Applying Fluid Inclusions to Petroleum Exploration and Production

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FIT
Innovations in Petroleum Risk Management

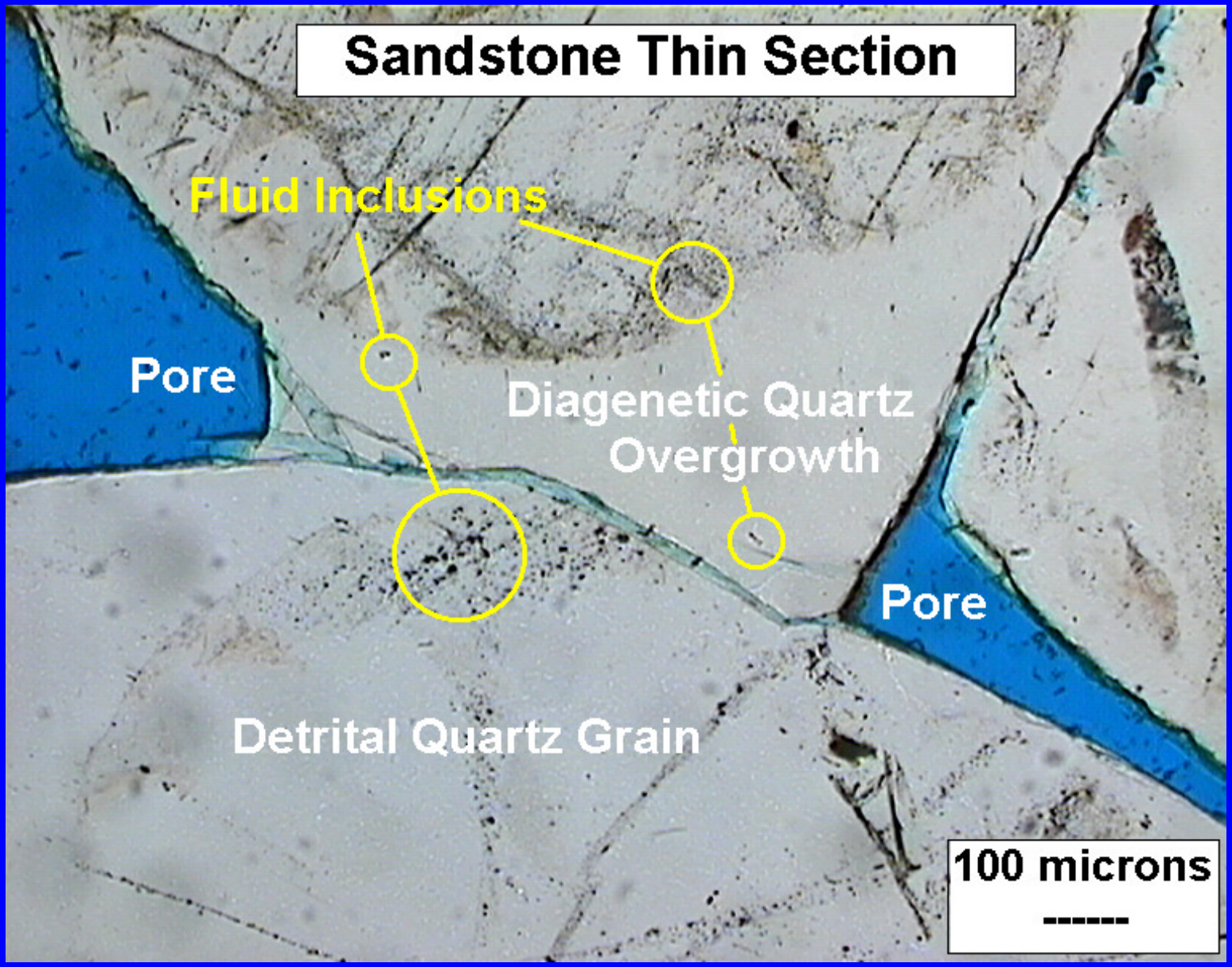
Main Points

- Fluid inclusion techniques are flexible tools applicable to fundamental E&P problems
- These techniques can increase our understanding of the petroleum system and help manage E&P risk by assessing the present and past distribution of petroleum, its sources and characteristics
- Fluid Inclusion Stratigraphy (FIS) can help high-grade present and future prospects

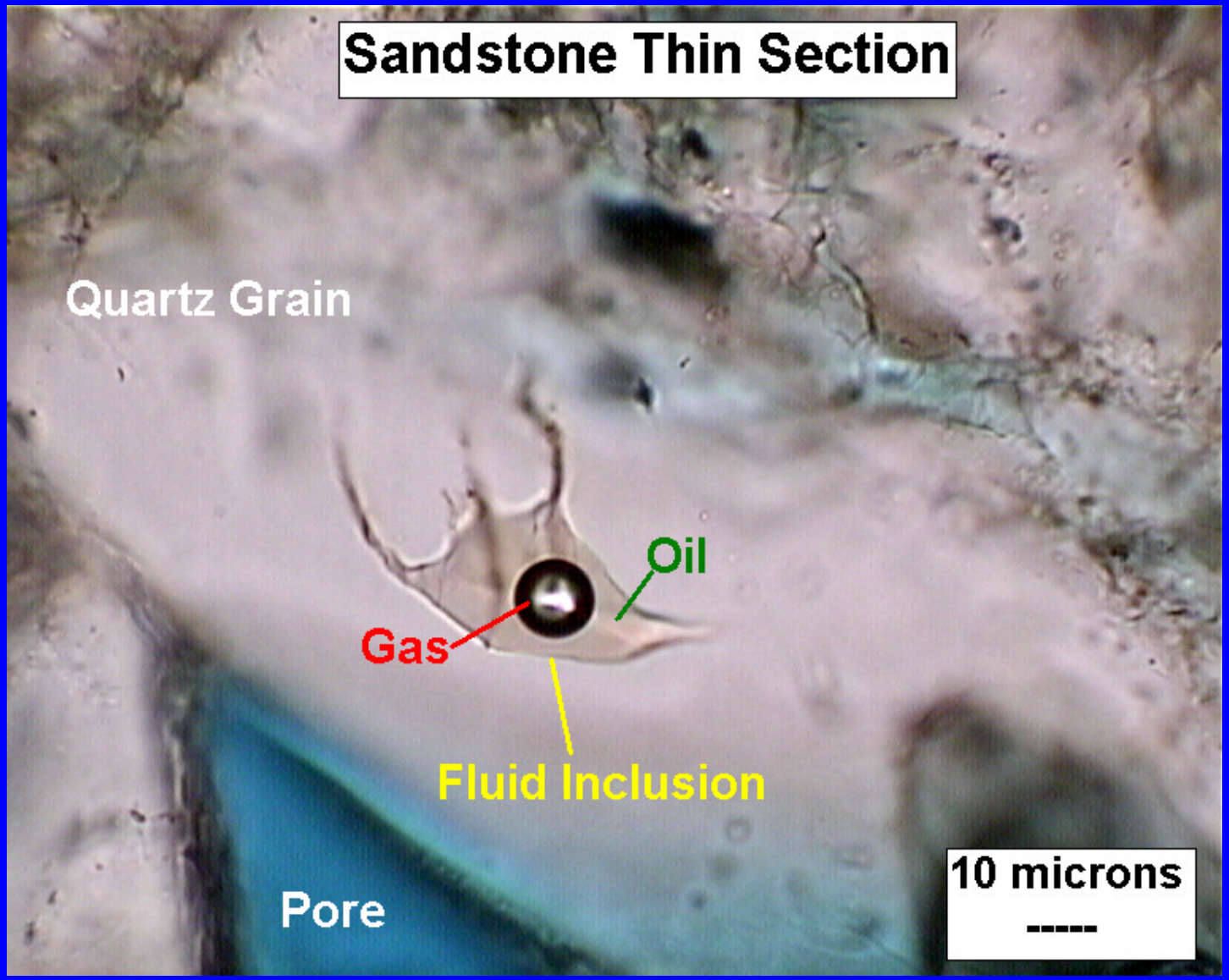
What are Fluid Inclusions?

- Micron-scale, fluid-filled isolated cavities in or between crystals in rock material
- Form during subsurface diagenetic process in which mineral cement is added to intergranular pore space or microfractures
- Are representative of past or near-present-day pore fluids. They track movement of aqueous and petroleum fluids

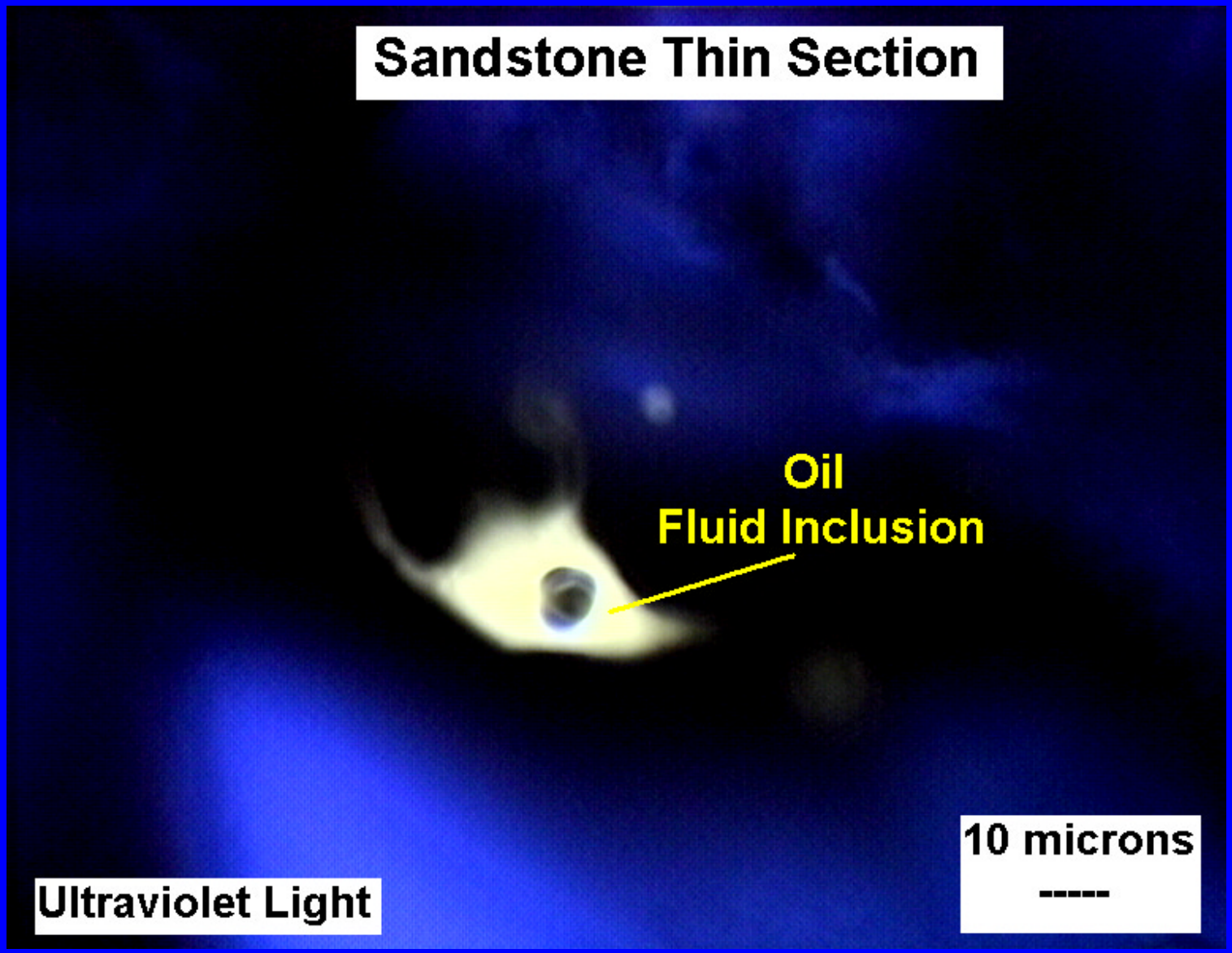
Fluid Inclusions in Sandstone



Petroleum Inclusion in Quartz



Petroleum Inclusion in Quartz



Why Care About Fluid Inclusions?

- May be the freshest samples of reservoir fluids we have
- Remain even after pore fluids change (applications for fossil migration paths, flushed reservoirs and tilted oil-water contacts)
- Record multiple charges, temperatures and pressures

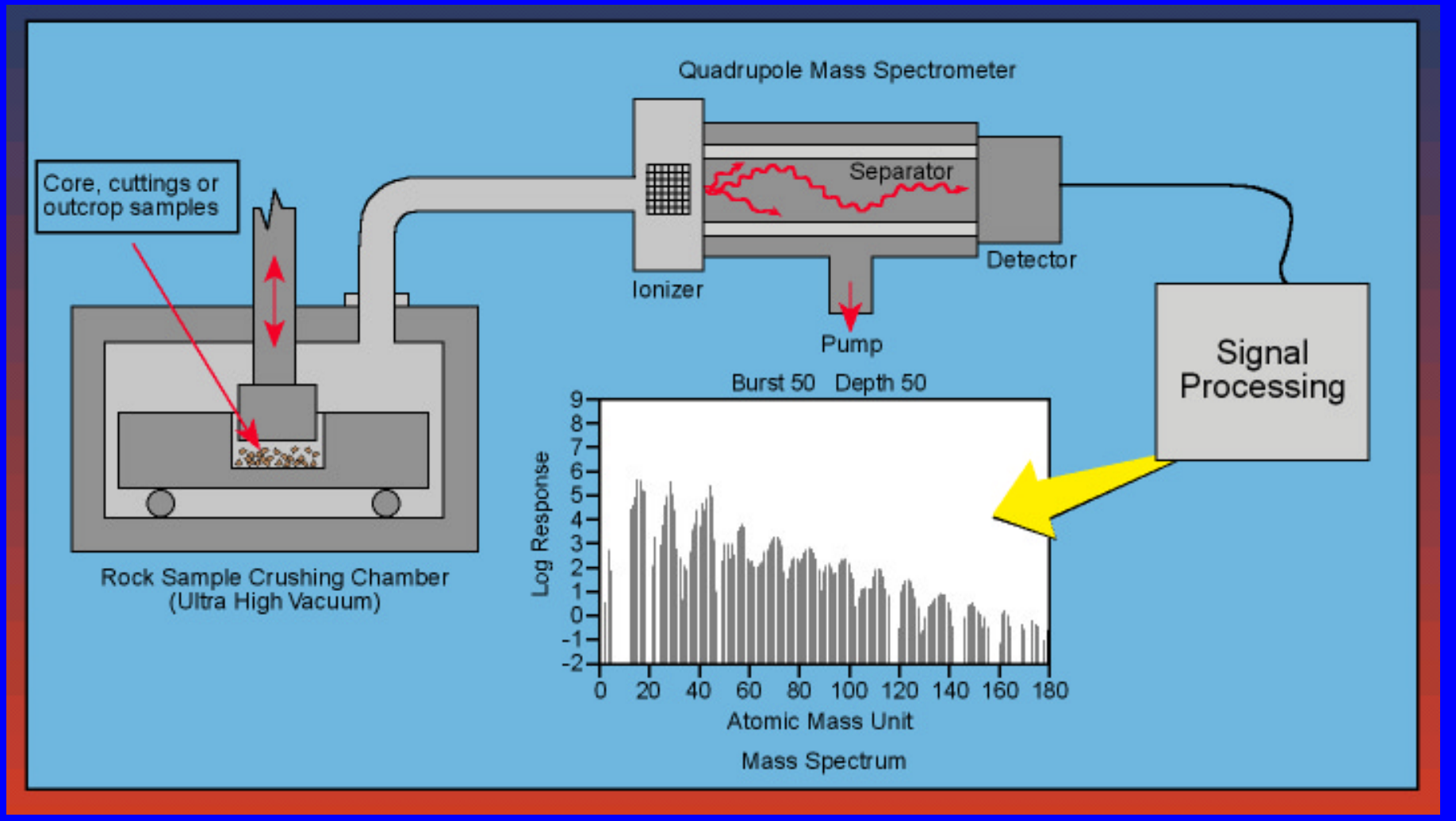
Classical Approach

- Thin section based
- Assumes selection of the most relevant samples for analysis
- Best applications are for P-T-X assessment; petroleum compositions typically are crudely constrained, or inferred by local production
- Difficult to apply to dry gas problems
- Regional evaluations are time-intensive

Fluid Inclusion Stratigraphy (FIS)

- Stratigraphic mapping of paleofluid chemistries through bulk mass spectrometric analysis of fluid inclusion volatile species (inorganics and organics to C13)
- Rapid, automated analytical system allows cost-effective, regional evaluation of thousands of samples in a matter of days

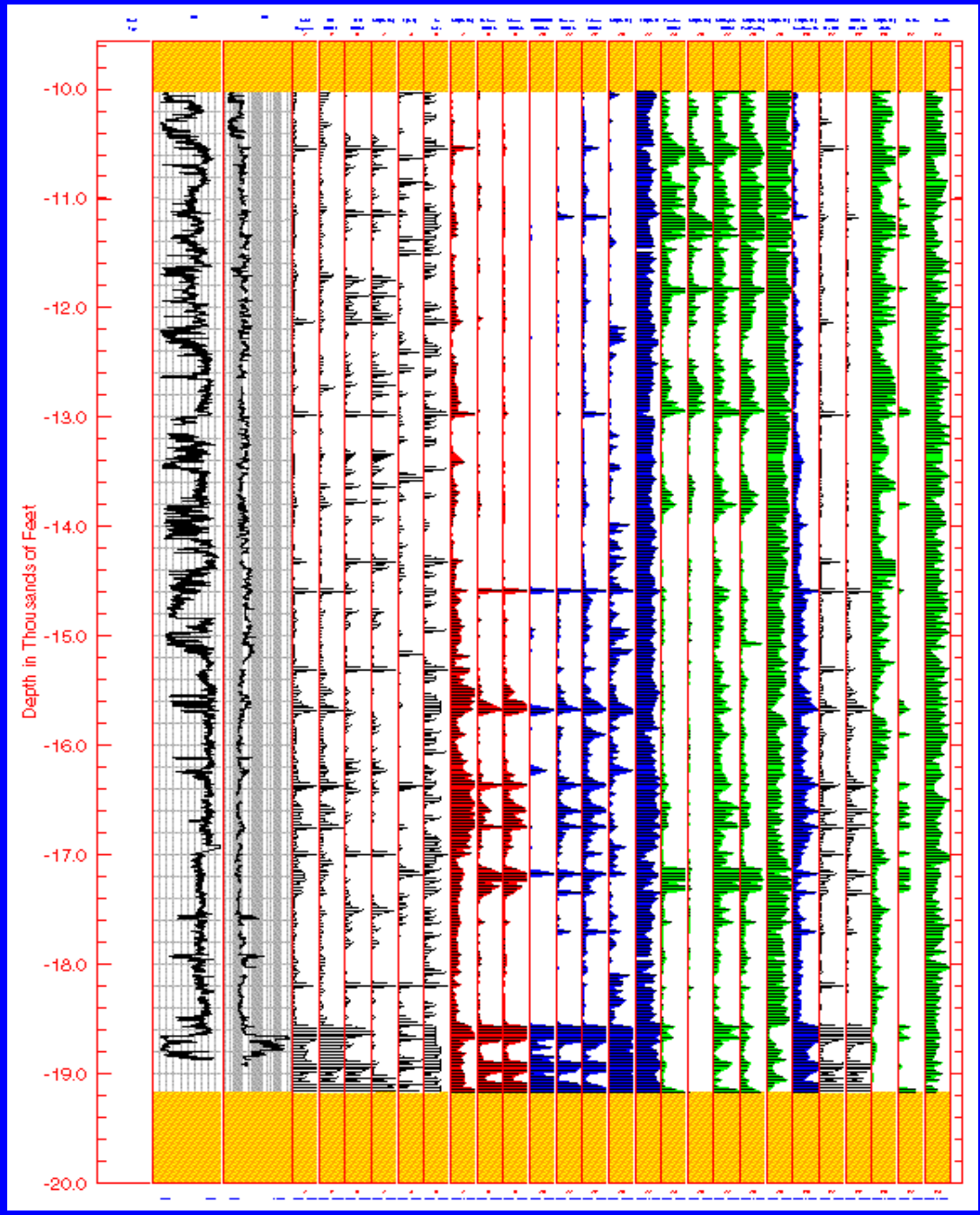
Schematic of FIS Technique



Automated FIS Instrumentation

FIS Data

Depth plots of critical species and compound ratios integrated with electric logs indicate petroleum inclusion distribution seals and proximal pay



E&P Applications of FIS

- Mapping migration pathways
- Pay delineation / relative fluid saturation / oil-water and gas-water contacts
- Implying up-dip pay from wet wells
- Implying deeper prospectivity from shallow drilling
- Product type and quality issues (sour gas, biodegradation, oil vs. gas)

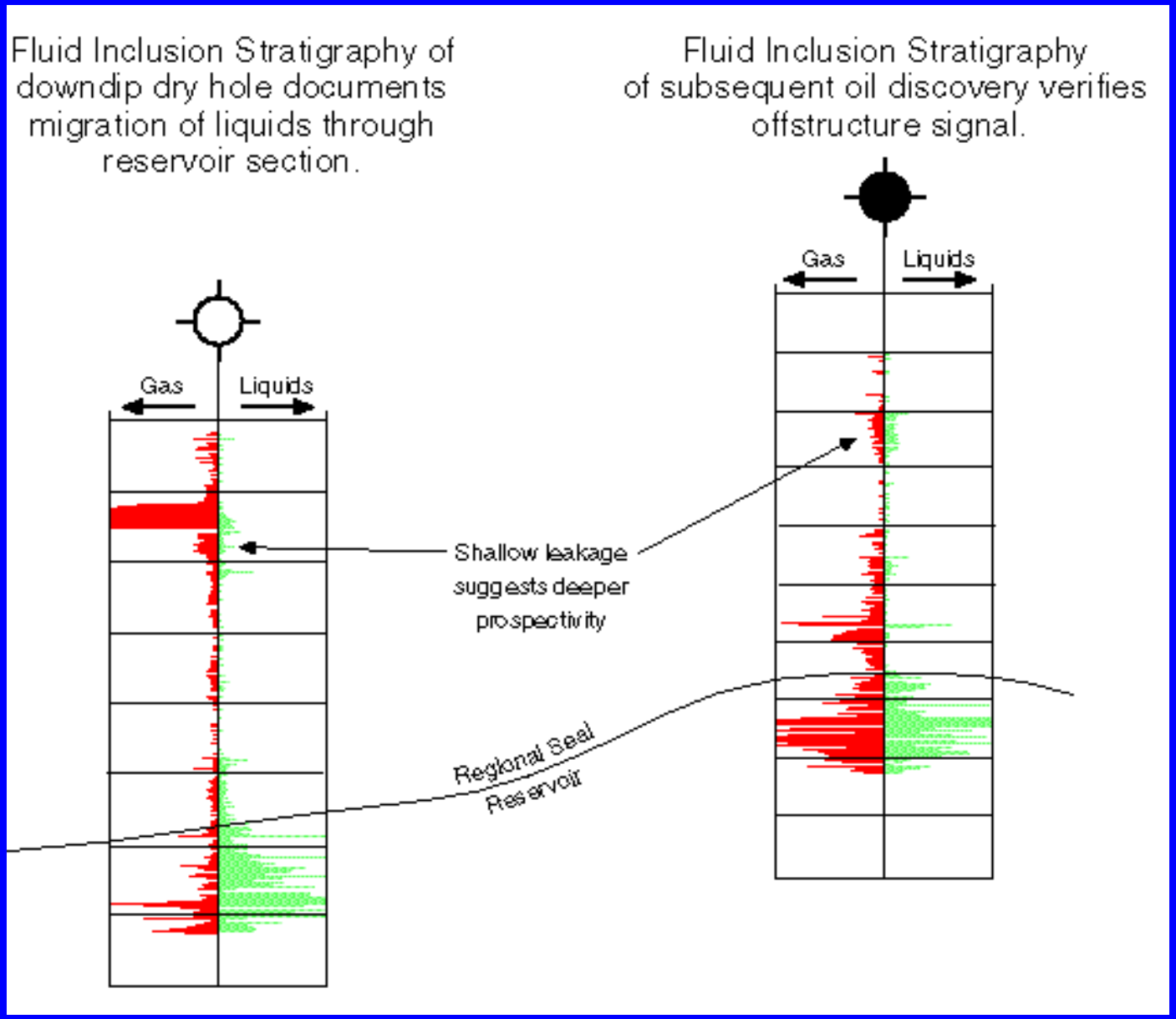
E&P Applications of FIS (Cont.)

- Reservoir connectivity
- Seal identification and effectiveness
- Pressure compartments
- Identifying products evolved from mature source rocks
- Fault location
- Exposure surface delineation

Inferring Up-Dip Prospectivity from a Wet Well

- Well drilled off structure with no shows; reservoir sand was wet
- Strong FIS liquid and gaseous petroleum indications were obtained on wet reservoir sand, suggesting that oil and gas migrated through target section
- Up-dip well discovered oil and gas in reservoir equivalent interval; API matched that measured in thin section on wet well

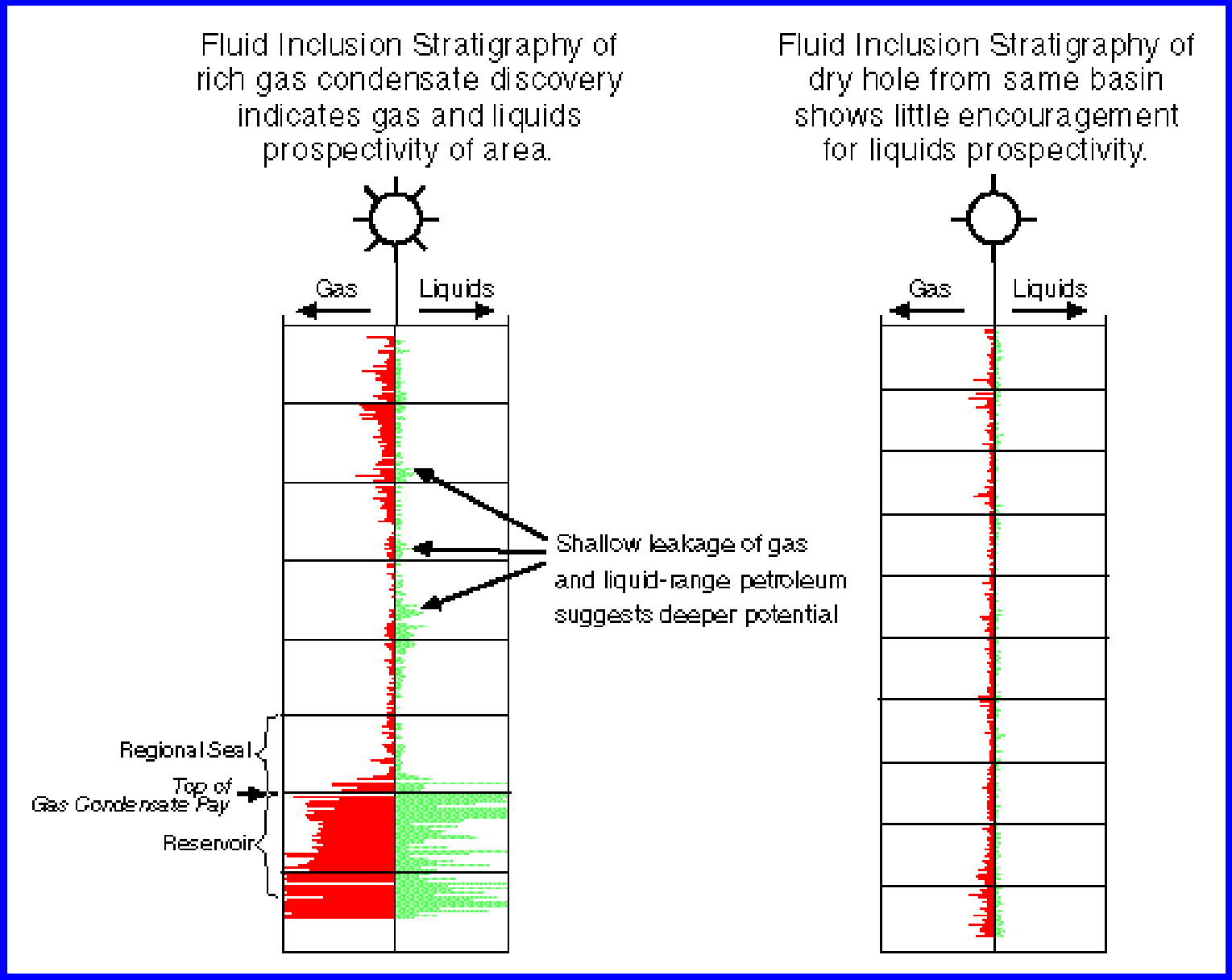
Up-dip Prospectivity from Wet Well



Local Prospectivity / Deeper Potential from Shallow Drilling

- FIS data from rich gas-condensate discovery delineates top of pay and regional seal
- Shallow leakage of gas and liquids is encouraging for deeper potential
- FIS data from dry hole in same basin does not show evidence of shallow seep signature nor migration through reservoir section

Local Prospectivity / Deeper Potential



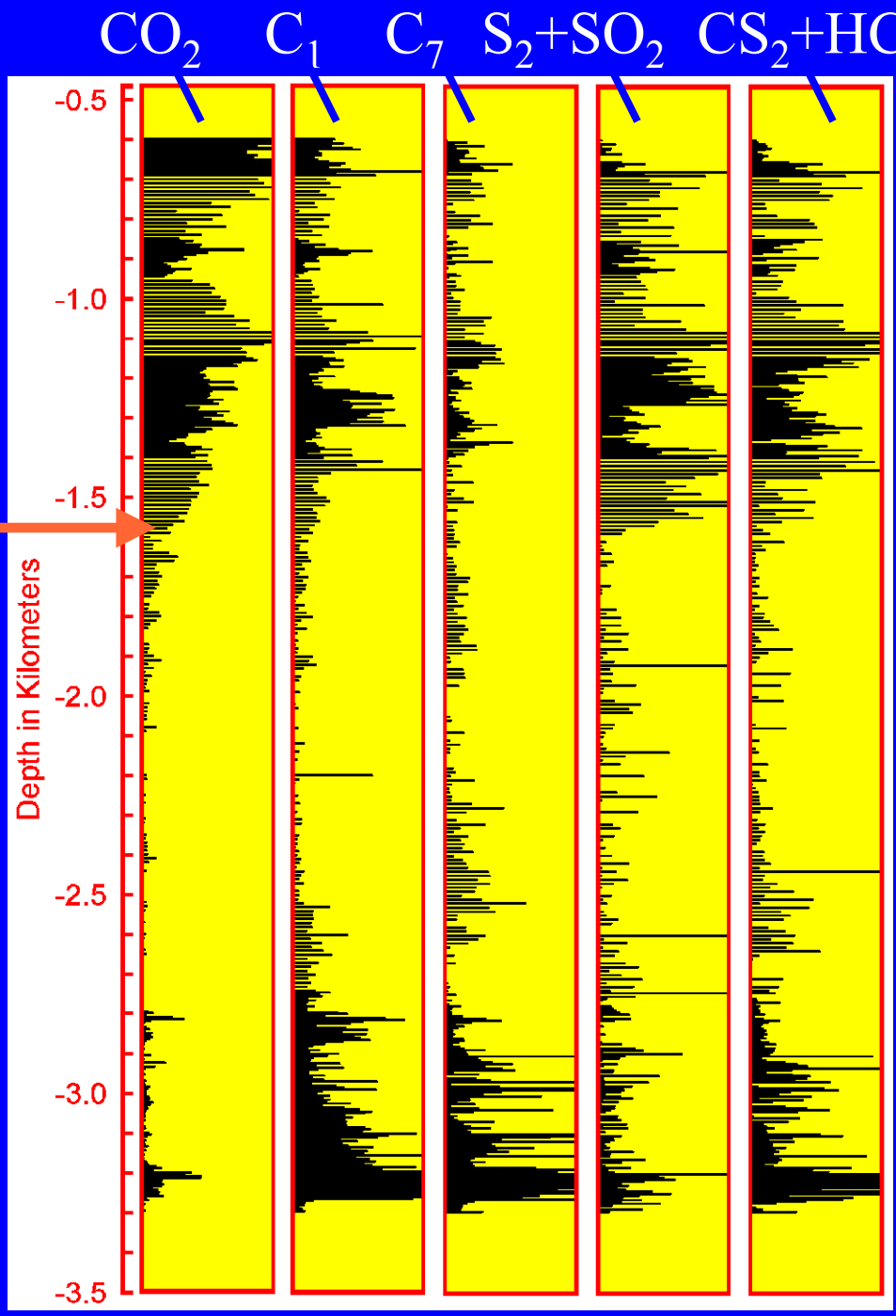
FIS Microseep Over Oil Reservoir

FIS Microseep

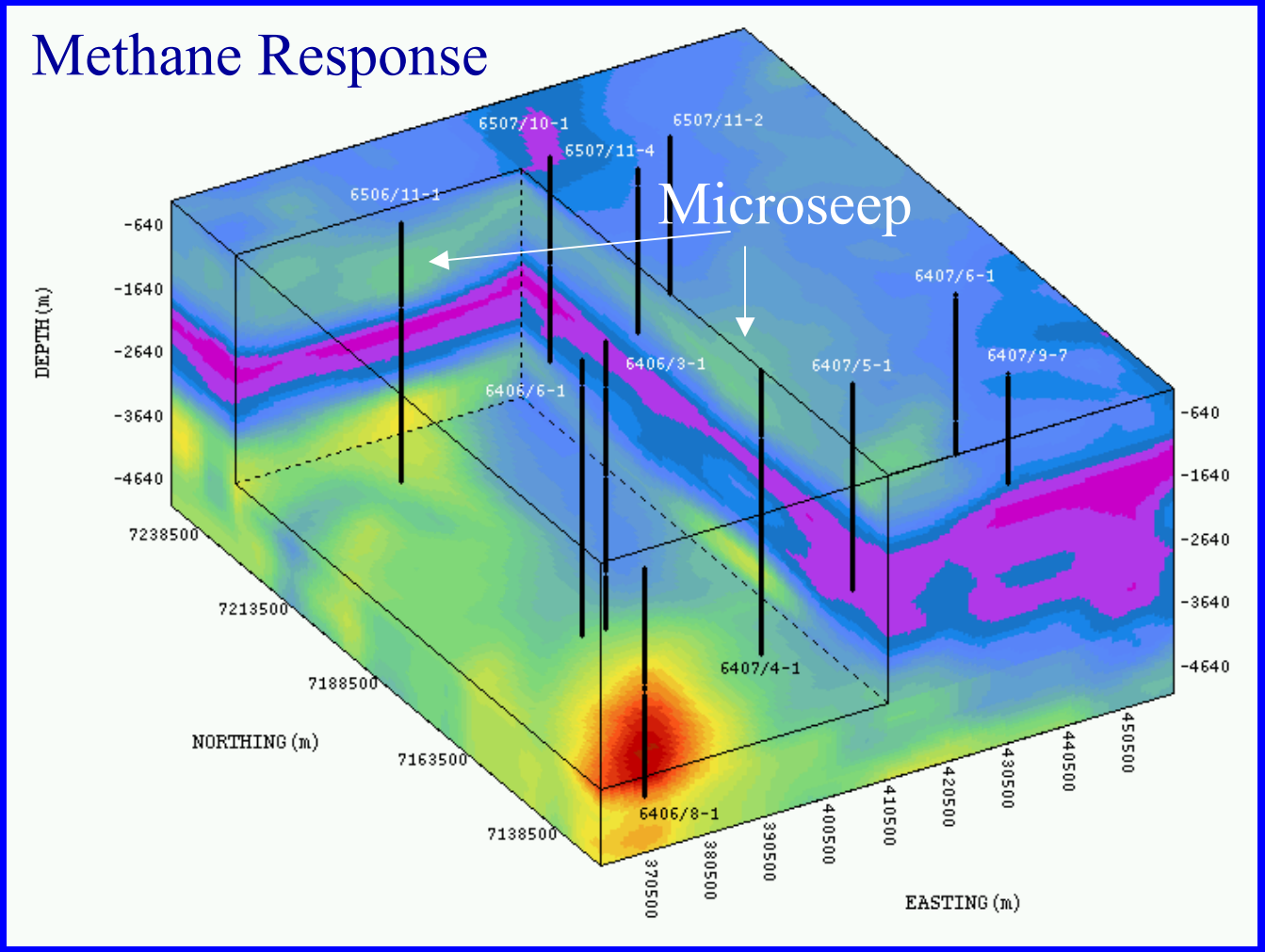
60°C

Sealing Interval

Main Reservoir Sand

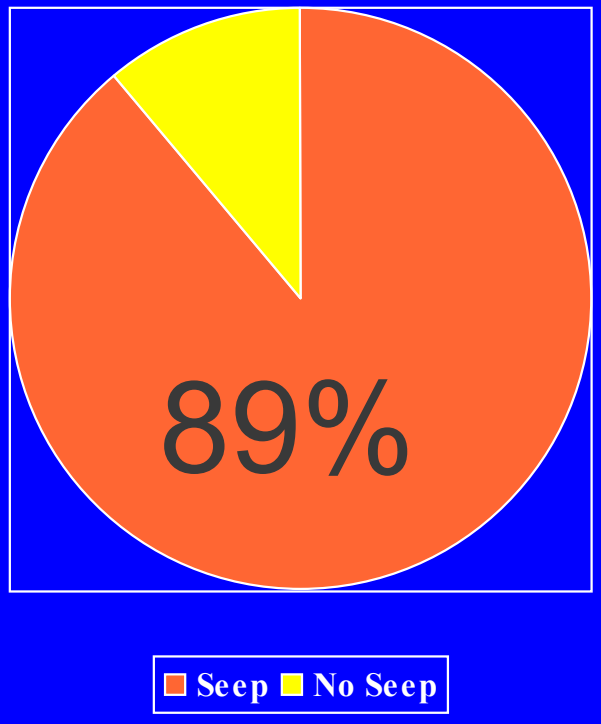


3-D Stochastic Modeling of FIS Data; Haltenbanken Area

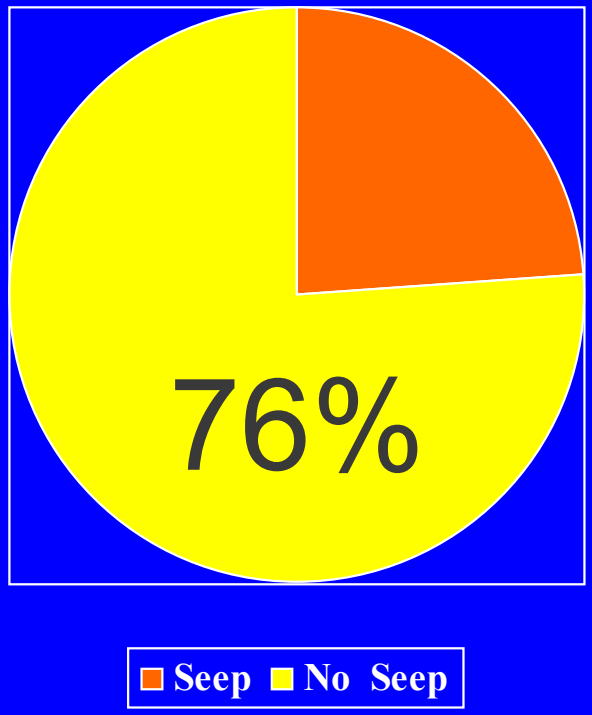


GOM FIS Seep Statistics

Producers



Deep Dry Holes



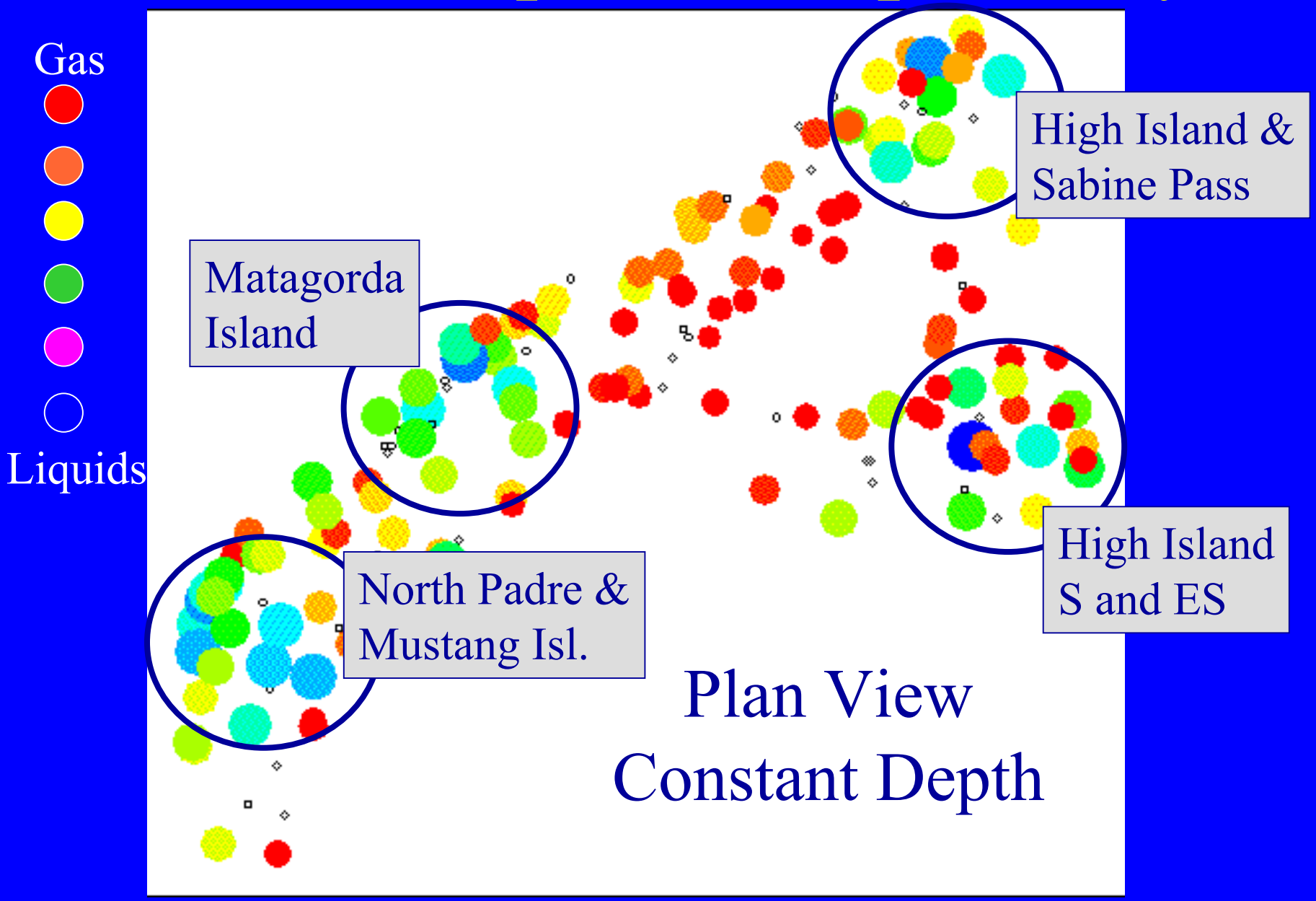
Predicted Drilling Success Rate

- 76% chance of deepening an existing shallow well *with* an FIS seep signal and encountering pay
- Only an 11% chance of deepening an existing shallow well *without* an FIS seep signal and encountering pay

Regional Evaluation

- 20,000 samples from 180 wells evaluated with FIS in 6 weeks
- Defined areas of gas, condensate and oil prospectivity
- Suggested deeper potential in areas with shallow well control.
- Basin-scale high-grading tool

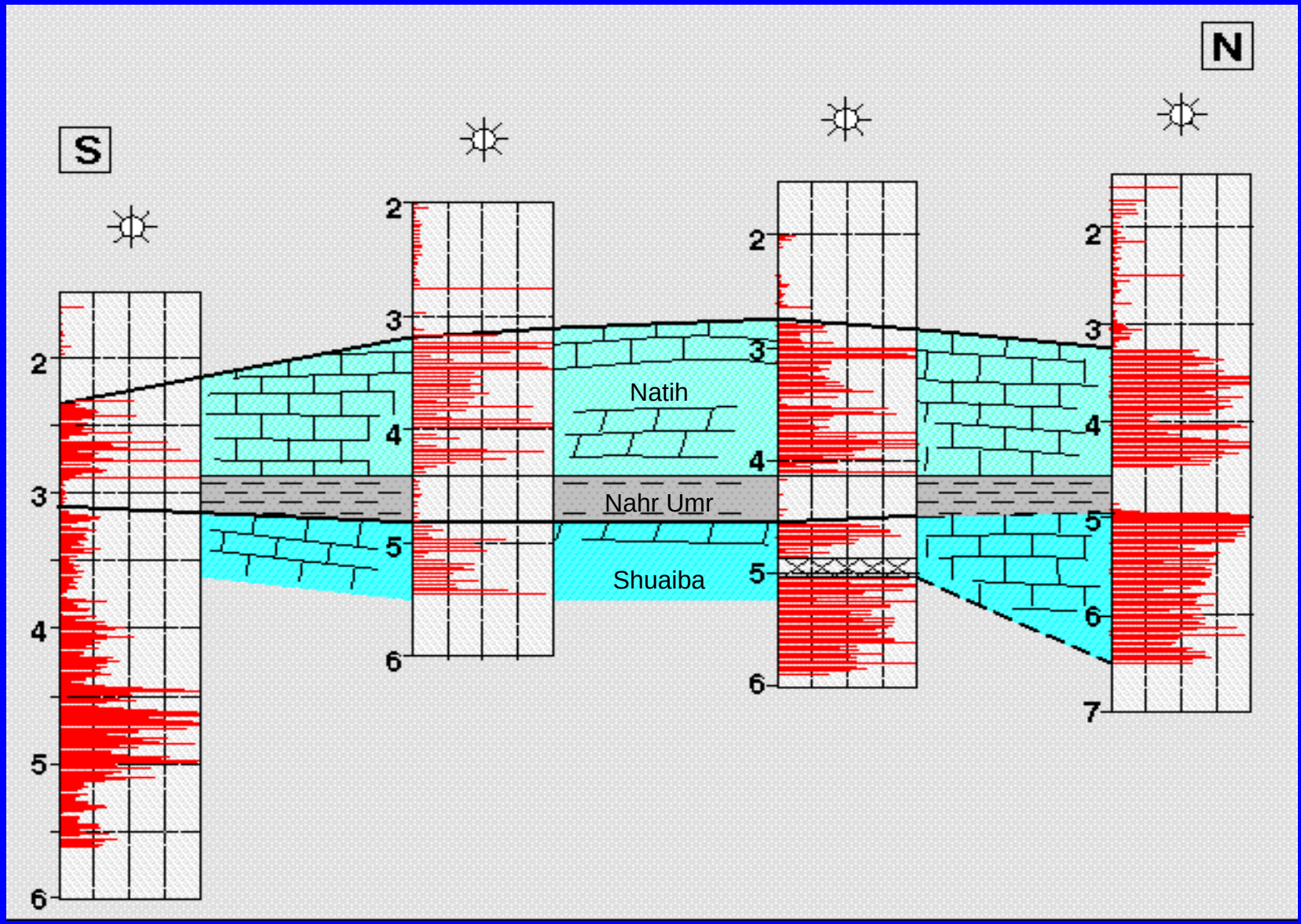
Gas vs. Liquids Prospectivity



Identifying Seals

- FIS methane distribution for several wells along transect document low abundance across regional seal
- Additional FIS data indicate that fluid on either side of seal has discrete chemistry, suggesting limited communication over geologic time
- Geochemical data suggest reservoirs produce petroleum from different source rocks

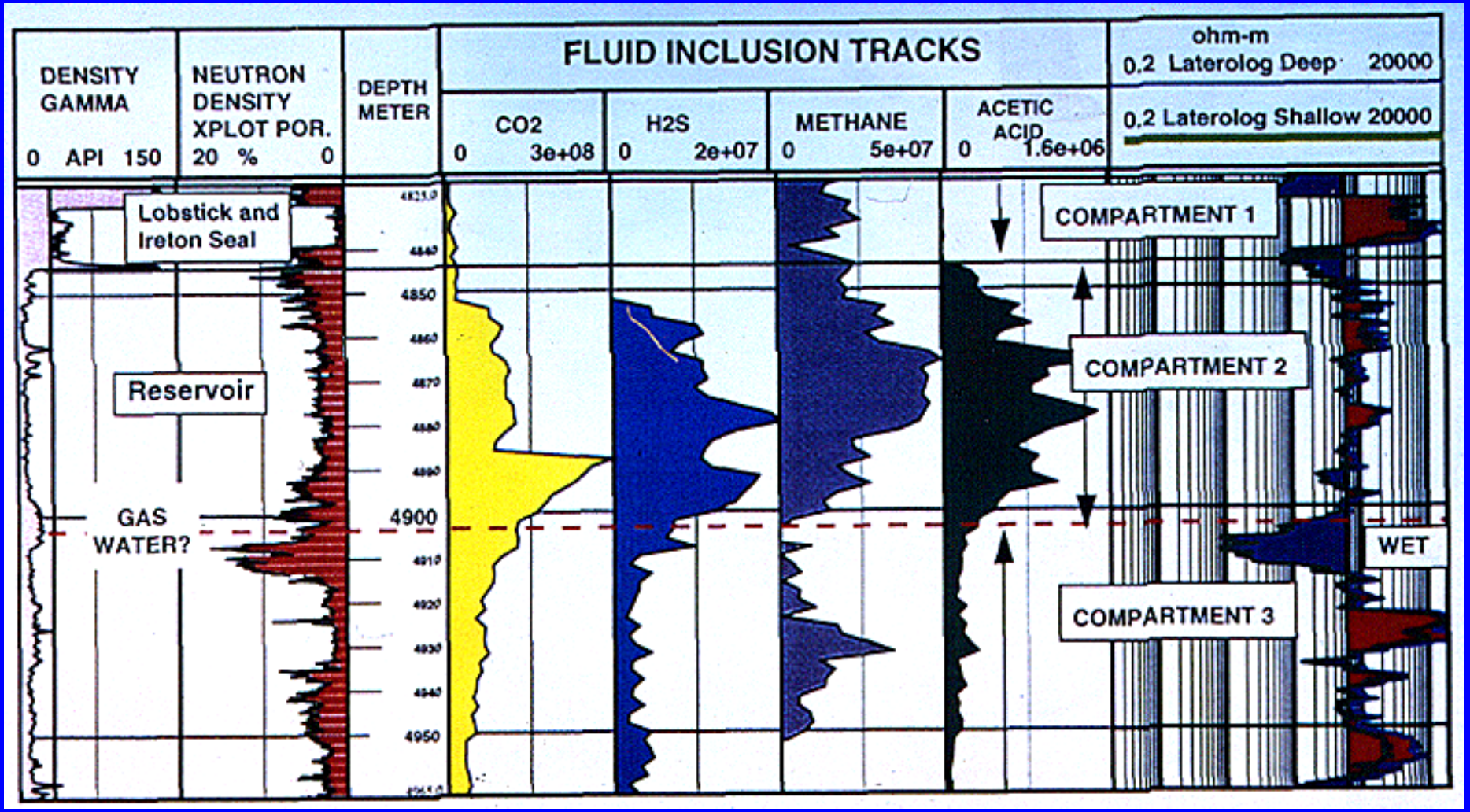
Seal Definition / Characterization



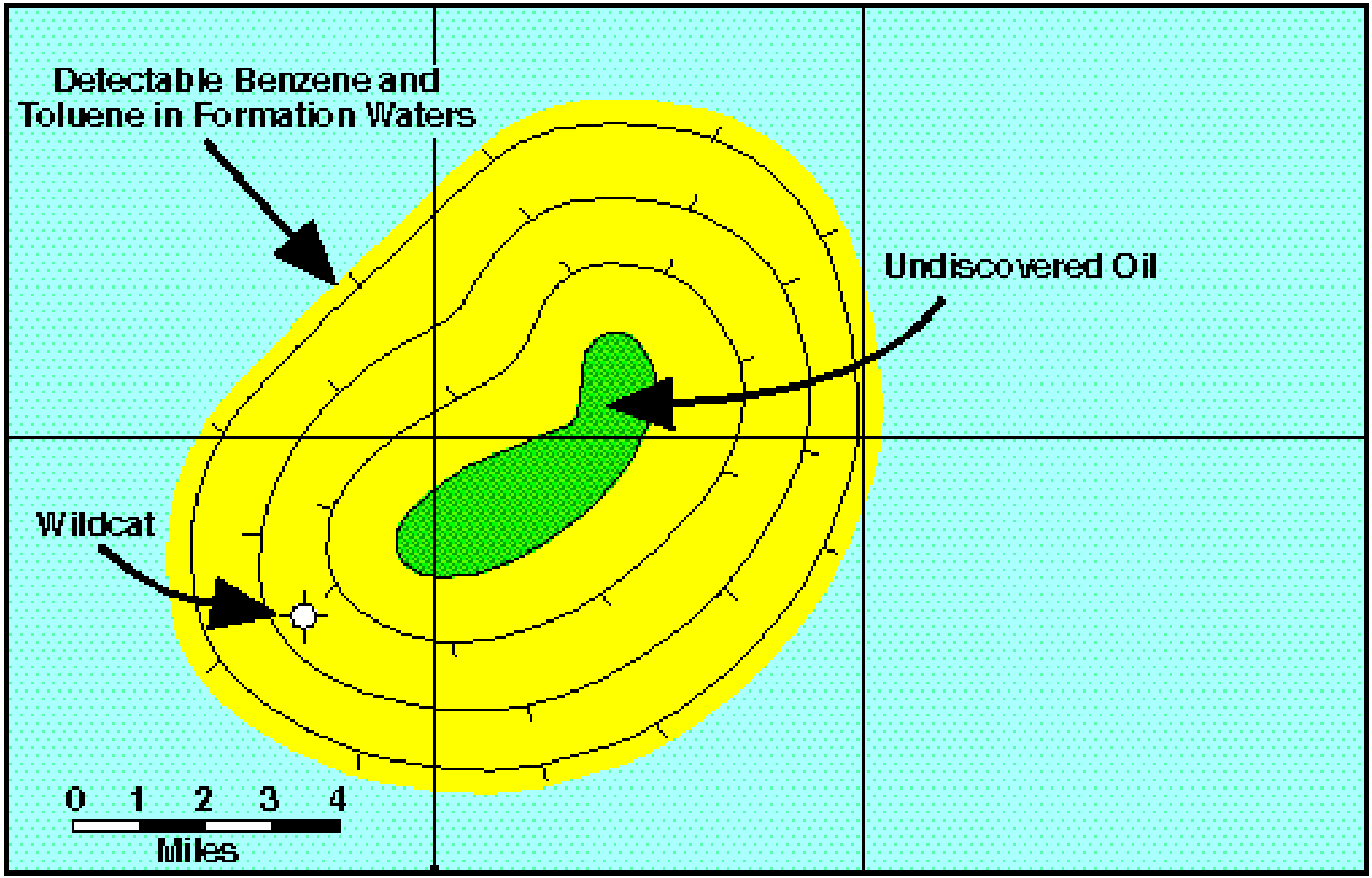
Seal Effectiveness

- Wet Leduc reservoir
- FIS data provide evidence for paleocolumn of gas
- Data also suggest leakage of top seal as possible failure mode for prospect
- Reactivation of nearby fault is implicated

Seal Effectiveness



Proximity-to-Pay Concept

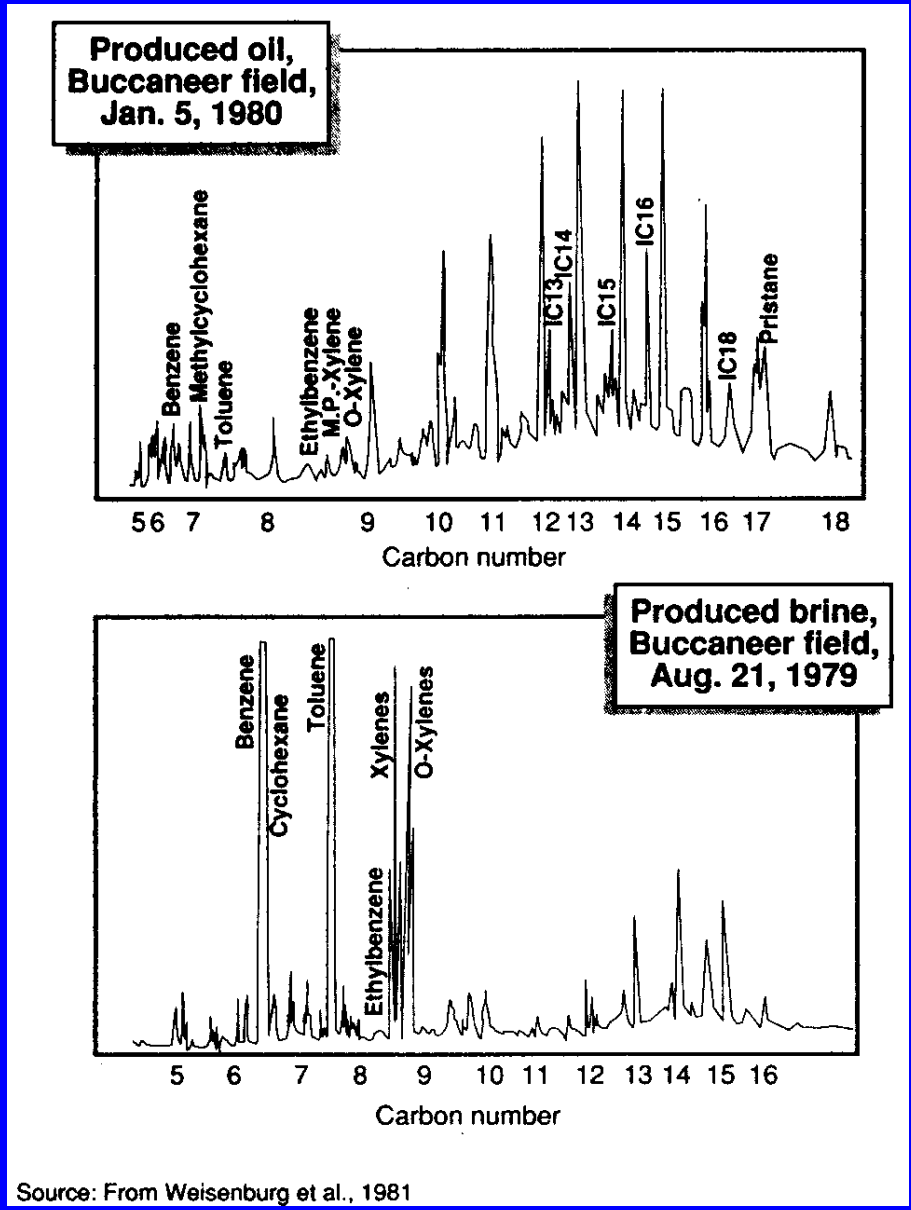


Benzene in Oil Field Brines

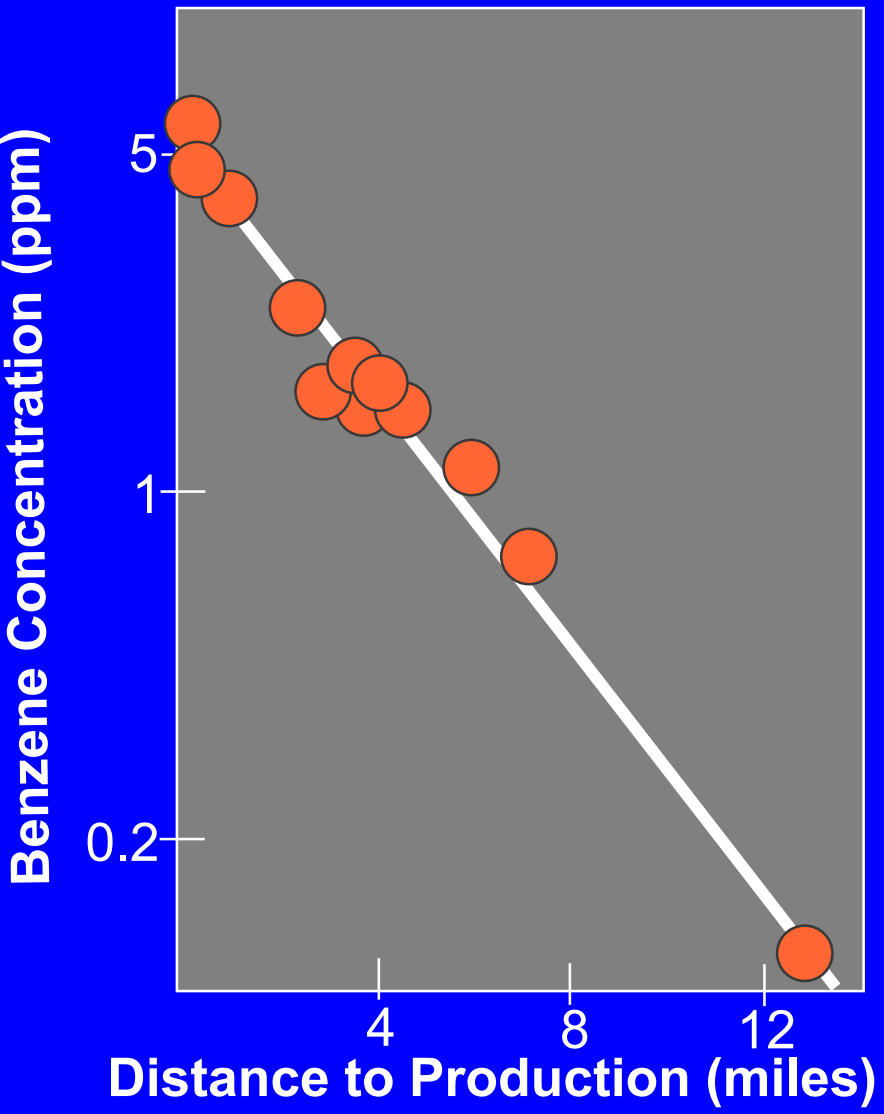
Buccaneer Field; Galveston Blks. 288 and 296; GOM

BTEX compounds are fractionated into brine due to their high solubility in water

From Burtell and Jones; OGJ; June '96



Benzene in Alberta Nisku Brines

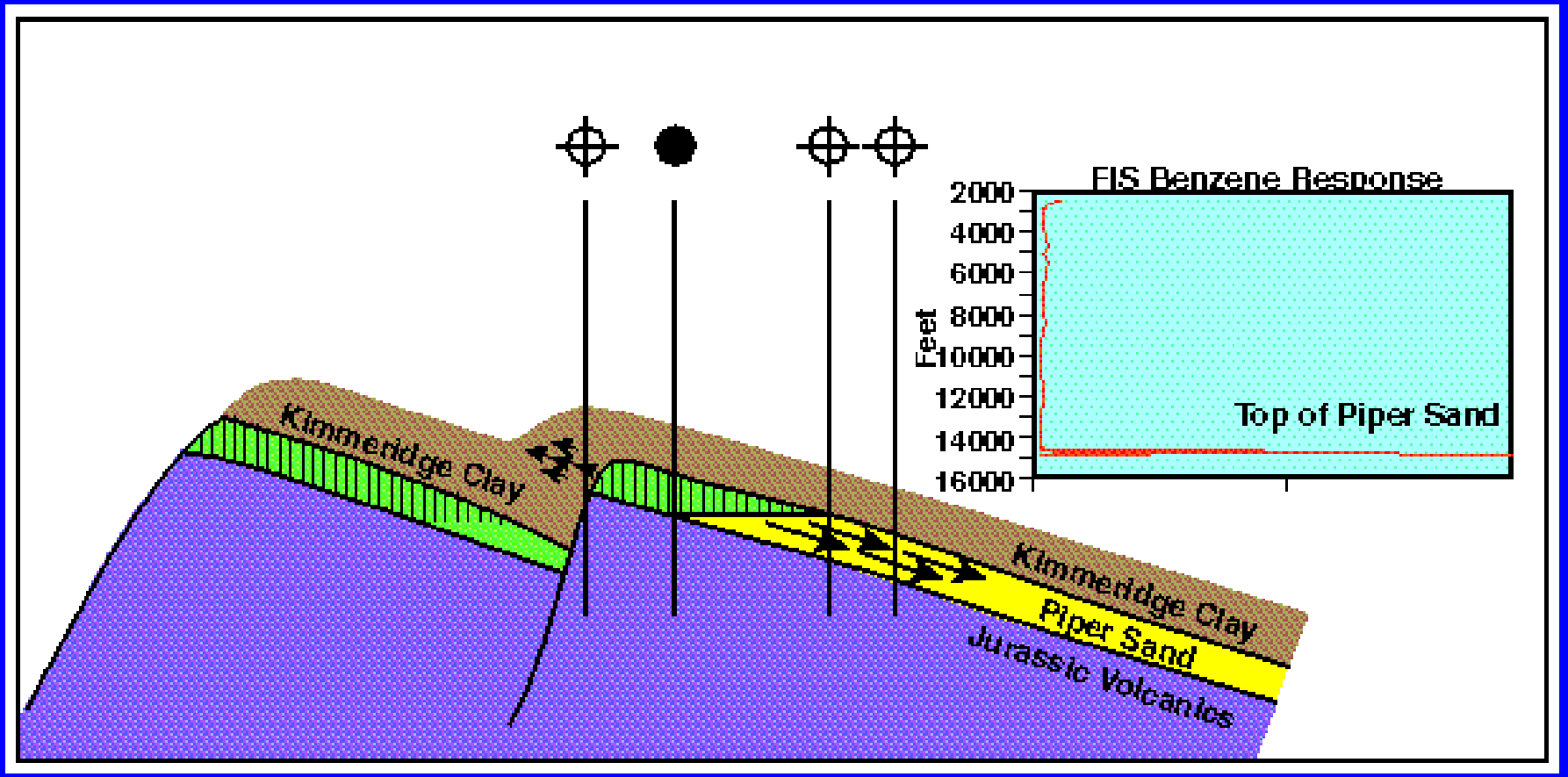


From Burtell and Jones;
OGJ; June '96

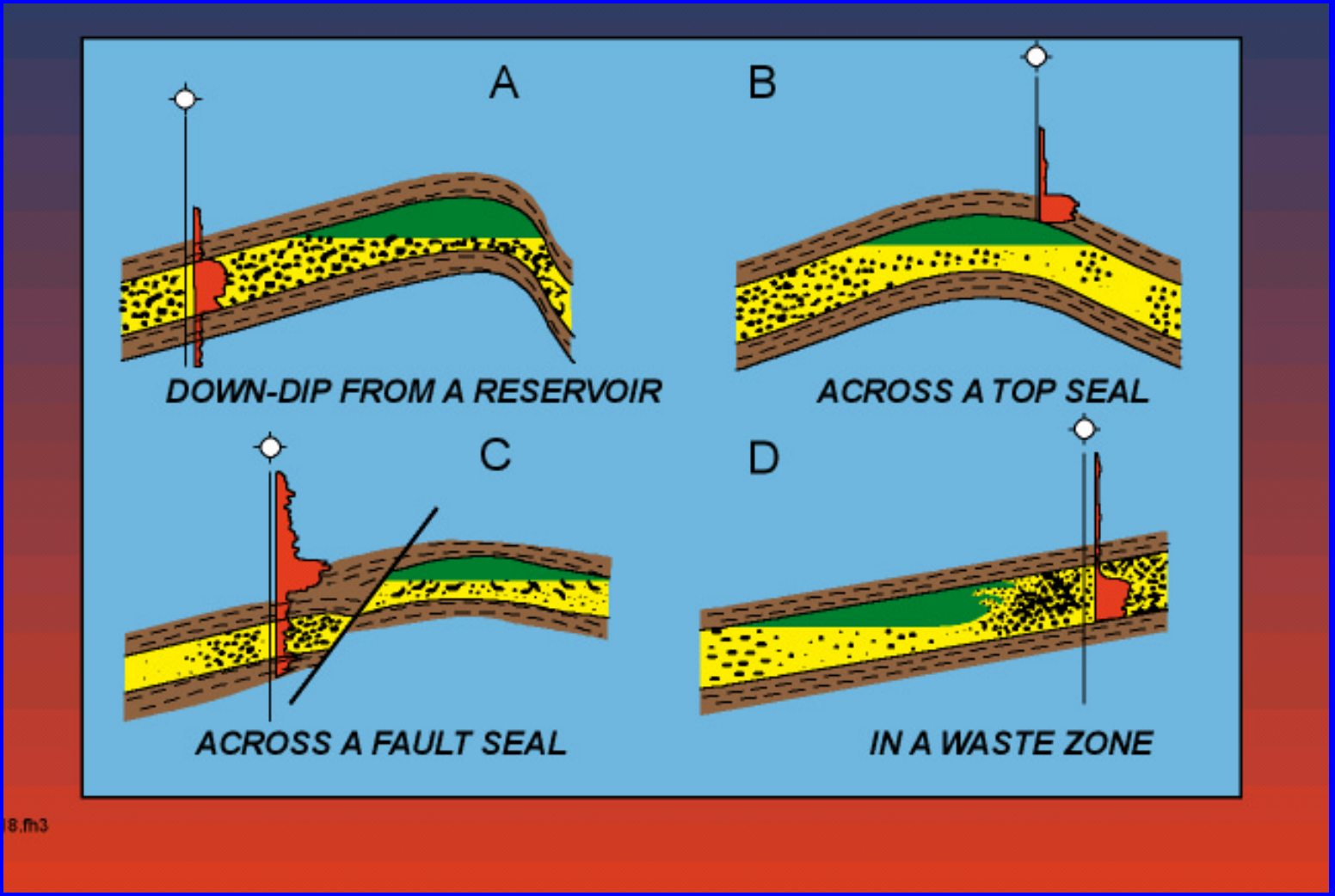
Inferring Nearby Undrilled Pay

- Well through center of prospect encountered no reservoir; had no shows
- Cuttings document anomalous levels of benzene, toluene and organic acids in the reservoir equivalent section (the lateral seal)
- Subsequent drilling discovered field
- Geochemical halo effect can be used to enlarge exploration target

FIS Infers Nearby Undrilled Pay



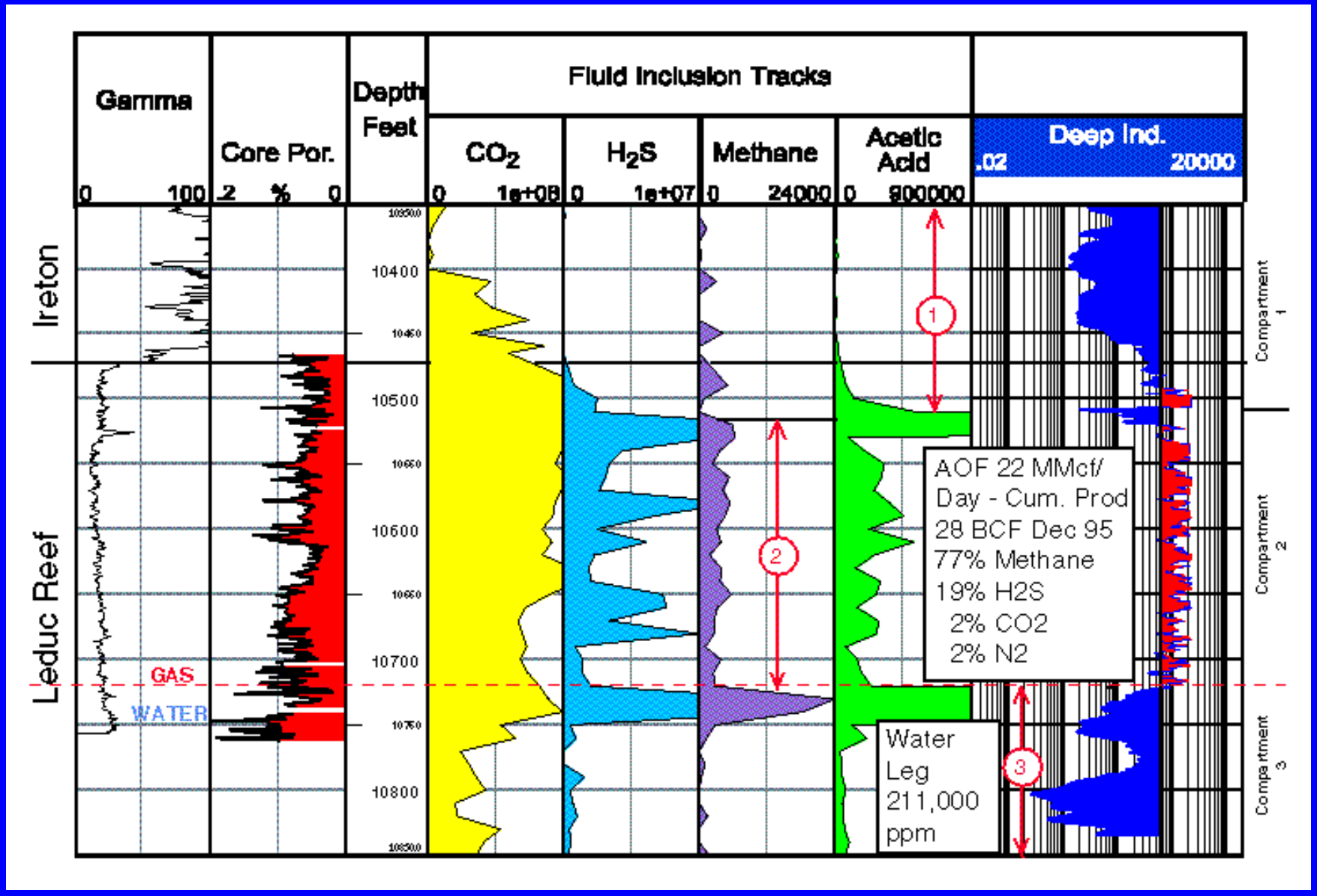
FIS "Proximity" Geometries



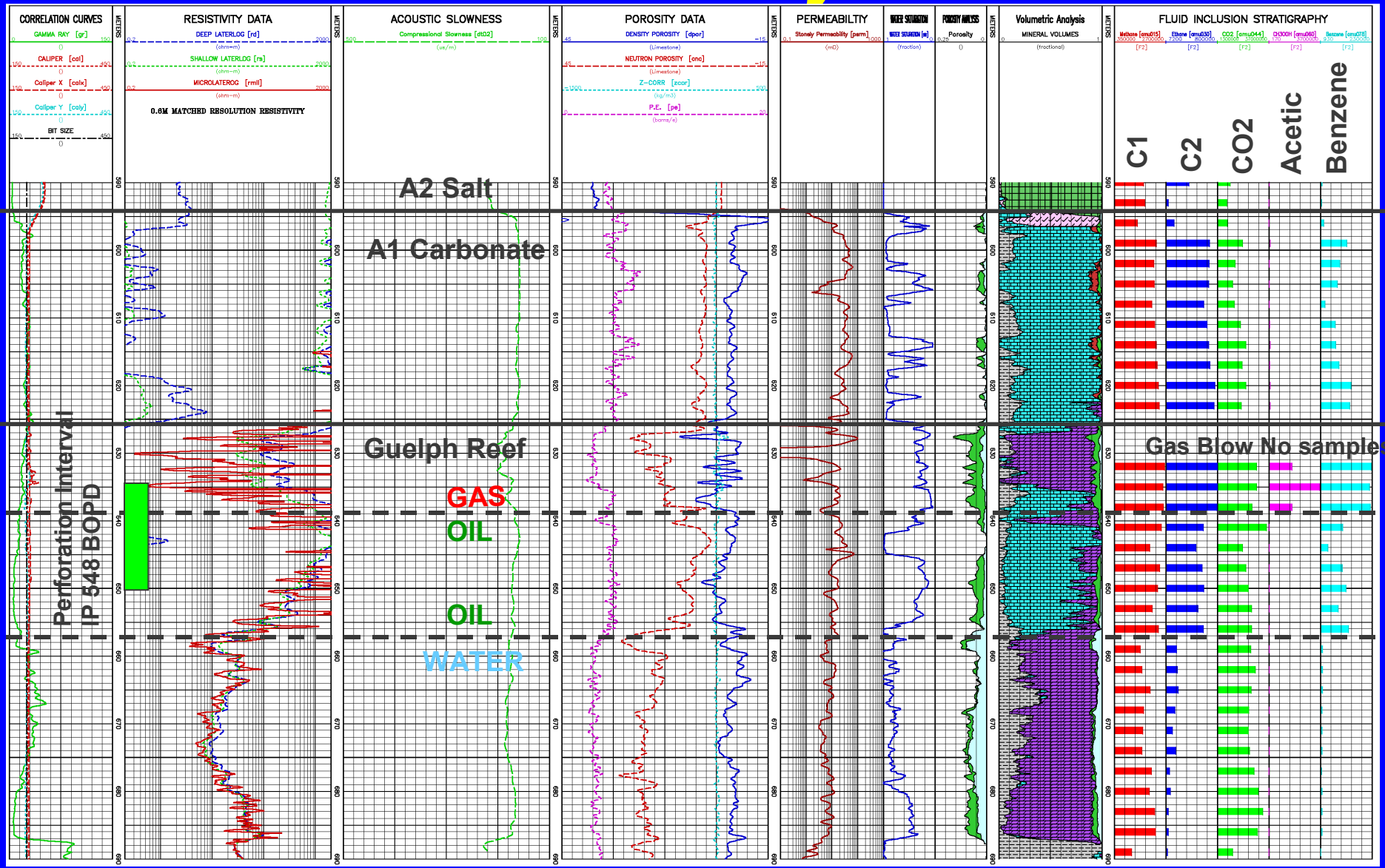
Pay Delineation

- Excellent top seal to gas reservoir
- Gas column delineated; chemistries track porosity
- Present-day gas-water contact defined
- TSR products identified; moderately sour gas is indicated
- Interpretations verified with production tests

Pay and Product Definition



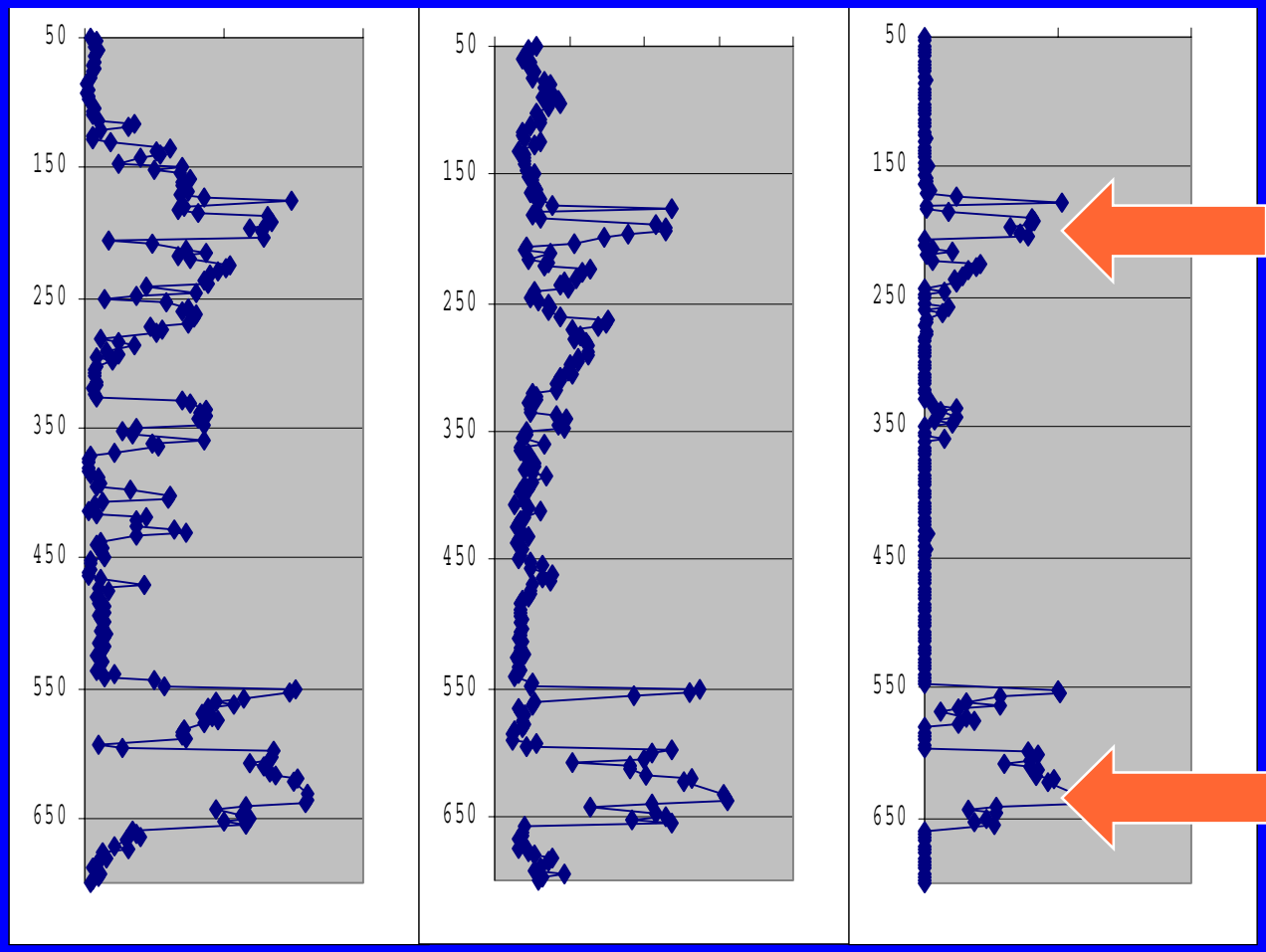
Range #1A Enniskillen 2-27-XI
Silurian Reef Discovery Well



Bypassed Pay Application

- Oil discovery in last example
- Shallow hole not logged
- Shallow FIS anomaly in regionally productive interval with porosity and staining
- Chemistry is analogous to deeper known pay zone

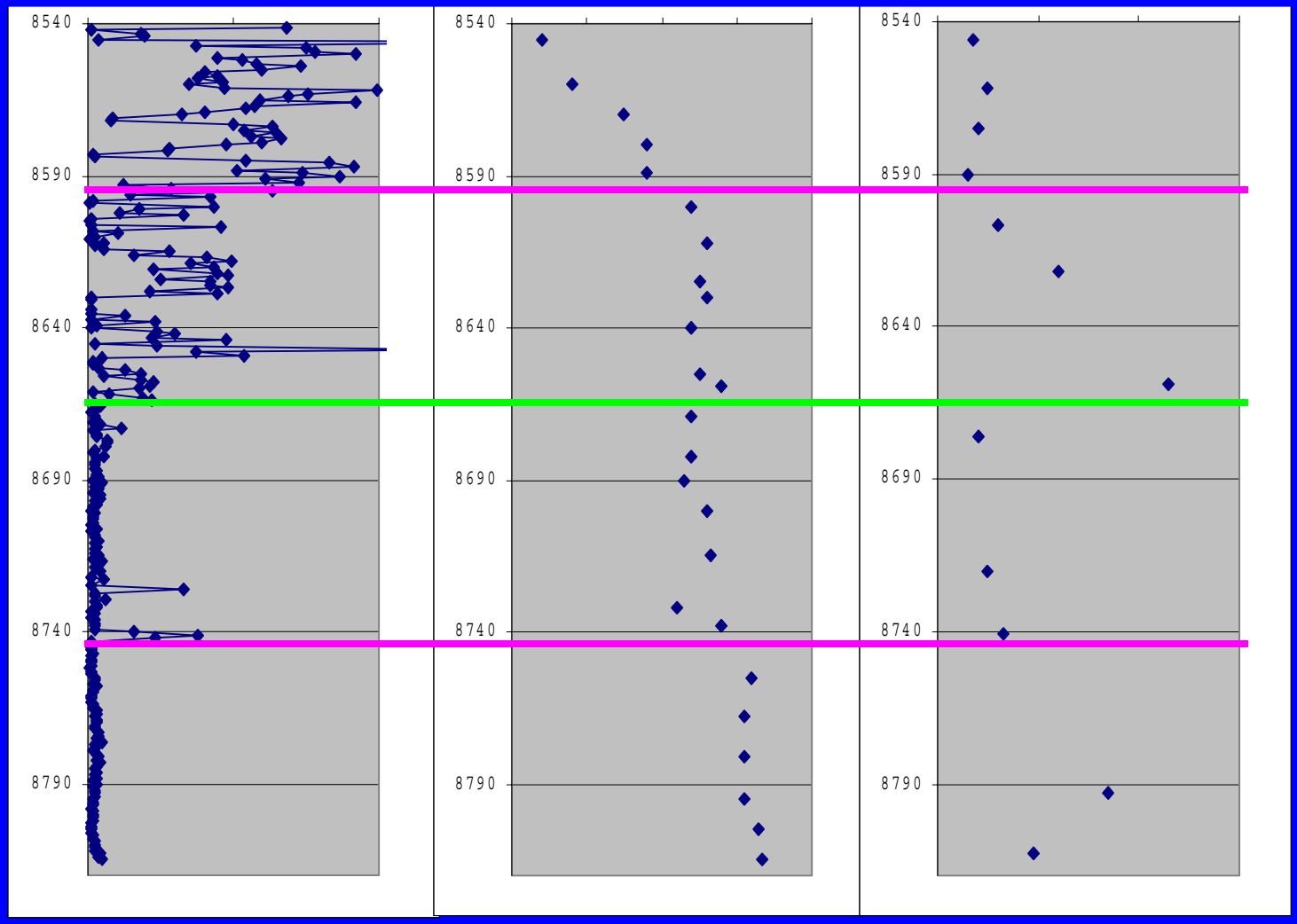
Identifying Bypassed Pay



FIS Pay Delineation Statistics

- 85% of pay zones have anomalous FIS response
- Distinction among migration, paleo-charge and present-day charge can be made by looking at detailed FIS chemistry and support technologies

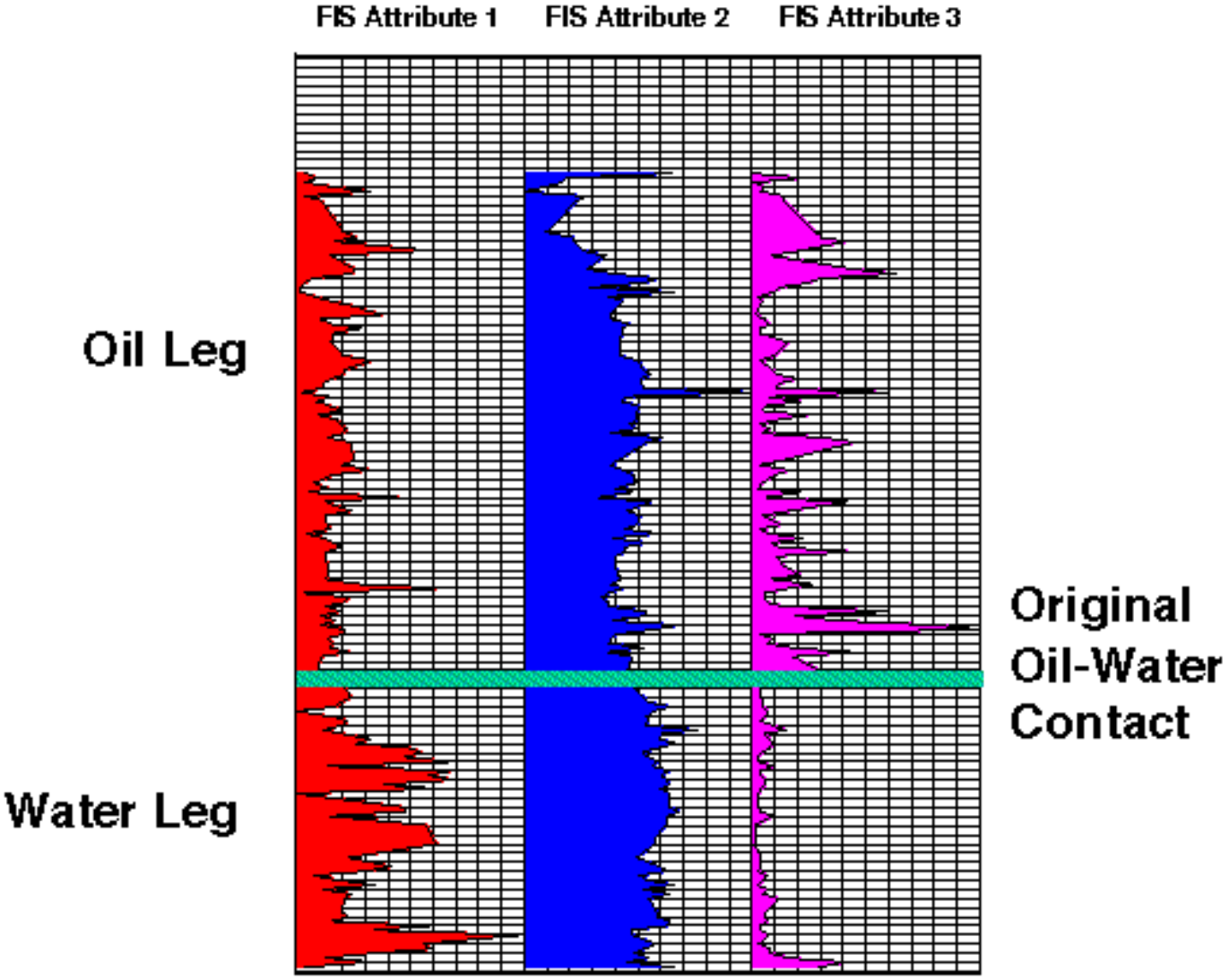
Reservoir Compartmentalization



EOR Application in a Mature Field

- Depth of original oil-water contact needed for waterflood planning
- Original contact was disturbed by production
- Wells were incrementally deepened over the history of field; log suites are minimal
- FIS data indicate the position of the OWC

EOR Application



Follow-Up Analyses: Tools

- Petrography
- Microthermometry
- API gravity determination
- Crush-GC
- TE or SE-GCMS
- Isotopic Analysis
- Confocal SLM

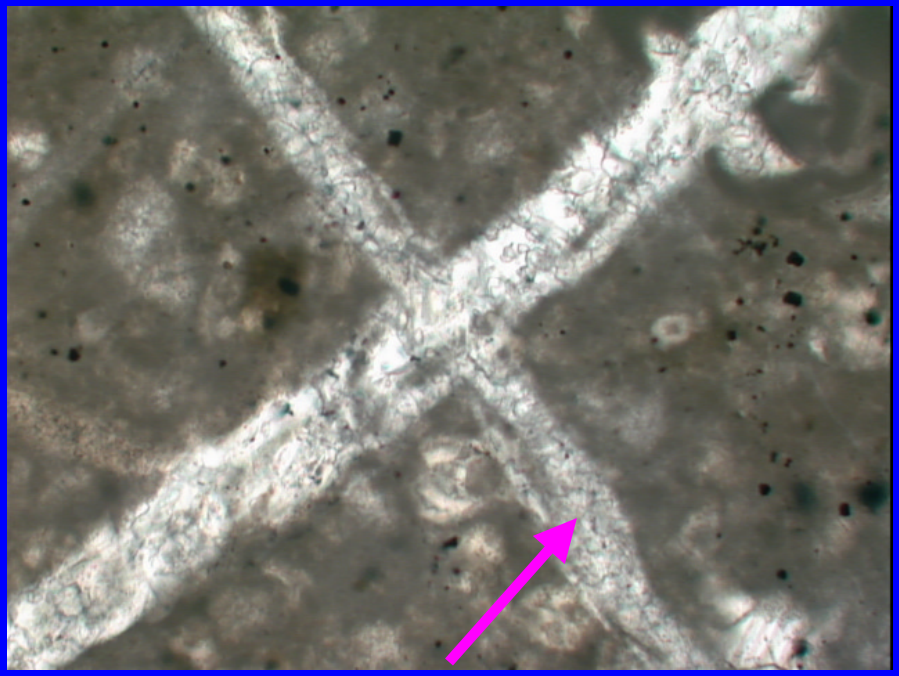
Follow-Up Analyses: Information

- Timing
- Temperature
- Pressure
- Composition
- Source
- Maturity
- Origin

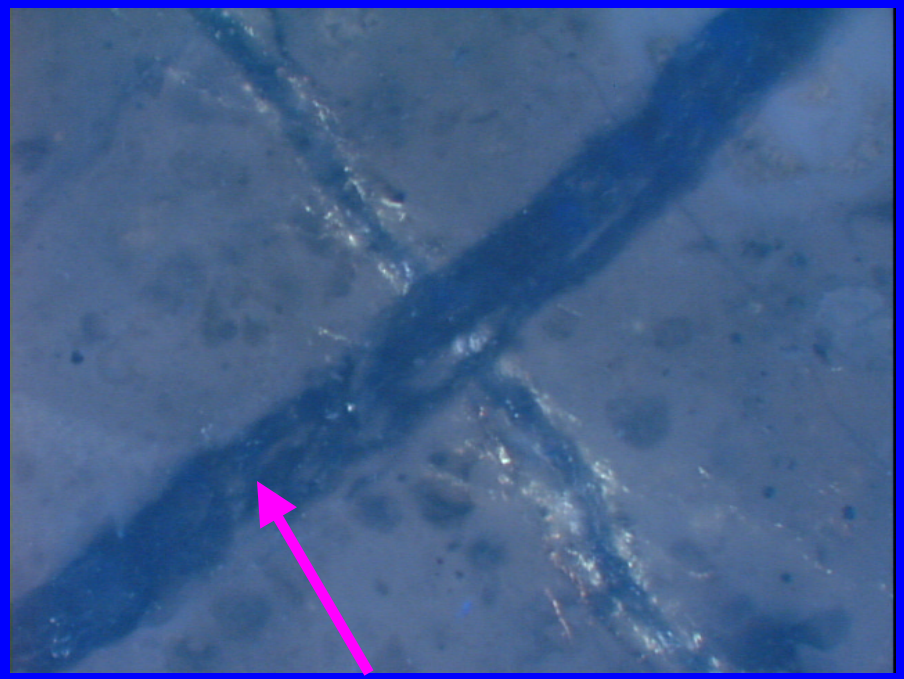
Petrography and HRCL

Fluid Inclusion Microthermometry

Timing of Biodegradation

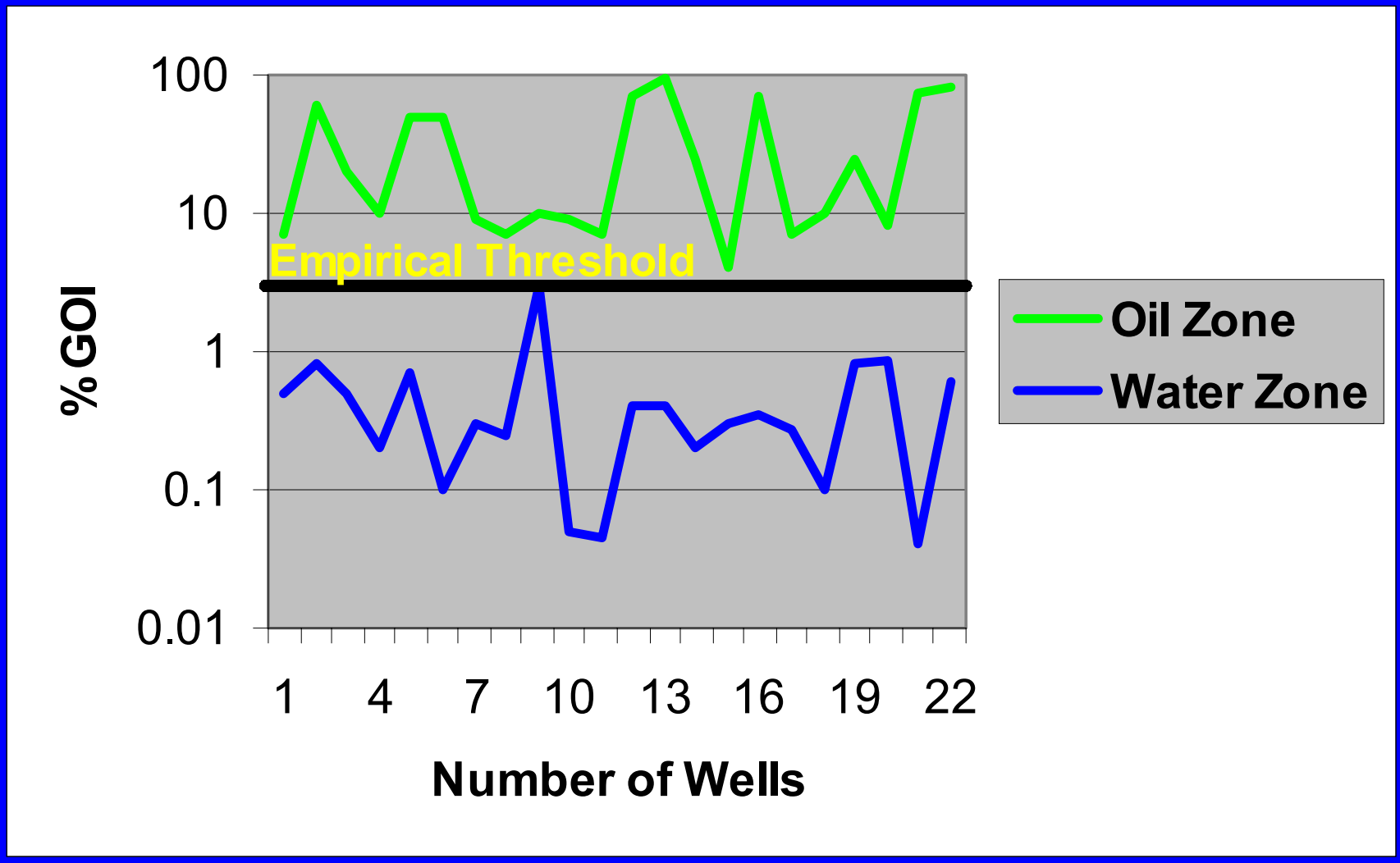


Relatively early carbonate vein contains interpreted original and biodegraded oil. Degradation may have occurred during vein formation.

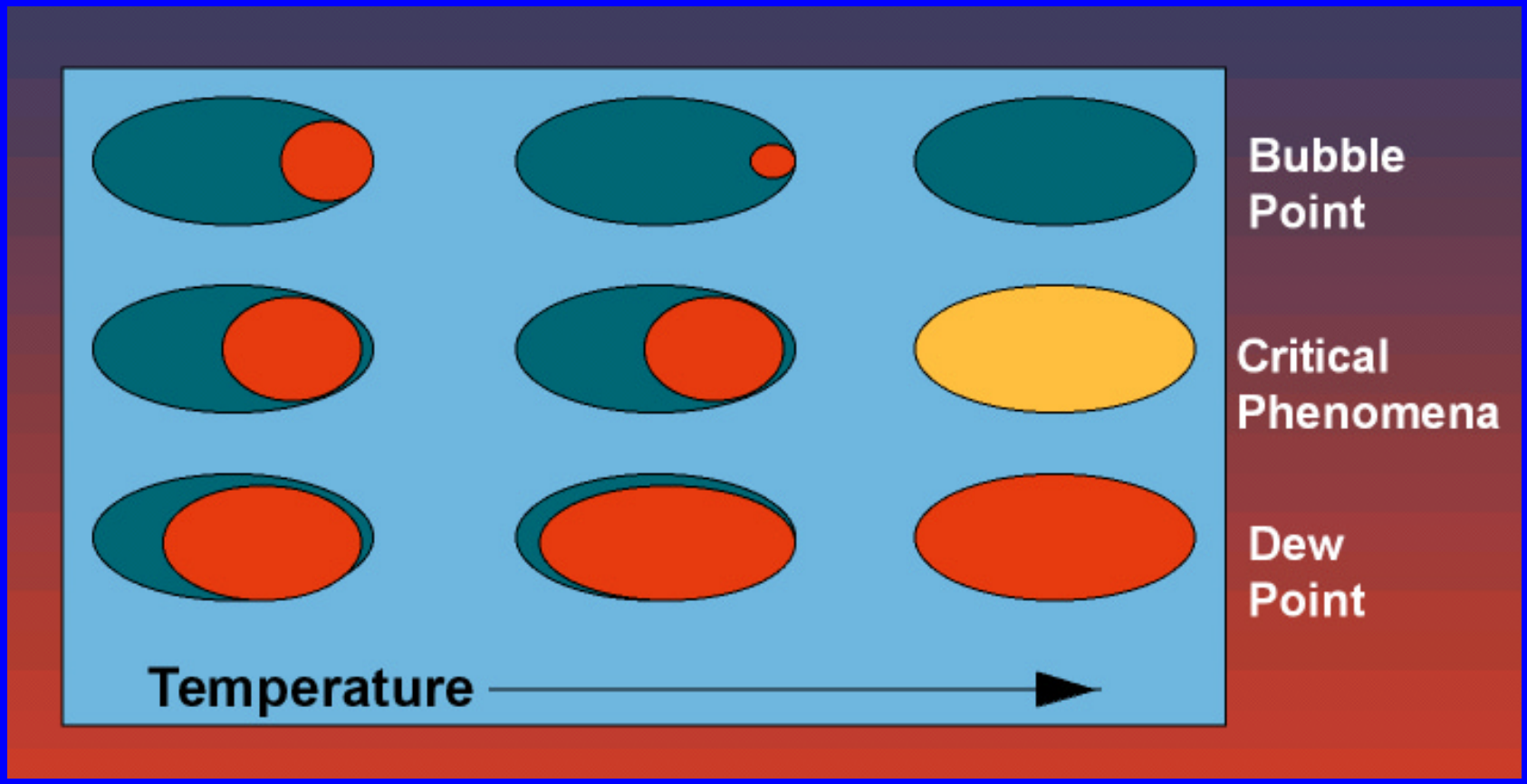


Later vein is barren, hence may postdate both petroleum migration and biodegradation. Collection of fluid data on inclusions from these respective veins may help constrain timing of these events.

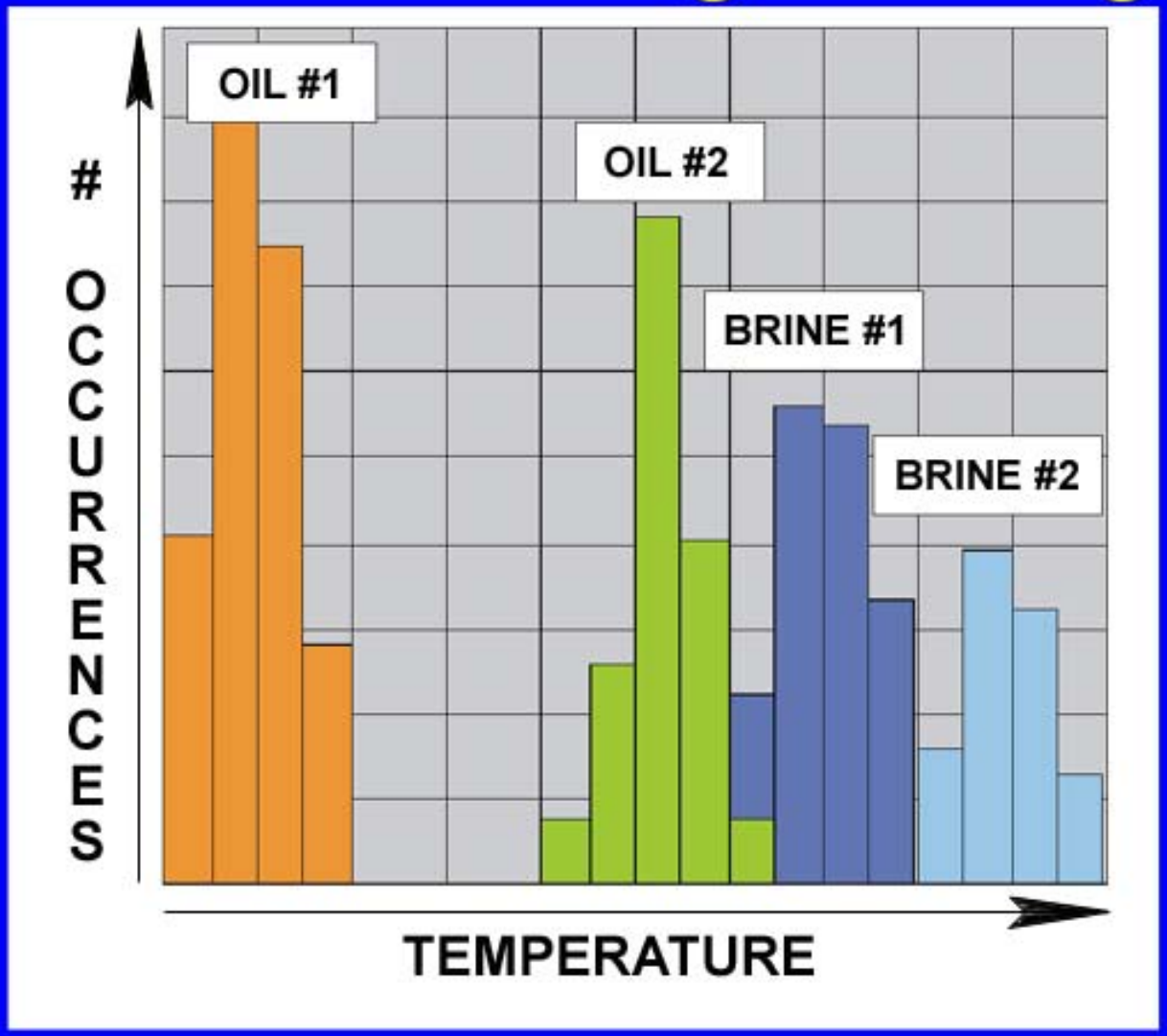
CSIRO's GOI Technique For Paleo-Saturation Determinations



Homogenization Behavior of Petroleum Inclusions



Paired Oil and Brine Analyses Help Constrain Charge Timing



Effect of Salinity on Reserv. Est.

PRACTICAL ARCHIE EQUATION

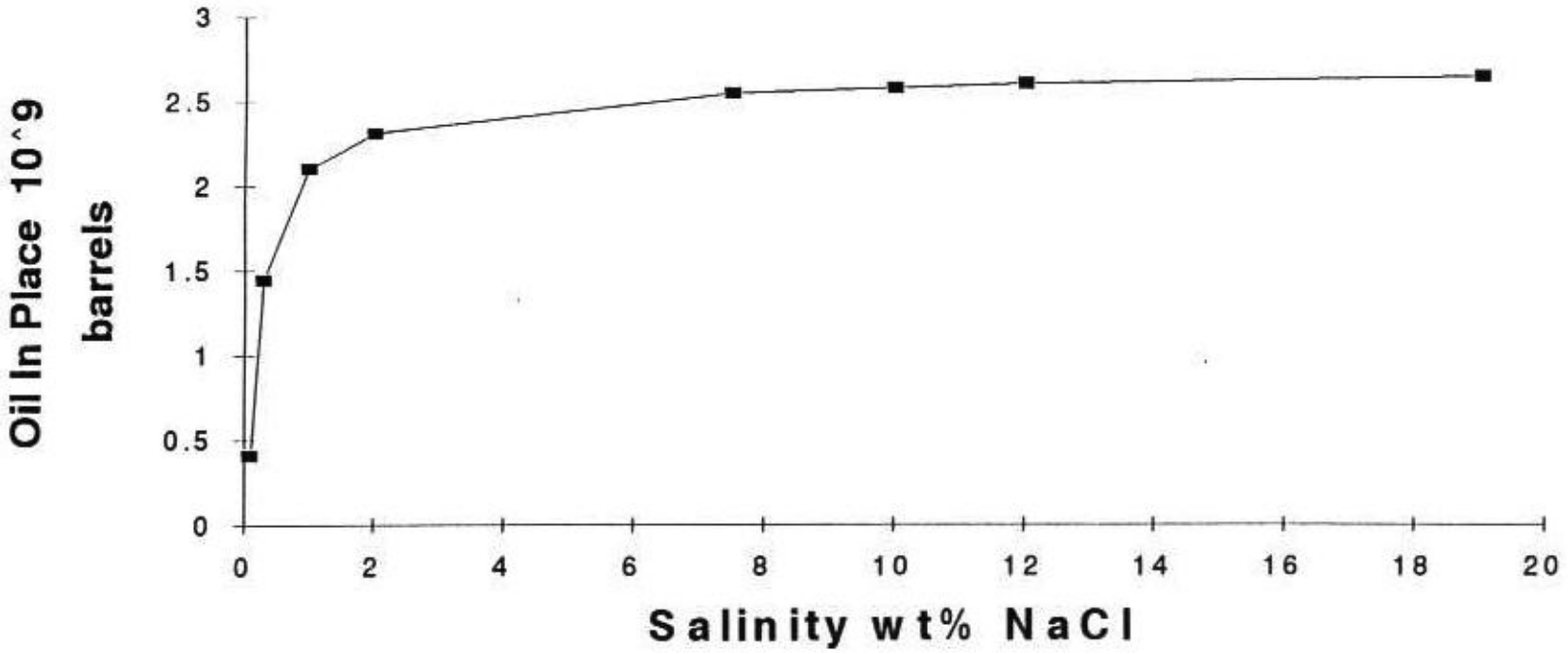
$$S_w = \sqrt{\frac{0.62 \bullet R_w}{\phi^{2.15} \bullet R_t}}$$

Sw = water saturation
Rw = resistivity of water (aquifer ?)
phi = porosity
Rt = resistivity of bulk rock

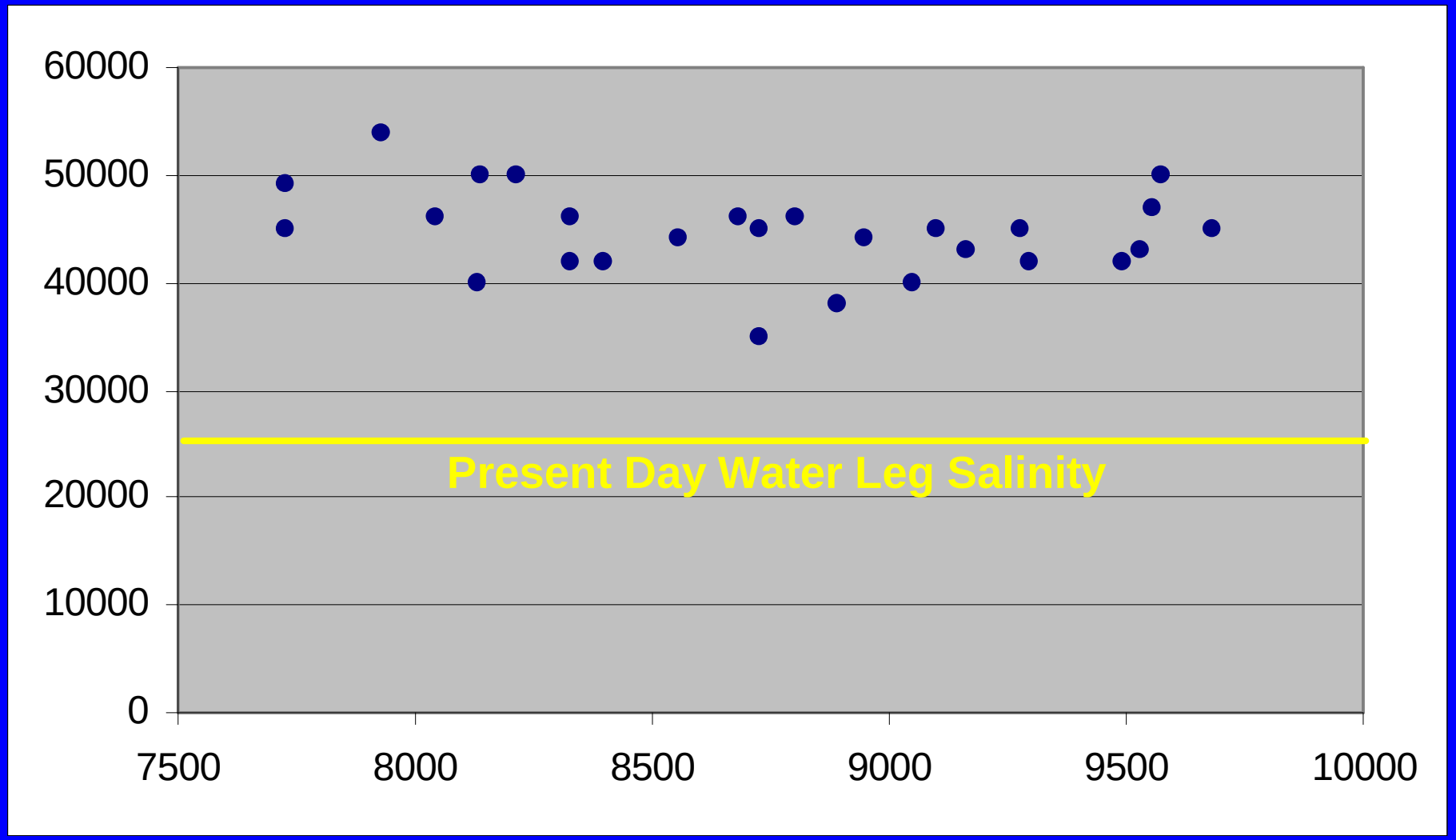
Oil-in-place = Vr (1-Sw)

Vr = bulk reservoir volume

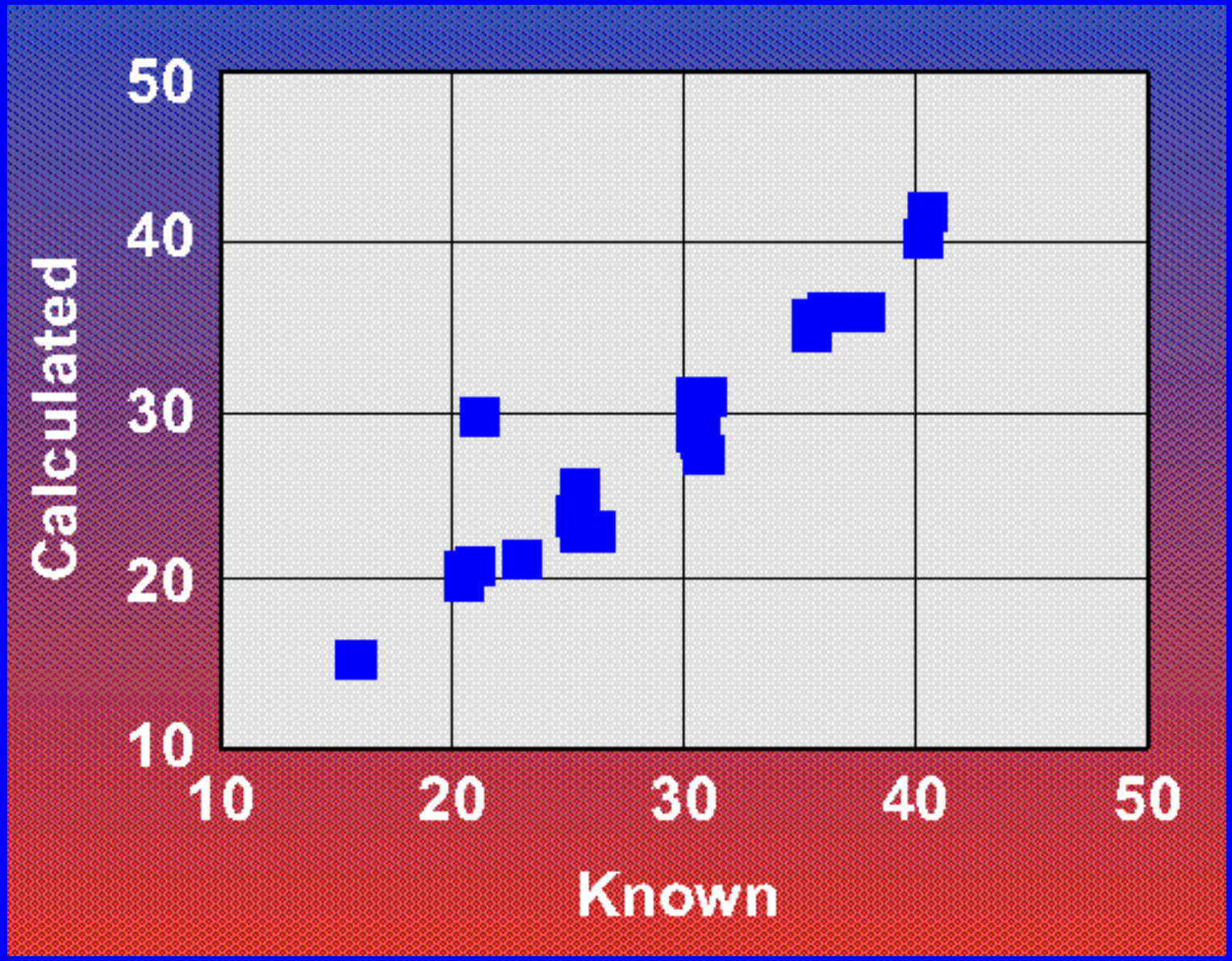
Assuming a reservoir volume 4.6x10^8m^3, Rt =80Ωm



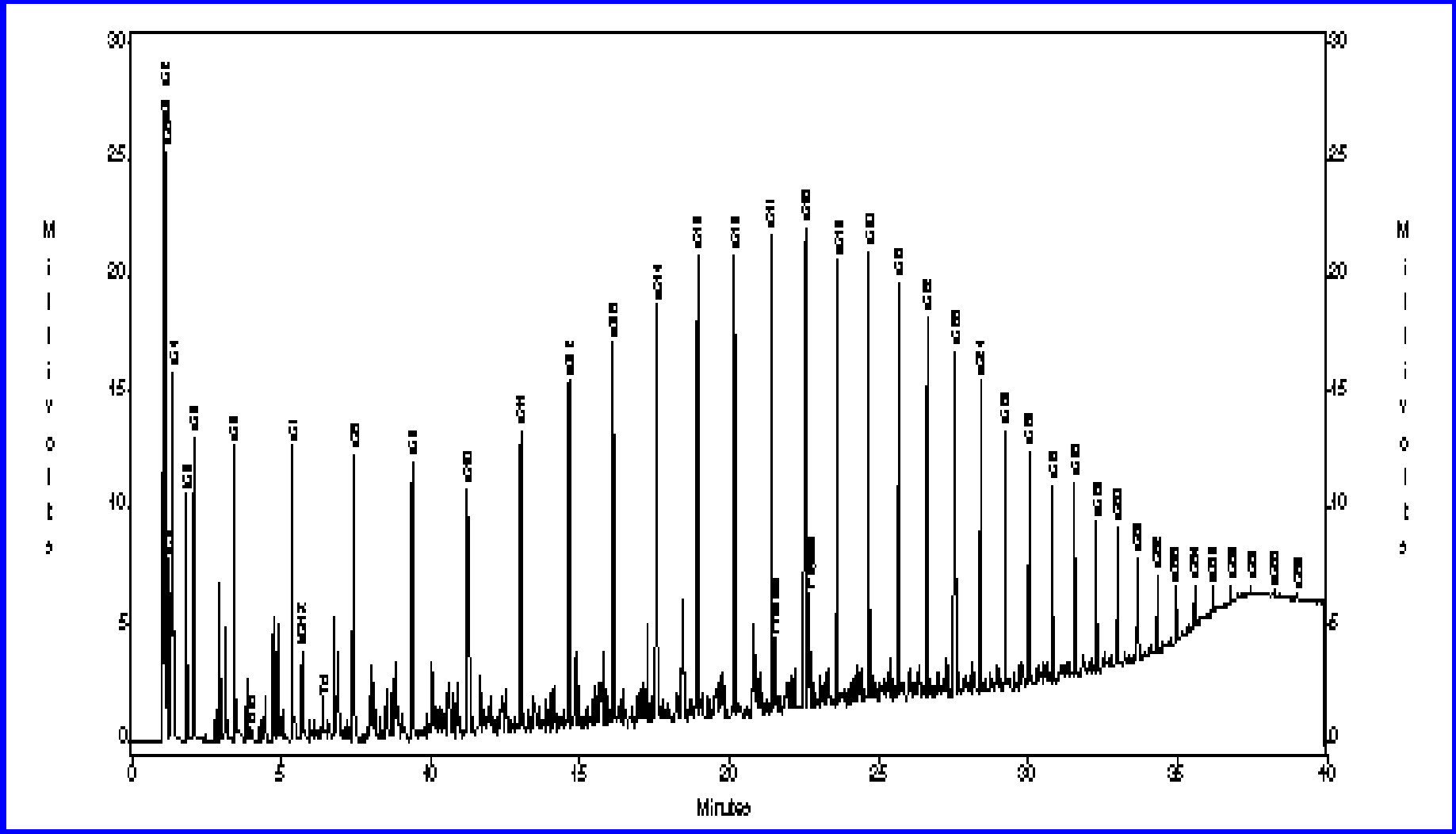
Fluid Inclusion Salinity Variation in Oil Reservoir



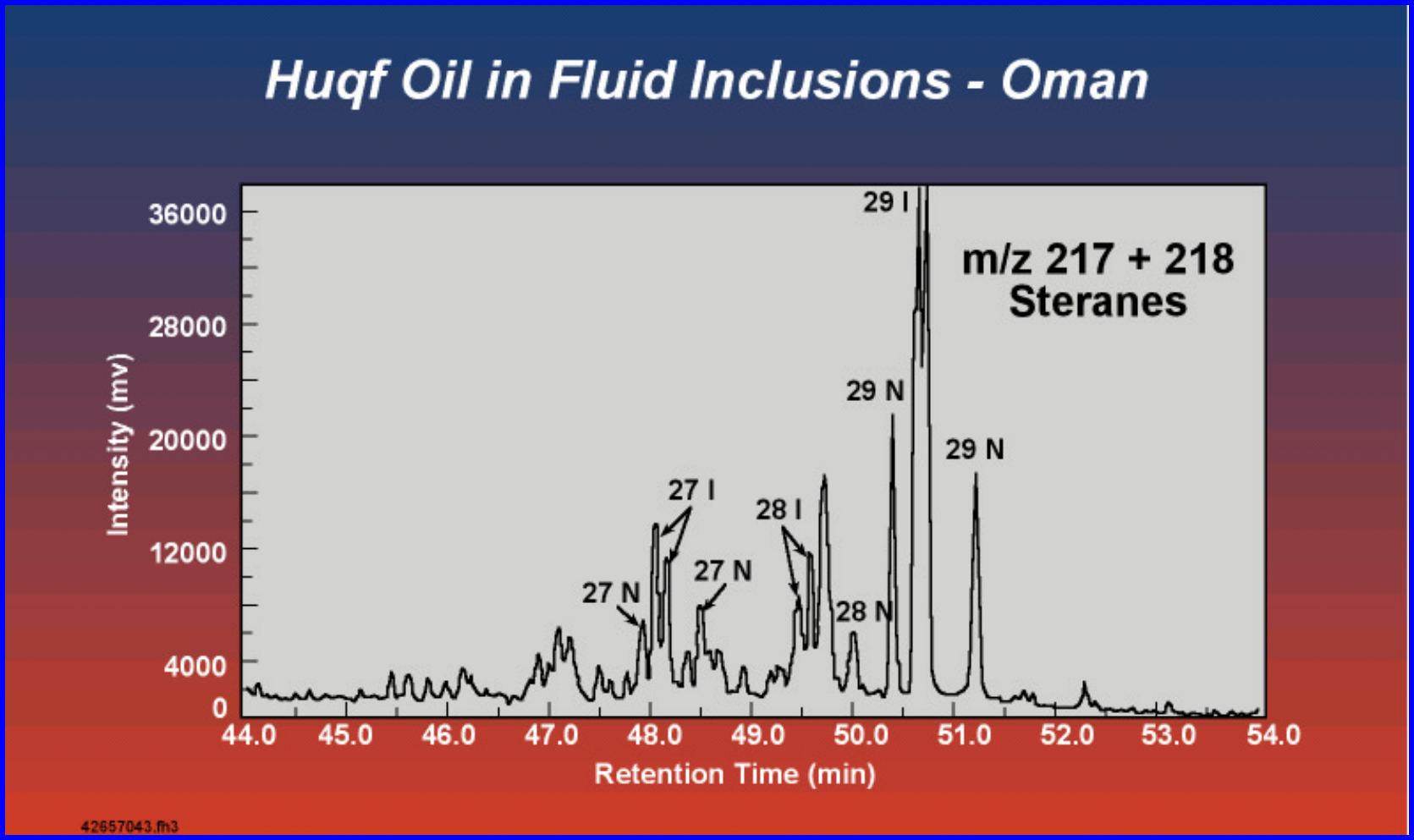
Oil Inclusion API Gravity



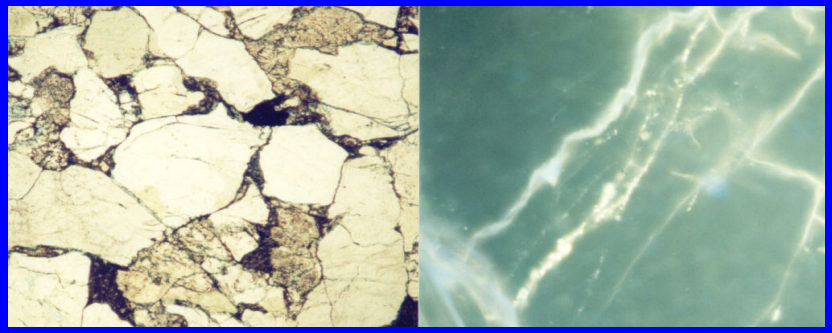
Crush GC Data on Fluid Inclusions

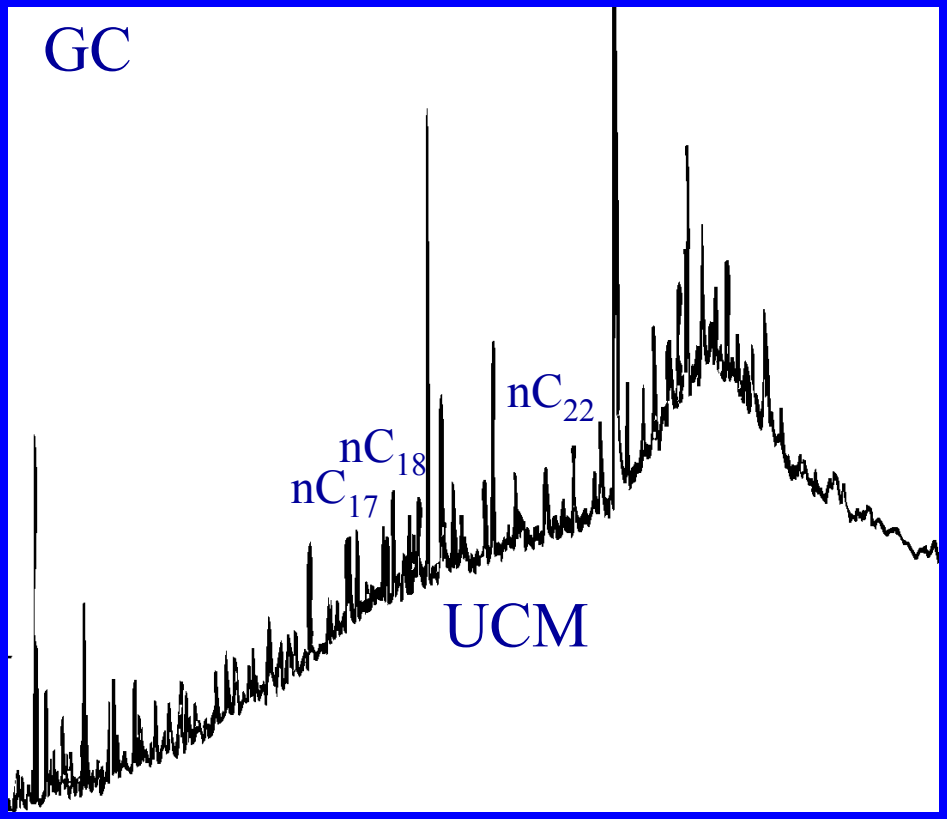


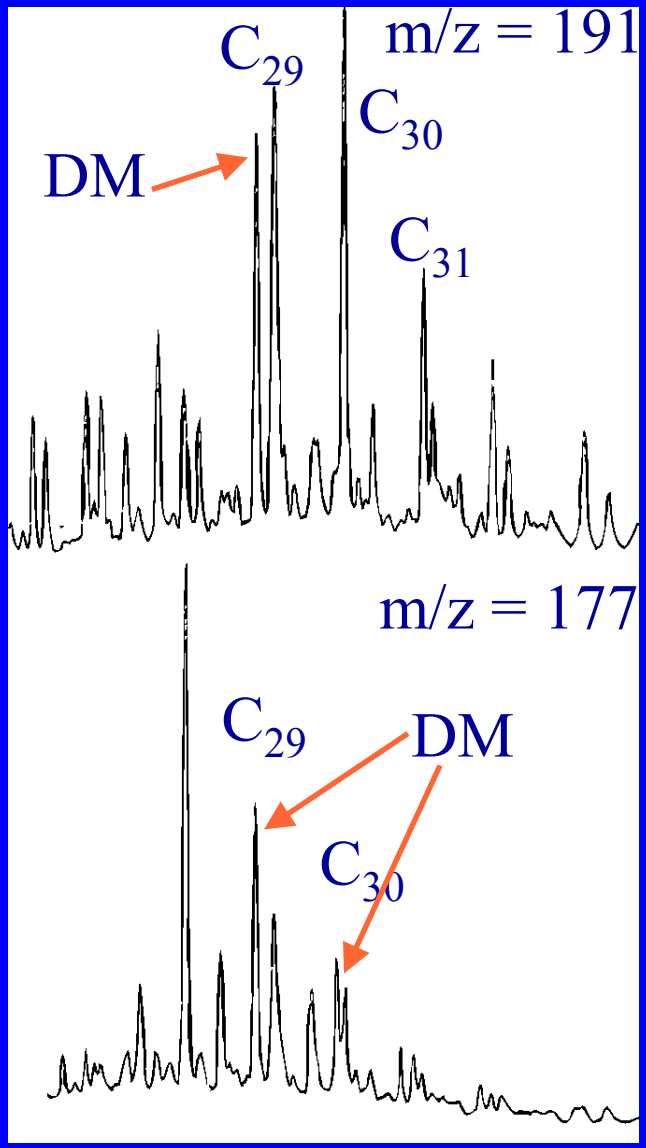
GCMS Data From Fluid Inclusions



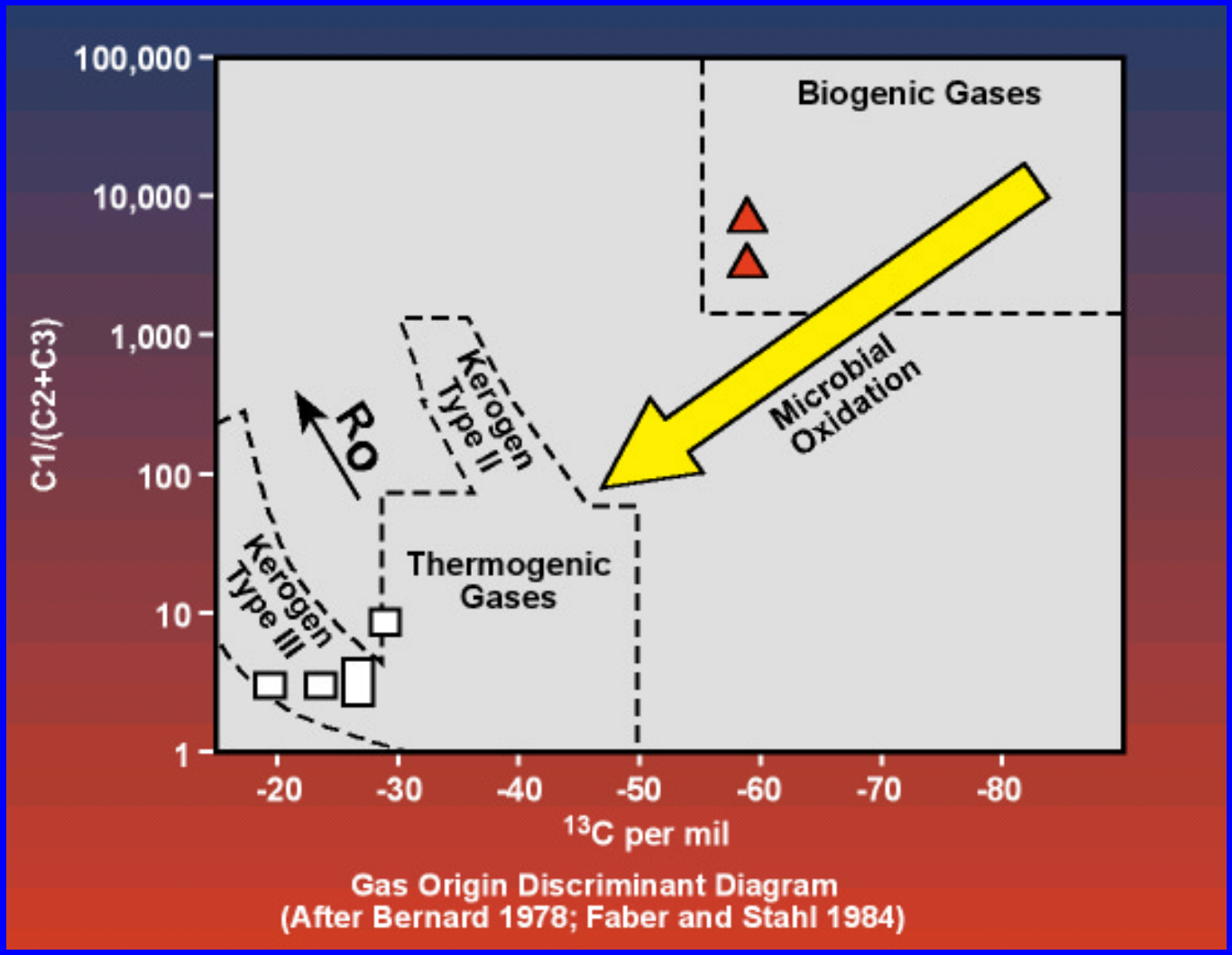
GCMS Data From Biodegraded Fluid Inclusions



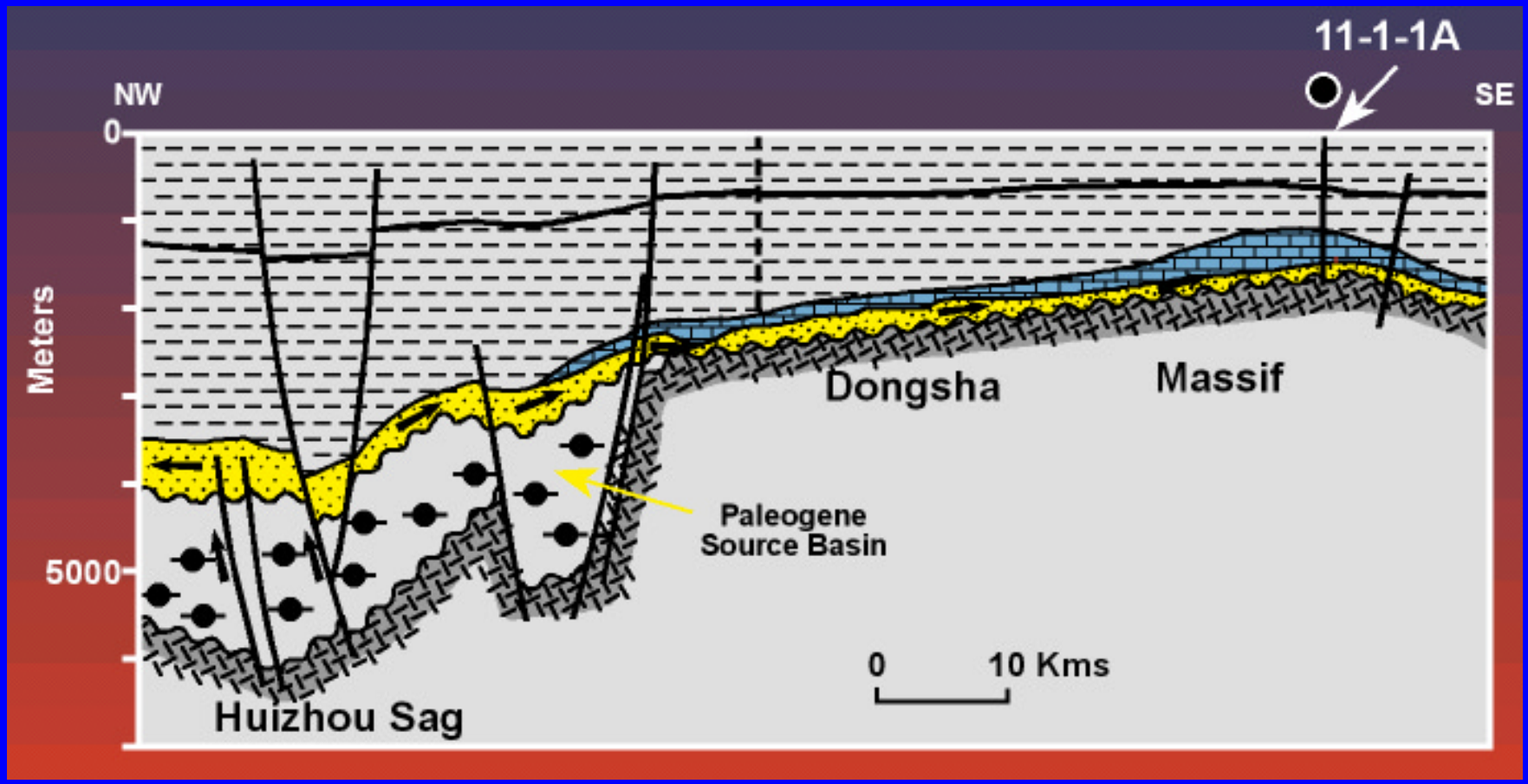




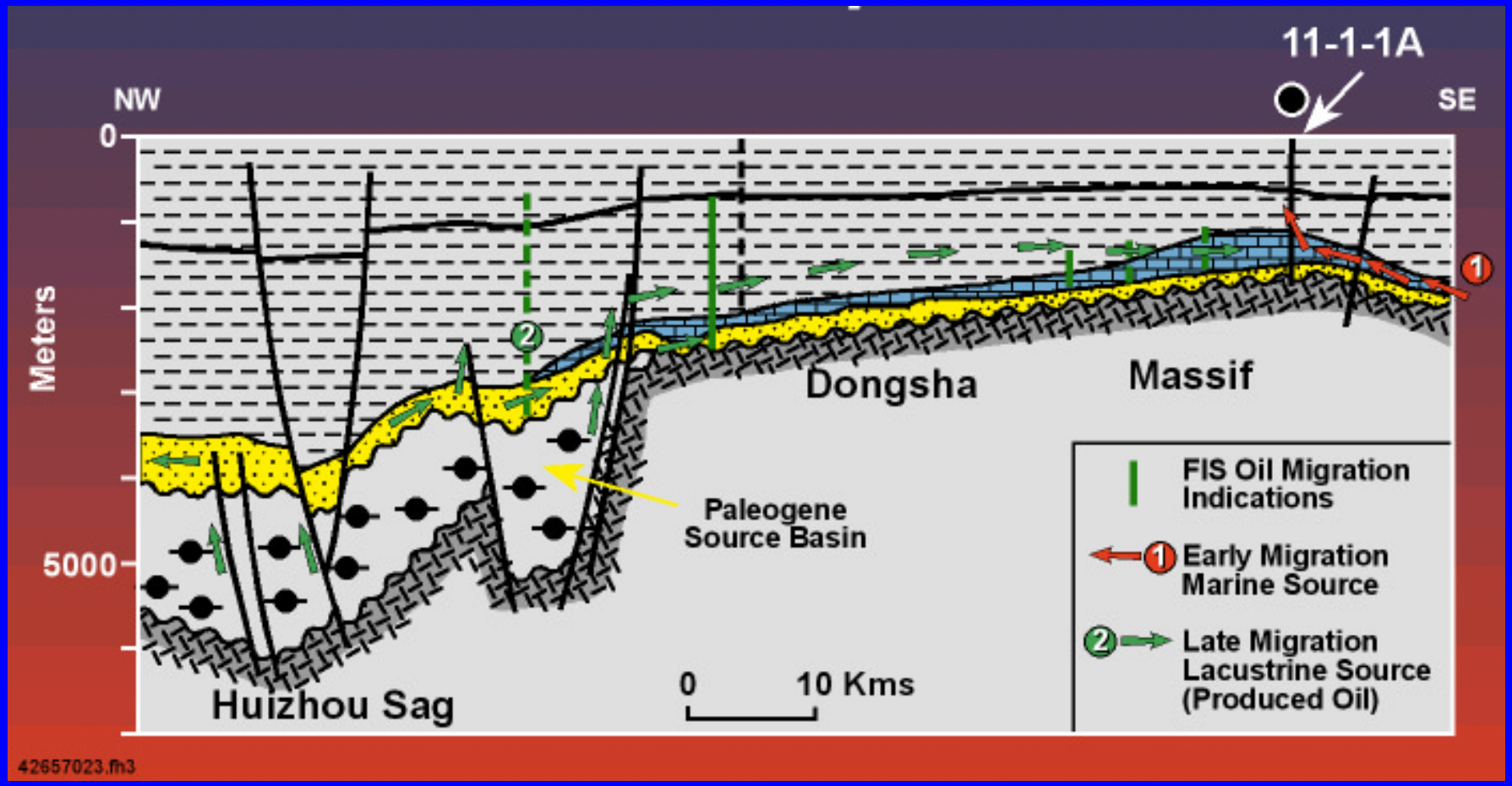
Biogenic vs. Thermogenic Gas in Fluid Inclusions



Prevailing Migration Model: Liuhua Area, Offshore China



Migration Model with Integration of FIS, GCMS and Isotope Data



Summary

- Fluid inclusion techniques are robust, and applicable to many fundamental E&P questions
- Inclusion petroleum is unfractionated and unaltered by sampling or storage procedures. Applicable to oil-based muds
- FIS allows rapid, regional evaluation of migration, seals and proximity to pay

Summary (Cont.)

- Coupling FIS with petrophysical data improves reservoir evaluation
- Coupling FIS with classical geochemical methods improves analysis of petroleum system and reservoir continuity
- FIS and conventional fluid inclusion analyses constrain basin models