Characterizing Canadian Shield Fractured Crystalline Rock Settings Using Geochemistry

Stefano D. Normani[1], Andrew P. Snowdon[1], Jonathan F. Sykes[1], Eric A. Sykes[2] and Mark R. Jensen[2]

[1]Department of Civil and Environmental Engineering, University of Waterloo, Waterloo, Ontario, Canada, N2L-3G1

[2]Nuclear Waste Management Organization, 22 St. Clair Avenue East, 6th Floor, Toronto, Ontario, Canada, M4T-2S3

Key words: discrete fracture zone network (DFZN) model, crystalline rock hydrogeology, Canadian Shield geochemistry

Introduction

For used nuclear fuel deep geologic repositories, numerical modelling methods are used to instill confidence in the geosphere as a barrier for a time frame commensurate with repository safety that can exceed 1 Ma. In fractured crystalline rock settings, the presence and distribution of fracture zones in the geosphere will strongly influence groundwater system stability and evolution, however, the characterization of hydraulic conductivity distributions in repository scale fracture zones through field testing is not achievable. By developing plausible geometric models of fracture zone networks that are directly linked to all field observations including geochemical data, 3-dimensional conceptual geosphere models can be developed to both synthesize geoscientific datasets and to provide a physically-based platform to test hypotheses.

For this study, numerical groundwater models were used as a means to assemble, integrate and illustrate the role of geosphere parameters and properties including topography, surface water features, fracture network models, and hydraulic conductivity distributions for both the rock mass and fracture zones. Although the data represent a hypothetical Canadian Shield site, the information is consistent with reported values obtained from site-specific investigations during the Canadian Nuclear Fuel Waste Management Program on the Canadian Shield [1–4]. This data is supplemented with a recently released database of crystalline rock hydraulic properties from [5].

Background

For the present hypothetical study, a 153 km^2 site (Figure 1) was selected from several candidate sites within a larger 5734 km^2 regional-scale model domain [3]. Model extents were based on surface water divides, and assumed groundwater divides, along the western, northern, southern, and eastern domain boundaries. A major river flows east to west through the domain. Also shown in Figure 1 are surface lineaments inferred from air photo interpretation by Srivastava [6], and generated using MoFrac [7]. The MoFrac code enables the generation of geostatistically and structurally possible fracture network models for potential use in future site characterization activities and for geosphere simulations to support the safety case and repository design for potential crystalline rock sites. MoFrac is capable of creating 3D discrete fracture network models (Figure 2) at the tunnel, site and regional scale. The modelling of deterministic features allows MoFrac to be directly linked to field observations.

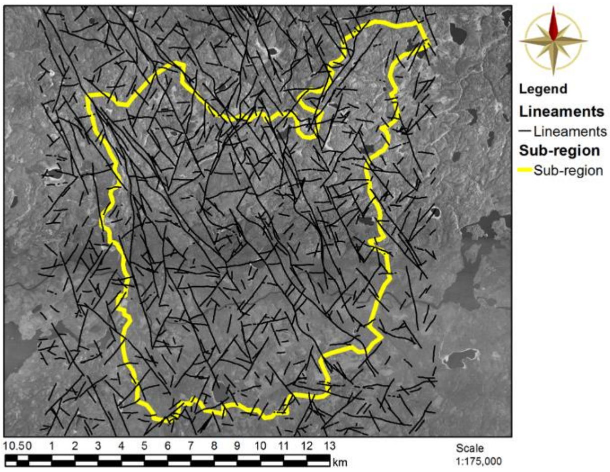

Figure 1: View of modelling domain, aerial photo and surface lineaments

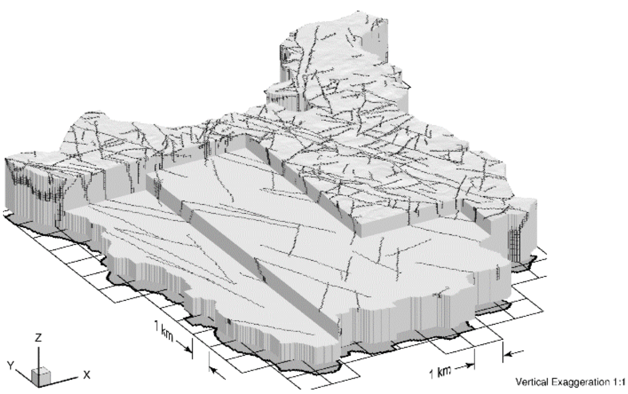

Figure 2: Block-cut view of discrete fracture zone network

The numerical groundwater modelling was performed using the computational model HydroGeoSphere (HGS) [8]. HGS is a computational model capable of solving 3-dimensional variably-saturated groundwater flow and solute transport in discretely-fractured media. The model includes a dual continuum formulation while discrete fractures are represented as 2-dimensional features, defined by hydraulic conductivity and width. The numerical solution to the governing equations is based on implementations of both the control volume finite element method and the Galerkin finite-element method. HGS couples fluid flow with salinity transport through fluid density, which is dependent on the total dissolved solids concentration.

Analysis

Of particular interest in this study is the evolution of the groundwater system over geologic time-scales. The evolution of groundwater system geochemistry in a fractured crystalline rock setting is explored through a series of numerical experiments in which both model hydraulic and transport properties are varied. In the models developed for this study, salinity profiles which can have concentrations in Canadian Shield granitic rock that are greater than typical seawater levels, are included. Various fracture zone hydraulic conductivity distributions such as uniform, varying with depth, and stochastic are included. The degree of importance of both matrix and fracture zone hydraulic properties to the geochemical evolution of the groundwater system, and preservation of the vertical salinity profile typically observed in Canadian Shield fractured crystalline rock settings, is demonstrated through the use of performance measures such as groundwater age, mean life expectancy (MLE), and salinity distributions in both the rock mass and discrete fracture zone network.

The use of high fracture zone hydraulic conductivities can lead to reduced salinity distributions which may not correspond to measured or observed field data. Geochemical data are essential to constrain the fracture and matrix rock properties and provide greater confidence in the robustness and resilience of the groundwater system to external perturbations.

References

[1] F. Garisto, J. Avis, T. Chshyolkova, P. Gierszewski, M. Gobien, C. Kitson, T. Melnyk, J. Miller, R. Walsh, and L. Wojciechowski. Glaciation scenario: Safety assessment for a used fuel geological repository. Technical Report NWMO TR-2010-10, Nuclear Waste Management Organization, Toronto, Canada, 2010.

[2] J. F. Sykes, S. D. Normani, E. A. Sudicky, and R. G. McLaren. Sub-regional scale groundwater flow within an irregular discretely fractured Canadian Shield setting. Technical Report 06819-REP-01200-10133-R00, Ontario Power Generation, Nuclear Waste Management Division, Toronto, Canada, November 2004.

[3] J. F. Sykes, S. D. Normani, M. R. Jensen, and E. A. Sudicky. Regional-scale groundwater flow in a Canadian Shield setting. *Canadian Geotechnical Journal*, 46(7):813–827, July 2009. doi: 10.1139/T09-017.

[4] S. D. Normani, Y.-J. Park, J. F. Sykes, and E. A. Sudicky. Sub-regional modelling case study 2005-2006 status report. Technical Report NWMO TR-2007-07, Nuclear Waste Management Organization, Toronto, Canada, November 2007.

[5] P. Achtziger-Zupančič, S. Loew, and G. Mariéthoz. A new global database to improve predictions of permeability distribution in crystalline rocks at site scale. *Journal of Geophysical Research: Solid Earth*, 122(5):3513–3539, 2017. doi: 10.1002/2017JB014106.

[6] R. M. Srivastava. The discrete fracture network model in the local scale flow system for the Third Case Study. Technical Report 06819-REP-01300-10061-R00, Ontario Power Generation, Nuclear Waste Management Division, Toronto, Canada, December 2002.

[7] S. Bastola, L. Fava, and M. Cai. Validation of MoFrac 2.0 using the Äspö dataset. Technical Report NWMO-TR-2015-25, Nuclear Waste Management Organization, Toronto, Canada, 2015.

[8] Aquanty. *HGS 2013: HydroGeoSphere User Manual, Release 1.0*. Aquanty Inc., Waterloo, Ontario, Canada, 2013.