High Resistivity, High Porosity (Apparently) Monterey Formation: What Is Its Lithology and How Is It Recognized on Logs?

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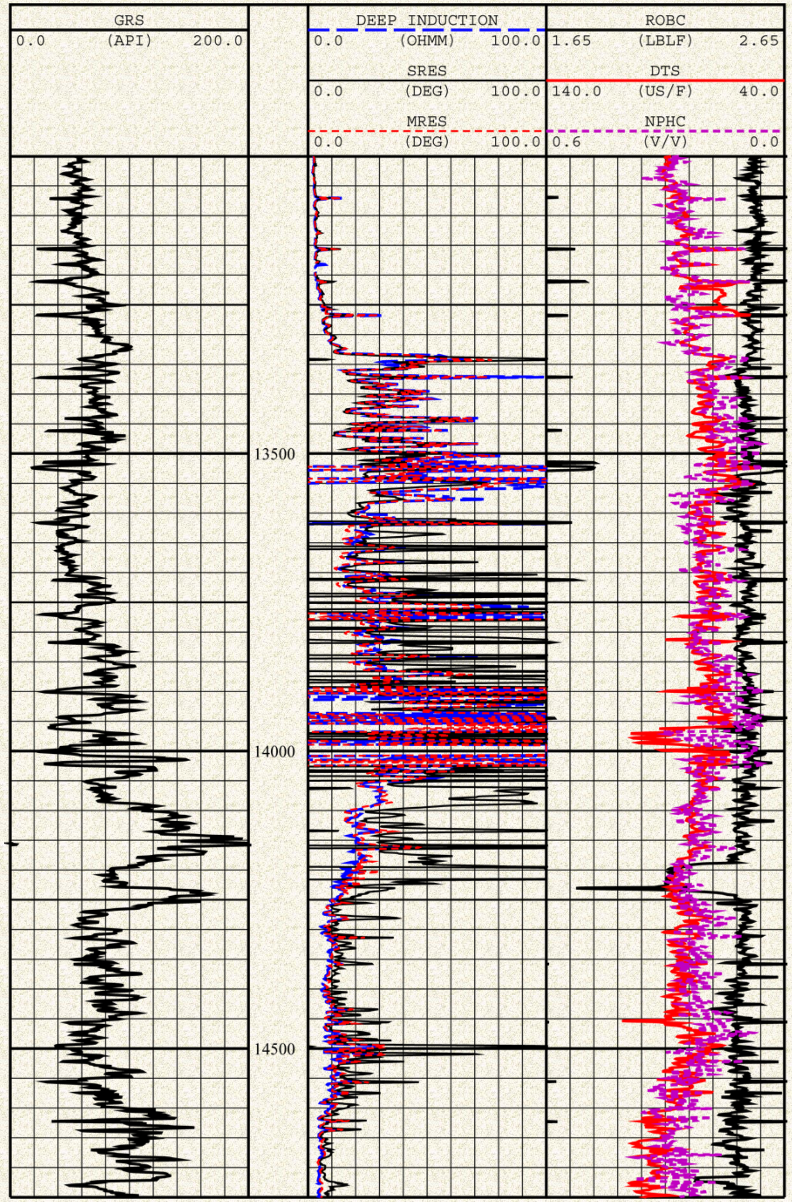
Background

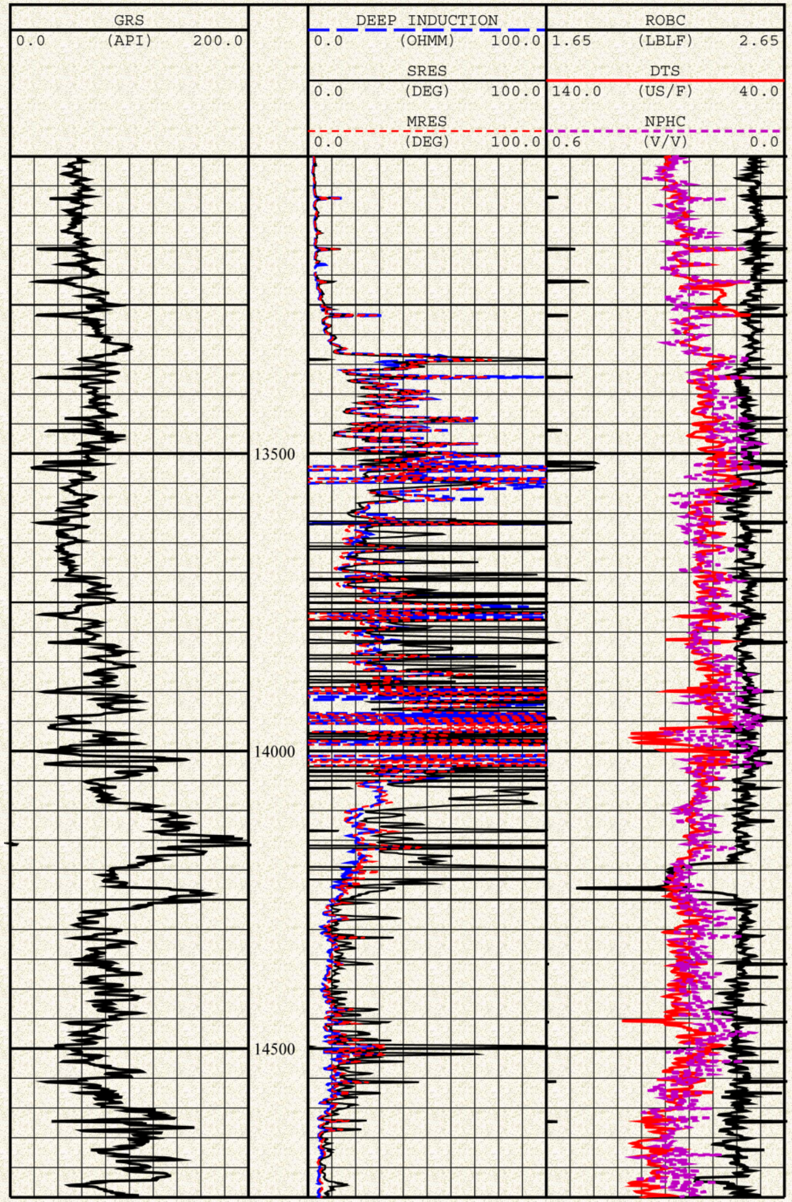
- We first encountered the log sections and rocks I am going to show you today through client work, when we were presented with logs and well performance data that did not agree
- Our initial goal was to adapt our models to provide our clients with accurate quantitative results
  - But to do this we had to learn what these rocks were and their characteristics that were affecting the log responses
- On the basis of our research, we have refined our Monterey petrophysical model to handle these unique rocks



The Problem

Below the Ct/Quartz transition in the San Joaquin Valley, there is a facies of the Monterey Formation characterized by:

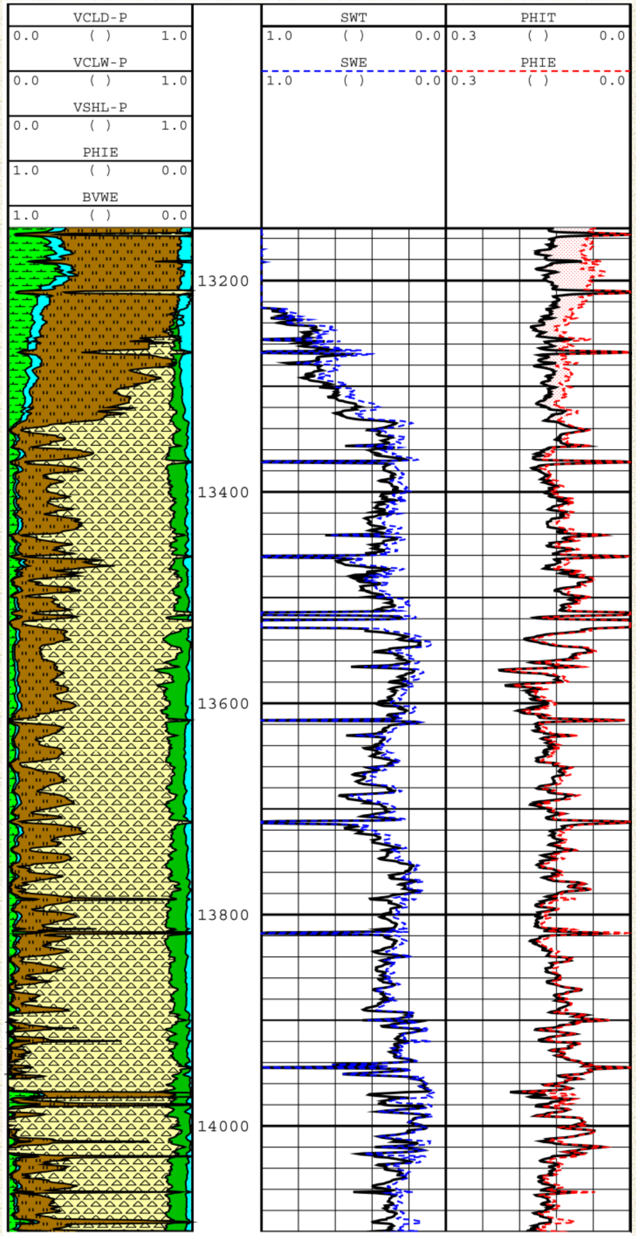
- **High resistivity, usually spiky, higher with depth (can be >100 ohm-m in deep sections)**
- **Moderate to high apparent porosity for the depth (>20% at 8000’-9000’, can be >10% below 13000’)**
- **Gamma logs are variable but not necessarily high; GR is moderate in this example**



The Problem contd…

Mudlog descriptions show chert and porcelanite: generally hard, brittle rock with low clay/clastic content

- **Colors are dark brown to black, sometimes mudlogs mention organic matter**
- **In many wells with this log signature, mudlog shows of oil are minimal to none, though they may have moderate total gas and some or all of C1-C5 spectrum**
- **LVT muds complicate the evaluation of mudlog hydrocarbon shows in these rocks**

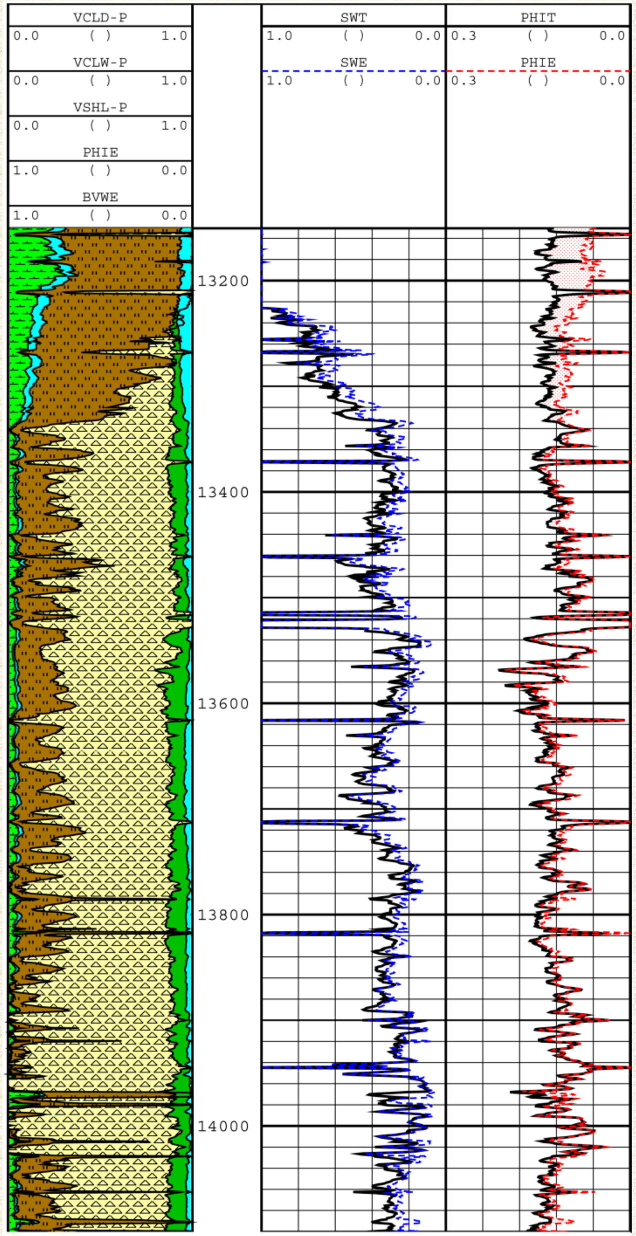


Results from Standard Petrophysical Analysis

If you use conventionally acceptable parameters for clean siliceous rocks (in this case for a deep section >12,000’) and Rw consistent with ~30K ppm, this is what you get from the analysis. Oil everywhere!

But the mudlog says:

“No cuttings gas, no significant hydrocarbon indicators”



What Happened???

The mudloggers missed the shows, it was LVT mud

But these guys are good, they know LVT and PDC bits, they even mention that there are no HC indicators beyond the LVT background

The mud was too heavy and therefore suppressed the shows

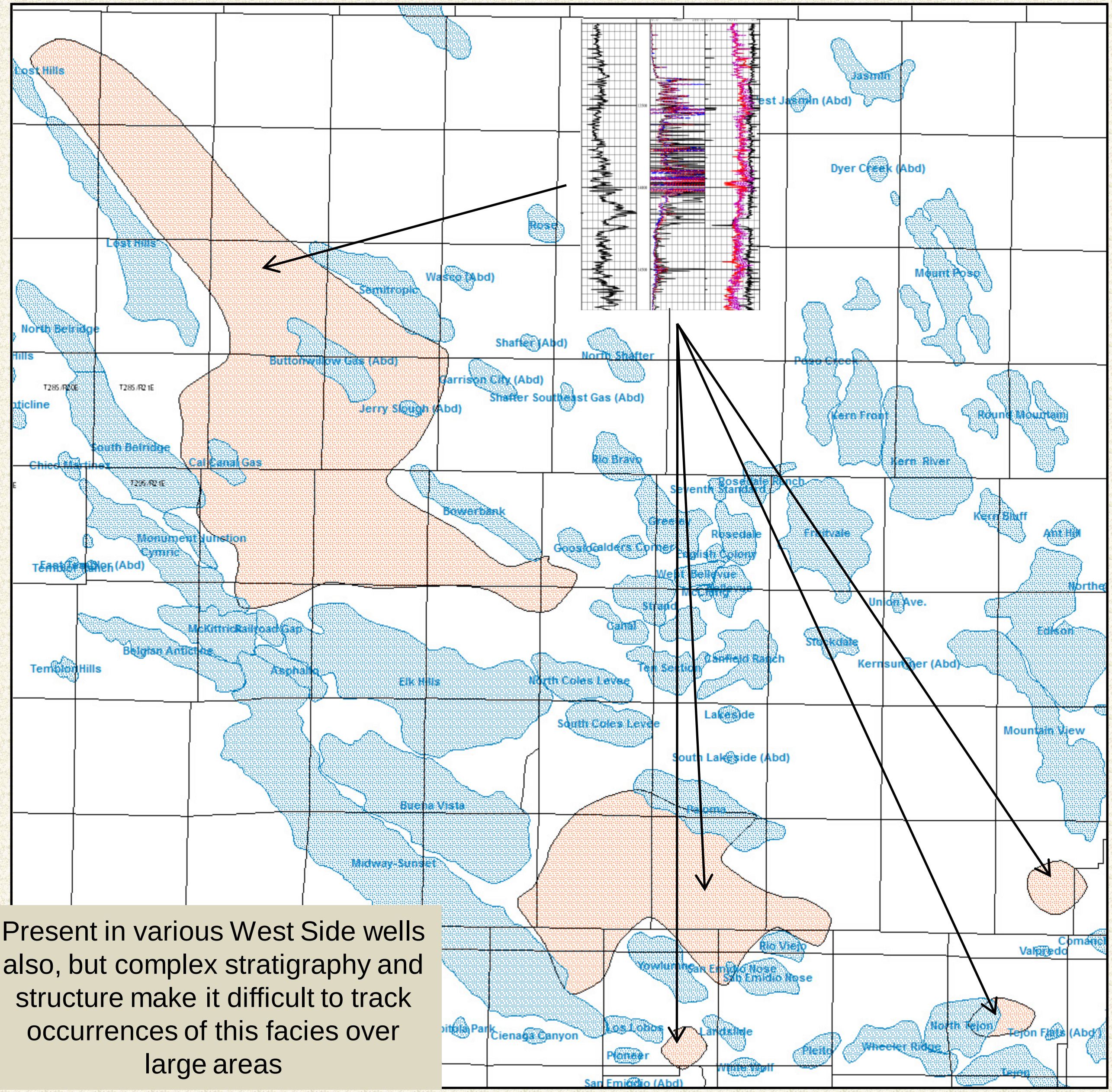
Well, maybe, but if there's this much oil is it reasonable that there are no shows anywhere in the zone?

It's deep, it's all gas

Could be, but there are oil indications at similar depths elsewhere, and there are shallower sections definitely in the oil window that look just like this

Is This Important?

- We believe that it is very important to understand this Monterey facies
- It is not an isolated occurrence in a few areas, and it can be very thick (>1000')
- The potential Monterey "resource play" as identified by the USGS and others is probably based, in part, on the high-resistivity log signature of this facies in the deep basin areas



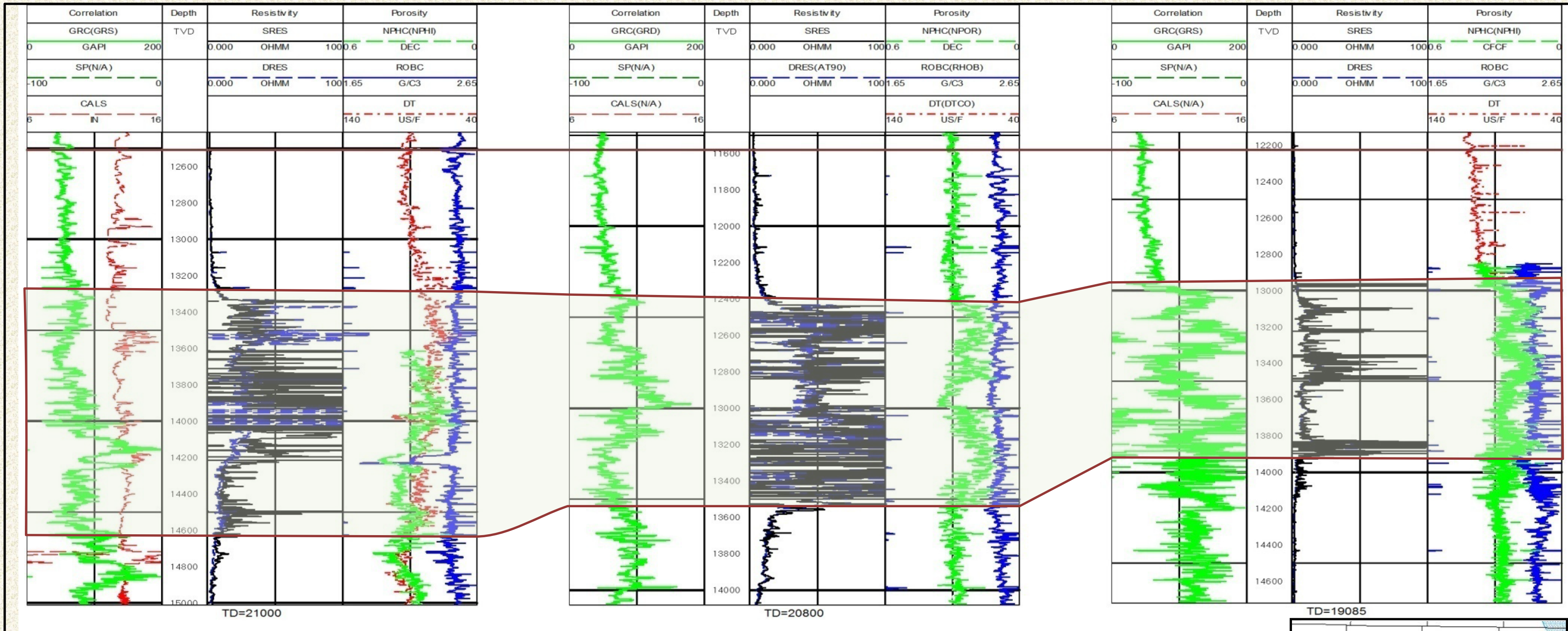
Present in various West Side wells also, but complex stratigraphy and structure make it difficult to track occurrences of this facies over large areas

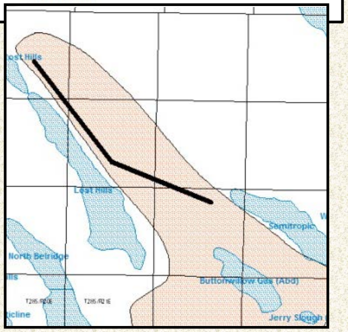
Areas of the SJV Where High-Resistivity Deep Monterey is Present

This is not a comprehensive map. Some deep basin areas are undrilled to sufficient depth, and we have not looked at all the deep wells which exist. This Monterey facies probably is present in much of the deep Maricopa basin, as it is in the Buttonwillow basin. It is also present in places west of the Belridge trend.

Deep Basin Wells on East Flank of Lost Hills

NW SE



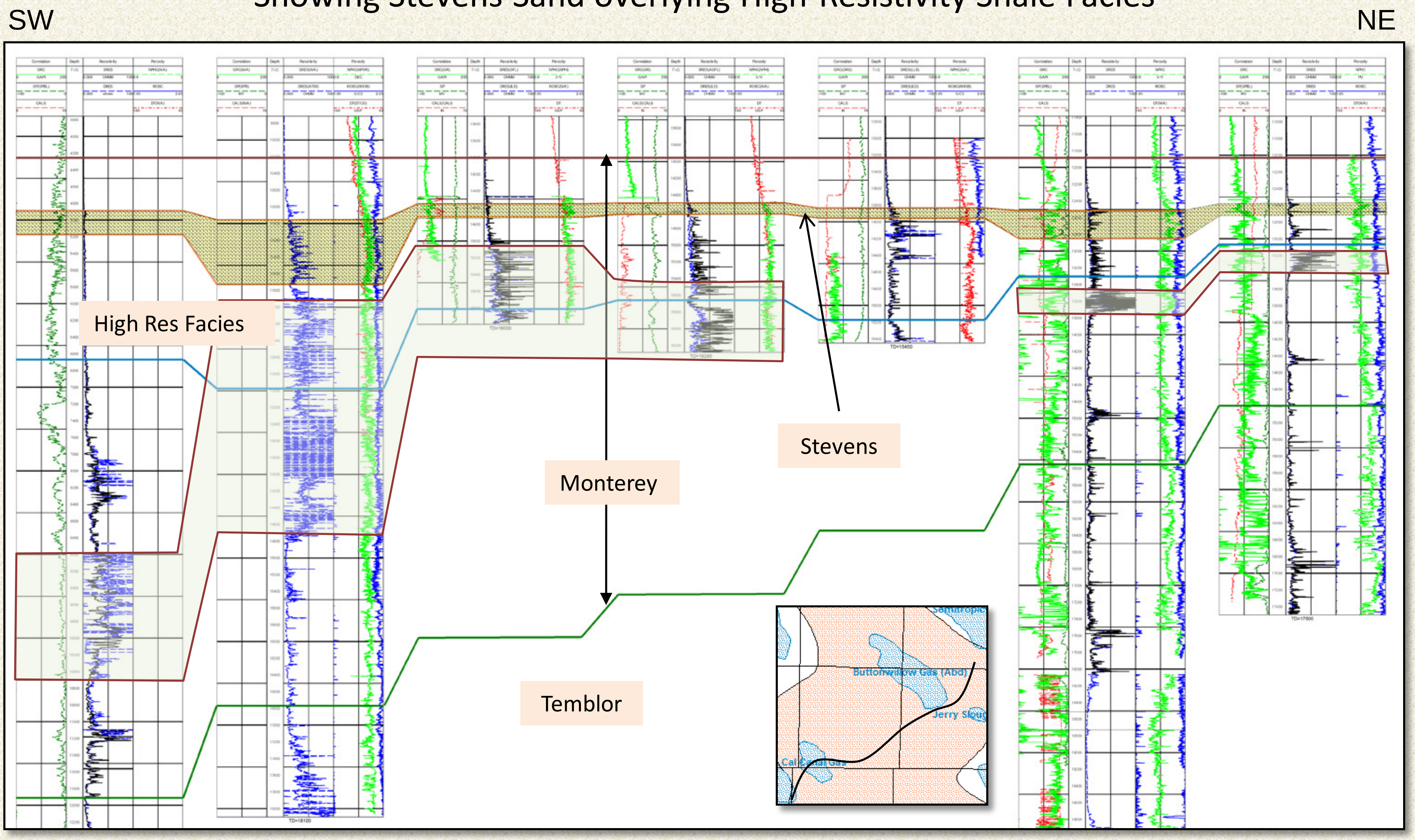


This high-resistivity Monterey facies is well developed on the deep eastern flank of the Lost Hills anticline. The facies begins to lose some of its distinctive resistivity character eastward onto the eastern platform of the Buttonwillow basin, although it maintains most of its thickness.

Sands vs High-Resistivity Shale Facies

- Towards the Bakersfield Arch, the high-resistivity shale facies is interbedded with deep Stevens sands and it can be difficult to distinguish between the two rock types on logs
- Mudlogs are very helpful to correlate the Stevens and shale facies correctly

Cross Section Across Buttonwillow Basin from Cal Canal to Near Semitropic Showing Stevens Sand overlying High-Resistivity Shale Facies



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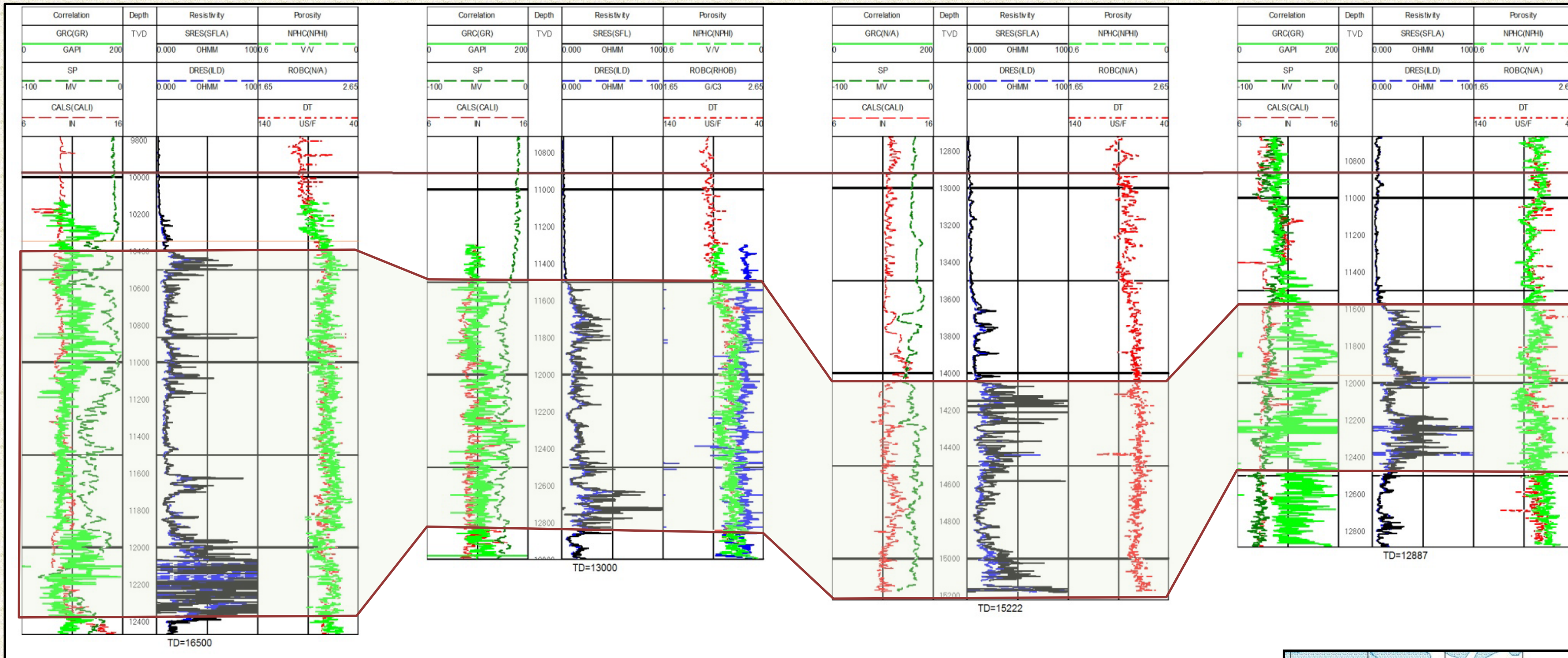
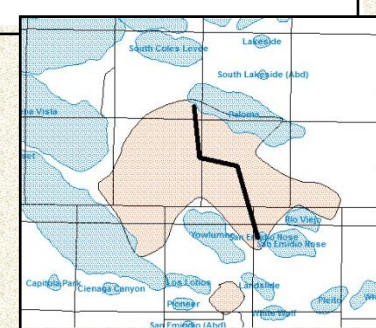
Maricopa Basin Paloma - Yowlumne

N S





The character of the high-resistivity Monterey facies is more variable in the Maricopa basin but appears to be widely distributed.

High-Resistivity Shale Facies

- The occurrence of this facies, as shown in the cross sections, is most obvious in the deep basin
  - It has also been noted in a Monterey section at ~5500' (just into quartz phase) with the characteristic spiky resistivity but the range of values was 8-12 ohmm
    - Initial analysis showed more oil than the mudlog or production tests indicated was present; lower resistivity is attributed to the shallow depth and log porosity of 27%-29%
  - Have seen several sections in wells on structure where the rock appears to be transitional to this facies
- The same analytical principals must be applied to these rocks wherever they are recognized to avoid overestimating So and interconnected porosity

So, What Is This Rock?

- What do we know about it?
  - Clean to very clean siliceous rock, generally described as glassy chert and porcelanite with conchoidal fracture and other indications of high silica and low detrital content, also some pyrite is mentioned
  - Probable high organic content:
    - colors are dark brown to black for all lithologies,
    - mudlogs and old core descriptions occasionally mention organic matter
  - Quartz phase diatomite has undergone significant diagenesis and reshaping of the pore network
- It is therefore a sequence of porcelanite and chert with high TOC and probably a significant amount of secondary or at least highly altered primary porosity

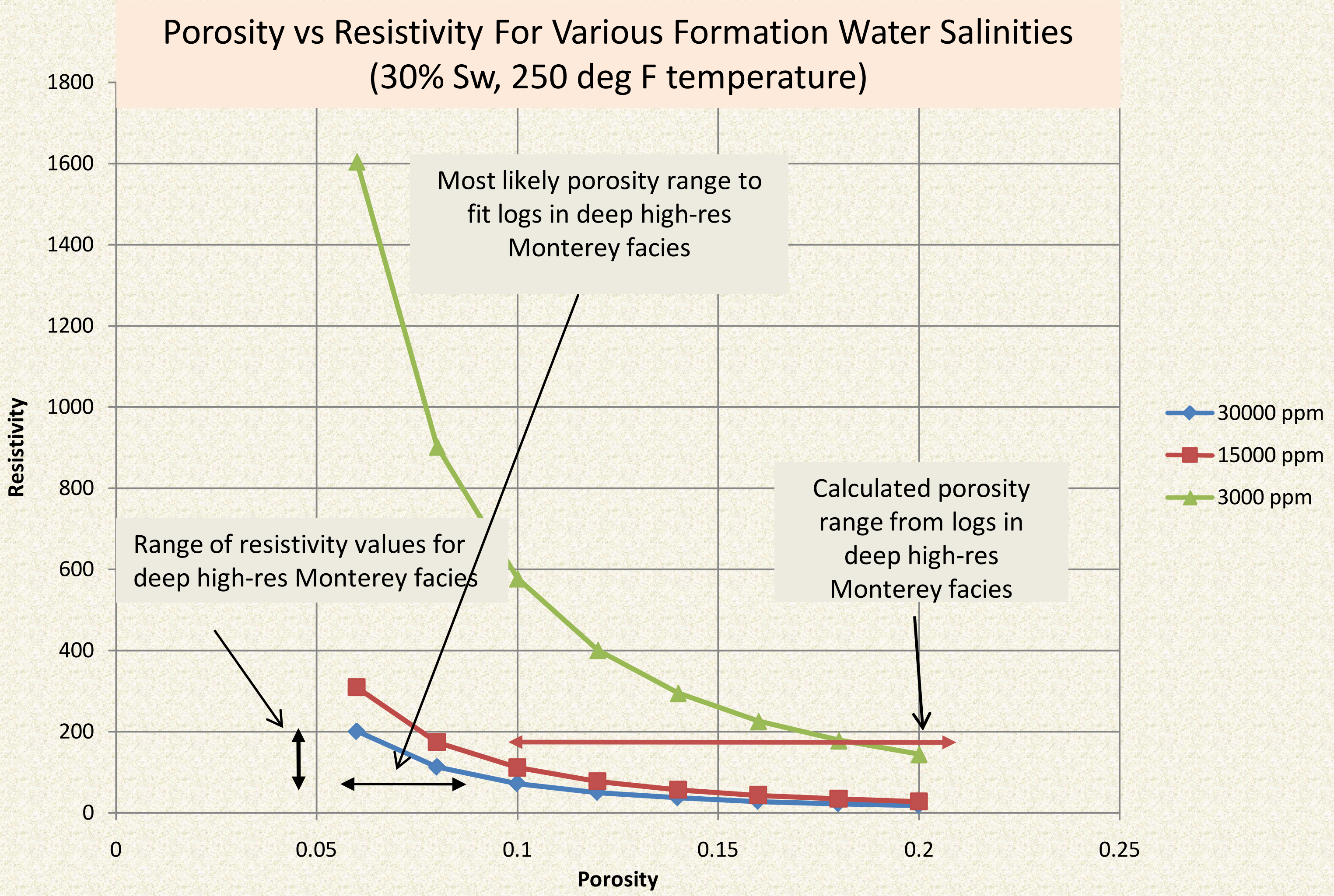
Clues

- Most obvious: high resistivity
- Apparent density/neutron/sonic porosity of (in most occurrences) 10%-29%, depending on depth
- Variable GR, probably affected in part by U associated with the organic matter, but not consistently high
- Standard analysis shows low Sw in intervals with minimal mudlog shows
- Well completions/tests show high water cut, low rate, or other less than satisfactory result

Unraveling the Mystery

- The main problem, from a log analysis standpoint, appears to be that the porosity is too high
  - The resistivity log reading in a given rock is a function of the amount of porosity, the volume fraction of conductive fluid filling that porosity, the conductivity of that fluid, the presence of any conductive clays, and the tortuosity of the current path.
- RT is generally proportional to the bulk volume of water present in the interconnected pore system
- For a given porosity, RT will increase if:
  - Some of the water is replaced by hydrocarbons
  - Some of the water is trapped in isolated pores
  - Cementation or other processes have greatly increased the tortuosity of the current path

You Can't Get There From Here: The Calculated Porosity is Too High For the Measured Resistivities



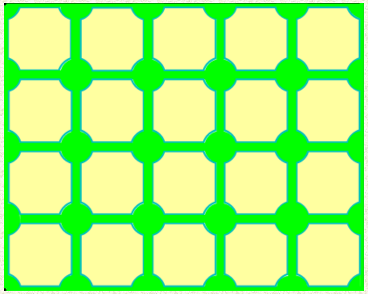
Resistivity Logs

- The induction and laterolog-type resistivity logs "see" the electrical conductivity of materials within interconnected pores of the rock
  - Conductive materials include salt water and clay minerals
  - The magnitude of the measurement depends on the flow of current through the conductive medium
  - If there are pores present which do not communicate with other pores, they look like infinitely resistive rock to the logging tool
- So, the resistivity logs in this Monterey facies are behaving as if they do not "see" all of the porosity apparently measured by the porosity logs

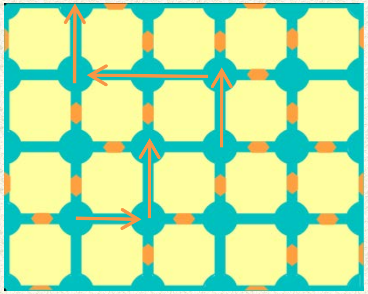
What Causes the Apparent Porosity Anomaly?

- Grain density is 2.65 g/cc or higher, so we cannot look to a low matrix density to reduce the computed porosity
- Our research and observations indicate that the high-resistivity, apparent high porosity Monterey facies is:
  - A rock whose **high kerogen content** is plugging a significant fraction of the porosity
  - And/Or
  - A rock in which extensive diagenetic alteration of the siliceous material has created a number of **isolated pores** filled with non-movable fluid
- Most likely, these rocks have both kerogen plugging and diagenetically-isolated pores

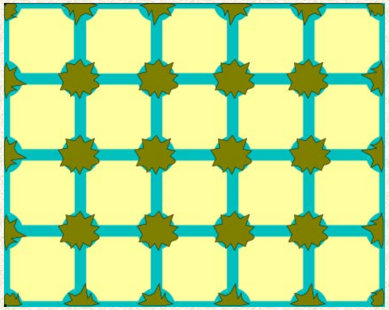
Simple Model of the Pore System in Biogenic Siliceous Facies



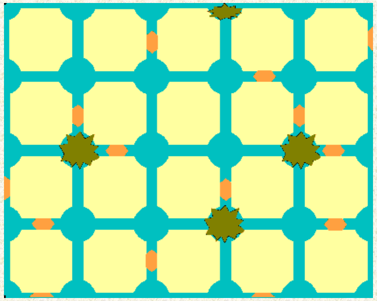
Oil-Saturated Water Wet



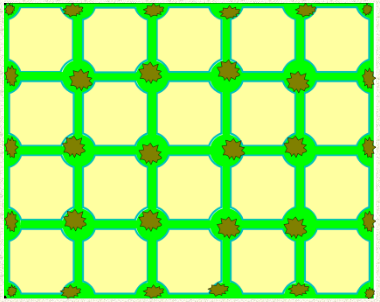
Heavily Cemented Water Wet



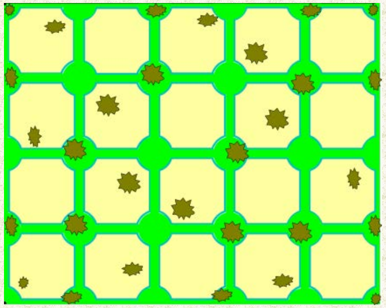
Immature Kerogen in Wet Pore System



Partially Cemented with Kerogen in Wet Pore System



Mature Kerogen and Oil in Open Pore System



Mature Kerogen in Matrix With Oil in Open Pore System

Proof?

- We do not have sufficient laboratory measurements for robust quantification of either the isolated pore or the kerogen filling attributes in the Monterey.
- Our models were programmed years ago to account for an isolated pore network that was cored and described in highly siliceous shales in **Pennsylvania**. The same algorithm, modified to account for Kerogen, can be used effectively in the **Monterey**.
- The descriptive work of others found in recent literature is sufficient to characterize the role of immature kerogen in the partial or complete occlusion of an otherwise open pore system.

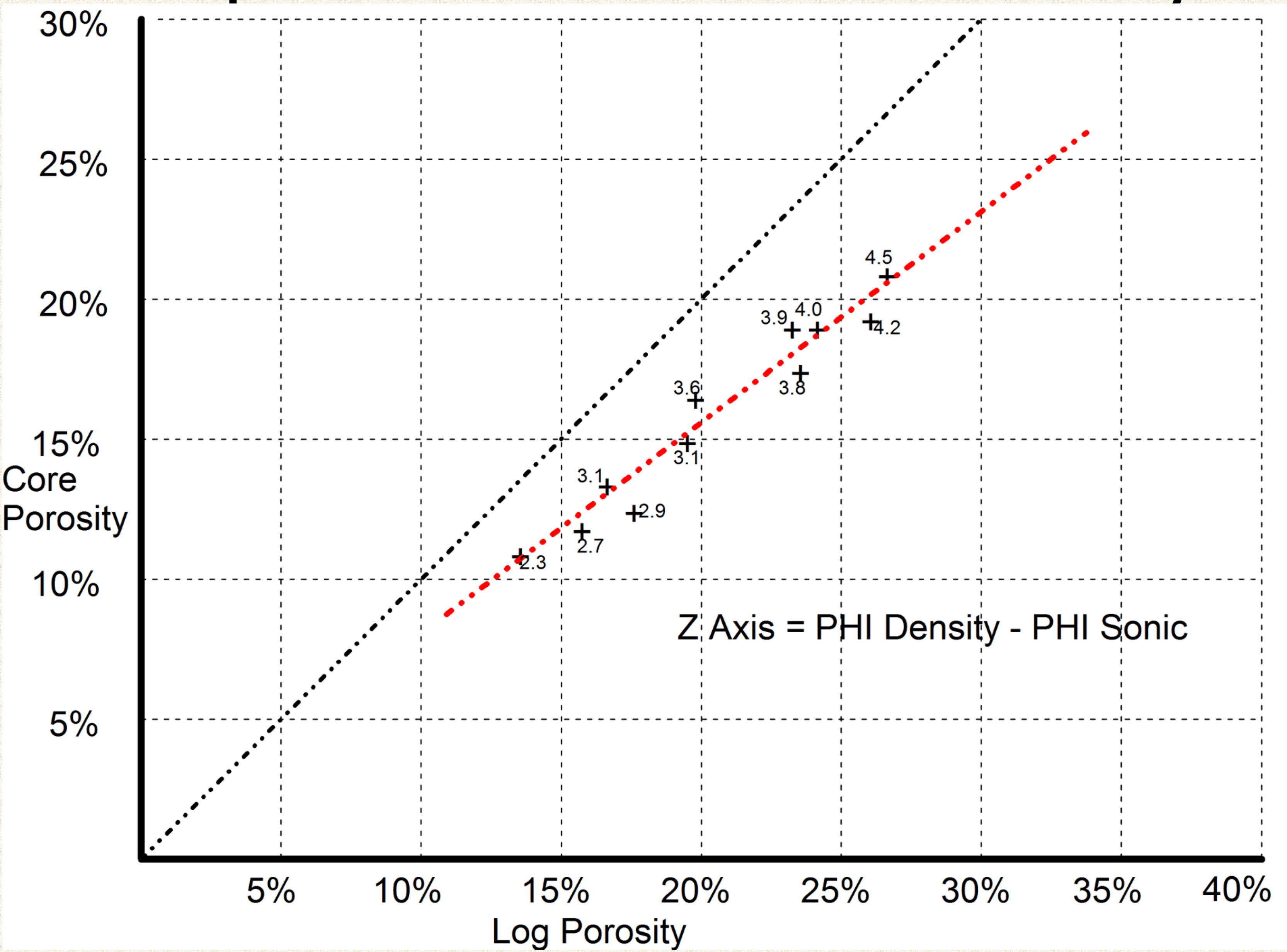
Proof?

- In the few instances where core data covered the high-res rocks, we have interpreted anomalously low core measured porosity as having isolated pores that were not measured by the lab porosimeter.
- While the data are sparse, low lab measured values of matrix density (<2.65 in chert) suggest the rock contains isolated pores.
- The theory fits the available data and explains the high resistivity readings in rocks with apparently normal formation water salinity but low free hydrocarbon content

Introducing: "**Isolated Porosity Factor**"

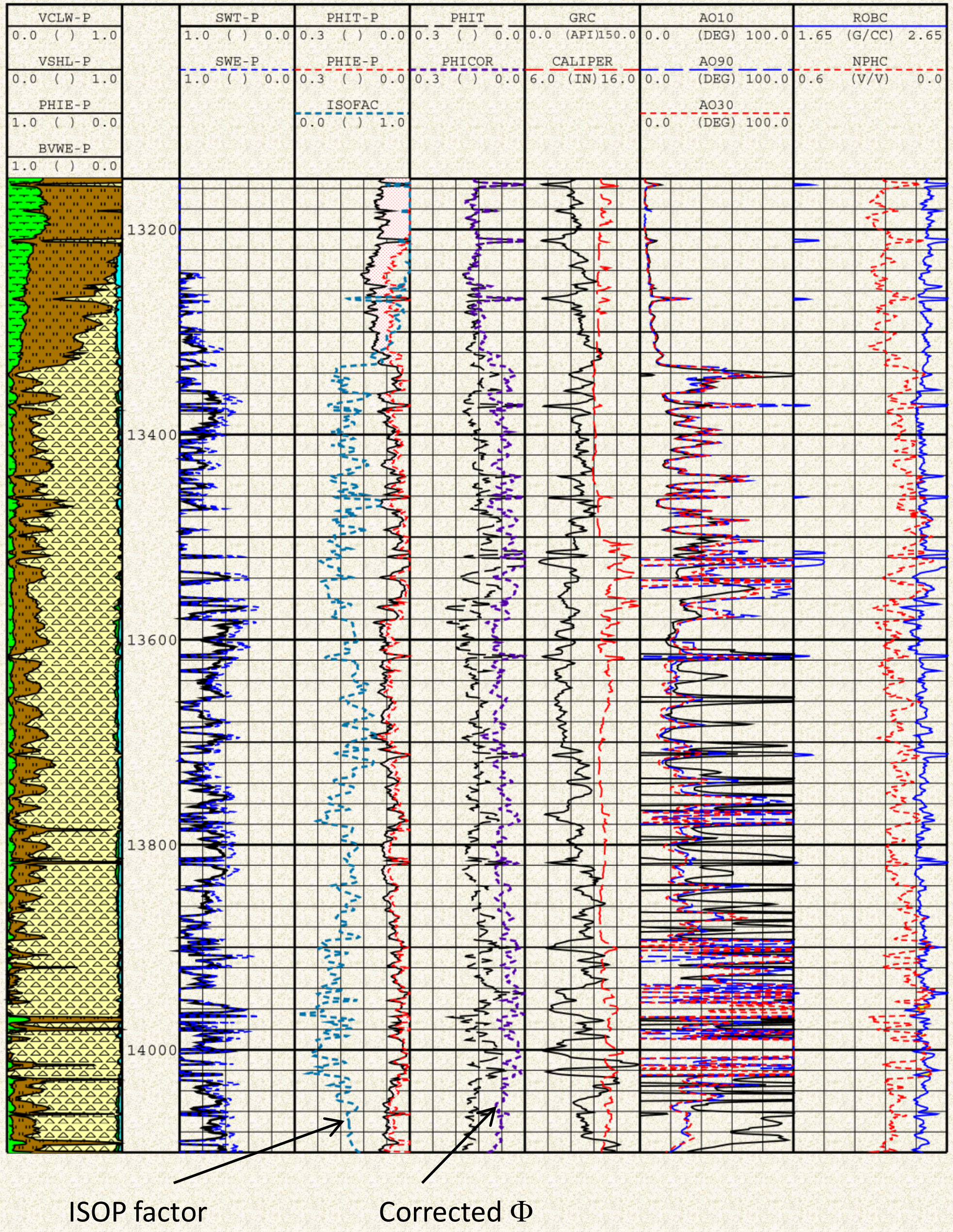
- The Isolated Porosity Factor (ISOP) quantifies the fraction of the porosity which is not interconnected with the fluid system in the rock.
  - PHIc = connected porosity
  - PHIi = isolated porosity
  - PHIlog = f(PHIc + PHIi)
  - PHIi = PHIlog * ISOP
  - PHIc = PHIlog * (1-ISOP)

Cross plot of Core PHI vs Density PHI



Solving for "Isolated Porosity Factor"

- In determining interconnected porosity, isolated pores are treated as "rock"
  - The simple approach assumes that all kerogen is in the interconnected pore system. However, it may be necessary to account for kerogen that is not in the interconnected pore system.
  - Interconnected porosity is the porosity used in the shaly sand analysis model (generally use Dual Water)
  - Use conventional parameters for F = a/(PHI^m)
  - Shaly sand model now yields Sw of the interconnected porosity system.



Application of Isolated Porosity Factor

The ISOP is scaled 0 – 1.0 and represents the fraction of the log porosity which is isolated, or not in communication with the "normal" pore system. The value (1-ISOP) is multiplied by the log-derived porosity to yield inter-connected porosity. This value is then treated like total porosity and used in the standard shaly-sand log analysis methodology to derive Sw and PHIE.

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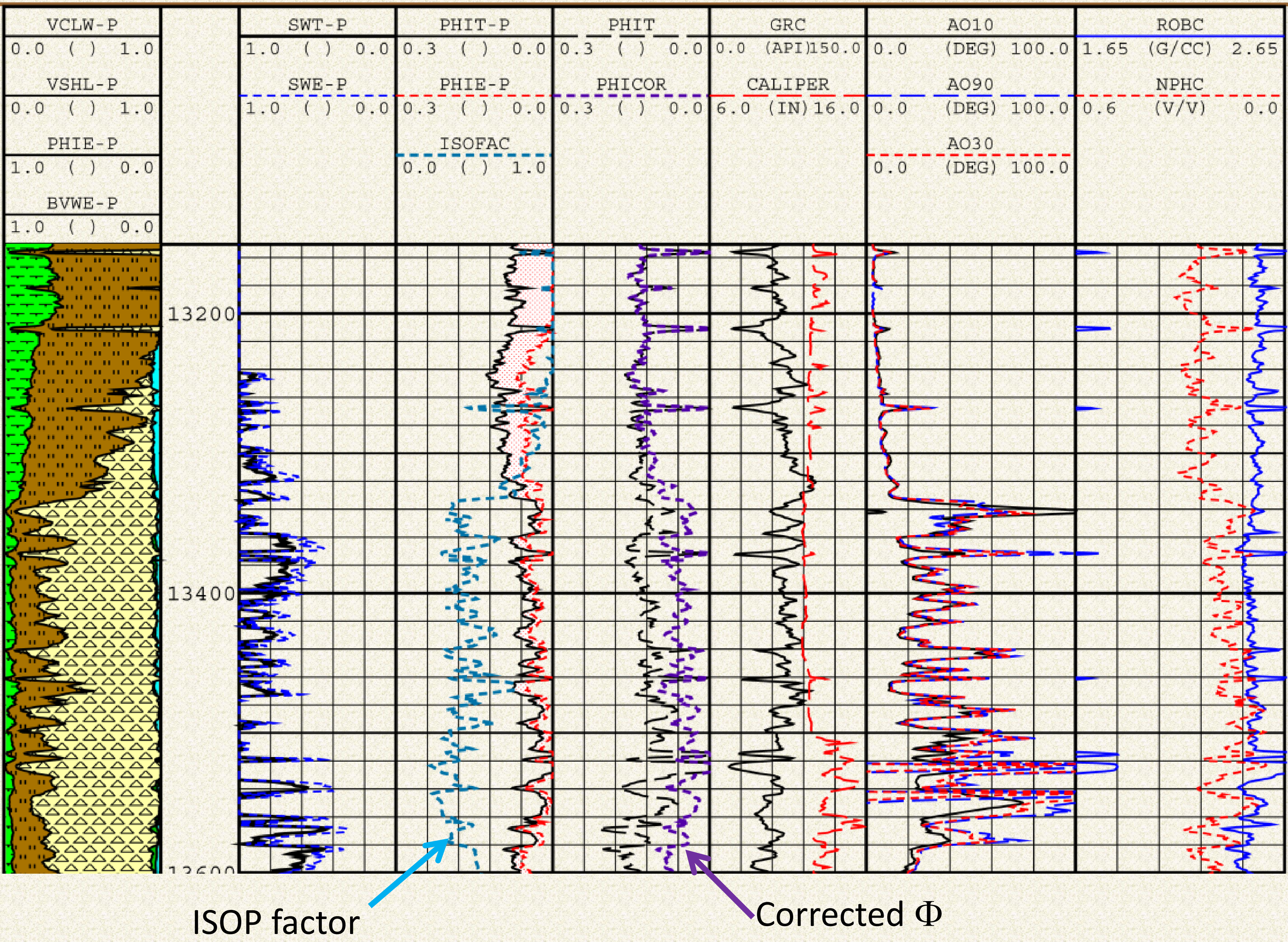
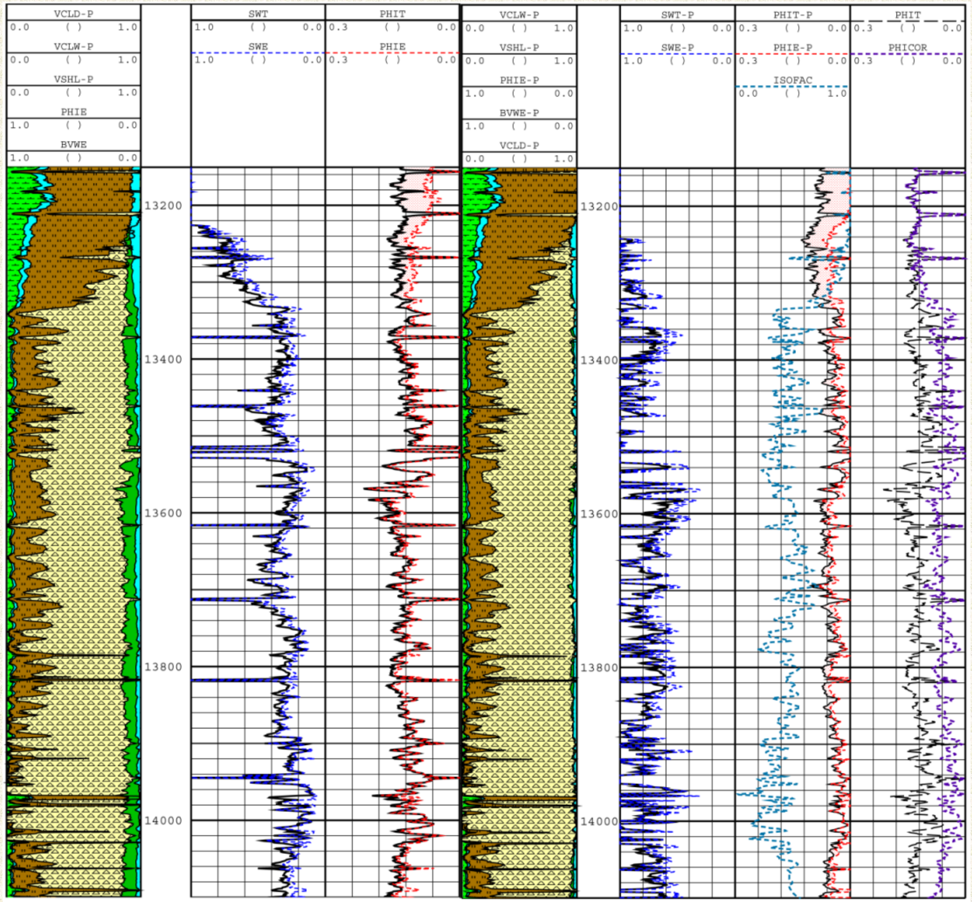


VCLW-P
0.0 ( ) 1.0
VSHL-P
0.0 ( ) 1.0
PHIE-P
1.0 ( ) 0.0
BVWE-P
1.0 ( ) 0.0
SWT-P
1.0 ( ) 0.0
SWE-P
1.0 ( ) 0.0
PHIT-P
0.3 ( ) 0.0
PHIE-P
0.3 ( ) 0.0
ISOFAC
0.0 ( ) 1.0
PHIT
0.3 ( ) 0.0
PHICOR
0.3 ( ) 0.0
GRC
0.0 (API) 150.0
CALIPER
6.0 (IN) 16.0
AO10
0.0 (DEG) 100.0
AO90
0.0 (DEG) 100.0
AO30
0.0 (DEG) 100.0
ROBC
1.65 (G/CC) 2.65
NPHC
0.6 (V/V) 0.0
13200
13400
ISOP factor
Corrected Φ

Comparison of results from standard analysis and isolated porosity analysis

Standard Analysis



Isolated Porosity Analysis

- **The analysis on the left indicates a high amount of hydrocarbons in a seemingly porous interval. An operator seeing these results would be tempted to complete and test the well.**
- **UNFORTUNATELY the results will be very disappointing.**
- **The analysis on the right indicates that the interval has very low interconnected porosity and is either wet or has only residual hydrocarbons.**

Bad News & Good News

- The bad news is that conventional analysis of these types of rocks can yield over- optimistic hydrocarbon saturations. This has led operators to spend large amounts of money completing and testing wells that were tight and non productive.
- The good news is that we now have a model that can distinguish between pay and non pay in these very challenging rocks.

Questions that have been asked:

- Are you implying that the transitional Monterey facies*, if thermally oil-mature, would be a good candidate for resource type drilling and completion methods?
  - ***That's the big question***
- 2) Could the pore-plugging kerogen in the transitional facies be migrated-oil trapped by diagenetic processes?
  - ***The logs alone cannot distinguish between the two***
- 3) Do the transitional facies you have documented ever occur where there is a structural trap or recent uplift?
  - ***Yes, we have seen this in client wells that have been sent to us for analysis, located in fields and on structures***

Answer (sort of):

- PayZone's principals have pondered these questions and others with regard to the Monterey. The industry spotlight is now shining in our back yard. The oft-quoted USGS report predicts reserves that we believe to be optimistic. However, if we find only 10% to 20% of what has been suggested, the future for California is bright.
- Unfortunately, there are not sufficient data in the public domain to substantiate conclusive answers.

Acknowledgements

- The petrophysical models now in use by PZI were first developed by Digital Petrophysics Inc. in the mid to late 1980’s.
- William R. Berry II (Rick) developed the “Pennsylvania” solution while preparing log examples for a school presented in Pittsburg in 1986.