

^{AV} Regional Petroleum Systems Evaluation and New Play Identification in an Uplifted Paleozoic Basin: Arkoma Basin, Oklahoma, USA*

Harris Cander¹ and Thomas L. Patton²

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¹BP America, Houston, TX (harris.cander@bp.com)

²BP Exploration, Sunbury on Thames, United Kingdom

Abstract

A detailed basin modeling, petroleum migration, and pore pressure study of the Arkoma Basin, Oklahoma, was used to identify new exploration opportunities and maximize resources in a heavily exploited province. We determined the specific pathways, timing, and mechanisms of petroleum migration, as well as the timing and location of formerly overpressured compartments. The resulting maps explain known accumulations and delineate new opportunities. This study also provides insights into the effects of uplift on gas migration, pore pressure history, and reservoir quality that are applicable to uplifted basins around the world.

Woodford oil and gas initially migrated laterally in the pre-Atokan autochthon in late Pennsylvanian time through both sandstone and carbonate carrier beds. Vertical migration above the Spiro sand was inhibited by a pressure seal near the base of the Atoka-age synorogenic, foreland sediments. With continued burial, most oil was flushed from the system but remaining oil was cracked to gas in reservoirs. During subsequent uplift, the supra-Spiro pressure seal was breached and large volumes of gas were able to migrate vertically upward into the foreland sediments. Uplift also caused expansion of gas that flushed water from down dip, cemented reservoir sections and created a tight gas play. Today, most of the Arkoma foreland is normally pressured, but we believe that sonic and resistivity logs preserve the record of paleo-overpressure proposed by this study. Gas isotopes and petrography also support the results of the petroleum migration analysis. Deep autochthon and shallow foreland reservoirs have similar isotopic compositions with consistent vertical trends that include very heavy methane compositions, indicating a similar origin. Pyrobitumen is ubiquitous in autochthon petroleum carrier beds but far less common in the synorogenic sequence, indicating that most oil migration was restricted to the autochthon by the paleo-pressure seal.

Regional Petroleum Systems & New Play Identification in an uplifted Paleozoic basin: Arkoma Basin, Oklahoma, USA

Harris Cander

Tom Patton

BP

E&P Technology





Purpose

- **Understand origin, migration, and distribution of gas**
- **Integrate with other risk elements**
- **Identify new opportunities**
...in a heavily drilled Paleozoic gas basin



Paradigms

- There's gas everywhere!
 - No need for petroleum systems study
- It's "unconventional tight" gas
- It's "basin-centered" gas
- Porosity and permeability are unpredictable

Themes

- *Conventional Charge & Traps*
- *Value of regional understanding petroleum system in a gas basin*

Petroleum System Modeling



■ Inputs

- Tectonics, Structure, Stratigraphy
- Burial + Uplift history
- Source rock(s)
- Heat flow / thermal regime
- Carrier beds



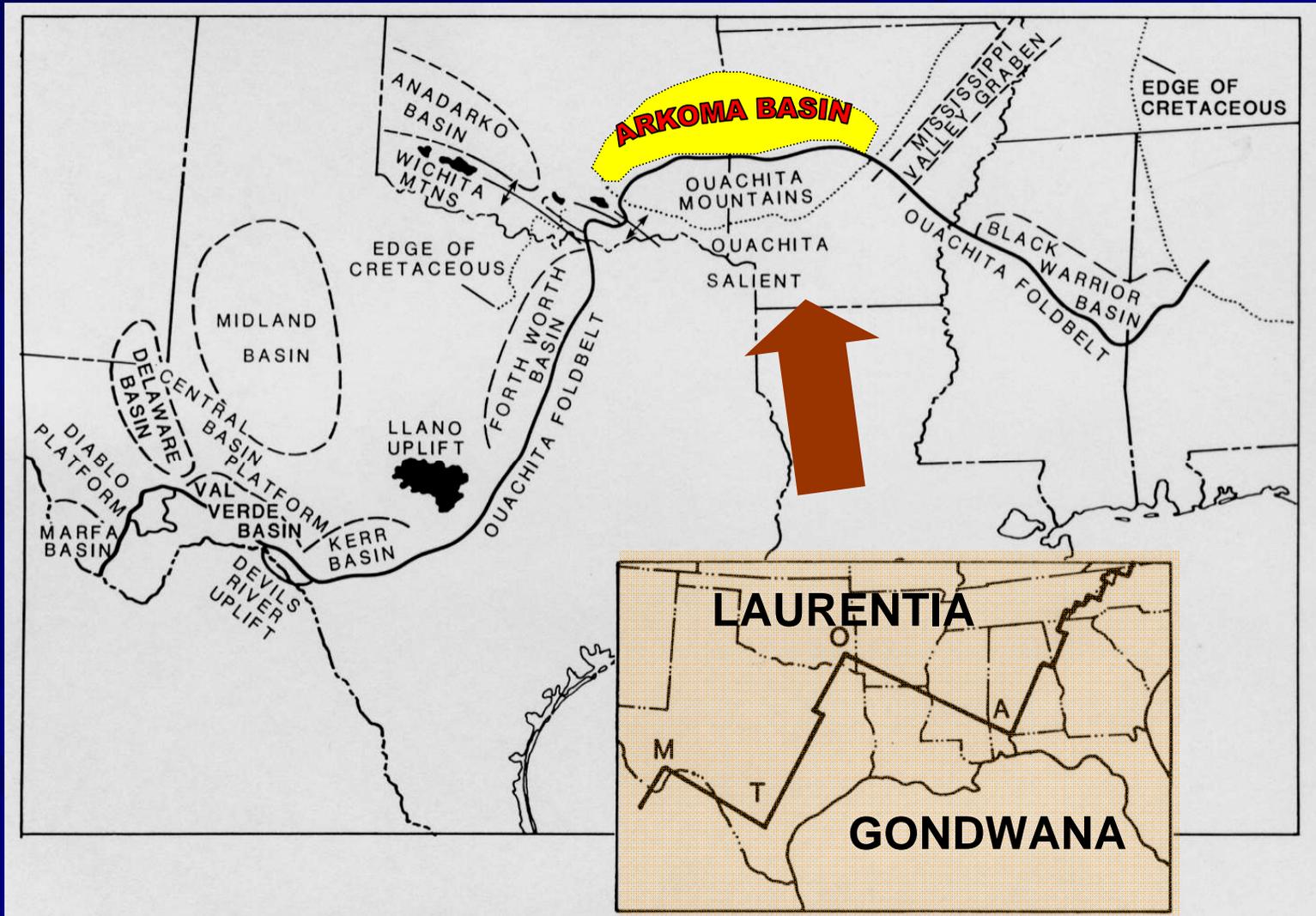
Petroleum System Modeling

■ Outputs

- T, P, and fluid flow history
- Petroleum expulsion
- Migration pathways
- Maps of accumulations
- New opportunities

Arkoma Basin - SE Oklahoma

Pennsylvanian Convergence



Tectonic History



Permian
L. Penn

Erosion, uplift
Thrusting ends;
Source rock thru gas window

E. Penn

Foreland: Thrusting, rapid
subsidence, Paleozoic source
rocks enter oil & gas window;

Miss.

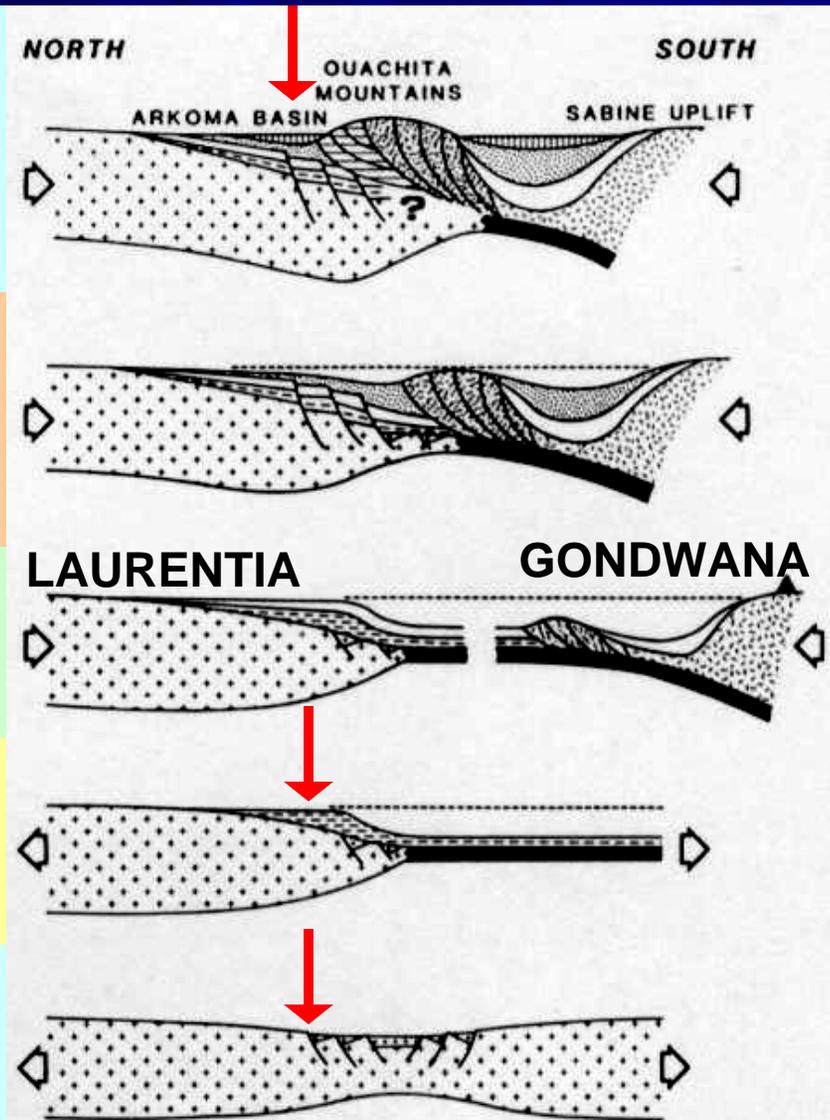
Carbonate-Clastic shelf

Devonian
Silurian
Ordovician

Woodford Source
Passive margin
Carbonate shelf

Cambrian

Rift-drift

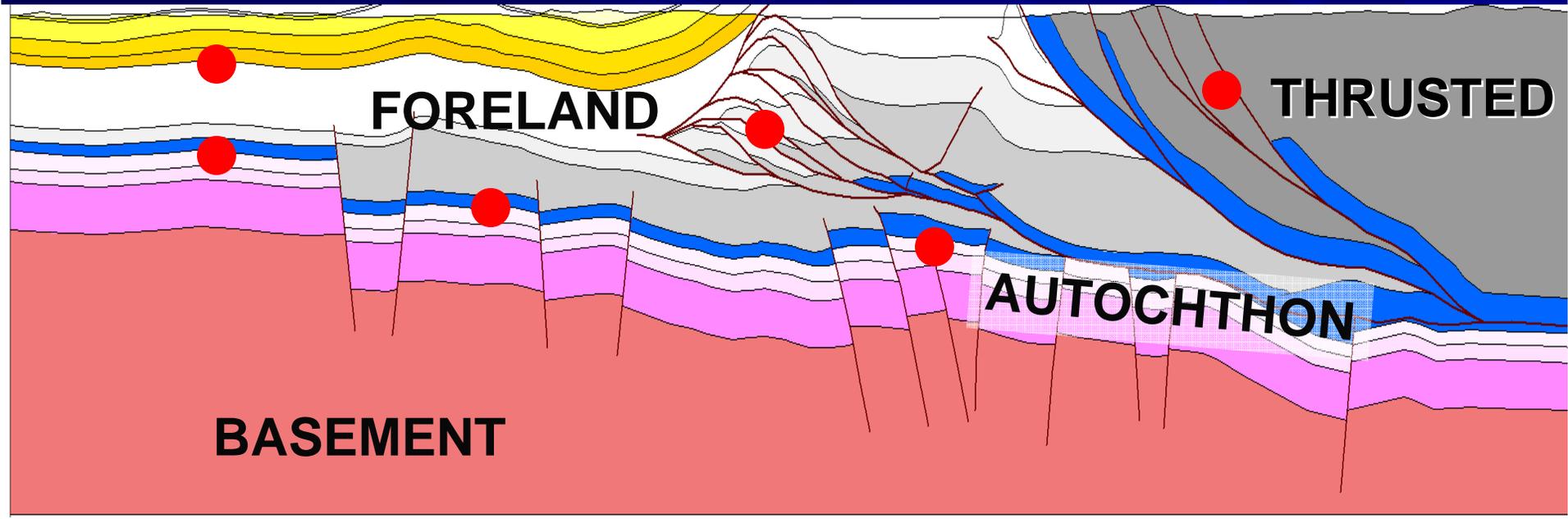


Occurrence of Gas



NORTH

SOUTH



BASEMENT

FORELAND

AUTOCHTHON

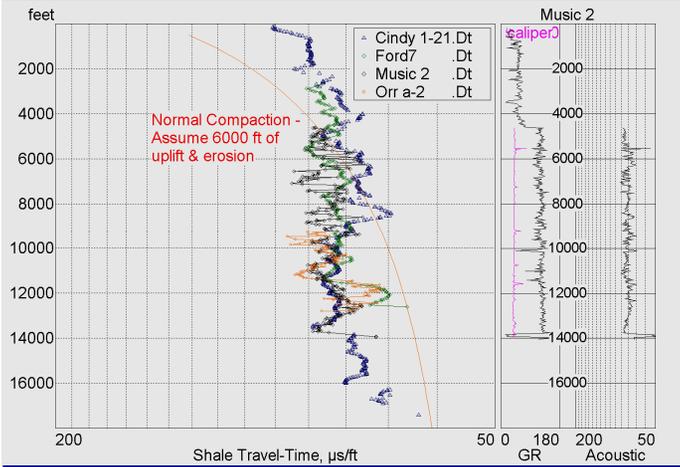
THRUSTED

Erosion & Uplift

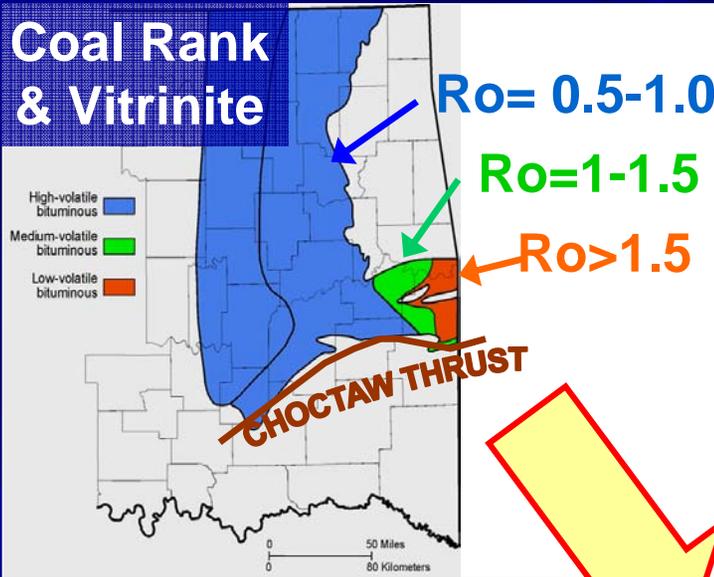


Convergence of data → > 4 km erosion

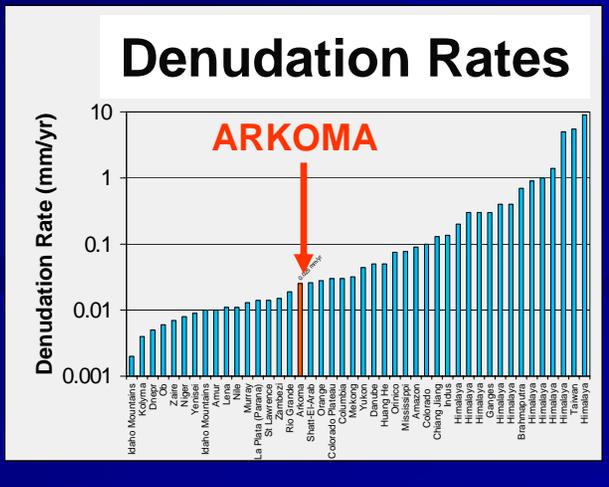
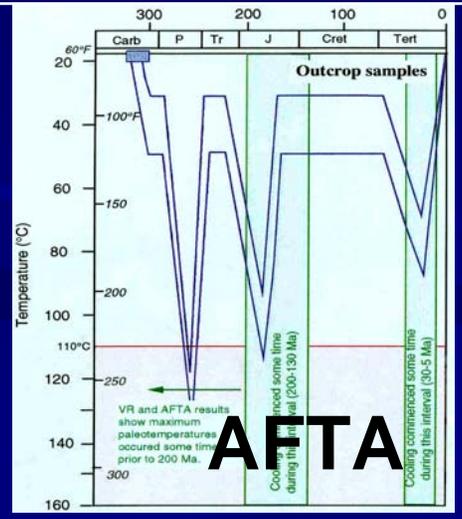
Shale Velocities



Coal Rank & Vitrinite

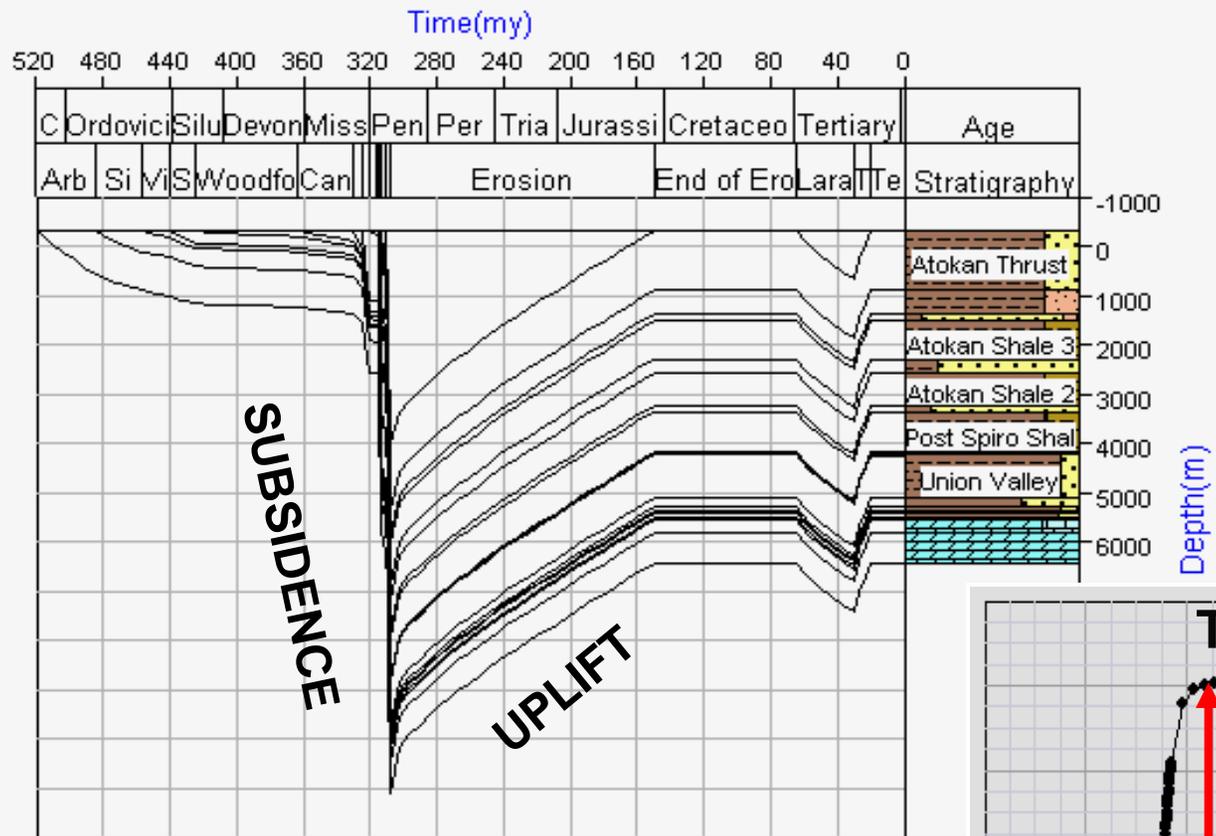


Rock-Eval Maturity
Fluid Inclusions T_H
 $\delta^{18}O$ Late cements



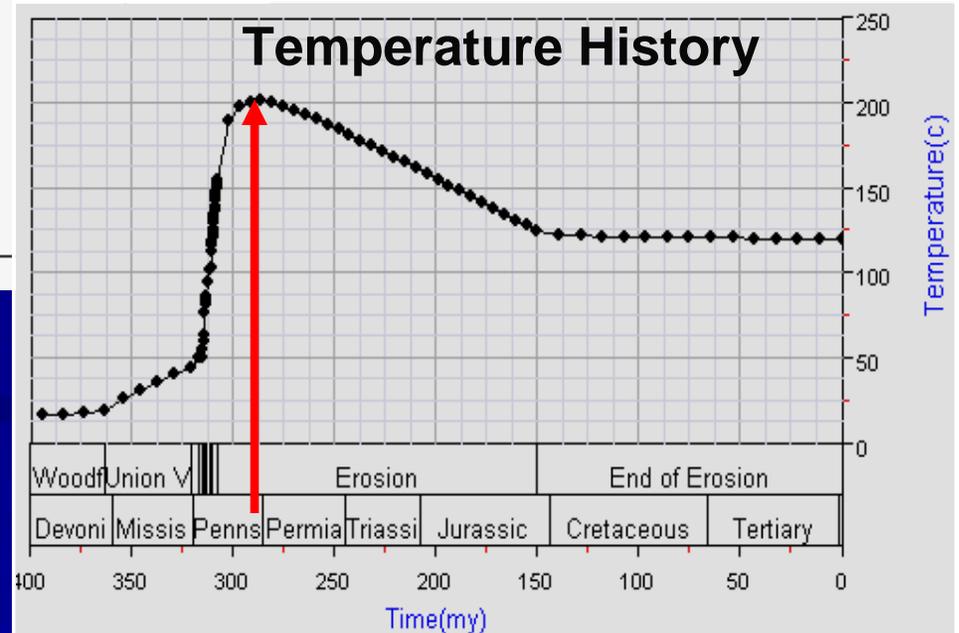
4 to 4.5 km Erosion & Uplift

1D Burial & Temperature History



Max Burial 311 Ma
Max T° ~ 290 Ma

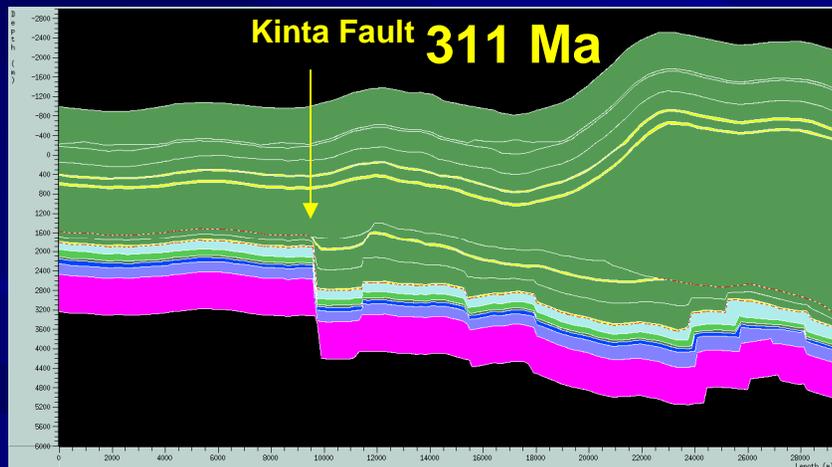
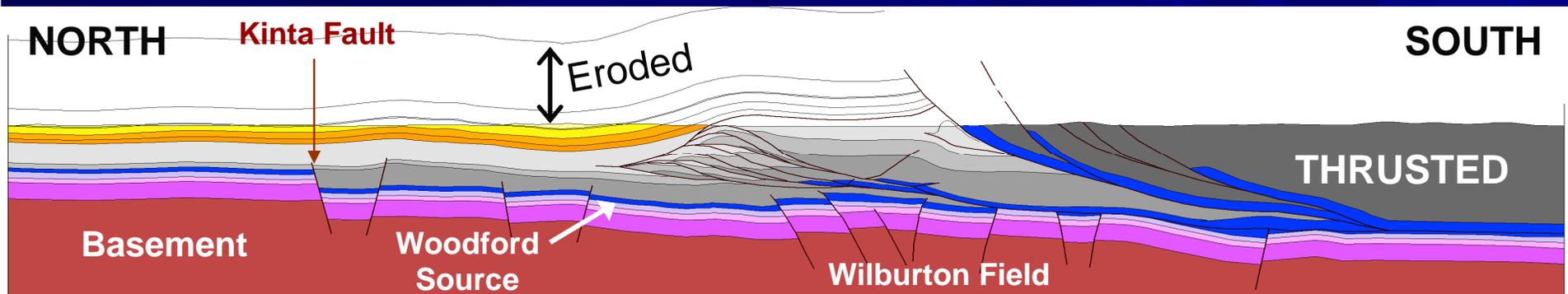
Thermal transient effect





2D Modeling

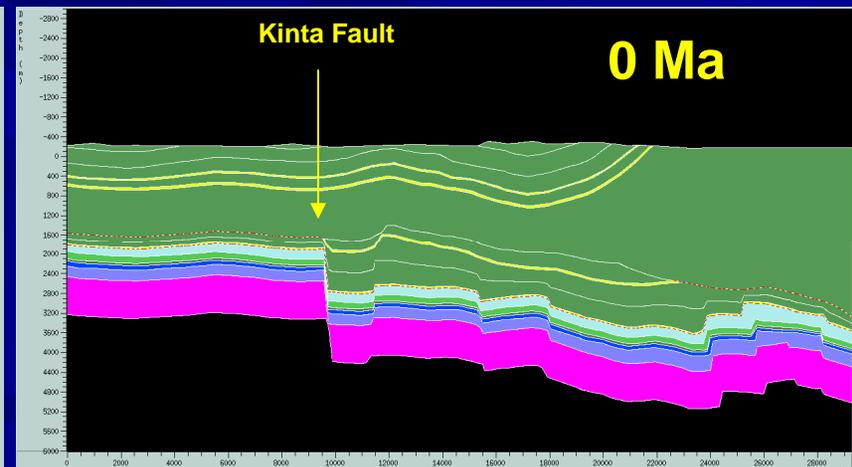
Need Tectonic & Structural model



Run: run0-L140
Age: 311.004 Ma
% Length in m
% Depth in m

LITHOLOGY

- Shale_10sh
- Shale_20sh
- Shale_30sh
- Shale
- micr_line
- carbon
- dolomite
- SO_20to_50_m
- Upper_Crust
- Lower_Crust
- Upper_Mantle



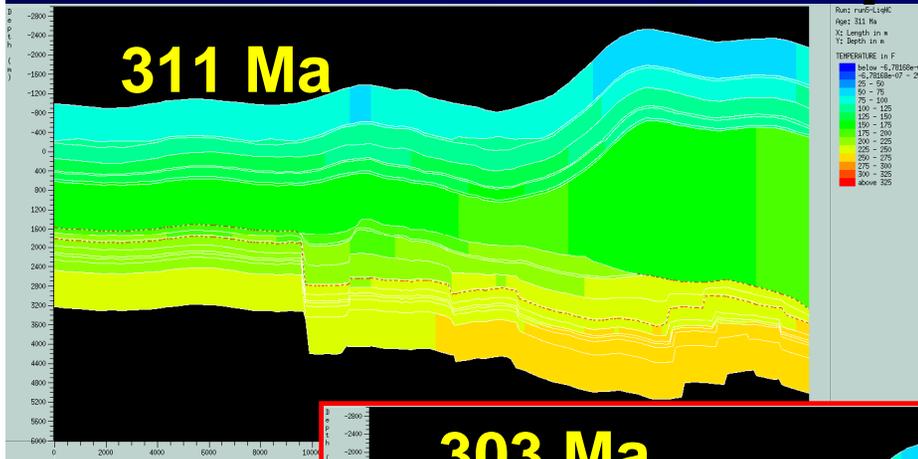
Run: run0-L140
Age: 0 Ma
% Length in m
% Depth in m

LITHOLOGY

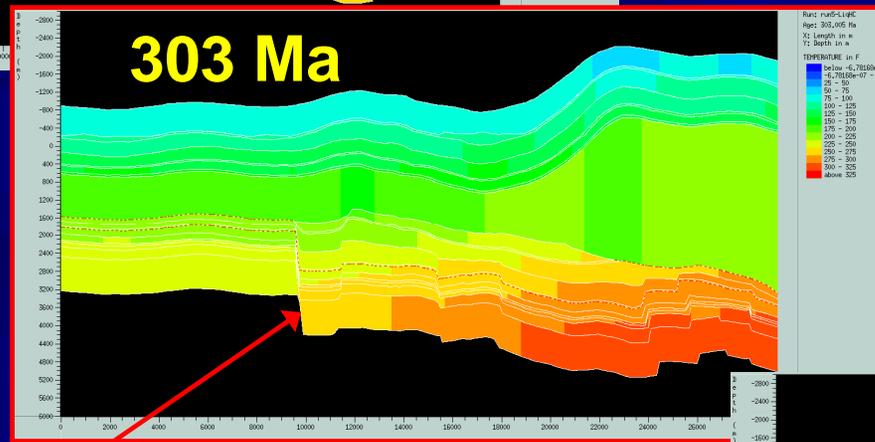
- Shale_10sh
- Shale_20sh
- Shale_30sh
- Shale
- micr_line
- carbon
- dolomite
- SO_20to_50_m
- Upper_Crust
- Lower_Crust
- Upper_Mantle

Critical to use 'reasonable' cross section – need good structural history!

Burial & Temperature History

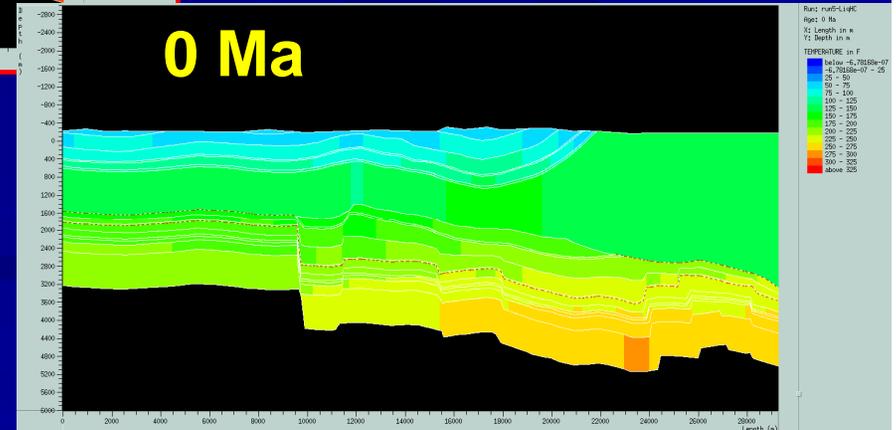


Maximum burial,
but not maximum temperature!



Eroding & Uplifting,
but still heating up!

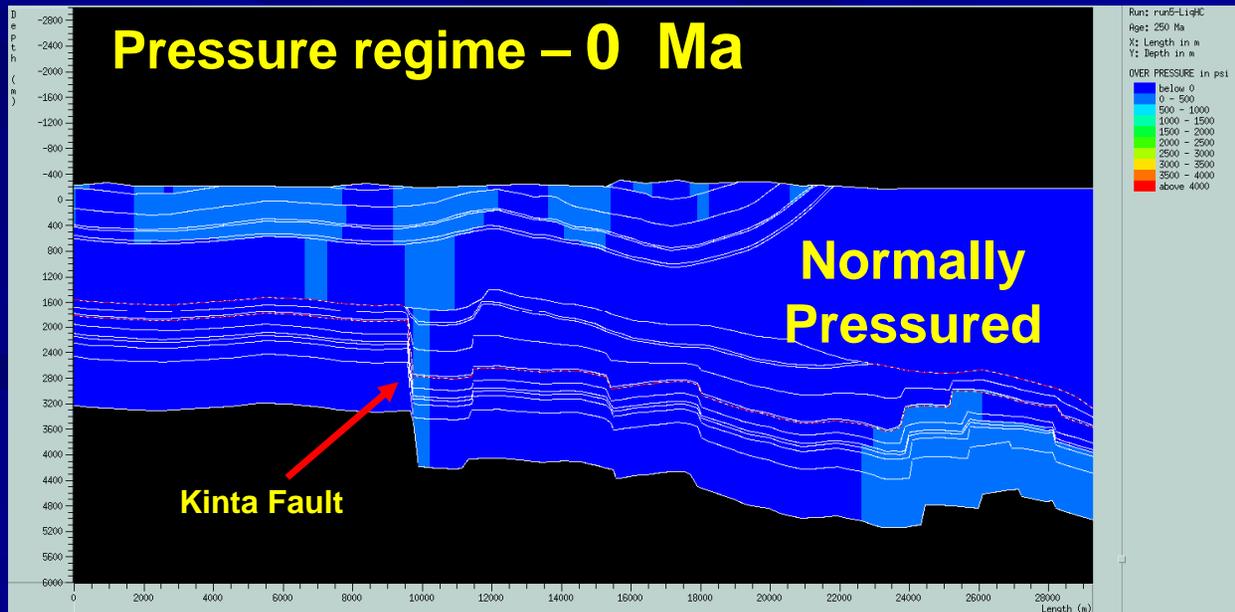
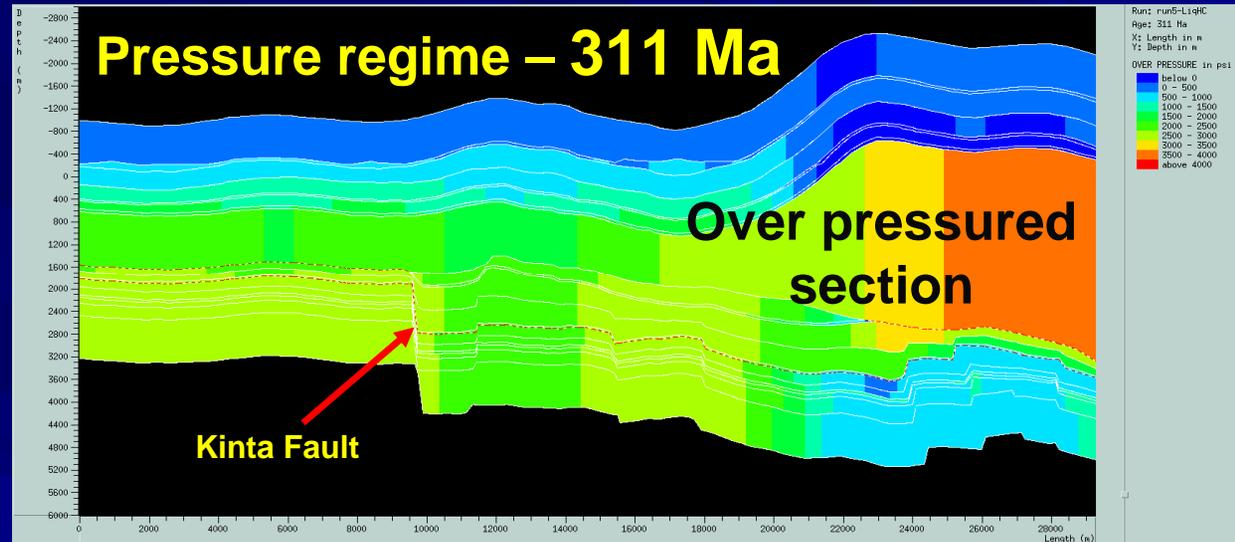
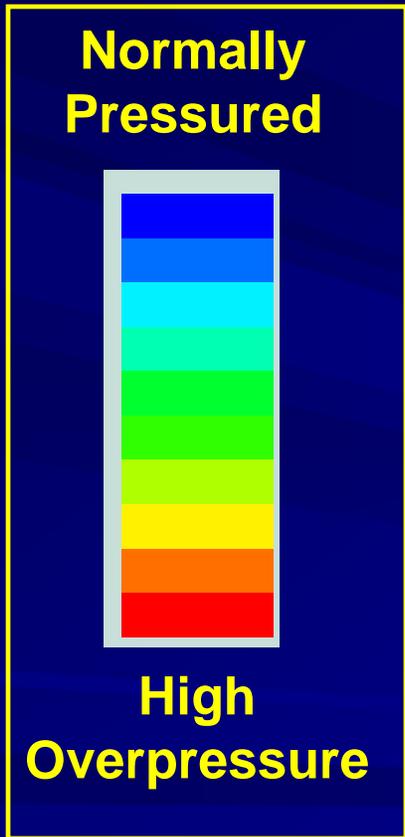
Kinta and Cartersville faults





Pressure History

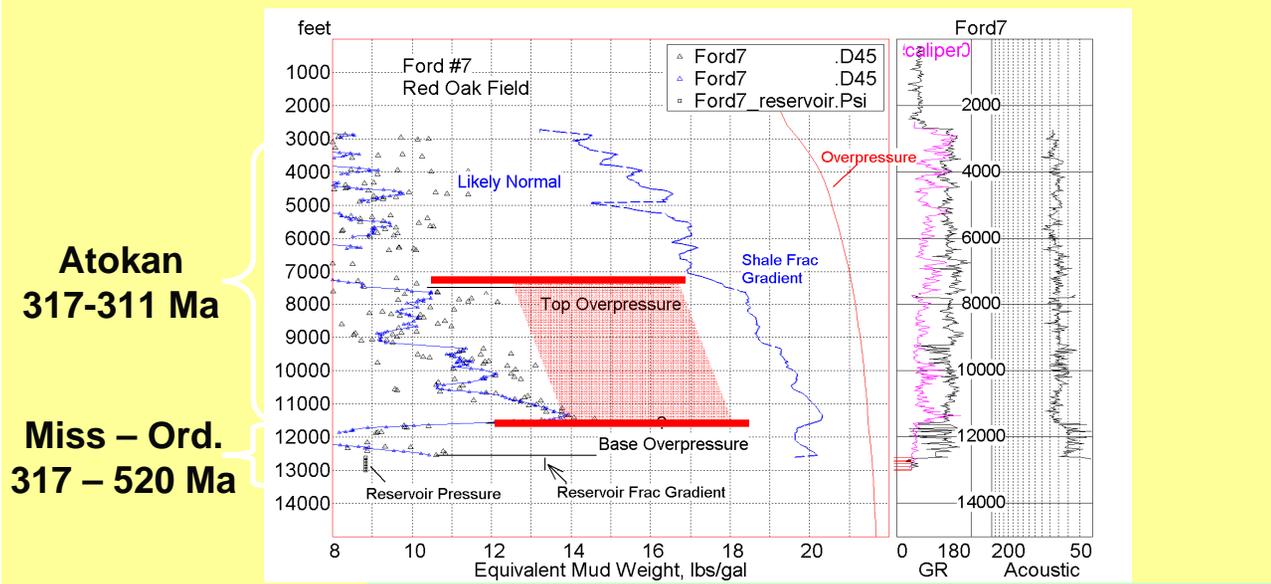
Loss of Overpressure through Uplift & Erosion



The “False Positive” on Logs



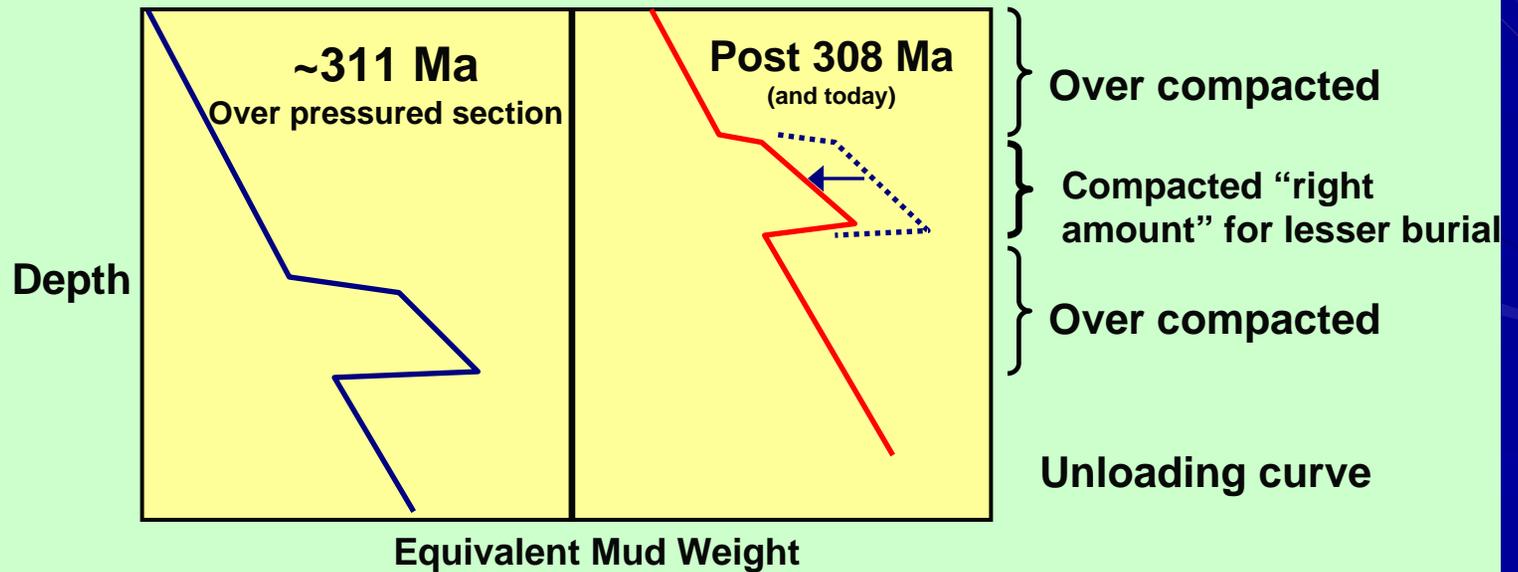
Uplifted: Log response does not prove present-day overpressure



Atokan
317-311 Ma

Miss – Ord.
317 – 520 Ma

Logs give
“false positive”
reading for over
pressure...
‘paleo-overpressure’



Depth

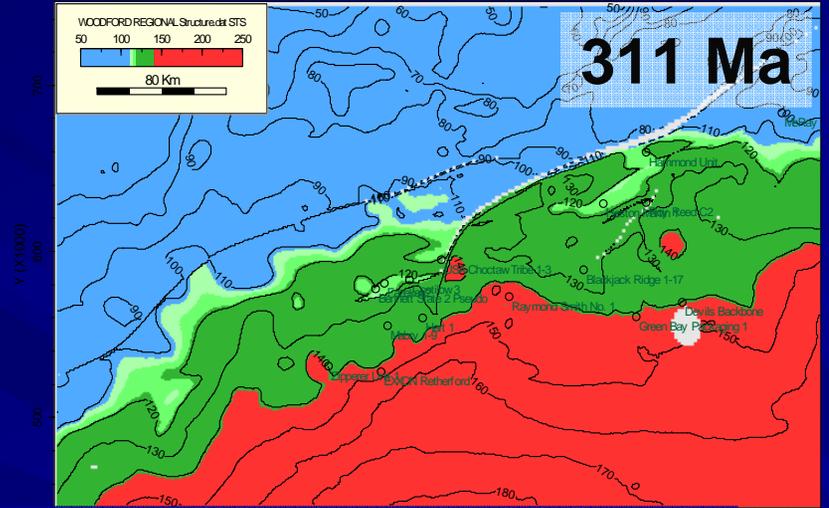
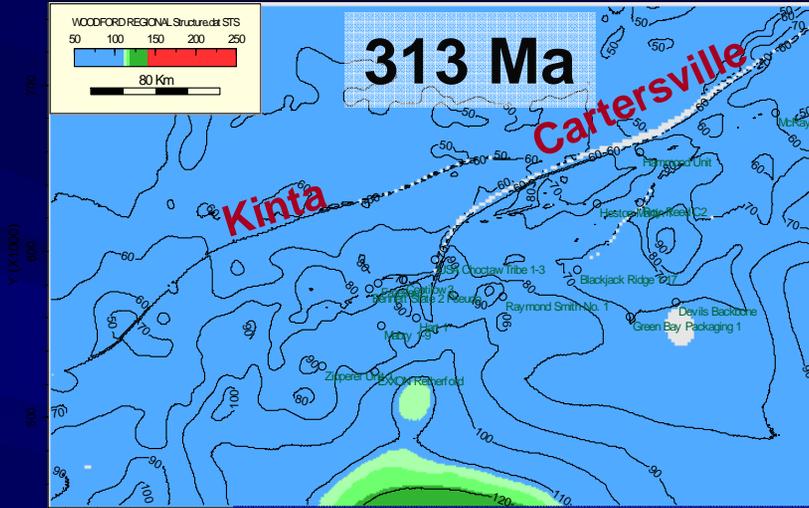
Equivalent Mud Weight

Over compacted
Compacted “right amount” for lesser burial
Over compacted
Unloading curve

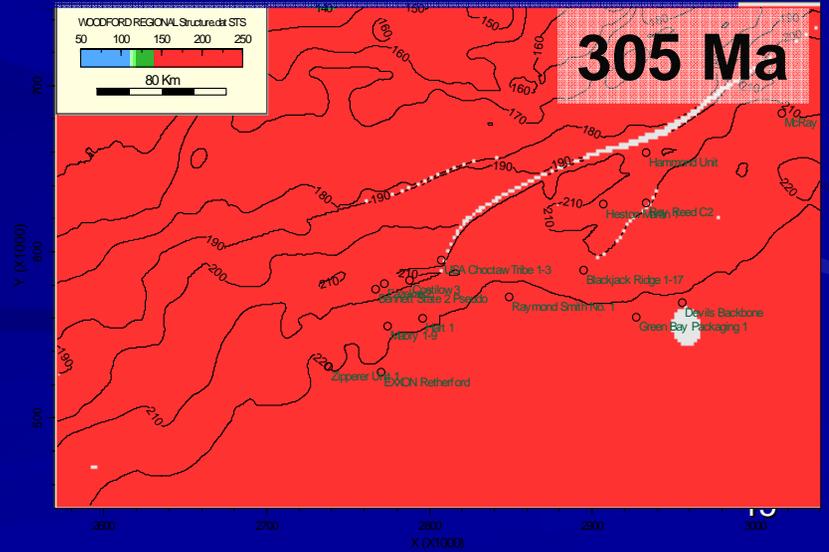
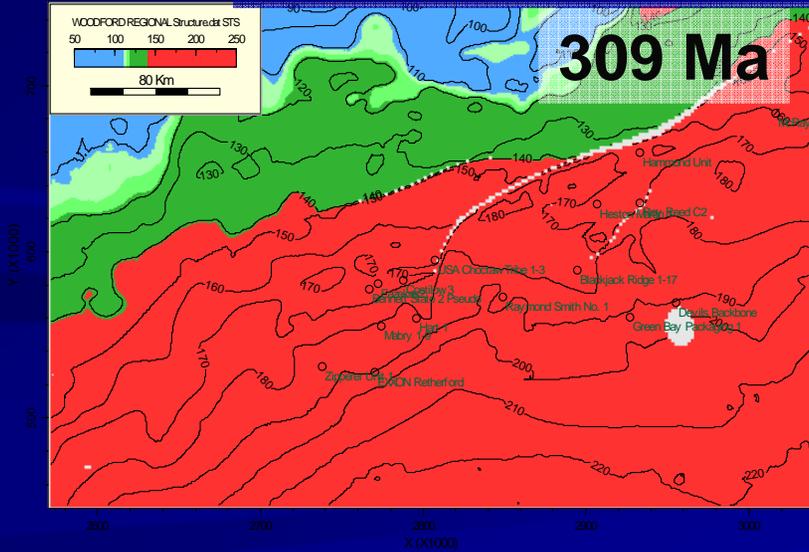


Woodford Petroleum Expulsion

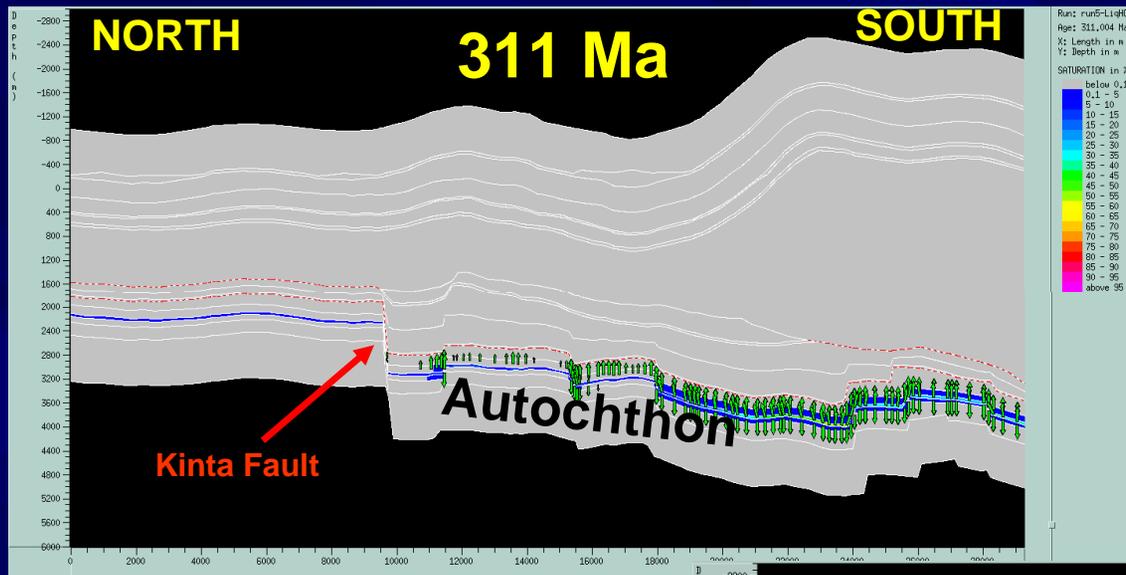
Immature Early oil window Oil window Gas window



By 310 Ma, gas is flushing oil from system

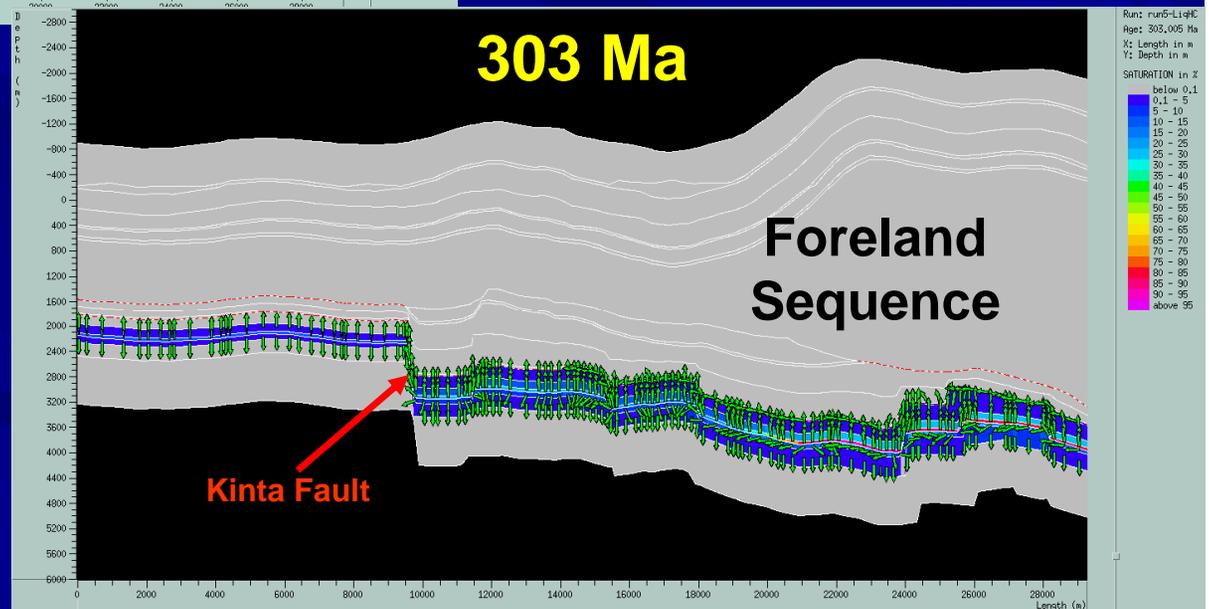


Expulsion & Migration

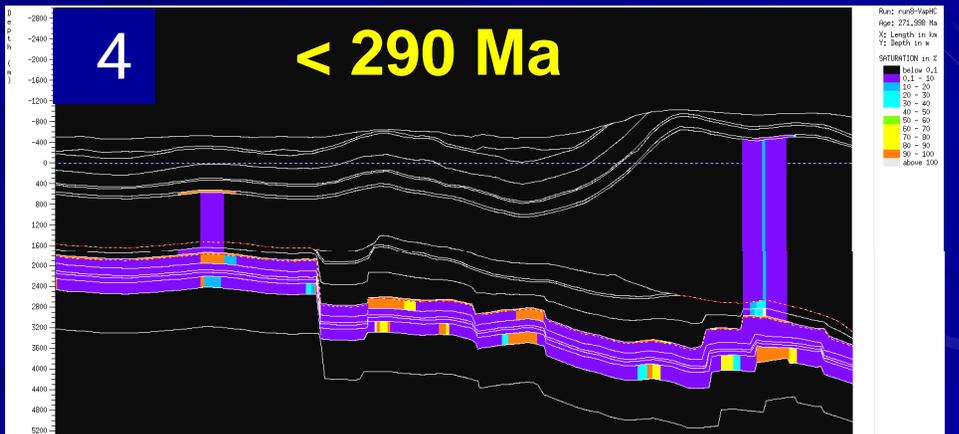
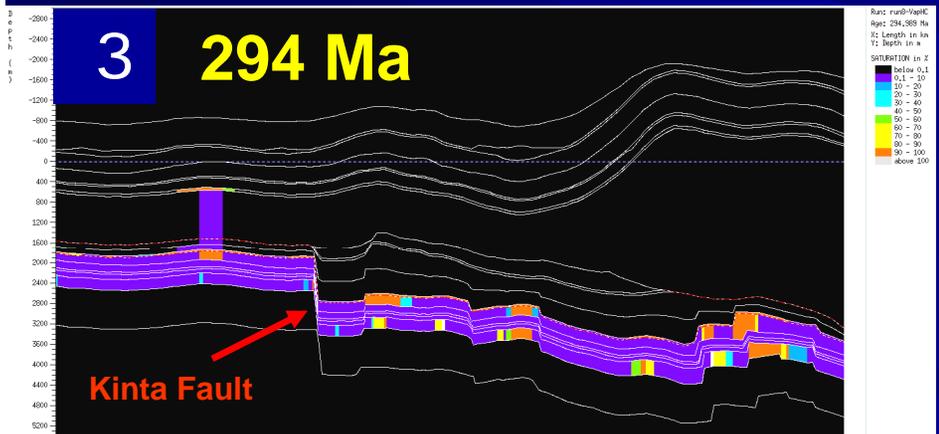
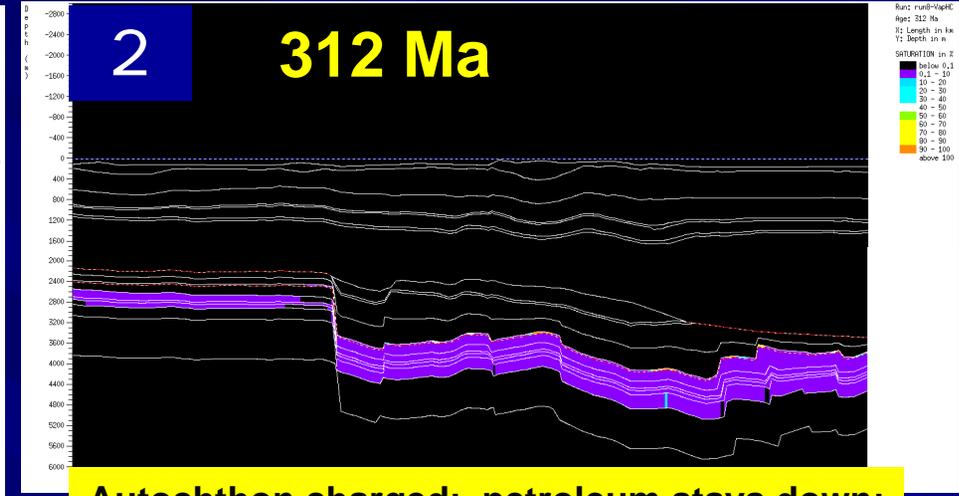
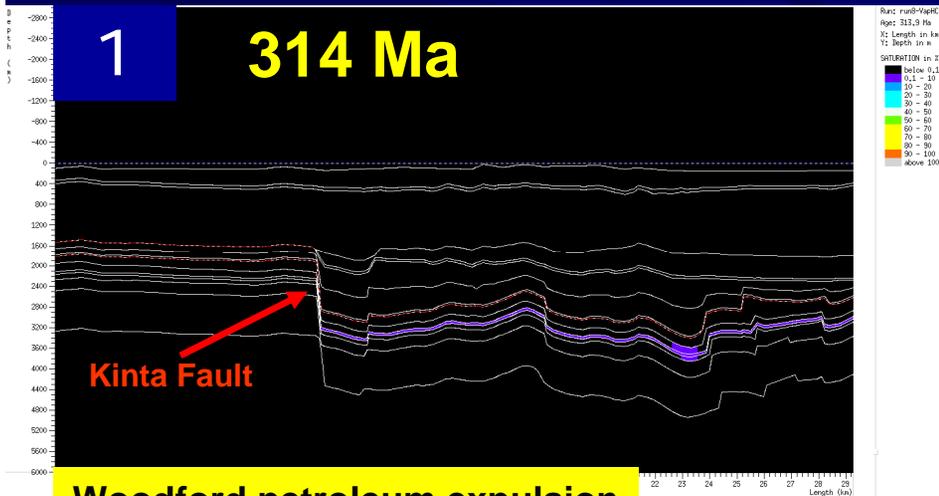


Expulsion continues after uplift begins
...thermal transient

Early migration stays down in autochthon due to overlying pressure seal



Petroleum Migration Lateral then vertical

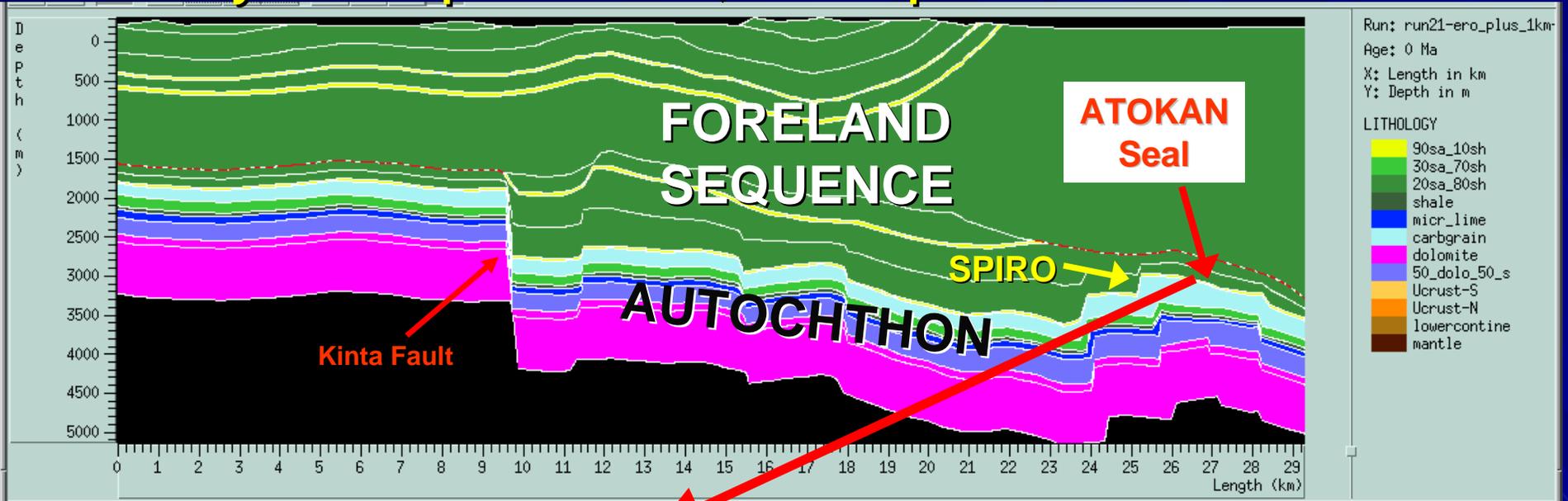


Seal & Pressure State

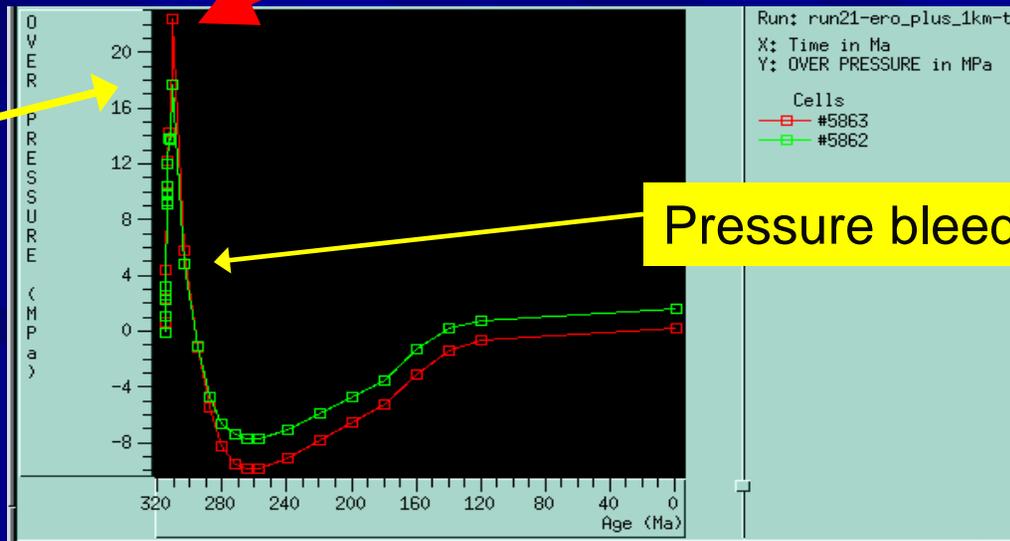
bp



Early over pressure, then pressure bleed-off



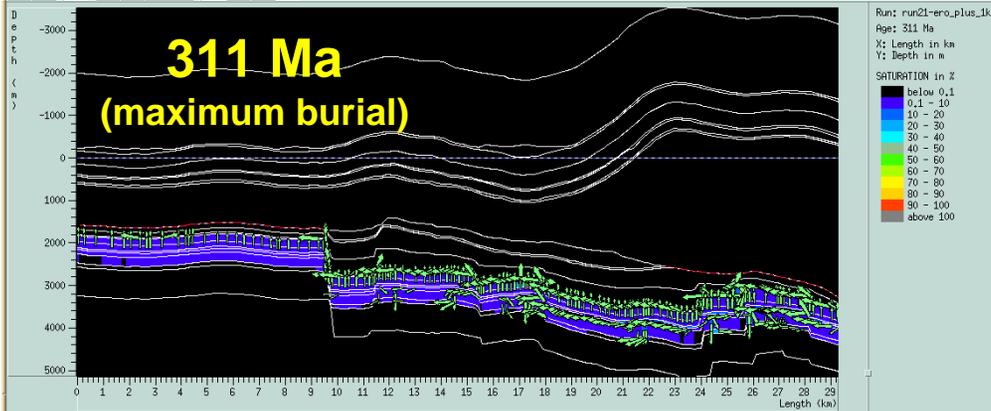
Over pressure



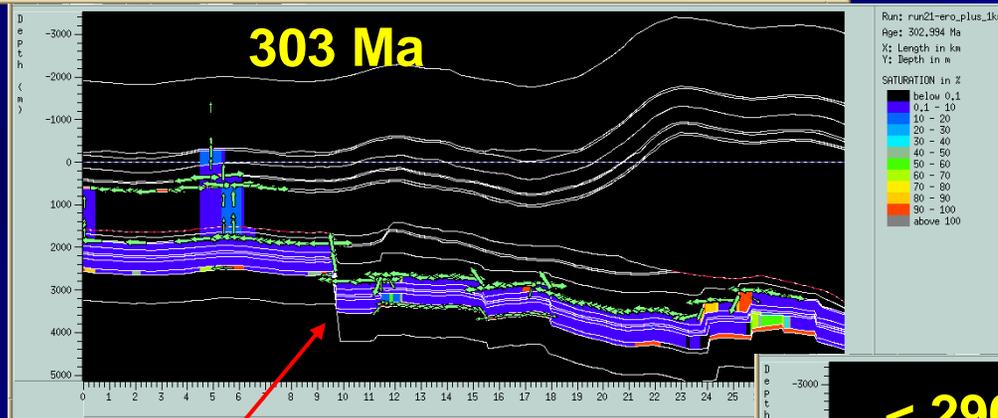
Pressure bleeds off



Petroleum Migration Summary

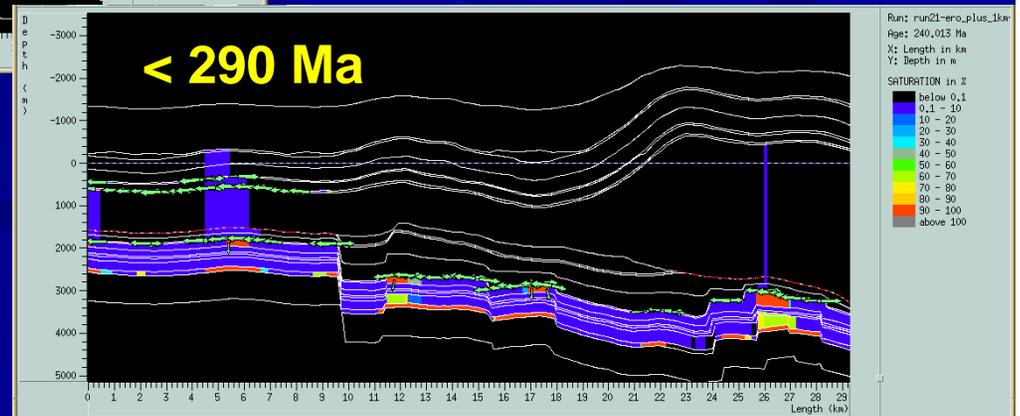


- Oil charges autochthon.
- Oil stays below hydrodynamic seal.



- Erosion. Gas flushes most oil from system.
- Hydrodynamic seal is breached.
- Gas charges shallower reservoirs.

Kinta and Cartersville Faults





Does this make sense?

- Are other data consistent with model?

- What do rocks and fluids say?

- Petrography

- Isotopes

- Bitumen seeps



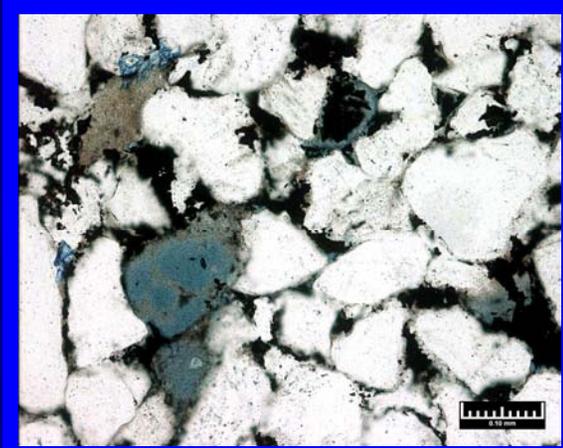
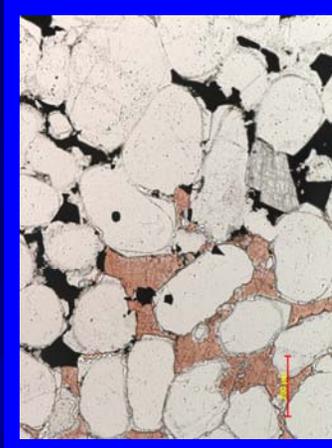
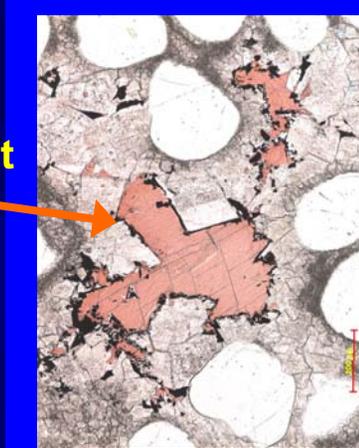
Petrography of autochthon sands and dolomites

Bromide Dolo.

Bromide Sand

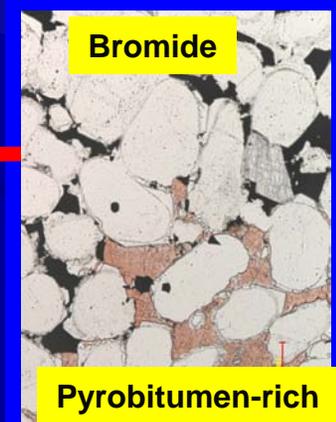
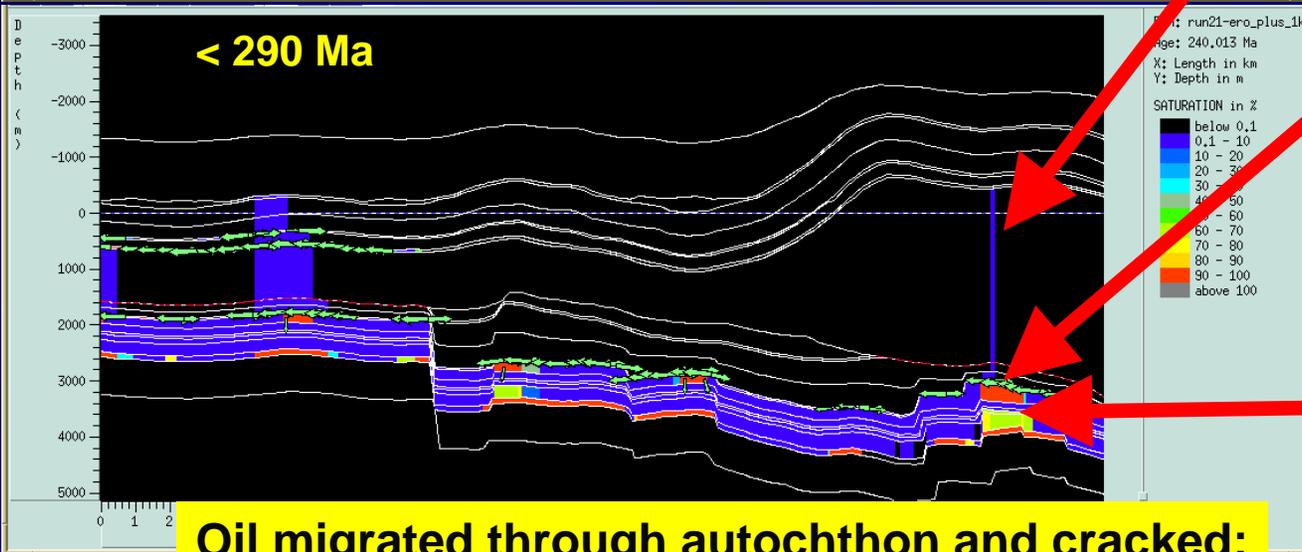
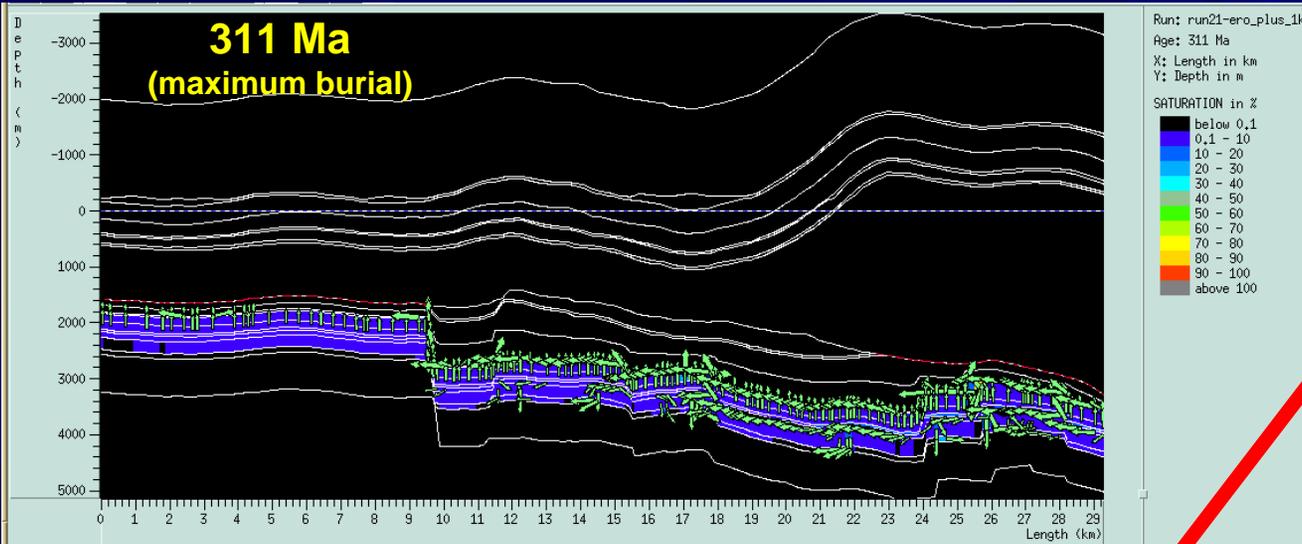
Spiro Sandstone

Pyrobitumen
pre-dates
calcite cement



- Rock was permeable during oil emplacement
 - Carrier beds

Migration & Pyrobitumen

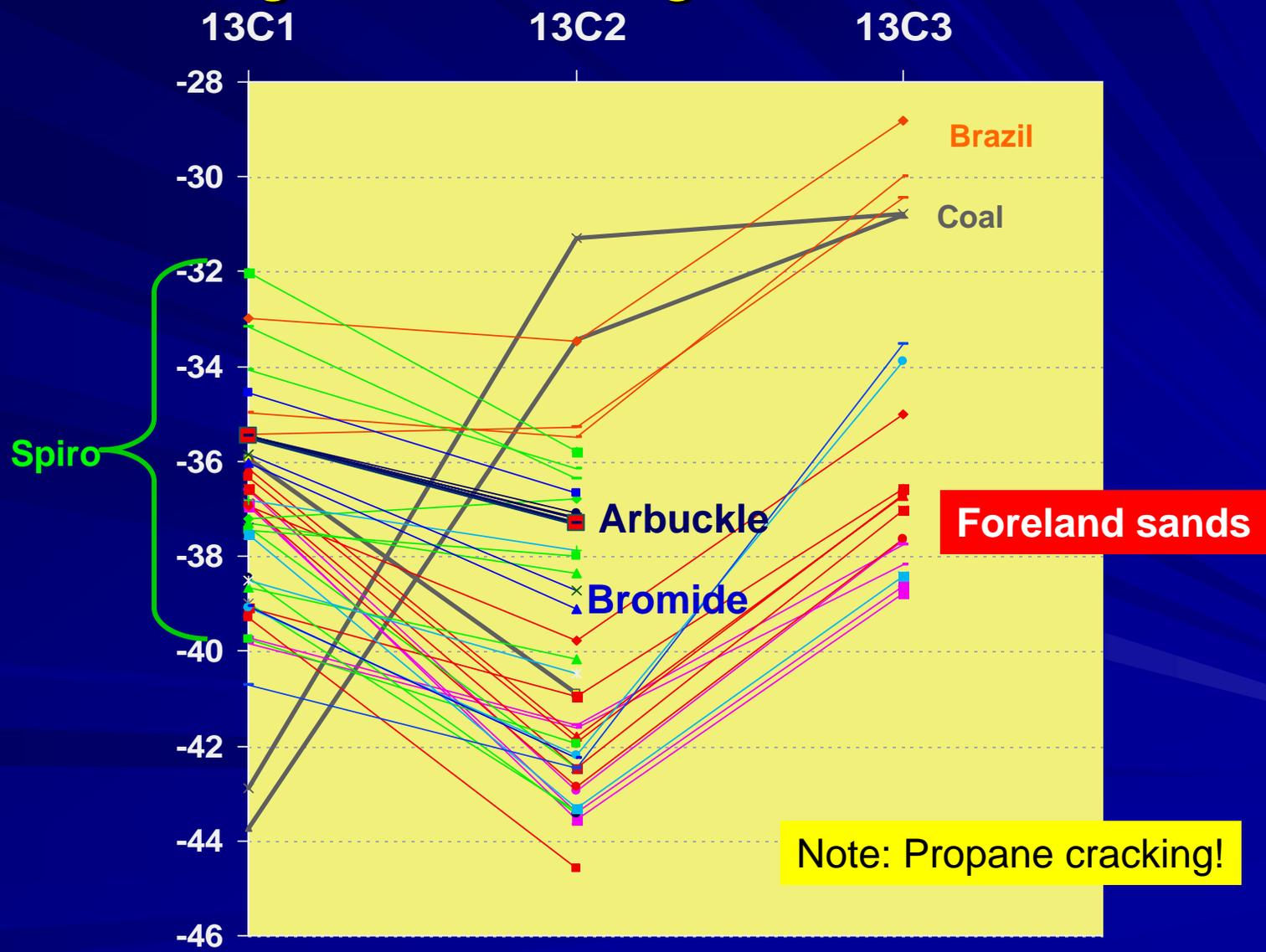


**Oil migrated through autochthon and cracked;
Only gas migrated above the Spiro**



Gas Isotopes

Vertical Migration + High Thermal Stress





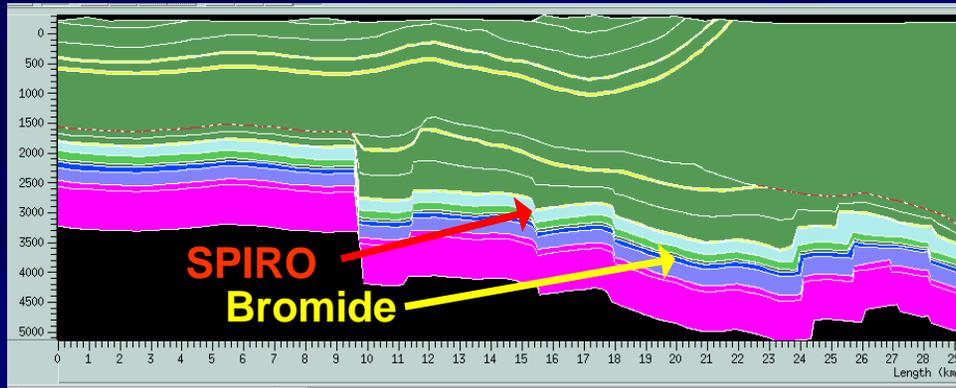
Finding New Plays

- **Understand petroleum migration**
 - Pressure history
 - Petroleum carrier beds
- **Integrate basin history, migration, petrography, etc.**
 - *Does it make sense within tectonic framework?*
- **Make migration pathway maps!**

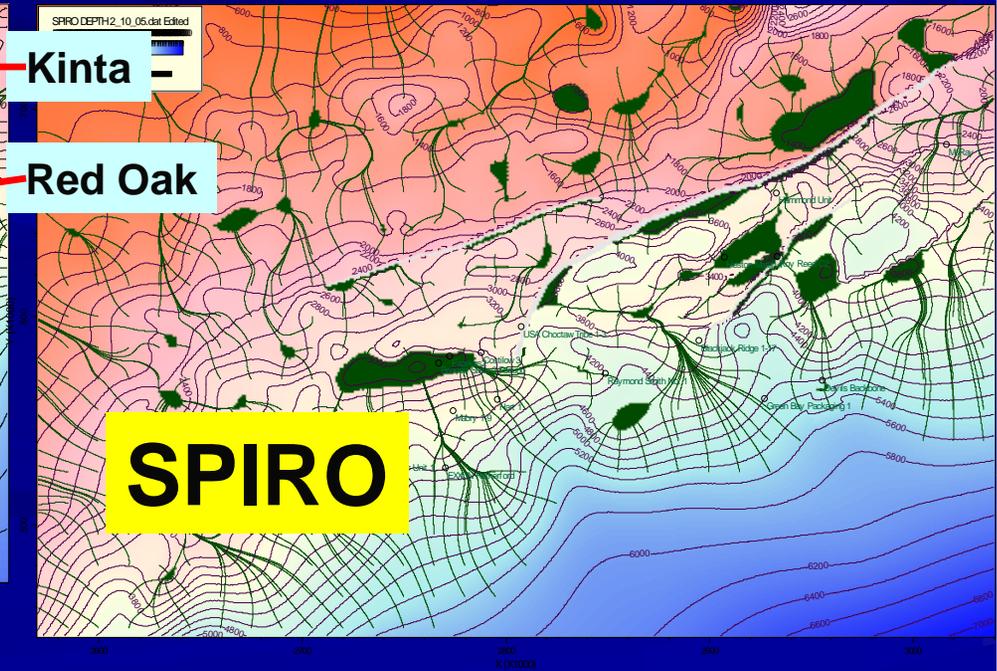
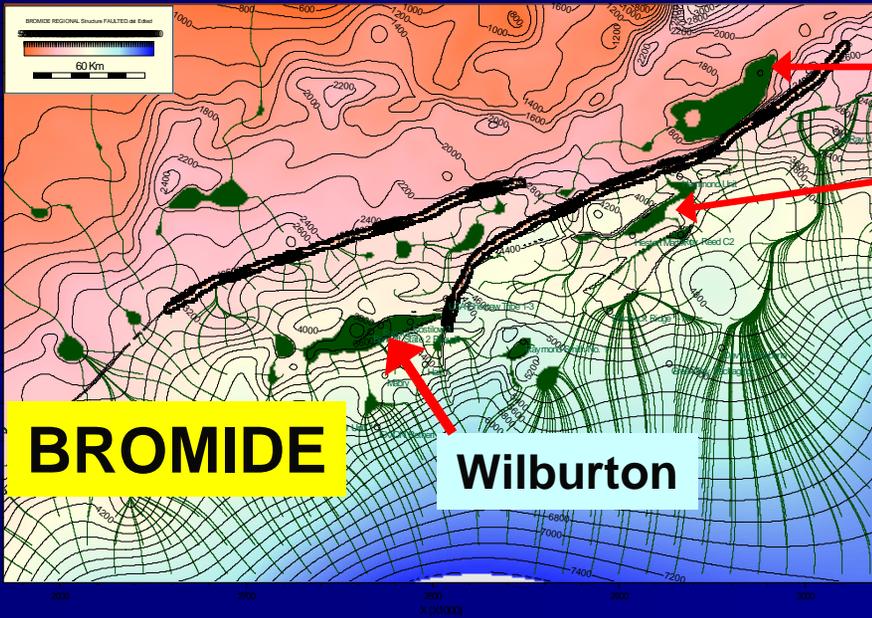


Migration Pathways in Carrier Beds

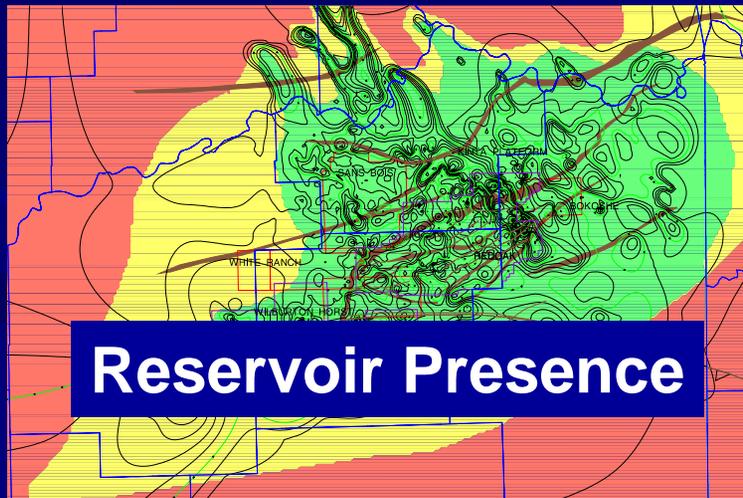
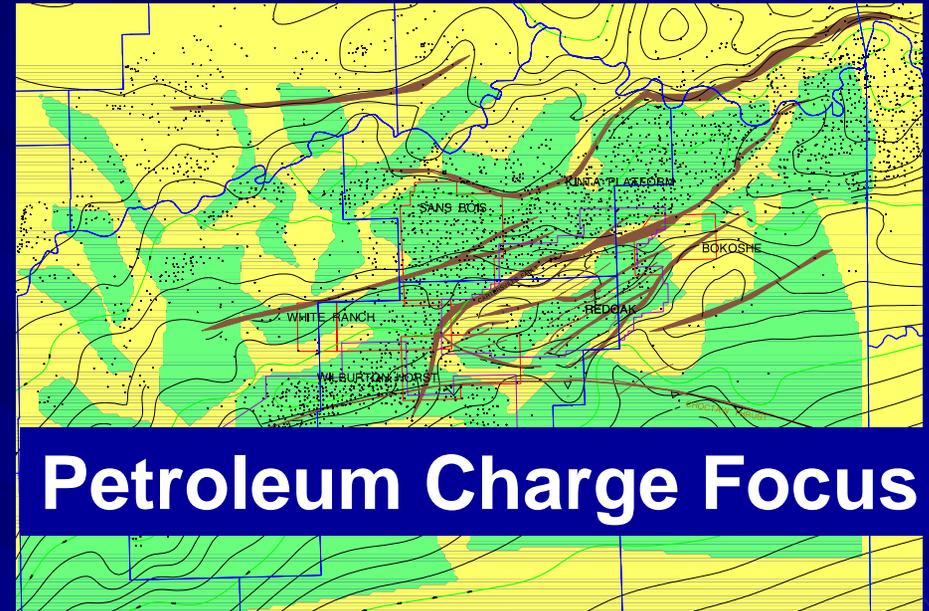
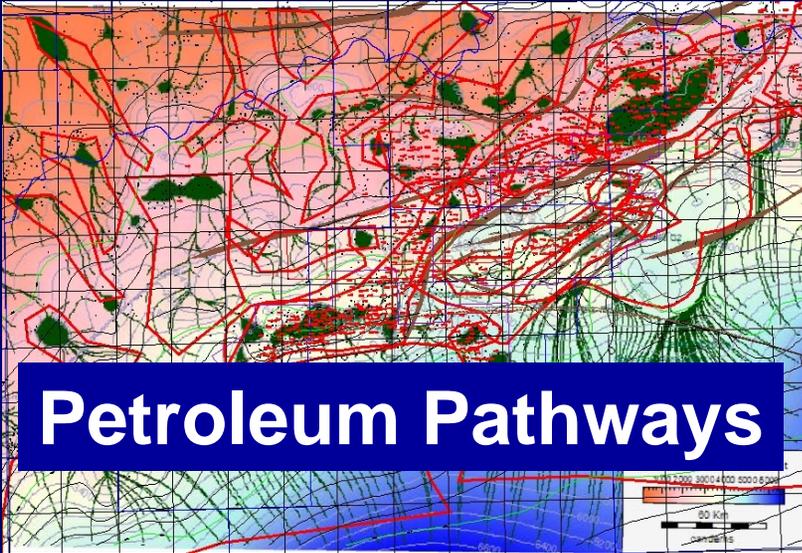
Use paleo-structure maps



Migration in key carrier beds explains the major gas accumulations



Charge & Trap Risk Maps





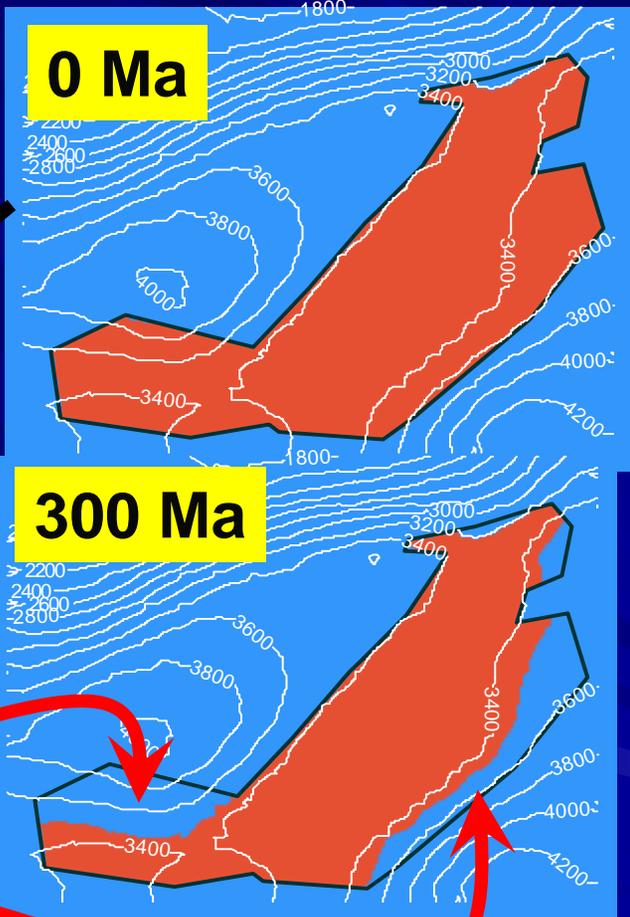
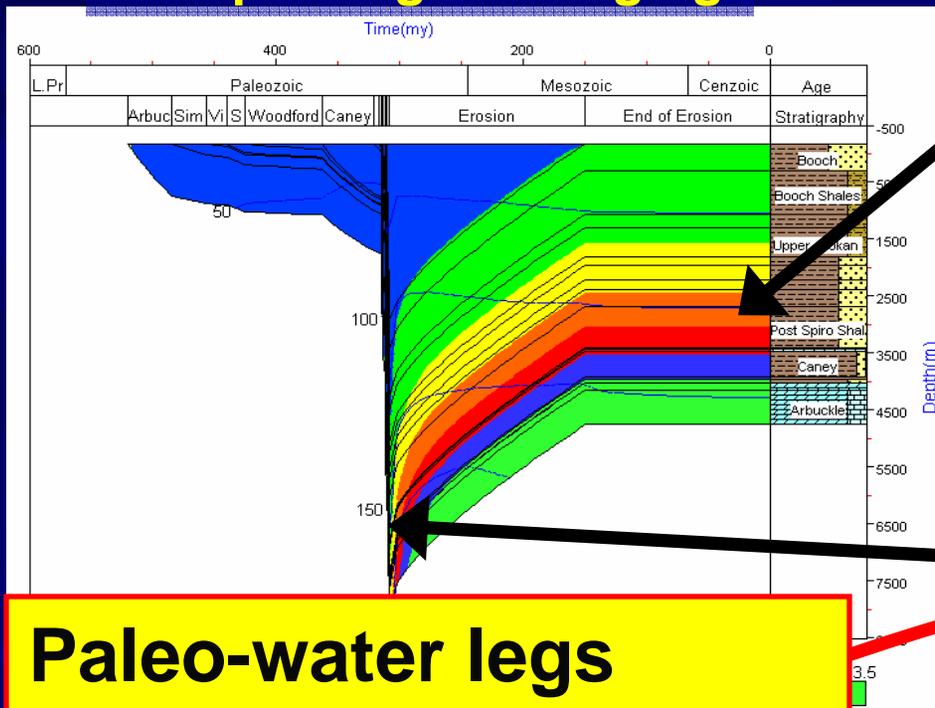
New Opportunities

- Understand petroleum system
- Map migration and accumulations
- Compare to existing fields
- Look for under exploited accumulations
- Implications for reservoir quality?



Reservoir Quality & Burial History: *Gas expansion during uplift*

Re-bury Spiro reservoir
to depth of gas charging



300 BCF
 693 m gas column
 110 F, 4100 psi
 10,000' burial
 H=25 m, 0.6 N/G,
 14% ϕ
 85% Gas Sat.

300 BCF Equivalent
 256 m gas column
 167 F, 8200 psi
 16,000' burial
 H=25 m, 0.6 N/G,
 14% ϕ
 85% Gas Sat.

Paleo-water legs

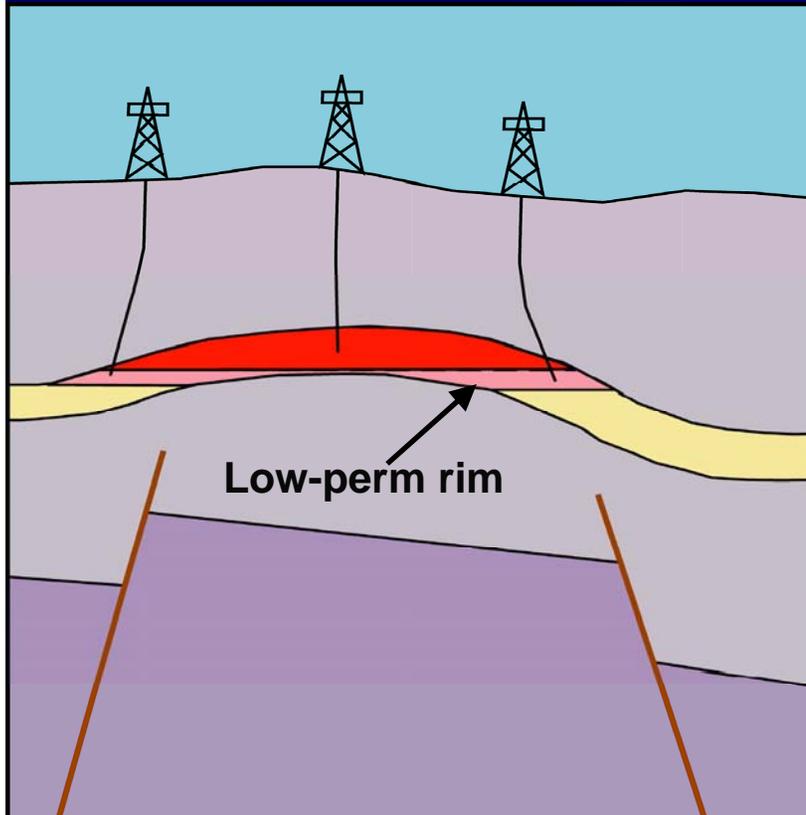
- Zones of high Sw
- Zones of quartz cementation

Today

- Tight gas reservoirs



Gas Expansion Upon Uplift



- Early gas charge preserves ϕ , K
- Reservoir in transition zone or water leg suffers ϕ , K degradation
- Upon uplift, gas expands downward
- Tight gas play on down-dip, flanks of structure



Synthesis

- **Lateral migration** in autochthon, then **vertical gas migration** into foreland sequence
- Oil and early gas remained in autochthon
 - **Below pressure seal**
- **Pressure seal leaked during erosion & uplift**
 - Mature gas plus cracked-oil gas migrated vertically
 - Shallow gas is underlain by deep gas
- **New opportunities exist**
- Uplift caused **gas expansion** and **re-migration** of gas
 - **Paleo-water legs** were zones of **high Sw** & cementation
 - **Currently a tight-gas play**



Mature & Tight Gas Basins

- **Tight gas basins are quite conventional!**
 - Gas migration & charge
 - Gas trapping
- **Conventional geology and petroleum system analysis can explain the accumulations**
- **... and help identify new opportunities**

- ***Regional geology matters in mature, tight gas basins***



***Thanks to BP
And
Thank You!***

Harris Cander

Tom Patton

BP

Exploration & Production technology