Focus on Geology to Define Subsurface Migration Pathways

Outline
- Introduction
  - Why does geology matter?
  - What is Environmental Sequence Stratigraphy?
- Proof of concept
- The technology
- Case Studies

Introduction

Why does geology matter?

What is Environmental Sequence Stratigraphy?

Proof of concept

The technology

Case Studies

Technology Established in the Oil Industry

In the early days of exploration and production, once a reservoir was discovered, production was limited by facilities capacity (engineering focus).

As technology improved and fields matured, the "easy stuff" had been recovered. Problems such as water production became critical. Understanding the geology and predicting reservoir architecture became increasingly critical for economical operations.

Subsurface Heterogeneity and Groundwater Remediation

• Historically, simplifying assumptions of aquifer homogeneity and isotropy applied to designing and implementing groundwater remediation programs – the "water supply legacy"
• While heterogeneity was recognized, it was thought that we could "engineer around geology"

Subsurface Heterogeneity and Groundwater Remediation

With heterogeneous geology groundwater flow may not match gradient and result in:
• Off-gradient contaminant migration
• Poor distribution of in situ reagents
• Production of byproducts during in situ injection
• Poor pump-and-treat performance

Why Geology Matters

• At least 126,000 sites across the U.S. have contaminated groundwater that requires remediation
• Over 12,000 of these sites are considered "complex"
• "There is general agreement among practicing remediation professionals, however, that there is a substantial population of sites, where due to inherent geologic complexities, restoration within the next 50-100 years is likely not achievable."
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Environmental Sequence Stratigraphy (ESS) Process

1. Determine depositional environment which is the foundation to the ESS evaluation
2. Leverage existing lithology data to identify vertical grain size trends and correlate between boreholes
3. Map the permeability architecture to predict contaminant migration

All sites currently have high resolution data...

Boring Logs  CPT Logs  Geophysical Logs

...lithology data that is not being used to its full capacity.

Where is Environmental Sequence Stratigraphy applied?

- Fractured rock?
- Clastic (sand/silt/clay mixtures)
- Sedimentary deposits?

Clastic (sand/silt/clay mixtures) sedimentary deposits?
- River deposits
- Desert systems
- Coastal settings
- Marine deposits
- Glacial deposits

Focus on geology improves site characterization throughout the remediation life cycle:
- Data gaps investigations, high-resolution site characterization programs
- Optimizing groundwater monitoring programs
- Contaminant source identification for cominpled plumes
- Mass flux/mass discharge analysis (contaminant transport vs contaminant storage zones)
- In situ remediation (optimize distribution)
- Optimizing pump and treat programs
- Alternative endpoint analysis

Proof of Concept
Base-Wide Conceptual Site Models

Have successfully applied this technology to assess groundwater contaminant pathways at several Air Force facilities.
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OK, but what IS IT already?

ESS is “Pattern Recognition”

- Patterns in grain size are the language of heterogeneity
- Sequence Stratigraphers are the translators
- Can correlate/predict heterogeneity at all scales
- There are grain size patterns buried within existing boring tops of every site
- Experience and background of the practitioner is a prerequisite

The Problem of Aquifer Heterogeneity

- Outcrop analog of meandering fluvial deposits
- At aquifer remediation site scale
- Ability to explicitly map sand body architecture in 3 dimensions
- Facies Models provide predictive tool for characterization based on depositional environments
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The Problem of Aquifer Heterogeneity

“Hidden” Stratigraphic Data

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"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...

Existing data is formatted for stratigraphic interpretation

Reveals the “hidden” stratigraphic information that is available with existing lithology data

This SM interval is a fine to medium grained Silty Sand

This SM interval is a fine to coarse grained Silty Sand with gravel, representative of a channel deposit.

Both were logged as SM, but the details show that they have significantly different depositional characteristics.
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The ESS Workflow in a Nutshell:
1. Reformating existing data to identify sequences, and
2. Applying facies models, stratigraphic “rules of thumb” to correlate and map the subsurface, predict character of heterogeneity present

Mapped Sand Channels

Case Study #1: In situ Bioremediation

Industrial Facility: Ethanol injection to reduce hexavalent chromium plume
Scale: Hundred acres, ~60’ depth of investigation
Lithology Data: CPT logs, borehole logs
Approach: Apply ESS to explain Mn by-product
Takeaway: Even with “high-resolution” lithology data, a depositional model is needed for successful remediation

Grain Size Trends in CPT Data
- Site CPT data
- Coarsening upward vertical grain-size pattern
- Stacked alluvial fan deposits bounded by clays

Surface dips of 2-8 degrees, steeper at proximal fan and decreasing down fan

Mapped Sand Channels

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Case Study #1: In situ Bioremediation

**Cross Section of Hydrostratigraphic Units (HSUs)**

- Brown = silt/clay
- White = sand/gravel

Kriging of CPT Data to Correlate Lithology

(Same cross section) Misrepresents thin clay beds giving appearance of randomness in stratigraphic architecture

Conclusions

- Saturated zone consists of discrete HSUs (sand-rich alluvial fans)
- Stratigraphic dip of alluvial fan units is responsible for preferential pathways, channelization is not the primary mechanism
- Kriging correlations are not representative of the stratigraphy
- Not all fan units impacted; injection into clean zones responsible for Mn byproducts

Case Study #2: Plume Containment Strategy

**Munitions Manufacturing Site:** Perchlorate plume impacting municipal wells

**Scale:** Thousand acres, ~700’ depth of investigation

**Lithology Data:** Geophysical logs, borehole logs

**Approach:** Apply ESS on existing data to improve CSM and Design Plume Management Program

**Takeaway:** Detailed stratigraphy has significant impact on remediation design, project cost.

Site Overview

- 996-acre (403-hectare) site Santa Clarita, CA
- Complex geology, over 600’ of stratigraphy, dipping beds
- Impacted mainly with perchlorate (ClO4\(^-\)), but locally CVOCs, including TCE
- AECOM awarded contract to implement containment pilot study
- Geologic setting, AECOM expertise prompted CSM review

3-D ESS Cross Section Network

Site-wide analysis for design of containment system
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Case Study #2: Plume Containment Strategy

ESS Process: Datum (flatten) Logs on Well-Defined Floodplain Unit

ESS Process: Correlate Floodplain Surfaces

Case Study #2: Plume Containment Strategy

ESS Process: Define Aquifer/Permeability Architecture Based on Stratigraphic Rules


Case Study #2: Plume Containment Strategy

ESS Process: Identification of Breach of Floodplain Aquitard, Map Likely "Hot Zones"

ESS Process: Create 3-D ESS Stratigraphic Framework
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Case Study #2: Plume Containment Strategy

ESS Process: Testing and Validating the CSM – Pathways and Communication

- Aquifer tests were performed sequentially, instead of concurrently, to avoid interference from different pumping wells
- HSU designations, groundwater flow paths verified

Case Study #2: Plume Containment Strategy

ESS Outcome: Overhauled CSM, verified CSM, gained regulatory and stakeholder approval for wholesale modification of containment system design = $55MM savings

Before ESS

125’ extraction interval; includes non-impacted strata
Capital cost = $7 MM
Treatment cost = $2.5MM/yr; 30 yr = $75 MM
Total cost = $82 MM

After ESS

35’ extraction interval; impacted strata only
Capital cost = $2.5MM
Treatment cost = $800K/yr; 30 yr = $24MM
Total cost = $26.5 MM

Takeaways Regarding ESS

Addresses Aquifer Heterogeneity with Existing Data

- Existing data contain important information and recognizable patterns
- Low cost, very high Return on Investment

Questions & Answers

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