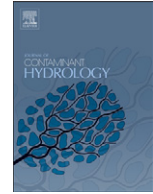




Contents lists available at ScienceDirect

Journal of Contaminant Hydrology

journal homepage: www.elsevier.com/locate/jconhyd

Reconstruction of in-situ porosity and porewater compositions of low-permeability crystalline rocks: Magnitude of artefacts induced by drilling and sample recovery

D.B. Meier^{a,*}, H.N. Waber^a, T. Gimmi^{a,b}, F. Eichinger^c, L.W. Diamond^a^a Rock–Water Interaction, Institute of Geological Sciences, University of Bern, Baltzerstrasse 3, 3012, Bern, Switzerland^b Paul Scherrer Institut PSI, 5232 Villigen, Switzerland^c Hydroisotop GmbH, Woelkestrasse 9, 85301 Schweitenkirchen, Germany

ARTICLE INFO

Article history:

Received 5 August 2015

Received in revised form 16 October 2015

Accepted 21 October 2015

Available online 23 October 2015

Keywords:

Drilling artefacts

Stress release

Diffusion

Porosity

Porewater

ABSTRACT

Geological site characterisation programmes typically rely on drill cores for direct information on subsurface rocks. However, porosity, transport properties and porewater composition measured on drill cores can deviate from in-situ values due to two main artefacts caused by drilling and sample recovery: (1) mechanical disruption that increases porosity and (2) contamination of the porewater by drilling fluid. We investigated the effect and magnitude of these perturbations on large drill core samples (12–20 cm long, 5 cm diameter) of high-grade, granitic gneisses obtained from 350 to 600 m depth in a borehole on Olkiluoto Island (SW Finland). The drilling fluid was traced with sodium–iodide. By combining out-diffusion experiments, gravimetry, UV-microscopy and iodide mass balance calculations, we successfully quantified the magnitudes of the artefacts: 2–6% increase in porosity relative to the bulk connected porosity and 0.9 to 8.9 vol.% contamination by drilling fluid.

The spatial distribution of the drilling-induced perturbations was revealed by numerical simulations of 2D diffusion matched to the experimental data. This showed that the rims of the samples have a mechanically disrupted zone 0.04 to 0.22 cm wide, characterised by faster transport properties compared to the undisturbed centre (1.8 to 7.7 times higher pore diffusion coefficient). Chemical contamination was shown to affect an even wider zone in all samples, ranging from 0.15 to 0.60 cm, in which iodide enrichment was up to 180 mg/kg_{water}, compared to 0.5 mg/kg_{water} in the uncontaminated centre.

For all samples in the present case study, it turned out that the magnitude of the artefacts caused by drilling and sample recovery is so small that no correction is required for their effects. Therefore, the standard laboratory measurements of porosity, transport properties and porewater composition can be taken as valid in-situ estimates. However, it is clear that the magnitudes strongly depend on site- and drilling-specific factors and therefore our results cannot be transferred simply to other locations. We recommend the approach presented in this study as a route to obtain reliable values in future drilling campaigns aimed at characterising in-situ bedrock properties.

© 2015 Elsevier B.V. All rights reserved.

* Corresponding author at: Cohen Geochemistry Group, School of Earth and Environment, University of Leeds, Leeds LS2 9TJ, United Kingdom.

E-mail addresses: eedbm@leeds.ac.uk (D.B. Meier), waber@geo.unibe.ch (H.N. Waber), gimmi@geo.unibe.ch (T. Gimmi), fe@hydroisotop.de (F. Eichinger), diamond@geo.unibe.ch (L.W. Diamond).

1. Introduction

The two major fluid reservoirs in crystalline rocks are groundwater flowing in interconnected fracture networks and porewater residing in the connected pore space of the low-

permeability rock matrix surrounding the fractures. In fracture networks solute transport occurs by advection. In contrast, the continuous exchange of solutes between fracture-hosted groundwater and porewater is dominated by molecular diffusion (also known as matrix diffusion). The efficiency and extent of such exchange in fractured crystalline rocks under in-situ conditions have been under debate for several decades (e.g. Bodin et al., 2003; Grisak et al., 1980; Maloszewski and Zuber, 1990; Neretnieks, 1980; Shapiro, 2001; Sudicky and Frind, 1984). Difficulties mainly include the quantification of the porosity accessible to solutes, the distribution and connectivity of pore space and thus the diffusivity of the rock matrix.

Within the context of deep geological disposal of radioactive waste, for which matrix diffusion is viewed as a significant long-term transport mechanism, numerous laboratory studies have been conducted to derive porosity and diffusion properties of the rock matrix of deep-seated crystalline rocks (Bradbury and Green, 1985; Hellmuth et al., 1993; Johansson et al., 1998; Sardini et al., 2007; Siitari-Kauppi et al., 1994; Skagius and Neretnieks, 1986; Vilks et al., 2003). However, when compared to in-situ values, these laboratory-based investigations of drill core samples overestimate the porosity by up to 3 times and the diffusion properties by more than 10 times (Jokelainen et al., 2013; MacQuarrie and Mayer, 2005; Ota et al., 2003; Schild et al., 2001; Tullborg and Larson, 2006; Vilks et al., 2003; Waber et al., 2011). These discrepancies are attributed to perturbations of the drill core samples by (1) stress release and (2) mechanical disruption during the drilling process. Stress release describes the elastic relaxation (i.e. expansion) a core sample undergoes as soon as it is released from its lithostatic overburden by coring and recovery from the borehole. The mechanical disruption during drilling is due to the friction of the drill bit and is therefore limited to the outermost rim of the drill core. The magnitudes of stress release and mechanical disruption are controlled by the local stress field, sampling depth, sample lithology (e.g. quartz content) and texture (foliation and grain size) and thus strongly depends on the sample location (Gorbatsevich, 2003; Kowallis and Wang, 1983; Meglis et al., 1991; Morrow et al., 1994).

Both of these processes may enlarge pre-existing pores and create new pore space. Waber et al. (2011) assessed the artefacts introduced during drilling and core recovery of medium-grained, isotropic granodiorite from 560 m below surface at Forsmark, Sweden, combining out-diffusion experiments with diffusion simulations. The 5 cm diameter cores were shown to have physically disrupted rims of ~0.6 cm thickness, in which diffusion coefficients were increased compared to the remainder of the core, which presumably reflected the in-situ state of the rock. Furthermore, Waber et al. (2011) showed that these perturbations facilitated penetration of drilling fluid up to 0.03 cm into the core, thereby contaminating ~2.4% of the porewater residing in the connected porosity.

In addition to the perturbations caused during drilling and sample recovery, sample preparation in the laboratory can also introduce artefacts. Most methods to determine porosity in crystalline rocks, such as buoyancy weighing, mercury injection porosimetry, water saturation gravimetry and pycnometric techniques, rely on the preparation of subsamples only a few cm³ in size. The preparation of these small samples by sawing can increase their porosity by factors of 1.5–3 compared to in-

situ values (Ota et al., 2003; Schild et al., 2001; Tullborg and Larson, 2006). The formation of additional porosity during sawing of rock samples was visualised by Kelokaski et al. (2006) using the PMMA-method. In addition to the creation of additional pore space during sample preparation, Vilks et al. (2003) showed that small subsamples are also much more susceptible to alteration during storage, which can additionally increase the porosity by up to 50%. Studies estimating the transport properties of crystalline rocks (i.e. pore diffusion coefficients) also commonly employ small samples to reduce the time required for through-diffusion experiments. As the pore diffusion coefficient depends on the porosity of a sample, a similar trend between decreasing sample thickness and increasing diffusivity would be expected and has indeed been observed in several studies (Johansson et al., 1998; Kumpulainen and Uusheimo, 1989; Skagius and Neretnieks, 1986).

As the degree of perturbation depends on the mineralogical composition, texture, sampling depth and the local natural stress field of the crystalline rock in question, the above results from previous studies cannot be transferred simply to other localities. The present case study focuses on core samples from 350 to 600 m depth in a borehole on Olkiluoto Island, SW Finland, a site which has been under investigation for the deep geological disposal of radioactive waste for more than 20 years. We build on and expand the earlier studies to quantify the magnitude of two artefacts induced by drilling in the crystalline bedrocks: (1) enhanced porosity due to mechanical damage along the rims of the cores, and (2) contamination of the porewater by the drilling fluid. The core samples were drilled with fluid containing sodium-iodide (NaI) as a tracer and then subjected in the laboratory to out-diffusion experiments using the method of Waber and Smellie (2008) to determine porewater anion compositions. Large drill core samples (200 to 380 cm³) were used to minimise sawing and disruption during sample preparation. Therefore, the perturbations identified and quantified are expected to originate dominantly from the drilling process.

The new results, presented in the first part of this article, allow laboratory measurements of bulk porosity and porewater solute concentrations to be corrected for the two artefacts. In the second part of this article, we improve the numerical simulation approach of Waber et al. (2011) to estimate separate pore diffusion coefficients for the mechanically disturbed rim and the undisturbed interior of the rock matrix, thereby explicitly accounting for the two drilling artefacts. All these derived parameters have direct implications for the reconstruction of in-situ porewater and transport properties and they are applicable to the modelling of the long-term behaviour of the planned deep waste repository at Olkiluoto.

2. Geology and hydrogeology of Olkiluoto Island

The bedrock of Olkiluoto Island is composed of Palaeoproterozoic migmatites and gneisses that underwent high-grade metamorphism (660–700 °C, 3.7–4.2 kbar) and partial melting during the Palaeoproterozoic Svecofennian orogeny (1.86–1.79 Ga). Retrograde alteration resulted in sericitisation and saussuritisation of feldspars and chloritisation of mafic minerals. Upon early Mesoproterozoic intrusion of Rapakivi granites (ca. 1.57–1.54 Ga), the rocks were

Download English Version:

<https://daneshyari.com/en/article/4546379>

Download Persian Version:

<https://daneshyari.com/article/4546379>

[Daneshyari.com](https://daneshyari.com)