CPT/CPTU Interpretation of Stratigraphy: Soil Layering and Soil Classification

1. Stratigraphy – Key signatures of soil layering from CPT/CPTU data

2. Soil Classification - development and application of soil classification charts

3. Examples of results in different soil types.

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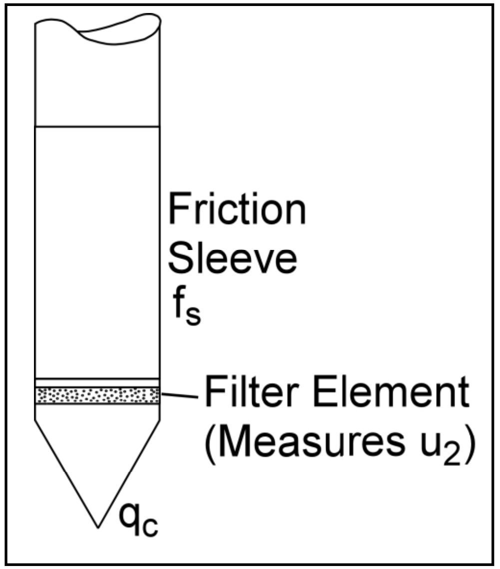
Measured Data and Calculated Variables

1. Measured Data

- most common = q_c, f_s, and u_2



2. Calculated Variables (for u_2 measurement):

- Corrected tip resistance: $q_t = q_c + u_2(1\text{-}a)$
- Excess pore pressure $\Delta u = u_2 - u_0$
- Friction Ratio: $R_f = f_s/q_c$
- Normalized net tip resistance: $Q_c = (q_c - \sigma_{vo})/\sigma'_{vo}$
- Normalized sleeve resistance: $F_r = f_s/(q_c - \sigma_{vo})$
- Pore Pressure Parameter: $B_q = (u_2 - u_o)/(q_t - \sigma_{vo})$
- Normalized Excess Pore Pressure: $U = (u_2 - u_o)/\sigma'_{vo}$
- Normalized Corrected Tip Resistance: $Q_t = (q_t - \sigma_{vo})/\sigma'_{vo}$

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Stratigraphic Profiling

Excellent application for the CPT and especially the CPTU

Approach:

1.Reply on fundamentals of soil behavior, i.e., stiffness (e.g., dense sand vs. soft clay) and drainage (drained behavior during shear in sand vs. undrained behavior during shear in clay).

2.Use all information available – q_c or q_t, f_s, u, Q_t, R_f, B_q (+ other sensors when available).

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Stratigraphic Profiling

Key Signatures to look for in measured data, e.g.:

1. Shape and magnitude of q_t profile – e.g., high in dense sand, low in soft clay

2. Shape of u profile and magnitude, especially relative to equilibrium pore pressure profile – e.g., high in soft clay, $\Delta u = 0$ in medium density sand

3. Magnitude of R_f relative to that of q_t – e.g., if high and coupled with low q_t = soft clay.

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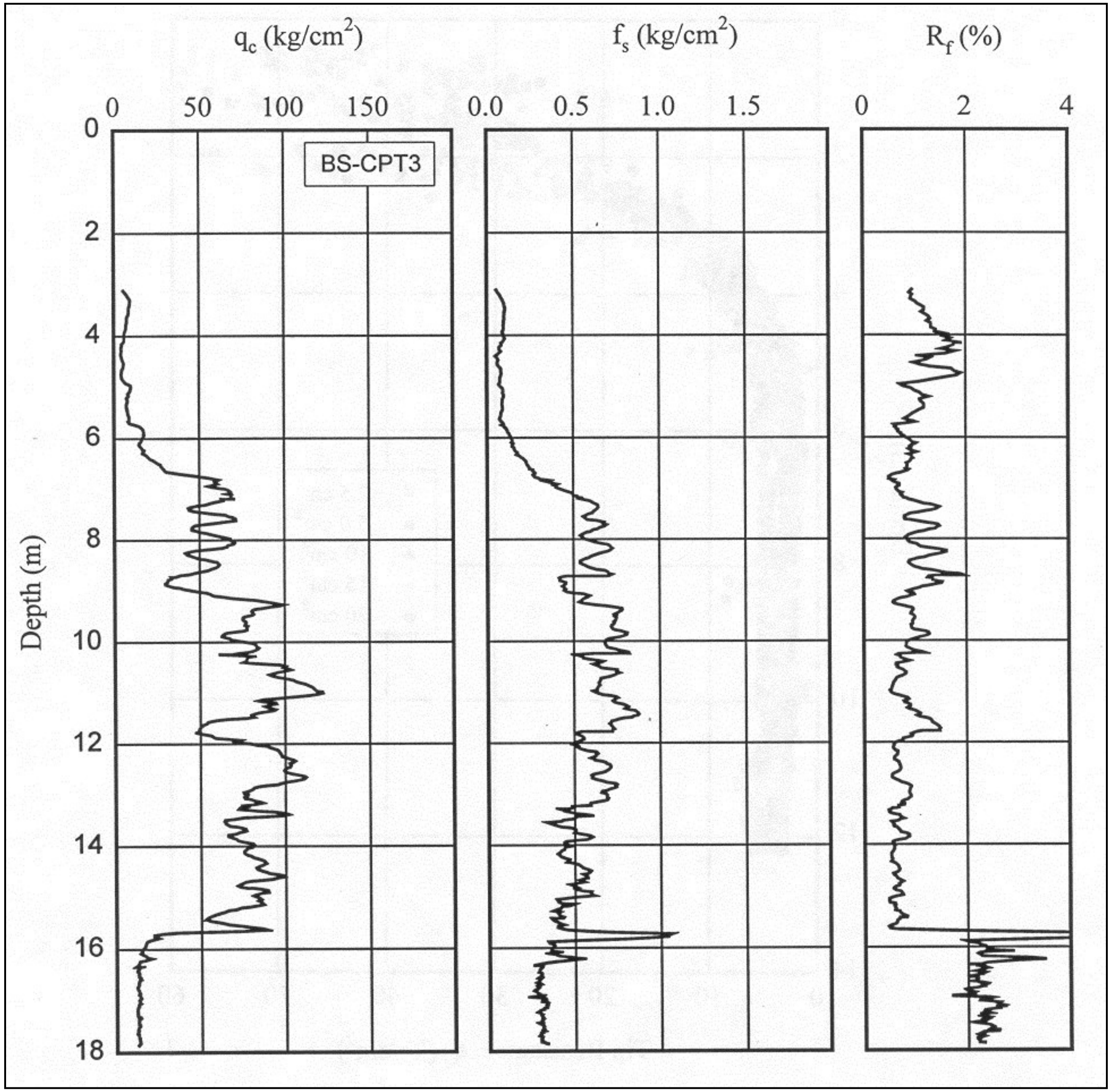
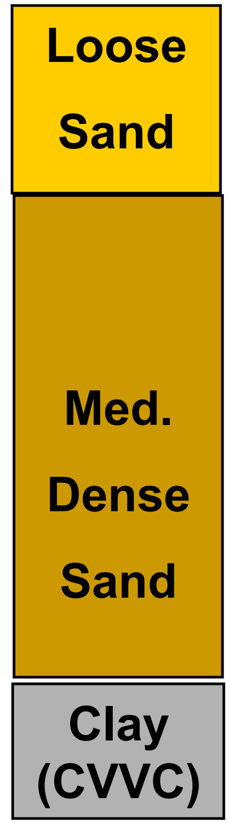
Example CPT in Western Massachusetts

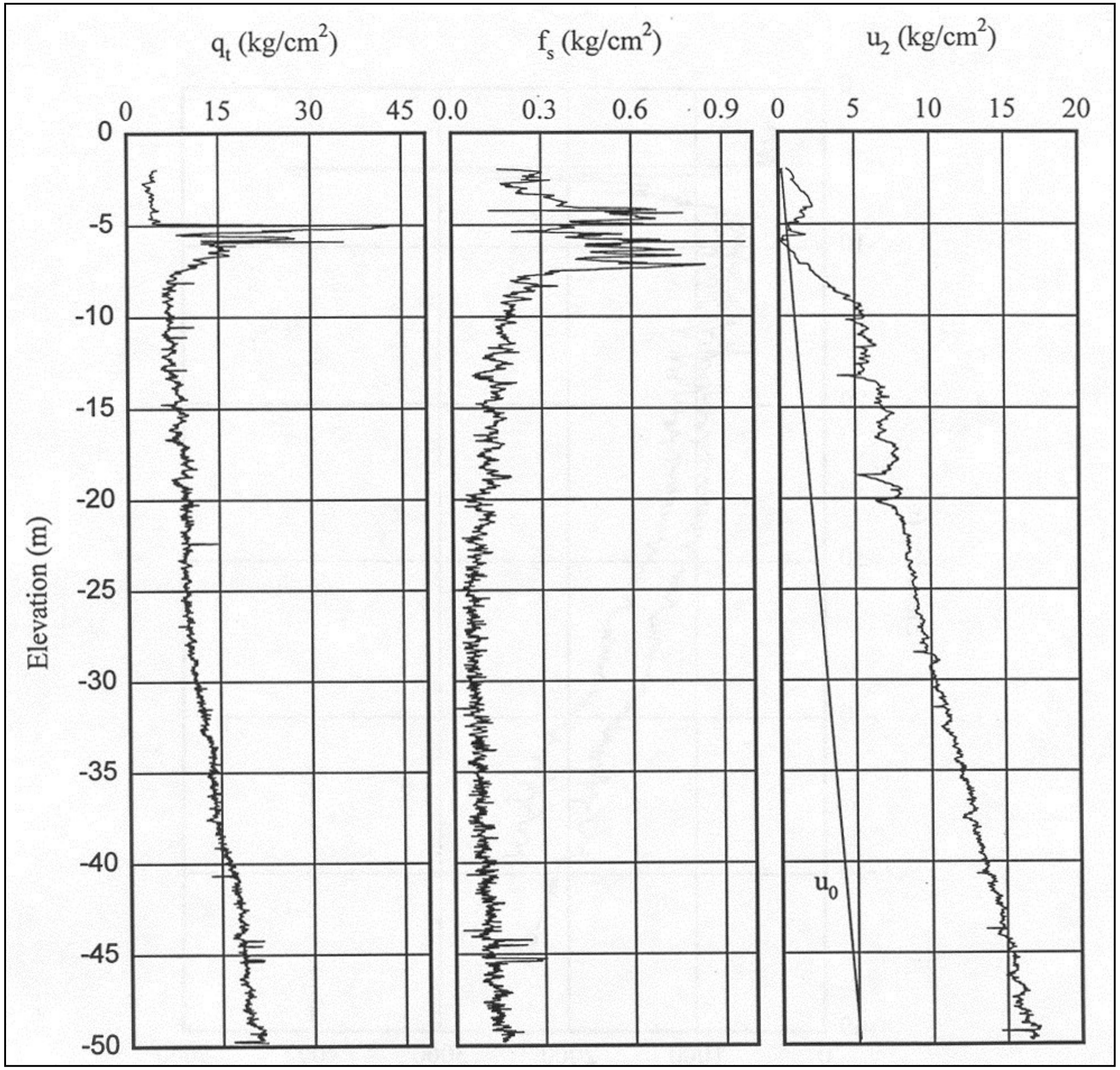


Inspect relative values of q_c, f_s and R_f



UNITS:
1 ksc
≈ 100 kPa
≈ 0.1 MPa
≈ 2000 psf
≈ 1 tsf

Example CPTU in Eastern Massachusetts



Boston Blue Clay

Stiff Clay Crust

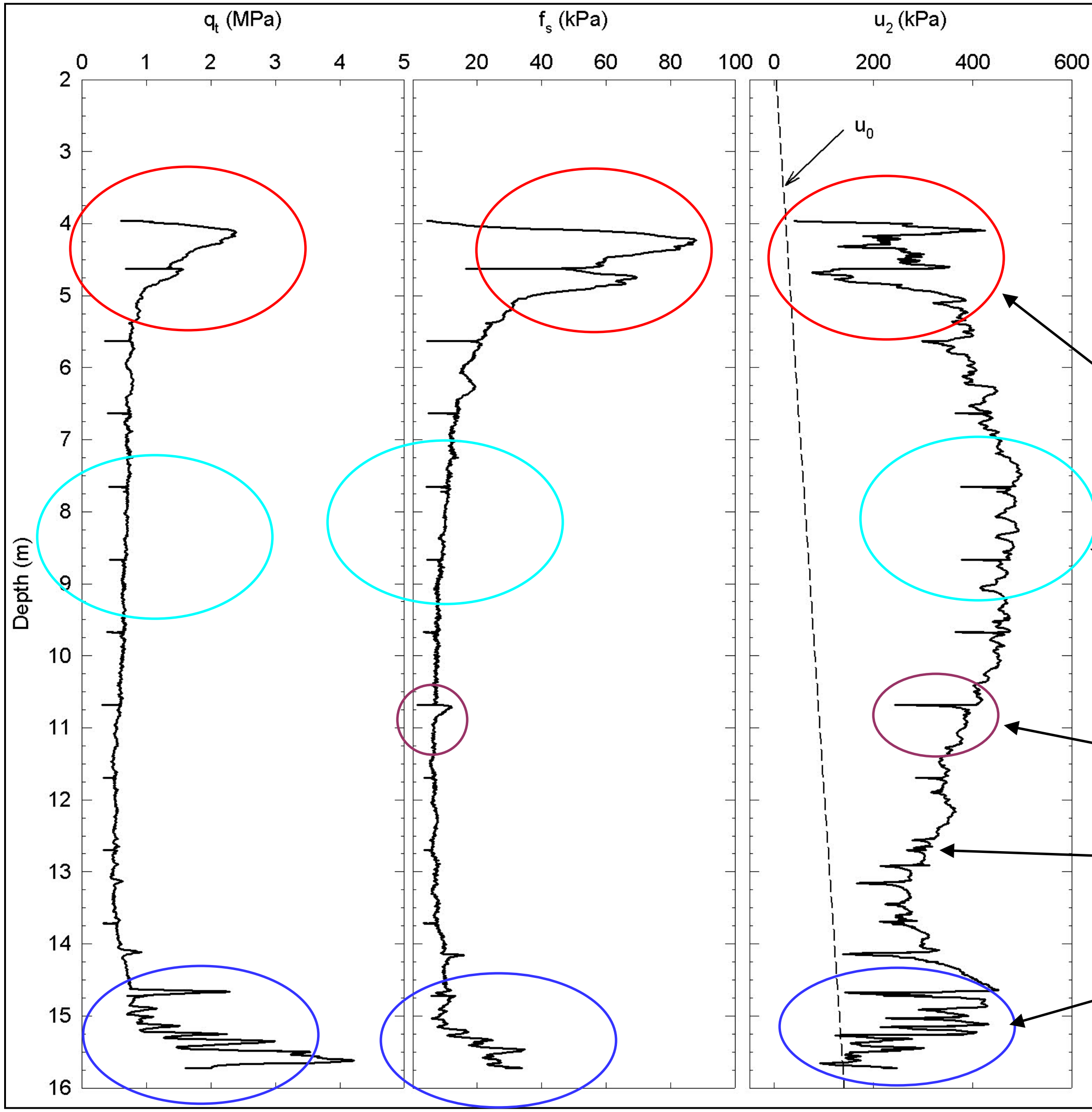
Uniform Soft Clay

SPT N = WOR (i.e., = 0)

Linear increase in q_t and u_2 with depth

High u_2 relative to u_0

Example CPTU in NE Massachusetts



Boston Blue Clay
- Newbury, MA

Significant variations in q_t, f_s and u_2 with depth

Stiff, high OCR CLAY Crust

Sensitive, soft CLAY

Dissipation Test

Increasing silt content

Interbedded Layers, Silt, Clay, Sand

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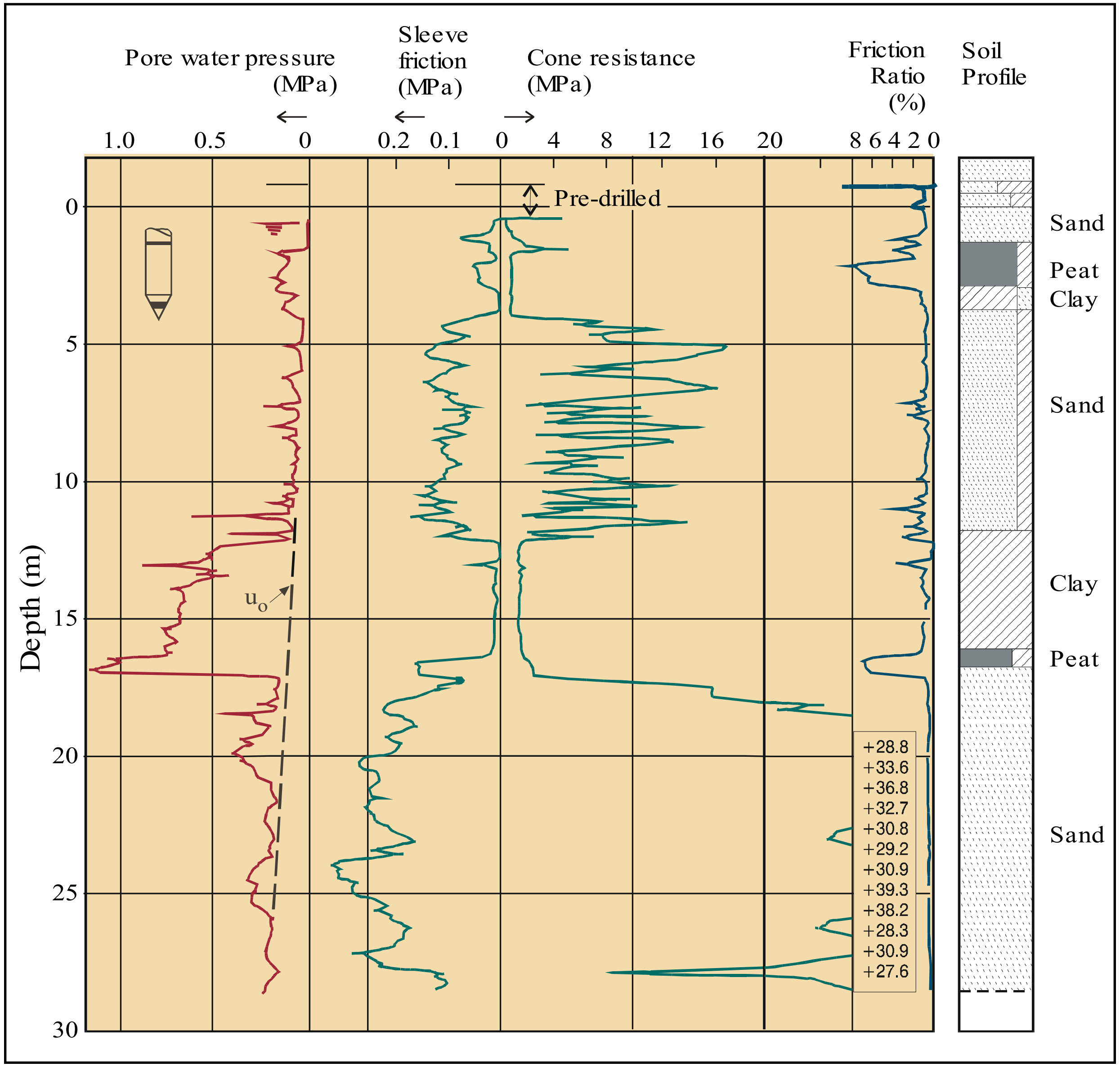
Example CPTU - Holland

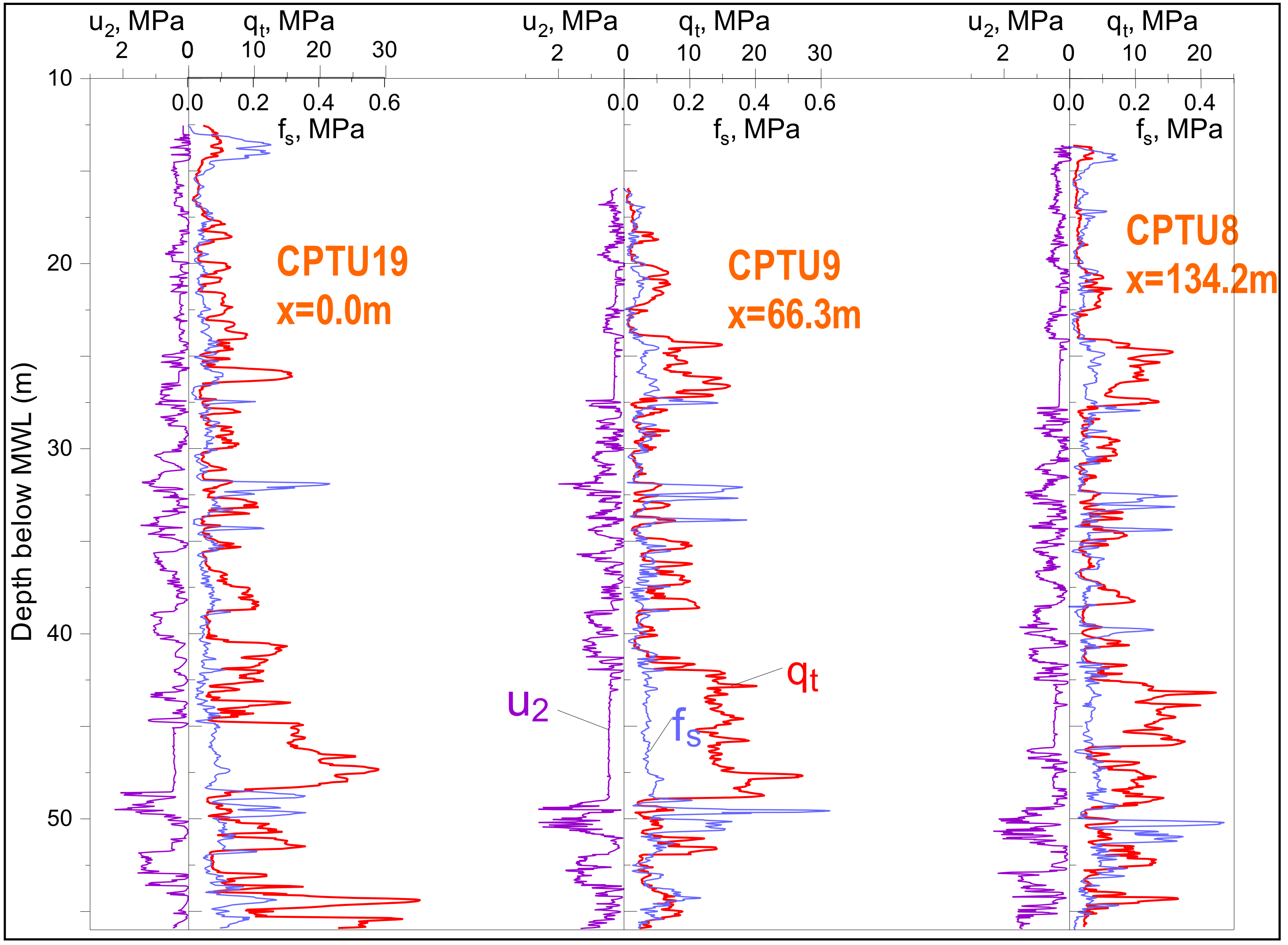


<u>Note</u>:

- jump in R_f in Peat Layers
- low q_c, f_s but high u in Clay
- high q_c, f_s but low R_f in sand + u close to u_0
- apparent significant stratification in middle sand layer

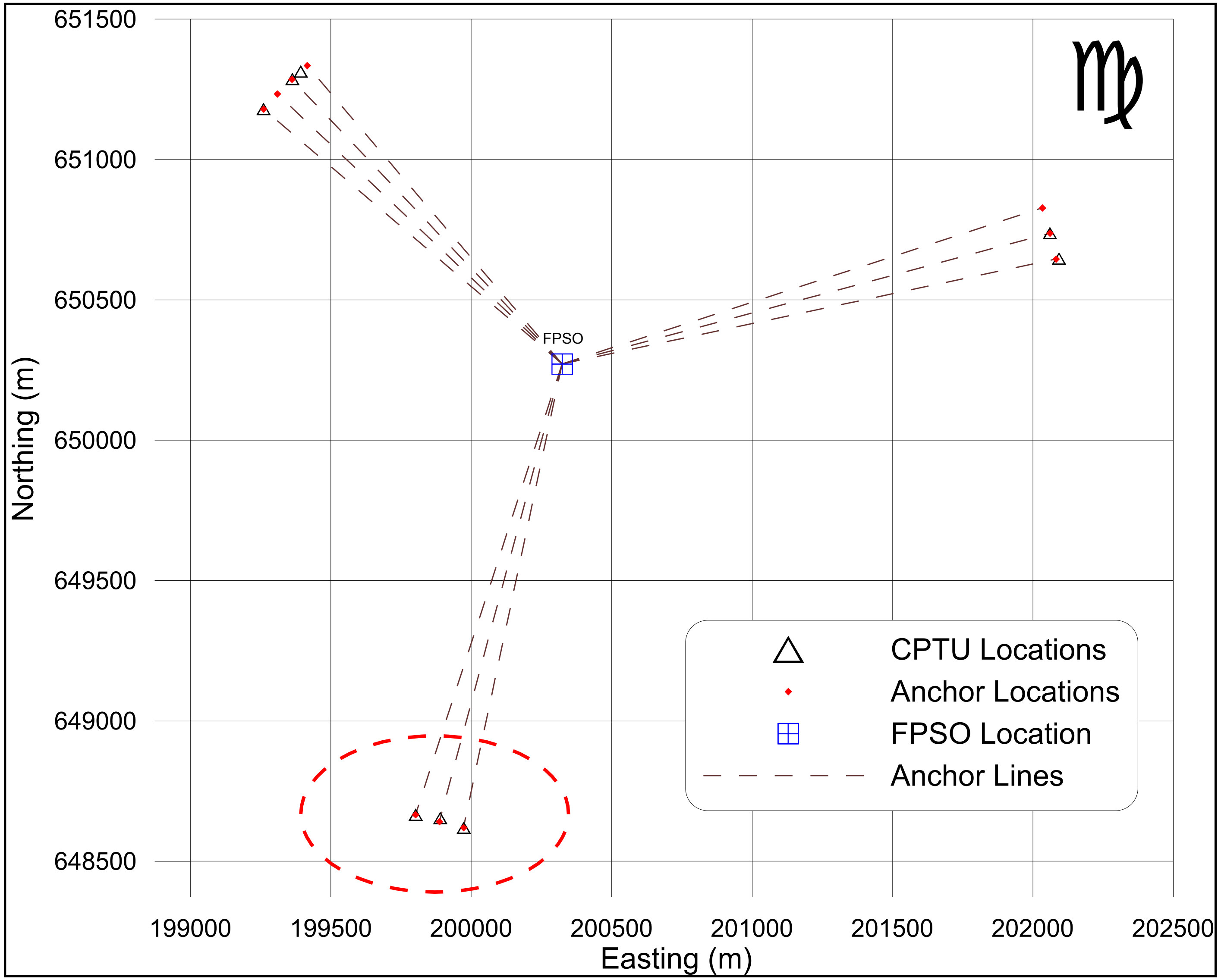
[Zuidberg et al. 1982]

Example CPTU profiles in Venetian soils



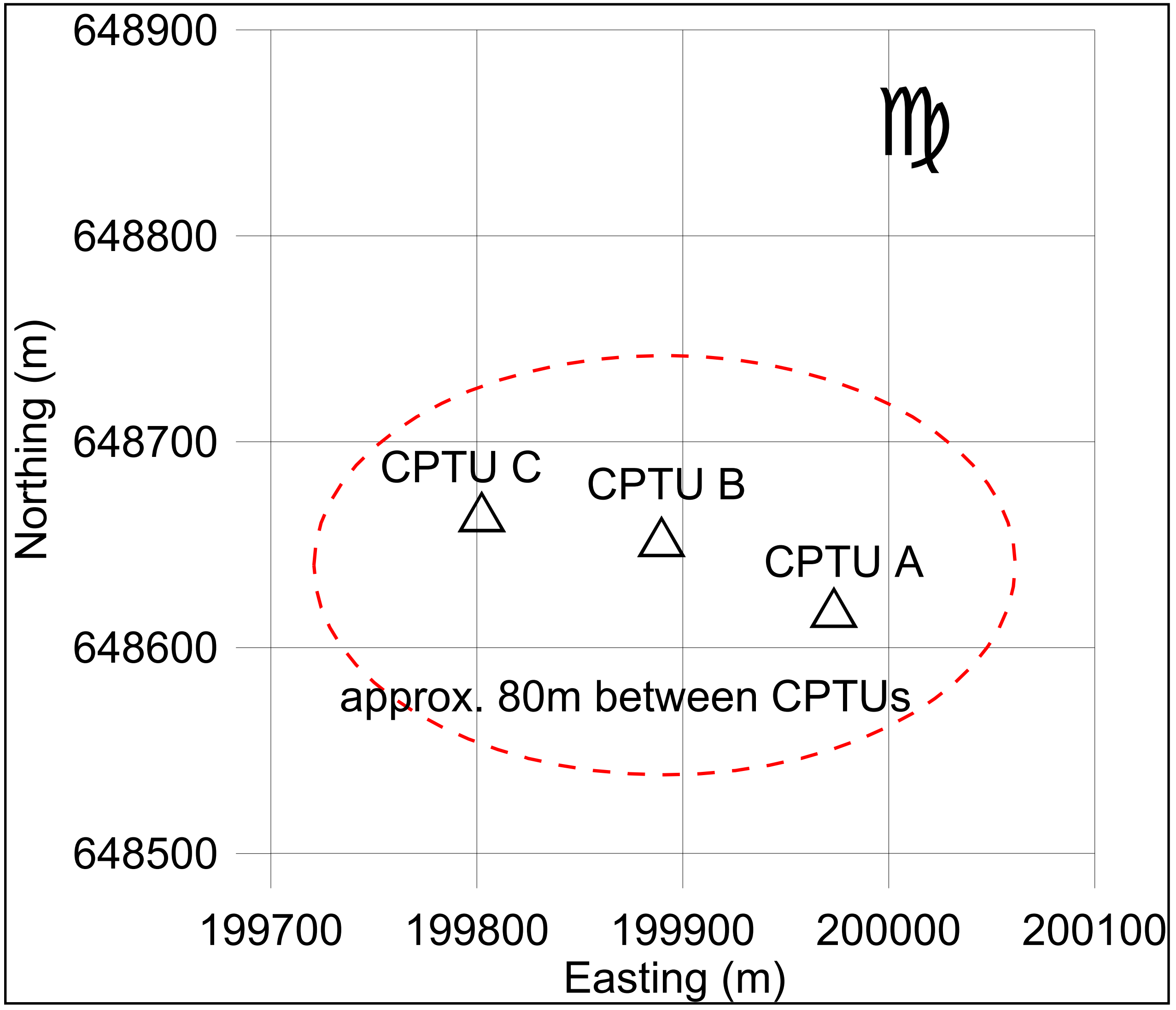
Significant interbedding of soils from sands to silty clays

Example CPTU – Offshore Deep Water Site



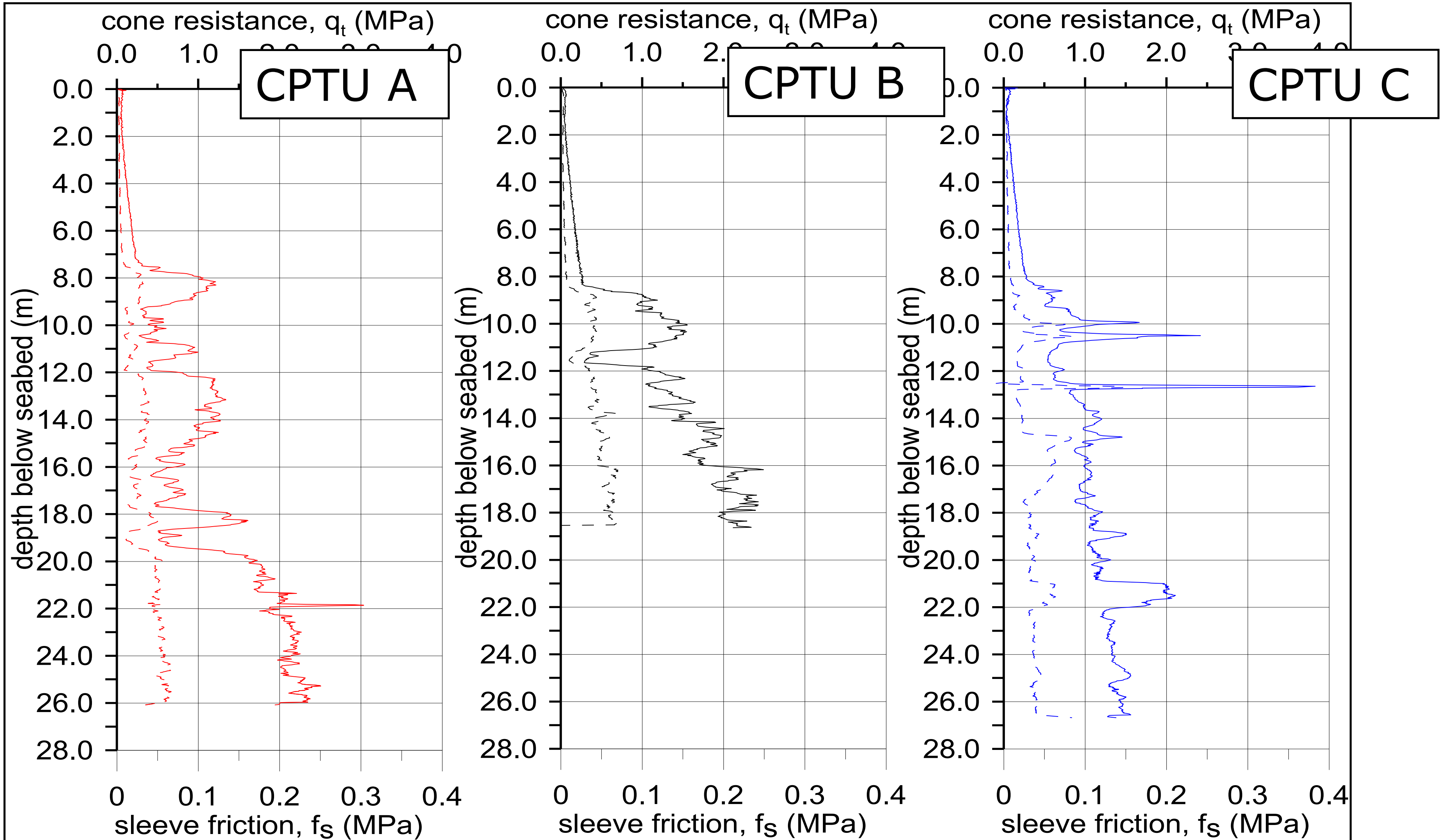
Location of seabed anchors

Deep water site

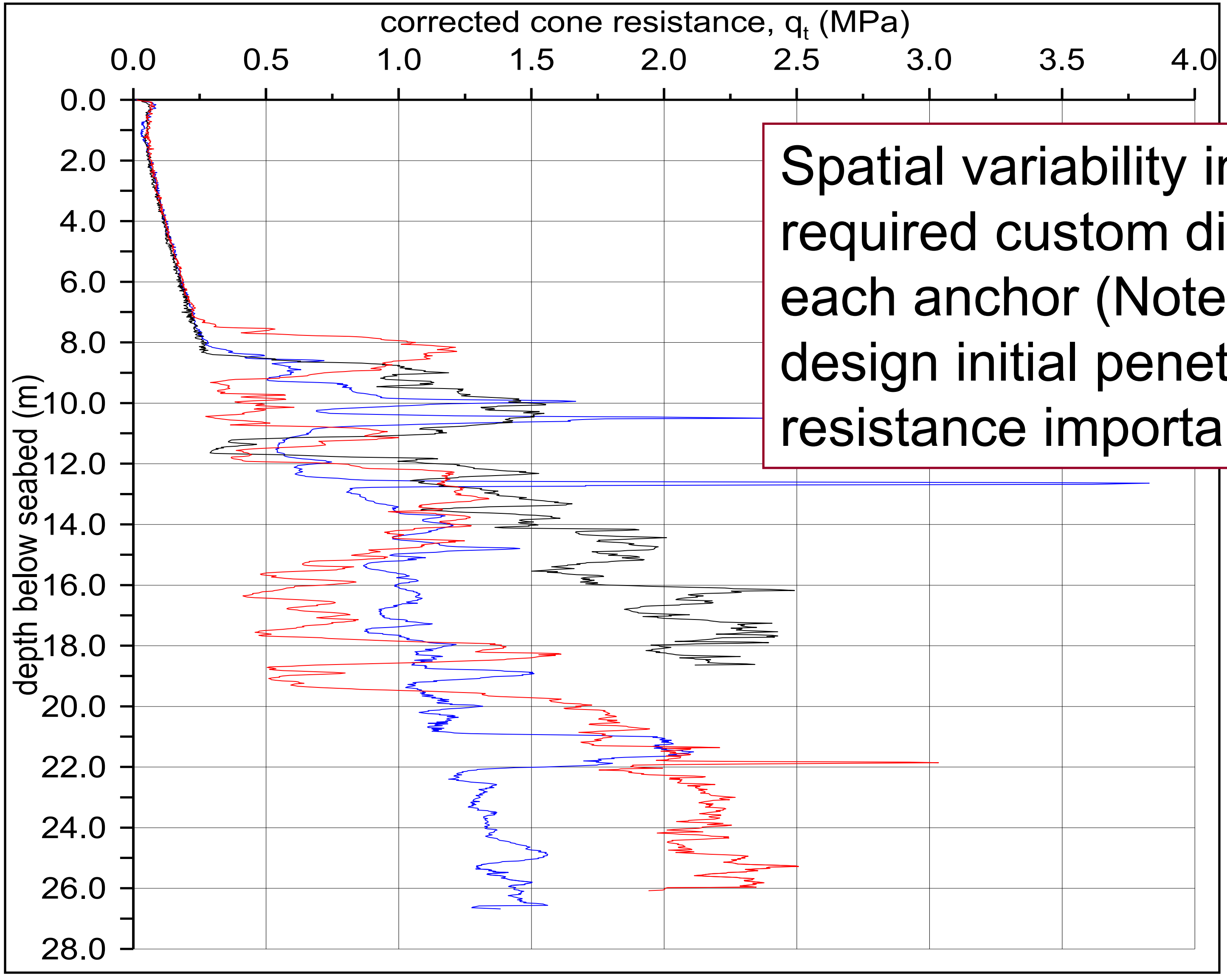


CPTUs conducted at one anchor location

Deep water site – CPTUs at one anchor location

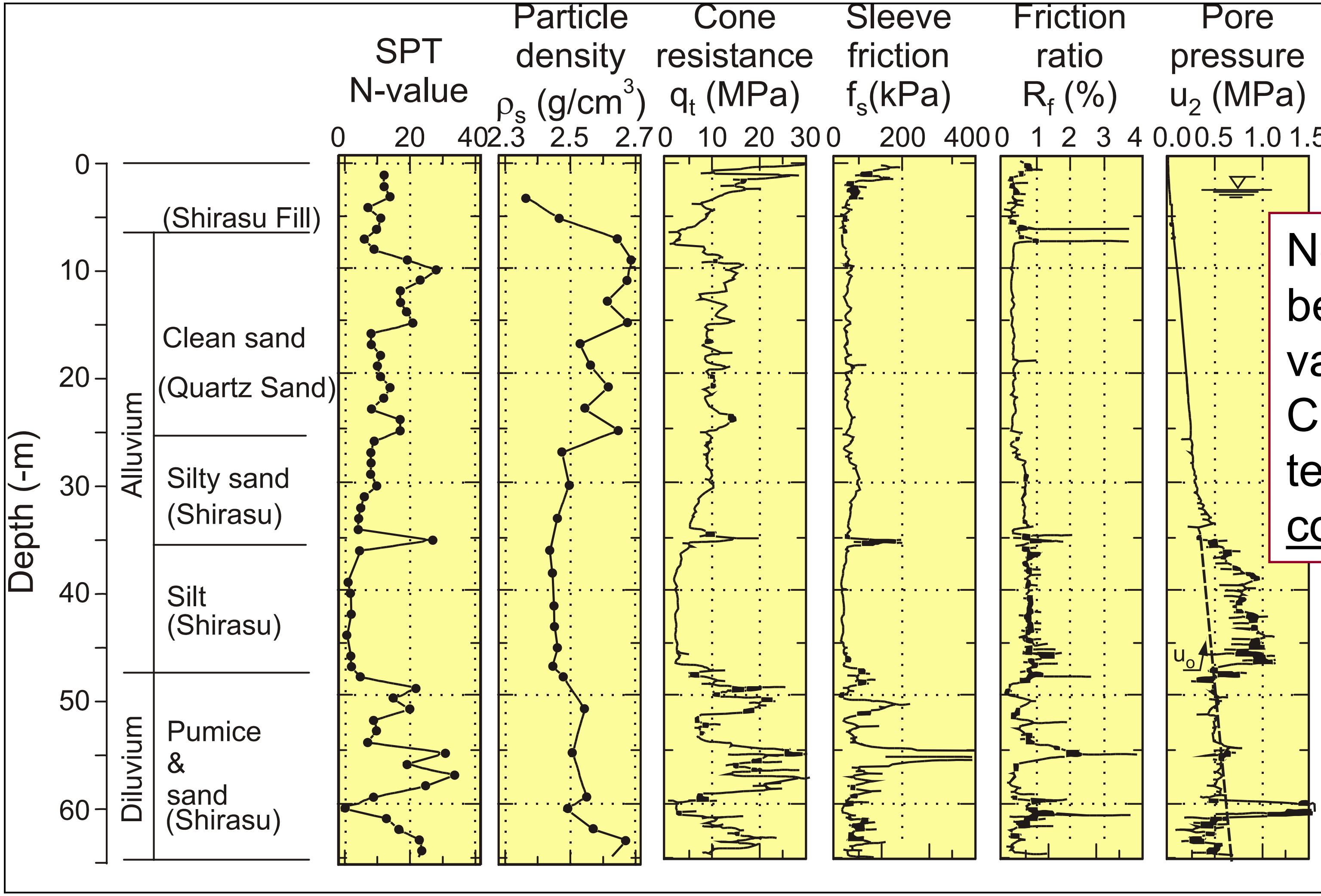


Deep water site – CPTUs at one anchor location



Spatial variability in CPTU data ⇨ required custom dimensions for each anchor (Note: for anchor design initial penetration <u>and</u> final resistance important)

Example CPTU in Japanese volcanic soil



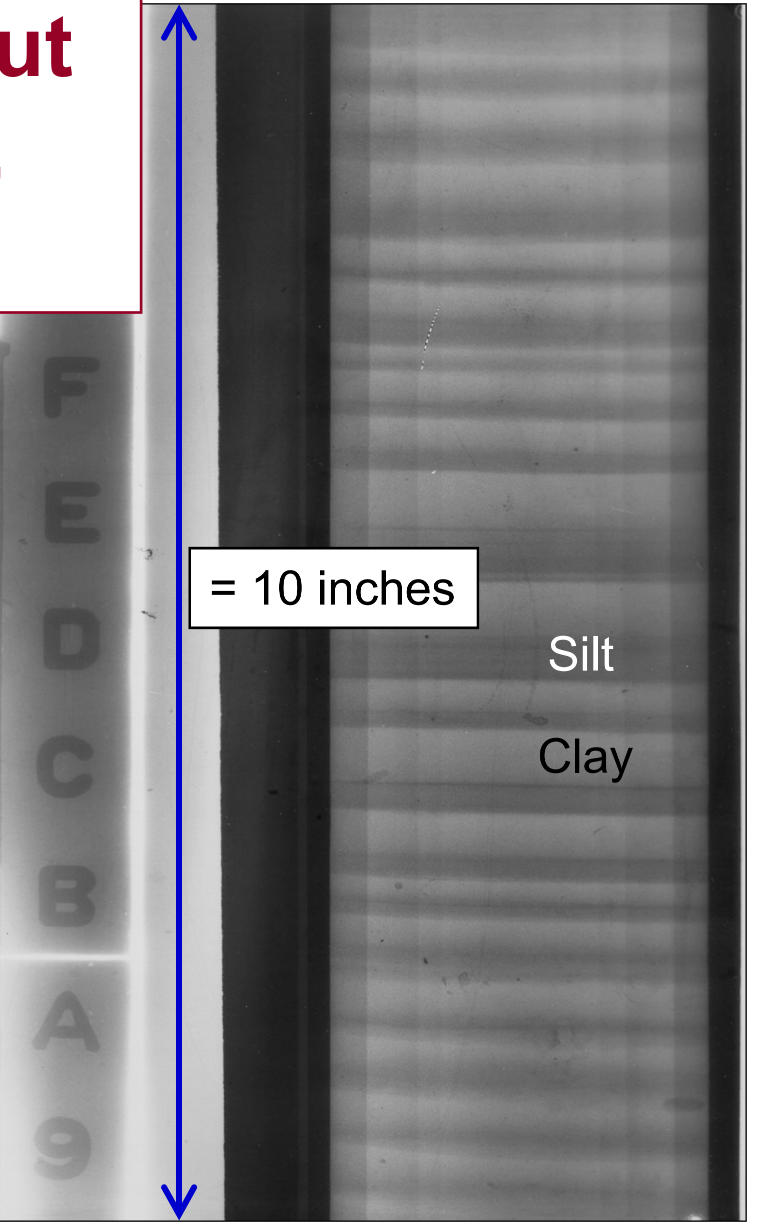
Note correlation between SPT N values and CPTU but SPT testing was <u>continuous</u>

[Takesue et al. (1995)]

Example CPTU in Connecticut Valley Varved Clay (CVVC), Western MA

X-ray of fixed piston sample of Connecticut Valley Varved Clay (CVVC) – Amherst, MA

Silt = "summer" deposit
Clay = "winter" deposit



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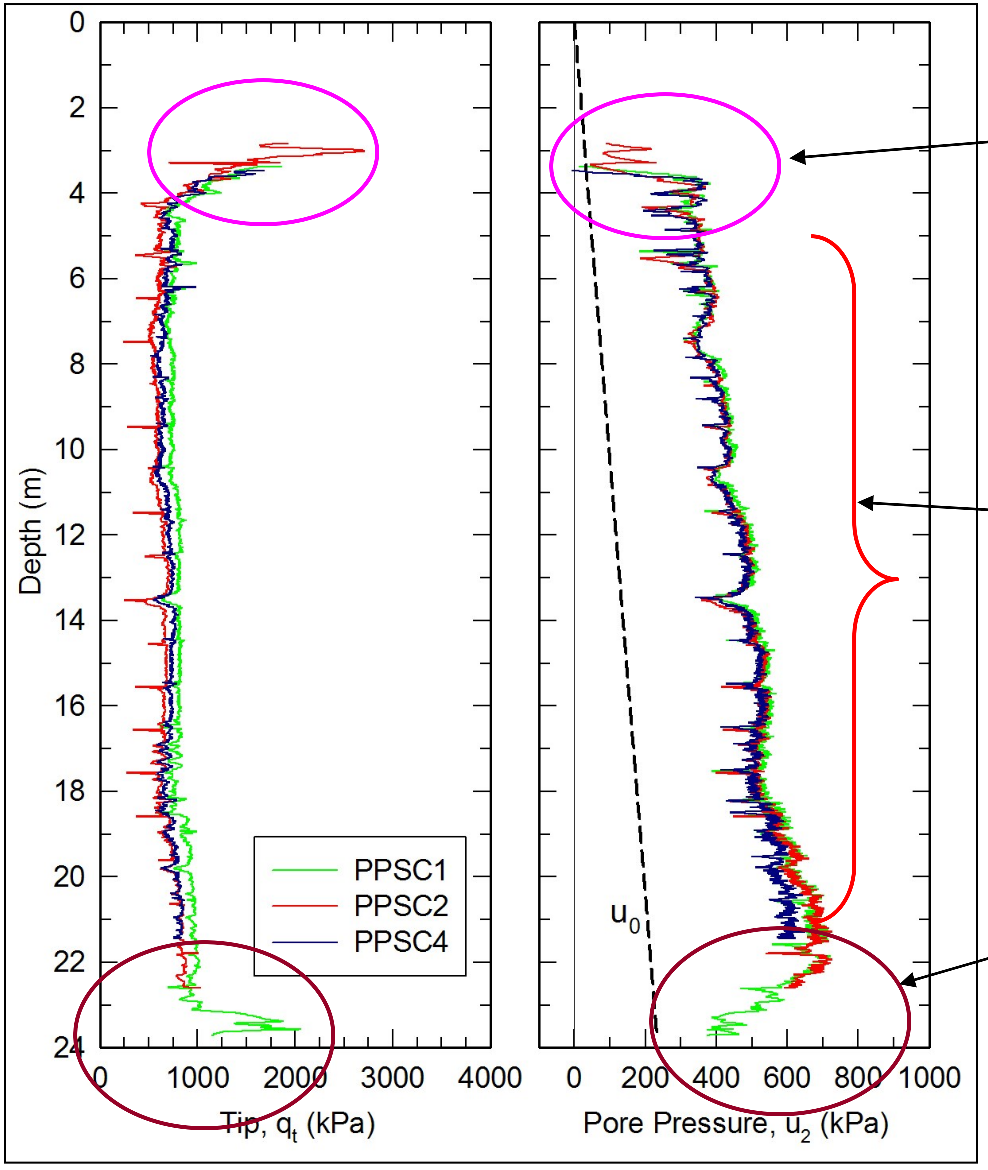
Example CPTU in CVVC, Amherst, MA



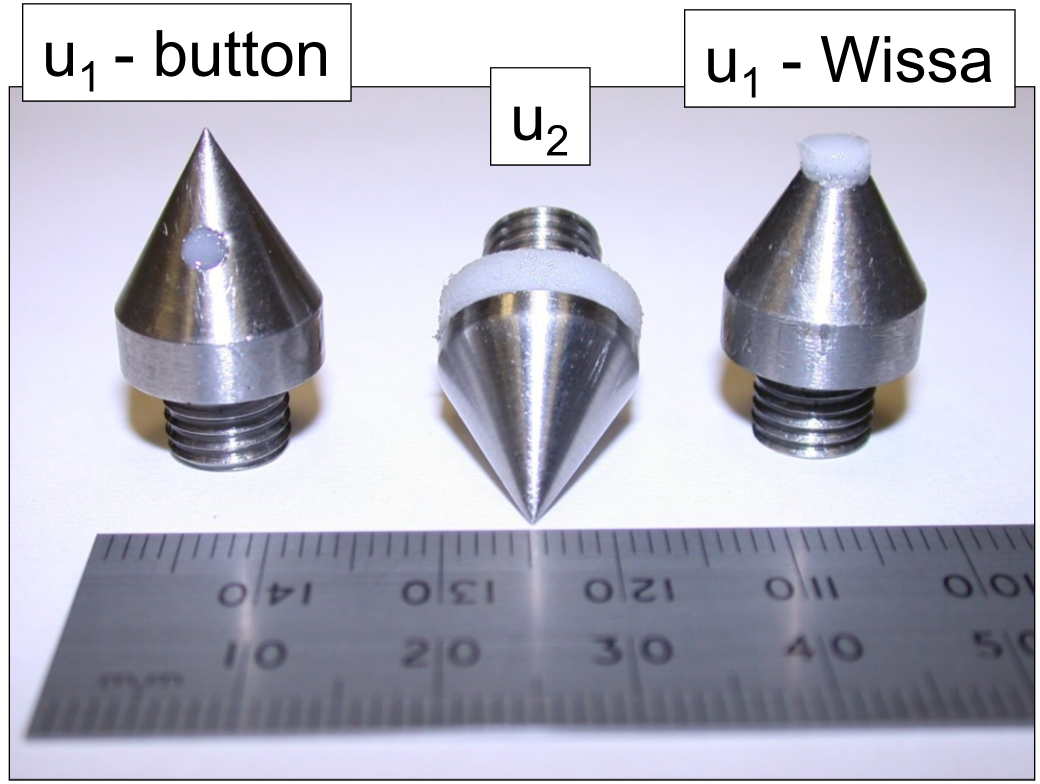
Stiff desiccated CVVC crust

Lightly overconsolidated CVVC = soft, moderately sensitive "clay"

Increasing silt content and thickness of silt layers

Miniature Piezoprobe for high resolution profiling of thin soil layers

Projected tip area = 1.25 cm^2



u_1(face), u_2, u_1(tip)

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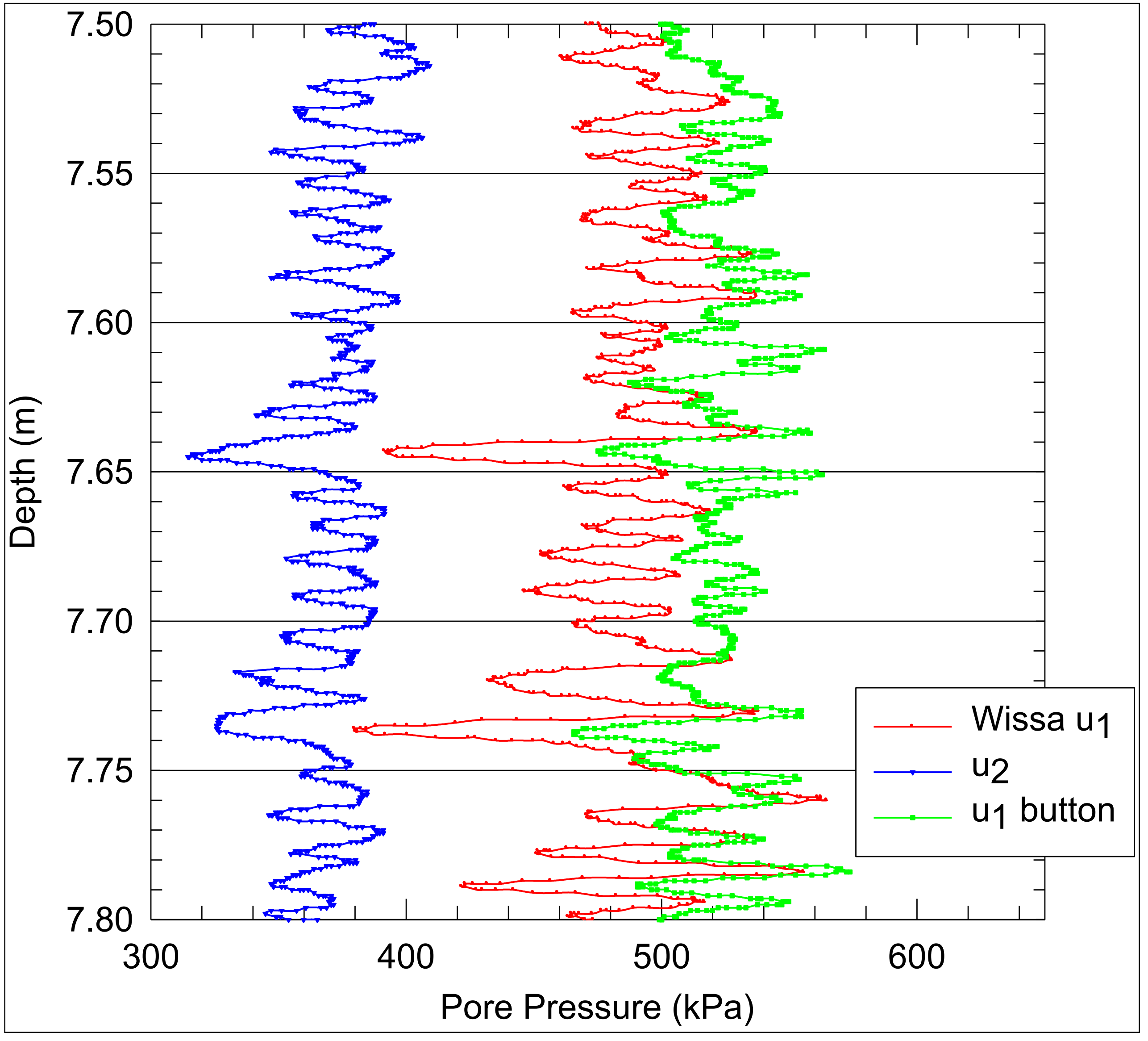
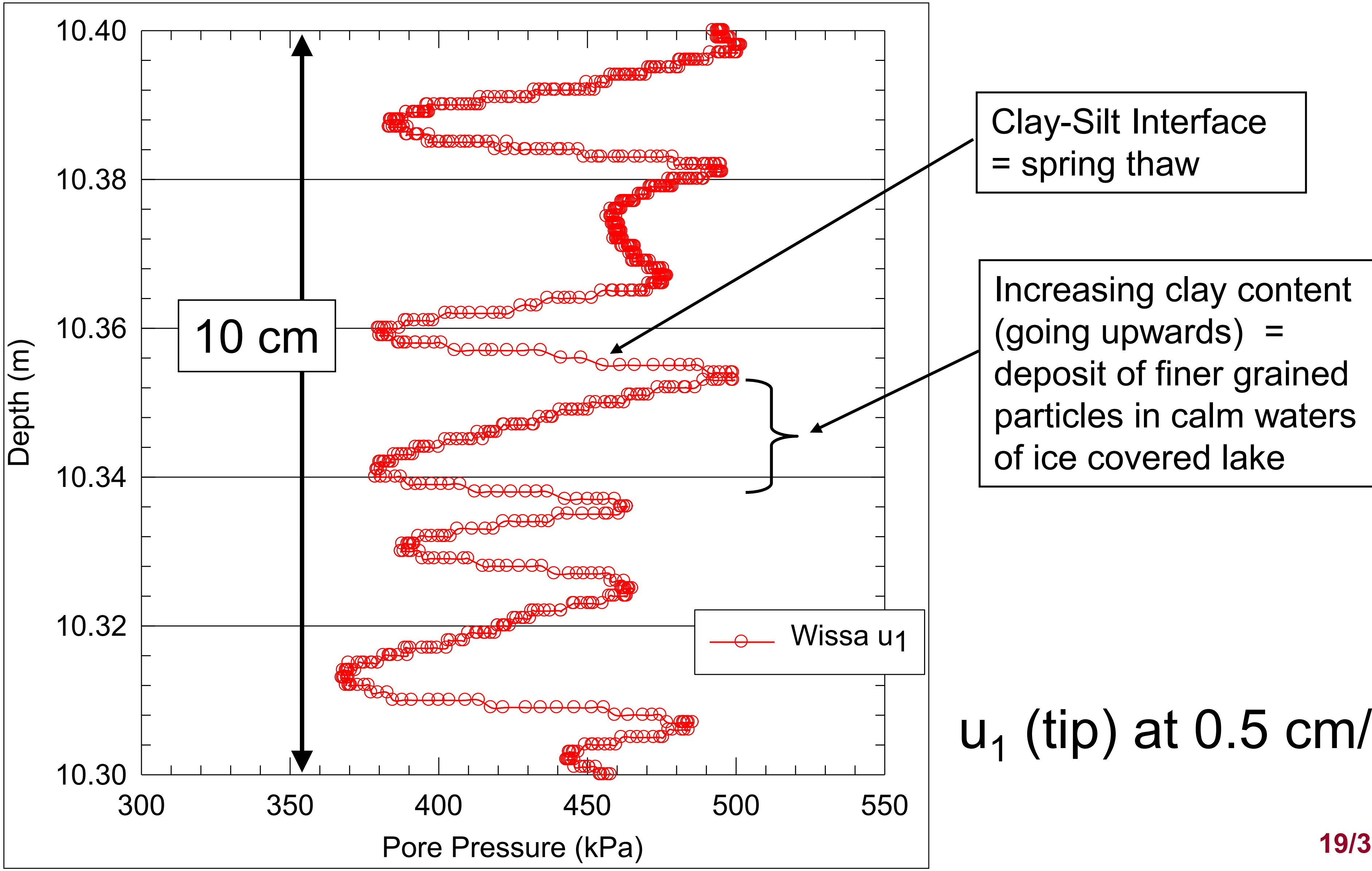
Example Miniature Piezoprobe – CVVC Amherst, MA



- push at 2 cm/s
- sample at 64 Hz

Example Miniature Piezoprobe – CVVC Amherst, MA



u_1 (tip) at 0.5 cm/s

Soil Classification from CPT/CPTU data

Methodology:

1. Quantify observations used to identify soil stratigraphy.

2. Empirically based, i.e., measured CPT/CPTU data are correlated with know soil profiles.

3. Early charts relied on direct use of reduced data, e.g., q_c or q_t and f_s or R_f.

4. Later charts make use of normalized parameters to account for increasing overburden stress with depth, e.g., Q_t, B_q.

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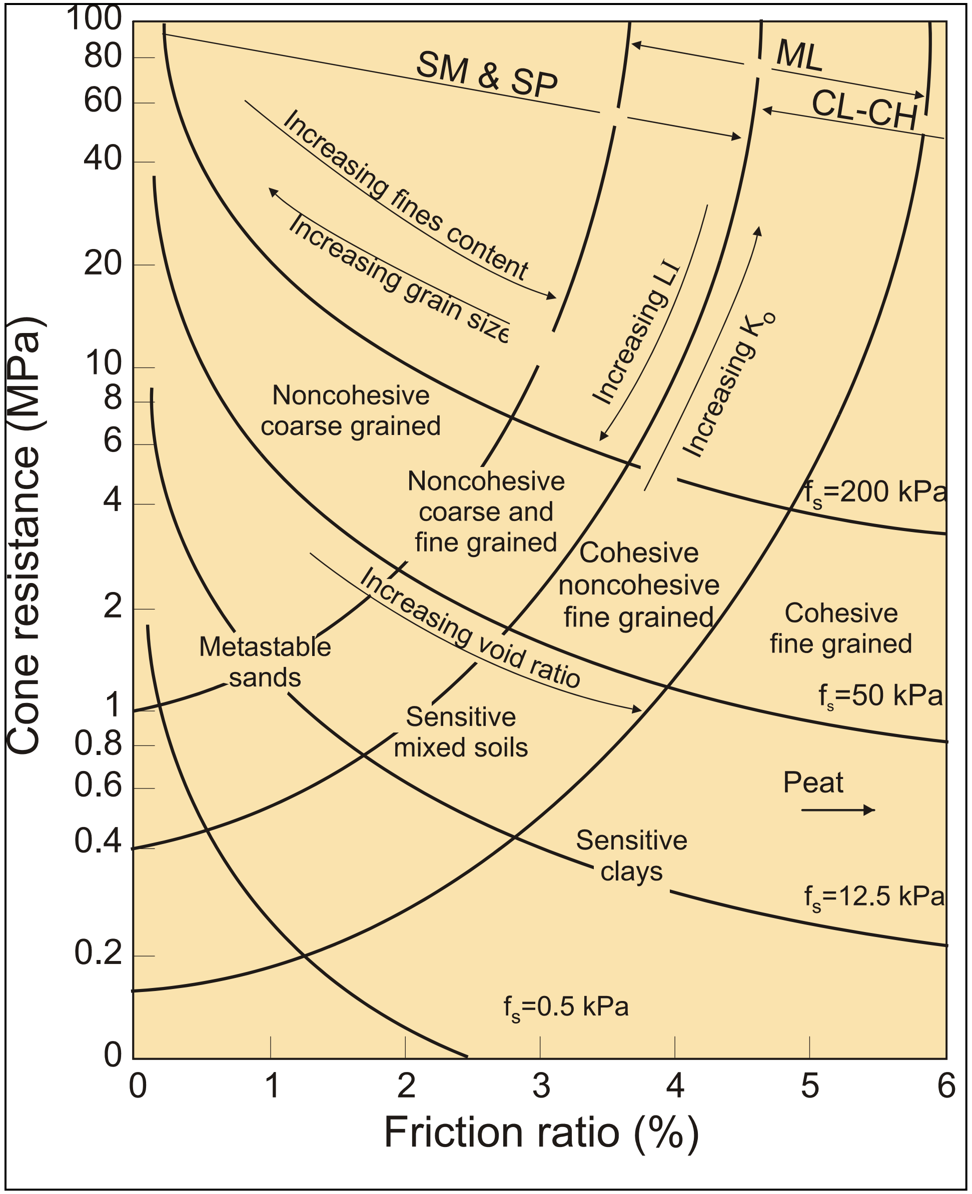
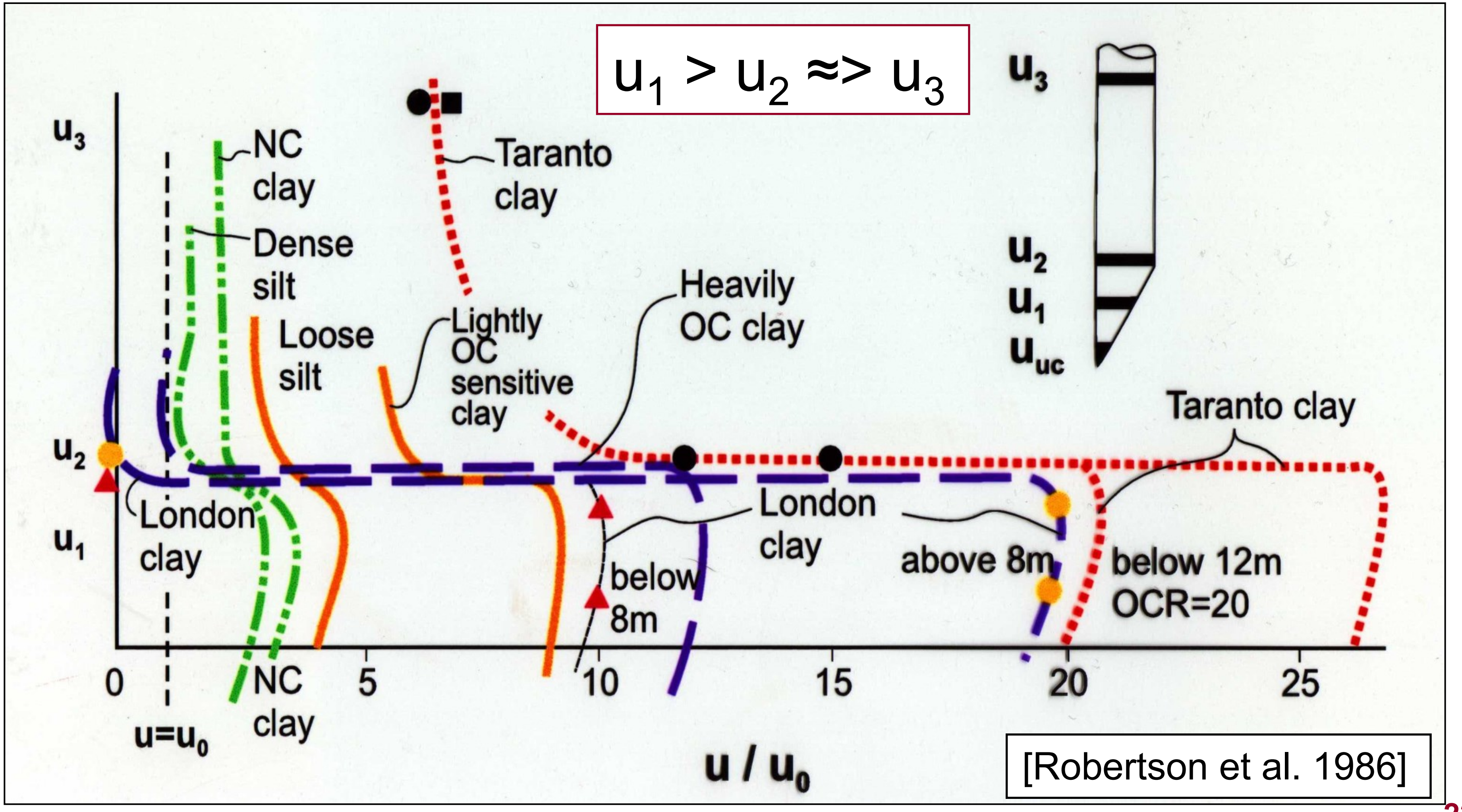
CPT Soil Classification/Behavior Chart



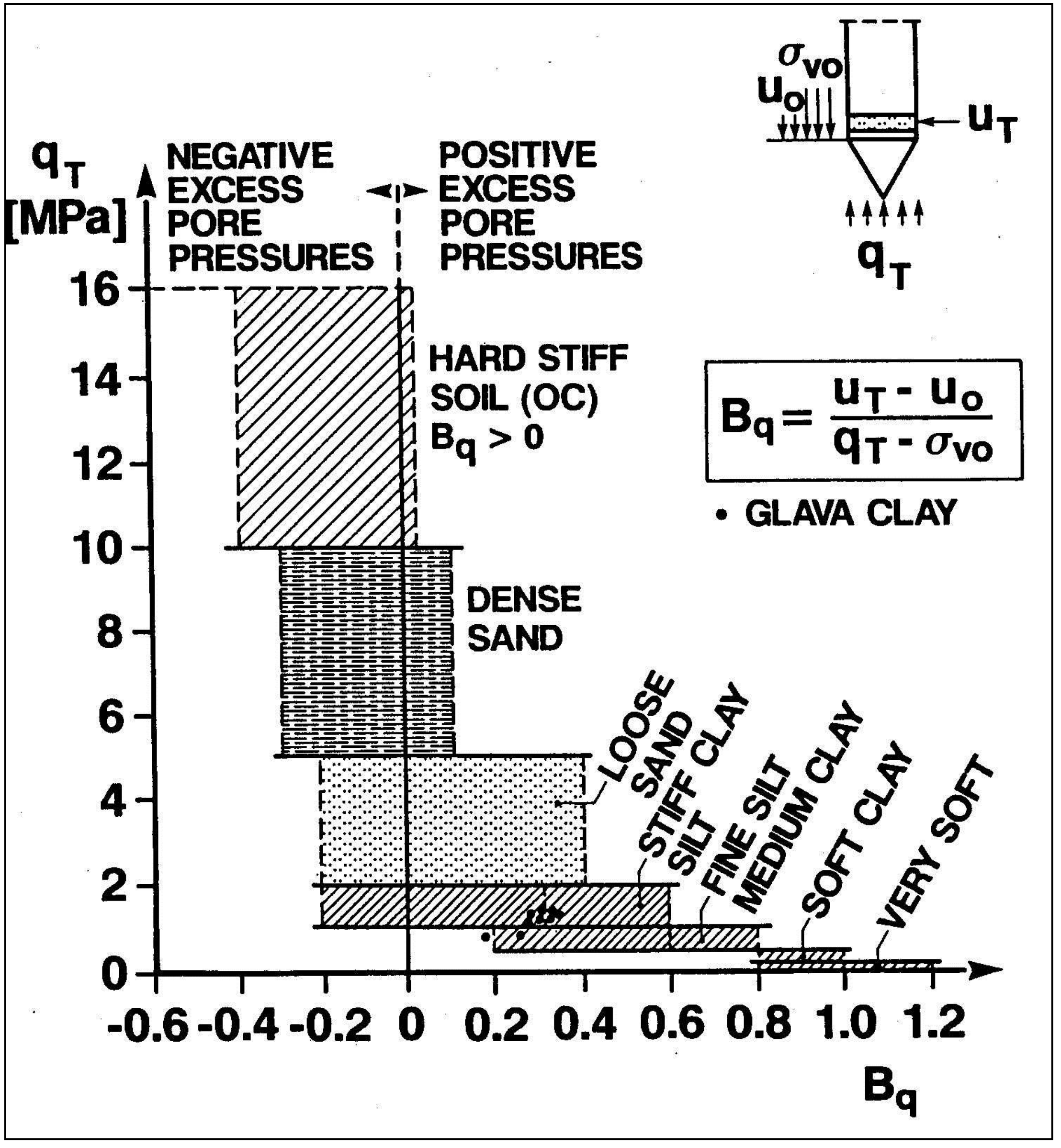
Based on q_c and f_s from CPT

[Figure 5.6
Douglas and Olsen 1981]

Measured CPTU pore pressure by location and soil type



Pore Pressure (via B_q) for soil Classification

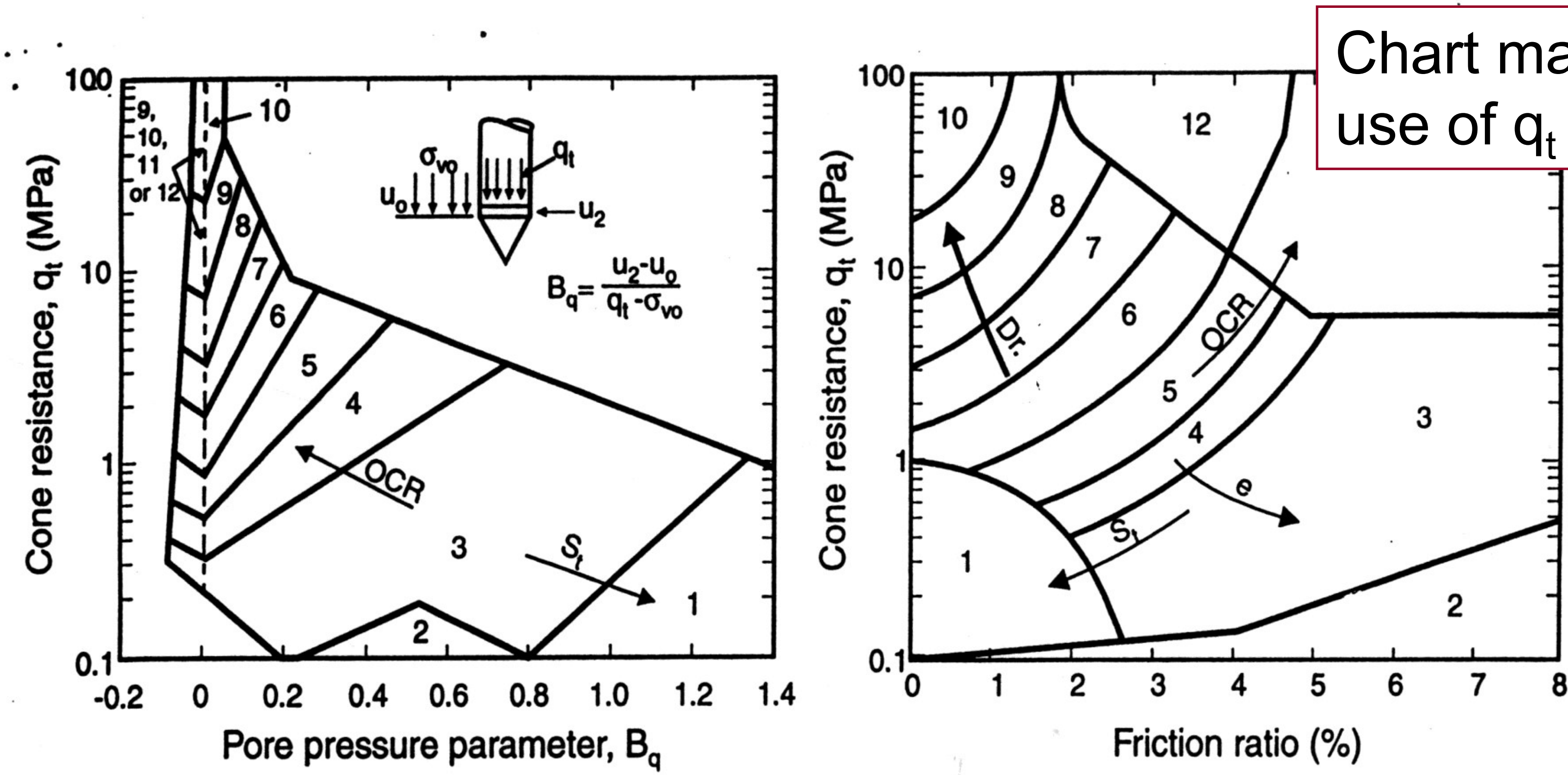


Note: measured u is function of location – chart is for u_2 position. Hence, negative pore pressures can occur.

[Janbu and Senneset 1984]

Soil Behavior Type Classification Chart

Chart making use of q_t

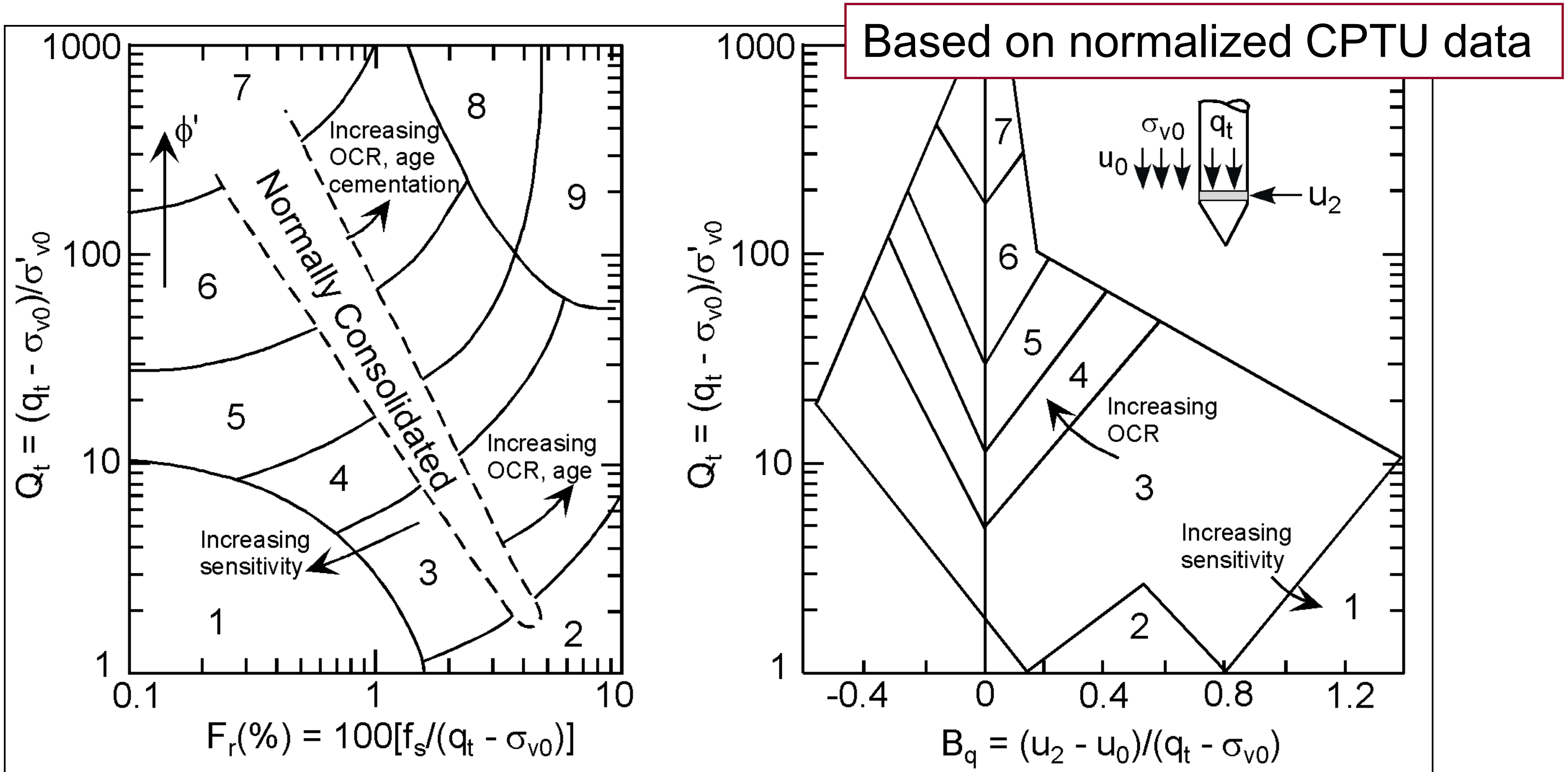


[Robertson et al. 1986]

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*

Soil Behavior Type Classification Chart



[Robertson 1990]

Soil Behavior Type by Zone Number

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

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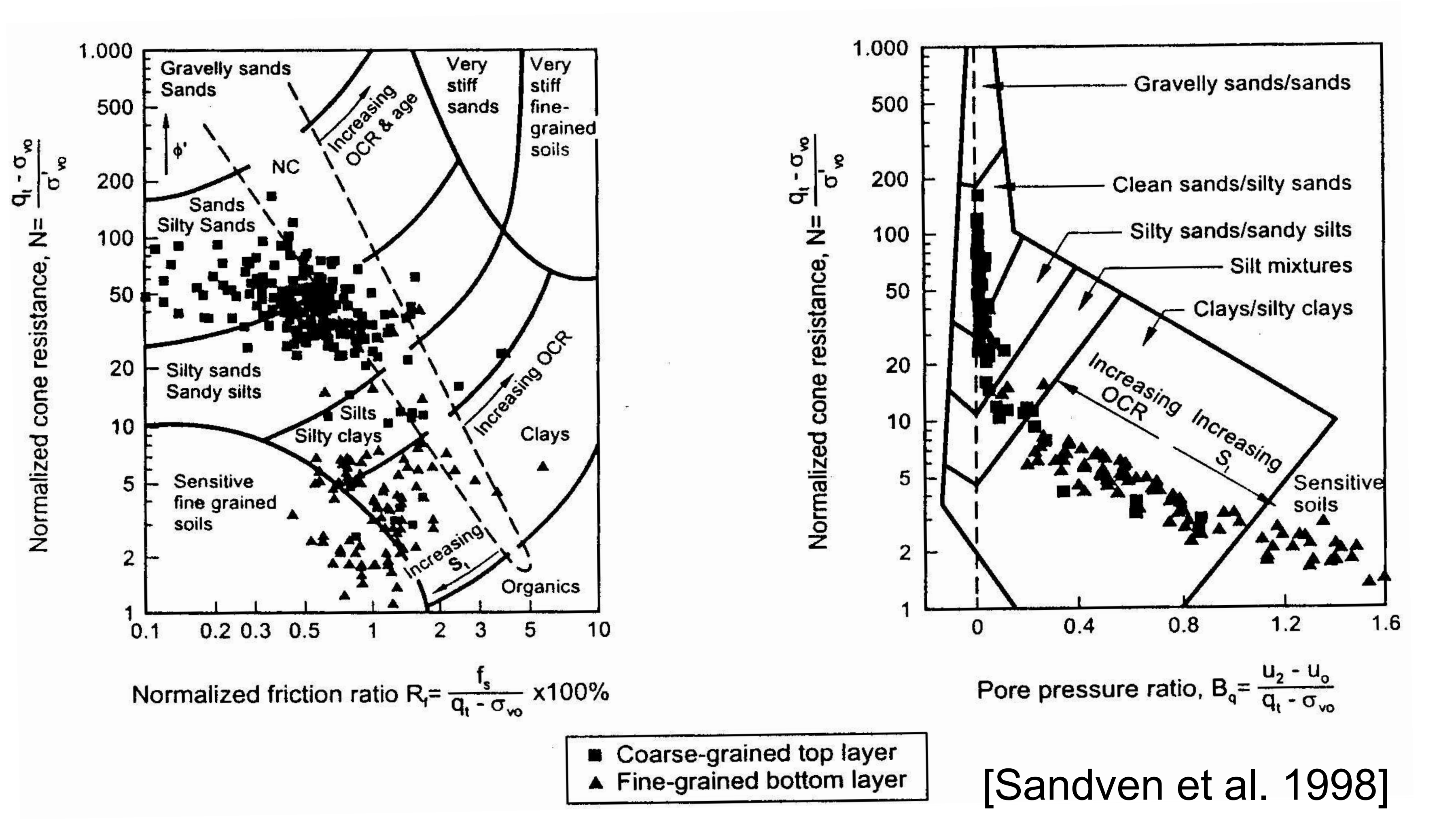
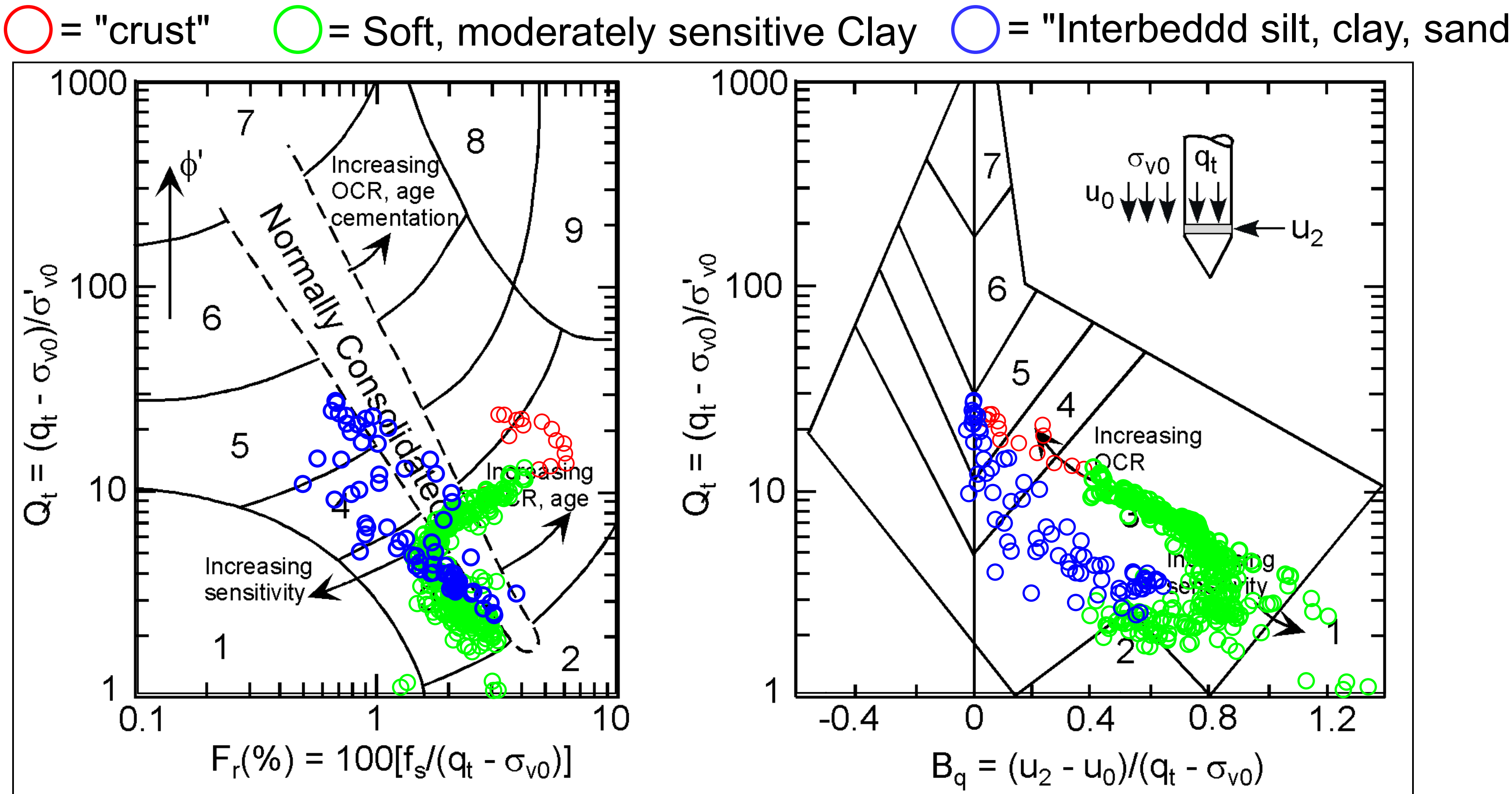
Example CPTU Soil Classification – Oslo Airport



[Sandven et al. 1998]

Newbury BBC classification chart



Soil Behavior Type by Zone Number

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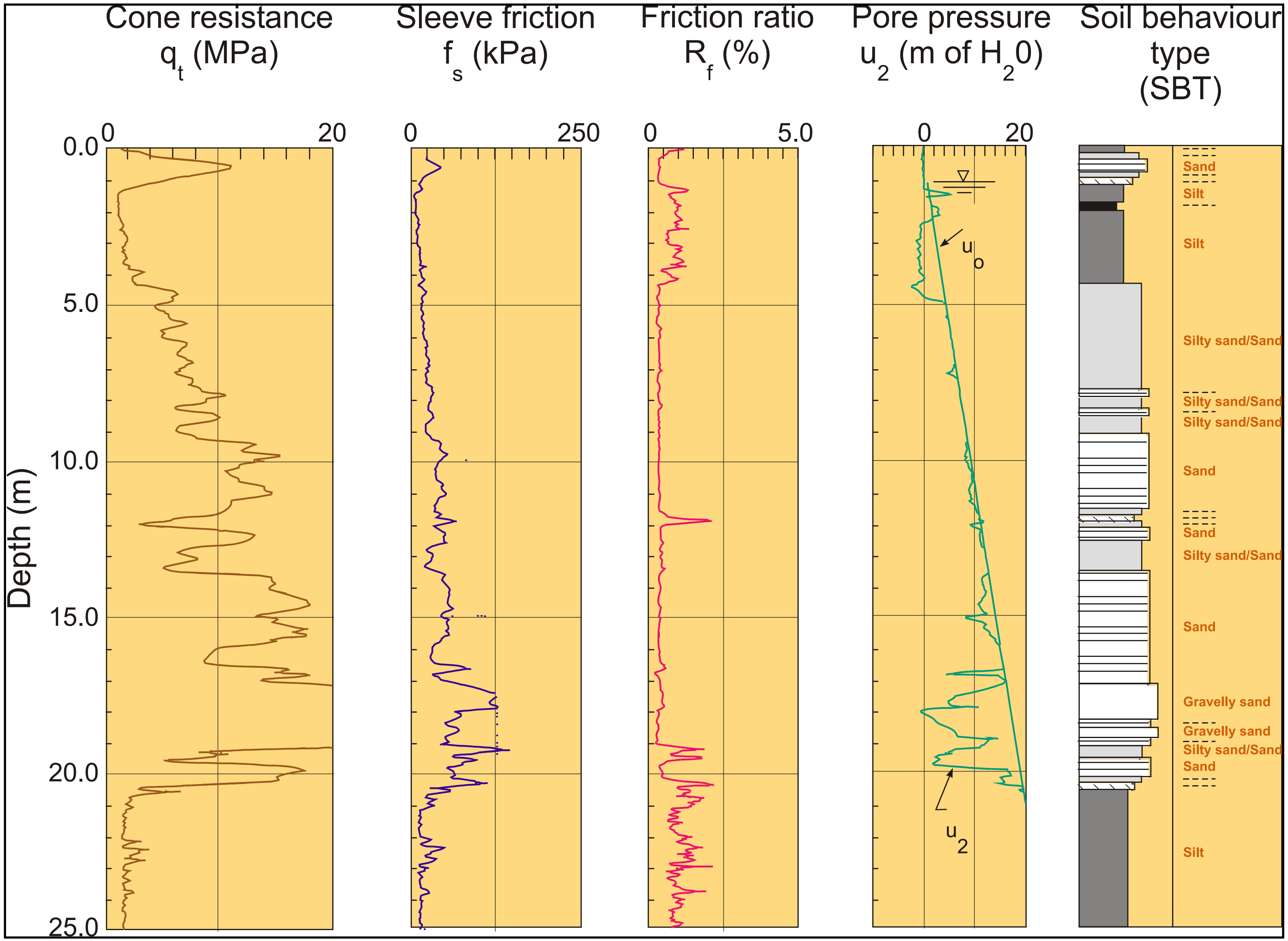
5. Sand mixtures; silty sand to sand silty
6. Sands; clean sands to silty sands
7. Gravelly sand to sand
8. Very stiff sand to clayey sand
9. Very stiff fine grained

Example of "Automated" Soil Identification Chart



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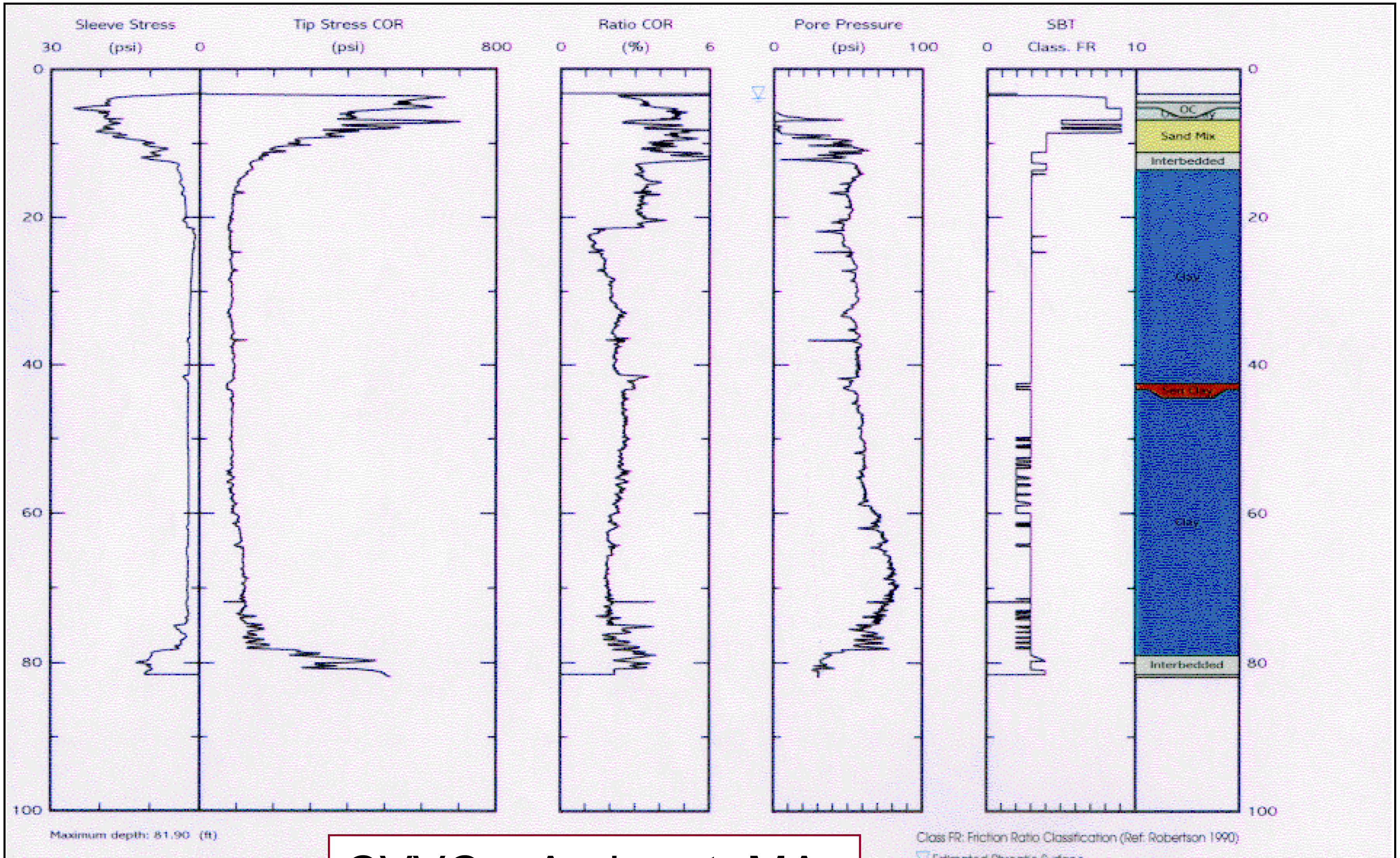
Example of "Automated" Soil Identification Chart



CVVC – Amherst, MA

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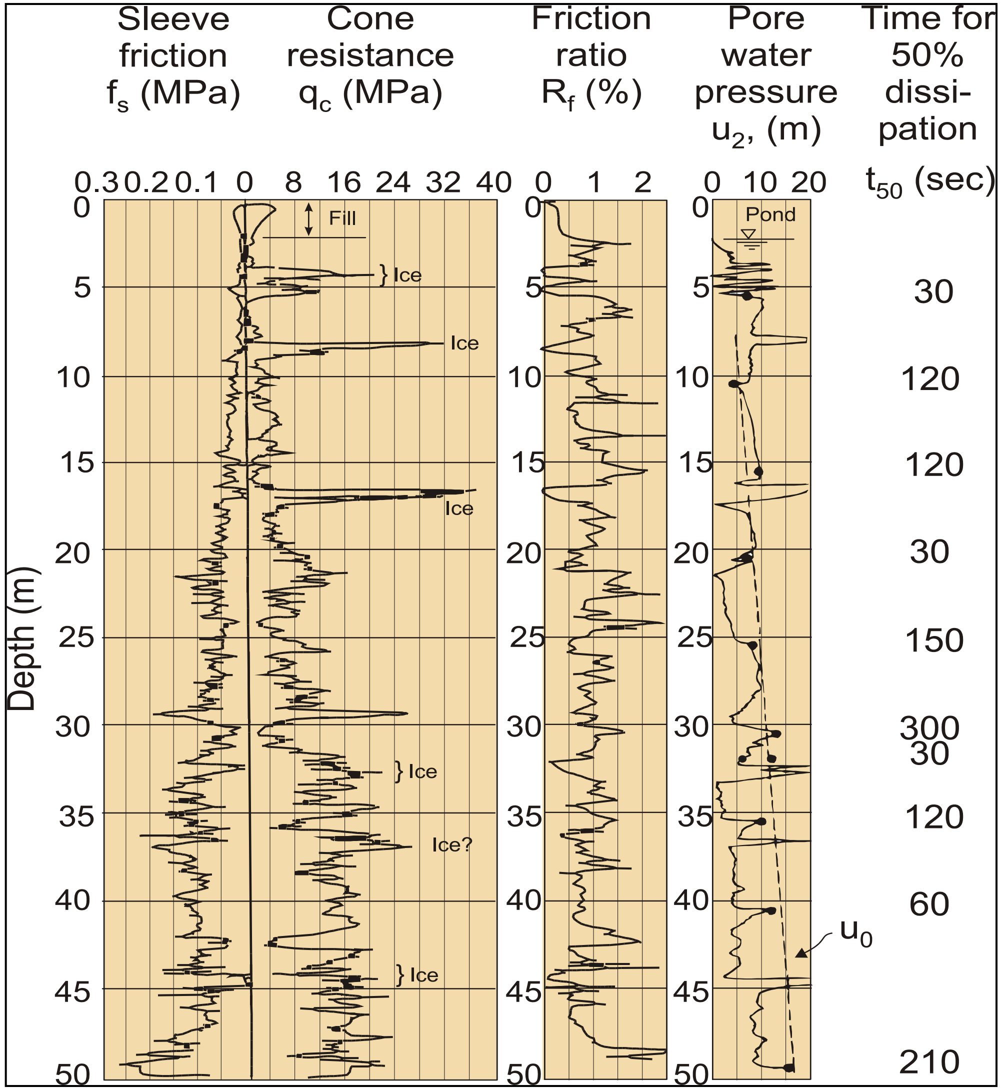
Additional Measurements for better definition of soil type/behavior

Options include:

[Note: additional sensors covered in later topic]

- Short dissipation tests with CPTU
- Dual or Triple element (pore pressure) CPTU
- Seismic CPTU to get Shear Wave Velocity (V_s)
- Electrical conductivity (or resistivity) = relate to soil porosity, degree of saturation, relative density, leaching of quick clays
- Nuclear density/Gamma Cone = density of soil units

Example CPTU – Mine Tailings with ice lenses

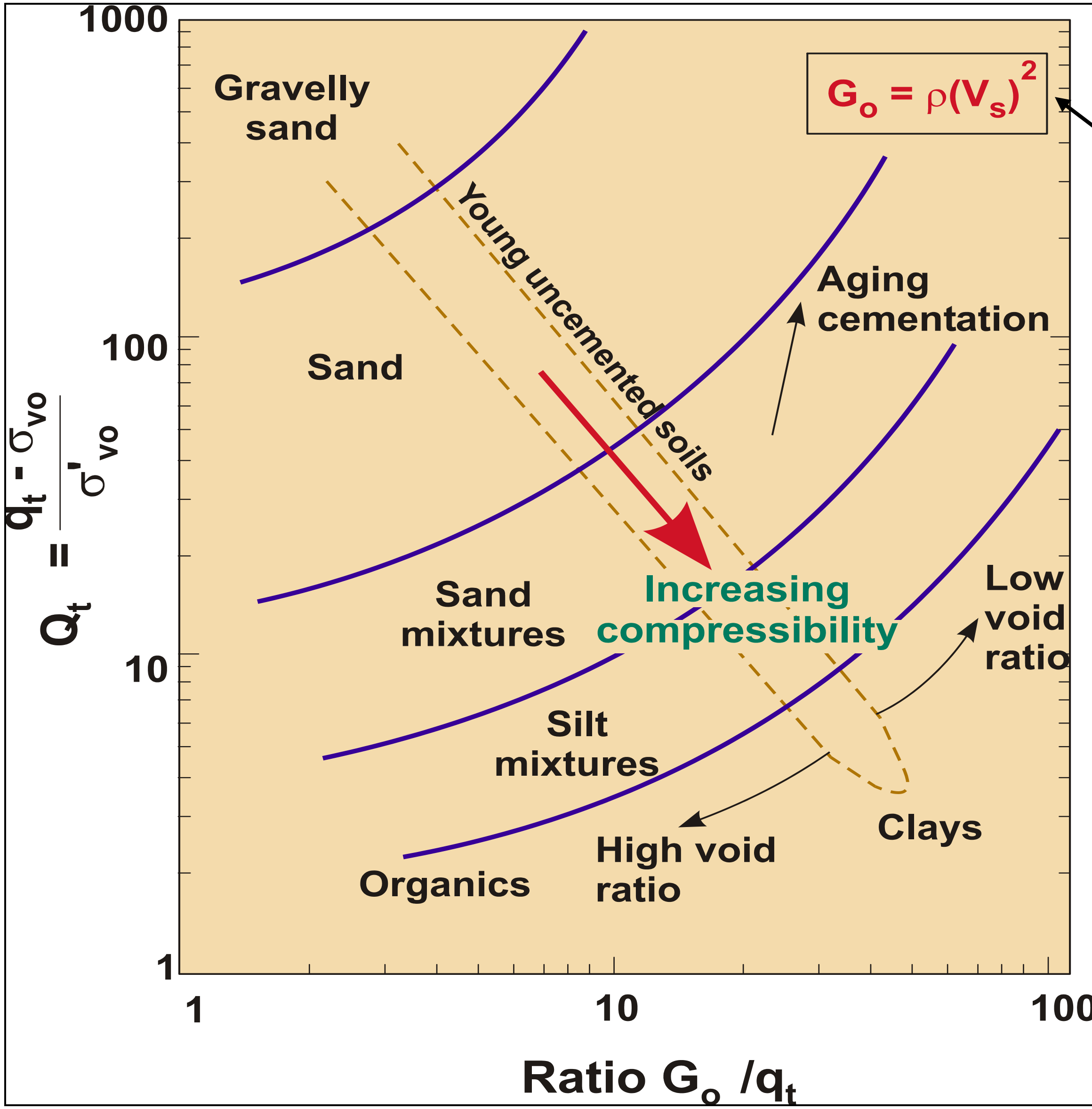


Ice lenses = sharp spikes in q_c and u_2

Use of dissipation tests to aid in classification

[Campanella et al, 1984]

Soil Classification/Behavior Chart using G_{max}



- $G_0 = G_{max}$
- V_s direct measure from seismic CPTU
- ρ_t must be estimated

[Robertson et al. 1995]

Recommendations: CPT/CPTU based Soil Identification/Classification

- Use all information available, e.g., q_c or q_t, f_s, u, F_r, B_q

- Shape and magnitude of q_t profile gives indication on whether you are in uniform clay layer, sand layer, etc.

- Pore pressure profile readily indicates a drained condition (e.g., sand with $\Delta u = 0$) or undrained (e.g., clay with $\Delta u > 0$)

- Use q_t - R_f - B_q and/or Q_t-F_r-B_q diagrams to identify soil type. Accumulate local experience to create/modify diagrams.

- Short dissipation tests can help in identifying soil type

- Measurements using other sensors (e.g., V_s) can enhance soil identification

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