

PS High Resolution Stratigraphy and Facies Architecture of the Upper Cretaceous (Cenomanian-Turonian) Eagle Ford Formation, Central Texas*

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Abstract

The Upper Cretaceous Eagle Ford Formation has long been recognized as an important source rock for productive reservoirs throughout Texas. Heightened industry focus on the Eagle Ford is a result of recent discoveries of producible unconventional petroleum resources in this emerging play. However, little has been published on the facies and facies variabilities within this mixed carbonate-clastic mudrock system. The objectives of this study are to: 1) Define the Eagle Ford lithofacies present in the Austin, Texas area, 2) Determine the lithofacies continuity on various scales, 3) Calibrate geochemical data to the lithofacies that it represents, 4) Explore the effectiveness of geochemical signals in identifying variations within the Eagle Ford system, 5) Identify potential risks that could render subsurface correlation unreliable, and 6) Compare local facies architecture to region trends. This study utilizes a rare dataset comprised of 8 cores and 2 outcrops spanning a nearly 11 mile transect in Austin, providing a uniquely high-resolution perspective for any mudrock system. Energy Dispersive X-Ray Fluorescence (ED-XRF), XRD, TOC, and thin section synthesis further enhance this study.

Application

Mudrock depositional processes are recognized to be more complicated and involved than solely hemipelagic suspension settling as conventionally supposed. Core and outcrop studies reveal that ocean water chemistry and bottom current activity result in high degrees of facies variability within mudrock intervals. This study helps to answer the following crucial questions regarding mudrock systems: What is the continuity of units expressed by wireline log events? What causes variable well flows, and how can production be optimized across a large play area? What controls rock character that impacts reservoir properties? This rock-based study is fundamental to understanding the controls, types, and scales of inherent facies variabilities and heterogeneities, which have implications for enhanced comprehension of the Eagle Ford Formation and other mixed carbonate-clastic mudrock systems worldwide.

Results and Conclusions

Core and outcrop descriptions enhanced with thin sections, ED-XRF, and XRD analyses reveal that the Eagle Ford facies in Central Texas include: 1) Massive argillaceous mudrock, 2) Massive argillaceous foraminiferal mudrock, 3) Laminated argillaceous foraminiferal mudrock, 4) Laminated foraminiferal wackestone, 5) Cross-laminated foraminiferal packstone/grainstone, 6) Thin bentonites, and 7) Nodular foraminiferal packstone/grainstone.

High degrees of facies variability are observed even at small scales (50 feet), characterized by pinching and swelling of units, erosional truncation, lateral facies changes, and locally restricted beds. Facies variability is primarily attributed to bottom current reworking and increased planktonic productivity.

The degree of continuity observed at the 10-mile scale approaches the resolvability of units on a pseudo gamma ray curve. Gamma ray CGR (K-Th) curves define a four-fold Eagle Ford stratigraphy, consisting of a basal zone of high CGR (Pepper Shale), overlain by a decreasing CGR signature (Waller Member), a calcareous, low but highly variable CGR, middle zone (Bouldin Member), and an upper, decreasing CGR interval (South Bosque). Using integrated lithologic and well log data, cored wells in the study area can be correlated across the San Marcos Arch, but due to inherent heterogeneities, the facies resolution is limited.

Despite low TOC values and high energy facies, restricted basin conditions prevailed during deposition of the Bouldin Member, as indicated by paleo-redox proxies (Mo, Mn, U, V/Cr, $\delta^{13}\text{O}$). Sediment input was controlled by water column productivity, and deposition was influenced by bottom currents. These primary controls on Eagle Ford stratigraphy and character are de-coupled from eustatic fluctuation, rendering classical sequence stratigraphy unreliable in the Central Texas Eagle Ford Formation. Caution needs to be employed when correlating Eagle Ford intervals, as localized nodular facies, ash beds, erosional truncations, and other heterogeneities greatly increase stratal complexity.

Selected References

- Algeo, T.J., and T.W. Lyons, 2006, Mo-total organic carbon covariation in modern anoxic marine environments: Implications for analysis of paleoredox and paleohydrographic conditions: *Paleoceanography*, v. 21/1, 23 p.
- Algeo, T.J., and H. Rowe, 2011, Paleooceanographic applications of trace-metal concentration data: *Chemical Geology Online* 9 September 2011. Web accessed 10 May 2012.
<http://dx.doi.org/10.1016/j.chemgeo.2011.09.002>
- Galloway, W.E., 2008, Depositional evolution of the Gulf of Mexico sedimentary basin, *in* A.D. Miall, (ed.), *The sedimentary basins of the United States and Canada*: Elsevier, Amsterdam, Netherlands, v. 5, p. 505-549.

Harbor, R.L., 2011, Facies characterization and stratigraphic architecture of organic-rich mudrocks, Upper Cretaceous Eagle Ford Formation, South Texas: Thesis (M.S.), The University of Texas at Austin, 195 p.

Rowe, H.D., R.G. Loucks, S.C. Ruppel, and S. Rimmer, 2008, Mississippian Barnett Formation, Fort Worth Basin, Texas: bulk geochemical inferences and Mo-TOC constraints on the severity of hydrographic restriction: *Chemical Geology*, v. 257/1-2, p. 16-25.

Rowe, H.D., N. Hughes, K. Robinson, 2012, The quantification and application of handheld energy-dispersive x-ray fluorescence (ED-XRF) in mudrock chemostratigraphy and geochemistry: *Chemical Geology*, online 8 January 2012. Web accessed 10 May 2012.
<http://dx.doi.org/10.1016/j.chemgeo.2011.12.023>

Salvador, A., J.M.Q. Muñeton, and J. Manuel, 1991, Stratigraphic Correlation Chart, Gulf of Mexico Basin, *in* A. Salvador, (ed.), *The Gulf of Mexico Basin: GSA, The Geology of North America*, v. J., 568 p.

Schlanger, S.O., M.A. Arthur, H.C. Jenkyns, and P.A. Scholle, 1987, The Cenomanian-Turonian Oceanic Anoxic Event, I. stratigraphy and distribution of organic carbon-rich beds and the marine delta ¹³C excursion: *Geological Society of London, Special Publications*, v. 26, p. 371-399.

Introduction

Problem:

The Eagle Ford Formation has long been recognized as an important source rock in Texas, and recent focus has resulted from petroleum resource in this emerging play. However, little has been published on the facies and facies heterogeneities within this mixed carbonate-clastic mudrock system. The following crucial questions are posed:

- What is the continuity of units expressed by wireline log events?
- What causes variable well flows, and how can production be optimized across a large play area?
- What controls rock character that impacts reservoir properties?

This rock-based study is fundamental to understanding the controls, types, and scales of inherent heterogeneities and facies variabilities, which have implications for enhanced comprehension of the Eagle Ford Formation and other mixed carbonate-clastic mudrock systems worldwide.

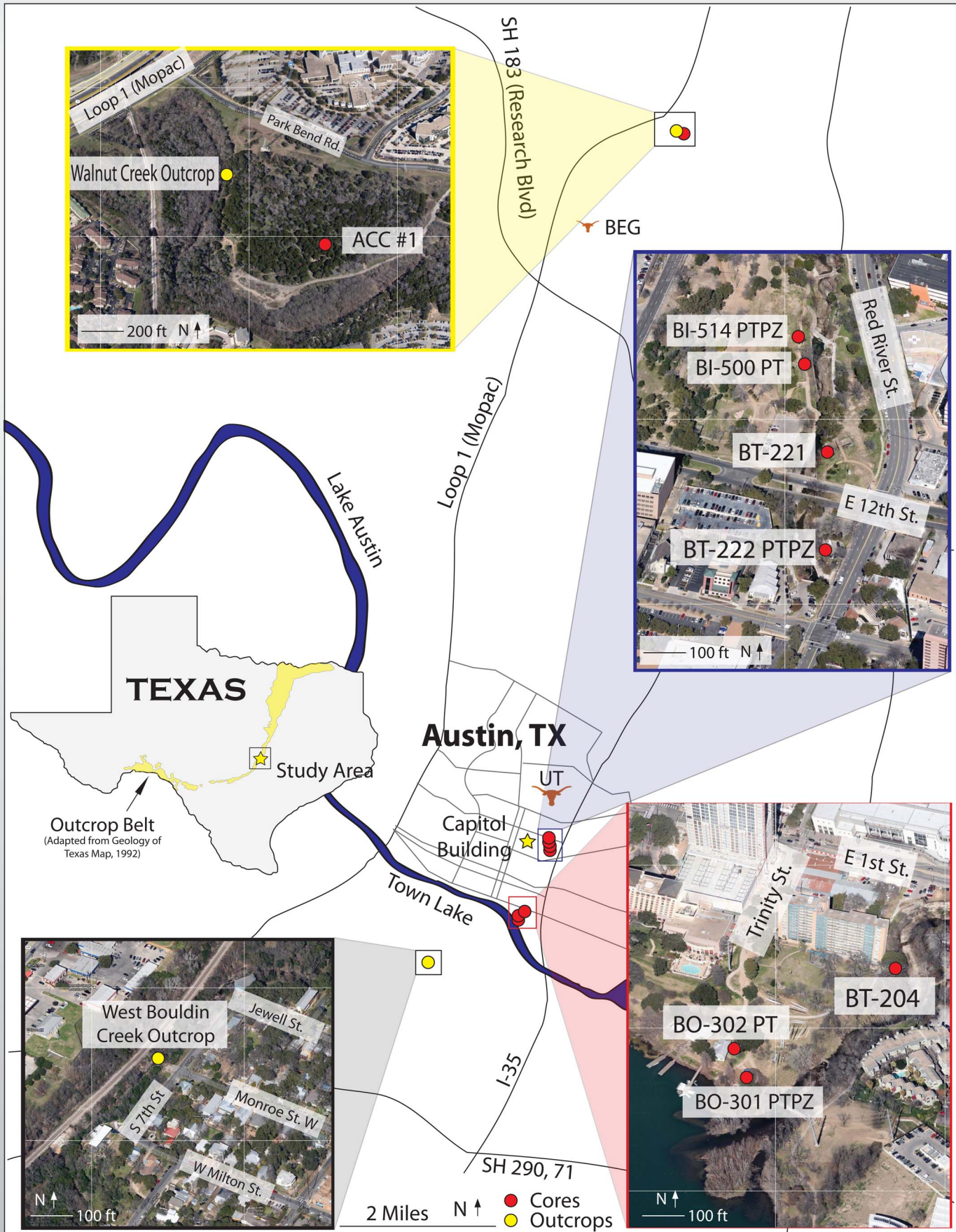
Objectives:

- 1) Define the Eagle Ford lithofacies present in the Austin, Texas area.
- 2) Determine the lithofacies continuity on various scales.
- 3) Calibrate geochemical data to the lithofacies that it represents.
- 4) Explore the effectiveness of geochemical signals in identifying variations within the Eagle Ford.
- 5) Identify potential risks that could render sub-surface correlation unreliable.
- 6) Compare local facies architecture to regional trends.

Key Observations:

- 1) High degrees of facies heterogeneity exist within extremely small scales (50 ft).
- 2) CGR (Gamma Ray Th-K) analysis provides a similar resolution of strata continuity as a 10-mile lithostratigraphic correlation.
- 3) Maximum basin restriction occurred within the Bouldin Member, as evidenced by enrichment in Mo, Mn, U, V/Cr, and $\delta^{13}\text{C}$.
- 4) Primary controls on Eagle Ford stratigraphy and character are de-coupled from eustatic fluctuation, rendering classical sequence stratigraphy unreliable.
- 5) Caution needs to be employed when using CGR curves, as localized nodular facies, ash beds, or other heterogeneities can dramatically alter log character.

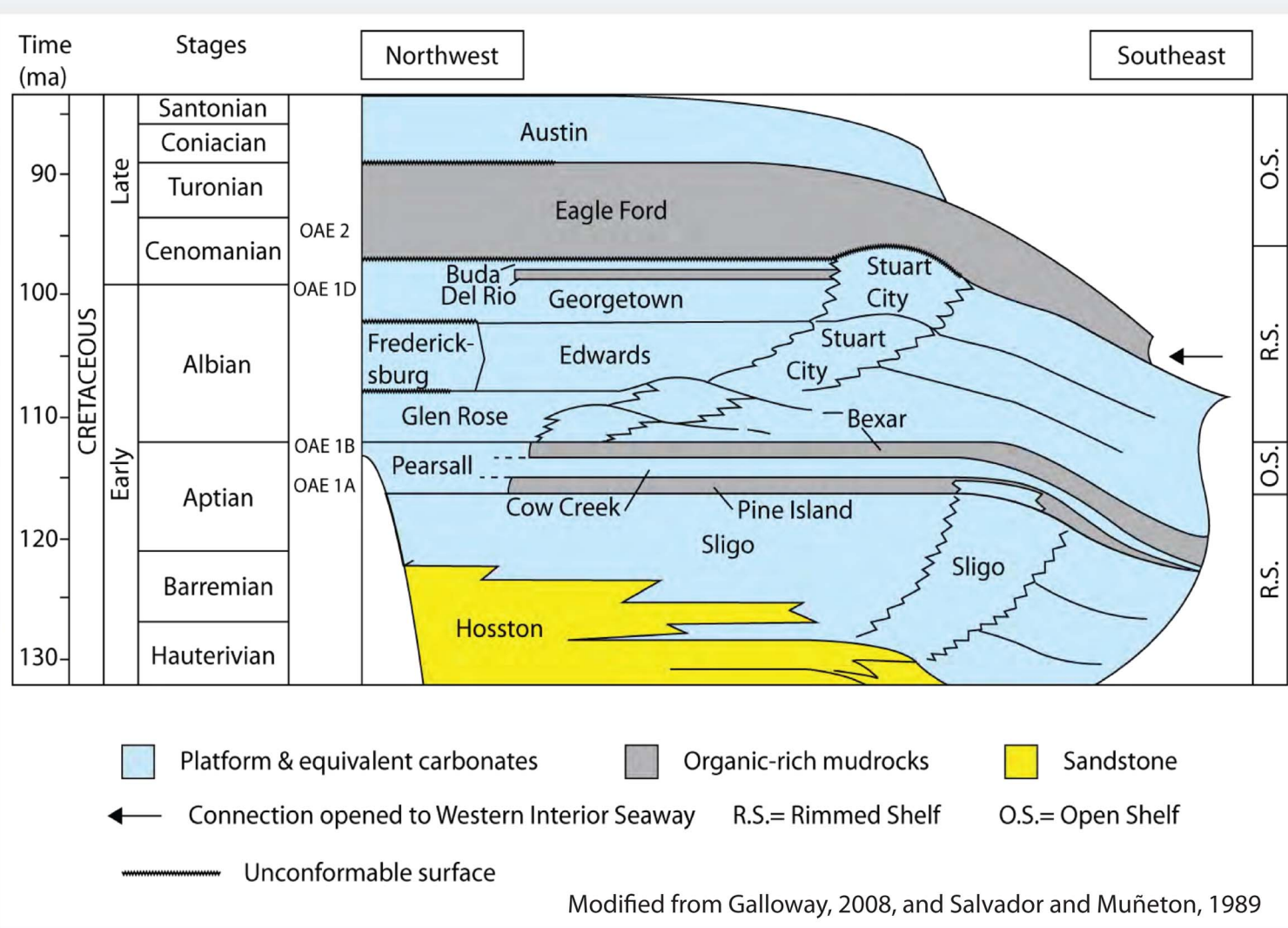
Study Area



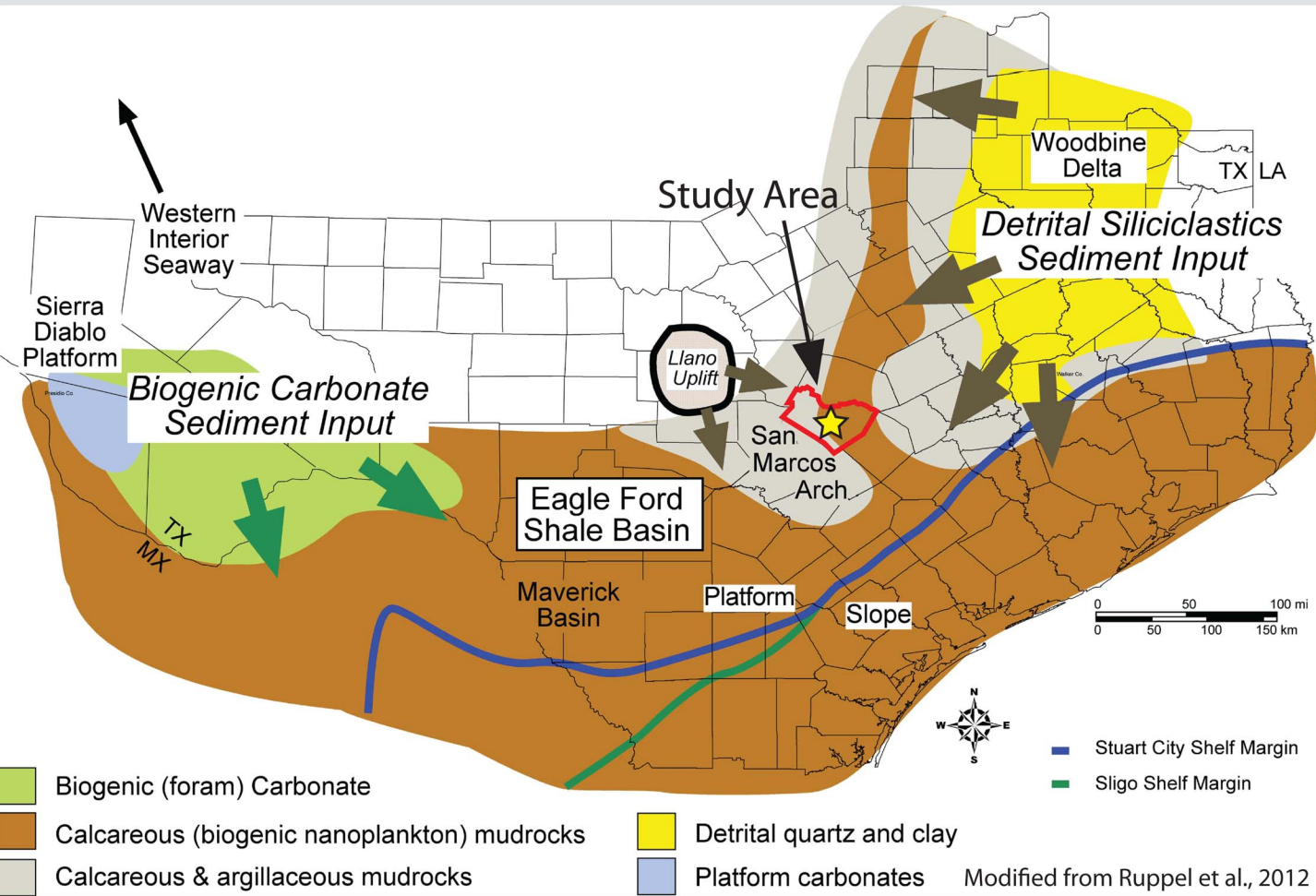
Map showing the study area in the Austin, TX locality. 8 cores and 2 outcrops are utilized for this study, comprising a nearly 12 mile, N-S transect. Energy Dispersive X-Ray Fluorescence (ED-XRF), XRD, Stable Isotopes, thin sections further enhance this study. The close spacing (50 ft. to 10 miles) provides a high density subsurface perspective that is unique to this study. Facies heterogeneities are observed along various scales (50 ft., 500 ft., 1 mile, 10 miles).

Paleogeographic map of South-Central Texas. The study area lies on the northeastern flank of the San Marcos Arch, where 95% thinning occurred relative to the Maverick Basin. The study area exhibits an interplay of argillaceous facies and calcareous nanoplankton facies. The Woodbine Delta to the northeast supplied siliciclastic material to the Eagle Ford Basin.

Regional Geology



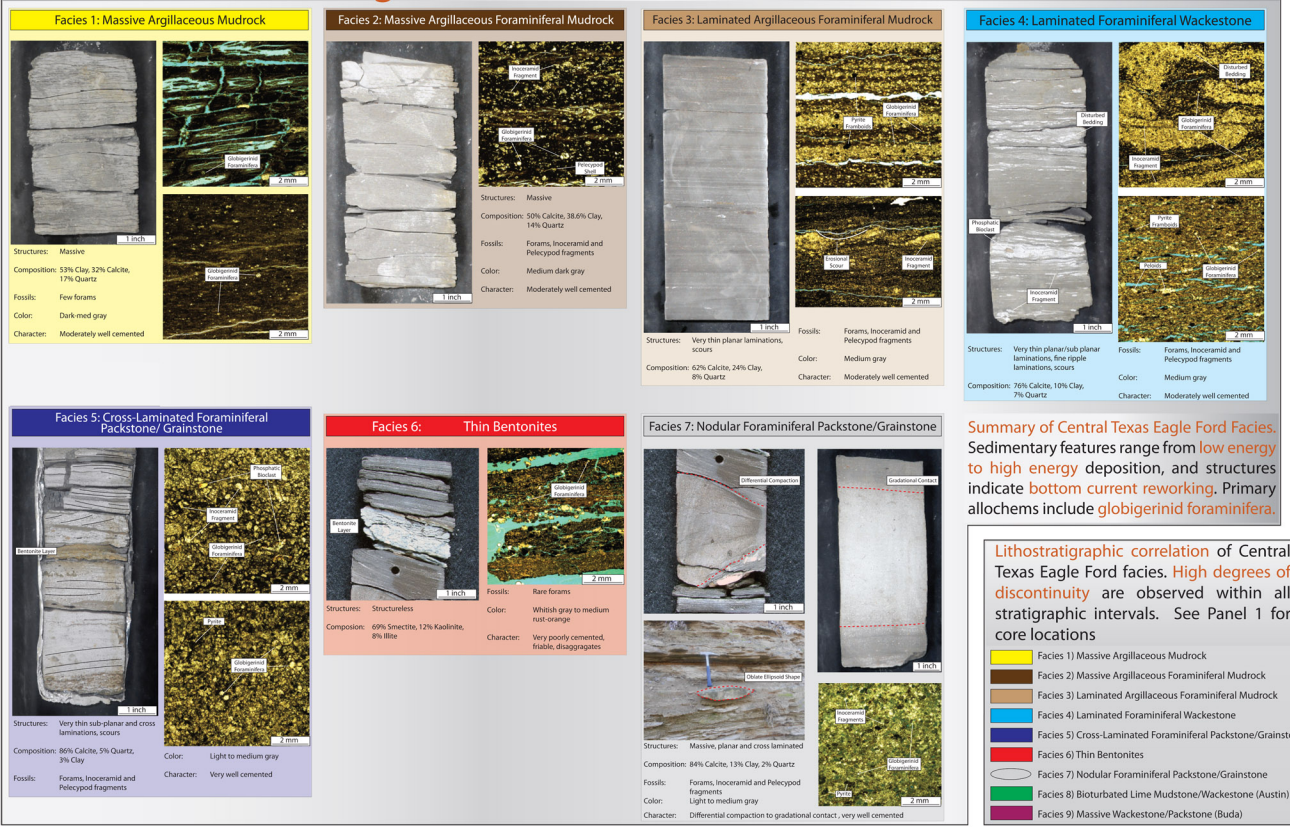
Stratigraphy of the South Texas Cretaceous. Progradational carbonate platforms with retrogradational black shale intervals comprise the Comanche shelf, bounded by the Sligo and later Stuart City raised rim shelf margins. The Eagle Ford is a Late Cretaceous interval (Cenomanian-Turonian) and is bounded below by the Buda and above by the Austin Chalk.



High Resolution Stratigraphy and Facies Architecture of the Upper Cretaceous (Cenomanian-Turonian) Eagle Ford Formation, Central Texas

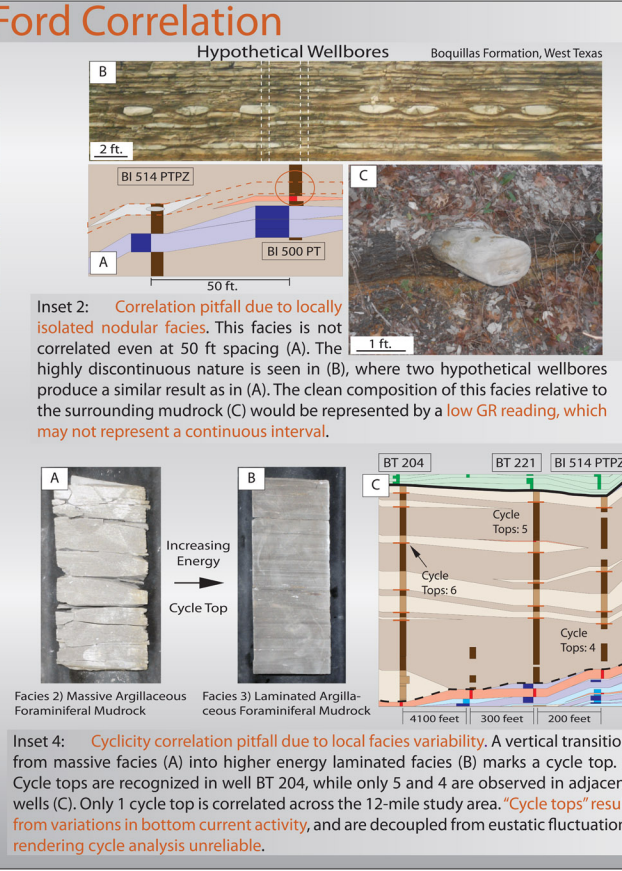
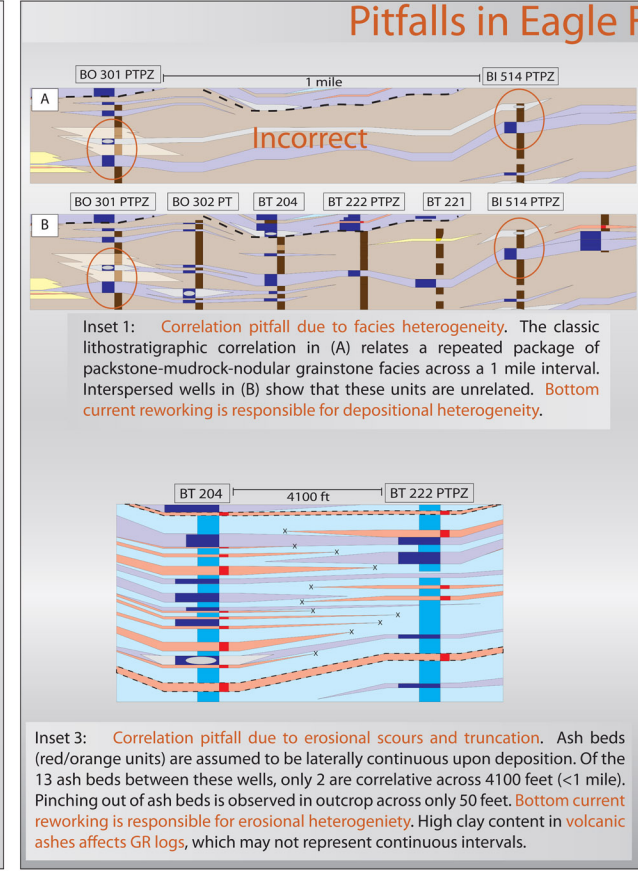
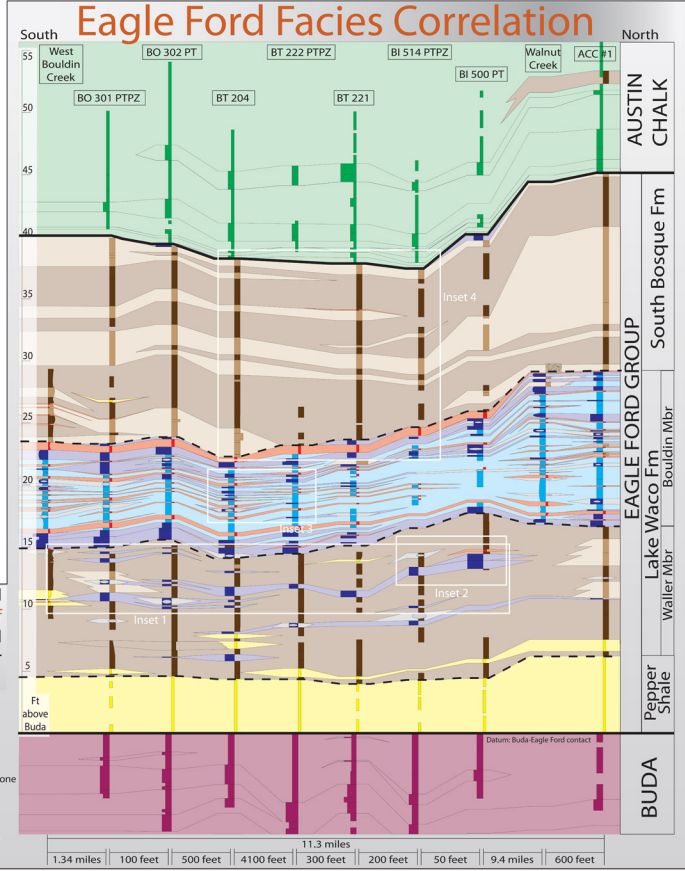
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Eagle Ford Facies of Central Texas



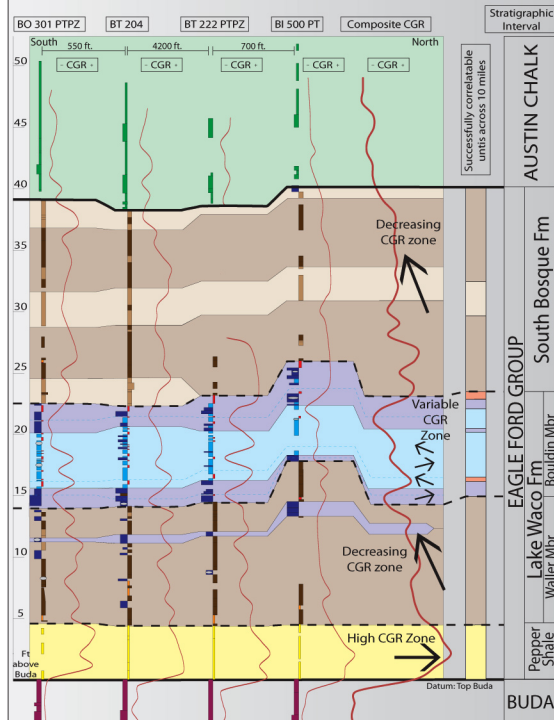
Summary of Central Texas Eagle Ford Facies. Sedimentary features range from **low energy to high energy** deposition, and structures indicate **bottom current reworking**. Primary allochems include **globigerinid foraminifera**.

Lithostratigraphic correlation of Central Texas Eagle Ford facies. High degrees of **discontinuity** are observed within all stratigraphic intervals. See Panel 1 for core locations



Part 2: Chemostratigraphic Analysis of the Eagle Ford Formation, Central Texas

CGR Correlation

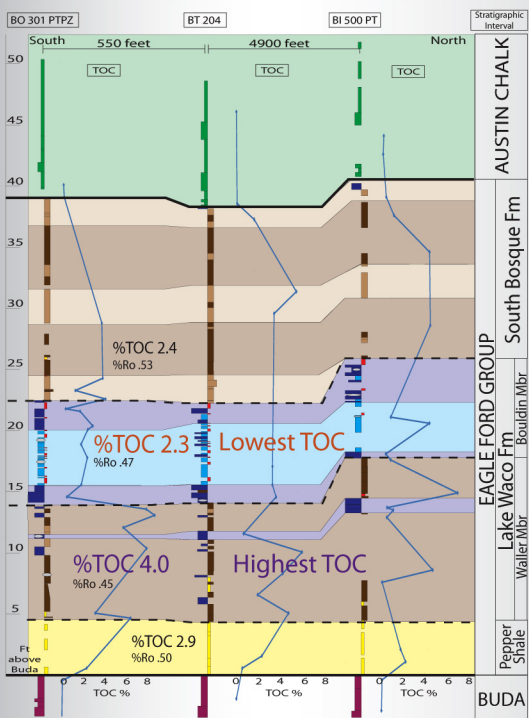


Correlation of facies based on CGR (GR Th-K) logs. The resolvability of facies based on CGR approaches the degree of correlatability of lithofacies across 10 miles. A distinct 4-fold stratigraphy emerges.

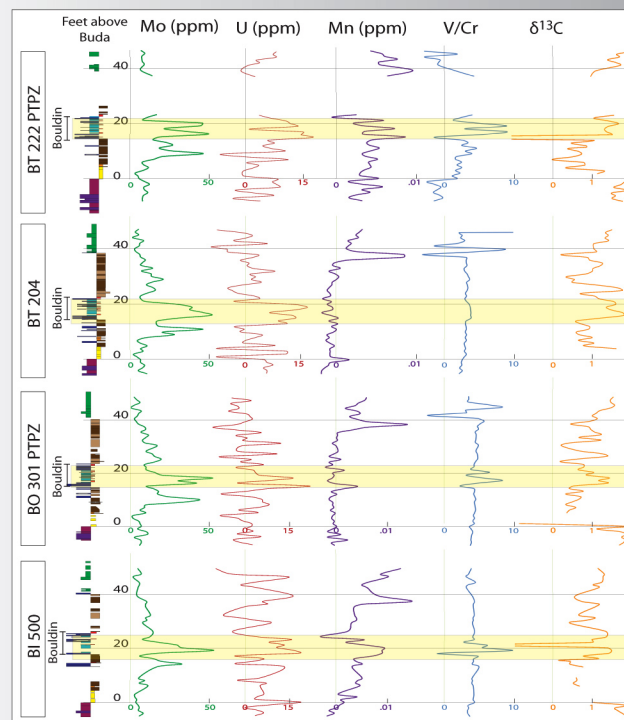
- 1) Pepper Shale is a clay-rich, high CGR zone.
- 2) Waller Member is a marly mudrock with decreasing CGR.
- 3) Bouldin Member is a calcareous variable CGR zone.
- 4) South Bosque Formation is a marly mudrock with decreasing CGR.

TOC Analysis

Comparison of TOC data per stratigraphic interval. The Central Texas Eagle Ford Formation is organically enriched in Type II organic material, but immature (avg %Ro = .49). Highest average TOC enrichment is in the Waller Member, with the lowest average TOC enrichment in the Bouldin Member. The Pepper Shale and the South Bosque Formation provide TOC values of 2.9% and 2.4%, respectively.



Chemostratigraphy



Chemostratigraphic analysis of the Central Texas Eagle Ford Formation. Mo, U, Mn, V/Cr, and $\delta^{13}C$ are paleo-redox indicators (Algeo and Lyons, 2006; Algeo and Rowe, 2011; Rowe et al., 2008; Rowe et al., 2012; Schlanger et al., 1987). Enrichment of these proxies indicates that maximum basin restriction occurred within the Bouldin Member. Another minor episode of basin restriction may have occurred within the Waller Member, as evidenced by Mo enrichment.

Discussion

The Bouldin Member contains the highest carbonate content, the highest energy facies, and the lowest average TOC. These factors could justifiably lead to the conclusion that the Bouldin Member represents a highstand carbonate platform. This is in general accordance with transgressive nature of the lower Eagle Ford (Pepper Shale-Bouldin Member). However, chemostratigraphic analysis indicates anoxic, restricted basin conditions prevailed during deposition of the Bouldin Member.

Explanation for the discrepancy:

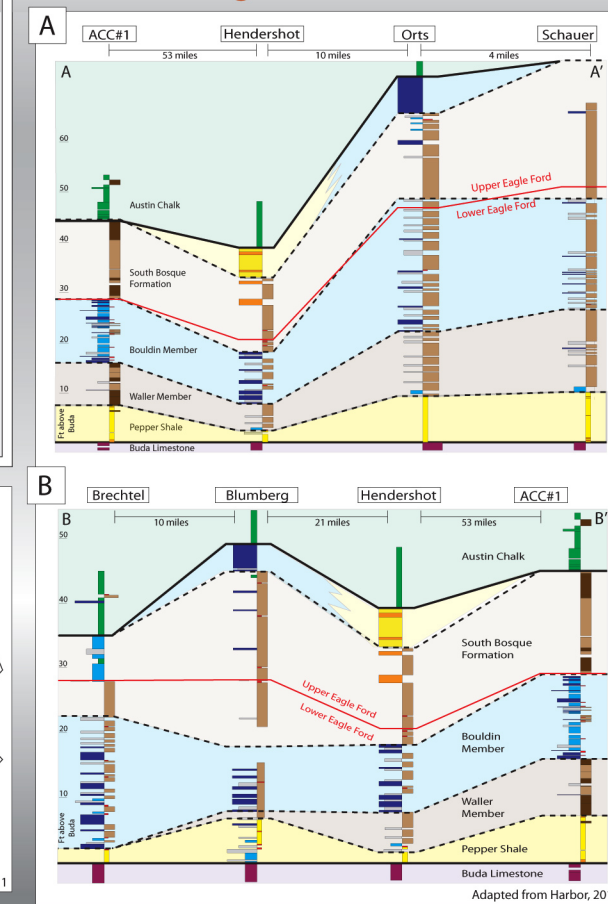
Heightened carbonate content is controlled by productivity of globigerinid foraminifera within the oxic zone. A strong association with high carbonate content and volcanic ash beds suggests that volcanic input may stimulate productivity.

Low TOC results from carbonate sediment dilution due to planktonic productivity.

High energy facies do not include wave or storm driven structures, but rather current-related features. Bottom current activity resulted in high energy deposition.

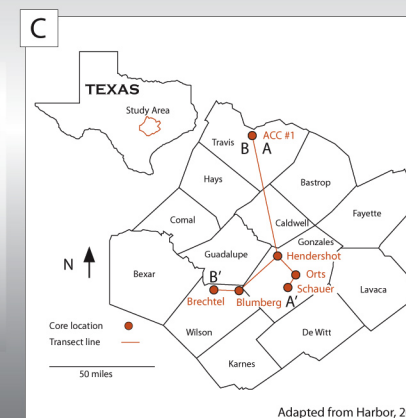
The dominant processes controlling Eagle Ford facies character, planktonic productivity and bottom current activity, are de-coupled from eustatic fluctuation, rendering classical sequence stratigraphy unreliable.

Regional Trends



Regional lithofacies correlation across the San Marcos Arch. In (A), The 4-fold stratigraphy observed in the Austin locality continues and thickens to the south off the San Marcos Arch. The distal expression of the Bouldin Member has a lower carbonate concentration.

Westward across the arch, the Waller Member pinches out before the Brechtel well (B). Substantial thickening and thinning are observed in all stratigraphic intervals. Cross section location is depicted in (C).



Adapted from Harbor, 2011

Adapted from Harbor, 2011

Summary/Conclusions

Eagle Ford lithofacies in Central Texas include:

- 1) Massive argillaceous mudrock
- 2) Massive argillaceous foraminiferal mudrock
- 3) Laminated argillaceous foraminiferal mudrock
- 4) Laminated foraminiferal wackestone
- 5) Cross-laminated foraminiferal packstone/grainstone
- 6) Thin bentonites
- 7) Nodular foraminiferal packstone/grainstone

High degrees of facies heterogeneity and variability are observed within the Eagle Ford Formation even at very small scales (50 ft) in cores and outcrops. Facies variability is attributed to erosional scouring and depositional reworking by bottom current activity, and also by changes in sediment supply.

Caution must be employed when correlating units within the Eagle Ford Formation. Potential pitfalls result from a generally underestimated concept of mudrock complexity. Depositional heterogeneities, erosional scours, and truncations add complexity to facies continuity, while localized nodular concretions and ash beds dramatically alter GR signatures.

CGR analysis (with 1 ft sampling) provides a resolution of stratal continuity that is only as robust as a 10-mile lithostratigraphic correlation, depicting a 4-fold stratigraphy corresponding to stratigraphic intervals.

Although the highest TOC is recorded in the Waller Member, maximum basin restriction prevailed within the Bouldin Member, as evidenced by enrichment of paleo-redox indicators including Mo, Mn, U, V/Cr, and $\delta^{13}\text{C}$.

Primary controls on Eagle Ford stratigraphy and character include bottom current activity, and productivity of globigerinid foraminifera in the photic zone, both of which are de-coupled from eustatic fluctuation, rendering classical sequence stratigraphy unreliable in the Central Texas Eagle Ford Formation.



Bouldin Member, Austin, TX



Boquillas Formation, West Texas



Boquillas Formation, West Texas

References

Algeo, T.J., and Lyons, T.W., 2006, Mo-total organic carbon covariation in modern anoxic marine environments: Implications for analysis of paleoredox and paleohydrographic conditions: *Paleoceanography*, v. 21.

Algeo, T.J., and Rowe, H., 2011, Paleooceanographic applications of trace-metal concentration data: *Chemical Geology*.

Galloway, W.E., 2008, Depositional evolution of the Gulf of Mexico sedimentary basin, in Miall, A.D., eds., *The sedimentary basins of the United States and Canada*: New York, Elsevier, 610 p.

Harbor, R.L., 2011, Facies characterization and stratigraphic architecture of organic-rich mudrocks, Upper Cretaceous Eagle Ford Formation, South Texas: The University of Texas at Austin

Ruppel, S.C., Loucks, R.G., Frébourg, G., 2012, Guide to field exposures of the Eagle Ford-equivalent Boquillas Formation and related Upper Cretaceous units in Southwest Texas, Bureau of Economic Geology, The University of Texas at Austin.

Rowe, H.D., Loucks, R.G., Ruppel, S.C., Rimmer, S., 2008. Mississippian Barnett Formation, Fort Worth Basin, Texas: bulk geo chemical inferences and Mo-TOC constraints on the severity of hydrographic restriction. *Chemical Geology* 257, 16–25.

Rowe, H.D., Hughes, N., Robinson, K., 2012, The quantification and application of handheld energy-dispersive x-ray fluorescence (ED-XRF) in mudrock chemostratigraphy and geochemistry: *Chem Geo*, doi:10.1016/j.chemgeo.2011.12.023

Salvador, A., and Muñeton, J.M.Q., 1989, Stratigraphic Correlation Chart Gulf of Mexico Basin, in Salvador, A., ed., *The Gulf of Mexico Basin*: Boulder Colorado, Geological Society of America, *The Geology of North America*, v. J., plate 5.

Schlanger, S.O., Arthur, M.A., Jenkyns, H.C., and Scholle, P.A., 1987, The Cenomanian-Turonian Oceanic Anoxic Event, I. stratigraphy and distribution of organic carbon-rich beds and the marine $\delta^{13}\text{C}$ excursion: Geological Society, London, *Special Publications*, v. 26, p. 371-399.

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