PS Application of DQMS Analysis in an Oil Producing Fractured Carbonate System*

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Abstract

The practice of characterizing the nature of produced hydrocarbons from mud gas data using Component analysis has been common for over 70 years. A popular component analysis method is a set of ratios known as Wetness, Character, and Balance equations. For a vertical well drilled in conventional reservoirs, inferences were drawn from these ratios related to pay intervals of the well. The interpretive guideline for that ratio set is prefaced upon analysis of a production gas sample using laboratory equipment, conditions and protocols, including QA/QC. The drilling environment, inferior equipment, protocols, and the sample differences in the field simply do not match lab precision and quality. This may explain the mixed results in the use of these techniques for the characterization of hydrocarbon zones and the prominent skepticism of the resulting indications. The introduction of direct quadrupole mass spectrometry (DQMS) and its field application on horizontal wells has shown positive results in the application of these traditional component ratios using the significantly better precision and more linear data of the DQMS. The gas data reported here was collected using the Divining Quad 1000 TM from Fluid Inclusion Technologies, Inc. TM. The DQ 1000 TM produces data, which is essentially linear through 7+ orders of magnitude and reflects reasonably accurate determinations of concentrations for CI through CIO, which can then be used in component ratio calculations, yielding scores that are more consistent. This study demonstrates an analytical use of DQMS-derived component ratios. In this study, the component ratio application is used to predict the production character of horizontal shale wells. When performed on DQMS-derived data, scores for component ratios are shown to confidently differentiate shale wells that will produce significant liquids. In these shale exploration laterals, guidelines for the interpretation of DQMS-derived component ratios are directly suggested by the data itself.

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Introduction There has been a notable increase in shale exploration recently in the US. In certain shale plays, significant variation in production character exists within a small geographical area. Operators typically elect to not run electric log suites in shale laterals due to expense and risk factors. A low cost and low risk alternative which can provide a degree of analytical insight for many shale laterals is mud gas analysis. A common method used in mud gas analysis of non-shale exploration has been gas component ratio calculations, such as Wetness, Character, and Balance equations, Wh, Ch, and Bh respectively. Here, in use, is a variant of Wh which the authors introduce as Wh_1 .

These ratio calculations were originally formatted for vertical penetrations of reservoirs as a lab technique. Typical mud gas analysis is conducted with gas chromatograph (GC) field instruments on a high percentage of drilled wells. One thing which should be expected of data collected this routinely is definitive scalable output. Here we demonstrate that the DQMS-derived data is capable of data quality sufficient to reliably predict the hydrocarbon production character in shale laterals. This DQMS data has been demonstrated to correlate to lab and production calculations very well.

Methods Continuous gas sample extracted from drilling mud was analyzed while drilling the (eventual) producing portion of 105 wells from 5 basins within the mid-continent region. Component ratio data was calculated for these shale laterals. DQMS measurements were made using the DQ 1000 ™. This data was collected in the normal course of work for these laterals and was not screened or selected for reasons other than permission. Of the 105 wells, 52 were drilled with water-based drilling mud (WBM) and 53 were drilled with oil-based drilling mud (OBM).

The use of OBM and hydrocarbon-containing mud additives contribute to the wet hydrocarbon composition of the mud gas profile. DQMS data was transformed using proprietary algorithms and techniques to calculate for the effects of diesel and other mud additives and to correct for underrepresented species due to lower discovery limits (LDL). These methods standardize the data between OBM and WBM allowing geologic composition of wells to be compared.

Averages for concentrations for each of C1, C2, C3, C4, and C5 were prepared from the horizontal portion of each well. These concentration averages were then used in the following equations to calculate the Wh_1 , Bh, and Ch for each well:

Eq. 1 $Wh_1 = (C2+C3+C4+C5)/(C1+C2+C3+C4+C5)$ **Eq. 2** $Bh = (C1+C2)/(C3+C4+C5)$ **Eq. 3** $Ch = (C4+C5)/C3$

These ratio values were catalogued by basin and production type. Unless indicated otherwise, the differentiation between dry wells, trace liquids, and wet wells was based solely on published production numbers. Trace liquids is defined as 0 to 0.5 Bbls/mmcf.

Conclusions A value for DQMS-derived Wh_1 exists above which there will be liquids production and below which only gas is produced for shale laterals. Wh_1 above 0.1 predicted liquids production with one false positive. Wh_1 below 0.1 predicted dry gas with 3 false negatives, all 3 of which were nominal liquids producers (<0.5bbl/mmcf). Bh results inversely mimic Wh_1. The raw accuracy percentages for both Wh_1 and Bh are the same, 96.2%.

Wh_1 is effective alone as an indicator of liquids production. With 96.2% of the wells studied being sorted accurately, it is with good confidence that predictions of production type can be derived from mud gas analysis using DQMS data. This data is available as soon as a well reaches TD and may be useful in correlation with other thermal maturity indicators to increase map point density. Even though Bh and Ch are not necessary to define liquids production, they should be investigated as indicators for other parameters concerning the hydrocarbon profile of a shale lateral. it may be worthwhile to investigate a possible correlation of the wetness profile to an estimate of bbls/mmcf production.

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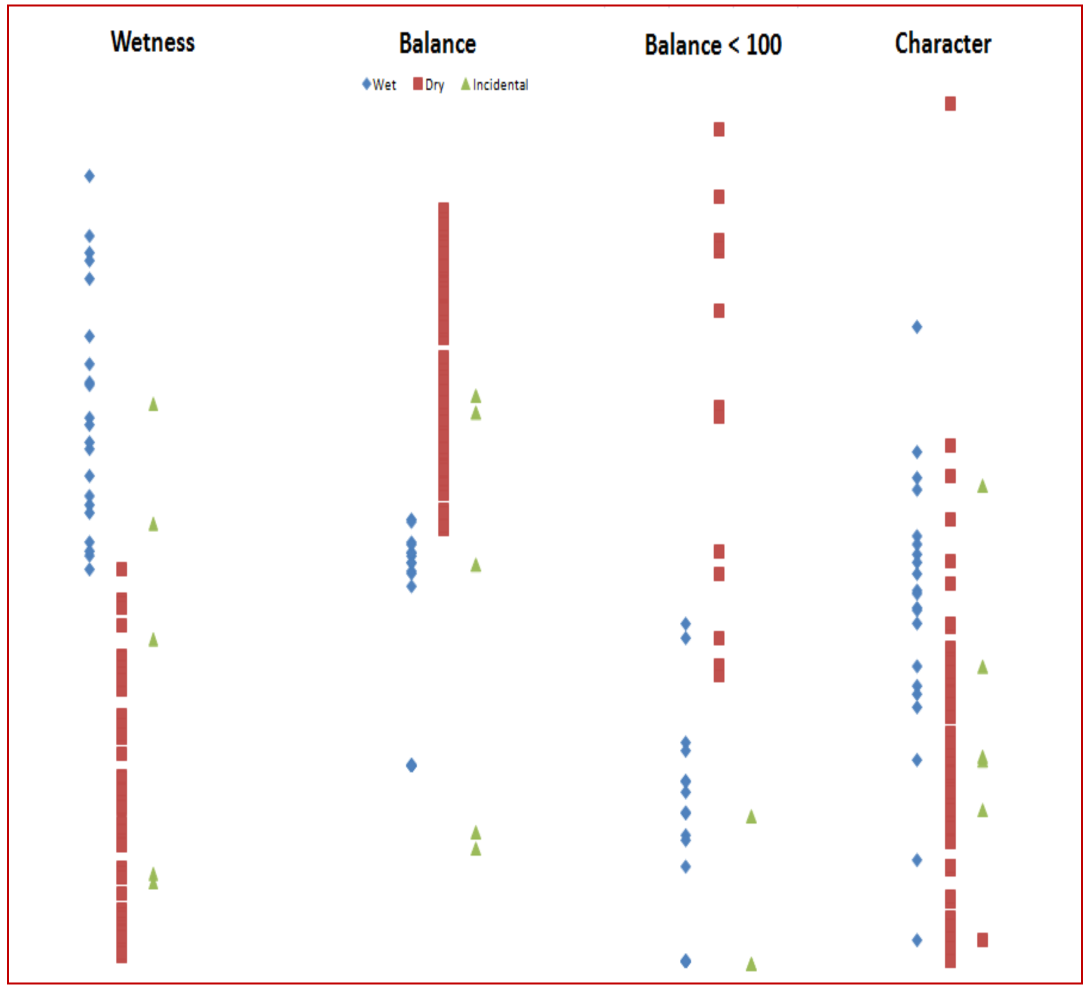

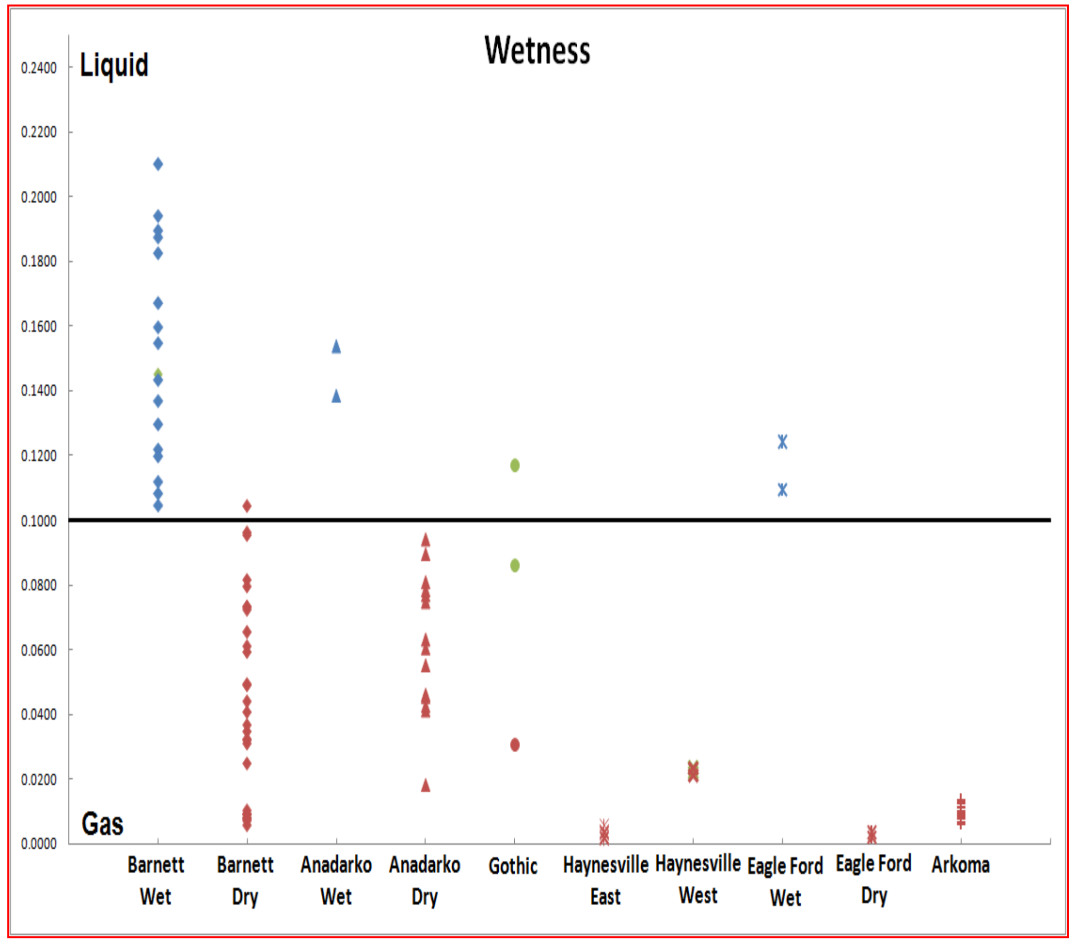

Figure 1

Figure 1 illustrates DQMS-derived results for Wh_1, Ch, and Bh calculations for the 105 shale laterals in the study. The blue diamond markers represent liquid producing wells (>0.5 bbl/mmcf), green triangles represent minimal liquids production (<0.5 bbl/mmcf), and red squares represent gas only wells (0 bbl/mmcf).

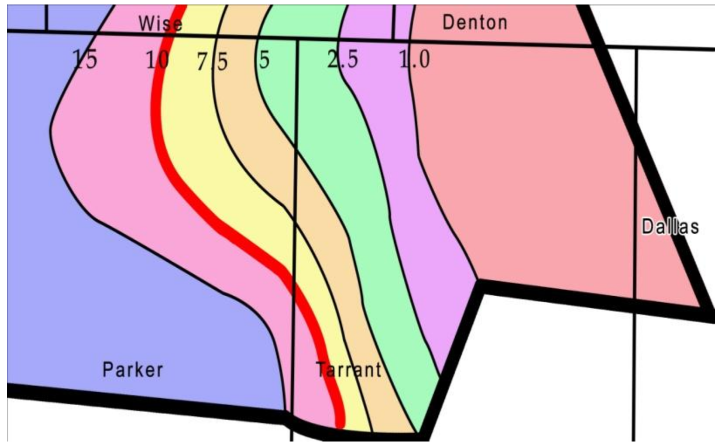

Figure 3

Fig 3 illustration presents an initial estimate for a **proposed** Wh data (Wh_1 data expressed in Wh scale) contour map for a portion of the Barnett Shale. West of the bold red contour would be expected to produce more than the 0.5 Bbls/mmcf defined earlier as "nominal liquids".

The values for Wh_1 suggest variability in the significant digit range for this value set given that 10% to 15% variability can exist between nearest data points . This may be related to differences in drilling programs from one well to another, etc. The general trend correlates to other thermal maturity indicators such as Ro (Fig. 4) and BTU (Fig. 5).

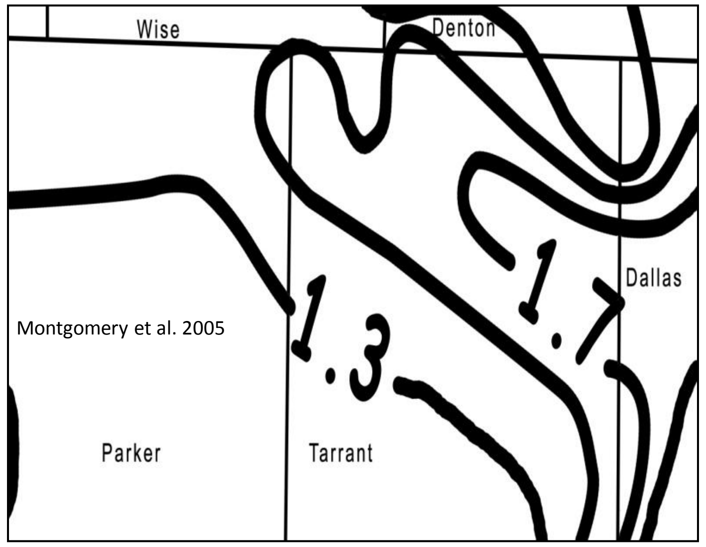

Figure 4.
Ro map of Tarrant and Parker Co., Texas

Figure 5.
BTU map of Tarrant and Parker Co., Texas

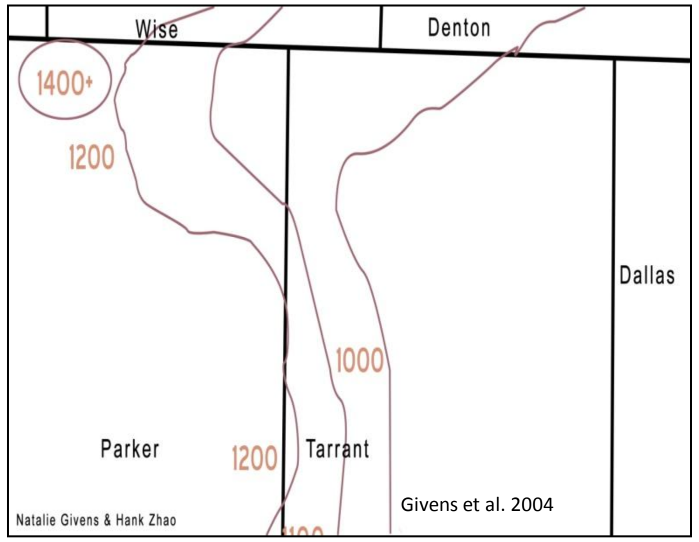

Figure 2

Figure 2 represents Wh_1 by basin for all wells within the study. The detail line which divides liquids producers from gas producers is drawn at the 0.1 value level.

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Introduction

The importance of geochemistry in the oil and gas industry has increased much over the last decade. This is also true of mud gas geochemistry. Since the introduction of direct quadrupole mass spectroscopy (DQMS) for mud gas analysis, the precision and amount of data eclipses current methods of analyzing mud gas. Typical mud gas analysis data includes n-alkane hydrocarbons from C1-C5. The DQMS utilized here, the Dq1000 by FIT, not only analyzes n-alkane hydrocarbons from C1 to C10, but also aromatic compounds such as benzene, naphthenic compounds such as cyclohexane, as well as inorganic species such as helium, hydrogen, and carbon dioxide.

Advances in drilling and fracing have given rise to revisiting older plays. The Mississippi Lime of northern Oklahoma has once again become alive with the prospect of economical oil production. This region is riddled with matrix and fracture density variation. The use of mud gas geochemistry has been applied to resolve matrix variation and presence of liquid hydrocarbons.

There are several factors making DQMS mud gas analysis in the Mississippi Lime extremely important. First, the low volume of measurable hydrocarbons requires an analytical instrument with superior detection limits. The low volume of mud gas hydrocarbons is partly due to the direct relationship of ROP to concentration of hydrocarbons in the mud and partly due to measuring the vapor phase of liquid hydrocarbons. The DQ1000 is capable of ppb resolution with a linear signal response through 7+ orders of magnitude. Second, DQMS can accurately measure the liquid hydrocarbon portion of the hydrocarbon profile. If you're drilling for oil, it makes more sense to use an instrument that can detect the liquid hydrocarbons. Third, it is a common drilling practice to use some sort of drill lube or to use diesel as a solvent for mixing in mud additives. DQMS can distinguish geologic hydrocarbons from hydrocarbons related to mud additives and diesel.

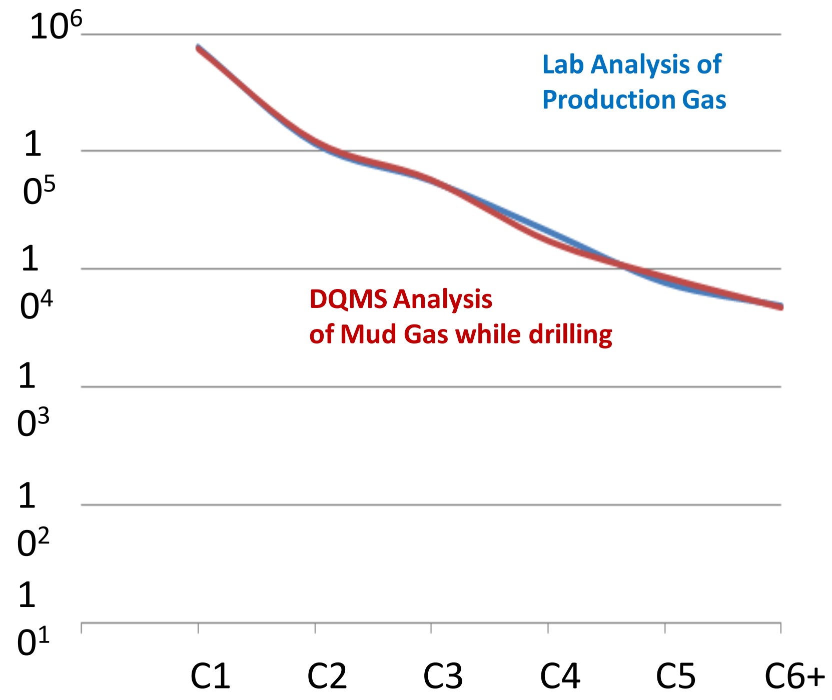

Figure 1

This graph illustrates the high correlation of DQMS mud gas analysis to production gas laboratory analysis. Hydrocarbon basis BTU differed by 1.44%. Slide taken from "Gas Production Composition Determined with Direct Quadrupole Mass Spectometer (DQMS) While Drilling", Scott Lashbrook and Bruce Warren, to be presented at 2011 AAPG Mid-Con Section Meeting.

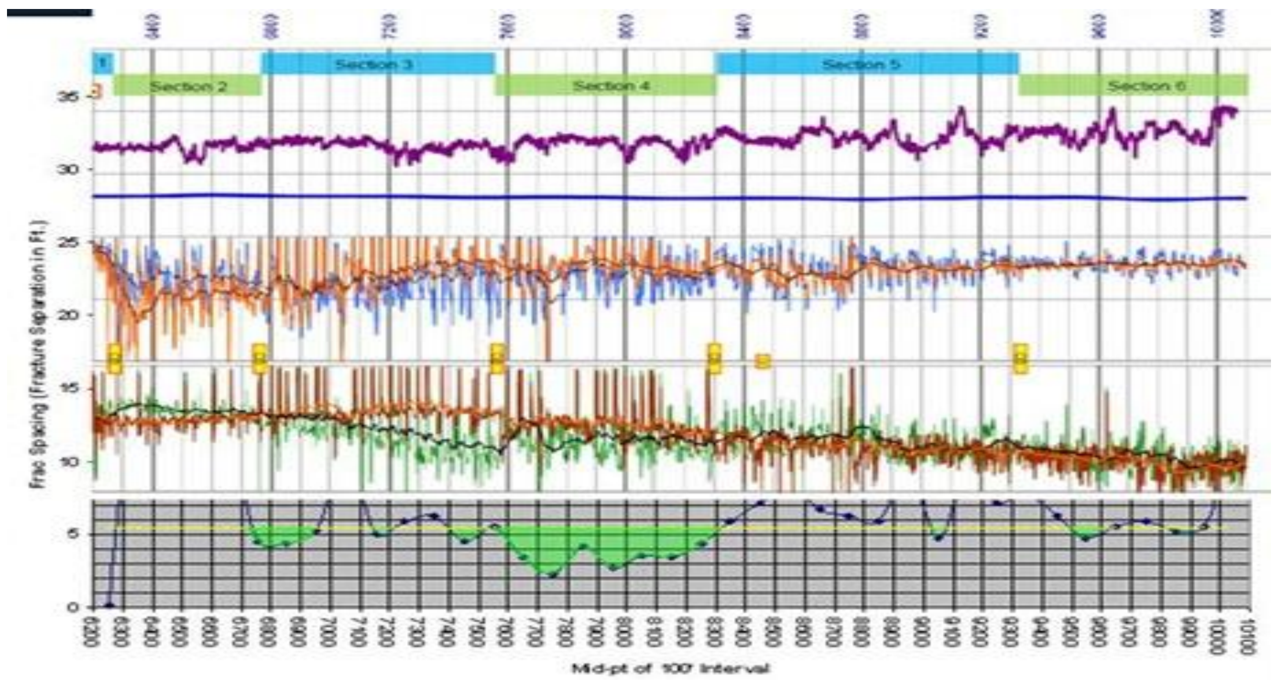

Figure 2

This illustration shows the correlation of DQMS data to fracture density. Higher frac frequency and lighter gas composition is charted as downward deflections. There is an average of 5.6 ft/frac for this data set, with better than average highlighted with green highlight shading. DQMS gas data has lighter gas composition in the more fractured interval. This DQMS interpretation was available to the operator within 24 hours of TD. Slide taken from "The Pennsylvanian Gothic Shale, Possibly the New Gas Shale Resource Play from the Paradox Basin", Peter Moreland, AAPG Rocky Mountain Section Meeting, 2010.

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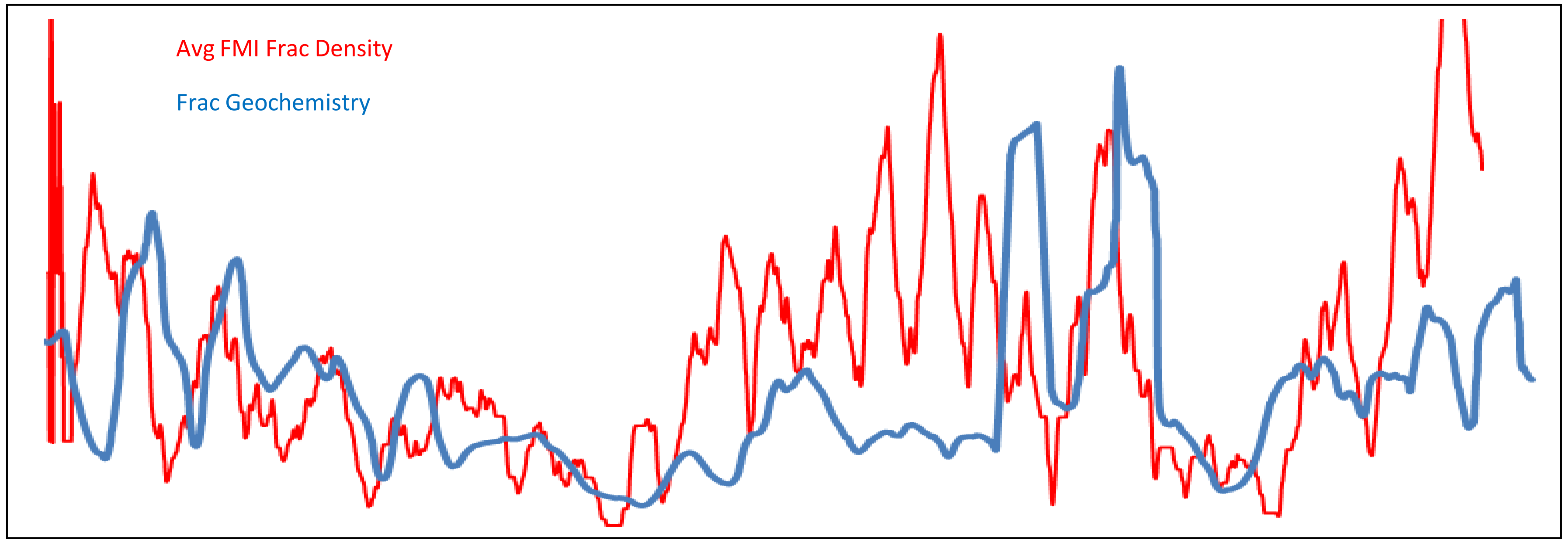
Methods

Continuous gas sample extracted from drilling mud was analyzed while drilling the (eventual) producing portion of a lateral. DQMS measurements were made using the DQ 1000 ™ from FIT. The data is analyzed both quantitatively and statistically. The qualitative and quantitative assessment compares different molecular species. These comparisons include molecule size, water solubility, organics vs. inorganics, source, and hydrocarbon class (paraffins, naphthenes, or aromatics). The comparisons assess trends, gas distribution changes (cross-plot analysis), hydrocarbon volume, and gas phase hydrocarbon composition. The statistical analysis assesses hydrocarbon volume and distribution relative to ROP for light organics (methane), water soluble organics (benzene), water insoluble organics (cyclohexane), and inorganics (helium). This assessment is used to distinguish if higher volumes of hydrocarbons are related to an increase in ROP or an increase in geologic supply.

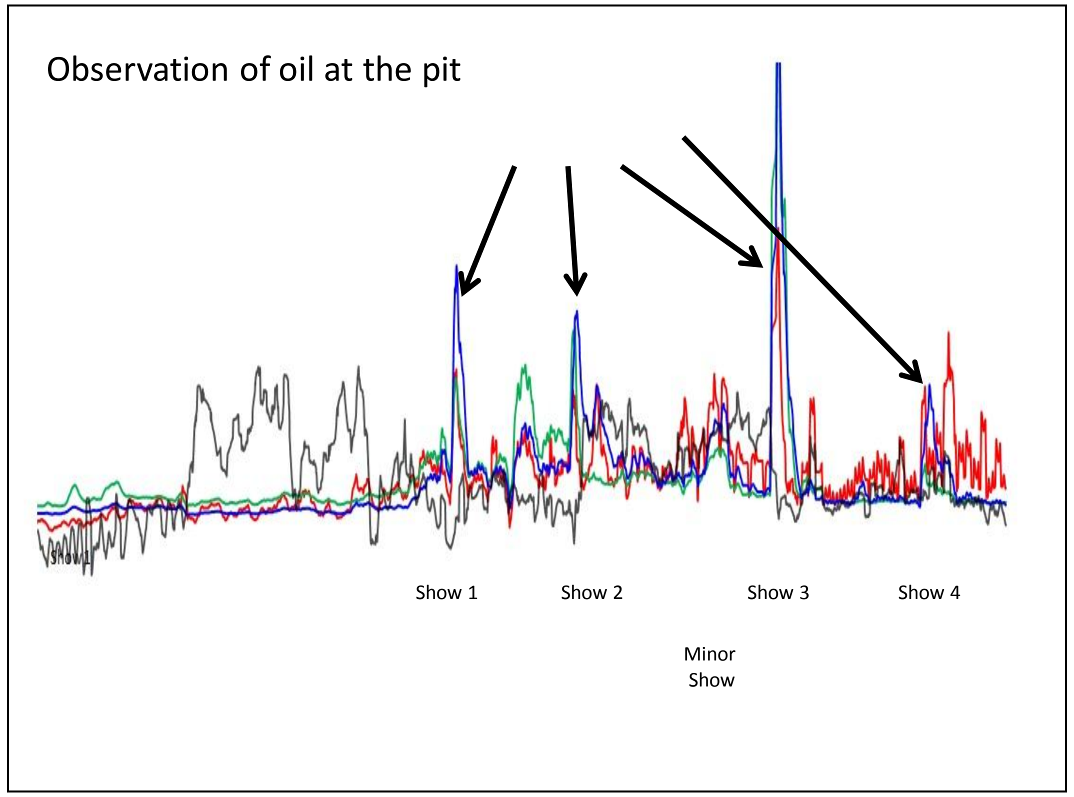
The data collected using DQMS technology provides accurate and reproducible data such that mud gas composition correlates to production (Figure 1) and data correlates to other sciences (Figure 2).

Conclusions

The DQMS mud gas analyzed data provides information that may be unavailable from other sciences due to cost or risk. The data correlates well to other sciences and observations and has been shown that well to well comparisons can be made once enough data is collected. DQMS mud gas analysis clearly surpasses traditional mud log gas data. While striving to generate more accurate field data, it is not a replacement for lab analyses or other sciences. However, it does provide low cost, low risk information when making completion design decisions . Further considerations of the data should be analyzed for use in reservoir evaluation and production rates.



Example 2 illustrates a correlation of geochemical markers to average fracture density determined by FMI log interpretation. The red curve represents fracture density, and the blue curve represents geochemical markers normalized to ROP.



Example 1 illustrates the correlation of mud geochemistry liquid hydrocarbon shows and visual observations of oil at the pit. The average measured concentration of hydrocarbons was less than 0.2% for this lateral. Notice that during the majority of the shows, the heavy hydrocarbons (blue and green lines) outperform methane (red line) in the areas observed to have oil flowing into the mud system.

Examples

Examples 1 and 2 are from different Mississippi lime laterals in northern Oklahoma. The matrix variability and presence of liquid hydrocarbons create a very complex system. High fracture density does not always correlate to presence of liquid hydrocarbons, but since the response to hydraulic fracturing would differ significantly for fractured vs. non-fractured formation, both factors are important for completion design.

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