International Journal of Rock Mechanics & Mining Sciences 70 (2014) 332–342

Contents lists available at ScienceDirect

International Journal of Rock Mechanics & Mining Sciences

journal homepage: www.elsevier.com/locate/ijrmms

# Seven-year history of vertical Hydraulic diffusivity related to excavation around an underground facility

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ARTICLE INFO

*Article history:*
Received 1 February 2013
Received in revised form
17 February 2014
Accepted 23 February 2014
Available online 14 June 2014

*Keywords:*
Hydraulic diffusivity
Groundwater
EdZ
URL
Horonobe

ABSTRACT

Significant amounts of groundwater drain induced by the excavation of an underground facility will influence various site formation parameters such as permeability. In this study, a spectral analysis was applied to long-term records of pore-pressure responses to atmospheric loading in order to clarify the history of rock permeability changes at the Horonobe Underground Research Laboratory (URL) in Japan. This study revealed that excavation of the URL influenced nearby aquifers and reduced their vertical hydraulic diffusivity. At a point approximately 130 m distant from the URL, it was found that hydraulic diffusivity has decreased by approximately 7 to 55% in the five years since the excavation started. At a point approximately 860 m distant from the URL, the vertical hydraulic diffusivity was found to have decreased by approximately 26%, even though pore pressure had not changed significantly. This study confirmed that long-term permeability changes could be monitored via pore and atmospheric pressure records. More specifically, during the development of a geological disposal system, which can take several tens of years, the vertical permeability of the site can be continuously monitored from the period before the start of the excavation through to the repository's post-closure period.



## 1. Introduction

The Japan Atomic Energy Agency (JAEA) began the Horonobe Underground Research Laboratory Project (Horonobe URL Project) as part of efforts to enhance the reliability of technologies used during the geological disposal of high-level radioactive waste (HLW) in Japan. As part of this project, 11 deep boreholes (Horonobe Deep Borehole: HDB) were drilled to obtain information on the hydrogeological characteristics of this area.

In a development of an underground facility, significant amounts of groundwater drain induced by the excavation of an URL will influence hydrological properties (e.g., hydraulic head, permeability, and porosity) at the URL site. The creation of an excavation disturbed zone (EdZ) or an excavation damaged zone (EDZ) is expected for all artificial openings in geologic formations. Because of the contrasting properties of different rock types, the various definitions of the terms EdZ and EDZ differ in emphasis [1]. Tsang et al. [2] suggested that each term should be defined in terms of the rock type of indurated clay (which has similar properties to those of the siliceous mudstone of the Horonobe area) as follows: (1) The EdZ is a zone with hydromechanical and geochemical modifications, without major changes in flow and transport properties. These changes are elastically or hydrologically reversible processes. (2) The EDZ is a zone in which hydromechanical and geochemical modifications induce significant changes in both flow and transport properties. These changes can include an increase in flow permeability of one or more orders of magnitude. These changes represent irreversible deformation involving the creation and propagation of fractures.

Theoretically, it is impossible to define the outer limit of the EdZ, because the disturbance caused by stress redistribution reaches a considerable distance from the created opening. In contrast, the dimensions of the EDZ can be more clearly defined. In the Horonobe URL, P-wave tomography surveys have been conducted at the 250 m gallery, and the EDZ was found to extend less than 1 m into the drift wall [3]. However, the spatial extent of the EdZ at the Horonobe URL has not yet been reported.

During the excavation and operation of the URL, a possible reduction in porosity or compaction of sedimentary rock due to groundwater drainage was predicted by a stress–water coupled analysis [4], and therefore rock permeability is also expected to change. After a closure of the URL, a saturation following backfill is considered as possible future evolutions of the URL [5]. During this post-closure period, reduced pore pressure induced by the URL excavation is expected to recover to its previous level, and then, following possible porosity recovery and permeability recovery to

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http://dx.doi.org/10.1016/j.ijrmms.2014.02.023
1365-1609/

those previous levels are also considered. Although it is considered that the EdZ has no adverse effect on the operational and/or long-term safety of HLW disposal systems, temporal decreases in either pore pressure or permeability may have adverse effects on the groundwater production of the surrounding region. However, the stress–water coupled analysis in the annual report of Nakayama et al. [4] dealt only with a $100 \times 100\ m^2$ area centered around a vertical shaft, and did not consider the temporal variation in hydraulic conductivity. Moreover, the focus of the stress–water coupled analysis [4] was the prediction of ground surface tilt due to both rock excavation and subsequent groundwater drainage, not the compaction of materials or changes in permeability. This means that a discussion of the extent of the EdZ based only on the results of the previous analysis is insufficient. Therefore, site EdZs should be monitored over their entire lifecycles (from construction through post-closure).

In this paper, we investigate the influence of a URL excavation on rock permeability during the URL-excavation period. To reveal the influence during the URL-excavation period, we investigate rock permeability before the URL excavation, and evaluate possible errors involved in making analysis. Then, we estimate permeability change after the start of the URL-excavation.

The analysis of pore-pressure responses to atmospheric loading provides a potential way of producing accurate formation parameter

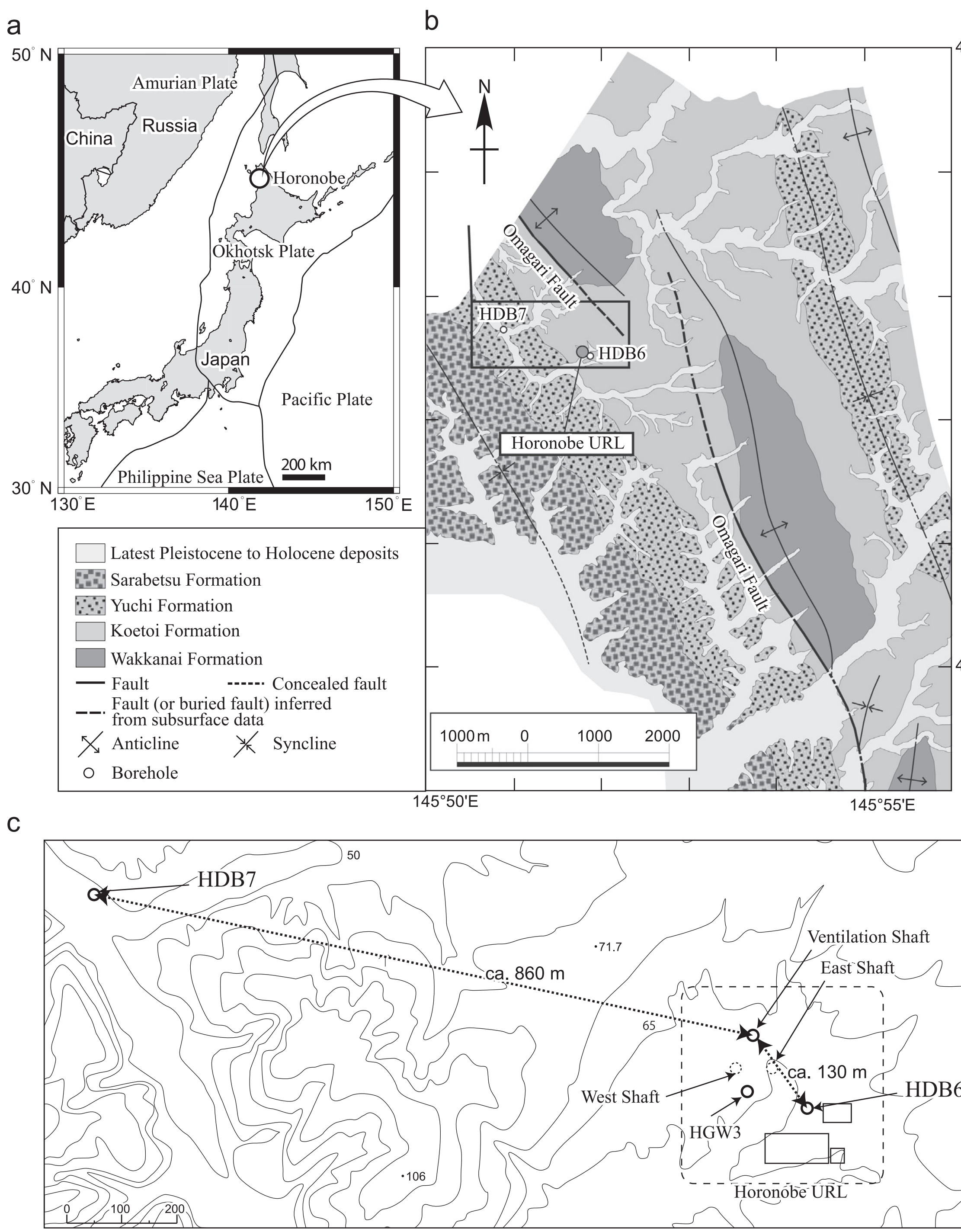


**Fig. 1.** Geological map of Horonobe area (after Ishii et al. [31]), showing the locations of boreholes and the Horonobe URL. Plate boundaries in the map in the upper left area from Wei and Seno [13]. The distance between HDB6, HDB7, and the ventilation shaft are indicated in the magnified map (c).