Evaluation of shale volume using a combination of the gamma-ray logs and core analysis in terms of sedimentology and geochemistry: a case study of the Nagaoka site, Japan

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Evaluation of spatial distribution of shales is important for selecting of reservoir rocks suitable for geological storage of CO_2. Shale volume from well logs is useful as deterministic data for evaluation of spatial distribution of shales in the strata. Gamma-ray log can be used to evaluate shale volume in the reservoir. Gamma-ray logging is a method of measuring naturally occurring gamma radiation from ^{238}U, ^{232}Th, and ^{40}K in the strata. Mudstone generally has higher total GR value than sandstone. However, it is difficult to evaluate reliable shale volume if the mineralogical composition significantly changes during deposition of the strata. This means that understanding the minerals which have an effect on the total GR value is essential for evaluation of shale volume, but few studies have focused on that. Herein we present the results of reservoir characterization in terms of sedimentology and geochemistry, and comparison among core analysis and gamma-ray logging as a case study of the Nagaoka geological storage site, Japan. Furthermore, we show the importance of sedimentological interpretations of the strata for reliable evaluation of shale volume.

In the Nagaoka project, total of about 10,000 tons of CO_2 was injected into the saline aquifer, which situates about 1,000m depth below the Niigata Plain. The target saline aquifer is correlated to the early Pleistocene Haizume formation. During the project, one injection well (IW-1) and three observation wells (OB-2, -3 and -4) were drilled. Sediment core of the target reservoir rock was taken from the IW-1. Standard GR logging was carried out at all the wells, and spectral gamma-ray logging, which can measure ^{238}U, ^{232}Th, and ^{40}K contents, was performed at all observation wells.

We carried out the interpretation of depositional environments, measurements of major and minor elements by XRF analysis, and identification of minerals by XRD analysis in the target strata. The target reservoir comprises two depositional sequences characterized by fining-upward to coarsening-upward succession that developed on the erosional contact. According to core description, the deposits can be interpreted as prodelta to deltafront deposits. Total GR value has high sensitivity to depositional environments. Profile of total GR value is basically consistent with that of mud content (<1/16mm), and this suggests that main source of total GR value is mainly attributed to minerals in mud fraction. Comparison between total GR value and spectral GR logging shows that distribution range of K content against total GR value show low contrast between prodelta and deltafront deposits, and this trend suggests that K content is not carrier of radioactivity. On the other hand, distribution range of U and Th contents against total GR value show basically high contrast between two deposits and have positive correlation. This result indicates U and Th-bearing minerals are main carrier of radioactivity. Comparison between total GR value and major and minor elements shows that minerals including MgO, TiO_2, Th, and Zr are likely to be main source of total GR value. The XRD analysis using samples of mud fraction shows that those minerals can be attributed to zircon grains, smectite and chlorite, because it is known that these minerals contain or adsorb the Th andor U ions.

As stated earlier, stratigraphic profiles of GR logging show two depositional sequences at all wells. The scatter diagrams of radioactive elements by spectral GR logging against total GR value shows similar trend basically in two depositional sequences, implying that no significant changes of mineralogical composition during deposition. However, maximum of total GR value is significantly different between two

sequences. The result indicates that the endmembers of total GR value for evaluating shale volume by gamma-ray logging should be selected in each depositional sequence. Detailed studies in terms of sedimentology are essential for reliable evaluation of shale volume.

Keywords: Nagaoka site, Sedimentology, Geochemistry, Natural gamma-ray logging, Spectral gamma-ray logging, Shale volume