[PS]Quantitative Facies Analysis of the Eagle Ford Formation: South Texas, U.S.A.*

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Abstract

Lithofacies of the Eagle Ford in South Texas were identified and quantified to: 1) determine the distribution and degree of facies heterogeneity 2) develop a vertical facies succession, and 3) map out the depositional regimes in the region. The study provides a quantitative approach and a better predictive tool of the potential resource play (net-to-gross) of the Eagle Ford in South Texas. In addition, the study also quantifies the degree of facies heterogeneity within the Eagle Ford Formation. The vertical order of facies successions in the Lower- and Upper Eagle Ford were also analyzed using the Markov Chains.

The core description study identified at least nine Eagle Ford facies. The transition from Facies 1A, 2A, 2B, 2C and 3 are interpreted to represent an increase in the flow velocity at the time of deposition. Facies 1A and 2A contain the highest TOC_{pd} of all the lithofacies ranging from 2 to 9 wt%. Facies 1A is a thin horizontal laminated, dark (N2-N3), organic-rich, lime mudstone/wackestone. Facies 2A is similar to Facies 1A except it contains some very thin, planktonic foraminifera layers. Facies 1A and 2A are interpreted as pelagic suspension deposits in a suboxic to anoxic conditions. Facies 2B consists of interlaminated, organic-rich and light-colored layers. The light-colored layers consist primarily of planktonic foraminifera. Facies 2B represents periods of alternate current ripple activity and quiescence. Facies 2C is a light-colored, ripple laminated recrystallized calcite. Facies 3 is light-gray to cream, planar to hummocky stratified, recrystallized calcite. Facies 3 is of multi-origin and possibly represents storm, turbidite, and possibly bottom current deposits.

Facies 1B and 1C are bioturbated, lime mudstone/wackestone. Facies 1B is darker and more argillaceous than Facies 1C. Facies 1C is a highly bioturbated, light colored lime mudstone/wackestone. Facies 1B and 1C are indicative of favorable organism activities possibly resulting from an oxygenated water condition. Facies 5 and Facies 6 are slumps and debris flow deposits, respectively.

The quantitative facies analysis reveals that the combined Facies 1A + 2A are thickest in the paleo-deeps, e.g., Karnes Trough and basinward of the Sligo margins. Facies 3 + 2C are highest in the four corners of Atascosa, Frio, La Salle, and McMullen counties. Three vertical facies transitions are common in the Lower Eagle Ford. Sequence 1 (S1) consists of almost exclusively Facies 1A/2A with rare interbedded Facies 1B. Sequence 1(S2) consists of Facies 1A/2A overlain by Facies 3. Sequence 3 (S3) consists of Facies 1A/2A overlain by Facies 2B. The

vertical facies transition in the Upper Eagle Ford is dominated by sequence 3 (S3) or sequence 4 (S4). Sequence 4 (S4) is characterized by facies 1A/2A grading into Facies 1B/1C. Facies 5 and facies 6 are locally present in the two wells adjacent to the San Marcos arch.

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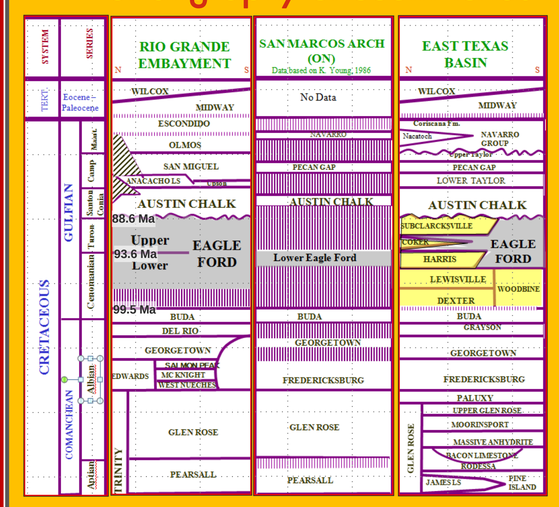
Objectives

Lithofacies of the Eagle Ford in select cores in South Texas were identified and quantified to : 1) determine the distribution and degree of facies heterogeneity, 2) develop a vertical order of facies succession, and 3) map out the depositional regimes in the region.

Applications

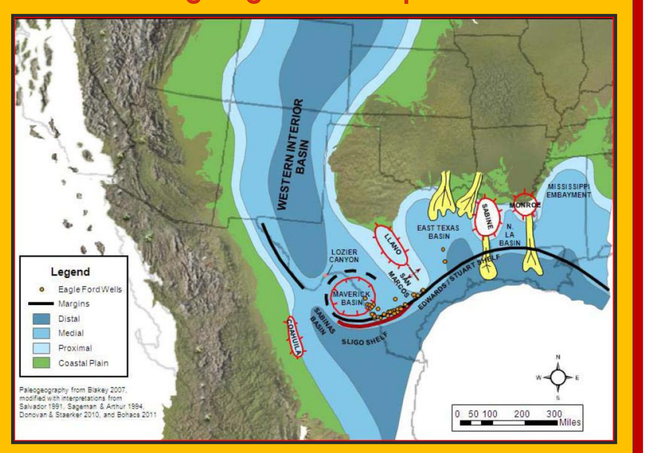
The study provides a quantified approach and possibly a better prediction of the potential resource play (N/G) of the Eagle Ford in South Texas than the typical qualitative core descriptions. The study also quantifies the degree of facies heterogeneity within the Eagle Ford Formation.

Stratigraphy of South Texas



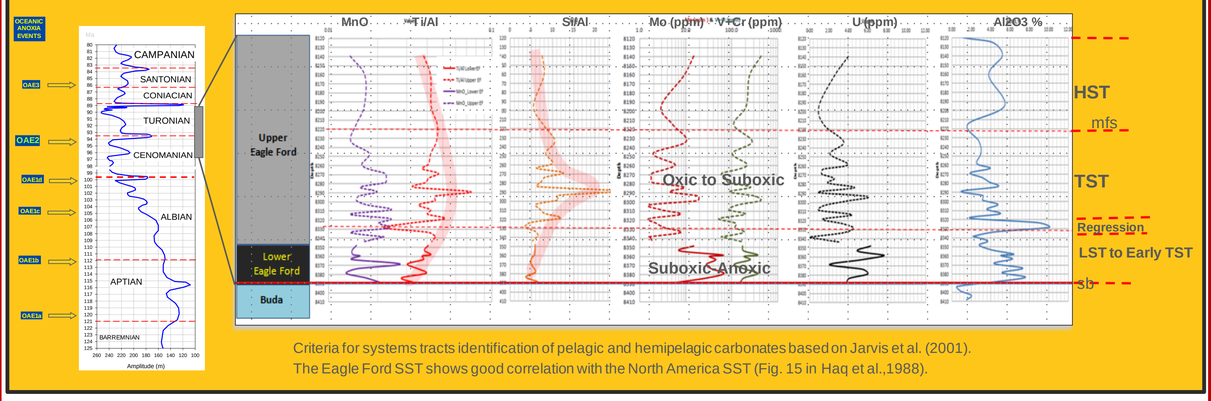
Modified after Koster et al., 1989
San Marcos Arch Stratigraphy after Young, 1986

Paleogeography of North America During Eagle Ford Deposition



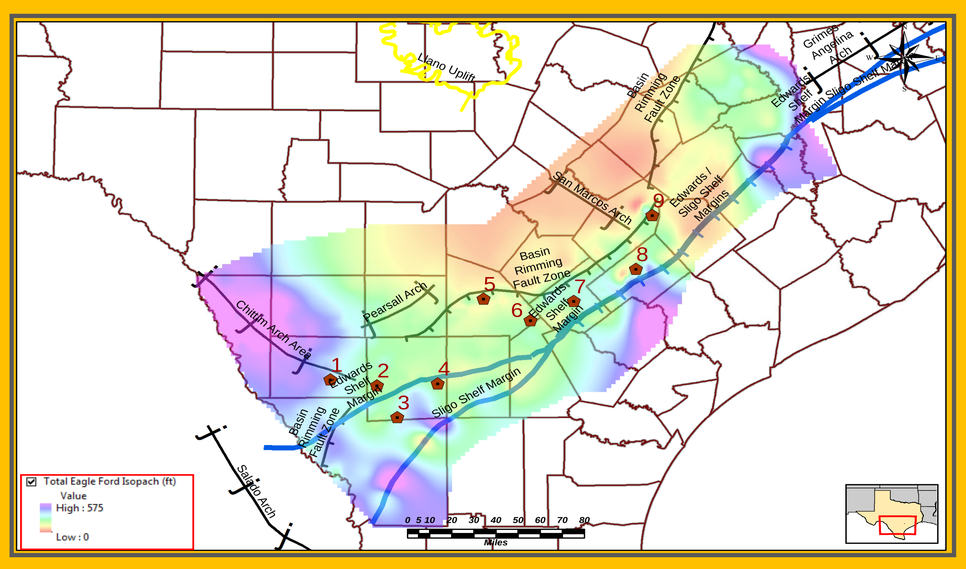
Paleogeography from Blakey 2007, modified with interpretations from Salvador 1991, Sageman & Arthur 1994, Donovan & Staerker 2010, and Bohacs 2011

Sea Level Curve (Haq et al., 1988) & Sequence Stratigraphy During Eagle Ford Deposition



Criteria for systems tracts identification of pelagic and hemipelagic carbonates based on Jarvis et al. (2001).
The Eagle Ford SST shows good correlation with the North America SST (Fig. 15 in Haq et al.,1988).

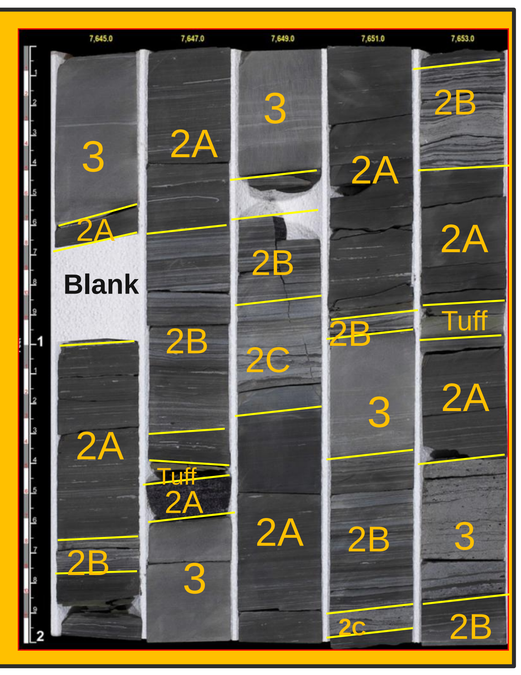
Well Locations & Total Eagle Ford Isochore Map



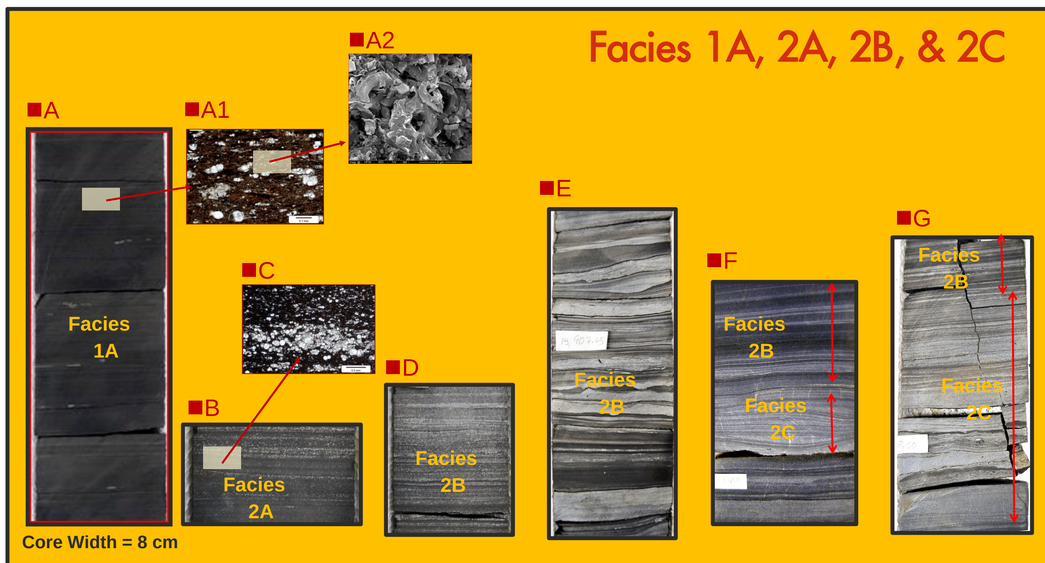
Methodology

- Calibration of selected wells/cores (courtesy of Core Lab consortium) using cores with age dates & geochemical data.
- Direct measurement of top and bottom depths of each facies (see figure on right)
- Statistical analysis for overall facies thicknesses
- Application of Markov Chains to determine vertical order of facies (Graham, 1988, p. 52 – 62)

Note that names of wells & operators were removed for propriety reasons.



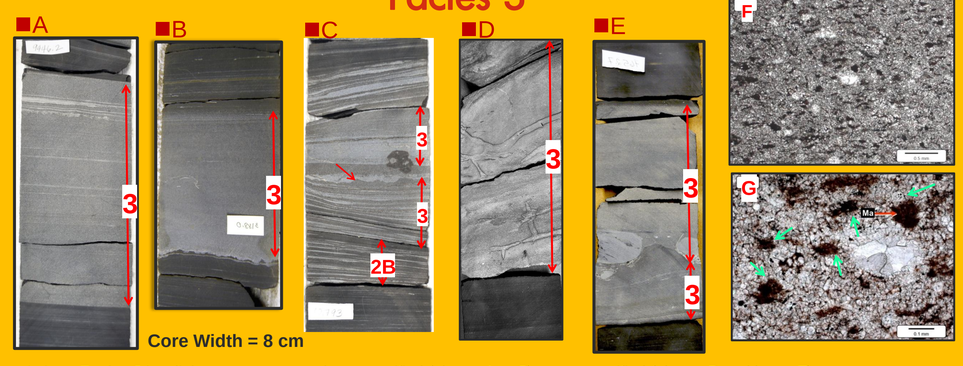
Facies 1A, 2A, 2B, & 2C



Description: ***Facies 1A and 2A*** are black to dark gray (N2 to N3), thinly laminated, lime-mudstone wackestone (Photos A &B). ***Facies 2A*** consists of thin streaks of foraminifera in an organic-rich, matrix (photo C). Thin photomicrograph and SEM from Facies 1A reveal organic-rich matrix with scattered foraminifera (photo A1). The matrix consists of comminuted coccoliths, microcrystalline calcite, organic fragments, and clay (photo A2). ***Facies 2B*** consists of interlaminated organic-rich and light-colored layers (photos D, E, & F). ***Facies 2C*** is a light colored, ripple laminated recrystallized packstone - grainstone.

Interpretation: Facies 1A and 2A are interpreted as pelagic, suspension deposits in a suboxic to anoxic conditions. Minor reworking by currents may occur but to a lesser degree compared to Facies 2B and 2C. Facies 2B represents periods of alternate current (ripple) activity and quiescence, e.g., tidal currents and /or bottom currents. Facies 2C are current ripple laminations.

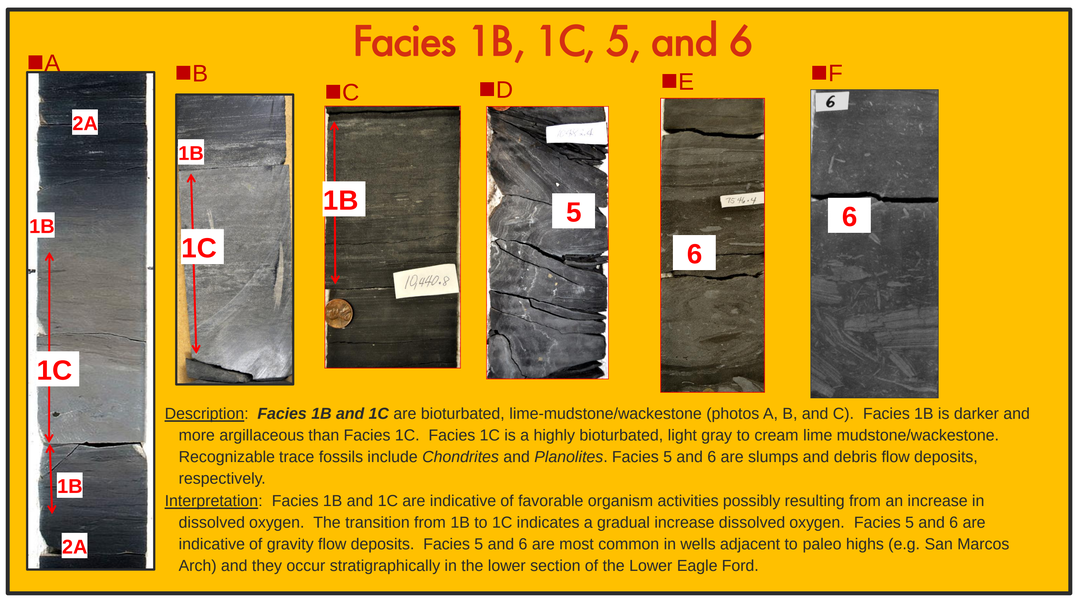
Facies 3



Description: ***Facies 3*** is a light gray to cream, planar stratified (photos A to C), cross-stratified (photos D and lower E), to structureless (Upper E), recrystallized packstone – grainstone. Facies consist of 70 to 90% recrystallized calcite (photos F & G) that may contain faint outline of the original skeletal grains (green arrows in photo G). Facies 3 ranges from sharp base and top (photos A & E), sharp base and gradational top (photo B), and gradational upper and lower contacts. Scoured base with gravel lag (photo E) are rare.

Interpretation: Facies 3 appears to have multi-origins. The planar to hummock-like cross beds with oscillation ripples (arrow, in photo C) are possibly storm deposits. Photos D & E are also possible storm deposits. Facies 3 in photo B with sharp base and gradational upper contact can be interpreted as either distal turbidites or storm beds. Facies 3 with sharp base and top (photo A) with planar stratification can be interpreted as bottom-current deposits.

Facies 1B, 1C, 5, and 6



Description: ***Facies 1B and 1C*** are bioturbated, lime-mudstone/wackestone (photos A, B, and C). Facies 1B is darker and more argillaceous than Facies 1C. Facies 1C is a highly bioturbated, light gray to cream lime mudstone/wackestone. Recognizable trace fossils include *Chondrites* and *Planolites*. Facies 5 and 6 are slumps and debris flow deposits, respectively.

Interpretation: Facies 1B and 1C are indicative of favorable organism activities possibly resulting from an increase in dissolved oxygen. The transition from 1B to 1C indicates a gradual increase dissolved oxygen. Facies 5 and 6 are indicative of gravity flow deposits. Facies 5 and 6 are most common in wells adjacent to paleo highs (e.g. San Marcos Arch) and they occur stratigraphically in the lower section of the Lower Eagle Ford.

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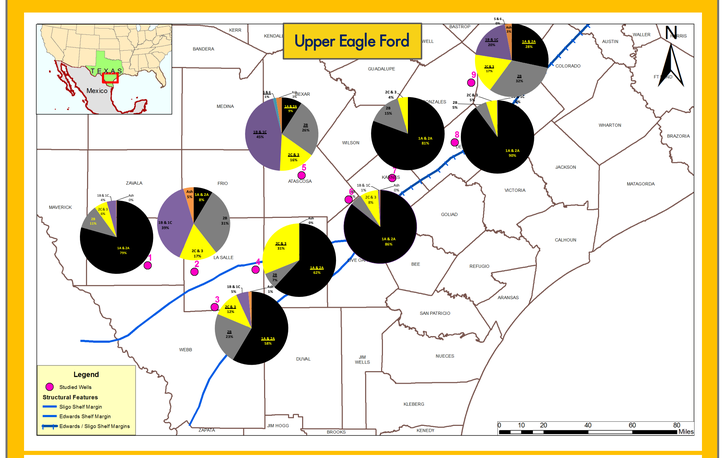
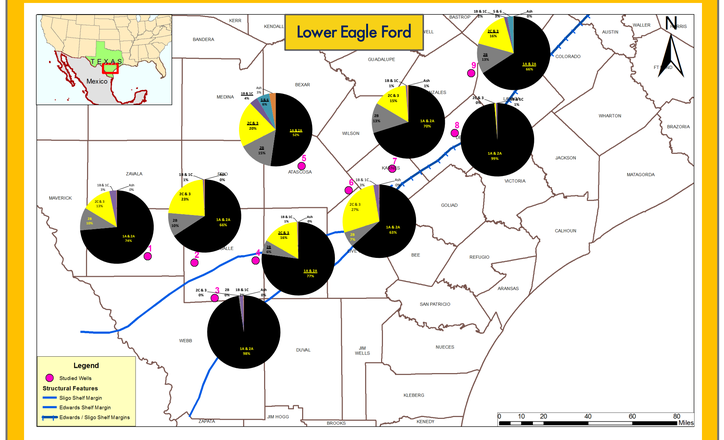
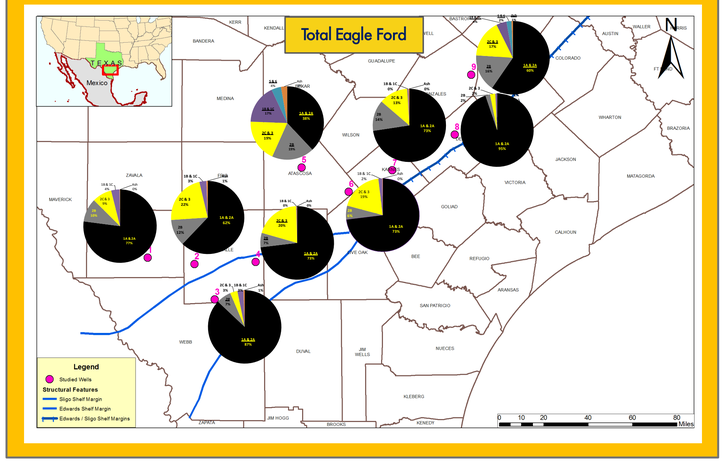
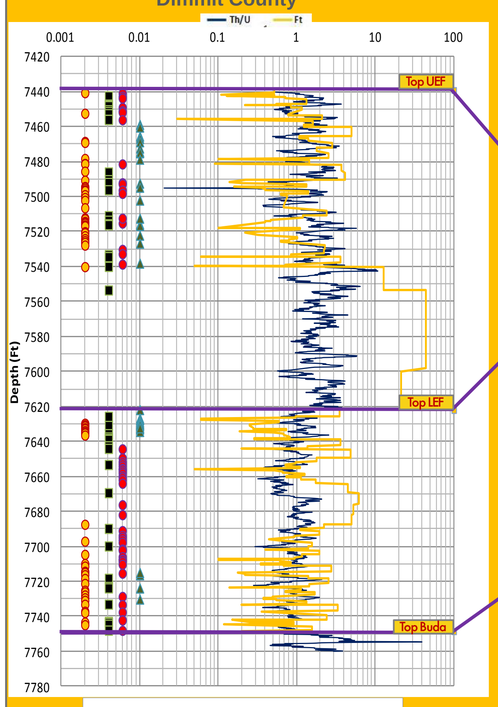
Facies Distribution Maps

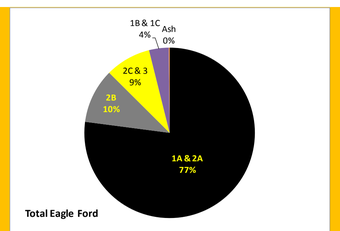


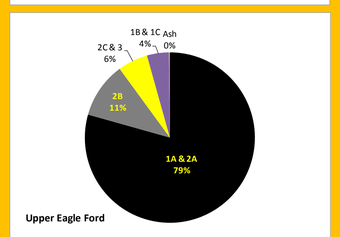


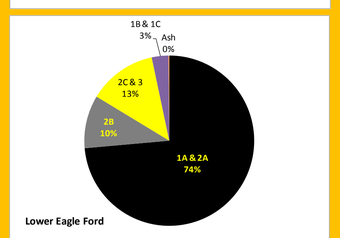


Well #1 Dimmit County

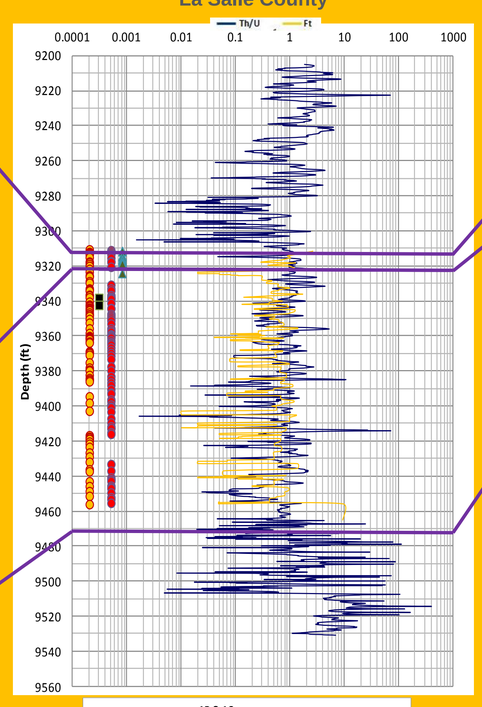


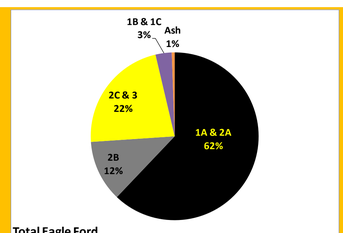


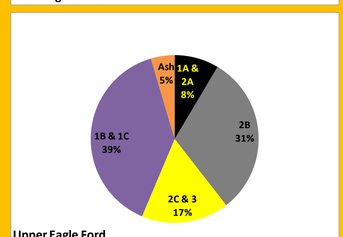


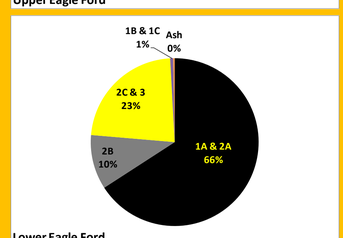


Well #2 La Salle County

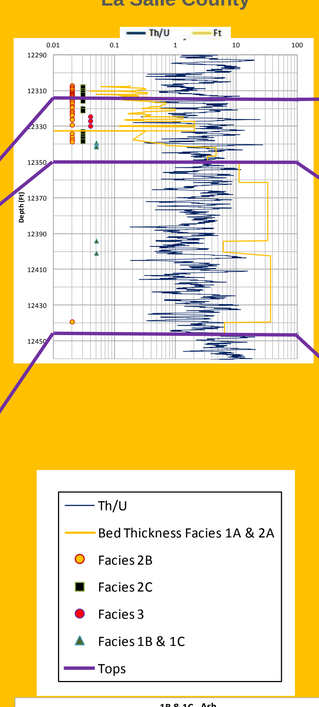


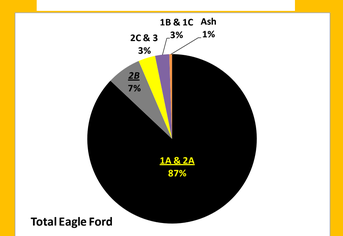


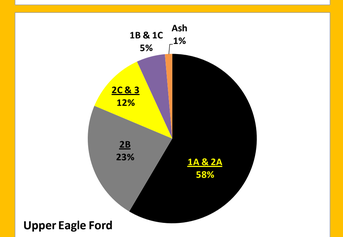


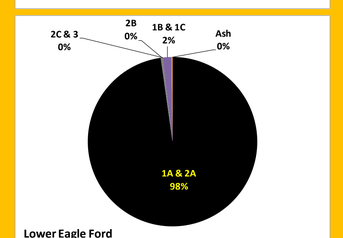


Well #3 La Salle County

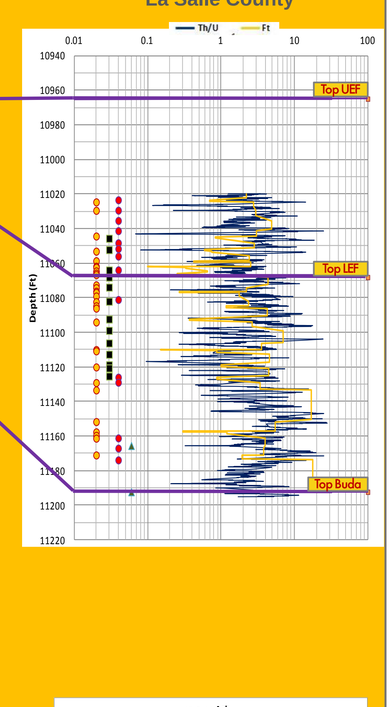


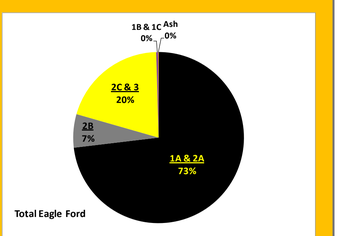


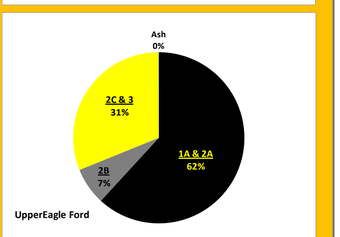


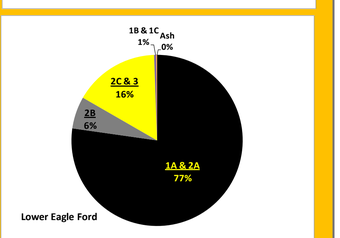


Well #4 La Salle County



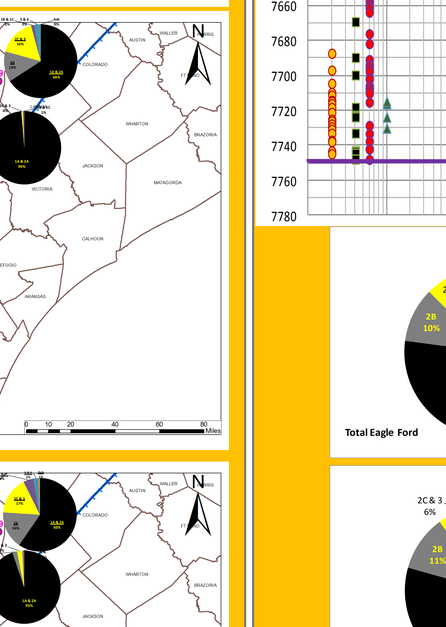






Well #5 Atascosa County

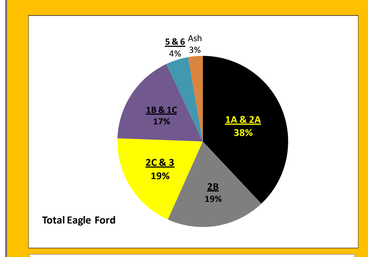
Well #6 Atascosa County

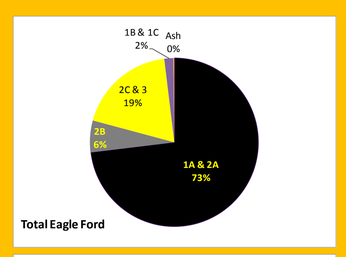


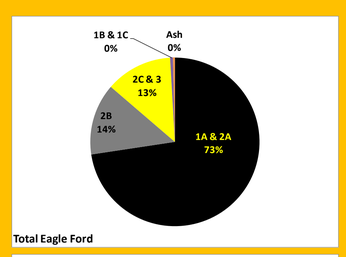
Well #7 Karnes County

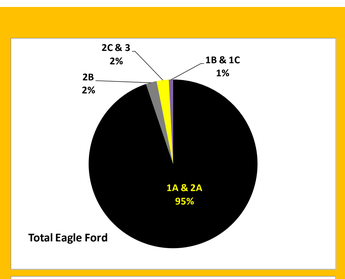
Well #8 De Witt County

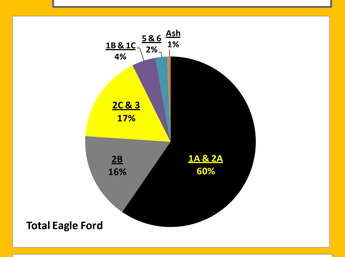
Well #9 Gonzales County

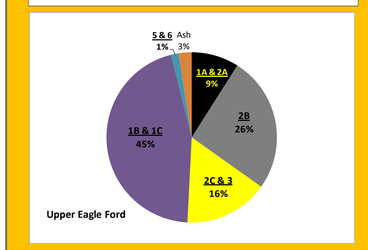


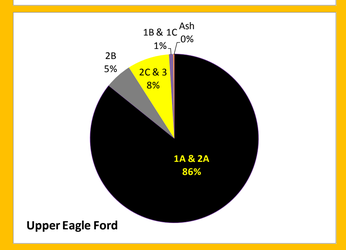


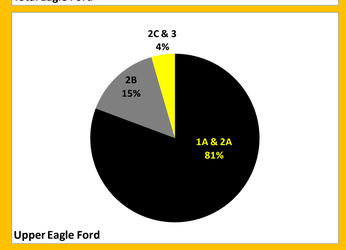


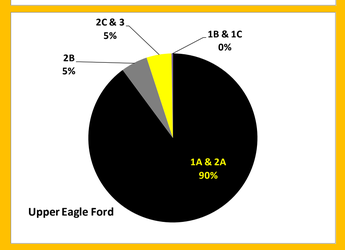


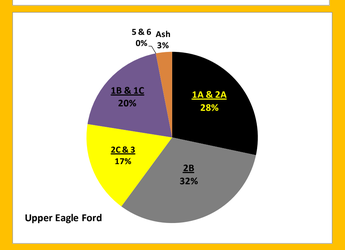


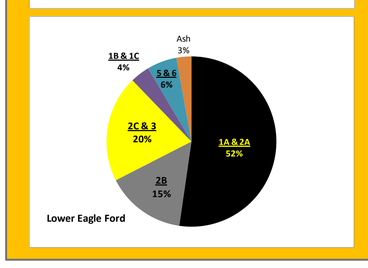


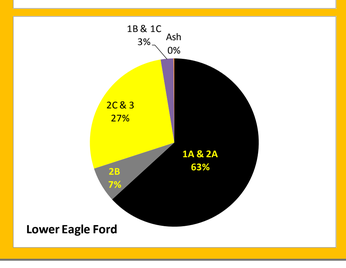


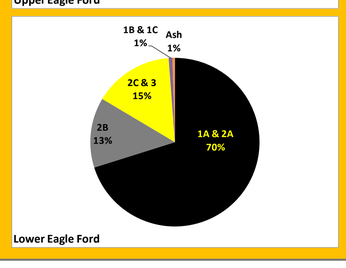


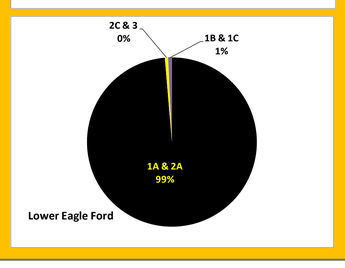


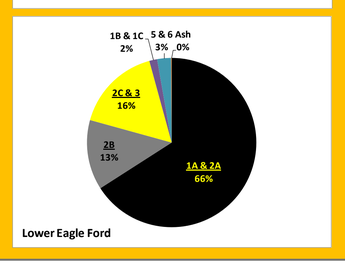












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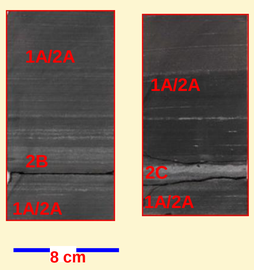
Summary of Vertical Facies Transitions (Markov Chains) Lower Eagle Ford & Upper Eagle Ford

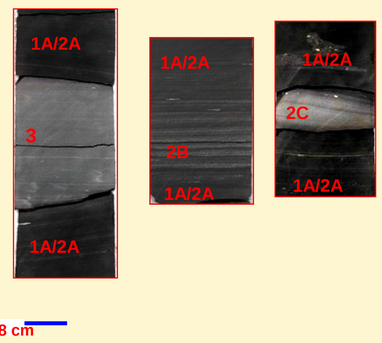
Well # 1
Dimmit County
Upper Eagle Ford

Facies 1A/2A → 32% Facies 2B → 66% Facies 1A/2A
Facies 1A/2A → 28% Facies 2C → 64% Facies 1A/2A



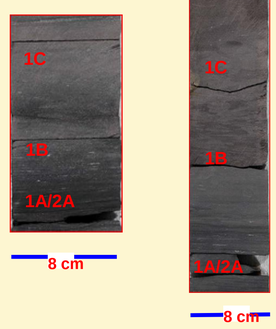
Lower Eagle Ford

Facies 1A/2A → 44% Facies 3 → 88% Facies 1A/2A
Facies 1A/2A → 23% Facies 2C → 62% Facies 1A/2A
Facies 1A/2A → 23% Facies 2B → 73% Facies 1A/2A



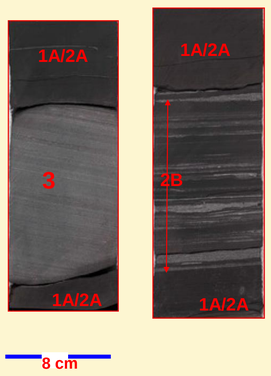
Well # 2
La Salle County
Upper Eagle Ford

Facies 1A/2A → 42% Facies 1B → 63% Facies 1C



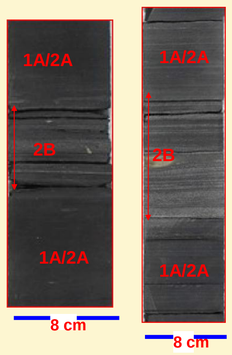
Lower Eagle Ford

Facies 1A/2A → 47% Facies 3 → 65% Facies 1A/2A
Facies 1A/2A → 44% Facies 2B → 74% Facies 1A/2A



Well # 3
La Salle County
Upper Eagle Ford

Facies 1A/2A → 58% Facies 2B → 67% Facies 1A/2A

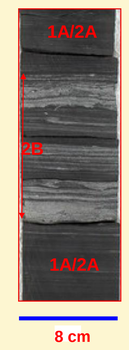


Lower Eagle Ford

Facies 1A/2A → 90% Facies 1A/2A → 40% Facies 1B

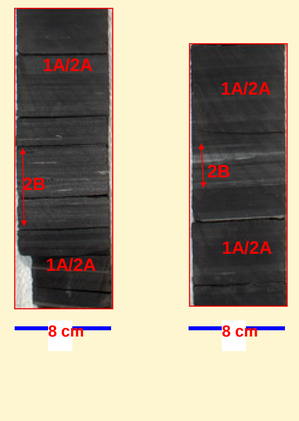
Well # 4
La Salle County
Upper Eagle Ford

Facies 1A/2A → 53% Facies 2B → 89% Facies 1A/2A

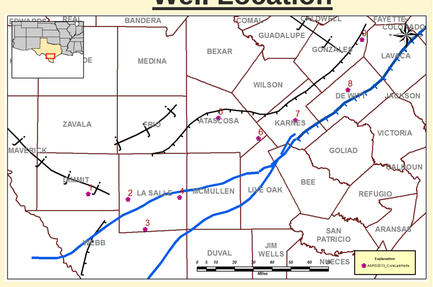


Lower Eagle Ford

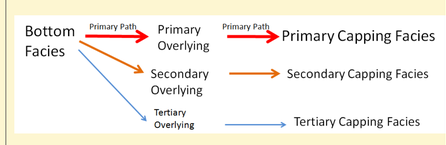
Facies 1A/2A → 56% Facies 2B → 79% Facies 1A/2A



Well Location

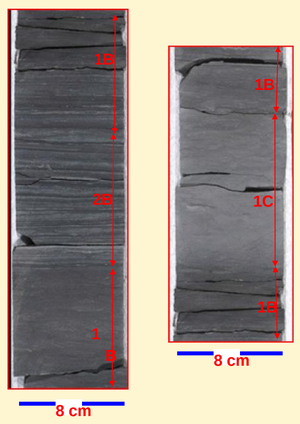


Legend



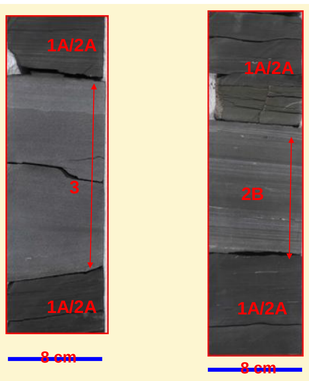
Well # 5
Atascosa County
Upper Eagle Ford

Facies 1B → 38% Facies 2B → 41% Facies 1B
Facies 1B → 17% Facies 1C → 54% Facies 1B



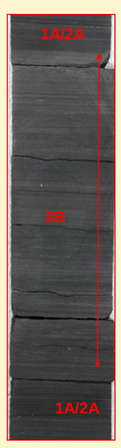
Lower Eagle Ford

Facies 1A/2A → 21% Facies 3 → 58% Facies 1A/2A
Facies 1A/2A → 21% Facies 2C → 40% Facies 1A/2A
Facies 1A/2A → 17% Facies 2B → 30% Facies 1A/2A



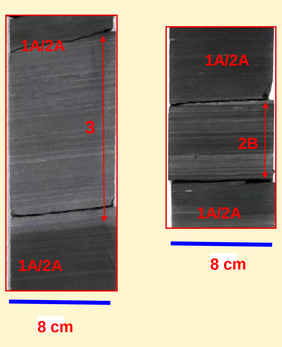
Well # 6
Atascosa County
Upper Eagle Ford

Facies 1A/2A → 45% Facies 2B → 68% Facies 1A/2A
Facies 1A/2A → 29% Facies 3 → 83% Facies 1A/2A



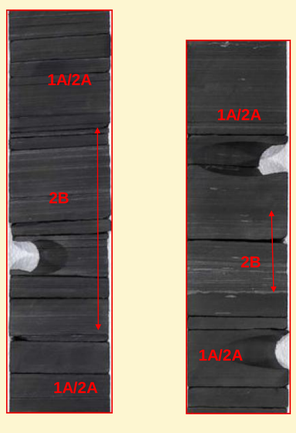
Lower Eagle Ford

Facies 1A/2A → 42% Facies 3 → 62% Facies 1A/2A
Facies 1A/2A → 31% Facies 2B → 53% Facies 1A/2A



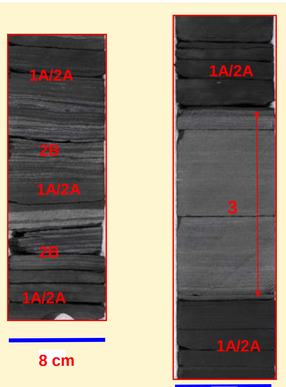
Well # 7
Karnes County
Upper Eagle Ford

Facies 1A/2A → 87% Facies 2B → 86% Facies 1A/2A



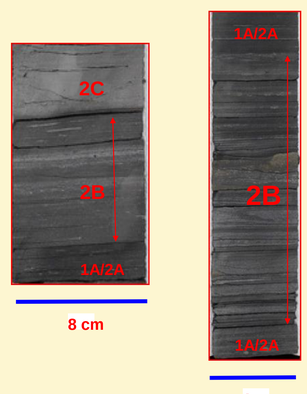
Lower Eagle Ford

Facies 1A/2A → 58% Facies 2B → 74% Facies 1A/2A
Facies 1A/2A → 16% Facies 3 → 64% Facies 1A/2A



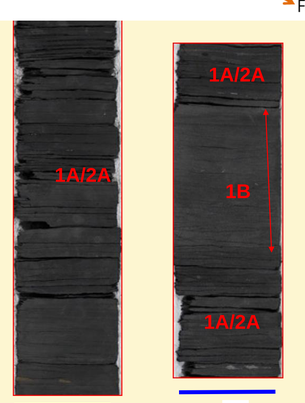
Well # 8
De Witt County
Upper Eagle Ford

Facies 1A/2A → 50% Facies 2B → 42% Facies 2C
Facies 1A/2A → 33% Facies 1A/2A
Facies 1A/2A → 30% Facies 2C → Facies 2B



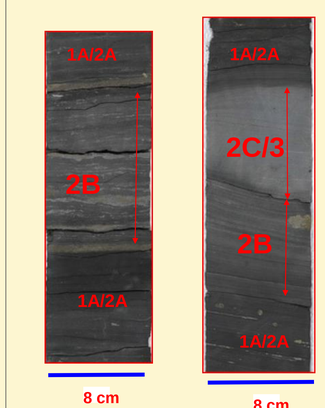
Lower Eagle Ford

Facies 1A/2A → Facies 1A/2A → 50% Facies 1B
Facies 1A/2A → 42% Facies 2C



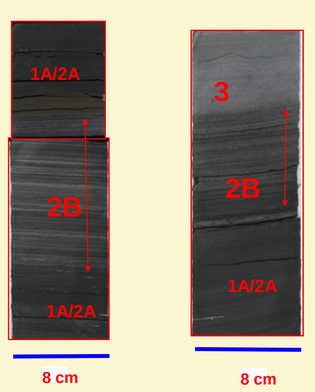
Well # 9
Gonzales County
Upper Eagle Ford

Facies 1A/2A → 57% Facies 2B → 47% Facies 1a/2a
Facies 1A/2A → 32% Facies 2C
Facies 1A/2A → 21% Facies 3 → 50% Facies 2B



Lower Eagle Ford

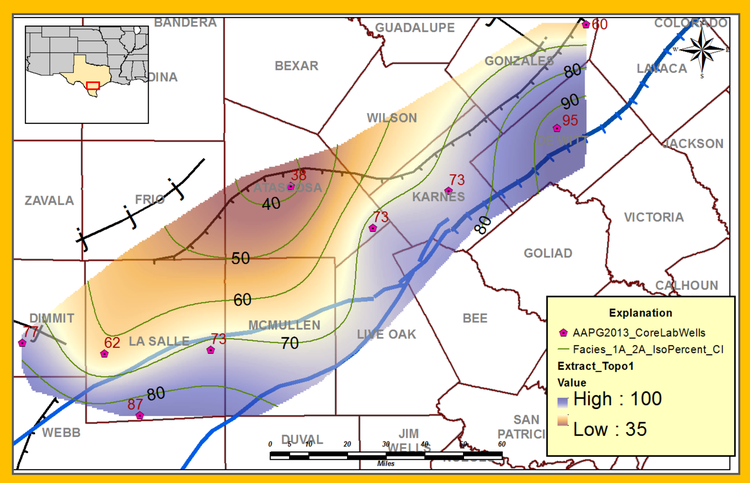
Facies 1A/2A → 51% Facies 2B → 53% Facies 1A/2A
Facies 1A/2A → 33% Facies 3 → 31% Facies 3
Facies 1A/2A → 56% Facies 2B



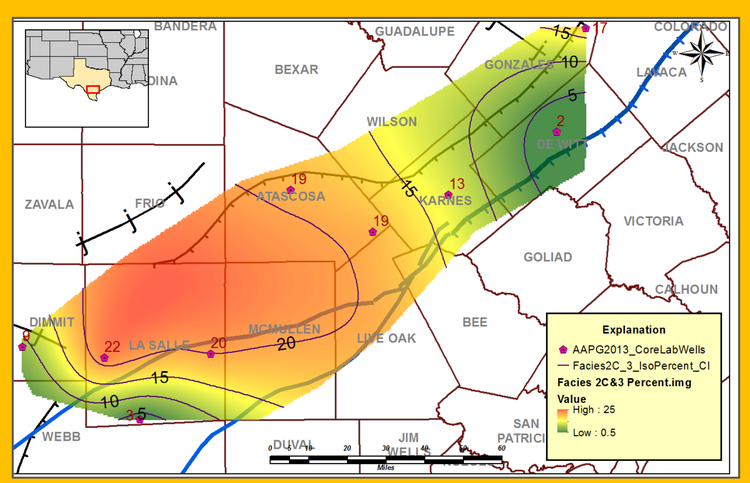
Quantitative Facies Analysis of the Eagle Ford Formation: South Texas, U.S.A.

Ariel Malicse & Judit Garcia Garcia (Shell SEPCO UAU/G/UO)

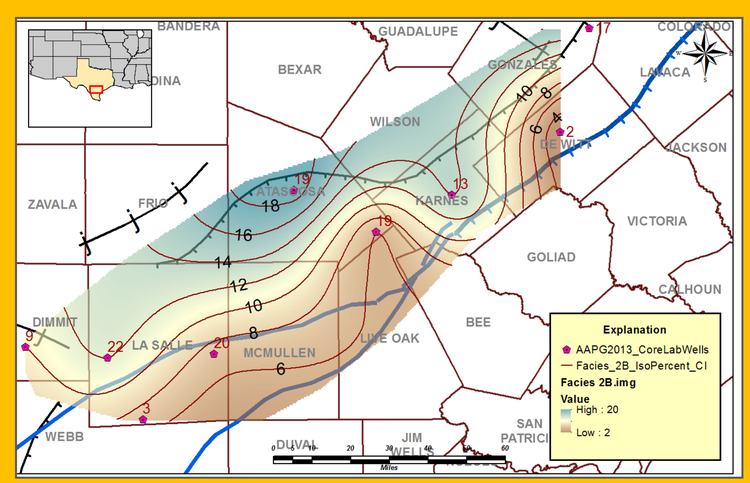
Contour of Percent Facies 1A + 2A: Total Eagle Ford



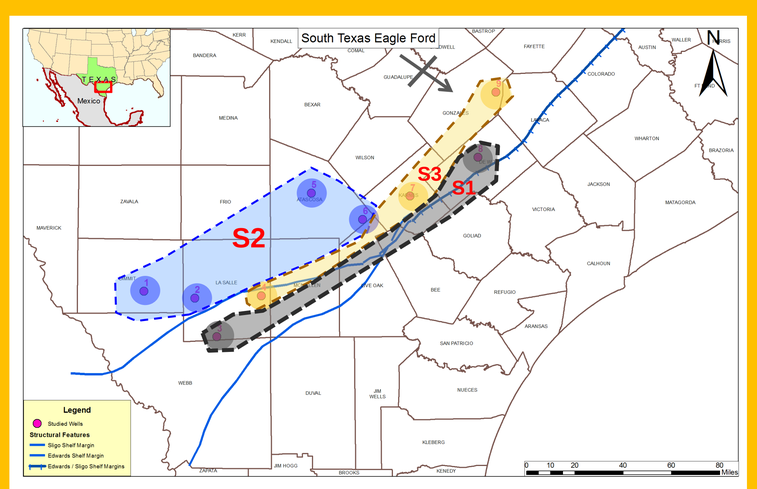
Contour of Percent Facies 3 + 2C: Total Eagle Ford



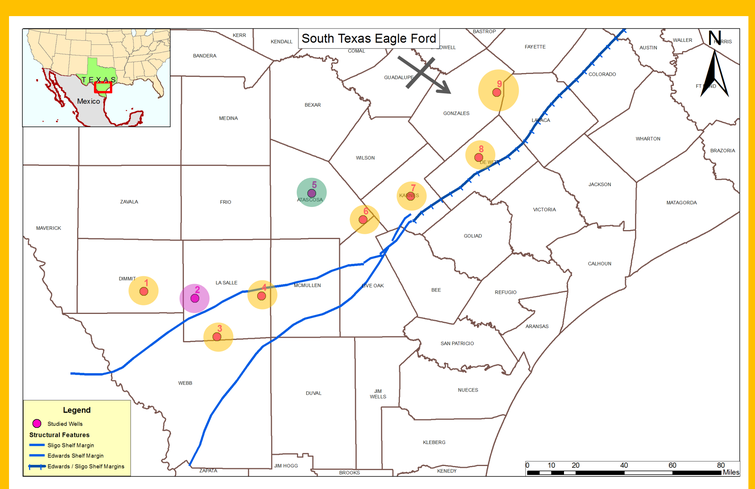
Contour of Percent Facies 2B: Total Eagle Ford



Vertical Facies Succession Lower Eagle Ford



Vertical Facies Succession Upper Eagle Ford

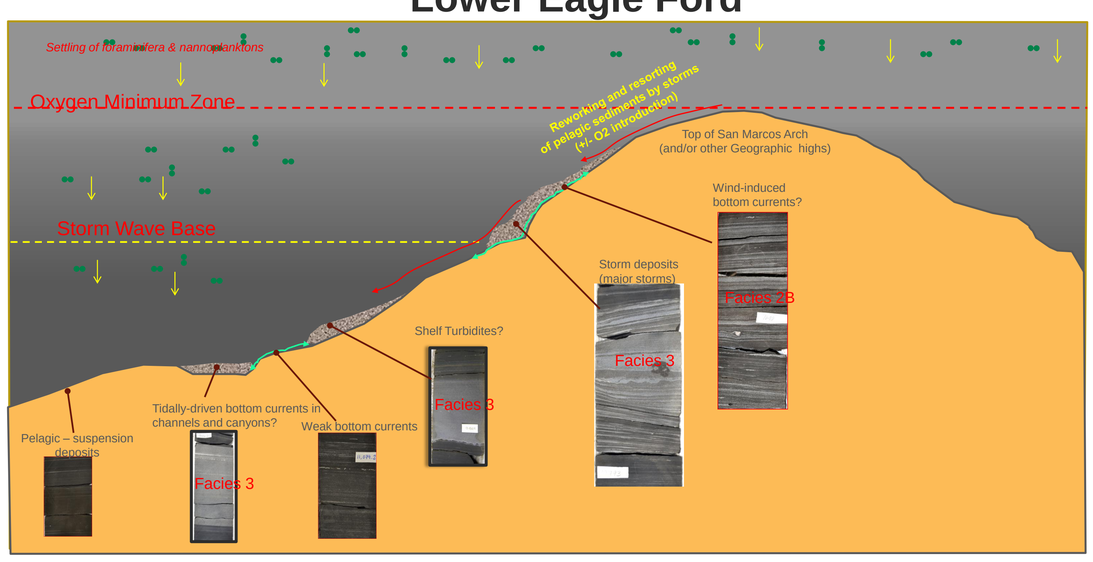


Most Common Vertical Facies Transition (Bottom to Top)

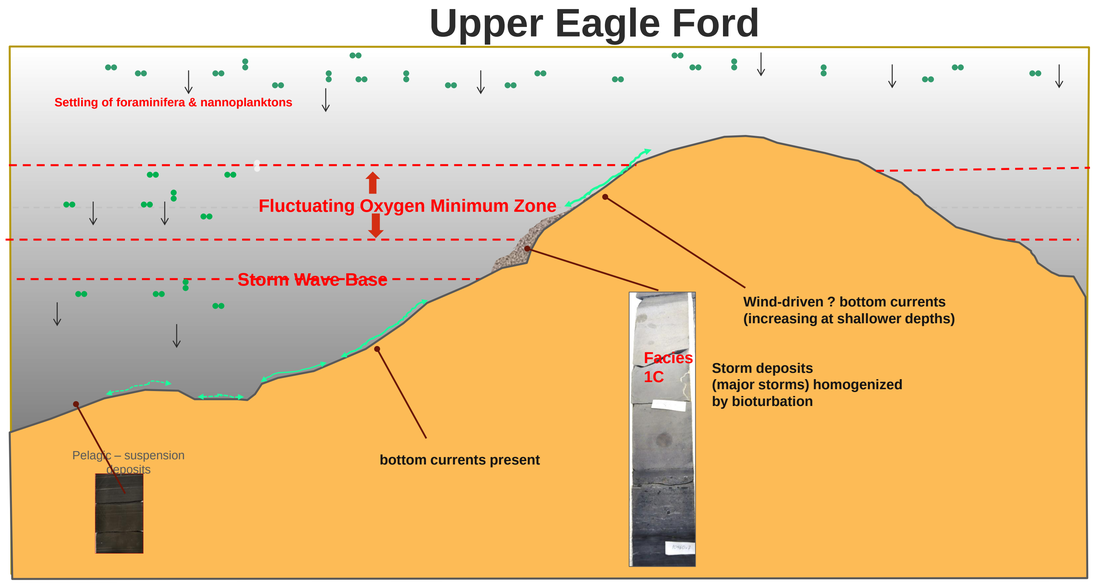
S1	Facies 1A/2A	→	Facies 1A/2A	→ Facies 1B
S2	Facies 1A/2A	→	Facies 3	→ Facies 1A/2A
S3	Facies 1A/2A	→	Facies 2B	→ Facies 1A/2A
S4	Facies 1A/2A	→	Facies 1B	→ Facies 1C
S5	Facies 1B	→	Facies 2B	→ Facies 1B

Depositional Models

Lower Eagle Ford



Upper Eagle Ford



Conclusions

- Direct measurements of facies in the cored Eagle Ford Formation provide quantitave data that can be used for various purposes, e.g., 1) to calculate net-to-gross of the resource play facies, 2) to determine the degree of facies heterogeneity, and 3) to predict depositional facies sequence.
- The Eagle Ford consists of at least 9 lithofacies. The iso-percent distribution of some of the critical facies, e.g., Facies 1A+2A, Facies 2C+3, and Facies 2B reveal both predictable and suprising patterns. The organic-rich Facies 1A + 2A are thickest in the paleo-deeps, e.g., Karnes Trough. Facies 3 and 2C have the highest percentage in the four corners of Atascosa, Frio, La Salle, and McMullen counties. Facies 2B, which represents fluctuating ripple-quiescence, is common near the San Marcos Arch and decreases away from it.
- Three (3) vertical facies successions are common in the Lower Eagle Ford. S1: Facies 1A/2A → Facies 1A/2A → 1B; S2: Facies 1A/2A → 3 → 1A/2A; and S3:Facies 1A/2A → Facies 2B → 1A/2A.
- Vertical successions in the Upper Eagle Ford are dominated by sequence S3 and the bioturbated sequence S4 and S5. Weak bottom currents and bioturbation appear more pervasive in the Upper Eagle Ford than in the Lower Eagle Ford.
- Slumps (Facies 5) and debris flows (Facies 6) are locally present in two wells adjacent to the San Marcos Arch. These gravity flows occur in the lower sections of the Lower Eagle Ford.

Acknowledgments

We thank Robin Hamilton, Marcel De Jong, and Jeff Fritz for their support in this study. We also thank Core Laboratories for allowing us to use the data in the Eagle Ford Consortium and the various Shell groups that are working in the Eagle Ford for their discussions and input to this study.

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