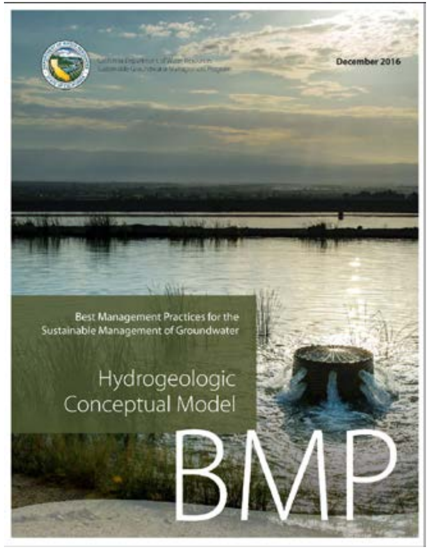
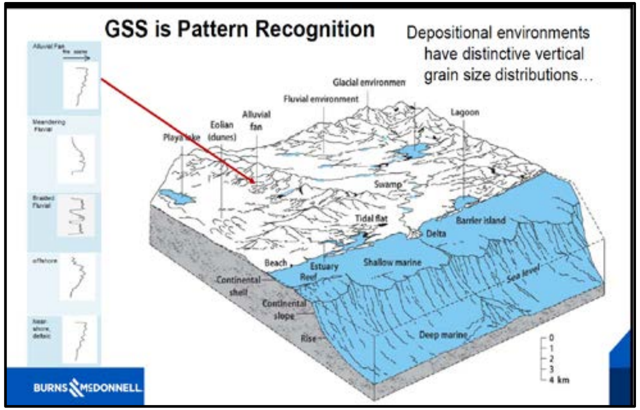
Groundwater Sequence Stratigraphy:
A Geology-based Approach for Developing Accurate and Representative Hydrogeologic Conceptual Models for Successful Groundwater Sustainability Plans


December 2016

Best Management Practices for the
Sustainable Management of Groundwater

Hydrogeologic
Conceptual Model

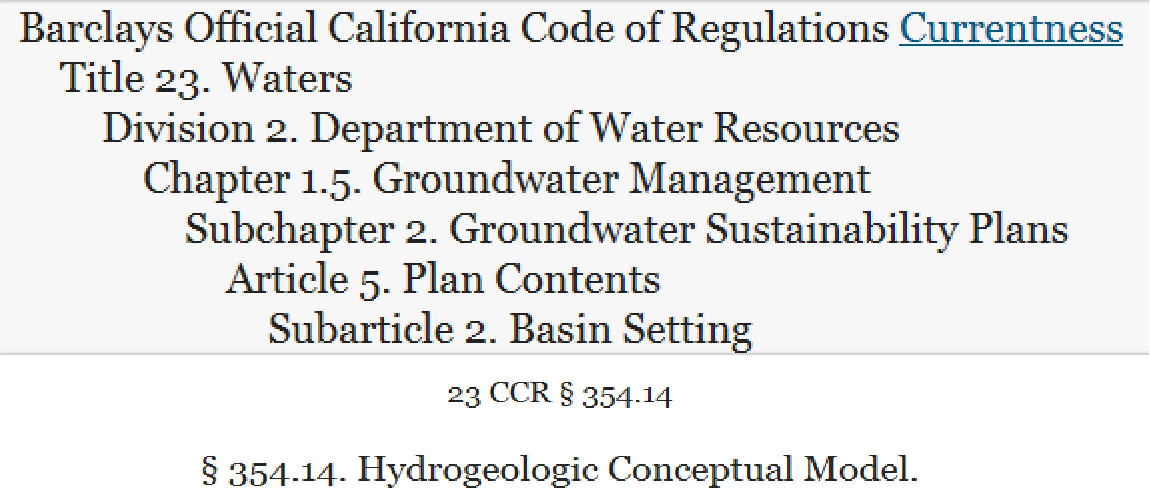
BMP


GSS is Pattern Recognition

Depositional environments have distinctive vertical grain size distributions…

Rick Cramer, Burns & McDonnell
Chris Bonds, CA-DWR;
Mike Shultz, Burns & McDonnell; Colin Plank, Burns & McDonnell; Galen Kenoyer, Burns & McDonnell

May 4, 2017



Barclays Official California Code of Regulations Currentness
Title 23. Waters
Division 2. Department of Water Resources
Chapter 1.5. Groundwater Management
Subchapter 2. Groundwater Sustainability Plans
Article 5. Plan Contents
Subarticle 2. Basin Setting

23 CCR § 354.14

§ 354.14. Hydrogeologic Conceptual Model.

*Each Plan shall include a descriptive **hydrogeologic conceptual model** of the basin based on technical studies and qualified maps that characterizes the physical components and interaction of the surface water and groundwater systems in the basin*

From BMP Document

Geologic cross-sections should be constructed by a professional geologist…A full understanding of, and appreciation for, the variety of depositional environments, like **sequence stratigraphy**, is needed to construct accurate geological cross sections.

Focus on Geology in the Oil Industry – 1960s

In the early days of exploration and production production was limited by facilities capacity (engineering focus).

However, as production declined the geology became increasingly critical for economical operations.
Billions of dollars have been invested in research and development of stratigraphic controls on fluid flow.

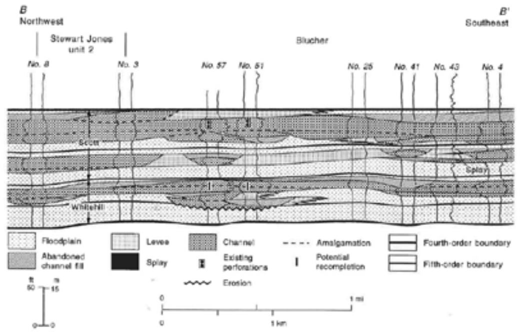


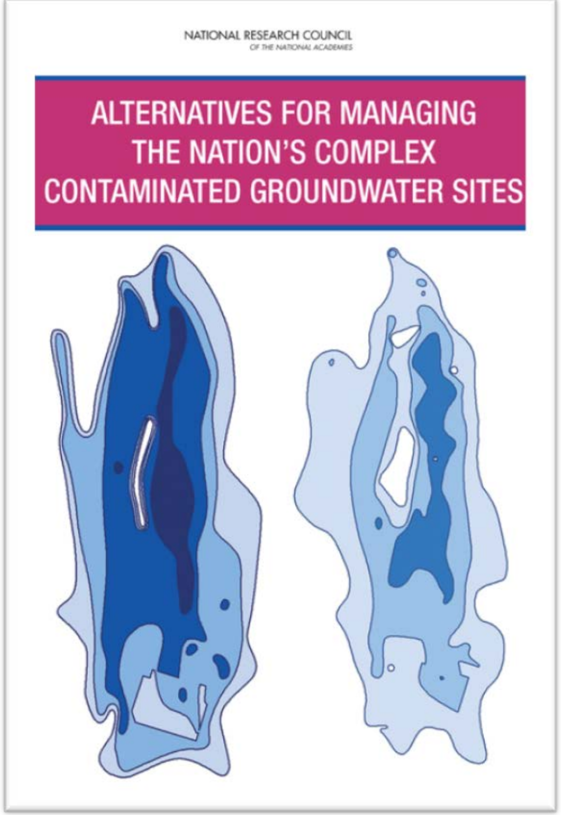
Figure 3. Dip-oriented stratigraphic cross section B-B' through amalgamated channel sandstones and floodplain shales in the Scott/Whitehill intermediate-frequency unit in T-C-B field. Note that the four high-frequency units, the lower and upper Whitehill and the lower and upper Scott, exhibit a successive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

Focus on Geology in Environmental Industry – 2013

- At least 126,000 sites across the U.S. have contaminated groundwater that requires remediation
- Over **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

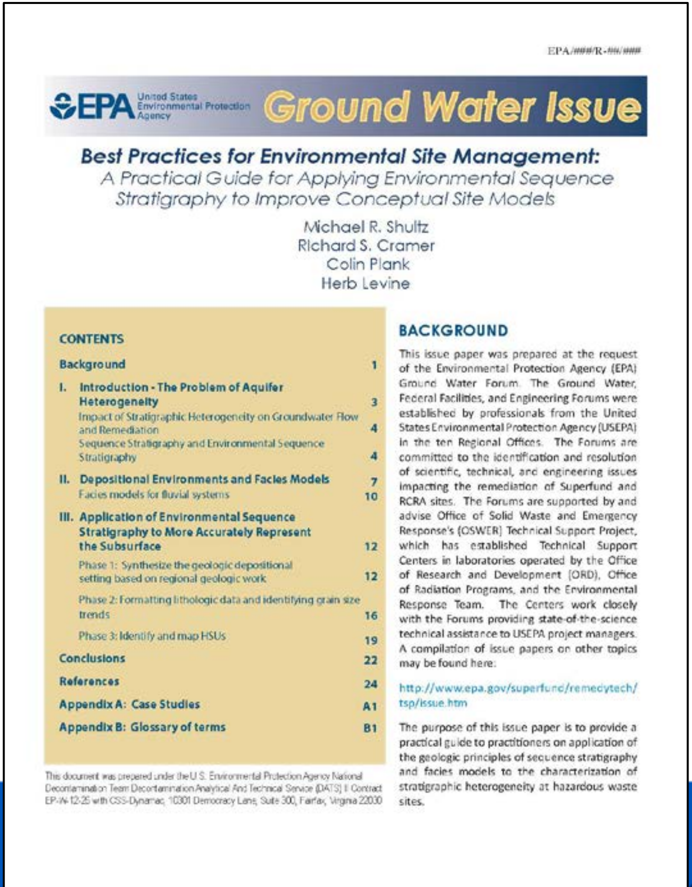


NATIONAL RESEARCH COUNCIL
OF THE NATIONAL ACADEMIES

ALTERNATIVES FOR MANAGING
THE NATION'S COMPLEX
CONTAMINATED GROUNDWATER SITES

Environmental Sequence Stratigraphy Technology Considered Best Practice by US EPA

US EPA Technical Issue Paper presents Environmental Sequence Stratigraphy (ESS) as an emerging best practice for Conceptual Site Models



EPA/###/R-##/####

EPA United States Environmental Protection Agency

Ground Water Issue

Best Practices for Environmental Site Management:

A Practical Guide for Applying Environmental Sequence Stratigraphy to Improve Conceptual Site Models

Michael R. Shultz
Richard S. Cramer
Colin Plank
Herb Levine

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-12-25 with CSS-Dynamac, 10301 Democracy Lane, Suite 300, Fairfax, Virginia 22030

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:

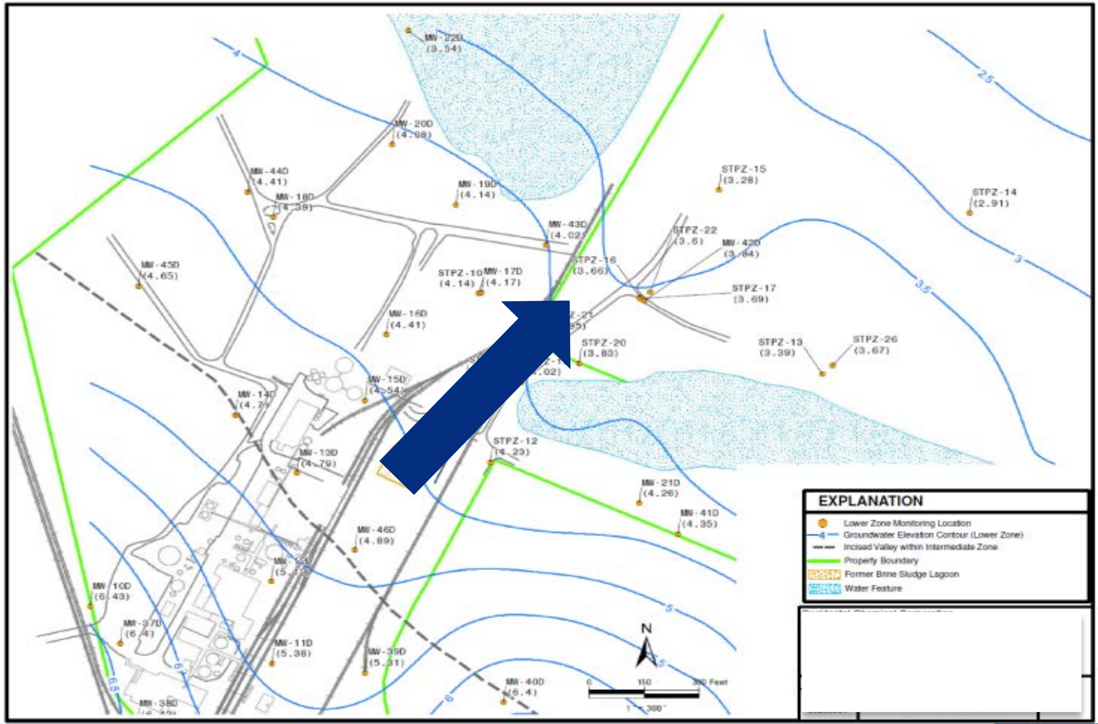
http://www.epa.gov/superfund/remedytech/tsp/issue.htm

The purpose of this issue paper is to provide a practical guide to practitioners on application of the geologic principles of sequence stratigraphy and facies models to the characterization of stratigraphic heterogeneity at hazardous waste sites.

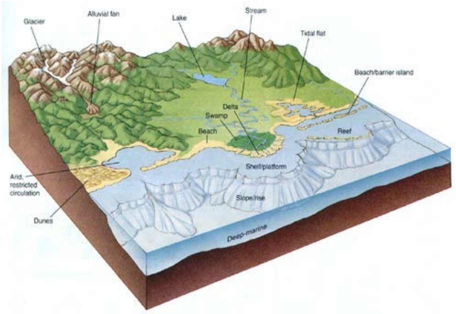
Groundwater Production Industry
Traditional Approach to the Subsurface

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

Groundwater gradient = groundwater flow



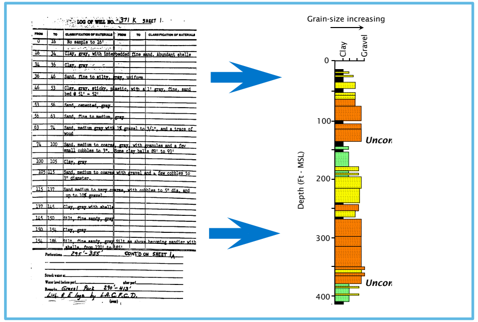
Geology-Based HCM: Groundwater Sequence Stratigraphy (GSS) Process



1

Determine depositional environment which is the foundation to the GSS evaluation

Borehole Log to Graphic Grainsize Log



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.

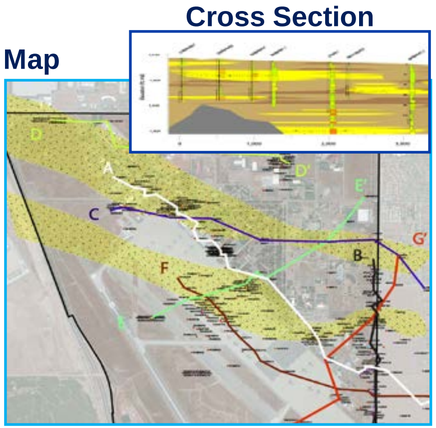
Remarks Gravel Pack 290'-413'

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

(over)

2

Leverage existing lithology data: format to emphasize vertical grainsize distribution

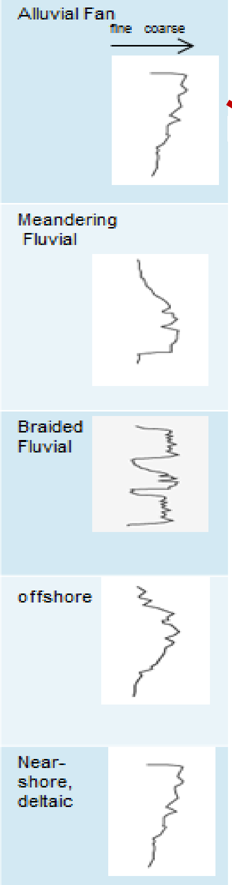


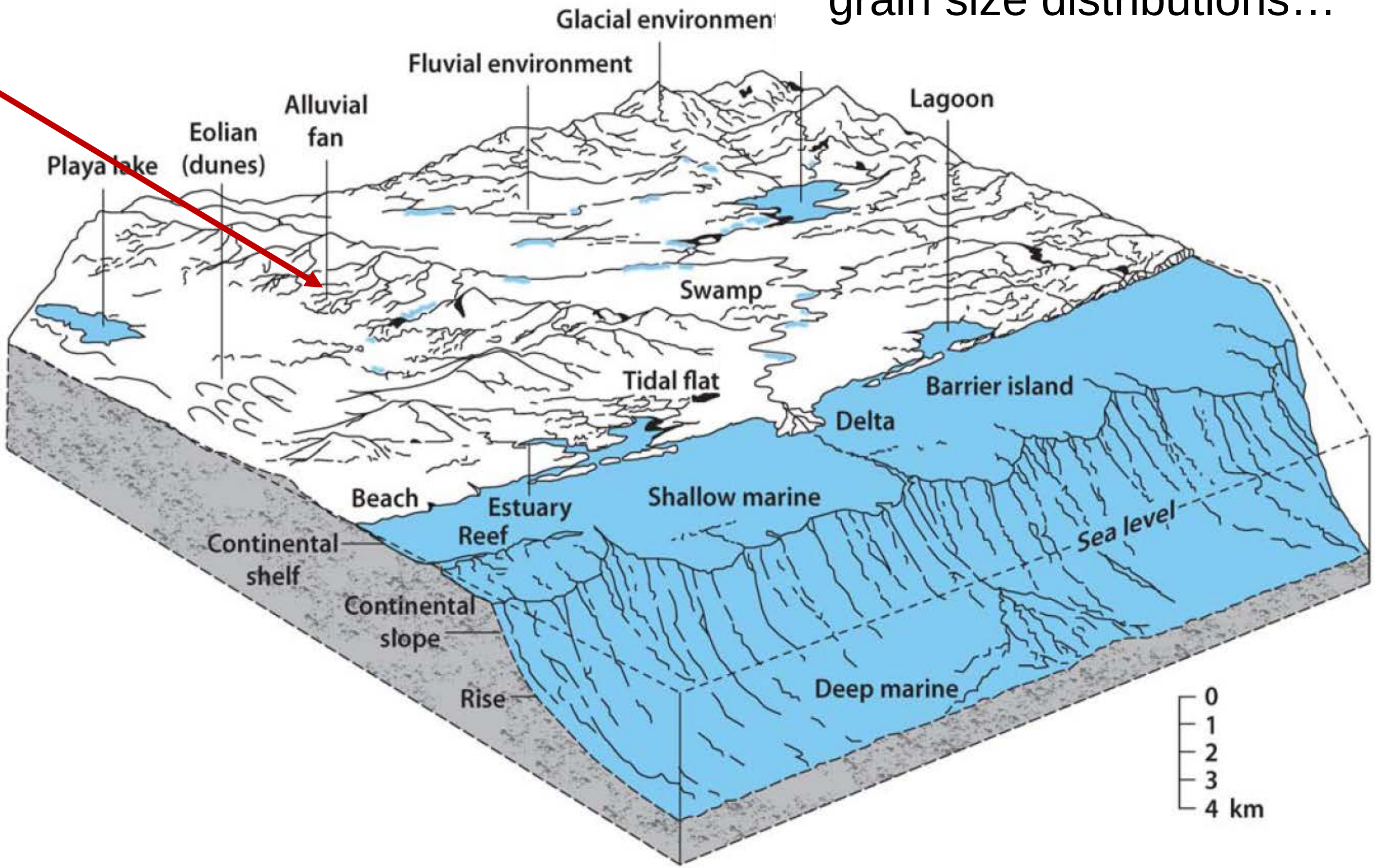
3

Predict and Map in 3D the subsurface conditions away from the data points

GSS is Pattern Recognition

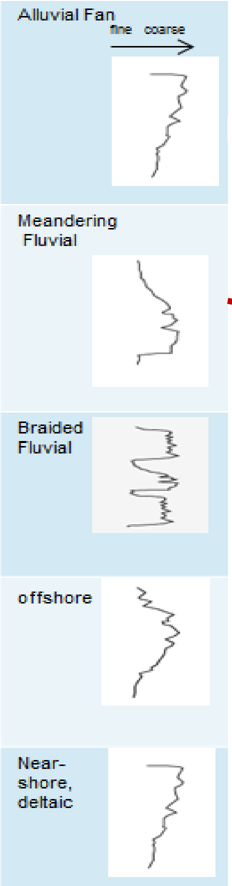
Depositional environments have distinctive vertical grain size distributions…

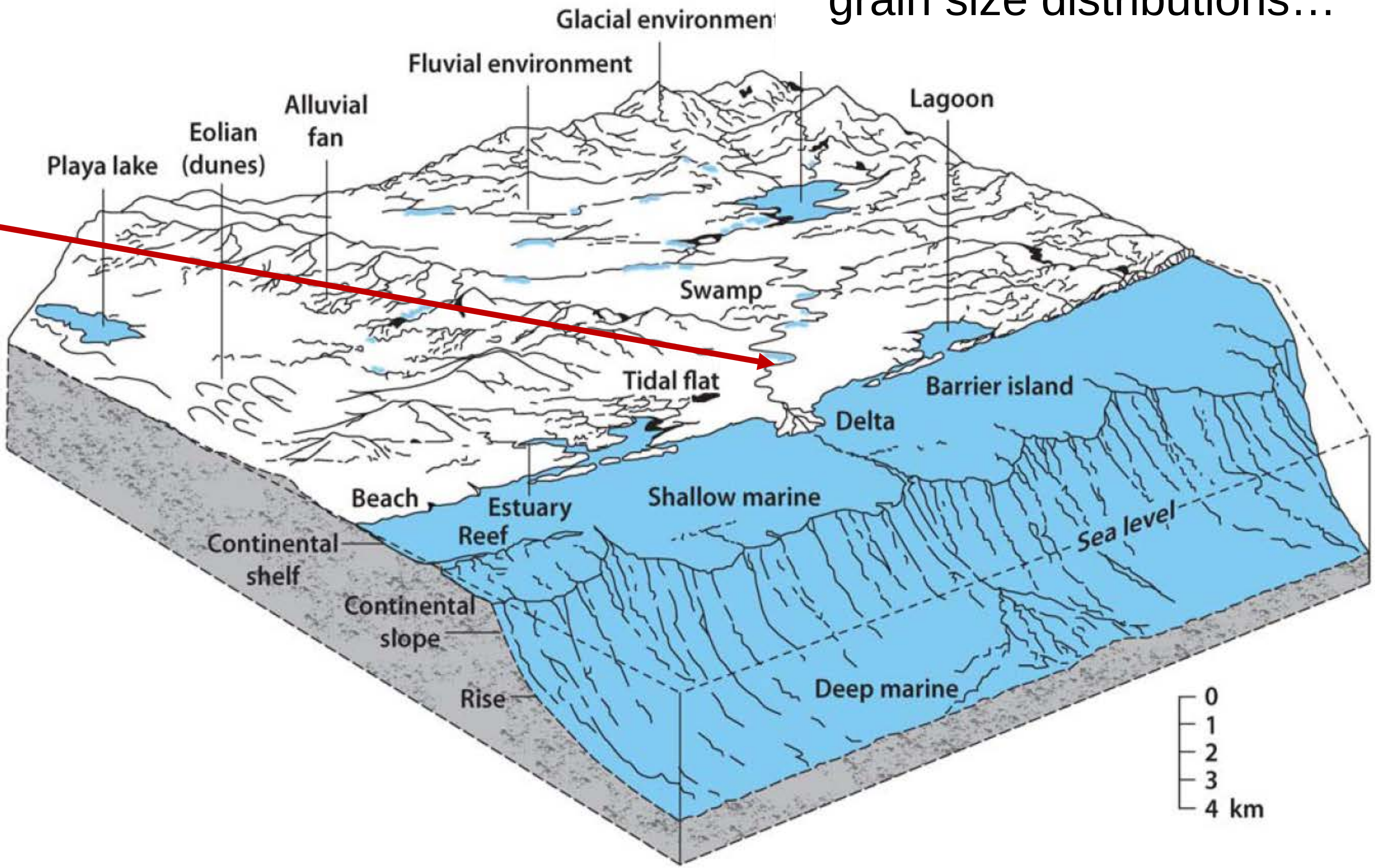




GSS is Pattern Recognition

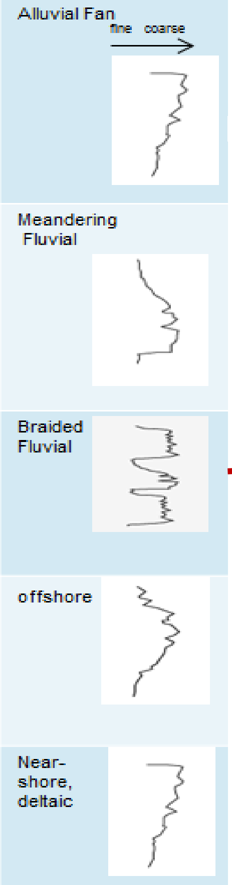
Depositional environments have distinctive vertical grain size distributions…

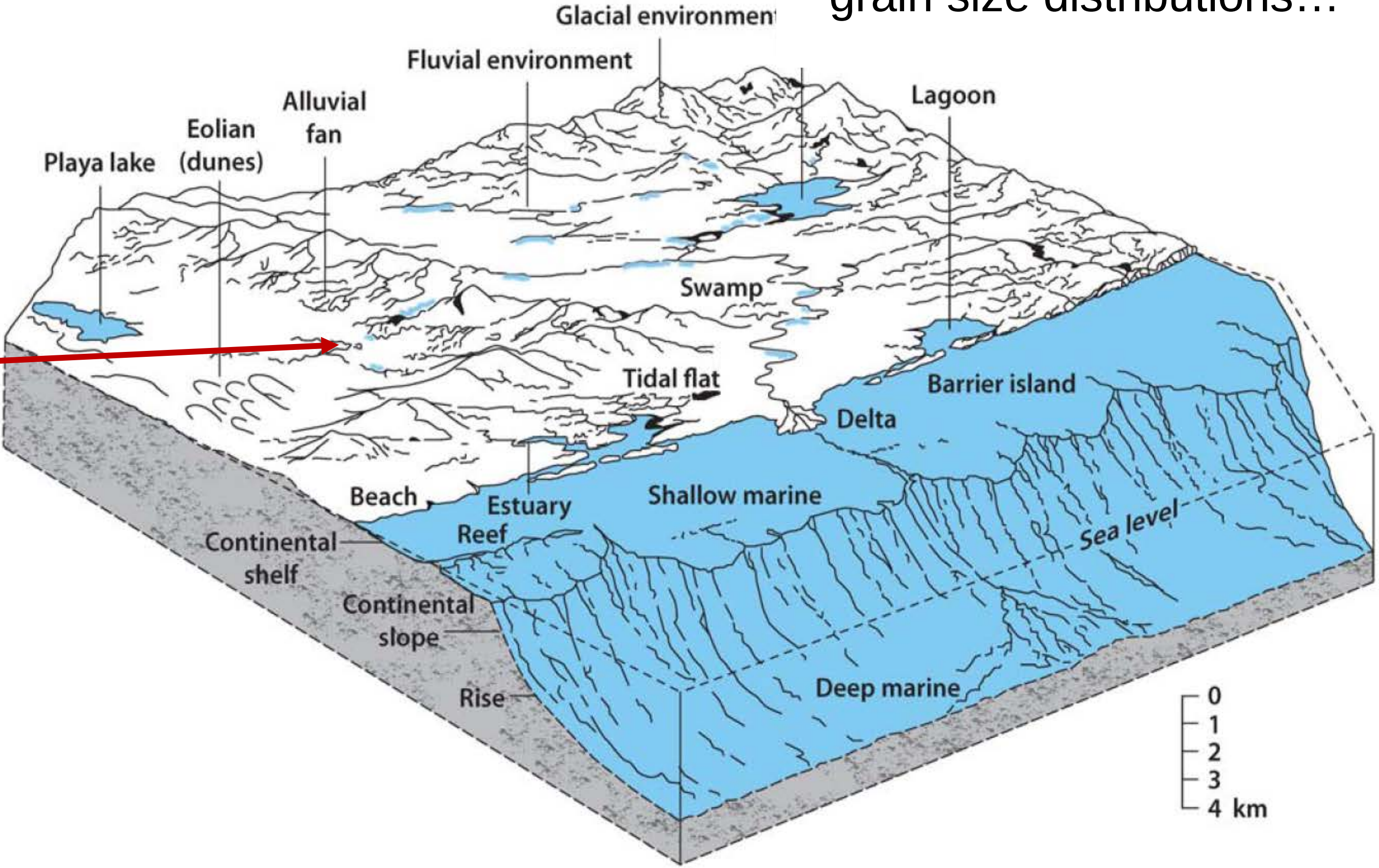




GSS is Pattern Recognition

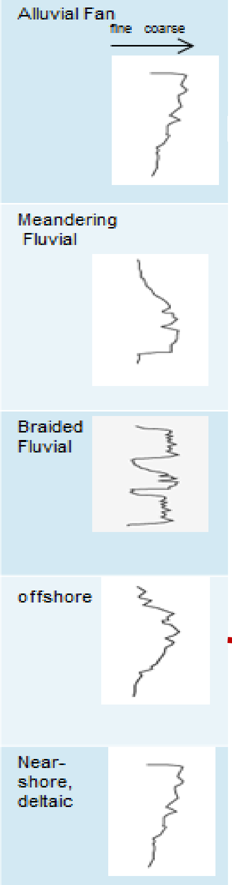
Depositional environments have distinctive vertical grain size distributions…

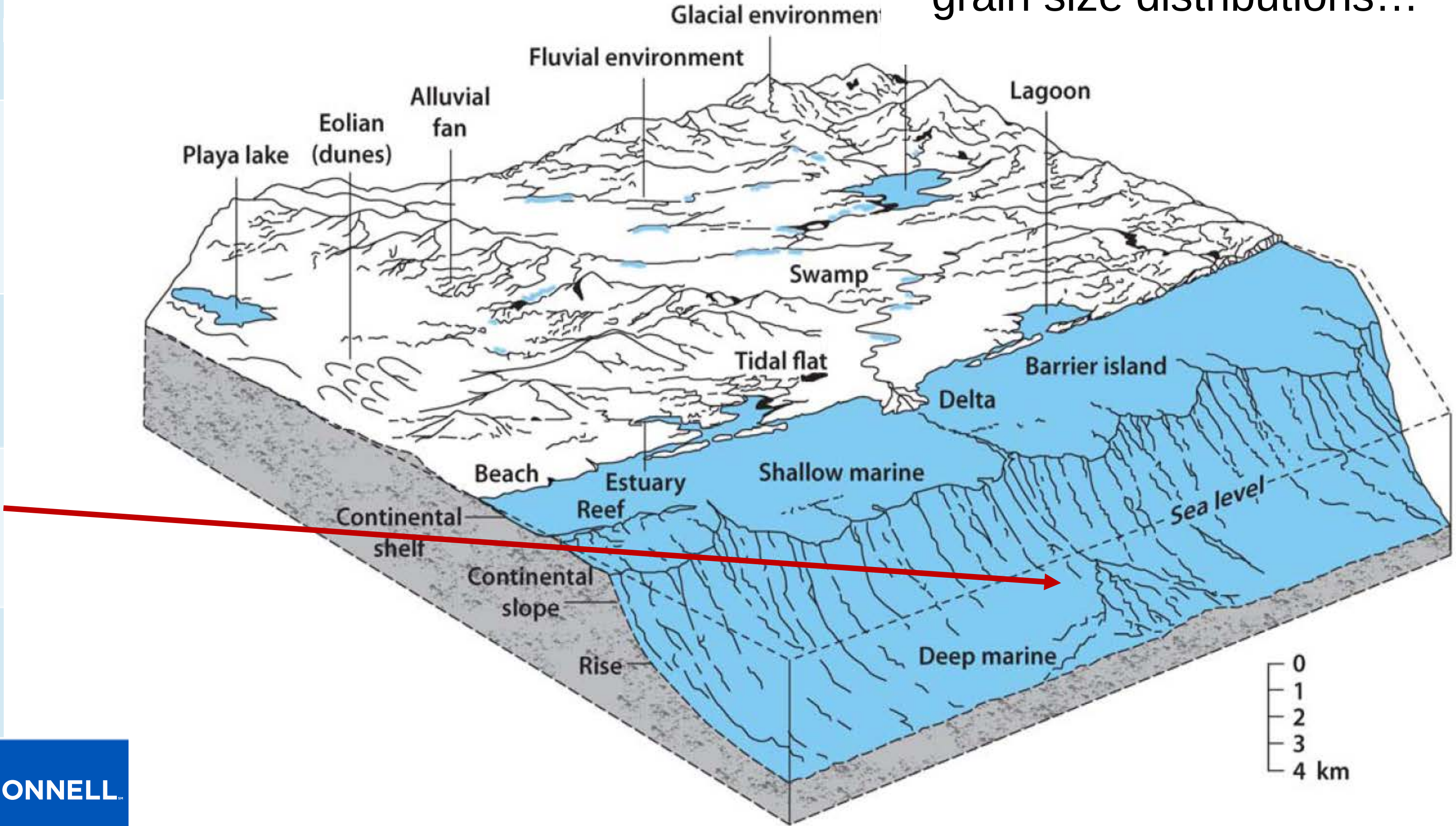




GSS is Pattern Recognition

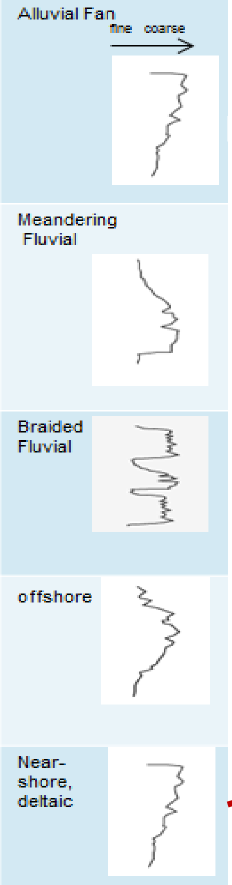
Depositional environments have distinctive vertical grain size distributions…

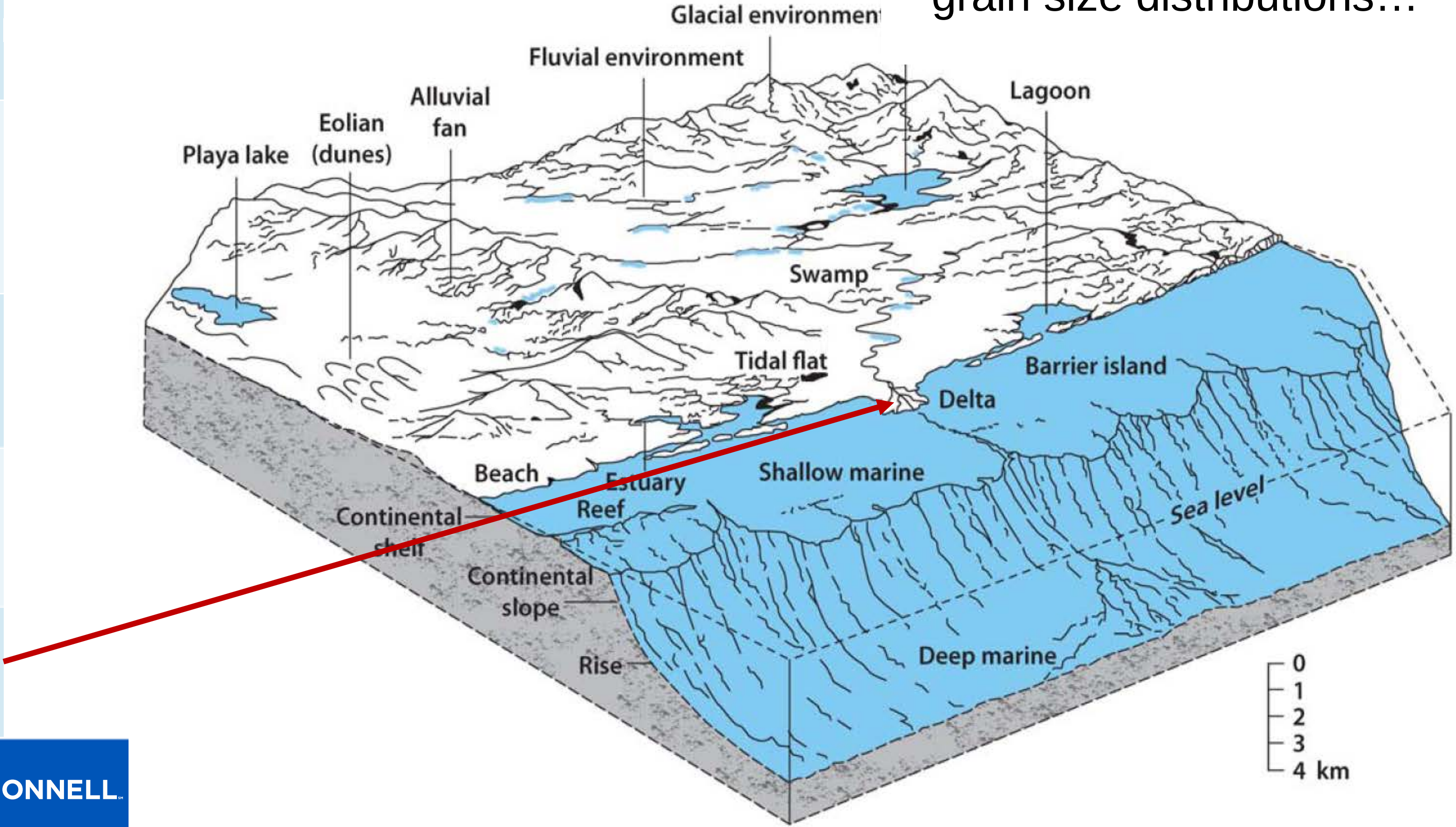




GSS is Pattern Recognition

Depositional environments have distinctive vertical grain size distributions…

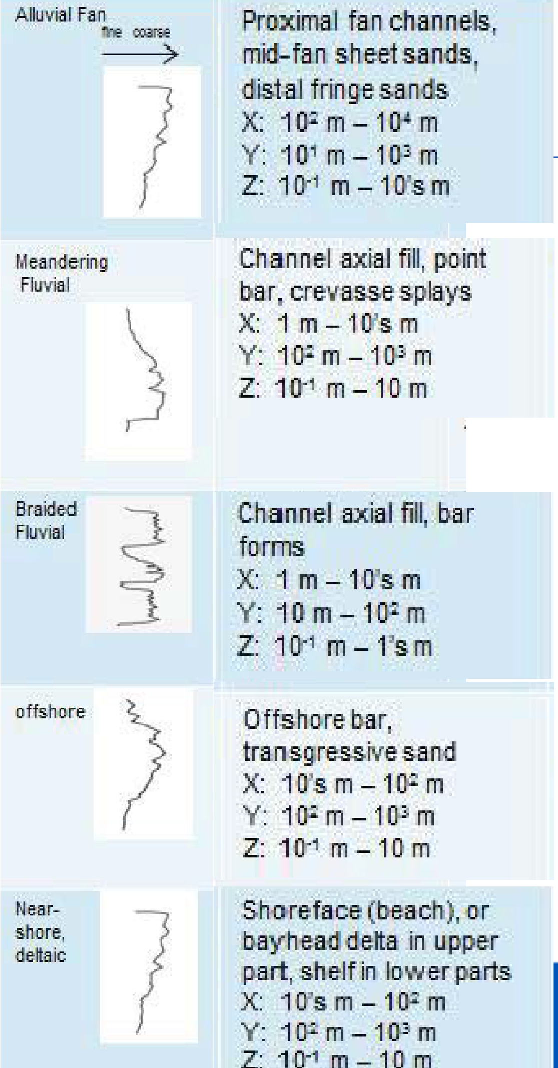




GSS is Pattern Recognition

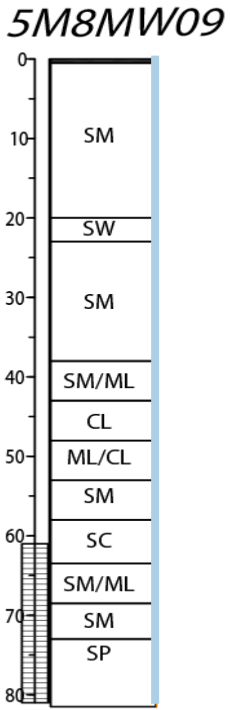
…and the associated sand bodies have characteristic/predictable dimensions and continuity.

Stratigrapher using GSS methodology can predict subsurface conditions away from the data points.



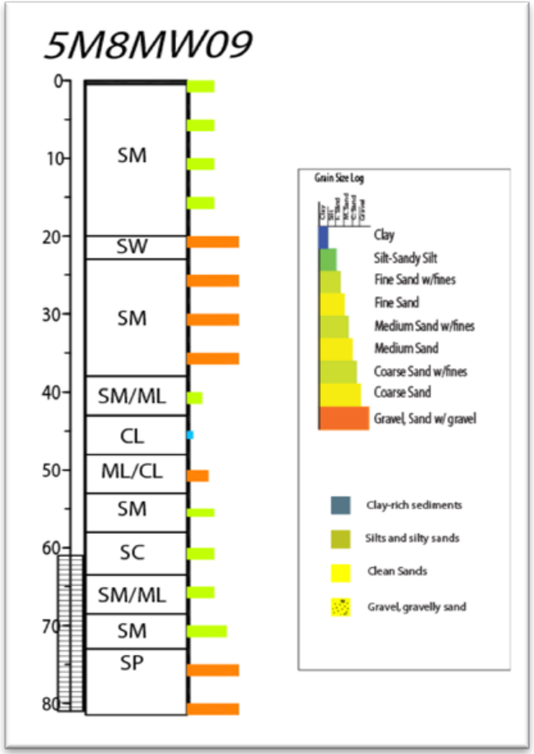
Alluvial Fan	Proximal fan channels, mid-fan sheet sands, distal fringe sands X: 10^2 m – 10^4 m Y: 10^1 m – 10^3 m Z: 10^{-1} m – 10's m
Meandering Fluvial	Channel axial fill, point bar, crevasse splays X: 1 m – 10's m Y: 10^2 m – 10^3 m Z: 10^{-1} m – 10 m
Braided Fluvial	Channel axial fill, bar forms X: 1 m – 10's m Y: 10 m – 10^2 m Z: 10^{-1} m – 1's m
offshore	Offshore bar, transgressive sand X: 10's m – 10^2 m Y: 10^2 m – 10^3 m Z: 10^{-1} m – 10 m
Near-shore, deltaic	Shoreface (beach), or bayhead delta in upper part, shelf in lower parts X: 10's m – 10^2 m Y: 10^2 m – 10^3 m Z: 10^{-1} m – 10 m

Unleashing the Power of Existing Site Data



- “USCS is not a geologic description of the subsurface”
- Different geologists
- Different drilling methods
- Different sampling intervals
- Etc…

How to “tease out” detailed stratigraphy with existing data

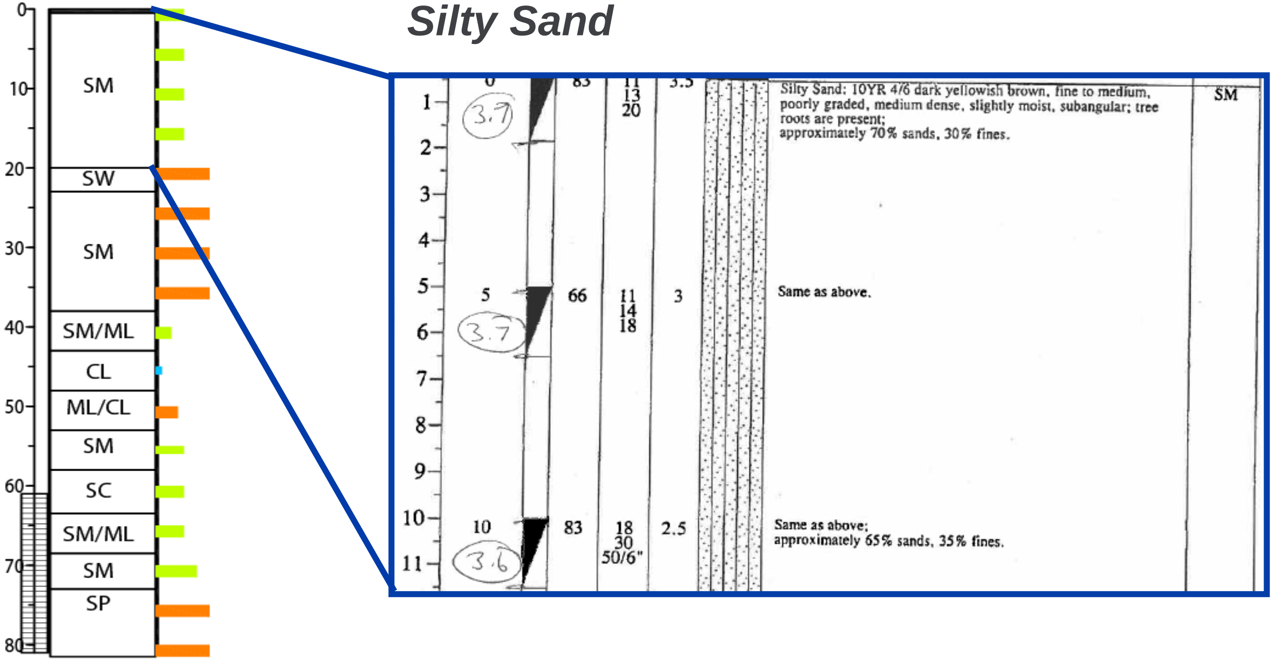


- Existing data is formatted for stratigraphic interpretation
- Reveals the “hidden” stratigraphic information that is available with existing lithology data

How to “tease out” detailed stratigraphy with existing data

This SM interval is a fine to medium grained Silty Sand

5M8MW09

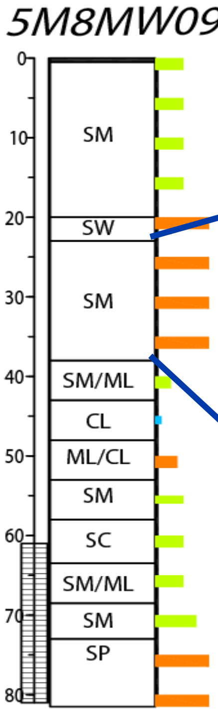


Silty Sand: 10YR 4/6 dark yellowish brown, fine to medium, poorly graded, medium dense, slightly moist, subangular; tree roots are present; approximately 70% sands, 30% fines.

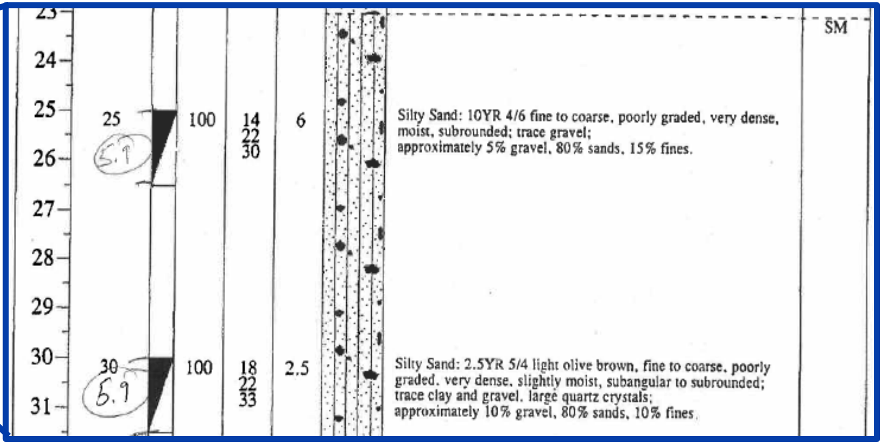
Same as above.

Same as above; approximately 65% sands, 35% fines.

How to “tease out” detailed stratigraphy with existing data



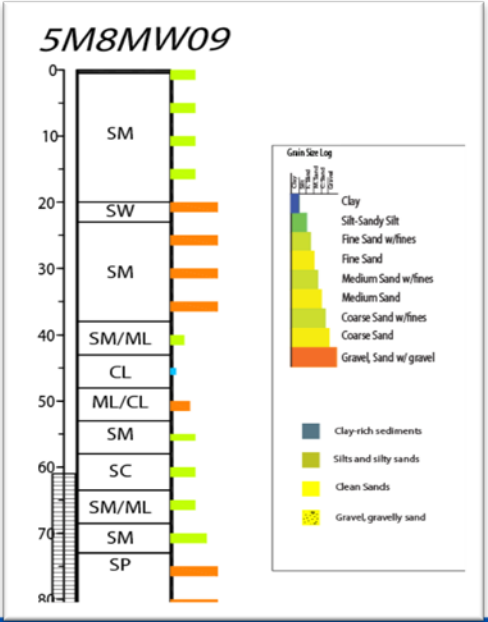
This SM interval is a fine to coarse grained Silty Sand with gravel, representative of a channel deposit.

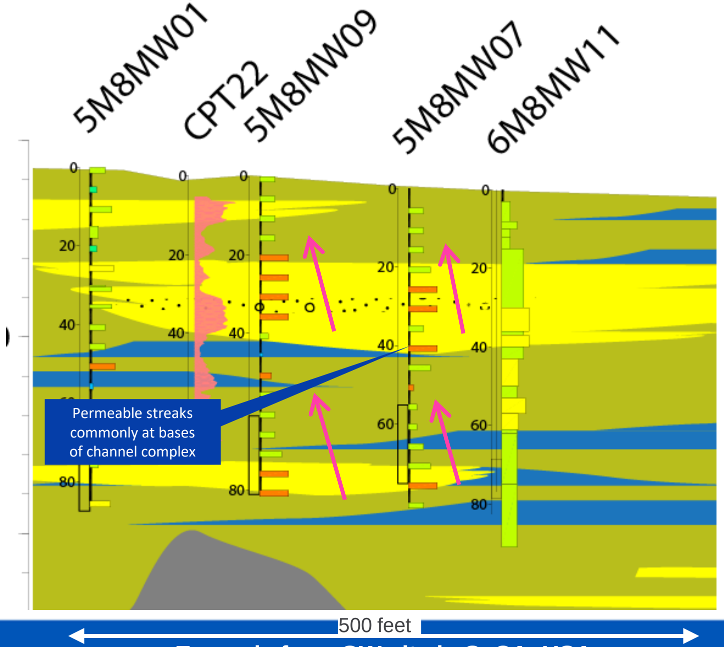


25	5.9	100	14 22 30	6	Silty Sand: 10YR 4/6 fine to coarse, poorly graded, very dense, moist, subrounded; trace gravel; approximately 5% gravel, 80% sands, 15% fines.
30	5.9	100	18 22 33	2.5	Silty Sand: 2.5YR 5/4 light olive brown, fine to coarse, poorly graded, very dense, slightly moist, subangular to subrounded; trace clay and gravel, large quartz crystals; approximately 10% gravel, 80% sands, 10% fines.

How to “tease out” detailed stratigraphy with existing data

1. Reformatting 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

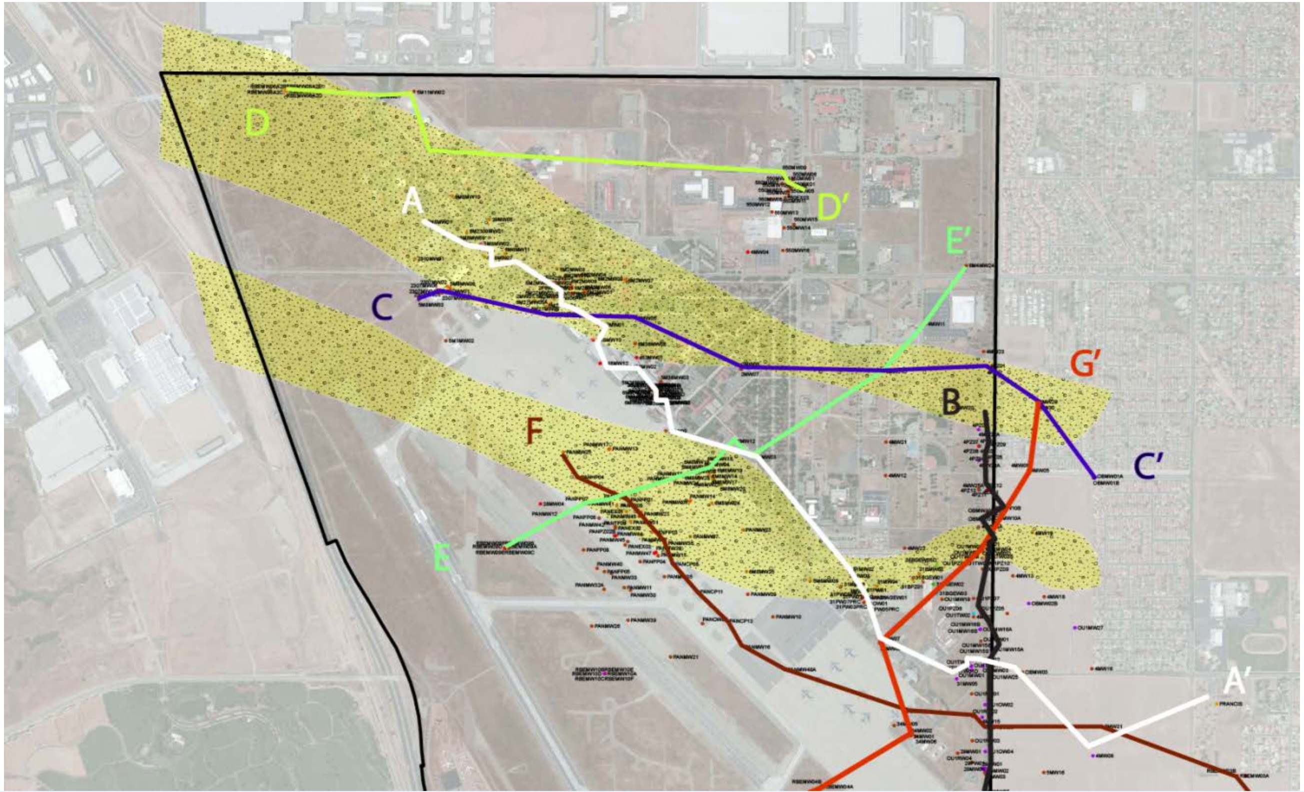




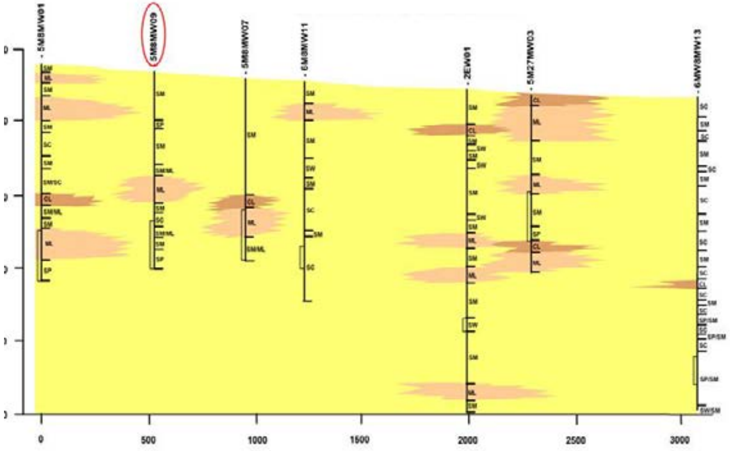
Permeable streaks commonly at bases of channel complex

Example from GW site in S. CA, USA

Mapped Buried Sand Channels

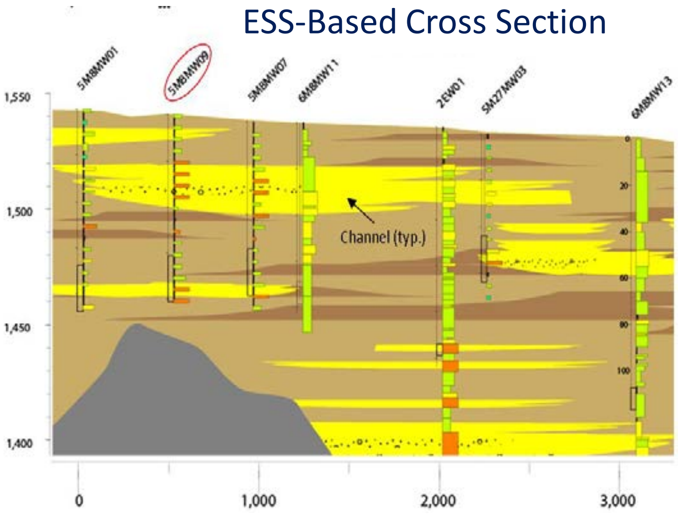


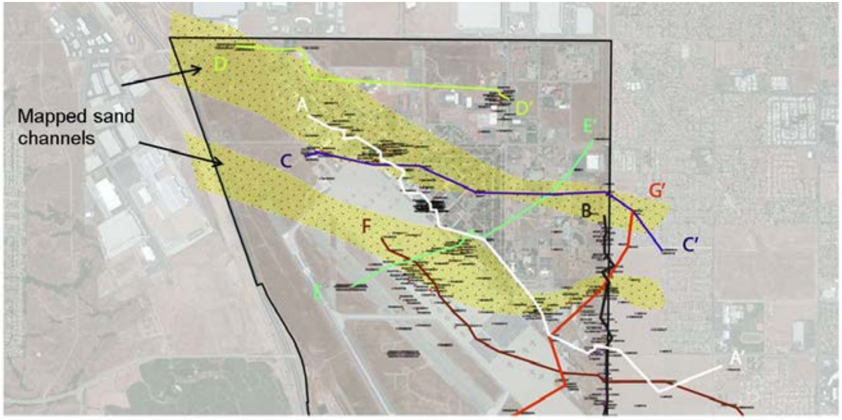
USCS-Based Cross Section



VS

ESS-Based Cross Section

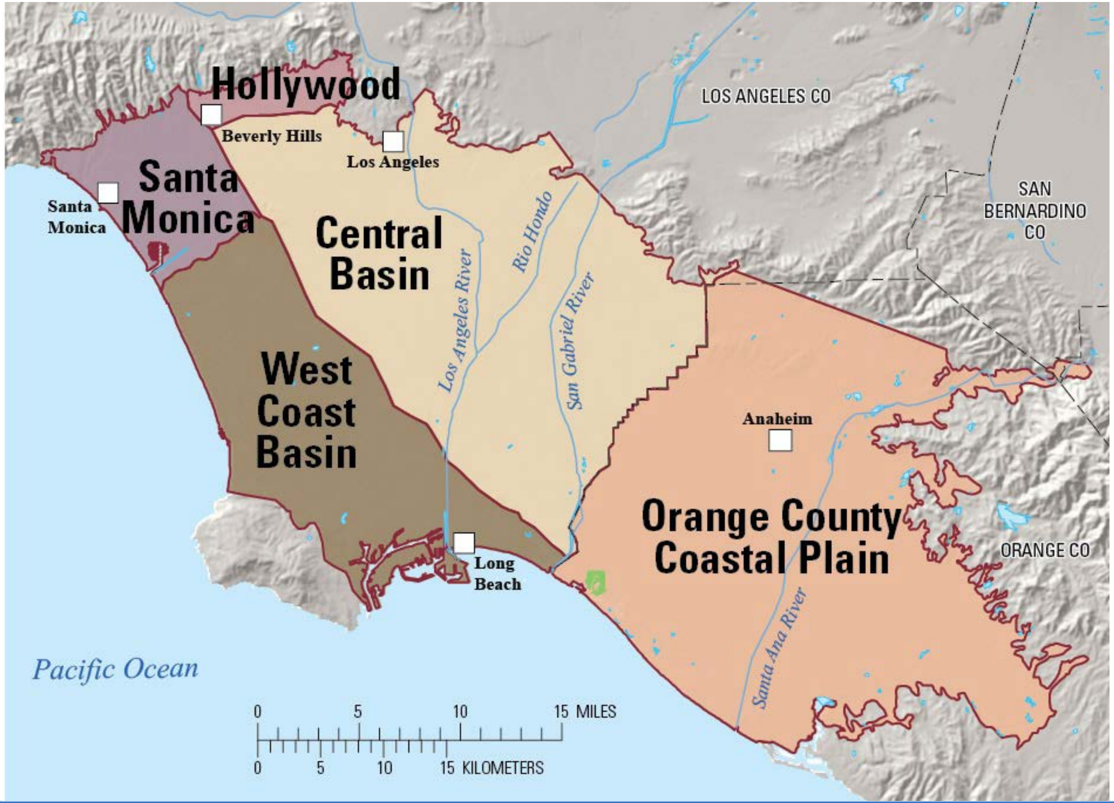


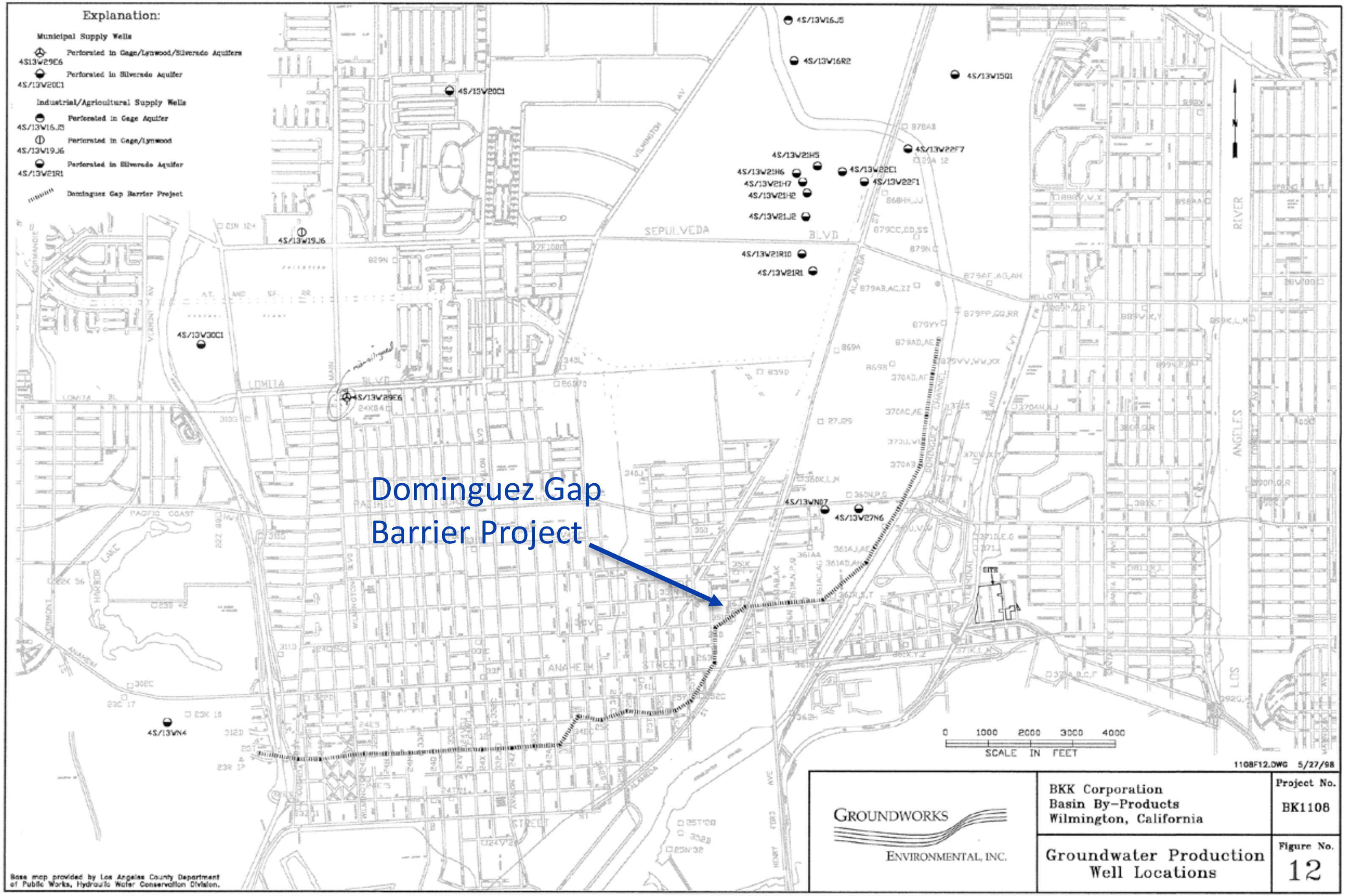


Groundwater Production Projects

Groundwater Contamination Projects

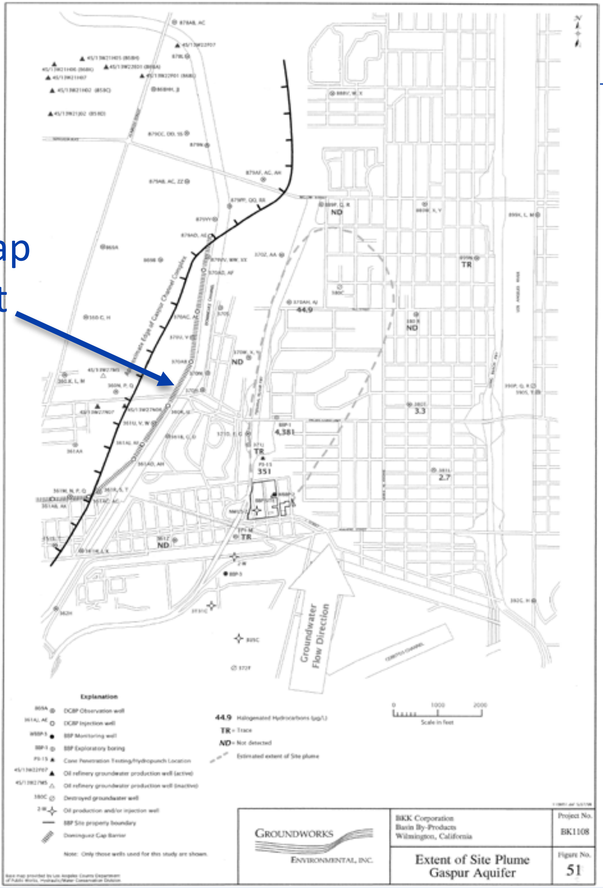
Dominguez Gap Seawater Intrusion Barrier, West Coast Basin – WRD

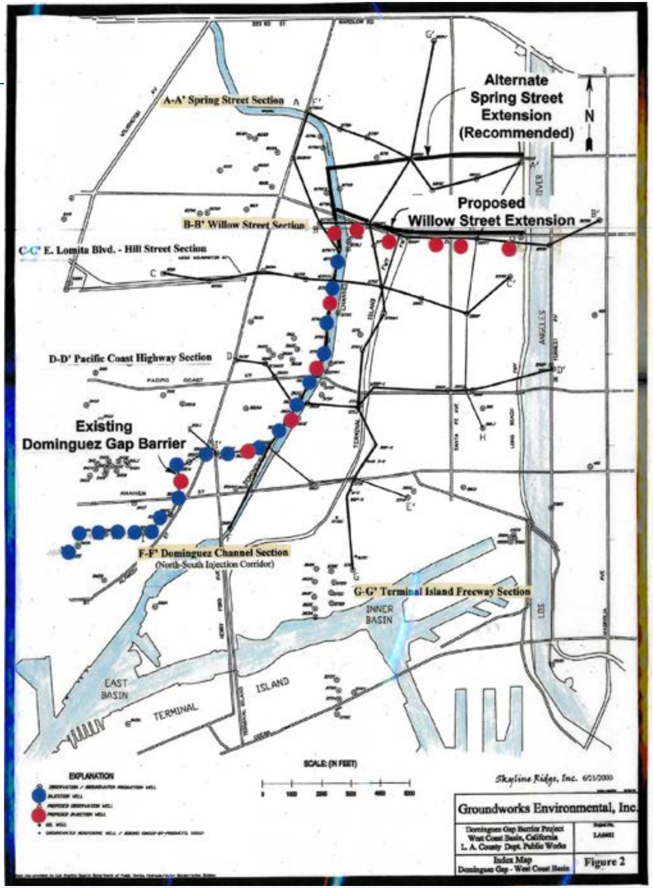




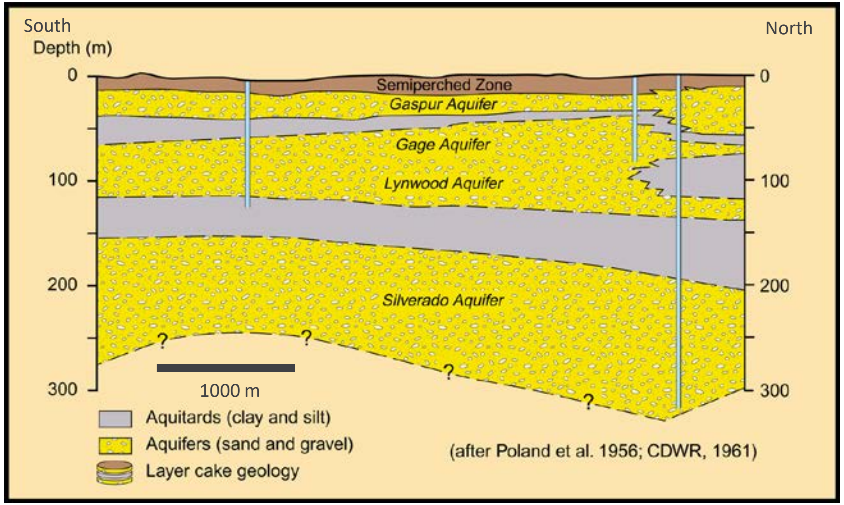
Dominguez Gap Barrier Project

Dominguez Gap Barrier Project

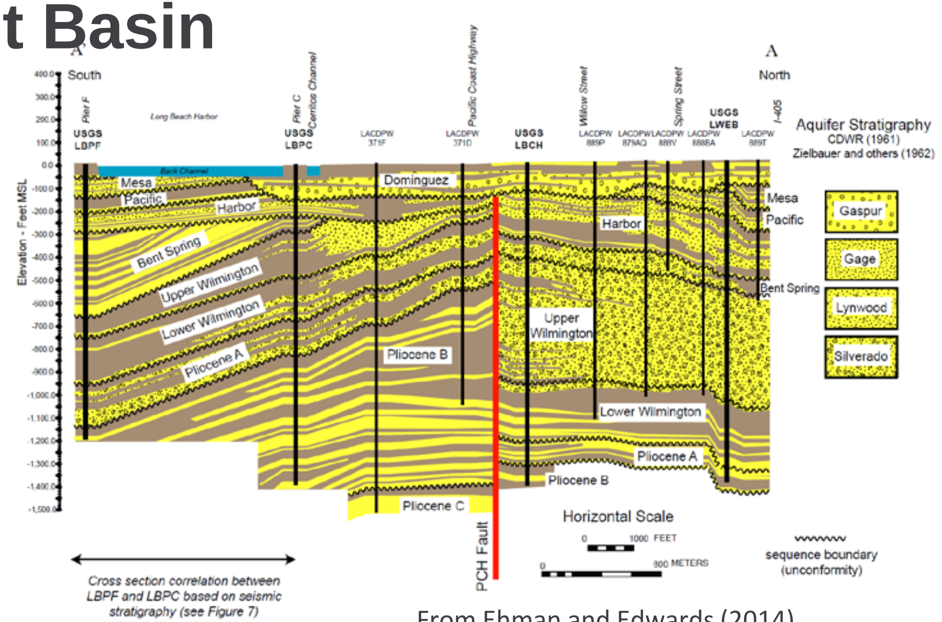




Dominguez Gap Seawater Intrusion Barrier, West Coast Basin



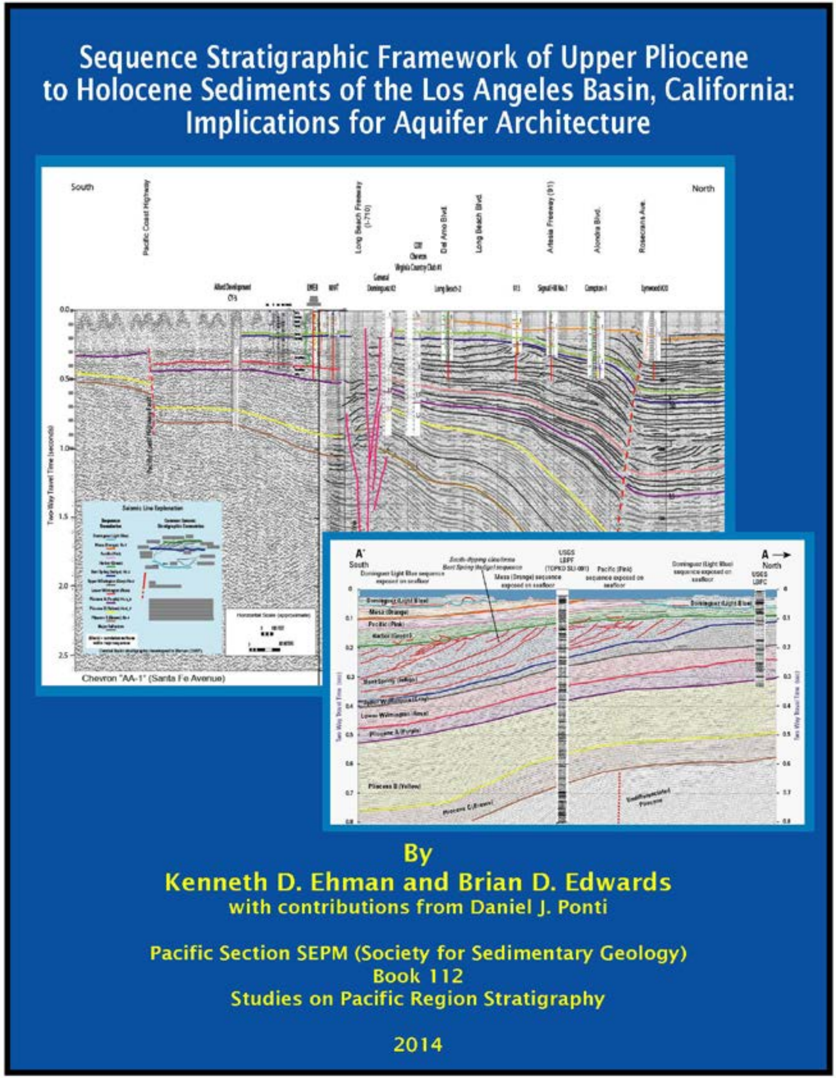
Layer Cake aquifer stratigraphy:
continuous layers



From Ehman and Edwards (2014)

Aquifer architecture is much more complicated than previously understood. Implications for

- Seawater intrusion pathways
- Contaminant migration pathways



Sequence Stratigraphic Framework of Upper Pliocene to Holocene Sediments of the Los Angeles Basin, California: Implications for Aquifer Architecture

By

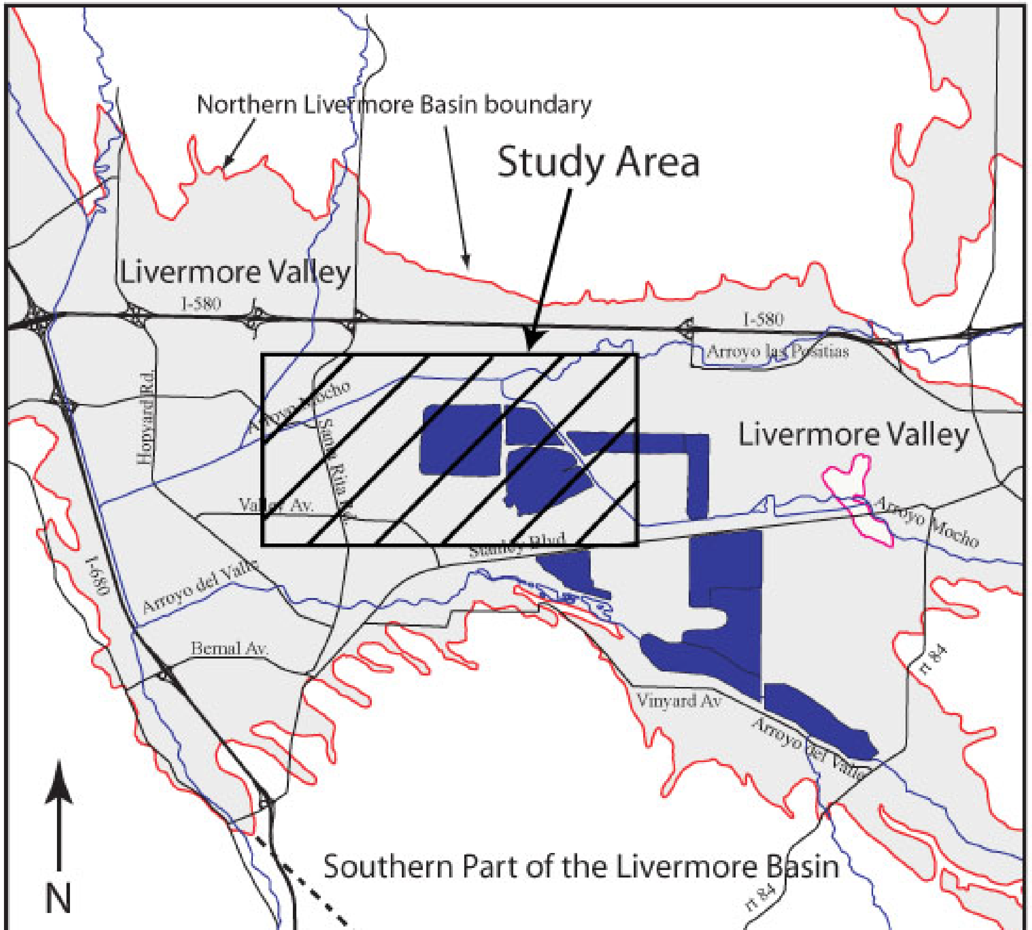
Kenneth D. Ehman and Brian D. Edwards

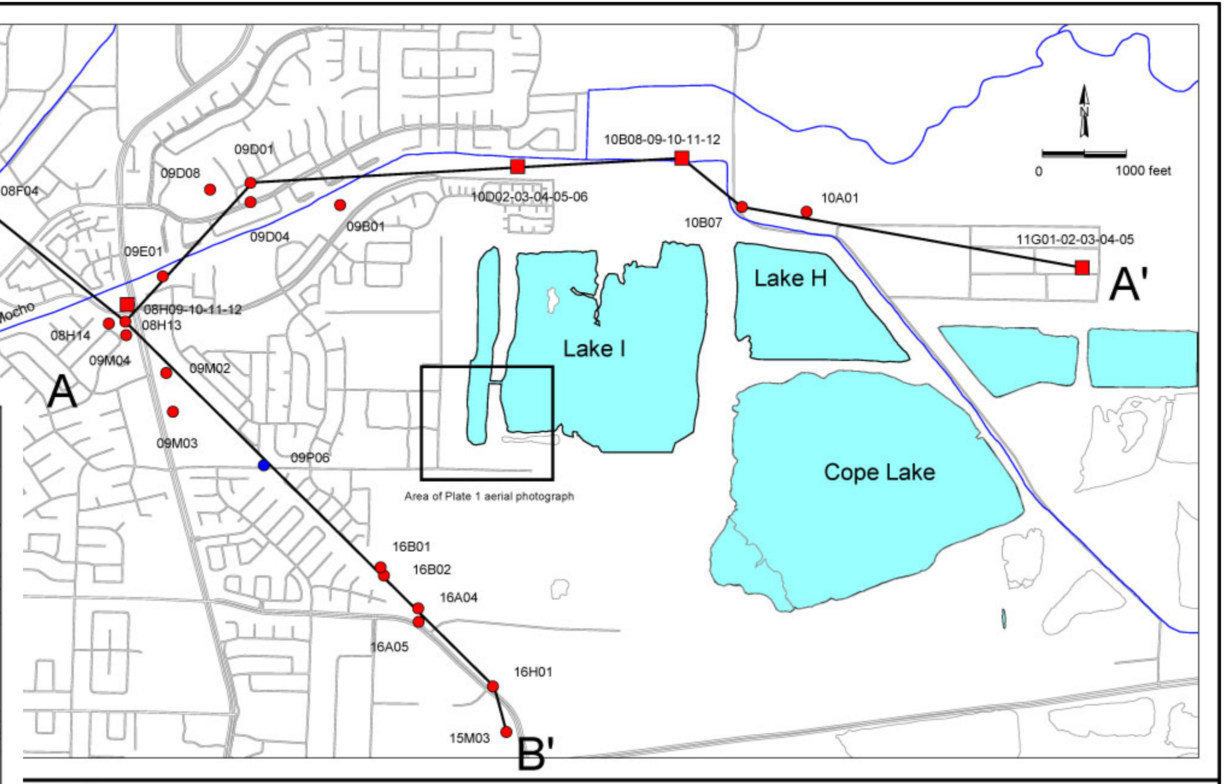
with contributions from Daniel J. Ponti

Pacific Section SEPM (Society for Sedimentary Geology)
Book 112
Studies on Pacific Region Stratigraphy

2014

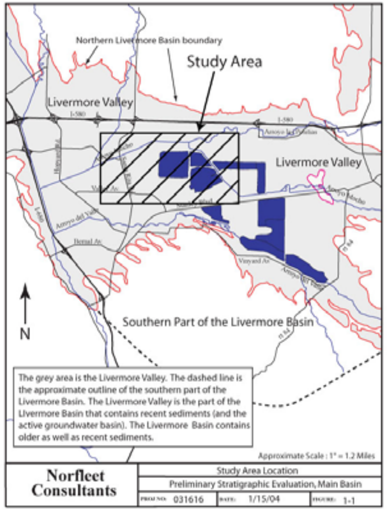
Livermore Groundwater Basin - Zone 7 Water Agency





n investigation
Cluster
ed in investigation

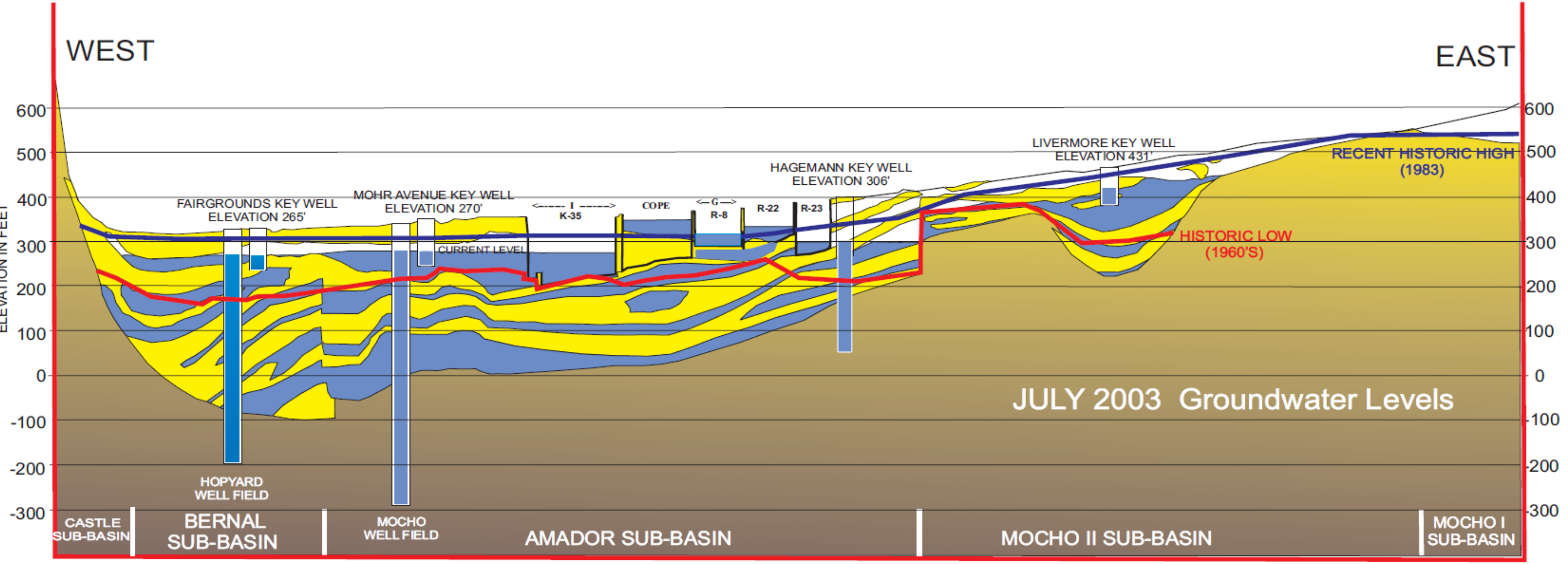
Figure 4-1. Main Stratigraphic Evaluation Area

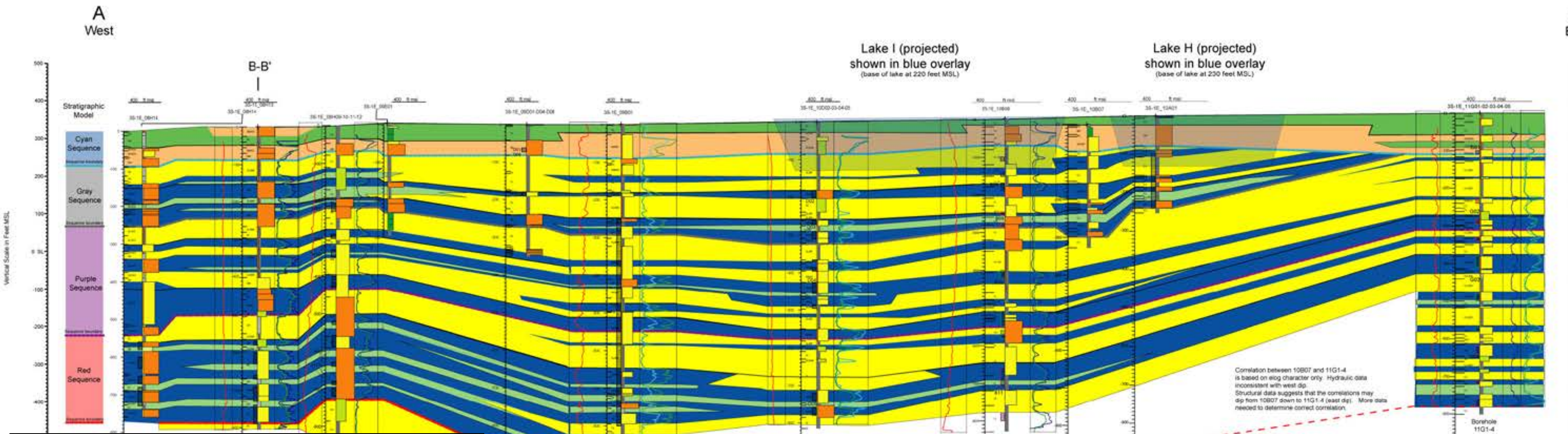


The grey area is the Livermore Valley. The dashed line is the approximate outline of the southern part of the Livermore Basin. The Livermore Valley is the part of the Livermore Basin that contains recent sediments (and the active groundwater basin). The Livermore Basin contains older as well as recent sediments.

Norfleet Consultants
Study Area Location
Preliminary Stratigraphic Evaluation, Main Basin
PROJ NO: 031616 DATE: 1/15/04 FIGURE: 1-1

LIVERMORE-AMADOR VALLEY GROUNDWATER BASIN
WEST-EAST CROSS-SECTION





Correlation between 10B07 and 11G1-4 is based on elog character only. Hydraulic data inconsistent with west dip.
Structural data suggests that the correlations may dip from 10B07 down to 11G1-4 (east dip). More data needed to determine correct correlation.

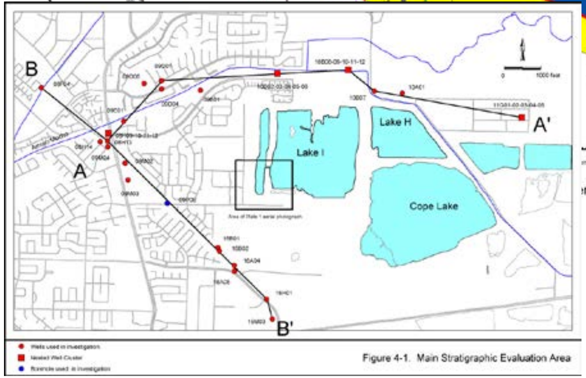


Figure 4-1. Main Stratigraphic Evaluation Area

3000 4000 5000

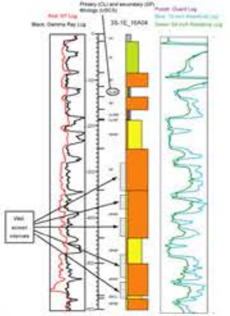
Approximate Horizontal Scale in Feet

Vertical Exaggeration

Explanation

Major Generalized Stratigraphic Facies

- 🟩 Overbank and lacustrine clays and silts (aquitard facies) exposed at Lake I.
- 🟧 Fluvial gravels ("Carol's Cut Gravel") (aquifer facies) exposed at Lake I.
- 🟩 Fluvial overbank and floodplain clays and silts (aquitard facies). May include lacustrine facies.
- 🟦 Fluvial and deltaic(?) sands and gravels (aquifer facies)
- 🟨 Regional correlative lacustrine clay and silt units (aquitard facies). May include floodplain and overbank



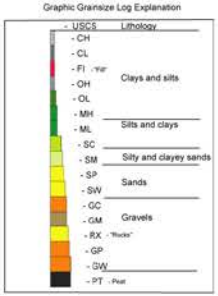


Plate 3.
Cross Section A-A' Chain-of-
Livermore Valley

Zone 7 Water Agency

Stratigraphic Interpretation by
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