Depositional Processes and Impact on Reservoir Quality in Deepwater Paleogene Reservoirs, U.S. Gulf of Mexico*

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Search and Discovery Article #30402 (2015)**
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Abstract

Reservoir deliverability is a critical risk for deep-water Paleogene reservoirs in the Gulf of Mexico. Permeability can vary two orders of magnitude (1's to 100's of mD) for a given porosity within a single lithofacies. The objective of this paper is to frame reservoir quality within the architectural elements of submarine gravity flows in a deep-water Paleogene field. Around 380 metres of core was described from a lower and upper reservoir, and core descriptions were integrated with routine core analysis, petrography, and laser grain size analysis data. We distinguished specific rock property suites, textural, and mineralogical characteristics for channel, lobe, and lobe margin depositional environments. Channel architectural elements have the best reservoir quality because they are generally fine-grained, and have a relatively low abundance of silt-sized particles (average 24 %) and ductile grains (average 17%) dispersed among framework grains. Lobe architectural elements in the lower reservoir display moderate reservoir quality, and are composed of fine- to very fine-grained sandstone, with an average of 34% silt and 18% ductile grains. Upper reservoir lobes contain more silt (average 40%) and ductile grains (average 29%), and lower reservoir quality. Reservoir quality is overall poor in the lobe margins where silt-sized particles and ductile grains are most abundant. The observed textural and mineralogical differences from the channel, lobe, to lobe margin environments are the result of grain segregations during transport within submarine gravity flows. As a best practice, reservoir quality should be examined in a depositional environment context.

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Understanding the Impact of Depositional Processes and Environments on Reservoir Quality in Deepwater Reservoirs:

A Case History from the US Gulf of Mexico Paleogene Play Trend

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AAPG Deepwater GTW, January 2015, Houston

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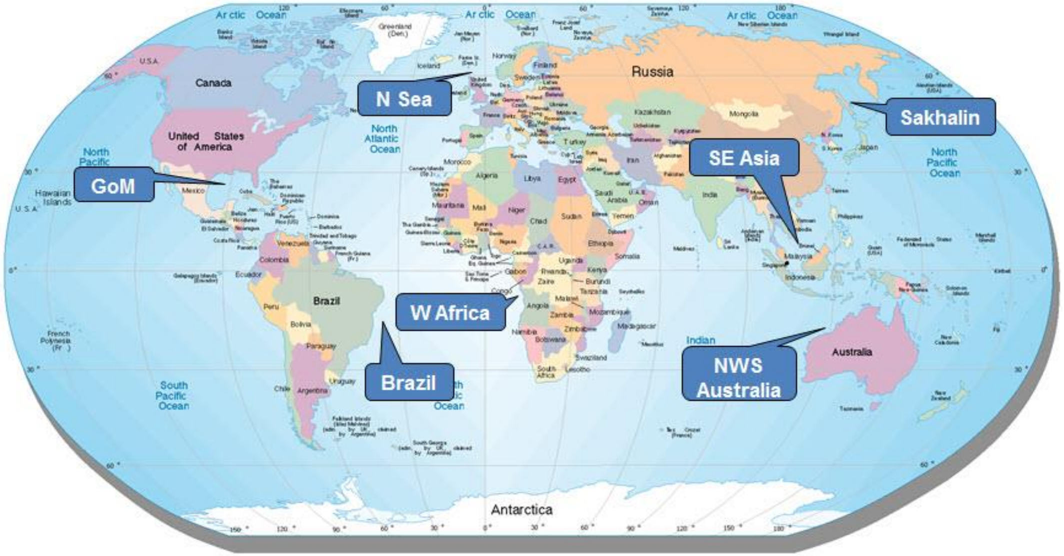
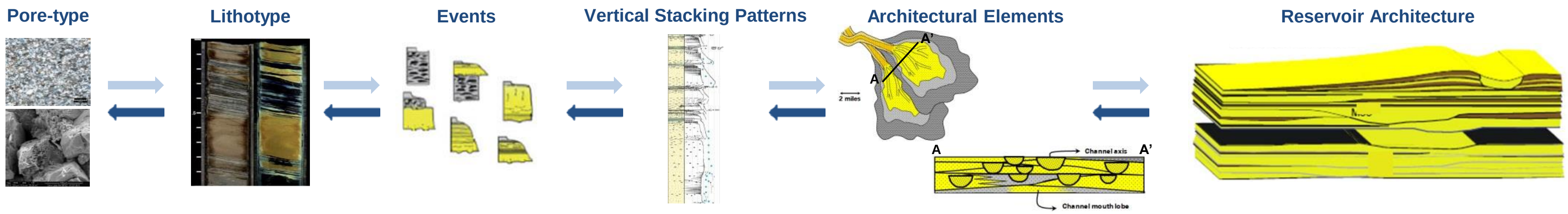
Deepwater Turbidite Reservoirs & Challenges



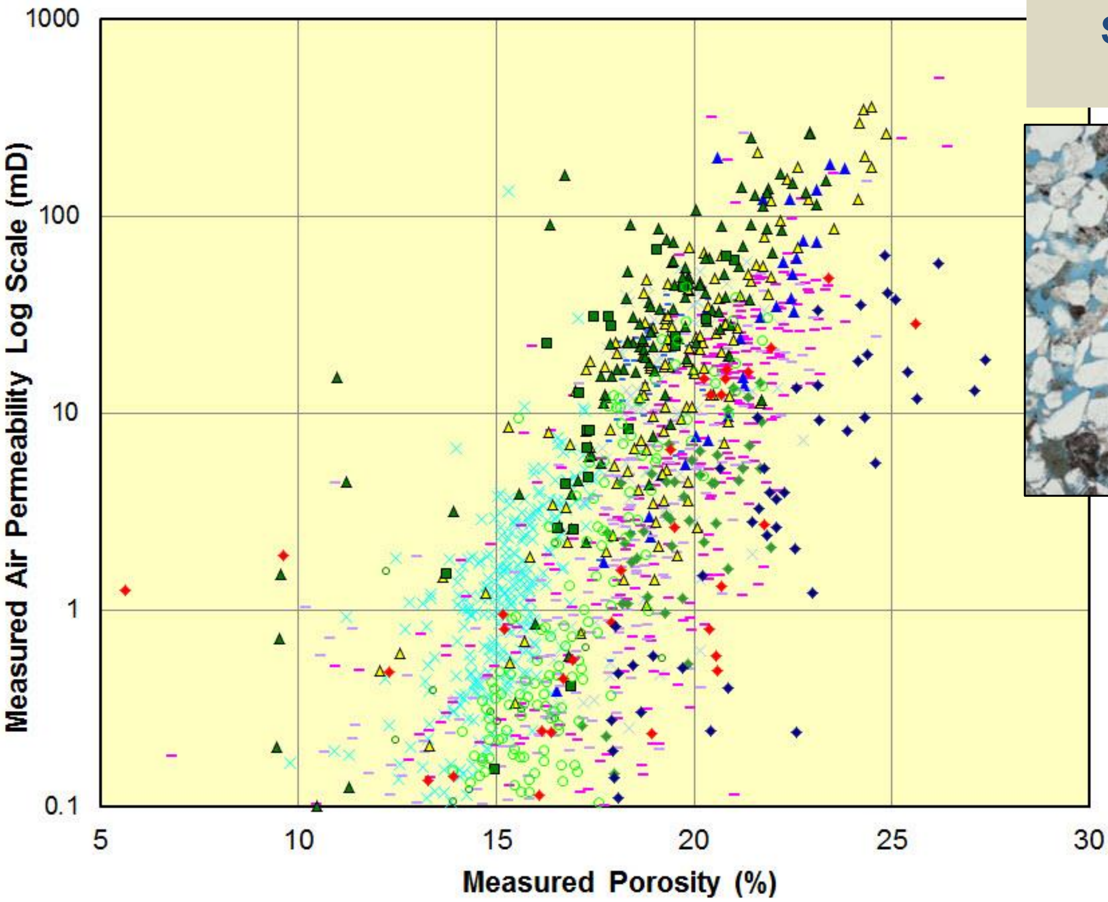
- Active exploration and development worldwide
- Major drilling & infrastructure costs
- Geological challenges:
  - Contrasting reservoir architectural styles & complex spatial distributions
  - Variety of flow processes and sediment mixtures
  - Variable rock types and stacking patterns
  - Highly variable reservoir quality resulting in reservoir characterization uncertainties
  - Predictability of high and low permeability reservoir units is not straightforward
  - Difficult to forecast appropriate production profiles

Presentation Objectives

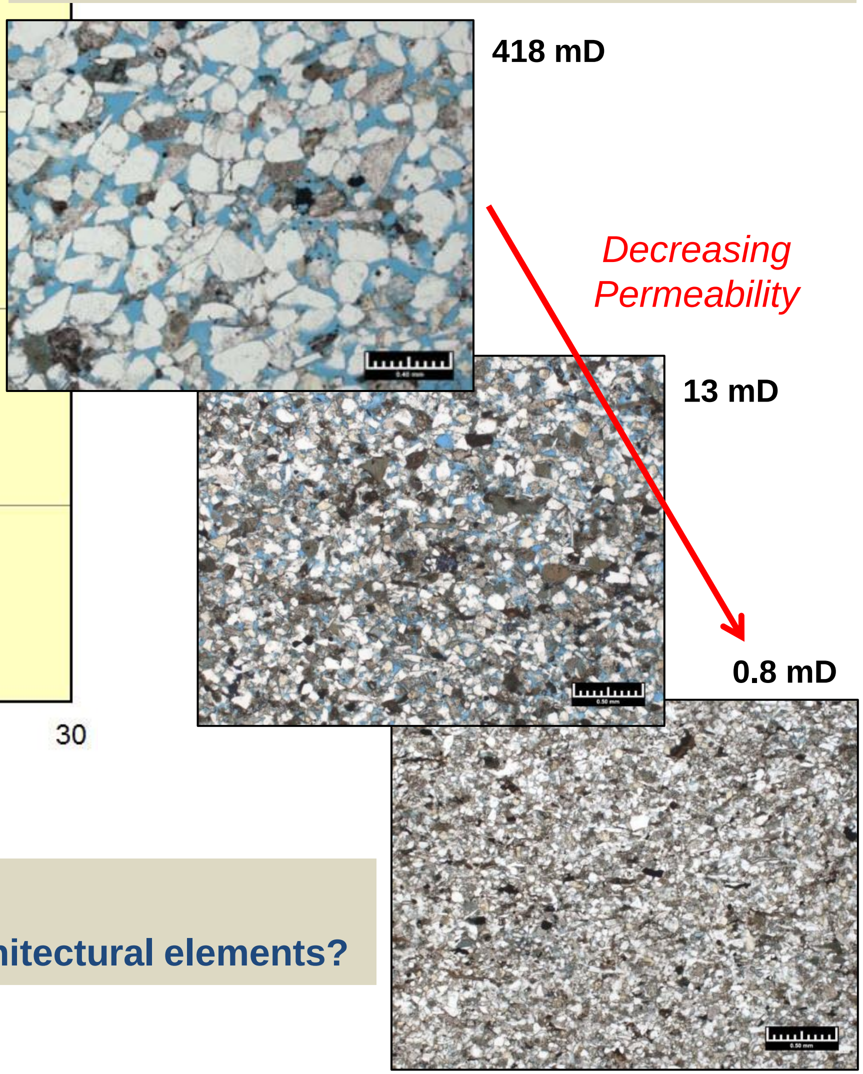
- Explore the relationship between reservoir quality and large-scale depositional (architectural) elements in a deepwater turbidite reservoir
- Understand how reservoir quality varies laterally across turbidite deposits (connectivity)
- Understand how reservoir quality varies vertically (temporal)
- Formulate rules for reservoir quality prediction



Reservoir Quality Variability in Turbidite Reservoirs of the Paleogene Play Trend



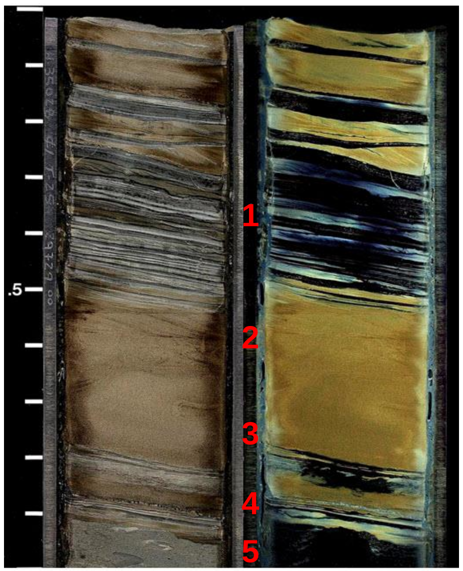
SAND HETEROGENEITY WITHIN 15' OF RESERVOIR:



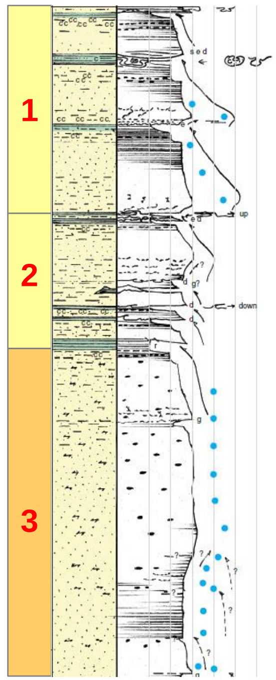
- **How are textures fractionated in submarine fans?**
- **How do lithotypes stack in larger (predictable) scale architectural elements?**

From Lithotypes to Architectural Elements

Lithotypes → ← **Vertical Stacking Patterns** → ← **Architectural Elements** → ← **Reservoir Model**

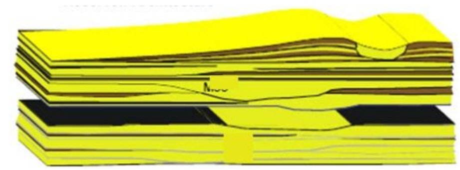


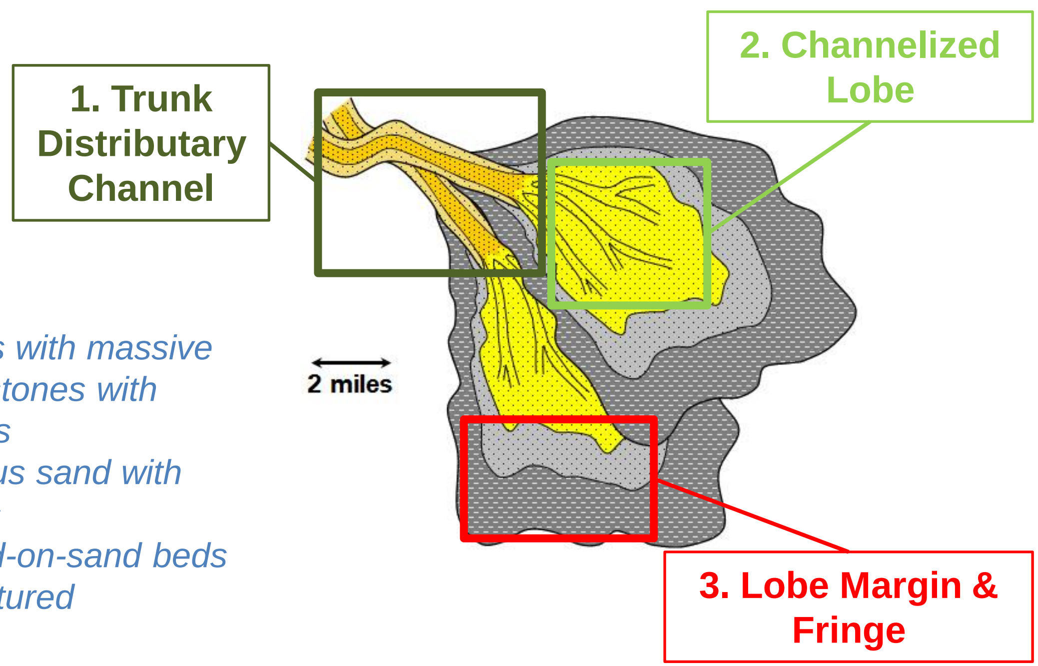
1. *Laminated mudrock*
2. *Ripple cross-laminated sandstone*
3. *Massive sandstone*
4. *Laminated sandstone*
5. *Mudclast-rich mudstone*



1. *Amalgamated beds with massive to structured sandstones with preserved bed caps*
2. *Stacked argillaceous sand with preserved bedcaps*
3. *Amalgamated sand-on-sand beds of massive to structured sandstones*

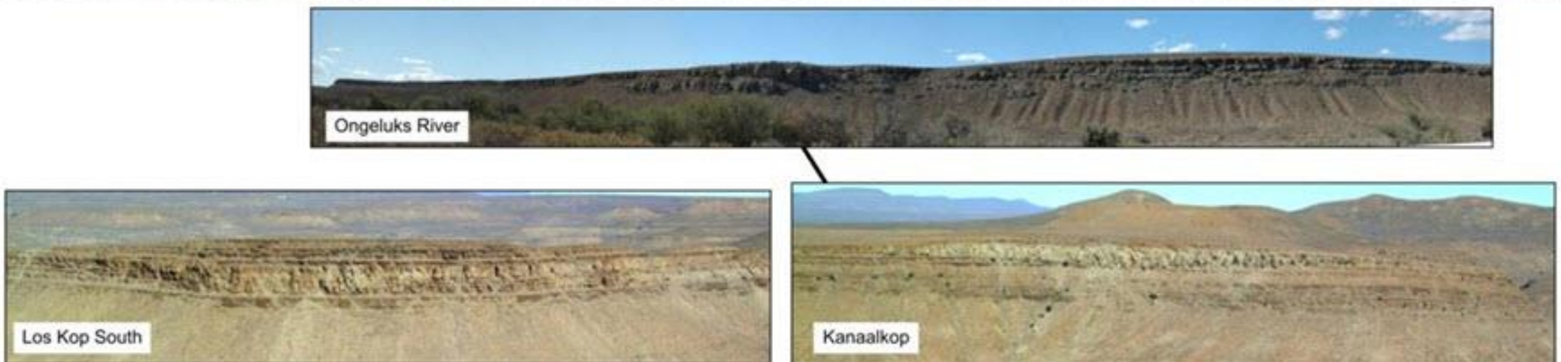
1. *Major distributary channels (**trunk distributary channels**)*
2. *Minor distributary channels & lobe sandsheets (**channelized lobe**)*
3. ***Lobe** sandsheet **margin & fringe***





Reservoir Architectural Element Characterization: Analog Outcrop Data

Trunk Channel complex:
Up to 1 mi wide
50-200' channel fills

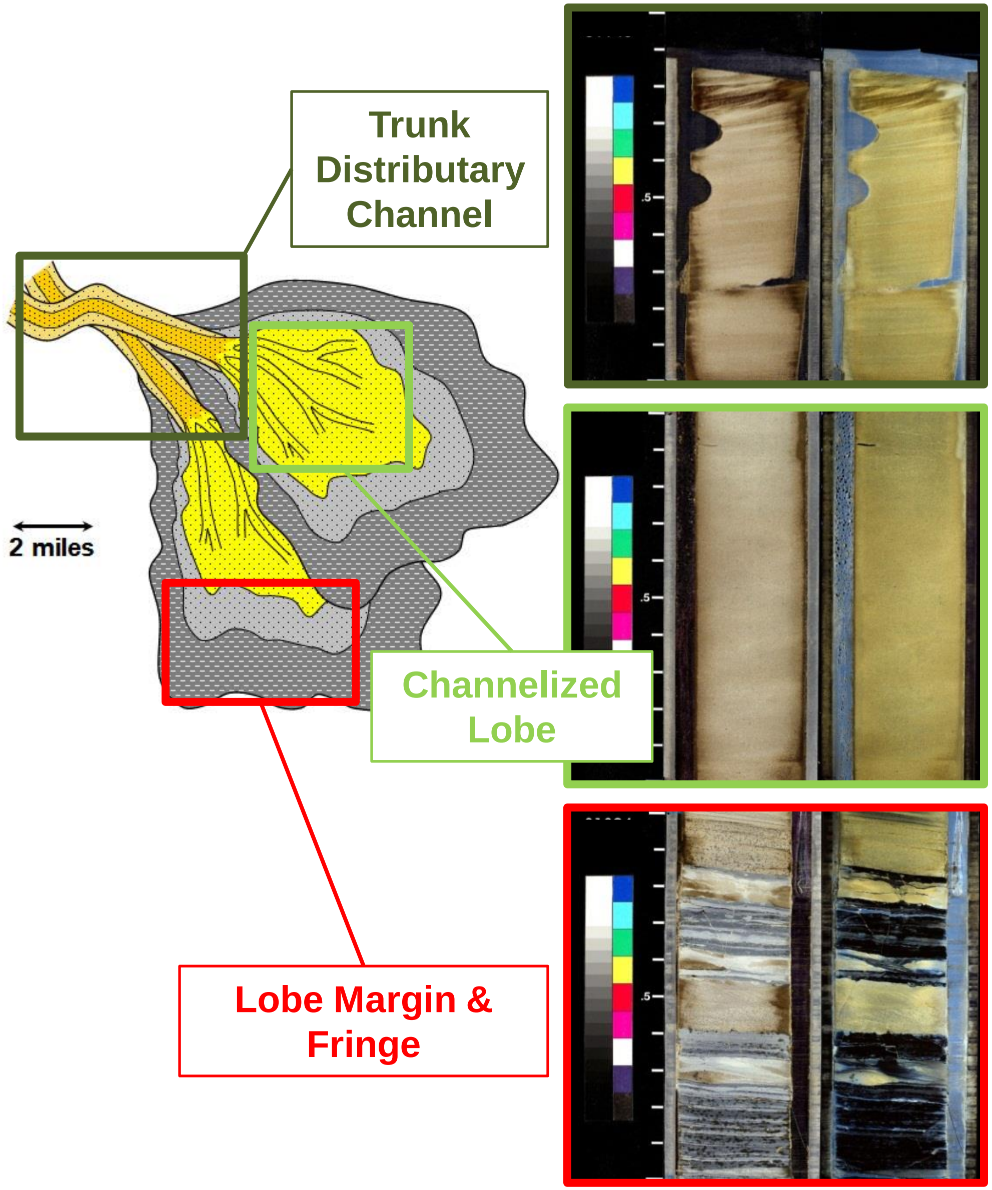


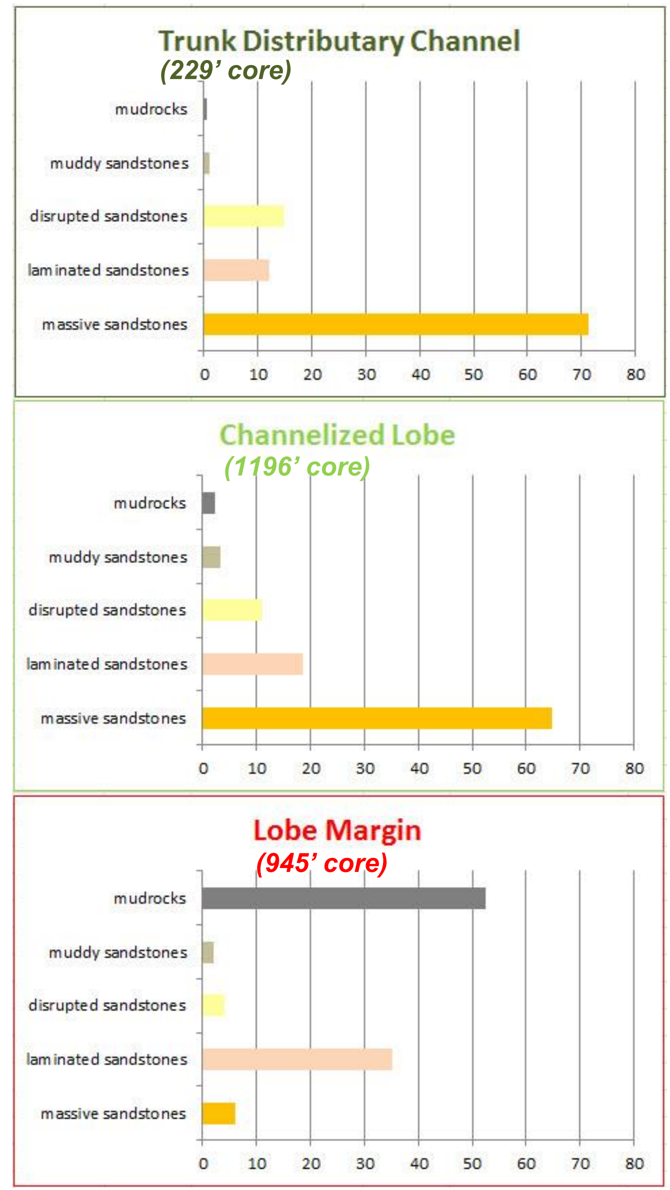
Distal lobe margin:
Thinner beds
Increasing mudrock divides
Poorer connectivity

Channelized lobes:
Sand on sand amalgamation with good connectivity
Lobes compensationally stack to form lobe complex (up to 20 mi wide and 100' thick)

Figure x. Cartoon timeslice through Fan 3 with representative photopanels to indicate the changes in the outcrop expression o f the Fan 3 lowstand systems tracts.

Reservoir Architectural Element Characterization: Rock Type Distribution

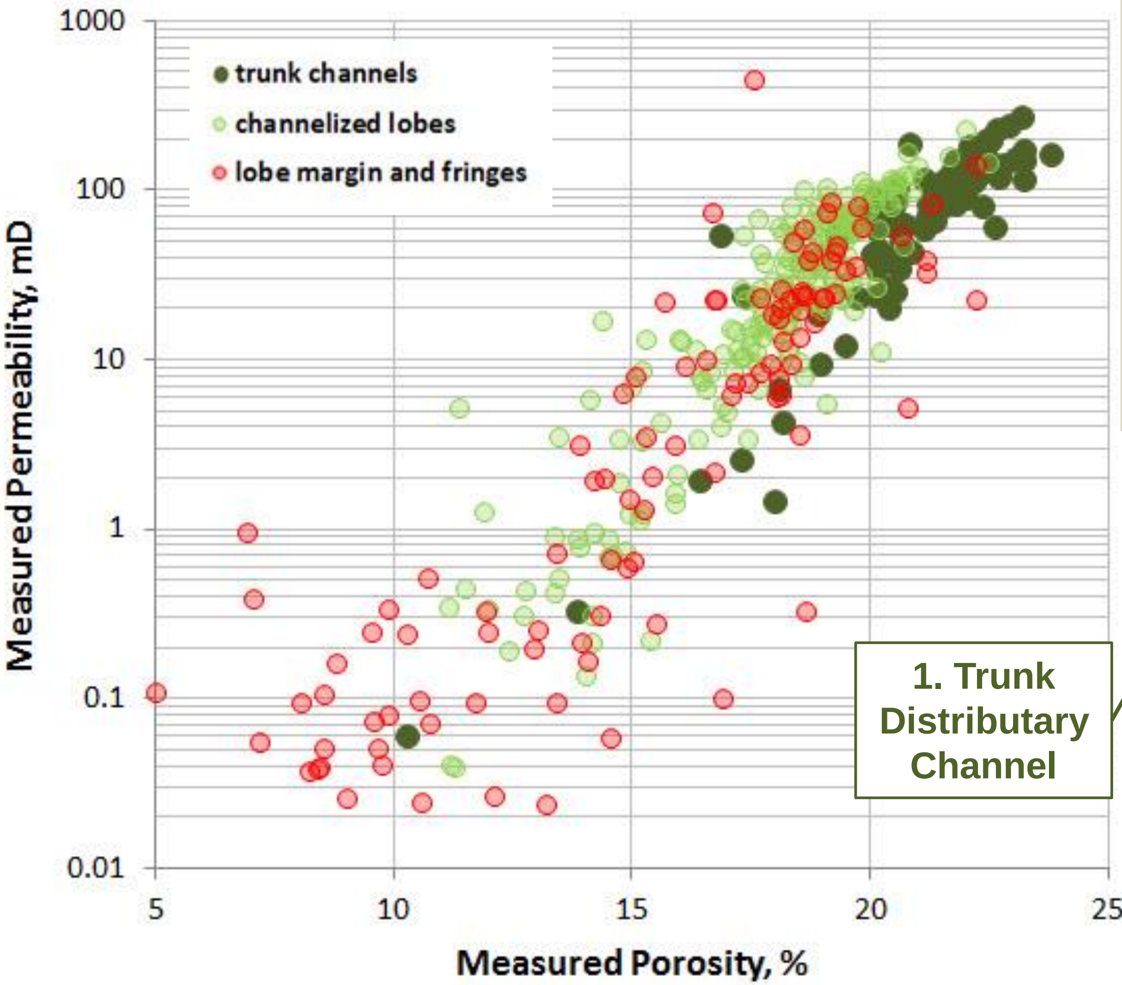




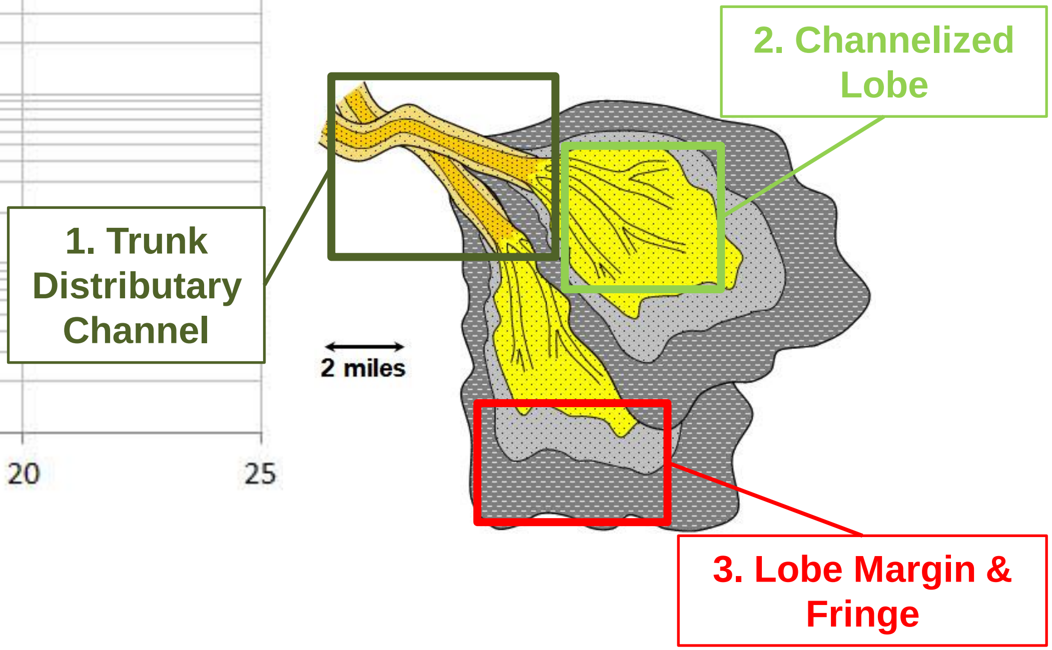
X-axis in % of core footage

Based on work by John Mbibi (BP)

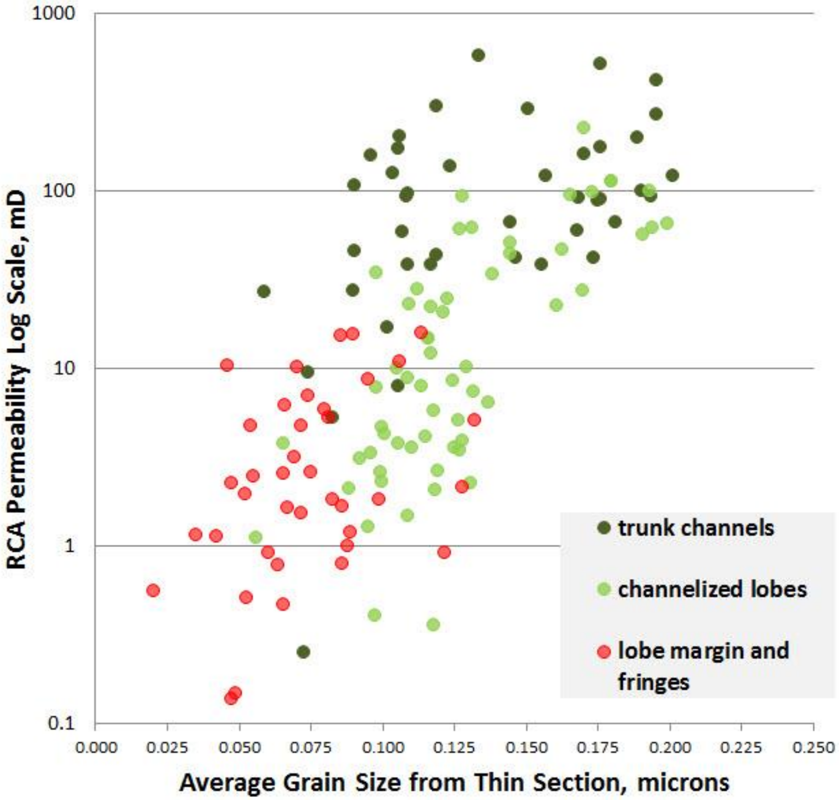
Reservoir Architectural Element Rock Properties

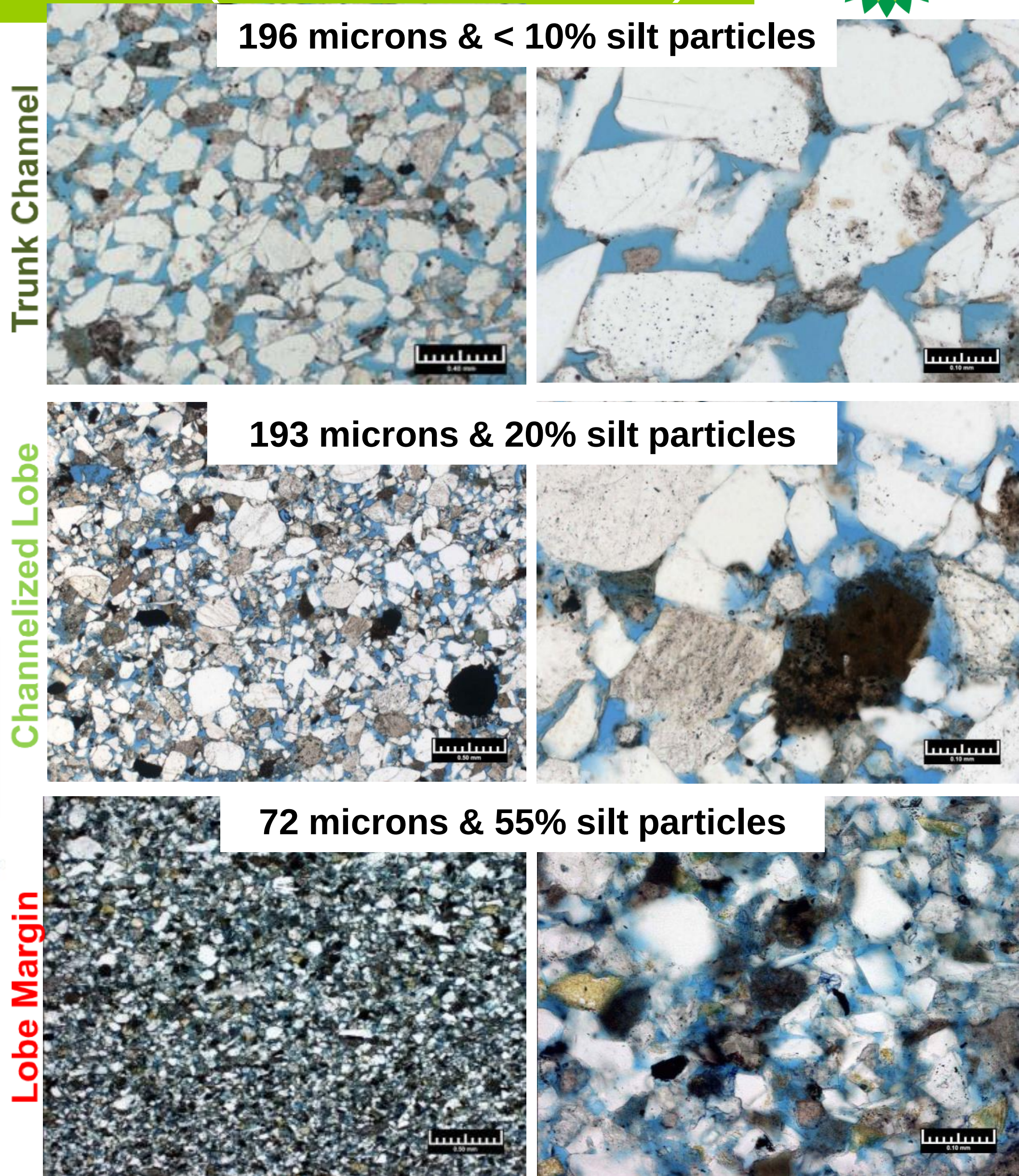


- Trunk distributary channels have some of the highest permeabilities (K 59 mD)
- Channelized lobes (axis, proximal, lobe sheet sands & distributary channels) also yield moderate permeabilities (K 17 mD)
- Lobe margin and fringe settings have poorer permeability for largely the same porosity range as channelized lobe samples (K 3 mD)



Reservoir Architectural Element Textural Characterization: Grain Size (from thin section)



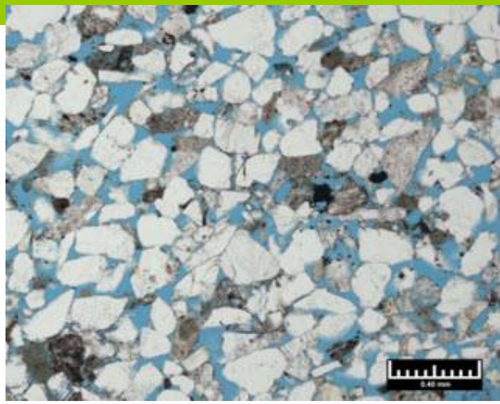


Reservoir Architectural Element Textural Characterization: Silt & Clay Content (LPSA)

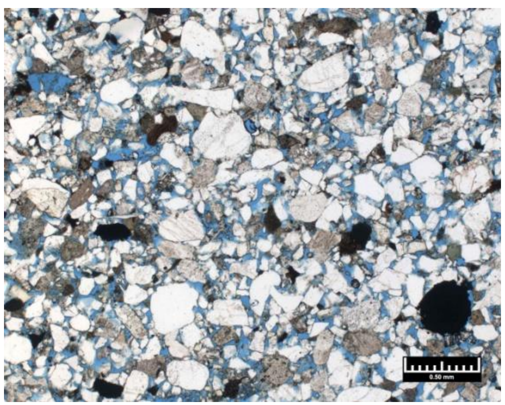
SILT HISTOGRAMS

CLAY HISTOGRAMS

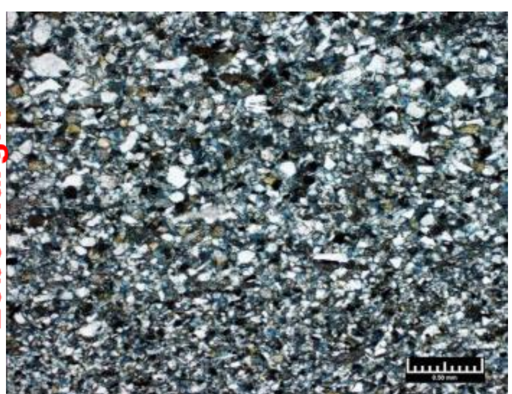
Trunk Channel

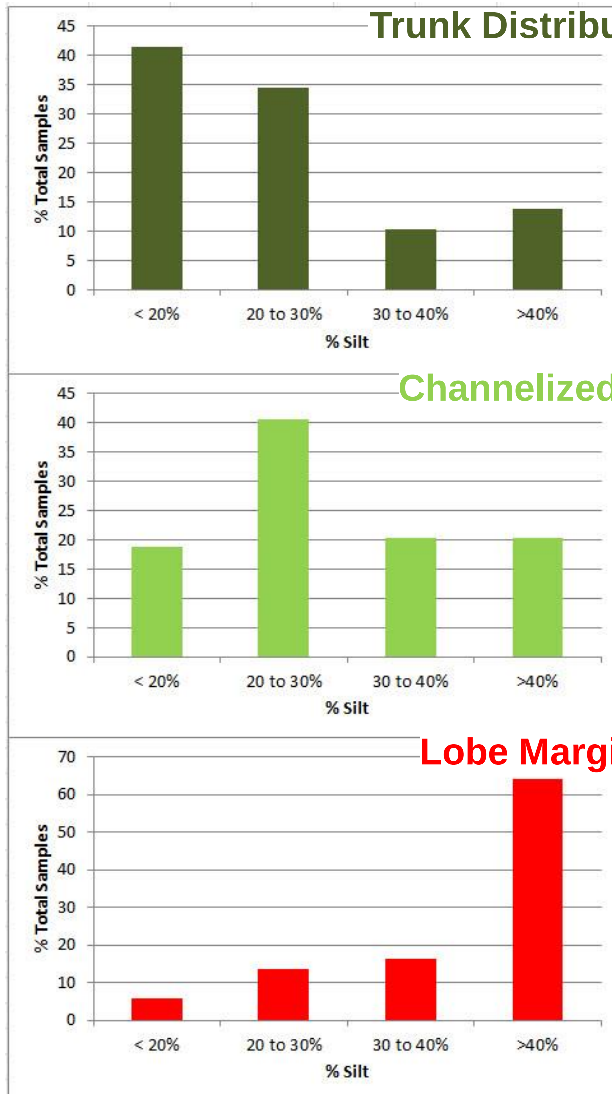


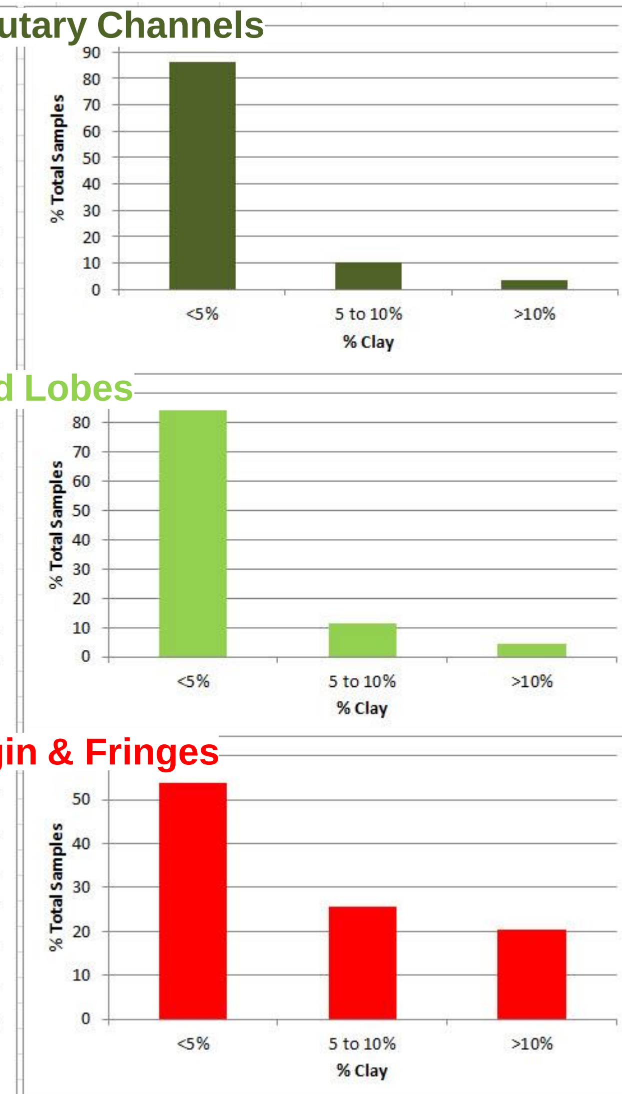
Channelized Lobe



Lobe Margin

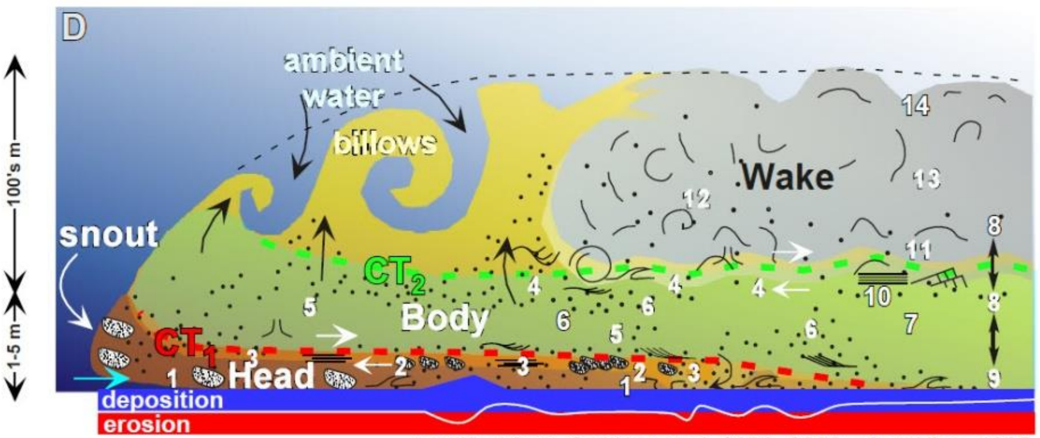




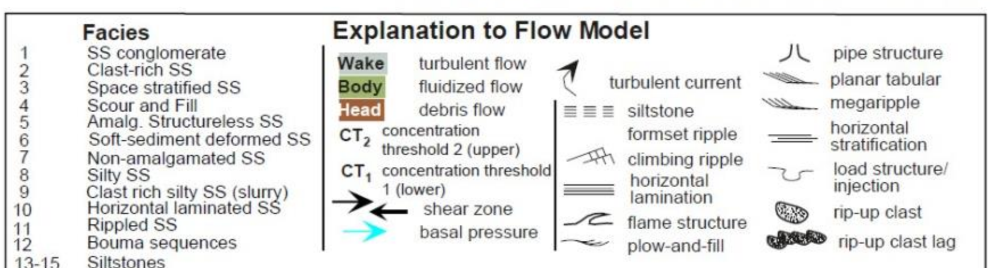


Why Does Textural Segregation Occur in Submarine Fans?

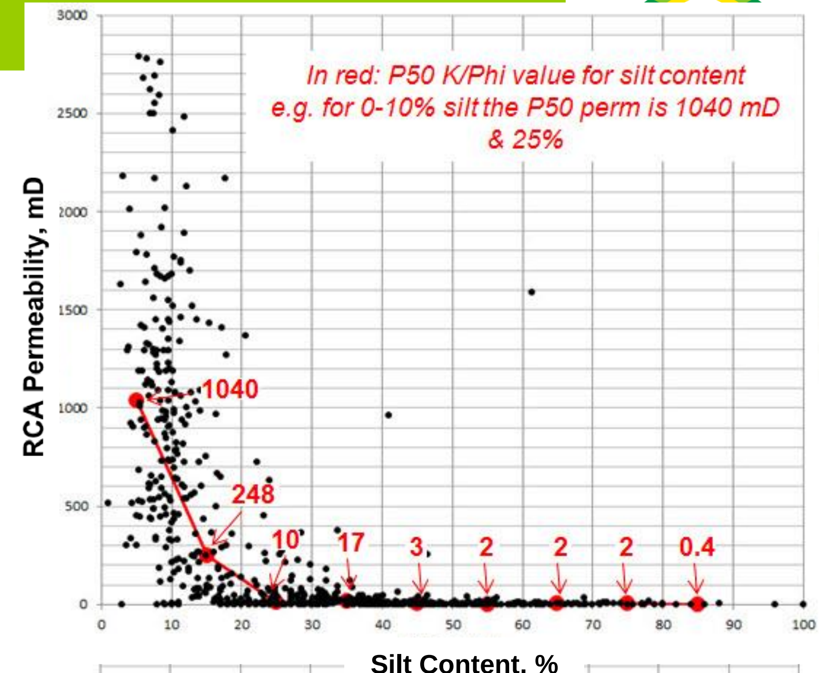
- •Textural segregation well documented in analogue studies (e.g. Brushy Canyon TX)
- •Presence of flow regions confirmed by experimental flume work
- •Textural segregation influences permeability in our deepwater reservoirs

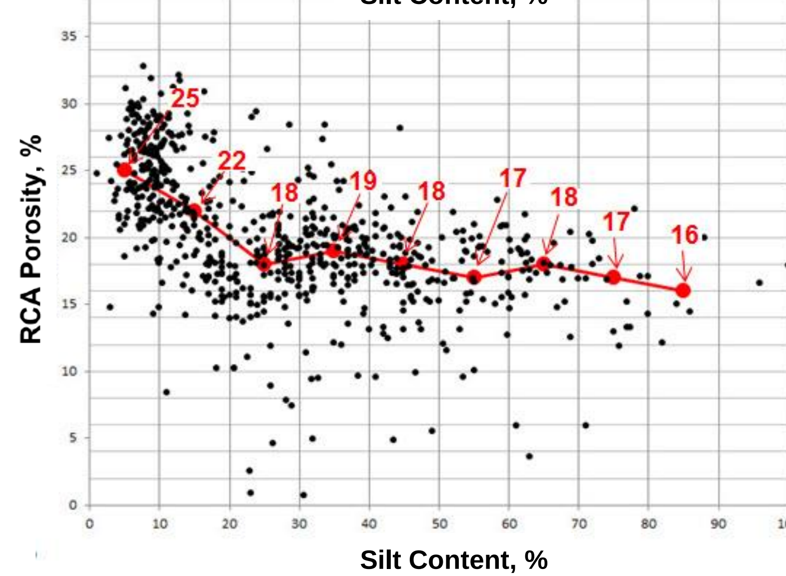


modified from Gardner et al. 2000, 2003, after Allen, 1985

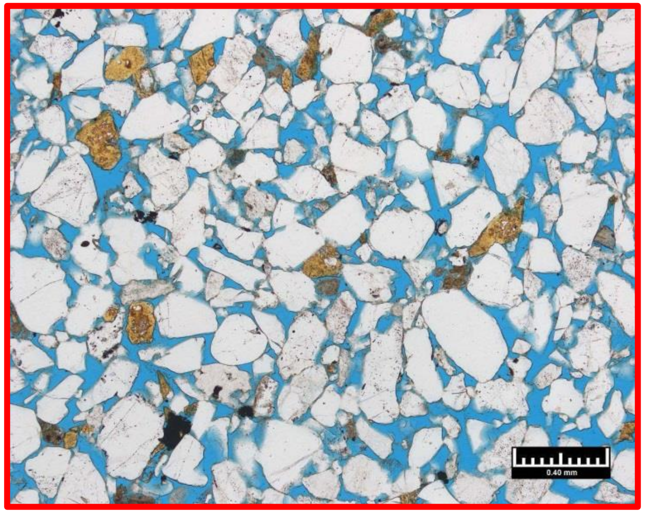


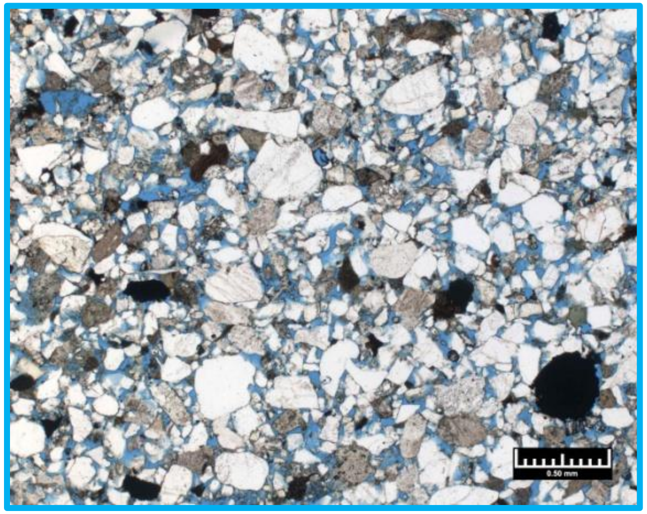
From: Gardner et al. 2000 & 2003, After Allen, 1985

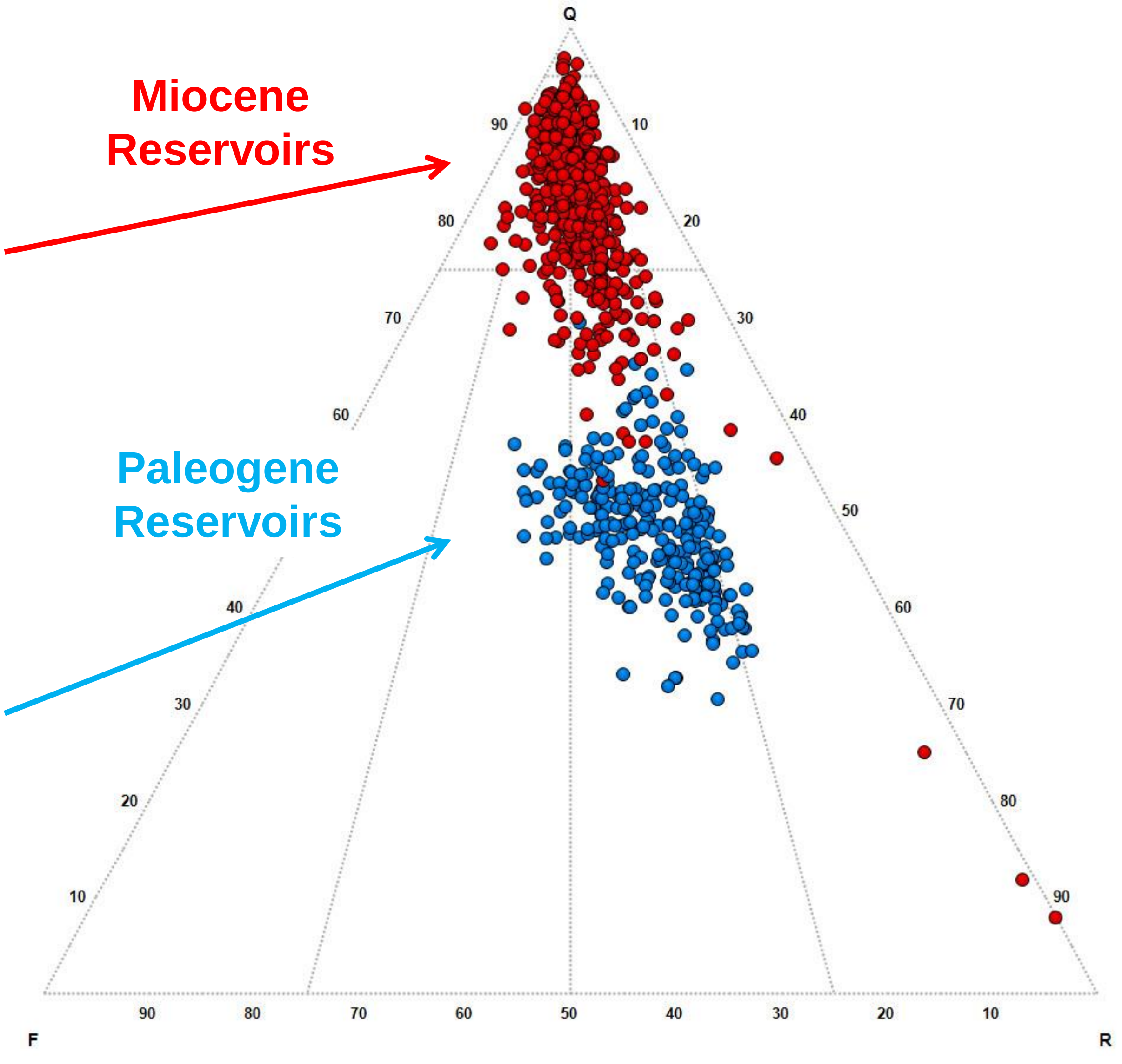




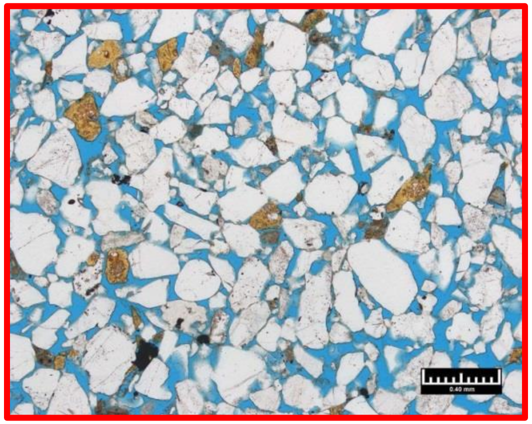
Reservoir Compositional Characterization





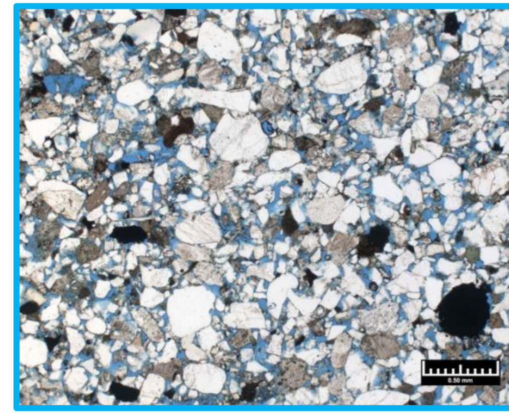


Reservoir Compositional Characterization: Detrital Framework Grains

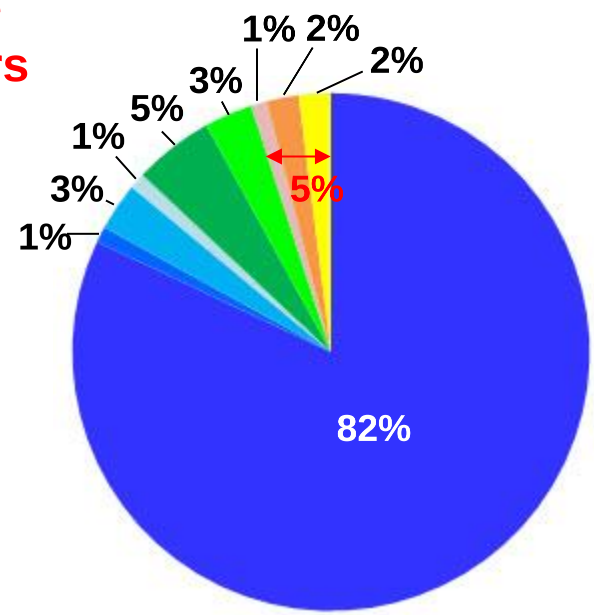


Rigid minerals:
- Quartz
- Plutonic fragments
- Chert
- Sandstone fragments
- K-feldspar
- Plagioclase
- Rigid metamorphics

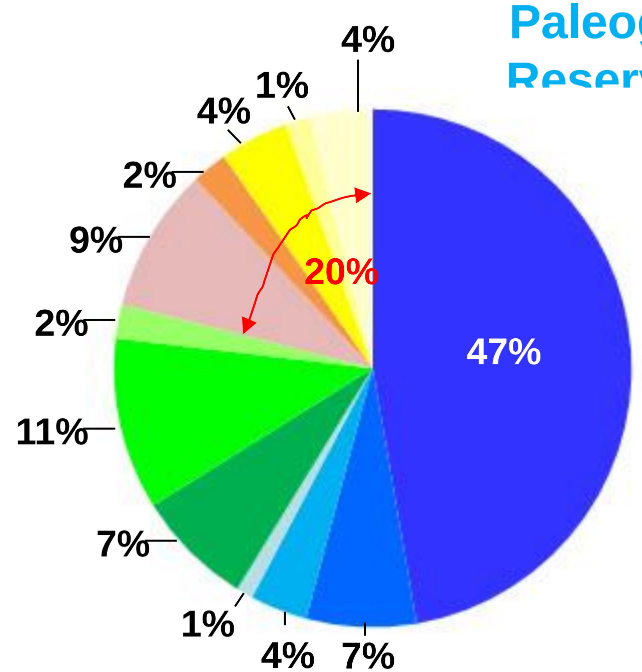
Ductile minerals:
- Volcanic fragments
- Mudclasts
- Siltstone fragments
- Ductile metamorphics
- Organic material
- Mica



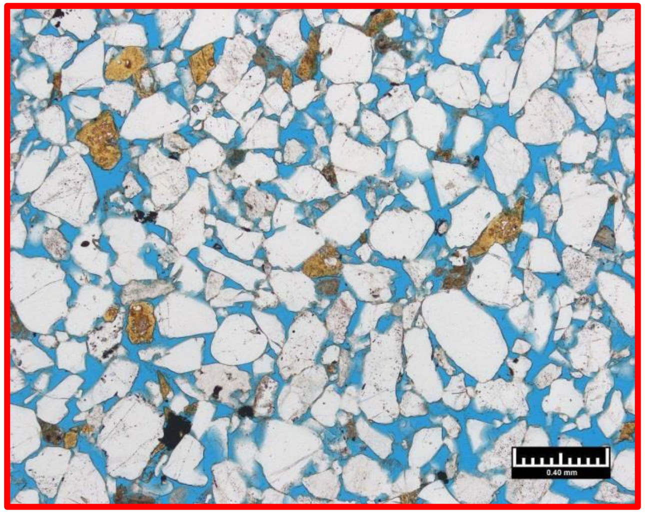
Miocene Reservoirs



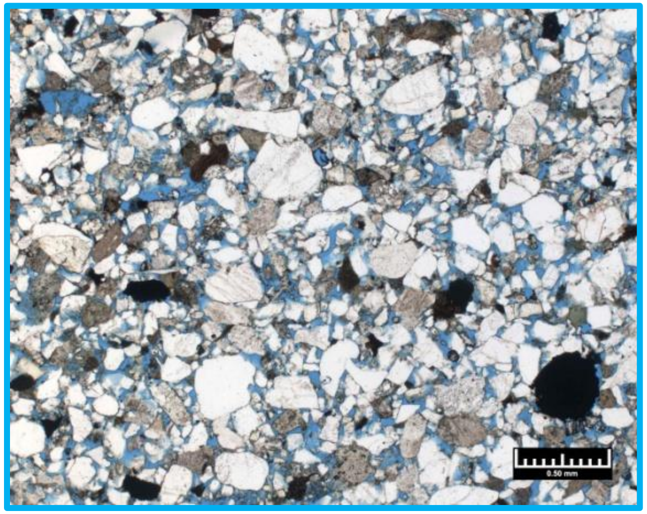
Paleogene Reservoirs



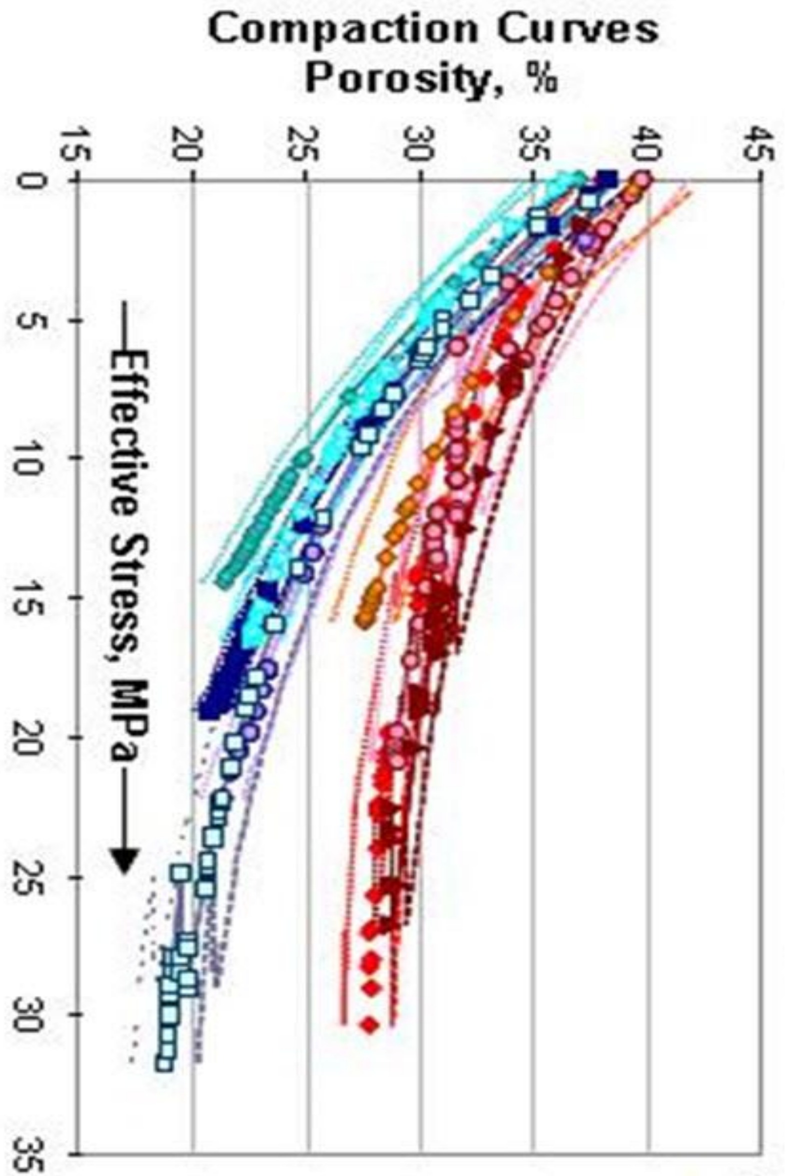
Reservoir Compositional Characterization



Miocene Reservoirs



Paleogene Reservoirs

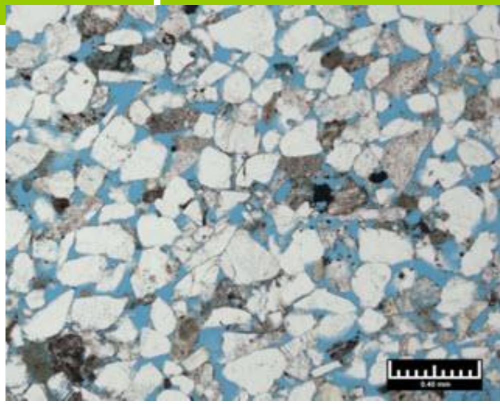


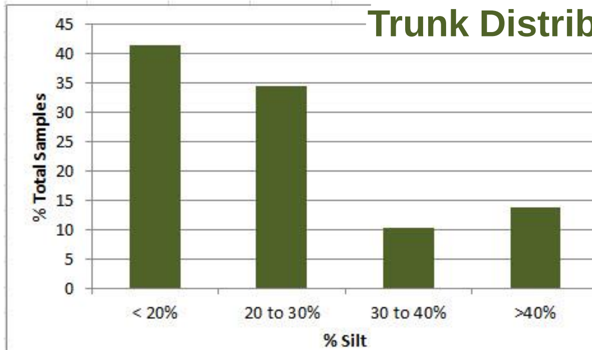
Reservoir Architectural Element Compositional Characterization

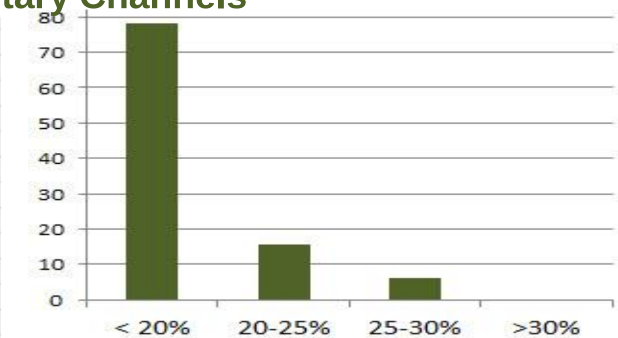
SILT HISTOGRAMS | **DUCTILE GRAIN HISTOGRAMS**

Trunk Distributary Channels

Trunk Channel

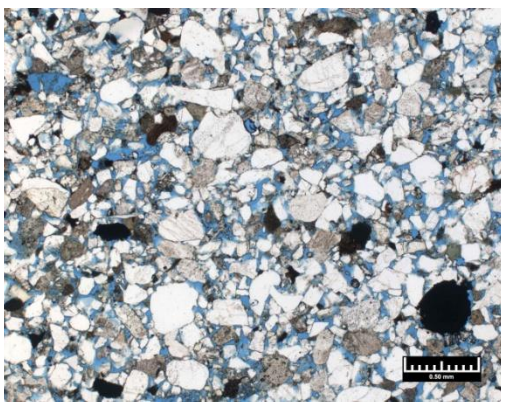


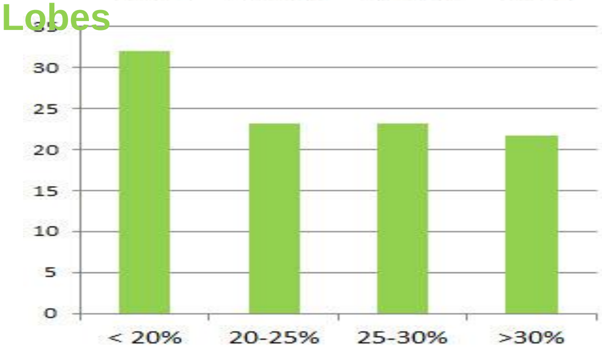




Channelized Lobes

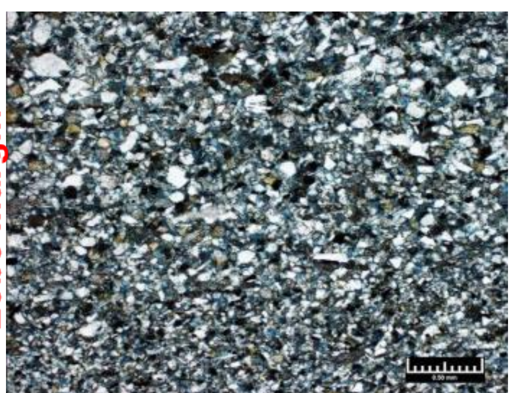
Channelized Lobe

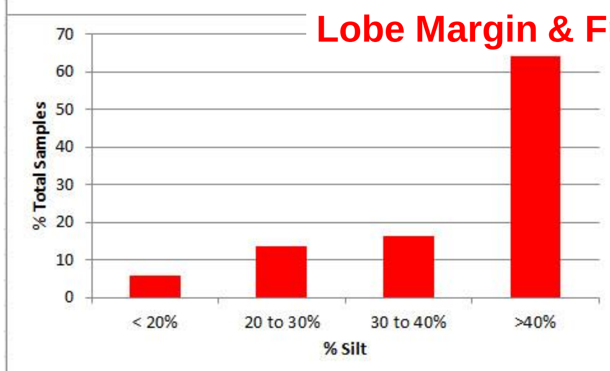




Lobe Margin & Fringes

Lobe Margin

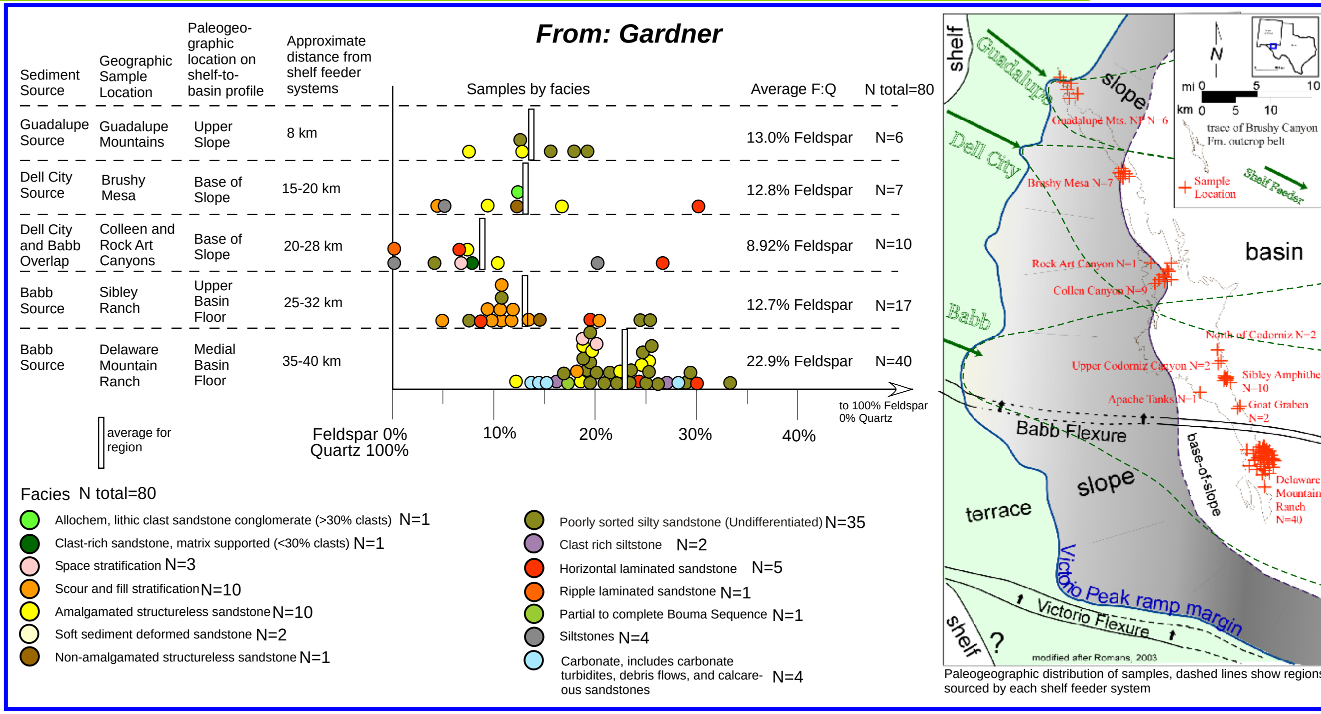




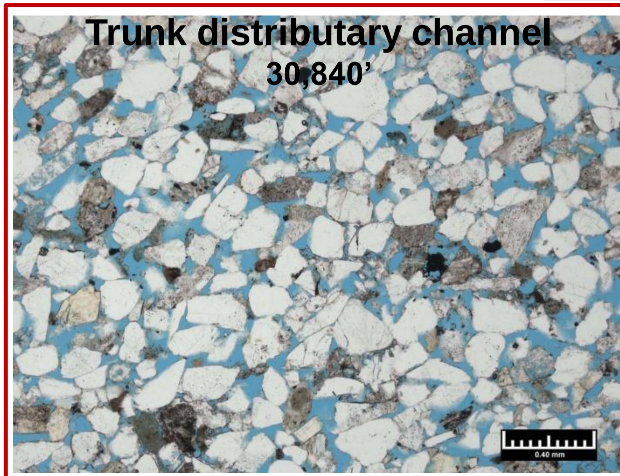
Mineralogical Segregation During Longitudinal Evolution and Flow Transformation of Turbidity Currents

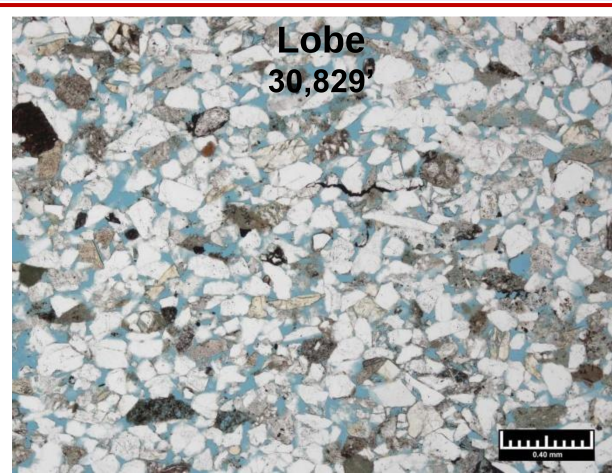
Published Examples:

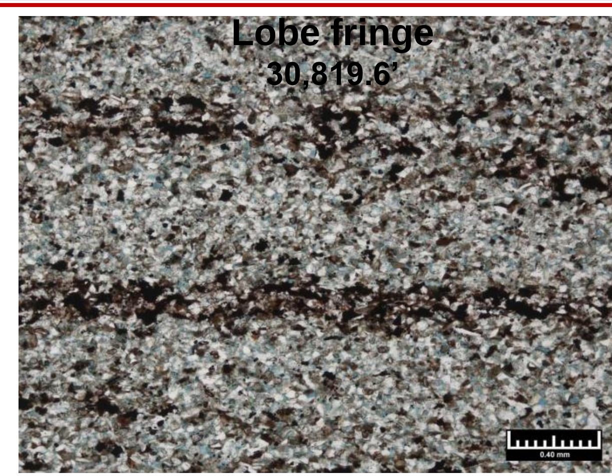
- **Gardner: feldspar increase from slope to basin floor**
- **Stammer (AAPG & Geocosm RQC 2014): Flows segregate minerals based on density and shape**



Paleogeographic distribution of samples, dashed lines show regions sourced by each shelf feeder system

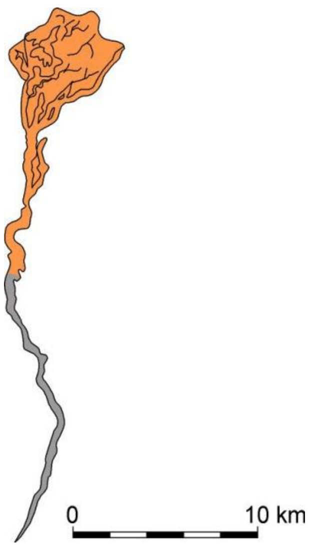




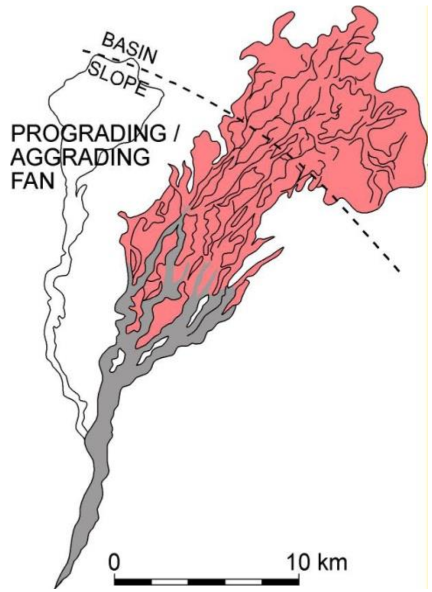


Spatial and Temporal Reservoir Quality Variation in Submarine Fans

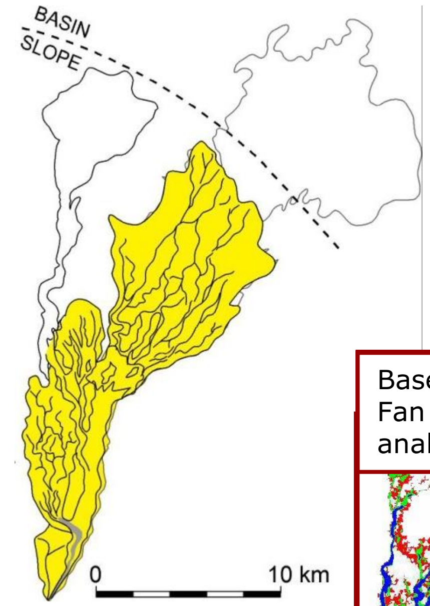
Initiation Phase

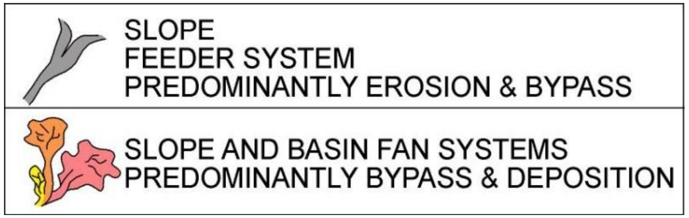


Growth Phase

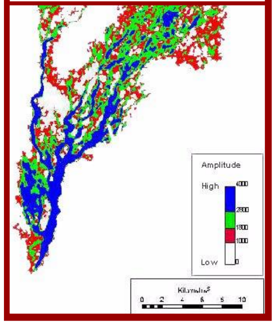


Retreat Phase





Base map for Fan evolution analysis

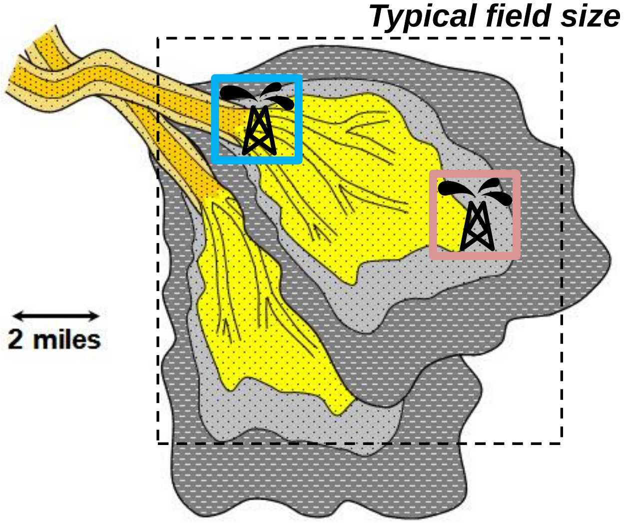


Hadler-Jacobsen *et al.*, 2005

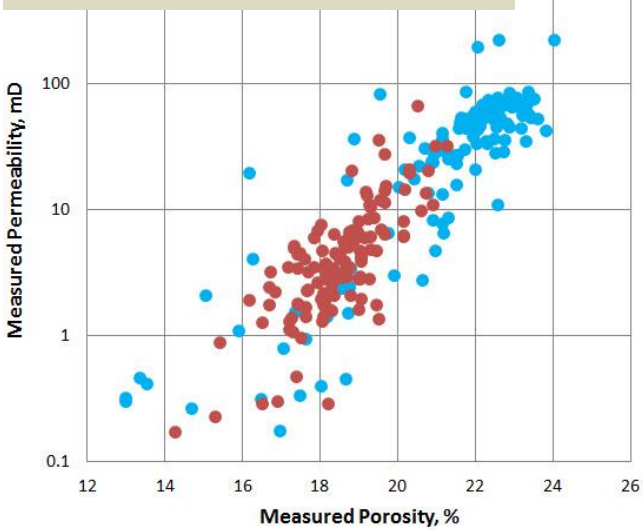
MONTANA STATE UNIVERSITY Mountains & Minds

SBC Slope & Basin Consortium

Spatial Variation in Reservoir Quality in Submarine Fans

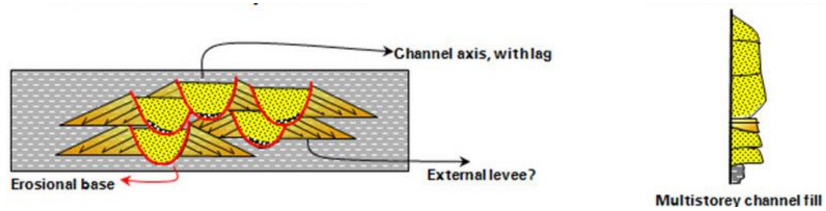


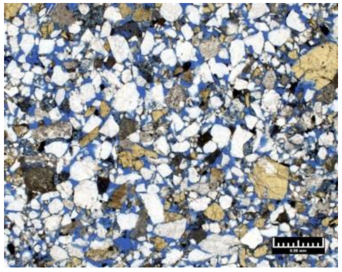
ROCK PROPERTY COMPARISON: PROXIMAL vs. DISTAL WELL (channel sandstones)



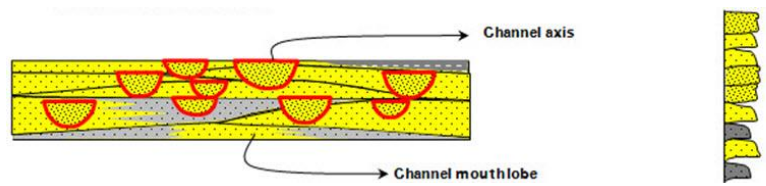
Reservoir Characteristics	Stacking Patterns	Reservoir Quality

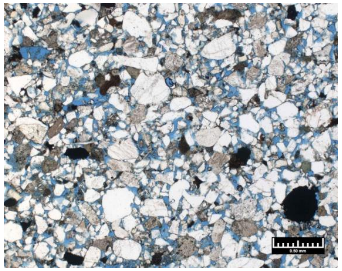
PROXIMAL





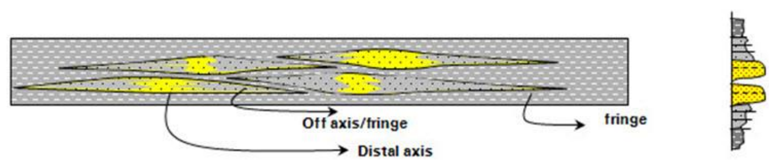
- Amalgamated, mostly structureless sandstones
- N:G varies depending on facies and channel architecture
- Good connectivity if vertically and laterally clustered

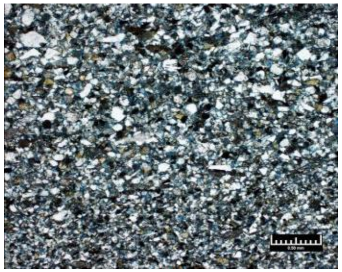




- Mostly amalgamated, structureless sandstones
- Potentially high N:G
- Good to moderate vertical and lateral connectivity

DISTAL

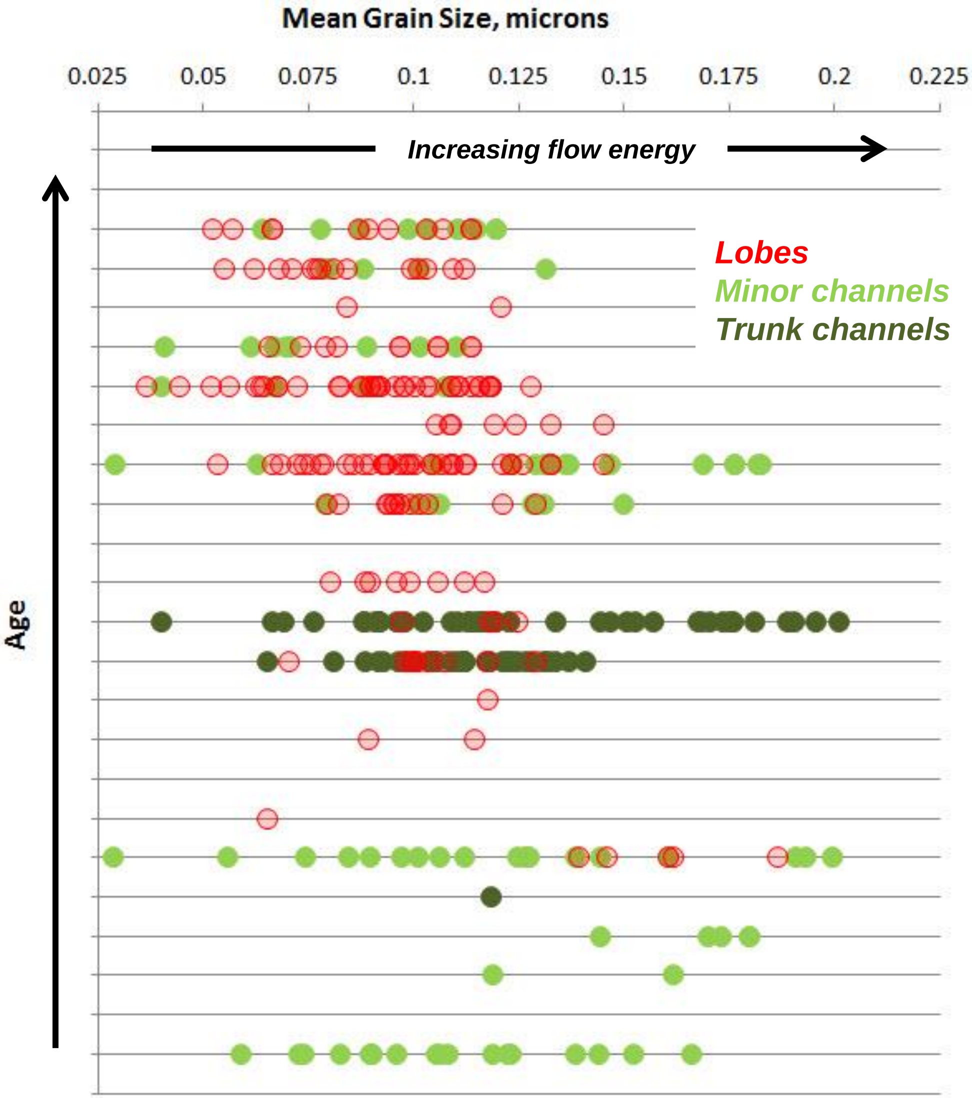




- Mostly non-amalgamated, thin- to medium-bedded sandstones
- Poor connectivity because of interbedded mudstones

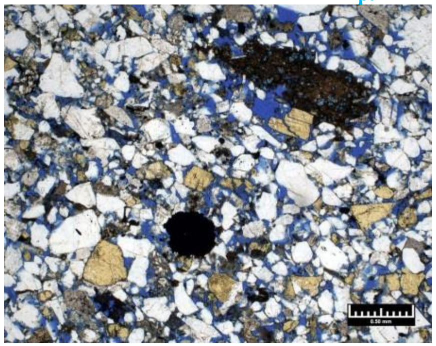
From: Weiguo Li, Rob McDonald, Laura Rumelhart (BP); Based on learnings from Lobes & Slopes Consortia with University of Leeds (D. Hodgson)

Temporal Variation in Reservoir Quality in Submarine Fans

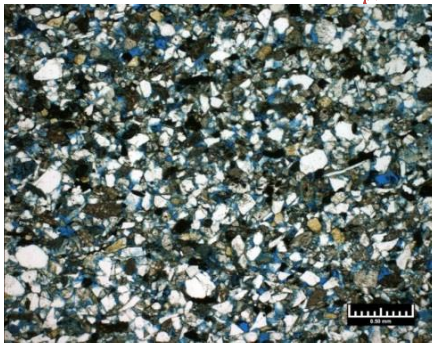


Grain size variations reflect changing depositional energy through time:

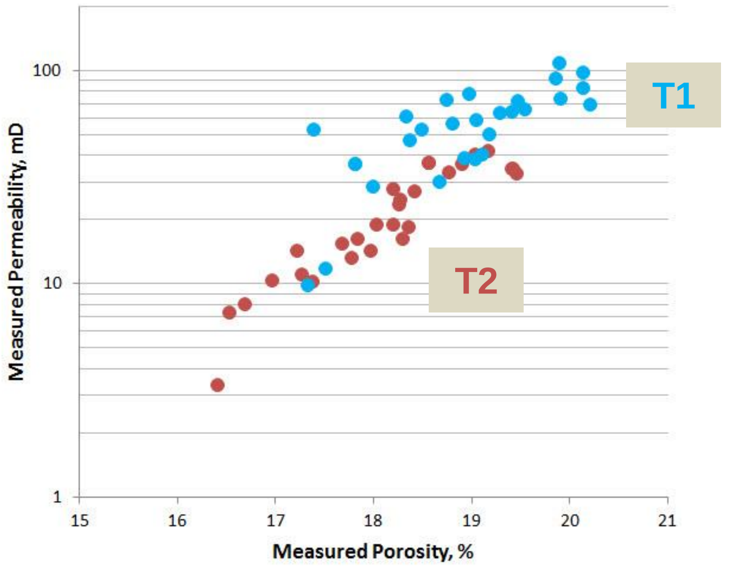
T1 Channel Sand 199 μm



T2 Channel Sand 110 μm

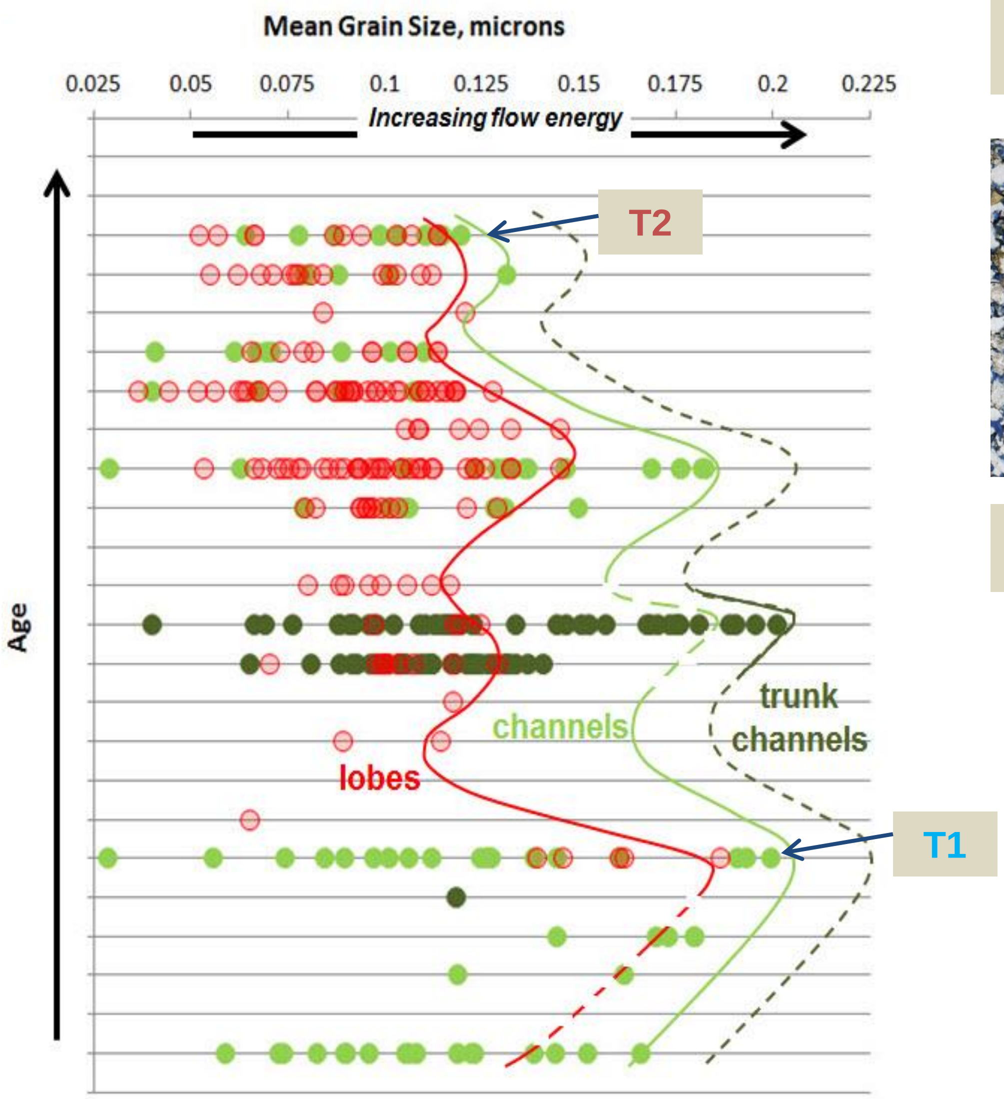


Rock properties change through time for any given architectural element:



Based on learnings from GAIA with Montana State University (M. Gardner)

Temporal Variation in Reservoir Quality in Submarine Fans



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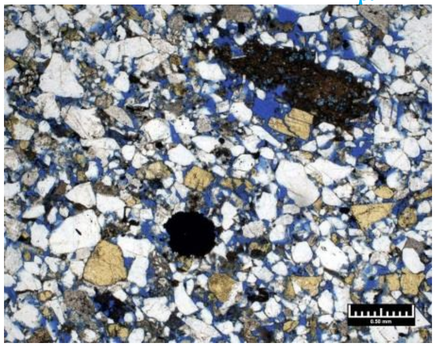

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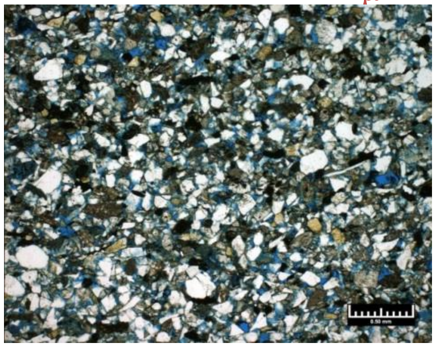


Rock properties change through time for any given architectural element:

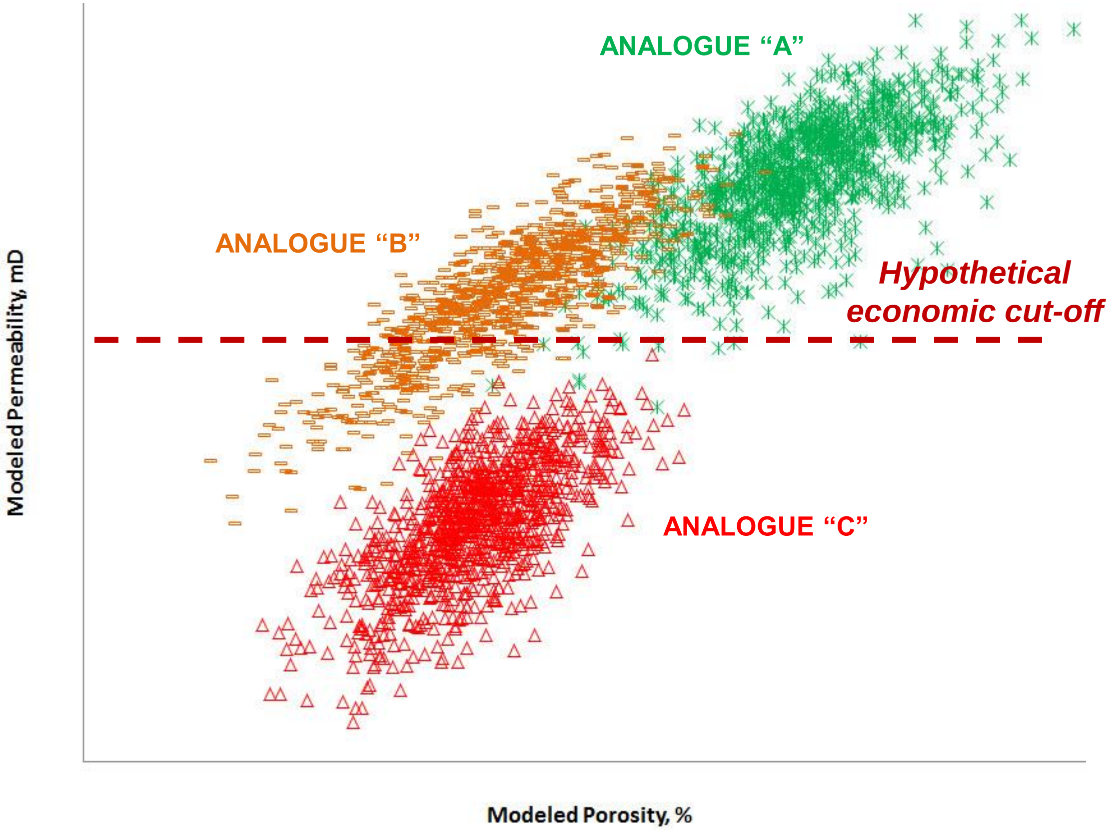
Deepwater Reservoir Reservoir Quality Prediction: An Example From Touchstone Modeling

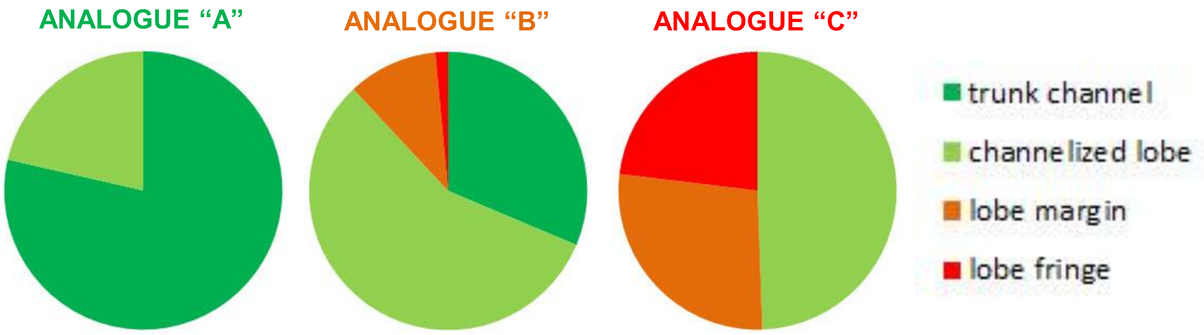
- Data gathering in deepwater fields is difficult and expensive so often decisions need to be made with small amounts of data

- Uncertainties (burial & EOD) must be identified and quantified for different reservoir scenarios so informed decisions can be made

- Depending on what analogue sand is used in the model, a range of outcomes is possible

- Where possible, prospect needs to be placed in regional & stratigraphic context in order to reduce uncertainty around reservoir style & quality





Conclusions

•Flow and depositional processes exert a clear control on reservoir quality in deepwater systems

•There is a relationship between reservoir quality and the architectural elements of deepwater deposits

•Deepwater systems shift and compensate at all scales, so there are systematic (predictable) spatial changes in reservoir quality

•Architectural elements evolve systematically through time in response to larger-scale processes, so there are systematic (predictable) changes in reservoir quality through time