#### PSReservoir Characterization and Petrology of the Bakken Formation, Elm Coulee Field, Richland County, MT\*

#### Chloe Spencer Alexandre<sup>1</sup>, Stephen A. Sonnenberg<sup>1</sup>, and J Frederick Sarg<sup>1</sup>

Search and Discovery Article #20108 (2011) Posted July 18, 2011

#### Abstract

Elm Coulee Field, discovered in 2000 in Richland County, Montana, is the largest oil field in the Williston Basin. This field produces from the Devonian-Mississippian middle Bakken Formation and has an estimated ultimate recovery of 200-250 million barrels of oil. Horizontal drilling and hydrofracturing lead to large recoveries from this low permeability and porosity field.

The Bakken Formation in Elm Coulee Field is composed of three main members with an average total thickness of 40 feet. The lower Bakken member consists of laminated, brown to black, marine shale. This member is siltier in Elm Coulee than in other parts of the Williston Basin. It pinches out in the western and southern limits of the field and is not present locally in portions of the field. The middle Bakken member contains five shallow marine silty-dolostone facies including two brachiopod-rich facies, two bioturbated facies, and one laminated facies. Like the lower member, the upper Bakken member is laminated, dark, marine shale, but it is continuous across the field and contains less silt than the lower Bakken member does at Elm Coulee. The upper Bakken member is the main source bed for the oil found within the middle Bakken reservoir at Elm Coulee. Production in the middle Bakken member within Elm Coulee is closely tied to the high percentage of dolomite located in the reservoir quality sections. The main types of porosity within the middle Bakken are intercrystalline, dissolution, and intergranular. The first two types of porosity listed are the result of dolomitization and subsequent dissolution. Within portions of the middle Bakken member containing the highest dolomite percentages (up to 60%) and lowest clay percentages, some of the rhombohedral dolomites have 10 micron gaps along the edges of the crystals. These "slot" pores connect, thus acting like microfractures, and lead to preferential pathways that contribute to increased permeability and production.

The results of this study in conjunction with previous analyses of the Elm Coulee Field indicate that the Bakken system within the Williston Basin has huge potential for future discoveries. Understanding the distribution of facies and porosity and the diagenetic stages that have occurred within the middle Bakken reservoir member is the key to determining new drilling targets within Elm Coulee and also to the search for similar fields in this basin that may be good targets for future production.

<sup>\*</sup>Adapted from poster presentation at AAPG Annual Convention and Exhibition, Houston, Texas, USA, April 10-13, 2011

<sup>&</sup>lt;sup>1</sup>Geology and Geological Engineering, Colorado School of Mines, Golden, CO (csalexan@mines.edu)

#### References

Blakey, R.C., 2011, North American paleogeographic Maps—Late Devonian (360Ma), Colorado Plateau Geosystems, Web accessed 28 June 2011,

http://cpgeosystems.com/namD360.jpg

Flannery, J., and Kraus, J., 2006, Integrated analysis of the Bakken Petroleum System: U.S. Williston Basin: AAPG National Convention, Houston, Texas. Search and Discovery Article #10105. Web accessed 28 June 2011, http://www.searchanddiscovery.com/documents/2006/06035flannery/index.htm?q=%2BtextStrip%3A10105

Meissner, F.F., 1978, Petroleum geology of the Bakken Formation Williston Basin, North Dakota and Montana, *in* D. Rehrig, (chair), The economic geology of the Williston Basin; Montana, North Dakota, South Dakota, Saskatchewan, Manitoba: Montana Geological Society, p. 207-227.

Nordeng, S.H., 2009, The Bakken petroleum system; an example of a continuous petroleum accumulation: DMR Newsletter, v. 36/1, p. 19-22.

Pitman, J.K., L.C. Price, and J.A. LeFever, 2001, Diagenesis and fracture development in the Bakken Formation, Williston Basin: Implications for reservoir quality in the middle member: U.S. Geological Survey Professional Paper 1653, p. 19.

Pramudito, A., 2008, Depositional facies, diagenesis, and petrophysical analysis of the Bakken Formation, Elm Coulee Field, Williston Basin, Montana: Colorado School of Mines, M.S. thesis, 195 p.

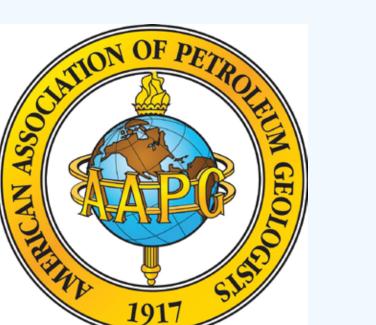
Smith, M.G., and R.M. Bustin, 1996, Lithofacies and paleoenvironments of the Upper Devonian and Lower Mississippian Bakken Formation, Williston Basin: Bulletin of Canadian Petroleum Geology, v. 44/3, p. 495-507.

Sonnenberg, S.A., and A. Pramudito, 2009, Petroleum geology of the giant Elm Coulee field, Williston Basin: AAPG Bulletin, v. 93/9, p. 1127-1153.

Webster, R.L., 1984, Petroleum source rocks and stratigraphy of the Bakken Formation in North Dakota, *in* J. Woodward, F.F. Meissner, and J.L. Clayton, (eds.), Hydrocarbon Source Rocks of the Rocky Mountain Region: Rocky Mountain Association of Geologists, Denver, Colorado, p. 57-81.



# Reservoir Characterization and Petrology of the Bakken Formation, Elm Coulee Field, Richland County, MT



Chloe Spencer Alexandre, Stephen A. Sonnenberg, J. Fredrick Sarg, Colorado School of Mines Department of Geology and Geological Engineering, Golden, Colorado

### (Abstract)

Elm Coulee Field, discovered in 2000 in Richland County, Montana, is the largest oil field in the Williston Basin. This field produces from the Devonian-Mississippian middle Bakken Formation and has an estimated ultimate recovery of 200-250 million barrels of oil. Horizontal drilling and hydrofracturing lead to large recoveries from this low permeability and porosity field.

The Bakken Formation in Elm Coulee Field is composed of three main members with an average total thickness of 40 feet. The lower Bakken member consists of laminated, brown to black, marine shale. This member is siltier in Elm Coulee than in other parts of the Williston Basin. It pinches out in the western and southern limits of the field and is not present locally in portions of the field. The middle Bakken member contains five shallow marine silty-dolostone facies including two brachiopodrich facies, two bioturbated facies, and one laminated facies. Like the lower member, the upper Bakken member is laminated, dark, marine shale, but it is continuous across the field and contains less silt than the lower Bakken member does at Elm Coulee. The upper Bakken member is the main source bed for the oil found within the middle Bakken reservoir at Elm Coulee.

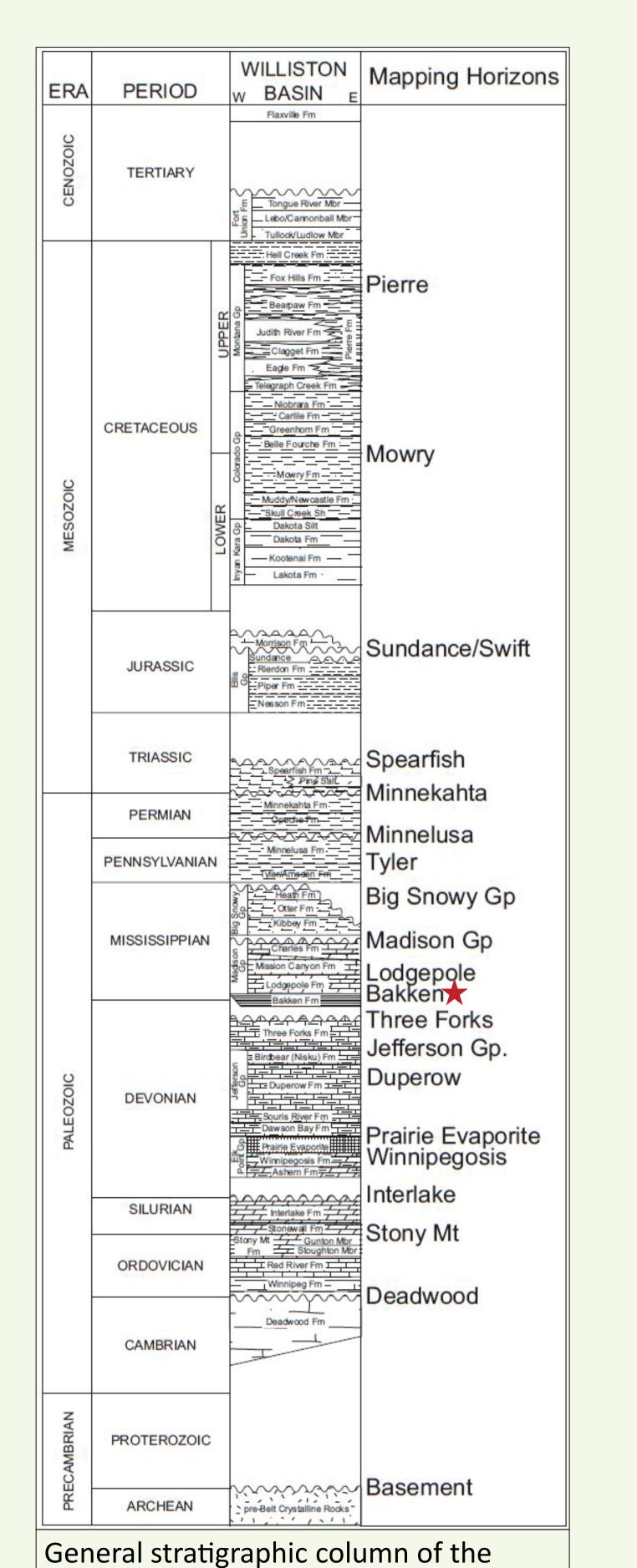
Production in the middle Bakken member within Elm Coulee is closely tied to the high percentage of dolomite located in the reservoir quality sections. The main types of porosity within the middle Bakken are intercrystalline, dissolution, and intergranular. The first two types of porosity listed are the result of dolomitization and subsequent dissolution. Within portions of the middle Bakken member containing the highest dolomite percentages (up to 60%) and lowest clay percentages, some of the rhombohedral dolomites have 10 micron gaps along the edges of the crystals. These "slot" pores connect, thus acting like microfractures, and lead to preferential pathways that contribute to increased permeability and production.

The results of this study in conjunction with previous analyses of the Elm Coulee Field indicate that the Bakken system within the Williston Basin has huge potential for future discoveries. Understanding the distribution of facies and porosity and the diagenetic stages that have occurred within the middle Bakken reservoir member is the key to determining new drilling targets within Elm Coulee and also to the search for similar fields in this basin that may be good targets for future production.

## (Background Figures)



Paleogeographic map showing the location of the Williston Basin during the Late Devonian while the first half of the Bakken was deposited. At this time, the basin was located in the tropics near the equator (Nordeng, 2009; image modified from Blakey, 2011).



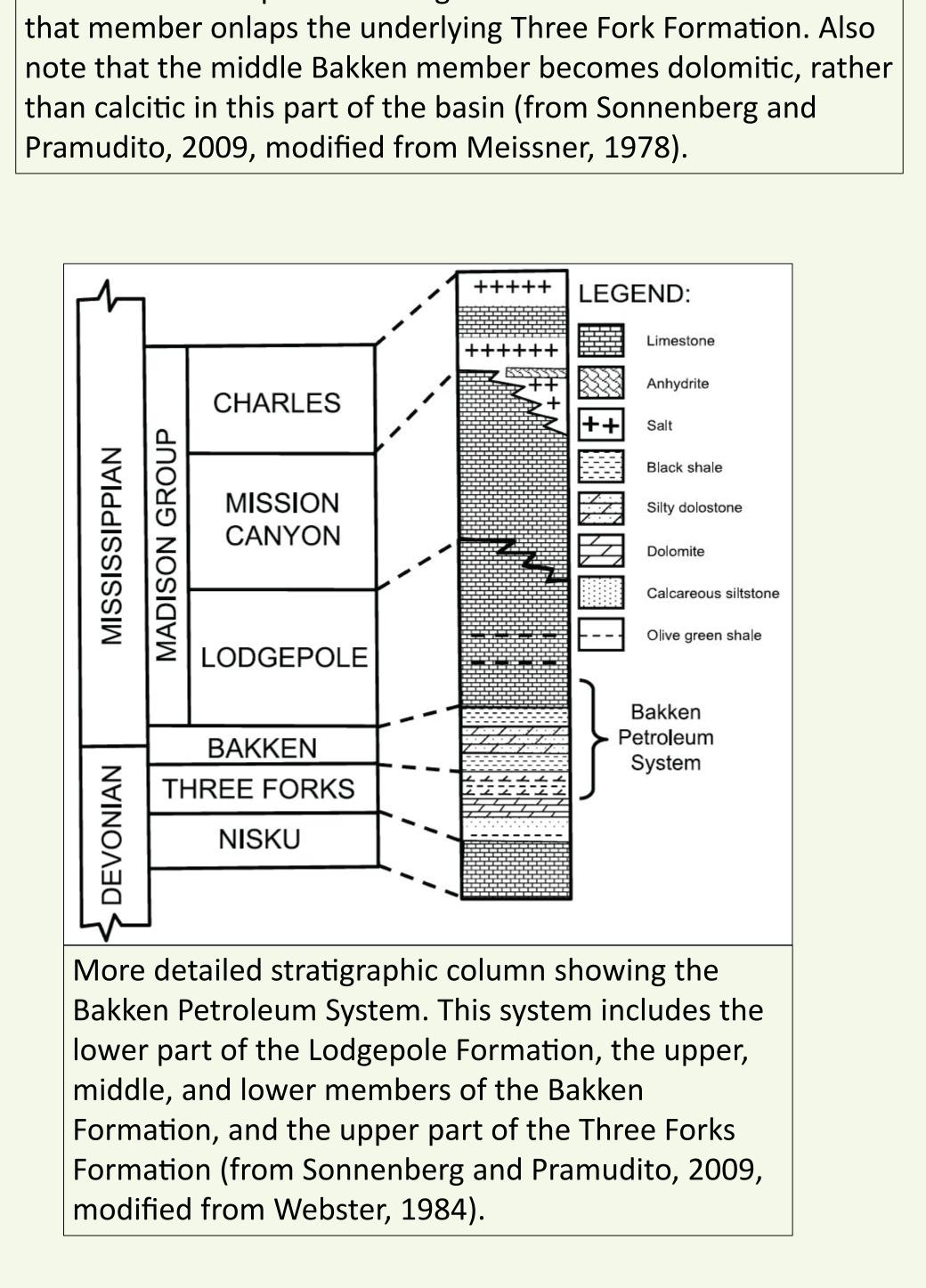
Williston Basin. Roughly 16,000 feet of

deposited from Cambrian until Tertiary

times (Pitman et al., 2001; image from

sediment was nearly continuously

Flannery and Kraus, 2006).



Contour map of the Williston Basin on the

base of the Mississippian. The basin covers

portions of Montana, South Dakota, North

Dakota, Saskatchewan, and Manitoba (from

Sonnenberg and Pramudito, 2009, modified

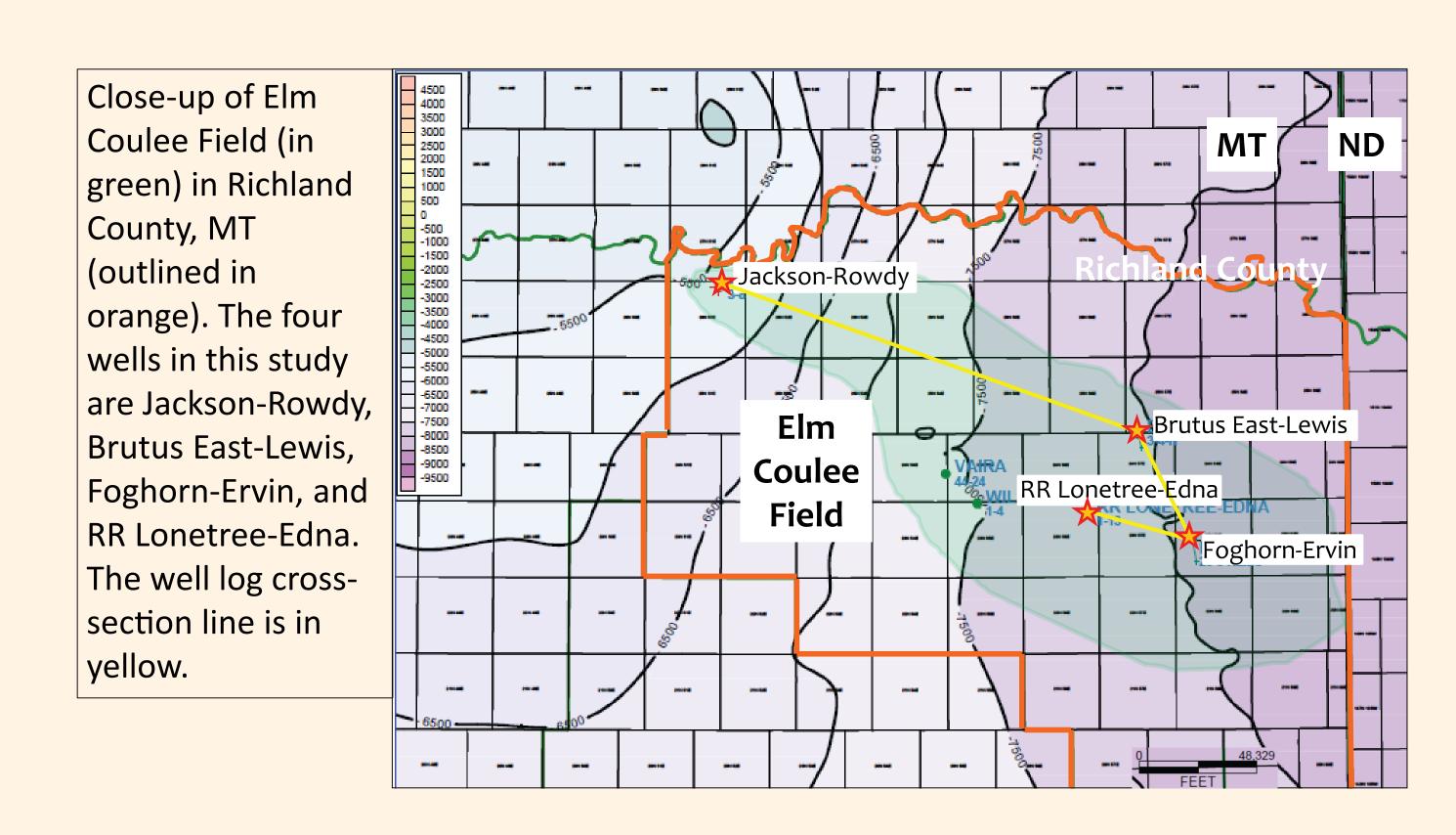
ross-section of the Williston Basin showing the location of Elm

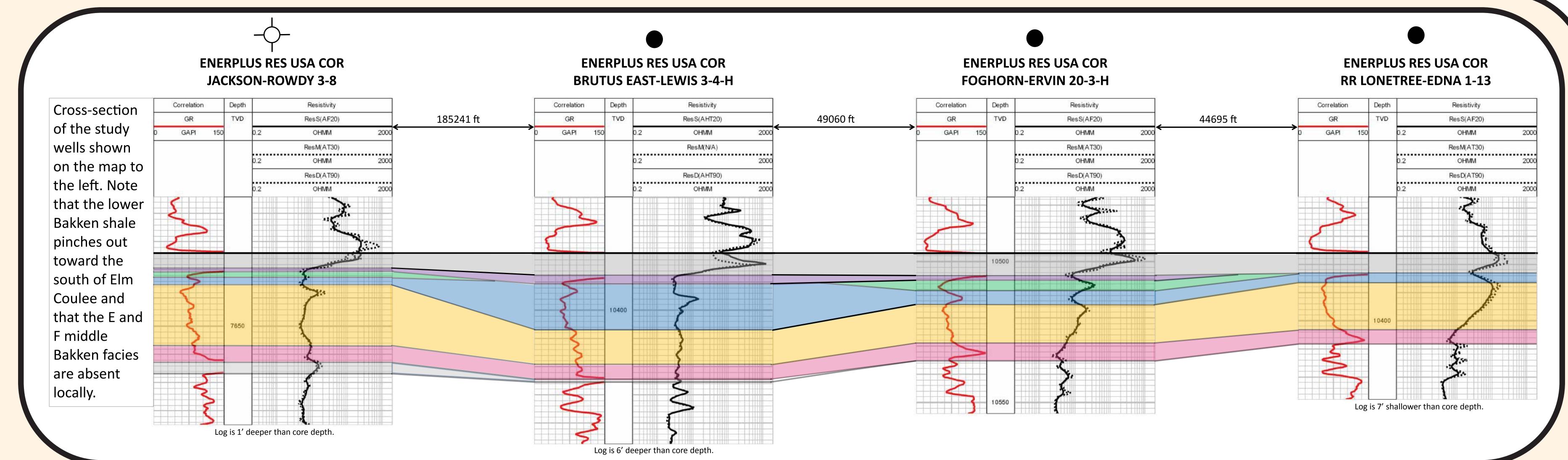
pulee in relation to the three Bakken members. Note how it

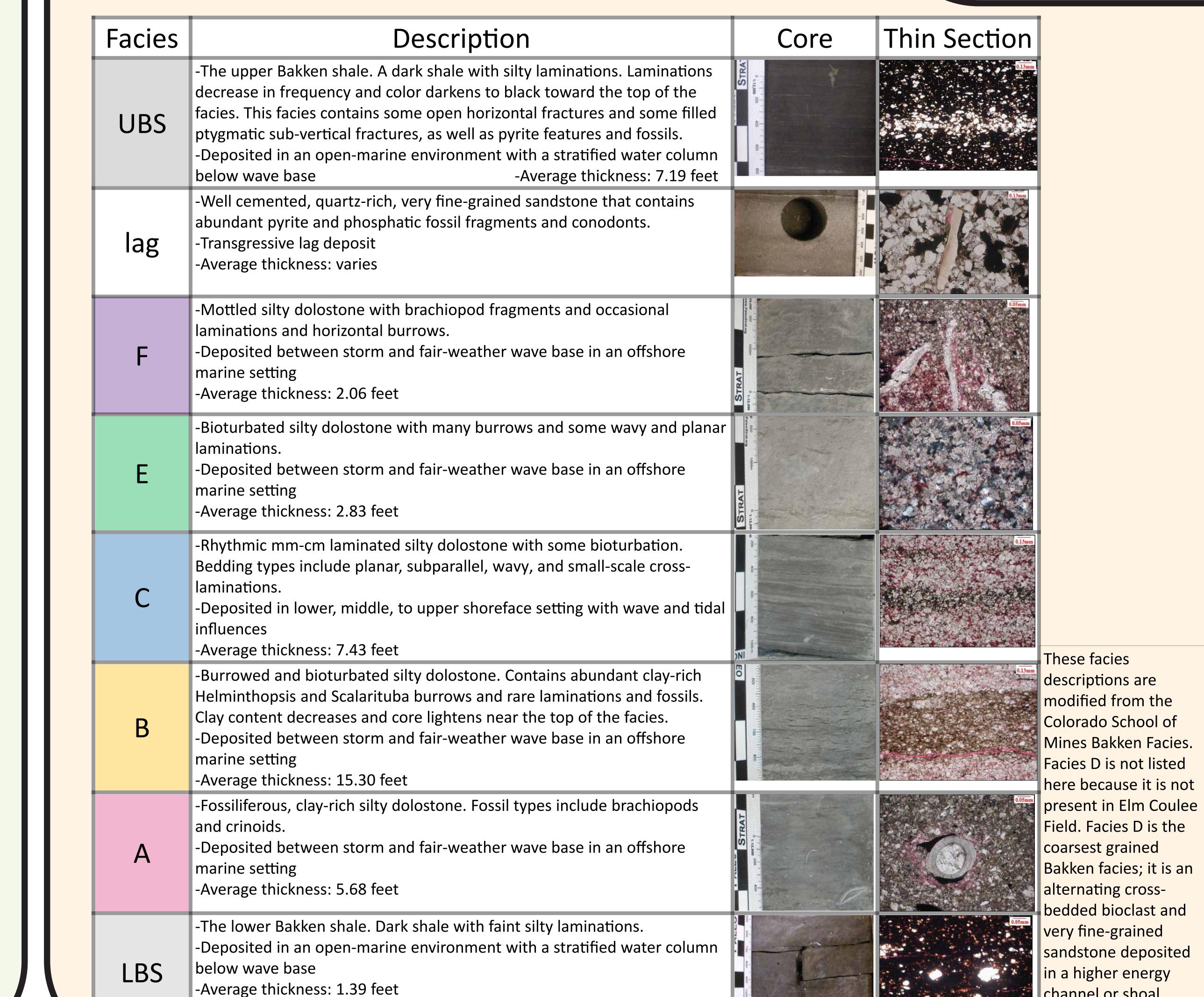
ocated on the depositional edge of the lower member where

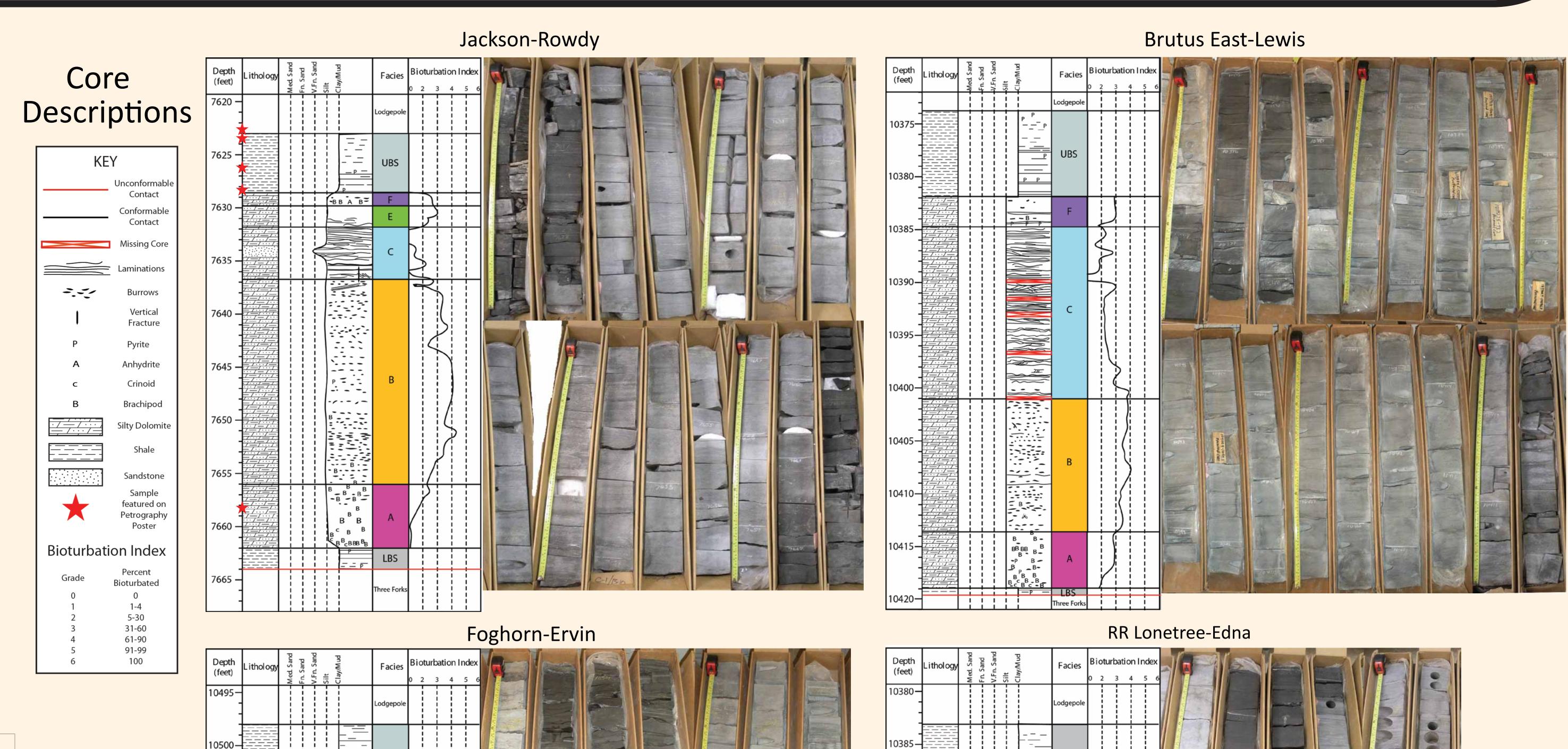
from Webster, 1984).

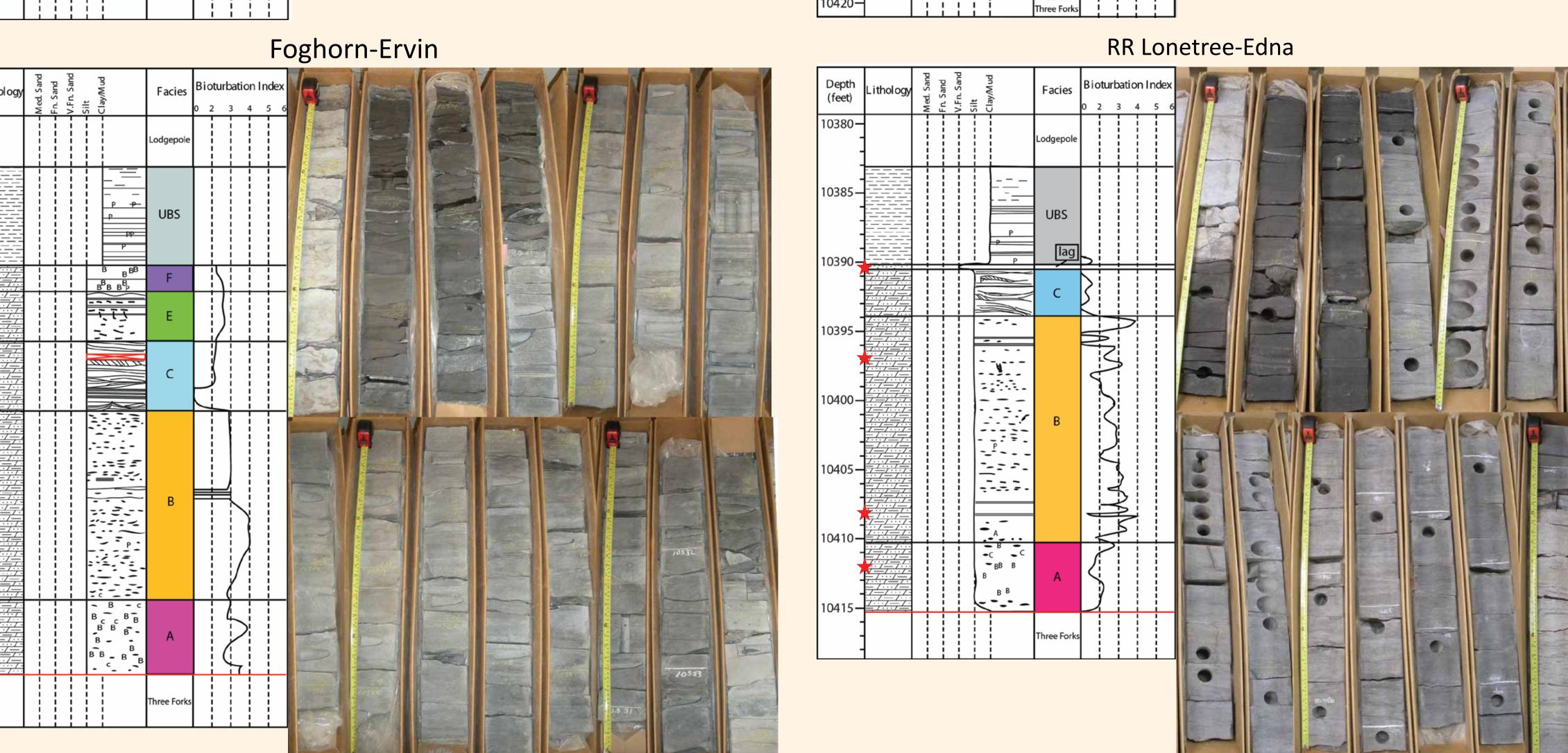
## (The Cores)











## A Petrographic Look at the Facies Present at Elm Coulee

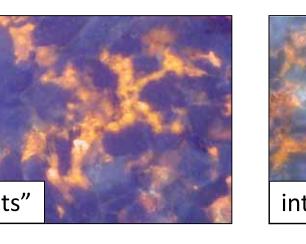
The pictures on this poster have been selected from 123 thin sections to represent the facies present in a "type well" at Elm Coulee Field. When studying these images, pay close attention to the relative percentages of clay, detrital quartz, and dolomite. Higher dolomite and lower clay percentages lead to better porosity in a sample. In general, facies LBS, A, E, F, and UBS are not reservoir, and portions of B or C are the reservoir intervals.

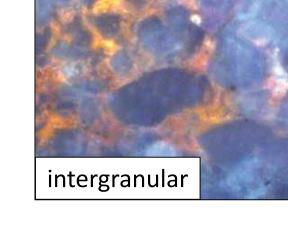
There are five main types of porosity present in these images: secondary due to dolomite dissolution, "slot" pores (intercrystalline), intergranular, fractures, and intracrystalline. Intracrystalline pores are rare and do not really increase overall permeability. Natural fractures at Elm Coulee are still of a debatable importance. Though some fractures in the shales seem real, many found in the middle Bakken appear to be induced. In thin section, these are often wide and cut across the sample or occur along boundaries of burrows or fossils, which are oddities that could affect the integrity of the rock being cut. Intergranular pores are common between the quartz grains and carbonate crystals. And finally, "slot" pores and secondary pores due to dolomitization and subsequent dissolution are very similar to one another. "Slot" pores are 10 micron gaps present in some reservoir quality samples. They form either from the dissolution of dolomite rhomb edges or from dolomite crystals not quite growing together—either way, a rectangular "slot" exists, and if many are present an increased permeability network forms.

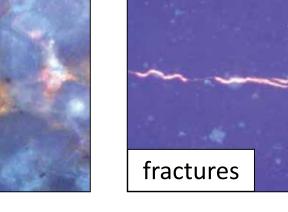
Note: These thin sections are injected with a pink epifluorescent epoxy. When subjected to a fluorescent light, exposed epoxy (like in fractures and pores) fluoresces to an orange color. Typically, the brighter orange or yellow the epoxy glows, the clearer the pore space.

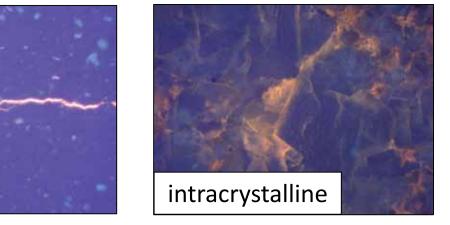


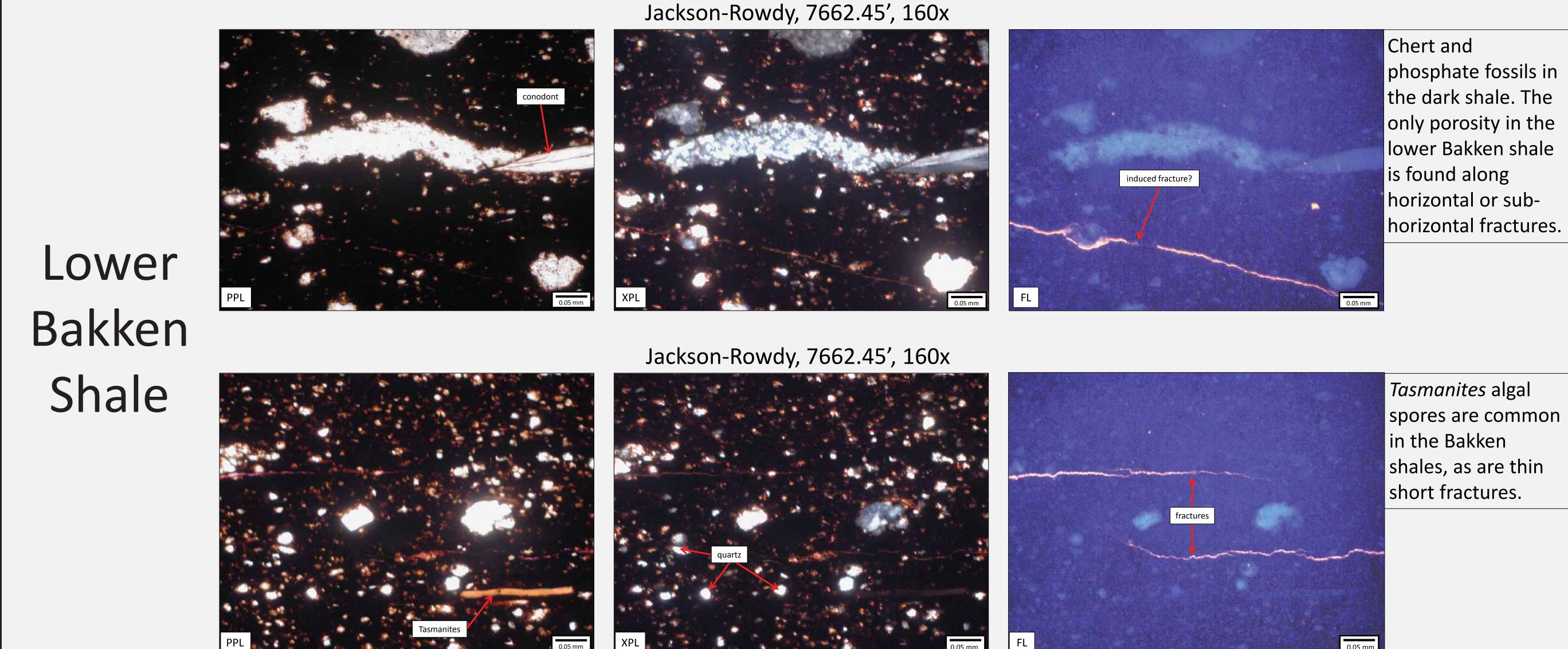


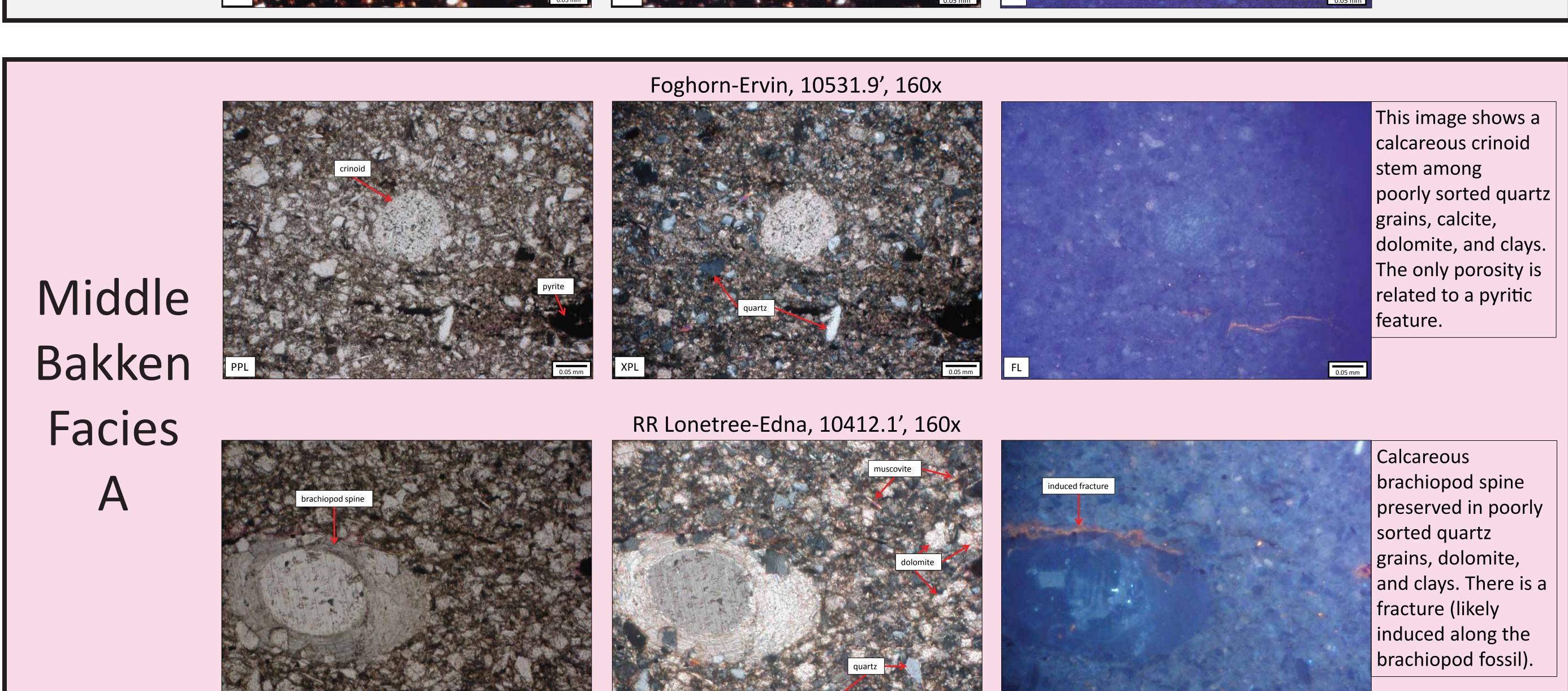


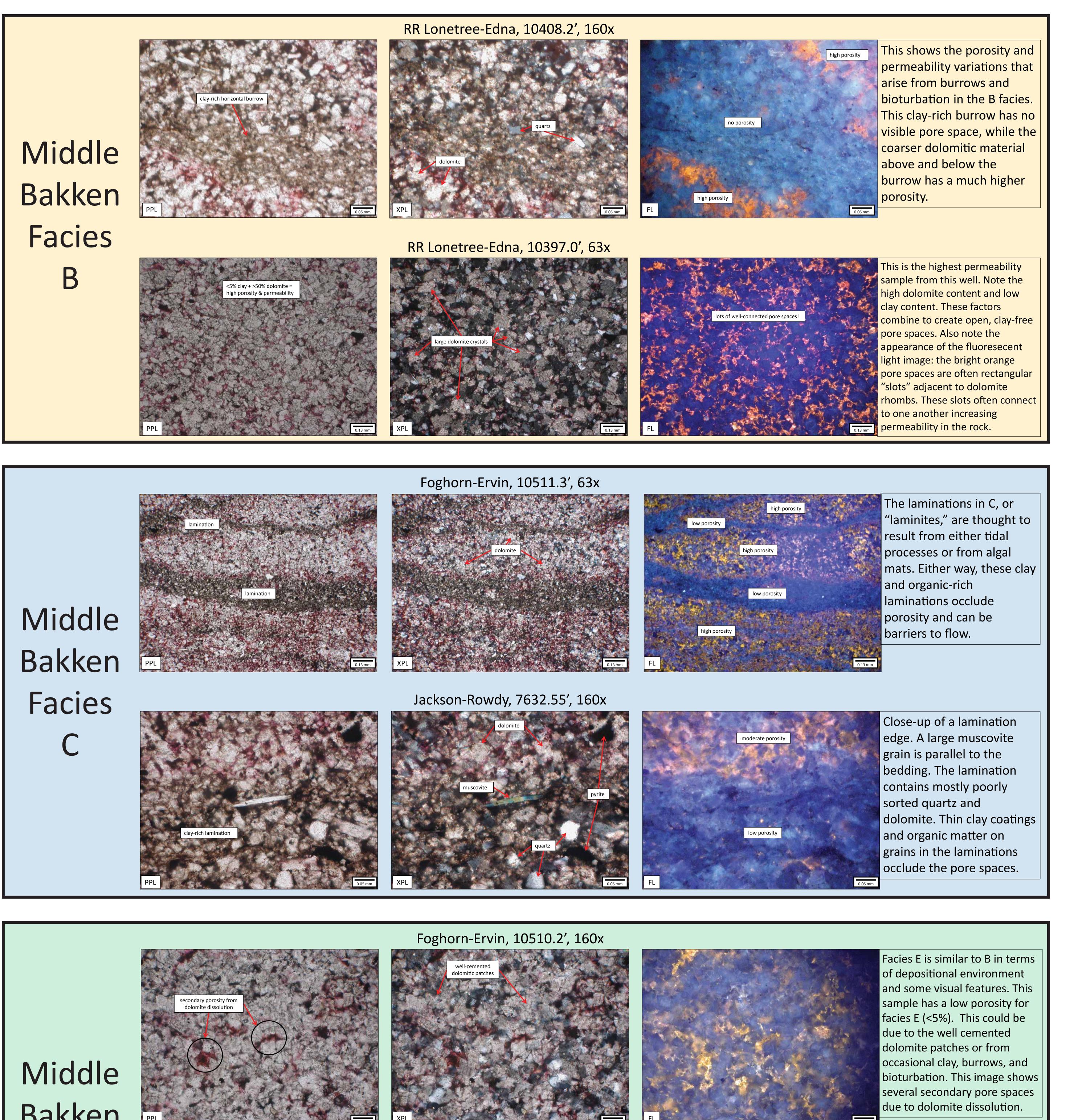


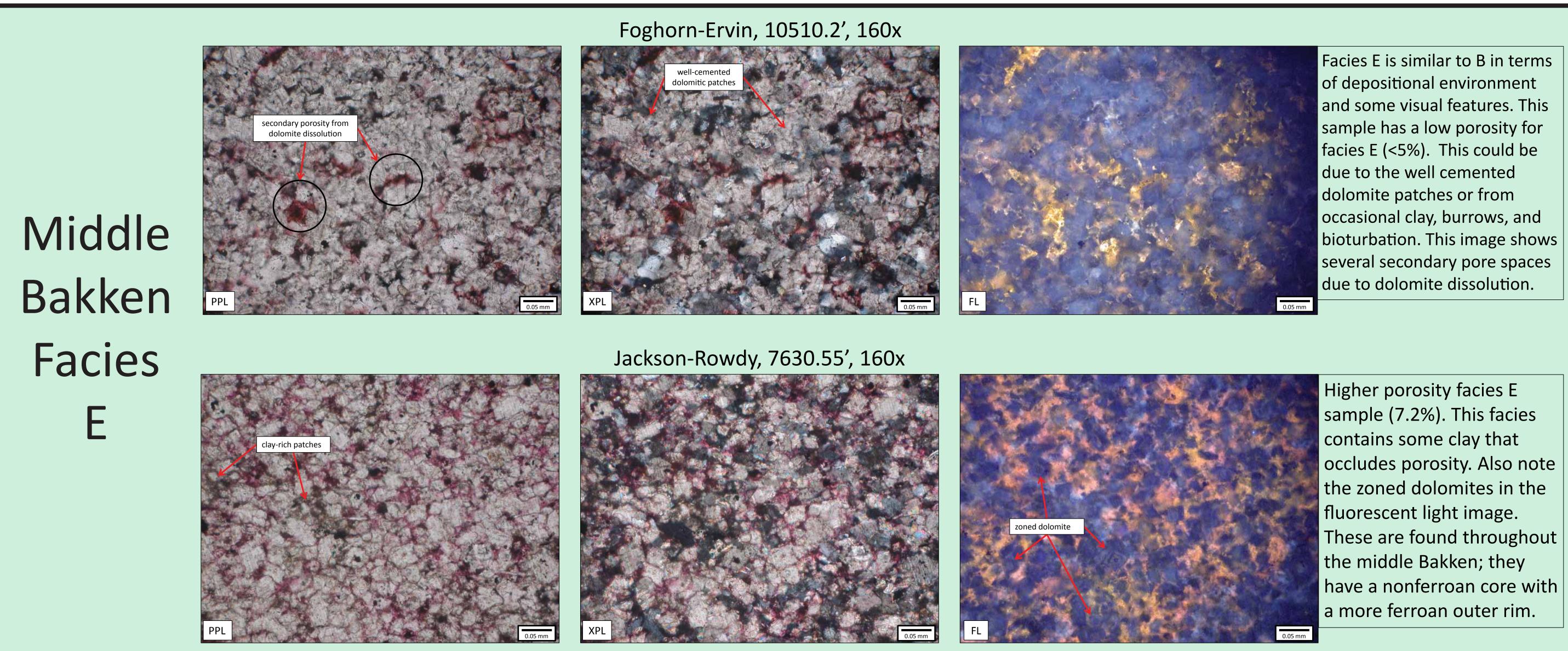


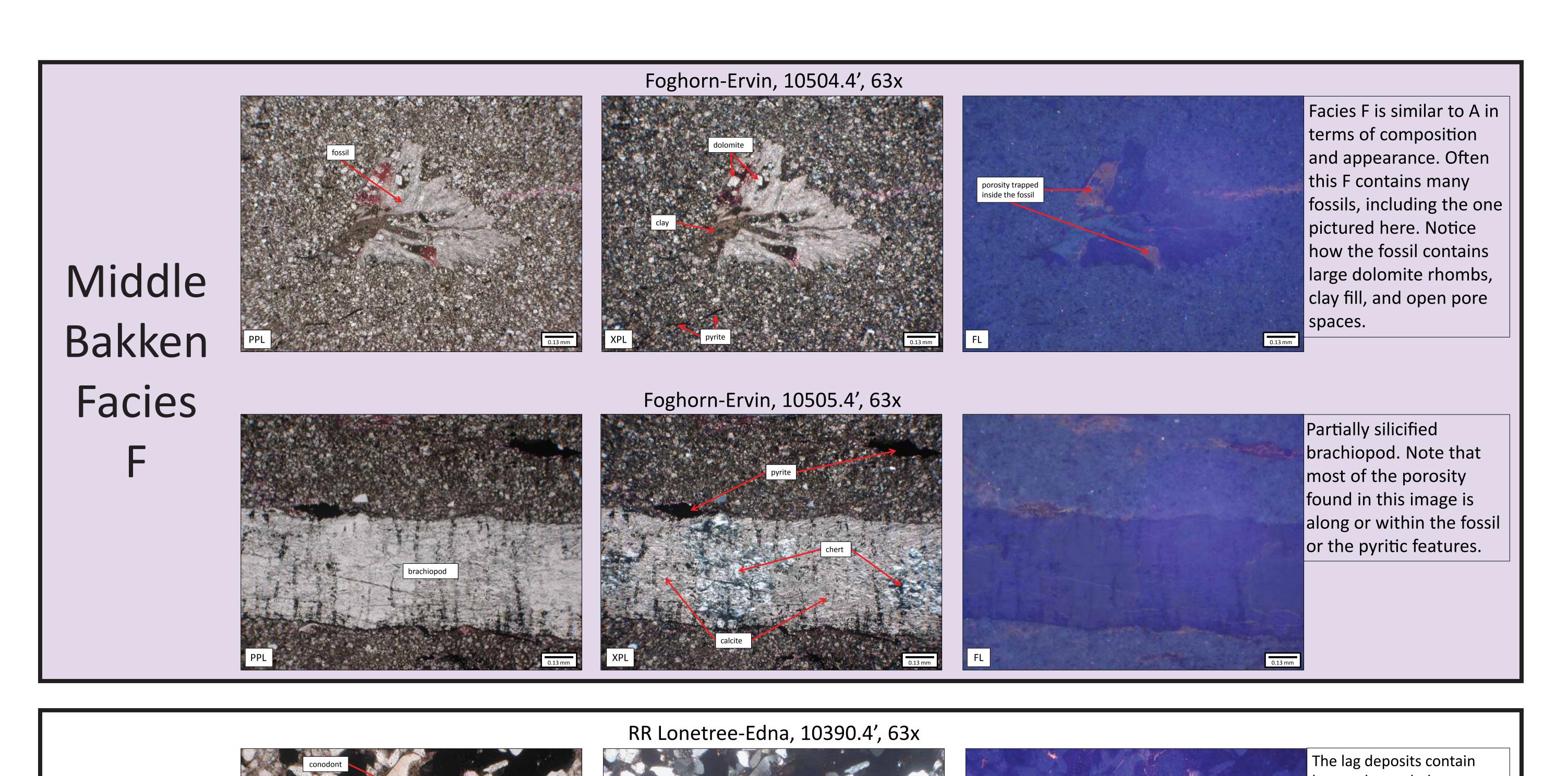


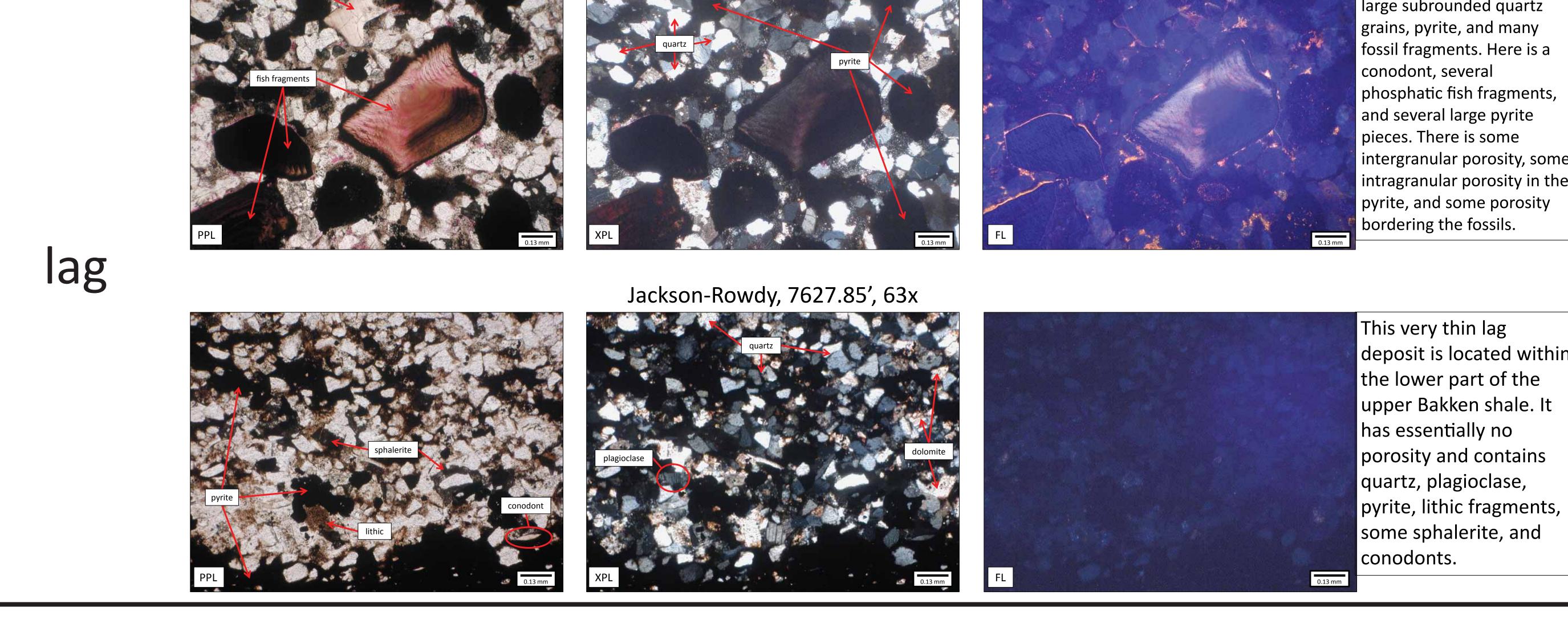


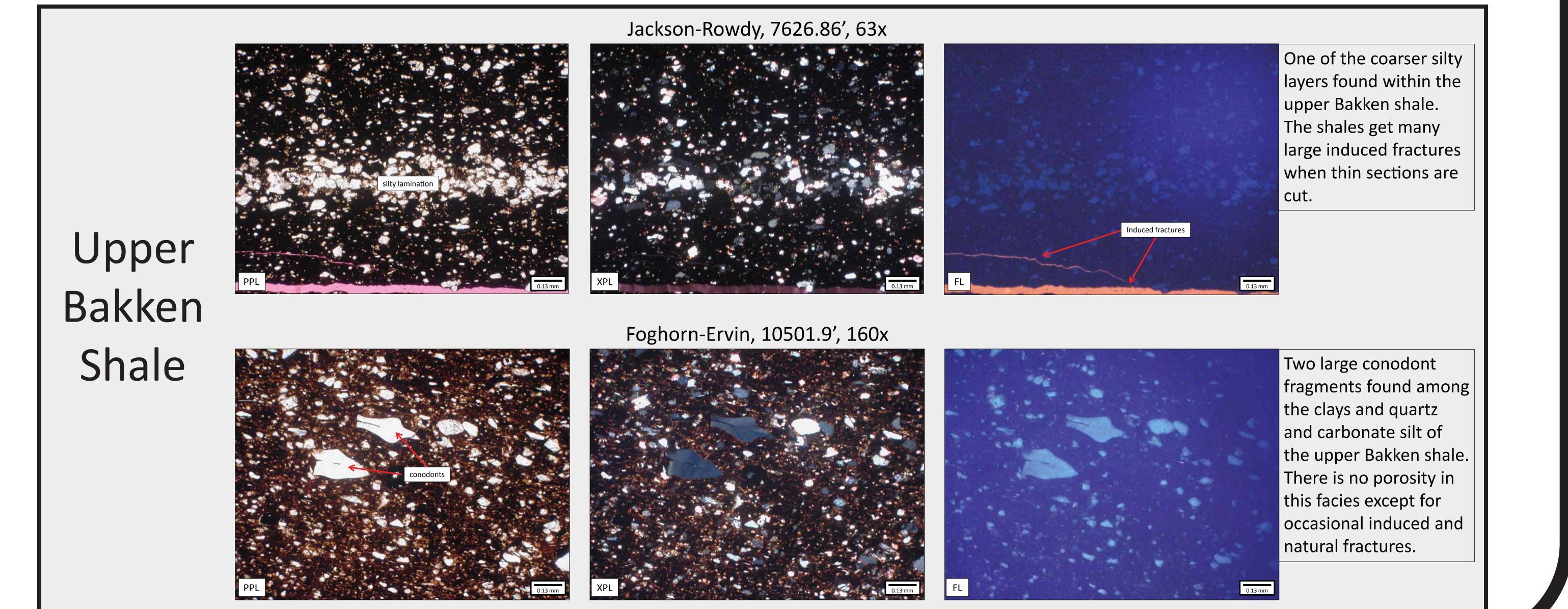












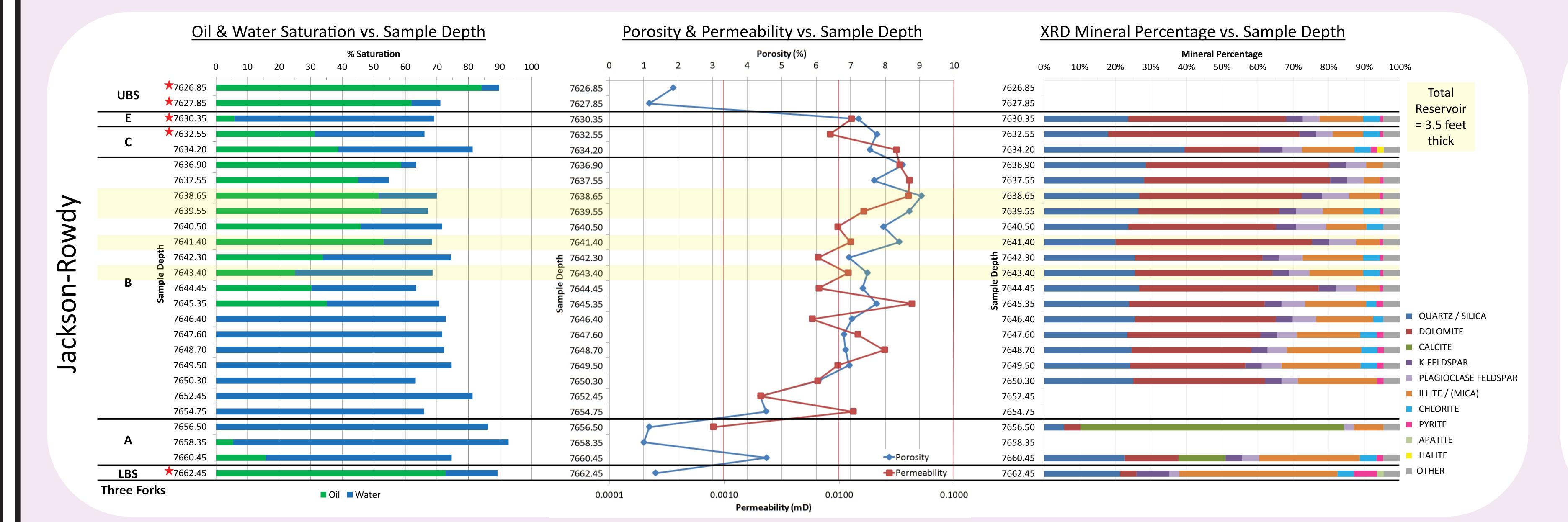
## (Core Plug and X-Ray Diffraction Analysis)

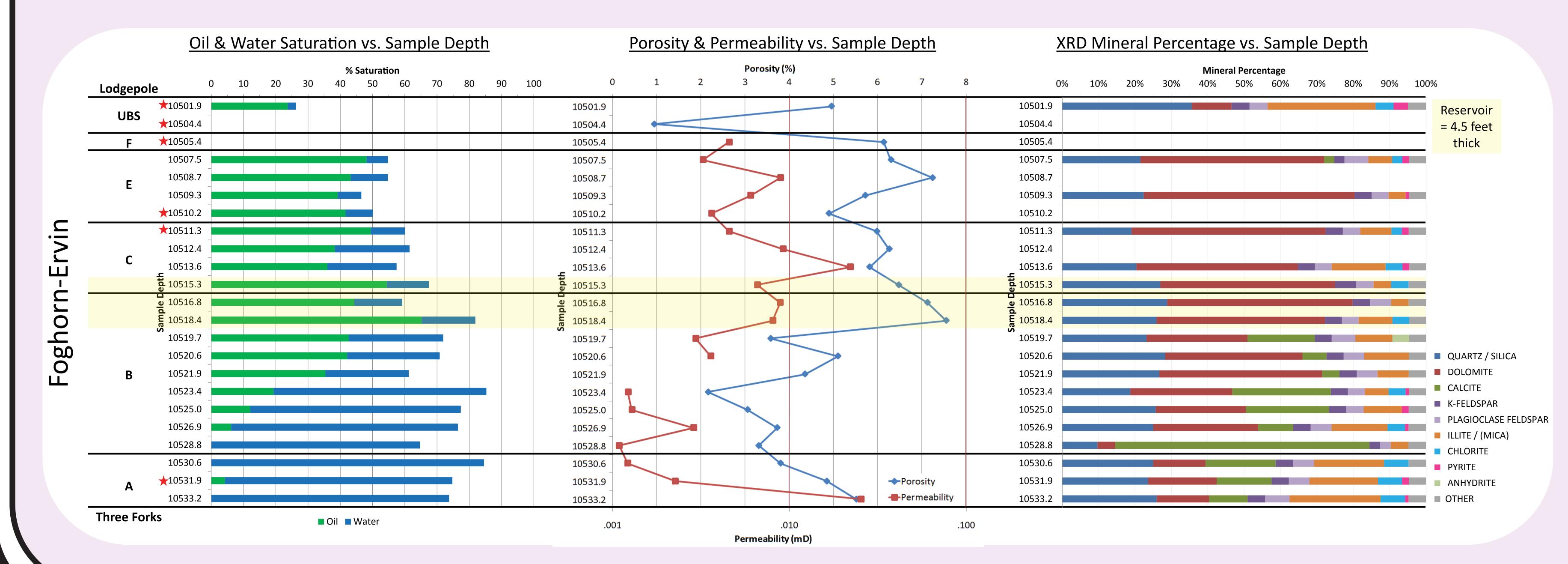
#### **Key Observations from the Graphs:**

- The reservoir interval occurs within the B and C facies and generally corresponds to porosity greater than 7% and to high oil saturation percentages.
- Reservoir quality increases as illite, chlorite, and calcite content decrease and as dolomite content increases.
- Based on the oil saturations, the upper Bakken shale appears to be the source for the oil in the middle Bakken. Even when the lower Bakken shale is present, there are only minor oil shows in the adjacent A facies.
- Usually changes in porosity and permeability directly correlate to one another.
- Clastic quartz and feldspar content stays fairly consistent.

### Other notes:

- Abnormally high permeabilities, like some values in the Brutus East-Lewis and RR Lonetree-Edna wells, could be due to partings induced by cutting the plugs.
- Black lines mark the facies boundaries.
- Yellow shading indicates the reservoir interval.
- Red stars correspond to depths of samples featured on the Petrography Poster

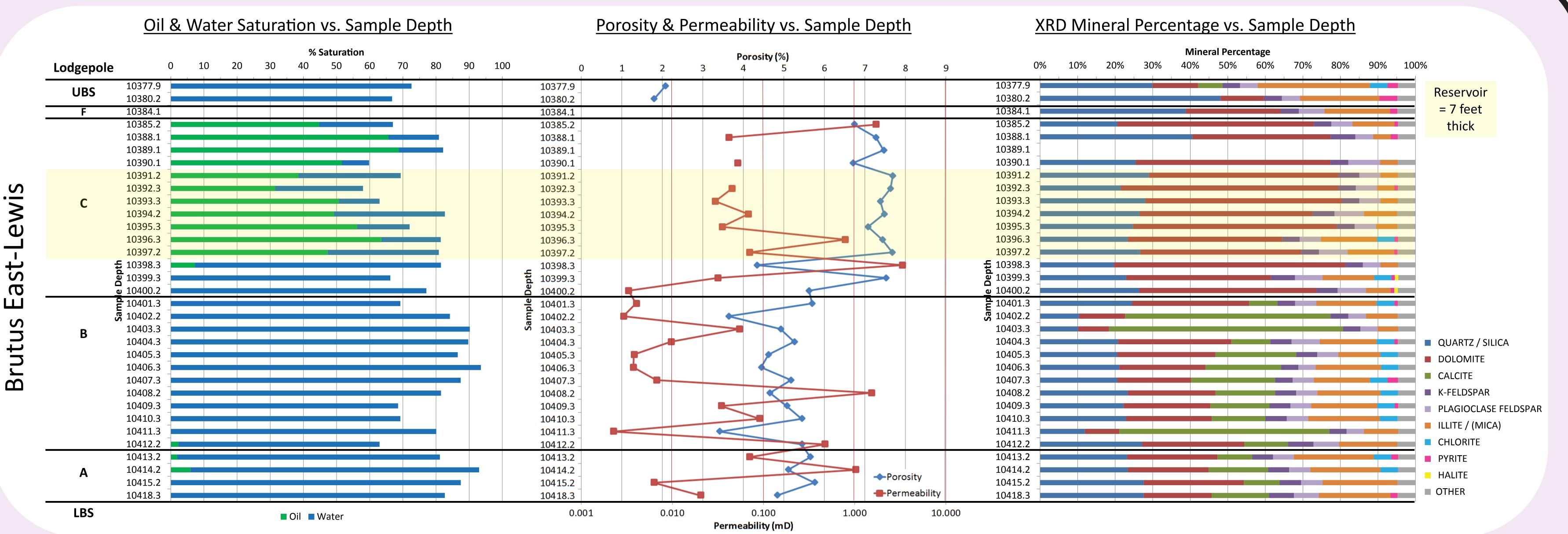


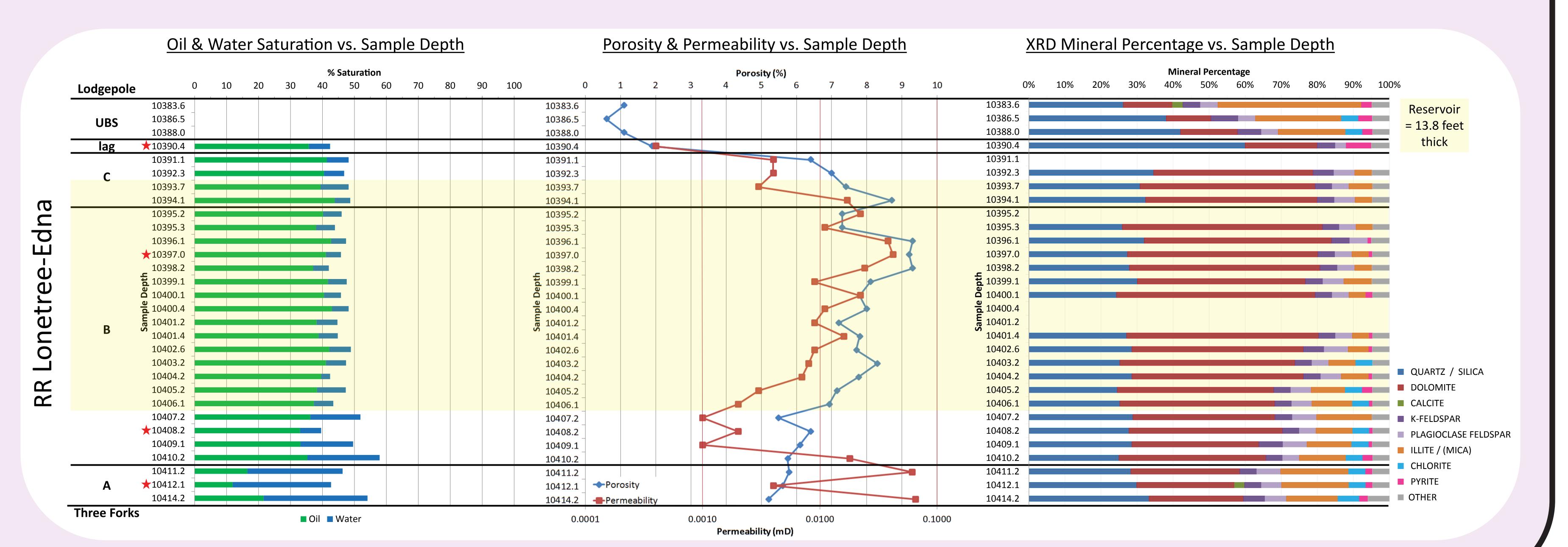


### Conclusions and Future Work)

#### Conclusions:

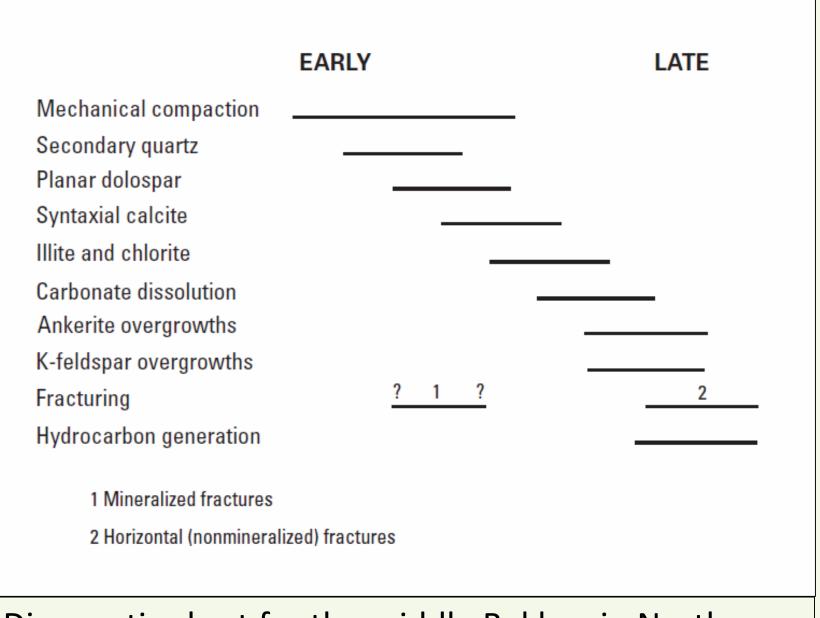
- There are five middle Bakken facies present at Elm Coulee. Facies A, B, and C are continuous across the field, while E and F are locally absent. The lower Bakken shale pinches out toward the southern and western limits of the field, so in part of Elm Coulee Field, the middle Bakken unconformably overlies the Three Forks Formation.
- The upper Bakken shale has a fairly consistent thickness across the field. Based on its widespread occurrence and oil saturation data from the four wells in this study, the upper Bakken shale is the main source rock for this field.
- Though describing thin sections from all parts of the Bakken is useful in understanding the formation's diagenetic history, careful observations of the porosity
  with the aid of a fluorescent microscope is extremely helpful when describing the characteristics that distinguish the reservoir intervals from nonreservoir.
- As a typical rule, middle Bakken intervals with the highest dolomite percentage and the lowest the clay and calcite percentages make the best reservoir targets at Elm Coulee.
- The main types of pores seen in reservoir intervals are intergranular, intercrystalline, and secondary pores due to dolomite dissolution.
- Core plug analysis, including oil and water saturation data and porosity and permeability measurements, along with XRD measurements help support thin
  section and core descriptions and well log interpretations.



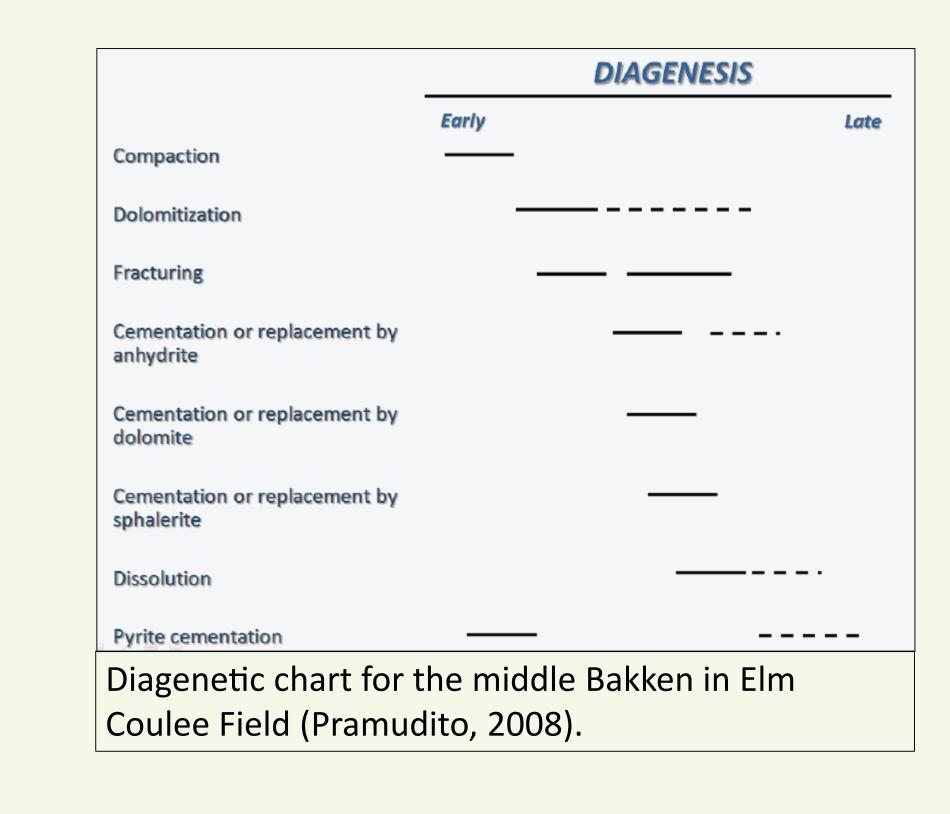


Future work on this project will include:

- The creation of a diagenetic chart for Elm Coulee Field based on thin section observations and core data (see the figures below for two diagenetic charts recently published by authors)
- An analysis of dolomitization processes and a proposition for what events might have led to the high dolomite contents found in Elm Coulee
- Continued porosity characterization, including determining the causes of pore types and their distributions within each well. The possible role of fracture porosity also needs to be explored further at Elm Coulee, as does the concept of "slot" porosity.
- Integration of source rock data to core and thin section shale observations



Diagenetic chart for the middle Bakken in North Dakota (Pitman et. al, 2001).



### References and Works Cited

- Blakey, R.C., 2011, North American Paleogeographic Maps—Late Devonian (360Ma), Colorado Plateau Geosystems, <a href="http://cpgeosystems.com/namD360.jpg">http://cpgeosystems.com/namD360.jpg</a>.
  Flannery, J., and Kraus, J., 2006, Integrated Analysis of the Bakken Petroleum System: U.S. Williston Basin: Poster at
- AAPG National Convention, Houston, Texas.
- Meissner, F.F., 1978, Petroleum Geology of the Bakken Formation Williston Basin, North Dakota and Montana, in Rehrig, D. ed., Williston Basin Symposium, Montana Geological Society, Billings, Montana.

  Pitman, J.K., Price, L.C., and LeFever, J.A., 2001, Diagenesis and Fracture Development in the Bakken Formation,
- Williston Basin: Implications for Reservoir Quality in the Middle Member: U.S. Geological Survey

  Professional Paper 1653, p. 19.
- Coulee Field, Williston Basin, Montana [Master of Science]: Colorado School of Mines.

  Smith, M.G., and Bustin, R.M., 1996, Lithofacies and Paleoenvironments of the Upper Devonian and Lower

  Mississippian Bakken Formation, Williston Basin: Bulletin of Canadian Petroleum Geology, v. 44, no. 3, p.
- 495-507.
  Sonnenberg, S.A., and Pramudito, A., 2009, Petroleum geology of the giant Elm Coulee field, Williston Basin: AAPG Bulletin, v. 93, no. 9, p. 1127-1153.
- Webster, R.L., 1984, Petroleum Source Rocks and Stratigraphy of the Bakken Formation in North Dakota, in Woodward, J., Meissner, F.F., and Clayton, J.C. eds., Hydrocarbon Source Rocks of the Rocky Mountain Region, Rocky Mountain Association of Geologists, Denver, Colorado, p. 57-81.