The influence of formation water geochemistry on microbial community composition, biogeochemical pathways, and biodegradation rates in oil sands microcosms

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Abstract

Petroleum hydrocarbon biodegradation via methanogenesis has been identified as the major post-emplacement alteration process in the Athabasca oil sands region (AOSR) (Wilhelms et al., 2001; Head et al., 2003; Adams et al., 2004; Jones et al., 2008). However, biodegradation is also responsible for economic accumulations of natural gas in some areas of the AOSR (and other gas deposits such as the Antrim shale), and biodegradation in sedimentary basins has been suggested as a possible driver of the global carbon cycle and Earth's climate system (Kroeger et al., 2011; Berbesi et al., 2014). Shallow hydrocarbon reservoir environments in the AOSR are favorable to hydrocarbon biodegradation due to low temperature, moderate pH, availability of water and nutrients, and an abundant carbon source (Zengler et al., 1999; Widdel et al., 2001; Roling et al., 2003; Larter et al., 2003; Larter et al., 2006; Oldenburg et al., 2006; Bennett et al., 2013). However, formation water chemistry is thought to exert a substantial control on rates and pathways of biodegradation, and McMurray Formation water

geochemistry is highly variable across the AOSR. Total dissolved solids concentrations in McMurray Formation water range from 220−280 000 mg/L (Cowie et al. in review), and dissolved sulfate varies from 0 to 4 000 mg/L.

Microbial communities are sensitive to changes in formation water geochemistry (Waldron et al., 2007). Therefore under the variable geochemical conditions observed in the modern McMurray Formation, microbial processes and hence biodegradation rates and pathways are anticipated to be disparate across the AOSR. The objective of this study was to investigate changes in microbial community composition, and to identify changes in rates of methanogenesis and bacterial sulfate reduction that are attributable to variability in aqueous geochemistry under controlled laboratory conditions.

Laboratory microcosms containing well-characterized microbial communities (derived from Berdugo-Clavijo et al., 2012) were grown on an oil sands substrate with three different aqueous geochemical compositions that are typical of McMurray Formation waters in the Athabasca region (TDS values 1000, 7000, 20000 mg/L). Microbial community composition was monitored using 16S rRNA pyrosequencing, while methane generation rates, and stable isotope compositions of CO_2 ($\delta^{13}C$), gas-phase hydrocarbons ($\delta^{13}C$ and $\delta^{2}H$) and dissolved sulfate ($\delta^{34}S$) were measured over twelve months to assess changes in redox and hydrocarbon biodegradation pathways. Distinct differences in microbial community composition, rates of methane generation, and stable isotope geochemistry were observed between microcosms with different water properties. Therefore, we conclude that formation water geochemistry exerted a significant control on biogeochemical processes in our experiments. The direct extension of our bench-scale experiments to field-scale predictions is not yet prudent. However the obtained results strongly suggest that differential biodegradation related to formation water properties is likely across the AOSR. As such, microbial composition analyses may help predict biodegradation potential in various locations across the AOSR. Comparisons of hydrocarbon properties in reservoirs with distinct formation water chemistry may reveal distinct differences in hydrocarbon geochemistry and petroleum properties that may have significant economic impacts.

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