WEDNESDAY AM POSTER ABSTRACTS

WED, SEPT 28; AM SESSION

Lithofacies of the Wolfcamp and Lower Leonard interval, Southern Midland Basin, Texas

Robert W. Baumgardner, Jr., H. Scott Hamlin, and Harry D. Rowe

Basinal mudrocks and associated facies assigned to the Wolfcamp and lower Leonard lithostratigraphic units in the Midland Basin are prolific producers of oil and gas. Four facies are recognized in core on the basis of macroscopic examination, XRD analysis, and EDelemental chemistry: (1) siliceous mudrock, (2) calcareous mudrock, (3) muddy bioclast-lithoclast floatstone, and (4) skeletal wackestone/packstone. Mudrocks are largely hemipelagic deposits of fine-grained sediment delivered by suspension settling. Floatstones were deposited by debris flows that originated on carbonate shelves around the basin. Wackestone/packstones are finer-grained sediment density flow deposits, probably turbidites, reworked by local bottom currents. These sediments were deposited below storm wave base in a basin having limited connection to the open ocean. During deposition low-oxygen conditions prevailed in bottom waters and sediments as shown by presence of agglutinated foraminifera, rarity of burrows, widespread prevalence of small (<6 mm) pyrite framboids, presence of phosphatic nodules, and elevated molybdenum concentrations. Total organic carbon (TOC) content reaches 6.8 percent. TOC is facies-dependent (highest in siliceous mudrock), and varies widely within small vertical distances. Cyclicity is evident in individual meter-thick, upward-fining cycles of floatstone or wackestone/packstone, overlain by calcareous and siliceous mudrock. strength increases as calcite content increases, likely as a result of diagenetic cementation. Most kerogen in the lower Leonard/Wolfcamp interval is in the oil-production window and has matured to Type II-III ("oil-gas-prone").

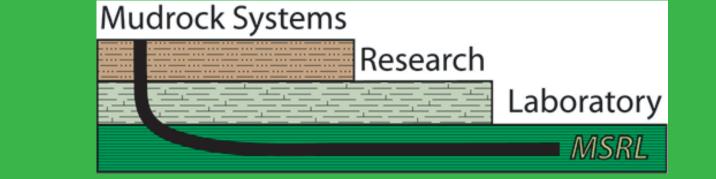
Based on their TOC and hydrogen content, the siliceous mudrocks have the highest potential for hydrocarbon generation.





Lithofacies of the Wolfcamp and Lower Leonard Intervals, Southern Midland Basin, Texas

Robert W. Baumgardner, Jr., H. Scott Hamlin, and Harry D. Rowe



Jackson School of Geosciences Bureau of Economic Geology

Report of Investigations 281

Abstract

The study summarized here, Bureau of Economic Geology Report of Investigations 281, is a sequel to RI 277 (Hamlin and Baumgardner, 2012), a regional treatment of Wolfberry deep-water depositional systems in the Midland Basin. Herein are described the basinal mudrocks and associated facies of the Wolfcamp and lower Leonard lithostratigraphic units as found in cores near the center of the southern Midland Basin.

Four facies are recognized in core: (1) siliceous mudrock, (2) calcareous mudrock, (3) muddy bioclast-lithoclast floatstone, and (4) skeletal wackestone/packstone. Mudrocks are largely hemipelagic deposits of fine-grained sediment delivered by suspension settling. Floatstones were deposited by debris-flows that originated on carbonate shelves around the basin. Wackestones/packstones are finer-grained sediment density-flow deposits, probably turbidites, reworked locally by bottom currents.

During deposition, low-oxygen conditions prevailed in bottom waters and sediment. Total organic carbon content (TOC) content reaches 6.8 percent. TOC is facies-dependent and varies widely within small vertical distances.

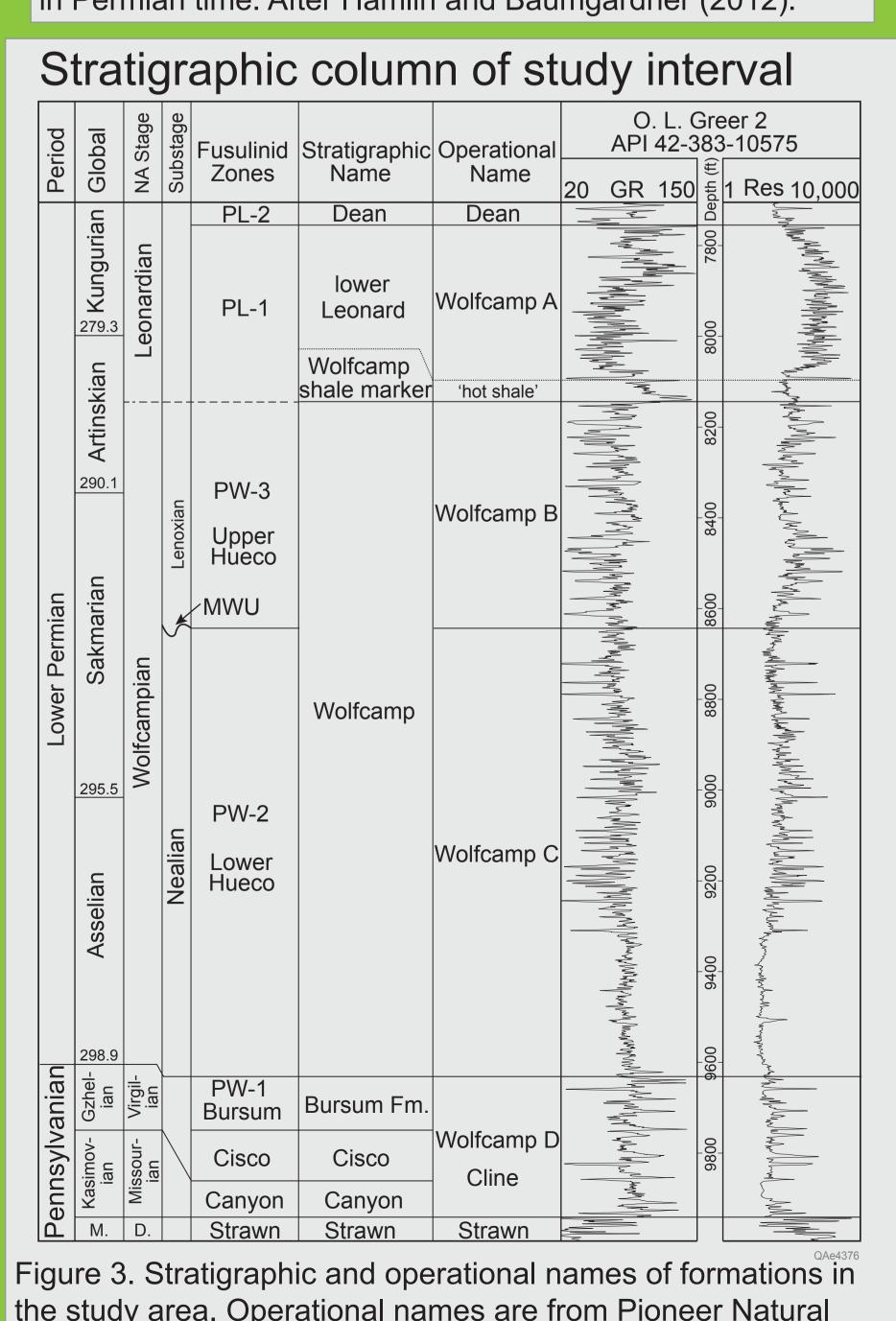
Cyclicity is evident in individual meter-thick, upward-fining cycles of floatstone or wackestone/packstone overlain by mudrock.

Rock strength increases with calcite content.

Most kerogen in the lower Leonard-Wolfcamp interval is in the oil-production window and has matured to Type II-III ("oil-gas prone"). Based on TOC and hydrogen content, siliceous mudrocks have the highest hydrocarbon-generating potential.

Map of study area Matador Arch

Figure 1. Principal structural elements of Midland Basin area in Permian time. After Hamlin and Baumgardner (2012).



Resources (2013). Substages and fusulinid zones from

Wahlman and Tasker (2013), after Ross (1963) and Wilde (1990)

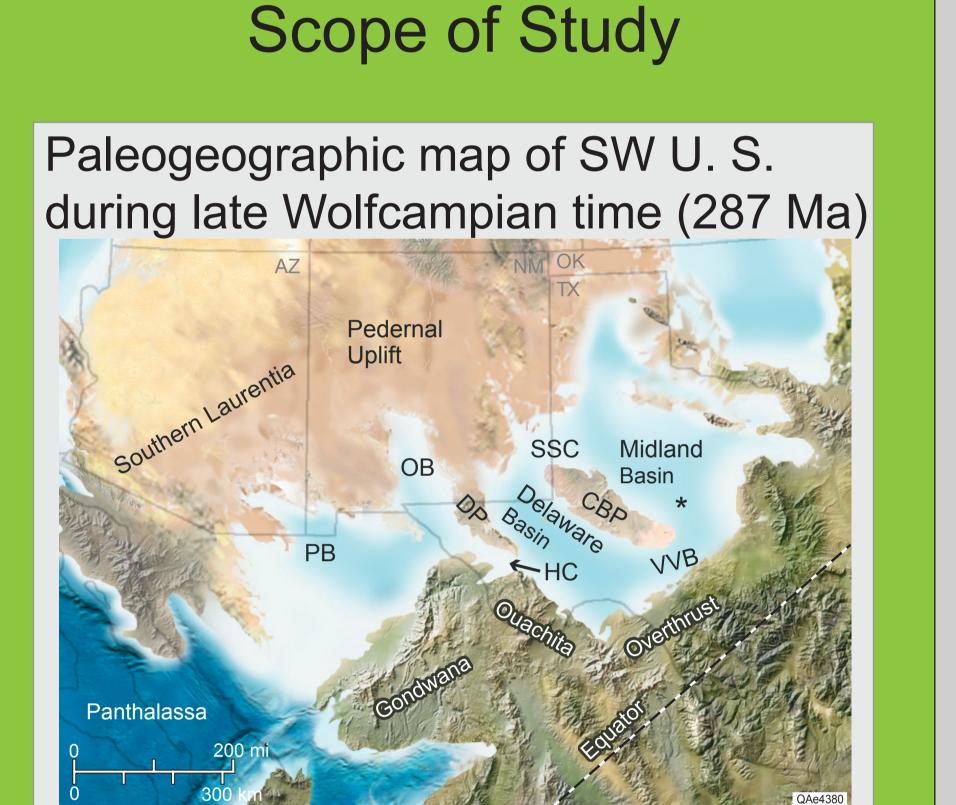


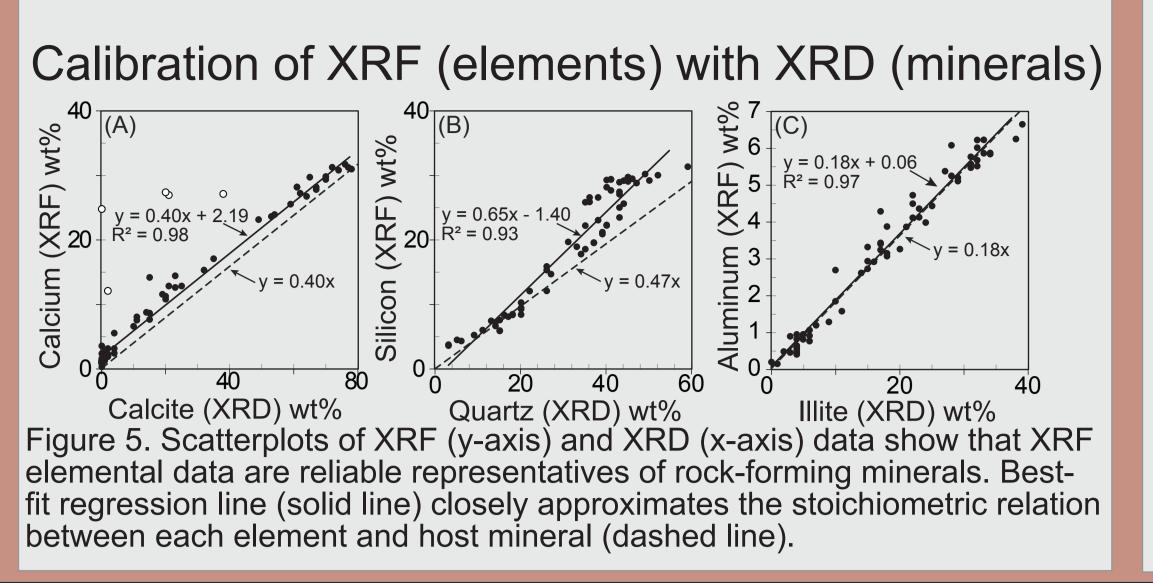
Figure 2. The Midland Basin was separated from open ocean by the Val Verde (VVB), Delaware (DB), Orogrande (OB) and Pedregosa Basins (PB), connected by channels such as the San Simon (SSC) and Hovey (HC). Isolation from oceanic circulation enhanced development of anoxia. Position of paleoequator from Walker and others (1995). After Blakey (2014), used with permission.

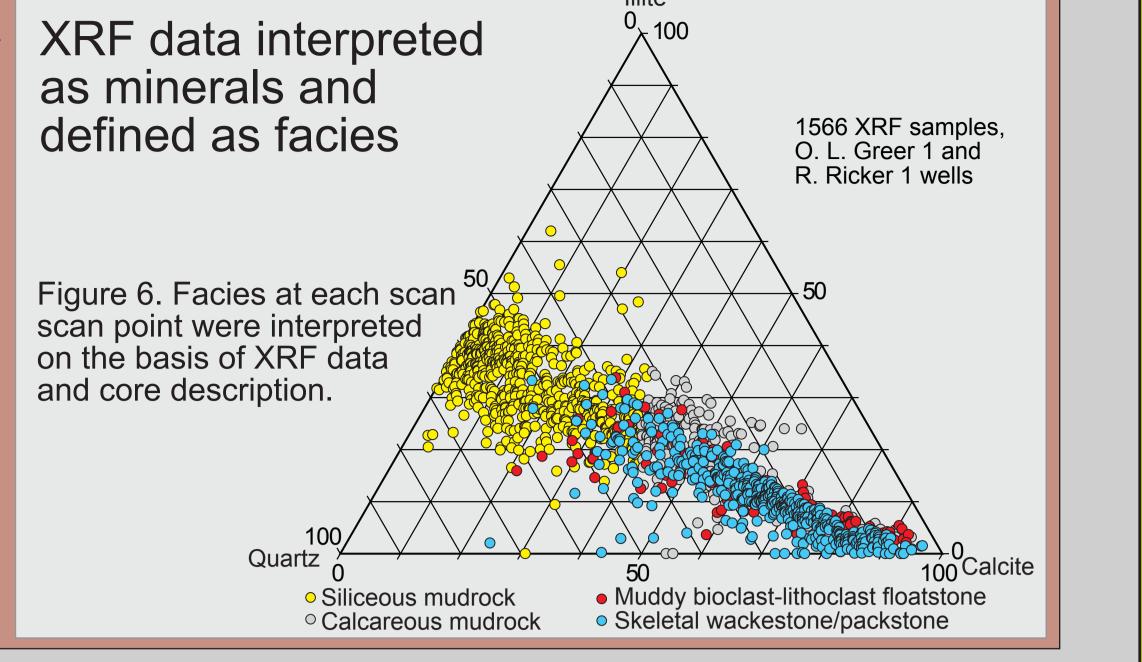
Cores used in study

000 000 000 000 000 000 REAGAN CO.,TX • ← 0.75 mi → • ← 4.0 mi → • ← 3.1 mi → • QAe4384 Figure 4. The most complete basinal cores publicly available were chosen for study. Greer 1 is the most continuous core; description is shown in Fig. 8. All cores are described in RI 281. Map of correlative carbonate beds (green boxes) is shown in Fig. 11. Lowest correlative carbonate bed in Rupert P. Ricker 1 core is shown in Fig. 7D. Location

of Reagan County is shown on Figure 1.

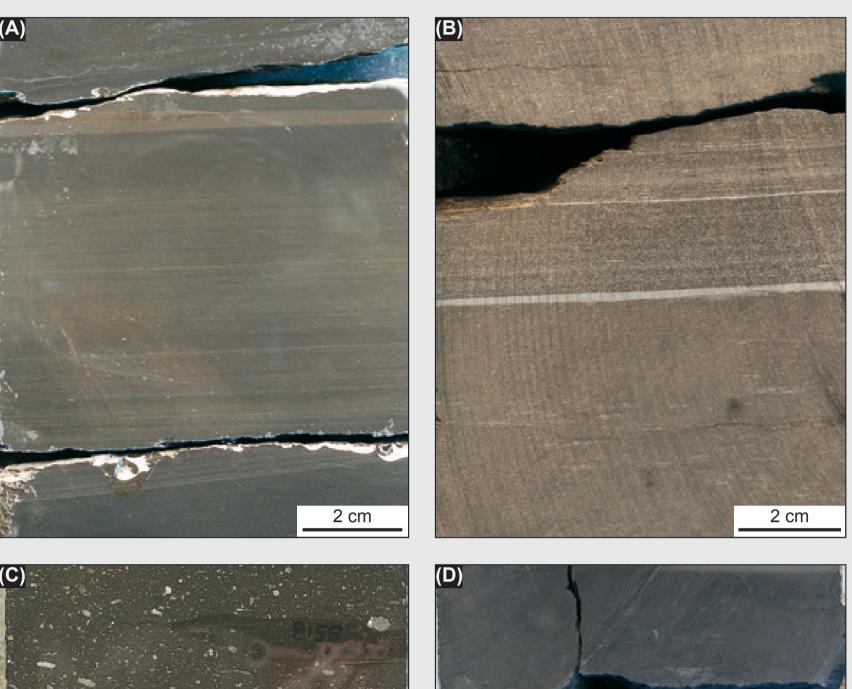
Facies Based on XRF, XRD, Core Data XRF data interpreted





Characteristics of Interpreted Lithofacies





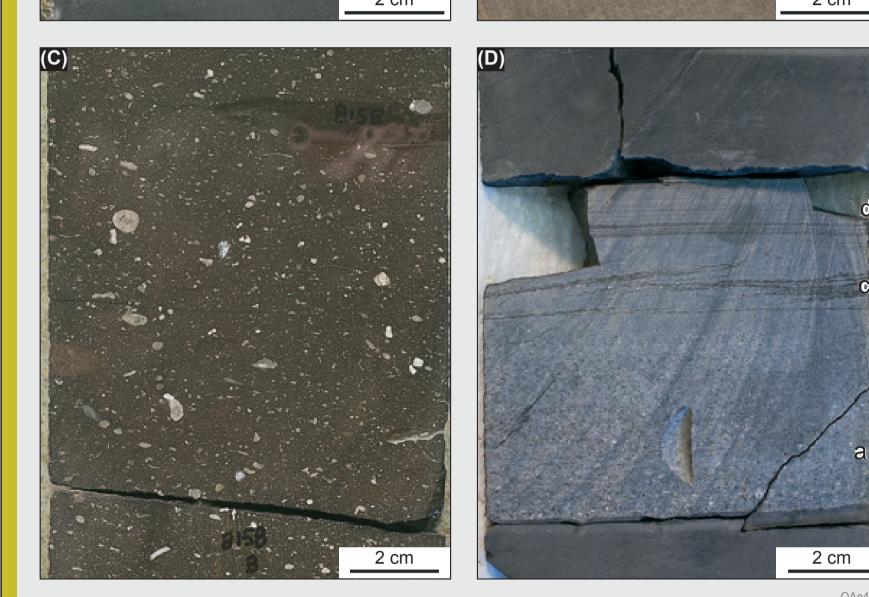


Figure 7. Photographs of slabbed core showing interpreted facies. (A) Siliceous mudrock. (B) Calcareous mudrock. (C) Muddy bioclast-lithoclast floatstone. Unsorted, chaotic character indicates rapid flow and deposition. (D) Skeletal wackestone/packstone. Letters indicate stages in Bouma (1962) sequence: a = graded interval; c = interval of current lamination; d = upper interval of parallel laminations. Absence of interval b is due to rapid change from upper-flow to lowerflow regime.

LOCATION MAP

Skeletal wackestone/ packstone

Figure 8. Facies interpreted from O. L. Greer 1 core, the most complete

common in the lower Leonard. The highest floatstone (arrow) lies near the

top of the Wolfcamp Shale marker (Fig. 3), and coincides with an era of

rapid rise in sea level. Low GR corresponds to relatively clay-poor facies.

core studied. Siliceous mudrocks and floatstones dominate the upper

Basinal facies in cores from Wolfcamp and lower Leonard

Facies	Composition	thickness	structures	Accessories	mechanism	elements
Siliceous	Mud to very fine carbonate sand, organic matter, clay minerals, rare terrestrial plant fragments, bioclasts <5%	1 inch to 13 ft	Massive to weakly laminated	Pyrite fram- boids, phos- phatic nodules, soft-sediment deformation, rare burrows, fissile locally	Hemipelagic settling	Hemipelagic sheets
Calcareous mudrock	Carbonate mud to very fine carbonate sand, organic matter, minor clay minerals, bioclasts <30%	1 inch to 6 ft	Massive to weakly laminated	Pyrite framboids, uncommon phos- phatic nodules, rare burrows	Hemipelagic settling	Hemipelagic sheets
Muddy bioclast- lithoclast floatstone	Matrix: argilla - ceous carbonate mudrock, minor clay minerals, minor organic matter Clasts: lime - stone lithoclasts and marine bioclasts	1 inch to 9 ft	Sharp upper and lower contacts, chaotic texture; sand to gravelsize clastsfloating in fine-grained matrix; clast- to matrix -dominated	Soft-sediment deformation, sutured grains, reworked phosphatic nodules, pyrite mostly crystals on clasts	Debris flow	Sheet deposi
Skeletal wacke- stone/ packstone	Limestone lithoclasts and marine bioclasts; carbonate and minor quartz sand and silt, carbonate mud matrix, minor clay minerals	0.5 inch to 4 ft	Erosional lower contacts, graded bedding, cross- beds, ripples, laminae, rare Bouma sequence	Soft-sediment deformation, sutured grains, pyrite mostly crystals on clasts, cherty lenses, rare burrows	Turbidity flow	Sheet deposi

Total organic carbon data by facies									
Facies	Min.TOC	Max. TOC	Ave. TOC	n					
Siliceous mudrock	0.44	6.80	3.61	238					
Calcareous mudrock	0.22	5.78	2.45	94					
Muddy bioclast-lithoclast floatstone	0.30	5.22	1.37	52					
Skeletal wackestone/packstone	0.15	4.98	1.63	170					
Table 2. Total organic carbon (TOC) is higher in siliceous mudrocks than									
in any other facies Data = 564 TOC samples from four wells									

Vertical Variability of Lithofacies in the O. L. Greer 1 core

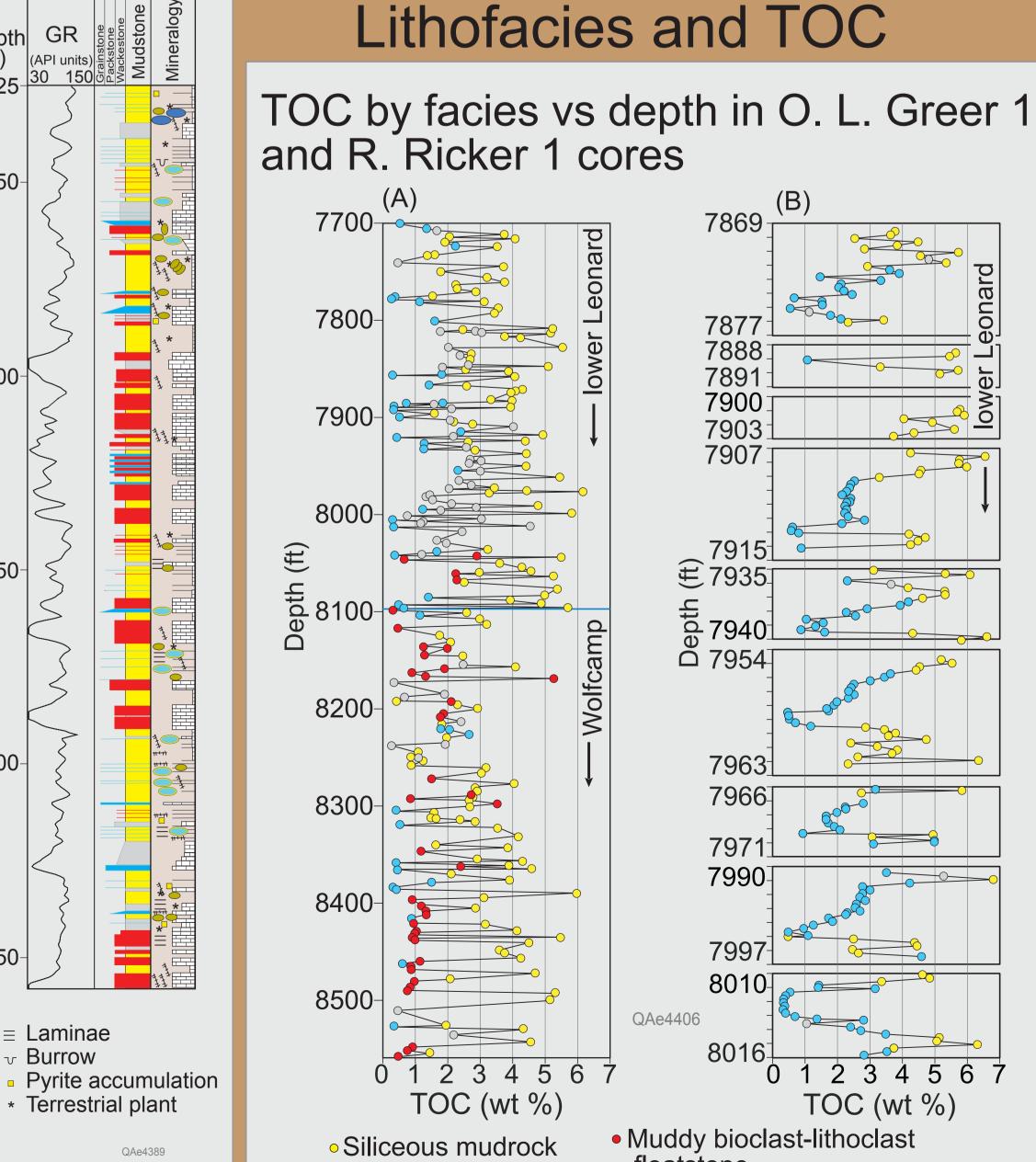
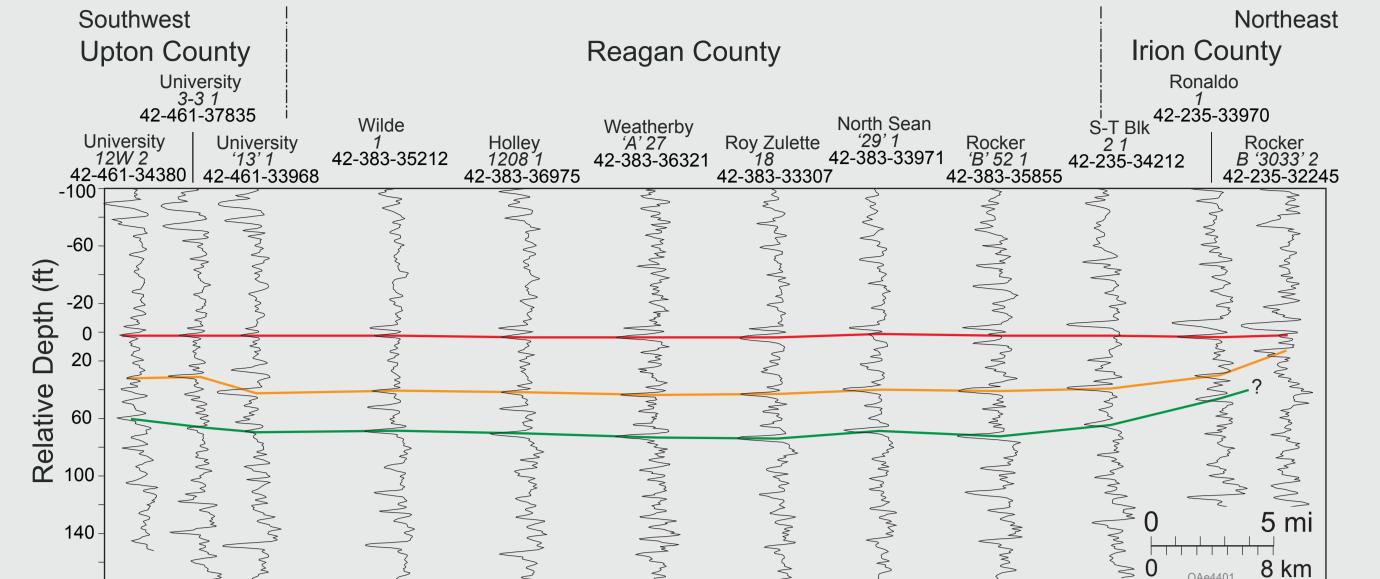


Figure 9. Depth plot of total organic carbon in O. L. Greer 1 core (A) and parts of R. Ricker 1 core (B). Vertical scale changes between cores. TOC values are largely faciesrelated and change abruptly over small vertical distances. Almost all values higher than 3% are in siliceous mudrock.

Lateral Continuity and Cyclicity of Lithofacies Cross section showing correlative carbonate beds



continuity are similar to Recent analogues (Bennetts and Pilkey, 1976). Location of cross section is shown on Figure 11. Stratigraphic position is shown on Figure 4.

Map of correlative carbonate beds

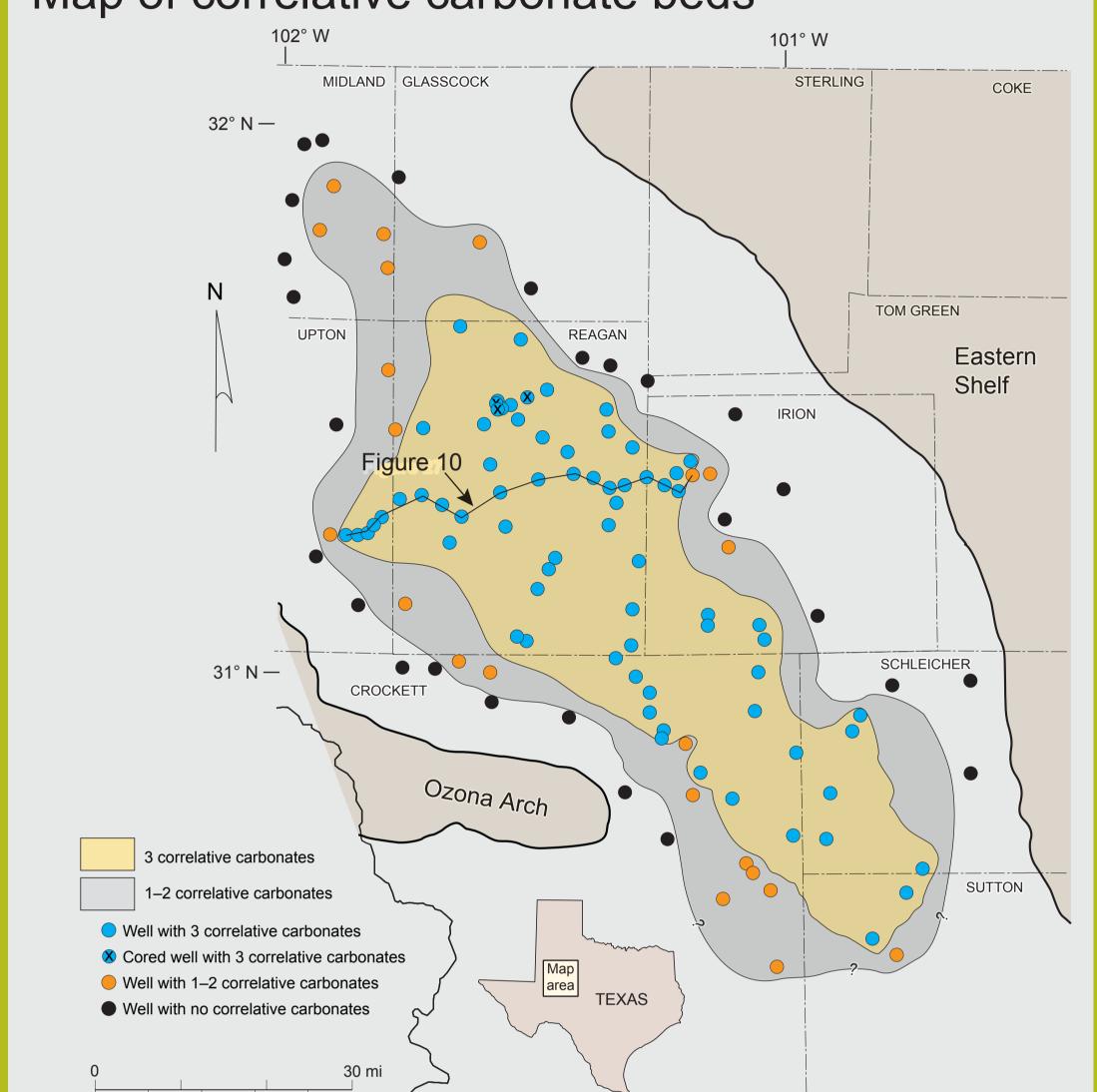
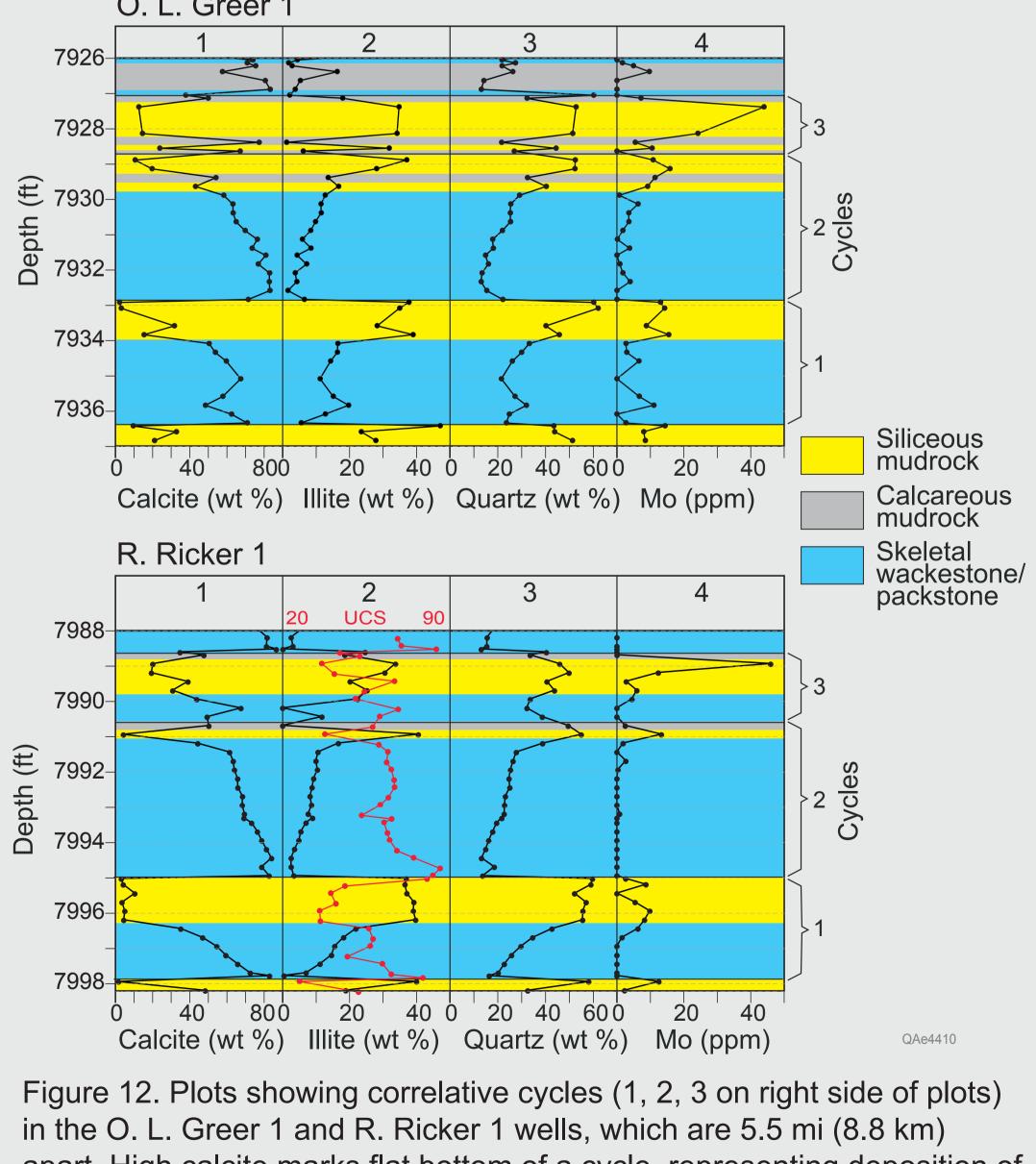


Figure 11. Map of three distinctive correlative carbonate-rich beds in the lower Wolfcamp interpreted from gamma-ray well logs. The three beds are shown on figure 4. Each carbonate bed forms a sheetlike deposit covering about 1,800 mi² (4,600 km²). Cross section line shows location of Figure 10

Small-scale cyclicity and lateral continuity of carbonate deposition



apart. High calcite marks flat bottom of a cycle, representing deposition show gradual upward increase above low values at the beginning of each cycle. Molybdenum (an indicator of reducing conditions) increases sharply near top of some cycles, reflecting return to background, low-oxygen (rock strength, shown in red) is negatively correlated with illite (See discussion of rock strength).

Rock Strength

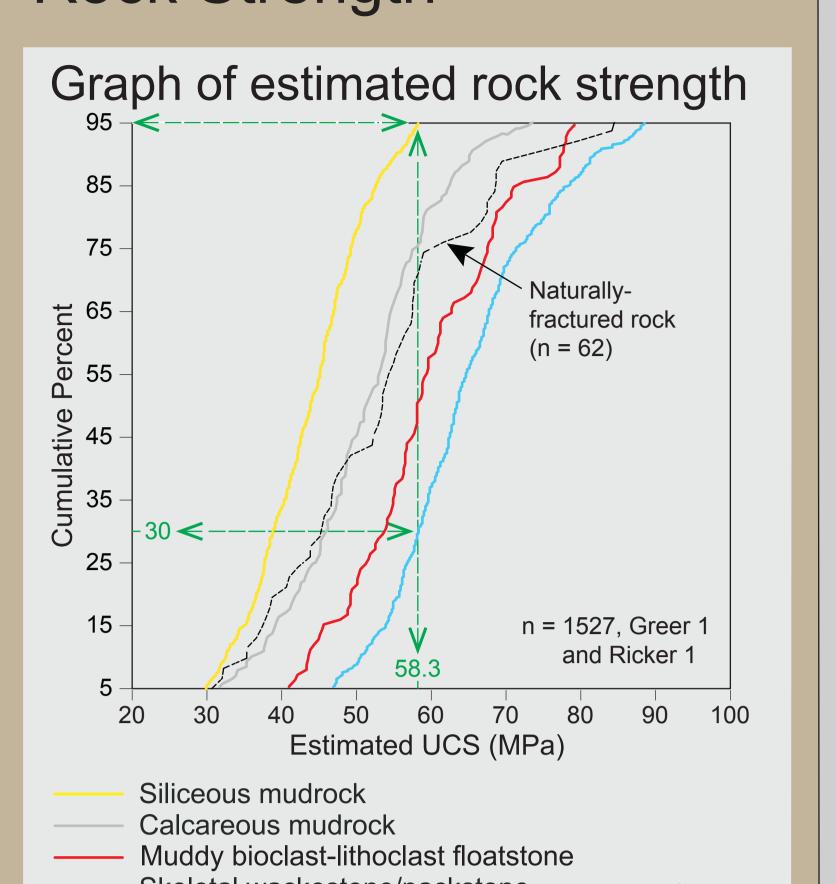


Figure 13. Most siliceous mudrocks (95%) have rock strength less than 58.3 MPa, while 70% of skeletal wackestones/packstones have rock strength greater than that. Combined with interbedded character of basinal facies, these data suggest that vertical variability in rock strength may contribute to small-scale complexity of hydraulic-fracture networks (Slatt and Abousleiman, 2011).

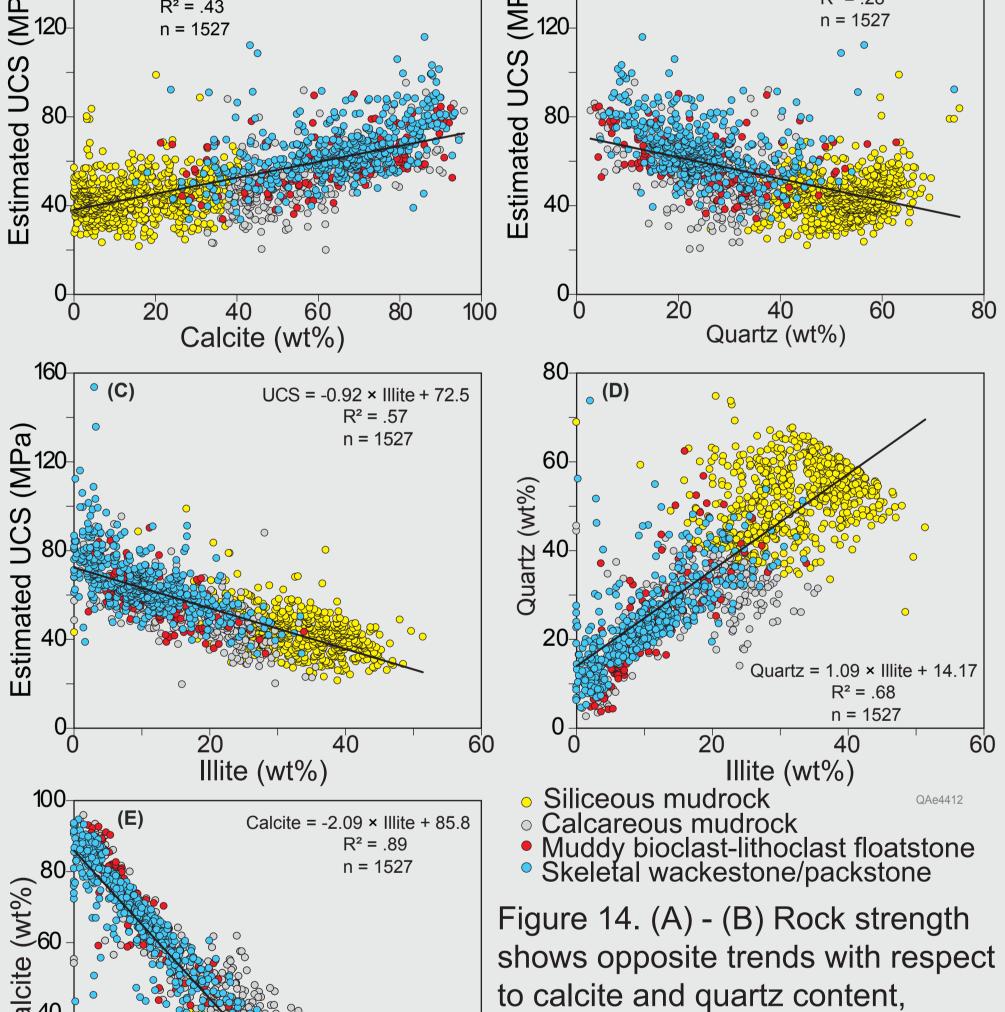
Unconfined compressive strength (UCS)

Calcareous mudrock

Muddy bioclast-lithoclast floatstone

Skeletal wackestone/packstone 473 33.7 153.4 65.4 * if one anomalously high (98.8) value is ignored Table 3. Estimated unconfined compressive strength (UCS) is lower for mudrocks than for other facies.

Crossplots of rock strength and mineralogy



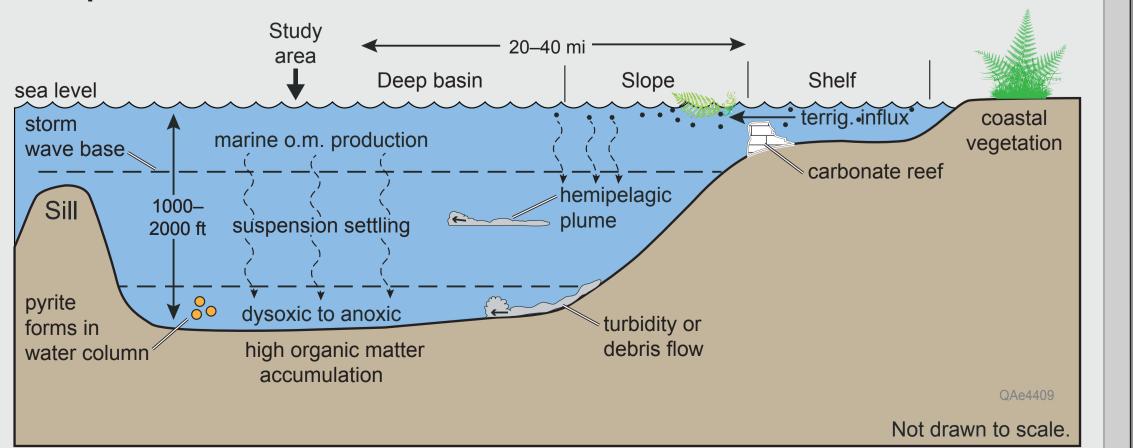
primarily because illite, which

lowers rock strength (C), is posi-

tively correlated with quartz (D)

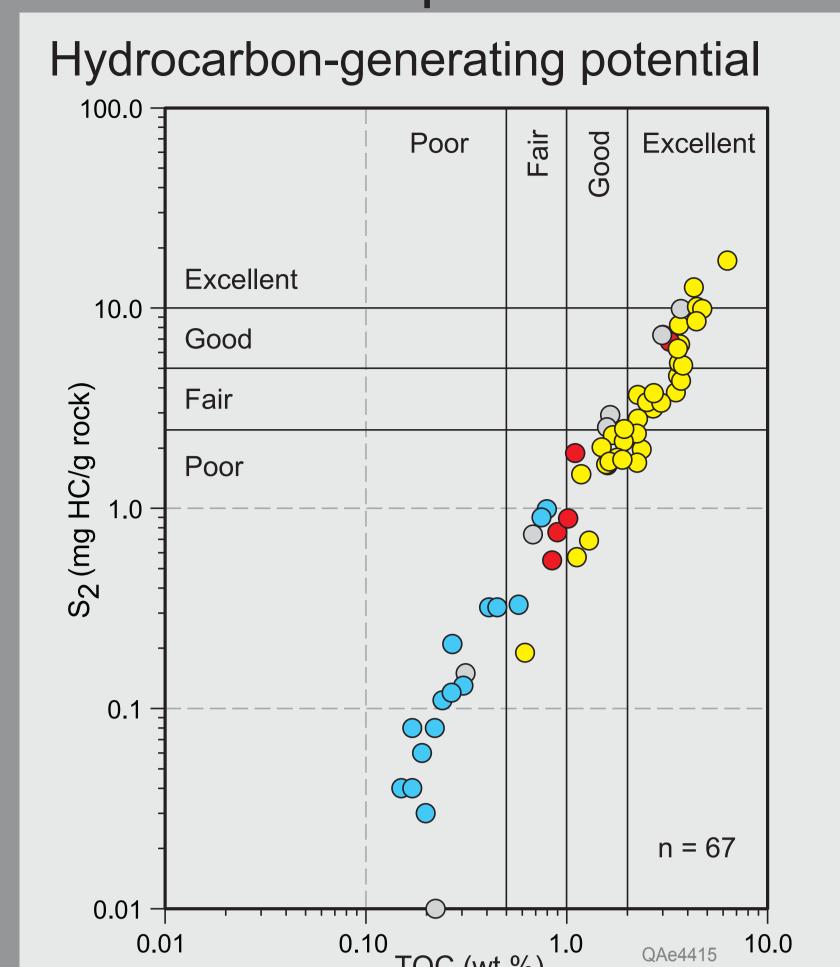
and negatively correlated with

Depositional model of basinal sedimentation



deposition of carbonate-rich, organic-matter-poor debris or turbidity flows that originated on basin margins. After Loucks and Ruppel (2007)

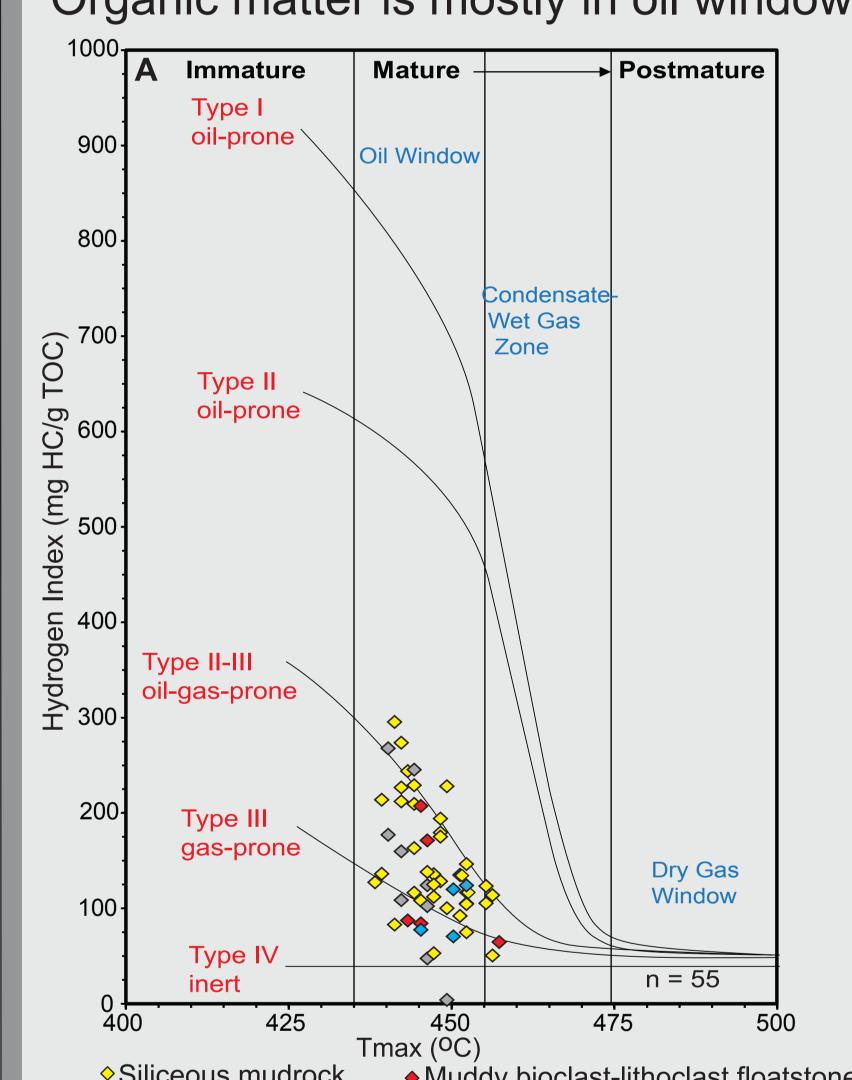
Reservoir Properties



○ Calcareous mudrock ○ Skeletal wackestone/packstone Figure 16. Siliceous and calcareous mudrocks have greater hydrocarbon-generating potential than floatston or wackestones/packstones. S_2 = hydrocarbon formed during thermal decomposition of kerogen. Data provided by Weatherford Labs and GeoMark Research. Categorie of hydrocarbon-generating potential after Dembicki (2

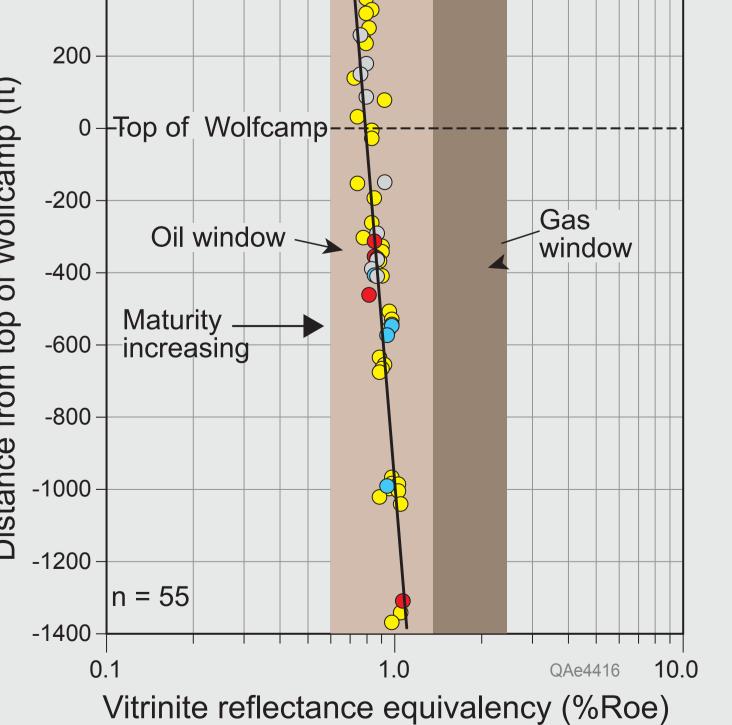
Siliceous mudrock Muddy bioclast-lithoclast floatstone

Organic matter is mostly in oil window

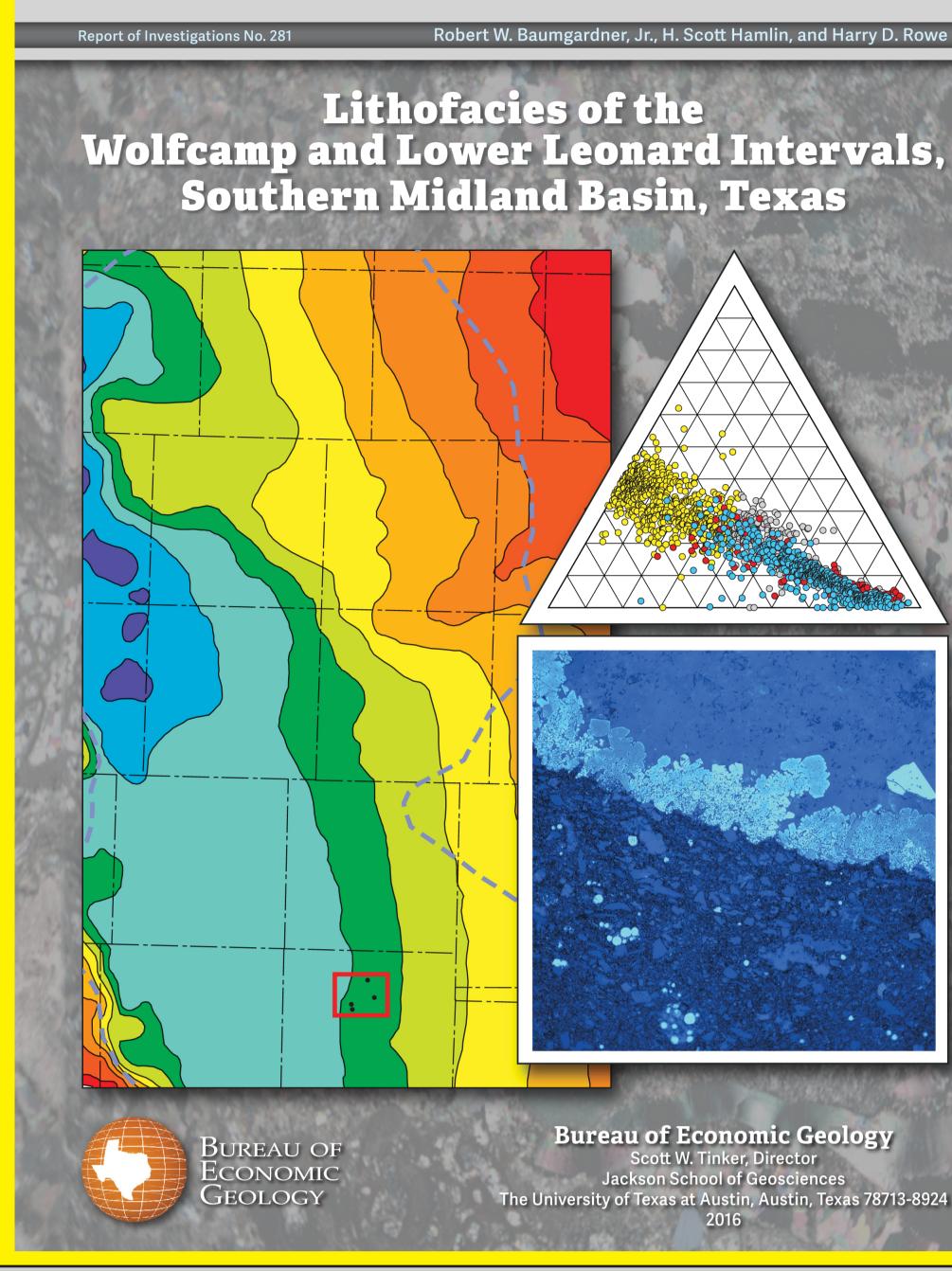


♦ Calcareous mudrock ◆ Skeletal wackestone/packstone Figure 17. Crossplot of hydrogen index vs. T_{max} showing that most rocks in the study area are in the oil window and are oil-gas or gas prone. Data provided by Weatherford Laboratories and Geomark Research.

Vitrinite reflectance vs. depth



Siliceous mudrock • Muddy bioclast-lithoclast floatstone Calcareous mudrock • Skeletal wackestone/packstone Figure 18. Lower Leonard and Wolfcamp are in the oil window, and maturity increases steadily with depth. Data provided by Weatherford Labs and GeoMark Research. Gas- and oil-window boundaries after Dembicki (2009).



Conclusions Basinal lithofacies of the Wolfcamp and lower Leonard are composed of

The upper Wolfcamp ("Wolfcamp B") is dominated by siliceous mudrocks and thick muddy floatstones, whereas the lower Leonard ("Wolfcamp A") is composed primarily of calcareous mudrocks and thin skeletal wackeston

These strata were deposited under mostly anoxic to dysoxic conditions, which inhibited bottom-dwelling biota and fostered preservation of organic

distance from backstepping carbonate shelf margins to the basin center. Values of TOC, rock strength, and hydrocarbon-generating potential are On average, siliceous mudrocks have the highest TOC, lowest rock

strength, and highest potential for generating hydrocarbons.

The lower Leonard and Wolfcamp are within the oil window, and average TOC content of mudrocks is greater than 2 weight percent.

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no. 7, p. 5-15, 28-33.

Virginia, Penn West, Pioneer, QEP, Samson, Shell, StatOil, Talisman, Texas scanned the cores with hand-held ED-XRF device. Paula Beard, Jamie oggins, and Jason Suarez of the BEG Media Group assisted with illustrations, which were edited by Cathy Brown.