論文内容の要旨

論文題目：GEOCHEMICAL STUDIES OF VOLATILE SPECIES FROM ACTIVE FAULT AREAS IN JAPAN AND TURKEY：IMPLICATION FOR EARTHQUAKE PREDICTION

（日本とトルコの活断層地帯から放出する 揮発性成分の地球化学的研究：地震予知に向けて）

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INTRODUCTION

Turkey is one of the most seismically active regions in the world. As a result, it has a long history of large earthquakes that have killed many thousands of people and caused economic devastation, including the Kocaeli (M = 7.4) and Düzce (M = 7.2) events of 17August and 12 November 1999, near İstanbul. Turkey is thus an excellent natural laboratory to study active strike-slip faulting, and active normal faulting. The chemical composition and transport of soil gases within fault zones has been the subject of extensive investigation due to the potential for geochemical anomalies to serve as precursors to seismo-tectonic activity. Volatile species such as Rn, H_2, CO_2, and He are observed to seep through active faults during quiescent periods when only micro-earthquakes occur intermittently at depth. Experimentally, these seeping species can be detected by chemical analyses of soil gases or soil gas efflux measurements along active faults. In this study, I have carried out geochemical studies of volatile species releasing from active faults in Turkey and Japan.

METHODS

Sampling : Soil gases were collected at 30-cm depth using a metallic probe (MU type gas collection tube; GL Sciences Inc., Japan) for chemical and carbon isotope analyses. Bubbling gases associated with hot spring or mineral spring discharges, or those emitting from river bottoms, were collected for chemical and C, He, Ne and Ar isotopic analyses. When bubbling gases were unavailable, water

samples from hot springs or mineral springs were collected to measure noble gas elemental and He, Ne and Ar isotopic compositions of their dissolved gases.

CO_2 efflux measurement: Diffuse CO_2 efflux measurements were performed using a Portable CO_2 flux meter (WEST System Srl., Italy) which is based on accumulation chamber method.

Gas Chromatography: Concentrations of CO_2, He, H_2, O_2, N_2 and CH_4 in soil gases were determined using a micro-gas chromatograph (Micro-GC CP2002; Varian Inc.).

^{13}C mass spectroscopy: Carbon isotope measurements for CO_2 in soil gases were carried out using a MAT delta-S GC/C/MS system (Finigan MAT GmbH). Correction for mass discrimination in analyses was done with the measurement of a standard gas (CO_2>99.95%, $\delta^{13}C$=-30.92‰), intermittently injected into the mass spectrometer during sample analyses.

Noble gas mass spectroscopy: The isotopic ratios of He, Ne and Ar and elemental abundances of five noble gases, He, Ne, Ar, Kr and Xe, were measured using a mass spectrometer system (MS-III) installed in the Laboratory for Earthquake Chemistry, University of Tokyo.

RESULTS AND DISCUSSION

Soil H_2 and CO_2 at several active faults in Japan

Seven active faults in western and central Japan are surveyed in this work. We selected the Atera, Atotsugawa, Neodani, and Yamasaki faults, because high H_2 concentrations in soil gases had been reported. The other faults chosen are the Nojima fault fractured at the 1995 Hyogoken-nanbu earthquake and two faults without historical displacement in Omaezaki. The maximum H_2 concentration in each active fault up to 500ppm seems to correlate with fault activity as exemplified by the time to the latest big earthquakes. Observed H_2 concentrations in four faults were markedly lower than those collected in the latter half of the 1970's. These differences in H_2 concentrations may attribute to different sampling depth or rock type in the active fault system. Even though we did not measure the same maximum values, we could observe the higher H_2 concentrations due to the addition of the fault gases close to the fault strikes based on CO_2/H_2 discussion.

Release of mantle helium from forearc region of the Southwest Japan arc

Noble gas abundances and He, Ne and Ar isotopic compositions were determined for 30 samples of bubbling gases and spring waters from Shikoku, which corresponds to the forearc region of the SW Japan arc. Using those composition data, this study investigates the behaviors of mantle volatiles in the subduction system. In addition, six gas samples were analyzed for chemical and carbon isotope compositions. Observed $^3He/^4He$ ratios for the 30 samples ranged from 0.17 R/R_A to 3.56 R/R_A, indicating that several samples contained mantle helium, and that others contained crustal helium. The geographical distribution of $^3He/^4He$ ratios shows that two areas are releasing mantle helium with $^3He/^4He$ ratios greater than 1.2 R/R_A. One area is along the Median Tectonic Line (MTL), a major active fault in Japan, which traverses northern Shikoku in an east-west direction. The other area is southwestern Shikoku, which coincides with a region where non-volcanic long-period tremors occur with epicenter depth of

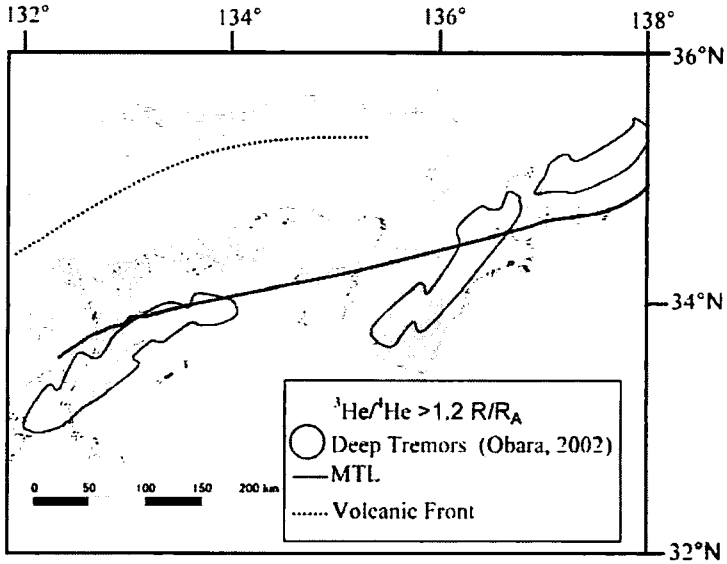

Fig.1 Areas of mantle helium release with $^3He/^4He$ ratios above 1.2 R/R_A and the epicenter distribution of the deep long-period tremors (Obara, 2002).

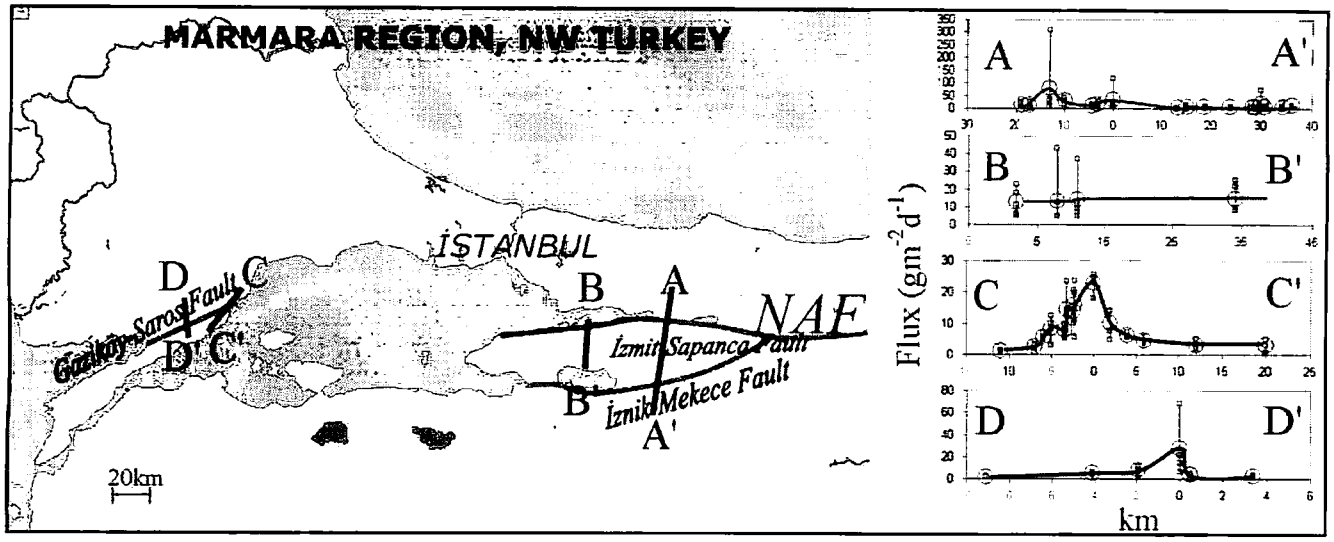

Fig.2 Location of soil gas survey transects and plot of each transect as a function of distance (km) from strike of fault and flux Flux ($gm^{-2}d^{-1}$). O km presents fault strike.

about 30 km (Fig.1). These two areas seem to overlap in northern Shikoku. Mantle helium, which is released in a similar manner to that from active faults and from deep tremor regions in Shikoku has also been observed in the Kii Peninsula region (Matsumoto et al., 2003). Non-volcanic deep tremors are thought to be caused by fluids that are librated from a subducting slab by dehydration in the forearc region (Obara et al., 2004). In Shikoku, the slab-derived fluids cause fracturing within the crust and ease transfer of fluids, mixed with mantle helium, to the surface. Our results also confirm that an active fault system can be an efficient path to transfer mantle helium, as Kennedy et al. (1997) suggested for the San Andreas faults.

Soil gas survey in Marmara region, NW Turkey

The effluxes, concentrations, and carbon isotopic compositions of soil CO_2 were measured along the north western North Anatolian Fault (NAF) in the İzmit-Sapanca Fault, İznik-Mekece fault and Gaziköy-Saros fault, in Marmara Region. CO_2 efflux was measured at 180 points along these faults with portable instrumentation in both faulted and unfaulted areas. Spatial and temporal variability of surface CO_2 effluxes was observed to be higher at faulted NAF, relative to comparable background areas (Fig.2). Carbon isotopic compositions of 42 soil gas samples measured show $\delta^{13}C$ (-23.3to -15.6‰) values of soil CO_2 in both faulted and unfaulted areas, which are indicative of biogenic CO_2, even though CO_2 effluxes in faulted areas reached values as high as 309 g m^{-2} d^{-1}. The CO_2 flux anomalies are therefore consistent with fault-related biogenic gas flow and do not yield evidence for degassing of deeply derived CO_2.

$^3He/^4He$ in Marmara region NW Turkey

Measured $^3He/^4He$ ratios for 36 samples in this study range from 0.26 R/R_A (M5) to 4.22 R/R_A (M67). Figure 3 shows the $^3He/^4He$ ratio plotted as a function of distance from a strike of the NAF. The $^3He/^4He$ ratios along the NAF are higher in two locations than those of other areas in Marmara. In the 70 km zone to the north and 90 km south of the strike of the NAF, four sites provide $^3He/^4He$ ratios above 1 R/R_A, with the highest ratio of 4.22 R/R_A at Şarköy. This result is attributable to the effective transfer of mantle helium through this fault system with fluids, as Kennedy et al. (1997) showed for the San Andreas Fault and Dogan et al. (2006) in Shikoku MTL.

The bubbling gas samples showed a wide range of $\delta^{13}C$ (CO_2) of -0.6 ~ -28 ‰, apparently in the range of mantle carbon (-6.5±2.5‰), marine carbonate (-1 ~ +2‰), and organic sediment (-20 ~ -40‰).

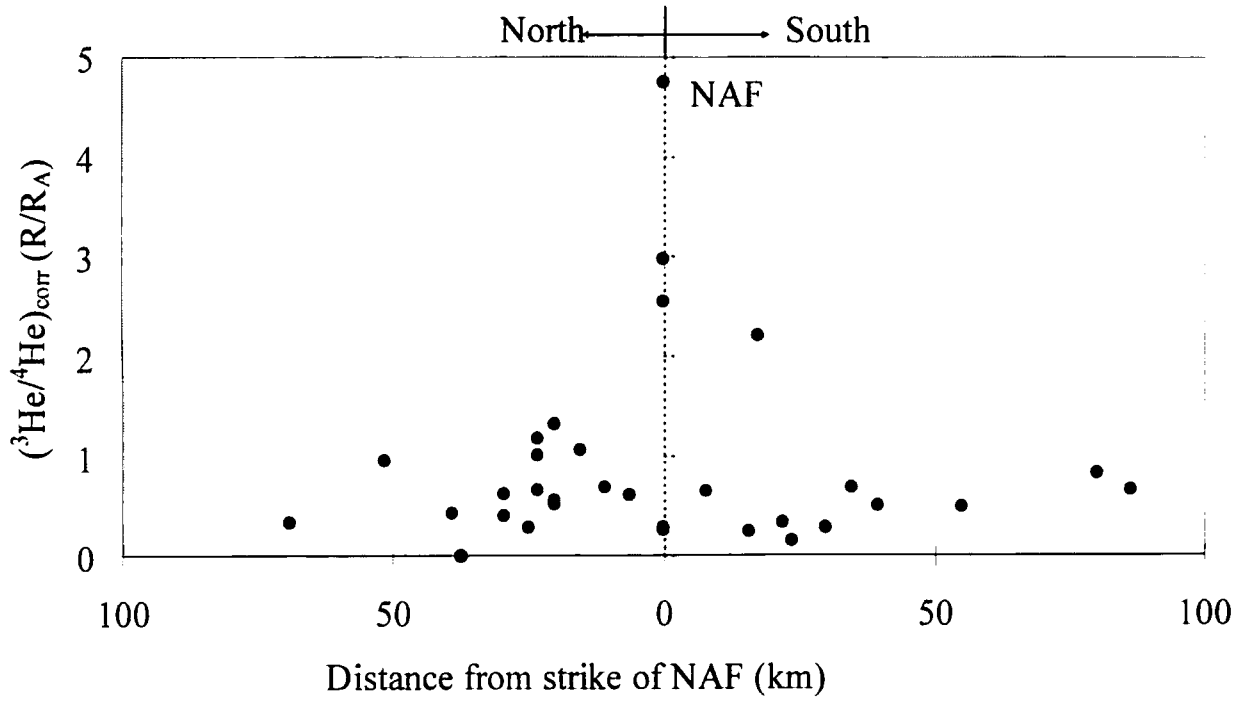

Fig.3 Plot of $^3He/^4He$ ratios as a function of distance from the main strike of the North Anatolian Fault (NAF).

CONCLUSION

(1) Helium isotope surveys in SW Japan and NW Turkey imply that helium with higher $^3He/^4He$ is transferred from mantle source through the pathways of active faults; MTL and NAF. Such a transfer of mantle helium is also observed at the San Andreas fault, USA (Kennedy et al., 1997). In addition, mantle helium appears to the surface in the region where non-volcanic long-period tremors occur in the fore-arc region of SW Japan (Obara, 2002)

(2) CO_2 effluxes are higher at faulted areas of the NAF than those in background area. However, $\delta^{13}C(CO_2)$ values of soil CO_2 are -23.3 to -15.6 ‰ both in faulted and unfaulted areas, indicative of biogenic origin. Therefore, CO_2 efflux anomaly may be caused by fault-related biogenic gas flow.

(3) Soil H_2 anomaly in the fracture zone is observed at active faults in Japan, which displaced recently. However, no H_2 anomaly is observed at NAF. This may attribute to the difference in basement rock and moisture environment around each fault.

(4) It is important to develop the continuous measuring system of volatile species released from the active fault, to monitor the fault activity or future seismic events.