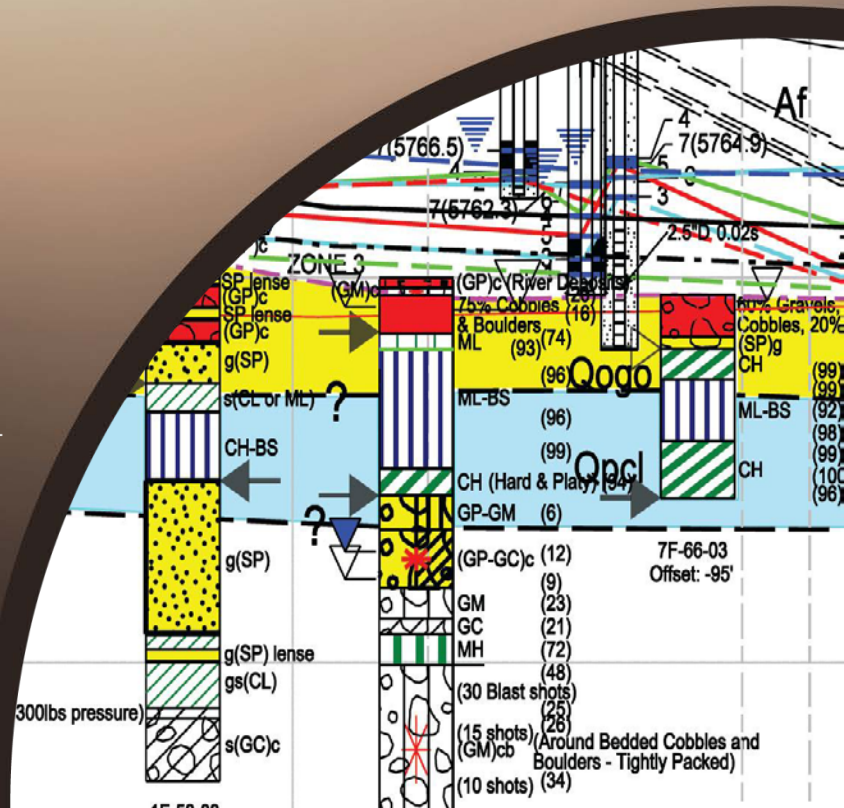
Best Practices in Dam and Levee Safety Risk Analysis

I-2. Geologic and Geotechnical Information Needed for Risk Analysis

16 Nov 2012



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Managing Water in the West

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Outline

- Collaboration of Geologists and Geotechnical Engineers
- What is needed from the geologists
- Road map to the Best Practice Chapter
- Some lessons learned on recent projects
- Tying geologic evaluations to potential failure modes, event trees and risk estimates
- Types of data evaluated and why
- The iterative process

Geologist's Dam Safety Function

- Study, explore, understand, portray and communicate the engineering properties of the dam foundation in the context of the geologic setting and key questions for risk analysis
- Working with geotechnical engineers, help develop products to help transfer knowledge to risk assessment teams, reviewers and decision-makers
- Stay involved and help risk teams interpret conditions and make difficult estimates

Most of our dam problems and risks are related to geology

- **We need geologic help:**
  - **Reviewing**, understanding and summarizing existing data **(SYNTHESIZING)**
  - **Separating** out the **RELEVANT** data
  - **THINKING** about potential failure modes and using subsurface data to help estimate performance and risk
  - **Applying Knowledge** of Geomorphology, sedimentation and stratigraphy to characterize depositional environments and infer continuity
  - **Creating** detailed **plan and section drawings** to display and summarize material properties and instrumentation data

Chapter 10. Evaluating, Understanding and Portraying Subsurface Data and Geologic Environments for Dam and Levee Safety

- Philosophy and Iterative Approach
- Data Evaluation and Summary Process
- Foundation Data Requirements for failure modes associated with embankment dam foundation Seepage
- Drawings necessary to summarize and communicate foundation and embankment material properties and behavior
  - Developing detailed cross sections to depict geology, material properties and instrumentation response
  - Developing detailed plan maps

Chapter 10. Evaluating, Understanding and Portraying Subsurface Data and Geologic Environments for Dam and Levee Safety

- Analysis and use of construction photographs
- Geomorphology for dam and levee foundation evaluations
- Evaluation of seepage and piping in karst terrain
- Mineral Extraction Failure Modes
- Important Reading for All Engineering Geologists
- Geologic Resources for Dam and Levee Geology Drawings
- National Geology and Mapping Resources

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We Have an Abundance of Data but a Lack of Knowledge

- Geologists need to focus on answering critical questions
- The key questions should be developed through collaboration with geotechnical engineers
- Report writing and drawing development needs to be focused on the potential failure modes
- Geologists need to stay involved throughout the process to help assure the information is used appropriately

Attributes of the successful geologist in dam and levee safety

- Must understand many different potential failure modes
- Must understand the properties that govern the risk estimates for various nodes in the event tree
- Must understand the basics of geology AND engineering, especially soil and rock mechanics
- Must continually learn and become an astute observer
- Must be genuinely excited to solve problems and puzzles
- Must have good imagination and the mind of a detective
- Must have skills to SORT data and create geologic drawings to portray foundation properties
- **MUST KNOW WHAT IS IMPORTANT and NECESSARY to evaluate foundations and solve engineering problems**
- **Must have excellent communication skills**

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Essential collaboration between engineering geologists and geotechnical engineers

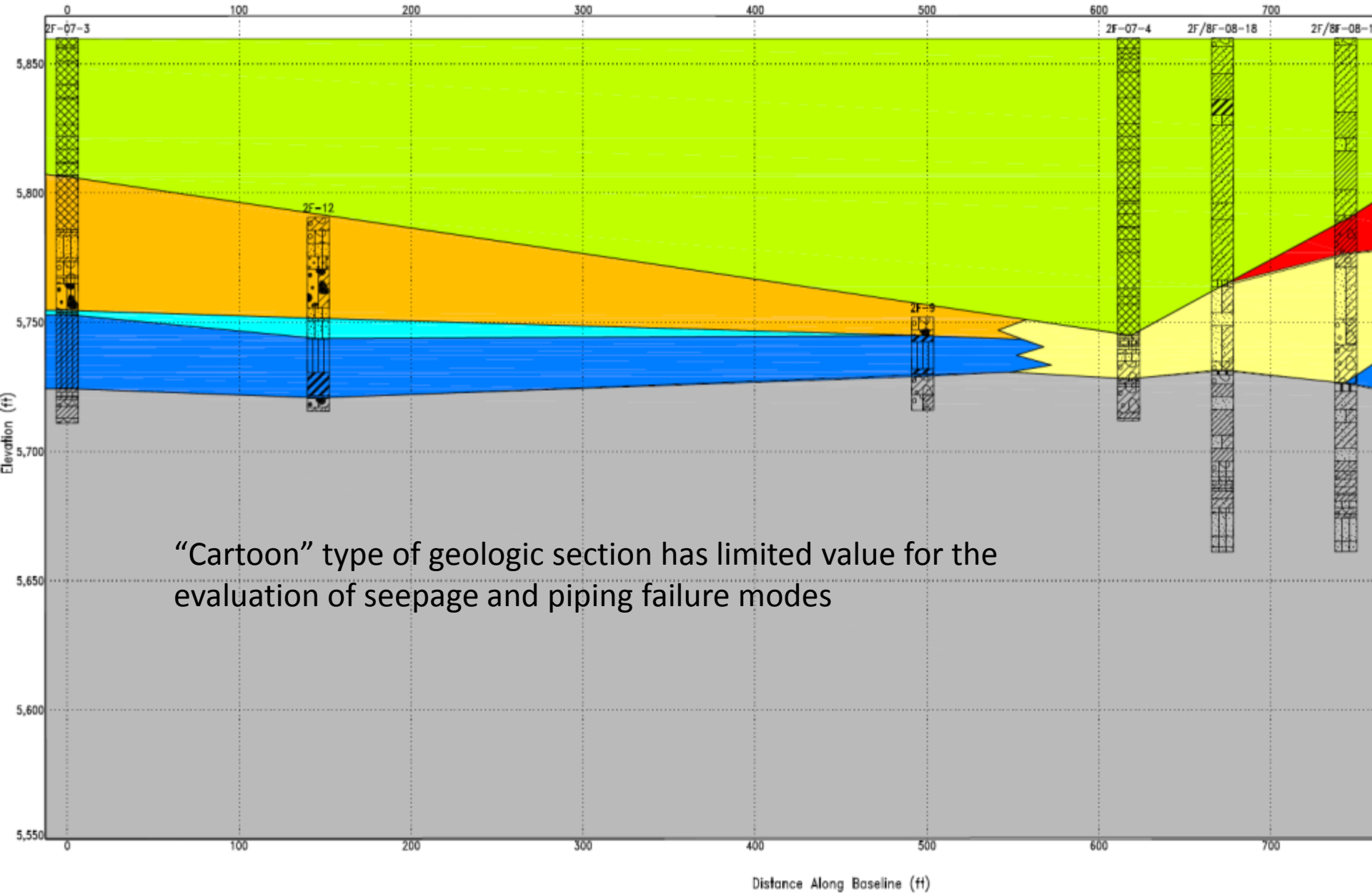
- The most important questions about the foundation performance must be defined before work begins
- The knowledge of depositional environments that help estimate material continuity must be communicated
- The drawing requirements need to be agreed on, what properties are critical, etc. (Scope of Work!)
- Knowledge and methods of soil or rock engineering analysis should be shared as a learning opportunity
- Geologists need to stay involved throughout the analysis to understand how the data are used
- Uncertainty in subsurface drawings requires continual dialog
- There is no clear line between geotechnical engineering and engineering geology, roles must be agreed upon

Lessons Learned on Many Projects

- Data must be sorted, understood, summarized to support risk estimates.
- The PROCESS of assembling the information and developing detailed drawings leads to a much better understanding of foundation conditions.
- Failure to review and assimilate soil, rock and instrumentation data into a set of meaningful drawings wastes hours and sometimes days during analysis, meetings, and reviews and often leads to erroneous conclusions.
- Can’t do evaluation without a detailed plan map and sections
- Can’t understand projected performance without detailed instrumentation evaluation

Lessons Learned on Many Projects

- For detailed Issue Evaluation Risk Analysis, must take the time (sometimes months) to read data and pull together complete information to support conclusions and estimates
- The sharing of ideas, observations, interpretations and disagreements amongst a highly functioning team is critical to increasing understanding and arguing the case
- Cannot fabricate geologic models without substantiating interpretation
- Can’t understand the truth without reading and understanding the project history, including past analyses
- The most important questions must be asked first before diving into the enormous available data in order to guide the sorting process.

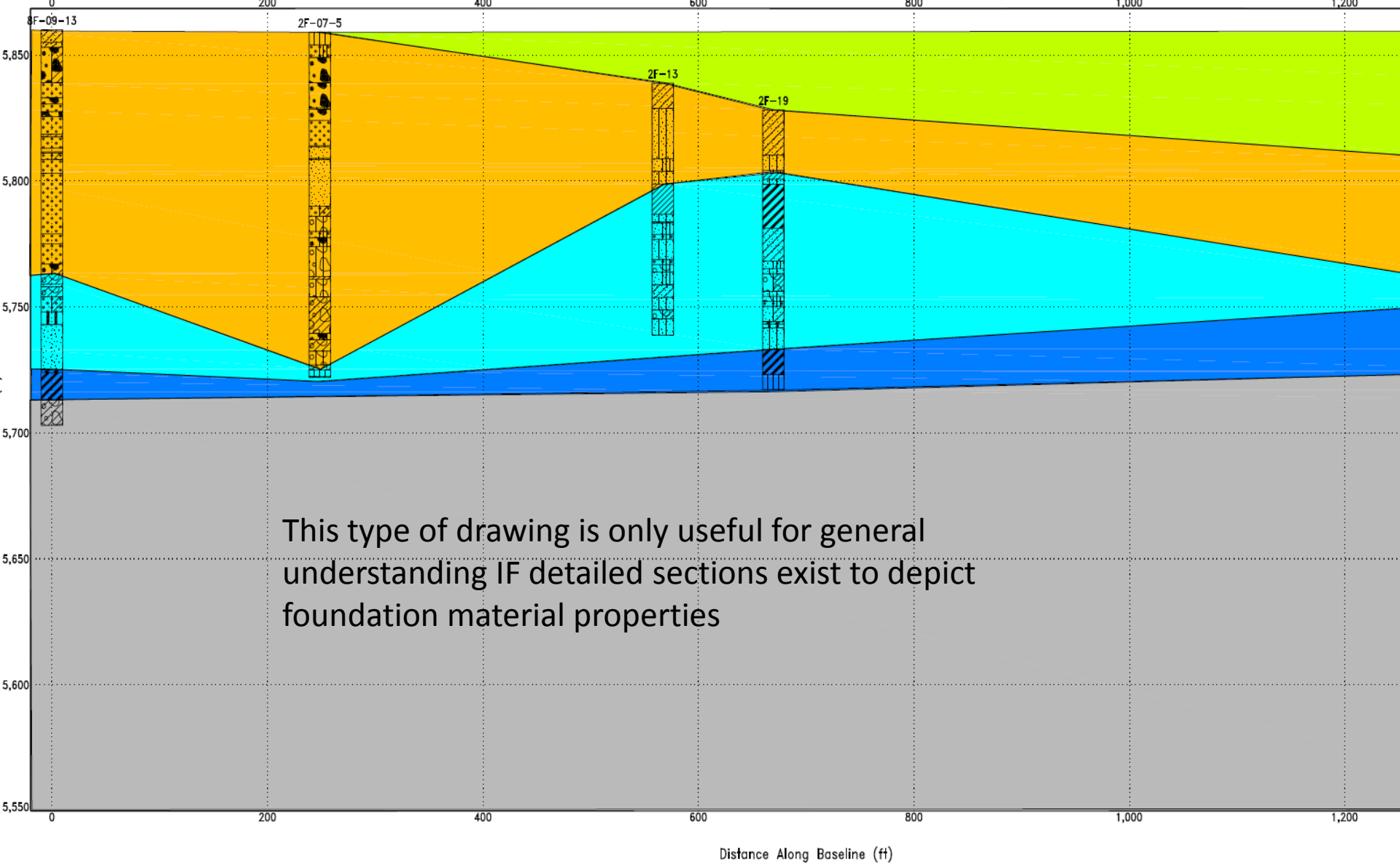


"Cartoon" type of geologic section has limited value for the evaluation of seepage and piping failure modes

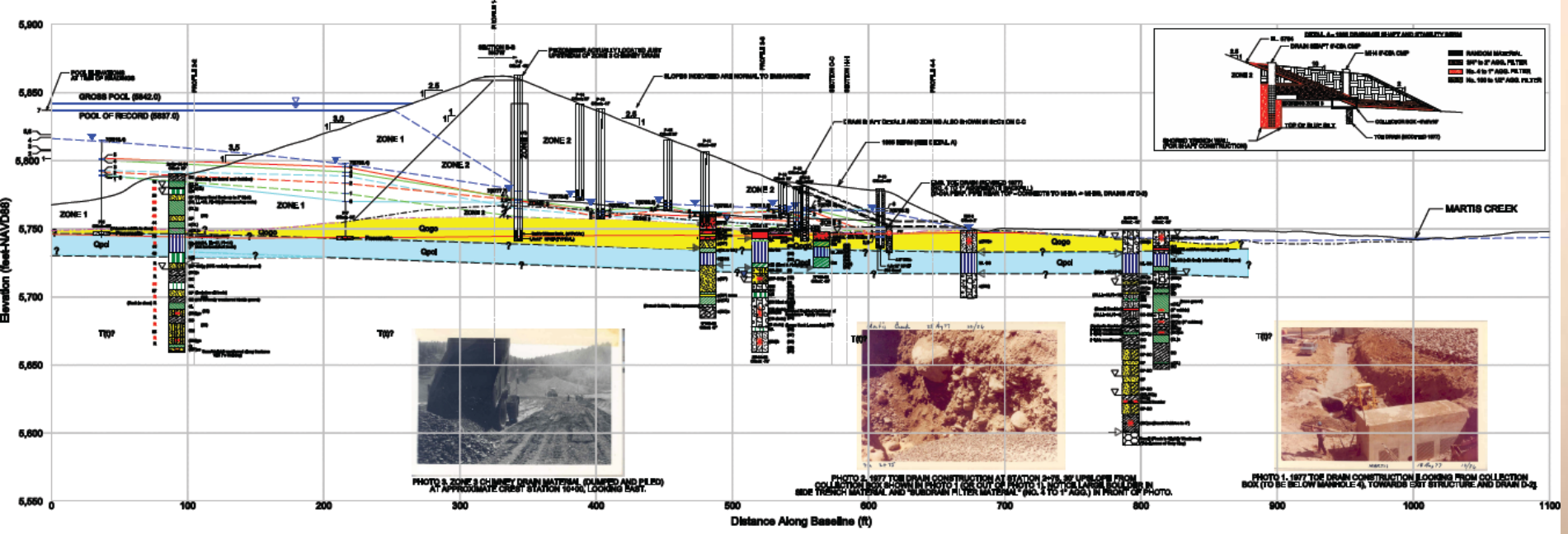
Artifical Fill
Colluvium
Older Alluvium
Donner Lake Outwash
Prosser Creek Formation Fluvial / Lacustrine Member
Prosser Creek Formation Lacustrine Member
Truckee Formation (?)

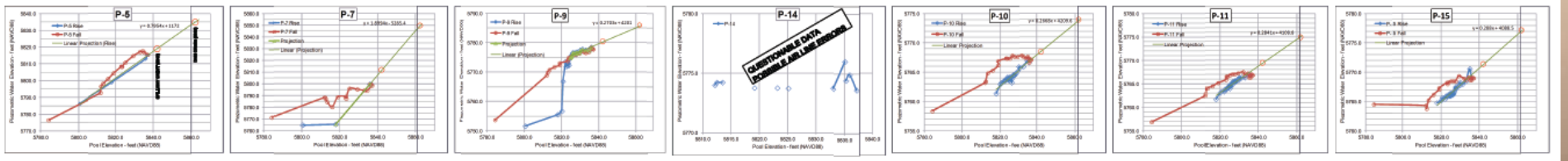
LITHOLOGY GRAPHICS

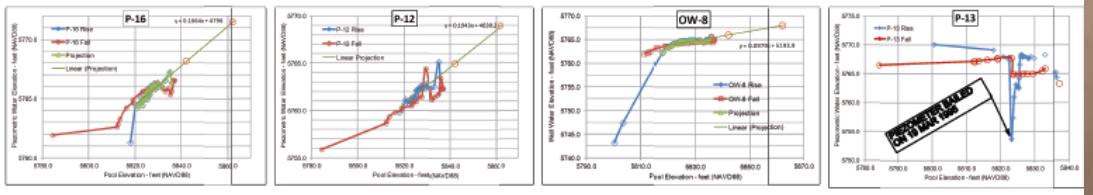
USCS Low Plasticity Sandy Clay
USCS Poorly-graded Gravel
USCS Clayey Sand
USCS Clayey Gravel
USCS Silt
USCS Silty Sand
USCS Poorly-graded Sand
USCS Well-graded Sand
USCS Low Plasticity Clay
USCS Poorly-graded Sandy Gravel
Basalt



This type of drawing is only useful for general understanding IF detailed sections exist to depict foundation material properties







GEOLOGIC UNITS (BY AGE):

- Qogo - Donner Lake Outwash - Sand, gravels, cobbles, and boulders.
- Qpcl - Prosser Creek Formation - Lacustrine member, Silts and Clays (including 'Blue/Gray Silt').

TEST FILLINGS

NO.	YEAR	MAXIMUM POOL ELEVATION (FT)	POOL ELEVATION AT TIME OF READING (FT)	LINE STYLE
1 -	1973	5803.8, 10 APRIL	5801a, 12aAPRIL	
2 -	1974	5809.0, 2 APRIL	5803.7, 3 APRIL	
3 -	1976	5807.6, 6 JUNE	5807.6, 2 JUNE	
4 -	1986	5816.7, 3 JUNE	5816.6 6 JUNE	
5 -	1980	5819.2, 11 MAY	5816.6, 14 MAY	
7 -	1995	5837.0, 15 MAY	5836.5±, 15±MAY	
		NON-TEST FILLING		
6 -	1997	5819.5, 5 JAN.	5816.6, 7 JAN.	

NOTE: NUMBERING BASED ON POOL ELEVATION AT TIME OF READING. IF A NUMBER IS NOT SHOWN FOR A PARTICULAR PIEZOMETER, THAT MEANS IT WAS DRY FOR THAT READING OR READING WAS NOT AVAILABLE.

SURFACES

- TOP OF GROUND SURFACE (2005 - LIDAR)
- FOUNDATION GROUND SURFACE (1970-1972)
- PIEZOMETRIC SURFACE FOR POOL OF RECORD - 15 MAY 1995 (BASED ON PIEZOMETER READINGS)
- ESTIMATED BOTTOM OF DONNER LAKE OUTWASH BASED UPON INTERPOLATED GEOPHYSICAL RESISTIVITY CONTRAST DATA.
- CONDUIT EXCAVATION SURFACE (PLATE III - NOV 1972 FDN REPORT)
- PIEZOMETER OR WELL READINGS FOR POOL OF RECORD

NOTES

1. CLOSED PIEZOMETERS (P-6 & P-7) APPEAR TO BE MALFUNCTIONING FOR FILLING # 6???
2. PIEZOMETER AND OBSERVATION WELL CHARTS ARE FOR THE 1995 TEST FILLING.

KEY DATES AND POOL ELEVATIONS INCLUDE:

8 FEB 1995	5800.5
11 MAR 1995	5817.9
15 MAY 1995	5837.0 (PEAK - POOL OF RECORD)
22 AUG 1995	5811.3
6 OCT 1995	5784.2 (MIN. POOL)

- WATER ENCOUNTERED DURING DRILLING
- WATER LEVEL AFTER A PERIOD OF 12 HRS OR MORE
- FORMATION CONTACT IDENTIFIED IN THE FIELD
- FORMATION CONTACT FROM OFFICE EVALUATION OF BOREHOLE LOGS

GEOLOGIC CONTACTS MAY NOT COINCIDE WITH EACH BORING DUE TO PROJECTION OF BORING ONTO PROFILE.

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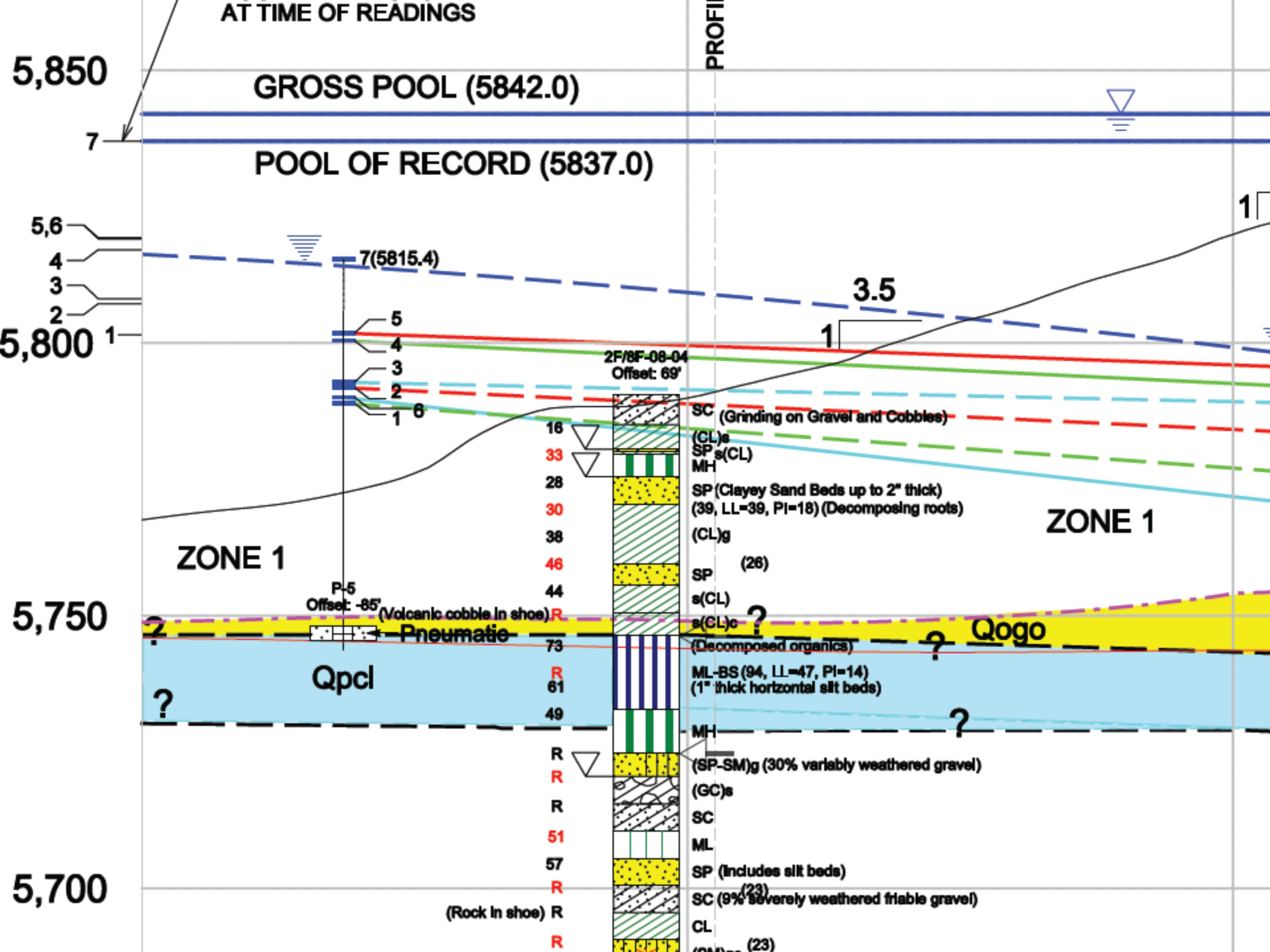
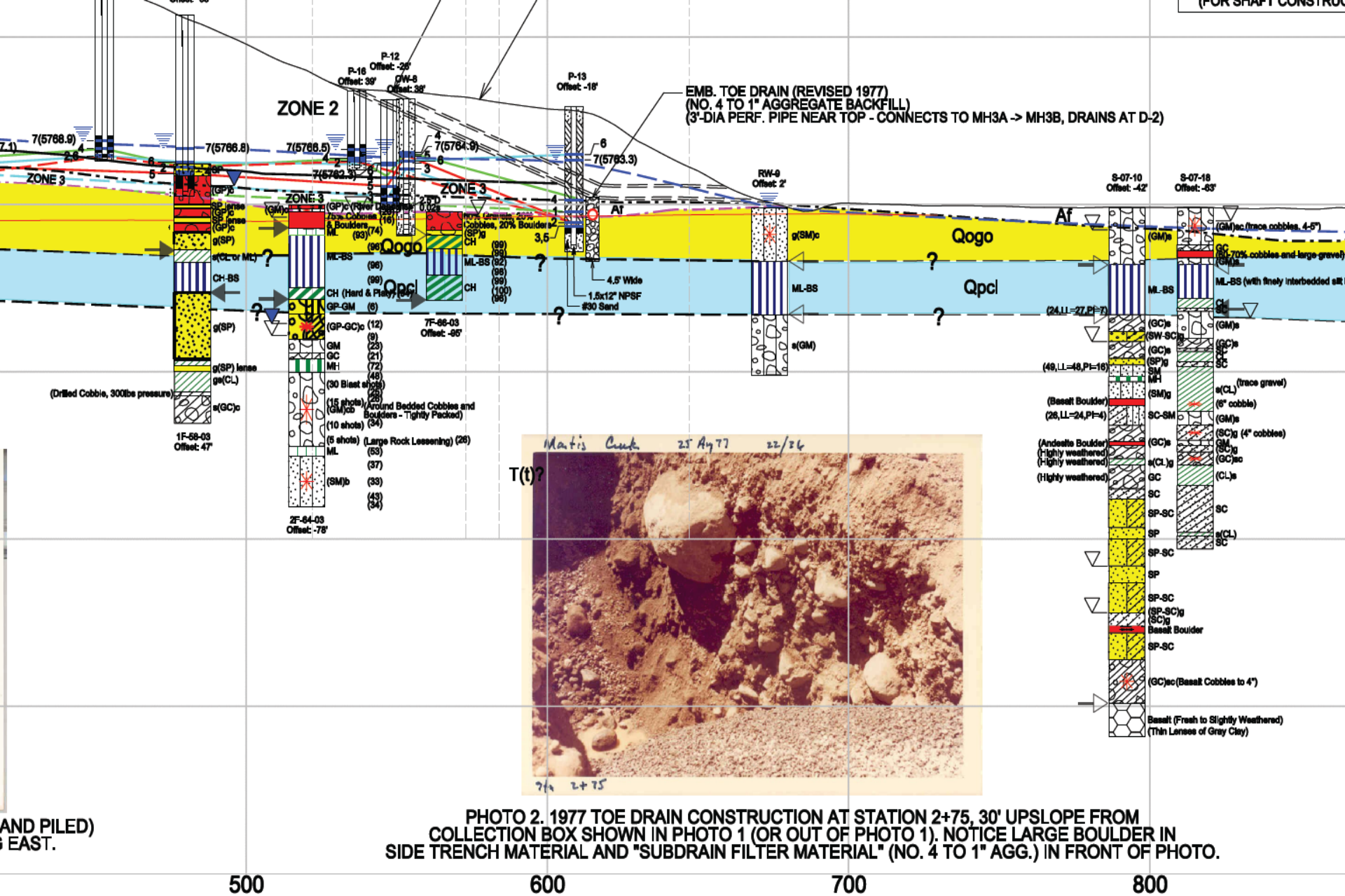
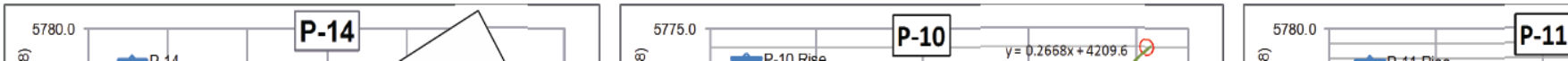
Same Project as previous slide

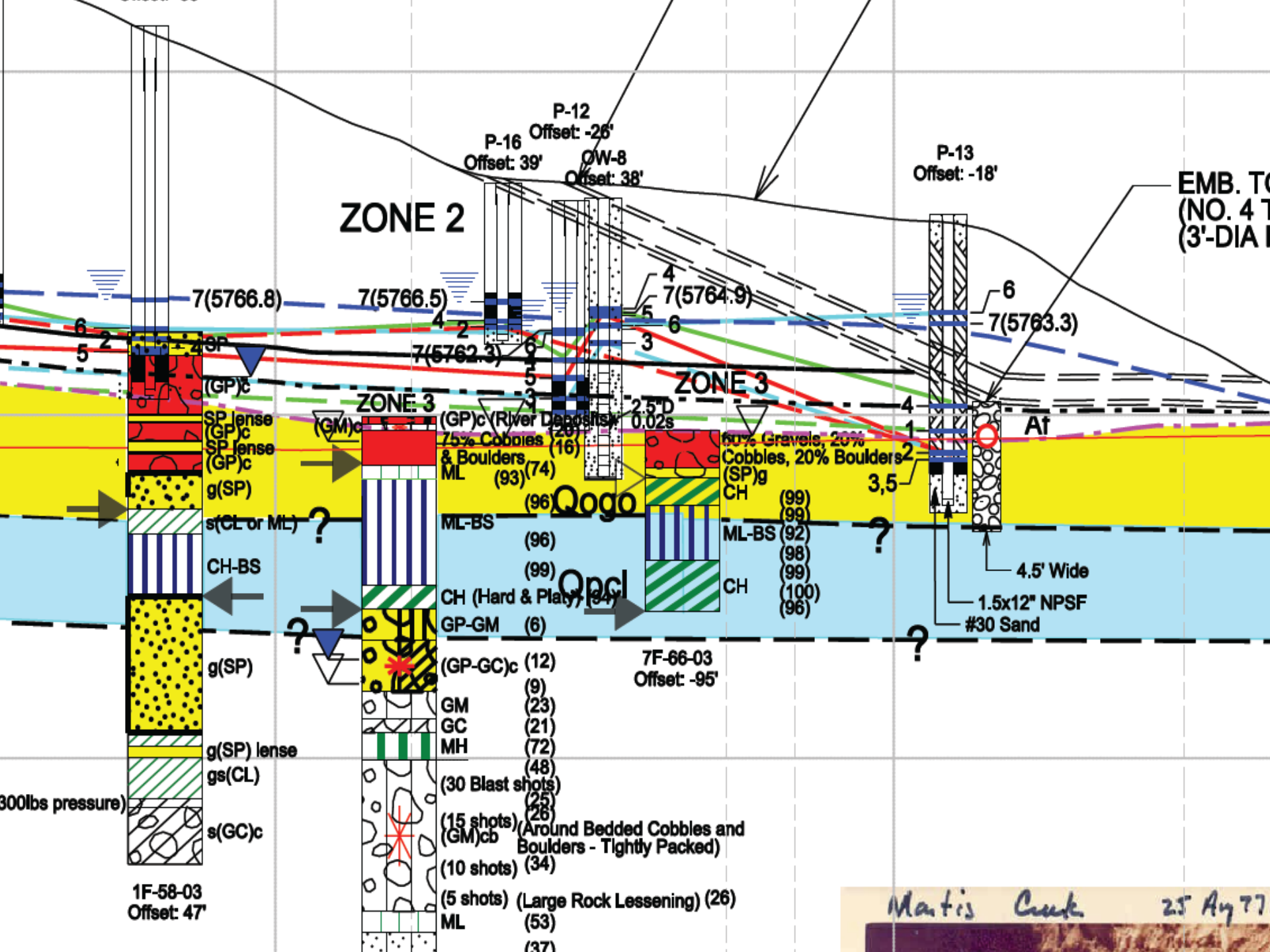

AT TIME OF READINGS
PROFI
5,850
GROSS POOL (5842.0)
7
POOL OF RECORD (5837.0)
5,6
4
3
2
5,800
1
7(5815.4)
5
4
3
2
1
6
3.5
1
1
2F/8F-08-04
Offset: 69'
SC (Grinding on Gravel and Cobbles)
16
(CL)s
33
SP s(CL)
MH
28
SP (Clayey Sand Beds up to 2" thick)
30
(39, LL=39, PI=18) (Decomposing roots)
38
(CL)g
ZONE 1
ZONE 1
46
SP
(26)
P-5
Offset: -85'
44
s(CL)
5,750
(Volcanic cobble in shoe) R
s(CL)c
?
Pneumatic
Qogo
73
(Decomposed organics)
?
?
Qpcl
R
ML-BS (94, LL=47, PI=14)
61
(1" thick horizontal silt beds)
?
49
?
MH
R
(SP-SM)g (30% variably weathered gravel)
R
(GC)s
R
SC
51
ML
57
SP (Includes silt beds)
5,700
R
(23)
SC (9% severely weathered friable gravel)
(Rock in shoe) R
CL
R
(23)

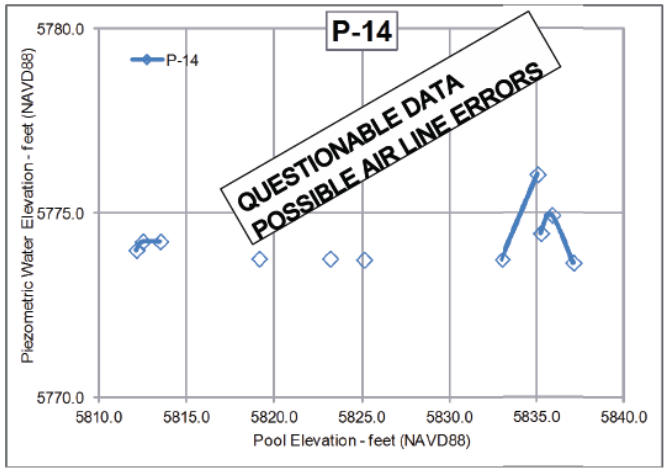


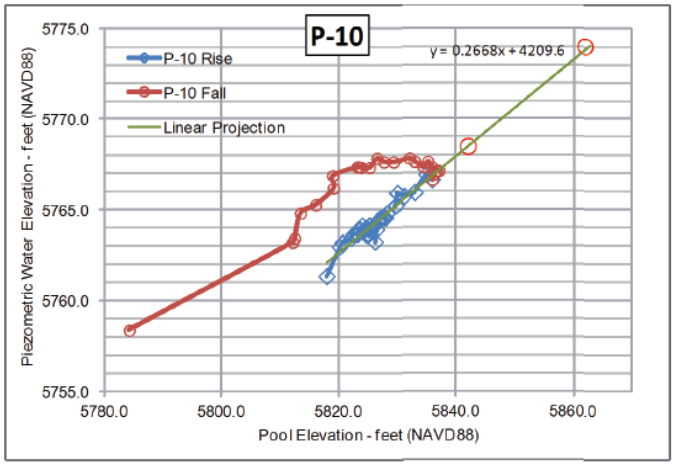
AND PILED)
G EAST.

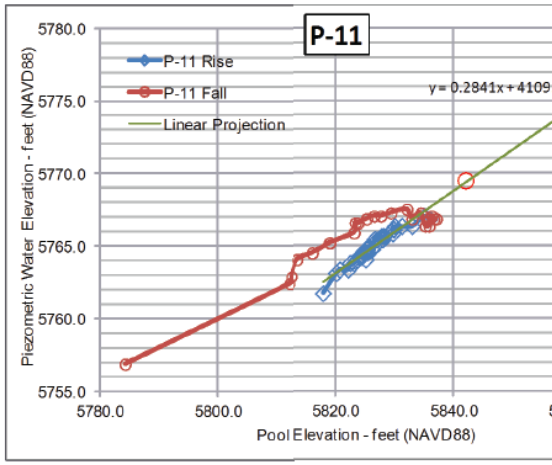
PHOTO 2. 1977 TOE DRAIN CONSTRUCTION AT STATION 2+75, 30' UPSLOPE FROM COLLECTION BOX SHOWN IN PHOTO 1 (OR OUT OF PHOTO 1). NOTICE LARGE BOULDER IN SIDE TRENCH MATERIAL AND "SUBDRAIN FILTER MATERIAL" (NO. 4 TO 1" AGG.) IN FRONT OF PHOTO.

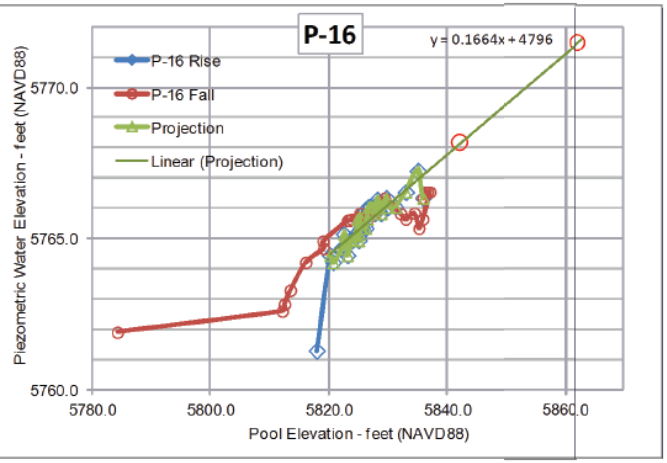


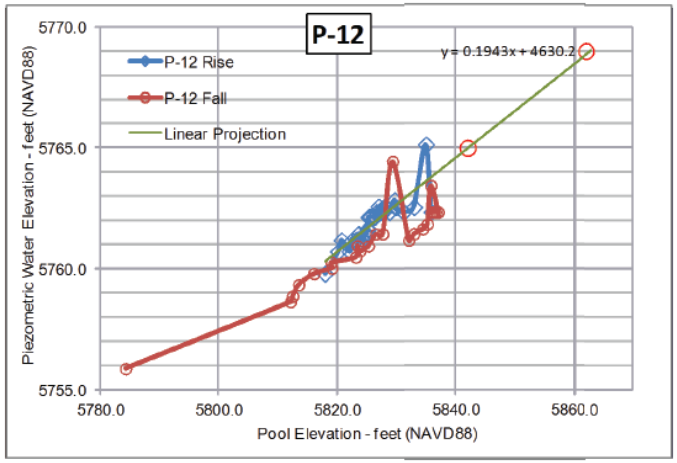

P-12
Offset: -26'
P-16
Offset: 39'
OW-8
Offset: 38'
P-13
Offset: -18'
EMB. T
(NO. 4 T
(3'-DIA
ZONE 2
ZONE 3
ZONE 3
7(5766.8)
7(5766.5)
7(5764.9)
7(5763.3)
7(5762.3)
SP
(GP)c
SP lense
(GP)c
SP lense
(GP)c
g(SP)
s(CL or ML)
CH-BS
g(SP)
g(SP) lense
gs(CL)
s(GC)c
300lbs pressure)
1F-58-03
Offset: 47'
(GM)c
(GP)c (River Deposits)
75% Cobbles
& Boulders
ML
ML-BS
CH (Hard & Platy)
GP-GM
(GP-GC)c
GM
GC
MH
(30 Blast shots)
(15 shots)
(GM)cb
(Around Bedded Cobbles and
Boulders - Tightly Packed)
(10 shots)
(5 shots)
(Large Rock Lessening)
ML
2.5"D
0.02s
Qogo
Qpcl
60% Gravels, 20%
Cobbles, 20% Boulders
(SP)g
CH
ML-BS
CH
7F-66-03
Offset: -95'
Af
4.5' Wide
1.5x12" NPSF
#30 Sand
Mattis Creek
25 Ag 77

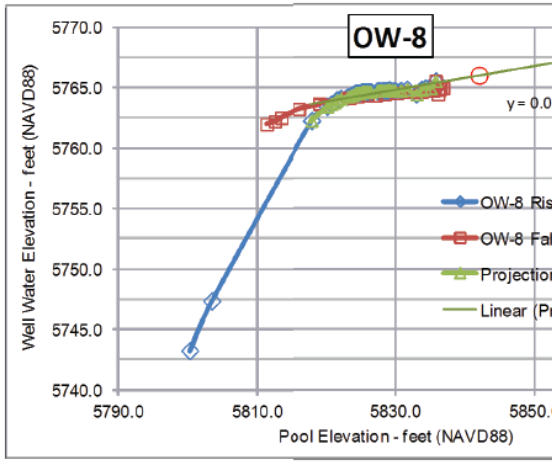

P-14
QUESTIONABLE DATA
POSSIBLE AIR LINE ERRORS
P-14
Piezometric Water Elevation - feet (NAVD88)
Pool Elevation - feet (NAVD88)


P-10
y = 0.2658x + 4209.6
P-10 Rise
P-10 Fall
Linear Projection
Piezometric Water Elevation - feet (NAVD88)
Pool Elevation - feet (NAVD88)


P-11
y = 0.2841x + 4109
P-11 Rise
P-11 Fall
Linear Projection
Piezometric Water Elevation - feet (NAVD88)
Pool Elevation - feet (NAVD88)


P-16
y = 0.1664x + 4796
P-16 Rise
P-16 Fall
Projection
Linear (Projection)
Piezometric Water Elevation - feet (NAVD88)
Pool Elevation - feet (NAVD88)


P-12
y = 0.1943x + 4630.2
P-12 Rise
P-12 Fall
Linear Projection
Piezometric Water Elevation - feet (NAVD88)
Pool Elevation - feet (NAVD88)


OW-8
Well Water Elevation - feet (NAVD88)
Pool Elevation - feet (NAVD88)

Example list from Best Practices Document

Material properties and descriptions of the embankment and/or foundation soils, including

- Gradations (graphs of all available lab results in dam and foundation)
- USCS classifications with plus 3 inch fraction include
- Plasticity
- Density
- Permeability and water loss zones from borehole drilling records
- Artesian pressures and confining layers
- Penetration data (SPT, CPT, Vane Shear, Becker Penetration Tests – drilling methods can influence results significantly)
- Cementation
- Dispersion potential

Title of bullet lists provided in Best Practices Document to Define Roles and Responsibilities

- Developing detailed cross sections to depict geology, material properties and instrumentation response
- Developing detailed plan
- Analysis and use of construction photographs
- Foundation Data Requirements for failure modes associated with embankment dam foundation Seepage
- Geologic descriptions of foundation soil properties and geomorphology
- Descriptions and properties of bedrock associated with seepage and piping
- Design and Construction Records related to seepage interception and control (original construction and subsequent modifications)
- Instrumentation data needed for risk analysis
- Consultant observations made throughout the history of the project

Where Geologists Need Help

- We struggle to depict materials using properties used in an engineering analysis
- This causes the geologic evaluation to be focused on geologic processes rather than differences in material properties
- The combined knowledge of both depositional processes and engineering properties can be critical to the evaluation.

What needs improvement?

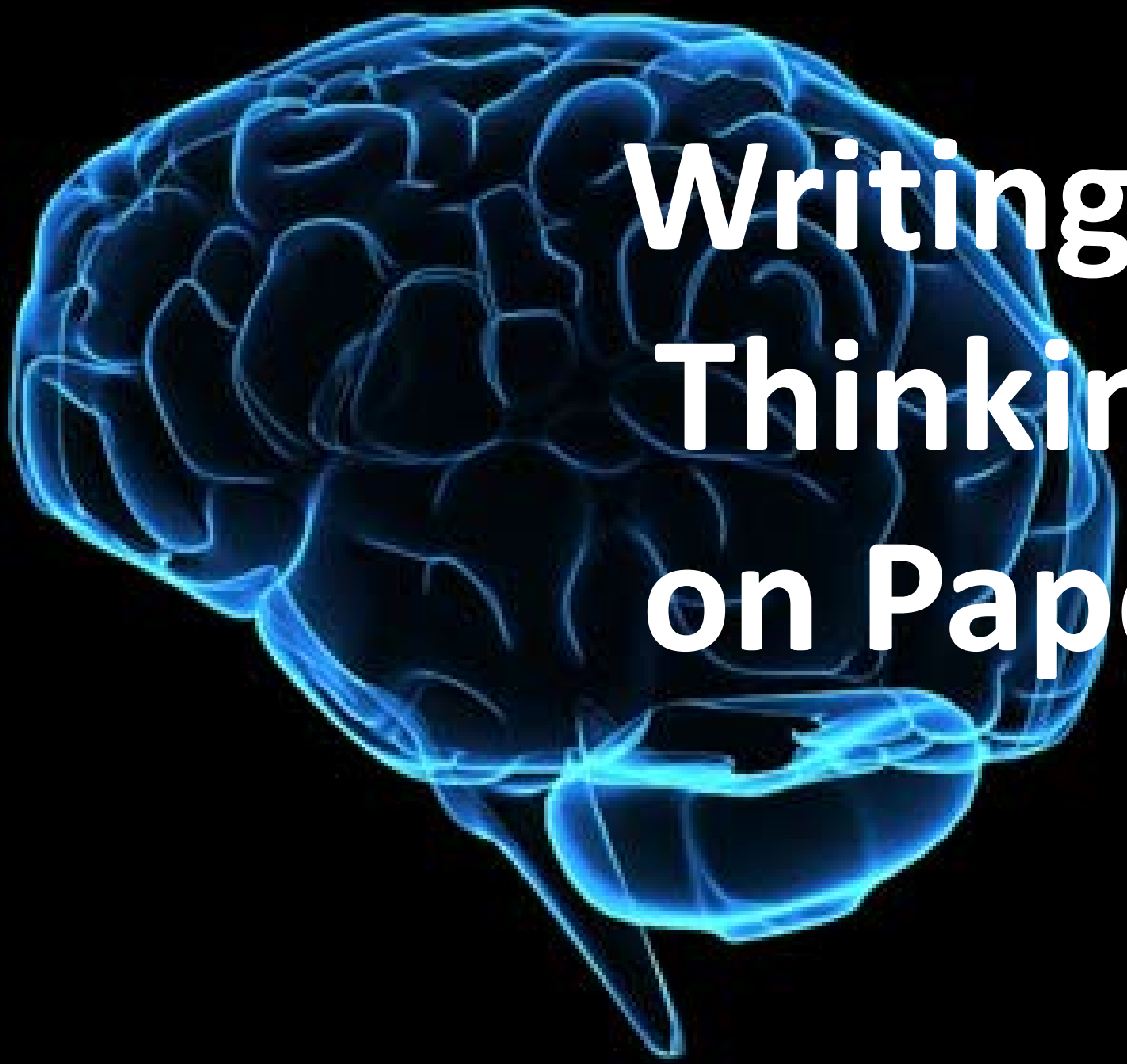
- We often struggle to create succinct and focused reports or drawings that tell the story of the potential failure modes and how existing information was used to estimate the risk.
- Our reporting is not taking advantage of geologic drawings, tables and figures that can help synthesize information.
- For some of our Risk Analysis meetings we are <u>not appropriately prepared</u> to discuss foundation material properties and geologic conditions as they relate to potential failure modes

Suggestions to improve the value of geologic input

- Start evaluating data (especially construction drawings and photographs) many months prior to risk analysis meetings,
- Work with and learn from geotechnical engineers to help understand potential failure modes and associated data requirements
- Define most critical questions tied to potential failure modes
- Update drawings to reflect best estimate of foundation conditions
- Assure all piezometer influence zones are plotted on the sections

Suggestions to Improve the Value of Geologic Input

- Assure detailed plots of piezometer response (and other data) are available. Review and understand these.
- Plot up the chronology of significant events in the history of the dam, including flood fighting, remedial actions, added drainage features, etc
- Assure plan map is available showing all exploration, instrumentation, useful geologic contacts and design details (toe drains, berms, blankets)
- Find all available lab gradations for foundation soils of concern
- Plot up highest recorded piezometer readings along with reservoir pool

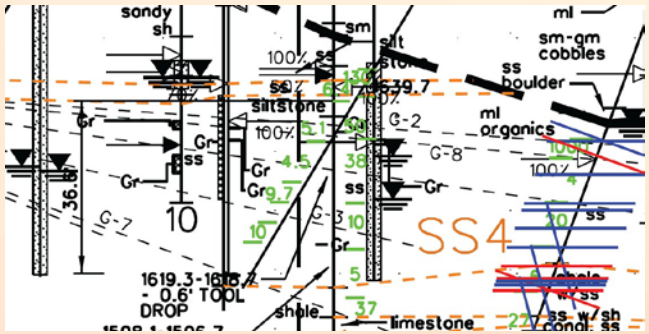


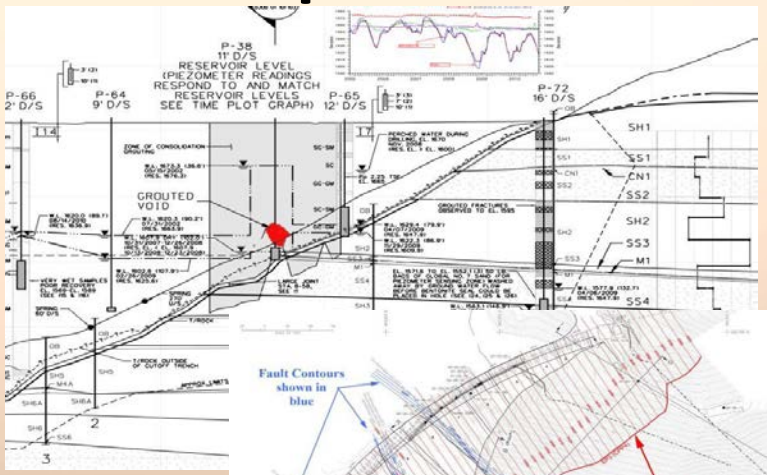
Writing is Thinking on Paper

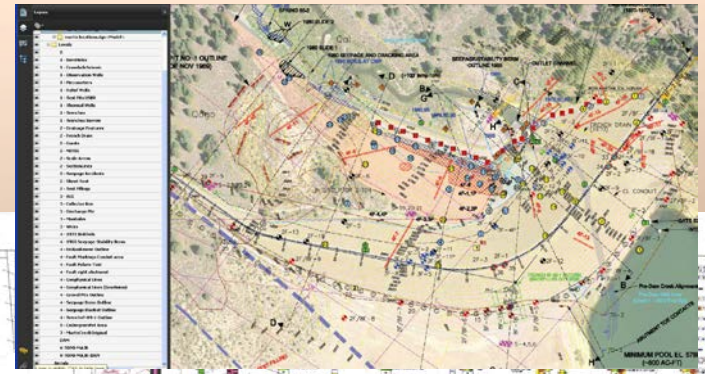
Examples of Important Questions

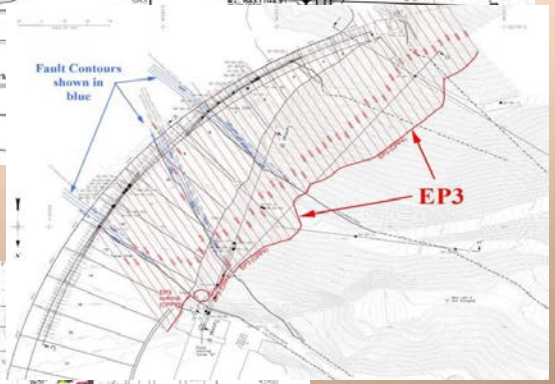
- Based on the depositional environment, what is the likelihood that erodible sands or silts are continuous from upstream to downstream?
- Based on the existing instrumentation performance, what are the estimated gradients along potential seepage paths?
- Are there construction photographs that can inform the estimates of foundation conditions or treatment?
- What did the designers and consultants write about the foundation conditions we are concerned with today?
- Are the drill hole samples representative of the range of conditions possible?

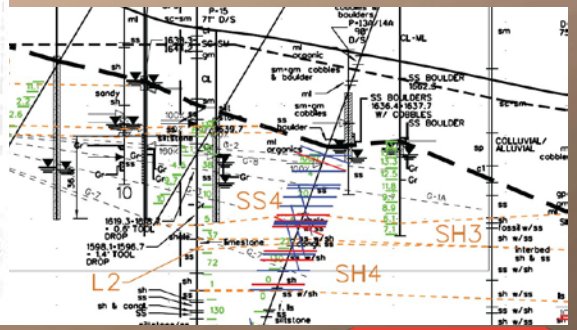
Some Good Example Drawings











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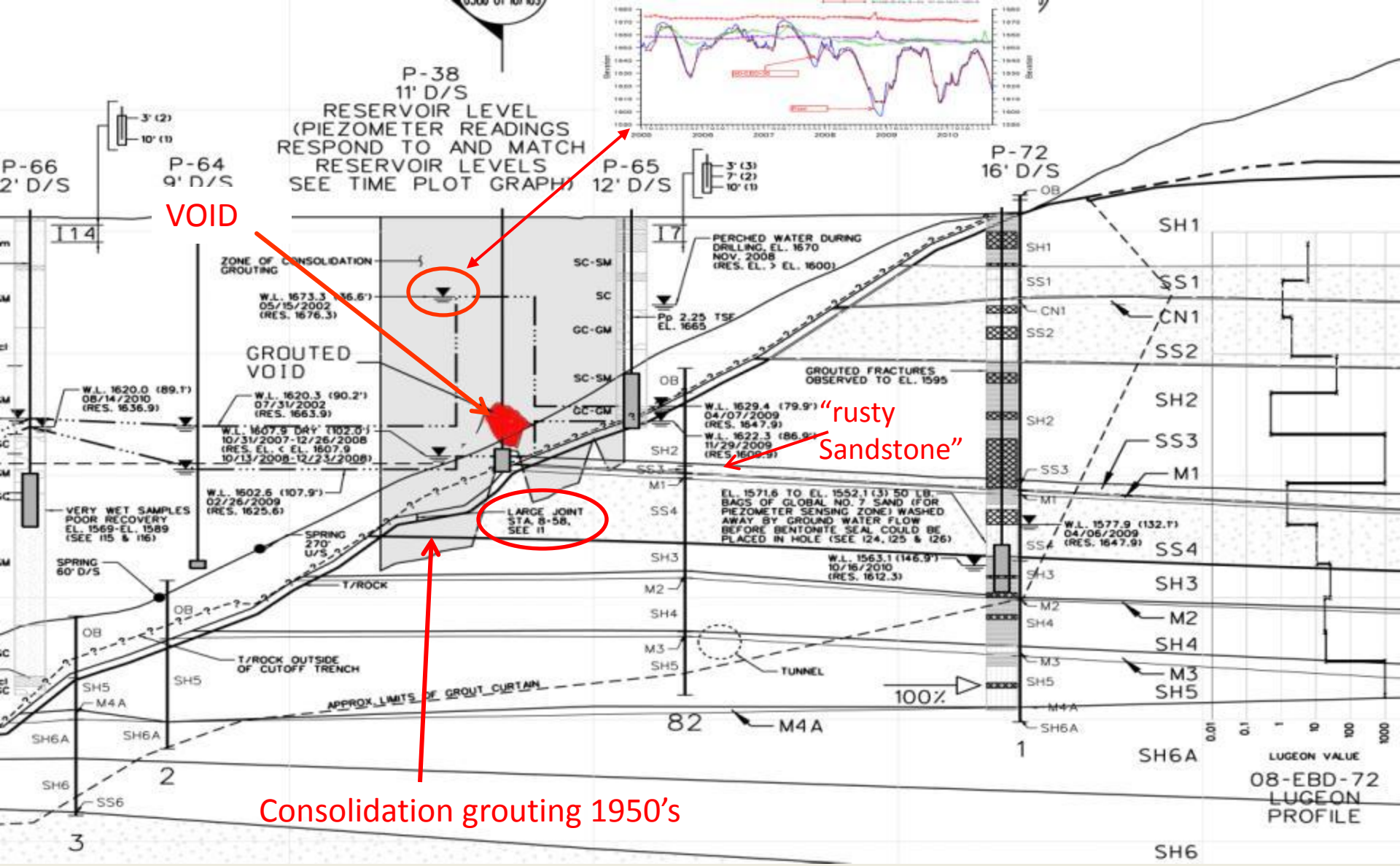
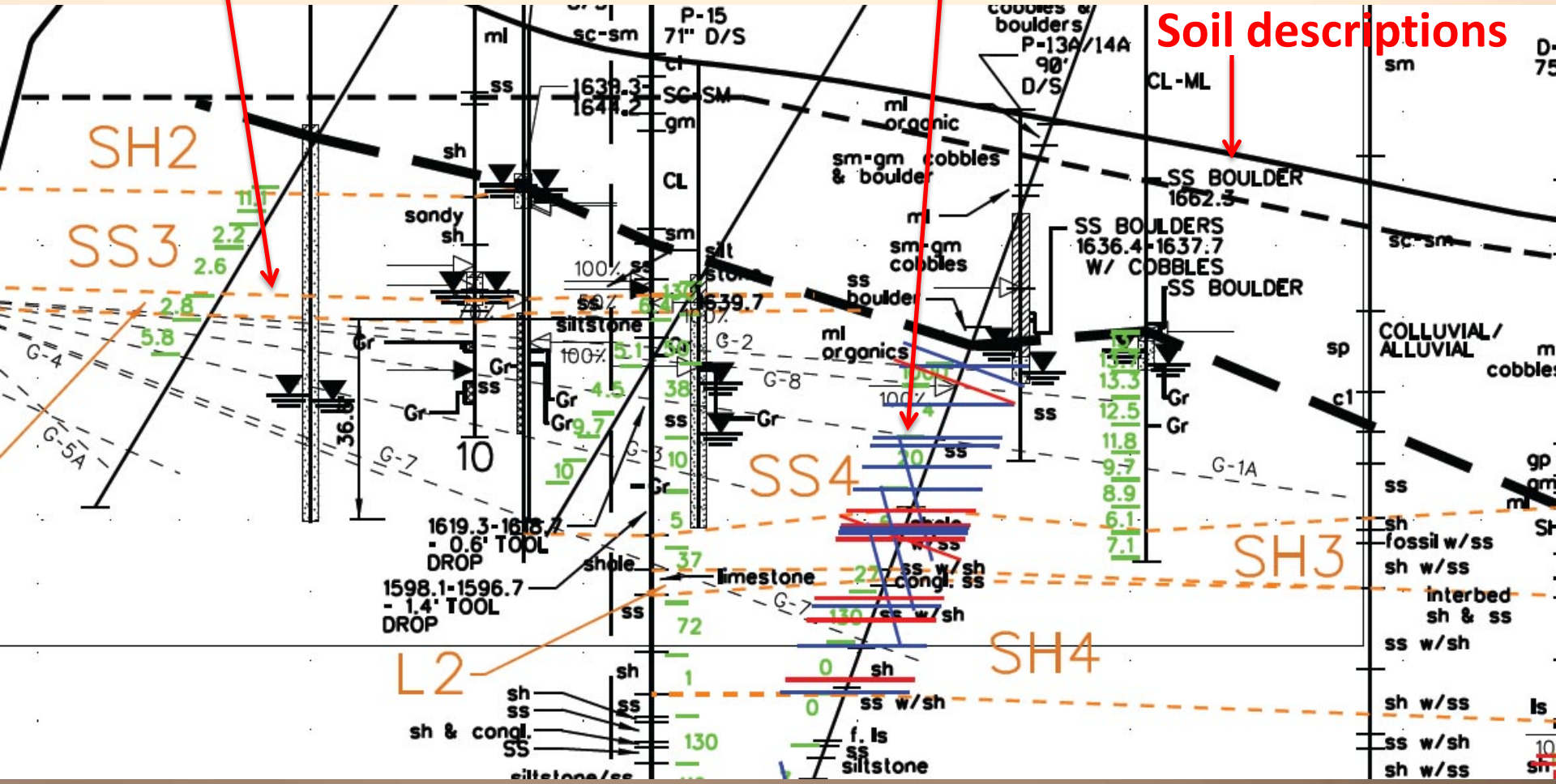


Geology, geotechnical engineering and instrumentation need to be integrated to focus on the same questions tied to failure modes

Old Grout Holes

Bedrock Discontinuity dip

Soil descriptions



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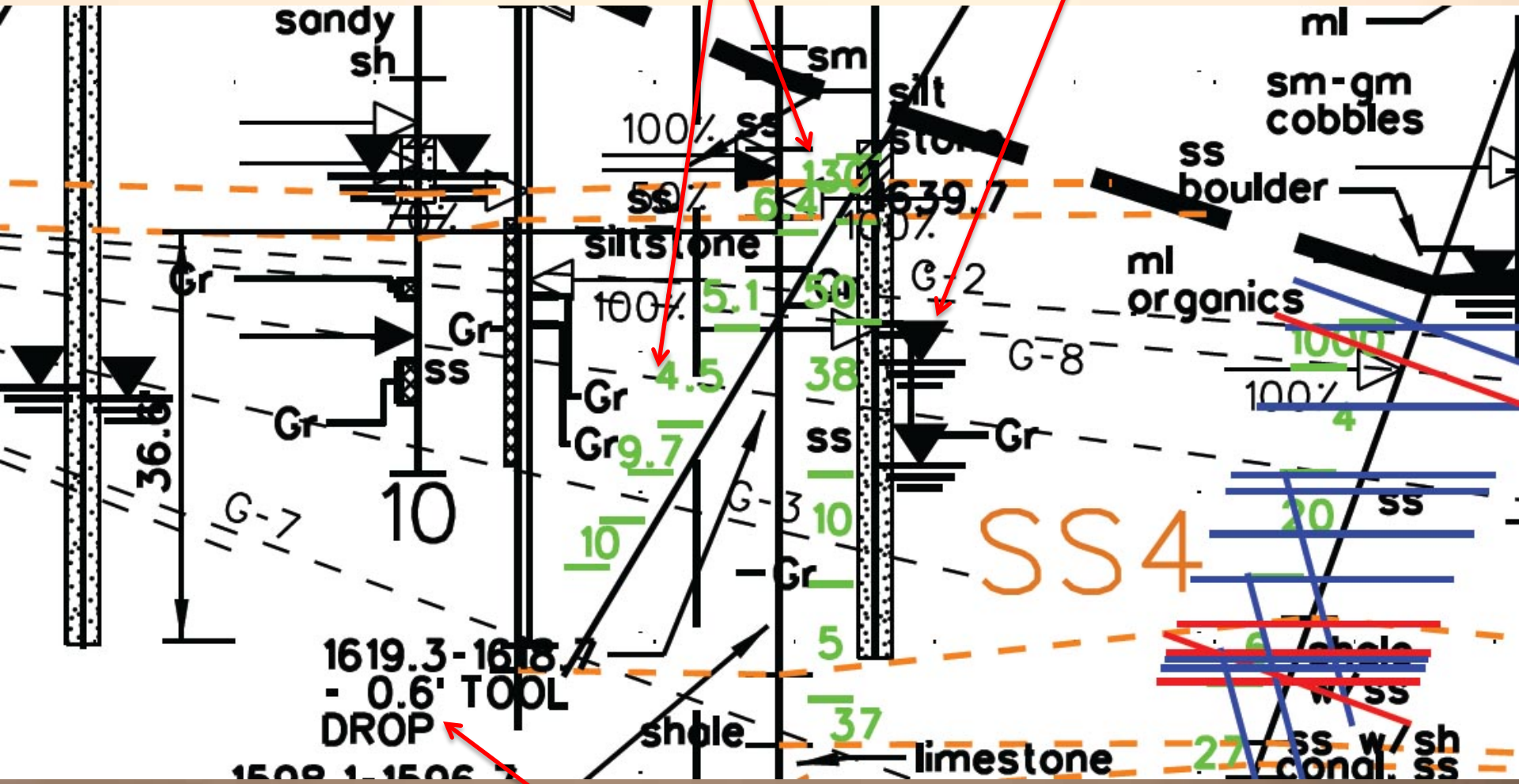
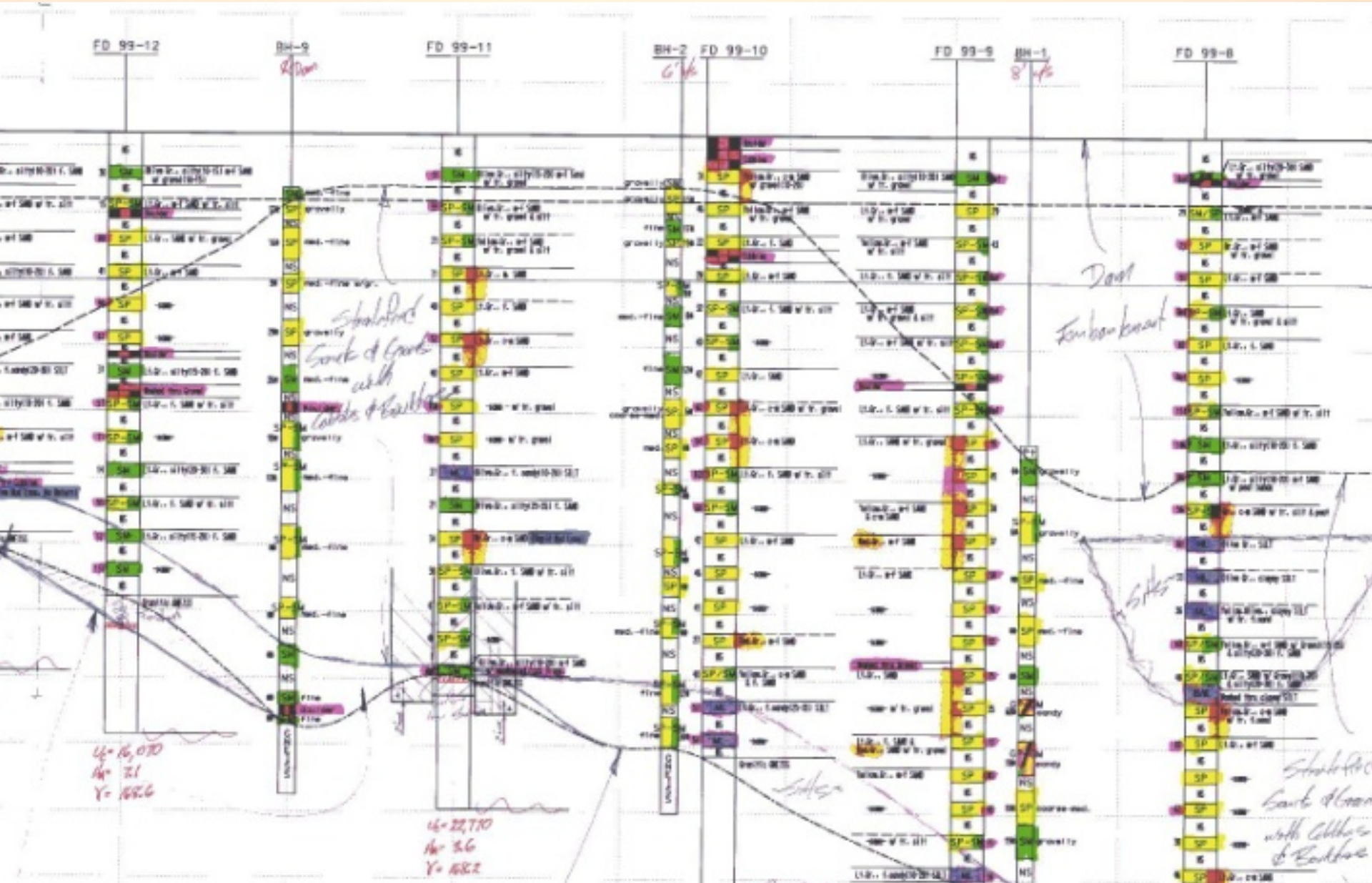
Lugeon permeability test values

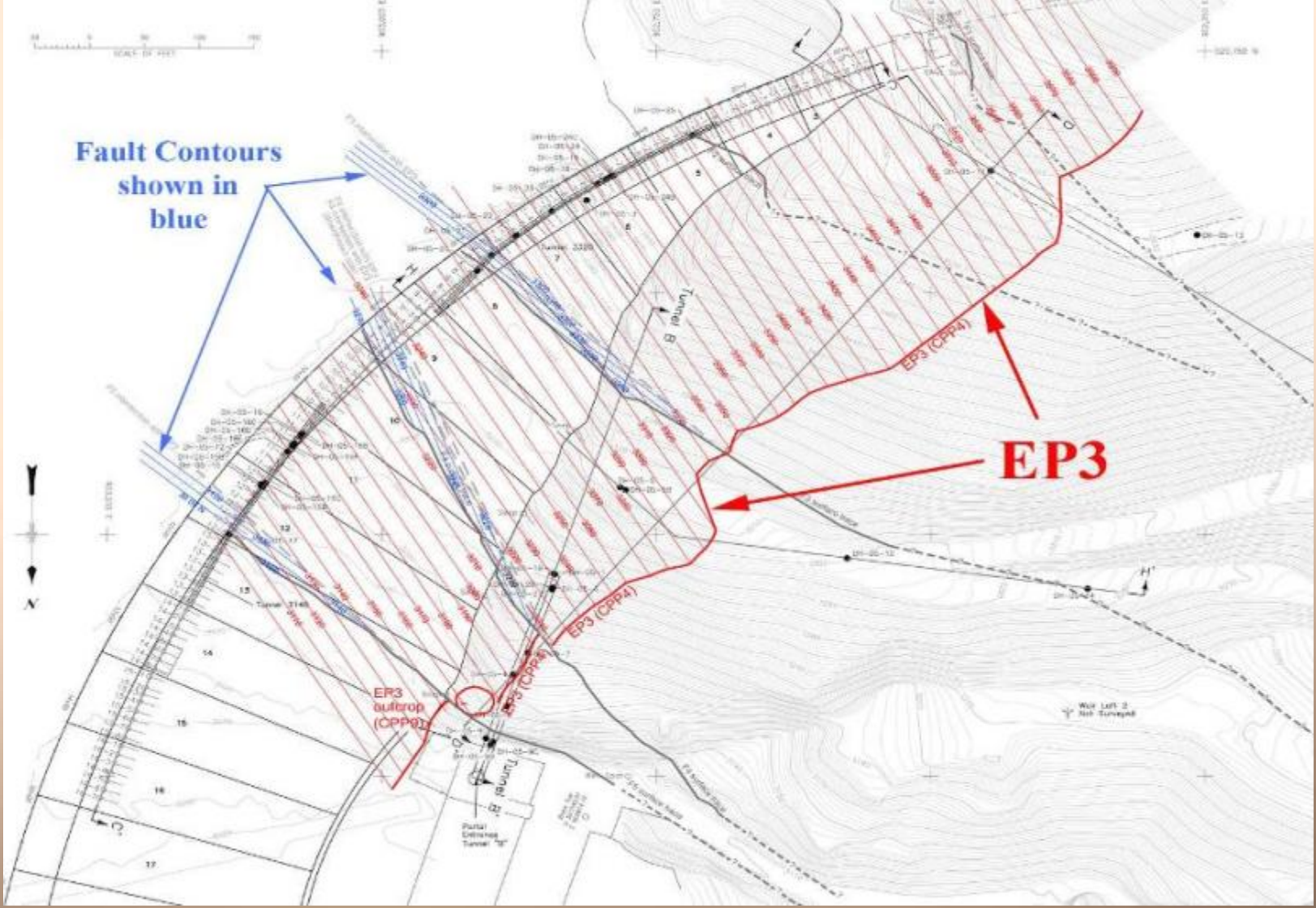
Piezometer readings



Drilling notes

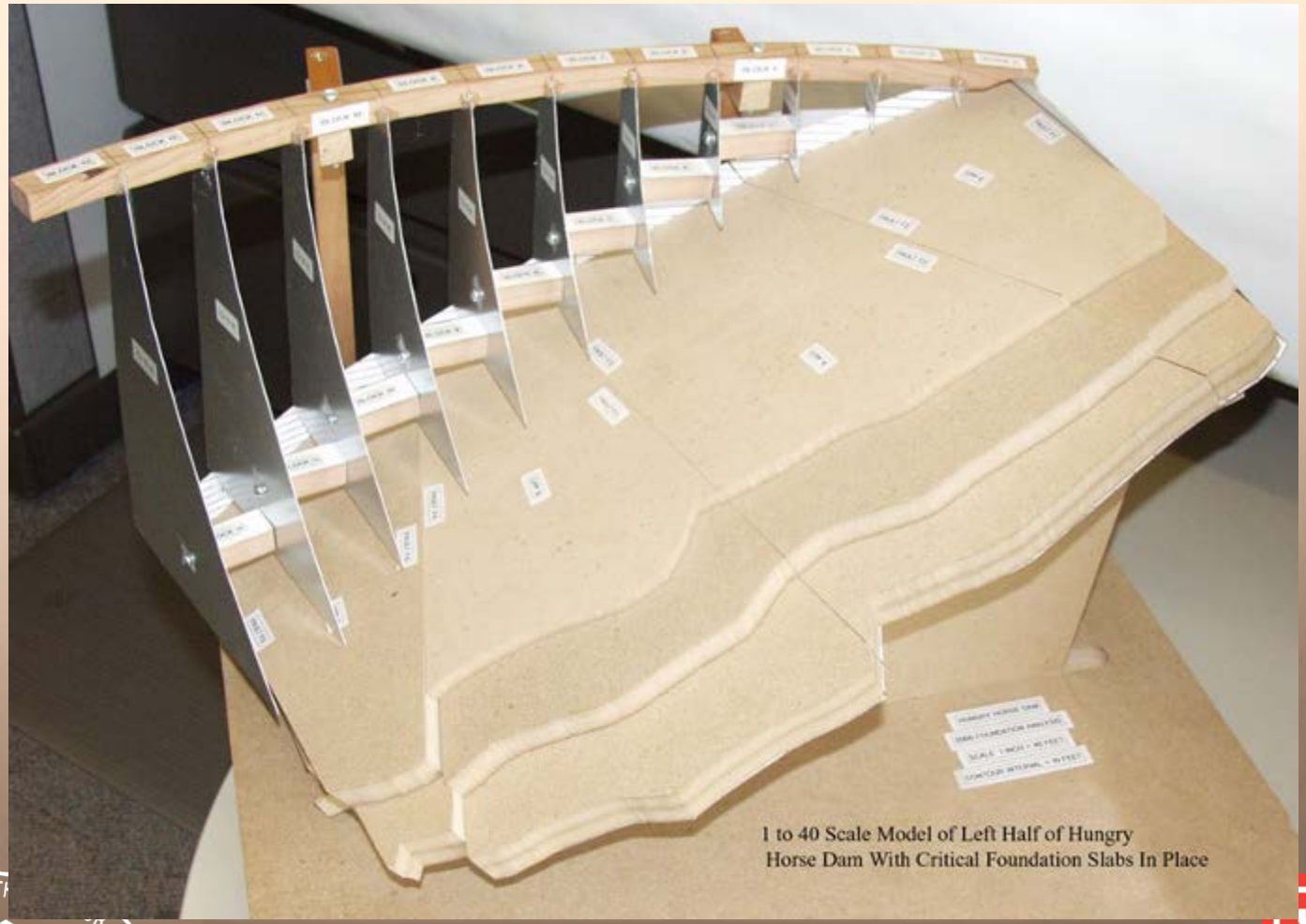
Useful drawings are not always pretty



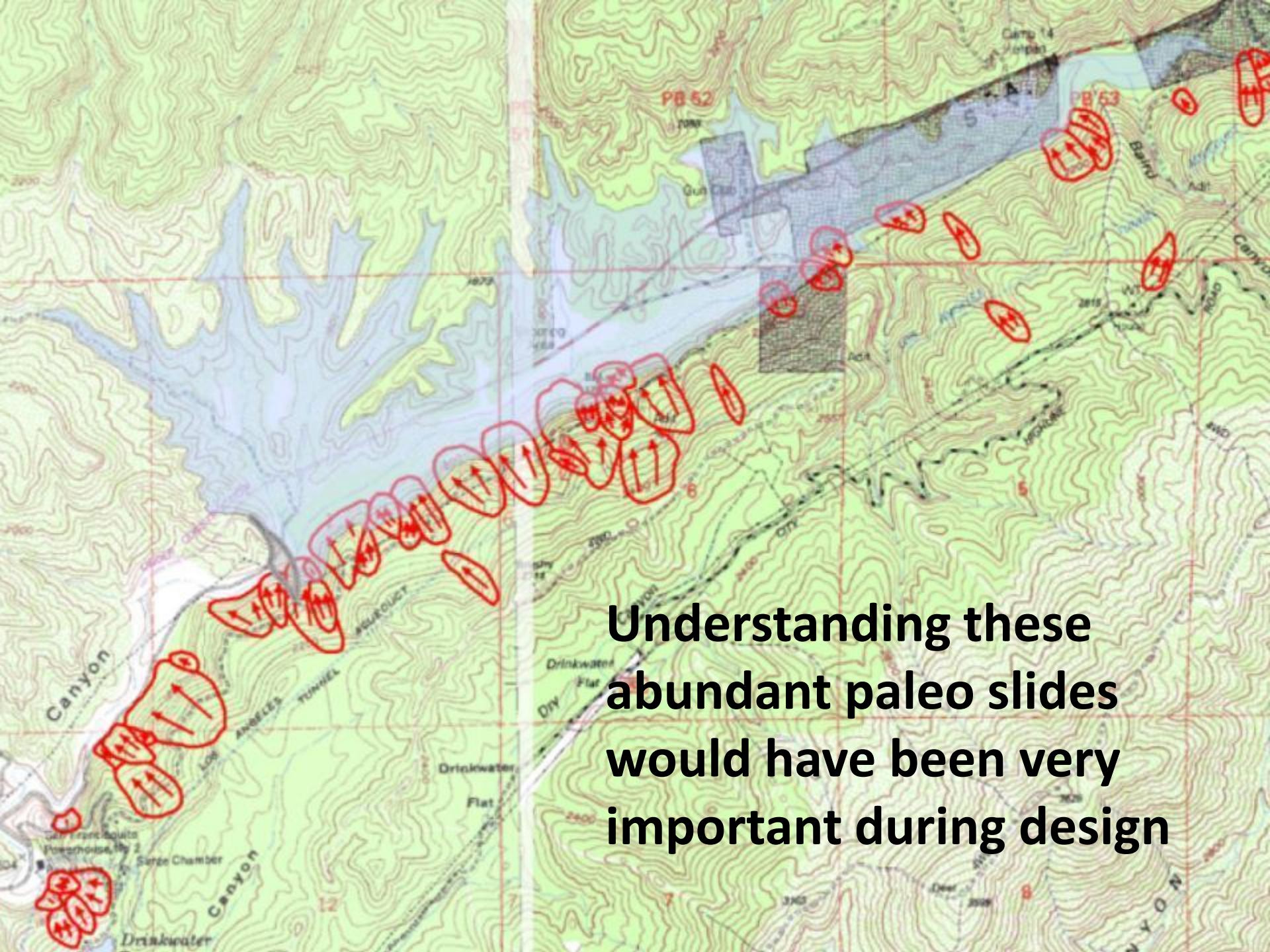


Structural Contours for Bedding and Faults

Physical Model
Showing Foundation Blocks

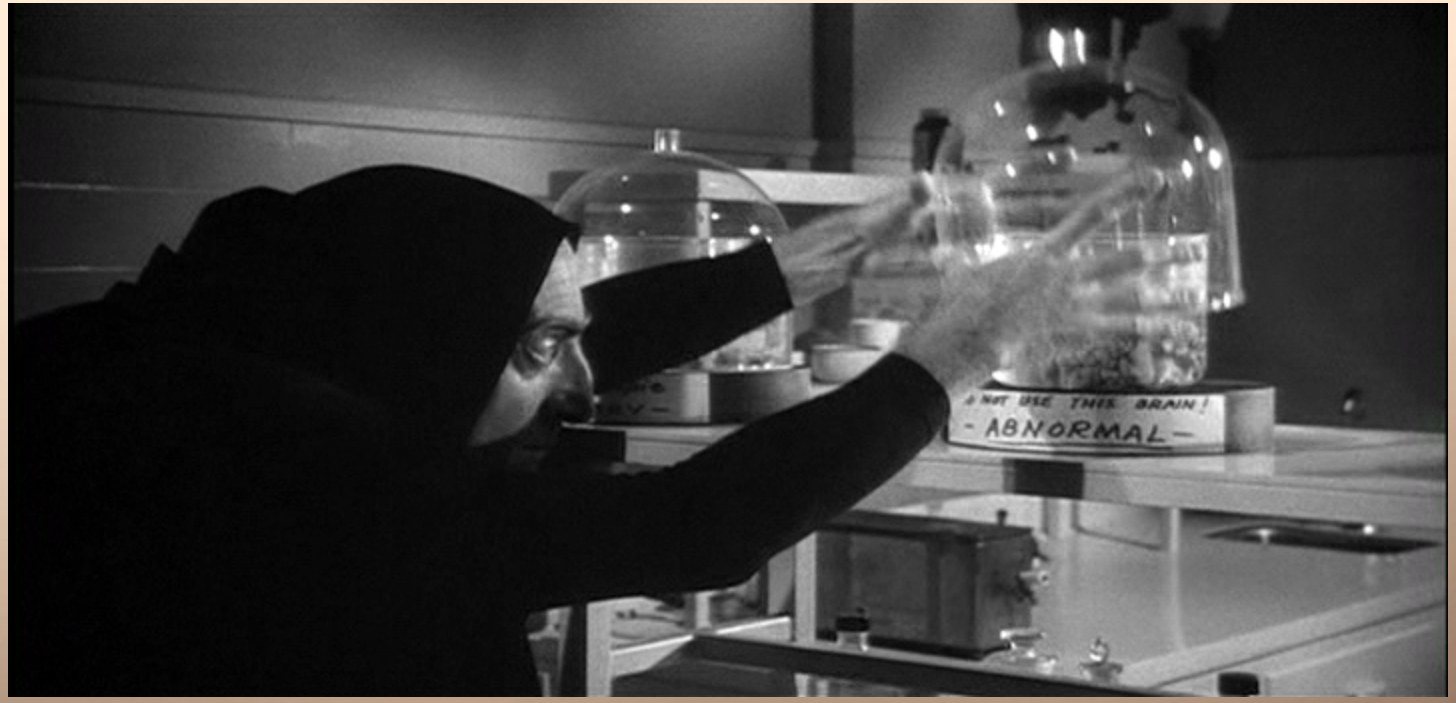


1 to 40 Scale Model of Left Half of Hungry Horse Dam With Critical Foundation Slabs In Place



Understanding these abundant paleo slides would have been very important during design

Decide What Type of Detective You Choose to Be!

Terzaghi
Berkey
Peck

Maximize Your Brain Power!
(writing is thinking on paper)