Proceedings of the ASME 13th International Conference on Environmental Remediation and Radioactive Waste Management
ICEM2010
October 3-7, 2010, Tsukuba, Japan

ICEM2010-40054

RELATIONSHIP BETWEEN HYPOCENTRAL DISTRIBUTION AND GEOLOGICAL STRUCTURE IN THE HORONOBE AREA, NORTHERN HOKKAIDO, JAPAN

Tetsuya Tokiwa
Japan Atomic Energy Agency
Horonobe, Hokkaido, Japan

Koichi Asamori
Japan Atomic Energy Agency
Tono, Gifu, Japan

Naoto Hiraga
Nittetsu Mining Co., Ltd.
Tokyo, Japan

Osamu Yamada
Japan Atomic Energy Agency
Horonobe, Hokkaido, Japan

Hirokazu Moriya
Graduate School of Environmental Studies, Tohoku University, Japan

Hikaru Hotta
Construction Project Consultants, Inc., Osaka, Japan

Itaru Kitamura
Construction Project Consultants, Inc.
Osaka, Japan

Hideharu Yokota
Japan Atomic Energy Agency
Horonobe, Hokkaido, Japan

ABSTRACT
In this paper, we discuss the relationship between the accurate hypocentral distribution and three-dimensional (3-D) geological structure in and around the Horonobe area in northern Hokkaido, Japan. The multiplet-clustering analysis was applied to the 421 micro-earthquakes which occurred from 1 September, 2003 to 30 September, 2007. The 3-D geological structure model was mainly constructed from previous seismic reflection profiles and borehole data.

As a result of this analysis, although with slight differences in depth between them, the hypocenters were found to be distributed in the NNW-SSE direction and become deeper from the west toward the east. The distributed pattern of the hypocenters is similar to that of the geological structure. These results indicate that the hypocentral distribution may represent existence of active zone related to the geological structure, and provide effective information which can contribute to establishing methods for estimating the future evolution of the geological environment.

Keywords: hypocenter, seismic, 3-D geological structure, multiplet-clustering analysis, Horonobe

1. INTRODUCTION
Japanese islands are located in a convergent zone of several continental and oceanic plates, and are one of the most tectonically active regions in the world. In order to assess the long-term safety of a geological disposal system in Japan, it is important to consider the impact of natural events and processes such as earthquake generation and fault movement, volcanism, uplift, and erosion. From these, the potential effects of earthquakes and fault movements on geological disposal system include hydrological and geochemical effects (i.e. destruction of waste package and repository, change of groundwater flow and water quality). Thus, understanding the behavior of earthquakes and fault movements is absolutely imperative for safety of geological disposal system.

Horonobe area is located at the eastern margin of a Neogene to Quaternary sedimentary basin which exists at the western side of northern Hokkaido (Fig. 1) [1]. Active structures and seismicity indicate that the Horonobe area is a most active tectonic region in northern Hokkaido [2-5].

The hypocentral distribution and fault movement are highly related to the geological structure because the geological structure is considered to be formed by accumulation processes of the tectonic events such as earthquake generation and fault movement. However, very few discussions have been made on the relationship between them. Recently, Moriya et al. [6] presented a relocation hypocenter method called multiplet-clustering analysis, which enabled a more accurate estimate of the distribution of hypocenters. In addition, recently, the effectiveness of this method was confirmed by Moriya et al. [7] in the Horonobe area. In this paper, the multiplet-clustering analysis is applied to shallow earthquakes occurring in the Horonobe area to discuss the relationship between the accurate hypocentral distribution and three-dimensional (3-D) geological structure.

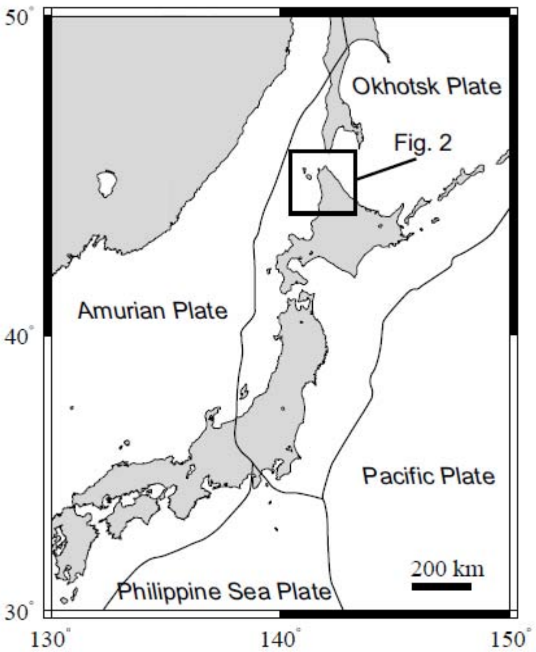

Fig. 1. Location map and Tectonic setting around northern Japan. Plate boundaries are from Wei and Seno [1]

2. HYPOCENTER DISTRIBUTION

2.1 Observation and Data

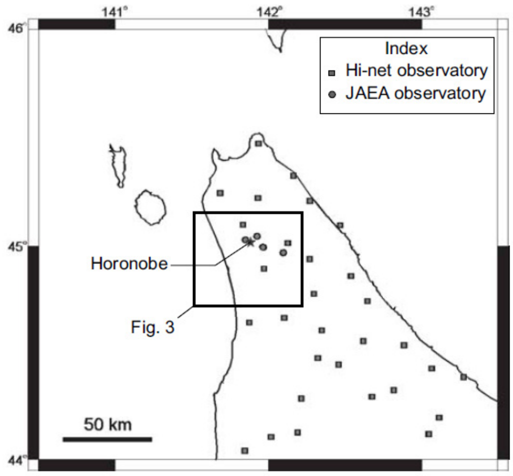

Fig. 2. Locations of observatory in northern Hokkaido

The earthquake waveform data used in this study were collected by the Hi-net system [8, 9] of the National Research Institute for Earth Science and Disaster Prevention (NIED) and the observatories of the Japan Atomic Energy Agency (JAEA) from 1 September, 2003 to 30 September, 2007 (Fig. 2), and the information on the source location was used from the data base of Japan Meteorological Agency (JMA). Most of the events had magnitudes of less than 3.0. Among a total of 4,614 events located by Hi-net, their events whose P- and S-wave arrival times were detected at the four observatories of the JAEA system were selected. A total of 421 events for analysis were analyzed in this study. The hypocenters were calculated by multiplet-clustering analysis.

2.2 Multiplet-Clustering Analysis

The multiplet-clustering analysis is a method for precise determination of hypocenters by combining multiplet analysis with clustering analysis [6]. It is able to relocate the relative source locations of similar events with quite high accuracy. The 1-D velocity structure proposed by Tamura et al. [4] was used for this analysis (Table 1).

Table 1. Velocity structure for multiplet-clustering analysis

Depth (km)	P-wave velocity (km/s)	S-wave velocity (km/s)
0-2	2.83	1.62
2-10	5.32	3.04
10-20	6.32	3.61
20>	6.69	3.82

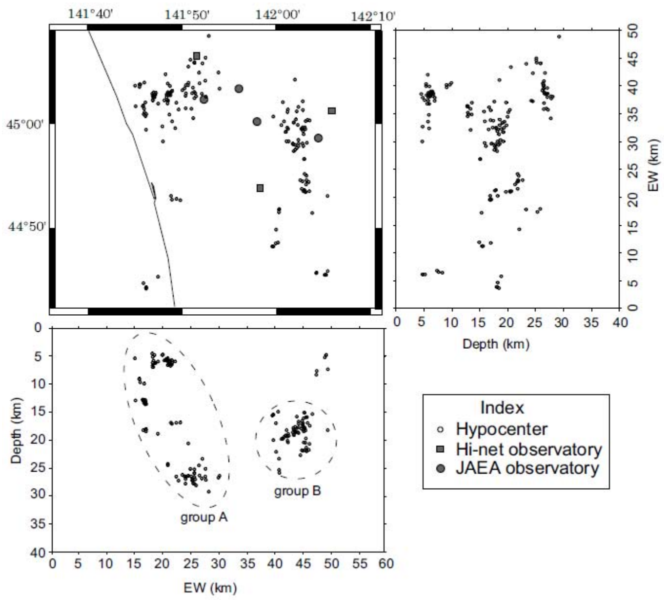

Fig. 3. Hypocentral distributions estimated by the multiplet-clustering analysis

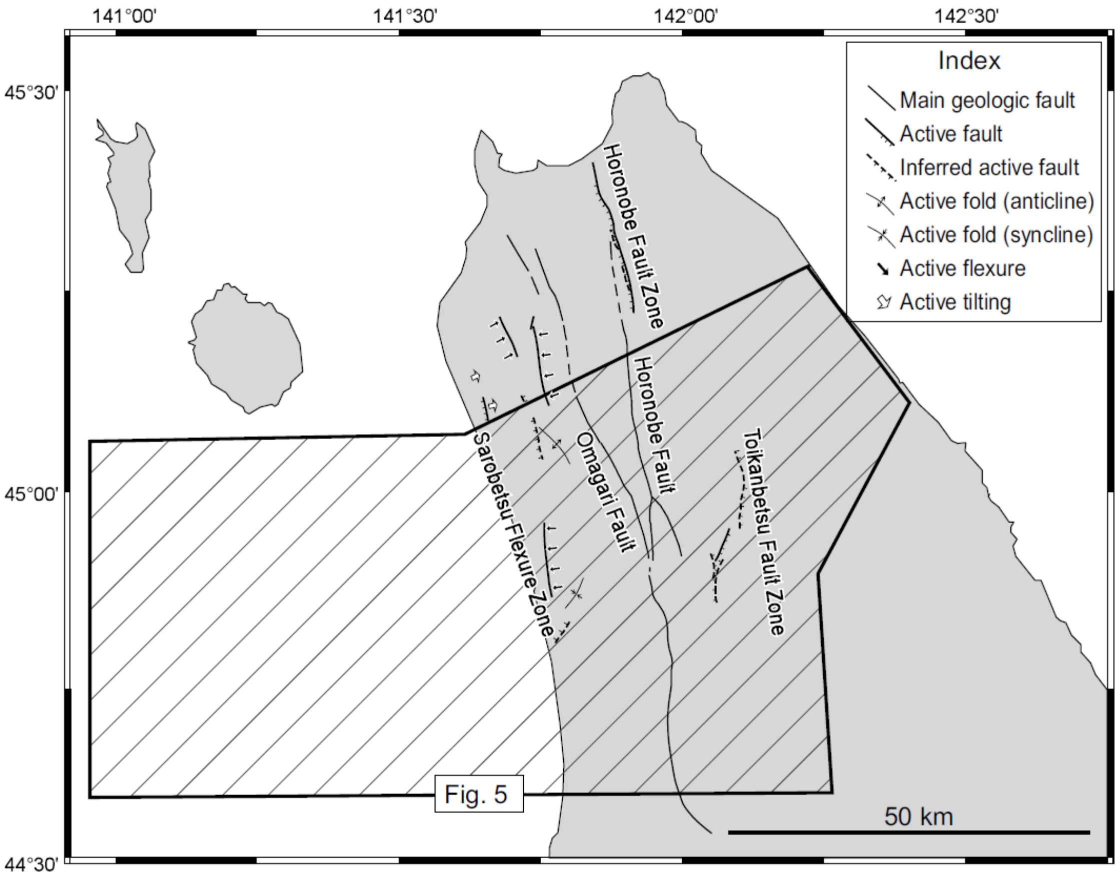

Fig. 4. Distribution of geological structures around the Horonobe area (modified from Nakata and Imaizumi [3])

As a result of this analysis (Fig. 3), hypocenters were found to be divided into two broad groups (groups A and B). The hypocenters of group A are not extended in the NS direction, and are sporadically distributed at the depth from 5 to 30 km. These hypocenters become deeper from the west to the east. The hypocenters of group B are distributed in the NNW-SSE direction, and are focused at the depth of 20 km.

3. GEOLOGY

3.1 Geological outline

The sedimentary basin exists in northern Hokkaido, where the Horonobe area is located, and is called the Tenpoku Sedimentary Basin [10]. The total thickness of the Neogene and Quaternary deposits has reached up to 6,000 m in this basin. It is situated at an active foreland fold-and-thrust belt near the boundary between the Okhotsk and Amurian plates. The previous seismic reflection surveys suggested that the ongoing EW compressive tectonics (neotectonics) in the western part of the Horonobe area has begun in 2-3 Ma [11, 12].

In this area, the Omagari Fault and the Horonobe Fault are presented as a geological fault from west to east (Fig. 4). In addition, the Sarobetsu Flexure Zone (correspond to Teshio Fault Zone [13] and the Sarobetsu Fault Zone [14]), the Horonobe Fault Zone, and the Toikanbetsu Fault Zone are recognized as an active fault zone from west to east. In this paper, we quote the above-mentioned name (Flexure Zone, Fault, Fault Zone) from references without changing.

3.2 3-D geological structure model

In order to construct a 3-D geological structure model, we attached importance to tectonics that fold-and-thrust belt in this area was formed under the influence of an E-W compressive stress. The characteristic geological structures of the fold-and-thrust belt include fault-related fold (e.g., fault-propagation fold and fault-bend fold) and detachment [15]. Therefore, Omagari Fault and Horonobe Fault are considered faults that branch off from the detachment, and the fold structures in this area are considered fault-related fold. Fig. 5 shows main geological structure in 3-D.

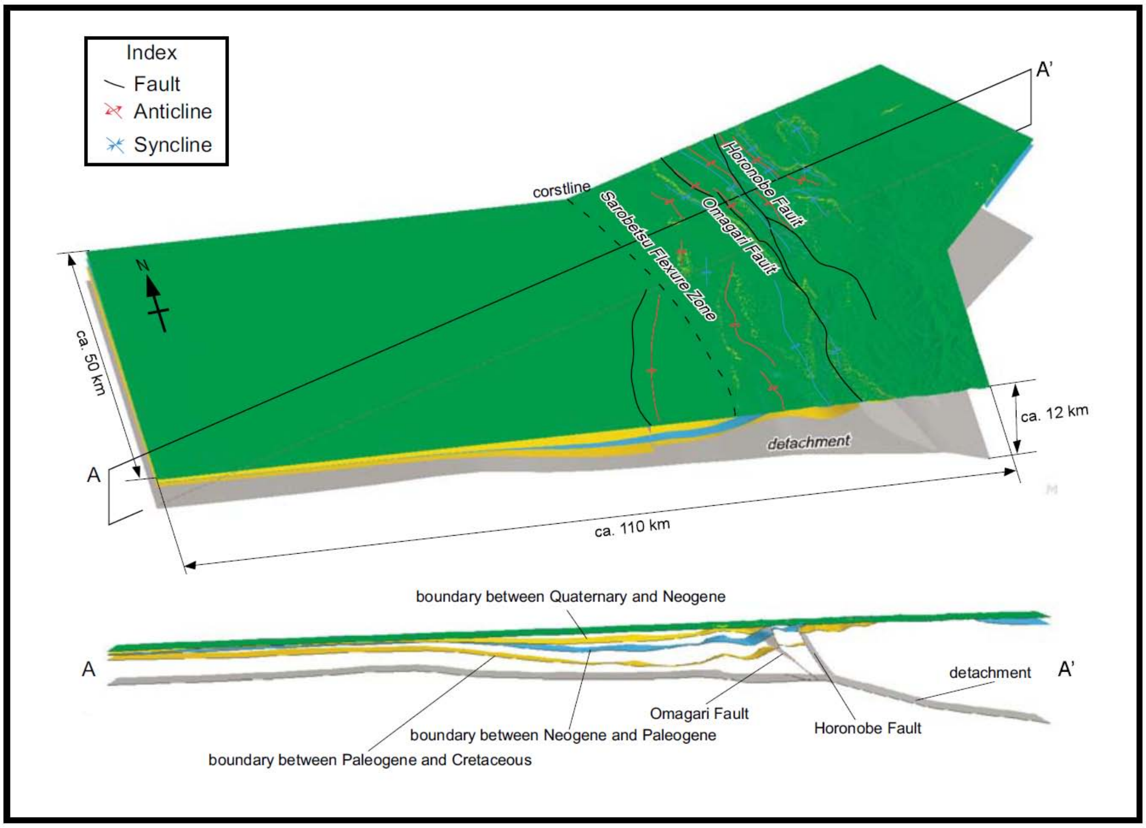

Fig. 5. 3-D geological structure model and the cross section

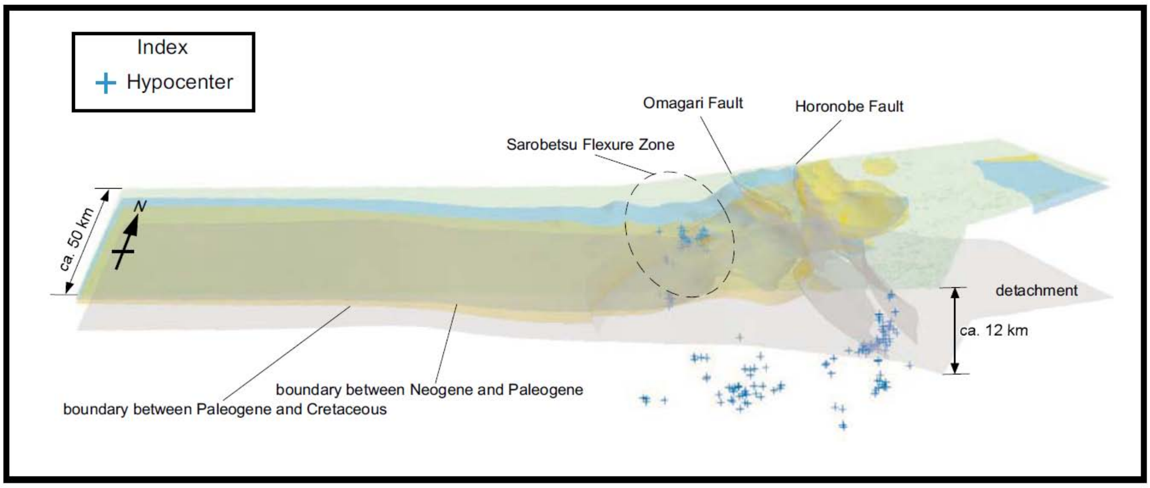

Fig. 6. Hypocentral distribution and 3-D geological structure at low angle view (15 degrees southward dipping)

In northern Hokkaido, several geological cross sections with several km in depth had been presented [16-20]. Advance Industrial Science and Technology [20] reported balanced cross sections based on seismic reflection profiles and borehole data. Hokkaido Promotion Committee of Mining [16] reported cross sections based on seismic reflection profiles and borehole data. The other cross sections were created by seismic reflection profiles that velocity sections had not been converted into depth sections. Therefore, the 3-D geological structure model was mainly constructed from cross sections proposed by Advance Industrial Science and Technology [20] and Hokkaido Promotion Committee of Mining [16]. As for the horizontal distribution of geology and geological structure, citations were taken from Geological Survey of Japan [21] and Sugiyama et al. [22] for land area and Ikeda et al. [13] for sea area.

4. DISCUSSION

4.1 Depth of hypocenter

According to deep borehole investigation (ca. 5 km in depth), the geothermal gradient in this study area indicates 2.7 ℃ per 100 m of depth [17]. Thus, the temperature at the depth of 13 km is expected to exceed 350 ℃, and it is difficult for brittle deformation to occur deeper than around this depth [23]. However, the hypocenters in this study area distribute up to 30 km in depth. The heterogeneous seismic velocity structure is cited as a cause of the difference. The low velocity layer is established the 1-D seismic velocity model proposed by Tamura et al. [4] used in this study, and the velocity model is suited for hypocenter determination in this area. However, the low velocity layer in this velocity model is set from 0 to 2 km in depth. The low velocity layer is considered thicker than that of this model because the total thickness of the Neogene and Quaternary deposits in this area has reached up to 6 km. In fact, it is reported that P-wave velocity at the depth of 4 km is 3 km/s and P-wave velocity of shallower than 1 km are in the range of 1.5 to 2.5 km/s [24, 25]. Therefore, it is highly possible that hypocenters are located much shallower than the result of this study. In this study, the depth of hypocenter is treated not as absolute depth but as relative depth. From now on, construction of the reasonable velocity model will be needed to clear up the absolute depth.

4.2 Relationship between hypocentral distribution and geological structure

The multiplet-clustering analysis revealed that the hypocenters are distributed in the NNW-SSE direction (group B) and become deeper from the west toward the east (group A). The distributed pattern of the hypocenters is similar to the one of the geological structure. The hypocenters in group A are located in the deep extension part of Sarobetsu Flexure Zone that is recognized as an active fault zone. Thus, the hypocenter distribution is consistent with the tectonics. Although, an obvious fault such as Omagari and Horonobe Faults have not been inferred in the deep extension part of Sarobetsu Flexure Zone [20], it is possible that the seismic clusters indicate the existence of these faults in the crust. Meanwhile, the hypocenters in group B might be related to detachment because one of this group is concentrated in deep part.

These results indicate that the hypocentral distribution may represent existence of an active zone related to the geological structure such as fault in this region. Thus, the analysis can provide effective information which can contribute to establishing methods for estimating the future evolution of the geological environment by discussing the relationship between hypocentral distribution and geological structure.

ACKNOWLEDGMENTS

The earthquake waveform data was downloaded from the web site of Hi-net owned by National Research Institute for Earth Science and Disaster Pretension (NIED), Japan, and the information on the source location was used from the data base of Japan Meteorological Agency (JMA) with the Ministry of Education, Culture, Sports, Science and Technology. These data have been provided by the National Research Institute for Earth Science and Disaster Prevention, Hokkaido University, Hirosaki University, Tohoku University, the University of Tokyo, Nagoya University, Kyoto University, Kochi University, Kyushu University, Kagoshima University, National Institute of Advanced Industrial Science and Technology, and the Tokyo Metropolitan Government. We would like to thank the above mentioned agencies. This paper benefited from helpful comments by an anonymous reviewer and Dr. K. Miyahara, Japan Atomic Energy Agency.

REFERENCES

[1] Wei, D., and Seno, T., 1998, “Determination of the Amurian plate motion,” Mantle Dynamics and Plate Interactions in East Asia, Geodynamics Series 27, Flower, M., Chung, S. L., Lo, C. H., Lee, T. Y., eds., American Geophysical Union, Washington, D.C., USA, pp. 337-346.

[2] Oka, T., 1997, “Study on the neotectonics of Hokkaido and its neighboring seas, with notes on the existence of active fault and occurrence of earthquake in Sapporo and its vicinity,” In Honor of Prof. Kato, M., Kawamura, M., Oka, T., and Kondo, T., eds., pp.426-449.

[3] Nakata, T., and Imaizumi, T., 2002, “Digital active fault map of Japan (with CD-ROM and attached map),” University of Tokyo Press.

[4] Tamura, M., Kasahara, M., and Moriya, T., 2003, “Micro-Seismicity and Crustal Structure in the Northern Part of Hokkaido, Inferred from Temporal Observation,” Journal of the Seismological Society of Japan, 55, pp. 337-350.

[5] Niizato, T., and Yasue, K., 2005, “A study on the long-term stability of the geological environments in and around the Horonobe area –Consideration of site specific features in assessing of the long-term stability of the geological environments–,” Journal of Nuclear Fuel Cycle and Environment, 11, pp. 125-138.

[6] Moriya, H., Niituma, H., and Baria, R., 2003, "Multiplet-clustering analysis reveals structural details within the seismic cloud at the Soultz geothermal field," Bulletin of the Seismological Society of America, 93, pp. 1606-1620.

[7] Moriya, H., Asamori, K., Kitamura, I., Hotta, H., Ohara, H., and Niizato, T., "Estimation of Crustal Structure in Horonobe Area, Hokkaido, Japan, by using Multiplet-Clustering Analysis," Journal of Acoustic Emission, in press.

[8] Okada, Y., Kasahara, K., Hori, S., Obara, K., Sekiguchi, S., Fujiwara, H., and Yamamoto, A., 2004, "Recent progress of seismic observation networks in Japan -Hi-net, F-net, K-NET and KiK-net-," Earth Planets and Space, 56, xv-xviii.

[9] Obara, K., Kasahara, K., Hori, S., and Okada, Y., 2005, "A densely distributed high-sensitivity seismograph network in Japan: Hi-net by National Research Institute for Earth Science and Disaster Prevention," Review of Scientific Instruments, 76, 021301-doi:10.1063/1.1854197.

[10] Yamamoto, H., 1979, "The geologic structure and the sedimentary basin off northern part of the Hokkaido Island," Journal of the Japanese Association for Petroleum Technology, 44, pp. 260-267.

[11] Ogura, N., and Kamon, M., 1992, "The Subsurface Structures and Hydrocarbon Potentials in the Tenpoku and Haboro Area, the Northern Hokkaido, Japan," Journal of the Japanese Association for Petroleum Technology, 57, pp. 33-44.

[12] Ito, T., 1999, "When does the on-going tectonic phase of active tectonics in Hokkaido begin?," Chikyu Monthly, 21, pp. 608-613

[13] Ikeda, Y., Imaizumi, T., Togo, M., Hirakawa, K., Miyauchi, T., and Sato, H., eds., 2002, "Atlas of Quaternary thrust faults in Japan," University of Tokyo Press.

[14] Headquarters for Earthquake Research Promotion (jisinn-cyousa-kenkyu-honbu), 2005, "Focused Research and Observation Program in the Future," Earthquake Research Committee Headquarters for Earthquake Research Promotion Prime Minister's Office, Government of Japan.

[15] Twiss, R. J., and Moores, E. M., 2006, "Structural Geology, second ed.," W. H. Freeman and Company, New York.

[16] Hokkaido Promotion Committee of Mining (Hokkaido-Kougyo-Shinko-Iinkai), 1990, "Oil- and gas-resources in Hokkaido –Exploration and development– (1977-1988)," Resource and Energy Division, Department of Commerce, Industry, Tourism and Labor.

[17] Japan National Oil Corporation, 1995, "Kiso-Shisui "Tenpoku" (METI "Tenpoku" Well)," Japan National Oil Corporation.

[18] Imai, H., Maeda, N., Shiozaki, I., Amemiya, K., and Chijimatsu, M., 2002, "Study on Regional Groundwater Flow Analysis relevant to the Horonobe Underground Research Program," JNC-TJ 2002-004.

[19] Kato, N. and Sato, H., 2002, "Active tectonics in the central Hokkaido," Chikyu Monthly, 24, pp. 481-484.

[20] Advance Industrial Science and Technology, 2006, "Activity and Paleoseismological Survey of the Sarobetsu fault zone," In working paper of the additional and complementary survey of the primary survey of fault zone. No. H17-1.

[21] Geological Survey of Japan, Advance Industrial Science and Technology, 2002, "Geological Maps of Japan 1:200,000 (Images) Version 2.0.," Geological Survey of Japan, Advance Industrial Science and Technology.

[22] Sugiyama, Y., Awata, Y., and Hata, M., 1987, "1: 500,000 Neotectonic map sheet 3 Asahikawa," Geological Survey of Japan.

[23] Scholz, C. H., 1988, "The brittle-plastic transition and the depth of seismic faulting," Geologische Rundschau, 77, pp. 319-328.

[24] Kanekiyo, T., 1999, "Collection and arrangement of the Geological data in the northern part of Hokkaido," JNC TJ1440 99-005.

[25] Ota, K., Abe, H., Yamaguchi, T., Kunimaru, T., Ishii, E., Kurikami, H., Tomura, G., Shibano, K., Hama, K., Matsui, H., Niizato, T., Takahashi, K., Niunoya, S., Ohara, H., Asamori, K., Morioka, H., Funaki, H., Shigeta, N., and Fukushima, T., 2007, "Horonobe Underground Research Laboratory Project Synthesis of Phase I Investigations 2001 - 2005 Volume -Geoscientific Research-," JAEA Reesearch, 2007-044.