

Assessing differences between using landowner versus dedicated monitoring wells for baseline groundwater testing in prospective shale gas development areas: preliminary results from C isotope and redox parameter measurements

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Abstract

A comparison of aqueous geochemistry, gas concentration and gas isotope data obtained from shallow groundwater samples obtained from dedicated monitoring wells and domestic landowner wells in the same study area was conducted to assess the suitability of these well types for baseline groundwater sampling in shale gas development areas. Preliminary data evaluation reveals that the results of gas chemistry and carbon isotope analyses in free gas samples obtained from groundwaters in dedicated monitoring wells versus those from landowner wells are quite comparable. Also, the patterns of occurrence and the concentrations of terminal electron acceptors (TEAPs) in groundwater samples containing methane obtained from dedicated monitoring wells and landowner wells is comparable in principal, although the concentration thresholds of selected TEAPs are somewhat higher in groundwater samples from landowner wells. This is presumably caused by the longer screen intervals of landowner wells that may facilitate mixing of waters under different redox conditions. Further evaluation of this data set is required before recommendations can be formulated for future baseline groundwater monitoring programs in areas of unconventional energy resource development.

Introduction

Natural gas extraction from unconventional energy resources such as shale is currently transforming the global energy outlook. The recent expansion of the unconventional gas industry in North America and the planned advent of this technology in parts of Europe have, however, generated public concern regarding the potential contamination of shallow groundwater and surface waters by natural gas and by hydraulic fracturing flow-back fluids containing saline formation waters together with fracturing chemicals¹.

A major challenge for environmental impact assessment in the context of unconventional petroleum exploitation is the determination of the non-impacted baseline conditions often termed environmental baseline assessment. Groundwater and surface water resources overlying the low-permeability host rocks of shale oil and gas may be impacted to different extents by naturally occurring saline fluids and by natural gas emanations²⁻⁴. Therefore, it is of key importance to determine chemical and isotopic compositions of water, dissolved constituents, and dissolved or free gases including methane in surface waters and shallow aquifers prior to development of unconventional energy resources. There is, however, a debate whether it is suitable to take baseline groundwater samples from shallow aquifers using often long-screened wells owned and used by landowners (e.g. domestic wells) or whether dedicated monitoring wells are required.

The objective of this ongoing study is to compare aqueous and gas geochemistry and isotope data in a region of southeastern Alberta (Canada) where shallow groundwater samples were obtained from both dedicated monitoring wells and landowner wells. The aim was to quantify similarities and detect potential discrepancies between key baseline monitoring parameters and test for the suitability of both sampling approaches in light of achieving effective groundwater baseline data.

Sampling and Methods

Groundwater was sampled in a region of south-eastern Alberta (Canada) from numerous monitoring and landowner wells and water quality parameters were analysed using standard approaches. The isotopic composition of groundwater ($\delta^2\text{H}$ and $\delta^{18}\text{O}$) was determined using a Los Gatos Research 'DLT-100' laser spectroscopy instrument. Free gas samples were obtained and concentrations of methane, ethane, propane and butane, N_2 and CO_2 were determined by gas chromatography. The $^{13}\text{C}/^{12}\text{C}$ and $^2\text{H}/^1\text{H}$ ratios of methane and ethane (where possible) were analyzed by isotope ratio mass spectrometry (IRMS) coupled to GC combustion and pyrolysis with precisions of $< \pm 0.5\%$ and $< \pm 3\%$, respectively.

Results

For samples obtained from landowner wells, results are summarized below. We found that methane is ubiquitous in free gas samples obtained from groundwater sampled throughout the study area. Methane concentrations in free gas samples ranged from <10 ppmv to $>1,000,000$ ppmv. Methane was detected in 787 of 808 free gas samples (97.4 %) with concentrations above the detection limit. Box-Whisker plots summarizing the distribution of concentrations of methane and higher alkanes are provided in Figure 1a.

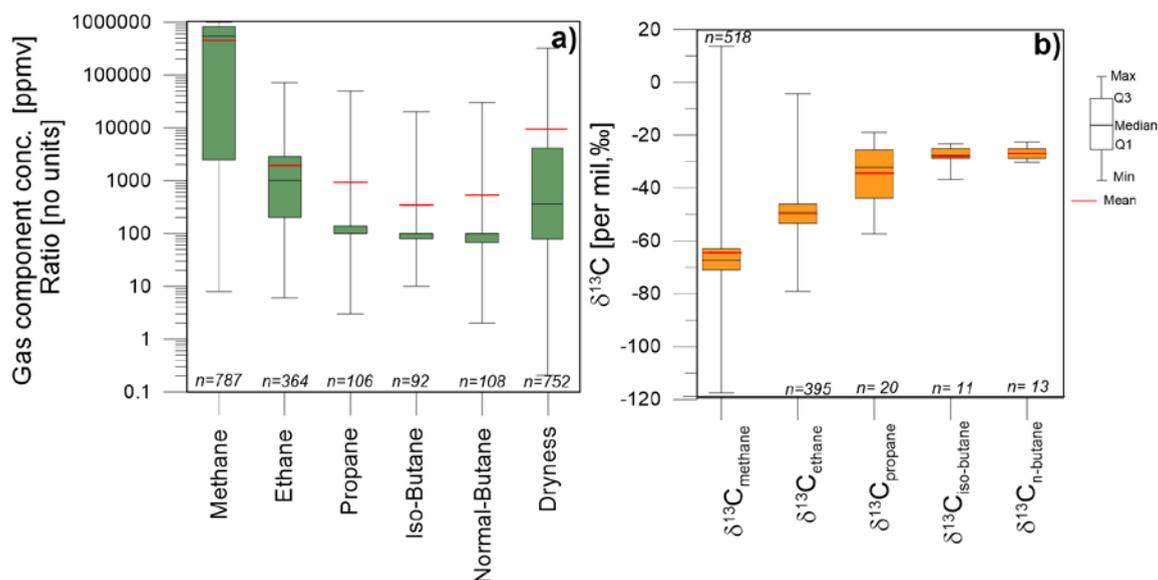


Figure 1: a) Box-Whisker plots displaying concentrations of methane and higher alkane chain components and the dryness parameter with Q1, Q2, and Q3 values shown in the box; arithmetic mean values are shown as red lines; b) Box-Whisker plots depicting $\delta^{13}\text{C}$ values of methane and higher alkanes chain components with Q1, Q2, and Q3 values shown in the box; arithmetic mean values are shown as red lines.

The methane concentrations in free gas samples have median and mean values of 543,300 and 454,699 ppmv ($n=787$). The first (Q1) and third quartile (Q3) values for methane concentrations are 2,625 and 837,050 ppmv respectively. Ethane was detected in 364 free gas samples with reliable concentration data above the detection limits. Ethane concentrations in free gas samples have median and mean values of 1,007 and 1,928 ppmv ($n=364$). The first (Q1) and third quartile (Q3) values for ethane concentrations are 200 and 2,861 ppmv respectively (Fig. 1a). The highest reported ethane concentration was 70,500 ppmv. Propane was detected in 106 free gas samples with concentrations above the detection limits. Propane concentrations in free gas samples have median and mean values of 100 and 931 ppmv, respectively. The first (Q1) and third quartile (Q3) values for propane concentrations are 100 and 132 ppmv, respectively (Fig. 1a).

The dryness parameter was also calculated for 752 samples. For free gas samples with concentrations of higher alkanes at or below the detection limit, the detection limit value was used for this calculation. Therefore, the reported dryness parameters may be underestimated in many cases and additional variability is introduced due to different detection limits reported by different laboratories. The dryness parameter in free gas samples has median and mean values of 350 and 9,274 respectively (n=752). The first (Q1) and third quartile (Q3) values for the dryness parameter are 77 and 4,029. A total of 338 free gas samples had a dryness parameter > 500 (Fig. 1a).

Box-Whisker plots summarizing the carbon isotope ratios of methane, ethane, propane, iso-butane and normal butane expressed in $\delta^{13}\text{C}$ values are summarized in Figure 1b. Methane in free gas samples had median and mean $\delta^{13}\text{C}_{\text{CH}_4}$ values of -67.3 and -64.4 ‰ (n = 518) respectively. The first (Q1) and third quartile (Q3) $\delta^{13}\text{C}$ values of methane are -71.1 and -62.9 ‰ (Fig. 1b). Ethane in free gas samples had median and mean $\delta^{13}\text{C}_{\text{CH}_4}$ values of -49.1 and -49.8 ‰ (n= 395) (Fig. 1b). The first (Q1) and third quartile (Q3) $\delta^{13}\text{C}$ values of ethane are -53.3 and -46.1 ‰ (Fig. 1b). Propane in free gas samples had median and mean $\delta^{13}\text{C}_{\text{CH}_4}$ values of -32.1 and -34.3 ‰ (n= 20) (Fig. 1b). The first (Q1) and third quartile (Q3) $\delta^{13}\text{C}$ values of propane are -38.3 and -27.5 ‰ (Fig. 1b).

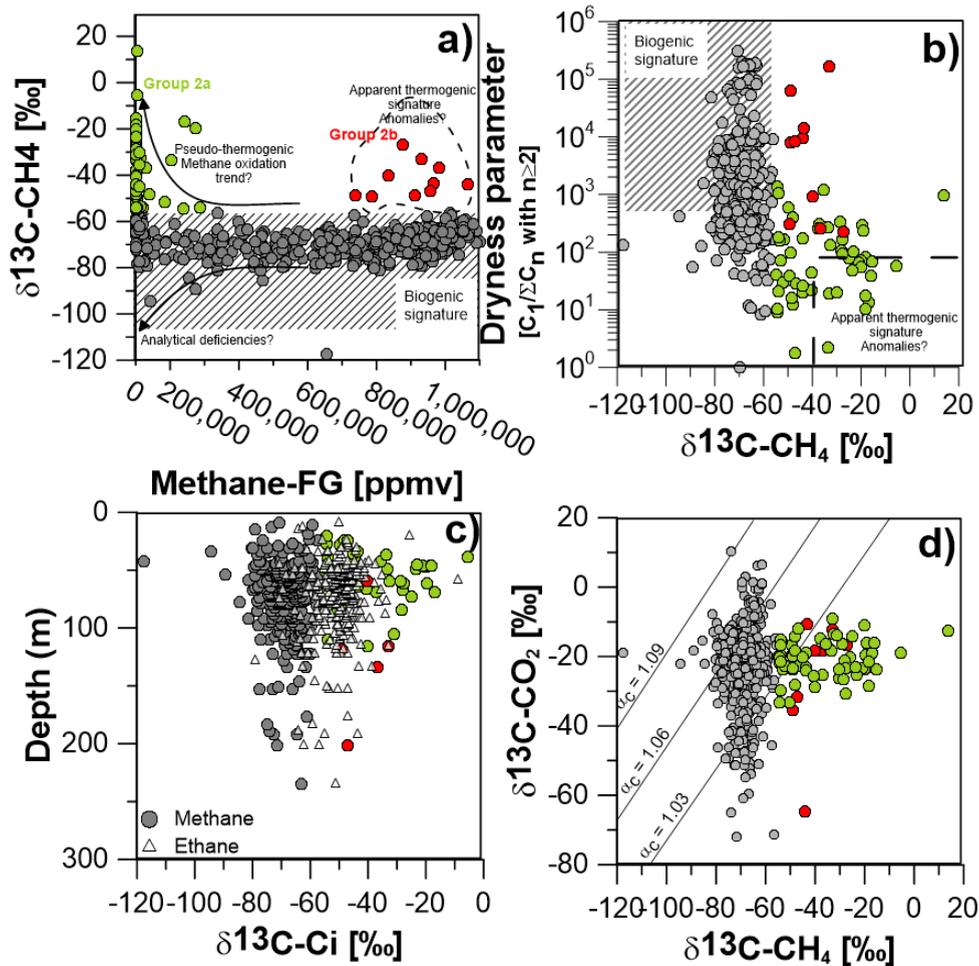


Figure 2: a) $\delta^{13}\text{C}-\text{CH}_4$ values versus methane concentrations; b) dryness parameter versus $\delta^{13}\text{C}-\text{CH}_4$ values; c) $\delta^{13}\text{C}-\text{CH}_4$ values of methane and ethane versus depth; d) $\delta^{13}\text{C}-\text{CH}_4$ versus $\delta^{13}\text{C}-\text{CO}_2$ values to assess methane formation pathways.

Discussion

For samples from landowner wells, we found that the majority of the methane-containing samples were characterized by $\delta^{13}\text{C}$ values of methane $< -55\text{‰}$ ($n=447$; Fig. 2a) while low to negligible concentrations of higher alkane chain components such as ethane resulted in high gas dryness values ($D>500$) (Fig. 2b).

This, together with water chemistry data indicating highly reducing conditions, is indicative of in-situ formation of biogenic methane in the sampled aquifers for the majority of the samples in the landowner database. For a smaller number of samples ($n=71$), methane with elevated $\delta^{13}\text{C}$ values of $> -55\text{‰}$ was identified (Fig. 2a). Group 2a of these samples is characterized by low methane concentrations, which may be consistent with the occurrence of methane oxidation. Group 2b is characterized by high methane concentrations and elevated $\delta^{13}\text{C}$ values of methane. We have commenced with an assessment whether these occurrences indicate migration of thermogenic gas into shallow aquifers or whether they are related to oxidation of biogenic methane within shallow aquifers resulting in “pseudo-thermogenic” gas samples.

We have also compared the occurrence of methane in free gas samples obtained from landowner wells with the occurrence and concentrations of terminal electron acceptors (TEAPs) such as O_2 , NO_3 , Mn, Fe, and SO_4 in the water samples. We found that in most samples ($>95\%$) the occurrence of elevated concentrations of methane was only identified in water samples where TEAPs such as O_2 , NO_3 , Mn, Fe, and SO_4 were either not present or occurred only in negligible concentrations (Fig. 3). For most of the investigated samples, this is consistent with an in-situ formation of methane within the aquifer. An alternate explanation that also needs to be considered is the potential migration of methane into the aquifer thereby triggering removal of TEAPs via redox buffering reactions.

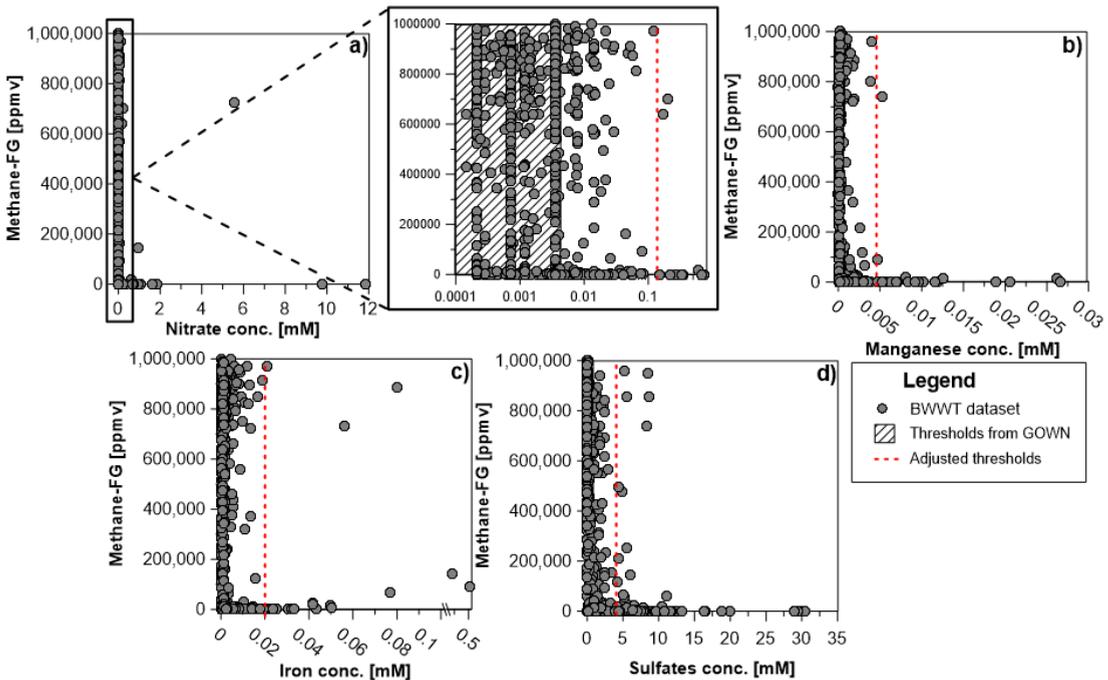


Figure 3: Diagrams showing relationships between concentrations of a) methane/nitrate b) methane/manganese c) methane/iron and d) methane/sulfate in water and free gas samples from landowner wells and identification of redox sensitive species thresholds that enable occurrence of methane (red dashed lines).

A comparison with aqueous geochemistry, gas concentration and gas isotope data obtained from shallow groundwater samples obtained from dedicated monitoring wells in the same study area was conducted. Preliminary data evaluation reveals that the results of gas chemistry and carbon isotope analyses in free gas samples obtained from groundwaters in dedicated monitoring wells versus those from landowner wells are quite comparable. Also, the patterns of occurrence and concentrations of terminal electron acceptors (TEAPs) in groundwater samples containing methane obtained from dedicated monitoring wells and landowner wells is comparable in principal, although the concentration thresholds of selected TEAPs are somewhat higher in groundwater samples from landowner wells. This is presumably caused by the longer screen intervals of landowner wells that may facilitate mixing of waters under different redox conditions. Further evaluation of this data set is required before recommendations can be formulated for future baseline groundwater monitoring programs in areas of unconventional energy resource development.

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