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Geoscientific investigation for the site selection of high-level radiowaste disposal in South Korea

Dae-Sung Cheon(cds@kigam.re.kr)

Dae-Sung Cheon / primary author
Korea Institute of Geoscience and Mineral Resources, Daejeon, South Korea
Kwangmin Jin, You Hong Kihm, Won-Kyong Song, Jae-Yong Park
Korea Institute of Geoscience and Mineral Resources, Daejeon, South Korea

ABSTRACT

According to the 2nd master plan for high-level radioactive waste(HLW) announced by the South Korean government in 2021, the operation of the HLW disposal repository from site selection is planned to be carried out within 37 years. In particular, the site selection was decided within 13 years after the start of the project through a step-by-step process like other countries. Unlike Northern Europe such as Sweden and Finland, where crystalline rocks are the main composition, South Korea has various rock types similar to Switzerland. The Korea Institute of Geoscience and Mineral Resources published 8 types of geoenvironmental information maps, including rock types, lineament, faults, and geothermals etc., which can be used in the national screening stage. Geoscientific researches are being conducted for each rock type in consideration of the distribution area of rock types in the South Korea obtained from the geoenvironmental information map. Considering the depth of HLW disposal repository, drillings are performed at a depth of 750 m according to the rock types, and evaluation parameters for each research field used in basic and detailed investigations are obtained. Investigations using deep boreholes, which began in 2020, were conducted in granite, sedimentary rocks including mudstone and sandstone, and gneiss. Another investigation is planned for volcanic rocks next year. The evaluation parameters obtained during the geoscientific investigation include geological parameters such as lithology, joint and fault, hydraulic parameters such as hydraulic conductivity and storage coefficient, geochemical parameters such as hydrochemistry, sorption and nuclides, and geothermal parameters such as thermal conductivity and geothermal gradient. There are also mechanical parameters such as strength, and in-situ stress. These data are expected to be used as basic data for site selection for HLW disposal in Korea in the future.

KEYWORDS

high-level radiowaste(HLW); geoenvironmental information; site selection; evaluation parameter; rock type

1. INTRODUCTION

Since Kori nuclear power plant unit 1 started commercial operation in 1978, South Korea has operated a total of 25 nuclear power plants as of May 2017. As Kori unit 1 in June 2017 and Wolseong unit 1 in December 2019 entered the permanent shutdown phase, a total of 25 nuclear power plants are operating as of December 2022. Disposal of spent nuclear fuel generated from the operation of nuclear power plants is an important factor that must be considered indispensably in nuclear power generation, and a total of 504,809 bundles occurred by the third quarter of 2021. Considering the capacity of temporary storage facilities in power plants, discussions on interim storage or permanent disposal are inevitable as it is expected to be saturated sequentially starting with the Hanbit nuclear power plant in 2031.

According to the Korean government's second master plan for high-level radioactive waste (Figure.1), it aims to secure permanent disposal facilities within 37 years after the start of the site selection procedure, and to select sites for 13 years after establishing an investigation plan. Site selection for the deep geological disposal of high-level radioactive waste is considering a step-by-step approach worldwide, and South Korea also has a 3-step site selection procedure: exclusion of unsuitable areas, basic investigation, and detailed investigation, along with social consensus such as resident opinions and referendum for site.

This paper deals with the 8 types of geoenvironmental information maps that are expected to be used in the first stage of site selection and the geoscientific investigation according to the types of rocks required in the second and third stages.

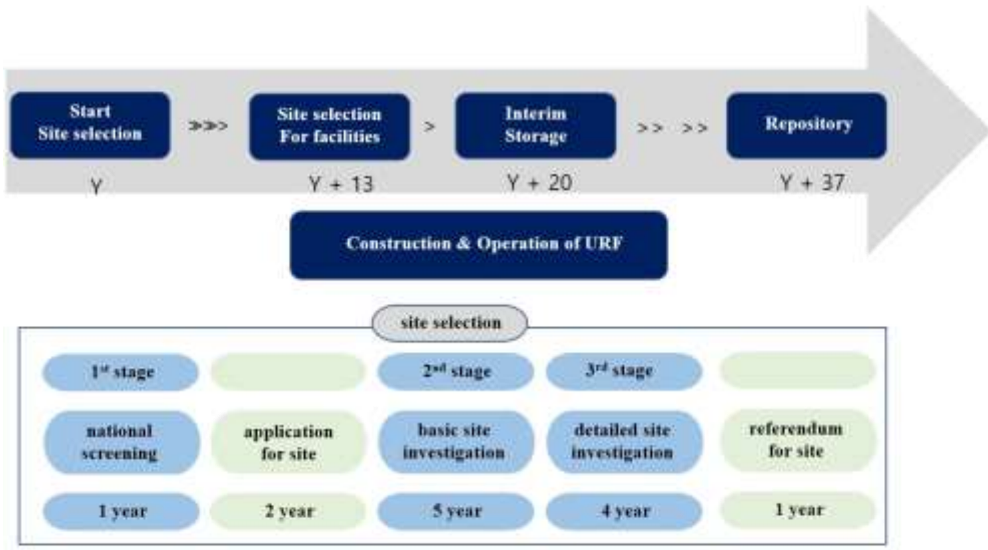


Figure 1. Site selection procedure in 2nd master plan for HLW management in South Korea.

2. NATIONWIDE GEOENVIRONMENTAL INFORMATION MAP

The Japanese government published a scientific feature map (Figure 2) in 2017 to promote public understanding the geological disposal of high-level radioactive waste. The “Scientific Features Map” is a rough view of what scientific characteristics need to be considered when determining geological disposal areas and how scientific characteristic values are distributed throughout Japan. Detailed maps can be checked on the NUMO(Nuclear Waste Management Organization of Japan) website, and individual geoenvironmental information maps were prepared for each criterion. These maps include volcanic activity, fault activity, uplift and erosion, geothermal activity, and mineral resources etc.

The Korea Institute of Geoscience and Mineral Resources(KIGAM), Korea's national research institute on geology and resources, comprehensively analyzed the items used by leading countries in high-level radioactive waste disposal projects when reviewing exclusion areas at the national level. Afterwards, considering the situation of Korea, geovironmental information maps were produced for all eight items, including rock types, mineral deposits, lineaments, faults, earthquakes, uplift, groundwater, and geothermal properties. Figure 3 presents an example of the geoenvironmental information map produced.

Since each rock type has different geological, thermal, and mechanical characteristics, the HLW disposal system is determined according to the rock type, and it is a very important item in site selection (Kim et al., 2020). Using the geological map(1:50K geological map, 1:250K geological map, 1:250K 1st integrated & harmonized geological map) published by the KIGAM, a 1:25K harmonized geological map(Figure 3 left) was produced through data integration and verification processes and investigation of boundary mismatched areas.

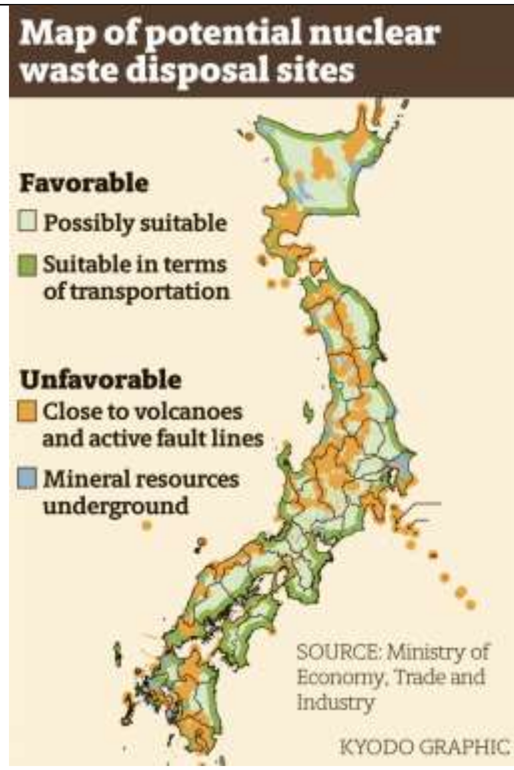


Figure 2. Nationwide map of 'Scientific features' relevant for geological disposal in Japan(www.numo.jp).

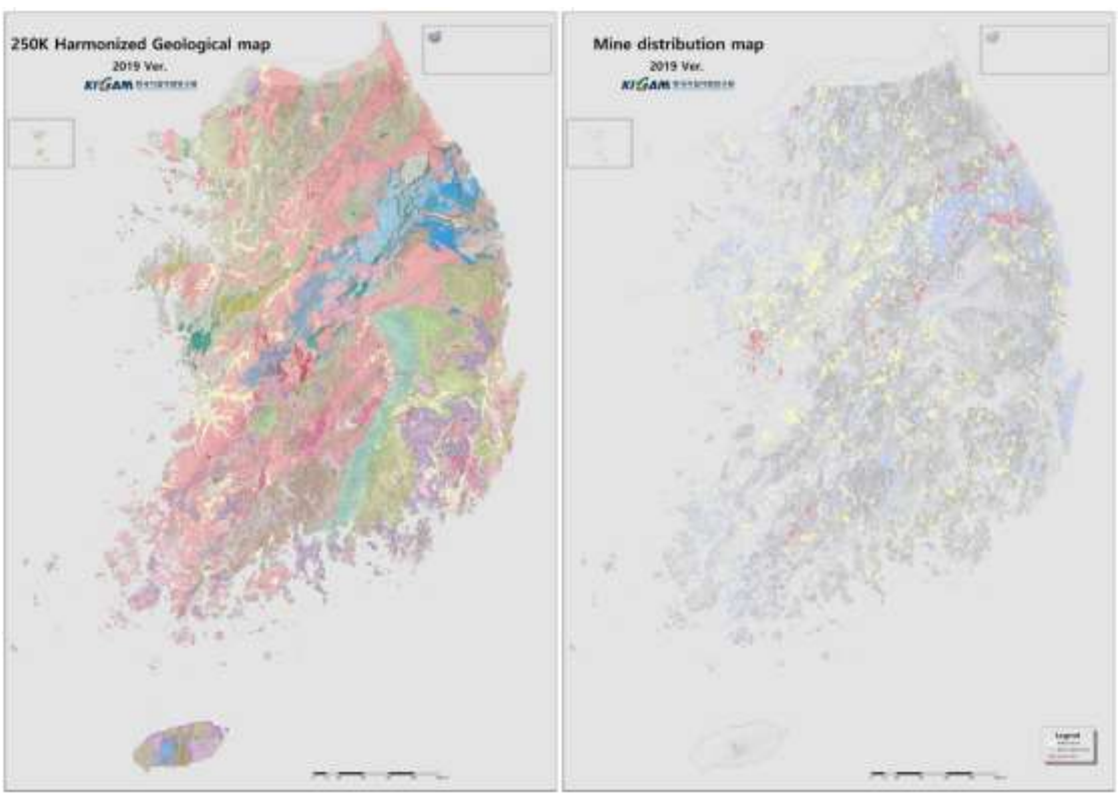


Figure 3. Examples of geoenvironmental information maps in South Korea(left: 250K harmonized geological map, right: mine distribution map, KIGAM 2019).

At least 100,000 years, the disposal period of high-level radioactive waste, is a very long time. The location of the previously developed mine is one of the important evaluation items because it is possible to search for useful deposits and excavate for mining in the high-level radioactive waste disposal facility in the future due to loss of information on the disposal site or other reasons. The mine distribution map(Figure 3 right) was produced through mutual verification using the data of Korea Mineral Resources Corporation, Korea Mine Reclamation Corporation, and KIGAM, which have mine information.

In the same way as above, the geoenvironmental information map for lineaments, faults, earthquake, uplift/subsidence, hydraulic conductivity, and geothermal was published in 2019.

When preparing the geoenvironmental information maps, a verification system (named GIVES) for the history and verification of data was produced together, and it was made accessible to the public through web services. Figures 4 presents an example of the overall flow of geoenvironmental information and verification system.

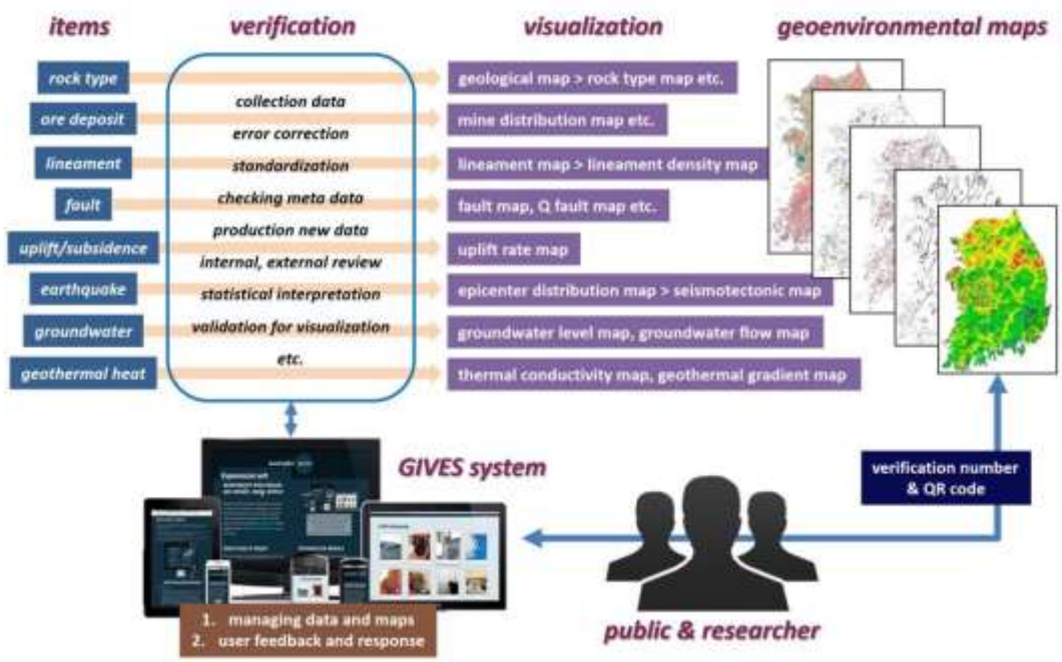


Figure 4. Overview of the nationwide geoenvironmental information maps and verification system (KIGAM, 2019).

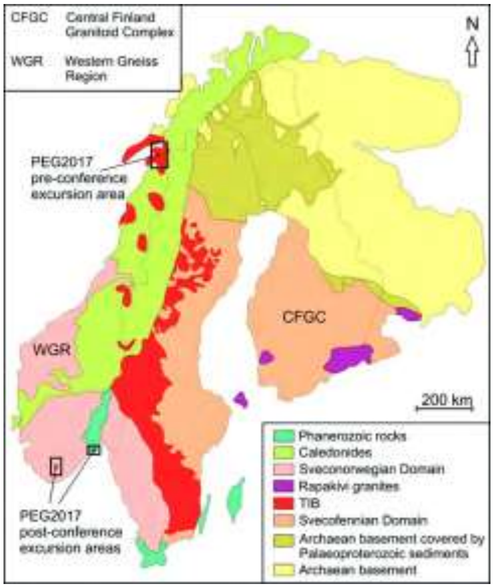
3. GEOLOGICAL ENVRIONMENT OF SOUTH KOREA

For the safe geological disposal of high-level radioactive waste, it is very important to determine a disposal system suitable for the geological environment of South Korea. The most basic matter in determining the disposal system is the disposing host rock. This is because the disposal system is determined according to the disposing host rock type. Table 1 briefly presents the geological distribution of some countries and the disposing host rocks determined by them in the field of geological disposal of high-level radioactive waste.

Table 1. HLW disposing rock type and geological distribution in some countries.

	Determined disposing rock type	Major geological distribution
Finland	Crystalline rock	Crystalline rock
Sweden	Crystalline rock	Crystalline rock
Switzerland	Sedimentary rock	Crystalline rock/ Sedimentary rock
France	Sedimentary rock	Crystalline rock/ Sedimentary rock
South Korea	Not yet	Crystalline rock/ Sedimentary rock

Sweden and Finland used the KBS-3 system, which relies on multi-barriers for a crystalline rock as disposing host rock, while Switzerland determined a sedimentary rock as disposing host rock and developed a disposal system that relies on natural barriers. Unlike Sweden and Finland, the reason for the difference in the disposal system proposed by Switzerland and others is that it takes into account the local disposal environment, that is, geological characteristics. As can be seen from Figure 5, Sweden and Finland are mostly composed of crystalline rocks, while the geological distribution (Figure 6) in Switzerland is not only crystalline rocks, but also various types of rocks such as mudstone and sandstone.



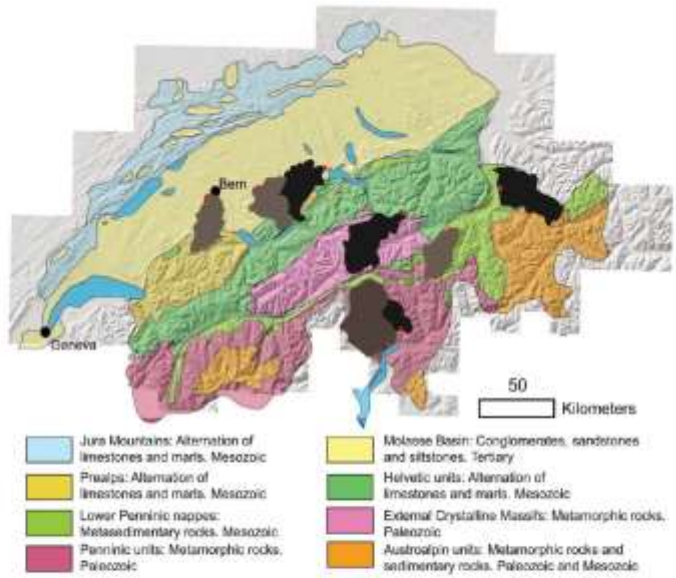


Figure 5. Generalized geological map of Scandinavia (Müller et al., 2017).

Figure 6. Simplified geological map of Switzerland (Litty and Schlunegger, 2017).

South Korea's geological environment is composed of complex geology such as those in Switzerland and France rather than Northern Europe, and no decision has been made on disposing host rock. Distributed rock types in South Korea are largely classified into the Precambrian metamorphic rock complex, Paleozoic sedimentary rocks, Mesozoic granite, and Cenozoic igneous rocks. Figure 7 presents the distribution area by rock type and era by classifying the rock types distributed in Korea based on the 250K harmonized geological information map published in 2019. Plutonic and metamorphic rocks occupy the largest area, each accounting for 30%, followed by sedimentary rocks, accounting for 25%.

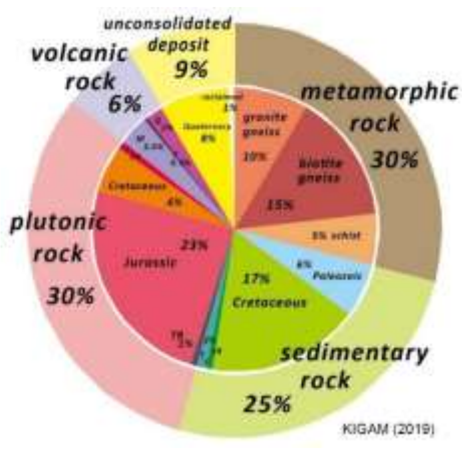


Figure 7. Rock distribution area in Korea by rock types and era(KIGAM, 2019).

The tectonic characteristics of the Korean Peninsula are located on the eastern edge of the Eurasian plate, and the tectonic structure is largely divided into the Gyeonggi massif, Yeongnam massif, Okcheon belt, and Gyeongsang basin (Kim et al., 2008; KIGAM, 2010; Cheong and Kim, 2012).

4. GEOSCIENTIFIC INVESTIGATION CONSIDERING TECTONIC STURCUTRE AND ROCK TYPE

Deep geological disposal facilities for high-level radioactive waste are generally assumed to be built at a depth of 300 to 500 m from the surface. Considering these target depths, at least 500 m deep drilling should be performed, and deep drilling at least 1 km corresponding to twice the disposal depth is recommended for modeling.

Deep drilling in South Korea is being carried out in various fields for the purposes of CCUS, geothermal energy, and seismic activity monitoring, in addition to the purpose of radioactive waste disposal. Depending on the purpose of drilling, there may be some differences in tests or methods performed during(or while) or after drilling, but there is no more certain way than drilling to identify the characteristics of deep rocks. Among them, only about 10 deep drilling drills were conducted for the purpose of disposing of high-level radioactive waste, mostly in crystalline rocks such as Goseong in Gangwon province, Yuseong in Daejeon city, and Andong city in Gyeongbuk province. As mentioned above, in order to determine the disposing host rock, it is essential to first understand the various rock types in Korea. This is because hydrological, geochemical, mechanical, and thermal characteristics, along with geological characteristics, appear differently depending on the type of rock.

Recently, KIGAM has been conducting more than two deep drilling every year since 2020 to investigate the characteristics of deep rock for the deep geological disposal of high-level radioactive waste. Table 2 summarizes the drilling status and plans for the deep geological disposal of high-level radioactive waste.

Table 2. Deep Drillings for HLW related purpose performed or planned according to tectonic structures and rock types(updated from Cheon et al., 2022).

	Gyeonggi massif	Okcheon belt	Yeongnam massif	Gyeongsang basin
Plutonic rock (Granite)	Chuncehon (1 hole) Goseong (2 holes) Goseong (planned)	Daejeon (7 holes) Wonju (1 hole)	NA	NA
Sedimentary rock (Mudstone)	NA	NA	NA	Daegu (1 hole) Jinju (1 hole) Changwon (1 hole)
Metamorphic rock (Gneiss)	Hongcheon(1 hole)	NA	Andong (2 holes) Taebaek (planned)	NA
Volcanic rock	NA	Mokpo (planned)		Tongyeong(planned)

In accordance with Kim et al. (2020), which suggested evaluation parameters for each step and field for site selection, major evaluation parameters that should be obtained first were selected and obtained through deep drilling in the selected area according to tectonic structure and rock type. In the field of geology, rock phase, fault, uplift rate, etc. are the key evaluation parameters. In the field of rock mechanics, uniaxial compressive strength, in-situ stress, joint distribution and rock mass classification are considered. In geochemistry, components, adsorption capacity, isotopes, etc. In the field of geophysical exploration, physical properties and discontinuities were selected, and in the field of geothermal thermal conductivity and geothermal gradient, etc. were selected. Figure 8 schematic presents the major evaluation parameters acquired by the different fields in the process of investigating the characteristics of deep bedrock.

Figure 8. Major evaluation parameters in the multidisciplinary fields for HLW geological disposal (KIGAM, 2021).

The drilling location was selected based on data such as geologic characteristics and era after identifying tectonic structure, distributed rock type, literature & surface geological survey, and lineament etc. The deep borehole investigation process is shown in Figure 9.

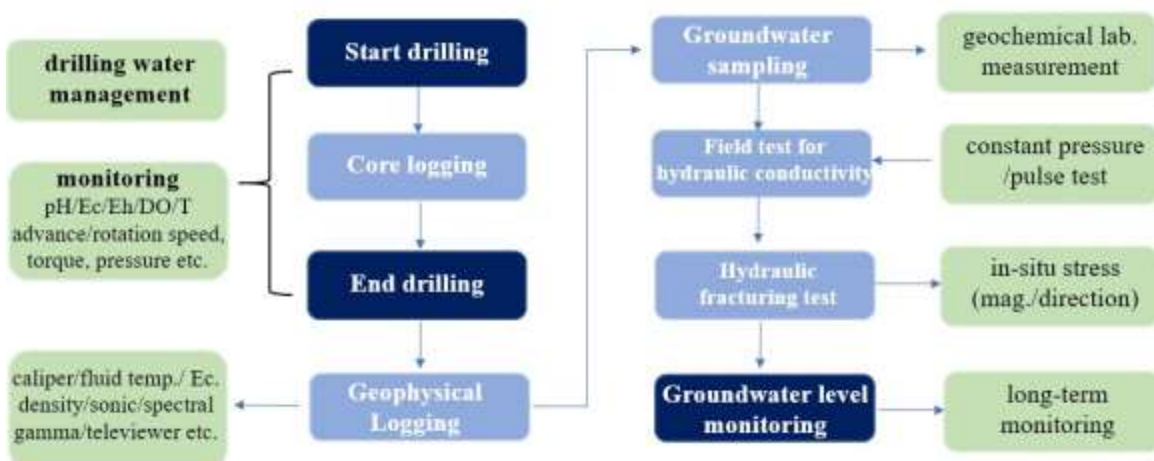


Figure 9. Deep borehole investigation and field tests process (Cheon et al., 2022).

While drilling, thrust and torque were monitored to understand the drilling conditions and mechanical characteristics according to the depth and bedrock, and the hydrogeological and geochemical effects were minimized by using a closed circulating water system. In addition, by dissolving a certain concentration of uranine in circulating water, the uranine concentration changes according to the depth, as well as hydrogen ion concentration (pH), electrical conductivity (Ec), dissolved oxygen concentration (DO), oxidation-reduction potential (Eh), temperature (T) etc. characteristics were monitored.

After drilling was completed, geophysical logging such as caliper logging, temperature-electrical conductivity logging, density logging, sonic logging, spectral gamma logging, acoustic televiewer etc. were performed to obtain rock properties according to the depth. Afterwards, geochemical analysis was performed using groundwater collected from boreholes to analyze geochemical characteristics in a specific section. In order to investigate hydraulic conductivity, hydraulic field tests using constant pressure test or pulse test were performed, and hydraulic fracturing tests were performed to determine the magnitude and direction of in-situ stress according to the depth.

Using the core recovered from the borehole, geochemical, geotechnical, mechanical, and hydrogeological characteristics were analyzed along with geological analysis such as drill log and structural geological characteristics including geological dating. For the intact rock, an analysis was performed for the thermal properties along with the mechanical properties.

This section introduces the case of a in-situ stress characteristic survey belonging to the field of rock mechanics among multidisciplinary investigations of deep bedrock. In-situ stress is also suggested as an important evaluation parameter necessary for site selection for the geological disposal of high-level radioactive waste in South Korea (Choi et al., 2017; Kim et al., 2020; Choi et al., 2020; Choi et al., 2021; Cheon et al., 2022). In-situ stress is estimated by hydraulic fracturing or overcoring methods, or by using fault or seismic mechanism.

According to the In-situ stress obtained with the depth at the disposal site in Finland or Sweden (Figure 9), even in the same area it was shown that magnitude and orientation of in-situ stress can change severely with the depth depending on the used method and geological structure.

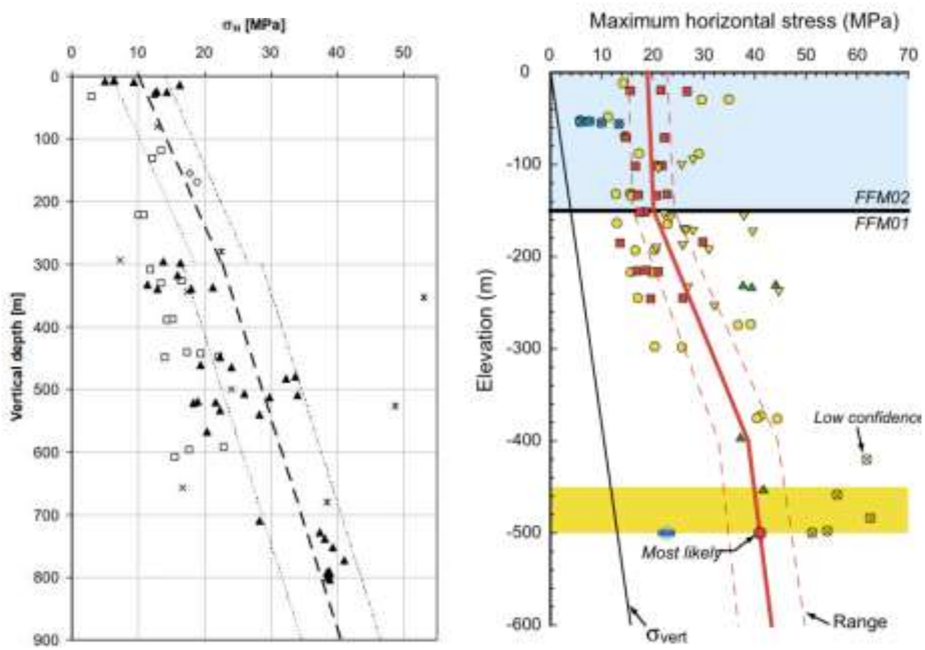


Figure 9. In-situ stress field model (left: Olkiluoto in Finland (Posiva, 2009), right: Forsmark in Sweden(SKB, 2007)).

The Korean stress map was published from field in-situ stress data conducted in Korea for the past 40 years (Kim et al. (2020)). The data used in the Korea stress map are obtained at a depth of less than 1 km underground. There are many data at a shallow depth above about 300 m, but relatively few at a depth below 300 m, which is considered a target depth for the geological disposal of high-level radioactive waste.

Considering that changes in in-situ stress may occur differently depending on the depth and that there is no experience in deep depth as an overcoring method in South Korea, the in-situ stresses were measured using a deep-depth hydraulic fracturing test system owned by KIGAM. The in-situ stresses were obtained by performing tests at more than 20 points for a 750 m test section using the HF (Hydraulic Fracturing) and HTPF (Hydraulic Testing of Pre-existing Fractures) methods. Figure 10 presents the magnitude of in-situ stress obtained in the Wonju area and Chuncheon area(rock type: granite) belonging to the tectonic structure of the Okcheon belt and Gyeonggi Massif, respectively. The trend of vertical stress, maximum horizontal stress, and minimum horizontal stress can be seen with depth, but as described above, it can be seen that the magnitude of the maximum horizontal stress may appear differently depending on some depth.

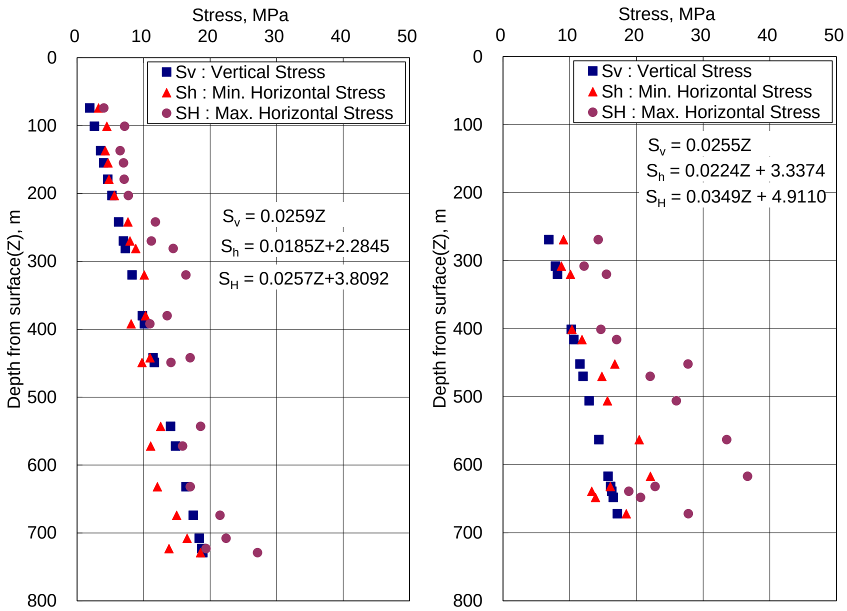


Figure 10. Magnitude and direction of in-situ stress in Wonju(left) and Chuncheon(right) area.

5. SUMMARY

The first step in deep geological disposal of high-level radioactive waste is the initiation of the site selection process. The site selection process begins with the establishment of a survey plan and the exclusion of unsuitable areas. For this purpose, geological data that can discriminate the exclusion and preference conditions on a nationwide scale must be the basis. Eight types of Korea's geoenvironmental information maps published by KIGAM in 2019 are expected to provide basic data for site selection like those of advanced countries.

This paper briefly introduced the 750 m deep drilling and related geoscientific investigations in order to obtain geoscientific evaluation parameters in relation to the deep geological disposal of high-level radioactive waste. The current deep drilling was selected in consideration of the South Korean policies and distribution of rock type, which had already been performed in 16 areas classified according to tectonic structure and type. In relation to the basic specifications for investigation research through deep drilling, drilling general, drilling circulation water management, measurement during drilling, and core management after drilling were presented. In addition, the contents and some results of multidisciplinary geoscientific investigations using deep boreholes were presented as examples. Multidisciplinary geoscientific investigations briefly introduced drill log reflecting geology and mechanical characteristics, geophysical logging to determine continuous physical characteristics, groundwater sampling to determine hydrochemical characteristics, constant pressure test to determine hydraulic conductivity, and in situ stress estimation. Evaluation parameters, that are considered important in site investigation or selection and must be obtained, are acquired and analyzed through the drilling process. It also is expected that analysis and research on specific methods and results for each field, as well as differences in characteristics according to rock type etc. can be utilized in site investigation, site selection, and generic URL construction for deep geological disposal of high-level radioactive waste in South Korea.

6. ACKNOWLEDGEMENTS

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