Marginal and Mature Field Development and Operation

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Multiphase Reservoir Fluid Characterization Using Pulsed Neutron Well Logging for Mature Fields in Low-Salinity Environments

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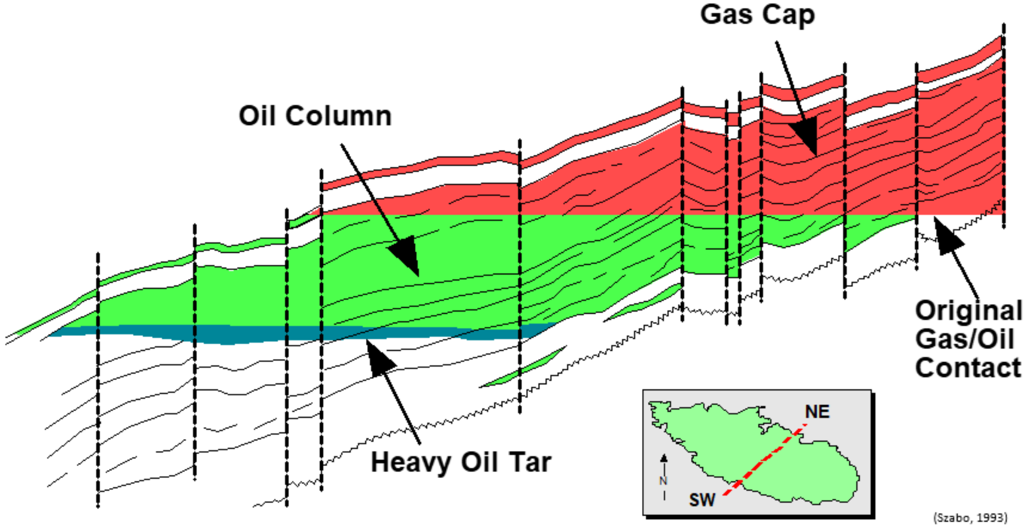
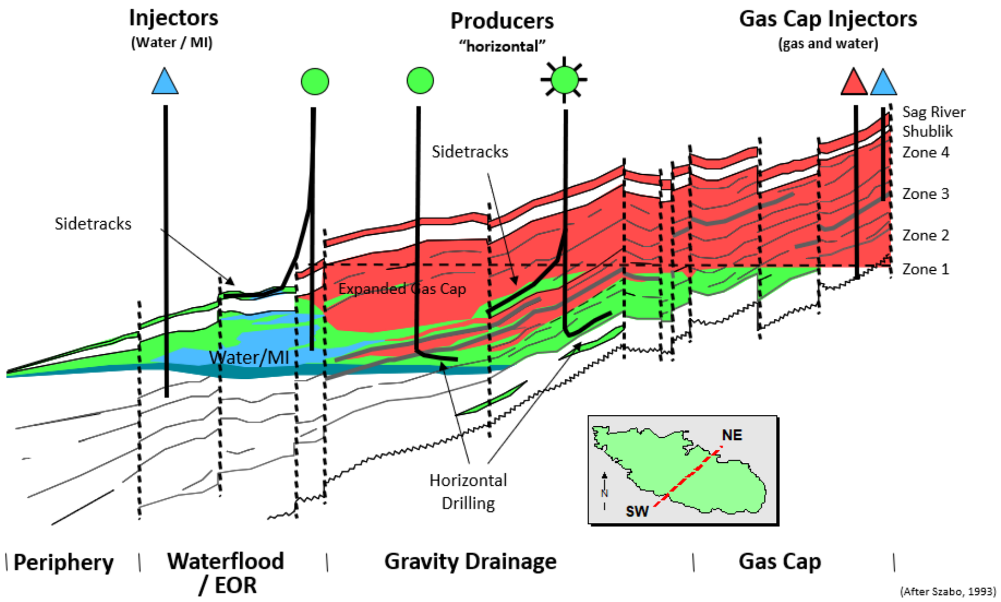
Initial vs. Current Fluid Distributions

Prudhoe Bay: Initial Fluid Distribution



Prudhoe Bay: Current Fluid Distribution



D. Itter et al., 2015

Reservoir Surveillance

- Understanding reservoir fluid saturation and distribution is critical for reservoir management decision-making
  - Pre- & post-production
  - Pre- & post-water or gas injection
  - Reservoir saturation end points
  - Fluid contact monitoring
  - Gas expansion or gas cap movement
- Identification of current hydrocarbon distribution profile in cased-hole (or open-hole) completions

Monitoring via Pulsed Neutron (PN) Logging

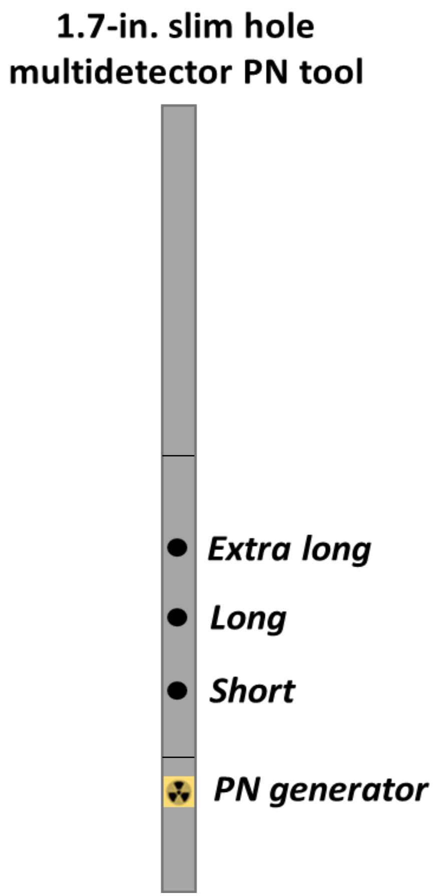
- PN well logging provides unique advantages
  - Cost-effective & efficient method
  - Quantification of fluid volumes
  - Well-centric interpretation expanding to multi-well interpretation
  - Capability to expand applications using a combination of other tools, such as production logging sensors

PN Applications in Low-Salinity Environments

- Salinity-independent measurements
  - Formation sigma is not applicable
- Two inelastic measurements
  - Gas-sensitive measurement
    - RIN13: inelastic time spectra-based measurement
  - Oil-sensitive measurement
    - Carbon/Oxygen (C/O): inelastic energy spectra-based measurement
- Three-phase formation saturation analysis
  - Forward models of measurements
  - Sequential vs. simultaneous method

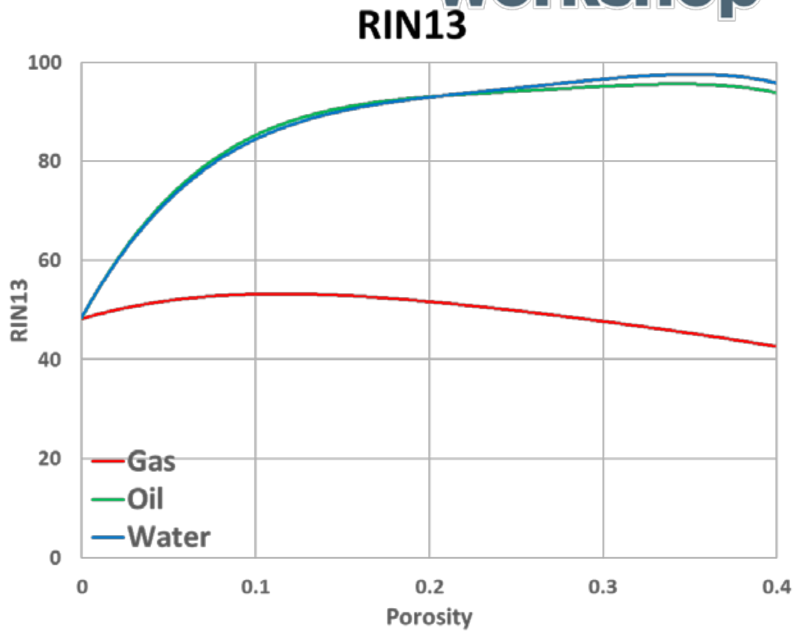
Multidetector PN Well Logging Tool & Update

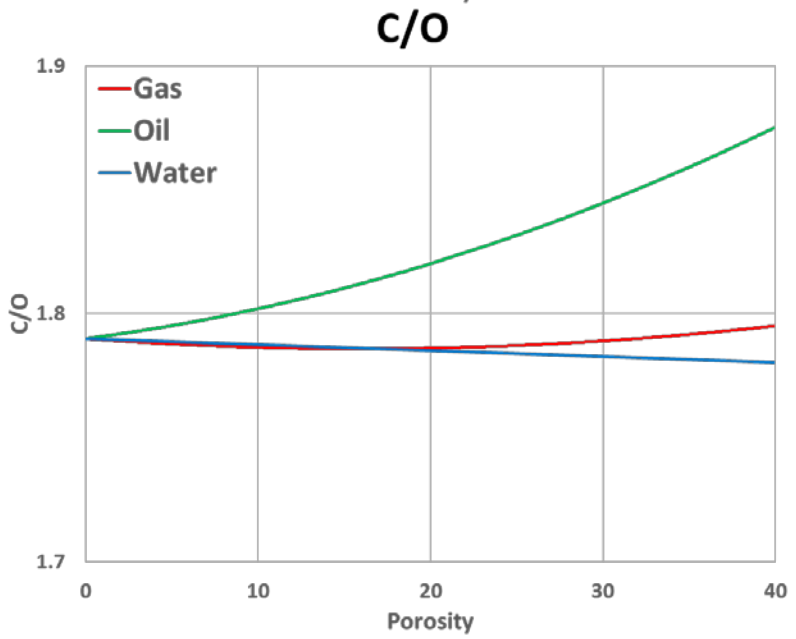
- Dual vs. three gamma-ray (GR) scintillation detectors
  - Improved formation sensitivity
  - Approximately three times higher gas sensitivity
- Enhancements in the latest PN tool
  - Upgrade on PN generator
  - High-resolution GR scintillation detector crystal
  - Digital electronics
- Tool improvements enabled
  - Faster data acquisition
  - Elemental yield analysis
  - Simultaneous multimode data acquisition



Forward Modeling of PN Responses

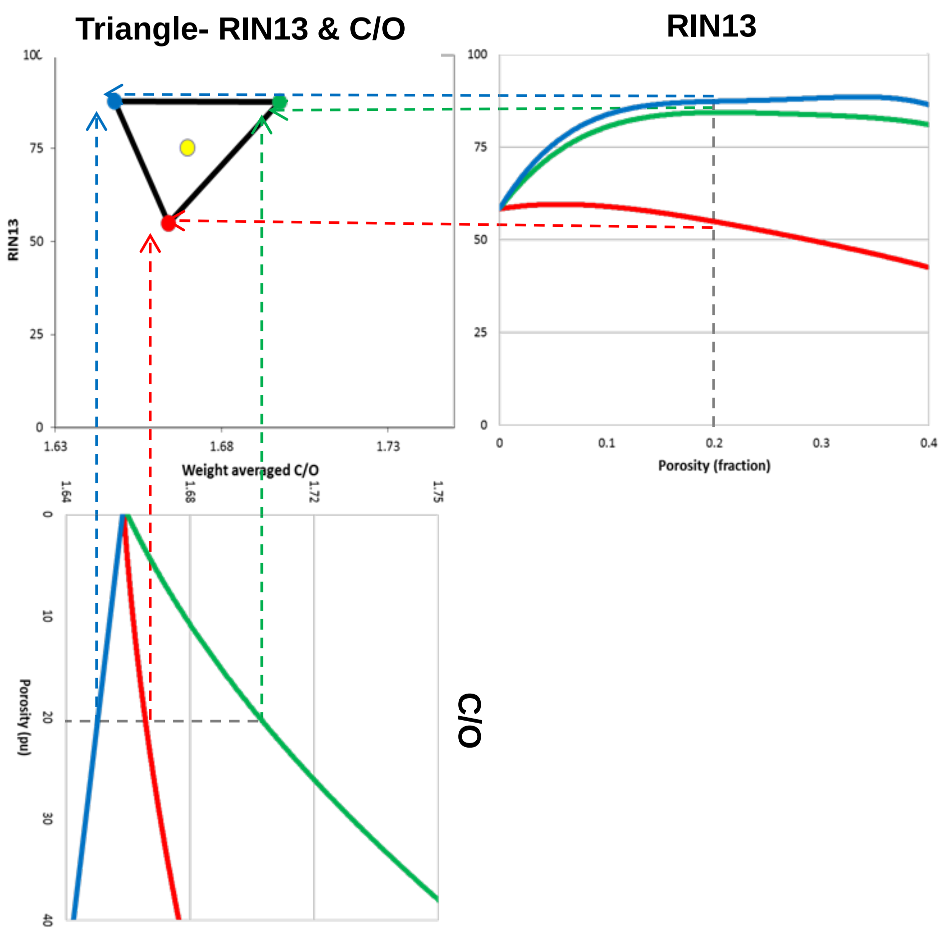
- Monte Carlo N-Particle (MCNP) modeling of tool responses
  - Probabilistic framework
  - Predict RIN13 and C/O ratios
- Necessity
  - Formation saturation analysis workflow component
- Modeling parameters
  - Completion specifications
  - Borehole fluid
  - Formation properties





Simultaneous Three-Phase Saturation Approach

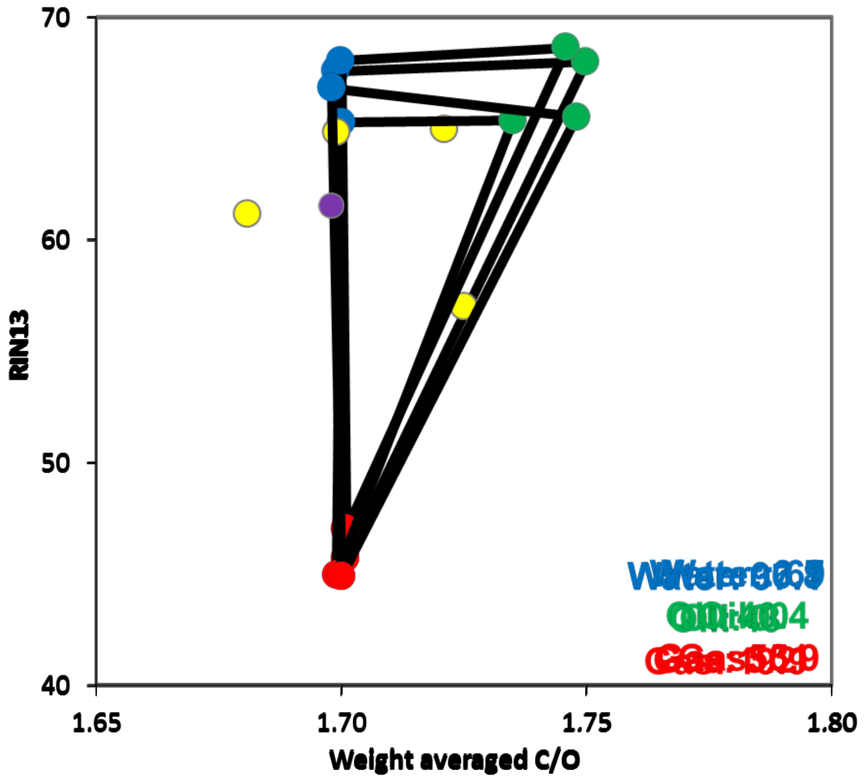
- Triangulation method components
  - Measured RIN13 and C/O
  - MCNP modeled water-, oil and gas-filled formation RIN13 and C/O responses
- A simultaneous quantification of each fluid component
  - Translations of relative distances between measured data to modeled responses



Kim & Chace, 2016

Saturation Calculation

- Relative distance from a measured point to each theoretical point
- Measurements outside of a triangle are projected to the nearest point on a triangle

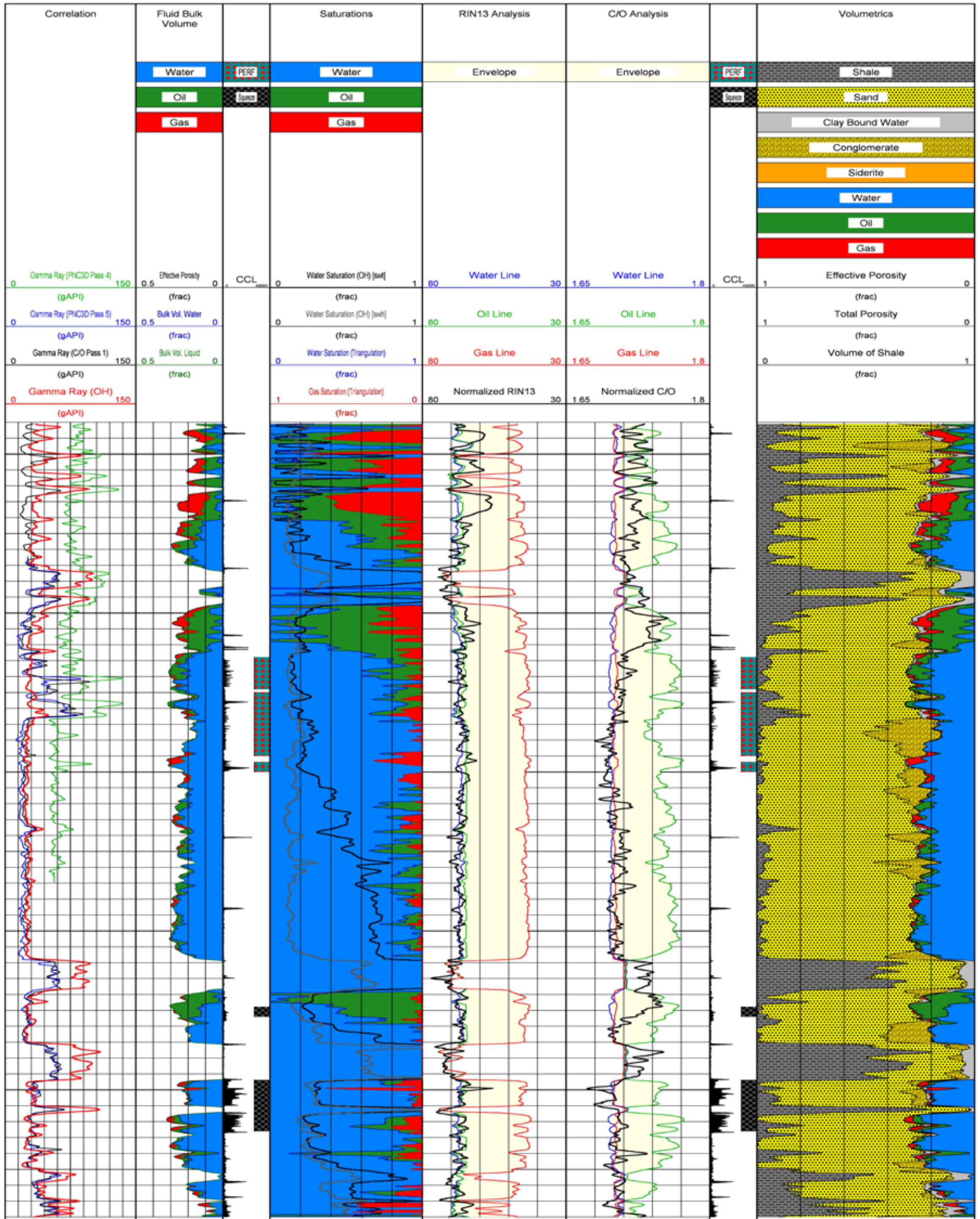


Kim & Chace, 2016

Example 1

By-passed Oil Saturation

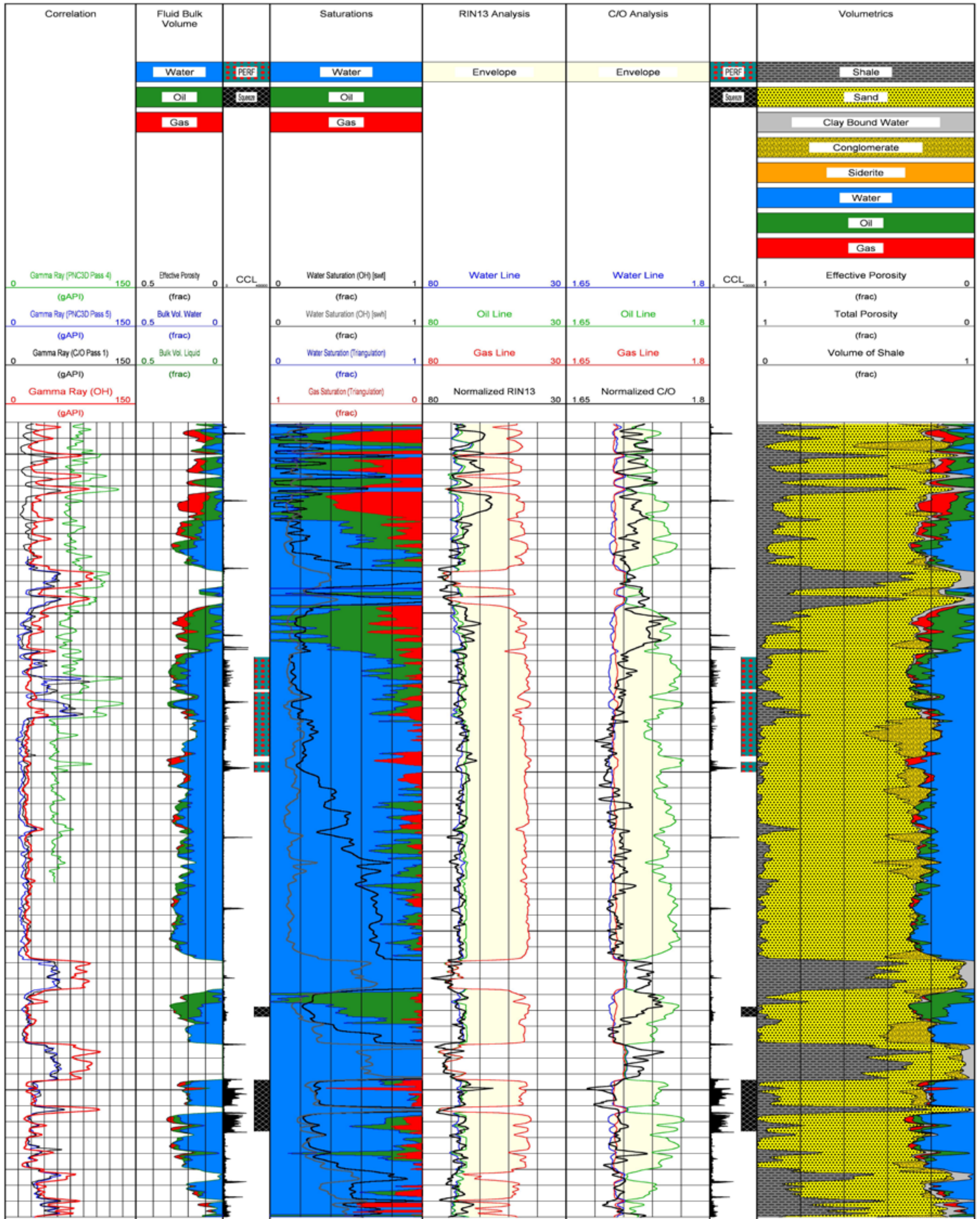
- A giant oil-producing field
  - The main oil-bearing reservoir is under the gas cap
  - Relatively freshwater environment (~35 kppm)
  - In-situ oil density of 0.78 g/cc
  - Mineralogy/ lithology includes quartz, conglomerate, and siderite



Example 1

By-passed Oil Saturation

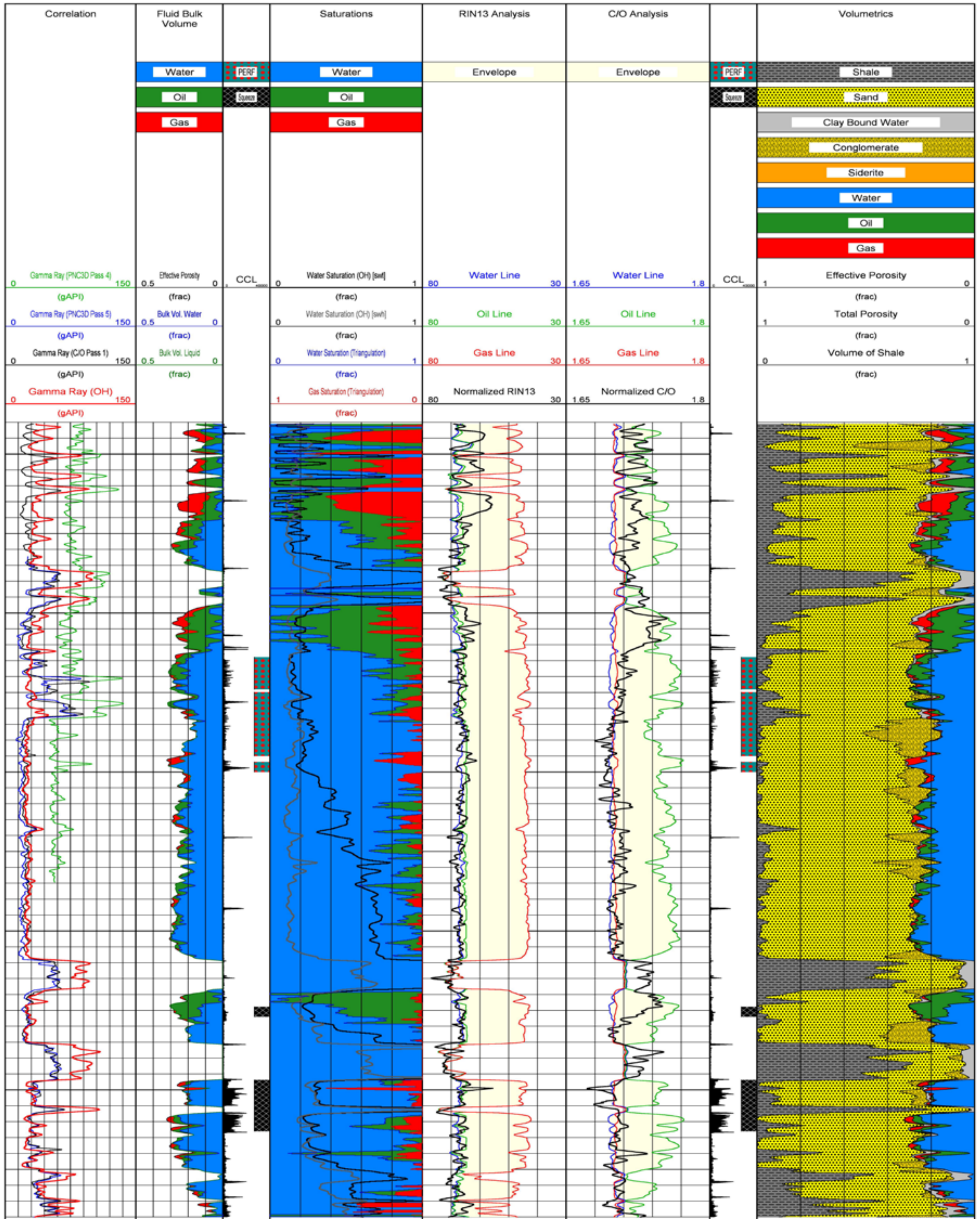
- Challenges
  - The operator couldn’t obtain reliable three-phase saturation using conventional PN or cased-hole resistivity logs
  - Gas in the borehole
  - Post-waterflood recovery resulted in unpredictable/ various water salinity range
    - Sigma analysis is not applicable



Example 1

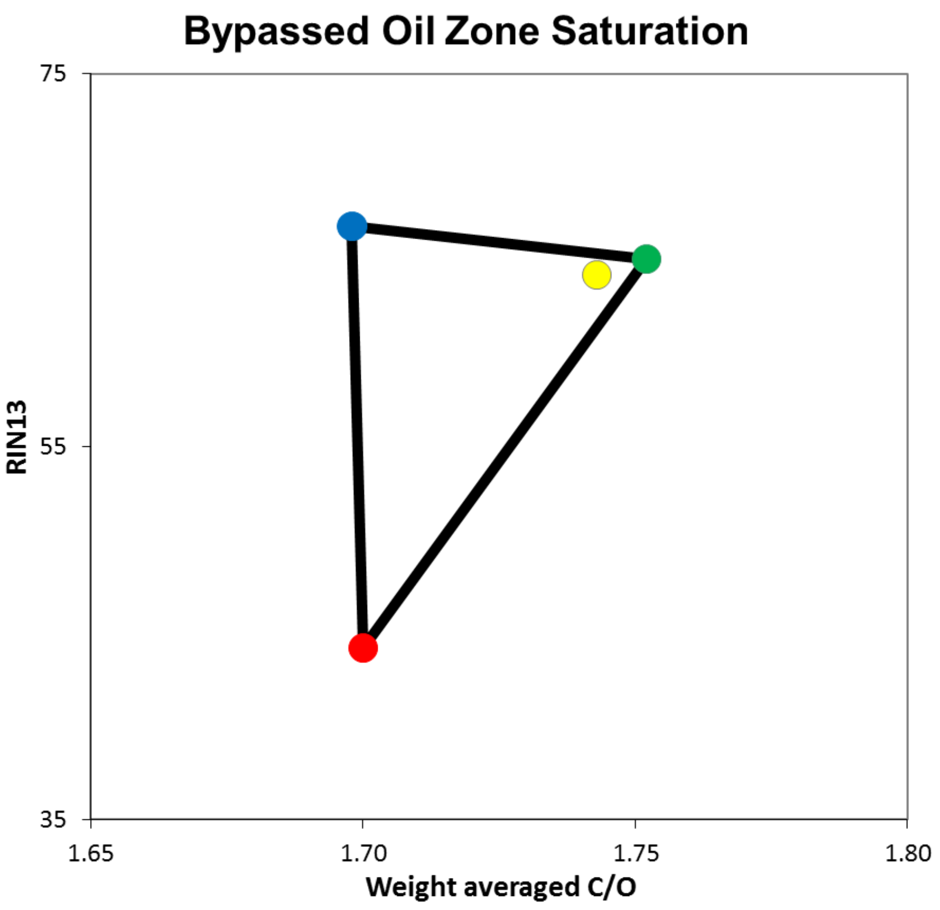
By-passed Oil Saturation

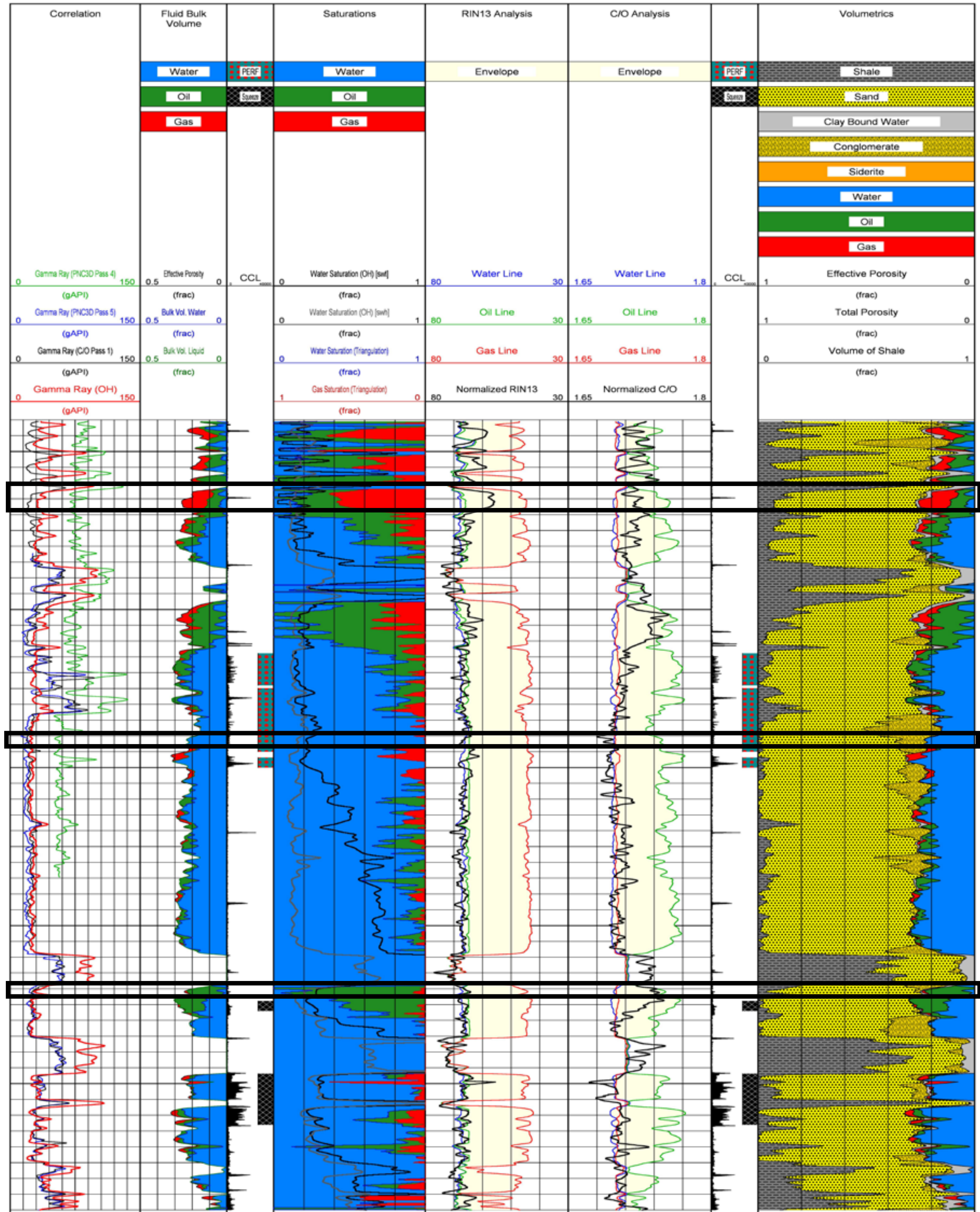
- Objectives
  - Current reservoir fluid identification
  - Understanding of gas cap and fluid contact movement
  - Identification of perforation addition intervals



Example 1

By-passed Oil Identification

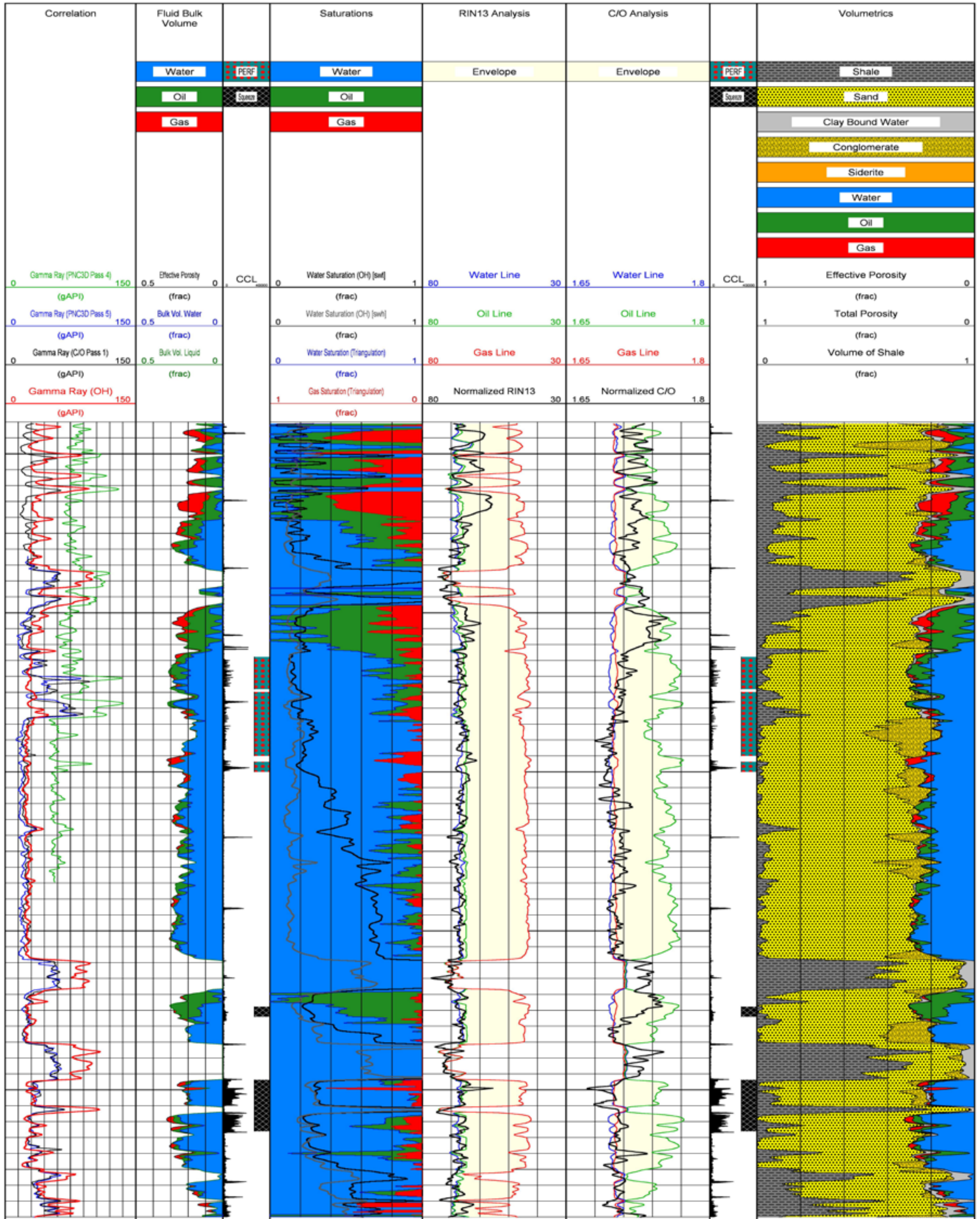




Example 1

By-passed Oil Identification

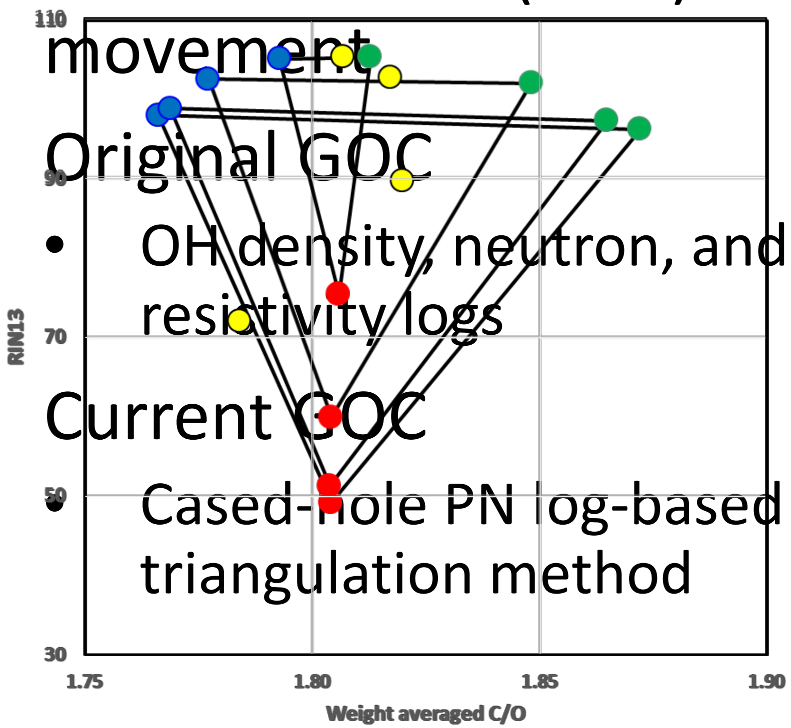
- Delivered solutions
  - Identified watered-out zones
  - Quantification of oil saturation for potential perforation zones
  - Gas cap development characterization
  - The customer added and squeezed perforation based on the delivered solution
  - A highly successful campaign resulted in a significant increase in production
    - Vertical and horizontal wells

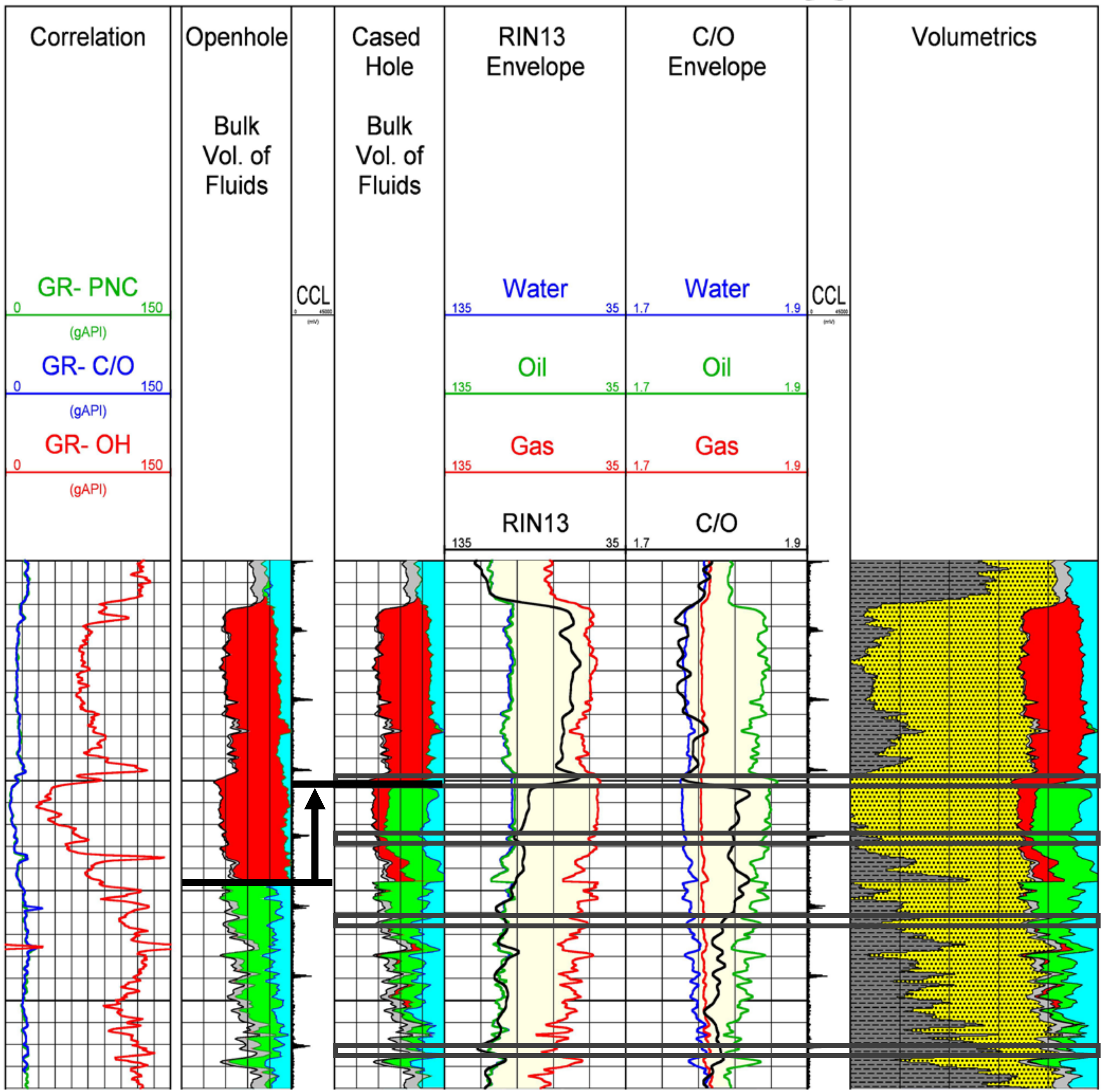


Example 2

Fluid Contact Monitoring

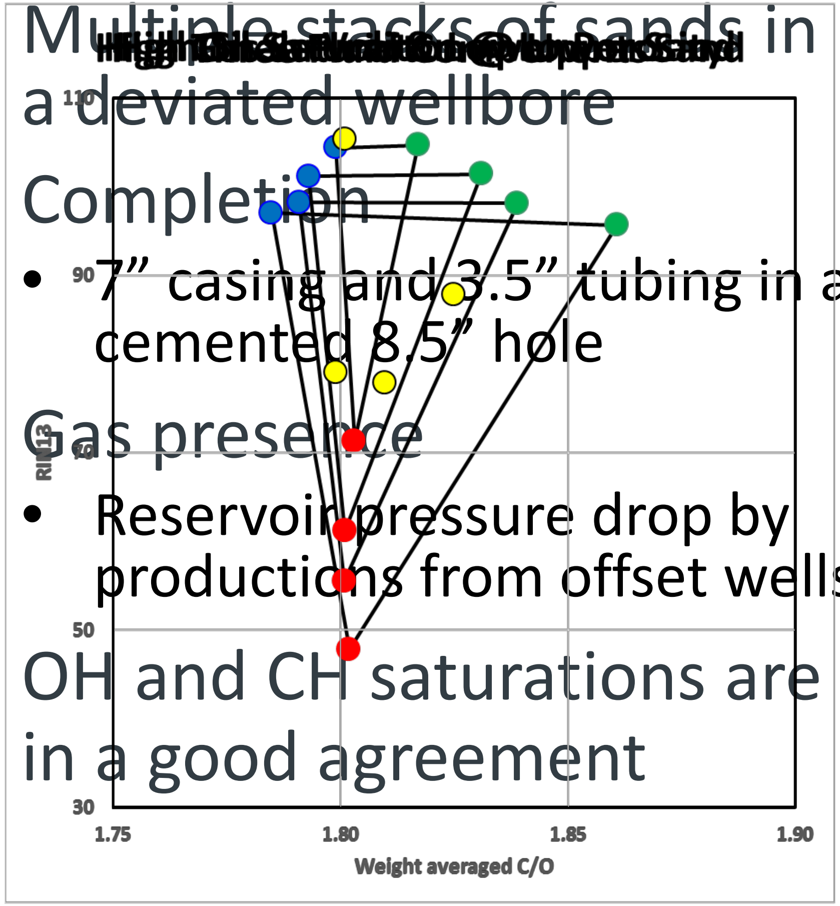
- Gas-oil contact (GOC) movement
- Original GOC
  - OH density, neutron, and resistivity logs
- Current GOC
  - Cased-hole PN log-based triangulation method



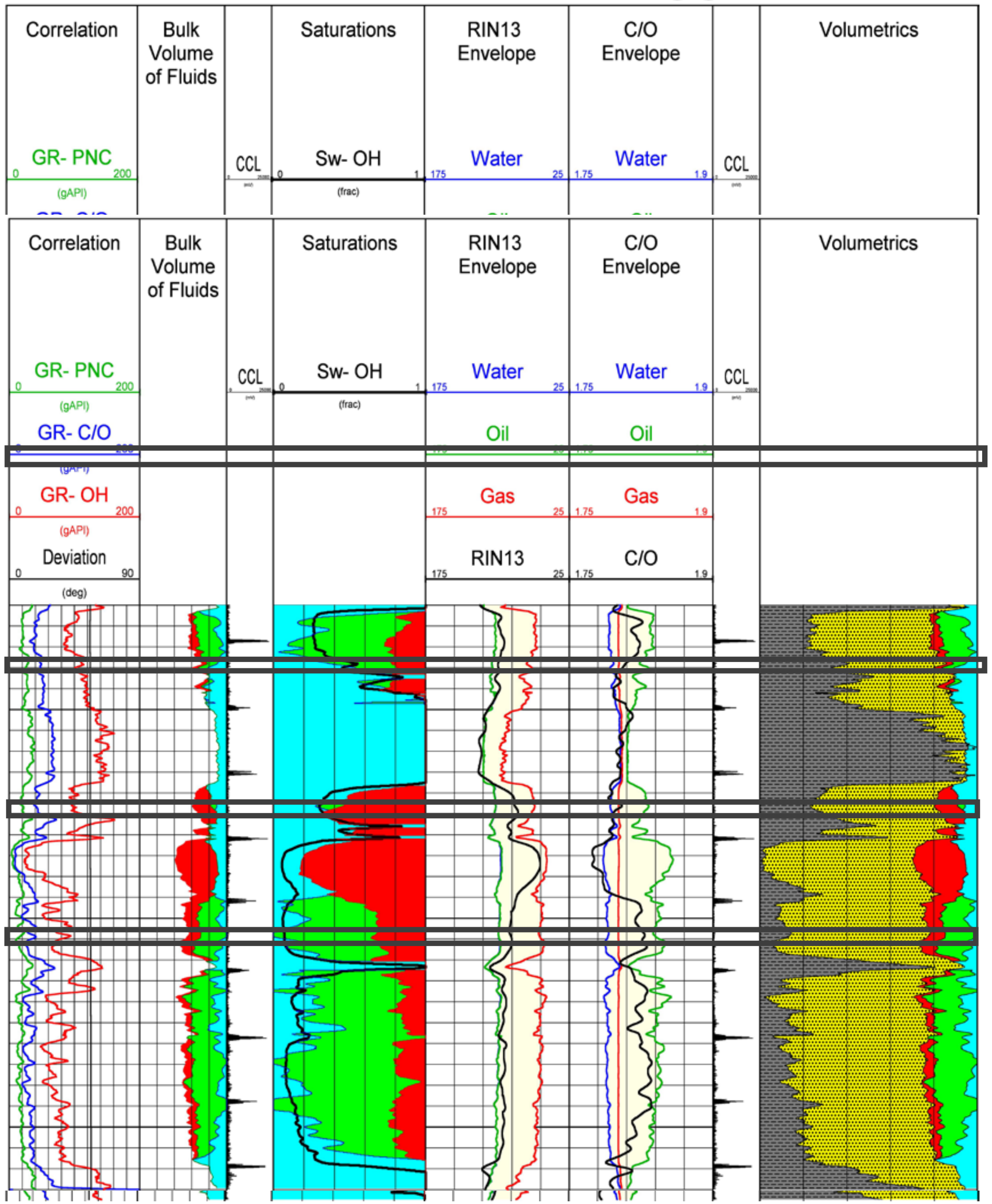


Example 3

Multiple Stacks of Sands



- Multiple stacks of sands in a deviated wellbore
- Completion
  - 7” casing and 3.5” tubing in a cemented 8.5” hole
- Gas presence
  - Reservoir pressure drop by productions from offset wells
- OH and CH saturations are in a good agreement



Summary and Conclusions

1. Multidetector PN well logging allows the surveillance of multiphase reservoir fluid components in open- and cased-hole completions
2. Continuous upgrades and developments in PN tools and analysis algorithms/workflows
3. A salinity-independent triangulation technique is a powerful data analysis method
   I. Avoid two-step PN data use and correction algorithm
   II. Combination of two inelastic PN measurements and MCNP models
   III. Simultaneous solution of three-phase formation fluid saturations
   IV. Applicable in any reservoir conditions

Summary and Conclusions

4. The triangulation method has been successfully applied in various onshore and offshore wells around the globe
5. Solutions have enabled the operator to
   i. Understand current reservoir fluid saturations
   ii. Perform subsequent well and reservoir management activities