Quick identification of water-conducting fractures in an underground tunnel using a trace methane gas measurement by cavity ring-down spectroscopy: a case study in the Mizunami Underground Research Laboratory, central Japan

*Masakazu Niwa[1], Kenji Amano[2], Ryuji Takeuchi[1], Koji Shimada[1]

1. Tono Geoscience Center, Japan Atomic Energy Agency, 2. Geological Disposal Research and Development Department, Japan Atomic Energy Agency

Permeability in low-porosity fractured media such as granitic rock of the upper crust is considered to be fault-bound where advective fluid flow mostly concentrates along permeable faults and their damage zones. Faults and fractures can also form impermeable barriers due to infilling of fine fragments and clays resulted from intense cataclasis and hydrothermal water-rock interactions, as well as often representing major fluid flow pathways. Thus, identification of permeable faults, or more specifically, identification of water-conducting fractures (WCFs) from all observed fractures is important for the safety assessment on the underground projects such as radioactive waste disposal.

Identification of WCFs in an underground tunnel is principally based on detailed geological and hydrological investigations on gallery walls and using boreholes. Geophysical and geochemical investigations (electric well logging, gas measurement, etc.) can also contribute to the identification of WCFs. The recent development of gas measurements at ambient levels using wavelength-scanned Cavity Ring-Down Spectroscopy (CRDS; O’ keefe and Deacon, 1988, Review of Scientific Instruments) enabled us to measure trace methane gas concentration with an exceptional precision (a few ppb), a short measurement interval (~1 sec), a low drift (<1 ppb per 1 day), and a short response time (several seconds). Portable analytical system using CRDS has been also developed, allowing us to operate the analyzer in remote areas, especially those that can only be reached by foot, and on the move. In this study, we examined an applicability of a scan of methane gas concentration by a backpack type analyzer using CRDS (Picarro GasScouter TM G4301) to quick identification of WCFs in an underground tunnel.

Case study using the G4301 was conducted at a ground level (GL) -500 m gallery in the Mizunami Underground Research Laboratory (MIU), central Japan, where two vertical shafts and two horizontal research galleries had been excavated into the Late Cretaceous Toki Granite (zircon U–Pb ages of 75–70 Ma: Yuguchi et al., 2016, JMPS). Detailed fracture data including their distribution, orientation, and inflow points in MIU has been collected as a part of the scientific research for deep underground since 2004 (Saegusa and Matsuoka, 2011, JAEA-Research 2010-067; Kawamoto et al., 2014, JAEA-Data/Code 2014-014; Hama et al., 2016, JAEA-Review 2016-014). Previous geochemical researches have reported that methane in much higher concentration (>200 ppm) than in the atmosphere is dissolved in groundwater from MIU (Ino et al., 2018, ISME Journal). In the GL-500 m gallery, wall rock granite is still exposed without mortar or concrete covering in parts of the eastern side of the north-facing gallery.

We measured by two approaches to obtain the profile of methane concentration along the eastern side of the gallery: 1) round trip scans by walking at a speed of 0.5 m/sec, 2) monitoring for 30 sec at a 0.5 m or 1 m interval. In the case of 1), we examined a diagram of an integration value of methane concentration in four round trip scans vs a distance along the gallery. According to comparison between four round trip scans, data from the G4301 were well-reproducible. Because a maximum response time of our G4301 is 5

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sec, distance was corrected short of 2 m for realistic value. Three large, clear peaks at 61–62 m, 66–67 m, and 79–81 m from the measurement start location were identified. Concerning a wind direction to the main shaft due to ventilation, 62 m, 67 m, and 81 m locations are considered to be locations of methane emission. These correspond well to the locations of WCFs with water inflow of 1–10 L/min.

In the case of 2), we examined a diagram of mean value of methane concentration in each monitoring location vs the distance. In this diagram, large, clear peaks at 61 m and 66 m were identified. In contrast, no clear, prominent peak was identified at 79–81 m, though methane concentration around this interval is relatively high. This is considered to be due to the difference of the monitoring intervals from locations of methane emission.

While it takes more than 50 min to obtain a profile of 100 m by the case of 2), it only takes 3 min 20 sec to obtain one way measurement by the case of 1). Thus, trace gas scan using a portable analyzer by the CRDS system is helpful for quick, brief identification of WCFs.

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