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Influence of a fault system on rock mass response to shaft excavation in soft sedimentary rock, Horonobe area, northern Japan

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ABSTRACT

This paper focuses on the stress field that produced a fault system in the Horonobe area of Japan, and considers the relationship between the fault system and the rock mass response to shaft excavation in soft sedimentary rocks. In this area, hydraulic fracturing investigations in boreholes and tectonic plate movements indicate that the major horizontal principal stress is oriented E–W; however, during shaft excavation, the greatest convergence in the shaft was oriented NNE–SSW. Therefore, it is necessary to understand the influence of the fault system on the rock mass response to shaft excavation.

We performed a fault-slip analysis of faults in the shaft wall and reconstructed the paleostress field that produced the fault system. The maximum horizontal principal stress was oriented mainly NNE–SSW, and the minimum horizontal principal stress was oriented mainly WNW–ESE. These directions are similar to the directions of maximum and minimum convergence in the shaft, respectively. The results show that a fault system can affect the rock mass response to shaft excavation in soft rock, and it is considered that the rock mass deformation is controlled by the fault system. In addition, it may be possible to assess and predict the rock mass behavior by focusing on paleostress field that produced the fault system.

1. Introduction

An understanding of the rock mass behavior is important for the development and improvement of technology and engineering related to the construction of deep underground facilities, such as those used for radioactive waste disposal, power plants, and petroleum reservoirs.

The Japan Atomic Energy Agency (JAEA) has initiated the Horonobe Underground Research Laboratory Project to understand the characteristics of the geological environment relevant to the disposal of high-level radioactive waste (HLW) in Japan. In the Horonobe area, boreholes HDB-1 to HDB-11, and PB-V01 were sunk and underground facilities (Ventilation and Access Shafts) were excavated in soft sedimentary bedrock, all since 2005.

In general, the rock mass behavior of hard rock is influenced by existing discontinuities such as faults; consequently, an understanding of such discontinuities is important in understanding the rock mass behavior (e.g. [1]). In fact, fault systems have a strong influence on the rock mass behavior (e.g. [2–4]). In addition, numerical analyses have been performed to investigate the rock mass behavior, revealing that an understanding of the fault system is important in terms of resolving debates regarding the rock mass behavior (e.g. [5–7]).

In the case of soft rocks, previous studies have sought to understand the post peak region where the inelastic deformation remarkably occurs (e.g. [1,8]); consequently, few studies have considered the relationship between the rock mass behavior and the fault system in underground excavations such as shafts. However, it is important to address this relationship in order to provide a technical basis for the design and construction of underground facilities for the geological disposal of HLW, because such facilities require a high degree of safety during their construction and operation, and during post-closure period. Given the difficulties encountered in gaining an understanding of a fault system because the faults have a complex geometry, reflecting the complexity of the deformation, it is necessary to develop a better understanding of the characteristics of the fault system.

Recently, Yamaji [9] presented a new method of fault-slip analysis (the multiple inverse method) for heterogeneous fault-slip data. Using this method, it is easy to estimate the paleostress field that led to the formation of the fault system, although the stress magnitudes cannot be estimated. Although, no previous

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study has explicitly considered the relationship between the rock mass behavior and the stress field, a number of studies of tectonics have used this method to estimate the paleostress field that produced the fault systems (e.g. [10–12]).

Knowledge of the paleostress field that controlled the formation of a given fault system may provide clues to the distribution and orientation of faults. If a rock mass deforms under the control of pre-existing fault system, the direction of rock mass response has a direct relationship with the stress field that produced the fault system. Therefore, in the present study, we focused on the paleostress field that produced the fault system, and performed a fault-slip analysis and measured convergence to determine the direction and magnitude of the convergence of a shaft, in order to understand the relationship between the fault system and the rock mass response to excavation of the shaft in soft rock.

2. Geological setting

The Horonobe area is located on the eastern margin of a Neogene to Quaternary sedimentary basin in western north Hokkaido, where an active foreland fold-and-thrust belt developed in the Quaternary near the boundary between the Okhotsk and Amurian plates [13–15]. The sediments in the basin consist of (from old to young) the Wakkanai Formation (siliceous mudstones with opal-CT), to the Koetoi Formation (diatomaceous mudstones with opal-A), to the Yuchi Formation (fine- to medium-grained sandstones), and the Sarabetsu Formation (alternating beds of conglomerate, sandstone and mudstone, intercalated with coal seams), all overlain by late Pleistocene to Holocene deposits (Fig. 1). In the Horonobe area, a map-scale fault, the Omagari Fault, strikes NNW–SSE, generally subparallel to major folds in the area. The Omagari Fault is an oblique fault with reverse dip-slip and sinistral strike-slip components, and possesses an E–W step-over at the surface that possibly converges at depth [16].

The Ventilation Shaft at the Horonobe Underground Research Laboratory (URL), which is located on the west side of the

Fig. 2. Photograph of the roadheader in the Ventilation Shaft.

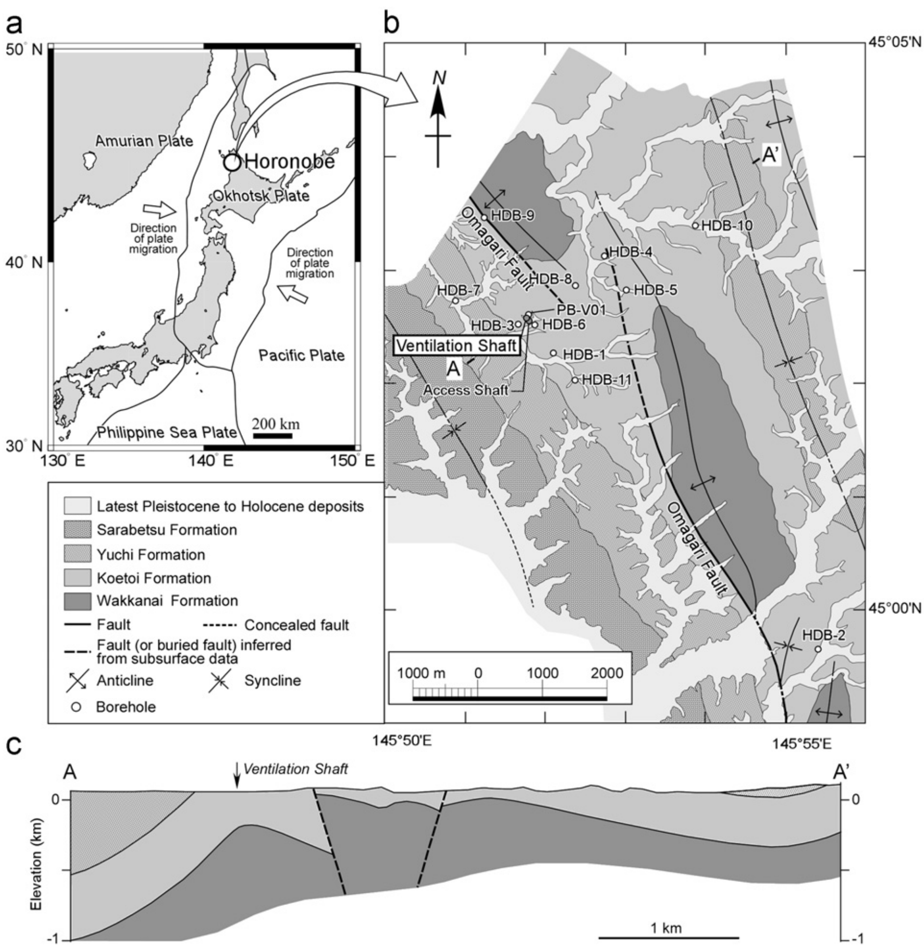

Fig. 1. Location map (a), geological map (b), and geological cross-section (c) of the Horonobe area (after [26]), showing the locations of shafts and boreholes. Plate boundaries and directions of plate movement in the location map are from Wei and Seno [14].