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Flow and geochemical modeling of drainage from Tomitaka mine, Miyazaki, Japan

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ABSTRACT

The chemistry and flow of water in the abandoned Tomitaka mine of Miyazaki, western Japan were investigated. This mine is located in a non-ferrous metal deposit and acid mine drainage issues from it. The study was undertaken to estimate the quantities of mine drainage that needs to be treated in order to avoid acidification of local rivers, taking into account seasonal variations in rainfall. Numerical models aimed to reproduce observed water levels and fluxes and chemical variations of groundwater and mine drainage. Rock–water interactions that may explain the observed variations in water chemistry are proposed. The results show that: (1) rain water infiltrates into the deeper bedrock through a highly permeable zone formed largely by stopes that are partially filled with spoil from excavations (ore minerals and host rocks); (2) the water becomes acidic (pH from 3 to 4) as dissolved oxygen oxidizes pyrite; (3) along the flow path through the rocks, the redox potential of the water becomes reducing, such that pyrite becomes stable and pH of the mine drainage becomes neutral; and (4) upon leaving the mine, the drainage becomes acidic again due to oxidation of pyrite in the rocks. The present numerical model with considering of the geochemical characteristics can simulate the main variations in groundwater flow and water levels in and around the Tomitaka mine, and apply to the future treatment of the mine drainage.

Introduction

There are more than 5000 abandoned non-ferrous metal mines in Japan from which issues acid mine drainage containing heavy metals such as Pb, Zn, and As. The mine drainage means that groundwater issues from the ore mine. Typically the drainage is treated by neutralization with carbonate minerals and heavy metals are removed. After this treatment, the groundwater is discharged into rivers. The total treatment cost is *ca.* 3 billion JPY/year (Ueda and Masuda, 2005). In order to cut the cost, several engineering techniques such as sealing mine exits have been investigated. Groundwater flow models and simulations of chemical changes during groundwater flow could be used to help decide the most appropriate method for treating mine drainage safely (Tomiyama et al., 2010a). There have been several previous studies of mine drainage outflow monitoring in Japan (*e.g.* Okumura, 2003; Iwatsuki and Yoshida, 1999; Mahara et al.,

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2006; Tomiyama and Ii, 2008; Tomiyama et al., 2009) and in the world (Razowska, 2001; Hazen et al., 2002; Sracek et al., 2004; Lee and Chon, 2006; Gammons et al., 2010). These studies have involved analyzing the chemical and isotopic compositions of the mine drainage. These geochemical approaches give us information about the sources and chemical evolution of groundwater, but they do not enable to predict the water flux through a mine. On the basis of the geochemical characteristics of groundwater, numerical models for groundwater movement (Wunsch et al., 1999; Sracek et al., 2004; Tomiyama et al., 2009, 2010a,b,c; Kageyama et al., 2010) and water–rock interaction (Bain et al., 2000; Molson et al., 2005; Castendyk and Webster-Brown, 2007) in several localities have been proposed.

In this paper, we describe the chemical and isotopic characteristics of mine drainage in Tomitaka mine, which is an abandoned non-ferrous mine in western Japan, and also discuss the chemical evolution of the drainage by using a kinetic water–rock interaction model. A numerical model of groundwater movement in this area was proposed previously by Tomiyama et al. (2010b), but could not simulate the variations of water levels and fluxes. In this paper, a revised model is proposed based on the addition of new data. The objective is to simulate the flow and geochemical interaction in the Tomitaka mine and to simulate the flow after sealing major rainwater infiltration area in the mine. We could recognize the flow and geochemical interaction in the mine and the effect of the sealing.

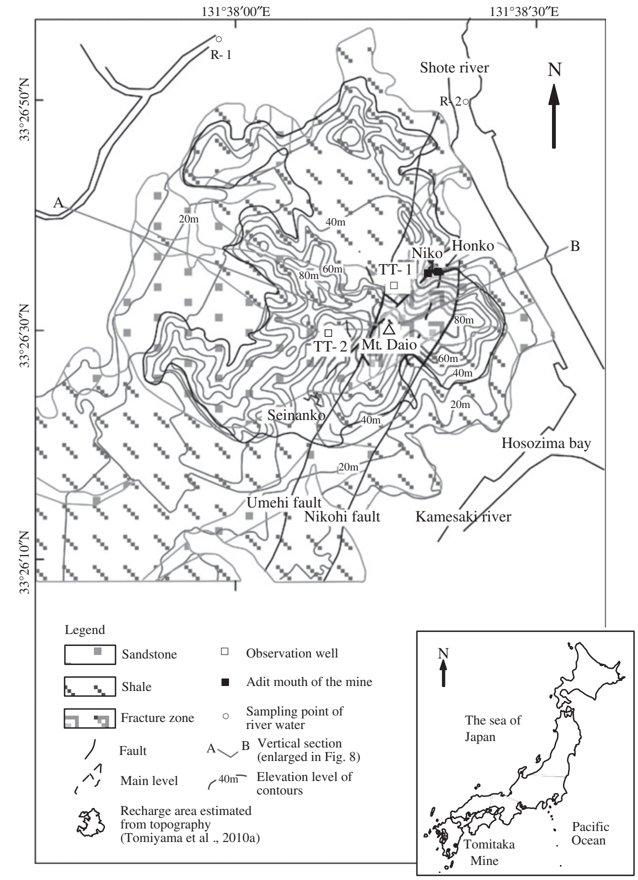

Fig. 1 – Localities of water sampling at the Tomitaka mine. The geological map is modified from Tomiyama et al. (2010b). Sample numbers correspond to those in Table 1. Groundwater was sampled at observation well, mine drainage was sampled at adit mouth of the mine and surface water was sampled at sampling point of river water.

1. Geology and core sample

1.1. *Outline of geology in the study area*

Tomitaka mine is a vein type deposit, located in Hyuga city in the southwest of Kyushu, Japan (Fig. 1). The mine operated from *ca.* 1870 to 1958, producing gold-bearing quartz and sulfide minerals (max. 1000 ton/day). Ore minerals from the Tomitaka mine were recovered by a shrinkage stope method, which involved excavating the ore in an upwards direction from a mine tunnel. After removal of the ores from the mine, open spaces were left as stopes. These spaces were mostly backfilled by host rock, but part of the ore body still contacts with air. The geological formation consists of Paleogene sandstone and shale (Hyuga F.) and two big faults (Umehi and Nikouhi faults), which are orientated in a NNE–SSW direction and located in the eastern part of the studied area (Tomiyama et al., 2010b). In contrast, the main ore mineral vein in Tomitaka mine is observed along faults with a NW–SE orientation, which cut the Umehi and Nikouhi faults (Kinoshita, 1961). In the main body of the mine, seven veins with lengths from 100 to 200 m and thicknesses from 0.4 to 1 m are observed. Relatively thick veins occur in sandstone formations and relatively thin veins occur in shale formation (Inai, 1963). In the mine, there is one main tunnel that was used for recovery of ore minerals and secondary transverse tunnel that connects to the excavated veins. The main tunnel is named Honko and the secondary tunnel is named Niko. Mine drainage issues from two areas: one is from a tube with 150 mm inner diameter in an air bulkhead within the mine, 14 m from the adit mouth of Honko; and the second is from the adit mouth of Niko, which is already buried (Fig. 1).

1.2. *Observation of core samples*

Two observation wells are drilled at TT-1 (40 m depth) and TT-2 (30 m depth) in the northwestern part of the study area (Fig. 1). The lithology in well TT-1 is surface soil (0 to −5 m depth), shale (−5 to −28 m) and sandstone (below −28 m) (Fig. 2; Tomiyama et al., 2010b). The microscopic examination and modal analyses of sulfide minerals were done in this study on six polished thin sections from the core samples in the boreholes TT-1 and TT-2. The dominant sulfide minerals are pyrite (40 to 95 wt.%) and sphalerite (5 to 55 wt.%). There are a trace amount of chalcopyrite, galena, and pyrrhotite (Table 1). The rocks except for sulfide minerals consist mainly of quartz and microcline, albite, muscovite, and a trace amount of siderite (Table 2).

The spatial distributions and dip angles of fractures were measured in the cores from the wells (Fig. 2; Tomiyama et al.,