Open file report of Geological Survey of Japan, no. 425

Bentonite in Japan –Geology and Industries–

Tetsuichi Takagi
Research Center for Deep Geological Environments, Geological Survey of Japan
National Institute of Advanced Industrial Science and Technology (AIST)

1. Summary of clay mining industries in Japan

Production of non-metallic mining industries in Japan reached 220 billion JPY (= about 2 billion USD) as of 1990. The production is more than the metallic, oil, and coal industries in Japan; it makes up 47.4 % of the total production of Japanese mining industries (Sudo and Hirano, 1994). There are about 500 operating non-metallic mines in Japan (excluding rock aggregate and building stones). The mines have produced limestone, clays, silica stones, feldspars, and other products (e.g., zeolite, diatomite, talc, and olivine), and 40 % are limestone mines, 25 % are clay mines, and 20 % are silica stone mines.

Production of clay mining industries is 33% of the total production of non-metallic mining industries except for limestone and related products, and has been used for industrial raw materials for roofing tiles, table ware, sanitary ware, glass fiber, and other products. Clay resources in Japan can be divided into three types:

(1) Sedimentary clay (e.g., kaolin deposits in Neogene sediments)

(2) Hydrothermal clay (e.g., pyrophyllite, kaolin, and sericite deposits with igneous rocks)

(3) Clays formed by mainly diagenesis (bentonite and fuller's earth)

Types of clay deposits that are mined are: 48 % are sedimentary clay, 38 % are hydrothermal clay, and 14% are bentonite and fuller's earth. Concerning the output of the clay mines, 47% is hydrothermal clay, 35% is sedimentary clay, and 18% is bentonite and fuller's earth as of 1990.

2. Geology of bentonite deposits in Japan

During the Miocene to Pliocene, intense volcanic activities occurred extensively and large-scale

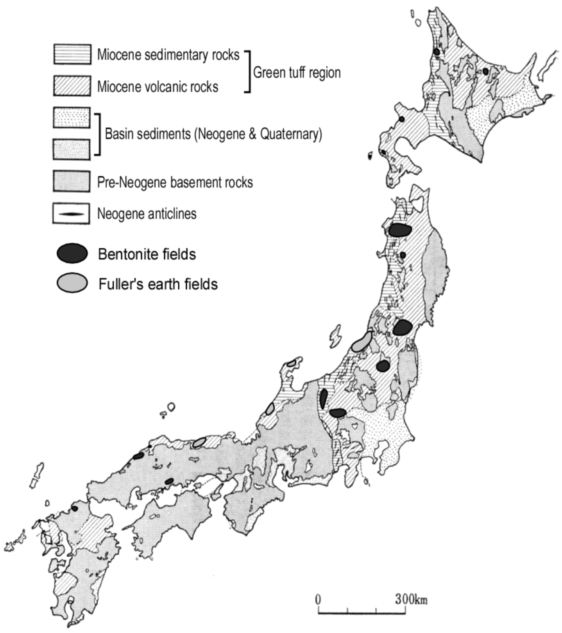


Fig. 1 Distribution of Neogene Tertiary sedimentary and volcanic rocks, and bentonite and fuller's earth fields in Japan.

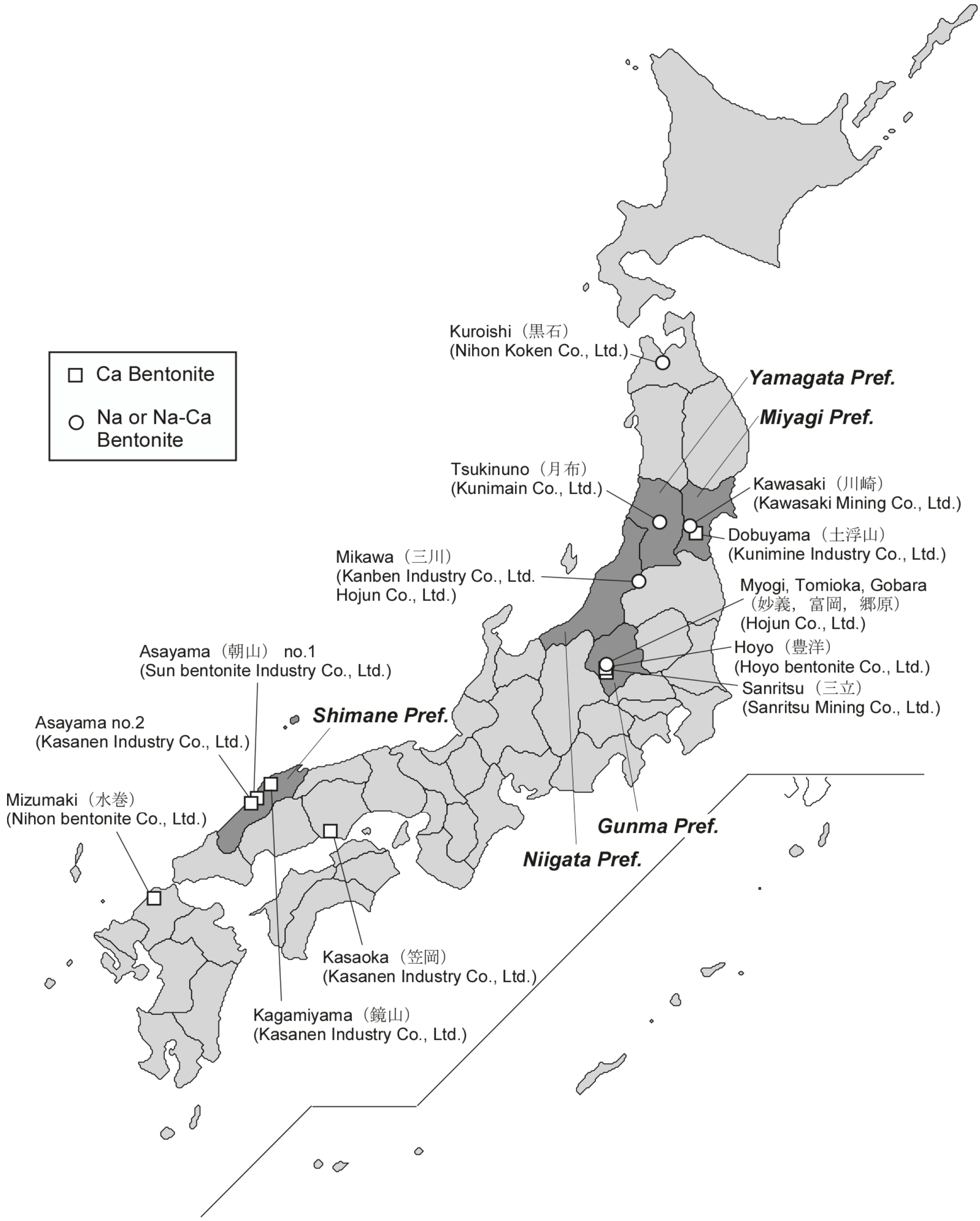


Fig. 2 Location of bentonite deposits and types, and their operating mining companies in Japan as of 2005.

sedimentary basins were formed along the back-arc side (Fig. 1). Thick formations of clastic sediments and pyroclastic rocks have been deposited on the sedimentary basins. Bentonite deposits in Japan are mostly embedded in the Neogene sedimentary and pyroclatic rocks. Parent rocks of bentonite are mostly silicic vitric tuff, and bentonitization of the tuff generally occurred due to diagenesis or low-temperature hydrothermal alteration. The bentonite deposits can be divided into Na or Na-Ca bentonite deposits and Ca bentonite deposits with respect to the compositions of interlayer exchangeable cations of smectite. The Na or Na-Ca bentonite deposits generally occur as large- to medium-scale stratified ore bodies and are mostly distributed in the Yamagata-Miyagi and Gunma-Niigata regions (Fig. 1). Representative Na bentonite deposits are Tsukinuno deposit (Yamagata prefecture) and Myogi deposit (Gunma prefecture); diameters of their distribution fields are more than several tens of kilometers based on exploration drill hole data. These deposits have been exploited as major mines of Japanese bentonite industries. In contrast, Ca bentonite deposits occur as medium- to small-scale and irregular-shaped or lenticular ore bodies. Major fields of the Ca bentonite deposits are the Niigata and Shimane regions (Ca bentonite deposits in the Niigata region are eliminated from Fig. 2 and Table 1 because they have been mined as fuller's earth). In the next section, we will make a summary of bentonite deposits in the Yamagata-Miyagi region as an example.

2.1. Bentonite deposits in the Yamagata-Miyagi region

Three bentonite deposits, Dobuyama, Kawasaki, and Tsukinuno, are distributed in this region (Fig. 2). Geologic maps of the Dobuyama-Kawasaki and Tsukinuno regions are shown in Appendices 1 and 4.

Dobuyama deposit: This deposit occurs as a small-scale irregular-shaped ore body (Appendix 2). The Dobuyama bentonite consists mainly of Ca smectite with subordinate opal, quartz, and zeolite. Parent rocks of the bentonite are Upper Miocene rhyolitic lapilli tuff, and bentonitization was caused by hydrothermal alteration associated with rhyolite intrusion. Behavior of each element suggests that the bentonitization occurred at a shallow level under alkalic conditions (Ossaka et al., 1981). This deposit has been exploited by Kunimine Industries Co., Ltd. since 1967.

Kawasaki deposit: This deposit occurs as medium-scale stratified ore bodies (Appendix 3). The Kawasaki bentonite consists of Na-Ca smectite with subordinate opal-CT (cristobalite), quartz, and zeolite. Parent rocks of the bentonite are two horizons of thick felsic tuff beds intercalated in Middle Miocene sandstone-siltstone alternation (Itoh et al., 1999). Bentonite sections near the surface tend to be converted to Ca bentonite due to meteoric water circulation and weathering. Geological occurrences and spatial variations of bentonite properties suggest that the Kawasaki deposit was formed by diagenesis at a level deeper than the Dobuyama deposit. A full-scale exploitation of the Kawasaki deposit has been conducted since 1970 by Kawasaki Mining Co., Ltd. At the present, the mine is the largest open pit bentonite mine in Japan. The estimated ore reserve of the Kawasaki mine is about 5 million tons.

Tsukinuno deposit: This deposit consists of large-scale stratified ore bodies. The geologic map of the Tsukinuno deposit is shown in Appendix 5. The Tsukinuno bentonite is composed of Na smectite with subordinate quartz, feldspars, illite, calcite, and zeolite. Calcite is commonly concentrated into elliptical nodules up to several tens of centimeters. Parent rocks of the bentonite are felsic tuff beds intercalated in Middle Miocene hard shale. There are 35 bentonite layers in the mining area, and nine layers are thicker than 1 meter. Exploitation of this deposit has been conducted since 1949 by Kunimain Co., Ltd. and the mine is the largest underground bentonite mine in Japan. Bentonite layers No. 29 (7 m) and No. 31 (1.5-2.4 m) are the main layers for mining, and total ore reserve is estimated to be about 17 million tons (Brochure of the Kunimine Industries Co., Ltd.).

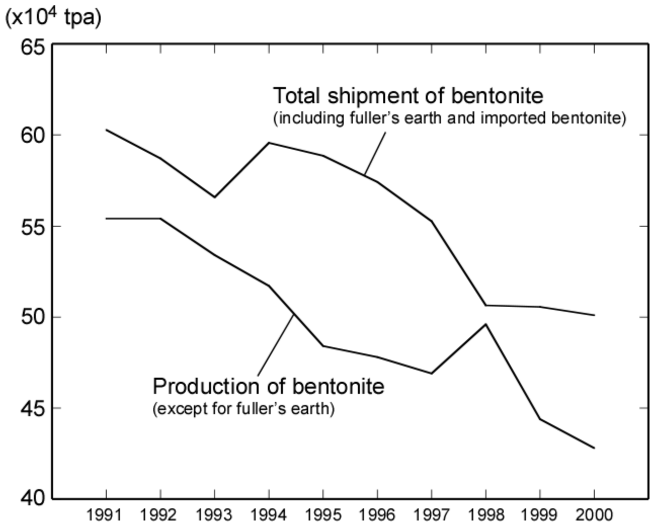


Fig. 3 Total shipment and production of bentonite in Japan from 1991 to 2000.

3. Bentonite industries in Japan

After World War II, many bentonite deposits have been exploited, and bentonite production has rapidly increased with the great demand from metal casting and construction industries during rapid economic expansion. Peak production was over 600,000 tons in 1990-1991 (excluding imported bentonite). However, since the collapse of the bubble economy in 1990, the production decreased gradually, and the annual production of bentonite decreased below 500,000 tons (Fig. 3). Total 1995 bentonite production (478,000 tons) is 4.32 % of the world bentonite production (Fig. 4). Since the Japanese economy has been in recession since 1990, each bentonite company has endeavored to keep its market share and has developed new techniques to expand uses for bentonite and make value-added bentonite products.

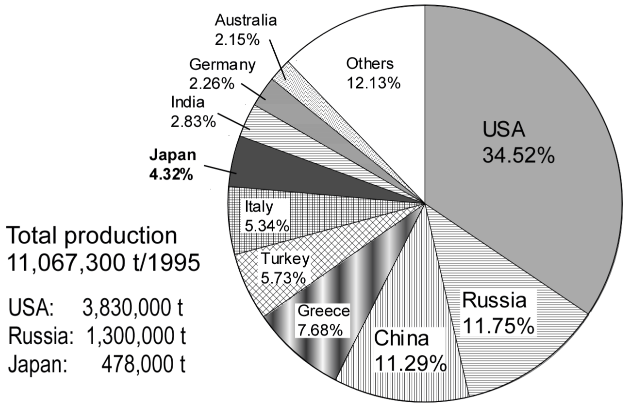


Fig. 4 1995 World bentonite production by country in percent.

3.1. Bentonite production

Although there are 16 operating bentonite mines in Japan as of 2005 (Fig. 2), there are less than ten places where mines operate year-round. The largest bentonite production area is the Yamagata-Miyagi region; the production reaches nearly one half of the total bentonite production. Next is the Gunma-Niigata region. The bentonite mines in the Shimane region are generally small scale.

Table 1 shows the 1998 production of bentonite for each company by Pearson et al. (1999). The leading company is Kunimine Industries Co., Ltd., and the second leading company is the Hojun Co., Ltd. Large imports of bentonite are from countries such as the United States (e.g., Wyoming and Montana states), China (e.g., Liaoning and Jiangsu provinces), and India. The largest company importing bentonite is Volclay Japan Co., Ltd., which is a subsidiary of the Amcol International Corporation of the United States.

Table 1 Domestic production and imports of bentonite for company in 1998 (Pearson et al., 1999).

Japanese bentonite producers

Company	Location	Production (tpa)
Kanto Bentonite	Niigata	36,099
Kunimine	Yamagata	167,782
Sun Bentonite	Shimane	16,163
Sanritsu Kogyo	Gunma	11,942
Nihon Bentonite	Fukuoka	25,578
Hojun	Gunma	130,713
Hoyo Bentonite	Gunma	118,113
Total		506,390

Bentonite imports

Company	Source	Volume (tpa)
Kunimine	BlackHills, USA	50,000
Volcaly Japan	Amcol, USA	85,000
Mitsubishi Corp.	Baroid, USA	14,000
Hojun	M-I Drilling, USA	24,000
Shinagawa Yozai	China	12,000
Sobue Clay	China	7,000

3.2. Uses of bentonite

In Japan, the major uses of bentonite are construction, metal casting and cat litter. These three uses make up more than 80 % of the total consumption of bentonite (Fig. 5). The consumption rate for cat litter is smaller than that in the Europe and United States because keeping cats inside the house is not common in Japan due to the lack of space. Bentonite for drilling mud or agricultural medicine has decreased gradually this decade.

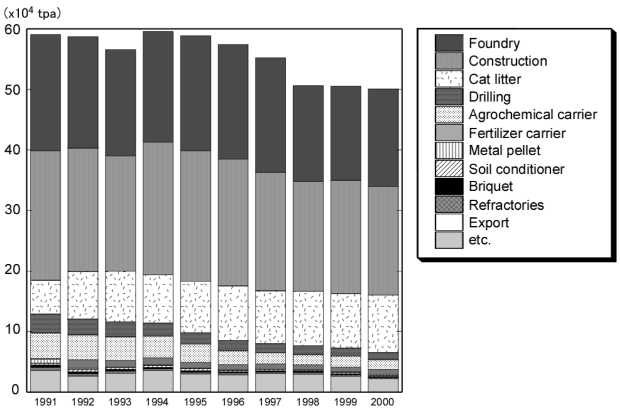


Fig. 5 Uses of bentonite products in Japan in 1991-2000.

3.3. Mining of bentonite

Most bentonite mines in Japan are open pit with only two underground mines, the Tsukinuno and Myogi mines (the Hojun Co., Ltd.). The Tsukinuno and Myogi mines have extracted high-grade Na bentonite. The bentonite ores have been used as raw materials for high-value products equivalent such as mud for deep drilling or high-purity smectite. In the case of the Tsukinuno mine, thick bentonite beds (5 to 7 m) are mined by the sublevel-stoping method, and thin bentonite beds (about 1 m thick) are mined by the shrinkage method. Quality inspection is conducted for ores mined from each bentonite bed, and the ores are separated for suitable uses (Kobayashi and Itoh, 1992). In the cases for open pit mines, surface soil is removed by power shovels or bulldozers, and bentonite ores are generally mined with backhoes using a bench cut method. Bulldozers mix and stockpile the mined ores in the stockyards. At the Kawasaki mine, quality assessment of bentonite layers is carefully carried out by exploration prior to mining, and mining procedures and uses of ores in the open pits are determined based on the assessment data (Kobayashi and Itoh, 1992). Now cooperation and agreement between mining companies and inhabitants or local governments are indispensable for large-scale exploitation because of the high public awareness of environmental problems and strict regulations for land development.

3.4. Production and processing of bentonite

Mined crude bentonite ores are processed by the following two methods:

(1) Simple drying and crushing of crude Na or Ca bentonite ores

(2) Drying and crushing of alkali-activated Ca bentonite ores

The former has been performed at all bentonite factories. Crude ores are usually roughly crushed with jaw crushers or roll crushers and dehydrated with rotary driers to 6-10 % moisture. The ores are crushed to 200-300 mesh with centrifugal roller mills. Impurities such as quartz and feldspars are removed as much as possible during this process. Final products are packed in bags or containers of various volumes for each use and shipped to users.

In the latter, the process of mixing sodium carbonate powder with roughly crushed bentonite ores is added to the former process. Most bentonite companies have alkali-activation lines in their factories. Each factory has specific know-how of the alkali-activation method because suitable capacity and usage of equipment, treatment time, and reaction temperature depend on the properties of crude ores. Blends of domestic and imported bentonite (mixed bentonite) have commonly been produced for foundries. Bentonite for cat littler is generally granulated to 2-5 mm in diameter because fine bentonite powder is cumbersome for home use. Common granulation methods are as follows: (1) cutting noodle-like bentonite paste made with an extrusion machine in several millimeter lengths, (2) accretion of fine bentonite powder to small bentonite cores on vibrating saucers. Deodorants and antibacterial chemicals are generally added to cat litter.

3.5. New technologies of bentonite and smectite

Now major bentonite companies in Japan have produced high-purity Na smectite. This product is made by the complete removal of impurities from natural Na bentonite through the repetition of precipitation and centrifugal separation. Main uses of Na smectite are cosmetics, drugs, abrasives, and wax. The major bentonite companies have developed organo-bentonite, which is produced by the substitution of organic materials for interlayer exchangeable cations of natural smectite. Organo-bentonite commonly swells and disperses in organic solvents and raises the viscosity of organic solvents. Thus, the products have been used for paints, ink, thickener for grease, and adhesives (Suzuki, 2000). Production of synthetic smectite has also been started by the major bentonite companies. The synthetic smectite is an inorganic high-molecular compound produced by hydrothermal synthesis of chemicals within autoclaves. In the case of the Kunimine Industries Co., Ltd., synthetic saponite has been produced as a synthetic smectite. The synthetic saponite is a snow-white powder, and its gel is colorless, transparent, and highly viscous relative to natural smectite gel. The product has used for cosmetics, drugs, raw materials of chemicals, and special drilling mud. Thus, the synthetic saponite is expected to be used for electronic or optical equipments (Suzuki, 1999, 2000).

3.6. New uses of bentonite and smectite

The most notable new use of bentonite is buffer and loading materials for geological repositories of high-level nuclear waste (HLW). Geological disposal of HLW will be implemented in underground repositories at a depth of -300 to -1000 m. Bentonite will be loaded around containers of HLW to raise the long-term stability of HLW repositories by the high performance of bentonite for groundwater cut-off, self-sealing, adsorptivity of nuclides, thermal conductivity, chemical buffering capacity, and stress relaxation (Itoh, 1993). In Japan, the policy of a geological disposal of HLW was enacted in 2000, and the procedures for the selection of potential disposal sites have been started. The studies for the assessment of the long-term stability of bentonite in various conditions have also been conducted by universities and public research institutes to establish the techniques of HLW geological disposal. When geological disposal is implemented, one million tons of bentonite would be needed at an early stage, and annual demand of bentonite would be several tens of thousand tons until the end of the disposal project (Iwasaki, 1992).

Nano-composite of smectite is also one of new uses. This is a technique that disperses smectite into resin or plastics to raise their heat resistance and mechanical strength. The nano-composite techniques have already been used for automobiles, cameras, and home electronics, The techniques of pillared clays (clays set up oxide pillars between layers) have been put to practical uses as a novel microporous material (Iwasaki, 1992). In the future, further research and development will provide great potential for the expansion of new uses for natural bentonite, synthetic smectite, and their processed materials.

4. Conclusion

In Japan, the mining industry has been recognized as a depressed industry since the late 20th century. There are only two operating major metallic mines (Toyoha Zn-Pb mine and Hishikari Au-Ag mine), and all coal mines have been already closed as of 2005. However, non-metallic mining industries have continued their operation for the following reasons: (1) non-metallic mining industries commonly have a close connection with industries in the local economy such as cement and ceramics, (2) industries often utilize specific mineral properties of each mine, and no alternative has been found. Bentonite corresponds to the latter. Fortunately, there are abundant high quality bentonite resources in the Japan Arc. Bentonite industries will change into high-technology industries through the development of composite materials. Furthermore, bentonite will play an important role for the construction of nuclear waste repositories. From a long-term viewpoint, we believe that bentonite industries in Japan will grow.

Acknowledgement

The author greatly appreciates M. Itoh, T. Sawada, and M. Shijime for providing technical and statistical information on Japanese bentonite industries.

References

Itoh, M. (1993) New development of bentonite application. *Journal of the clay science society of Japan*, vol. 33, no. 4, p. 193-201. (in Japanese with English abstract)

Itoh, M., Ishii, T., Nakashima, H., and Hirata, Y. (1999) The study of genesis and formation condition of bentonite. *Journal of the clay science society of Japan*, vol. 38, no. 3, p. 181-187. (in Japanese with English abstract)

Iwasaki, T. (1992) Smectite and zeolite. *Resource*

Geology, special issue, no. 13, p. 143-150. (in Japanese)

Kobayashi, K. and Itoh, K. (1992) Recent bentonite production process at Kunimine Industries. *Journal of the clay science society of Japan*, vol. 31, no. 4, p. 222-230. (in Japanese)

Ossaka, J., Hirabayashi, J., Okada, K., and Kato, M. (1981) The occurrence and its chemical composition changes in the Dobuyama montmorillonite deposit, Miyagi Prefecture. *Journal of the mineralogical society of Japan*, vol. 15, special volume, p. 150-186. (in Japanese with English abstract)

Otsuki, K., Saito, T., and Yoshida, T. (1986) Island arc transection route No. 24, In Kitamura, S. ed., Geological data files on Neogene of Northeast Japan Arc, vol. 3, no. 3, 19p. (in Japanese)

Pearson, K. and Senior Assistant Editor (1999) Bowed down with imports. A review of Japan's mineral industry. *Industrial Minerals*, December 1999, p.49-59.

Shimizu, D., Fujita, Y., and Suzuki, Y. (1981) Structural regions of the Japan Arc and their characteristics, in Y. Fujita and Y. Suzuki ed., Kozo-Chishitsu, p. 170-182, Kyoritsu, Tokyo. (in Japanese)

Sudo, S. and Hirano, H. (1994) Industrial minerals in Japan. Part 1. *Chishitsu News*, no. 484, p. 25-32. (in Japanese)

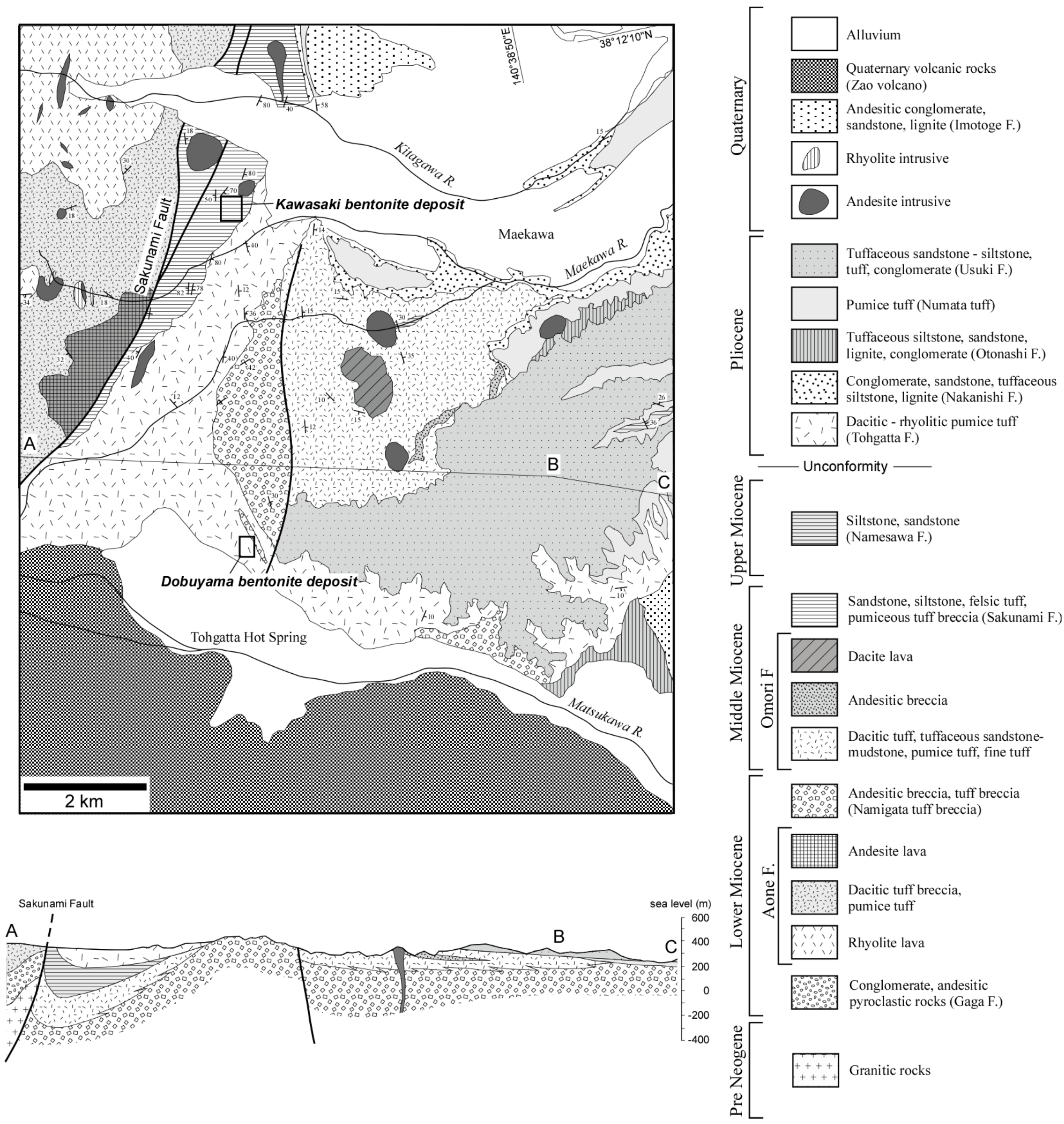
Suzuki, K. (2000) Clay minerals for nano-composite materials. *Plastics*, vol. 51, no. 9, The Japan Plastics Industry Federation. (in Japanese)

Suzuki, K. (1999) Natural and synthetic smectite. *Filler*, vol. 4, no. 6, p. 144-157, The Japan Filler Society. (in Japanese)

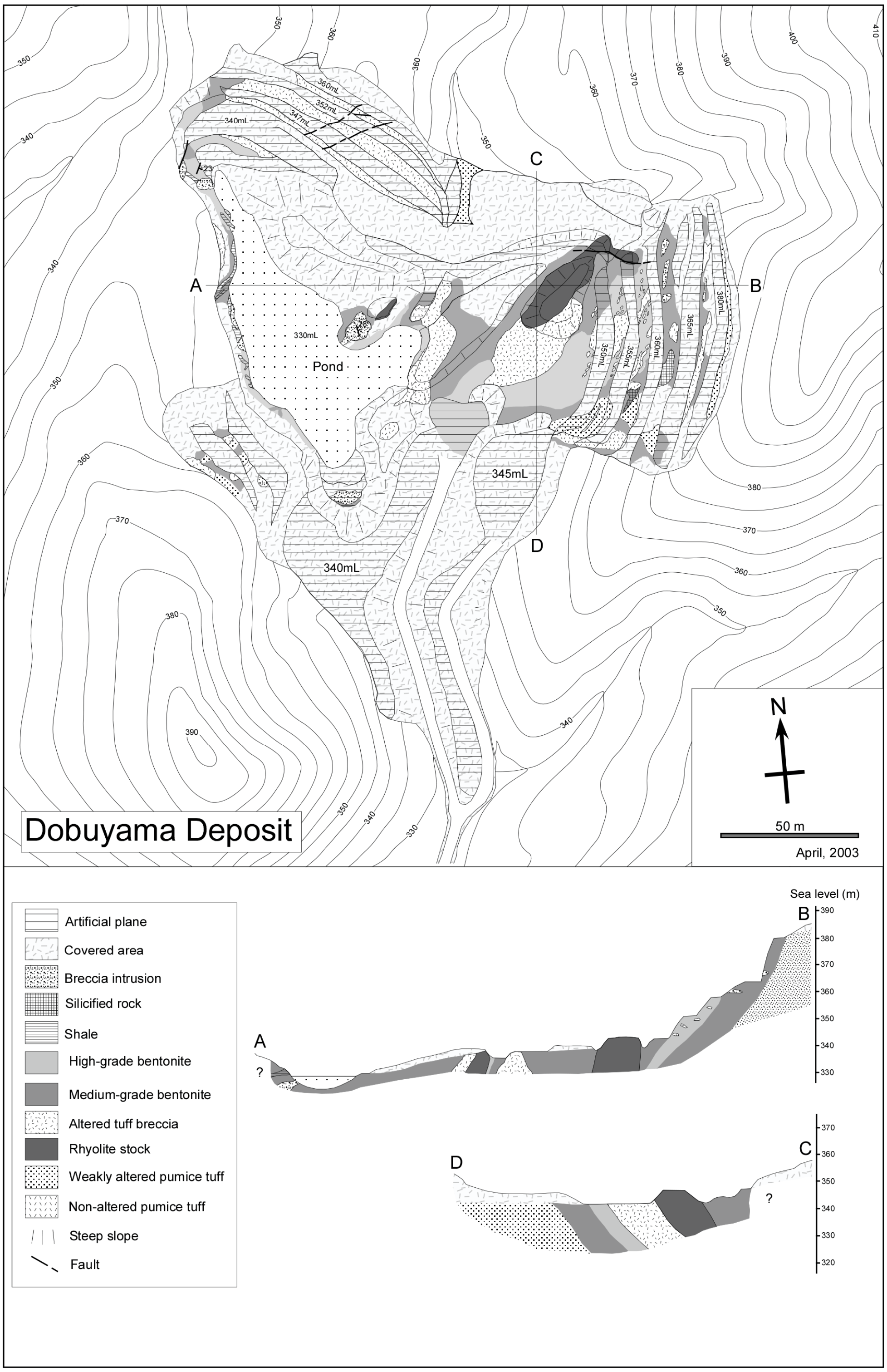
Takagi, T., Koh, S-M., Song M-S., Itoh, M., and Mogi, K. (2005) Geology and properties of the Kawasaki and Dobuyama bentonite deposits of Zao region in northeastern Japan. *Clay Minerals*, vol. 40, p. 333-350.

Yamaji, A., Amano, K., Otsuki, K., and Ishii T. (1986) Island arc transection route No. 23, in S. Kitamura, ed., Geological data files on Neogene of Northeast Japan Arc, vol. 3, no. 2, 36p. (in Japanese)

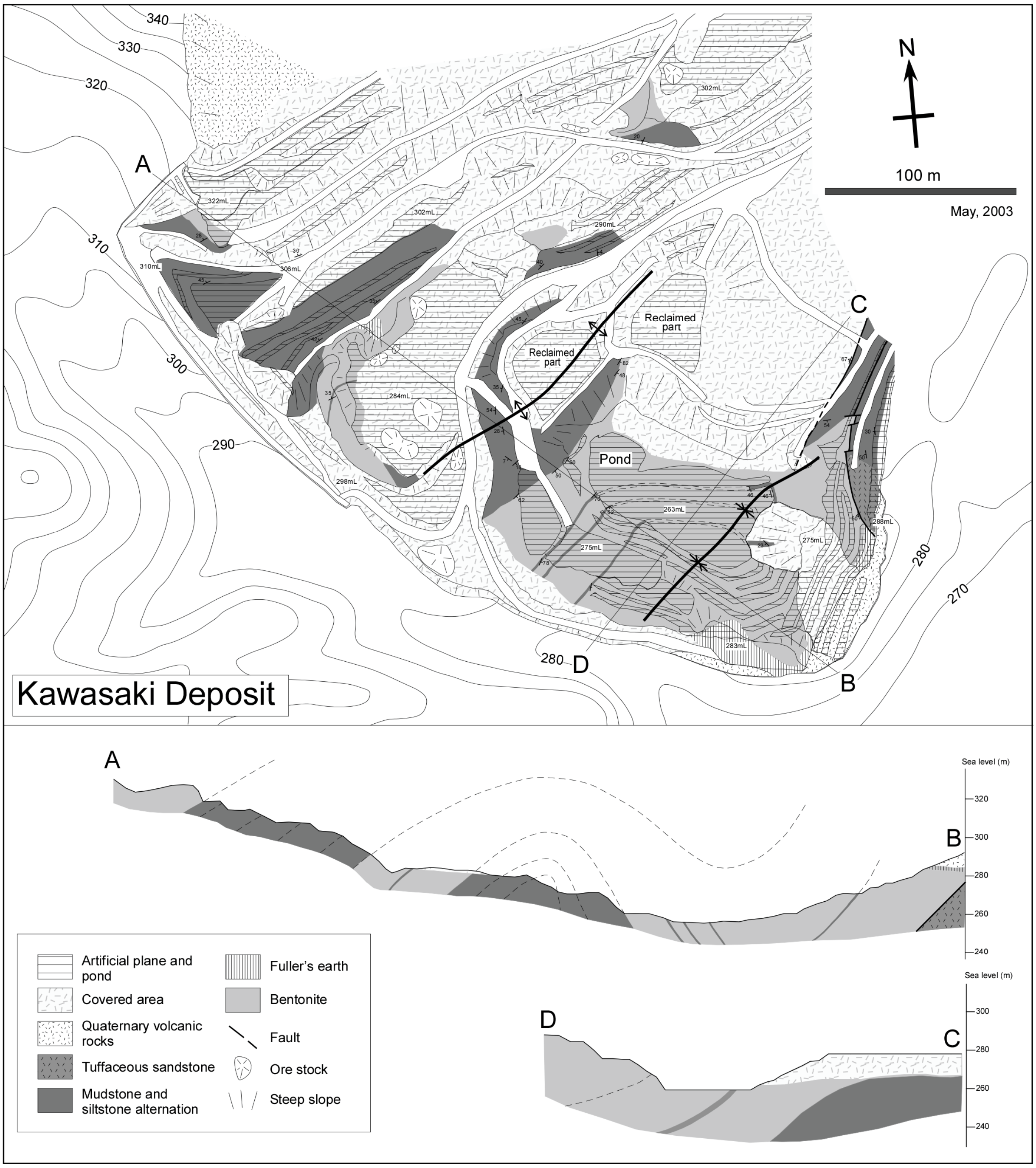
2005/07/22
2005/12/12 revised



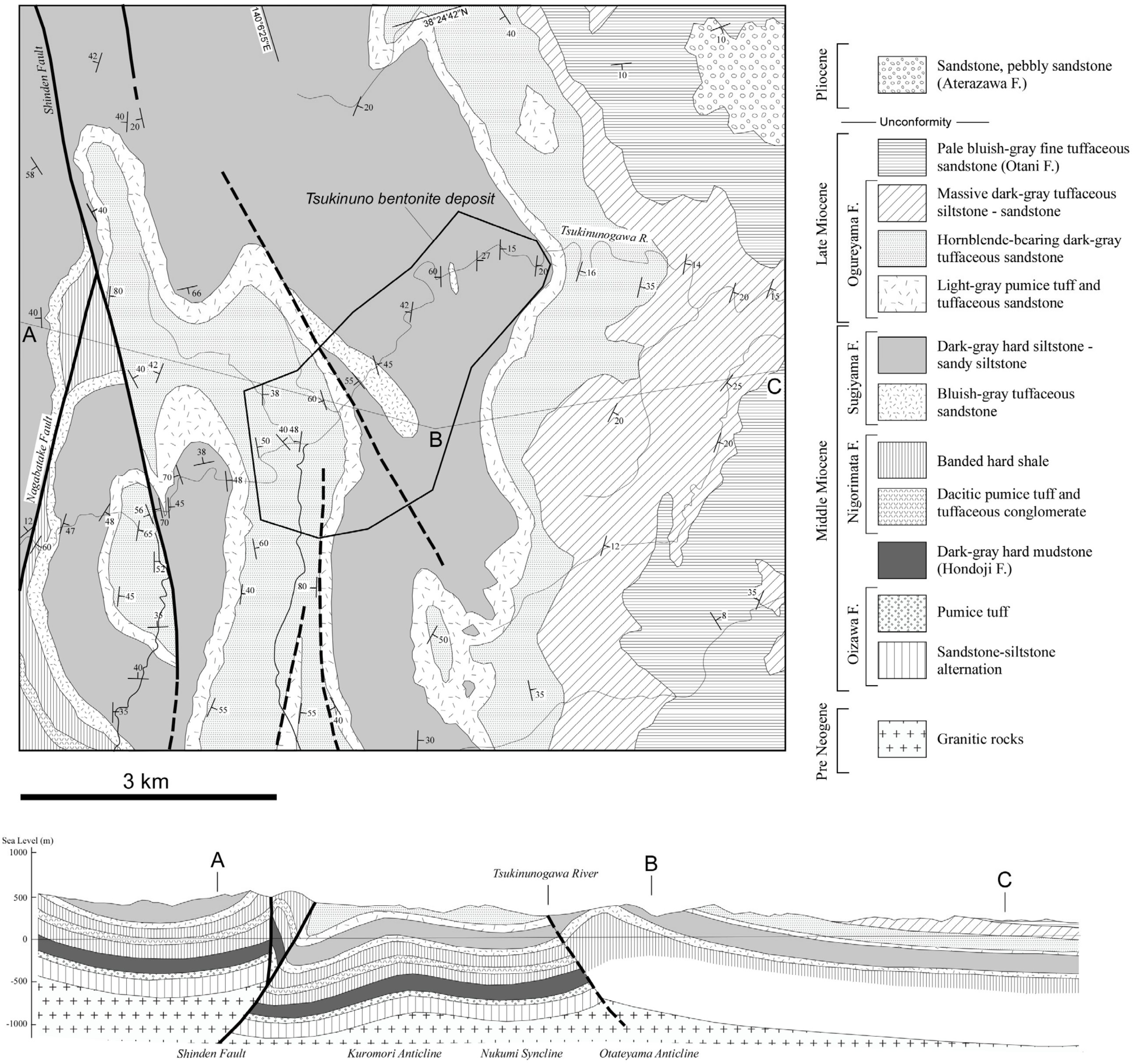
Appendix 1 Geologic map of the northern Zao region, Miyagi prefecture (Otsuki et al., 1986). The Dobuyama and Kawasaki bentonite deposits are located in this region.



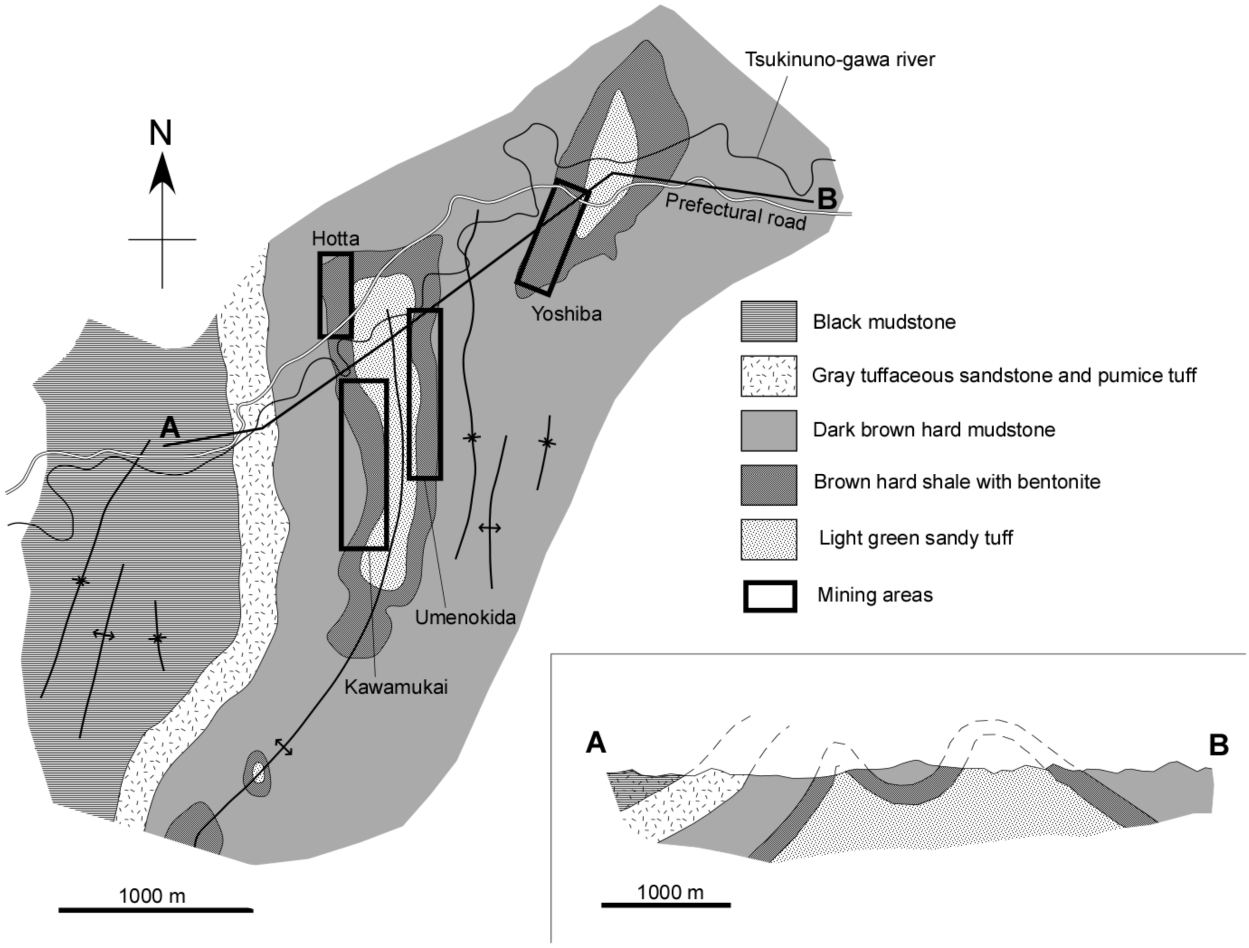
Appendix 2 Plan figure and cross sections of the Dobuyama bentonite deposit (Takagi et al., 2005).



Appendix 3 Plan figure and cross section of the Kawasaki bentonite deposit (Takagi et al., 2005).



Appendix 4 Geologic map of the Ohe region, Yamagata prefecture (Yamaji et al., 1986). The Tsukinuno bentonite deposit is located in this region.



Appendix 5 Plan figure and cross section of the Tsukinuno bentonite deposit after Kobayashi and Itoh (1992).