Mesaverde Tight Gas Sandstone Sourcing from Underlying Mancos-Niobrara Shales*

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Abstract

Recent drilling of Mancos-Niobrara shales in the Piceance Basin has identified a significant gas resource in the southern Piceance Basin, where numerous vertical and horizontal wells have encountered thick shale intervals with pervasive gas saturation that are locally highly pressured. Pressure data indicates Mancos-Niobrara pressure gradients near 1 psi/ft in some areas. Geological and geochemical data indicate that the Mancos-Niobrara has been a major source of gas for the overlying Mesaverde tight-gas accumulation. Vertical gas migration from thick, shaly Mancos-Niobrara to the Mesaverde may have occurred primarily along fault and fracture zones. The top of continuous gas saturation rises significantly adjacent to major structural features, such as the Rulison nose, the Crystal Creek anticline, and the Gibson Gulch graben. Mesaverde gas production is commonly enhanced in these areas. Very high capillary pressures are required to achieve the low water saturations that have been measured in Mesaverde sandstones that have microdarcy permeability. High capillary pressures could have been provided by vertical migration of highly pressured gas from the Mancos-Niobrara into the Mesaverde. Additionally, the highly pressured gas would have enhanced natural fracturing during migration and filling of the tight sandstone reservoirs, while significantly increasing reservoir permeability.

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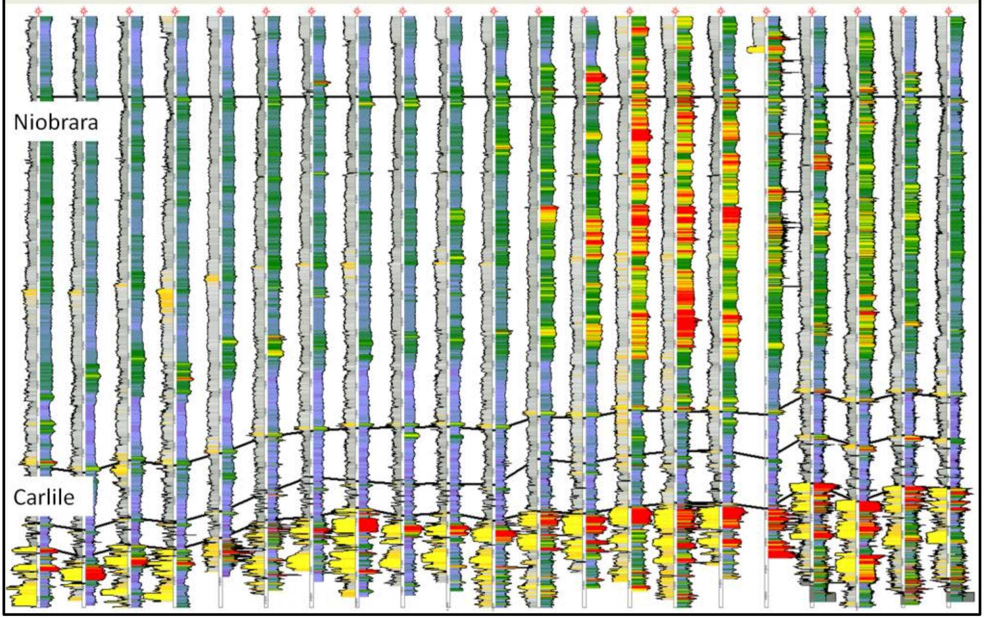
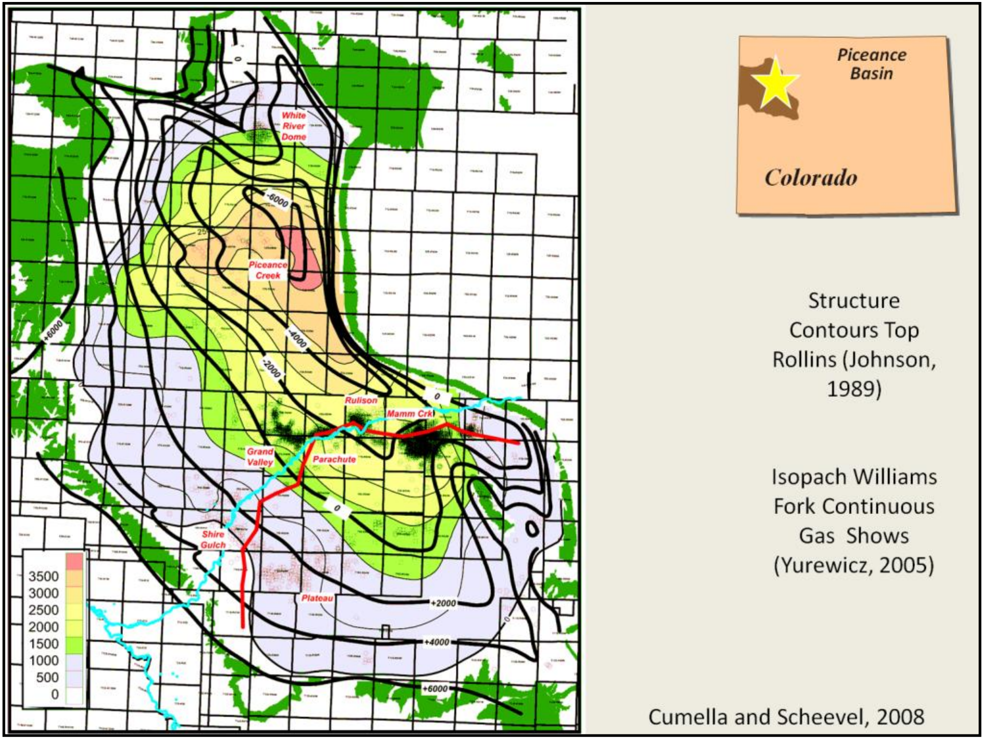
Mesaverde Tight Gas Sandstone Sourcing from Underlying Mancos-Niobrara Shales

Steve Cumella, Endeavour International   Jay Scheevel, Scheevel Geo Technologies

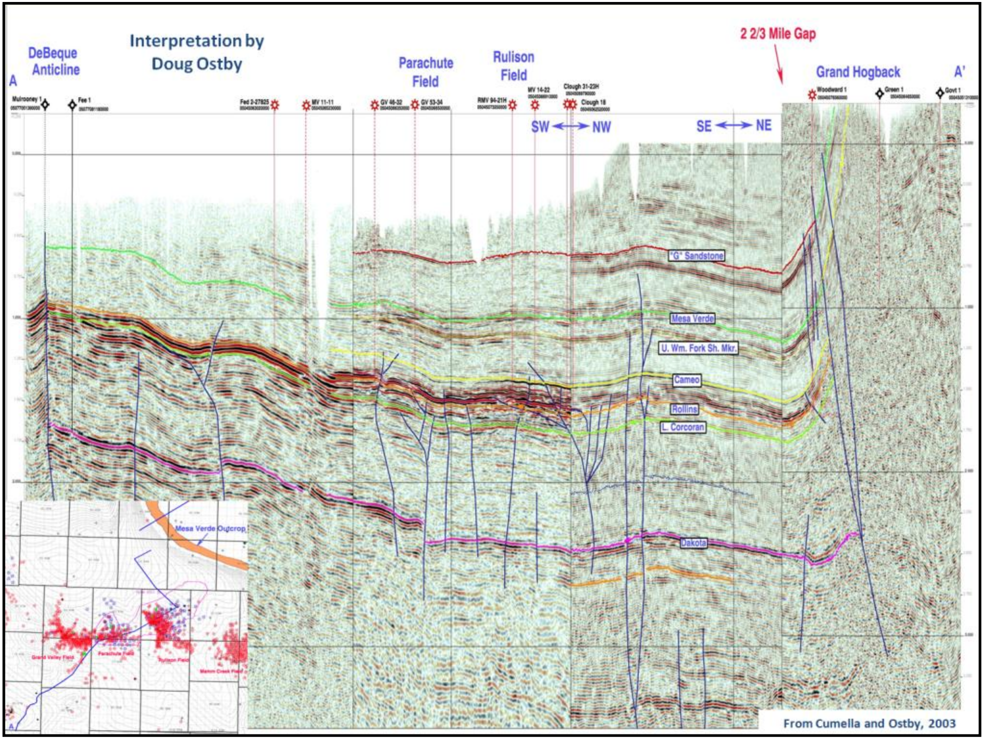


Outline

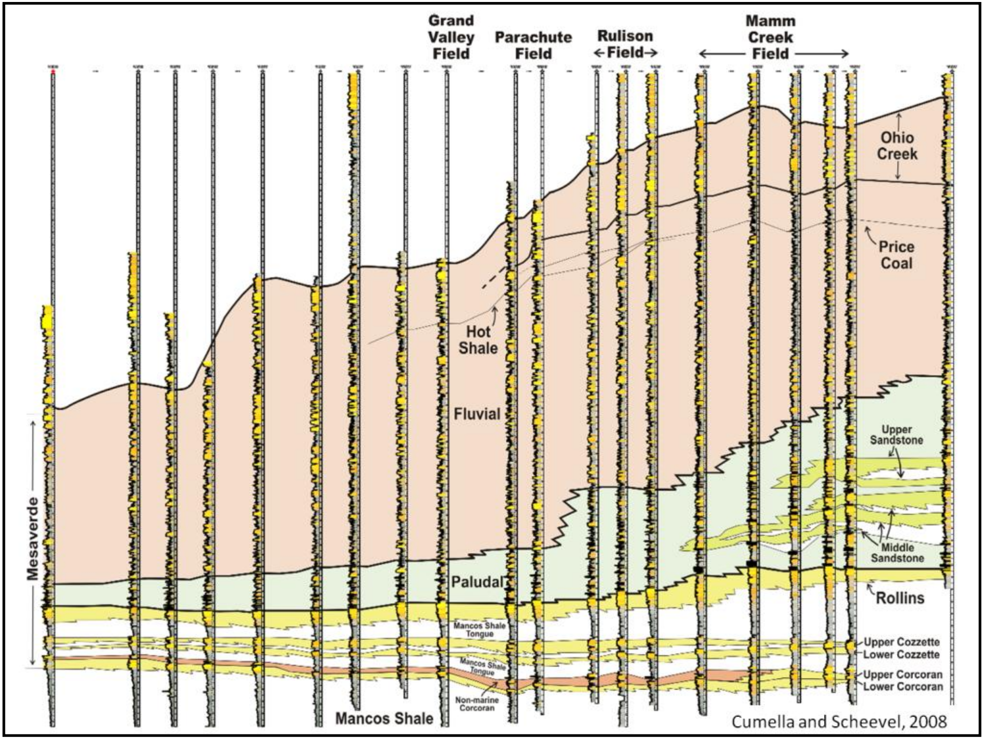
- Review of Piceance Mesaverde basin-centered gas model
- Presentation of data indicating that underlying Mancos-Niobrara marine shales are a source of some the Mesaverde gas
- Mancos-Niobrara log characteristics
- Discussion of decrease in Niobrara resistivities with increasing maturity



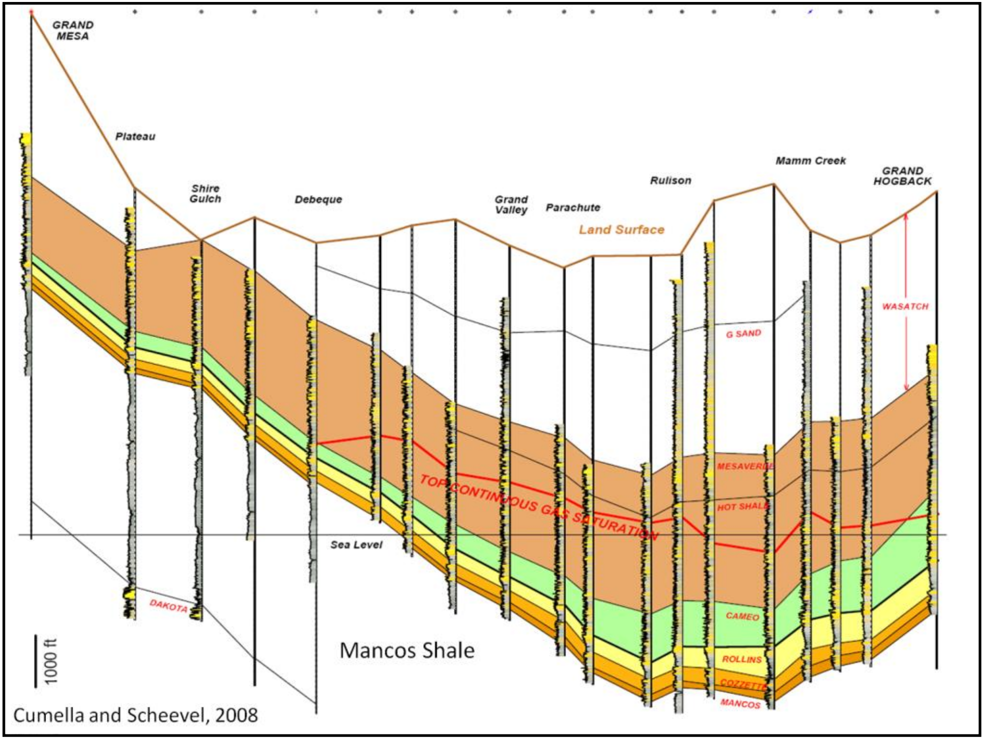
Presenter's notes: The Piceance Basin is located in northwest Colorado. The outline of the basin is shown by the outcrop of the Mesaverde Group in green. The color-filled contours show the thickness of the continuously gas-saturated interval of the Williams Fork. The thickest gas-saturated interval is located in the deepest part of the basin. The gas-saturated interval thins toward the basin margins. A thickness of about 1500 ft or more of gas-saturated interval is necessary for commercial Williams Fork production. The cross-section line for following cross sections is shown in red.



Presenter's notes: Seismic line across the southern part of the Piceance Basin. Inset map shows the location of the seismic line in blue.



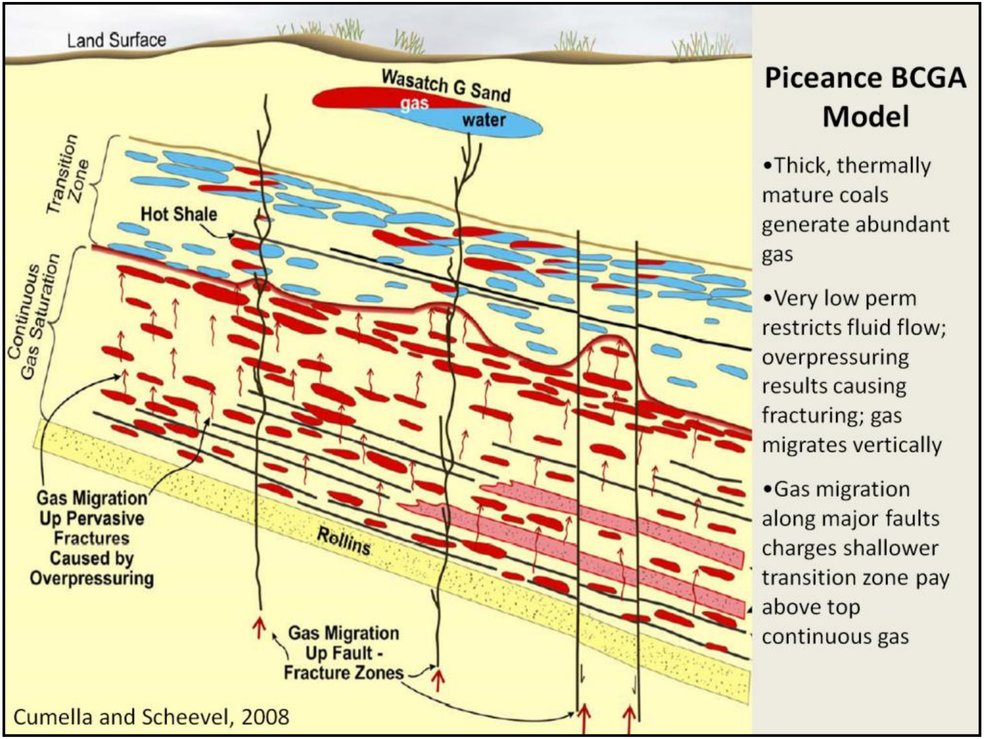
Presenter's notes: Cross section showing the stratigraphy of the Mesaverde Group. The Iles Formation comprises the lower part of the Mesaverde. It contains three marine sandstone intervals, the Corcoran, Cozzette, and Rollins. The Williams Fork Formation extends from the top of the Rollins to the top of the Mesaverde. The lower part of the Williams Fork contains coals (shown in black), and is commonly referred to as the Cameo coal interval. Most of the sandstones in the Williams Fork are discontinuous fluvial sands. An exception is the middle and upper marine sandstones that are present in the southeast part of the Piceance Basin. Almost all production from the Piceance basin-centered gas accumulation is derived from the fluvial sandstones of the Williams Fork.



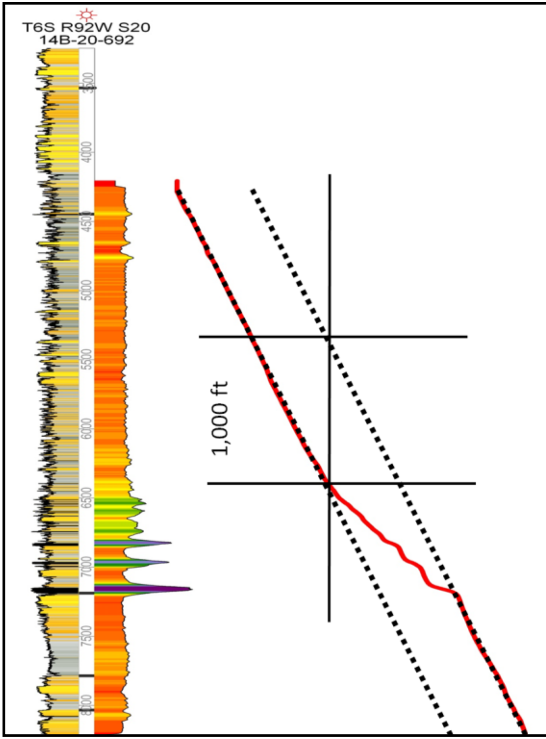
Presenter's notes: This is the same cross section that was shown in the previous slide, but it is structurally datumed. The Williams Fork gas-saturated interval extends from the top of the Rollins to the top of continuous gas saturation (shown in red). It is thickest in the deepest part of the basin, where thermal maturities are highest and the greatest amount of gas was generated.

Important Characteristics of Piceance Basin-Centered Gas Accumulation

- Very low (microdarcy) permeability was reached before and during maximum gas generation
- *High heat flow* matured thick lower Williams Fork coals at relatively shallow depths, producing very large volumes of gas in relatively short amount of time
- Restricted fluid movement during peak gas generation resulted in *overpressuring* that caused *pervasive fracturing*
- Gas migration was primarily vertical through the pervasive fracture system



Presenter's notes: Schematic cross section showing the Piceance basin-centered gas accumulation (BCGA) model. Gas-saturated sandstones are shown in red, water-saturated sandstones in blue. Coals in the lower Williams Fork, shown in black, are the main source of gas for the BCGA. Gas generation within a very low permeability setting resulted in overpressuring that caused a pervasive fracturing shown by small red arrows. In addition to the pervasive fracture system, vertical gas migration was aided by migration along major fault and fracture zones from the underlying thick marine shales of the Mancos-Niobrara interval.



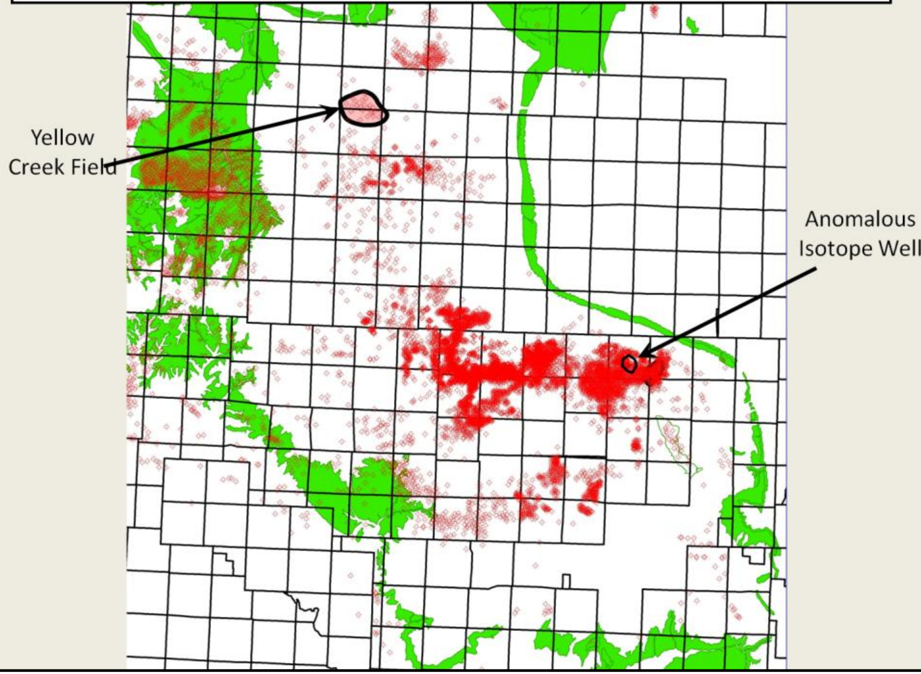
Coals act as insulators to heat flow. The insulating effect of the Cameo coals is roughly equivalent to adding an additional 1,000 ft of overburden. The red line is the actual temperature curve. Black dashed trend lines above and below the coal interval are subparallel. The offset of those trend lines is equivalent to about 1,000 ft. The color-filled curve in track 2 is the first derivative of temperature; insulating lithologies (e.g., coal) are cool colors.

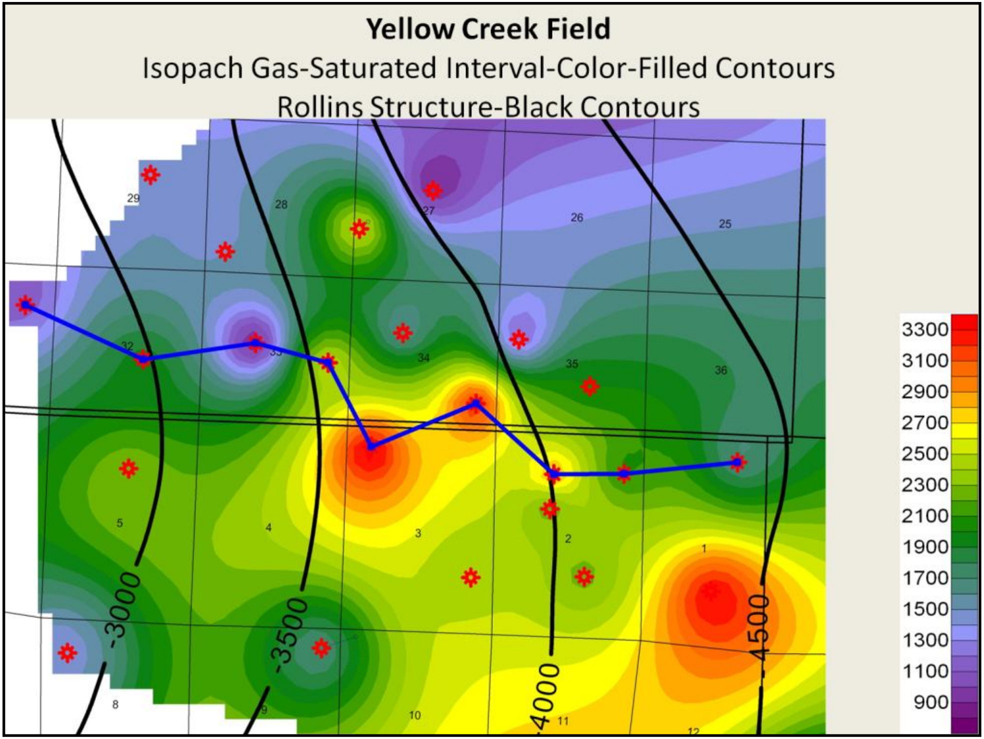
Presenter's notes: In addition to providing a major source of gas, coals act as insulators to heat flow.

Evidence for Sourcing from Underlying Mancos Shale

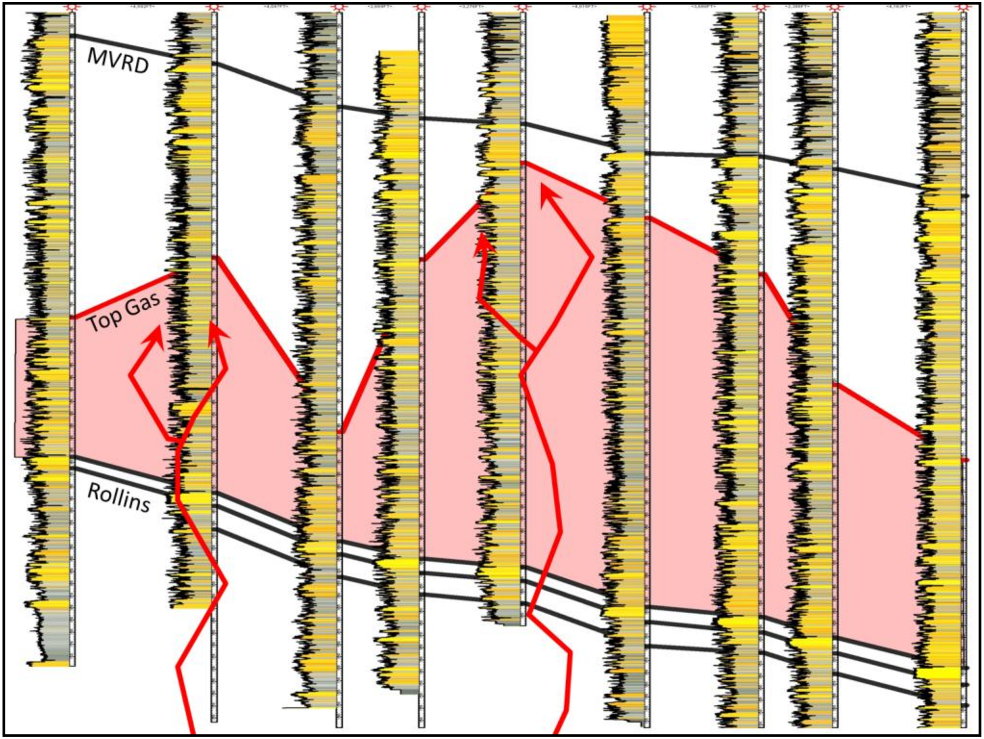
- Recent drilling of numerous Mancos-Niobrara wells in the Piceance Basin has revealed an abundant, areally extensive gas resource
- EURs can exceed 6 BCF for horizontal Niobrara wells
- Very high pressures are encountered in the Mancos-Niobrara (e.g., up to 20 lb mud weights have been used to control pressures)
- Well log analysis and correlations indicate the presence of thick, laterally extensive organic-rich intervals
- Isotopic and gas composition data support a deep gas source

Piceance Basin - Examples of Deep Sourcing

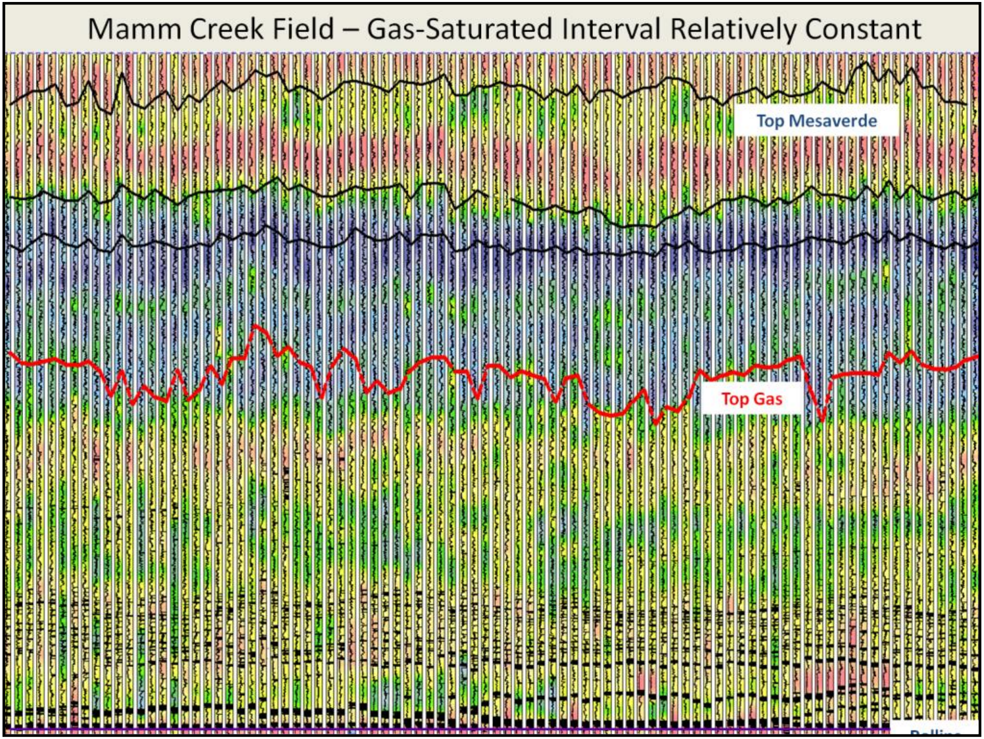




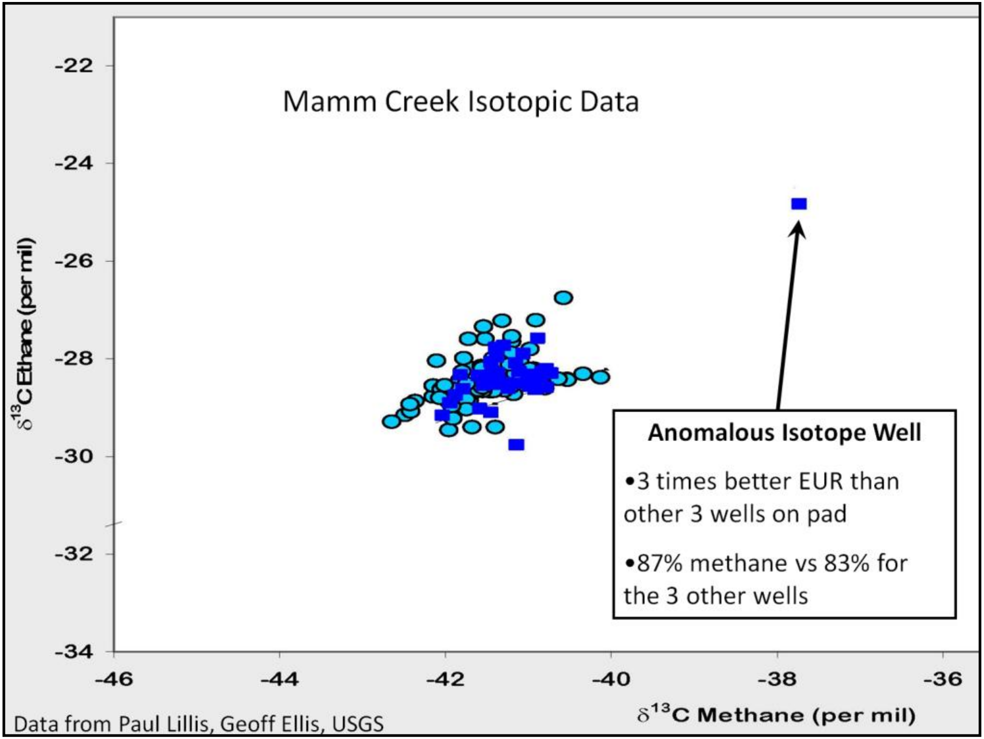
Presenter's notes: Yellow Creek Field is located on a plunging nose in the northern Piceance Basin. The thickness of the gas-saturated interval varies dramatically over relatively short distances. EURs are generally proportional to the thickness of the gas-saturated interval. In areas with thick intervals, EURS can be greater than 4 BCF; in area with thin intervals, EURs are about 0.5 BCF. Perhaps the best explanation for the dramatic variation in gas-saturated thickness is that most of the gas charge is a result of vertical migration along a major fault system that runs along the plunging nose. The primary gas source is the thick underlying Mancos-Niobrara marine-shale interval.



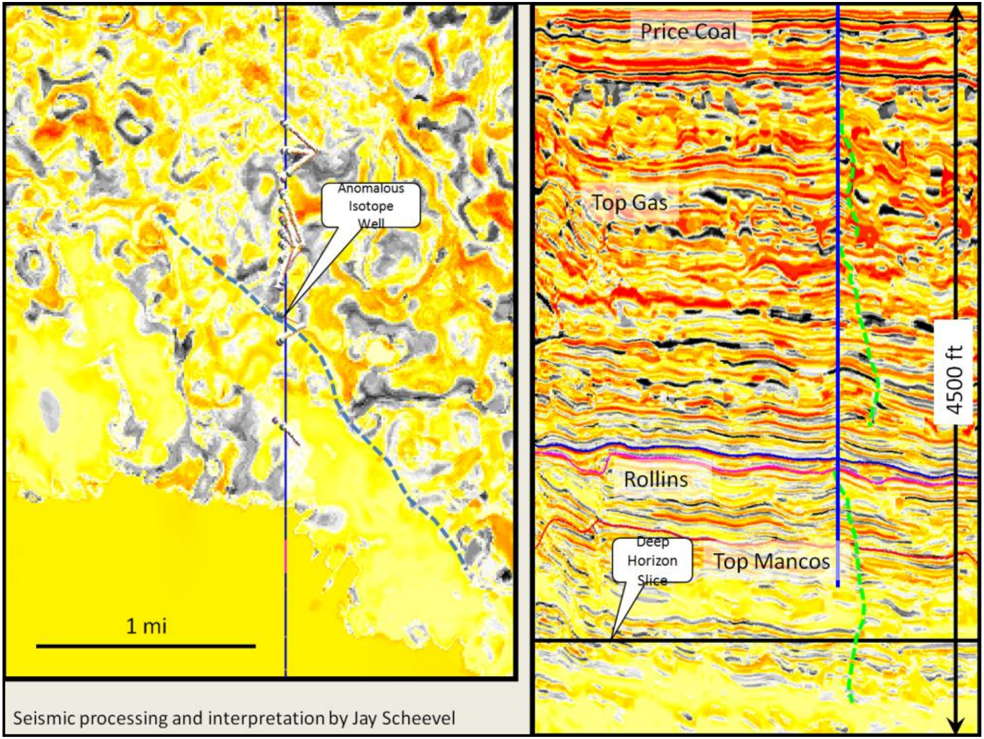
Presenter's notes: This cross section shows the dramatic variation in the thickness of the gas-saturated interval of the Williams Fork. The red arrows show the interpreted gas charge from underlying Mancos-Niobrara marine shales along a major fault system.



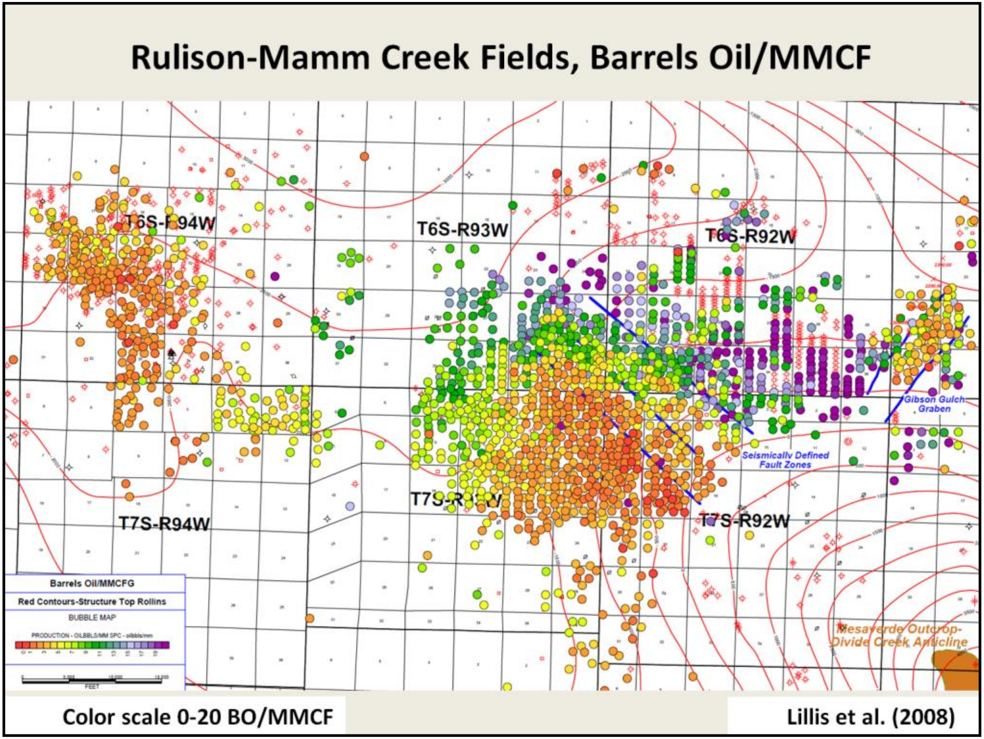
Presenter's notes: This cross section of numerous wells in Mamm Creek Field shows that, in contrast to the previous cross section across Yellow Creek Field, the gas-saturated interval is relatively constant. In Mamm Creek Field, abundant gas charge from the thick, thermally mature coals results in a relatively uniform gas-saturated interval.



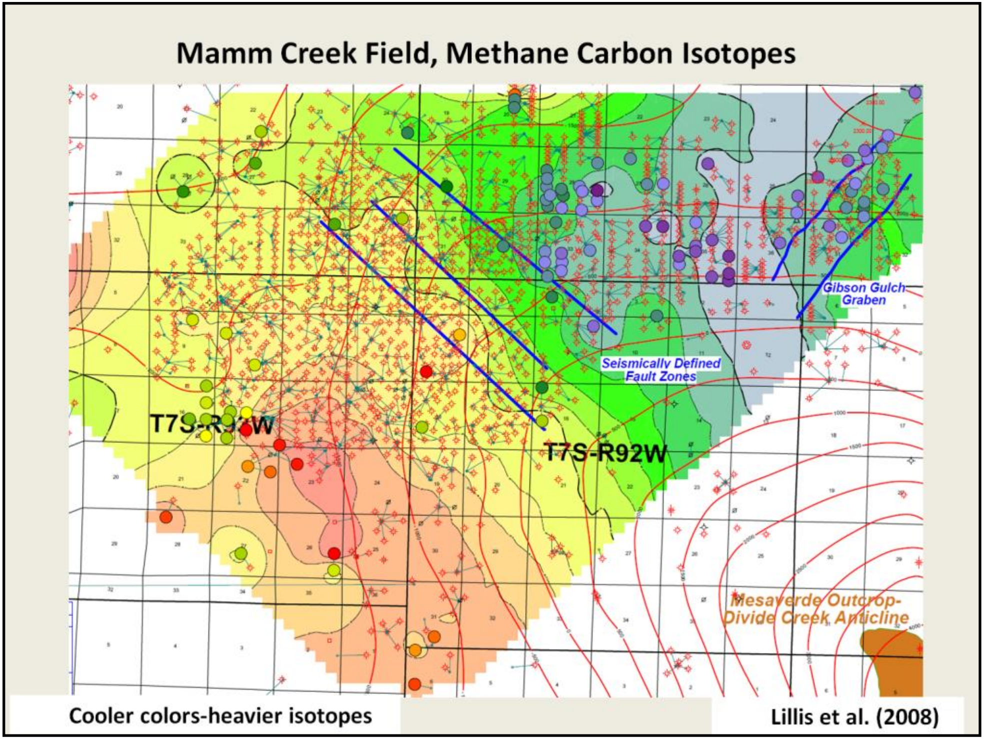
Presenter's notes: Anomalous isotopic data from a well in Mamm Creek Field indicates a deep source for a well that has much heavier carbon isotopes, much higher methane content, and has an EUR that is three times better than the three other wells on the pad. All wells were drilled and completed in a similar manner at the same time and had a similar pay interval in terms of sand thickness.



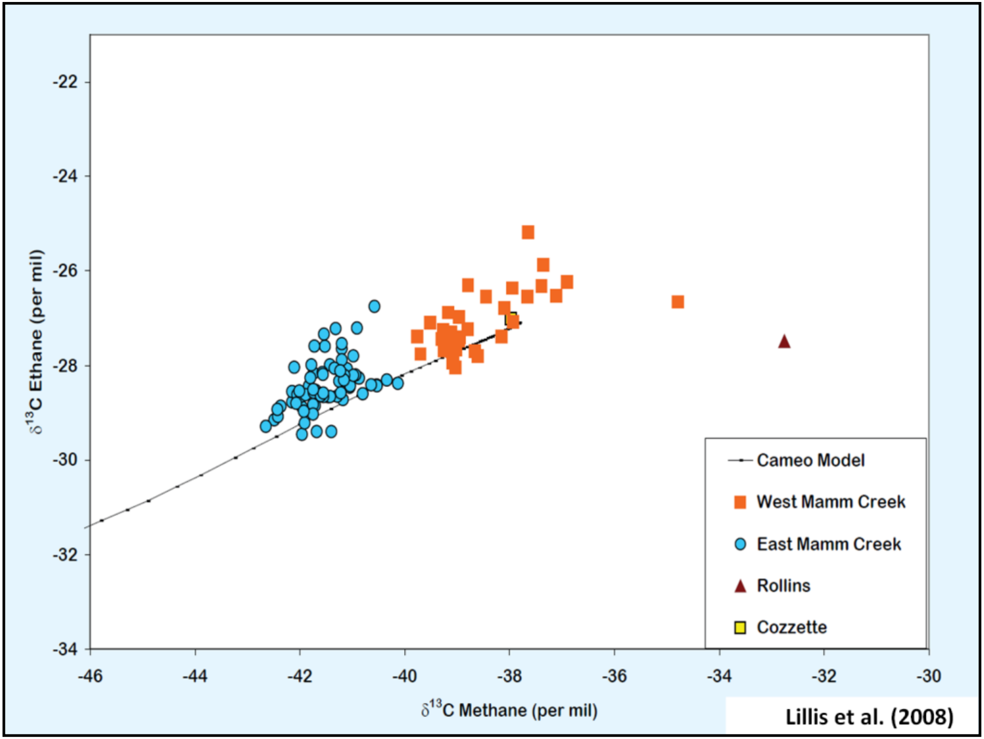
Presenter's notes: Seismic data indicates that the well with the anomalous isotopic composition is located on a fault that might be a conduit for gas migration from the underlying Mancos-Niobrara interval. The interval for the horizon slice on the left is shown on the seismic section on the right.



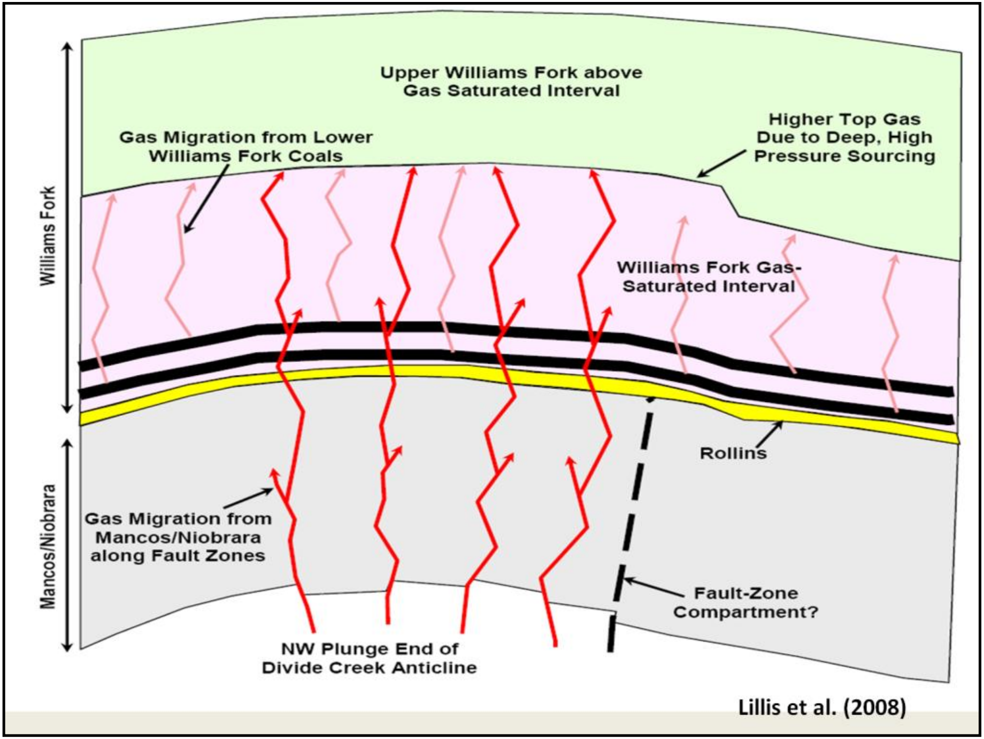
Presenter's notes: The barrels of oil per MMCF changes dramatically across seismically defined fault zones in Mamm Creek Field.



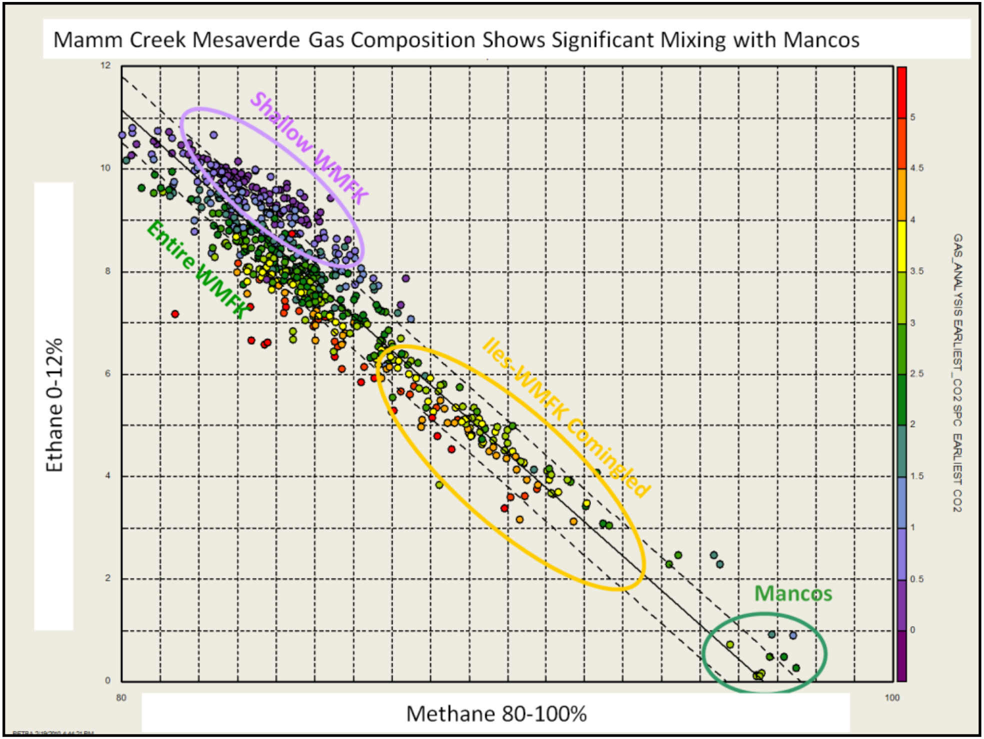
Presenter's notes: Carbon isotopes in produced methane gas show significant changes across the same seismically defined fault zones shown in the previous map. The heavier isotopic values southwest of the fault zones indicate a more mature source.



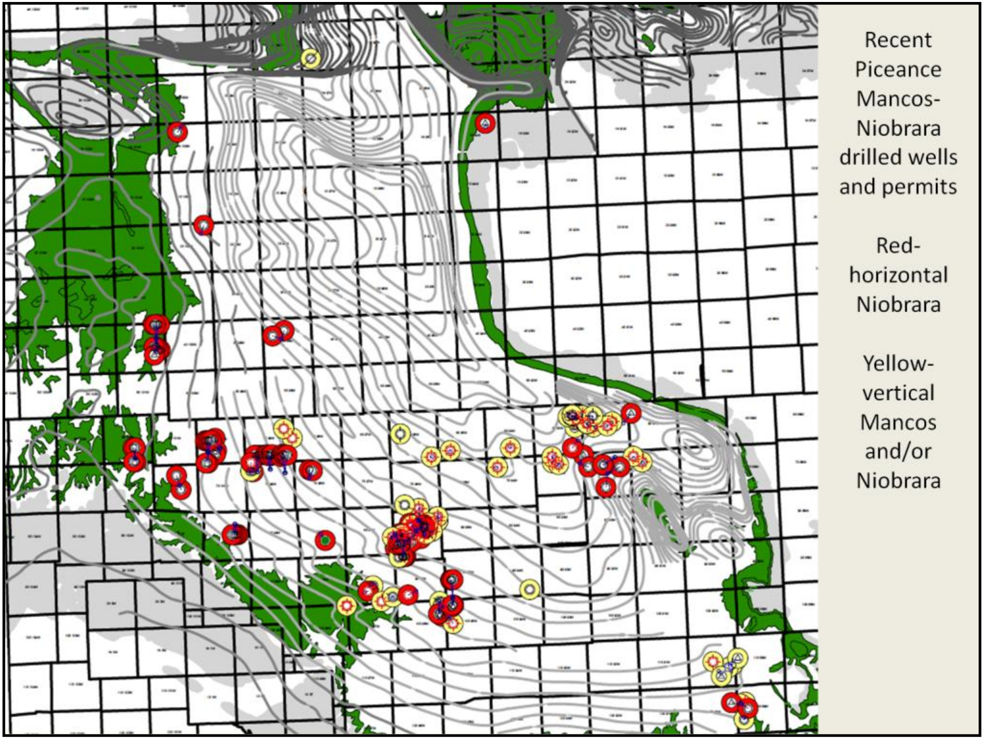
Presenter's notes: This cross plot shows the data presented on the map in the previous slide. Two distinct populations of data are evident.



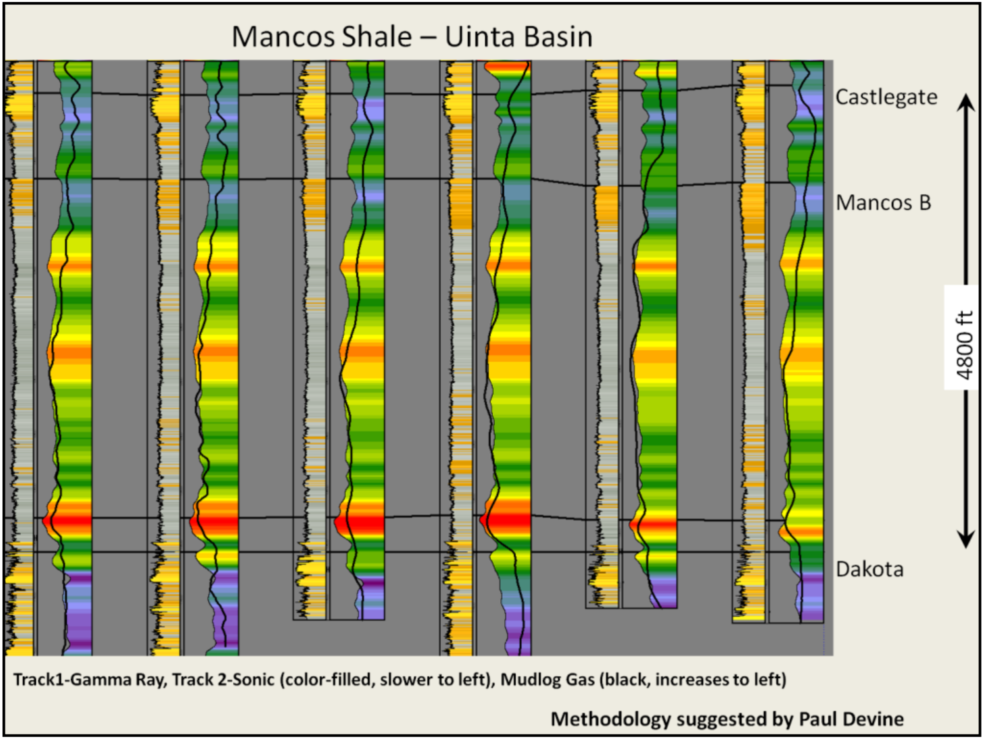
Presenter's notes: Geologic section to explain different gases produced from the Williams Fork in Mamm Creek Field. Thick, mature coals in the lower Williams Fork are an abundant source of gas that pervasively charges the Williams Fork throughout the field. This pervasive gas charge is indicated by the pink arrows. Additional gas charge is provided by vertical migration of Mancos-Niobrara gas along major fault zones (indicated by the red arrows). This gas is from an overmature source and has heavier carbon isotopes and higher methane content.



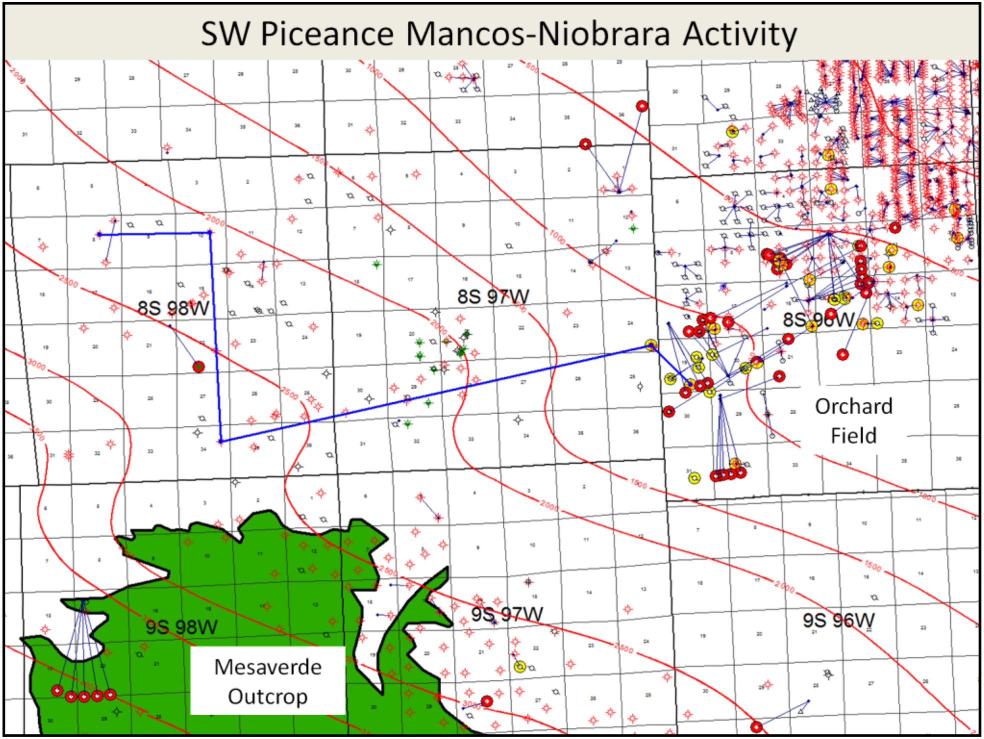
Presenter's notes: This cross plot of methane and ethane content from gas wells in Mamm Creek Field indicates a mixing line between Mancos wells that produce almost all methane and Williams Fork wells that produce much higher ethane. Some wells are completed in the Cozzette-Corcoran interval of the Iles Formation that immediately overlies the Mancos. These wells have compositions indicating a mix of Mancos and Mesaverde sources.



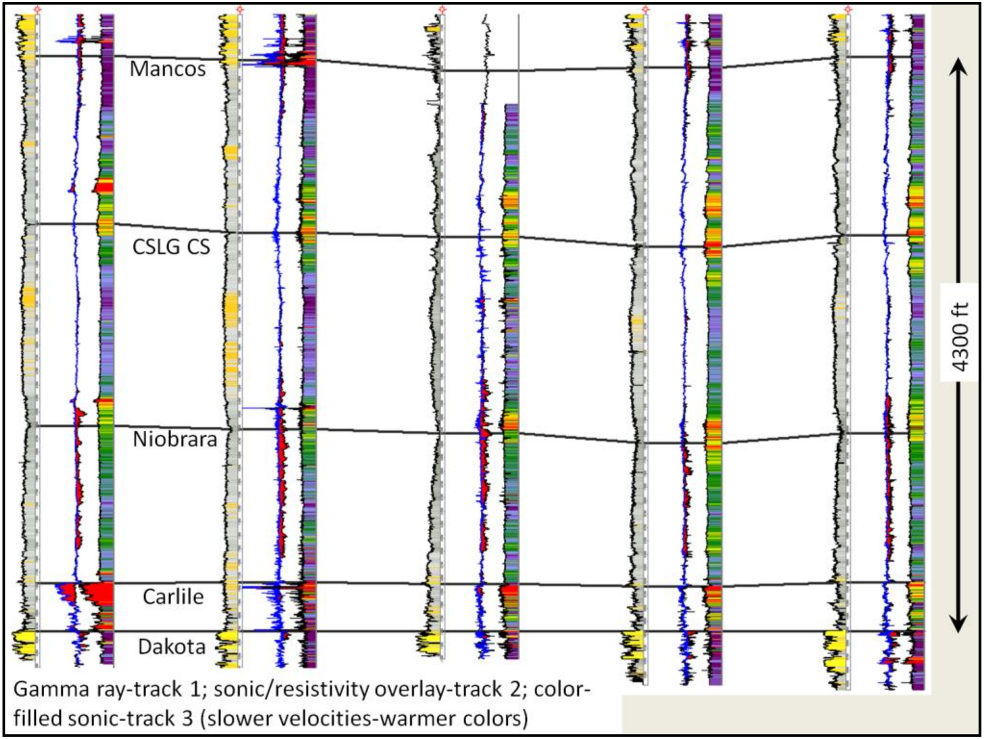
Presenter's notes: Numerous recent Mancos-Niobrara wells have demonstrated the presence of an abundant, laterally extensive gas resource.



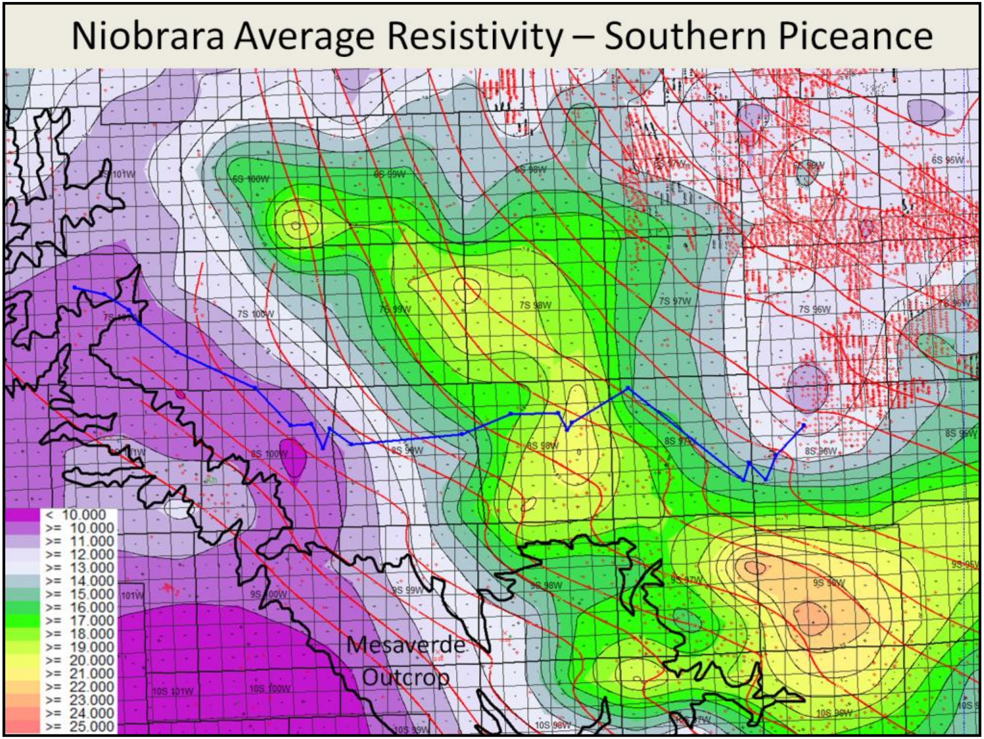
Presenter's notes: Sonic logs and mudlogs from deep wells in the Uinta Basin indicate the presence of widespread organic-rich intervals. Organic-rich intervals have high gamma ray values, high mudlog gas and slow sonic velocities.



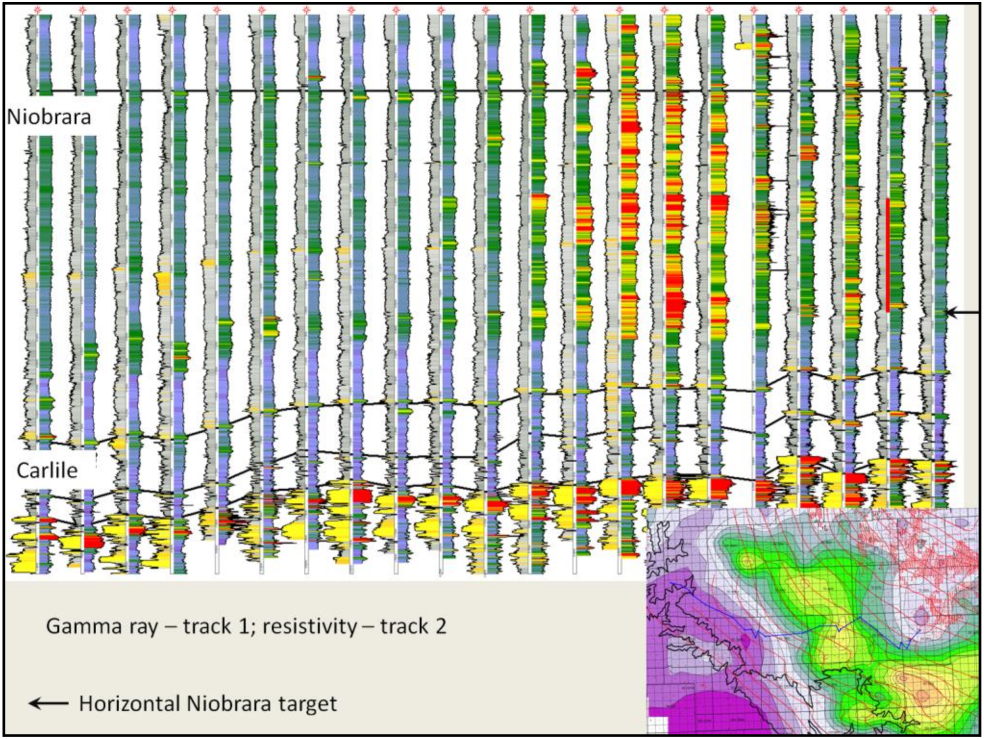
Presenter's notes: This map shows the location of the cross section in the following slide. Niobrara horizontal wells in Orchard Field have estimated EURs of 5-6 BCF.



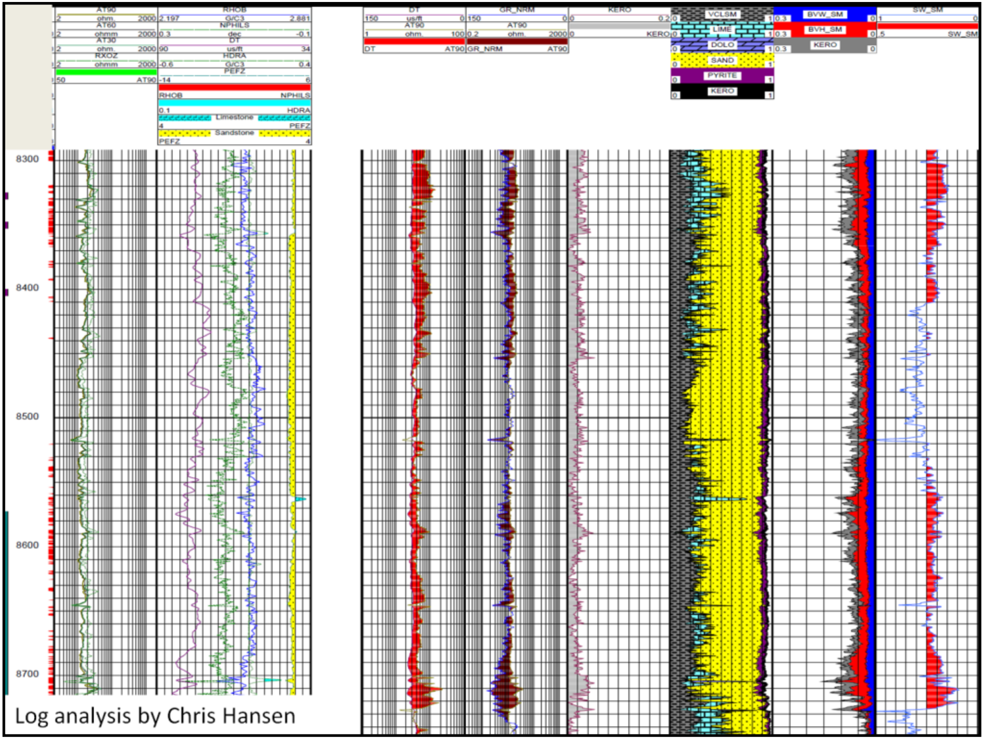
Presenter’s notes: This cross section shows the stratigraphy of the Mancos-Niobrara interval in the southwestern Piceance Basin. Gamma ray is in track 1, resistivity and delta-T are cross-plotted in track 2 (red areas are intervals where resistivity is higher and sonic velocity is slower), and color-filled delta-T is in track 3. Organic-rich intervals tend to have high gamma-ray values, slow sonic velocities, and high resistivities.



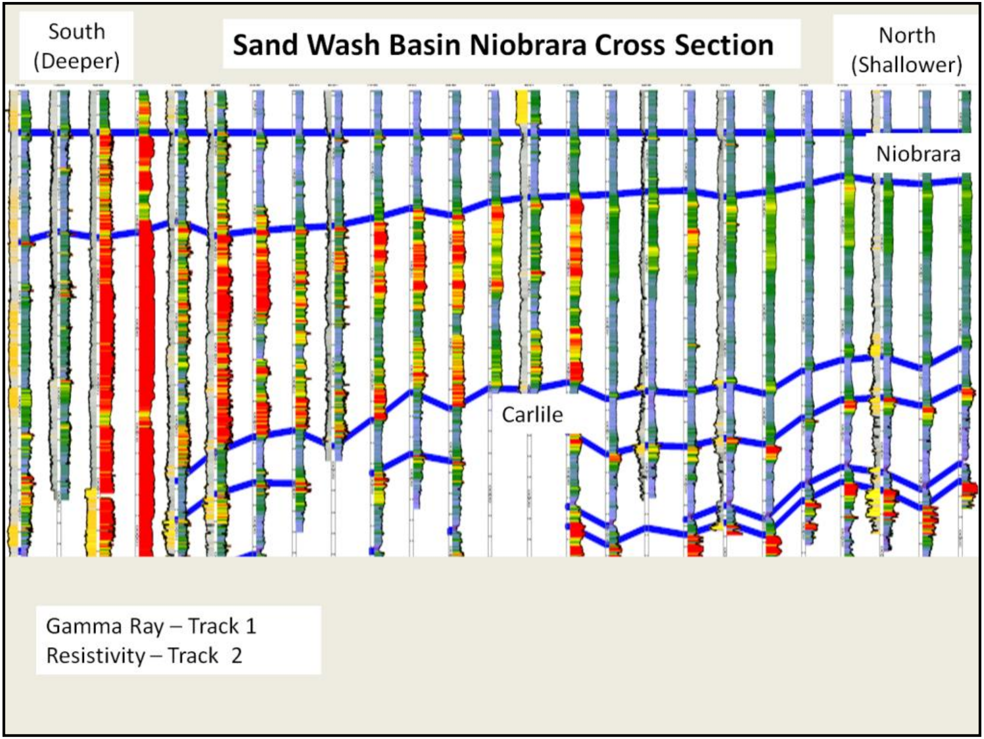
Presenter's notes: Average Niobrara resistivities are shown by the color-filled contours (the legend for the resistivity values is shown in the lower left). Structure contours on top of the Rollins are shown in red (structure deepens to the northeast). Niobrara resistivities are low in the shallow, relatively immature area on the left side of the map. Resistivities increase with depth and increasing maturity toward the center of the map. There is an anomalous decrease in resistivity with even greater depth and higher maturity in the northeast part of the map. This anomalous resistivity reversal can be seen in the cross section in the following slide (cross section line shown in blue).



Presenter's notes: This cross section shows the change from low resistivity from the shallow area on the left to higher resistivities with depth. An anomalous decrease in resistivity occurs in the deepest, most mature wells on the left side of the cross section. The black arrow shows the interval targeted by many of the horizontal Niobrara wells. The interval on the well log in the following slide is shown by the red line on the second well from the right.

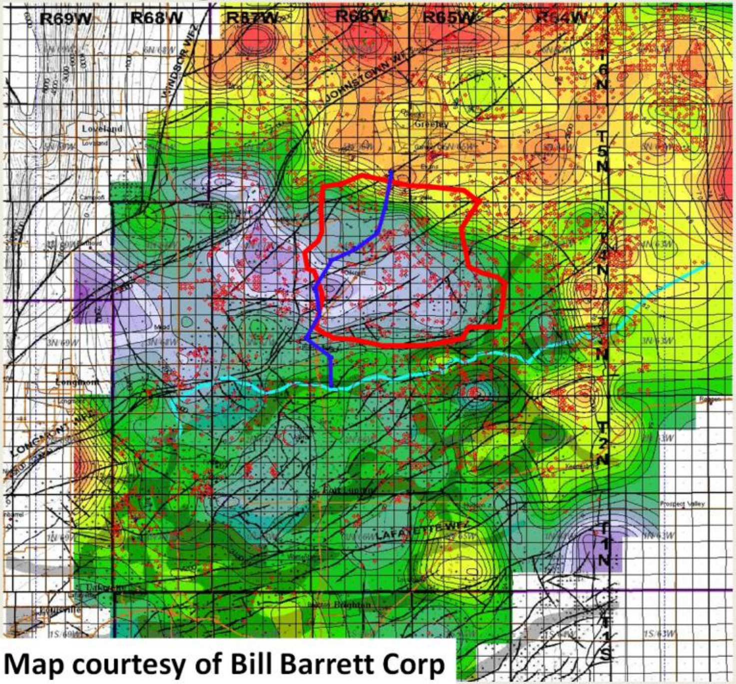


Presenter's notes: Log analysis by Chris Hansen of part of the Niobrara shown by the red line on the second well from the right in the previous slide.



Presenter's notes: A anomalous decrease in resistivity in the two deepest, most mature wells on the left side of the cross section is similar to the resistivity decrease shown on the Niobrara cross section in the southern Piceance.

Wattenberg Field Area Maximum Niobrara B Bench Resistivity



Map courtesy of Bill Barrett Corp

Warmer colors – higher resistivities

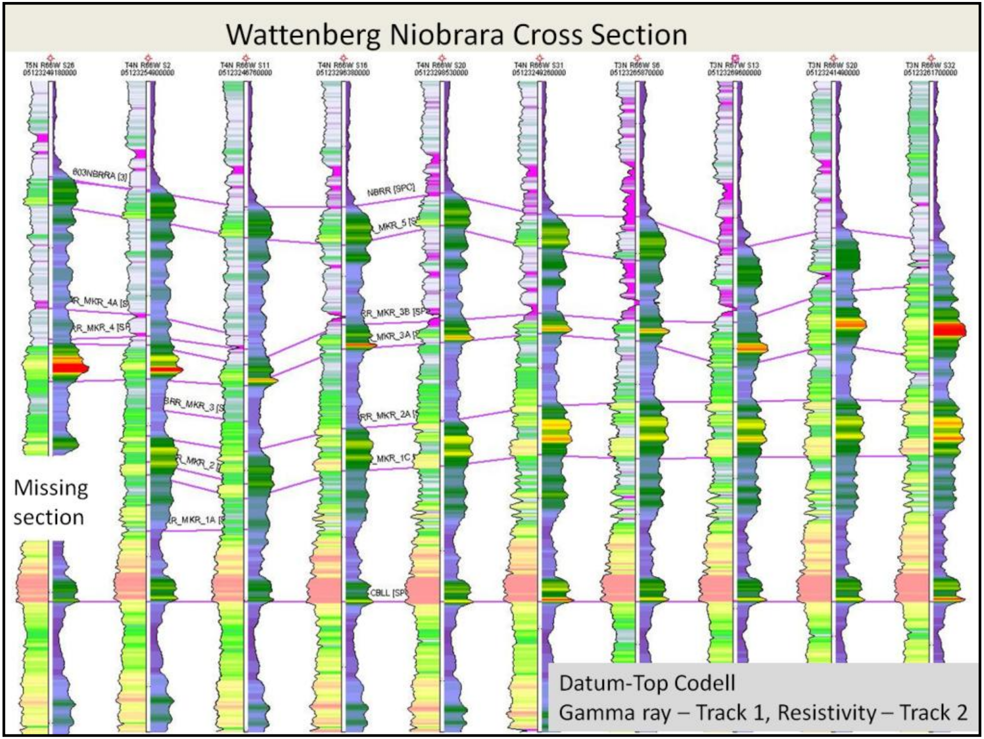
Mowry fault trends, Ladd (2001)

Red outline – Codell GOR > 20,000 (Ladd, 2001)

Cross section line in blue

Resistivity low in Wattenberg may be associated with high thermal maturities (Jack Wiener)

Presenter's notes: Color-filled contours show maximum resistivities of the B bench of the Niobrara. The correlation of resistivity changes with fault trends indicates a possible structural control of resistivities. In general, resistivities increase with increasing thermal maturities. Indeed, resistivity mapping of the Niobrara has been a primary exploration tool for the Niobrara play in the DJ Basin. However, resistivities decrease in the most thermally mature area of Wattenberg. GORs increase with increasing thermal maturity, and the 20,000 GOR contour shown in red indicates the area with the highest thermal maturity.



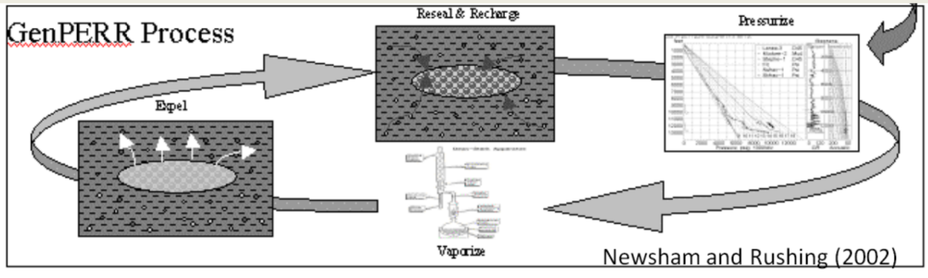
Presenter's notes: The line for this cross section is shown in blue on the previous slide. The top of the Niobrara B Bench is shown by the "MKR_3B" on the cross section. The lower resistivities of the B Bench in the middle part of the cross section correspond to the low-resistivity area in the most thermally mature part of Wattenberg.

Finally, in some shale-gas reservoirs that are at very high maturities (Ro>>3), the overall rock resistivity can be 1-2 orders of magnitude less than is observed in the same formation at lower thermal maturities (Ro between 1 and 3). It was thought that perhaps the carbon in the organic matter is recrystalizing to the mineral graphite, which is electrically conductive, but preliminary studies indicate that pure mineral graphite (as indicated by XRD) is not present in abundance at these thermal maturities.. Thus, it is likely that a precursor to graphite is forming, and further studies are warranted. It is sufficient to state that in extremely high maturity organic-rich rocks (Ro>3), the rock may be much more electrically conductive due to other mineral phases being present rather than solely formation water, clay, and pyrite (as usually considered).

Passey et al., 2010

The decrease in Niobrara resistivities with increasing maturity in the Piceance, Sand Wash, and DJ basins occurs approximately at the wet gas to dry gas transition (far below the Ro>>3 mentioned in the Passey paper).

Presenter's notes: Passey (2010) noted that some shale-gas reservoirs at very high maturities can be significantly less than in the same formation at lower thermal maturities. However, the decrease in resistivity in the Niobrara maturity in the Piceance, Sand Wash, and DJ basins occurs approximately at the wet-gas-to-dry-gas transition (far below the Ro>>3 mentioned in the Passey paper). Passey (2010) suggests that a conductive precursor to graphite may be causing the reduction in resistivity.



A mechanism for removing water from organic-rich shales proposed by Newsham and Rushing (2002) may provide a possible explanation for the decrease in resistivity with increased maturation. They propose that the key element required to move water effectively is the process of vaporizing connate water into the gas phase. Laboratory data suggests that, at temperatures exceeding 280° F to 300° F, significant volumes of water vapor may be dissolved in the hydrocarbon gas. The water that is dissolved in the gas phase is very fresh, and as the fresh water dissolved in the hydrocarbon gas is expelled, the water remaining in the formation becomes increasingly saline. This increase in salinity would lower Rw, which would in turn lower formation resistivity.

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Summary

- Recent drilling of numerous Mancos-Niobrara wells in the Piceance Basin has revealed an abundant, areally extensive gas resource
- EURs can exceed 6 BCF for horizontal Niobrara wells
- Very high pressures are encountered in the Mancos-Niobrara (e.g., up to 20 lb mud weights have been used to control pressures)
- Well log analysis and correlations indicate the presence of thick, laterally extensive organic-rich intervals
- A decrease in resistivity appears to correlate with a change from wet to dry gas in the Niobrara
- Vertical migration of gas through the thick marine shales of the Mancos-Niobrara to the Mesaverde is difficult due to the very low permeability of the shales and the presence of thick, ductile, clay-rich intervals
- Major fault and fracture zones may provide a conduit for vertical gas migration
- Indications of deep sourcing for Mesaverde gas include an elevated top gas, EUR sweet spots, dry gas, and heavy carbon isotopes