The Niobrara: the Maturity goes up, but the Resistivity goes down. What's going on?

This presentation was given by Steve Cumella, consulting geologist, at the monthly DIPS meeting held at the Wynkoop Brewing Company on December 12, 2014. Mr. Cumella holds BS and MS degrees in geology from the University of Texas at Austin. His Rocky Mountain experience began with Chevron in 1981 and continued with Barrett Resources, Williams Exploration, and Bill Barrett Corporation. In 2011, he was named an AAPG Distinguished Lecturer.

The following is taken from the meeting publicity: "The Cretaceous Niobrara Formation is a prolific organic-rich hydrocarbon reservoir throughout the greater U.S. Rocky Mountain region. Resistivity mapping is a common tool used for maturity mapping of the Niobrara because a good correlation exists between increased resistivity and increased thermal maturity. Niobrara resistivity is low in thermally immature areas on basin margins. Resistivity progressively increases as maturity increases from the oil window into the wet-gas window. However, this trend of increasing resistivity with increasing maturity is reversed as maturity increases from the wet-gas to dry-gas window. Examples of this anomalous resistivity reversal are present in the Piceance, Sand Wash, and DJ basins. Possible mechanisms to explain decreasing resistivity with increasing maturity include the existence of a conductive petroleum phase (pyrobitumen) and the increase in residual water salinity driven by water vapor solubility in the produced gas. However, the current study concludes that the development of petroleum-expulsion fractures combined with changes in wettability in the Niobrara provides the best explanation for the process of decreasing resistivity with higher thermal maturity. Low-maturity Niobrara is water wet and has low resistivity. In the oil-generation window, generated polar organic compounds (resins and asphaltenes) compete with water to coat grain surfaces and the rock changes from water-wet to oil-wet, resulting in a significant resistivity increase (Jack Breig, personal communication). In the advanced stages of maturation, liquid and solid hydrocarbons are cracked to gas. As the resins and asphaltenes become cannibalized, the oil-wetting behavior is reversed, releasing grain surfaces to be rewetted by connate water. The conductive water phase, even at low water saturations, is restored and resistivity drops."

Mr. Cumella first noticed that the transition from a wet gas to a dry gas reservoir is accompanied by a decrease in formation resistivity two and a half years ago when working in the Piceance basin. He regards it as a poorly understood phenomenon and mentioned recent papers that reference the subject: Mohammed et al. in 2014, presented at URTEC; and another paper published the same year by RMAG on the Piceance Horizontal Niobrara Play. This effect has been observed in shale plays outside the Rocky Mountain region, including internationally. The phenomenon is important to understand if companies hope to extrapolate such prolific production as found in the wells along the I-70 corridor, where a horizontal well drilled by WPX Energy (known as "the beast") had an IP of 16 MMcfd. Color coded resistivity plots in the southern

Piceance basin illustrate this resistivity change. Mr. Cumella performed the same analysis for the Niobrara in the Sand Wash Basin, but the data was limited because of fewer wells.

In the Niobrara of the DJ basin the resistivity increases as the structure becomes deeper going east to west. Exploration is driven largely by these resistivity changes. A cross section of the C Bench of the Niobrara illustrates the phenomenon best, as C Bench lithology is uniform and most of the variation is due to changes in thermal maturity. A consistent gamma ray reading across the unitS confirms this consistency. A 20,000 GOR contour in the Wattenberg Field due to localized heat flow is a good proxy for thermal maturity, as are vitrinite reflectance and gas isotope ratios. There is also a decrease in resistivity in the middle of the Wattenberg Field.

Mr. Cumella stated that there was no consensus for what is causing the resistivity drop, but there have been several suggestions for the possible mechanisms:

- A paper by Passey et al., 2010, mentions the resistivity reversal occurring at an Ro of greater than 3; however, Mr. Cumella has seen the effect at Ro of 1.4. Passey suggests graphite as a possible cause of the resistivity drop while Mr. Cumella thinks this unlikely at the lower resistivities of 1.4.
- Another possibility is a drop in the value of Rw (formation water resistivity). Flow backs from shale fracking jobs indicate very saline formation water. A 2002 paper by Newsham and Rushing on the Bossier Tight Gas Sands suggests that a mechanism to remove water from organic-rich shales involves vaporized water in overpressured hydrocarbons that causes fracturing and a subsequent loss of fresh water.
- Jack Breig noticed a pronounced change in resistivity in the Woodford Formation of the Anadarko Basin that he suggests may be caused by transition from an oil-wet to a water-wet rock corresponding to the change from a wet gas to a dry gas situation, as all the liquid hydrocarbons are gone. Mr. Cumella believes this is the most likely explanation for the resistivity change.
- Another possibility is the presence of horizontal micro-fractures that could lower the resistivity.

This resistivity reversal is not as pronounced in the DJ Basin as in the Piceance and Sand Wash basins, as the hydrocarbons in the DJ Basin do not reach a true dry gas condition. In the most mature part of the Wattenberg Field, there is still a 30,000 GOR, a condition which does not approach dry gas.

Also, there are important changes in the Niobrara associated with faulting. Hydrocarbon generation creates over-pressured zones that cause more fracturing near existing tectonic faults. These fractures are thermally insulated by the hydrocarbons, a situation which creates higher temperatures. This, in turn, leads to a positive feedback loop for increased hydrocarbon generation.

A member of the audience asked where the water came from in the Sand Wash Basin. Mr. Cumella replied that there was not much water associated with hydrocarbon production in that basin and where there was, it was associated with deeper faulting. In general, there is very little water associated with hydrocarbons in the Niobrara in Rocky Mountain Basins.

.