Geology and Hydrogeology of the Basal Aquifer in the Prairie Region of Canada: Characterization for CO_2 Storage

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The study of the CO_2 storage capacity and effects of CO_2 injection in the Basal Aquifer in western Canada is a multi-province, bi-national (Canada-USA) project that aims to define the area suitable for CO_2 storage, and evaluate the storage capacity of the lowermost Cambro-Ordovician saline-aquifer system in the Northern Plains – Prairie Region of North America. Within Canada, the Basal Aquifer has an area ~811,000 km^2 and underlies 20 large CO_2 sources in 16 locations with combined annual emissions of 83 Mt, representing 12% of Canada's annual CO_2 emissions. Geological characterization of the Canadian portion of the aquifer and hydrogeological characterization of the entire aquifer have been completed to date.

The Basal Aquifer consists of diachronous Middle Cambrian to Lower Ordovician clean sandstones (up to 90% quartz) of the Basal Cambrian Sandstone unit, and Deadwood and Winnipeg formations that overlie the crystalline Precambrian basement in the Alberta and Williston basins (Figure 1). The depth to the top of the Basal Aquifer varies from close to 5000 m in the Alberta Basin east of the Rocky Mountain Deformation Front, and more than 3300 m in southeastern Saskatchewan close to the depocenter of the Williston basin, to zero at the basin edge in east-central Saskatchewan and central Manitoba. The thickness of the aquifer is highly variable, ranging from less than 50 m in Alberta close to the Rocky Mountain Deformation Front and in southwestern Manitoba, to more than 400 m in the vicinity of the Meadow Lake Escarpment in eastern Alberta and western Saskatchewan. Aquifer zero thickness at the aquifer/basin edge in central Alberta and Saskatchewan, and east-central Manitoba, respectively, is a result of erosional truncation. The average well-scale porosity of the Basal Aquifer varies from less than 1% in the deep portions of the Alberta basin, to more than 25% in shallower regions, particularly close to the northern edge of the aquifer in eastern Alberta – western Saskatchewan. Aquifer permeability varies in a very wide range, from <10 mD to several thousand mD.

The aquifer is overlain by a primary caprock comprising mainly Cambrian and Ordovician shales, but also tight carbonates and evaporites. In east-central Saskatchewan and central Manitoba, where the shales of the Icebox Member of the Winnipeg Formation become sandy, there is no aquitard separating the Basal Aquifer from the overlying Ordovician and Silurian carbonates, such that the Basal Aquifer in this area is inferred to comprise both sandstones at the base and a series of carbonates at the top. Due to erosional events, the Basal Aquifer outcrops and becomes unconfined in central Manitoba under a veneer of Cenozoic unconsolidated sediments.

The temperature in the Basal Aquifer increases with depth towards the Alberta Syncline in the west and towards the depocenter of the Williston Basin in the south. The temperature values range from >150°C in the northwest of the Alberta Basin and >130°C in the Williston Basin in North Dakota, to <30°C at the aquifer's southern and northeastern flanks. The total dissolved solids (TDS) range from >300,000 mg/L in central Alberta and the deep parts of the Williston Basin, to <10,000 mg/L at the aquifer's edges and outcrop areas in the south and northeast. The hydraulic heads based on average groundwater density

of 1090 kg/m^3 range from >1200 m in south-central Montana to <300 m in northeastern Saskatchewan and western Manitoba. The vertical pressure gradient in the aquifer ranges from 10 kPa/m to 11.5 kPa/m, and strongly depends on the TDS and groundwater density.

The groundwater in the Basal Aquifer flows from its southern recharge areas in Montana, Wyoming and South Dakota to the north and northeast, towards the Alberta Basin and the discharge areas in northeastern Saskatchewan and central Manitoba. Significant density effects marked by quasi-stagnant flow conditions are present in the deepest parts of the aquifer due to high TDS and water density, resulting in negative buoyancy effects.

The area suitable for CO_2 storage of approximately 450,000 km^2 was determined based on water salinity greater than 10,000 mg/L, porosity greater than 4%, CO_2 dense phase and storage depth of minimum 1000 m. The regional-scale CO_2 storage capacity of the Basal Aquifer in Canada is estimated to be 85 Gt CO_2 (23 Gt in Alberta, 60.6 Gt in Saskatchewan and 1.3 Gt in Manitoba), which will last for 1150 years for storing CO_2 emissions at current levels from the locations under consideration, or for ~144 years if a 5% annual rate of increase in CO_2 emissions at these locations is assumed. These calculations are based on the presented data and the most recent regulatory framework for CO_2 storage in Alberta and the USA.

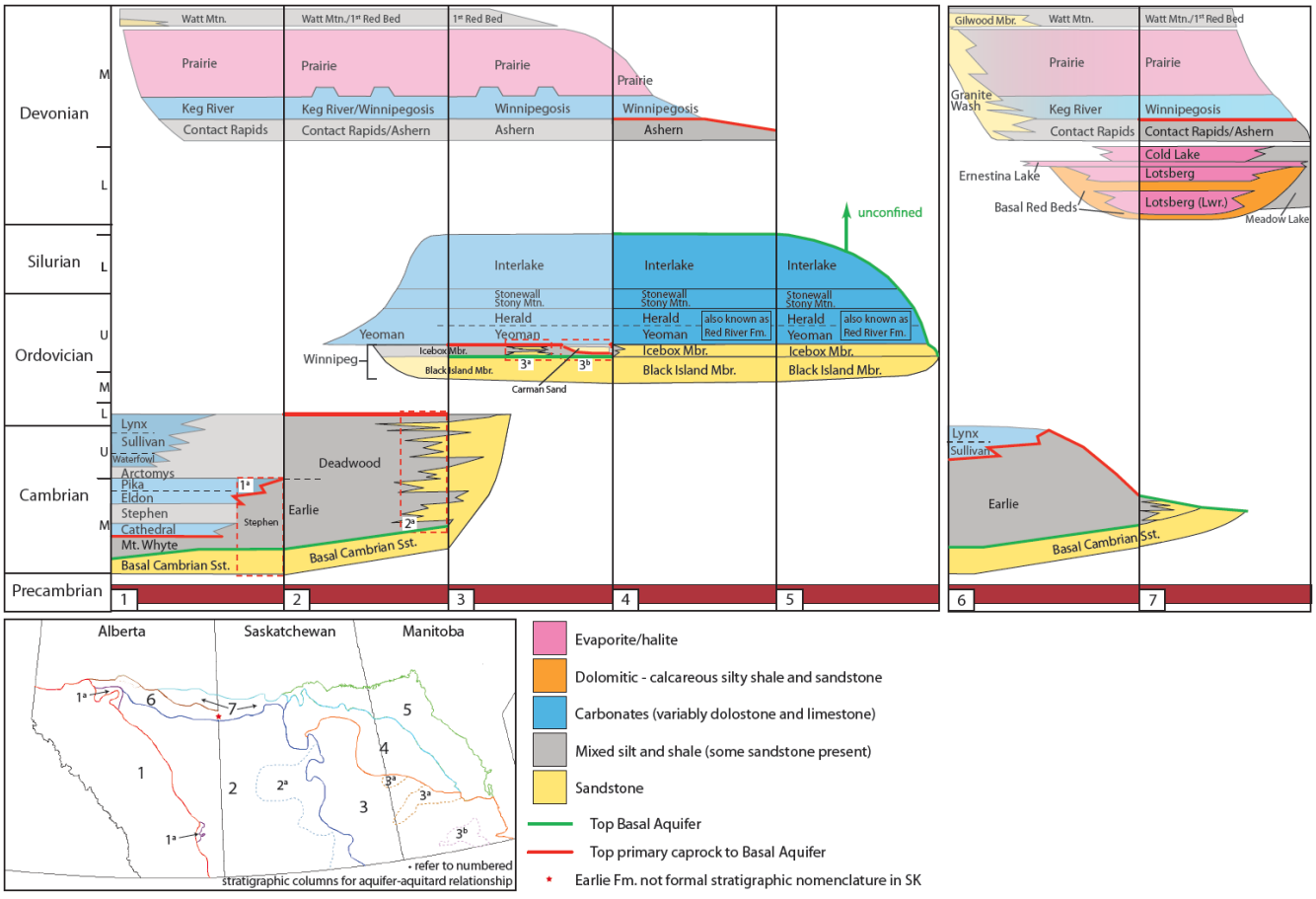

Figure 1: Stratigraphic column and aquifer-aquitard relationships at various locations covered by the Basal Aquifer in the Prairie Region of Canada.