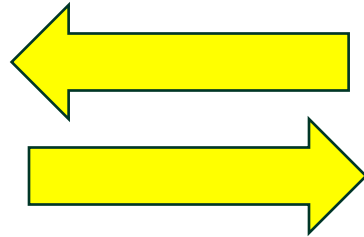


When Life Gives You Lemonade, Make Lemons:

*How to Reverse Engineer Valid
Geological Data from Analogs,
Outcrops and Regional Geology
in a Remediation Project*

Junaid Sadeque, PhD., AECOM

When
Life
Gives You
Lemonade



Make Lemons



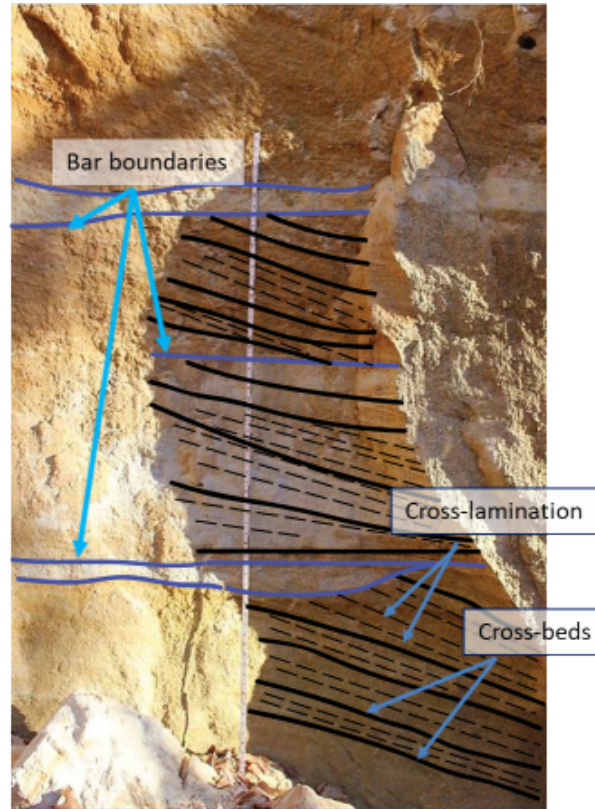
The Abundance of Site Analogs vs. Poor dataset

When Site Gives You Good
Analog But Poor Data



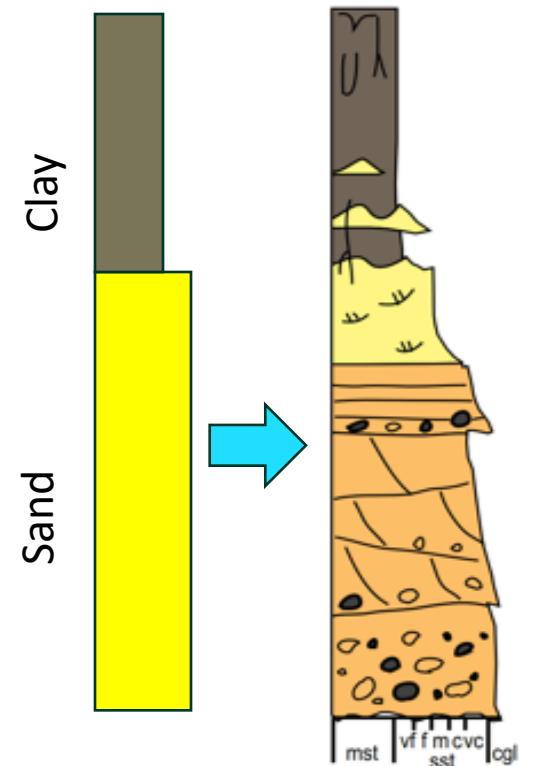
Ucayali River in
Peru

Zoltan
Sylvester2021



Fort Belvoir, Maryland

Reverse Engineer Analog
Information to Generate
Better Data



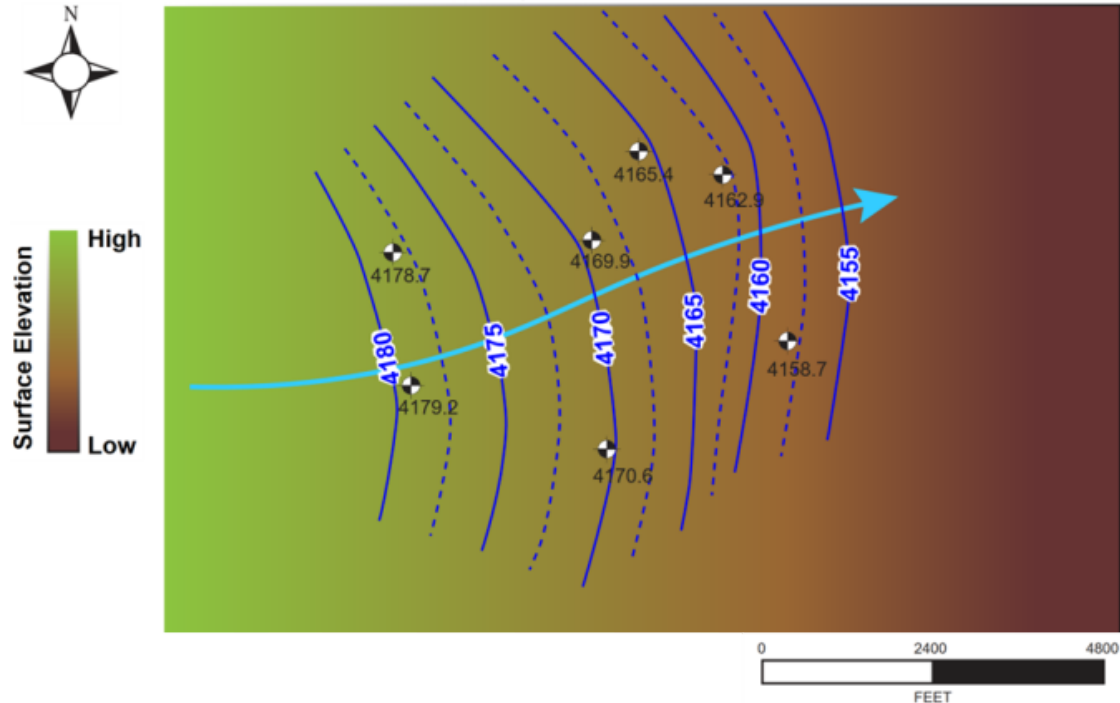
Channel sand from 'somewhere'

Talking Points

- Why do we need stratigraphy?
- Why are most of our geological cross-sections so hopeless?
- Data challenges in the environmental world
- But is there still hope?
 - Understanding of regional geology
 - Facies Models
 - Site outcrops and outcrop analogs
 - Present-day geomorphological analogs
- Going forward with generating better cross-sections

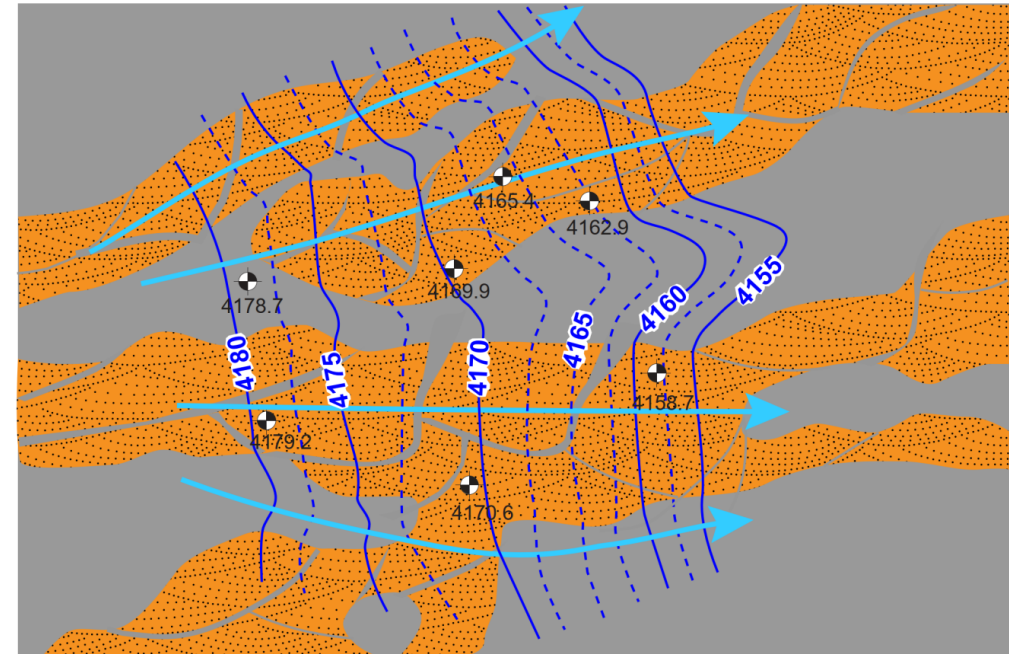
What's the Big Deal with Stratigraphy?

A: Regional Water Table Map



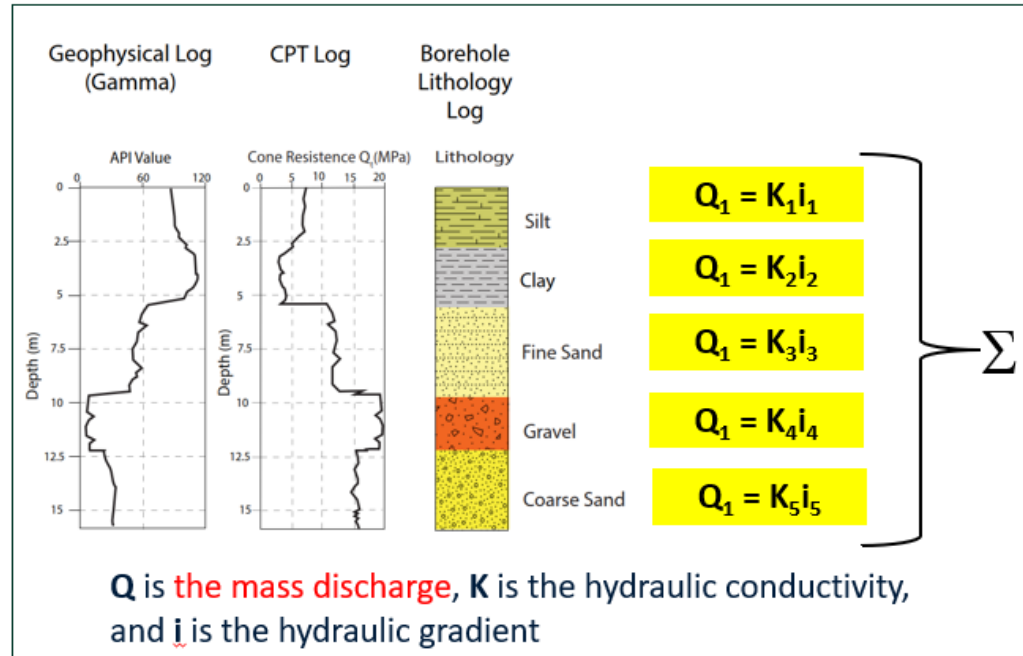
- Interval Contour
- Contour
- Groundwater flow direction
- Groundwater elevation (ft amsl)

B: Stratigraphy-Informed Water Table Map

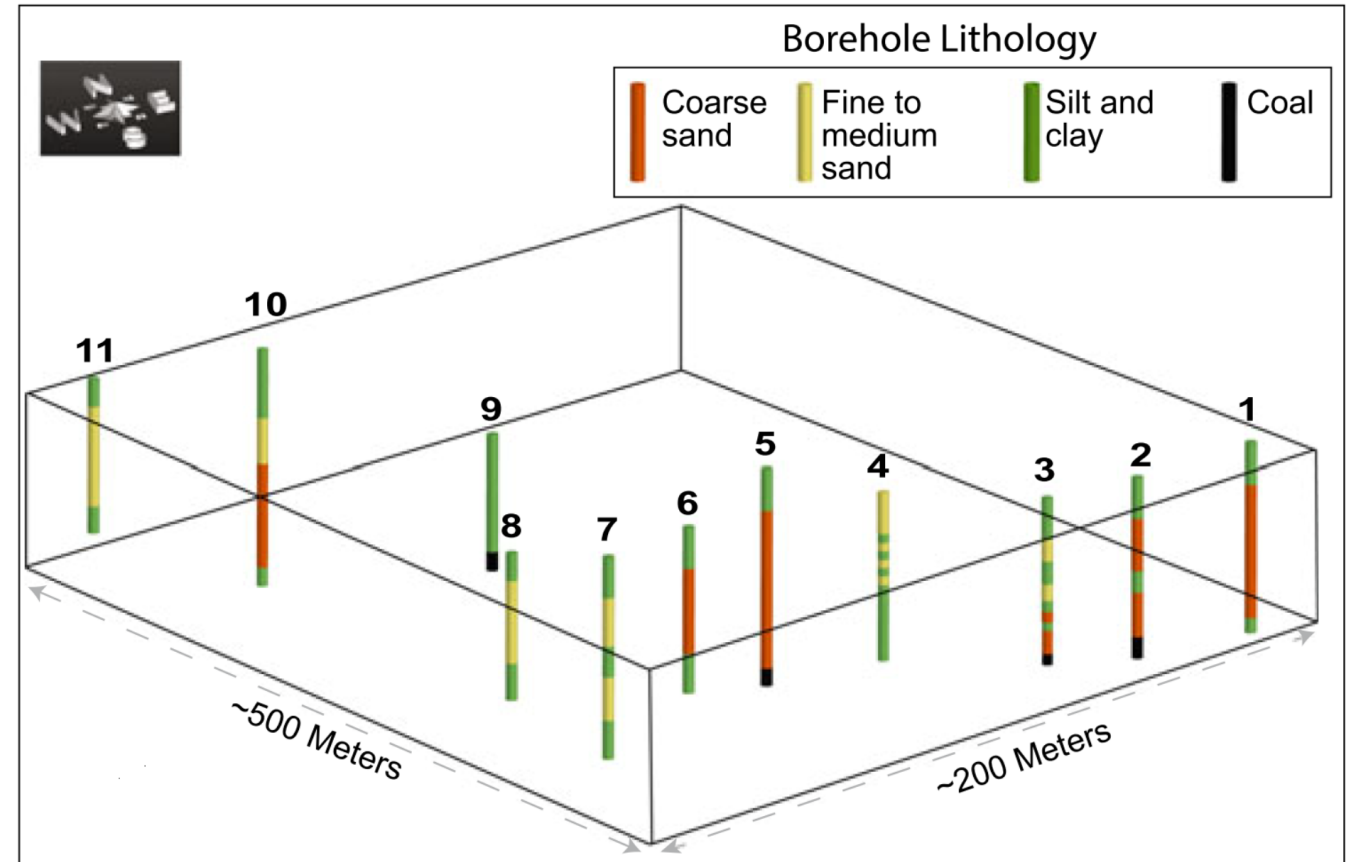


Geological heterogeneity of the subsurface dictates ground water flow. Therefore, hydrogeology must be informed by geology (stratigraphy).

The Stratigraphic Challenge



Life in 1-D is easy



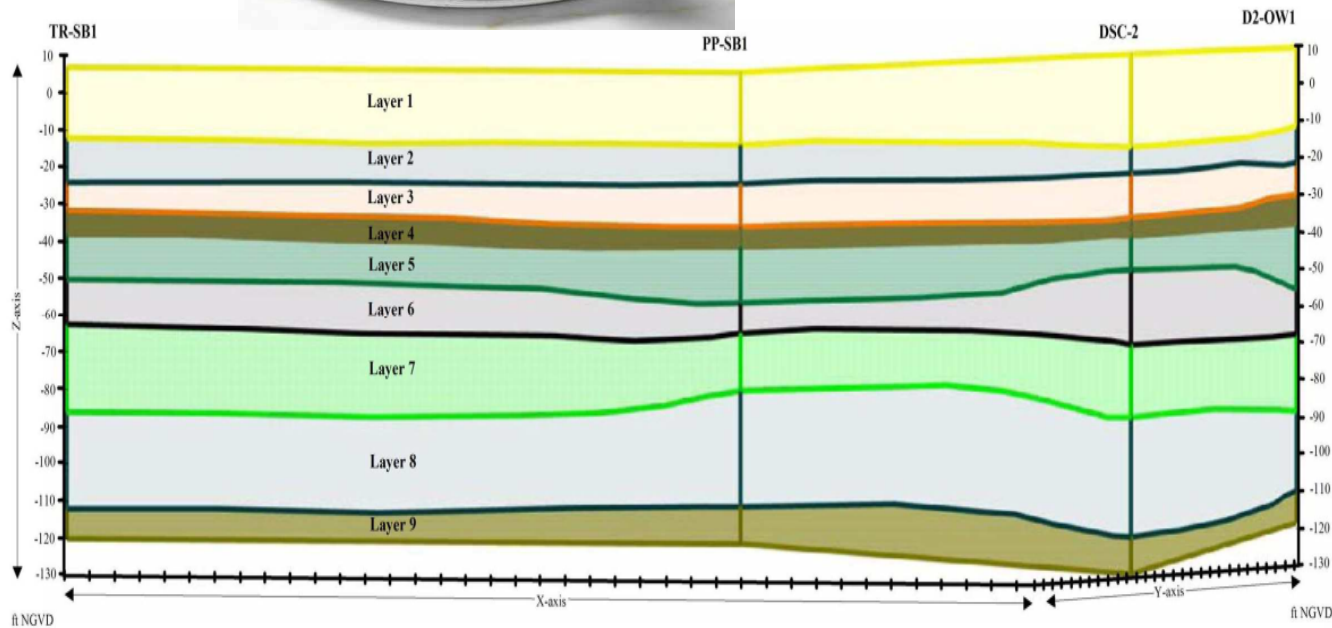
In 3-D...not so easy!

Even 2-D correlation can often be a non-trivial challenge!

Silent Quiz: Guess the Year!

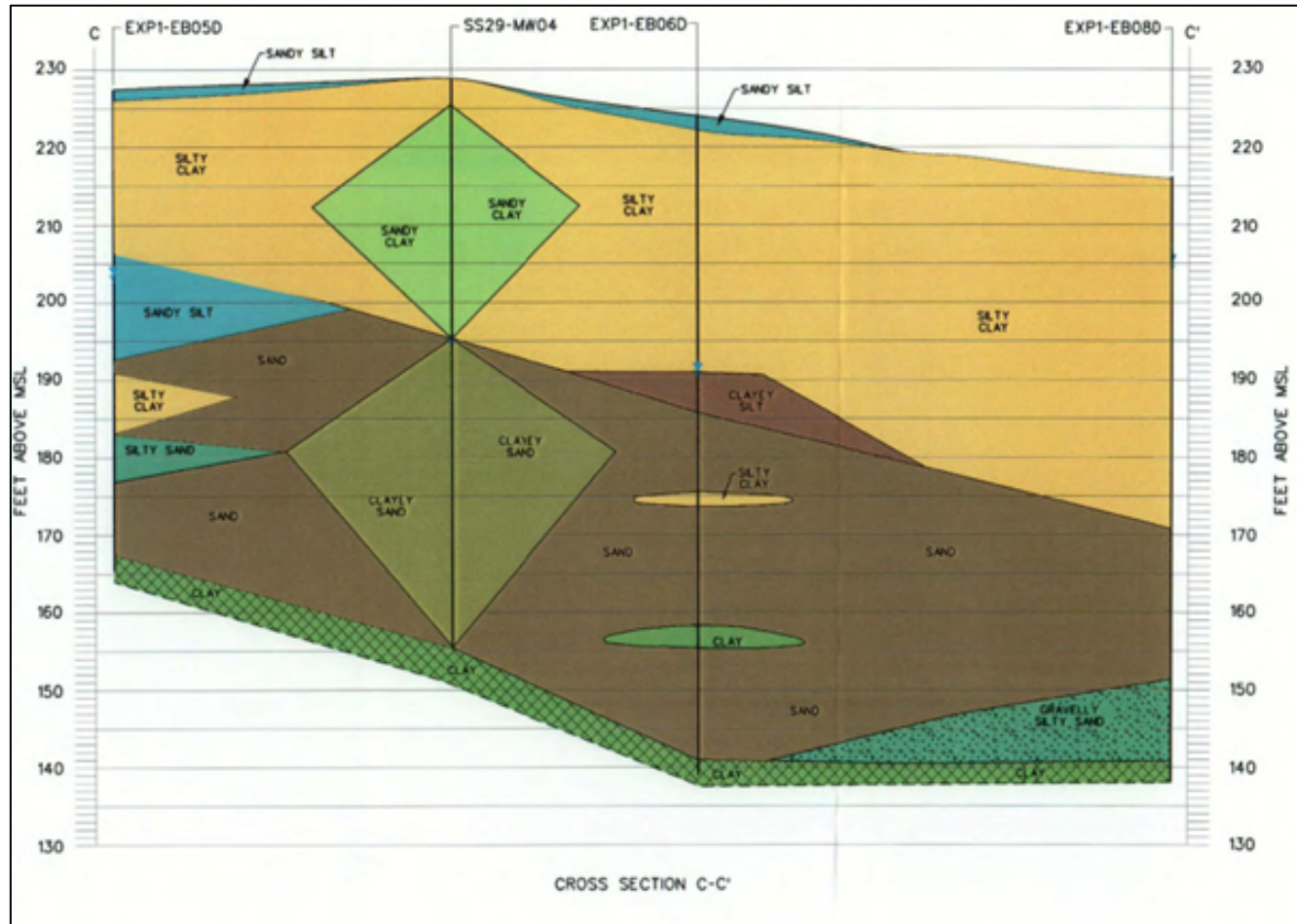


The Layer-cake Model



- ☐ 1825 (First railway line in the world in England)
- ☒ 2017 (Nasa announces its Lucy Mission to visit asteroids)
- ☐ 1970 (Beginning of contemporary art)
- ☐ 1940 (The first Cheesecake Factory opens in California)

Silent Quiz: Guess the Year!



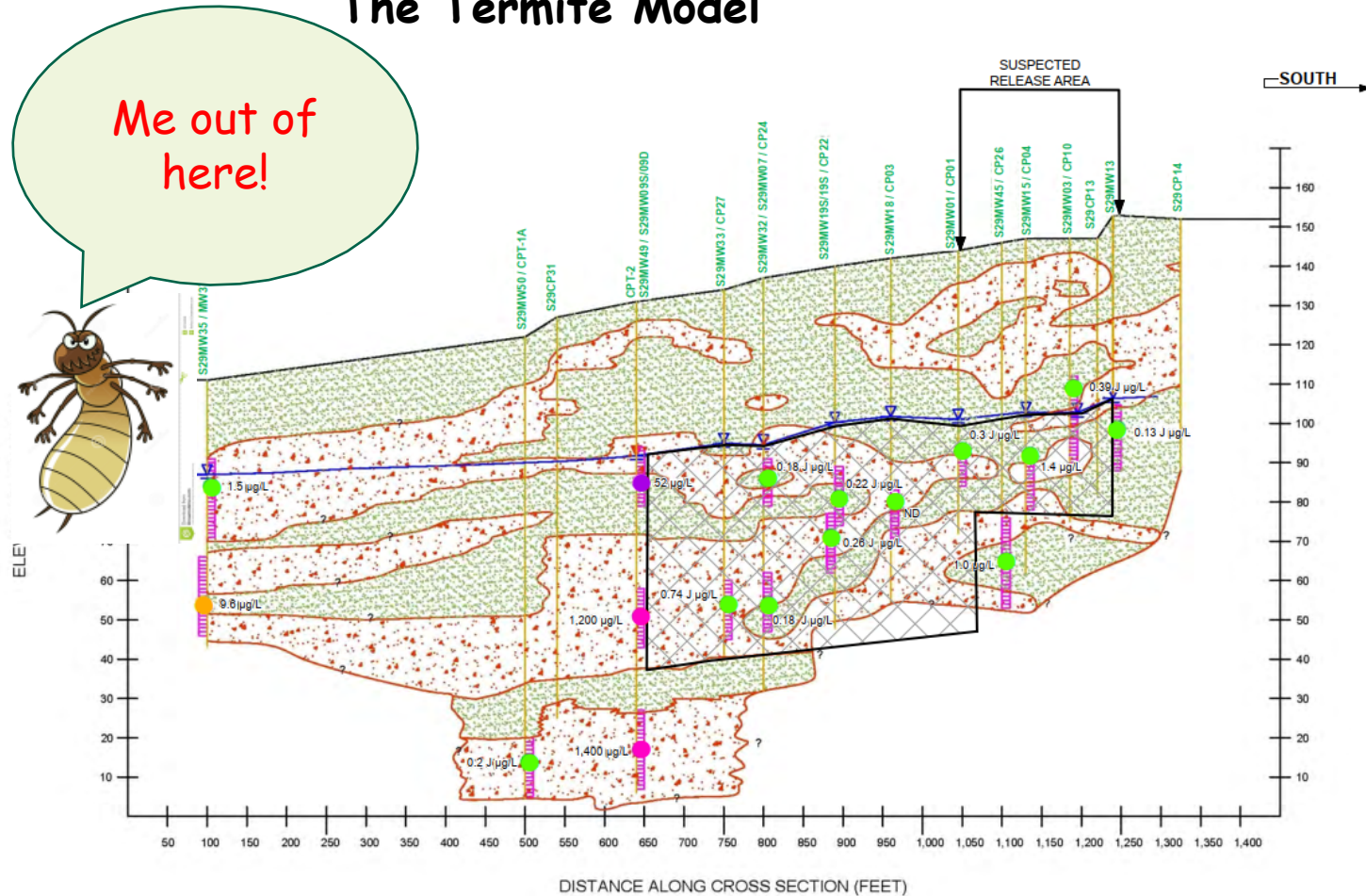
The kite Model



- ☐ 1917 (Bolshevik revolution)
- ☒ 2005 (Xbox 360 released)
- ☐ 1515 (High Renaissance)
- ☐ 549 AD (First paper kites in China)

Silent Quiz: Guess the Year!

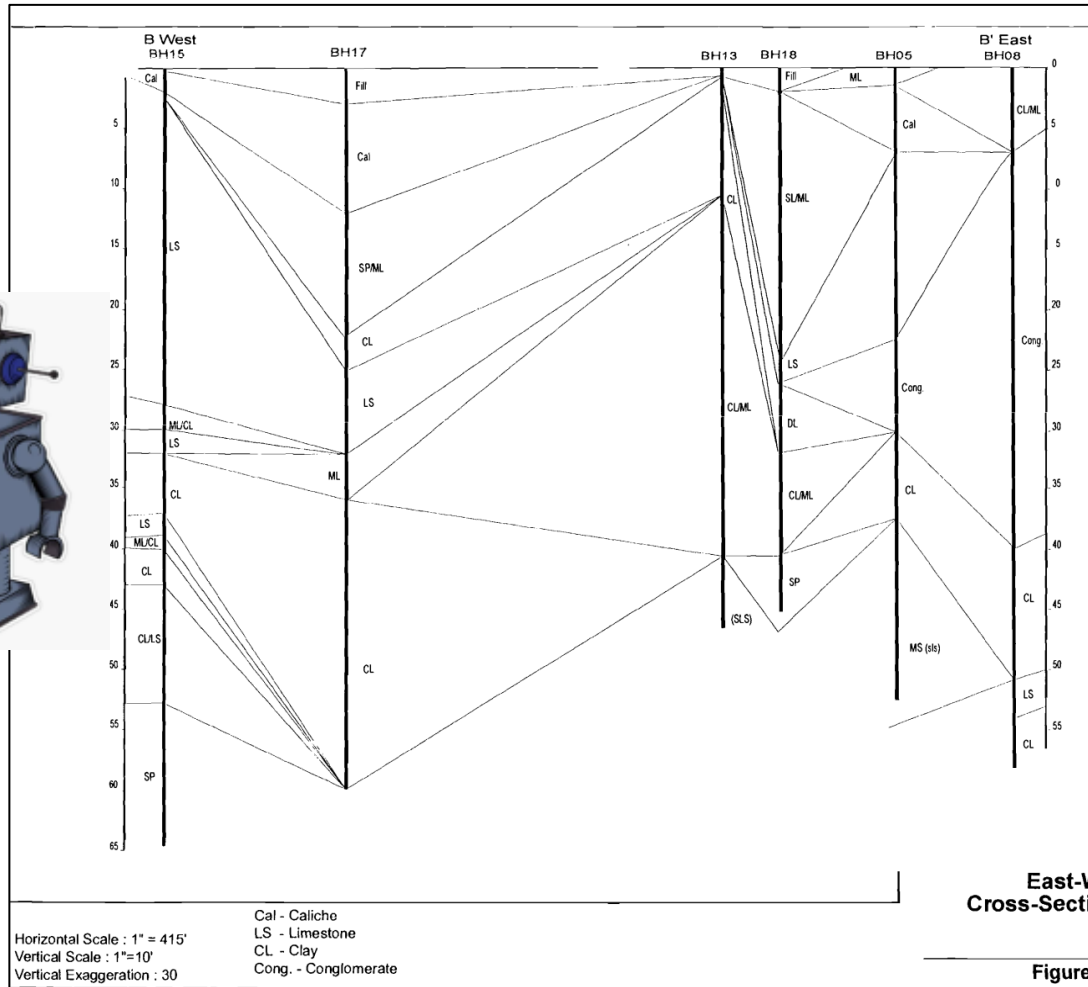
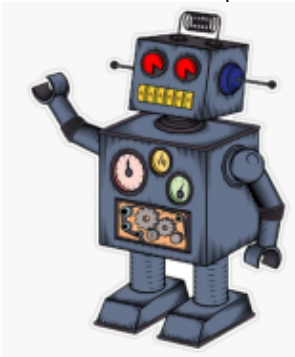
The Termite Model



- 2019 (England wins the World Cricket Cup)
- 1258 (Mongols conquer Baghdad)
- 1940 (Discovery of the Lascaux cave paintings in France)
- 1978 (The first seminal paper on termites)

Silent Quiz: Guess the Year!

The AI Model



- ☐ 1977 (The first sequence stratigraphy paper)
- ☐ 2009 (The Tesla Roadster is in the market)
- ☒ 2015 (The Rise of Deep Learning)
- ☐ 3025 (Aliens take over human civilization)

Why are our Cross Sections so Hopeless?

- Not sure why the stratigraphic correlation needs to be done (*it is simply for the beautification of tech-memo, no?*)
- Incomplete dataset (*most wells are less than 20ft deep, or the next well is 5 miles away*)
- Poor resolution of data (*it's all a blob of sand!*)
- No clear understanding of depositional environment (*“if it is sand, then it got be a channel”*)
- A lithostratigraphic approach (*“of course, sand matches with sand and clay matches with clay”*)
- No clue of correlation length (does this clay connect with that clay 5000ft away?)

Understanding your Site in Regional Context

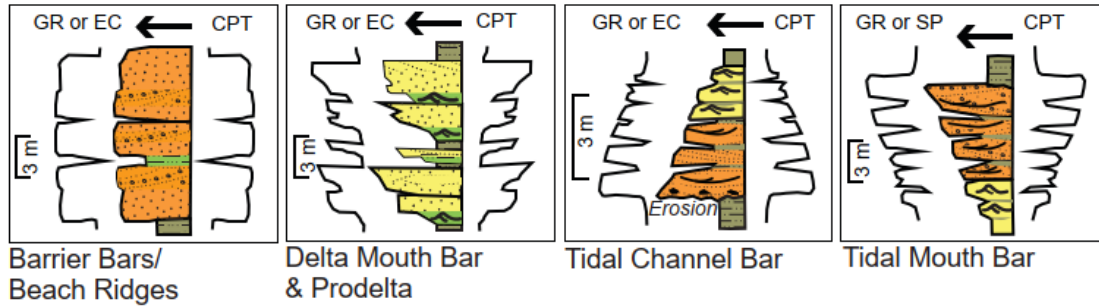


Mitchell River Delta, Northern Australia

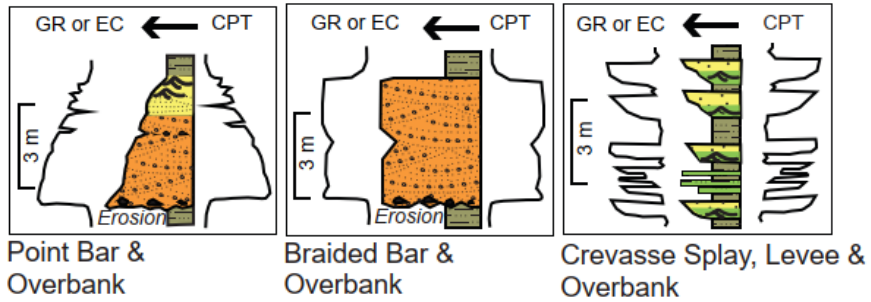
- Where do I see my site in the big picture?
- Is present the day geomorphology applicable to the subsurface interval of my interest?

Application of Facies Models

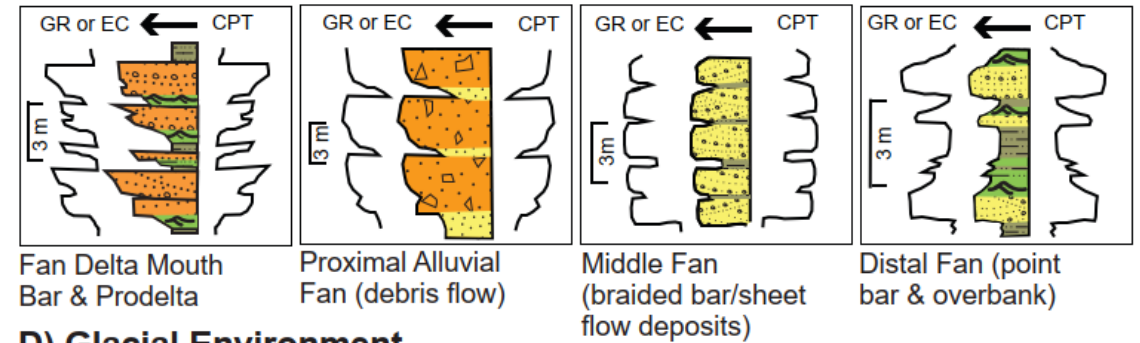
A) Coastal Environment



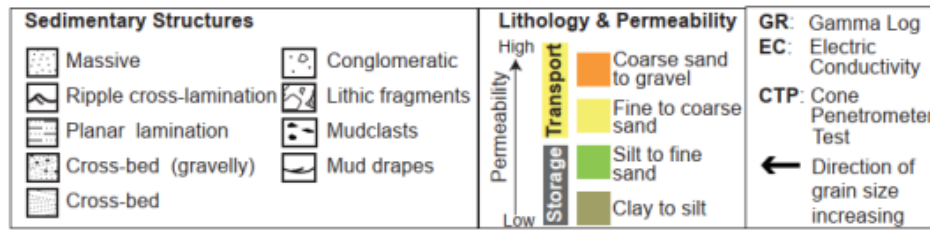
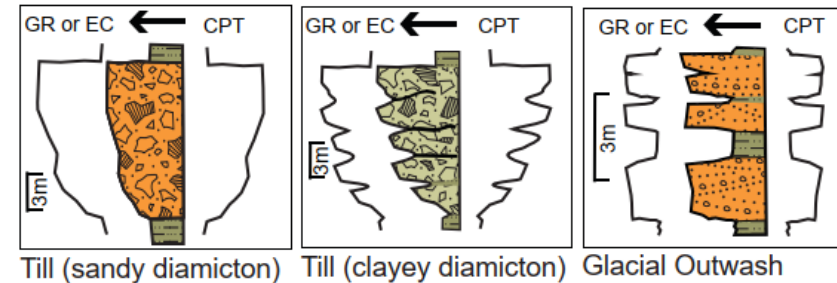
B) Fluvial Environment



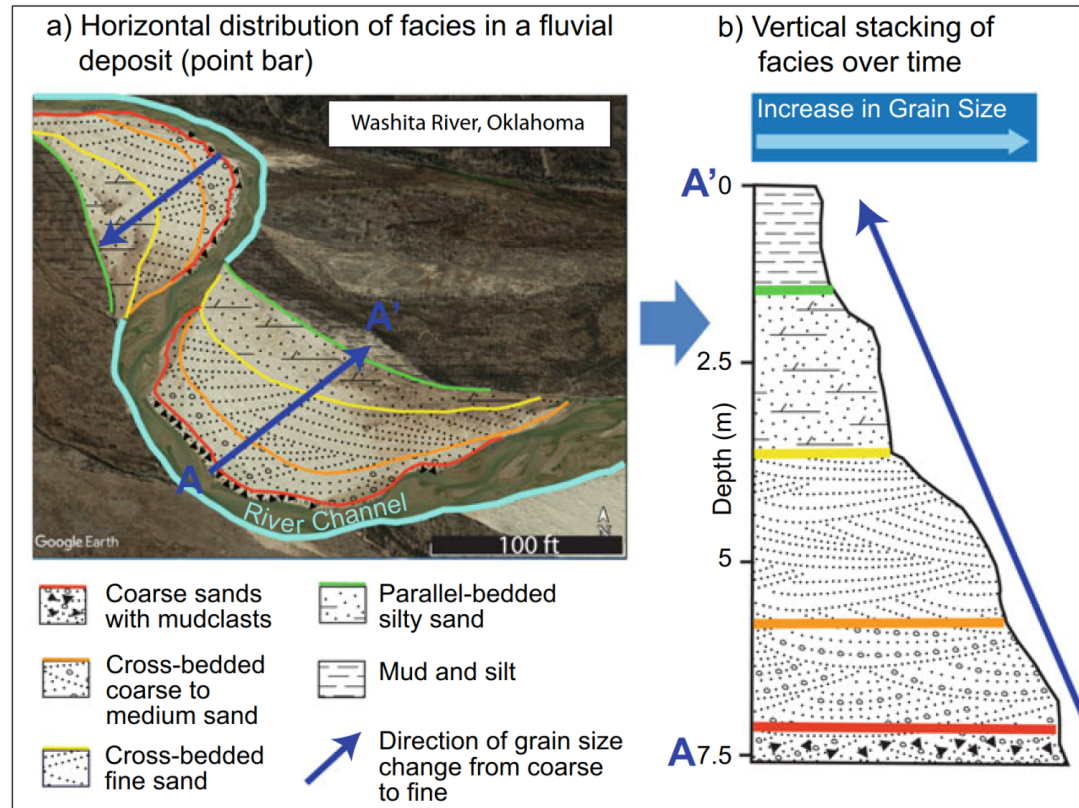
C) Alluvial Fan Environment



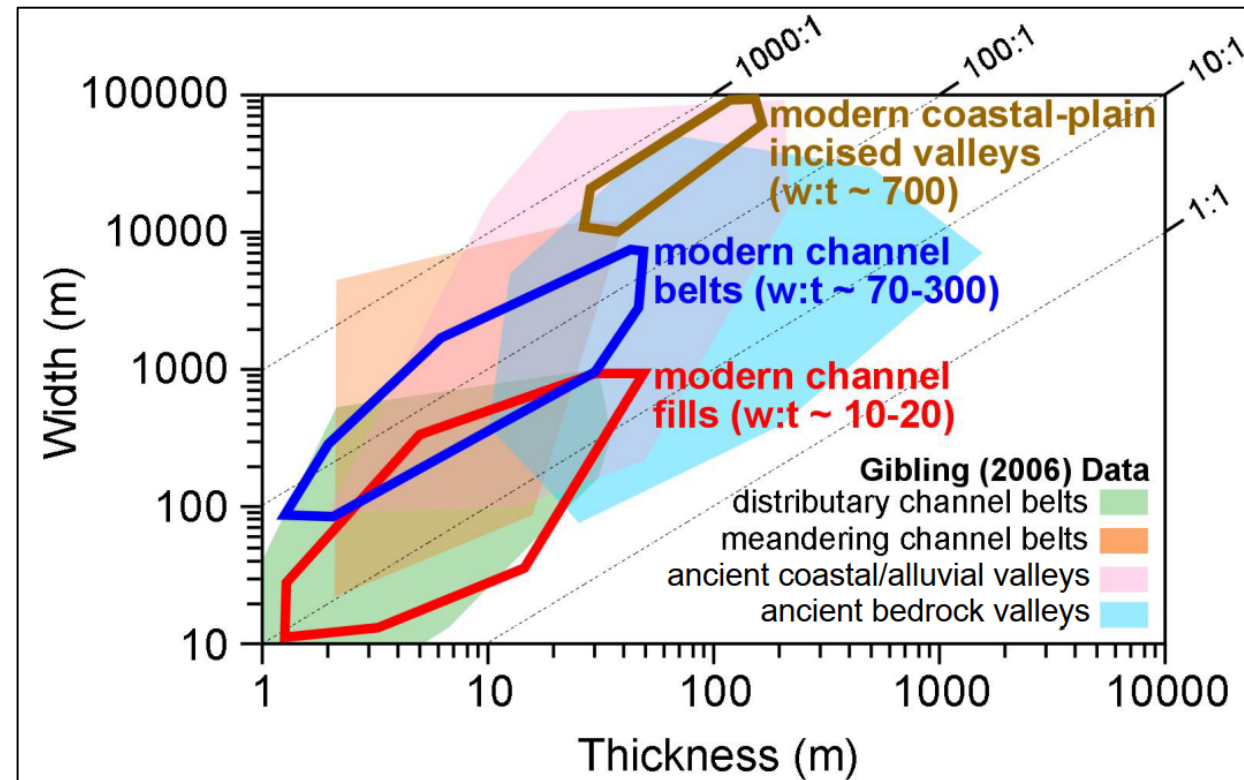
D) Glacial Environment



Relating Vertical Facies to Spatial Distribution

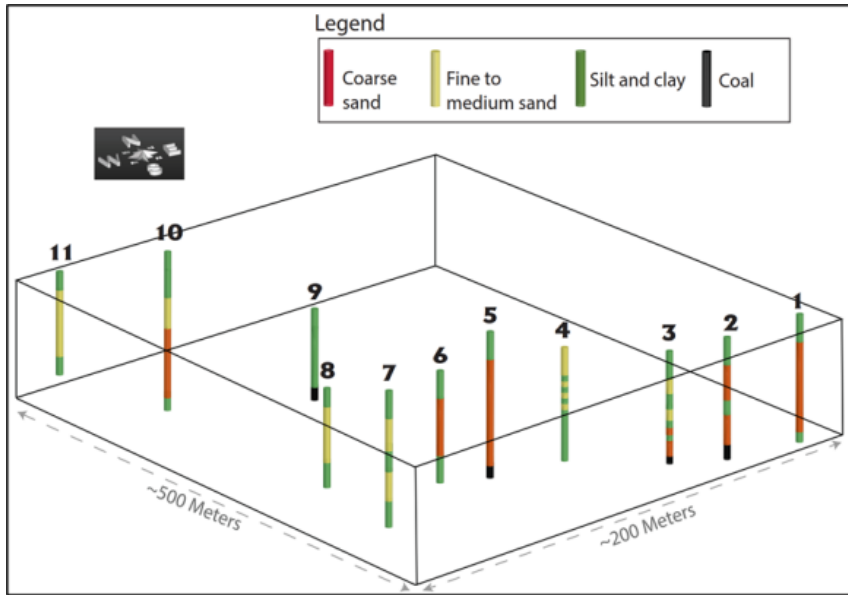


Applying the Walther's Law

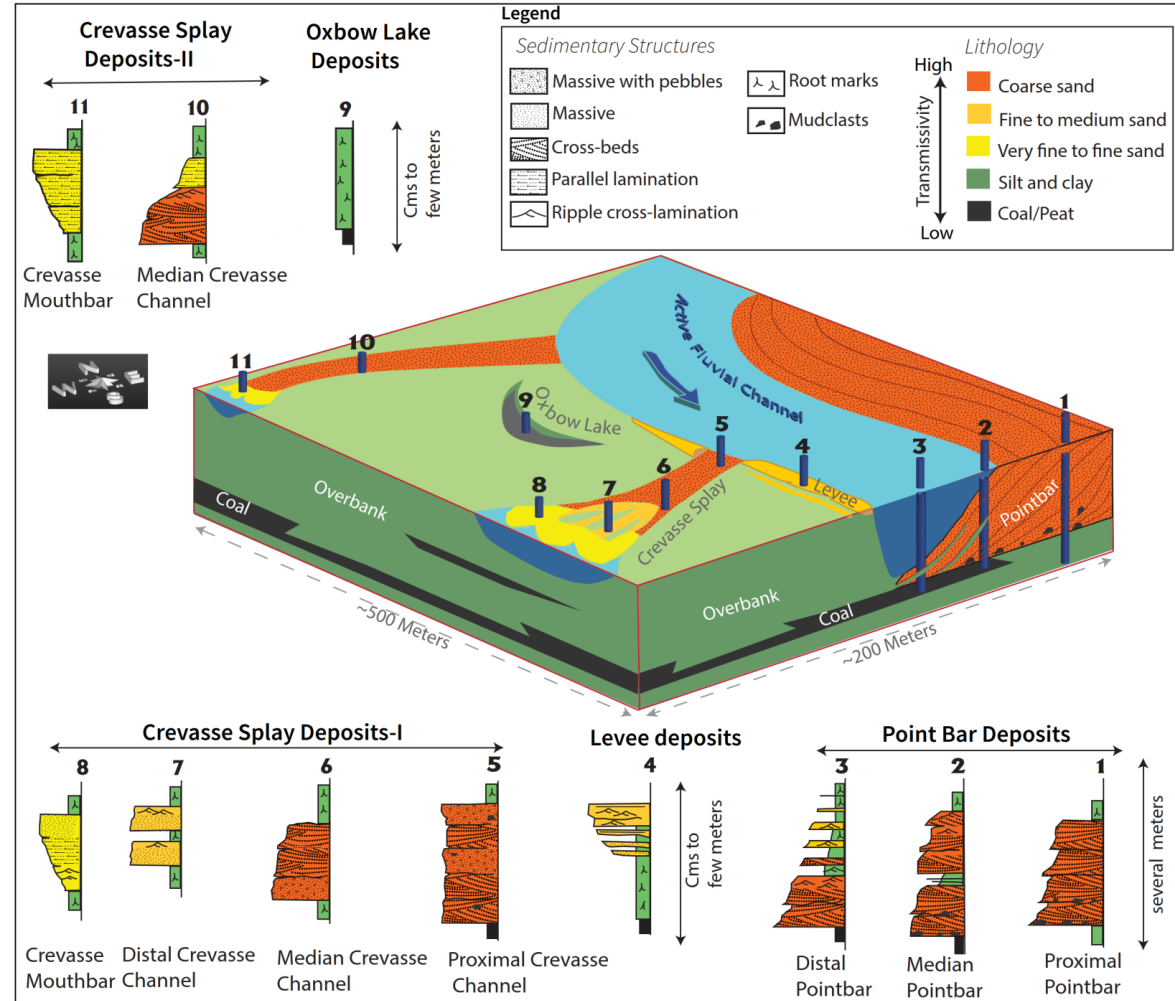


Consulting width-thickness ratios from outcrop studies

Application of 3-D Facies Models

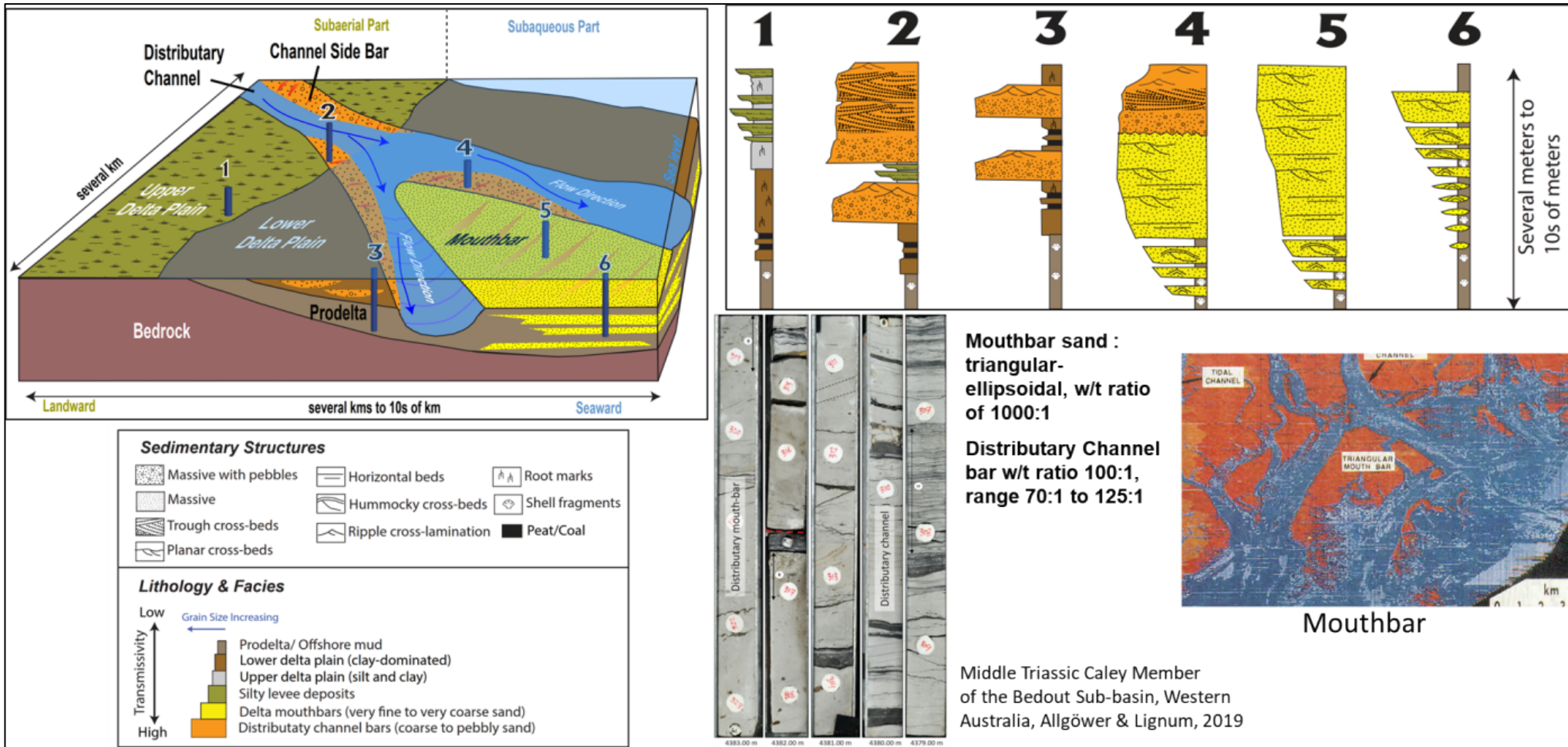


Depositional environments provide a predictable geologic framework for better understanding spatial relationship between boreholes.

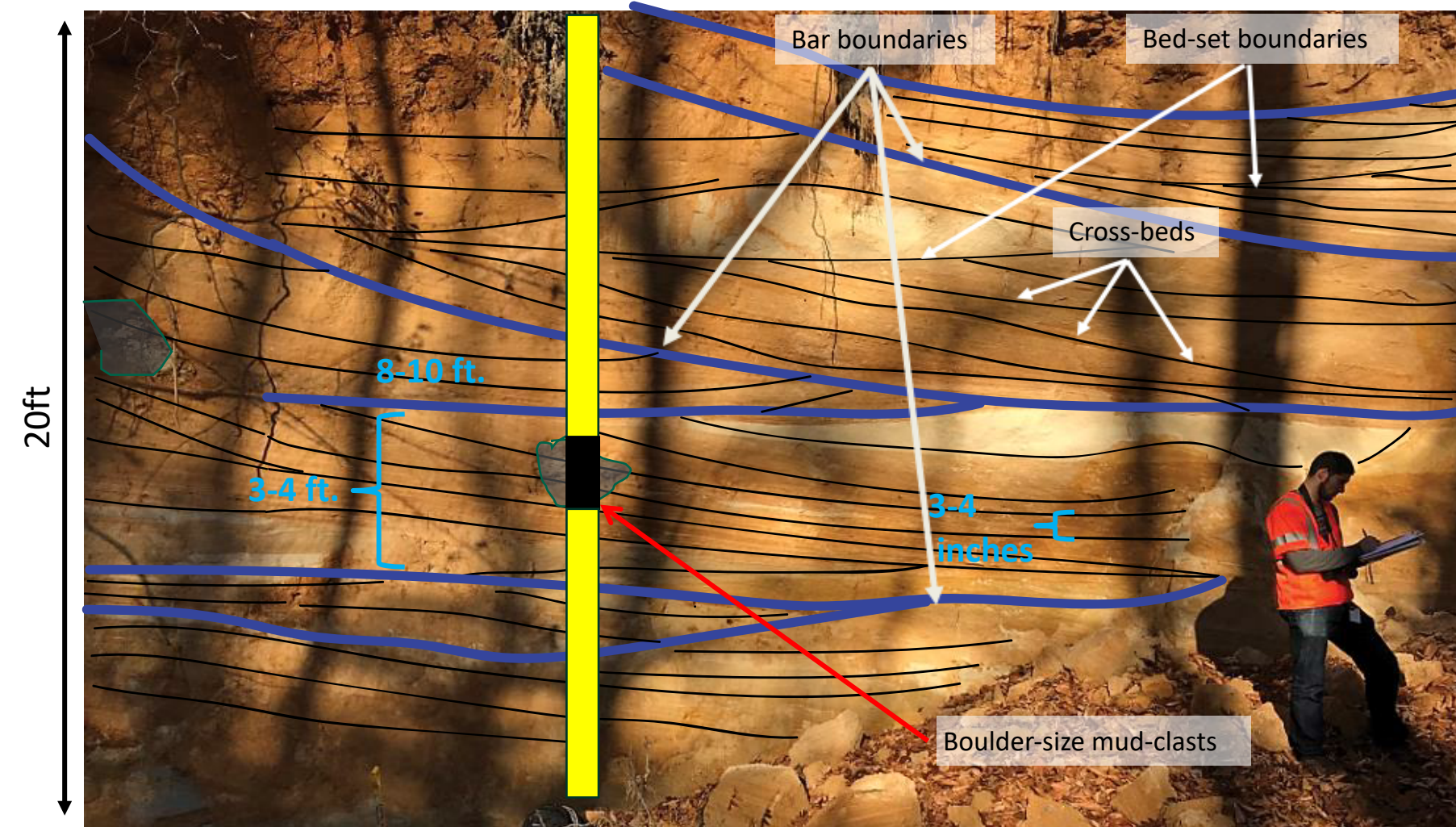


Application of 3-D Facies Models

Depositional environments provide a predictable geologic framework for better understanding spatial relationship between boreholes.



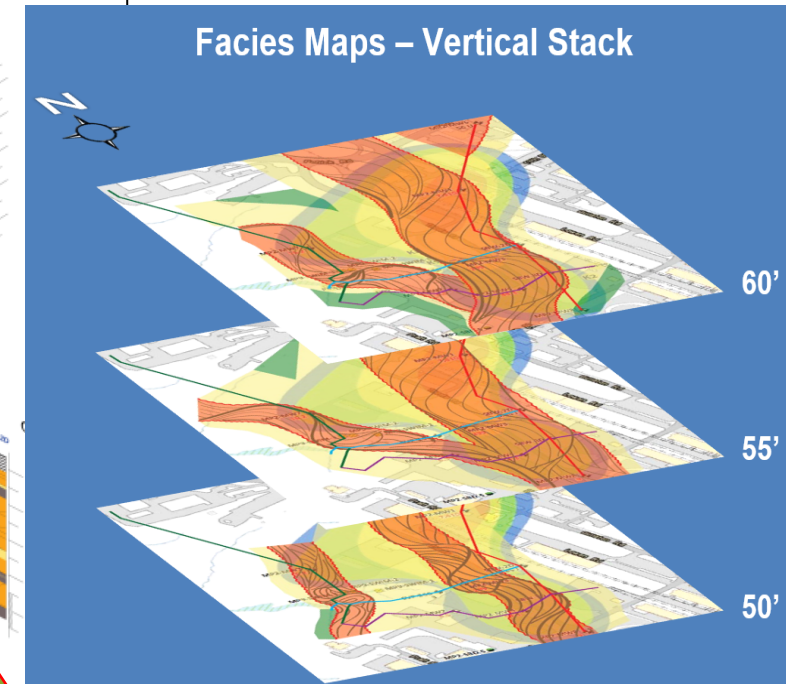
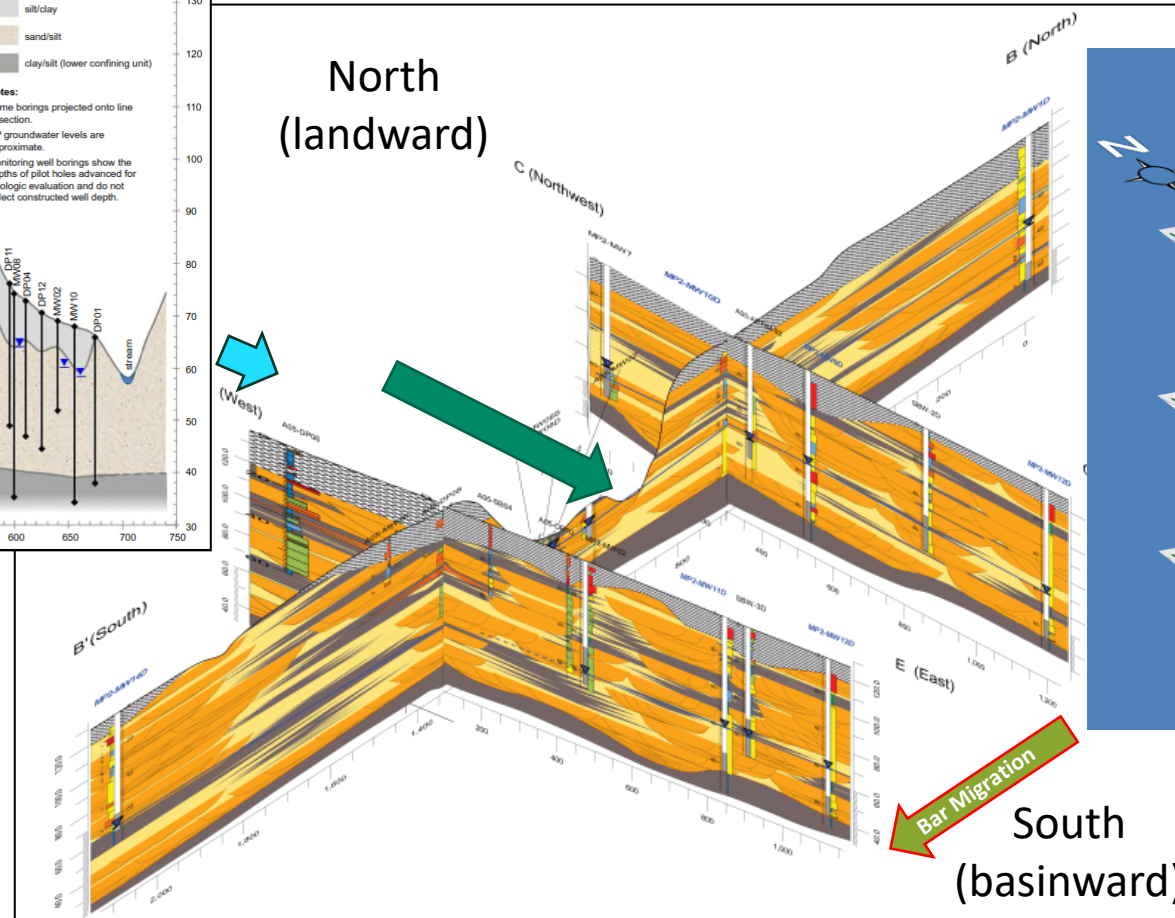
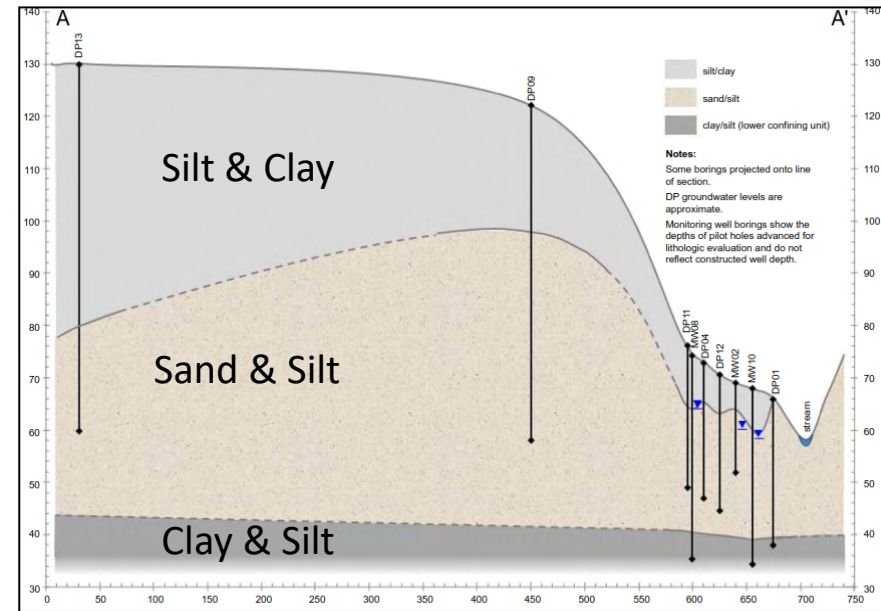
Site Outcrop as Correlation Data



Point Bar Deposits (Interpreted) from site outcrop

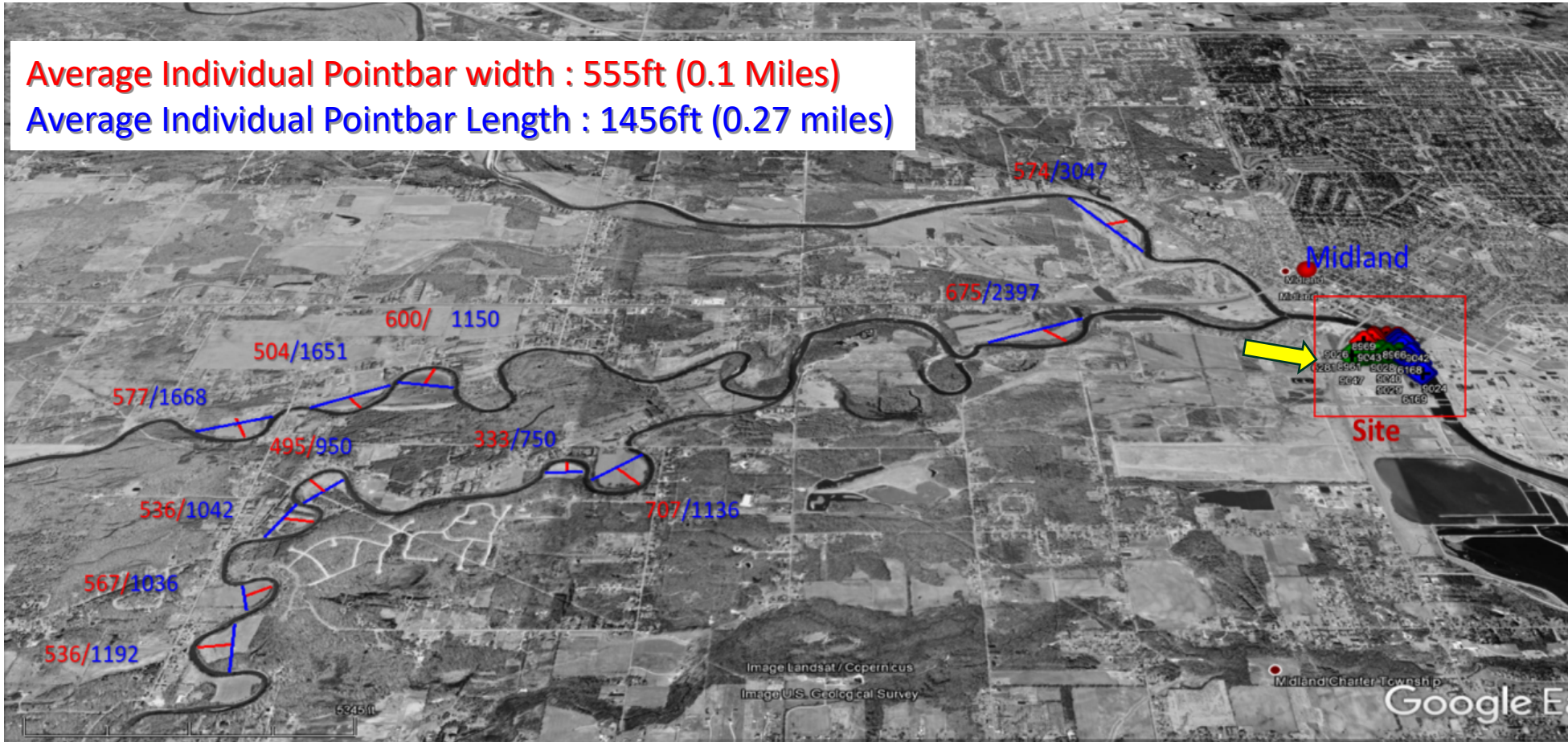
- Can my measurements be a proxy for valid data?
- What important lessons can be learned from the outcrop that is not reflected in the boreholes?

Site Outcrop as Correlation Data



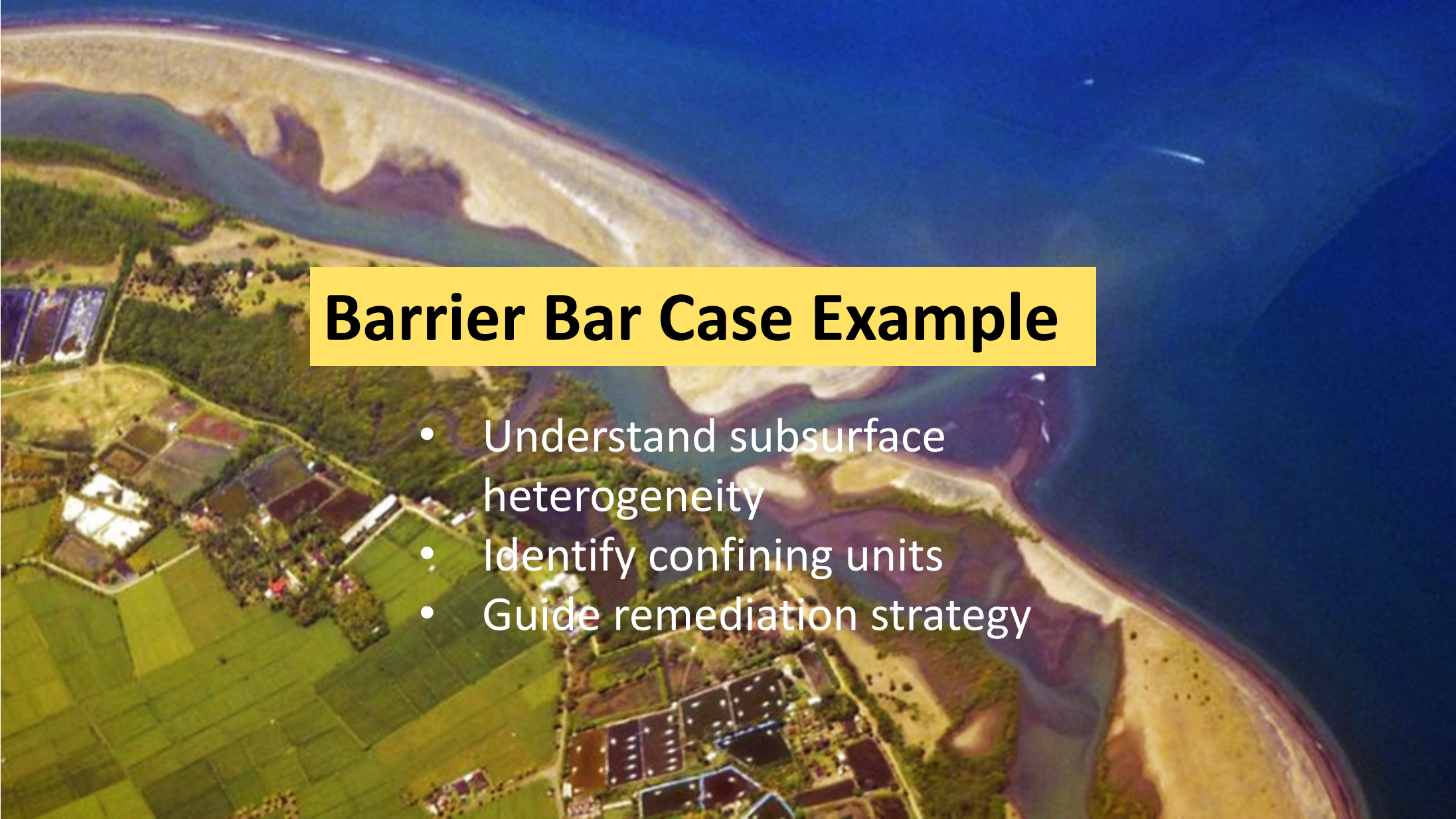
Present Site Geomorphology as Site Analog

Average Individual Pointbar width : 555ft (0.1 Miles)
Average Individual Pointbar Length : 1456ft (0.27 miles)



Often, the analog for a contaminated site is right there on the surface!*

*Small font disclaimer:
Check regional geological history to confirm no major change in depositional environment in the subsurface



Barrier Bar Case Example

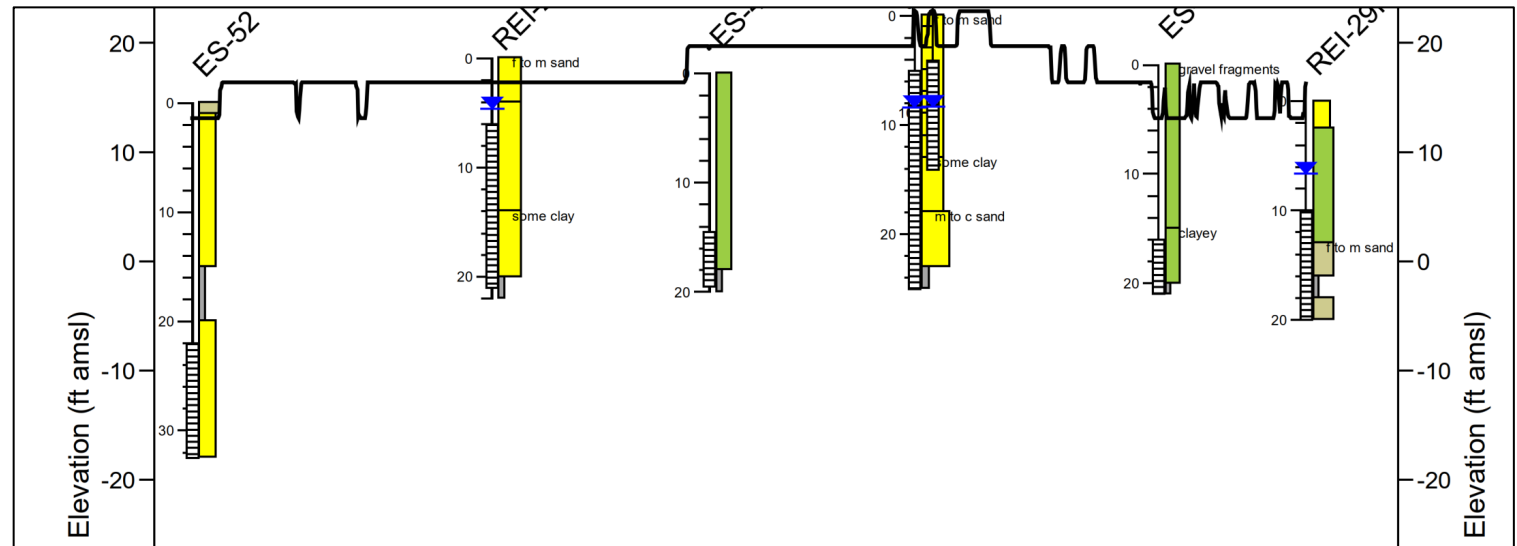
- Understand subsurface heterogeneity
- Identify confining units
- Guide remediation strategy

Dealing with Poor Lithologic Data

Barrier Bar Case Example



Site

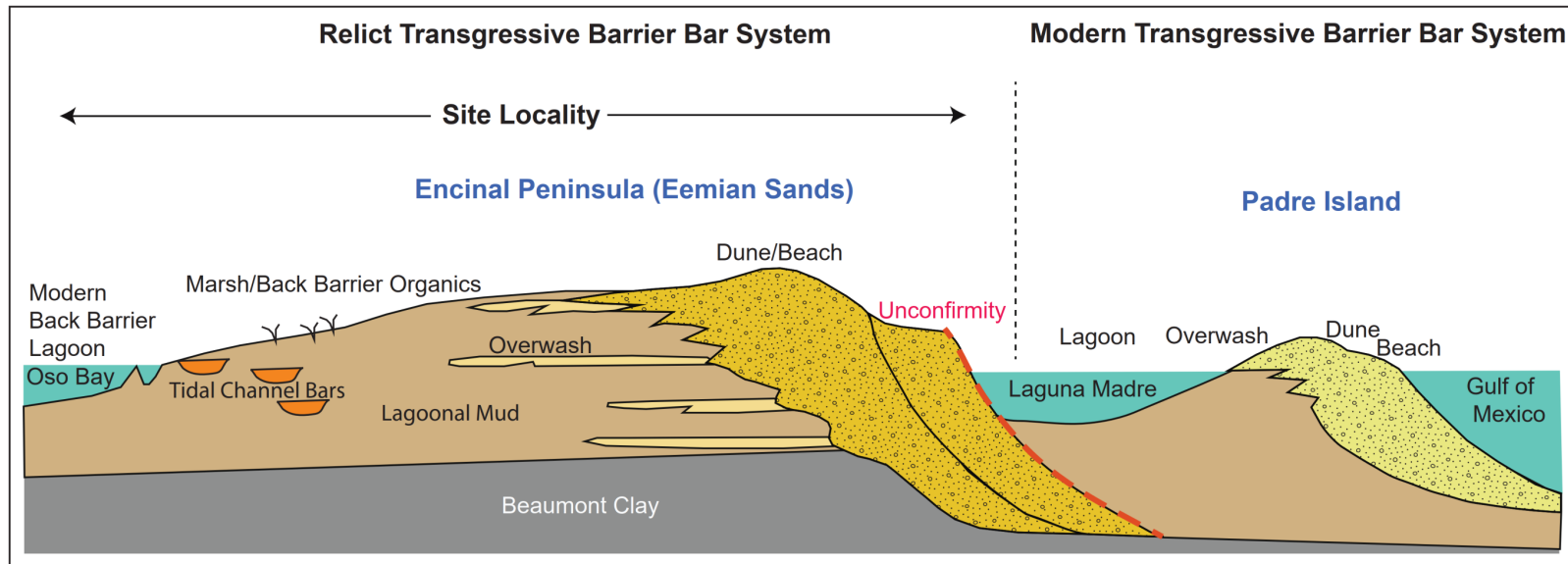


Example dataset

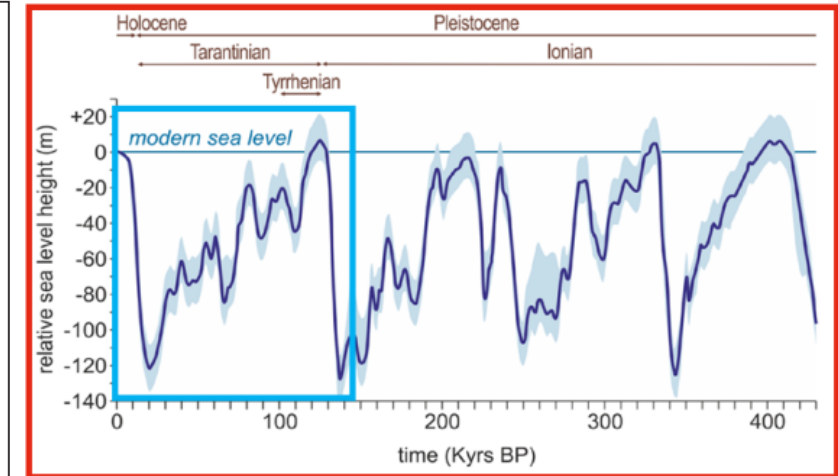
- Very poor resolution of facies changes in well lithology data
- Mostly shallow boreholes
- No geophysical logs available

Using Site Model for Understanding Heterogeneity

Barrier Bar Case Example



Regional depositional Model

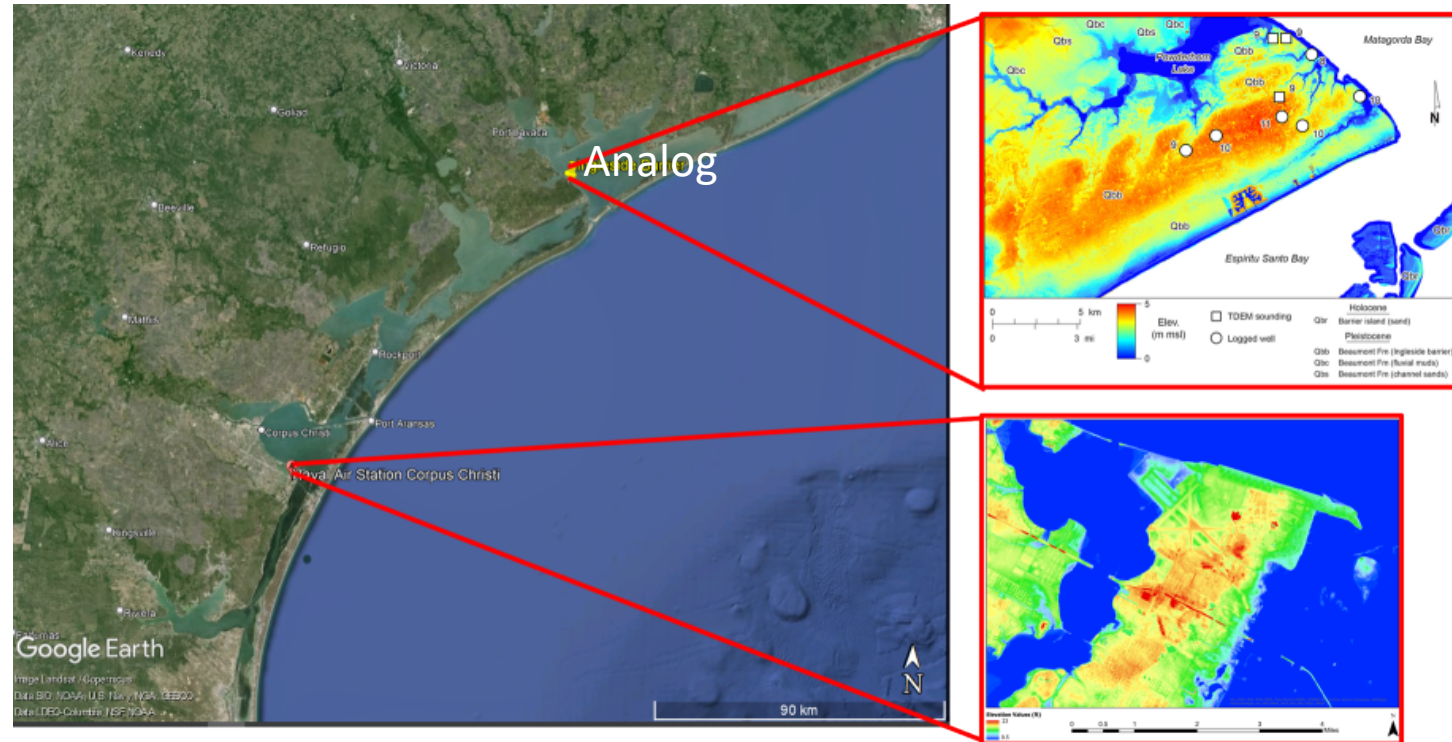
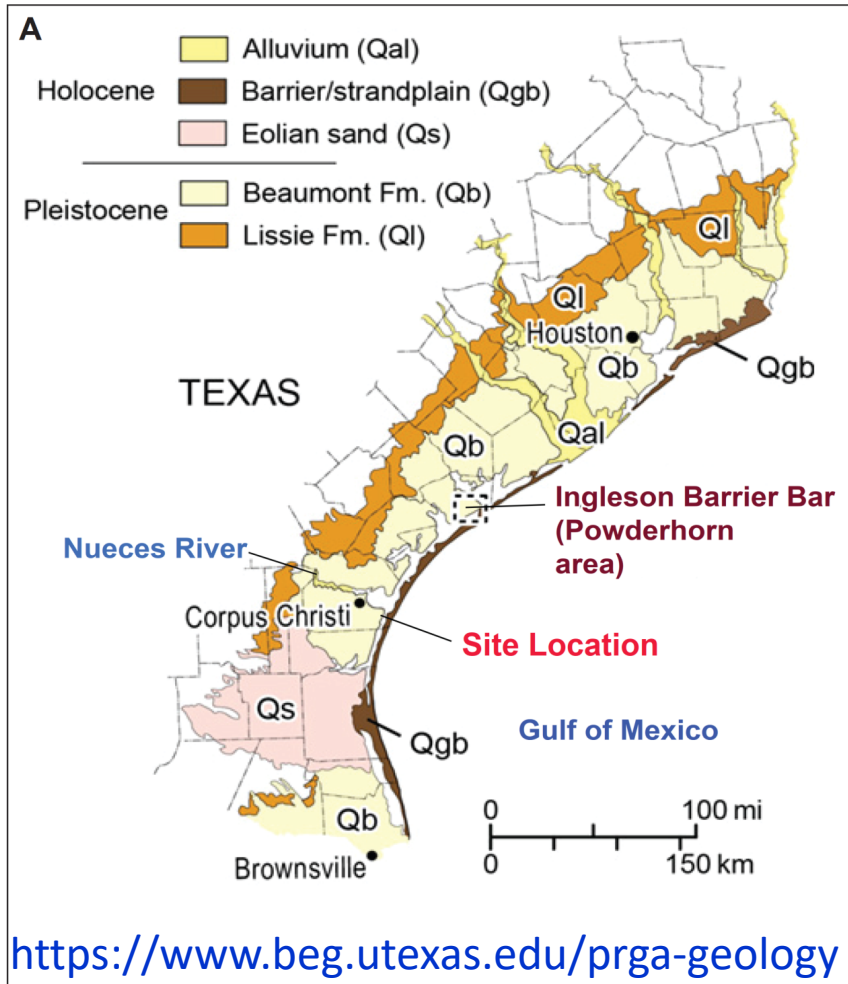


Quaternary sea level changes

Late Quaternary sea-level curve based on Wright (2000), Waelbroeck et al. (2002), and Peltier (2005)

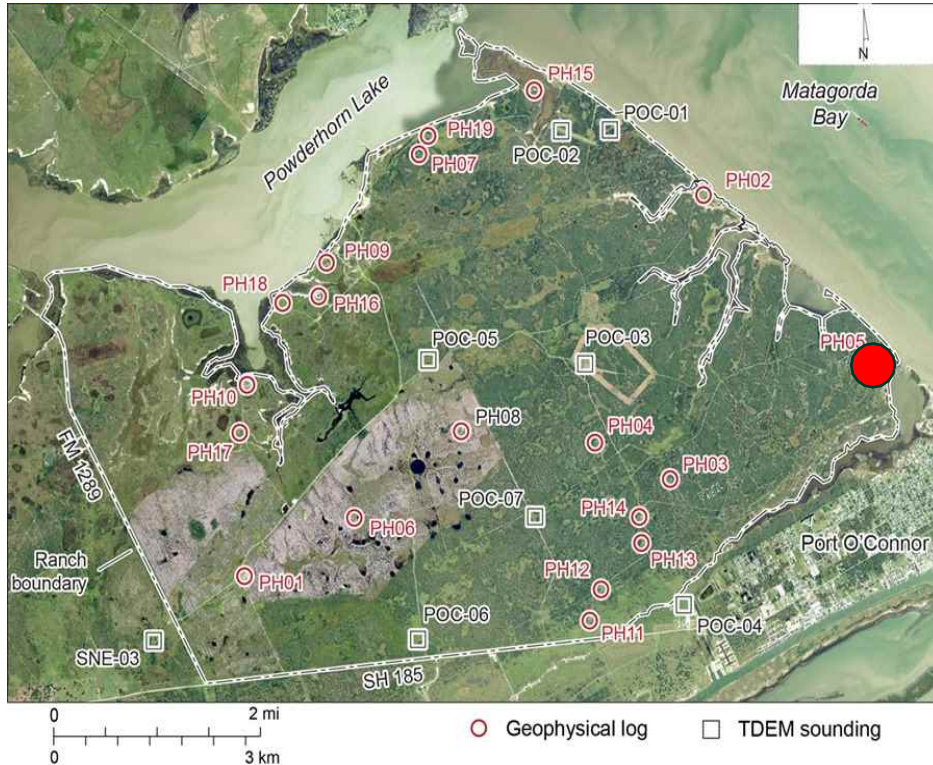
Identifying a Regional Analog

Barrier Bar Case Example



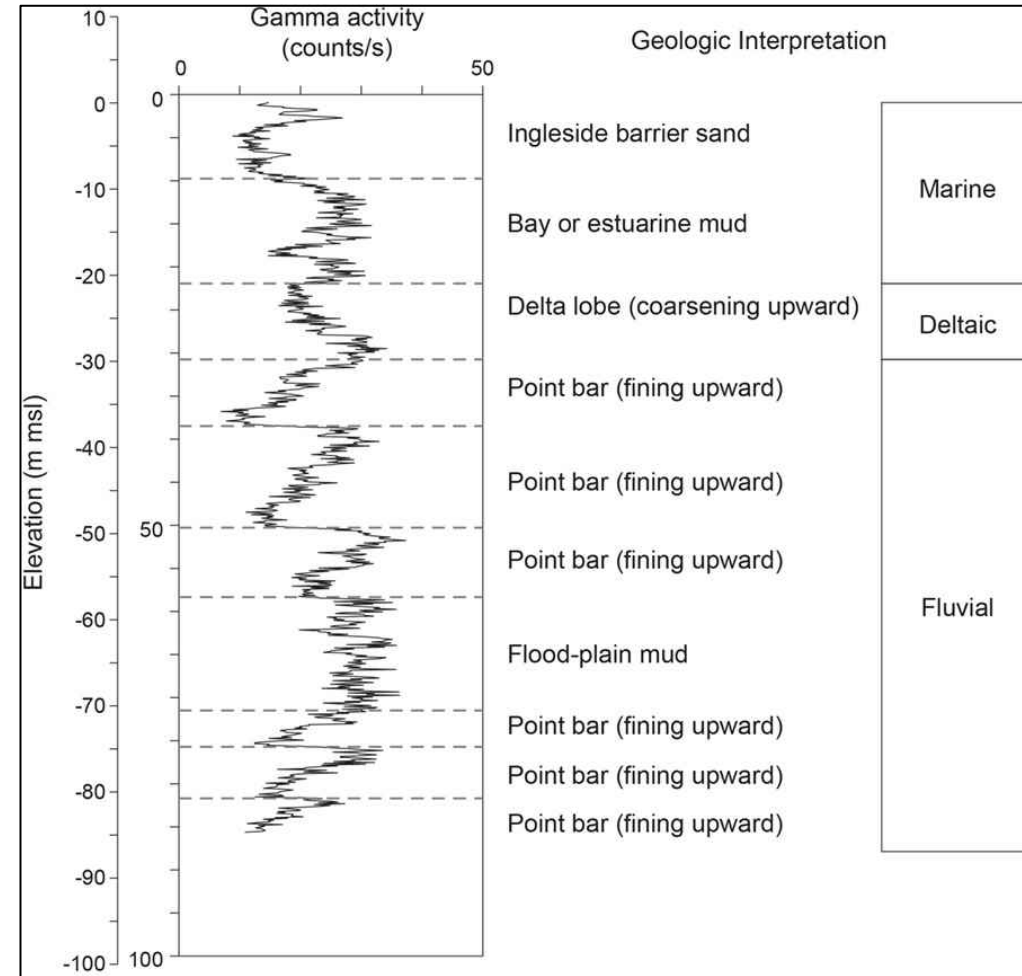
The analog is more than 100 miles north of the site. But both belong to the Ingleside Barrier Islands of South Texas, and show similar settings

Using Facies Information from the Regional Analog



● Borehole location at analog site

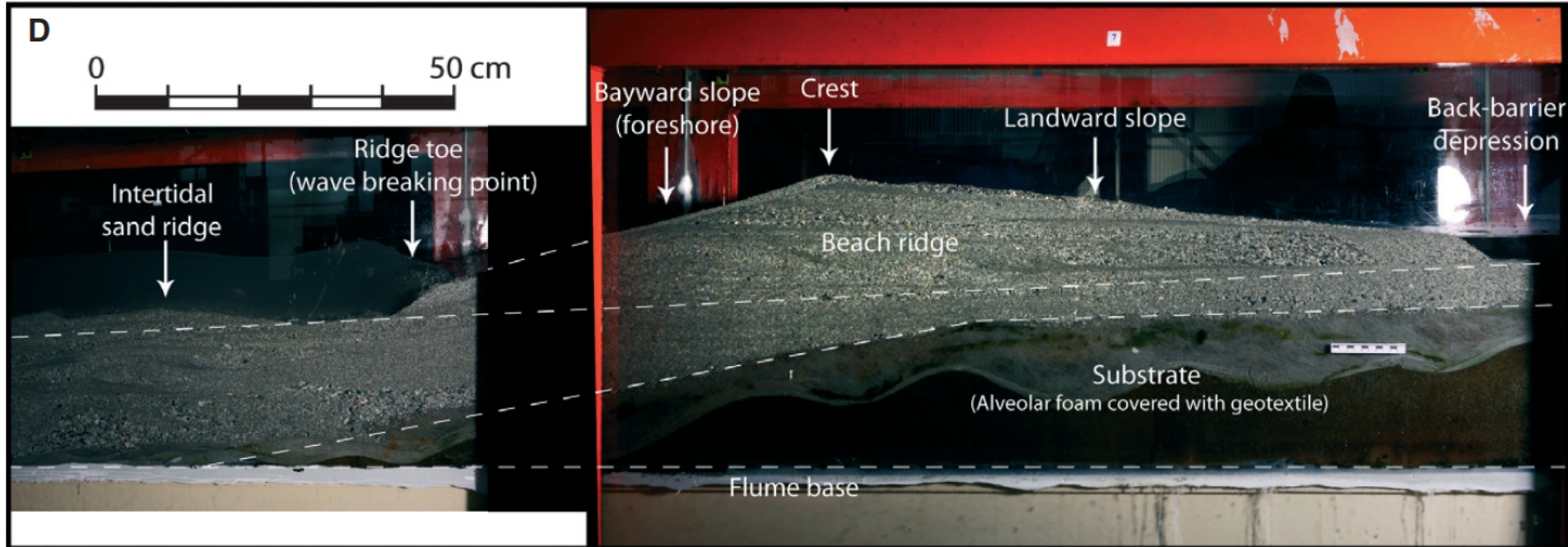
<https://www.beg.utexas.edu/prga-geology>



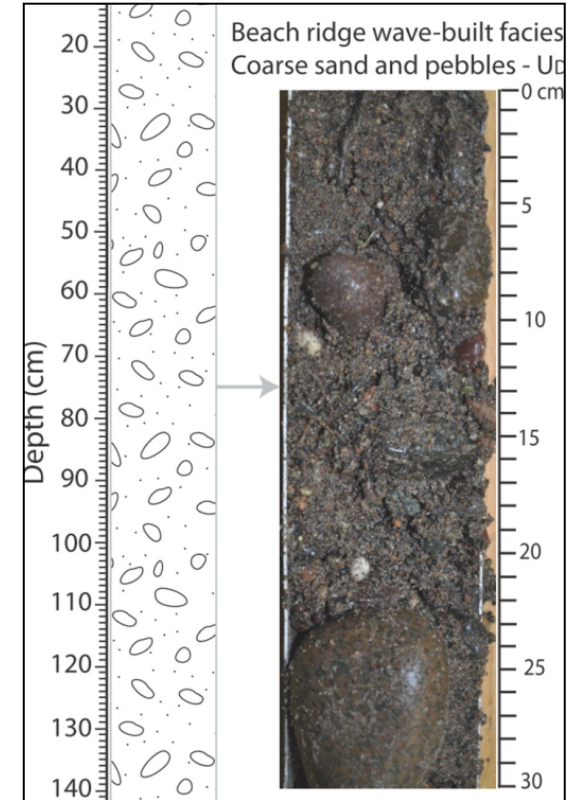
Gamma log interpretation at the borehole

Understanding Barrier Bar Ridges from Research

Barrier Bar Case Example



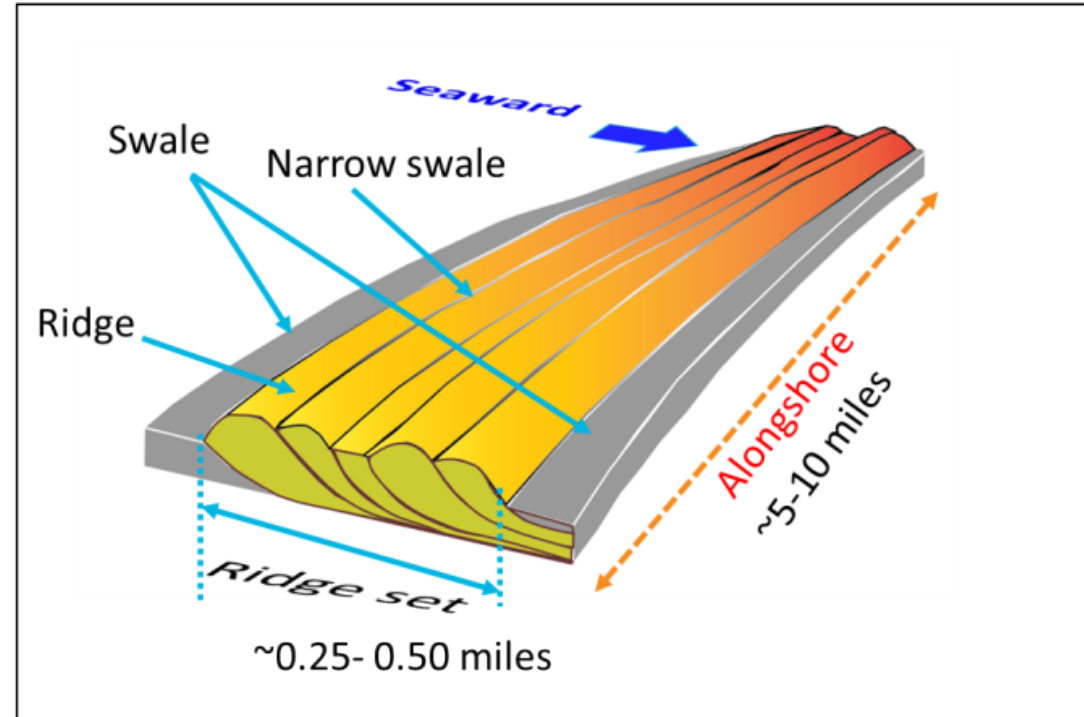
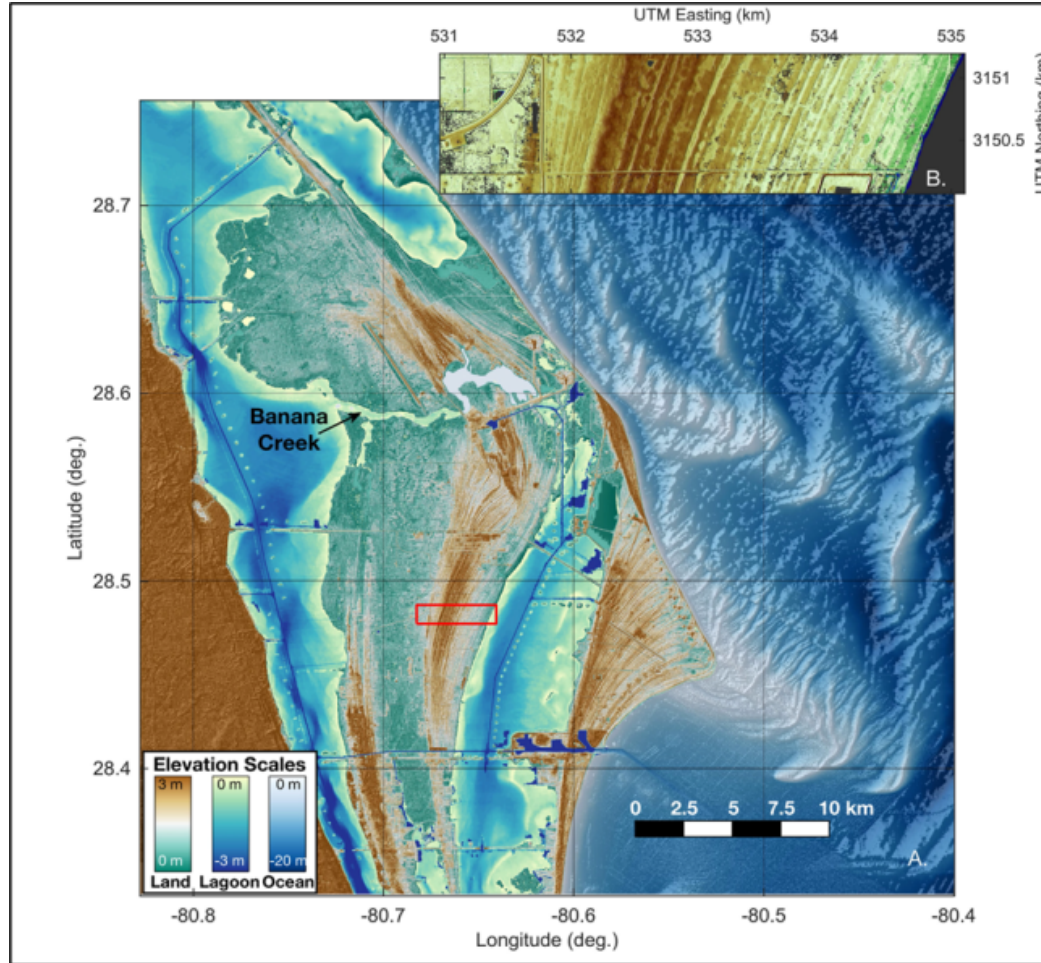
Lab flume experiment showing stratigraphic features of beach Ridges



Mostly coarse to medium sand, with shell fragments

Barrier Bars in Modern Geomorphological Analogs

Barrier Bar Case Example



- Ridges are shore-parallel sand dominated high-k units with good lateral continuity
- Swales are depressions (wetlands subject to tide) between ridges and ridge sets.

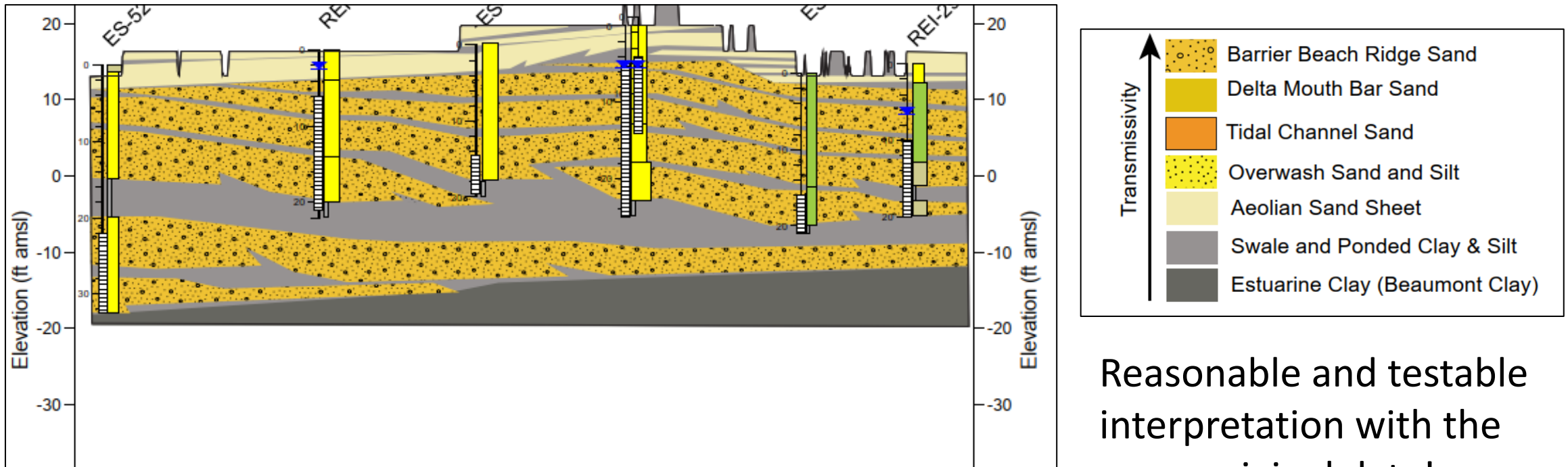
NOAA Digital Coast website: <https://coast.noaa.gov/dataregistry/search/collection>).

Better Correlation using Site Model and Analog

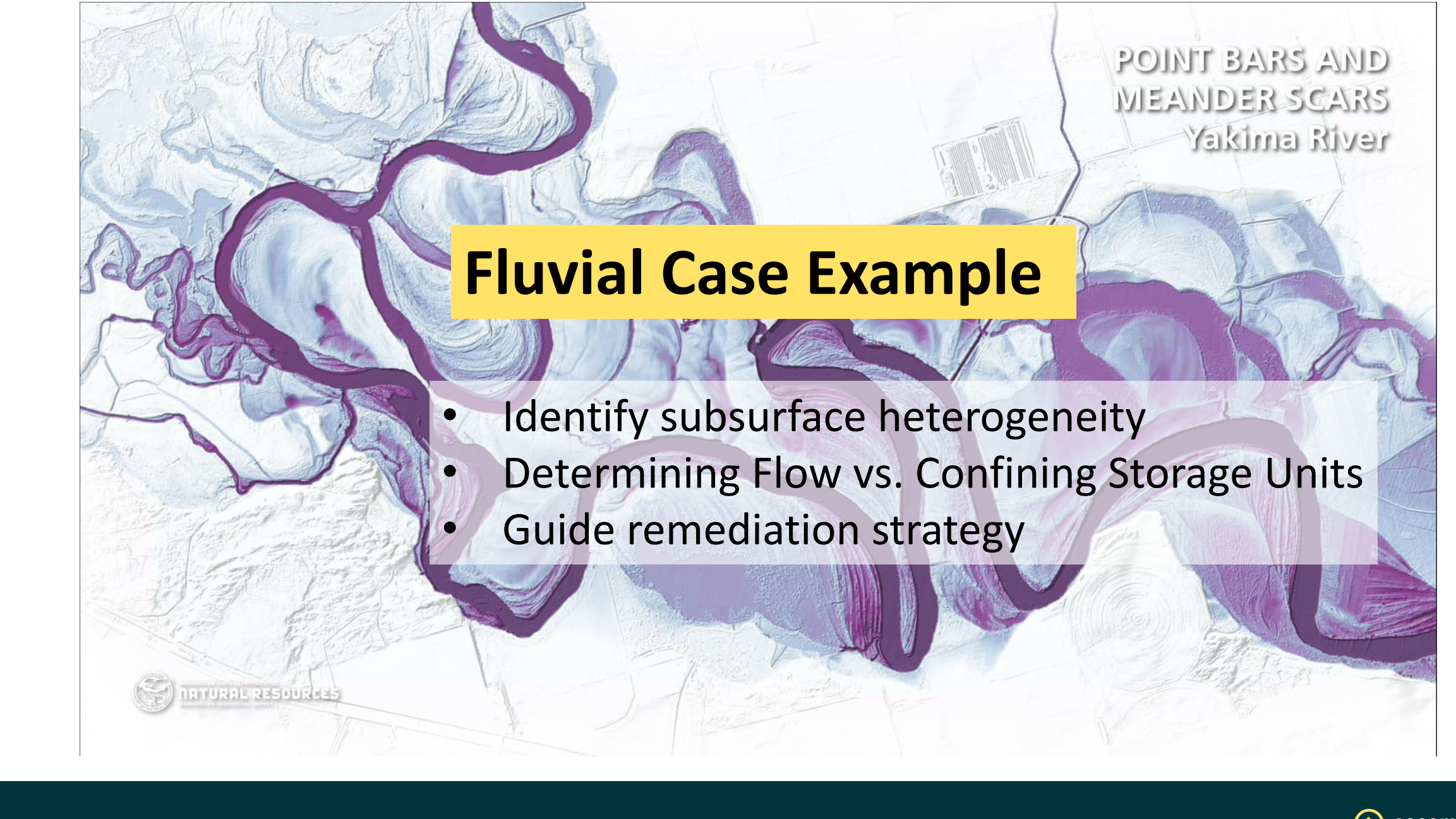
Barrier Bar Case Example

Landward

Bay-ward



Reasonable and testable interpretation with the same original data!



POINT BARS AND
MEANDER SCARS
Yakima River

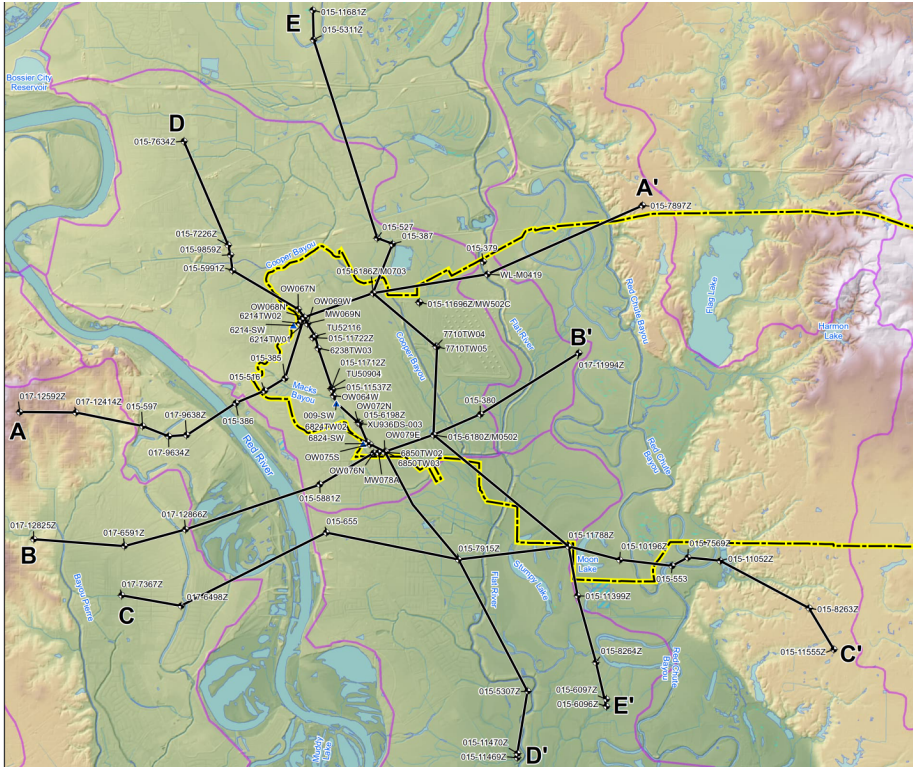
Fluvial Case Example

- Identify subsurface heterogeneity
- Determining Flow vs. Confining Storage Units
- Guide remediation strategy

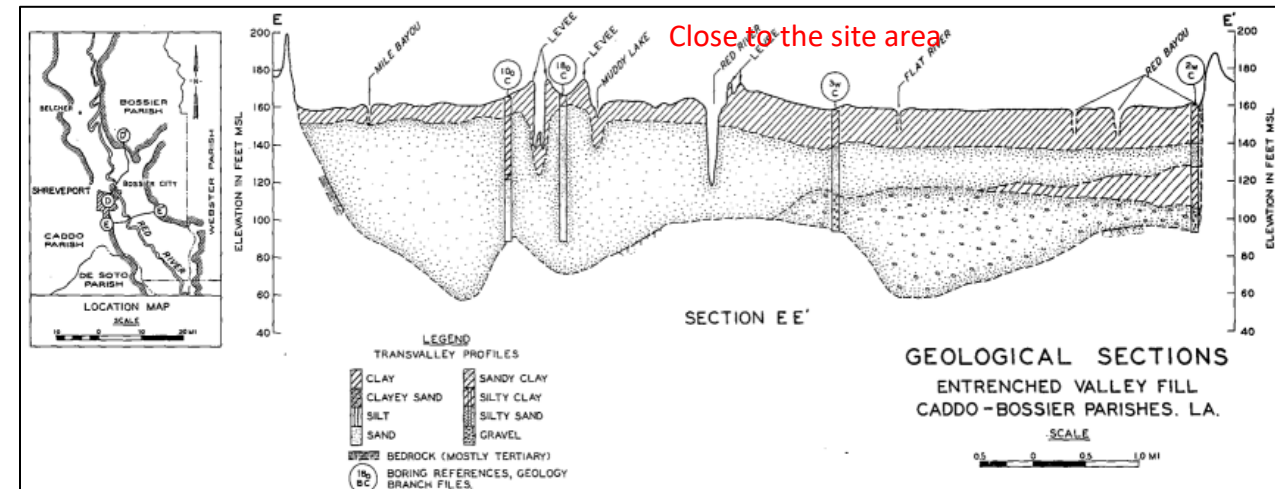


Dealing with Poor Lithologic Data

Fluvial Case Example



Proposed cross section map based on “best” lithologic data and areas of concern

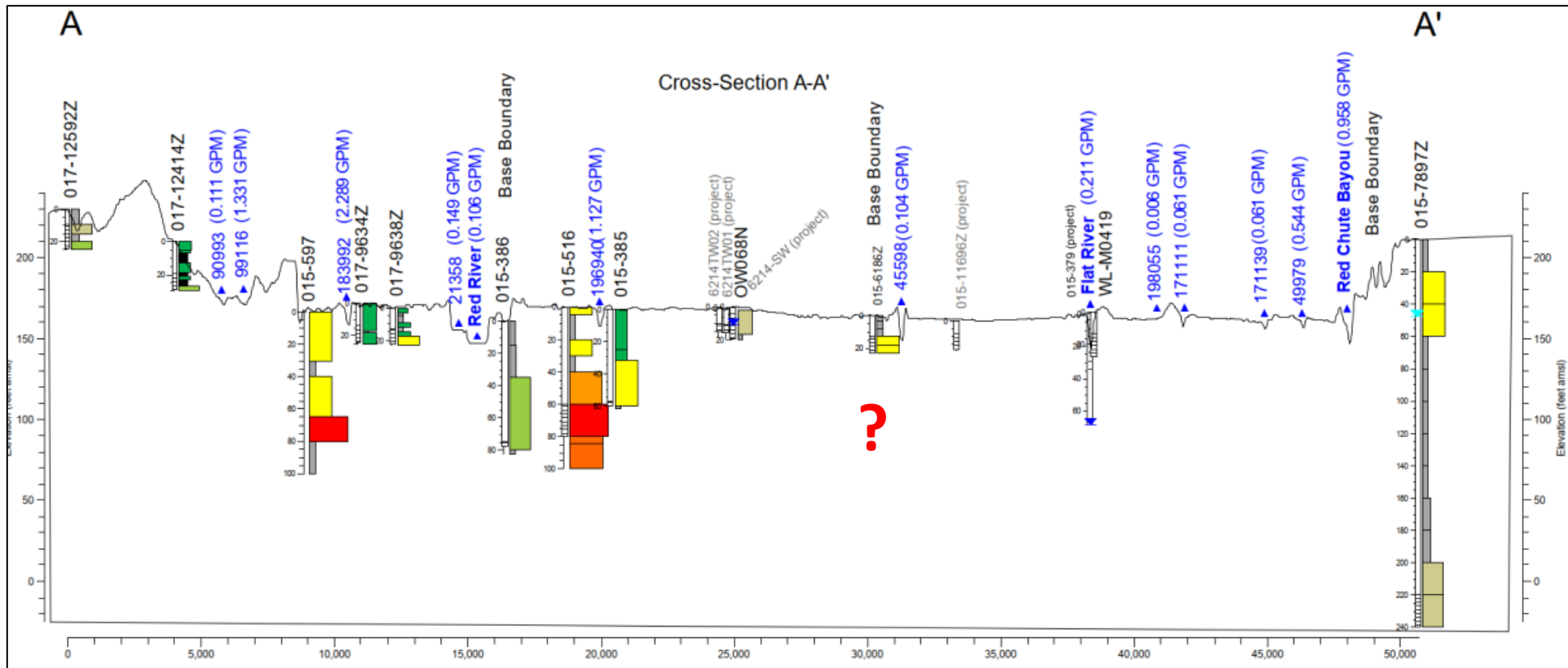


Previous cross section example

From Geology of Red River, Corps of Engineers, US Army (Dr. H. N. Fisk), 1950

Dealing with Poor Lithologic Data

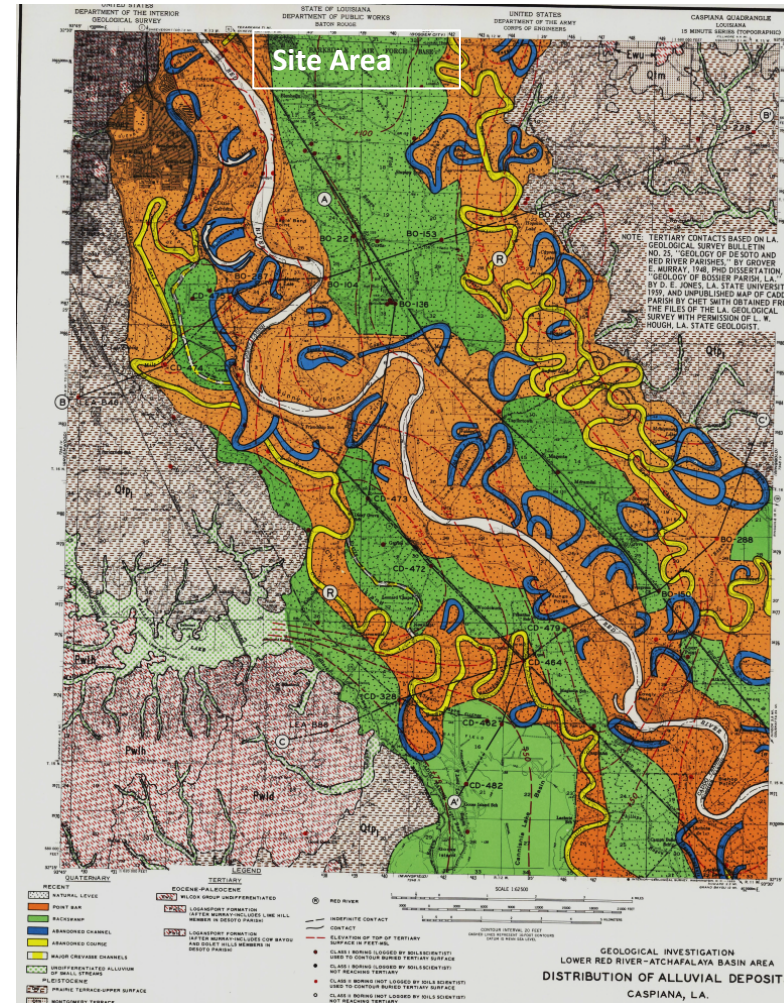
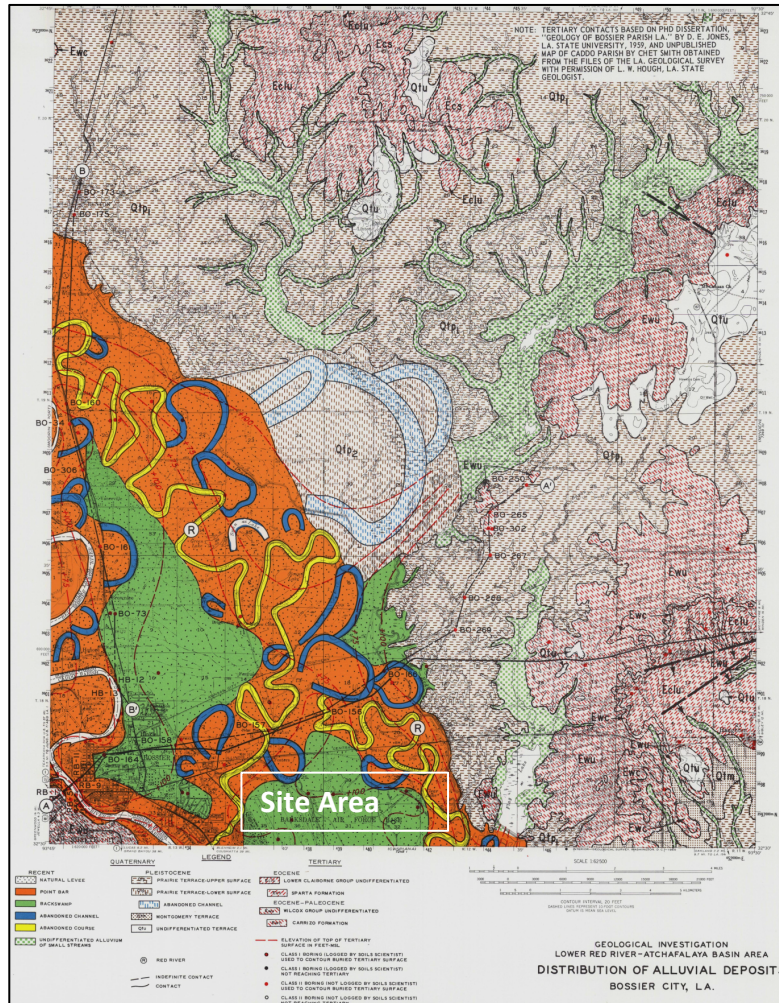
Fluvial Case Example



- Poor quality of dataset
- Major data gap, vertically and spatially!
- No geophysical log

Document Research for Regional Understanding

Fluvial Case Example



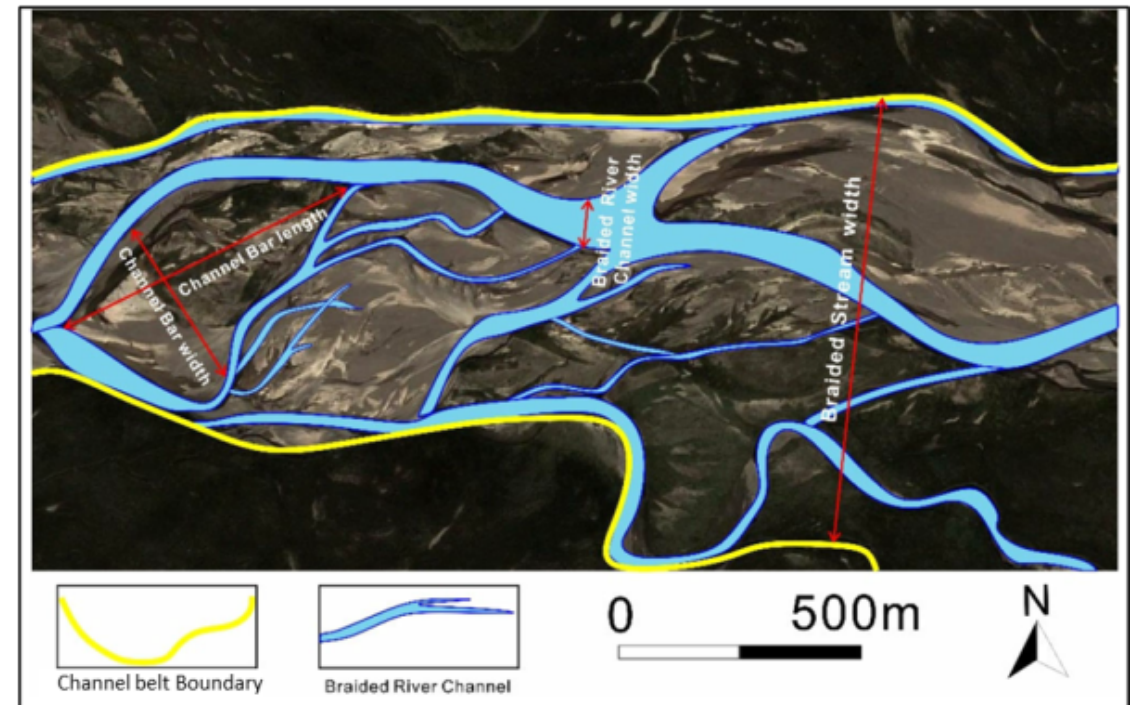
Technical Report S-74-5 - Geological Investigation Of The Lower Red River-Atchafalaya Basin Area,
Smith and Russ, 1974

What is a Channel Belt?

Fluvial Case Example



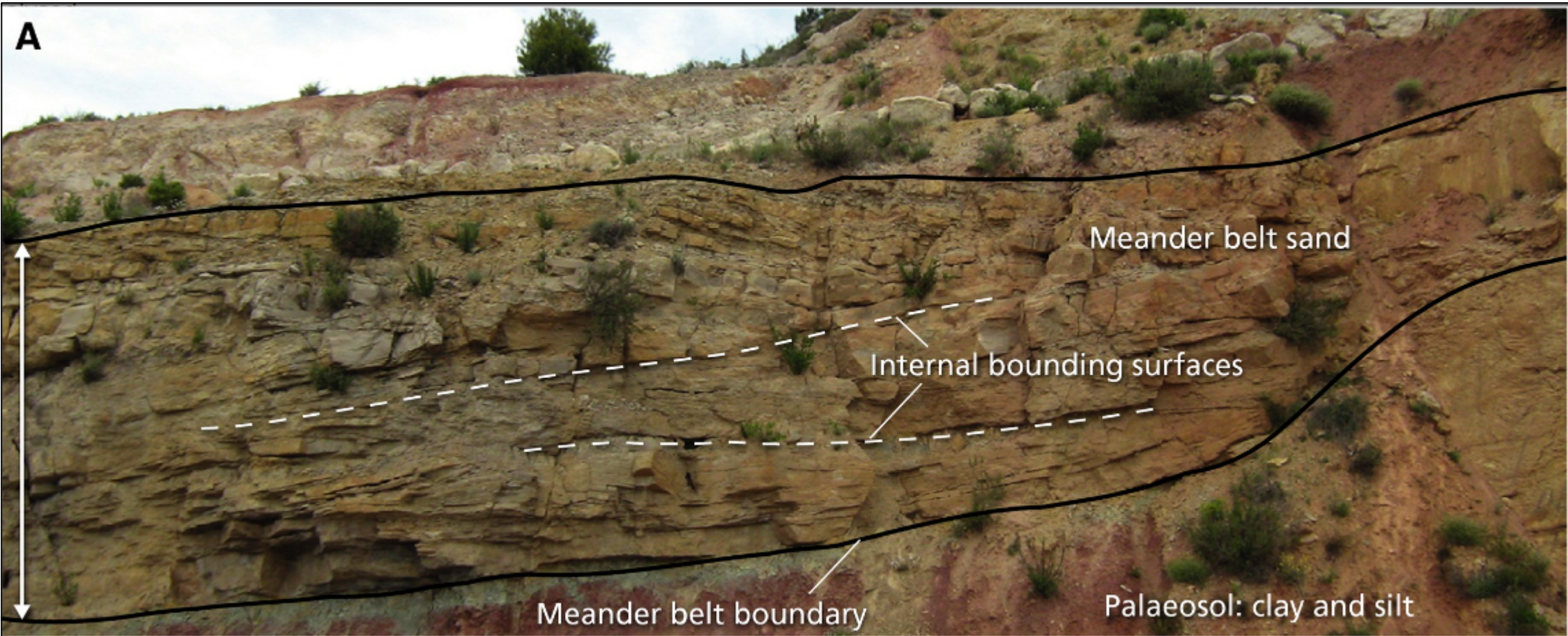
Modern Meandering River Channel Belt



Modern Braided River Channel Belt

What is a Channel Belt?

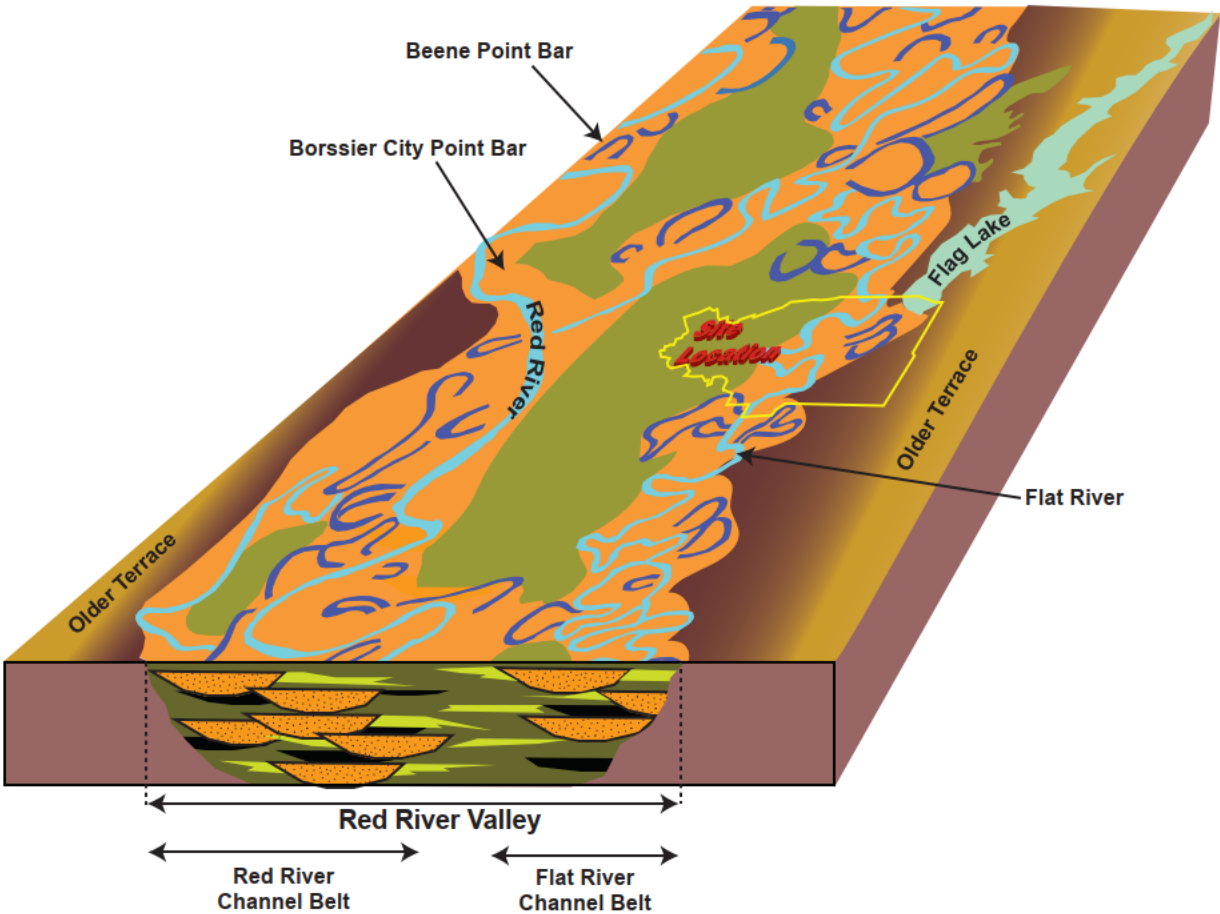
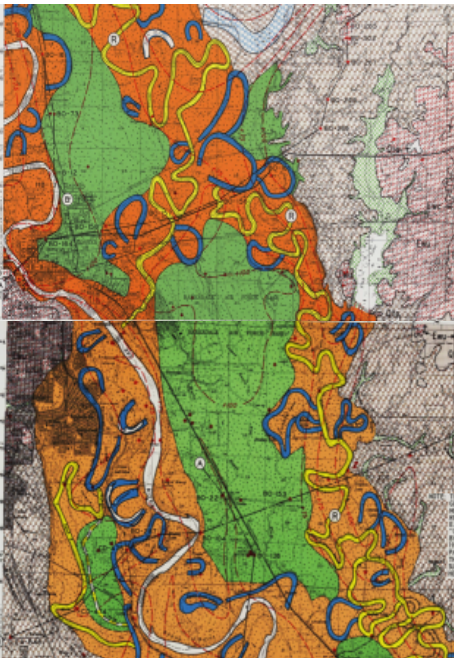
Fluvial Case Example



From Lageweg et al., 2016

Site Model Developed from Channel Belt Map

Fluvial Case Example



Legend

Surface Geomorphology

- Channel Belt
- Floodplain (Backswamp)
- Older (Pleistocene-Paleocene) Terrace
- Active Channel
- Ox-bow Lake/ Abandoned Channel

Subsurface Geology

- Point Bar Deposits (Sand-dominated)
 - Levee Deposits (Silt-dominated)
 - Floodplain Deposits (Clayey to Silty)
 - Wetland (infilled Ox-bow Lake) Deposits (Clay-dominated)
 - Older Terrace Deposits (mixed clastic lithology)
- Increasing Transmissivity

Extracting Data from Outcrop Analog

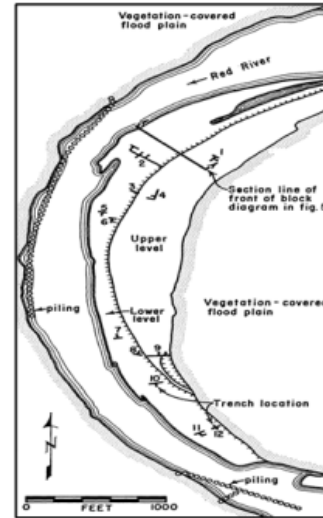
Fluvial Case Example



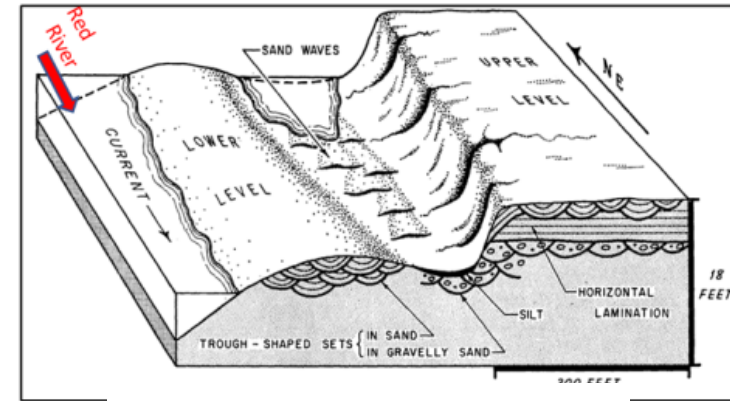
Major point Bar Locations



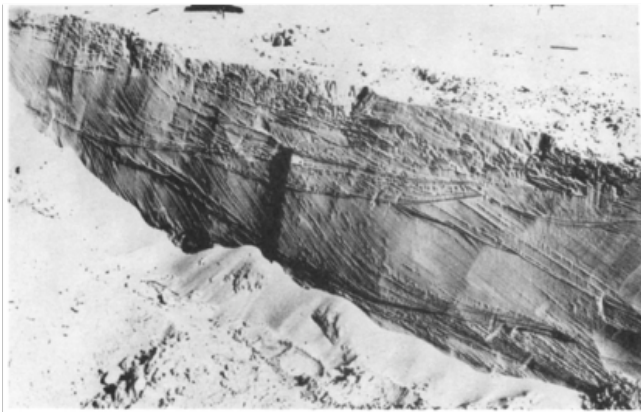
Beene Point Bar
Aerial Photomosaic



Point Bar Planview
Geometry



Beene Point Bar Block Diagram



Trough Cross-stratified Sand in Point Bar

- The width of the river at bank-full stage: ~800 feet
- Thickness of the Beene point bar: 18ft
- Approximate thickness: width: length ratio for the x-sets is 1:5:20+

From, Harms et al., 1962, AAPG

Major Conclusions

- There is a dire need for better data in the environmental industry (geophysical data/CPT/better logging)
- While waiting for better data we can add value to existing dataset by incorporating:
 - Regional understanding
 - Facies Models
 - Present geomorphology (Satellite image study)
 - Outcrop analog measurements

THANK YOU!

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