PS Core-based Geochemical study of Mudrocks in Basinal Lithofacies in the Wolfberry Play, Midland Basin, Texas, Part II*

Robert W. Baumgardner, Jr.[1] and H. Scott Hamlin[1]

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[1]The Bureau of Economic Geology, Jackson School of Geosciences, University of Texas at Austin, Austin, TX (Robert.baumgardner@beg.utexas.edu)

Abstract

Wolfberry production (including Leonardian, Wolfcampian, and underlying Upper Pennsylvanian formations) totals 232 million barrels of oil and 592 billion cubic feet of gas from 1998 to 2011 (>50 million barrels of oil in 2011, alone). The Lower Permian Wolfcamp and Leonard are part of the Wolfberry play in the Midland and northern Val Verde Basins of Texas. Core-based study provides ‘ground truth' about the source rocks and carrier beds in this unconventional reservoir. Analysis of more than 1,000 feet of core from three wells near center of the Midland Basin in northern Reagan County shows that these rocks can be divided into four facies: 1-siliceous mudrock, 2-calcitic mudrock, 3-muddy carbonate-clast conglomerate, and 4-skeletal wackestone/packstone. These facies are interpreted as hemipelagic deposits and sediment gravity-flow deposits reworked, locally, by bottom currents. Facies are interbedded on scales ranging from centimeters (predominantly) to meters. Siliceous mudrocks contain relatively high total organic carbon (up to 6.3 percent), low manganese content, rare burrows, and common phosphatic nodules and pyrite framboids. Collectively, these features indicate that anoxia prevailed during deposition of these fine-grained sediments. Siliceous mudrocks display values of Corg/N <10, indicating that the associated organic matter has a large marine component. Measurements of total organic carbon and geochemical proxies (obtained by hand-held ED-XRF scans on 1-foot spacing) for marine productivity, reducing conditions, and organic matter accumulation do not co-vary consistently, suggesting that production, accumulation, and preservation of organic matter are multivariate processes that operate independently. Measurements of unconfined compressive strength show that most wackestone/packstones are more brittle than all siliceous mudrocks. Even so, mineralized fractures are present in all facies. The combination, in close vertical proximity, of abundant organic carbon, brittle mudrock, and thin, potentially ‘frackable' beds in the basinal Wolfcamp and Leonard makes these intervals attractive targets for fracture stimulation and horizontal well completion.

Core-based geochemical study of mudrocks in basinal lithofacies in the Wolfberry Play, Midland Basin, Texas, Part I

AAPG Meeting, May 2013

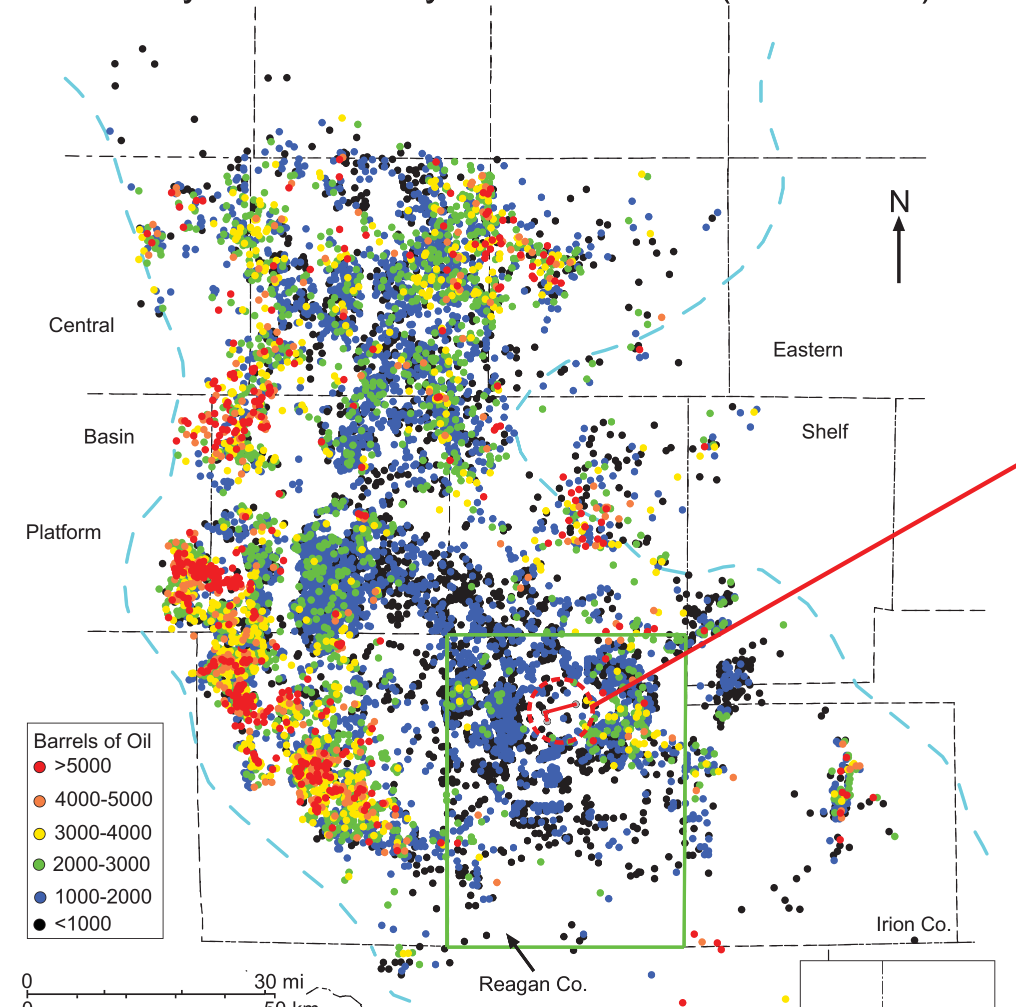
Robert W. Baumgardner, Jr. and H. Scott Hamlin
Bureau of Economic Geology

INTRODUCTION TO THE WOLFBERRY STUDY AREA

Important Observations I

- In the central Midland Basin Wolfcamp and lower Leonard rocks can be divided into 4 facies: 1. siliceous mudrocks, 2. calcitic mudrocks, 3. carbonate-clast conglomerates, and 4. wackestone/packstones. Facies 1 and 2 are interpreted as hemipelagic deposits. Facies 3 and 4 are interpreted as sediment density flow deposits,reworked, locally, by currents.
- Core examination reveals many features that indicate anoxia prevailed during deposition of fine-grained sediments.
- End of conglomerate deposition in early Leonard suggests change in distance to source or in carbonate production on shelf, relative to late Wolfcamp time.
- TOC (total organic carbon) is highest in siliceous mudrocks and varies widely over small vertical distances as a function of change in facies.

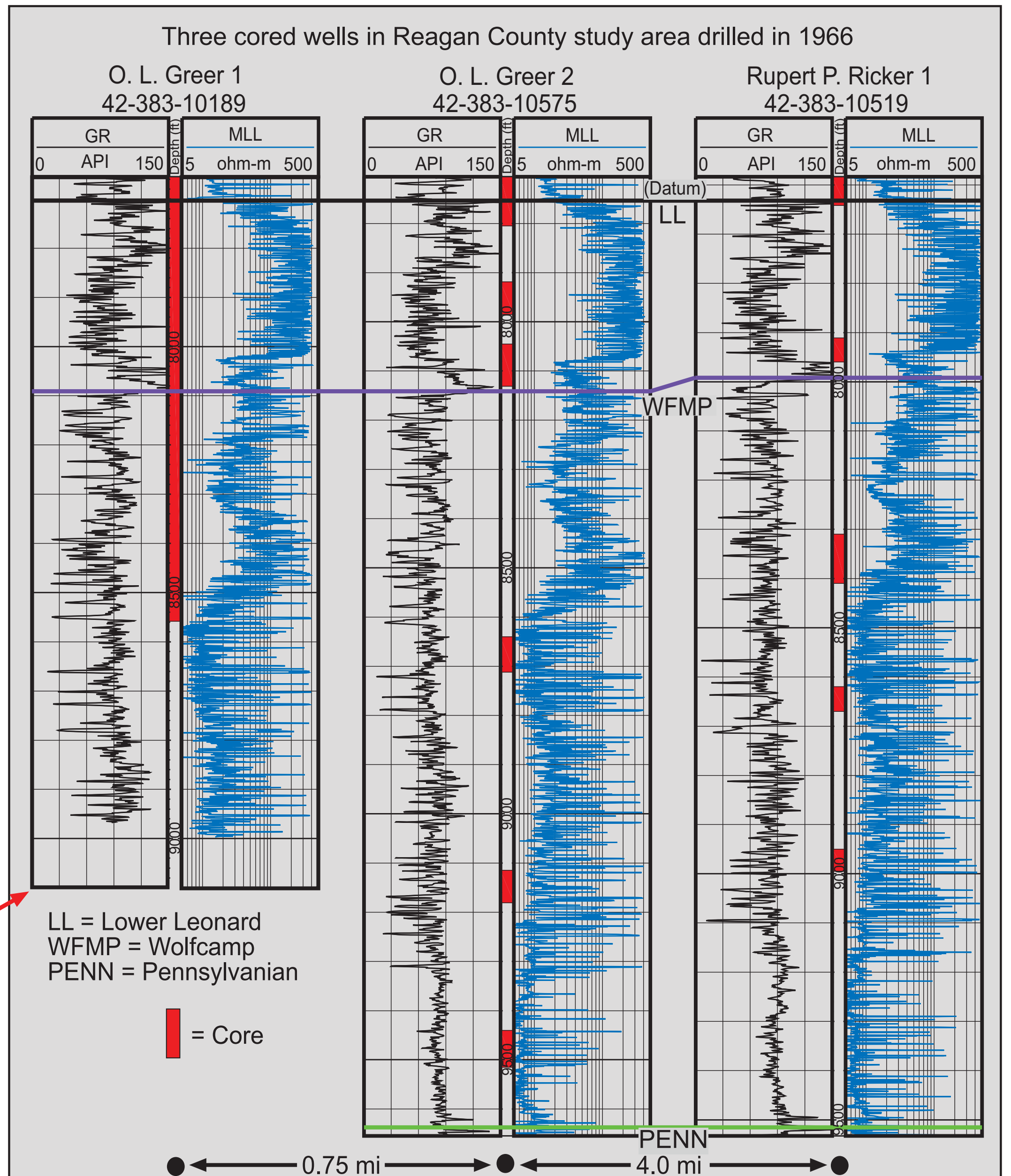
Wolfberry Best Monthly Oil Production (1998-2011)



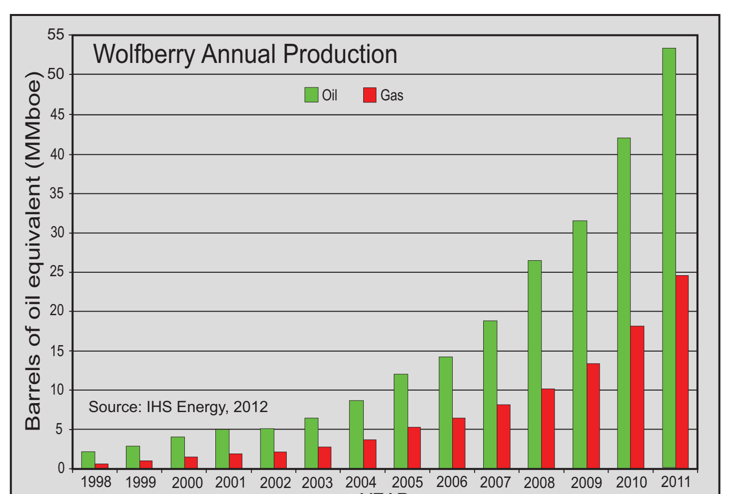
Wolfberry completions on this map identified by: (1) Producing formation=Spraberry, Dean, Lower Leonard, Wolfcamp, and/or Upper Penn, (2) >3 fracture stimulation stages, and (3) perforated interval>1,000 ft, or perforations extend across formation boundaries.

Best wells are found where Wolfcampian detrital carbonates are best developed, along basin margins.

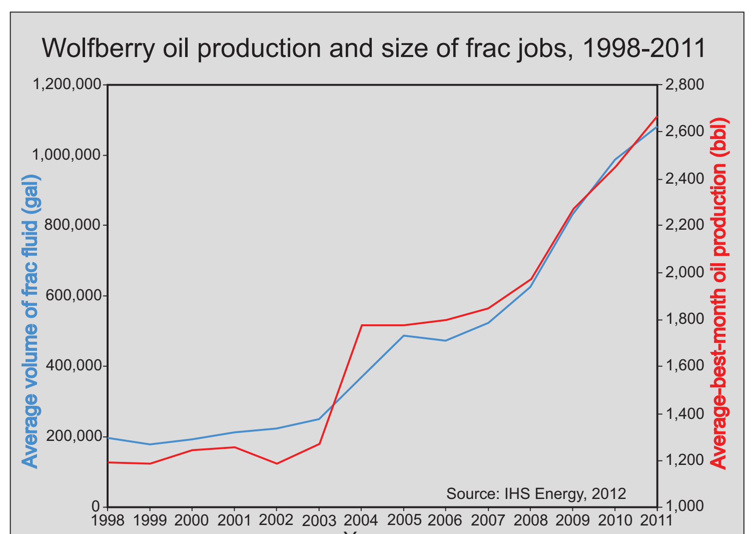
Based on data from IHS Energy (2012).



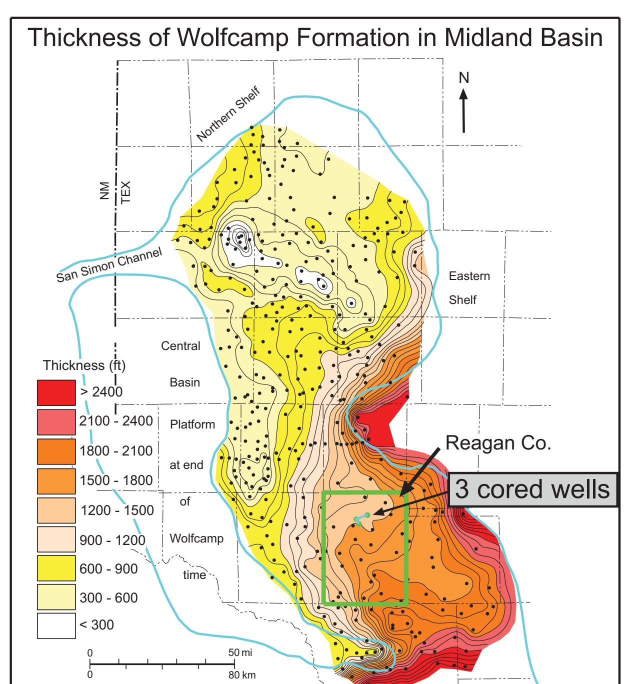
Similar log responses in study wells indicate facies are continuous over several miles.



Production totals 232 MMbbl of oil and 592 Bcf of gas from 1998 - 2011. Increase in production accelerated in 2003 due to advances in completion technology and increased size of hydraulic fracturing jobs.



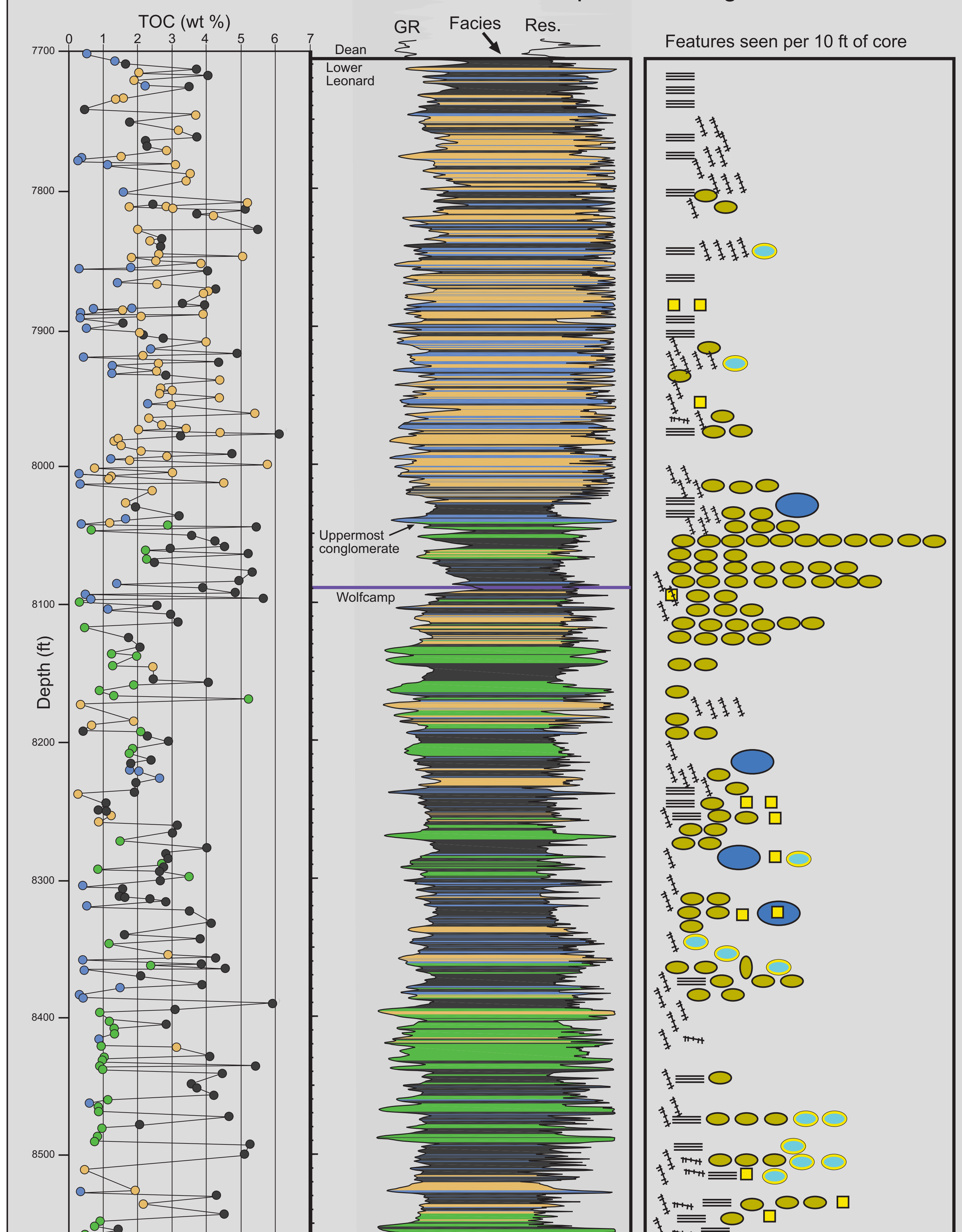
Oil production and size of frac jobs increased significantly in 2003.



Wolfcamp thickens to the south in the basin. Thickness at study wells is about 1450 ft.

CORE DESCRIPTION, FACIES, AND MINERALOGY

O. L. Greer # 1 Core Description and Logs

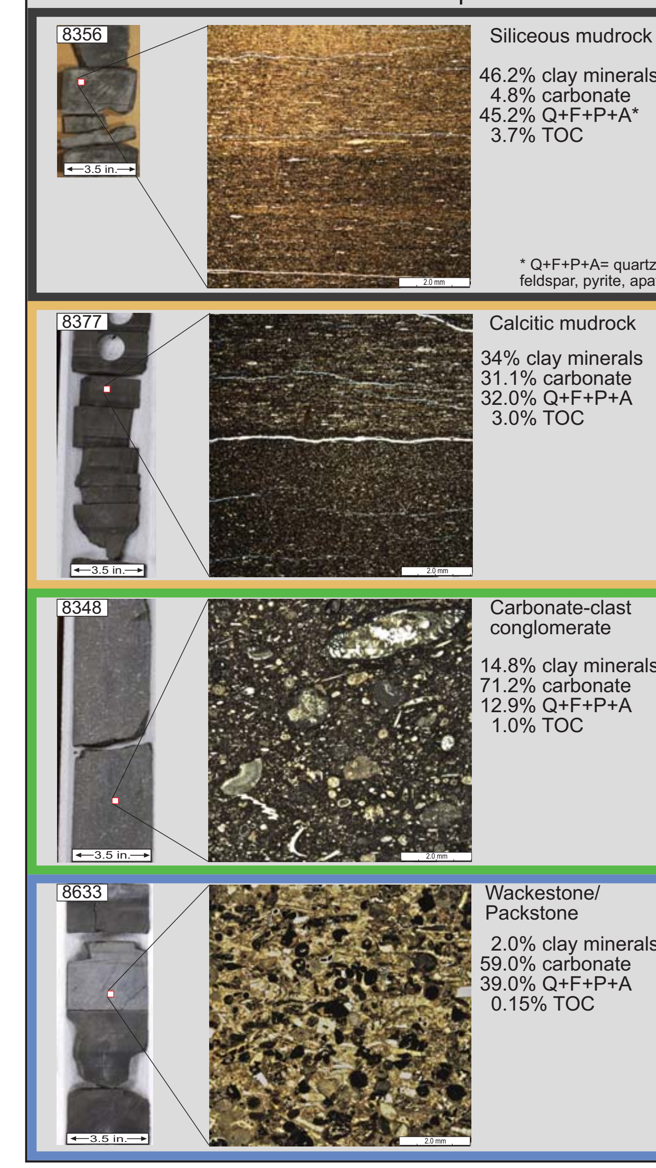


Facies based on core description
- Siliceous mudrock
- Calcitic mudrock
- Carbonate-clast conglomerate
- Wackestone/Packstone

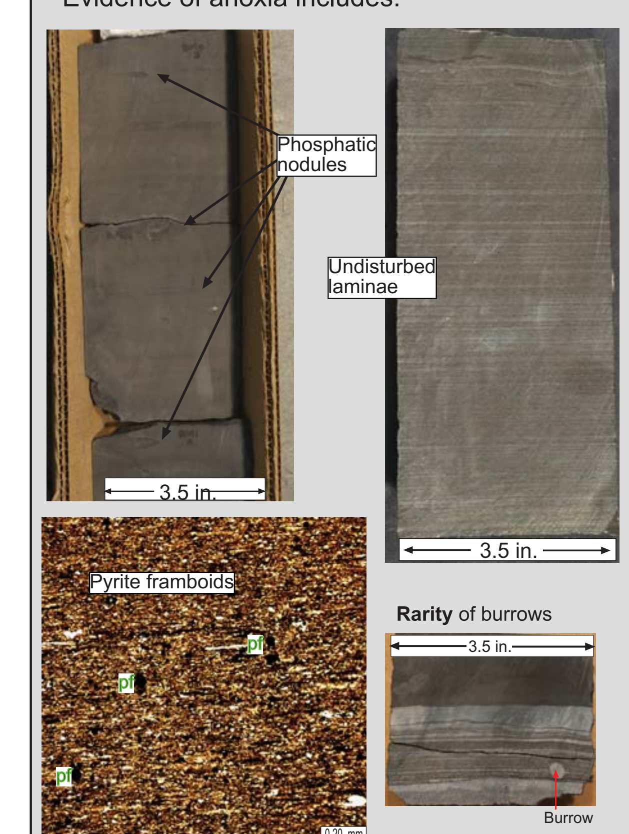
Key to Symbols
- Laminations
- Pyrite accumulation
- Fractures (vertical, horizontal)
- Carbonate concretion
- Phosphatic nodule
- Chert lens with pyrite rim

- TOC is highest in mudrocks, which are interbedded with high-carbonate facies.
- Laminations, phosphatic nodules, pyrite, and lack of burrows in fine-grained deposits indicate prevalence of anoxia in accumulating sediment.
- End of conglomerate deposition in early Leonard suggests change in distance to source (relative sea-level change) or in carbonate production, compared to late Wolfcamp time.
- Mineralized natural fractures are present throughout the cored interval, even in mudrocks.

Core/Thin Section Photos from Rupert P. Ricker #1



Evidence of anoxia includes:



Mean Values Mineralogy of Lithofacies

Lithofacies	XRD Mineralogy (wt %)			TOC
	Clays	Carb	Q+F+P+A	
Siliceous mudrock	38.8	5.8	52.4	3.0
Calcitic mudrock	13.7	51.9	32.3	2.1
Carbonate-clast conglomerate	12.9	61.3	24.7	1.2
Wackestone/Packstone	8.0	59.8	31.9	0.4

103 samples from 3 wells

Clay, siliciclastics, and TOC highest in siliceous mudrock. Carbonate highest in conglomerate and wackestone/packstone.

Mudrock Systems Research Laboratory
AAPG Meeting, May 2013
Bureau of Economic Geology

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Robert W. Baumgardner, Jr. and H. Scott Hamlin
Bureau of Economic Geology
Jackson School of Geosciences
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AAPG Meeting May 2013

INTRODUCTION TO GEOCHEMICAL STUDY

Important Observations II

- ED-XRF data can define (and provide detailed information about) facies not visible in core or on wireline logs.
- Total organic carbon (TOC) is highest in siliceous mudrocks, covaries strongly with productivity and siliciclastic proxies, and is ‘diluted’ by carbonate.
- Mo is not a reliable indicator of reducing conditions in these rocks, probably due to Mo-depletion caused by deepwater restriction.
- Multiple proxies indicate that organic matter is mostly marine, not terrestrial, in origin.
- Water column stratification and deepwater restriction changed near the end of Wolfcamp time.
- 3 levels of cyclicity exist: (1) cycles of sediment density-flow and hemipelagic deposits (few ft thick), (2) cycle sets (10s of ft thick), (3) megacycles of dominantly calcareous or siliceous cycle sets (100s of ft thick).
- Rock strength and facies cyclicity data enhance understanding of hydraulic fracture propagation.
- TOC and S_2 data locate zones of potential hydrocarbon production.

Major, minor, and trace element data were collected using ED-XRF (energy-dispersive x-ray fluorescence) scans on 1-ft spacing on an 858-ft continuous core. Elemental data are used to define facies and describe stratigraphic changes in geochemistry.

Principal geochemical proxies:

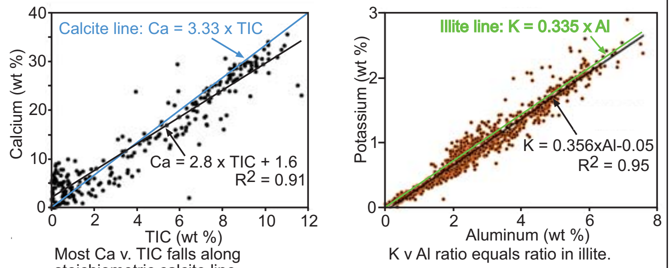
Sedimentology
Al, K = proxies for illite.
Si = proxy for quartz (Si not in illite).
Ti = proxy for terrigenous sediment.
Ca = proxy for calcite.

Paleo-redox, paleo-productivity
Cu, Ni, Zn = proxies for marine productivity.
Mo = proxy for reducing depositional setting.

Others
C_{org}/N_{tot} = marine vs. terrestrial organic matter.
Total organic carbon (TOC) = result of productivity, reducing conditions, and sedimentation rate/dilution.
$\delta^{13}C_{org}$ = paleoclimate/productivity/carbon source proxy.
$\delta^{15}N$ = denitrification/stratification proxy.

MINERALOGY, FACIES DEFINED WITH XRF

Ca, Al, and Si provide basis for defining mineralogy

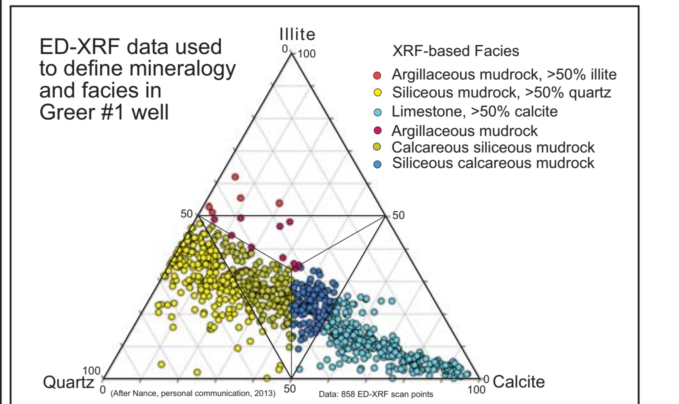


Most Ca v. TIC falls along stoichiometric calcite line.

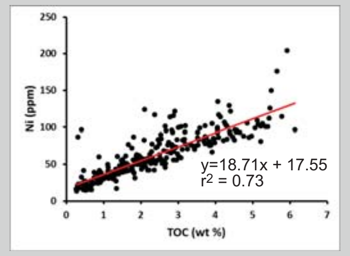
K v Al ratio equals ratio in illite.

Most Ca is in calcite and most Al is in illite. Assuming the remaining Si is in quartz provides basis for ternary diagram. Calculate each % based on molar ratios and normalize all to total 100%.

ED-XRF data used to define mineralogy and facies in Greer #1 well

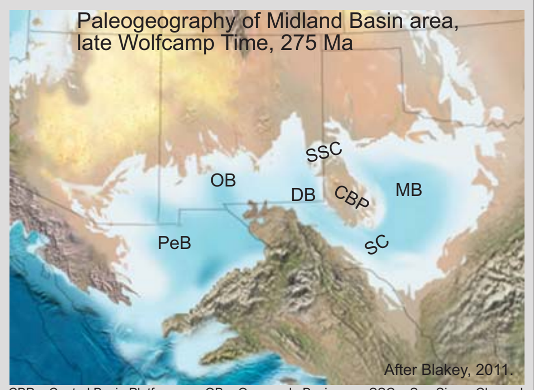


Facies based on dominant mineral in each sub-triangle. Carbonate varies most. Clay minerals are subordinate component.



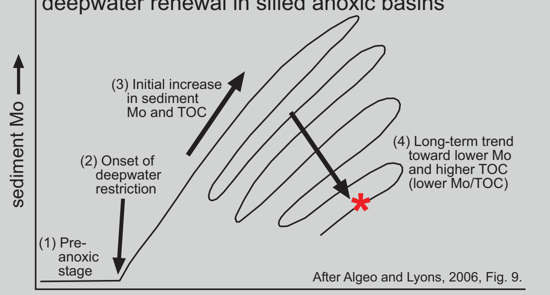
Ni (marine productivity proxy) is closely correlated with TOC, which indicates TOC is primarily marine organic matter.

DEEPWATER RESTRICTION



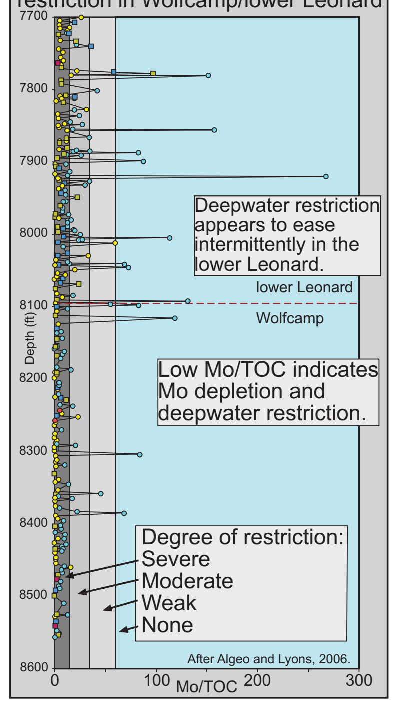
CBP = Central Basin Platform; DB = Delaware Basin; MB = Midland Basin; OB = Orogrande Basin; PeB = Pedregosa Basin; SC = Sheffield Channel; SSC = San Simon Channel

Water exchange between ocean (lower left) and Midland Basin was restricted in Wolfcamp time, producing stagnation and/or stratification.

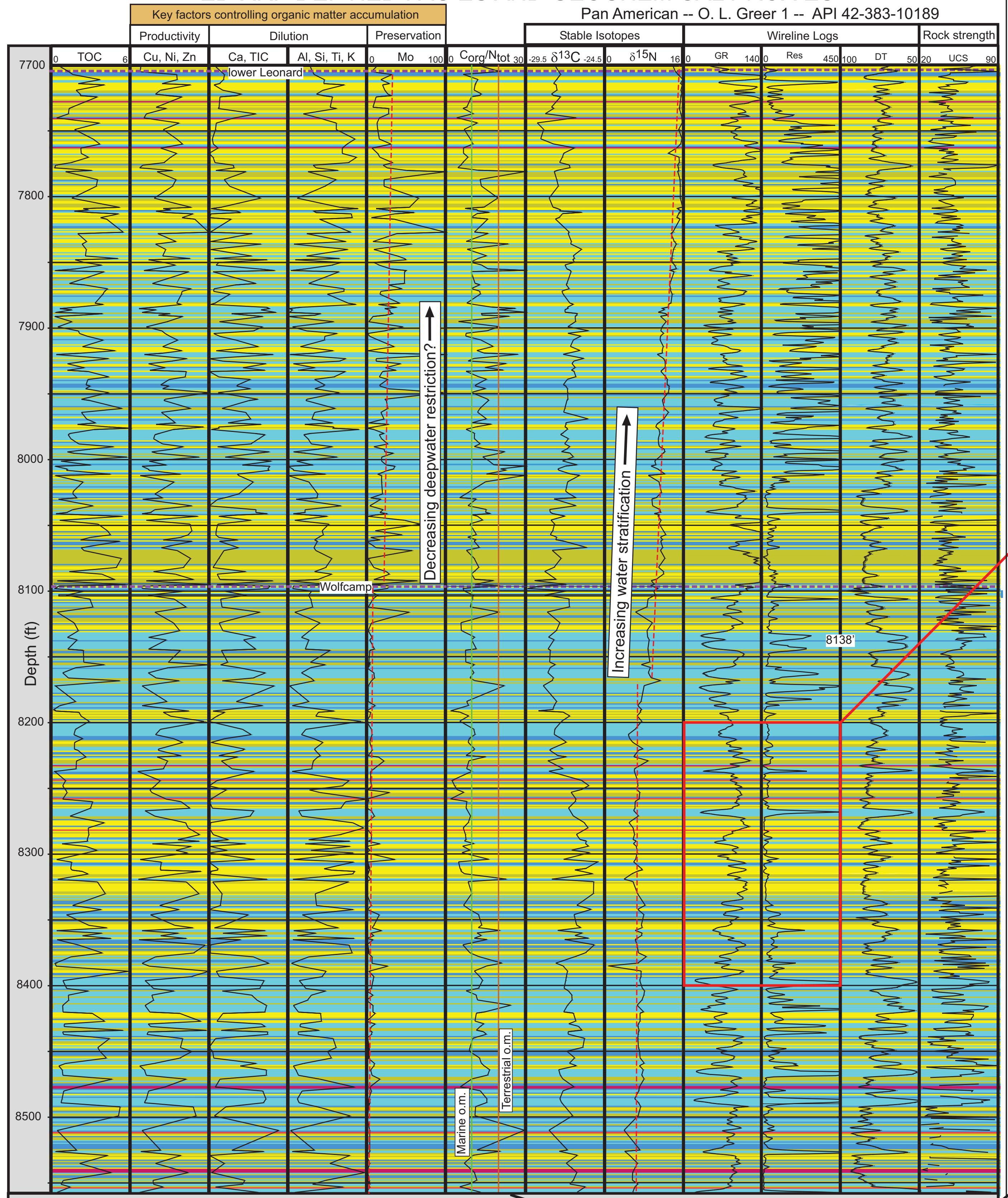


In late Wolfcamp time represented by Greer 1 core (red asterisk), low Mo values, decoupled from TOC values, suggest deepwater was Mo-depleted due to restricted circulation.

Mo/TOC ratio shows deepwater restriction in Wolfcamp/lower Leonard



ED-XRF-DEFINED FACIES AND GEOCHEMICAL PROXIES



XRF-based Facies: Argillaceous mudrock; Siliceous mudrock; Limestone; Argillaceous mudrock; Calcareous siliceous mudrock; Siliceous calcareous mudrock

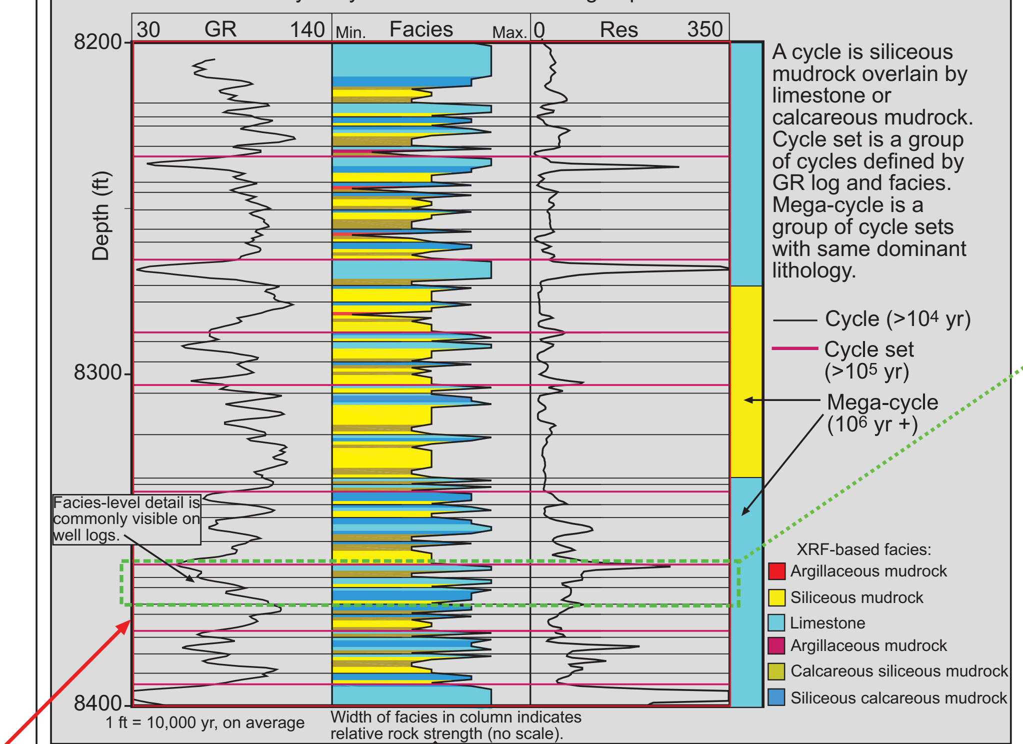
Best-fit line

Proxy data = 258 ED-XRF data points at TOC, isotope sample points.

- TOC varies most directly and correlates best with marine productivity proxies, indicating organic matter is mostly marine.
- TOC varies inversely with (is ‘diluted’ by) carbonate proxies.
- TOC varies directly with siliciclastic proxies, indicating organic matter and terrigenous detrital fraction accumulated together.
- Primary lithologic components--carbonate and siliciclastics--offset (’dilute’) one another.
- Mo is not a reliable indicator of reducing conditions here, probably as a result of Mo-depletion.
- C_{org}/N_{tot} ratio indicates most organic matter is marine.
- $\delta^{13}C_{org}$ mostly varies inversely with C_{org}/N_{tot}, suggesting that high (enriched) $\delta^{13}C_{org}$ indicates marine organic matter.
- Mo and $d^{15}N$ increase near end of Wolfcamp time, indicating: (1) deepwater restriction eased, but (2) stratification in upper water increased.
- Wireline logs respond to facies, commonly, at about 1-ft resolution, e.g., 8138 ft.
- Unconfined compressive strength (UCS) varies directly with sonic (DT) log response.

FACIES-BASED CYCLICITY

Three levels of cyclicity are seen in facies and groups of facies

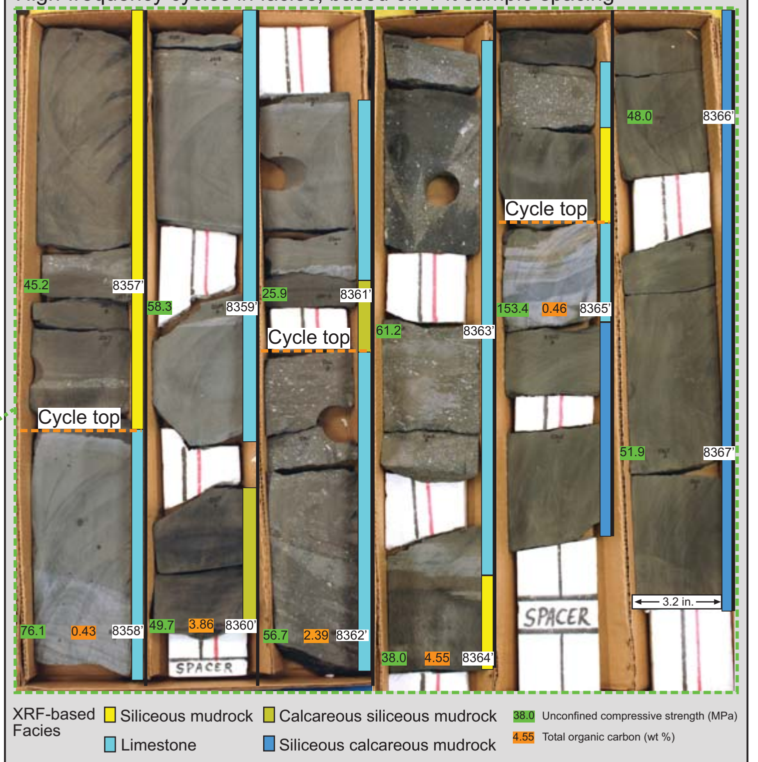


A cycle is siliceous mudrock overlain by limestone or calcareous mudrock. Cycle set is a group of cycles defined by GR log and facies. Mega-cycle is a group of cycle sets with same dominant lithology.

1 ft = 10,000 yr, on average

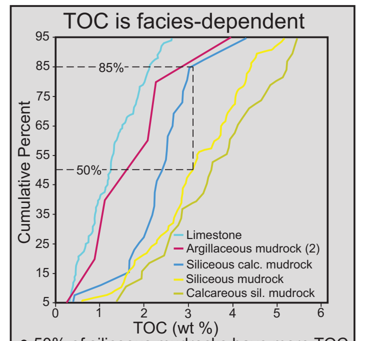
Width of facies in column indicates relative rock strength (no scale).

High-frequency cycles in facies, based on 1-ft sample spacing



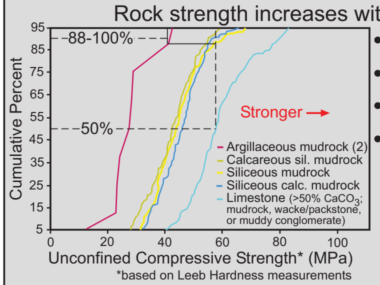
Interlayering (cyclicity) of facies with different strengths may affect vertical propagation of fractures. High-strength rocks have low TOC and vice versa.

TOC is facies-dependent



- 50% of siliceous mudrocks have more TOC than at least 85% of all other facies.
- Most TOC above 2% in siliceous mudrocks.

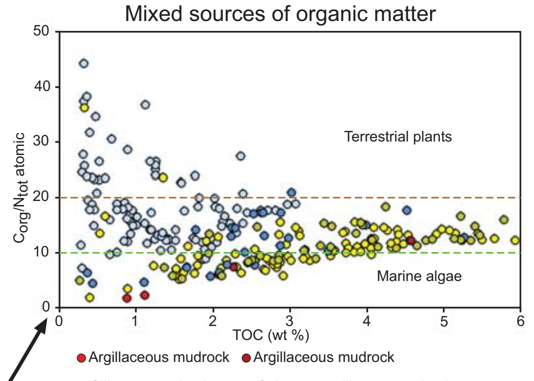
Rock strength increases with calcite content



*based on Leeb Hardness measurements

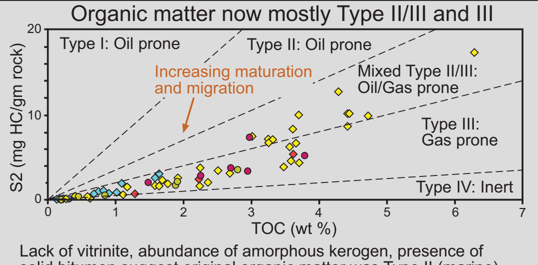
- 50% of limestones are stronger than 88-100% of all other facies.
- Argillaceous mudrocks are much weaker than other facies.
- Siliceous and calcareous mudrocks are almost indistinguishable.
- Factors important for hydraulic fracturing: 1. stacking patterns (cyclicity) of brittle and weak beds, 2. high-TOC facies.

Mixed sources of organic matter



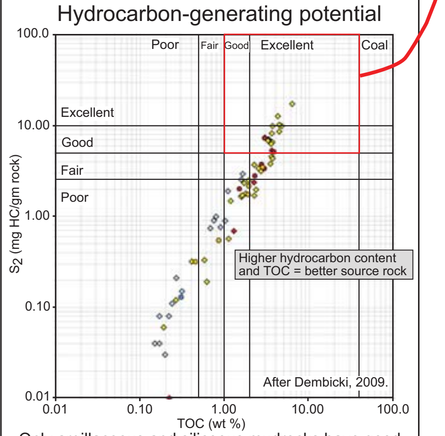
Terrestrial plants have higher C_{org}/N_{tot} ratio than marine algae (Algeo and others, 2008). Siliceous facies have more marine signature and higher TOC than calcareous facies.

Organic matter now mostly Type II/III and III



Lack of vitrinite, abundance of amorphous kerogen, presence of solid bitumen suggest original organic matter was Type II (marine), now matured to mixed Type II/III and Type III.

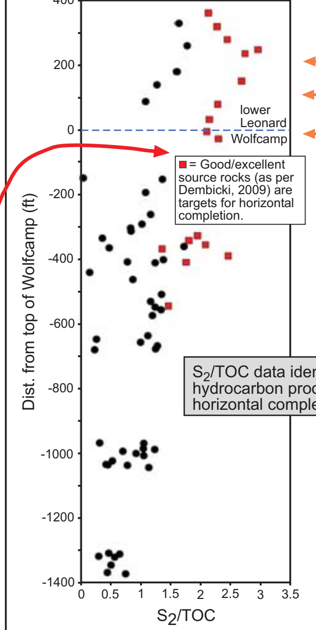
Hydrocarbon-generating potential



Only argillaceous and siliceous mudrocks have good to excellent hydrocarbon-generating potential.

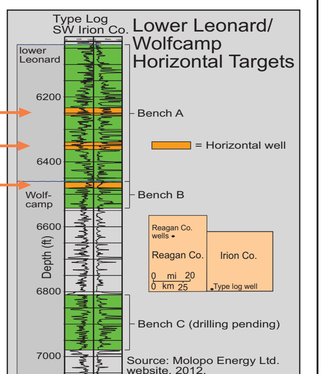
TOC AND ROCK EVAL ID FACIES TARGETS

Good source rocks identified in lower Leonard and Wolfcamp



Data from 3 Reagan Co. wells: O.L. Greer 1, 2; Rupert P. Ricker 1.

Lower Leonard/ Wolfcamp Horizontal Targets



Source: Molopo Energy Ltd. website, 2012.

S_2/TOC data identify zones of potential hydrocarbon production targeted for horizontal completion.

ACKNOWLEDGMENTS

ED-XRF data in collaboration with Harry Rowe, Bureau of Economic Geology. XRD data from Necip Guven, UT San Antonio; Weatherford Labs. TOC, $\delta^{13}C$, $\delta^{15}N$ data from UT Arlington lab. Thin sections from Spectrum Petrographics. Rock Eval, TOC, vitrinite reflectance data from: Weatherford Labs, GeoMark Research. Core preparation and access: Core Research Center, Bureau of Economic Geology.

REFERENCES

Algeo, T. J., and Lyons, T. W., 2006, Mo-total carbon covariation in modern anoxic marine environments: Implications for analysis of paleoredox and paleohydrographic conditions: Paleoceanography, v. 21, PA1016, doi: 10.1029/2004PA001112.
Algeo, T. J., Rowe, H., Hower, J. C., Schwark, L., Herrmann, A., and Heckel, P., 2008, Changes in ocean denitrification during Late Carboniferous glacial-interglacial cycles: Nature Geoscience, v. 1, p. 709-714.
Blakey, R., 2011, North American series, 275 ma: http://cpgeosystems.com/paleomaps.html.
Dembicki, H., Jr., 2009, Three common source rock evaluation errors made by geologists during prospect or play appraisals: AAPG Bulletin, v. 93, no. 3, p. 341-356.
IHS Energy, 2012, Online production and completion data: All rights reserved.
Rowe, H., Loucks, R. G., Ruppel, S.C., and Rimmer, S. M., 2008, Mississippian Barnett Formation, Fort Worth Basin, Texas: bulk geochemical inferences and Mo-TOC constraints on the severity of hydrographic restriction: Chemical Geology, v. 257, p. 16-25.