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Effect of brine injection into shallow formation on land subsidence in the Southern Kanto gas field, in Japan

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Abstract. Our association plans to construct in situ formation deformation monitoring wells for shallow formation. In the pilot test, production and injection will be conducted to make the formation deform. Based on the result of the pilot test, we will investigate whether the compaction behavior was perfectly elastic or not. In addition, we plan to conduct coring and core tests to obtain rock properties.

In the future, we would like to select the suitable constitutive equation for this gas field based on the obtained data and construct a prediction methodology to control subsidence. Once the land subsidence control technology is established in this study, it is expected that reservoir management for production will be performed.

1 Introduction

The Southern Kanto gas field, which contains natural gas dissolved in water, is located in the Boso Peninsula close to Tokyo (Fig. 1). The eight operation companies produce 460 million m^3 yr^{-1} of natural gas in this field. It is a mature field that has been operated for 90 years. In the Southern Kanto gas field, the Kazusa Group is a reservoir. It consists of mostly semi-consolidated sand intercalated with mudstone and some good correlative tephra beds. The bed thicknesses are the range from several centimeters to the order of meters.

To produce natural gas, lots of brine must be pumped up (withdrawn) from the subsurface reservoir, and it is considered to be one of the causes of the land subsidence problem. As a result, the amount of brine produced is regulated in the present. Therefore, it is necessary to resolve this problem to maintain and expand the industry.

Natural gas developing companies in this area are making efforts to address environmental problems. The companies think there is a possibility that "injection water into shallow and soft formation" is one of the solutions to mitigate and control this problem. It was decided that a pilot test would be conducted in the project and that produced brine would be used as injection water. The reasons are below.

1. The large amount of brine is still pumped from the subsurface for production of natural gas.

2. There is the brine in the formation of the pilot test field in this project.

3. The mudstone that constitutes the Southern Kanto gas field contains clay minerals. In general, clay minerals have the property of swelling.

The geological characterization and the well completion of this test are shown in Fig. 2.

2 Purpose and methods

In the past study, it was confirmed that there is a tendency for Young's modulus of Kazusa Group mudstone to depend on depth (Fig. 3). It is expected that the shallow formation will largely deform in comparison to the deep formation if the effective stress change is the same. Theoretically it is true, but we have no practical experience of it, and additionally we do not have enough data of the shallow formation; thus, it is difficult to estimate the effect quantitatively.

Takeuchi et al. (2001) investigated the deformation behavior of the mudstone of the Kazusa Group through the

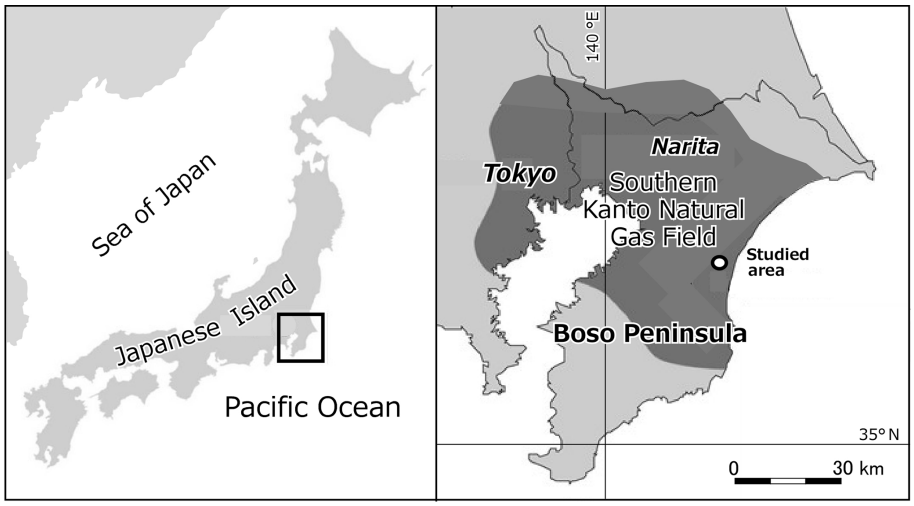


Figure 1. The Southern Kanto gas field (modified Ikeda et al., 2015, based on AIST, 2015).

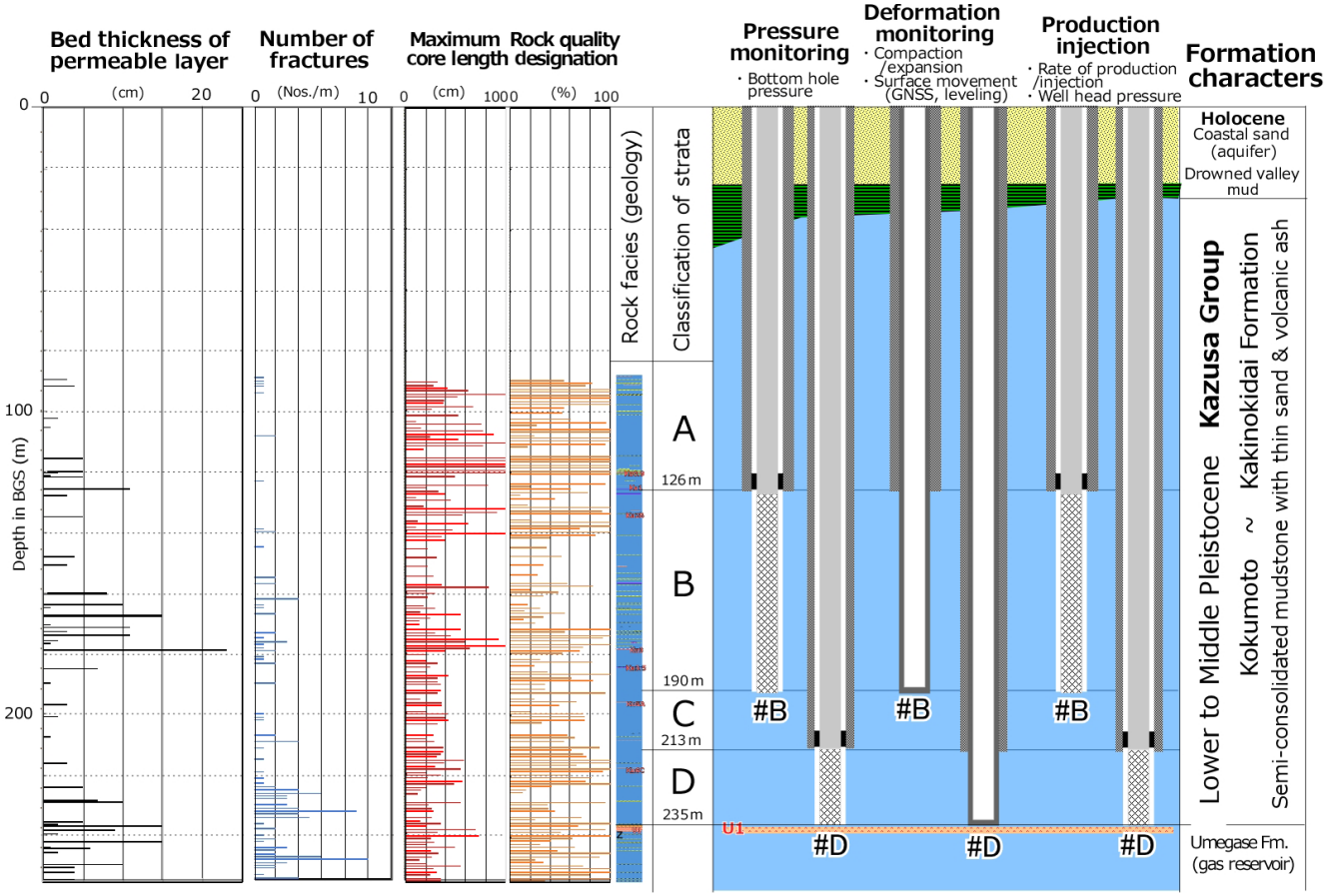


Figure 2. Geological characterization and the well completion of the pilot test.

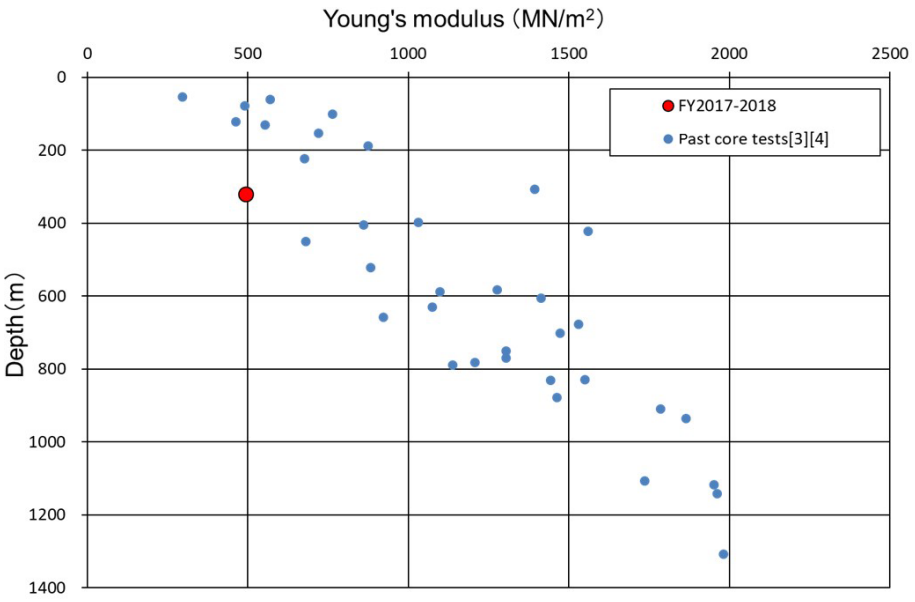


Figure 3. Correlation of Young's modulus and depth (Nakagawa and Sekine, 2018).

laboratory study and found that the reservoir mudstone exhibits hysteresis in the stress–strain relationship. Once the core sample was compressed with pore pressure decrease, the strain was not completely recovered when the pore pressure was returned to the initial value even though the samples are not yet reached to the consolidation yield stress. It is suggested that residual strain will occur after loading and unloading of stress.

In the present, a simulation model, which is used by the eight operation companies, is assumed an elastic model for predicting land subsidence. However, there is the difference between core results (Takeuchi et al., 2001) and the simulation model. Therefore, it is necessary to select the suitable constitutive equation of considering the hysteresis for predicting land subsidence.

Though our target shallow formation is over 100 m deeper than the formation used for daily life, a water and impermeable layer exists between them, from the environmental point of view, we are going to confirm that the injected brine does not affect it.

In this study, we are going to conduct a pilot test and build a geomechanical reservoir simulation model to estimate and evaluate the effect of this project. Some of the works are summarized below.

- *Data acquisition for formation evaluation.* Determining the geomechanical properties of shallow formation is necessary to estimate the land subsidence mitigation. Therefore, we have performed coring and logging on the shallow formation. The main formation properties are density, permeability, porosity, Poisson's ratio, hysteresis of deformation behavior, and so on.
- *Environmental impact assessment.* Before the start of the pilot test, electrical resistivity surveys were conducted to get the baseline data. We will conduct it also after the brine injection and, comparing its results with the baseline data, we plan to evaluate the permeation of injected brine to the aquifer.

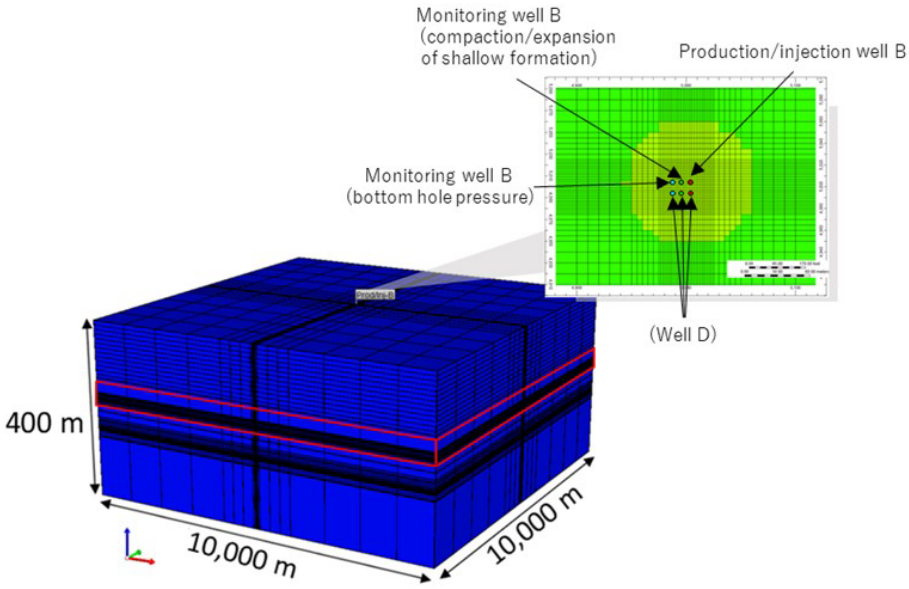
3 Previous study

To evaluate the effect on land subsidence mitigation by injection into shallow formations in the future, the pore pressure changes and deformation of a shallow formation associated with the injection are needed for investigation through the field pilot test.

A simulation model, which covers the whole pilot test field, was created by STARS to decide the placements of wells and the basic plan of the test (Fig. 4). STARS is a 3-D reservoir simulator using FDM in flow analysis and FEM in stress–strain analysis, provided by Computer Modelling Group Ltd. (CMG). The input parameters in the simulation model are based on Adachi et al. (2015) and private documents the Environmental Technology Research Association for Natural Gas Dissolved in Water has.

4 Conclusions and future work

Brine injection into the shallow formation is expected to be an effective method for land subsidence control in the Southern Kanto gas field. However, we consider we do not obtain enough data to estimate the effect of the brine injection into the shallow formation. We plan to get the data from the core



Model size	X 10,000m Y 10,000m Z 400m	
Porosity	Mudstone 0.45 Sandstone 0.40	Adachi et al. (2015)
Permeability	Mudstone 0.05 md Sandstone 1 – 100 md	Adachi et al. (2015) Estimated value

Figure 4. Simulation model.

tests and field pilot test and select the suitable constitutive equation for predicting land subsidence. In the future, we plan to construct a prediction methodology to control land subsidence. Once the land subsidence control technology is established in this study, it is expected that reservoir management for production will be performed.

Data availability. For more information about the used data, please contact the corresponding author Kenjiro Kawano (k.kawano@k-and-o-energy.co.jp).

Author contributions. The Environmental Technology Research Association for Natural Gas Dissolved in Water conceived and designed the research. The authors carried out work on field surveys with KK, HI and YH. KK wrote the paper with support by HI, DM, TE, TS and TN.

Competing interests. The authors declare that they have no conflict of interest.

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