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Coupled hydromechanical paleoclimate analyses of density-dependant groundwater flow in discretely fractured crystalline rock settings

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A high resolution sub-regional scale (84 km^2) density-dependent, fracture zone network groundwater flow model with hydromechanical coupling and pseudo-permafrost, was developed from a larger 5734 km^2 regional scale groundwater flow model of a Canadian Shield setting in fractured crystalline rock. The objective of the work is to illustrate aspects of regional and sub-regional groundwater flow that are relevant to the long-term performance of a hypothetical nuclear fuel repository. The discrete fracture dual continuum numerical model FRAC3DVS-OPG was used for all simulations. A discrete fracture zone network model delineated from surface features was superimposed onto an 789887 element flow domain mesh. Orthogonal fracture faces (between adjacent finite element grid blocks) were used to best represent the irregular discrete fracture zone network. The crystalline rock between these structural discontinuities was assigned properties characteristic of those reported for the Canadian Shield at the Underground Research Laboratory at Pinawa, Manitoba. Interconnectivity of permeable fracture features is an important pathway for the possibly relatively rapid migration of average water particles and subsequent reduction in residence times.

The multiple 121000 year North American continental scale paleoclimate simulations are provided by W.R. Peltier using the University of Toronto Glacial Systems Model (UofT GSM). Values of ice sheet normal stress, and proglacial lake depth from the UofT GSM are applied to the sub-regional model as surface boundary conditions, using a freshwater head equivalent to the normal stress imposed by the ice sheet at its base. Permafrost depth is applied as a permeability reduction to both three-dimensional grid blocks and fractures that lie within the time varying permafrost zone. Two different paleoclimate simulations are applied to the sub-regional model to investigate the effect on the depth of glacial meltwater migration into the subsurface. In addition, different conceptualizations of fracture permeability with depth, and various hydromechanical loading efficiencies are used to investigate glacial meltwater penetration. The importance of density dependent flow, due to pore waters deep in the Canadian Shield with densities of up to 1200 kg/m^3 and total dissolved solids concentrations in excess of 300 g/L, is also illustrated. Performance measures used in the assessment include depth of glacial meltwater penetration using a tracer, and mean life expectancy. Consistent with the findings from isotope and geochemical assessments, the analyses support the conclusion that for the discrete fracture zone and matrix properties simulated in this study, glacial meltwaters would not likely impact a deep geologic repository in a crystalline rock setting.