

PS Middle Bakken Facies, Williston Basin, USA: A Key to Prolific Production*

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Abstract

The middle Bakken Formation of the Williston Basin is the focus of current horizontal drilling activity. The middle Bakken consists of six distinct facies over much of the basin. Each facies represents deposition in shallow to deep shelf environments (neritic). Facies are subdivided on the basis of lithologic and biologic aspects. Contacts between individual facies are generally transitional. Individual facies pinch out towards the basin margins.

The middle Bakken has poor reservoir qualities with low porosities (< 8%) and permeabilities (< 0.1 md). Diagenesis plays an important role in controlling reservoir quality. Horizontal drilling and multi-stage fracture stimulation are necessary for commercial production.

For mapping purposes the six facies are combined into three geophysical log facies. Thickness variations in these facies are one of the keys to “sweet spot” identification in the Bakken. Thickness variations are influenced by paleo-basin configuration, paleostructures located within the basin, and deeper evaporite dissolution (Prairie) that was concurrent with Bakken deposition.

The mineralogy of the middle Bakken ranges from a silty to very fine grained dolomitic sandstone to a silty dolostone. The source area for clastics appears to be the Canadian Shield area to the north. Overall carbonate content increases in the southern part of the Williston Basin. Ichnofacies within the middle Bakken range from *Skolithos* to *Zoophycos*.

Knowledge of middle Bakken facies distributions and thickness variations, lithologic variations, diagenesis and paleostructure identification along with upper and lower Bakken shale thickness (source beds), quality, and maturity are keys to finding future “sweet spot” areas in the Williston Basin.

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Knowledge of middle Bakken facies distributions and thickness variations, lithologic variations, diagenesis and paleostructure identification, along with upper and lower Bakken shale thickness (source beds), quality, and maturity are keys to finding future "sweet spot" areas in the Williston Basin.

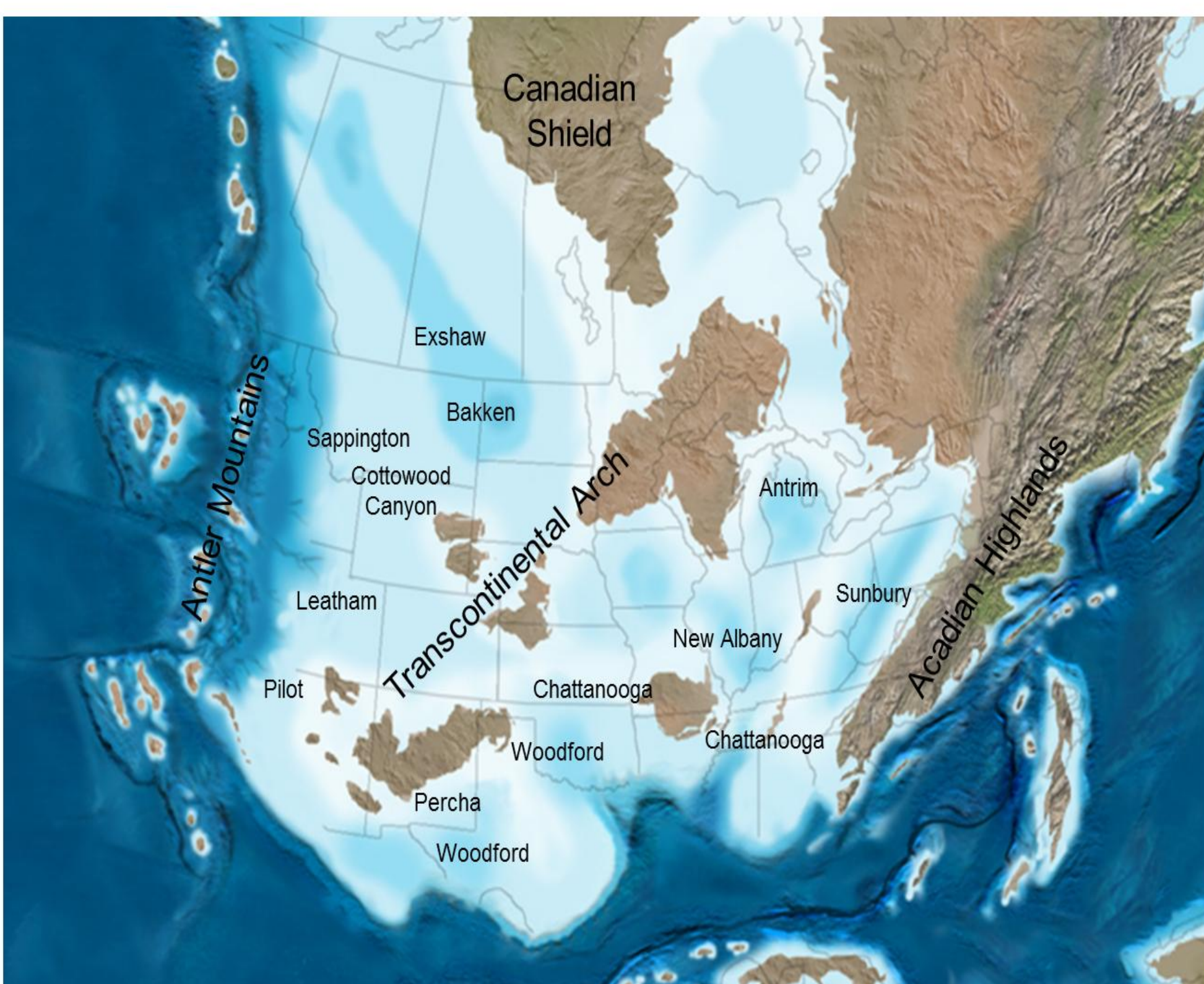


Figure 1. Paleogeologic map Late Devonian-Early Mississippian. Proto-Williston Basin evolved as a craton=margin basin.

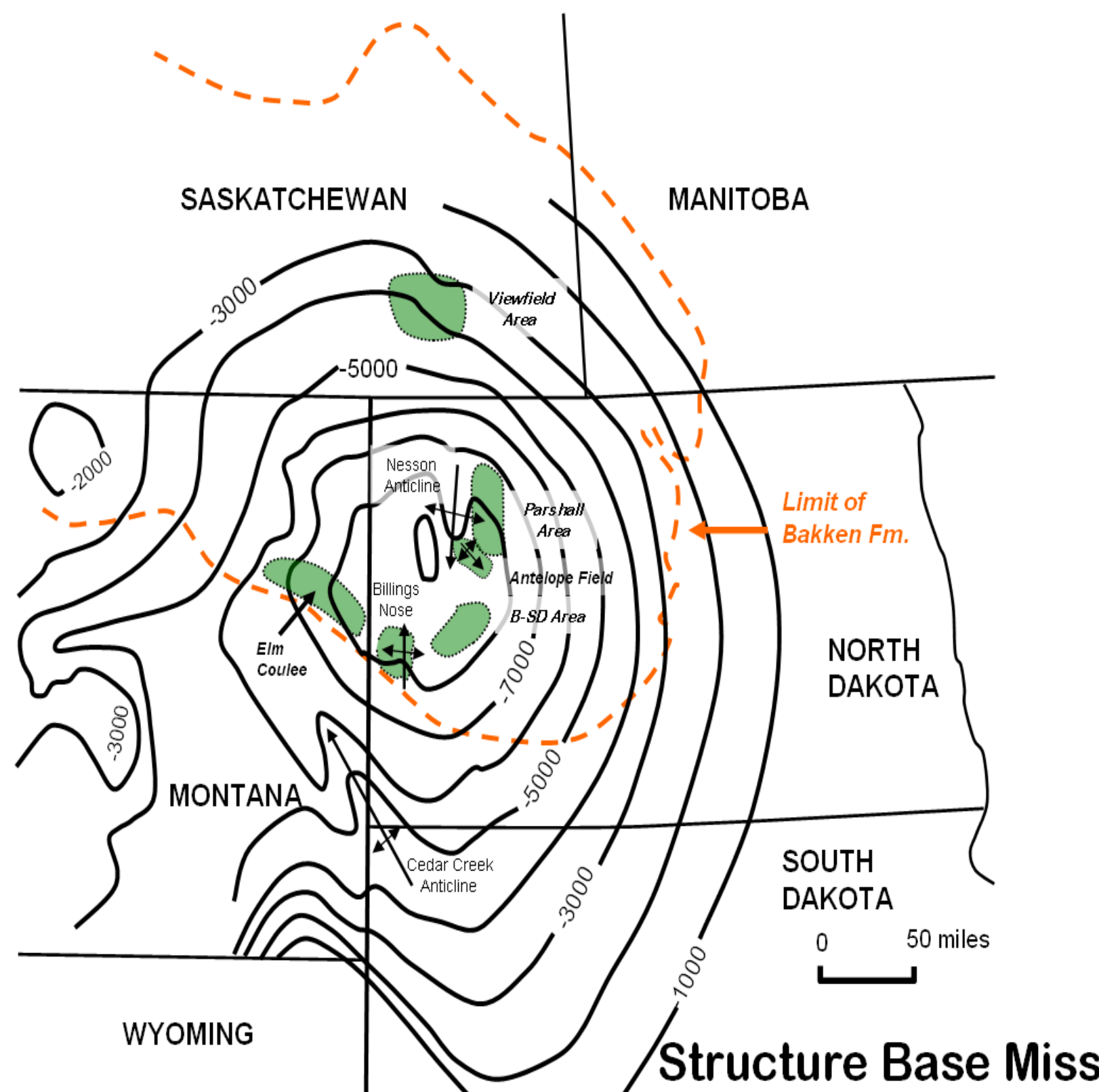


Figure 2. Structure, base Mississippian, Williston Basin.

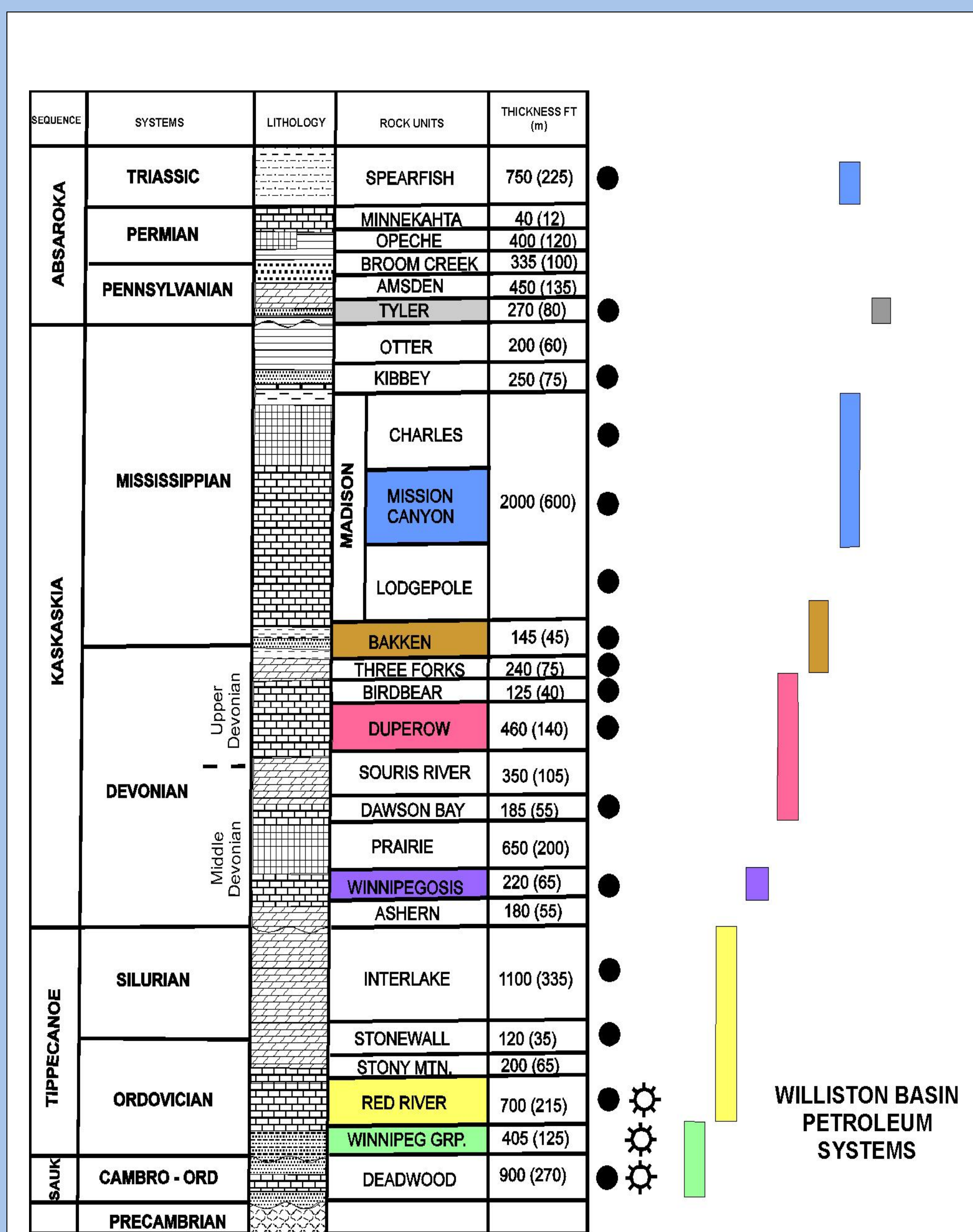


Figure3. Stratigraphic column for Williston Basin and the associated petroleum systems.

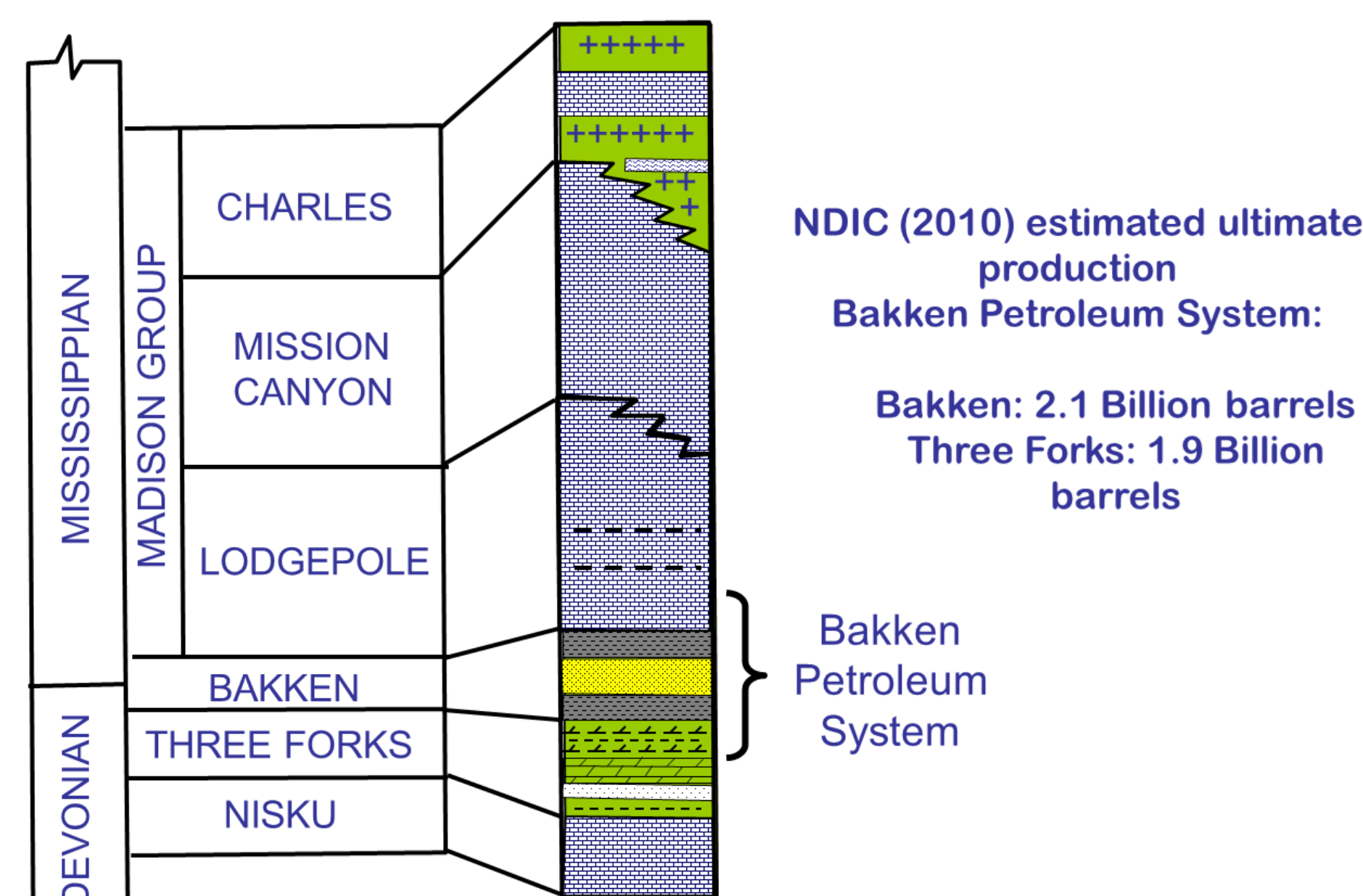


Figure 4. Stratigraphic column illustrating the Bakken Petroleum System.

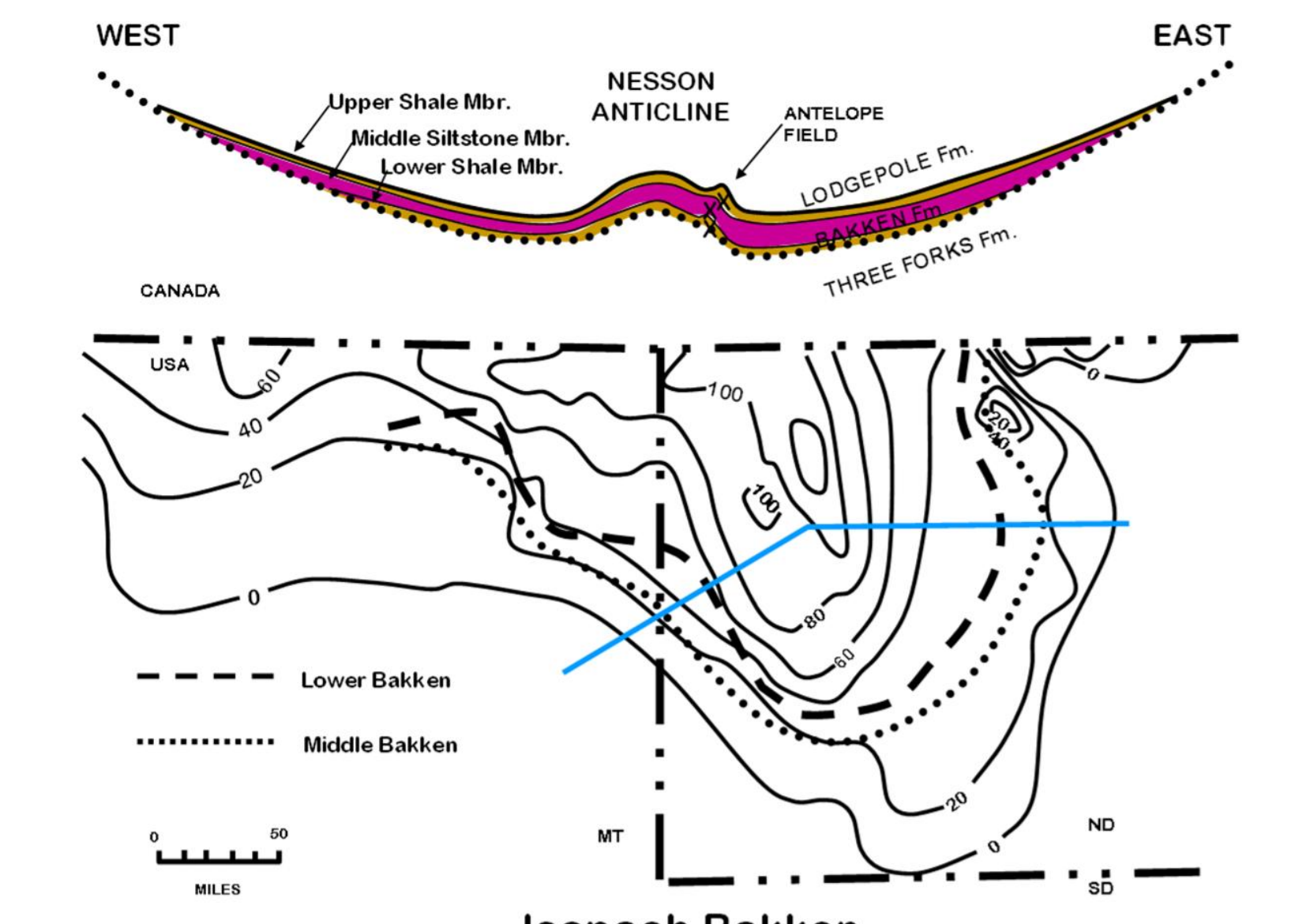


Figure 5. Isopach map and cross section of Bakken.

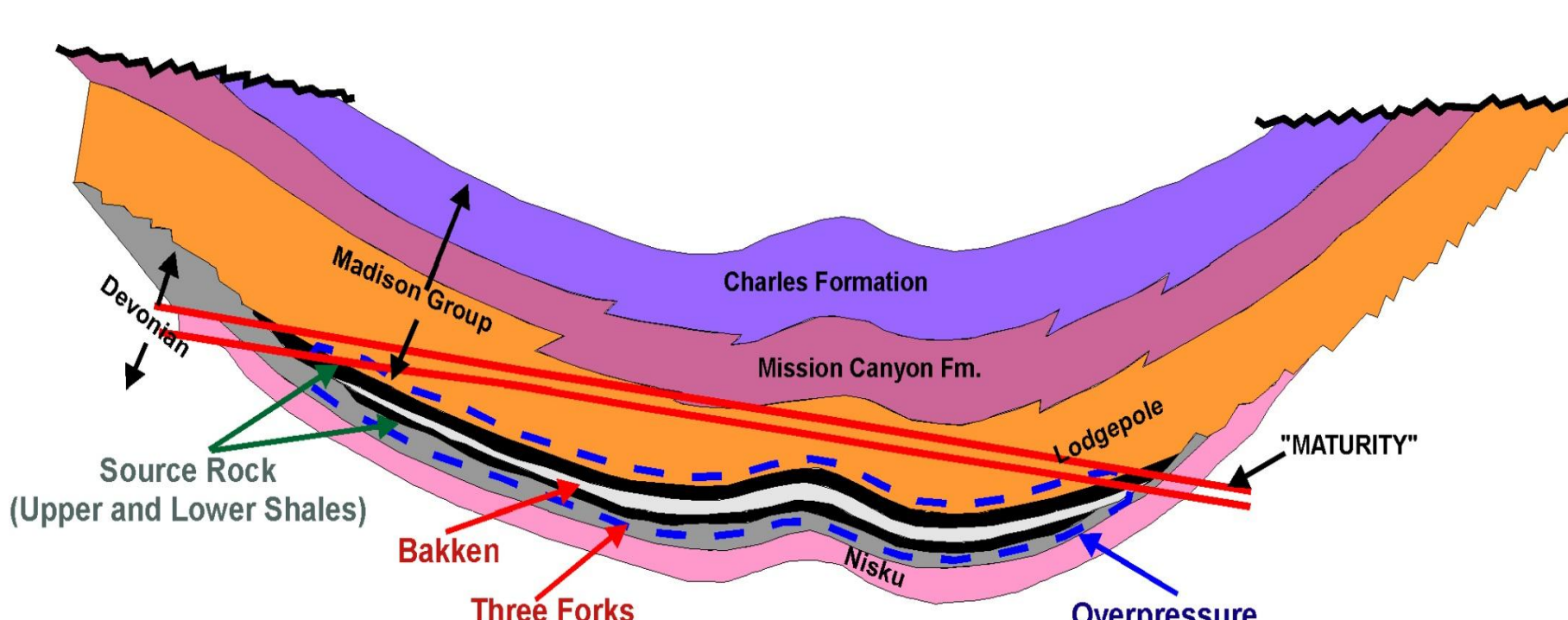


Figure 6. Cross section illustrating the maturity area of the Bakken and associated overpressure.

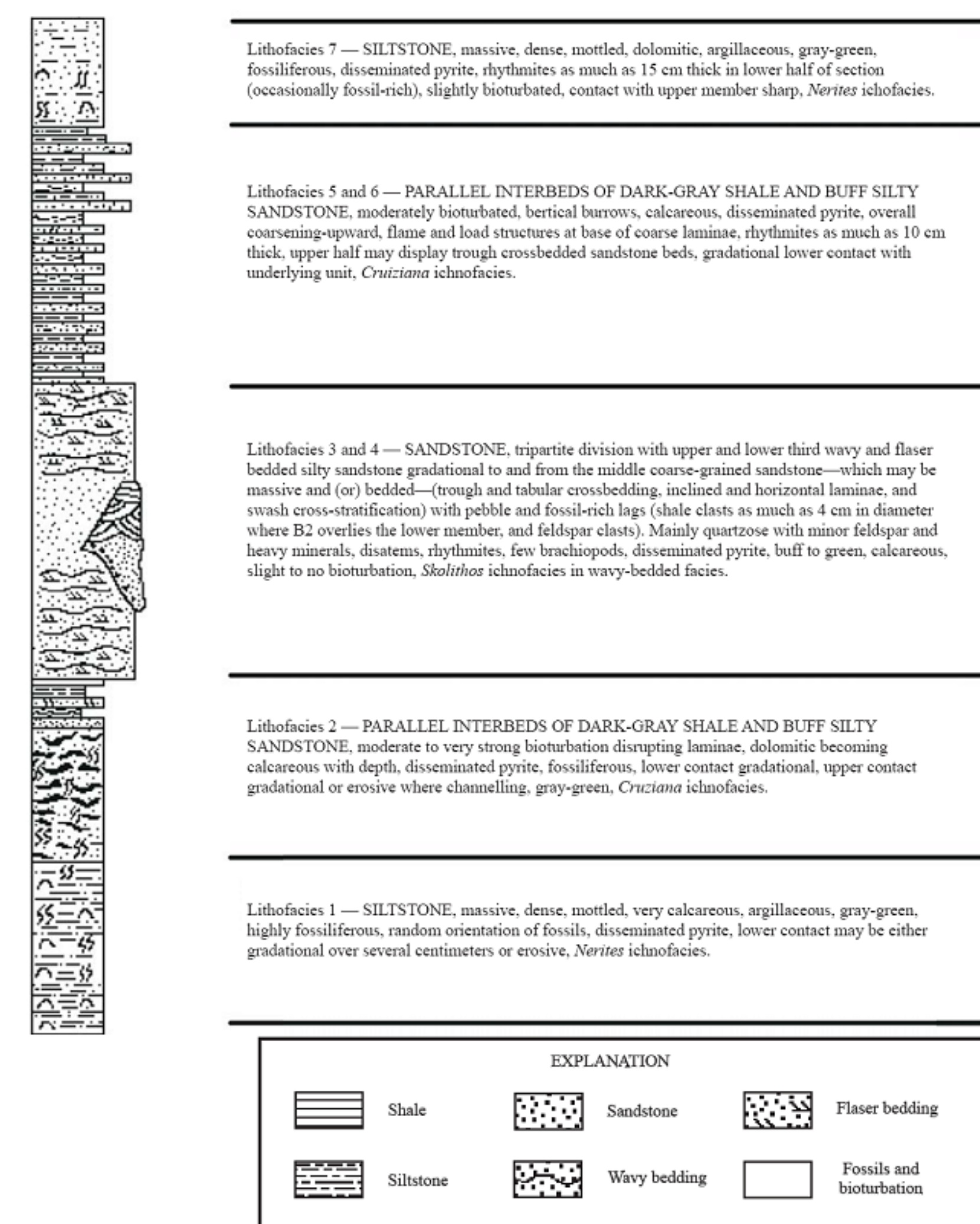


Figure 7. Lithofacies of the middle Bakken (Pitman et al., 2001; LeFever et al., 1991).

CANTER ET AL. FACIES (2009)

A0 Patterned pyritic dolostones

A1 Calclitic, whole fossil, dolo- to lime wackestones: fossil rich storm beds

A2 thin-bedded dolo mud/wackestone, more dolomitic

A3 thin organic-rich mudstone, gamma ray marker

B1 highest energy, coarsest grained alternating cross-bedded bioclast, v.f.g. sandstone, deposited sub-tidally in shoals

B2 muddy calcareous sandy/silty disturbed facies, syndimentary microfaults, slumps

C rhythmic, varve-like, mm to cm laminated, well sorted, v.f.g. sandstone and siltstone with calcite cement, hummocks and wave ripples

D Bioturbated, argillaceous, calc. poorly sorted, v.f.g. sandstone/siltstone with helminthopsis/sclerituba: offshore below storm wavebase

E Muddy intraclastic-skeletal lime wackestone, 1-4 ft thick

Figure 8. Facies of the middle Bakken from Canter et al., 2009.

MIDDLE BAKKEN LITHOFACIES			
Nickel & Kohnen, 2009	LeFever & Nordeng, 2008	Canter & Sonnenfeld, 2009	CSM, 2010
L5 - Siltstone, gray-green, massive, mottled, dolomitic, Nerites ichnofacies.	L4 - Interbedded dark-gray shale and buff, silty sandstone, coarsens upward, moderately bioturbated (Cruziana ichnofacies).	A0 - Patterned pyritic dolostones.	F1 - Pyritic dolostones.
C - Siltstone, laminated, argillaceous, v.f.g. sandstone, bioturbated, soft sediment deformation. Physosiphon, Planolites & Teichichnus.	L3 - Sandstone, upper & lower wavy to flaser silty sandstone. Skolithos ichnofacies. Middle coarse-grained, massive to xbedded.	A1 - Calclitic, whole fossil, dolo- to lime wackestones: fossil-rich beds.	F - Calclitic, whole fossil, dolo- to lime wackestones: fossil-rich beds.
B - Sandstone, fg, sharp basal contact, from base upwards, massive to xbedded to laminated. Rare Planolites.	L2 - Interbedded dark-gray shale and buff, silty sandstone, moderate to intense bioturbation (Cruziana ichnofacies), fossiliferous.	A2 - Thin-bedded dolo-mud/wackestone, more dolomitic.	E - Thin-bedded dolo-mud/wackestone, more dolomitic.
A - Siltstone, gray-green, argillaceous, abundant bioturbation, Nerites & Physosiphon.	L1 - Siltstone, gray-green, massive, bioturbated (Nerites ichnofacies), fossiliferous.	A3 - Thin organic-rich mudstone, gamma ray marker.	D - Highest energy, coarsest grained alternating cross-bedded bioclast, v.f.g. sandstone.
		C - Rhythmic, varve-like, mm to cm laminated, well sorted, v.f.g. sandstone and siltstone with calcite cement, hummocks and wave ripples.	C - Rhythmic, varve-like, mm to cm laminated, well sorted, v.f.g. sandstone and siltstone with calcite cement, hummocks and wave ripples.
		D - Bioturbated, argillaceous, calc. poorly sorted, v.f.g. sandstone/siltstone with helminthopsis/sclerituba.	B - Bioturbated, argillaceous, calc. poorly sorted, v.f.g. sandstone/siltstone with helminthopsis/sclerituba.
		E - Intraclastic-skeletal lime wackestone, 1-4 ft thick.	A - Intraclastic-skeletal lime wackestone, 1-4 ft thick.

Figure 9. Comparison of Middle Bakken lithofacies. Right column illustrates lithofacies used by CSM, 2010.

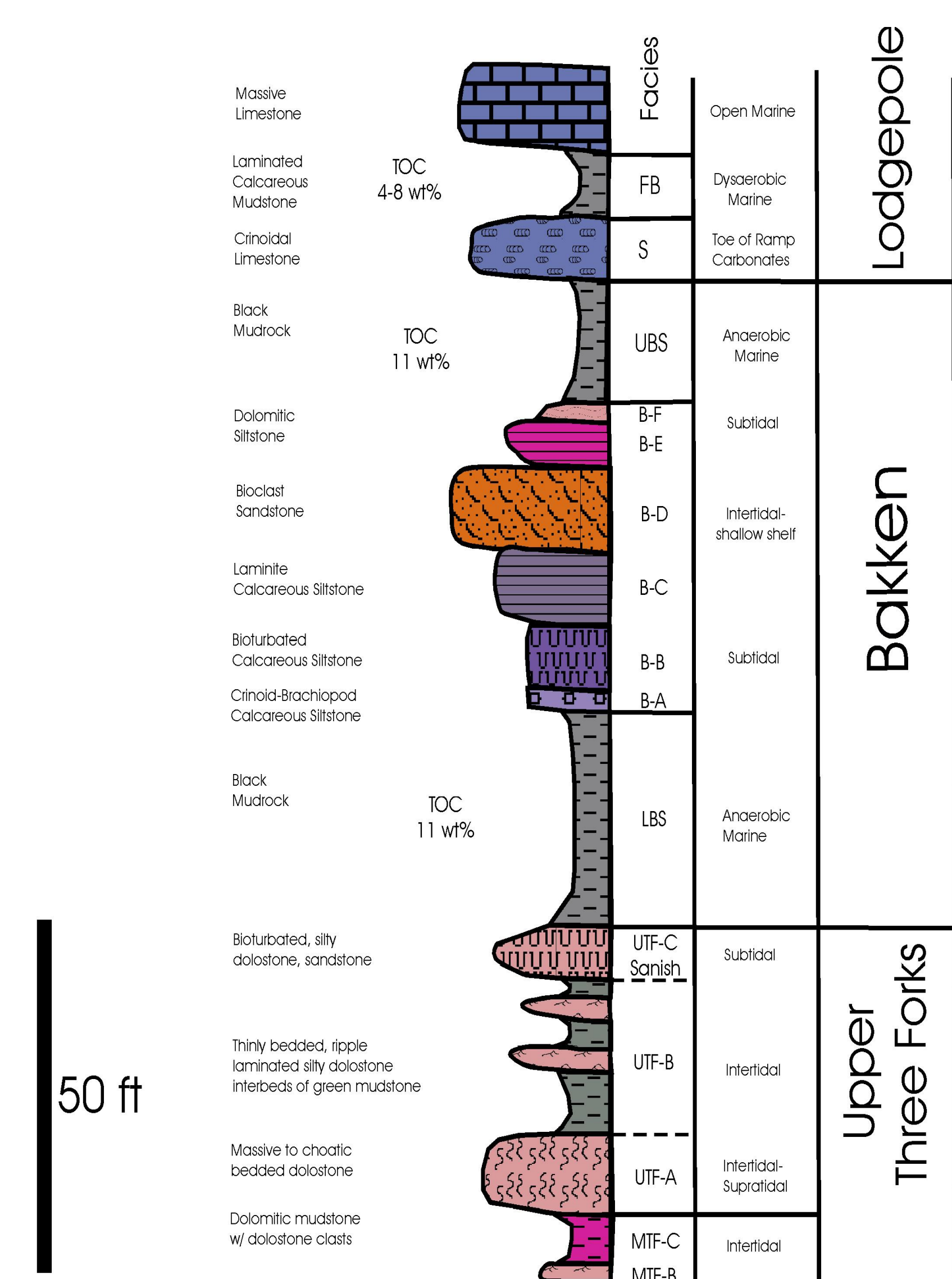


Figure 10. Generalized lithofacies for upper Three Forks, Bakken, and lower Lodgepole.

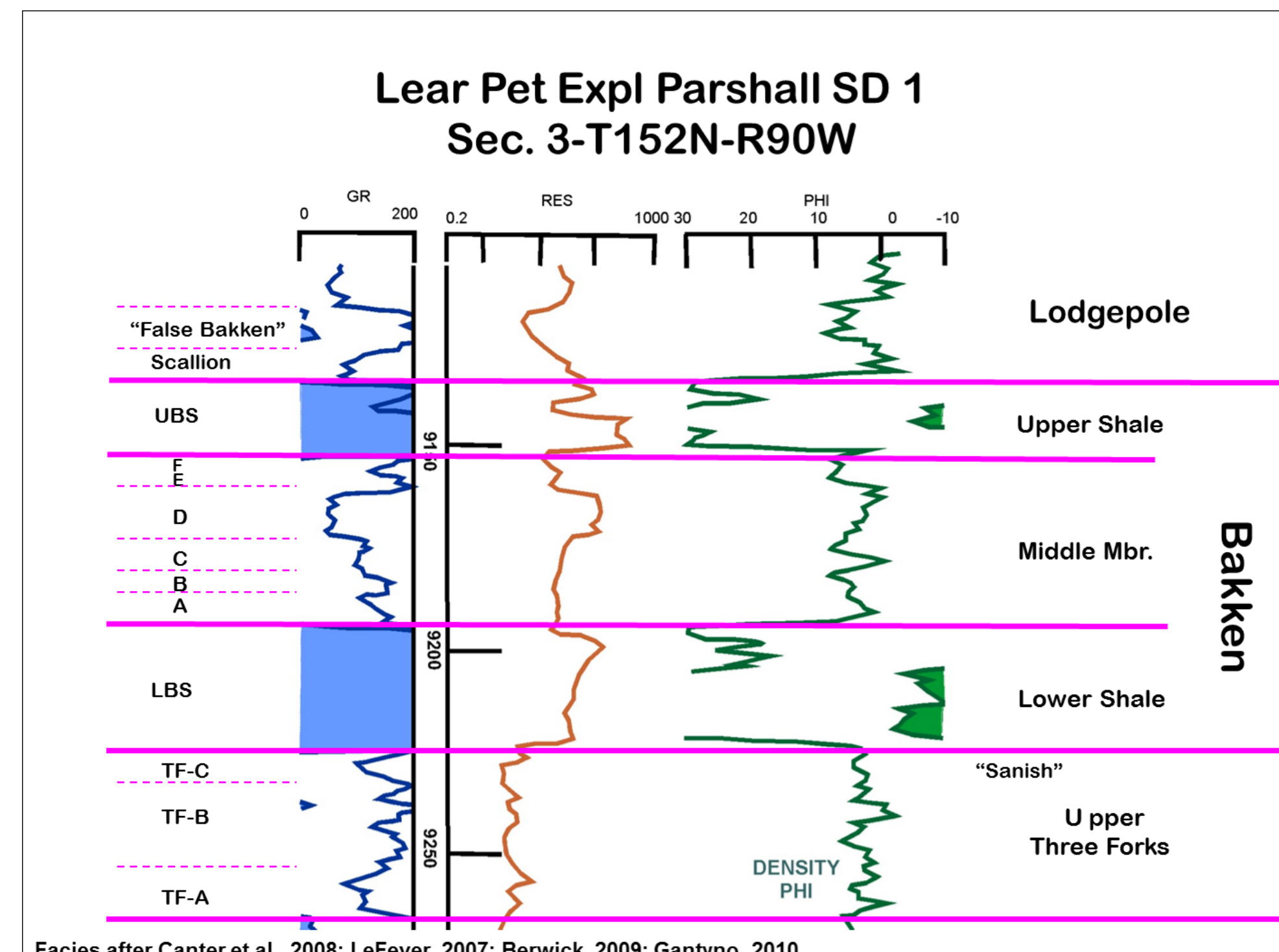


Figure 11. Well log showing Bakken and upper Three Forks lithofacies.

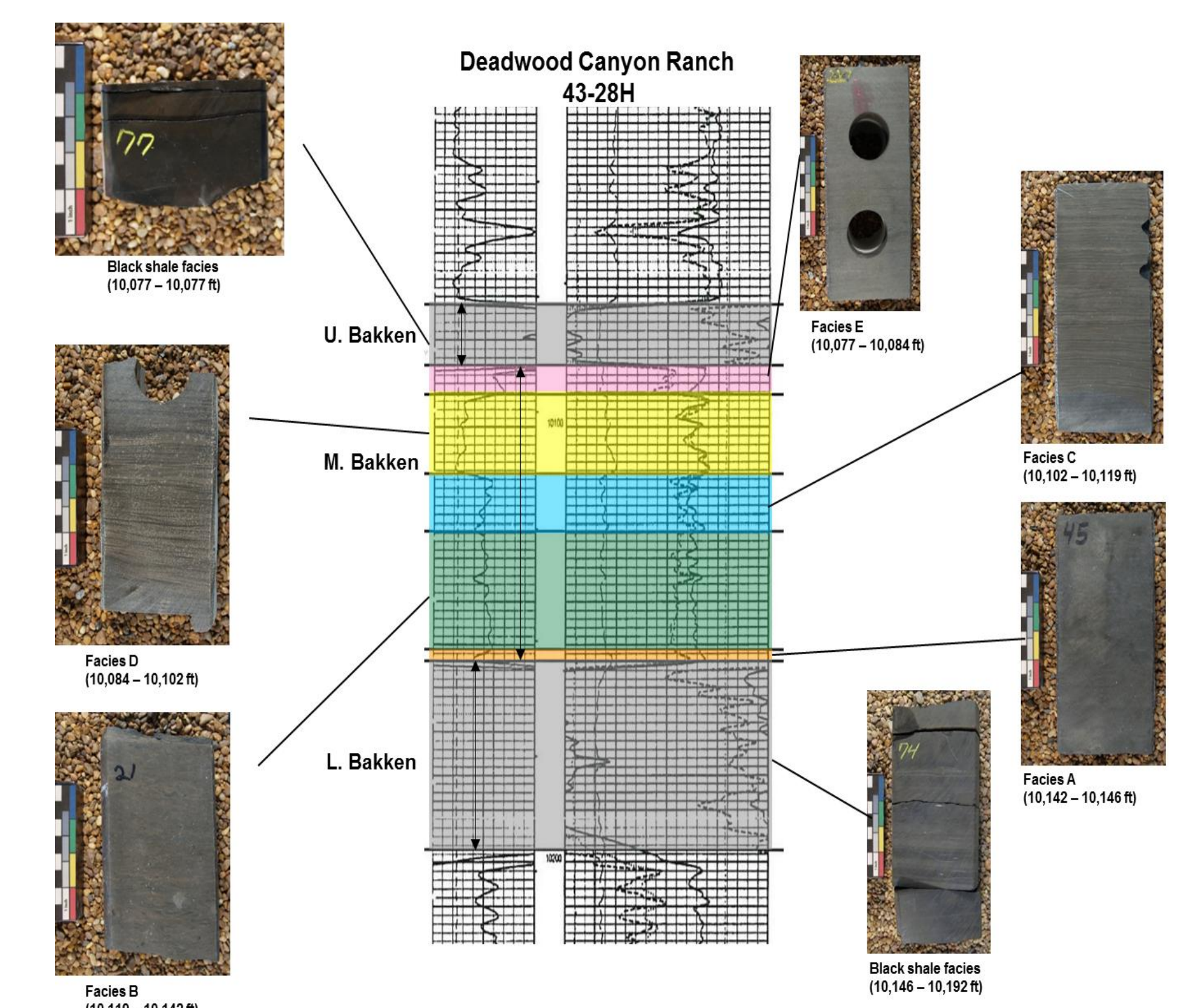


Figure 12. Well log showing Bakken lithofacies and core photographs. Facies modified from LeFever (1991) and Canter et al. (2009).

Middle Bakken Facies, Williston Basin

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Depositional Environment

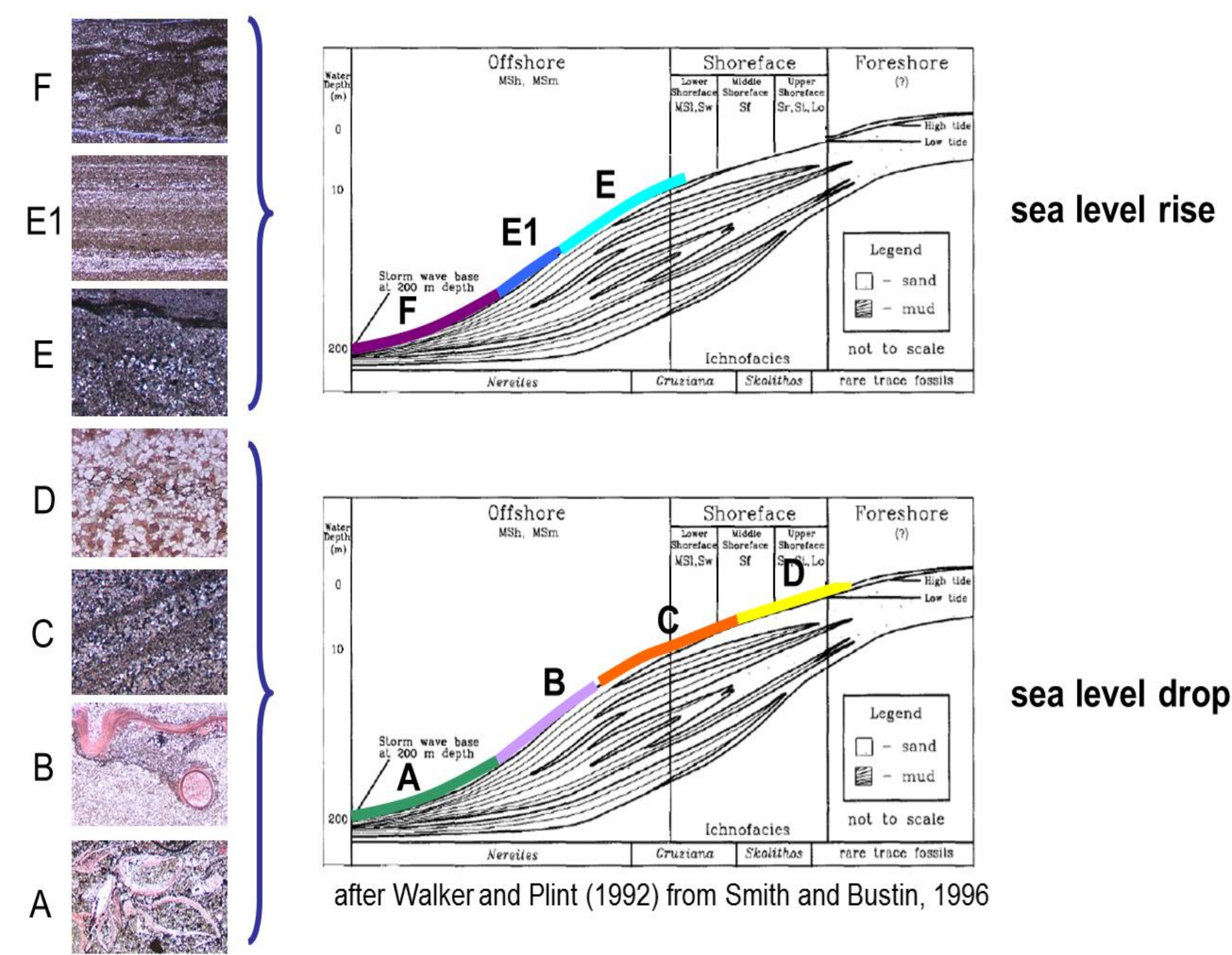


Figure 13. Middle Bakken deposition environments and associated water depths.

Depositional environment-Shallow Shelf

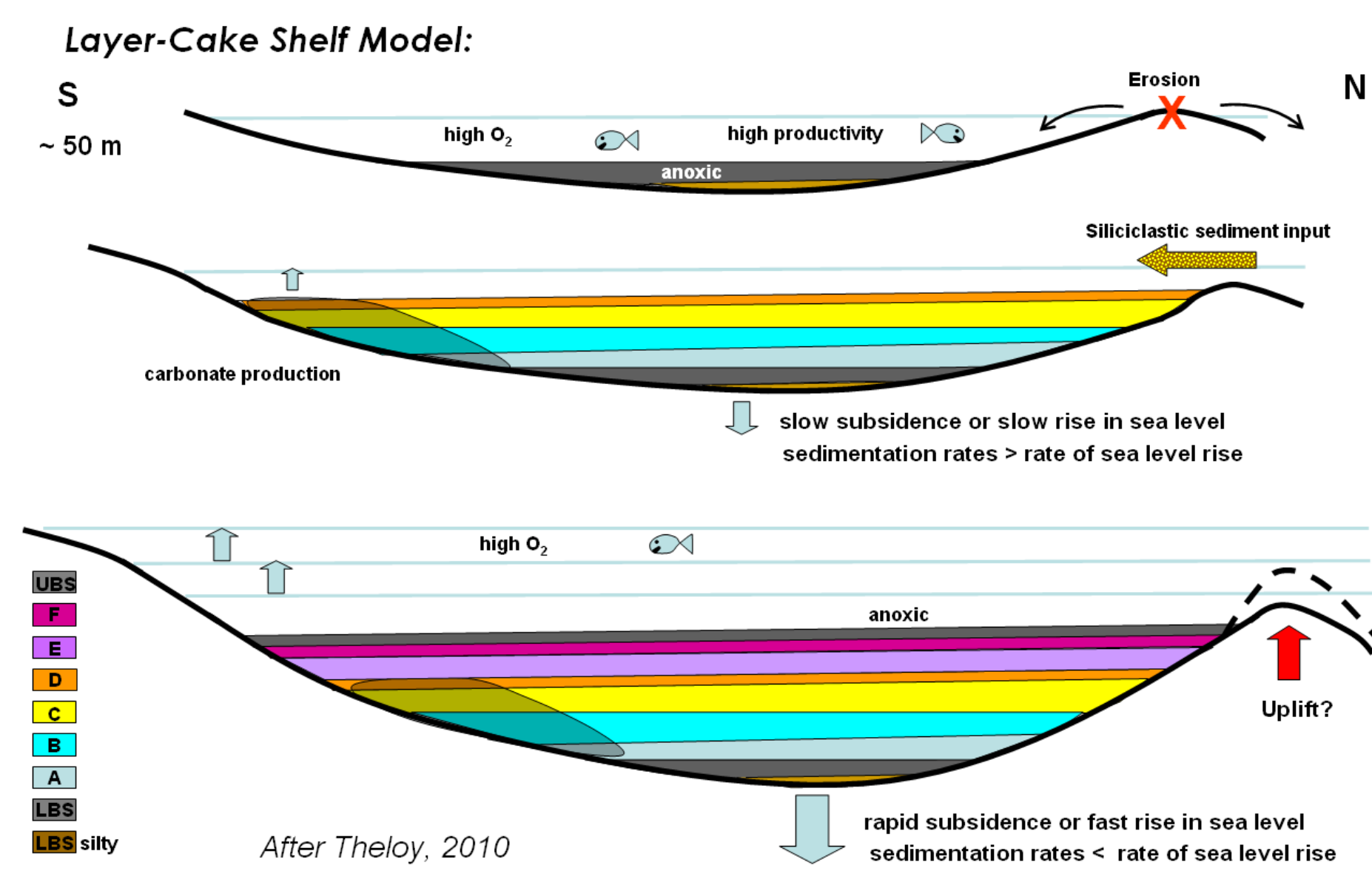


Figure 14. Layer-cake shelf model for middle Bakken. Source area for clastics is to the north (Canadian shield).

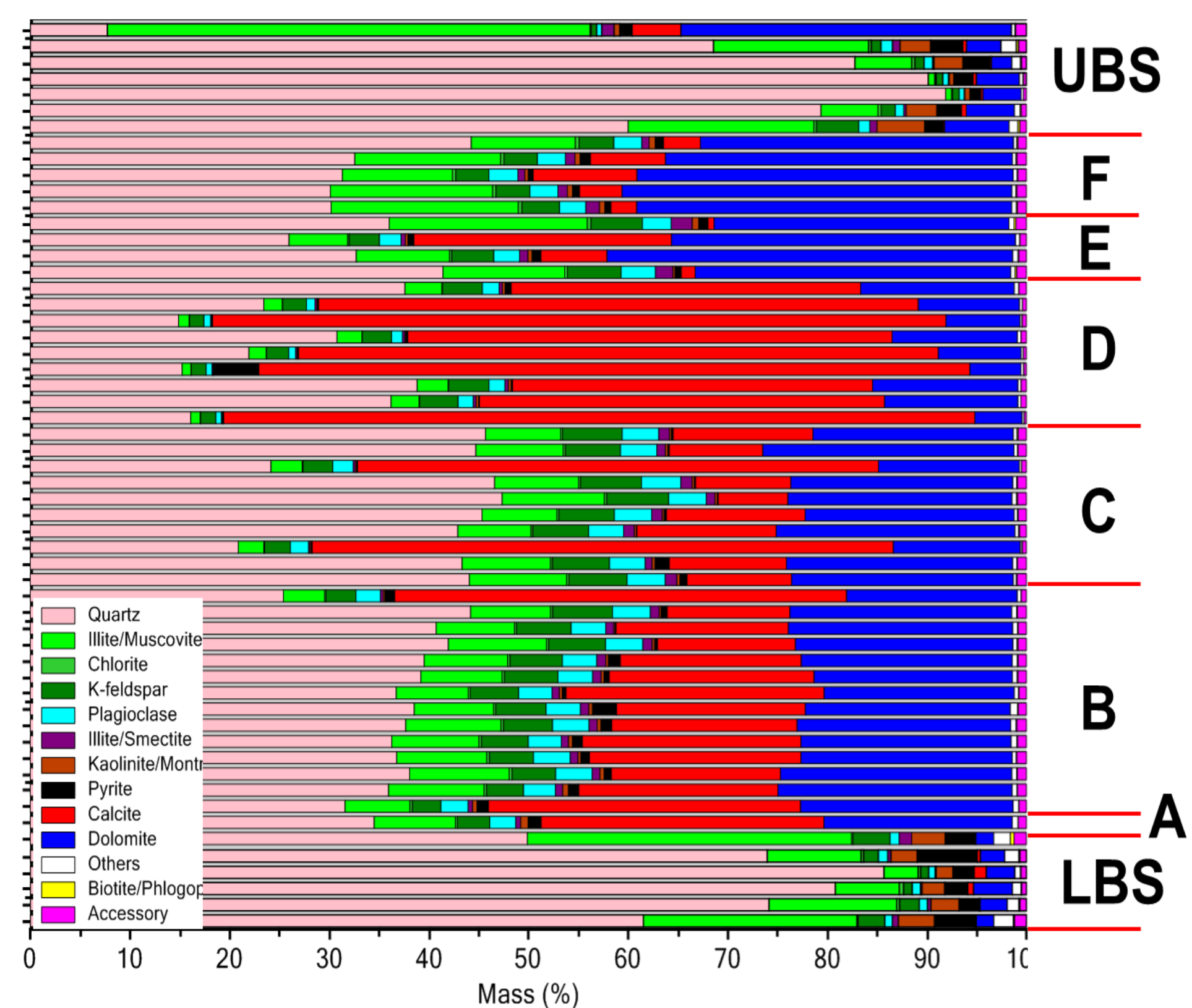


Figure 15. QEMSCAN mineralogy of the Bakken.

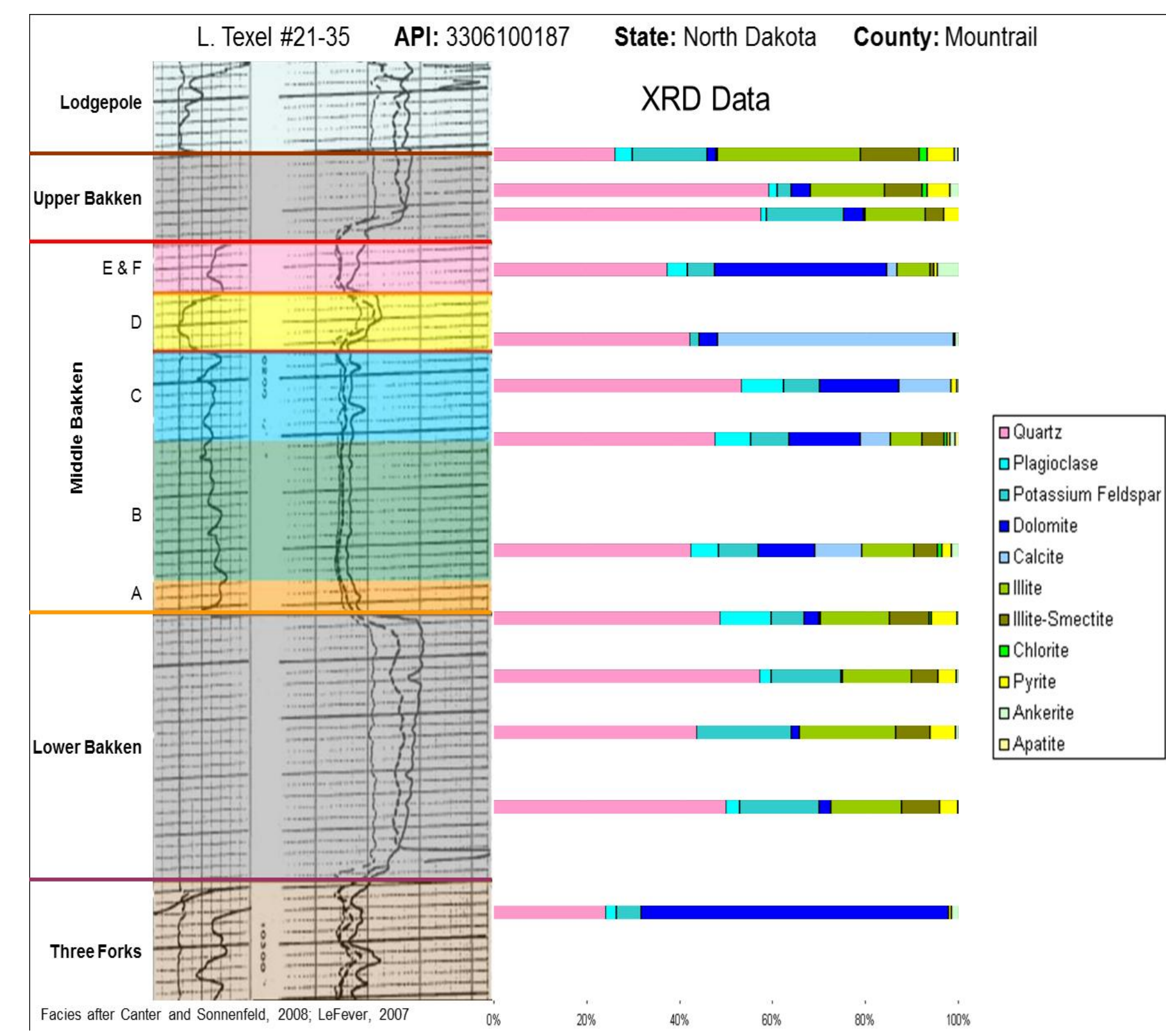


Figure 16. XRD mineralogy of the Bakken.

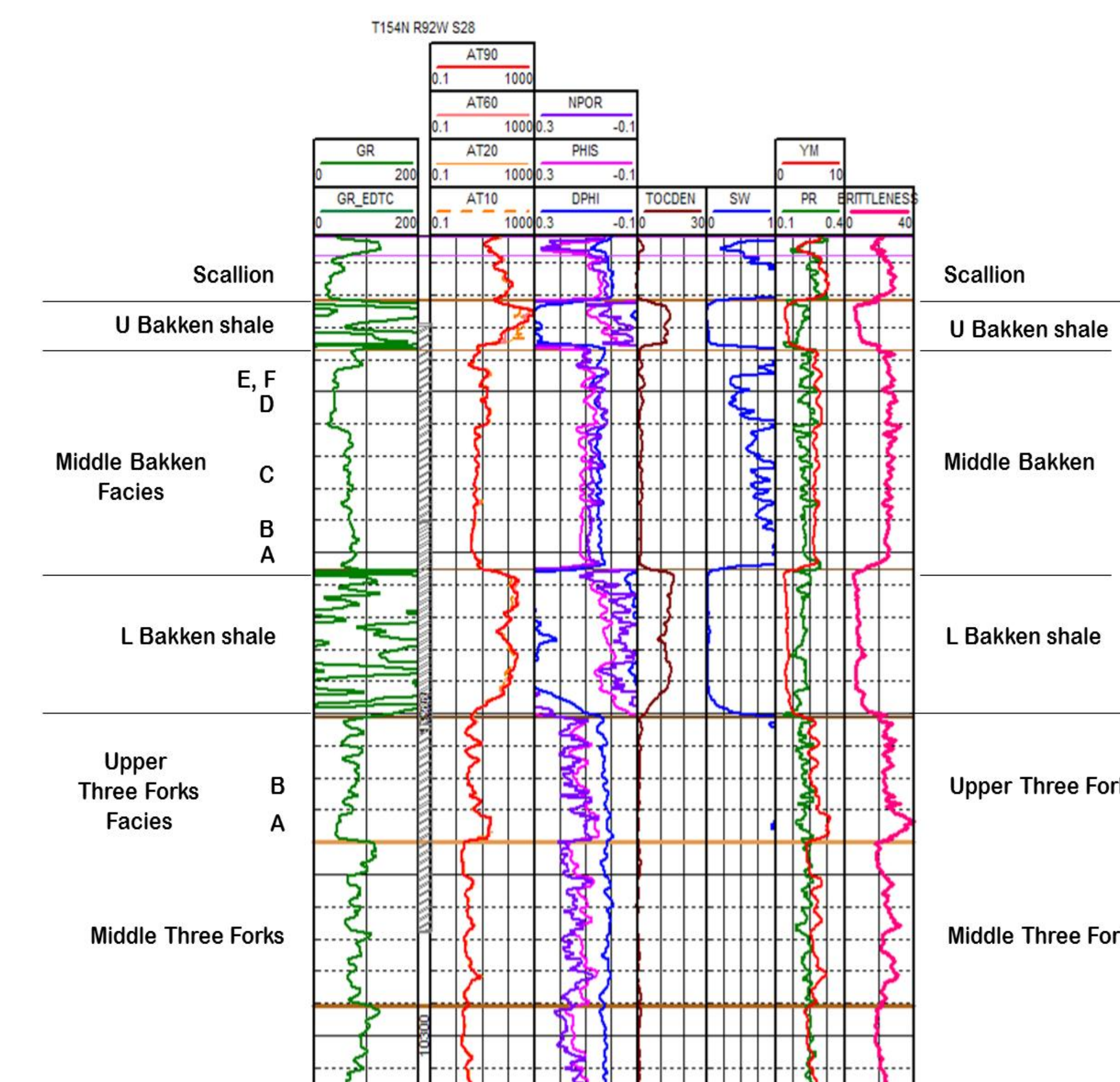


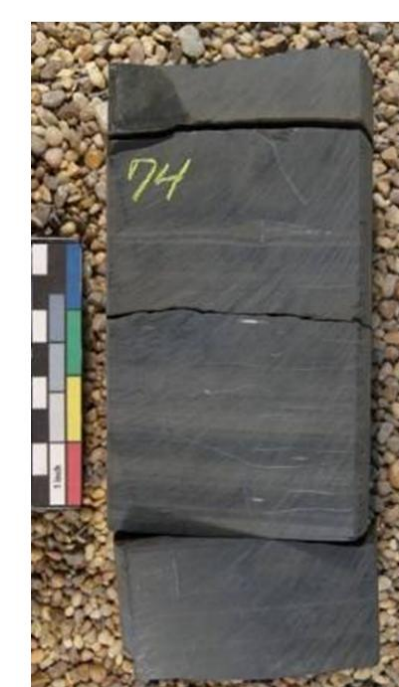
Figure 17. Well logs, TOC, water saturation, Poisson's ratio, Young's modulus, and brittleness for Bakken and upper Three Forks.

Upper Shale



Black, massive to locally parallel-laminated shale.

Lower Shale



Black, massive to locally parallel-laminated shale.

Black shale facies (10,146 – 10,192 ft)

Figure 18. Core photographs of upper and lower Bakken shales. Photographs courtesy of North Dakota Geologic Survey.

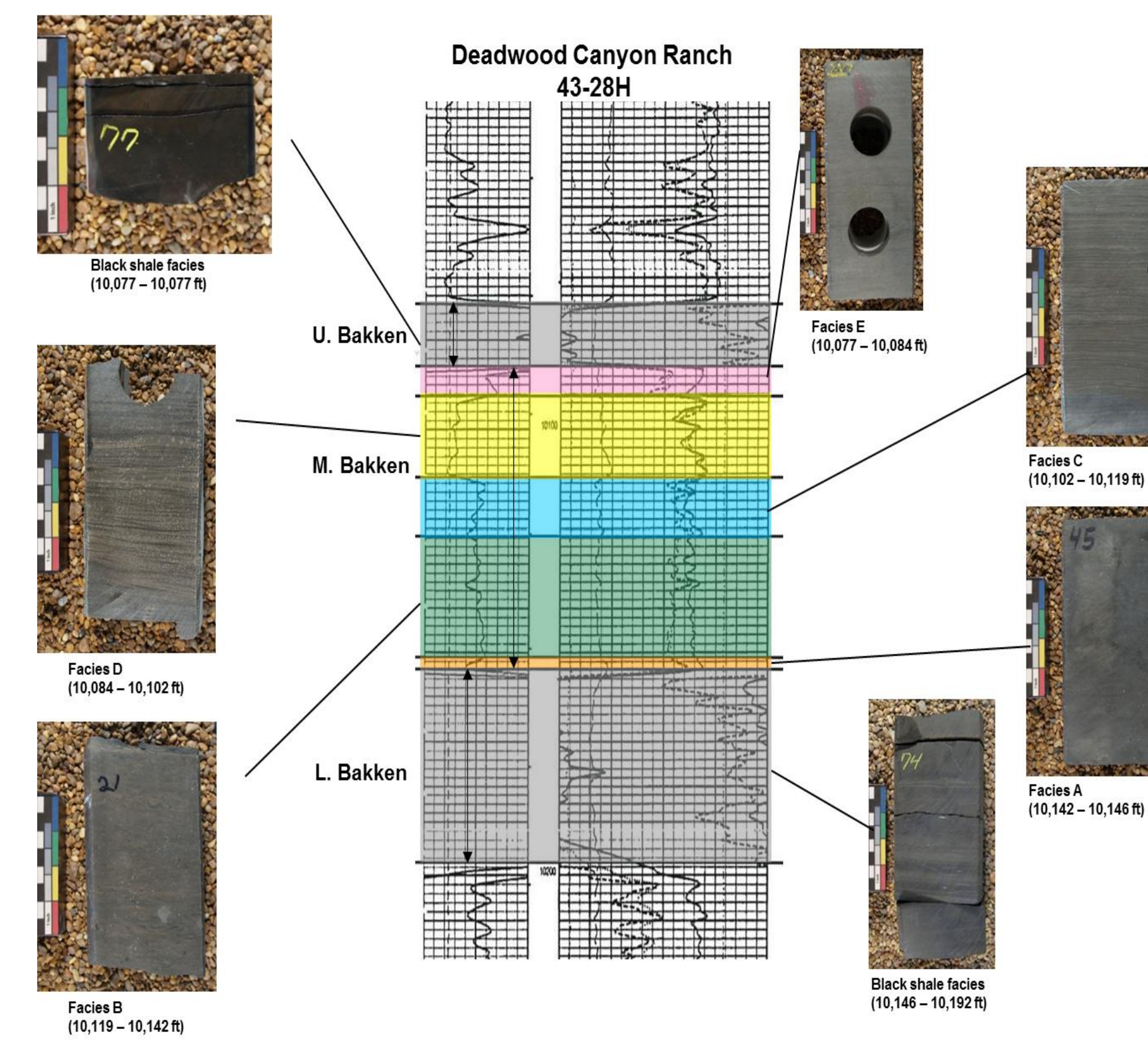


Figure 19. Core photographs of Bakken lithofacies. Facies modified from LeFever (1991); Canter et al. (2009).

Facies F

Pyritic dolostones

Subtidal



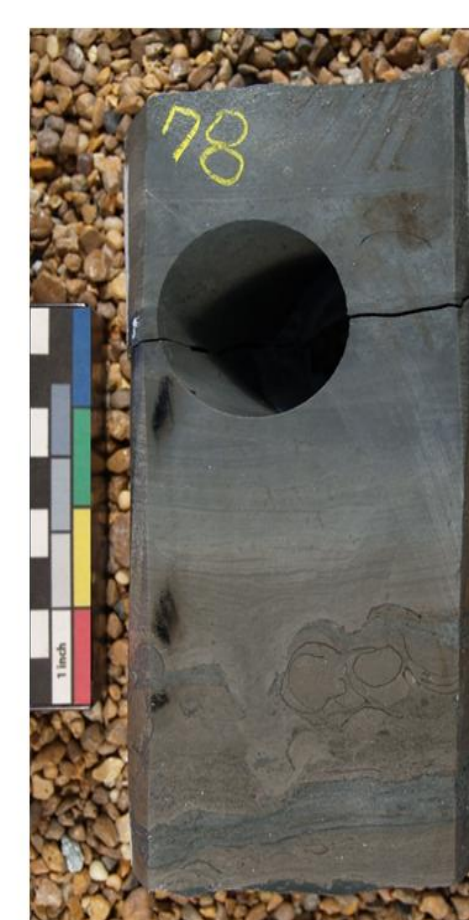
DC-10077

Facies F

Calcitic, whole fossil, dolo- to lime wackestones: fossil-rich beds.

Fossil beds may represent storm deposits

Absence of waves and currents, suspension deposition



DC-10078

Facies E

Thin-bedded dolo-mud/wackestone, dolomitic.

Can be rhythmically bedded

Offshore setting
Rhythmically interlaminated sandstone and muddy siltstone may represent tidal processes

Thin sandstone beds interpreted as tempestites strongly reworked by biogenic action

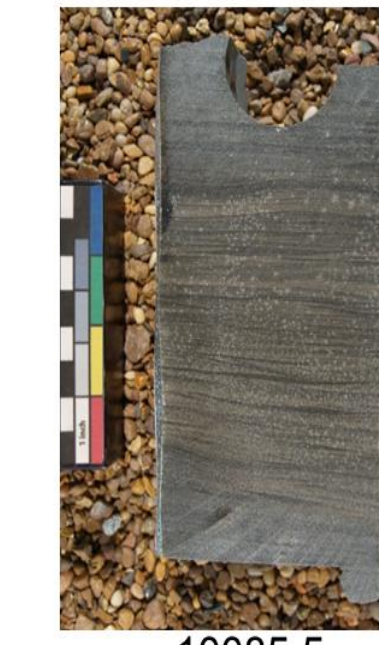


DC-10080

Facies D

Highest energy, coarsest grained alternating cross-bedded bioclast, v.f.g. sandstone.

Interpreted as having been deposited in a high-energy region: channel fill to shoal



10085.5

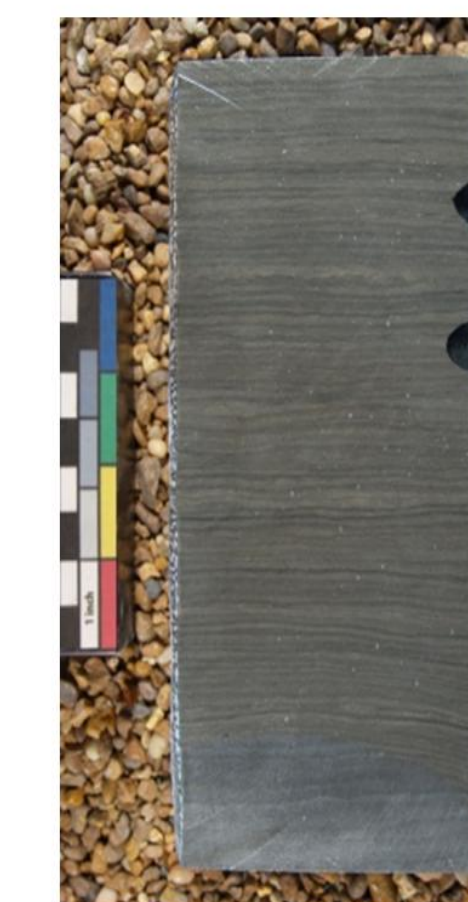


DC-10094.7

Facies C

Rhythmic, varve-like, mm to cm laminated, well sorted, v.f.g. sandstone and siltstone with calcite cement, hummocks and wave ripples.

Rhythmically interlaminated sandstone and muddy siltstone may represent tidal processes

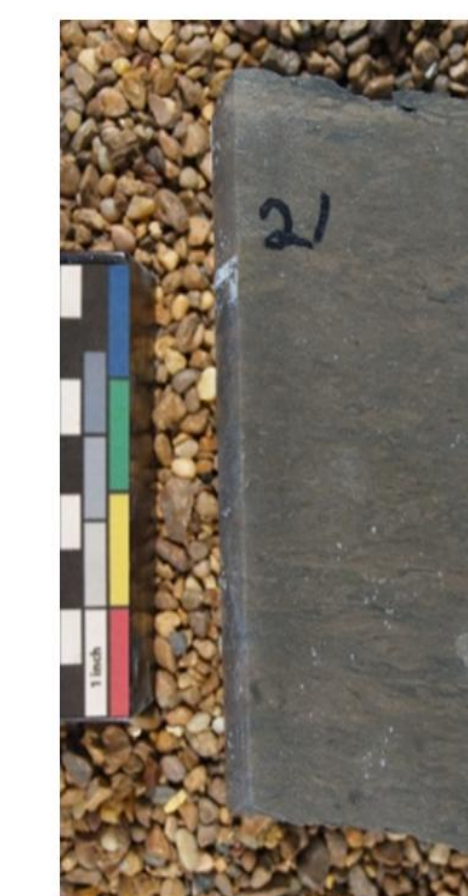


10112.7

Facies B

Bioturbated, argillaceous, calc. poorly sorted, v.f.g. sandstone/siltstone with helminthopsis/sclerituba.

Open-marine, below wave base, reworking by deposit feeding ichnofauna

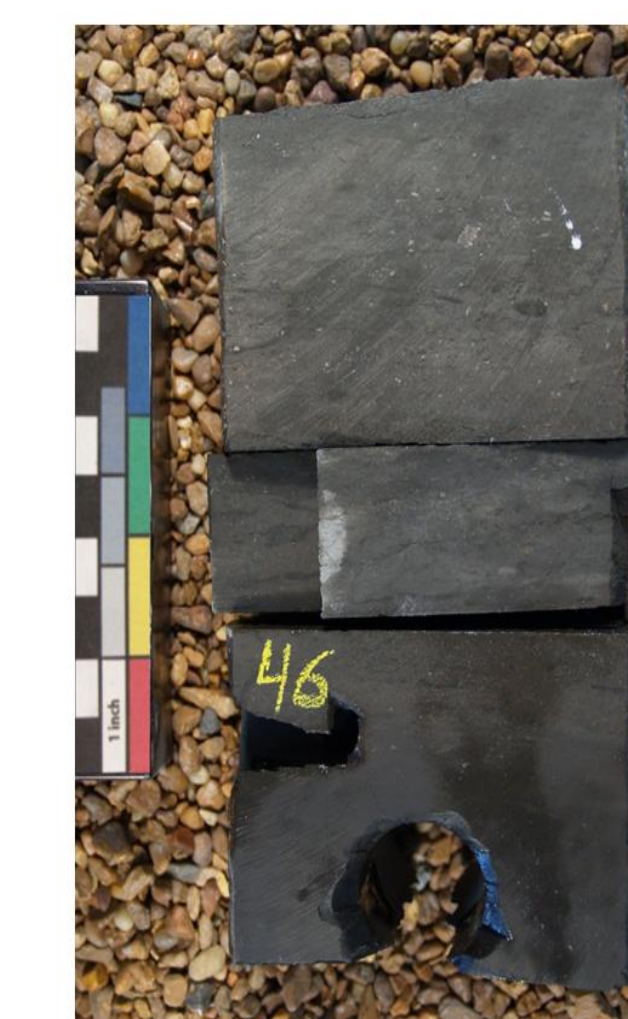


DC-10121

Facies A

Intraclastic-skeletal lime wackestone

Absence of waves and currents, suspension deposition, deposit-feeder traces. High index of bioturbation and common shell fragments



DC-10146

Figure 20. Core photographs of Bakken lithofacies A-E. Photographs courtesy of North Dakota Geologic Survey.

Middle Bakken Facies, Williston Basin, USA

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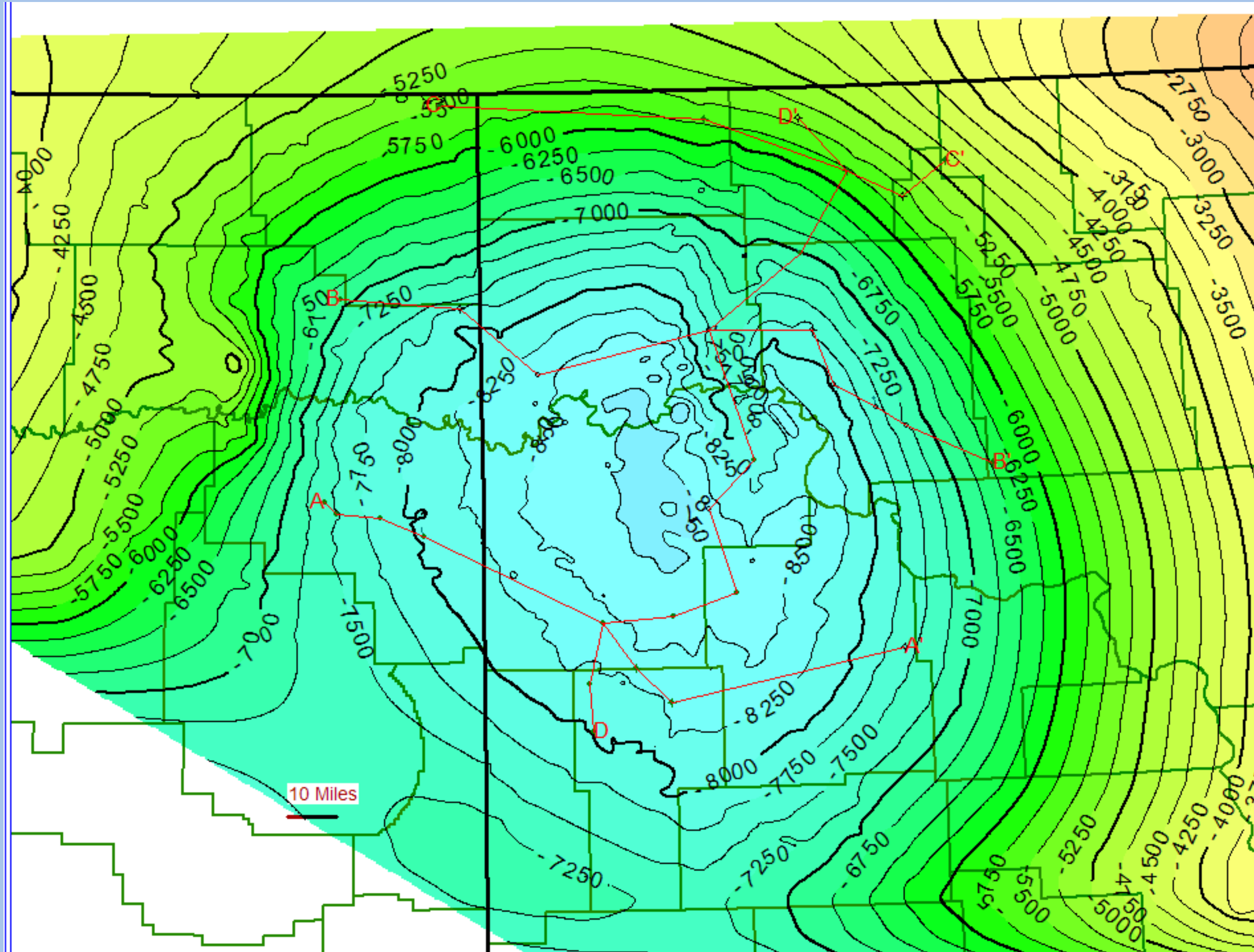


Figure 21. Structure map, top Bakken, Williston Basin.

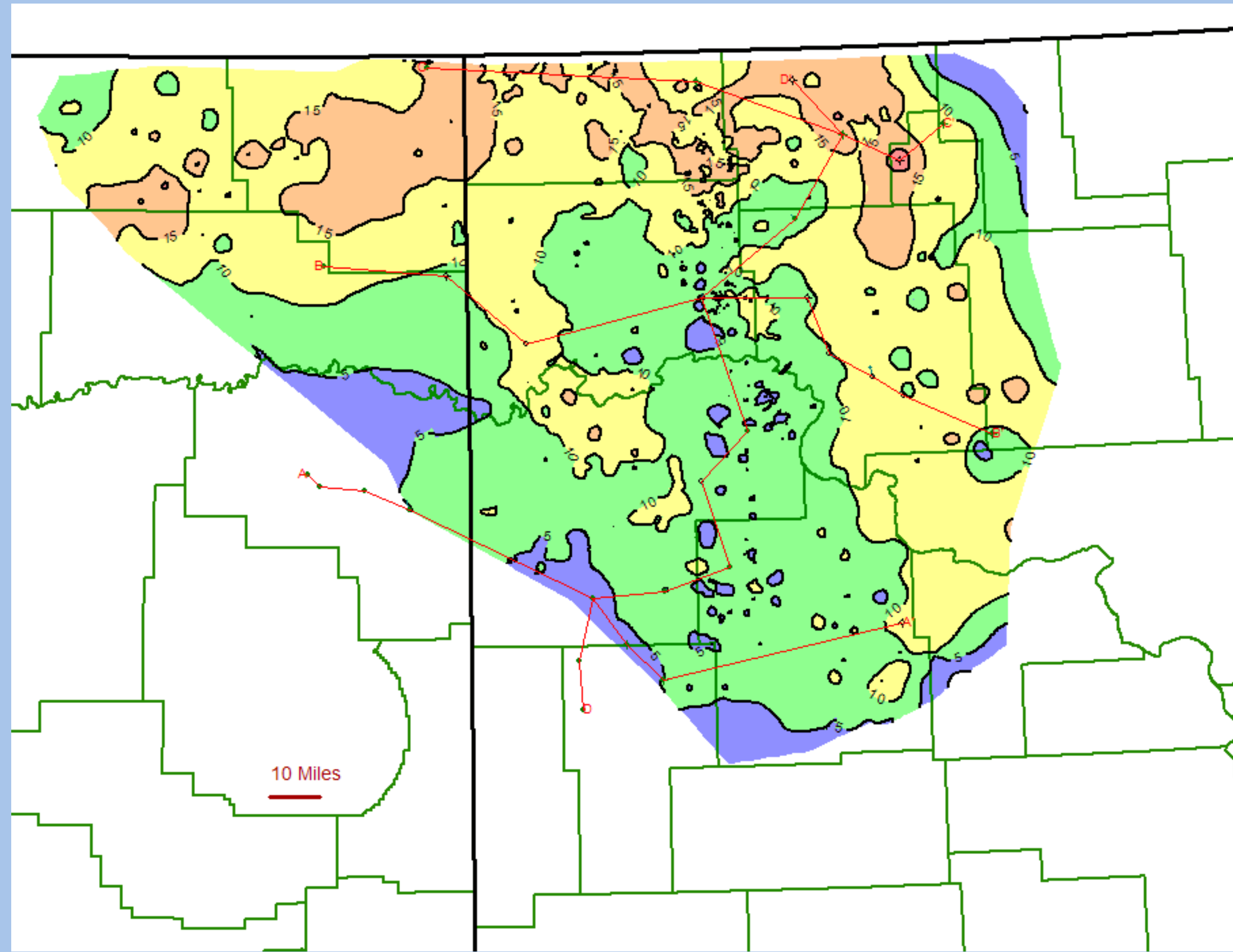


Figure 23. Isopach map, middle Bakken Facies E-F, Williston Basin.

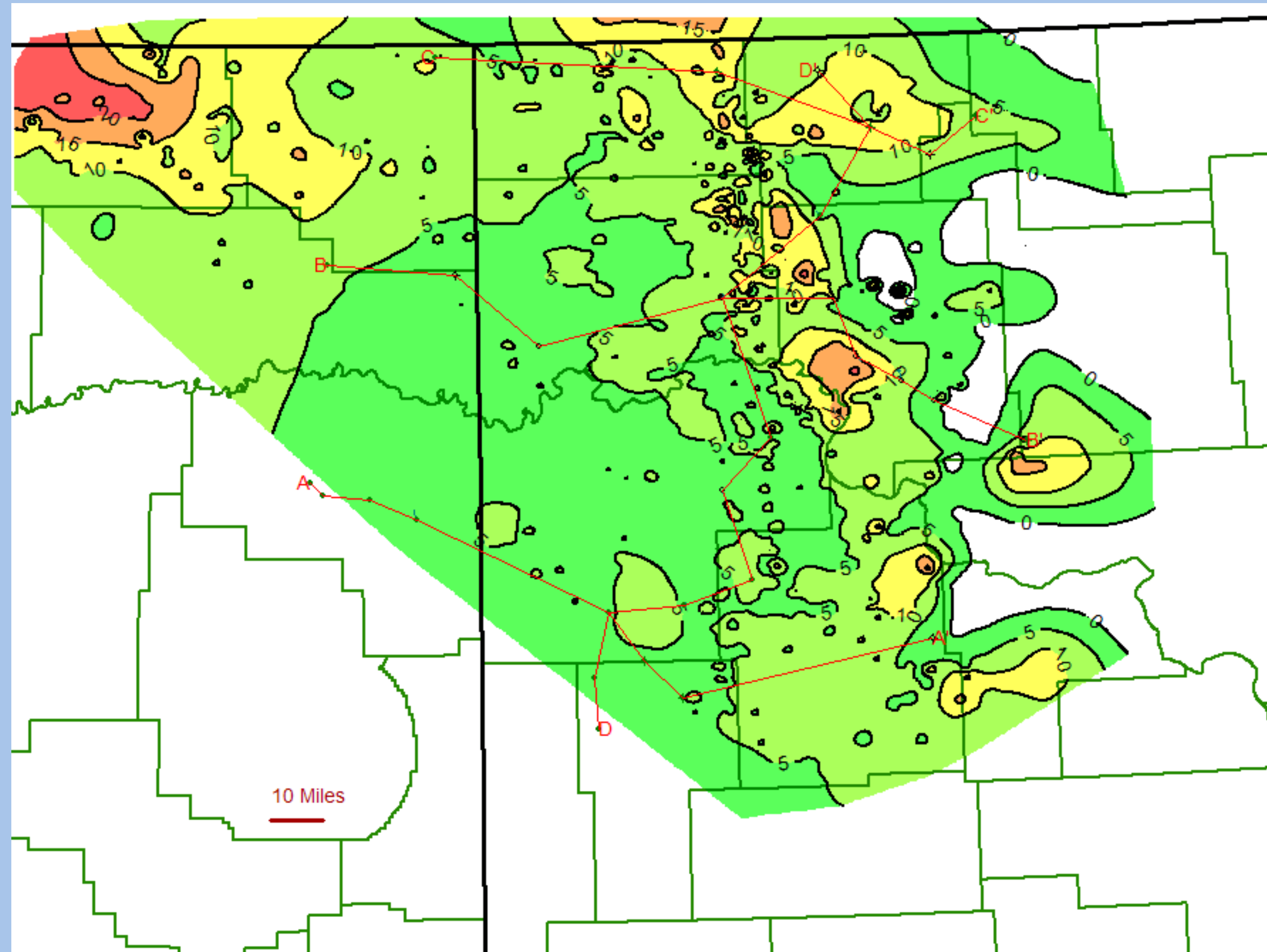


Figure 24. Isopach map, middle Bakken Facies D, Williston Basin.

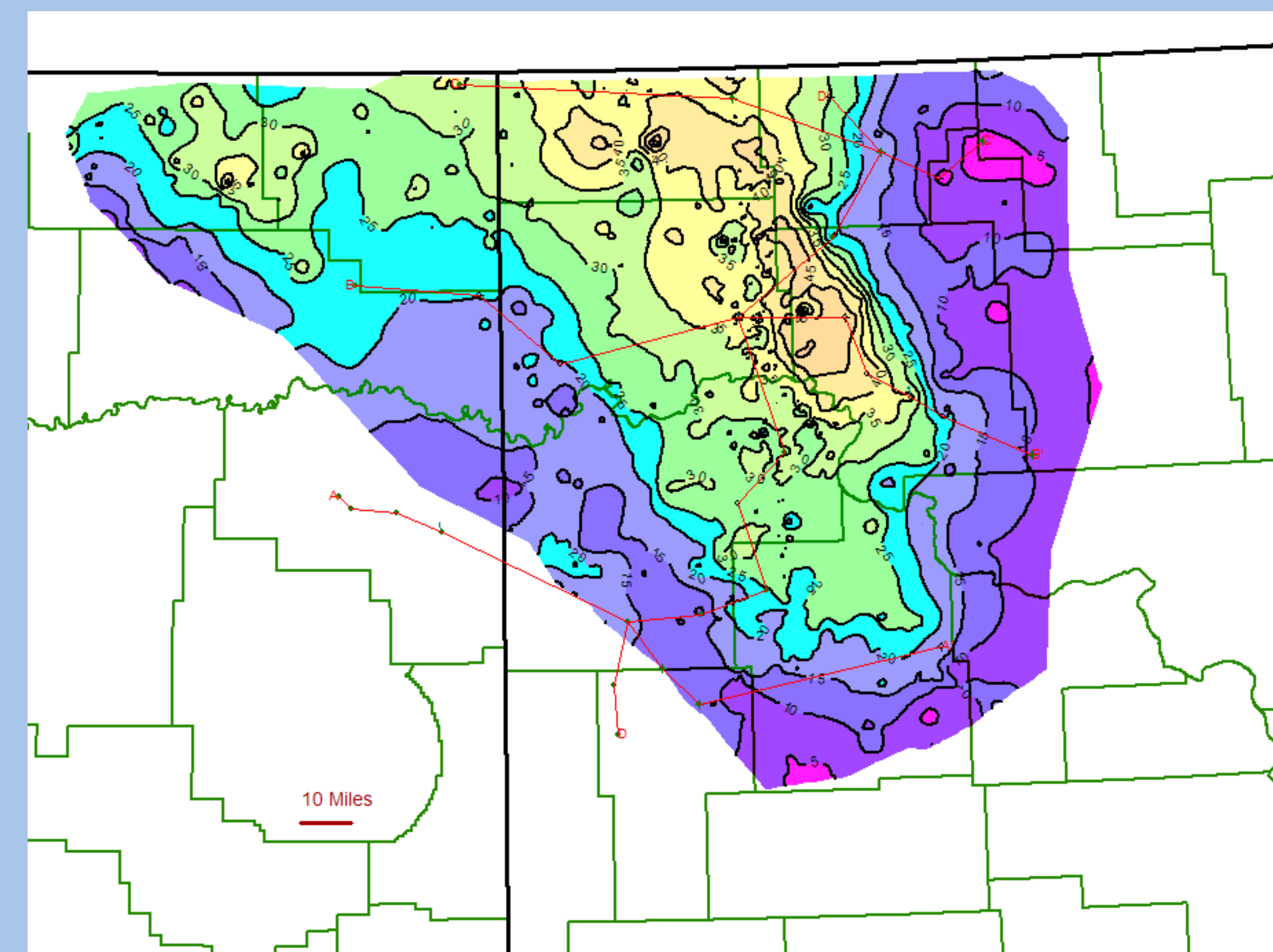


Figure 25. Isopach map, middle Bakken Facies A-C, Williston Basin.

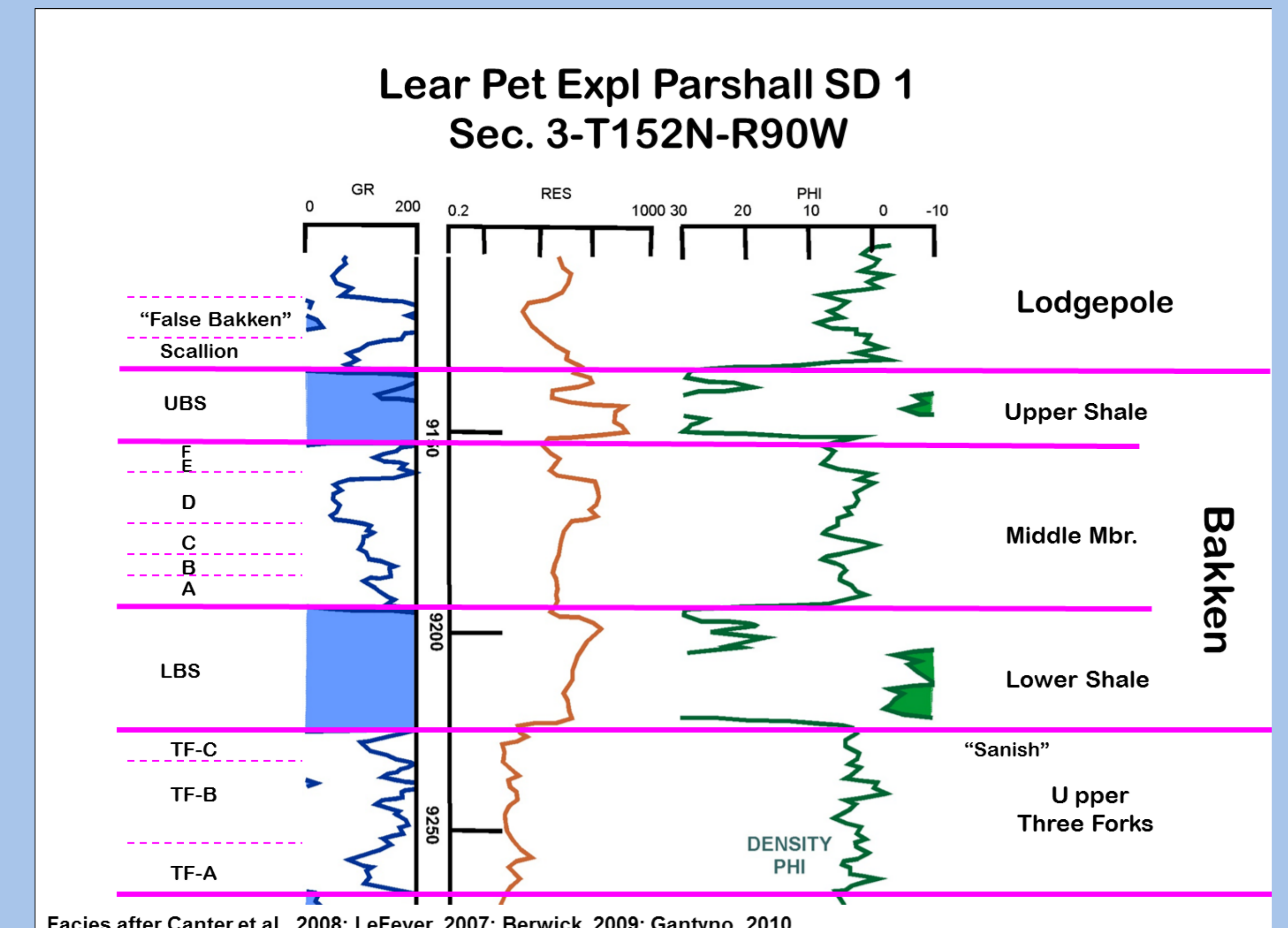


Figure 26. Well log showing Bakken and upper Three Forks lithofacies.

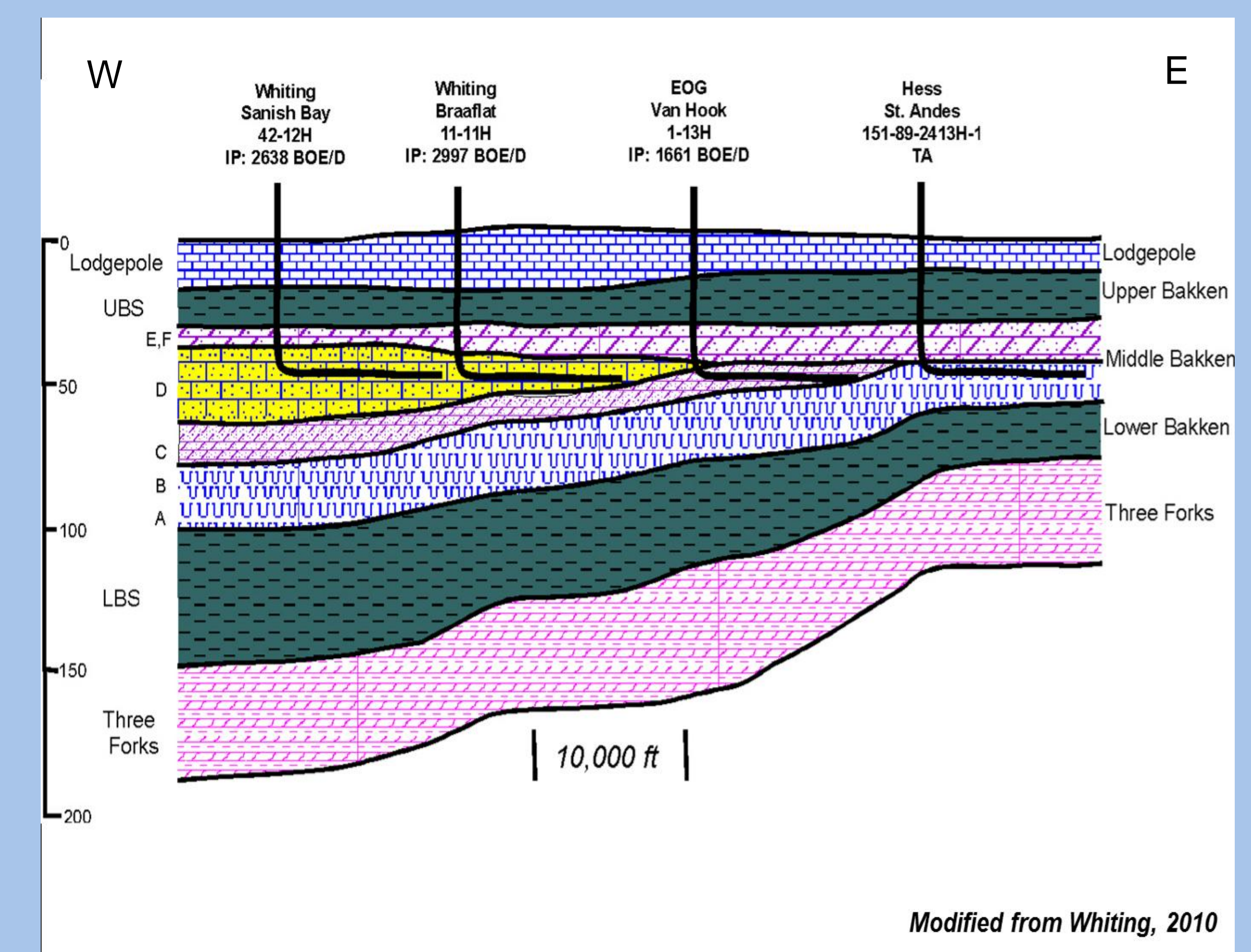


Figure 27. Bakken lithofacies at Sanish-Parshall fields. Note pinching out of facies C and D to the east. The trap in this area is largely stratigraphic. MAIN TARGET OF HORIZONTAL DRILLING FACIES C and D.

Middle Bakken Facies, Williston Basin

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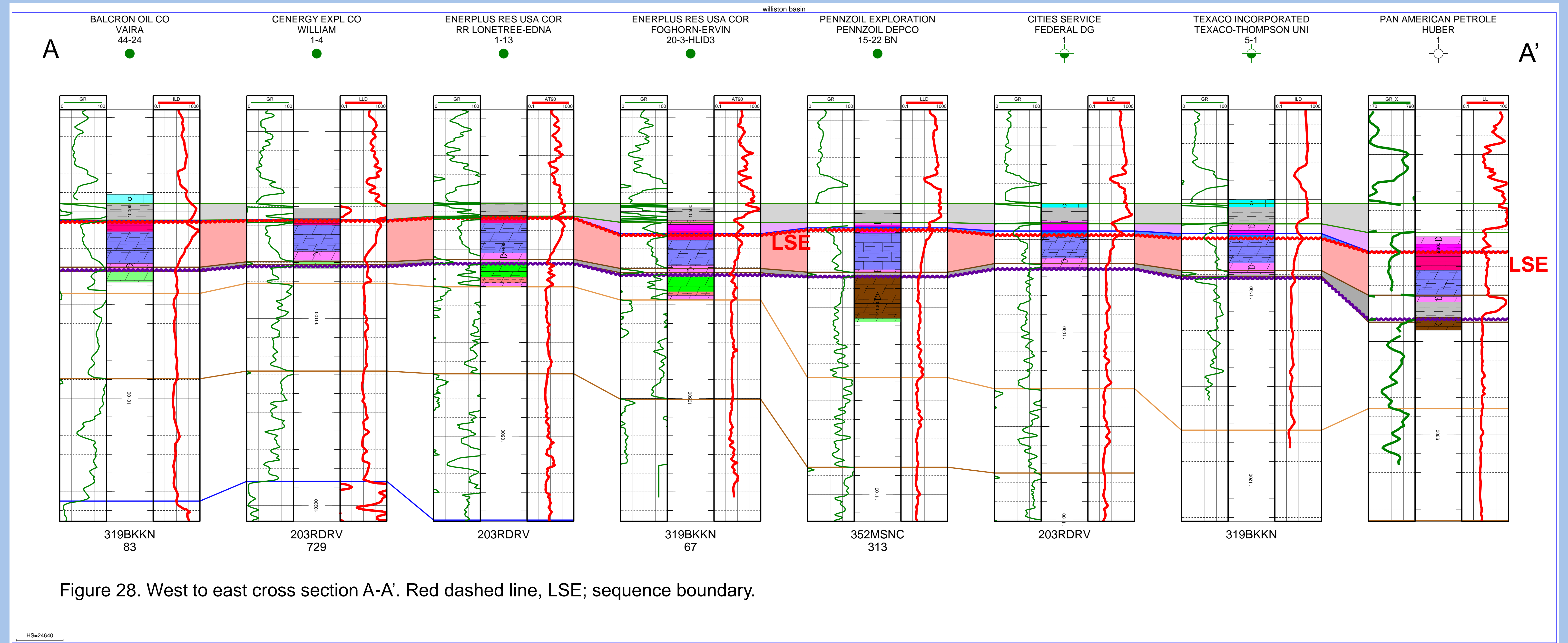
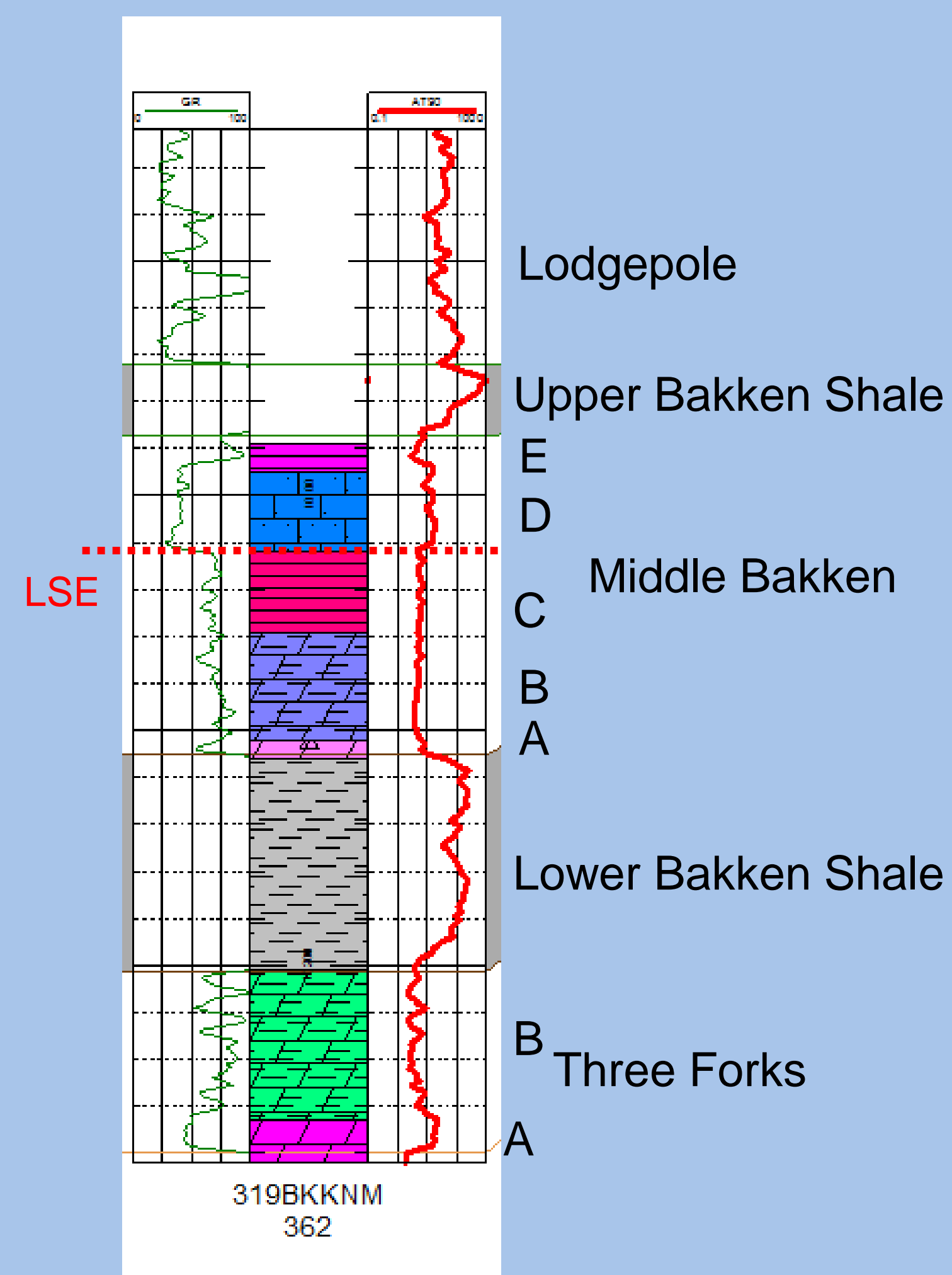


Figure 28. West to east cross section A-A'. Red dashed line, LSE; sequence boundary.

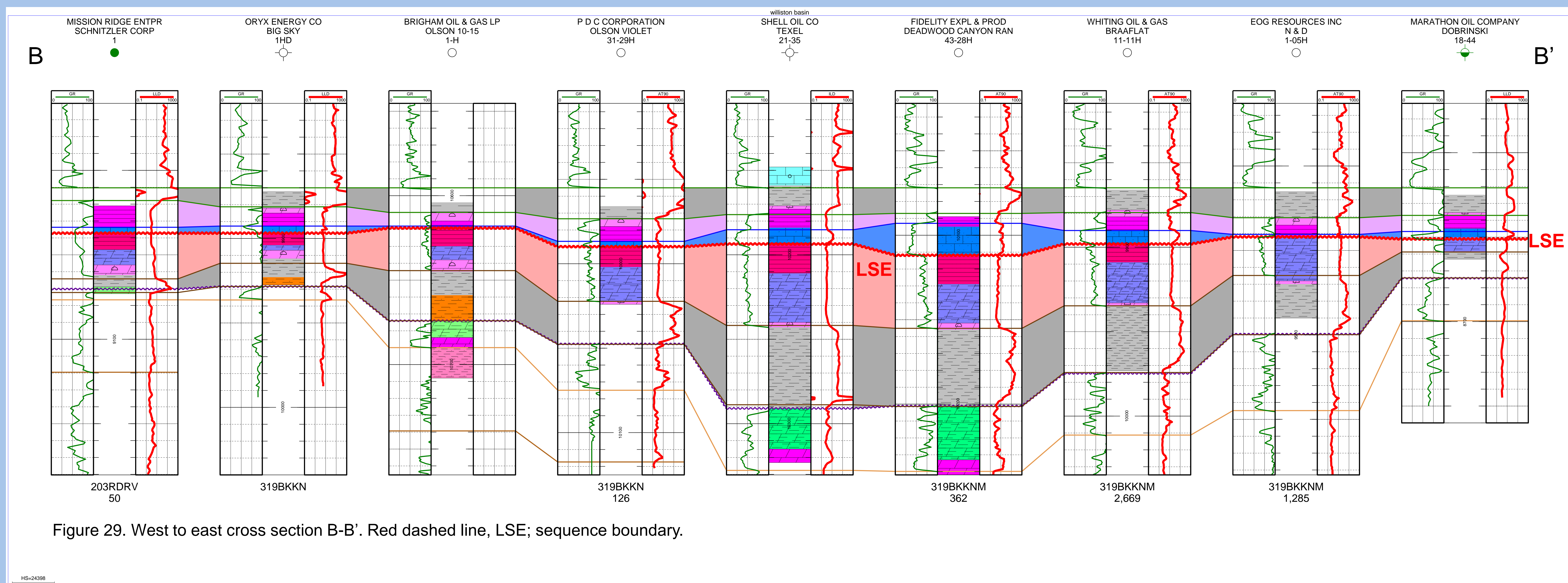
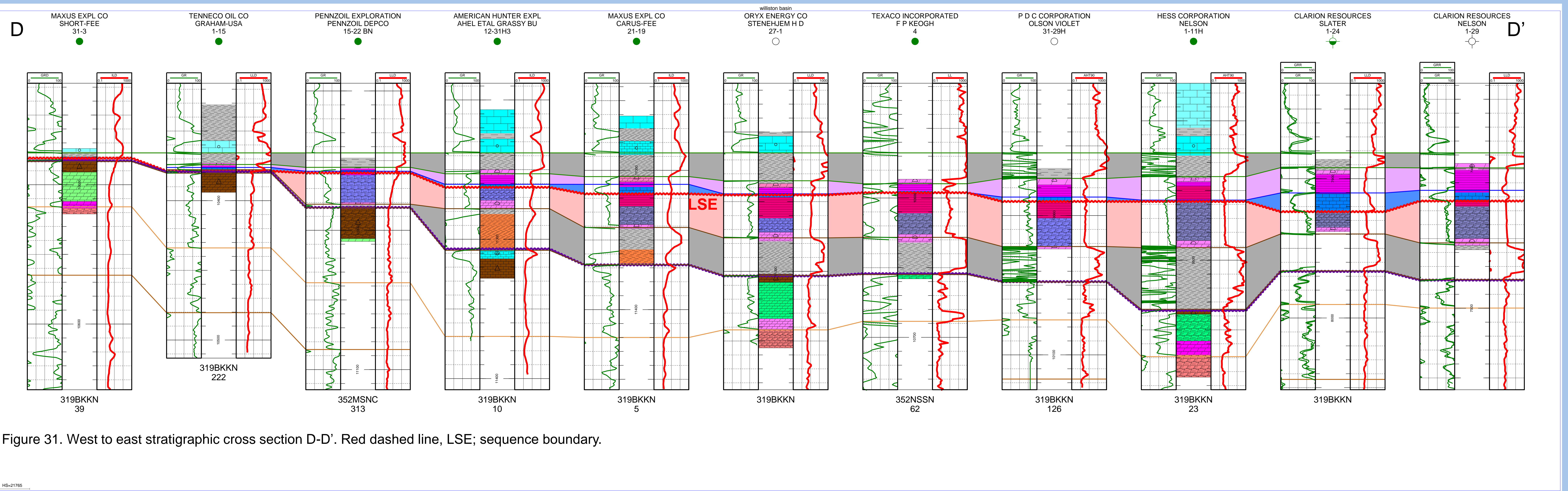
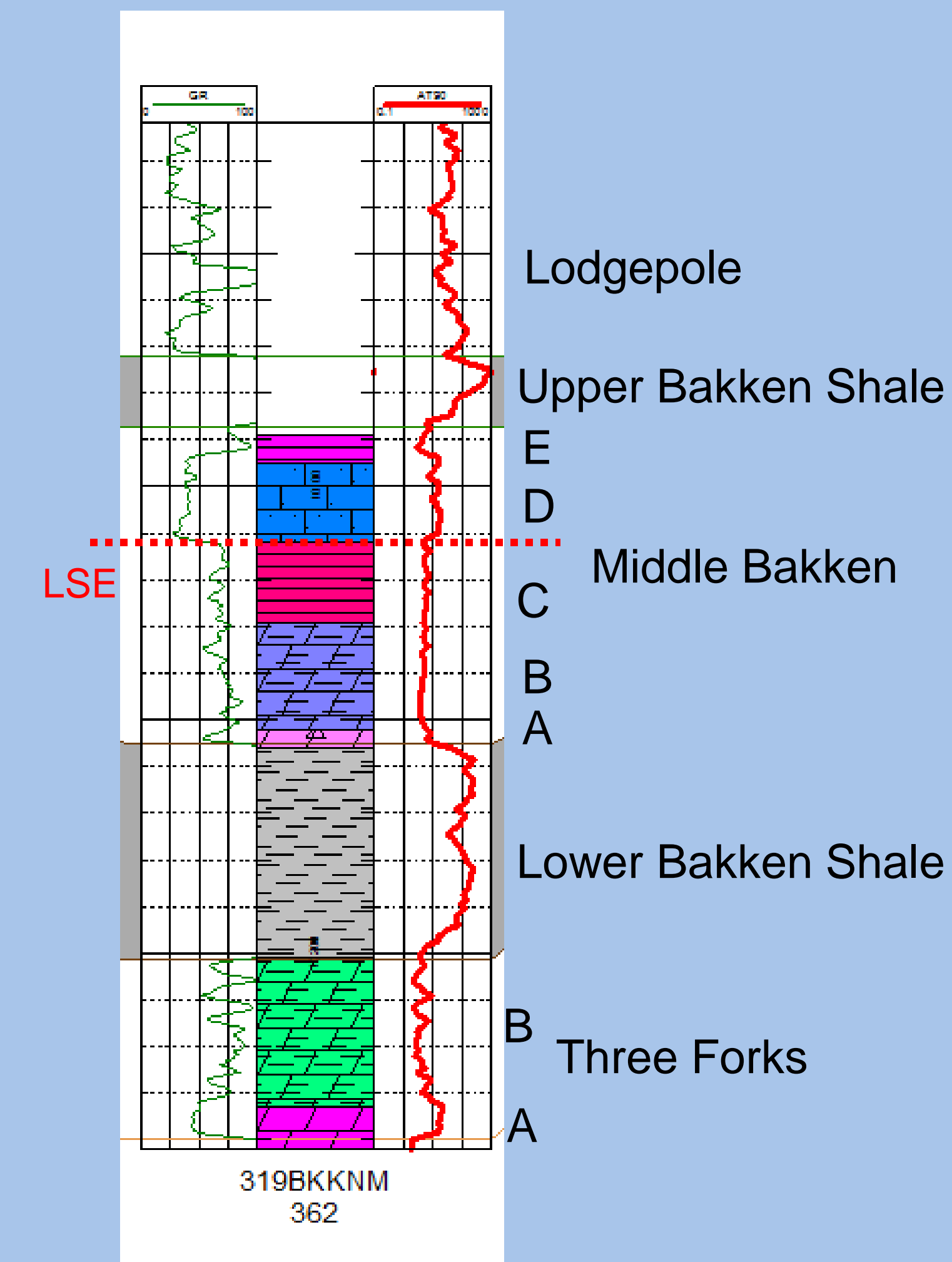
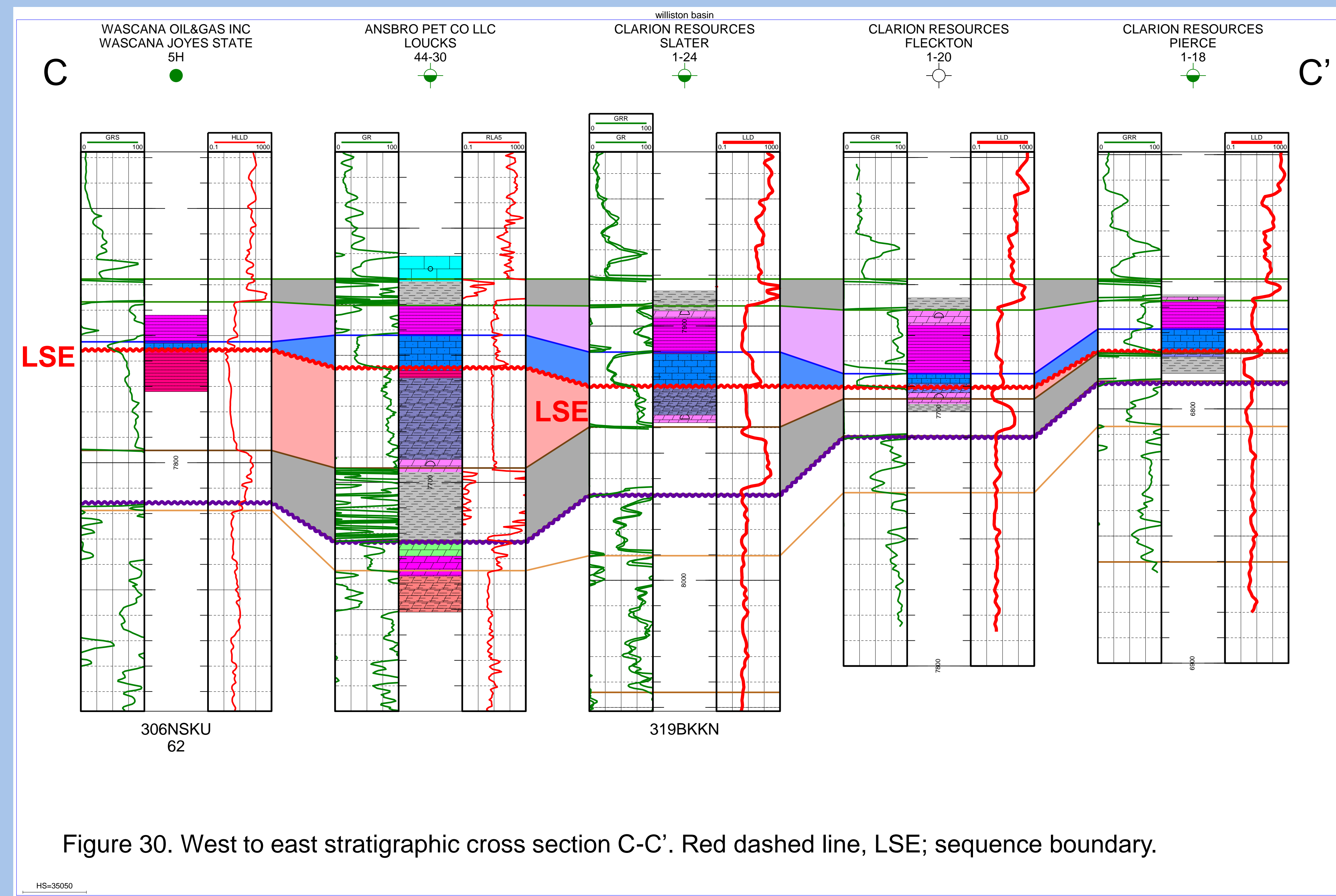


Figure 29. West to east cross section B-B'. Red dashed line, LSE; sequence boundary.

Middle Bakken Facies, Williston Basin

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Middle Bakken Facies, Williston Basin

6



Acknowledgements

- DOE/NETL
- Consortium Members
 - EOG, Whiting, Enerplus, Marathon, Red Willow, Total, Mike Johnson, Hendricks and Associates, Discovery Group, Samson, Fidelity, Savant, QEP, XTO, StatOil, Husky Energy, Shell, Newfield, Chesapeake, Rosetta, Husky, Anschutz
- IHS
- MJ Systems, TGS A2D
- NDIC, North Dakota Geological Survey
- EERC, University of North Dakota
- USGS Williston Basin Team
- Geomark

Project Reports:
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NOTE: All thesis and reports are posted on the CSM Bakken Consortium website.