A Geologic Comparison of the Oil Window and Dry Gas Window within the Tow Creek Member of the Niobrara Formation in the Piceance Basin of Northwestern Colorado*

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Abstract

The Piceance Basin of northwest Colorado has historically produced significant amounts of oil and natural gas from shallow Upper Cretaceous Mesa Verde Group reservoirs. In the past decade a deeper target has earned attention within the Mancos Shale interval. The Niobrara Formation is a proven resource in the highly explored Denver Basin. More recently it has become a target in western basins, such as the Sand Wash, San Juan, and Piceance basins of the Rocky Mountains. Although compositionally the Niobrara differs within the Piceance Basin, production from the interval has taken place in large quantities. Varying organic thermal maturities exist in the same stratigraphic interval across the basin. This is seen with the production of oil in the north and the production of dry gas in the south. This study analyzes the strata in each of these locations in an attempt to better understand why differing levels of maturity exist within the same stratigraphic interval and what factors are affected by this differing maturity.

Through the use of core and thin section descriptions, six fairly similar lithological facies with slightly differing depositional environments were determined. Bulk mineralogy shows a major difference from the Denver Basin, with an introduction of a significant amount of siliciclastic material. However, within the Piceance, both the northern and southern Niobrara strata contain a very similar make up consisting of a near even mix of siliciclastic, carbonate, and clay material. This mixture classifies the strata as a mixed mudstone. Source rock analysis confirms the two different maturity levels within the basin and highlights the good to very good amount of total organic carbon present. Subsurface mapping correlates the strata across the basin and shows a thickening trend within each member of the Niobrara to the northwest. Fracture analysis through the use of borehole image logs, shows a structurally complex basin that causes sporadic quantities and orientations of natural fractures. FE-SEM analysis demonstrates a dramatic increase in organic microporosity with increased thermal maturation of the Niobrara source rock.

Selected References

Cumella, Stephen P., Erik Graven, Paul Weimer, and Nathan Rogers, 2014, Piceance Basin Niobrara-Mancos: Piceance Basin Niobrara Mancos Gas Accumulation, *in* Oil and Gas Fields of Colorado: Rocky Mountain Assoc. Geologists, p. 236-257.

Dyman, T.S., E.A. Merewether, C.M. Molenaar, W.A. Cobban, J.D. Obradovich, R.J. Weimer, and W.A. Bryant, 1994, Stratigraphic transects for Cretaceous rocks, Rocky Mountains and Great Plains regions, *in* M.V. Caputo, J.A. Peterson, and K.J. Franczyk, eds., Mesozoic systems of the Rocky Mountain region, USA, Denver, Colorado: Rocky Mountain Section SEPM, p. 365-392.

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Colorado School of Mines

Outline

- Geologic Overview
- Mapping
- Facies Analysis
- Organic Geochemistry
- Image Log Fracture Analysis
- Microporosity
- Conclusions and Future Work

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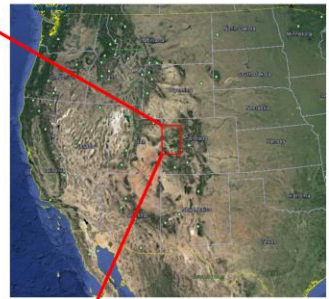
Depositional Setting

(Modified from Blakey)

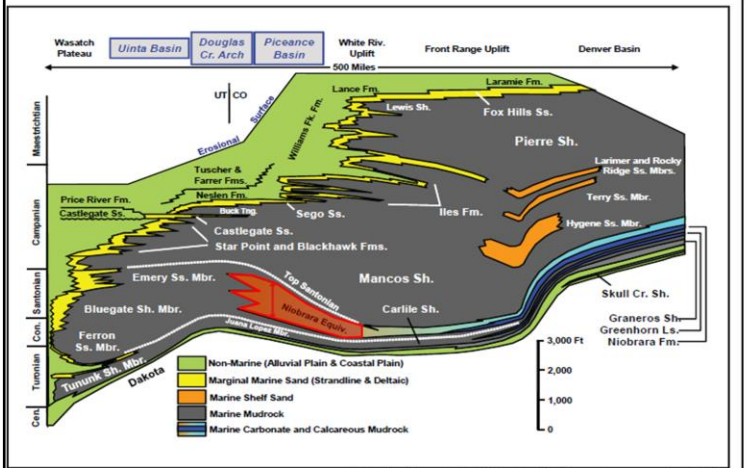
Presenter's notes: Deposition- inter Cretaceous Seaway that filled the foreland basin to the west of the Sevier Highlands.
The inter cretaceous seaway extended from the present day Arctic Ocean to present day Gulf of Mexico, (ON LEFT)
Note the Piceance Basin is outlined in ***purple*** on both of these maps. During the deposition of the Niobrara the Piceance received a much higher siliciclastic input due to its paleogeographical location and close proximity to the western Sevier highlands. This higher siliciclastic input is synonymous with ***lower total organic content, as well as a decrease in percent of calcareous material***. Also present is an introduction of ***type III organic matter*** input from those western Sevier Highlands.

Study Area

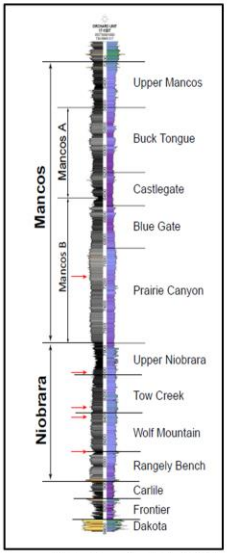


Presenter's notes: After deposition the basin was uplifted and segmented by the Laramide Orogeny. The bounding uplift surrounding the basin shown here consist of the ***Uinta Uplift and Axial Basin Anticline to the north***, the ***White River Uplift and Elk Mountains to the east***, the ***Uncompahgre and Gunnison uplift to the south***. To the ***west the Douglas Creek Arch*** separates the Piceance from the ***Uinta*** Basin.

Stratigraphy and Nomenclature



(Modified from Cole, 2008; Modified from Dyman et al., 1994.)

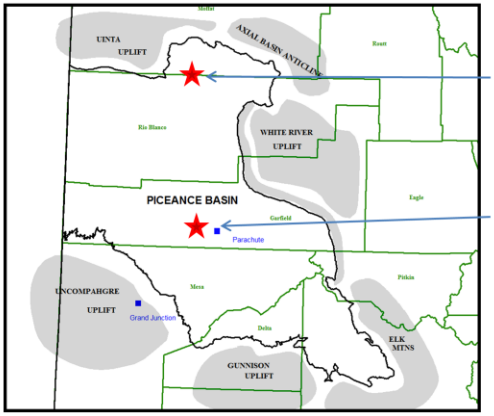


(From Cumella et. al., 2014)

Presenter's notes: This figure shows the Late Cretaceous stratigraphy from the Uinta Basin through the Piceance Basin and into the Denver Basin. The focus of this study will be the Niobrara highlighted in red within the Piceance Basin. The overall thickness of the Mancos section within the Piceance is much greater than what is seen in the Denver Basin due to an increase in accommodation space closer to the Sevier Highlands where subsidence would have been the greatest at time of deposition. The nomenclature that was used in this study is borrowed from the Sand Wash Basin, as the stratigraphic section is much more similar to that of the Sand Wash versus that of the Denver which contains alternating sequences of chalks and marls. From base to top the strata consists of four benches with unnamed marly sequences in between. The four benches are the Rangely Bench, the Wolf Mountain Member, The Tow Creek Member, and the Buck Peak Member.

Motivation and Significance

- Better understand the differing maturities that exist within the same section of source rock at similar total vertical depths.
- Understand and analyze the factors that contribute to the overall petroleum systems.



Wiley IP: 805 BOPD + 1.5 MMCF/D
Niobrara TVD: 9,684 ft.

GM-701-4-HN1 IP: 16 MMCF/D
1 BCF in first 100 days on production
Niobrara TVD: 9,963 ft.

Presenter's notes: The two cores I will be using for this study are from the center of the basin and the basin margin. The Wiley core on the basin margin came from a well that had an IP of 805 BOPD and 1.5 MMCF/D. The GM 701 core in the basin center came from a well that had an IP of 16 MMCF/D and within its first 100 days on production produced 1 BCF.

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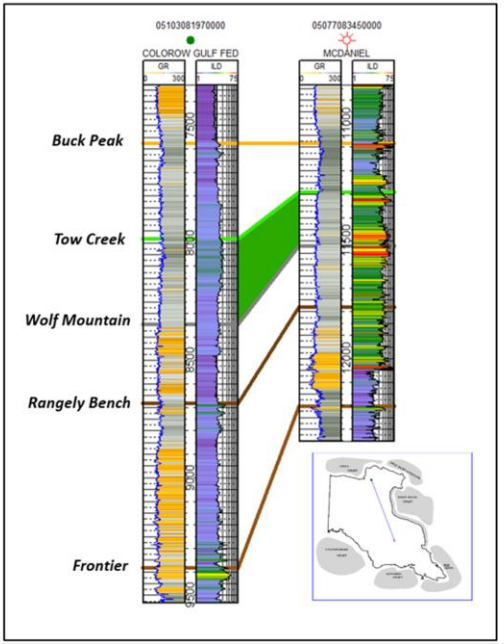
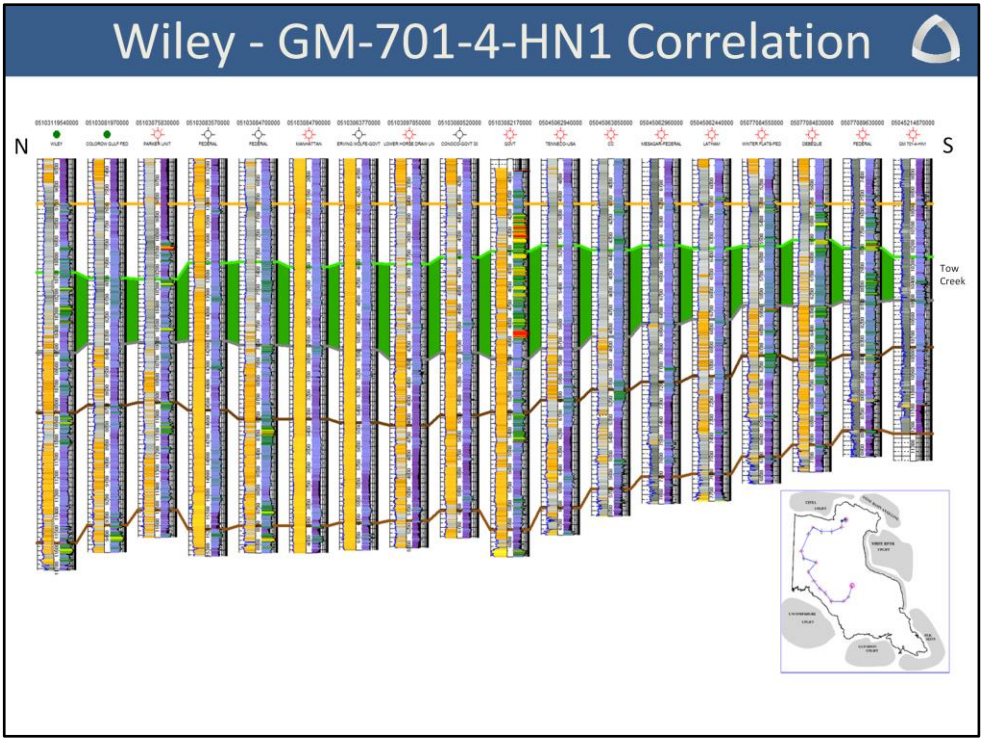
North to South Correlation

N



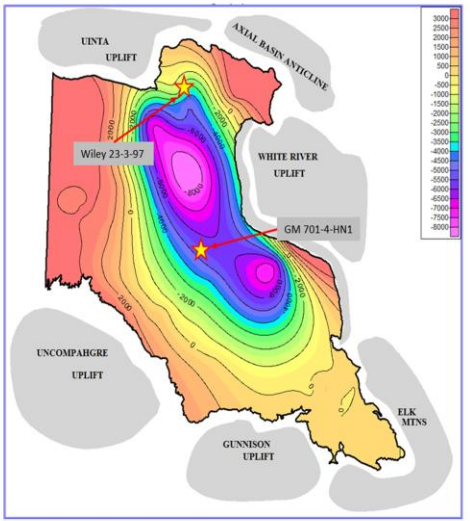
S

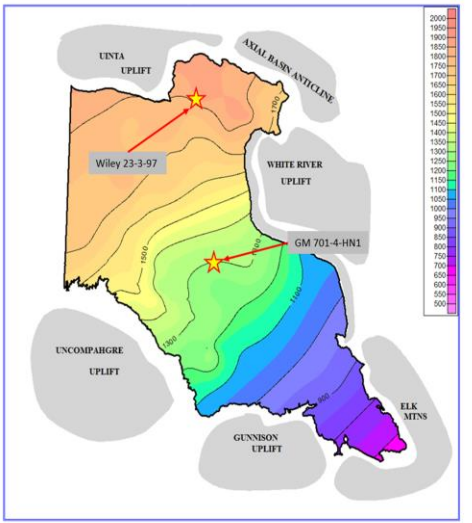
- Over a thousand foot increase in thickness from south to north.
- Each bench/ member contains a resistivity spike and a slight gamma spike.
- Relative variation in log response throughout the basin. – Most notably the resistivity spike seemed to vary from the top of the bench to slightly below.



Presenter's notes: So I Began my project with mapping the Niobrara throughout the basin. I connected the Wiley well in the north to the WPX-GM-701-4-HN1 well in the south and observed an overall thickening to the northwest.

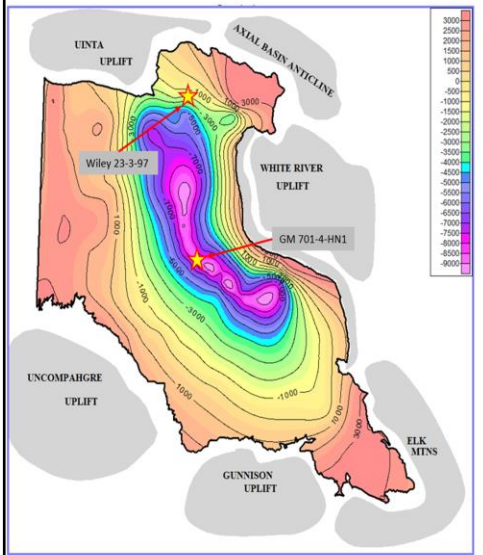
Niobrara Structure and Isopach

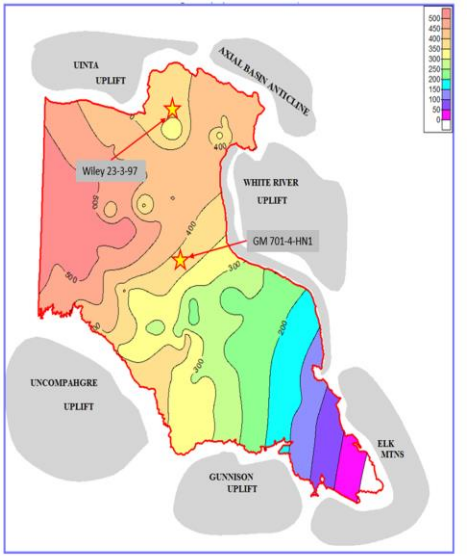




Presenter's notes: The maps that I was able to create throughout my mapping process show an increase in thickness from southeast to northwest. The structure map of the top of the Niobrara shows an increase in depth towards the center of the basin, with a shallow dipping western edge and a steep dipping eastern edge.

Tow Creek Structure and Isopach





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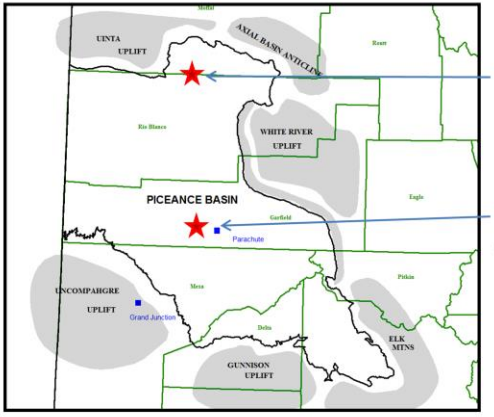
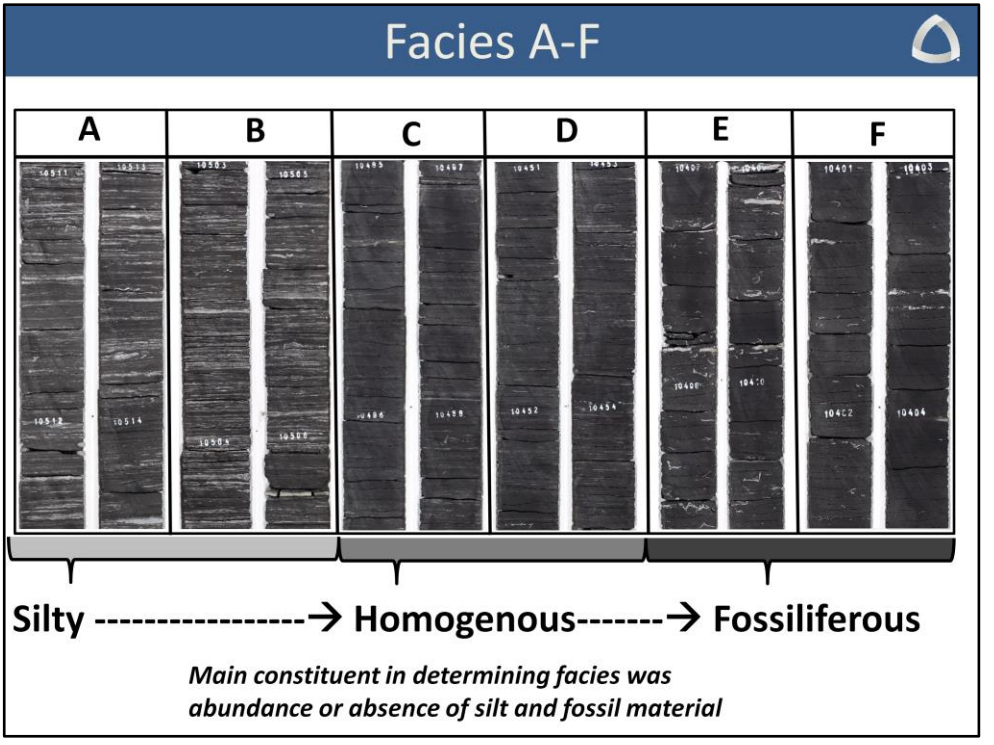
Cores



Wiley 59' core through the Buck Peak and Tow Creek Members

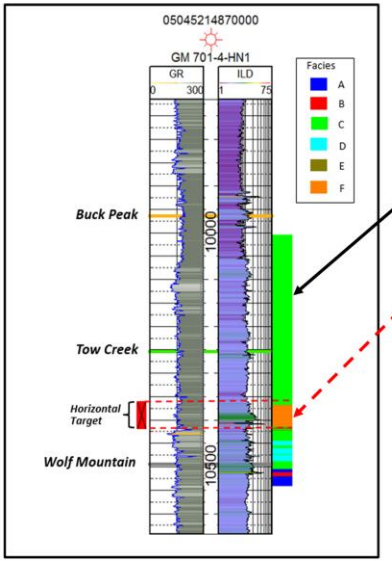
GM-701-4-HN1 – 535' core through the Tow Creek and Wolf Mountain Members

Presenter's notes: Each of the two wells in this study consisted of a cored section. The wiley in the north had a 59 foot core that covered the base of Buck Peak marly section and the top of the Tow Creek Member. The GM-701 in the south contained 535' of core through the Tow Creek, and top of the Wolf Mountain Member.



Presenter's notes: Six facies were determined within these cores A-F. The major differences within the faces were the silt content and the fossil content. Facies A and B contained an increased amount of silt, where facies E and F contained and increased amount of fossil content and very little visible silt content. The majority of the core was very homogenous and looked like C and D.

GM-701-4-HN1 Facies Distribution

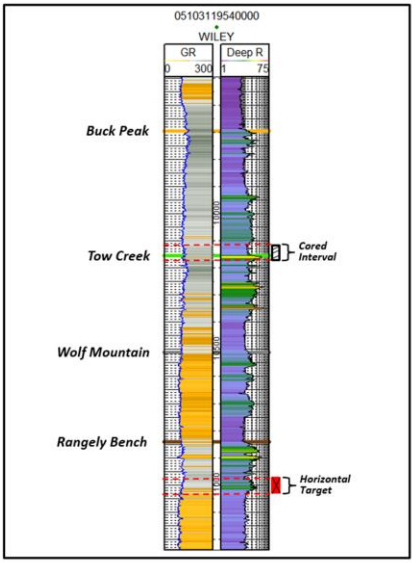


- Facies C was the most abundant facies within this core.
- Facies E and F represent the majority of the horizontal target for this well and correspond to a high resistivity response.

Presenter's notes: As I mentioned Facies C was by far the most dominant facies in this core. Also to note was the horizontal target for this well was in the two most fossiliferous facies and corresponds to the high resistivity reading within the Tow Creek Bench.

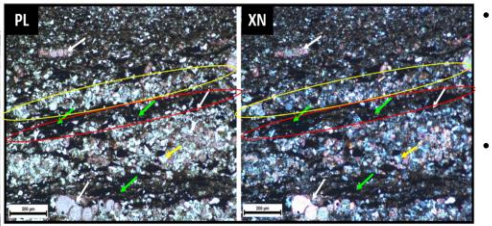
Wiley Core

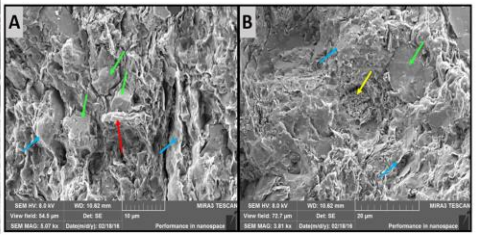
Only Facies C was present in the Wiley Core.



Presenter's notes: The Only facies present in the Wiley core was the C facies. Also point out that the horizontal target was in a zone that was not cored, however it was in an increased resistivity zone, similar to the beast core.

Silty Facies A & B



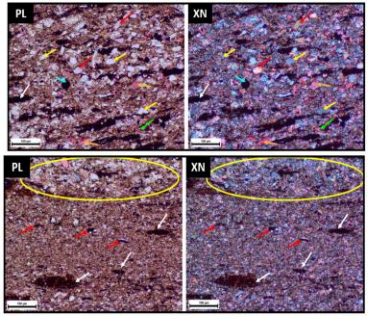


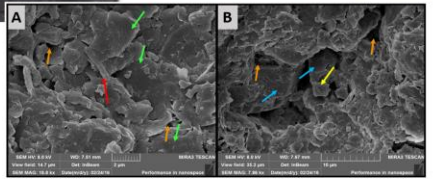
- The silty facies consisted of layers of siliciclastic material that were interbedded with muddy layers.
- Organic matter aggregates were most abundant in the muddy layers, foraminifera were present throughout.

- **A** shows a siliciclastic portion of the facies containing clay and nano fossils.
- **B** shows a more clay rich – muddy layer

Depositional interpretation: **Sea regression creating lower overall sea level over a shallow marine shelf. A higher influx of siliciclastic material due to the shortened distance to the shoreline. Individual silt beds could be an indicator of individual storm events.**

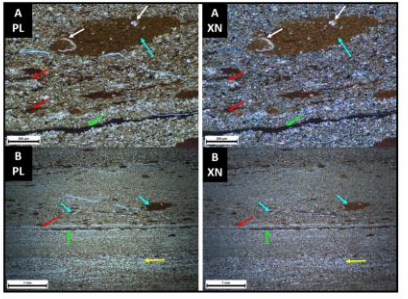
Homogenous Facies C & D



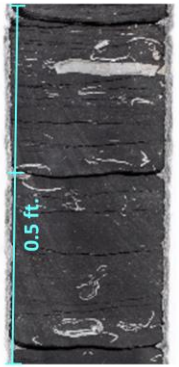


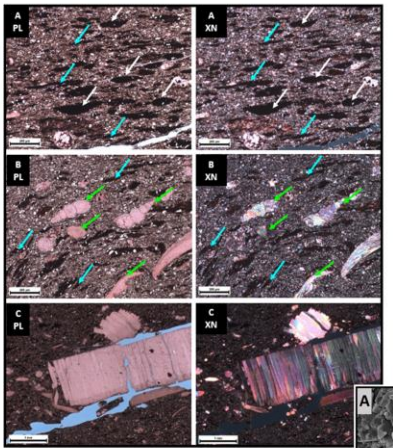
***Depositional interpretation*: Sea transgression creating a deeper overall sea level over a marine shelf. A better mixing of siliciclastics from the shoreline and carbonates and clay from the marine setting exist in combination with foraminifera, fecal pellets and organic matter.**

- Facies C and D were represent the majority of the core.
- Even mixture of siliciclastics, carbonates and clay.
- Fecal pellets of varying sizes and organic matter aggregates present throughout.
- Foraminifera present in random orientations
- Some silt layers present.
- Some organic rich layers present.
- Bitumen filled fracture present in Wiley Core
- A mix of quartz grains, clay and calcite grains is seen in FE-SEM micrographs.

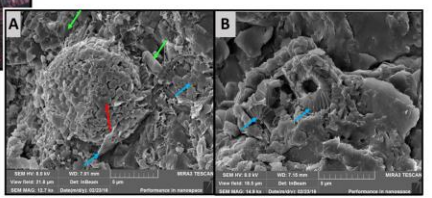


Fossiliferous Facies E & F



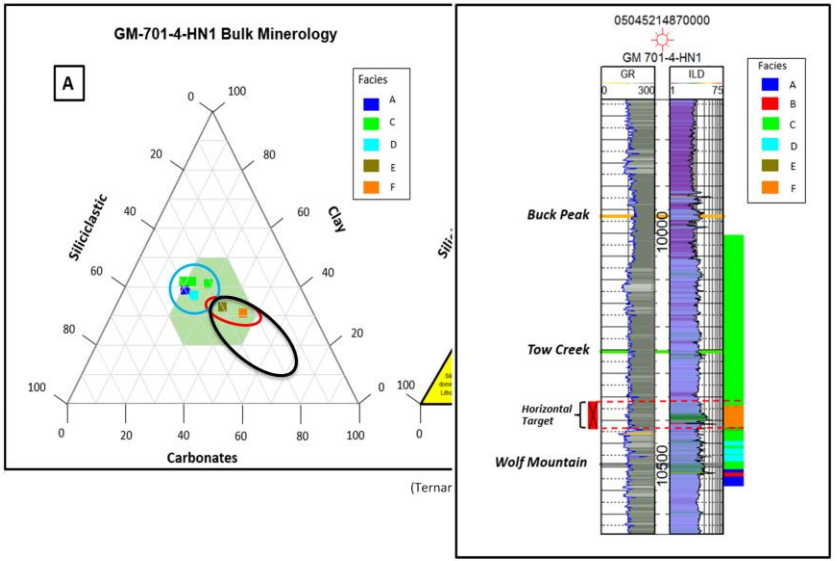


- Fossiliferous Facies A & F contained an abundance of *Inoceramid* and *oyster* fragments in the core.
- No silty laminations.
- A much higher content of fecal pellets and organic matter aggregates as well as an abundance of foraminifera in thin section.
- The matrix consisted of a mixed siliciclastic, clay and carbonate material.
- The increase of calcite present in these facies corresponds to the resistivity spike noted in the log.
- Facies E was the only facies that contained coccospheres.



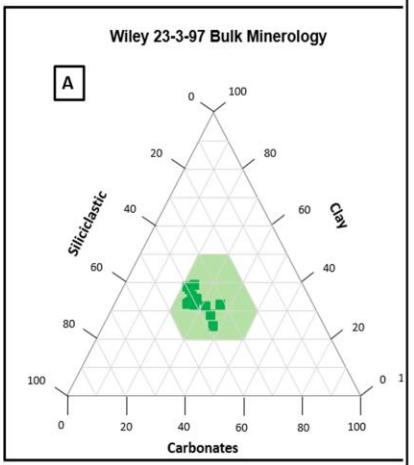
***Depositional interpretation*: High stand sea level over a shallow marine shelf. An increase in fossils and foraminifera can be attributed to a warmer climate or more oxygenated waters. Another possible interpretation for the most fossiliferous Facies E is a tempestite that has a possible correlation to the B bench in the Denver Basin.**

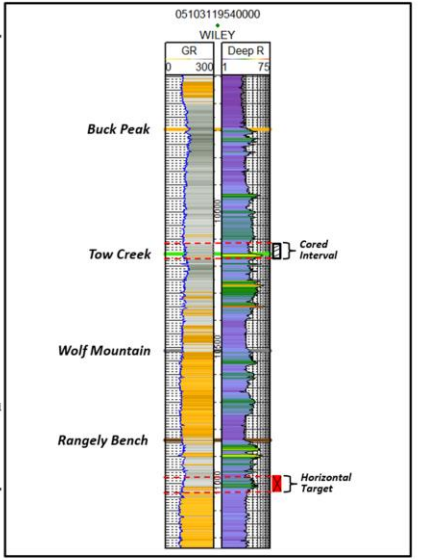
GM-701-4-HN1 XRD



Presenter's notes: The XRD analysis done on samples from the GM-701 well all plot within the mixed mudstone classification as determined by Gamero-Diaz et al. An important note here is this is where the marlstones of the Denver Basin plot while the chalk reservoir facies plot much closer to the Carbonate dominated lithotype. The colors shown on this plot correspond to the facies determined from the core. As you can see the two fossiliferous facies plot the closest to the carbonate rich section showing a decrease in clay. I believe this is one of the main factors that is attractive about these facies as a horizontal target.

Wiley XRD





Presenter's notes: The XRD analysis done on the Wiley well samples also shows that all of the samples plot within this mixed mudstone classification. This cored interval was not through a high resistivity bench and no fossiliferous facies were seen in the core and therefore we also see no data points towards the mixed carbonate mudstone lithotype. This is likely due to the cored interval only accessing one facies.

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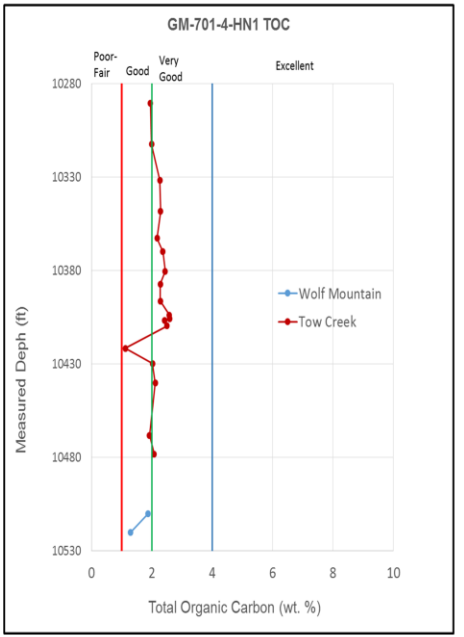
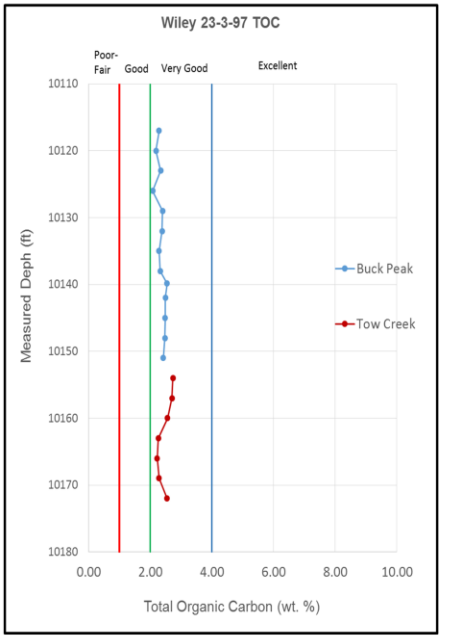
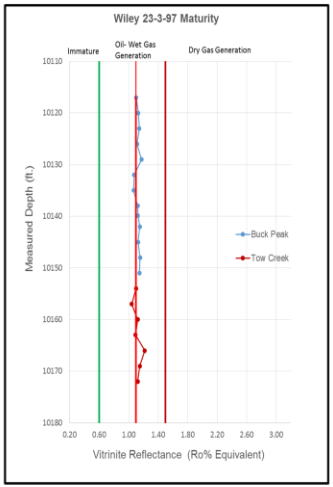
Total Organic Carbon

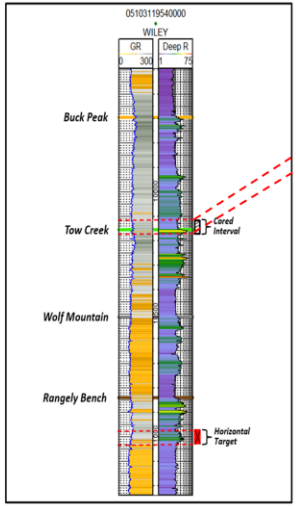


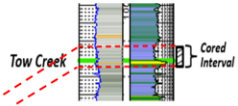


Presenter's notes: Peters and Cassa (1994) distinguish quality ranges.

Wiley Maturity



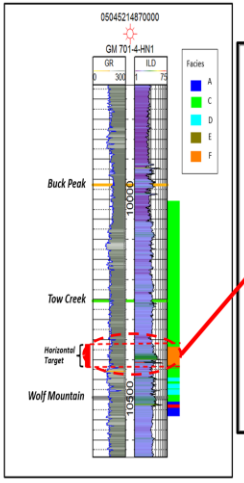


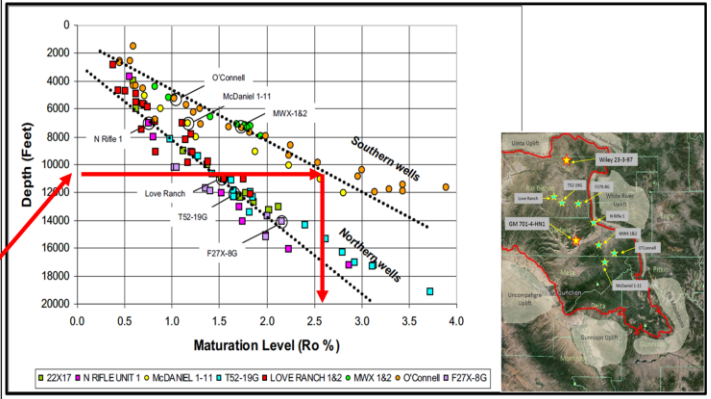


- Vitrinite reflectance equivalent is calculated from Tmax values.
- Production from the Wiley is volatile to wet gas.
- Source rock analysis is consistent with production-plotting within the oil-wet gas window.

Presenter's notes: Tmax was converted to vitrinite reflectance based on the method suggested by Jarvie et al (2001) where you plot measured vit R against Tmax and use a trend line. The pyrolysis data came from the cored section in the Tow Creek, and the production came from the Rangely Bench, however, considering that the type of production matches the SRA in the cored interval you can see that the entirety of the section lies within the oil- wet gas window.

GM-701-4-HN1 Maturity





(Modified from Yurewicz et al., 2003)

Using a maturation profile from near by wells it was determined that the depth of the core should be within the mature dry gas window which is consistent with production.

Presenter's notes: To replace the maturity data from the SRA I extrapolated depth to maturity using trend lines from near by wells. The chart on the right came from a study done by Yurewicz et al in 2003. The locations of the wells they used are shown on the map in comparison with the GM-701 well. When taking the depth of the Tow Creek and placing it on their trend line for near by wells a vit reflectance value of 2.5-2.6 is established which is consistent with the dry gas production from this horizon.

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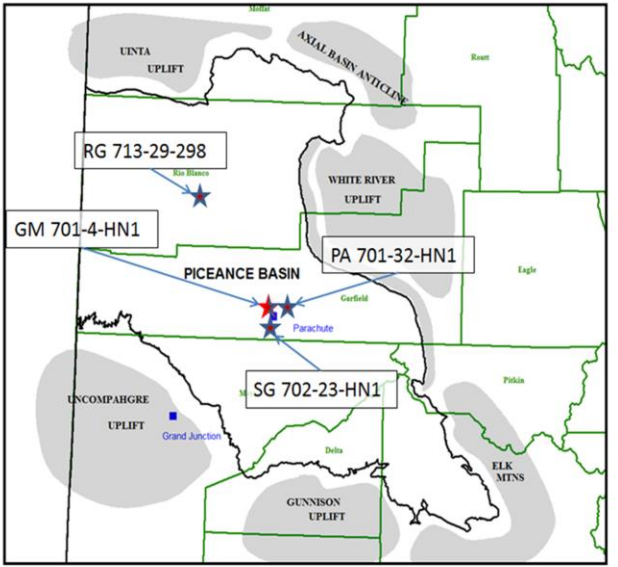
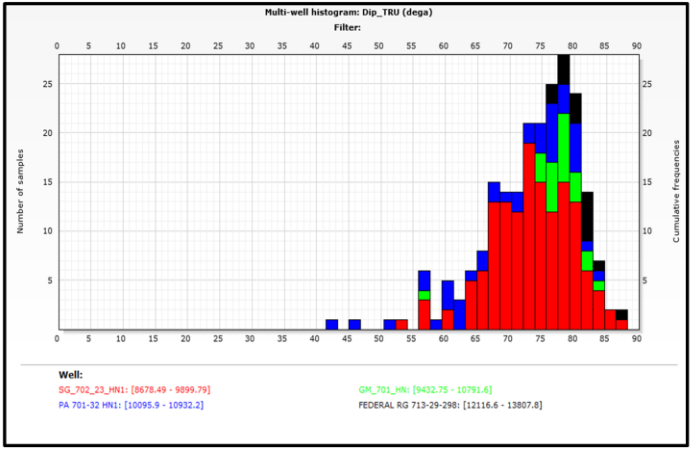
Data Available



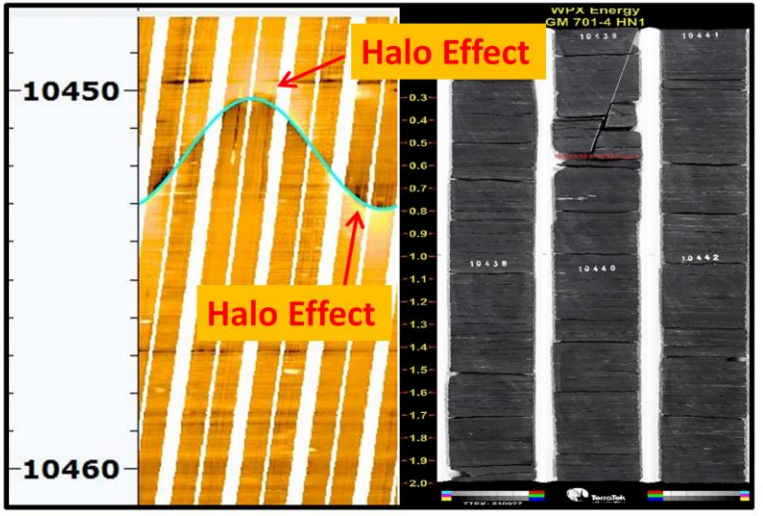
Presenter's notes: Four wells contained formation image logs which were analyzed for fractures.

High Angle Fractures

Well	Average Dip (degrees)
GM-701-4-HN1	77.0
SG- 702-23-HN1	76.6
PA-701-32-HN1	69.4
RG-713-29-298	77.2



Calcite Lined Fractures

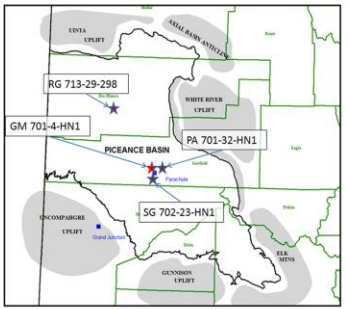


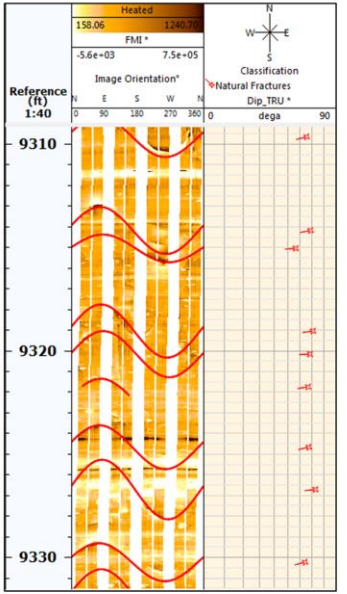
"Depending on the matrix and the degree of mineralization, the mineralization may be stronger than the host rock and therefore may not be a point of weakness"

-Lorenz

Varying Amounts of Fractures

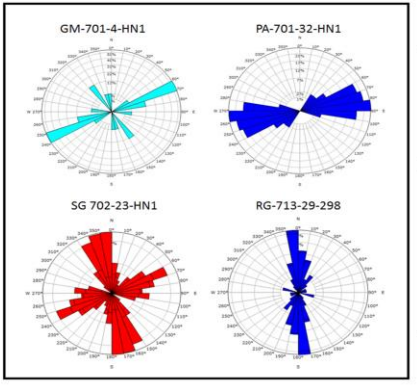
Well	Number of Fractures	Interpreted Interval	Fracture Density
GM-701-4-HN1	22	1,760 ft.	0.013 fracture/ft.
SG- 702-23-HN1	228	1221.3 ft.	0.18 fracture/ft.
PA-701-32-HN1	41	860 ft.	0.05 fracture/ ft.
RG-713-29-298	178	1,674 ft.	0.11 fracture/ ft.

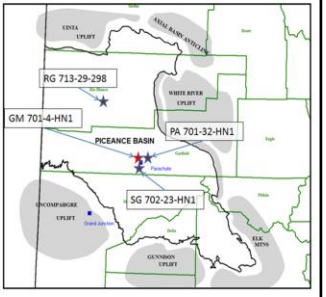




Fracture Azimuth

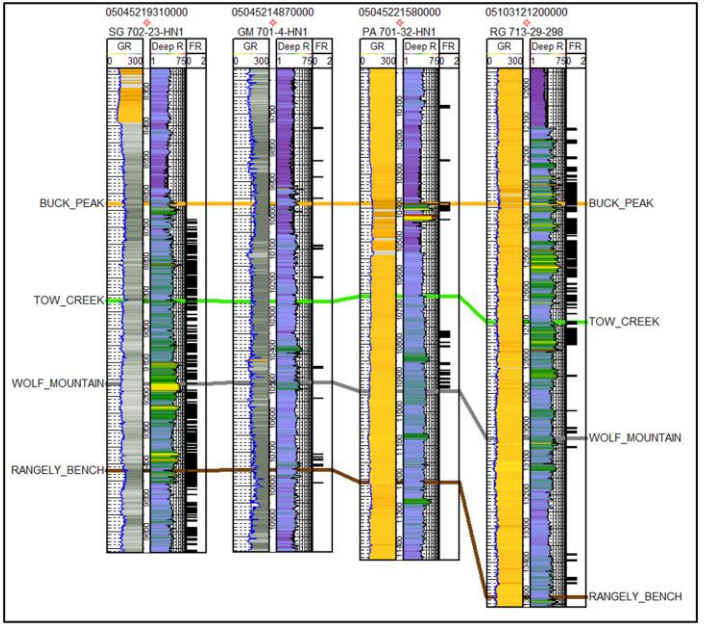
Well	Dominant Strike Direction (Degrees)
GM-701-4-HN1	240-250
SG- 702-23-HN1	340-360
PA-701-32-HN1	260-270
RG-713-29-298	350-360





Varying amounts of fractures and variable fracture orientations is attributed to a complex structural basin history. Varying times of Laramide uplifts and preexisting fault regimes created weaknesses within relatively small field area.

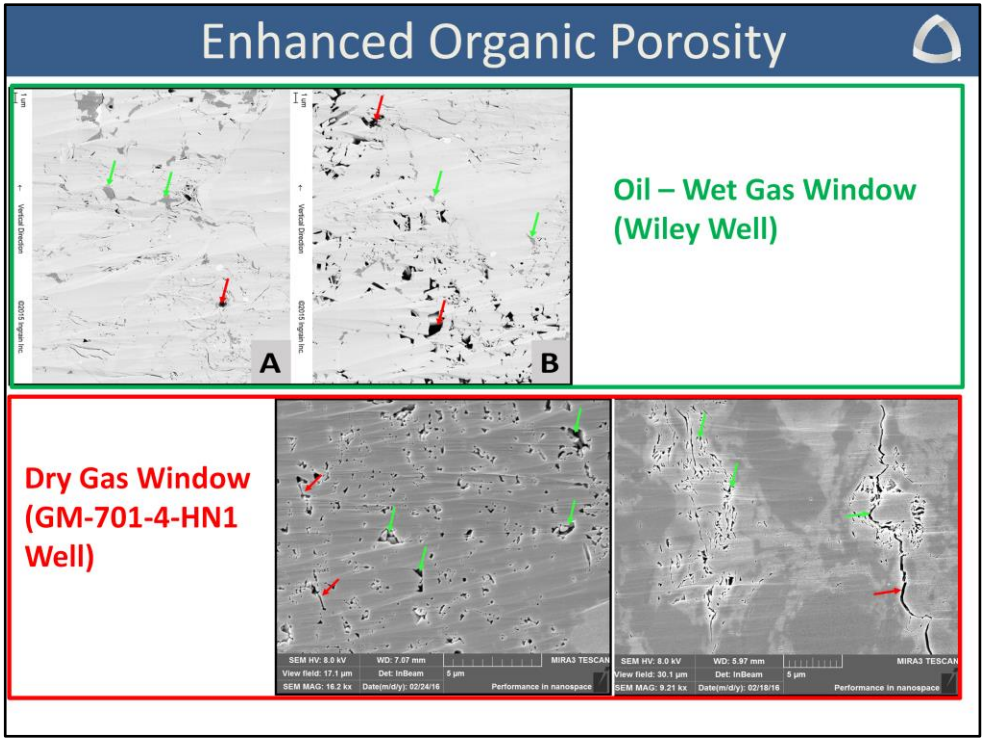
Resistivity Bulk Shift



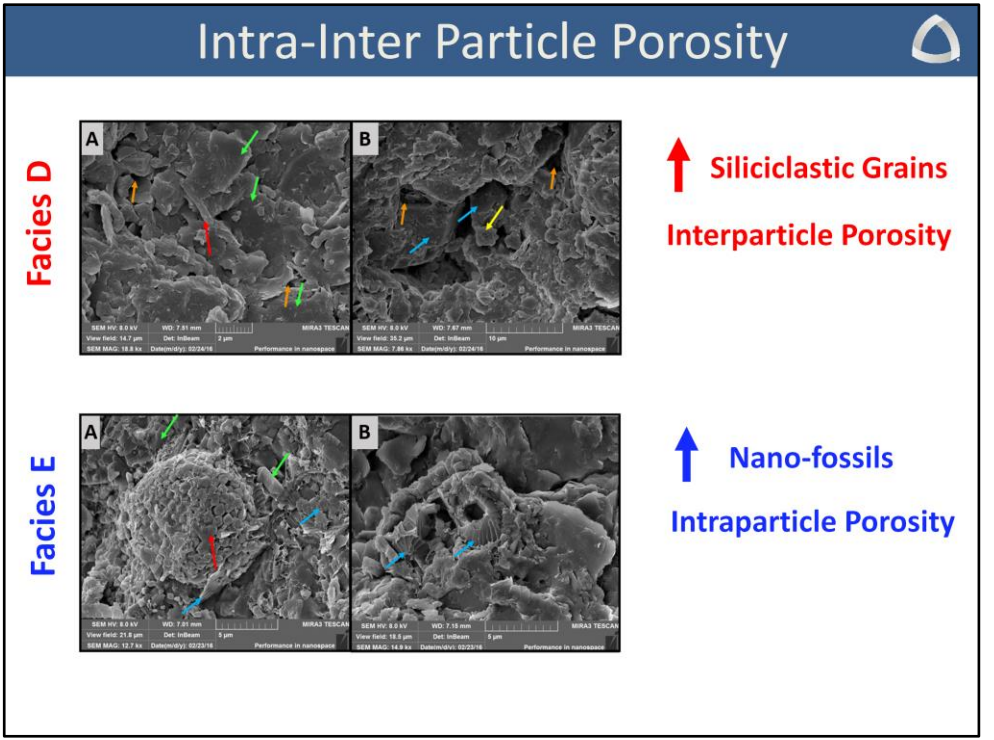
Presenter's notes: This figure shows the fracture densities plotted next to the well logs. One of the original goals of my thesis work was to determine why there was a bulk shift of resistivity across these four wells. I believe that bulk shift is due to the higher density of natural fractures present in several of the wells and the associated calcite within them. The variance in number of fractures present and the variance of fracture azimuth is explained with the complex structural past of the Piceance Basin in which different uplifts and preexisting fault regimes could have affected different areas even within a short distance.

Outline

- Geologic Overview
- Mapping
- Facies Analysis
- Organic Geochemistry
- Image Log Fracture Analysis
- Microporosity
- Maturity and Basin Modeling
- Conclusions and Future Work

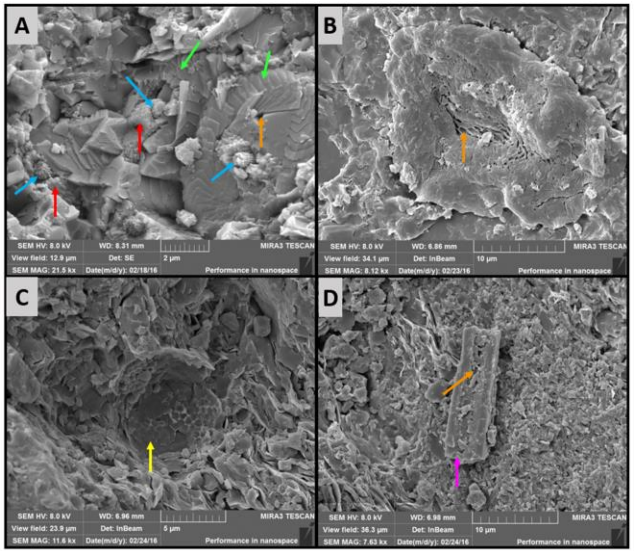


Presenter's notes: The analysis done on the Wiley well was performed by Ingrain labs and provided to me by Endeavour for this study. I attempted to replicate their report with the samples from the GM-701 well here at CSM. This upper micrograph is from the Wiley in the oil window, the most important thing to note here is the amount of remaining organic matter across the sample. In some areas you get little pochs of porosity within this organic matter, however it is almost always in combination with organics. As we move down the GM-701 well in the Dry gas window we see far less of that remaining organic matter and much more developed organic porosity



Presenter's notes: Both intraparticle and interparticle porosity was present in this reservoir. Interparticle porosity was much more common in areas near siliciclastic grains, especially in areas with larger grains as seen above. Intraparticle porosity was more prolific in areas where nano fossils were more abundant and better preserved. The bottom micrograph was one of the few cocosphers that I was able to locate in Facies E and you can see the availalbe pore space present within it.

Intraparticle Porosity



Presenter's notes: Here is another look at a micrograph I showed you earlier, which displays some of the available interparticle pore space around the siliciclastic grains and some of the intraparticle pore space inside the spine here or even in the clay here.

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Conclusions

- Six facies were determined throughout two cores.
- Climate changes paired with sea level affected distribution of siliciclastics and carbonate material
- Higher carbonate rich and fossiliferous facies acted as the horizontal target
- Natural fracture density is highly variable throughout the basin and when present can create a higher resistivity reading
- Organic microporosity is much more developed with higher maturity
- Several high resistivity benches exist throughout this section, providing the possibility for stacked pay
- The oil and dry gas provinces can exist at similar total vertical depths based on differing burial histories (i.e. depth and heat flow)
- Reservoir targets in the Piceance Basin are considered source beds in the Denver Basin and should potentially be reexamined as potential reservoirs.