

Hydration of bentonite in natural waters: Application of “confined volume” wet-cell X-ray diffractometry

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Received 12 April 2005; received in revised form 14 January 2006; accepted 15 February 2006

Available online 17 October 2006

Abstract

The hydration behavior of compacted bentonites (Na- and Ca-montmorillonite varieties) in natural ground and sea water is studied using in situ wet-cell X-ray diffraction monitoring techniques. This approach allows us to determine the mechanism and rate of solution uptake in a confined volume, flow-through reactor and serves as an experimental analogue for predicting the performance of repository clay sealants. The pressed bentonite powders (densities of 0.94–1.14 g/cm³) show continuous and strongly partitioned water uptake into montmorillonite interlayers, onto clay particle surfaces and within open pore spaces. During the hydration of compacted Na-bentonite in both ground and sea water, roughly equal quantities of both interlayer and non-interlayer water enter the material. In contrast, the Ca-bentonite was dominated by the intake of more loosely bound, surface and pore water, which amounted to roughly three times more than that incorporated into interlayer sites. Our experiments demonstrate how a confined reaction volume and the strength of the ionic solution both inhibit the interlayer expansion process. Based on the weakly compacted Na-bentonite analogue, a 1 m thick clay sealant is predicted to saturate within 7 years when infiltrated by typical continental ground water, and within 3 years in the case of a sea water breach. As significant volumes of solution are incorporated as loosely bound, non-interlayer water, quantification of the mechanism and rate of water storage is a necessary requirement for improved modeling of elemental transport in a hydrating bentonite medium.

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Keywords: Bentonite; Backfill; Montmorillonite; Hydration; Natural water; Waste repository; Confined volume; Wet-cell XRD

1. Introduction

One of the most important technical properties of bentonite (montmorillonite-rich) clay is its ability to swell and self-seal when hydrated by the inflow of natural waters (Bradly et al., 1937; Norrish, 1954). As a result, this fine-grained material is considered as suitable backfill in the disposal of waste because it significantly restricts movement of aqueous fluids and thus helps retain toxic elements over significant periods of time (Karnland et al., 2000; Hermanns-Stengele and Plötze, 2000; Pusch, 2001). The hydration process not only influences permeability and fluid migration, but also affects chemical transport, pore pres-

sure, material strength and diagenetic mineral reactions both within the backfill and the adjacent wall rock of underground repositories (Montes et al., 2003, 2004; Melkior et al., 2004; Warr et al., 2004).

During swelling, constituent montmorillonite clays hydrate and expand by sorption of water molecules around exchangeable cations that are attracted to the weakly charged interlayers of the sheeted tetrahedral–octahedral–tetrahedral structure (Farmer and Russell, 1971). The water layers order themselves in a structured arrangement, mirroring the charge sites of the tetrahedral sheets, and build up a number of discrete levels each between 2.3 and 2.8 Å in thickness (Karaborni et al., 1996). During this type of intracrystalline swelling up to 4 discrete water layers can form as a function of water activity (varying humidity), layer charge characteristics, type of interlayer cation and the ionic concentration of infiltrating solution (Jasmund

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