Role of Stratigraphic Models to Refine Site Assessments

Ben Campanaro, PG

PRISM®
PREdictive Integrated Stratigraphic Modeling

Delivering a better world

Battelle - International Symposium on Bioremediation and Sustainable Environmental Technologies
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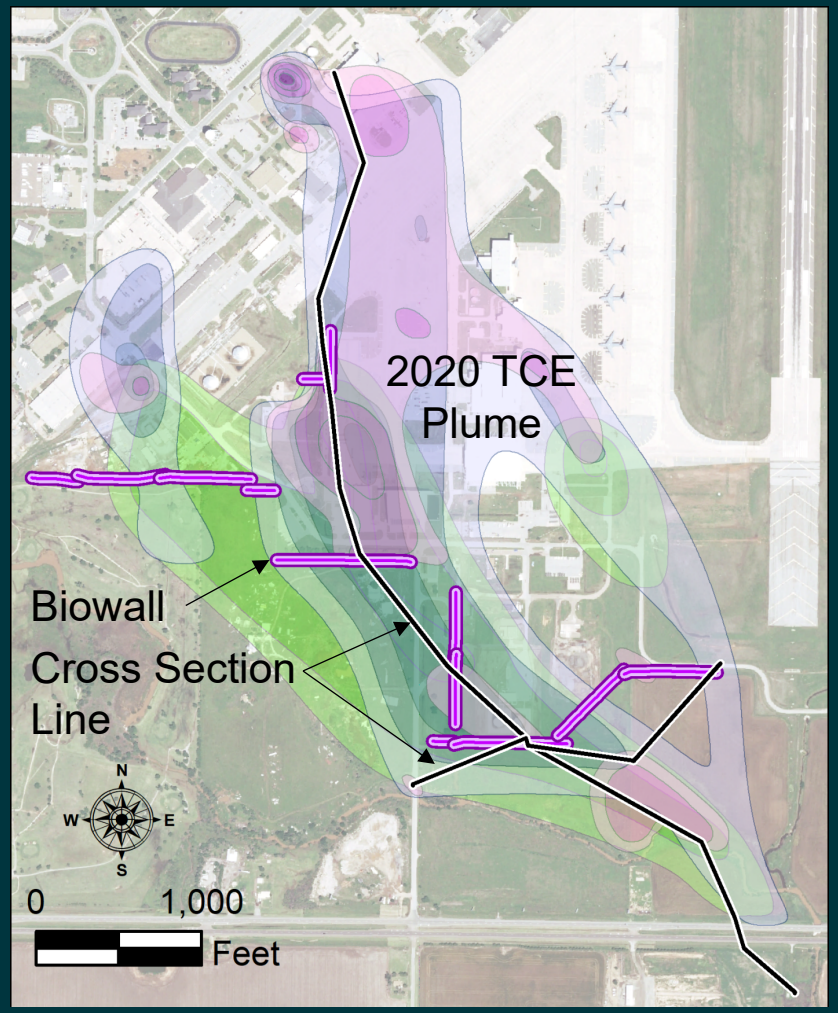
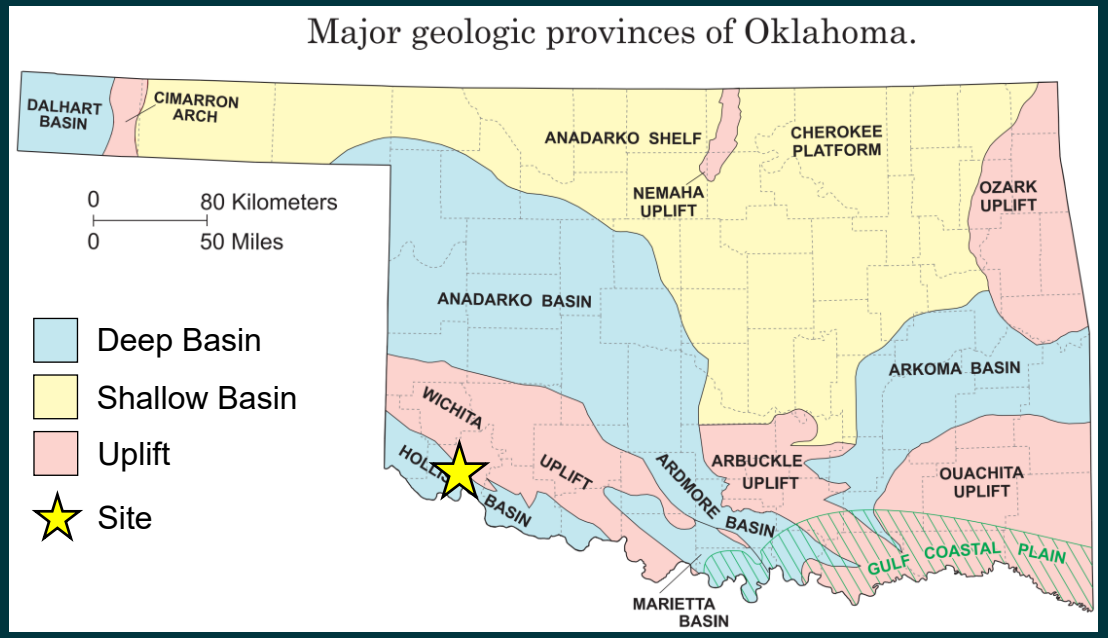
Case Study: Southwest Oklahoma



Data: Borehole descriptions, downhole geophysical logs, 2D resistivity surveys, groundwater elevations, aquifer tests, chemistry

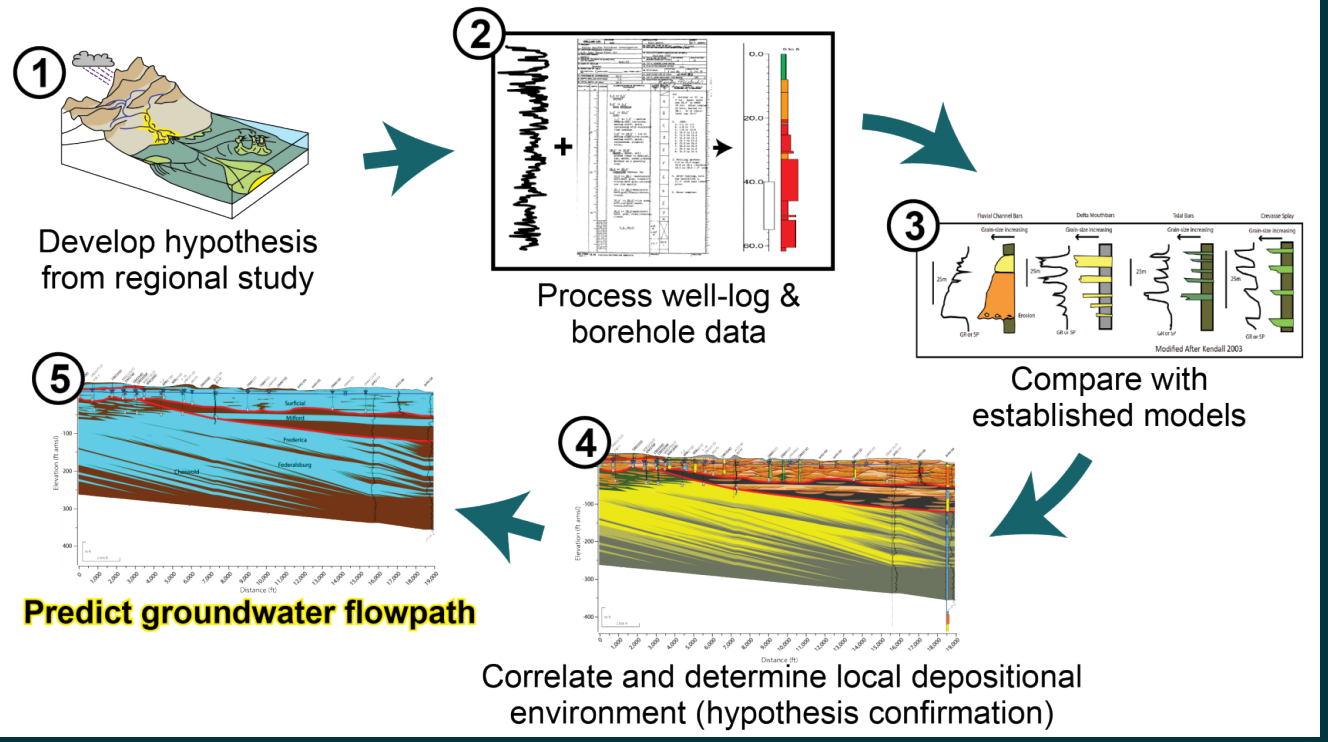


Goals:

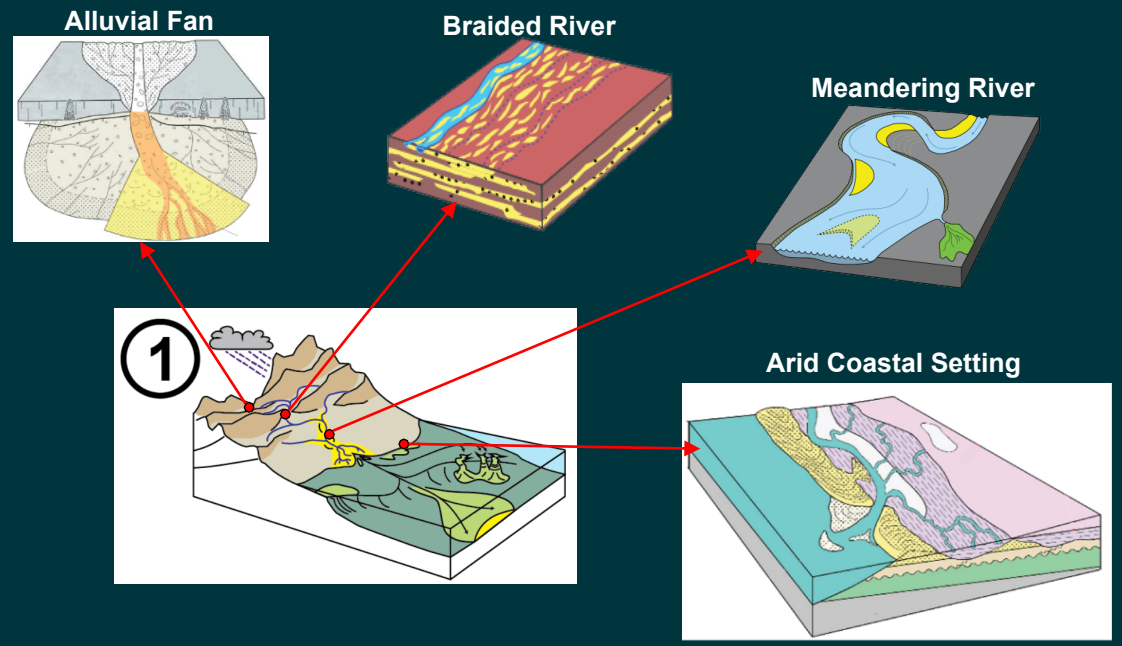
- Understand site subsurface heterogeneity by reinterpretation of site data using understanding of depositional environments & principles of sequence stratigraphy
- Predict location of preferential groundwater pathways to identify mass flux of biowall areas

Predictive Geologic Tools:
Sequence Stratigraphy and Depositional Environments

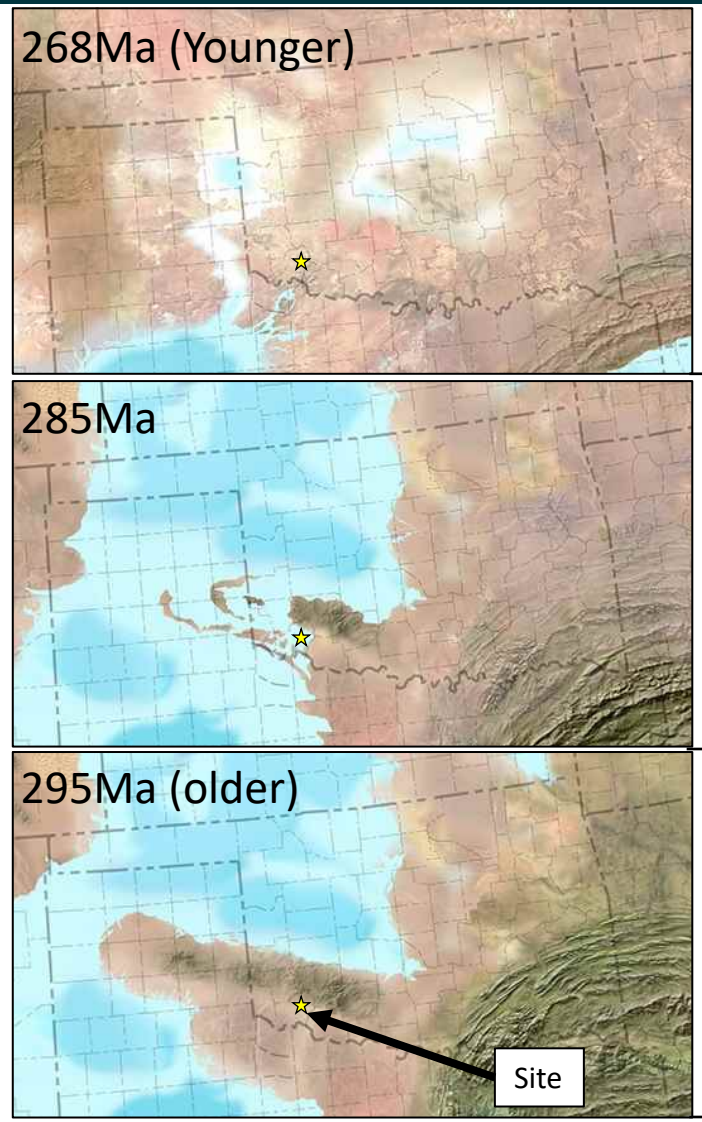
Fig. 1: Predictive Integrated Stratigraphic Modeling (PRISM®)



Infer depositional environments in relation to sediment supply and basin accommodation – a predictive way of understanding deposition!



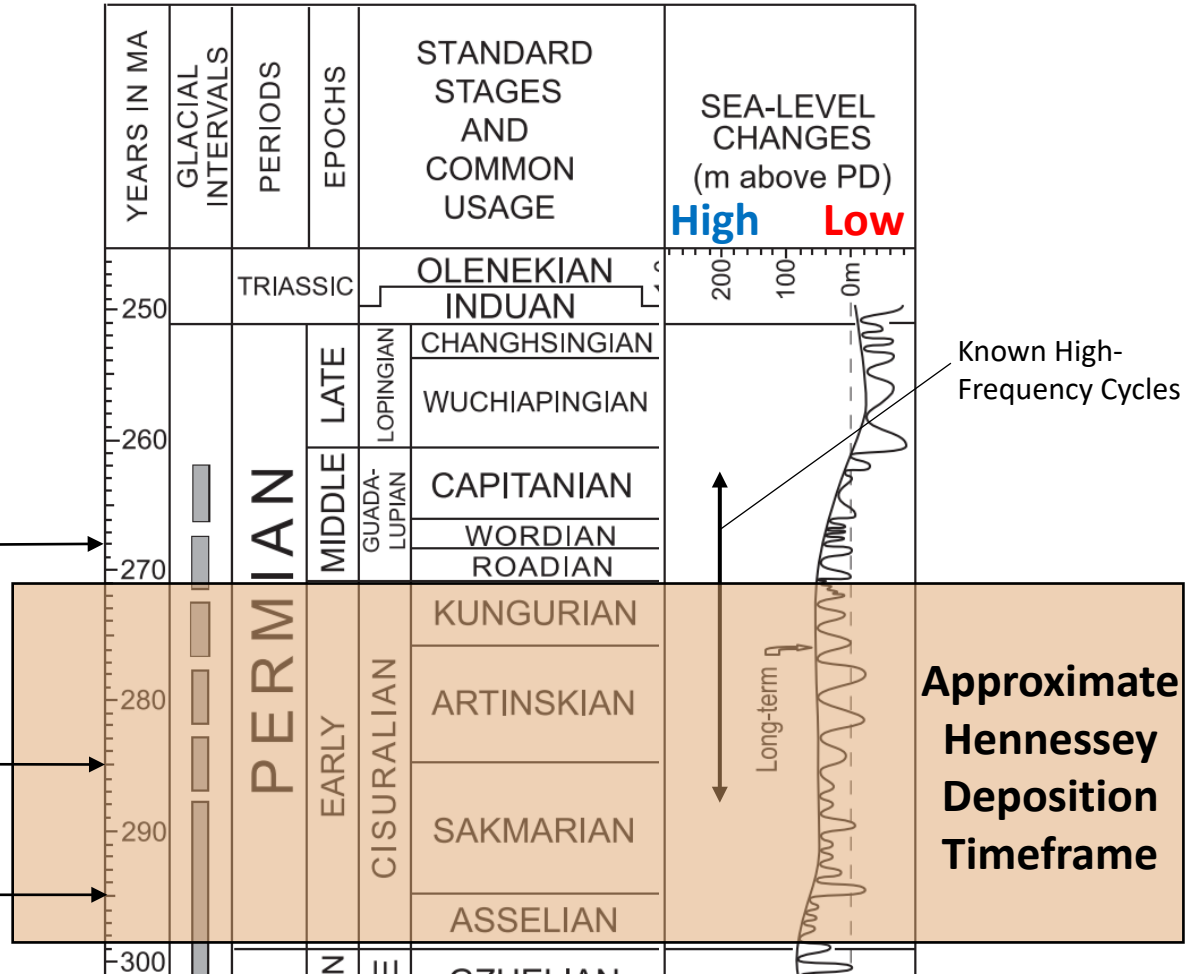
Permian Oklahoma: Sea-level and Paleogeography



Erosion and/or non-deposition

Sabkha to Shallow Marine

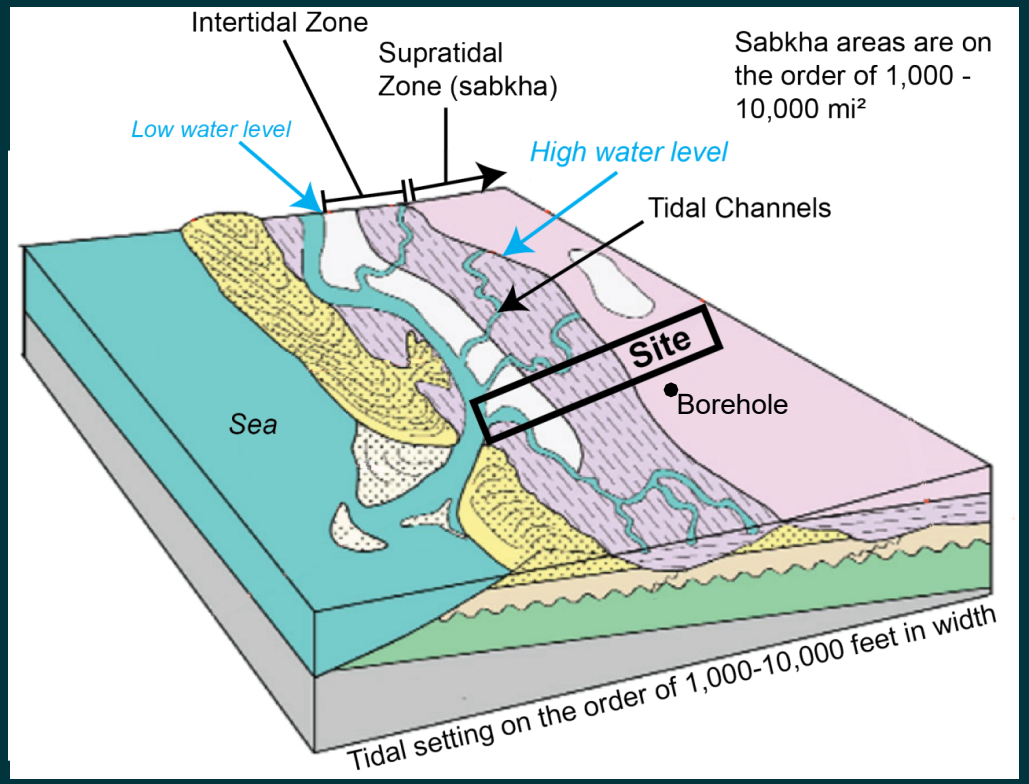
Sabkha to Shallow Marine



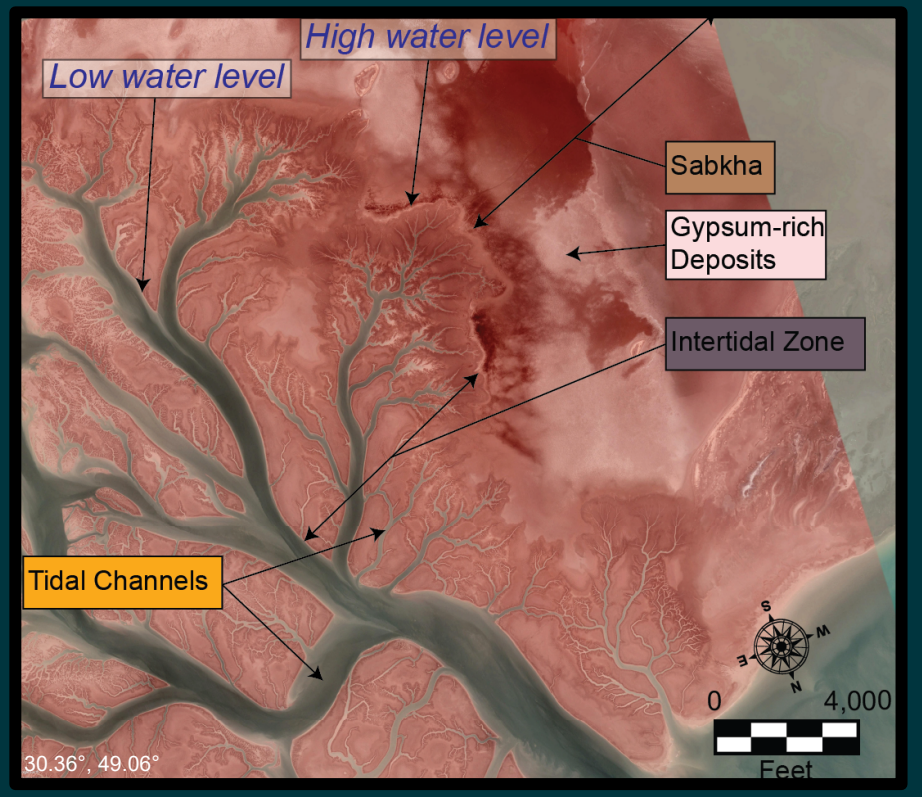
Modified from Montanez et al. (2007) and DeepTimemaps.com

Sabkha and Shallow Marine Depositional Environment

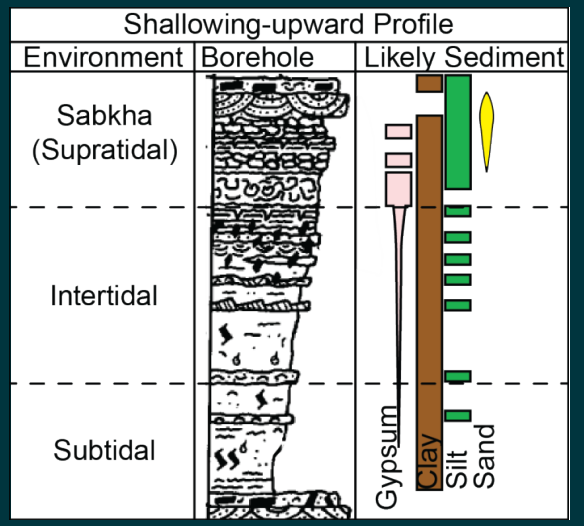
Ancient Depositional Model



Modern Sabkha Environment



Vertical Depositional Model



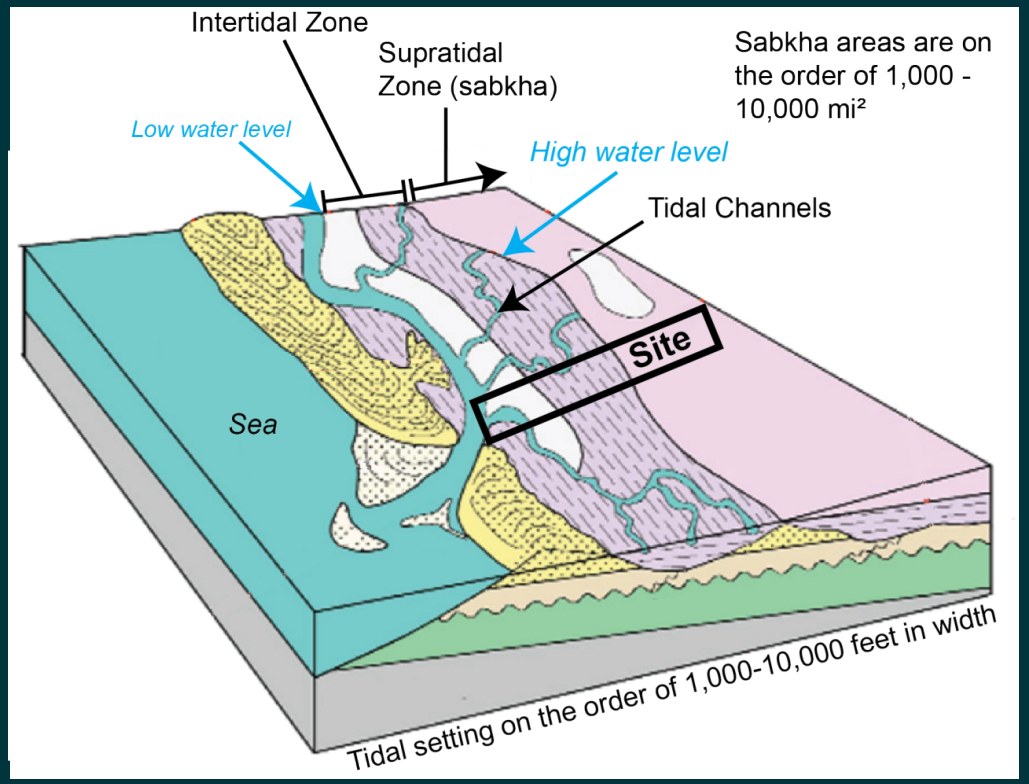
Depositional Environment Observations

- Sabkha = Arid coastal setting with a high groundwater table
- Intertidal and supratidal are dominantly fine-grained sediments
- High evaporation rates generate gypsum at ground surface and within subsurface
- Groundwater pathways: Tidal channel silts & Dissolving gypsum within intertidal strata

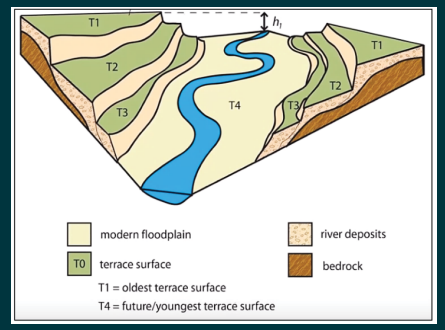
Modified from Warren and Kendall (1985) and James and Cowan (1992)

Facies Model for Case Study

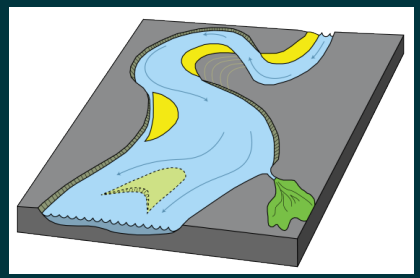
Ancient Depositional Model



Modern Depositional Model

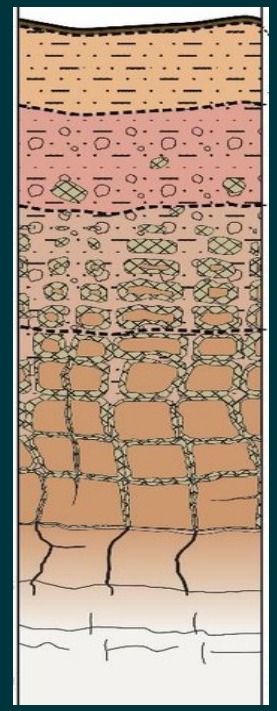


River Erosional Model



River Depositional Model

Imprinted Weathering Profile



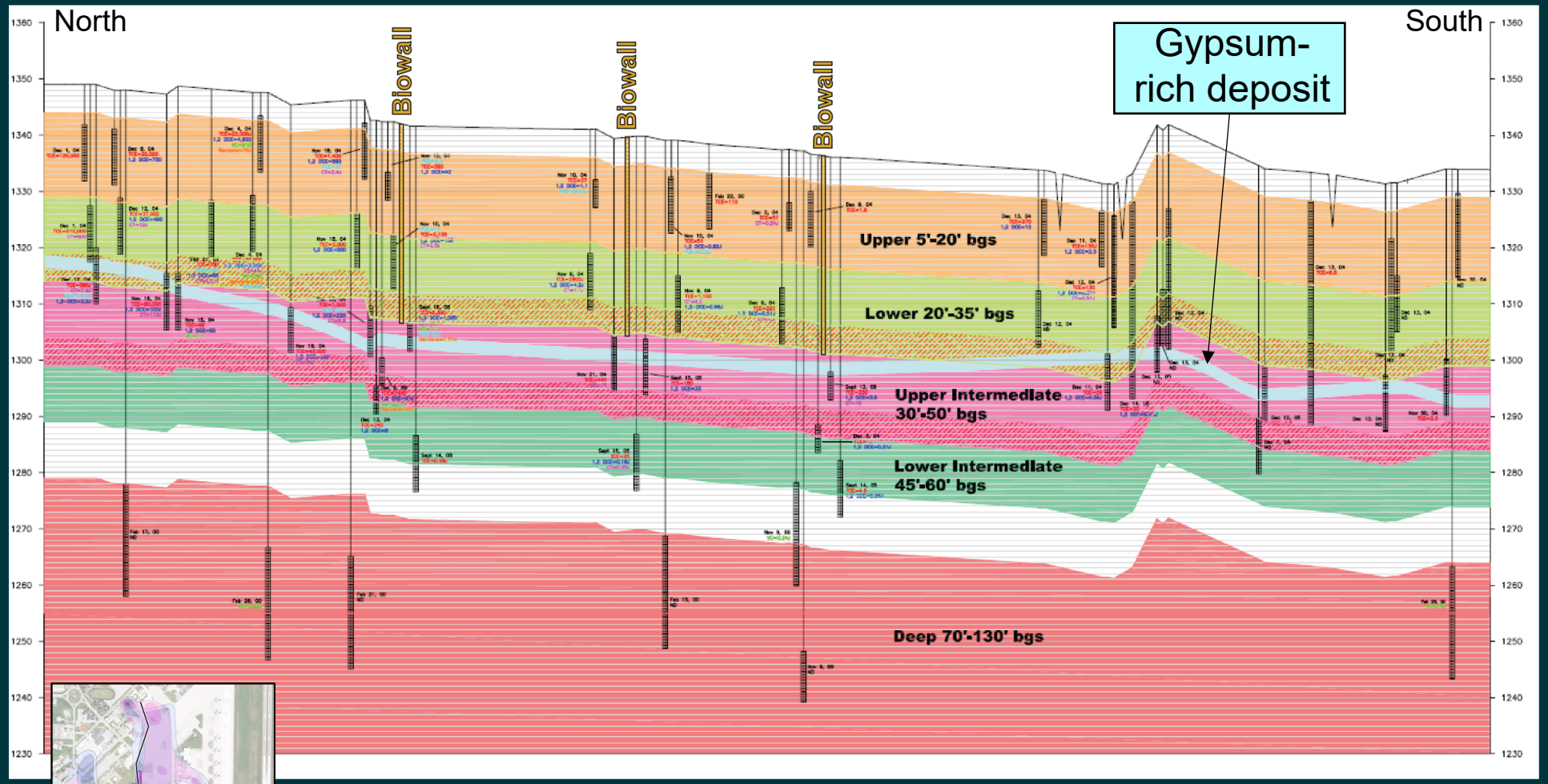
Completely Weathered Bedrock

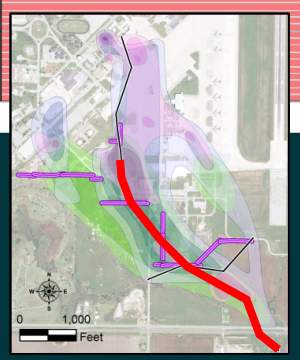
Competent Bedrock

PRISM® Stratigraphic Perspective:

- Geologic deposits change vertically and laterally due to changes in depositional environments
- Geometry, extent, and orientation of geological deposits dictate groundwater and contamination flow.
- Mass Flux calculation is impacted by stratigraphic heterogeneity

Previous Site Cross Section



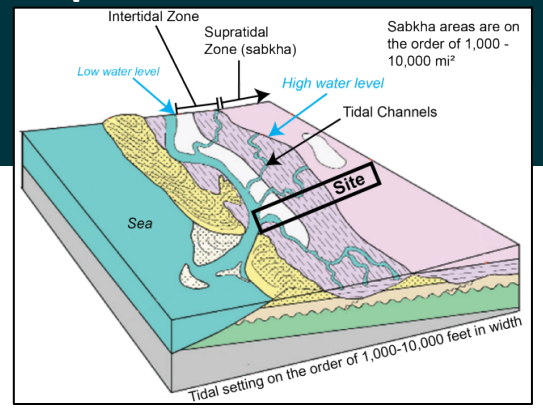


- Excellent borehole and 2D geophysical data
- Detailed borehole descriptions noting lithology, weathering, and gypsum habit
- Fair approximation of gypsum-rich interval locations

Does not have the resolution for accurate plume migration and, therefore, can't properly place remedial technology

Stratigraphic Cross Section

Depositional Model



Landward

Sabkha (Clay with 0-15% VF sand)

Migrating Sabkha

Tidal Channel (Silty Clay)

Basinward

North

South

Elevation (feet amsl)

1,350

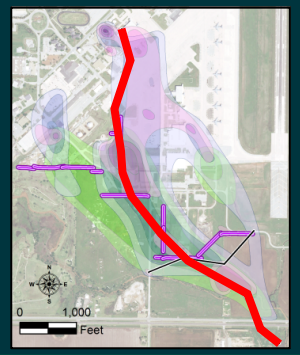
1,300

0 500 1,000 1,500 2,000 2,500 3,000 3,500 4,000 4,500 5,000 5,500 6,000 6,500 7,000

Distance (feet)

Intertidal Deposits

Gypsum-rich deposits



Lithofacies & Depositional Environments

Relative Transmissivity

- Fill or Disturbed Ground
- Transmissive Gypsum-rich Deposit
- River Channel Bar Deposits
- Silty Tidal Channel Deposits
- Overbank Splay Deposits
- Gypsum-rich Deposit
- Sabkha Silts and Clays
- Overbank Fines
- Intertidal Deposits (Weathered Shale)
- Intertidal Deposits (Competent Shale)

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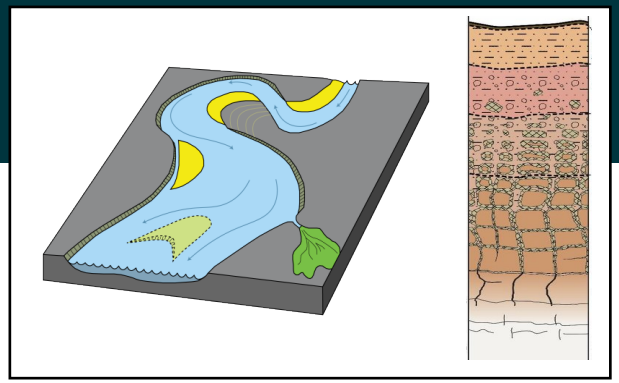
Stratigraphic Cross Section

Geologic Models



Landward

North

South

Basinward

Disturbed Ground

Base of Alluvium

River Bar Deposits

Splay

Elevation (feet amsl)

1,350

1,300

0 500 1,000 1,500 2,000 2,500 3,000 3,500 4,000 4,500 5,000 5,500 6,000 6,500 7,000

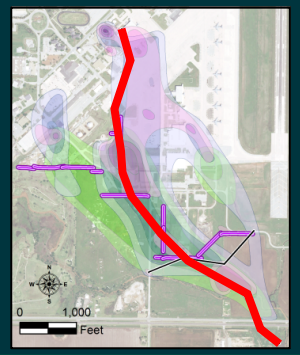
Distance (feet)

Top of Competent Bedrock

Unweathered Gypsum

Weathering Gypsum

Gypsum Missing



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River Erosional Surface

Top of Competent Bedrock

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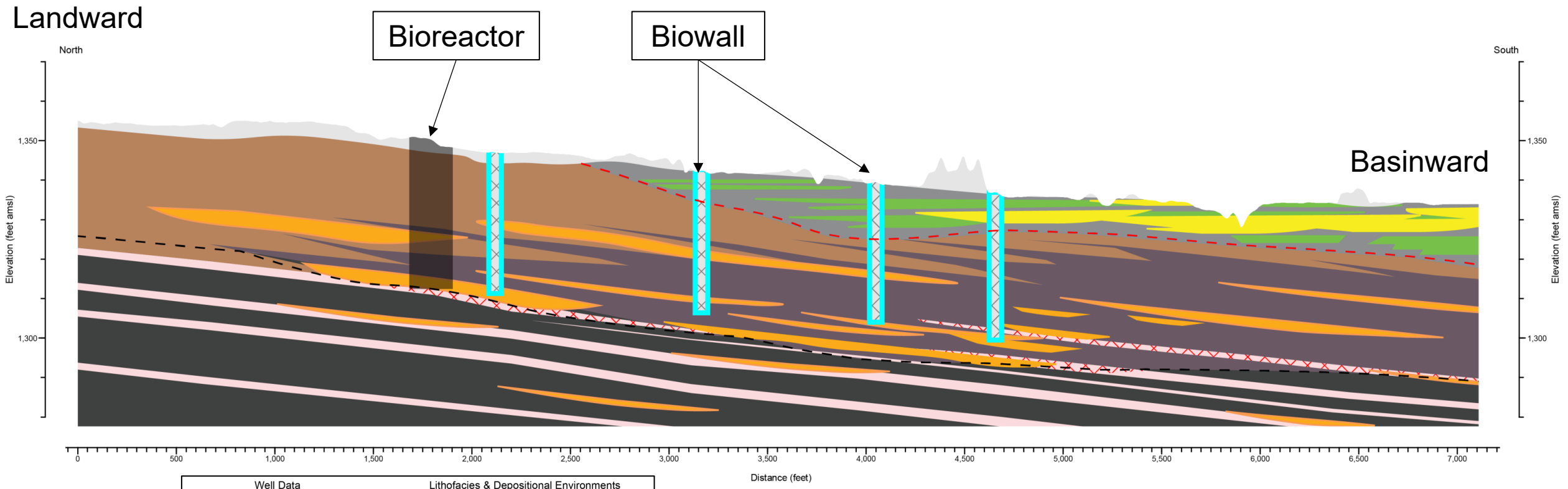
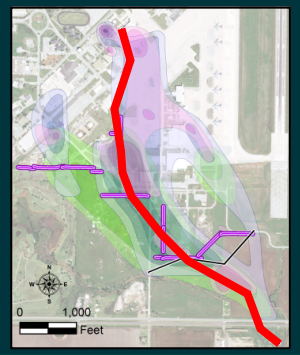
Stratigraphic Cross Section





Well Data

Biowall

River Erosional Surface

Top of Competent Bedrock

Lithofacies & Depositional Environments

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Observe that the biowalls encounter different depositional environments with varying heterogeneity

Stratigraphic Cross Section

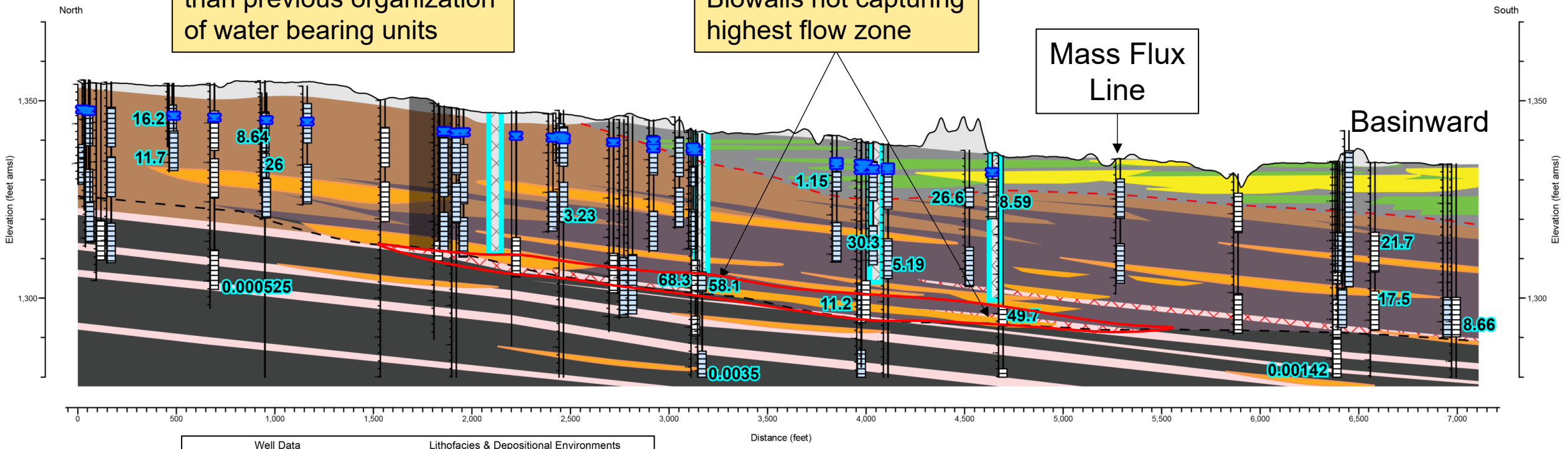
Landward

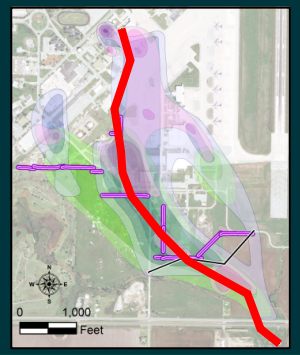
Stratigraphic dip is greater than previous organization of water bearing units

Biowalls not capturing highest flow zone

Mass Flux Line

Basinward





Well Data

- MW-1 (0 / 20 / 40) — Location ID (projected distance and direction from line); Well Stem Notes Depth in Feet Below Grade; Well Screen (blue = projected)
- Groundwater Elevation November/December 2022
- Biowall
- 17.5 — Hydraulic Conductivity (ft/day)
- River Erosional Surface
- Top of Competent Bedrock

Lithofacies & Depositional Environments

Relative Transmissivity

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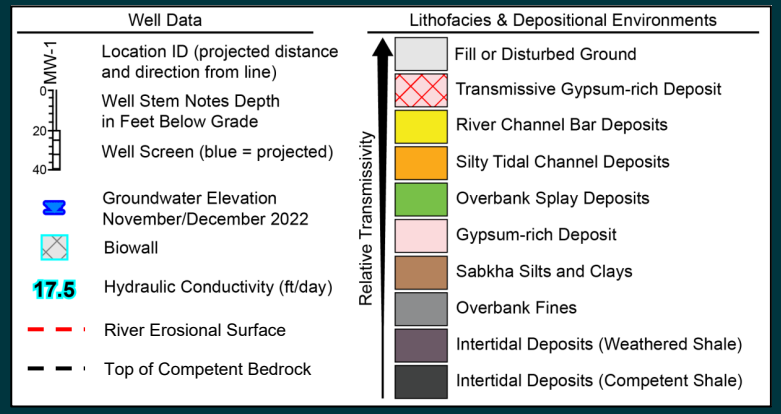
Critical Features for Groundwater Flow

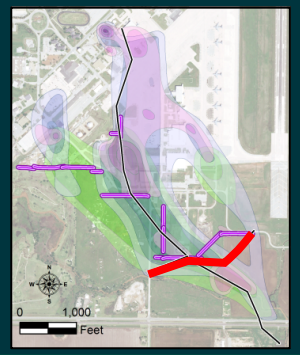
1 – Tidal channels
2 – Mudcracked intertidal deposits
3 – Dissolved gypsum
4 – Weathered/Competent contact

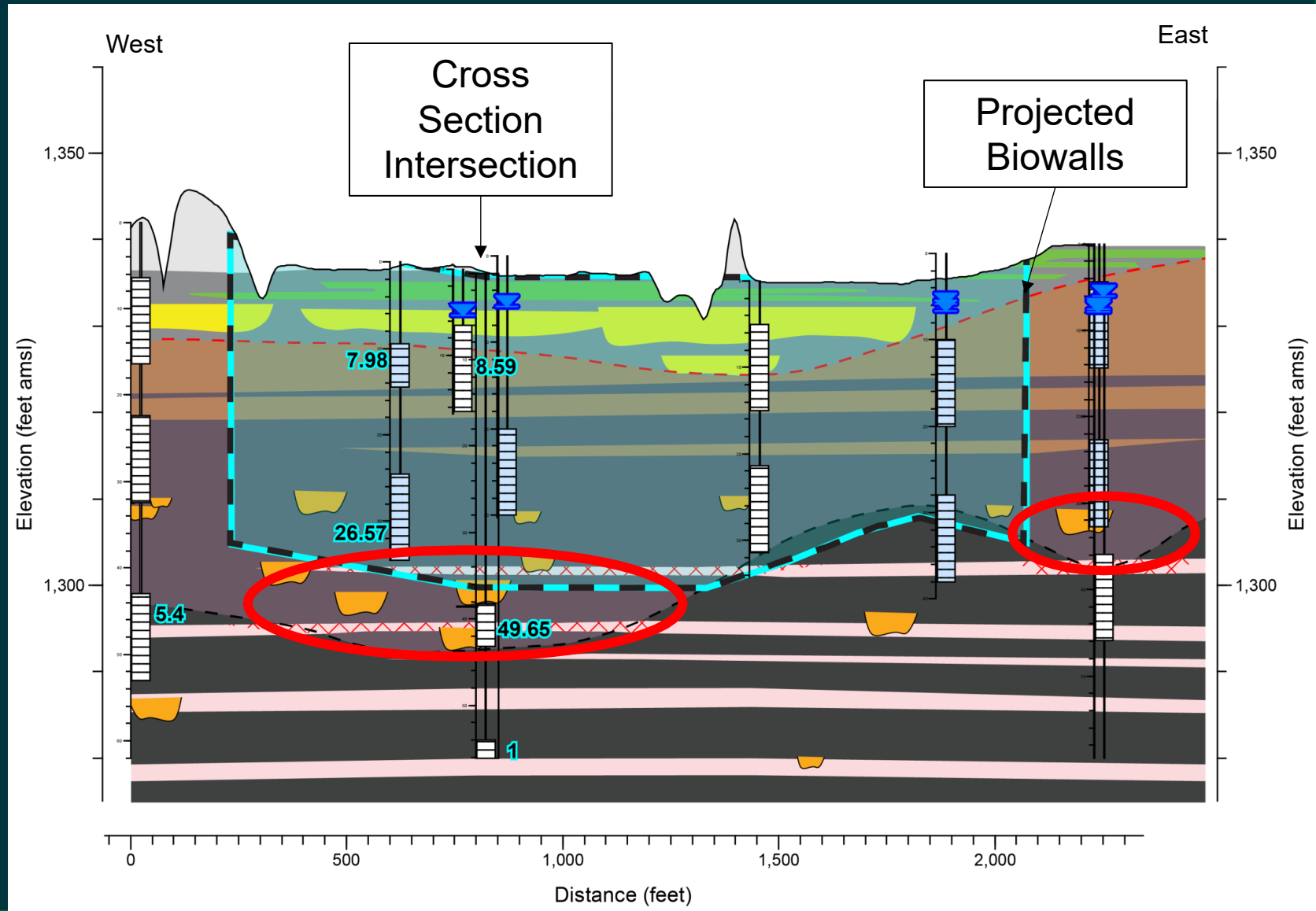
Stratigraphic Cross Section: Mass Flux

Critical Features for Groundwater Flow
1 – Tidal channels
2 – Mudcracked intertidal deposits
3 – Dissolved gypsum
4 – Weathered/Competent contact

High flow zone



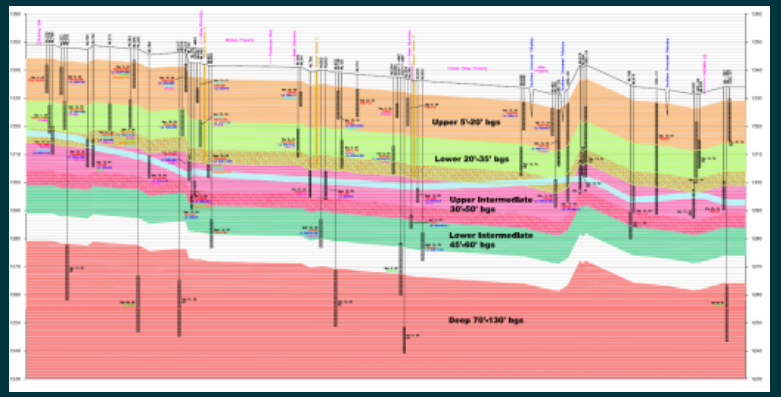




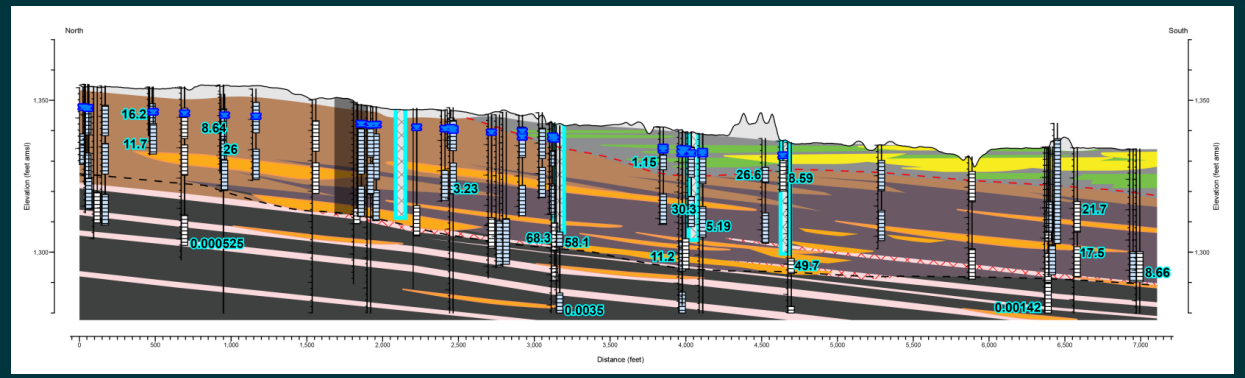
Conclusions & Lessons Learned

- Geologic heterogeneities in the sedimentary record are **predicable** using the principles of sequence stratigraphy and understanding of depositional environments
- Layer cake, homogeneous models or statistically correlated geology is not advisable. Sediments and their distribution change vertically and laterally related to the processes that placed them.
- Optimal placement of bioremediation tools (i.e., biowalls) require understanding of plume migration relative to regional and local geology

Before



After



- Based on known facies models
- Heterogeneity is predicted
- Permeable zones identified & correlated

Thank You!

Acknowledgements: John Gillespie (AFCEC/CZTE), Leslee Alexander*, Dave Parse*, Liz Larsen*, Tom Champion*, Ryan Samuels* (*AECOM)

Author Contact

Sadeque J. and Samuels R. (2023), 'The application of sequence stratigraphy to the investigation and remediation of LNAPL contaminated sites', in Advances in the Characterization and Remediation of Sites Contaminated with Petroleum Hydrocarbons. **Springer Nature** (in press).

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