

Significance of Fluvial/Alluvial Stratigraphy in Conceptual Models of Monitored Natural Attenuation Effects on Chlorinated Solvent and 1,4-dioxane Fate and Transport

J.P. Brandenburg*
Charles Payne
Murray Einarson
Peter Bennett
Jacob Chu

*Corresponding Author: JBrandenburg@HaleyAldrich.com



From Detailed Fluvial/Alluvial Stratigraphy to a Site Conceptual Model for Monitored Natural Attenuation

- 1 Environmental Sequence Stratigraphy: roots in the oil and gas world
- 2 Sequence Stratigraphy in numerical models
- 3 Upscaling stratigraphy to model properties
- 4 Capturing uncertainty
- 5 Benefits of these exercises

Environmental Sequence Stratigraphy

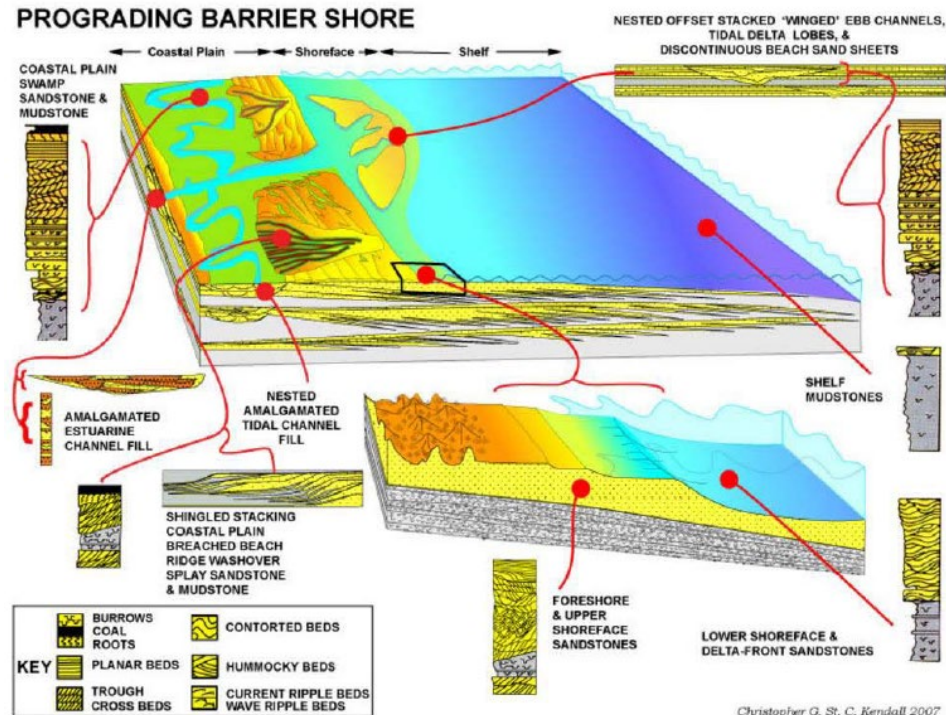
September 2017



Groundwater Issue

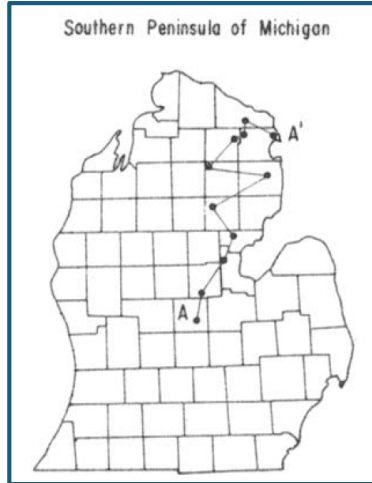
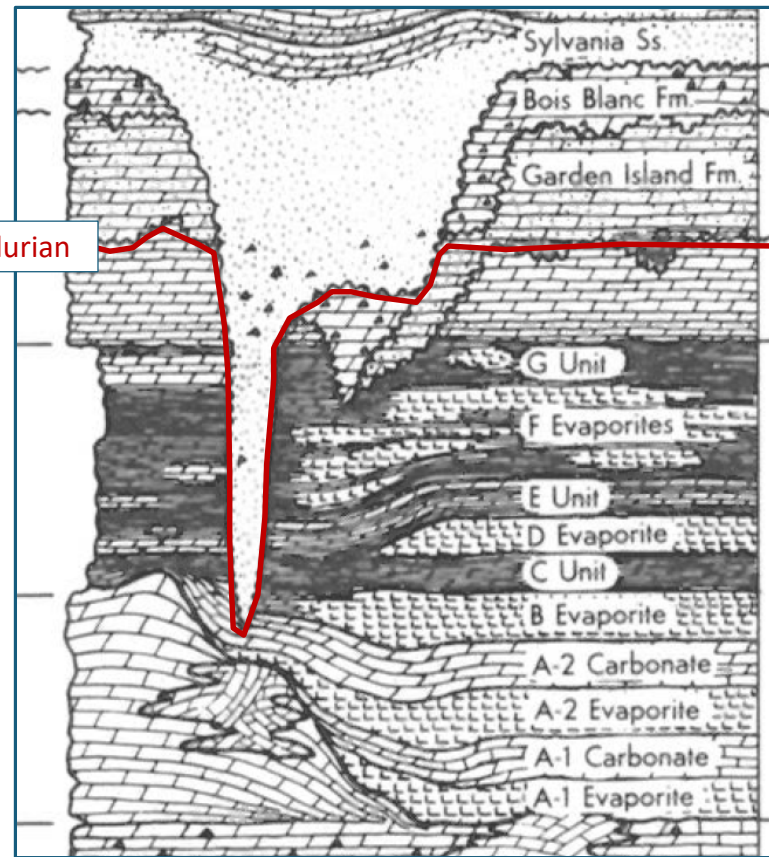
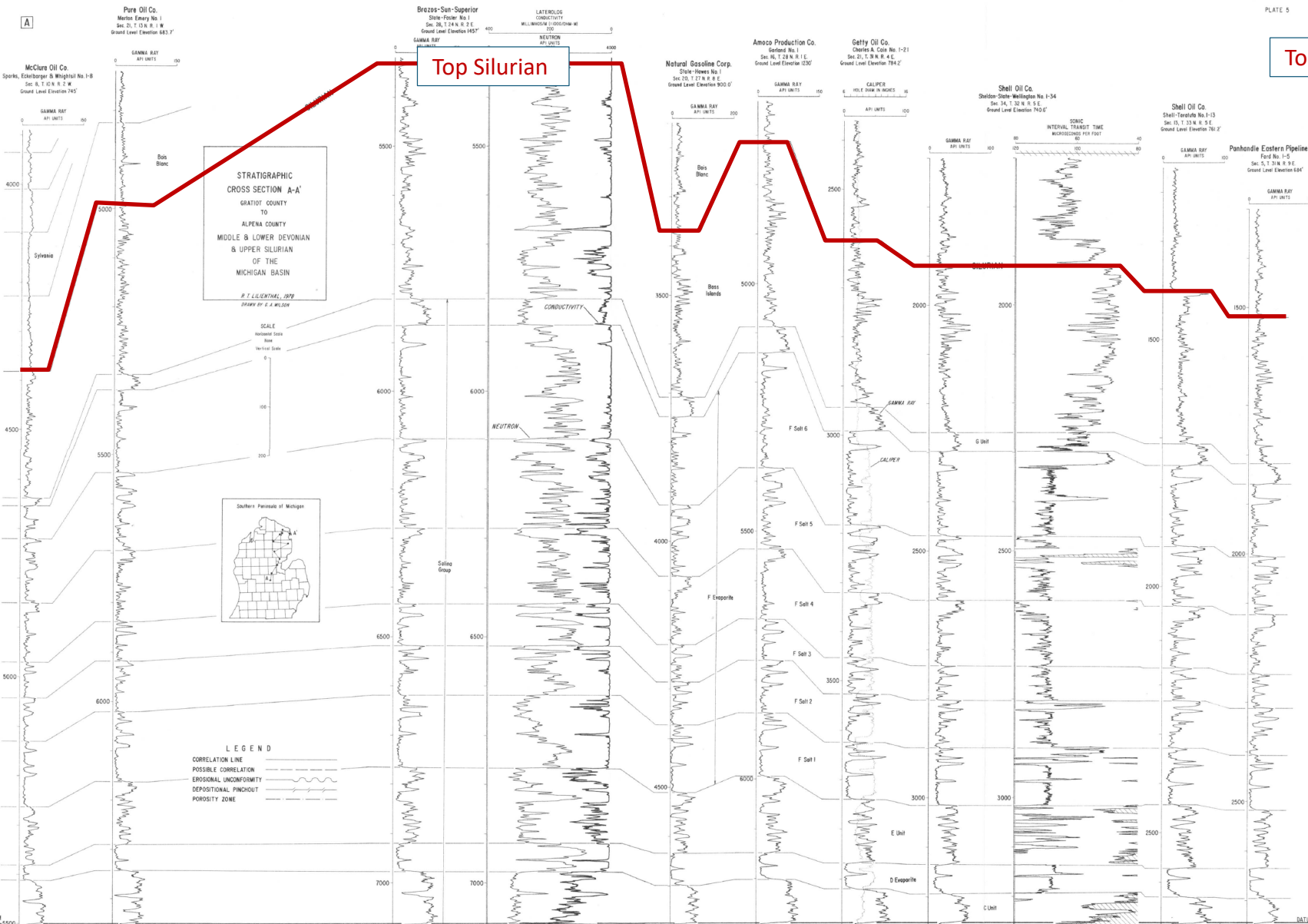
Best Practices for Environmental Site Management: *A Practical Guide for Applying Environmental Sequence Stratigraphy to Improve Conceptual Site Models*

Michael R. Shultz¹, Richard S. Cramer¹, Colin Plank¹, Herb Levine², Kenneth D. Ehman³



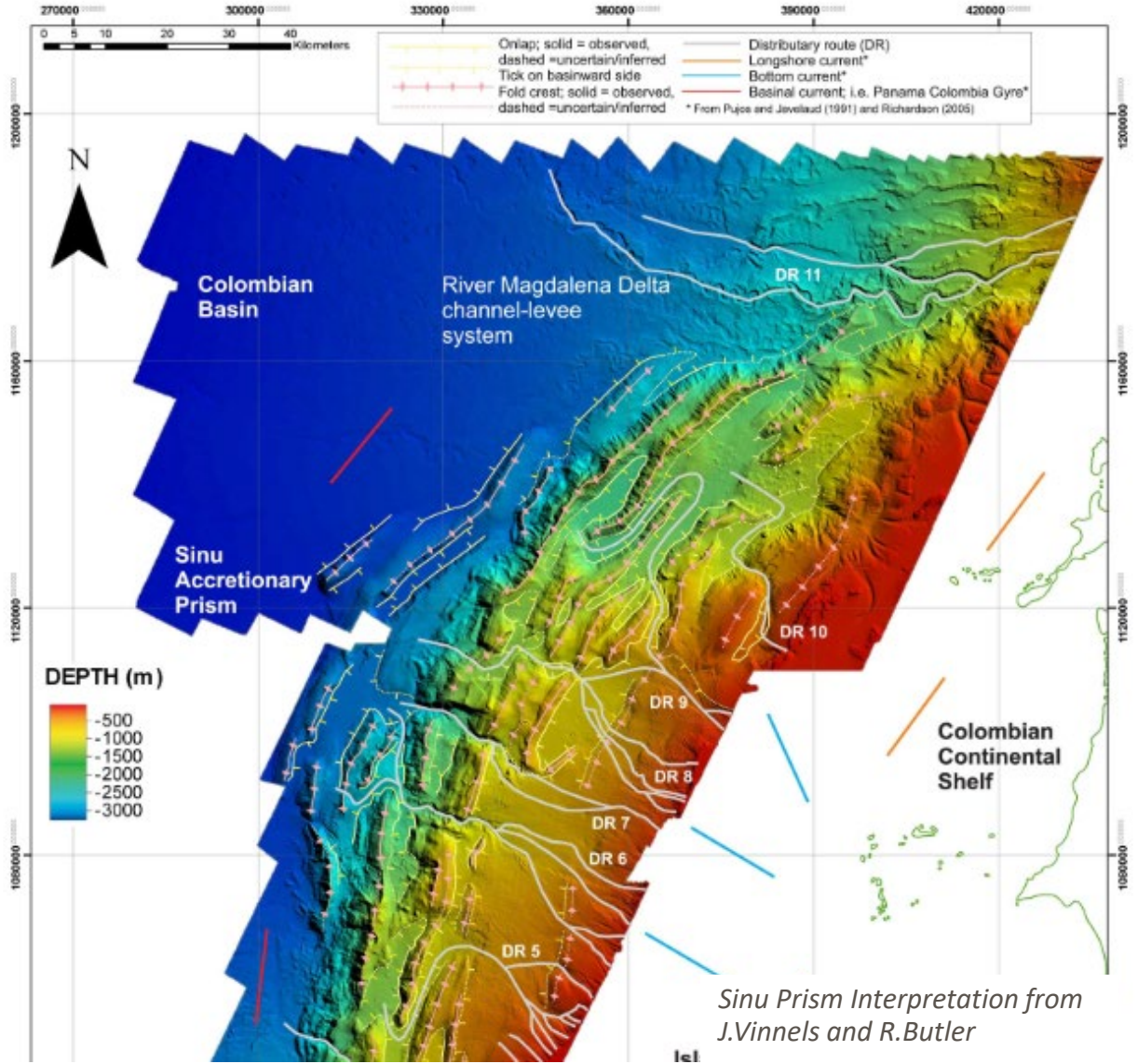
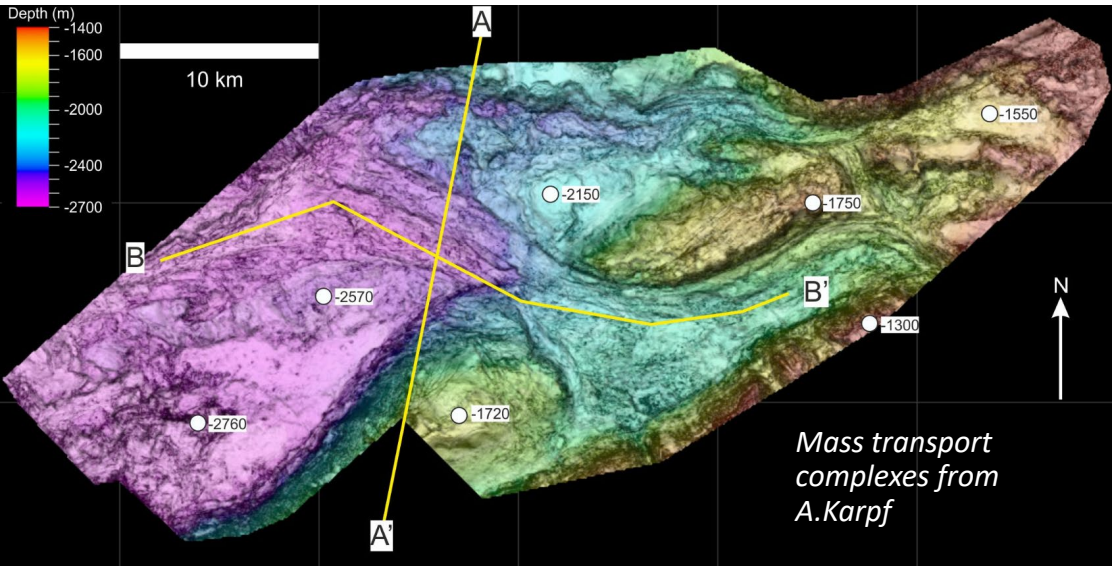
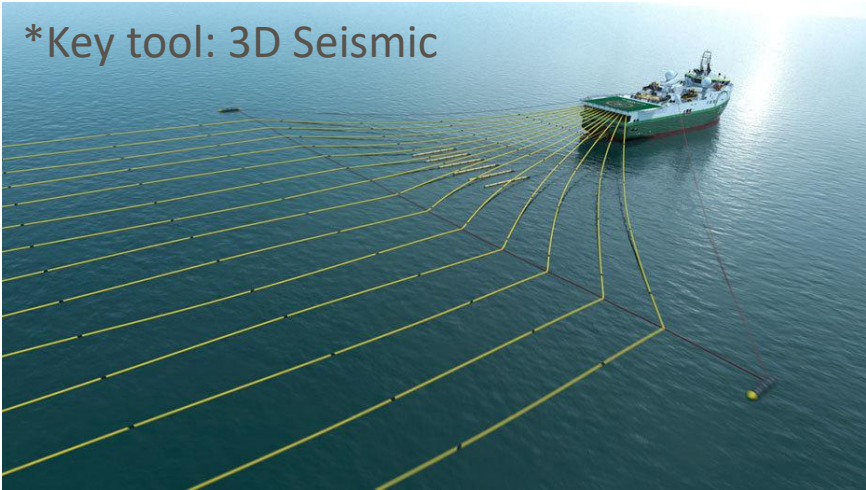
- Very useful tools for interpretation and site conceptual models.
- Not as easy to apply quantitatively.
- Groundwater models that incorporate high-resolution stratigraphy are challenging (and expensive) to construct
- Key limitation: what is the maximum detail of interpretation supported by the data?
- Other geologic disciplines struggle with the same issues.

Classic Sequence Stratigraphy: Well Ties



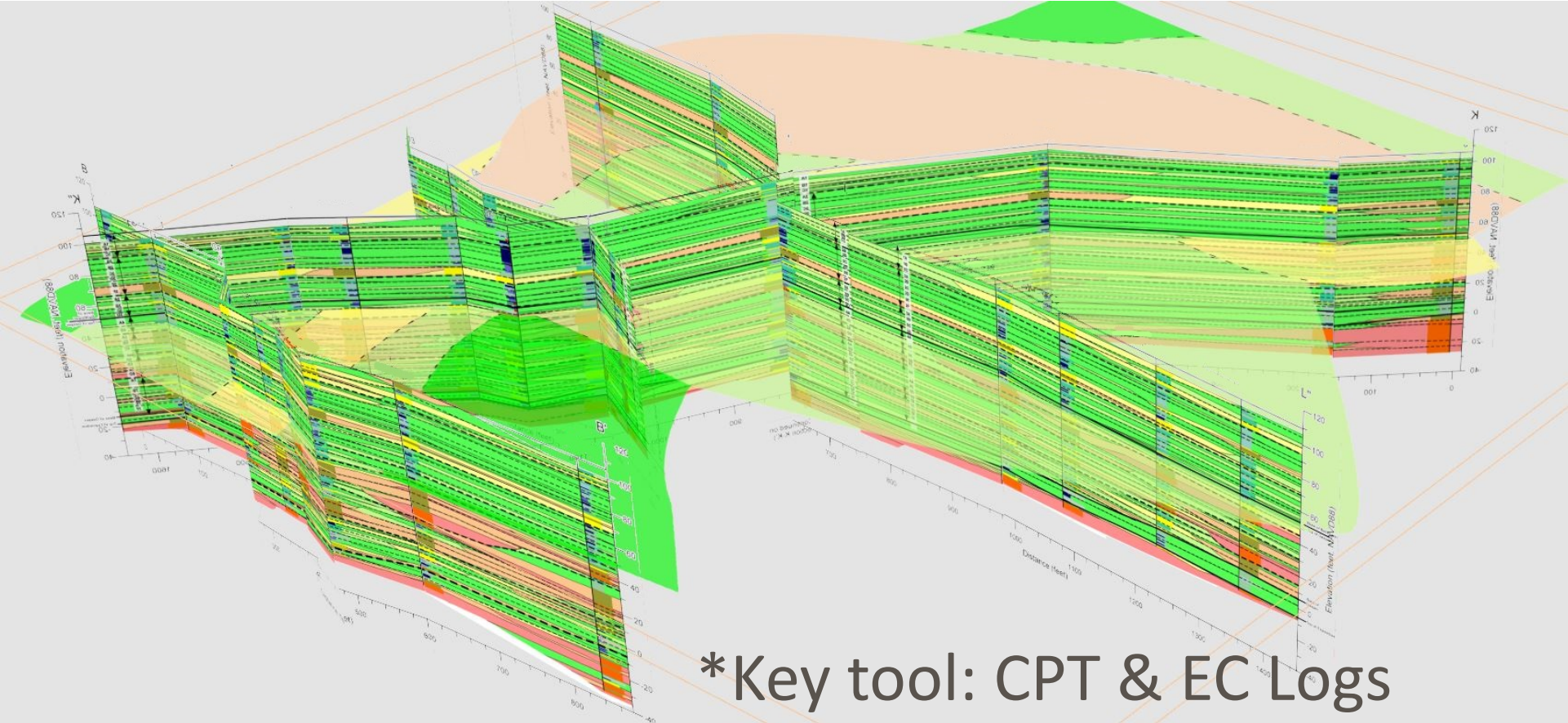
From
Lilienthal,
1978

Sequence Stratigraphy with Modern 3D Seismic Surveys



Examples from Virtual seismic atlas: www.seismicatlas.org

Environmental Sequence Stratigraphy



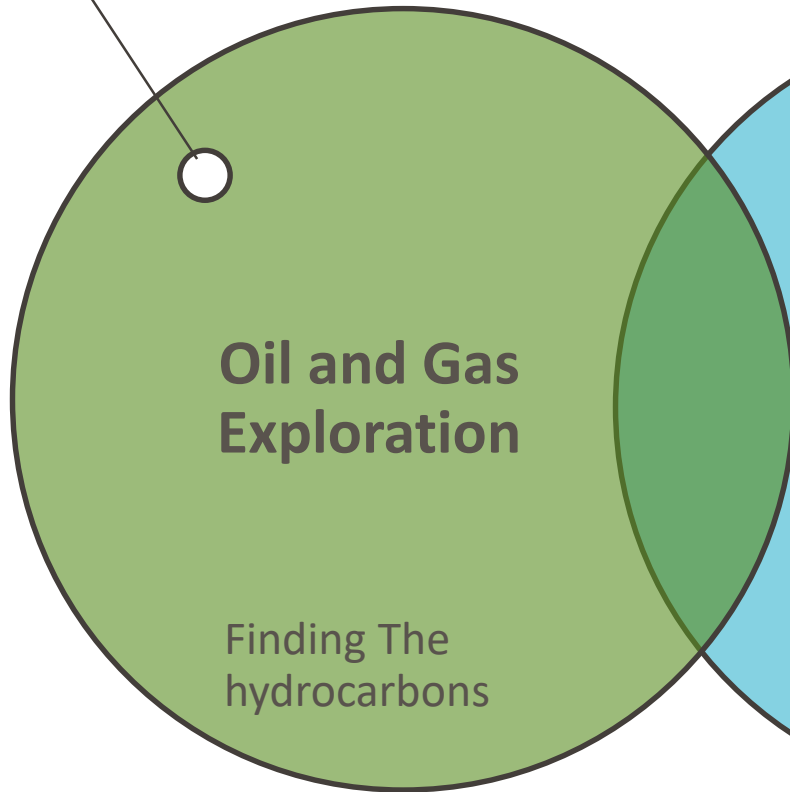
*Key tool: CPT & EC Logs

3D stratigraphic interpretation, Dominguez Sequence aquifers, Los Angeles Basin

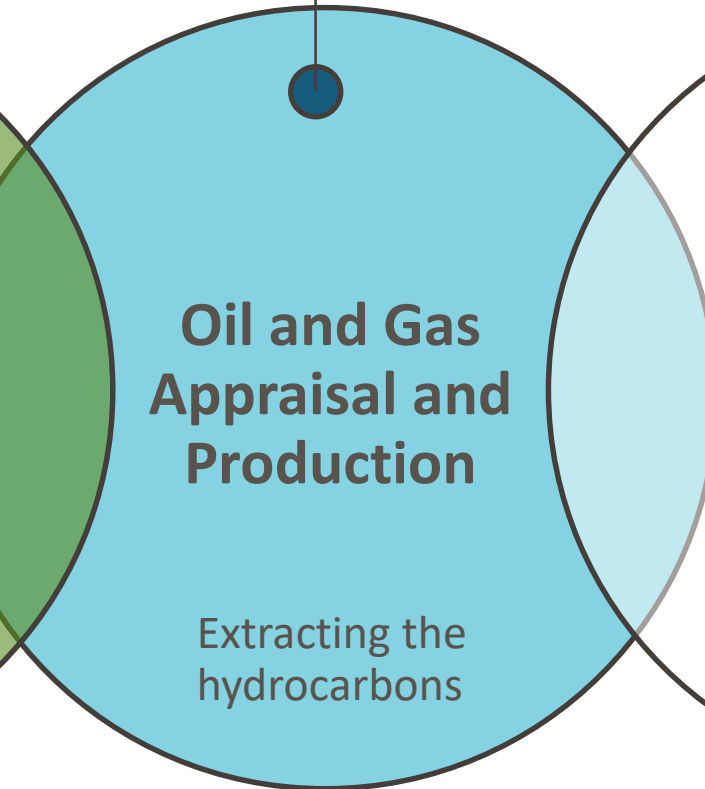
CONE PENETRATION TESTING (CPT) SOIL BEHAVIOR TYPE (SBT) OF ROBERTSON ET AL. 1986				GEOLOGIC EXPLANATION			
■	1 - SENSITIVE FINE GRAINED	■	7 - SILTY SAND TO SANDY SILT	FACIES ASSOCIATION CHANNEL-FILL/BAR AND BASAL CHANNEL CHANNEL-FILL/BAR CHANNEL-FILL/BAR/MARGIN	■	1	FLOOD-PLAIN AND CHANNEL MARGIN FACIES ASSOCIATION CREVASSE SPLAY/LEVEE OVERBANK
■	2 - ORGANIC MATERIAL	■	8 - SAND TO SILTY SAND		■	2	
■	3 - CLAY	■	9 - SAND		■	3	
■	4 - SILTY CLAY TO CLAY	■	10 - GRAVELLY SAND TO SAND		■	4	
■	5 - CLAYEY SILT TO SILTY CLAY	■	11 - VERY STIFF FINE GRAINED (*)		■	5	
■	6 - SANDY SILT TO CLAYEY SILT	■	12 - SAND TO CLAYEY SAND (*) <small>*OVERCONSOLIDATED OR CEMENTED</small>				

Discipline Overlap

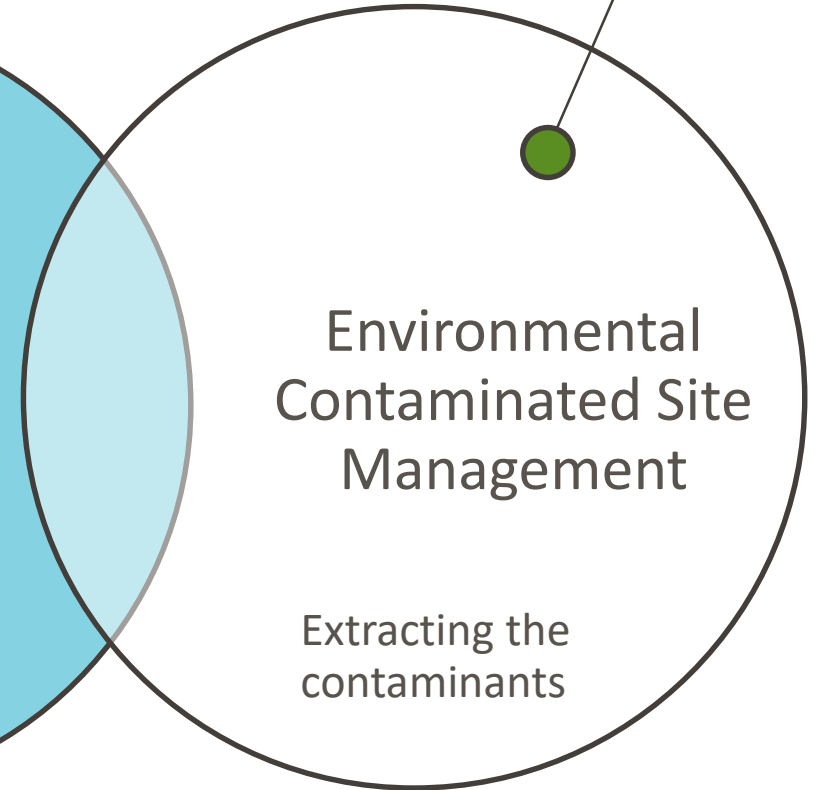
Sequence Stratigraphy started here



Sequence Stratigraphy improved here

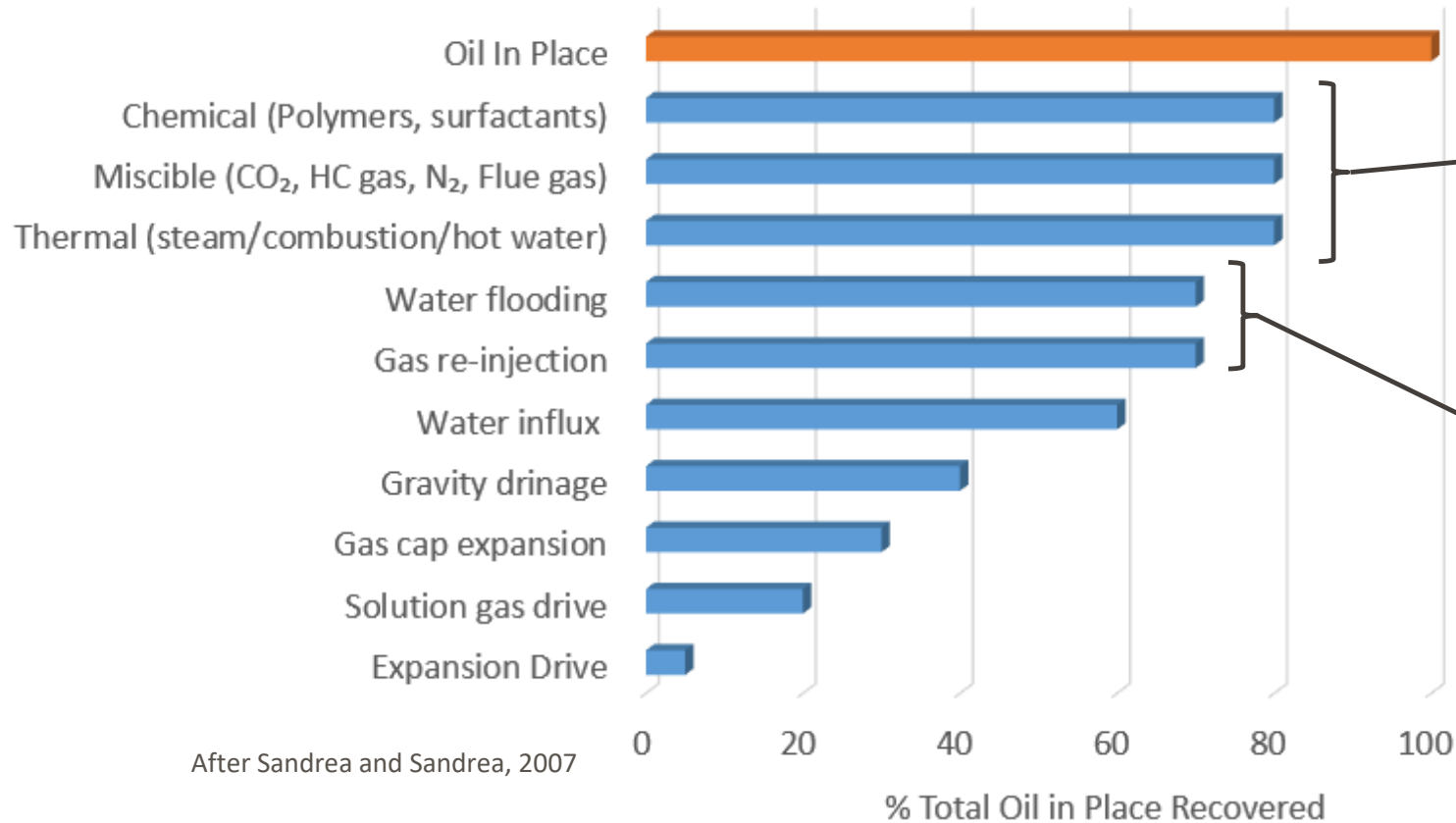


Environmental Sequence Stratigraphy



Discipline Overlap: Oil Recovery Efficiency (= NAPL Recovery)

Expected Oil Recovery Efficiencies



After Sandrea and Sandrea, 2007

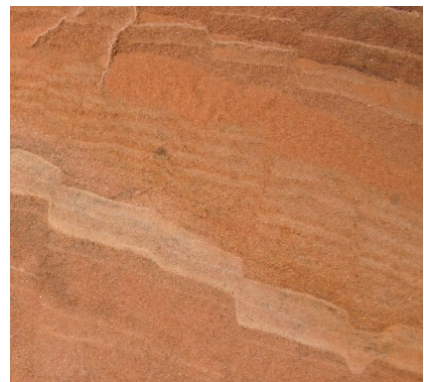
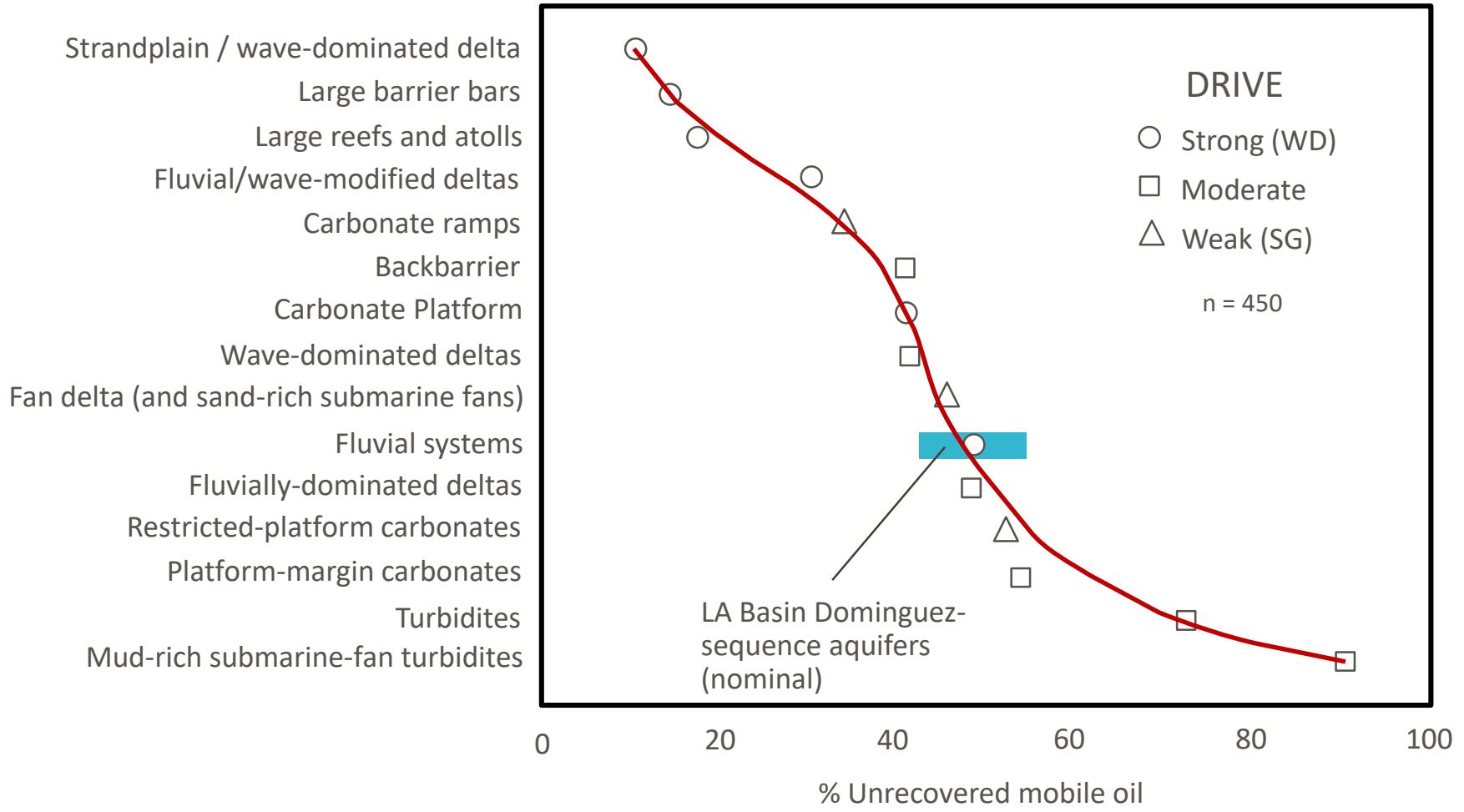
Oil:
Tertiary Recovery

Environmental:
Groundwater Recirculation,
Surfactant Flush, etc..

Oil:
Secondary Recovery

Environmental:
Pump and treat, Soil Vapor
Extraction

Relationship between NAPL recoverability and geologic facies

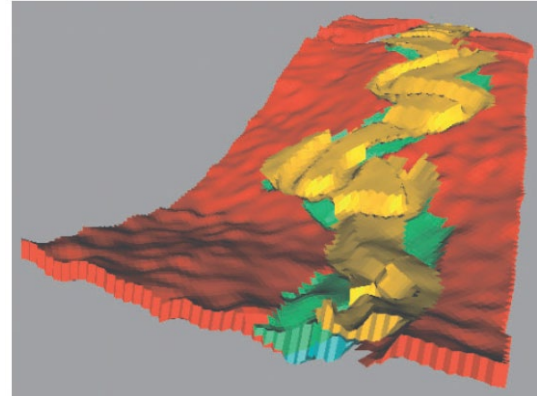


From Tyler and Finley, 1992. 'Architectural Controls on the Recovery of Hydrocarbons from Sandstone Reservoirs.' SEPM

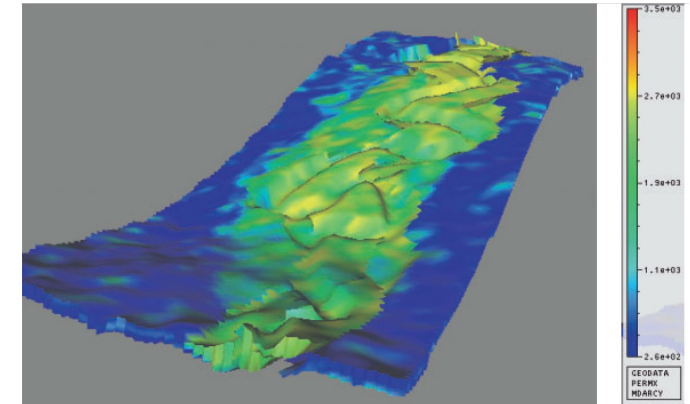
Numerical Models: Oil and Gas Reservoir Simulations

- Tend to focus on engineering aspects
- Multi-phase flow
- Key property is relative permeability
- Analogous to numerical models for NAPL recovery

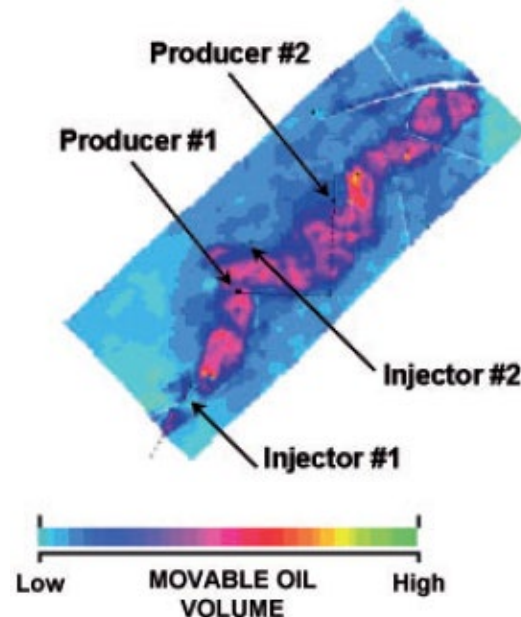
Stratigraphic Facies



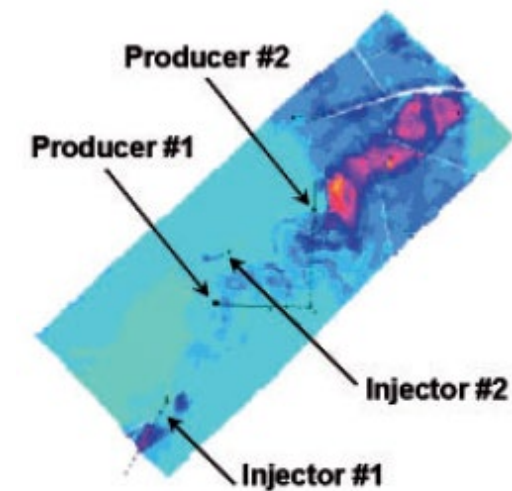
Permeability



Movable oil map at time zero



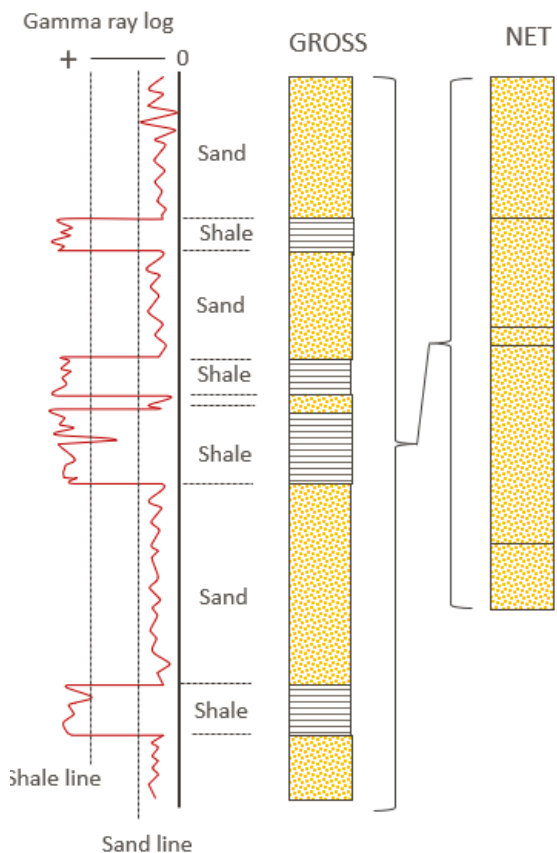
Post-Forecast



From Alpak et al. 2011

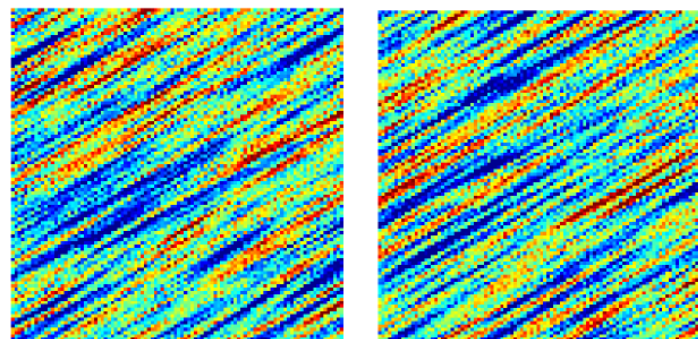
Assigning properties in reservoir simulations

Upscaled Borehole Interpretation



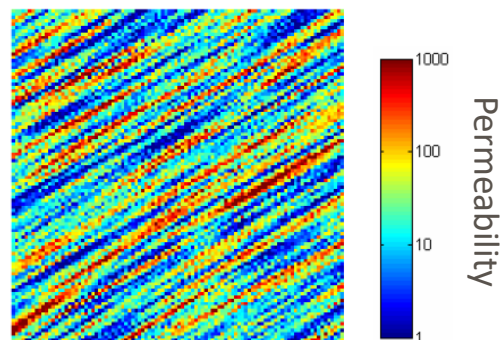
From M. Shepherd. AAPG Memoir 91

Geostatistical Models



(a) Realization 1

(b) Realization 2

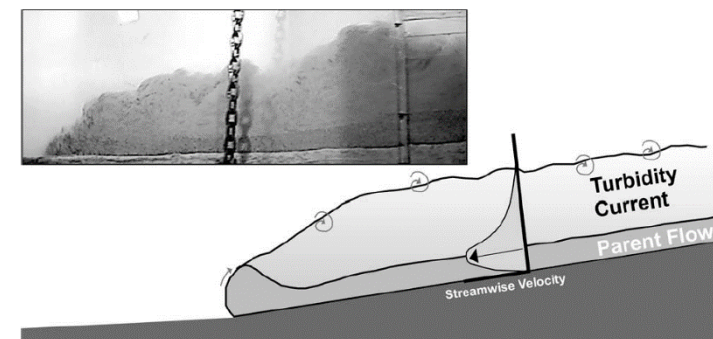


(c) Realization 3

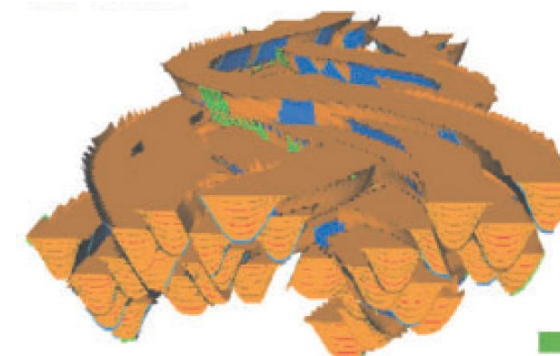
From Chen, 2009

- Have the same statistical properties as geologic analogs

Process-Based Models



Mohrig and Marr, 2003



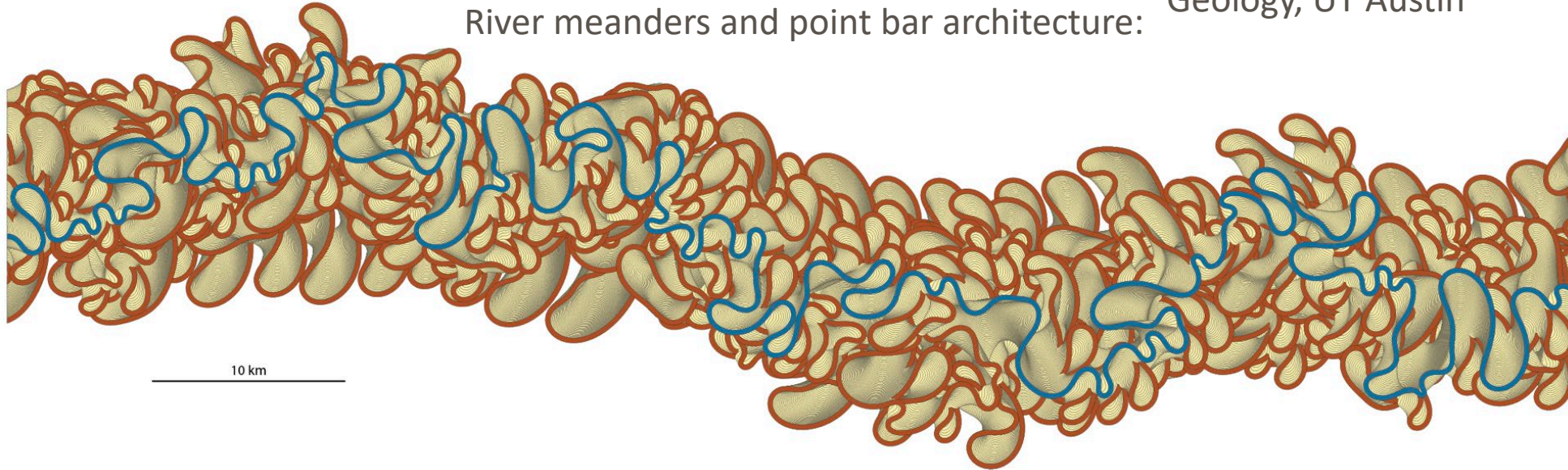
From Alpak et al., 2011

- Created from models of geologic processes

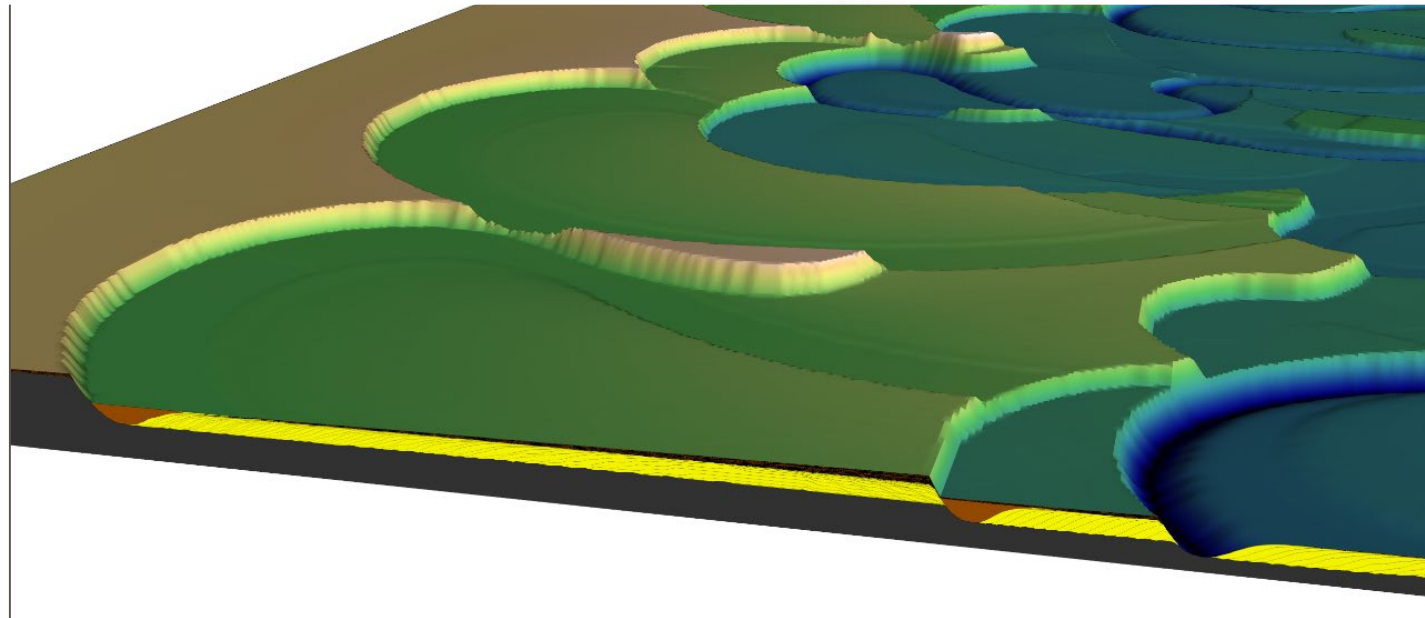
Process Based Stratigraphic Modeling

From Z. Sylvester, Bureau of Economic Geology, UT Austin

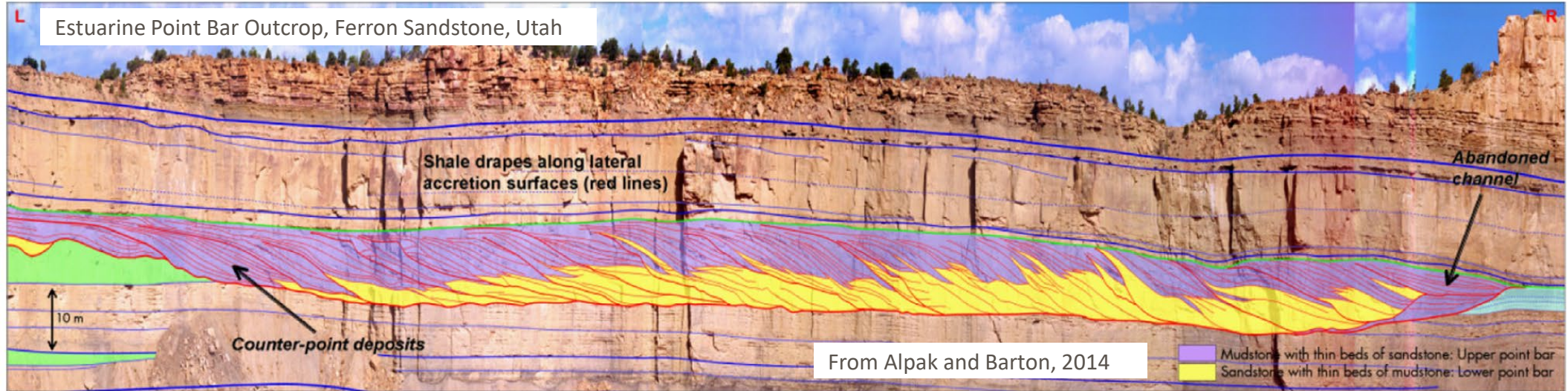
River meanders and point bar architecture:



3D model of incised meandering river:



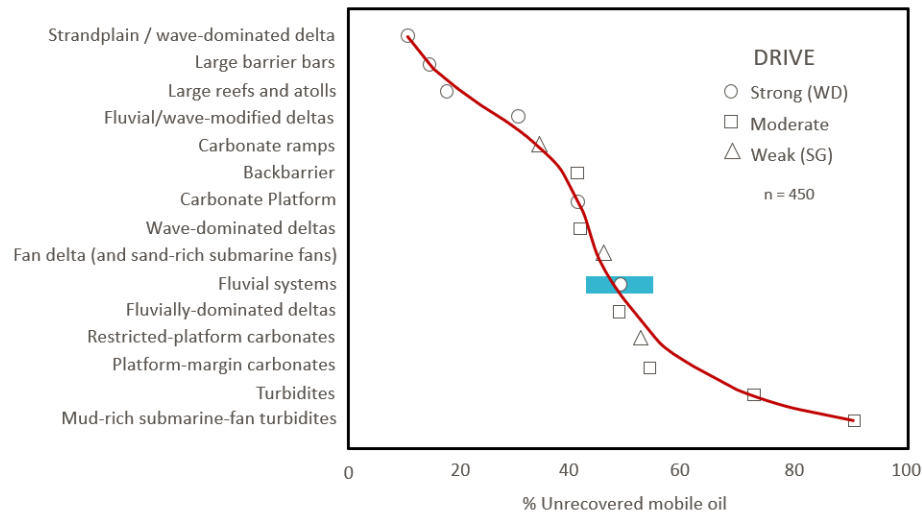
When building a model: is one interpretation enough?



Model results
less sensitive to
stratigraphic
details



Model results
more sensitive to
stratigraphic
details



Stochastic Modeling: Look at many similar models

Many (+tens of thousands) numerical simulations of similar models that fit the observations



Sensitivity analysis of results – what details of the geology actually affect the outcome?

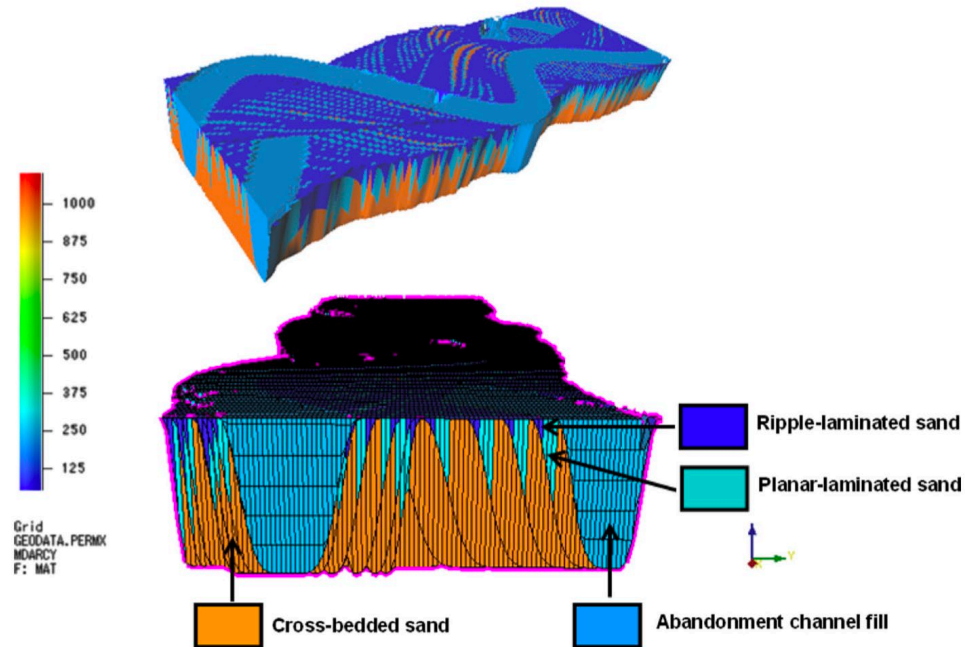
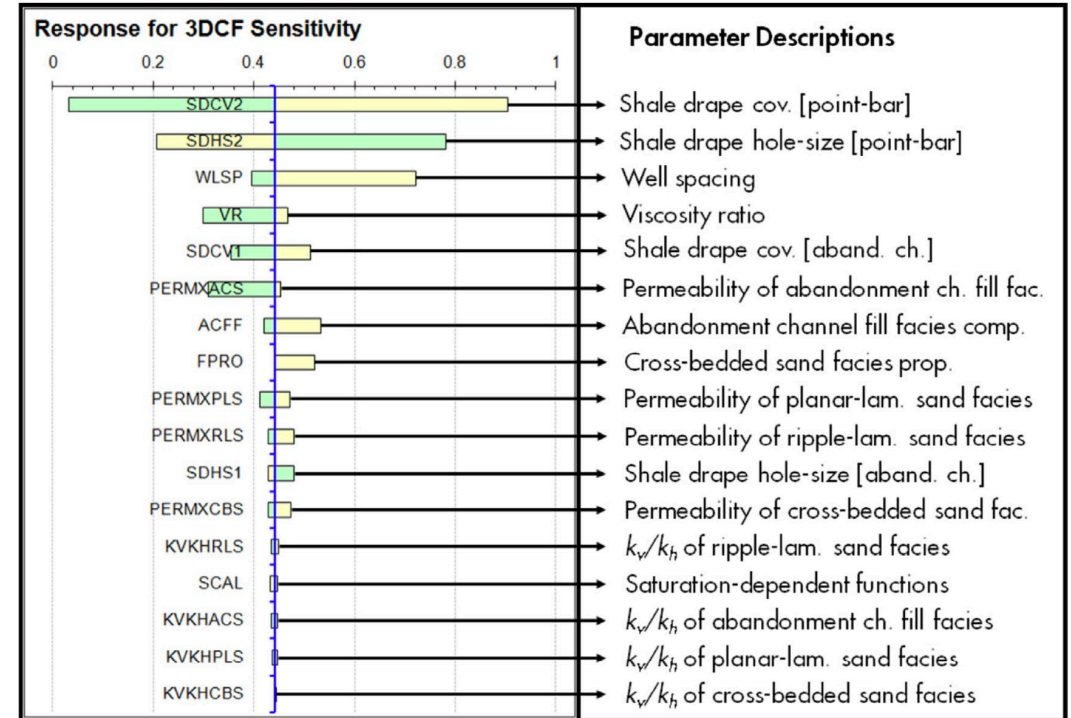


Fig. 5. Example 3D views of the mid-case estuarine point-bar model. Legends show permeability and facies information.



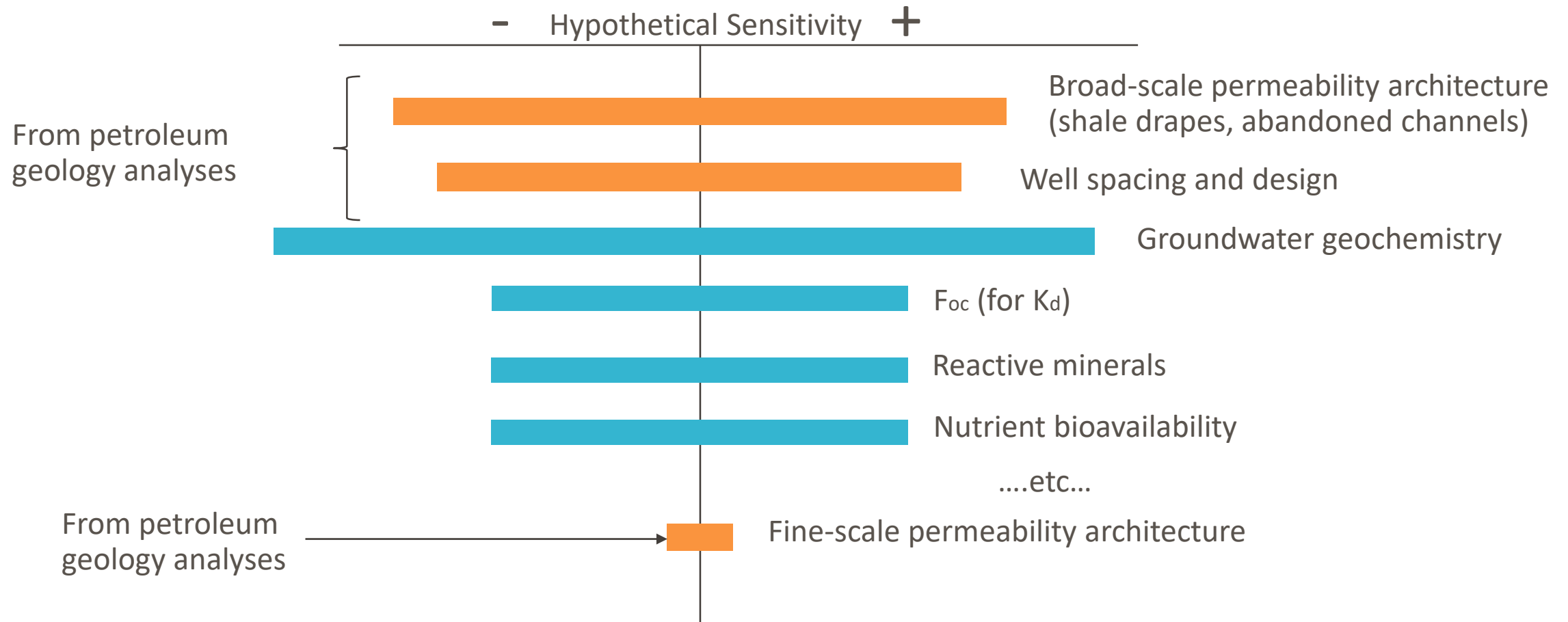
Large range: details critical

Small range: geologic details less important

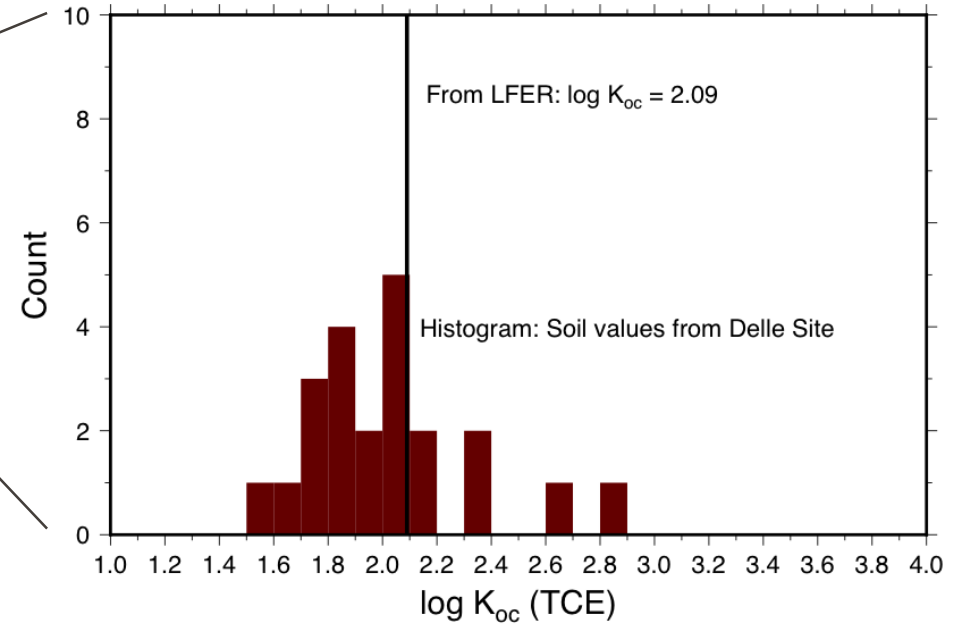
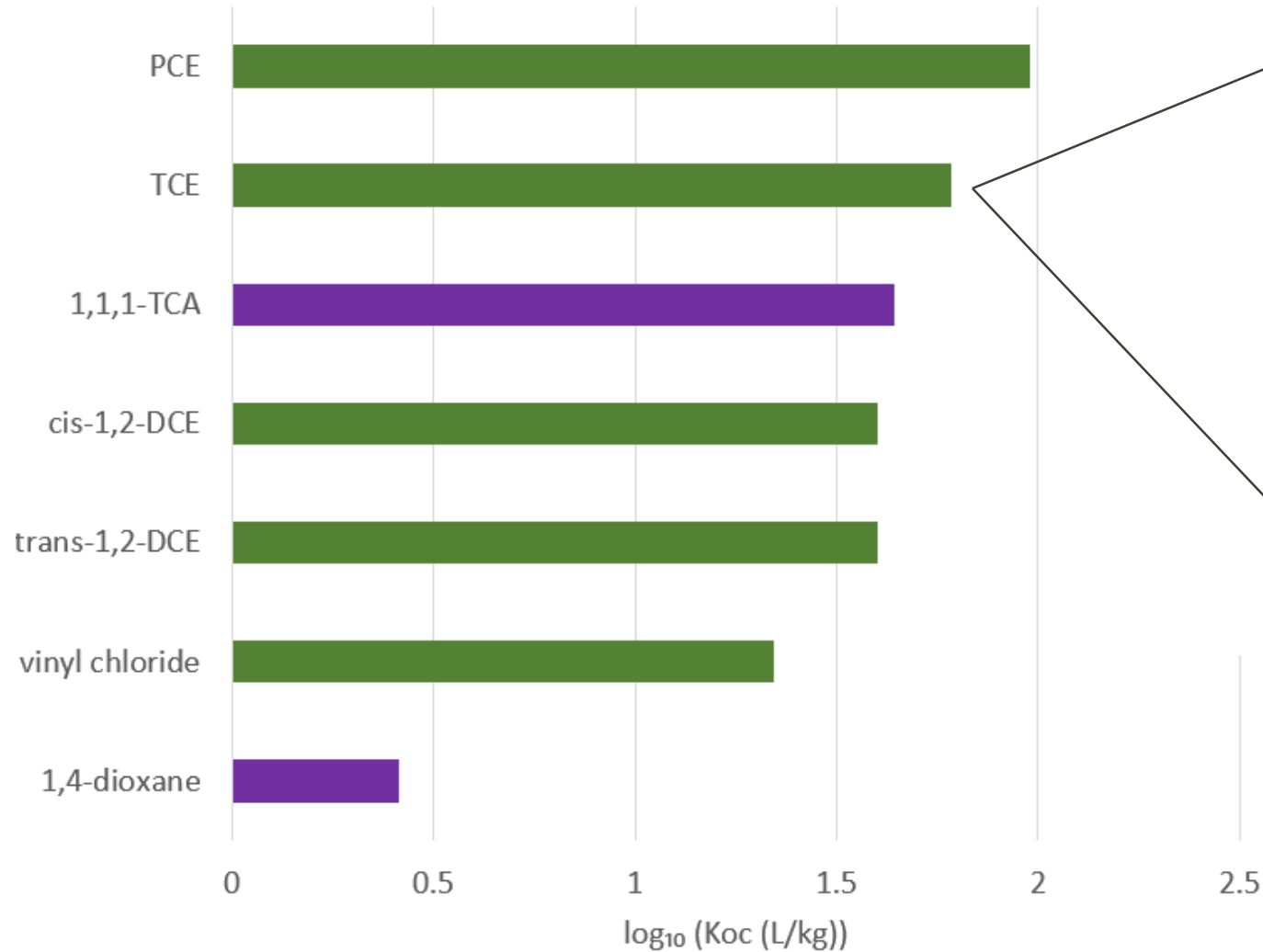
From F.O. Alpak and M.D. Barton, 2014.

* This is sometimes called “Flow-Based Upscaling”

Question: What sequence stratigraphy variables affect contaminant fate and transport?



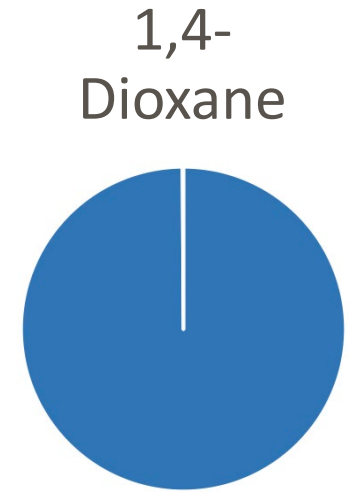
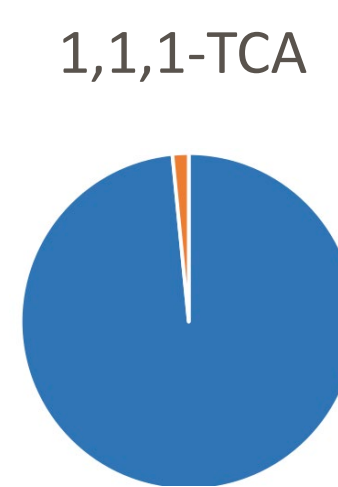
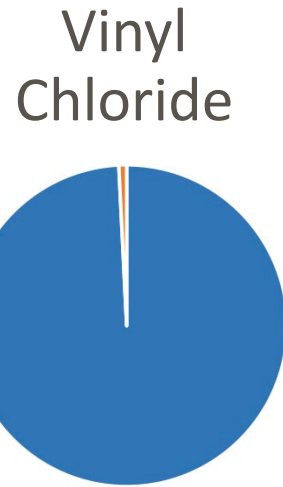
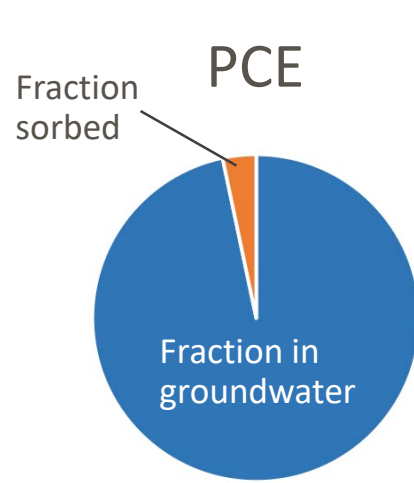
Contaminant mobility as a function of soil organic content: Koc



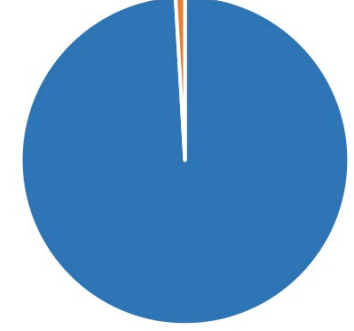
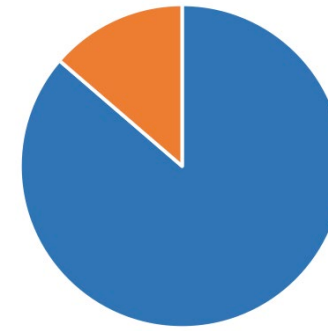
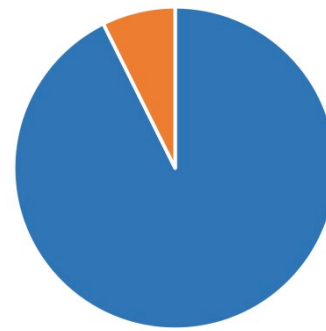
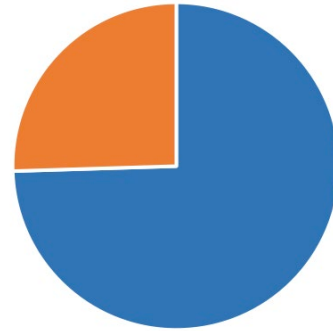
*Type of organic matter is also important

Mass Fraction Organic Carbon (foc)

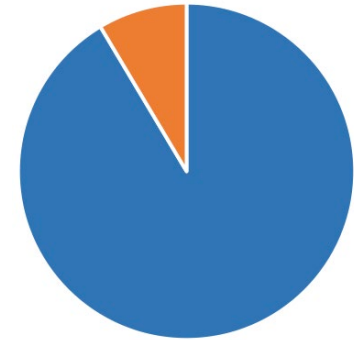
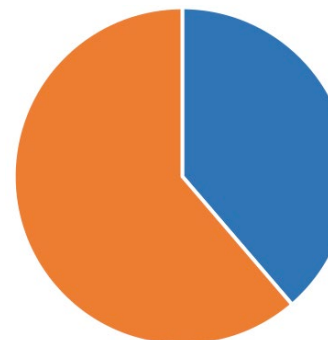
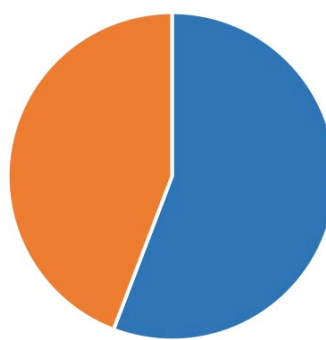
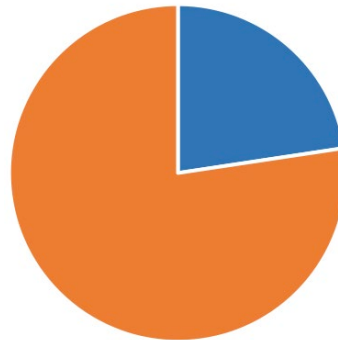
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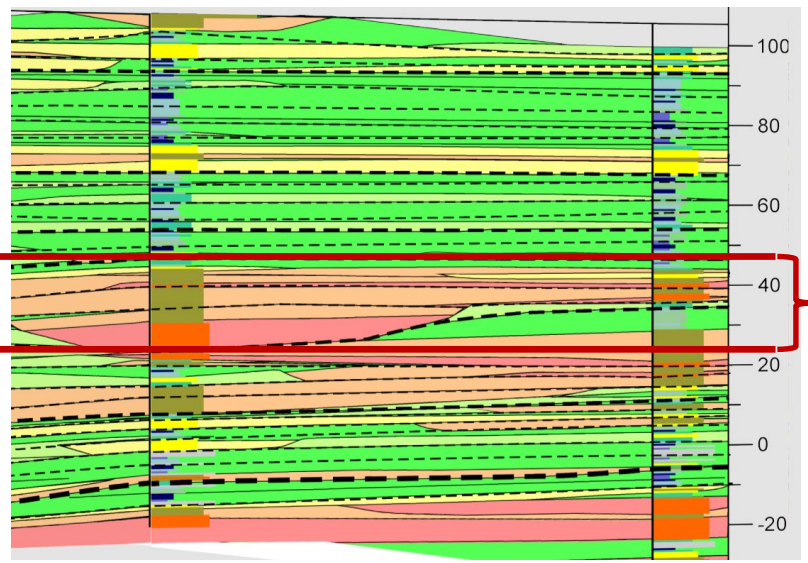


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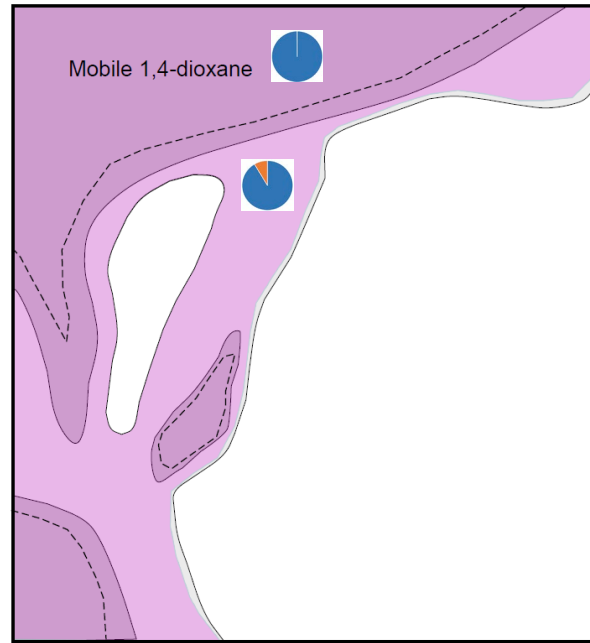
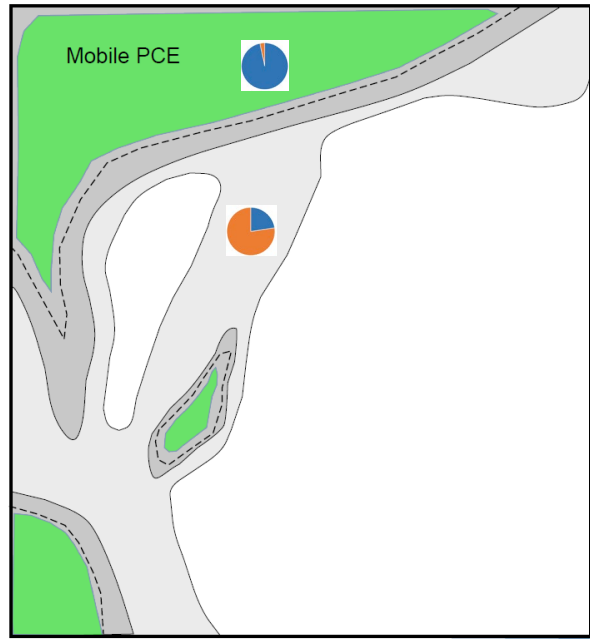
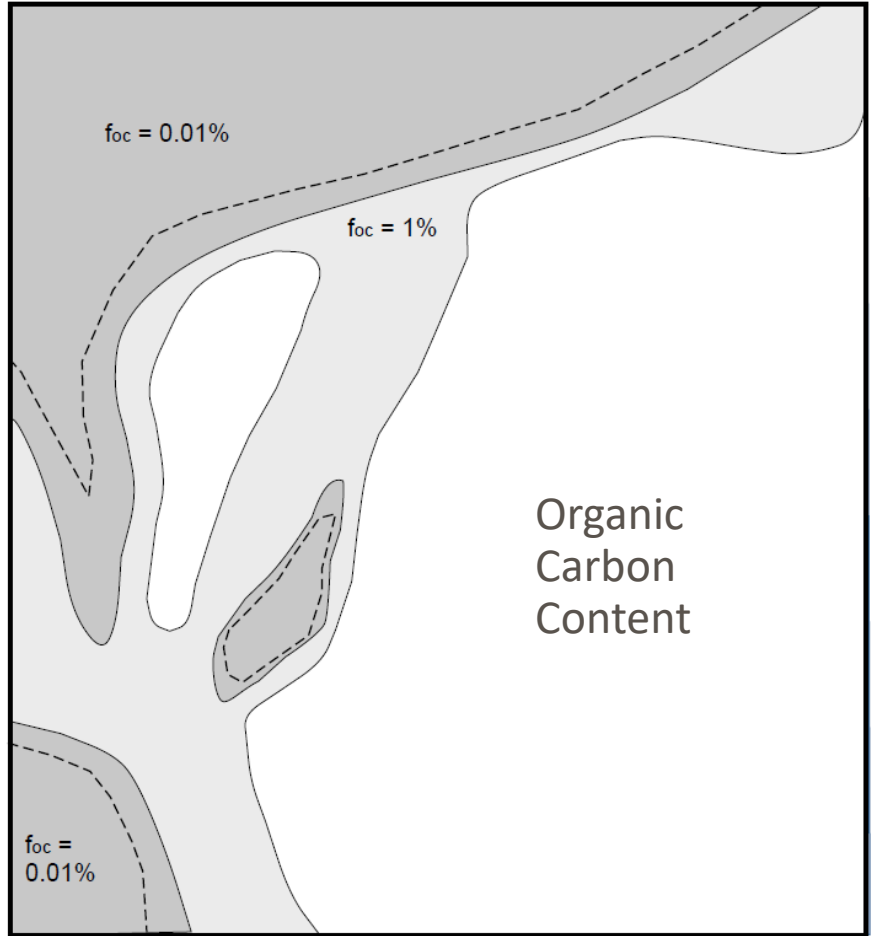


Upscaling: Dominguez Group Aquifers, LA Basin

Sequence-Stratigraphic Cross Section



Map for Gross Section Interval



GEOLOGIC EXPLANATION

CHANNEL FACIES ASSOCIATION		FLOOD-PLAIN AND CHANNEL MARGIN FACIES ASSOCIATION	
FACIES	DEPOSITIONAL ENVIRONMENT	FACIES	DEPOSITIONAL ENVIRONMENT
1	CHANNEL-FILL/BAR AND BASAL CHANNEL	4	CREVASSE SPLAY/LEVEE
2	CHANNEL-FILL/BAR	5	OVERBANK
3	CHANNEL-FILL/BAR/MARGIN		

(Figures are schematic)

Conclusions

1

Instructive to consider oil and gas roots of sequence stratigraphy

2

Many ways to make detailed models, need to define the cost/benefit

3

Exploring variability by using many simulations: a useful path.

4

Key environmental parameters: permeability, porosity, mineral composition, f_{oc} , and others all vary with facies

5

On the horizon: Process-based stratigraphic modeling