Consideration of the Possibility of Deep Borehole Disposal in Japan

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1. Introduction and current Japanese situation with respect to the selection of high level radioactive waste disposal sites

Over the past several decades, Japan has chosen to rely extensively on nuclear power for its electricity supply, and has sought to develop a nuclear fuel recycling option. At present (as of early 2013), a national discussion on Japan's future energy sector plans is underway, including reconsideration of how "well-balanced energy supplies" for Japan should be configured. This reconsideration is being undertaken in recognition that the present Japanese energy system may need to be modified to avoid possible risks from accidents at nuclear power plants. This consideration is one of the consequences of the March 11, 2011, earthquake and accompanying tsunami that devastated the eastern coast of the northeast Japan and caused serious problems for the nuclear power plants in Fukushima prefecture.

Japan has conducted a research and development program related to the disposal of high-level radioactive waste. The following description is a summary based on Masuda (2003). Starting with a research and development program in 1976, the intensive development of a high-level radioactive waste disposal program based on the use of generic technologies and sites has been undertaken for more than three decades.

One important milestone of Japanese research on nuclear waste disposal was the issuing of what was called the second progress report, referred to as H12 (JNC, 2000), which examined a multi-barrier system with a mined repository as a disposal concept. Based on the technical achievements outlined in H12, the Japanese government promulgated a law named the "Specified Radioactive Waste Final Disposal Act" and through this law established the implementing organization, Nuclear Waste Management Organization of Japan (NUMO) in October, 2000. NUMO worked to clarify the scientific and technical basis for siting of disposal facilities, specified the regulatory processes for such sites, and provided a summary "Information Package for Volunteer Site" in December 2002 (NUMO, 2002). This package was sent to all 3,239 municipalities and other relevant organizations in Japan as the start of an open solicitation process for selecting disposal sites. The December 2002 documents stated that all municipalities have a right to apply to the open solicitation, for which no application deadline was set at the time. As of this writing, the solicitation remains open and no final deadline for submission has been set.

The first step of the process of placing an application as a volunteer site is for a municipality to accept the preparation of a survey of existing literature as a means of making an initial judgment as to whether the site would be problematic as a host of a disposal site. Since the start of the open solicitation, the following reactions were observed. The first voice to express an interest in being a volunteer site came from the Izumi Village, Fukui Prefecture, on April 2003. Since then, eight additional municipalities expressed their interest. Six municipalities of the original nine, however, decided to call off further consideration as soon as the local newspapers exposed their interest in hosting a high-level waste repository. All of the mayors of these municipalities commented that they lacked the confidence to answer growing public concerns over the safety of siting a nuclear waste repository in their local communities. Also, most governors of the prefectures in which the municipalities were located persuaded the mayors of local municipalities to give up on consideration of hosting a repository. The mayors of the two remaining municipalities out of three consulted with their town councils about the possibility of circulating petitions to their constituents asking for their views on hosting a repository, but plans for circulating petitions were dismissed as a result town council deliberation. Only Toyo town in Kochi prefecture formally applied to NUMO for a literature survey, which is the first step for the site selection process. The mayor of the Toyo town was recalled because of the application, and the decision of the subsequently elected new mayor resulted in the withdrawal of the application. Since then, no active reaction to NUMO's Package has been observed among potential host communities in Japan.

2. The deep borehole disposal concept as an alternative to mined repositories

The deep borehole disposal concept for nuclear spent fuel and high-level nuclear wastes is summarized in SKB (2010). Based on the SKB (2010) report, the concept entails the drilling of a number of boreholes vertically from the ground surface down to great depth, approximately 5 km, into bedrock (see Figure 1). Canisters containing radioactive materials to be disposed of are then lowered into the holes and stacked on top of one another (see Figure 2). Emplacement of the canisters is expected to be at a depth of between two and four kilometers in the boreholes. The canisters are surrounded by a buffer material consisting of a mixture of bentonite—a clay mineral—and a deployment mud. Highly compacted bentonite is placed between the canisters as the canisters are placed. The upper two kilometers of the borehole is sealed with a combination of bentonite, asphalt and concrete. Figure 2 shows a schematic illustration of the concept.

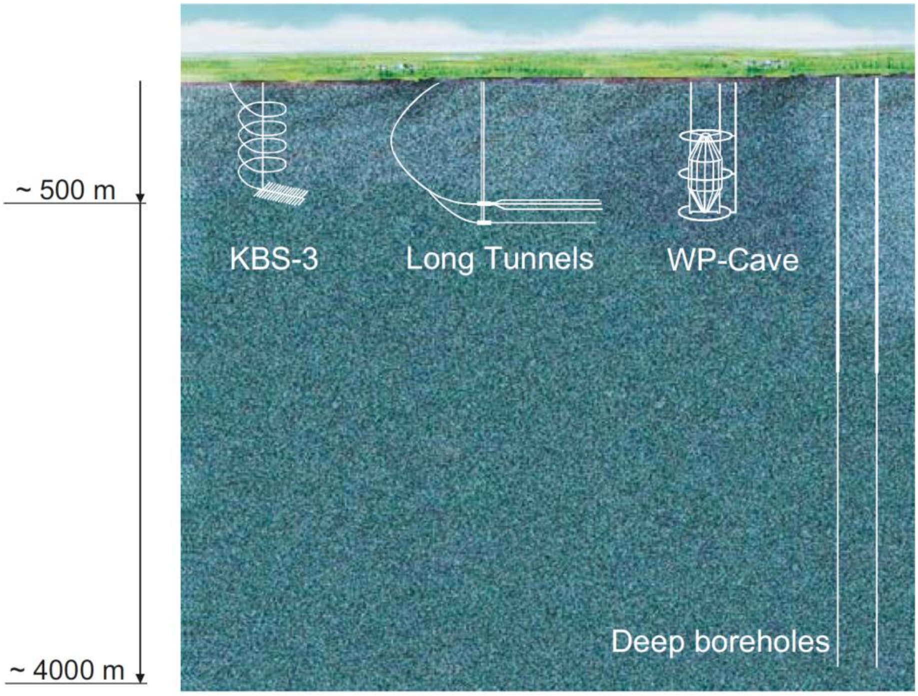

Figure.1. Possible options for geologic disposal discussed by SKB (2010).

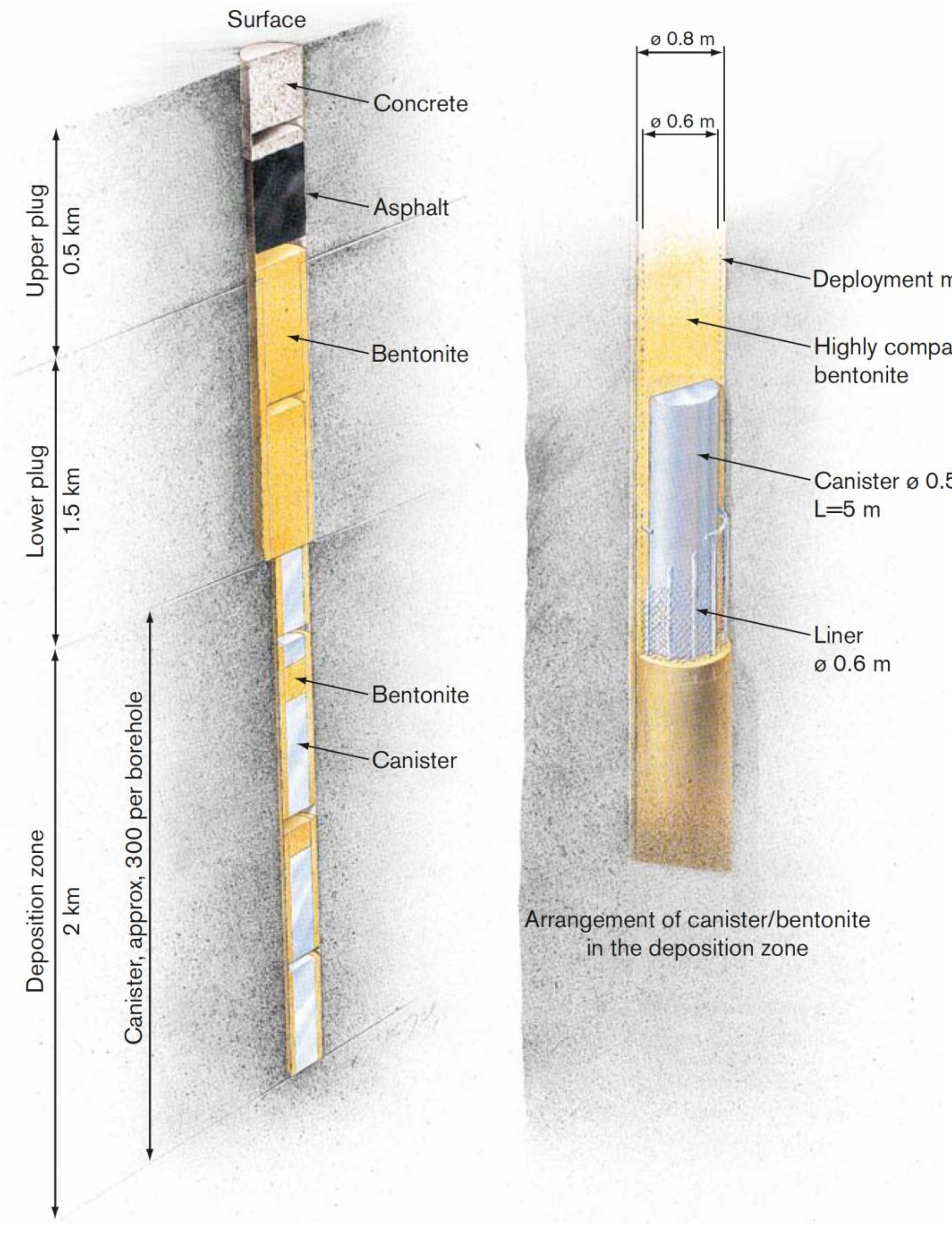

Figure 2. Schematic design for disposal in deep boreholes (SKB, 2010).

SKB (2010) discussed the pros and cons of deep borehole disposal. Based on SKB (2010), the possible advantages of the deep borehole disposal include better protection against human intrusion and diversion of nuclear materials because of the great depth of disposal. Also, groundwater movement is expected to be slow at disposal depths, due to typically stagnant groundwater conditions in the deep geosphere in many continental settings; this lack of groundwater movement is considered to be the main safety feature of the deep borehole disposal concept. Challenges for this concept are, firstly, very little is known about the geological, hydrological and geochemical conditions at the disposal depths being considered. With regard to this challenge, site investigation to learn more about conditions at depth will be very difficult. In addition, the possibility of aggressive environments at disposal depths, for example, high temperature and high concentrations of dissolved components in groundwater, makes the long-term behavior of engineered barrier systems uncertain.

Deep borehole studies have been conducted in several countries, including the United Kingdom (Beswick, 2008; Baldwin et al., 2008), Canada (Jackson and Dormuth, 2008), and the United States of America (Brady et al., 2009). No study related to the deep borehole concept for disposal of nuclear materials has, however, been conducted in Japan, insofar as the author is aware.

3. Deep drilling experience in Japan

In Japan, several deep drilling activities have been conducted. These include wells drilled for oil and gas exploration, monitoring of seismic activities, and geothermal and hot spring exploration. As of year 2010, eighty five exploration wells had been drilled by METI/JOGMEC (Ministry of Economy, Trade and Industry/Japan Oil, Gas and Metals National Corporation) (Japan Natural Gas Association, 2012). Among them, fifty eight wells were drilled on shore and twenty seven offshore. The total number of wells drilled to date for oil and gas exploration in Japan is 1,620 (Japan Natural Gas Association, 2012). Some of these wells are up to 6 km in depth, and the majority of the wells are, or were, situated in petroliferous sedimentary rocks (see Figure 3).

Since the early 1970s, NIED (the National Research Institute for Earth Science and Disaster Prevention) has drilled boreholes for monitoring seismic activities. Among them, two boreholes were drilled deeper than 3 km, eleven boreholes were drilled to depths between 2 and 3 km, and sixteen boreholes were drilled to between 1 and 2 km (NIED homepage). Figure 4 shows an example of the characteristics of one of deeper boreholes drilled by NIED (Suzuki et al., 1981). The total depth (TD) of this borehole is 3,510 m, and the diameters of the boreholes are 12 1/4’’ from 0 to 2,599 m, and 8 5/8’’ from 2,599 m to the bottom of the borehole.

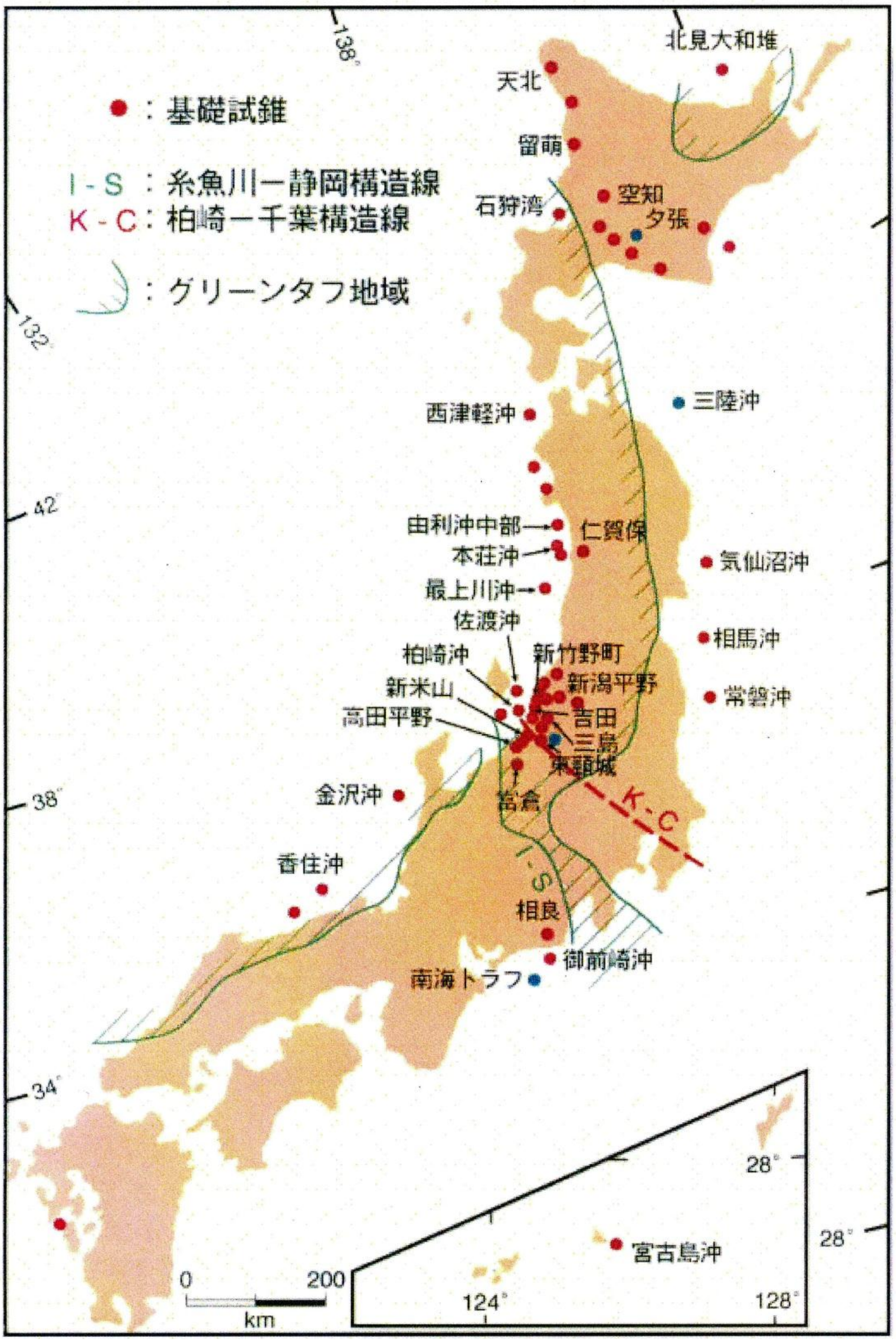

Figure 3. Location map of exploration wells drilled by METI/JOGMEC (RIST (Research Organization for Information Science and Technology) Homepage, http://www.rist.or.jp/atomica/data/pict/01/01030203/02.gif). Red dots indicate the locations of the exploration wells. I-S indicates the Itoigawa Shizuoka tectonic line. K-C indicates the Kashiwazaki Chiba tectonic line. The green hatching denotes the area where what is called “green tuff” rocks are distributed.

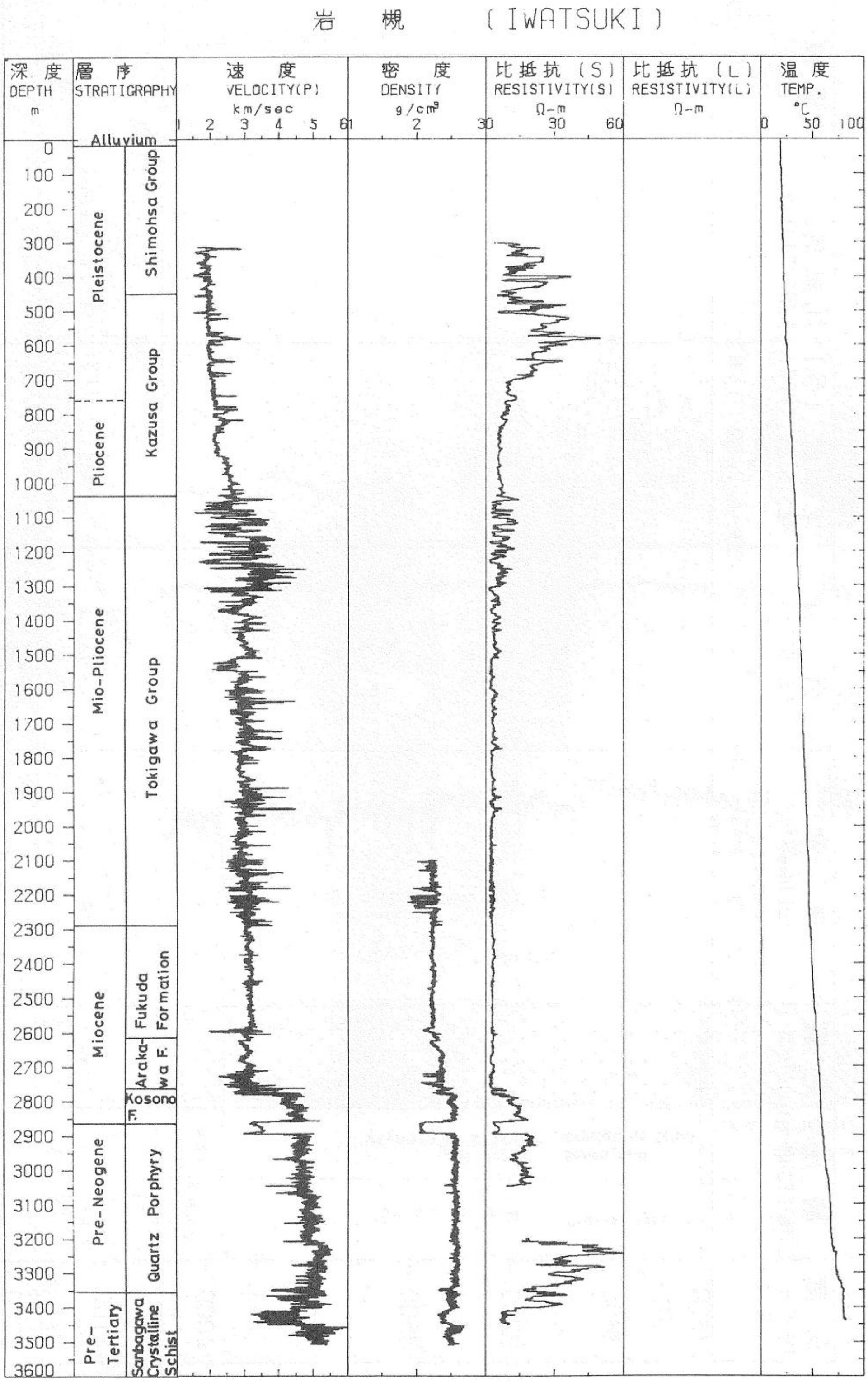

図3−1−B　岩槻孔井検層図　　Fig. 3−1−B　Well log (Iwatsuki).

Figure 4. Well log of the borehole for the Iwatsuki seismic monitoring station run by NIED (Suzuki et al., 1981).

Exploration to assess geothermal energy resources and identify hot springs is active in Japan. To date, however, the author has been unable to obtain quantitative information related to these exploration activities.

4. Characteristics of the geological situation in Japan related to the deep borehole disposal concept

4.1 General setting of Japan and its surroundings

As is well understood, Japan is located at a complicated tectonic setting caused by the convergence of four geologic plates (see Figure 5). Because of this situation, fairly active tectonic processes such as earthquakes and volcanic eruptions occur frequently, and Japan's geology is considered to be complex (see Figure 6).

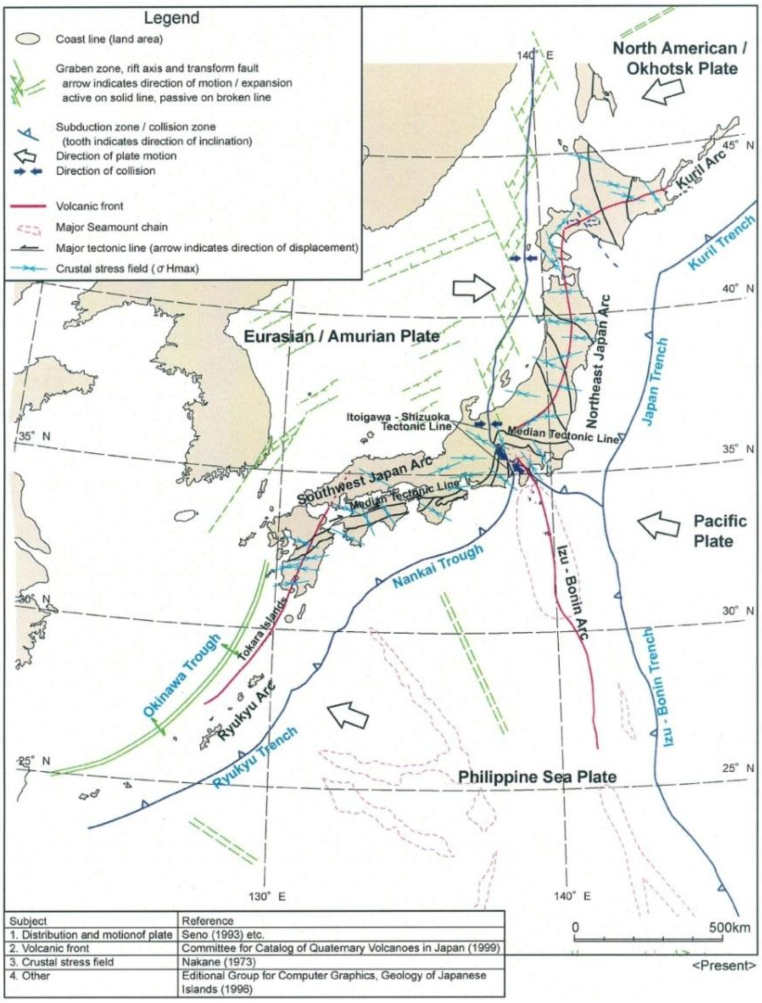

Figure 5. Generalized tectonic setting around Japan (NUMO, 2004).

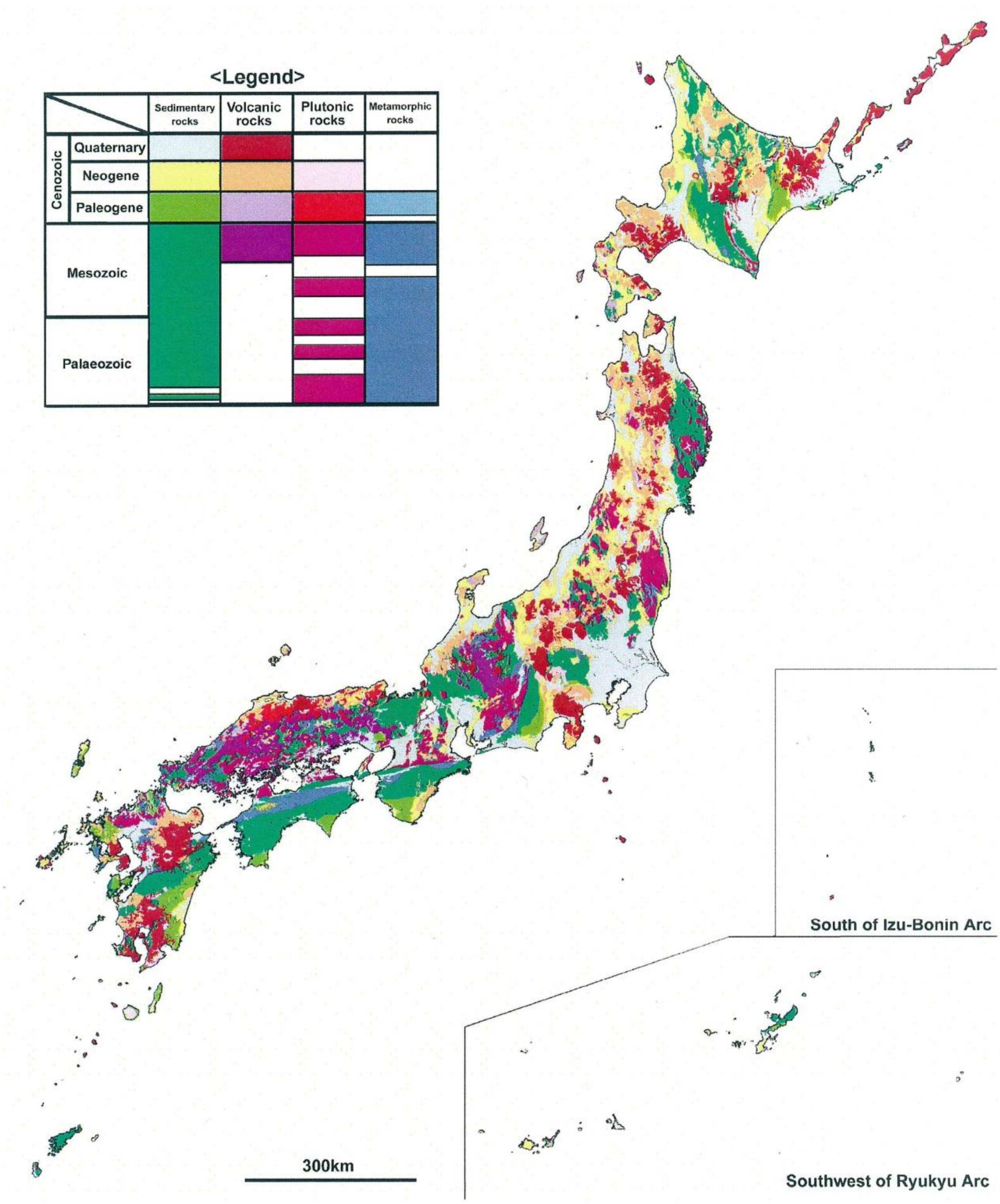

Figure 6. Geologic sketch map of Japan (NUMO, 2004).

Even though the geology of Japan is known to be very complex, the spatial distribution of geological bodies has been fully described in detail, especially near the surface (as shown in Figure 6).

4.2. Existence of deep-seated fluid and its significance

Recently, research related to the hydrology of deep geological bodies and its effect on tectonics and earthquake occurrence has been carried out. Hasegawa et al. (2012) summarized the present understanding of the relationship between deep-fluids and inland earthquakes. Hasegawa et al. explained that the concentrated flow of fluid from the mantle wedge and its accumulation in the lower crust reduces the strength of the lower crust, making these fluids one of the causes of inland earthquakes. Figure 7 provides a schematic showing overpressured areas distributed along the fault planes of the Niigata Chuetsu, where a major earthquake and large aftershocks occurred in year 2004 (Sibson, 2007). In addition, Matsushiro earthquake swarms have been interpreted to be caused by the upwelling of deep-seated overpressured saline fluids (e.g., Mogi, 1988). Other examples of the migration of deep-seated fluids to the surface were shown in the analysis of sediments obtained from a mud volcano located in Niigata Prefecture, and in the helium isotopic study of hot spring water. The former example suggested that mud that had originated from a depth of 3 to 4 km was brought up to the surface by “eruption” of the remobilized mud with natural gas (Shinya and Tanaka, 2009), and the latter study suggested that the gas signature in hot spring water showed that the gas was derived from the earth’s mantle, that is, well below the depth proposed for deep borehole disposal (see, for example, Sano and Wakita, 1985).

As already mentioned in section 2 of this paper, one of the main safety features expected for deep borehole disposal is dependent on the existence of stagnant groundwater conditions at the depths considered for materials disposal. In typical continental settings, stagnant groundwater conditions are highly likely because of the low topographic reliefs and the increase of groundwater salinity as a function of depth. The former condition yields a quite small topographically-driven component to the hydraulic gradient, and the latter suggests an expectation of gravitational stability of groundwater at disposal depths such that deep groundwater is unlikely to mix significantly with groundwater coming into contact with the biosphere. However, as discussed in this section, there exists significant geological evidence suggesting incidences of upward migrations of deep-seated fluid in the islands of Japan. Considering the existence of a variety of evidence that deep-seated fluid could migrate up to the surface, further study is considered necessary to accumulate knowledge of ultra-deep geological environments in Japan before deep borehole or similar disposal can be undertaken.

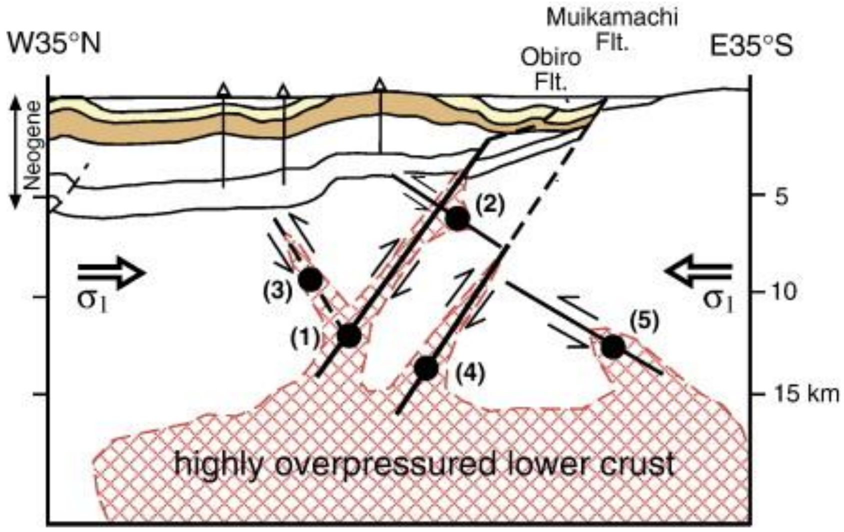

Figure 7. Schematic figure showing the distribution of highly overpressured fluid in the lower crust and its relation to the hypocenters of the Chuetsu earthquake and its large aftershocks (Sibson, 2007)

4.3. Stress fields in Japan

Because of the complex and active tectonics in Japan, which are due to the nation's unique plate tectonic setting, strongly anisotropic stress fields have developed in the crust (see Figure 8), meaning that stress fields vary substantially at different depths and in different locations. Here, stress fields denote the state of stress in the crust, that is, the forces per unit area that are acting on the crust. The stress field can be described by three orthogonal principal stresses, in which one of three is normally vertical in orientation. Lines appeared in Figures 8 indicate the orientation of the maximum horizontal stress, which is one of the principal stresses. As shown in Figure 8, the maximum horizontal stress is oriented sub-perpendicular to the plate boundary in Northeast Japan while it is oblique to the plate boundary in Southwest Japan. The orientation also varies within the plates. The relative magnitudes among principal stresses also vary. Blue dots and lines in Figure 8 indicate that the faulting regime is thrust faulting, that is, that, the maximum horizontal stress is the largest principal stress and the vertical stress the smallest. Green dots and lines indicate that the faulting regime is strike-slip faulting, that is, that the maximum horizontal stress is the largest principal stress and the minimum horizontal stress the smallest. Red dots and lines indicate the faulting regime is normal faulting, that is, the vertical stress is the largest and the minimum horizontal stress the smallest. The characteristic distribution of the faulting regime with respect to the plate tectonic setting in Japan can be seen in Figure 8. Both the faulting regime and the orientation of the stress can vary locally in Japan. The feasibility of drilling ultra-deep borehole under conditions of highly anisotropic stress fields and complex geology need to be carefully checked, and, if necessary, development of a proven technology for deep drilling under such conditions, should be considered if deep borehole disposal is chosen as one of the possible options for the disposal of high-level radioactive wastes or nuclear spent fuel in Japan.

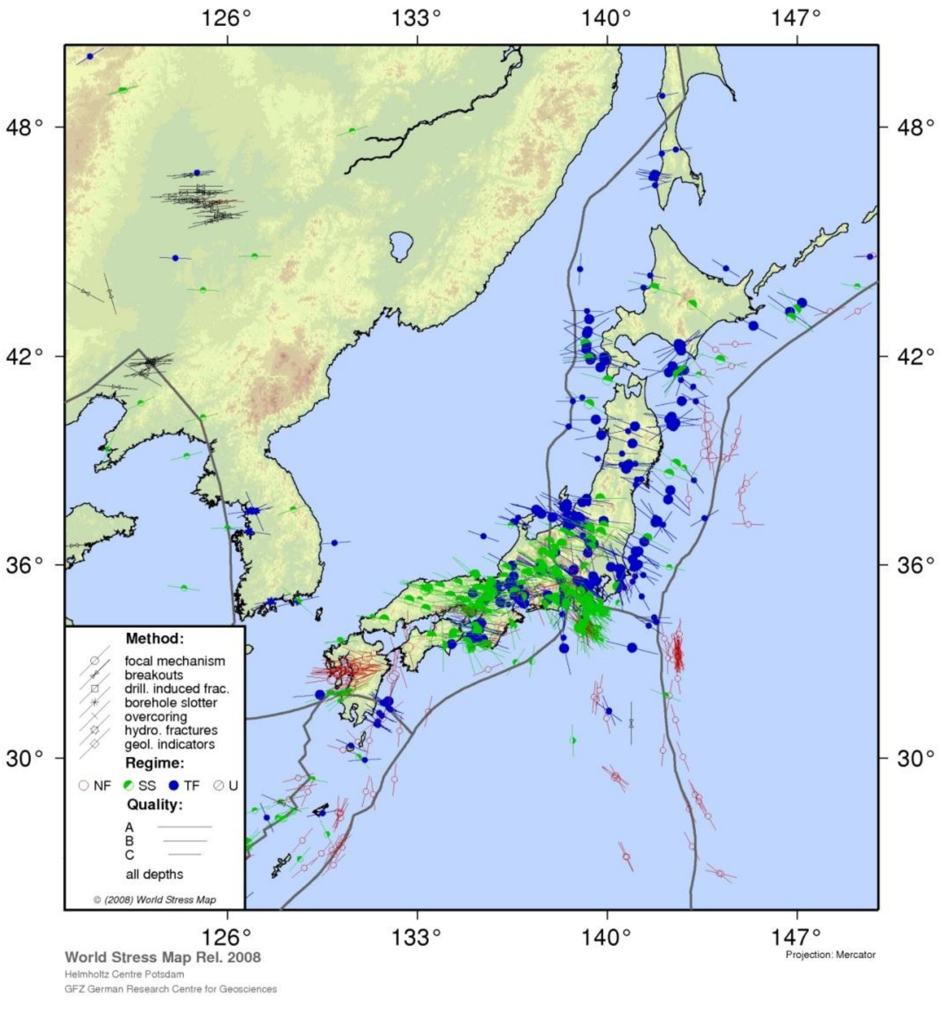

Figure 8. Stress conditions in and around Japan (Heidbach et al., 2008). The symbols appearing on lines, as shown in the legend, indicate the methods used for estimating stress conditions. Lines indicate the orientation of the maximum horizontal stress. In the legend, the codes “NF”, “SS”, “TF”, and “U” indicate “normal faulting” regimes, “strike slip” faulting regimes, “thrust faulting” regimes, and “unknown”, respectively. “Quality” indicates the quality of the available data for estimating stress conditions in different locations. See Heidbach et al. (2008) for details.

5. Some considerations related to the deep borehole disposal concept in Japan and summary of paper

The present situation of the disposal program for high level radioactive in Japan was briefly summarized above, and the general concept of the deep borehole disposal was described. The history of deep drilling activities in Japan was presented. Possible problems for deep borehole disposal in Japan related to the active migration of deep-seated fluids in Japan were discussed, and stress condition in and around Japan was presented.

Based on the surveys of the deep borehole disposal concept and the geological/tectonic situation in Japan provided above, the following studies are considered to be necessary for further investigating the possibility of deep borehole disposal in Japan.

(1) Scenarios for safety assessment should be developed specifically to test the applicability of the deep borehole disposal concept. These assessments are necessary in consideration of the possibly aggressive deep subsurface environments in many potential deep borehole locations in Japan, environments that may render engineered barriers less effective in isolating wastes from the biosphere for tens or hundreds of thousands of years. Also, the assumption that deep groundwater in the vicinity of waste emplacement in a deep borehole will be stagnant may not hold well in Japan.

(2) It is necessary to develop proven technologies for deployment of waste, possible retrieval of waste canisters, and radiation shielding at the borehole mouth. Methods of stacking canisters during deployment could be one of the technical challenges that need to be overcome. The possible advantages of deep borehole disposal, however, are worthy of consideration and further exploration. These include that the deep borehole disposal could be less expensive compared with mined repository techniques, that long-term management of a facility based on deep borehole disposal may not be necessary because emplaced wastes are, under the right geologic conditions, not likely to be a threat to the biosphere, and safe from most forms of human diversion. Moreover, almost all of the activities associated with deep borehole disposal can be accomplished at the surface, without the need for humans to go underground, and drilling technologies used in the oil and nuclear industries can be used without massive modification for deep borehole disposal.

(3) Considering the tectonic setting and active fluid-related processes, extensive efforts are needed to obtain the knowledge of the ultra-deep geological environments to discuss the possibility of the deep borehole disposal option in Japan.

The deep borehole disposal concept has not been seriously discussed in Japan as far as the author is aware. Deep borehole disposal, however, could be an alternative option to the mined repository concept, which has been studied in Japan for about forty years. At present, the Japanese government is considering the mined repository concept as the only practical option for the disposal of high-level radioactive waste, which might reduce the potential for the study of other disposal concepts in Japan. Consideration of a wider range of options/concepts may allow the development of disposal facility designs tailored to both existing geological environments and the desires of potential host communities.

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