A Conceptual Hydrogeochemical Model for Groundwater Evolution in Western Canada with Applications to the Energy Sector

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ABSTRACT

Groundwater compositions and water types in Canada’s prairie provinces are diverse and reflect the immature geoscape within which they evolve. About ten thousand years ago glaciers receded revealing a landscape dominated by tills, glaciolacustrine, and glaciofluvial deposits comprising comminuted bedrock, dominantly marine shale. Exposure of fresh, fine-grained shale to oxygenated groundwater resulted in rapid oxidation and dissolution of reactive shale components under open system conditions followed by the onset of microbially mediated reducing conditions as the groundwater hydrogeochemical system transitioned to closed system conditions beyond the influence of atmospheric oxygen.

The evolution from open to closed system conditions is governed by several factors and mediated chiefly by microbial reactions involving oxidized components known as “electron acceptors” and reduced sedimentary organic material (SOM) comprising organic geopolymers, the remnants of ancient organisms and plants, as well as pyrite. These microbially mediated reactions occur in a thermodynamically predictable sequence and as a result, groundwater hydrogeochemistry evolves predictably. Understanding these principles is the foundation of the proposed conceptual hydrogeochemical model (CHM).

A number of processes important to the energy industry can be examined within the context of the groundwater CHM. Open system oxic conditions are important to surface and near-surface processes such as the attenuation and remediation of hydrocarbon spills, but also to understanding the oxidation of reduced SOM and pyrite in shale-derived tills that contribute to natural background distributions of nitrate, sulphate, and acidic conditions caused by pyrite and SOM oxidation. The transition from open (oxic) to closed system (anoxic) conditions is fundamentally important to groundwater types and provides a unidirectional pathway against which to track groundwater evolution. Pyrite and SOM oxidation generates acid that is buffered by carbonate dissolution or silicate hydrolysis reactions. Where carbonate minerals are present, shallow oxic conditions are characterized by Ca-Mg-HCO₃±SO₄-type groundwater. The transition to closed system anoxic conditions results in a change to Na-HCO₃±SO₄-type groundwater due to a drop in CO₂ production hence reduced carbonate mineral dissolution. Similarly, the transition to sulphate reduction and methanogenesis results in addition of H₂S and CH₄ to the dissolved gases carried in groundwater. This is important for groundwater evolution under thermal gradients because the rate of microbial processing of SOM increases by an order of magnitude for each 10 C-degree increase in temperature. These temperature sensitive microbial reactions trigger thermal effects by driving the closed groundwater system towards methanogenic conditions causing the dissolution of metal-adsorbing iron-hydroxide minerals, releasing trace metal cations along with the concomitant generation of first H₂S under sulphate reducing conditions, then methane. It is now being recognized that dissolved gas generation in warming aquifers is a widespread effect related to thermal recovery of bitumen.

BIOGRAPHY

CSPG HYDROGEOLOGY TECHNICAL DIVISION
Hugh Abercrombie is a Calgary based geochemist currently working in the environmental consulting field. His background is diverse and includes mineral exploration, geochemical thermodynamics, aqueous geochemistry, government scientific research, laboratory operations and analytical instrumentation, technology development, resource estimation, financial valuation, environmental permitting, monitoring and remediation.

He is the inventor of a US patent for recovery of natural nanoclusters and was the founding chairman of a not-for-profit corporation involved in volunteer fundraising in Alberta.