学　位　論　文　内　容　の　要　旨

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学　位　論　文　題　名

Study on the Effects of Covering and Adsorption layers on Immobilizing Arsenic from Hydrothermally Altered Rock
(熱水変質岩からのヒ素の不溶化に及ぼす覆土層および吸着層の影響に関する研究)

Hydrothermally altered rocks are frequently excavated by construction of a number tunnels located in Hokkaido, Japan. They generally contain substantial amounts of arsenic (As). If the excavated rocks are not disposed properly, As and other contaminants will contaminate the surrounding environments, especially groundwater and soil. A massive amount of hydrothermally altered rocks is expected to be produced from the ongoing projects of road and railway tunnels. Although landfills specially designed for disposing of the rocks have been constructed, they are economically infeasible and unsustainable. Thus, many researchers have focused on investigating factors controlling the mobility of As from hydrothermally altered rocks to develop a reasonable technique for disposing of these waste rocks. Recently, several studies have investigated the mechanisms of As migration from hydrothermally altered rocks by using laboratory column experiments. In this dissertation, more in-depth study of the mechanisms controlling the movement of As was conducted by focusing on two concerns: (1) developing a method to demonstrate the effects of water content and oxygen (O_2) concentration in relation to adding covering and adsorption layers on As leaching by introducing water content and O_2 concentration sensors into columns, and (2) modeling of As migration to provide insights into the transport phenomena of As through an adsorption layer by using Hydrus 1-D. The results would be further extrapolated for designing and establishing a sustainable technique for disposal of hydrothermally altered rocks. This dissertation contains 5 chapters.

Chapter 1 illustrates a literature review on basic knowledges about As including general properties, effects on human health, sources specifically in rock-forming minerals, and common techniques to remove aqueous As. This chapter also includes the fundamental adsorption theories and general knowledge on modeling of solute migration in a vadose zone. At the end of the chapter, the objectives and outline of the study are introduced.

Chapter 2 describes the effects of water content and O_2 concentration in relation to additional layer(s), i.e., surface covering and bottom adsorption layers, on As leaching by using laboratory columns with water content and O_2 concentration sensors. The results showed that the use of additional layer(s) had a significant effect on lowering As migration. This was due not only to the adsorption capacity of As by the adsorption layer but also to the water content and O_2 concentration inside the rock layer. The accumulation of pore water was increased in the rock layer in cases with additional layer(s), which resulted in lower O_2 concentration in the rock layer. Consequently, the leaching of As by the oxidation of As-bearing minerals in the rock layer was reduced. Moreover, a longer water-resident time in the rock layer may induce precipitation of iron (Fe) oxy-hydroxide/oxide. These results suggest that the geochemical conditions of the rock layer affect As leaching and migration.

After identifying the effects of the water content and O_2 concentration in relation to the additional layer(s) on As migration, simulation of reactive solute transport was conducted to investigate the performance of unsaturated adsorption layer on retarding the As from the hydrothermally altered rocks. Compared to the modeling of As migration under saturated condition, unsaturated condition requires more complicated water flow equations. This, however, leads to more accurate prediction since water movement is an important factor affecting solute migration. Thus, in chapter 3, simulation of water movement in multilayer soil profile was carried out using Hydrus 1-D to evaluate the capability of this software package in simulating the solute migration from column experiments. The assessment of the accuracy of the model was done by comparing the simulated results with observed ones. The water movement was successfully modeled with the high level of accuracy. Therefore, Hydrus 1-D is capable of simulating the reactive solute transport with accurate water movement. The results from this chapter will be used as an input to evaluate the As migration in chapter 4.

In chapter 4, performance of a river sediment on immobilizing As from hydrothermally altered rocks was evaluated using laboratory column experiments and Hydrus 1-D. The results revealed that the river sediment significantly reduced As migration. Arsenic retarded by the river sediment occurred in three patterns. The first was an adsorption onto minerals originally contained in the river sediment. The next pattern was a combination of reduction of As generation by oxidation of As bearing-minerals, irreversible adsorption, and adsorption onto newly precipitated Fe oxy-hydroxide/oxide. The last pattern was a depletion in As leaching due to a further reduction of oxidation of sulfide mineral. The observed breakthrough curves of As agree with the simulated results by considering the above three patterns.

Finally, conclusions as well as tentative design of disposal technique for excavated rock containing high content of As are discussed in chapter 5. The designed structure composes of low permeable covering and adsorption layers on the top and underneath the rock, respectively. In addition, layers of neutralizer should be added to the waste rock, containing high pyrite but low-buffer mineral content.