Multi-well Case Study Using Real Time Target Optimization and Geosteering with AWD XRD, XRF, and Mass Spectrometry, Niobrara and Codell Formations, DJ Basin

Abstract
Eleven wells in the DJ Basin were drilled utilizing acquired-while-drilling (AWD) Geochemistry in an effort to aid real-time geosteering in best target quality, to provide petrophysical characterization useful to completion design, and to identify geohazards and fluid compartmentalization.

The data collected from this effort profoundly improved the ability to geosteer in the best target consistently and was immediately relevant and incorporated into completion design. Geochemical signatures for subseismic faults and fractures were also detected, along with clear identification of stratigraphic location of the borehole. Mass spectrometry (MS), combined with collected thermal maturity data helped advance petroleum system mapping and understand well performance.

These methods were found to be lower risk and more cost effective to run than horizontal wireline logs, while providing detailed petrophysical characterization.

Statement of the background
In a pilot study, two extended reach laterals, one Niobrara C well and one Codell well, were drilled in 2017, with samples collected every 100 feet and tested for energy-dispersive X-ray Fluorescence (ED_XRF), bulk X-ray Diffraction (XRD), and HAWK Pyrolysis to compliment MS analyzing the full hydrocarbon spectrum of C1-C12 and inorganic gasses collected while drilling. The data was synthesized after completion and four main observations were made: 1.) Mineralogical characterization using XRD along the borehole could immediately and precisely identify rock type and stratigraphic zone of drilling (In-zone/Out of zone). 2.) Mineralogical brittleness obtained from XRD was immediately correlated to completion issues and incorporated into completion design 3.) XRF trace elemental data yielded a surprising fault and fracture indicator that also became useful to completion design 4.) MS also yielded interesting qualitative comparisons of hydrocarbon fluids and gases and provided further
compartmentalization characterization for each well. Together, these collected components led to a significant greater understanding of the borehole than gamma ray, cuttings, mudlogs, and horizontal logs combined.

These findings were immediately incorporated into a real-time drilling protocol for the 2018 program consisting of total of nine wells: a mix of short and extended reach laterals in the Niobrara A, Niobrara B, Niobrara C and Codell. A mobile lab was set up for the program and XRF, XRD, and MS were collected real-time. XRF proxies were created for the key mineralogical and brittleness criteria associated with the optimum reservoir target for each zone. All nine wells were drilled with this protocol, improving our in-zone statistics across the program within optimal zone, as well as providing key information (mineralogical brittleness and subseismic faulted zones) utilized directly in completion design. Utilization of this data on a real time basis represents a step change in geosteering to better place lateral in the optimum intervals in each zone drilled.

Aims and Objectives

While massive advances in completions and low cost per barrel to produce horizontal wells are the driving forces behind shale production in the US, optimization of target and steering into the best rock is a choice that operators can make to increase well performance, efficient recoveries, and ultimate recoveries from the well. The idea that geology doesn't matter and "you can frac into it" is a limiting thought process and practice. This case study presents work where the best rock was identified and calibrated by geologic, engineering, and completions data and XRD and XRF measurements taken along two laterals. Great lengths were taken to design a subsequent 9-well program to steer in the best rock throughout the well using real time acquired-while-drilling data based on the two well calibration, drilling subsequent 9 wells in better rock and ultimately outperforming type curve.

This paper presents a case study in the Denver-Julesbeg (DJ) Basin where two wells drilled in 2017 collected Energy-dispersive X-ray Fluorescence (ED-XRF), Bulk X-ray Diffraction (XRD), HAWK Programmed Pyrolysis, and Mass Spectrometry (MS) analyzing the full hydrocarbon spectrum of C1-C10 and inorganic gasses collected while drilling. These analyses were performed on one Niobrara C two-mile lateral, and one Codell two-mile lateral. These data were carefully synthesized to provide a chemostratigraphic characterization that was integrated with completion data to create a set of best practices for geosteering protocol in a 9-well multi-target drilling program executed in 2018.

Materials and methods

XRD and XRF were performed on cuttings for all eleven wells presented in this case study, with the 2017 program having samples analyzed post-drill, and the 2018 wells analyzed while-drilling. Mass Spectrometry was performed while-drilling on one of the 2017 wells, and all nine of the 2018 wells.

A mobile lab was set up on location that allowed near real time analysis of cuttings samples for XRD, XRF, and MS.
Cuttings samples were collected from the shakers at predetermined intervals (every 10 feet through the build section and every 100 feet through the lateral section). A minimum of 20 grams of sample was collected across the shaker to represent the interval as opposed to point samples from a single depth. Samples were taken to the mobile lab on location for preparation and analysis. Once drilling reached TD and all wellsite analysis (XRD and XRF) was completed; the samples were sent to the Reservoir Group Rapid Answer Lab (RAL) in Houston, TX for programmed pyrolysis.

In a feasibility study one Niobrara well and one Codell well were drilled in 2017 that captured cuttings for XRD, XRF and HAWK pyrolysis to integrate with MS while drilling. All samples were analyzed post-drill and post-completion in an effort to ascertain the value of real time data acquisition and to create a best practice protocol for real-time steering into the best completion quality rocks for future drilling programs.

Results and discussion

Collaboration with completions investigated/identified discrete frac stages that did not initiate as planned. Two primary relationships with the AWD data were found that addressed all stages with completion issues. Calculated Brittleness Index (BI) from XRD was found to accurately indicate rock with best completion characteristics, and XRF Barium was indicative of compartmentalization interfaces where completions were difficult.

An additional characterization benefit from the AWD data included the ability to characterize rock type and rock quality families in the Niobrara, Codell, and associated formations as well as the fluid within these strata using the MS data. Additionally, Hawk Pyrolysis TMAX data collected along the lateral yielded a Tmax gradient that is inherently more useful than discrete pyrolysis points.

Conclusions

AWD XRD, XRF, and MS were utilized in the 2018 nine well drilling program to steer in the most brittle rock and to provide completion flags to the team where barium anomalies were noted. The program showed tremendous results utilizing real-time data to stay in zone in the Codell and to avoid shale strikes in the Niobrara A.

Completions were designed with the characterizations in mind, and as of April 2019, the 2018 well program is outperforming type curve. All nine wells were drilled with this protocol, improving our in-zone statistics across the program within optimal zone, as well as providing key information (mineralogical brittleness and subseismic faulted zones) utilized directly in completion design. Utilization of this data on a real time basis represents a step change in geosteering to better place laterals in the optimum interval of each zone and to ultimately improve production metrics for the bottom line.
References


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