

# **Fracture Characterization and Analog Modeling of the Woodford Shale in the Arbuckle Mountains, Oklahoma, USA\***

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## **Abstract**

Understanding the mechanisms under which shales deform is fundamental to improving exploration success in unconventional resource plays. An outcrop of the Woodford Shale has been chosen to characterize fracture patterns at the outcrop level, and relate them to the structural regime of the study area and internal stratigraphy of the formation. The outcrop is located along a syncline in the Arbuckle Mountains of Oklahoma (Sec 34, T. 1 S., R. 2 E.) between Vines Dome and Dougherty Anticline. Gamma ray logs of the outcrop were obtained, the section was measured, samples were collected, and fracture orientations along various points were recorded. A unique fracture pattern was mapped, where fracture orientations are different at the various points along the structure. Also, natural fractures are abundant and perpendicular to bedding in brittle cherty layers, and scarce and slanted in ductile, thin-bedded mudstones. The recognition of these patterns is in agreement with measurements obtained in the laboratory of the mechanical properties of the Woodford Shale. Alternating sequences of laminated mudstones are rich in organic content. They are also mechanically ductile. Interbedded cherty layers are less organic-rich, and mechanically brittle. Therefore, the Woodford Shale can be defined as an axially anisotropic material in the direction perpendicular to the laminations and an isotropic material in the direction parallel to the laminations. An analog model constructed in the laboratory is used to examine the regional relationship between folds and the development of natural fractures in a brittle-ductile material. Another analog model examines small-scale deformation in materials with varying mechanical properties. The hypotheses for these experiments based on field observations are: 1) laminations in shale formations are an important control in the propagation of natural fractures along with bed thickness and mineralogy, and 2) fracture patterns in shales are predictable along folds assuming the stress field is understood. A 3D computer model is constructed with the data from the analog models, to refine a conceptual model that can be applied to predicting fracture patterns in brittle-ductile materials and other shale formations.

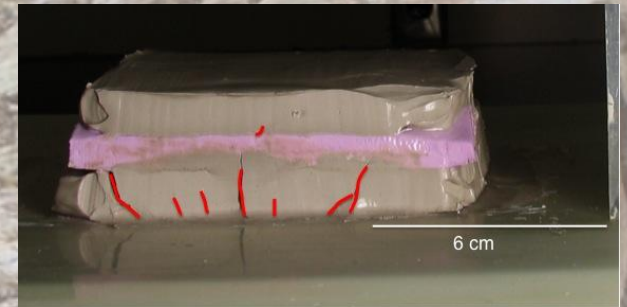
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# ACKNOWLEDGEMENTS



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**Dr. Neil Suneson, Dr. Ze'ev Reches, Mr. Bob Allen, Dr. Stanley Paxton, and many more**

**This work has been entirely possible thanks to my academic advisor Dr. Roger Slatt**





# OUTLINE

- **Why are fractures in unconventional shales important?**
- **Geologic setting of the Woodford Shale and Arbuckle Mountains**
- **Problems with fractures in the Woodford Shale**
- **Methodology of study**
- **Results**
- **Conclusions and applications to unconventional shales**
- **QUESTIONS**







# INTRODUCTION



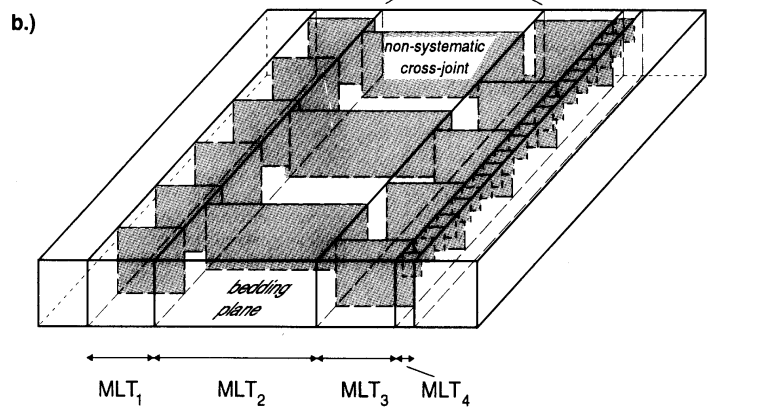
- **Fractures in unconventional shales are important:**
  - **Increase porosity (if open)**
  - **Increase permeability (if connected)**
  - **Horizontal well placement**
  - **Hydraulic fracture stimulation**
  - **Microseismic monitoring**
  - **3D seismic interpretation**



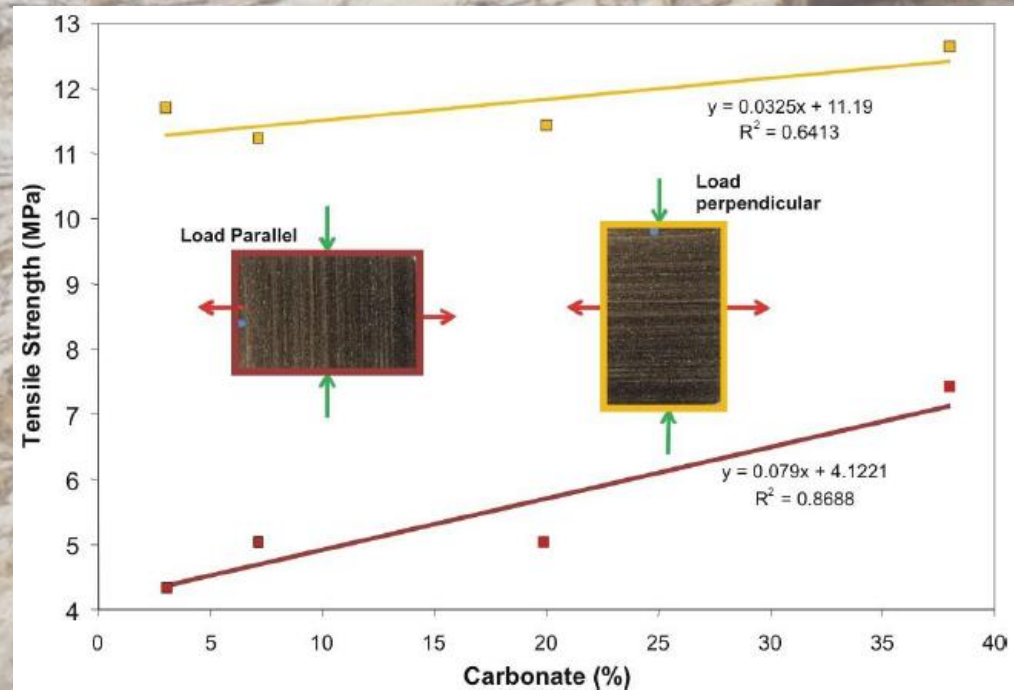


# INTRODUCTION

- Mechanical layers control fracture nucleation and propagation
- Layers create mechanical anisotropy



**Gross (1993)**



**Sierra et al. (2010)**





# GEOLOGIC SETTING



Series/System		Arbuckle Mountains
Mississippian	Meramecian	Caney Shale
	Osagean	Sycamore Limestone
	Kinderhookian	Woodford Shale
Devonian	Famennian	
	Middle	
	Early	
Silurian	Late	
	Early	
Ordovician	Late	
	Middle	
	Early	

Hunton Group	Chimneyhill Subgroup	Frisco Formation
		Haragan-Bois d'Arc Fm
		Henryhouse Formation
		Clarita Formation
		Cochrane Formation
	Keel Formation	
		Sylvan Shale
		Viola Group
		Simpson Group
		Arbuckle Group

## Woodford Shale

- **Marine deposition (392-359 mya) along continental failed rift known as Southern Oklahoma Aulocogen (Type II & III kerogen)**

- **Major transgression, low oxygen conditions and high productivity led to organic preservation (~7% TOC)**

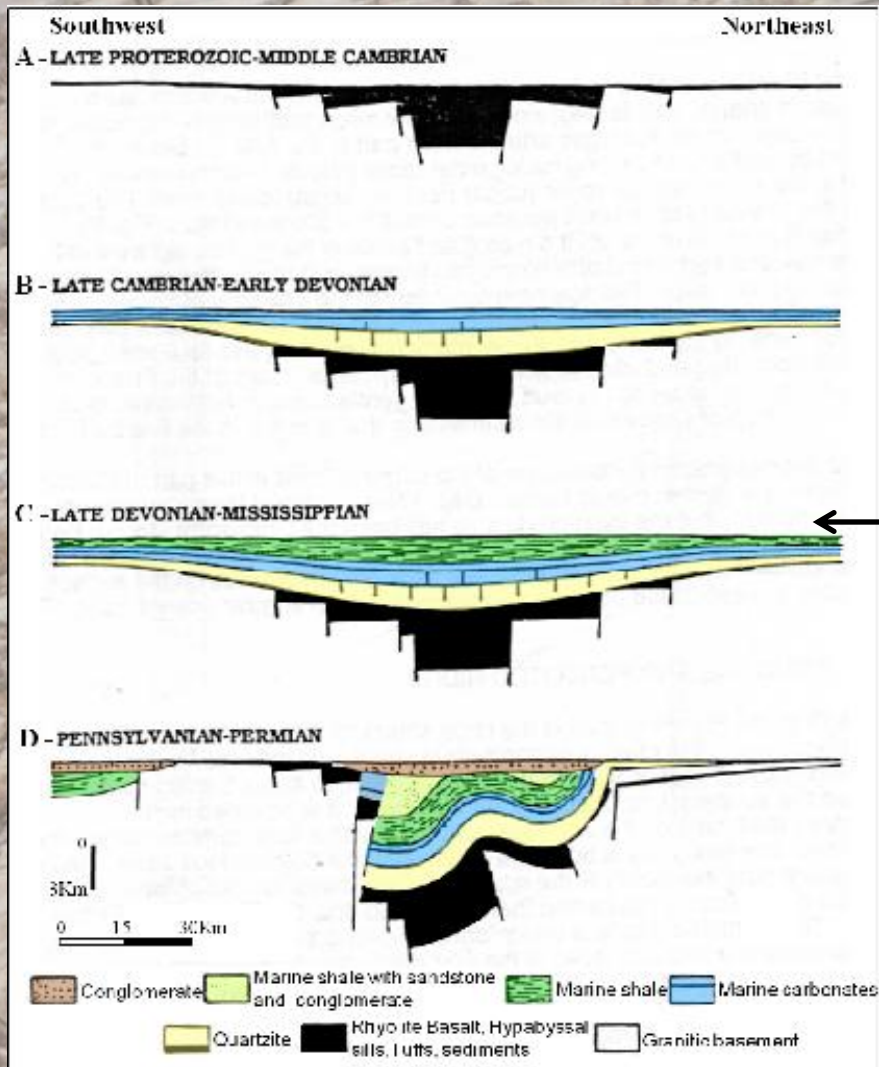
- **Woodford Shale exposed in Arbuckle Mountains of Oklahoma along folds, as result of Late Pennsylvanian uplift**

**Modified from Ham (1969) and Cardott (2005)**

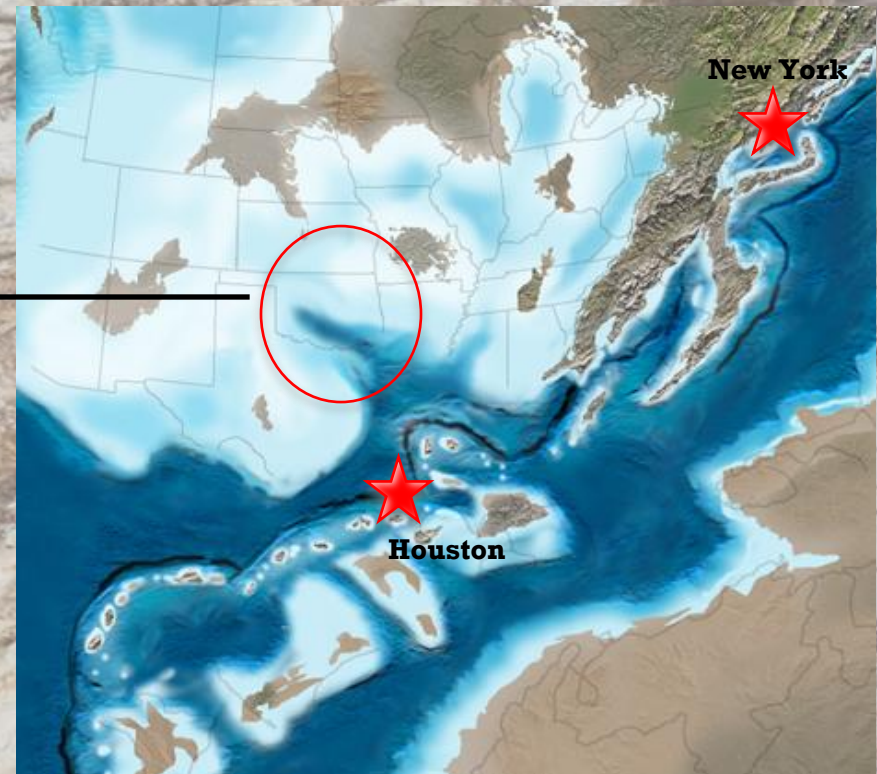




# GEOLOGIC SETTING



~359 ma



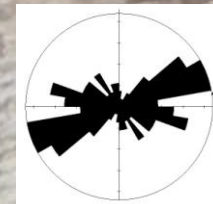
**Late Devonian - Early Mississippian**

Modified from Suneson (1997) and Blakey (<http://www2.nau.edu/rcb7/namM345.jpg>)





# GEOLOGIC SETTING

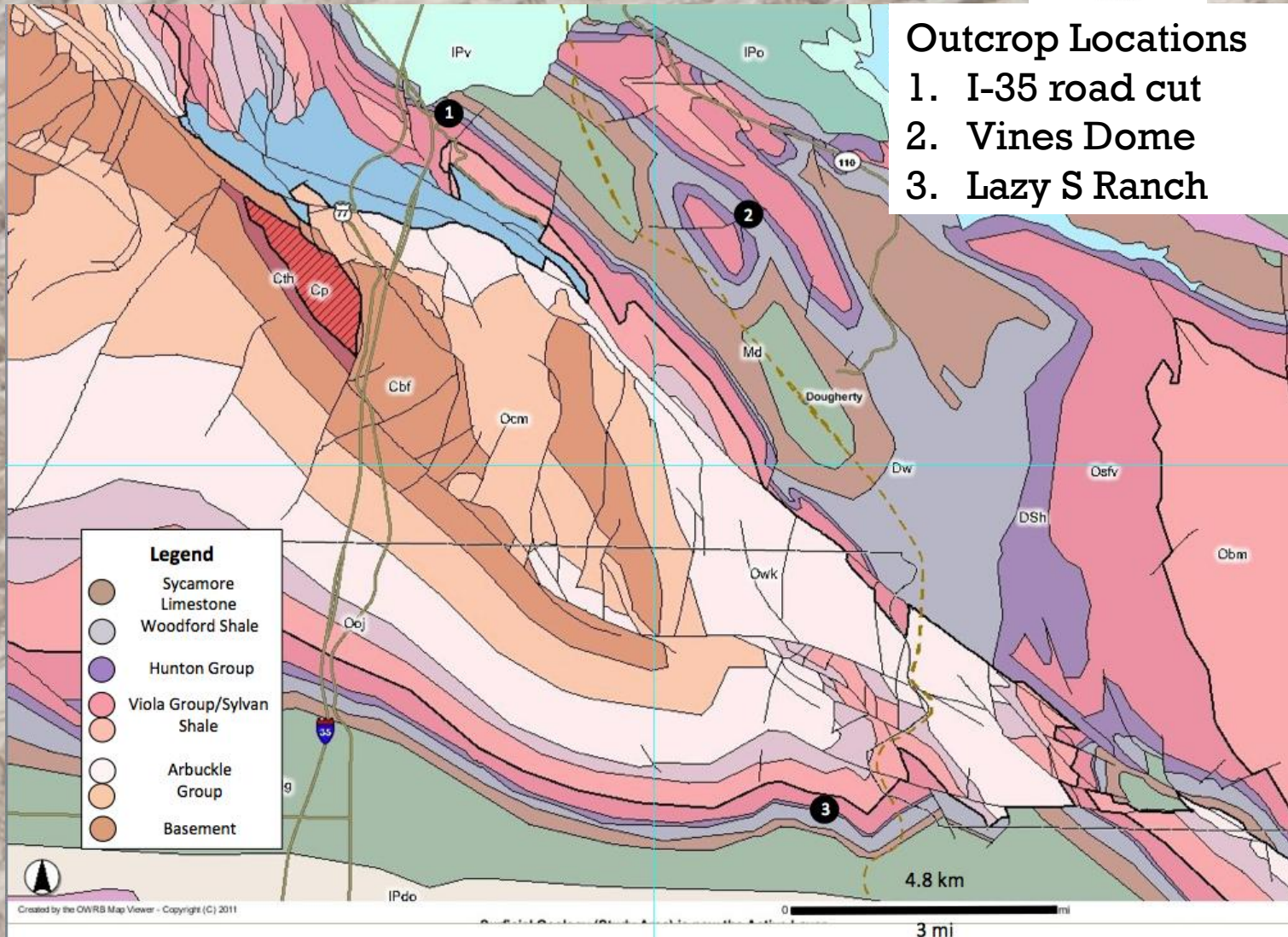


SHmax



## Outcrop Locations

1. I-35 road cut
2. Vines Dome
3. Lazy S Ranch



Modified from Ham 1969, Suneson 1997 & OWRB 2006





# PROBLEMS

- **What is the nature of fractures in the Woodford Shale?**
- **What is the role of lithofacies in natural fractures?**
- **How do natural fractures interact with mechanical boundaries?**
- **How to recognize horizontal drilling 'sweet spots' and improve stimulation techniques?**







# Methods



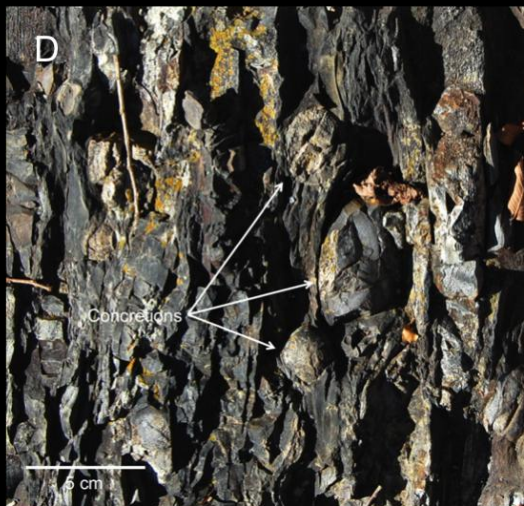
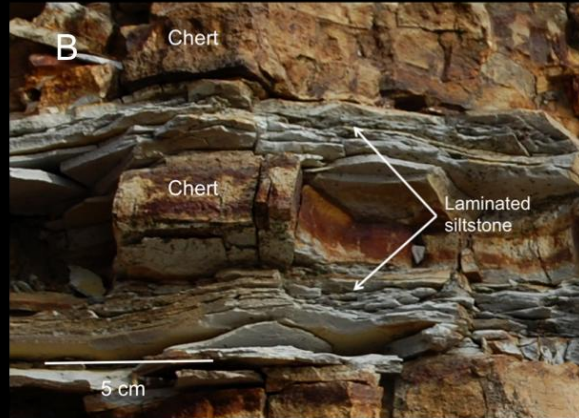
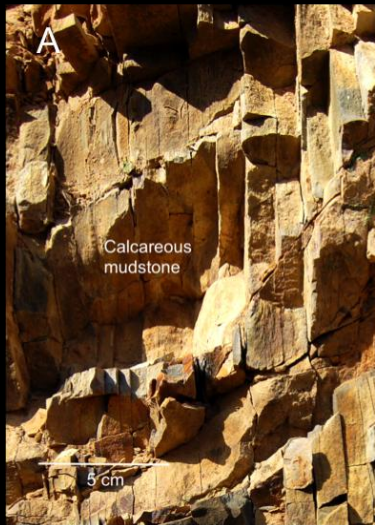
- **Field**
  - **Outcrop gamma ray logging**
  - **Rock types (lithofacies descriptions)**
  - **Fracture mapping and orientations**
- **Lab**
  - **Analog clay modeling**





# RESULTS

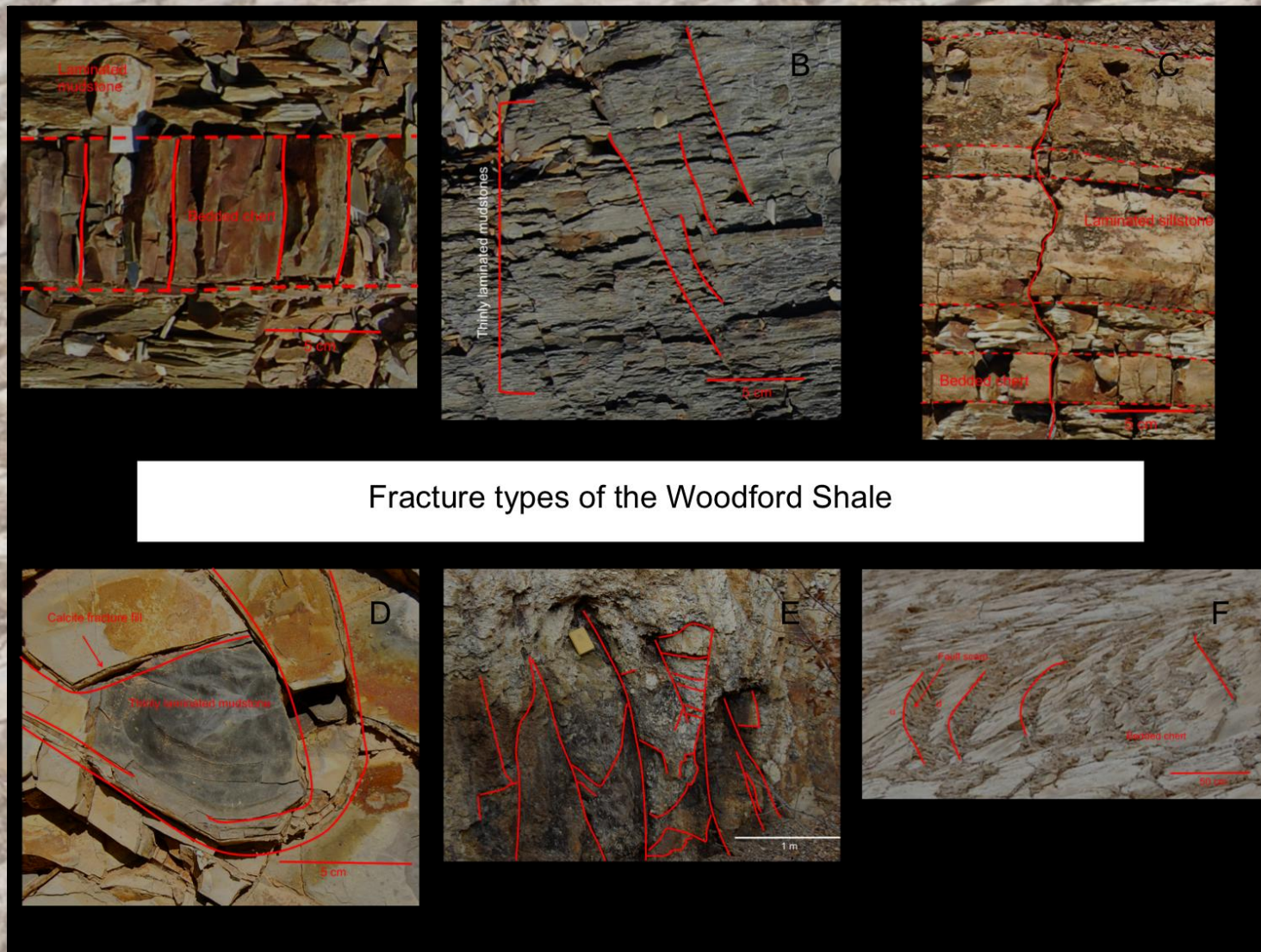
## Lithofacies of the Woodford Shale outcrops







# RESULTS





# +RESULTS

I-35 road cut ~ 500 ft (155 m) of exposed Woodford Shale



6 ft (2m)

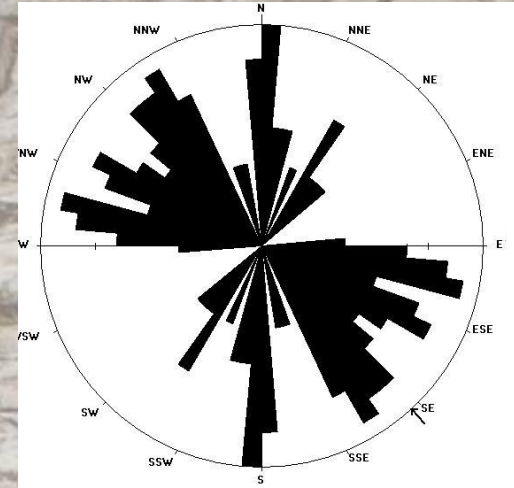
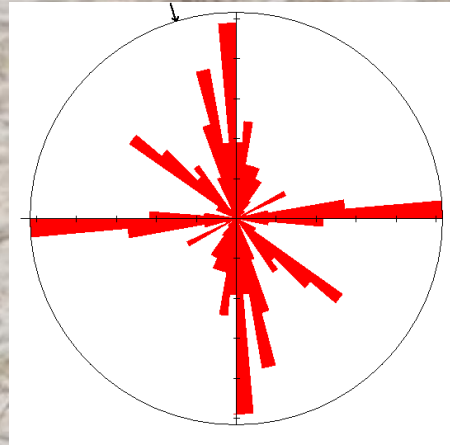




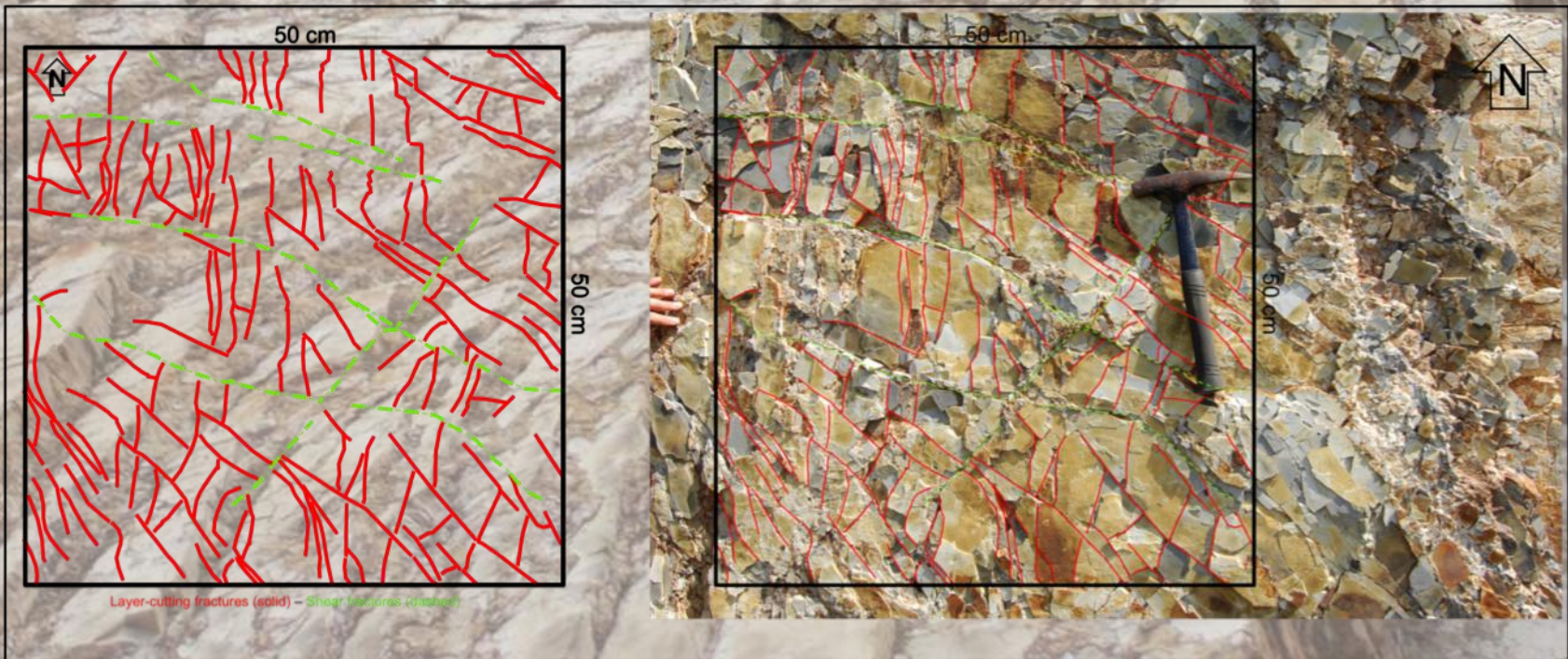
# RESULTS

**2 dominant fracture sets present**

- N-S/E-W conjugate set
- NW-SE set



E



Layer-cutting fractures (solid) – Shear fractures (dashed)



+

# RESULTS

S

N



10 ft (3.5 m)

**Vines Dome outcrop, approximately 240  
feet (75 meters) of tilted Woodford Shale.**



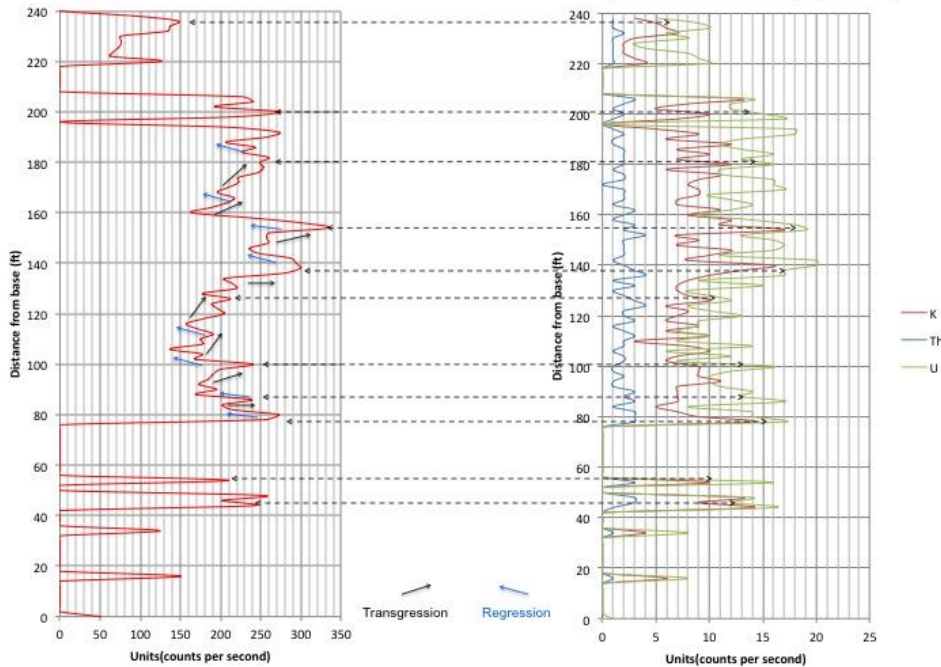


# RESULTS



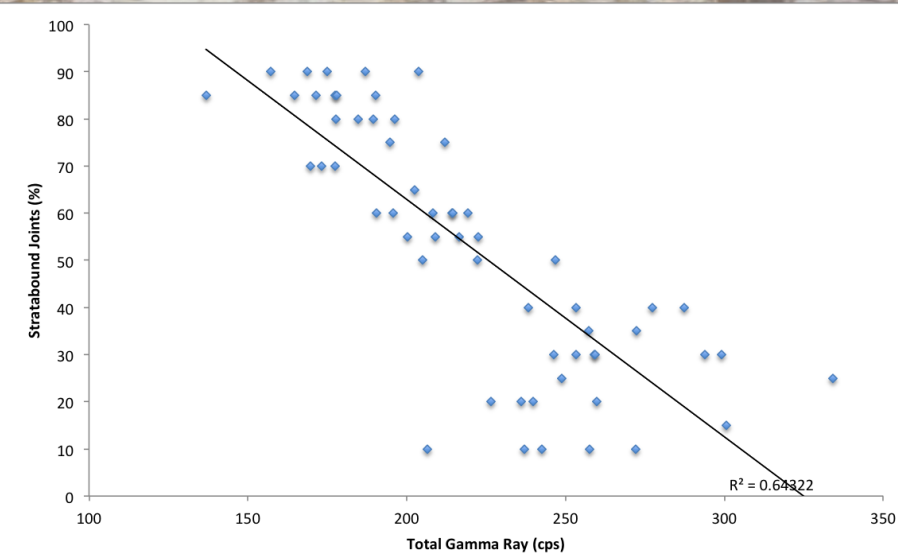
Gamma Ray

Spectral Gamma Ray (K-Th-U)



- **Total of 75m of exposed Woodford Shale**
- **Frequency of lithbound fractures decreases with higher gamma ray**

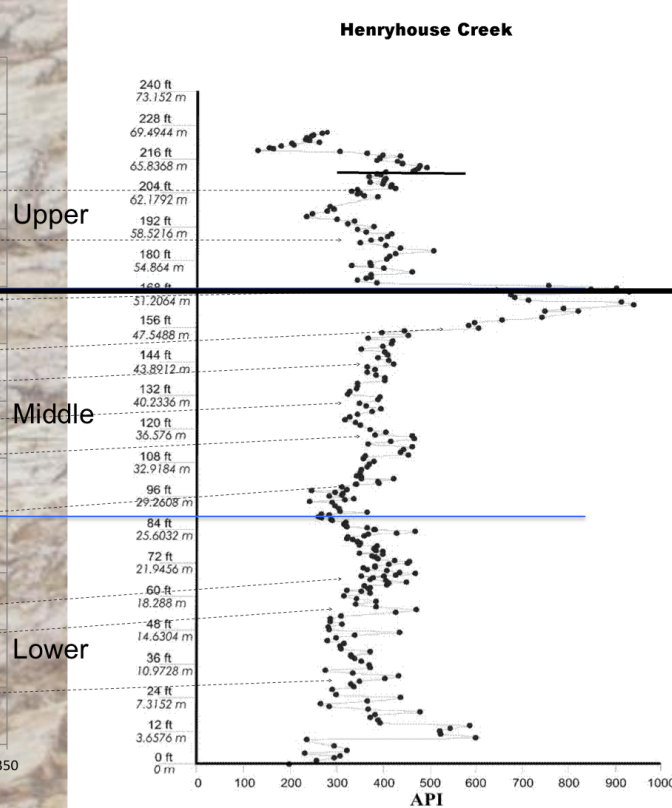
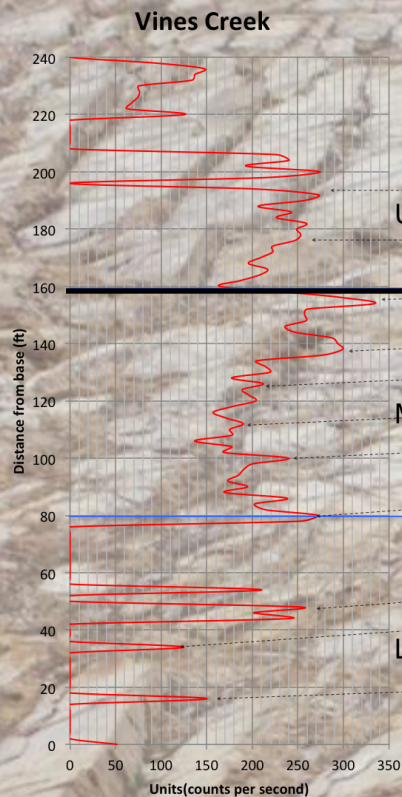
- **‘Hot’ gamma ray intervals contain more uranium**
- **High uranium indicative of chemically reducing depositional environment**



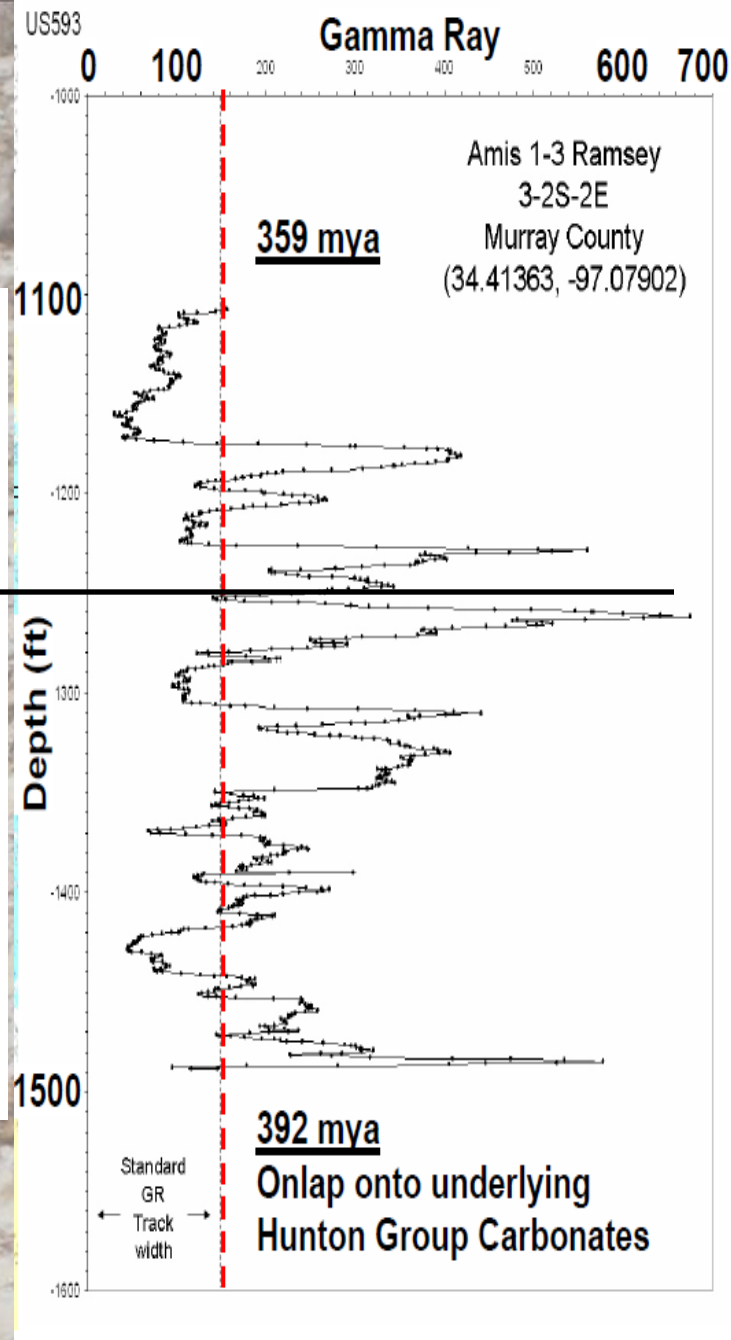




# Results



**Krystyniak  
(2005)**

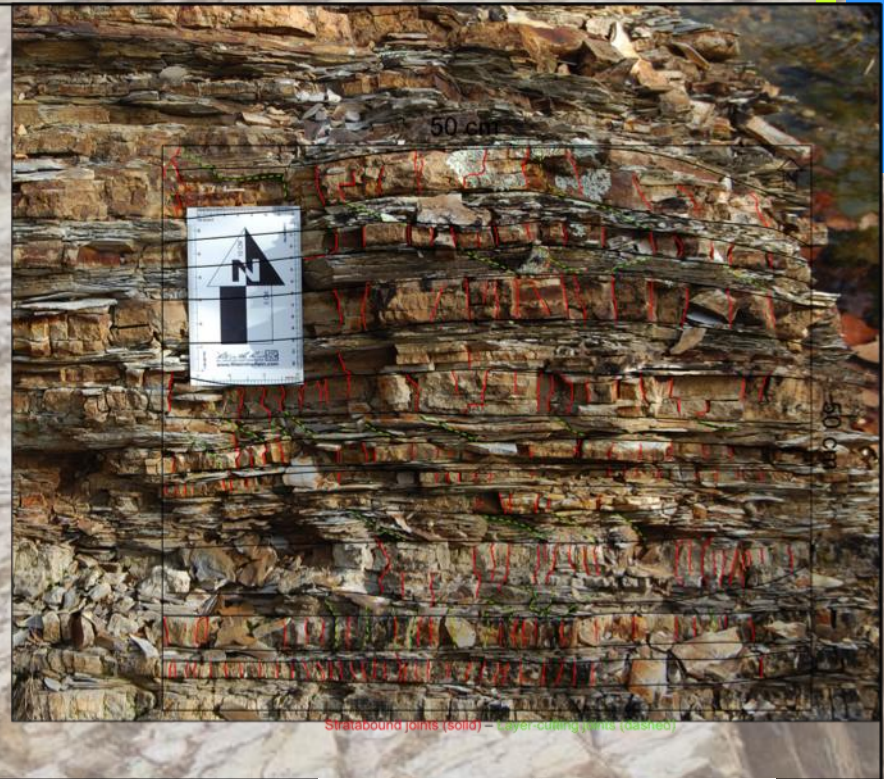
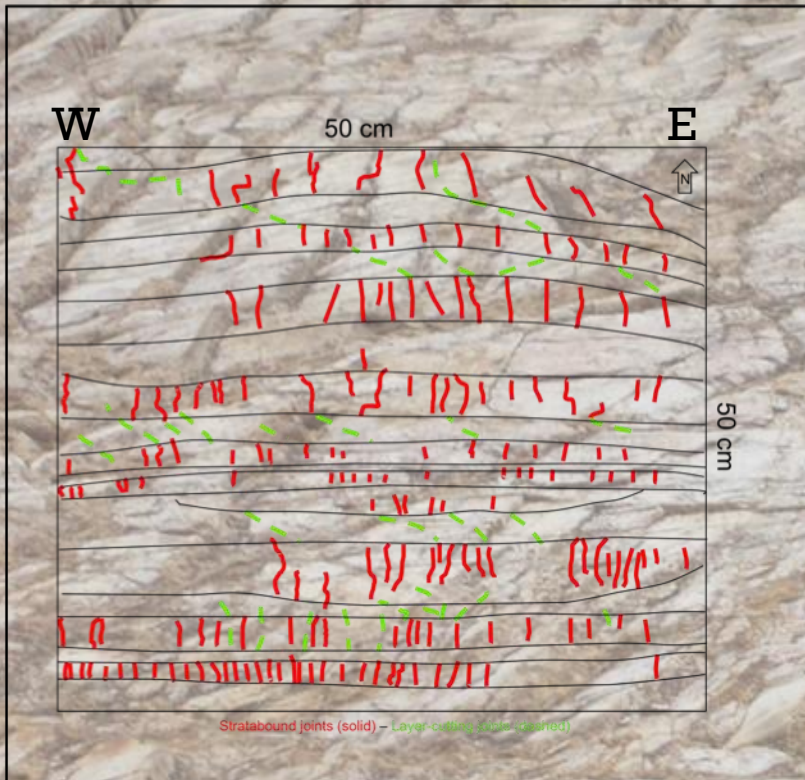


**Subsurface data from Paxton (2006)**



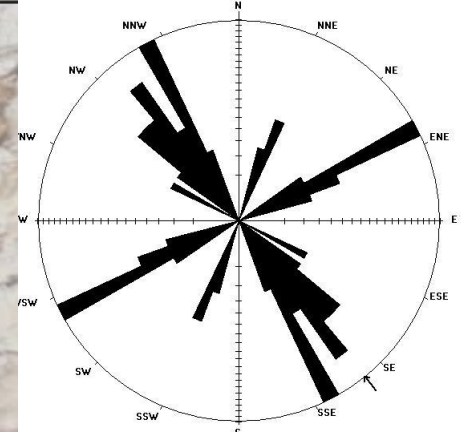
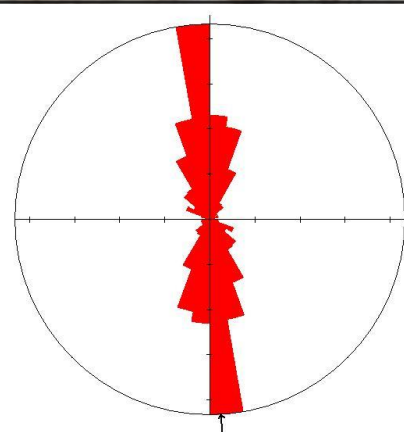


# RESULTS



**2 dominant  
fracture sets  
present**

- N-S set
- NW-SE/NE-SW  
conjugate set

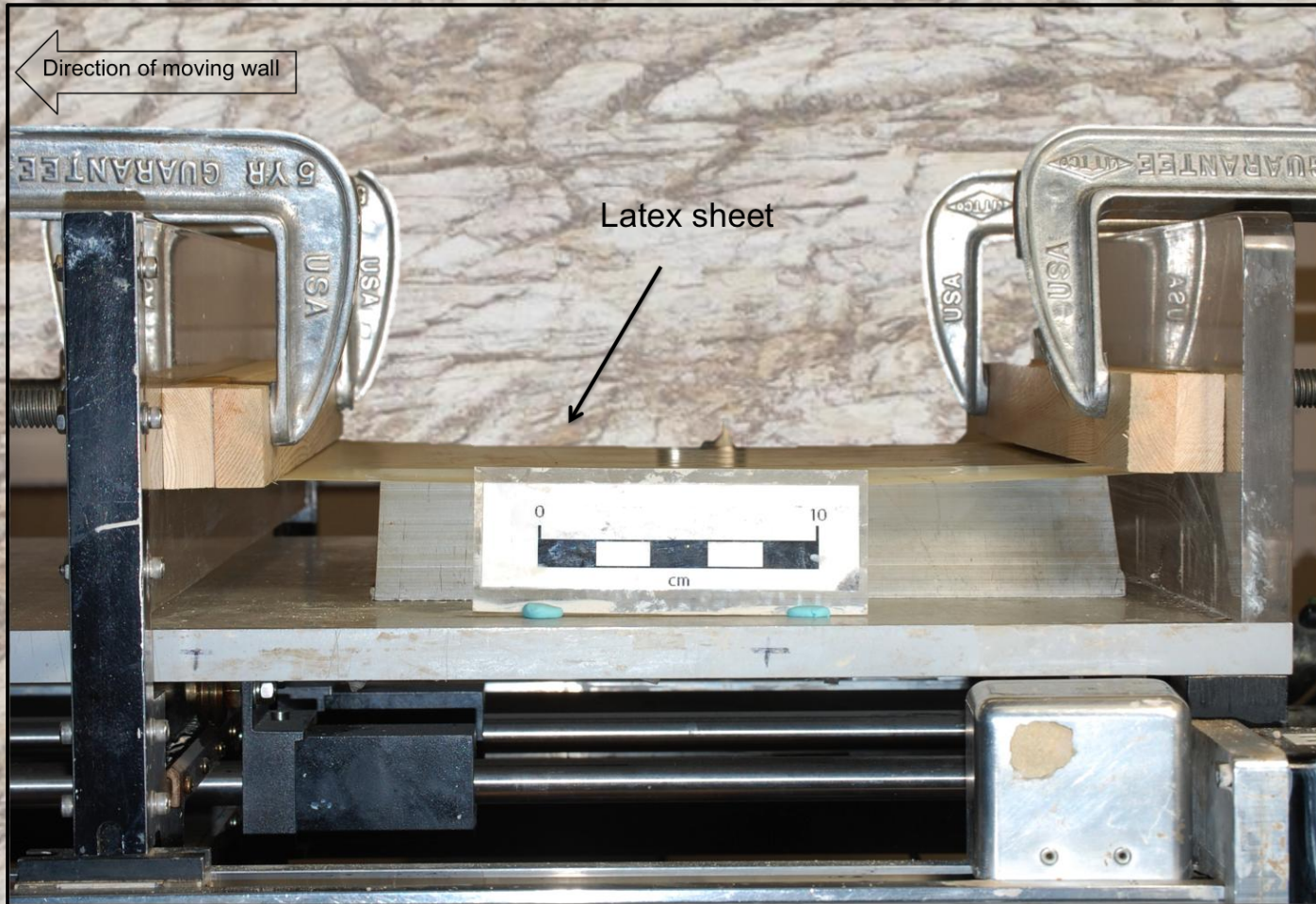






# RESULTS

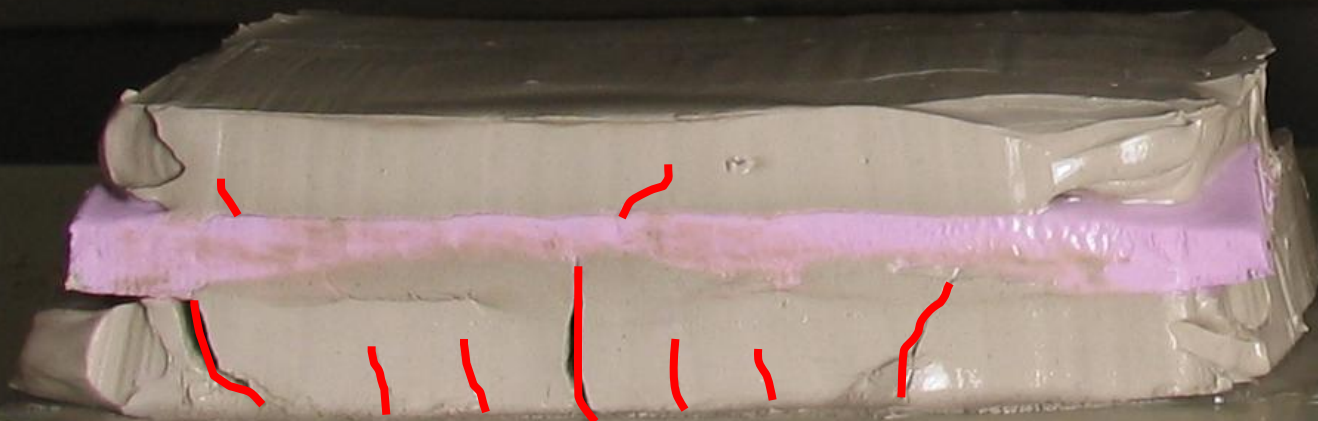
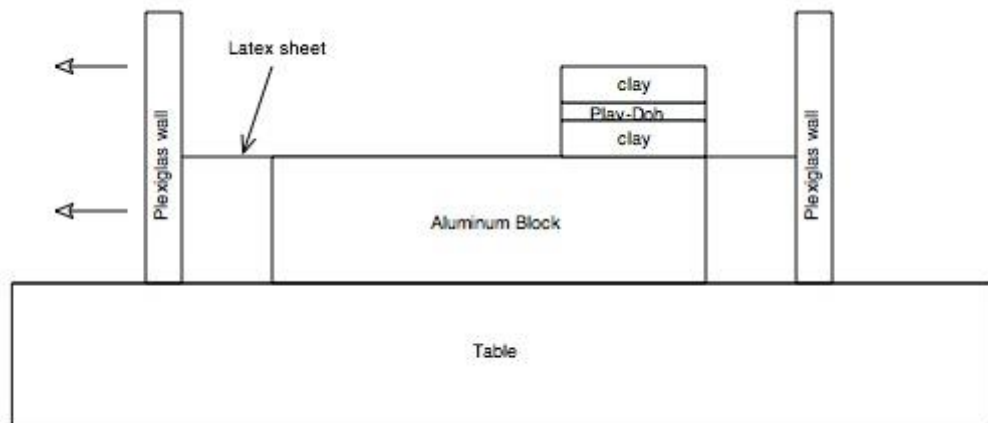
## Analog modeling apparatus







# RESULTS

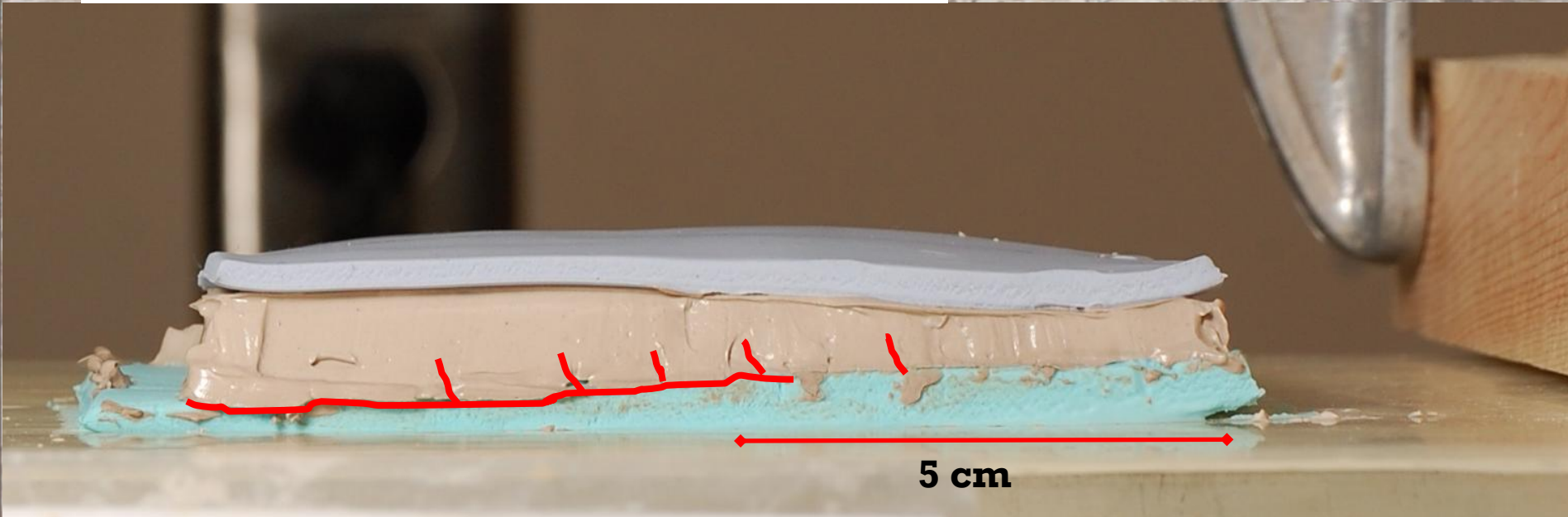
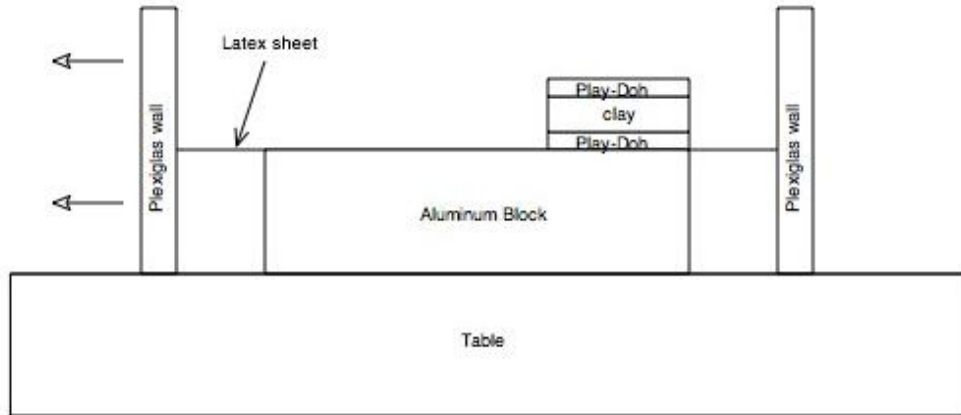


5 cm






# RESULTS



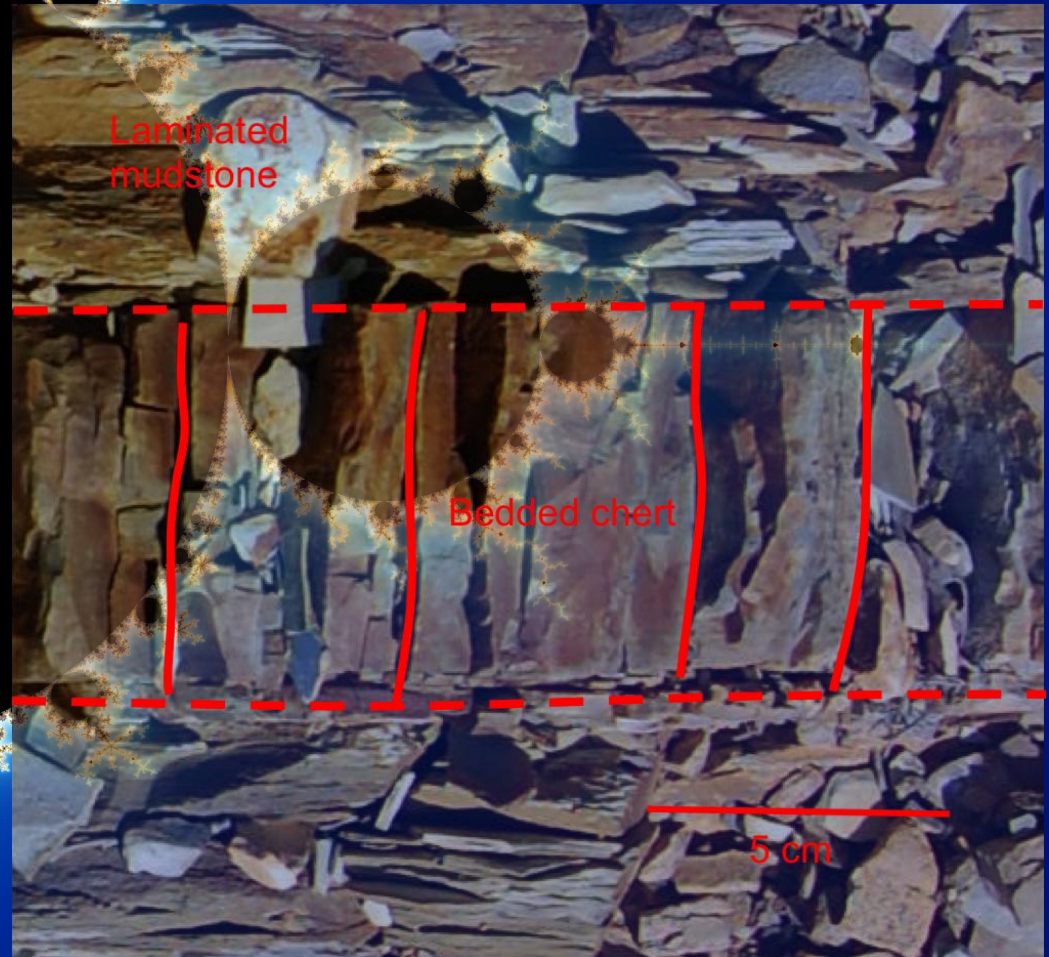
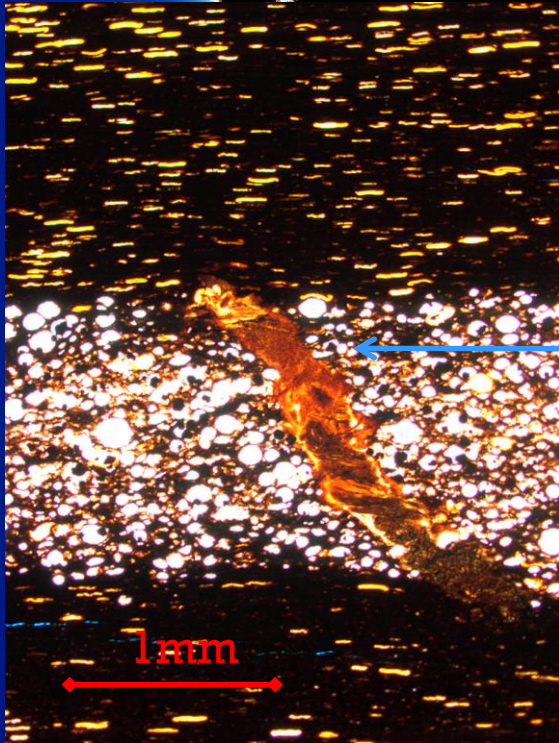


# **CONCLUSIONS and APPLICATIONS**

- 
- 1. Spectral gamma ray profile shows good correlation of U to total gamma ray.**
  - 2. Dominant N-S/E-W conjugate set likely formed in early deformation during burial and increased pore pressure (tensile fracturing).**
  - 3. NW-SE/NE-SW conjugate set formed at later stage due to cross-cutting relationship and alignment with major structures in the Arbuckle Mountains.**
  - 4. Low gamma ray and low uranium indicative of more brittle lithofacies, better drilling targets for horizontal wells, leads to faster drilling and better steering.**
  - 5. High gamma ray and high uranium indicative of more ductile lithofacies; intervals can act as hydraulic fracture barriers or baffles; highly fissile intervals can create borehole stability problems.**
  - 6. Mechanical boundaries in the Woodford Shale are very weak planes, can be easier to stimulate with hydraulic fractures.**



# Questions







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