[PS]30+ Years – Petroleum Geochemistry: Basin Evaluation and Field Development*

Paul C. Henshaw[1]

Search and Discovery Article #42457 (2019)**
Posted September 30, 2019

*Adapted from poster presentation given at AAPG Hedberg Conference, The Evolution of Petroleum Systems Analysis: Changing of the Guard from Late Mature Experts to Peak Generating Staff, Houston, Texas, United States, March 4-6, 2019
 DOI:10.1306/42457Henshaw2019

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Abstract

The role of Petroleum Geochemistry in Basin Evaluation & Field Development has changed significantly over the past 50 years. It will continue to change as industry develops energy resources to power society for the future. It is critical to remember that we deal with a PETROLEUM SYSTEM. To impact Value and Success, we need to understand all aspects of the five petroleum system parameters of: Source Rock; Reservoir Rock; Seal Rock; Migration Route and Trap. As Geologists, we also need to understand the sequential timing of all these critical parameters. We must ensure that we integrate these parameters across the Earth Science and Engineering platforms. Early exploration focused on finding reservoirs / traps. Classic structural and stratigraphic geology drove exploration. The development of seismic and well logging technologies utilized simple models. Many fields were discovered and developed near seeps and existing fields. Most offshore programs were limited to stepouts. Saudi Arabia's major discovery was made by identifying a slight dip anomaly sighted from Bahrain. As seismic technology and sequence stratigraphic concepts were developed, more "wildcat" exploration plays were pursued with improved mapping and modeling of geologic trends, aided by newly developing tectonic concepts. Exploration risk decreased as worldwide experience grew. The 1960's and early '70's ushered in an expansion of exploration with data from the Deep Sea Drilling Project and the continued development of plate tectonic concepts (Cox, 1969). Oceanographic ideas of source material types, accumulation, preservation and burial were added to the "System's" approach (Lisitzin, 1972; Degens & Ross, 1974; Tissot & Welte, 1978; Hunt, 1979). This period increased the use of geochemistry in the spectrum of technologies, to better define the petroleum system (Katz, ed., 1994). "Early" geochemistry was used with electric and petrophysical logs, development of models for water/rock chemistry, and isotopic measurements of oils and gases. Organic geochemistry started making an impact not only for Production, but also Exploration as various types of oils were identified. "Biomarkers" were identified and studied relative to various source materials and thermal alteration processes. 1970's - 80's the FUN begins: Computer technologies and modeling concepts stepped in with "Super" computers. The Oil/Gas industry was a first user along with the military and automobile industries. Seismic processing and modeling took leaps forward. However, without good geologic and geochemical data, "Nintendo" geology and "End of Oil" hysteria drove research as well as Exploration/Production efforts, leading to poorly defined Exploration plays. Fortunately, some research and development programs "allowed" geologists/geochemists to "Beta" test seismic modeling packages, adding "real" rock and fluid properties to geophysical modeling programs. Satellite remote sensed data improved oceanographic circulation

models and our understanding of global tectonics. For example, early exploration (and related geophysics) in the Gulf of Mexico was driven by the “model” that the oil was sourced from post- Salt deposited source materials – the salt was considered a “basement”. When biomarkers indicated that the oil was from pre-Salt sources, geophysical research shifted to developing “through/under” salt seismic techniques. Salt “tectonic” models were improved as data from post-salt fields indicated migration of fluids up salt dome flanks and through fault systems. Satellite images enabled identification of coastal salt and mud diapiric structures. R&D projects reexamined “old” DSDP cores, core data and maps to identify “new” offshore/deep water plays. Today: Computer research and development experienced a dilemma seen by geochemists in the 1970 - 80’s – “the study of petroleum is too complicated…too many variables!” Exploration and Production groups have tried to deal with “BIG DATA” for decades. We were early adopters of Cray and other Super computers, now we need to drive new developments in computing technologies. Automated SCADA systems and power micro-grids are being tested to continuously monitor fields for fluid production, pump efficiencies, power grid usage, etc. The key is to use the data in real time for continuous optimization: increased efficiency, lower operating costs, and improved reservoir drainage. New procedures are being developed for drilling and oilfield production monitoring including fluid DNA analyses to optimize well placement and completions, and Frac patterns. Continuous, “real-time” seismic networks are “listening” to well operations and micro-seismic responses. Measurement while drilling capabilities and logging tools are improving. EOR concepts also are improving. To add value, these technologies must be incorporated into dynamic reservoir/production models. The old days of using static models with infrequent updating are over. We must move toward real time, inline, geochemical analyses and monitoring to improve reservoir production optimization. Identifying changing fluid flow patterns in the reservoir can lead to significant improvement in optimization. It also must lead to increased value through volume/quality of hydrocarbons produced. We need to increase our fundamental understanding of reservoir compartmentalization, fluid flow, and changes in rock/fluid properties. We need to build “intelligent” systems that will improve company performance and stay away from Nintendo geology! There is still a strong future for Oil & Gas Exploration and Production technology development: conventional, unconventional, or alternative energy.

References Cited

James, K., 2018, Not Written in Stone: Plate tectonics at 50: AAPG Explorer, Web Accessed September 15, 2019, https://explorer.aapg.org/story/articleid/44931/not-written-in-stone

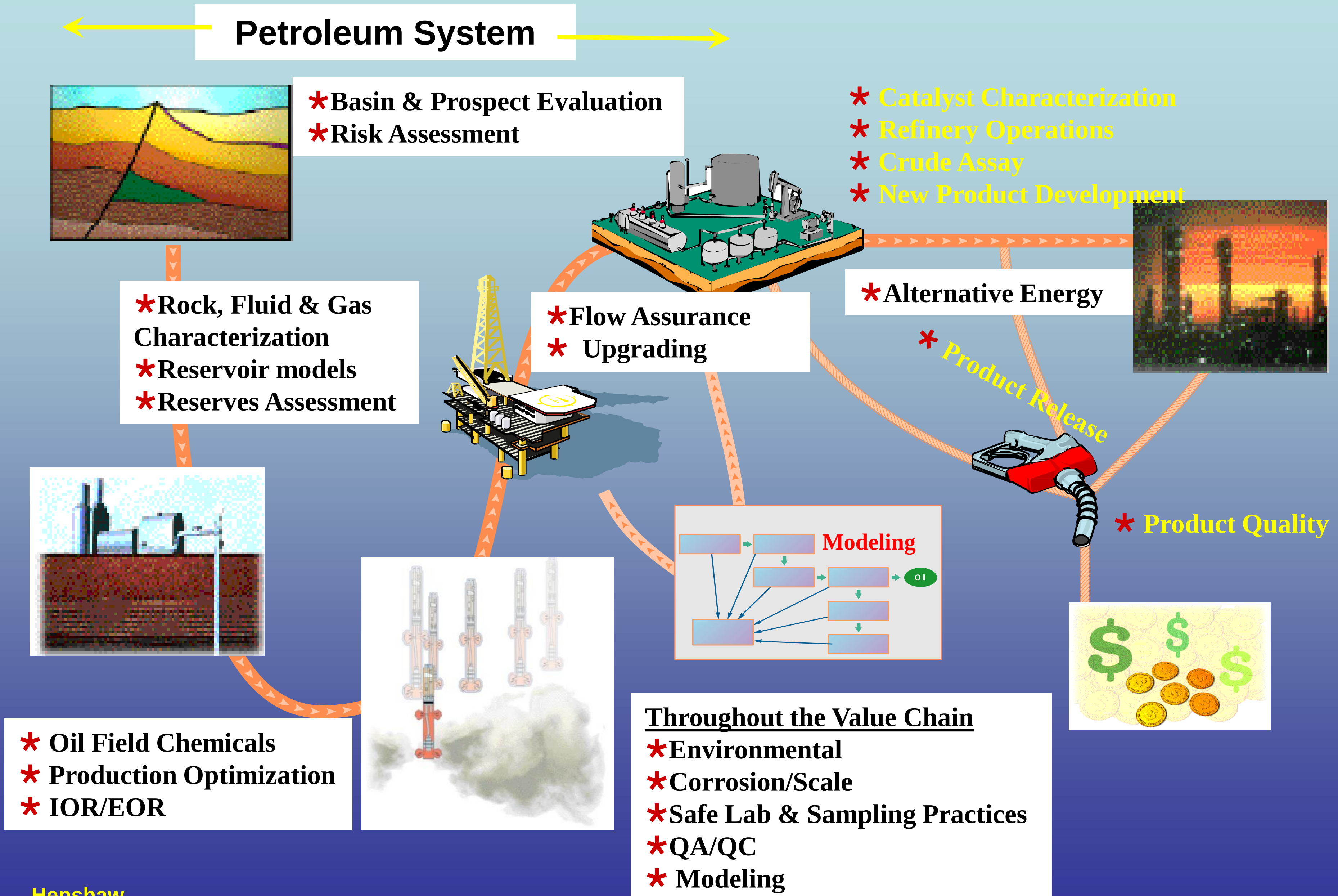
Smalley, P.C., and N.A. Hale, 1995, A toolkit for early identification of reservoir compartmentalization: Annual meeting of the Society of Petroleum Engineers (SPE), Dallas, TX (United States), 22-25 Oct 1995.

Hedberg Conference 2019 Poster Abstract
30+ Years - Petroleum Geochemistry: Basin Evaluation & Field Development

Paul C. Henshaw, PhD (Retired: Chevron, PetroSkills, UC Berkeley)

The role of Petroleum Geochemistry in Basin Evaluation & Field Development has changed significantly over the past 50 years. It will continue to change as industry develops energy resources to power society for the future. It is critical to remember that we deal with a PETROLEUM SYSTEM. To impact Value and Success, we need to understand all aspects of the five petroleum system parameters of: Source Rock; Reservoir Rock; Seal Rock; Migration Route and Trap. As Geologists, we also need to understand the sequential timing of all these critical parameters. We must ensure that we integrate these parameters across the Earth Science and Engineering platforms.

Geochemistry across the Petroleum Value Chain



Henshaw

Petroleum Geochemistry – Source to Oil & Gas

- **Oil Composition: Pre-1960's**
  - **Saturated Hydrocarbons: Straight Chain, Branched & Cyclic Paraffins**
  - **Aromatic Hydrocarbons**
  - **Resins: Nitrogen, Sulfur & Oxygen (NSO)-Containing Hydrocarbons**
  - **Asphaltenes**
- **Oil Analysis by Chromatography – pre-1960's**
- **How Oil Composition and Properties Are Affected by: 1960's-Present**
  - **Source Rock Type**
  - **Thermal Maturity Levels**
  - **Petroleum Alteration Occurring in Reservoirs (e.g., Biodegradation)**
- **Biomarkers – Fossil Compounds dissolved in petroleum: 1970's - Present**
  - **Source Rock Type and Age (Oil Correlation to Source)**
  - **Thermal Maturity (Extent of Oil and Gas Generation)**
  - **Oil Biodegradation (Formation of Heavy Oils in Reservoirs)**
- **Diamondoids: Nanodiamonds that survive metagenesis: 1980's to present**
- **DNA: Deoxyribonucleic Acid – Genetic compound (bacterial): 2014 to present**

Petroleum Formation is a Series of (Organic-Geo-) Chemical Reactions

Diagenesis *Catagenesis* *Metagenesis*

Source Formation

Ancient Biological Material → **Kerogen** Solid Organic Matter from which Petroleum is Generated → **Bitumen** Un-expelled Oil (Extractable) in Source Rock → **Carbon Residue** (Low Hydrogen Content) + **CH_4**

Expulsion/ Migration

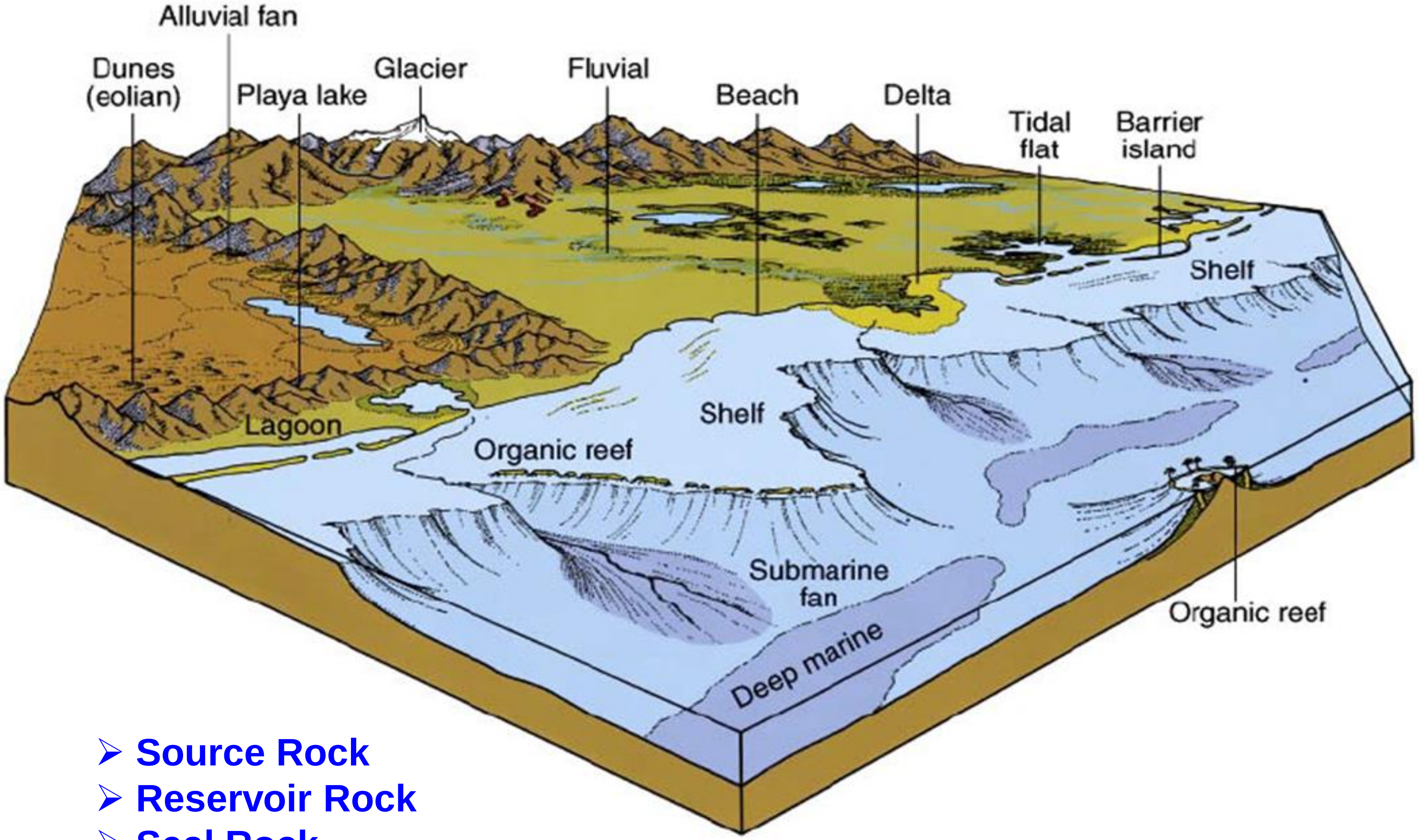
Reservoir Formation

Oil
Expelled from Source rock
+
Gas
Early: CO_2, CH_4
→
CH_4
+
Carbon Residue

Source Rock & Oil Characterization for compound classes, biomarkers, etc.

- **GC**
- **GC-MS**
- **Infra-red, etc.**

SEDIMENTARY DEPOSITIONAL SYSTEMS



- Source Rock
- Reservoir Rock
- Seal Rock

All play a role in petroleum systems – some good, some not so good

Plate Tectonics & Development of Source Rocks

Significant Anoxia – Oceanographic Models

Atlantic – 20 Myrs + of Anoxia

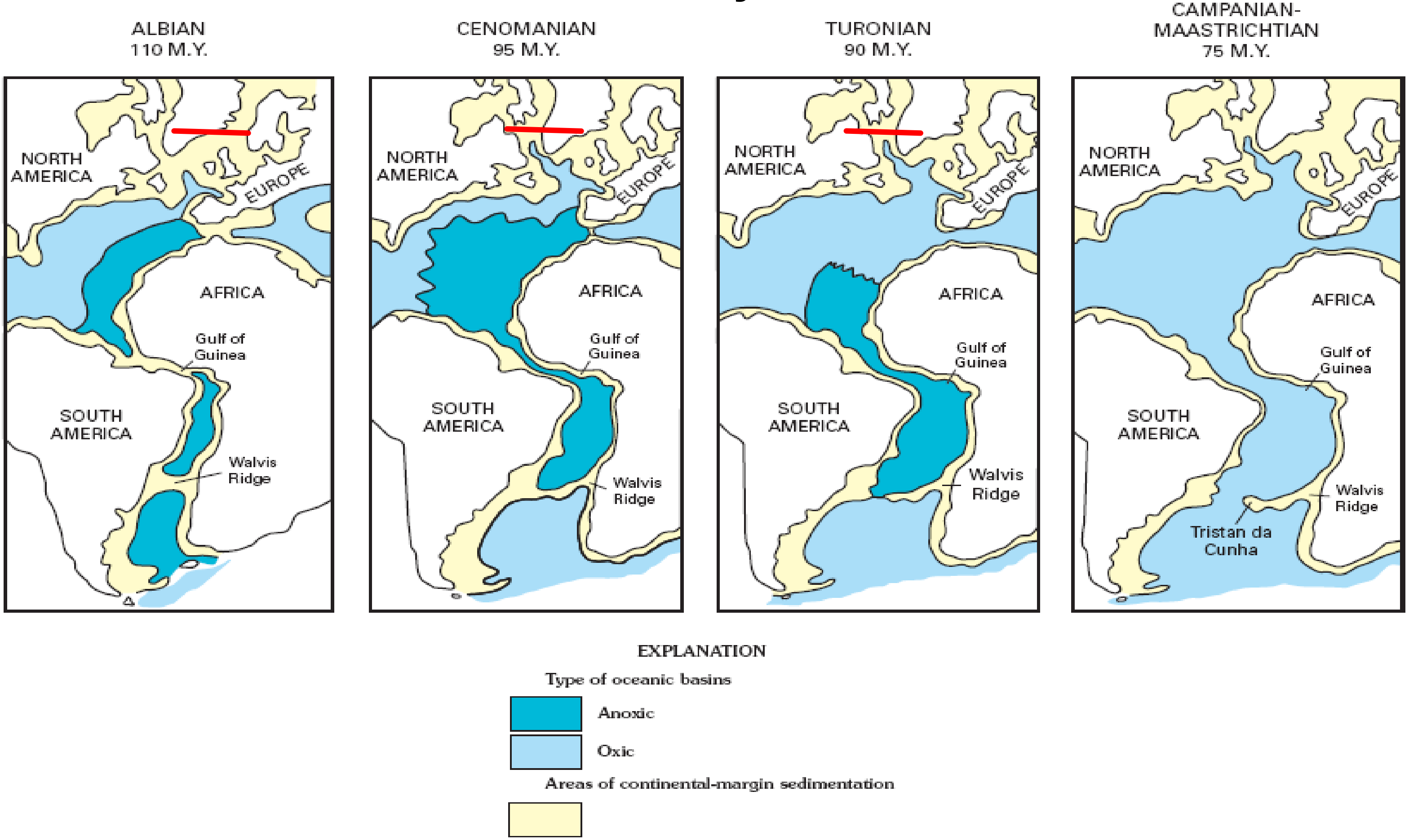
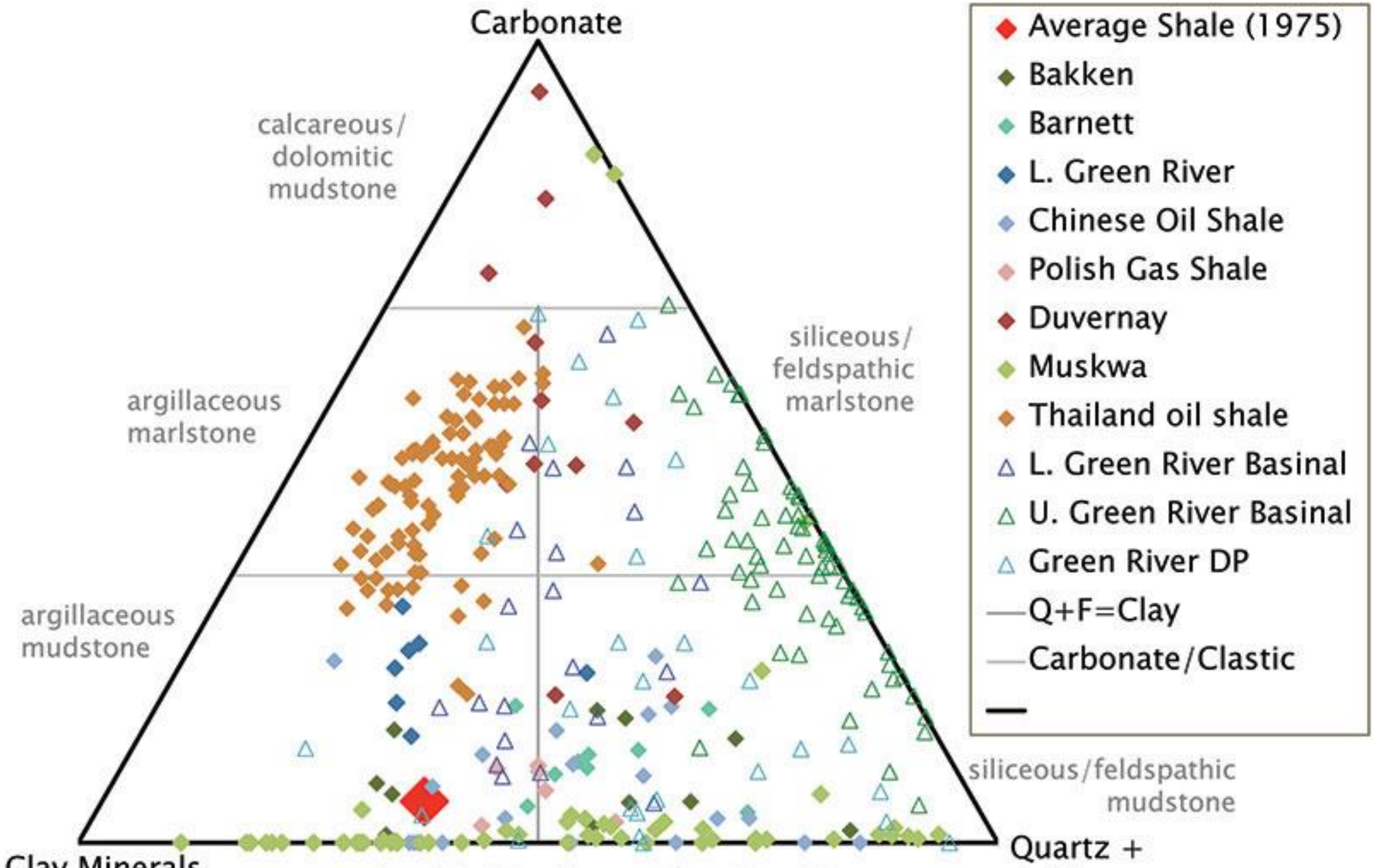


Figure 5. Paleogeographic maps of the Cretaceous breakup of Africa and South America, showing the approximate location of the Gulf of Guinea and the Walvis Ridge. Modified from Tissot and others (1980).

YouTube - Plate tectonic - South America and Africa.mht

USGS_West Africa.url

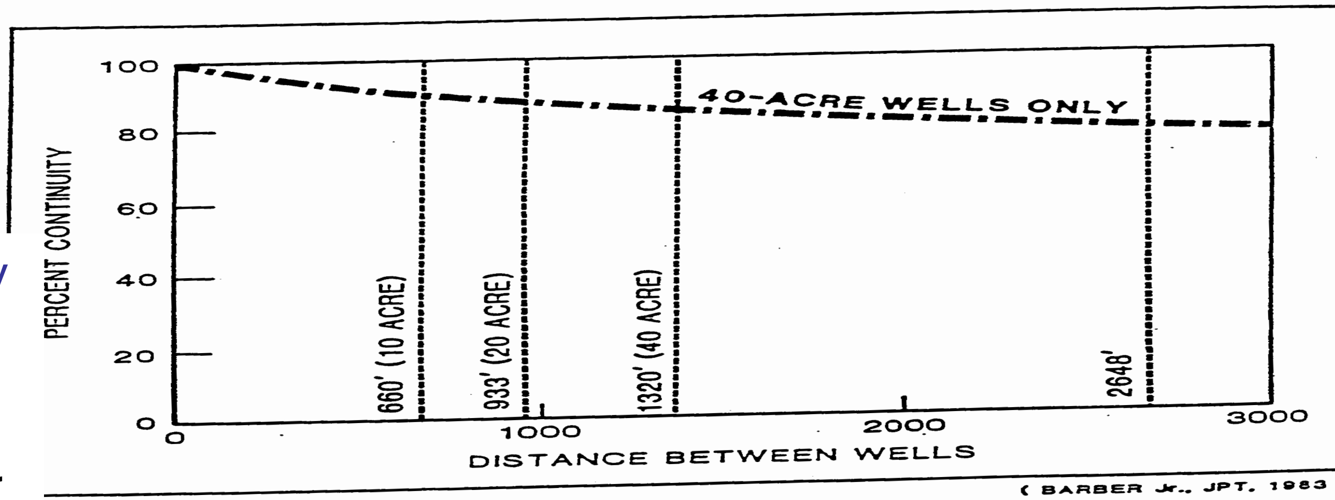


Mineralogy of oil shale, oil-bearing shale, and gas shale.

Geochemistry & Mineralogy can impact fluid flow and reservoir continuity

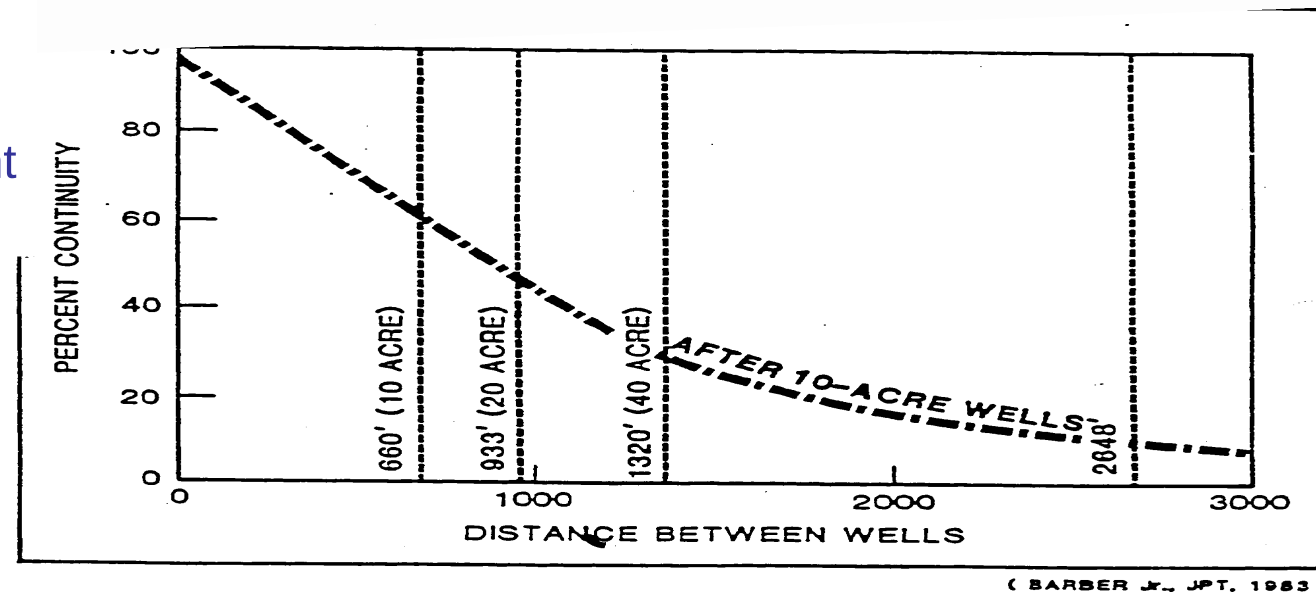
Pay "Continuity" Changes With Increased Data

Early in Field History
40 Acre Spacing

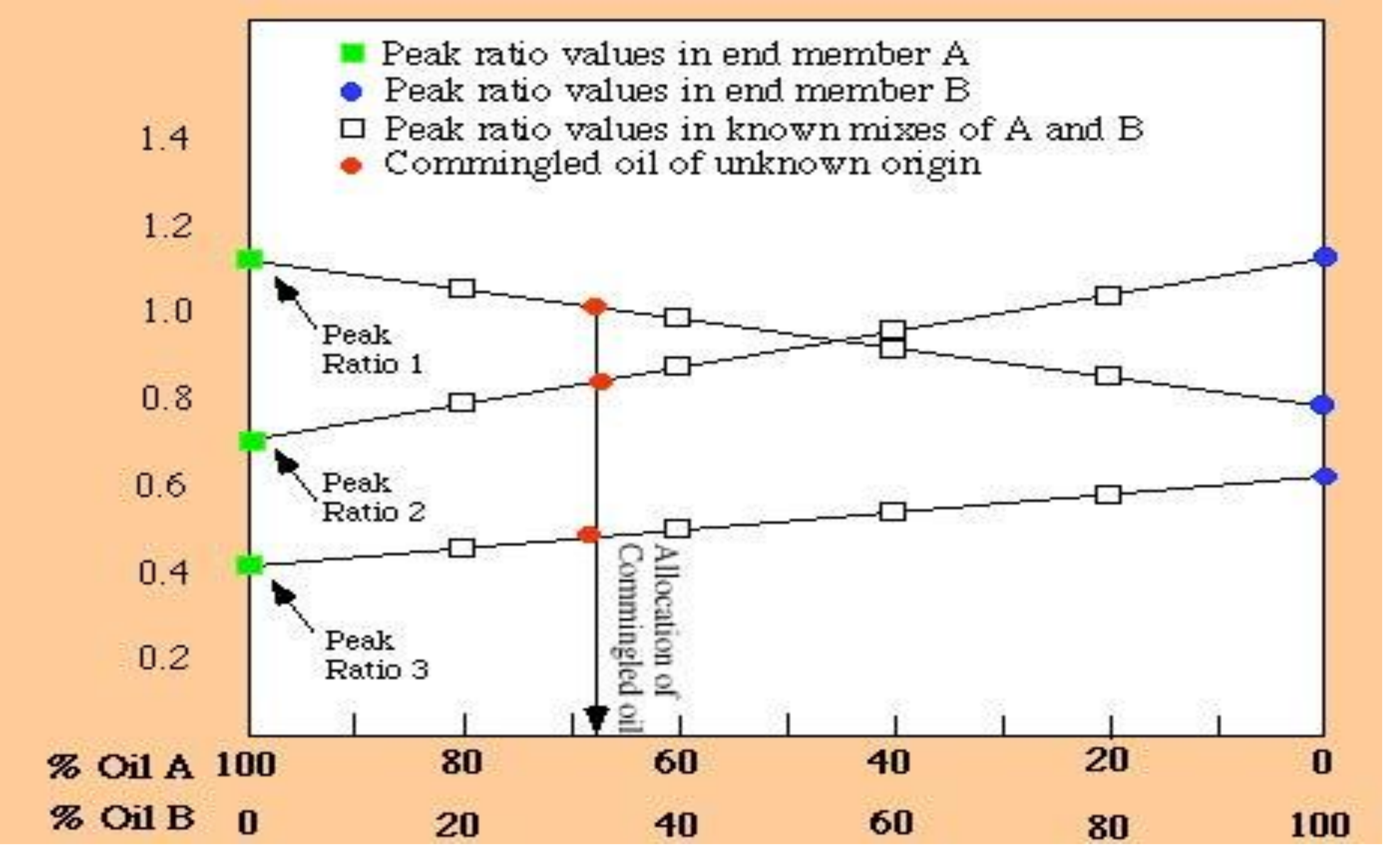


Field Production & Geologic Data 1980's

Later in Development
10 Acre Spacing



Oil Peak height Ratios to assist in Zonal Variations



Out-Dated (Obsolete) Geochemical Allocation of Two-Zone Commingled Production From OilTracers

Source Rock for Petroleum – Core Data

Organic-Rich **Thin Laminae**

Measured Values

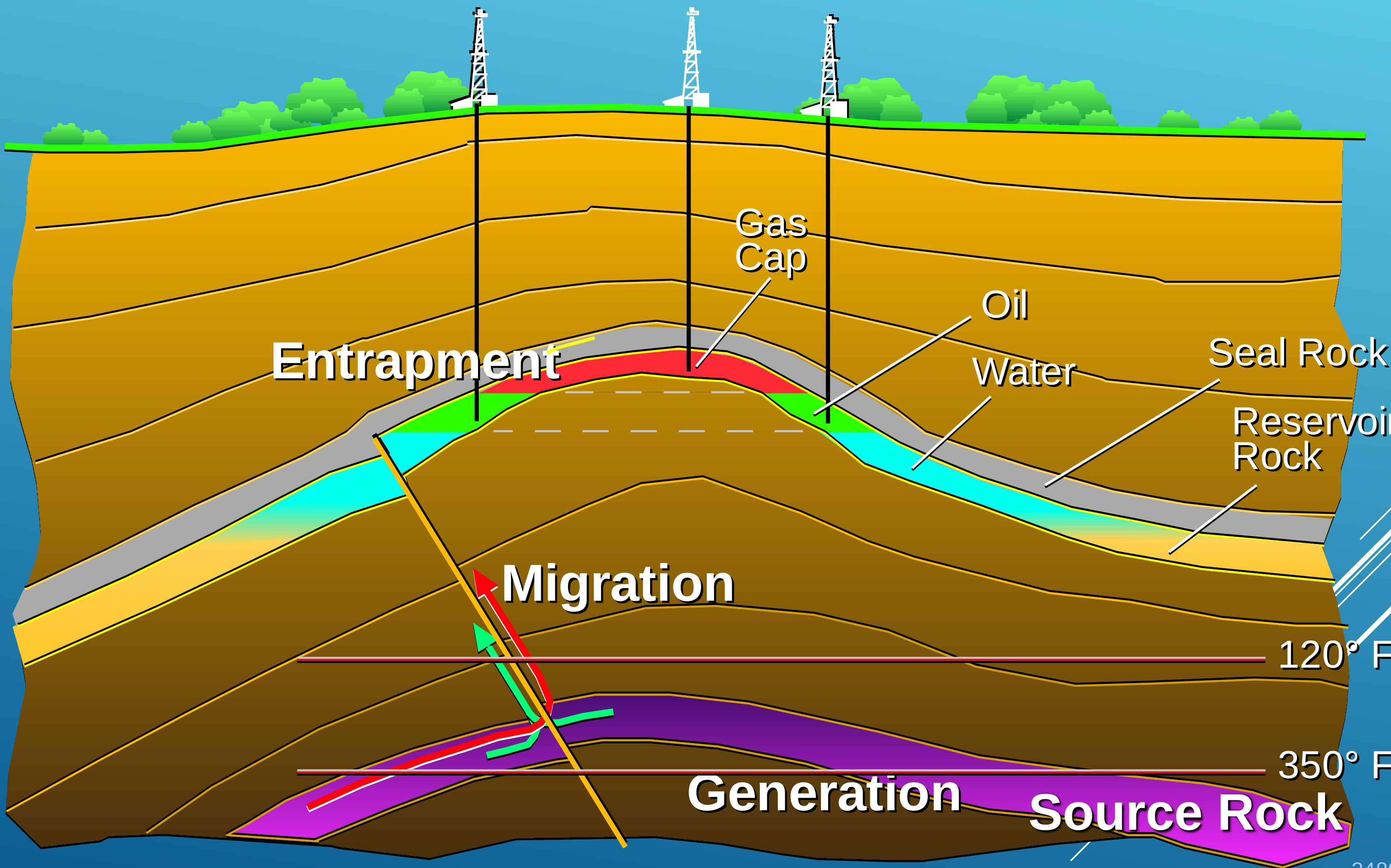
Total Organic Carbon	Hydrogen Index
3.39	378

In-Place Petroleum S_1	Pyrolytically Generated Petroleum S_2
2.24	12.80

LOMPOC Quarry Sample
Monterey Formation, CA

Petroleum System Processes

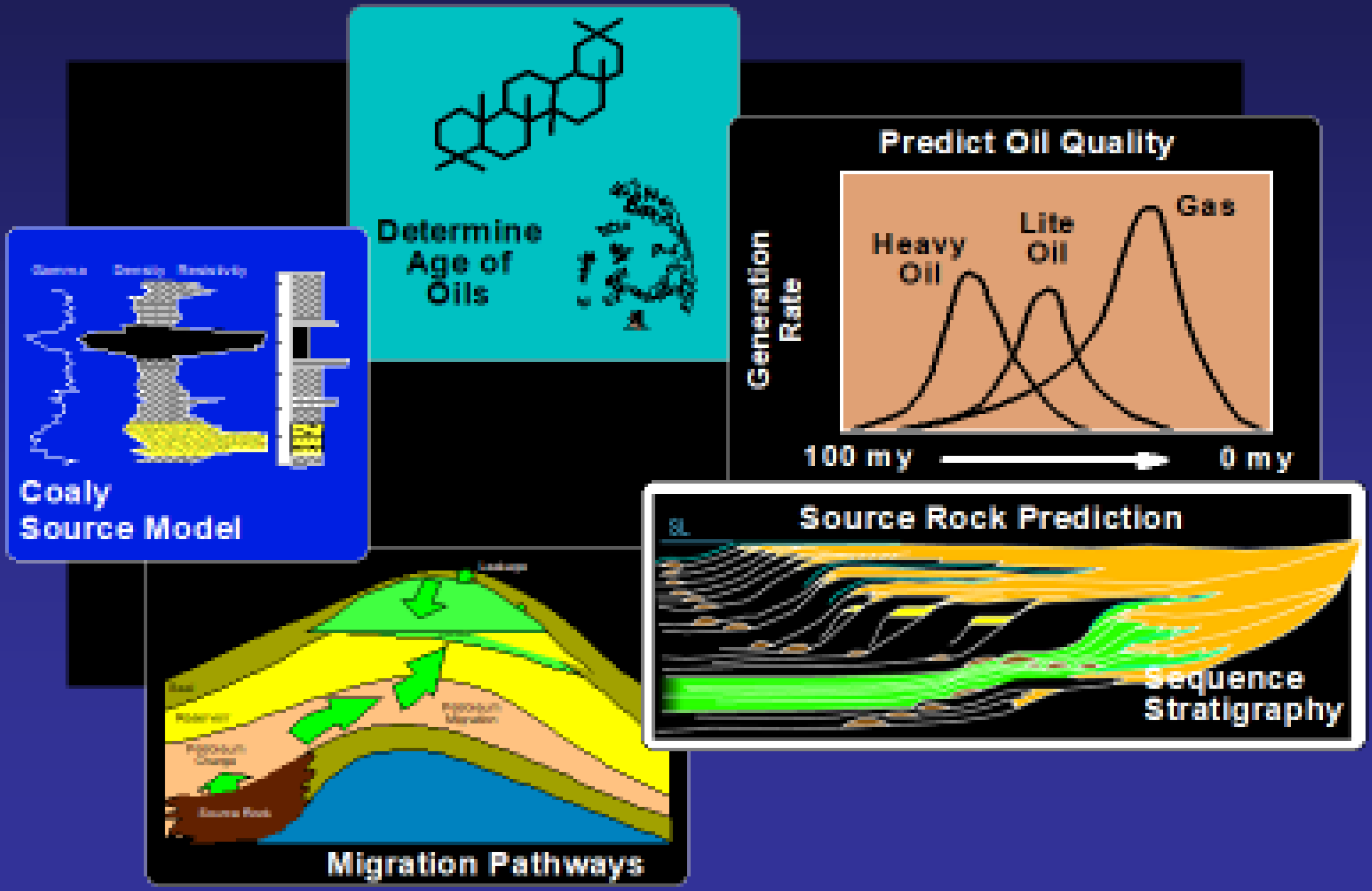
It is ALL or nothing



Exploration Geochemistry:

Inorganic and Organic Sedimentology

Characterizing the type, history and origin of petroleum



Identification of Compartmentalization

Integration of Several of these 'tools' usually required for confirmation

Early Indicators

- 3-D Seismic
- RFT / MDT Data
- Oil / Water Geochemistry
  - GC Fingerprinting / DNA (?)
  - Oil Maturity Indexing
  - Water Analyses
- PVT Data
- Well Tests
- Depositional Models
- Formation Water (Residual Salt Analysis - RSA)
  - 87SR/86SR ratios extracted from non-preserved cores
- Fault Seal Modeling
- Depositional Model / High-resolution stratigraphy

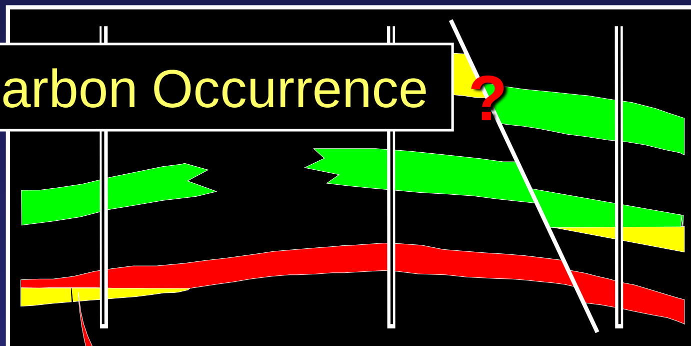
List partially derived from SPE 30533, "A Toolkit for Early Identification of Reservoir Compartmentalization", Smalley, et.al. (1995)

Production Geochemistry:

Geochemistry of Hydrocarbons, Fluid Flow, Sedimentology

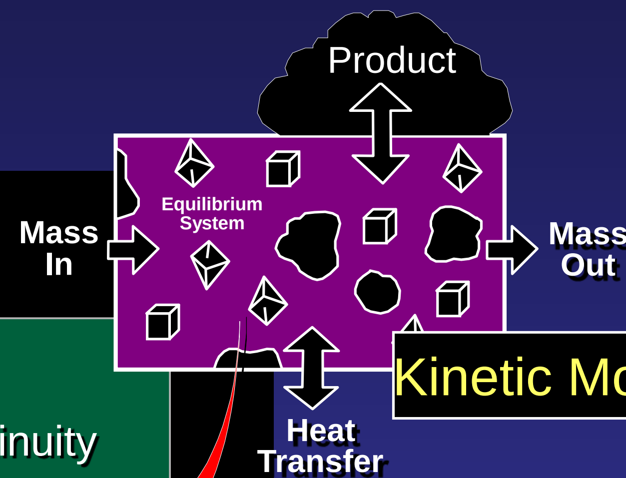
Correlation of hydrocarbon types to define reservoir connectivity

Hydrocarbon Occurrence

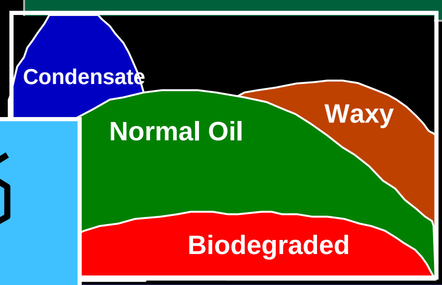


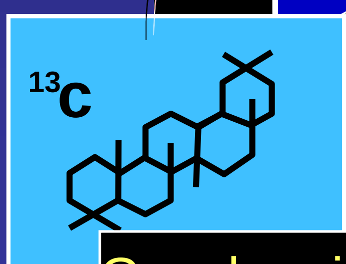
Project Goals:

- ✓ Predicting Reservoir Continuity
- ✓ Predicting HC Quality
- ✓ Modeling Frac & Remediation
- ✓ Training



Kinetic Models





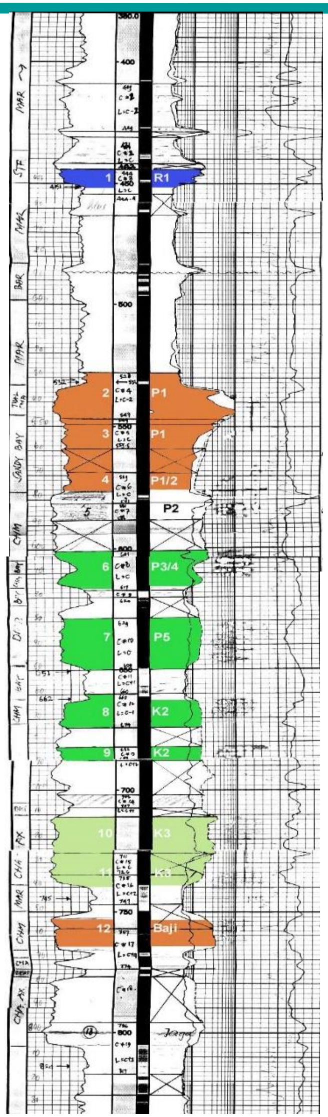
Geochemistry

Applications:

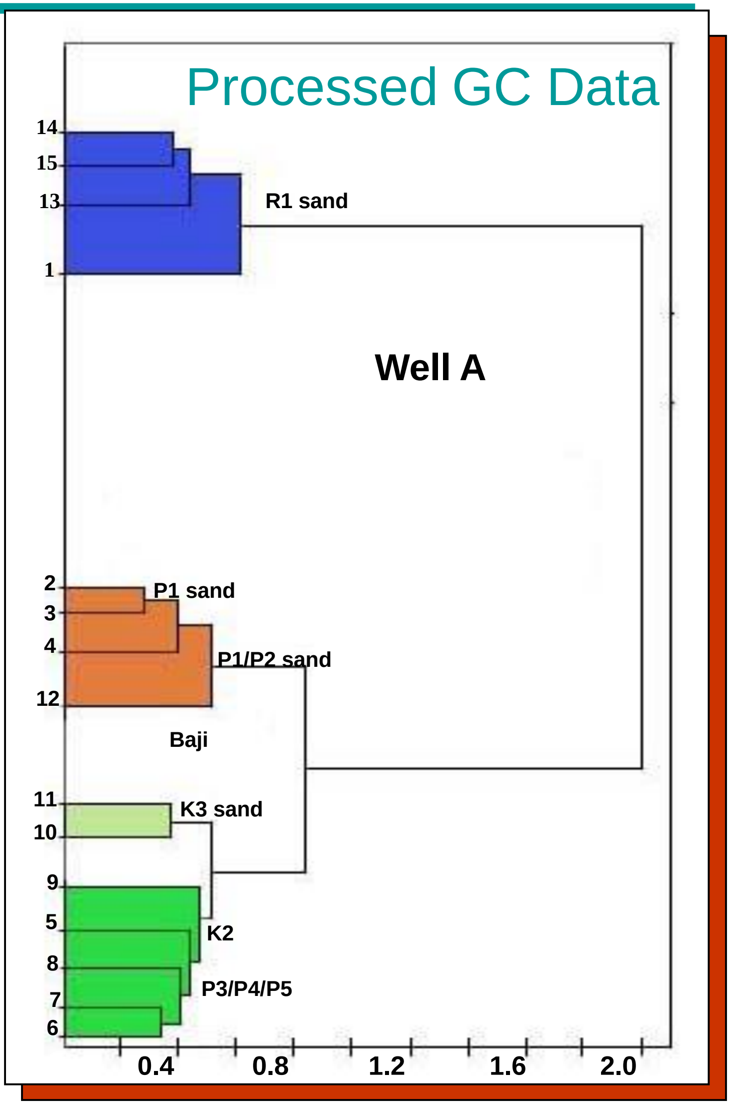
- ★ Exploitation / Development
- ★ Producing

Oil Chromatography Fingerprints Help Define Reservoir Zones

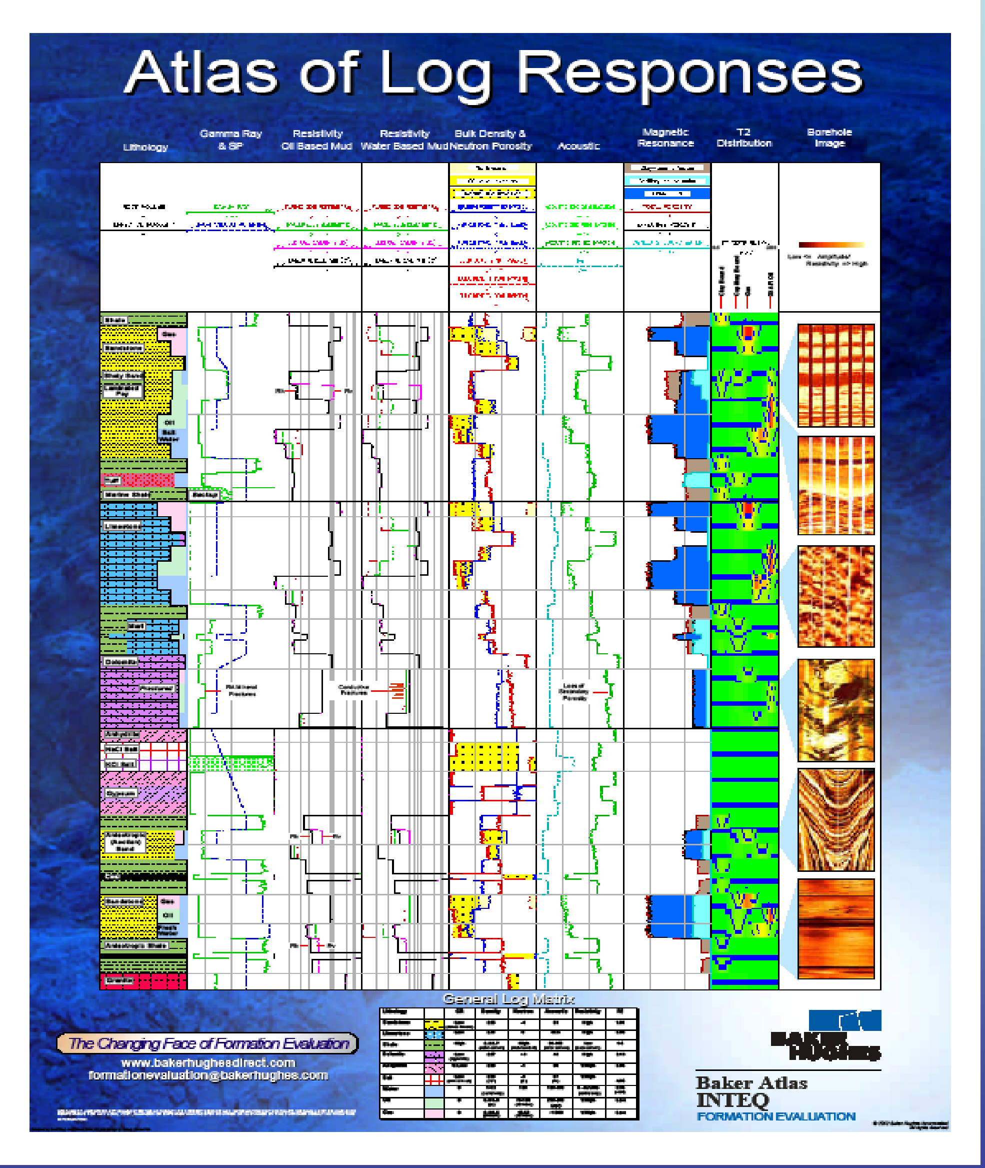
Processed gas chromatographic data is used with geologic information to help determine reservoir continuity



Petrophysical Well Log Data



It is all about reading the rocks & fluids



Lot's of Tools "measure" properties downhole and in labs:

- **Physical properties: resistivity, density, fluid saturations**
- **Rock properties: type, porosity, sonic velocities, organic matter maturity, diagenesis/cementation**
- **Fluid properties: type, salinity, permeability**

Combination of Interpretation & Models :

- **Geology: Sedimentology, Stratigraphy, Characterization**
- **Geophysics: Remote measurements & imaging**
- **Rock & Fluid Properties: PKS**

Log Data: Measured vs Calculated (using "Models")

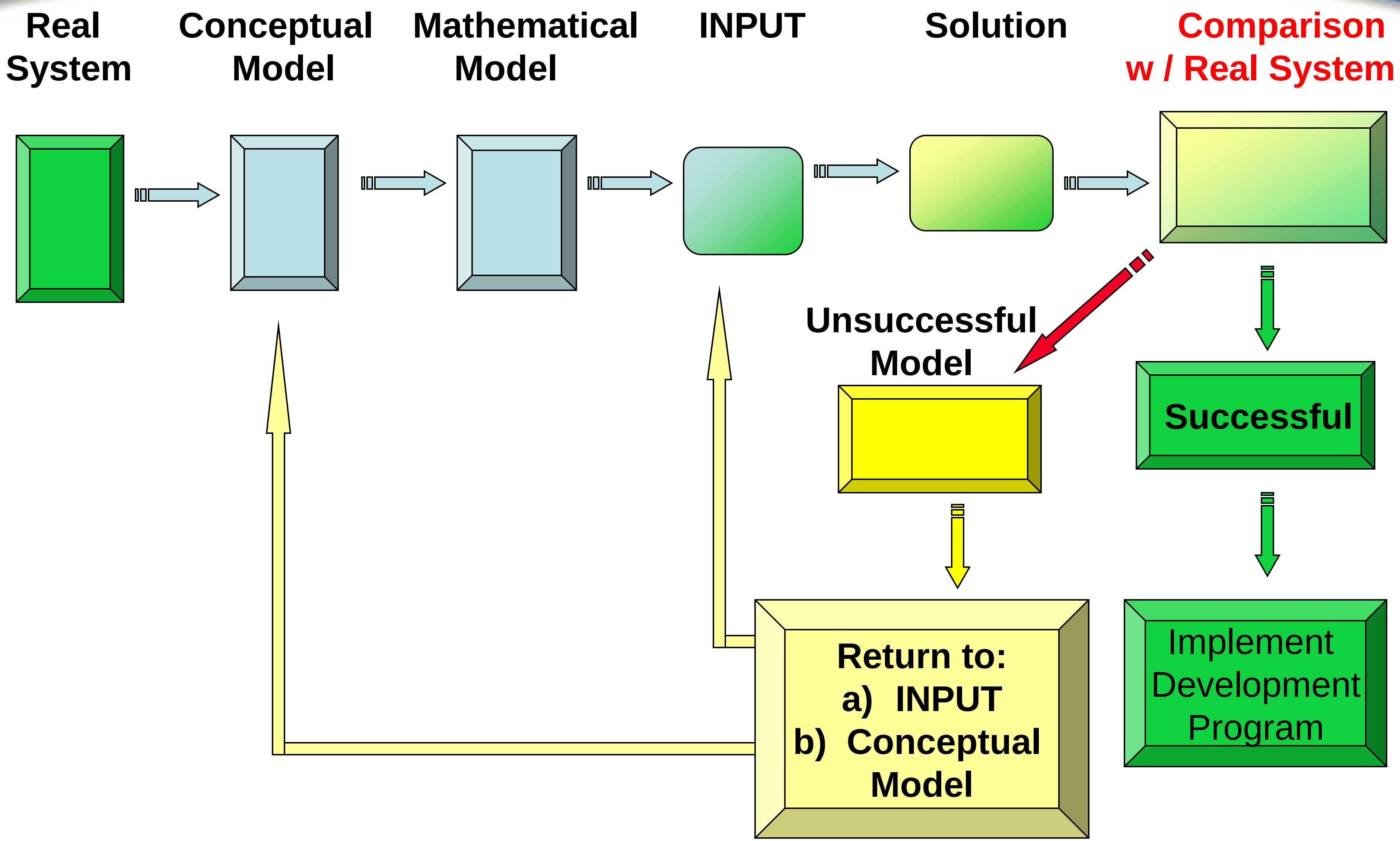
"PRIZM" Wireline logs

Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Column Name	Caliper/ DR	Correlation	Depth	PhotoElec	K, κ	Res	Phi (Greek) Curves	Sonic	Lith/ Show	Chromatography	Pore Space	Archie S_w	Reserves	Equations
Type / Measured vs Calculated	Hole size & Drill Rate / Measured	GR - Gamma Ray / Measured	MD - Measured Depth / Measured	Photo Electric Effect / Measured Downhole & Core	K (Greek) - Permeability / Modeled - Downhole, Measured - Core	Res - Resistivity / Measured	Core Porosity / Measured	Sonic - Rock Sound Velocity / Measurement	Rock Types and Oil Presence / Observed (Mudlog data)	C1-C5 Chromatography / Measured online samples from mudline/pit	Pore Space Various / Calculated	Archie Equations / Calculated	Oil / Gas Reserves / Calculated	Special Equations / Calculations
		SP - Spontaneous Potential / Measured	TVD - Total Vertical Depth / Calculated			MSFL - "Micro", near wellbore	Dphi - Density Porosity / Calculated	RhoB (Greek) - Bulk Density / Calculated	Rock Types observed Mudlogger/Wellsite Geologist		PhotoElec data / Calculation	Core S_w - Water Saturation / Measured	Net Pay - Estimated "good" reservoir thickness / "Measured" from logs	S_oPhi (Greek) - Oil Saturated Porosity / Calculated
		GRK - GR Potasium / "Measured"				LLS - Intermediate distance from Well bore	Nphi - Neutron Porosity / Calculated	DT - Delta Time / Measured 2 way time (Velocity is calculated from model)			BVW - Bulk Volume Water / Calculated	Core S_o - Oil Saturation / Measured	BBL - Barrels of Oil Reserves / Calculated	HCPV - Hydrocarbon Pore Volume / Calculated
		GRU - GR Uranium / "measured"				LLD - Long distance from well bore	Xplot / Nomagrams - Calculated	Sphi - Sonic Porosity / Calculated			ϕA - Phi Area - Pore Area / Calculated	S_{wa} - Water Saturation (Archie's Eq) / Calculated		
		GRTH - GR Thorium / "Measured"				RT/RT(LLD) - Resistivity "True" / Assumed using LLD		Dphi - Density Porosity / Calculated			Hydrocarbon filled / Calculated	R_{wo} - Residual Water (original) resistivity / Measured - Calculated		
		GRT - GR Total / Summation						Nphi - Neutron Porosity / Calculated			Clay Water - sometimes called "bound water" / Calculated			
								Oil Cut - Solvent put on cuttings / Observed - Natural & UV light						
How Collected	Drilling equipment & caliper logging tool	Gamma Ray logging tool	Drilling equipment & logging tools	Gamma Ray logging tool	Core Sample in lab / Model of log data for non-cored intervals	Resistivity logging tool	Core Sample in lab / Model of log data for non-cored intervals	Core Sample in lab / Model of log data for non-cored intervals	Data from Mudlog	Data from online GC	Calculated from log data/models	Calculated from log data/models	Calculated from log data/models	Calculated from log data/models
Reliability	Very good	Very good	Very good	Good	Core - good "log" - Fair	Very good	Core - good "log" - Fair	Very good to good	Very good to good	Very good to good	Good	Good	Depends on your model	Depends on your model

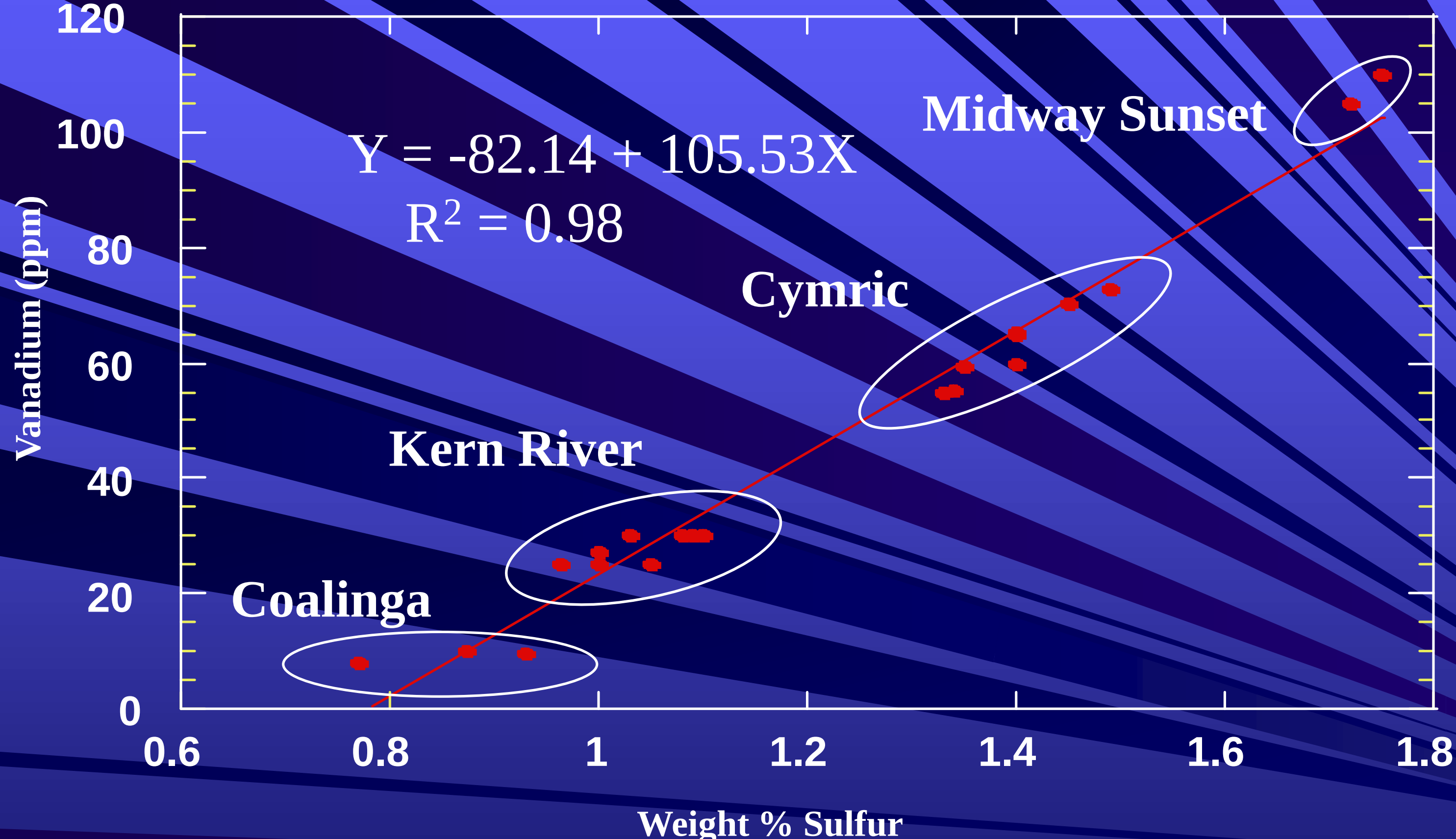
Color KEY

Yellow	Measured, Independent Variable
Blue	Calculated from other logs

Basin Modeling Workflow – Include Geochem



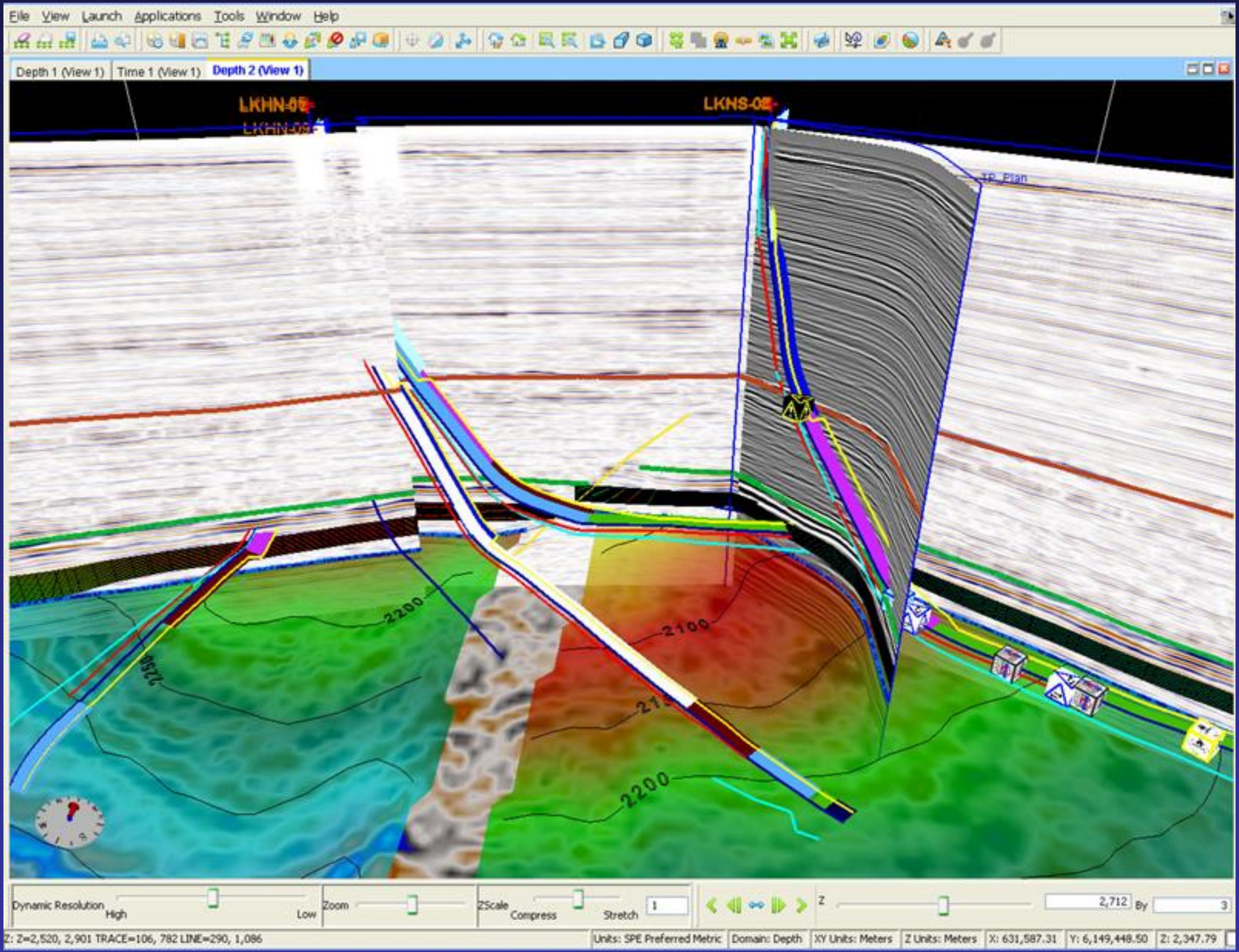
Oil Quality/Producibility
Weight % Sulfur vs Vanadium ppm



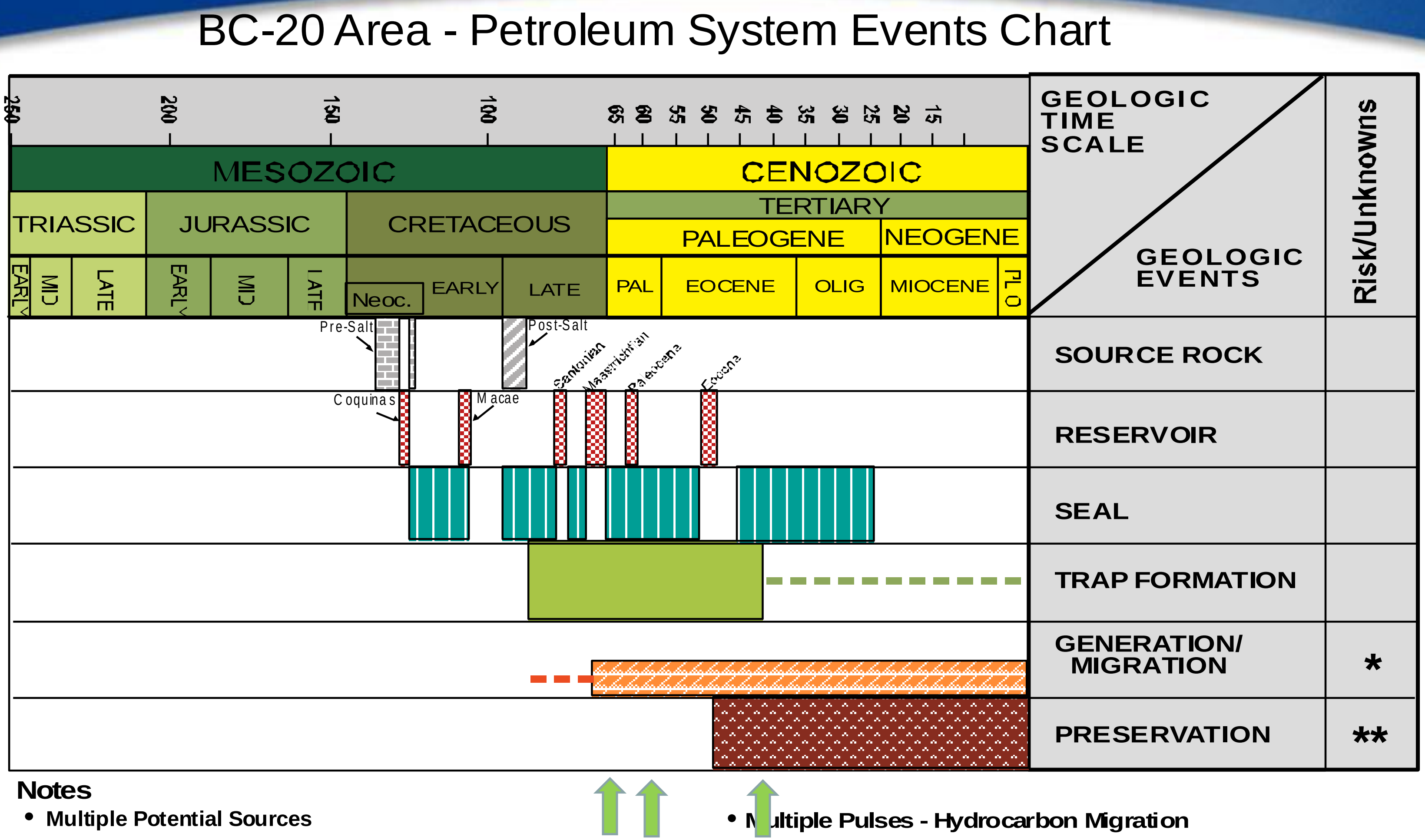
- Consistent with a similar source for the oils and varying degrees of biodegradation
- Variations within fields show impact of multiple processes. Carlson et al, 1998

Henshaw et al, JPT - 1998

Well Bore Track with Seismic Data



Petroleum System Elements with Time



Notes

- **Multiple Potential Sources**

  Pre-Salt lacustrine
    Neocomian-Barremian
      Alagoas
      Coquina - Jiquia
      Buracica?
  Post-Salt Marine
    Albian (?)
      Turonian/Cenomanian

- **Multiple Reservoirs**
  Cretaceous - Santonian, Maastrichtian

- **Multiple Pulses - Hydrocarbon Migration**

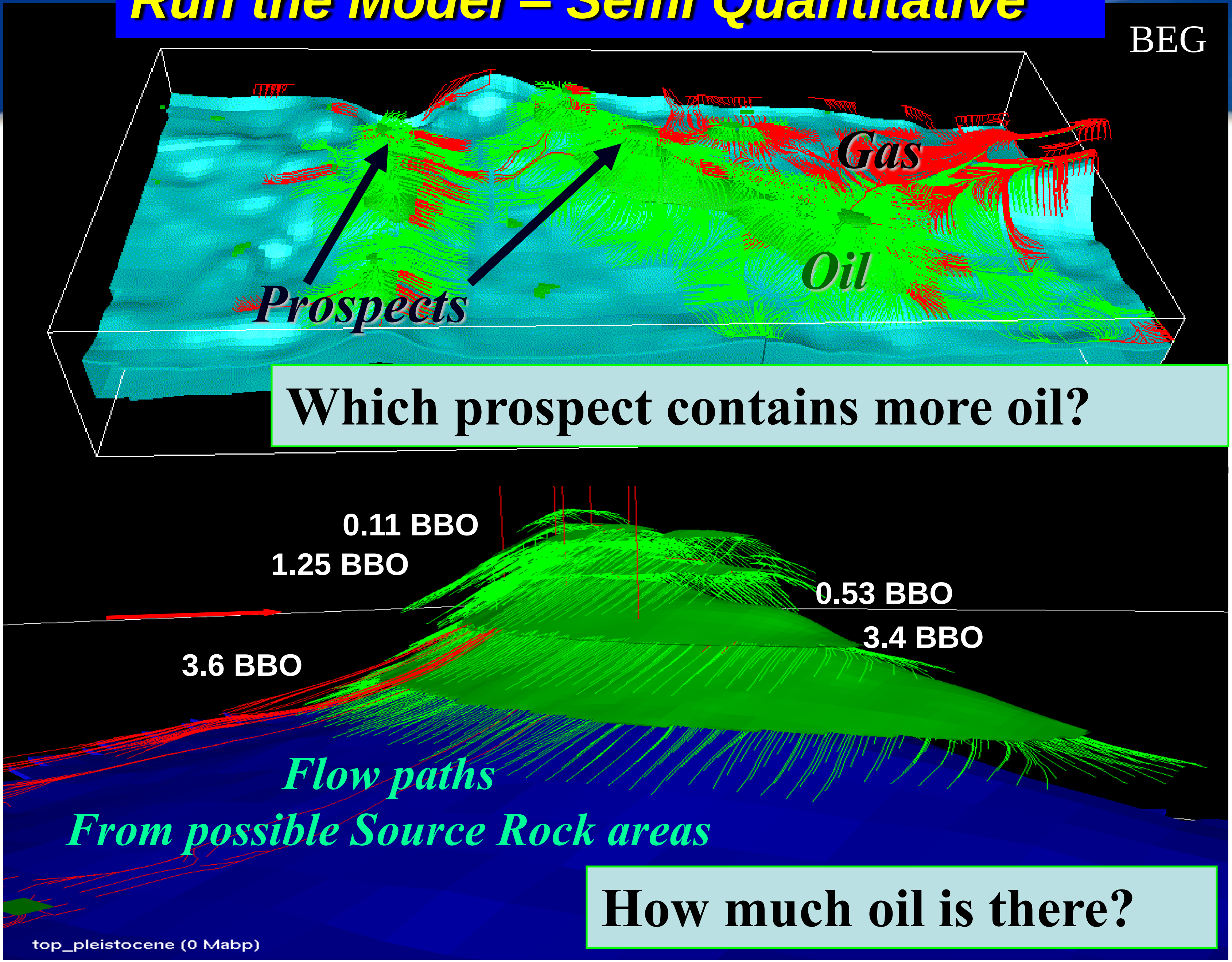
- **Preservation**

  Biodegradation

How many Critical Moments?

Array of Data Elements

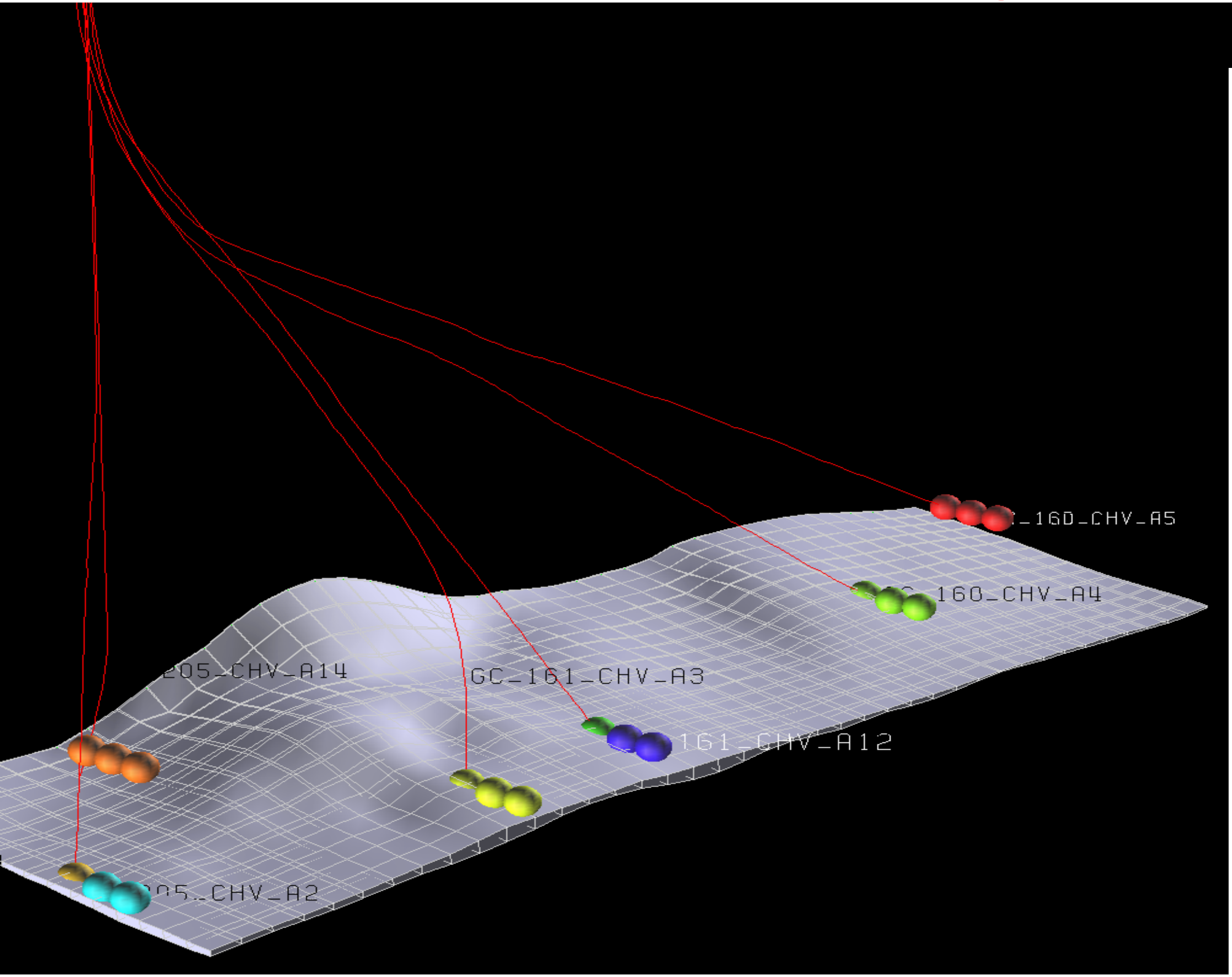
Run the Model – Semi Quantitative



Reservoir Characterization - Dynamic Process

- Requires continual updating and upgrading due to:
  - Data becoming available only in a piecemeal manner
  - Data applicability and reliability is often uncertain and improves with time
  - Rock & Fluid properties may vary with time
  - Better interpretation techniques become available
  - Newer insights are gained with time
  - Unanticipated problems surface during the productive life requiring a different/fresh look

Monitoring Oil Composition through Time - 4D Monitoring



6 wells shown in 3 dimensions with 1 geologic horizon

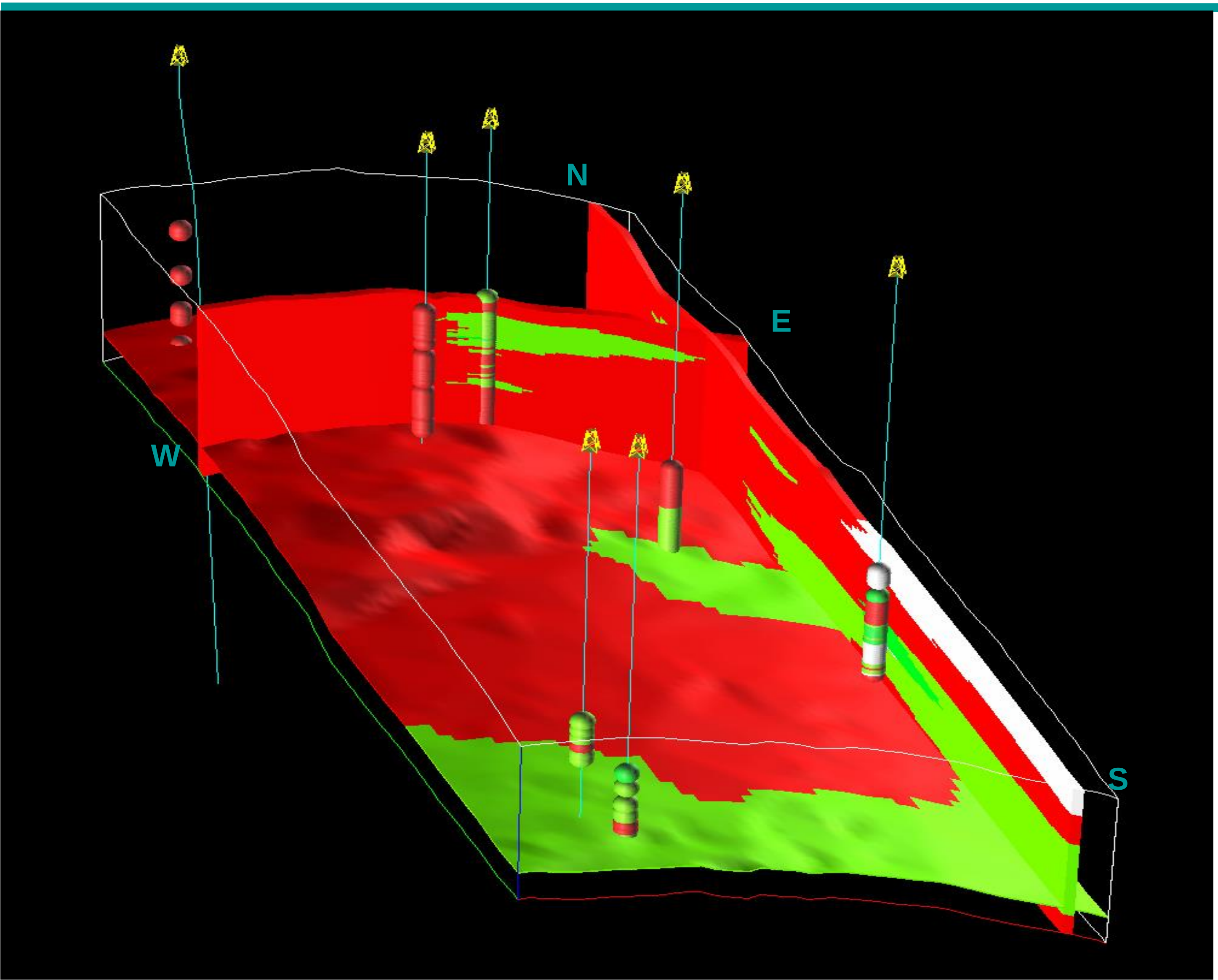
Oil samples taken on 2 different days, plus 1 replicate sample - spheres

Colors of spheres indicate oil composition factor

- **A5 & A14 well samples are from shallower horizon**
  - **Different from other oils and each other**

- **A2, A3, A12, & A4 well samples are from same horizon**
  - **Differences within horizon**
  - **Some changes with time**

Oil Composition Data in Reservoir Simulation 3-Dimensional Grid



7 Wells shown in 3 dimensions

3 projections are shown through the reservoir model
- **1 geologic horizon**
- **1 W-E vertical**
- **1 N-S vertical**

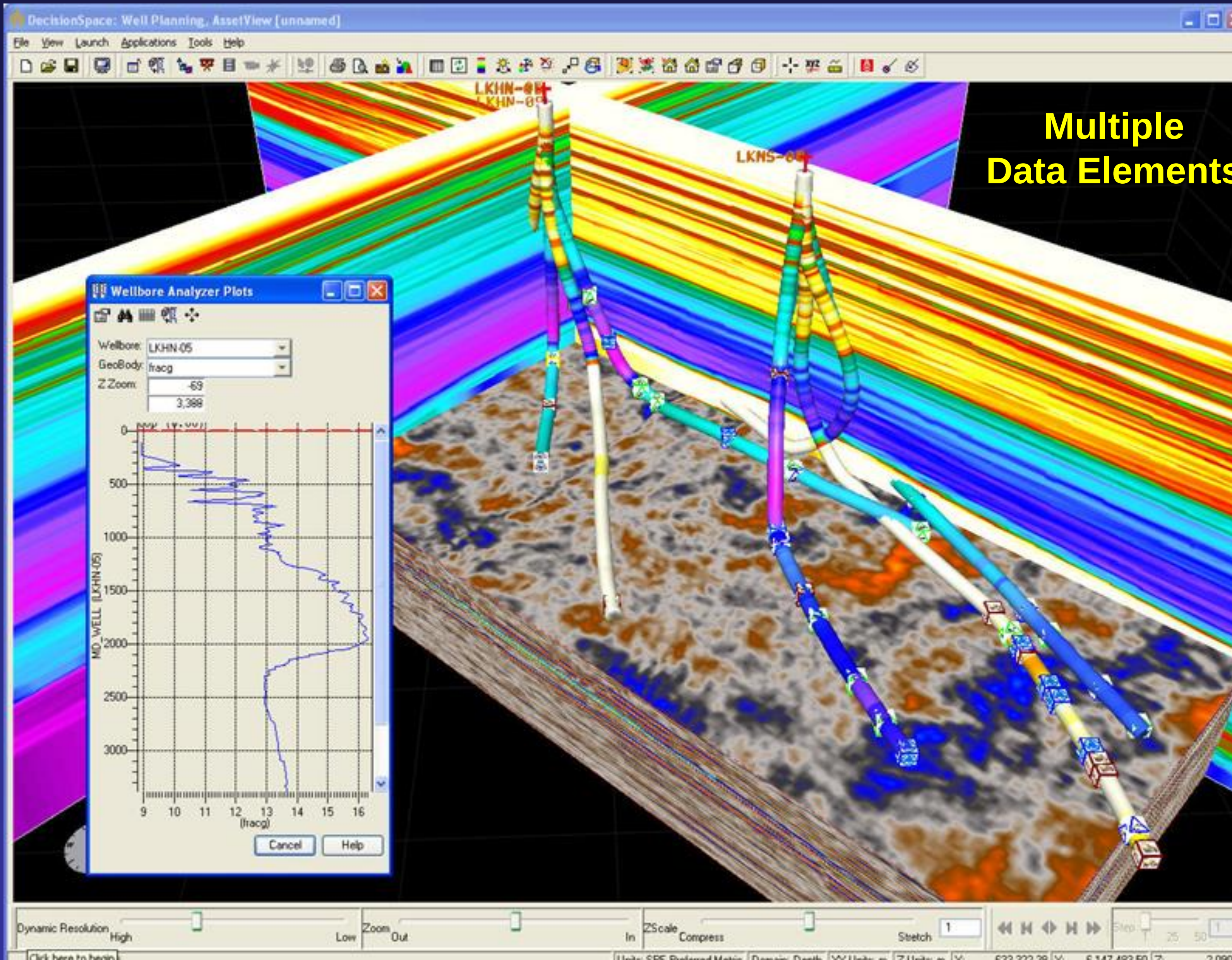
Oil samples were extracted from core at multiple depths - spheres

Colors of spheres indicates oil composition factor

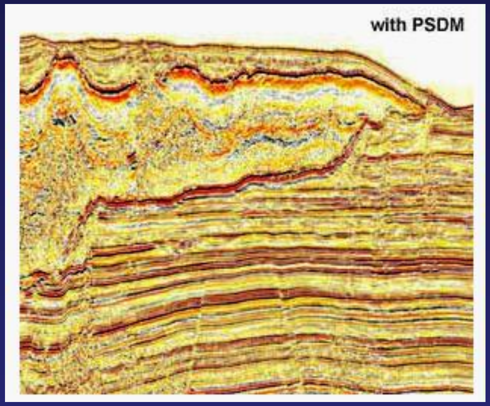
White, Red and Green areas indicate different reservoir zones - created from statistical analysis of oil data

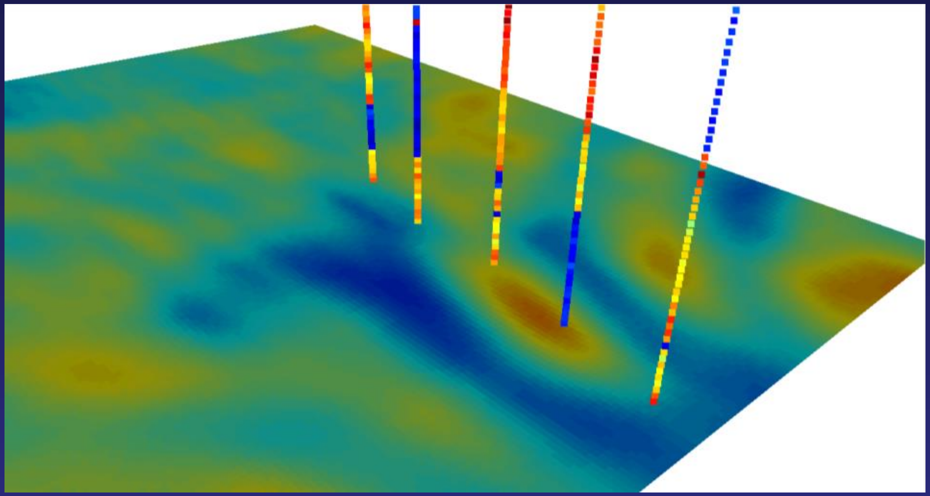
Geology as objects incorporated into Models

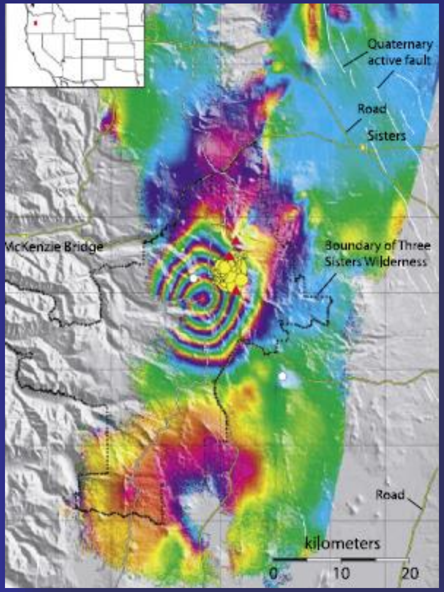
Well Bore Track with Rock "Properties" - Geology

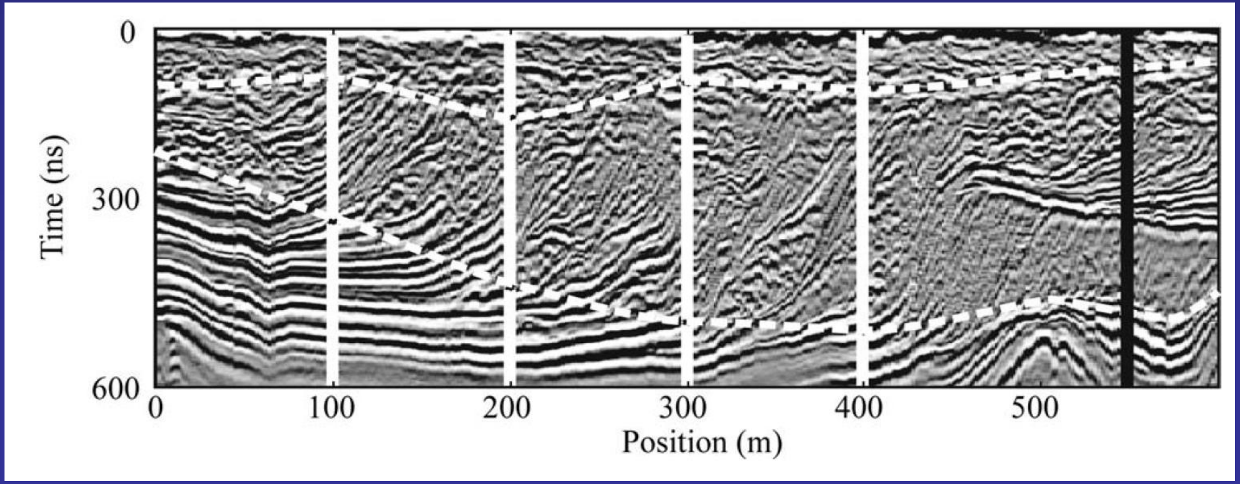


We may have diverse data sources

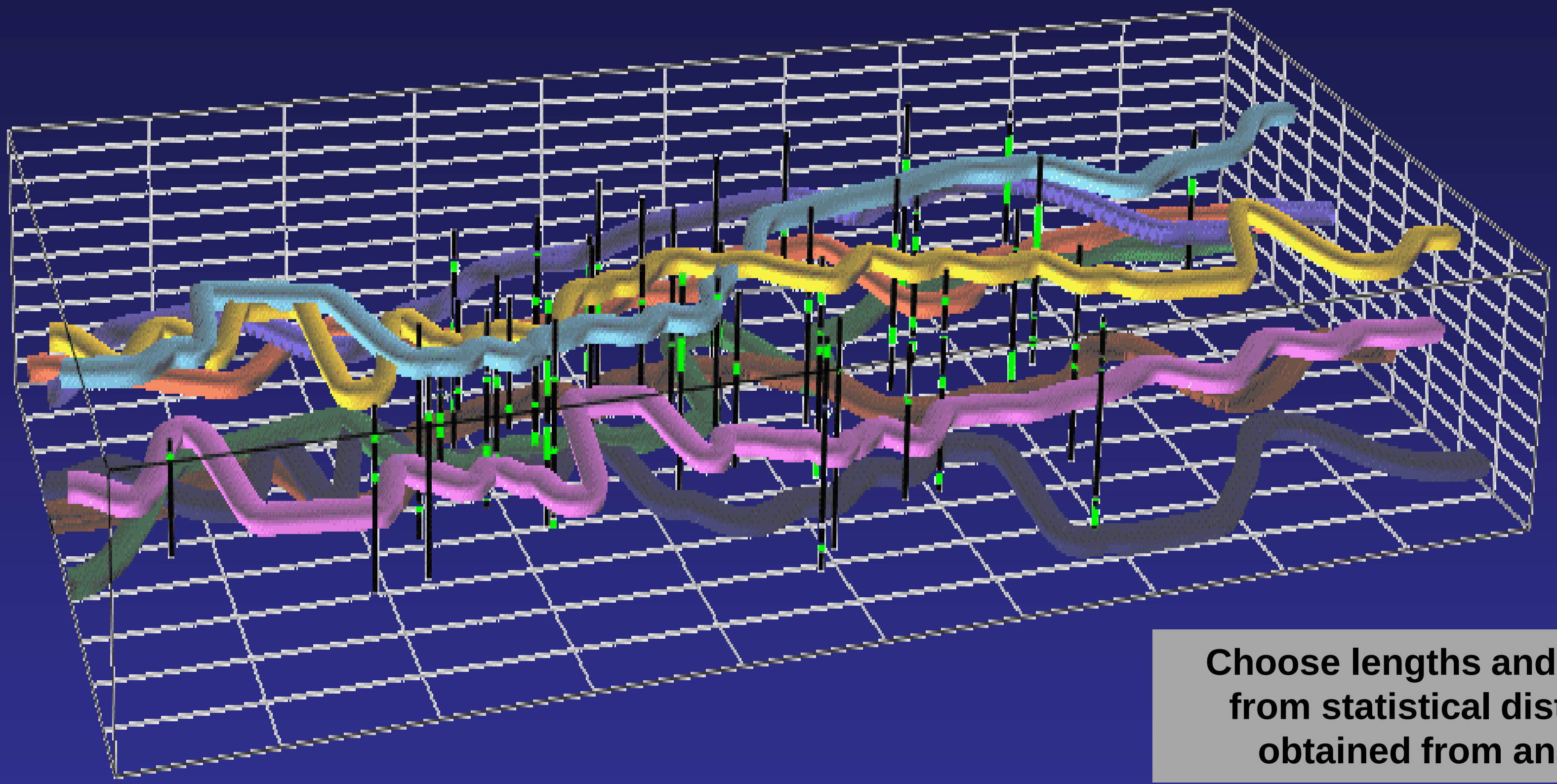








Channel System Boolean Models



Choose lengths and sinuositys from statistical distributions obtained from analogues

Difficult to constrain to data –
Geochem can help constrain models

Jef Caers, Stanford

Not Written in Stone, AAPG Explorer, 2018

Plate tectonics at 50

February 2018 Keith James

The Plate Tectonic paradigm – “the unifying theory of geology” – has just turned 50.

One objective, to model paleoclimate and thence source rock presence, requires knowledge of ocean currents. Mid-Jurassic/Miocene shallow-water deposits and subaerially weathered rocks, now 1 – 7 kilometers deep, in Deep Sea Drilling Project sites in the Atlantic, Indian and Pacific Oceans must have been influenced by these, but reconstructions do not show them. Those large subsided continental masses need to be taken into account as well.