Defining the Updip Eastern Limit of Commercial Bakken Oil Production, McLean and Dunn Counties, North Dakota*

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Abstract

With the high density of horizontal wells drilled in the Devonian-Mississippian middle member of the Bakken Formation in Parshall Field, the eastern updip limit of commercial oil production from the Bakken in this area is reasonably well defined and understood. Similar patterns governing the commercial limit of Bakken production in Parshall should hold true south of Parshall Field where exploitation of the Bakken reservoir currently is expanding on the Fort Berthold Reservation.

By evaluating mud-gas shows, utilizing water saturation calculations from vertical and horizontal wells, and integrating oil- and water-production data, a transitional zone of non-commercial oil production is identified on the eastern updip edge of the Bakken oil accumulation on the Fort Berthold Reservation similar to that observed at Parshall Field. Progressive updip decrease in Bakken oil production across this non-commercial zone is accompanied by a progressive increase in percent water produced, reflecting a west-to-east transition zone with water saturation progressively increasing updip.

Mudlogs from several updip laterals drilled roughly normal to the east-flank of the Bakken transition zone record strong oil and gas shows downdip reflecting commercial Bakken oil, deteriorating shows structurally updip through a transition zone (less than 1,000 feet wide in one well), and poor shows farther updip, reflecting non-commercial Bakken oil. Approximately four townships south of Parshall Field toward the southern boundary of the Fort Berthold Reservation, two horizontal wells drilled in opposite directions from

the same pad exhibit mud-gas shows that reflect the updip transition from commercial to non-commercial oil production and clearly define these zones.

The observed progressive updip increase in the amount of water produced relative to oil on the east flank of Parshall Field is accompanied by increasingly higher calculated water saturations in the more limited suite of vertical wells and in the triple-combo logs run in the horizontal leg of a recent Bakken well. Increase in water saturation is associated with an updip decrease in porosity, which restricts updip movement of oil, and is controlled in part by depositional facies. Water saturations calculated along the length of the lateral increase updip to the east, suggesting that this wellbore likely spans part of the transition from commercial production to poorer, possibly non-commercial, Bakken production.

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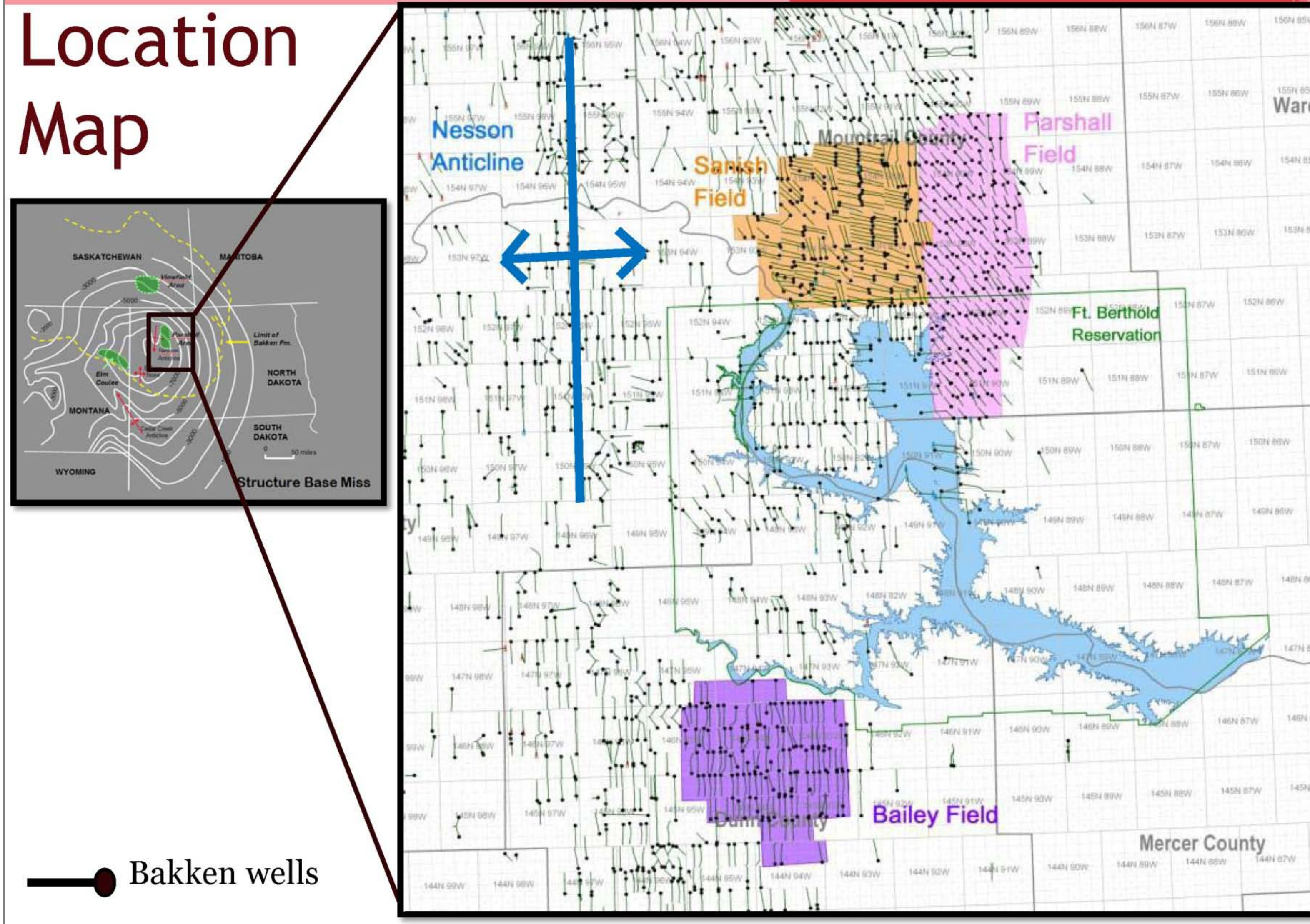
Presenter's Notes: Good morning my name is Eryn Bergin and I'll be discussing our most recent work to define the updip eastern limit of the commercial Bakken oil production on the Fort Berthold Reservation. As other presenters today will go in-depth into the geology, I'll be talking about the Bakken from an operators point of view and focusing more on the production side and some easy tools, that have been maybe overlooked, that can be used to define the commercial limits.

Objectives

- History of Bakken development on the eastern side of the Williston Basin
- Defining the edge of commercial Bakken oil production using:
  - Bakken oil and water production
  - Mudlog gas shows
  - Water saturation calculations in vertical and horizontal wells
- Identify
  - Commercial oil production limit
  - Transition zone
  - Non-commercial oil production limit – “Line of Death”

Presenter’s Notes: Today I’ll start out with a brief history of Bakken development on the eastern side of the Williston Basin, then jump into how we define the edge using Bakken oil and water production, mudlog gas shows, and water saturation calculations in vertical and horizontal wells. Through this, we will be able to identify a commercial oil production limit, transition zone, and non-commercial oil production limit or “line of death.”

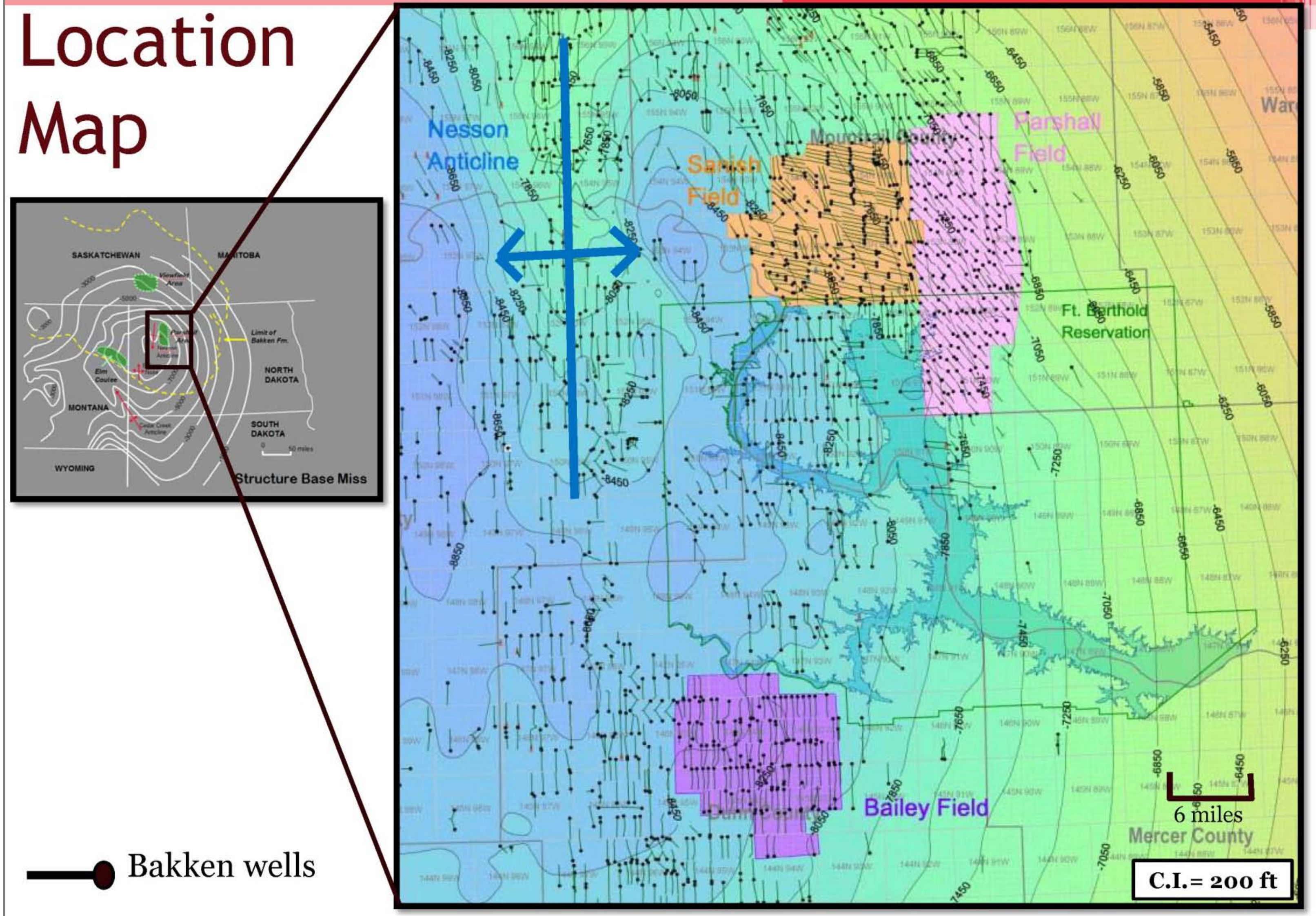
Location Map



Presenter's Notes: The Fort Berthold Reservation is located in the eastern part of the Williston Basin in western North Dakota. To orient ourselves, to the north is Parshall Field and Sanish Field. The Nesson Anticline is to the west and Bailey Field is to the south. The Fort Berthold Reservation in outlined in green. This map is showing only Bakken wells.

Here you can see the Bakken subsea structure map showing the location of the reservation in relation to the other fields. As you can see the Bakken on the Reservation is at similar depths to Parshall and Sanish Fields.

Location Map



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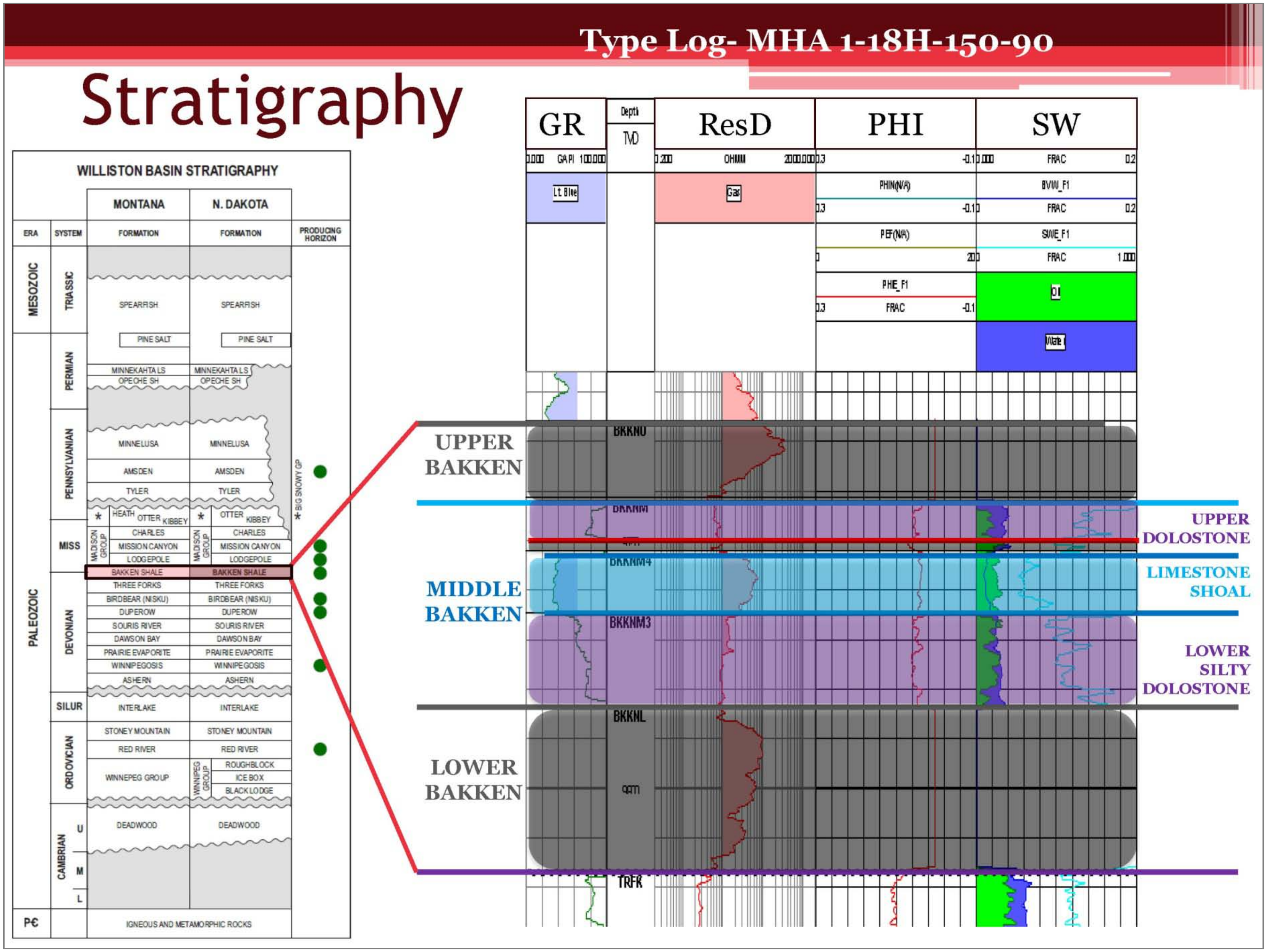
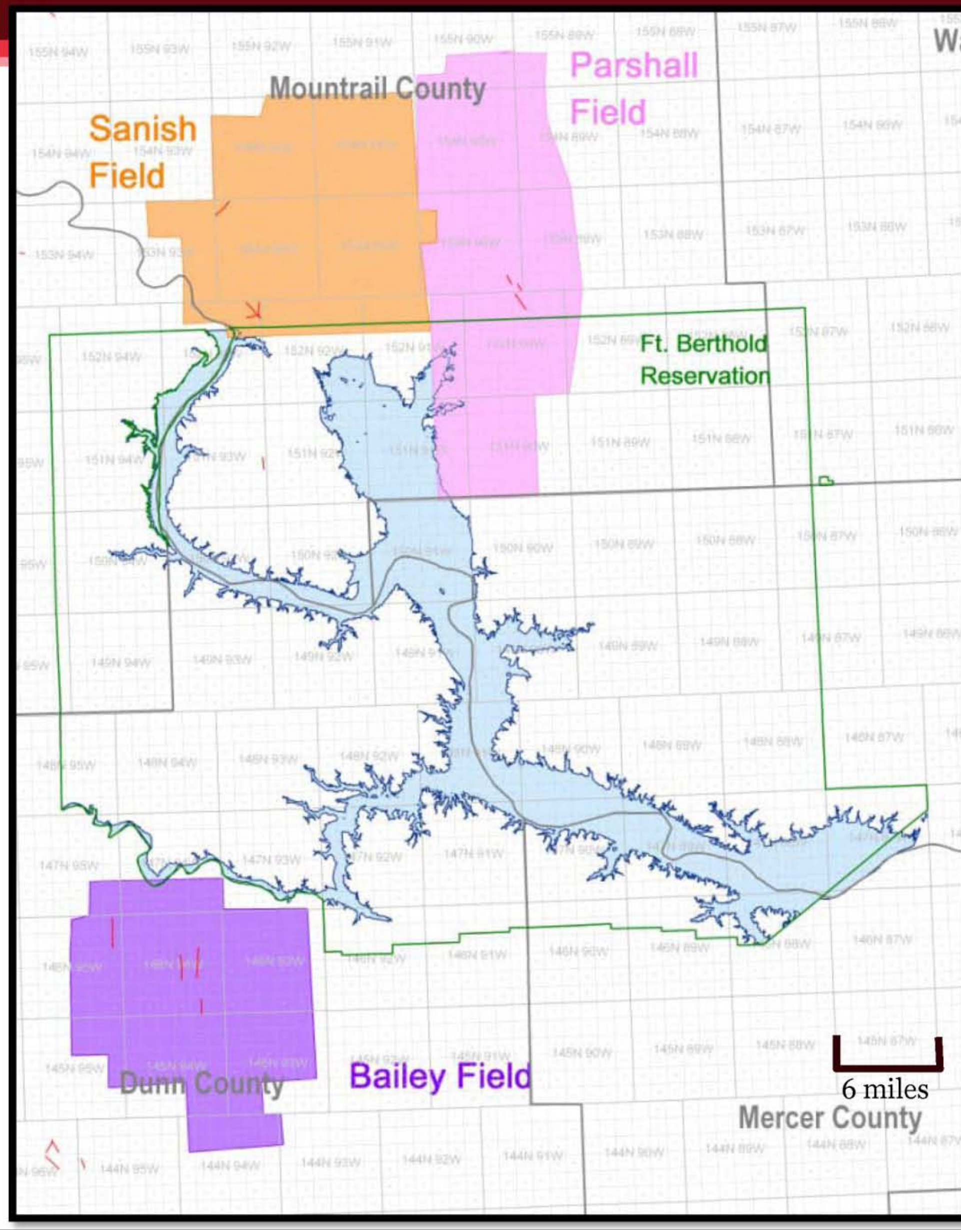


Presenter's Notes: The Bakken Formation lies between the Lodgepole and the Three Forks and consists of an organic rich upper shale member, mixed clastic-carbonate middle member, and organic rich lower shale member. On much or QEP's acreage the Middle Member can be further subdivided into an upper dolostone, limestone shoal, and lower silty dolostone. This is the type log for the area and was QEP's first Bakken well, the MHA 1-18H-150-90.

History

- Up to end of 2006

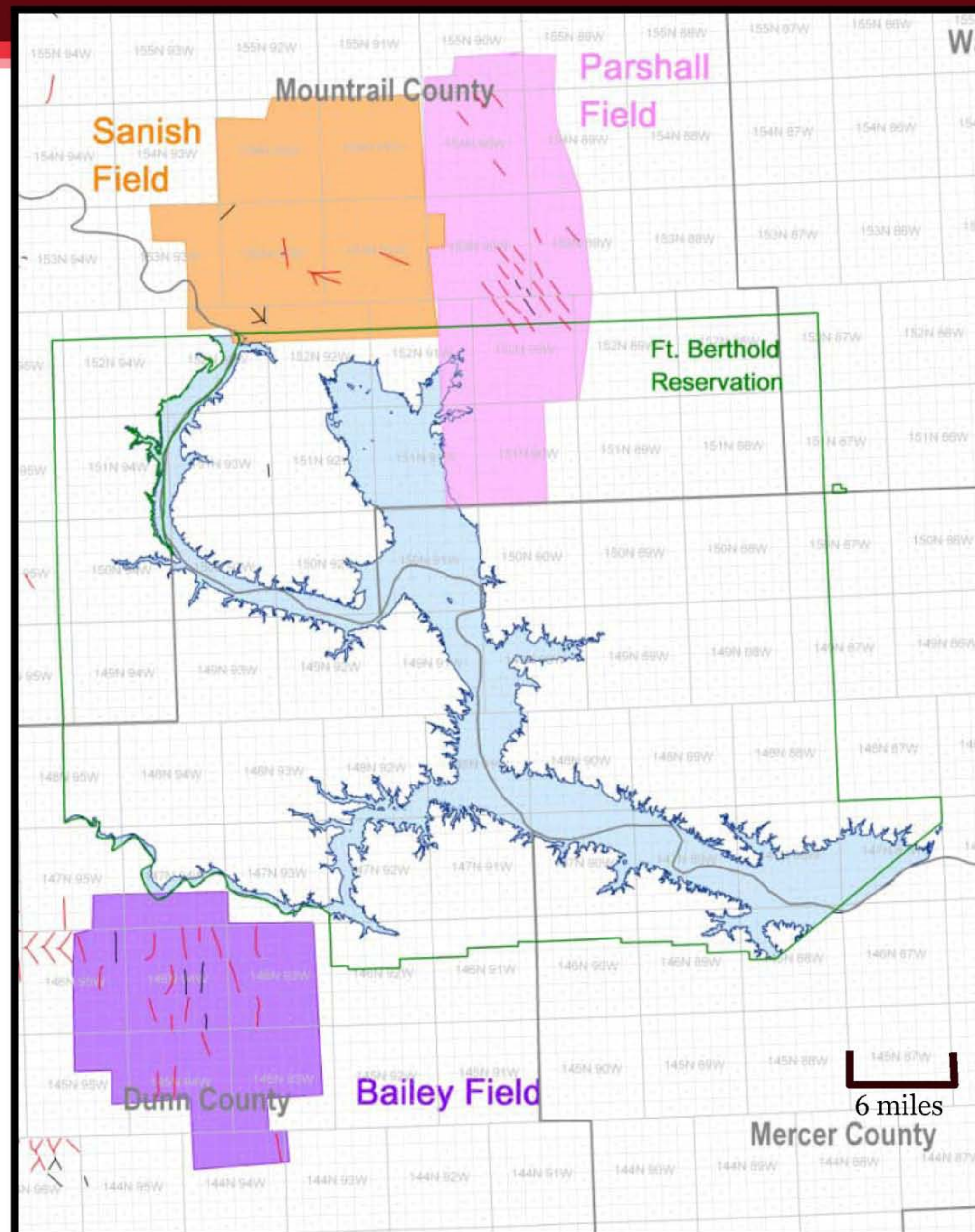
Total Wells =18



Presenter's Notes: So now we'll discuss the recent history of Bakken activity in the last five years. Highlighted in red we can see the Bakken activity up to the end of 2006, with just a few scattered wells to the north and south of the reservation as different operators were just starting to figure out what made this play work. Note the total well count at the bottom at just 18 in the study area by the end of 2006.

History

- Up to end of 2006
- 2007

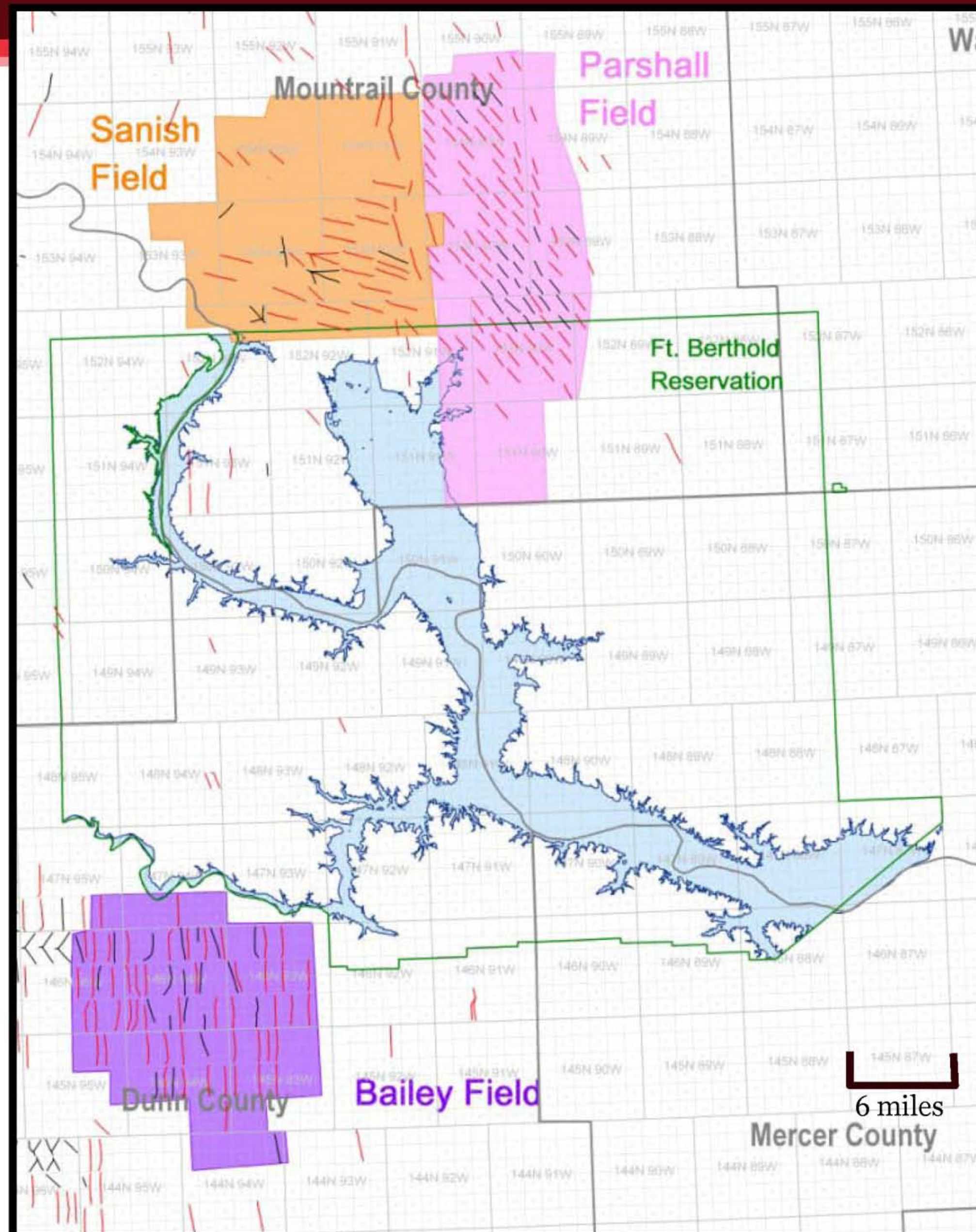


Total Wells =85

Presenter's Notes: Then as you can see in 2007, development really began to take off in Parshall and Bailey with some long laterals in Sanish, but still no activity on the reservation.

History

- Up to end of 2006
- 2007
- 2008



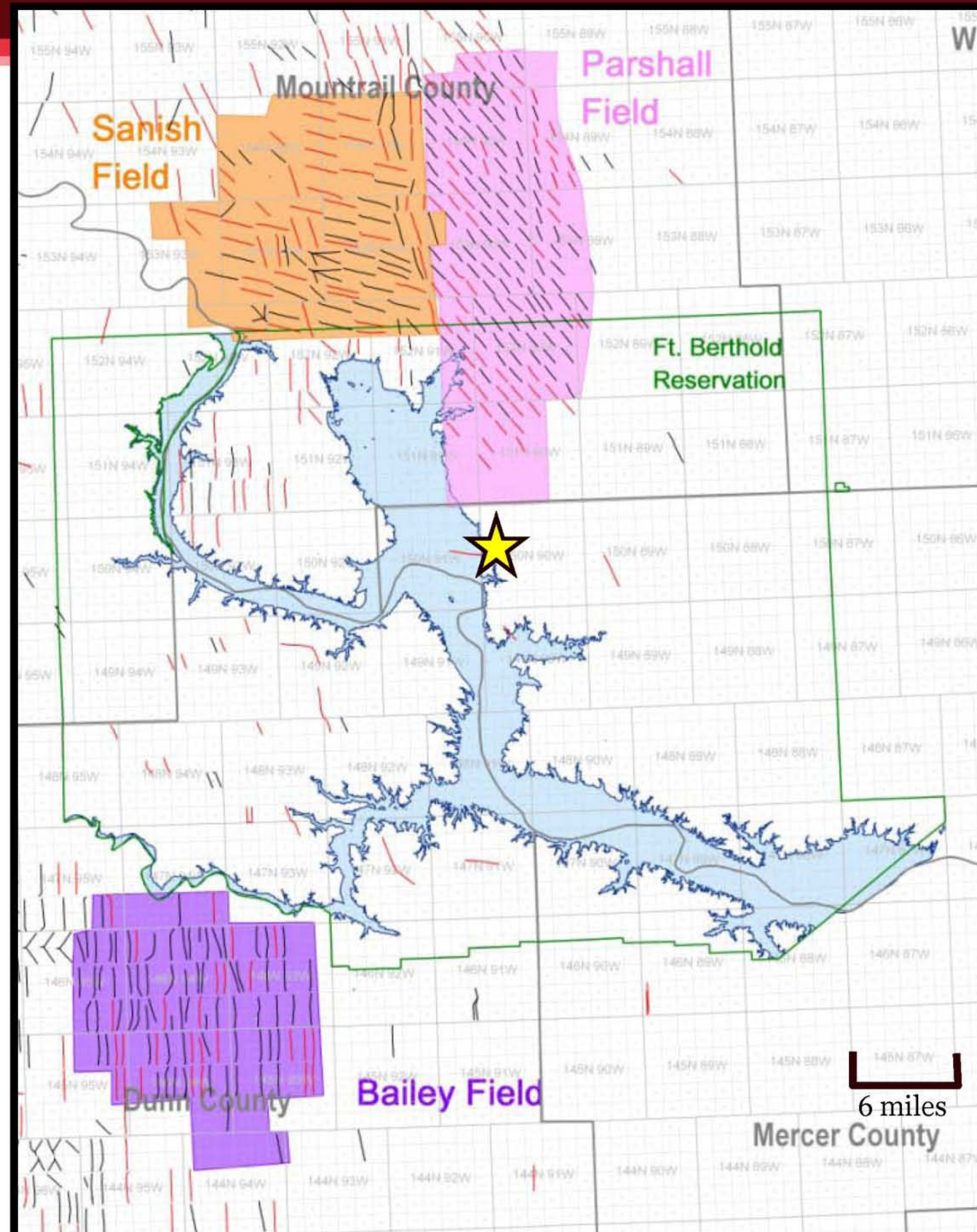
Total Wells =323

Presenter's Notes: By 2008 Pashall, Bailey and Sanish fields were under full development mode. As you can see, there is some activity starting to creep onto the Reservation, but it's still relatively unexplored.

History

- Up to end of 2006
- 2007
- 2008
- 2009

★ QEP completes the MHA 1-18H-150-90

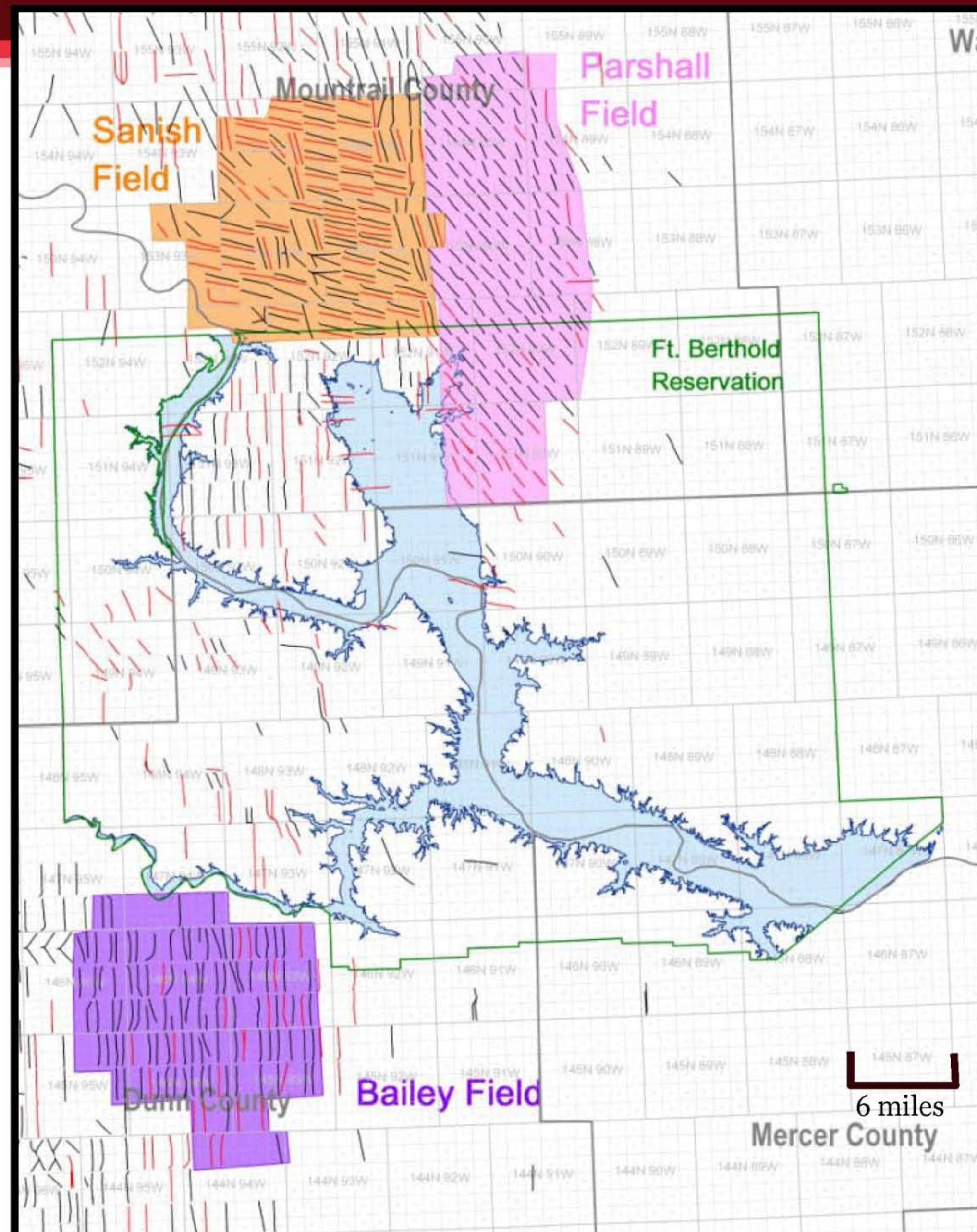


Total Wells =574

Presenter's Notes: In 2009, QEP completed our first Bakken well, the MHA 1-18H-150-90 . By the end of 2009, you can see that the other fields are almost completely developed with some scattered tests across the reservation.

History

- Up to end of 2006
- 2007
- 2008
- 2009
- 2010



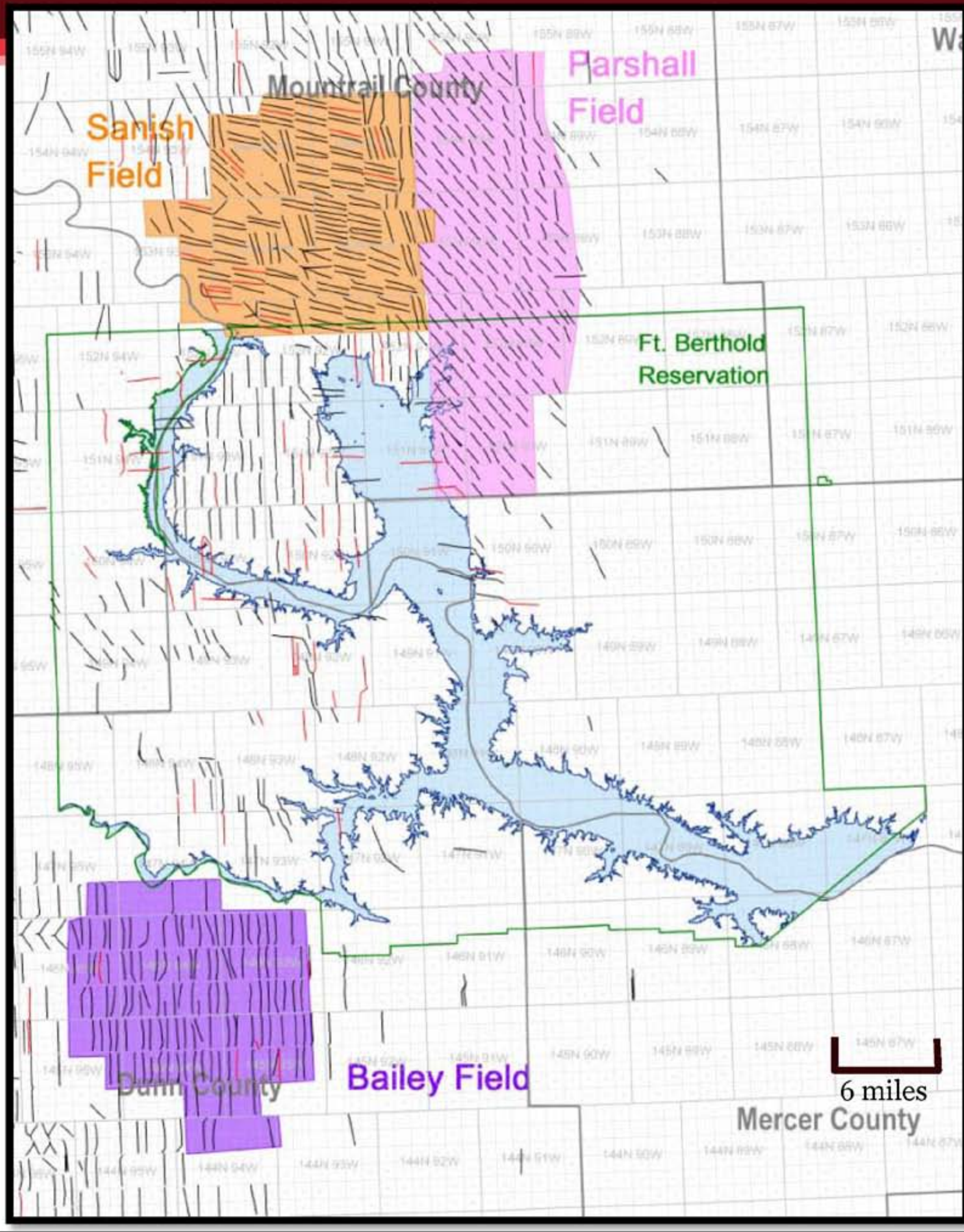
Total Wells =889

Presenter's Notes: And then by the end of 2010 we can see development of the Bakken in the western part of the reservation, but still the eastern boundary is relatively untested, but for a few scattered successes and dry holes.

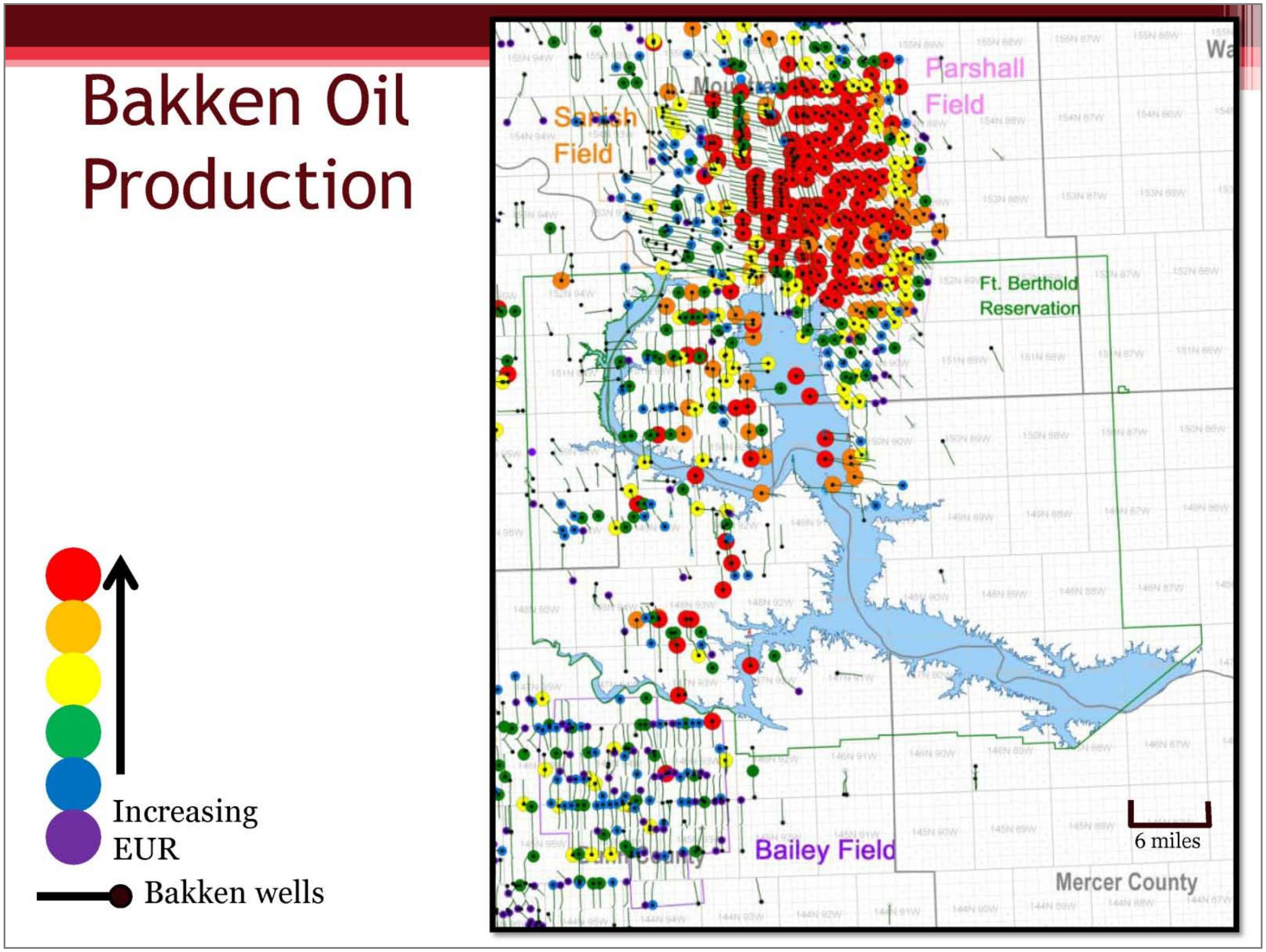
History

- Up to end of 2006
- 2007
- 2008
- 2009
- 2010
- 2011

Total Wells = 991



Presenter's Notes: And finally in 2011 we can see development of the Bakken in the western part of the reservation, with QEP's most recent delineation test on the east side. Also note the total wells over the last 5 years or so is almost 1000 Bakken wells.



Presenter's Notes: Here we have the map representing the study area. The interpretations and relationships I'll be establishing, I'm only making for this area. The Williston Basin has many Bakken "plays", and while these interpretations might apply to other areas of the basin, I haven't made those assumptions.

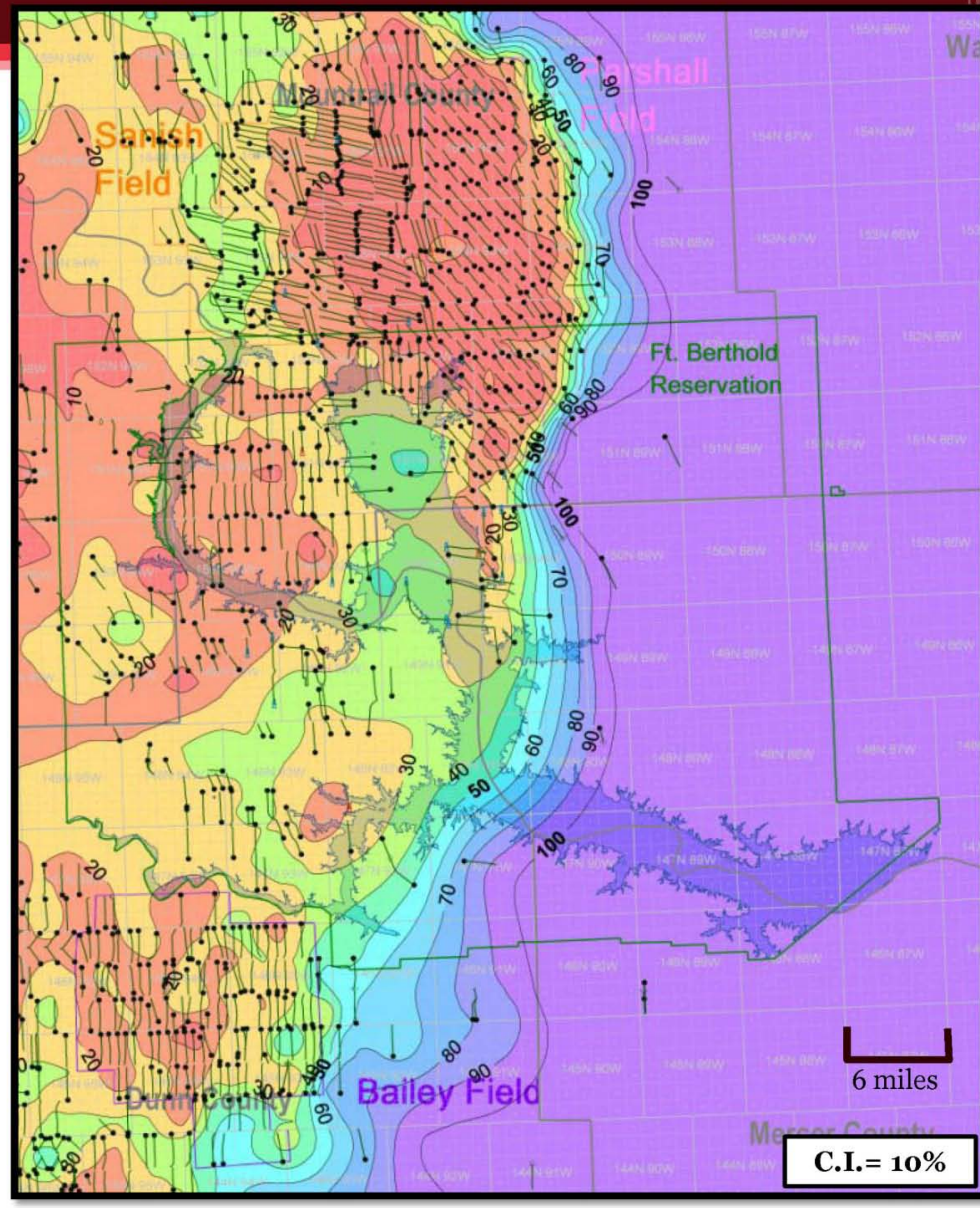
Ok so this is a map showing Bakken oil production as of 2nd Quarter 2011. We have increasing EUR and bubble size as we go from purple to red. I'll be showing this layer several times throughout the presentation to highlight the tie between oil production, and the parameters I'm using to help define the commercial limit. As you can see, the commercial edge of Parshall Field has been pretty well defined by strong and weak producers. Similar patterns governing the commercial limit of the Bakken production in Parshall, should hold true south of Parshall Field where development of the Bakken is currently expanding on the Fort Berthold Reservation. Knowledge gained from Parshall Field will be applied to help understand the eastern updip commercial limit on the Reservation.

Percent Produced Water

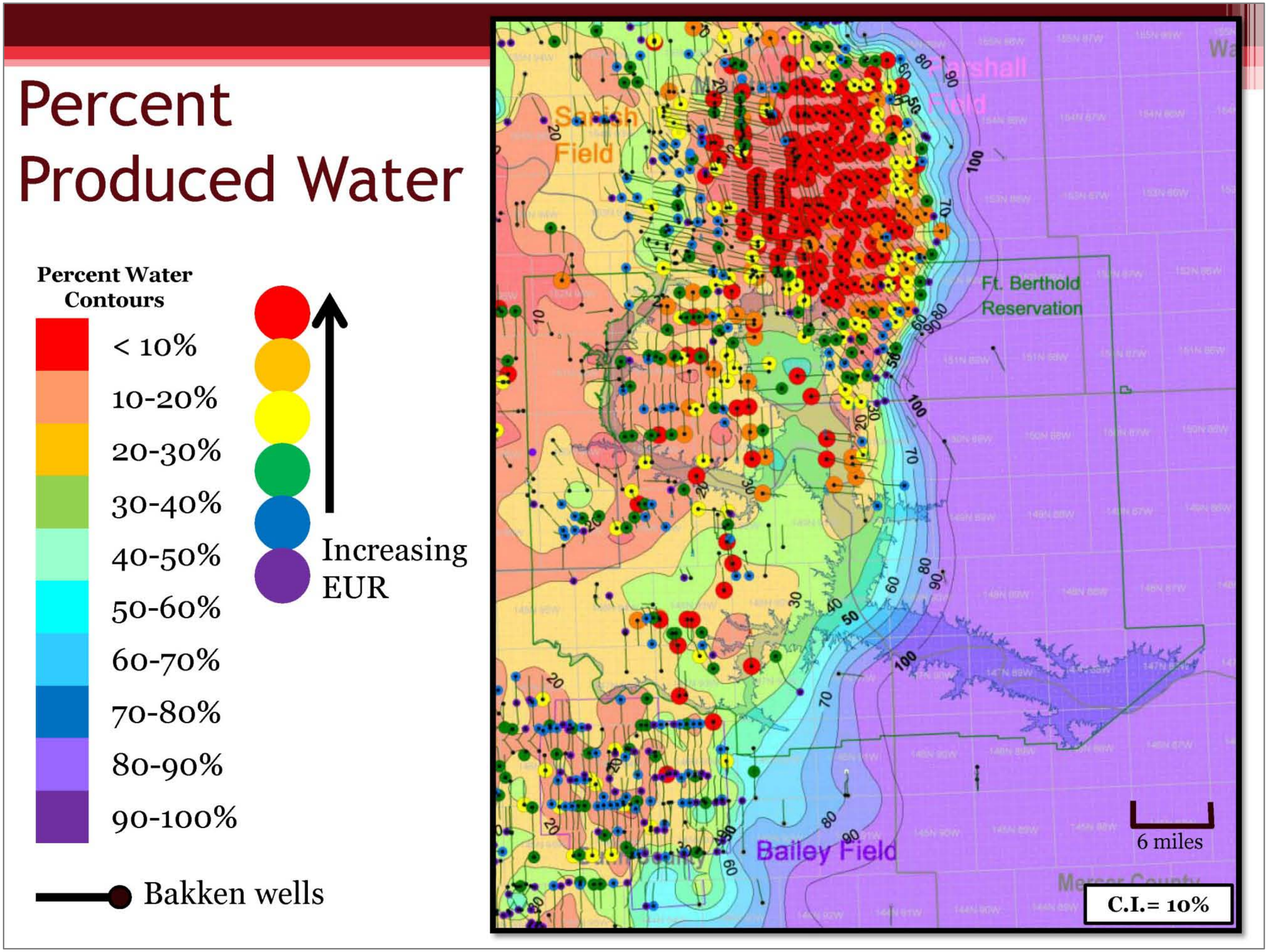
Percent Water Contours

- < 10%
- 10-20%
- 20-30%
- 30-40%
- 40-50%
- 50-60%
- 60-70%
- 70-80%
- 80-90%
- 90-100%

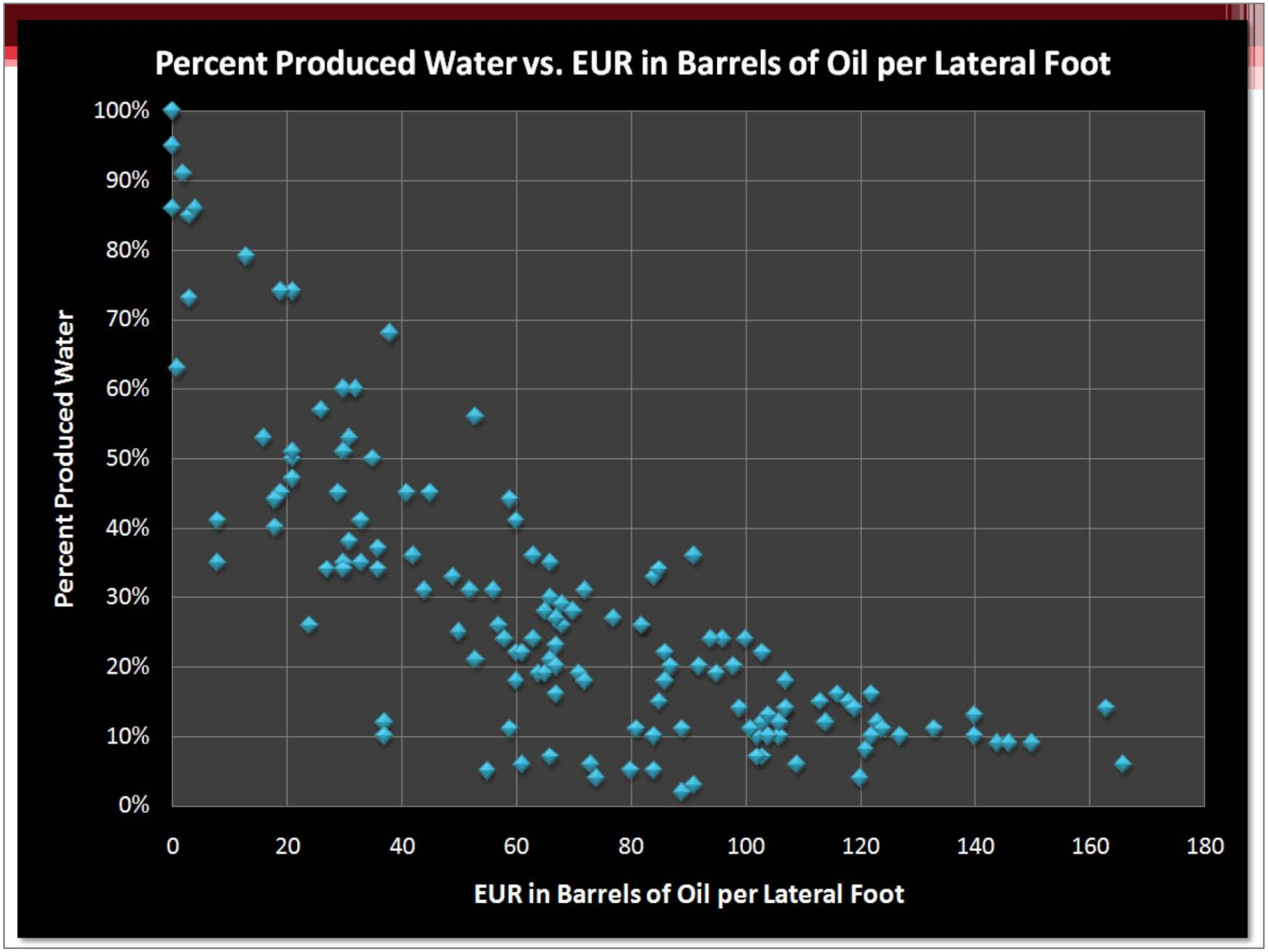
Bakken wells



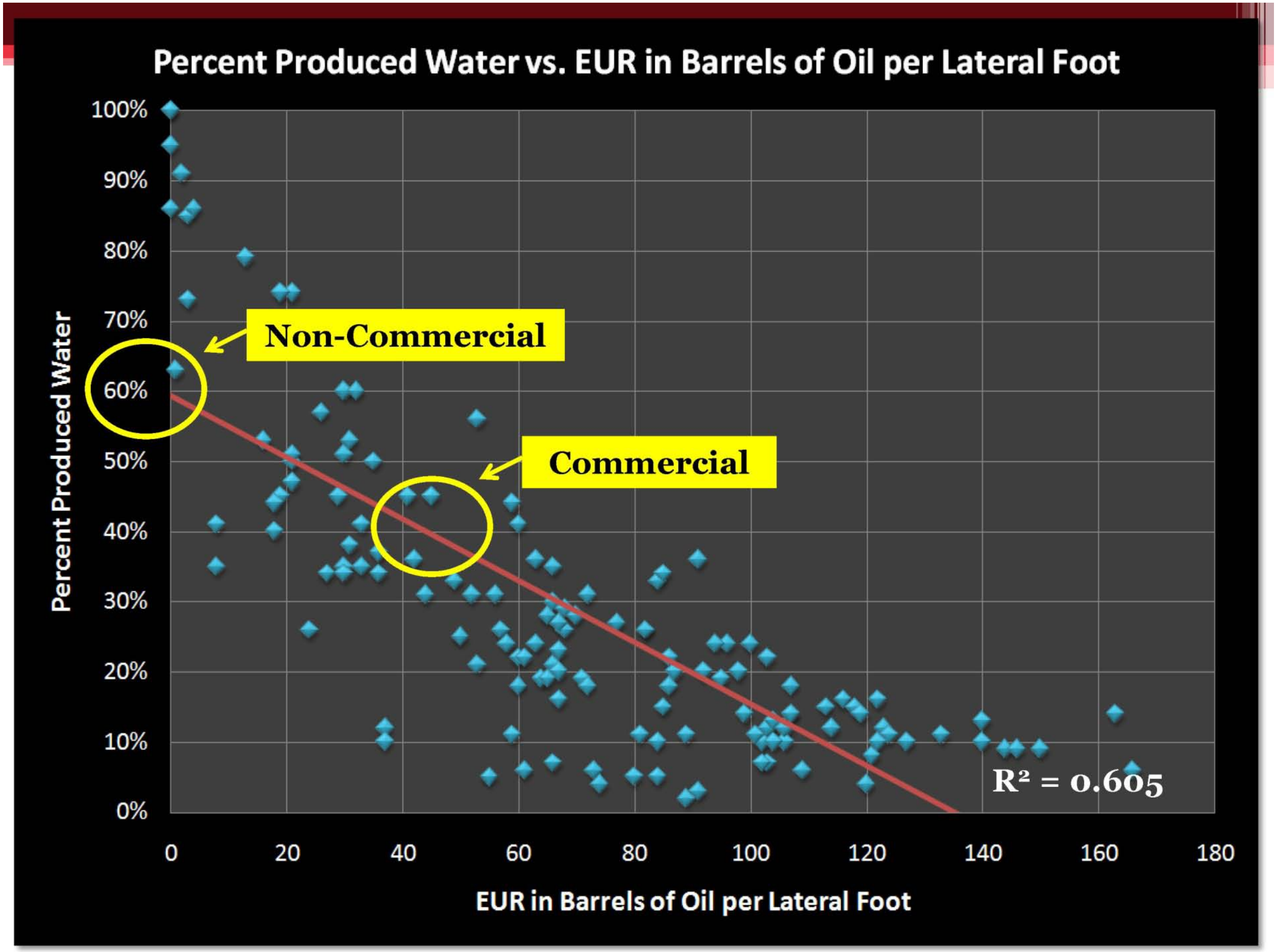
Presenter's Notes: The first factor we looked at was percent water. This map shows water production as a percentage of total liquid production, with 10 percent contours. You can see the sharp increase in water production as you travel east. In Parshall, these contours have been well defined by water production from wells testing the edge.



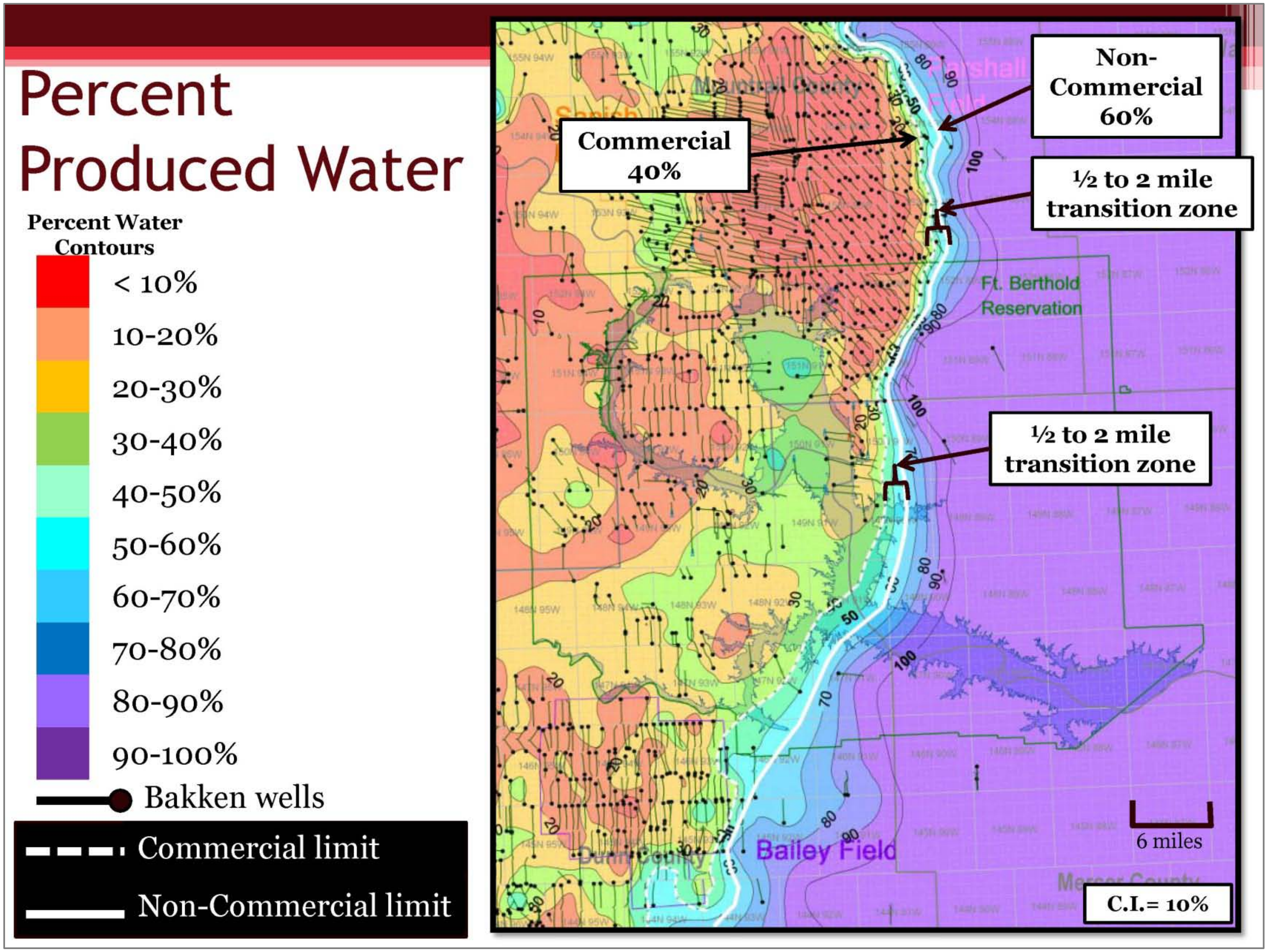
Presenter's Notes: Overlaying the EUR bubbles on top of the percent water contours shows a good correlation of higher EUR to lower water production.



Presenter's Notes: Now we'll look at this same relationship graphically. Here we have percent produced water vs. EUR per lateral foot. It's important to look at EUR per lateral foot as opposed to straight EUR because most wells in Parshall are 1 mile laterals, but most of the wells outside of Parshall are 2 mile laterals, and we want to be able to compare the two. So if we have 50 barrels of oil per lateral foot, and you drill a 10,000 foot lateral, that should equal a 500 MBO well. Also of note is that the data I'm using in these graphs has been filtered to only include wells with multi-stage completions. So here we can see a pretty good correlation between decreasing percent produced water, and increasing EUR per lateral foot.

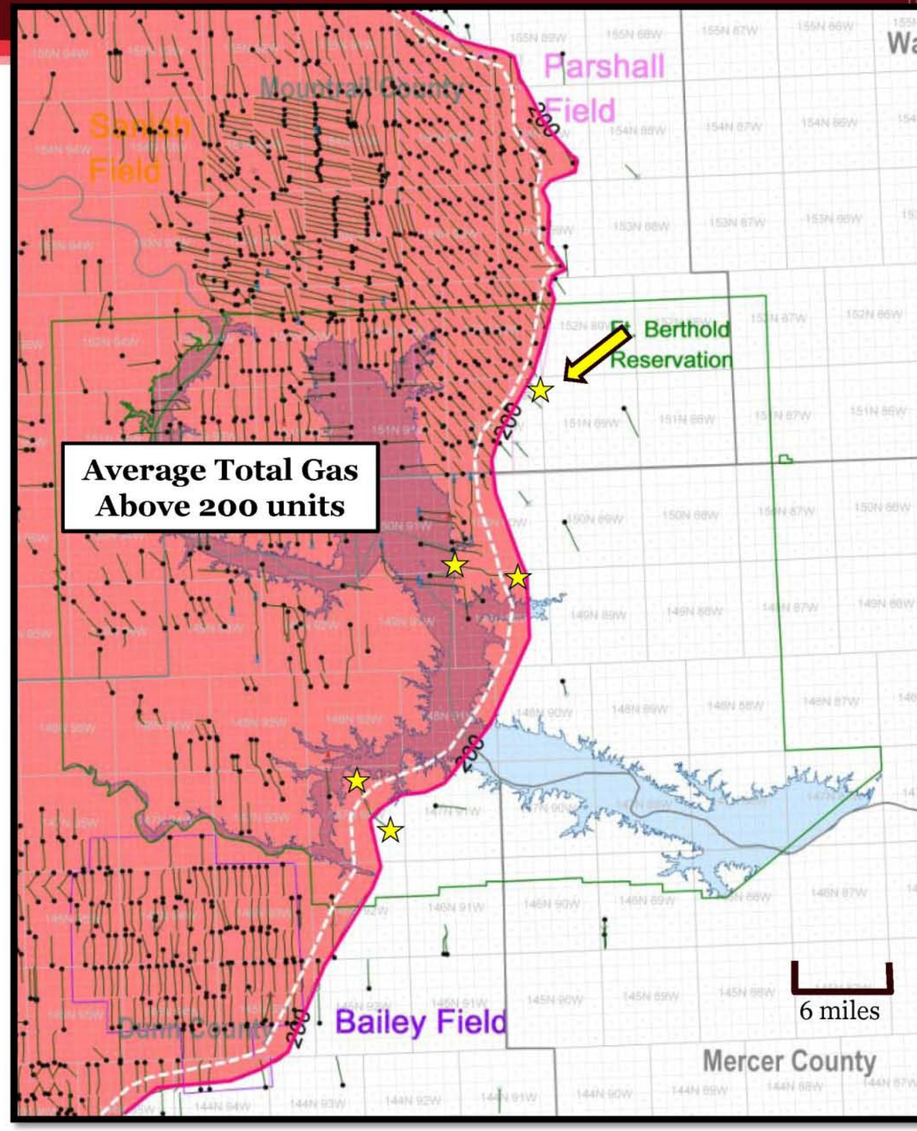


Presenter's Notes: And if we just fit a plain linear trendline to the data, we can see that the zero EUR point is at about 60% produced water, representing the "line of death" number, and where the trendline crosses the 40% line, we can pull an EUR between 450-500 MBO, which depending on your individual economics could be considered a commercial limit. So let's take a look back at the map and see what those two points map like.



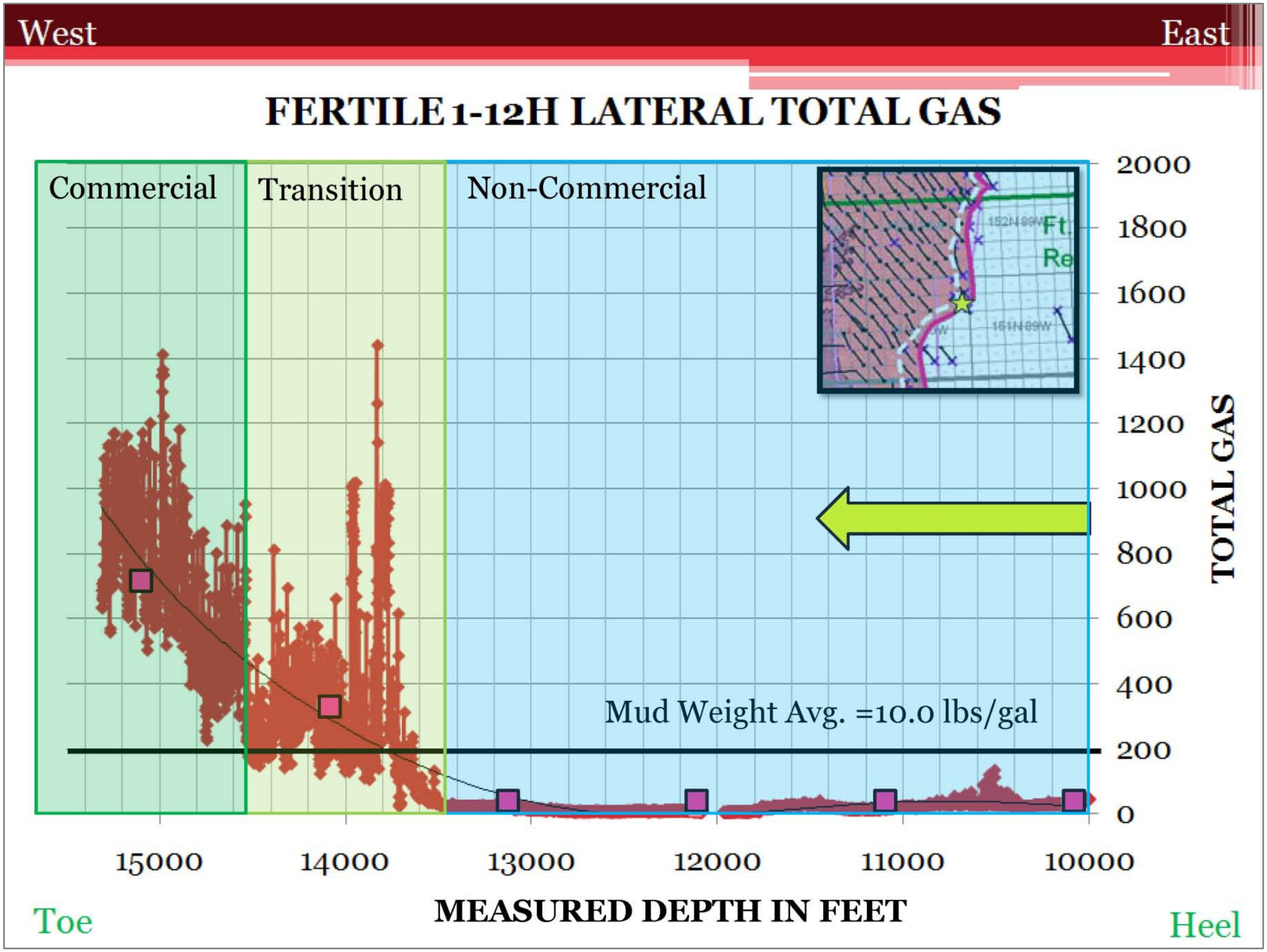
Presenter's Notes: Now by combining the EUR data with the percent water data, we can take our interpretation from the previous graph and highlighted the commercial limit, *shown with the white dashed line*, and non-commercial limit of Bakken oil production, *shown with the solid white line*, with a transition zone in-between. The commercial limit line corresponds to approximately 40 percent water production while the non-commercial limit line corresponds to approximately 60 percent water production. As you can see the transition zone varies a half mile to 2 miles wide on the edge of Parshall. Although we lack the same density of Bakken producers, and therefore data points on the reservation, this same transition zone, and approximate width, can be interpreted to exist on the reservation. We can therefore contour accordingly between the commercial producers and non-commercial producers and come up with these same limits on the reservation.

Mudlog Gas Shows Average



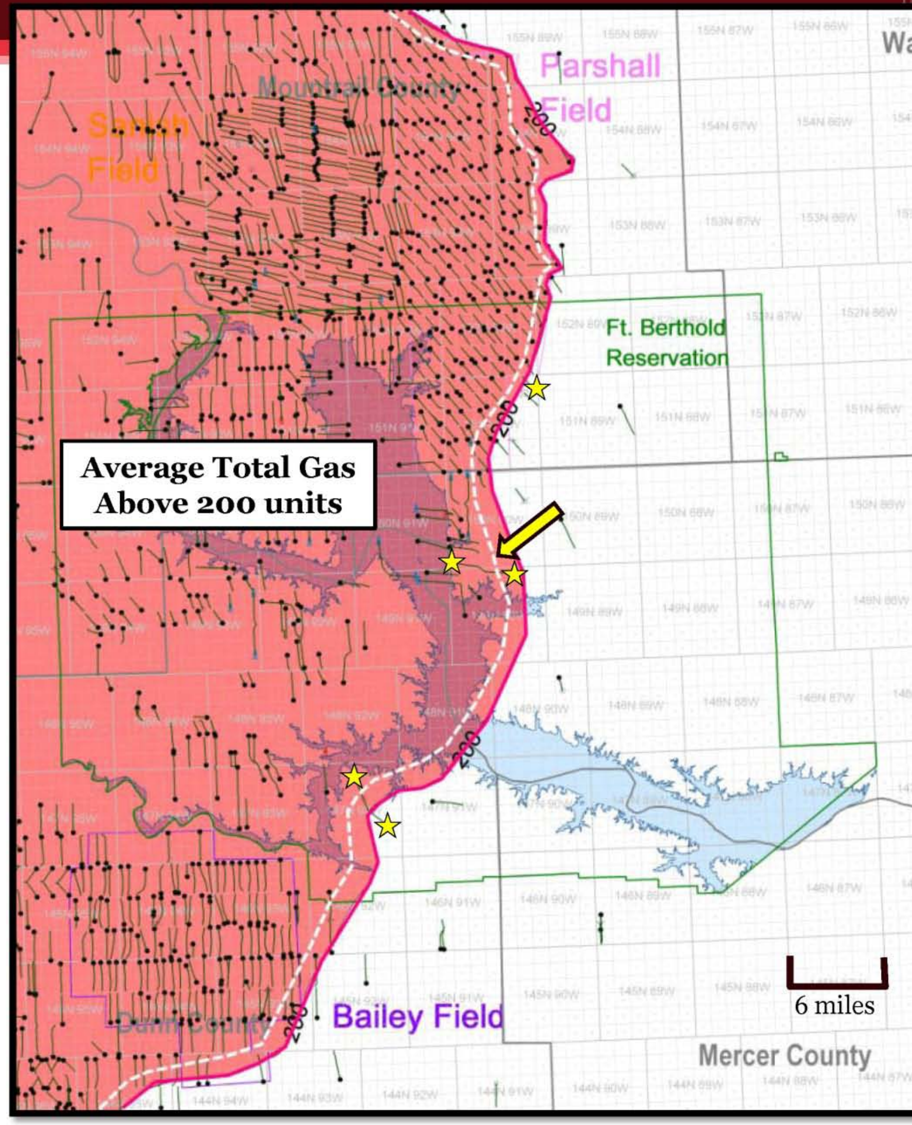
Charted Wells
Bakken wells
Commercial limit
Non-Commercial limit

Presenter's Notes: Moving onto the next factor, mudlog gas shows, we can see similar limits. This map was created by taking the average of the total gas for the first thousand feet of Bakken lateral, and the average of the total gas for the last thousand feet of the Bakken lateral, and plotting them up. The pink shading represents average total gas above 200 units. From looking at strong and weak wells along the edge of Parshall, and the shut in wells far east of the edge, I found that any average total gas approaching, or below 200 units, was almost always a poor producer or completely wet. I'll be presenting five wells that crossed the commercial limit into the transition zone, and then past the non-commercial limit. These wells are represented by the five stars. First I'll be showing the Fertile 1-12H on the edge of Parshall



Presenter's Notes: We've plotted measured depth versus total gas for the Fertile 1-12H lateral. This well was drilled from east to west. The 200 unit line represents the non-commercial limit line on the previous map and in the inset map. The squares on the chart are the thousand foot running averages of the total gas and the black line is the trend line. Here we have highlighted the interpreted non-commercial part of the wellbore, with average total gas less than 200 units. As the well drills into the field, the gas begins to increase representing the transition zone. And finally the well finishes off in commercial oil.

Mudlog Gas Shows Average



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Commercial limit
Non-Commercial limit

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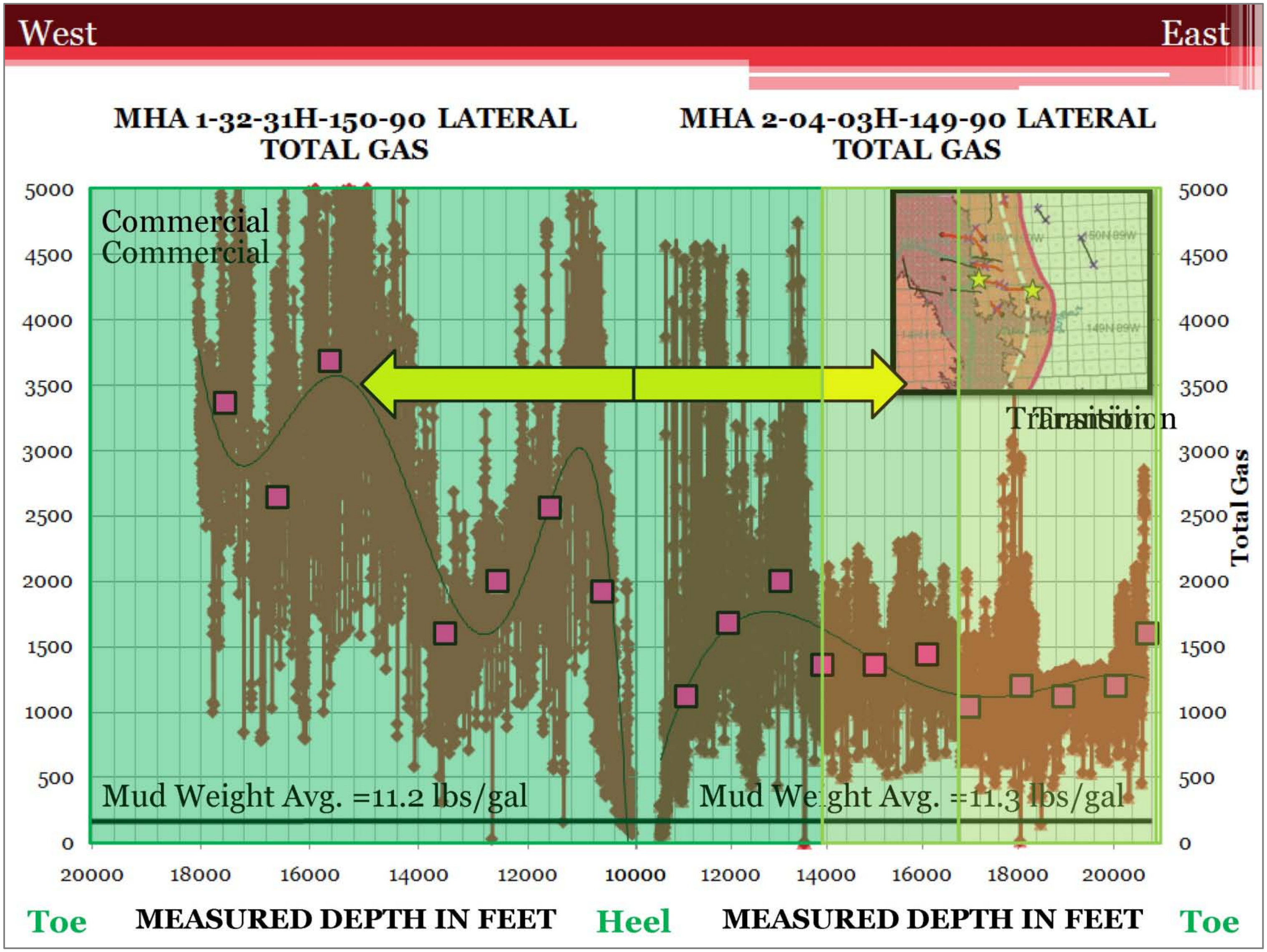
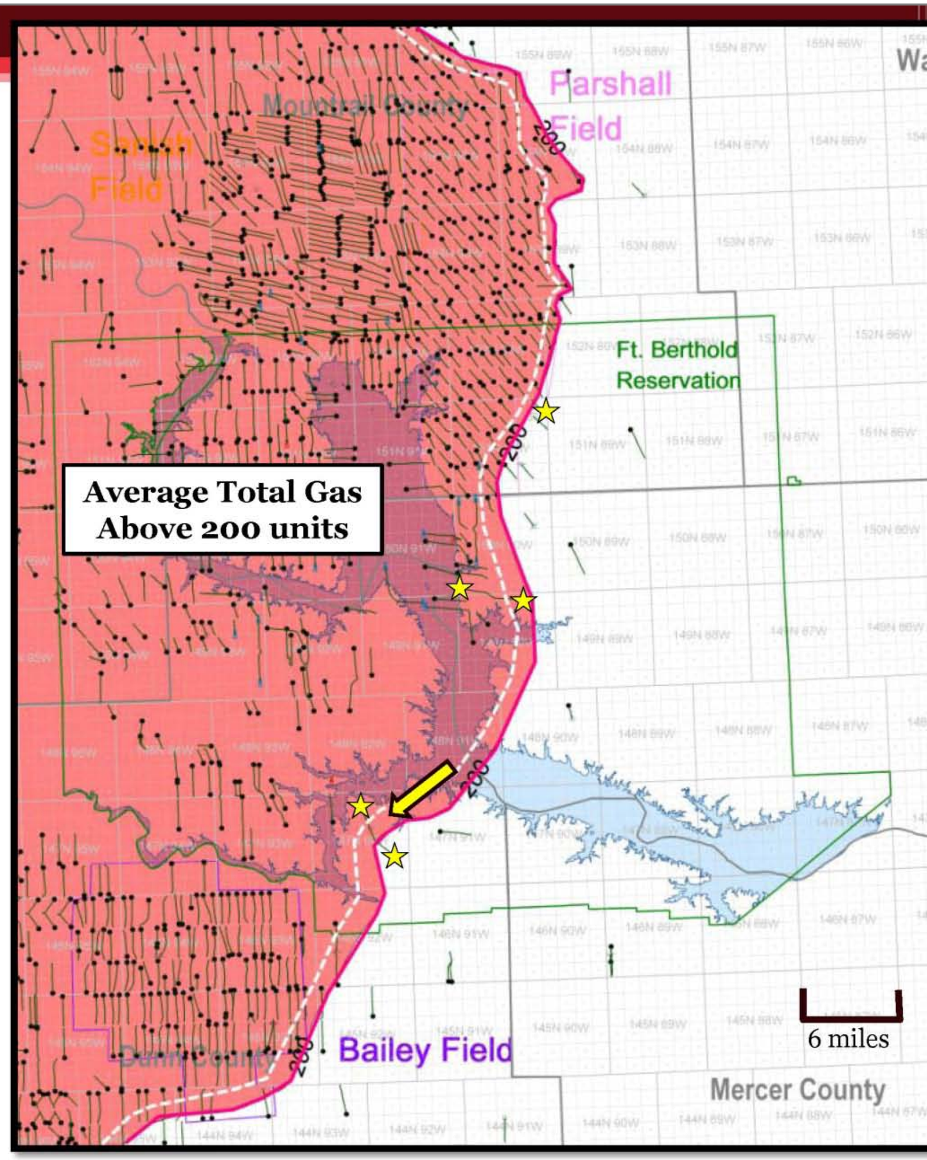


Presenter's Notes: Now moving about two townships to the south we have the MHA 1-32-31H and MHA 2-04-03H. These wells were both drilled from the same surface location in opposite directions. The 32-31 being drilled to the west and the 04-03 drilled to the east, basically representing 4 miles of continuous lateral near the edge of the field. As we can see the 32-21 lateral was drilled entirely in the interpreted commerical zone. However the 04-03 well drilled approximately 2000 feet of commercial zone and then there appears to be a step change in the average total gas at around 14000 feet. Now there does appear to be a second step change around 17000 ft MD as well. So this well had some ambiguity as to where to put the transition zone and this was why we decided to run the logs in the lateral that I'll discuss later in the presentation.

Mudlog Gas Shows Average



Charted Wells

Bakken wells

Commercial limit

Non-Commercial limit

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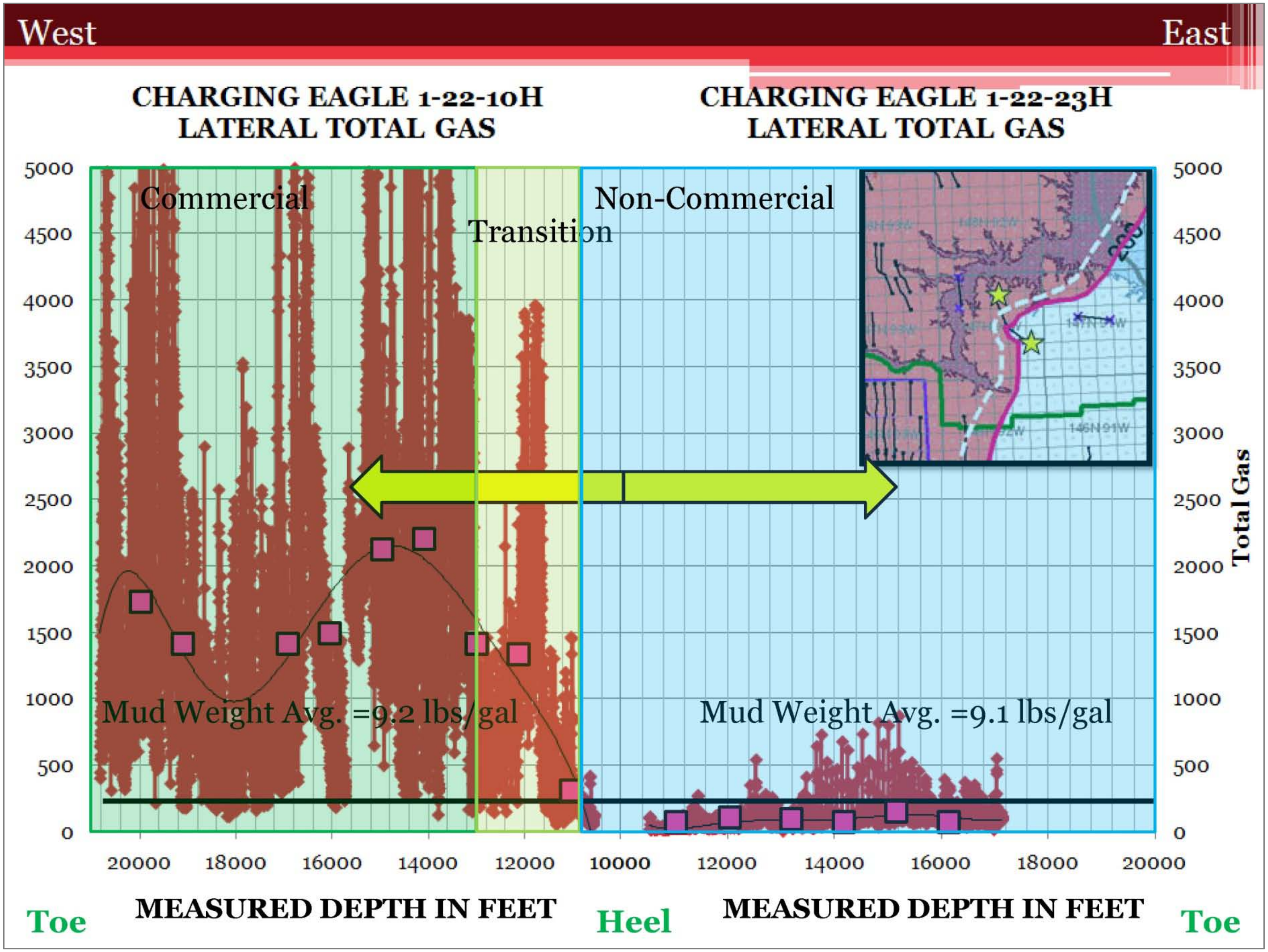
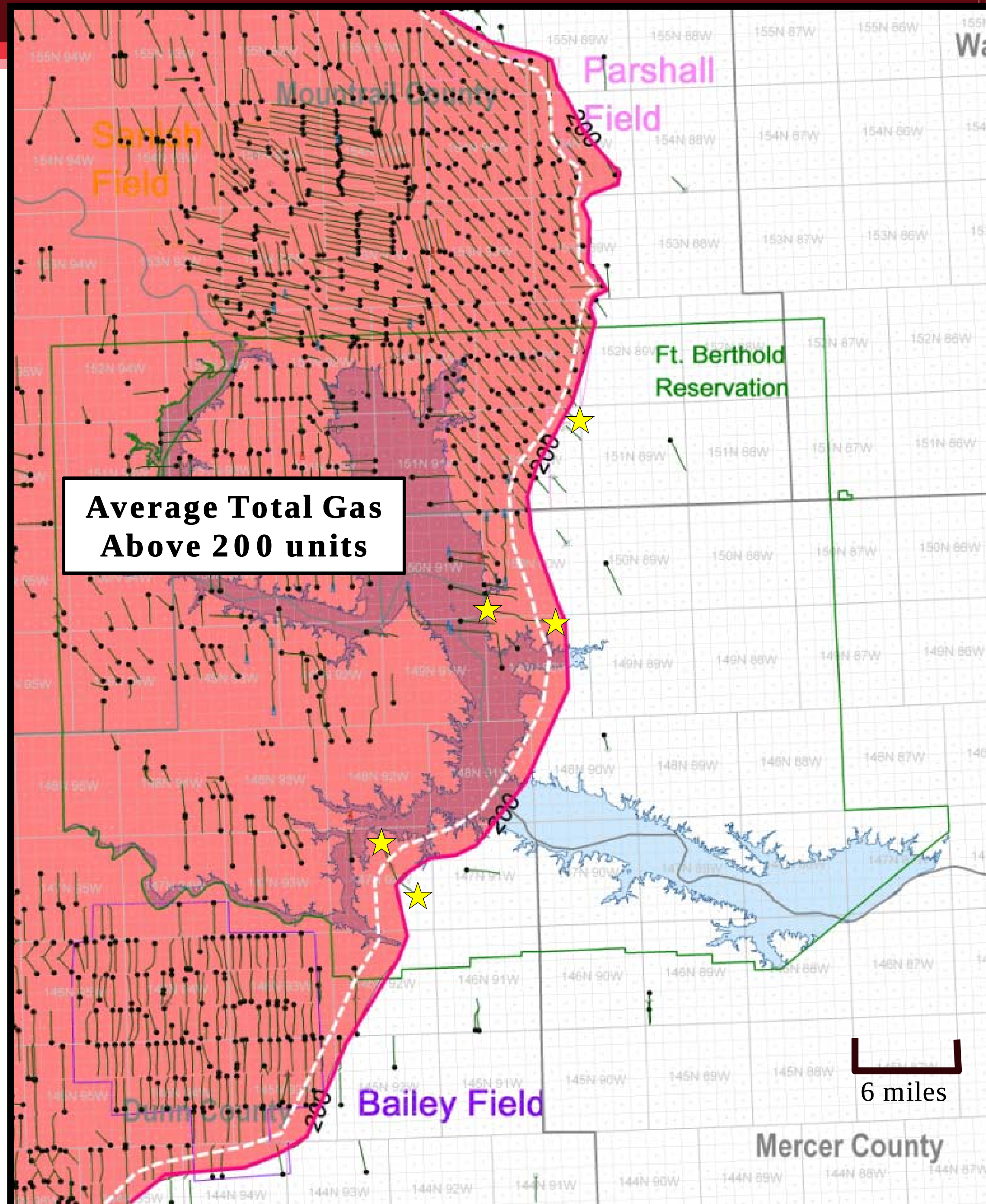


Presenter's Notes: Now again moving about two townships to the south we have the Charging Eagle wells, both drilled from the same surface location in opposite directions giving us approximately 3 miles of continuous lateral. You can see the shorter lateral drilling to the east was drilled almost entirely in the non-commercial zone. While the 1-22-10 encountered the transition zone, and then the commercial zone.

Mudlog Gas Shows Average



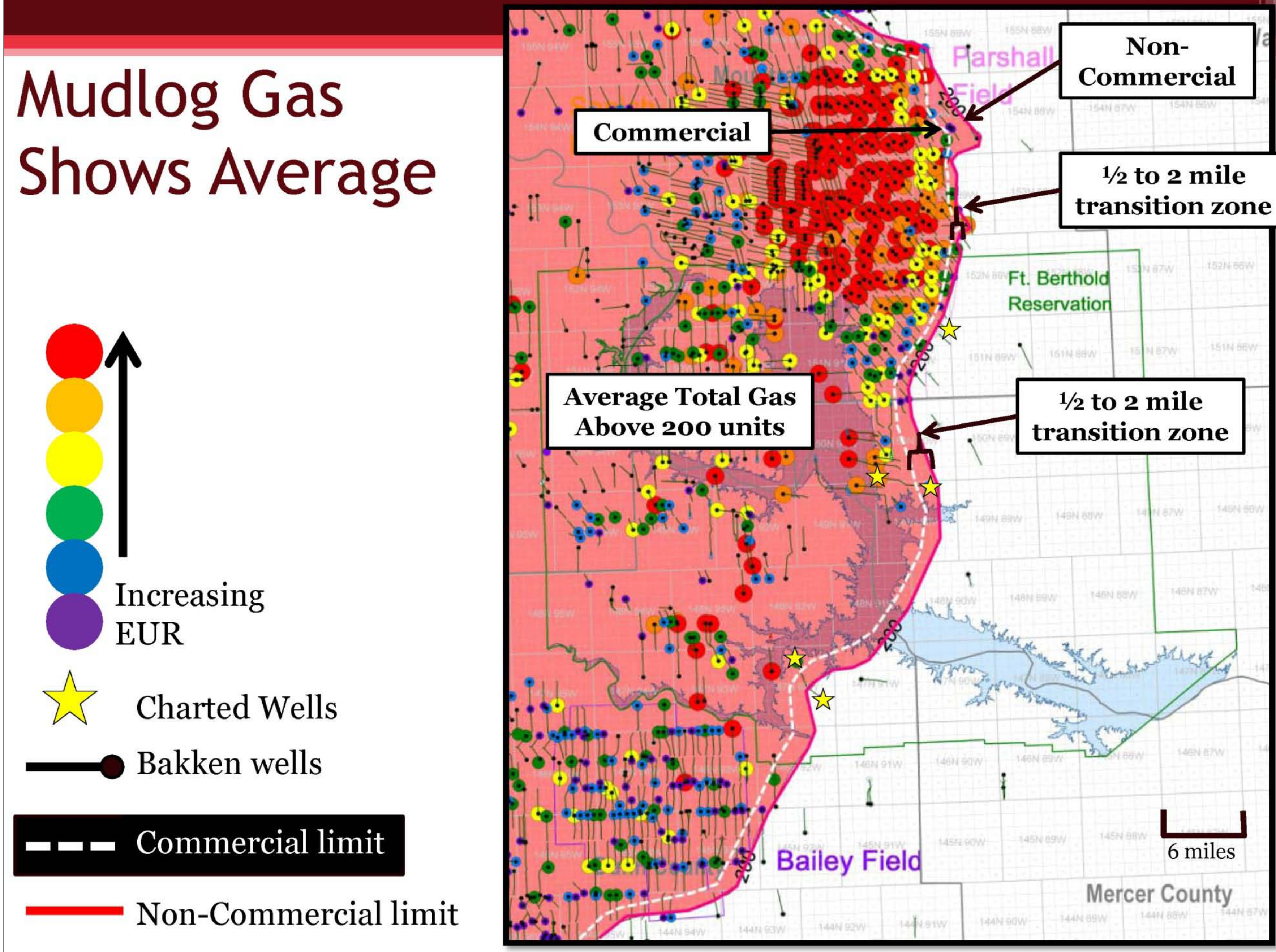
Charted Wells

Bakken wells

Commercial limit

Non-Commercial limit

Mudlog Gas Shows Average



Presenter's Notes: Now looking at the total picture.

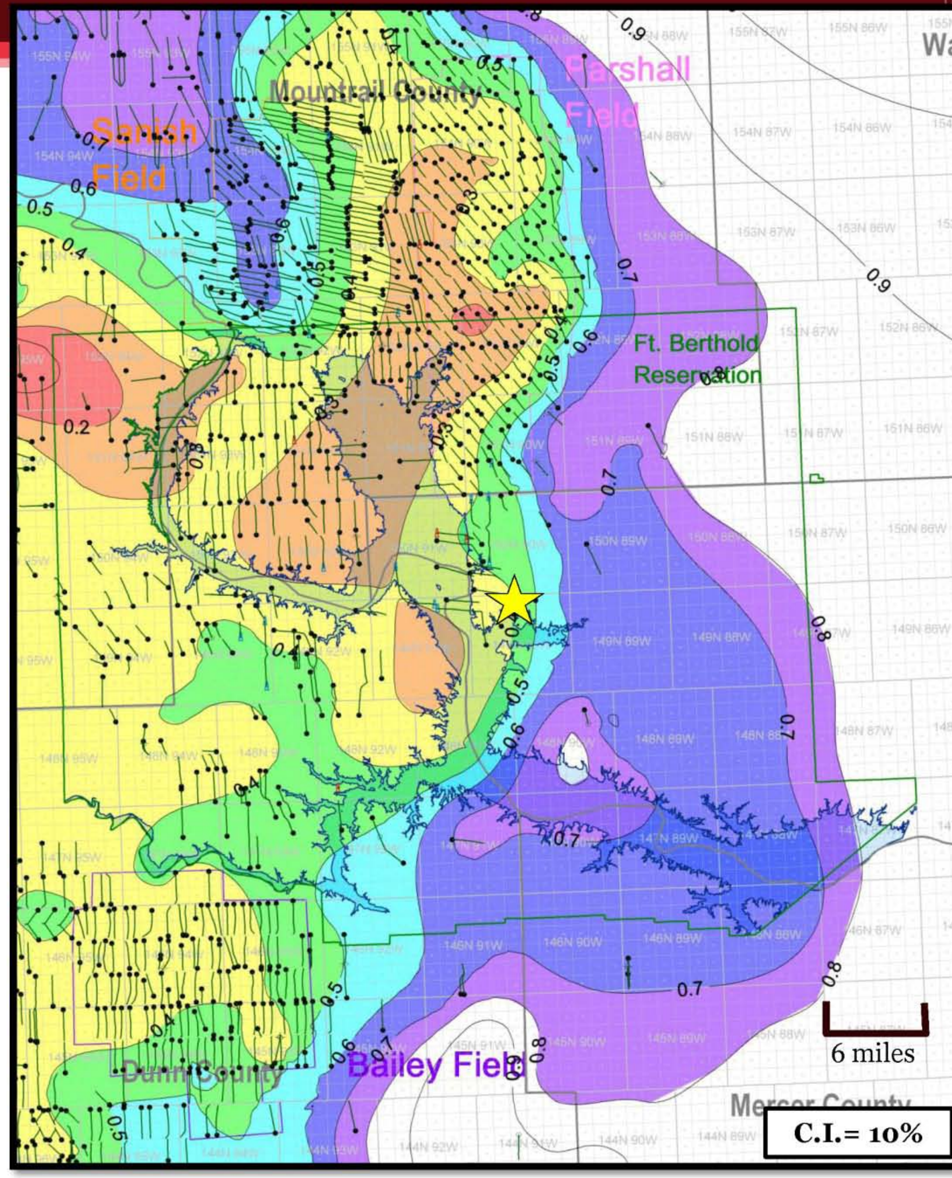
Calculated Water Saturation

Water Saturation Contours

- < 0.20
- 0.20-0.30
- 0.30-0.40
- 0.40-0.50
- 0.50-0.60
- 0.60-0.70
- 0.70-0.80

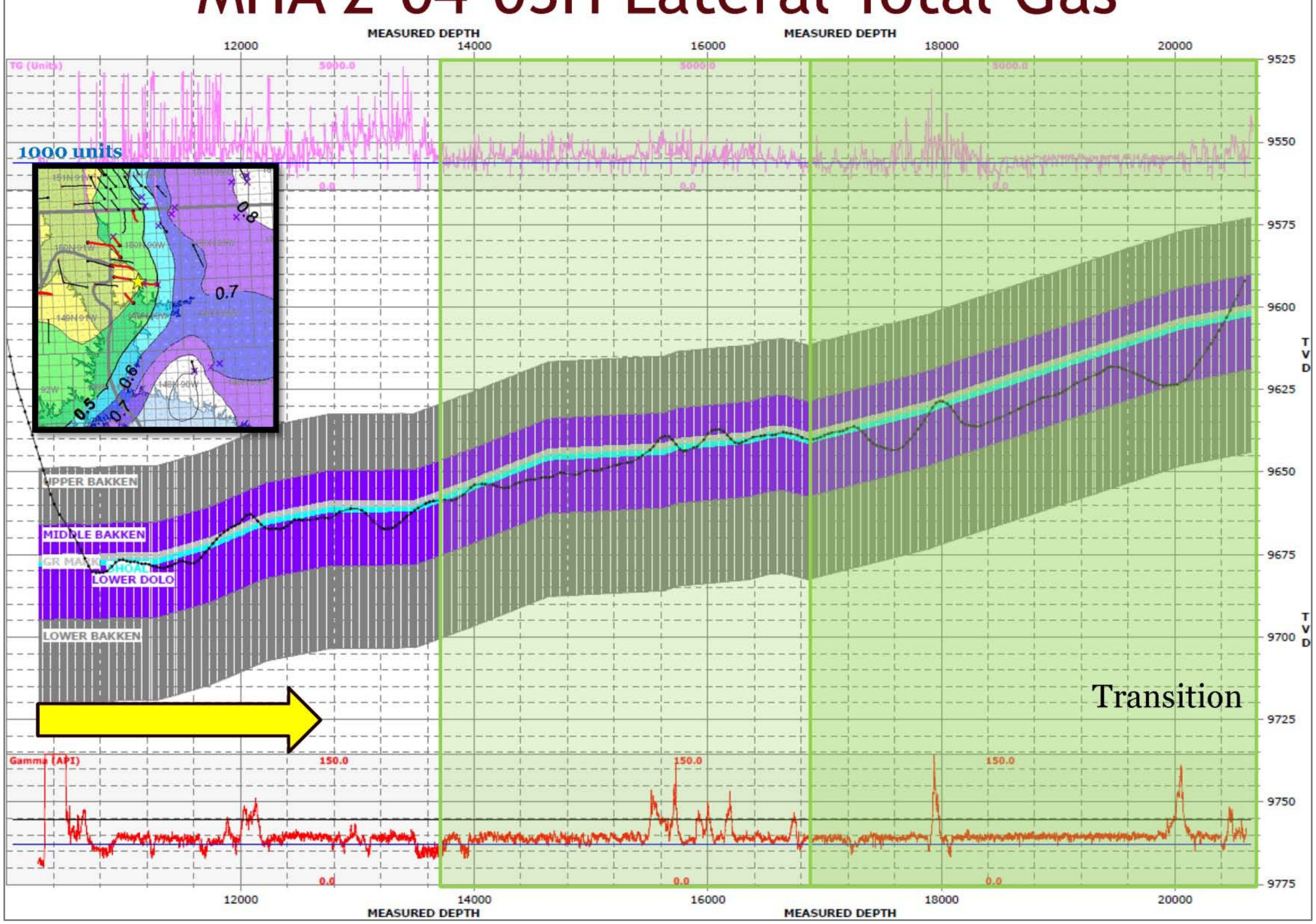
☆ Lateral logs

Bakken wells

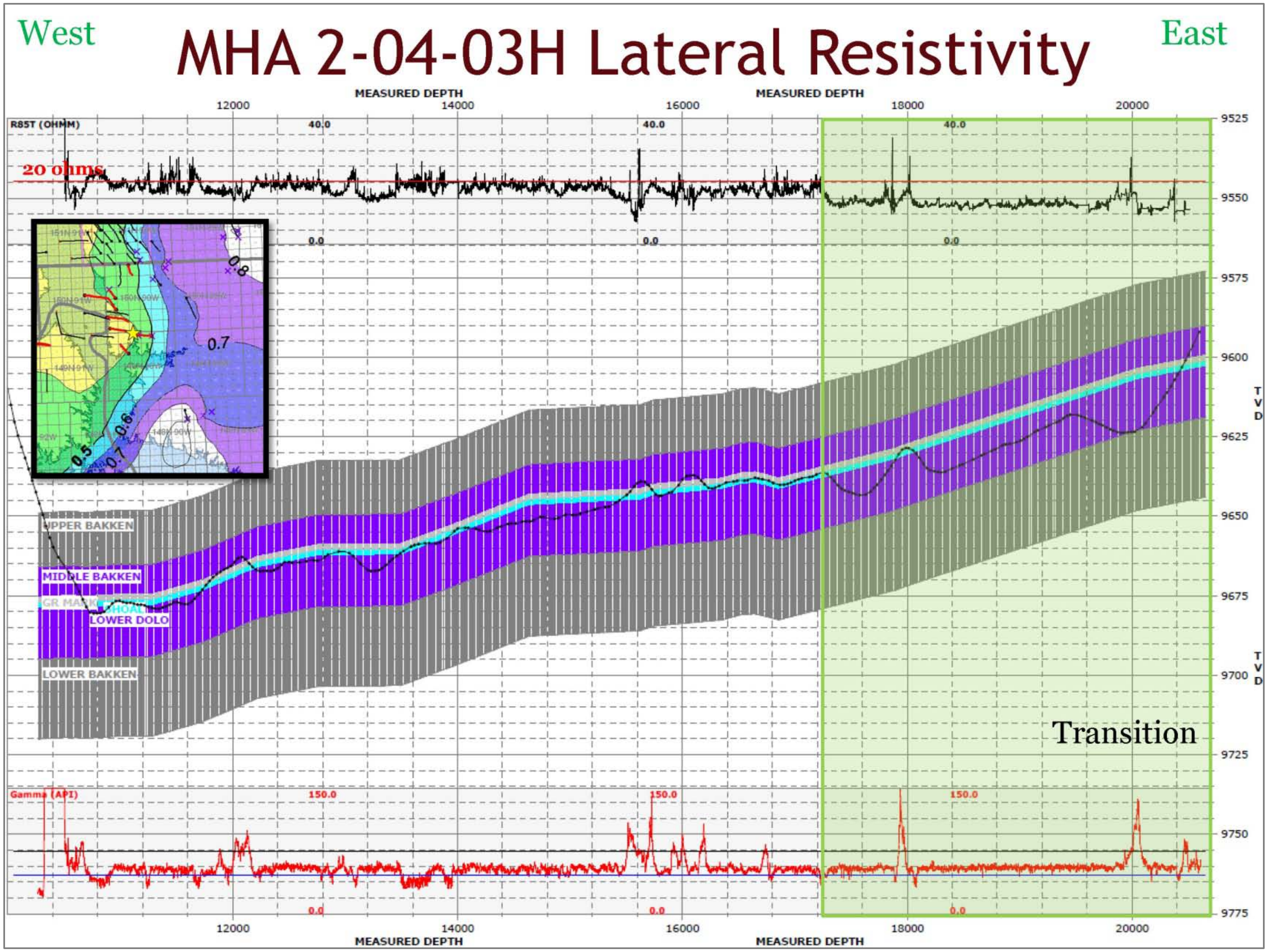


Presenter's Notes: Now looking at the total picture and adding in the EUR bubbles, we can see that the 200 unit average mudgas contour pretty well defines the non-commercial limit in Parshall. And the white dashed line again represents the commercial limit using the mudlog gas shows. We see about a half mile to 1 mile wide transition zone represented by the gas shows in the Parshall edge wells. Again this interpretation can be extended south onto the reservation, and used while drilling a well near the edge, to decide whether to cut the well short while drilling towards the east, or whether to spend the completion dollars on completing a well that had poor shows.

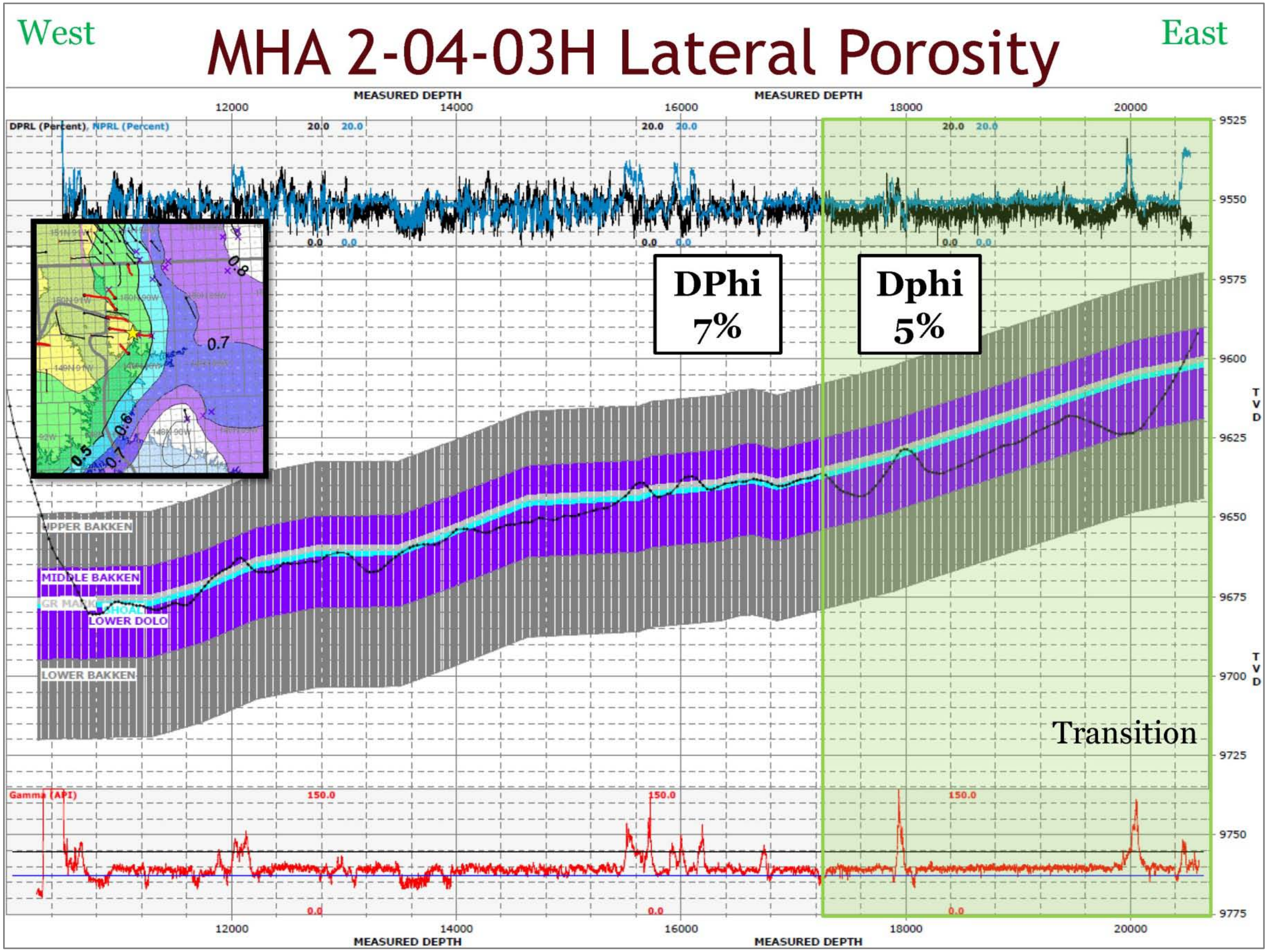
MHA 2-04-03H Lateral Total Gas



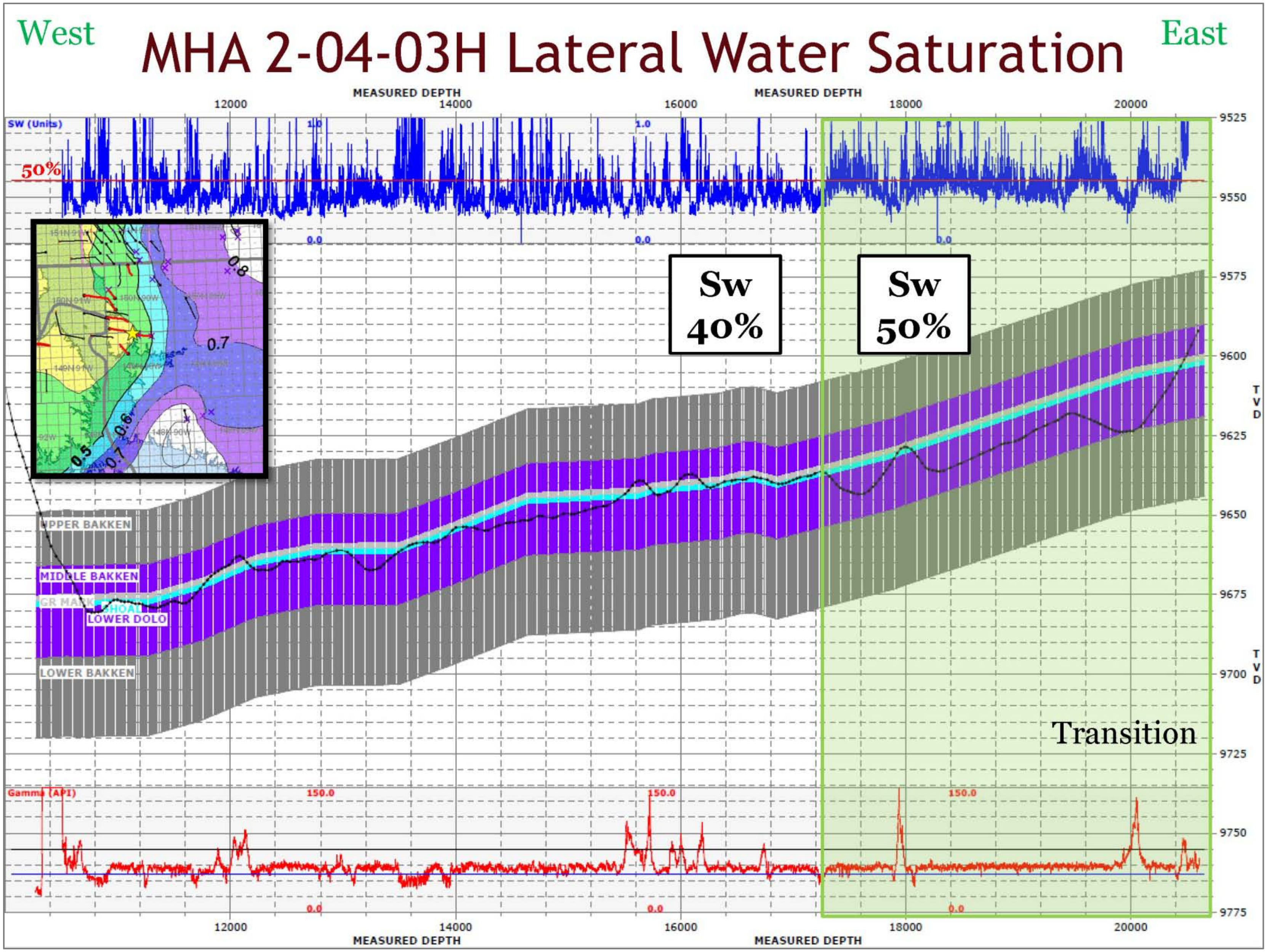
Presenter's Notes: Now moving on to our final factor, we can see increasing water saturation to the east using data obtained in vertical wellbores, as well as logs ran in the lateral portion of the MHA 2-04-03H by QEP late last year. These water saturations were calculated using the standard Archie's equation and an Rw of 0.015, m=1.8, n=2. While we knew we were drilling farther east than we had before, so we were keeping an eye out for a significant decrease in the mudgas averages. And while the averages did fall slightly as previous explained, we felt like we needed a more definitive answer before we completed the well. By using Weatherford shuttle technology, we were able to get the standard triple combo logs over the entire Bakken lateral.



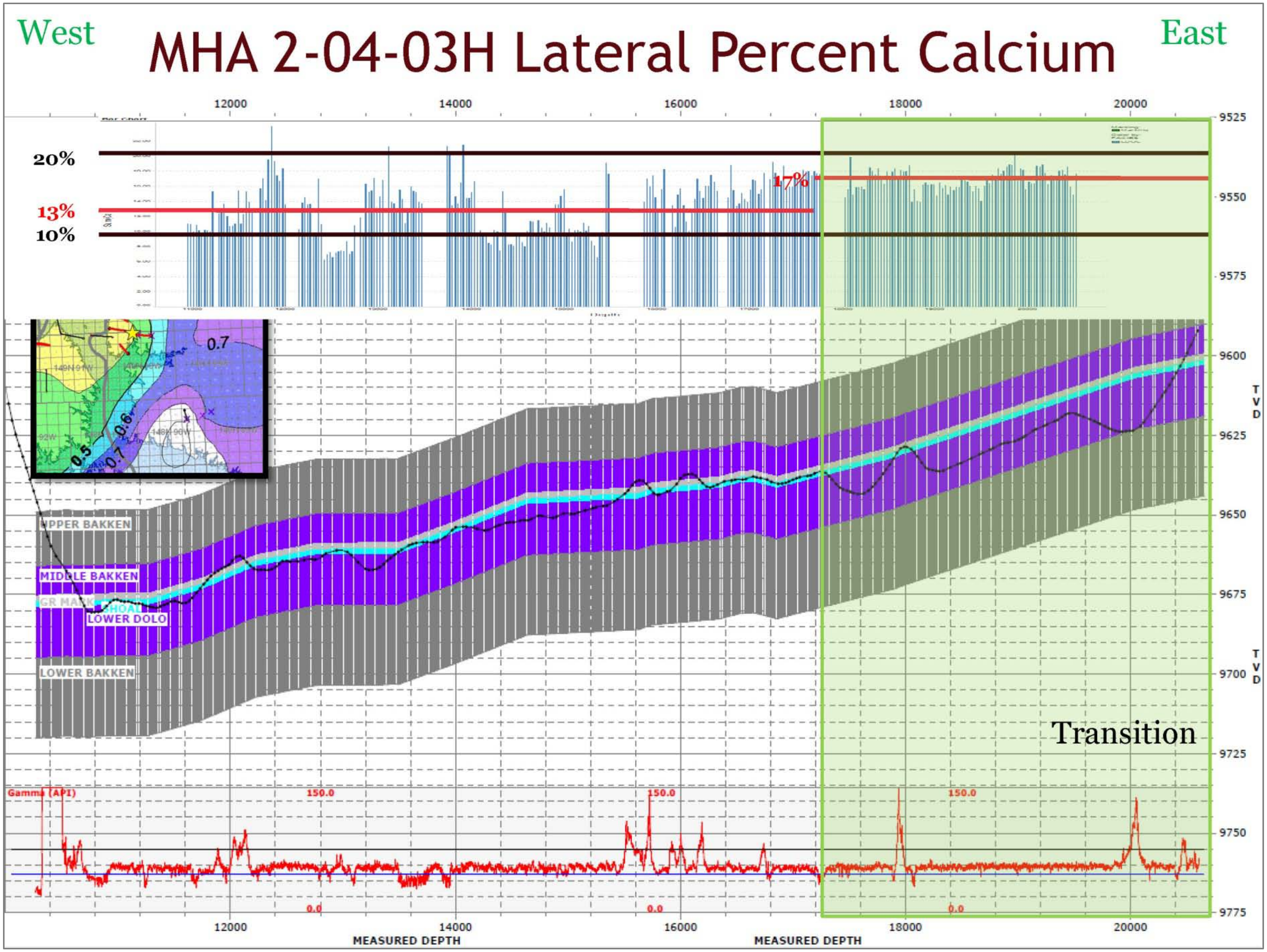
Presenter's Notes: And here are our results. This cross section created in SES, Stoner Engineering Software, shows the MHA 2-04-03H. It was drilled updip from west to east. The total vertical depth scale on the vertical axis has been exaggerated compared to the measured depth scale along the top. The Upper and Lower Bakken shales are shown in grey, while the Middle Bakken dolostone and silty-dolostone are shown in purple, with the limestone shoal in blue. The well path is the slightly undulating black line. We have the logging while drilling gamma ray in red at the bottom and total gas plotted at the top in pink with the 1000 unit line in blue. This was the same well that I showed previously when discussing the mudgas shows, I just wanted to show how the transition zone compared to the mudgas and water saturation increase. So this was where we saw the initial step change around 14000 feet, and here is where we saw the second step change around 17000 feet.



Presenter's Notes: Now we see the same cross section, but with the deep resistivity in black at the top. The red line represents the 20 ohmm line. As you can see when we reach approximately 17000 feet measured depth, we see a downward shift in the resistivity. We have interpreted this as the transition zone based on the logs and the second step change in the mudgas. It does not appear to be lithology driven, as we encountered similar lithologies at relatively the same point in the formation, before and after the resistivity drop.



Presenter's Notes: Now we see the same well and cross section, but with density and neutron porosity plotted along the top. Density is in black and neutron is in blue and the scale is 0 to 20 percent porosity. We can see that we have a slight separation of the density and neutron once we reach the transition zone at 17000 feet. The average density porosity before 17000 feet was approximately 7 percent and the average water saturation after 17000 feet was approximately 5 percent across all lithologies.



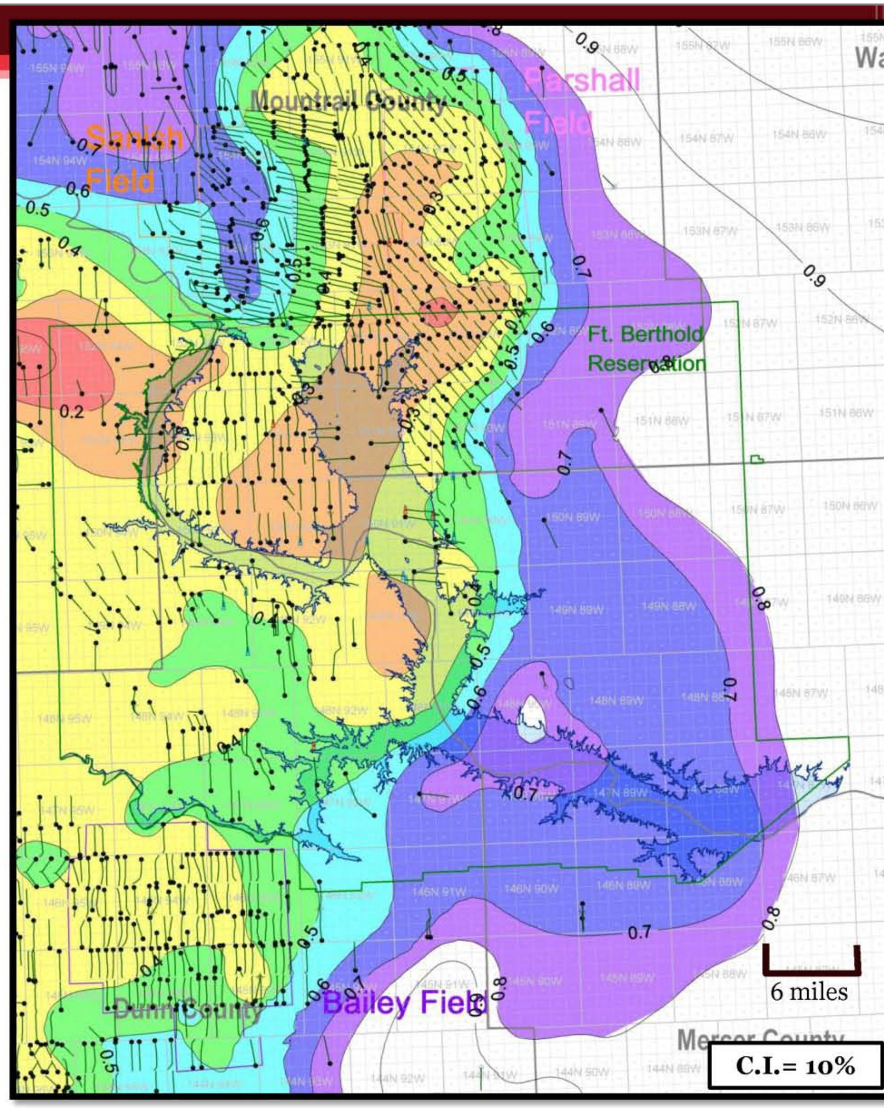
Presenter's Notes: Now putting it all together, we have calculated water saturation along the top plotted in blue. The 50 percent water saturation line is in red and the scale goes from 0 to 100 percent. Again you can see a shift in the water saturation at the transition point. The average water saturation before 17000 feet was approximately 40 percent and the average water saturation after 17000 feet was approximately 50 percent across all lithologies.

Calculated Water Saturation

Rw=0.015
m=1.8, n=2

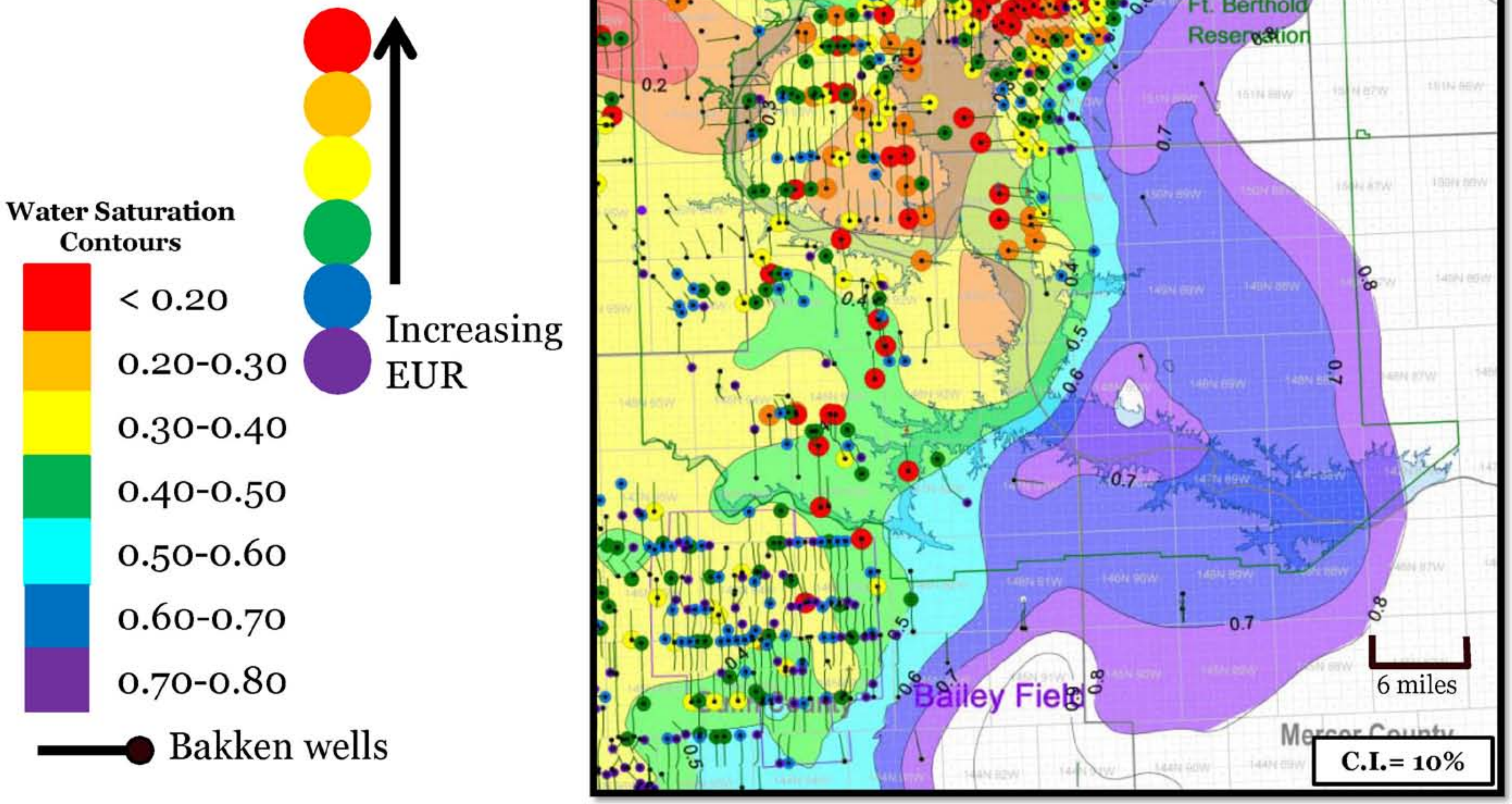
Water Saturation Contours

- < 0.20
- 0.20-0.30
- 0.30-0.40
- 0.40-0.50
- 0.50-0.60
- 0.60-0.70
- 0.70-0.80
- Bakken wells

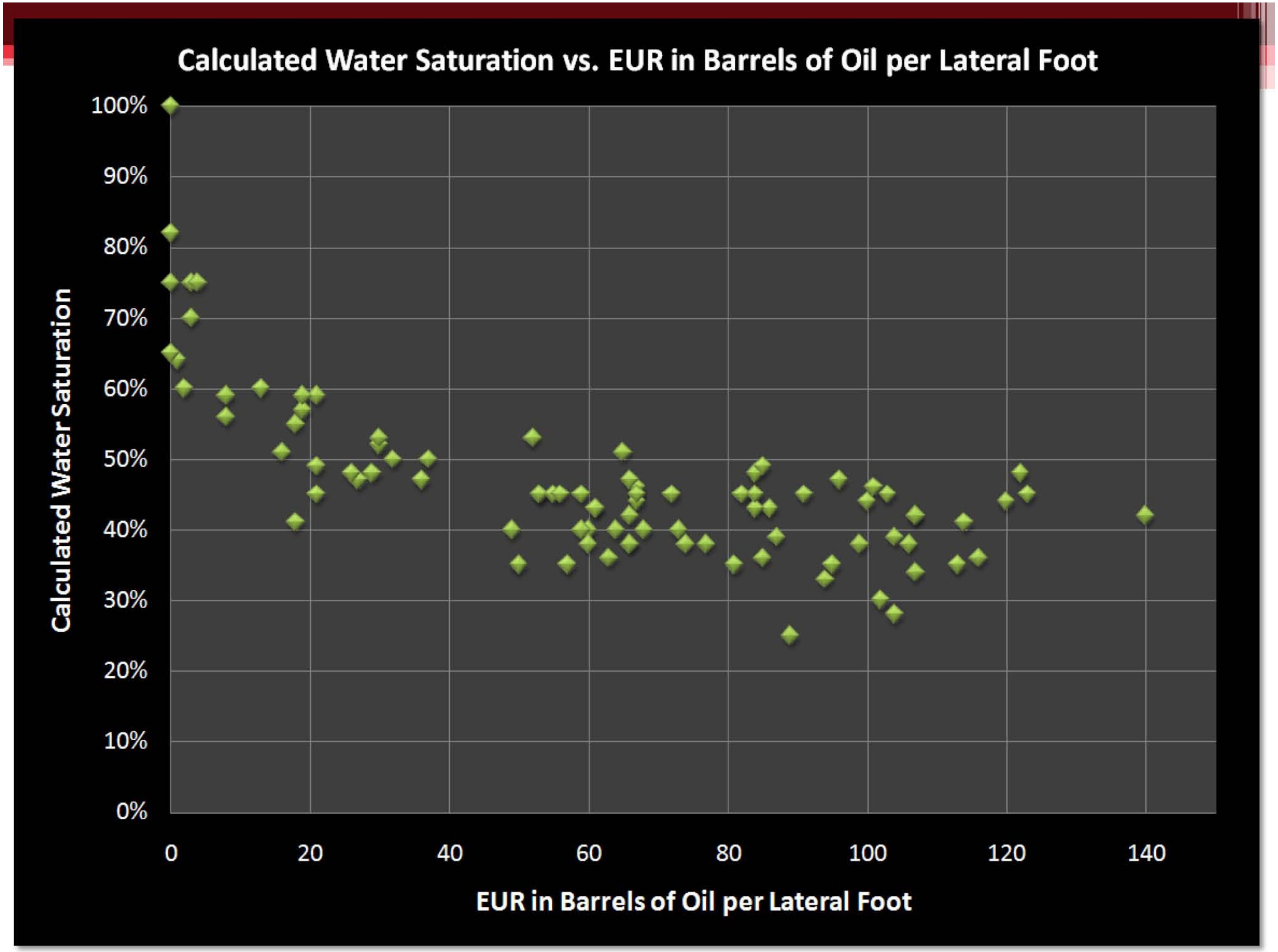


Presenter's Notes: Recently we decided to run the X Ray Flouresence gun on the samples to find out what elements are present and in what quantities and to see if we could see a potential diagenetic difference across that same interval. Here we have the Percent Calcium in the samples plotted along the top. You can see the 10 and 20 percent lines in black. This only showing the samples that we interpreted to be in the lower dolomite facies. As you can see there is a general increase in the percent calcium in the samples around the 17000 ft MD mark, with the average before being 13% and the average after being 17%. We can reasonably assume that this increase in calcium can be correlated to an increase in calcite, leading to a potential diagentic trap on the east side. This XRF technology could therefore be used to help define the line of death while drilling the lateral. This is all very preliminary work and Katie Kocman at the Colorado School of Mines will be doing more work on this in her upcoming thesis.

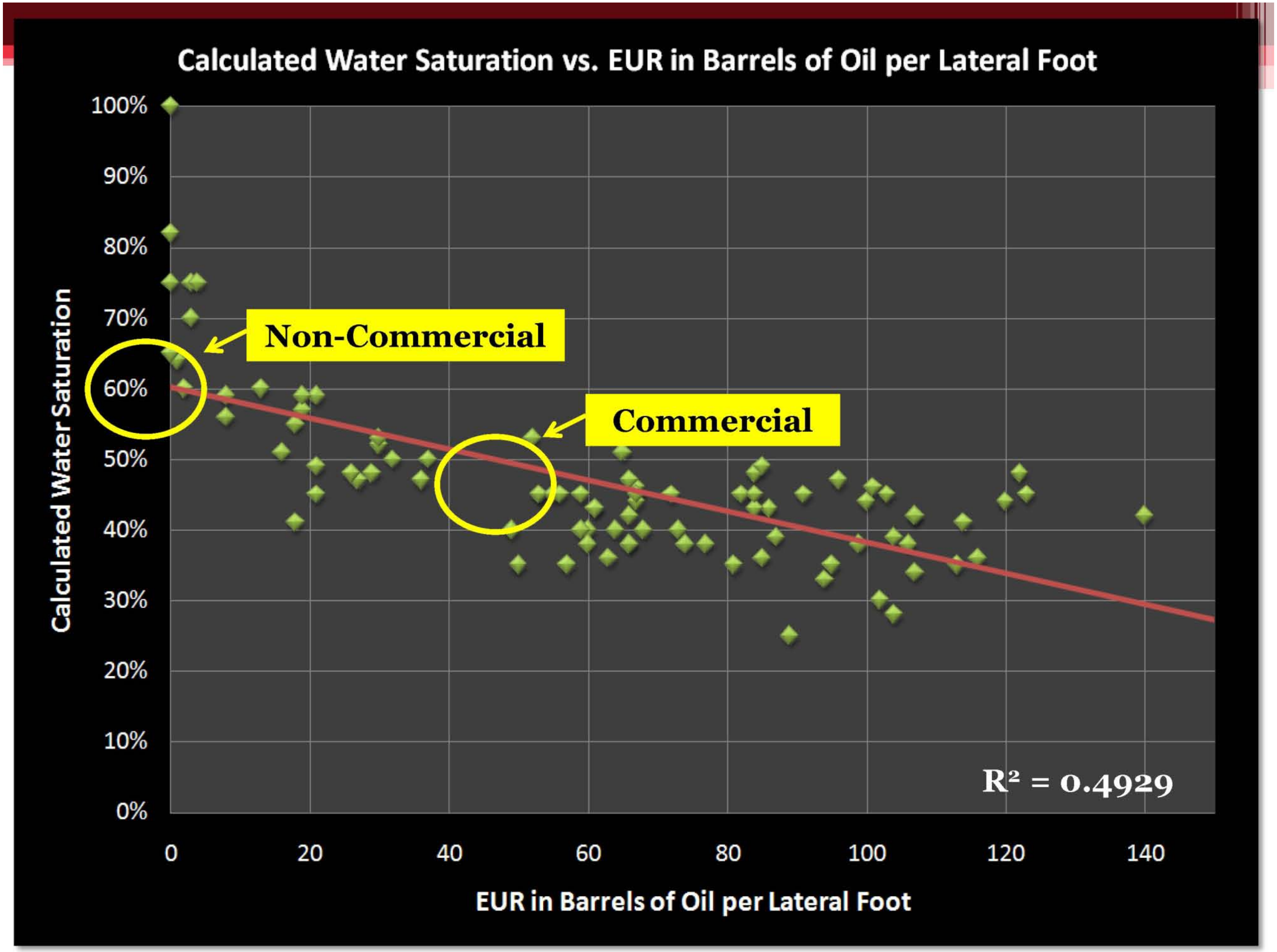
Calculated Water Saturation



Presenter's Notes: Now back to the water saturation map,



Presenter’s Notes: we can see when we overlay the EUR bubbles we still get a pretty good correlation of high EUR to low water saturation.



Presenter's Notes: And again looking at this graphically we can see that same relationship. This time we have percent water saturation versus EUR per lateral foot.

Calculated Water Saturation

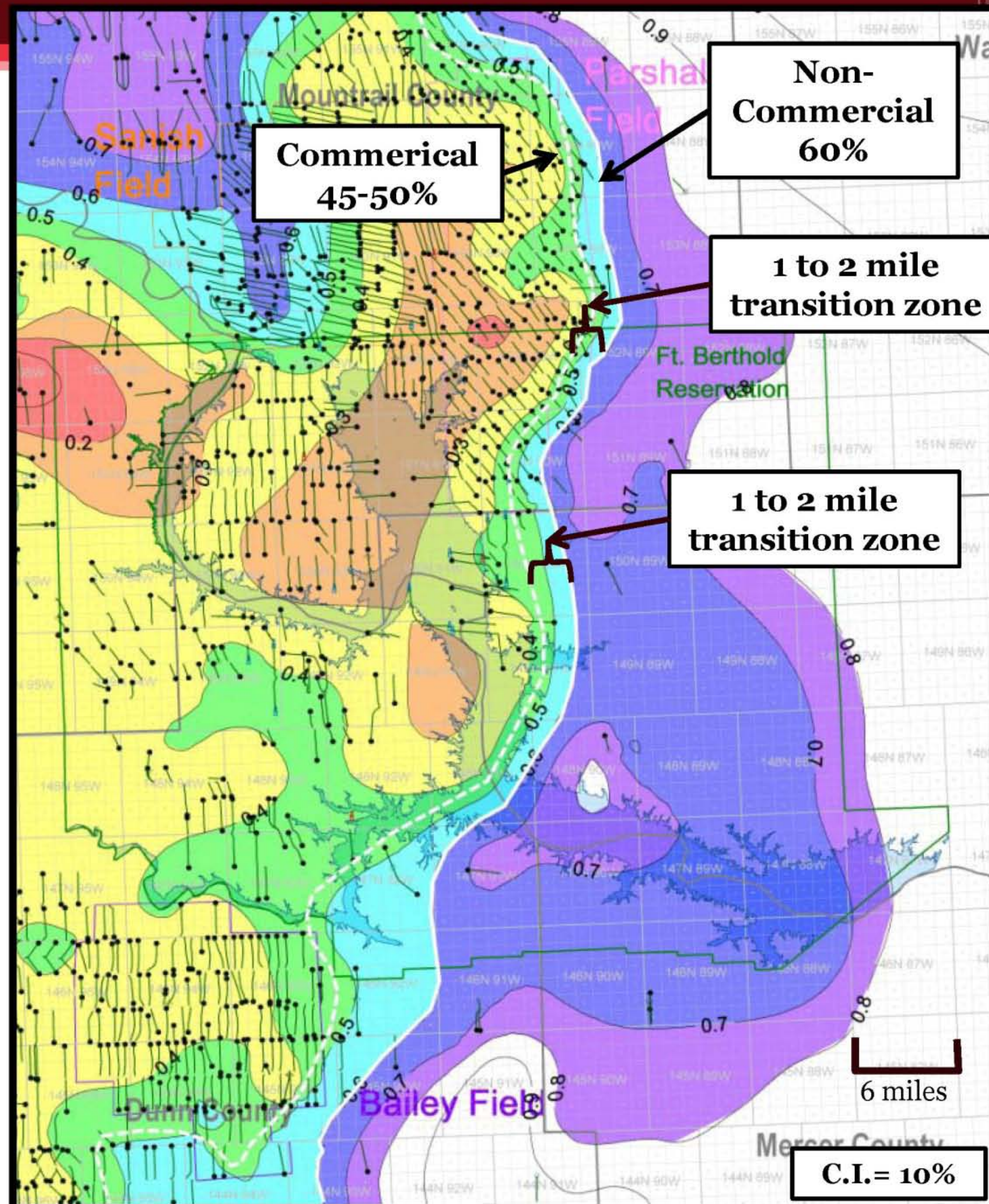
Water Saturation Contours

< 0.20
0.20-0.30
0.30-0.40
0.40-0.50
0.50-0.60
0.60-0.70
0.70-0.80

Bakken wells

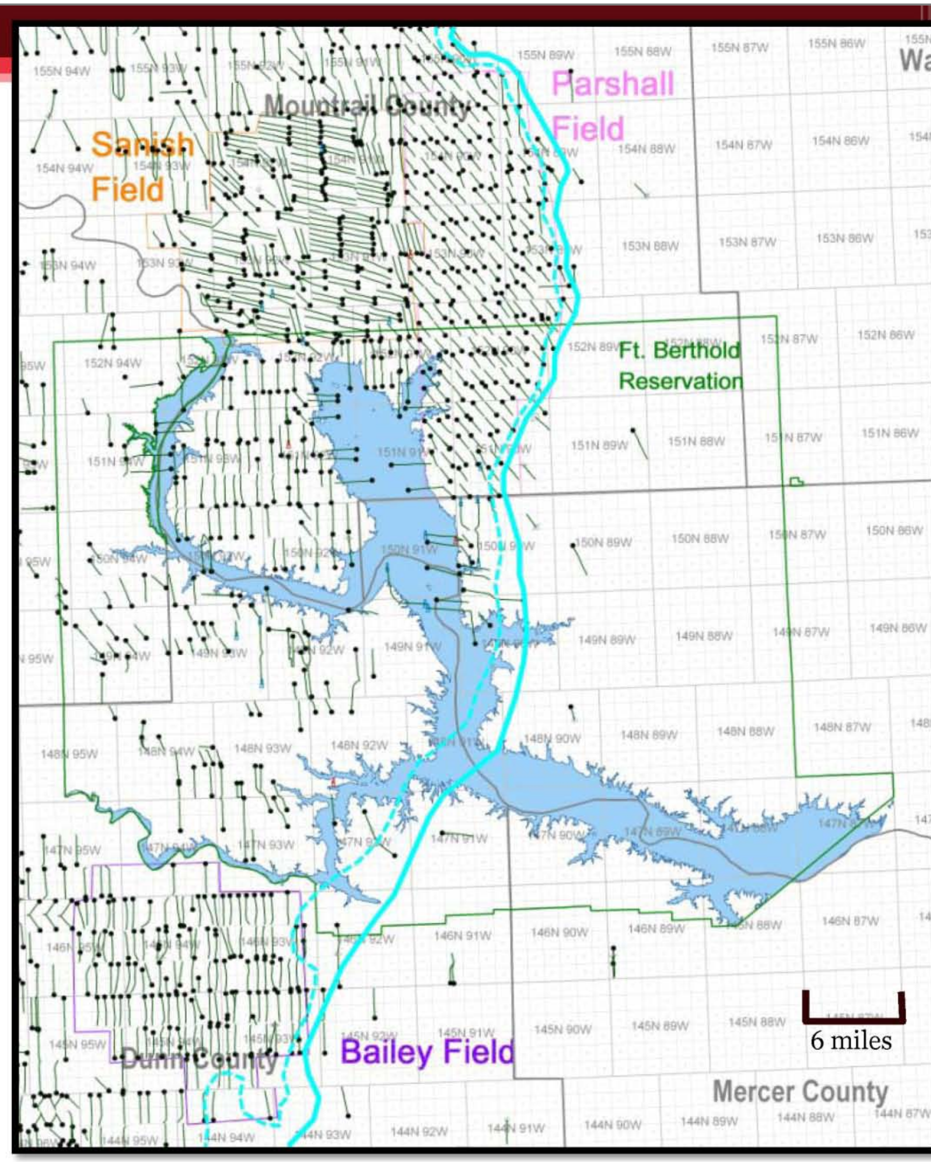
Commercial limit

Non-Commercial limit



Presenter's Notes: And if we fit a linear trendline to the data we can see that at the 0 EUR point is about 60% water saturation, and again where the trendline crosses the 45-50% water saturation, we see about 500 MBO EURs. Which again can be interpreted to be the commerical limit depending on your individual economics.

All Parameters
"Line of Death"

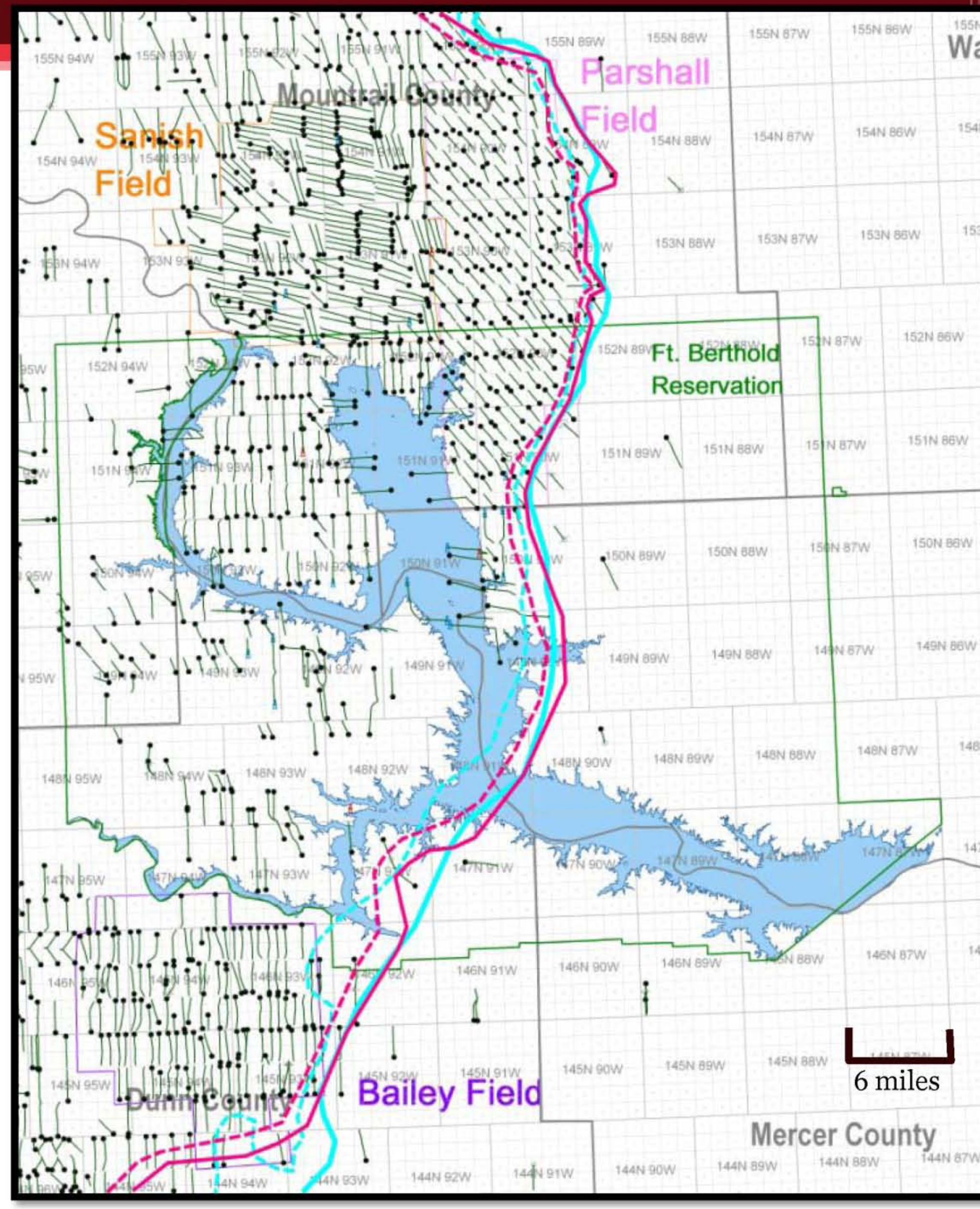


Percent Water Commercial limit

Percent Water Non-Commercial limit

Presenter's Notes: By combing the EUR data with the water saturation contours and taking our interpretation from the previous set of graphs, we can see the commercial limit in dashed white, representing approximately 45 to 50 percent water saturation, and the non-commercial limit in solid white representing approximately 60 percent water saturation. Again note you can see the transition zone varies about a mile to 2 miles wide along the edge of Parshall. And this same transition zone, and approximate width, can be interpreted to exist on the reservation. Therefore by using the patterns observed in Parshall with respect to water saturation and EUR, we can conclude that the last 3000 feet or so of the MHA 2-04-03H is indeed in the transition zone and should still produce at commercial rates from the toe. Albeit with a higher percent water.

All Parameters
"Line of Death"



Mud-gas Commercial limit

Mud-gas Non-Commercial limit

Percent Water Commercial limit

Percent Water Non-Commercial limit

Presenter's Notes: Now as we came up with similar percentages for the non-commerical limit and commerical limit for both the water saturation and the produced water, I just wanted to show the two parameters mapped and graphed against each other to show the linear relationship on the east side. So here we ca see the color and spacial relationship between the water saturation and the percent water.

All Parameters “Line of Death”

Water Saturation Commercial limit

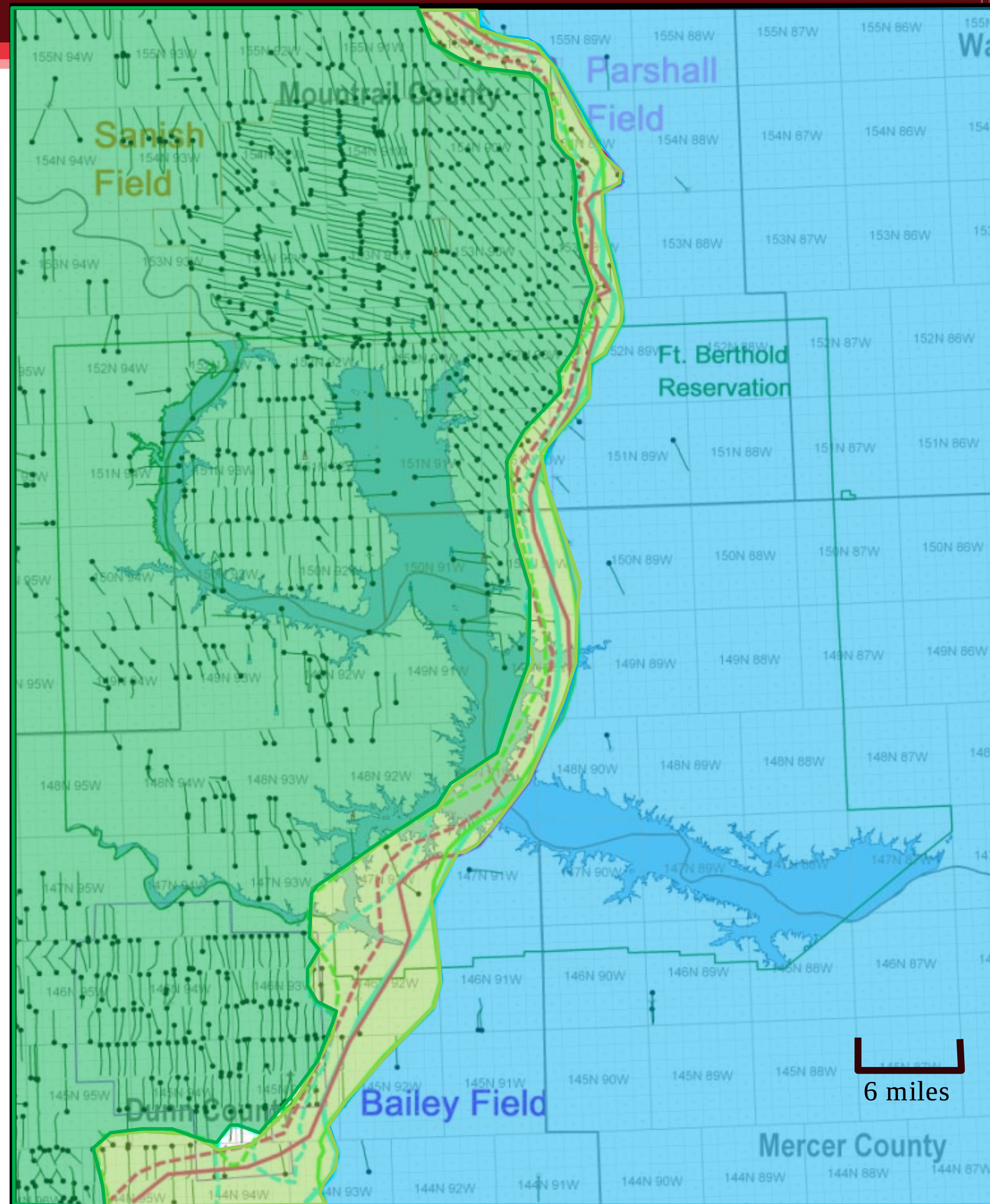
Water Saturation Non-Commercial limit

Mud-gas Commercial limit

Mud-gas Non-Commercial limit

Percent Water Commercial limit

Percent Water Non-Commercial limit



Presenter’s Notes: Then by using the eastern and western most limits of the three parameters, we can define a non-commercial zone, a commercial zone, and transition zone in-between.

Summary

- Patterns observed on the eastern commercial limit of Parshall Field hold true for the eastern commercial limit on the Fort Berthold Reservation
- Defined by:
  - Evaluating existing production data
  - Mudlogs from laterals
  - Calculated water saturations from wireline logs across the Bakken
- The eastern commercial limit ranges from 1000 feet to two miles wide.
- Identifying the commercial limit can save millions of unnecessary drilling and completion dollars

Presenter's Notes: In summary the patterns observed on the eastern commercial limit of Parshall Field hold true for the eastern commercial limit on the Fort Berthold Reservation. The limits can be defined by evaluating the existing production data, evaluating the mudlogs from the laterals, and calculating the water saturations from the wireline logs across the basin. We've found that the eastern commercial limit ranges from approximately 1000 feet to two miles wide at some points. And ultimately why we do all of this, is because identifying the commercial limit can save millions of unnecessary drilling and completion dollars.

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- Special thanks to QEP Energy for permission to make this presentation
- My co-authors Charlie Bartberger and Mark Longman
- Robert Coskey for his input
- Bob Povich at Weatherford Wireline Logging
- All colleagues who provided valuable data, suggestions, and constructive criticism

QEP Energy Company

Presenter's Notes: Finally I'd like to give a special thanks to QEP Energy for permission to make this presentation today, my co-authors Charlie Bartberger and Mark Longman, Robert Coskey for his input, Bob Povich at Weatherford, Simon Hughes at Weatherford Surface Logging, and all my colleagues who provided valuable data, suggestions, and constructive criticism. Thank you.