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Occurrences and genesis of two contrasting Kawasaki and Dobuyama bentonite deposits, northeastern Japan

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1. Introduction

In the Japan arc, medium- to large-scale bentonite deposits are extensively distributed in Neogene Tertiary sedimentary rocks (so-called the green-tuff region). The Yamagata and Miyagi prefectures of northeastern Japan is one of the largest bentonite fields, and three bentonite deposits, Tsukinuno, Kawasaki, and Dobuyama, have been exploited. In this study, we have investigated the genesis of the Kawasaki and Dobuyama deposits in the central Miyagi prefecture, which show contrasting occurrences and bentonite properties in spite of that those are located only 5 km apart.

2. Geology and occurrences

2.1 Kawasaki deposit

The Kawasaki deposit, which is exposed as an open pit 400 m in diameter, consists of a main bentonite layer and another thin bentonite layer. Host rocks of the Kawasaki deposit is the middle Miocene Sakunami formation, which consists of a siltstone and sandstone alternation, felsic tuff, and tuffaceous sandstone accumulating in a marine environment. The eastern margin of the main bentonite layer is bounded by a fault. The bentonite layers and the host rocks are complexly folded, a syncline and an anticline axes trending NNE are observed in the open pit. The axes in southern parts of the open pit are plunged 20 to 40 degree into SSW, though the axes in the central part are almost horizontal; it indicates a WNW trending anticline axis is overlapped on the NNE structure. The folding structures were formed due to active movements of the Sakunami fault, which is a NNE trending large Quaternary fault in 1 km west of the Kawasaki deposit. The main bentonite layer along the anticline is 15 to 20 m thick, though the layer is significantly thickened to more than 50 m along the syncline. Some thin siltstone beds 10 to 50 cm thick are intercalated in the bentonite layer, and ichnofossils (trace fossils) are commonly found on the surface of the beds.

2.2 Dobuyama deposit

The Dobuyama deposit occurs as a cone-shaped ore body 150 m in diameter surrounding two rhyolite dikes. Host rocks of the Dobuyama deposit are the lower Pliocene Tohgatta formation, which is composed mainly of rhyolitic to dacitic pyroclastic rocks. The bentonite deposit often includes silicified tuff breccia fragments and intrusive breccias in places.

3. Properties of bentonite and host rocks

3.1 Kawasaki deposit

Kawasaki bentonite shows a light-gray color and almost homogeneous quality. The portions near the surface are generally bleached by supergene process. Mineral assemblages of the bentonite are montmorillonite+opal-CT+cristobalite +quartz+zeolite. Zeolite occurs as mordenite and clinoptilolite. Swelling volume and pH of the bentonite range from 5 to 12 ml/2g and from 6.9 to 9.1, respectively. Although, methylene blue (MB) adsorption amounts range from 60 to 156 mmol/100g, the bentonite mostly shows the values more than 100 mmol/100g. The ratios of Na+/(Ca^{2+}+Na^{+}) of leached cations are widely changed from 0.05 to 0.71. SiO_2 and sulfur contents (anhydrous, wt. %) range from 69 to 85 and from 0.01 to 0.29, respectively. Host rocks consist of quartz, feldspars, vermiculite, and subordinate illite and zeolite, though we could not detect montmorillonite, opal, and cristobalite. This suggests that the host rocks have never been subjected to hydrothermal alteration. In the properties of the Kawasaki bentonite, we can find two regularities of variations: i.e., the variation with the distance from the surface, and the variation by horizons in the bentonite layer. The former are swelling volume, pH, and the ratio of Na^{+}/(Ca^{2+}+Na^{+}) of leached cations; those values tend to increase with depths. The latter are the abundance of minor minerals, MB adsorption amounts, and SiO_2 and S contents; the central horizon in the bentonite layer has less quartz and zeolite, higher MB adsorption amount, and lower SiO_2 and S contents than those of the marginal horizons. The ratio of leached cations of the bentonite is also influenced by the latter factor.

3.2 Dobuyama deposits

Dobuyama bentonite shows light gray to dark gray colors, and homogeneousquality except for impurities such as silicified breccia fragments. Although mineral assemblages of the bentonite are the same as those of the Kawasaki bentonite, the amounts of opal-CT, cristobalite, quartz, and zeolite are far less than those of the Kawasaki bentonite. The crystallinity of Dobuyama montmorillonite tends to be higher than that of the Kawasaki montmorillonite for the difference in XRD patterns. Swelling volume and pH of the bentonite range from 3 to 9 ml/2g and from 6.8 to 7.5, respectively. MB adsorption amounts range from 88 to 154 mmol/100g. The ratios of Na^{+}/(Ca^{2+}+Na^{+}) of leached cations range from 0.01 to 0.08 indicating typical of Ca-type bentonite. SiO_2 and sulfur contents (anhydrous, wt. %) range from 66 to 79 and from 0.01 to0.29, respectively. Host rocks consist mainly of rhyolitic pumice tuff including much zeolite, opal-CT, and cristobalite without illite and montmorillonite. This suggests that the host rocks were subjected to low-temperature alkaline hydrothermal alteration.

4. Discussion

In the Kawasaki deposit, an original rock of the bentonite, which would be rhyolitic vitric tuff, were accumulated under a shallow marine condition. The variations of some bentonite properties depend on horizons in the bentonite layer; these mean that diagenesis caused the alteration of vitric tuff to form the Kawasaki bentonite. The Na-Ca intermediate compositions and the common existence of zeolite suggest that the diagenetic alteration occurred under an alkaline condition. Subsequent to the uprising and folding of the bentonite deposit, the upper parts of the Kawasaki bentonite were converted to fuller's earth by a supergene process.

In contrast, an original rock of the Dobuyama bentonite, which would be rhyodacitic vitric tuff, was accumulated in a terrestrial environment. The cone-shaped ore body surrounding rhyolite dikes indicates that the bentonite was basically formed by hydrothermal alteration. The Ca-rich compositions and the paucity of zeolite suggest that the formation conditions of the Dobuyama deposit are more acidic and shallower than those of the Kawasaki deposit.

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