

Fracturing in Basin Models, Application to the Barnett Formation in the Fort Worth Basin, Texas*

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Abstract

Petroleum system modeling of geopressure and fracturing has been applied on a US case study of the Barnett Shale Formation. This project evaluates demonstrative workflows for petroleum system modeling of gas shale plays. It combines a study of the mineralized fractures sampled in cored Barnett Shale intervals and a sensitivity analysis of the regional-scale petroleum system and shale gas play of the Fort Worth Basin, northeast Texas. Results provide (i) the key characteristics of shale fracturing: geometry, spatial distribution, history of fluid movement based on mineralogy, geochemistry and fluid inclusions (i.e. fractures paragenesis from mineralized veins study), (ii) an improved understanding of the key factors controlling the temporal and spatial occurrence of fractures in shale, and (iii) recommendations and guidelines to populate basin models with permeability maps according to fracturing episodes

Barnett Shale mineralized fractures in cored intervals of a well found in the gas window, and two others in the oil window, reveal 4 distinct fracturing episodes. The timing of overpressuring modeled in the Fort Worth Basin case study demonstrates the controlling effects of sedimentation rates, kerogen maturation and the key role of the adopted compaction-permeability law. Knowledge of fracture paragenesis established is crucial to calibrate porosity-permeability laws and constrain simulation of hydraulic fracturing in basin models. A new methodology is proposed to take into account the regional tectonic stress field linked to fracture network and overpressure episodes and study fracture network's impact on estimated remaining gas in place.

References Cited

Behar, F., F. Lorant, and L. Mazeas, 2008, Elaboration of a new compositional kinetic schema for oil cracking: Organic Geochemistry, v. 39/6, p. 764-782.

Hill, R.J., E. Zhang, B.J. Katz, and Y. Tang, 2007, Modeling of gas generation from the Barnett Shale, Fort Worth Basin, Texas: AAPG Bulletin, v. 91/4, p. 501-521.

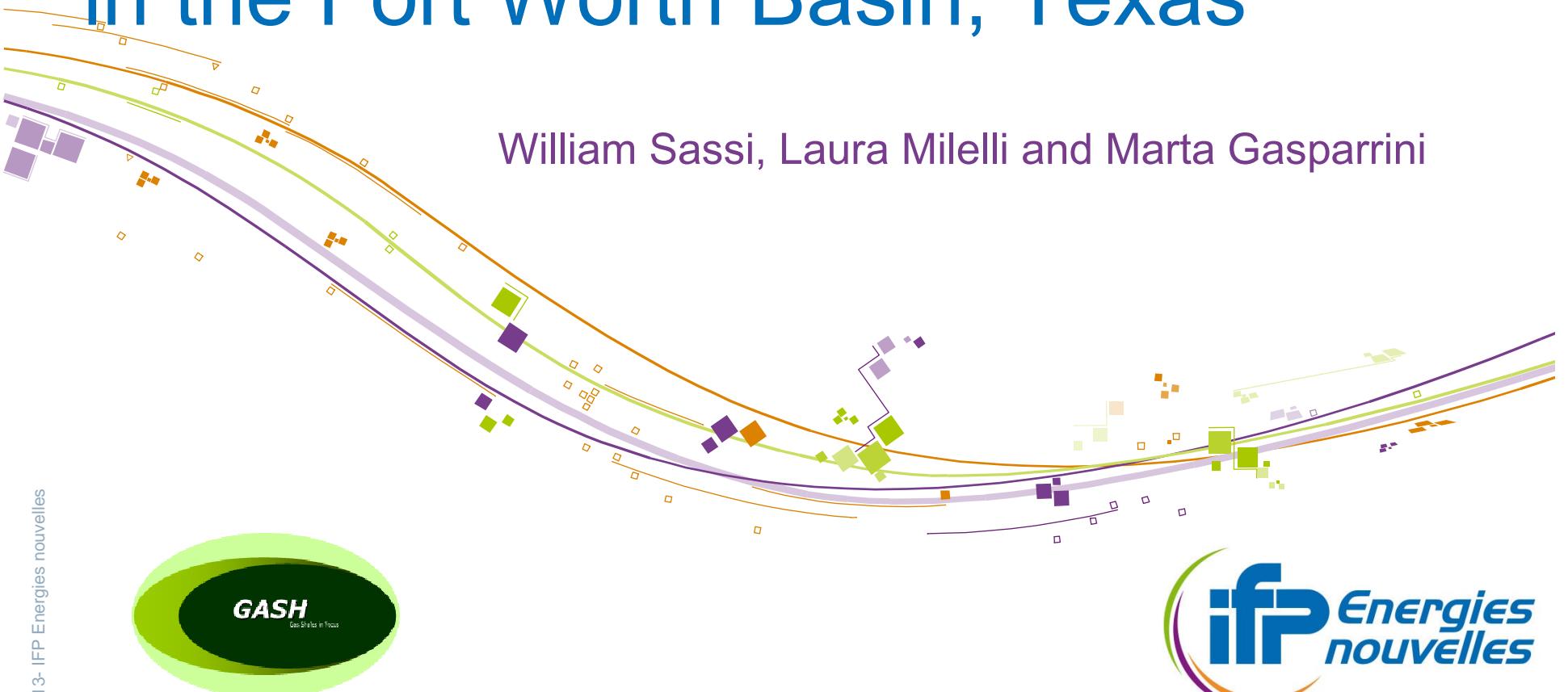
Montgomery, S.L., D.M. Jarvie, K.A. Bowker, and R.M. Pollastro, 2005, Mississippian Barnett Shale, Fort Worth basin, north-central Texas: Gas-shale play with multi-trillion cubic foot potential: AAPG Bulletin, v. 89/2, p. 155-175.

Romero-Sarmiento, M-F., M. Ducros, B. Carpentier, F. Lorant, M-C. Cacas, S. Pegaz-Fiornet, S. Wolf, S. Rohais, and I. Moretti, Quantitative evaluation of TOC, organic porosity and gas retention distribution in a gas shale play using petroleum system modeling; Application to the Mississippian Barnett Shale: Marine and Petroleum Geology, v. 45, p. 315-330.

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Objectives

- **Assessment of 3D fracture network**
 - developed according paleo-stress and paleo-fluid pressures
 - identify best drilling conditions
 - hydraulic stimulation
- **Hydrocarbons in place at present day**
 - is the source rock able to loose HC by hydraulic fracturing?
- **Results**
 - set-up appropriate Basin Modelling workflow for assessment of shale gas plays

Basin modeling: pressure

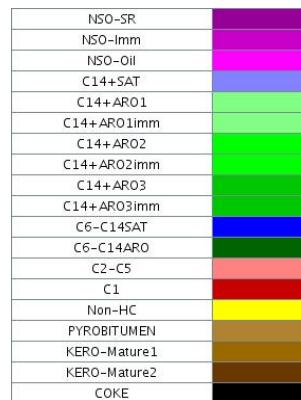
$$\blacksquare \quad P > \sigma_3 + T_0$$

■ Fort Worth Basin

- 3D block

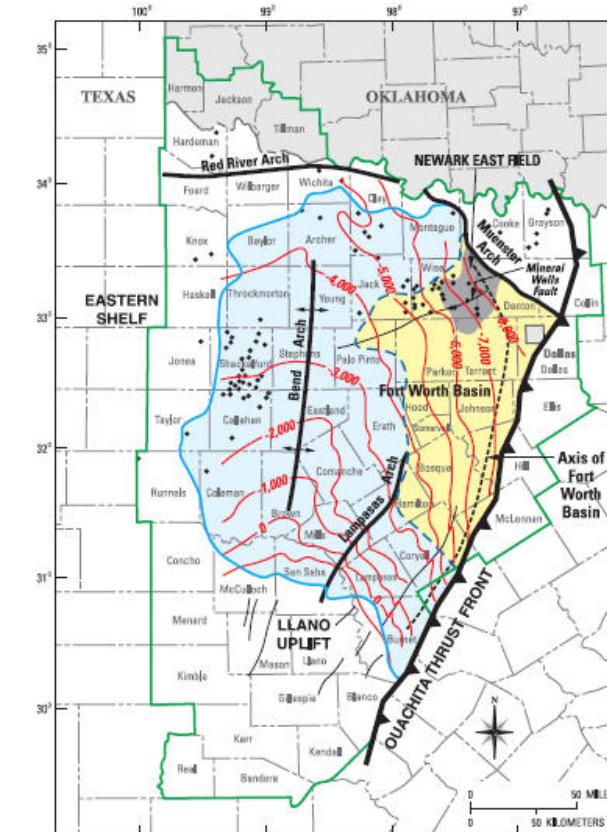


- Kerogen type II 19 classes



■ Pressure prediction

- overpressure
- total fluid pressure



EXPLANATION

- USGS PROVINCE 45 BOUNDARY-BEND ARCH-FORT WORTH BASIN
- AREA OF MAIN BARNETT SHALE GAS PRODUCTION (NEWARK EAST FIELD)
- FAULT
- GEOGRAPHIC EXTENT OF BARNETT SHALE IN THE FORT WORTH BASIN
- AREA OF POTENTIAL BARNETT SHALE GAS PRODUCTION
- AXIS OF FORT WORTH BASIN
- THRUST FRONT
- STRUCTURAL CONTOUR, TOP OF ELLENBURGER GROUP (INTERVAL 1,000 FEET)
- LOCATION OF WELLS SAMPLED FOR OIL AND GAS

source: Montgomery et al. (2005) and Hill et al. (2007a)



Basin modeling: pressure

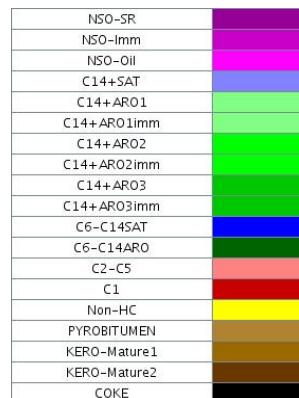
$$\blacksquare P > \sigma_3 + T_0$$

■ Fort Worth Basin

- 3D block

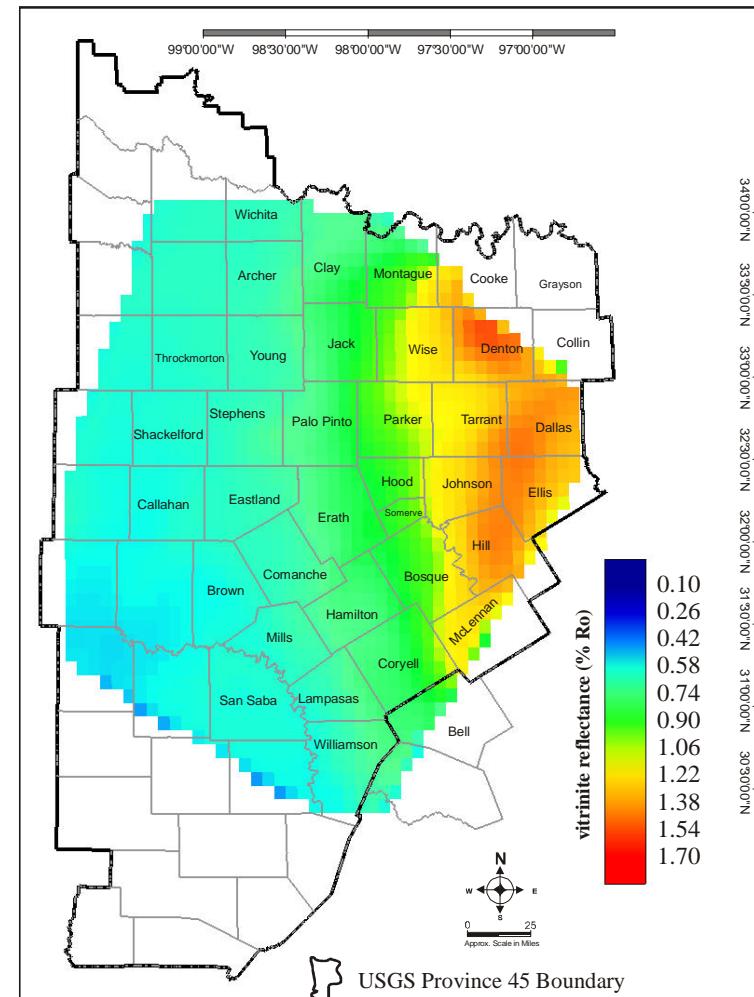


- Kerogen type II 19 classes



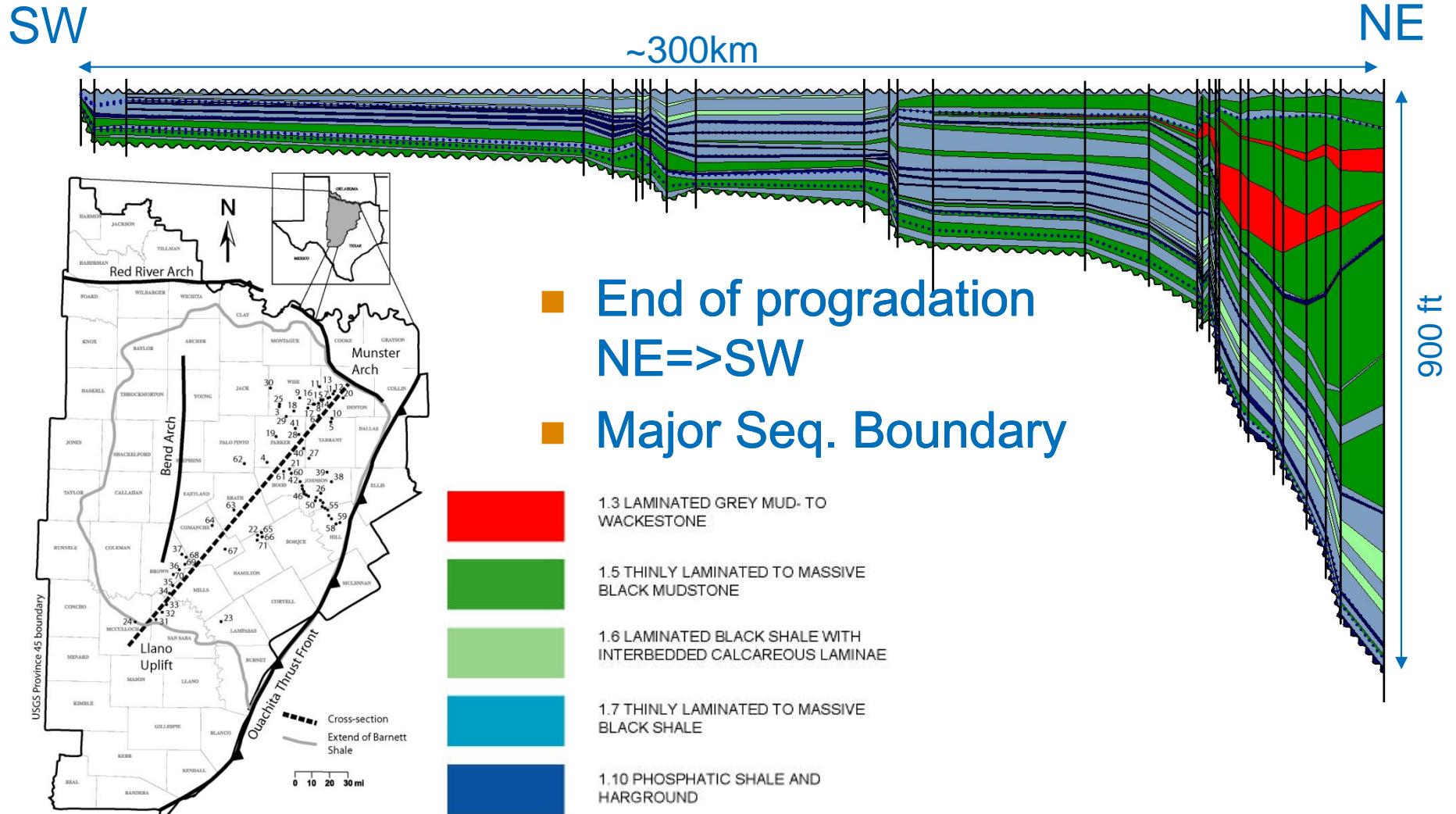
■ Pressure prediction

- overpressure
- total fluid pressure



Calculation based on specific kinetic and stoichiometric parameters determined for the Barnett Kerogen

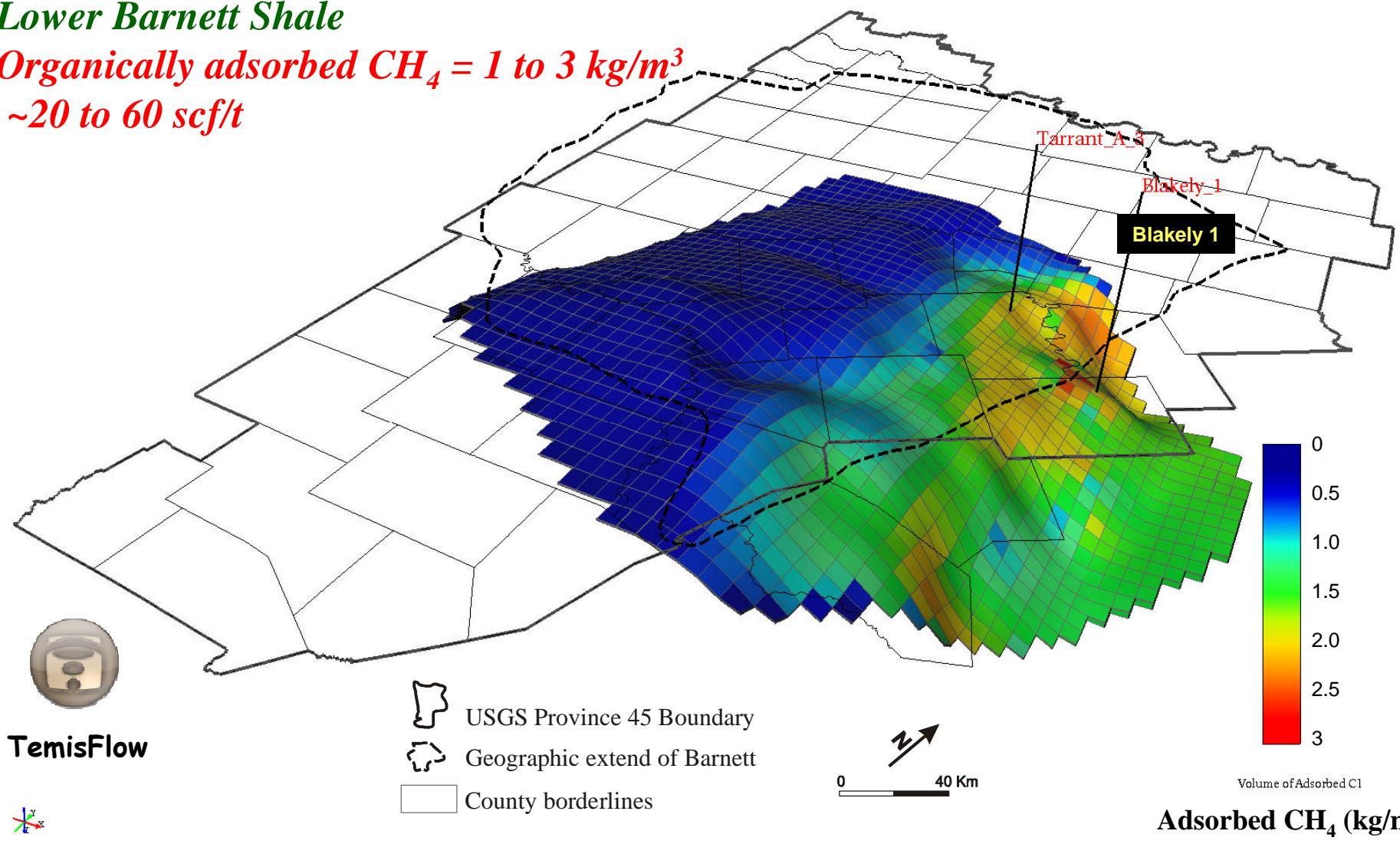
Barnett Shale – Basin dynamic



Computed amount of CH_4 adsorbed on Organic Matter (Romero-Sarmiento et al., 2013)

Lower Barnett Shale

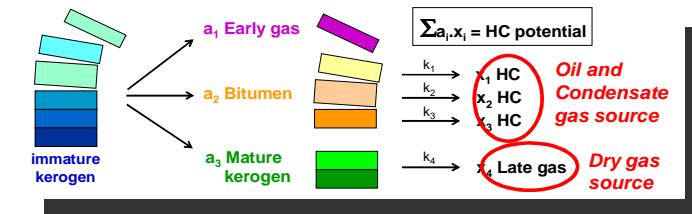
*Organically adsorbed $\text{CH}_4 = 1$ to 3 kg/m^3
 ~ 20 to 60 scf/t*



Petroleum System parameters

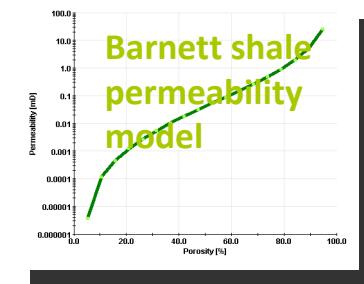
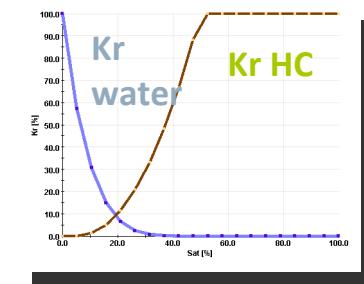
HC generation

- **Barnett shale model**
 - Kerogen type marine facies
 - Initial TOC = 5-10 %
- **Compositional kinetic scheme**
 - 19 fractions from Behar et al. 2008

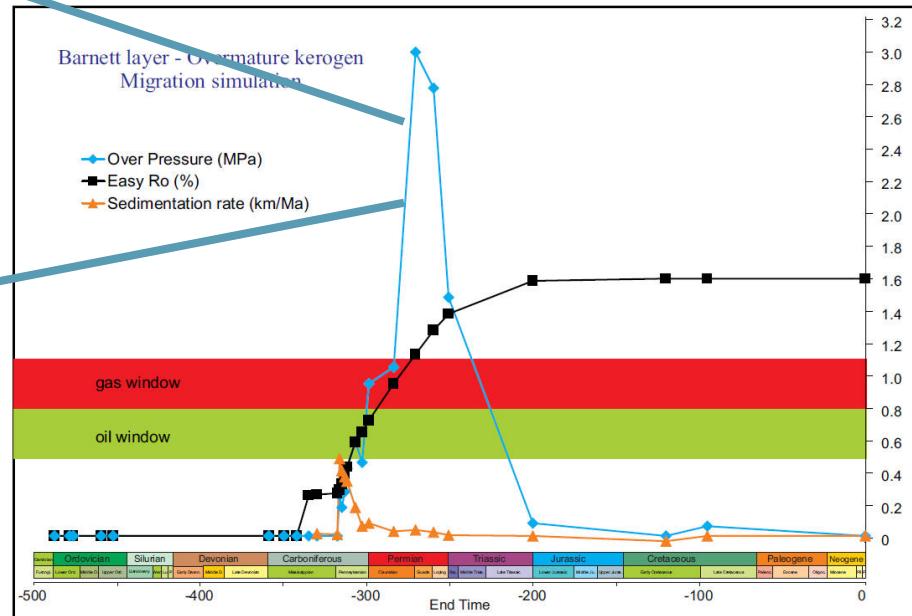
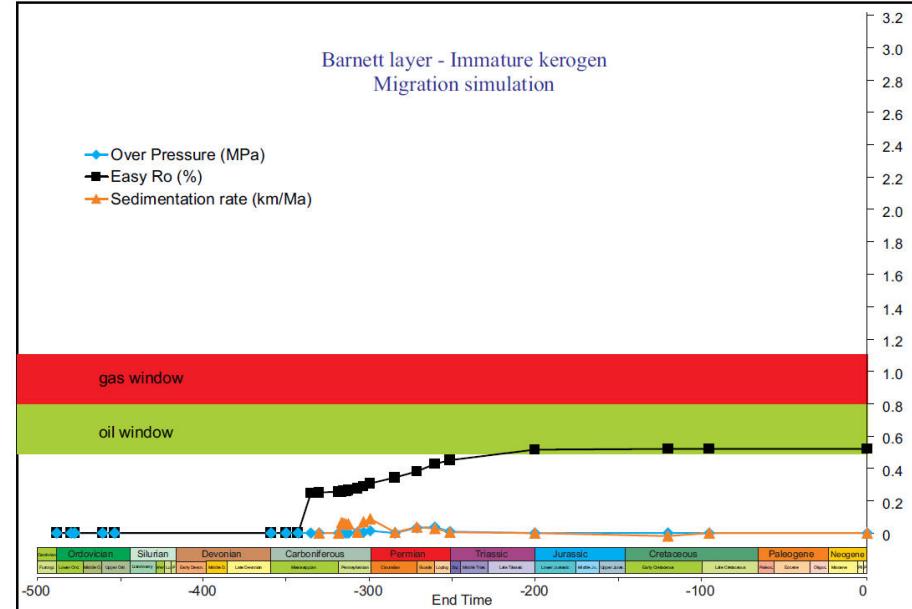
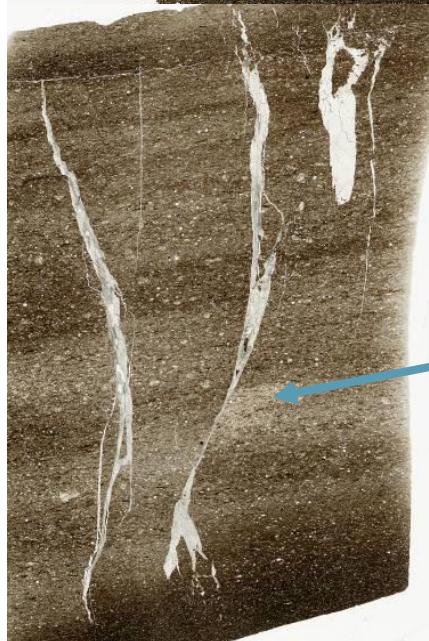


HC migration

- **Fluid flow model**
 - Fully implicit multi-phase Darcy flow (water / HC phases)
- **Shale properties**
 - Permeability
 - HC-Water relative permeabilities
 - Capillary pressures
 - Retention threshold model



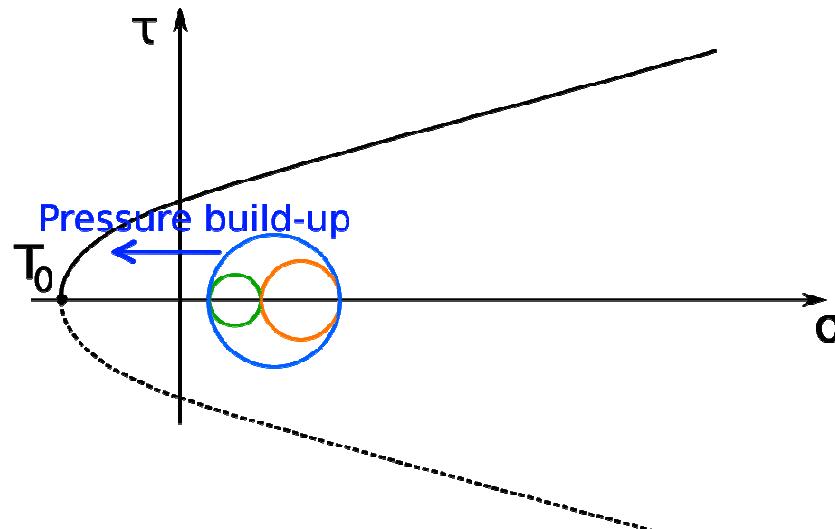
Overpressure-Fracturing related to OM maturation and expulsion?



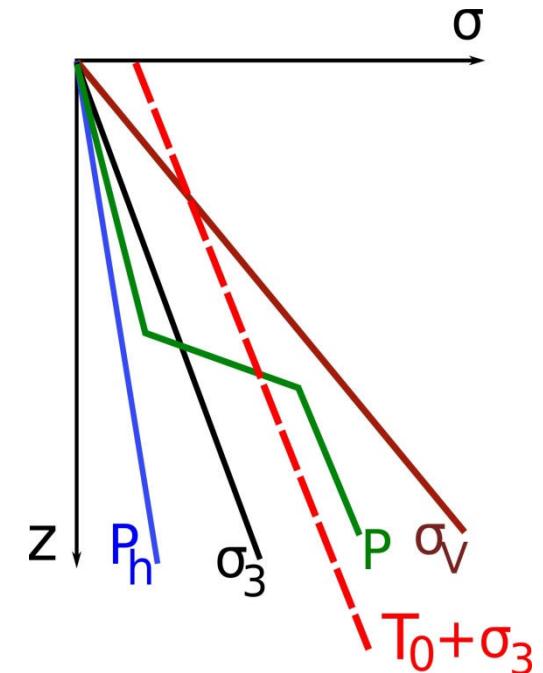
Onset of hydraulic fracturing

$$\blacksquare P > \sigma_3 + T_0$$

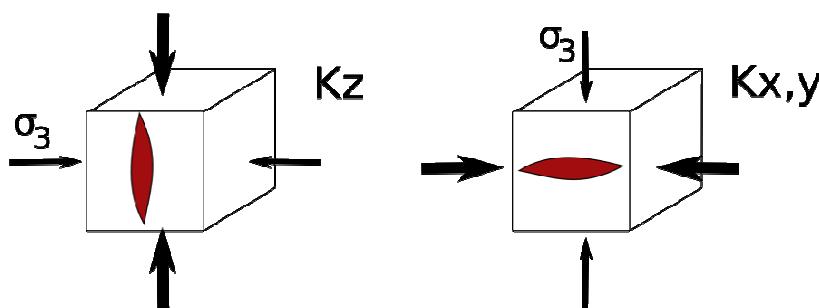
- For small deviatoric stress



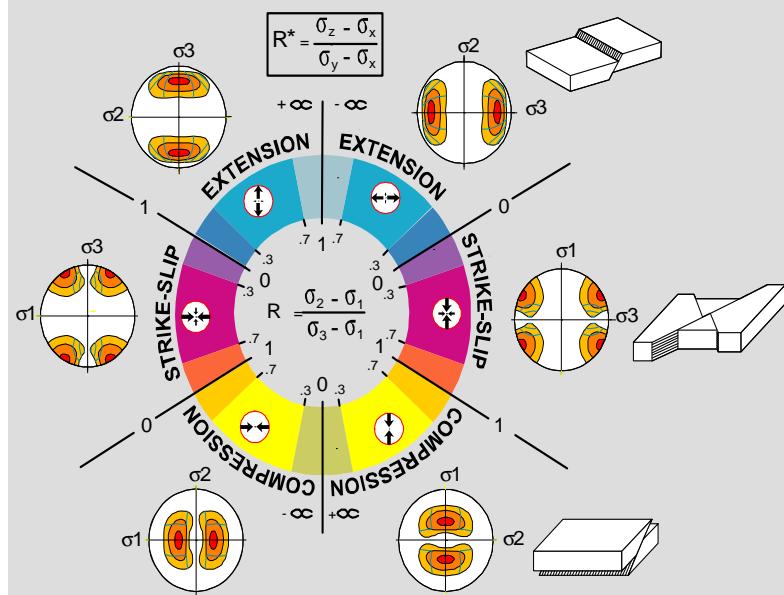
- For $\sigma_3 < \sigma_v$



- Fractures develop $\perp \sigma_3$

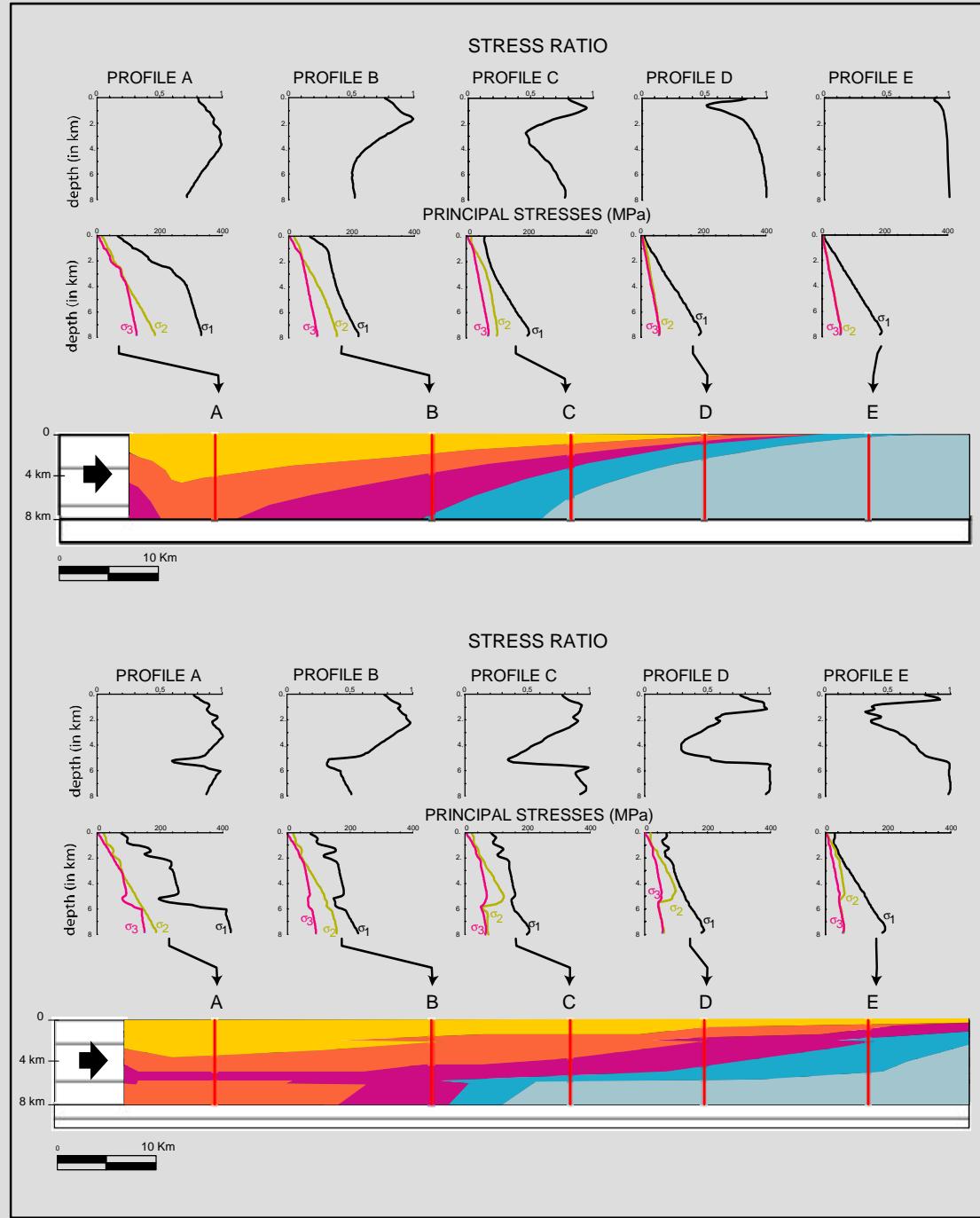


State of stress in foreland's overburden of active frontal thrusts



Stress regime

(Sassi and Faure, 1997)



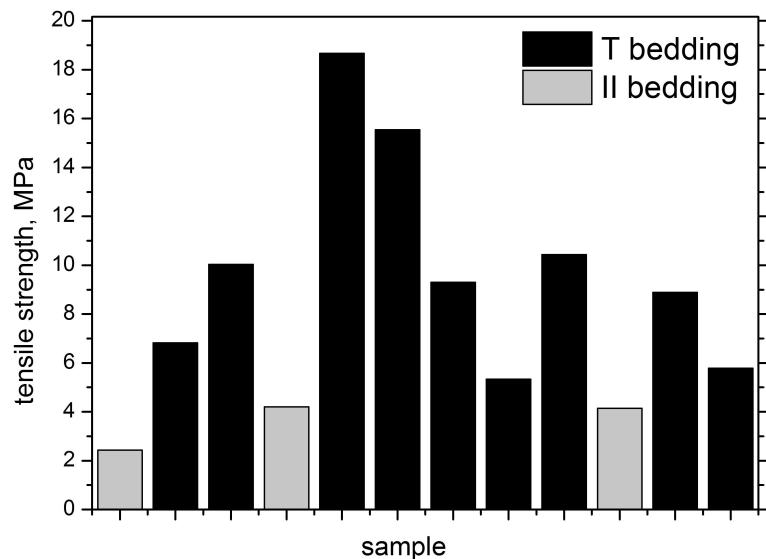
Tensile strength measurements

$$\blacksquare P > \sigma_3 + T_0$$

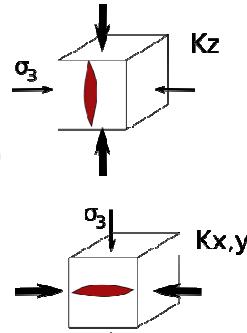
tensile strength_{BrD} T_0 :

10.1 ± 4.4 MPa (T bedding)

3.6 ± 1.0 MPa (II bedding)

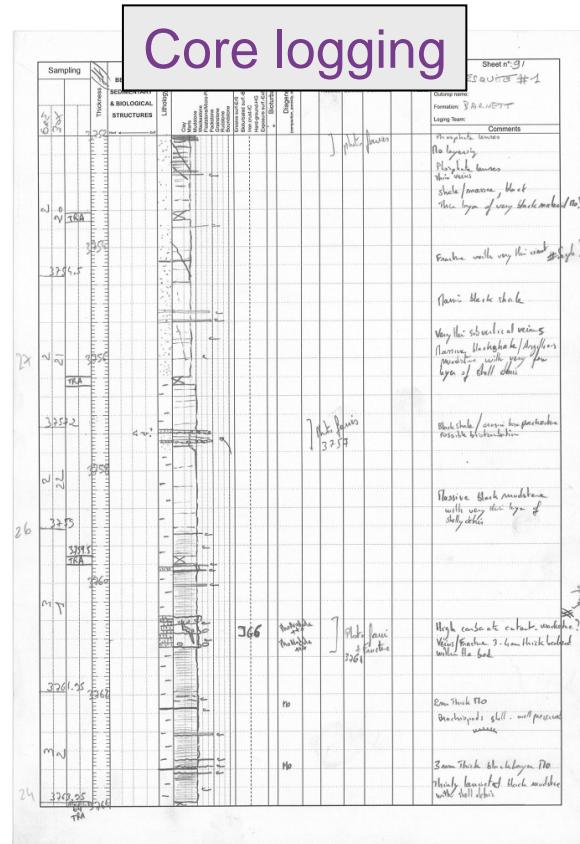


Source: rock mechanics experiments by Rybacki E. (GFZ)



horizontal fractures promoted

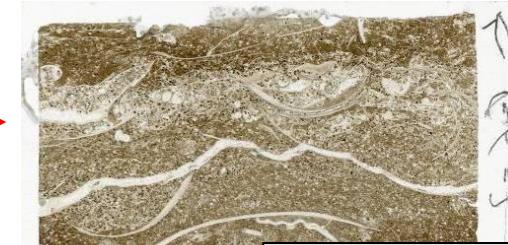
- lithology dependent parameter
 - soft shale / limestone
- fracturing history dependency
 - re-opening of pre-existing fractures privileged ($T_0 \downarrow$)



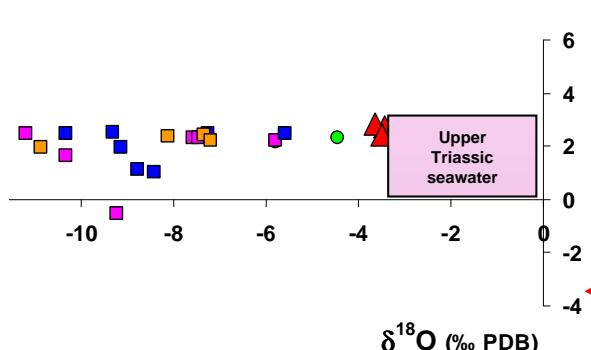
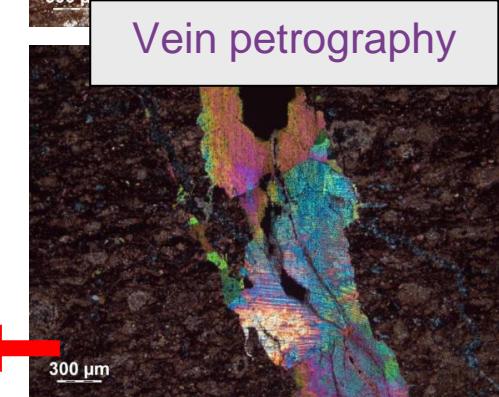
Core logging



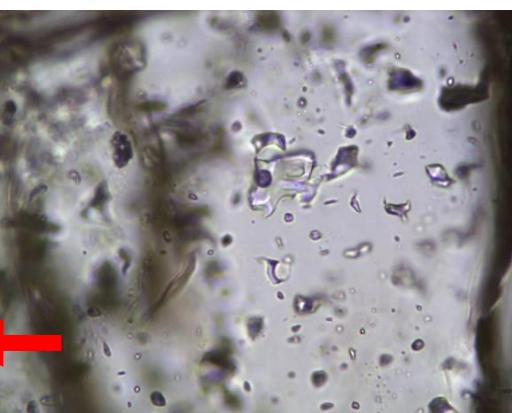
Macro-facies analysis



Micro-facies analysis

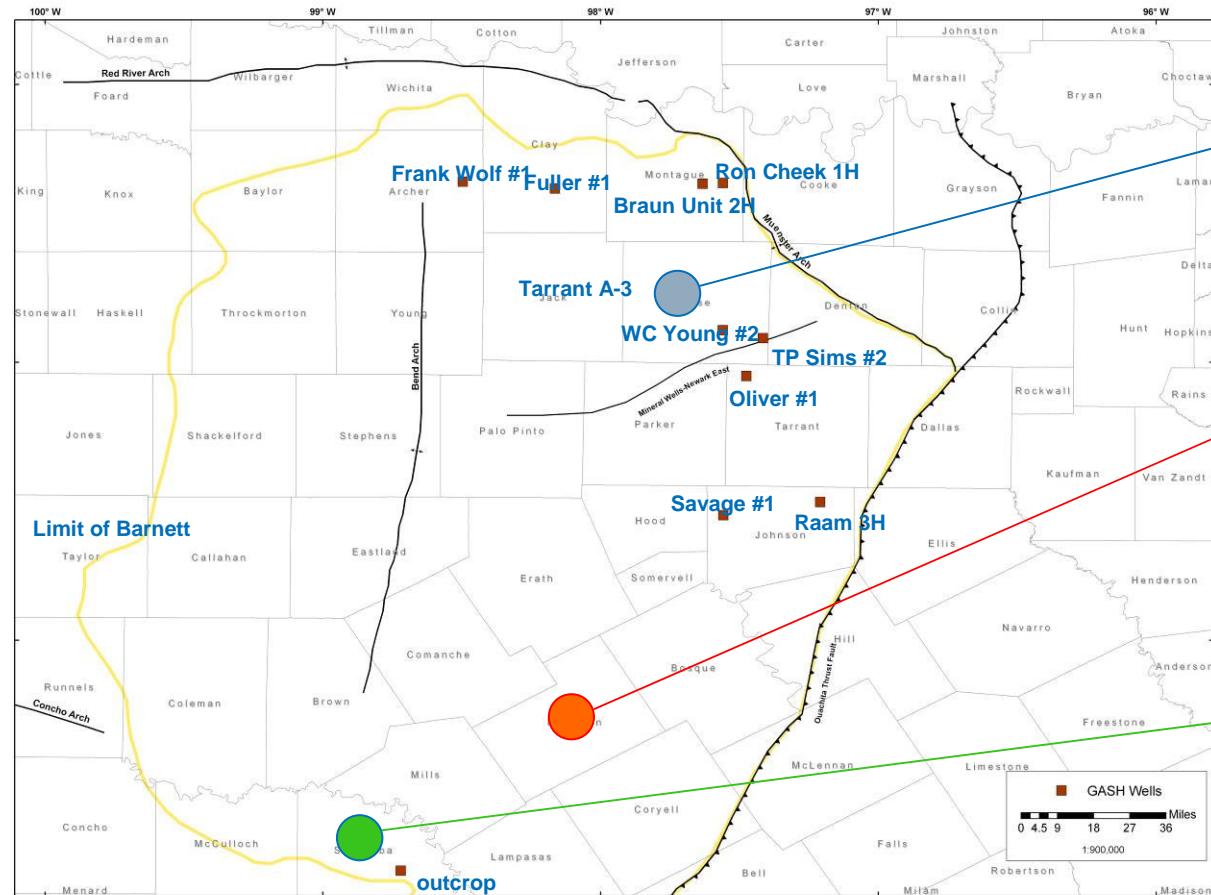


Geochemistry

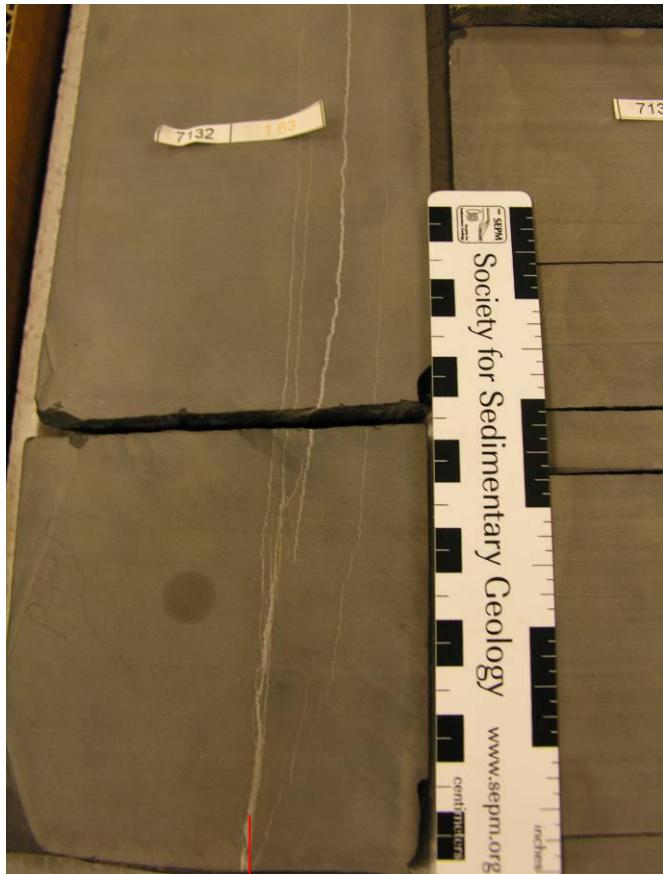


Fluid Inclusion Study

Location of the sampled fractures



Well B core fractures



Vein in Forestburg Lms



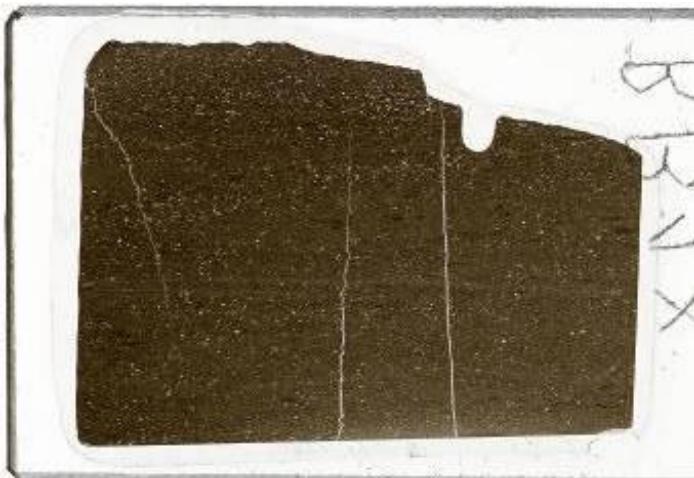
Vein in carbonate concretion facies, Uppermost Lower Barnett

Veins are sub-vertical, persistent over few cm to dm, mainly in the most carbonatic facies (carbonate concretions, Forestburg Lms, shell debris).

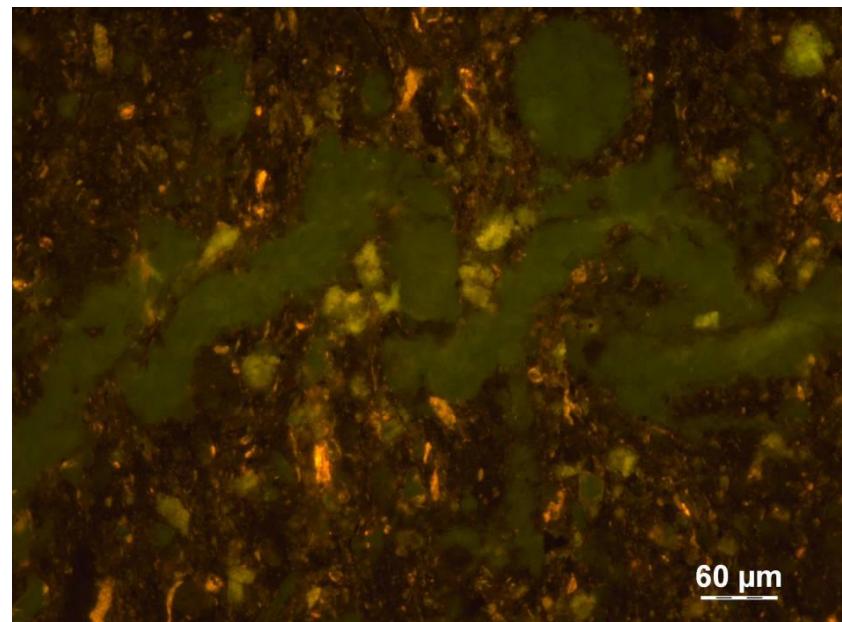
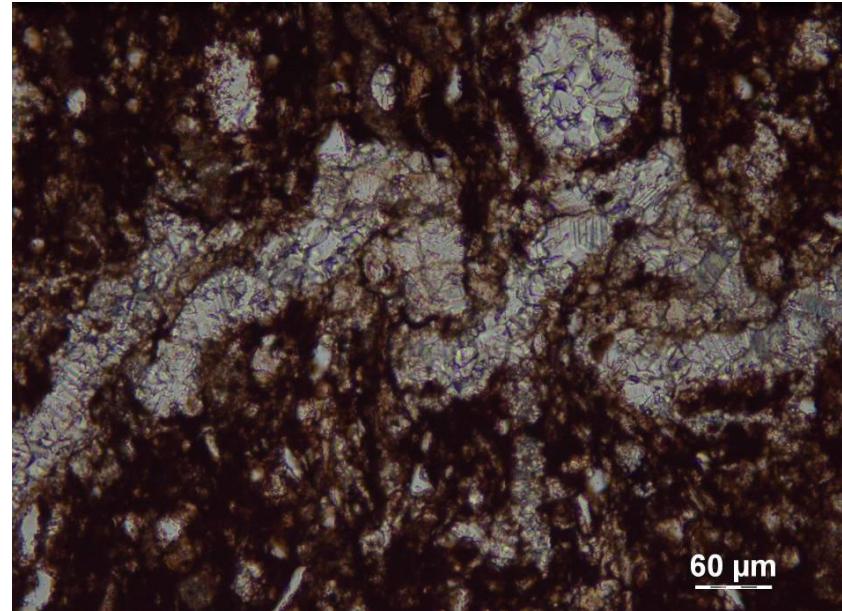
4 different veins were recognized...



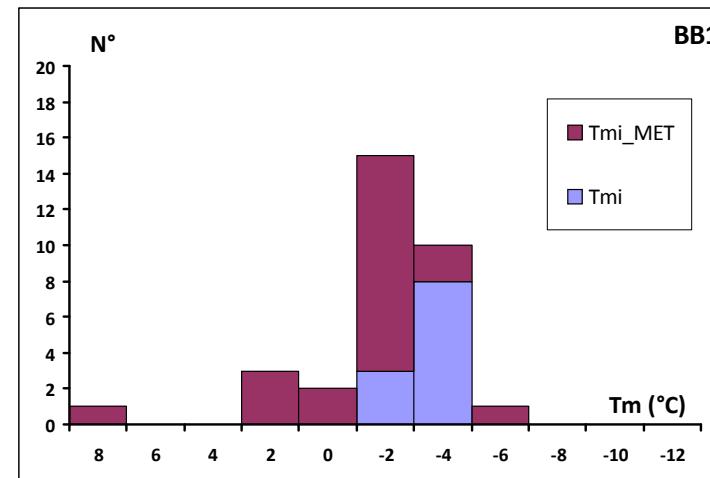
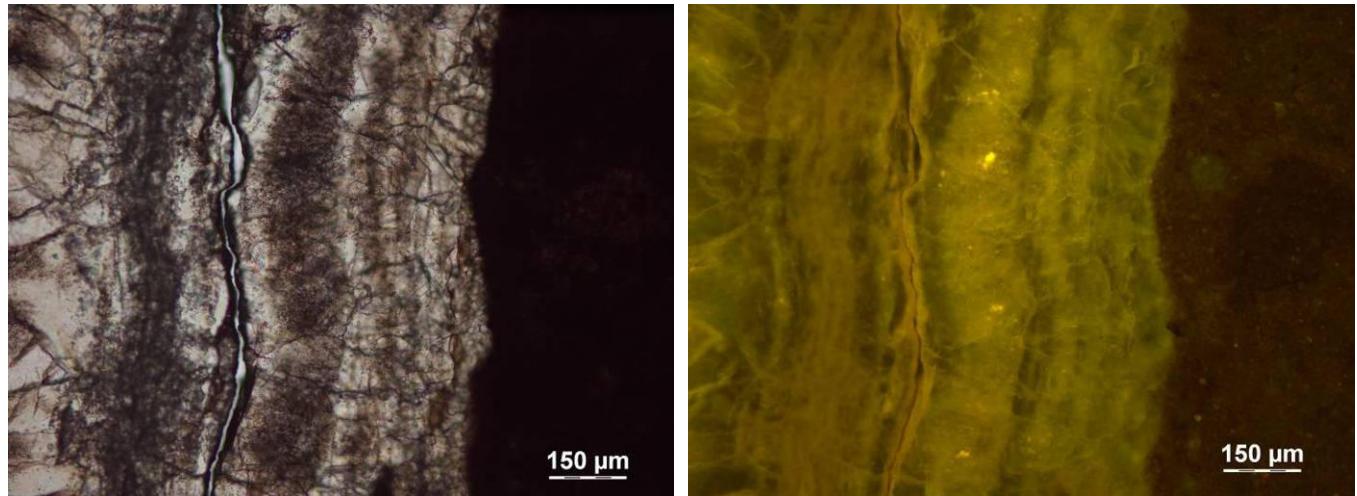
Fractures 1



Like those in San Saba and Well A.
Sub-vertical with deformation features.
Loss of persistency upwards.
Fibrous to granular calcite filling.



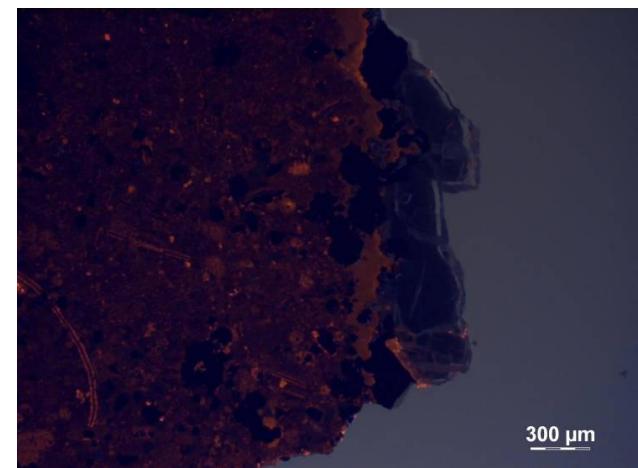
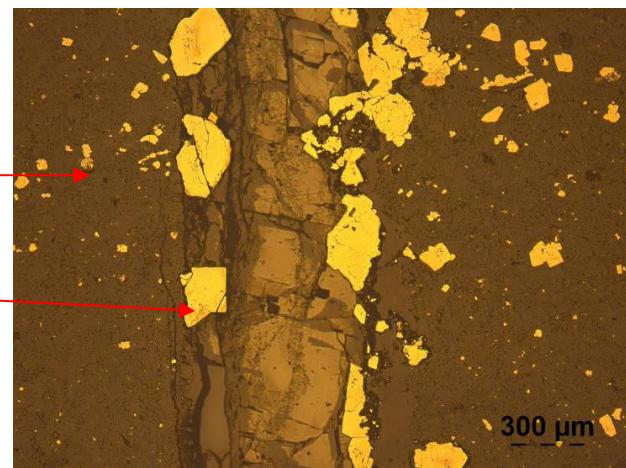
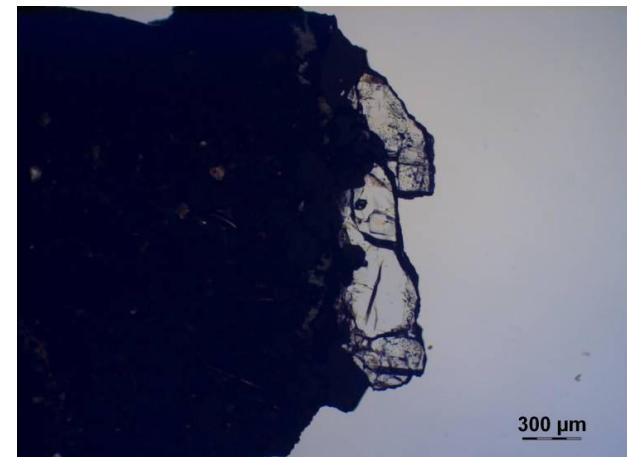
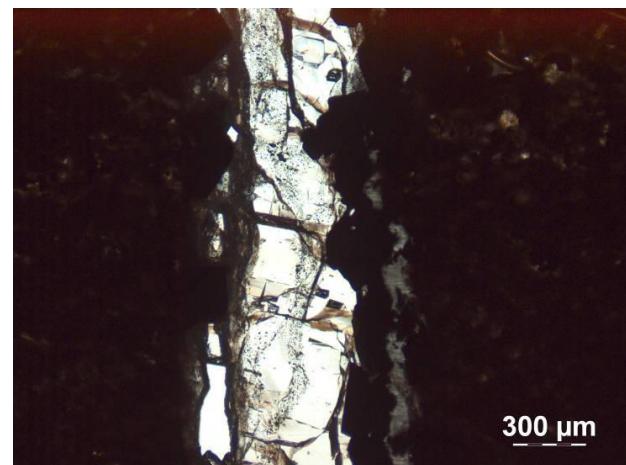
Fractures 2



Crack-seal mechanism. Several opening events.
Primary aqueous inclusions. Trapping < 50-60 °C
Fluid salinity is 5.6 to 7.9 eq. wt % NaCl
Marine derived fluids slightly modified during burial?

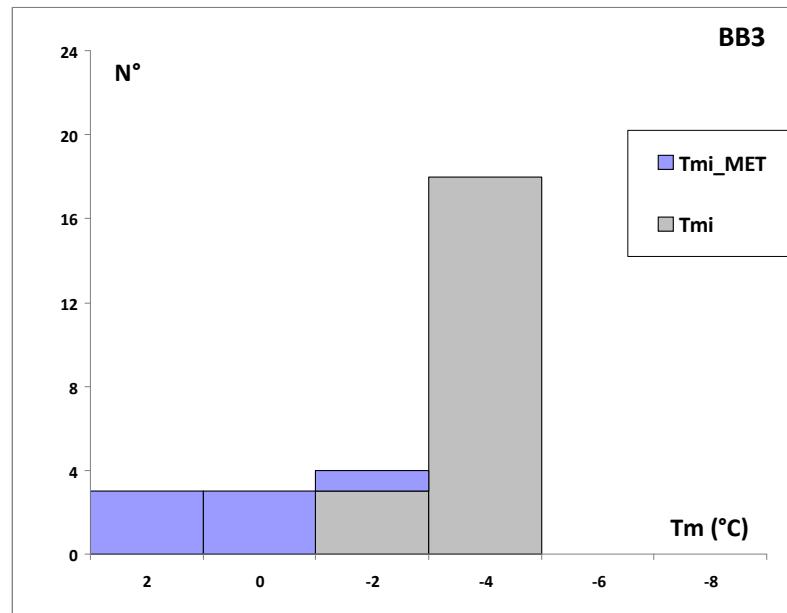
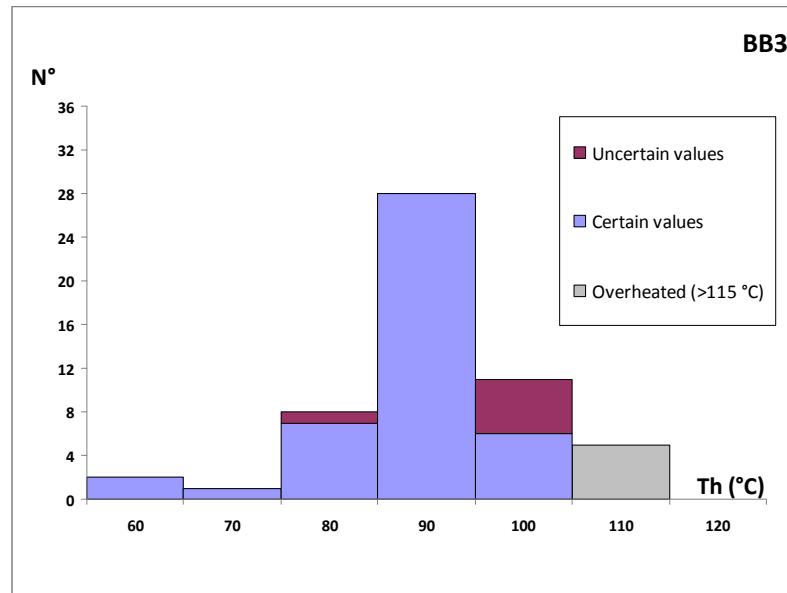
Fractures 3

Blocky calcite and megaquartz post-dating pyrite precipitation (pyrite is remobilized to the vein from pyrite-rich sediments).

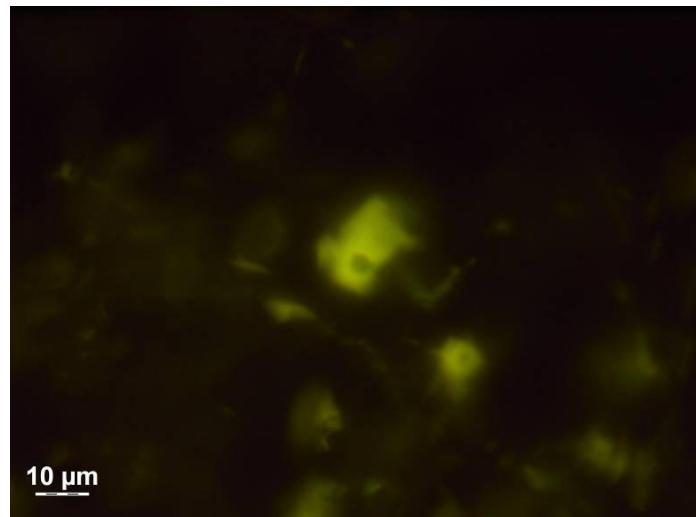
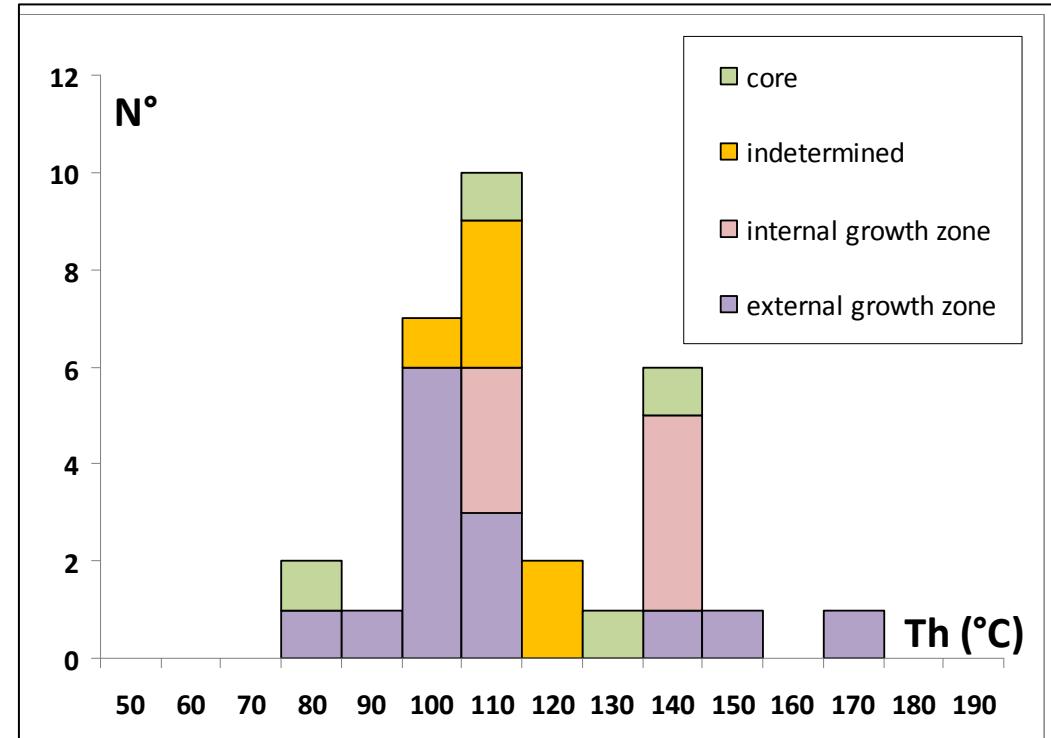
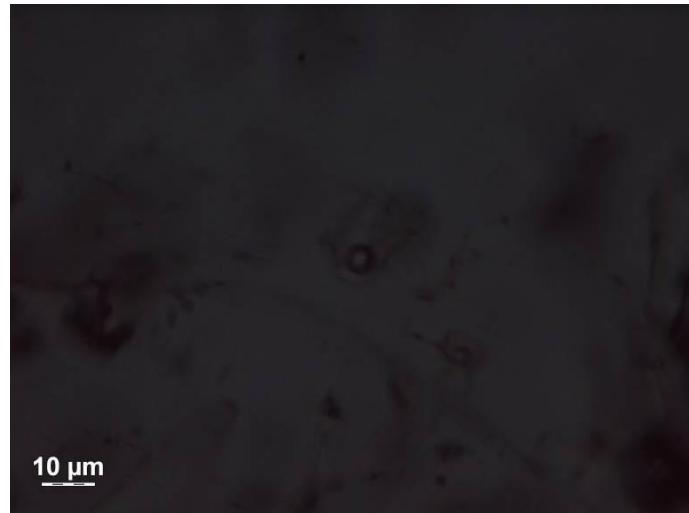


Fractures 3

Primary, aqueous inclusions.
Trapping > 90 °C
Fluid salinity: 4.8-8.7 eq wt % NaCl
Like fractures 2: marine derived fluids modified by burial.
No external fluid supply.
System still closed?

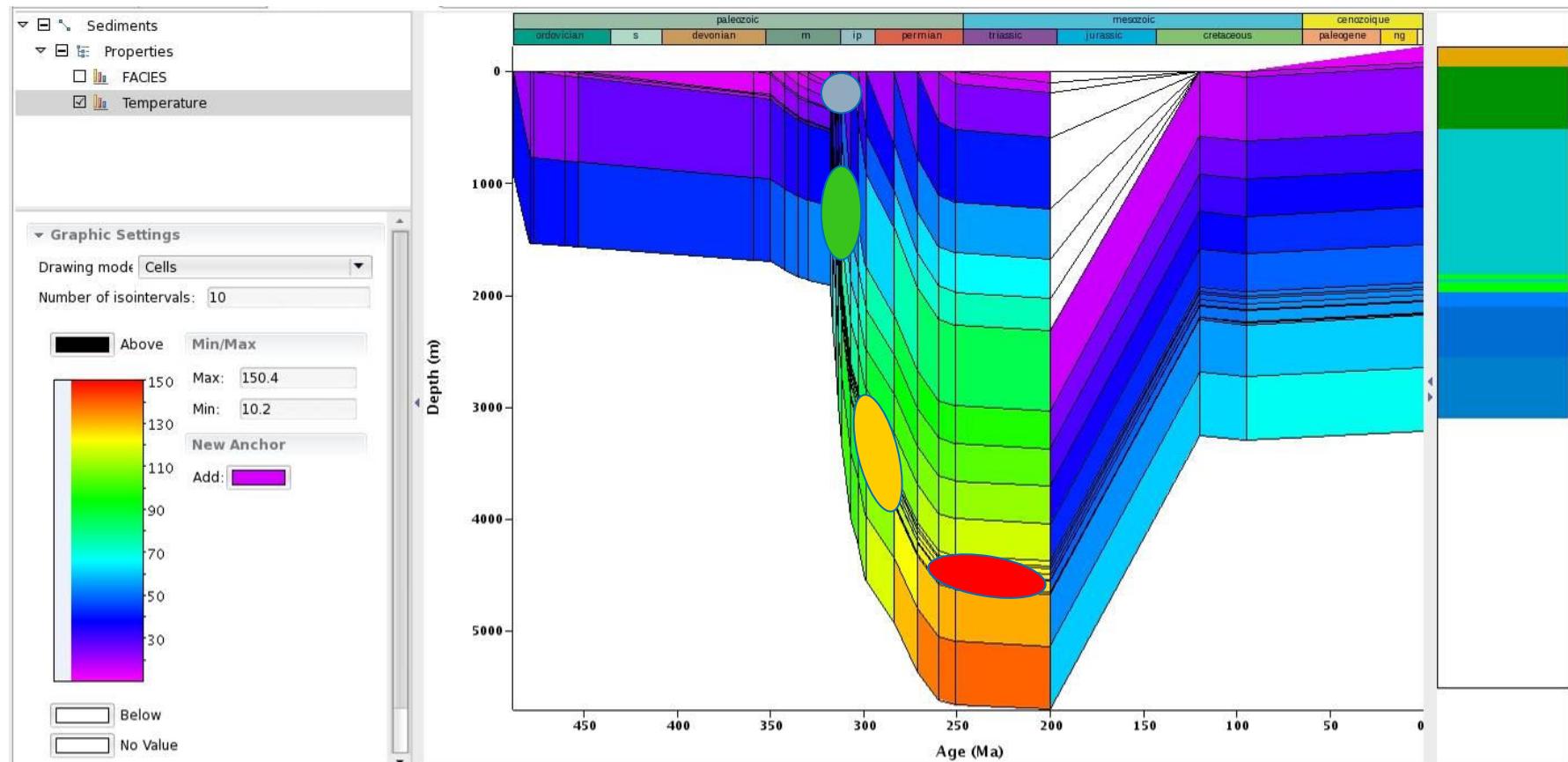


Fractures 4



A single opening event.
Blocky calcite cementation.
Green (UV-light) oil inclusions (20-30 API).
Trapping > 110 °C
Opening of the system due to HC migration
Arrival of «exhotic» fluids.

Fracture timing and burial history (Well B core)



Fractures 1
Calcite
Aqueous

Fractures 2
Calcite
Aqueous

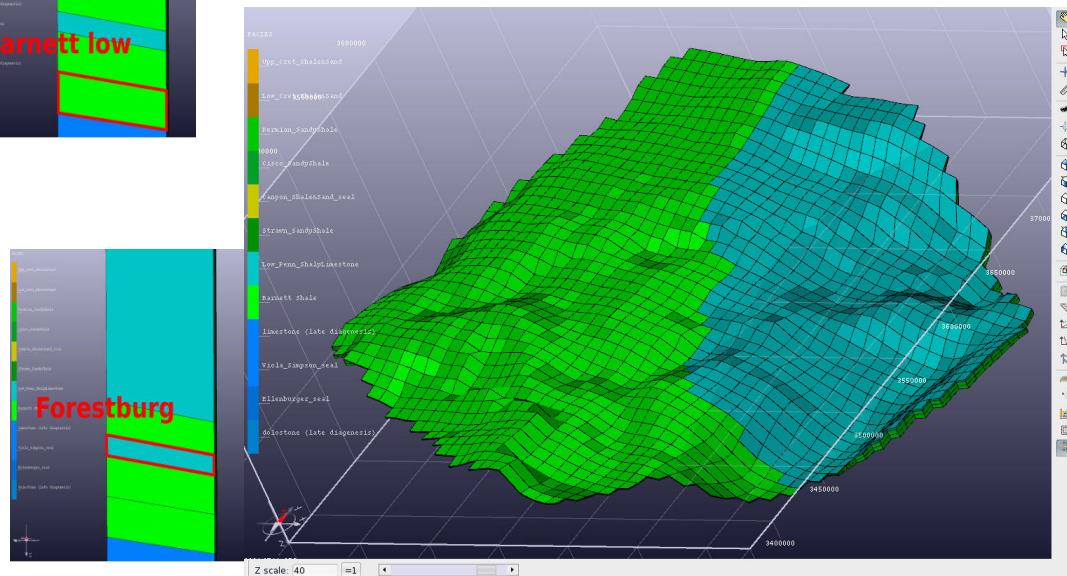
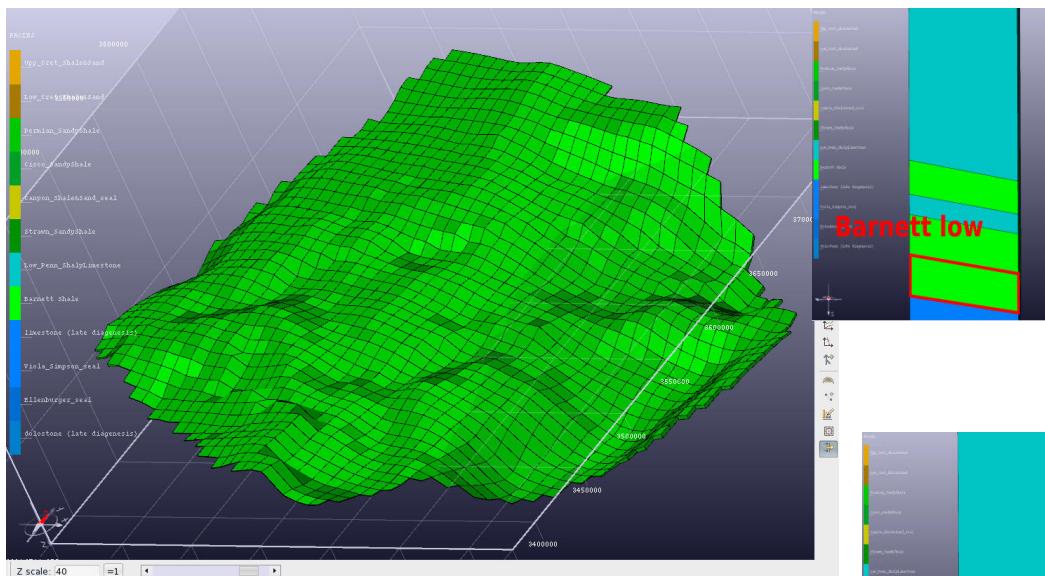
Fractures 3
Calcite-Qz
Aqueous

Fractures 4
Calcite
Oil (20-30 API)



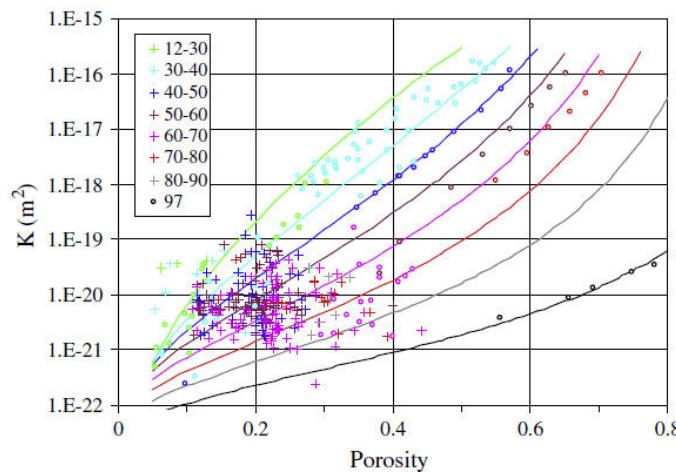
3D Barnett in Fort Worth Basin

- Source rock at max burial (260-200Ma)



Permeability laws

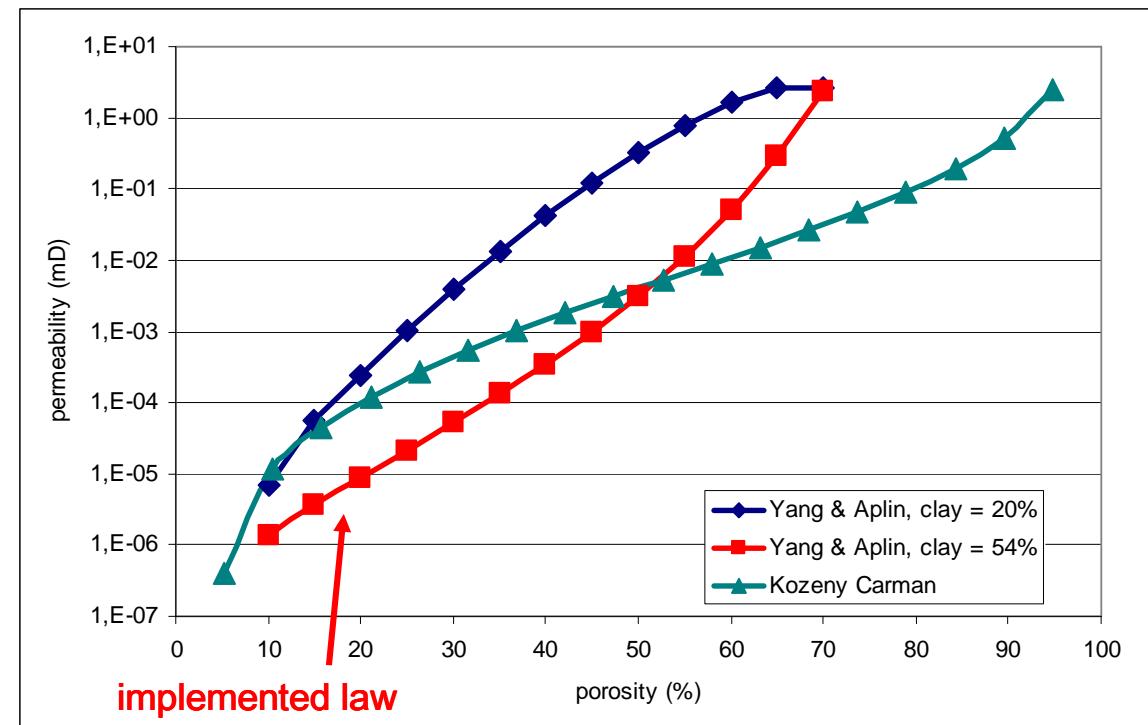
■ clay content



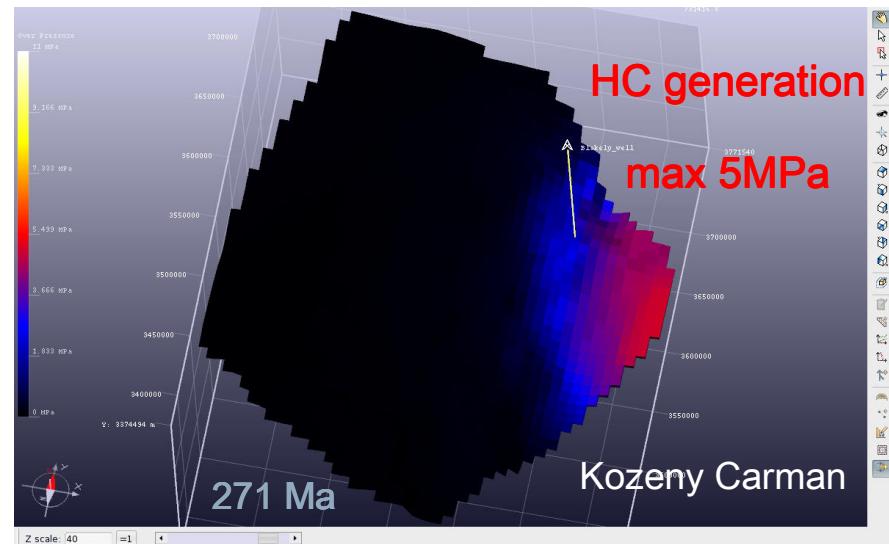
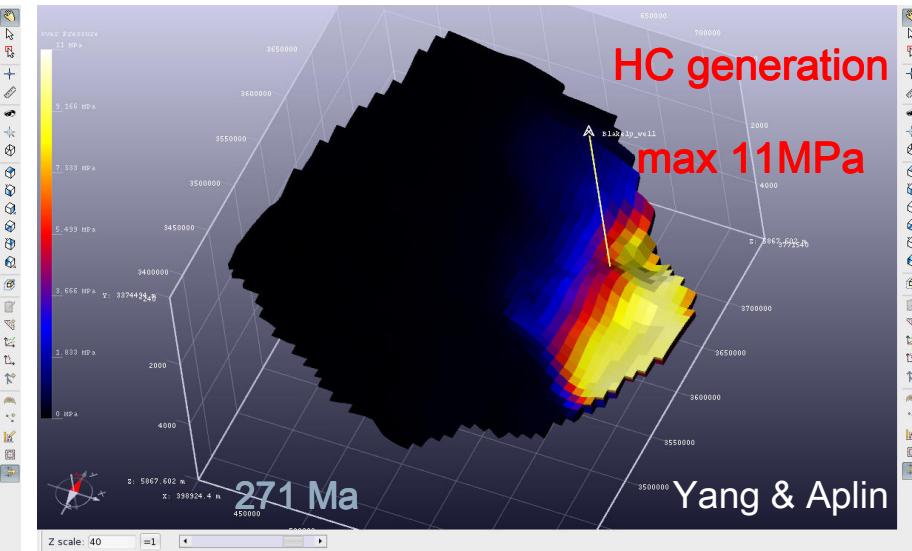
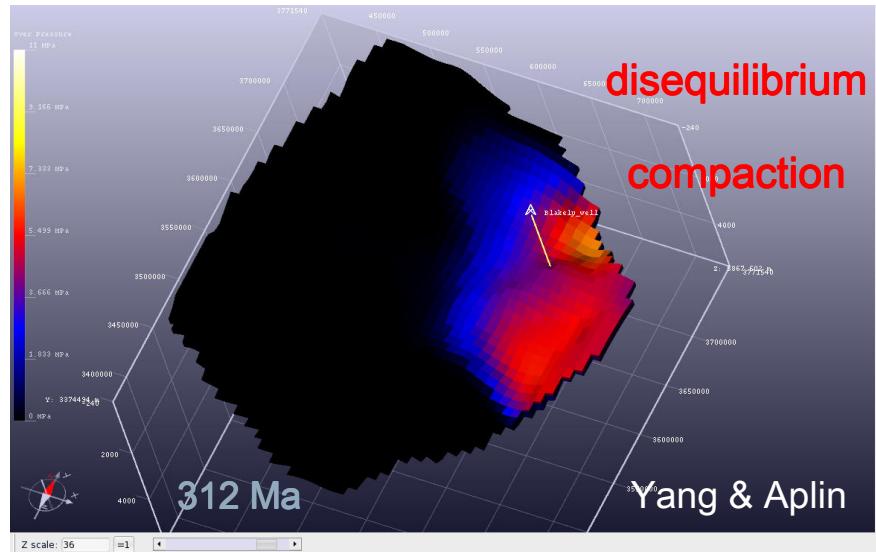
Yang & Aplin, 2010

■ Barnett shale [20-54]%

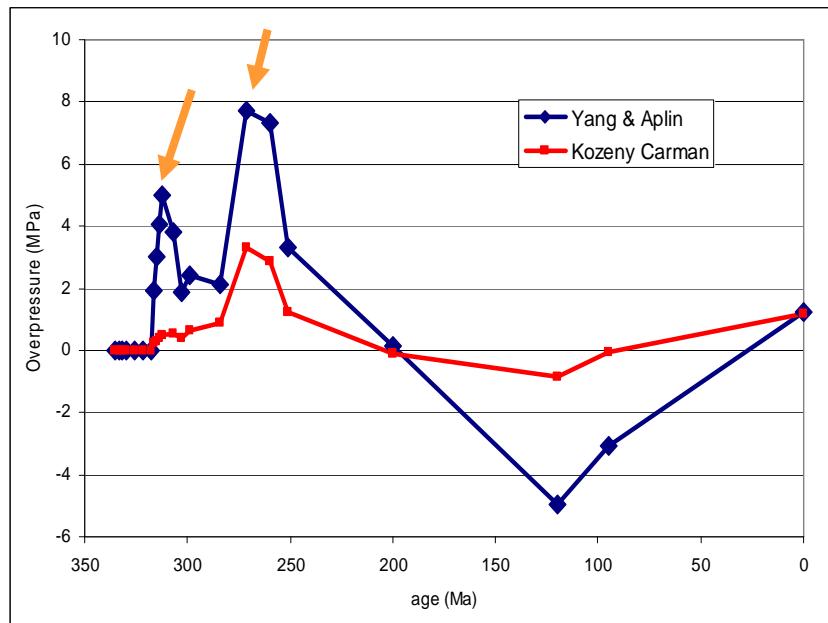
Bruner & Smosna, 2011



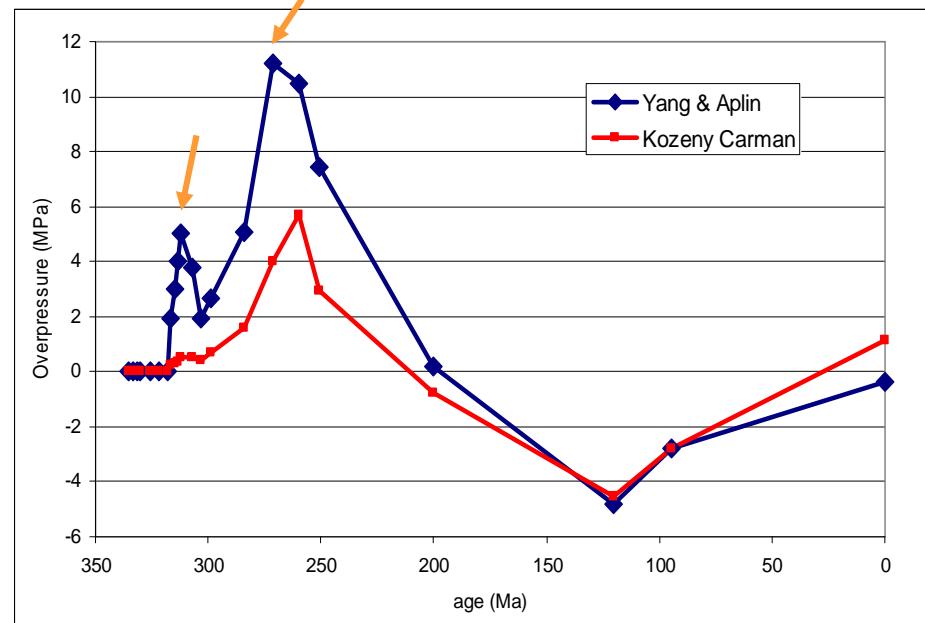
Overpressure maps



Permeability effect (Blakely well)



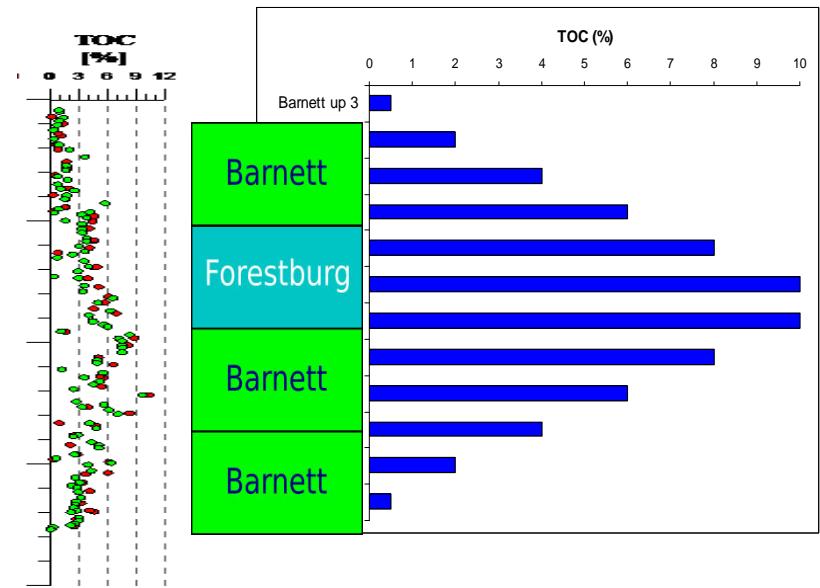
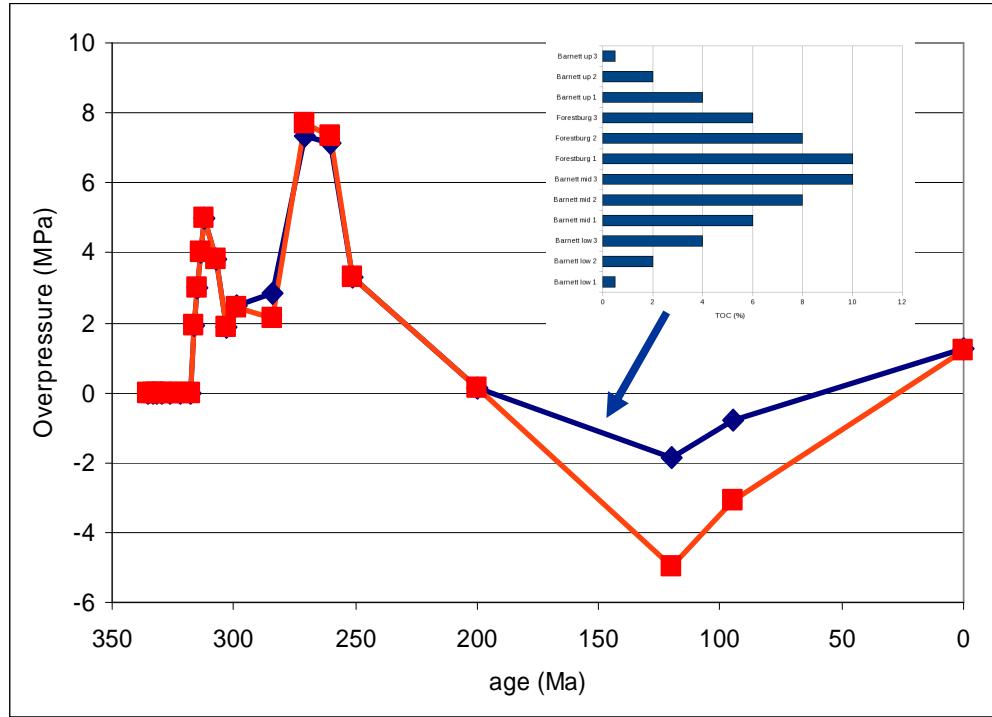
TOC = 5%



TOC = 10%

- 2 overpressure events
 - disequilibrium compaction
 - hydrocarbon generation
- Enhanced maximal overpressure
 - more than a factor 2

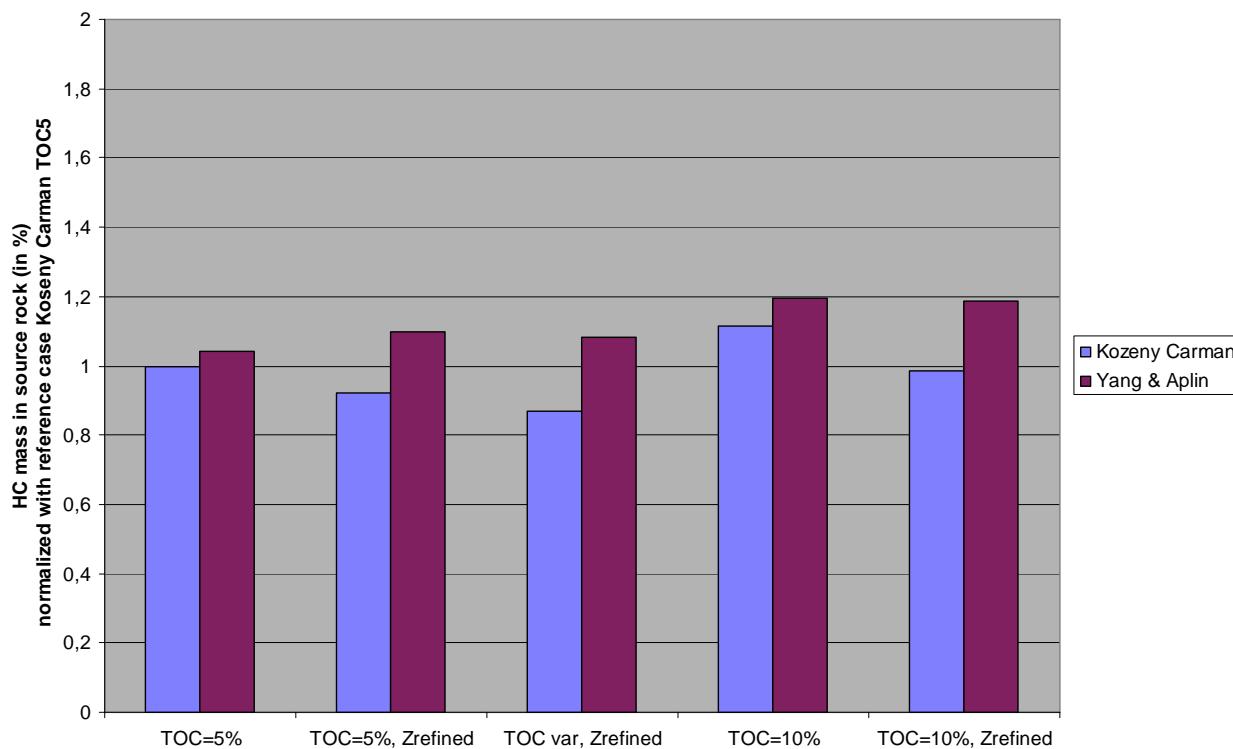
TOC profile effect



- No effect in the pressure build up

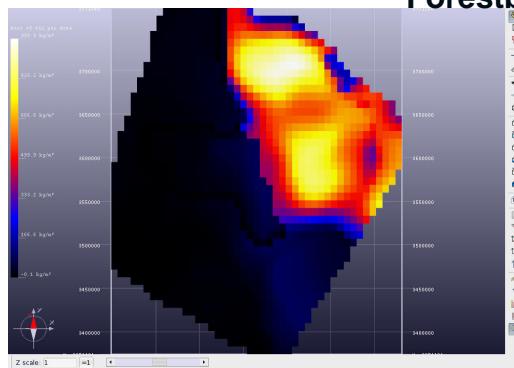
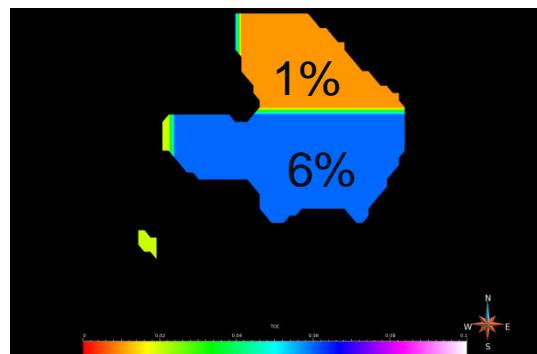
Remaining HC in source rock

- Poorly sensitive to
 - permeability laws
 - initial TOC (value or profile)
 - source rock vertical mesh refinement

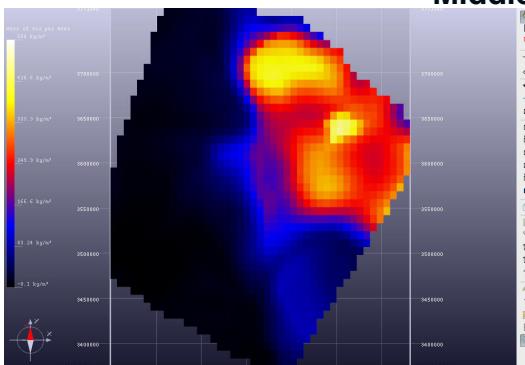
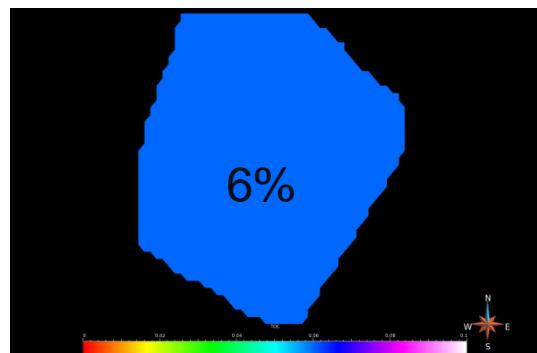
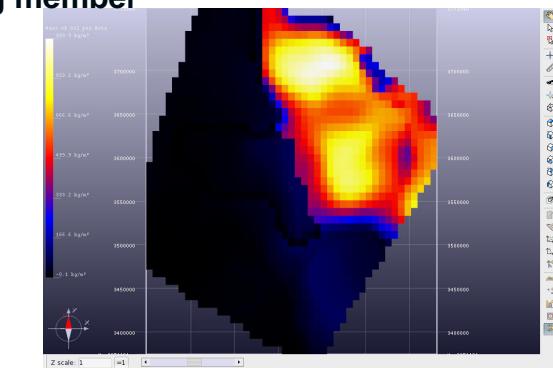


Maps of ultimate HC In Place

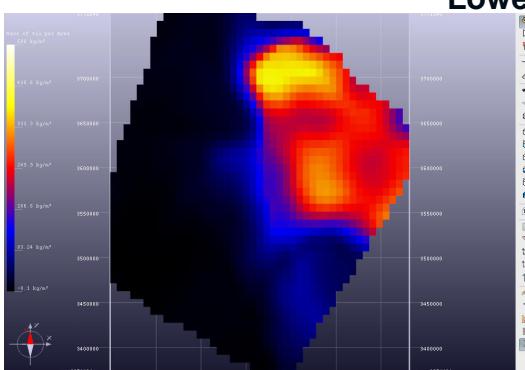
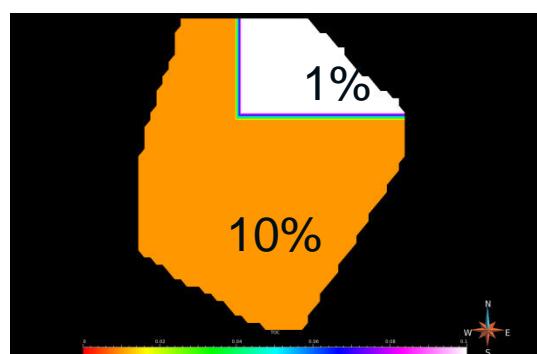
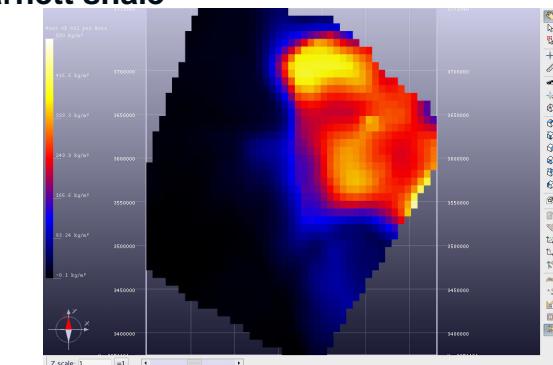
MAPS WITH VARIABLE INITIAL TOC



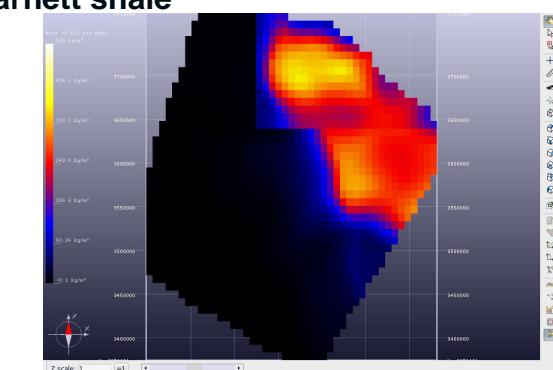
UNIFORM TOC (5.6%) Forestburg member



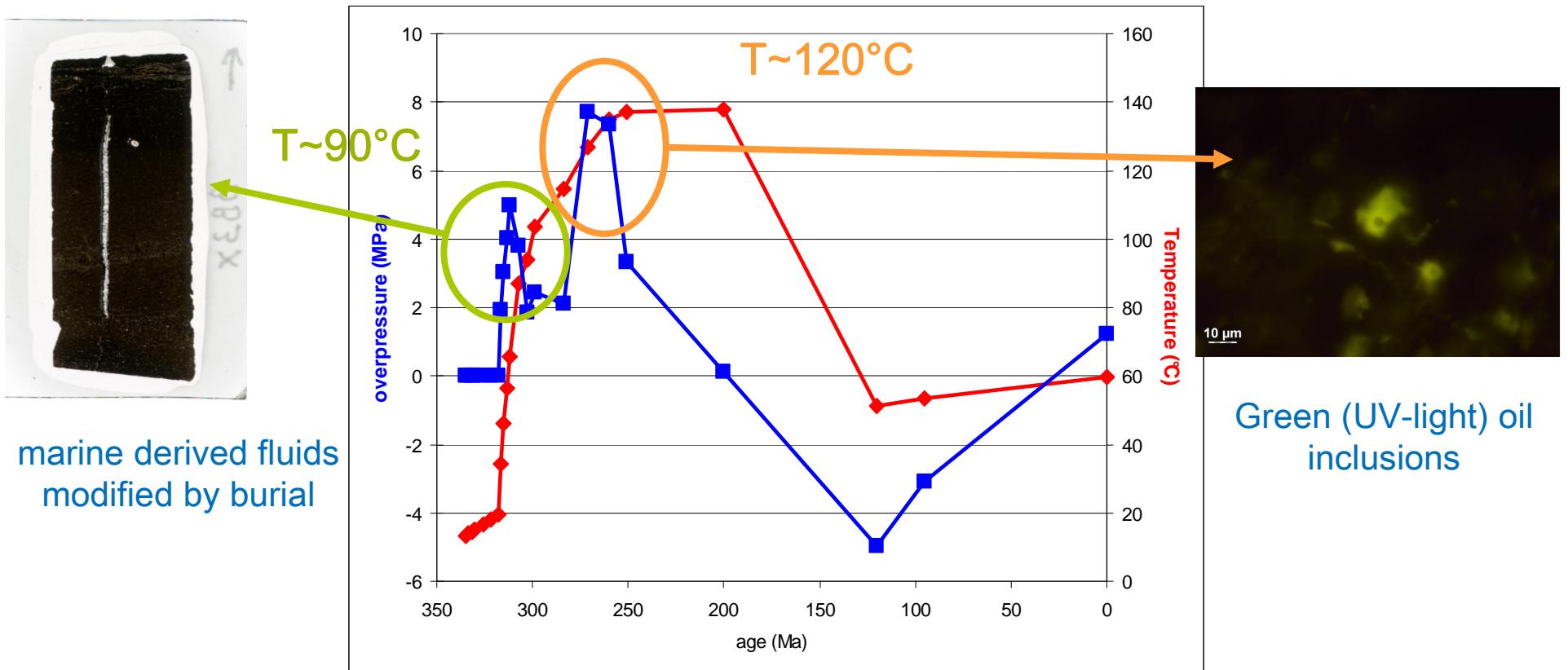
Middle Barnett shale



Lower Barnett shale



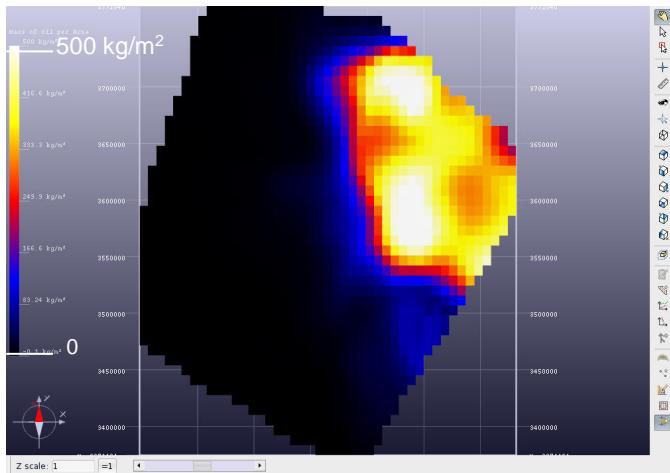
Overpressure events at Well B core



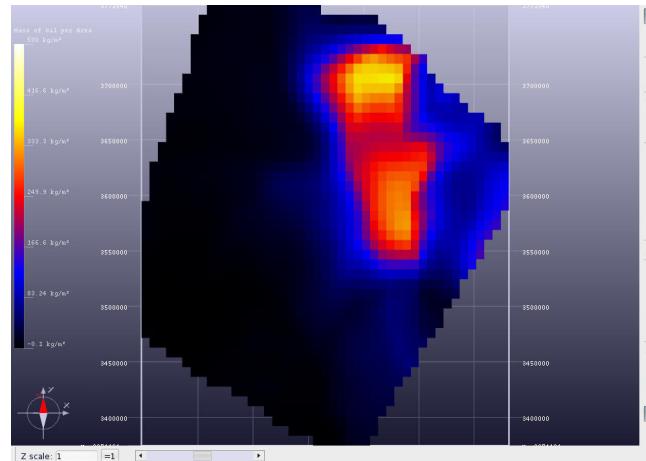
- No recovery of shallow fractures
 - need of higher resolution in time

Ultimate HC Mass in middle Barnett Shale for non fracturing and Satex= 0 type fracturing scenarios

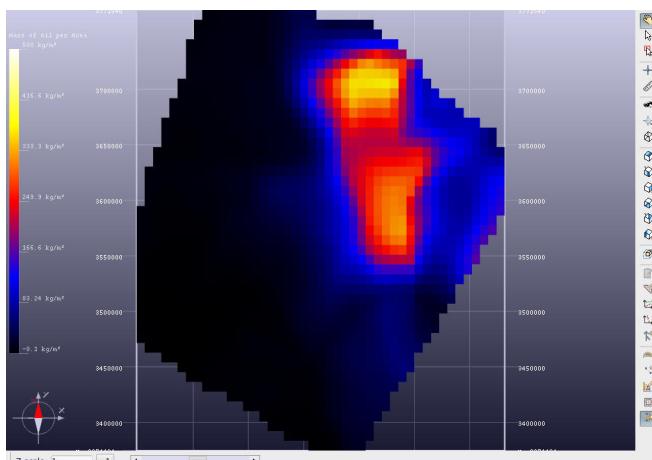
Reference run Satex= 15%



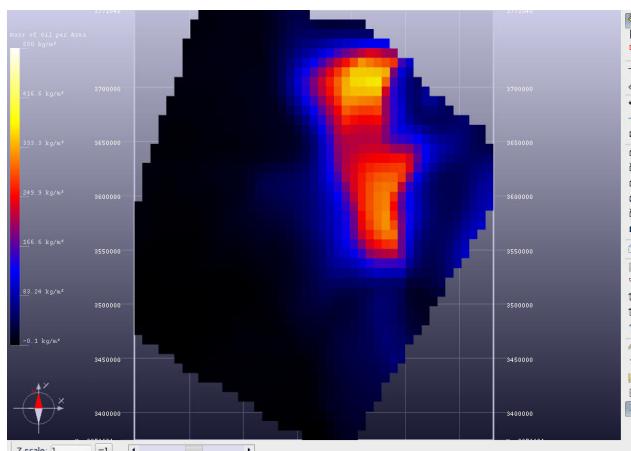
No Fracturing - Satex= 0



Horizontal Fractures Satex= 0

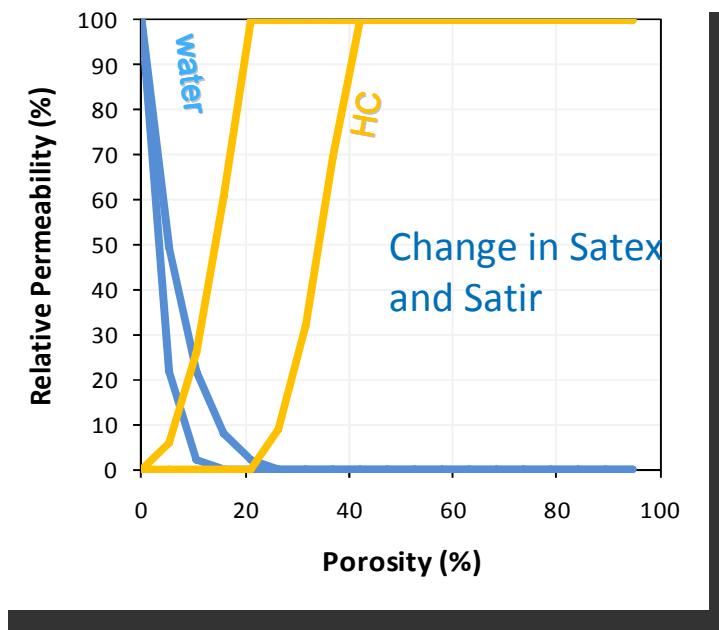
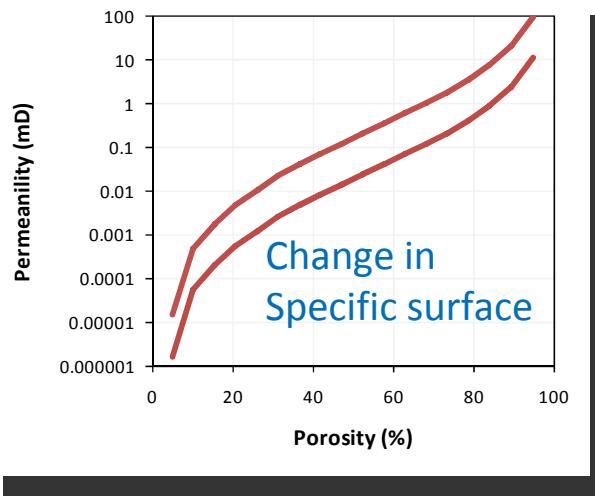


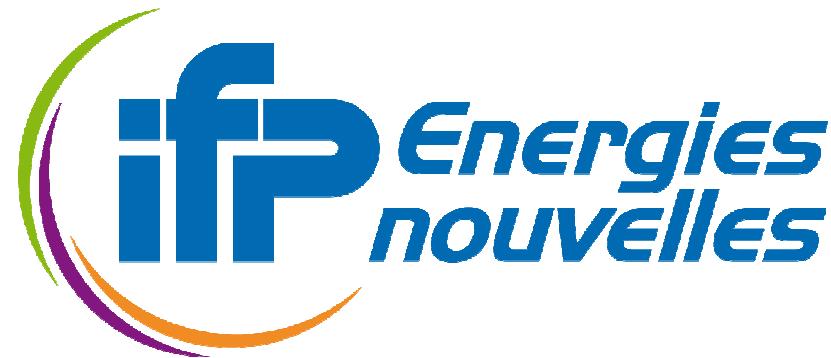
Vertical Fractures Satex= 0



Expulsion in Basin Models

- "Satex" = Saturation of expulsion
- Retention thresholds
- Capillary pressure
- Permeability
- Relative permeability





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