REMTEC & EMERGING CONTAMINANTS SUMMIT

OCTOBER 15-17, 2024

Groundwater Geology: State of the Practice in the *Environmental Industry and in Groundwater Production Projects*

Rick Cramer

10/17/2024

Why Geology 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."

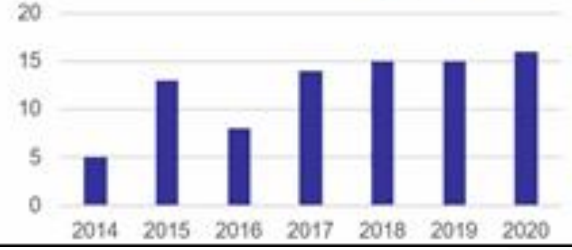
Alternatives for Managing the Nation's Complex Contaminated Groundwater Sites
National Academy of Sciences Committee on Future Options for Management in the Nation's Subsurface Remediation Effort, 2013

US Air Force Critical Process Analysis (CPA) Project Review

Primary Finding was Improved CSM = Remediation Optimization

Remedy Evaluations: 2014 – 2020

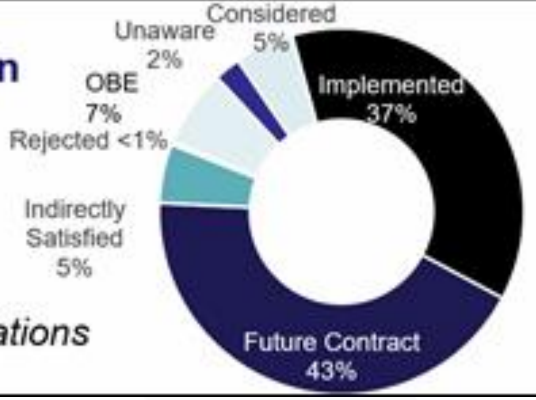
Sites Evaluated



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

Benefits of Geology-Focused Approach

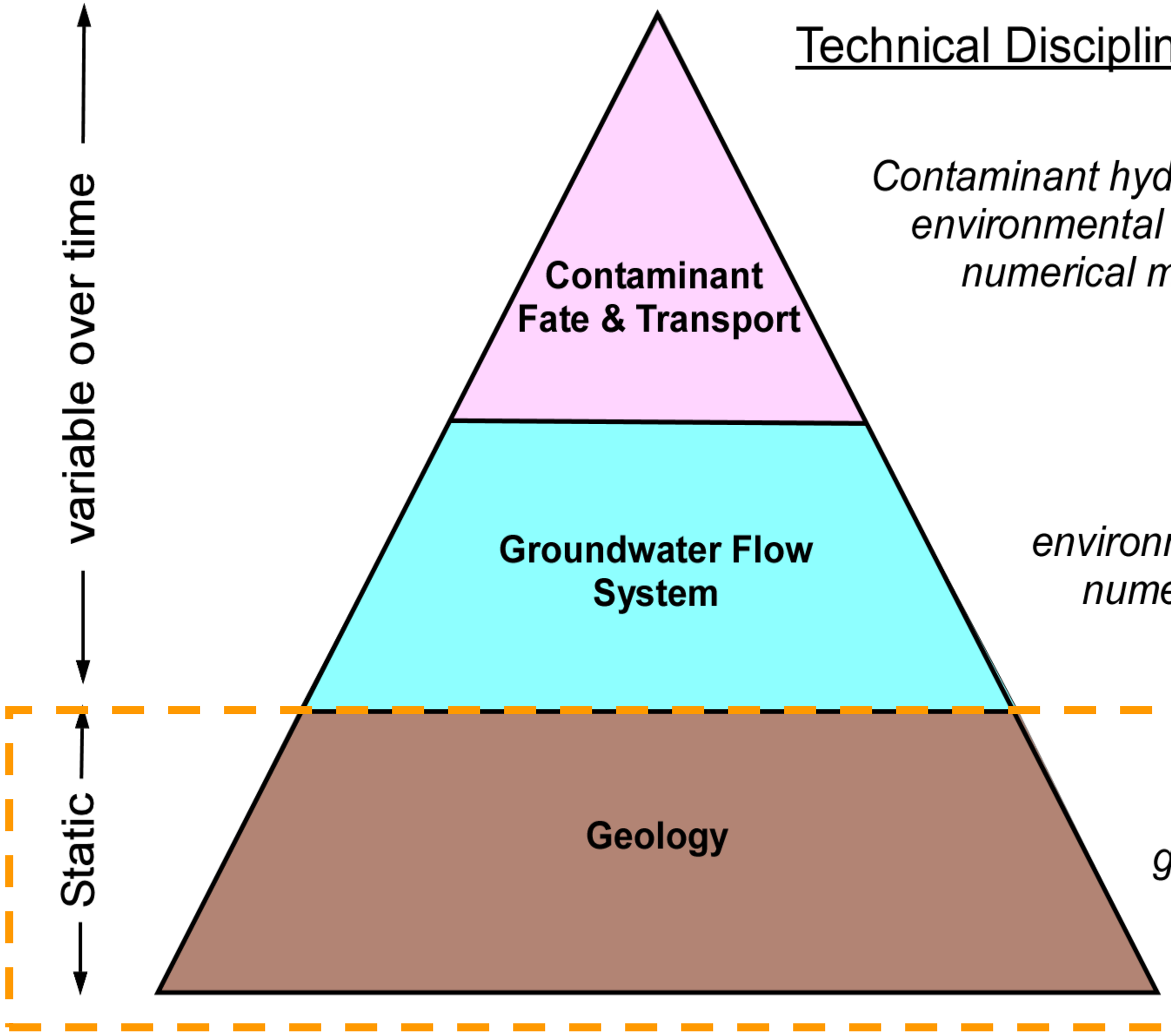
Address the greatest uncertainty, the subsurface

- Start with using existing data…investment has already been made by the client!
- Defines subsurface “plumbing”: Identify groundwater flow paths and preferential contaminant migration pathways
- Optimize data gap programs, groundwater monitoring programs, and remediation design

Key Point — **Focus your site strategy to save significant time and money**

Paradigm Shift ▶ Remediation Geology

ESS is a Geology-Focused Conceptual Site Model



<u>Technical Disciplines Required</u>

Contaminant hydrogeologists, environmental engineers, numerical modelers

hydrogeologists, environmental engineers, numerical modelers

Geologists, including stratigraphers, structural geologists, volcanologists (as needed); hydrogeologists

Ref: Murray Einarson, 2023

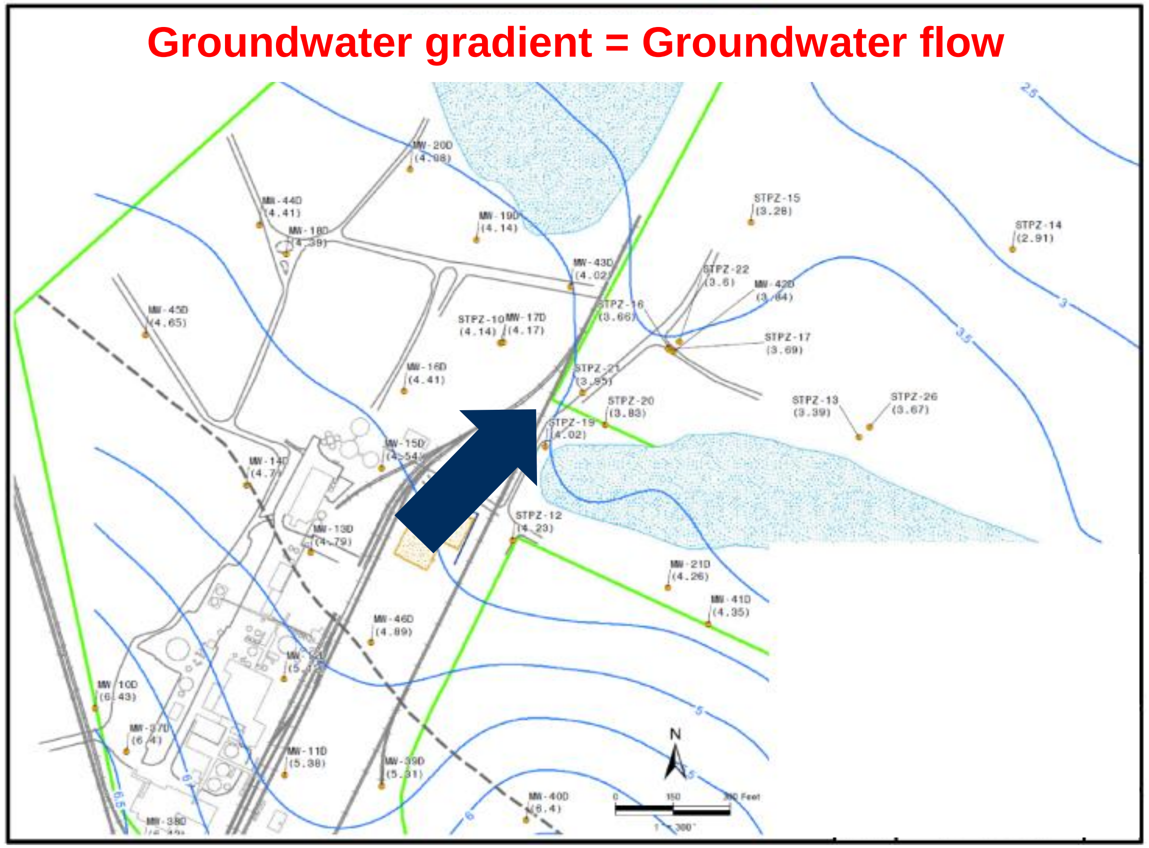
Groundwater Production Industry
Traditional Approach to the Subsurface

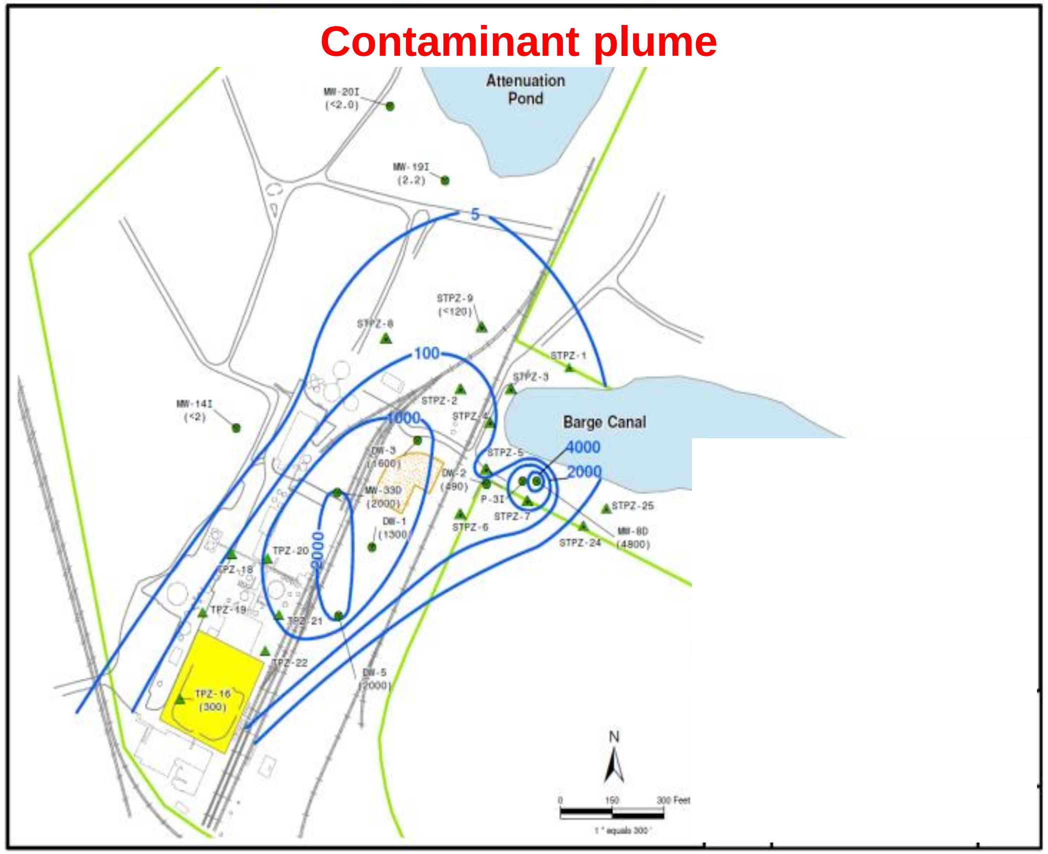
Groundwater supply studies based on assumptions of homogeneous and isotropic conditions, steady-state observations

Traditional Focus on Hydrology

State of the practice is to apply Darcy's law,

assume **homogeneous and isotropic** conditions within layers of interest





Traditional Focus on Engineering

Unified Soil Classification System (USCS): Standard Practice for Classifying Soils

(Chart from ASTM)

D 2487 – 06

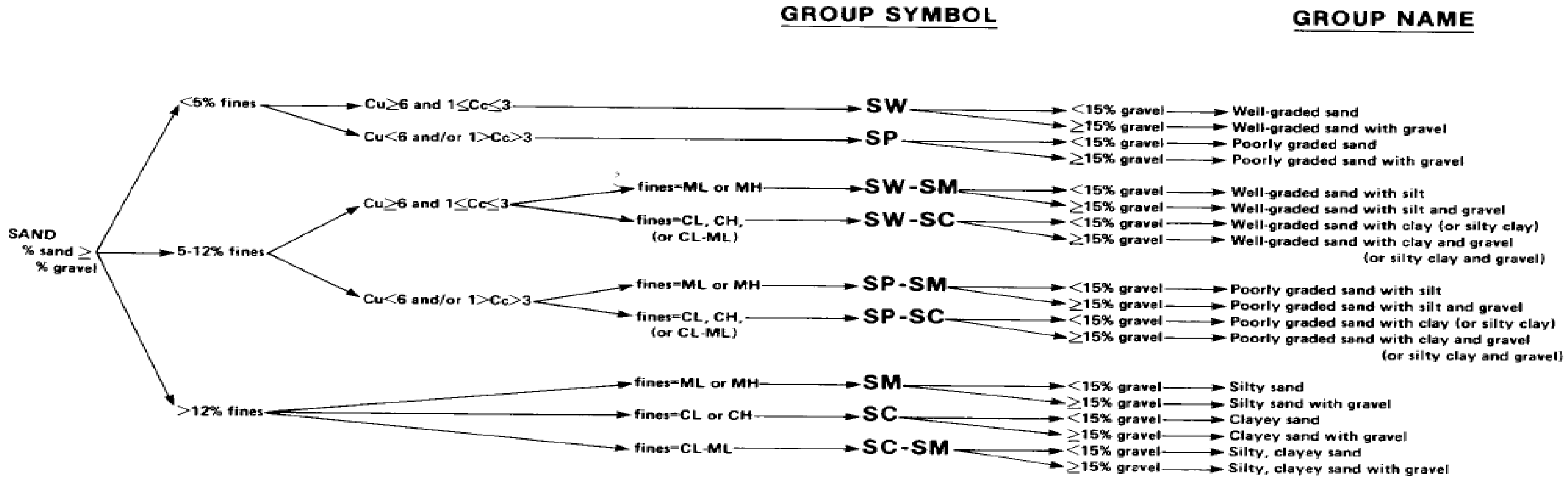
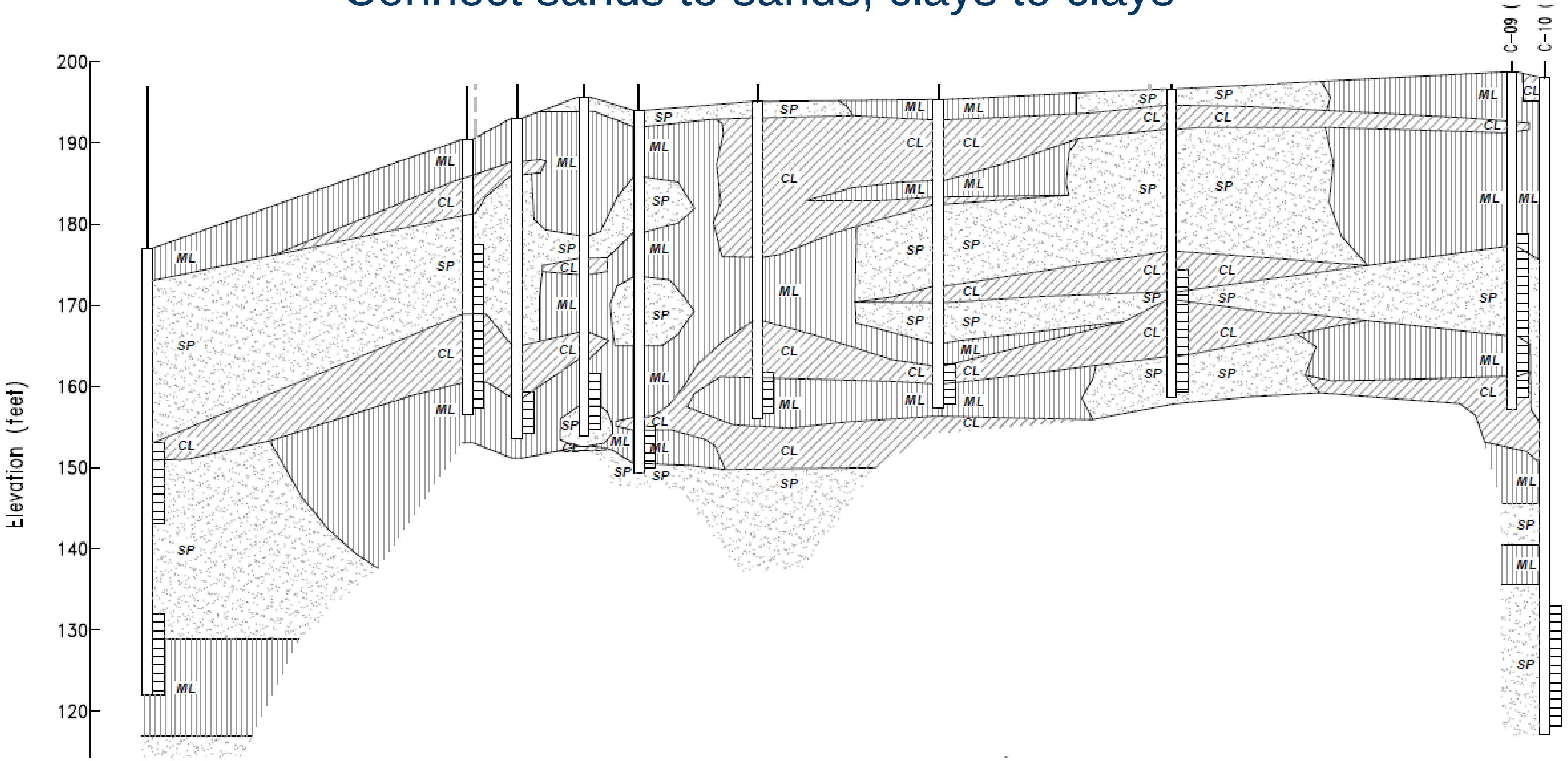


FIG. 3 Flow Chart for Classifying Coarse-Grained Soils (More Than 50 % Retained on No. 200 Sieve)

Lithostratigraphic Correlations

Connect sands to sands, clays to clays



Why
Environmental Sequence Stratigraphy (ESS)?

The Challenge of Subsurface Heterogeneity

Definition of ESS

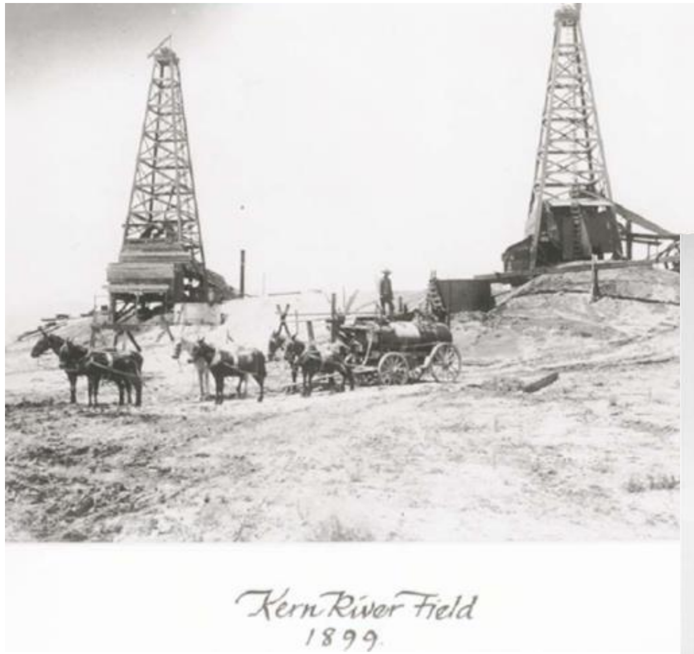
Environmental Sequence Stratigraphy or ESS:

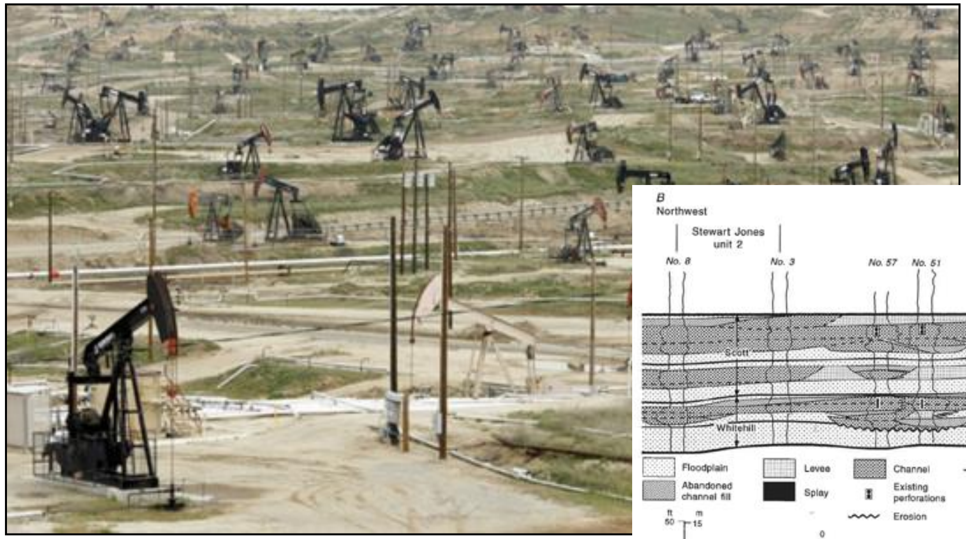
Refers to the application of the concepts of sequence stratigraphy and facies models to the types of subsurface datasets collected for environmental investigations.

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***





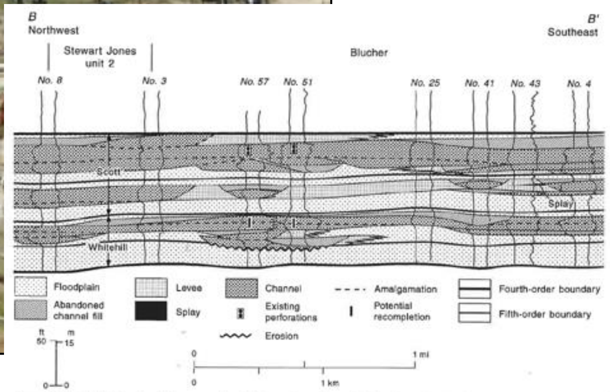


Figure 3. Dip-oriented stratigraphic cross section B-B' through amalgamated channel sandstones and floodplain shales in the Scott/Whitehill intermediate-frequency unit in T-C-B field. Note that the four high-frequency units, the lower and upper Whitehill and the lower and upper Scott, exhibit a successive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

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**
  - ➔…the geology controls where the groundwater flows and, thereby, where contaminants migrate.
- 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

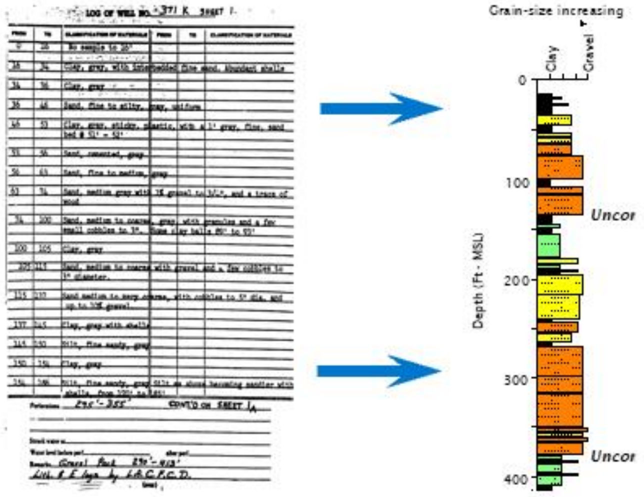
This issue paper was prepared at the request of the Environmental Protection Agency (EPA) Ground Water Forum. The Ground Water, Federal Facilities, and Engineering Forums were established by professionals from the United States Environmental Protection Agency (USEPA) in the ten Regional Offices. The 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:

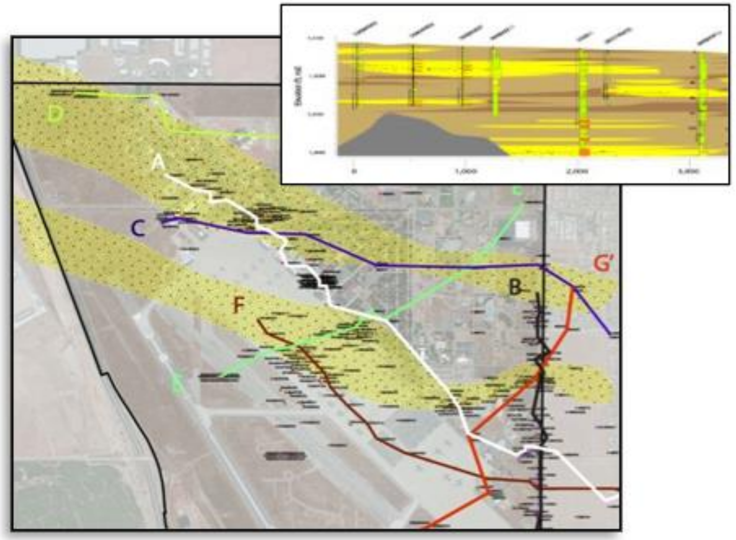
http://www.epa.gov/superfund/remedytech/tsp/issue.htm

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.

Environmental Sequence Stratigraphy (ESS) and Remediation Geology



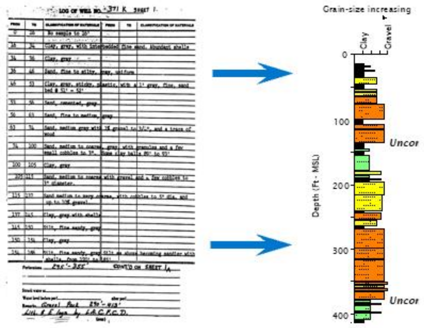


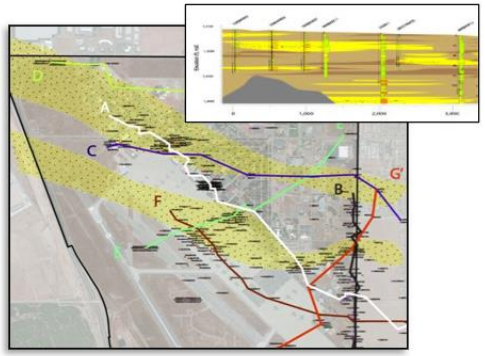
1 **Research regional geology** to determine depositional environment, the foundation of the ESS evaluation.

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

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

Environmental Sequence Stratigraphy (ESS) and Remediation Geology



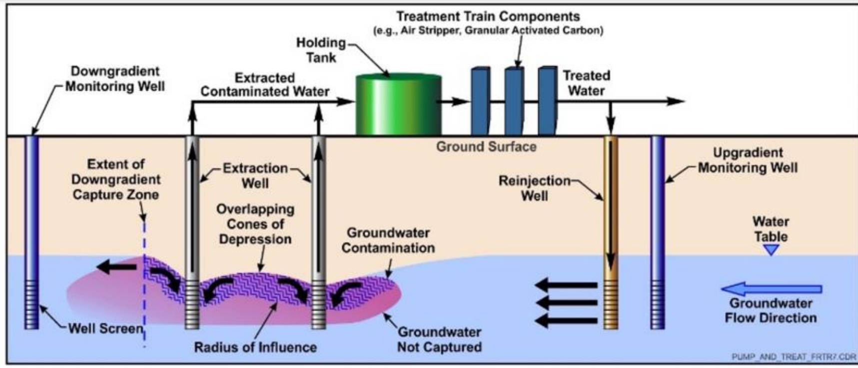


1 **Research regional geology** to determine depositional environment, the foundation of the ESS evaluation.

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.

- **===REMINDER, it’s all about the K!**



4 **Benefits to Remedial System Design and Operations**

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

Geosyntec's
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ESS is About Pattern Recognition

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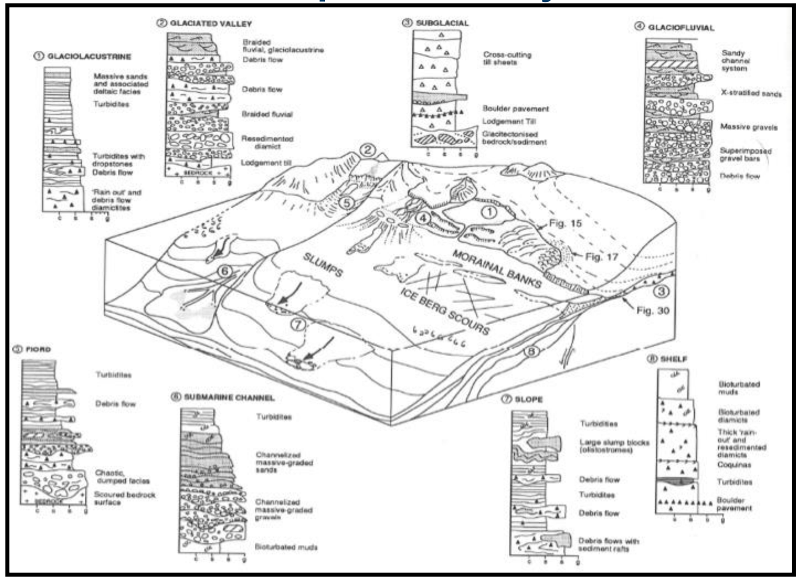
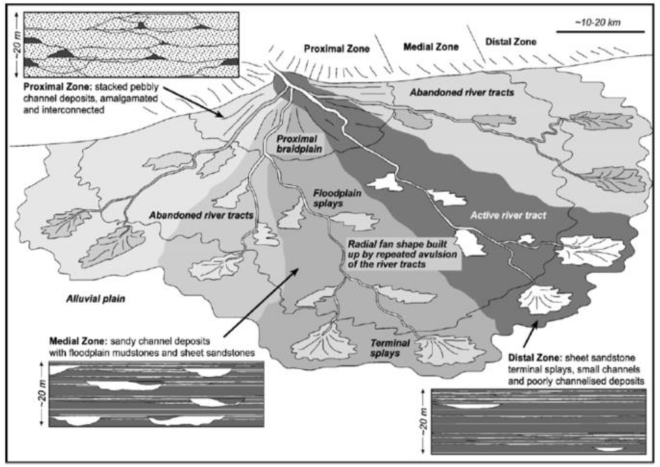
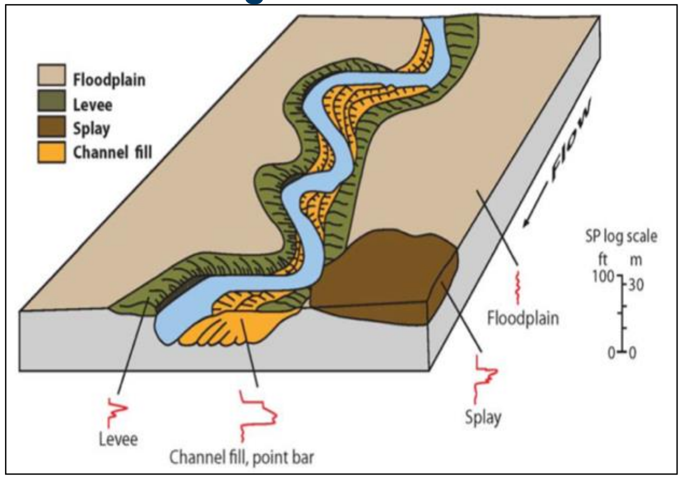
Glacial Depositional Systems



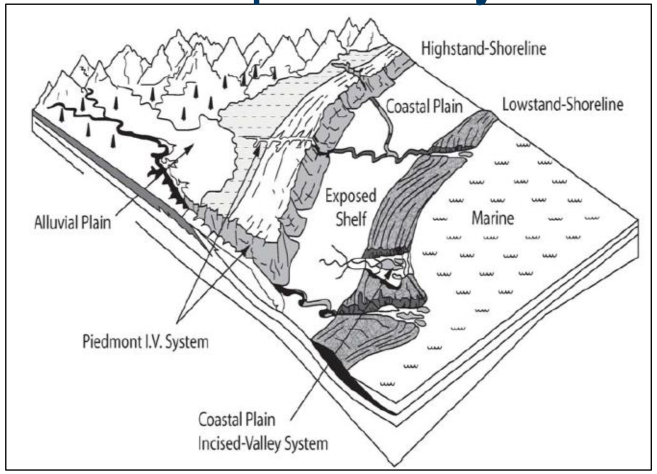
Alluvial Fan Facies Model



Meandering River Facies Model



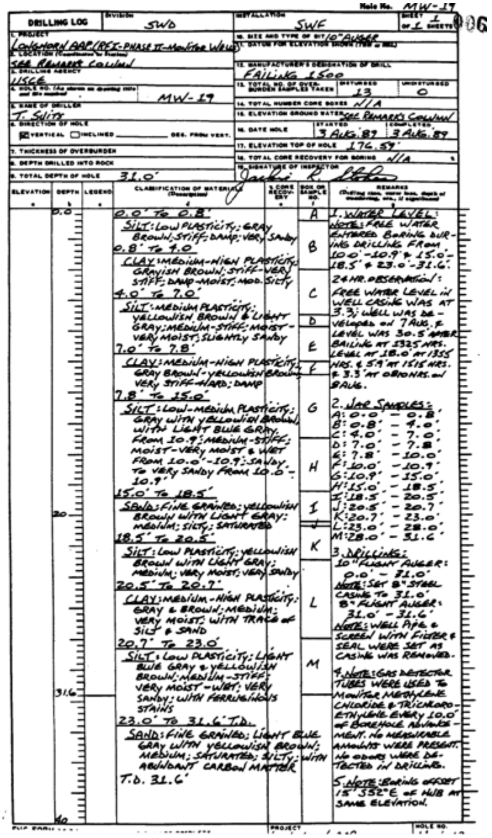
Coastal Depositional Systems



ESS is the Means to Optimize Existing Data

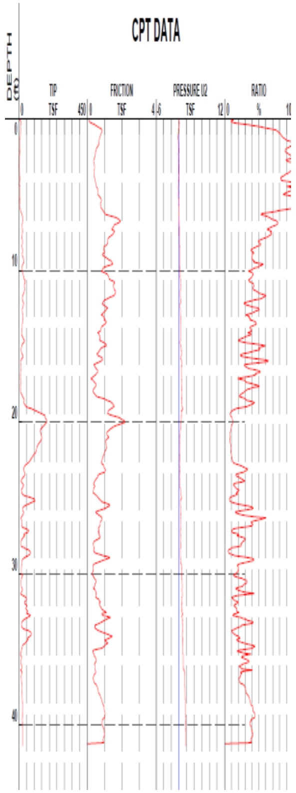
Examples of Lithology Data

Boring Logs

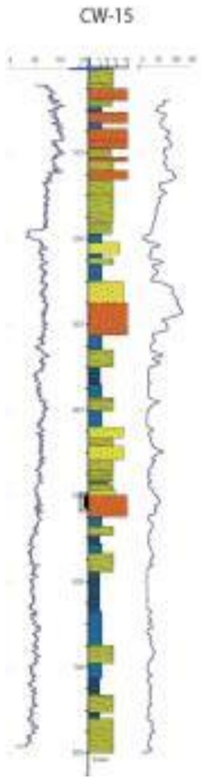

Hole No. MW-19
DRILLING LOG | DIVISION: SWD | INSTALLATION: SWF | SHEET 1 OF 1 SHEETS
1. PROJECT: LONGHORN AAP (RFI-PHASE II-Monitor Wells)
2. LOCATION: SEE REMARKS COLUMN
3. DRILLING AGENCY: USCE
4. HOLE NO.: MW-19
5. NAME OF DRILLER: T. SMITH
6. DIRECTION OF HOLE: VERTICAL
7. THICKNESS OF OVERBURDEN
8. DEPTH DRILLED INTO ROCK
9. TOTAL DEPTH OF HOLE: 31.0'
10. SIZE AND TYPE OF BIT: 10" AUGER
11. DATUM FOR ELEVATION SHOWN (TBM or MSL)
12. MANUFACTURER'S DESIGNATION OF DRILL: FAILING 1500
13. TOTAL NO. OF OVERBURDEN SAMPLES TAKEN: DISTURBED 13, UNDISTURBED 0
14. TOTAL NUMBER CORE BOXES: N/A
15. ELEVATION GROUND WATER: SEE REMARKS COLUMN
16. DATE HOLE: STARTED 3 AUG. 89, COMPLETED 3 AUG. 89
17. ELEVATION TOP OF HOLE: 176.59'
18. TOTAL CORE RECOVERY FOR BORING: N/A
19. SIGNATURE OF INSPECTOR

ELEVATION	DEPTH	LEGEND	CLASSIFICATION OF MATERIALS (Description)	% CORE RECOVERY	BOX OR SAMPLE NO.	REMARKS
	0.0		0.0' TO 0.8' SILT: LOW PLASTICITY; GRAY BROWN; STIFF; DAMP; VERY SANDY		A	1. WATER LEVEL: NOTE: FREE WATER ENTERED BORING DURING DRILLING FROM 10.0'-10.9' & 15.0'-18.5' & 23.0'-31.6'. 24 HR. OBSERVATION: FREE WATER LEVEL IN WELL CASING WAS AT 3.3'; WELL WAS DEVELOPED ON 7 AUG. & LEVEL WAS 30.5' AFTER BAILING AT 1325 HRS. LEVEL AT 18.0' AT 1355 HRS. & 5.9' AT 1515 HRS. & 3.3' AT 0810 HRS. ON 8 AUG.
			0.8' TO 4.0 CLAY: MEDIUM-HIGH PLASTICITY; GRAYISH BROWN; STIFF-VERY STIFF; DAMP-MOIST; MOD. SILTY		B	
			4.0' TO 7.0' SILT: MEDIUM PLASTICITY; YELLOWISH BROWN & LIGHT GRAY; MEDIUM-STIFF; MOIST-VERY MOIST; SLIGHTLY SANDY		C, D	
			7.0' TO 7.8' CLAY: MEDIUM-HIGH PLASTICITY; GRAY BROWN-YELLOWISH BROWN; VERY STIFF-HARD; DAMP		E, F	
			7.8' TO 15.0' SILT: LOW-MEDIUM PLASTICITY; GRAY WITH YELLOWISH BROWN; WITH LIGHT BLUE GRAY. FROM 10.9': MEDIUM-STIFF; MOIST-VERY MOIST & WET FROM 10.0'-10.9'; SANDY. TO VERY SANDY FROM 10.0'-10.9'		G, H	2. JAR SAMPLES: A: 0.0 - 0.8'; B: 0.8' - 4.0'; C: 4.0' - 7.0'; D: 7.0' - 7.8'; E: 7.8' - 10.0'; F: 10.0' - 10.9'; G: 10.9' - 15.0'; H: 15.0' - 18.5'; I: 18.5' - 20.5'; J: 20.5' - 20.7'; K: 20.7' - 23.0'; L: 23.0' - 28.0'; M: 28.0' - 31.6'
	20		15.0' TO 18.5' SAND: FINE GRAINED; YELLOWISH BROWN WITH LIGHT GRAY; MEDIUM; SILTY; SATURATED		I, J	
			18.5' TO 20.5' SILT: LOW PLASTICITY; YELLOWISH BROWN WITH LIGHT GRAY; MEDIUM; VERY MOIST; VERY SANDY		K	3. DRILLING: 10" FLIGHT AUGER: 0.0' - 31.0'. NOTE: SET 8" STEEL CASING TO 31.0'. 8" FLIGHT AUGER: 31.0' - 31.6'. NOTE: WELL PIPE & SCREEN WITH FILTER & SEAL WERE SET AS CASING WAS REMOVED.
			20.5' TO 20.7' CLAY: MEDIUM-HIGH PLASTICITY; GRAY & BROWN; MEDIUM; VERY MOIST; WITH TRACE OF SILT & SAND		L	
	31.6		20.7' TO 23.0' SILT: LOW PLASTICITY; LIGHT BLUE GRAY & YELLOWISH BROWN; MEDIUM-STIFF; VERY MOIST-WET; VERY SANDY; WITH FERRUGINOUS STAINS		M	4. NOTE: GAS DETECTOR TUBES WERE USED TO MONITOR METHYLENE CHLORIDE & TRICHLOROETHYLENE EVERY 10.0' OF BOREHOLE ADVANCEMENT. NO MEASURABLE AMOUNTS WERE PRESENT. NO ODORS WERE DETECTED IN DRILLING.
	40		23.0' TO 31.6' T.D. SAND: FINE GRAINED; LIGHT BLUE GRAY WITH YELLOWISH BROWN; MEDIUM; SATURATED; SILTY; WITH ABUNDANT CARBON MATTER. T.D. 31.6'			5. NOTE: BORING OFFSET 15' S52°E OF HUB AT SAME ELEVATION.

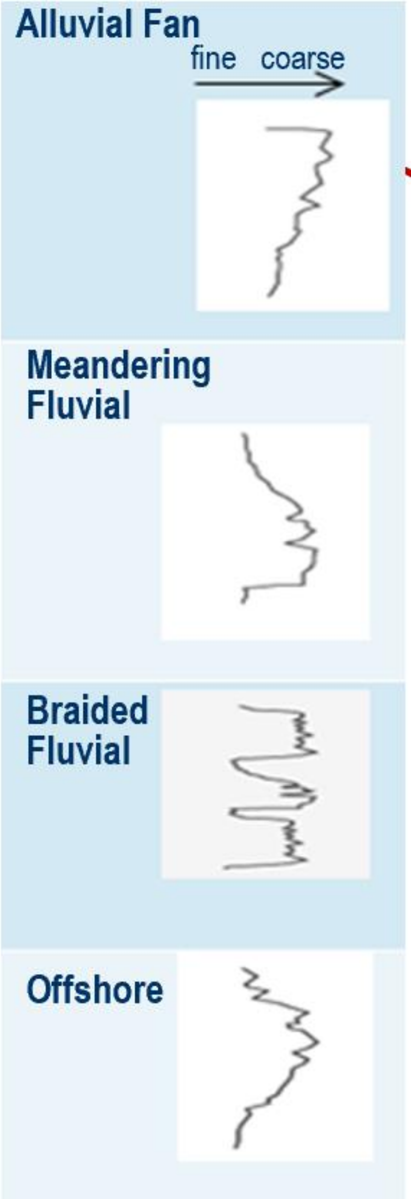
CPT Logs

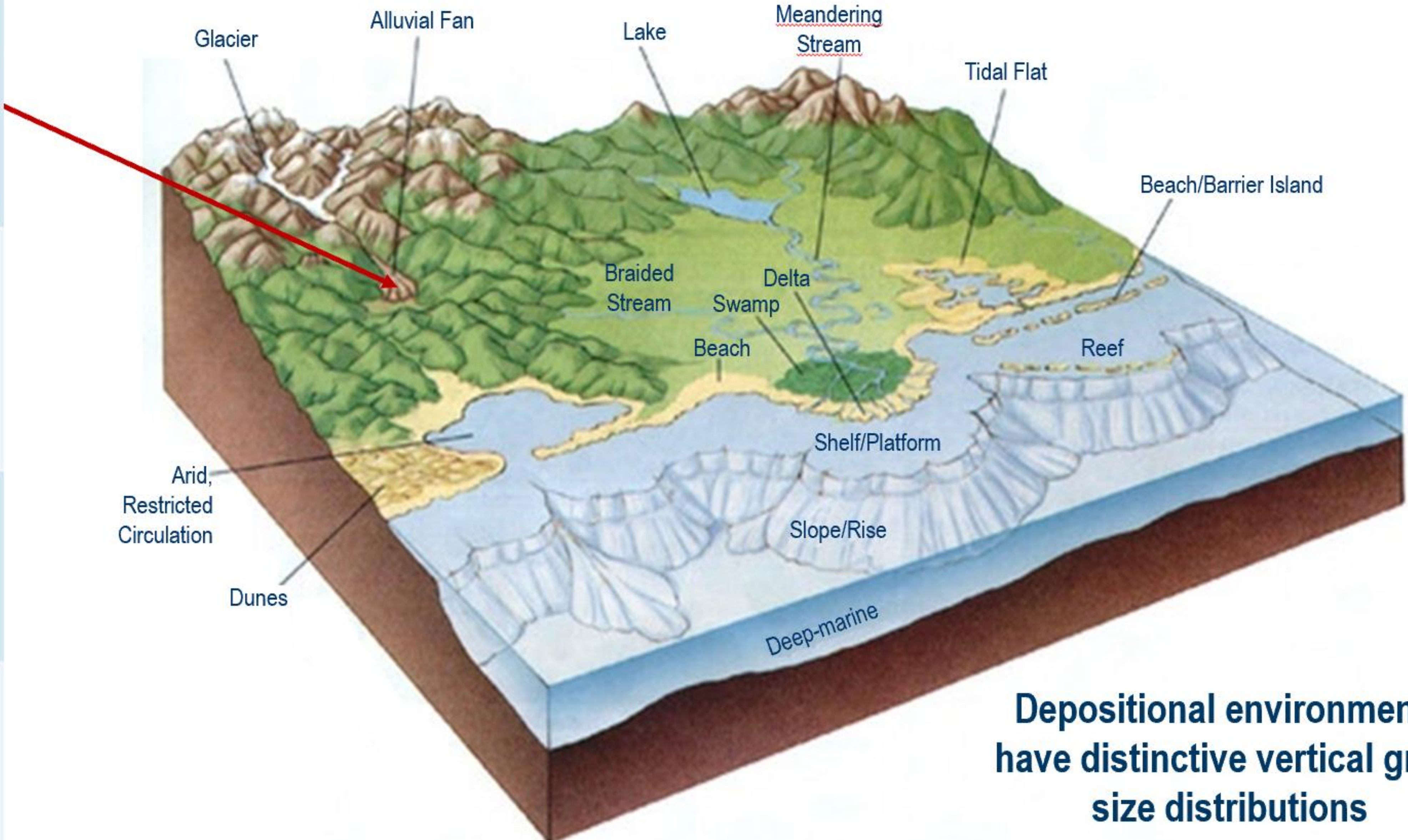


Geophysical Logs



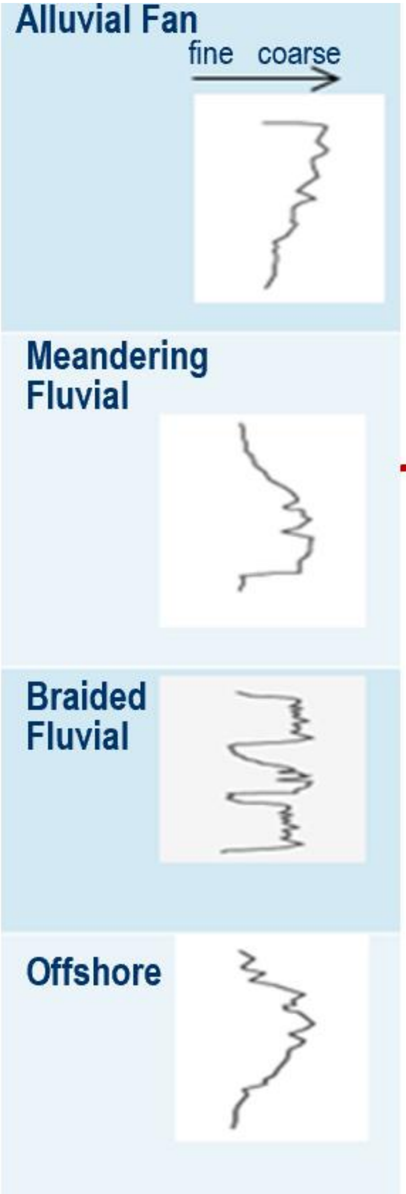
ESS is About Pattern Recognition (cont.)

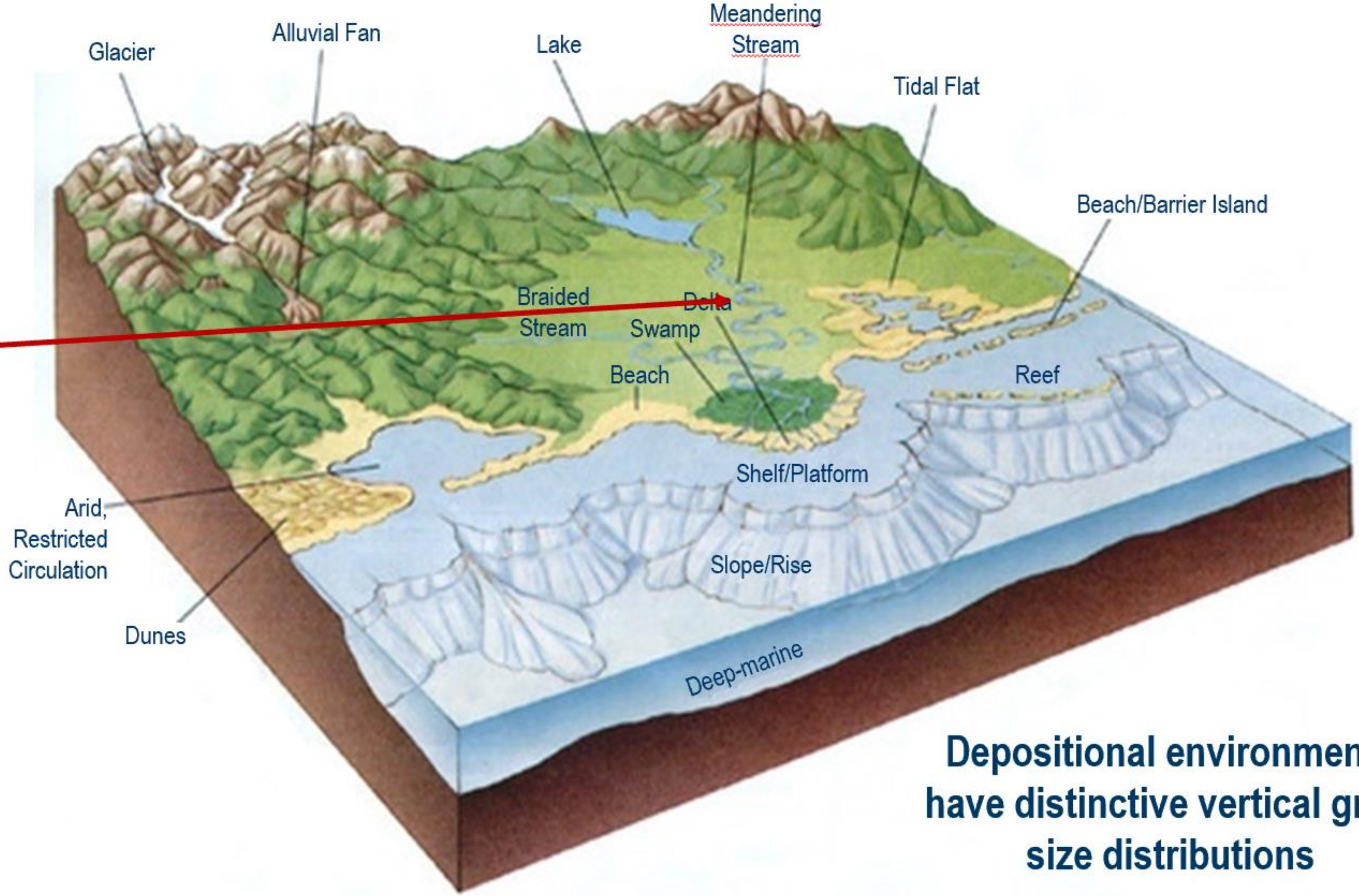




Depositional environments have distinctive vertical grain size distributions

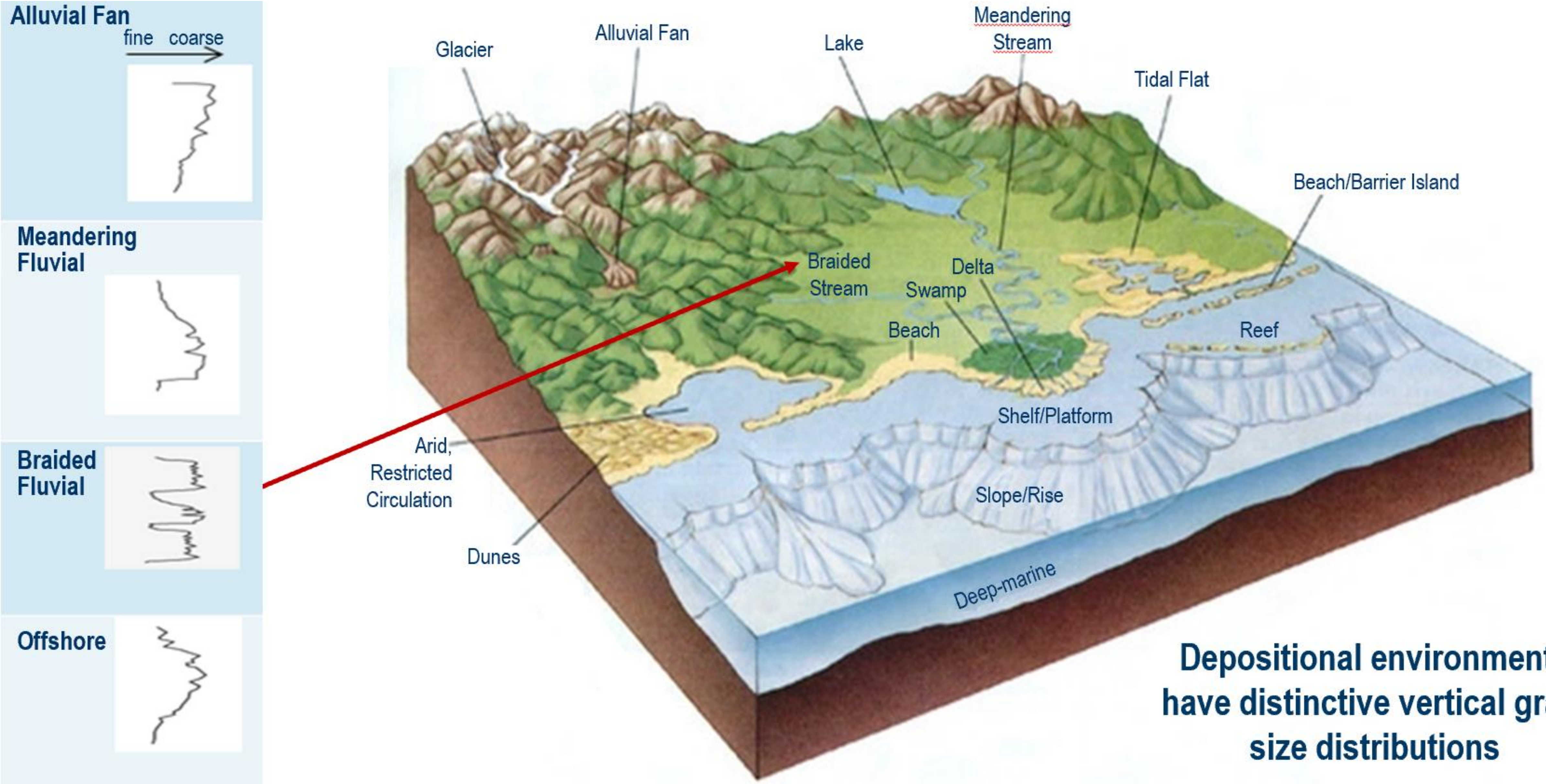
ESS is About Pattern Recognition (cont.)





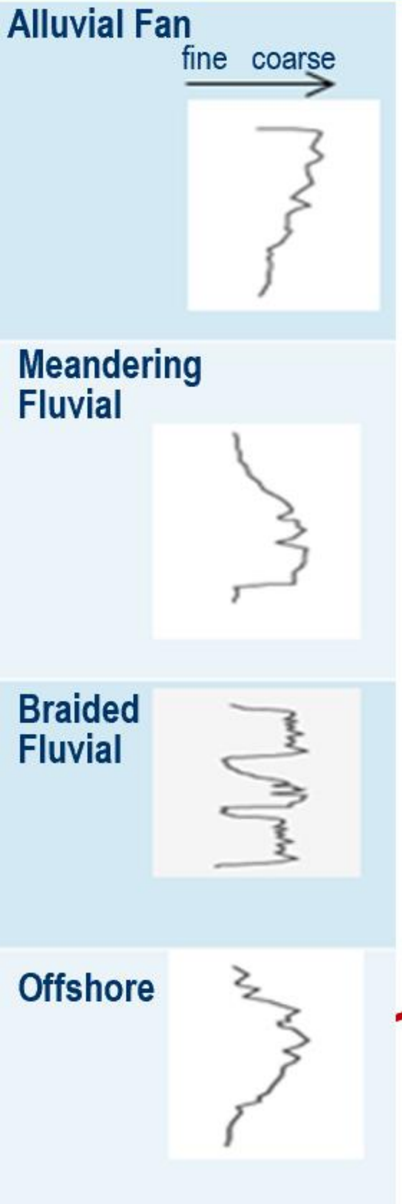
Depositional environments have distinctive vertical grain size distributions

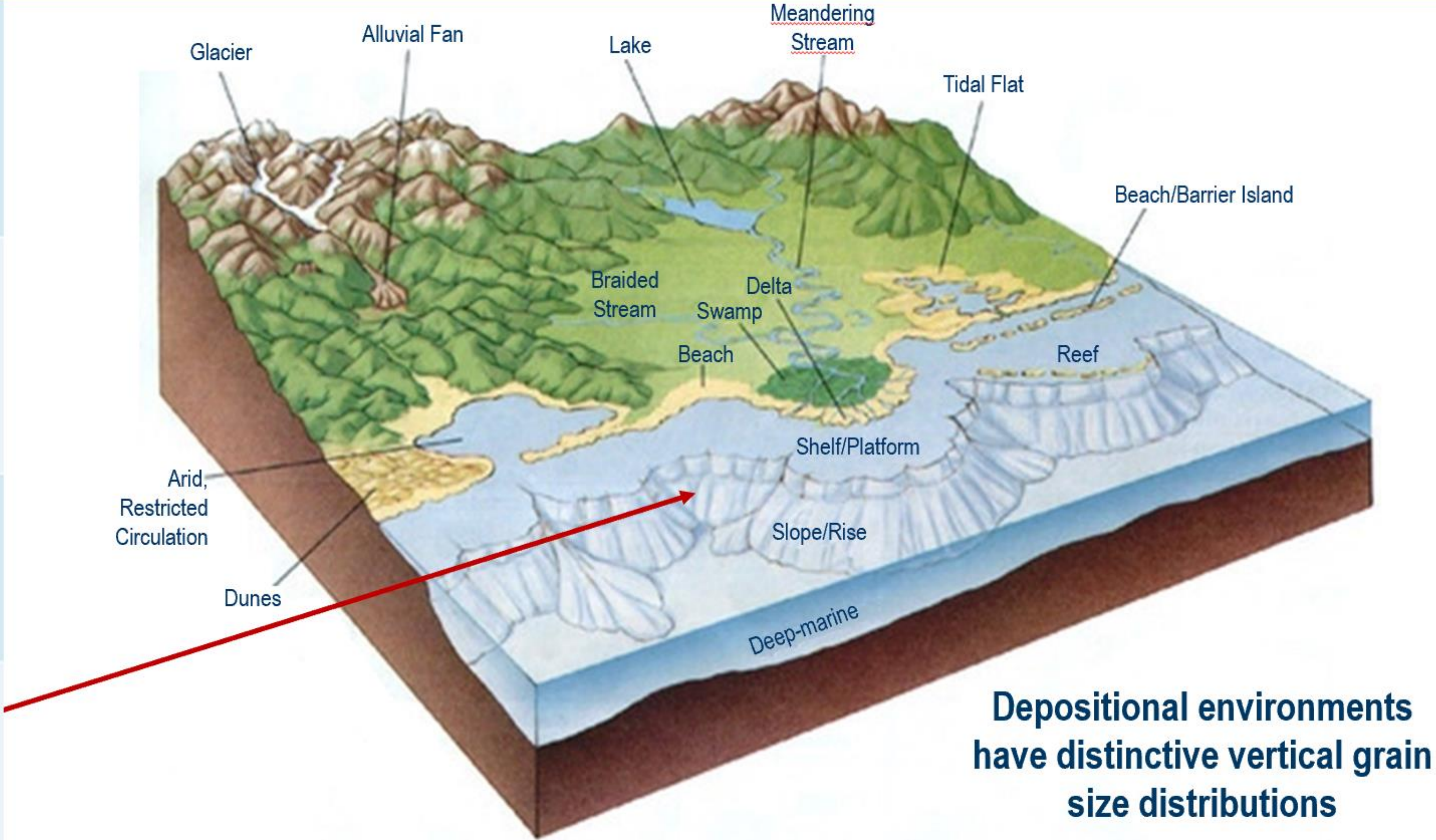
ESS is About Pattern Recognition (cont.)



Depositional environments have distinctive vertical grain size distributions

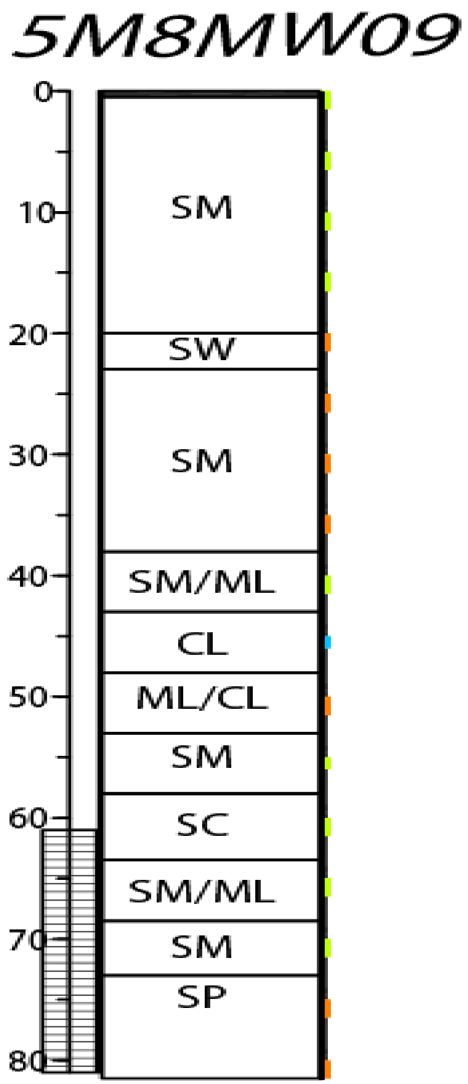
ESS is About Pattern Recognition (cont.)





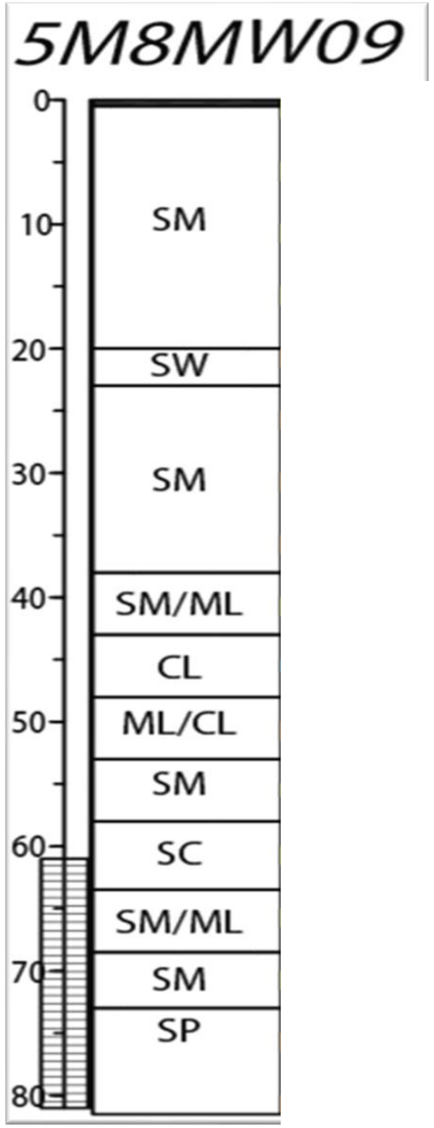
Depositional environments have distinctive vertical grain size distributions

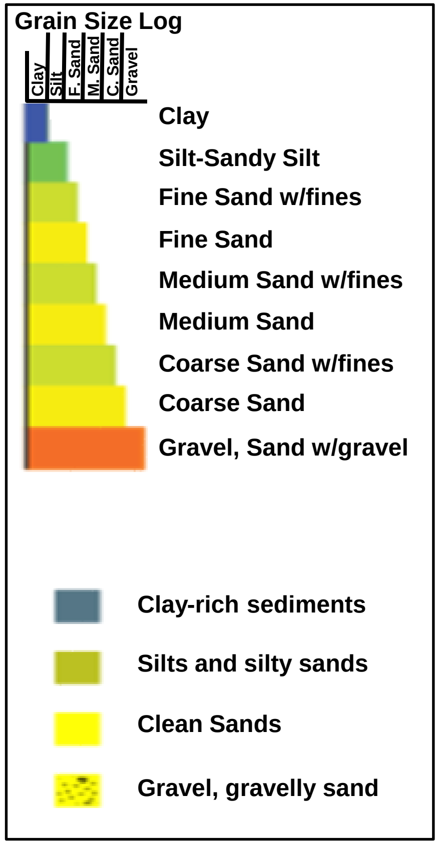
Getting more from existing data



- “All we have are these lousy USCS boring logs”
- USCS is not a geologic description of the lithology
- Different geologists
- Different drilling methods
- Different sampling intervals
- Etc.

Getting more from existing data





Graphic Grain-Size Logs (GSLs)

- Alternative to the standard of posting USCS symbols
- Existing data is re-formatted for stratigraphic interpretation

Key Point

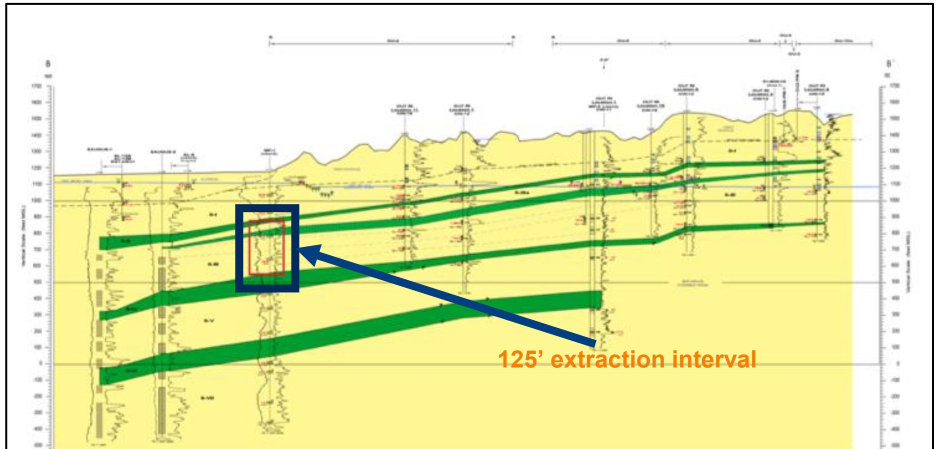
Reveals the "hidden" stratigraphic information available with existing lithology data

Question…

Why would you manage your remediation project with an inferior understanding of the subsurface?

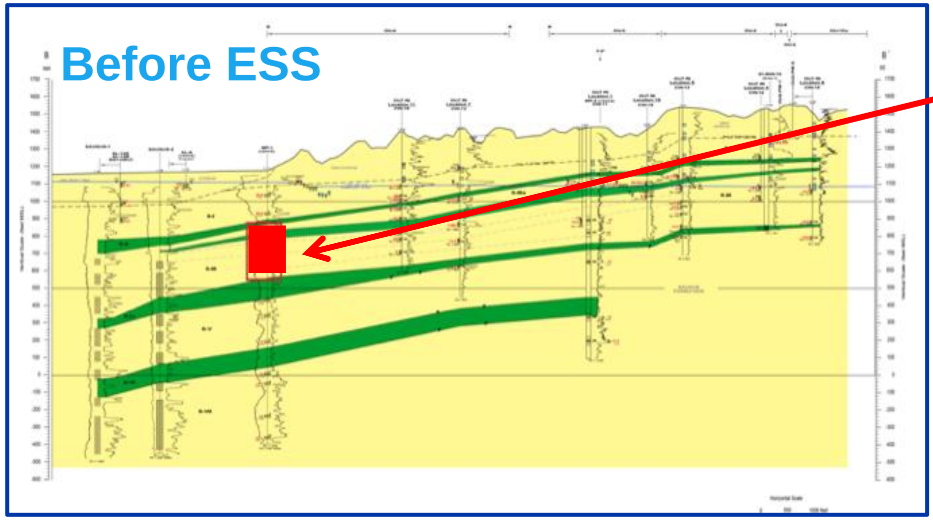
Case Study #5 from USEPA Technical Issue Paper

- **996-acre site** in Santa Clarita, California
- Complex geology, more than 600 feet of stratigraphy, dipping beds
- Impacted mainly with perchlorate (ClO_{4-}), but locally CVOCs, including TCE
- Awarded contract to implement containment pilot study for agency-approved RAP based on existing CSM
- But wait…

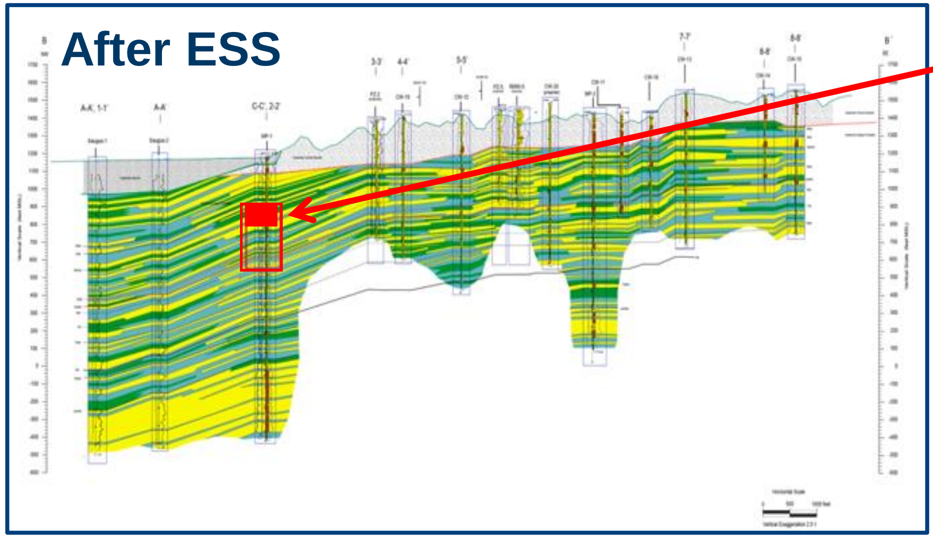


Pre-existing three-layer CSM

Cost of Oversimplifying Subsurface Heterogeneity



125' extraction interval (includes non-impacted strata)



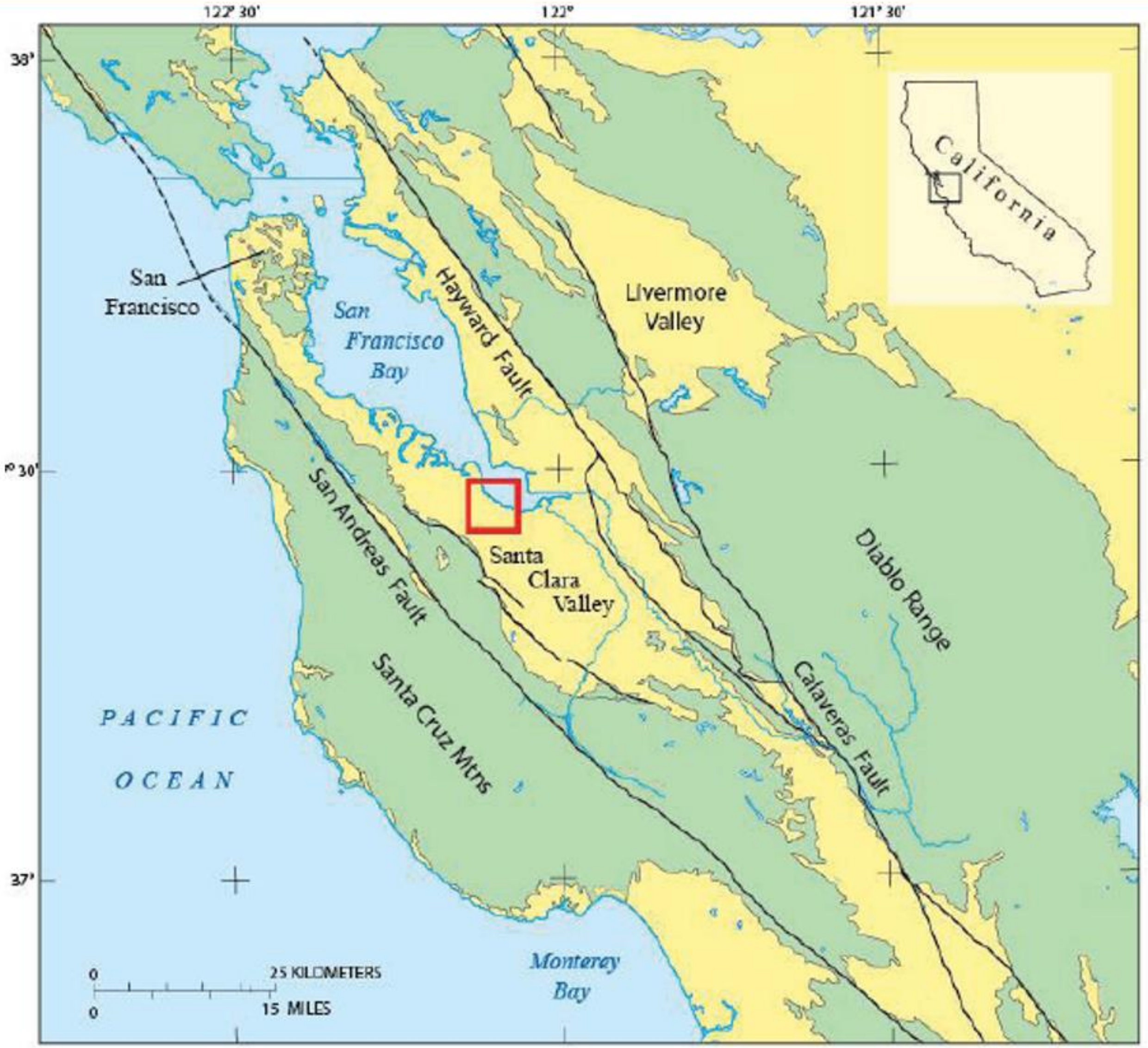
35' extraction interval (impacted strata only)

Significantly reduced quantity of extracted groundwater (by 75%)

Significantly reduced cost of remediation (by >$50 million)

Case Study #1 from USEPA Technical Issue Paper

- Former semiconductor manufacturing site with VOC groundwater plume
- Geology changed the regulatory direction of the project
- Definition of co-mingled plumes and related source areas
- Scale: **10-acre study area**
- Depositional Environment: Meandering river



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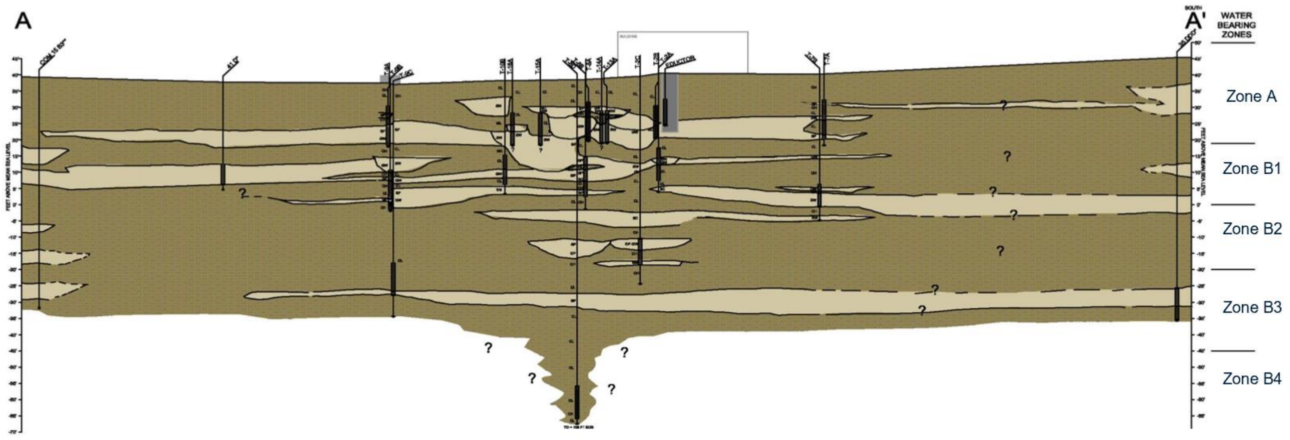
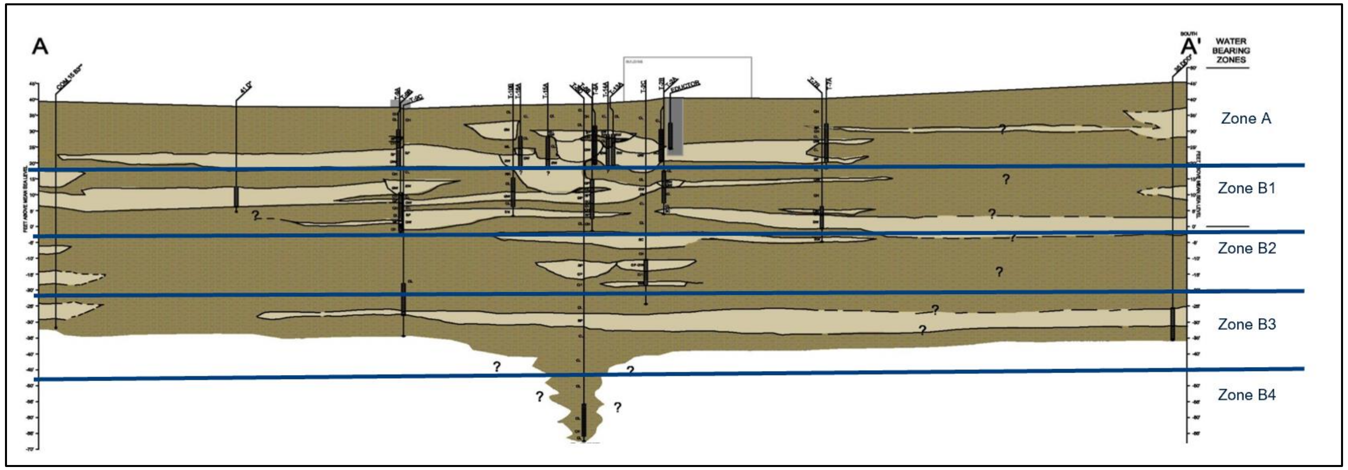


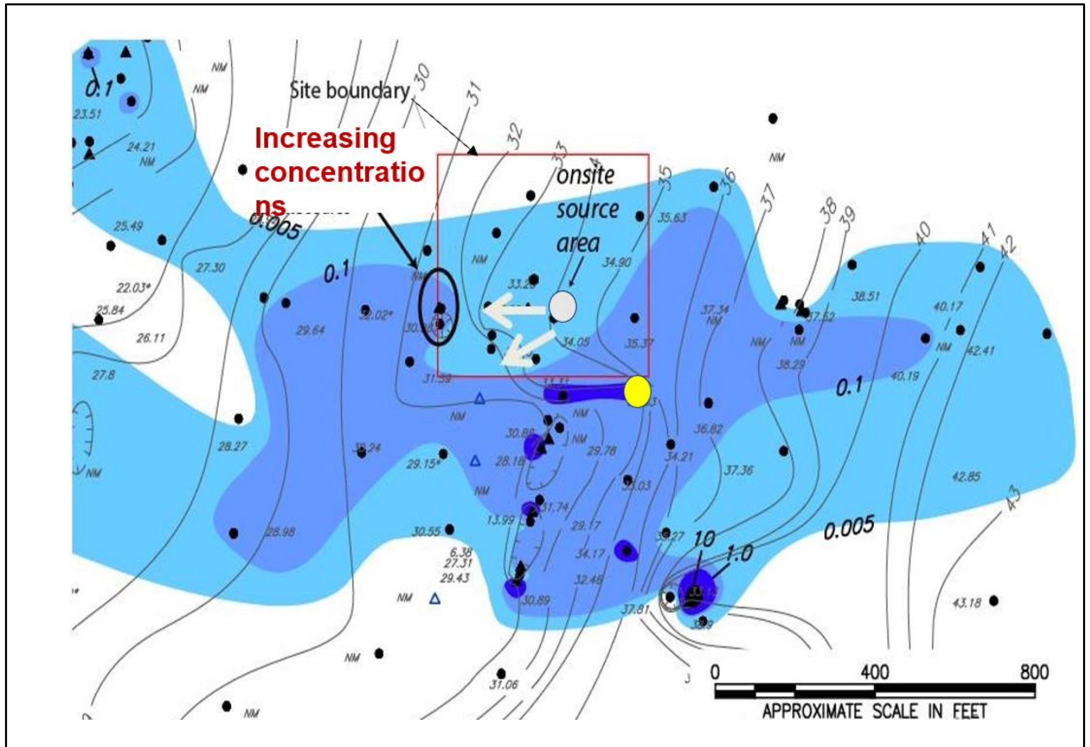
Lithostratigraphic correlations using USCS

Case Study #1 from USEPA Technical Issue Paper



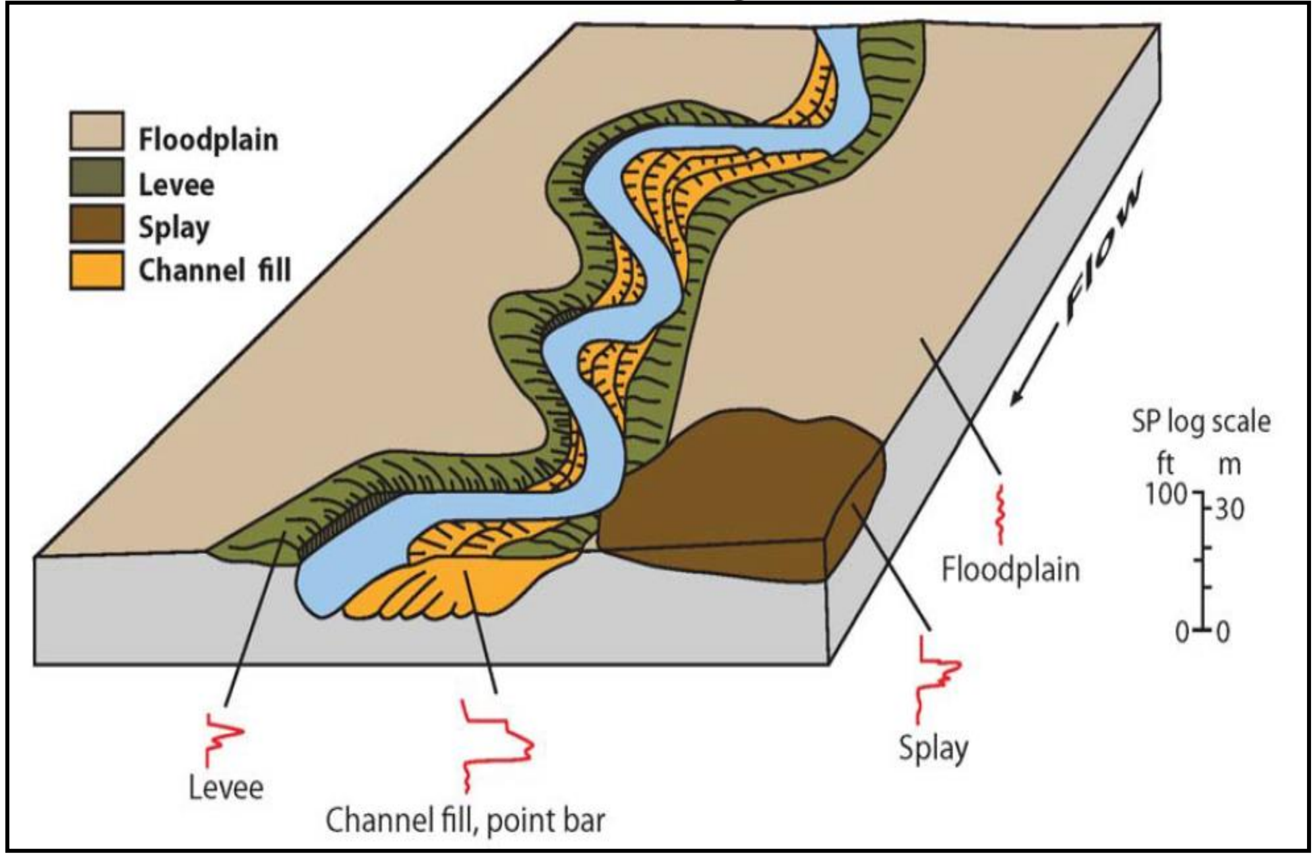
Lithostratigraphic correlations using USCS

Groundwater flow interpretations assuming homogeneous/Isotropic conditions

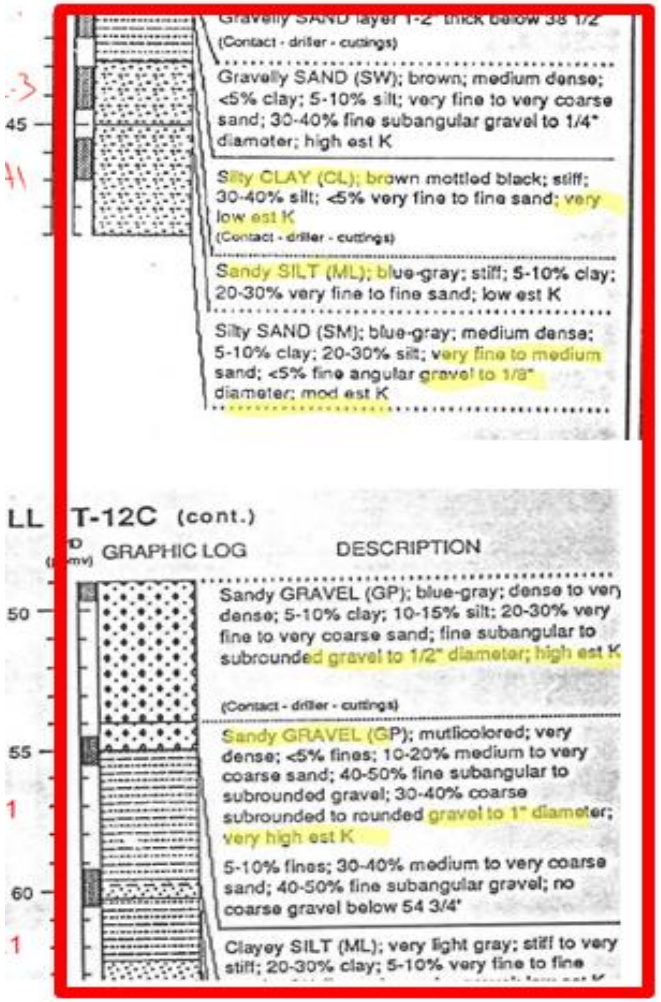


Grain Size Trends and Graphic Grain Size Logs

Depositional Environment – Meandering River



Boring Log



Gravelly SAND layer 1-2" thick below 38 1/2
(Contact - driller - cuttings)

Gravelly SAND (SW); brown; medium dense; <5% clay; 5-10% silt; very fine to very coarse sand; 30-40% fine subangular gravel to 1/4" diameter; high est K

Silty CLAY (CL); brown mottled black; stiff; 30-40% silt; <5% very fine to fine sand; very low est K
(Contact - driller - cuttings)

Sandy SILT (ML); blue-gray; stiff; 5-10% clay; 20-30% very fine to fine sand; low est K

Silty SAND (SM); blue-gray; medium dense; 5-10% clay; 20-30% silt; very fine to medium sand; <5% fine angular gravel to 1/8" diameter; mod est K

T-12C (cont.)

GRAPHIC LOG | DESCRIPTION

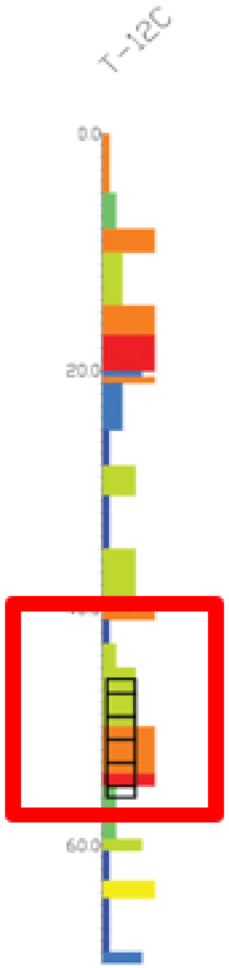
Sandy GRAVEL (GP); blue-gray; dense to very dense; 5-10% clay; 10-15% silt; 20-30% very fine to very coarse sand; fine subangular to subrounded gravel to 1/2" diameter; high est K
(Contact - driller - cuttings)

Sandy GRAVEL (GP); mutlicolored; very dense; <5% fines; 10-20% medium to very coarse sand; 40-50% fine subangular to subrounded gravel; 30-40% coarse subrounded to rounded gravel to 1" diameter; very high est K

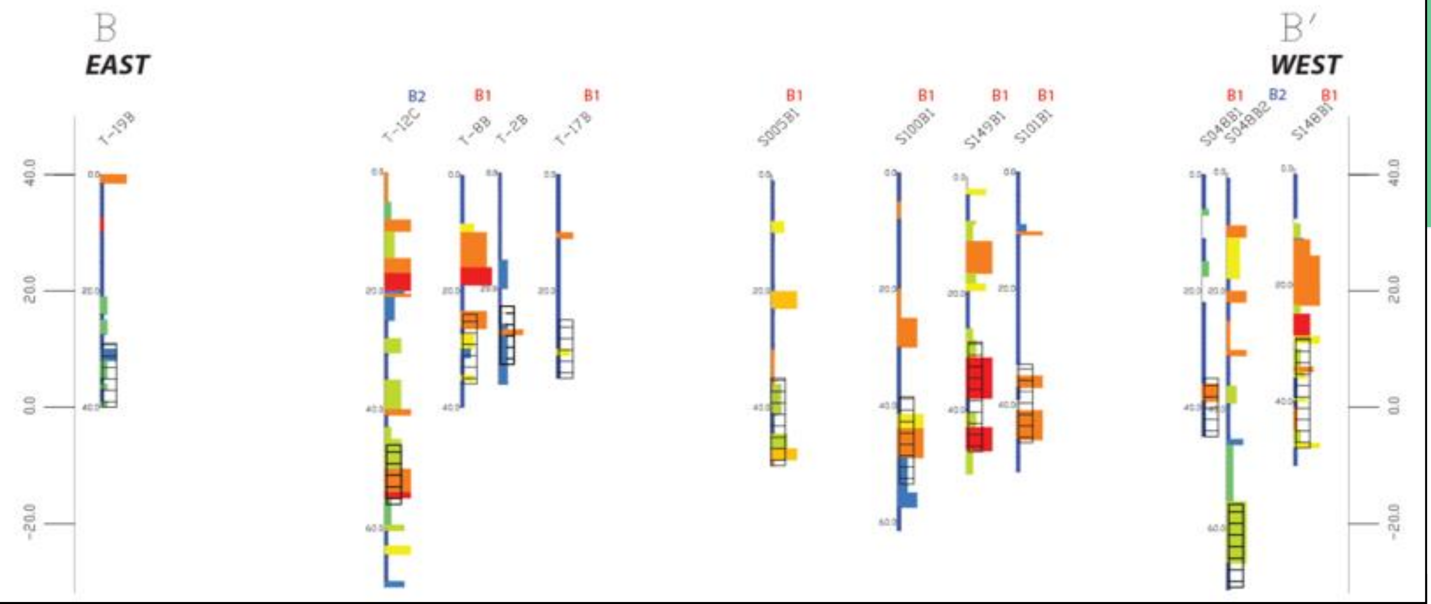
5-10% fines; 30-40% medium to very coarse sand; 40-50% fine subangular gravel; no coarse gravel below 54 3/4"

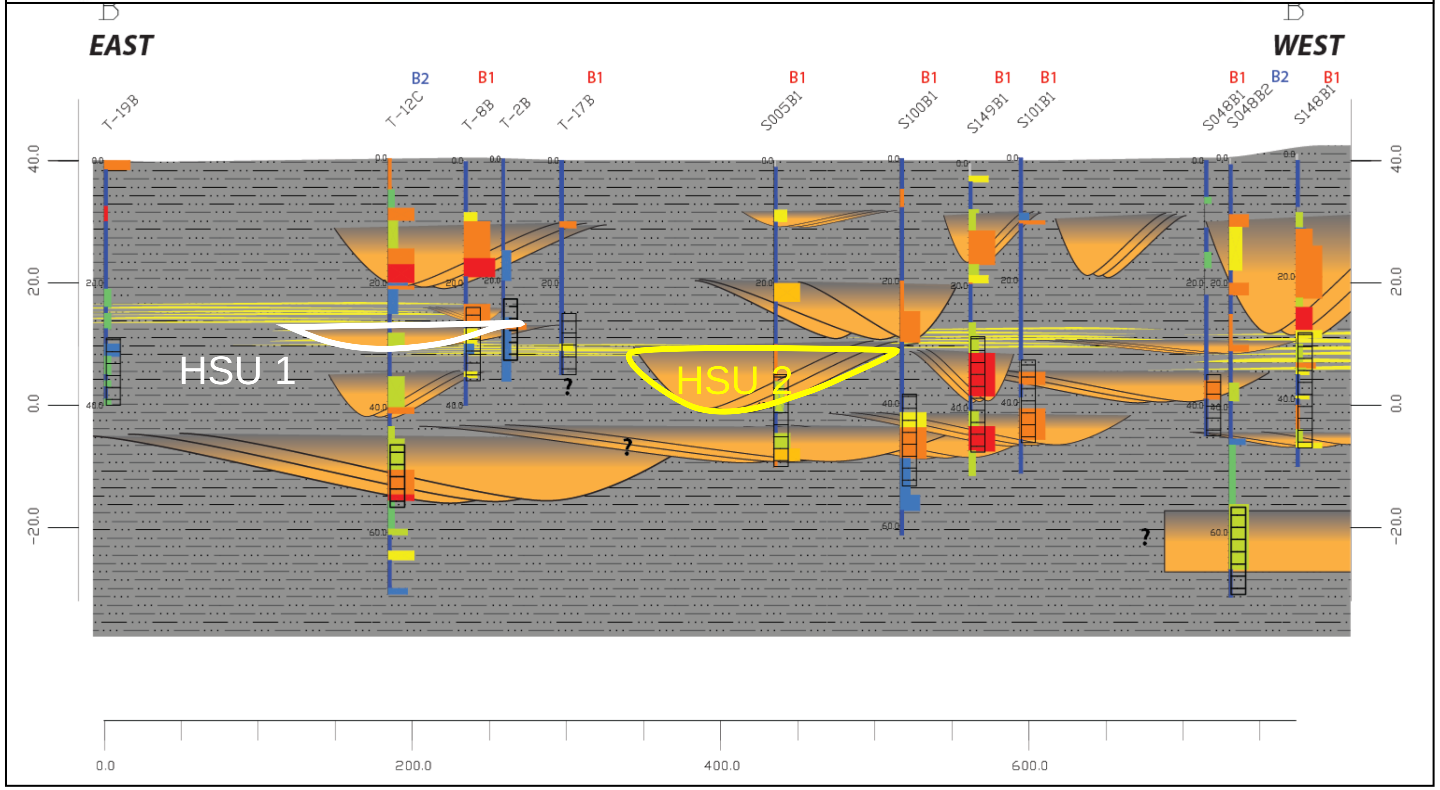
Clayey SILT (ML); very light gray; stiff to very stiff; 20-30% clay; 5-10% very fine to fine

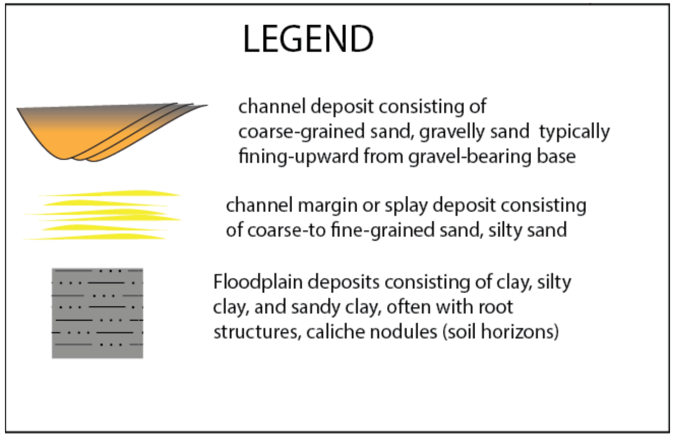
GSL



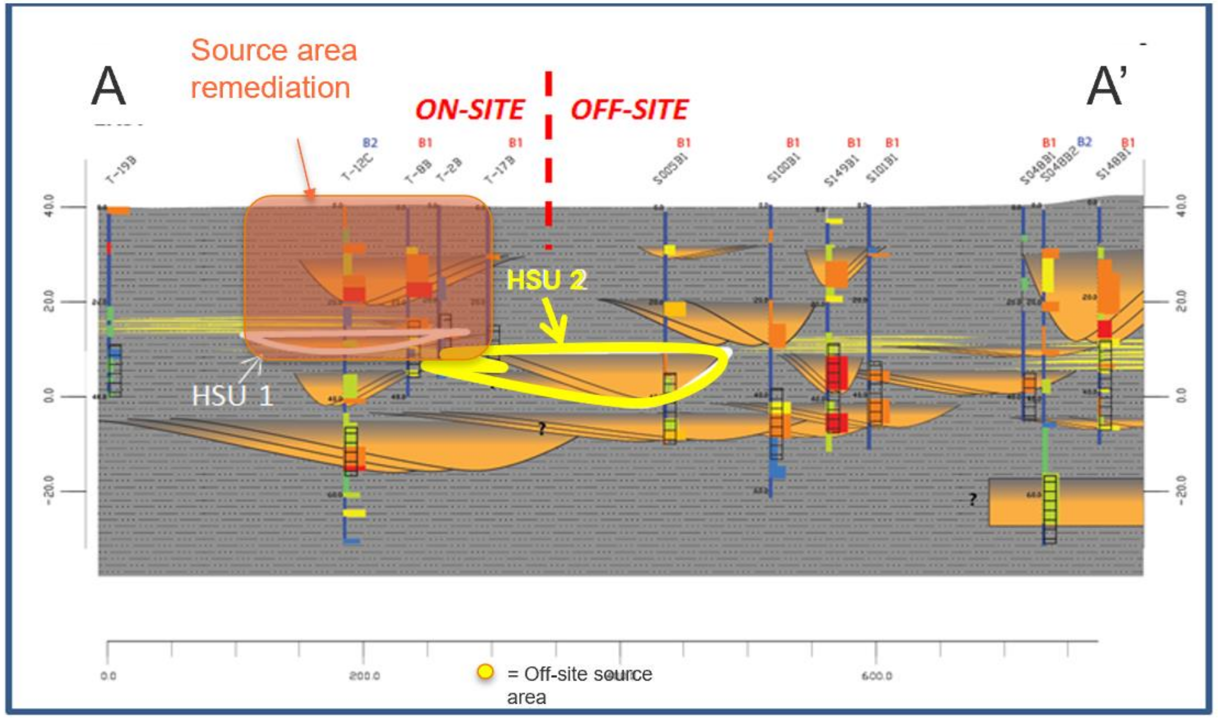
Case Study #1 Posting GSLs/Channel Interpretation





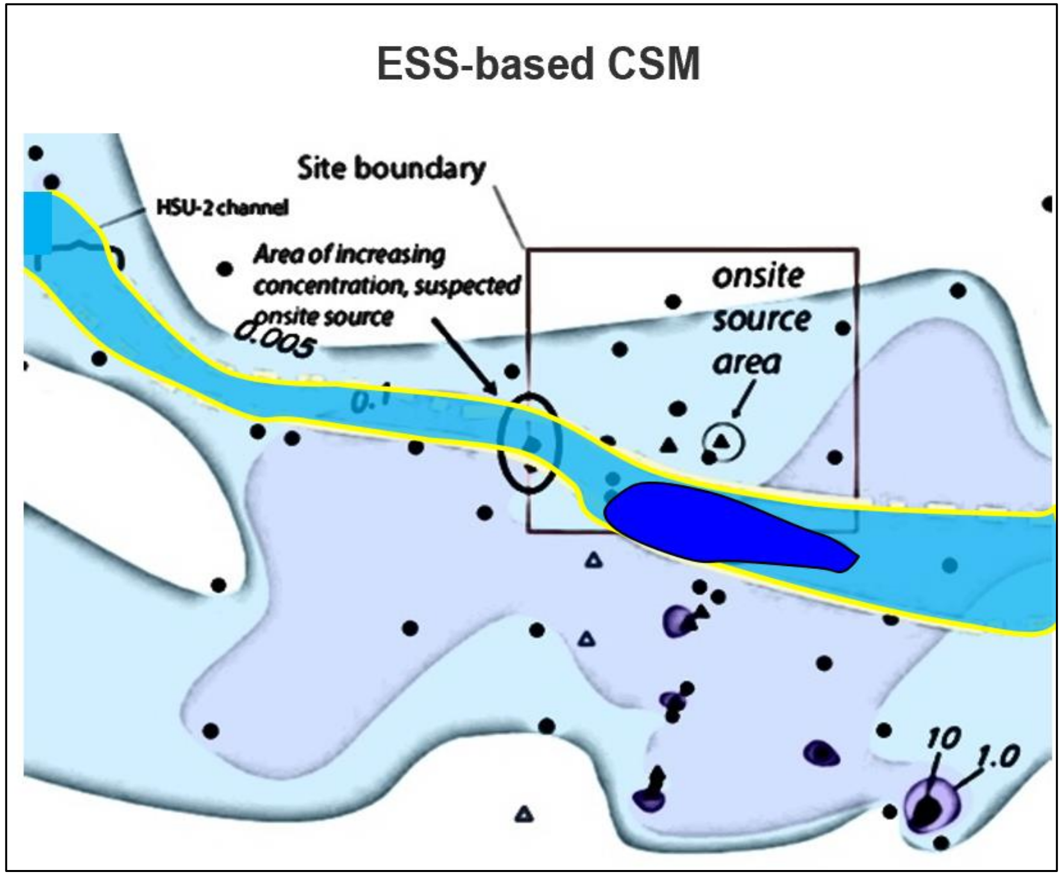


Case Study #1 from USEPA Technical Issue Paper



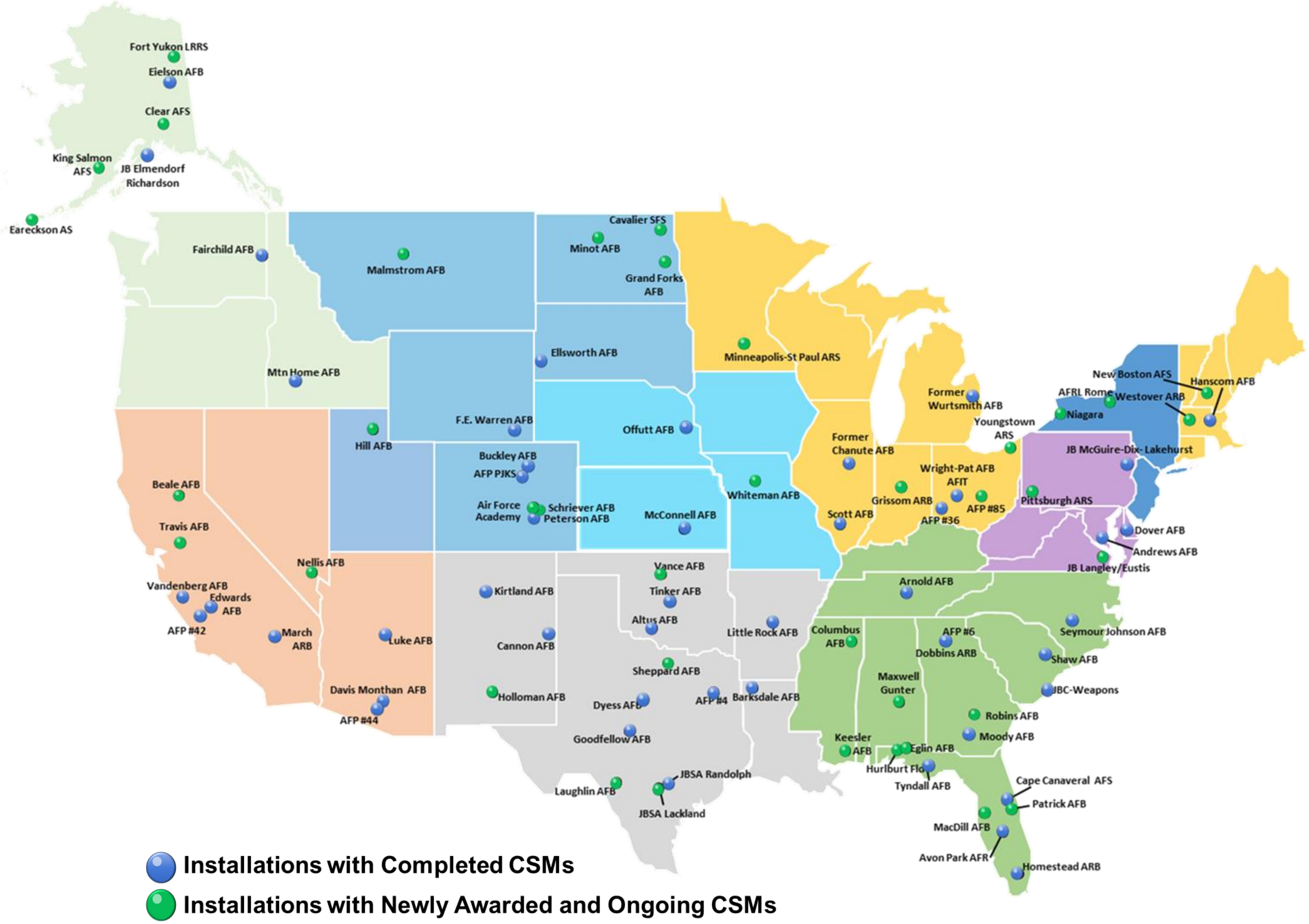
ESS-based correlations based on graphic grainsize logs

Groundwater flow interpretation based on ESS definition of hydrostratigraphic units



Air Force ESS Projects from 2010 to 2023

- Applied to over 80 Air Force Facilities
- **AFCEC conducted an enterprise-wide study**
- 58 ESS reports at active installations in the library
- Lead remediation engineer concluded, **remediation design requires an ESS-based CSM to adequately represent the subsurface**



Question…

Why would you **not** do a geology-focused evaluation of your groundwater project?

New Areas of Focus: Groundwater Management (SGMA) and Geotechnical Support

ESS Application to Groundwater Management

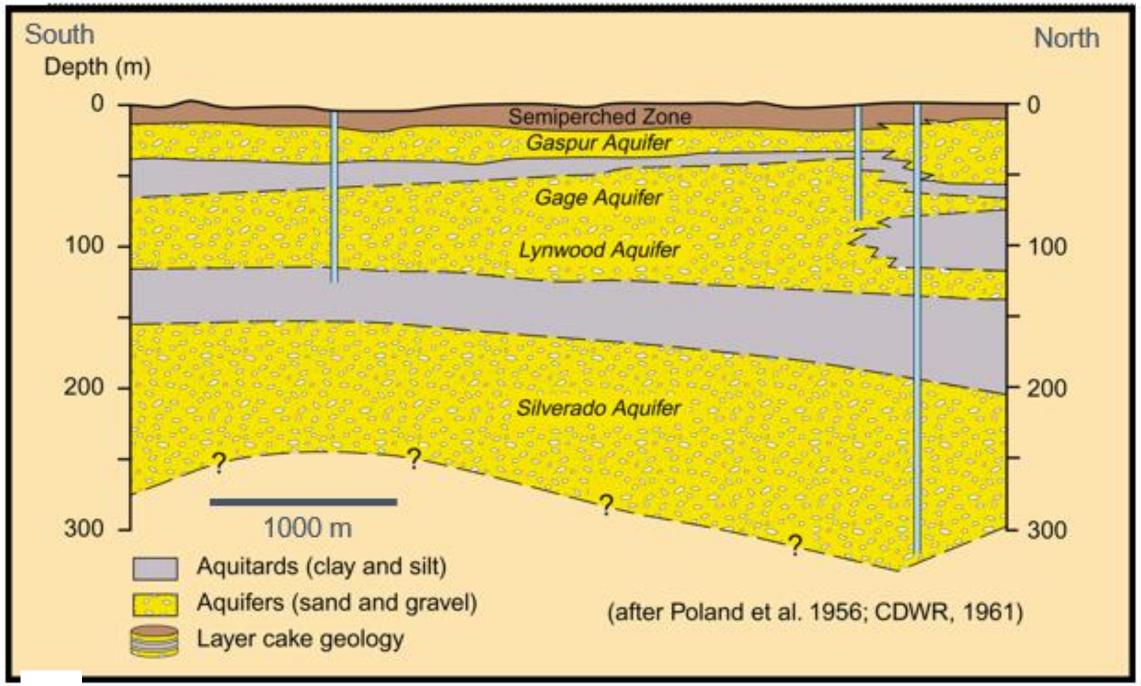
CONJUNCTIVE USE OF WATER RESOURCES: AQUIFER STORAGE AND RECOVERY
OCTOBER AMERICAN WATER RESOURCES ASSOCIATION 1997

APPLICATION OF SEQUENCE STRATIGRAPHY TO EVALUATE GROUNDWATER RESOURCES

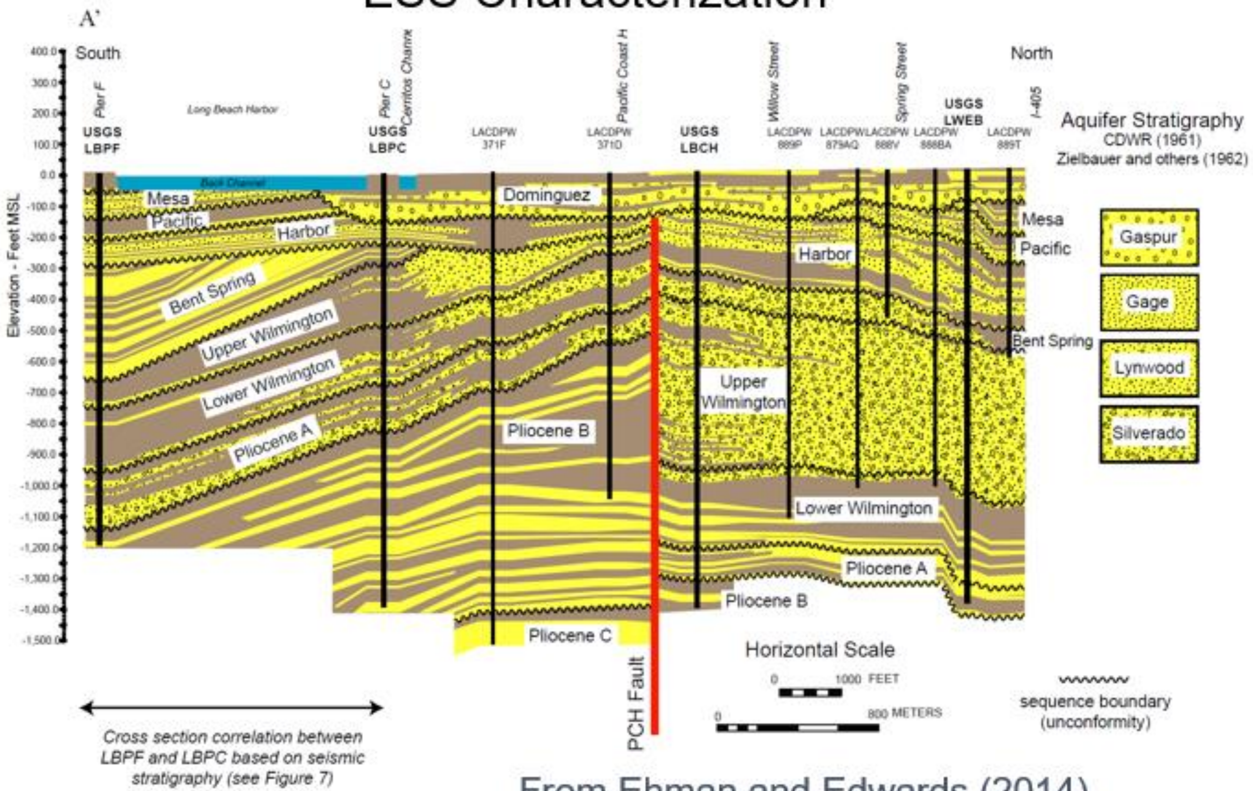
Kenneth D. Ehman and Richard S. Cramer[1]

California Groundwater Basin Characterization Program

Before ESS



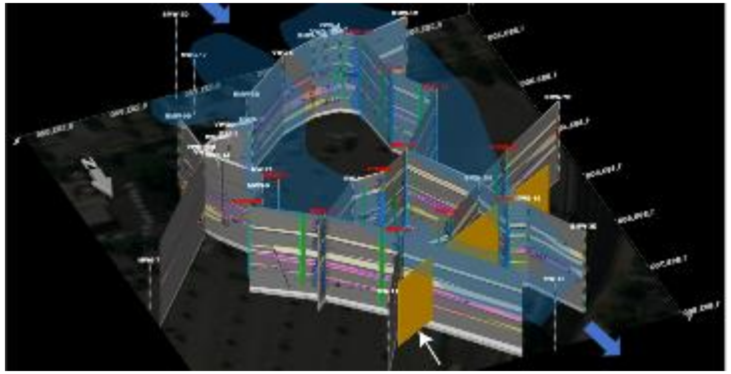
ESS Characterization



From Ehman and Edwards (2014)

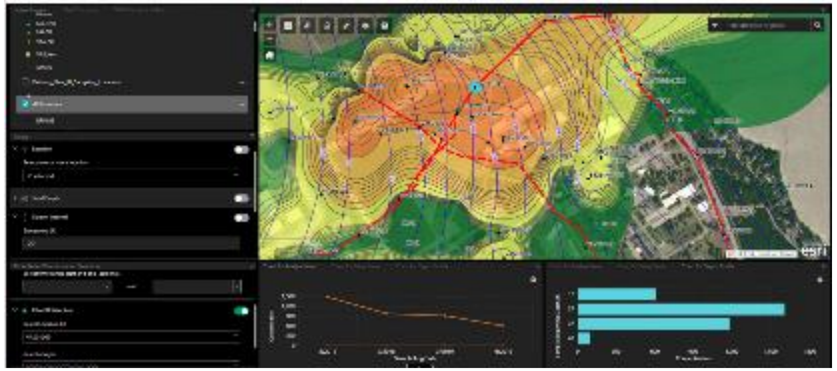
Detailed permeability architecture defined through the application of Environmental Sequence Stratigraphy

The State of the Practice



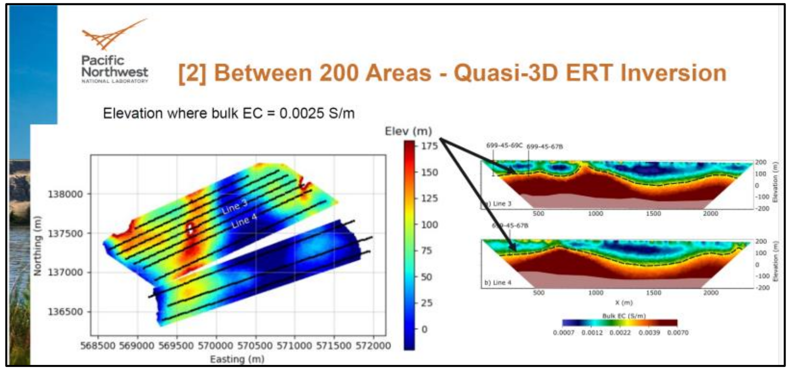
Advanced Methods of Data Interrogation and Visualization:

- ▶ Mapping Software and Database Management
  - Increased use of legacy and regional data
- ▶ 3D visualizations of HRSC data constrained by stratigraphic data:
  - Fence Diagrams and “dummy points”
  - *Stratigraphic Flux* type approaches



Advanced Methods of CSM Delivery:

- ▶ Digital CSMs
  - Web-Application approaches
  - XYZ data and Strat Surface Files
  - Increasing direct connectivity with numerical modeling approaches



“Marry” Geophysics Interpretations to Geologic Model

- ▶ Geophysics have helped provide a first line of evidence of subsurface structure
- ▶ Need a better understanding of electrical properties vs. hydraulic properties vs geologic features

Geophysics and CSMs

"While many seem to think AEM provides the definitive 'x-rays' and nothing further is needed, I have suggested that AEM only provides about 30% of the 'answer' in the quest to better define the regional hydrogeologic architecture. There remain some massive hydrostratigraphy research and characterization opportunities in CA, especially in the Central Valley."

- Dr. Graham Fogg, 2024
  Professor of Hydrogeology, UC Davis

Collect More Accurate, Representative, and Useful Geologic Logs Using a Graphical Approach (ER23-7659)

IOWA

Jessica R. Meyer[1], Colin Plank[2], Richard S. Cramer[2], Michael R. Shultz[2], Charles J. Newell[3], David T. Adamson[3]

[1] University of Iowa; [2] Burns & McDonnell; [3] GSI Environmental Inc.

Introduction - Problems with Standard Borehole Logging Forms

A common problem for the remediation field is that remediation performance does not match remediation expectations (McGuire et al., 2016). Much of this discrepancy can be attributed to conceptual site models (CSMs) that fail to properly represent back diffusion from low permeability zones. Geology (and the related permeability architecture) is the primary conrol on groundwater flow and dissusive mass transfer; therefore, highly accurate representations of the subsurface geology are critical to developing accurate CSMs to drive remediation sucess. The basic steps for building accurate geologic models include (Fig. 1):

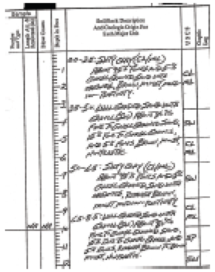
1. Determine the depositional environment(s)

2. Use geologic data to identify bodies of sediment/rock distinguished by characteristics related to the processes that formed them

3. Integrate steps 1 and 2 to map and predict the geology in 3-D

Fig. 1 - Basic steps for building an accurate geologic model.

One of the largest, and arguably most important, data gaps existing in nearly all groundwater remediation studies regardless of geologic setting is the lack of high quality subsurface geologic data in digital formats. This gap is due to collection of the wrong types of data in an inefficient format leading to a poor return on the investments in drilling. Traditional borehole logging forms capture primary geologic data in a paragraph format along a depth scale bar and often emphasize the Unified Soil Classification System (USCS) description of the materials (Fig. 2).



The paragraph style of geologic logging is flawed and results in:

- Long logging times (or incomplete log)
- Inconsistent data capture
- Loss of data for thin intervals (missing matrix diffusion)
- Text format does not facilitate real time decision making
- Digitization is so inefficient it is nearly impossible
- Missing critical data needed for accurate geologic interpretations

Fig. 2 - Standard paragraph format borehole logging form.

Inconsistent, inaccurate, and incomplete geologic data combined with a lack of advanced geologic training result in unrealistic geologic interpretations. These interpretations often focus on connecting like lithologies, or in many cases USCS classifications, at similar elevations. This results in unrealistic sediment bodies with unrealistic dimensions, continuity and geometries. Consequently, predictions of the geology and associated hydrogeologic properties away from borehole locations are highly uncertain.

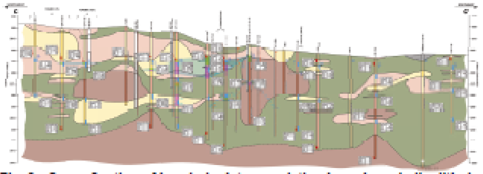


Fig. 3 - Cross Section of borehole data correlation based on similar lithology and no incorporation of the depositional environment and genetic relationships

Graphical Geologic Logs - A Solution

The purpose of this ESTCP technology transfer project is to introduce the groundwater remediation community to a better way to collect and record geologic data by using graphical geologic logs. The elements of a graphical geologic log are described by Fig. 4.

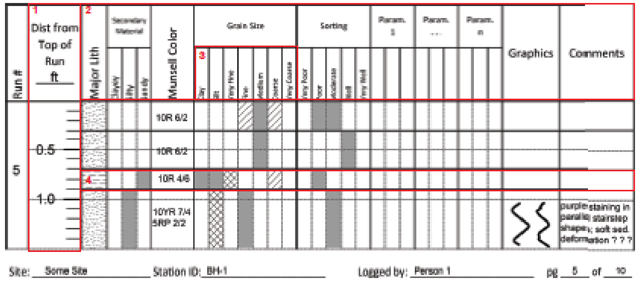


Fig. 4 - Elements of a graphical geologic log

1. A depth scale runs along the far left side of the log.
2. There is a vertical panel for each parameter being logged. Essential parameters for sedimentary systems typically include general lithology, color, grain size, sorting, sedimentary strucutres, and bedding. Other parameters of interest (e.g., grading, sediment distrubance, bulk mineralogy, etc.) are included by adding additional vertical panels.
3. Within each parameter panel there are columns containing the acceptable values for each parameter.
4. For each depth interval representing a consistent set of geologic materials the data is captured by shading in the correct cell-value for each parameter. Variations in shading (e.g., solid, hatched, cross-hatched) can be used to denote the relative proportion or intensity of a parameter.

Graphical geologic logs were developed and tested over the past 15 years during ongoing research at contaminated groundwater sites. This graphical style of log has been used to capture geologic data from siliciclastic (Fig. 5) and carbonate sedimentary rocks and unconsolidated sediments deposited in a variety of settings (Meyer et al. 2022).

Advantages of graphical geologic logs include:

- Easily learned
- Serves as a road-map to guide loggers and ensure consistent collection of all important geologic parameters
- Facilitates efficient collection of geologic data
- Log is prepared to scale so its immediately useful to suport real time decision making
- Is more efficient to digitize; data can be stored in complementary database
- Data is amenable to quantitative analysis

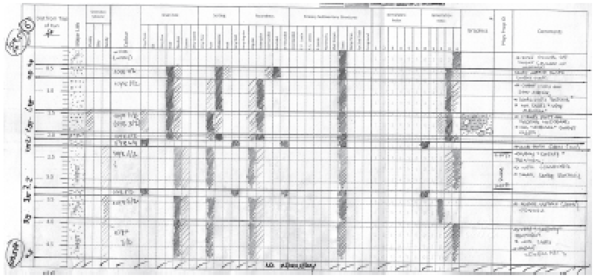


Fig. 5 - Example graphical geologic log for siliciclastic sediments depoisited in an inland sea on a broad shallow ramp

Benefits of Improved Geologic Data and Interpretations

Understanding of the depositional processes that form subsurface strata enables prediction of the 3-D distribution of sedimentary characteristics, geometry, and connectivity away from areas with detailed subsurface data (Fig. 6). This method of developing accurate 3-D geologic models has been honed specifically for groundwater remediation investigations and is referred to as Environmental Sequence Stratigraphy (ESS) (Shultz et al., 2017). Robust geologic models improve:

- Hydrostratigraphy, the framework for all CSMs
- Well construction to minimize blending and reduce uncertainty in hydrogeologic measurements
- Evaluation of the impact of diffusion on transport and remediation in source zones and plumes

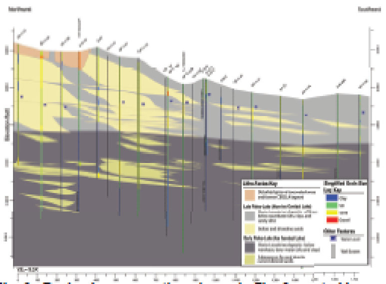


Fig. 6 - Revised cross-section shown in Fig. 3 created by trained stratigrapher applying geologic interpretation of glacio-lacustrine, deltaic sands and density current derived sediments. The revised cross-section shows the geometry, orientation, and connectivity of the sand and clay bodies

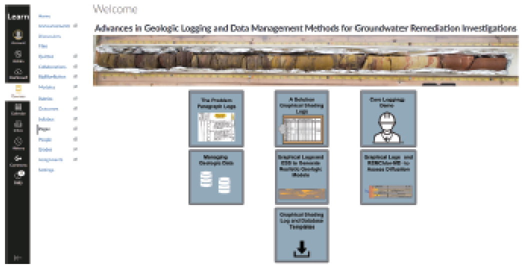
Coming Soon - Learn How to Use Graphical Geologic Logs

This ESTCP project includes creation of two types of open access educational materials designed to teach others how to capture geologic data using graphical geologic logs: 1) templates and tutorials prepared for current professionals and 2) a core logging laboratory activity for post-secondary courses.

The tutorial (Fig. 7) will include:

- presentations and videos describing the issues with traditional logging formats and graphical shading log techniques,
- templates for graphical shading logs designed for common depositional environments,
- access database templates to store the geologic data and interpretations,
- examples of how improved geologic data can be used to develop improved geologic models using ESS
- exmaples of how improved geologic data and models can be used to evaluate the influence of diffusion on transport and remediation

Fig. 7 - Example home page for the graphical geologic log tutorial prepared for current professionals



References and Other Info

Meyer, J.R., Munn, J.D., Kennel, J.R., Arnaud, E., Parker, B.L., 2022. Graphical shading logs – an improved approach for collecting high resolution sedimentological data at contaminated sites. Groundwater Monitoring & Remediation, 42(3): 59-74. https://doi.org/10.1111/gwmr.12521

Shultz, M.R., Cramer, R.S., Plank, C., Levine, H., Ehman, K.D., 2017. Best practices for environmental site management: A practical guide for applying environmental sequence stratigraphy to improve conceptual site models. 600/R-17/293, US EPA.

McGuire, T., Adamson, D.T., Newell, C.J., Kulkarni, P., 2016. Development of an expanded, high-reliability cost and performance database for in-situ remediation technologies. ESTCP Project ER-201120.

For more information follow the QR code

Log of Exploratory Boring

BURNS McDONNELL

Well No.

Page of

Drill Pad Sketch Map

Client:

Project No.:

Site:

Surface geologic unit and expected subsurface geology

Logged by:

Drilling Co.:

Driller:

Drilling Method:

Drill Rig Model:

Drilling Progress / Geologic Description

Depth	Time	FID/PID at surface casing (ppm)	Penetration rates/ drilling observations	Rig Motion	Sample recovery, type	Sample Interval	Munsell Color Code	% Clay	% Silt	Plasticity of fines	% Fine Sand	% Medium Sand	% Coarse Sand	Roundness of Sand	% Fine Gravel	% Coarse Gravel	Roundness of Gravel	Degree of sorting	Sand Composition	Cementation / HCl reaction	Mineral staining/Redox	USCS Code (if required)	Strat Log Sketch: LIMESTONES (mud, wacke, pack, grain, rud & bound); MUD (clay, silt); SAND (vf, f, m, c, vc); GRAVEL (gran, peb, cob, boul)	Texture Grain size and other notes (structures, palaeocurrents, fossils, color)	Comments (drilling-induced deformation or homogenization, fossils, root casts, other pedogenic features, sedimentary facies, potential confining bed or high-permeability unit)
	Date:		Ft/Min or Ft/Hr	Smooth, Chatter, Heavy Chatter, Loss of Circulation	Grab, Discrete					Non, High, Med, Low	0.0029" to 0.017", No 40-200	0.017" to 0.079", No 10-40	0.079" to 0.19", No 4-10	VR, A, SA, SR, R, VR	0.19" to 0.75", 20mm to No 4	0.75" to 3"	VR, A, SA, SR, R, VR	0, 1, 2, 3, 4	Rk frags, Quartz, Feldspar, Dark mins	None, Slight, High	Yellow, Ochre, Red, Gray, Black				

Drilling Progress								Geologic Description																
Depth	Time	FID/PID at surface casing (ppm)	Penetration rates/ drilling observations	Rig Motion	Sample recovery, type	Sample Interval	Munsell Color Code	% Clay	% Silt	Plasticity of fines	% Fine Sand	% Medium Sand	% Coarse Sand	Roundness of Sand	% Fine Gravel	% Coarse Gravel	Roundness of Gravel	Degree of sorting	Sand Composition	Cementation / HCl reaction	Mineral staining/Redox	USCS Code (if required)	Strat Log Sketch (LIMESTONES: mud, wacke, pack, grain, rud & bound; MUD: clay, silt; SAND: vf, f, m, c, vc; GRAVEL: gran, peb, cob, boul)	Texture: Grain size and other notes (structures, palaeocurrents, fossils, color)
					95% recovery (vibracore)						60	40		R				W (1)	Qtz.	N				Massive, fine to medium sand sparse bioturbation
											50	50		R				1						
											40	60		R										sparse bioturbation
1																								
											40	50	10	R										
																								sparse bioturbation
											20	50	30											
2																								grainsize grades to medium/coarse
											10	40	50	SR				MW 2	Q,D					Cross-bedding
3					95% recovery (vibracore)																			sharp contact
								95	5	H				–				–						clay, massive
								20	10	L	10	60		R				2	Q,D					
																								bioturbation and flaser bedding
								30	30		40													potentially cross bedded here
								20	10	L	10	60		R				2	Q,D					sparse flasers
4																								irregular contact
								50	40	L	10			R				2	Q,D					Lenticular sands in silty clay matrix, possible b
											10	10	80	R				1	Q,D					medium sand
								60	15	H	25			R					Q,D					Lenticular bedding grading downward
								30	20	H	50			R										to wavey
5																								

Thank you!

Rick Cramer
rick.cramer@geosyntec.com