Pacific Northwest
NATIONAL LABORATORY

RemPlex Seminar

April 23, 2024

Optimizing Remediation Outcomes through Integration of Geologic and Geophysical Data

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CENTER FOR THE REMEDIATION OF COMPLEX SITES
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Today’s Seminar and Speakers

Optimizing Remediation Outcomes through Integration of Geologic and Geophysical Data

Rick Cramer
Senior Project Manager/Geologist
Burns & McDonnell

Mike Shultz
Senior Geologist/Sequence Stratigrapher
Burns & McDonnell

Judy Robinson
Computational Scientist
Pacific Northwest National Laboratory

Remediation Geology and Application of Environmental Sequence Stratigraphy (ESS) to Optimize Groundwater Remediation Outcomes

RemPlex Seminar
April 23, 2024
Webinar

Rick Cramer, PG
Mike Shultz, PhD
(Burns & McDonnell)

Presentation Outline

What are Remediation Geology/Environmental Sequence Stratigraphy? (Rick)

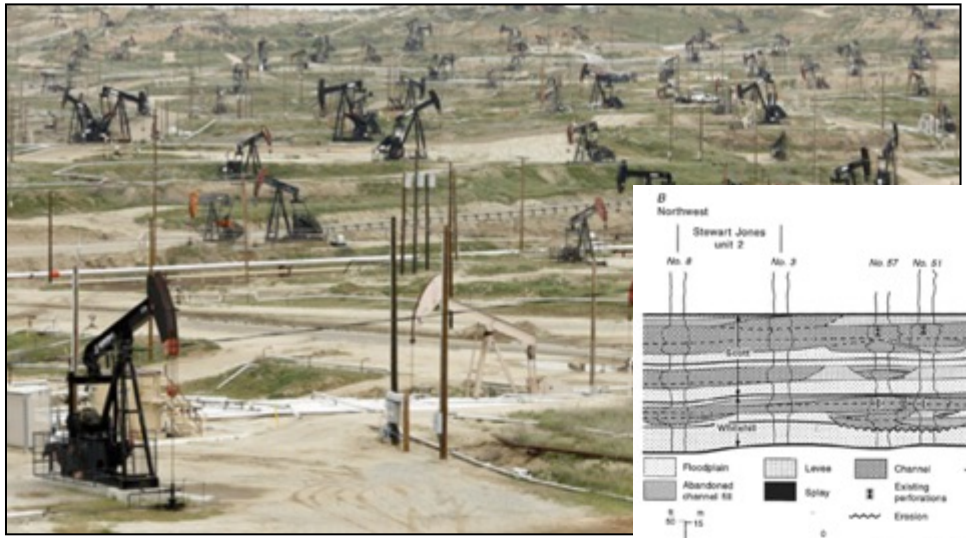
Why are they critical to groundwater remediation projects? (Rick)

How are these technologies applied to environmental restoration projects? – Case Studies (Mike)

Emergence of Petroleum Geology in the Oil Industry

- Early days of exploration and production, once oil reservoir was discovered, production was limited by facilities capacity (**engineering focus**)

- As production declined, **geology** became increasingly critical for economical operations
- ***Billions of dollars have been invested in research and development of stratigraphic controls on fluid flow***



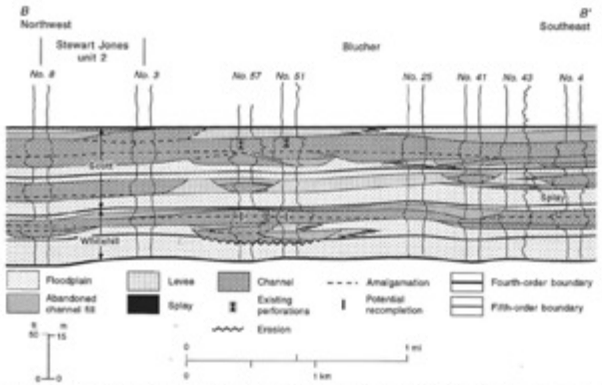
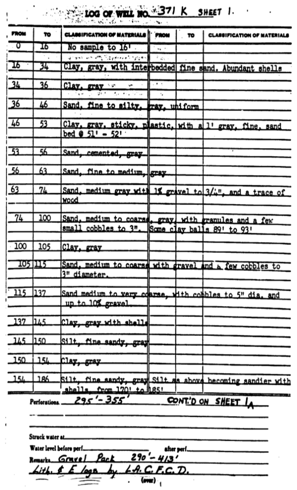


Figure 3. Dip-oriented stratigraphic cross section B-B' through amalgamated channel sandstones and floodplain shales in the Scott/Whitehill intermediate-frequency unit in T-C-B field. Note that the four high-frequency units, the lower and upper Whitehill and the lower and upper Scott, exhibit a successive increase in thickness from the lower Whitehill to the upper Scott. See Figure 4a for location. From Knox and McRae (1995).

The Environmental Sequence Stratigraphy (ESS) Process



LOG OF WELL NO. 371 K SHEET 1.

FROM	TO	CLASSIFICATION OF MATERIALS	FROM	TO	CLASSIFICATION OF MATERIALS
0	16	No sample to 16'			
16	34	Clay, gray, with interbedded fine sand. Abundant shells			
34	36	Clay, gray			
36	46	Sand, fine to silty, gray, uniform			
46	53	Clay, gray, sticky, plastic, with a 1' gray, fine, sand bed @ 51' - 52'			
53	56	Sand, cemented, gray			
56	63	Sand, fine to medium, gray			
63	74	Sand, medium gray with 1% gravel to 3/4", and a trace of wood			
74	100	Sand, medium to coarse, gray, with granules and a few small cobbles to 3". Some clay balls 89' to 93'			
100	105	Clay, gray			
105	115	Sand, medium to coarse with gravel and a few cobbles to 3" diameter.			
115	137	Sand medium to very coarse, with cobbles to 5" dia. and up to 10% gravel.			
137	145	Clay, gray with shells			
145	150	Silt, fine sandy, gray			
150	154	Clay, gray			
154	186	Silt, fine sandy, gray Silt as above becoming sandier with shells, from 170' to 185'			

Perforations 295'-355' CONT'D ON SHEET 1A

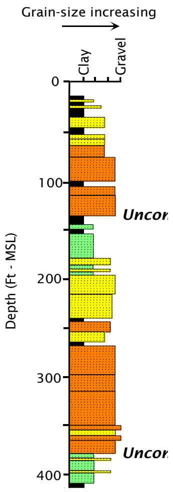
Struck water at

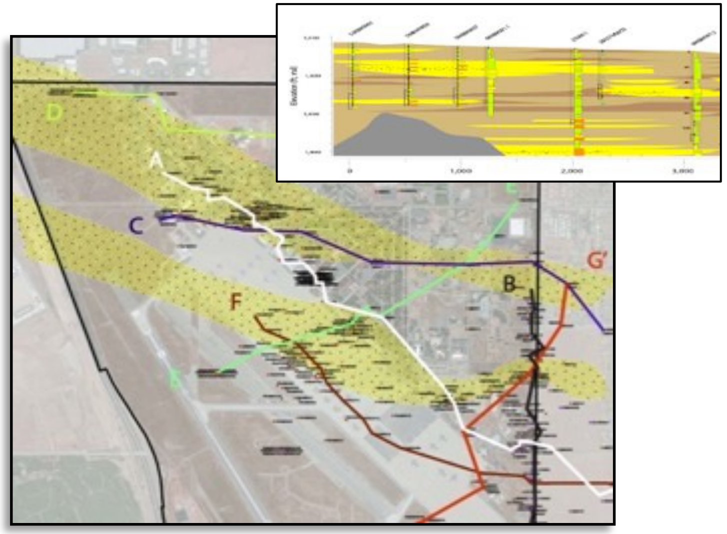
Water level before perf. after perf.

Remarks Gravel Pack 290'-413'

Lith. & E logs by L.A.C.F.C.D.

(over)





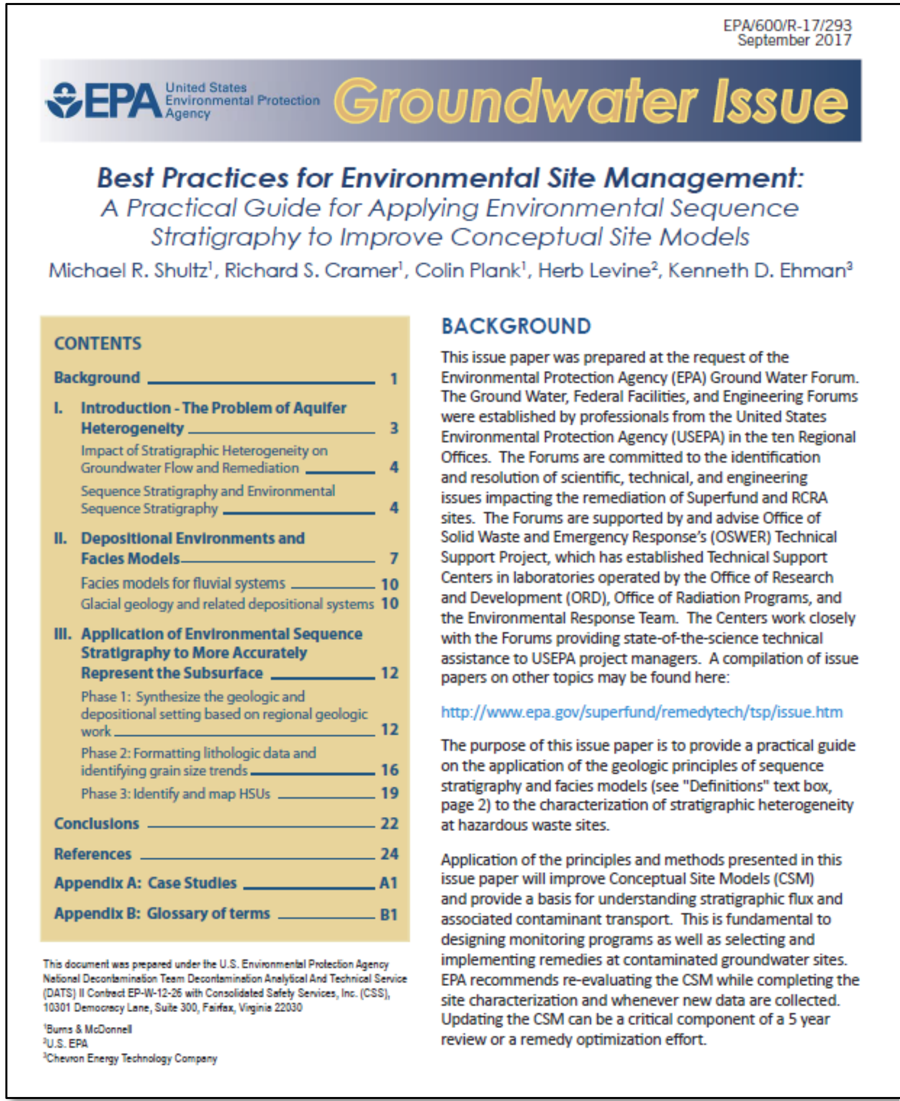
1 **Research regional geology** to determine depositional environment, the foundation of the ESS evaluation.

2 **Leverage existing lithology data:** vertical grain size patterns indicative of genetic relationships.

3 **Map and predict** the subsurface permeability architecture away from the data points.

ESS: US EPA Best Practice – 2017

- Step-by-step guidance document for CSM
- Objective is to improve remedy performance
- 90% of mass flux moves through only 10% of aquifer material…controlled by geology
- Link to Groundwater Technical Issue Paper: https://nepis.epa.gov/Exe/ZyPDF.cgi/P100TN2C.PDF?Dockey=P100TN2C.PDF



EPA/600/R-17/293
September 2017

EPA United States Environmental Protection Agency **Groundwater Issue**

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

Michael R. Shultz[1], Richard S. Cramer[1], Colin Plank[1], Herb Levine[2], Kenneth D. Ehman[3]

CONTENTS

This document was prepared under the U.S. Environmental Protection Agency National Decontamination Team Decontamination Analytical And Technical Service (DATS) II Contract EP-W-12-26 with Consolidated Safety Services, Inc. (CSS), 10301 Democracy Lane, Suite 300, Fairfax, Virginia 22030

[1]Burns & McDonnell
[2]U.S. EPA
[3]Chevron Energy Technology Company

BACKGROUND

This issue paper was prepared at the request of the Environmental Protection Agency (EPA) Ground Water Forum. The Ground Water, Federal Facilities, and Engineering Forums were established by professionals from the United States Environmental Protection Agency (USEPA) in the ten Regional Offices. The Forums are committed to the identification and resolution of scientific, technical, and engineering issues impacting the remediation of Superfund and RCRA sites. The Forums are supported by and advise Office of Solid Waste and Emergency Response's (OSWER) Technical Support Project, which has established Technical Support Centers in laboratories operated by the Office of Research and Development (ORD), Office of Radiation Programs, and the Environmental Response Team. The Centers work closely with the Forums providing state-of-the-science technical assistance to USEPA project managers. A compilation of issue papers on other topics may be found here:

http://www.epa.gov/superfund/remedytech/tsp/issue.htm

The purpose of this issue paper is to provide a practical guide on the application of the geologic principles of sequence stratigraphy and facies models (see "Definitions" text box, page 2) to the characterization of stratigraphic heterogeneity at hazardous waste sites.

Application of the principles and methods presented in this issue paper will improve Conceptual Site Models (CSM) and provide a basis for understanding stratigraphic flux and associated contaminant transport. This is fundamental to designing monitoring programs as well as selecting and implementing remedies at contaminated groundwater sites. EPA recommends re-evaluating the CSM while completing the site characterization and whenever new data are collected. Updating the CSM can be a critical component of a 5 year review or a remedy optimization effort.

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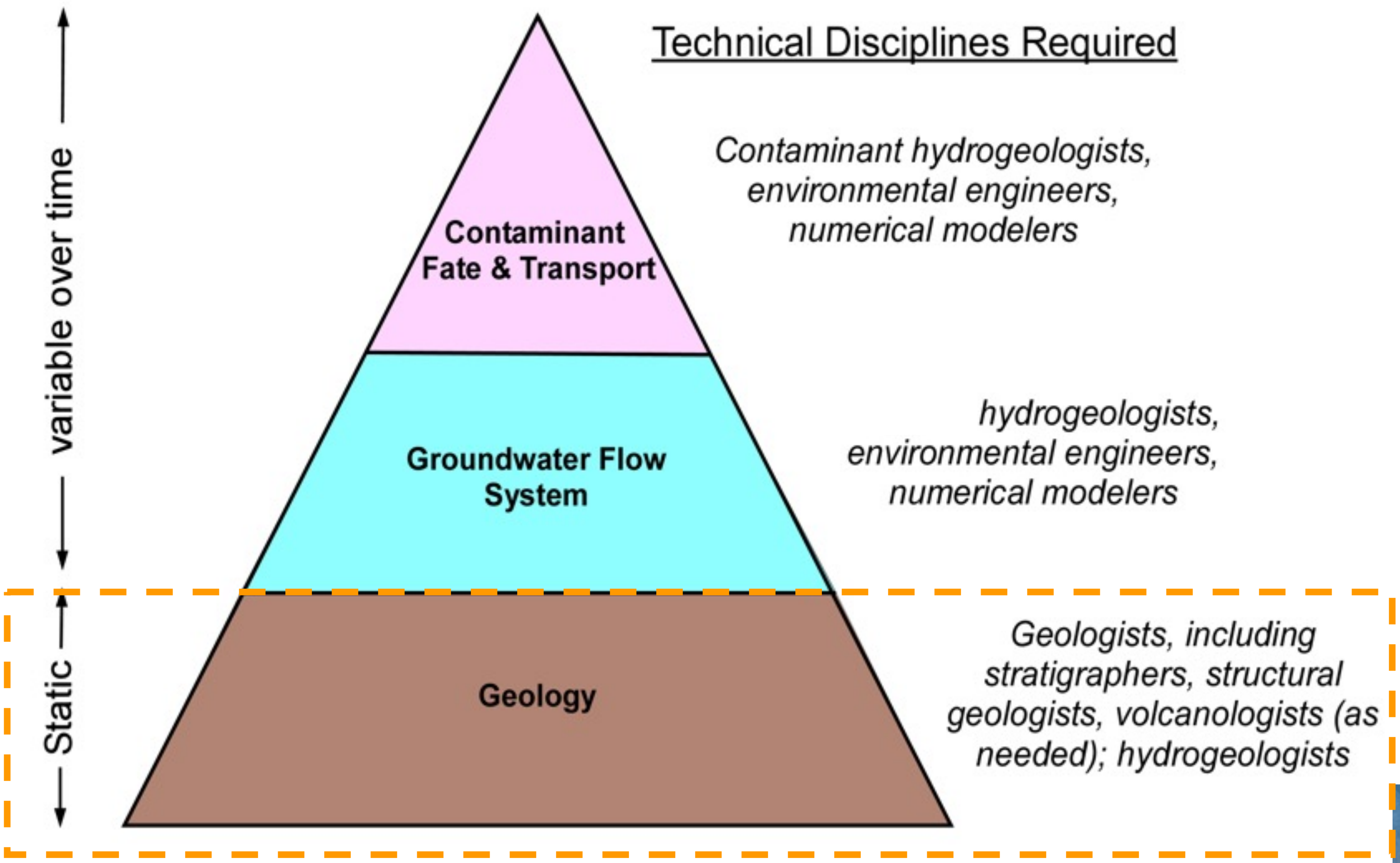
Components of a Conceptual Site Model (CSM) for a Groundwater Contaminated Site



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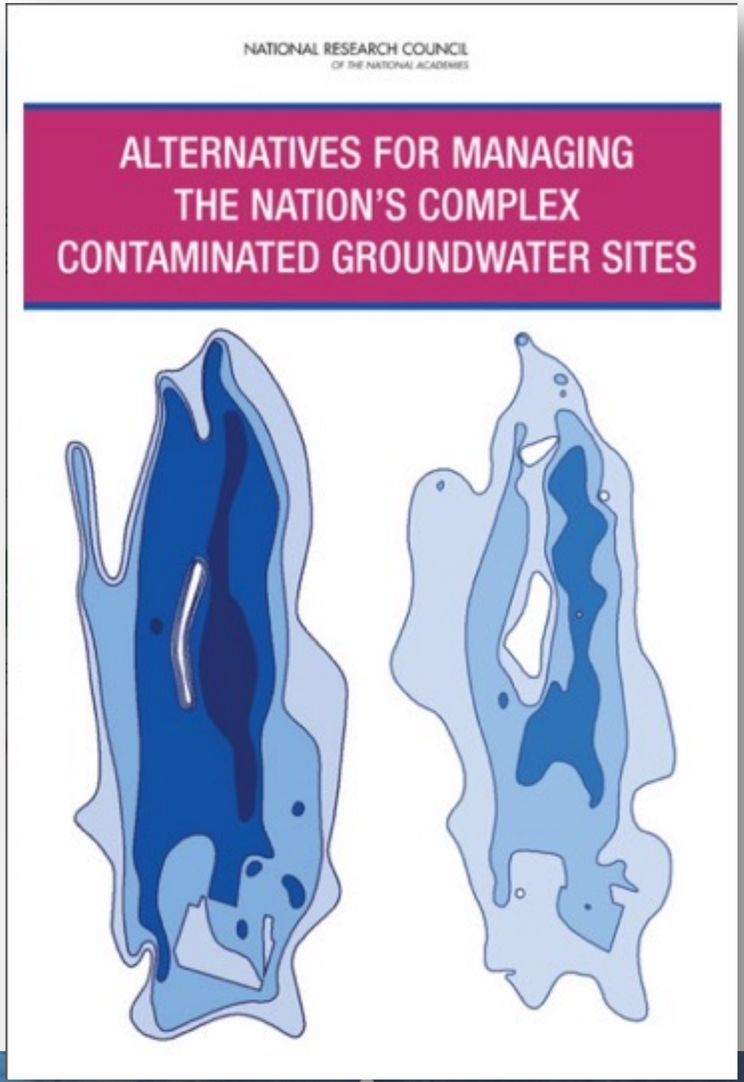
Geology/Heterogeneity Matters

- More than **126,000** sites across the U.S. require remediation
- More than **12,000** of these sites are considered "complex"
- "…due to **inherent geologic complexities**, restoration within the next 50-100 years is likely not achievable."



Alternatives for Managing the Nation's Complex Contaminated Groundwater Sites
National Academy of Sciences Committee on Future Options for Management in the Nation's Subsurface Remediation Effort, 2013

Expertise of the Practitioner

Geology

- Mineralogy
- Economic geology
- Geophysics
- Stratigraphy
- Marine geology
- Volcanology
- Geochemistry
- Structural geology
- Sedimentology
- Paleontology
- Seismology
- Hydrogeology
- Petroleum geology
- Tectonics
- Engineering geology
- Geomorphology
- Igneous petrology
- Metamorphic petrology

Expertise of the Practitioner…Pattern Recognition

Geology

- Mineralogy
- Economic geology
- Geophysics
- Stratigraphy
- Marine geology
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- Paleontology
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- Geomorphology
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Radiologist = Stratigrapher

Geology

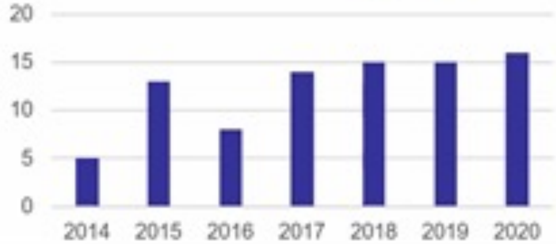
- Mineralogy
- Economic geology
- Geophysics
- **Stratigraphy**
- Marine geology
- Volcanology
- Geochemistry
- Structural geology
- **Sedimentology**
- Paleontology
- Seismology
- Hydrogeology
- Petroleum geology
- Tectonics
- Engineering geology
- Geomorphology
- Igneous petrology
- Metamorphic petrology

AFCEC Critical Process Analysis (CPA) Project Review

Primary Finding was Improved CSM = Remediation Optimization

Remedy Evaluations: 2014 – 2020

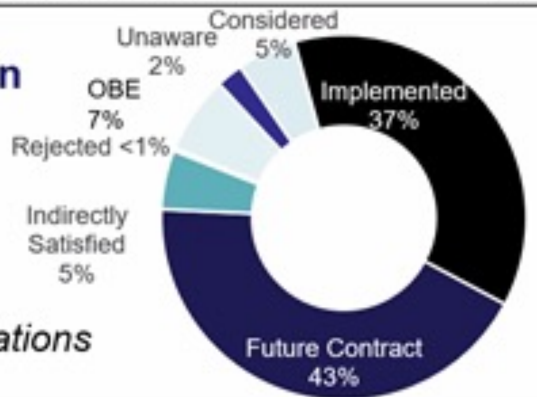
Sites Evaluated



82 sites

Site-Specific Results	Percent of Sites
Fill data gaps, refine CSM	96
Optimize remedial system or approach	62
Update objective and exit strategy	50
Implement contingency (Plan B)	23
Remedy effective and optimal	10

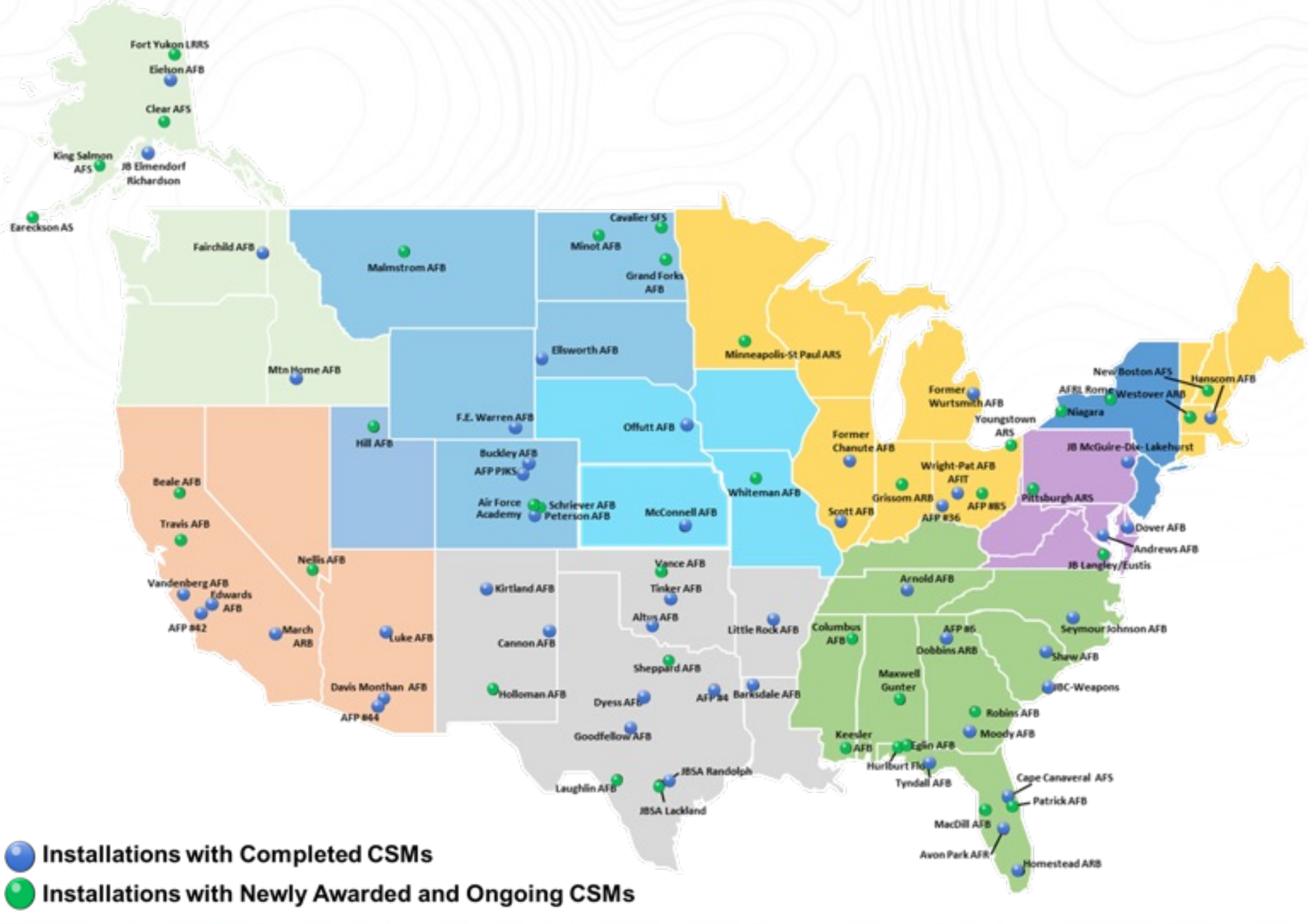
Recommendation Tracking



392 recommendations

Air Force ESS Projects = 2010 to 2023

- **AFCEC conducted an enterprise-wide study**
- **Over 80** base-wide ESS projects
- AFCEC standard approach for **PFAS RIs**
- Lead remediation engineer concluded, **an oversimplified CSM results in an over-engineered, high cost remedy**



Kirtland Air Force Base

Kirtland Air Force Base

U.S. AIR FORCE

HOME NEWS PHOTOS ART LIBRARY UNITS ENVIRONMENT QUESTIONS

JOIN THE AIR FORCE

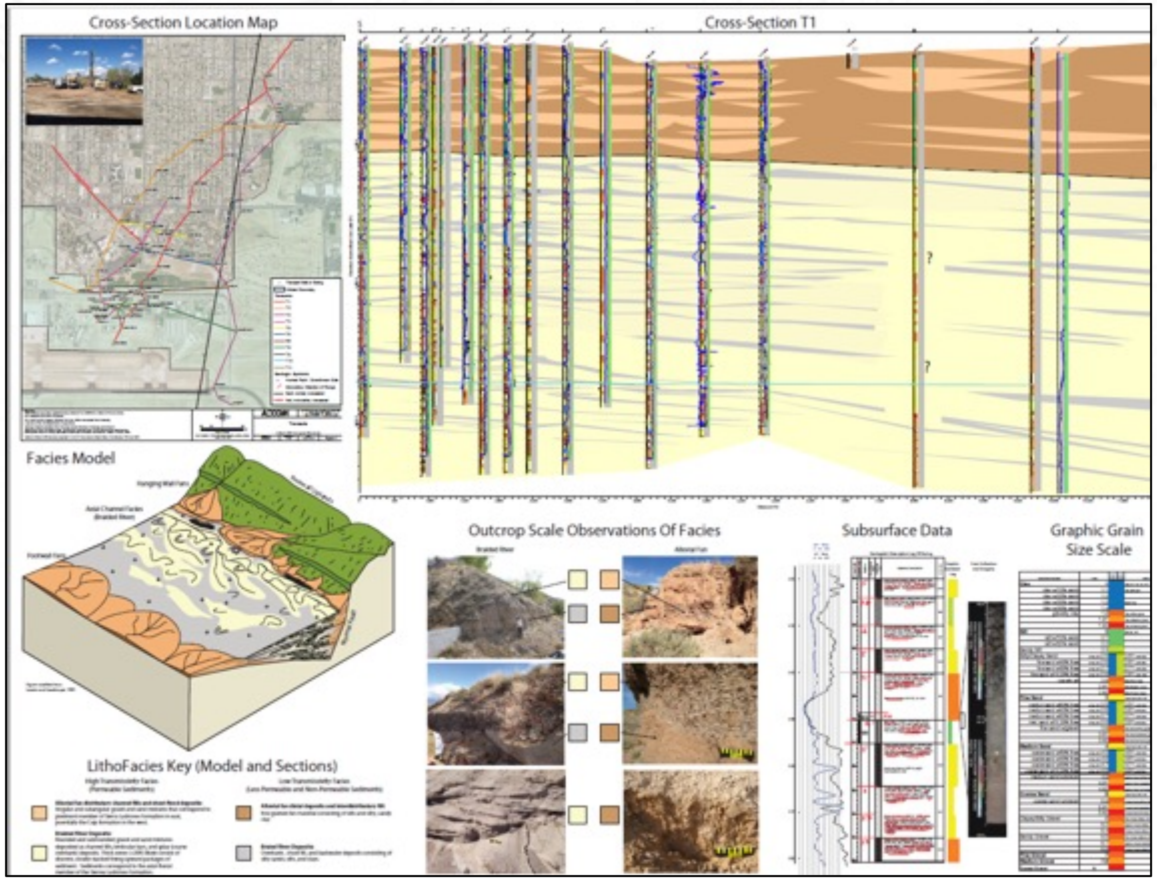
Community takes part in bulk fuels facility field trip

Posted 4/21/2015 Updated 4/21/2015 Email story Print story

Like 3 SHARE

by Jim Fisher
Kirtland Public Affairs

4/21/2015 - **KIRTLAND AIR FORCE BASE, N.M.** -- Concerned citizens, local residents, geology buffs and students from the University of New Mexico and New Mexico Institute of Mining and Technology joined local agencies engaged in cleaning up the Kirtland Bulk Fuels Facility leak April 18 to learn more about the science behind the assessment and cleanup. The group visited environmental cleanup sites around Albuquerque and geologically illustrative sites near and on Kirtland.



DEPARTMENT OF THE AIR FORCE
WASHINGTON DC

OFFICE OF THE ASSISTANT SECRETARY

AUG 12 2015

SAF/IE
1165 Air Force Pentagon
Washington, DC 20330-1665

Mr. Colin Plank
5555 Glenwood Hills Parkway SE, Suite 300
Grand Rapids, Michigan 49512

I offer my sincere and personal appreciation for your outstanding contributions to the Kirtland Air Force Base Bulk Fuels Facility cleanup effort. Your selfless dedication, professional diligence, and willingness to reach out and connect with the affected community and environmental regulators are commendable.

The Kirtland AFB Interim Measure Milestone event is but one indicator of the great progress you have helped achieve. It is also a preview of many more future successes as we work to rebuild the trust between the gracious citizens of Albuquerque and our United States Air Force.

Keep up the outstanding work!

Sincerely,

MIRANDA A. A. BALLENTINE
Assistant Secretary of the Air Force
(Installations, Environment, and Energy)

Environmental Sequence Stratigraphy for RemPlex 2024

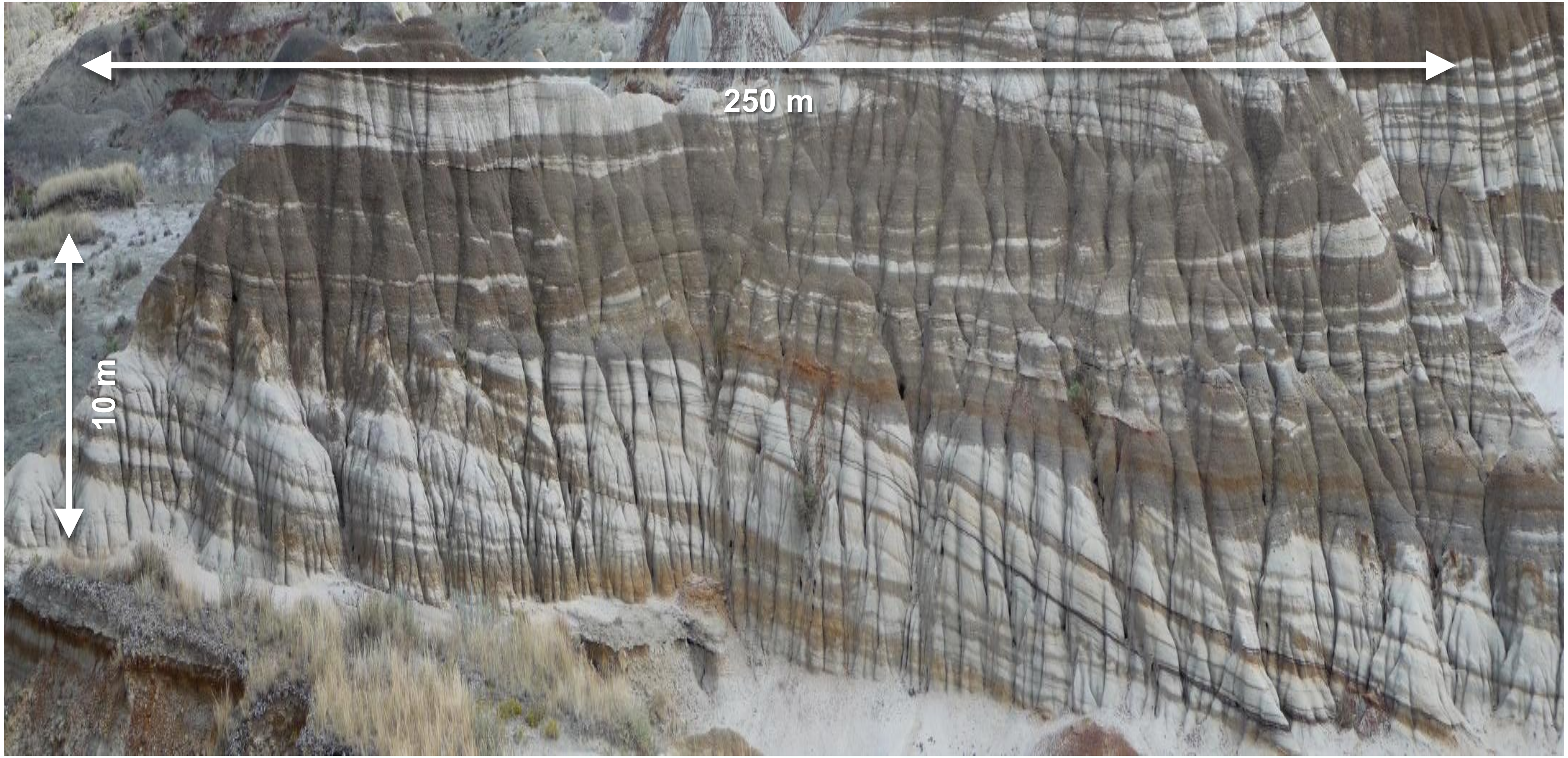
- What is Stratigraphic Heterogeneity and Why Does it Matter?
- Sequence Stratigraphy and Facies Models as a predictive framework for subsurface interpretation
- Case Studies of Application of ESS
  - Silicon Valley: Geologic Mapping and Forensic Source Partitioning
  - Eglin Air Force Base: Sequence Stratigraphy for Pump and Treat Optimization

Got More Work Than You Can Handle?
SEQUENCE STRATIGRAPHY Can Lighten Your Load

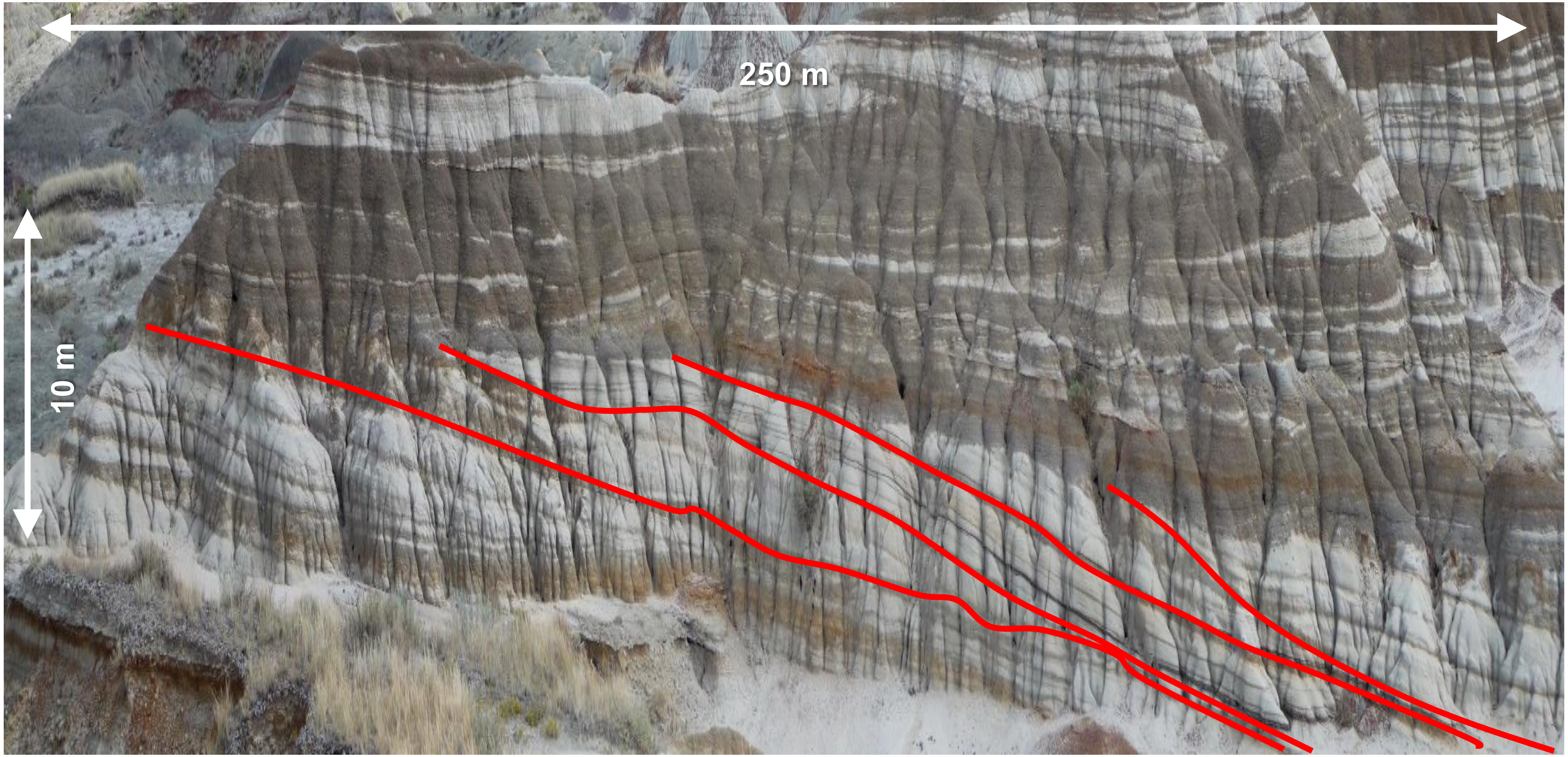
The Problem of Aquifer Heterogeneity

- Outcrop analog of meandering fluvial deposits (white is sand, brown is clay) (Upper Cretaceous Horseshoe Canyon Formation, Alberta, Canada)
- At aquifer remediation site scale
- Ability to map sand channels in three dimensions

The Problem of Aquifer Heterogeneity



The Problem of Aquifer Heterogeneity



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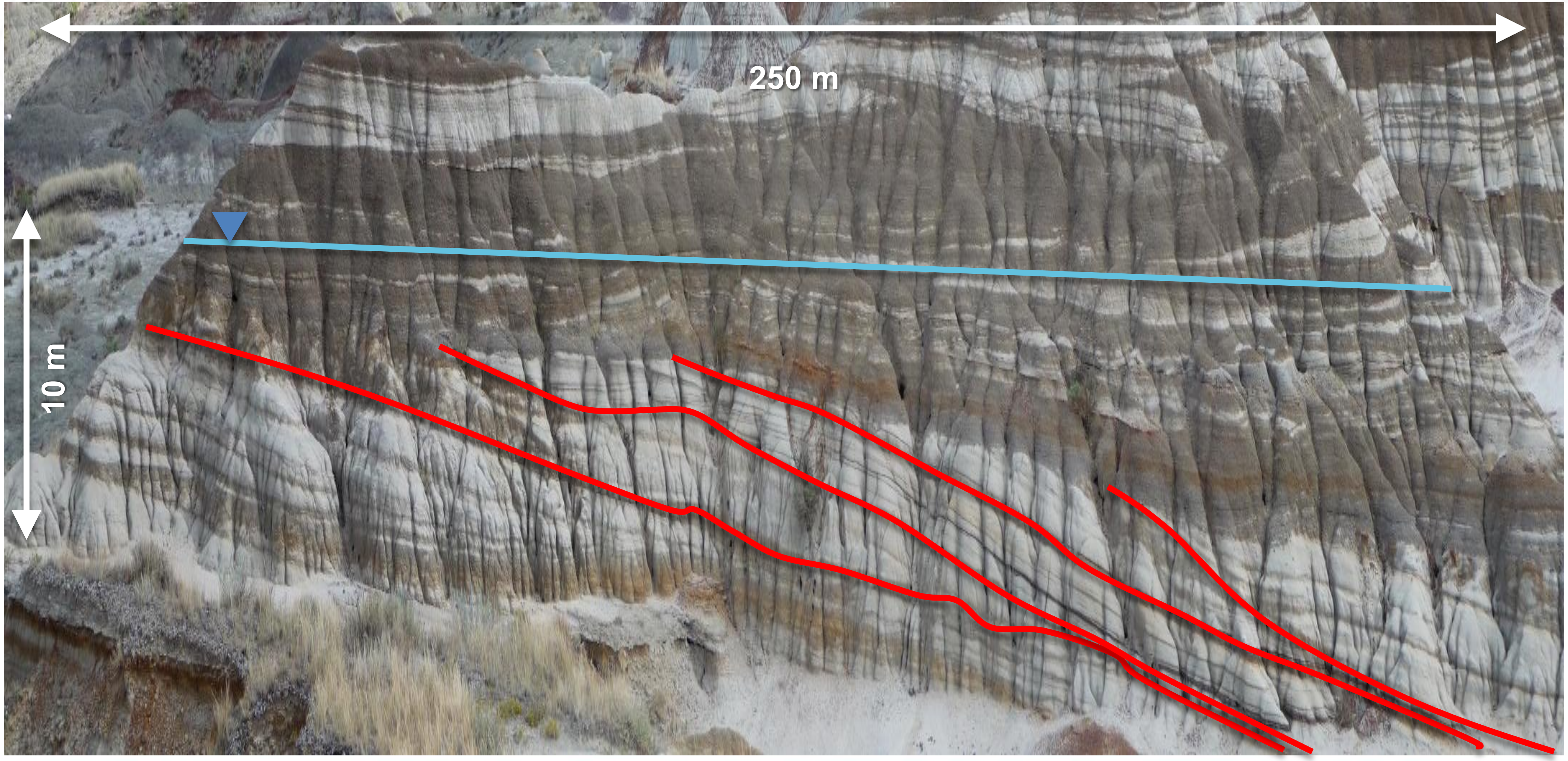

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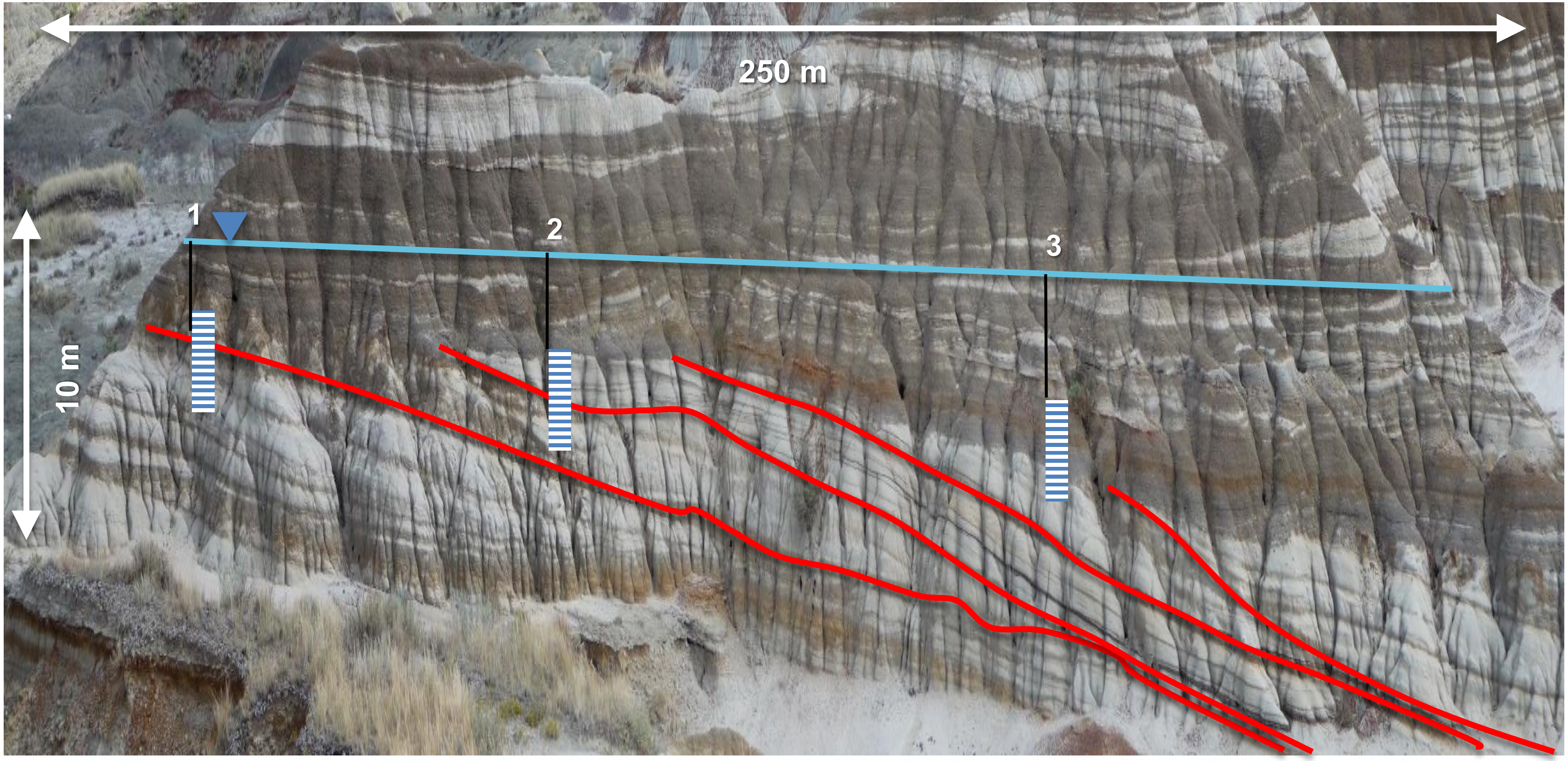
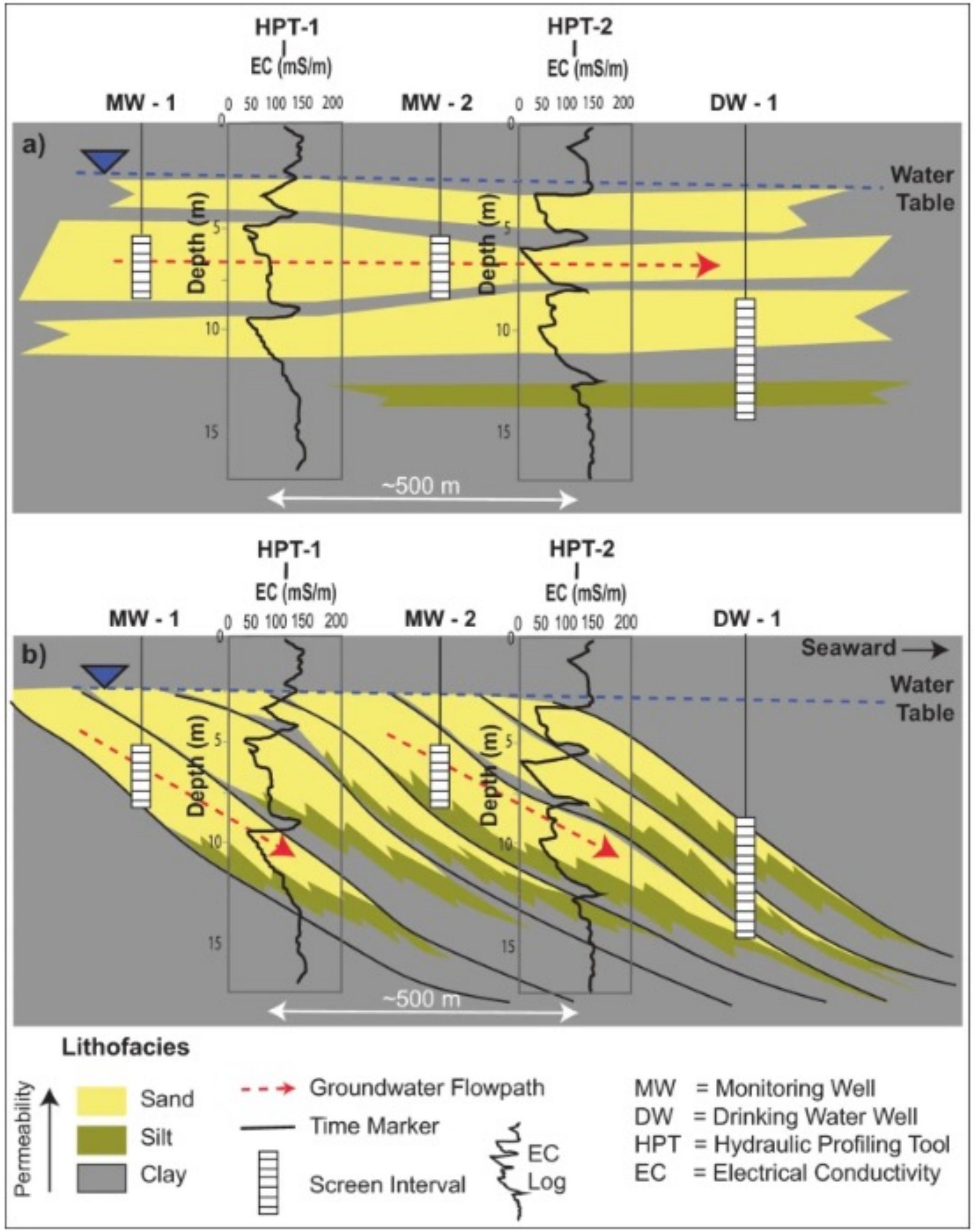


Cross Sections

- Correlating "first encountered sand" is common practice, but often is not the case and can be problematic
- Important implications for groundwater and contaminant flow paths
- Poses risks for accurate monitoring of contaminant plumes, remediation success



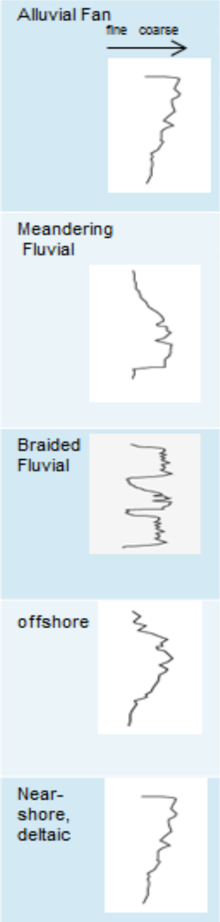
Sadeque, J., Samuels, R.C. (2024). The Application of Sequence Stratigraphy to the Investigation and Remediation of LNAPL-Contaminated Sites. In: García-Rincón, J., Gatsios, E., Lenhard, R.J., Atekwana, E.A., Naidu, R. (eds) Advances in the Characterisation and Remediation of Sites Contaminated with Petroleum Hydrocarbons. Environmental Contamination Remediation and Management. Springer, Cham. https://doi.org/10.1007/978-3-031-34447-3__4

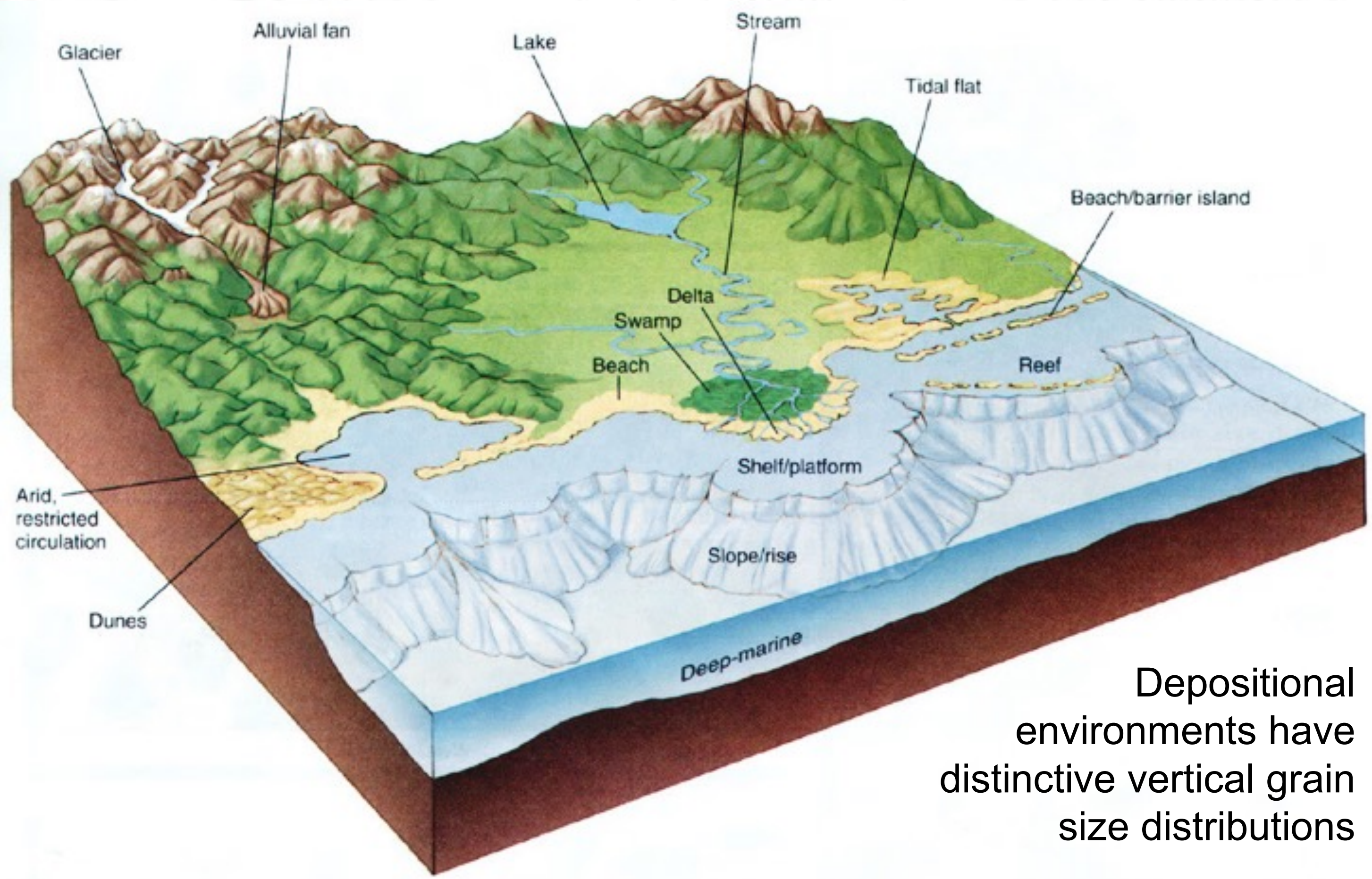
Facies Models: Filling in the Blank Spaces

For one who has seen the Mona Lisa many times, the smile is sufficient information to complete the picture

Same is true for those familiar with depositional environments, with the right clue the picture can be filled in (correlation between wells)

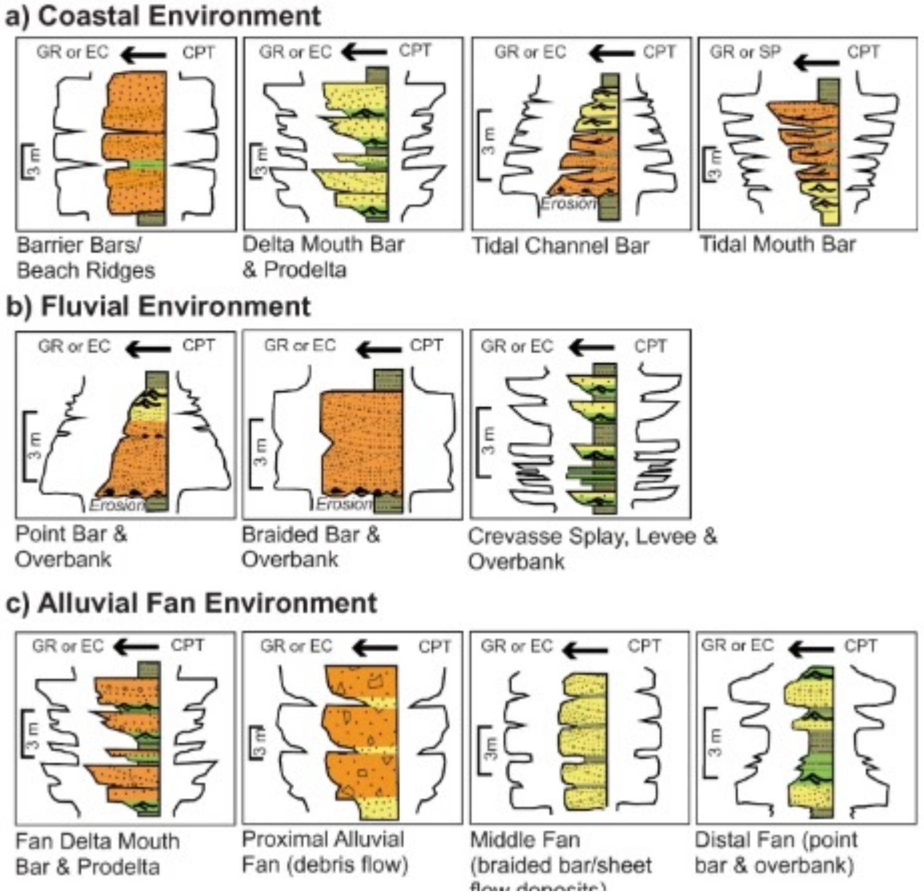
Introduction: ESS is About Pattern Recognition





Depositional environments have distinctive vertical grain size distributions

Depositional Environments and Log Signatures



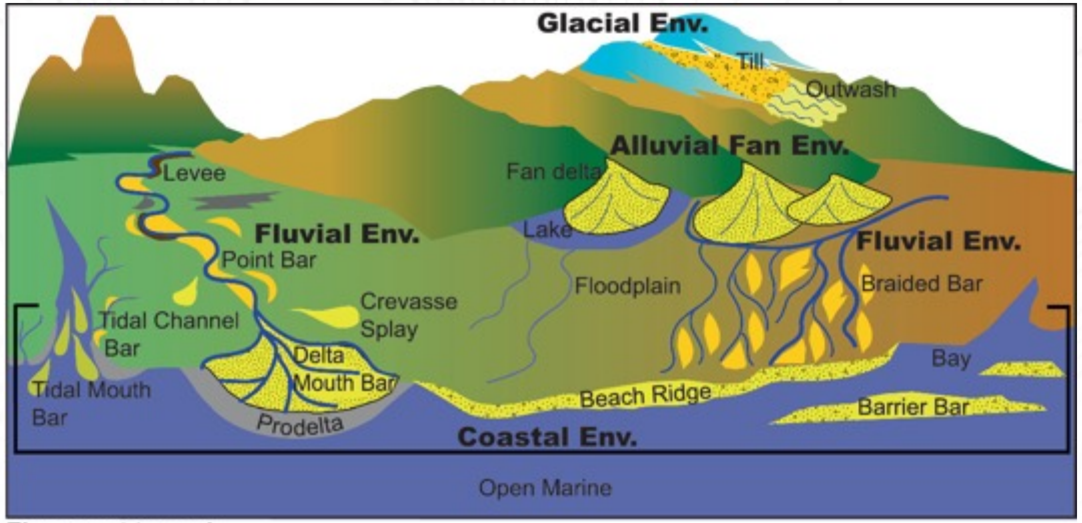
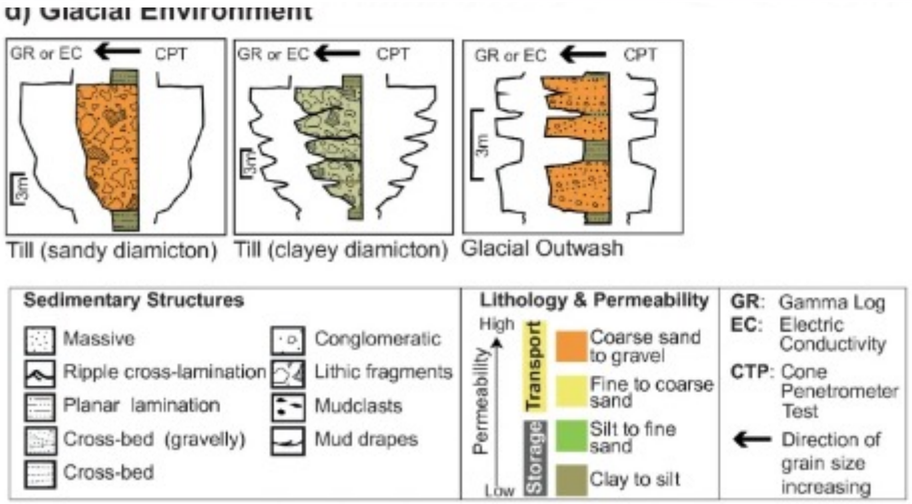


Figure not to scale



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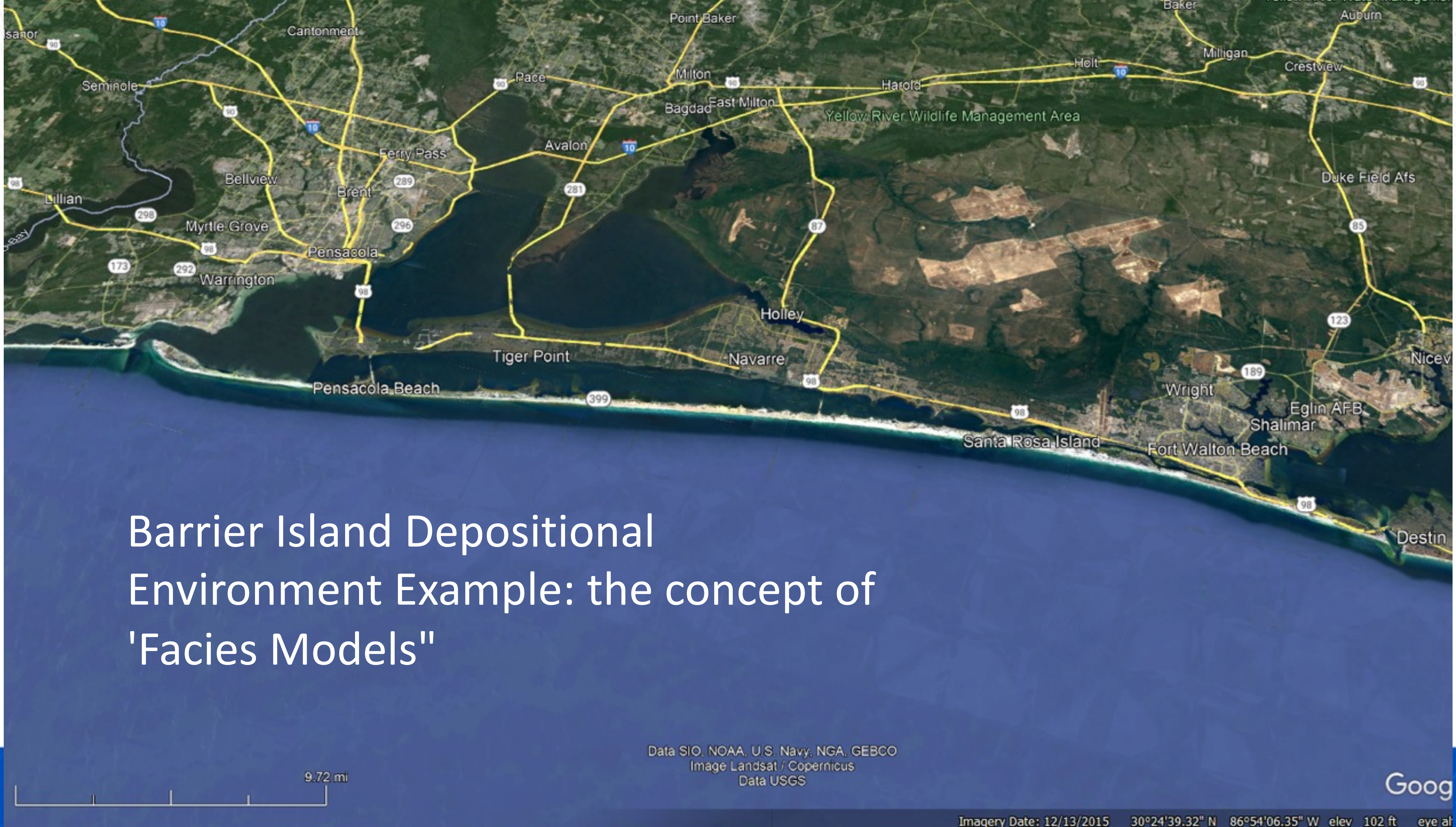
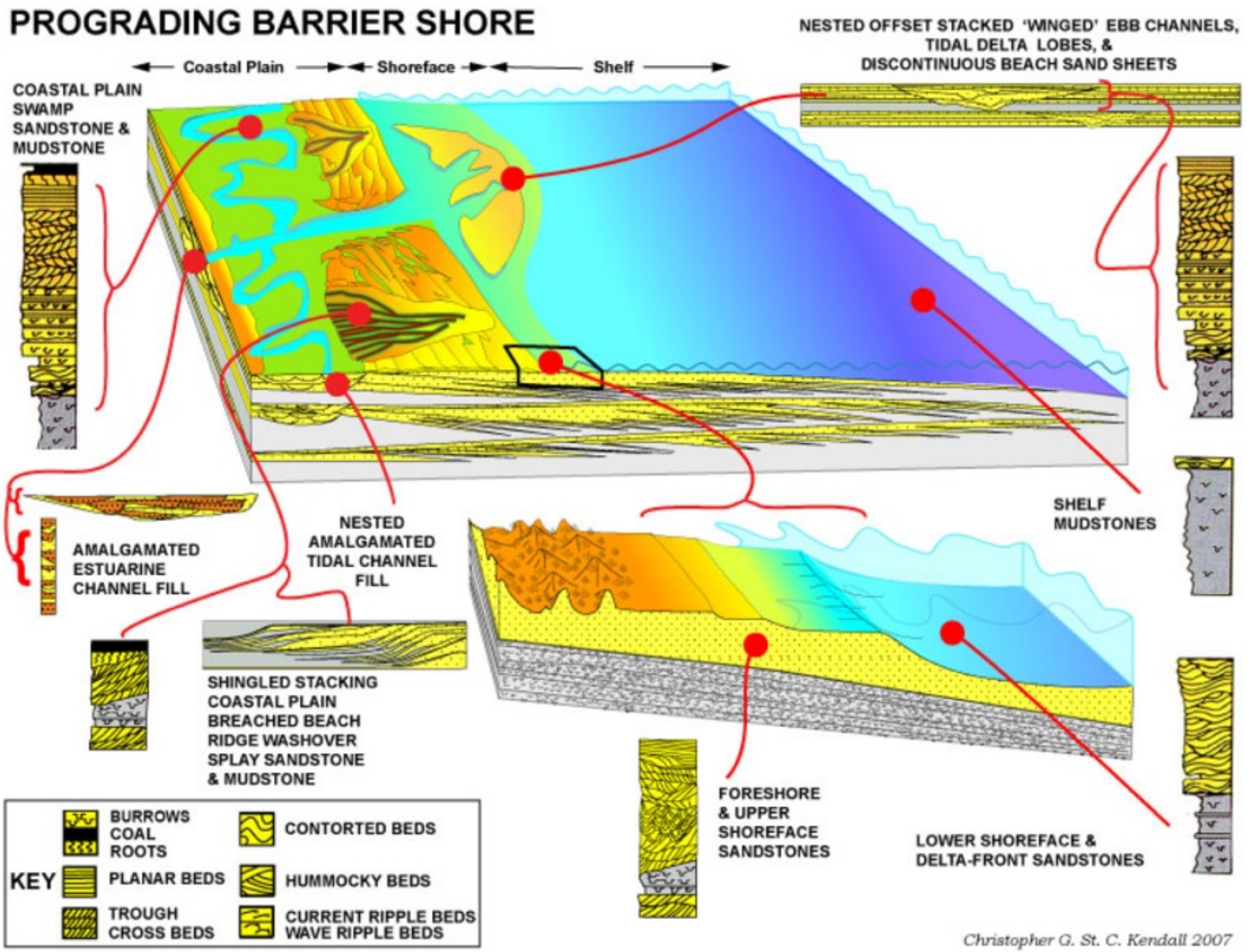
Barrier Island Depositional Environment Example: the concept of 'Facies Models"



Facies Models

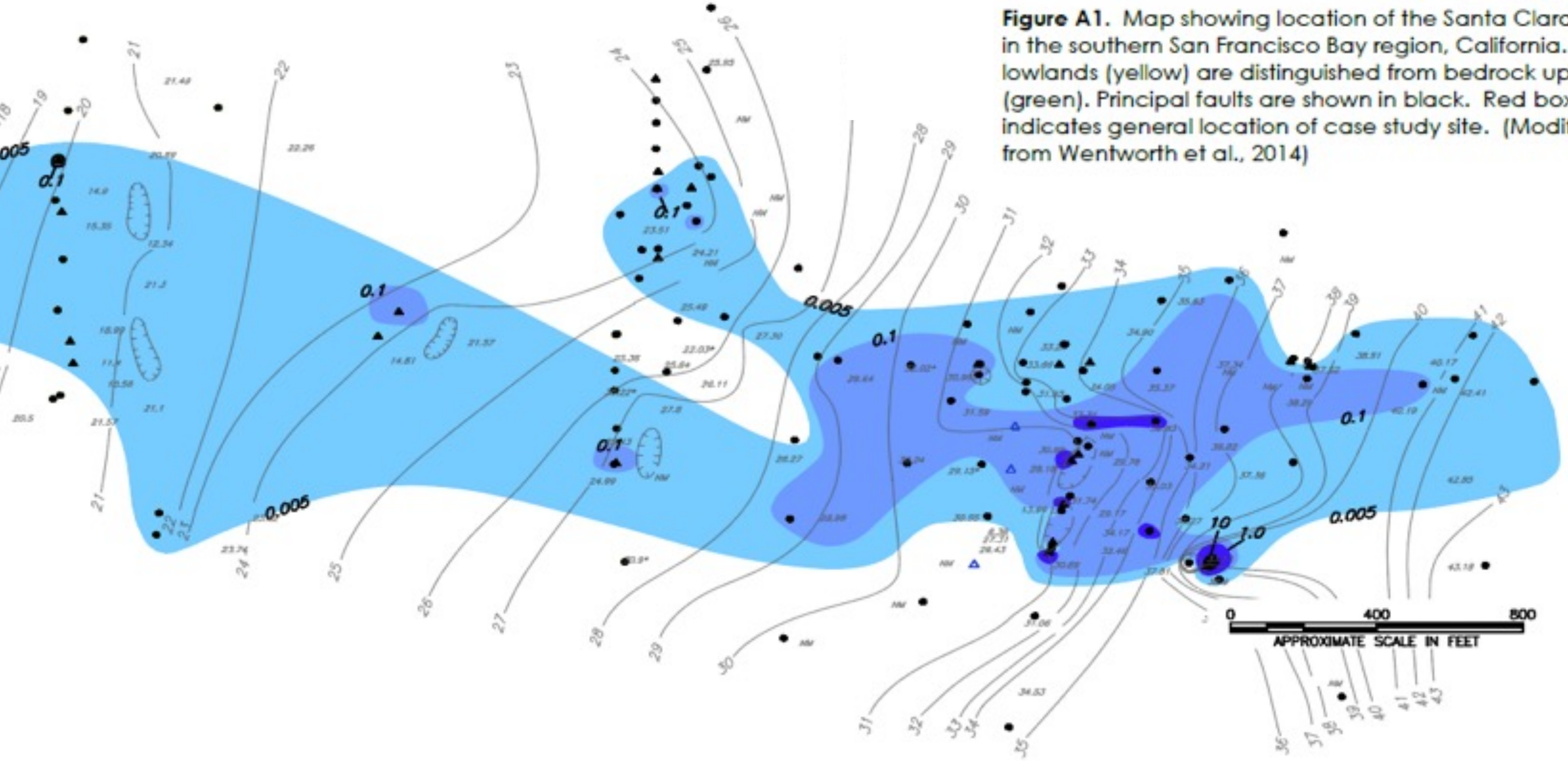
- Detailed model for a Barrier Shore
- "Distillation" of understanding of elements, processes, and preservation of strata, based on data acquired from:
- Modern systems
  - Imagery and surficial features
  - Drilling and coring
  - Remote sensing (geophysics)
  - Historical observations
  - Theoretical and computer models
- Ancient systems
  - Outcrops
  - Subsurface examples (oil and gas fields)
- Provides a predictive framework for subsurface architecture



Case Study #1 - Silicon Valley : Applying Facies Models for Contaminant Pathway Validation

- Silicon Valley, San Francisco Bay Area
- Former semiconductor and other electronics manufacturing, multiple source areas (complex commingled plume, TCE plus)

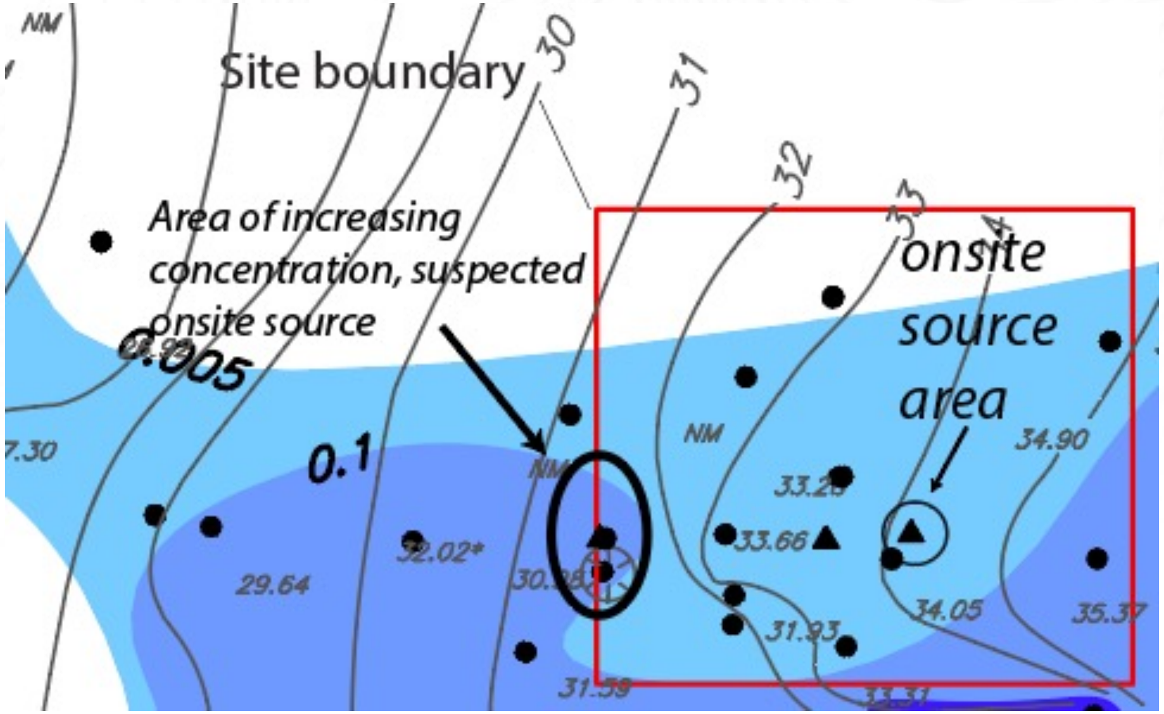
Figure A1. Map showing location of the Santa Clara Valley in the southern San Francisco Bay region, California. Alluvial lowlands (yellow) are distinguished from bedrock uplands (green). Principal faults are shown in black. Red box indicates general location of case study site. (Modified from Wentworth et al., 2014)



- Superfund EPA oversight
- Many remedial actions including in-situ, removal actions

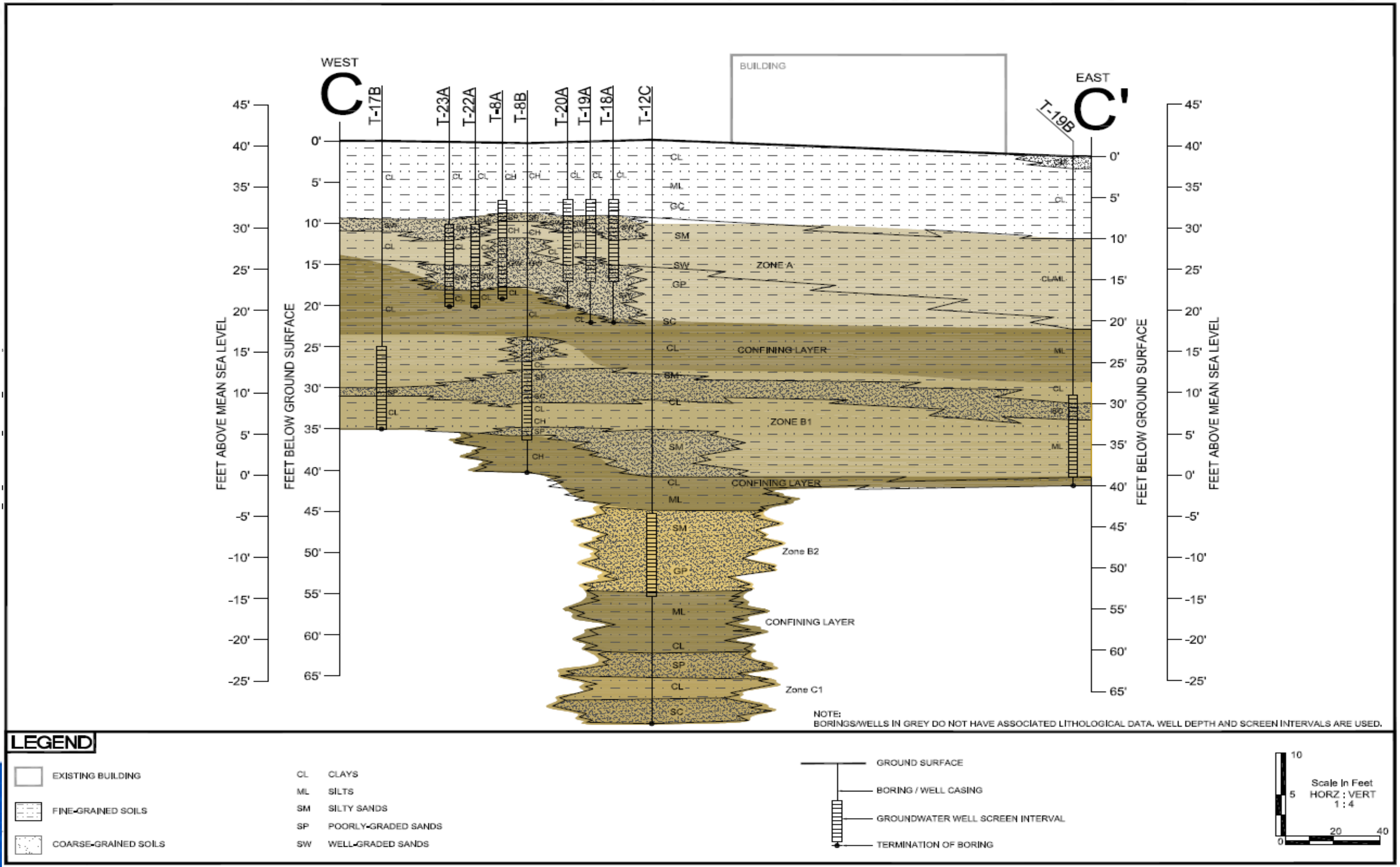
Original Conceptual Site Model

- EPA Five-Year Review flagged rising concentrations of TCE in T-9B as issue and suggested further source area remediation was needed (USEPA 5YR)
- potentiometric surface map suggested onsite source
- Source area within active office space
- Client turned to ESS to investigate
- Revised CSM confirmed off-site source of contamination, well screened through multiple channels



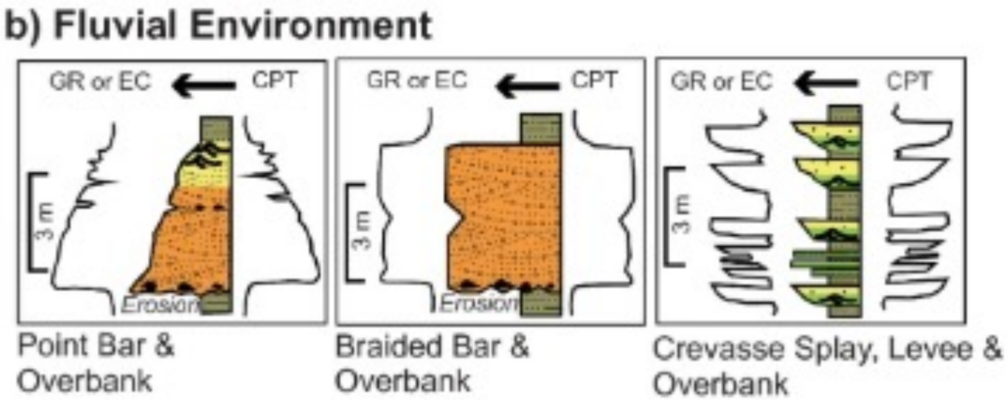
Original Conceptual Site Model

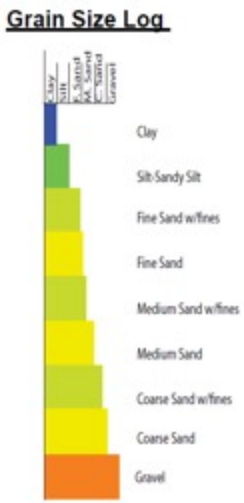
- Layer-cake stratigraphy
- Continuous confining zones
- Depth-based zonation (A, B1, B2)

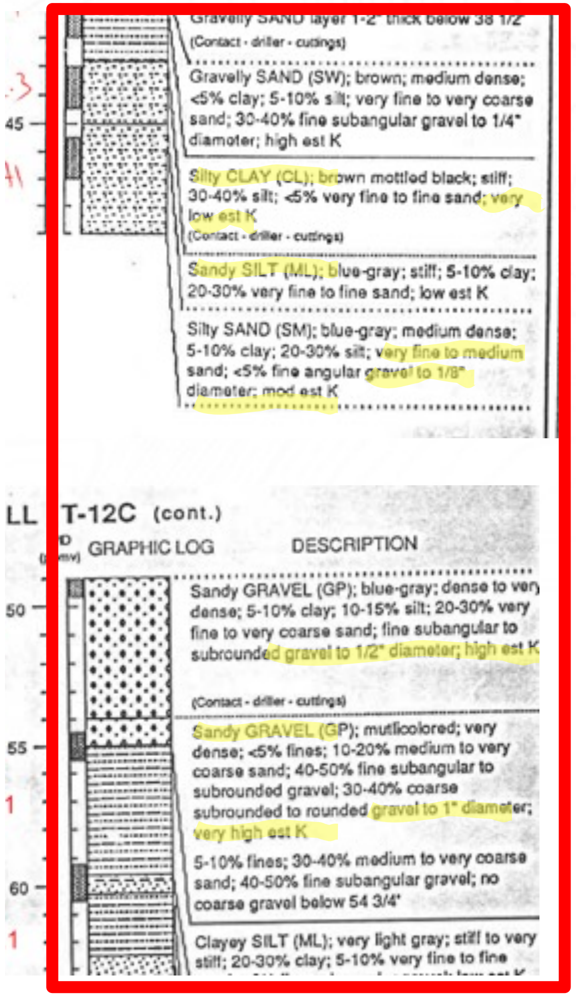


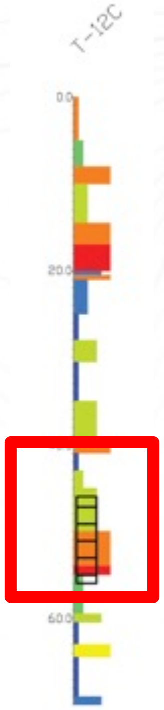
Workflow: Creating Graphic Grain Size Logs

- Normalize different vintages of data collection, sampling methods, geo-bias, etc.
- Identify trends in grain size (indicator of depositional processes)
- Logs show clear fining-upward channel deposits
- Frame expectations for channelized groundwater flow









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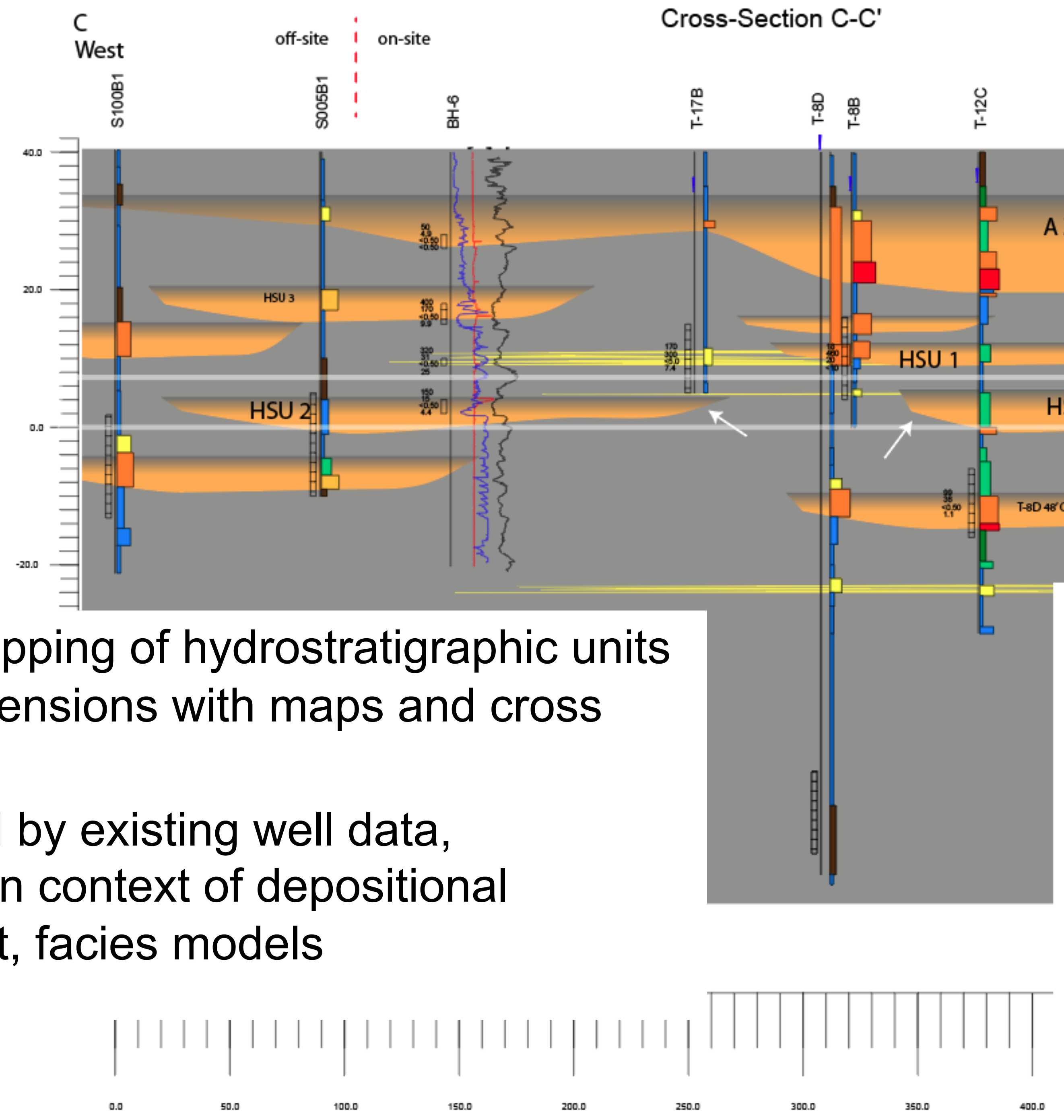
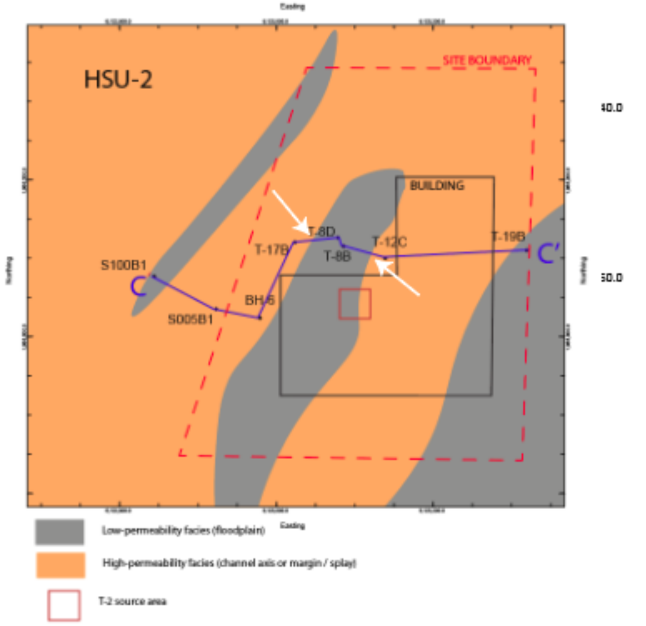
ESS Cross Section



- Detailed mapping of hydrostratigraphic units in three dimensions with maps and cross sections
- Constrained by existing well data, interpreted in context of depositional environment, facies models



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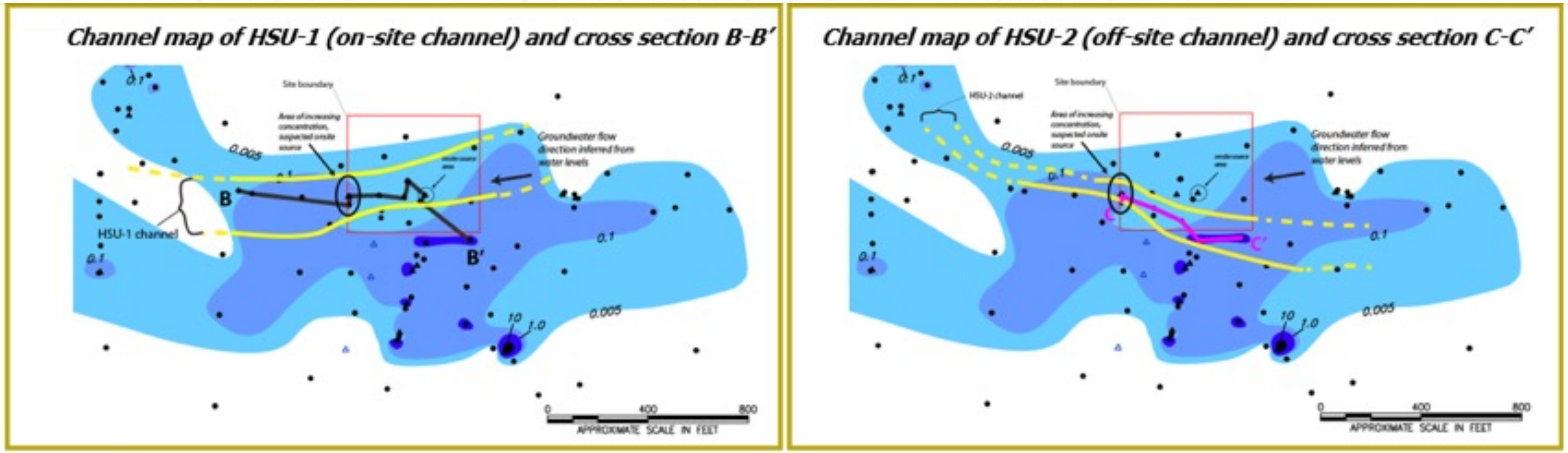
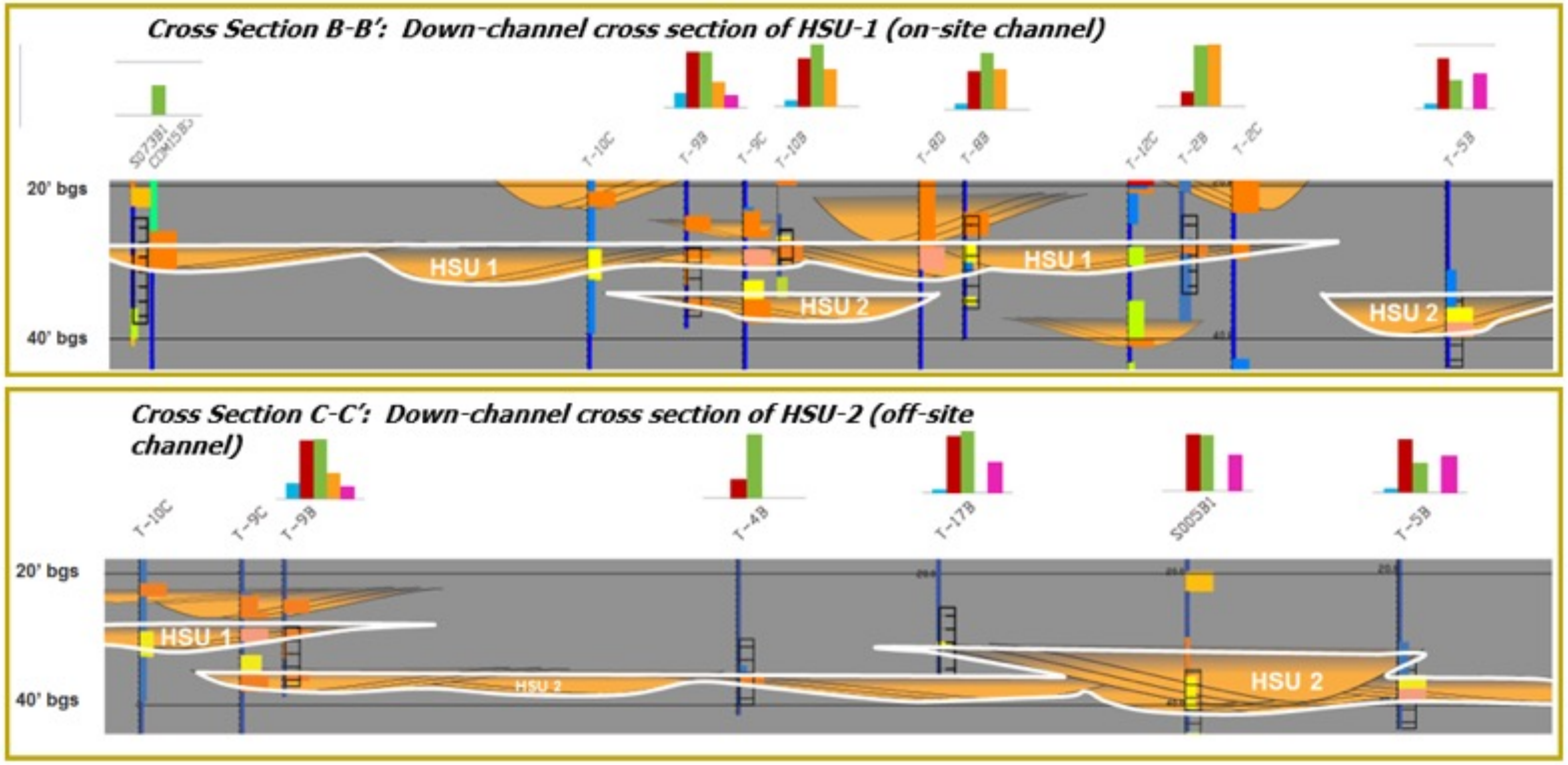
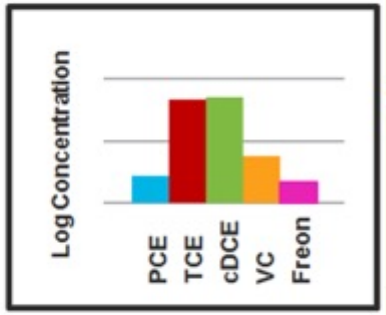
ESS-Based CSM

- Result: detailed understanding of source-to monitoring well hydraulic connection
- Confirmed by contaminant fingerprinting
- Resolved need for additional source area remediation







Case Study #2 - ESS for Pump and Treat Remedy Optimization

- Pump and Treat PCE Groundwater Plume
- Not achieving performance-based remediation (PBR) objectives
- ESS-Based CSM implementation: reconfigure extraction location, no change in capacity
- Dramatic improvement in mass removal, plume collapse

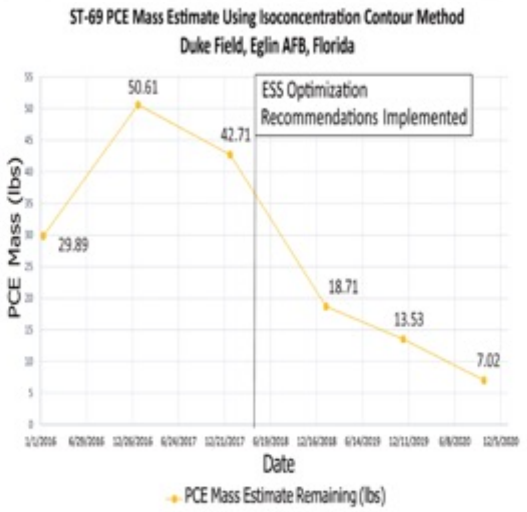


Figure 11. Site ST-69 PCE mass estimate using isoconcentration contour method between January 2016 to October 2020, Duke Field, Eglin AFB Florida.

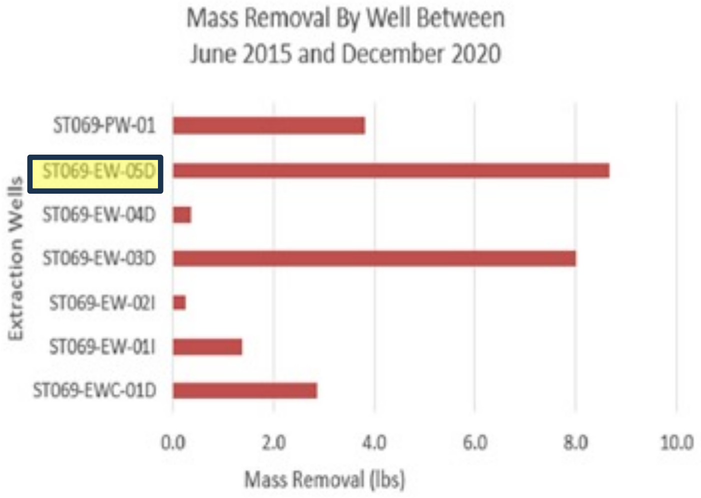


Figure 12. Normalized mass removal by well, 2015-2020.

Leveraging Sequence Stratigraphy to Accelerate Site Remediation: Pliocene Citronelle Formation, Eglin Air Force Base, Florida, USA

by Mike Shultz, Colin Plank, Mark Stapleton, Leo Giannetta and Rick Cramer

Abstract

At Eglin Air Force Base (AFB) in the Florida Panhandle, a groundwater extraction and treatment system was installed to contain and remediate a chlorinated solvent plume. After 2 years of operation, the system was not removing the contaminant mass at the rate predicted or required to meet performance-based contract terms. As a result, a sequence-stratigraphic analysis was initiated to develop a strategy to improve performance. Sequence Stratigraphy methods were employed to identify a marine flooding surface (mfs) formed during a relative sea level highstand. The analysis also found that the mfs was locally eroded away, indicating that incised valleys were eroded into the formation during a relative lowstand of sea level. These valleys were backfilled with coarse-grained fluvial and estuarine strata. The analysis concluded that the groundwater extraction system lacked an extraction well screened within the coarse-grained valley fill. An additional extraction well was installed, which targeted the incised valley fill and resulted in a significant increase in contaminant mass removal rate without increasing system capacity or operational costs. This case study suggests that efficiency improvements are tenable at many sites where groundwater remediation is occurring within the Surficial Aquifer System of the Gulf Coast (Citronelle Formation) as well as sites in similar geologic settings worldwide.

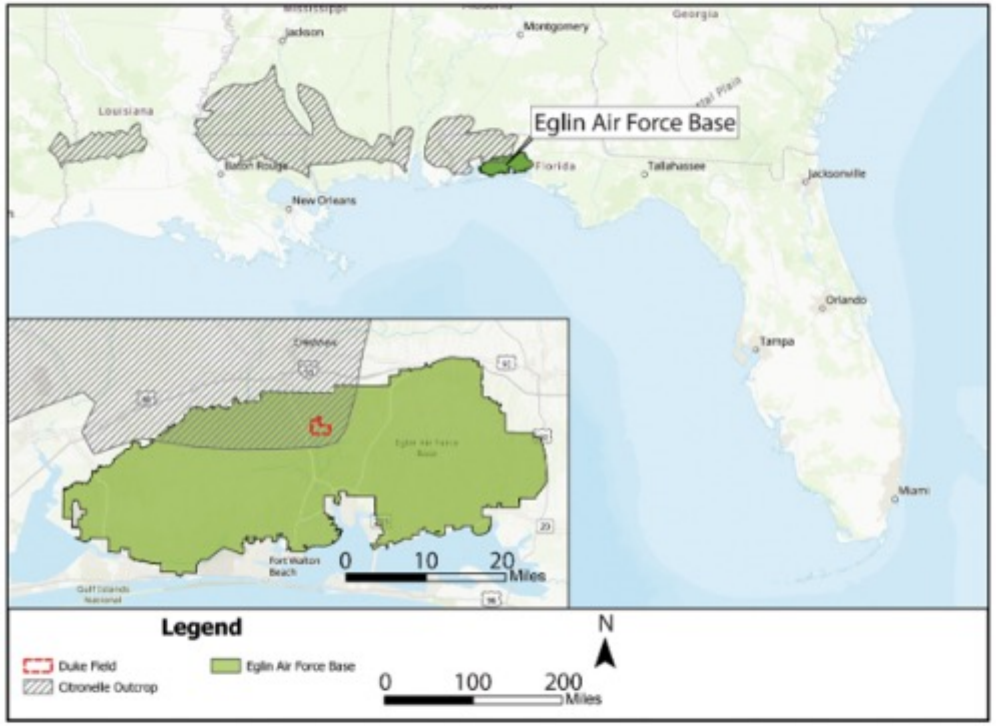


Figure 1. Location of Eglin Air Force Base, site ST-69 groundwater plume site, and Citronelle Formation outcrop belt.

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Classic Sequence Strat!

- Sea-level fluctuations caused by growth of continental glaciations (ice ages)
- Dramatic impact on shoreline dynamics, sedimentation
- Incised valleys are ubiquitous in the geologic record, high-permeability fluvial deposits
- Sea-level rise and the "maximum flooding surface": the key to remediation at Eglin

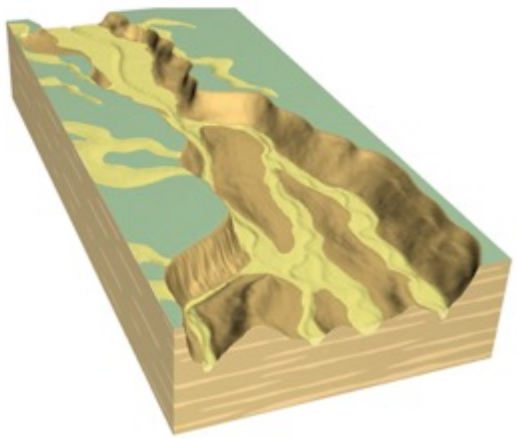
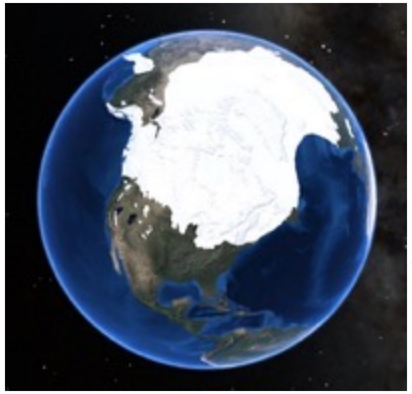
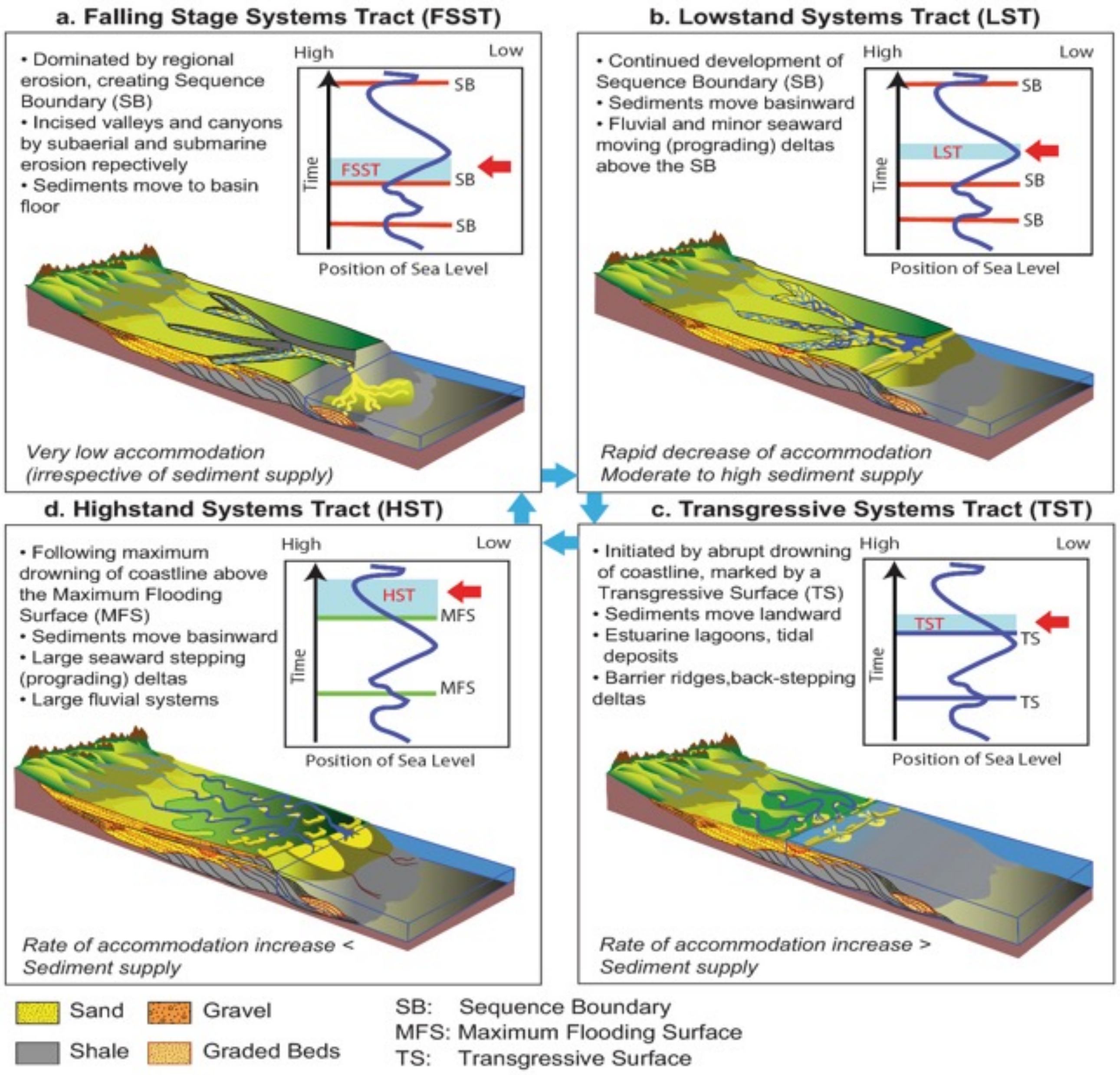


Figure 7. Block diagram illustrating downcutting of streams during a relative lowstand of sea level. From Ambrose and Hentz 2011, used with permission from the Bureau of Economic Geology, University of Texas.

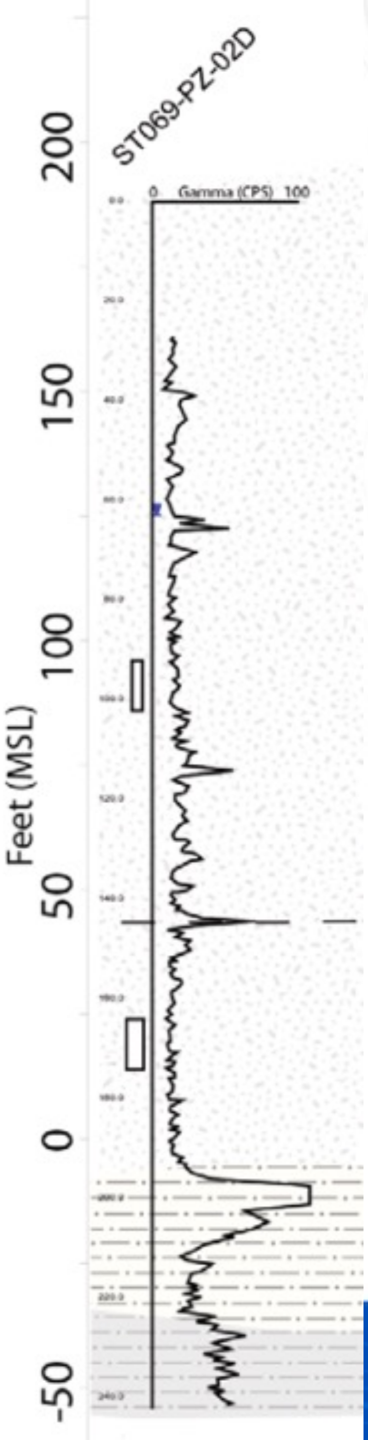




Sadeque, J., Samuels, R.C. (2024). The Application of Sequence Stratigraphy to the Investigation and Remediation of LNAPL-Contaminated Sites. In: García-Rincón, J., Gatsios, E., Lenhard, R.J., Atekwana, E.A., Naidu, R. (eds) Advances in the Characterisation and Remediation of Sites Contaminated with Petroleum Hydrocarbons. Environmental Contamination Remediation and Management. Springer, Cham. https://doi.org/10.1007/978-3-031-34447-3_4

ESS Cross Section

- Citronelle Formation overlying Alum Bluff regional confining unit
- Conspicuous gamma-ray spike most correlative a 50’ msl
- Revised interpretation identified incised valleys within Citronelle



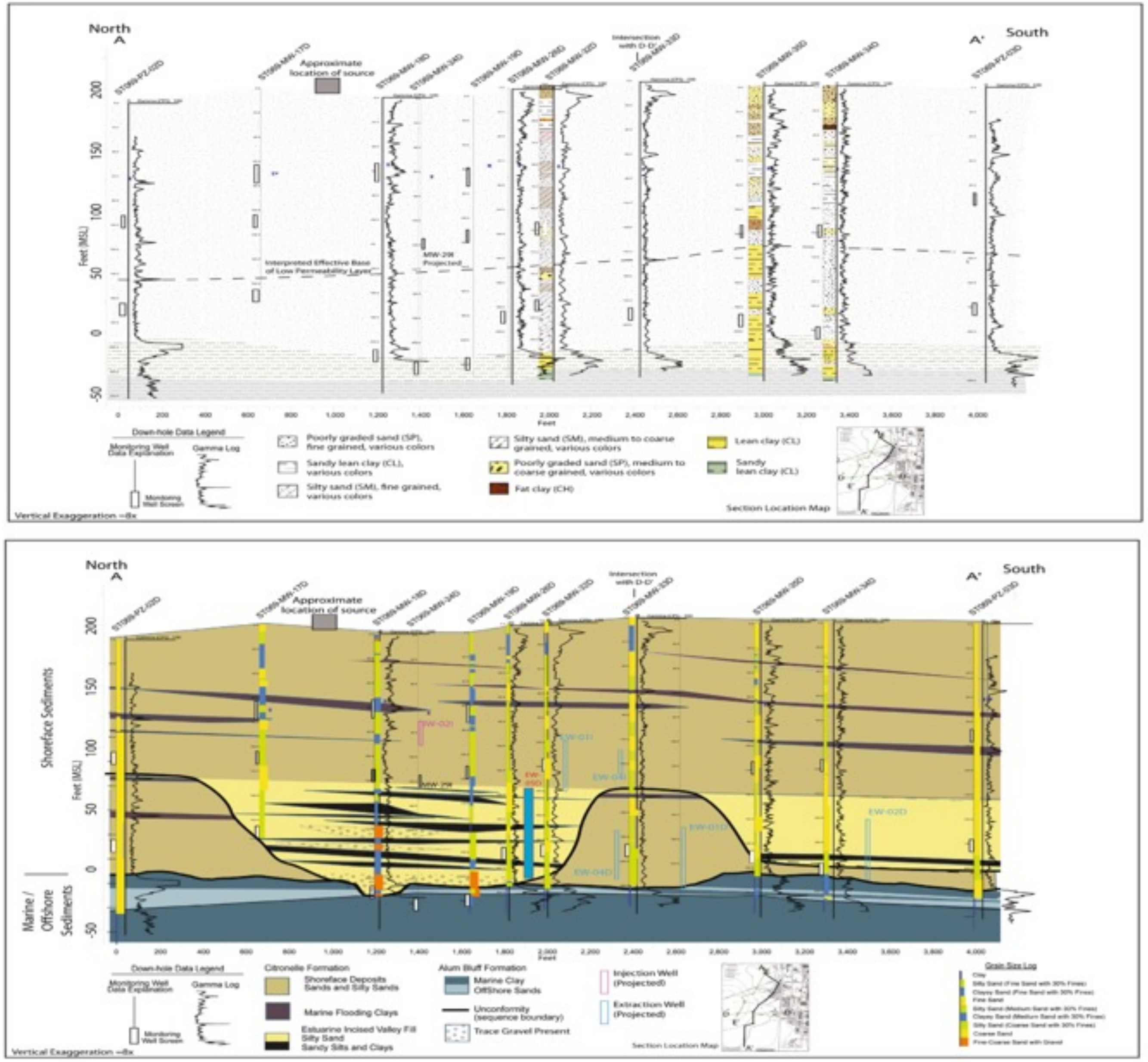


Figure 9. Site cross section illustrating the absence of the mfs where removed by the incised valley, and comparison with the CSM used in the original groundwater extraction and treatment system design. Also shown is the location of the extraction well placed in the incised valley fill downgradient from the source area. Note presence of gravel-bearing units in the heterolithic incised valley fill, and gravelly lag at the base of the incised valley.

ESS-Based CSM

- ► Mapping of MFS and Incised Valleys indicated a lack of extraction well in the IVF
- ► Addition of EW-05D in permeable IVF resulted in dramatic performance improvement, attainment of performance goals

There is no such thing as a "sandbox" when it comes to remediation! What's missing is often as important as what's there in stratigraphy!

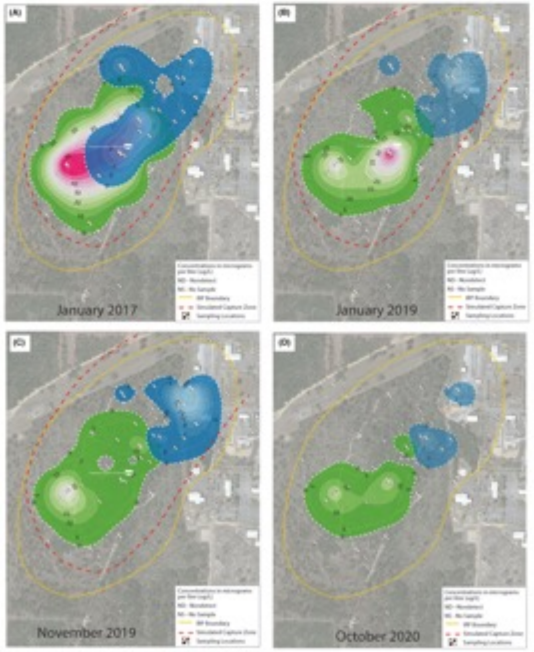
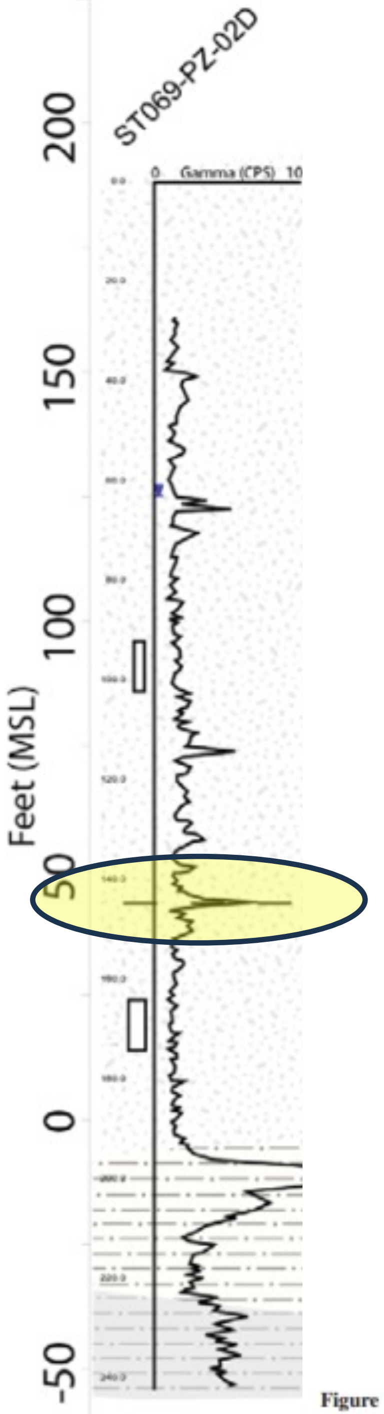


Figure 13. Evolution of the PCE plume after installation of EW-5D.



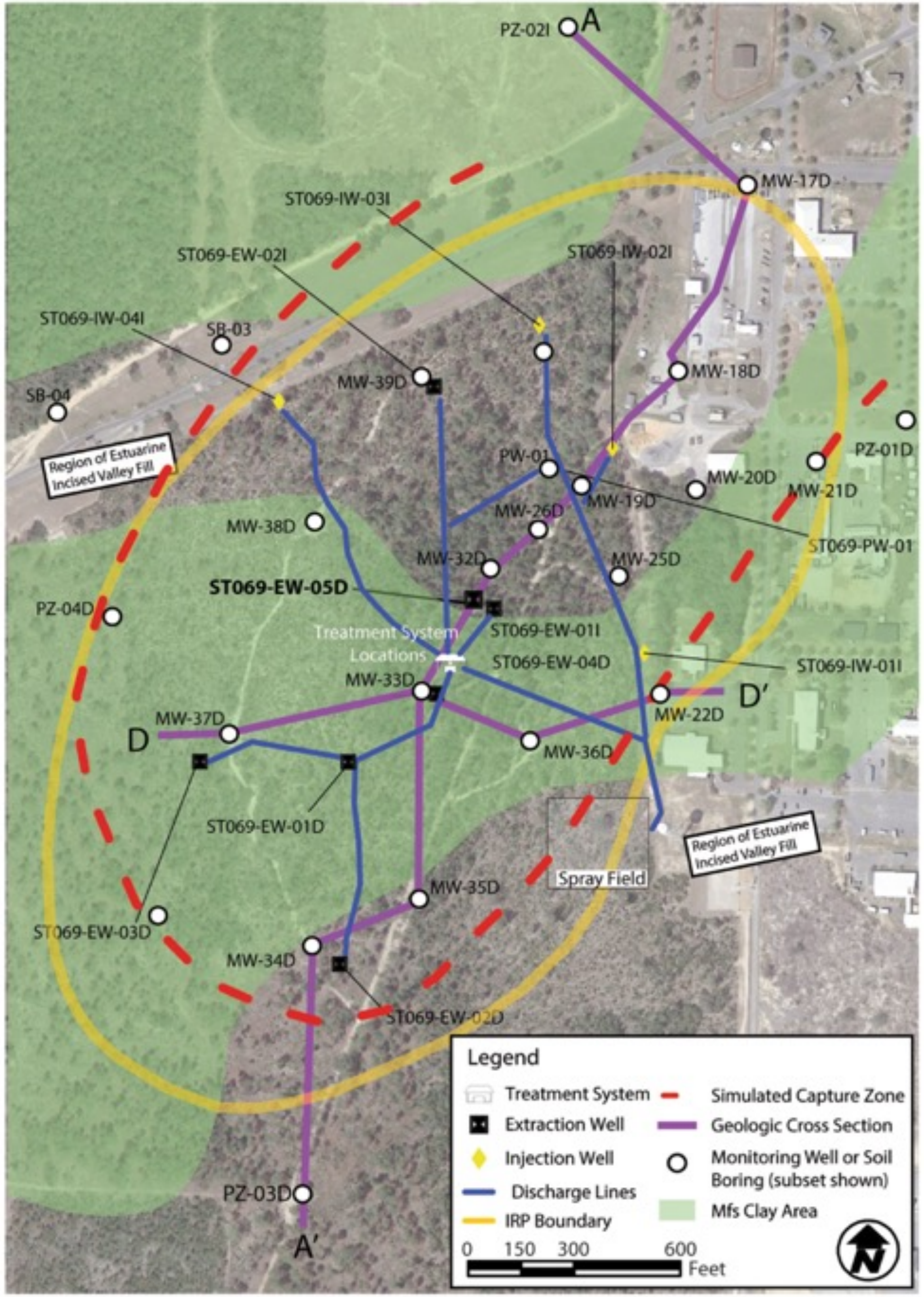
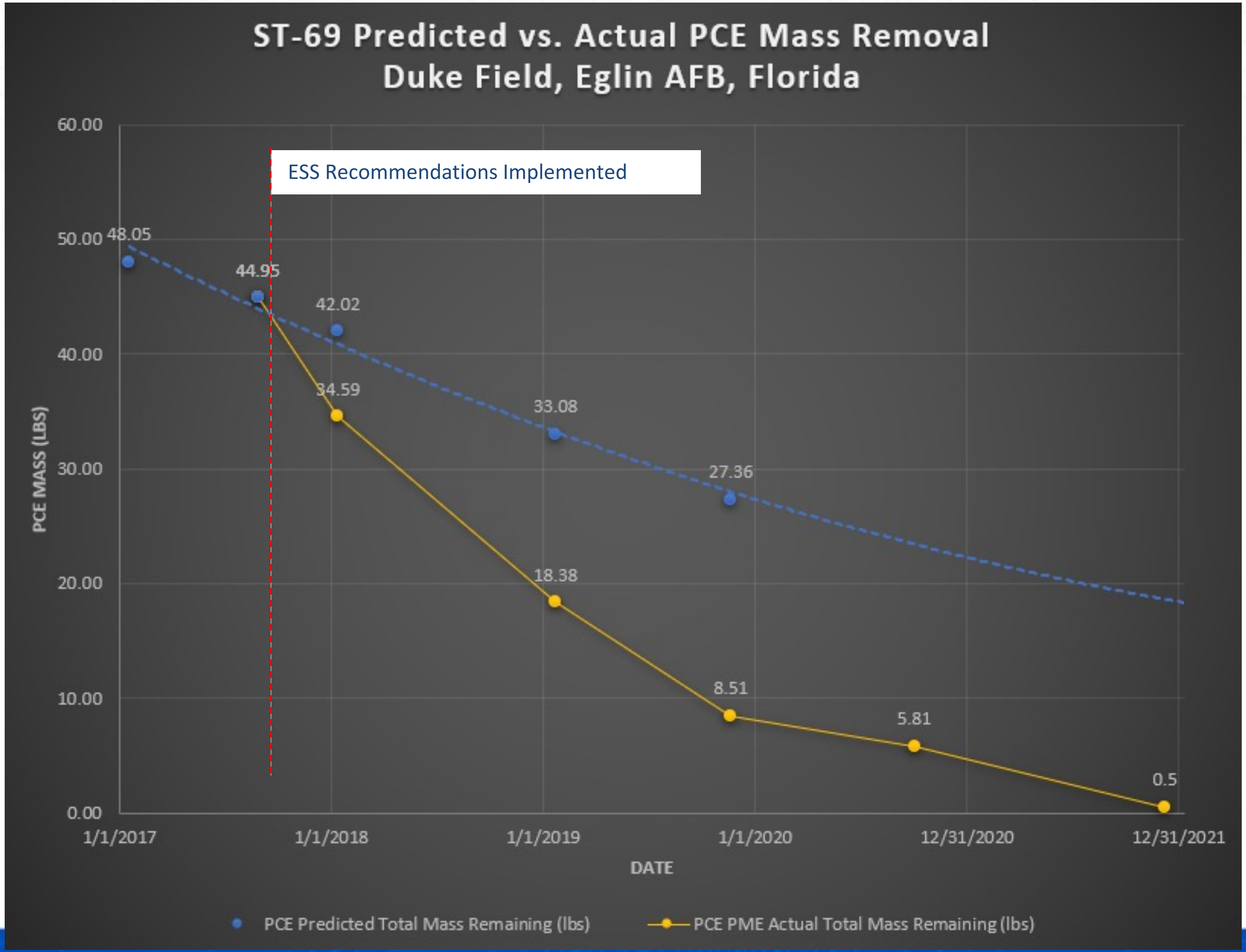


Figure 10. Site map illustrating cross section locations and areas of mfs preservation and incised valleys.

Remediation Performance Model

- Prior to ESS, predicted Site Closure (SC) date was 2032
- Post-ESS implementation Site Closure was 2022 plus Post Active Remedial Monitoring
- Implementation of ESS reduced the time to achieve Site Closure by 10 years
- 87% PCE Mass Reduction in 3 years



Sources: Eglin AR 31434, 31133, 32613

Take-Aways

1. Can’t overemphasize the importance of the practitioner (stratigrapher).
2. ESS is applicable to _____________ contaminants.
3. DOE can reduce the risk of uncertainty at radioactive waste sites and increase environmental and worker safety by
   - limiting exposure,
   - reducing inefficient engineering design, and
   - speeding up the remediation process through this targeted approach.

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Supply Chain Management Center (SCMC)
AE services contract

Pacific Northwest
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Enhancing Conceptual Site Models Through Integration of Geologic and Geophysical Data

Judy Robinson, James St Clair, Jon Thomle, Christian Johnson, Delphine Appriou, Rob Mackley

April 23, 2024

DEEP VADOSE ZONE PROGRAM @PNNL

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U.S. DEPARTMENT OF ENERGY BATTELLE

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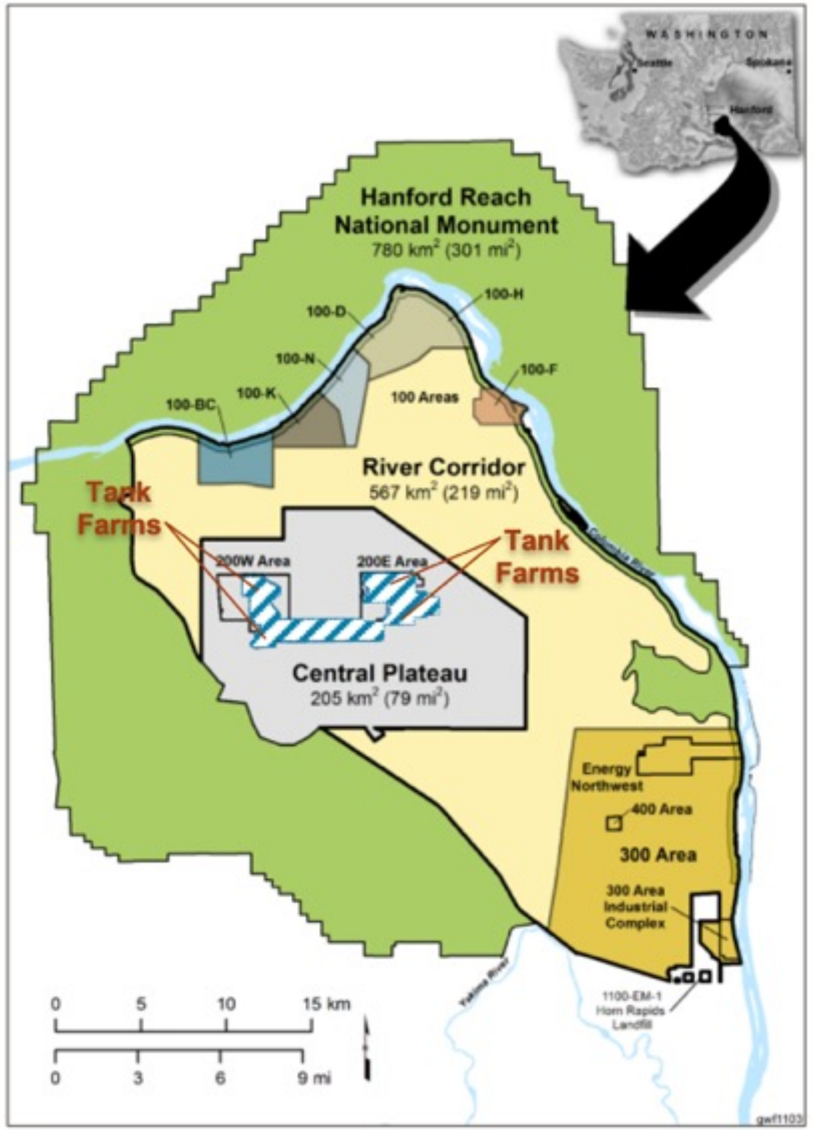
Hanford Site Introduction

- Plutonium was produced as part of the Manhattan project during WWII
- Continued through the Cold War until 1989
- The site’s mission since the early 1990s is focused on cleanup
  - Tank waste
  - Environmental remediation of contaminated waste sites; protection and treatment of groundwater and downstream surface water receptors



https://www.pnnl.gov/main/publications/external/technical_reports/PNNL-32055.pdf

Outline

- Background
  - Hanford geoframework model (GFM)
- Geophysical methods theory, data collection, information extracted
  - Seismic, electrical resistivity tomography (ERT)
- Field examples within the high-hydraulic conductivity zone (HCZ)
  - Southeast of 200 East Area
  - Between the 200 Areas
  - South of 200 East Area
- ERT visualization within SOCRATES
- Conclusions

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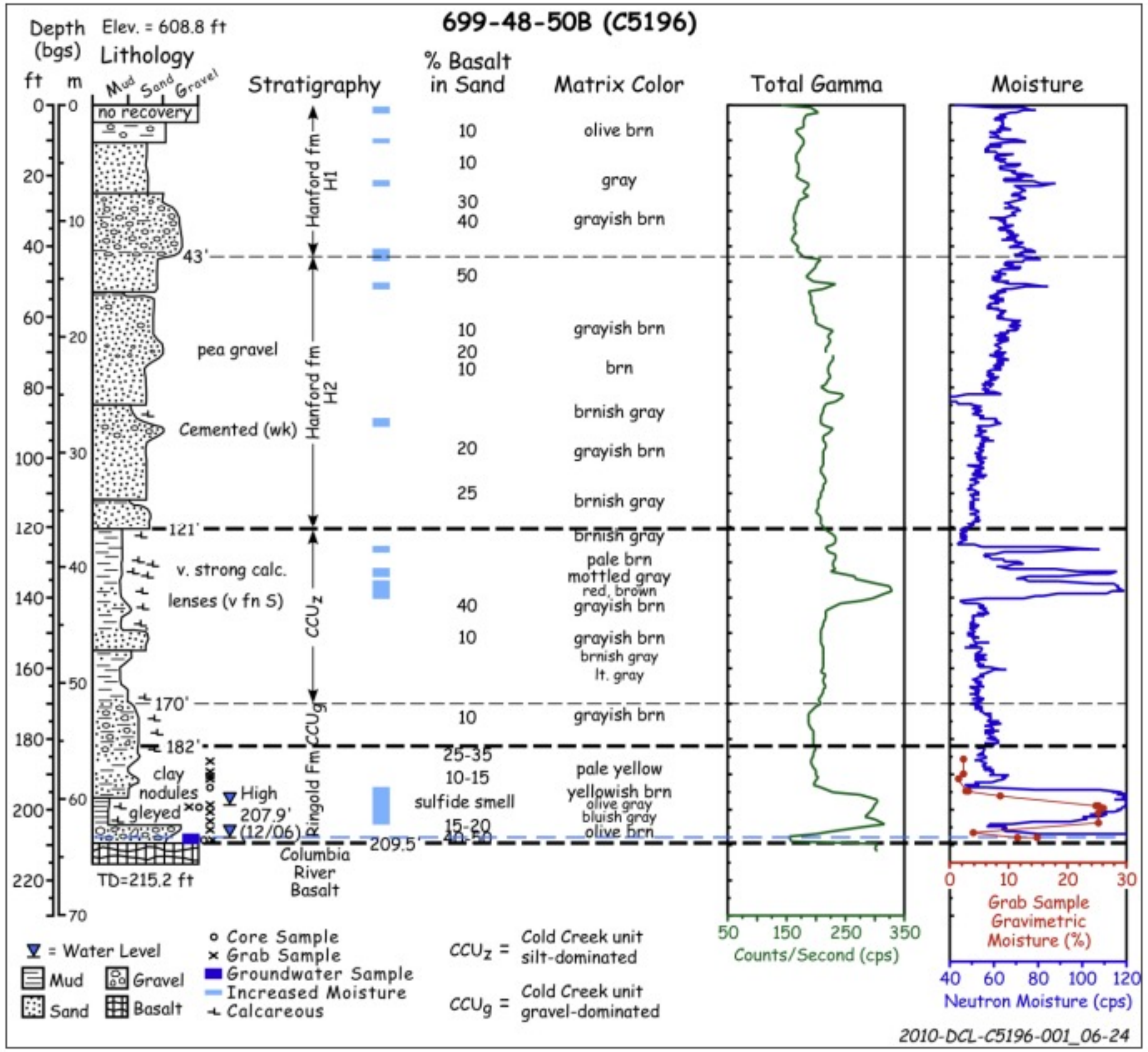
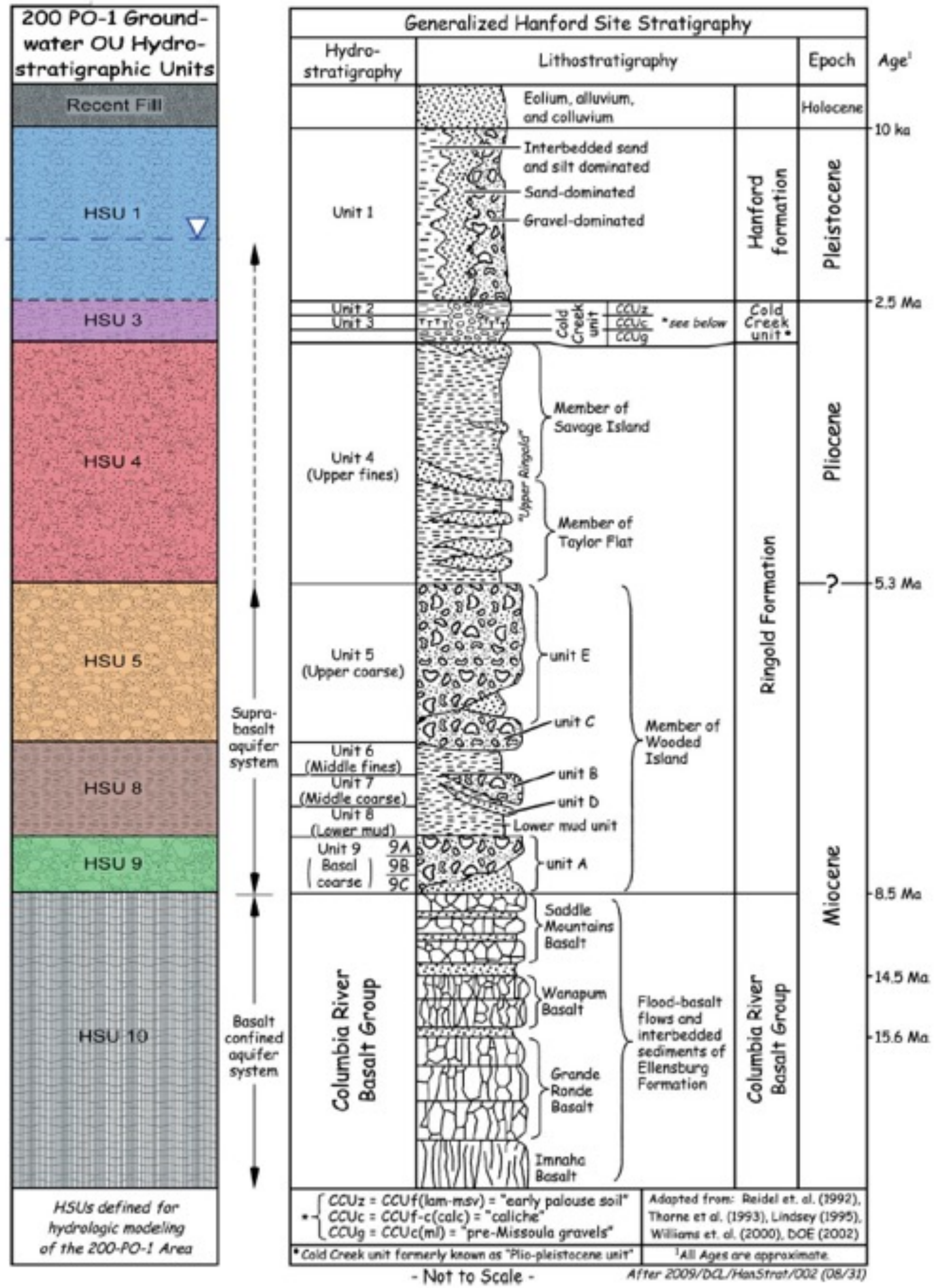
Hanford Site Stratigraphy

- Site stratigraphy is an interpretation of borehole data and observations
  - Core samples, borehole sampling/logs, hydraulic testing



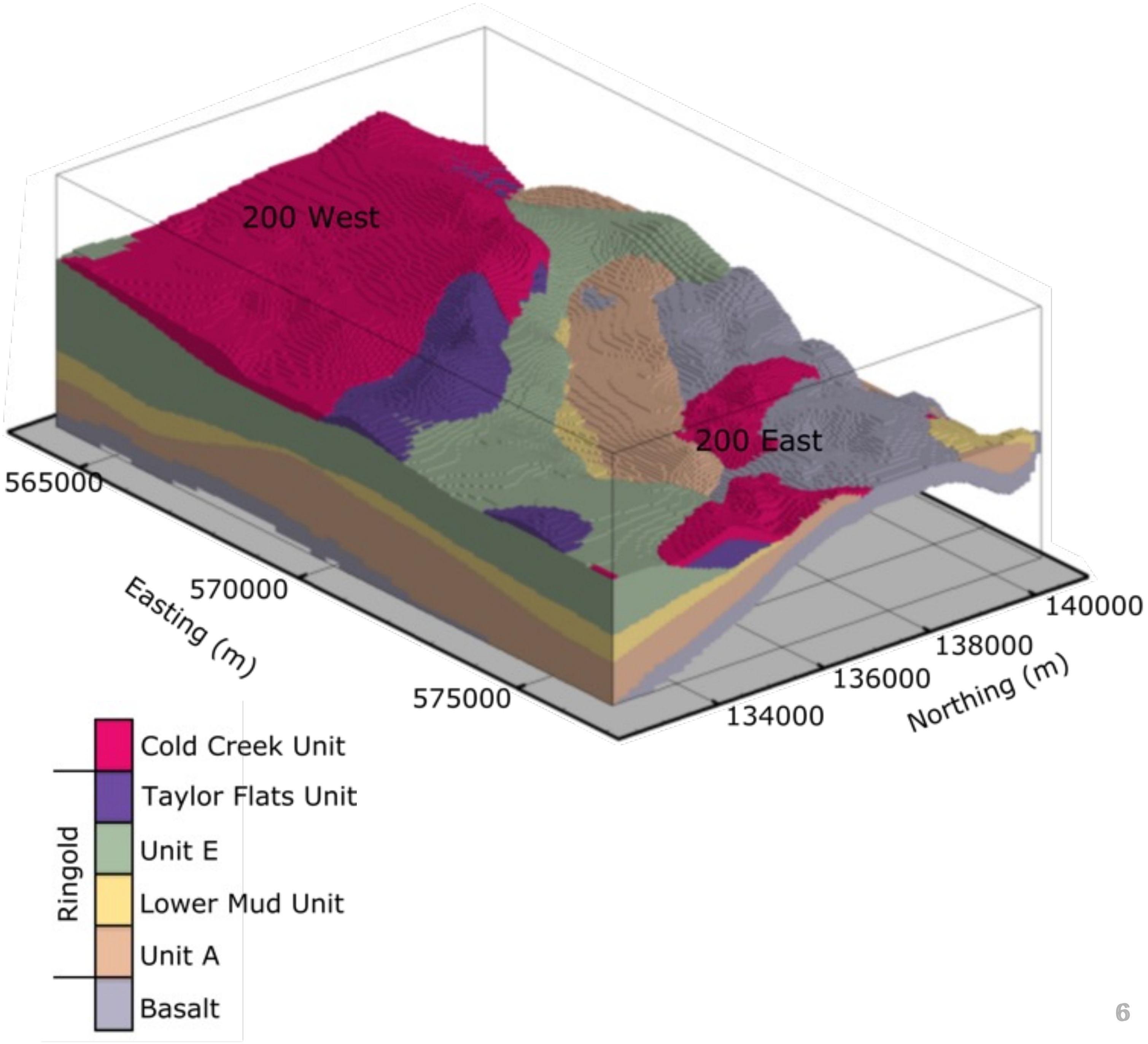
Hanford Site Stratigraphy

- Site stratigraphy is an interpretation of borehole data and observations
  - Core samples, borehole sampling/logs, hydraulic testing
- Represented as hydrostratigraphic units (HSUs)
  - Used within flow and transport simulations



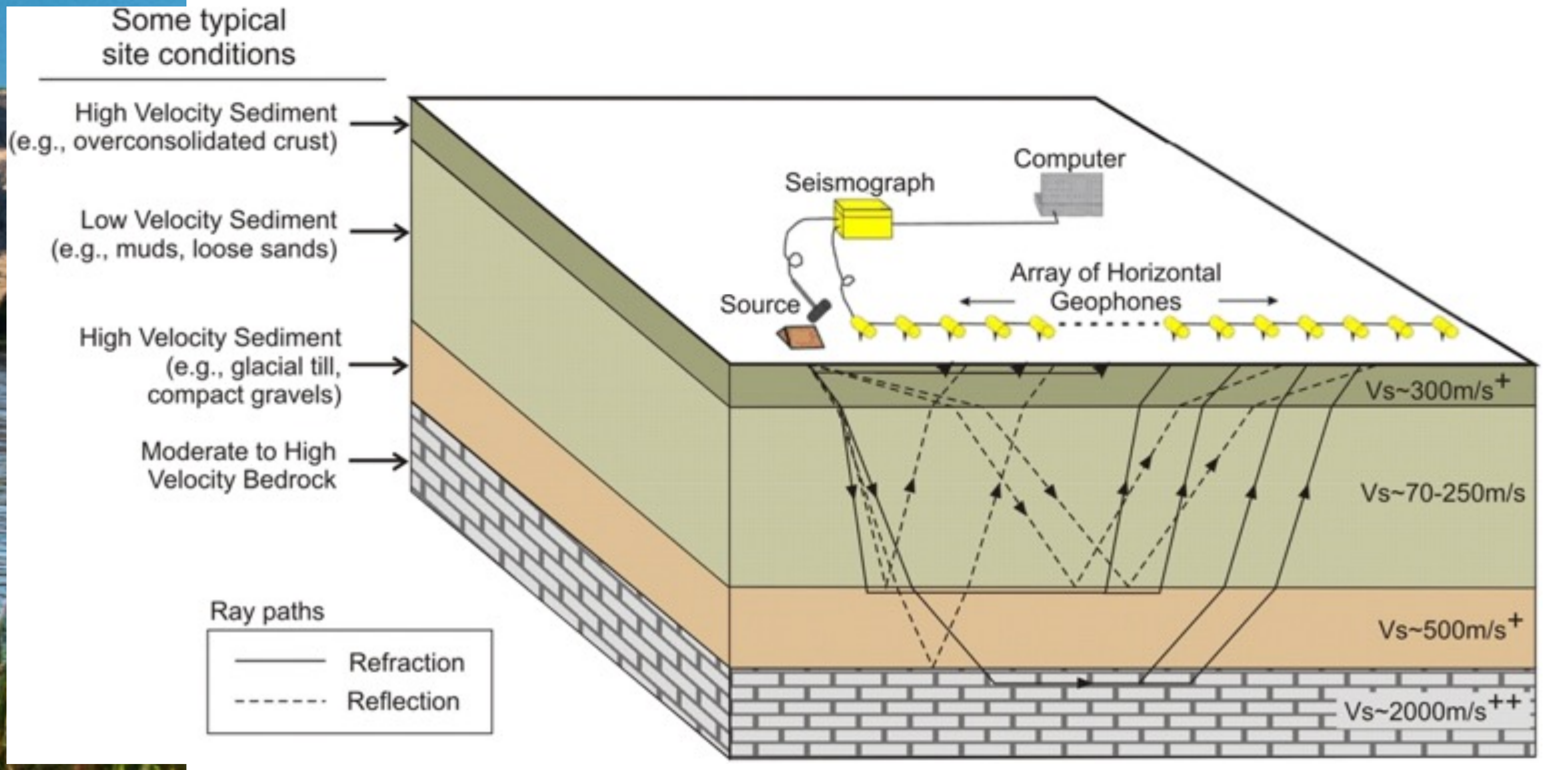
Hanford Geologic Framework Model (GFM)

- Geoframework model (GFM)
  - Defines the spatial arrangement of major hydrostratigraphic units (HSUs)
  - Forms the fundamental basis for decisions (siting wells, contaminant transport, distribution of contaminants)
- We need to interpolate between well locations
  - New wells are costly
  - How can we 'see' in between wells?



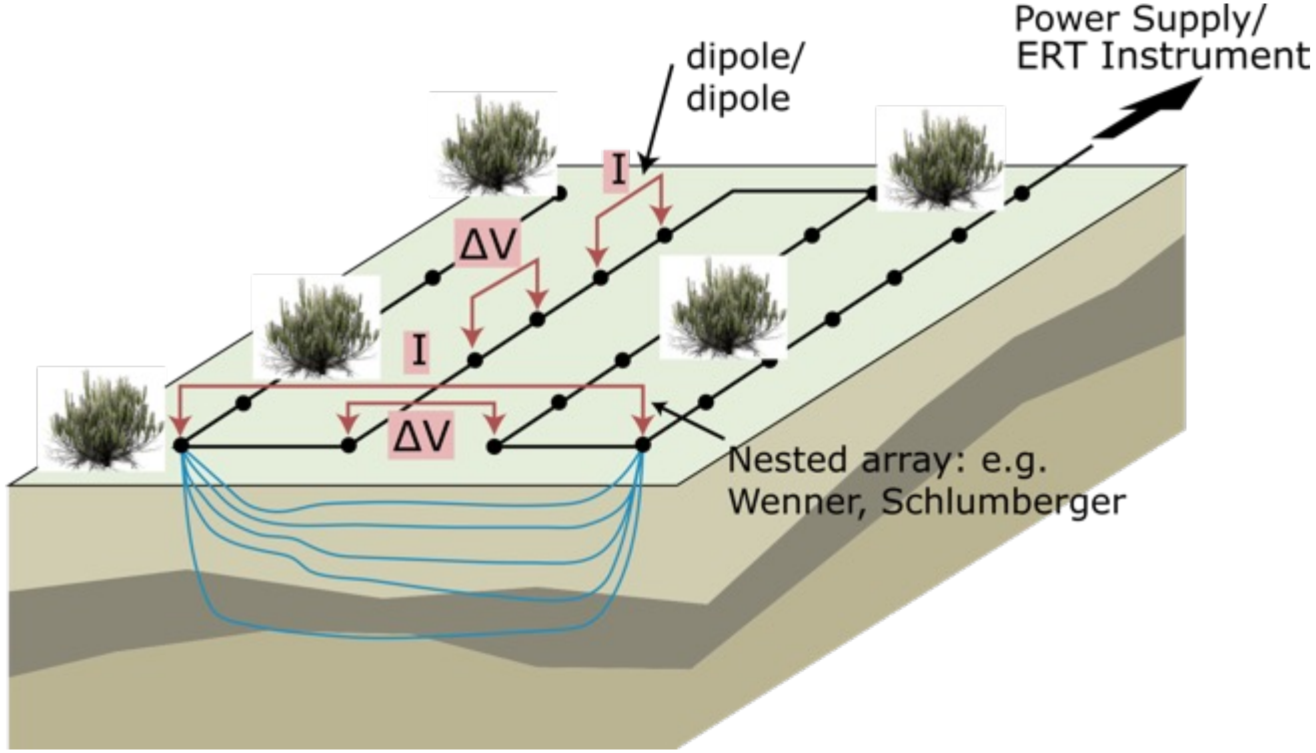
Geophysical Methods

Seismic Reflection, Refraction



Hunter et al. (2015, 2022)

Electrical Resistivity Tomography (ERT)



Seismic wave speeds vary depending on the density and the elastic properties of the material

Vs = shear wave velocity

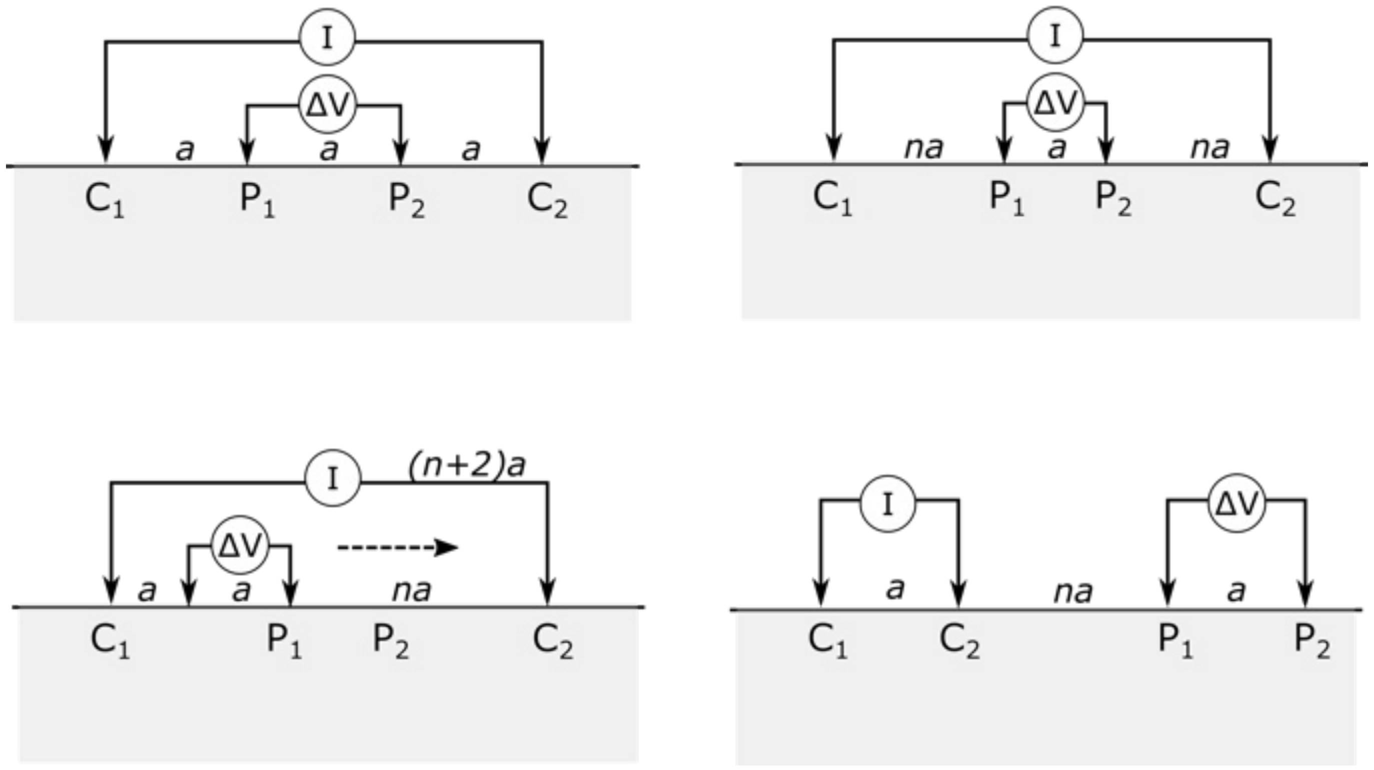
ERT is sensitive to porosity, pore fluid conductivity, moisture content, temperature, and lithology

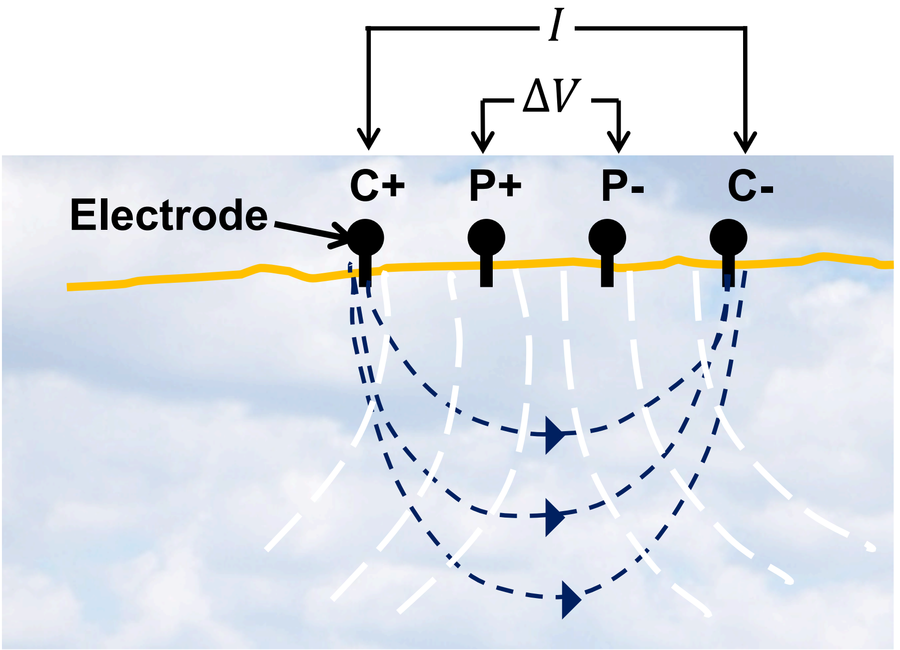
ΔV = change in potential   I = current

Using these geophysical methods together provides multiple lines of evidence of stratigraphic structure

ERT Data Collection

Variety of measurements collected

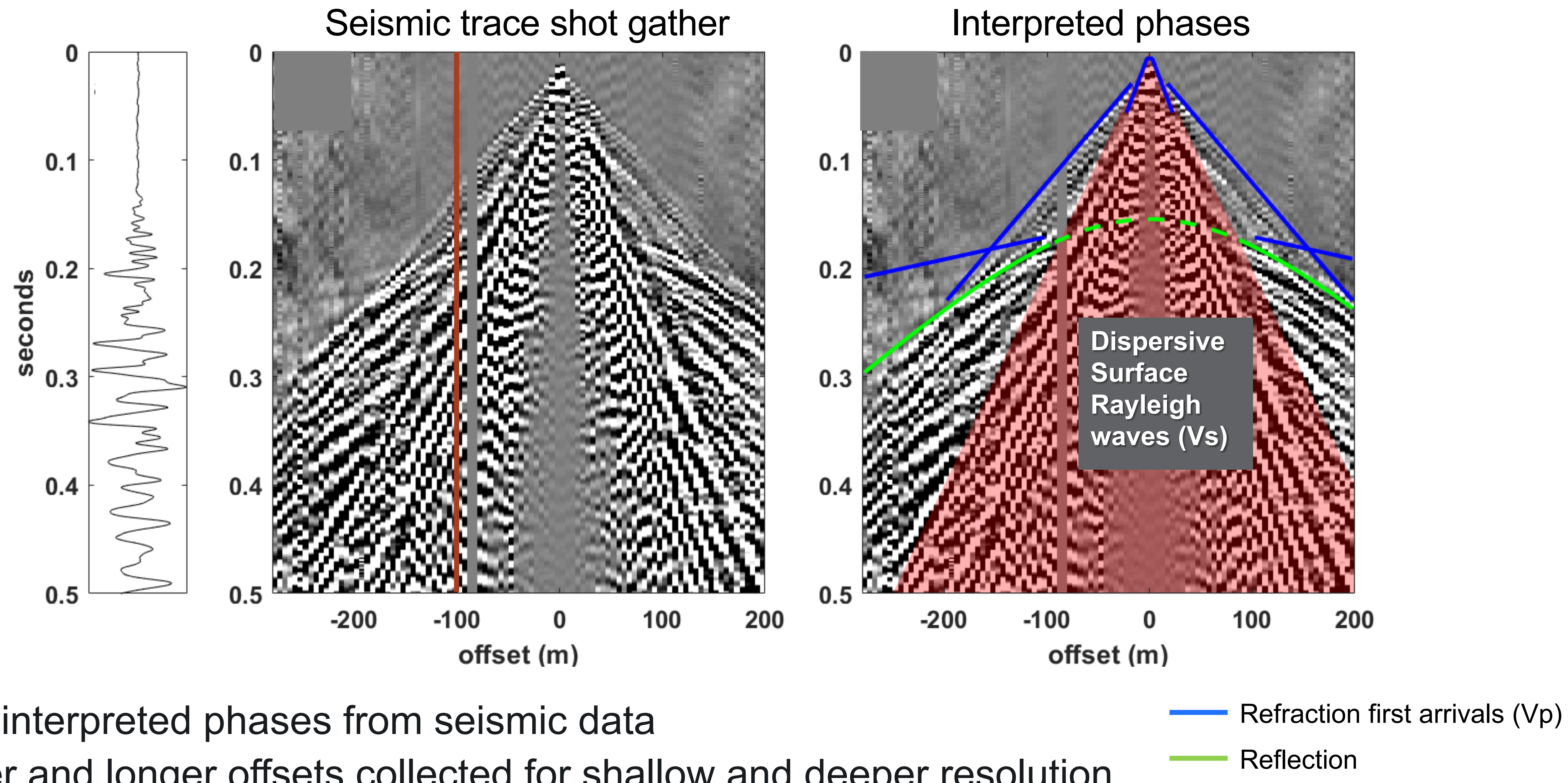




positive potential P+
negative potential P-
positive current C+
negative current C-

- Large and small electrode spacings provide higher resolution of deep and shallow features
- Different electrode configurations can also improve resolution

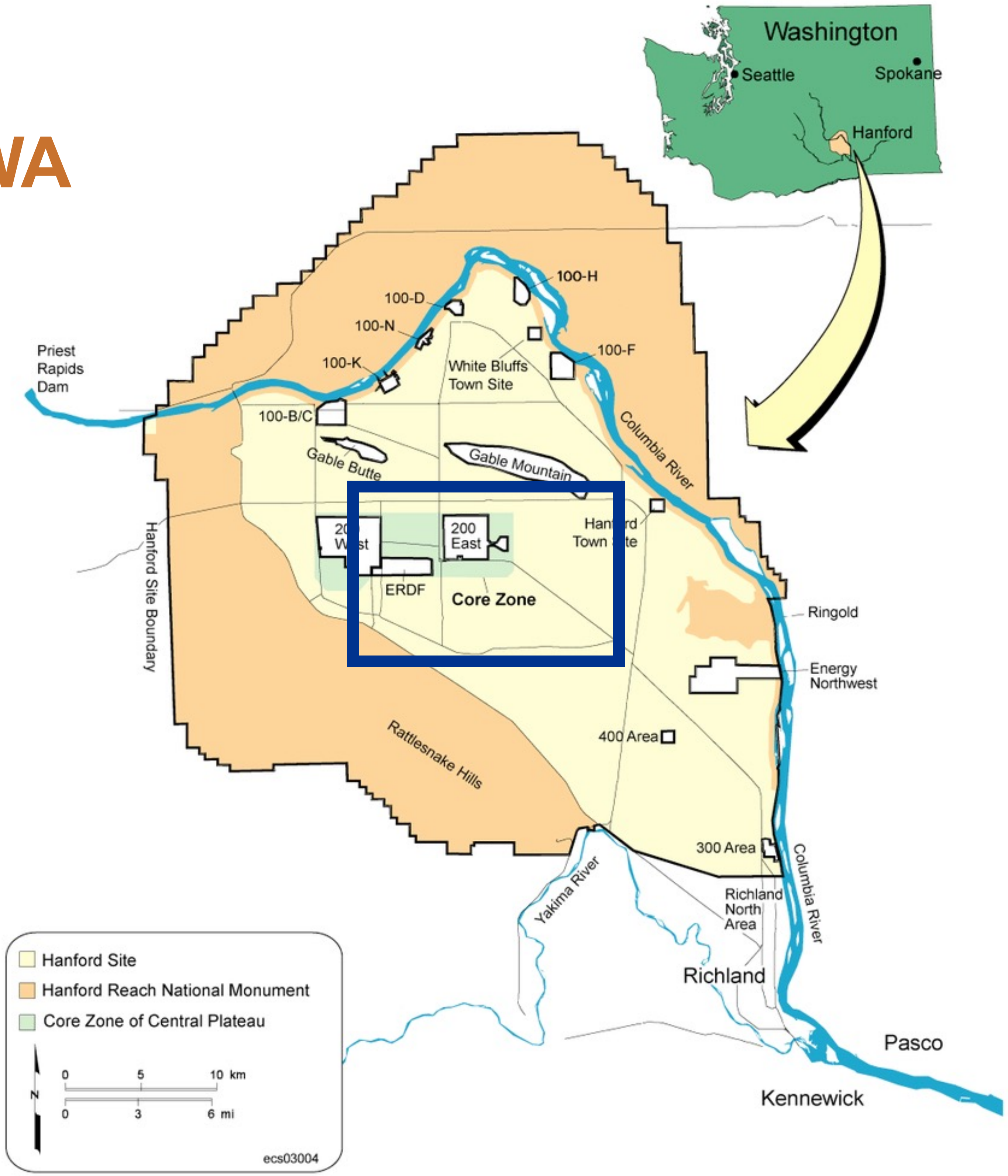
Seismic Data



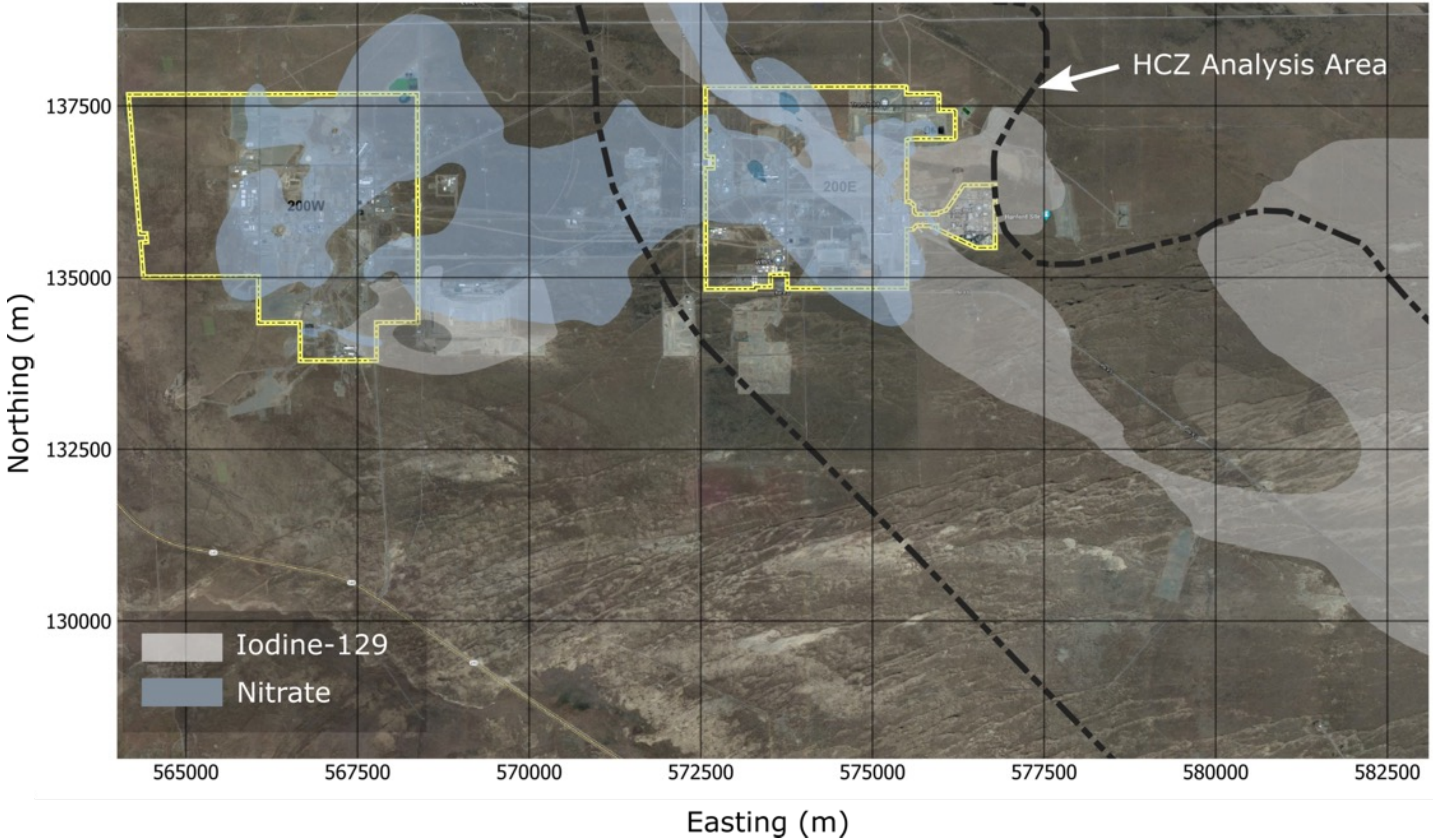
- Three interpreted phases from seismic data
- Shorter and longer offsets collected for shallow and deeper resolution

Hanford Site, WA

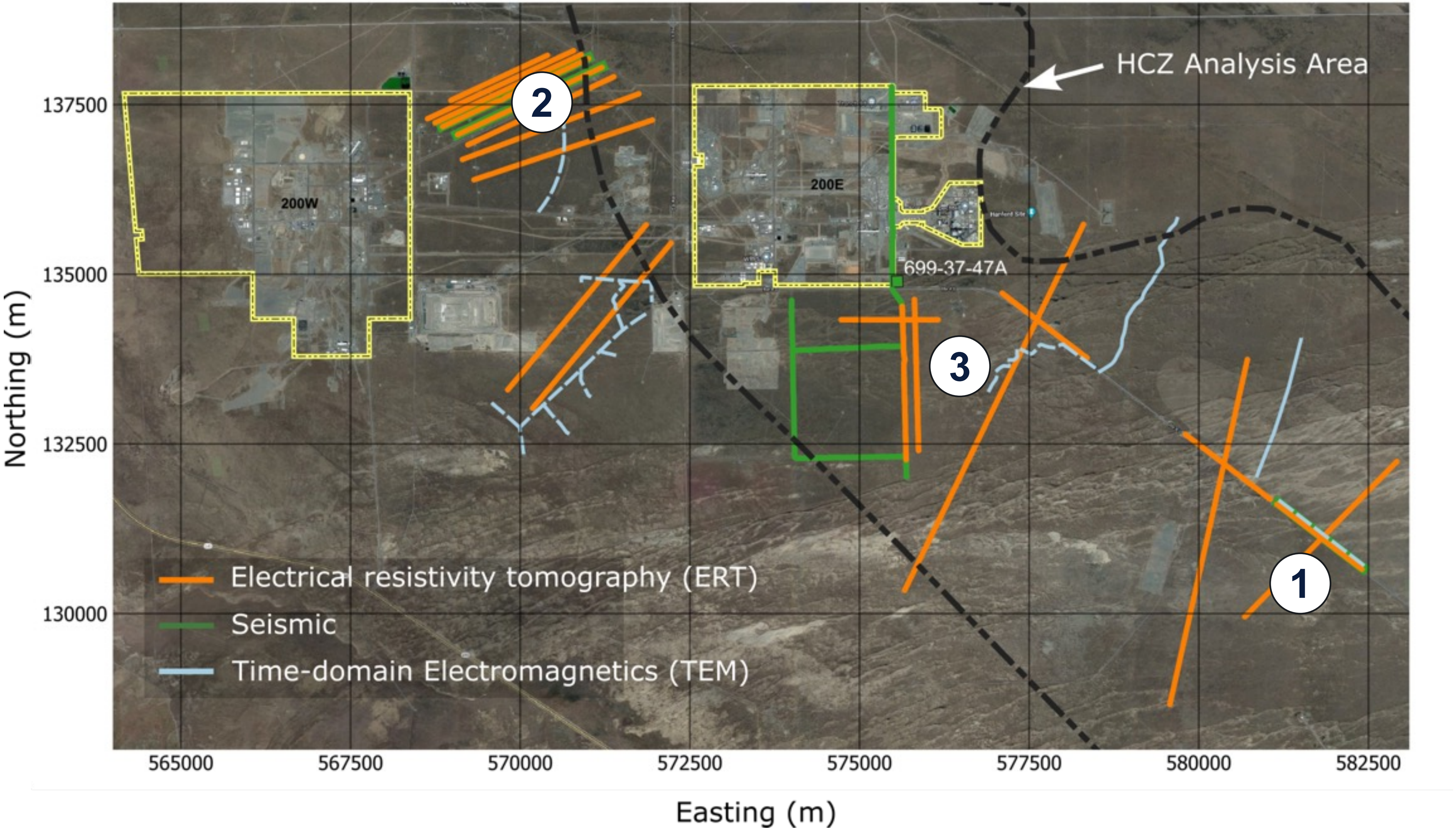
Geophysical investigations to investigate stratigraphic structure began with synthetic simulations and progressed to field studies



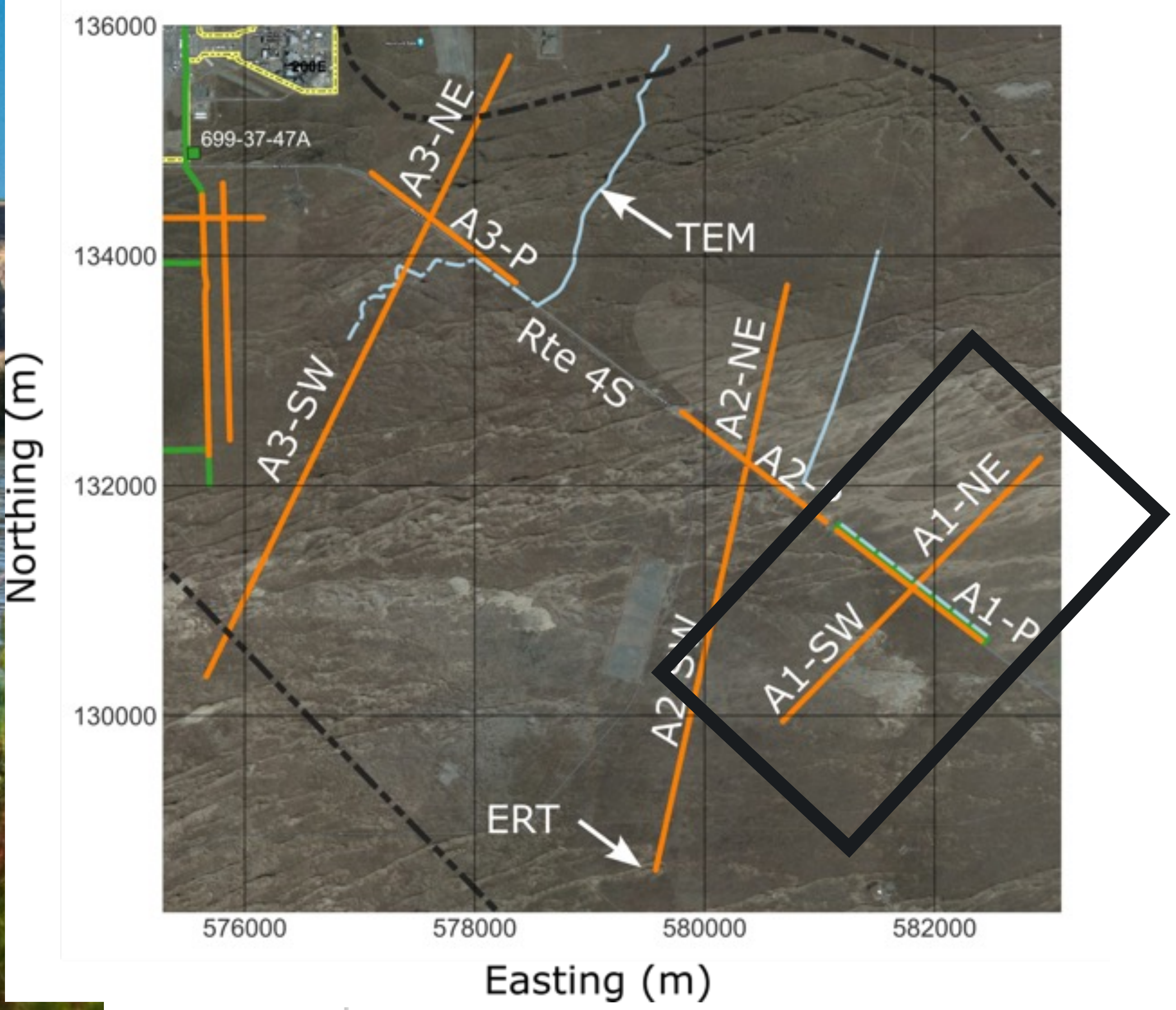
Plume Maps and HCZ at Hanford

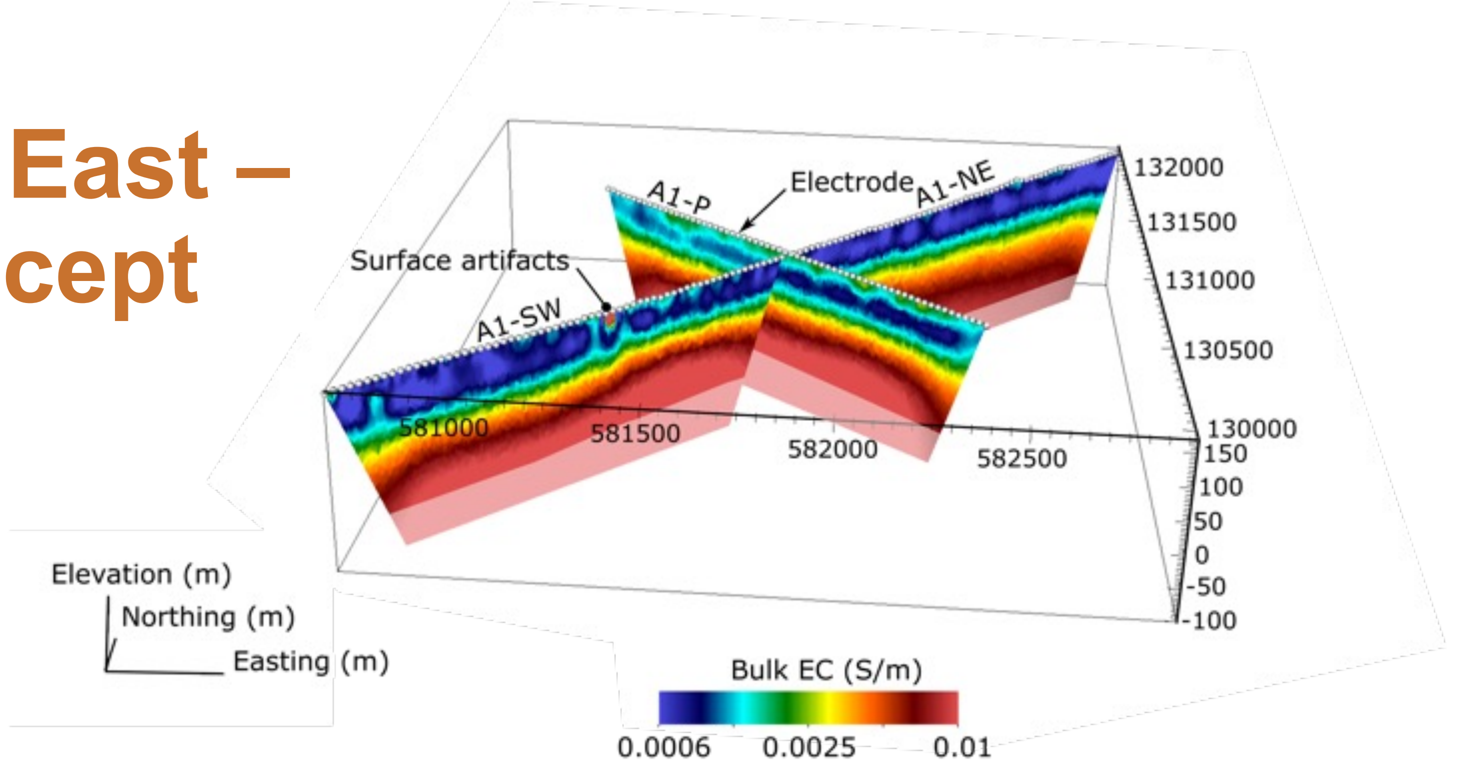


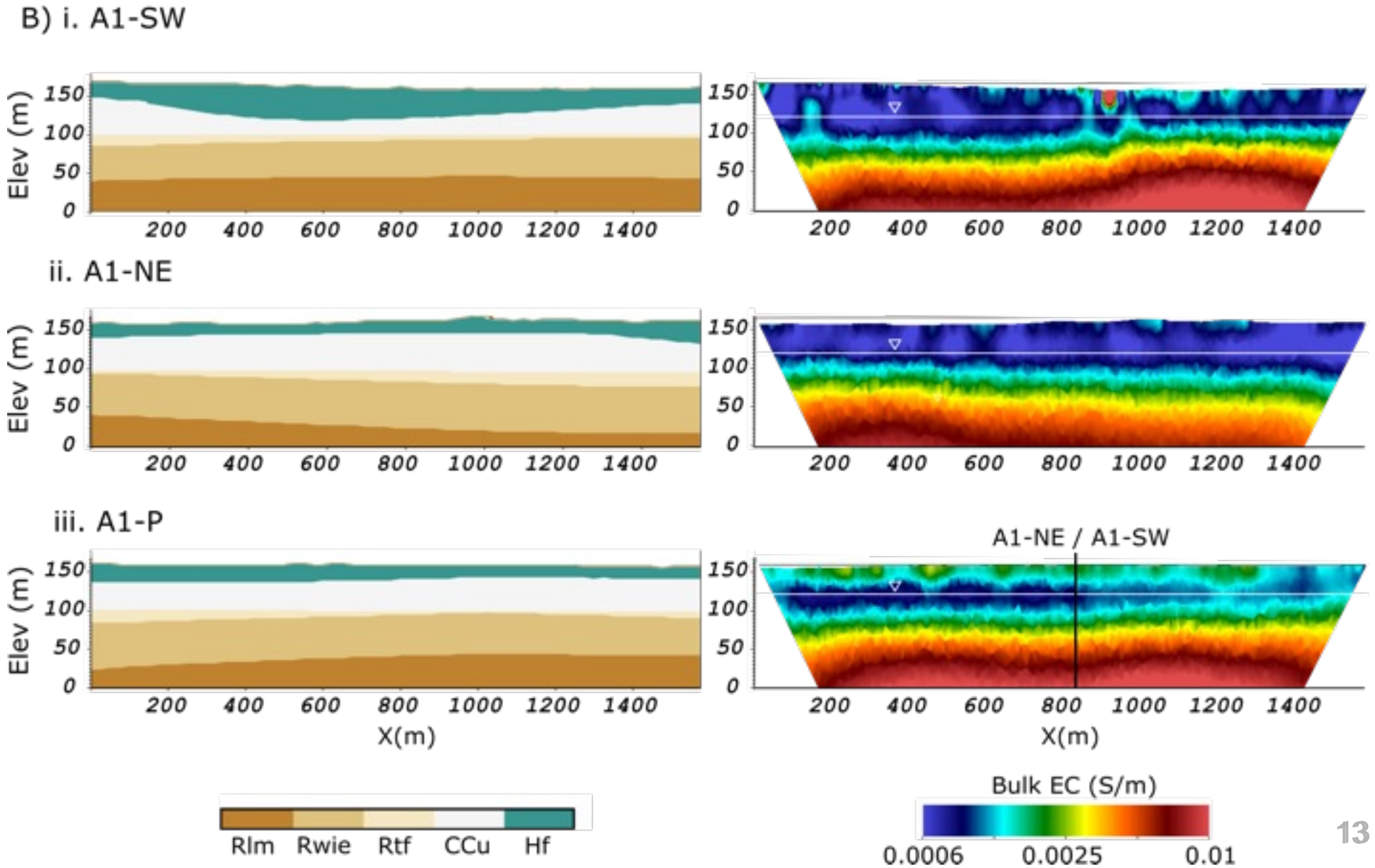
Stratigraphic Geophysical Investigations



[1] Southeast of 200 East – Area 1: Proof of Concept







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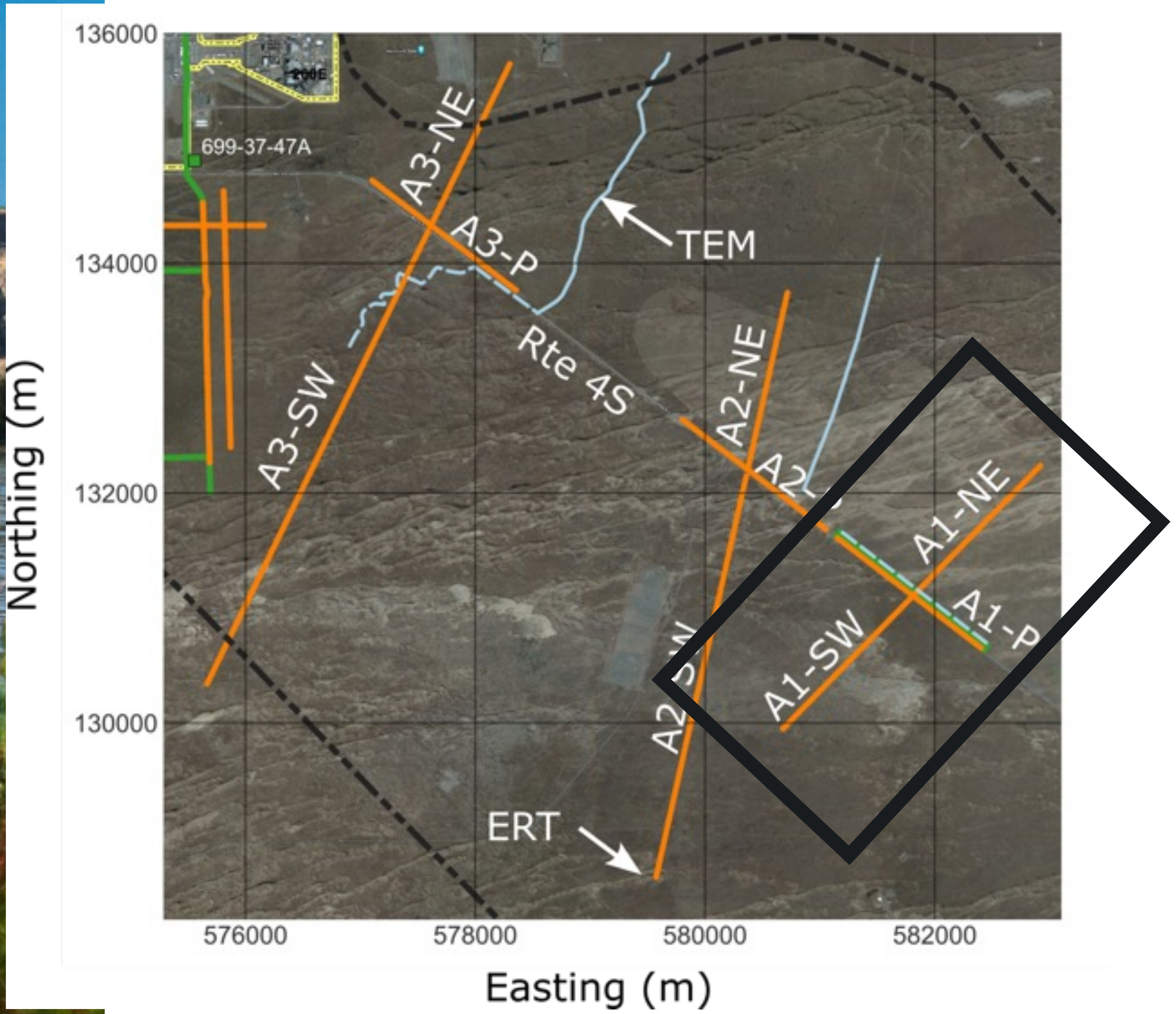
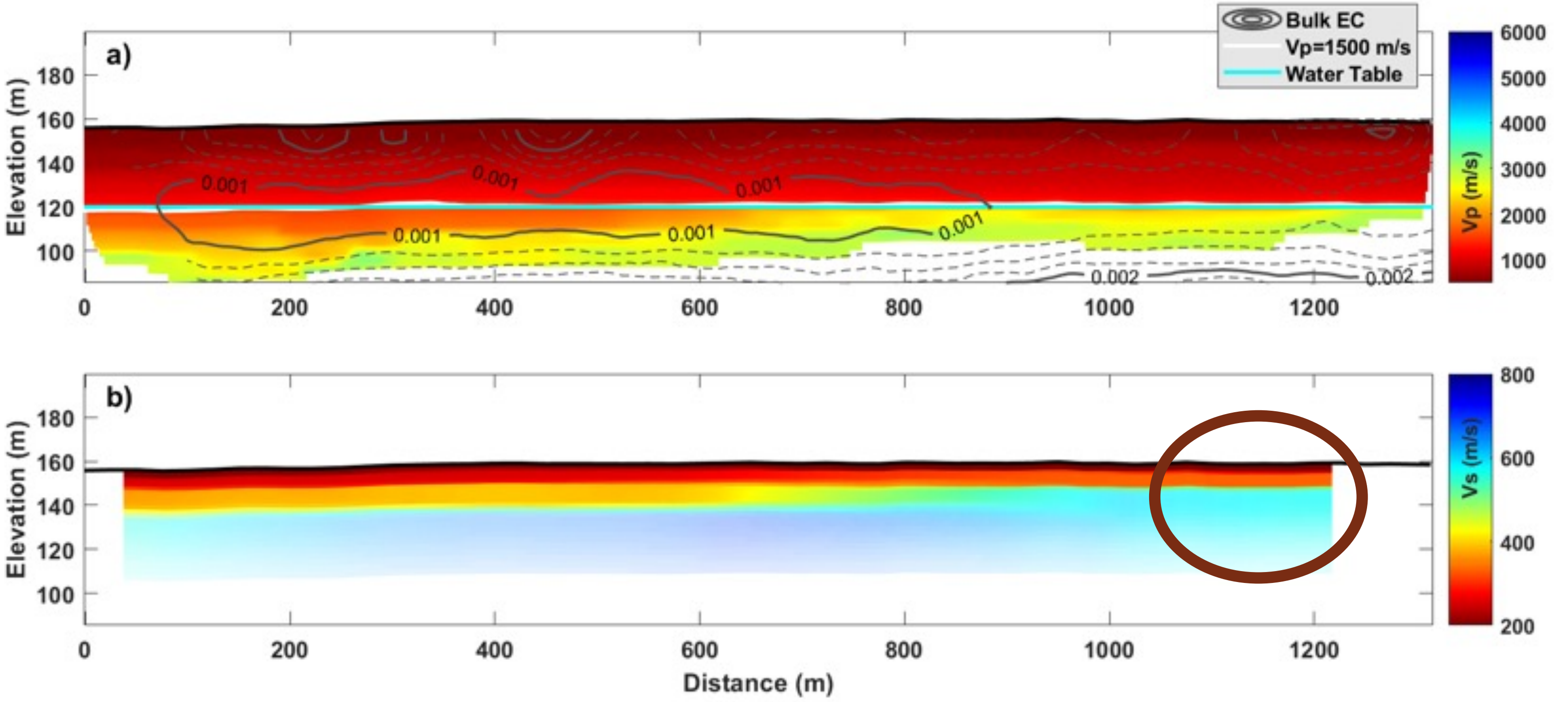
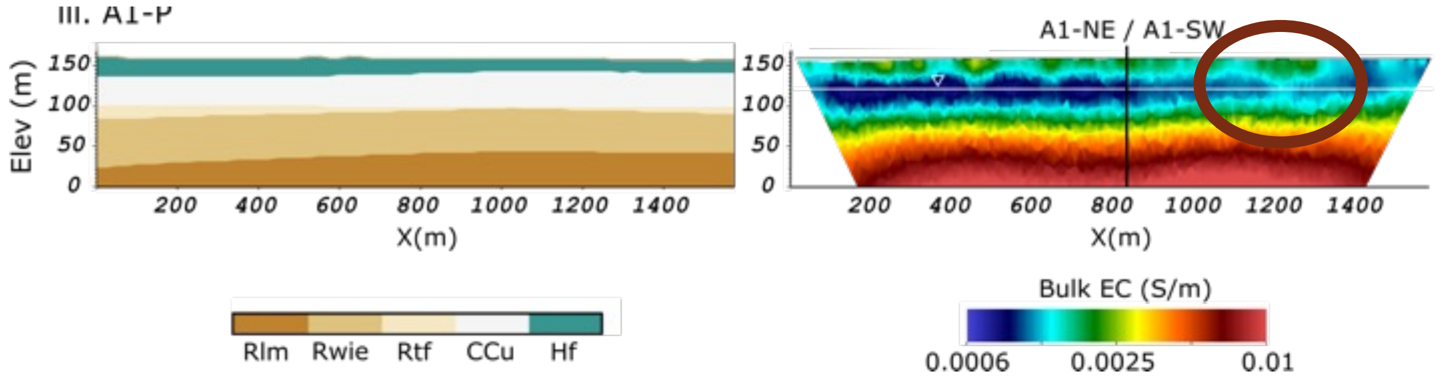
[1] Southeast of 200 East – Area 1







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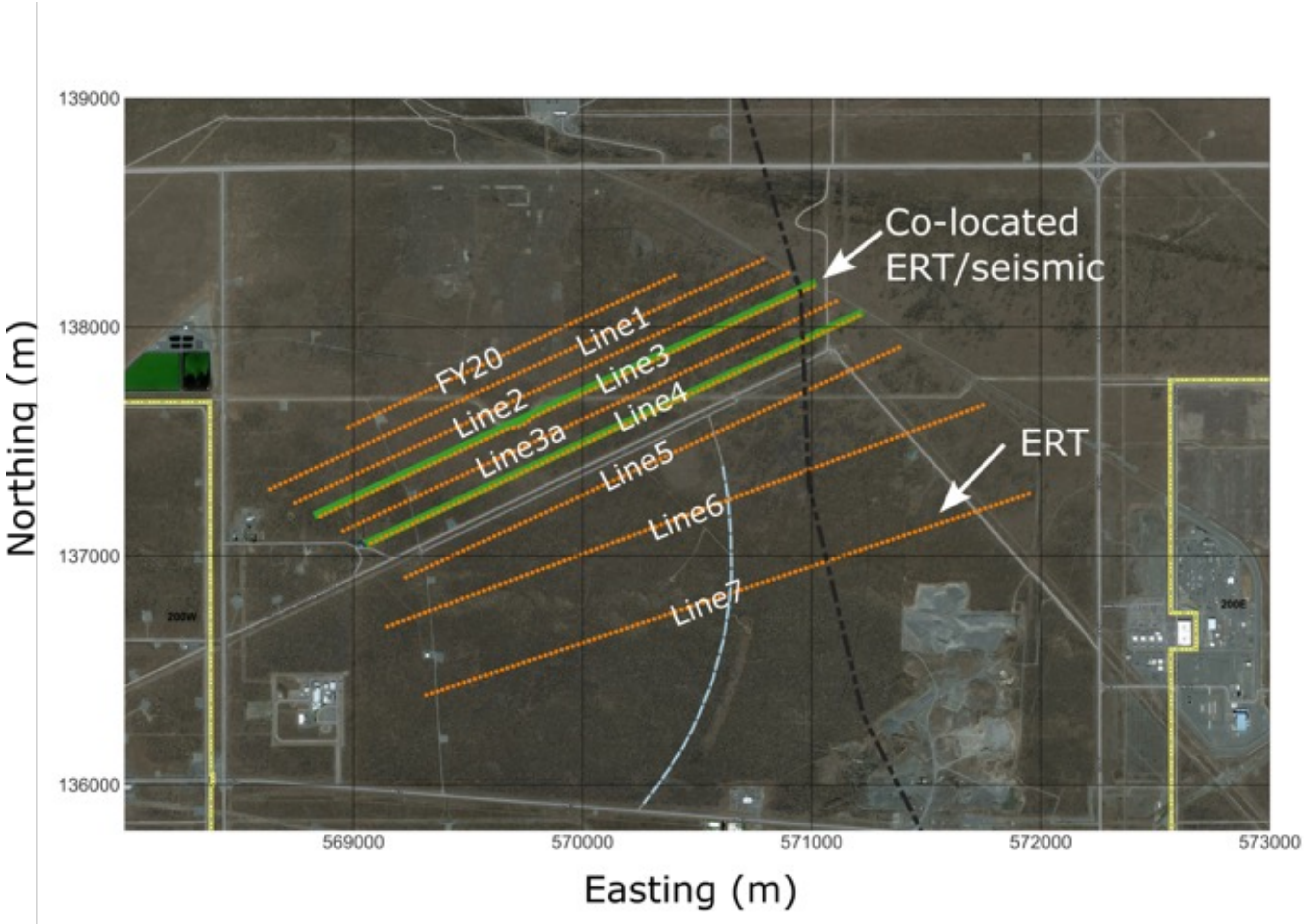
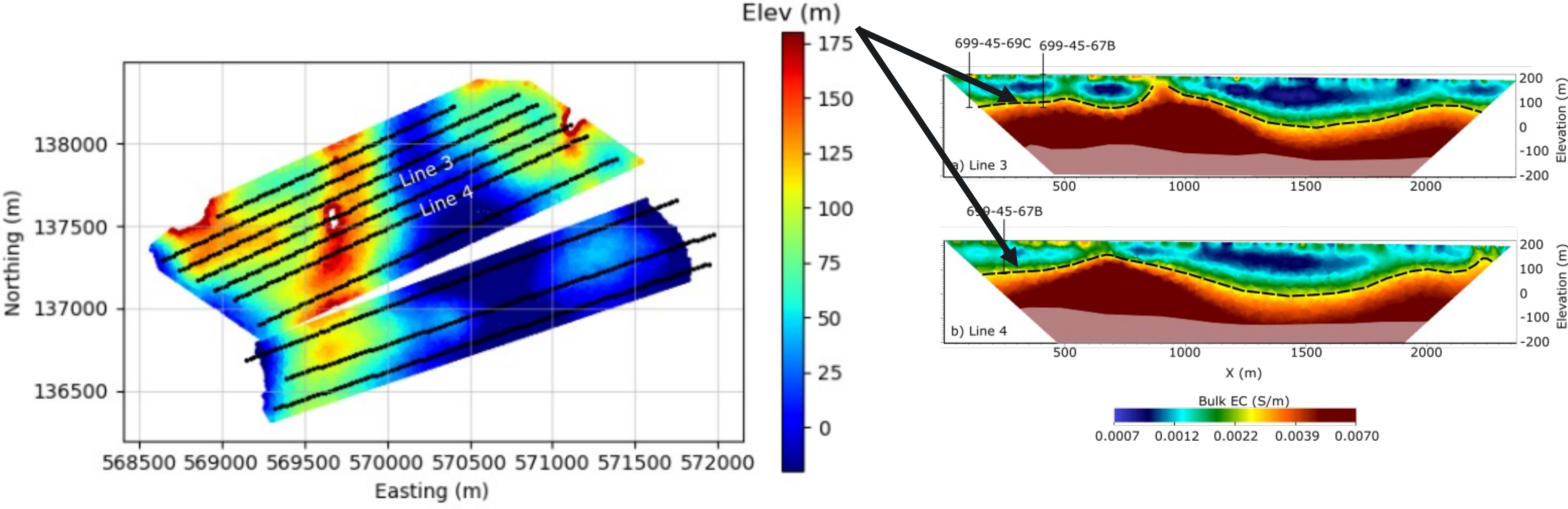
[2] Between 200 Areas



- Parallel ERT profiles were collected
- Subsequent profiles were located after reviewing results of previous profile
- Located where there is a suspected high transmissive area (e.g., paleochannel)
- ERT provides 1st line of evidence of stratigraphic structure - **Few wells to verify**

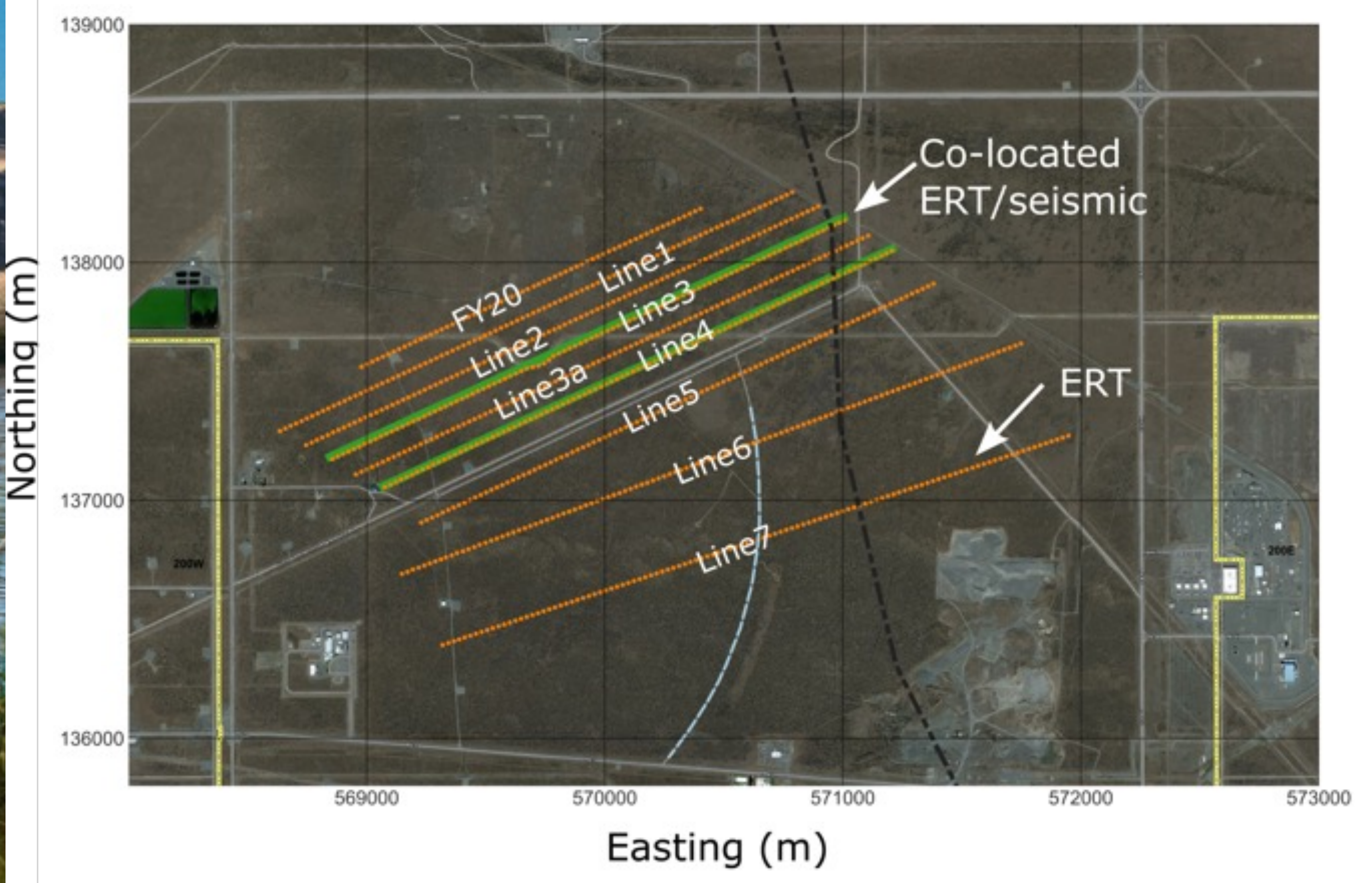
[2] Between 200 Areas - Quasi-3D ERT Inversion

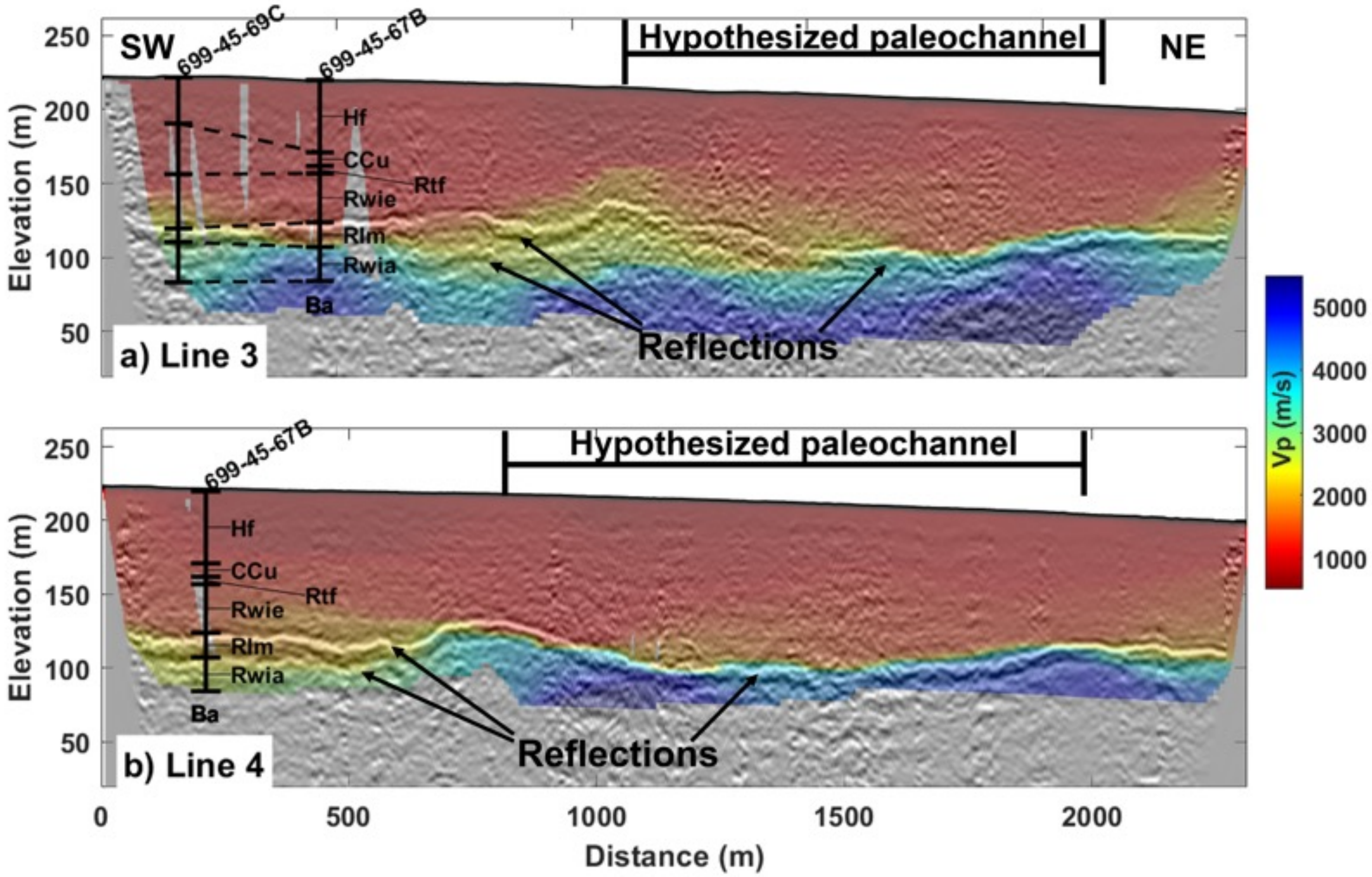
Elevation where bulk EC = 0.0025 S/m



- Geophysics has helped provide a first line of evidence of subsurface structure
- Need a better understanding of electrical properties vs. hydraulic properties

[2] Seismic Reflection and Refraction Tomography





- Compressional wave (Vp) contrasts (colored image) match reflection locations well
- Shallower resolution (shorter offsets) of features compared to ERT
- Channel like feature on NE side of line

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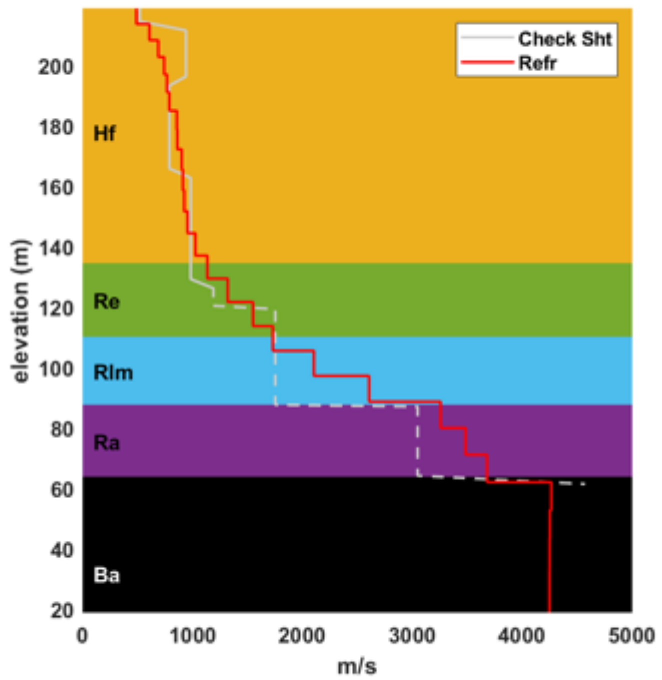
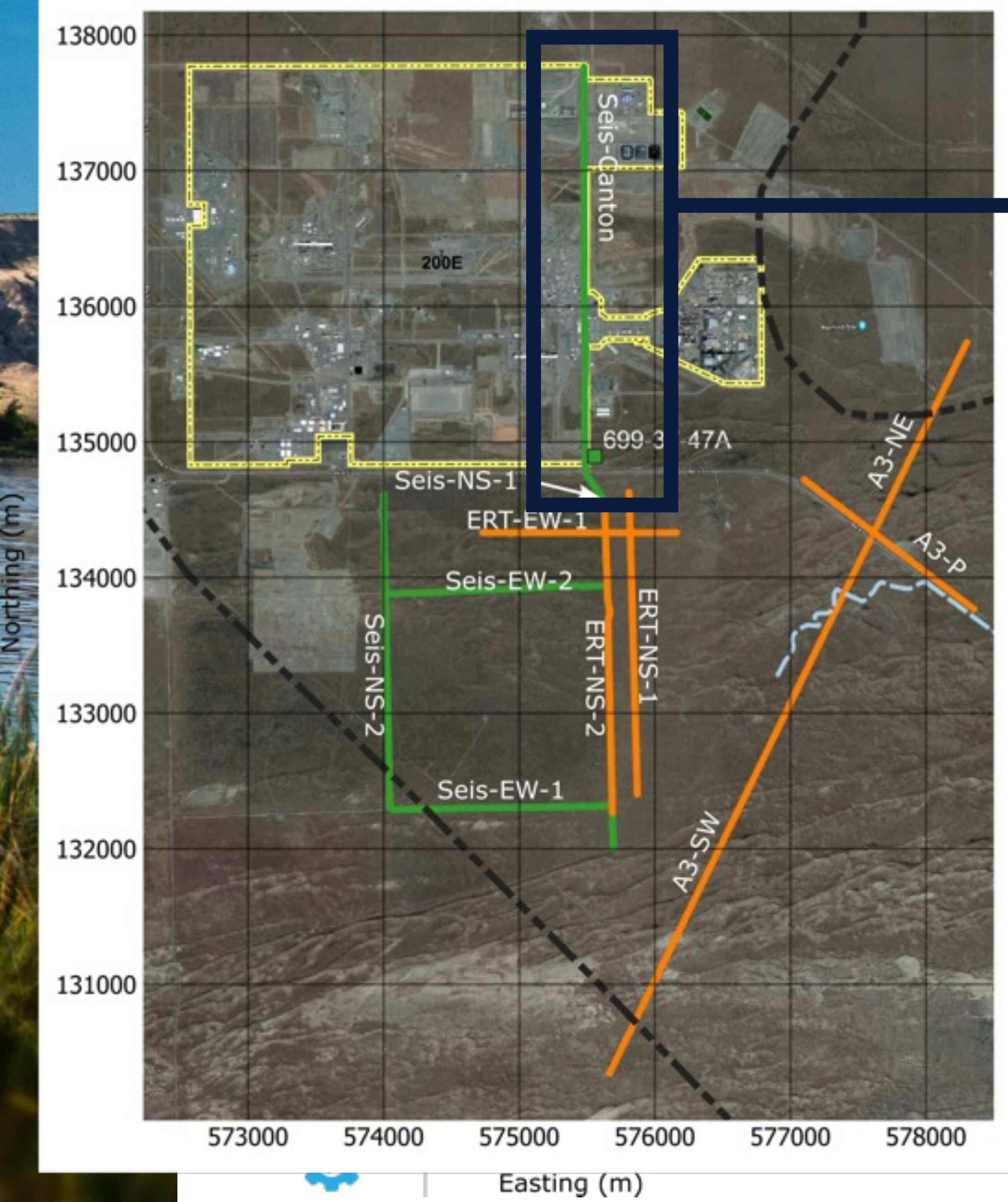
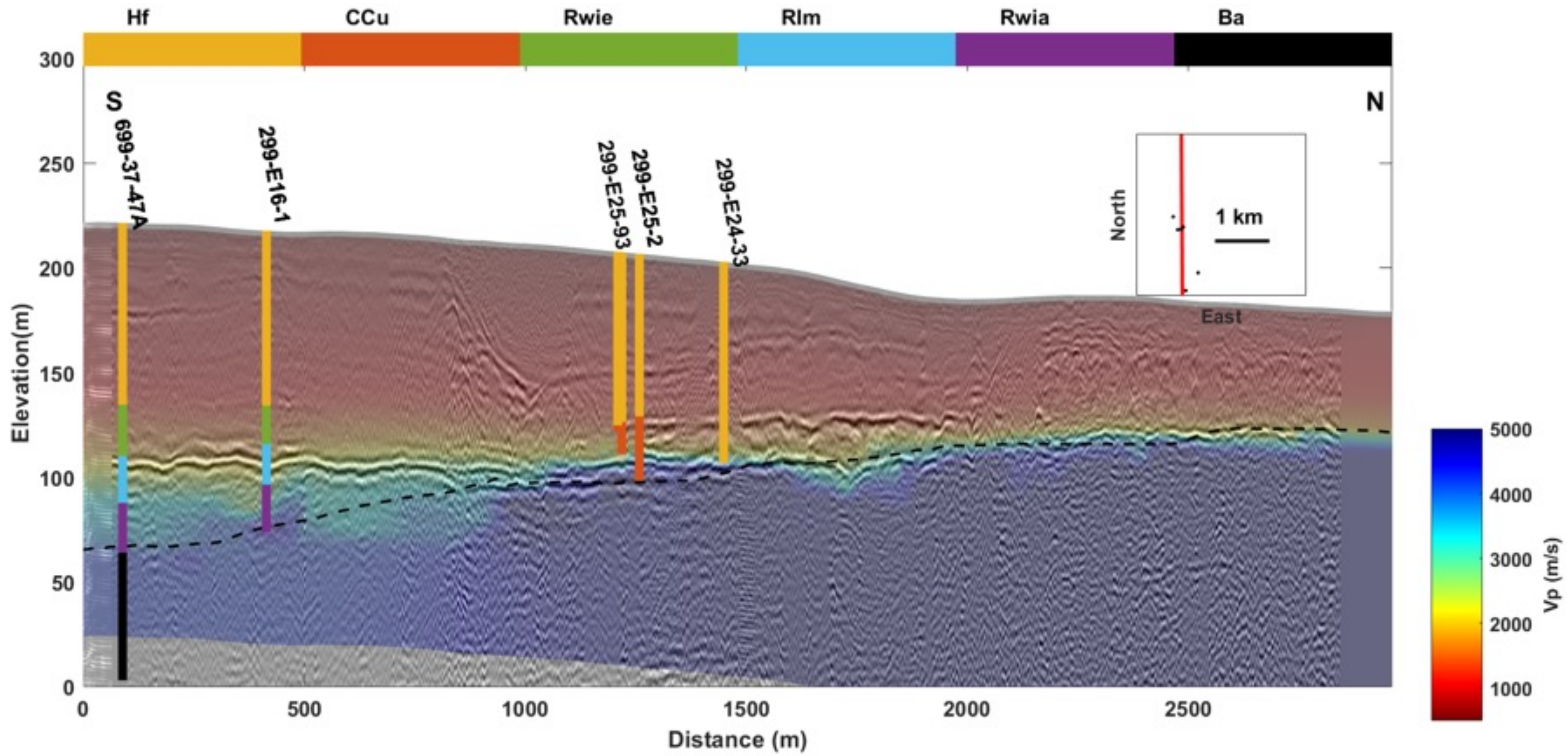
[3] South and within 200 East Area







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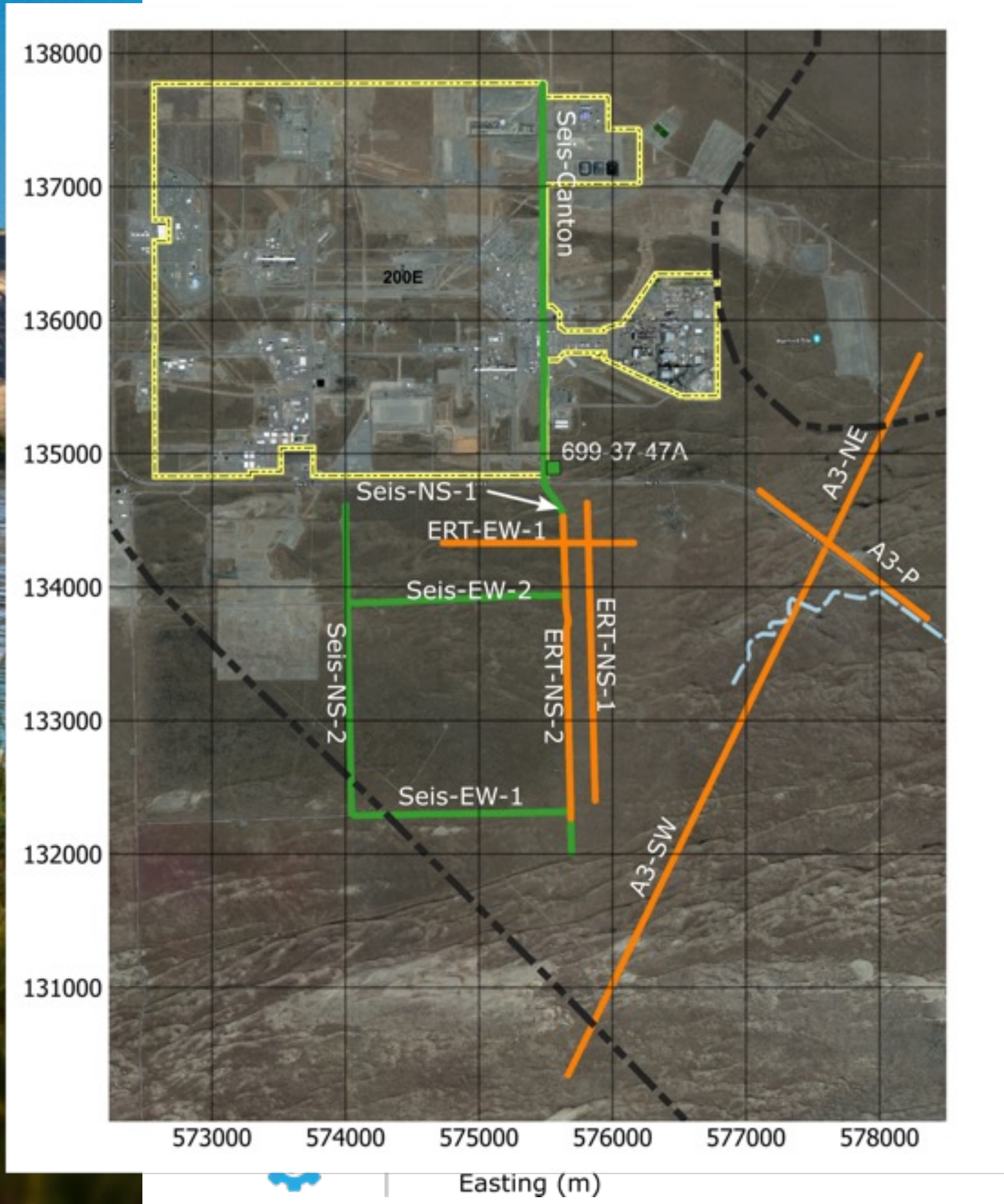
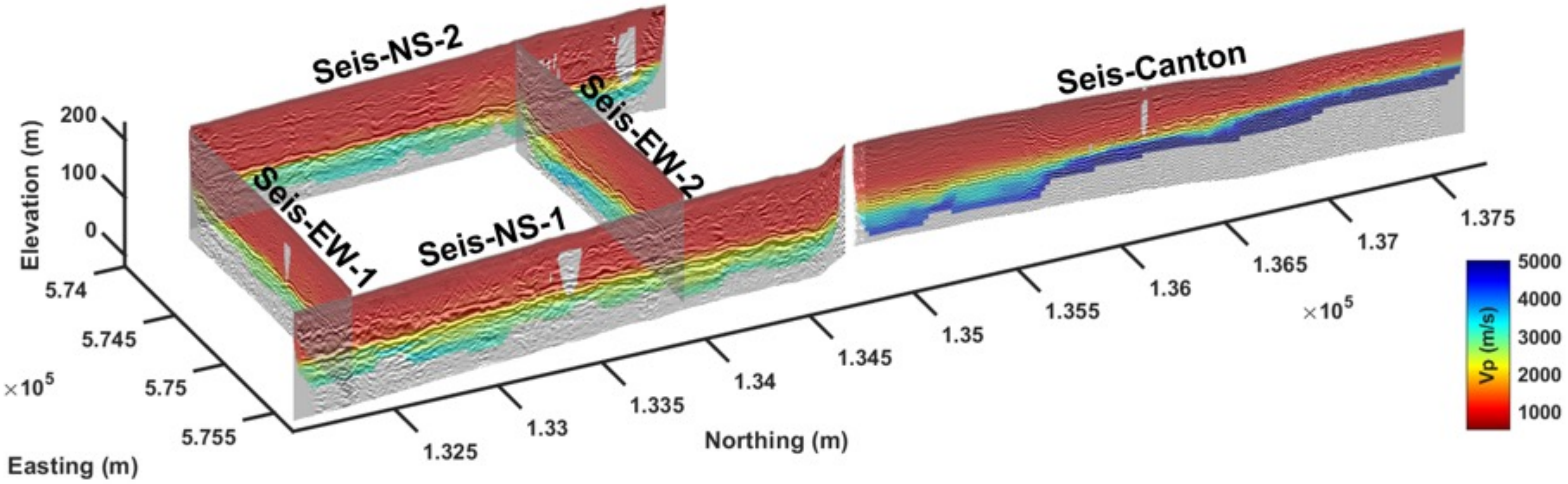


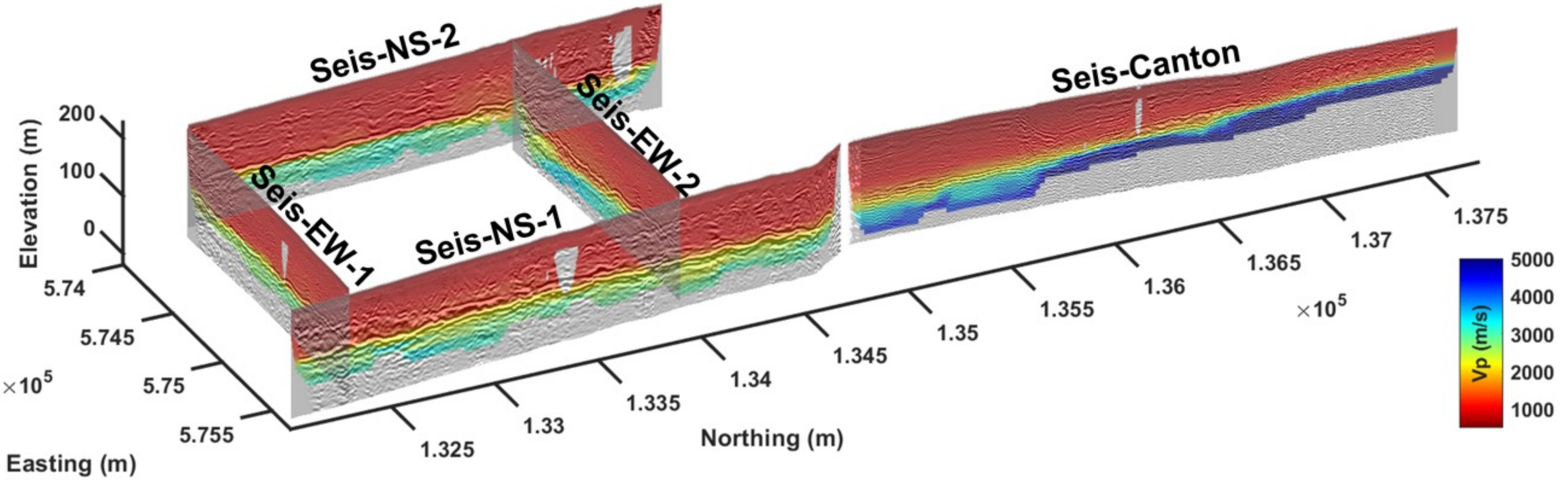
Co-located ERT along Seis-NS-1



- Coarse-grained, unconsolidated materials commonly exhibit lower Vp compared to more cemented and finer-grained material
- Seismic reflections can occur at stratigraphic contacts or incised channels

[3] South and within 200 East Area

Co-located ERT along Seis-NS-1



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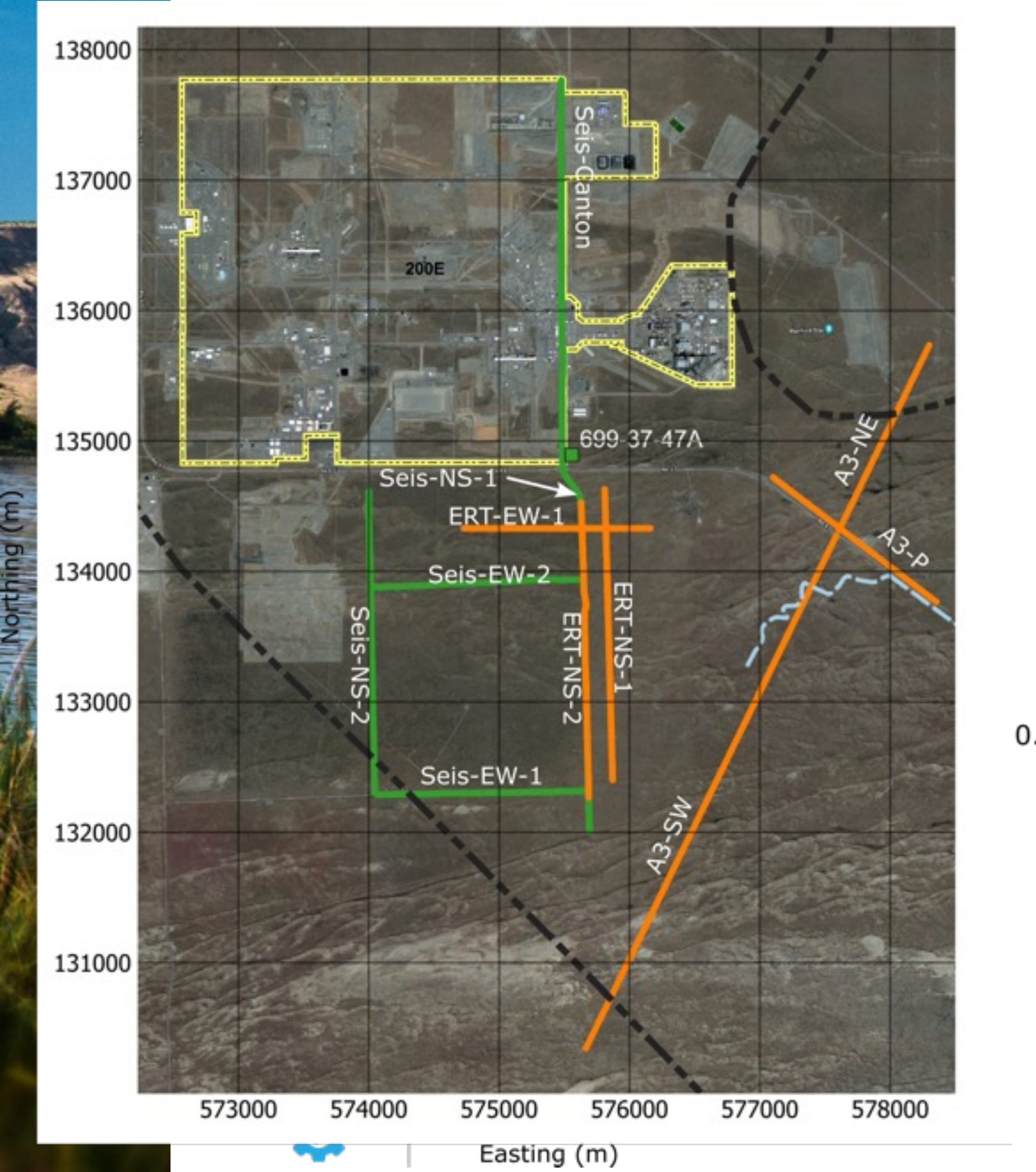
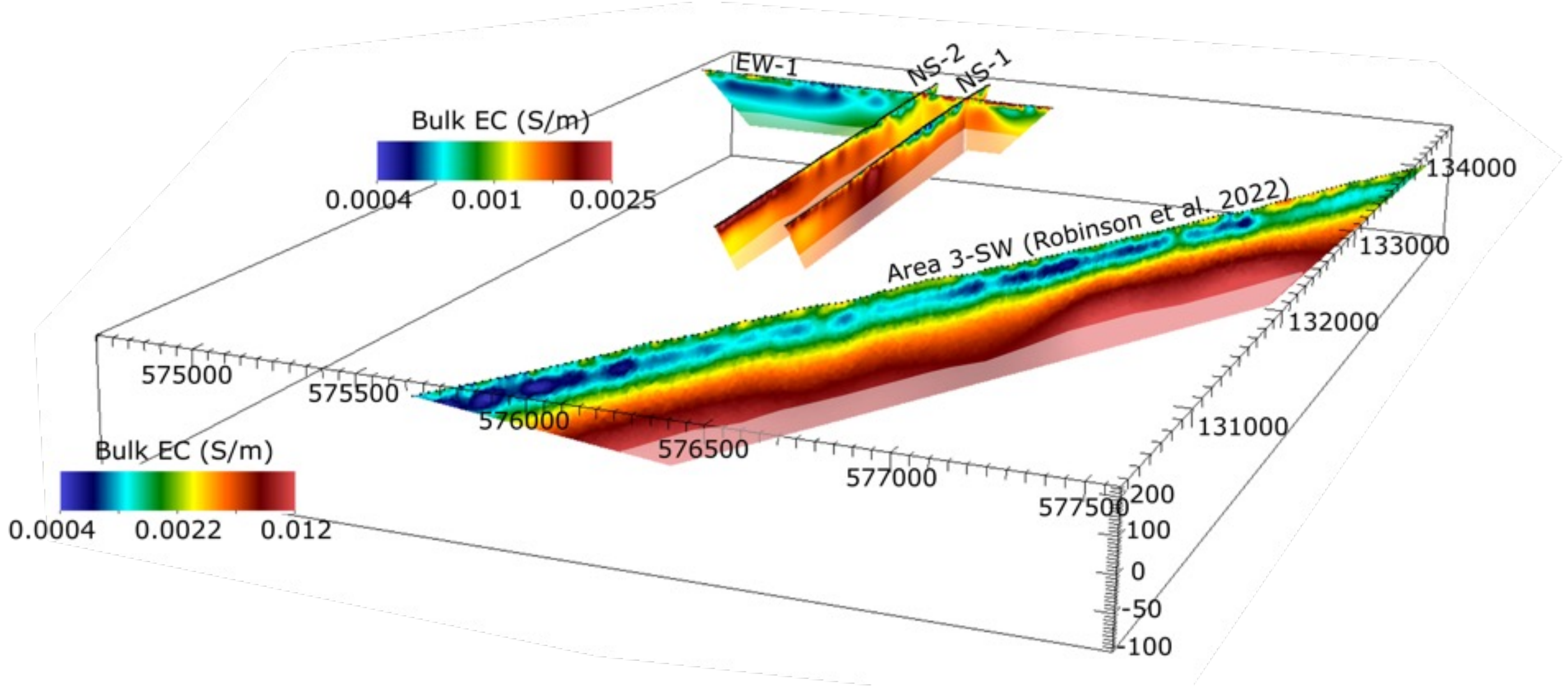


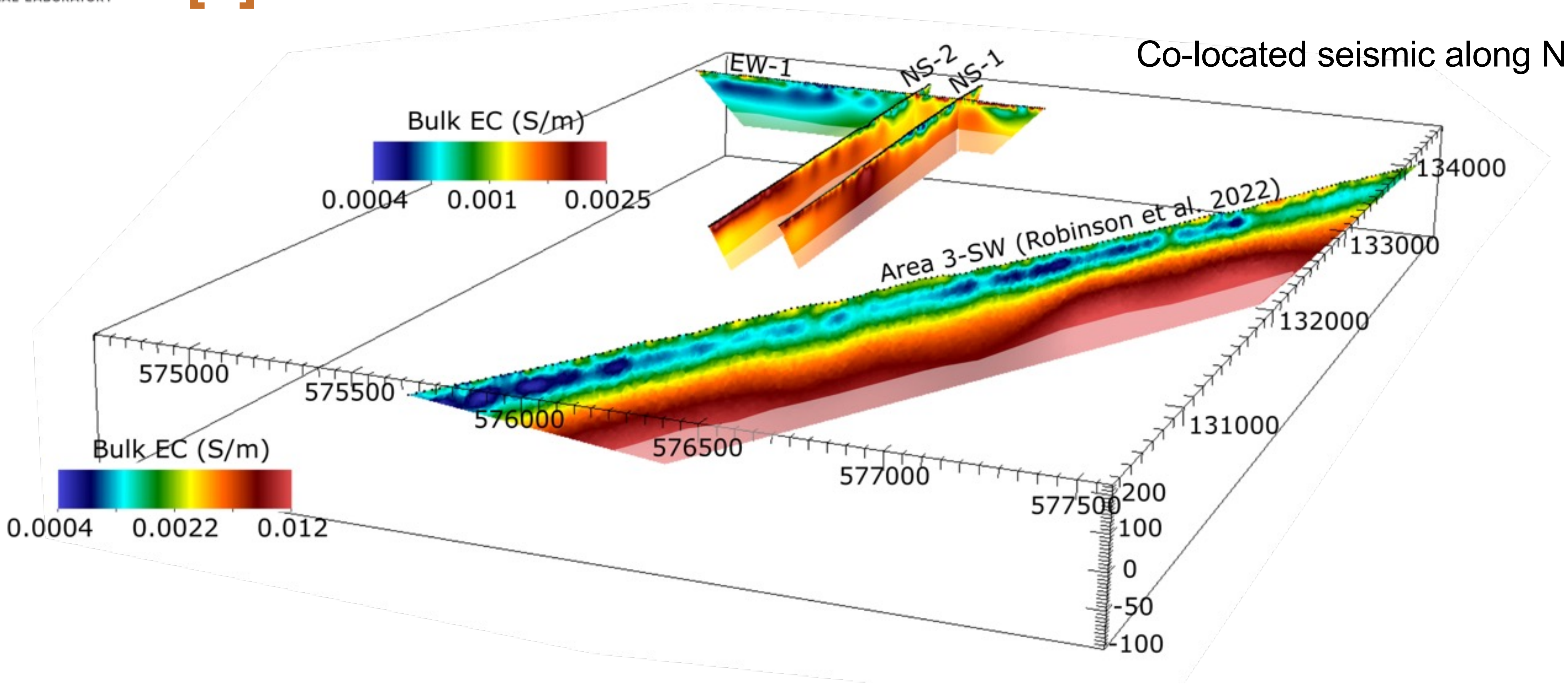
Co-located seismic along NS-2



- Coarser grained materials can exhibit higher bulk electrical conductivity (EC) but the site-specific relationship between hydraulic and EC needs to be studied

[3] South and within 200 East Area

Co-located seismic along NS-2



- Coarser grained materials can exhibit higher bulk electrical conductivity (EC) but the site-specific relationship between hydraulic and EC needs to be studied

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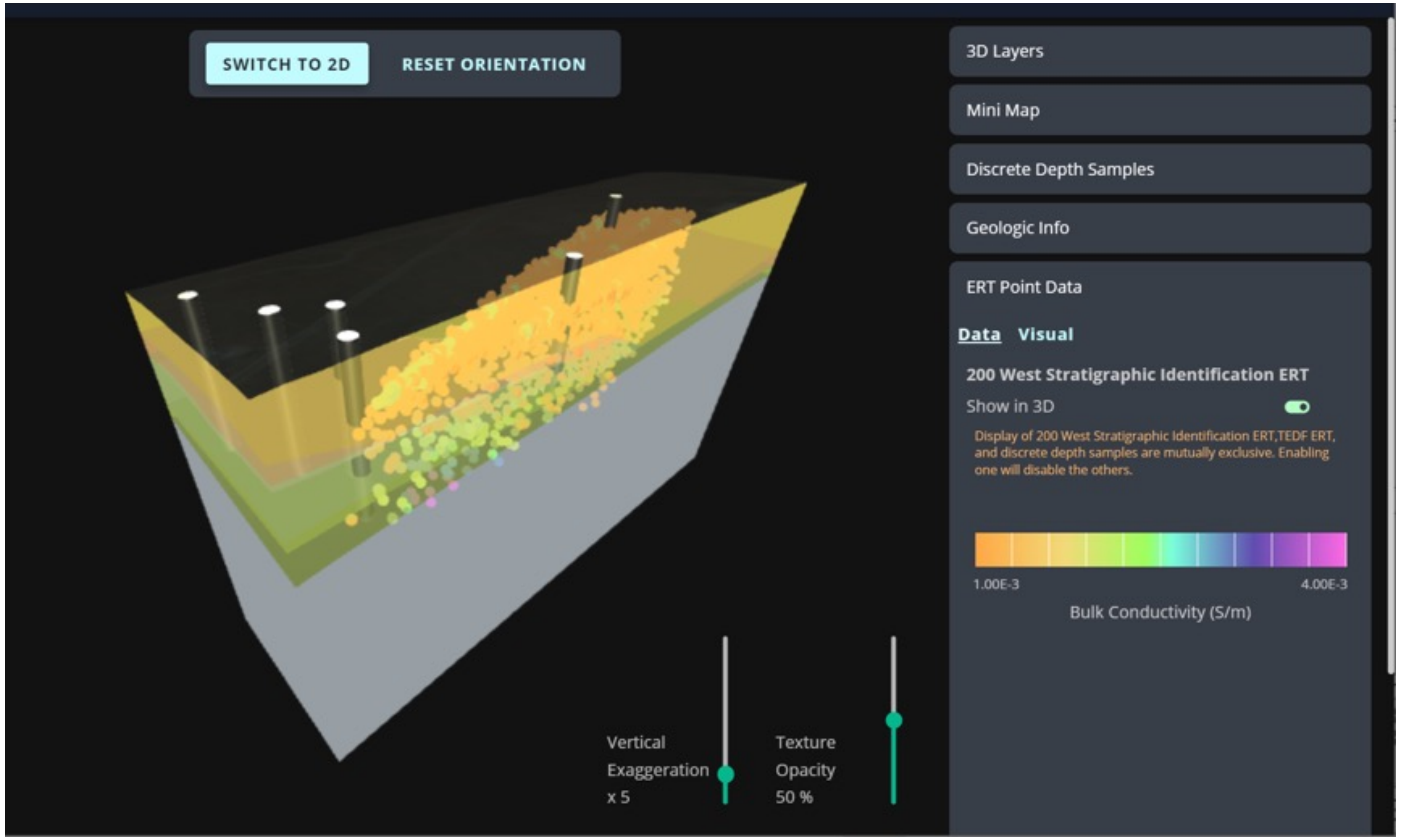
Visualization of Geophysical Data in SOCRATES

- ORIGEN module allows 3D visualization of ERT
  - ERT images in the context of the 3D geologic framework
  - Several ERT field campaigns have been prototyped
- ERT images as a point cloud
  - Bulk conductivity
  - Relative conductivity changes over time
- Can step through time for temporally varying ERT results



Visualization of ERT survey results as a point cloud in the ORIGEN 3D view.

https://socrates.pnnl.gov/

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Summary

- Surface geophysical methods are helping to provide stratigraphic information on the Hanford Site
  - First line of evidence
  - Supports decisions about locations and need for new subsurface characterization wells
  - Provide better spatial understanding of lateral transitions

- Ground truthing through well observations can better guide interpretations (seismic)
- We still have work to do to understand the relationship between geophysical properties and hydraulic properties
- Visualization of geophysical data is ongoing in SOCRATES

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