THE HYDROGEOLOGIC ENVIRONMENT FOR CARBON SEQUESTRATION: AN ANALYSIS OF ABNORMAL PRESSURES

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Understanding groundwater flow and the characteristics of deep geologic formations in sedimentary basins is necessary for carbon sequestration. The deep hydrogeologic environment of the Michigan Basin has been investigated in comprehensive field and characterization studies associated with a proposed Deep Geologic Repository (DGR) for Low and Intermediate Level Radioactive Waste for the Bruce site near Tiverton, Ontario, 225 km northwest of Toronto. The DGR concept envisions a repository excavated at a depth of 680 m within the low permeability (less than 10-14 m/s) limestone Cobourg Formation beneath 200 m of Ordovician age shale. Cambrian sandstone underlies the site. Pressure data from the DGR site investigation boreholes indicate that the Cambrian sandstone and the permeable Niagaran Group in the Silurian are over-pressured relative to density corrected hydrostatic levels. The Ordovician limestone and shale are significantly under-pressured. Sedimentary basins, when at hydrological equilibrium, normally show a near-hydrostatic pressure distribution. Under certain conditions some excess pressure or pressure greater than hydrostatic can develop in low-permeability layers or other hydraulically isolated parts of systems. The processes commonly invoked to explain these overpressures are compaction, hydrocarbon migration, diagenesis, tectonic stress or more simply topographic effects. Explanations of abnormal under-pressures include osmosis, exhumation, glaciation unloading, crustal flexure and the presence of a non-wetting gas phase in pores. A requirement of both abnormal overpressures and under-pressures is low hydraulic conductivity in either the formation in which the abnormal pressures are observed or in the overlying and underlying formations. The inference on hydraulic conductivity of, and the hypotheses for, abnormal pressures are developed using the three-dimensional saturated density-dependent flow model FRAC3DVS-OPG that includes mechanical coupling and the two-phase gas and water flow model TOUGH2-MP. The overpressure in the Cambrian can be described by density differences across the Michigan Basin and surface topography differences. The under-pressures can be described with a gas water analysis using TOUGH2. For the analysis, the capillary pressure saturation models were defined in the DGR laboratory program using high pressure mercury injection tests. The results indicate that the air entry pressures for the Ordovician rocks are greater than 5 MPa. Paleoclimate analyses and exhumation modeling that included mechanical loading and unloading and saturated conditions could not describe the under-pressures. Important to carbon sequestration, the data and study reveals that low permeability cap rocks may contain an immiscible, possibly discontinuous gas phase. The study also indicates that abnormal high pressures may occur in higher permeability confined units such as those of the Cambrian sandstone. Modelling at different scales is required to explain the over-pressures and the under-pressures.