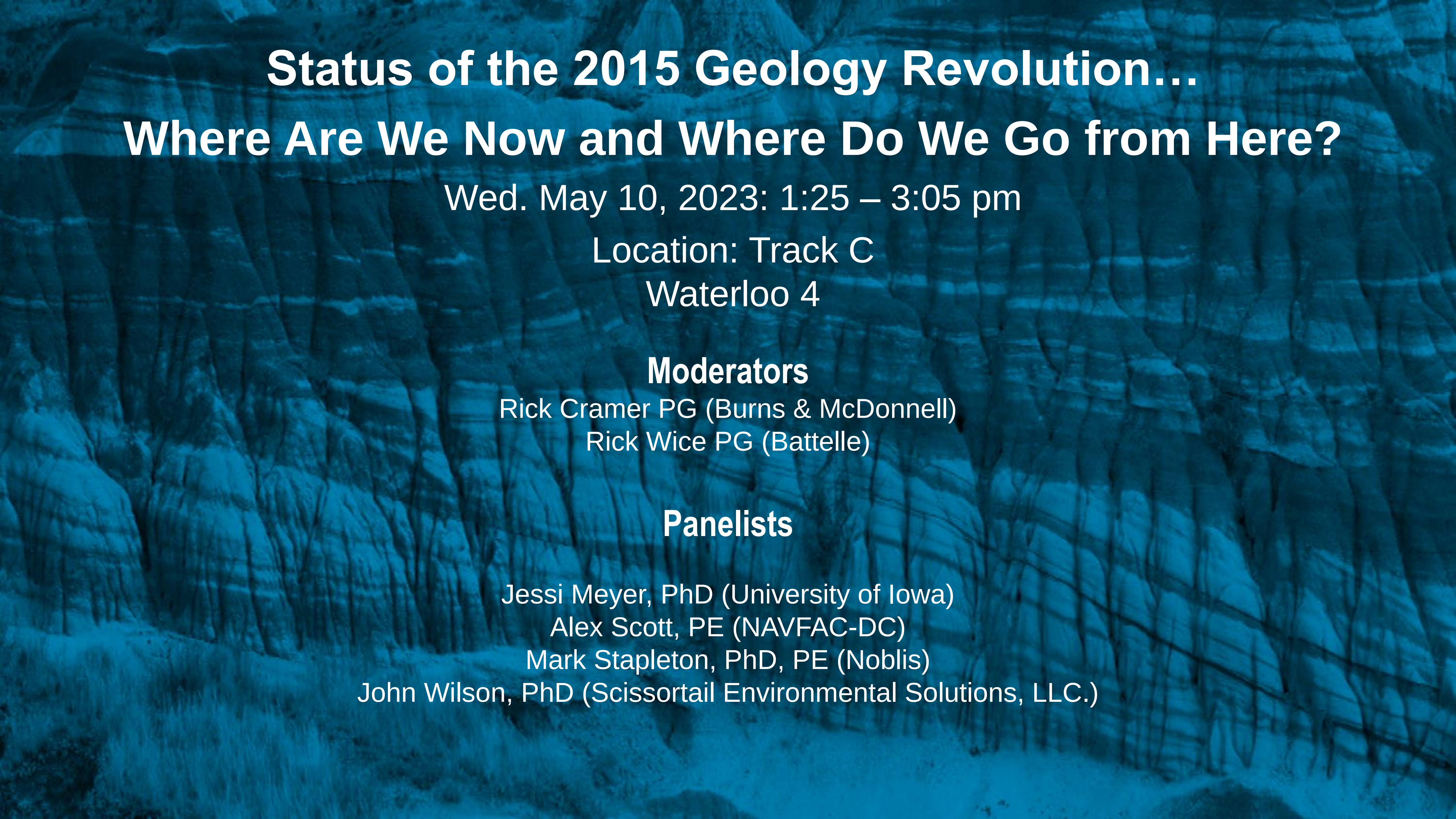


Status of the 2015 Geology Revolution…

Where Are We Now and Where Do We Go from Here?

Wed. May 10, 2023: 1:25 – 3:05 pm

Location: Track C
Waterloo 4

Moderators

Rick Cramer PG (Burns & McDonnell)
Rick Wice PG (Battelle)

Panelists

Jessi Meyer, PhD (University of Iowa)
Alex Scott, PE (NAVFAC-DC)
Mark Stapleton, PhD, PE (Noblis)
John Wilson, PhD (Scissortail Environmental Solutions, LLC.)

Outline of Panel - Wed. May 10, 2023: 1:25 pm – 3:05 pm (100 minutes)

Introduction – R Cramer (3 min.)

- Overview of Panel thesis, introduce panelist

R Wice (5 min.)

Evolution of the practice (as with the petroleum industry) into multidisciplinary teams

Engagement of the audience

Panelists' presentations

- Need to determine order and subject matter (8 min. each = 32 min.)…some ideas
  1. John Wilson: Evolution of CSMs
  2. Jessi Meyer: Upgrade of Geology data collection and calibrating Geology with hydrogeology
  3. Alex Scott: NAVFAC status…Regulatory and contract limitations?
  4. Mark Stapleton: AFCEC status…Examples of Geology and remediation optimization…why Geologic Model (e.g., ESS) is a "must" for remediation optimization

Open discussion (60 min.): Where are we now and where do we go from here?

R Cramer

Panel Description

Panel Title.
Status of the 2015 Geology Revolution… Where Are We Now and Where Do We Go from Here?

Panel Description.
The 2015 Battelle Bioremediation Conference in Miami was earmarked as the “Geology Revolution” in groundwater remediation. Since that conference, Environmental Sequence Stratigraphy (ESS) was published by US EPA as a best practice for developing representative conceptual site models (CSMs) and Air Force Civil Engineer Center (AFCEC) requires ESS to support their base wide CSMs. It has been established that geology is the primary control on subsurface fluid flow and the migration of groundwater contamination, yet many groundwater projects define contaminant plumes primarily with groundwater data, without even a basic geologic evaluation and representative geologic cross section.

Those who have joined the Revolution and focused on bringing in the geologic practitioners (e.g., stratigraphers) to develop more sophisticated geologic models have reaped the benefits of more successful remedy designs and project outcomes. Here are a few recent examples:

- In 2022 AFCEC conducted an enterprise-wide (>80 Air Force facilities) evaluation of the elements that affect remediation success.
- In a separate study conducted in 2022, AFCEC supported a third-party evaluation of the lessons learned from groundwater contaminant projects where ESS, a Remediation Geology approach, was used to develop the CSM.
- In 2021, Naval Facilities Engineering Systems Command (NAVFAC), as part of their Open Environmental Restoration Resources (OER2) Webinar series, presented ESS as a remediation optimization tool.

Remediation geology is scalable and applicable to commercial projects. The 6 case studies presented in the US EPA ESS Tech Issue paper are commercial sites. How many in situ bioremediation projects have not met the remedial action objective or saw significant rebound after multiple injections? Were they based solely on groundwater data and estimated radius of influence of injection points? 2015 was a call to arms. Today we ask the question “where are we now and where do we go from here?”

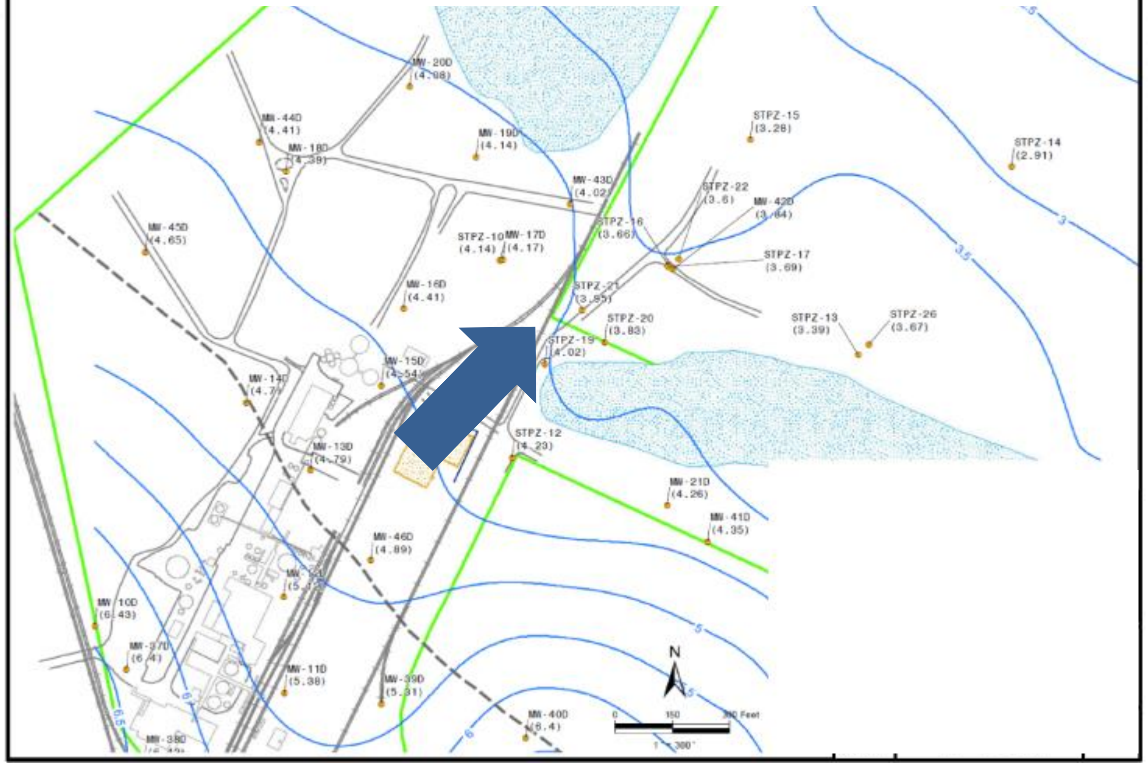
Additional Comments.
The panel will present examples of the success of remediation geology and the importance of ESS for insitu bioremediation and as tool to optimize remedial actions. Next steps for the geology revolution will be discussed.

Traditional Focus on Hydrology

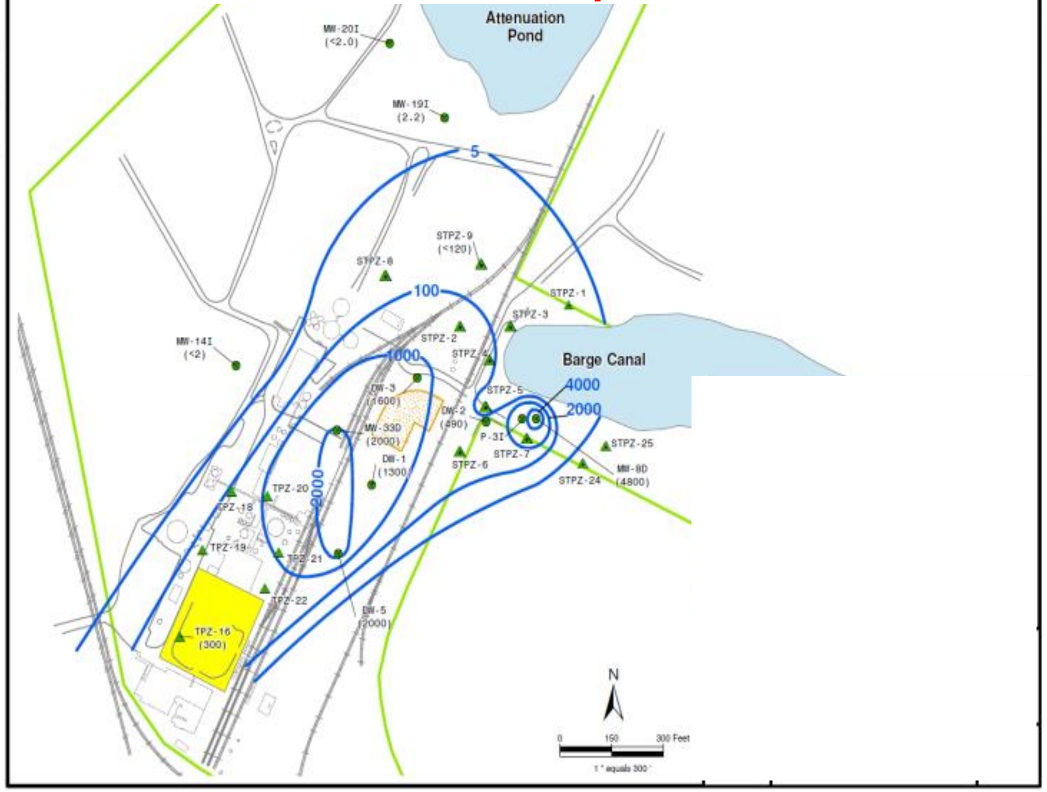
State of the practice is to apply Darcy’s law,

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

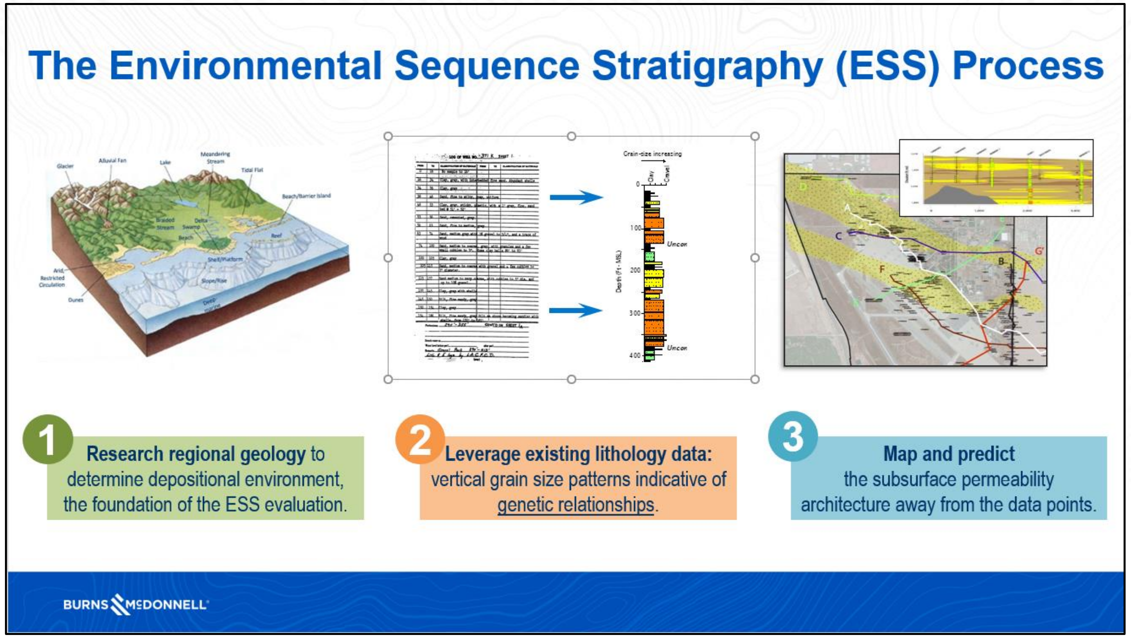
Groundwater gradient = Groundwater flow



Contaminant plume



Depositional Environment / Hydrostratigraphic Units (HSUs)



The Environmental Sequence Stratigraphy (ESS) Process

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

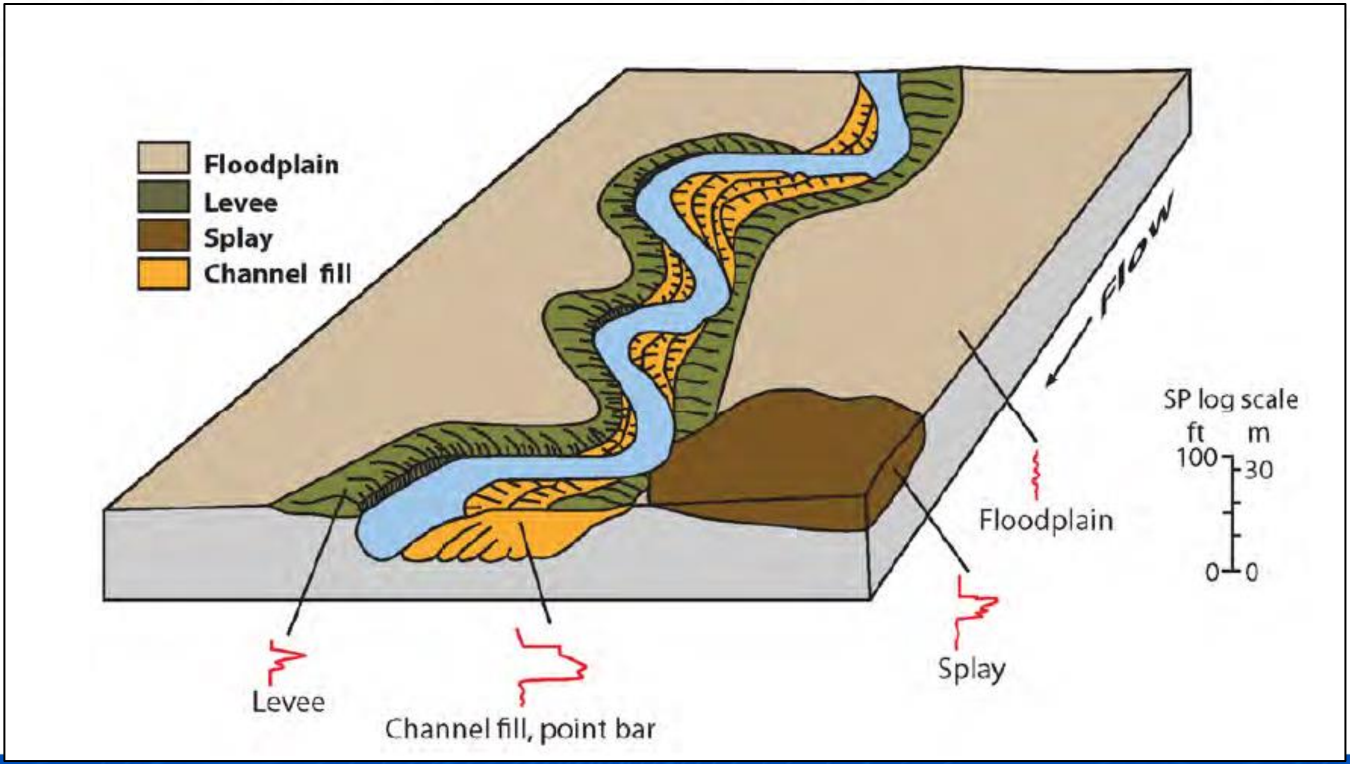
2 **Leverage existing lithology data:** vertical grain size patterns indicative of genetic relationships.

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

BURNS & McDONNELL

Contaminant Transport HSU: High permeability coarse-grained (sand/gravel) channelized deposits.

Contaminant Storage HSU: Low permeability floodplain fines (silts/clays) sheetlike deposits.



R Wice

J Wilson

Evolution of CSMs

where we started

Where is it?

Evolution of CSMs

where we are now

Where is it going?

Where is it?

Evolution of CSMs

what we need to add

What happens to it along the way?

Where is it going?

Where is it?

What happens to it along the way?

1) Matrix diffusion effects

2) Biodegradation

3) Abiotic degradation

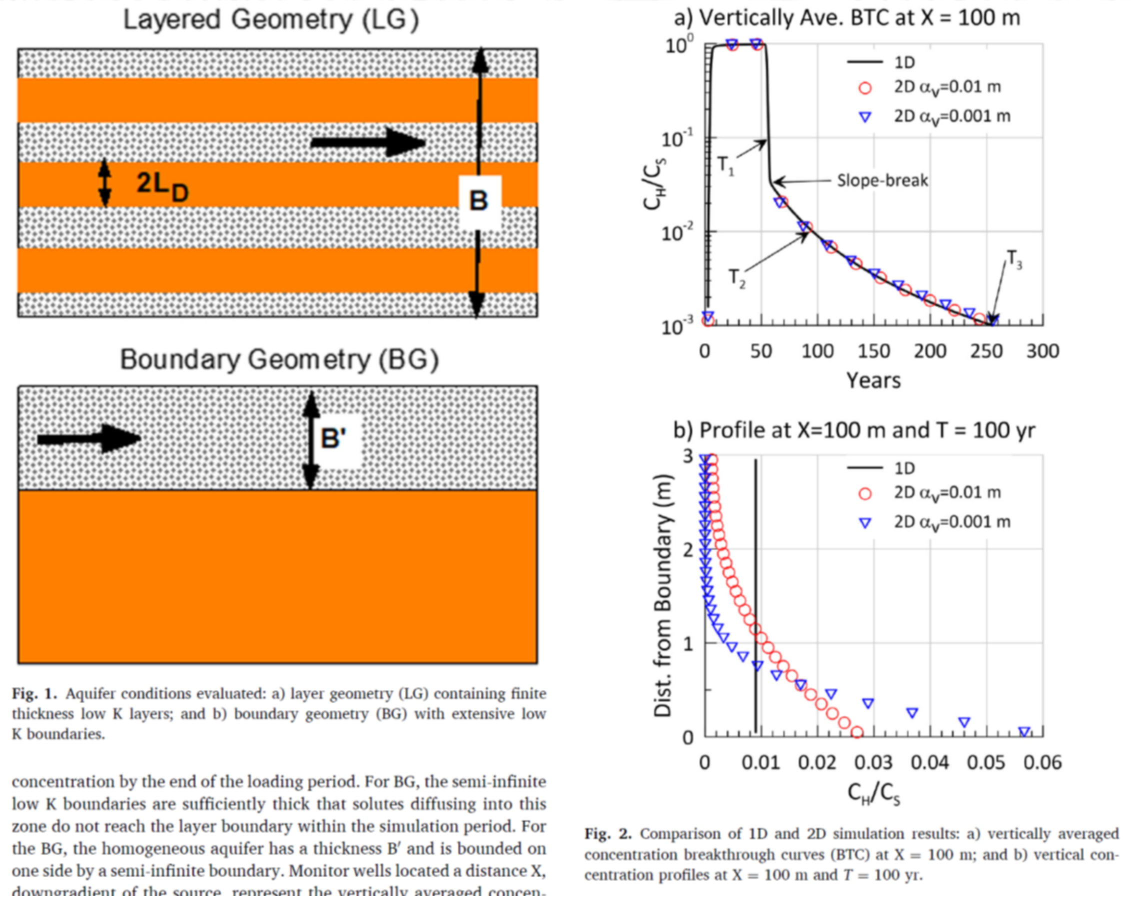


Fig. 1. Aquifer conditions evaluated: a) layer geometry (LG) containing finite thickness low K layers; and b) boundary geometry (BG) with extensive low K boundaries.

concentration by the end of the loading period. For BG, the semi-infinite low K boundaries are sufficiently thick that solutes diffusing into this zone do not reach the layer boundary within the simulation period. For the BG, the homogeneous aquifer has a thickness B′ and is bounded on one side by a semi-infinite boundary. Monitor wells located a distance X, downgradient of the source, represent the vertically averaged concen-

Fig. 2. Comparison of 1D and 2D simulation results: a) vertically averaged concentration breakthrough curves (BTC) at X = 100 m; and b) vertical concentration profiles at X = 100 m and $T = 100$ yr.

Borden and Cha, *Journal of Contaminant Hydrology* 243 (2021) 103889

Currently, we map composition and texture to understand the flow field.

Where is the plume going?

We need to map the distribution of hydraulic conductivity to understand matrix diffusion.

Degradation

Not all wells are the same.

Use the geological context to determine which wells should provide the best data to predict the behavior of the plume.

Biodegradation

Conventionally described by rate constants from empirical laboratory experiments.

These are very expensive, and they take too long.

Few people do these anymore, and they do them wrong.

Biodegradation

Replace empirical laboratory studies with molecular biological tools (MBTs) that:

1) use qPCR to determine DNA unique to active organisms

2) Proteomics that measure active enzymes.

For MNA applications, the molecular biological tools only provide the EPA second line of evidence.

Get the rate constants from the monitoring data, the EPA first line of evidence for MNA.

Use to the MBTs to determine if enough biological activity is possible to plausibly explain the rate constant extracted from the monitoring data.

It is easy to miss abiotic degradation

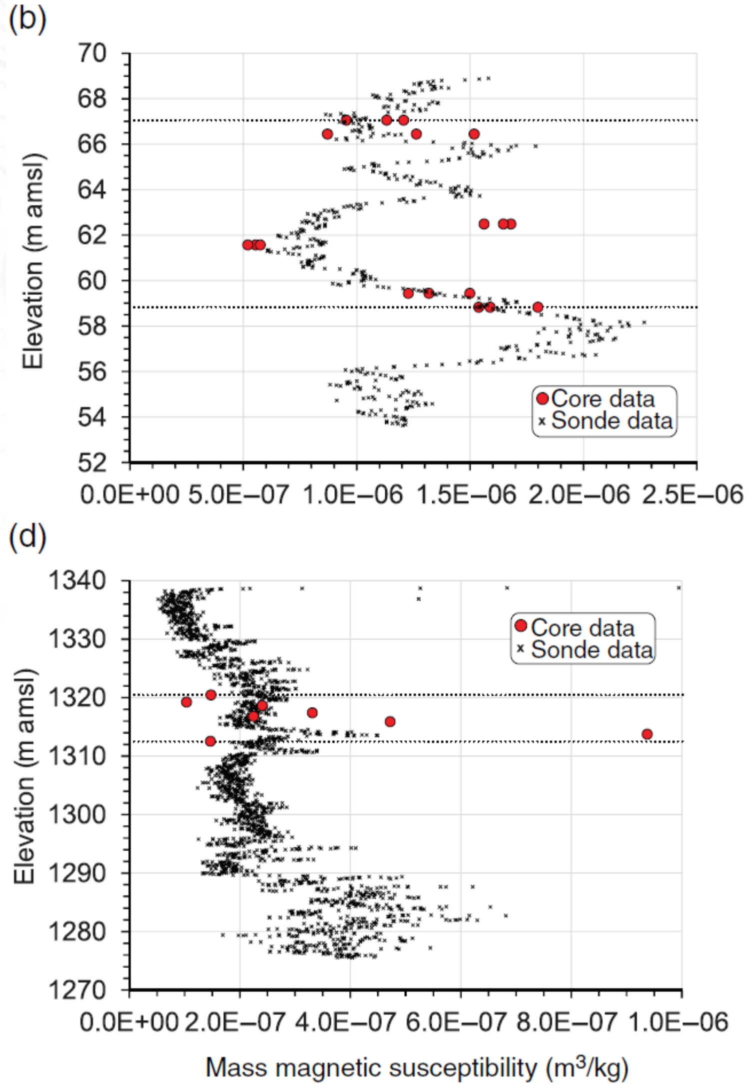
Under aerobic and mildly anaerobic conditions, the primary agent for abiotic degradation of PCE, TCE, DCE is magnetite.

The primary mechanism of degradation produces oxidized polar products such as CO_2 and organic acids.

You cannot see these degradation products with EPA 8260 purge-and-trap analyses.

A better way to evaluate abiotic degradation

The best approach to evaluate abiotic degradation of PCE, TCE and DCE by magnetite is to spike aquifer sediment with ^{14}C labeled PCE, TCE or DCE, and measure the accumulation of ^{14}C labeled degradation products.



Use geophysical tools to improve the CSM by mapping the distribution of reactive minerals such as magnetite in aquifer materials.

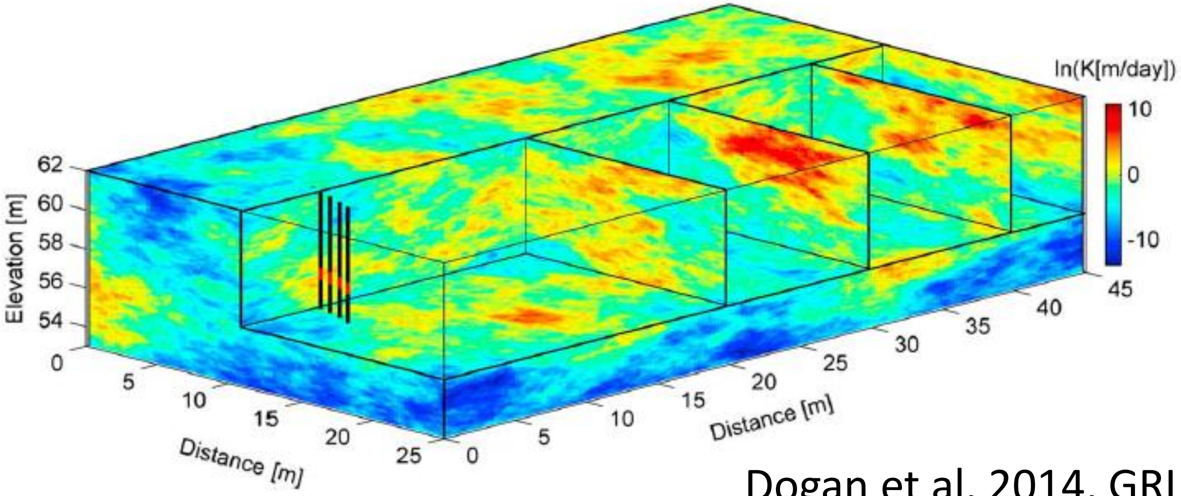
Figure 4 of Wiedemeier et al. 2017. Efficacy of an In-Well Sonde to Determine Magnetic Susceptibility of Aquifer Sediment. *Groundwater Monitoring & Remediation* doi: 10.1111/gwmr.12197

J Meyer

How Do We Use Geology in Groundwater Studies?

Used to inform the hydrostratigraphic framework for our sites

Hydrostratigraphy describes the distribution of hydraulic conductivity contrasts in the subsurface

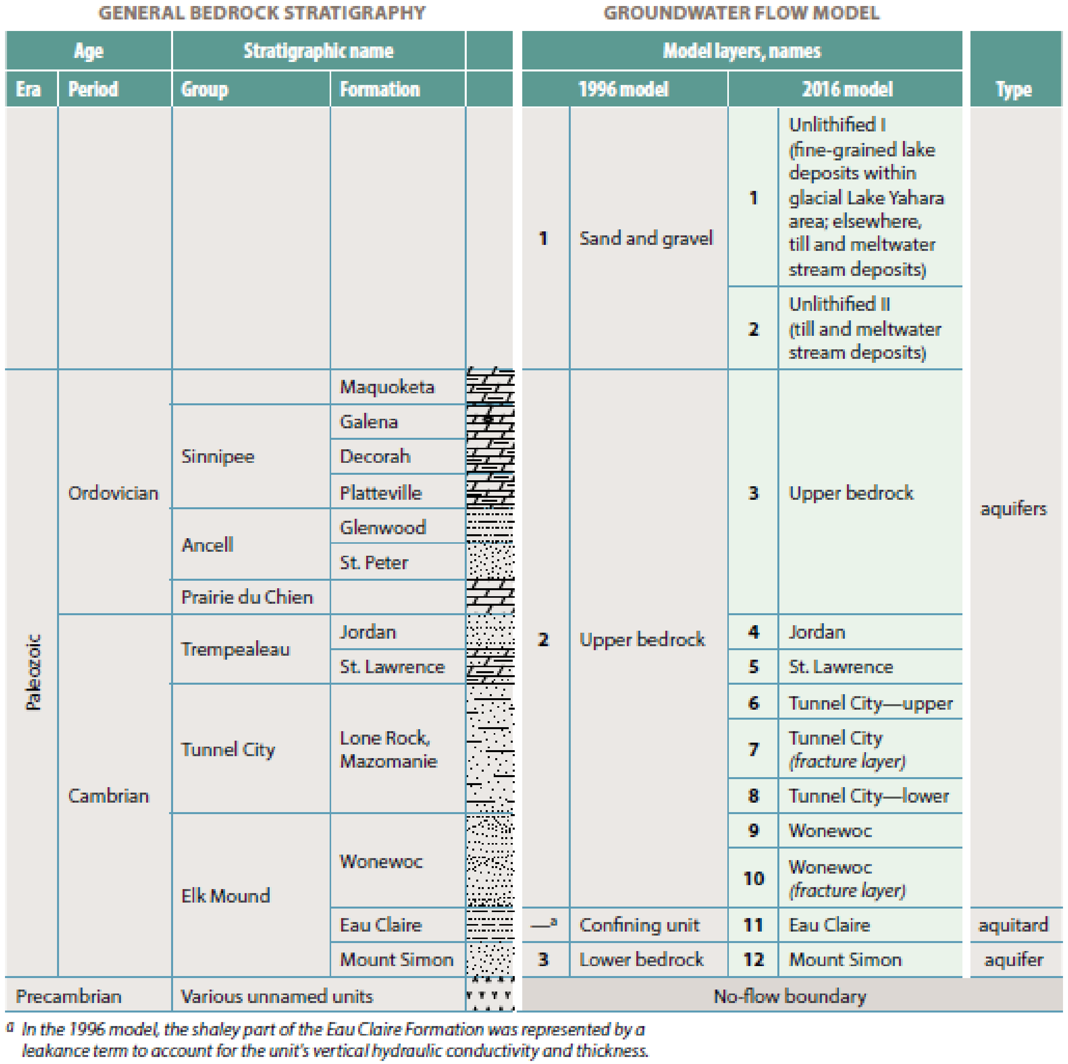


Dogan et al. 2014, GRL

Standard Approach to Hydrostratigraphy

Existing lithostratigraphic units are lumped together or split apart and categorized as aquifers or aquitards based on sparse hydrogeologic data

Parsen et al. (2016)



GENERAL BEDROCK STRATIGRAPHY

GROUNDWATER FLOW MODEL

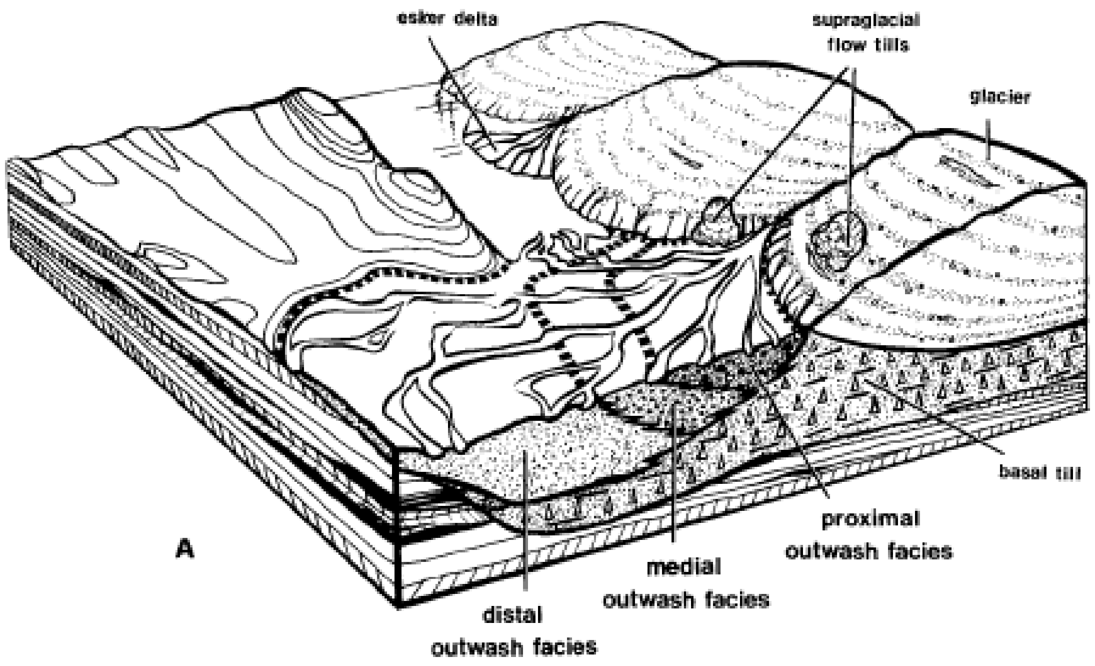
Age		Stratigraphic name			Model layers, names				Type
Era	Period	Group	Formation		1996 model		2016 model		
					1	Sand and gravel	1	Unlithified I (fine-grained lake deposits within glacial Lake Yahara area; elsewhere, till and meltwater stream deposits)	aquifers
							2	Unlithified II (till and meltwater stream deposits)	
Paleozoic	Ordovician		Maquoketa		2	Upper bedrock	3	Upper bedrock	
		Sinnipee	Galena						
			Decorah						
			Platteville						
		Ancell	Glenwood						
			St. Peter						
		Prairie du Chien							
	Cambrian	Trempealeau	Jordan				4	Jordan	
			St. Lawrence				5	St. Lawrence	
		Tunnel City	Lone Rock, Mazomanie				6	Tunnel City—upper	
							7	Tunnel City *(fracture layer)*	
							8	Tunnel City—lower	
		Elk Mound	Wonewoc				9	Wonewoc	
							10	Wonewoc *(fracture layer)*	
			Eau Claire		—[a]	Confining unit	11	Eau Claire	aquitard
			Mount Simon		3	Lower bedrock	12	Mount Simon	aquifer
Precambrian		Various unnamed units			No-flow boundary				

[a] *In the 1996 model, the shaley part of the Eau Claire Formation was represented by a leakance term to account for the unit's vertical hydraulic conductivity and thickness.*

We Need to Characterize the 3-D Geometry of Sediment Bodies in the Subsurface

Facies analysis is a tool that is used to distinguish a body of sediments/rocks based on the *processes* that formed them

Depositional processes create units with *predictable* geometries, scales, and lateral/vertical spatial relationships



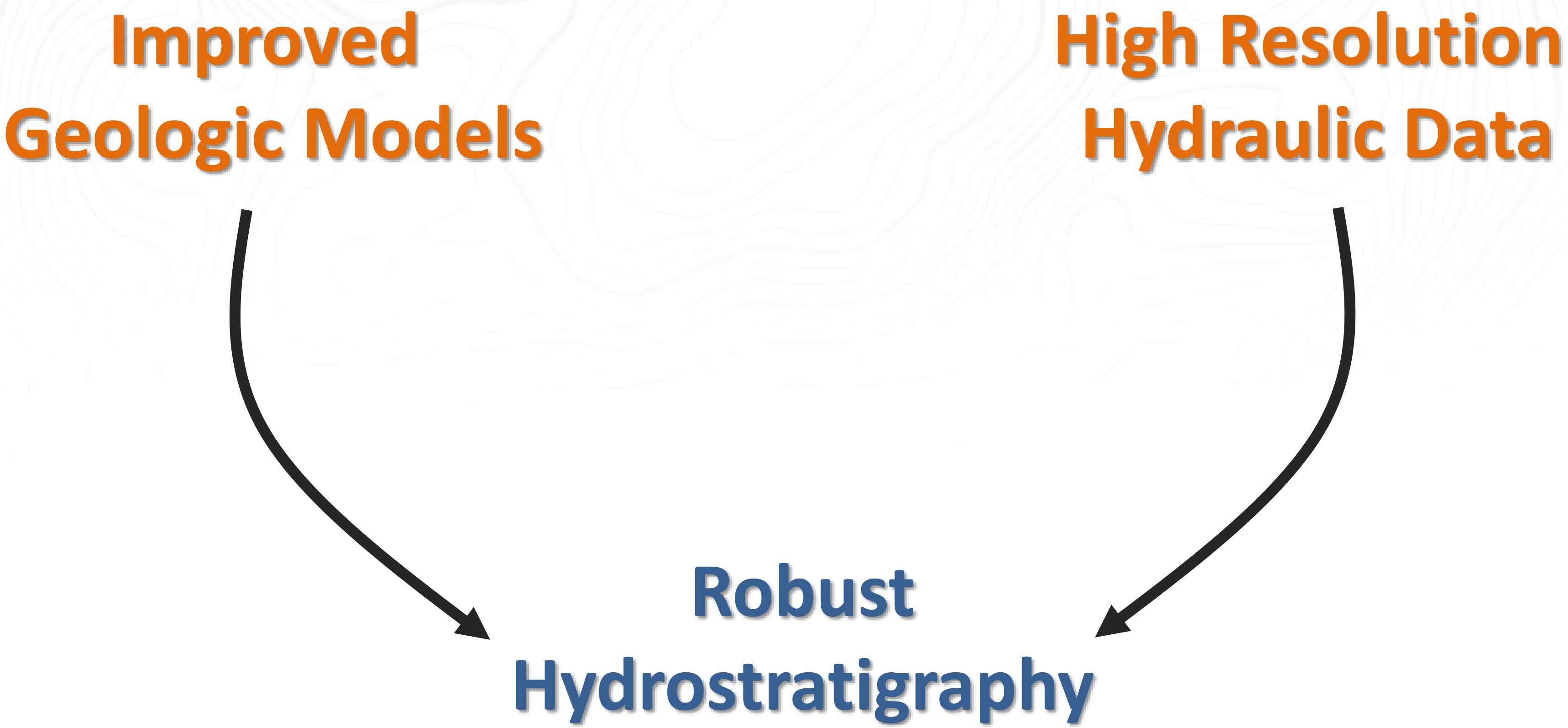
Anderson, 1989, GSAB

Assumption

Hydraulic properties are relatively uniform within each geologic unit and contrasting at their boundaries

To test this assumption, we need hydraulic data that is independent from the geologic conceptual model

Accurate Hydrostratigraphy Requires . . . . .



Improved Geologic Models

High Resolution Hydraulic Data

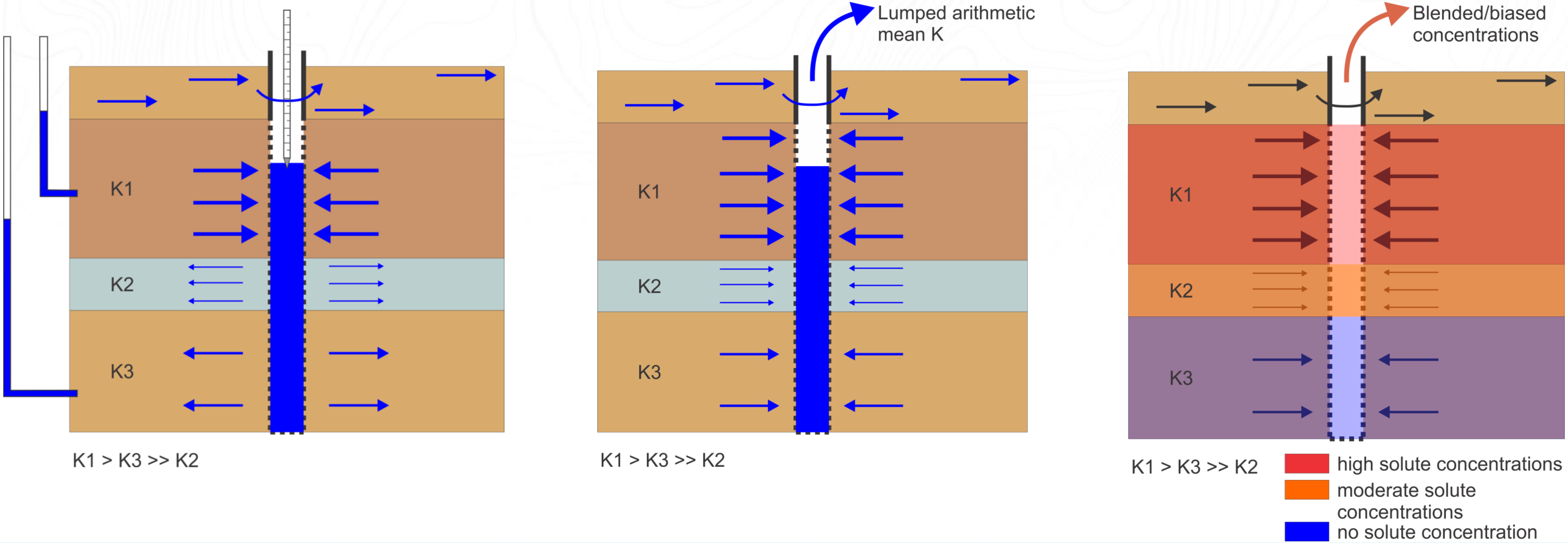
Robust Hydrostratigraphy

Accurate Hydrostratigraphy Improves:

- Prediction of flow and contaminant migration pathways
- Design and optimization of monitoring well networks
- Assessment of matrix diffusion
- Understanding of abiotic controls on transport and degradation

Accurate Hydrostratigraphy Improves the Design of Monitoring Wells

Well screens that cross-connect hydrostratigraphic units create bias and uncertainty in hydrogeologic data

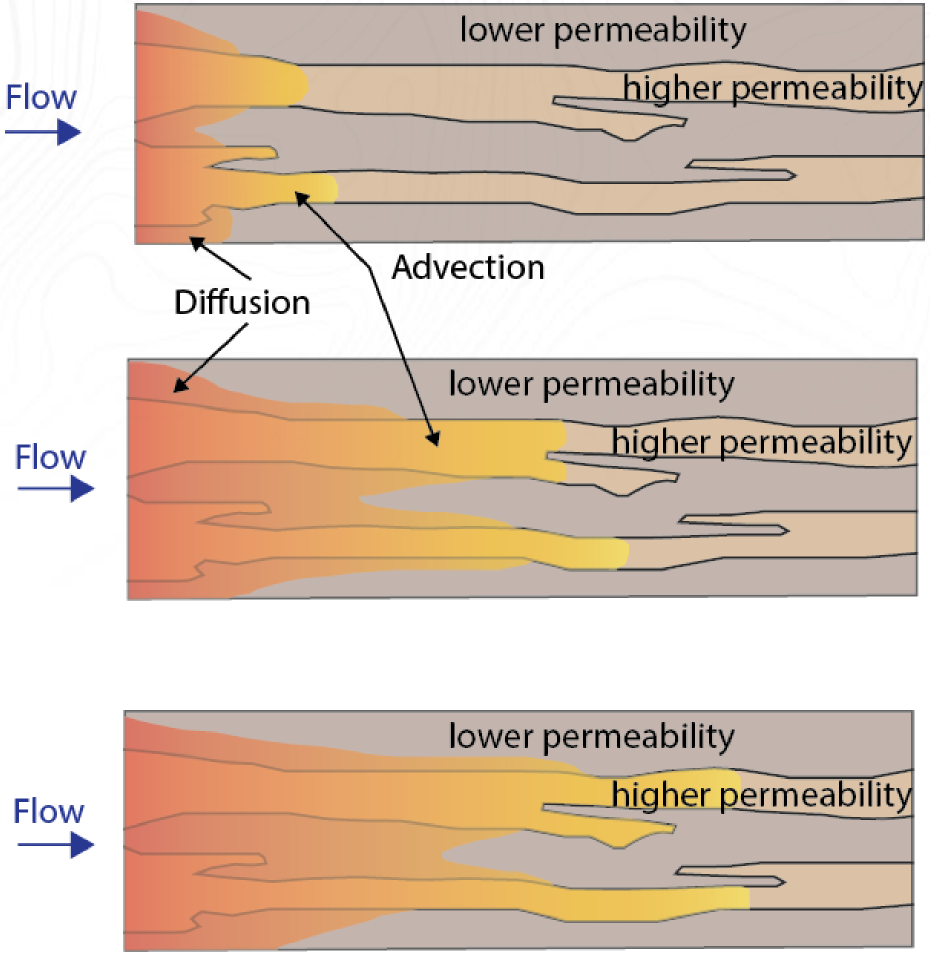


Accurate Hydrostratigraphy is Required to Assess the Influence of Diffusion on Transport and Remediation

Diffusion occurs at interfaces between contrasts in hydraulic conductivity

Improved hydrostratigraphy allows us to:

- ► Characterize where diffusion is occurring
- ► Assess the surface area available for diffusion



Modified from Gillham and Cherry, 1983, Fig. 10

What About the Spatial Distribution of Other Parameters that Control Transport and Degradation?

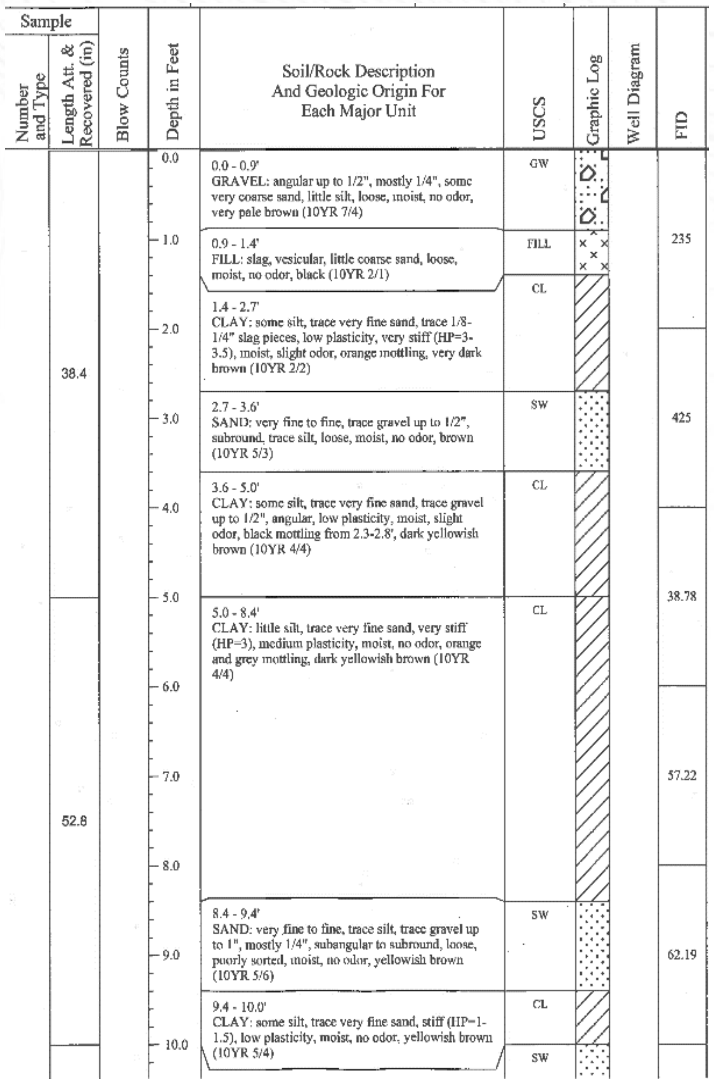
- Organic carbon
- Mineralogy

?

What is Preventing Us from Improving the Hydrostratigraphy for Our Sites?

- Inadequate geologic data
- Lack of emphasis on high quality head data

Paragraph Description Format Hinders Data Collection

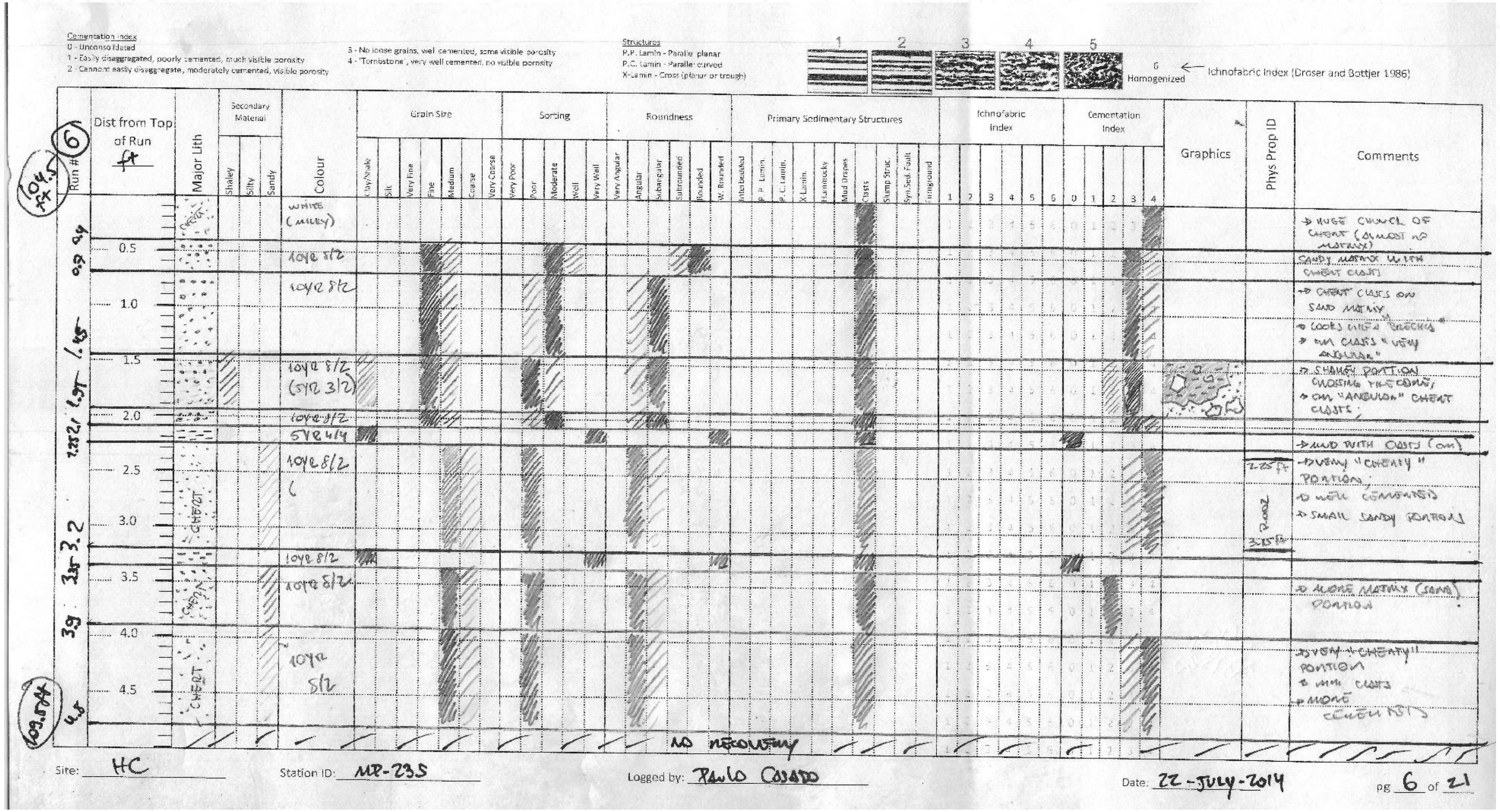


Sample								
Number and Type	Length Att. & Recovered (in)	Blow Counts	Depth in Feet	Soil/Rock Description And Geologic Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	FID
	38.4		0.0	0.0 - 0.9' GRAVEL: angular up to 1/2", mostly 1/4", some very coarse sand, little silt, loose, moist, no odor, very pale brown (10YR 7/4)	GW			
			1.0	0.9 - 1.4' FILL: slag, vesicular, little coarse sand, loose, moist, no odor, black (10YR 2/1)	FILL			235
			2.0	1.4 - 2.7' CLAY: some silt, trace very fine sand, trace 1/8-1/4" slag pieces, low plasticity, very stiff (HP=3-3.5), moist, slight odor, orange mottling, very dark brown (10YR 2/2)	CL			
			3.0	2.7 - 3.6' SAND: very fine to fine, trace gravel up to 1/2", subround, trace silt, loose, moist, no odor, brown (10YR 5/3)	SW			425
			4.0	3.6 - 5.0' CLAY: some silt, trace very fine sand, trace gravel up to 1/2", angular, low plasticity, moist, slight odor, black mottling from 2.3-2.8', dark yellowish brown (10YR 4/4)	CL			
	52.8		5.0 6.0 7.0 8.0	5.0 - 8.4' CLAY: little silt, trace very fine sand, very stiff (HP=3), medium plasticity, moist, no odor, orange and grey mottling, dark yellowish brown (10YR 4/4)	CL			38.78 57.22
			9.0	8.4 - 9.4' SAND: very fine to fine, trace silt, trace gravel up to 1", mostly 1/4", subangular to subround, loose, poorly sorted, moist, no odor, yellowish brown (10YR 5/6)	SW			62.19
			10.0	9.4 - 10.0' CLAY: some silt, trace very fine sand, stiff (HP=1-1.5), low plasticity, moist, no odor, yellowish brown (10YR 5/4)	CL			
					SW			

- Long logging times (or incomplete logs)
- Inconsistent data capture
- Loss of data for thin intervals
- Text format does not facilitate real time decision making
- Difficult to digitize

Geologic data/insight are never fully utilized

Graphical Logging Improves High Quality Data Capture



Cementation index
0 - Unconsolidated
1 - Easily disaggregated, poorly cemented, much visible porosity
2 - Cannont easily disaggregate, moderately cemented, visible porosity
3 - No loose grains, well cemented, some visible porosity
4 - 'Tombstone', very well cemented, no visible porosity

Structures
P.P. Lamin - Parallel planar
P.C. Lamin - Parallel curved
X-Lamin - Cross (planar or trough)

← Ichnofabric Index (Droser and Bottjer 1986)

Run #	Dist from Top of Run	Major Lith	Secondary Material	Colour	Grain Size	Sorting	Roundness	Primary Sedimentary Structures	Ichnofabric Index	Cementation Index	Graphics	Phys Prop ID	Comments
			Shaley, Silty, Sandy		Clay/Shale, Silt, Very Fine, Fine, Medium, Coarse, Very Coarse	Very Poor, Poor, Moderate, Well, Very Well	Very Angular, Angular, Subangular, Subrounded, Rounded, W. Rounded	Interbedded, P. P. Lamin., P. C. Lamin., X-Lamin., Hummocky, Mud Drapes, Clasts, Slump Struc., Syn.Sed. Fault, Firmground	1, 2, 3, 4, 5, 6	0, 1, 2, 3, 4			

Run # 6 (104.5 ft) – Dist from Top of Run: ft

0.5 · 1.0 · 1.5 · 2.0 · 2.5 · 3.0 · 3.5 · 4.0 · 4.5

0.4 · 0.7 · 1.45 · 1.95 · 2.25 · 3.2 · 3.35 · 3.9 · 4.5 (109.5 ft)

Major Lith: CHERT · CHERT · CHERT · CHERT

Colour: WHITE (MILKY) · 10YR 8/2 · 10YR 8/2 · 10YR 8/2 (5YR 3/2) · 10YR 8/2 · 5YR 4/4 · 10YR 8/2 (· 10YR 8/2 · 10YR 8/2 · 10YR 8/2

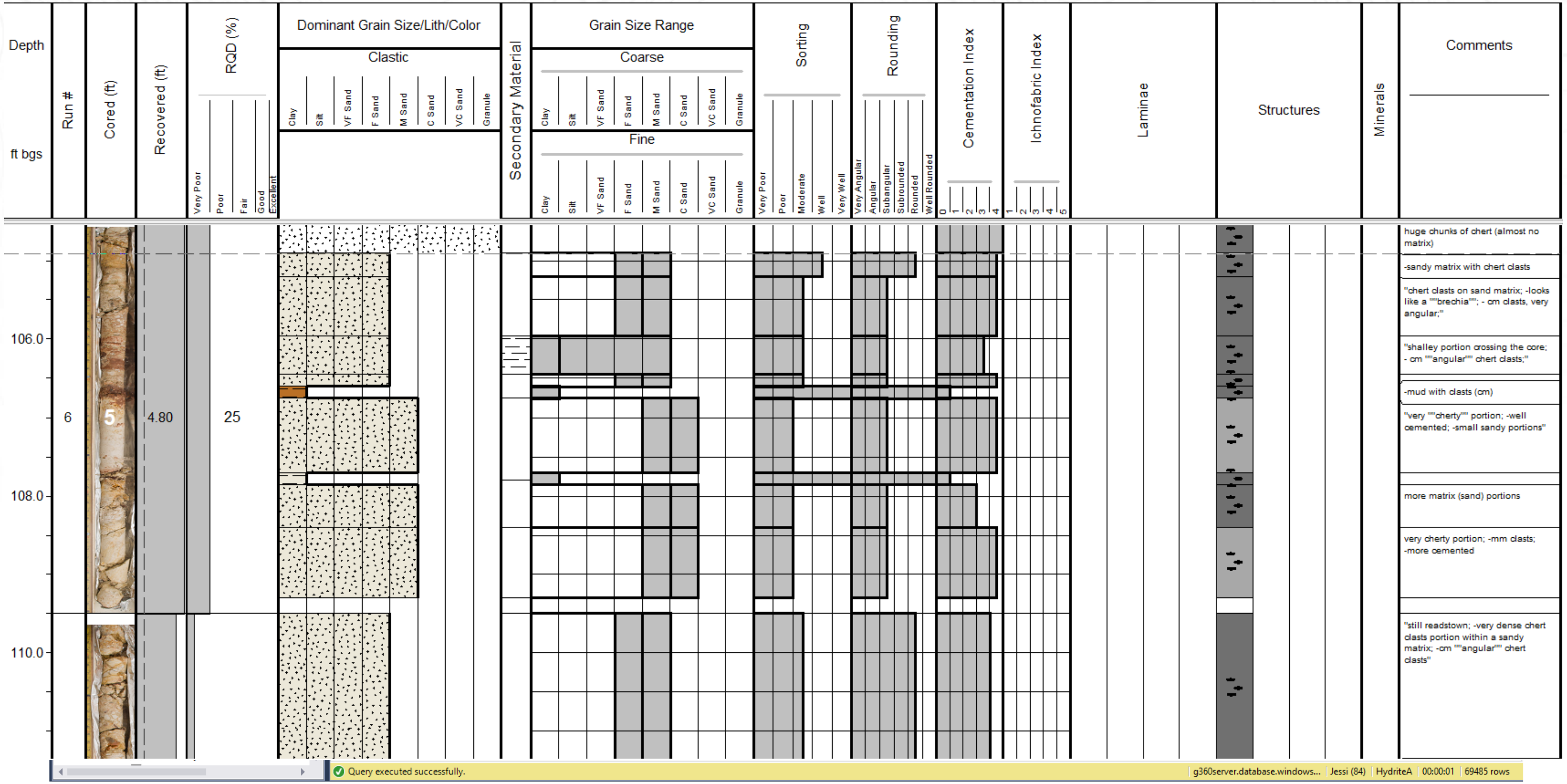
Phys Prop ID: 2.25 ft · 2002 · 3.15 ft

Comments:
→ HUGE CHUNCK OF CHERT (ALMOST NO MATRIX)
SANDY MATRIX WITH CHERT CLASTS
→ CHERT CLASTS ON SAND MATRIX
→ LOOKS LIKE A "BRECCIA"
→ cm CLASTS "VERY ANGULAR"
→ SHALEY PORTION CROSSING THE CORE;
→ cm "ANGULAR" CHERT CLASTS;
→ MUD WITH CLASTS (cm)
→ VERY "CHERTY" PORTION;
→ WELL CEMENTED
→ SMALL SANDY PORTION
→ MORE MATRIX (SAND) PORTION
→ VERY "CHERTY" PORTION
→ mm CLASTS
→ MORE CEMENTED

NO RECOVERY

Site: HC
Station ID: MR-235
Logged by: PAULO CASADO
Date: 22-JULY-2014
pg 6 of 21

Geologic Information Needs to be Managed as Data!



huge chunks of chert (almost no matrix)

-sandy matrix with chert clasts

"chert clasts on sand matrix; -looks like a ""brechia""; - cm clasts, very angular;"

"shalley portion crossing the core; - cm ""angular"" chert clasts;"

-mud with clasts (cm)

"very ""cherty"" portion; -well cemented; -small sandy portions"

more matrix (sand) portions

very cherty portion; -mm clasts; -more cemented

"still readstown; -very dense chert clasts portion within a sandy matrix; -cm ""angular"" chert clasts"

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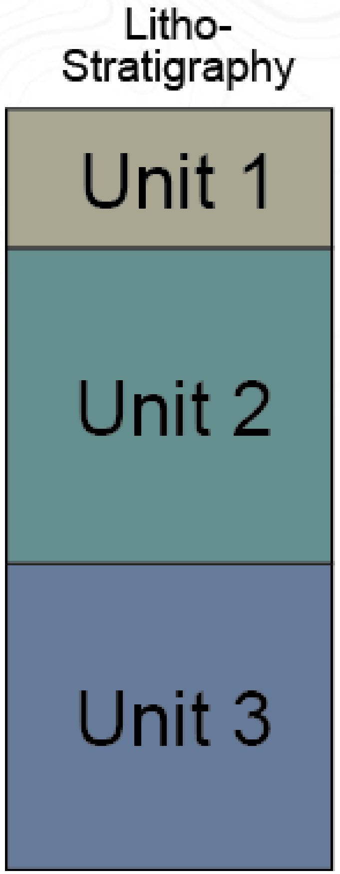
High Resolution Head Profiles Provide Valuable Hydrostratigraphic and Flow System Insight



Multilevel Systems are a Proven But Under Utilized Technology

Westbay

Westbay® Instruments

Waterloo

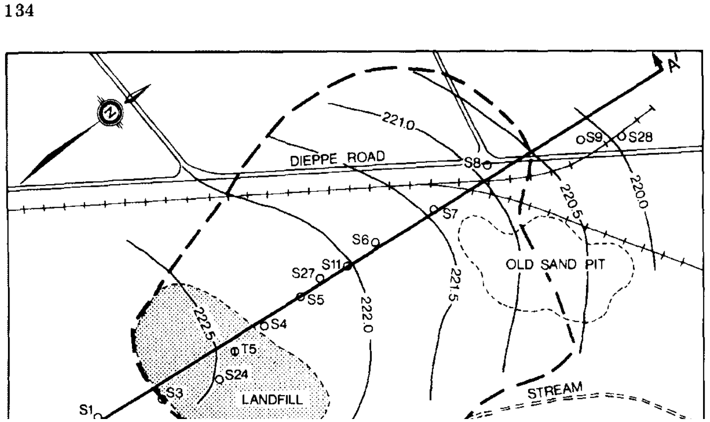
Solinst®

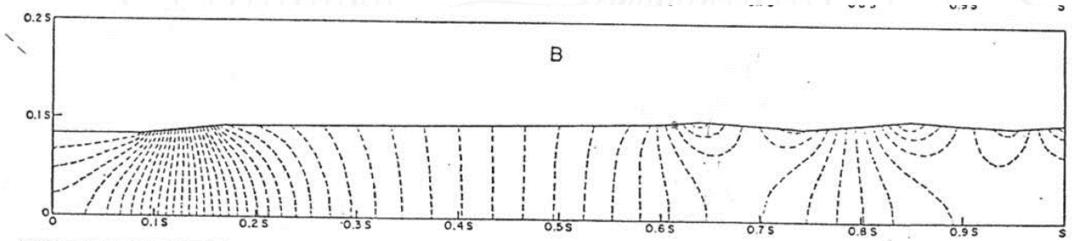
CMT

Solinst®

Water FLUTe

FLUTe™
Flexible Liner Underground Technologies, Ltd. Co.
A medley of innovative designs





Freeze and Witherspoon, 1967, WRR, v3 (2): 623 - 644

We *do not* teach students how to plot and interpret profiles of head versus depth

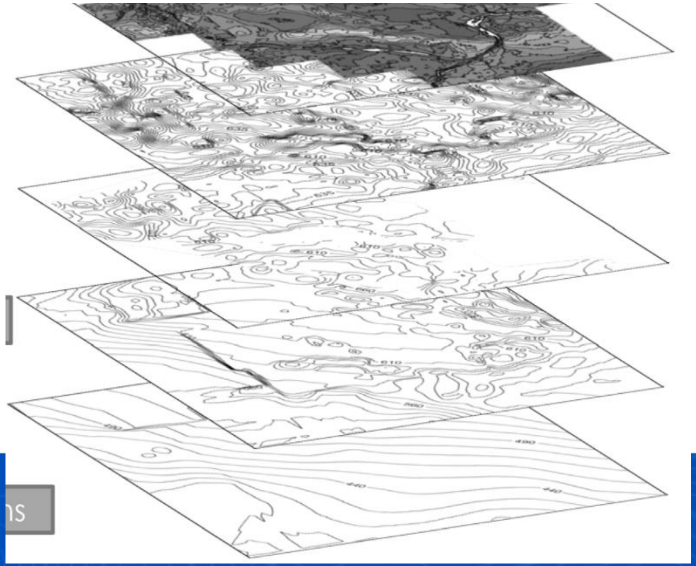


Image from: http://www.esaa-events.com/proceedings/watertech/2014/pdf/p26.pdf, Joe Riddell, Dylan King, WaterTech 2014

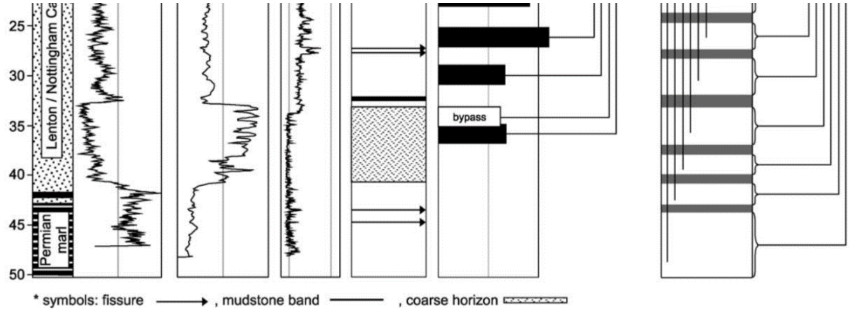


Fig. 4. Hydrostratigraphy of Permo-Triassic sediments at Old Basford, Nottingham. Presented static water levels (SWL) were recorded by packer testing in November 29 to December 1, 1999 and using a multilevel piezometer on November 15, 2000. Vertical exaggeration is × 500.

Taylor et al. (2003) JOH

Are We Training People with Expertise in Hydrostratigraphy?

- ►Team members with advanced training in subsurface geologic interpretation/correlation
  - Geologic pattern recognition
- ►Team members with advanced training in physical hydrogeology
  - Data integration for hydrogeologic interpretations

A Scott

The Future of Navy Environmental Restoration:

Requires a synthesized understanding of biogeochemistry and granular details of stratigraphy and hydrogeology to “un-stuck” complex sites.

- Better lines of evidence to revise RAOs and long-term site management strategies. Especially exit-criteria with chemical specific site remediation goal concentrations.

- Better data management to support better CSMs and knowledge transfer over the lifetime of a site in the ER,N program…these sites exists for decades/perpetuity.

The Challenges:

- **Navy contractual structures currently limit the scope of the project work:**
  - ☐ Only funded site-by-site efforts.
  - ☐ Limitations in contracts for data management after project delivery, i.e. the PDF of the report or binder on the shelf.
- **Fragmented/static data**
  - ☐ ESS analysis “lives” in PDFs. CSM updates exist in reports, and not in data driven info-systems.
  - ☐ Constraints CSM in a narrow-site lens often misleads remedy strategy.
- **System Compatibility/Cybersecurity Constraints**

Question: Why ESS and Digital Site Management Tool?

Answer: A better CSM results in better response actions and site management!

- Better processes and decision making in managing the DERP sites.

- Better understand the subsurface because it drives the remedial response costs and the long-term liabilities to the DOD.

Where We Are…

Examples of ongoing ESS projects:

- 4 Sites at NSF Indian Head MD
- These sites have long tail ends of in-situ remedy operations, and remedy performance appears stuck.

Older efforts:

- JBAB, DC
- Keyport, WA
- Bethpage, NY

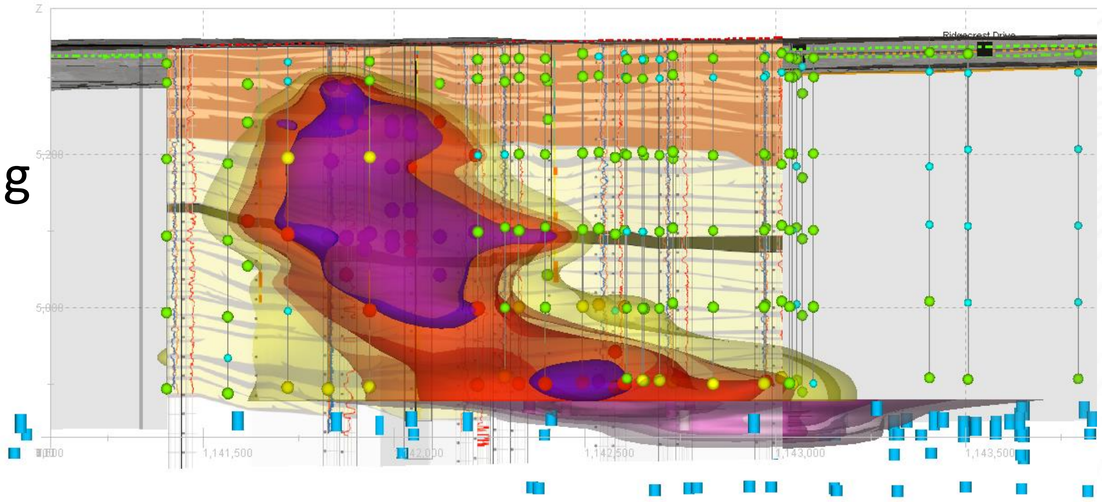
Desired Outcomes:

Better capability to answer…

- Where does contamination exist (distribution)?
- How is it migrating and transforming in the subsurface?
- Why remedy is sub-optimal?
- What can we do next?

M Stapleton

Evolution From a Remedial Specialist Perspective



- Informational Management and Systems
  - Legacy data management systems only capturing traditional site level information
  - Systems established during the VOC era
- Static to Dynamic Data Migration
  - 2 dimensional to 3 dimensional revolution
  - Data visualization and groundwater modeling
- Compartmentalized Business Practices vs. Holistic
  - Contractual Framework
    - Remedial Investigations at emerging contaminants is being driven through the optics of the VOC era
    - Subsurface investigation and characterization largely employing traditional conceptual site modeling approaches
    - Checking the box mentality - dropping the CSM into the remedial investigation, generating the report and then putting it up on a shelf
    - CSM are living documents - continuously being refined
  - Continuity and continued collaboration between the remedial specialist and the sequence stratigrapher - produced optimal remedial solutions and cost savings

Audience