[PS]Burial History Modeling and Paleogeomechanics of the Barnett and Haynesville*

Kenneth E. Williams[1]

Search and Discovery Article #50807 (2013)**
Posted June 30, 2013

*Adapted from poster presentation given at AAPG 2013 Annual Convention and Exhibition, Pittsburgh, Pennsylvania, May 19-22, 2013

[1]Halliburton C&P Digital Solutions, Houston, TX (ken.williams@halliburton.com)

Abstract

Burial history analysis of the Barnett source-rock reservoir (SRR) area shows a complex history of burial and uplift/erosion. The initial deep burial of the area as part of the Fort Worth foreland basin in front of the advancing Ouachita fold belt resulted in hydrocarbon generation and expulsion of oil and gas in the Pennsylvanian and Permian basins. This was accompanied by high overpressures that are capable of fracturing the source rock to allow the primary migration of hydrocarbons. The regional stress field at that time was related to foreland basin tectonics and was different from the current stress field. In the Triassic and Jurassic periods, when the Gulf of Mexico basin opened, the Barnett core area was uplifted, and 7,000 ft (2,134 m) of overburden was removed in some areas, which contributed to the filling in of the Permian basin to the west. The stress field was likely deviatoric, away from the uplifted eroding highlands, and another set of fractures may have been induced. At the present time, the stress regime is oriented such that the younger set of induced fractures is critically stressed. Hydraulic fracturing opens these younger fractures and reconnects the borehole to the older set of fractures, thereby creating a complex fracture system and allowing the production of hydrocarbons at a commercial rate.

Burial history analysis of the Haynesville SRR reveals a paleogeomechanic and paleogeographic explanation for horizontal fractures that have been observed in core. A compressional stress regime that allows the development of horizontal fractures requires that vertical or overburden is the minimum principal stress. Often, this is accompanied by the presence of thrust faults; however, thrust faulting is not readily observed in the Haynesville area, but horizontal fractures are present. The stress regime was developed during the mid-Cretaceous unconformity when the ancestral Sabine uplift was active. A deep-seated volcanic intrusion may be the ultimate cause of the uplift, which would have provided an increased heat flow that coincided with the maximum burial of the SRR. High internal pressures from hydrocarbon generation and migration, therefore, coincided with overburden removal with little horizontal compression, and the overburden was uplifted to allow the emplacement of horizontal mineral-filled fractures.

Burial History Modeling and Paleogeomechanics of the Barnett and Haynesville

Kenneth E. Williams
ken.williams@halliburton.com
Halliburton C&P Digital Solutions: Houston, TX

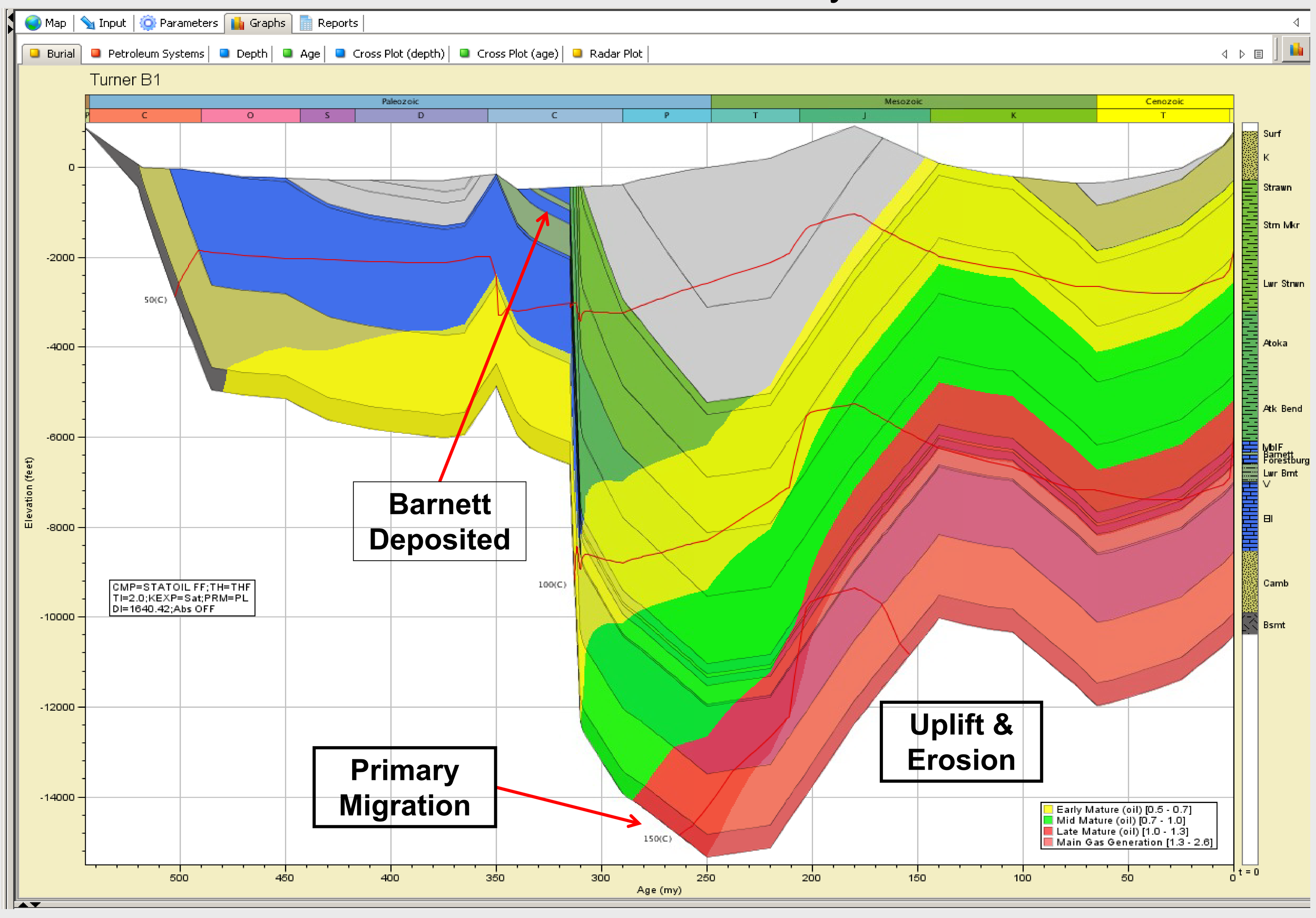
Abstract

Burial history analysis of the Barnett Source Rock Reservoir (SRR) area shows a complex history of burial and uplift/erosion. The initial deep burial of the area as part of the Fort Worth foreland basin in front of the advancing Ouachita fold belt resulted in hydrocarbon generation and expulsion of oil and gas in the Pennsylvanian and Permian. This was accompanied by high overpressures that are capable of fracturing the source rock to allow the primary migration of hydrocarbons. The regional stress field at that time was related to foreland basin tectonics and was different than the current stress field. In the Triassic and Jurassic, when the Gulf of Mexico basin opened, the Barnett core area was uplifted and 7,000 ft (2134 m) of overburden was removed in some areas and contributed to the filling-in of the Permian basin to the west. The stress field was likely deviatoric away from the uplifted eroding highlands and another set of fractures may have been induced. At the present time, the stress regime is oriented such that the younger set of induced fractures are critically stressed. Hydraulic fracturing opens these younger fractures and reconnects the borehole to the older set of fractures, thereby creating a complex fracture system and allows the production of hydrocarbons at a commercial rate.

Burial history analysis of the Haynesville SRR reveals a paleogeomechanic and paleogeographic explanation for horizontal fractures that have been observed in core. A compressional stress regime that allows the development of horizontal fractures requires that vertical or overburden is the minimum principal stress. Often this is accompanied by the presence of thrust faults, however thrust faulting is not readily observed in the Haynesville area, but horizontal fractures are present. The stress regime was developed during the mid-Cretaceous unconformity when the ancestral Sabine uplift was active. A deep-seated volcanic intrusion may be the ultimate cause of the uplift, and this would have provided an increased heat flow that coincided with the maximum burial of the SRR. High internal pressures from hydrocarbon generation and migration therefore coincided with overburden removal with little horizontal compression, and the overburden was uplifted in order to allow the emplacement of horizontal mineral-filled fractures.

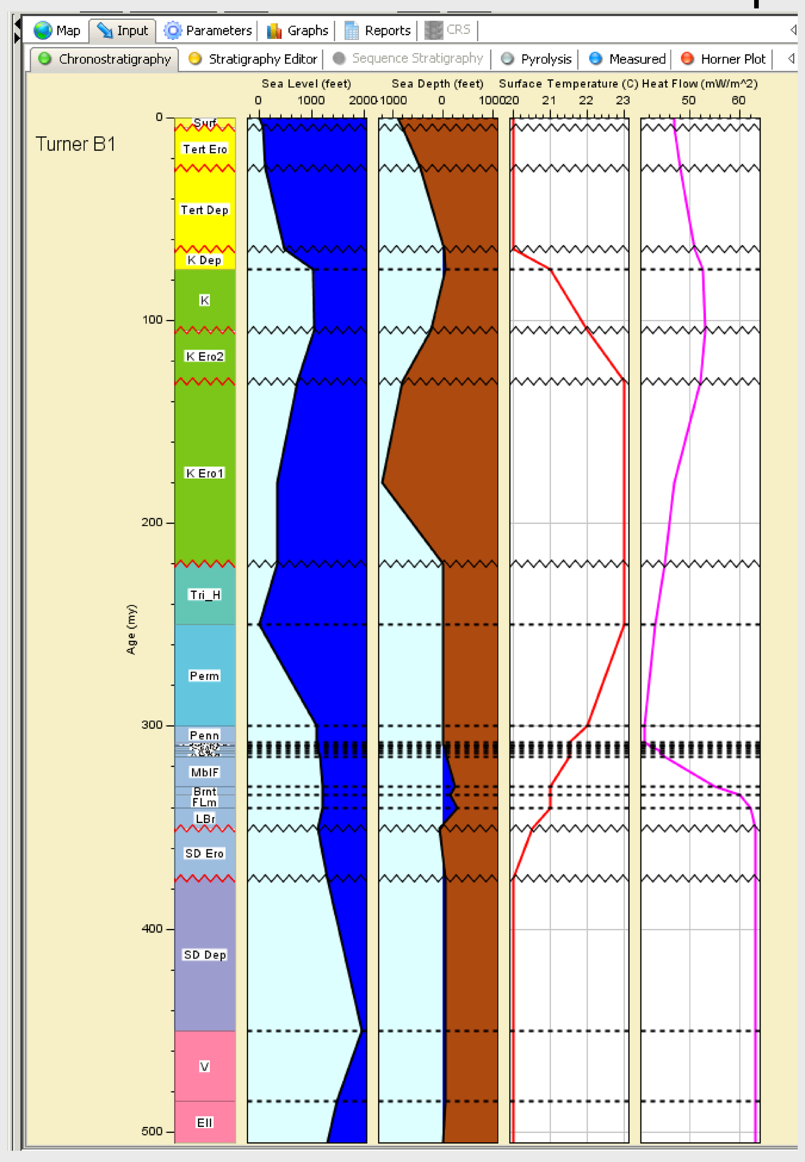
Barnett Shale Core Area: Modeling & Paleogeomechanics

1D Burial History



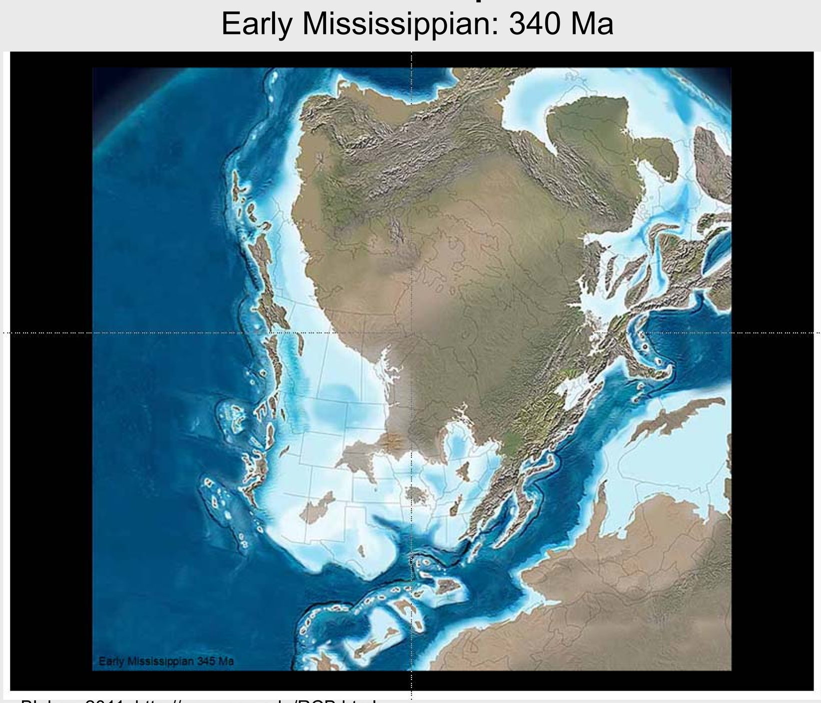
Present-day BHT & Ro in Barnett Calibrate OK

Paleo SL / WD / HF / Surf Temp



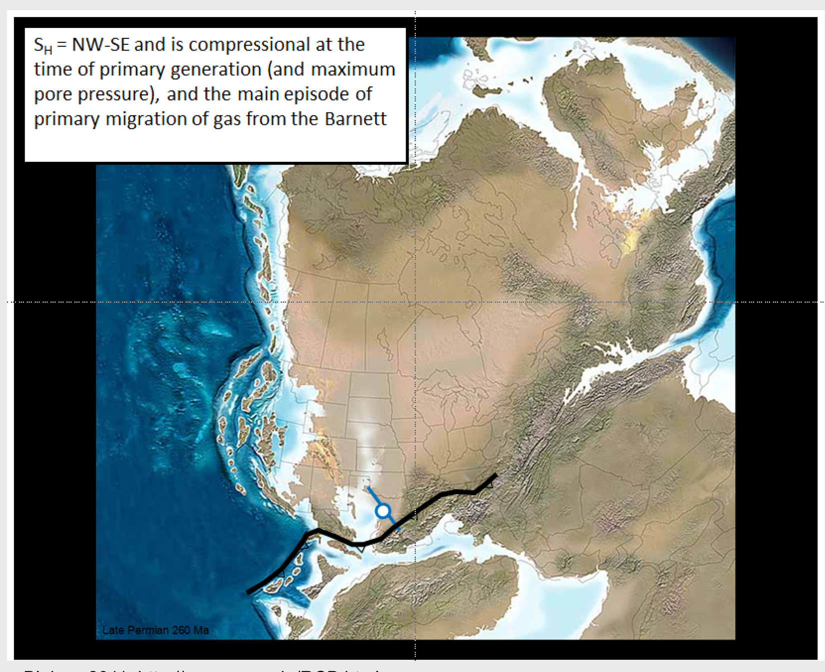
Low HF in Foreland Basin

Barnett SRR Deposition
Early Mississippian: 340 Ma



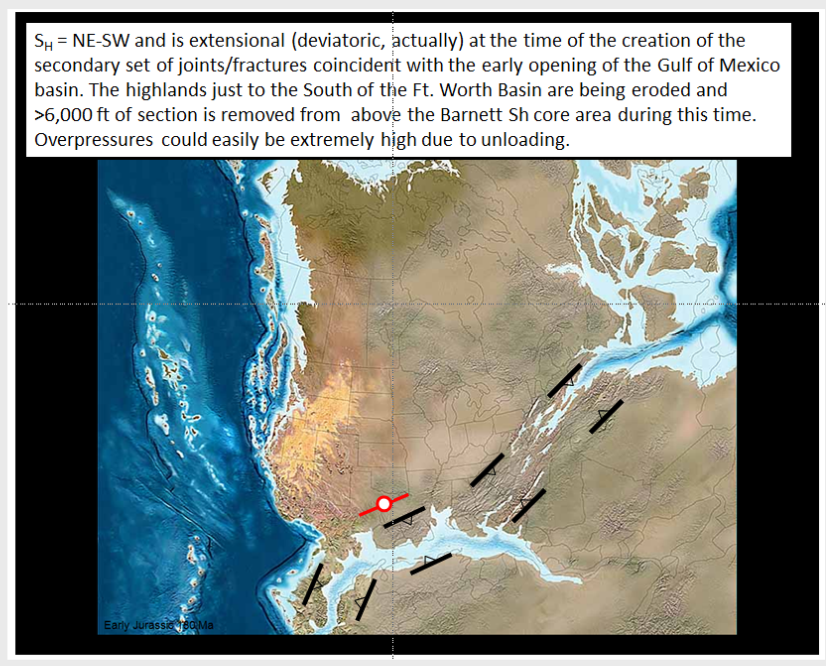
Blakey, 2011: http://www.nau.edu/RCB.html

Foreland Basin: Primary Migration
Late Permian: 260 Ma



Blakey, 2011: http://www.nau.edu/RCB.html

GoM Basin Rifting: Uplift / Erosion
Early Jurassic: 180 Ma



Blakey, 2011: http://www.nau.edu/RCB.html

Some Deep Burial Effects on SRRs

[ ] Increased temperature & hydrostatic pressure
[ ] Loss of porosity due to > overburden stress
[ ] Loss of permeability
[ ] Cementation
[ ] Clay diagenesis (smectite > illite)

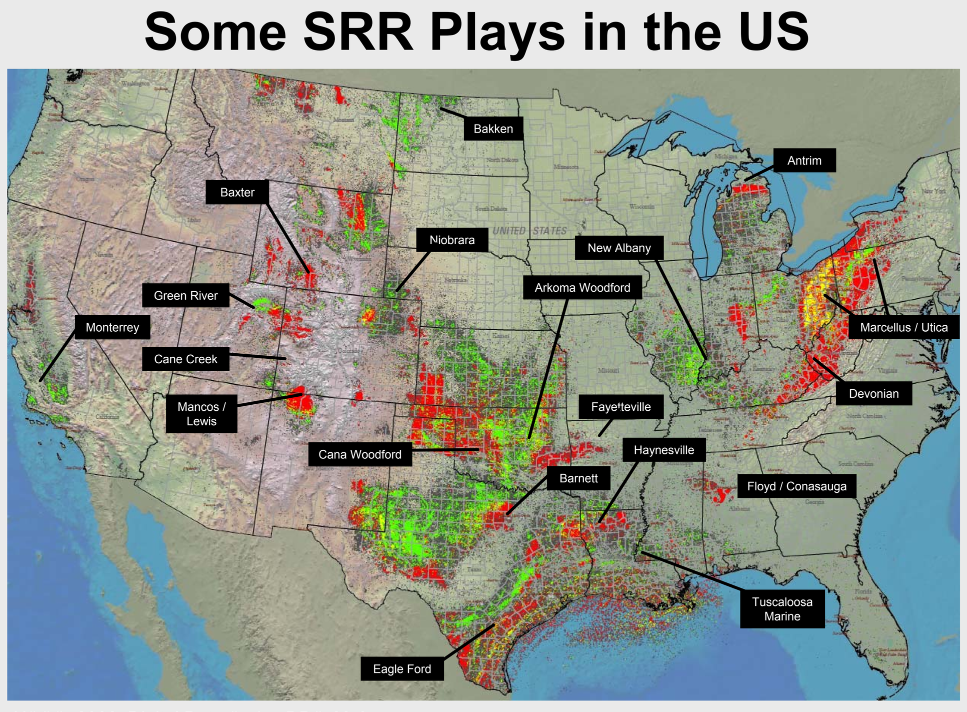
[ ] Hydrocarbon generation
[ ] Expulsion of oil, gas, and water
[ ] Cracking of unexpelled oil to gas & expulsion
[ ] Overpressuring and microfracturing w/i SRR
[ ] Macrofracturing oriented wrt regional stress field

Some Effects of Unloading by Erosion on SRRs

[ ] Lowered temperature & vertical stress
[ ] Porosity remains essentially the same & permeability remains low
[ ] Cementation of open fractures and large pores

[ ] Hydrocarbon generation & migration ceases
[ ] High overpressuring remains, due to low permeability
[ ] Stress field is reoriented and changes rom compressional to extensional
[ ] Macrofracturing (|| to S_h) due to S_v reduction while S_h remains high
[ ] Clays now become undersaturated wrt their temperature and pressure since rehydration water is not available (low perm) => sub-irreducible water saturation

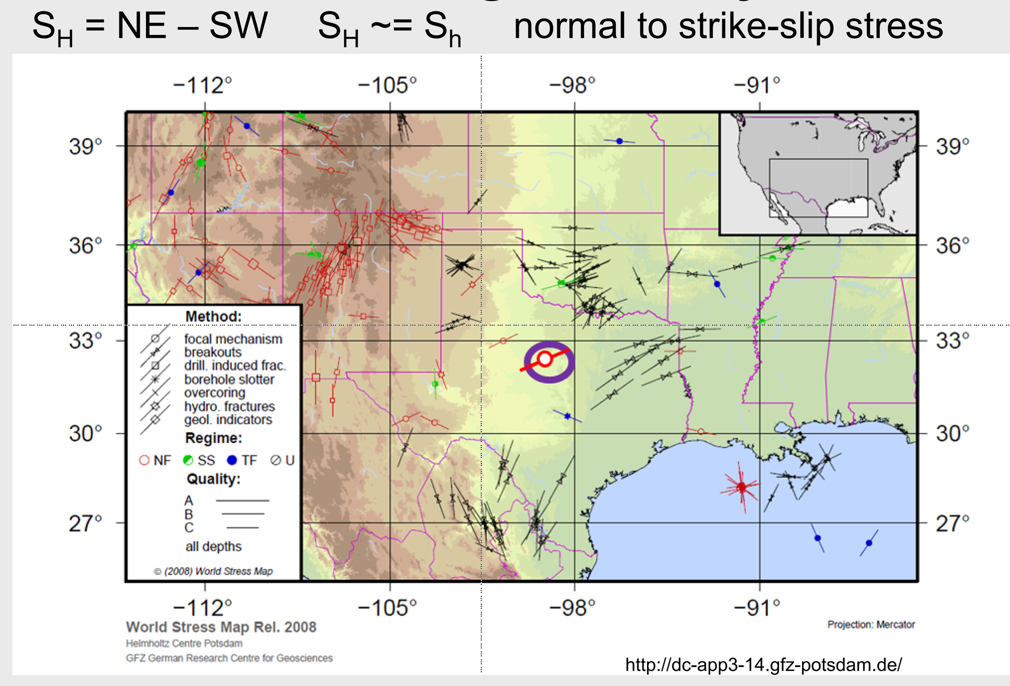
Some SRR Plays in the US



USGS, 2008, Digital Data Series DDS-69-0

Barnett Stress Regime Today

S_H = NE – SW S_H ~= S_h normal to strike-slip stress



http://dc-app3-14.gfz-potsdam.de/

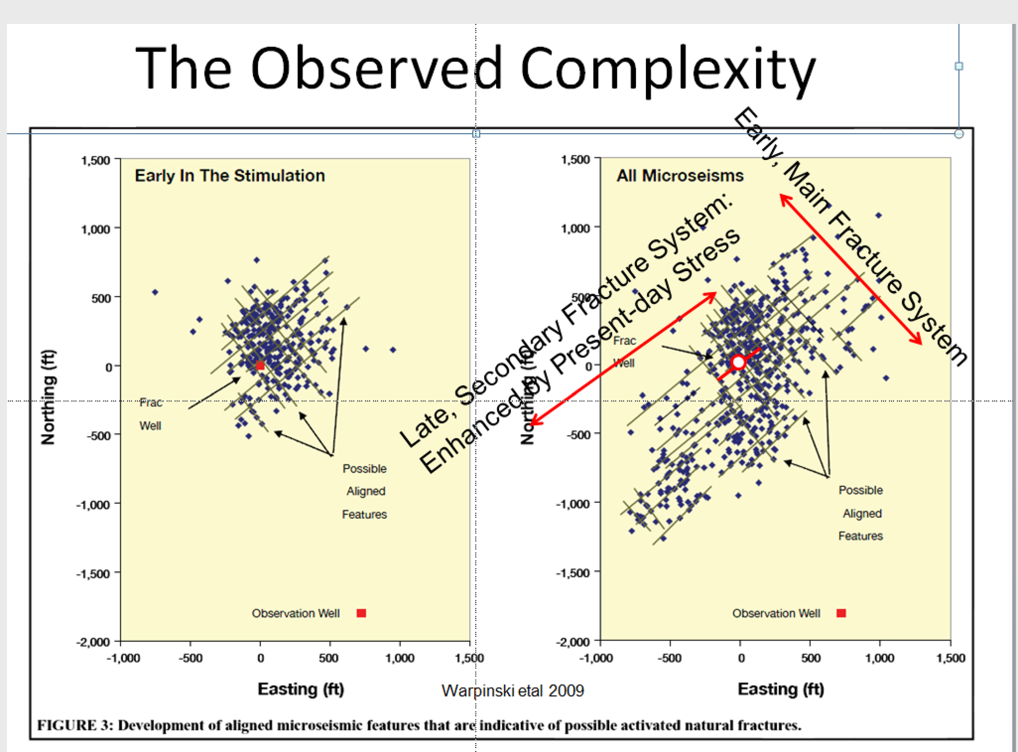
Some Basic Assumptions wrt Microseismic & Natural Fractures

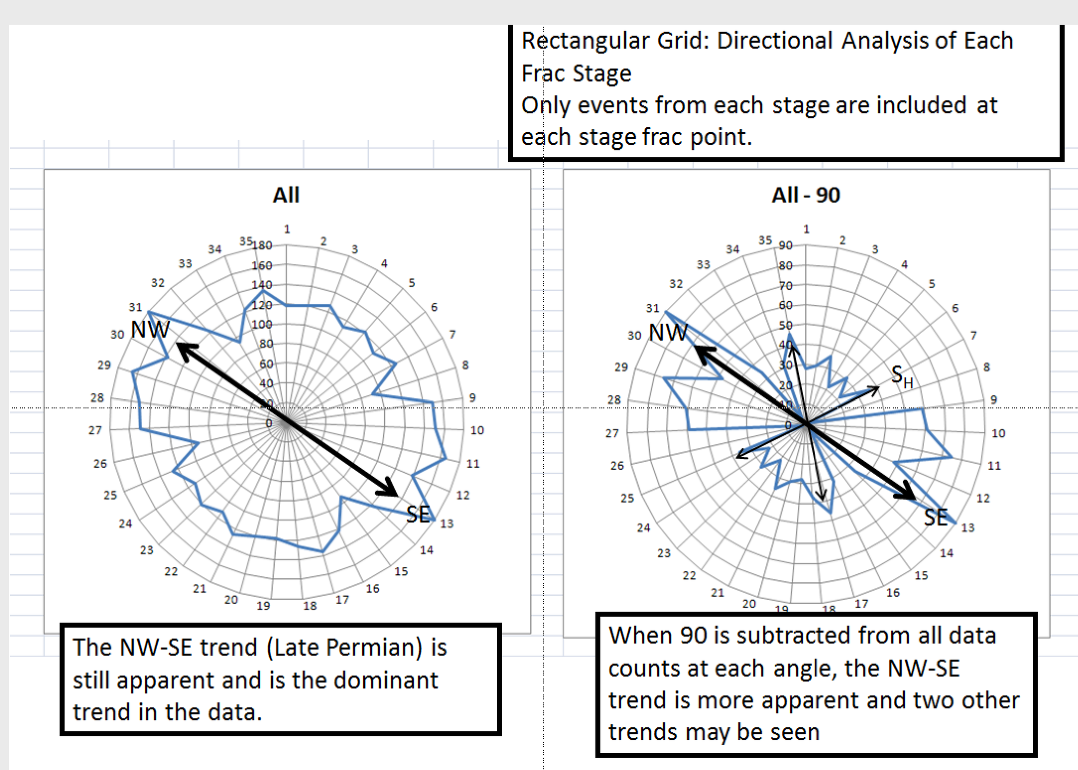
[ ] Microseismic Events (MSE) are associated with natural fractures that have been reopened or reoriented by hydraulic fracturing

[ ] MSEs occur along or near the induced hydraulic fractures
[ ] MSEs are not as extensive an the volume containing the actual fluid movement (ex: killed wells)

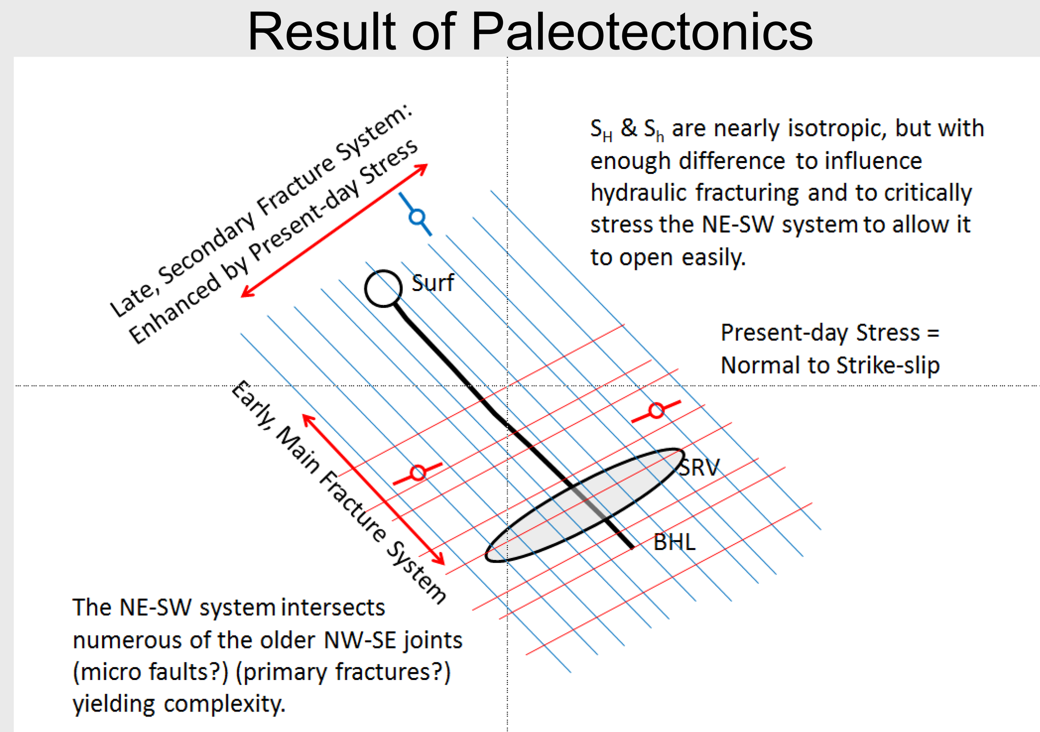
[ ] the dataset is therefore a subset of the zones of weakness that are in the Earth and that have been affected by the fracturing
[ ] Uncertainty in location needs to be included in the analysis

The Observed Complexity

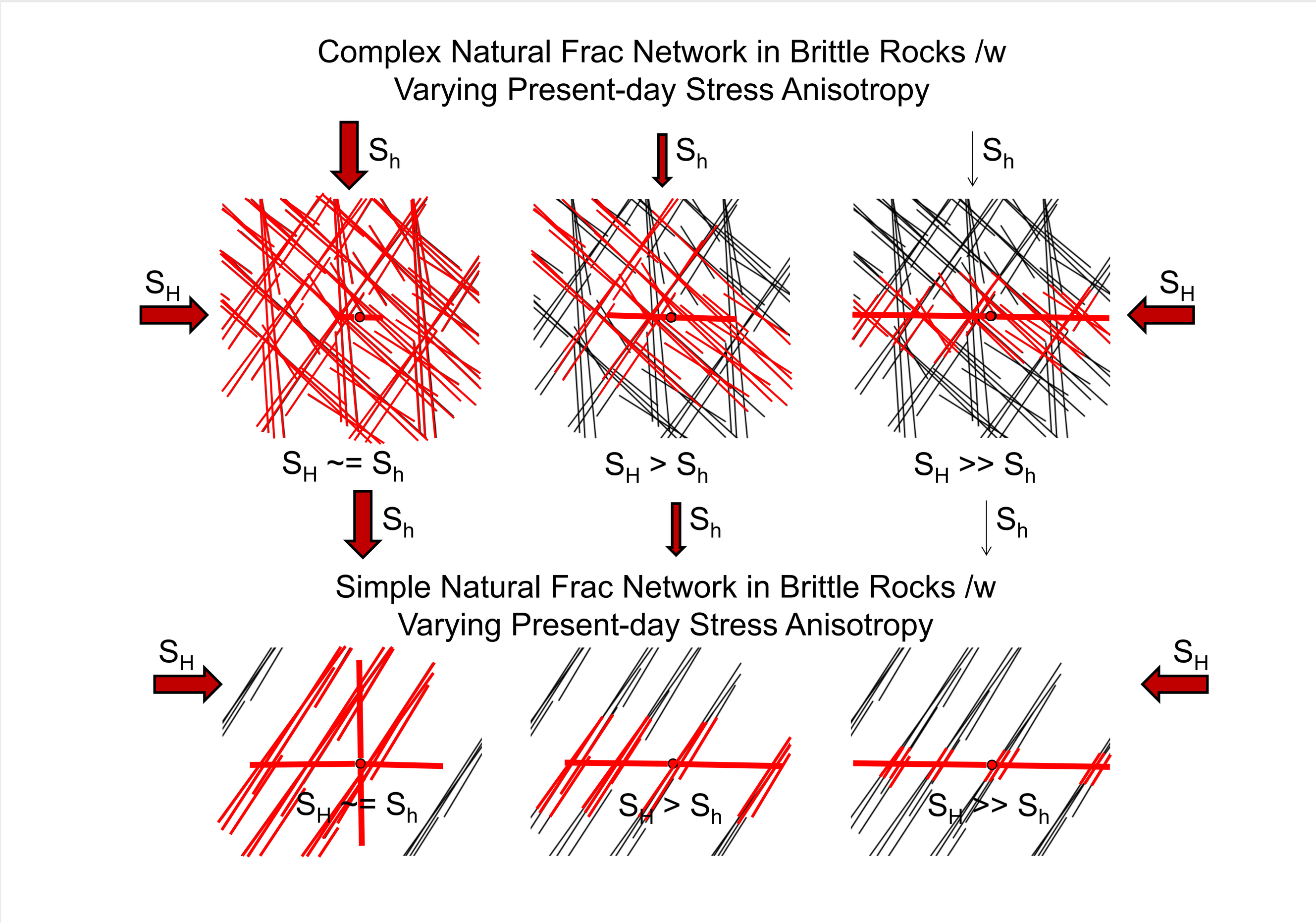


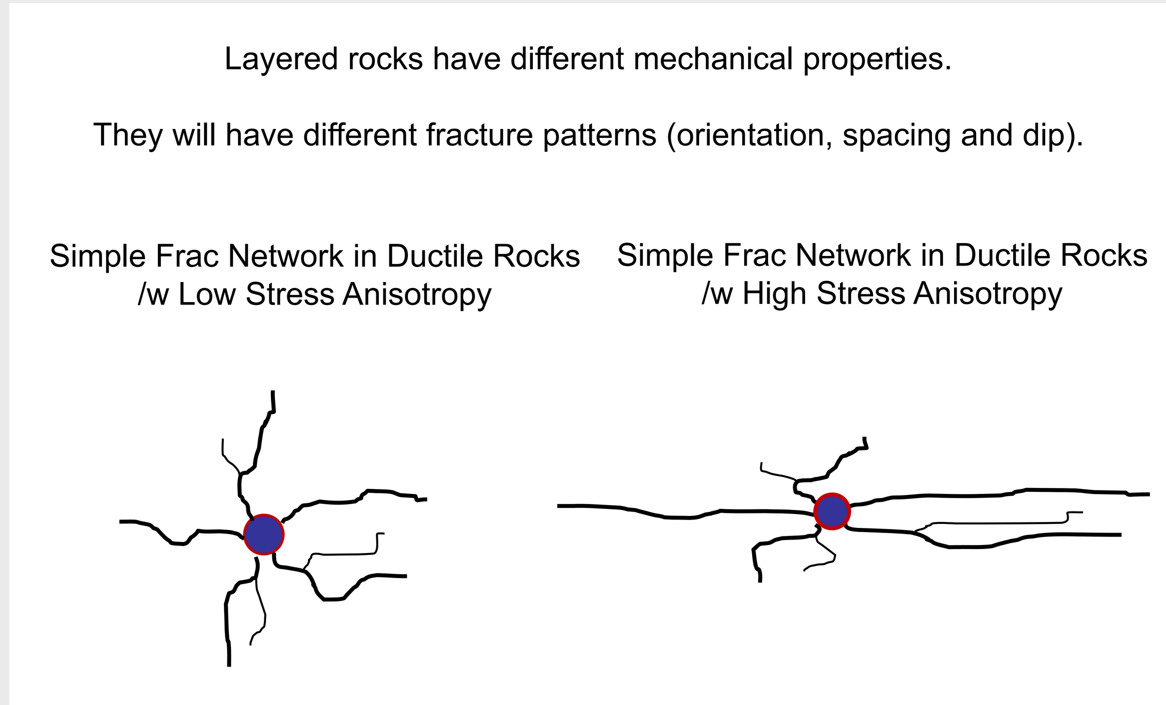


Complexity Interpreted to be mainly the Result of Paleotectonics



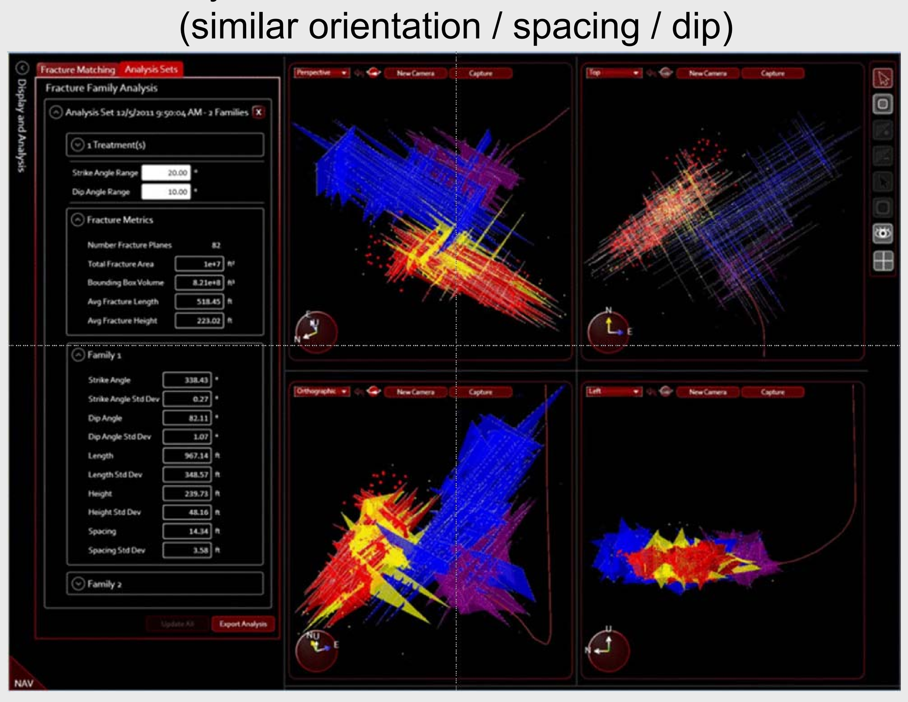
Complexity of the Final Hydraulic Fracture depends on:
1) Complexity of the Natural Fracture System
2) the Mechanical Properties of the Layers
3) the Stress Anisotropy, among others



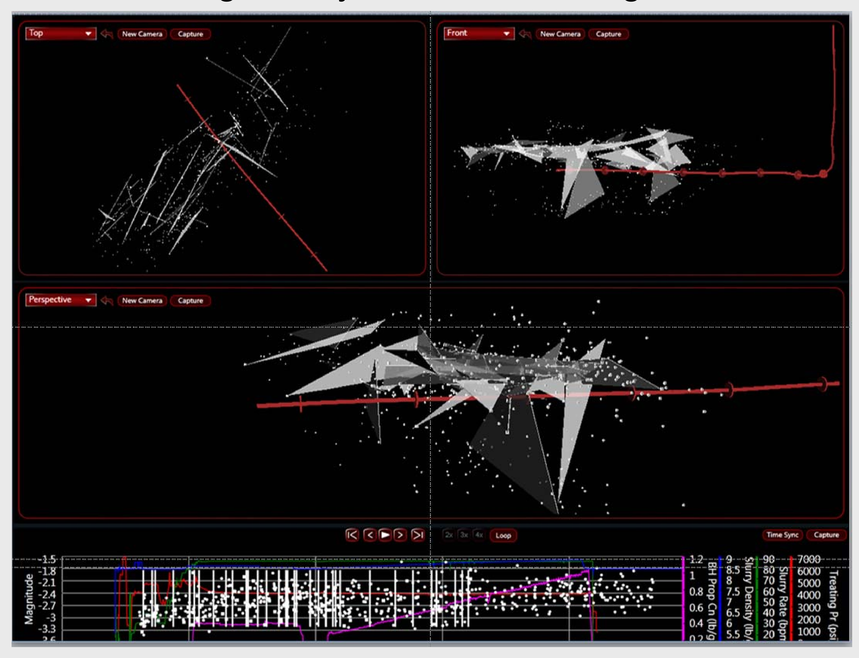


Fracture Network Analysis from MicroSeismic Data

Analysis of Individual Fracture Families (similar orientation / spacing / dip)



Identification of All Fractures in Real-Time during the Hydraulic Fracturing Job

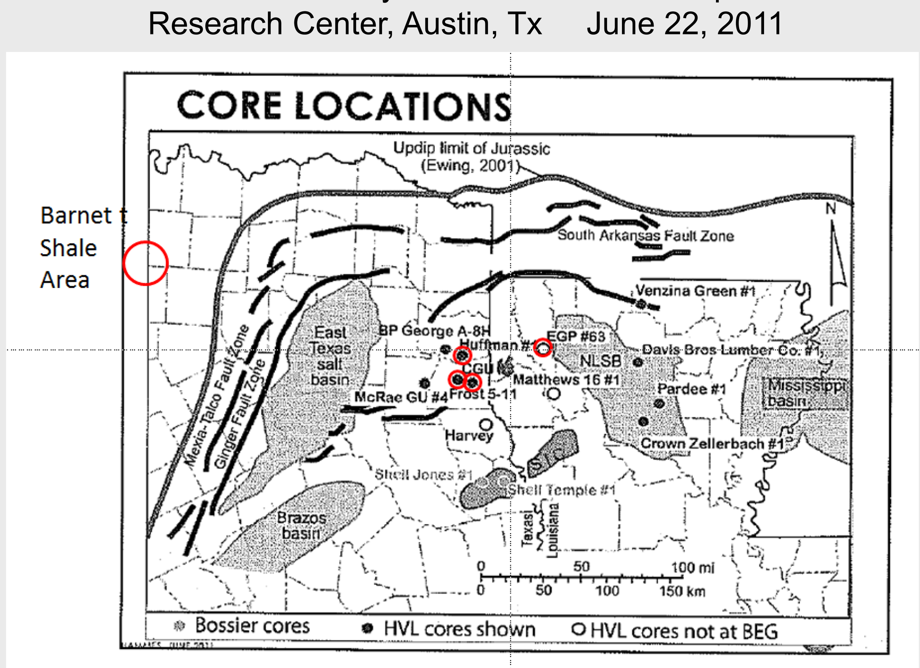


Haynesville Shale Horizontal Fractures: Modeling & Paleogeomechanics

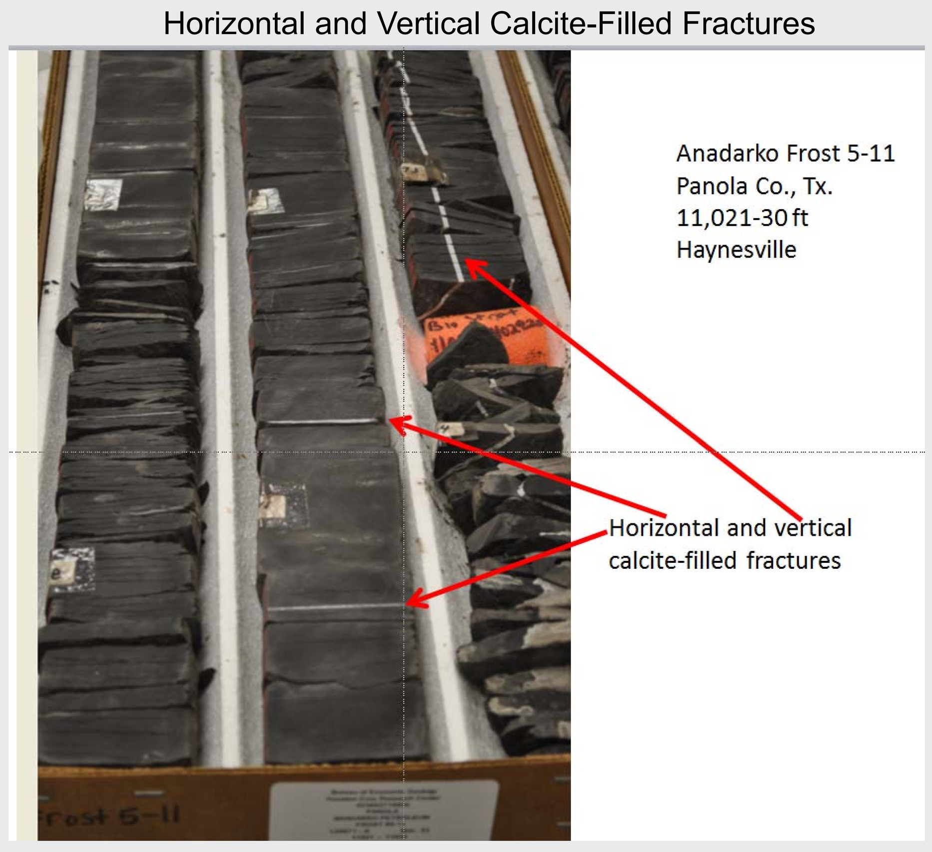
The Problem: How do Horizontal Fractures form in the absence of a thrust faulting stress regime?

[ ] Horizontal faults require that the overburden be lifted to provide the acommodation space for the fracture fill
[ ] The minimum stress must be vertical (SH > Sh > Sv)
[ ] No thrust faults or local folding is observed in the area: only regional uplift

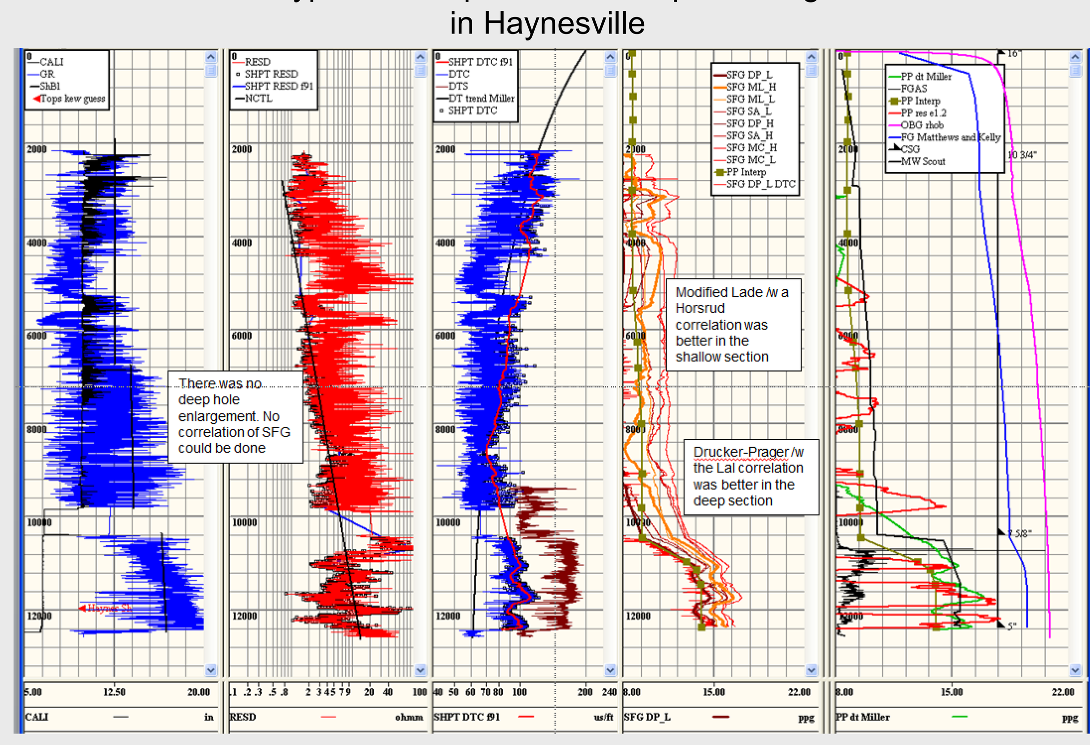
Cores Viewed in the Haynesville Core Workshop BEG Core Research Center, Austin, Tx June 22, 2011



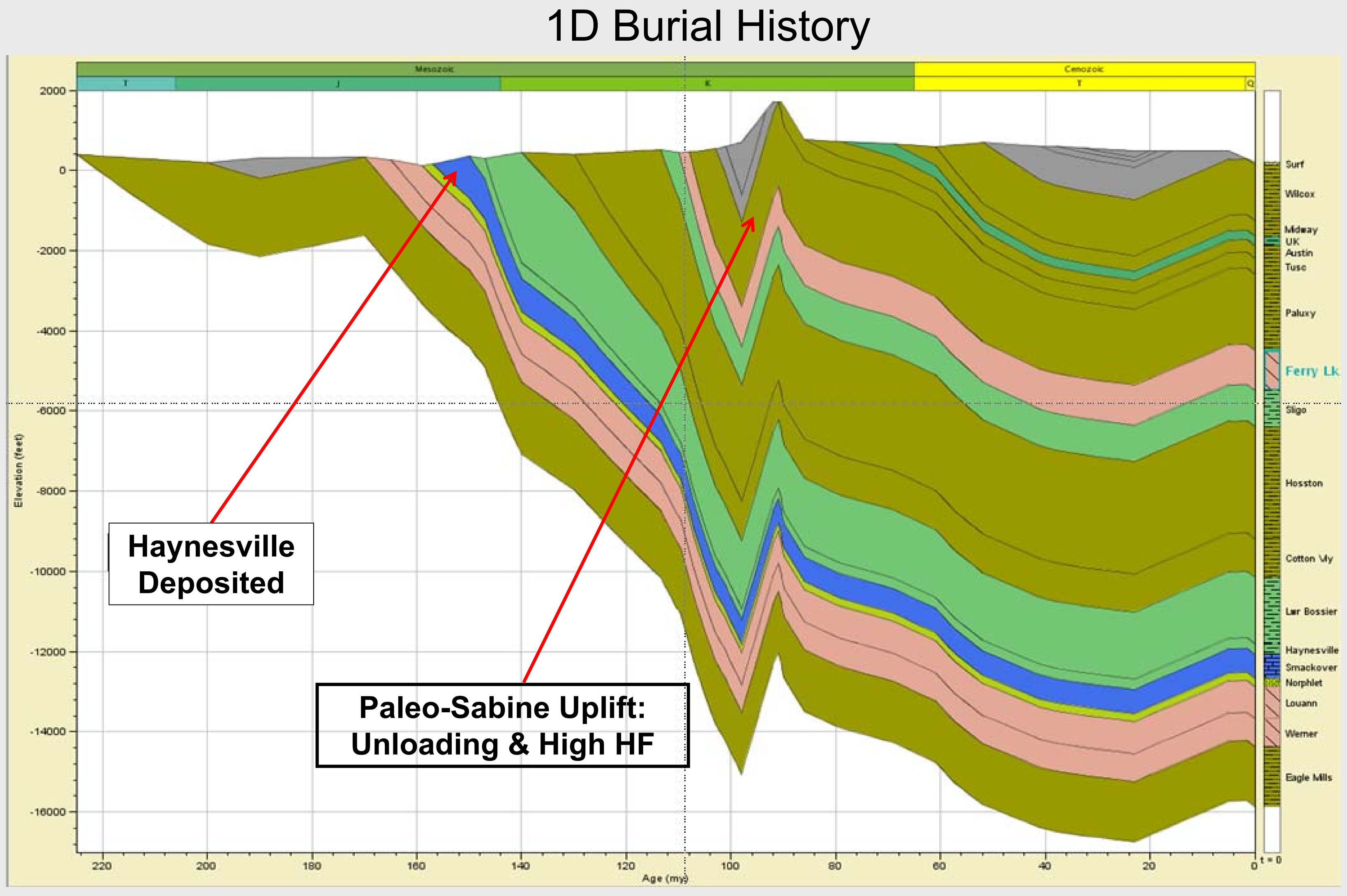
Horizontal and Vertical Calcite-Filled Fractures



Typical Example of the Overpressuring in Haynesville

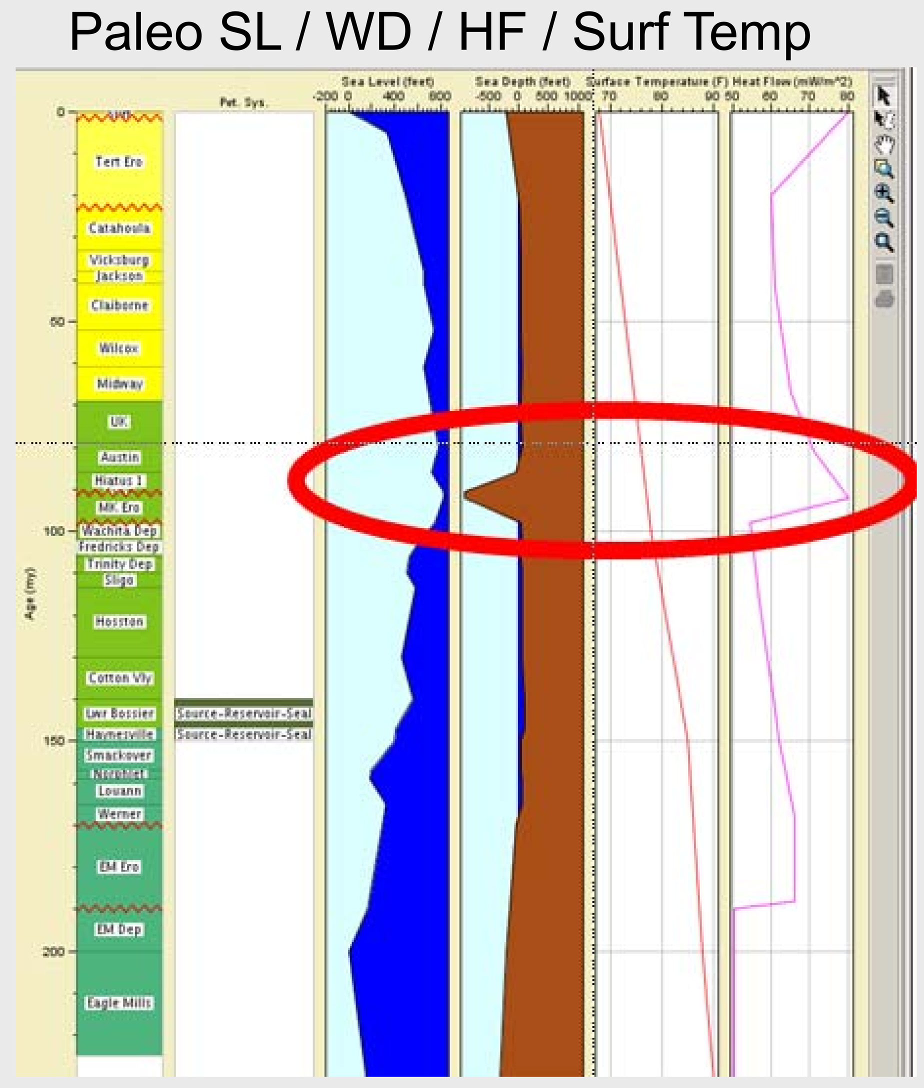


1D Burial History



Present-day BHT & Ro in Haynesville Calibrate OK

Paleo SL / WD / HF / Surf Temp



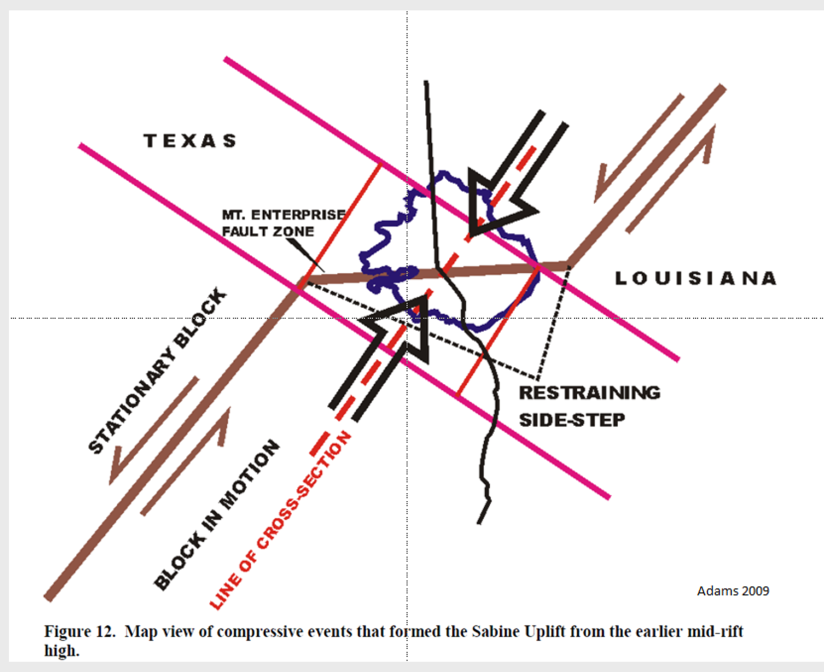
High HF & Unloading

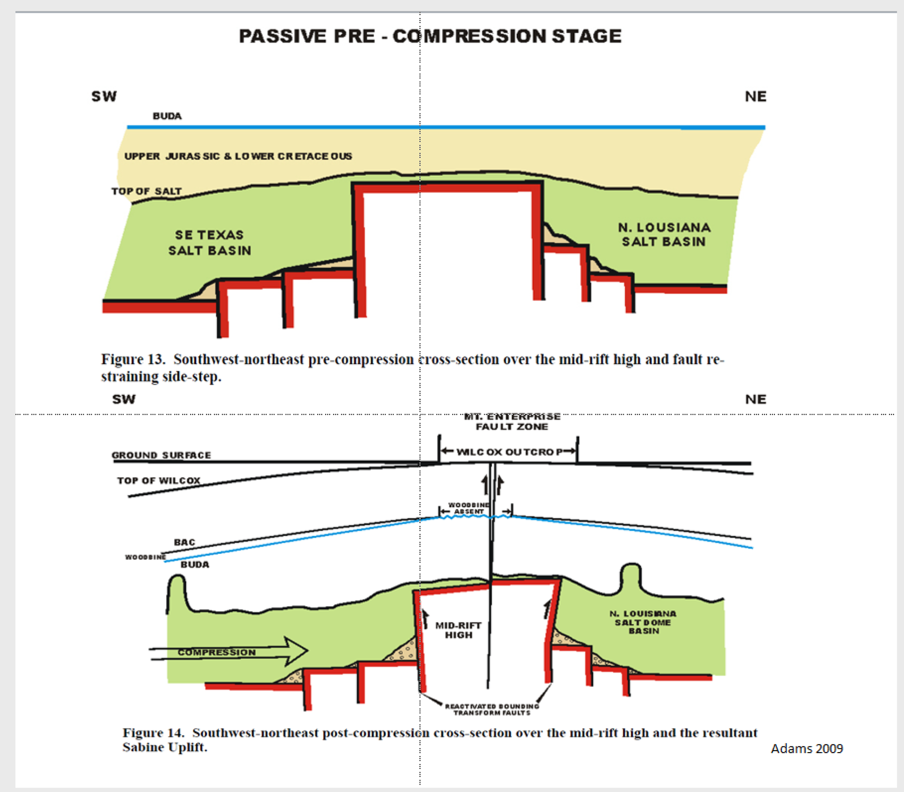
Origin of the Cretaceous Sabine Uplift

[ ] Far-field compression related to early Laramide tectonics in Mexico

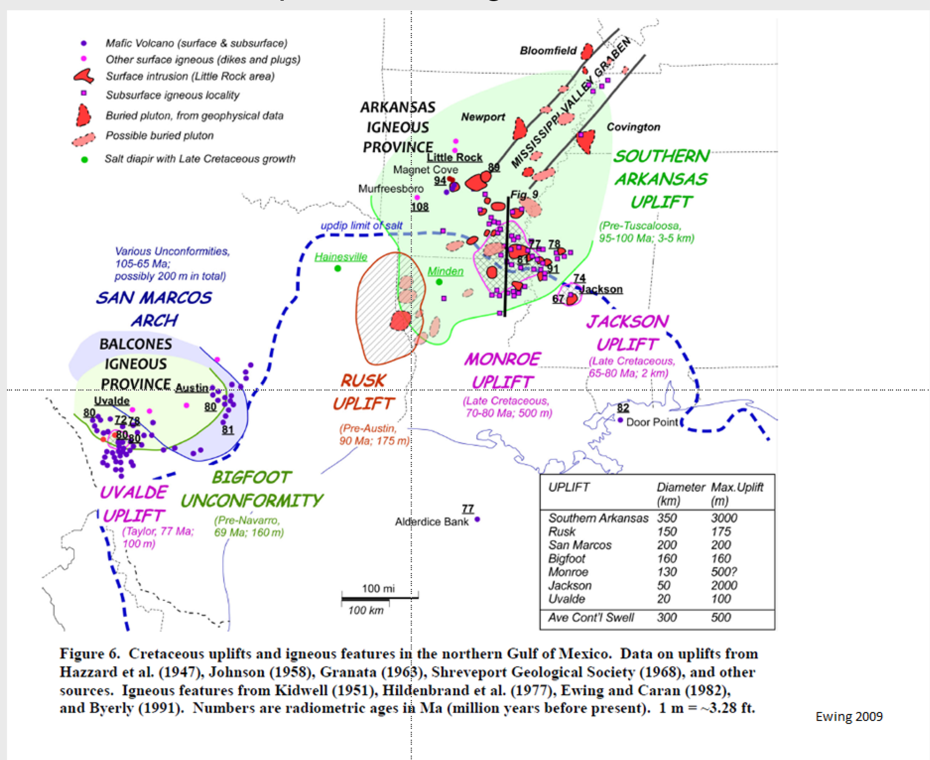
[ ] Deep-seated volcanic intrusion (related to the Arkansas volcanics)
Preferred Interpretation from Ewing (2009)

Regional Stress Regime from the Laramide tectonics in Mexico

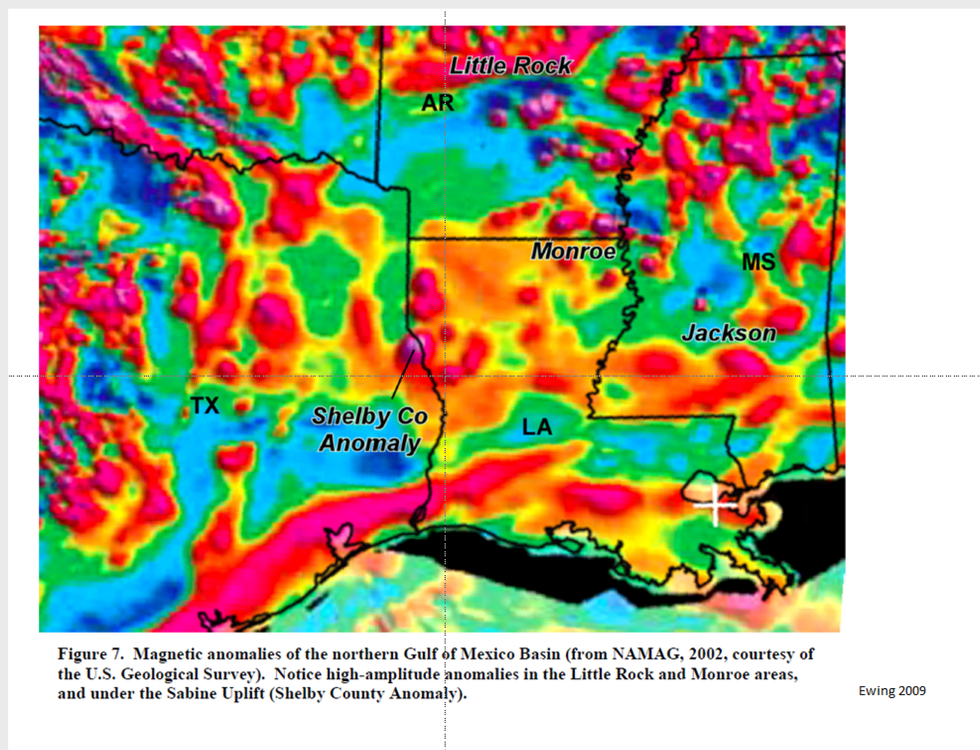




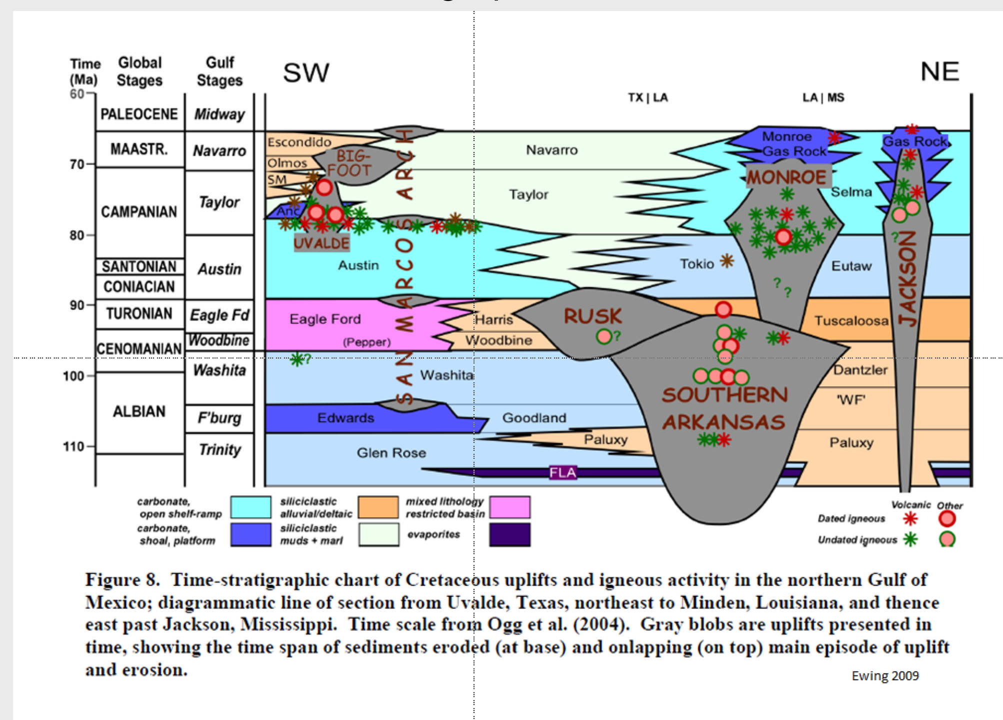
K Uplifts and Regional Features



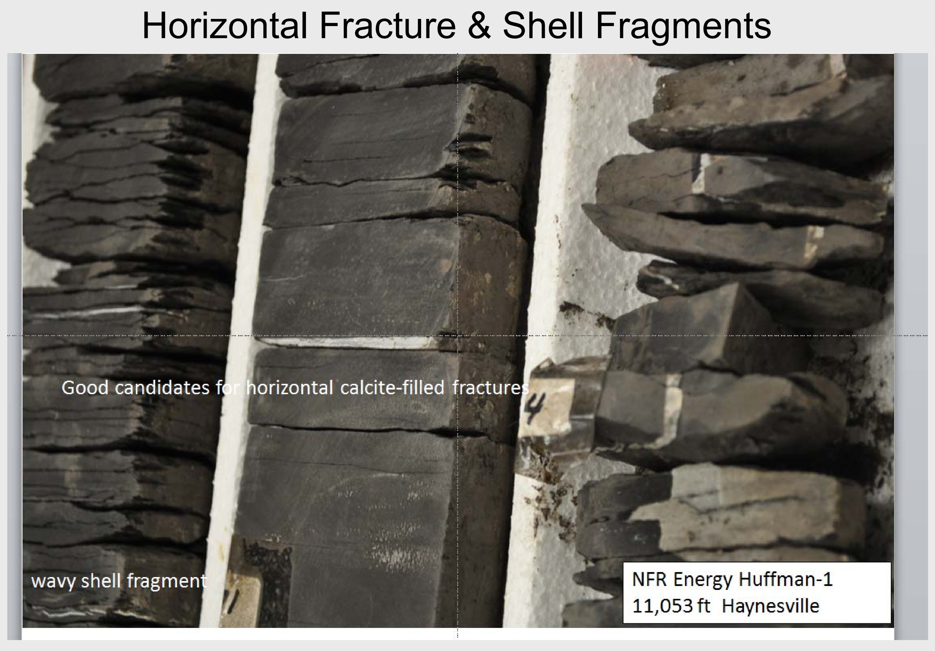
Regional Features Magnetic Anomalies



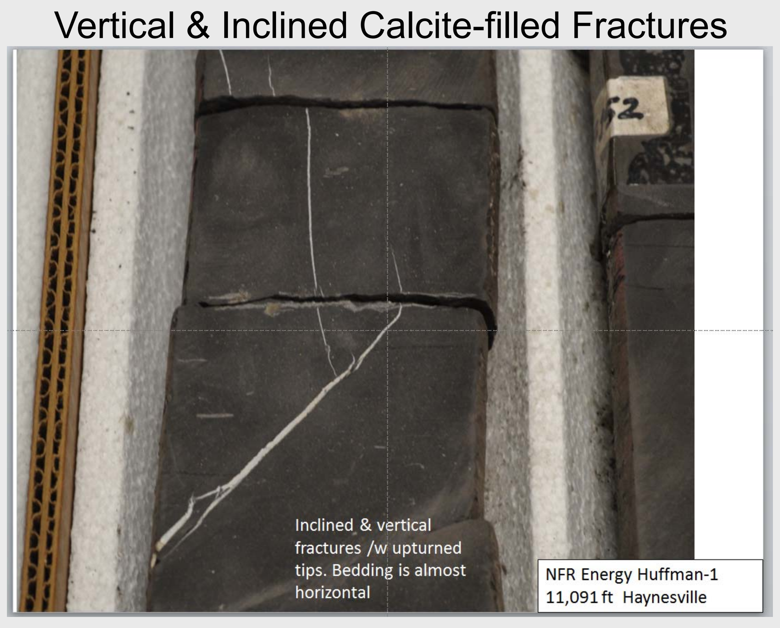
Time-Stratigraphic Correlation



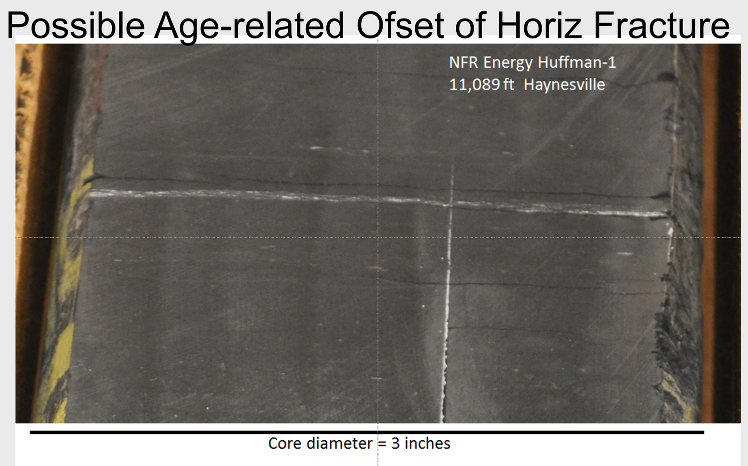
Horizontal Fracture & Shell Fragments



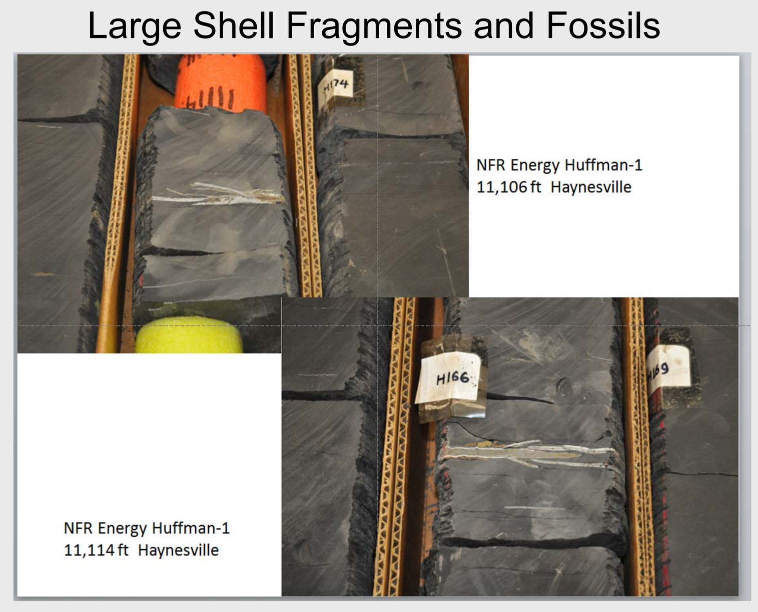
Vertical & Inclined Calcite-filled Fractures



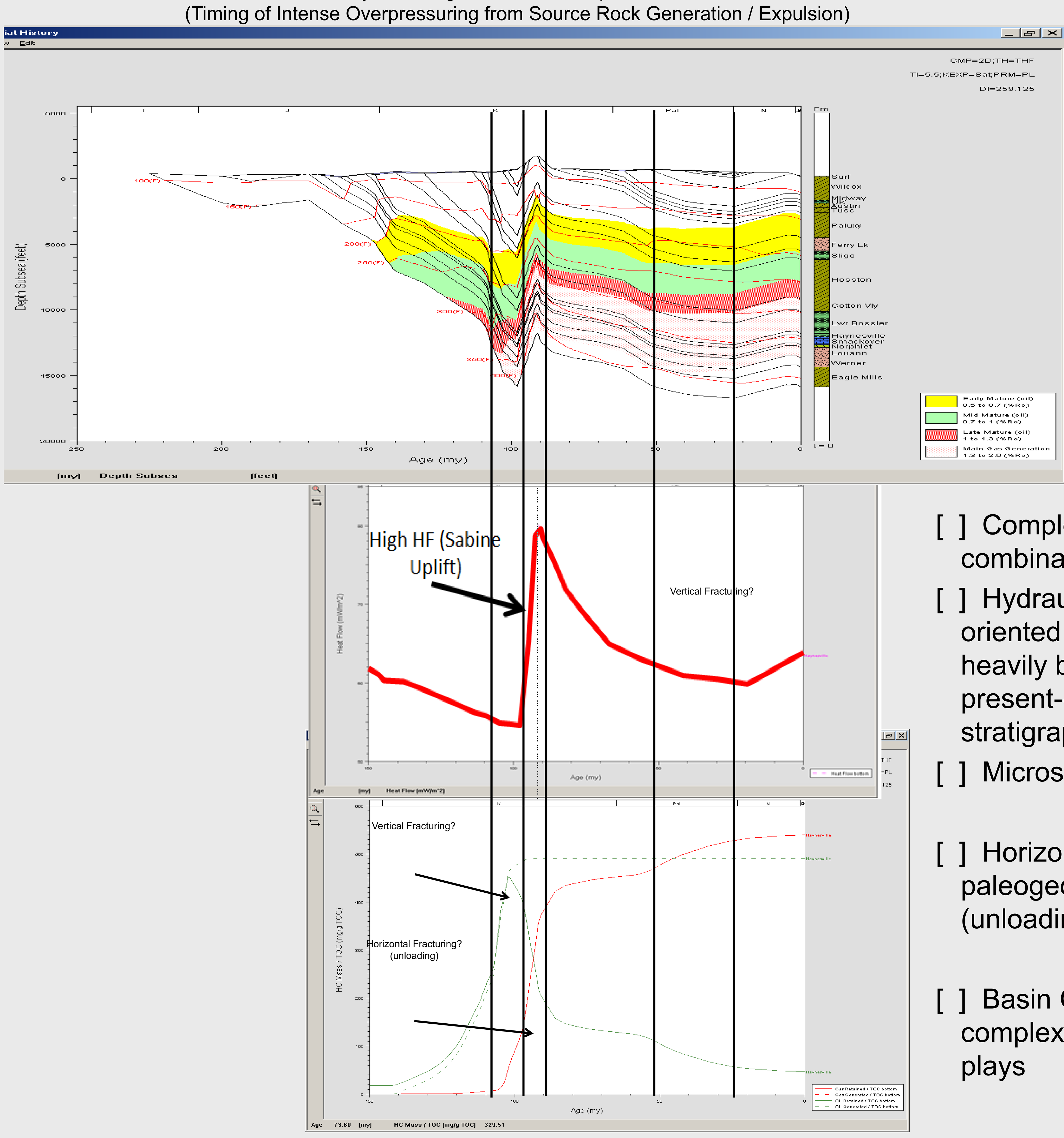
Possible Age-related Ofset of Horiz Fracture



Large Shell Fragments and Fossils



1D GeoHistory Modeling / Heat Flow / Expulsion of Oil and Gas
(Timing of Intense Overpressuring from Source Rock Generation / Expulsion)



Conclusions:

[ ] Complex Fracture Systems are established by a combination of HC generation and paleogeomechanics

[ ] Hydraulic Fracturing reopens the fractures that are oriented in the preferred stress direction and influenced heavily by the original complexity of the system. The present-day stress anisotropy and the mechanical stratigraphy

[ ] Microseismic analysis can identify fracture families

[ ] Horizontal Fractures in the Haynesville result from the paleogeomechanics related to the K Sabine Uplift (unloading accompanied by high HF)

[ ] Basin GeoHistory analysis can help understand the complex fracture systems that are observed in SRR plays

Acknowledgements:
Thanks to Halliburton C&P Digital Solutions and the Consulting and Tech Team members for their assistance and for many enlightening discussions.