Application of Quantitative Facies Analysis to Sedimentology-Stratigraphy & Geochemistry of Unconventional Shale Resources

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OBJECTIVES

- To show the applications of Quantitative Facies Analysis (QFA) in sedimentology, stratigraphy, and geochemistry.
- To link geochemistry facies to Markov Chain Analysis.

COMMENTS & ACKNOWLDEDGEMENTS

- The first part of the talk on Eagle Ford is from series of studies presented at the AAPG-ICE in 2013 (with J. G. Garcia, Shell) and AAPG, 2016 (with E. Van Dusen, B. Neff, D. Hurst, and H. McGarity-Beat). Data used was from the Core Lab Eagle Ford consortium.

- Geochemical data presented here are real data in the West Texas Permian Basin; however, location and actual depths are not shown.

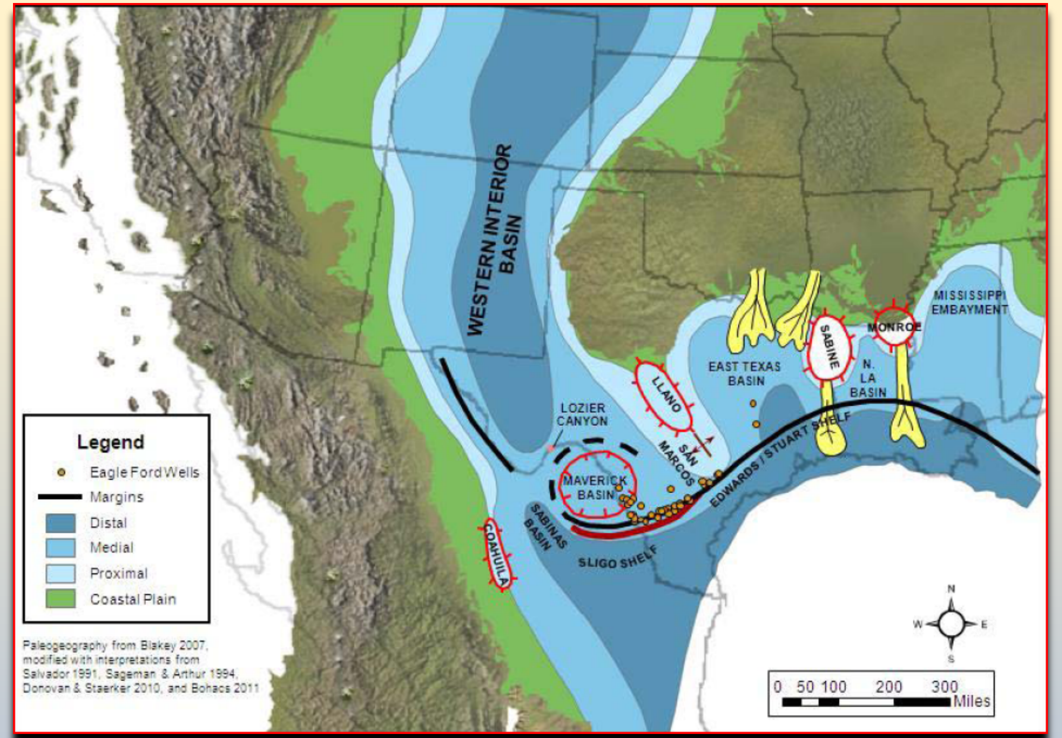
- Thanks to John Ballmer (Sr. Petrophysicist, Oxy), Core Lab, Premiere Laboratory, Shell, and Murphy Exploration & Production.

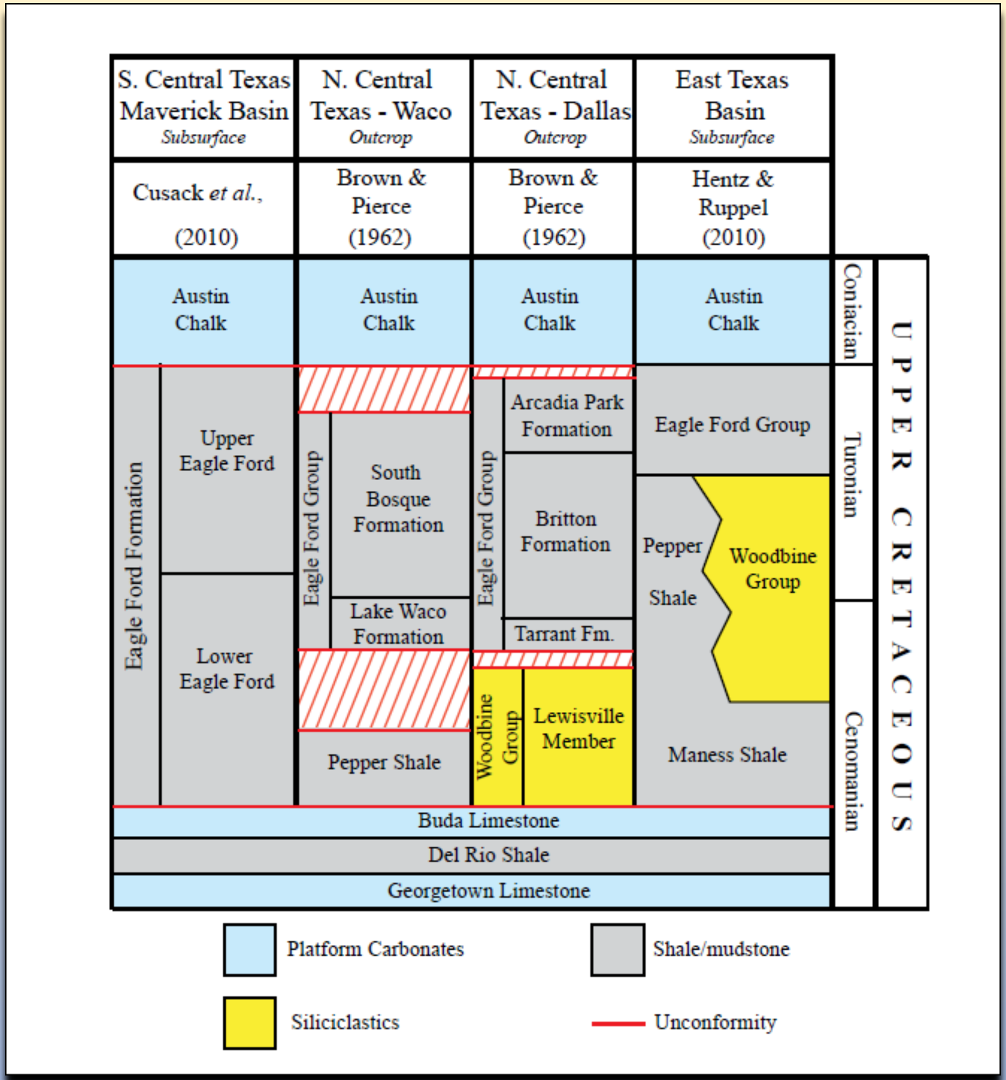
TALK OUTLINE

1. QFA as it applies to sedimentary facies in the Eagle Ford in South Texas
   - What are the Eagle Ford sedimentary facies?
   - Methodology – What are the steps in QFA
   - What does the data mean? Iso-percent of different Eagle Facies at various stratigraphic slices
   - Application to mechanical stratigraphy

2. Application of QFA to ~ geochemical facies derived from 6,000+ data points
   - Variation of geochemical facies as a function of sequence stratigraphic units (no discussion on sequence stratigraphy)
   - Application of Markov Chain from QFA

GEOLOGIC SETTING & STRATIGRAPHY

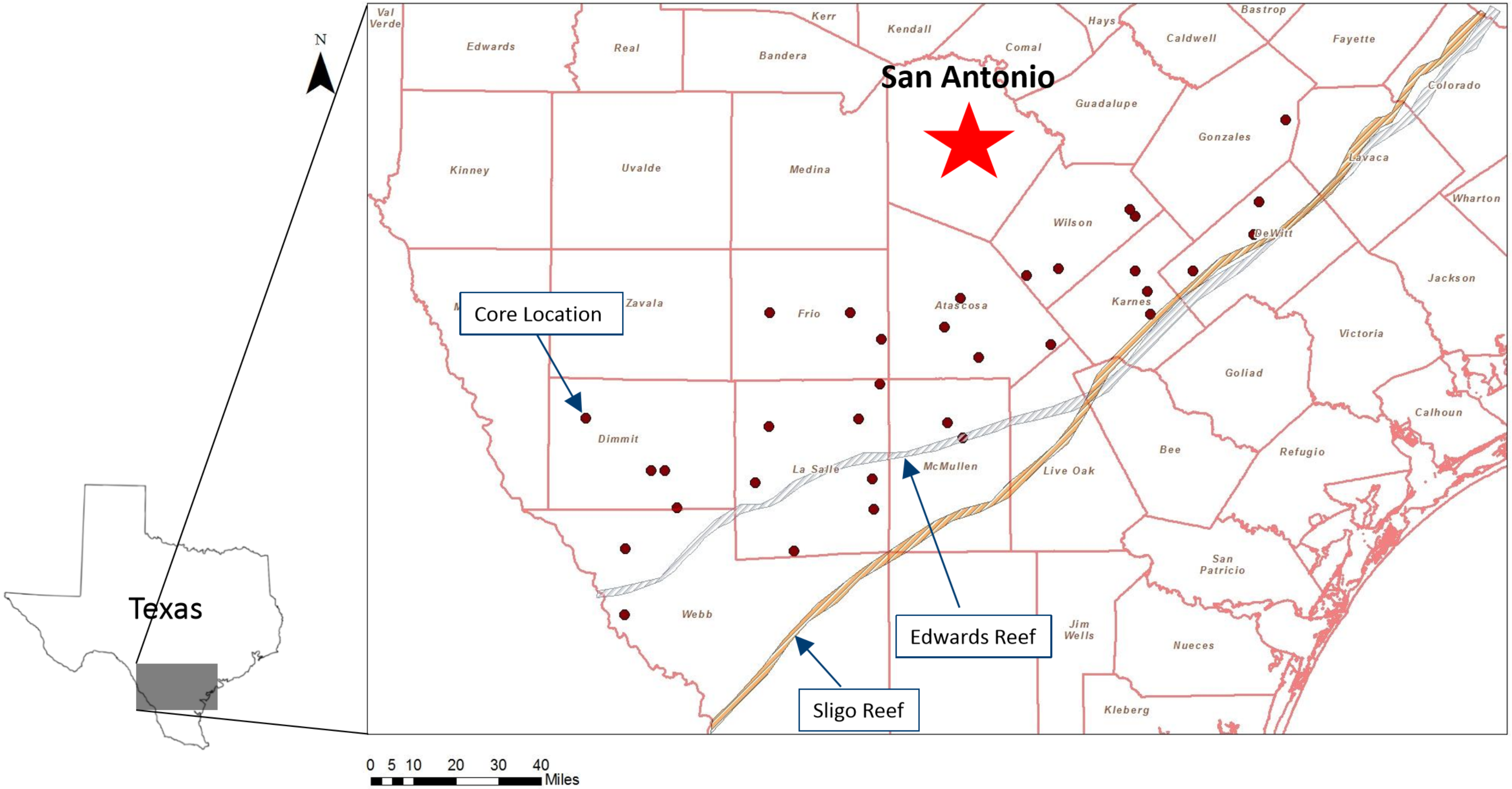




- Eagle Ford was deposited around Texas during Late Cenomanian to Turonian time (Late Cretaceous, 97 to 89.8 Ma)
- Deposition of the Eagle Ford Formation is coeval with oceanic anoxic event 2 (OAE 2).
- SW of the San Marcos Arch, Eagle Ford is primarily composed of organic-rich marls with interbedded with lean, lime mudstone.
- SE of the San Marcos Arch, Eagle is shaly, organic-rich marls and lime mudstones.

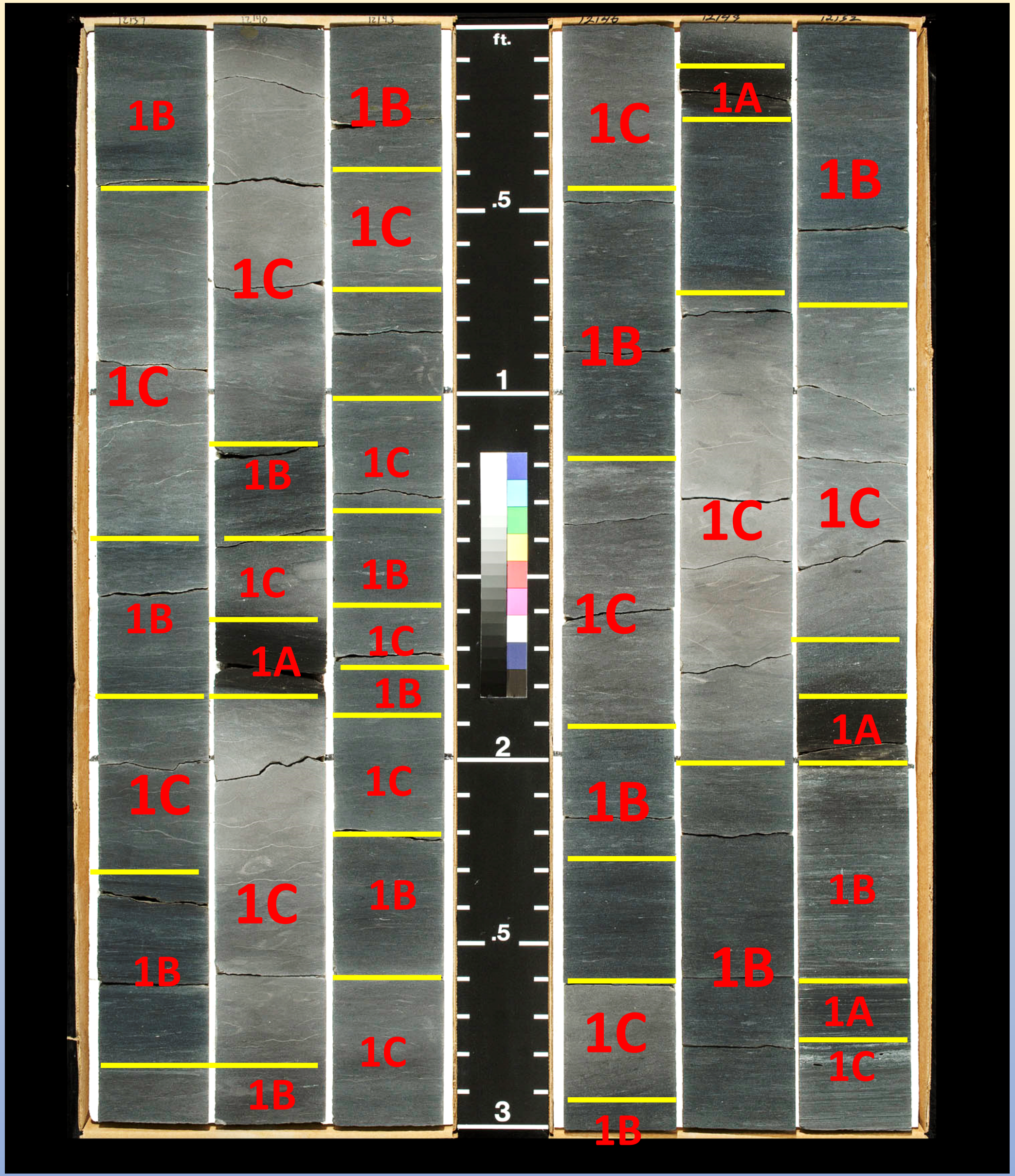
Workman, 2013

Study Area and Location of Cores – Eagle Ford Shale



37 cores

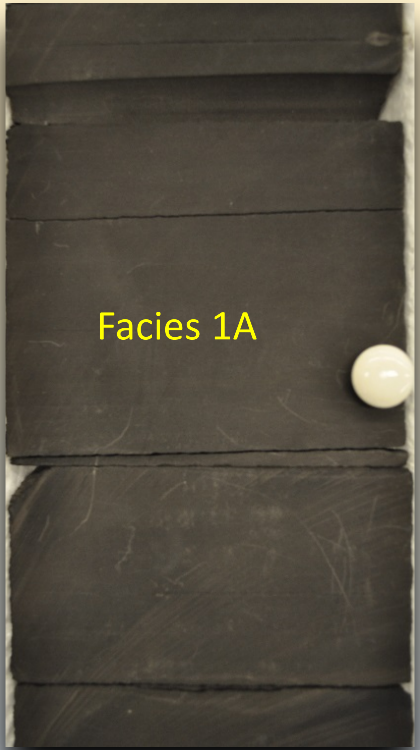
Quantitative Facies Tool Kit

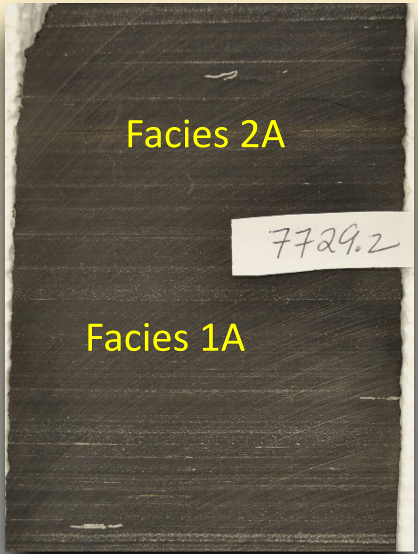


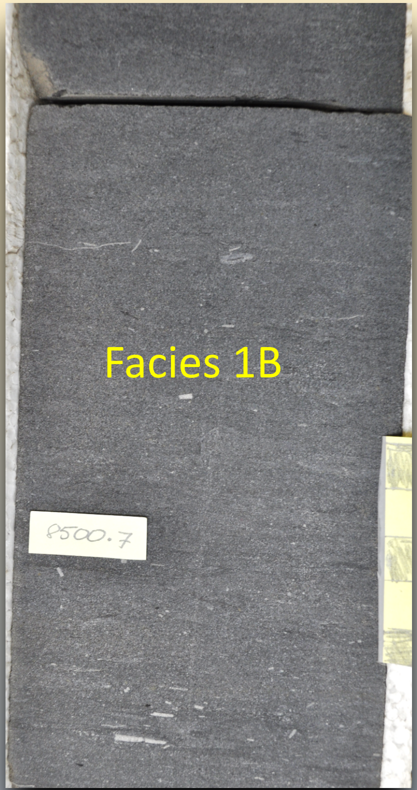
- **Subdivided cores into distinct sedimentary facies**
  - Initially divided: color, sedimentary structures, bioturbation
  - Enhance with XRD analysis: calcite content, TOC
- **Recorded:**
  - Color
  - The top and bottom depths of each facies
  - Sedimentary features
  - Nature of upper and lower contacts
  - Other features (faults, fractures, etc).
- **Incorporated other data**
  - Biostratigraphy
  - XRD
  - Rock mechanical data

FACIES TYPES 1

Core Diameter = 3.5”







Facies 1A/2A

Description

- Black to dark gray
- Thin laminations in 2A

Composition

- TOC = 3-8% (highest)
- Calcite = 40-70%

Interpretation

- Lowest energy suspension deposits
- Facies 2A occasional ripples

Facies 1B

Description

- Dark gray
- Thin laminations. Bioturbated (BI 2-5)

Composition

- TOC = 1-3%
- Calcite = 70-80%

Interpretation

- Suspension to ripple regime deposits
- Oxic to suboxic conditions

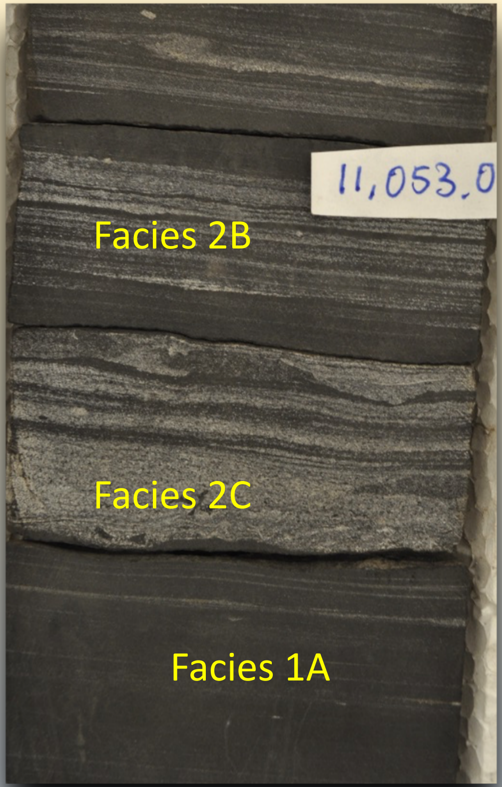
FACIES TYPES 1C, 2B, 2C

Core Diameter = 3.5”

Facies 1C
Description
- Light gray to cream
- Bioturbated (BI 4-5)

Composition
- TOC = <2%
- Calcite = 80-95%

Interpretation
- Suspension to ripple regime deposits
- Oxic condition



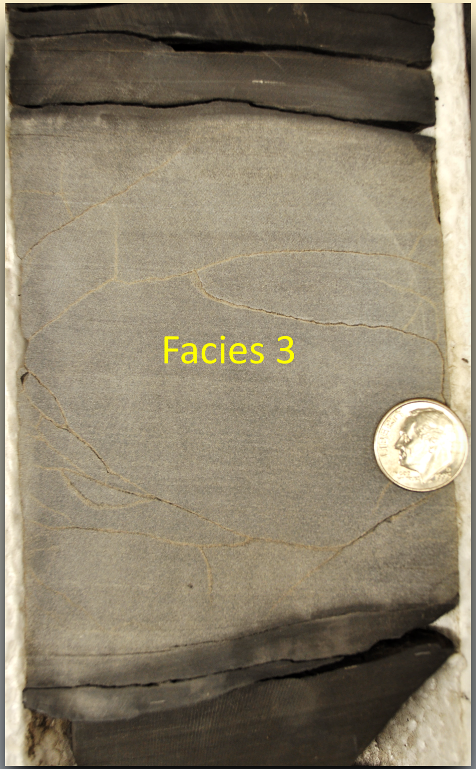
Facies 2B/2C
Description
- Alternating light & dark layers
- Ripple cross laminations in 2C

Composition
- TOC: 2B = 1-3%; 2C <2%
- Calcite = 70-80%

Interpretation
- Variable ripple regime conditions
- Alternating suspension-traction deposition

FACIES TYPES 3,5, 6

Core Diameter = 3.5”



Facies 3

Description

- Light gray
- Horizontal to low angle, cross-stratified

Composition

- TOC = <1%
- Calcite = 80-95%

Interpretation

- High energy traction deposits – storm/ turbidites

Facies 5/6

Description

- Dark to light gray
- Convoluted laminae (Facies 5)
- Matrix-supported clasts (Facies 6)

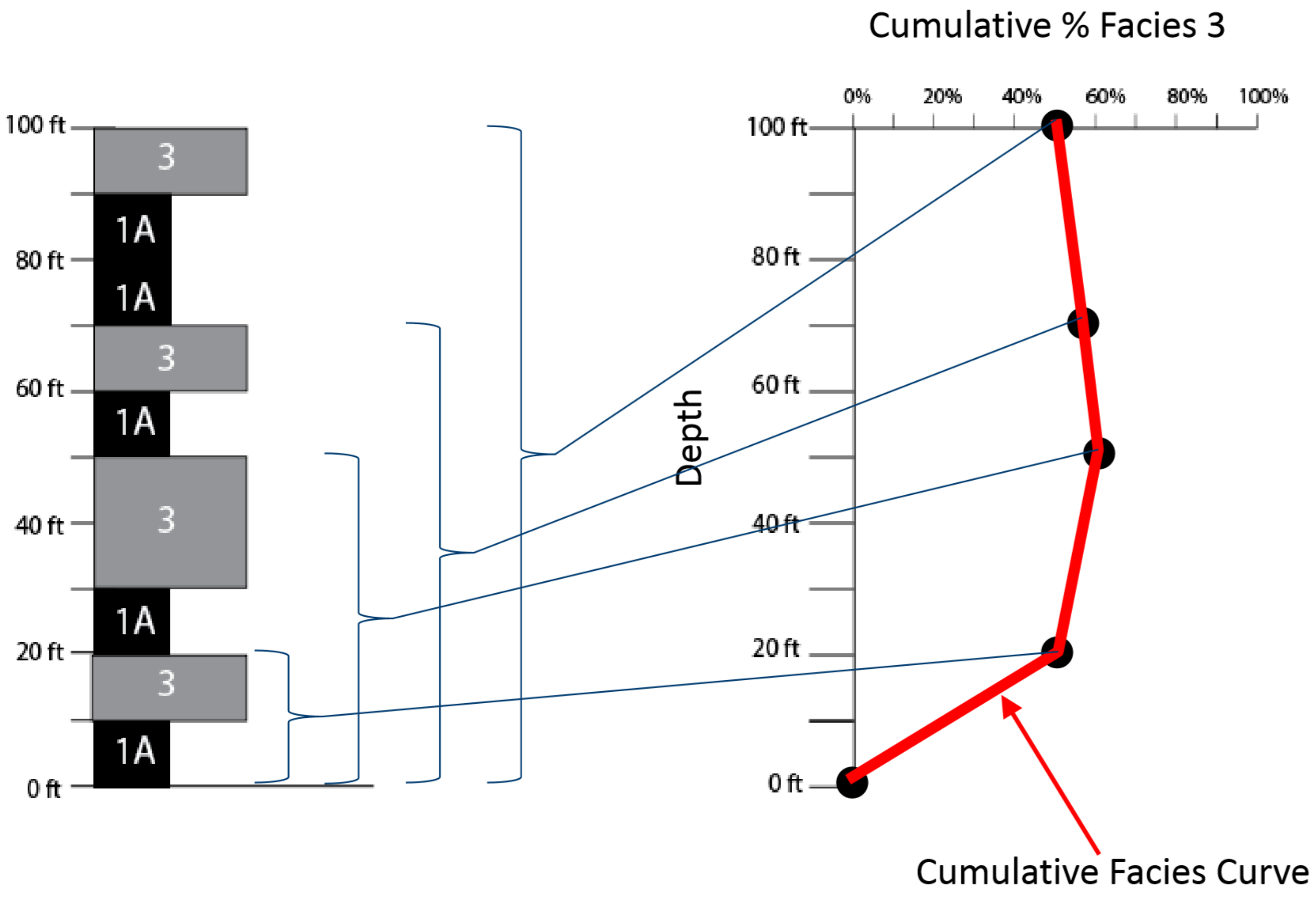
Composition

- Variable composition

Interpretation

- Slumps & debris flow structures

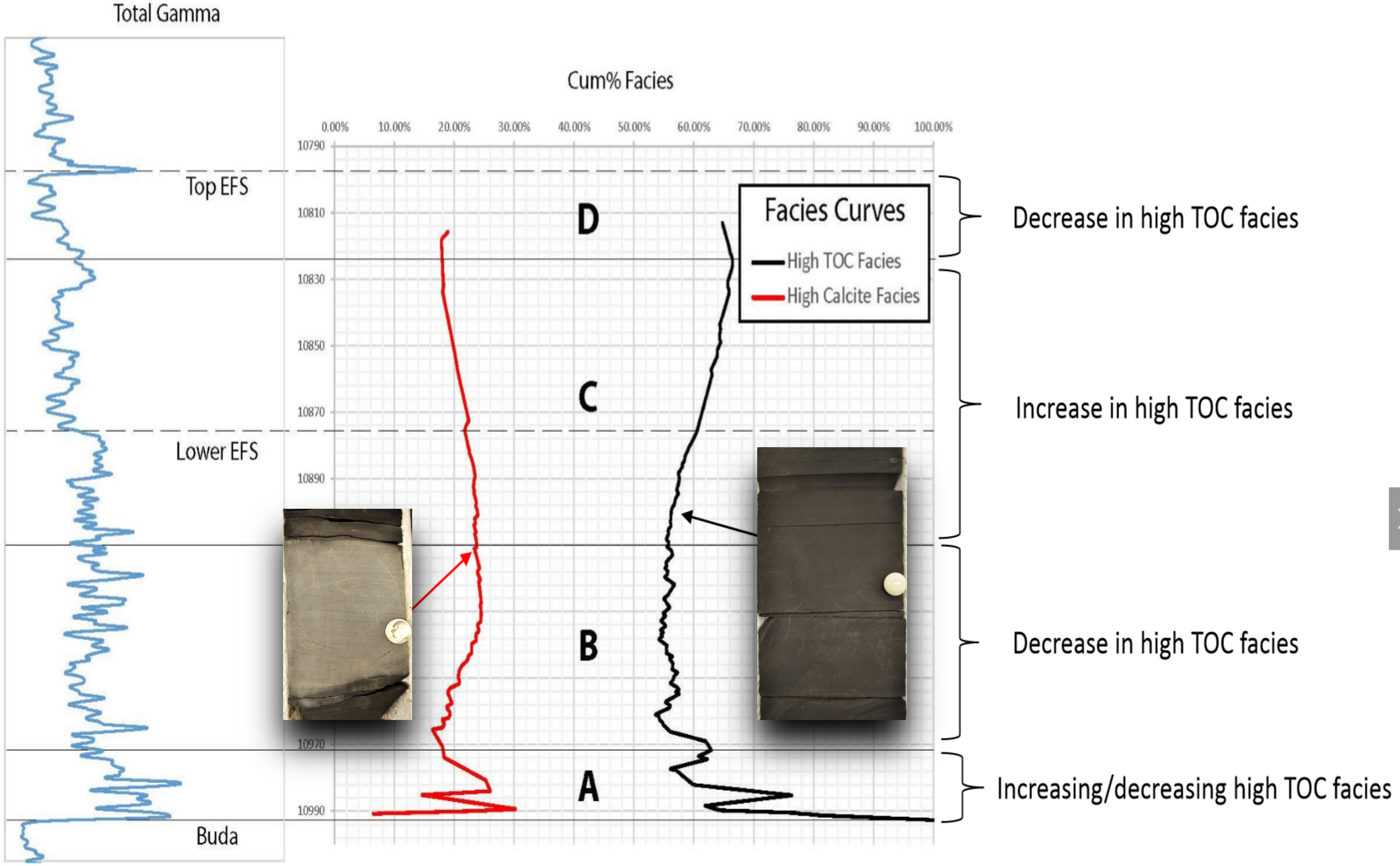
Quantitative Facies Methodology (QFM)



- **QFM is a running net-to-gross calculation**
  - Isolate facies type/group
  - Measure facies thickness over given interval
    - Calculate cumulative %
  - Incrementally expand interval
- **Generate a cumulative percentage curve**
  - Observed changes in facies abundance
    - Increasing cumulative % = higher abundancy
  - Different curves for different facies types.

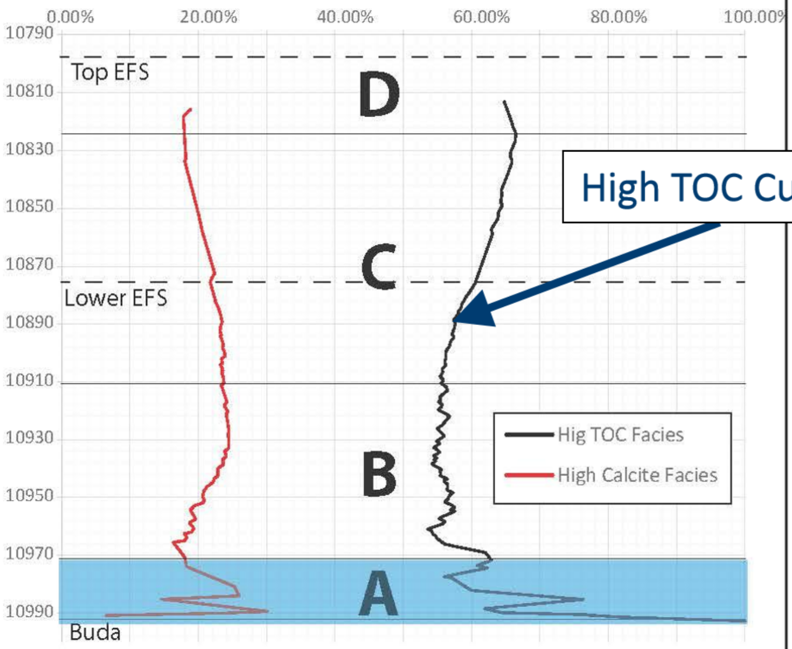
Cumulative Facies Curves: Eagle Ford

- **High TOC Facies:**
  - 1A, 2A
- **High Calcite Facies:**
  - 2C, 3

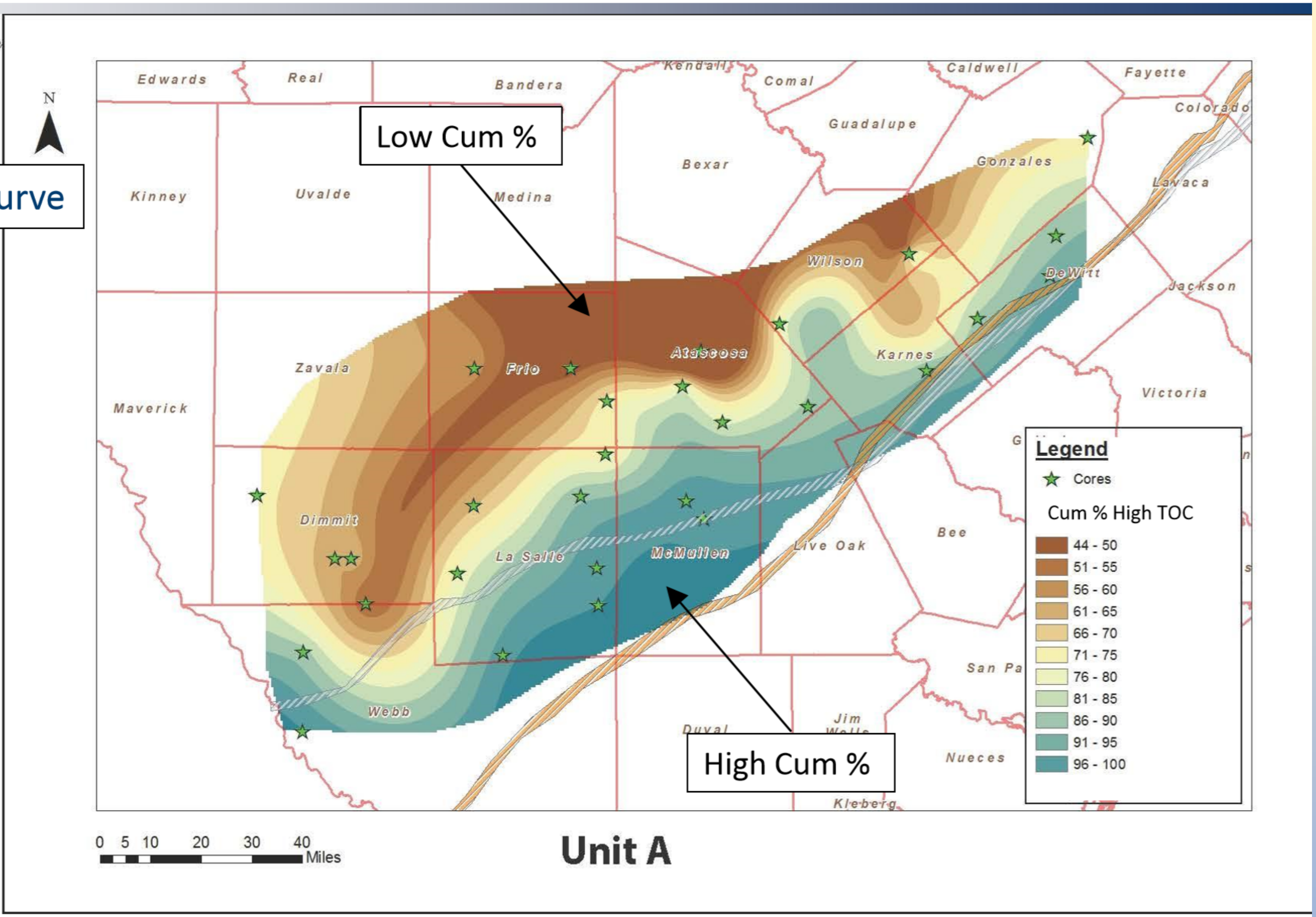


- Curves represent high calcite facies (red) and high TOC facies (black) – not all facies represented with displayed curves
- Curves subdivided by increases and decreases in cumulative %
- Pattern of cum% curves are controlled by sea level changes
- Cum% curve patterns change across the Eagle Ford Shale

Eagle Ford Facies Distribution

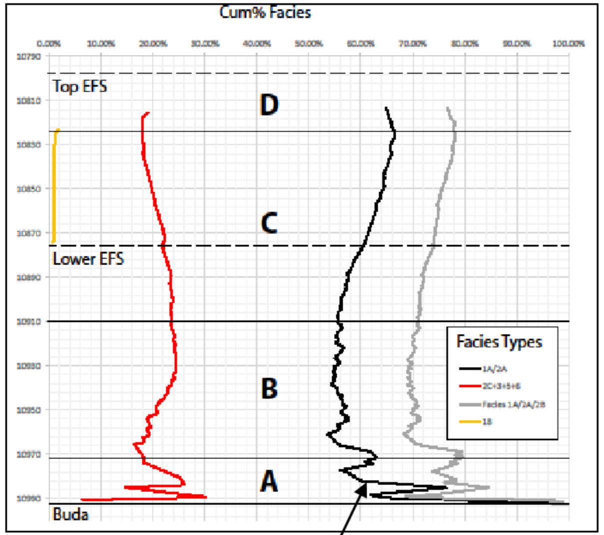


- **Cum % map: high TOC facies**
  - Top of Unit A
  - Brown = Low Cum%
  - Blue = High Cum%
- **Illustrates changes in facies abundancies across EFS**

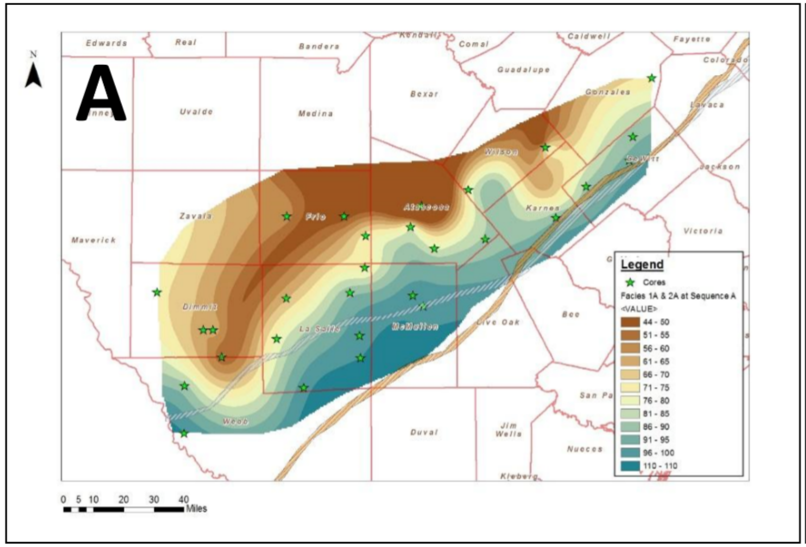


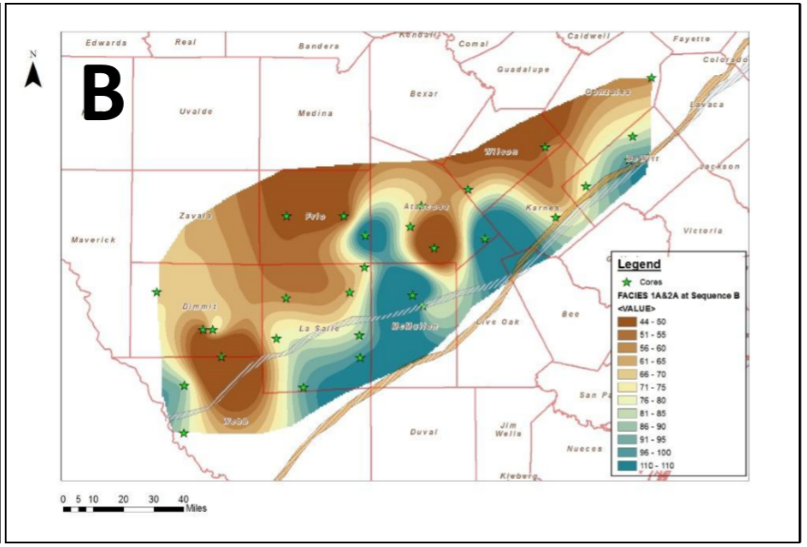
Cumulative Percent: High TOC Facies

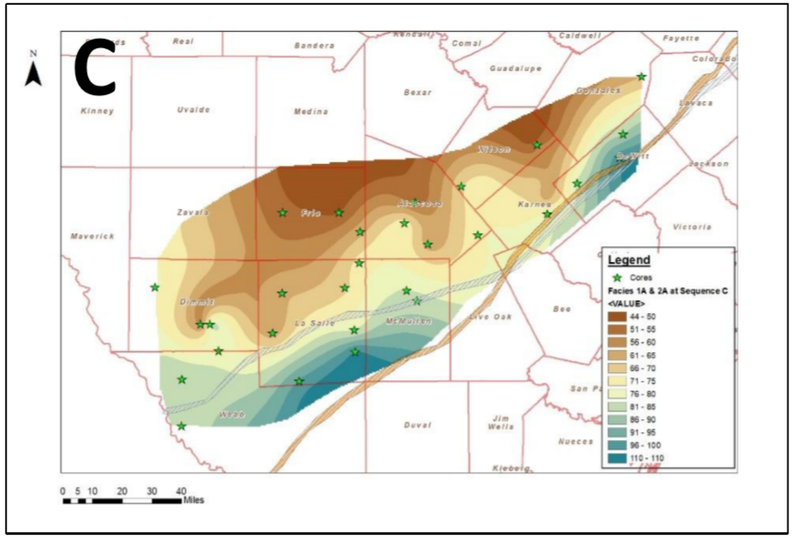
Eagle Ford Facies Distribution (High TOC)

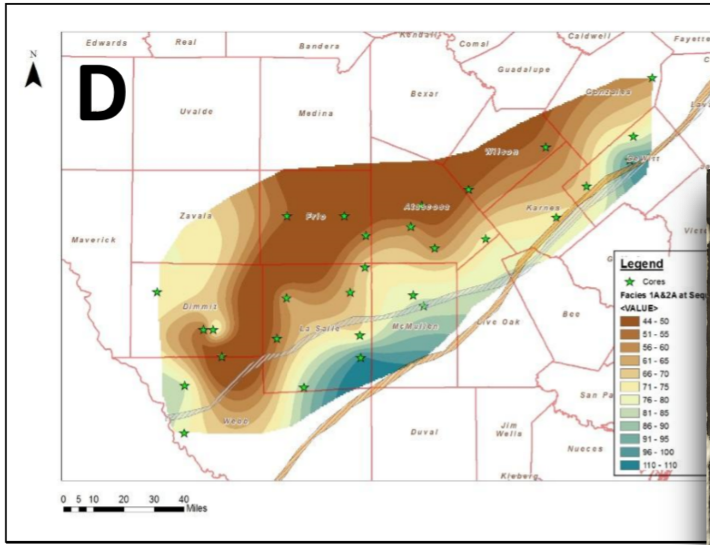


1A/2A Cumulative Facies Percent







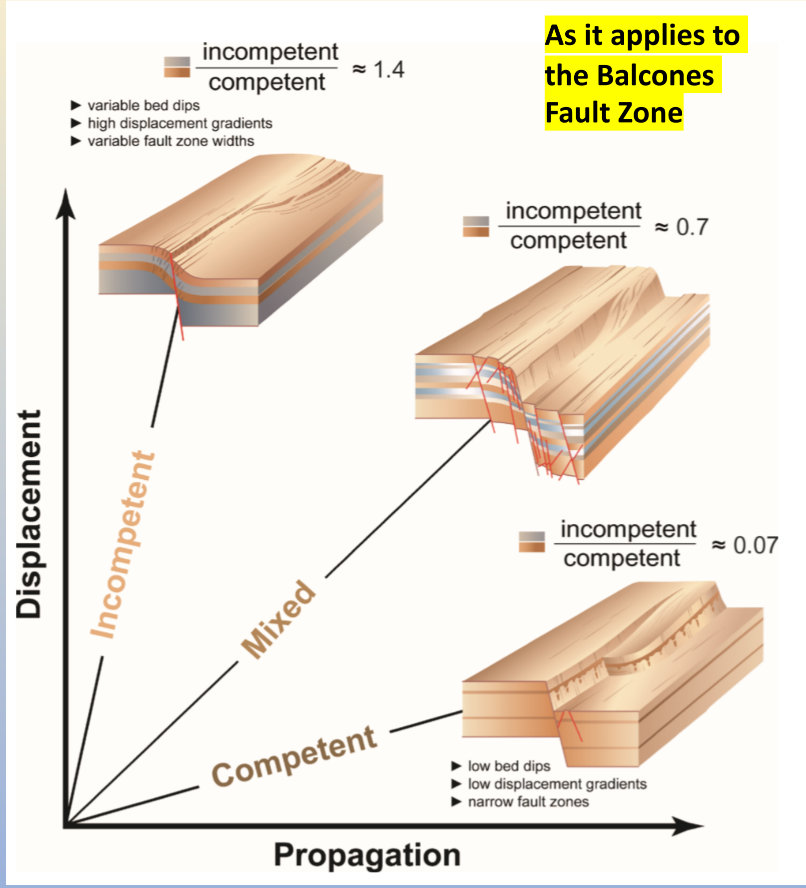


Ratio of Incompetent and Competent Facies

(Modified after Ferrill and Morris, 2008 & Smart et al., 2014)

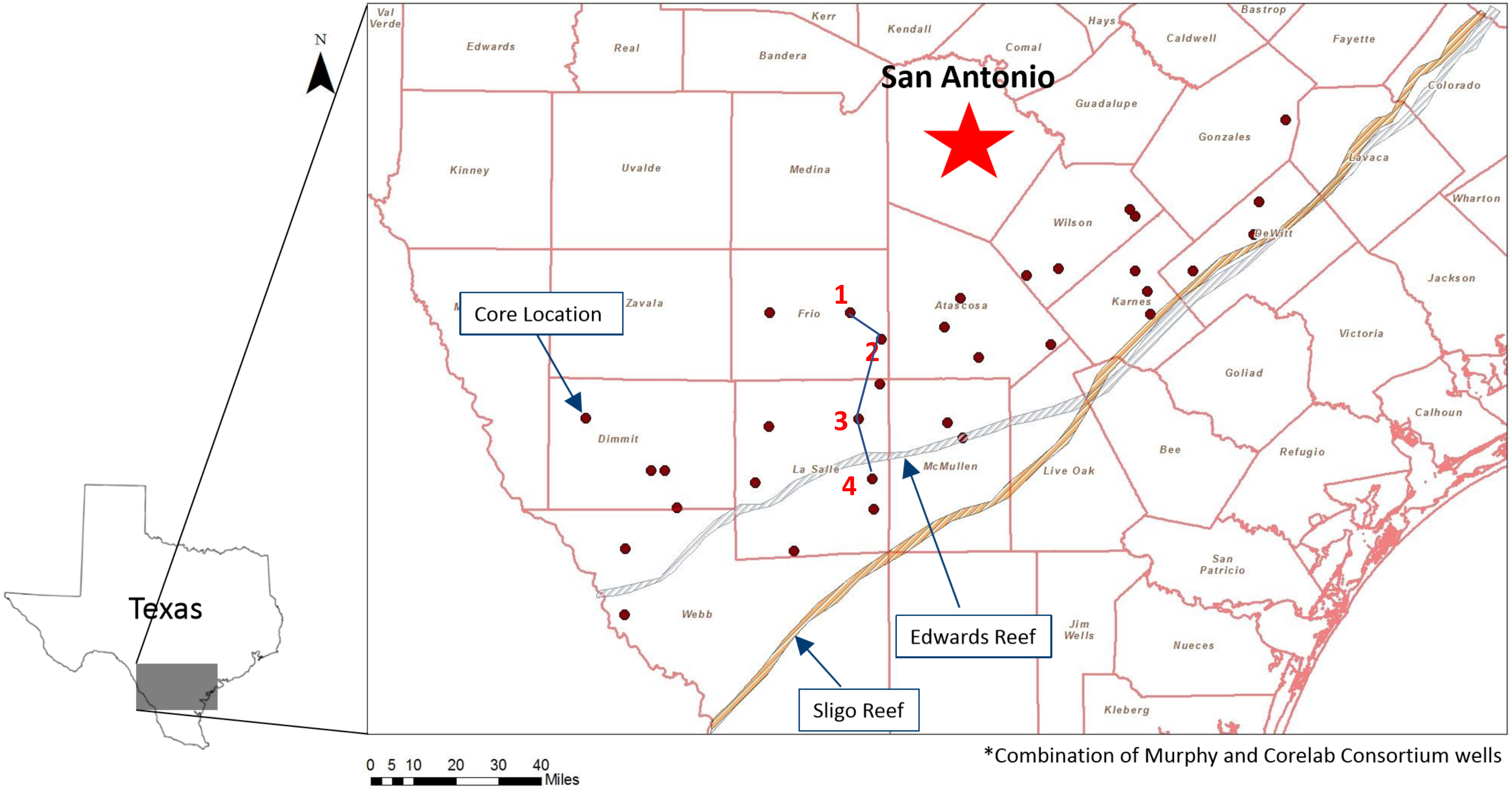
Fracture Patterns

- Incompetent Facies: Facies 1A, 2A, 2B, 1B, and Ash
- Competent Facies (Calcite-Rich): Facies 2C, and 3



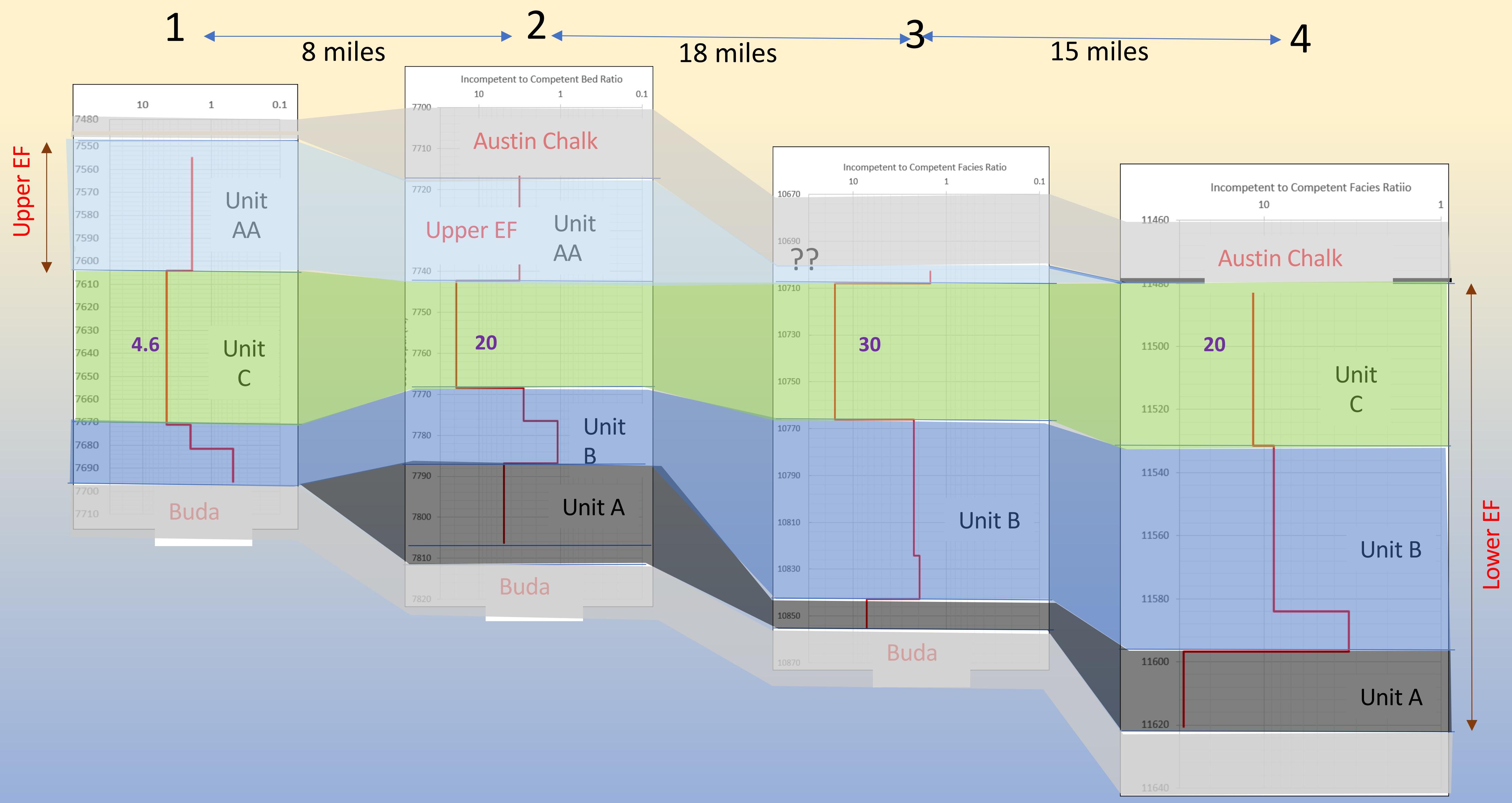
Ferrill and Morris, 2008

Study Area and Location of Cores – Eagle Ford Shale



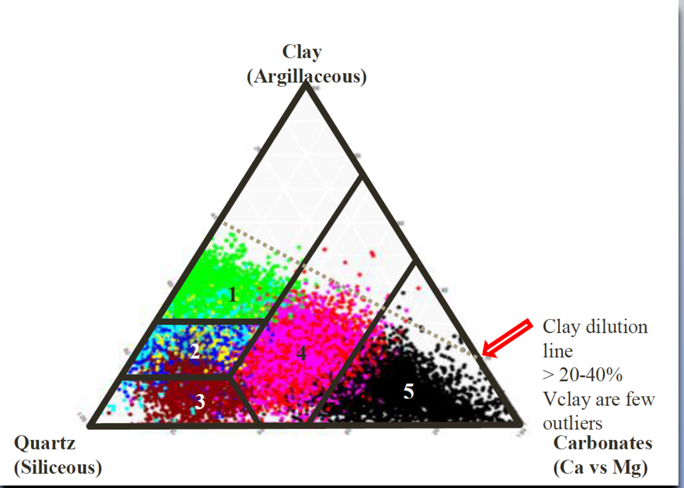
*Combination of Murphy and Corelab Consortium wells

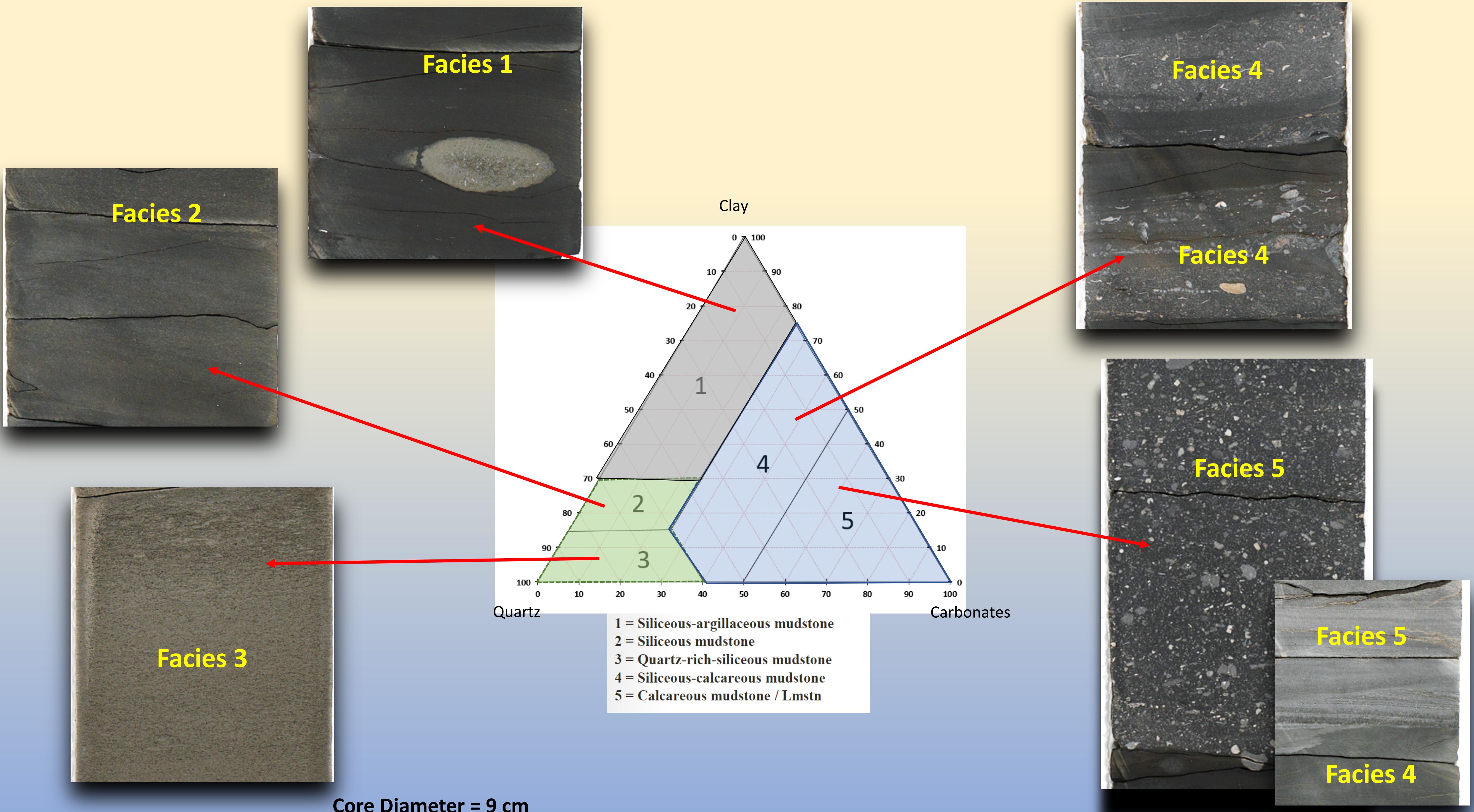
CROSS-SECTION OF INCOMPETENT TO COMPETENT BEDS PER DEFINED EAGLE FORD UNITS



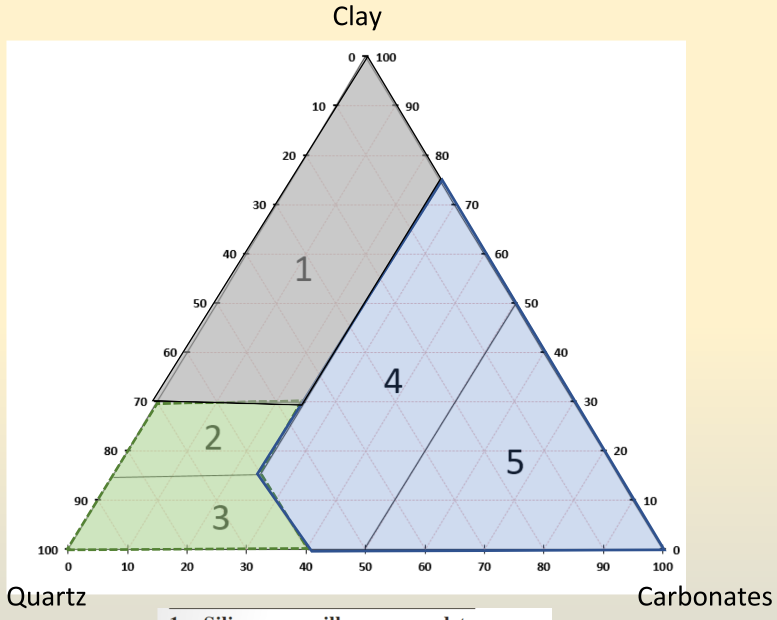
Materials - Objectives

- 6,000 plus XRF data from 305m of cores taken every 5 cm
  - Brueker handheld XRF, calibrated, rock surface cleaned, and avoid clasts
- Create a geochemical facies using the XRF mineral models: Quartz – Clay – Carbonates
- Apply Quantitative Facies Analysis (QFA) to determine:
  - How much geochemical facies per stratigraphic units?
  - How do geochemical facies vary vertically?
  - Can we predict vertical geochemical facies transition using Markov Chain?

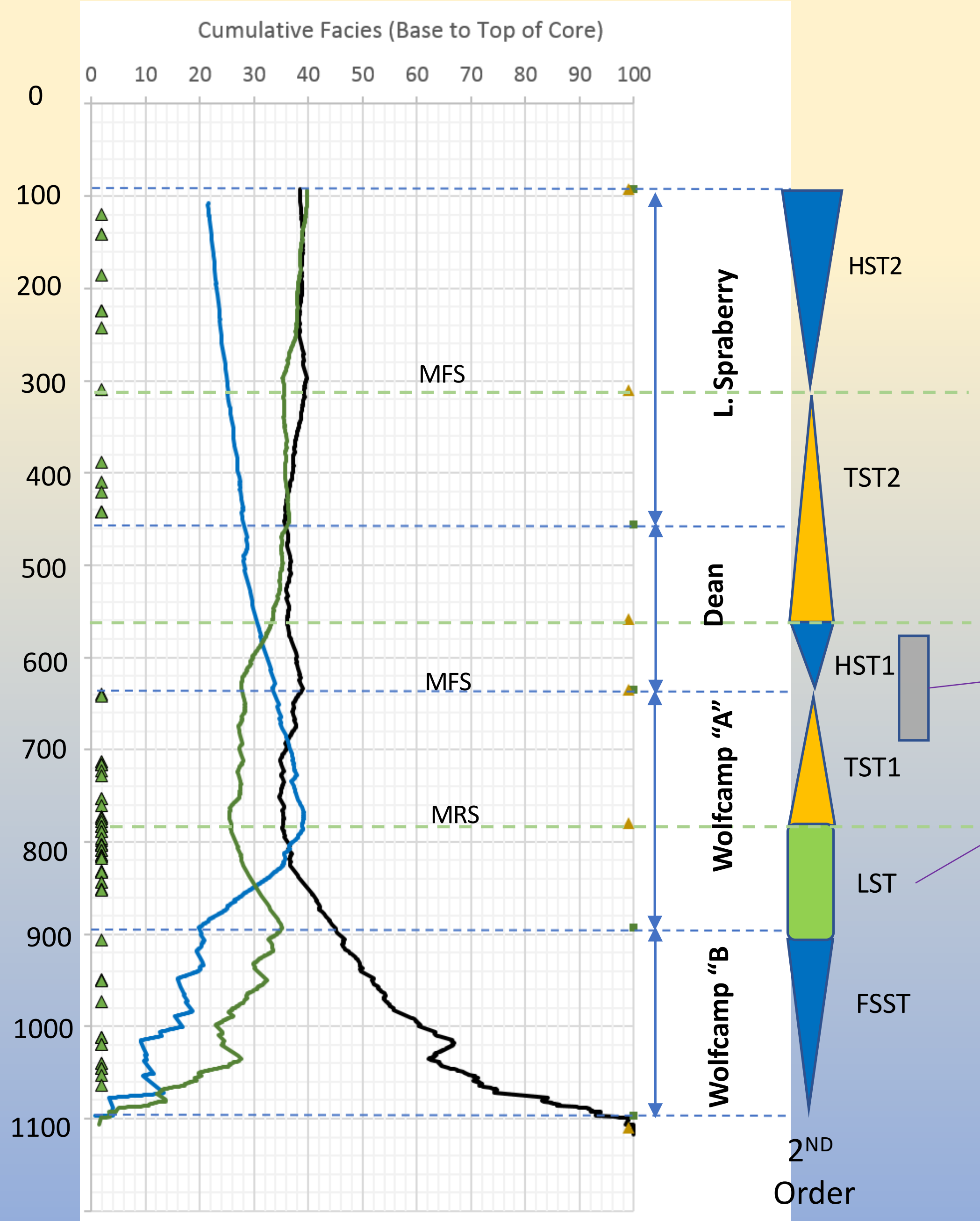




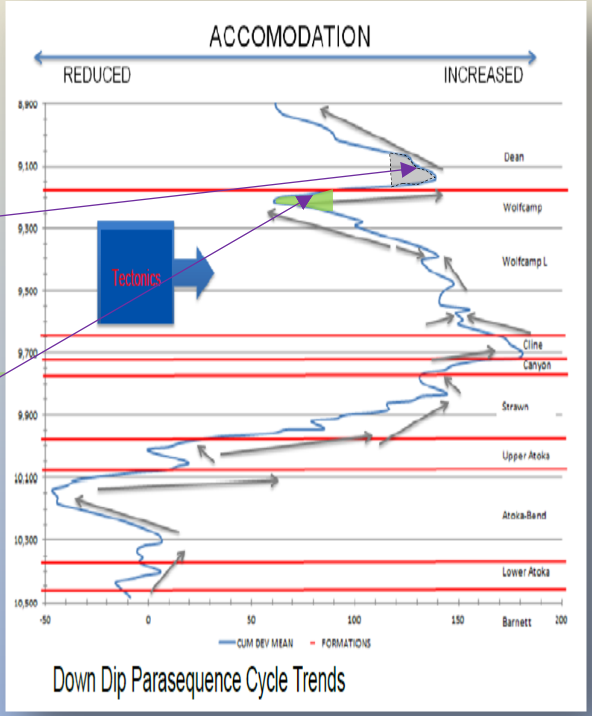
Core Diameter = 9 cm



1 = Siliceous-argillaceous mudstone
2 = Siliceous mudstone
3 = Quartz-rich-siliceous mudstone
4 = Siliceous-calcareous mudstone
5 = Calcareous mudstone / Lmstn

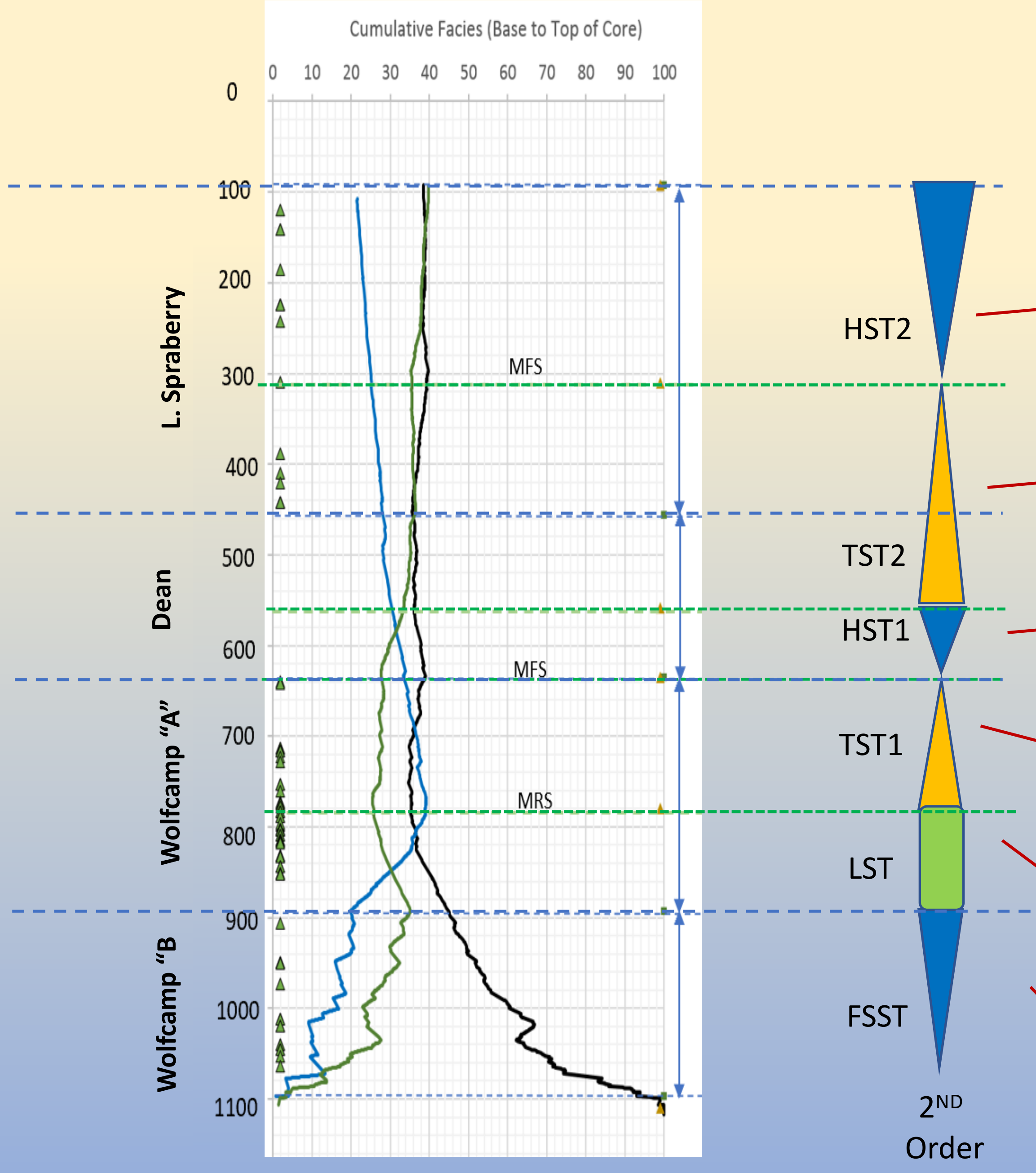


Sequence stratigraphy was based on a combination of seismic data from basin to shelf (Prochnow and Hinterlong, 2014 AAPG) combined with XRF data set.



Legend (After, Catuneaunu, 2006)
FSST= Falling Stage Systems Tract
LST = Low Stand Systems Tract
TST = Transgressive Systems Tract
HST = High Stands Systems Tract

FACIES TRANSITION_FREQUENCY DISTRIBUTION



FACIES TRANSITION	PERCENTAGE
2_1	29.15
1_2	28.41

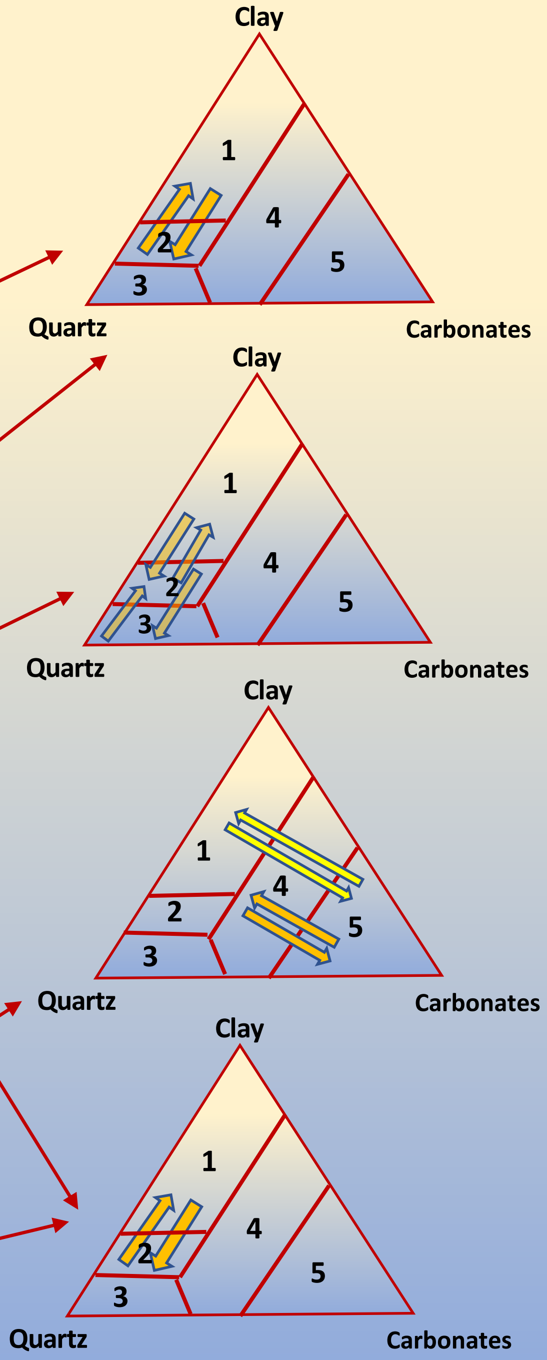
FACIES TRANSITION	PERCENTAGE
1_2	25.98
2_1	24.02

FACIES TRANSITION	PERCENTAGE
2_3	19.63
1_2	18.40
3_2	17.79
2_1	16.56

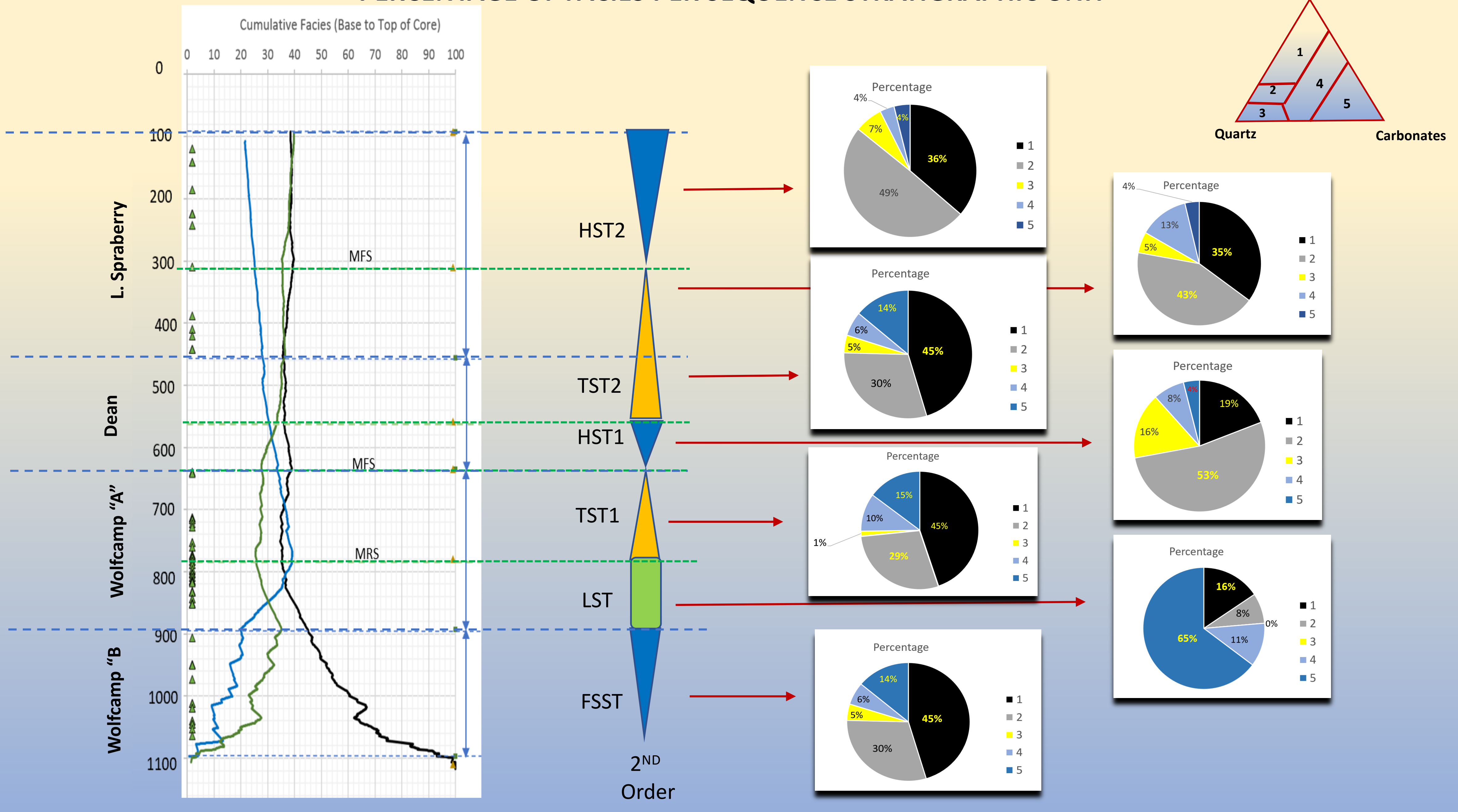
ACIES TRANSITION	PERCENTAGE
2_1	18.51
1_2	17.31

FACIES TRANSITION	PERCENTAGE
5_4	19.10
4_5	18.09
1_5	12.56
5_1	11.56

FACIES TRANSITION	PERCENTAGE
1_2	26.62
2_1	26.40



PERCENTAGE OF FACIES PER SEQUENCE STRATIGRAPHIC UNIT



WHAT IS MARKOV CHAIN?

- Is a stochastic *(having a random probability distribution)* model that describes the sequence of possible events where the probability of each event is dependent on the state attained in previous event (see Gingerich, 1969; Graham, 1988; Gagniuc, P.A., 2017).
- Markov Chain answers general questions: 1) is the vertical order of sequence random or ordered?; 2) in which way is it ordered? (Graham, 1988)

$$\boldsymbol{Next\ State} = (\text{Matrix of Transition of Probabilities})\ \text{X}\ (\text{Current State})$$

MARKOV CHAIN MATRIX
(After Gingerich, 1969)

Transition Count Matrix

	1	2	3	4	5
1	0	119	17	9	13
2	118	0	27	13	6
3	18	24	0	1	2
4	9	14	0	0	18
5	12	8	1	18	0

Transitional Probability Matrix

	1	2	3	4	5
1	0.00	0.75	0.11	0.06	0.08
2	0.72	0.00	0.16	0.08	0.04
3	0.40	0.53	0.00	0.02	0.04
4	0.22	0.34	0.00	0.00	0.44
5	0.31	0.21	0.03	0.46	0.00

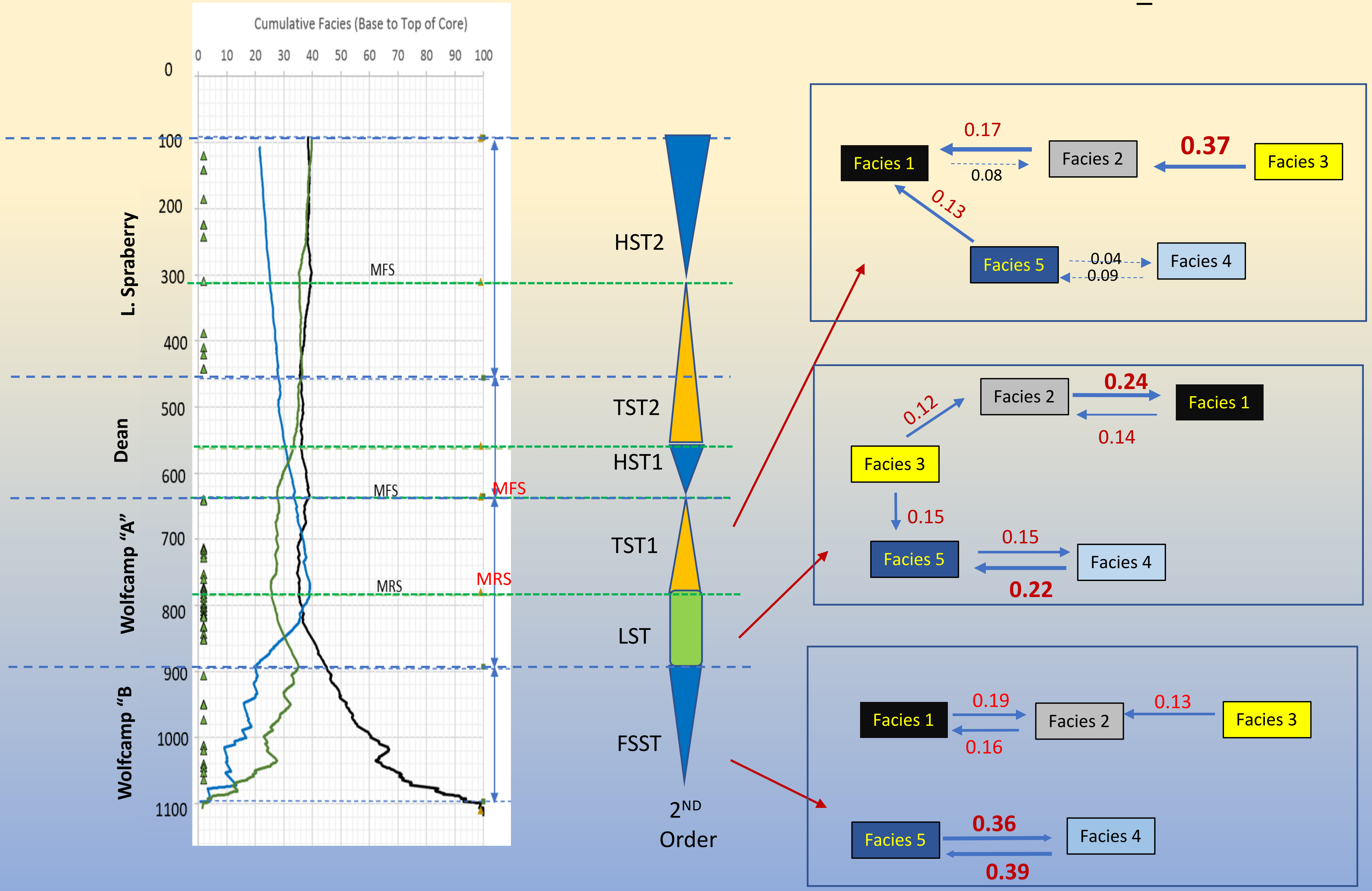
Independent Trial Matrix

	1	2	3	4	5
1	0.00	0.57	0.16	0.00	0.13
2	0.56	0.00	0.16	0.14	0.14
3	0.39	0.41	0.00	0.10	0.10
4	0.39	0.40	0.11	0.00	0.04
5	0.39	0.40	0.11	0.10	0.00

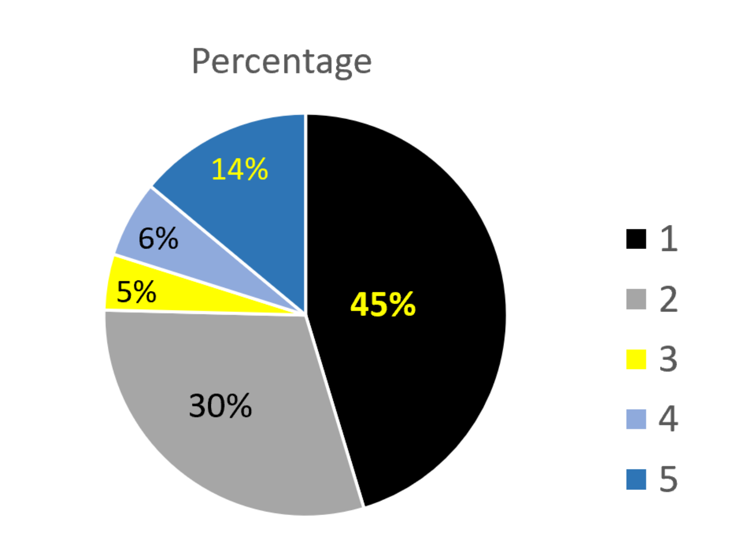
Difference Matrix (TPMx - ITMx)

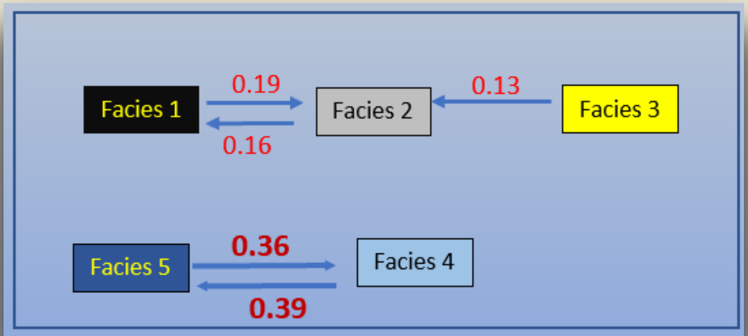
	1	2	3	4	5
1	0.00	0.19	-0.05	0.06	-0.05
2	0.16	0.00	0.01	-0.07	-0.10
3	0.01	0.13	0.00	-0.08	-0.05
4	-0.17	-0.06	-0.11	0.00	0.39
5	-0.08	-0.20	-0.08	0.36	0.00

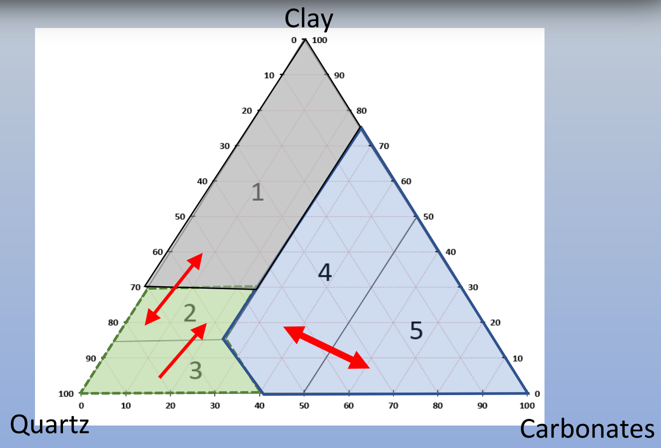
WOLFCAMP "B" AND WOLFCAMP "A" FACIES TRANSITION_MARKOV CHAIN

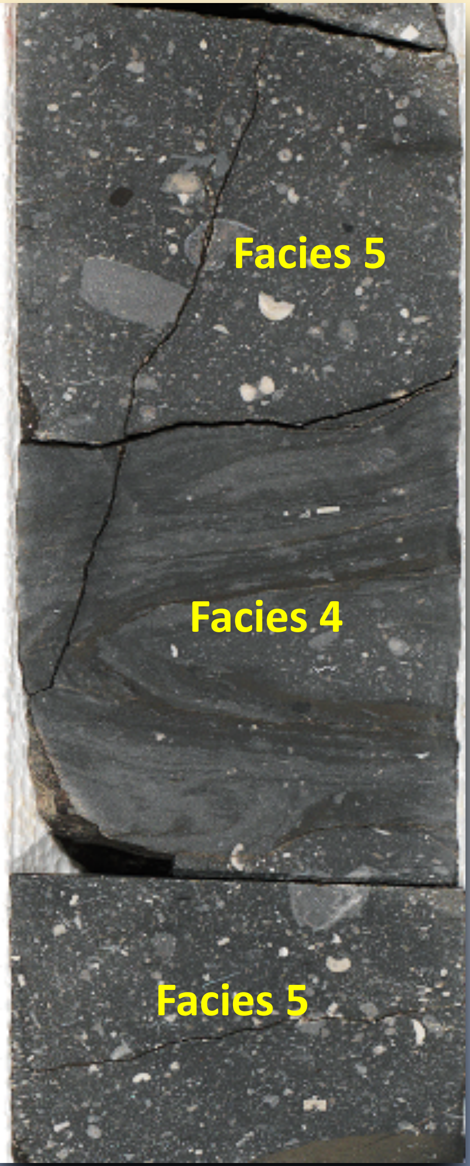


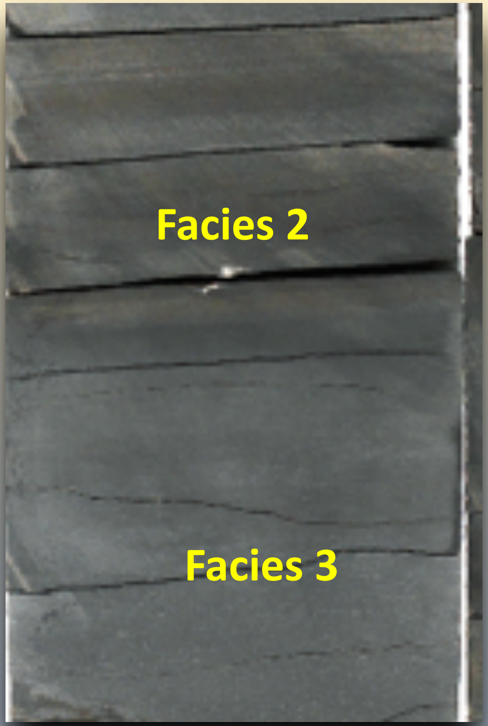
Wolfcamp "B" FSST FACIES TRANSITION _MARKOV CHAIN



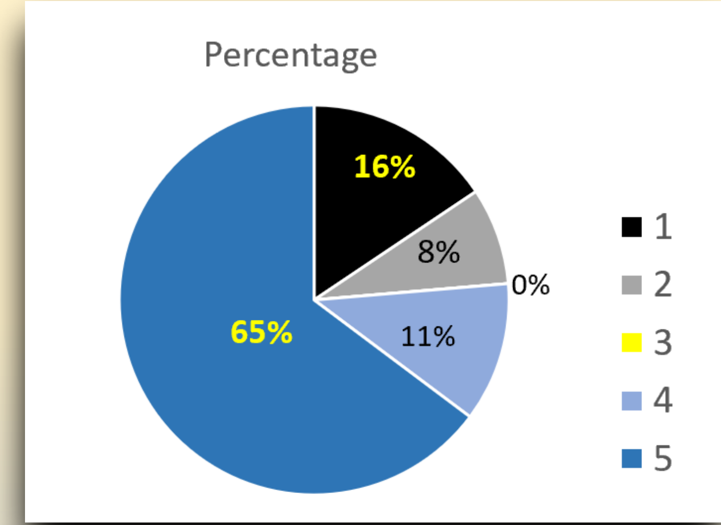


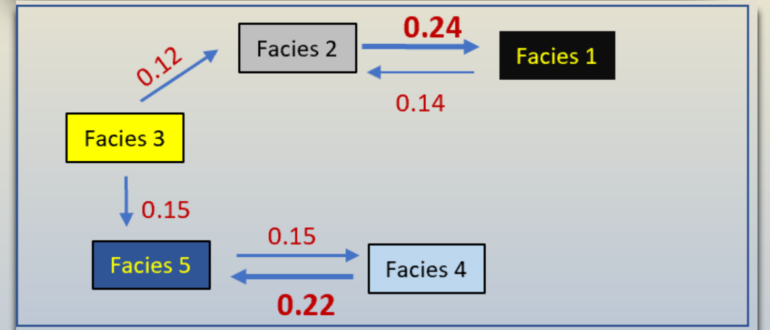


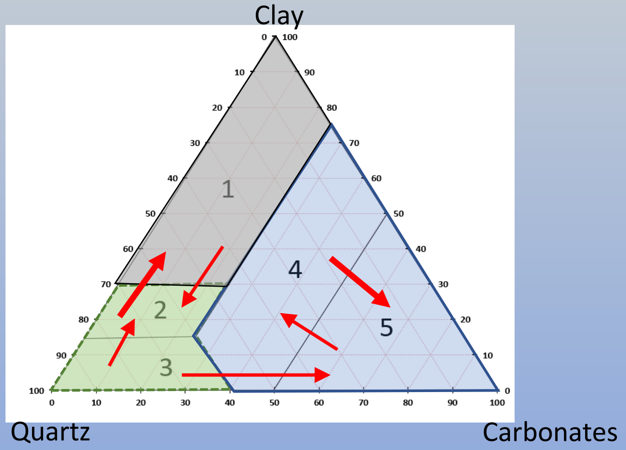


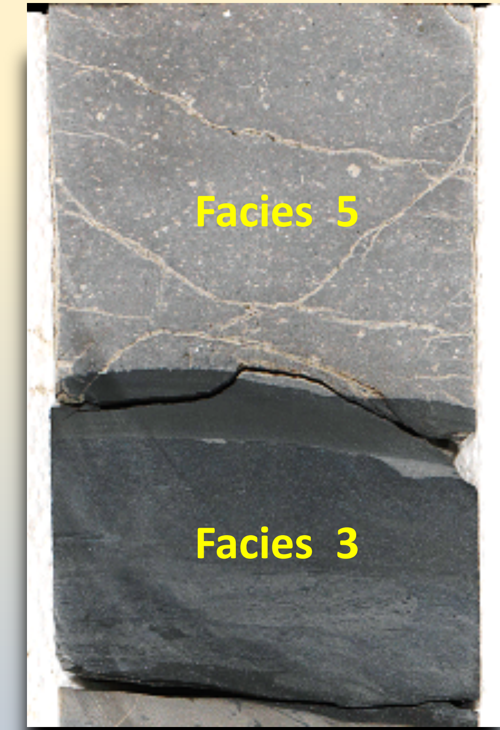


Wolfcamp "A" LST FACIES TRANSITION _MARKOV CHAIN









SUMMARY

- Quantitative Facies Analysis (QFA), either sedimentary- or geochemically- facies, provide various statistical methods to characterize each facies, e.g. mean, standard deviation, cumulative amounts, etc.

- QFA as applied to sedimentary facies allowed one to show how much facies (via iso-percent) at various stratigraphic slice. The amount of each facies per stratigraphic slice represents sedimentary condition at that particular stratigraphic interval.

- QFA can be used to translate the sedimentary facies to mechanical facies to show variability of stratigraphic units vertically or horizontally, i.e., incompetent- to competent facies ratio.

- QFA – Markov Chain as applied to geochemical facies allowed a predictive model for the “next state” vertical order of facies. This “next state” probability can be attributed to genetically related depositional process.

The End