978 mainshock; filled triangles: monitoring stations; open triangles: mountains) (adapted from Wakita et al., 1980).