Predicting Initial Production of Granite Wash Horizontal Wells Using Old Well Logs and Cores

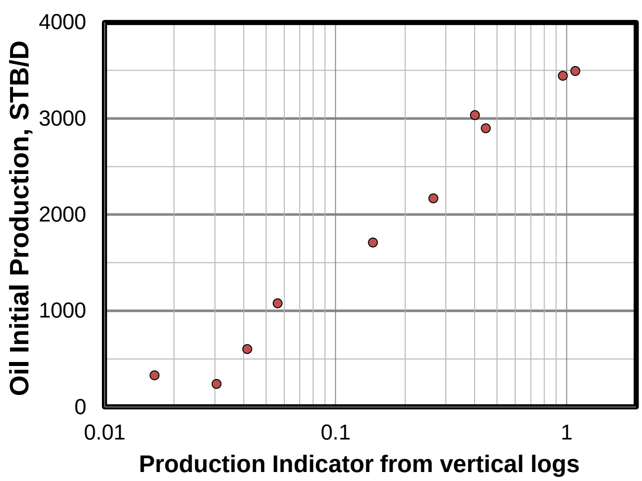
13 November 2014

Granite Wash Workshop

Sponsored by the Oklahoma Geological Survey

LINN Energy NASDAQ:LINE

Strong correlation, eh?



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Method and Outline for Talk

- Determine production contribution log (IP FOM)
  - Based on volumetrics and permeability
  - Petrophysics and Log Analysis Steps
- Sum over a reservoir interval and upscale to reservoir-scale permeability derived from well production data (PI parameter)
- Use PI to predict initial production of potential horizontal wells
  - Generate maps of PI parameter
  - Compare to production data

Note: more slides are included here than will be covered in the talk.

Twelve-Step Granite Wash Log Analysis

Groundwork

1. Geology discussions
2. Core & cuttings study
3. Log triage and repair
4. GR & neutron environmental corrections
5. Facies analysis

Calculations

6. VShale
7. Total & effective porosity
8. Saturation
9. Permeability & production
10. Flagging
11. Summations
12. Fraccability

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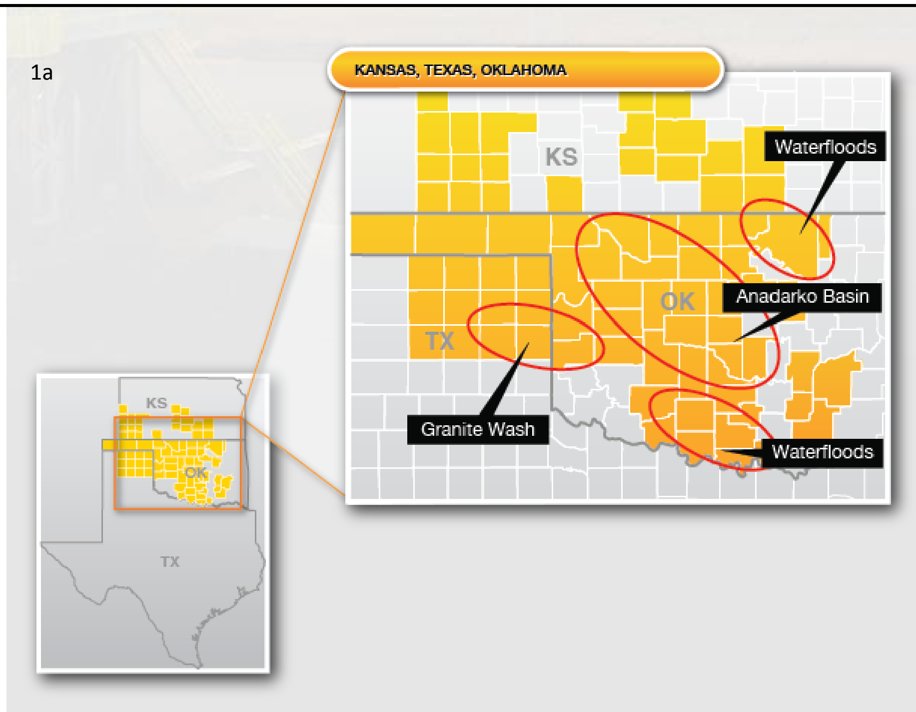
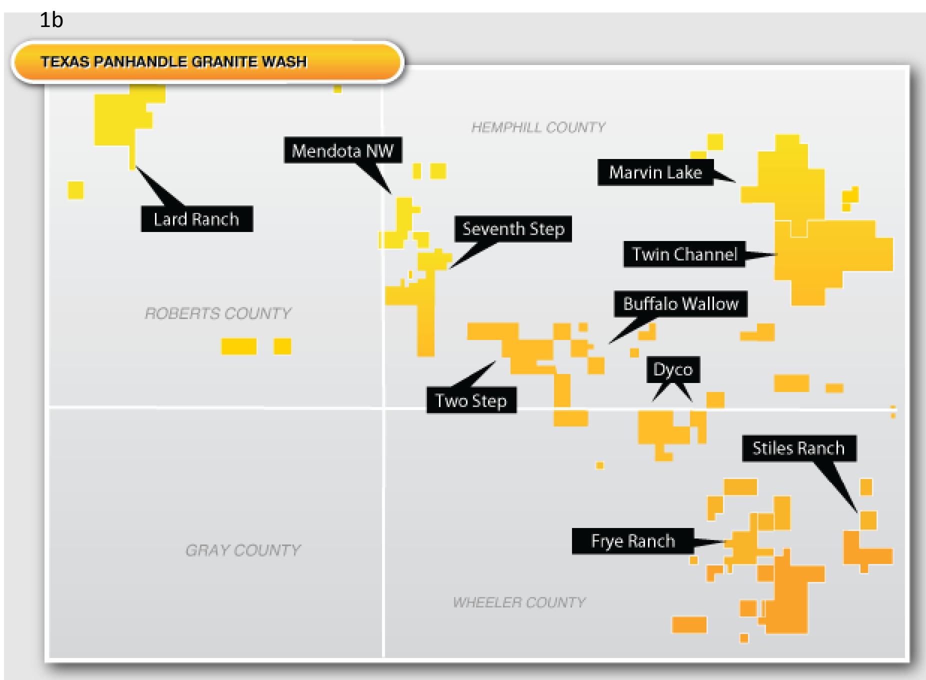
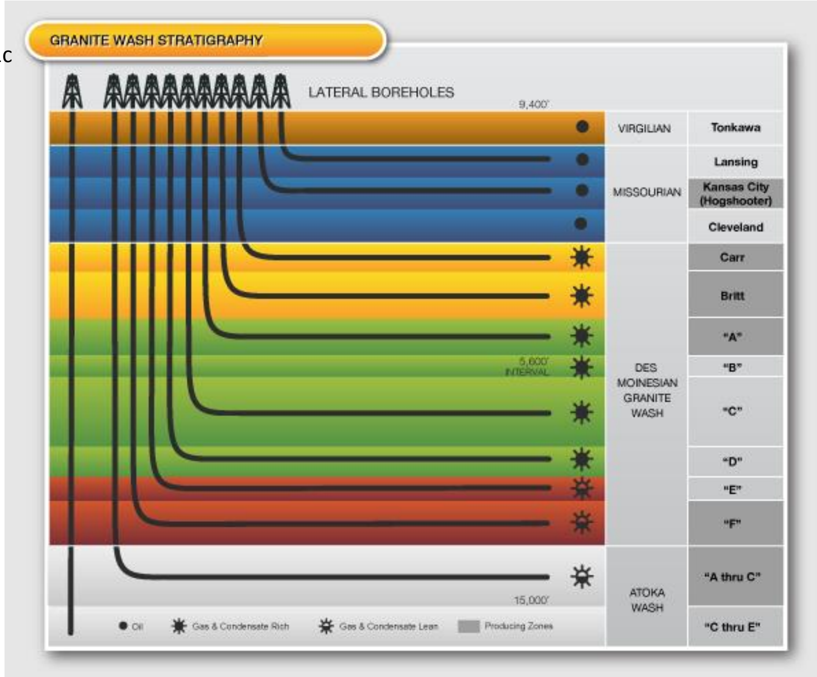
1a


KANSAS, TEXAS, OKLAHOMA
KS
OK
TX
Waterfloods
Anadarko Basin
Granite Wash
Waterfloods

1b


TEXAS PANHANDLE GRANITE WASH
HEMPHILL COUNTY
Mendota NW
Marvin Lake
Lard Ranch
Seventh Step
Twin Channel
ROBERTS COUNTY
Buffalo Wallow
Dyco
Two Step
Stiles Ranch
Frye Ranch
GRAY COUNTY
WHEELER COUNTY

1c



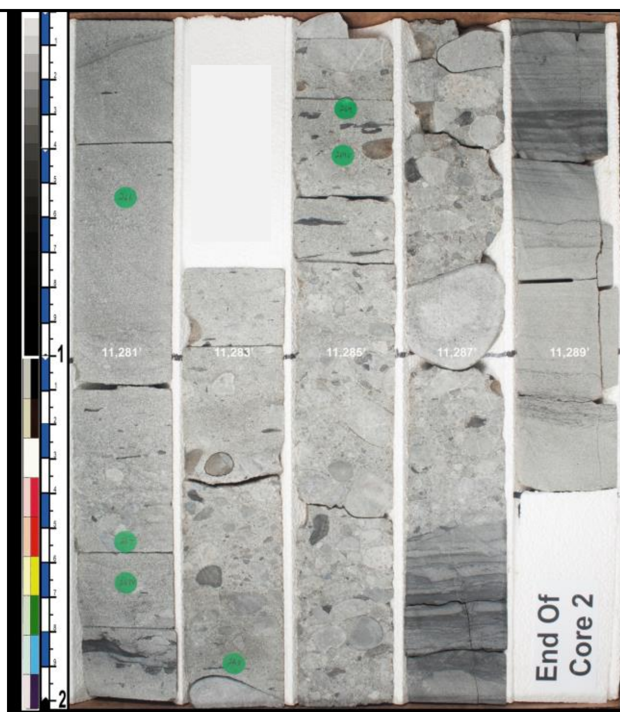
1d) Tx panhandle granite wash characteristics

- Source material is mostly uplifted Paleozoic sediments & carbonate, plus Precambrian granite, diabase, and granodiorite. There are a few thin beds of limestone and shale interspersed. Composition varies widely.
- The depositional environment is primarily stacked deltas, river channels, and turbidites. Paleoslopes range from steep to quiescent. There are many beds that contain re-worked material.
- Feldspar content, grain size, and alteration vary widely and wildly, vertically and areally. Chorite is ubiquitous.
- Reservoirs are often separated by 10-30 ft thick marine and terrestrial shales and flooding deposits.

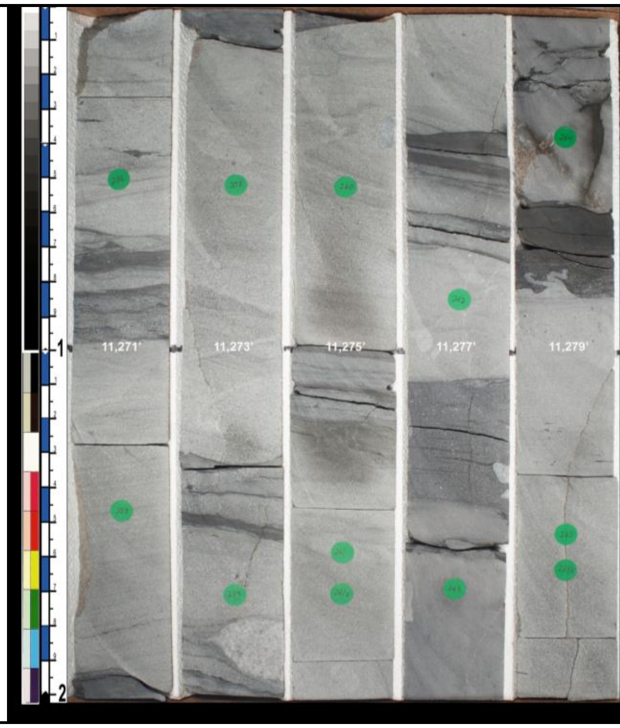
1e) Tx panhandle granite wash exploitation

- There are about 100,000 vertical wells through the granite wash; many reach below to the Morrow and other horizons.
- Perms of present-day reservoirs are typically near 500 nd.
- Two or three 5000-ft laterals are typically drilled per section in one horizon. There are often stacked laterals.
- Slickwater fracs appear to be the most effective.
- Fraccing severely “bashes” adjacent producing wells where pressures have been lowered.
- Prospecting is done by sifting through production data and old logs.
- Recently there has been some drilling of “pilot” holes, or vertical holes before the turn, with coring and logging.

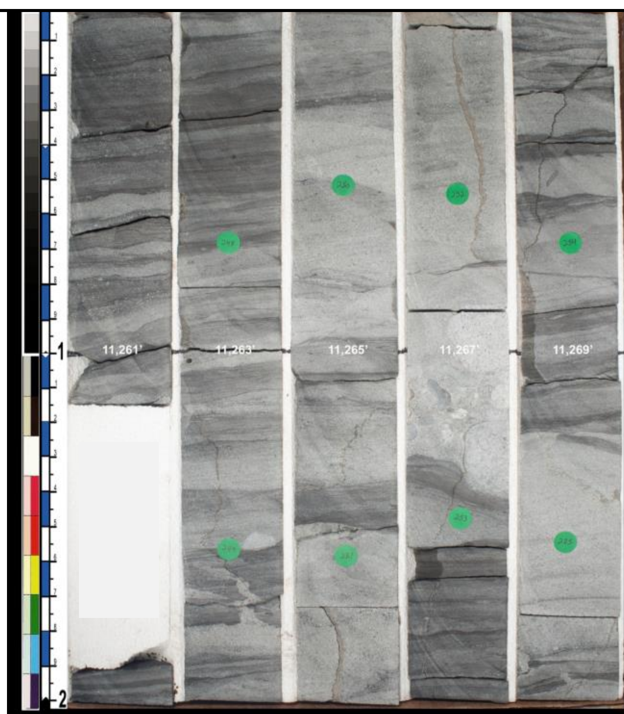
1g) box 12



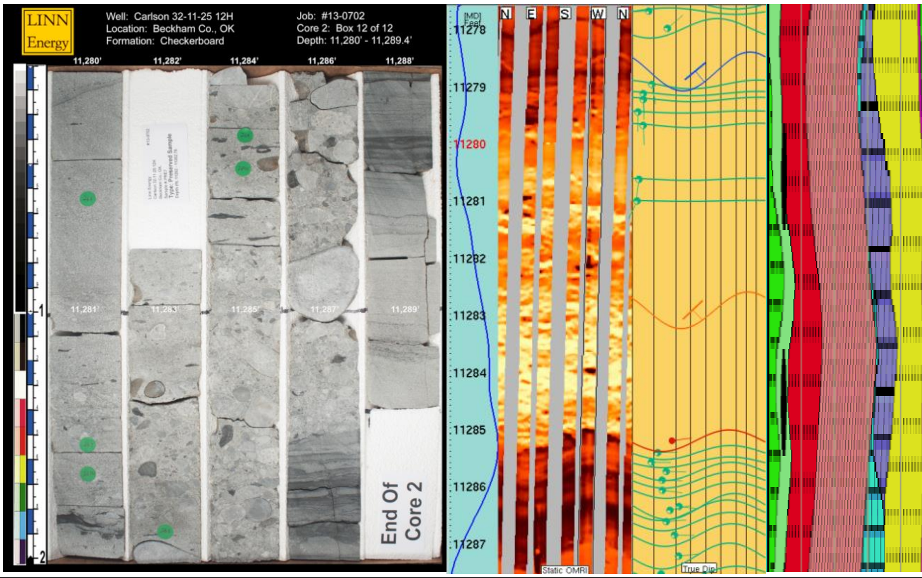
1f) box 11



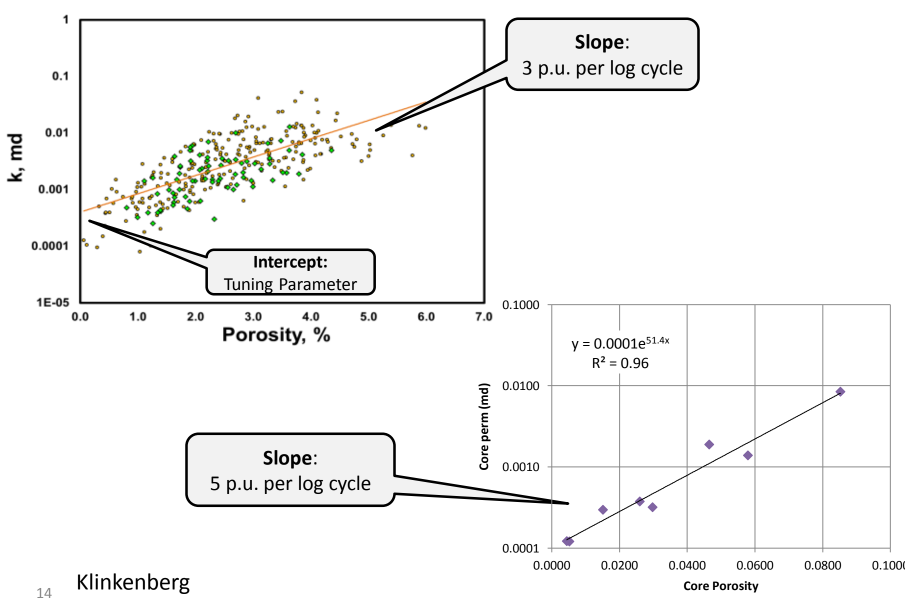
1h) box 10



1i) core and hi-res log

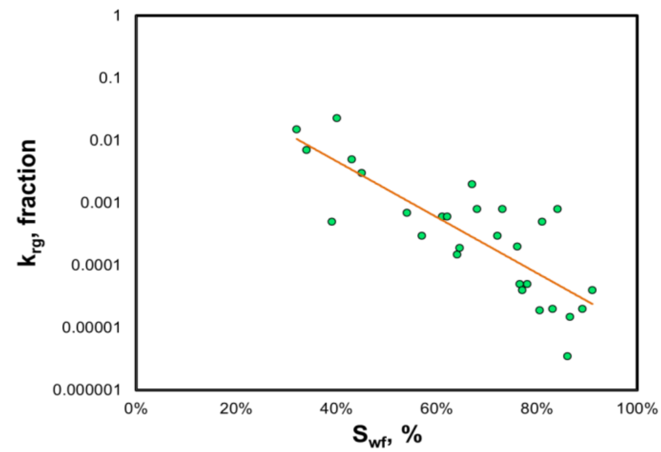


2a) Core permeability vs porosity



14 Klinkenberg

2b) More core permeability



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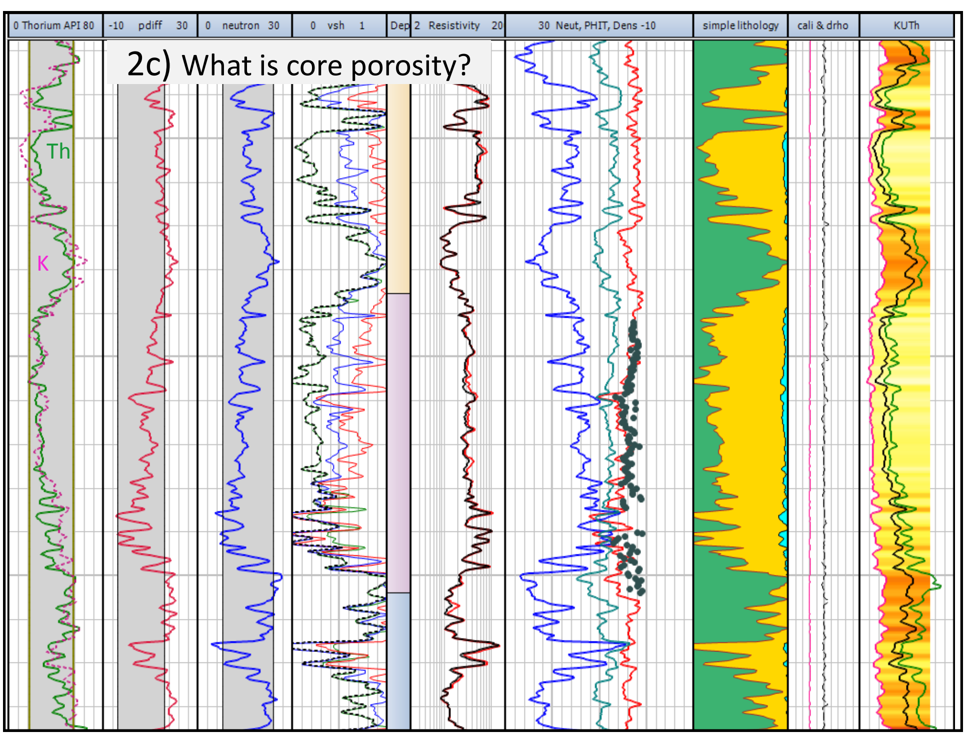
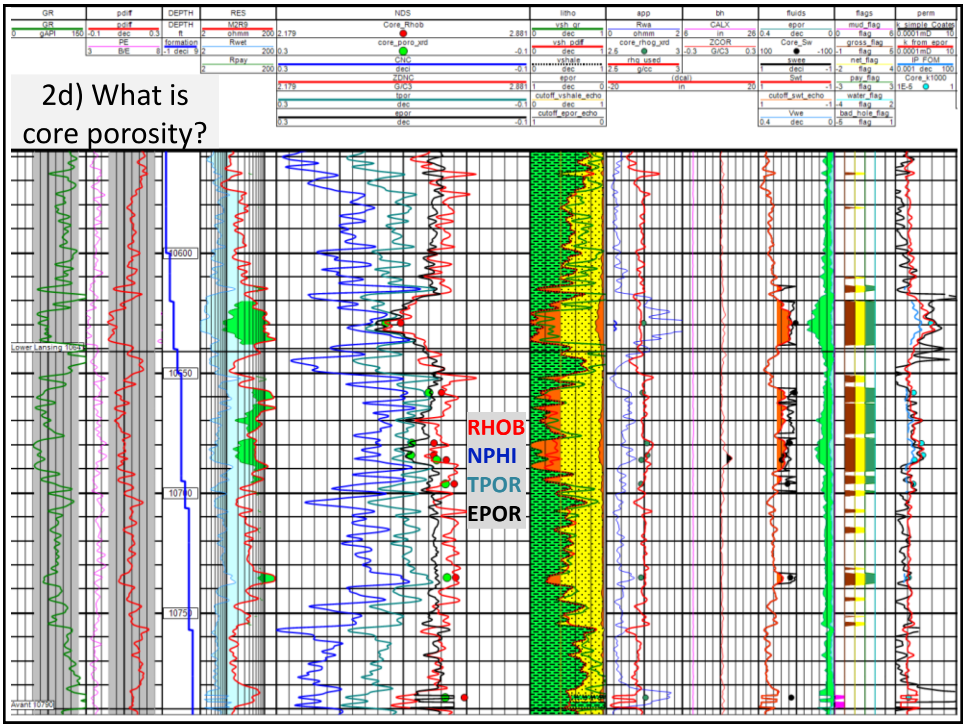
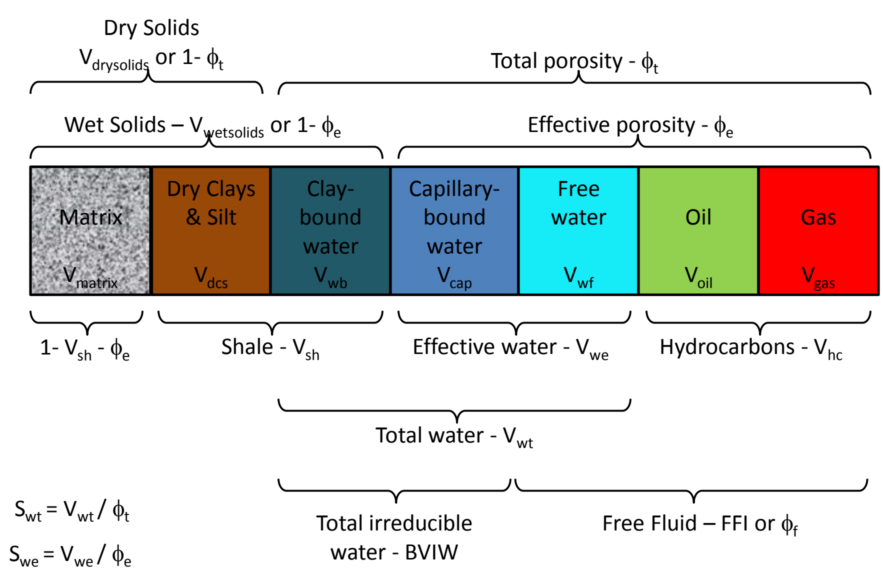
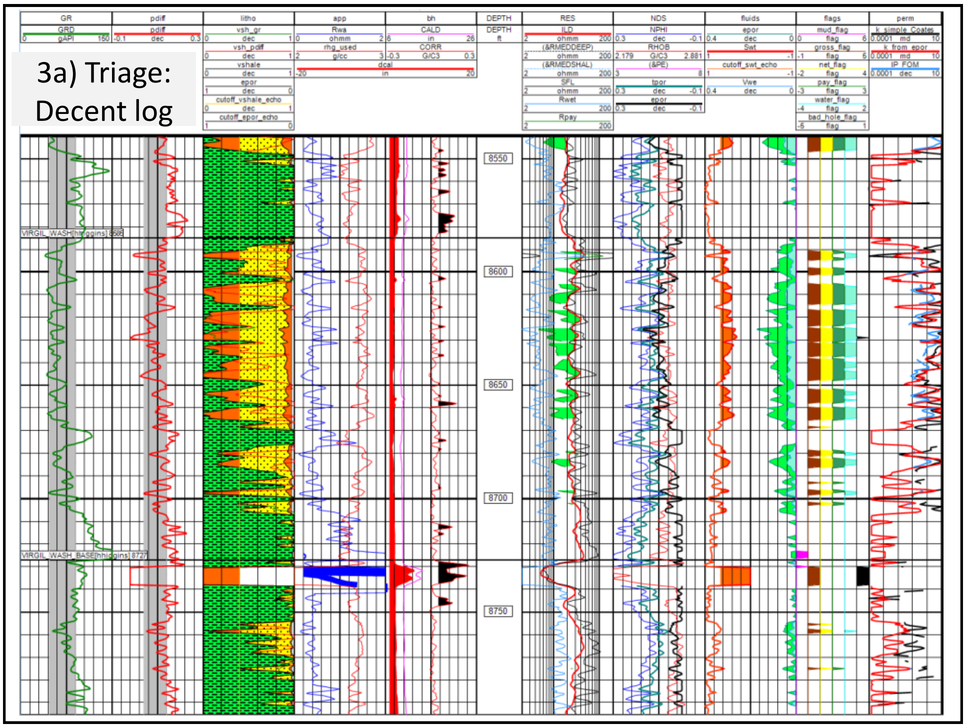


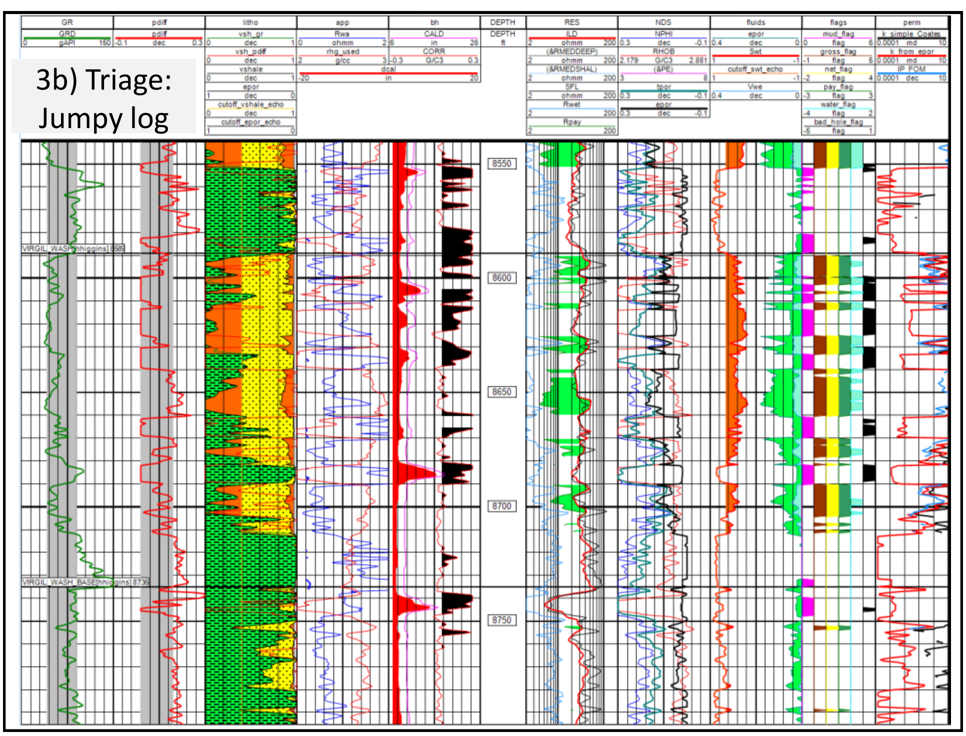
2d) What is core porosity?



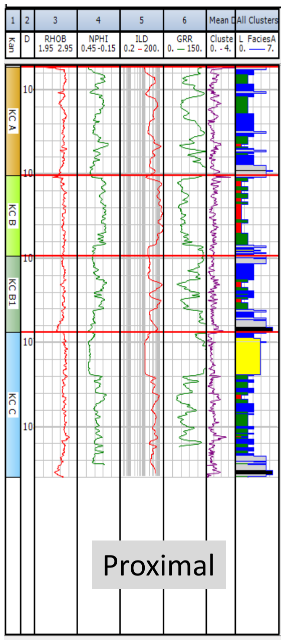
2e) Volume fractions of a formation

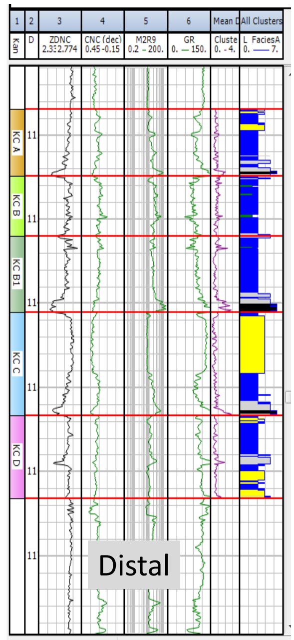



3a) Triage:
Decent log
8550
8600
8650
8700
8750


3b) Triage:
Jumpy log
8550
8600
8650
8700
8750

4e) Log Facies based on six wells





- Use Buckles plot to assess irreducible water for log facies
- Include results in Tixier or Coates perm calculations

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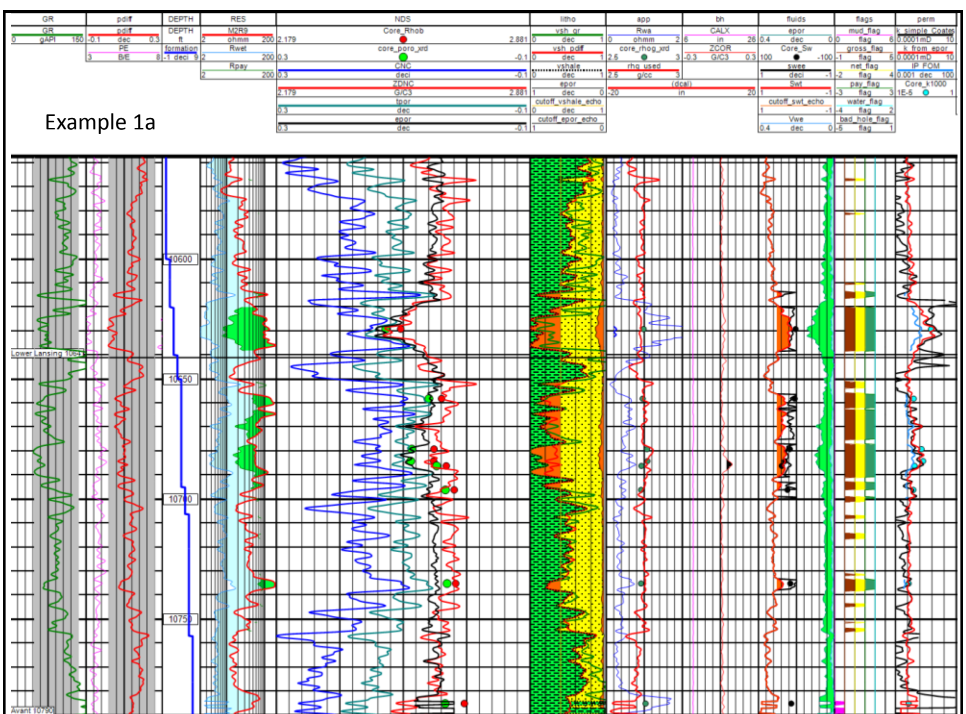
9) Definitions

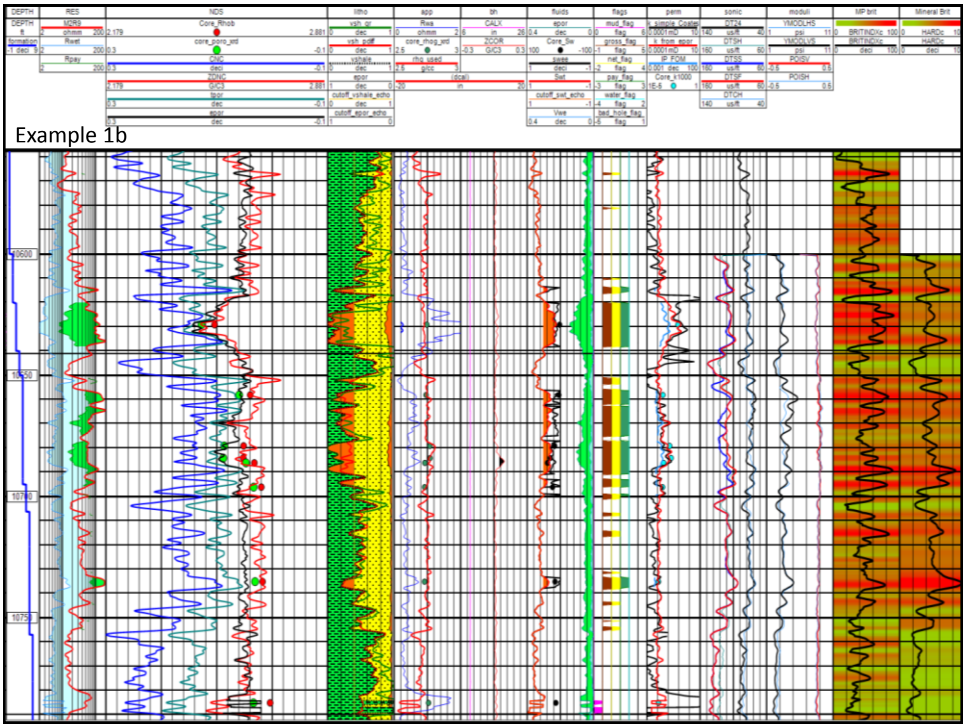
Log curve

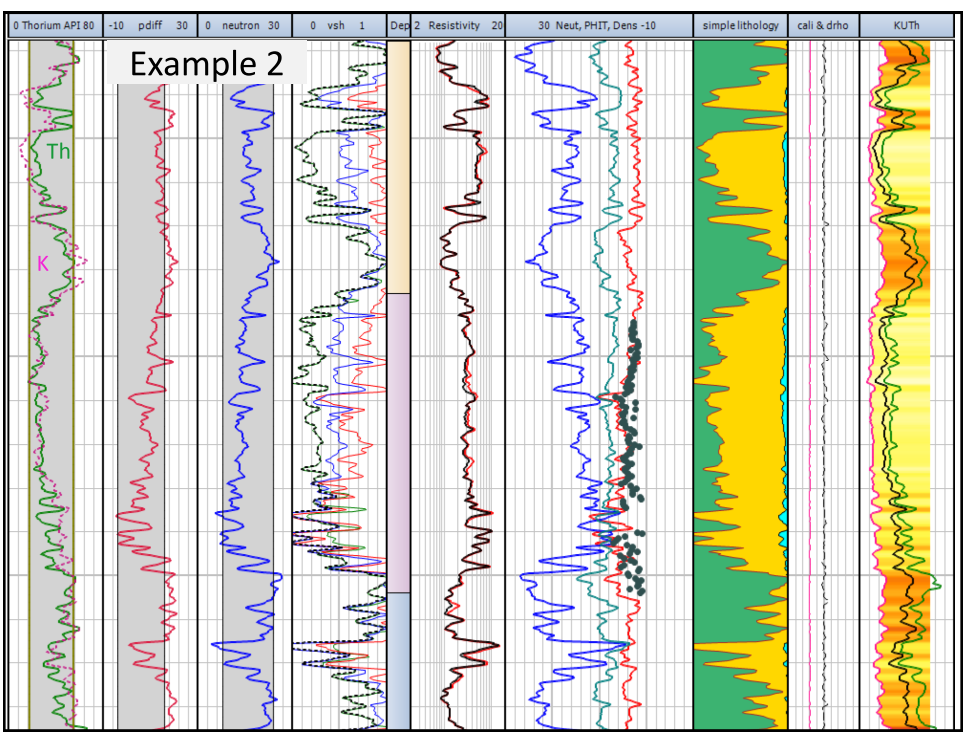
$$\text{IP FOM} = \sqrt{k_r \phi S_h}$$

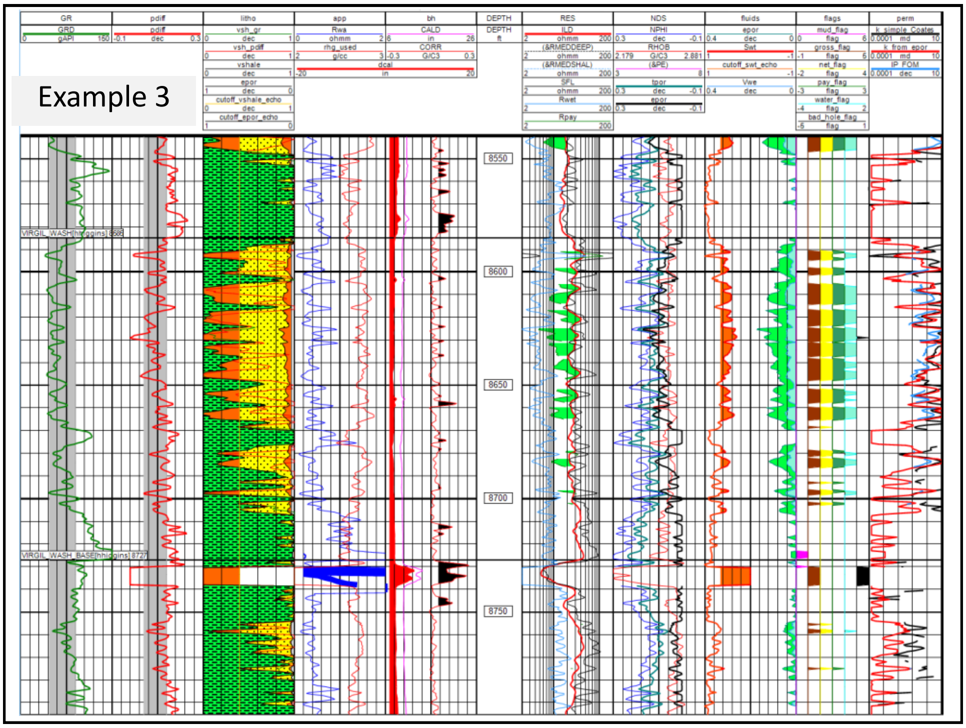
Log summation across interval

$$PI_{Indicator} \equiv \sum h_i \sqrt{k_r \phi S_h}$$

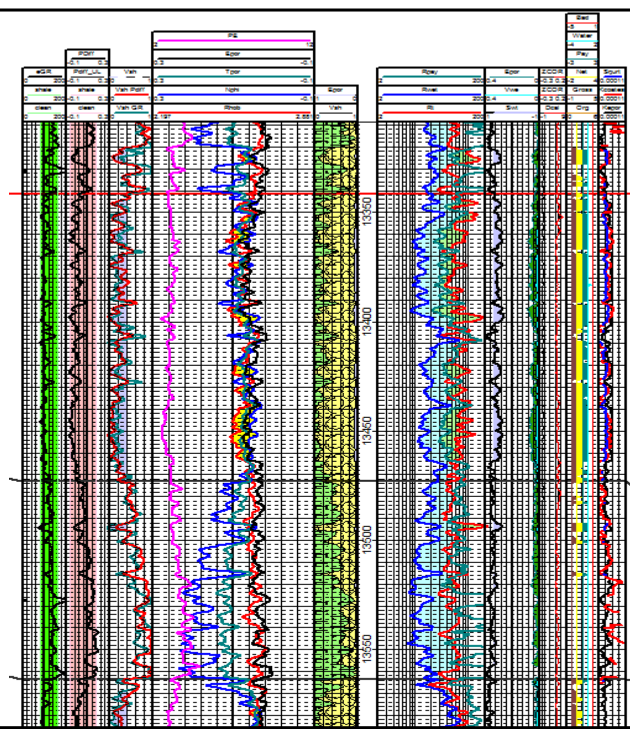



Example 1b


0 Thorium API 80
-10 pdiff 30
0 neutron 30
0 vsh 1
Dep
2 Resistivity 20
30 Neut, PHIT, Dens -10
simple lithology
cali & drho
KUTh
Example 2
Th
K



Example 3



Example 4
(sorry about the
poor resolution)

Reservoir Accounting

1. The initial production rates of a horizontal well in linear flow will be driven primarily by a lumped parameter J_{lt}, which is dependent on both rock quality (perm – k) and stimulation effectiveness (total frac surface area A_f), and pressure drawdown imposed on the well.
2. For comparing wells of similar initial reservoir pressures we can skip normalizing the initial formation volume factor B_i, initial viscosity μ_i, and approximate initial total compressibility c_{ti} using hydrocarbon saturation S_h. The permeability k_r is effective to primary hydrocarbon phase.
3. The flow rate of each flow unit (i) will be proportional to the net pay h, the fracture half-length propagated in each unit x_f, and its flow capacity. Fracture design related variations in x_f can be modeled as needed, for simplicity assume rectangular geometry – equal in all units.
4. Early life total flow rate in in tight reservoirs is the sum of the individual flow units; ignore crossflow. The total well rate is the sum of the net pay and flow capacity of each flow unit. For simplicity, the flow units can be the log sampling interval ½ feet intervals.
5. The productivity index indicator is defined and in LINE's experience is correlated to well performance; and can be used as a rock quality index.
6. The upscaled* values of permeability can be calculated from the PI indicator for the tuning to well production results.

$$Q_{IP} \propto J_{lt}\Delta P \qquad ❶$$

$$J_{lt} \propto A_f \sqrt{k_r \phi c_{ti}} \frac{1}{\sqrt{\mu_i B_i}} \qquad ❷$$

$$q_i \propto x_{fi} h_i \sqrt{k_r \phi S_h} \qquad ❸$$

$$q_T \propto \sum h_i \sqrt{k_r \phi S_h} \qquad ❹$$

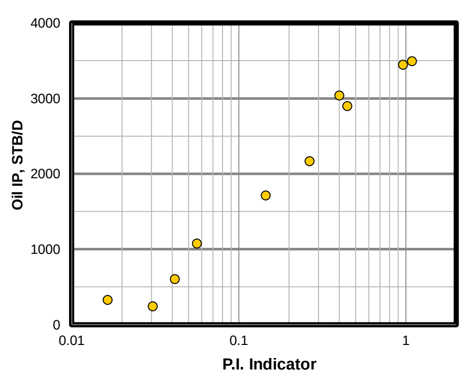
$$PI_{Indicator} \equiv \sum h_i \sqrt{k_r \phi S_h} \qquad ❺$$

$$k^* = \frac{1}{\phi^* S_h^*} \left(\frac{PI_{indicator}}{h} \right)^2 \qquad ❻$$

Review SPE 139097, 166468, and 166468 for theory and methods to normalize pressure drawdown, and completion practices.

SPE 139097, 162843, 166468

Lookback – Hz. Kansas City Oil Program



- The Kansas City is a matrix-flow dominated prolific reservoir in the Granite Wash play in Wheeler TX.
- Identical completion practices and pressure drawdown was used in Linn operated wells.
- Clear correlation between highest oil production rates seen in these hz. wells compared to log-calculated productivity index.

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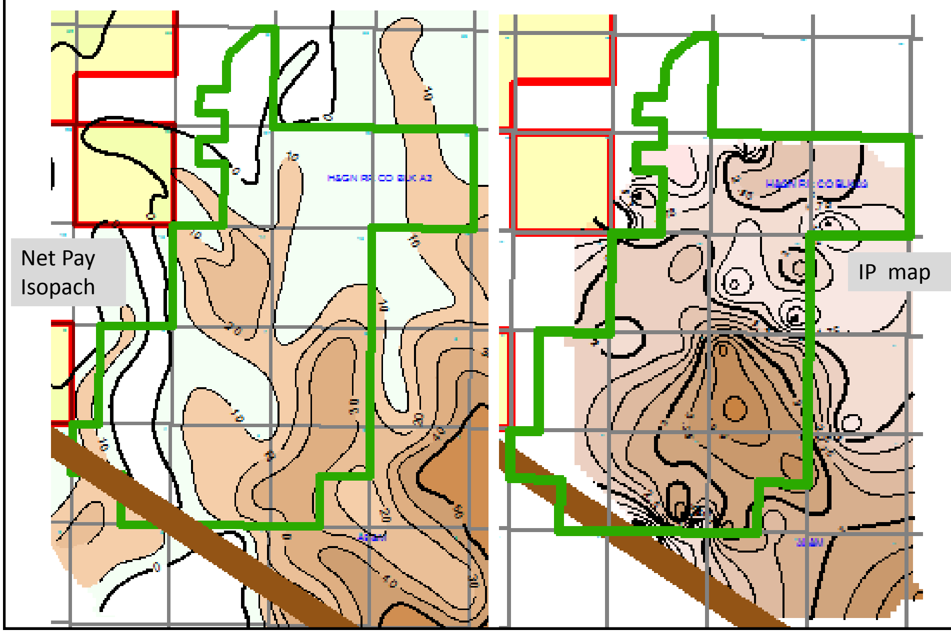
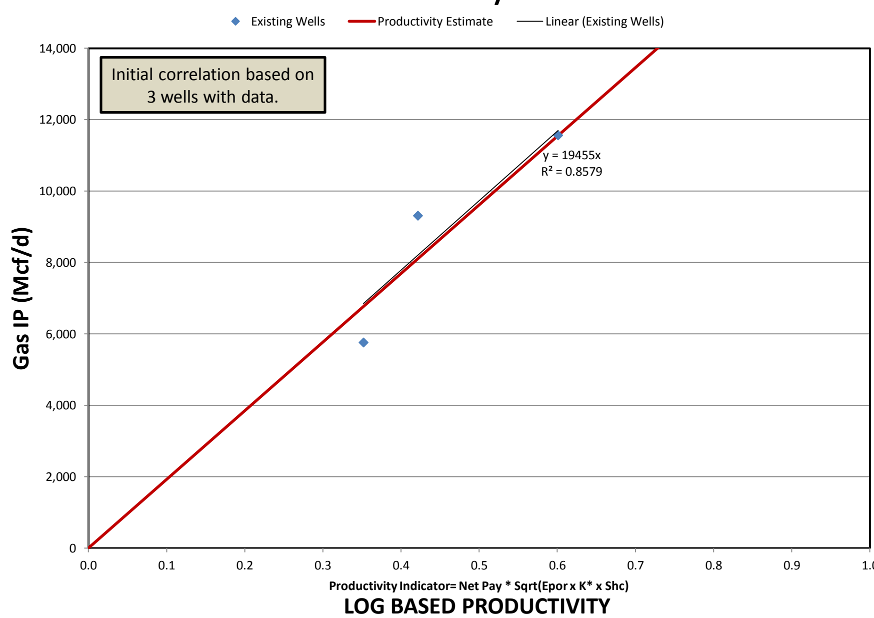
IP and Net Pay comparison



Dyco Granite Wash 'A' Example
IP vs. Productivity Indicator



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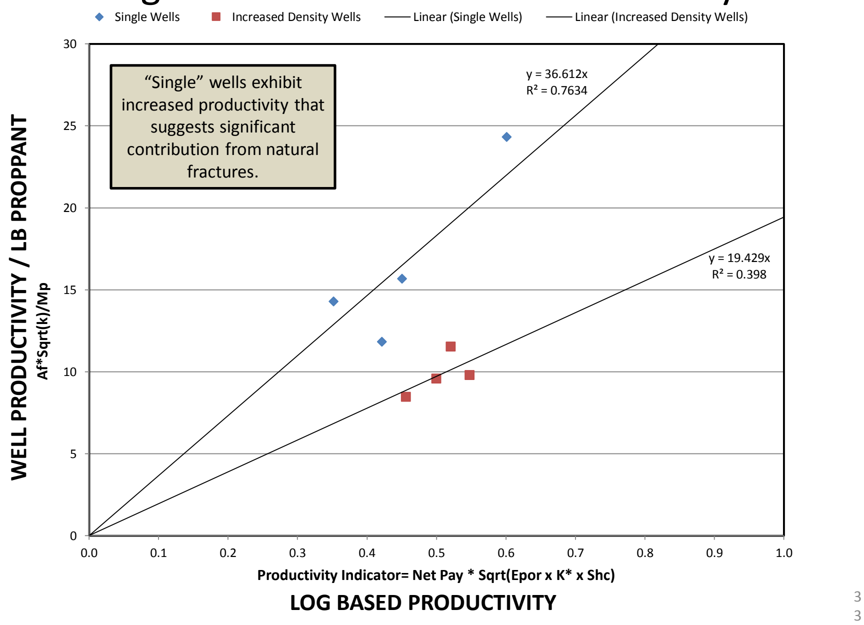
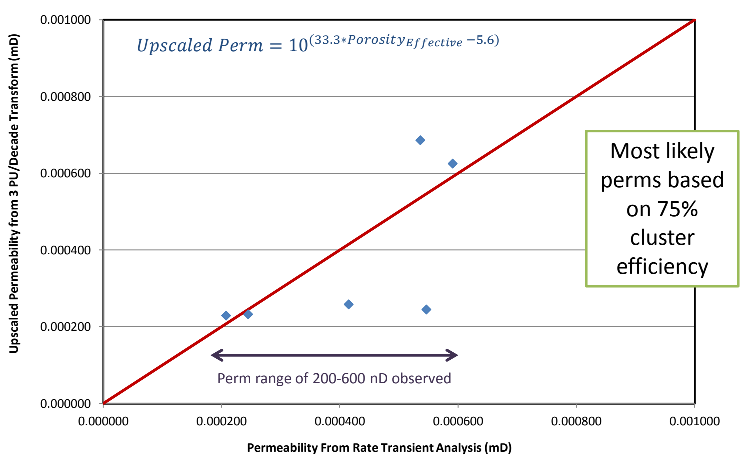
2

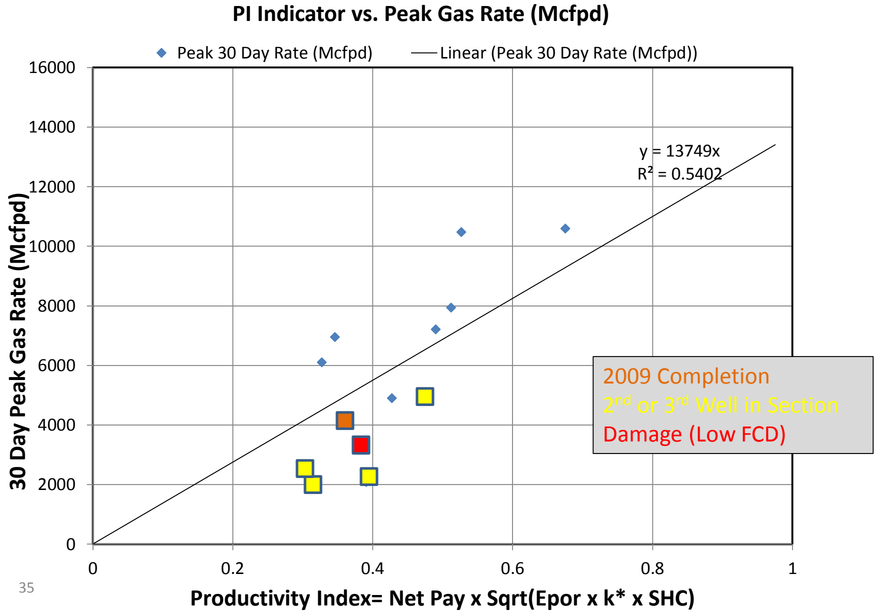
Dyco Granite Wash 'A' Example
Log Estimated vs. Actual Productivity



Dyco Granite Wash 'B'
Permeability Upscaling



Dyco Granite Wash 'B'
PI Indicator vs. Peak Rate



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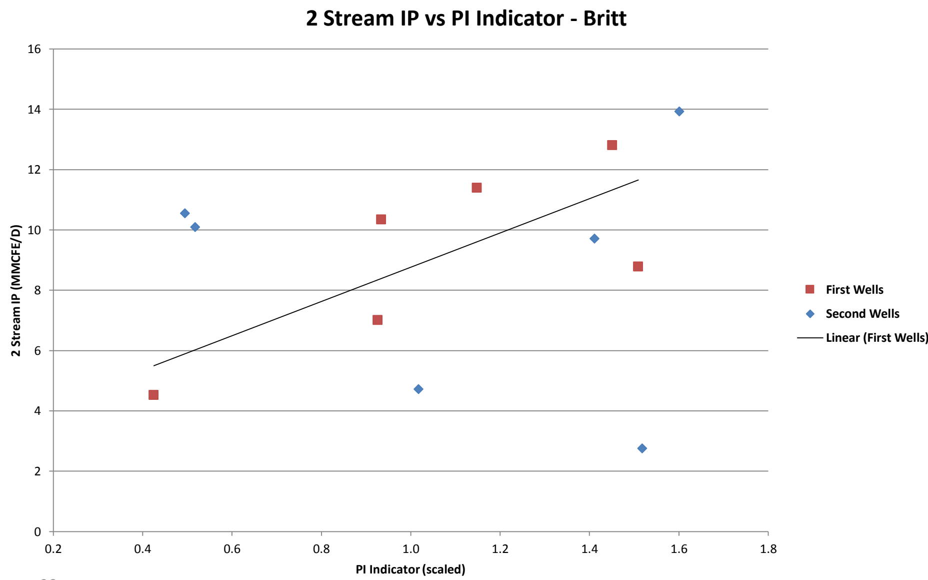
Dyco Britt
PI Indicator



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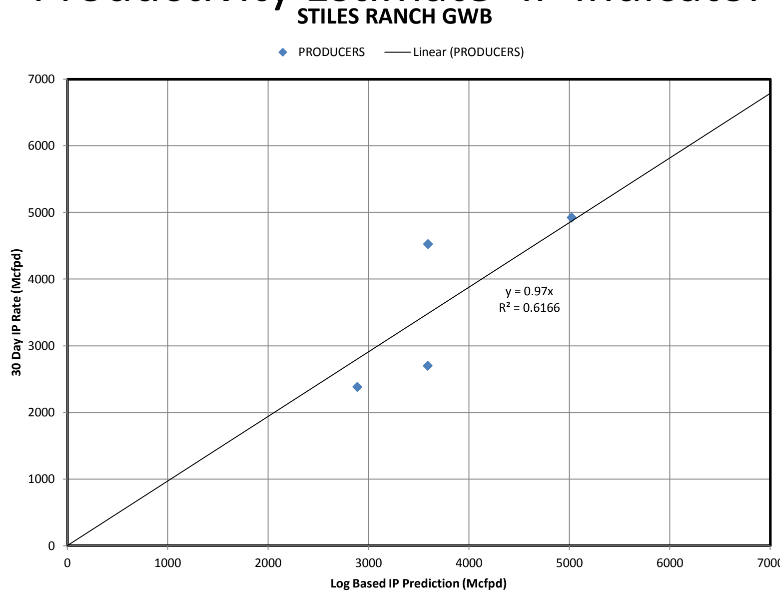
Stiles Ranch GWB
Productivity Estimate- IP Indicator



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Conclusions

- Maps based on PI can be used as supplements to more traditional net pay maps.
- PI is a valuable predictor of performance of proposed wells.
- This concept has been used over the past few years to improve bottom line success.