31st Oil Shale Symposium
Workshop on Principles for Oil Shale Resource Assessment
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Well Logging Methods in Oil Shale Assessment

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Acknowledgements

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What Can We Learn From Well Logging?

Barrels of oil equivalent in place

- substitute Fischer Assay or Rock Eval
- formation delineation

Heat requirement for pyrolysis

- detailed mineralogy

Inorganic CO_2 generation potential

- carbonate mineralogy

Hydraulic isolation indicator

- formation water salinity vs depth

Fracture engineering

- in situ stress & stress anisotropy

Baseline data for geophysical monitoring

- electrical and sonic properties

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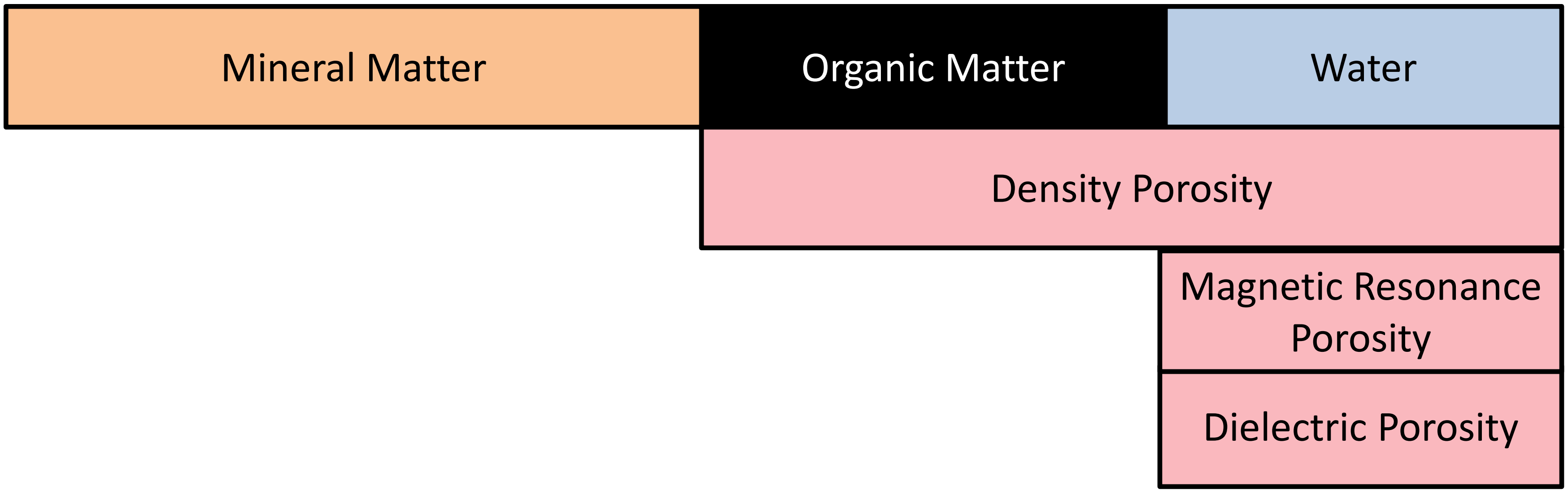
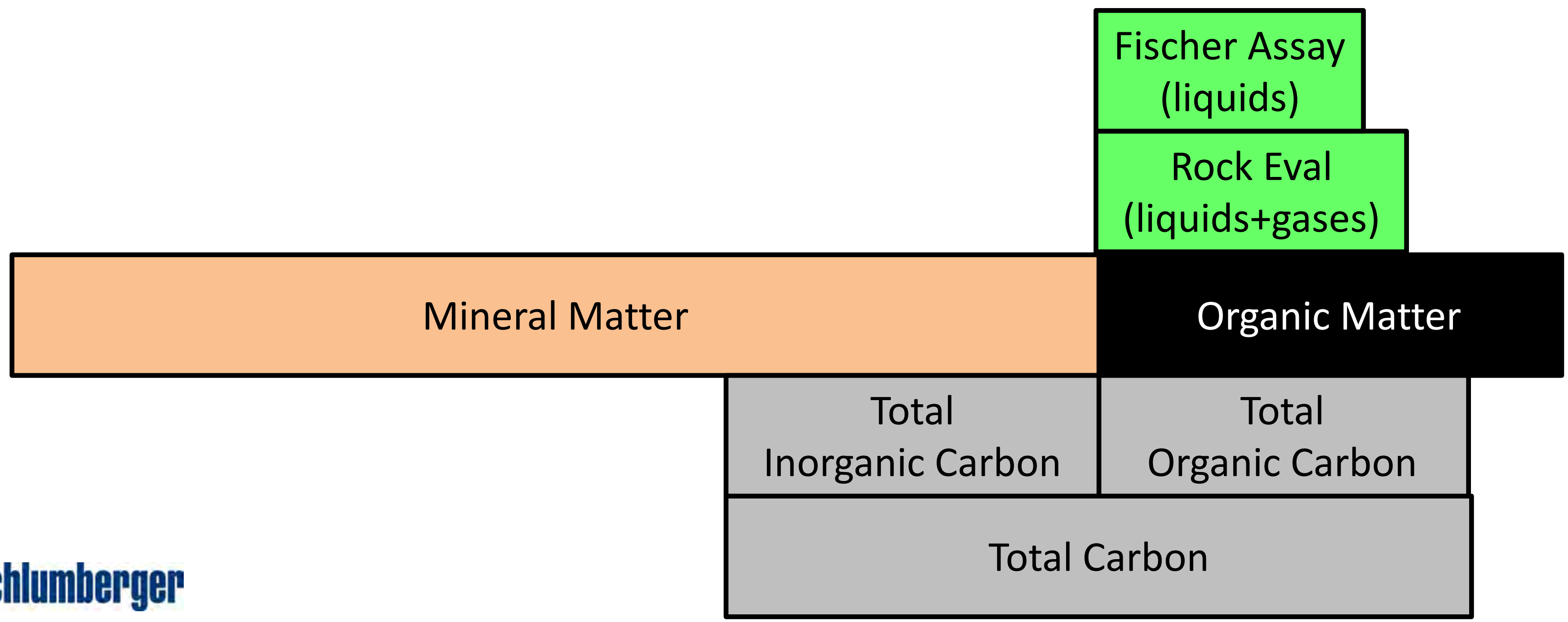
Porosity Model – Volume Fractions



Carbon Model – Weight Fractions



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Total Organic Matter

Well Log Methods

Density-Magnetic Resonance

TOM (w/w) = $(\phi_D - \phi_{MR}) \cdot (\rho_K/\rho_B)$

Density-Dielectric Scanner

TOM (w/w) = $(\phi_D - \phi_{DS}) \cdot (\rho_K/\rho_B)$

Nuclear Spectroscopy

TC: inelastic scattering (RST*)

TIC: elemental spectroscopy (ECS*)

TOM = (TC–TIC)/0.8097

Petrophysical Model

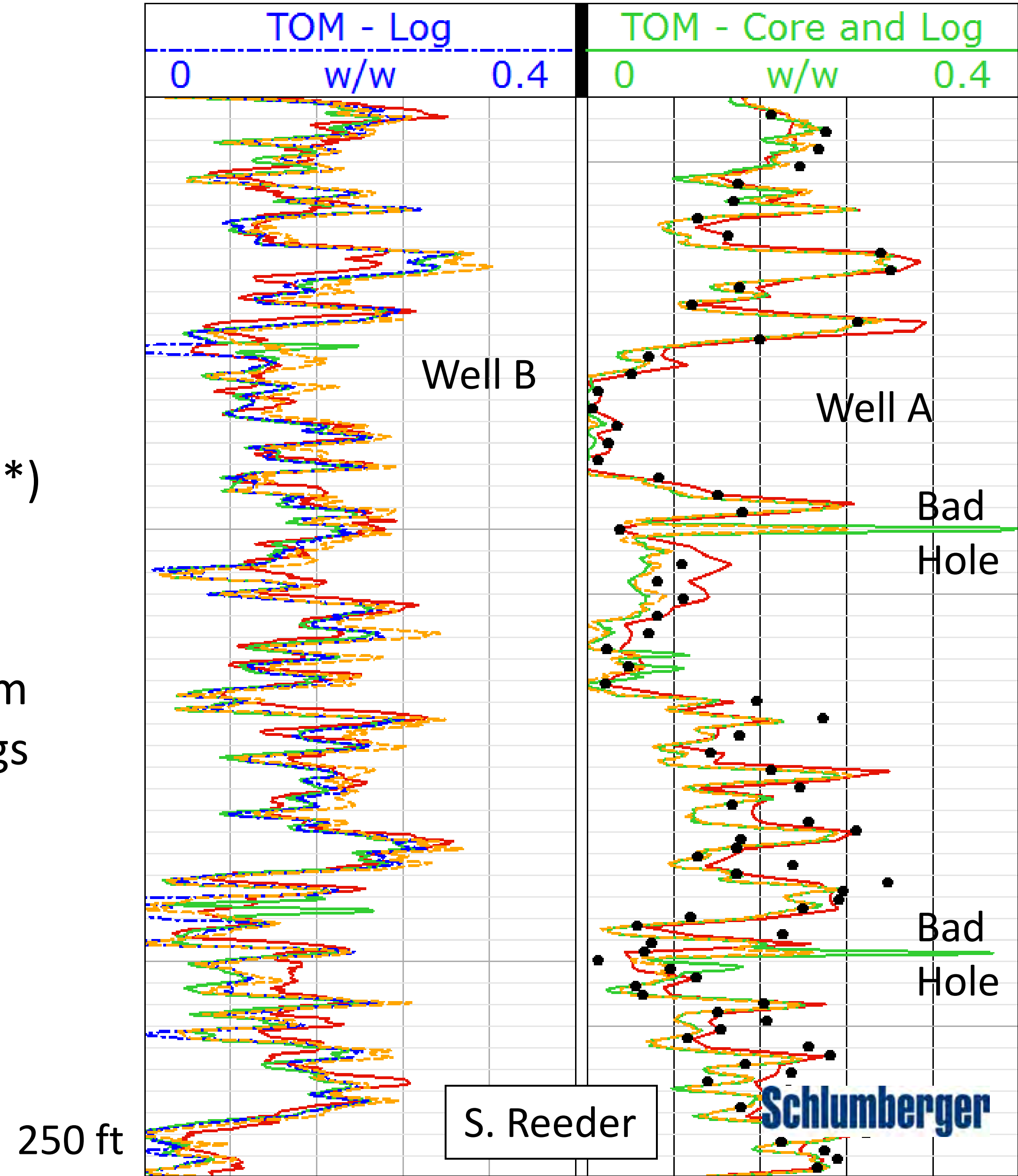
Mineralogy (including TOM) from linear combination of all logs

Core Method ("Indirect")

TC from combustion

TIC from acid treatment

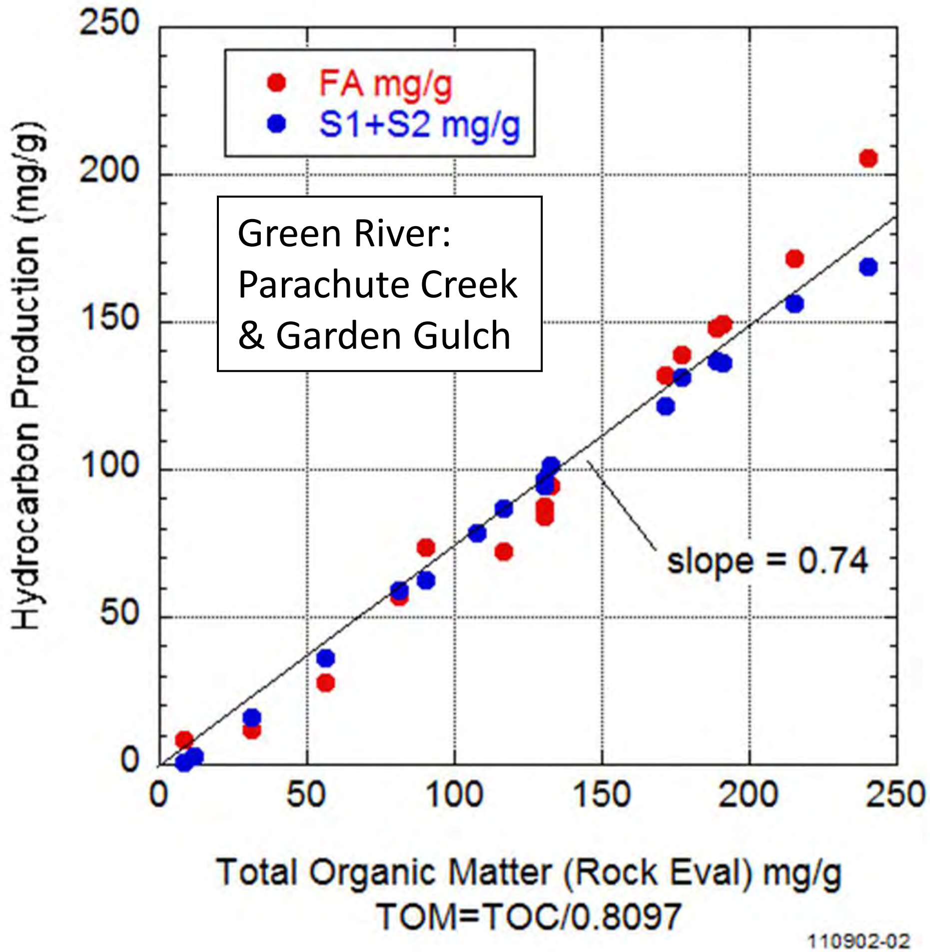
TOM = (TC–TIC)/0.8097



* Mark of Schlumberger

Core Calibration of Production Potential

Rock Eval = Hydrocarbon Liquids & Gases
Fischer Assay = Hydrocarbon Liquids



Carbon is 80.97% of Green River kerogen by weight.
[Brandt, Boak, Burnham, ACS Symposium Series 1032 (2010)]

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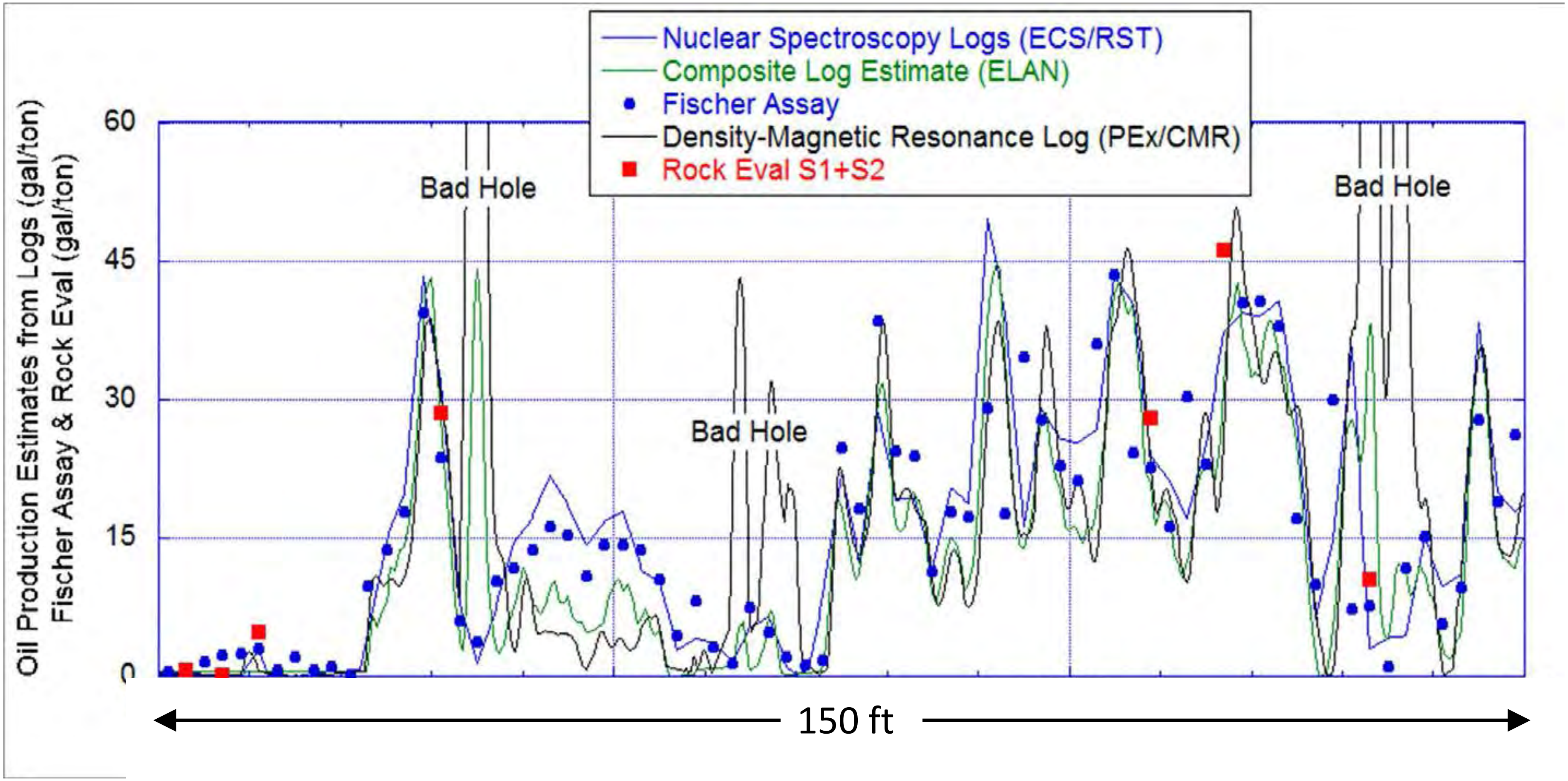
Oil Production Estimate
Well Logs Compared to Fischer Assay & Rock Eval



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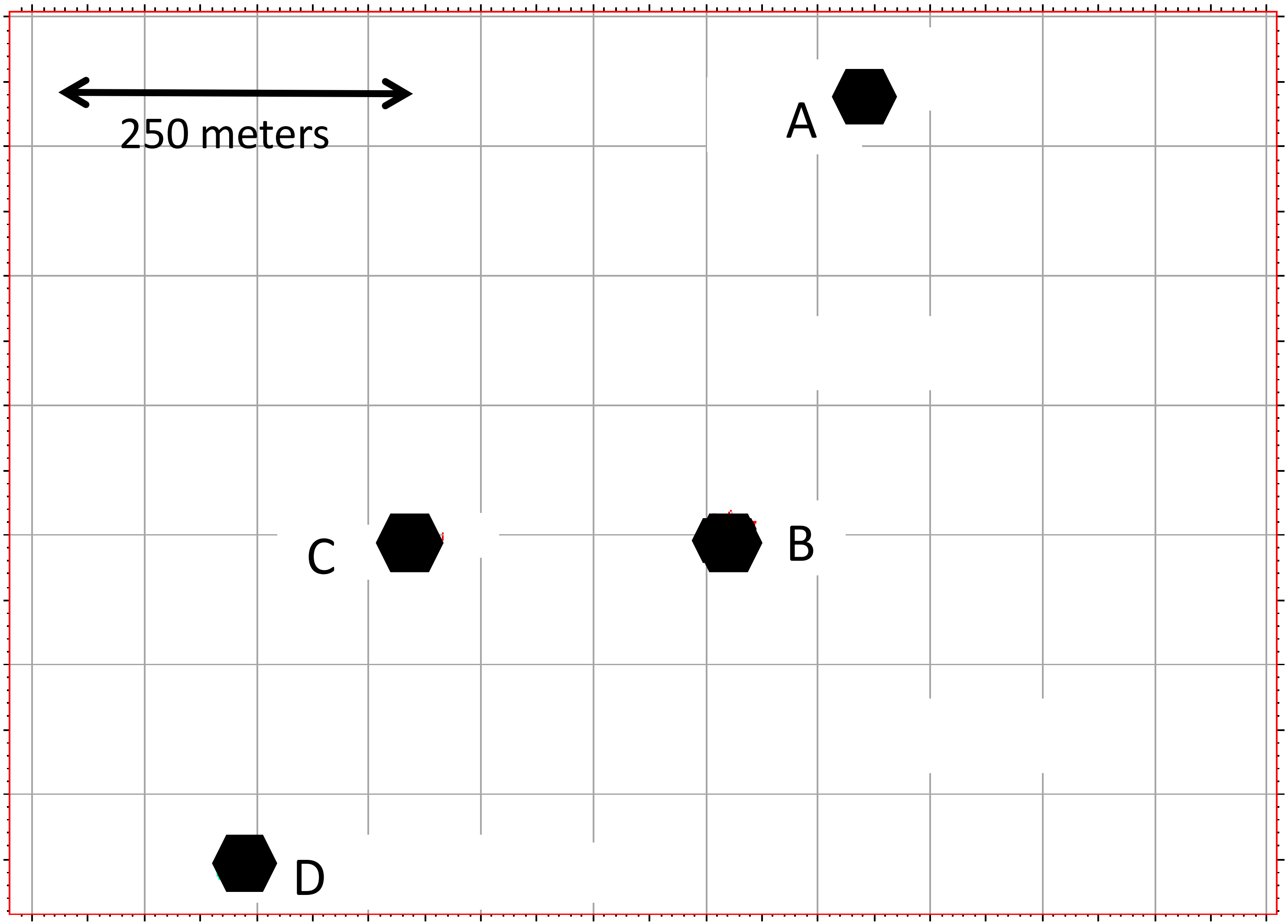
Productive Formation Delineation
Piceance Basin, Colorado

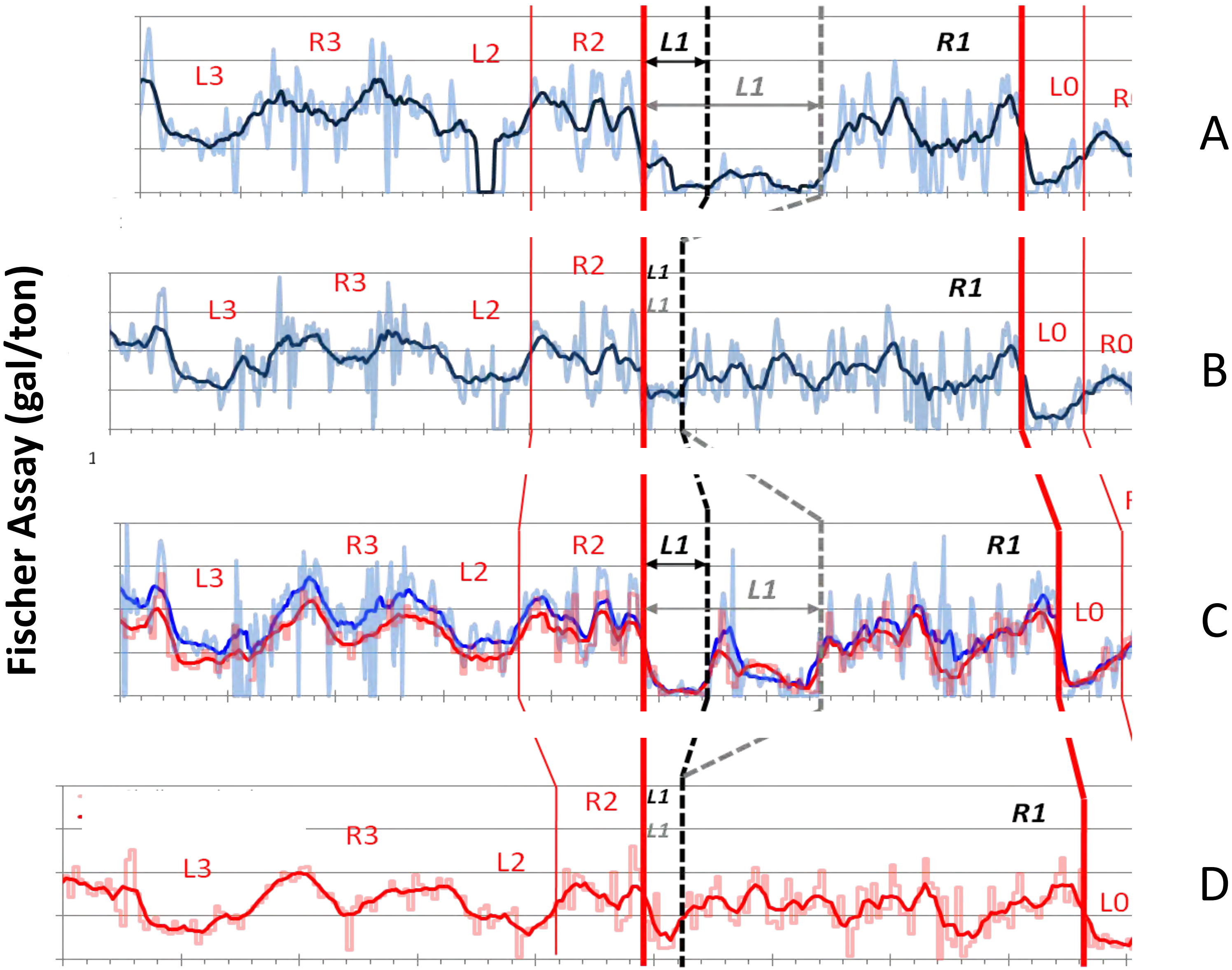


each square = 80 x 80 m

Hydrocarbon Richness from Core and Logs

Core Fischer Assay

Well Log Density-Magnetic Resonance



M. Machlus

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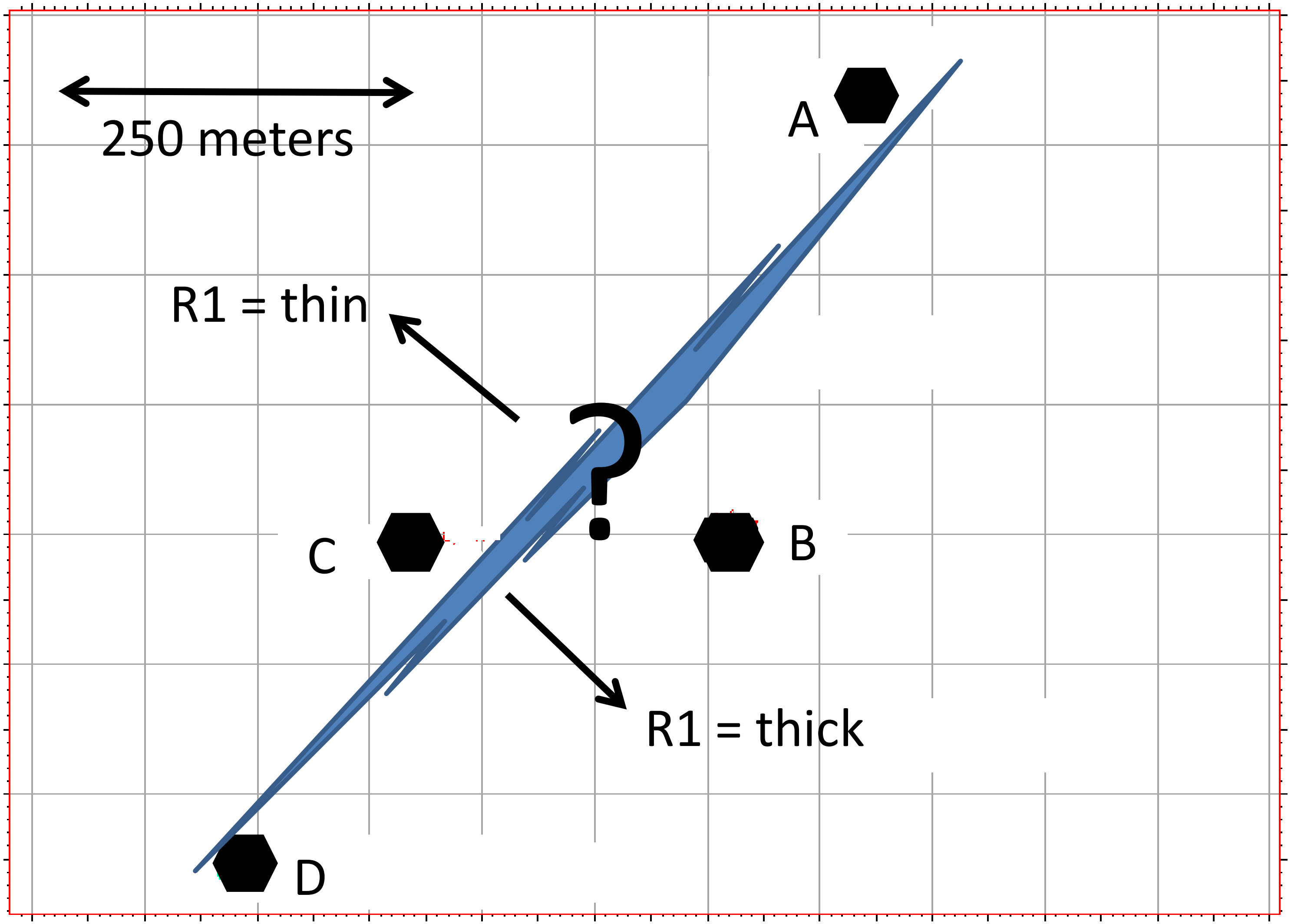
Productive Formation Delineation
Piceance Basin, Colorado



M. Machlus

each square = 80 x 80 m

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Heat Requirement for Pyrolysis

$$Q = \sum_j W_j \int_{T_i}^{T_p} C_j dT + \sum_j W_j \Delta H_j \qquad \sum_j W_j = 1$$

T_i (°C) = initial formation temperature

Tp (°C) = pyrolysis temperature

Q (MJ/ton) = heat required to raise formation temperature from T_i to T_p

W_j (w/w) = weight fraction of mineral *j*

C_j (MJ/ton·°C) = heat capacity of mineral *j*

ΔH_j (MJ/ton) = phase transition latent heat of mineral *j*

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Petrophysical Model

$$Log_i = C_{ij} \cdot W_j$$

- **Inputs (Log)**
  - Spectroscopy
    - Si, Ca, Fe, Al, S, K, Na
  - Total Carbon
  - Magnetic Resonance
  - Photoelectric Factor
  - Density
  - Neutron Porosity
- **Endpoint Matrix (C)**
  - Response of log i for 100% of mineral j
- **Mineral Weight Fractions (W)**
  - Clay Group
  - Quartz Group
  - Carbonate Group
  - Feldspar Group
  - Buddingtonite
  - Dawsonite
  - Nahcolite
  - Pyrite
  - Organic Matter

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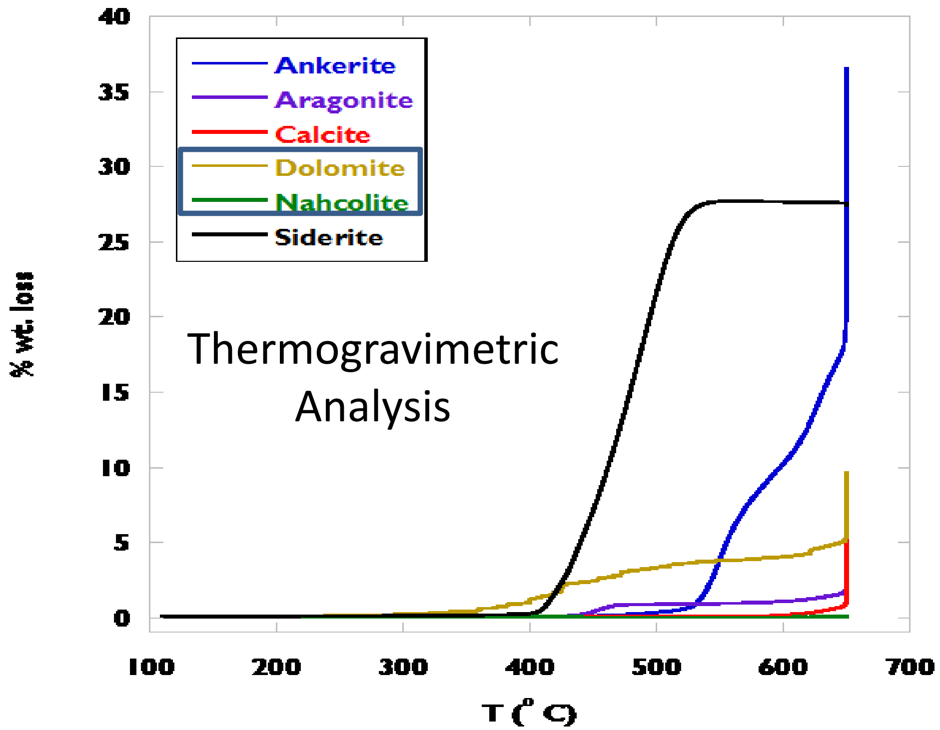
Estimated Carbon Dioxide Production from Mineral Decomposition

$$W_{CO_2}(T) = \frac{MW_{CO_2}}{\rho_{bulk}} \sum_i \frac{\alpha_i n_i \rho_i V_i}{MW_i}$$



W_{CO_2} (T)	mass of carbon dioxide produced per unit mass of heated rock at temperature T
MW_{CO_2}	44.01 g/mole = molecular weight of CO_2
ρ_{bulk}	bulk density of the rock
α_i(T)	fraction of mineral *i* decomposed at temperature T
n_i	number of carbons in molecular formula of mineral *i*
ρ_i	density of mineral *i*
V_i	volume fraction of mineral *i*
MW_i	molecular weight of mineral *i*

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Estimating Formation Salinity to Confirm Hydraulic Isolation

Well Log Methods

Resistivity-Magnetic Resonance

water saturation + formation resistivity $\rightarrow$ salinity

Nuclear Spectroscopy

pore water chlorine concentration

Core Measurement

Dry rock chlorine measurement

Hydrological Measurements

Well tests

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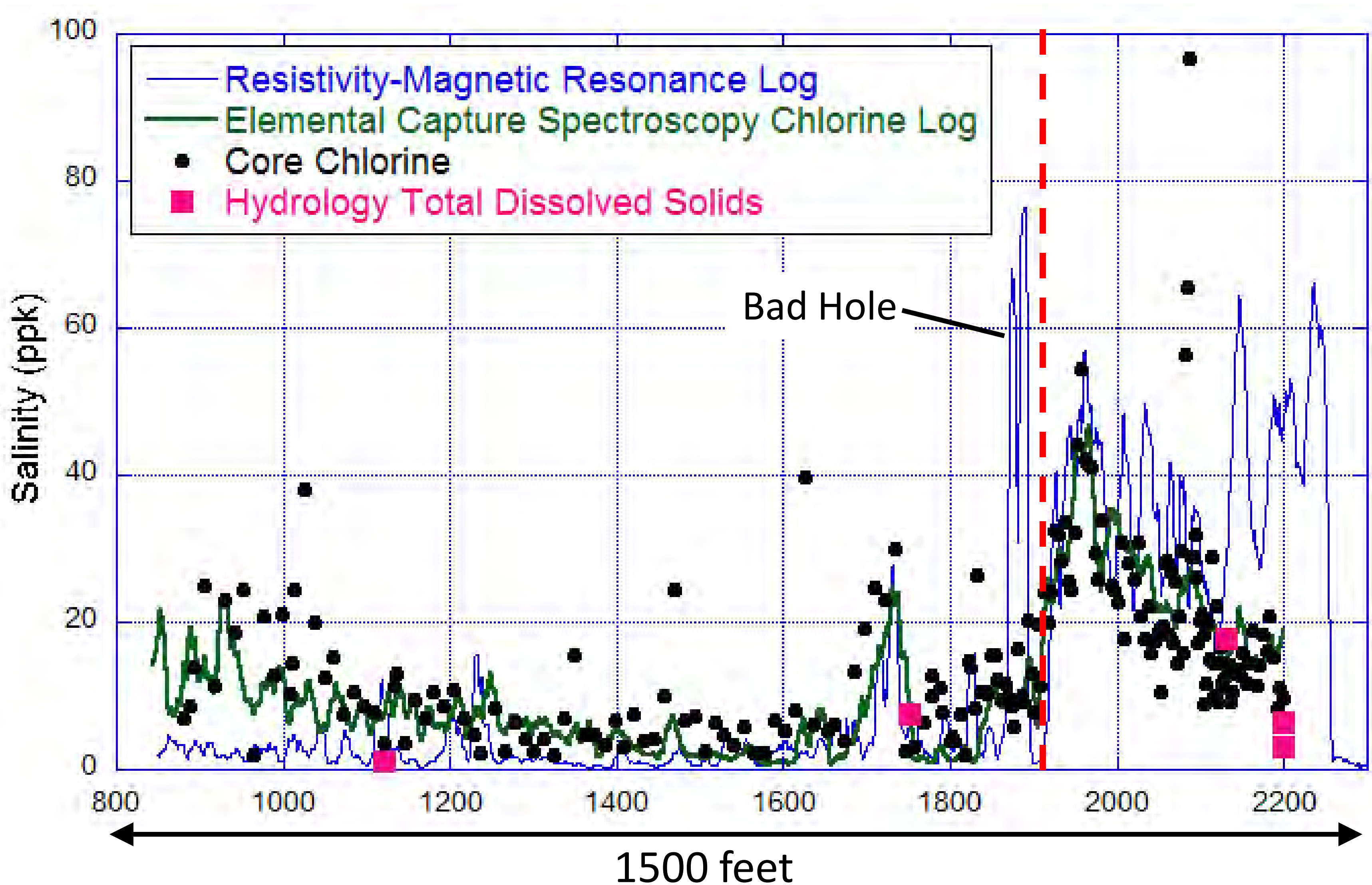
Multiple Methods for Estimating Water Salinity



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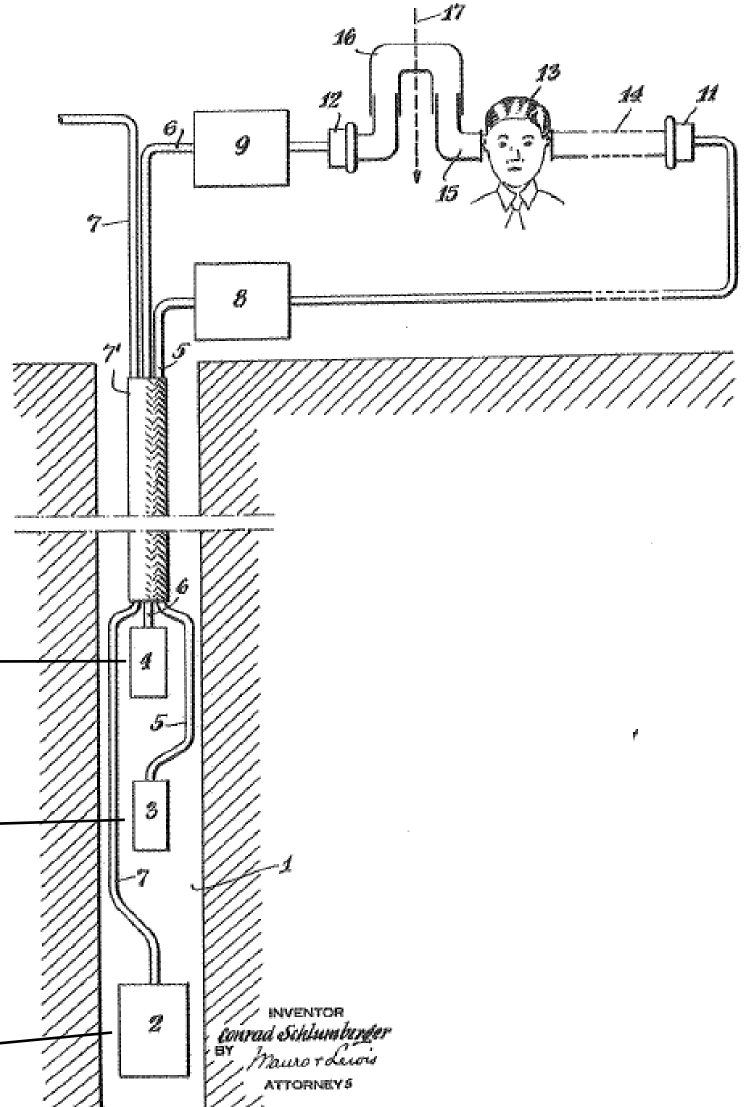
Early Borehole Acoustic Measurement



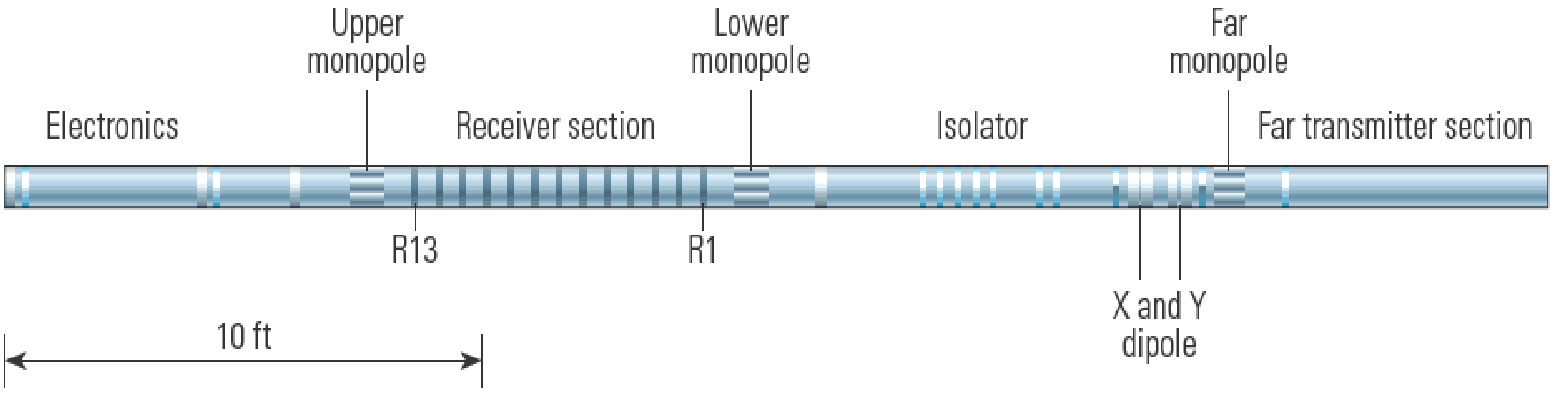
far receiver

near receiver

transmitter
(horn, Model A Ford)

C. Schlumberger, Patent 786,863 (France, 1935)
reproduced by Ellis & Singer

Modern Borehole Acoustics Instrumentation



5 Transmitters

3 monopole + 2 dipole

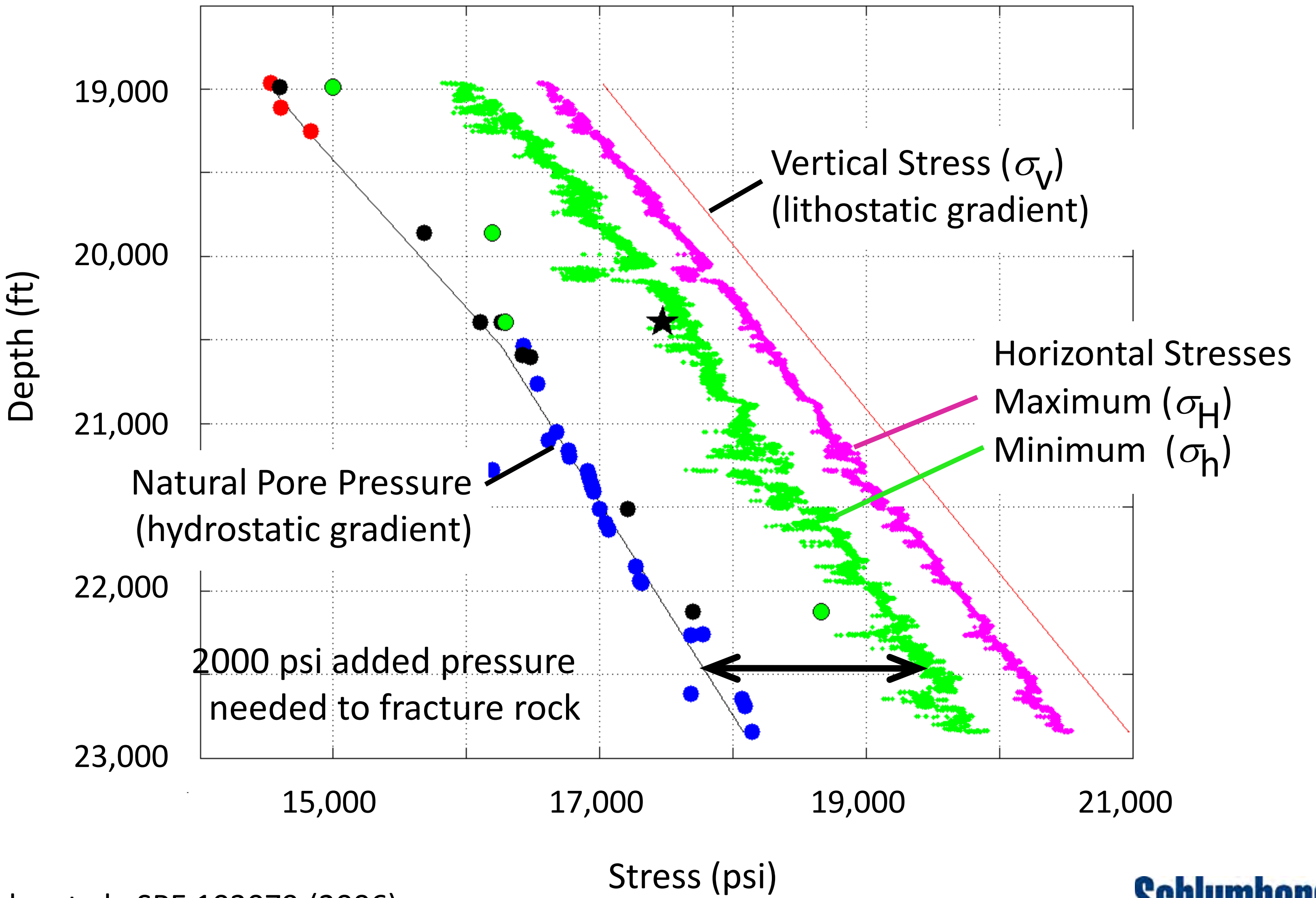
104 Receivers

13 axial locations x 8 azimuths

Many acquisition and processing options

Schlumberger Oilfield Review, Spring 2006

Stresses in the Earth



Sinha et al., SPE 103079 (2006)

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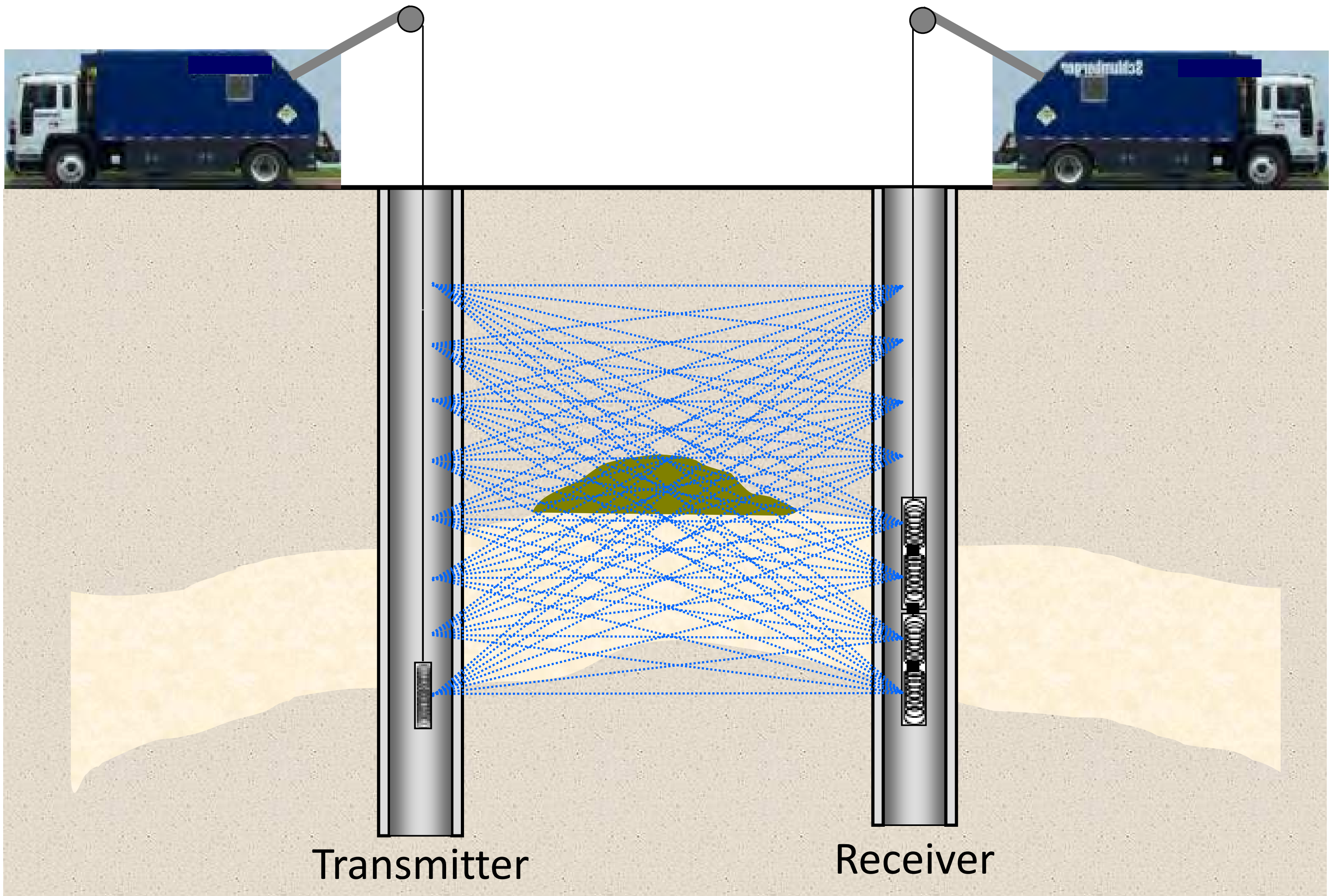
Crosswell Electromagnetic Monitoring



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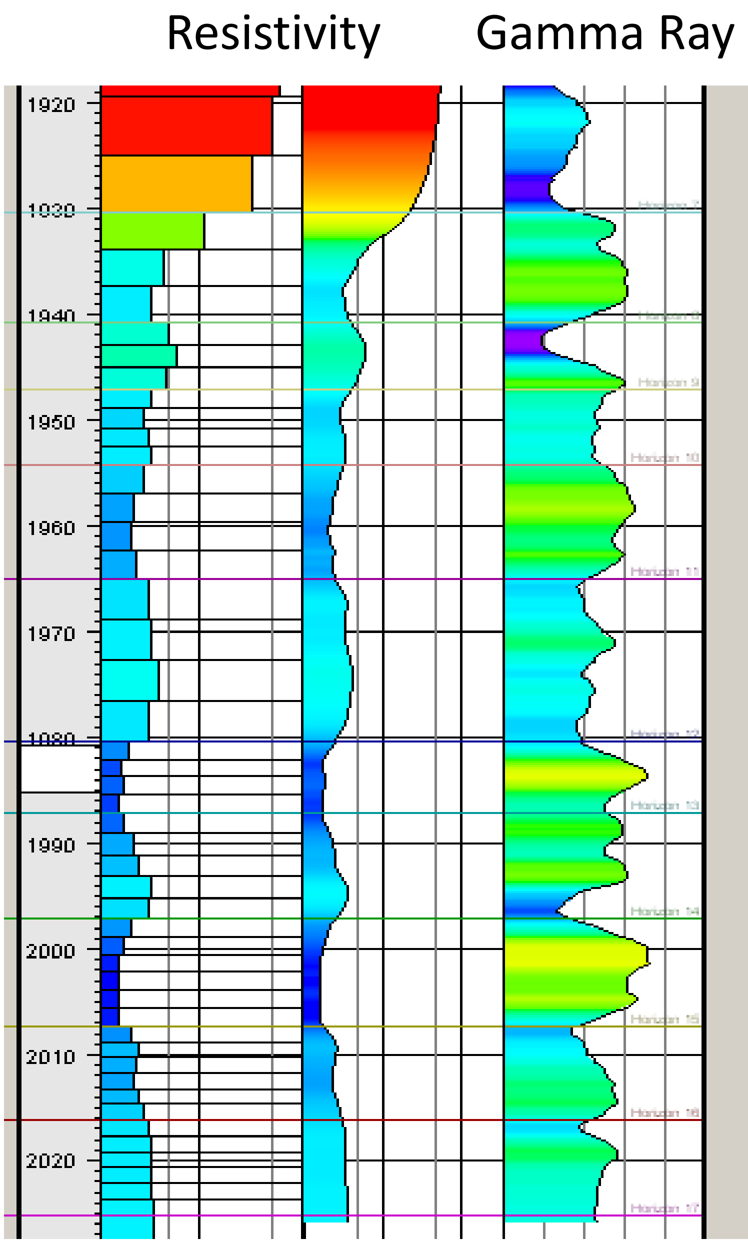
Log Data Provides Initial Ground Truth in Target Volume



In preparing the 3D resistivity model, the highly conductive zone was sampled at a finer scale to capture the resistivity contrast in the zone of interest.

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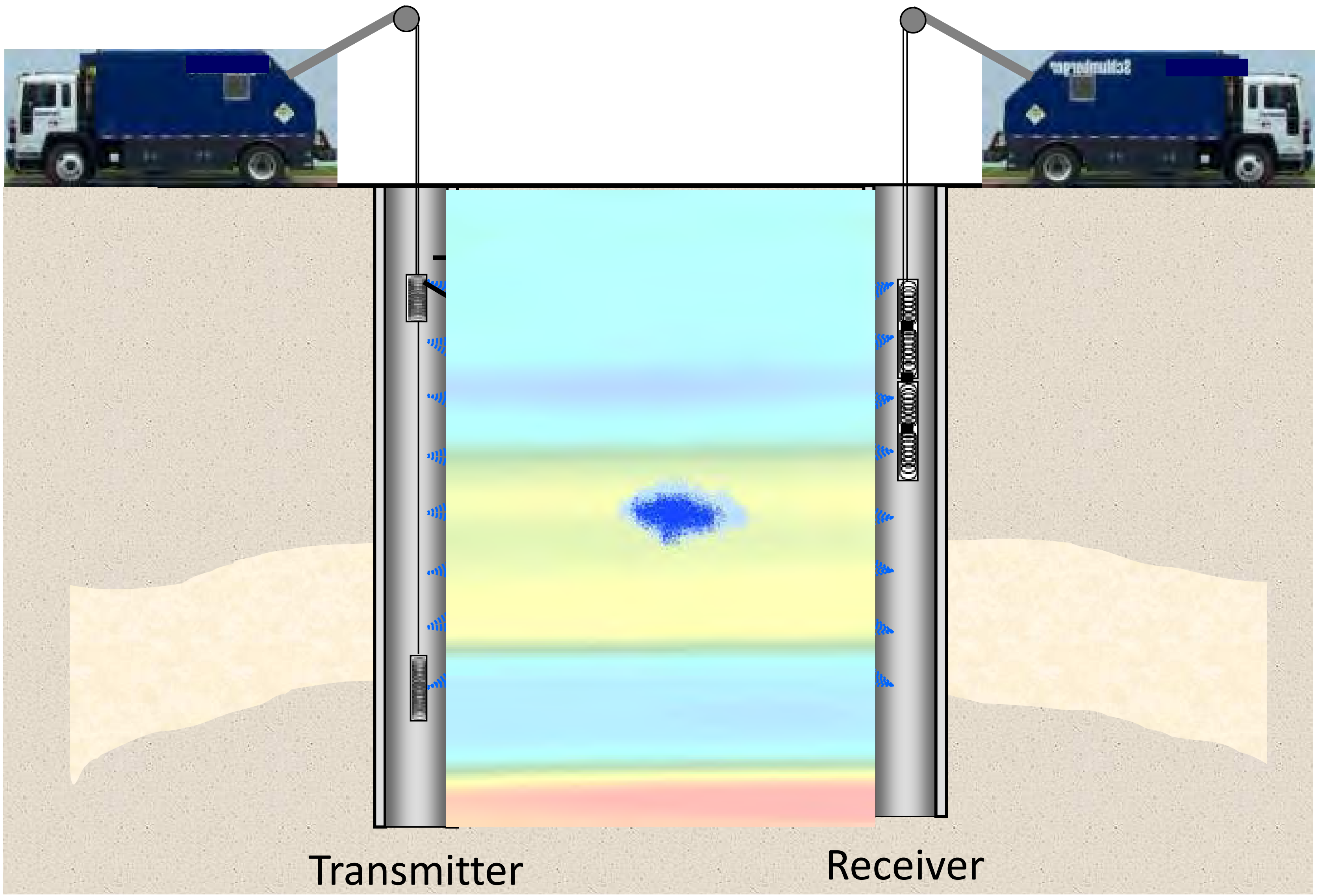
Crosswell Electromagnetic Monitoring



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