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Using Gas Carbon Isotopes to Design and Drill Better Shale Gas Wells

Marianne Molgat*, Talisman Energy Inc., Calgary, Alberta
mmolgat@talisman-energy.com
and
Jean-Yves Chatellier and Milt McCoy Talisman Energy Inc., Calgary, Alberta

Introduction

Historically, the upstream oil and gas industry utilized isotope geochemistry mainly as a forensic tool to address and mitigate problems such as gas migration or surface casing vent flows. It is now also commonly used as an exploration tool to better understand and target shale reservoirs.

Gas carbon isotopes were obtained from mud gas (Isotubes) and cuttings headgas (Isojars) at regular intervals across a 2000 meter thick shale-rich stratigraphic section from vertical and horizontal wells in Quebec. This unique dataset provides abundant insight on a basin's geological history, shale geochemistry, and can also help to design and drill better wells.

Observations

Because of the relatively impervious nature of the very thick Lorraine and Utica shale succession in the Saint-Lawrence Lowlands, gas carbon isotopes collected provided an ideal dataset for detailed geochemical analysis. The following general observations were made:

1) As a whole, there is a high confidence level that gas is in situ and there is no evidence for prevailing gas mixing or migration within the observed stratal succession. The $\delta^{13}C$ methane versus depth regression line shows a correlation coefficient generally greater than 0.86 (Fig 1)

2) The linearity of $\delta^{13}C$ data versus depth suggests that the bulk of Lorraine Shale deformation took place prior to maximum burial depth and generation of natural gas. In isolated cases, small offsets are observed within the linear trend across the Lorraine, indicating that minor reactivation along an existing thrust fault likely took place some time after maximum burial depth. Interestingly, the isotope profile slope above this break is different than below, which could be attributed to a change in bed dip.

3) Detailed analysis of isotope profiles may provide insights on minor structural elements within the sedimentary succession even though there is a high correlation coefficient This application of isotopes should, however, be used with caution.

4) For ethane and propane isotopes, a reversal in slope of $\delta^{13}C$ vs depth is systematically observed and <u>does not</u> correlate to stratigraphy. Ethane and propane $\delta^{13}C$ become heavier (less negative) and then lighter (more negative) at the reversal point (Fig 1). Notably, slope reversals were not observed for methane, which continues to enrich in ^{13}C with depth.

5) True vertical depths of isotope reversals in the Saint-Lawrence Lowlands is shallower in wells located in the southwest compared to those in the northeast, suggesting the former area experienced more uplift and/or erosion.

6) Extreme variability in $\delta^{13}C$ is commonly observed for methane, ethane and propane at the reversal point (Fig 2).

7) Data collected shows that the slope of $\delta^{13}C_1$ and $\delta^{13}C_3$ versus depth are systematically nearly identical above the reversal, whereas the slope of $\delta^{13}C_2$ is different (Figure 3). This observation is poorly understood.

8) In wells where a vertical pilot hole was drilled prior to drilling the build and horizontal sections, it was observed that $\delta^{13}C$ values are significantly lighter (more negative) at the start of the build section near the kick off point. This suggests that isotope fractionation takes place within a relatively short time frame if gas is able to migrate, and is not necessarily linked to the type of gas flowing (free gas vs adsorbed gas). It is therefore also expected that $\delta^{13}C$ signatures of produced gas will change through time since the lighter isotope is preferentially produced earlier in the well's history.

Although this dataset is specific to the Saint-Lawrence Lowlands the general observations made are helpful in understanding both the potential and limitations of using stable isotopes as an exploration tool. It is important to note that carbon isotope values at the reversal point are not absolute and will vary from basin to basin and even within a same basin. Attributing gas oil ratios to ethane $\delta^{13}C$ values should therefore be done with much caution and only after sufficient calibration.

Discussion and data integration into drilling design

In newer basins, where detailed drilling knowledge of the subsurface is not yet well established, carbon isotope data can be valuable source of information for designing new casing and cementing programs.

1) Many wells in the Saint-Lawrence Lowlands are reported to have SCVF. Isotopes were successfully used as a forensic tool to help identify the source of vent gas and execute effective remedial programs (Chatellier *et a*l 2012). Certainly, best casing and cementing practices should be in place to avoid such events. Other practices such as pressure testing green cement and using foam cement, which has been successfully used in the Horn River Basin, or setting an additional intermediate casing string above the isotope reversal and overpressured zone can also be considered as part of an exploration program to determine the best casing and cementing design for the local geology.

2) Isotope analysis could also help to optimize interwellbore distances and minimize capital overexpenditure related to stimulating reservoir-rock that may have already been stimulated. Since carbon isotope fractionation was observed in the build section adjacent to a pilot hole, this relationship can be used as a proxy in newly drilled offset horizontal wells to identify zones that may already benefit from good permeability (already stimulated, open fractures, or leaky faults). Identification of these zones could help improve the completion program. Similarly, the observed relationship can help with optimizing well spacing between stimulated horizontal legs if isotope fractionation is observed in a new well, relative to its offset well.

Acknowledgments

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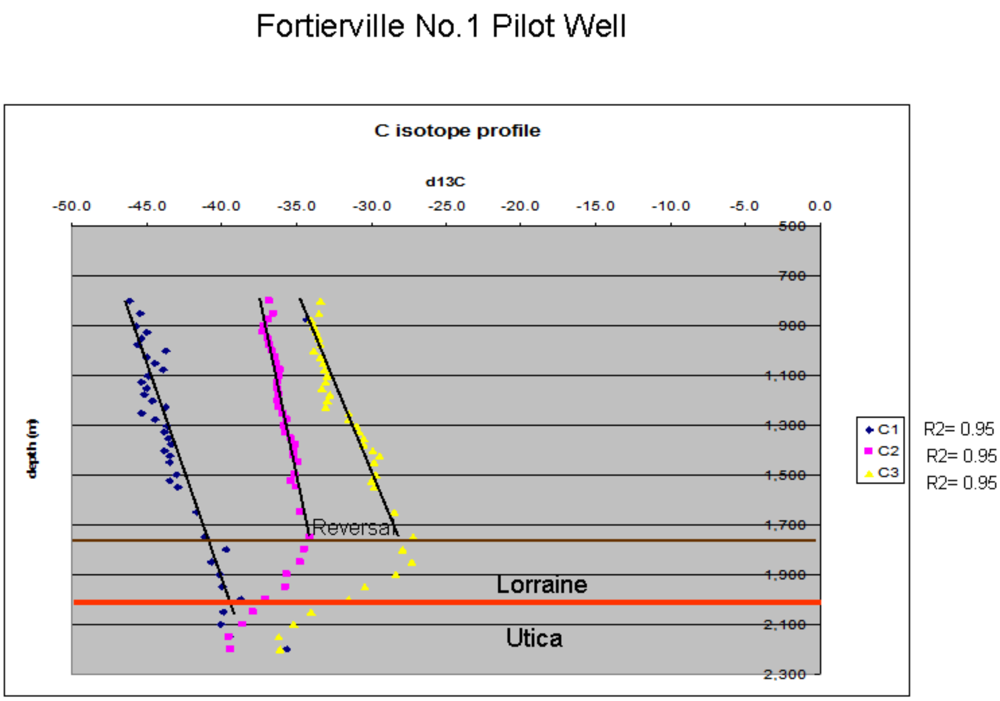

Figure 1. Carbon isotope profile for methane (C1), ethane (C2) and propane (C3) showing very good correlation coefficients. A reversal trends is observed where ethane and propane “crack” into methane. The reversal occurs at variable depths in the Saint-Lawrence Basin and is unrelated to stratigraphy. The slopes of methane and propane regression lines are commonly identical, but ethane is systematically at a slight angle both of these. This is a consistent observation but is not yet explained.

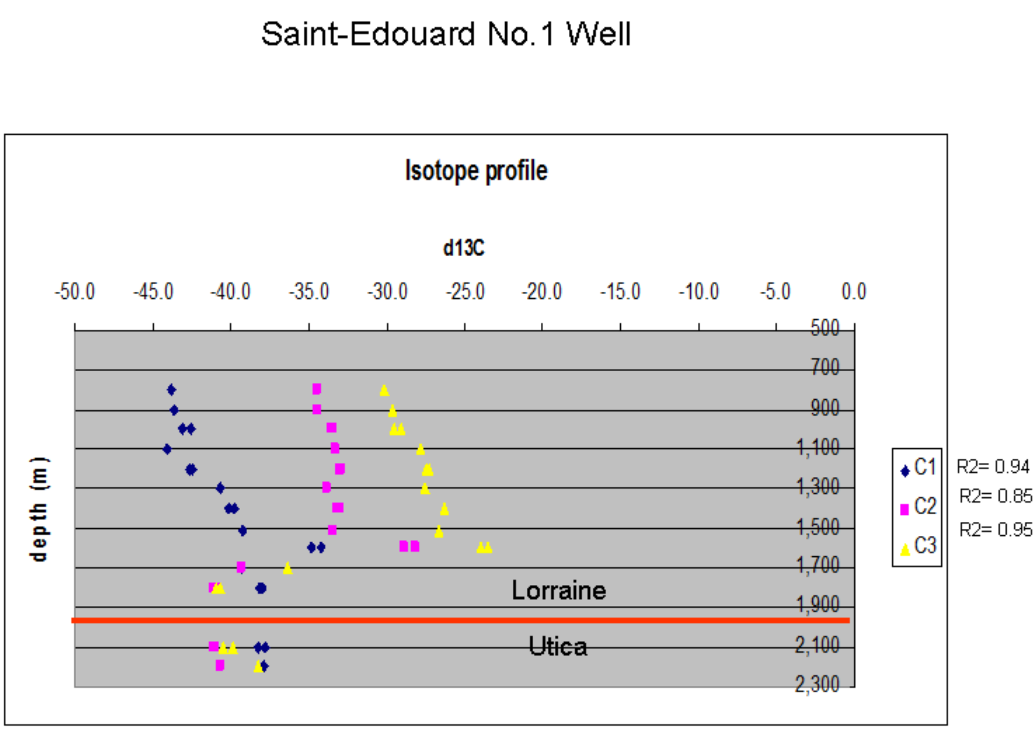

Figure 2. Carbone isotope profile for methane (C1), ethane (C2) and propane (C3) showing variability in isotope signature at the reversal point. Correlation coefficients were calculated without these points.