UNDERSTANDING THE FULL POTENTIAL OF AN INTEGRATED GEOSCIENCE STUDY

Alan G Young PE, M ASCE

Started Pioneering Journey in 1946

Helped develop technical practices in:

- Offshore engineering geology
- Site investigation methods
- Laboratory testing methods
- Analytical foundation design methods

McClelland's First Offshore Paper

Foundation Investigations for Offshore Structures in the Gulf of Mexico (McClelland, 1952)

Paper described Quaternary Geology of the Continental Shelf in the Gulf of Mexico and the physical properties of the Recent and Pleistocene soil.

Building Blocks of an Integrated Geoscience Study still Applicable Today

Lessons Learned from Bram McClelland

1. Employ an interdisciplinary team of experts to understand the regional processes and geology structure.

2. Use high-resolution geophysical equipment to thoroughly investigate seafloor and stratigraphic features over an extensive seafloor region.

3. Conduct the geotechnical investigation with equipment capable of performing *in situ* testing accompanied with high quality undisturbed samples.

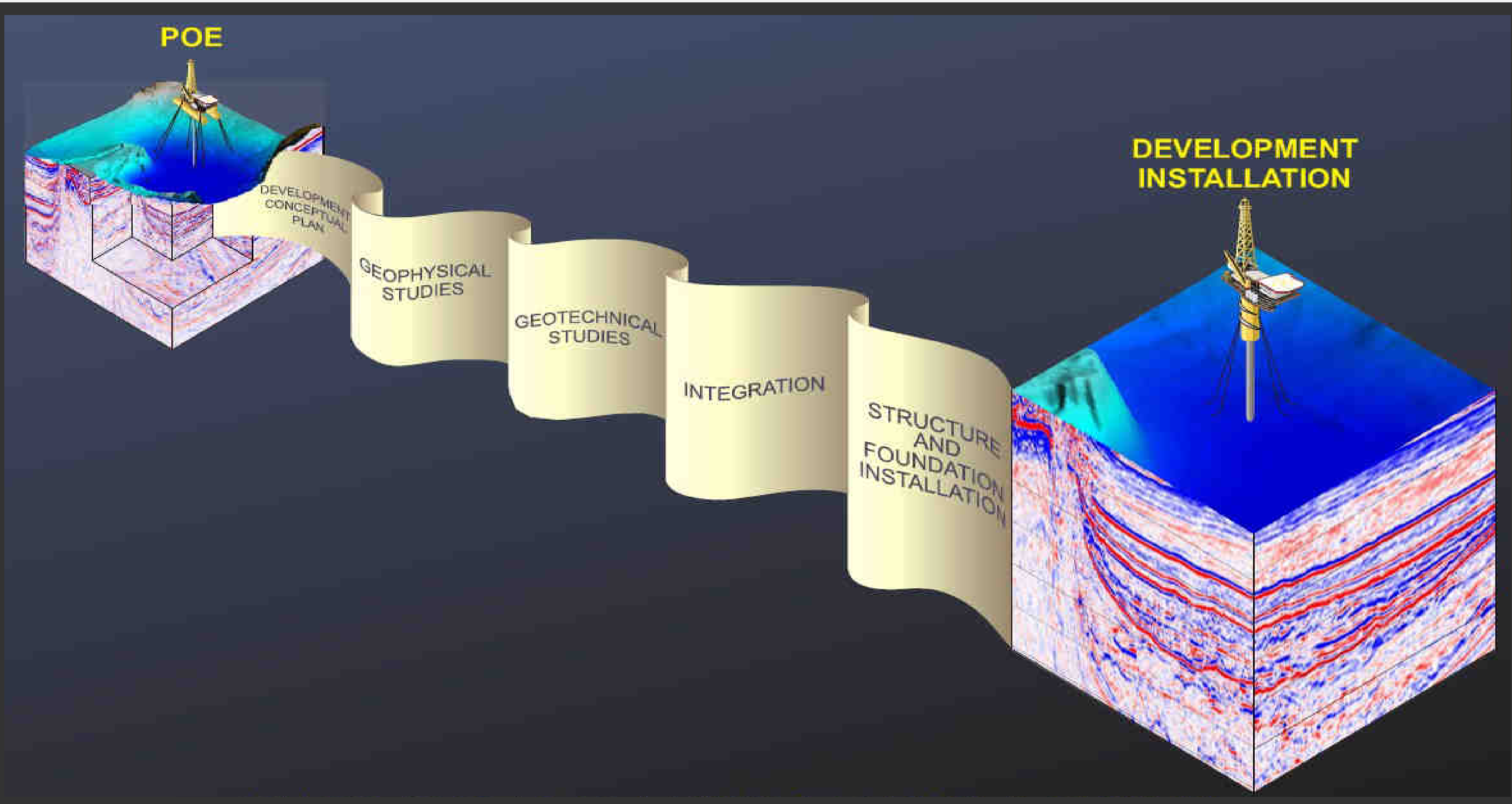
Lessons Learned (cont.)

4. Rely heavily on the *in situ* testing data to interpret the undrained strength profile and, in particular, to identify the disturbance effects of sampling on laboratory test data.

5. Rely on experimental testing and case studies to calibrate the empirical foundation design methods.

6. Develop an integrated geologic geotechnical model to assess risks and define constraints to site development.

Phases of an Integrated Study



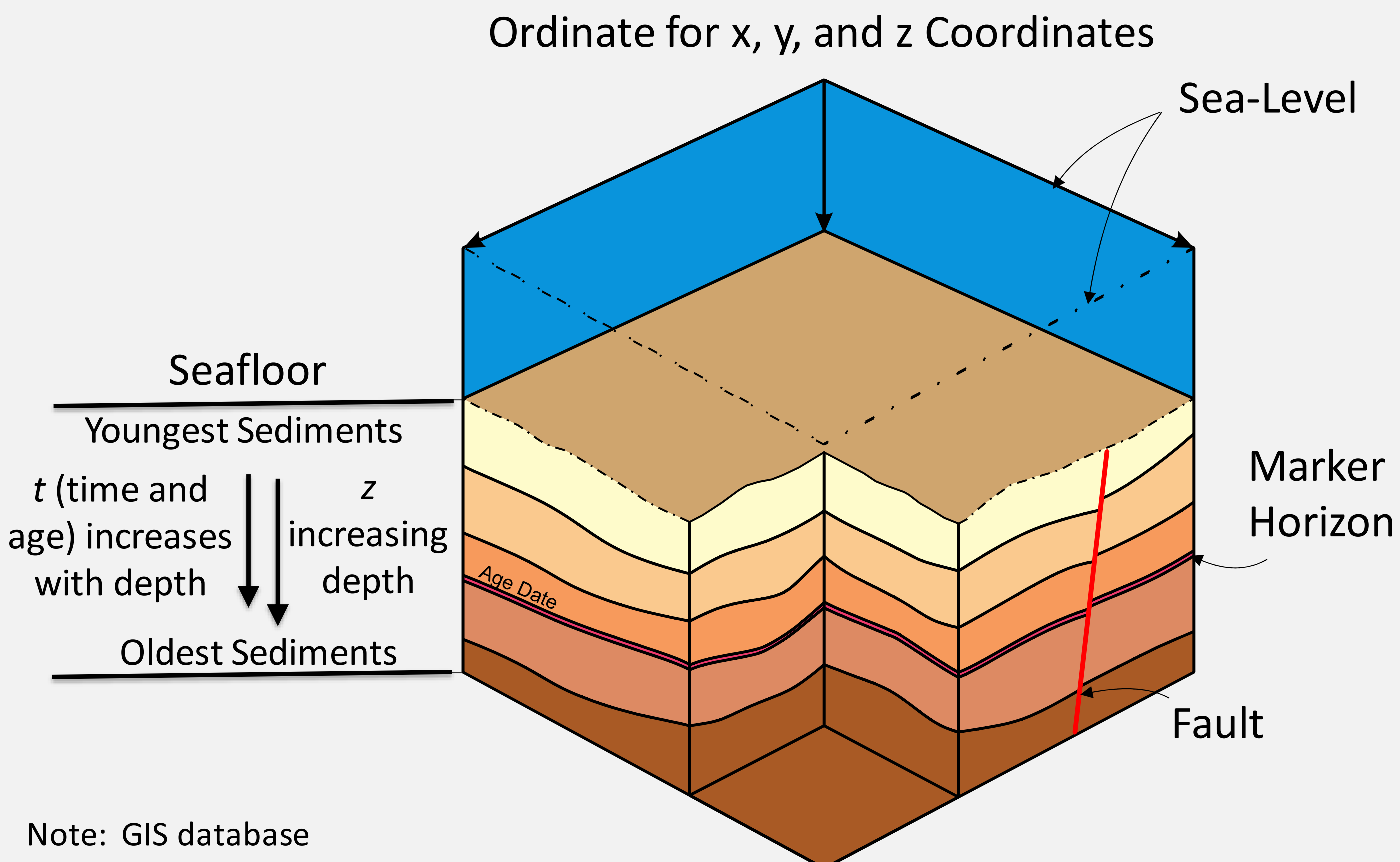
Objectives of an Integrated Geoscience Study

Provide a clear picture and understanding of:

1. Seafloor conditions
2. Shallow subsurface stratigraphy
3. Variability of soil conditions
4. Potential geo-constraints (geohazards), and
5. Impact of all these factors upon selection and placement of seafloor supported infrastructure.

Defining the 4D Geo-Site Model (aka Ground Model)

4D Geo-Site Model



Note: GIS database stores all geophysical, geotechnical, and geologic data.

Note: Model allows construction of seismic section, fence diagrams, bathymetric maps, and isopach/soil province maps.

Components of 4D Geo-Site Model

- Physiographic and Geomorphic Conditions
- Structural Framework
- Stratigraphic Framework and Definition
- Geotechnical Stratigraphy and
- Geochronologic Sequence.

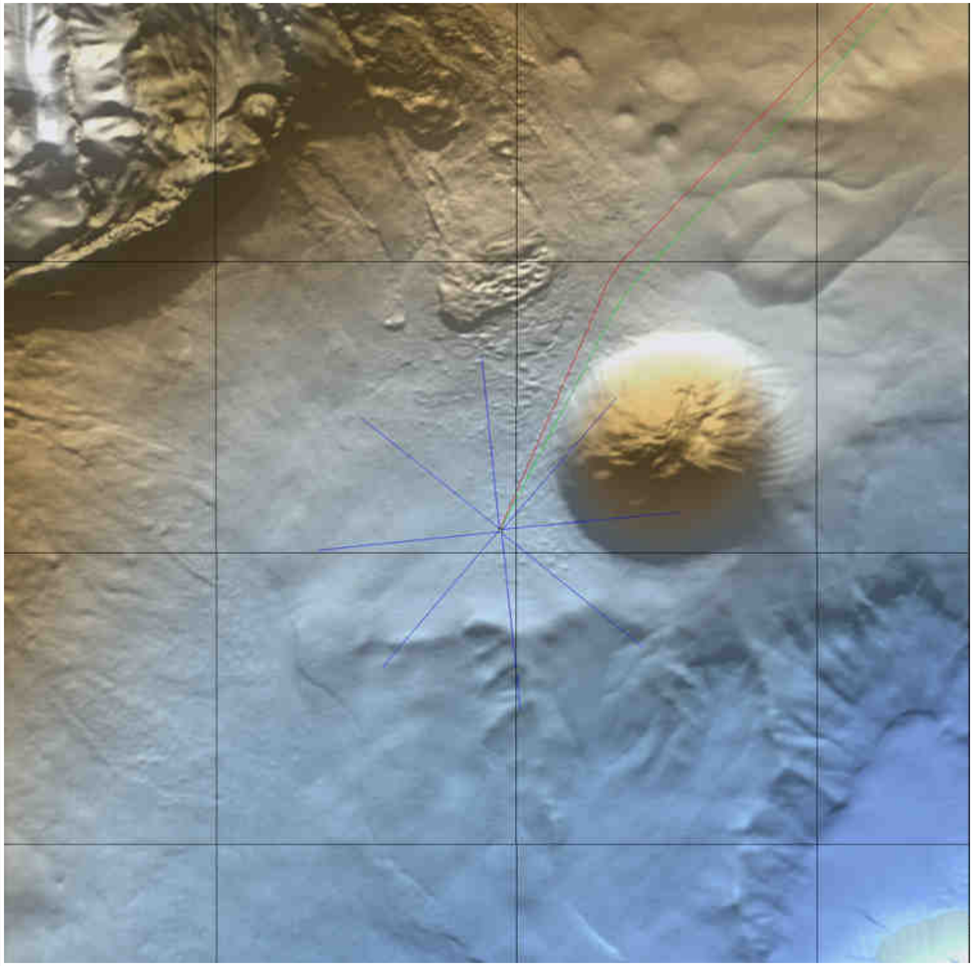
Regional Desktop Study

- Conducted first to understand regional geologic conditions and plan the scope of the geophysical program.

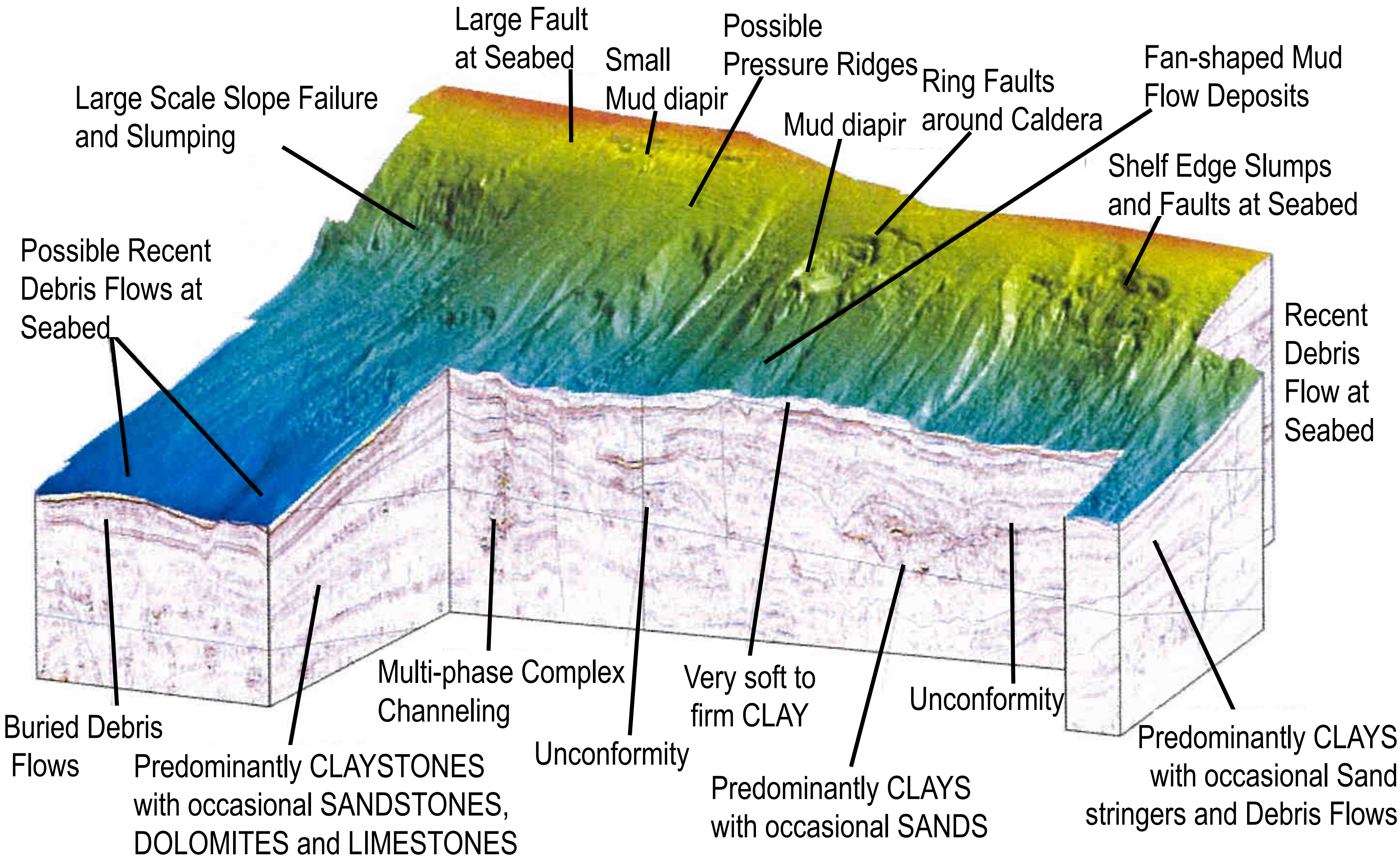
- Provides a framework for collecting other forms of *in situ* data and sediment samples, understanding environmental processes, and for achieving an optimal engineering design.

3D Enhanced Seafloor Rendering

Shell Auger Development



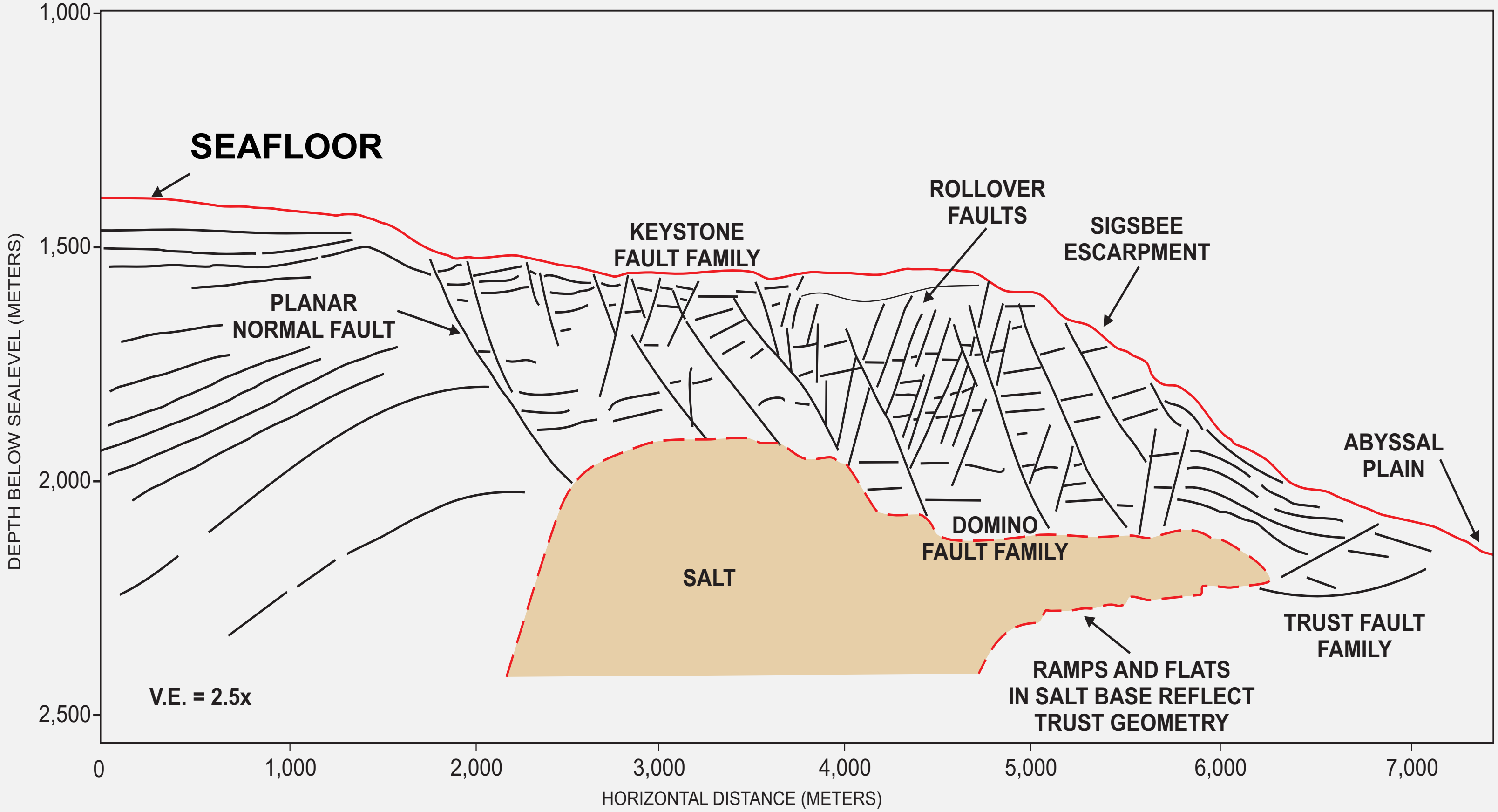
(Doyle et al., 1996)



(Horsnell et al., 2009)

Seismic Profile-Salt/Fault Interaction

Sigsbee Escarpment



(Young and Kasch, 2011)

Site Favorability Assessment Criteria

Geologic Process or Condition (Geo-Constraint)	Seafloor Lineaments (Pipelines, mooring lines, etc.)	Shallow Foundation (Mudmats, suction piles, etc)	Deep Foundation (Driven piles, conductors, etc.)	Geophysical Data Required
Steep Slope Gradients	Medium	High	Low	Multi-Beam Bathymetry
Slope Reversal (Irregular Seafloor Topography	High	High	none	Multi-Beam Bathymetry
Fault Displacement/ Offsets	Low	Medium	High	Side Scan Sonar & Sub-bottom Profiler
Shallow/Deep-Seated Slope Instability	High	High	Medium	Side Scan Sonar & Sub-bottom Profiler
Debris/ Turbidity Flows	High	Medium	Low	Side Scan Sonar & Sub-bottom Profiler
Spatial Soil Variability	High	High	Low	Side Scan Sonar & Sub-bottom Profiler
Currents and Erosion	High	Medium	Low	Multi-Beam Bathymetry, Side Scan Sonar & Sub-bottom Profiler
Gas/Fluid Expulsion Shallow Water Flow	Low	Medium	High	3D Seismic & 2D High Resolution

(Young and Kasch, 2011)

Integrated Geoscience Study Characterizes the Range of Geologic/Geotechnical Site Conditions

Study provides a reliable understanding of subsurface conditions important to achieve:

1. Realistic geohazard risk assessment
2. Reliable site selection of all facilities
3. Successful foundation design and installation

Critical Interactions of the Integrated Geoscience Team

- Integration is not a stand-alone task; rather, integration is a way of thinking and questioning adopted by all team members.

- Iterative process of analyzing the data sets to define the state of knowledge, uncertainty, consequences, and risks associated with the development of offshore facilities.

- Communication is especially important when more information is needed or when unfavorable conditions present obstacles.

Key Considerations of an Integrated Geoscience Study

- We must understand the natural processes that formed the soil deposits if we want to understand their inherent variability.

- Geology plays an essential and significant role and should guide all data acquisition activities.

- The credibility of the integrated assessment depends upon the resolution and quality of the geophysical and geotechnical data.

Importance of Stratigraphic Interpretation

Dr. Ralph Peck (1962)

Subsurface engineering is an art; soil mechanics is an engineering science. This distinction, often expressed but seldom fully appreciated, must be understood if we are to achieve progress and proficiency in both fields of endeavor.

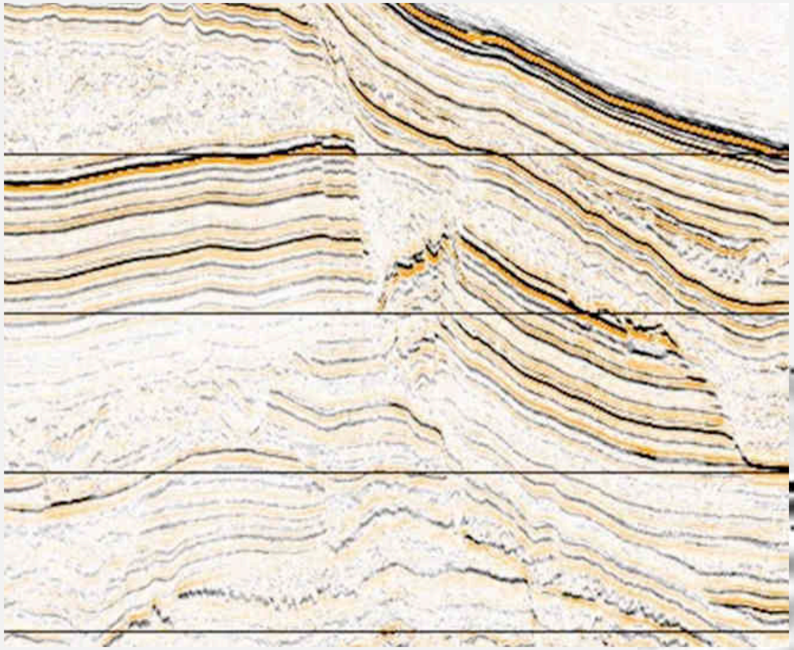
Whether we realise it or not, every interpretation of the results of a test boring and every interpolation between two borings is an exercise in geology.

Role of Stratigraphy

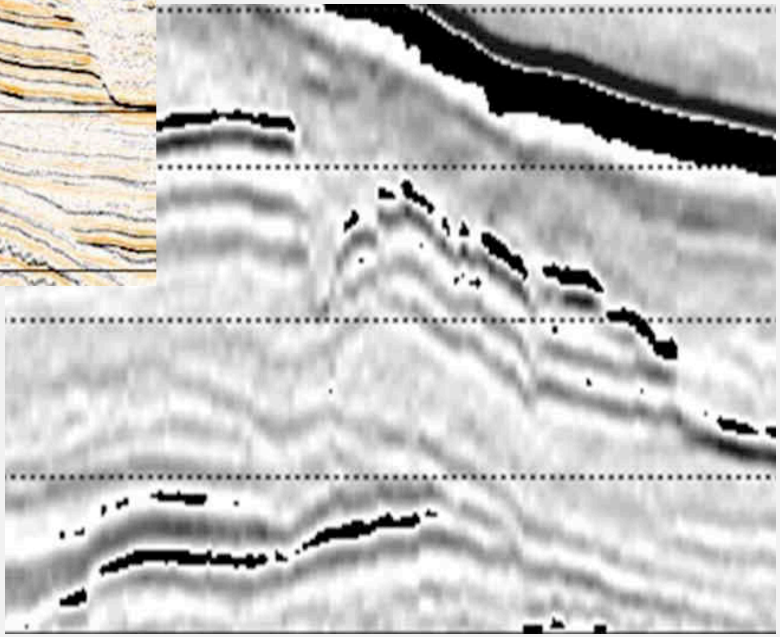
- Stratigraphy defines the lateral and vertical relationship of various sediment units.
- Defines the temporal framework of the continuum of processes and features defined in space over time.

"Stratigraphy is the great unifying agency of geology that makes possible the synthesis of a unified geological science from its component parts." – Weller 1947

Geophysical High-Resolution Data



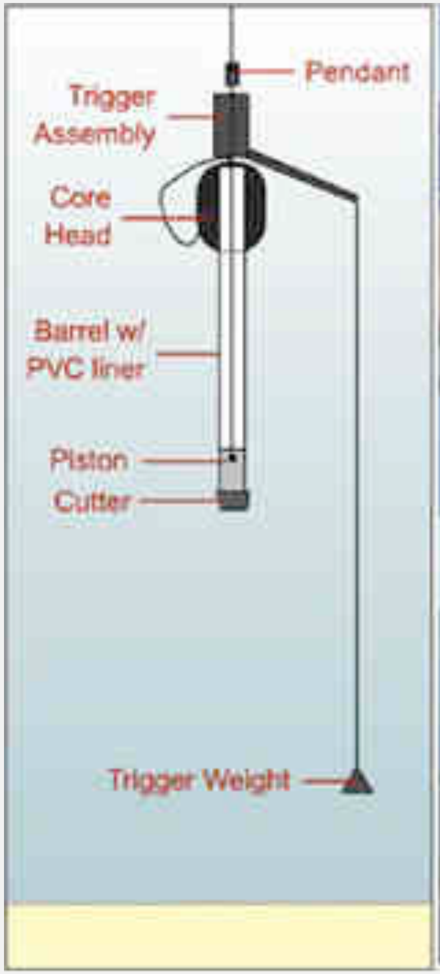
a) High-Resolution 3D Data



b) Exploration 3D Data

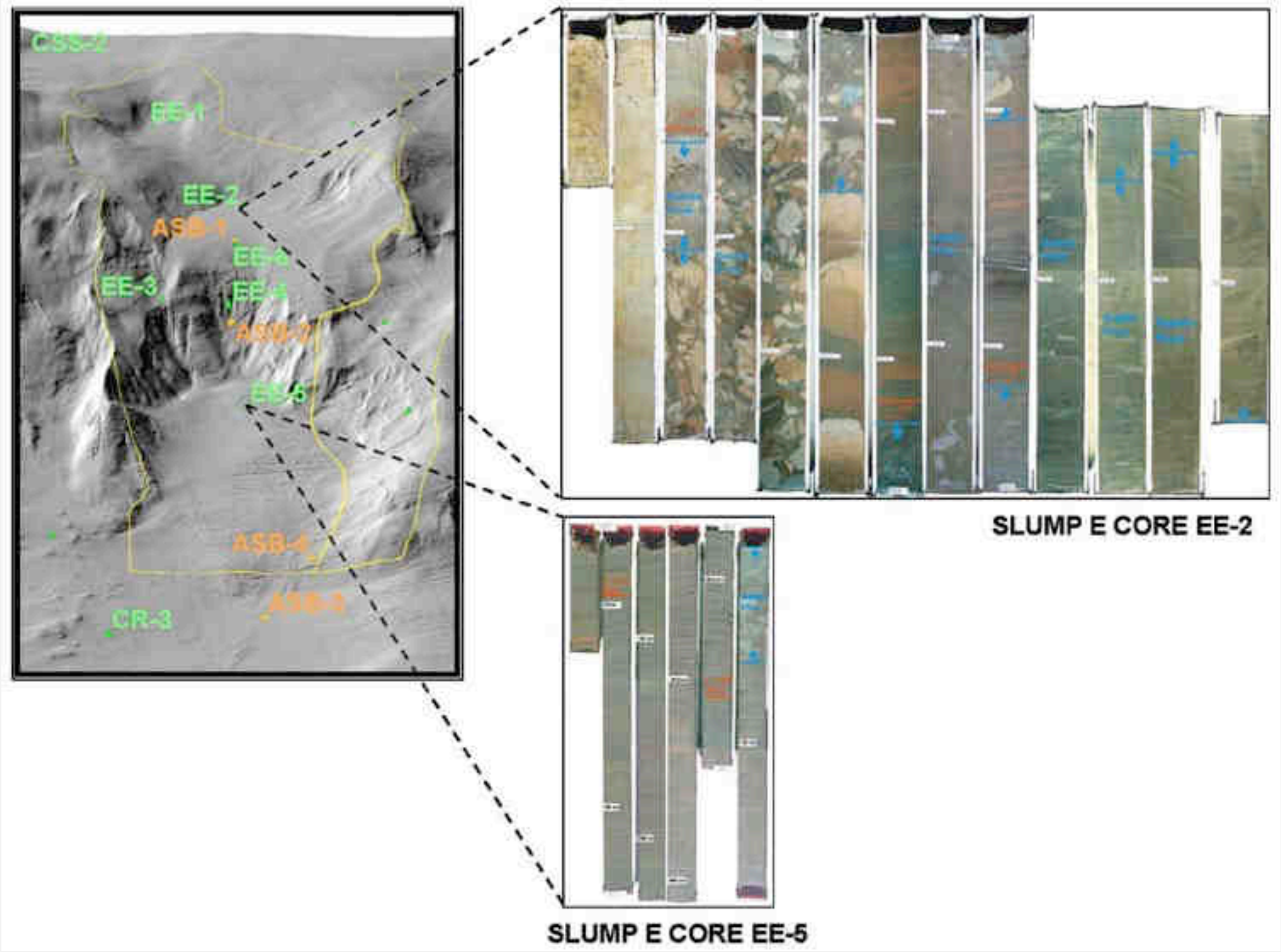
Methods Used to Ground-Truth Stratigraphic Interpretation

Jumbo Piston Coring Operation



Courtesy of TDI-Brooks International

Photo of Split Jumbo Piston Core



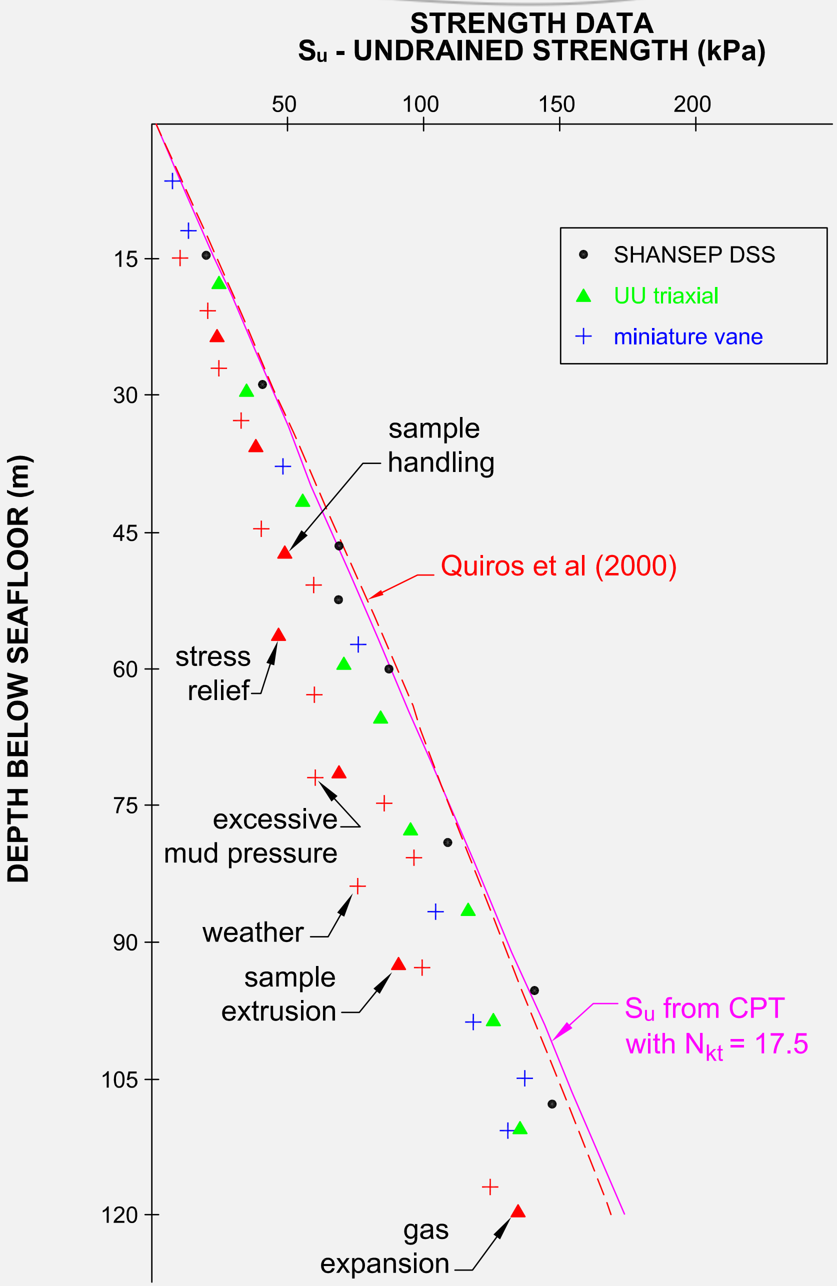
PROD System
Seafloor Sampling and In Situ Testing

Courtesy of Mr. Alan Foley with the Benthic Group

Critical Sample Quality Factors

- Weather conditions that induce motion of the drill-string during drilling and sampling;
- Sampling procedure and size of sampling tube;
- Stress relief during sampling recovery;
- Sample extrusion procedure;
- Sample handling, packaging, transportation processes;
- Sample storage methods;
- Adherence to laboratory testing standards;
- Unusual geologic and physio-chemical properties of sediment; and
- Gas expansion.

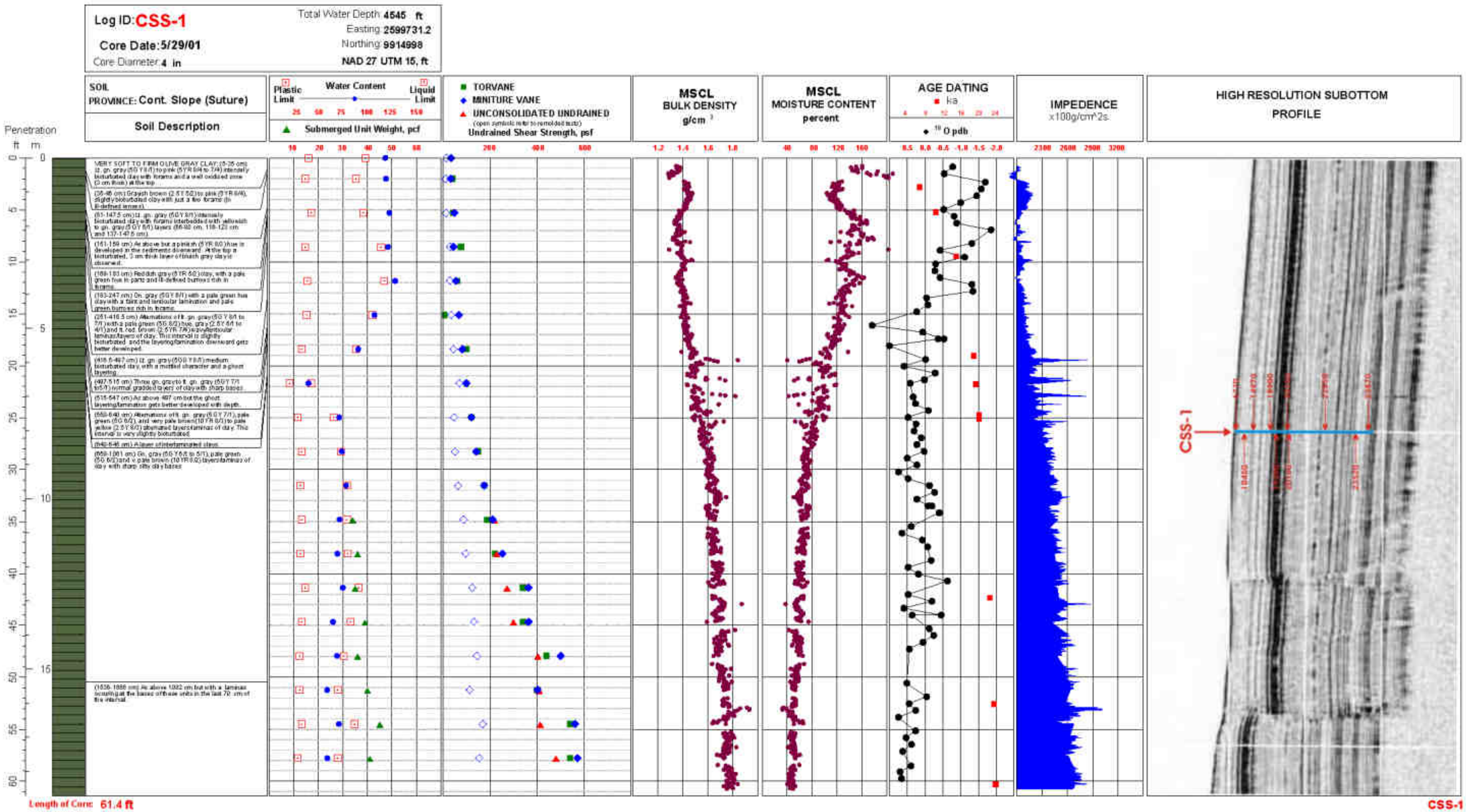
Reliable versus Disturbed Data



Note: Red strength data are 10 percent less than Su line based on CPT.

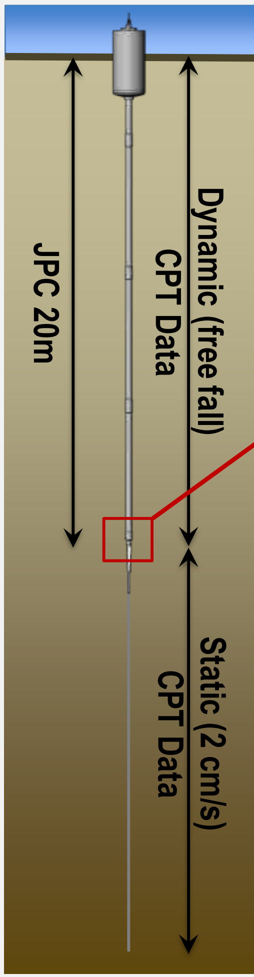
Lunne (2012) – 4th James K Mitchell Lecture

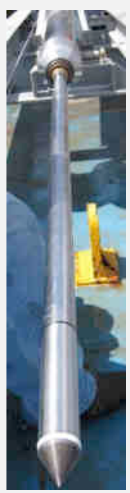
"It is of vital importance that the quality of the samples is good from a geotechnical viewpoint, otherwise the results of laboratory tests on the samples will not be representative for the in situ conditions".

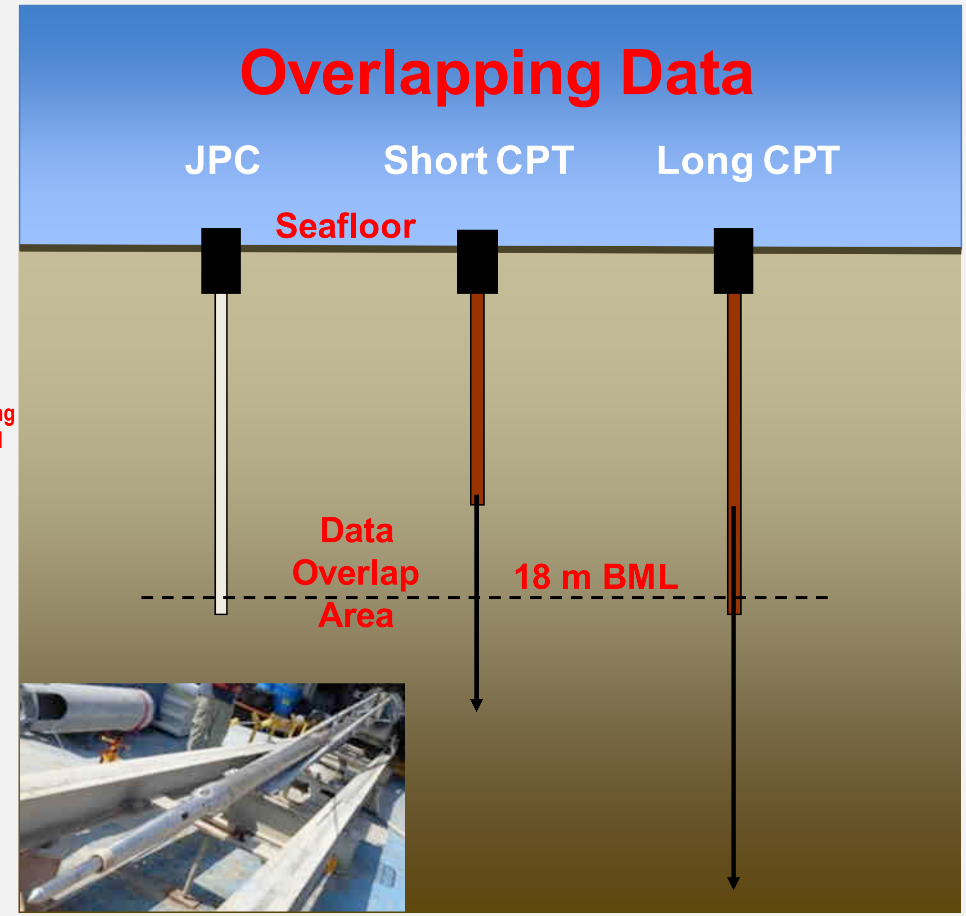


Log ID: CSS-1
Core Date: 5/29/01
Core Diameter: 4 in
Total Water Depth: 4545 ft
Easting: 2599731.2
Northing: 9914998
NAD 27 UTM 15, ft
SOIL
PROVINCE: Cont. Slope (Suture)
Soil Description
Penetration
ft m
Plastic Limit
Water Content
Liquid Limit
Submerged Unit Weight, pcf
TORVANE
MINITURE VANE
UNCONSOLIDATED UNDRAINED
Undrained Shear Strength, psf
MSCL
BULK DENSITY
g/cm³
MSCL
MOISTURE CONTENT
percent
AGE DATING
ka
¹⁸O pdb
IMPEDENCE
x100g/cm^2s
HIGH RESOLUTION SUBOTTOM
PROFILE
CSS-1
Length of Core: 61.4 ft
CSS-1

Overview of TDI-Brooks CPT Stinger System







Courtesy of TDI-Brooks International

Lunne (2012) – 4th James K Mitchell Lecture

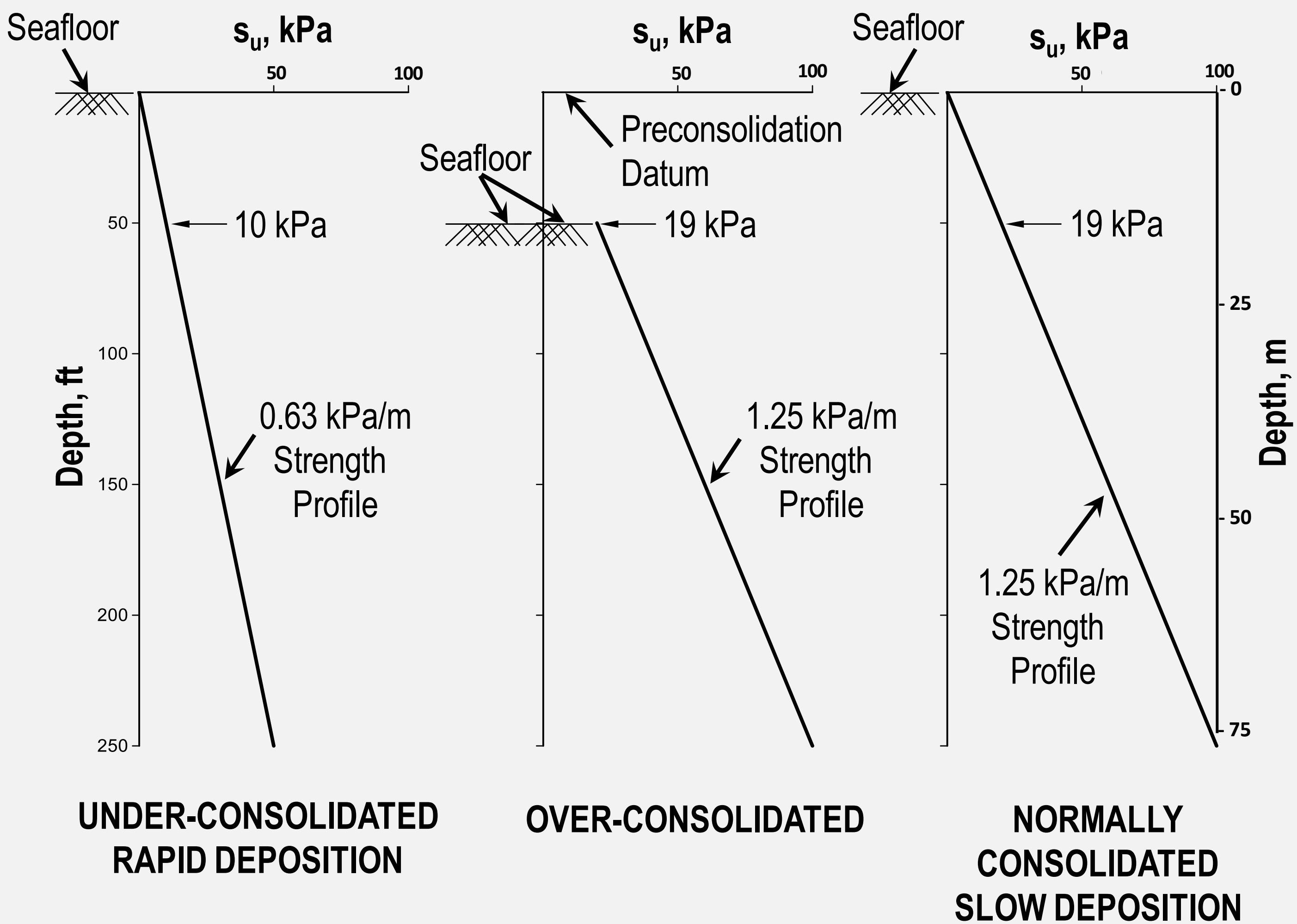
"…in most parts of the world it is hardly possible to consider an offshore soil investigation without the use of the CPT, and the results are essential input in establishing the soil profile and soil parameters for foundation design."

Advantages of Continuous Core and CPT Data Compared to Discontinuous Sampling

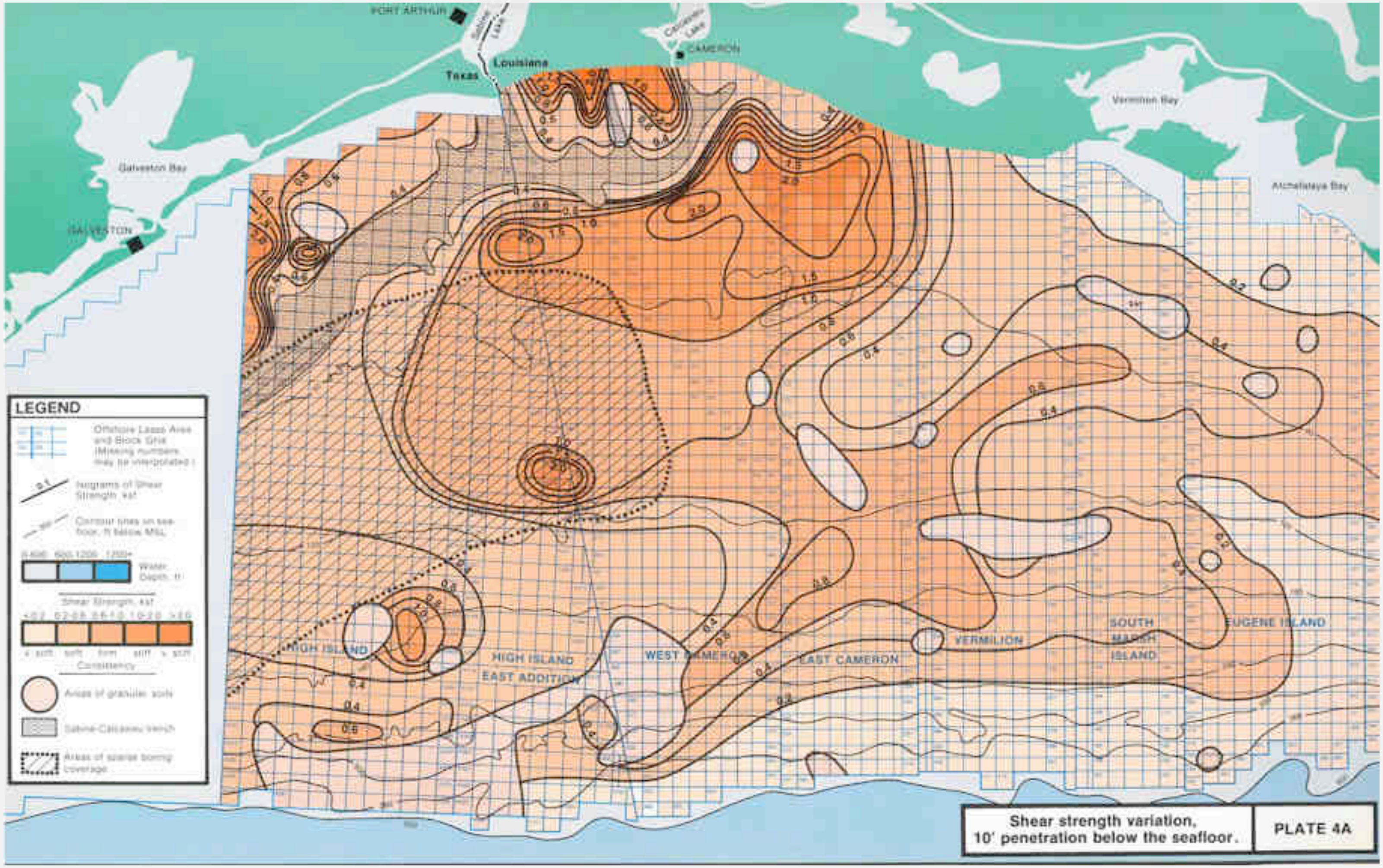
- Continuous core can be logged and compared to sub-bottom profiler data,
- Continuous CPT can be correlated with sub-bottom profiler data,
- Continuous core can be split and photographed to identify depositional changes,
- Effort and time for site investigations may be reduced, and
- Entire foundation design process is conducted with less uncertainty and fewer risks.

Extrapolation of Spatial Strength Properties

McClelland Paper - Types of Strength Profiles



Gulf of Mexico Continental Shelf Atlas



(Parker et al., 1979)

Wroth (1984) - 24th Rankine Lecture

The effect of different loading mechanisms means…

"Consequently, there cannot be a unique undrained shear strength of a soil, and different values will be observed in different tests."

Geology Defines Spatial Variability

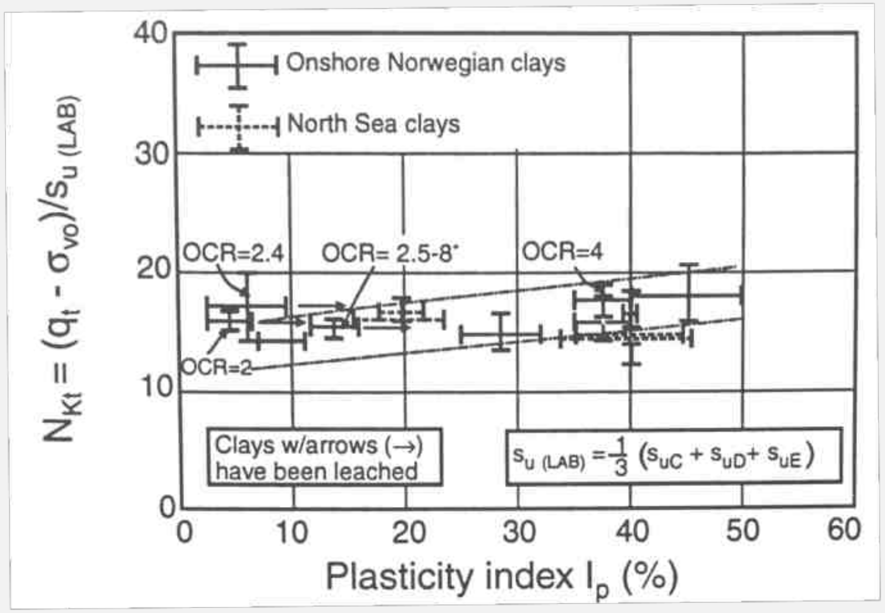
Baecher and Christian (2003) indicate that measured soil properties are often treated as if they are independent samplings of a random variable.

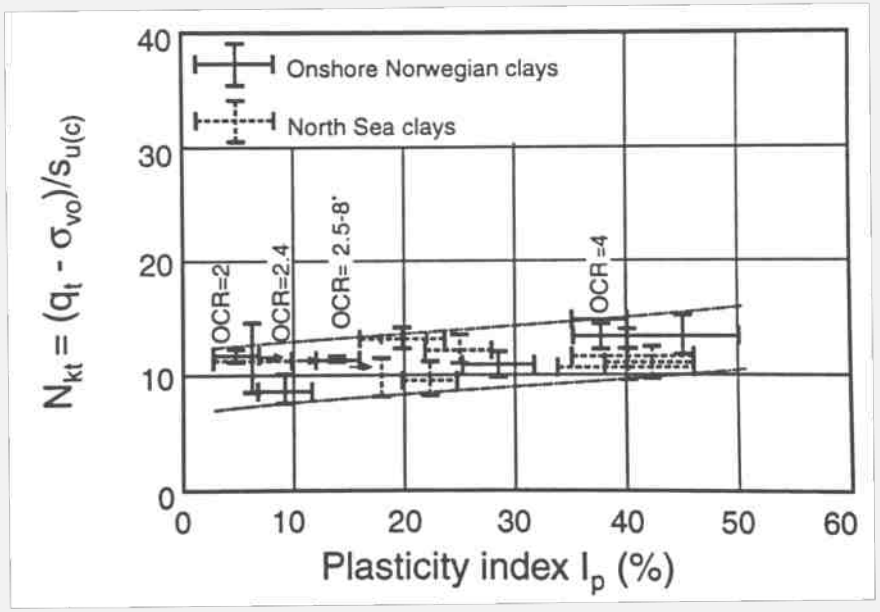
Offshore soils are frequently deposited in a uniform physical process over time, so their spatial variability is often not random. The uncertainty is frequently in the model or error in soil measurements and not in the soil deposit.

Interpretation of Undrained Shear Strength

- Traditional practice relies upon laboratory strength data instead of CPT data,
- Large scatter in laboratory data due to soil anisotropy, strain rate, stress history, and different loading mechanisms,
- CPT data is more consistent and representative measure of depositional nature of marine sediments and avoids other effects, and
- CPT is a great tool for obtaining continuous rapid and reliable soil profile.

$$q_{net} = N_{kt}\, s_u$$





Undrained shear strengths:
$s_{u\,(C)}$ triaxial compression
$s_{u\,(E)}$ triaxial extension
$s_{u\,(D)}$ direct simple shear

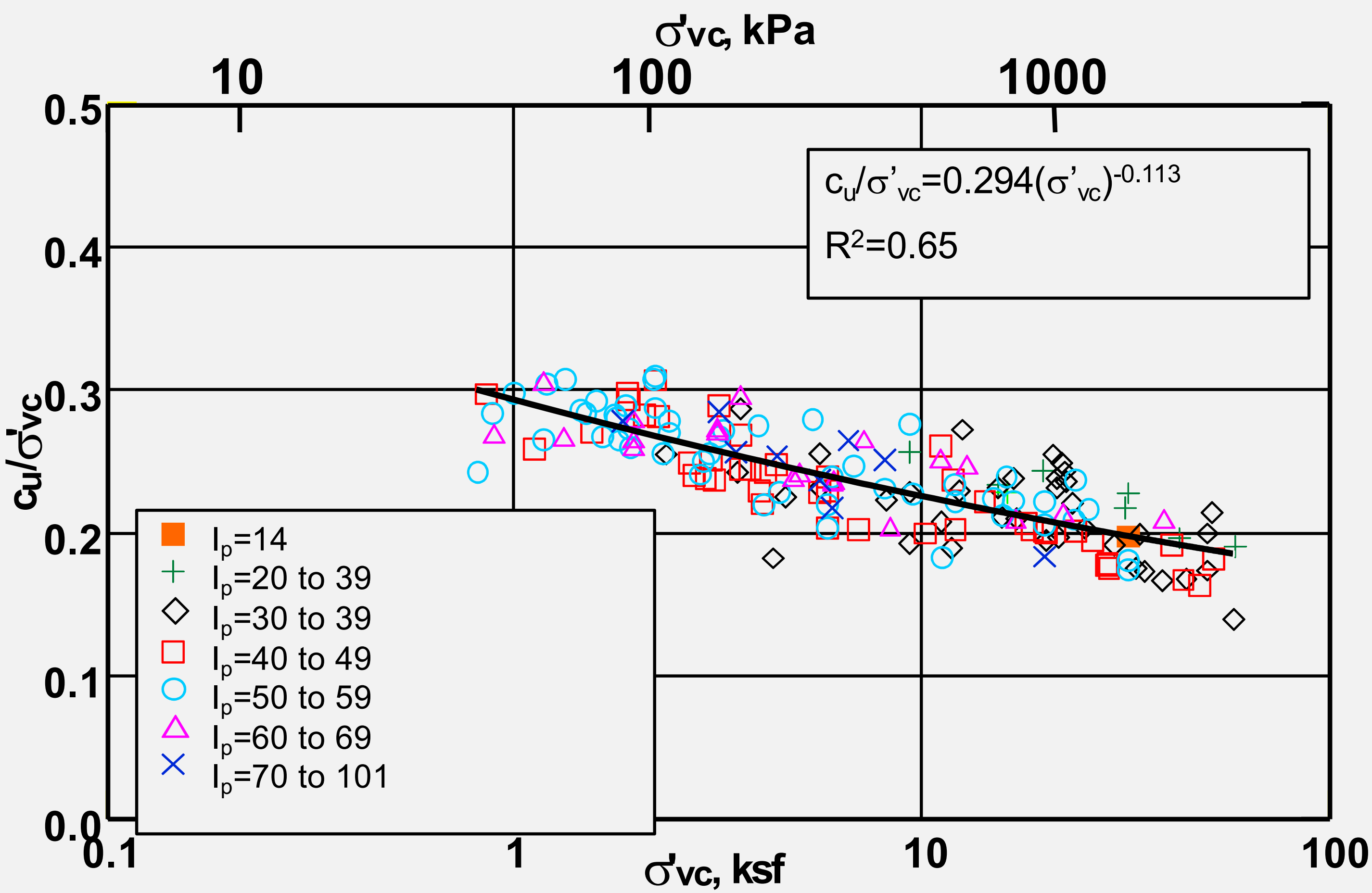
(Aas et al., 1986)

SHANSEP Method

Stress History and Normalized Soil Engineering Parameters

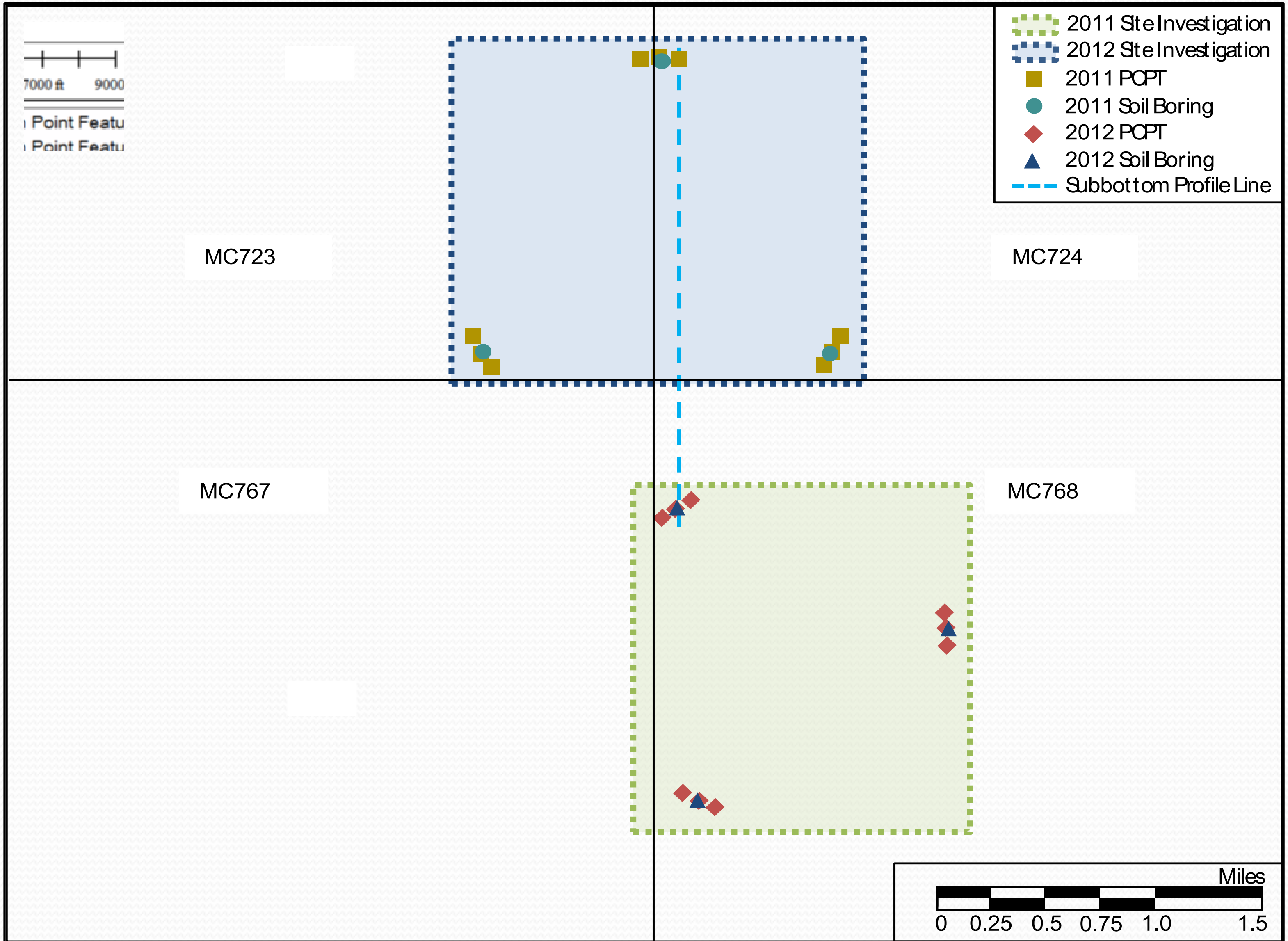
$$s_u = \sigma'_v \left(\frac{s_{u_{DSS}}}{\sigma'_{vc}}\right)_{nc} OCR^m$$

SPW Method

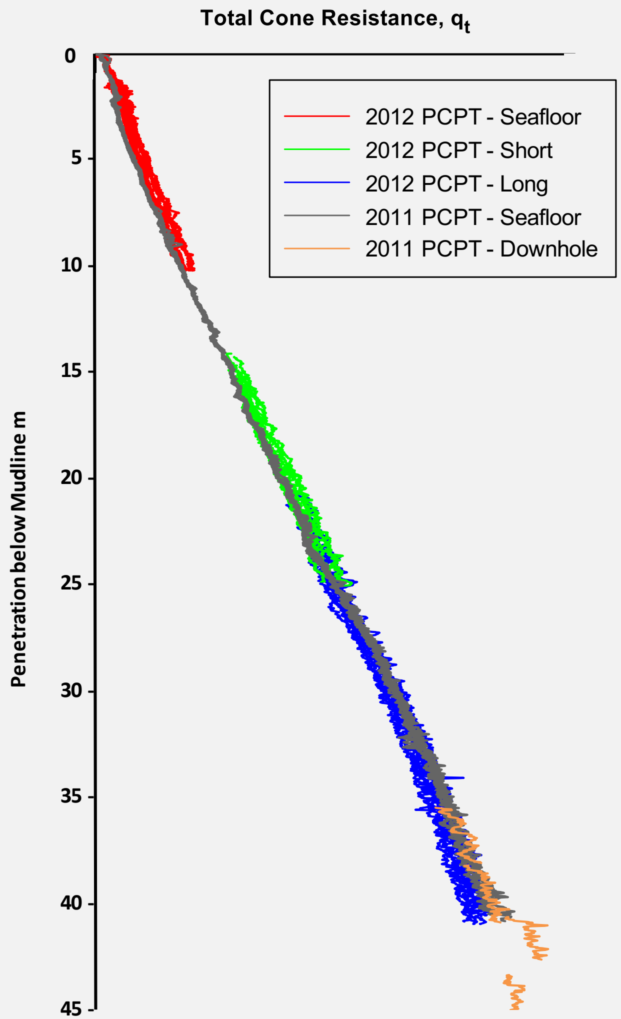


(Quiros et al., 2000)

Site Location Map

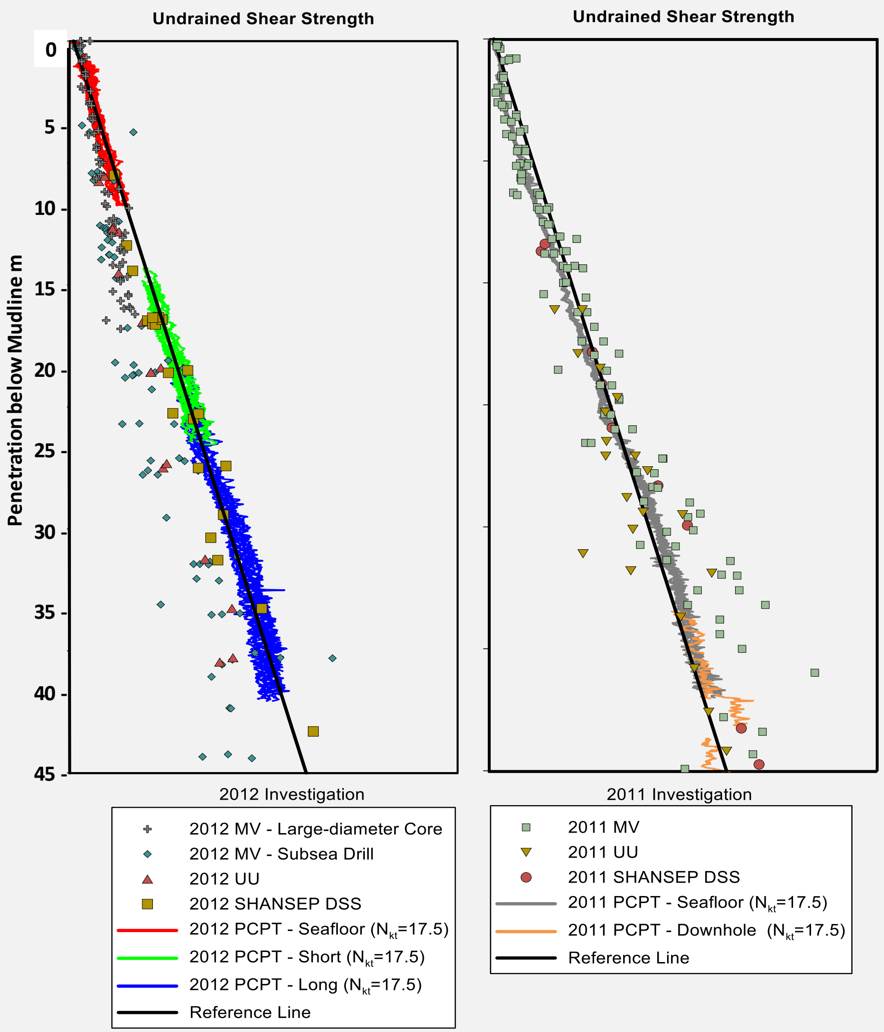


Comparison of CPT Data from Different PCPT Systems

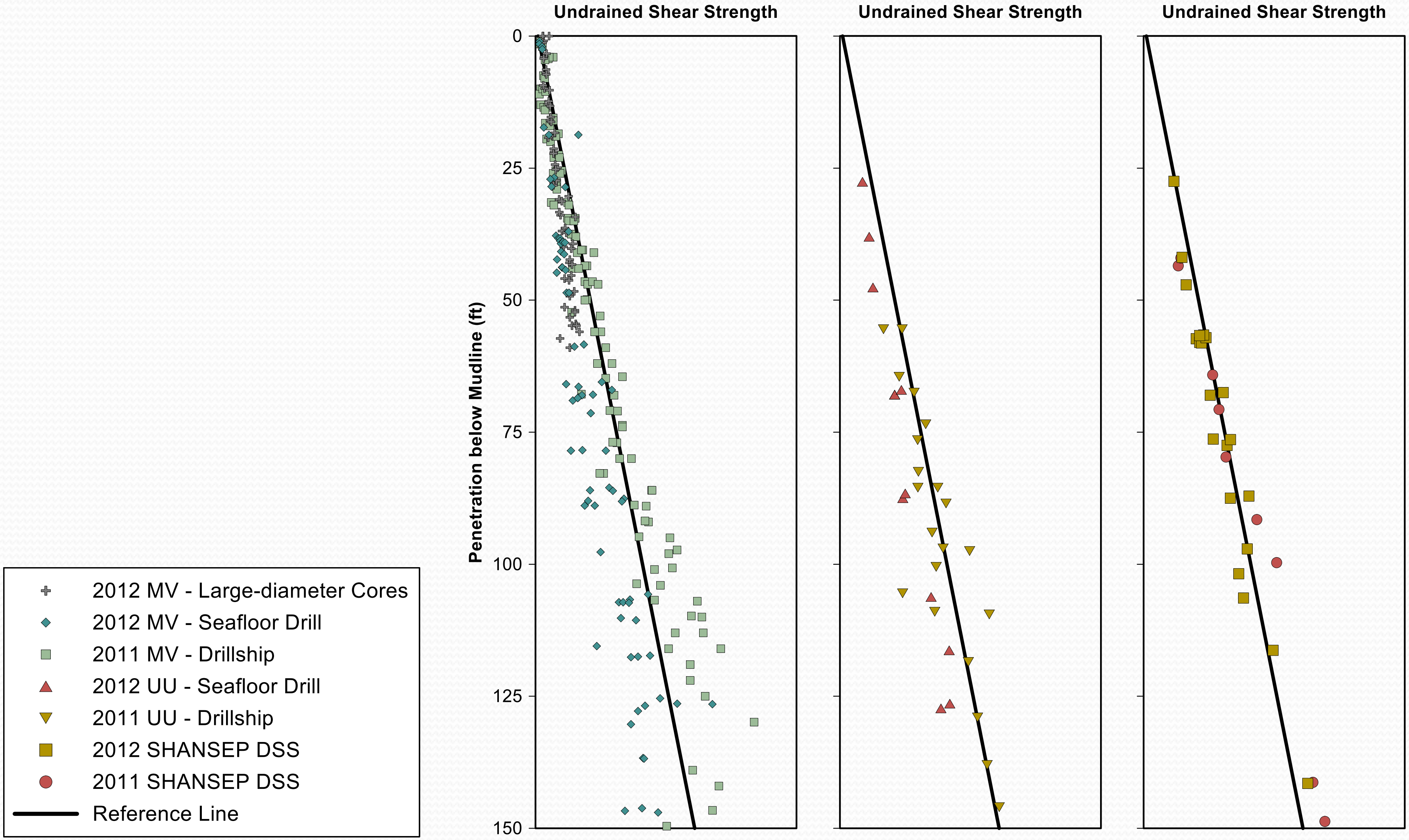


(Caruthers et al., 2014)

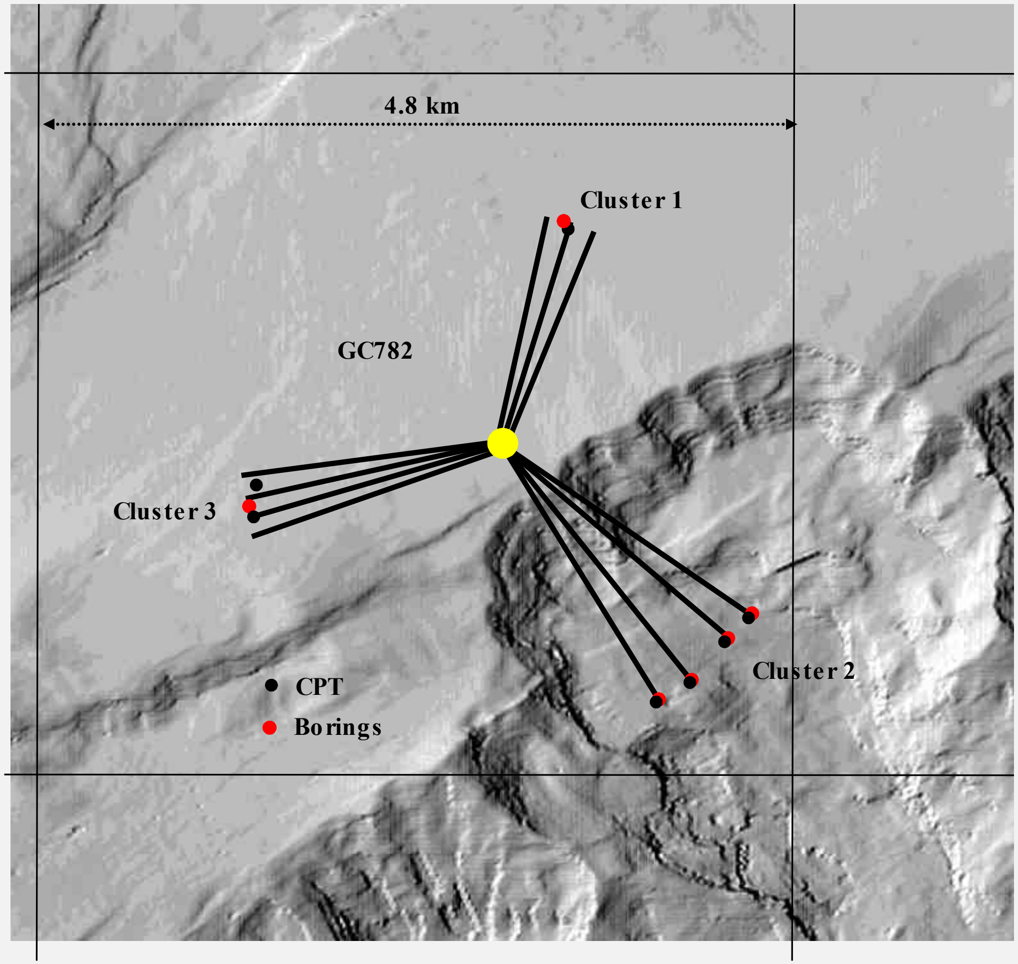
Laboratory and In Situ Strength Data for Two Investigations



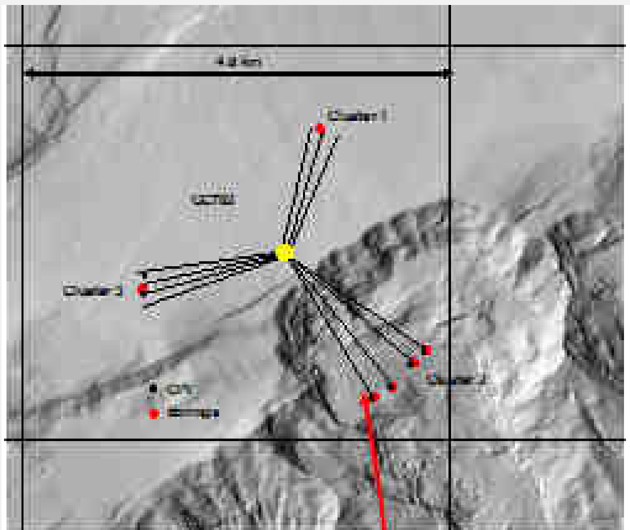
Data Comparison–Undrained Shear Strength



Mad Dog SPAR Mooring Spread with 11 Suction Piles

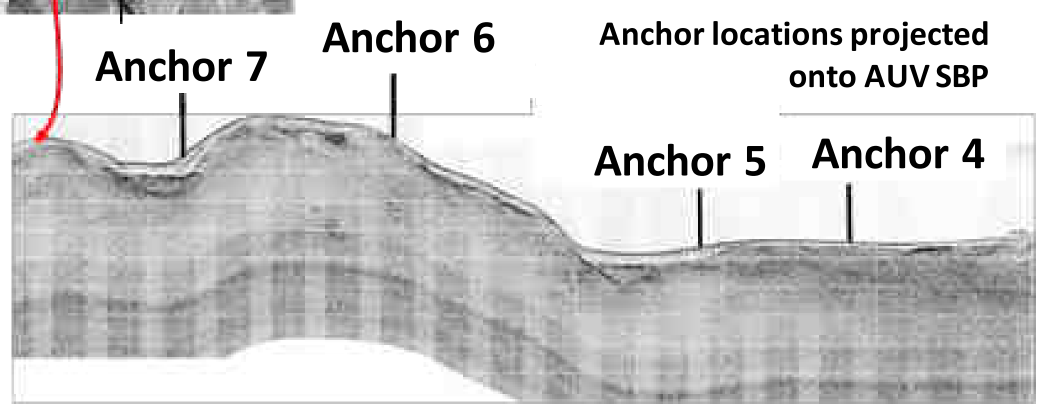


Mad Dog Slump 8 – Cluster 2 Geotechnical Work Scope

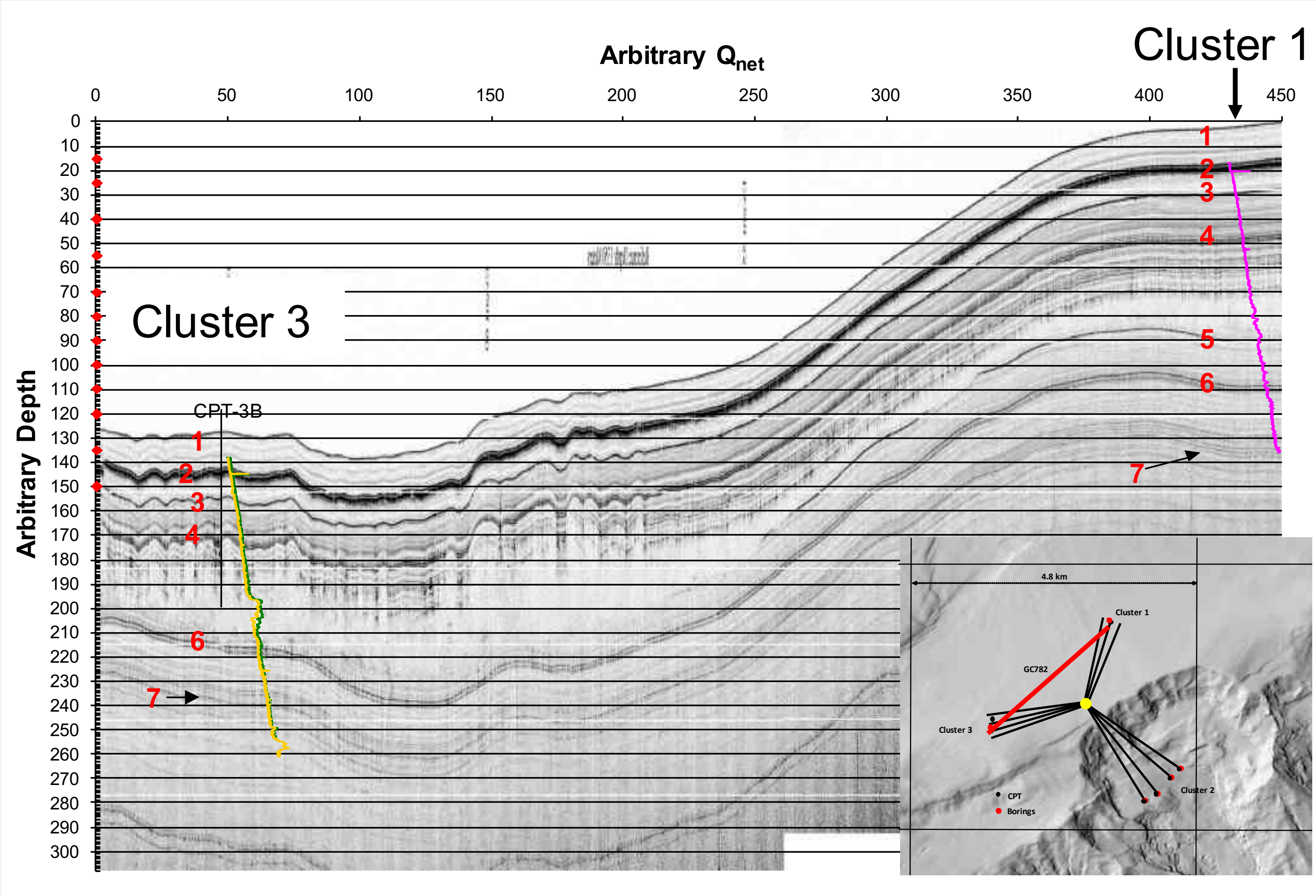


All the anchors were successfully installed to their target depths with appropriate sampling or extrapolation of data.

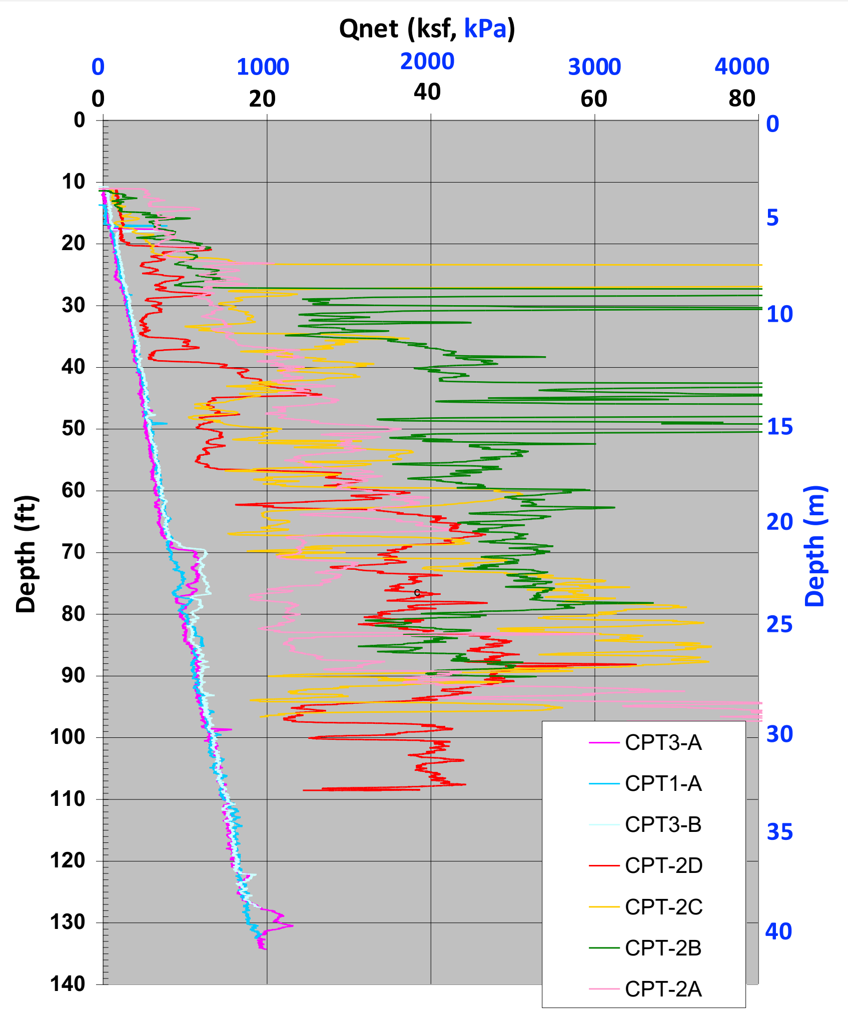
1 boring and CPT at each *anchor* location



Uniform Soil Stratigraphy between Pile Clusters 1 and 3

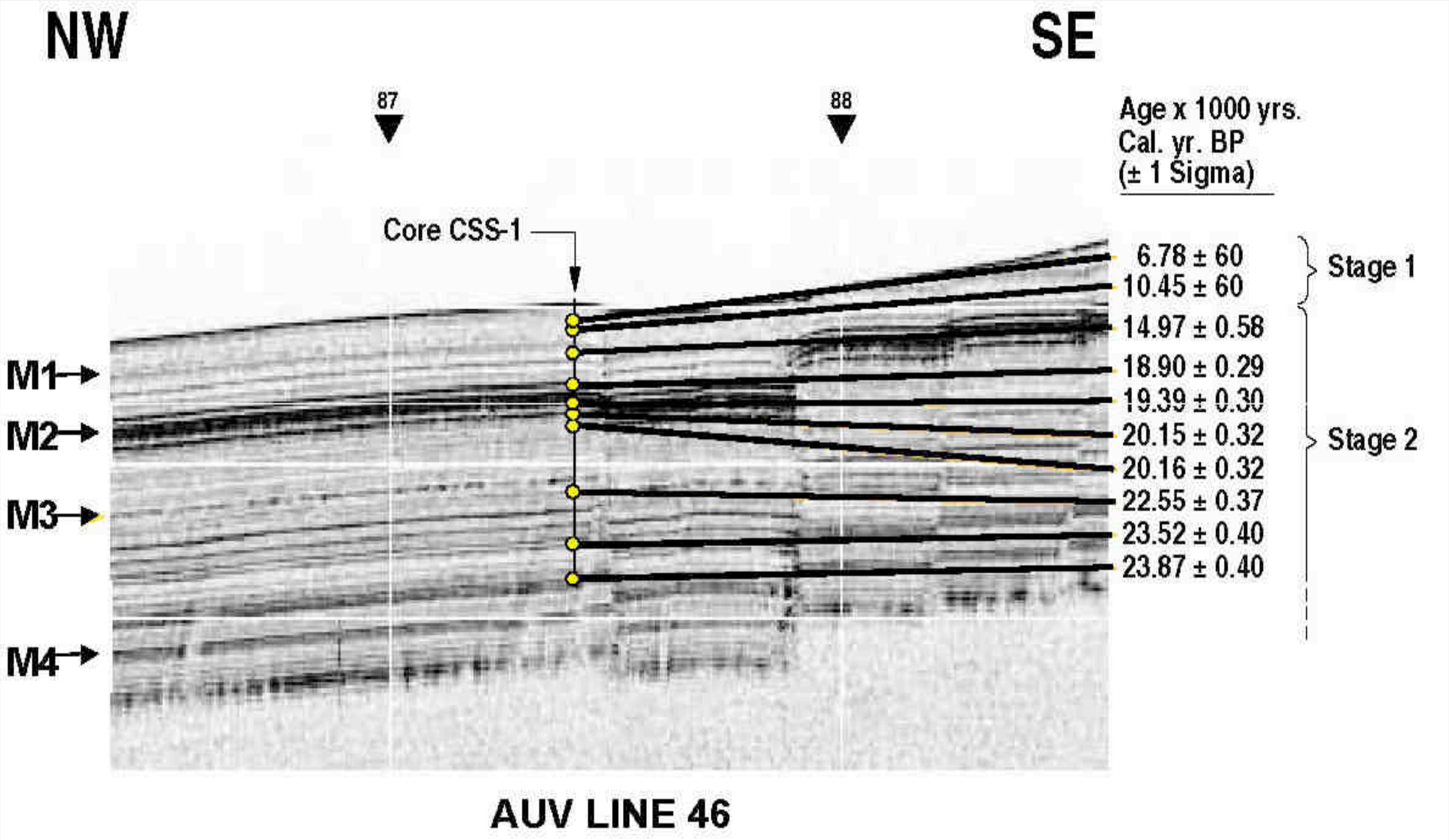


Comparison of 7 Mad Dog Soundings



Radiocarbon Analysis for Atlantis

Reference Core CSS-1



Objectives of Age Dating

- Provides understanding of spatial and temporal distribution of sediment stratigraphic units,
- Correlates sediment properties and lithologies to regionally persistent seismic reflectors, and
- Constrains past geological events (timing and frequency).

Ambiguous Regulatory Requirements

Minerals Management Service (MMS) Section 250.915b (2005) states.....

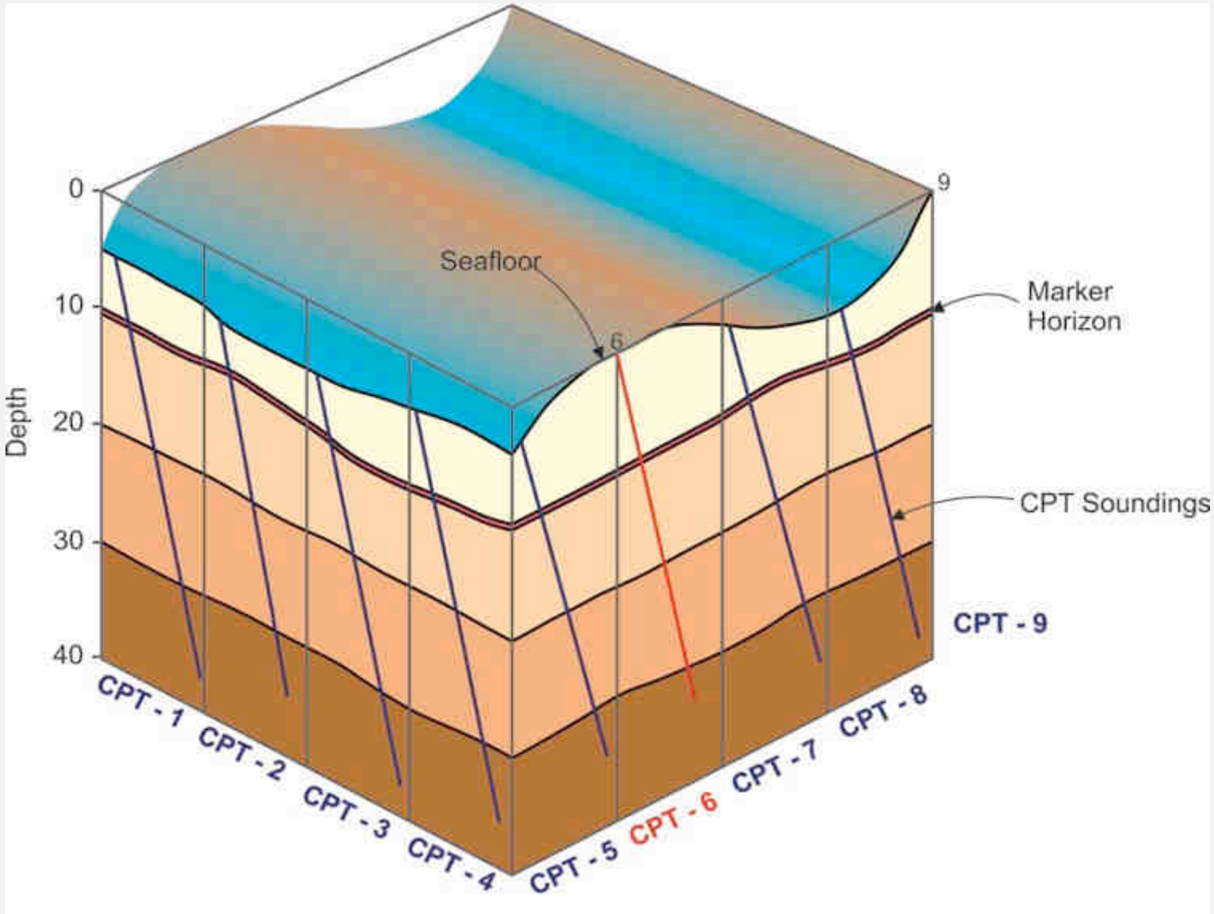
A boring must be taken at the most heavily loaded anchor location and at anchor points approximately 120° and 240° around the anchor pattern from the boring, and as necessary to establish a suitable soil profile.

Panel of Geotechnical Engineer Experts

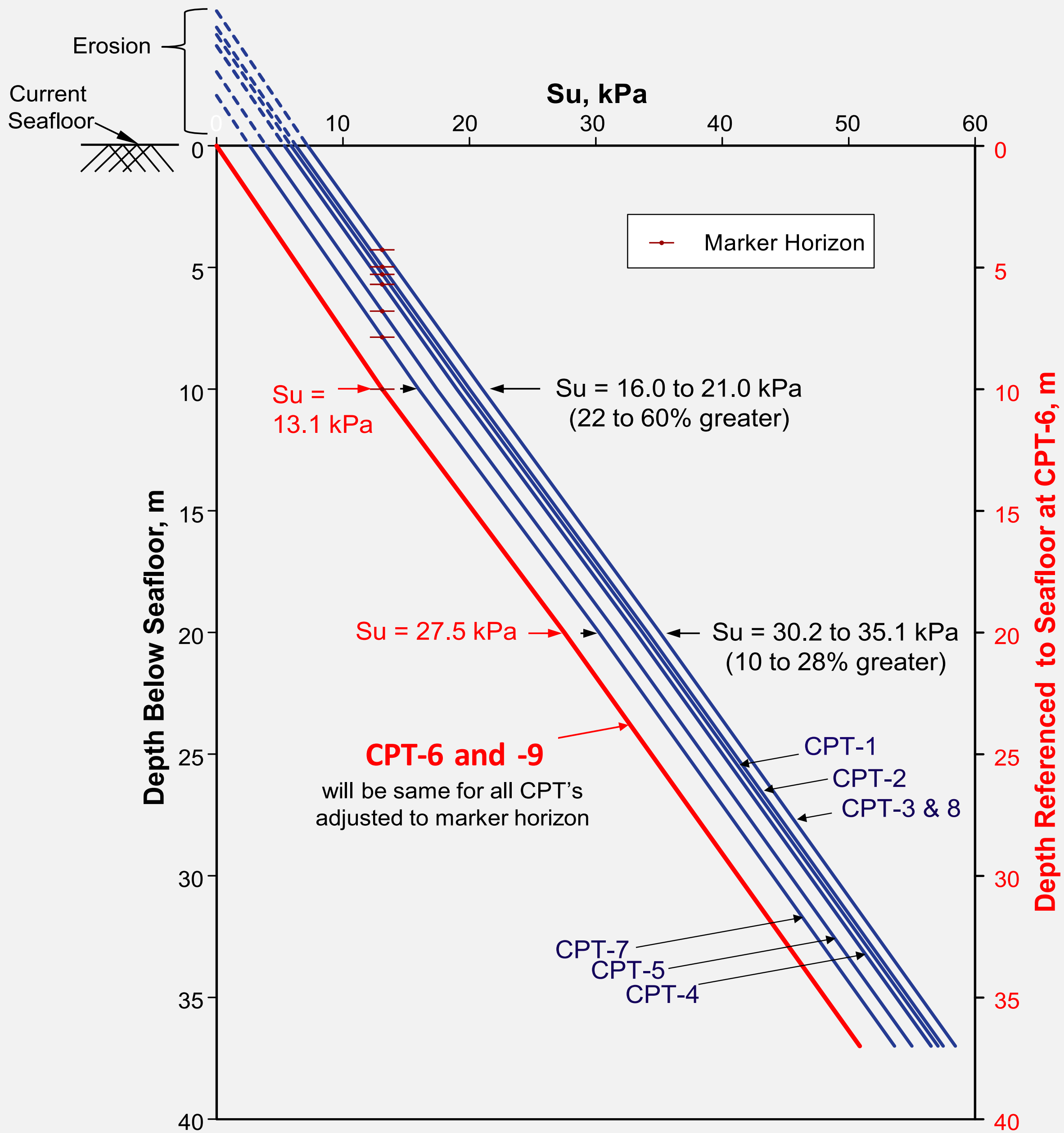
- Regulations are prescriptive in nature and do not take into consideration the site geology and the influence of site variability upon the required scope of the geotechnical investigation.

- Regulations should allow experienced engineers and geologists to serve their critical role in planning the scope of the site investigation.

Proper Reference Datum



SEAFLOOR VERSUS MARKER HORIZON
REFERENCE DATUM



Erosion
Current Seafloor
Su, kPa
0
10
20
30
40
50
60
Marker Horizon
Su = 13.1 kPa
Su = 16.0 to 21.0 kPa
(22 to 60% greater)
Su = 27.5 kPa
Su = 30.2 to 35.1 kPa
(10 to 28% greater)
CPT-6 and -9
will be same for all CPT's
adjusted to marker horizon
CPT-1
CPT-2
CPT-3 & 8
CPT-7
CPT-5
CPT-4
Depth Below Seafloor, m
Depth Referenced to Seafloor at CPT-6, m
5
15
25
35

Benefits of Integrated Geoscience Approach

- Existing data is used to maximum extent possible
- Provides information for design at an early stage
- Limits amounts of additional geophysical/ geotechnical data
- Decreases field acquisition time, thereby reducing field costs

Change Our Way of Thinking

- Geotechnical engineers often concentrate on defining engineering properties for a single site using widely scattered laboratory test data.

- Marine geologists focus on mapping “geohazards” and identifying seafloor constraints.

- When we change our way of collectively studying the seafloor; then an integrated study will reduce uncertainty in the overall design process.

“If you change the way you look at things, the things you look at change.”

Anonymous

“We must integrate the science of geology and geotechnics to master the art of seafloor engineering.

Young

Conclusions:

- Employ an interdisciplinary team of experts who understand the regional processes and geology structure.
- Use high-resolution geophysical data to develop 4D Geo-Site Model and reduce the scope of the geotechnical investigation.
- Perform age dating to constrain the timing of different depositional systems, establish sedimentation rates, and determine the timing and frequency of past geologic events.
- Conduct more CPT testing and less sampling and testing on samples in a soil boring.

Conclusions (cont.)

- Consider using N_{kt} of 17.5 to correlate with Quiros/SHANSEP DSS data to interpret Su in normally consolidated clays.
- The CPT, SHANSEP, and Quiros data should be used to select the design strength profile instead of relying upon widely scattered laboratory test data.
- Confirm regulations are not too prescriptive and allow experienced engineers and geologists to plan the scope of the site investigations.

Dedication and Acknowledgements

The paper is dedicated to Bram McClelland and Melinda Young – two special people that strongly influenced my life since 1971.

Ms. Jill Rivette motivated me and assisted with the text, figures, references, and other details of the paper.

My special thanks to some special mentors for helping to review and edit the text that included Dr. Don Murff, Dr. Philippe Jeanjean, Dr. Niall Slowey, Dr. Bernie Bernard, and Mr. Earl Doyle.