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Subsurface natural gas migration in heterogeneous Quaternary deposits of the Montney Resource play, northeastern British Columbia (NE BC), Canada: Insights provided by a controlled release experiment

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Summary

Ongoing petroleum resource development raises concerns about the unintentional release of fugitive gas into shallow aquifers. Given that limited field investigations have examined transport and fate of fugitive gas from real cases of wellbore leakage, we conducted a controlled-release experiment in a shallow confined aquifer typical of NE BC, where intensive petroleum resource development occurs. The subsurface at the site is highly complex, consisting of a 12 m thick silty diamict confining layer, underlain by 14 m of heterogeneous glacial outwash comprised of interbedded sands, silts and clays. Prior to the experiment the site was rigorously characterized at high resolution by sonic cores, cone penetrometer testing, downhole and surface-based geophysical surveys. We injected 100 m^3 of synthetic Montney natural gas (85% CH_4, 8% C_2H_6, 5% C_3H_8) at the base of the confined aquifer over 66 days and monitored gas migration using 19 multilevel monitoring wells with 50 sample ports, 5 single screen piezometers and 4 in-situ pressure transducers. After 12 days of injection, a subtle increase in dissolved CH_4 was detected (~ 0.1 compared to a baseline of ~10^{-3} mg/L) in 1 port at 16 m depth, 10 m up-gradient of the injection point. 5 ports showed clear increases in CH_4 (ranging from ~0.1 – 16 mg/L) during injection, whereas 17 ports showed elevated CH_4 274 days post-injection. Only half of the ports (n = 8/17) where elevated CH_4 was detected also contained elevated ethane (~0.003 – 1.9 mg/L), potentially a result of a higher effective solubility causing a chromatographic effect during gas migration. The greatest levels of dissolved CH_4 occurred mostly at 12 and 18 m depths concurring with an increase in subsurface resistivity, likely a result of capillary trapping caused by low-permeability units identified in sediment cores. Generally under saturated dissolved CH_4 conditions were observed, likely due to channeling of free-phase gas and limited mixing with groundwater in the complex and fine-grained soils. Gas migration in this Quaternary geological system appears to move in a highly discrete manner through localized, small preferential channels controlled by the presence and nature of capillary barriers. The preliminary estimate of field-scale mass transfer of CH_4 based on field-derived data, suggests that dissolution times will likely be on the order of decades to centuries.

Method

The Hudson's Hope Field Research Station (HHFRS) was established in the Peace Region of NE BC, where extensive petroleum resource development takes place. The subsurface geology of the site was rigorously characterized by collecting 13 continuous cores, 9 cone penetrometer (CPT) profiles, and 4 electrical resistivity tomography (ERT) profiles. Hydraulic properties (e.g., hydraulic conductivity) of HHFRS were estimated by a suite of hydraulic testing (i.e. pumping and slug tests) and grain-size analyses of 58 sediment samples. A hydrogeological conceptual model was developed to describe the heterogeneous nature of the Quaternary unconsolidated sediments, based on estimated hydraulic properties, core lithology, and stratigraphy extrapolated by core, ERT and CPT data.

In June 2018, we injected 100 m^3 of synthetic Montney gas near the bottom of the aquifer at 26 m depth for 66 days at a constant rate. Water chemistry and dissolved gas evolution were monitored through 35 discrete sampling ports before, during and after injection over 490 days. ERT profiles were collected before, during and after injection to monitor changes in resistivity.

Observations and Results

During the injection period, elevated dissolved CH_4 concentrations (0.1 – 15 mg/L) first appear at two locations that are upgradient and orthogonal to the groundwater flow direction, approximately 10 m from the injection well. After injection decommissions, elevated dissolved CH_4 concentrations display at 10 more locations across the site, showing an enhanced dissolution of CH_4 due to the likely collapse of gas channels from the termination of injection. ERT profiles indicate that a significant lateral migration of free-phase gas takes place beyond the monitoring well network (radius of 25 m) in directions upgradient, downgradient and orthogonal to the groundwater flow direction.

The hydrogeological conceptual model reveals that the overlying silty diamict is considered to limit vertical gas migration to the ground surface. Such glacially-derived, fine-grained deposits are very common throughout NE BC, suggesting regional confinement or limited vertical migration of gas and a commensurate accumulation of methane, if leakage occurs in such a setting. Aquifer of stratified deposits (i.e. the middle aquitard) promoted significant lateral gas migration. The preliminary estimate of field-scale mass transfer of CH_4 based on field-derived data, suggests that a considerably large amount of CH_4 remains as free-phase gas and dissolution times will likely be on the order of decades to centuries.

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