Geologic Controls on Formation Water Salinity Distribution, Southeastern Greater Natural Buttes Field, Uinta Basin, Utah*

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Search and Discovery Article #20272 (2014)**
Posted October 13, 2014

*Adapted from oral presentation given at AAPG International Conference & Exhibition, Istanbul, Turkey, September 14-17, 2014

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Abstract

Tight-gas sandstone reservoirs of the Upper Cretaceous Mesaverde Group in the Greater Natural Buttes (GNB) Field have variable fluid saturations along with low matrix porosity and permeability. In order to build more reliable saturation models, it is significant to determine resistivity of formation water, which is one of the input parameters in water saturation calculations. This study mainly investigates how formation water resistivity and salinity vary stratigraphically and spatially. For petrophysical analysis, the study interval was divided into seven stratigraphic zones based on net-to-gross ratio and variation in resistivity. Formation water resistivity derived from Pickett-plot analysis was used with formation temperature to determine formation water salinity distribution per zone. Temperature data from production logs show that the Wasatch Formation and Mesaverde Group have higher geothermal gradients than formations that are stratigraphically above. Therefore, formation temperature was estimated using these gradients, which are consistent through the study interval. Petrophysical analysis indicates more fresh water is present in the western part of the study area coinciding with the trace of a basement fault. Salinity decreases stratigraphically downward while water saturation is variable within the study interval. Average formation water resistivity per zone ranges between 0.048 ohm-m to 0.064 ohm-m based on Pickett- plot analysis, while average formation water salinity per zone ranges between 55,000 ppm to 86,000 ppm. Furthermore, the average effective bulk-volume water is nearly constant around 3.5% suggesting that as being a basin-centered gas accumulation, most sandstones within the study interval are close to irreducible water saturation. A combination of different geological mechanisms might account for

observed salinity variations. The increase in freshness stratigraphically downward may be due to basement faulting and associated natural fracture system enhancing upward movement of fresher formation water. In addition, coal and sediment dewatering in stratigraphic units below study interval might be the source of fresher formation water in this potentially closed hydrological system, whereas distinct horizontal layering and continuity of different petrophysical rock types might result in observed salinity trends in the area.

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GEOLOGIC CONTROLS ON FORMATION WATER SALINITY DISTRIBUTION, SOUTHEASTERN GREATER NATURAL BUTTES FIELD, UINTA BASIN, UTAH

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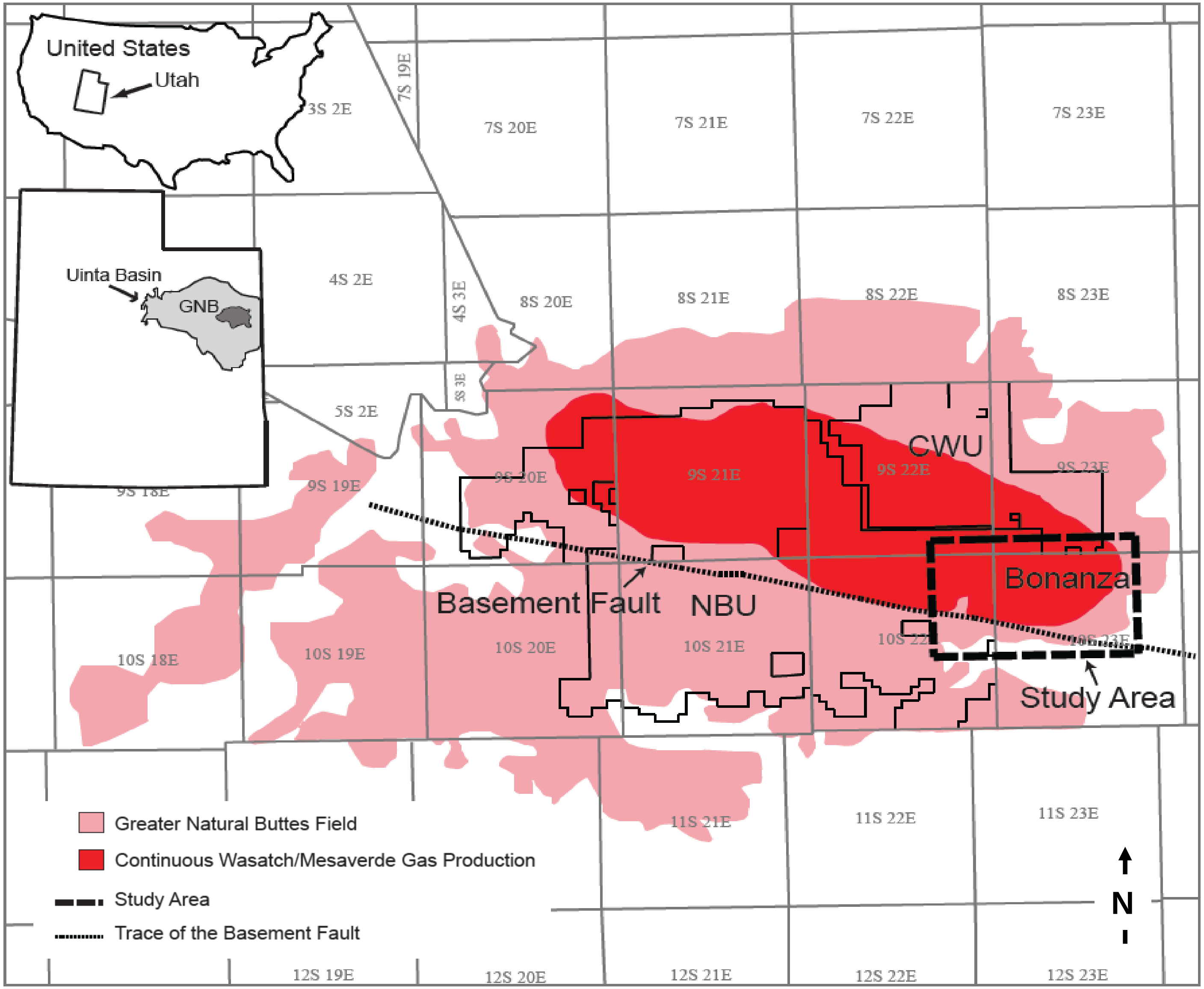
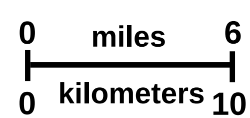
Outline

- Introduction
- Study Area
- Research Questions
- Stratigraphy and Depositional Setting
- Methods
    - Pickett Plot Analysis
    - Water Saturation Calculations
    - Mapping
- Results
    - Rock Type Model
    - Average salinity distributions for each zone
    - Average bulk-volume water distribution
- Conclusions

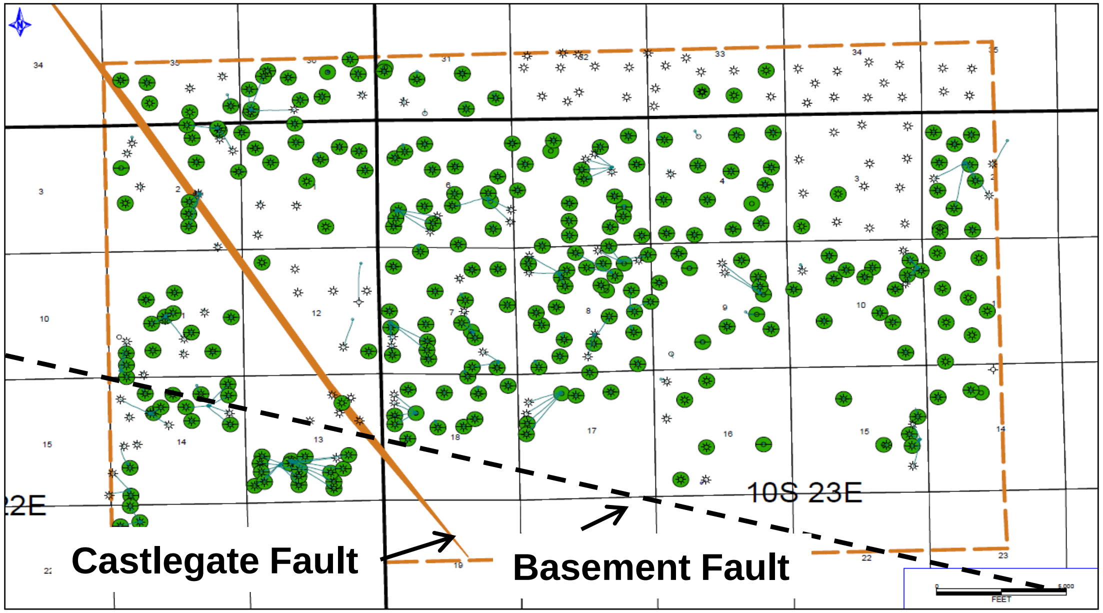
GNB Field and Study Area



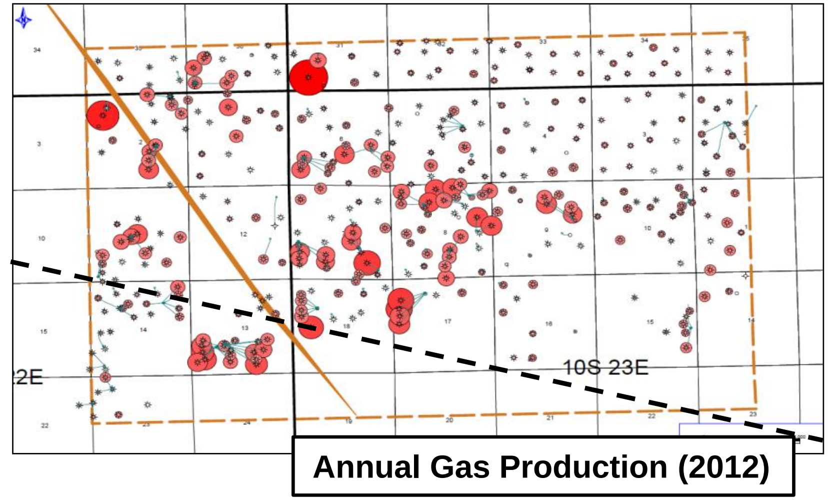


- GNB is the largest gas accumulation in the Uinta Basin.
- A west-northwest trending basement fault divides GNB Field to two different parts showing different production trends.

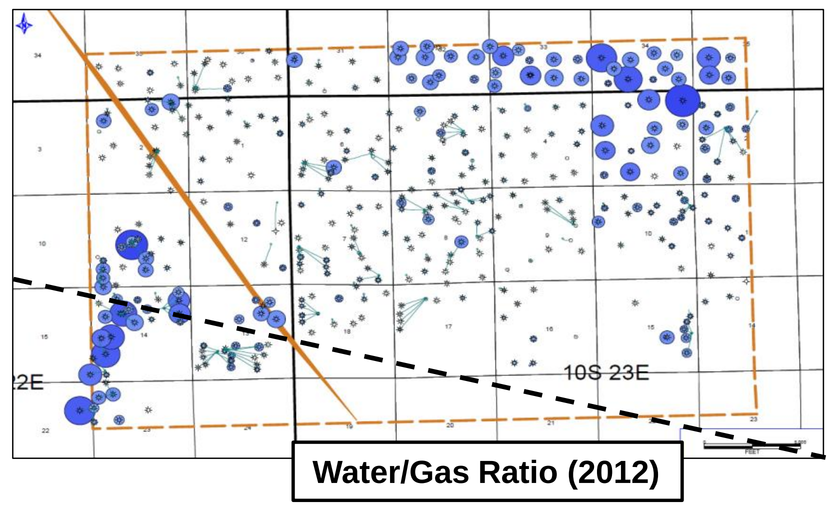
Detailed Study Area



Production Trends



Annual Gas Production (2012)



Water/Gas Ratio (2012)

- A 406 well database was used for stratigraphic framework.
- A 268 well database was used for petrophysical analysis (color coded green).

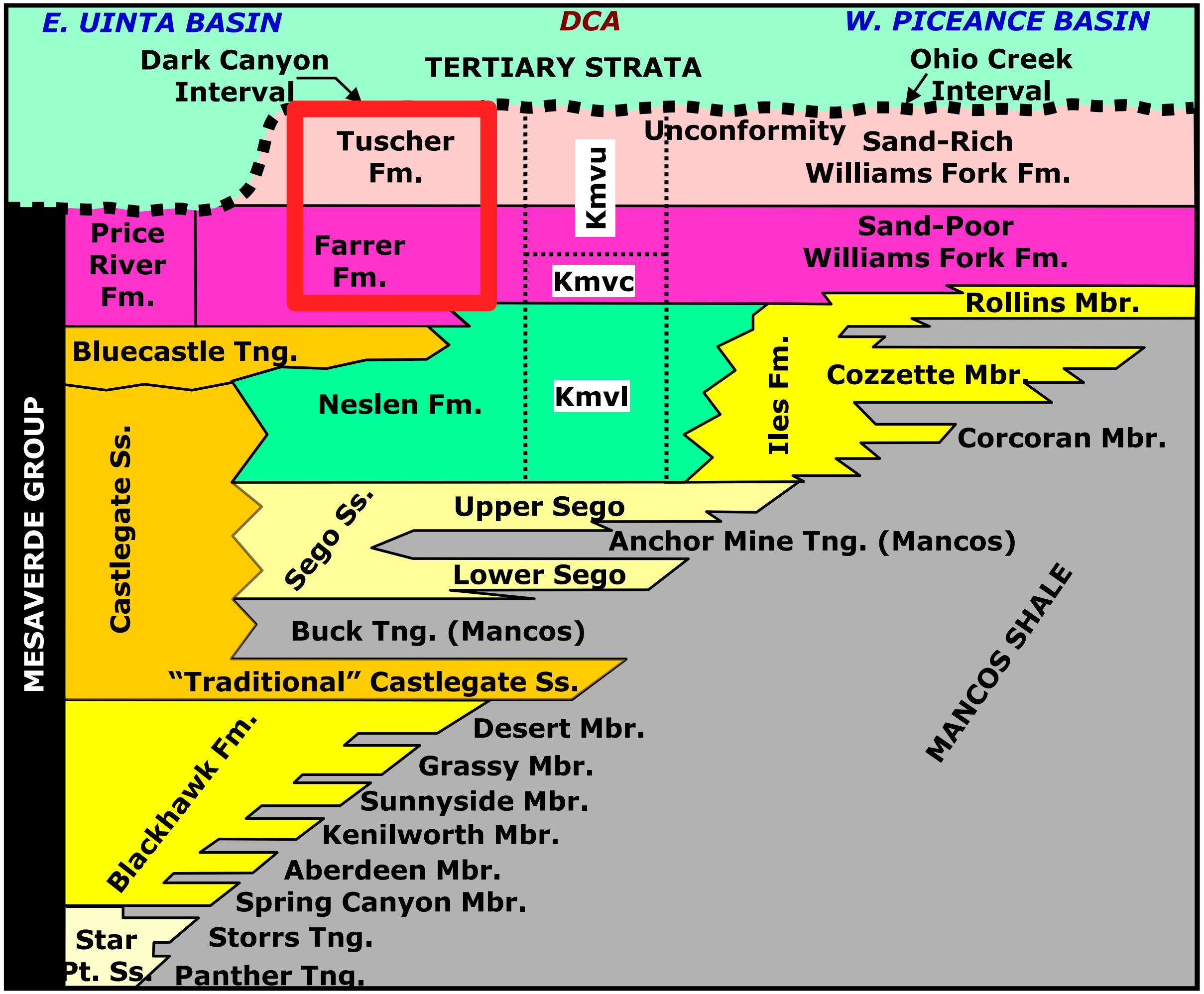
Research Questions

1. How does formation water salinity vary stratigraphically and spatially?

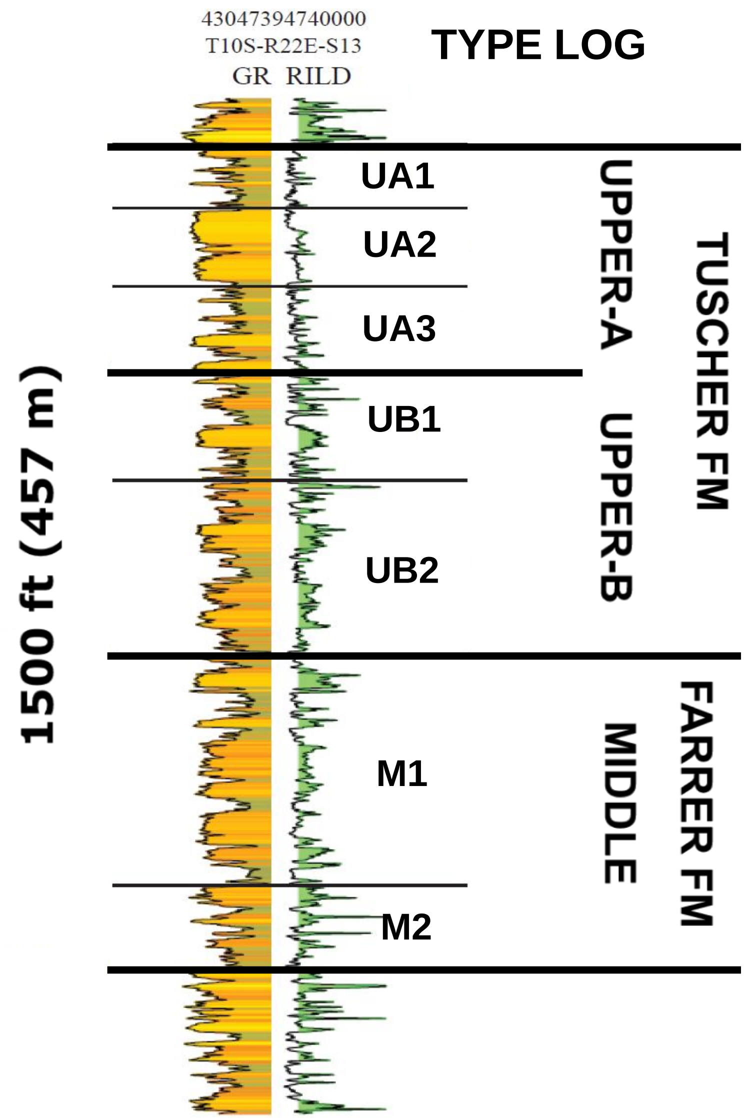
2. What interaction of mechanisms (e.g. faults) can result in variation of formation water salinity?

3. What is the spatial distribution of the highest reservoir quality rock type and its relation to salinity variation?

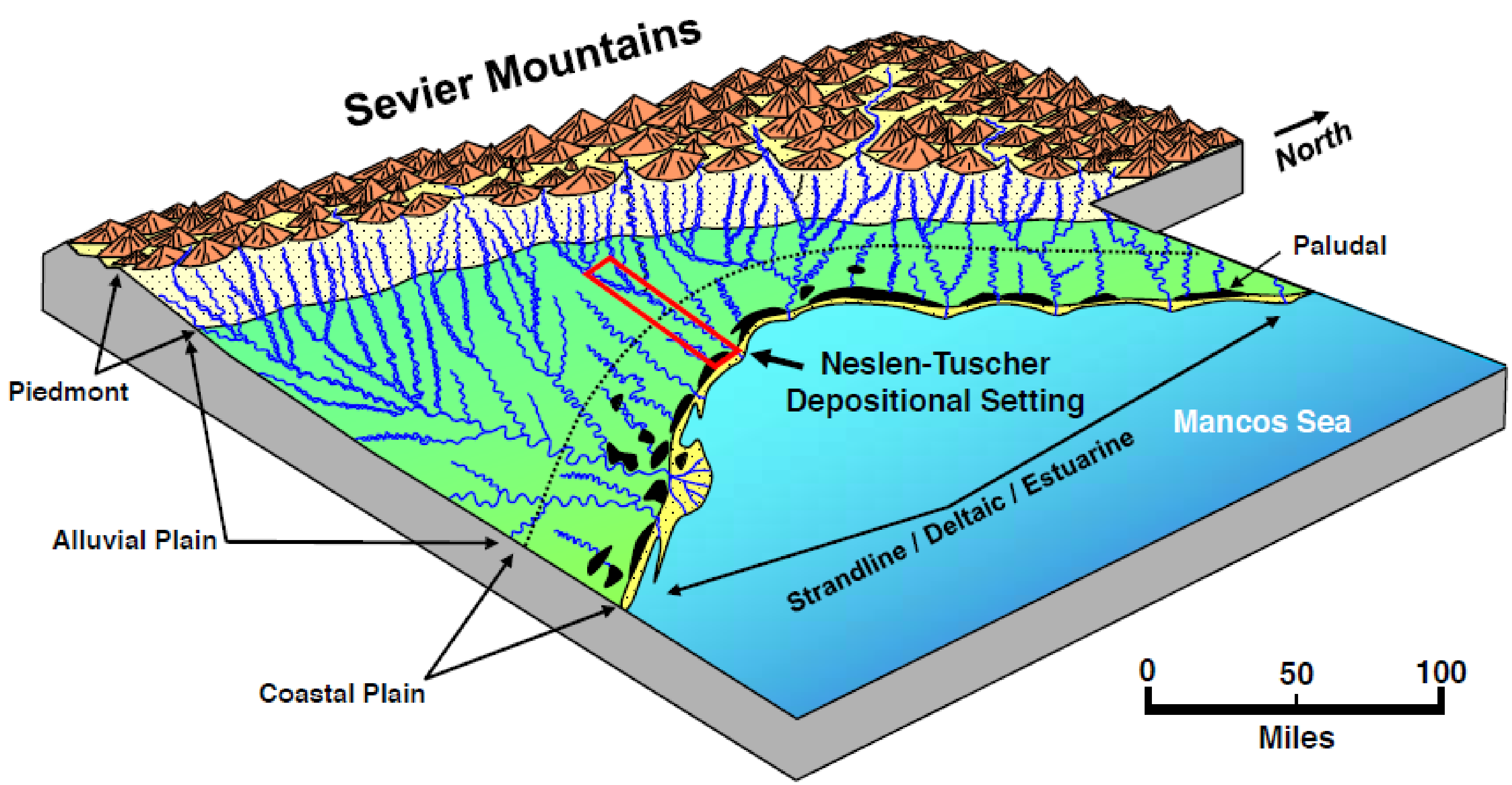
Stratigraphy



(Modified from Hettinger and Kirschbaum, 2003)

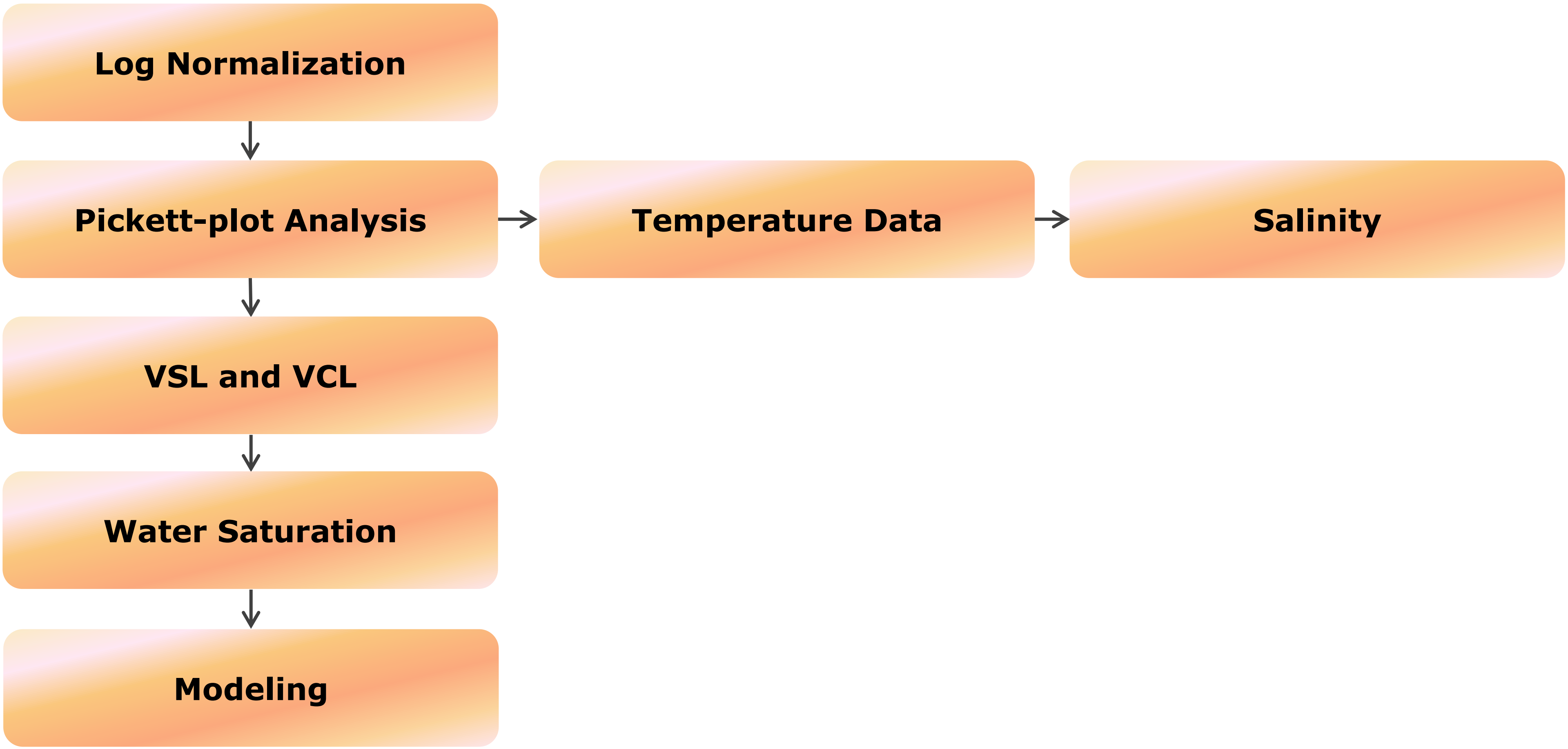


Depositional Setting

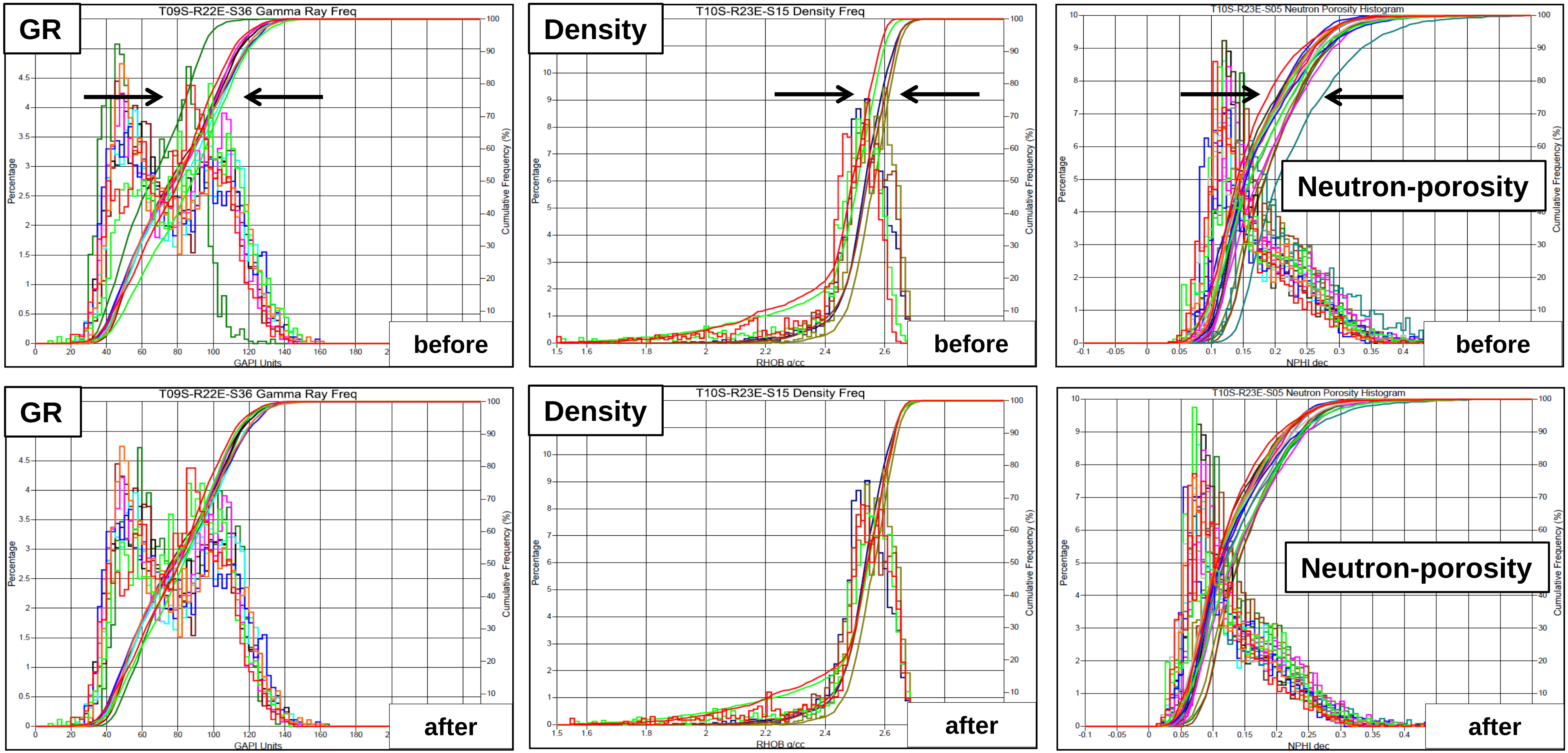


(Cole, 2005; White et al., 2008)

Petrophysical Workflow



Log Normalization



Archie's Equation

$$Sw = \left[\left(\frac{a}{\text{Ø}^{m}}\right)\left(\frac{R_w}{R_t}\right)\right]^{1/n}$$

Sw: Water saturation

Ø: Porosity

Rw: Formation water resistivity

Rt: Resistivity of the sand

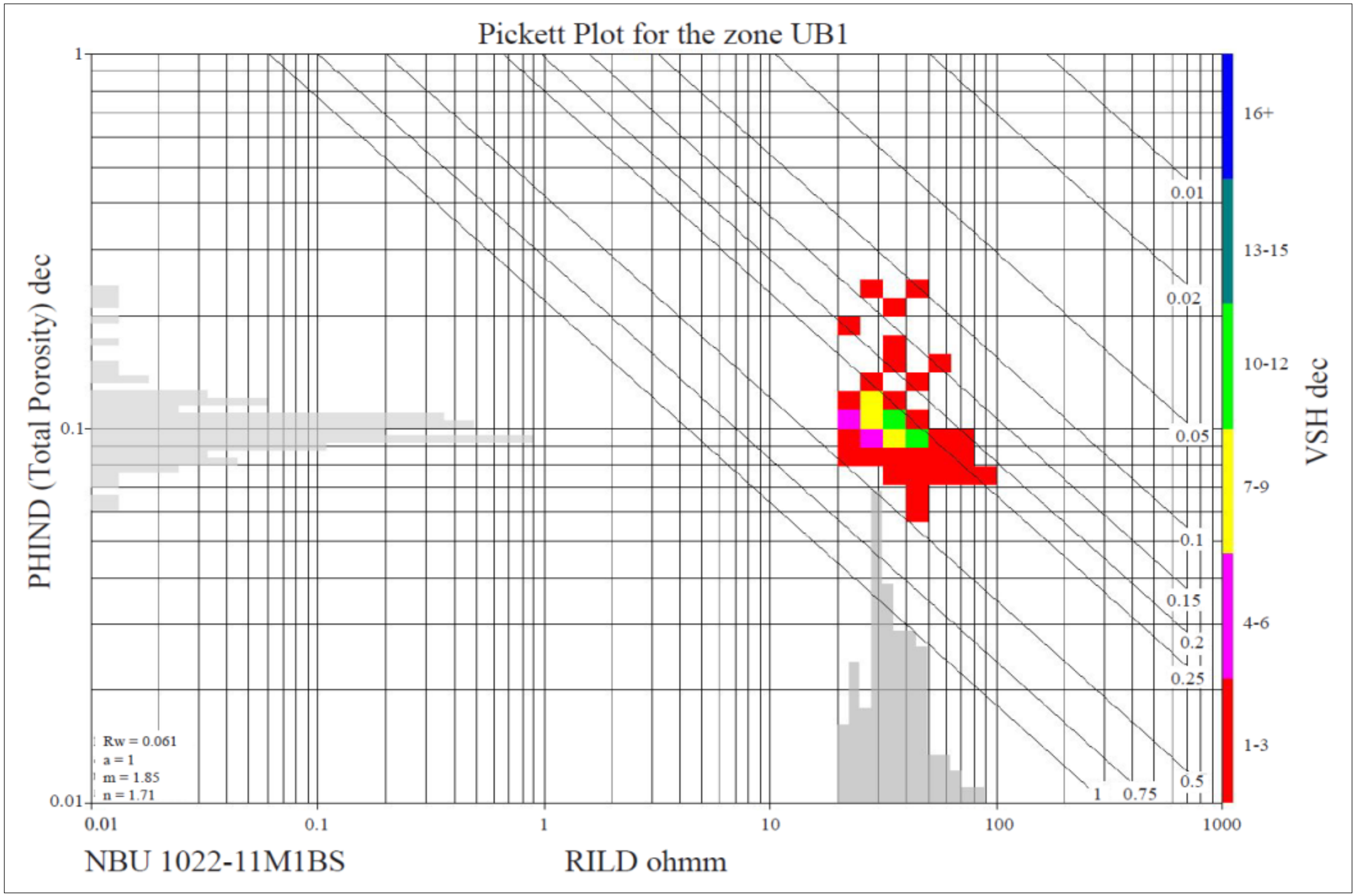
a: Tortuosity factor

m: Cementation factor (varies around 2)

n: Saturation exponent (generally 2)

(Archie, 1942)

Pickett-plot Analysis

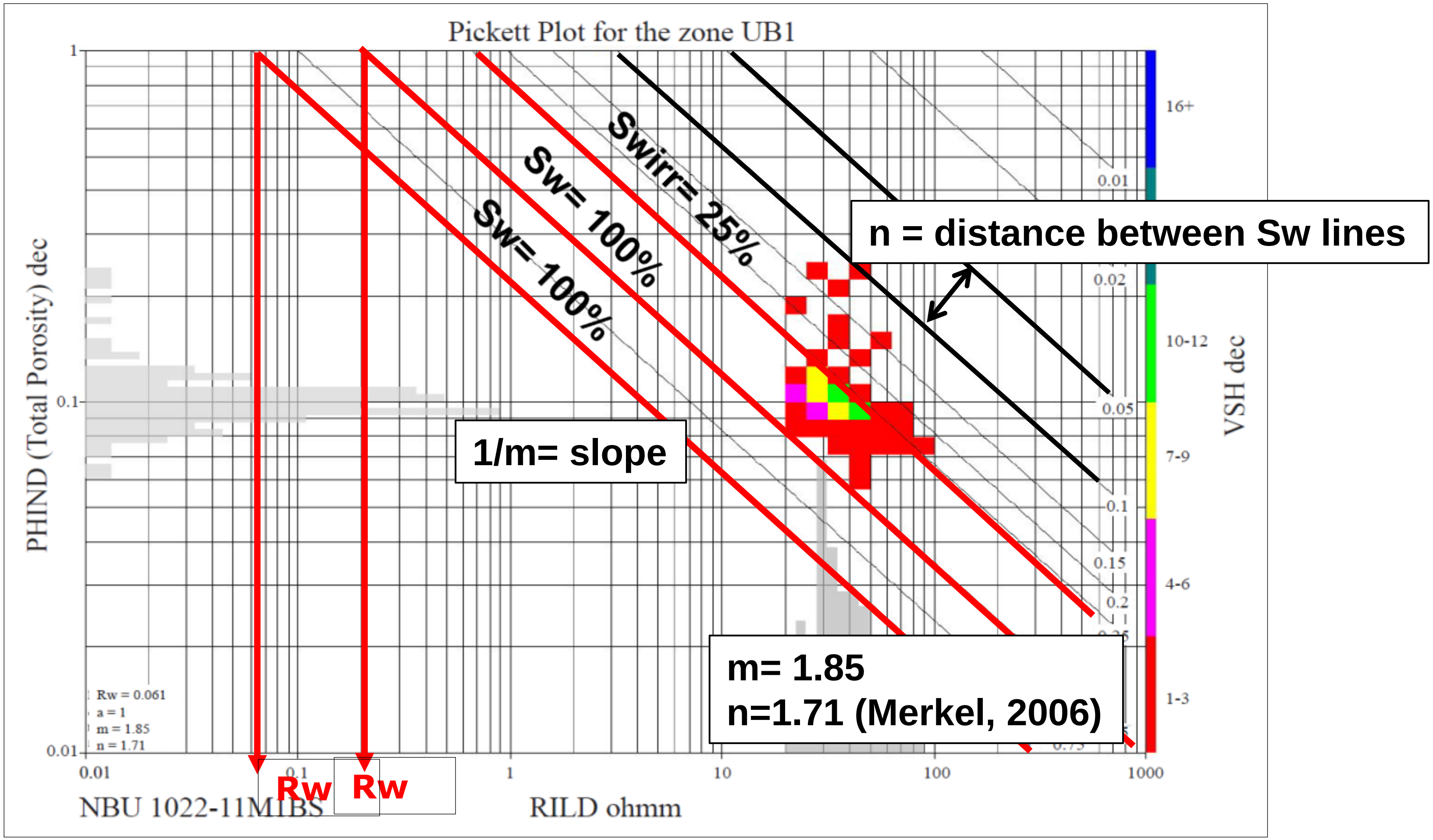


GR < 85 API

RILD > 20 ohmm

0.03 ≤ PHIND ≤ 0.15

Pickett-plot Analysis



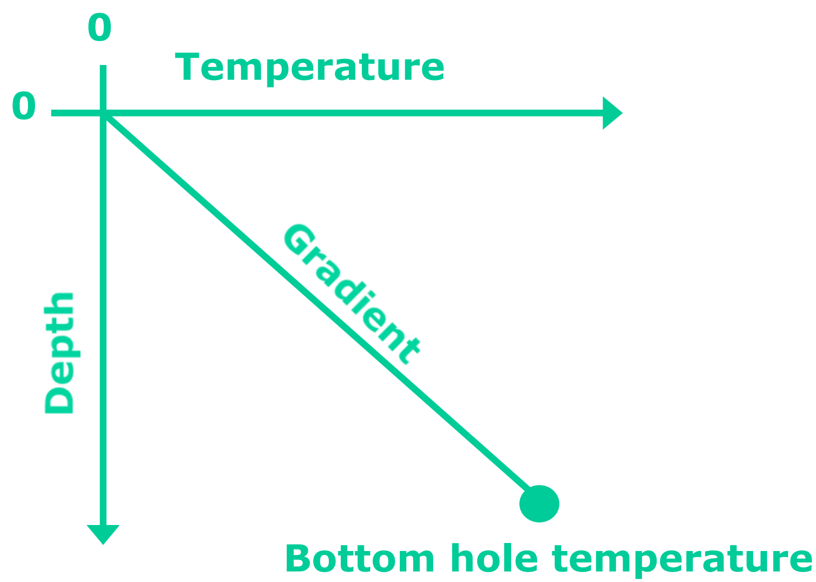
GR < 85 API

RILD > 20 ohmm

0.03 ≤ PHIND ≤ 0.15

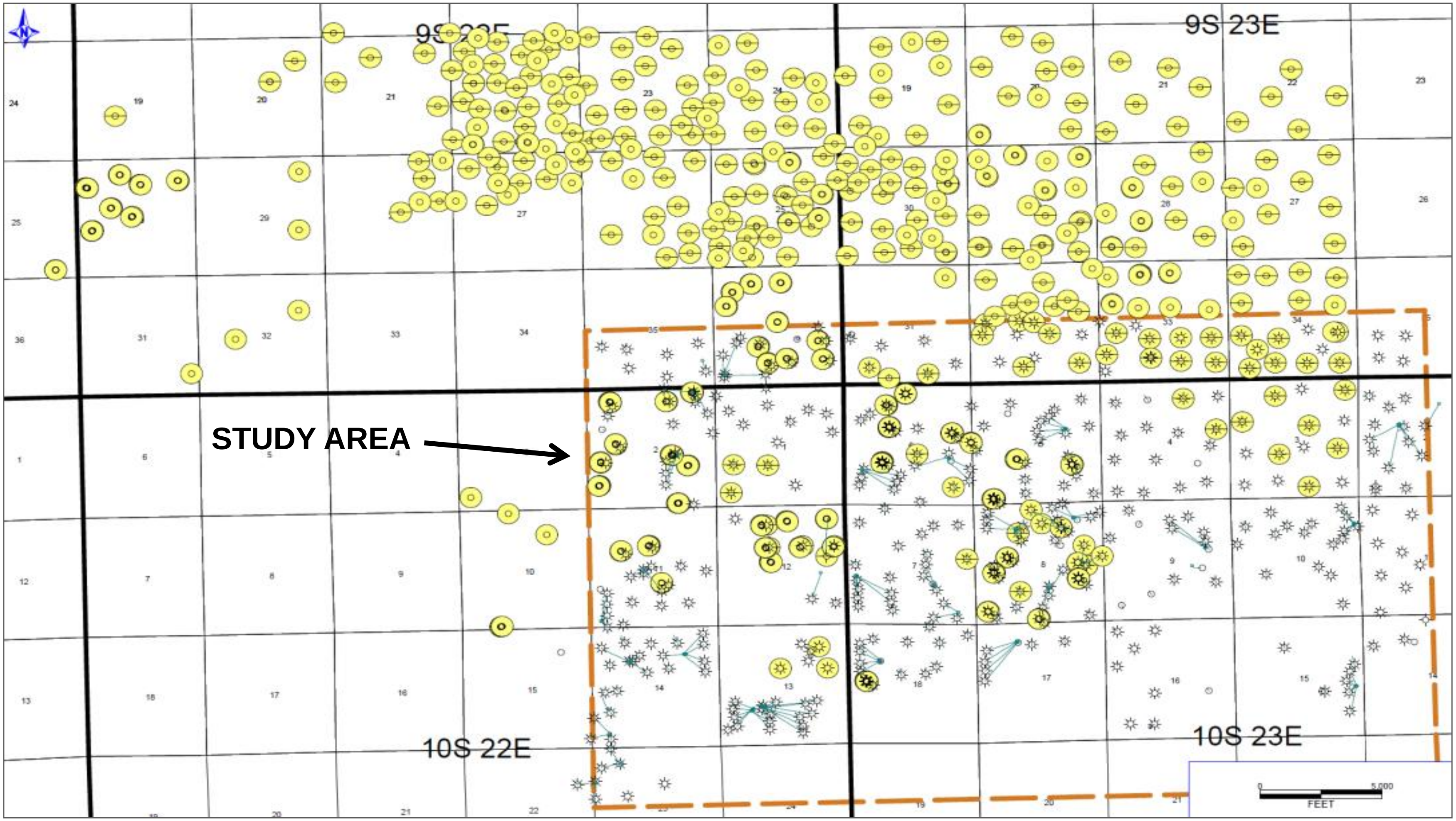
Temperature Data

- *Common approach*: Temperature is recorded at the bottom of the well (max recorded temperature), and it is assumed that the geothermal gradient is constant.



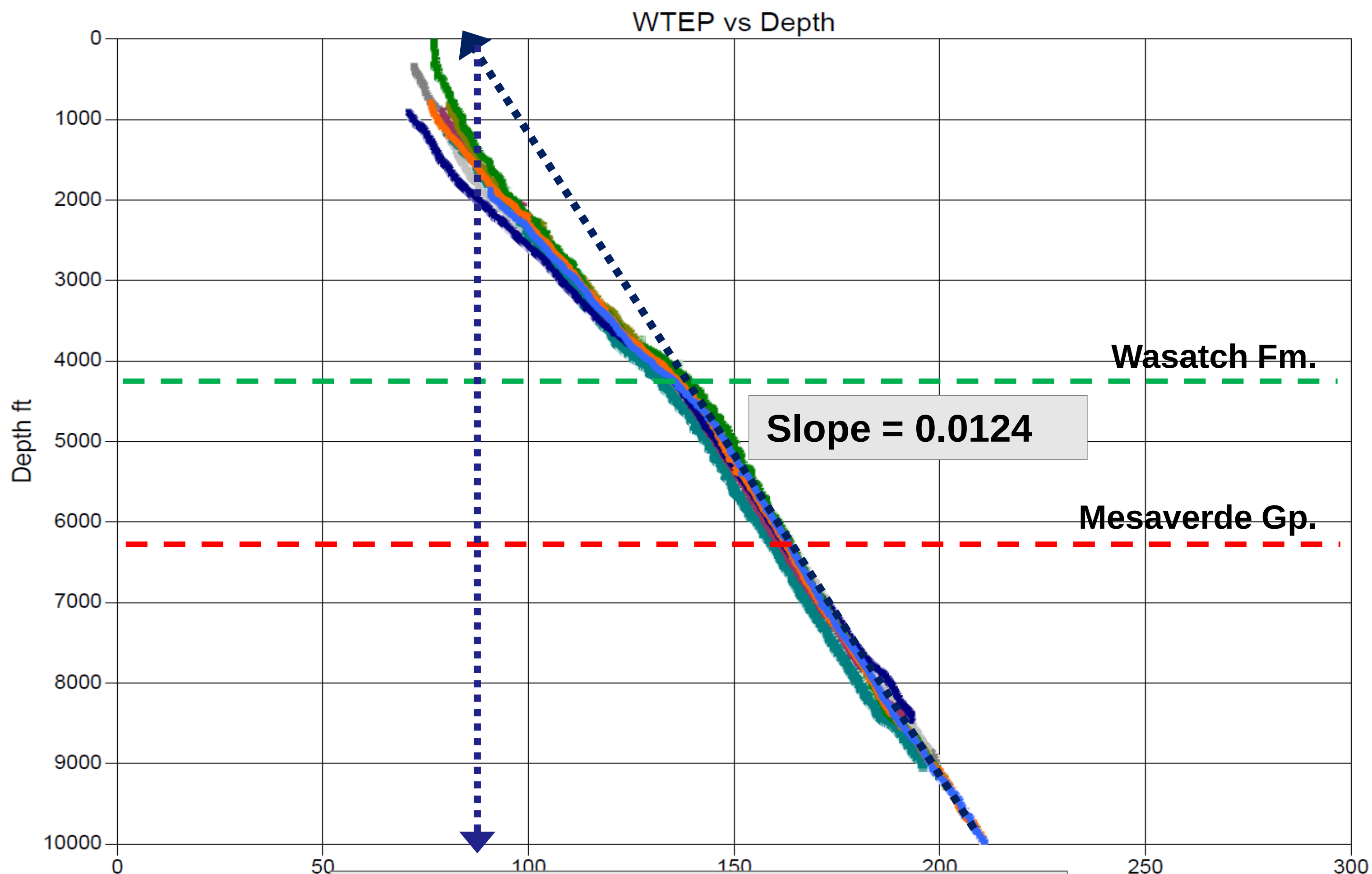
Temperature Data from CBL Tool

- Continuous temperature measurement from CBL (Schlumberger SCMT)



Temperature logs nearby and within the study area

Temperature Data



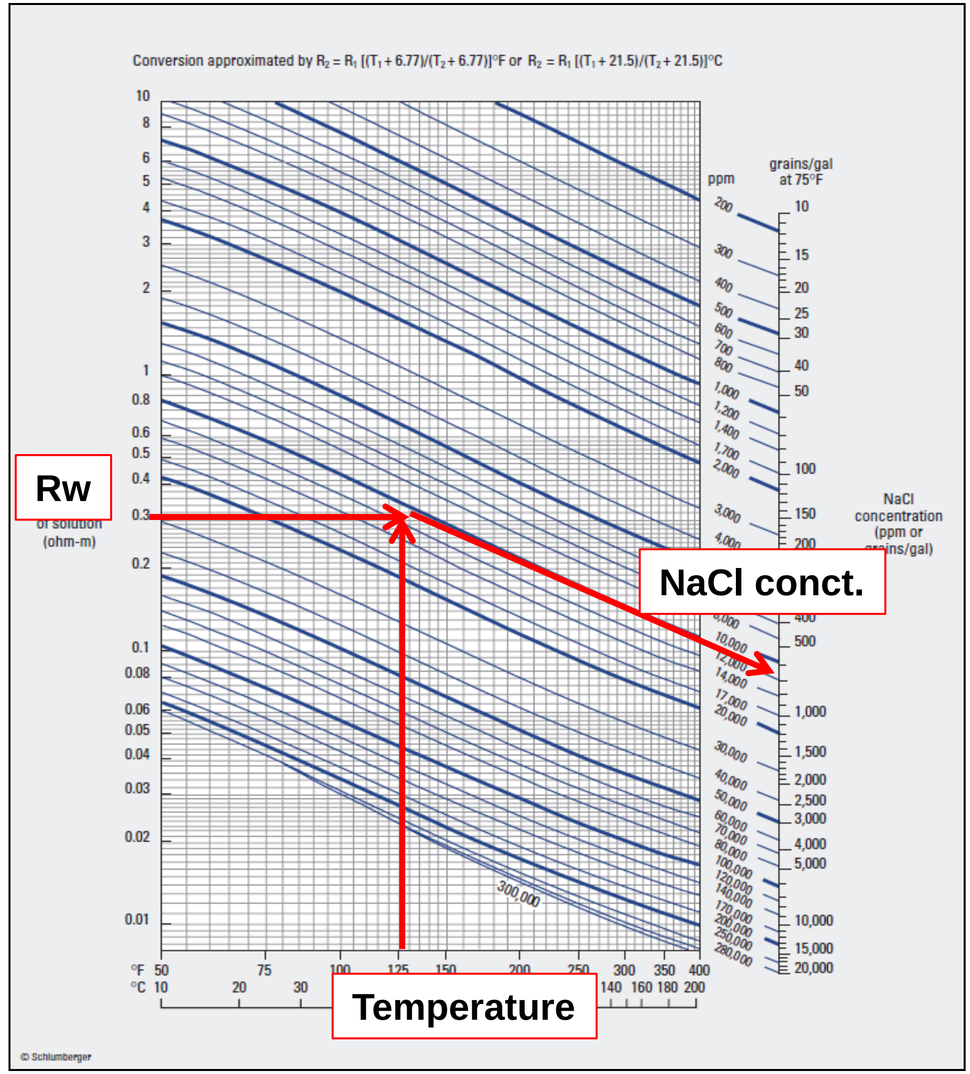
(Miller, Pers. Comm., 2013)

Est. Surface Temperature = 82 ^{0}F

Temperature= 82 ^{0}F + Depth*0.0124

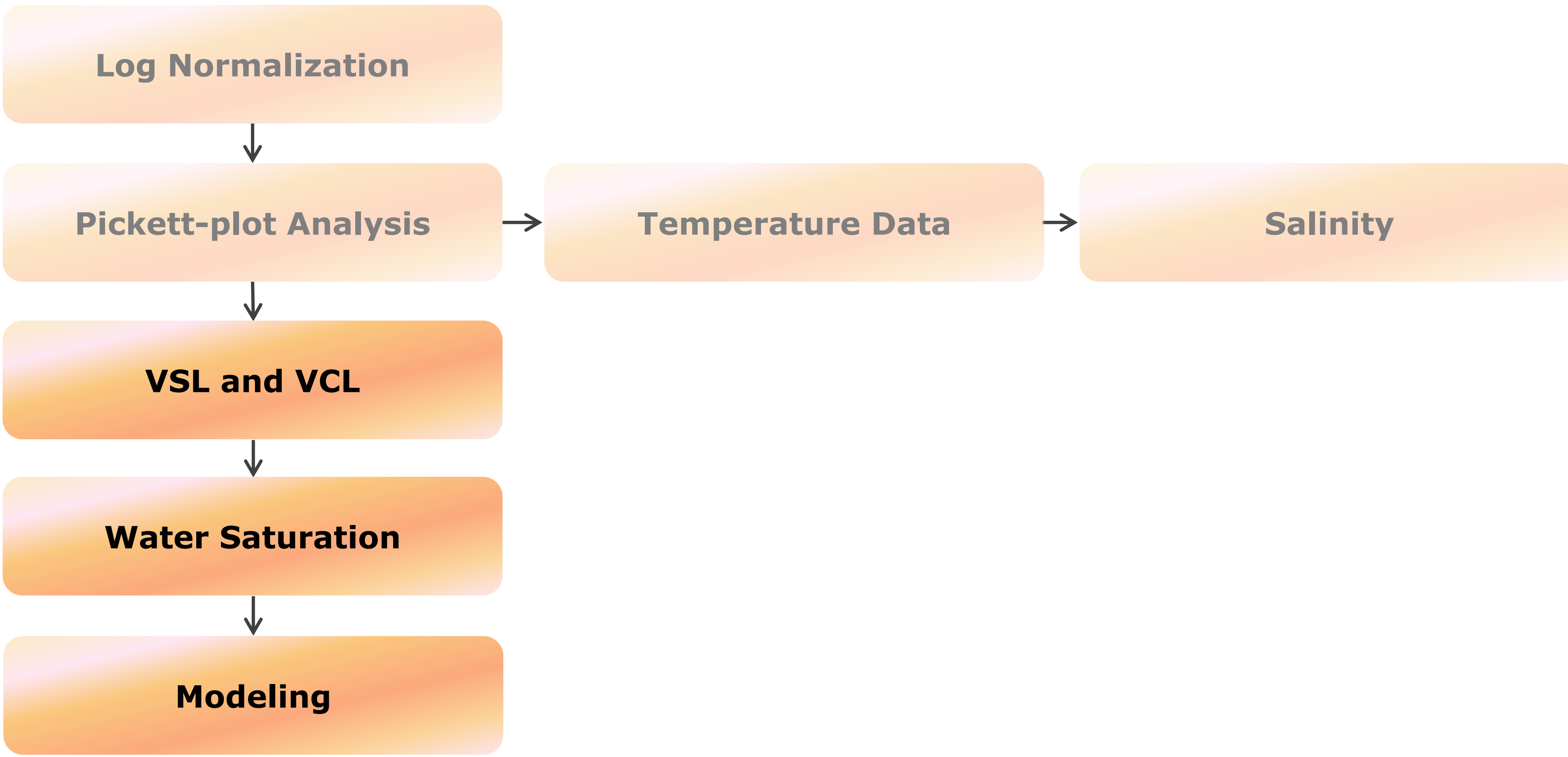
Salinity Calculations

- Salinity is both function of formation water resistivity and temperature.
- Salinities were calculated using *Crain's equation* (2010), and average salinities were mapped for each zone separately.



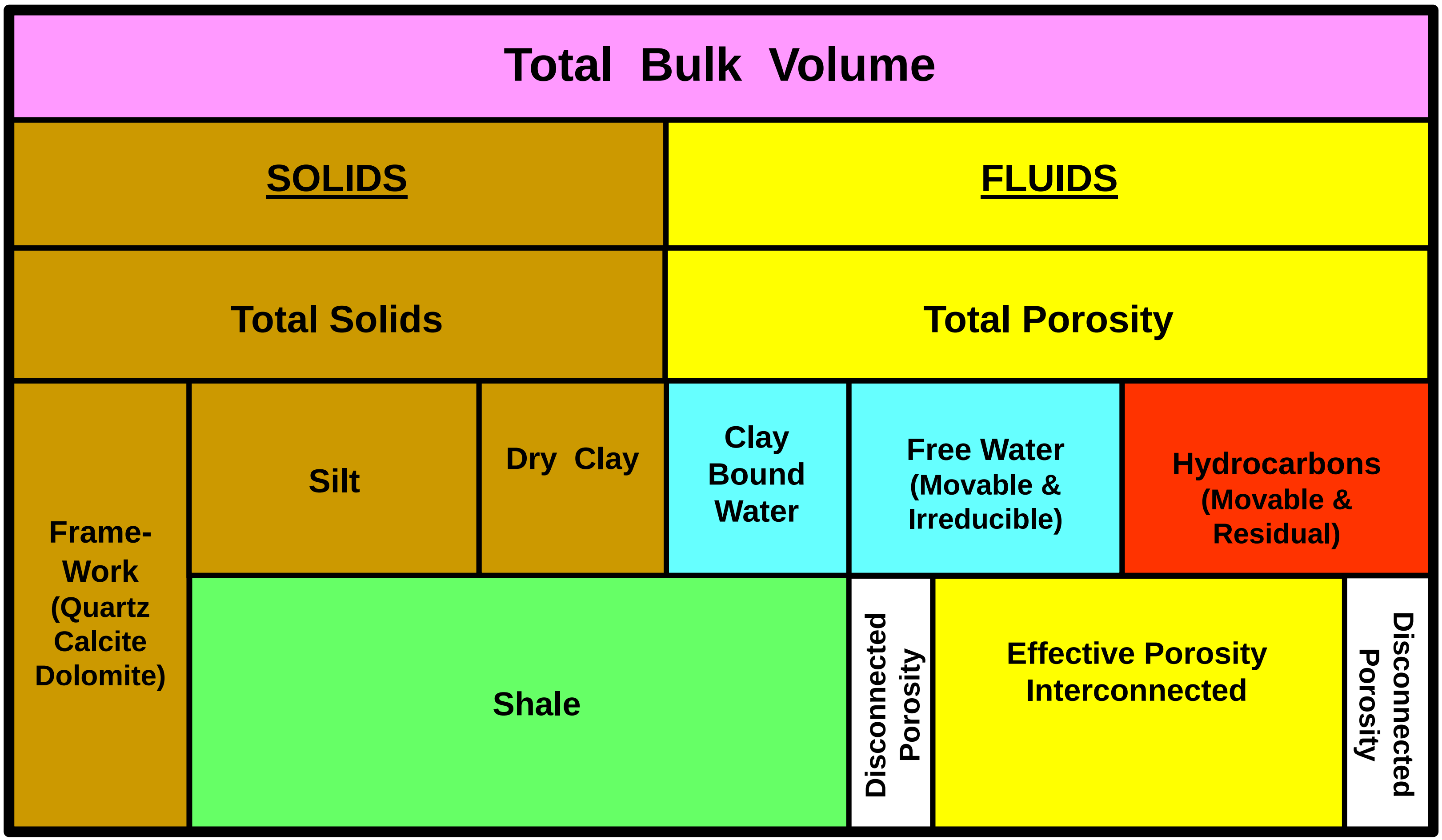
(Courtesy of Schlumberger)

Petrophysical Workflow



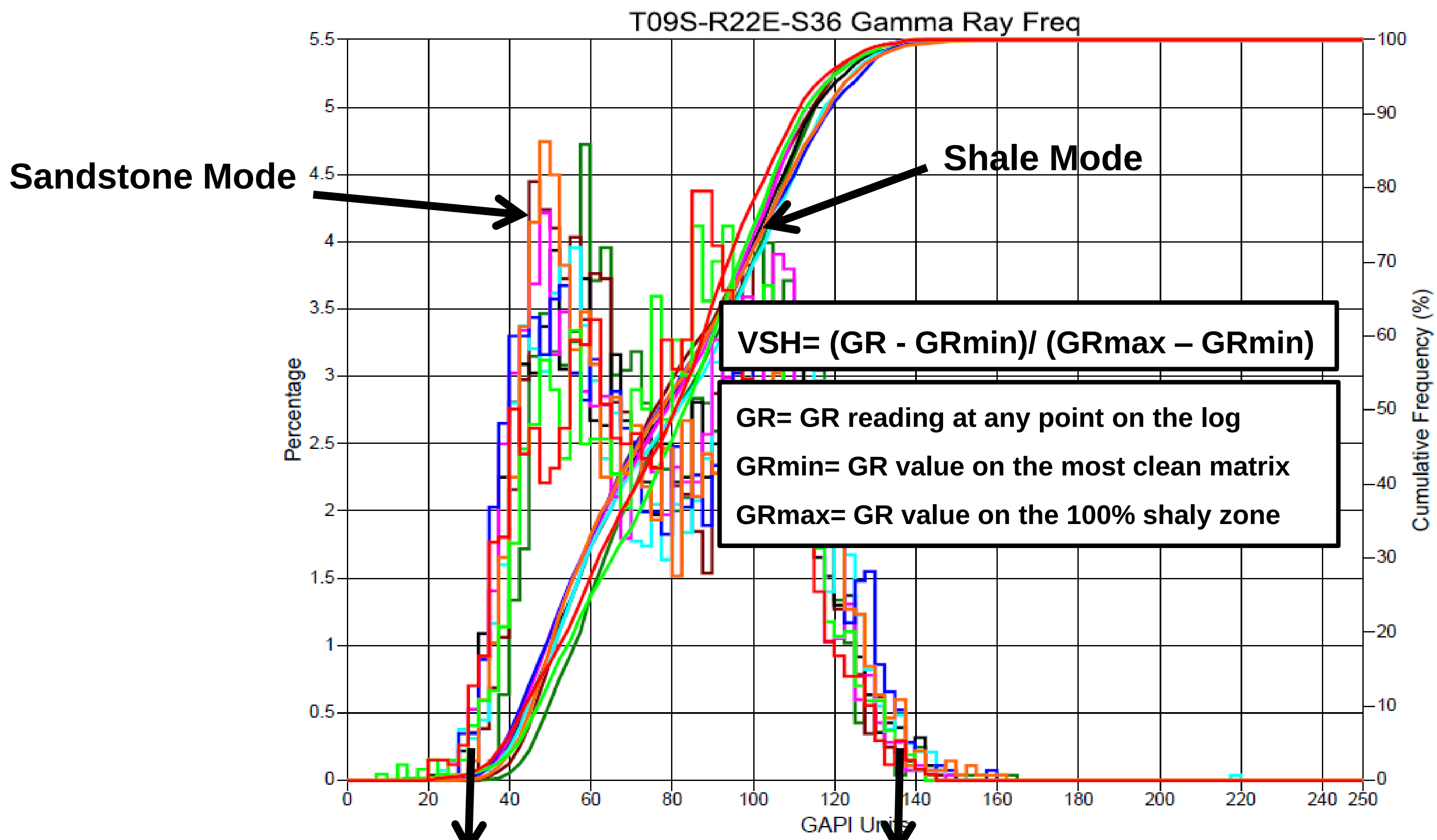
Conceptual Petrophysical Model

Dual Water (Bound & Free) Porosity



(Courtesy of Marc Connolly)

VSH Log from GR Log



VSH= (GR - GRmin)/ (GRmax – GRmin)

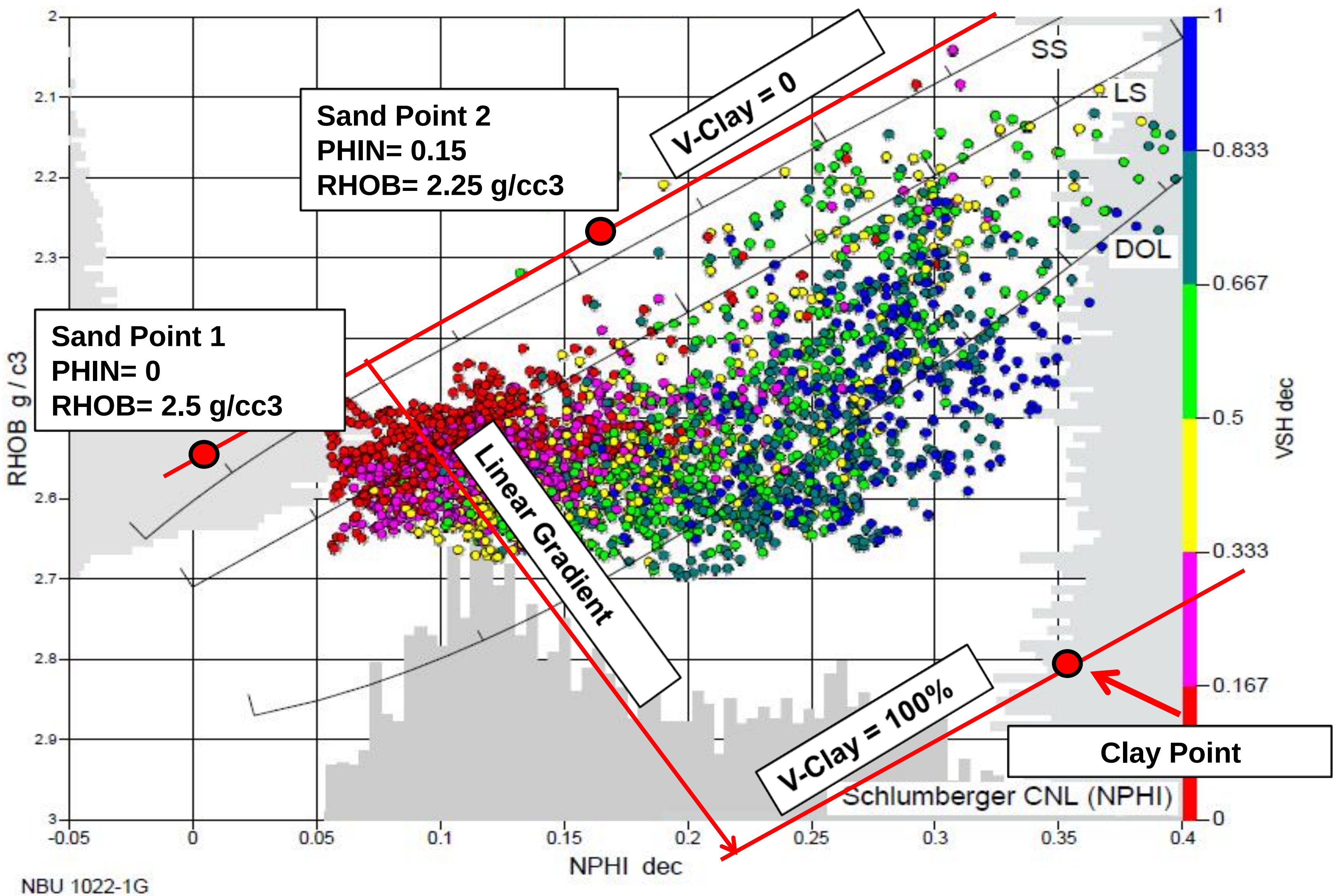
GR= GR reading at any point on the log

GRmin= GR value on the most clean matrix

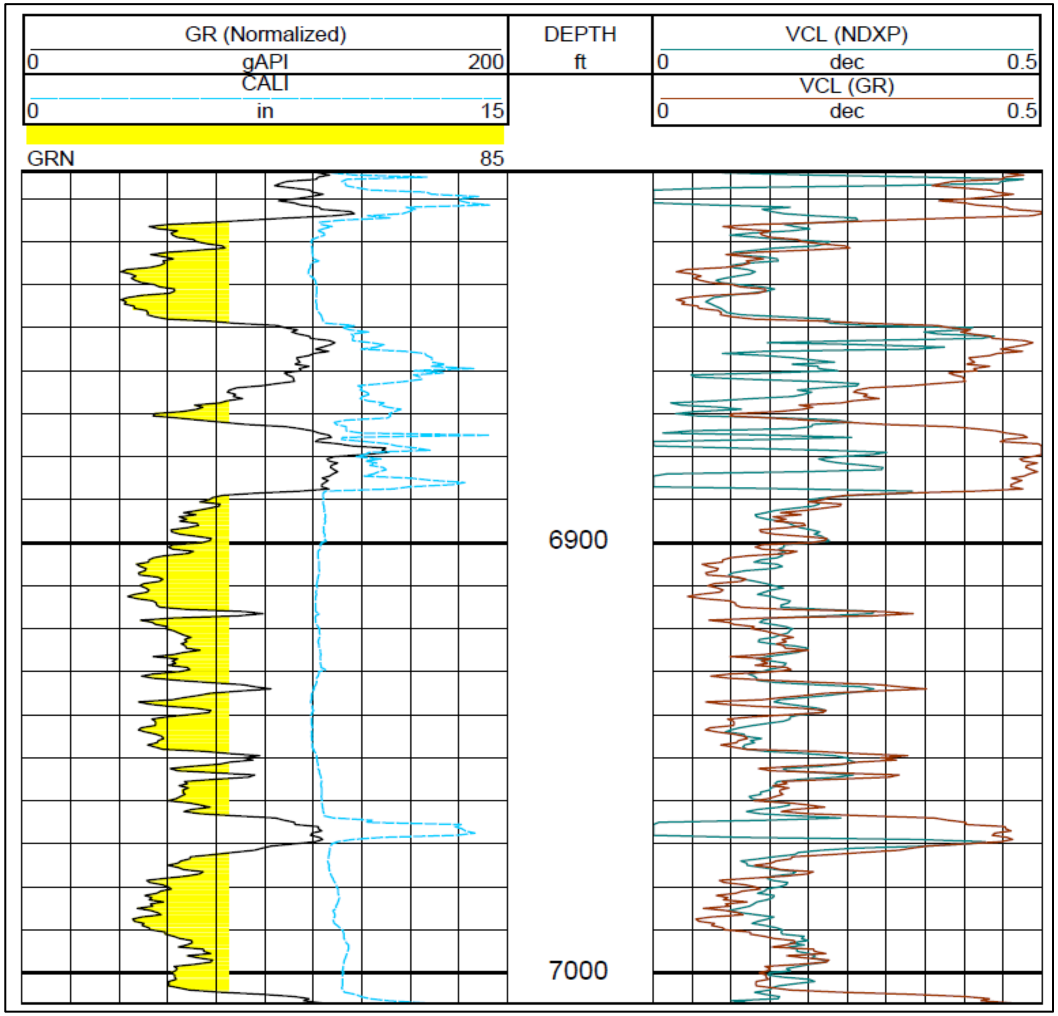
GRmax= GR value on the 100% shaly zone

GRmin= 40 gAPI **GRmax= 135 gAPI**

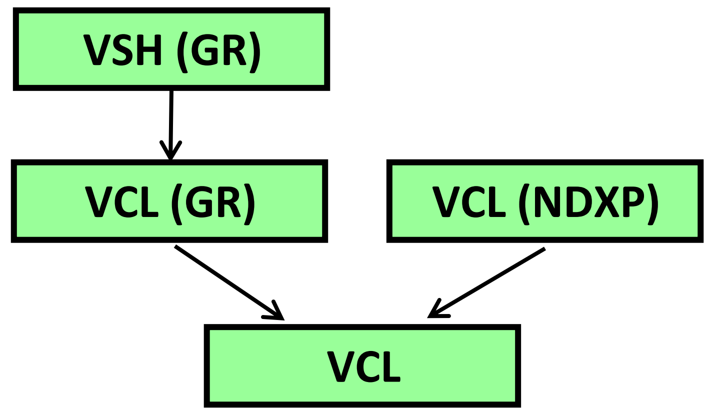
VCL from Neutron-Density Crossplot



Final VCL Curve

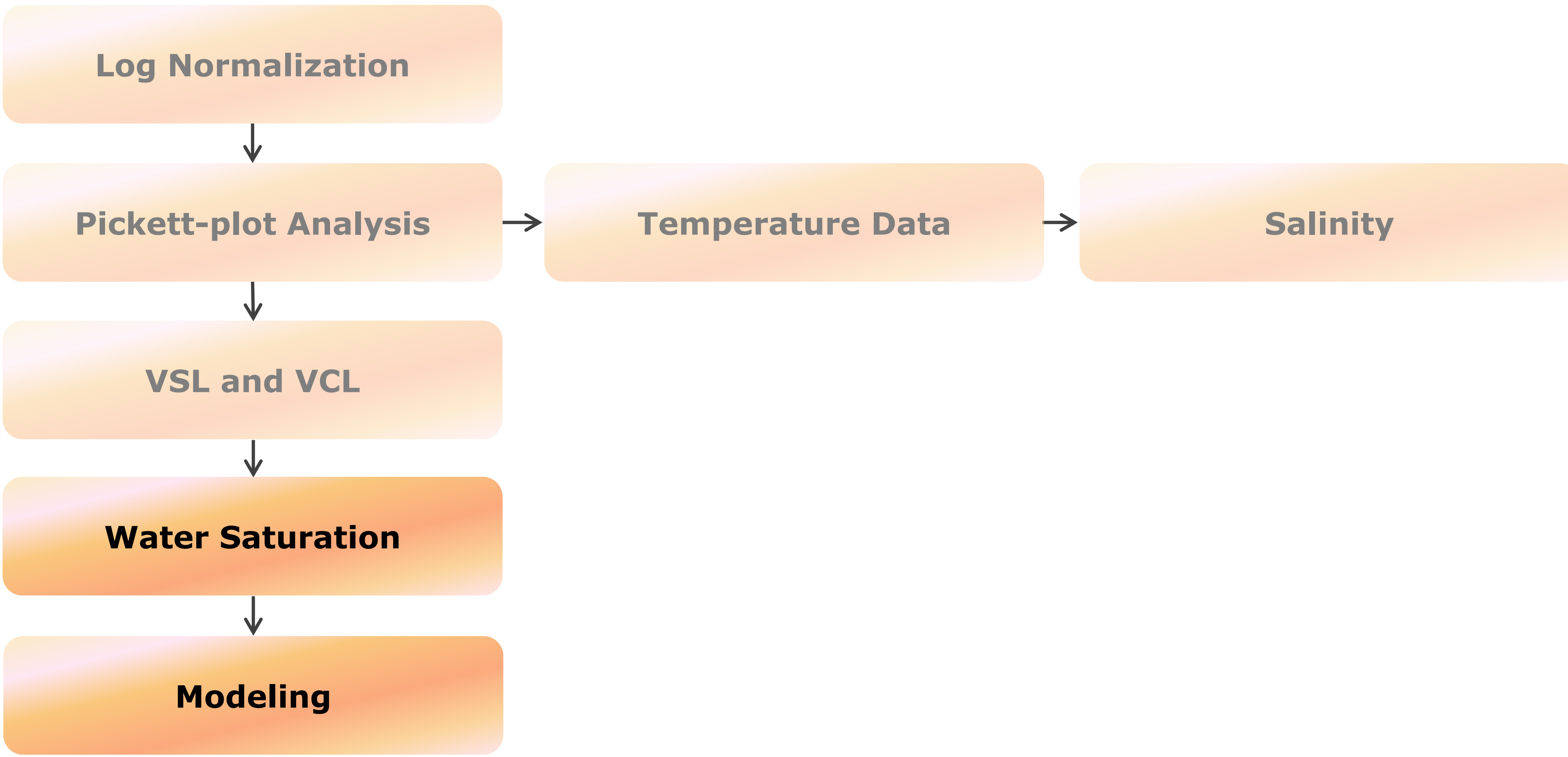


- Both VSH curve from GR and Neutron-Density crossplot (NDXP) were used to obtain the final VCL curve.



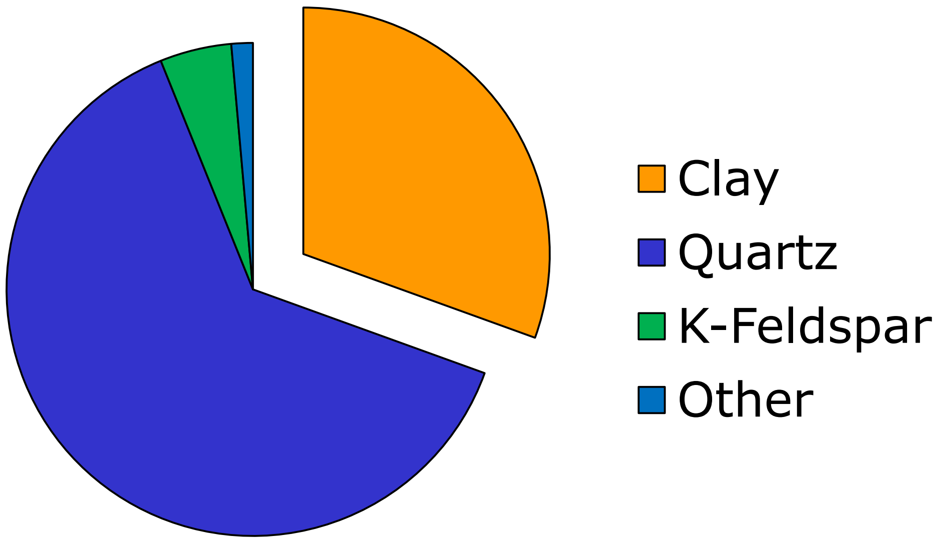
VCL = min (VCLGR, VCLND)

Petrophysical Workflow



Water Saturation Calculations

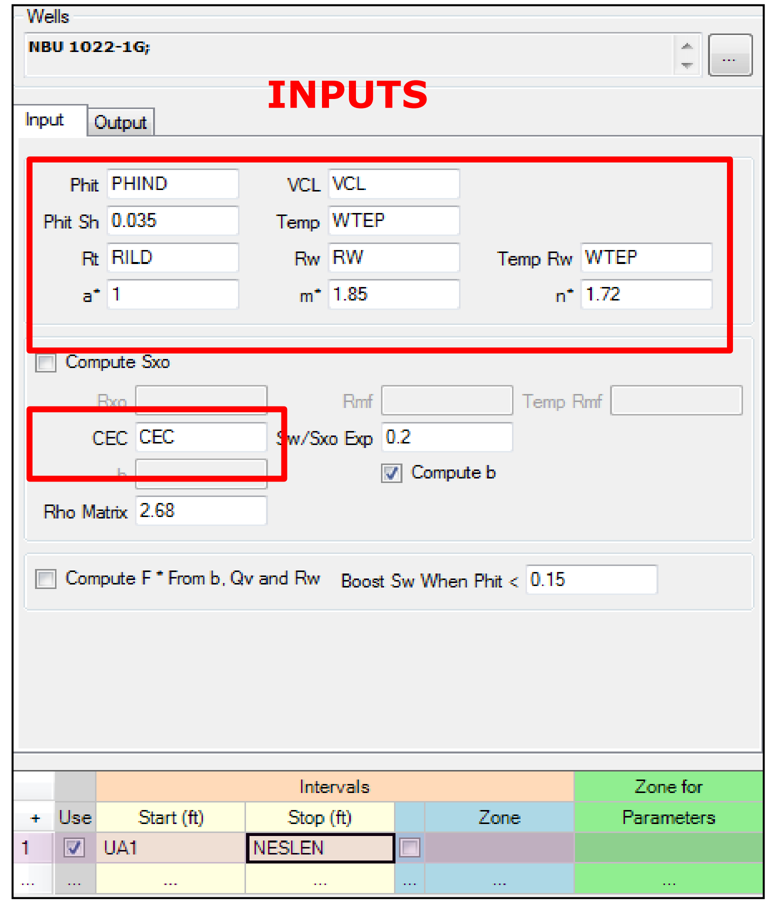
XRD Data



(Courtesy of Anadarko Petr. Corp.)

$$\uparrow Sw = \left[\left(\frac{a}{\phi^m}\right)\left(\frac{R_w}{R_t \downarrow}\right)\right]^{1/n}$$

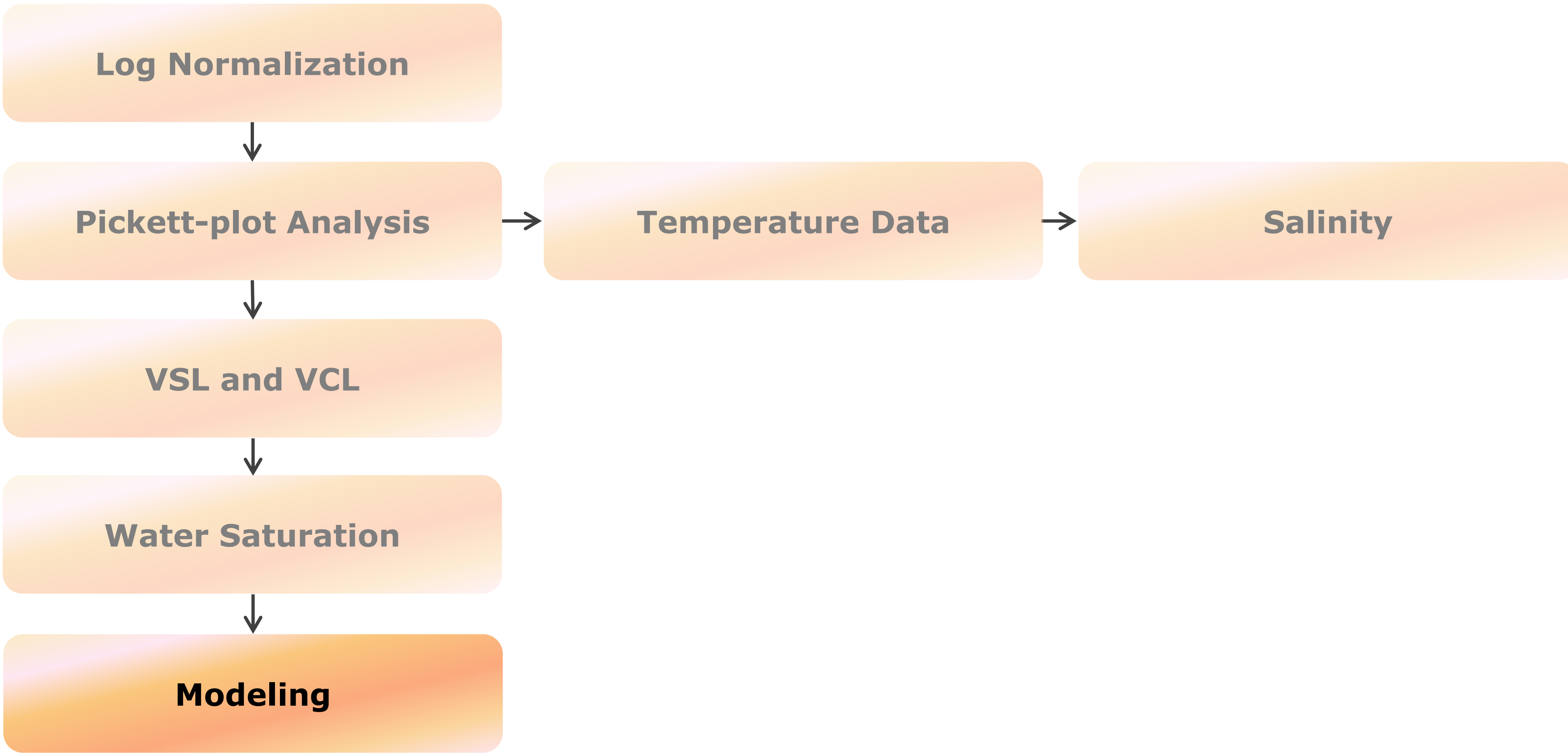
(Archie, 1942)



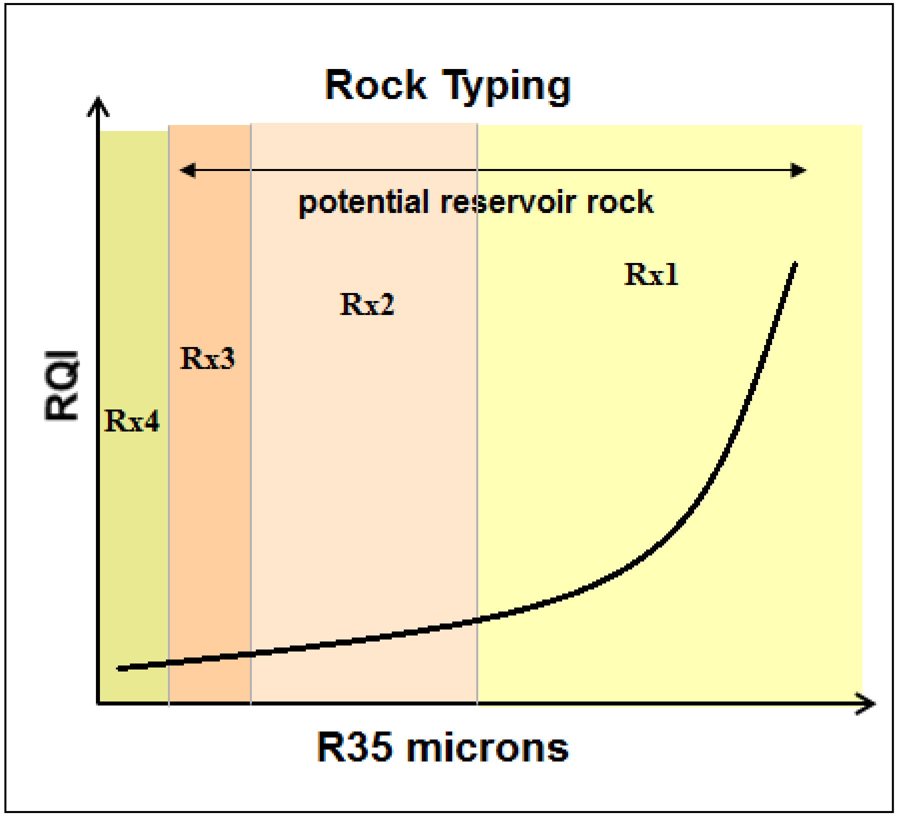
Waxman-Smiths (1968)

CEC is estimated from the VSH curve.

Petrophysical Workflow



Petrophysical Rock Types



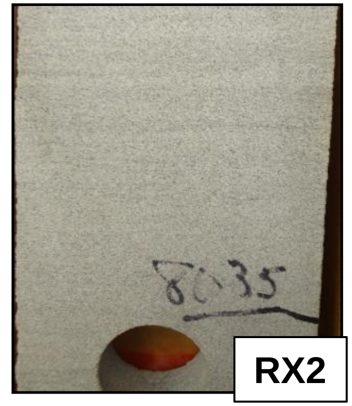
(Courtesy of Anadarko Petr. Corp.)

- Petrophysical rock types were divided into five category.
- Rock typing is based on pore throat radius measurements and rock quality index

RQI→ porosity/ permeability relationship

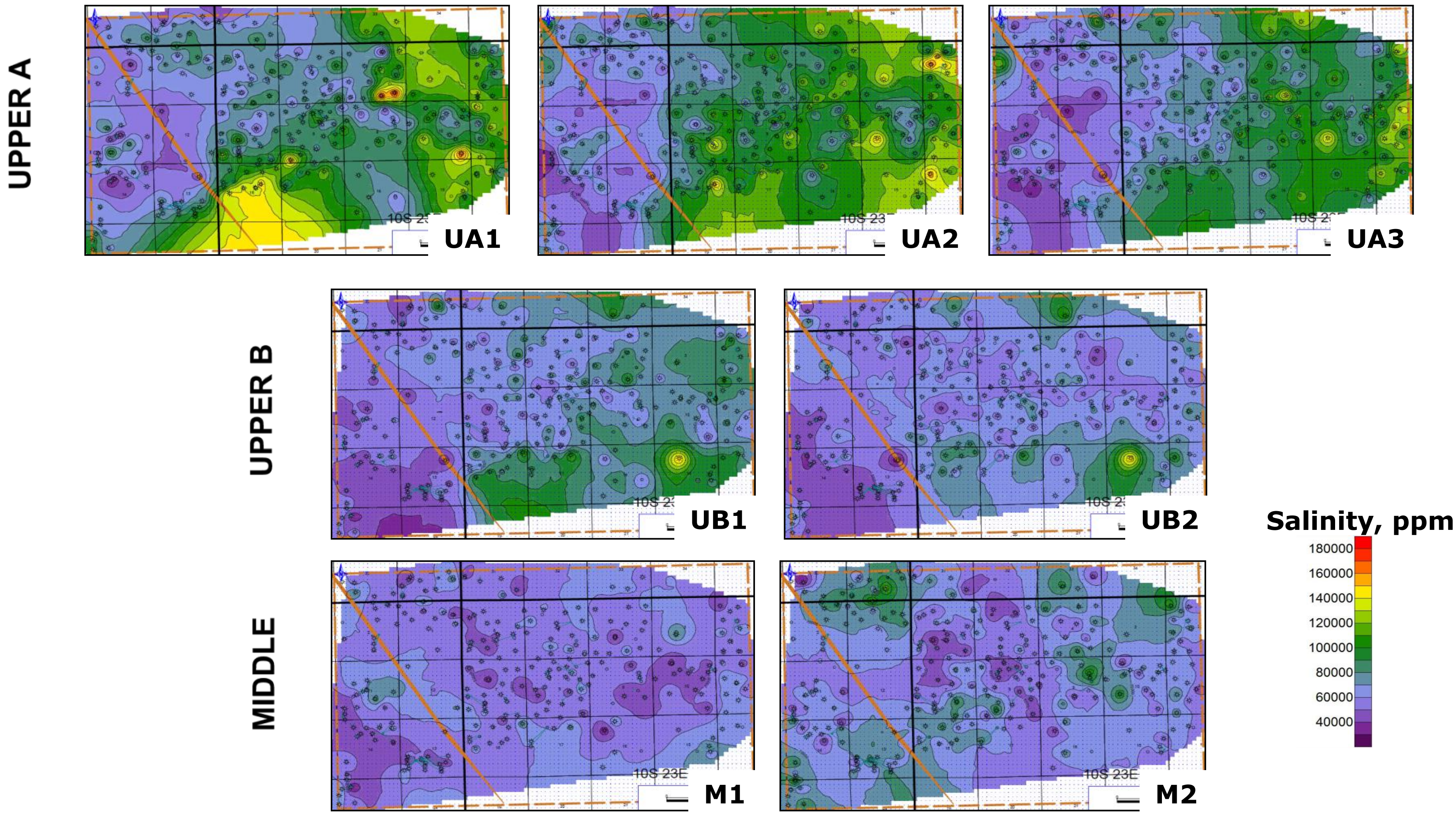
Petrophysical Rock Types

	Examples
RX1	Structureless sandstone, cross-bedded sandstone
RX2	Planar-laminated sandstone
RX3	Ripple cross-bedded sandstone, mottled sandstone
RX4	Mudstone
RX5	Mudstone, Coal (rarely)

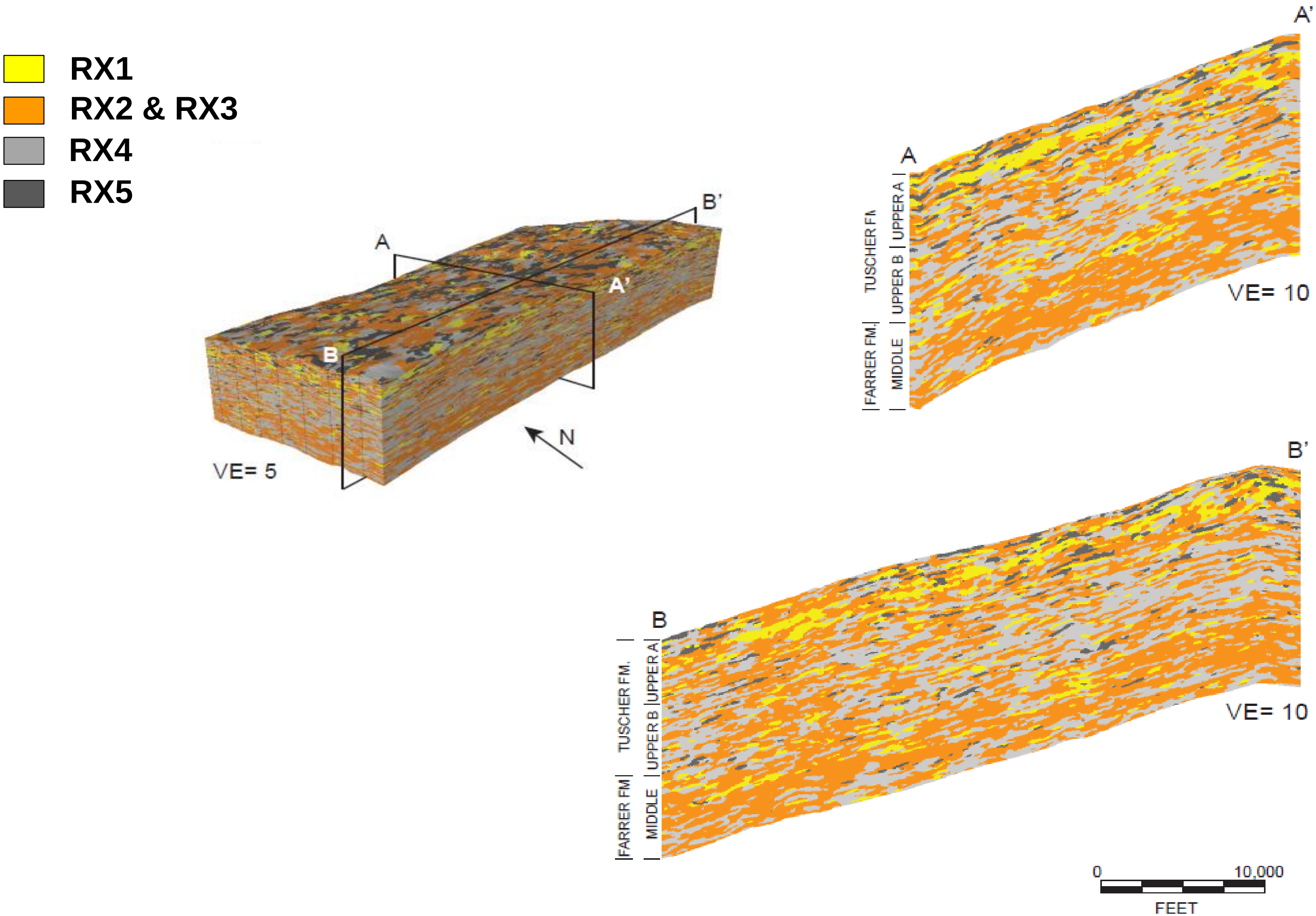


Results: Average Salinity Distribution

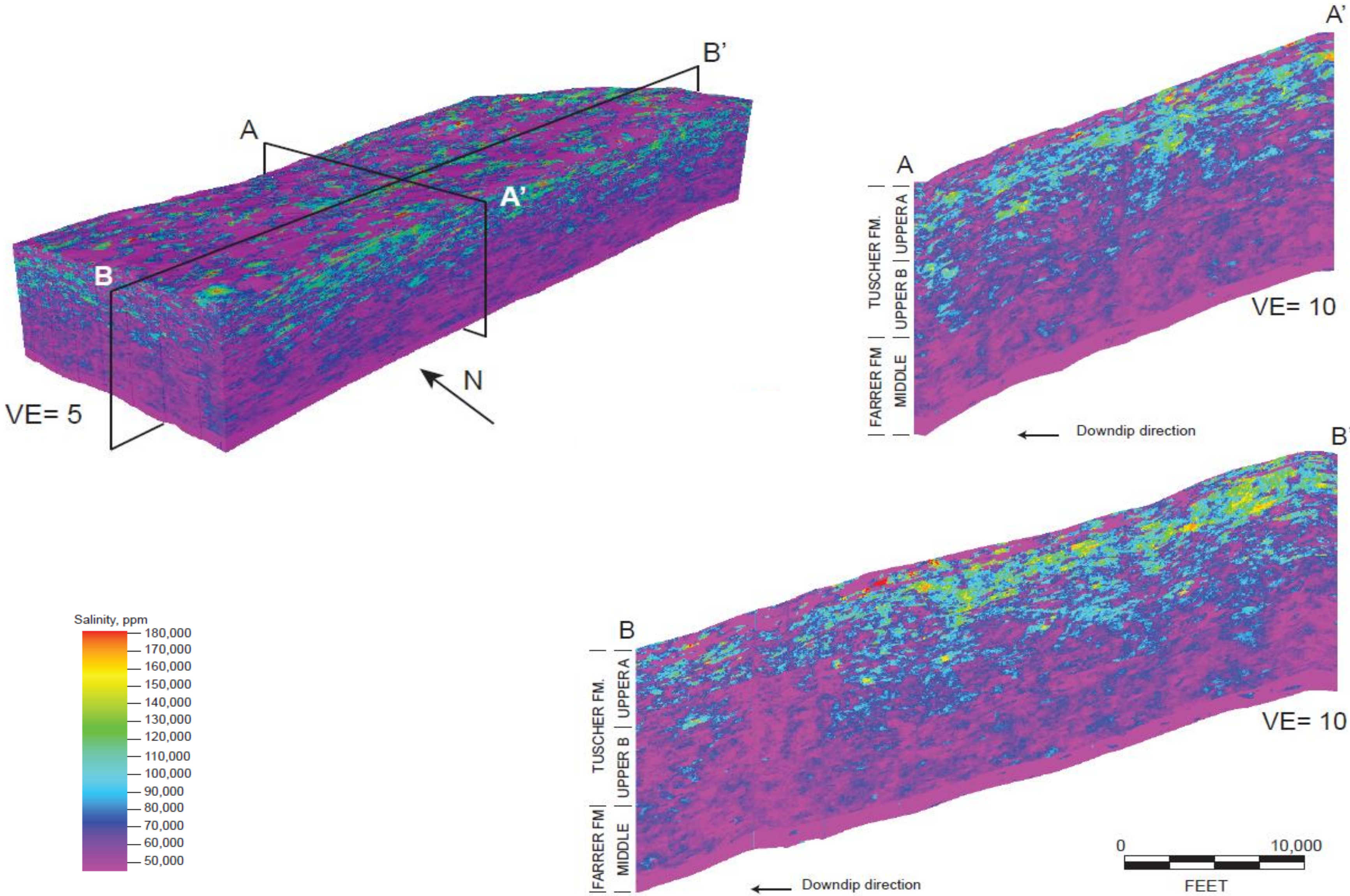
Between 55,200 - 86,350 ppm



Petrophysical Rock Type Distribution

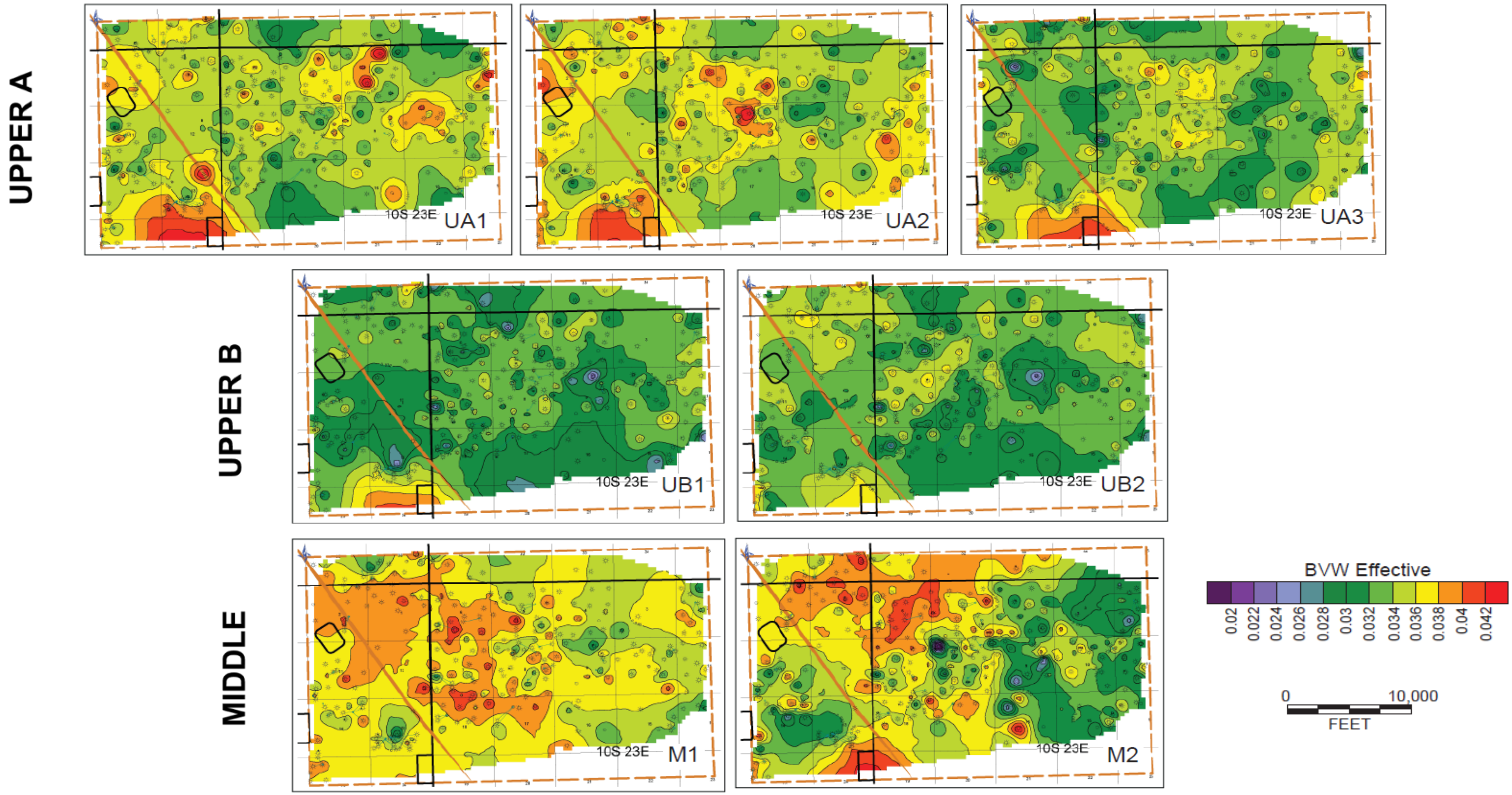


Vertical Salinity Profile



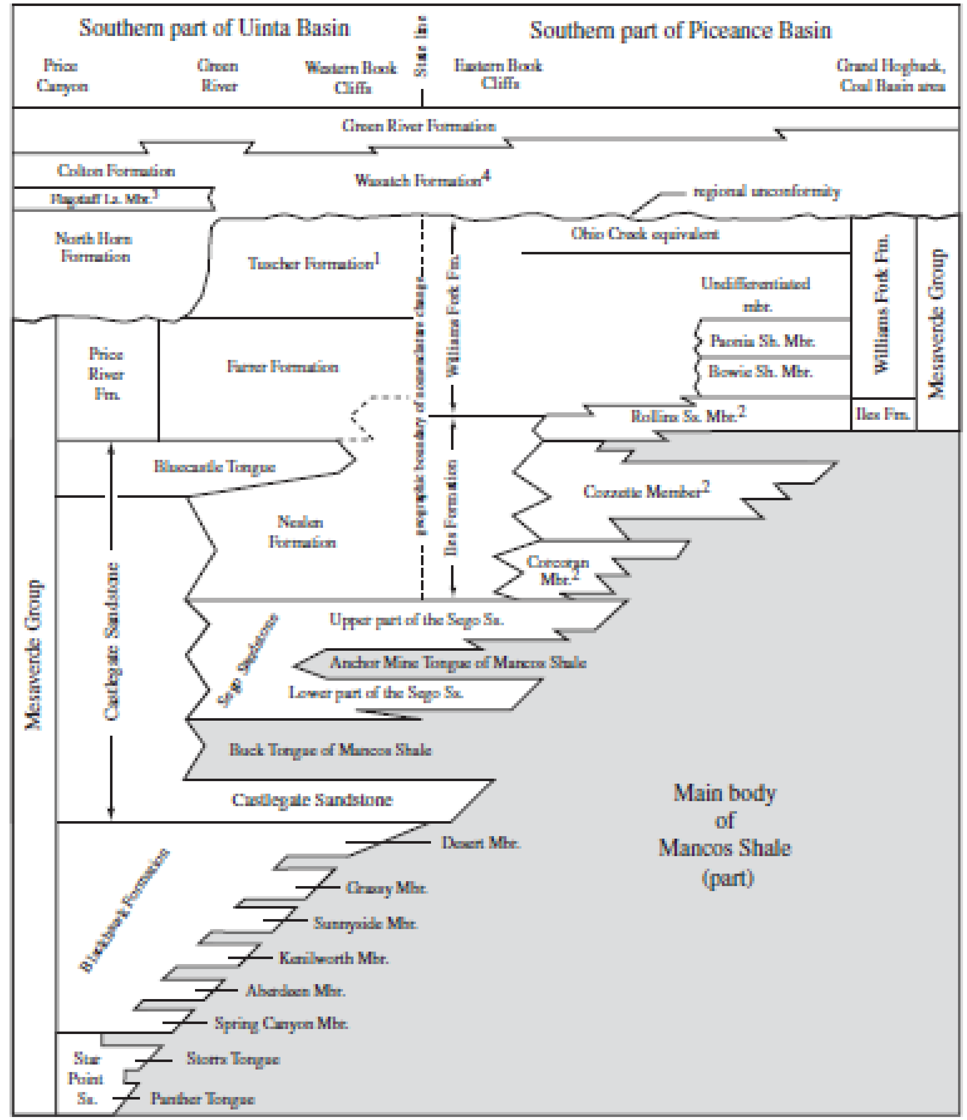
Average Bulk-volume Water

Between 0.032 and 0.037



Combination of Different Geological Mechanisms

- Sediment and coal dewatering; water expulsion from the Mancos Shale
- Castlegate Sandstone is leaky along the basement fault, and has a connection with meteoric water, causing the upward movement of fresher formation water.
- Evaporites in Green River Formation, their connection with meteoric water



(Hettinger and Kirschbaum, 2003)

Conclusions

- Petrophysical analysis indicates more fresh water is present in the western part of the study area, while salinity increases stratigraphically upward.
- The average formation water salinity ranges between 55,200 ppm to 86,350 ppm based on a log-derived methodology.
- A combination of multiple mechanisms; basement faulting, coal and sediment dewatering, and rock type distribution might have an effect upon salinity trends in the area.

Acknowledgements

TURKISH PETROLEUM

University of Colorado Boulder

Anadarko

RCML

Reservoir Characterization and Modeling Laboratory

Now at University of Oklahoma

Williams Fork Consortium (Phase VI) Sponsors

James Miller– Anadarko Petroleum Corporation, Denver, CO

Rex D. Cole– Colorado Mesa University, Grand Junction, CO

David A. Sawyer– USGS, Denver, CO

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