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SAND CREEK MONITORING WELL PROJECT

MEMO TO FILE, REMEDIATION PROJECT #9445

4/11/2016: DOLAN INTEGRATION GROUP (DIG) GAS COMPOSITION AND STABLE ISOTOPE DATA COMPILATION

Executive Summary

Dolan Integration Group (DIG) provided isotopic analysis and interpretation for various gas and water samples collected from the Sand Creek Monitoring Well and the Feit E23-97HZ, located Weld County, Colorado. Gas compositional and stable isotope analysis show that the Feit E23-97HZ Bradenhead gas, and gases sampled from the Sand Creek Monitoring Well are virtually indistinguishable with respect to carbon and hydrogen stable isotopes. Dolan Integration Group compared these results to the publicly available state (COGCC) database of production gas isotope data and found overall carbon stable isotope homogeneity in all gases produced from the Niobrara and Codell or comingled Niobrara-Codell within the vicinity of the Sand Creek Monitoring Well and Feit E23-97HZ. The overall stable isotopic homogeneity of Niobrara and Codell gas production proximal to the SCMW highlights the difficulty in "fingerprinting" the source of the stray gas in the SCMW. The lateral and the vertical variability of natural gases within the Wattenberg Field and the DJ Basin are well documented by DIG. The lack of compositional and isotopic variability within oil and gas infrastructure in the vicinity of the SCMW make a point source for gas very difficult to ascertain.

Introduction

The Greater Denver-Julesburg (DJ) Basin is an asymmetric syncline that has a straightforward subsidence history yet is highly complex with regard to its thermal history. This is an important consideration when one considers the distribution of the accumulated hydrocarbons and the effects of recent geological heating events in the DJ Basin. Stable carbon isotopes can help to understand the maximum temperature that accumulated hydrocarbons have experienced in the DJ Basin (Rice, 1984). The correlation of the heating history, although not completely explained from a tectonic perspective has linked the anomalous heat exhibited in the present day Wattenberg Field, Weld County, Colorado to the Colorado Mineral Belt (COMB) and the active mineral leases west of the Colorado Front Range (Figure 1) (Burack-Wilson and Sims, 2002). Understanding the heating history of the Wattenberg Field provides insight toward how the reservoir fluids are accumulated and developed. Fluids of various thermal maturity are seen to accumulate within the DJ Basin and, specifically, within the Wattenberg Field Unit.

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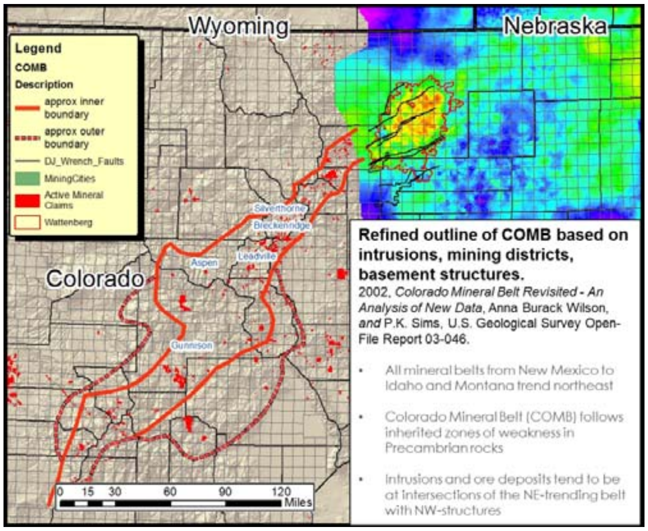

Figure 1: Relationship of active mineral leases and Wattenberg Field to the Colorado Mineral Belt (COMB) (DIG, 2016 modified from Burack-Wilson and Sims, 2002)

Dolan Integration Group (DIG) has been asked to provide isotopic analysis and interpretation for various samples collected for the Feit E23-97HZ, Township 6 North, Range 65 West, section 23 Weld County, Colorado (Figure 2). Our interpretation is focused on the variability that the samples exhibited in the stable carbon isotope values of the ethane (C2) and propane (C3) components of the natural gas. These components can be measured from the production stream gas that is associated with oil production, natural gas that is associated with pressure and fluids presented in the Bradenhead, and any thermogenic gas that may be dissolved in waters associated with aquifers in the near surface. Variability in the isotopic values of samples can arise if the fluids have a point source that is vertically or laterally distinct from the accumulated production.

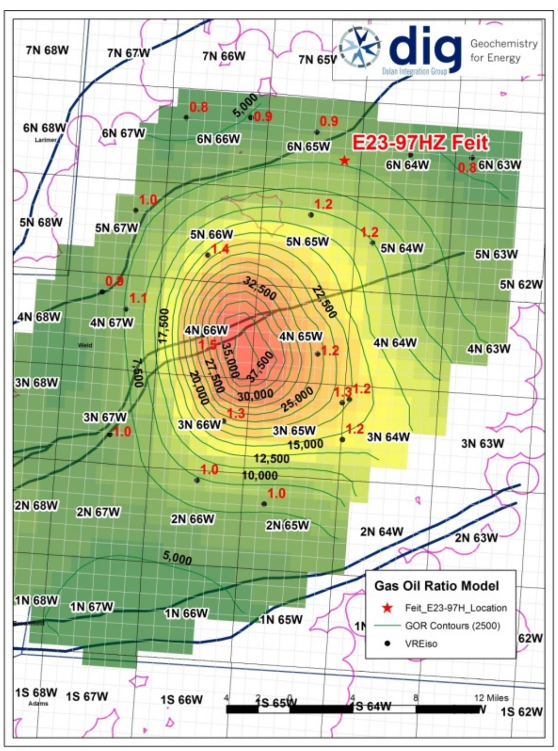

Figure 2: Niobrara/Codell GOR from Niobrara Modeled Maturity in Wattenberg Field. Black dots with red labels are production gases analyzed for isotopes and correlated to vitrinte reflectance equivalence maturity values (VREiso)(DIG, 2015).

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Site Investigation

As part of the Form 27 Site Investigation Work plan, DIG was requested to compile gas composition and stable isotope data analyzed from the following gas and water samples (in chronological order by date collected):

1. Noble Energy, as part of internal baseline monitoring programs in place since 2013, collected a gas sample on 4/16/2014 from the production stream of the Noble Feit E-23-97HZ Niobrara well (API 05-123-32595). Gas composition and stable isotope analysis were performed on this sample and reported by DIG to Noble Energy on 4/23/2014. This sample will be referenced henceforth in the data compilation and figures as "Feit E23-97HZ Prod."
2. The Colorado Oil and Gas Conservation Commission (COGCC) collected a water sample from the Sand Creek Monitoring Well (SCMW) on 12/11/2015. Gas composition and stable isotope analysis was performed on this sample and reported by DIG to COGCC on 12/17/2015. This sample will be referenced henceforth in the data compilation and figures as "Feit/ SC MW H2O (COGCC) – 12/11/2016."
3. ALS Environmental collected a water sample from the SCMW on 2/5/2016. Gas composition and stable isotope analysis was performed on this sample and reported by DIG to ALS Environmental on 2/23/2016. This sample will be referenced henceforth in the data compilation and figures as "Feit/ SC MW H2O (ALS) – 2/5/2016."
4. Olsson Associates collected a gas sample from the headspace of the SCMW on 2/5/2016. DIG provided Olsson Associates with an evacuated stainless steel cylinder for sample collection. Gas composition and stable isotope analysis was performed on this sample and reported by DIG to Olsson Associates on 2/19/2016. This sample will be referenced henceforth in the data compilation and figures as "Feit/ SC MW HS Gas – 2/5/2016."
5. On behalf of Noble Energy, Precision Analysis collected a gas sample from the bradenhead of the Feit E23-97HZ well on 2/17/2016. Gas composition and stable isotope analysis was performed on this sample and reported by DIG to Noble Energy on 2/25/2016. This sample will be referenced henceforth in the data compilation and figures as "Feit E23-97HZ BrHd."

Utilizing gas composition and stable isotope analysis performed on the above samples allows for an initial genetic classification of the hydrocarbon gas present. A gas classification (Schoell, 1983) plot of gas wetness versus methane $\delta^{13}C$ shows that all 5 of the above samples exhibit signatures consistent with thermogenic gas of a thermally mature, oil associated source (Figure 3). Another genetic classification plot from Whiticar (1994) of methane δD versus methane $\delta^{13}C$ confirms this interpretation, with all 5 samples plotting near one another in the thermogenic gas window (Figure 4).

The Haworth (1985) plot of gas wetness versus "Balance Ratio" shows that all gases collected also share a common associated fluid type – medium density gas/ medium gravity oil (Figure 5). DIG's proprietary Rocky Mountain calibration of rock thermal maturity to ethane and propane $\delta^{13}C$ facilitates the comparison of the thermal maturity at which the hydrocarbon gas in each sample was generated. As shown in Figure 6, all samples plot at a thermal maturity of 1.0-1.1 Vitrinite Reflectance Equivalent from gas isotope conversion (VRE_{iso}). This indicates that all of these gases share a common thermal history. In a laterally and vertically constrained maturity setting, this would also indicate a common source.

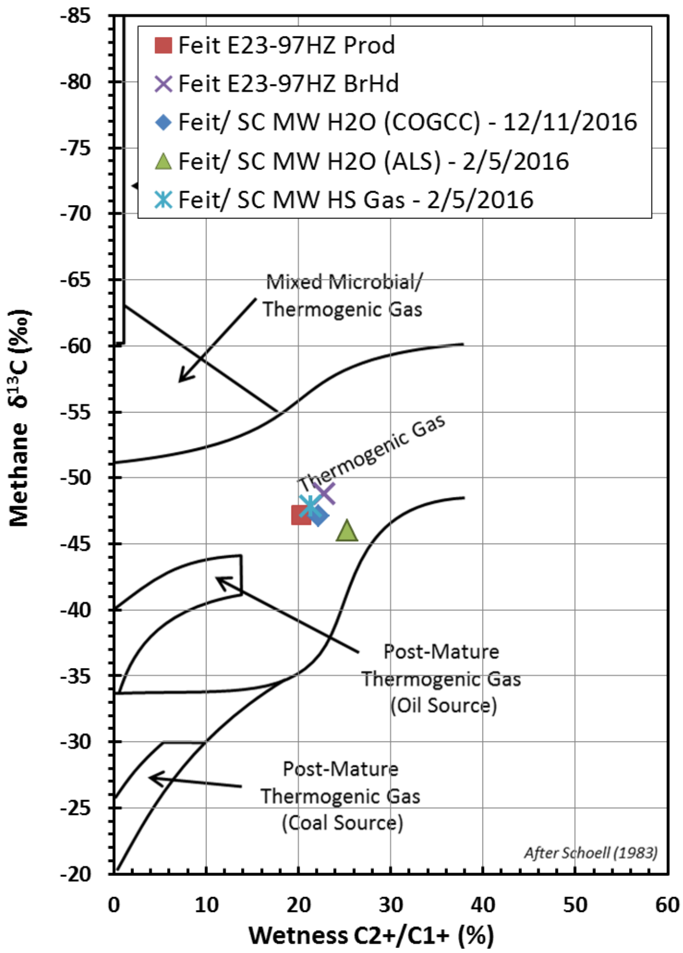

Figure 3: Gas Classification Plot (Schoell, 1983) of collected samples describe in the Site Investigation section of this report. This plot characterizes gas wetness and Methane carbon isotope.

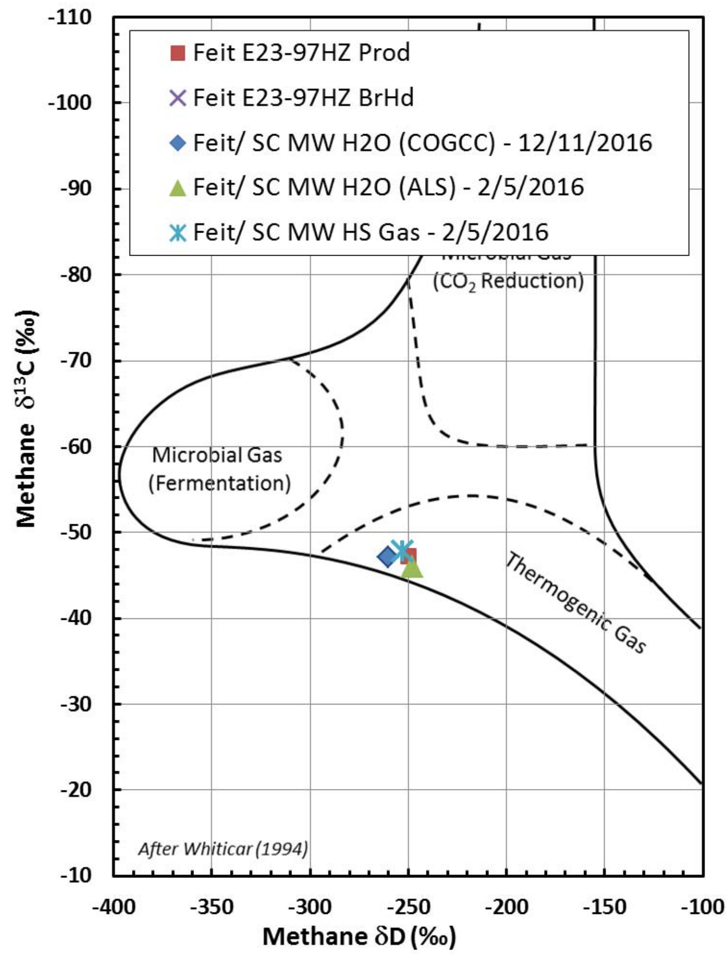

Figure 4: Gas Classification Plot (Whiticar, 1994) of collected samples describe in the Site Investigation section of this report. This plot characterizes Methane deuterium and Methane carbon isotope.

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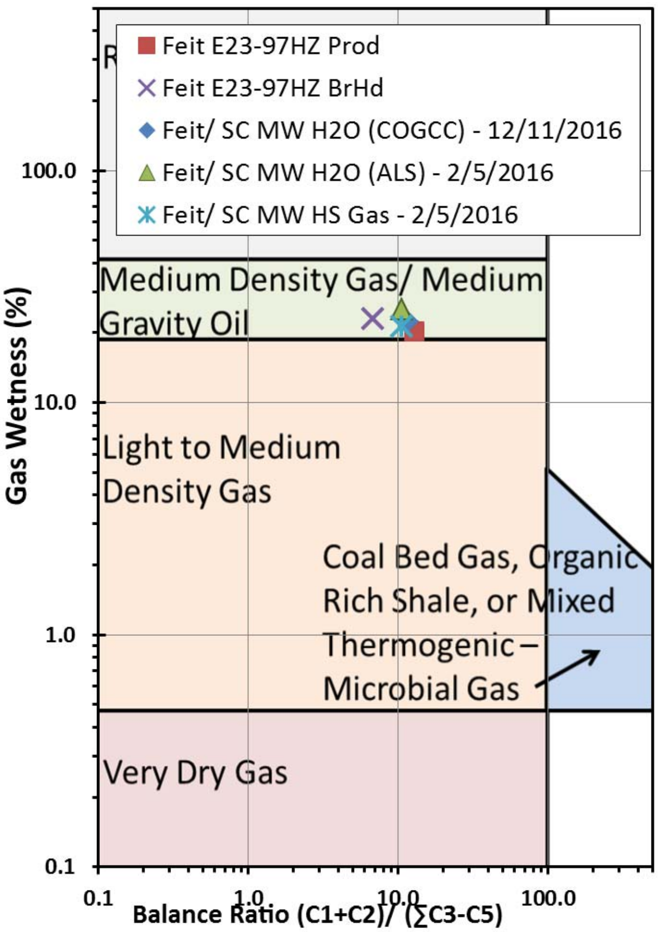

Figure 5: Haworth Plot (Haworth, 1985) of gas composition ratios. This plot characterizes the associated oil into a general fluid character.

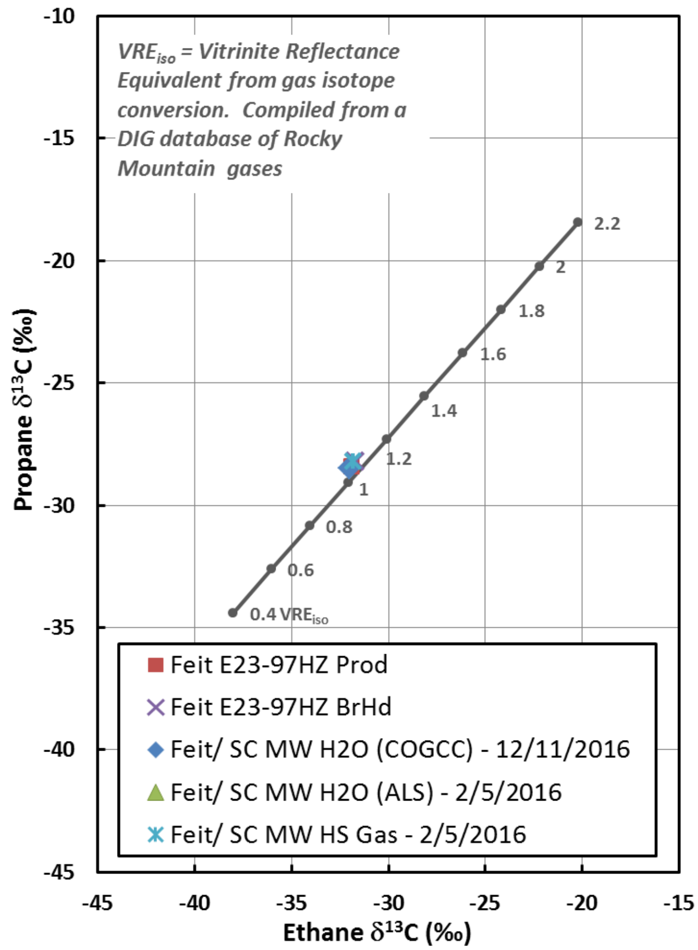

Figure 6: DIG Maturity Plot to describe the maturity at which this gas was generated and expelled from the source rock. This maturity may also characterize the thermal stress created to crack accumulated oil to its gas constituents. (Dolan et.al., 2007)

The normalized gas composition data shown in Figure 7 as carbon number versus molar percentage also displays similarities among the samples. The signature of the Bradenhead gas is notably different, however. Gas composition data alone are less robust tracers than the stable isotope composition, as the compositional makeup of a gas can be altered secondarily by migration, diffusion or sampling effects.

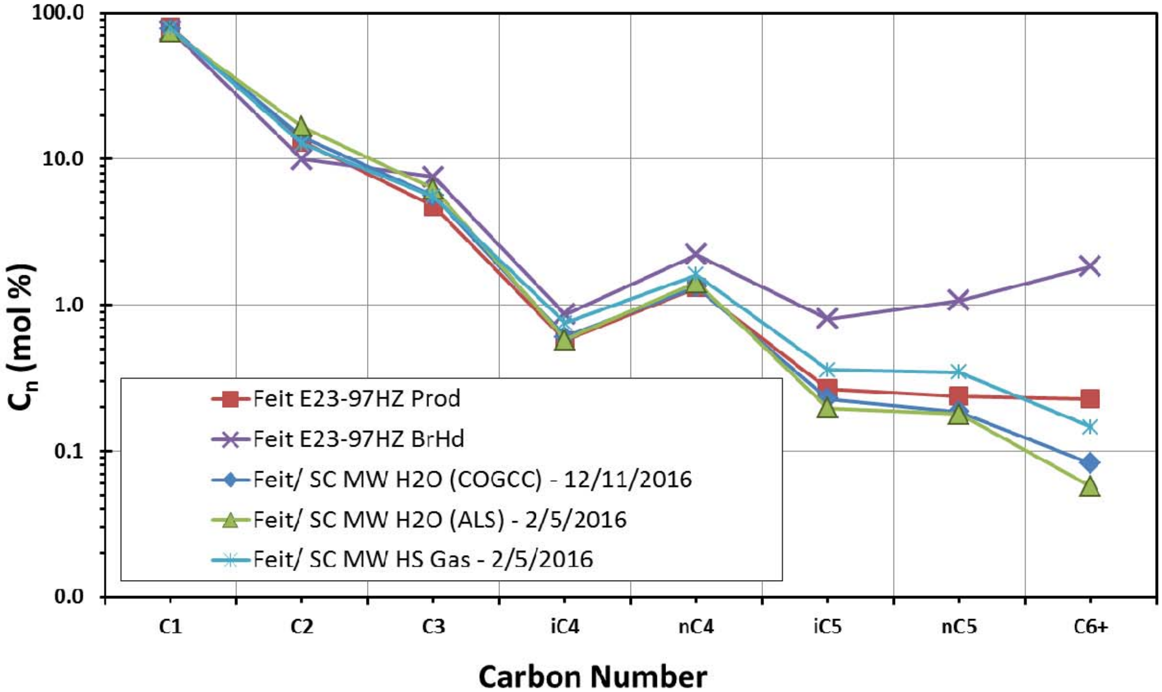

Figure 7: Concentration in mol percent (y-axis) plotted for each gas constituent molecule (x-axis).

A natural gas plot ("Chung Plot") of the reciprocal of the hydrocarbon number versus hydrocarbon $\delta^{13}C$ shows the similarities among samples, particularly in terms of the stable isotope composition of the ethane and propane (Figure 8). Variability in methane stable isotope composition is common, and can be an effect of microbial oxidation of the methane present or secondary mixing of the thermogenic gas with a microbially generated gas. The error bars shown for the initial Feit/ SCMW H2O (COGCC) sample collected on 12/11/2016 are derived from the analytical precision of the stable carbon isotope measurements (+/- 0.5 ‰).

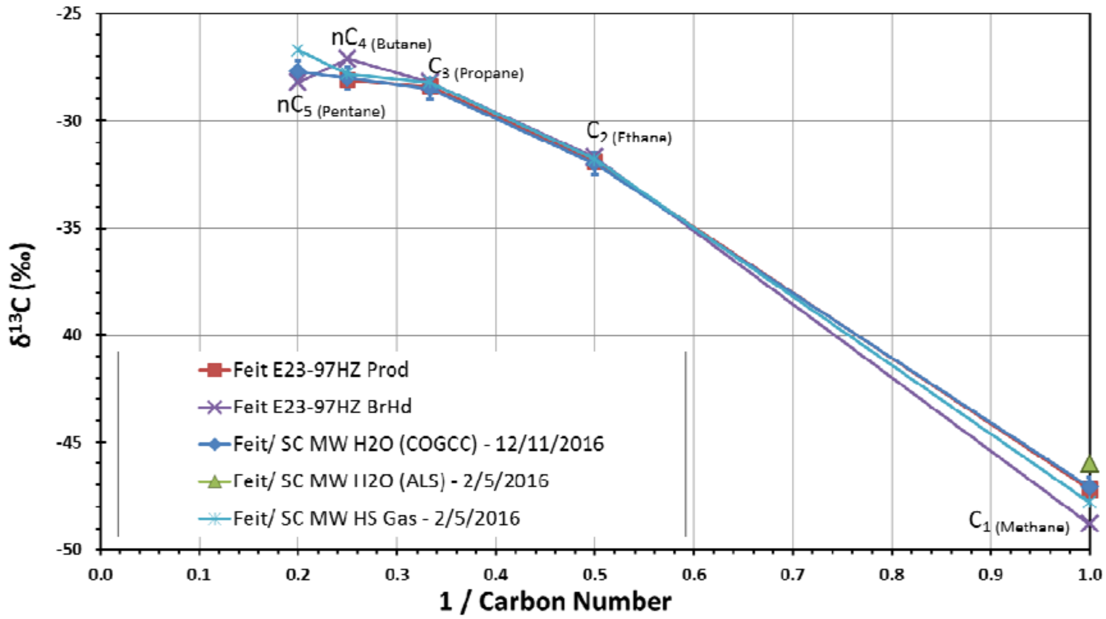

Figure 8: A Natural Gas (or "Chung") plot shows the inverse of the carbon number (methane on the far right) versus its carbon isotope value.

Comparison to the COGCC Database

The COGCC production gas database is a valuable resource for compositional and stable isotope data for production gases from across the state of Colorado. The database contains over 350 production and annular-space (Bradenhead) gases in Weld County, Colorado. Operators, consultants and the COGCC have made use of this publicly available dataset to help determine gas sources in the case of elevated Bradenhead pressures, or the presence of stray gas in the near-surface aquifer. The COGCC also stores water quality and dissolved gas data results from baseline and investigative studies. These data are useful in particular for determining whether bacterial, or biogenic, gas is prevalent within operating areas. Due to the thermal hotspot feature of the Wattenberg Field, production gas data for all formations is not available for every region due to limited or no production in these areas. This is particularly true of the Sussex and J-Sand formations. Figure 9 highlights the availability of production gas data from the COGCC and water chemistry data availability from the COGCC.

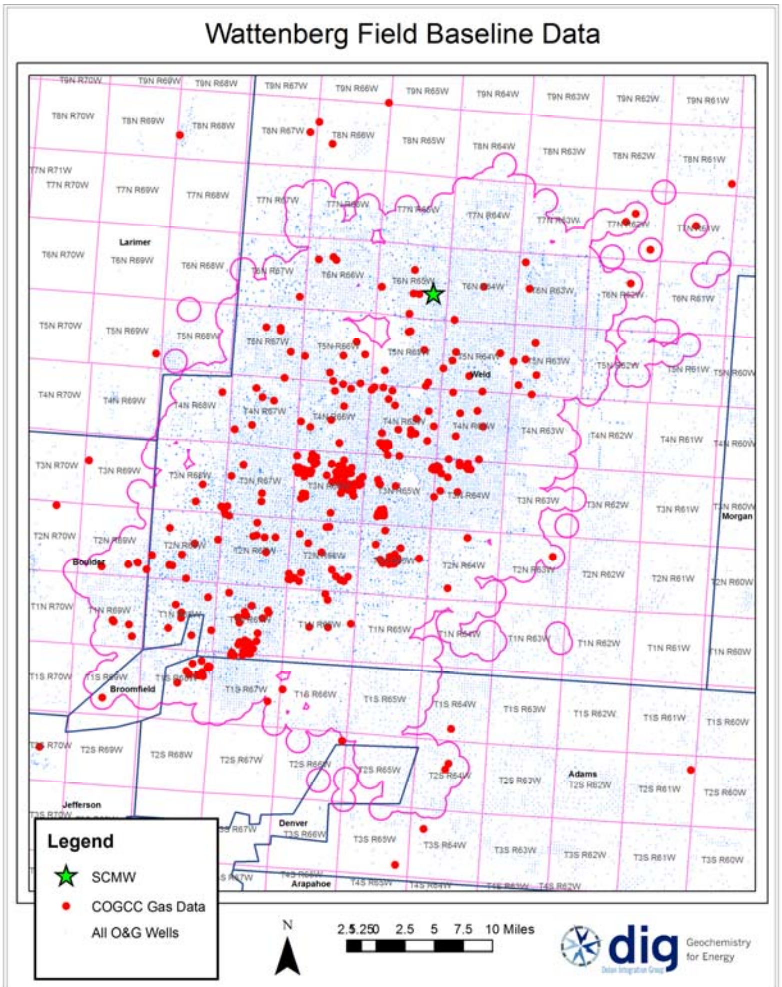

Figure 9: Map of Wattenberg Field with locations for gas geochemistry and water chemistry data. The location of the Sand Creek Monitoring Well (SCMW) is also shown for reference.

Within a four mile radius of the SCMW, the COGCC and Noble production gas databases only contain wells that produce from the Niobrara and Codell, or have comingled production from the Niobrara-Codell. Beyond a four mile radius, there are several J-Sand equivalent producing wells characterized for stable isotopes.

As mentioned earlier in this report, the stray gas in the SCMW is an isotopic match to the Noble Feit E23-97HZ Niobrara-sourced production gas (See Figure 10). We expanded our comparison to the COGCC data, and found there to be overall homogeneity of Niobrara and Codell production in this area of the basin. This homogeneity is evident in a Natural Gas Plot of the SCMW, Noble Feit E23-97HZ and nearby (approximately 4 miles radius) Niobrara-Codell production data from the COGCC (Fig 10).

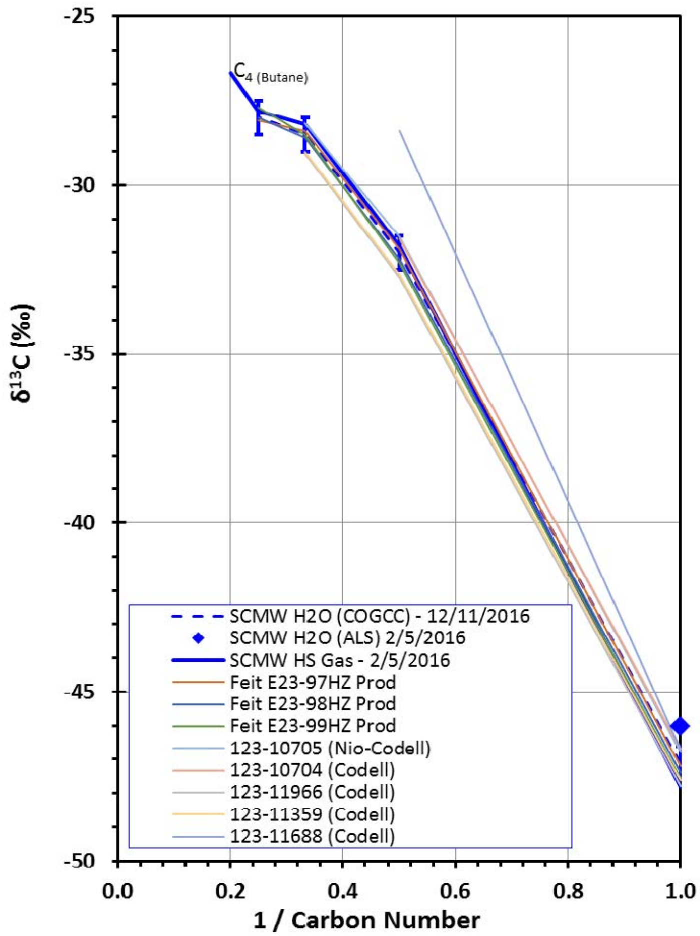

Figure 10: Natural gas plot of the SCMW dissolved gas, and well headspace (HS) gas compared with nearby Niobrara and Codell production gas stable isotopes.

The overall stable isotopic homogeneity of Niobrara and Codell gas production proximal to the SCMW highlights the difficulty in "fingerprinting" the source of the stray gas in the SCMW. The lateral and the vertical variability of natural gases within the Wattenberg Field and the DJ Basin are well documented by DIG. The lack of compositional and isotopic variability within oil and gas infrastructure in the vicinity of the SCMW make a point source for gas very difficult to ascertain.

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