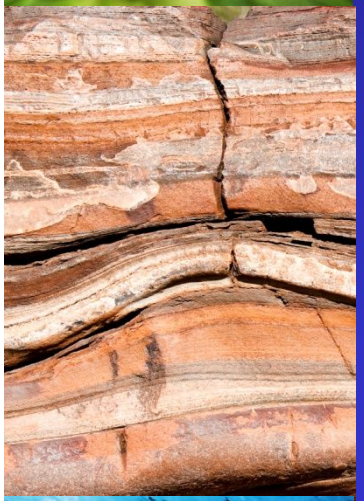
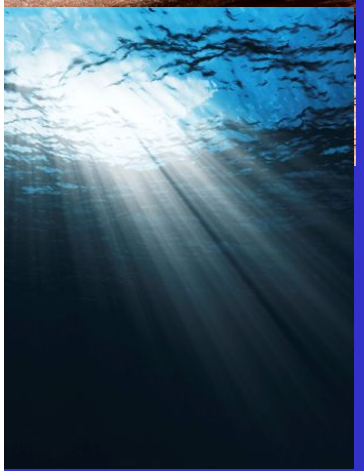




CPT Interpretation - Soil Type

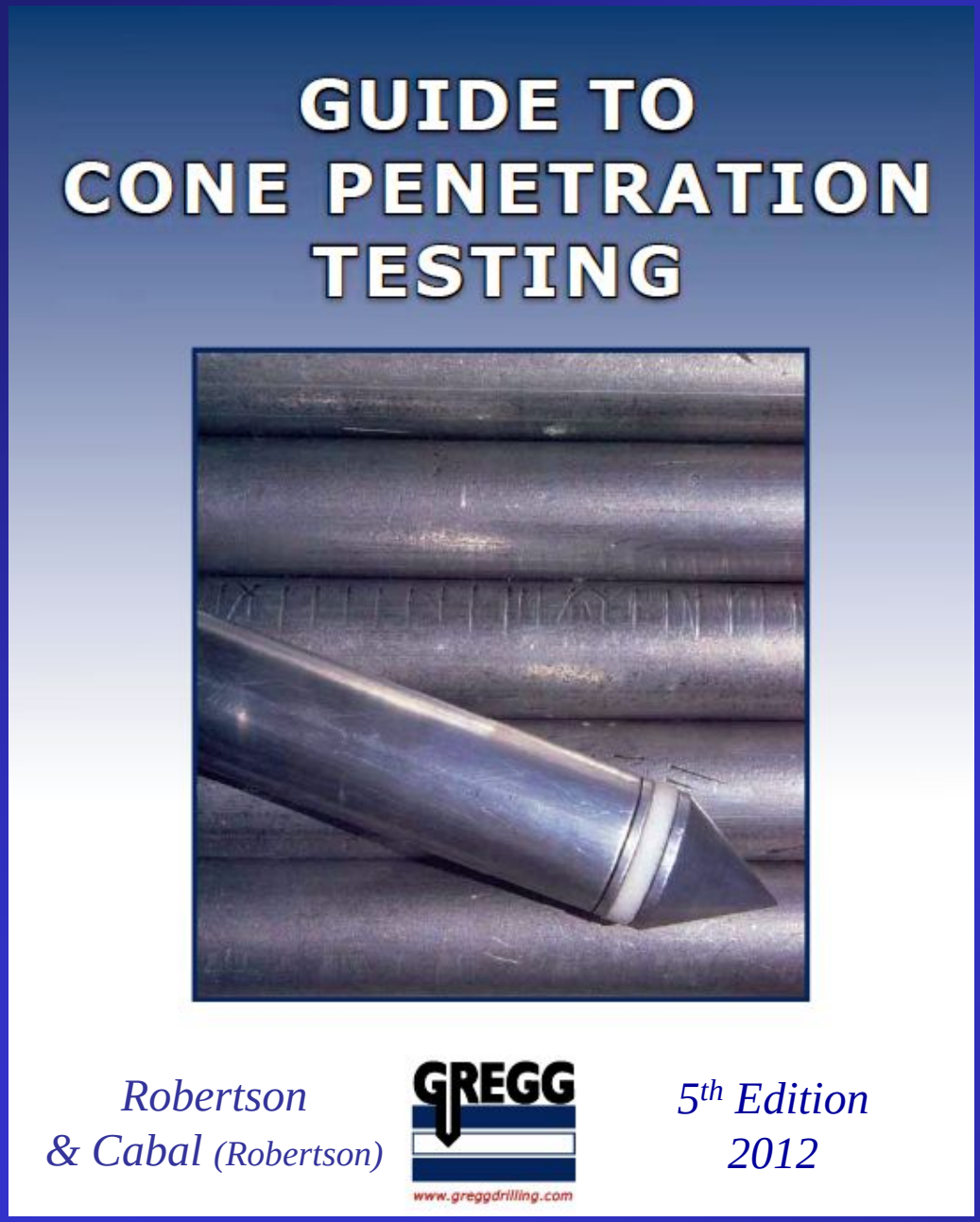
Peter K. Robertson

CPT in Geotechnical Practice

Santiago, Chile

July, 2014

FACULTAD DE CIENCIAS FÍSICAS Y MATEMÁTICAS UNIVERSIDAD DE CHILE



CPT Guide

5th Edition

Download ***FREE*** copy from:

www.greggdrilling.com
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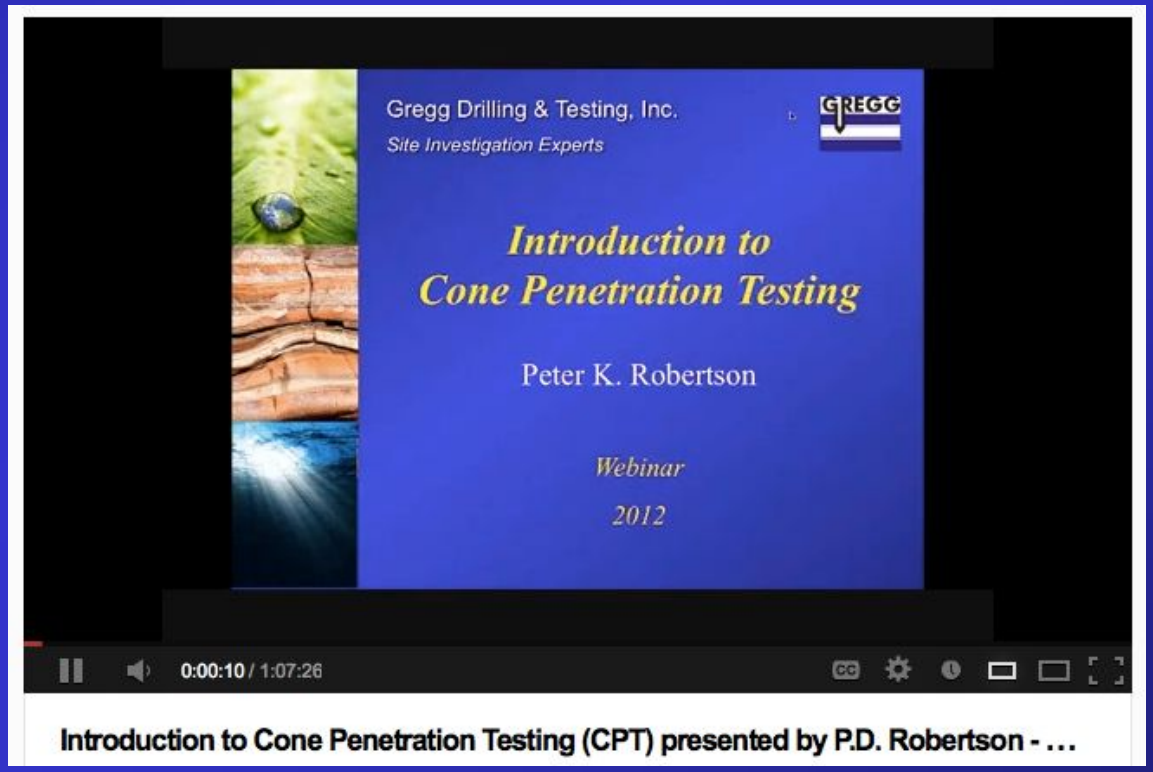
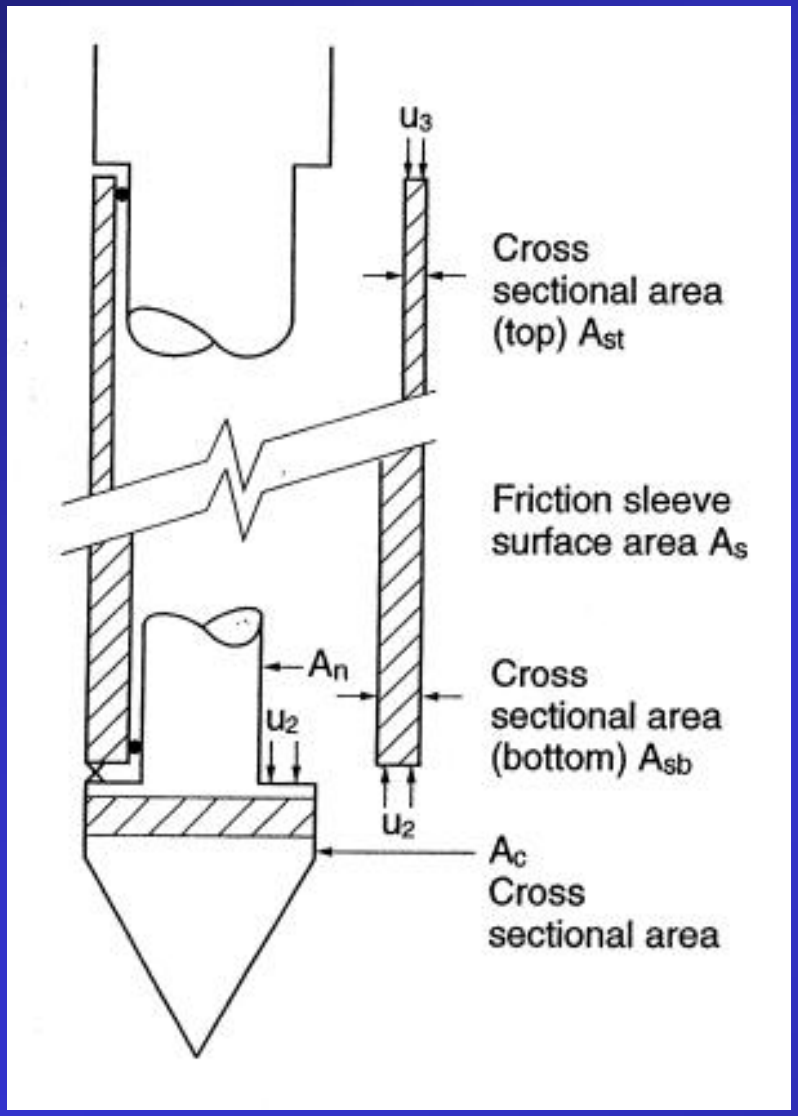
Webinars

Recordings of previous webinars are available on YouTube: search for '***CPT Robertson***' or

http://www.youtube.com/watch?v=alrzeelWpZc



Unequal End Area Effects on q_c



$$q_t = q_c + u_2(1-a)$$

a = 0.60 to 0.85

a = tip net area ratio
~ A_n/A_c

In sands: $q_t = q_c$

In very soft clays:
correction to q_t is important

Cones should have high net area ratio
a > 0.8

Role of CPT

CPT has three main applications:

- Determine sub-surface stratigraphy and identify materials present ***(Soil Type – SBT)***
- Estimate soil parameters
- Provide results for direct geotechnical design

Primary role is soil profiling and can be supplemented by samples, other in-situ tests and laboratory testing

Robertson, 2014

CPTu Interpretation

Soil Type

- Soil behavior type (*SBT*) & stratigraphy

In-situ State

- Relative density (D_r) or State Parameter (ψ) and *OCR*

Strength

- Peak friction angle (ϕ') and undrained strength (s_u)

Stiffness/compressibility

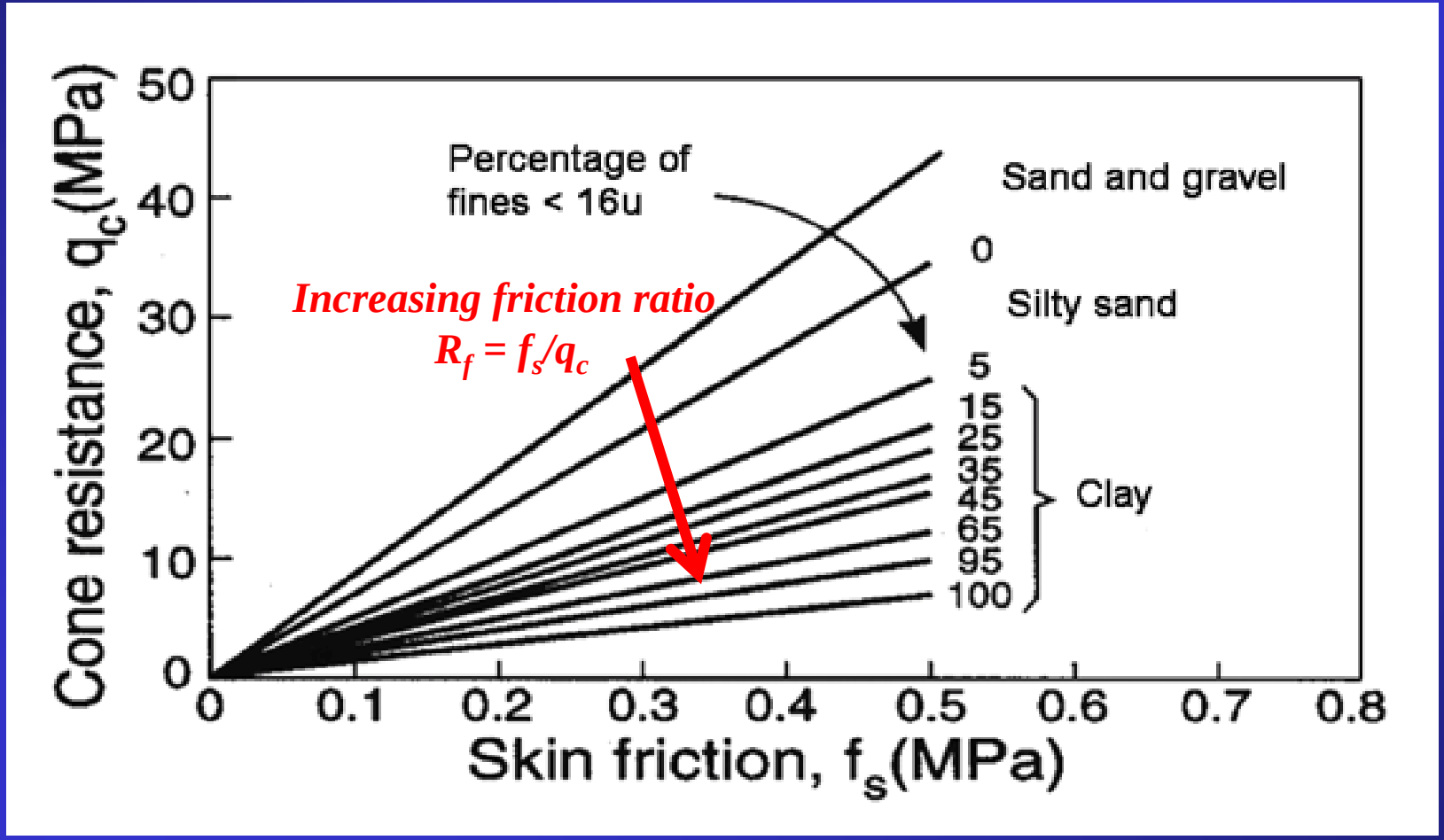
- Shear (G_o), Young's (E') and 1-D constrained (M)

Consolidation/permeability

- Coeff of consolidation (c_v) and permeability (k)

Robertson, 2014

First CPT 'soil classification' chart

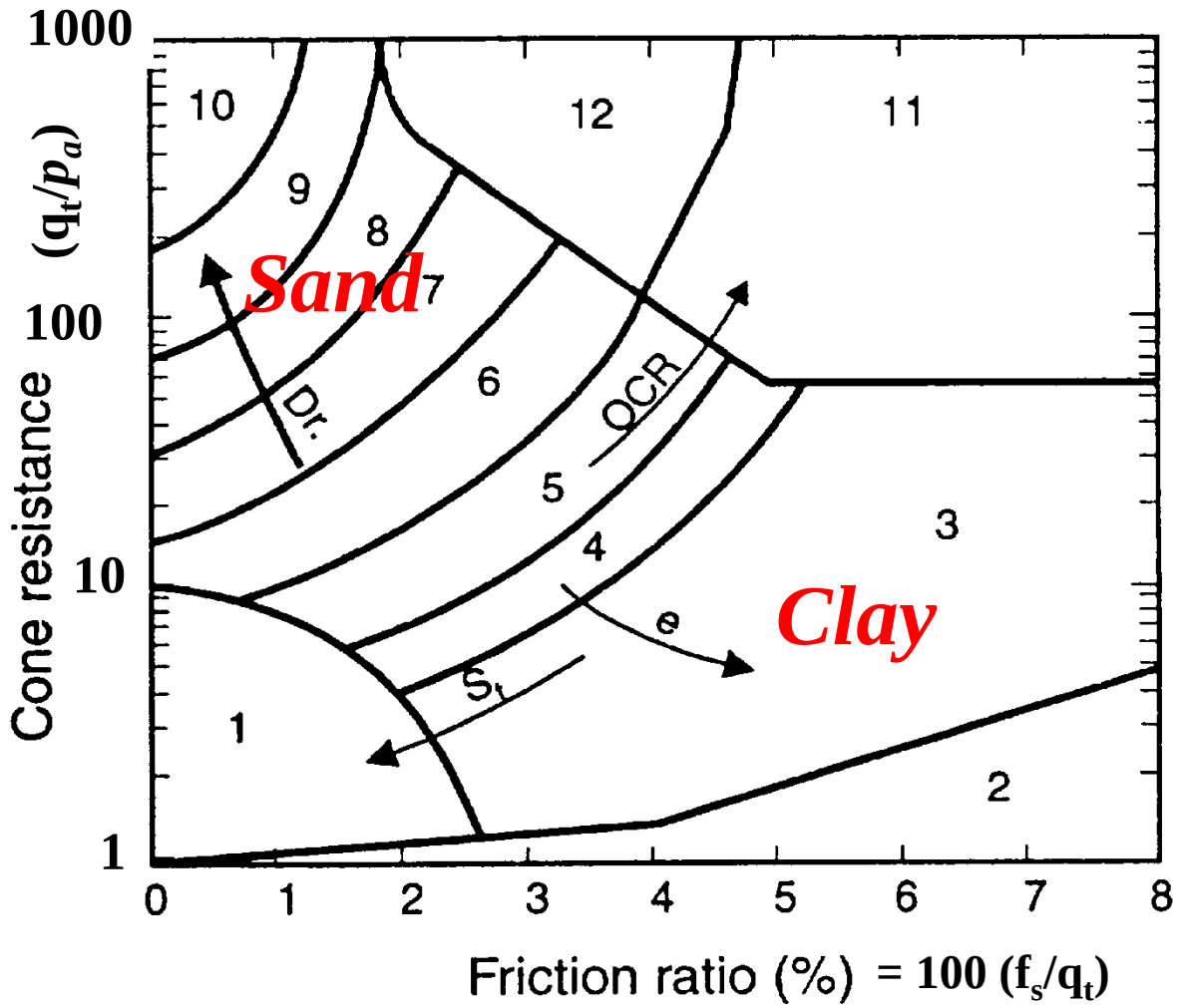


Begemann (1965) type mechanical cone

CPT-based "classification"

- CPT measurements are influenced by ***in-situ behavioral characteristics***, such as strength, stiffness and compressibility. These characteristics are controlled primarily by soil state, in-situ effective stresses, stress history, age, and cementation, as well as mineralogy.
- Traditional soil classification systems are based on ***physical characteristics*** obtained on ***remolded samples***, such as grain size, fines content and plasticity. These characteristics are controlled primarily by depositional environment and geology.

Soil Behaviour Type (SBT) Chart



Zone	Soil behaviour type
1	Sensitive fine grained
2	Organic material
3	Clay
4	Silty Clay to clay
5	Clayey silt to silty clay
6	Sandy silt to clayey silt
7	Silty sand to sandy silt
8	Sand to silty sand
9	Sand
10	Gravelly sand to sand
11	Very stiff fine grained*
12	Sand to clayey sand*

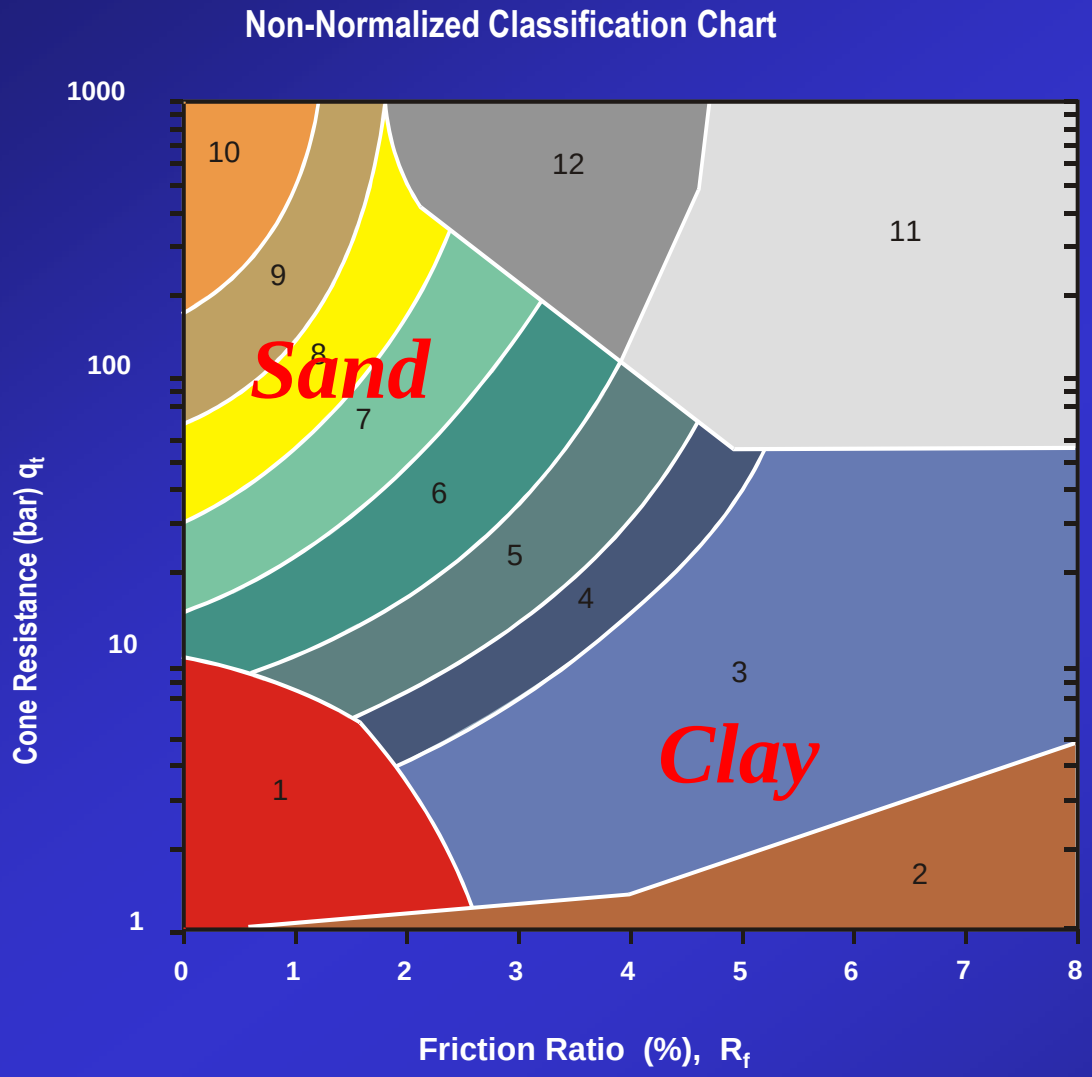
* Overconsolidated or cemented

SBT

Robertson & Campanella, 1986

Note: 1 tsf ~ 0.1 MPa

CPT - Soil Behavior Type (SBT)



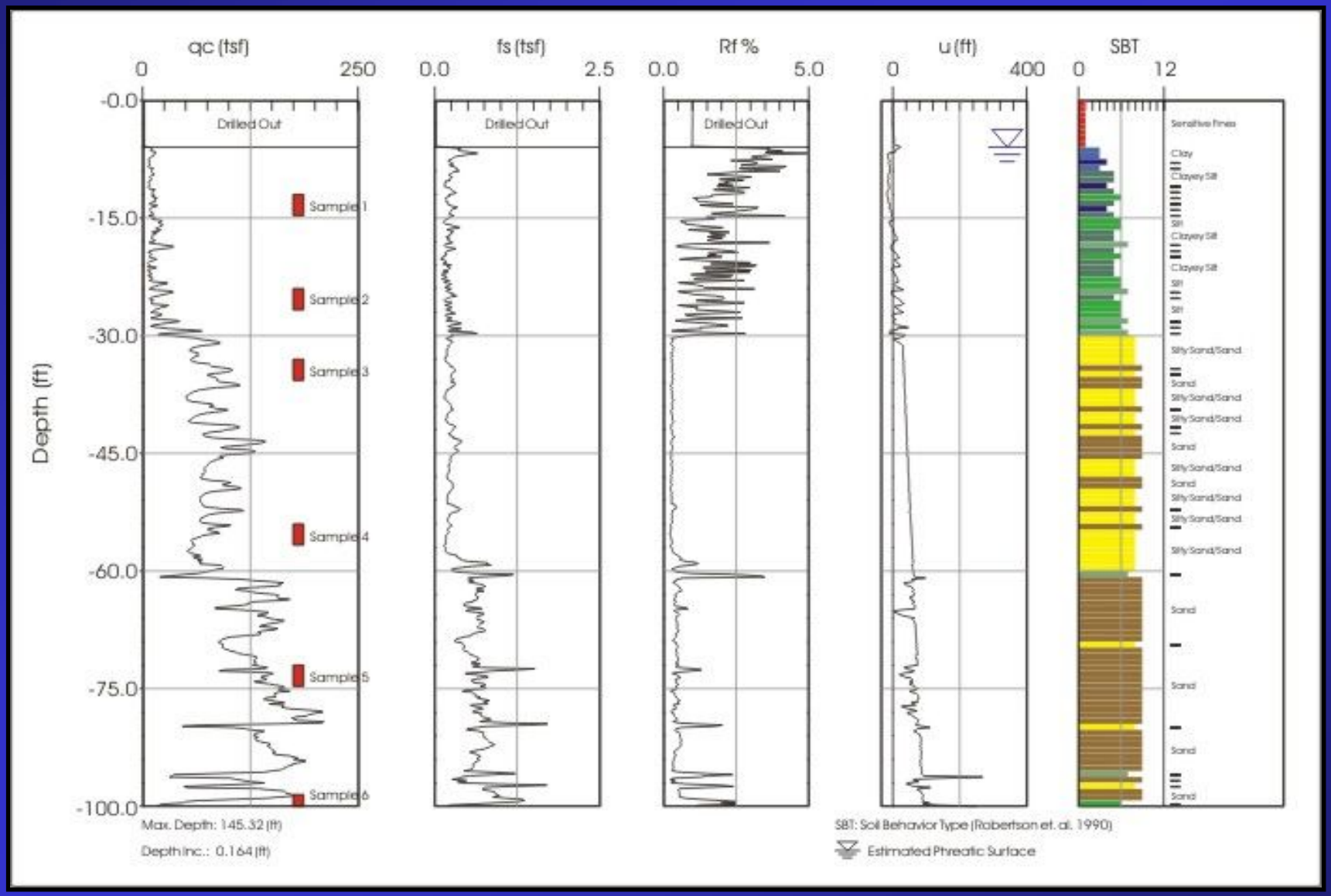
CPT SBT based on in-situ soil behavior (strength, stiffness, compressibility) - not the same as classification based Atterberg Limits and grain size carried out on disturbed samples

Robertson & Campanella, 1986

Note: 1 bar ~ 1 tsf ~ 0.1 MPa

Robertson, 2014

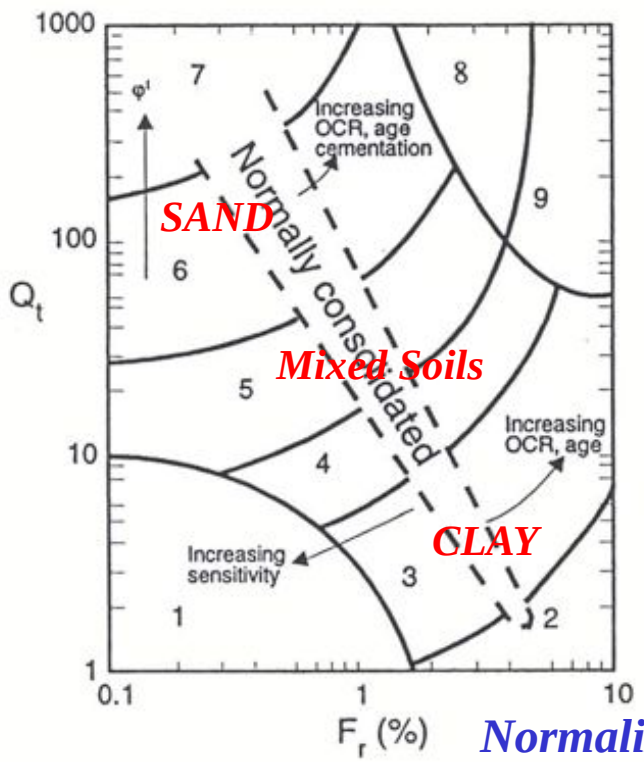
CPT Data Presentation

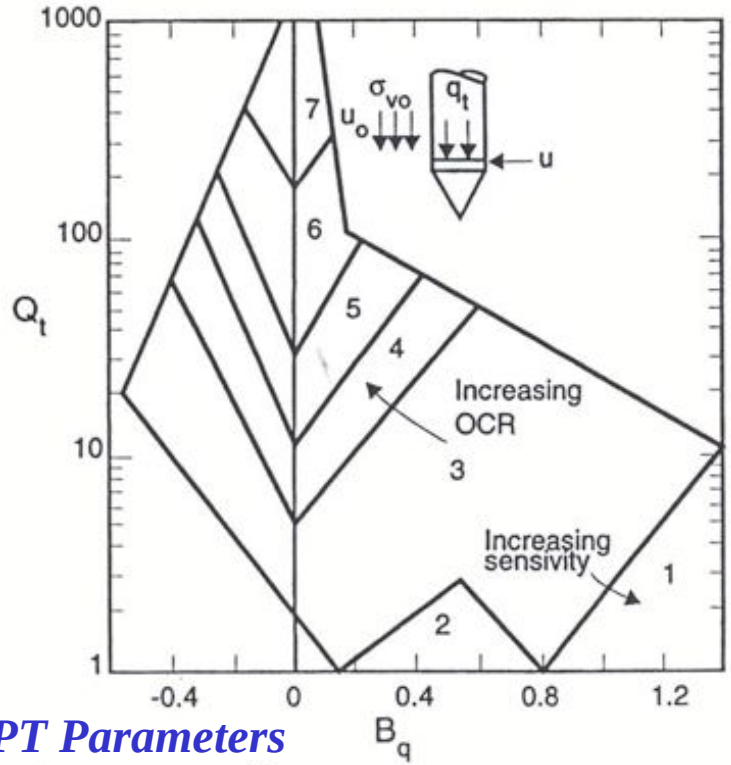


Example CPTu Plot

Robertson, 2014

Normalized SBTn Charts





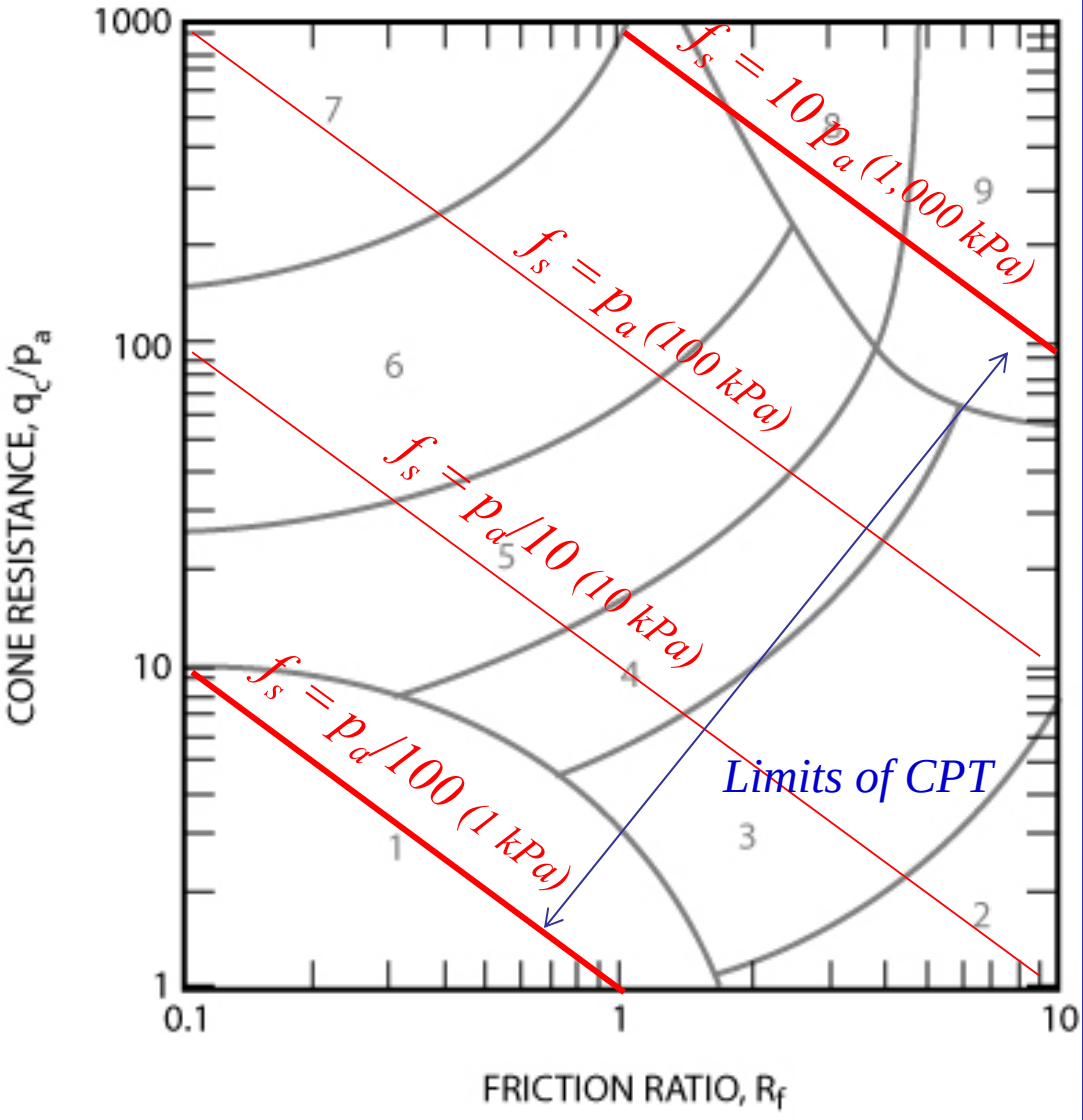
Normalized CPT Parameters

$$Q_t = \frac{q_t - \sigma_{vo}}{\sigma'_{vo}} \qquad B_q = \frac{u_2 - u_o}{q_t - \sigma_{vo}} \qquad F_r = \frac{f_s}{q_t - \sigma_{vo}} \times 100\%$$

Robertson, 1990

Zone	Soil behaviour type
1.	Sensitive, fine grained;
2.	Organic soils-peats;
3.	Clays-clay to silty clay;
4.	Silt mixtures clayey silt to silty clay
5.	Sand mixtures; silty sand to sand silty
6.	Sands: clean sands to silty sands
7.	Gravelly sand to sand;
8.	Very stiff sand to clayey sand
9.	Very stiff fine grained

Dimensionless SBT chart



In 2010 Robertson (CPT'10) updated the SBT chart to use dimensionless parameters and to simplify the chart to 9 zones to be consistent with the normalized SBT chart (Robertson, 1990)

p_a = atmospheric pressure = 100 kPa = 1 tsf

Robertson, 2014

Proposed common SBT zones

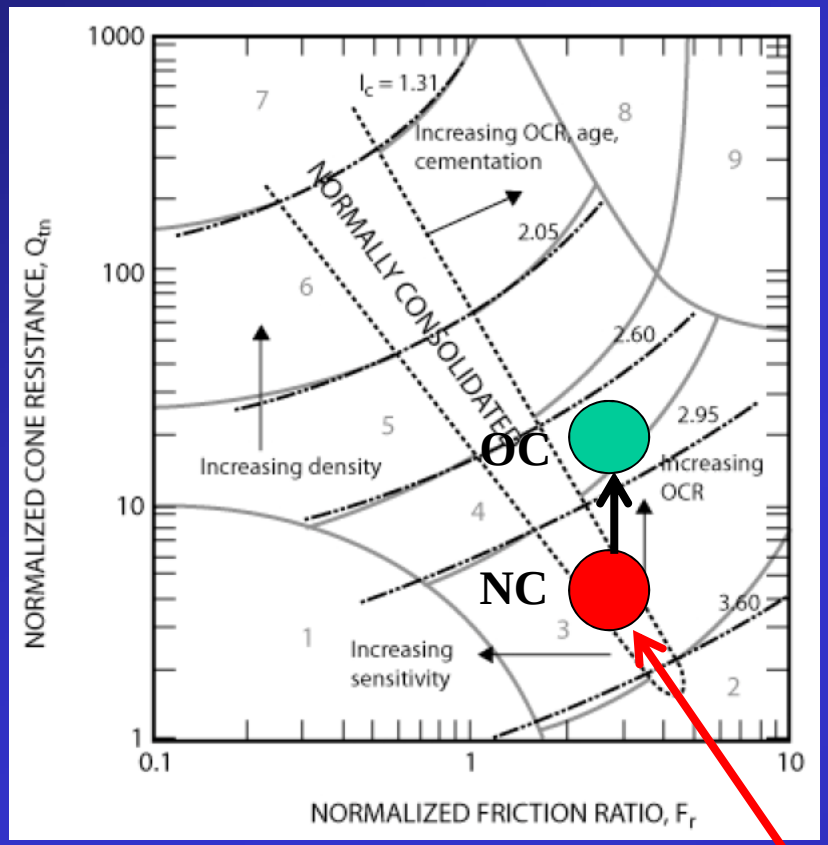
SBT zone Robertson et al (1986)	SBTn zone Robertson (1990)	Proposed common SBT description
1	1	Sensitive fine-grained
2	2	Clay: organic soil
3	3	Clays: clay to silty clay
4 & 5	4	Silt mixtures: clayey silt & silty clay
6 & 7	5	Sand mixtures: silty sand to sandy silt
8	6	Sands: clean sand to silty sand
9 & 10	7	Dense sand to gravelly sand
12	8	Stiff sand to clayey sand*
11	9	Stiff fine-grained*

Robertson, 2010

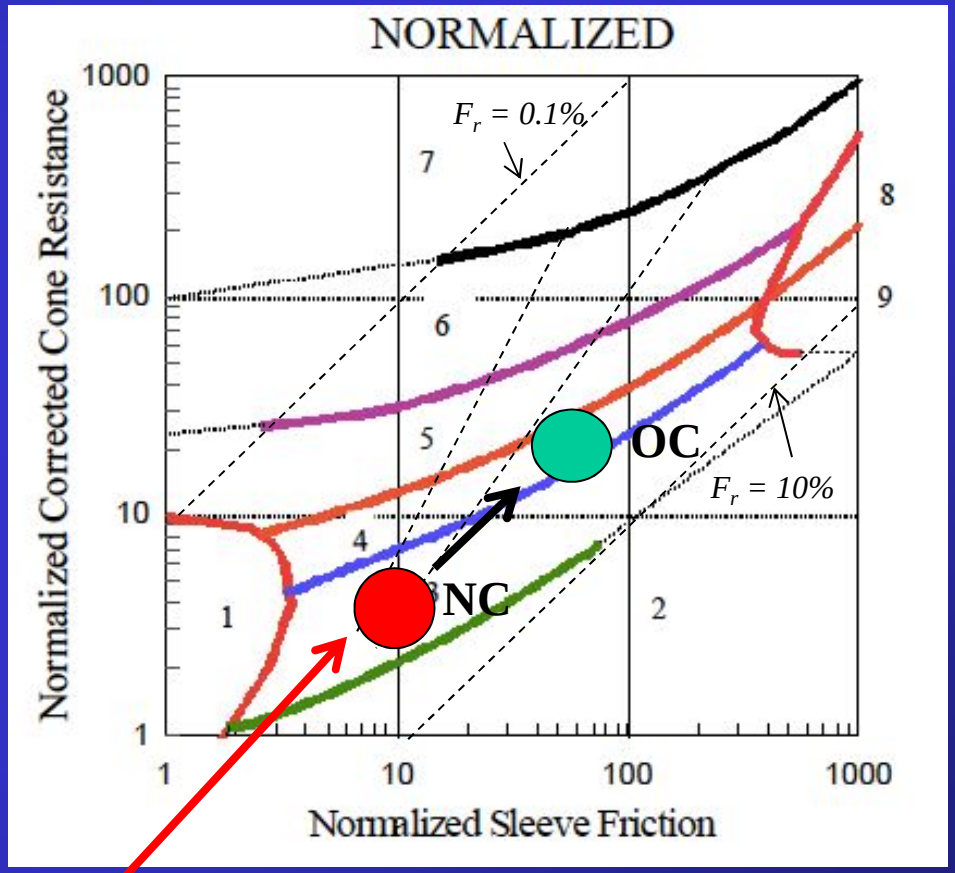
Robertson, 2014

Why Friction Ratio (f_s/q_t)?

$Q_t = (q_t-\sigma_{vo})/\sigma'_{vo}$



$Q_t = (q_t-\sigma_{vo})/\sigma'_{vo}$

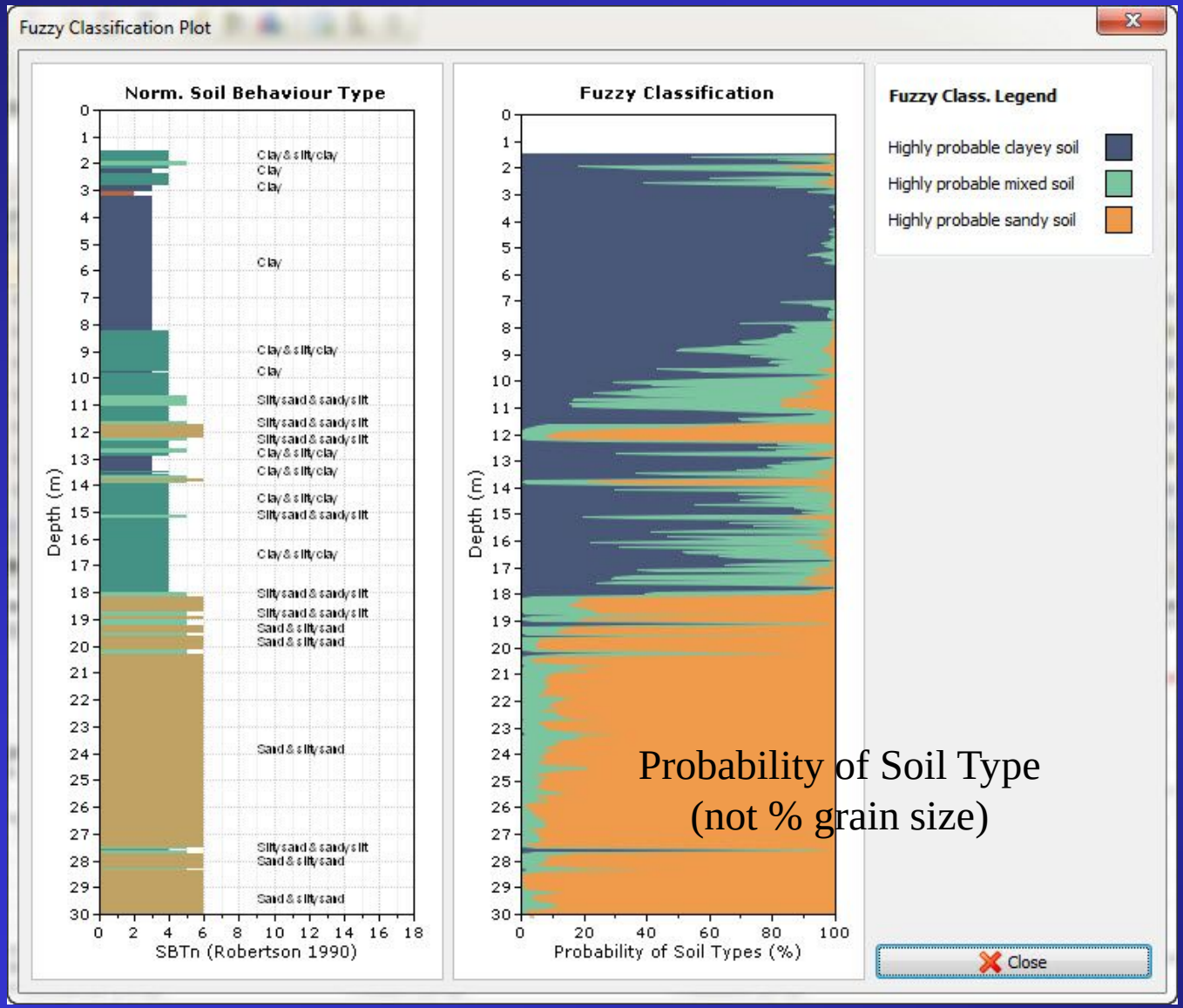


$F_r = 100[f_s/(q_t-\sigma_{vo})]$

$F = 100(f_s/\sigma'_{vo})$

Normally to OC consolidated clay, friction ratio, F_r ~ constant

Tumay Fuzzy-logic SBT

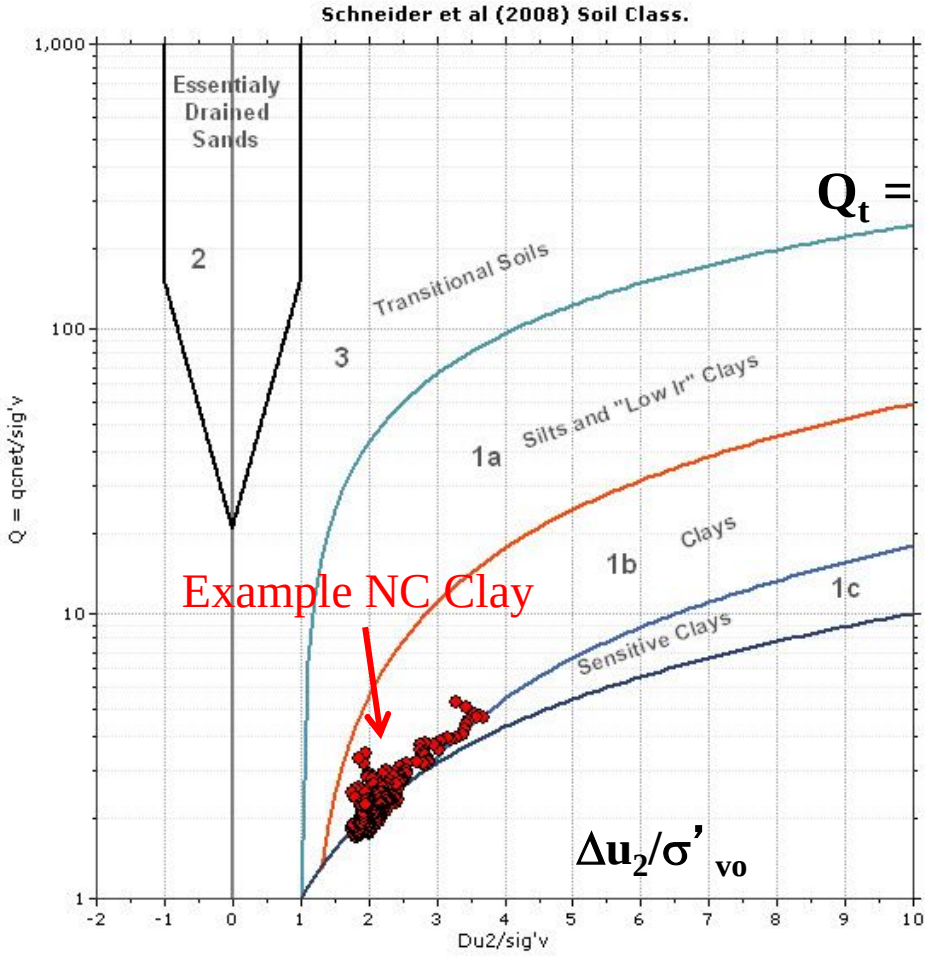


Probability of Soil Type
(not % grain size)

Applies fuzzy logic to SBT

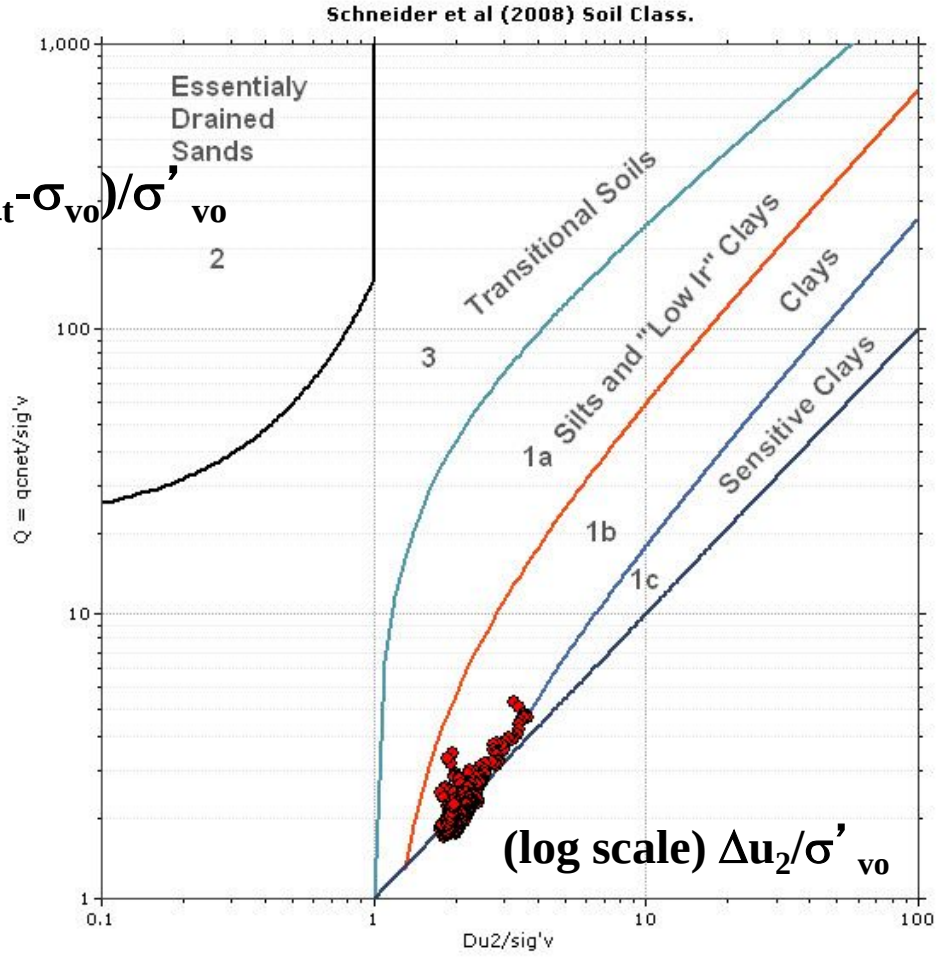
Robertson, 2014

Schneider et al (2008) chart



$$Q_t = (q_t - \sigma_{vo})/\sigma'_{vo}$$

$$\Delta u_2/\sigma'_{vo}$$

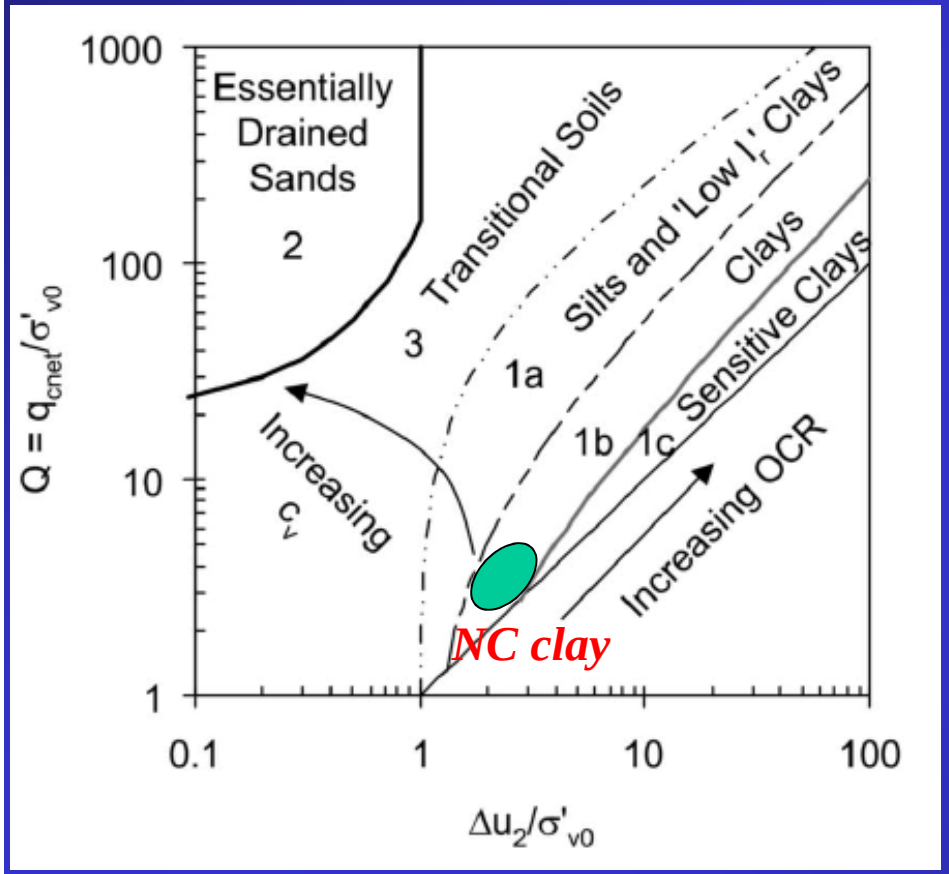


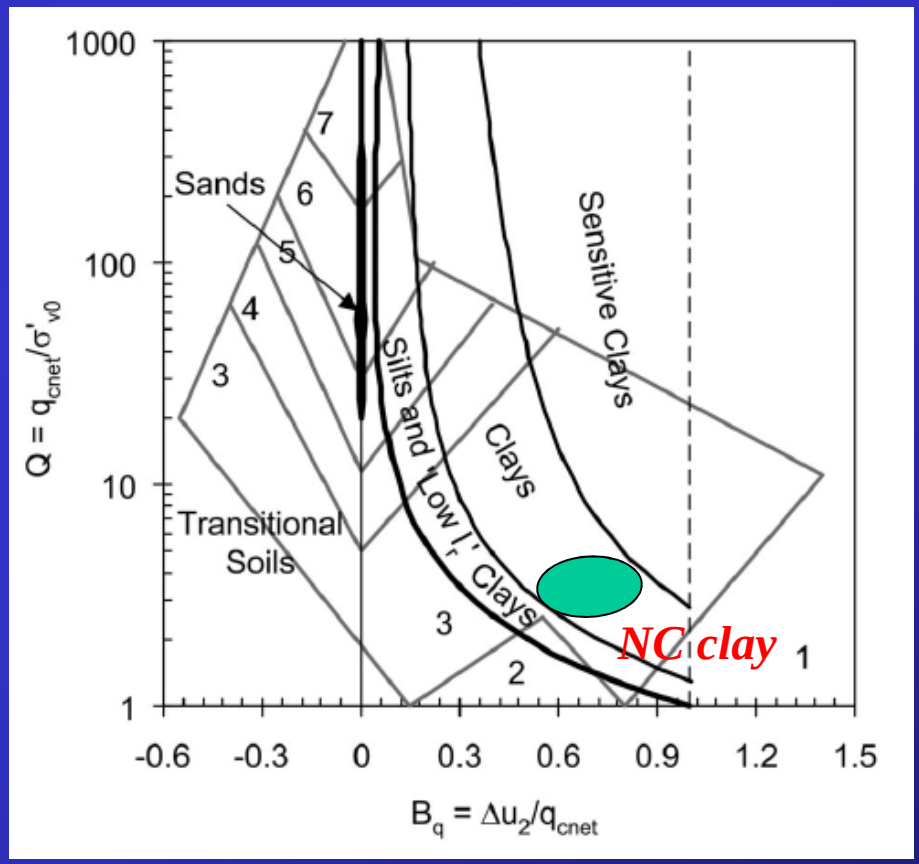
(log scale) $\Delta u_2/\sigma'_{vo}$

Combines normalized cone resistance (Q) and excess pore pressure ($\Delta u/\sigma'_v$)
Good offshore – less effective on-shore, where saturation can not be assured

Robertson, 2014

Compare pore pressure charts

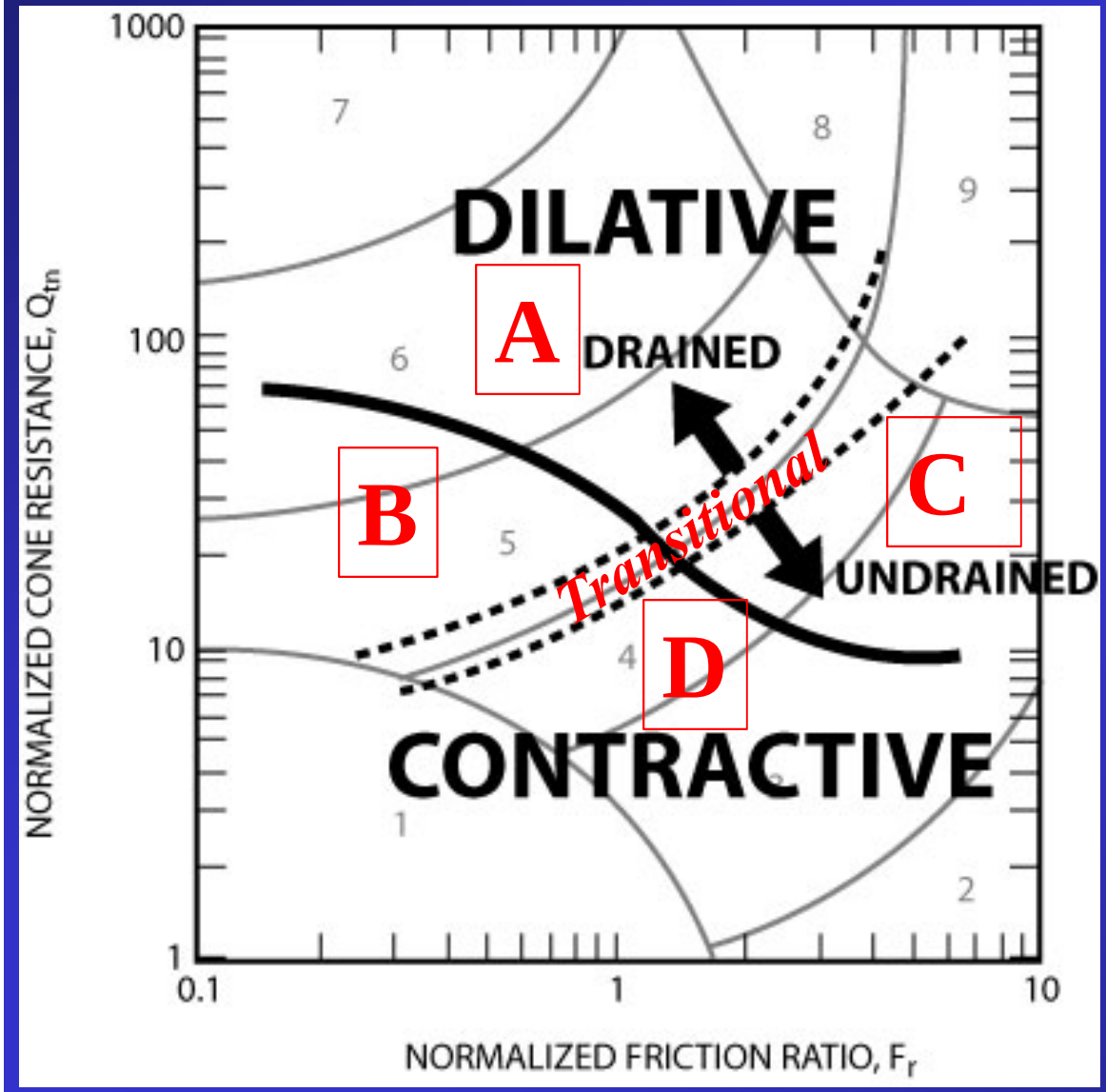




Schneider et al, 2008

Modified Robertson (1990)

Generalized CPT Soil Behaviour Type



CPT Soil Behaviour

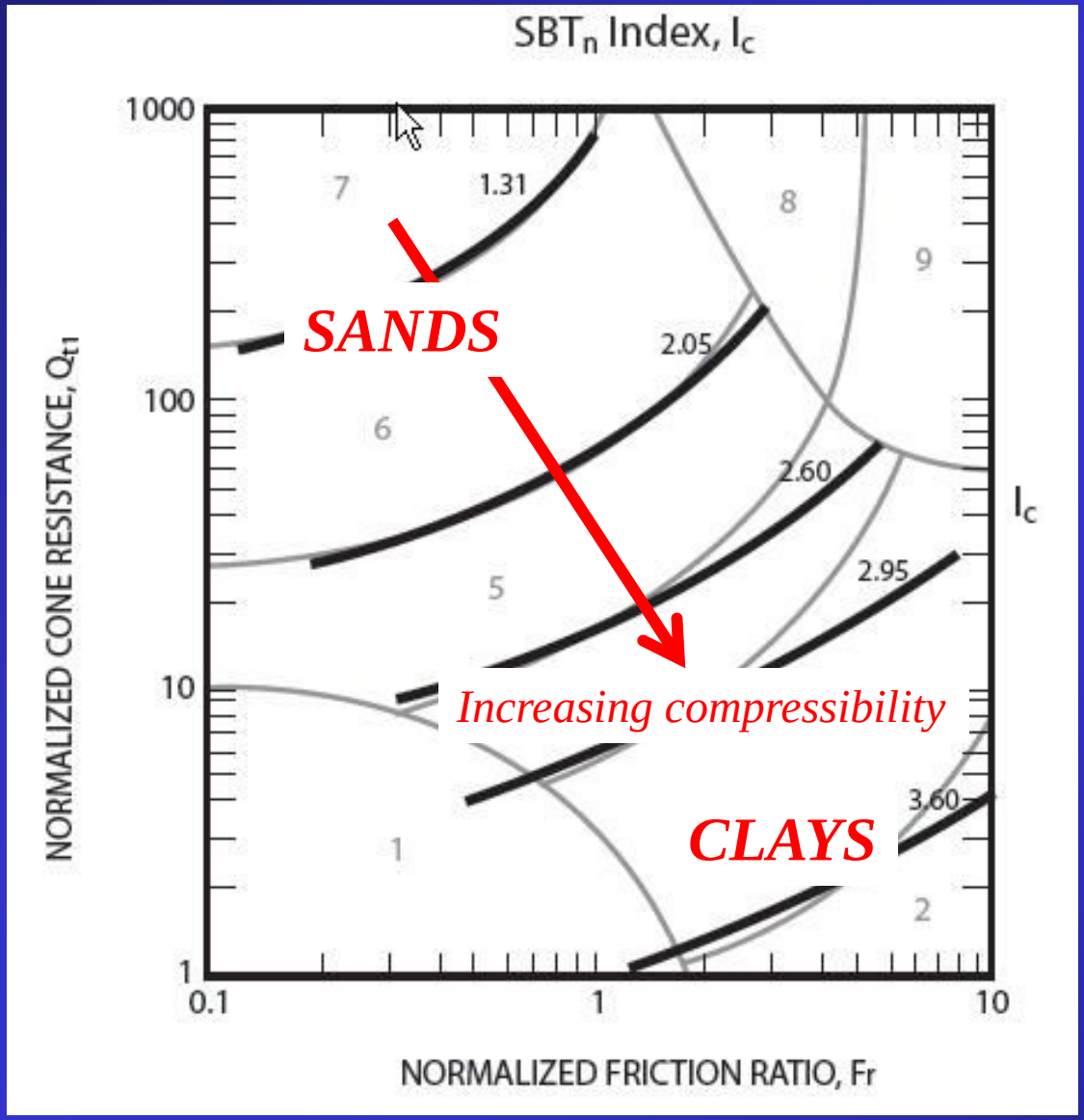
A: Coarse-grain-dilative

B: Coarse-grain-contractive

C: Fine-grain-dilative

D: Fine-grain-contractive

CPT SBT Index, I_c



Soil Behavior Type Index, I_c

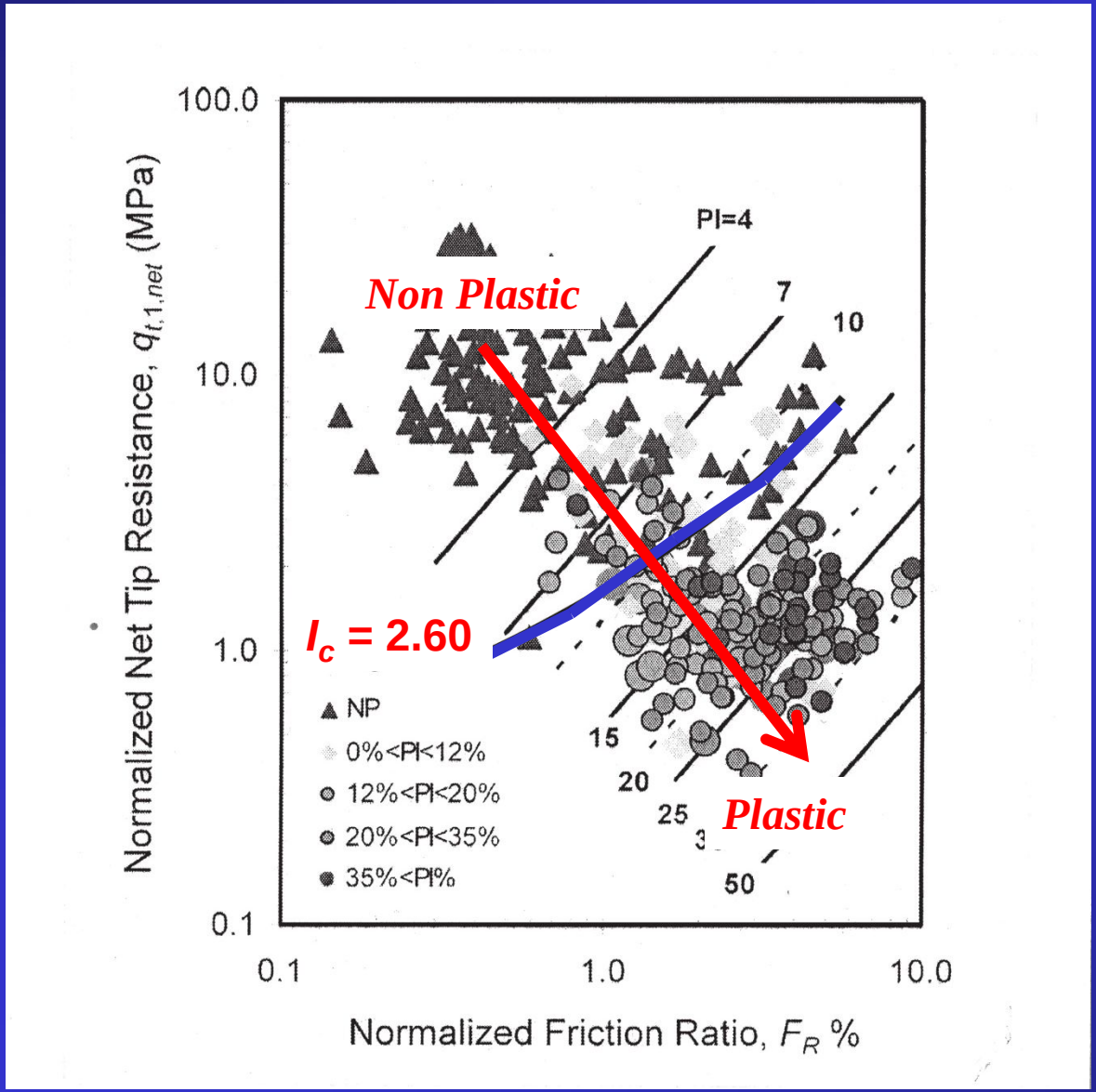
$Ic = [(3.47 - \log Q)^2 + (\log F + 1.22)^2]^{0.5}$

Function primarily of Soil Compressibility

I_c > 2.60 predominately fine grained 'clay-like' soil

Robertson, 2014

SBT from CPT



Plasticity Index as function of SBT I_c

Boundary between *sand-like* and *clay-like* soils is PI ~ 10

When I_c < 2.60
95% samples NP
84% with PI < 12%

Data from Cetin & Ozan, 2009

Robertson, 2014

CPT Normalization

- Early normalization based on theory for clays

$$Q_t = (q_t - \sigma_v) / \sigma'_v$$

- Recently normalization based on soil type, density and stress level

$$Q_{tn} = [(q_t - \sigma_v)/p_a] (p_a/\sigma'_v)^n$$

Where:

$(q_t - \sigma_v)/p_a$ = dimensionless net cone resistance,

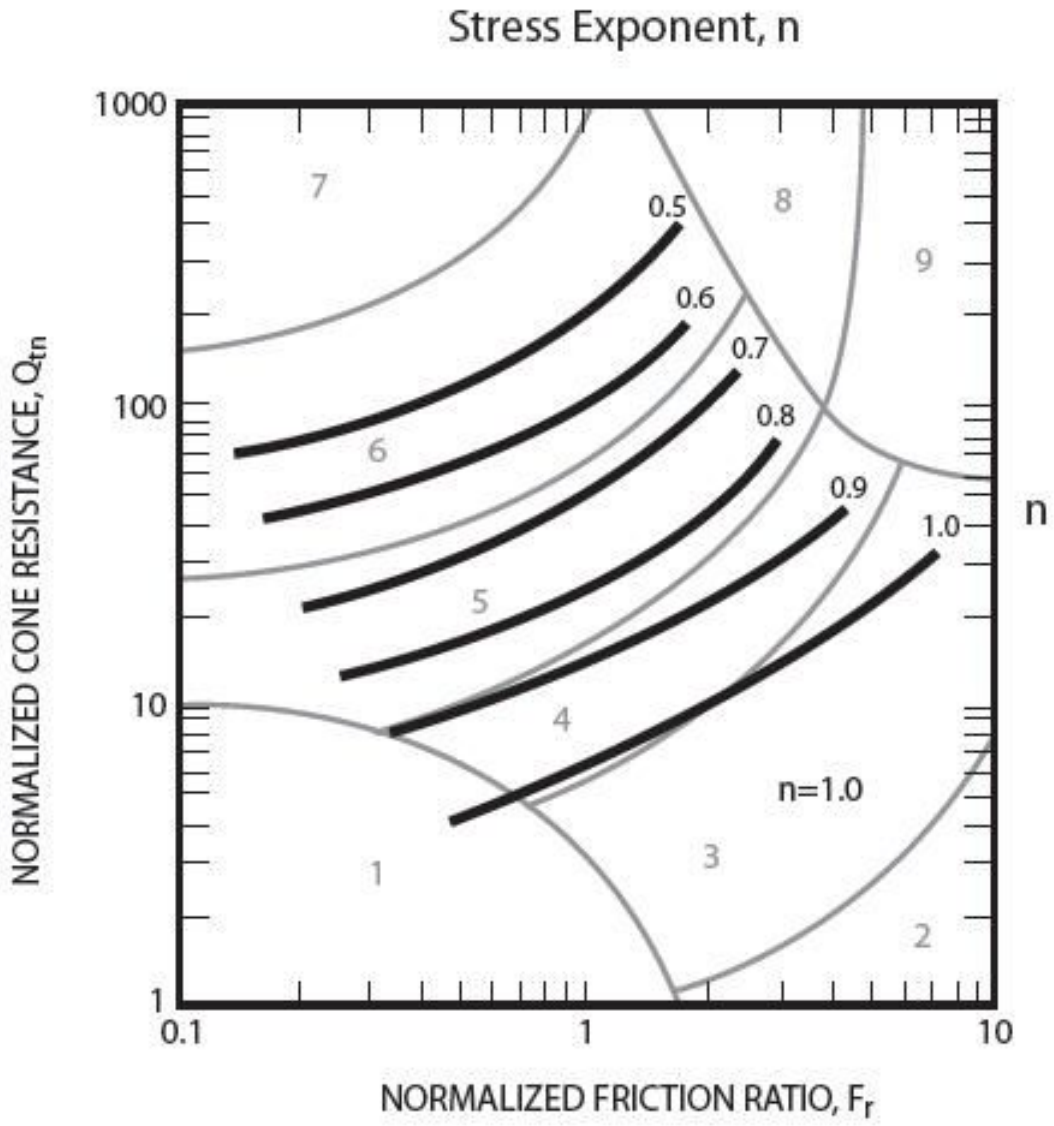
$(p_a/\sigma'_v)^n$ = stress normalization factor

n = stress exponent that varies with soil type, density & stress level

p_a = atmospheric pressure in same units as q_t and σ_v

Robertson, 2014

CPT Normalization



$$Q_{tn} = [(q_t - \sigma_v)/p_a] \, (p_a/\sigma'_{vo})^n$$

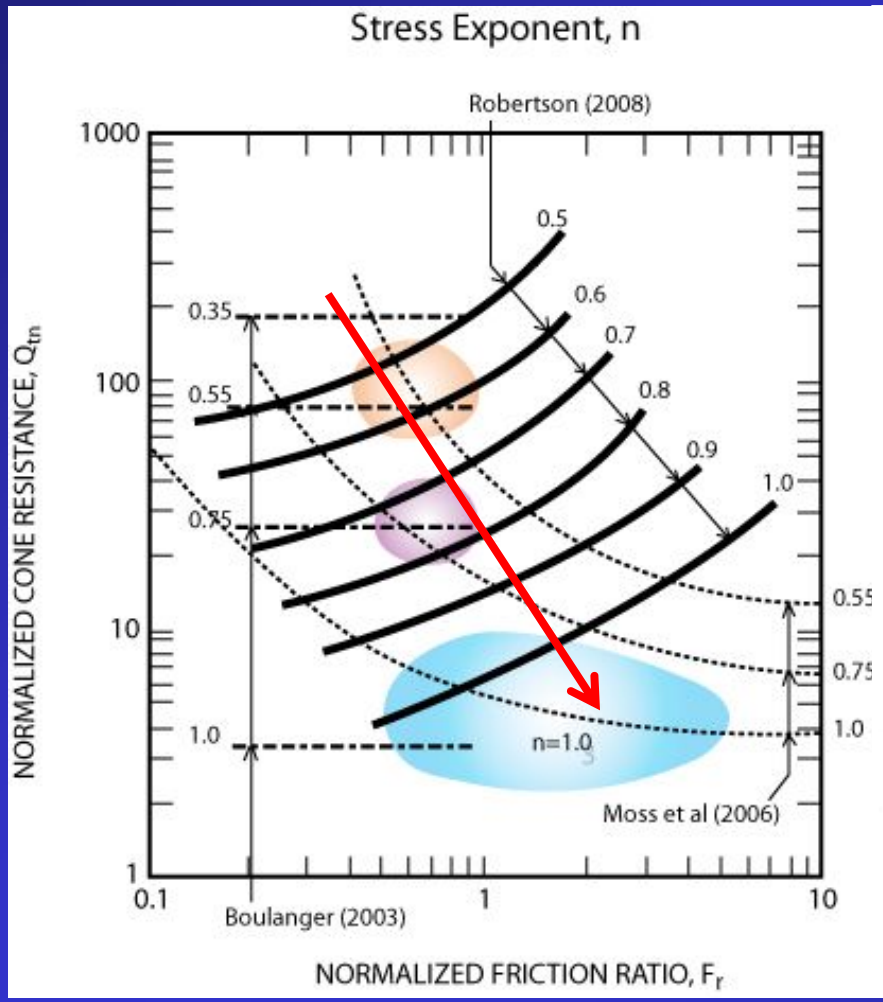
$n = 0.381 \, (I_c) + 0.05 \, (\sigma'_{vo}/p_a) - 0.15$

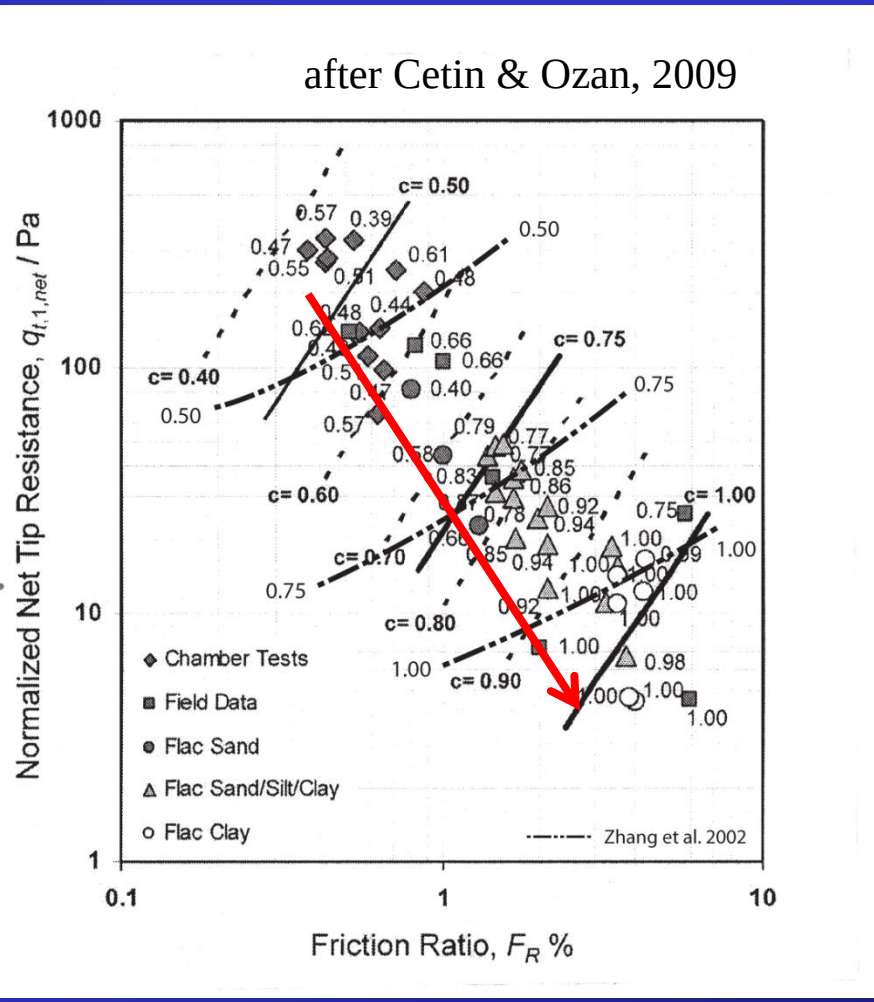
where $n \leq 1.0$

If stress normalization correct - no need for additional stress level corrections (e.g. K_s)

Robertson, 2014

Compare stress normalization





Robertson, 2014

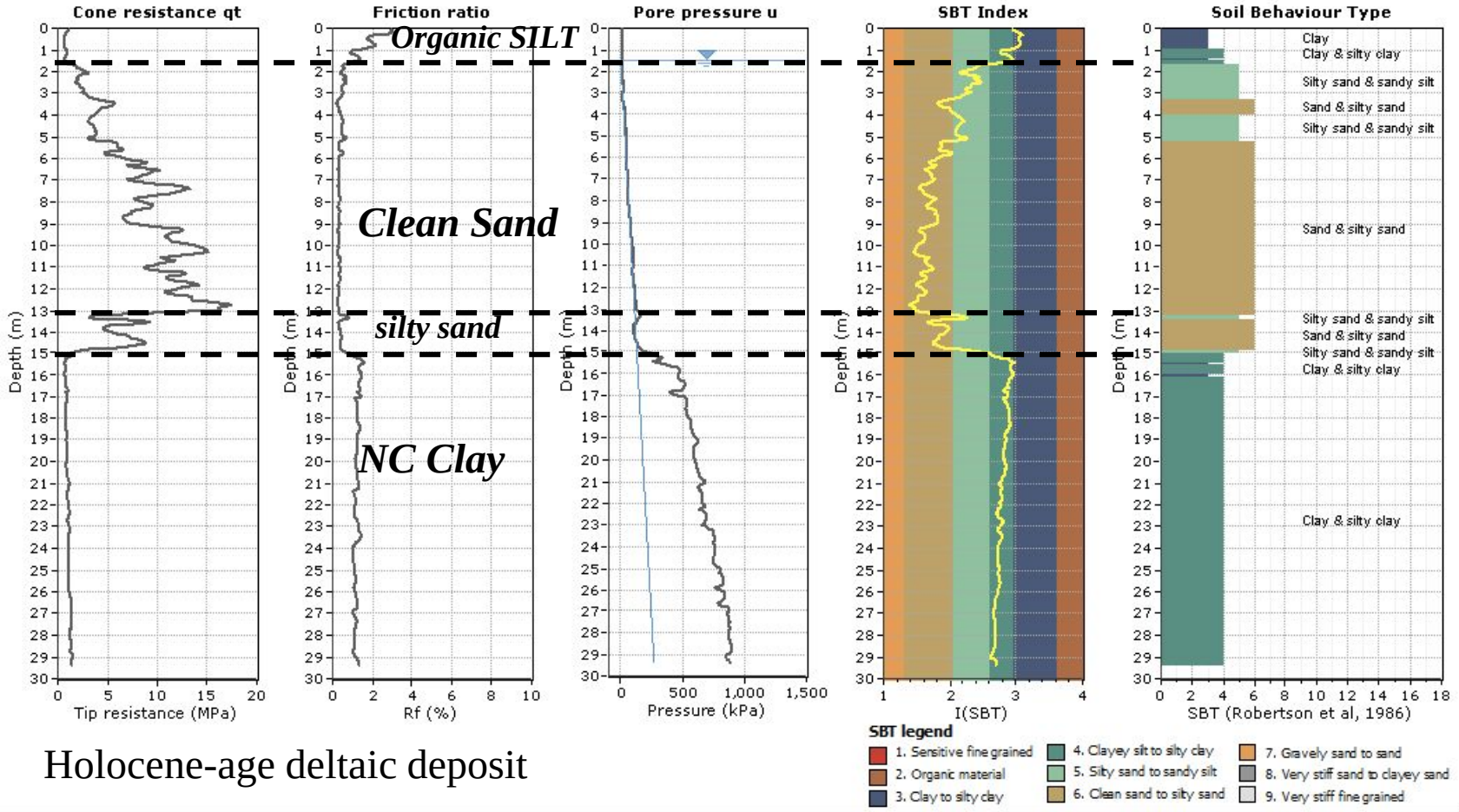
Example CPT - UBC Fraser River

P.K Robertson
Gregg Drilling & Testing Inc
www.greggdrilling.com

Fraser River Delta, Vancouver, BC (UBC)
Campanella & Robertson, 1983

Project: UBC McDonalds Farm
Location: Vancouver, Canada

CPT: UBC McD Farm, Canada
Total depth: 29.35 m



Holocene-age deltaic deposit

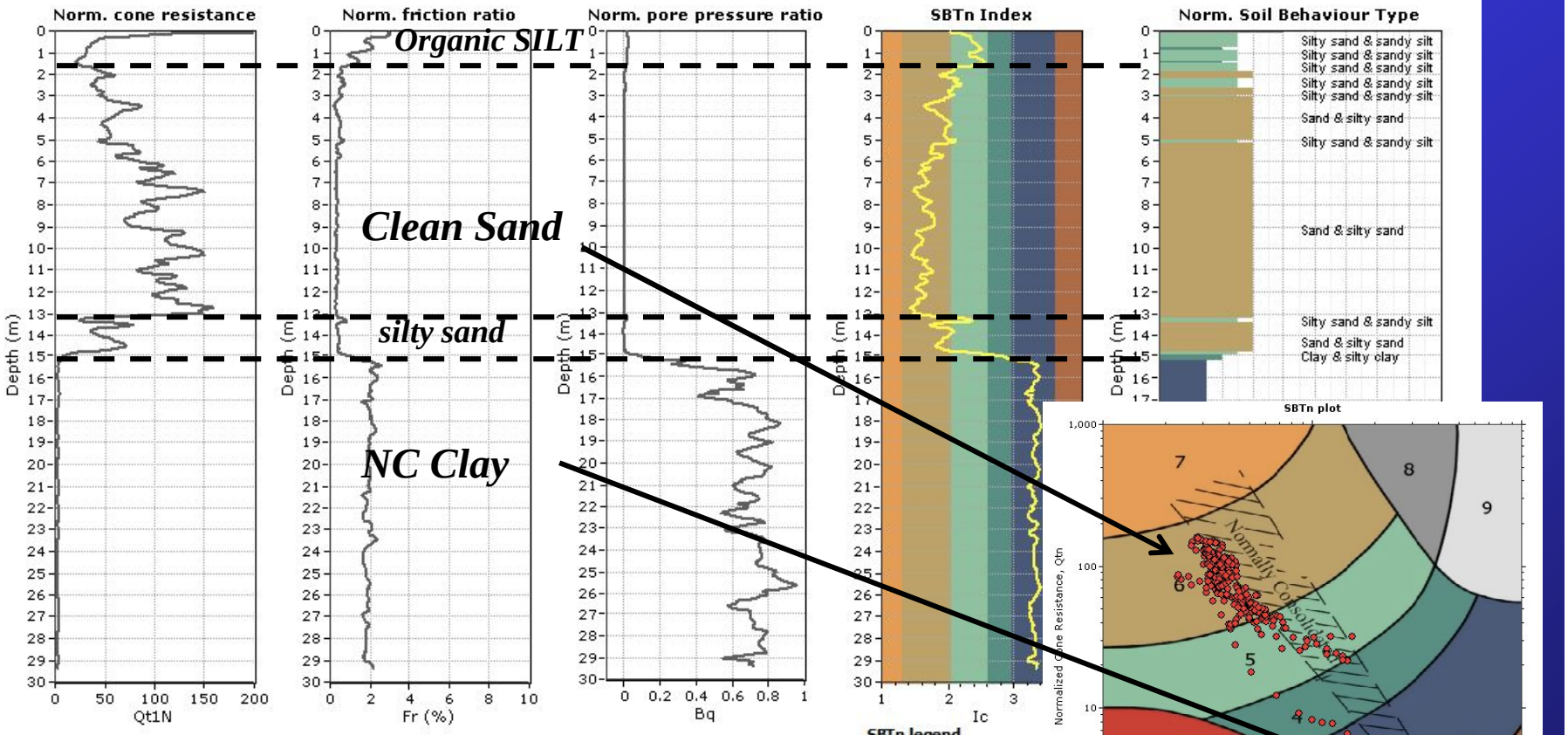
Example CPT - UBC Fraser River

P.K Robertson
Gregg Drilling & Testing Inc
www.greggdrilling.com

Fraser River Delta, Vancouver, BC (UBC)
Campanella & Robertson, 1983

Project: UBC McDonalds Farm
Location: Vancouver, Canada

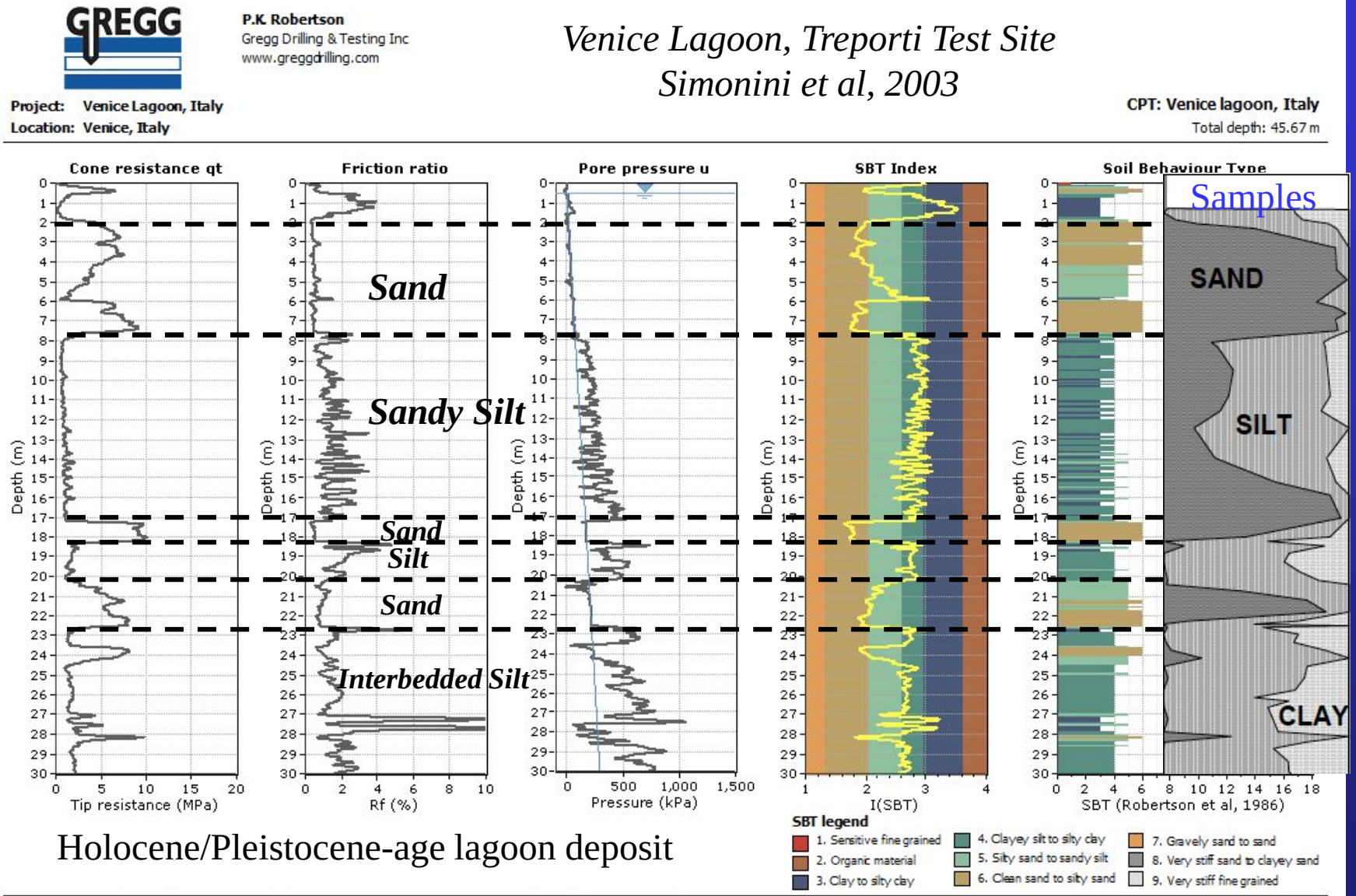
CPT: UBC McD Farm, Canada
Total depth: 29.35 m, Date: 12/4/2012



Normalized CPT Parameters

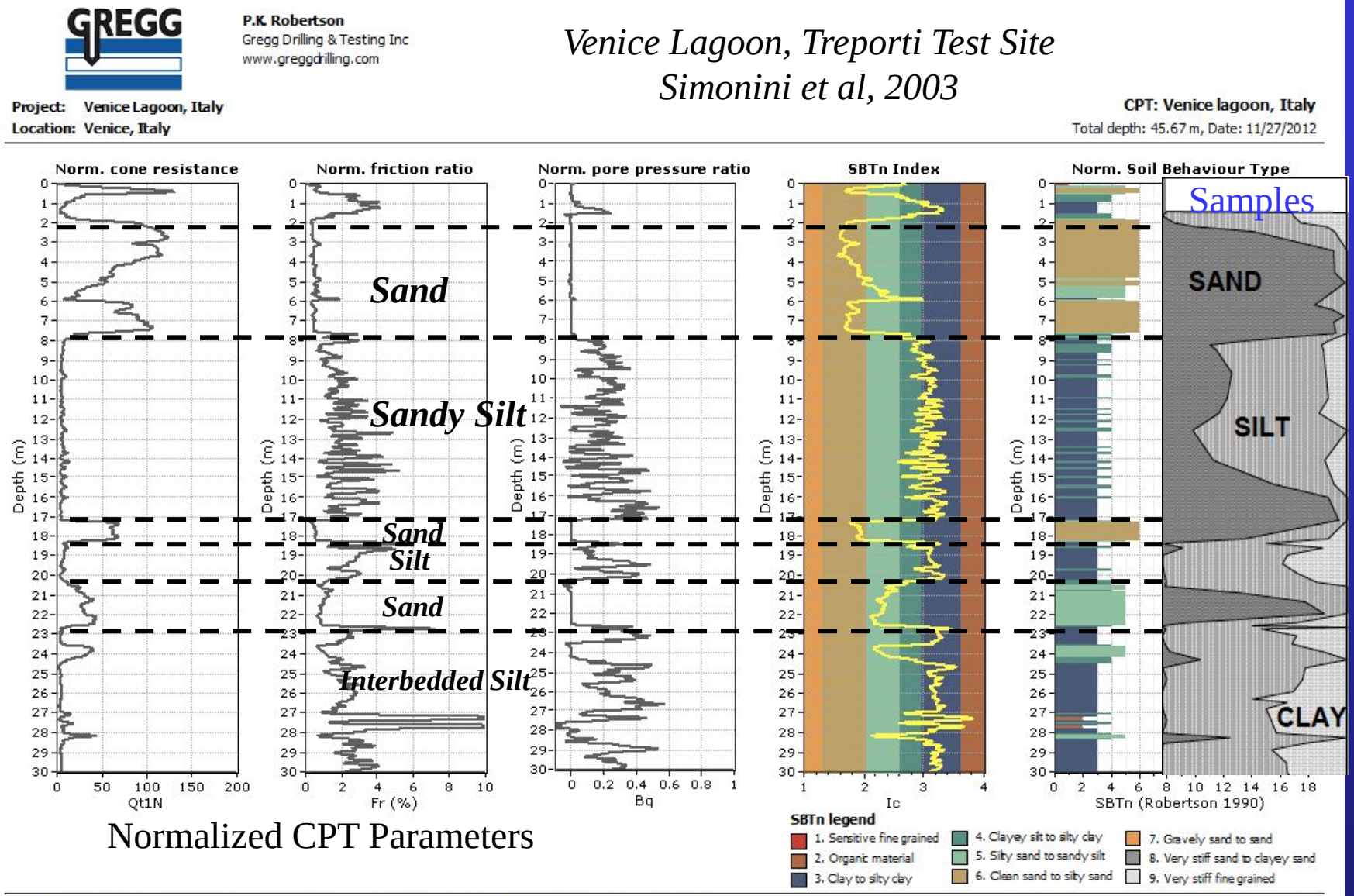
CPeT-IT v.1.7.5.8 - CPTU data presentation & interpretation software - Report created on: 12/11/2012, 2:21:18 PM
Project file: Z:\Documents\Peter\Software\CPeT-IT\CPT Database\Mixed soil sites\Mixed soil sites.cpt

Example CPT – Venice Lagoon



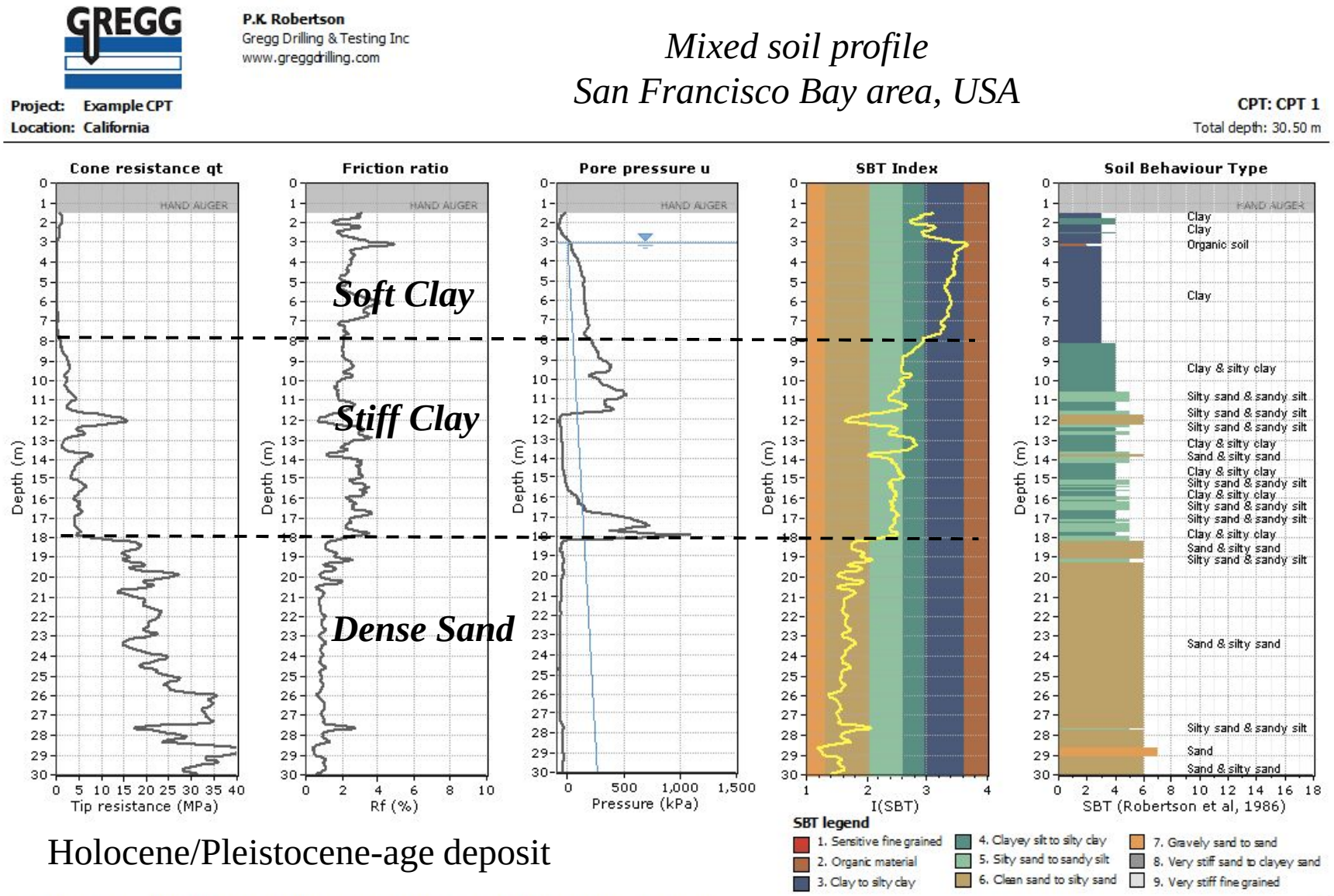
Holocene/Pleistocene-age lagoon deposit

Example CPT – Venice Lagoon



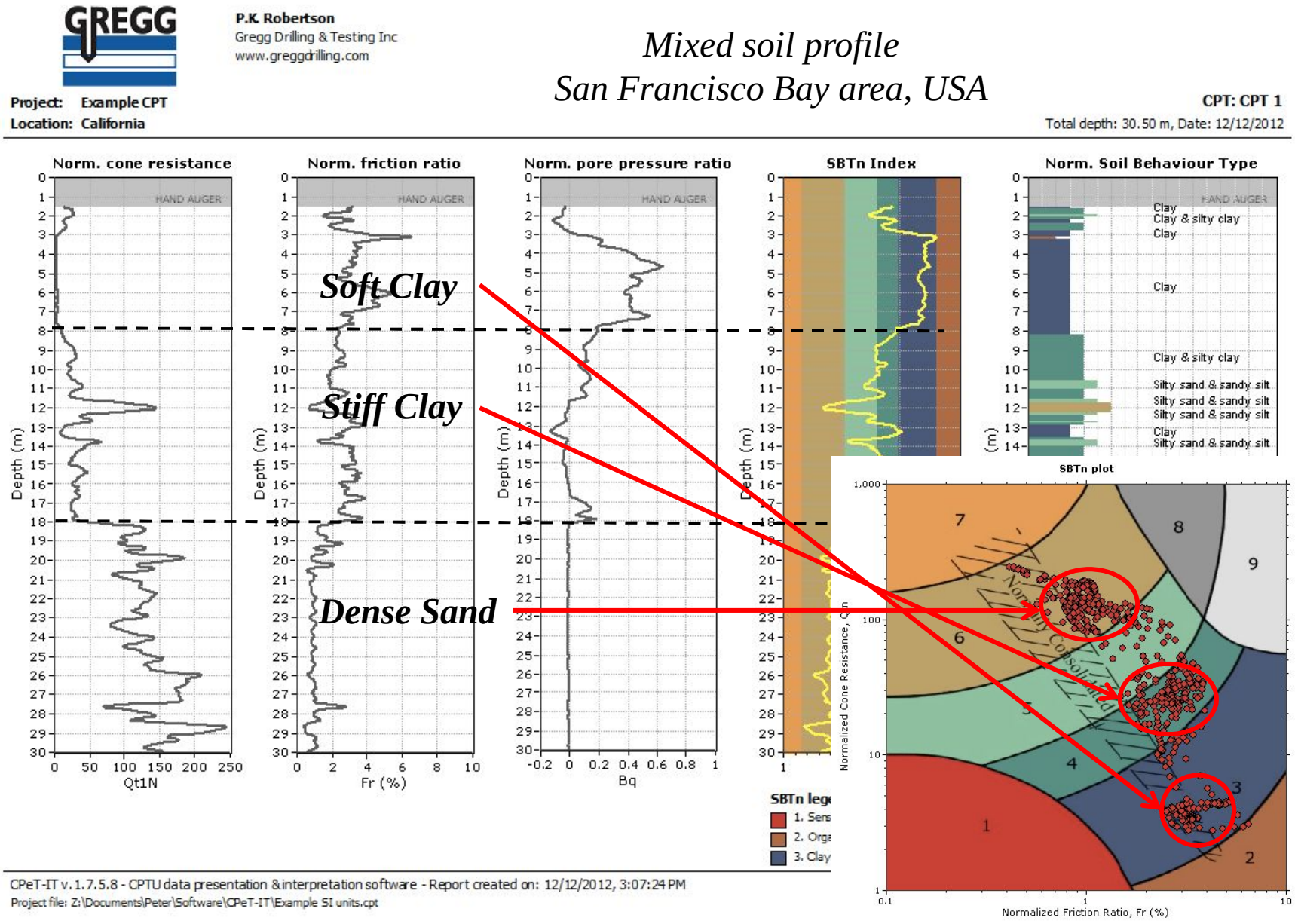
Normalized CPT Parameters

Example CPT

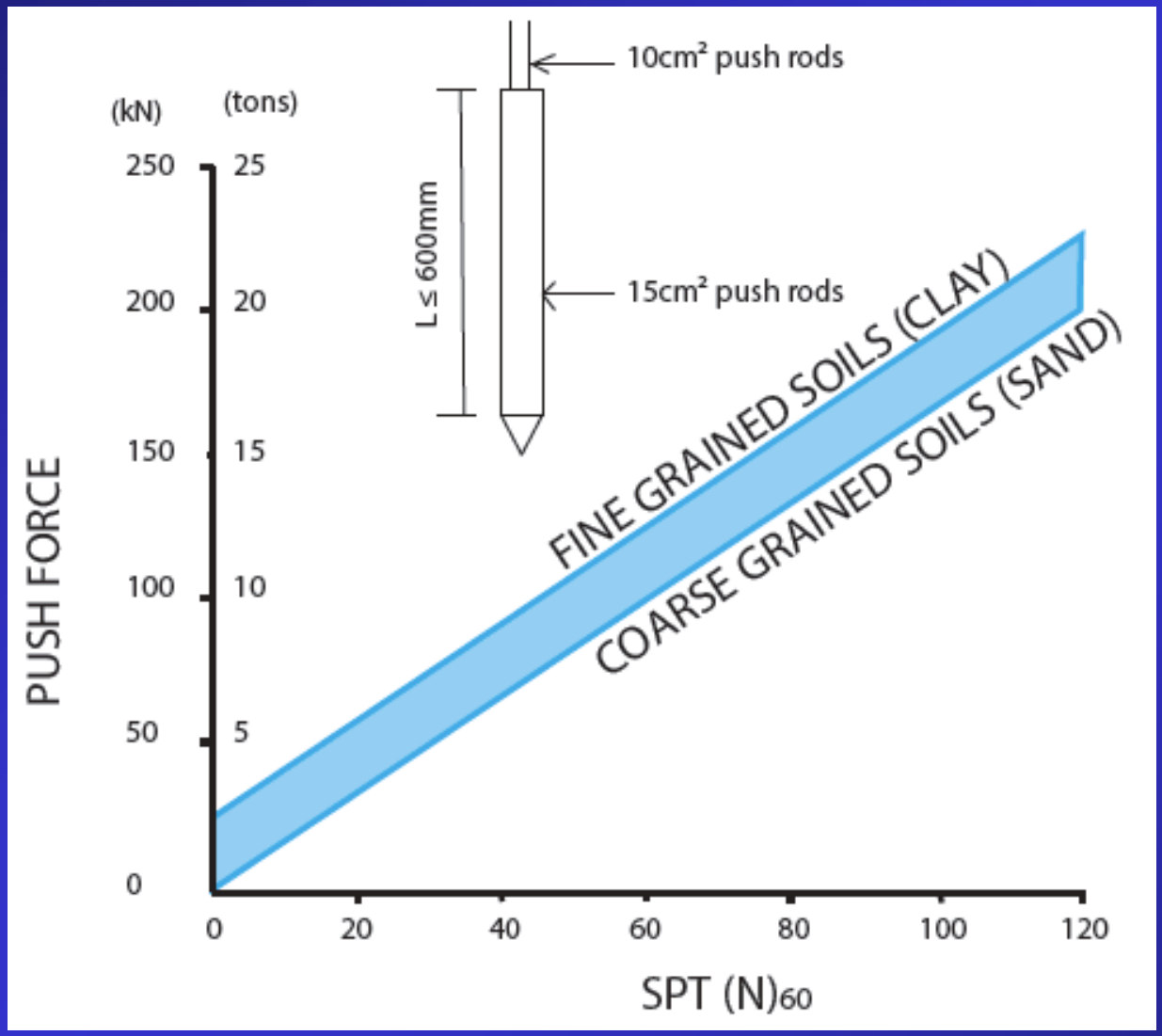


Holocene/Pleistocene-age deposit

Example CPT


GREGG
P.K Robertson
Gregg Drilling & Testing Inc
www.greggdrilling.com
Project: Example CPT
Location: California
Mixed soil profile
San Francisco Bay area, USA
CPT: CPT 1
Total depth: 30.50 m, Date: 12/12/2012
Norm. cone resistance
Norm. friction ratio
Norm. pore pressure ratio
SBTn Index
Norm. Soil Behaviour Type
HAND AUGER
Depth (m)
Qt1N
Fr (%)
Bq
Soft Clay
Stiff Clay
Dense Sand
Clay
Clay & silty clay
Silty sand & sandy silt
SBTn plot
Normalized Cone Resistance, Qtn
Normalized Friction Ratio, Fr (%)
Normally Consolidated
SBTn lege
1. Sens
2. Orga
3. Clay
CPeT-IT v. 1.7.5.8 - CPTU data presentation & interpretation software - Report created on: 12/12/2012, 3:07:24 PM
Project file: Z:\Documents\Peter\Software\CPeT-IT\Example SI units.cpt

How deep can you push the CPT?



Depends on:
1 - amount of reaction push force
2 - amount of rod friction

With 15 cm^2 cone (10cm^2 push rods) and 200 kN (20 tons) reaction – can penetrate soil with SPT $(N)_{60}$ > 100

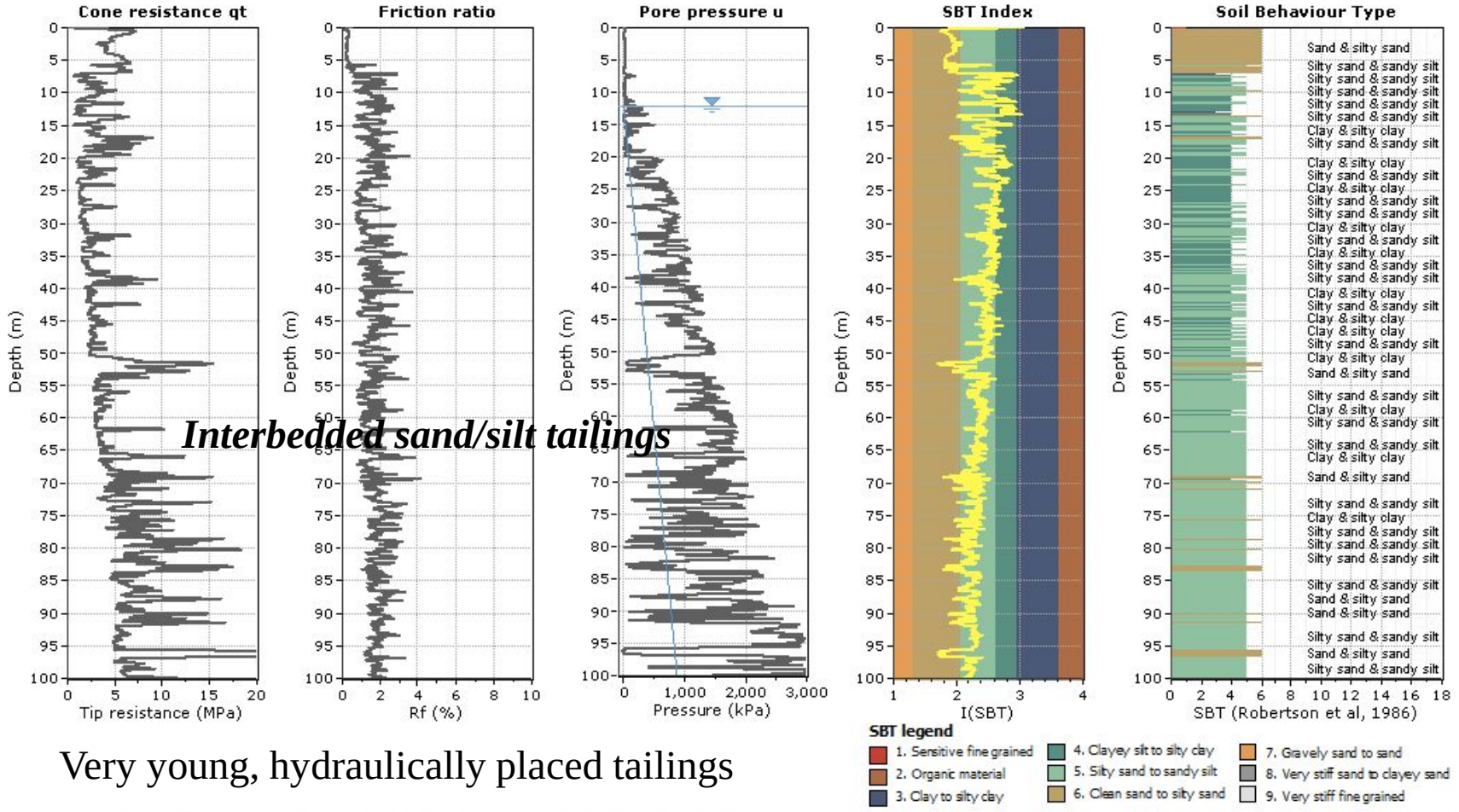
Example CPT – Mine Tailings

P.K Robertson
Gregg Drilling & Testing Inc
www.greggdrilling.com

Deep Mine Tailings
Southwest, USA

Project: Mine Tailings Example
Location: USA

CPT: Mine Tailings
Total depth: 101.05 m



Interbedded sand/silt tailings

Very young, hydraulically placed tailings

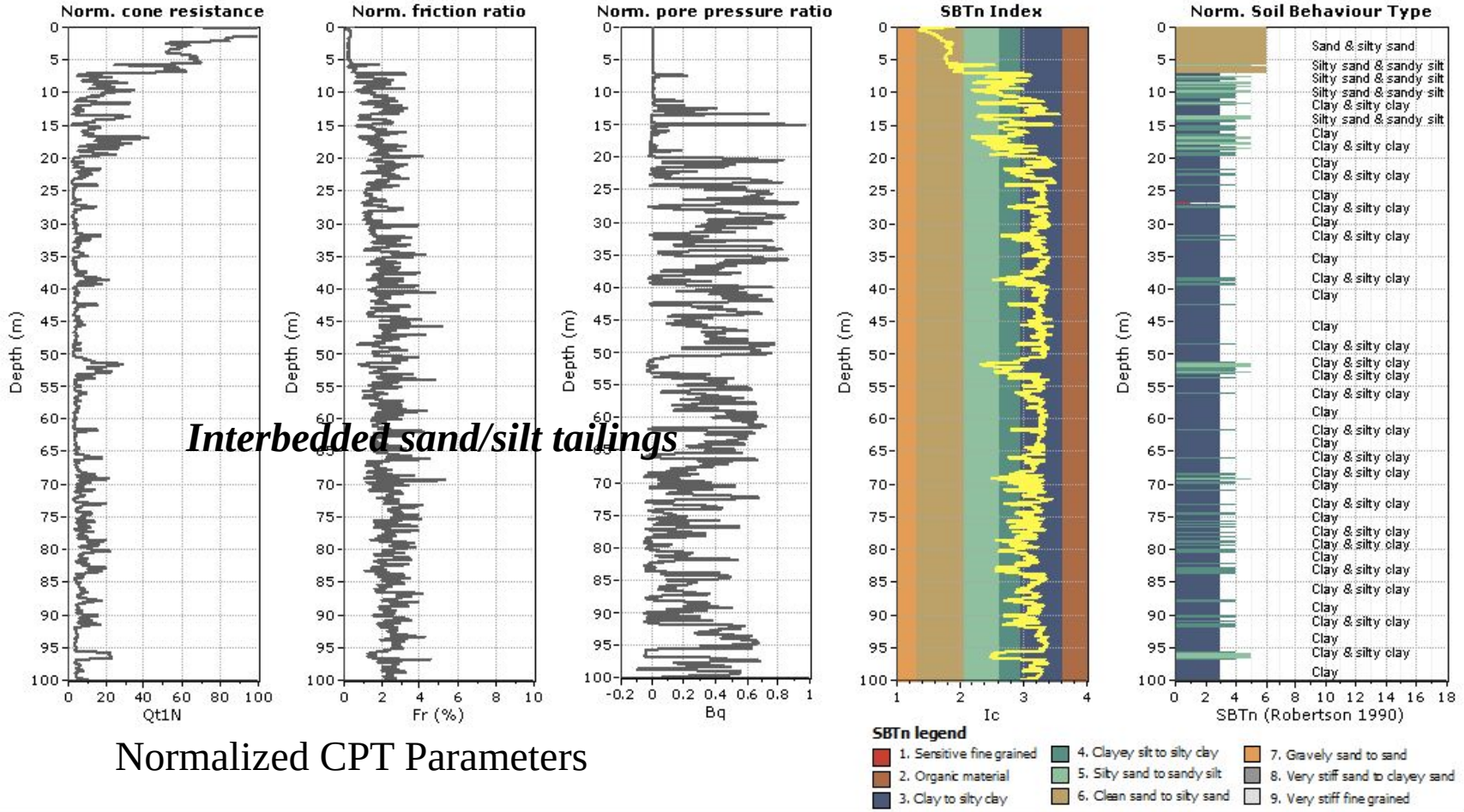
Example CPT – Mine Tailings

P.K Robertson
Gregg Drilling & Testing Inc
www.greggdrilling.com

Deep Mine Tailings
Southwest, USA

Project: Mine Tailings Example
Location: USA

CPT: Mine Tailings
Total depth: 101.05 m, Date: 8/9/2012



Interbedded sand/silt tailings

Normalized CPT Parameters

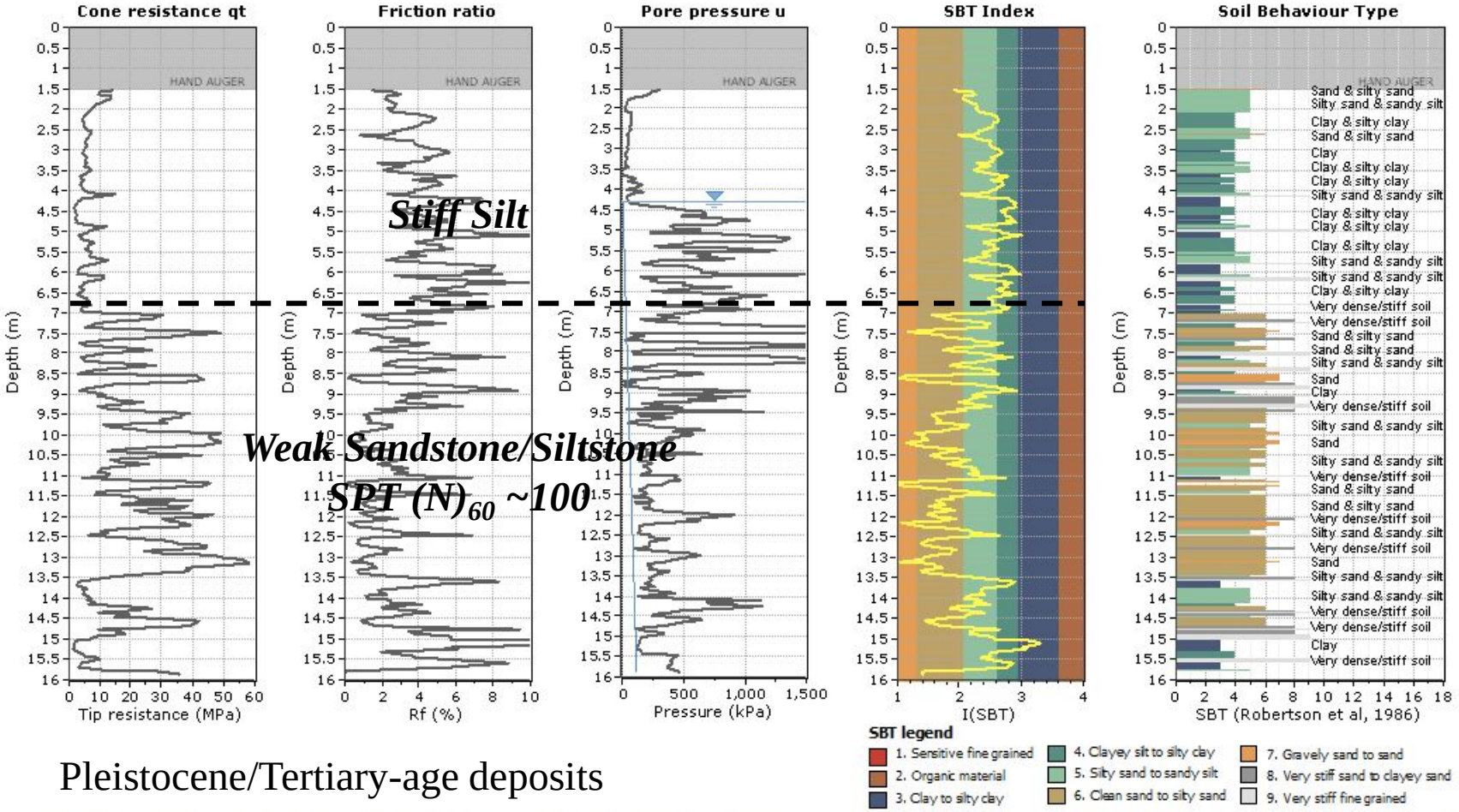
Example CPT – Soft Rock

P. K. Robertson
Gregg Drilling & Testing Inc
www.greggdrilling.com

Very stiff soil – soft rock
Newport Beach, CA, USA

Project: Stiff soil - soft rock
Location: Newport Beach, CA, USA

CPT: Newport Beach, CA
Total depth: 15.85 m



Pleistocene/Tertiary-age deposits

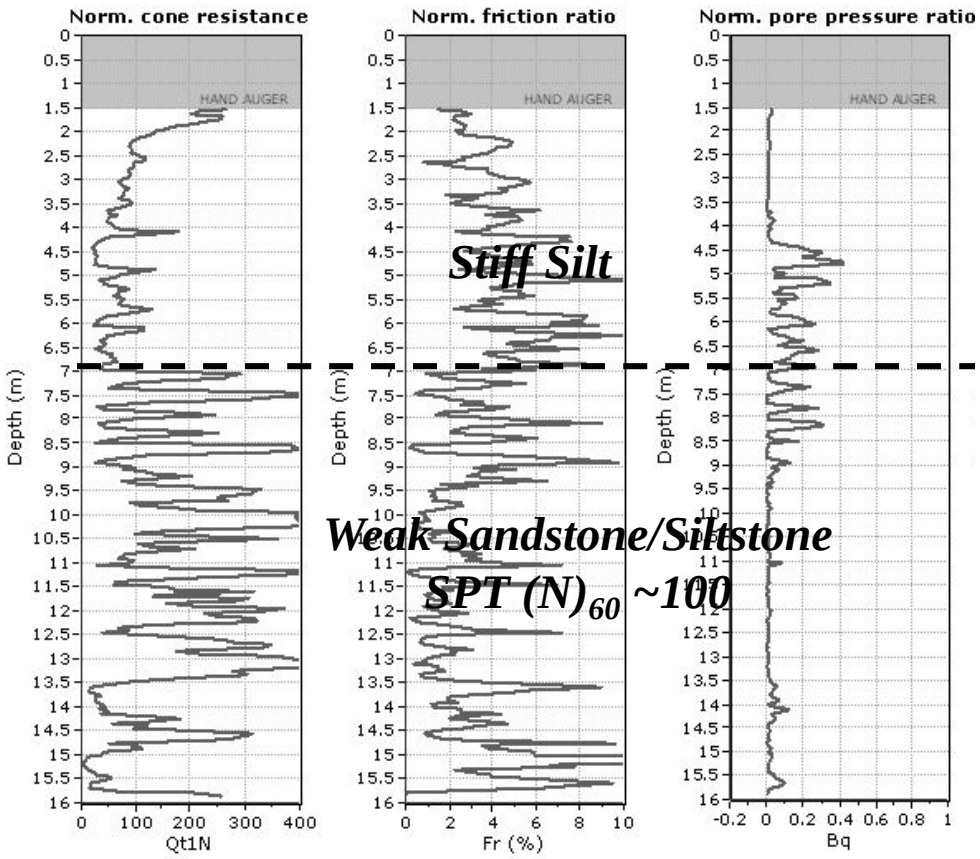
Example CPT – Soft Rock

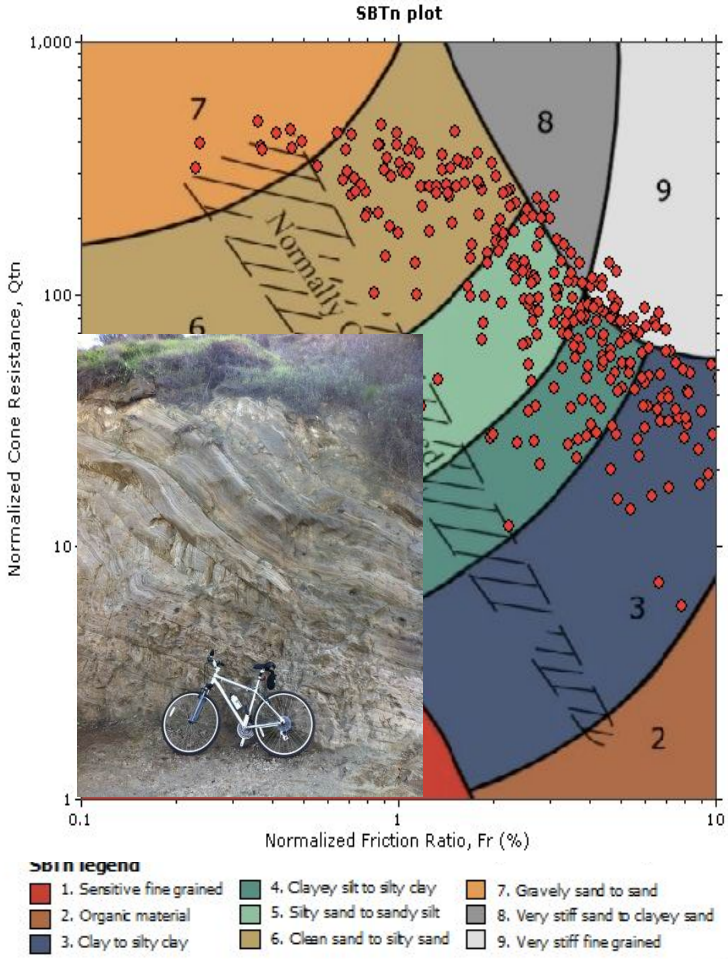
P. K. Robertson
Gregg Drilling & Testing Inc
www.greggdrilling.com

Very stiff soil – soft rock
Newport Beach, CA, USA

Project: Stiff soil - soft rock
Location: Newport Beach, CA, USA

CPT: Newport Beach, CA
Total depth: 15.85 m, Date: 12/12/2012





Normalized CPT Parameters

Summary

- CPT is a fast, reliable method to determine soil stratigraphy and soil type in a cost effective manner.
- CPT-based Soil Behaviour Type (SBT) charts available to estimate soil type, based on either tip-friction and/or tip-pore pressure measurements
- CPT equipment can be used to take small diameter push-in soil samples to verify soil type