Inversion Modeling of the SP Log

Resurrecting and Quantifying a Forgotten Measurement

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by

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Conventional Use of the SP Log

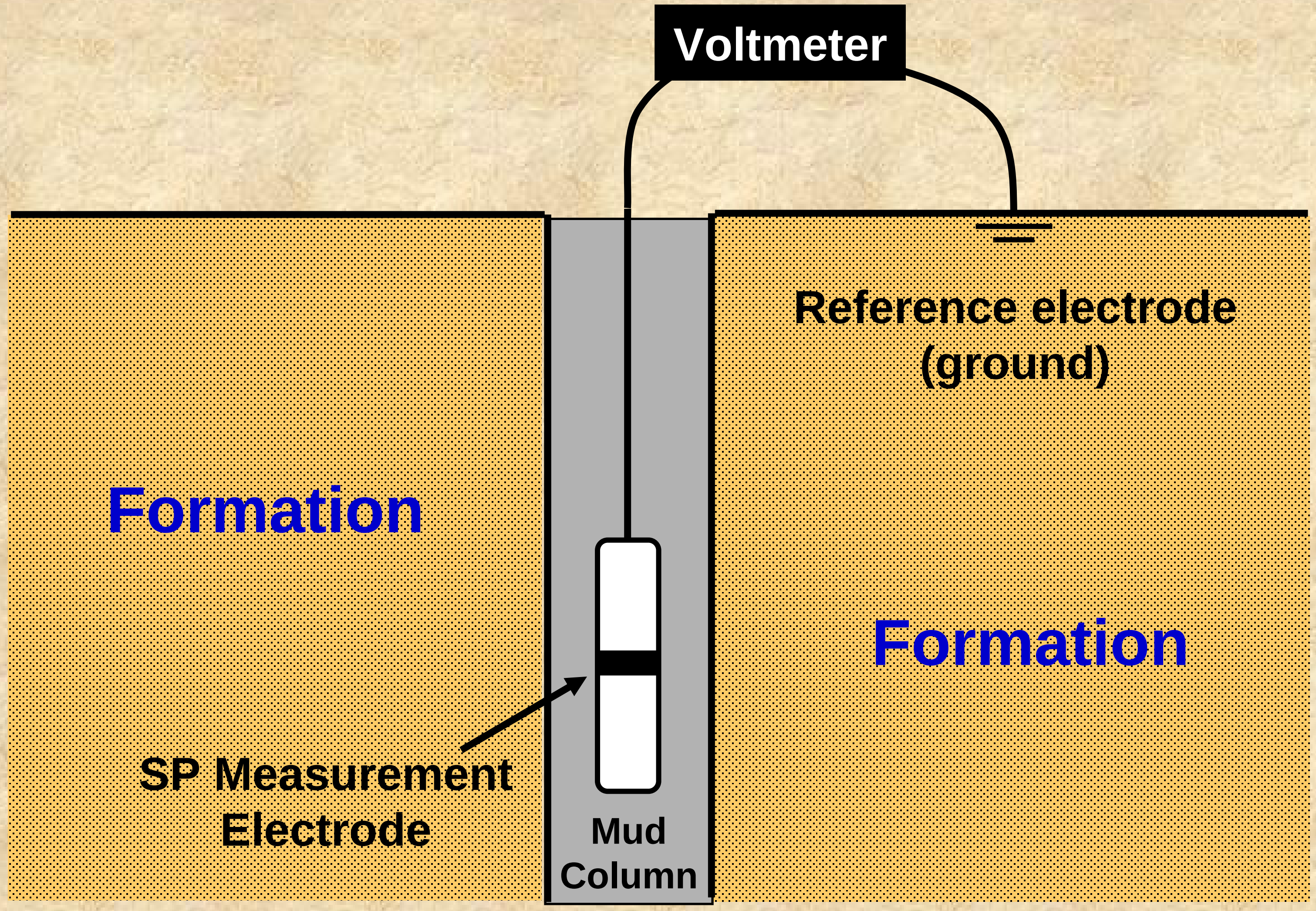
- Correlation
- Lithology
- Shaliness
- Porosity / Permeability
- Bed boundaries
- Rw calculation

Unfortunately, SP logs are affected by the logging environment.

Thin bed and resistivity effects can cause errors of 200 % or more.

A Quick Review of the SP Measurement

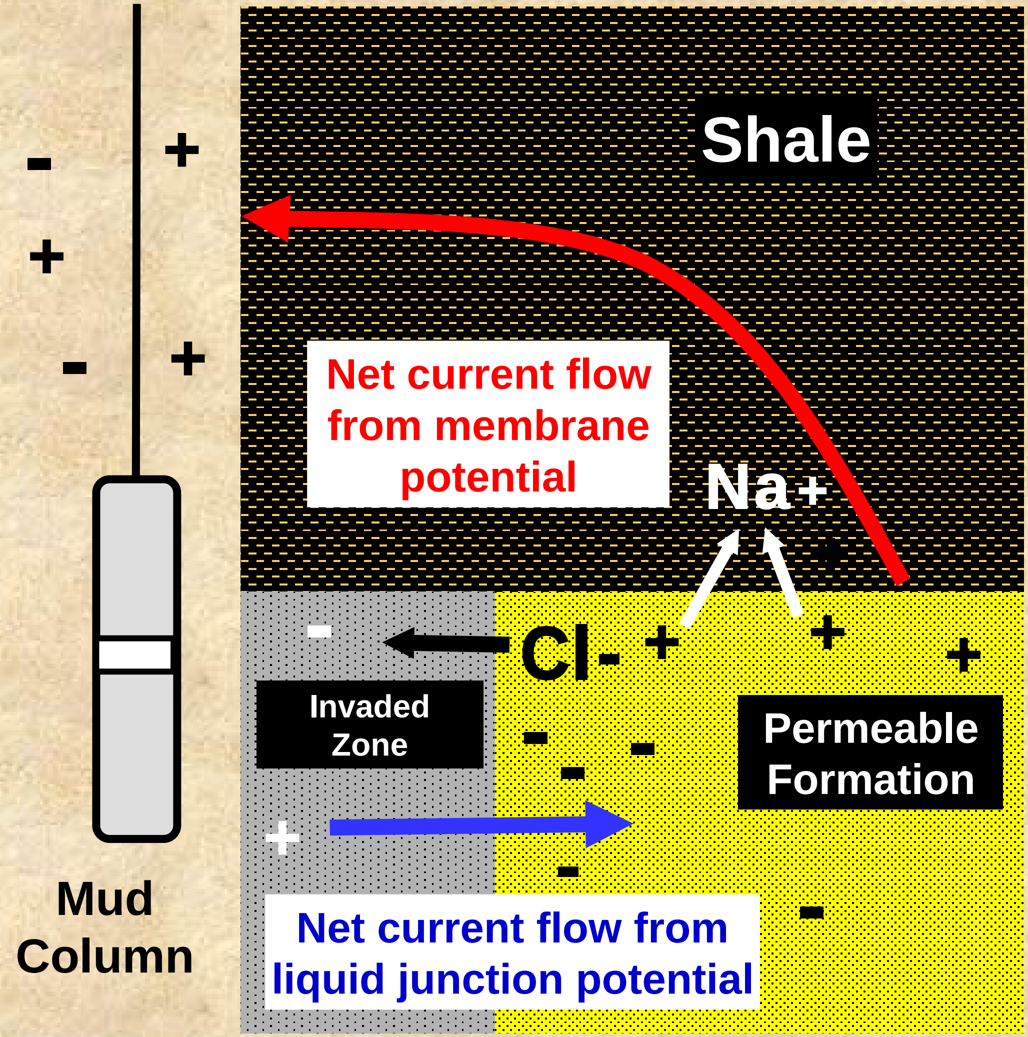
SP Recording Schematic



Components of the SP

- Electrokinetic
  - Streaming potential
- Electrochemical
  - Membrane potential
  - Liquid juncture potential

Electrochemical Components of the SP Measurement



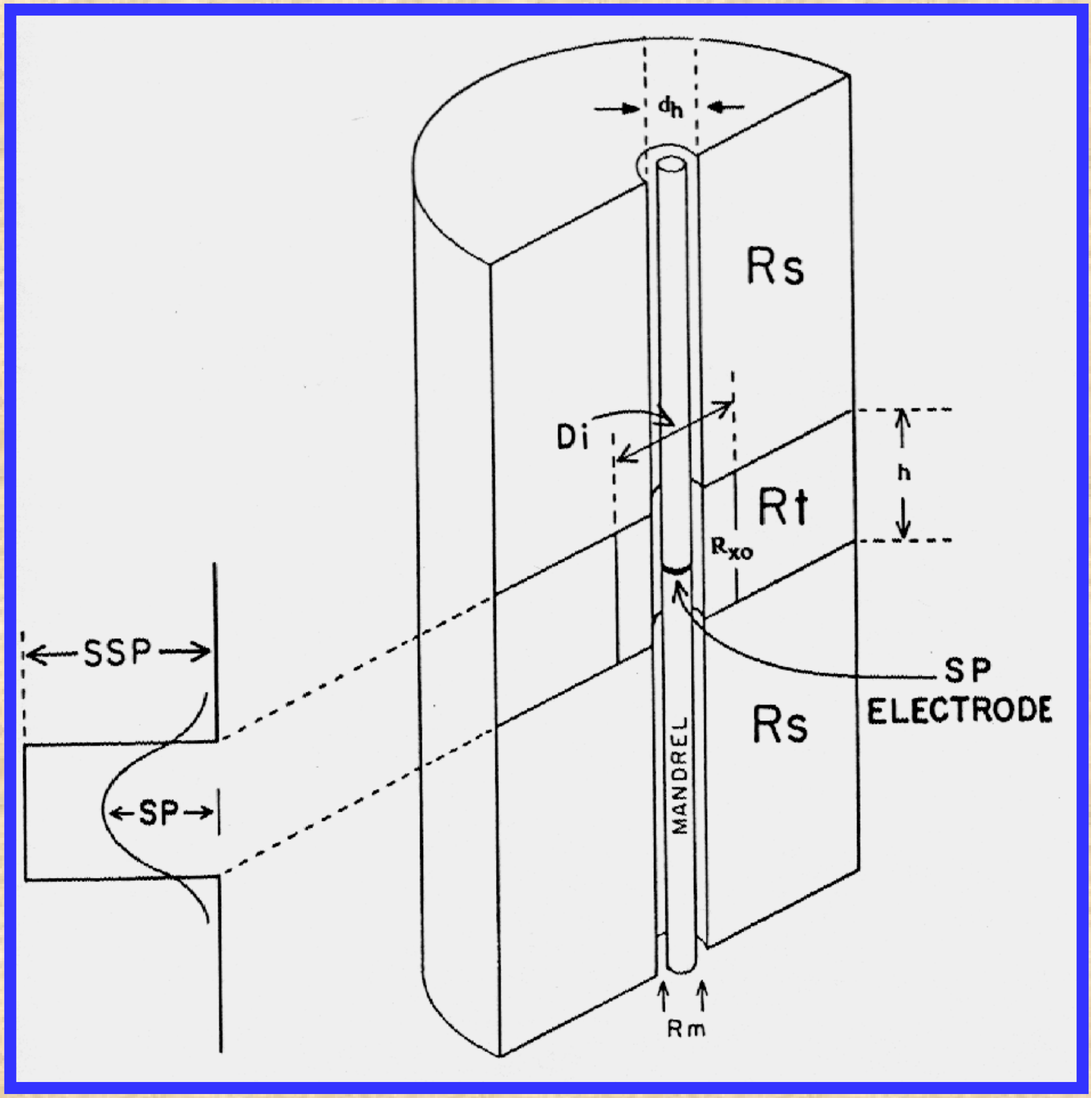
Membrane Potential (±80%)

Shale is ionic membrane allowing only the Na+ cations to move from the more concentrated permeable formation to the wellbore

Liquid Junction Potential (± 20%)

More active chloride ion's mobility (relative to sodium ions) in moving from high salinity to low.

SP Environmental Effects



Bateman, 1985

SP is heavily affected by bed thickness (h), and by the ratio of Rt / Rmud

Static SP (SSP) is the ideal SP response if there is no clay in the porous bed

Pseudo-static SP (PSP) results from correcting the effects of (h) and Rt / Rmud but allows the clay effects to remain in the measurement

5 Effects on the Electrochemical Component of the SP

Bed Thickness

Rmud/Rt

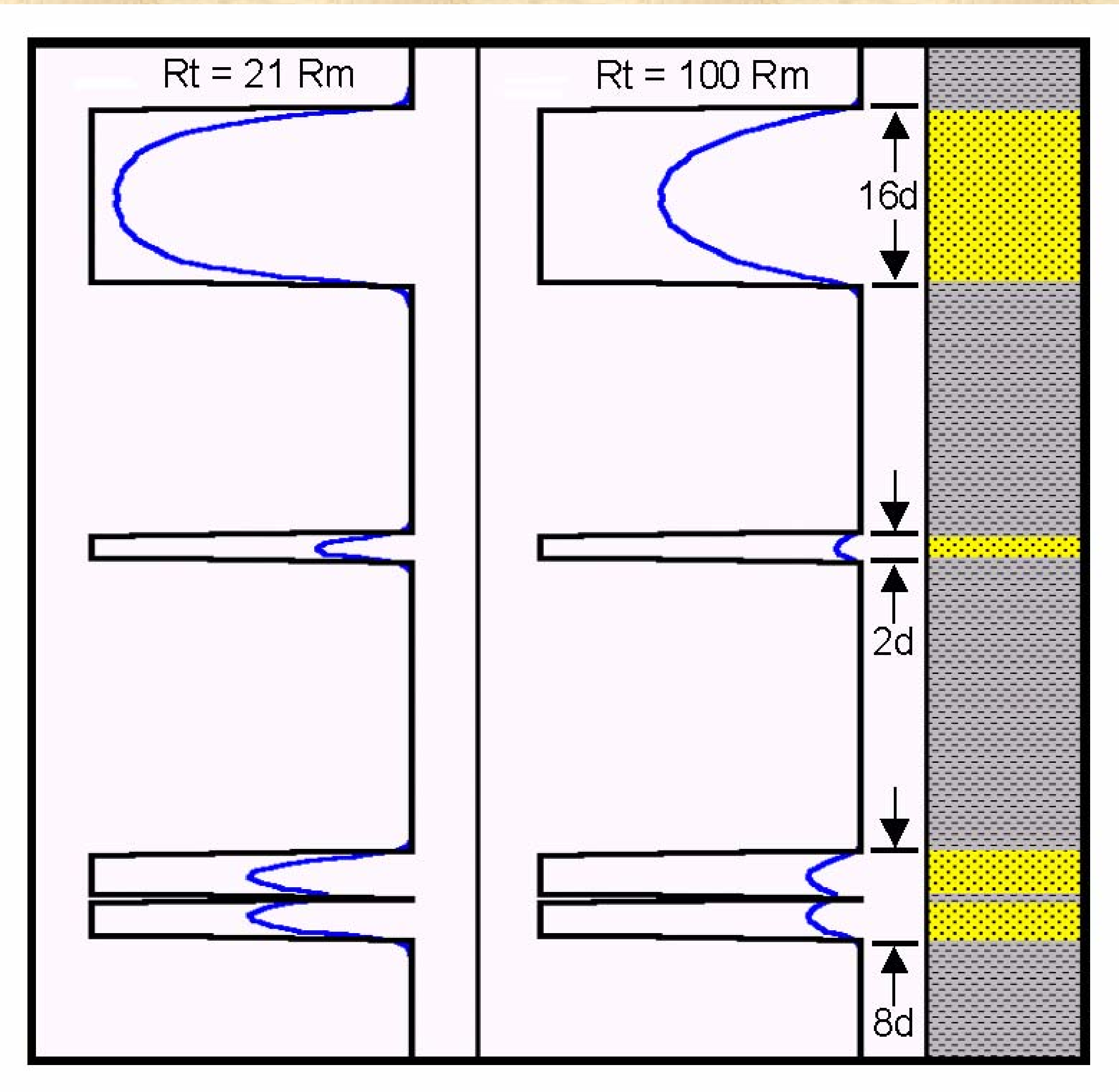
Rw

Rmf

Clay in the Permeable Zone (Rock Quality)

SP Environmental Effects

Rt / RM and Bed Thickness (h)



Modeled SP curve in beds of different thickness for:

Rt = 21 X Rm (left) and
Rt = 100 X Rm (right)
SSP = -100 mv in permeable formations

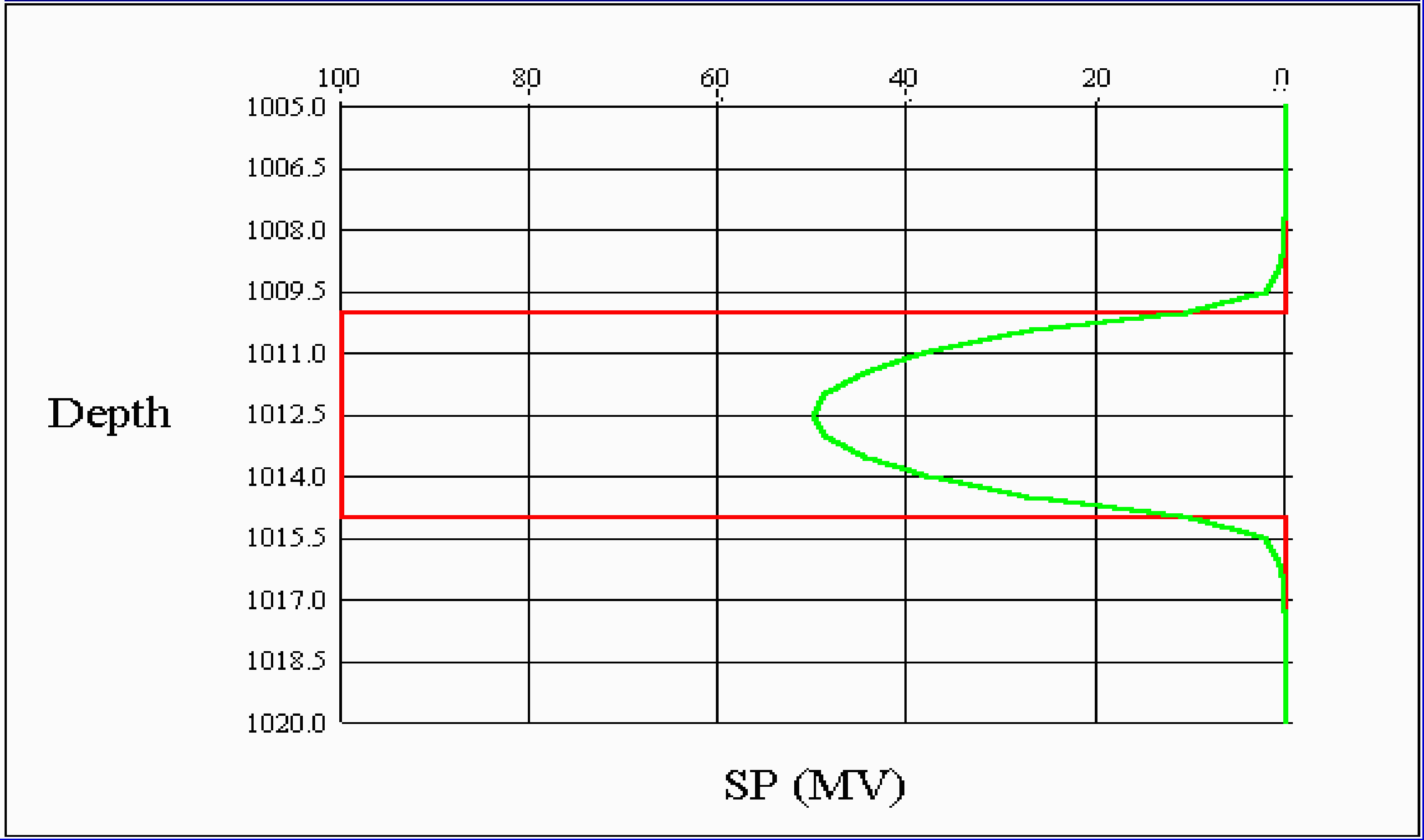
Created with SP inversion technology

SP Modeling

A **forward model** is built using finite element analysis. This model for electrochemical potentials describes the response of the SP measurement.

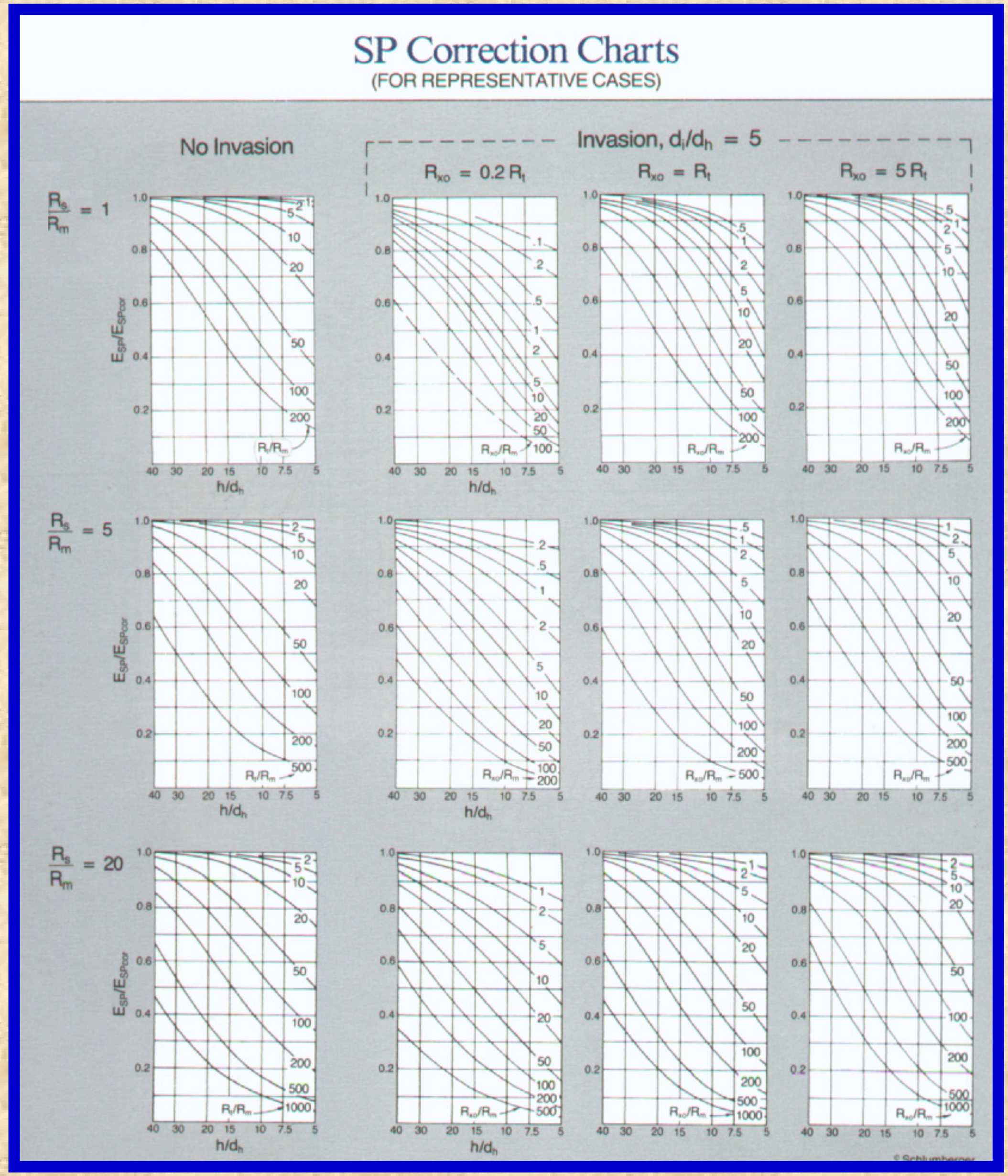
Inversion modeling uses the recorded SP data and proposes a first approximation of an earth model and presents this earth model to the forward model. It then uses that initial earth model approximation to construct an SP curve. Based on differences between the constructed SP and the original measured SP, the earth model is then adjusted until the best fit is achieved.

SP Forward Modeling



5 foot thick, 50 ohm-meter resistive bed
1 ohm-meter side bed
Static SP=100 mv
8-inch borehole

SP Correction Charts, 1962



Expensive laboratory process used to create charts

Only useful for “ideal” beds thicker than about 4 feet

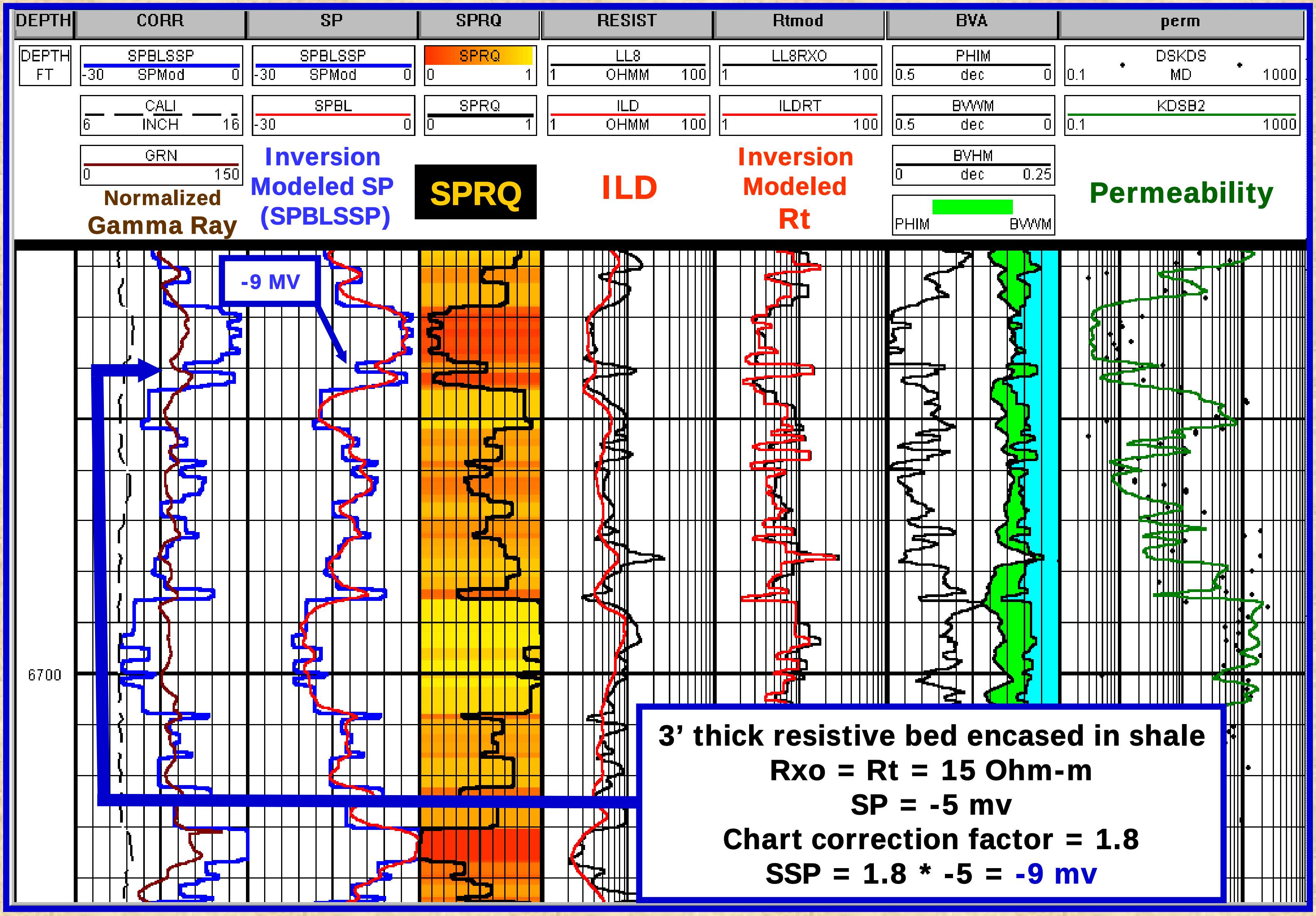
Approximate, requires interpolation

Does not work for compound beds

Tedious

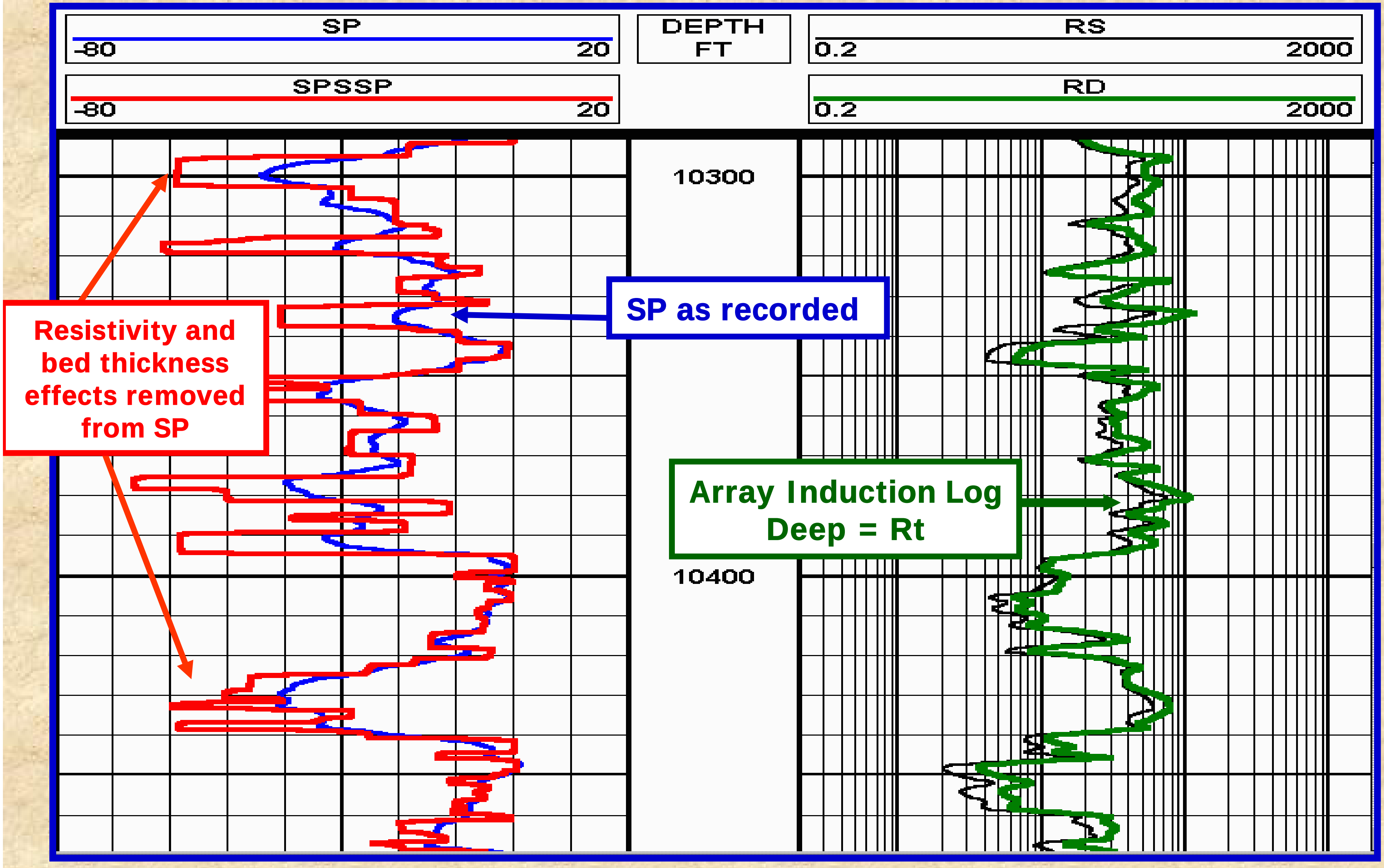
SP-Inversion Correction Thin Beds

National Petroleum Reserve, Elk Hills, CA



SP Inversion Example - Modern Logs

Jonah Field, Pinedale Wyoming



5 Effects on the Electrochemical Component of the SP

Bed Thickness*

Rmud/Rt Ratio*

Rw

Rmf

Clay in the Permeable Zone (Rock Quality)

***SP Modeling removes these effects to get SPSSP**

Now that I have an SPSSP... How do I use it?

Quantitative Rock Quality from the Inversion Modeled SP in Multi-well Applications

Normalization is required to account for changes in Rw and/or Rmf

VshaleSP

Baseline Shifted SP (SPBL)

Use a trend line method to set all shales = 0

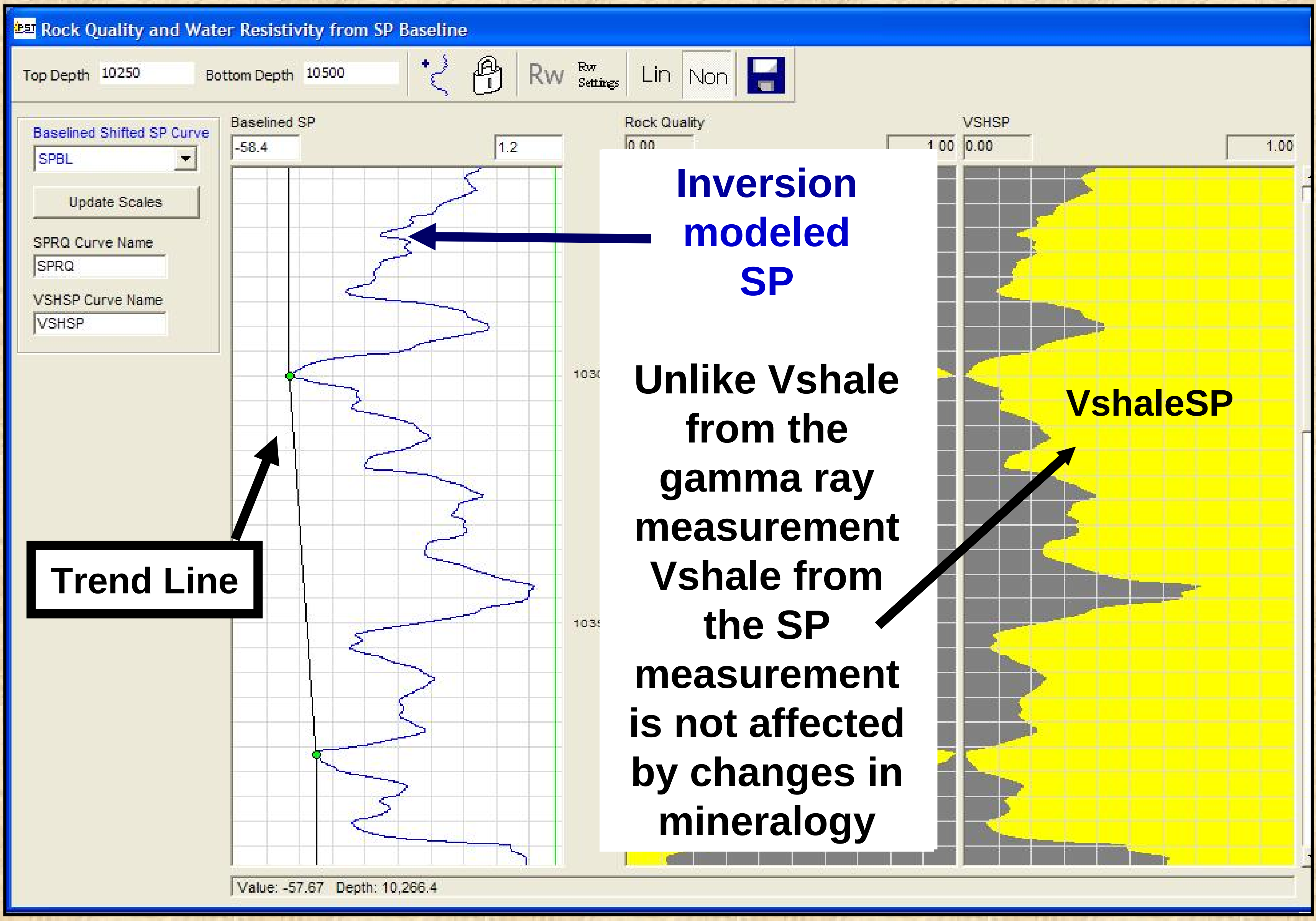
By applying a formula to create SPN from the baseline-shifted SP (SPBL) and trend line (SPBLT)

Normalized SP (SPN)

Using a trend line method set all clean sands = Constant (i.e. -50)

SPN = -50 * SPBL/SPBLT

Using a Trend Line to Normalize SPBL



5 Effects on the Electrochemical Component of the SP

Bed Thickness*
Rm/Rt Ratio*
Rw**
Rmf**
Clay in the Permeable Zone (Rock Quality)

*** SP Modeling removes these effects**
**** Normalization removes these effects**

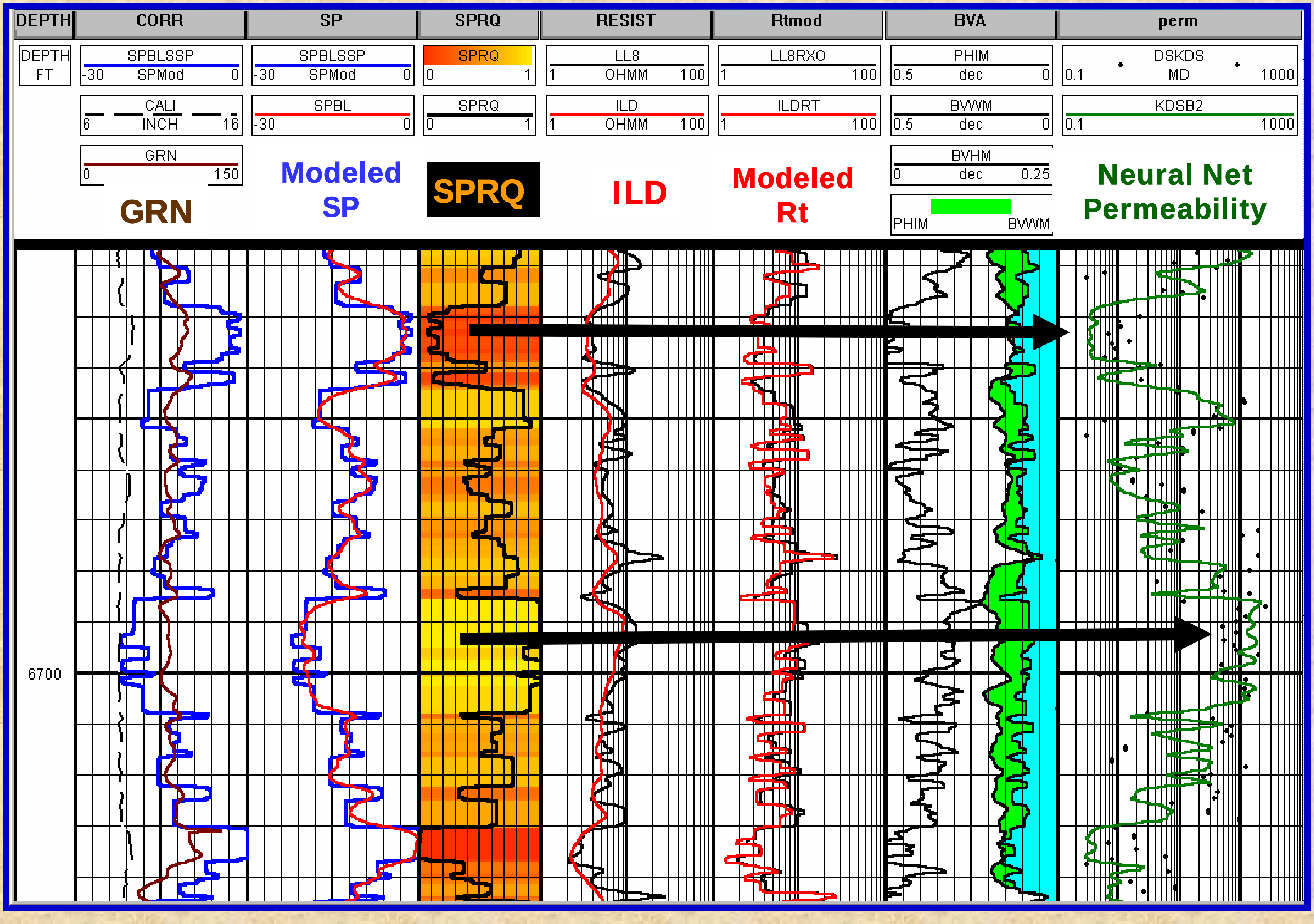
You are left with rock quality

SP Rock Quality (SPRQ)

$$SPRQ = 1 - (SPBLT - SPBL) / SPBLT$$

SPRQ is a measure of rock quality (0 = poorest, 1 = highest)
SPBLT = corrected SP (baseline shifted and trend normalized)
SPBL = corrected SP (baseline shifted)

Elk Hills National Petroleum Reserve



Permeability can be predicted quantitatively using the SPRQ

Multi-well Applications for Normalized SPSSP

Predicting permeability

Tracking changes in Rw

Creating synthetic acoustic logs

Editing poor-quality data

SP Inversion Summary

- Chartbook Corrections
  - Limitations: ideal beds greater than 3 feet thick
  - Approximate…requires interpolation
  - Tedious….nobody does the chartbook work
- Theoretical Forward Modeling
  - Matches chartbook corrections for ideal beds
- Continuous Inversion Modeling Applications
  - Resolve even non-ideal beds to 1 foot thick
  - Correlate lithology more accurately
  - Track changes in Rw, even in hydrocarbon-bearing formations which do not produce water samples
  - Predict permeability quantitatively from well to well
- Quantitative Use of the SPSSP
  - Baseline shifting and normalization required
  - SPSSP to predict porosity and permeability
  - SPSSP to create synthetic logs and edit poor-quality data

Questions?