Advances in the Characterization of Gravelly Soil Deposits

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Outline

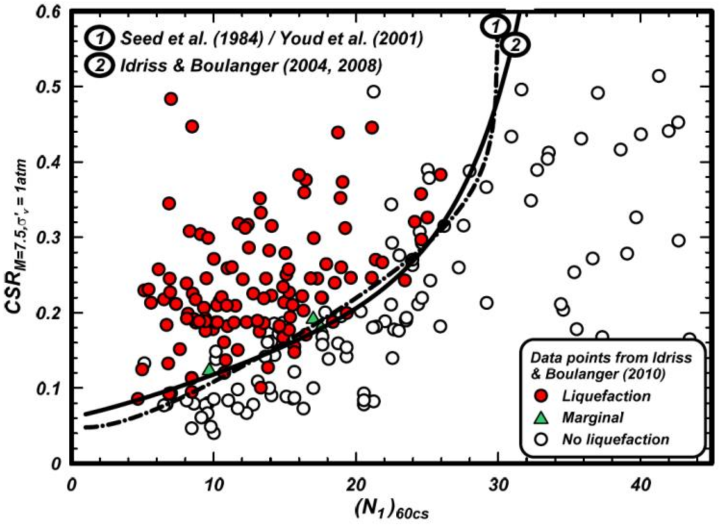
- *Motivation*
- *Integrated Site Characterization*
  - *Length scale of failure mechanisms & depositional structure*
- *Geologic Context*
  - *Depositional processes & spatial variability*
- *Characterization Challenges and Techniques*
- *Instrumented Becker Penetration Test*
  - *System design and operation*
  - *Energy normalized penetration resistance*
  - *Correlation to obtain equivalent SPT N_{60} values*
- *Example Application on Industry Project*
- *Summary*

Motivation

- *Water, hydro-electricity, and transportation infrastructure close to rivers, and therefore often in gravelly deposits*
- *Gravelly soils can be challenging to characterize*
- *Need for representative penetration resistance values in order to utilize sand-based methods for engineering property and liquefaction triggering evaluations*

Towhata et al. 2014

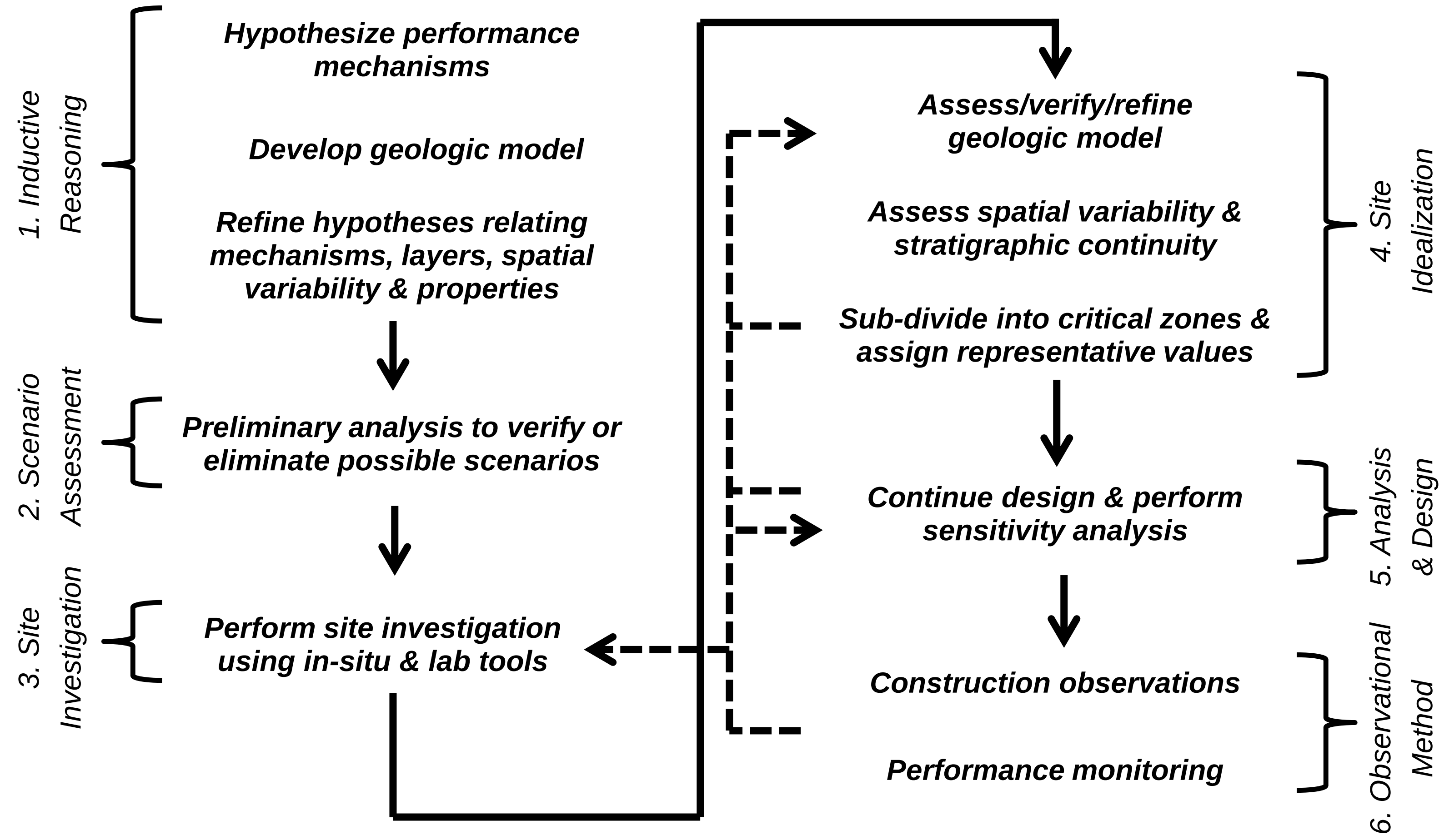
LADWP



Motivation

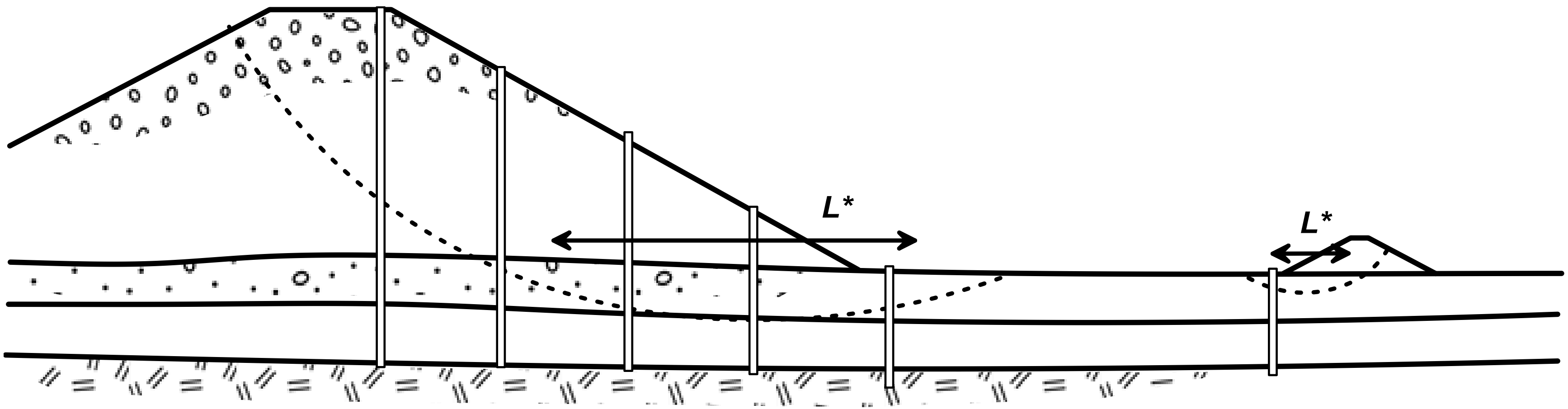
- *Gravel behavior*
  - *Mechanical behavior dependent on whether:*
    - *clast (gravel) controlled ➤ frictional behavior similar to sands*
    - *matrix (fines) controlled ➤ strength controlled by finer particles*
  - *Hydraulic behavior (pore pressure buildup & dissipation) governed by finer particles*
- *Insufficient documented case histories*
  - *Limited data for triggering correlation for gravels*
  - *Reasonable to assume gravel will behave like sand, and use sand triggering curves*
- *Equivalent penetration resistance value*
  - *SPT & CPT prone to elevated measurements in gravel*
  - *Must determine equivalent penetration resistance value (e.g. N_{60}, q_c) of gravel that would be measured if continuum penetration mechanism was not affected by particle-to-sampler size effects*

Integrated Approach to Site Characterization



Performance Mechanism Scales

- *Small-scale failure mechanisms – can be governed by the lower end of the distributions (the loosest zones, channels, etc.).*
- *Large-scale failure mechanisms – can allow for greater averaging of properties (but look out for continuous layers).*

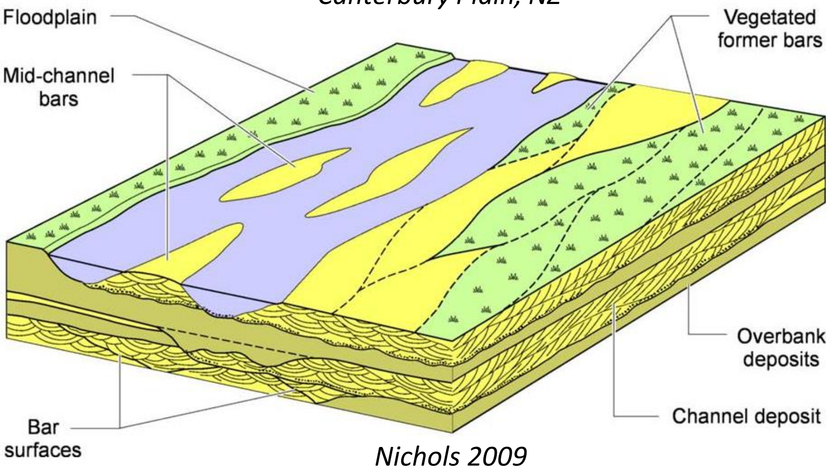


Geologic Model

- *Braided River Architecture in Open Plains*
  - *High energy flow transports gravel*
  - *Sands & fines deposited as flow recedes → upward fining sequence*
  - *Overbank flooding creates continuous layers → fining of soils away from channel*

Canterbury Plain, NZ

agu.org



Nichols 2009

Geologic Model

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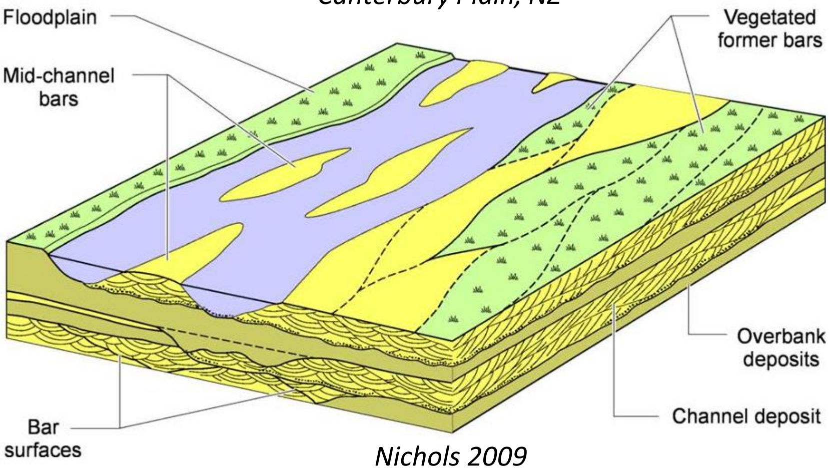
….Additional Complexities within Canyons

- *Overall upward fining as canyon widens*
- *Talus deposits from slopes interlayer with alluvium & can redirect flow*

Canterbury Plain, NZ



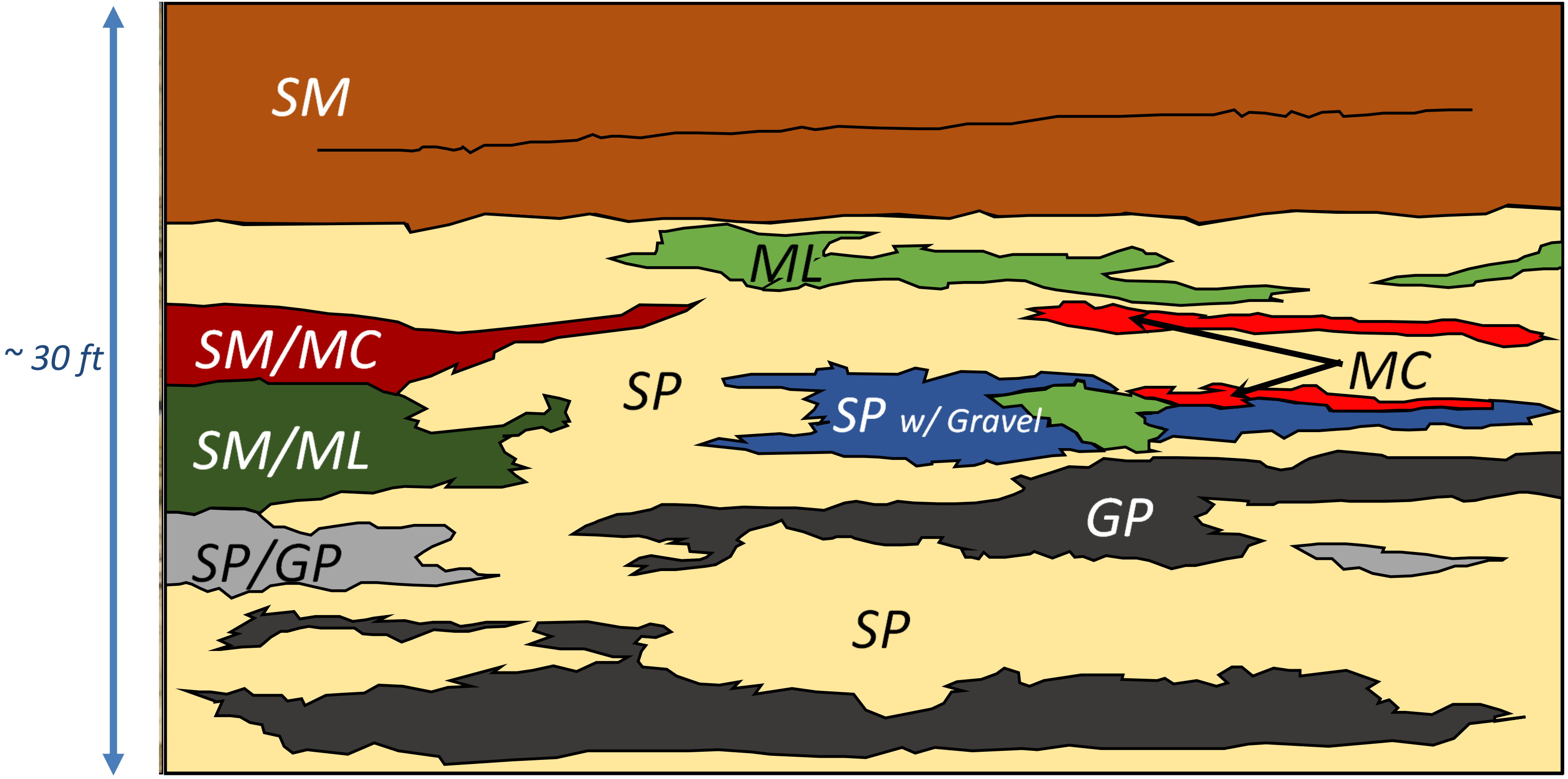
Nichols 2009

Geologic Model

~ 30 ft

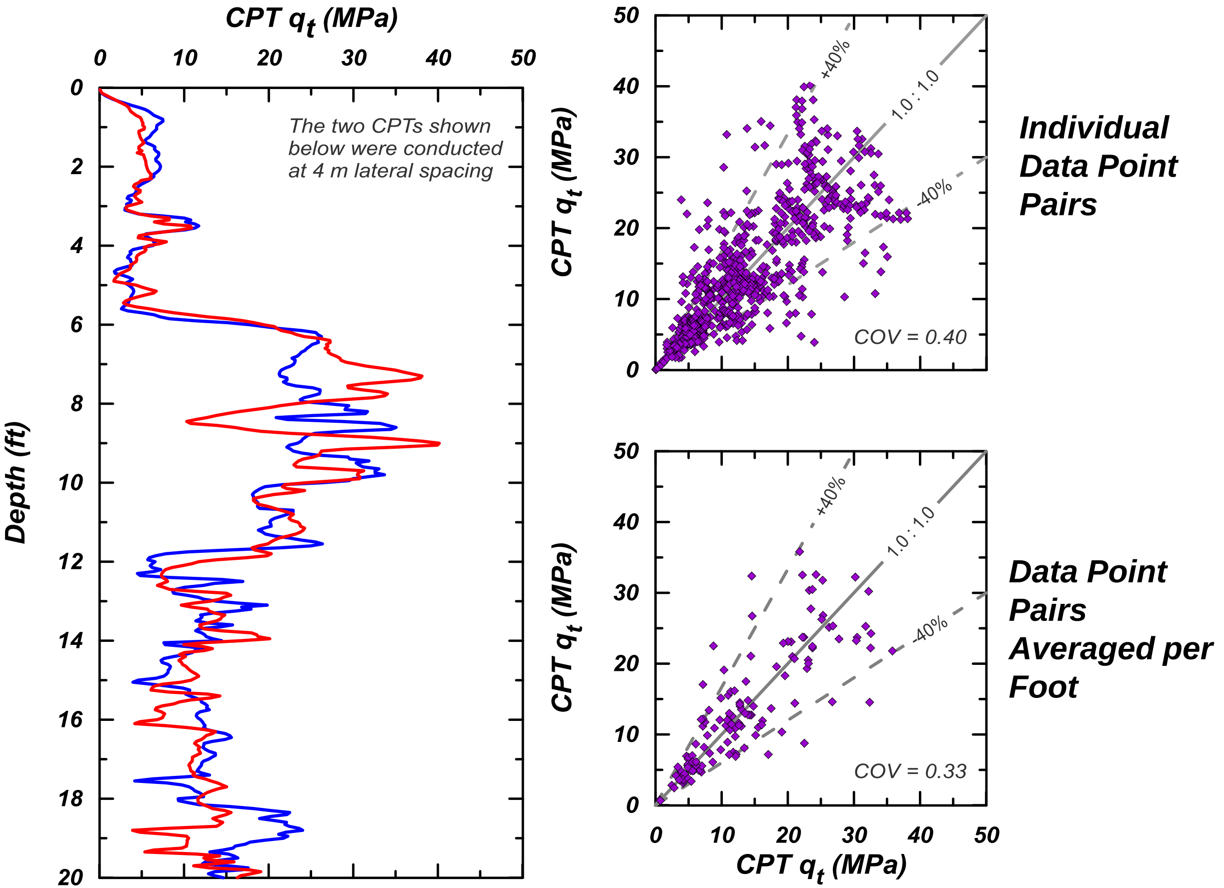
AMEC

Geologic Model



Spatial Variability

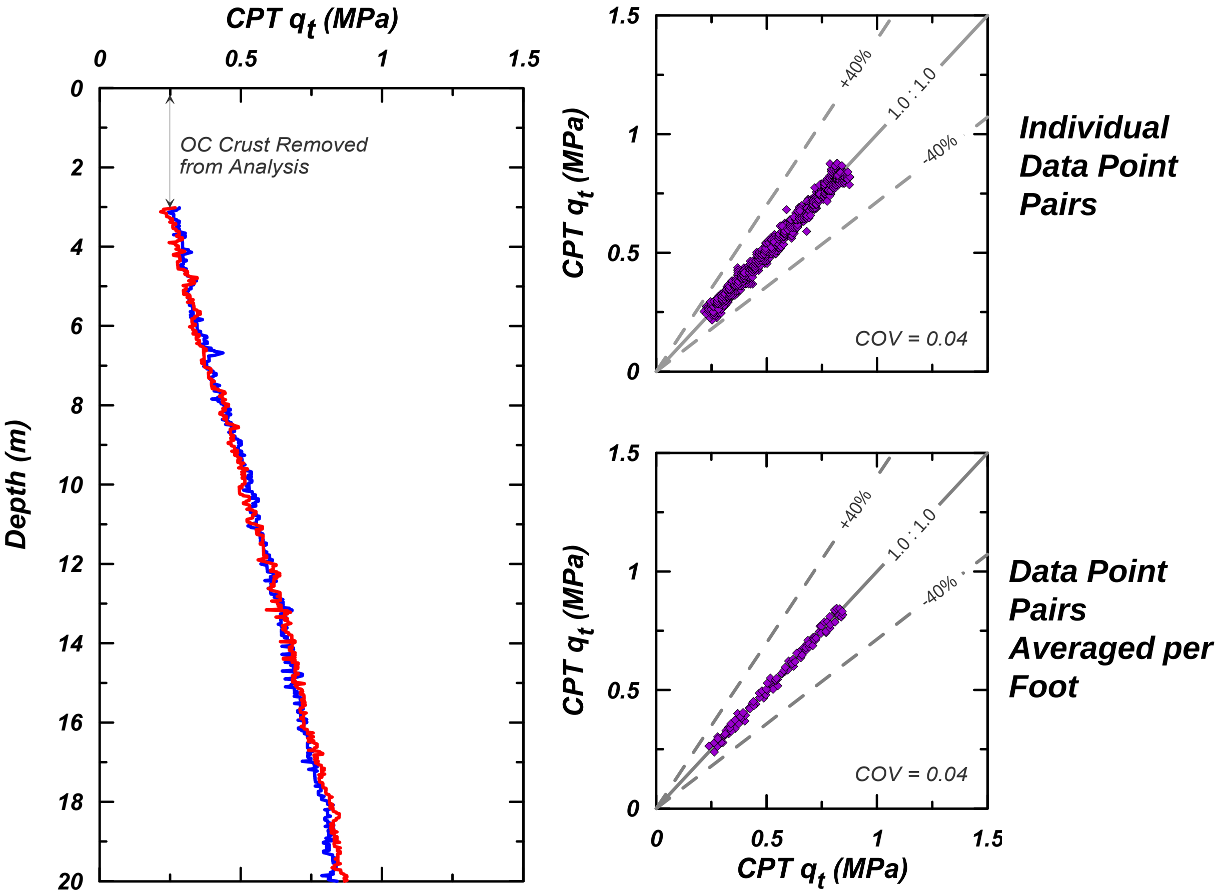
- *Overall a persistent process with continuous spatial and temporal variations in deposition*
- *Extent of variation function of stream width, slope, meander, freq. of avulsion, etc.*
- *Therefore, significant lateral variability expected*



North Haiwee Reservoir, CA

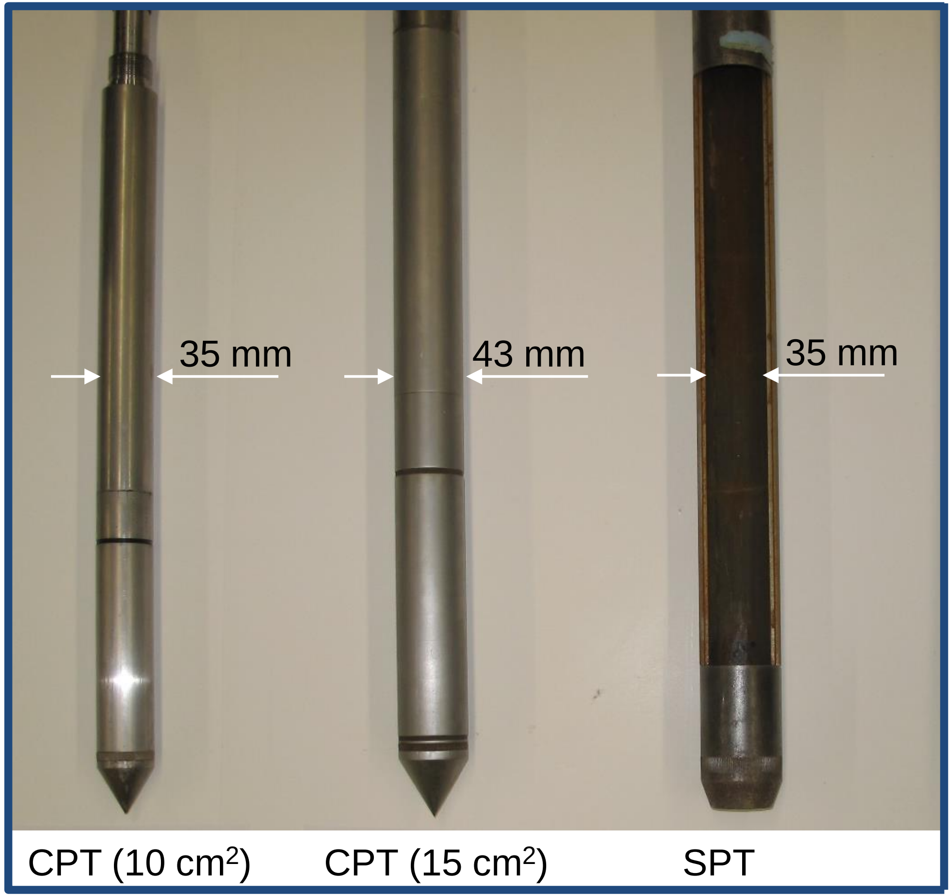
Spatial Variability

- *Overall a persistent process with continuous spatial and temporal variations in deposition*
- *Extent of variation function of stream width, slope, meander, freq. of avulsion, etc.*
- *Therefore, significant lateral variability expected*
- *Extent of variation much greater than 'ordinary soils'*



Onsoy, Norway

Particle to Penetrometer Scaling

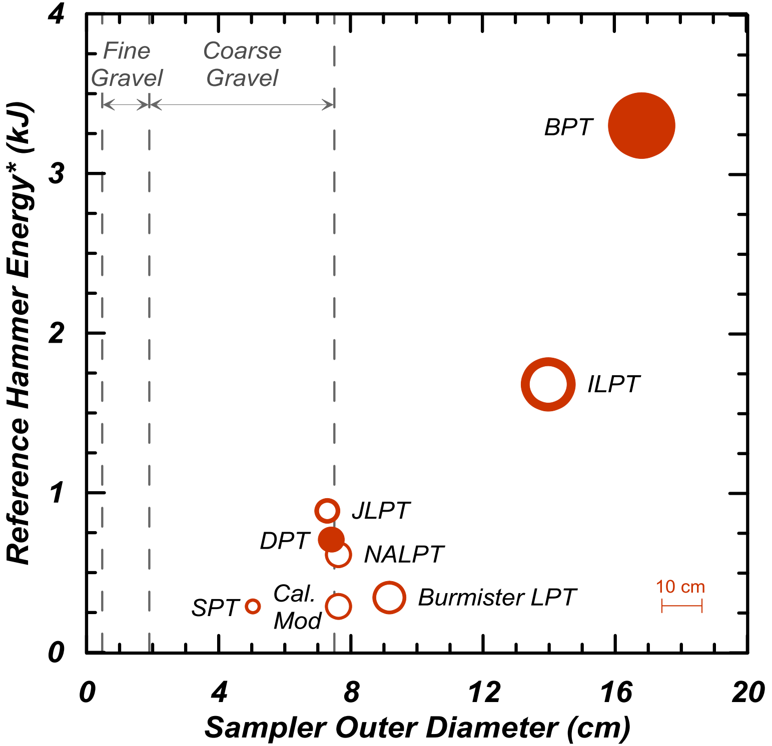


Particle to Penetrometer Scaling

- *Probe diameter-to-particle size primarily determines influence (D_p/d_g)*
- *LPTs upscaled SPTs by ~2x, so still influenced by larger gravels*
- *Becker Penetration Test only probe of sufficient size to be largely insensitive to gravel sized particles*

SPT

Cal. Mod.

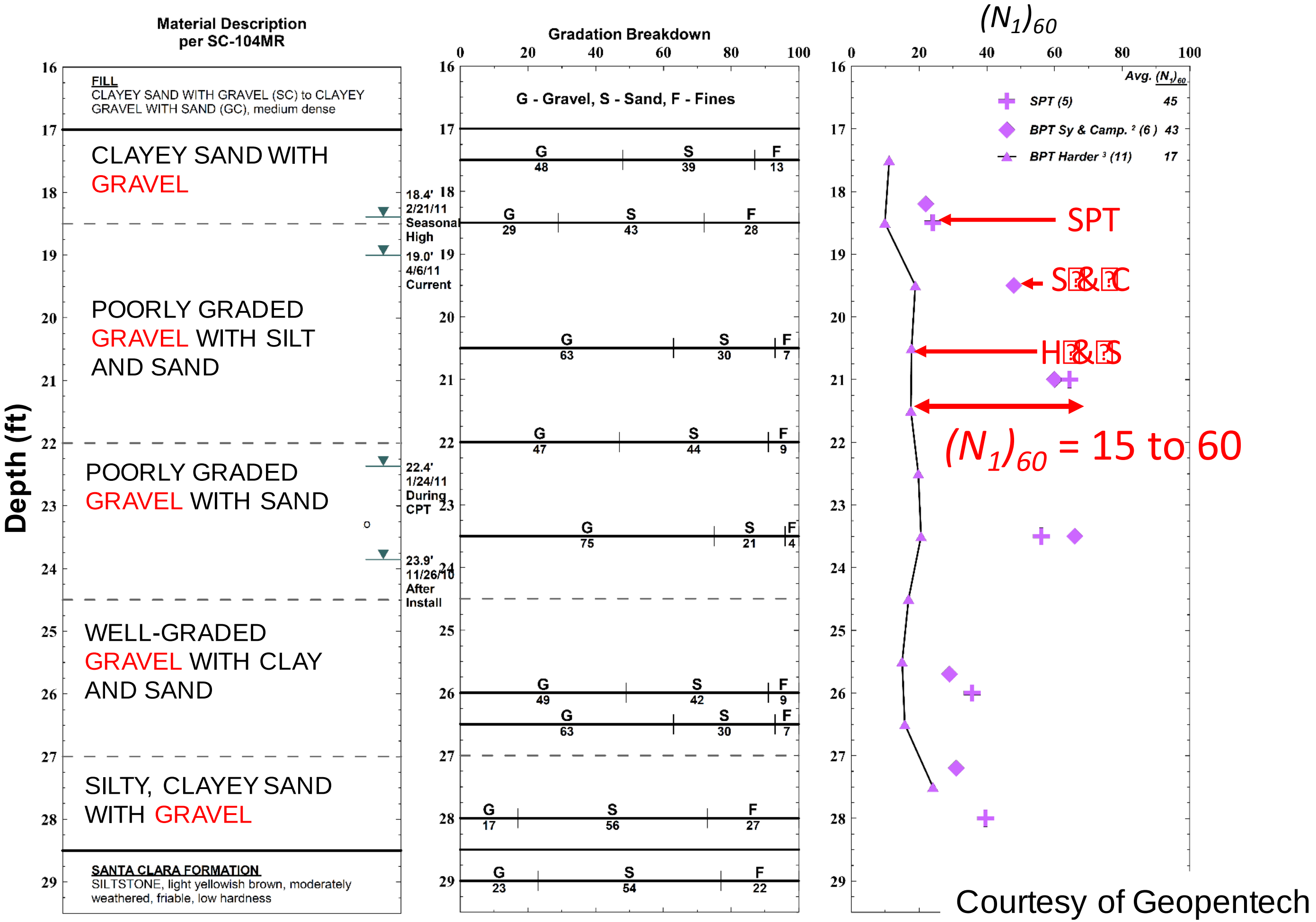


* Reference Hammer Energy is 30% of the maximum hammer energy for BPT and 60% for all other penetrometers.

The size and shape of the symbols are proportional to the actual dimensions of the penetrometers.

Previous BPT Methods

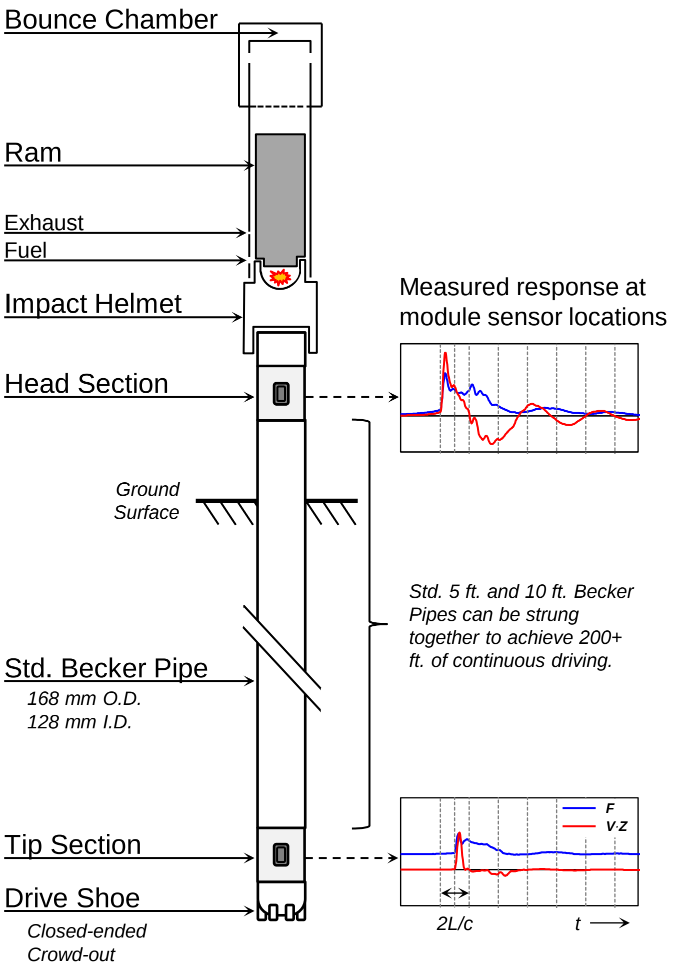
- *Harder & Seed (1986) – used hammer BCP as proxy for energy*
- *Sy & Campanella (1994) – used PDA w/ CAPWAP/WEAP analysis*
- *Both methods only use above ground measurements*



Courtesy of Geopentech

instrumented Becker Penetration Test (iBPT)

- *Prior Becker methods are limited & cannot directly account for variations in hammer energy, shaft friction, pre-drilling, & soft layers*
- *iBPT provides direct measure of energy and displacement at drill string tip for individual hammer blows*
- *Produces BPT energy normalized penetration resistance*

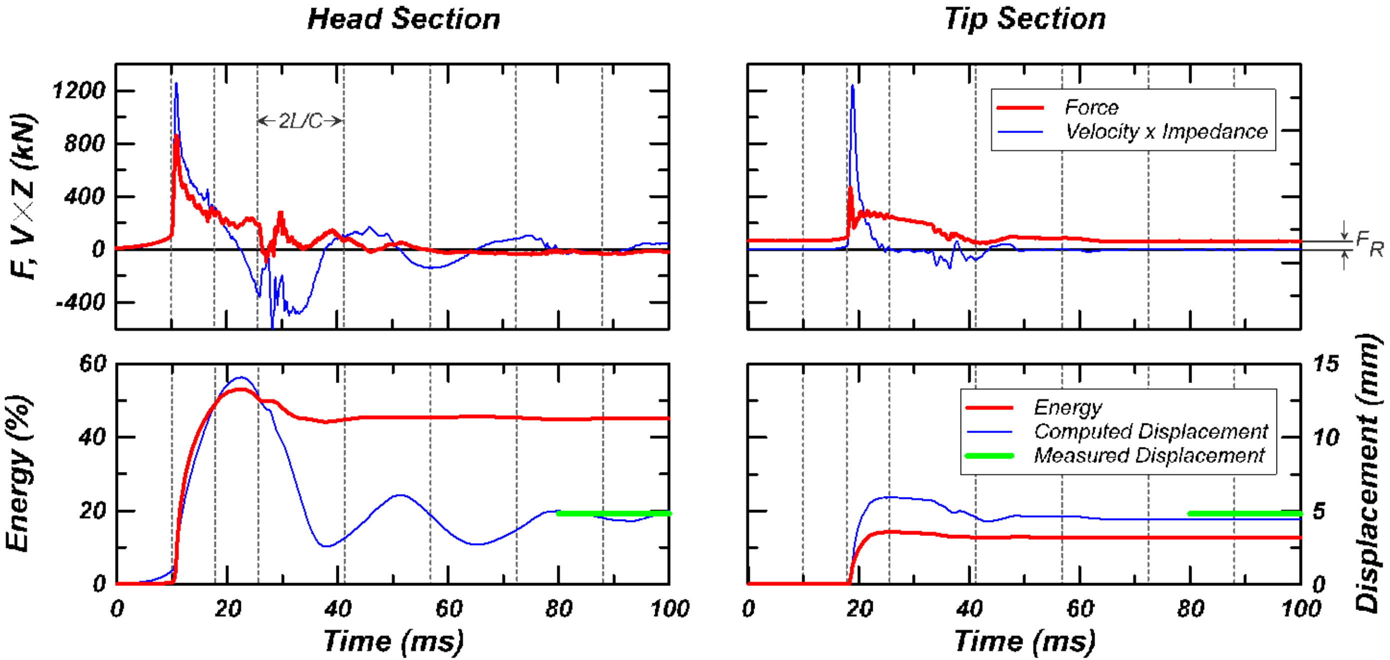


instrumented Becker Penetration Test (iBPT)

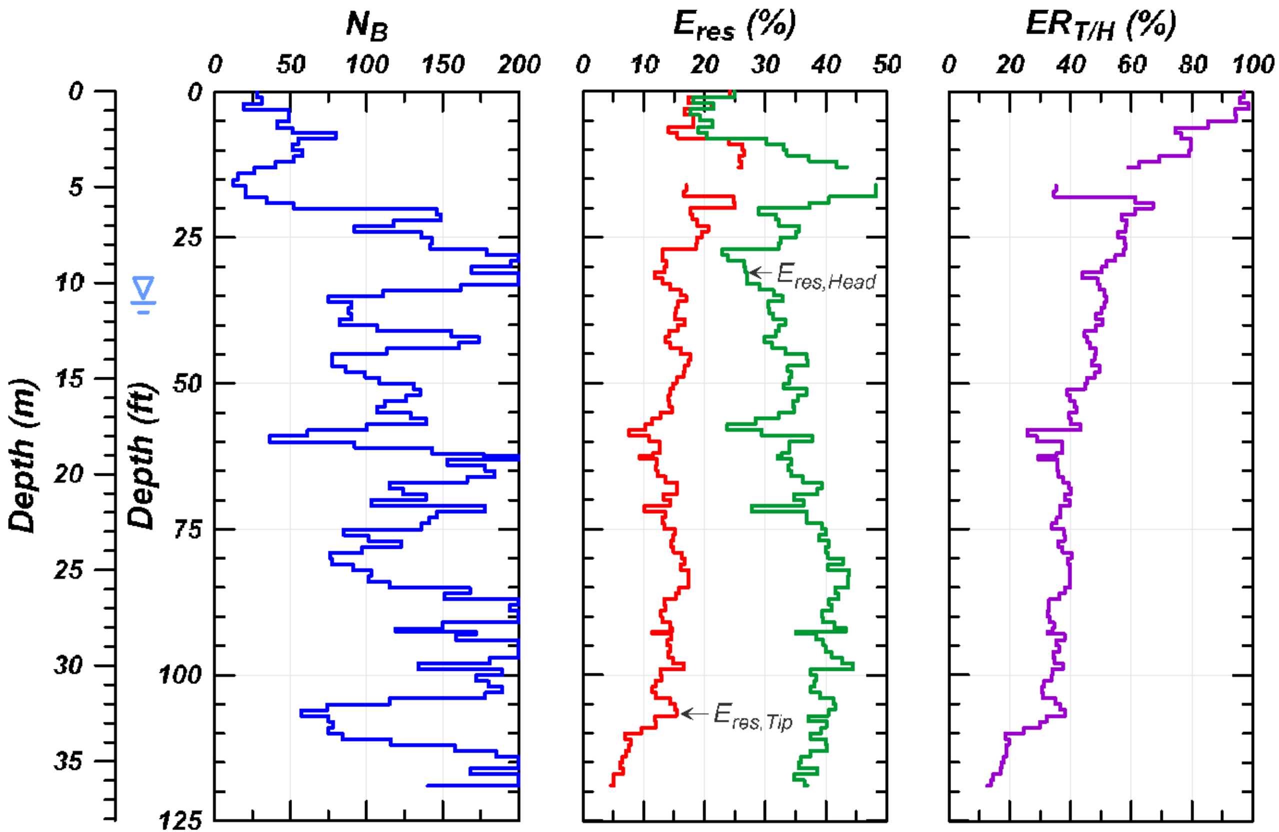
iBPT: Individual Blow Count Measurements

- *Residual energy at drill string tip ($E_{res,tip}$) used in energy normalization to correspond with residual displacement*

$$dE = FdU = FVdt \rightarrow E = \int FVdt \rightarrow E(\%) = \frac{\int FVdt}{11kJ}$$



iBPT: Example Output

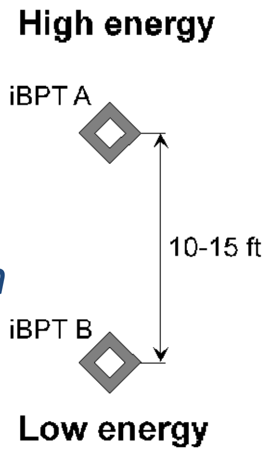


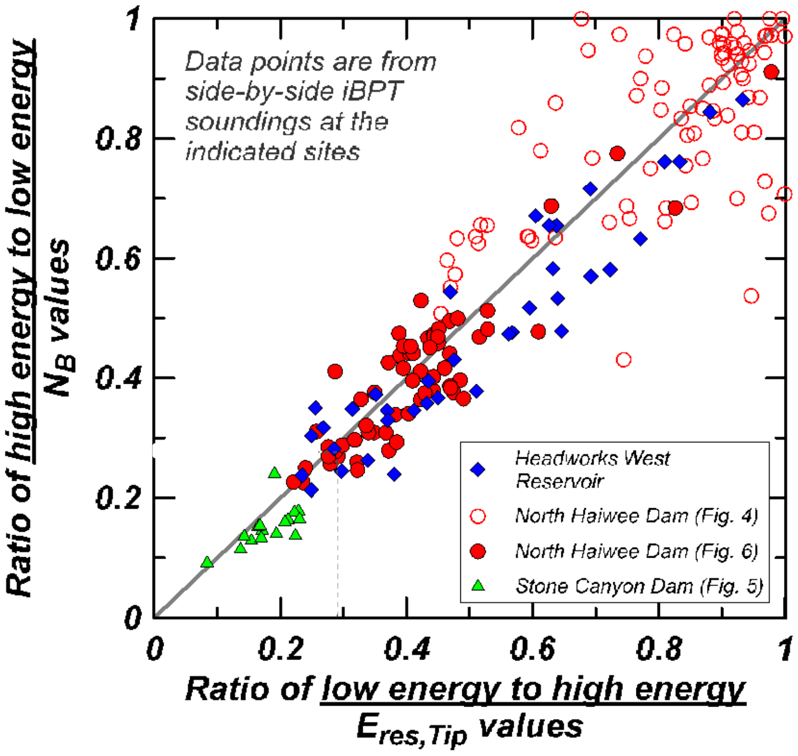
iBPT: Energy Normalization

- *Produces BPT energy normalized penetration resistance*

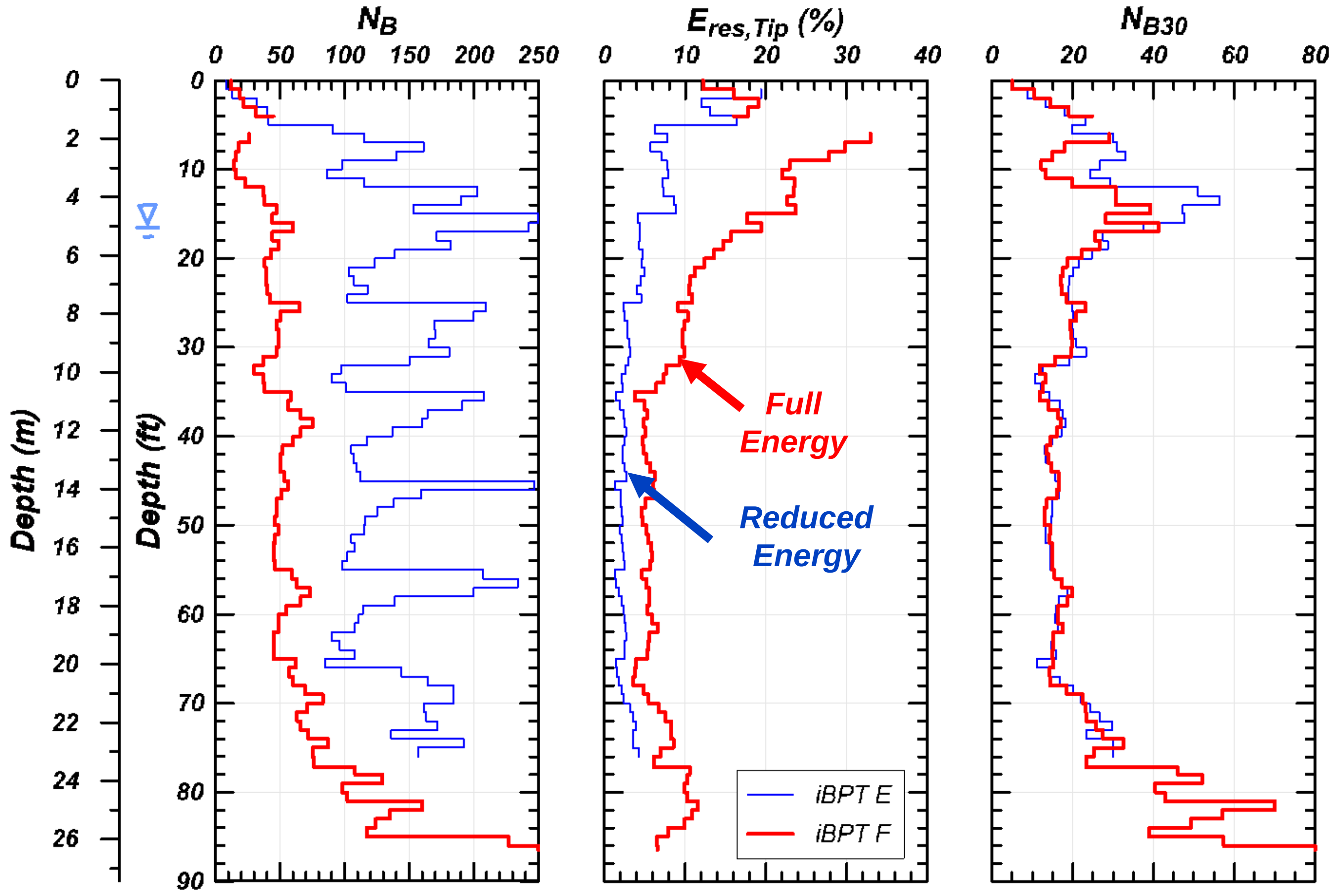
$$N_{B30} = N_B \frac{E_{res,tip}}{30}$$

  - *N_B measured blows*
  - *30% energy normalization for double-acting diesel hammer*
- *$E_{res,tip}$ necessary for robust energy normalization*
- *Energy normalization holds up to energy corrections of 4x*





iBPT: Energy Normalization

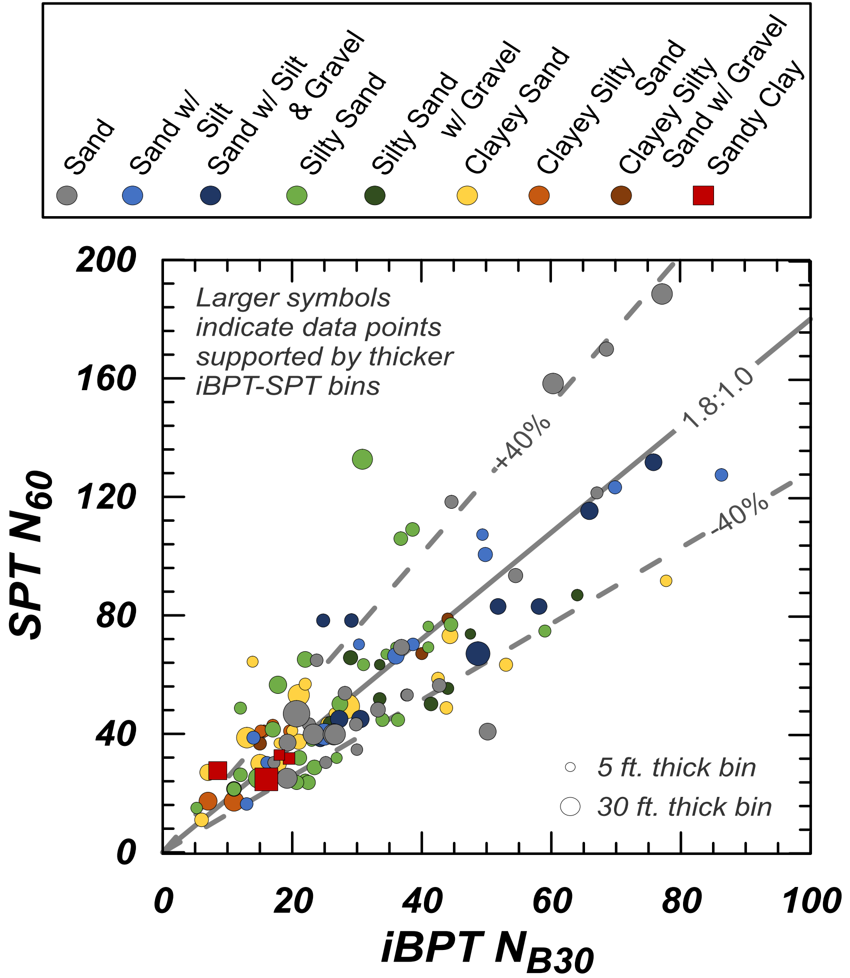


iBPT: Correlation to Equivalent N_{60} Values

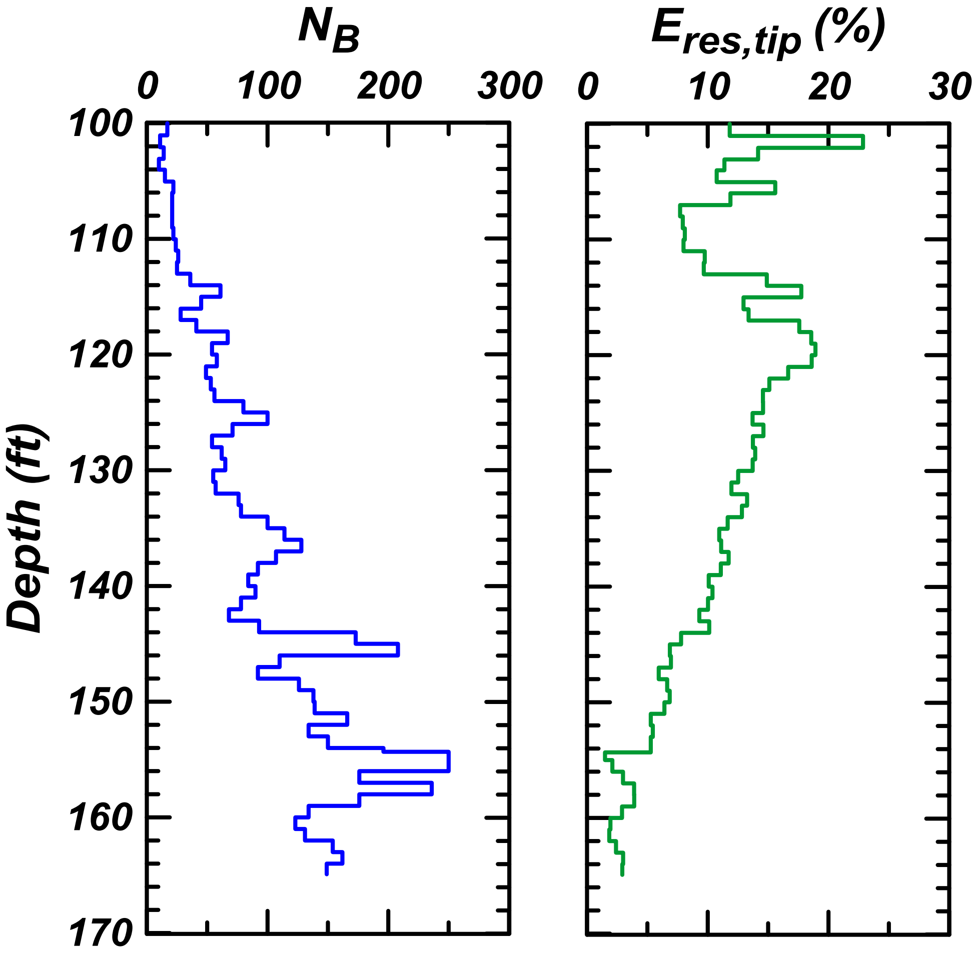
- *Correlation developed:*

$$N_{60} = 1.8\ N_{B30}$$

- *Data 'pairs' based on depth intervals of similar materials with similar penetration resistance in side-by-side SPT and iBPT profiles*
- *Correlation developed based on data 'pairs' in soils free of gravel influence*
- *Database consists of more than 590 SPTs and 915 m of iBPT data*
- *Scatter within correlation is indicative of spatial variability in alluvial deposits*



Instrumented Becker Penetration Test (iBPT)



$$N_{B30} = N_B \frac{E_{res,tip}(\%)}{30}$$

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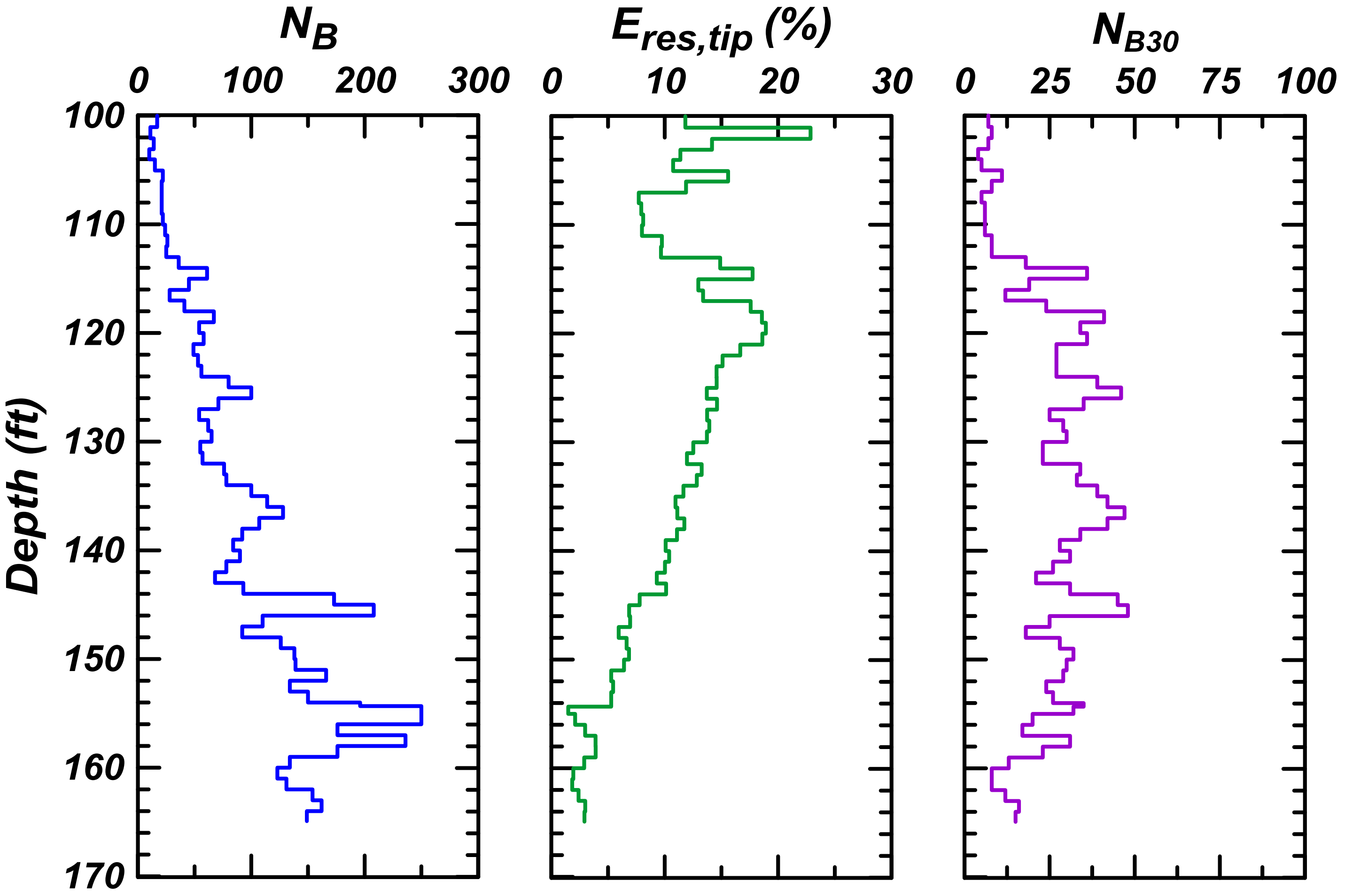

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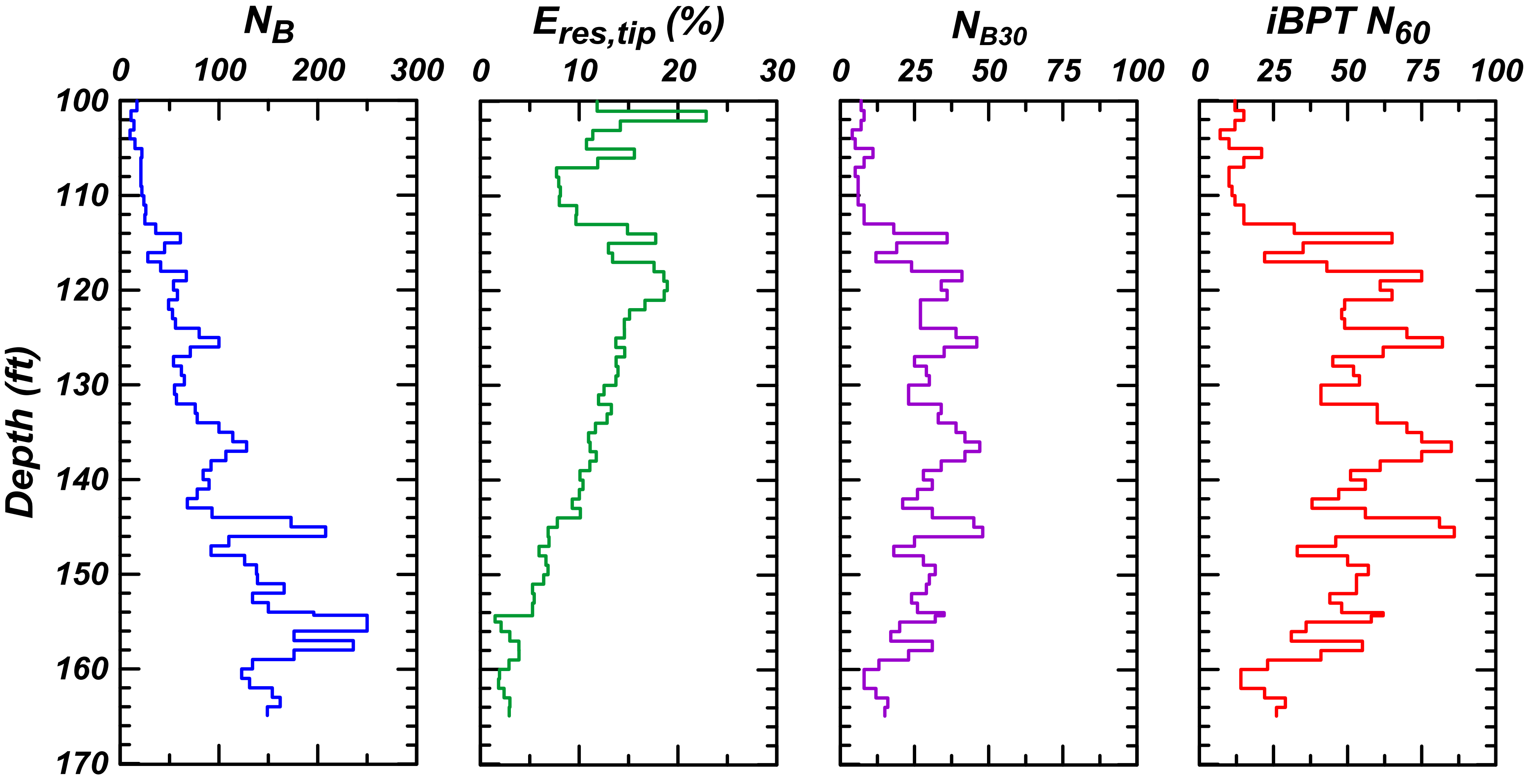

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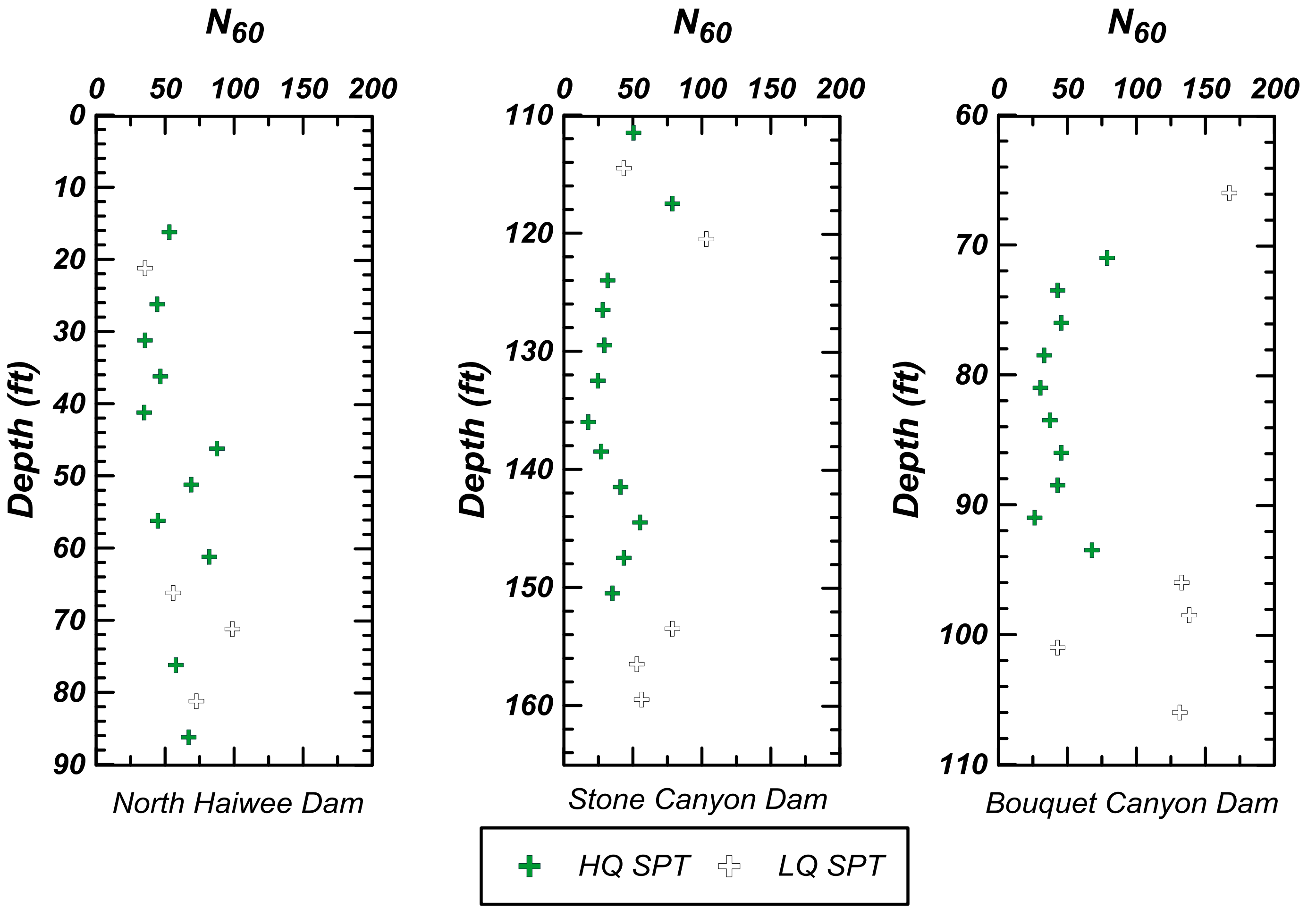

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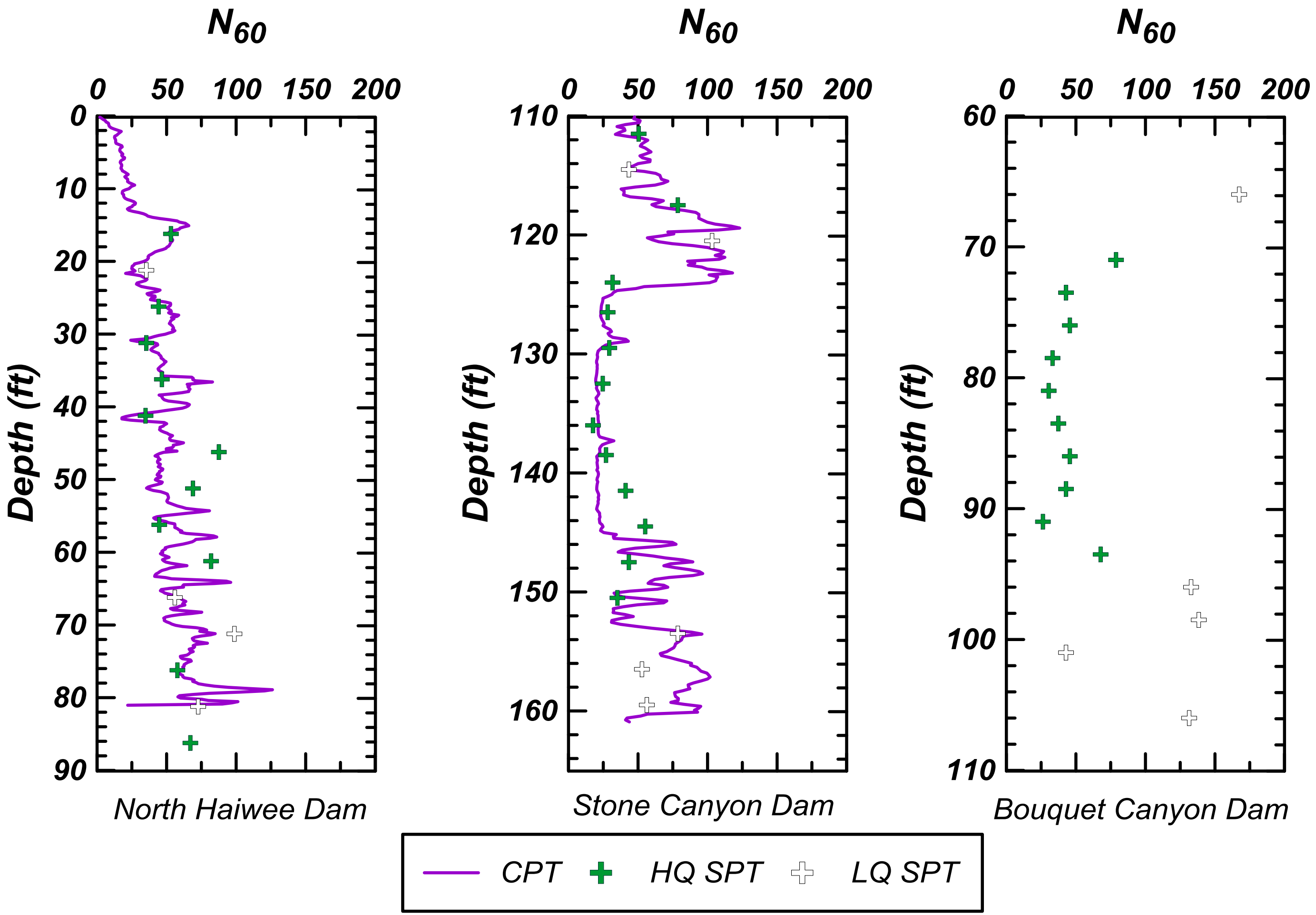

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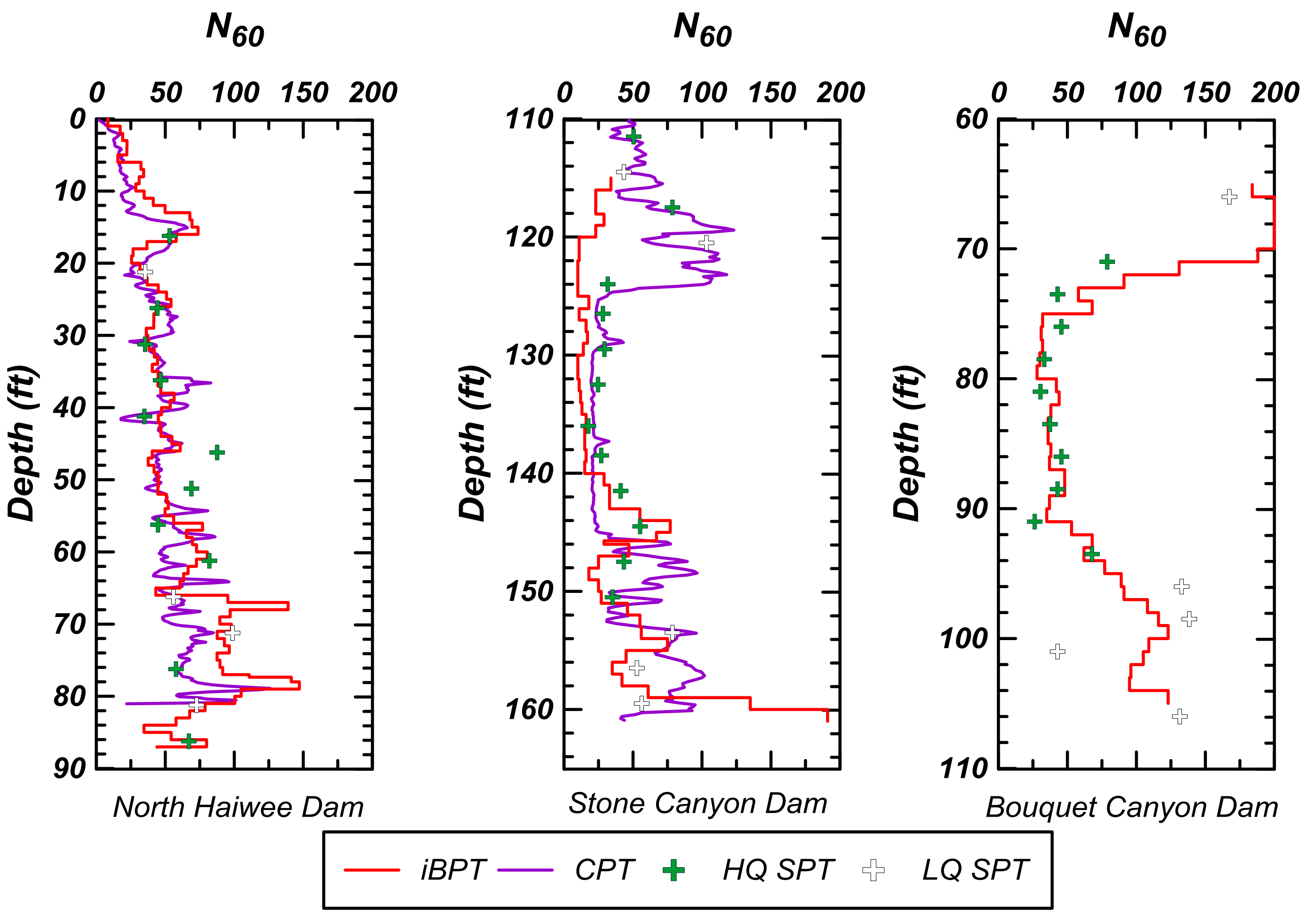
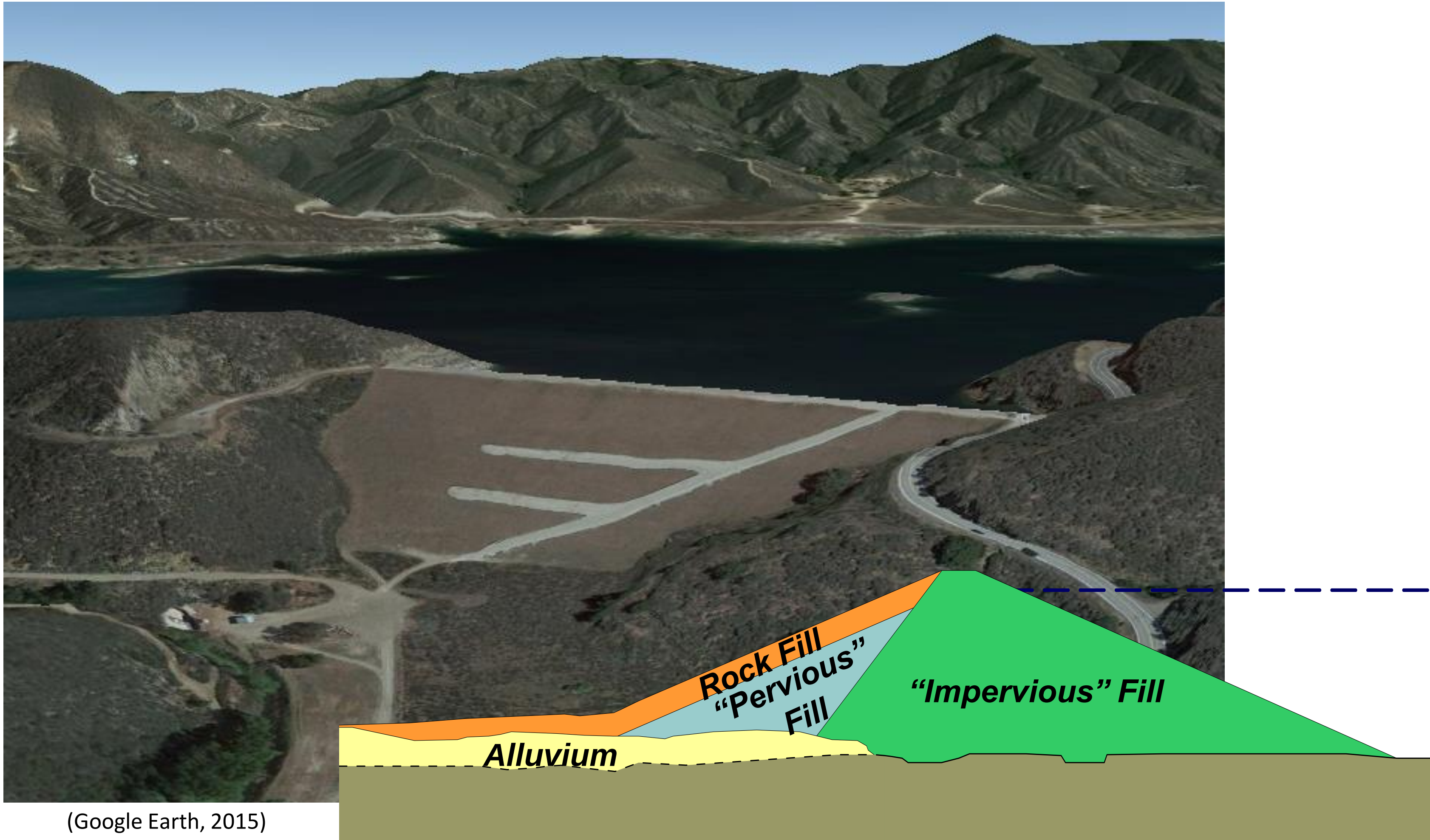


Example Application: Bouquet Canyon Dam

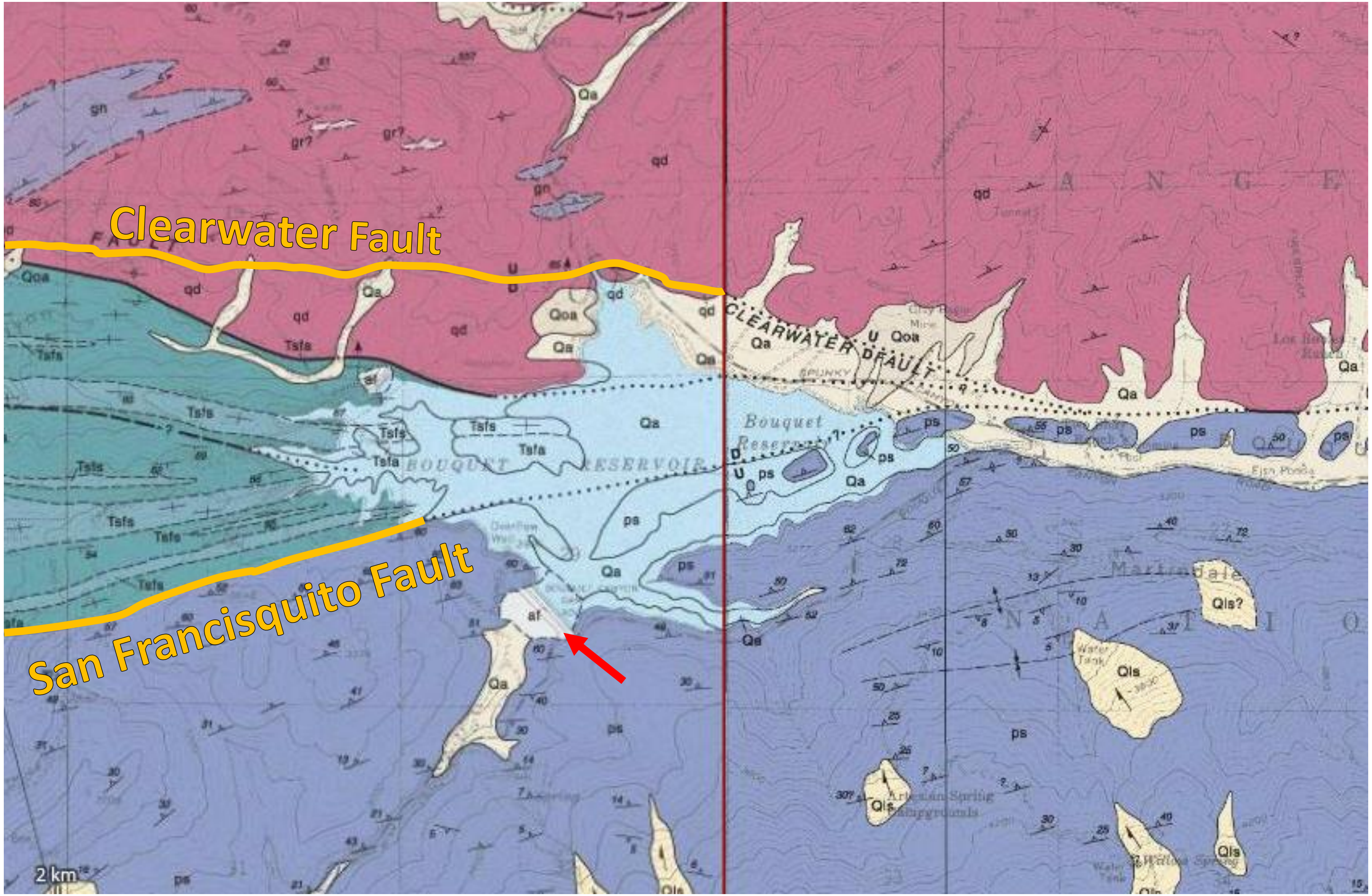
(USGS, 2015)

Example Application: Geologic Context



(Google Earth, 2015)

Example Application: Geologic Context



(Dibblee, T. W., 1961; Reprinted, 1997 (from GeoPentech))

Example Application: Geologic Context

(8/24/1933, Central Press Association (from GeoPentech))

Example Application: Geologic Context

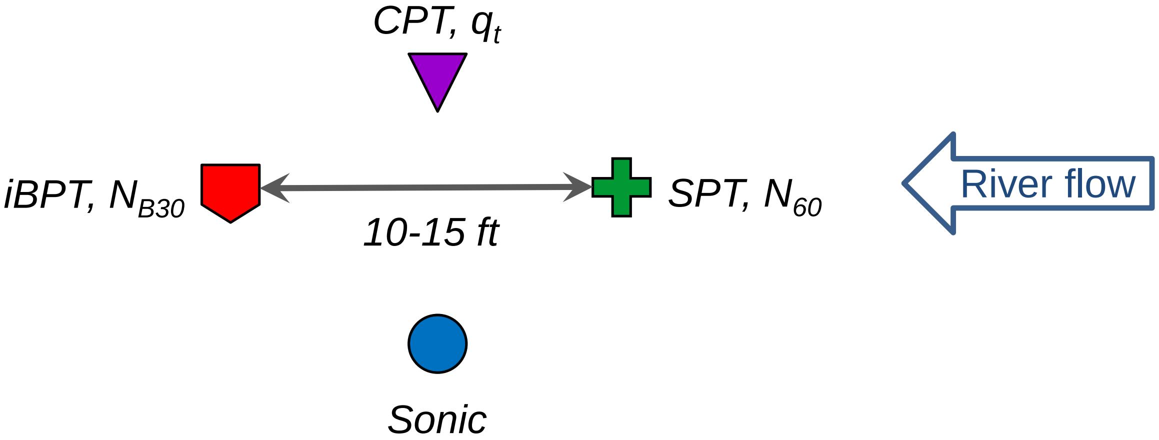
(8/24/1933, Central Press Association (from GeoPentech))

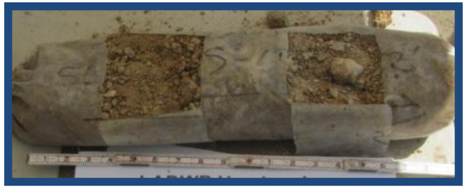
Example Application: Geologic Context

(Google Earth,2015 (from GeoPentech))

Example Application: Site Investigation

- *Clustering of in-situ testing to assess spatial variability & compare techniques*
- *Alignment of iBPT and SPT with river flow to minimize spatial variability*





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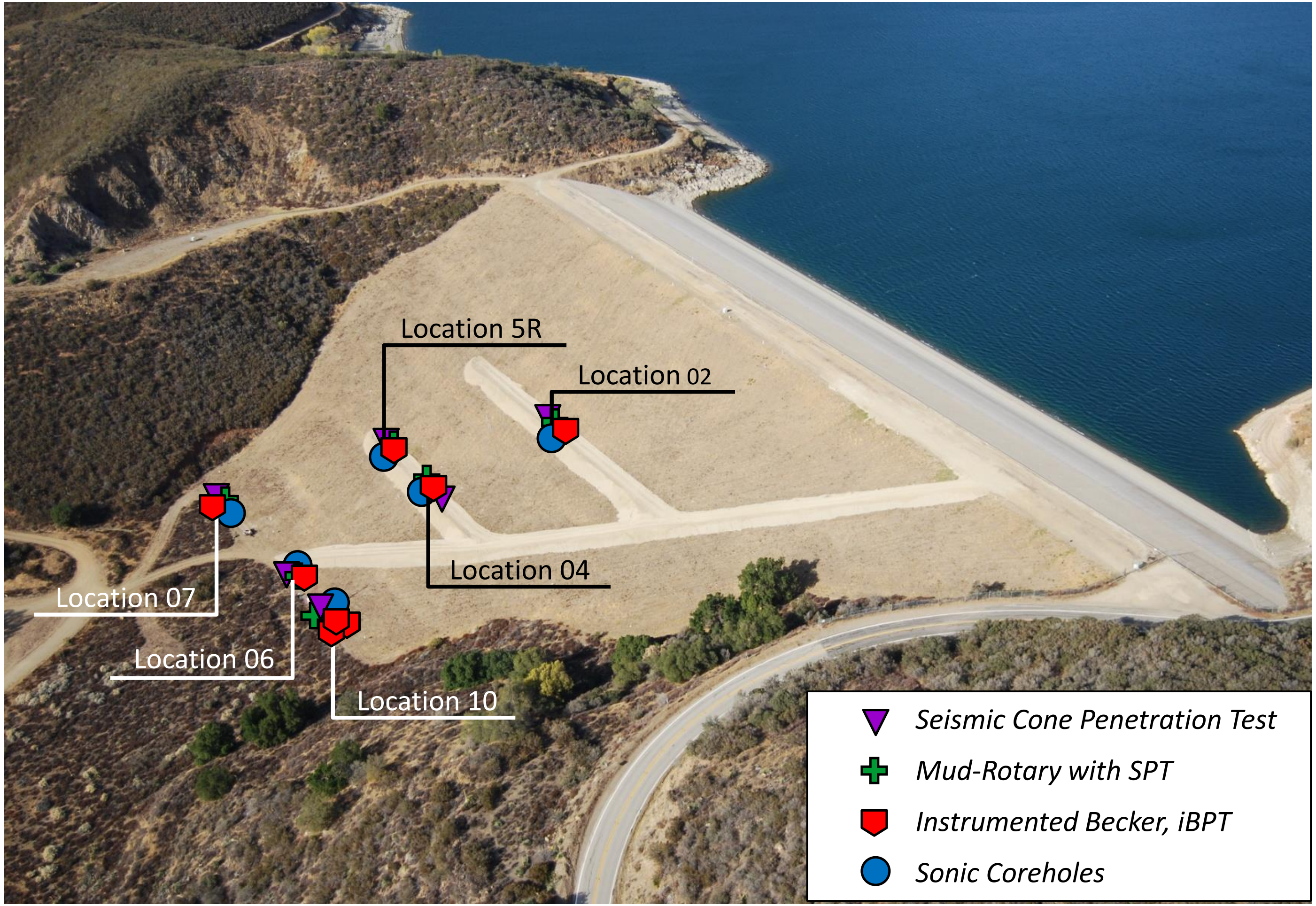
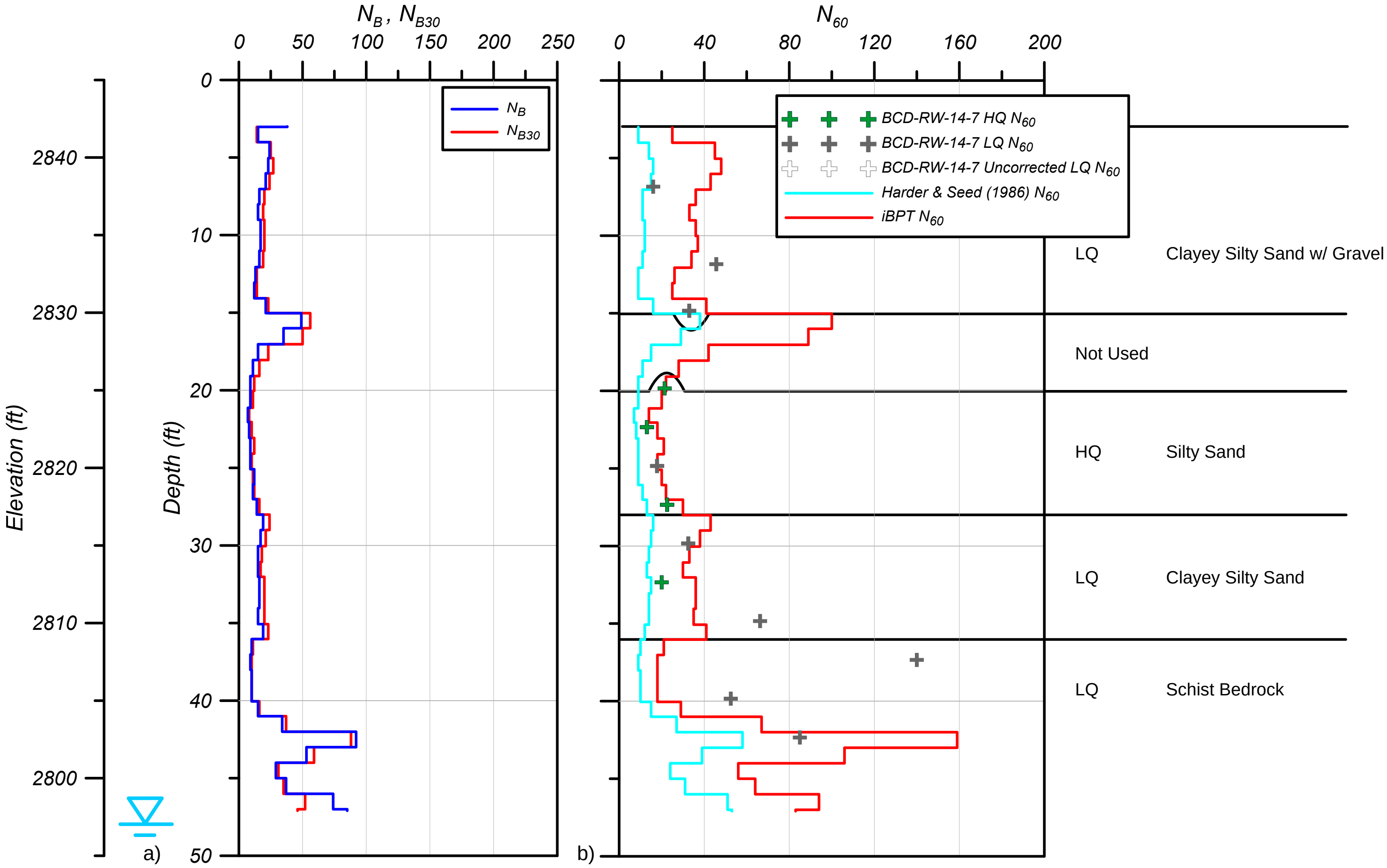
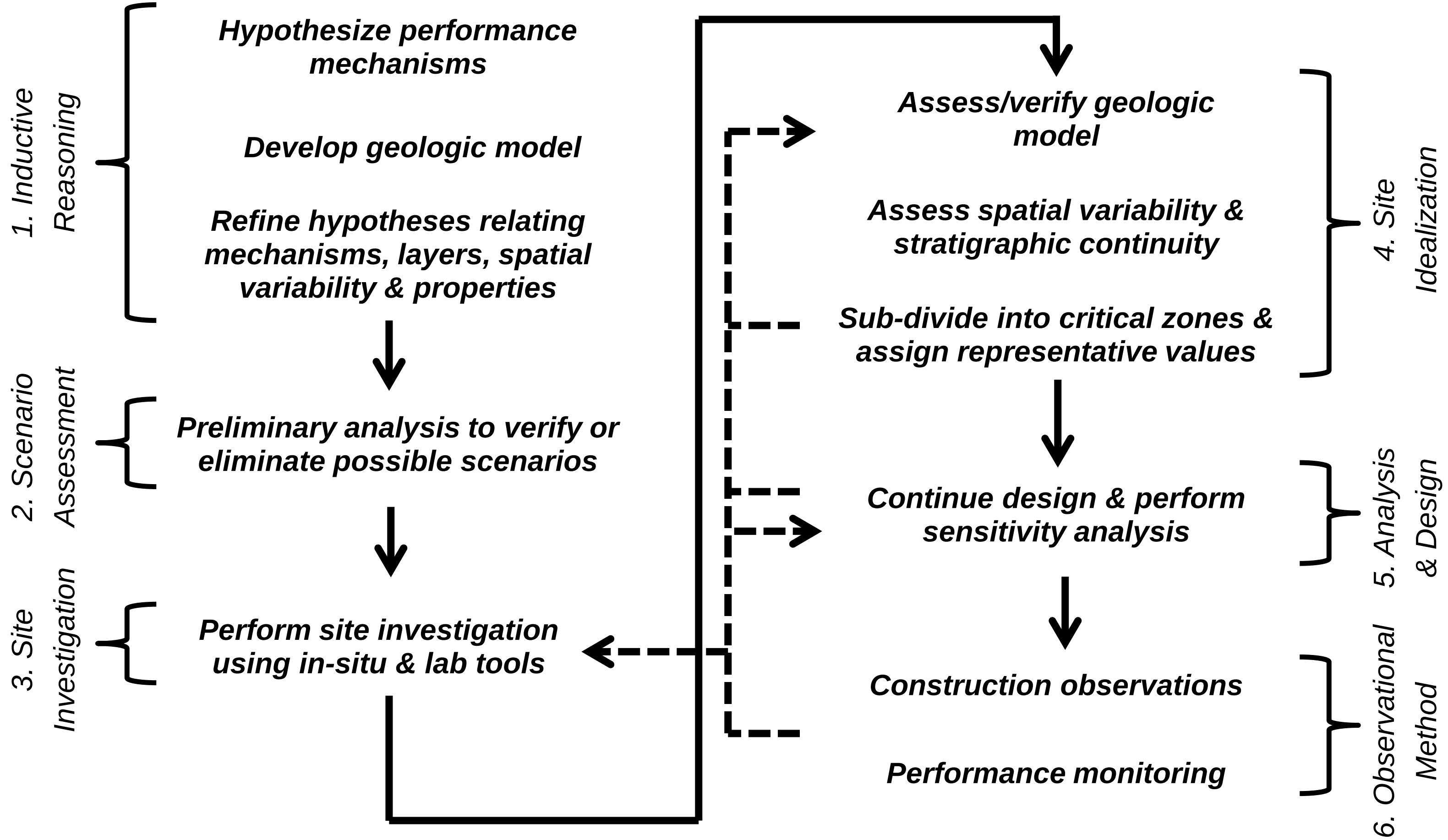


Example Application: iBPT Comparison w/ Historic Method



Integrated Approach to Site Characterization



Summary

- *The depositional process of gravelly alluvium is a complex, energy and sediment load dependent process that can result in highly interlayered deposits ➤ expect a high level of spatial variability (horizontally and vertically) with coefficient of variation values of 0.3 to 0.4*
- *An integrated site characterization approach is recommended for characterization of alluvial deposits to systematically integrate geologic processes*
- *Particle to probe diameter effects limit applicability of SPT and LPT samplers*
- *The instrumented Becker Penetration Test (iBPT):*
  - *directly measures the energy delivered to the drill string drive shoe*
  - *provides a continuous profile of energy normalized soil resistance*
  - *reliably estimates equivalent SPT N values for gravelly alluvium*
  - *accurately characterizes weak layers (sand or gravel) underlying competent soils*

Thank You

GeoPentech

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Great West Drilling
FONTANA, CA. CALGARY, AB.

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LA DWP

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80 years 1929-2009
CALIFORNIA DIVISION OF SAFETY OF DAMS

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