# Constraining Uplift in the Piceance Basin Using Diagenetic Modeling of Quartz Cementation in Upper Cretaceous Williams Fork Sandstones, Colorado*

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## Abstract

Burial history controls thermal exposure and influences pressure history, which in turn influence the timing and amount of gas generation, overpressuring, quartz cementation, natural fracture formation, and ultimately, reservoir quality. Studies based on apatite fission-track and thermal maturation suggest that maximum burial in the Piceance Basin occurred between 45 and 20 Ma, and that post-Laramide uplift began at approximately 10 Ma as the Colorado River system eroded large quantities of sediment. However, there is debate about the magnitude and pattern of this uplift. For tight gas reservoirs of the Upper Cretaceous Williams Fork sandstones estimates of eroded section using stratigraphy, vitrinite reflectance extrapolation, and basin modeling vary from 3800 ft to 6100 ft for the MWX well, from 3700 ft to 9167 ft for the MF31-19G well, and 4400 ft near the Last Dance 43C-3-792 well.

Because quartz cementation is sensitive to thermal exposure, diagenetic modeling (TouchstoneTM) of quartz cement abundance can be used to better constrain both the amount and timing of uplift. In our study, we tested multiple burial history scenarios for these three well locations. The burial scenarios that led to the closest match between petrographically measured and predicted quartz cement abundances suggest that the maximum burial depth and removed overburden at the base of the Williams Fork are 13,575 ft and 5,147 ft for the MWX well, 15,163 ft and 3,157 ft for the MF31-19G well, and 13,067 ft and 5,068 ft for the Last Dance 43C-3-792 well respectively. We used the same approach for the Rifle Gap outcrop locality (Grand Hogback). The scenario that gave the best match of model results with present-day quartz cement abundance from point-count analyses indicates that the base of Williams Fork reached its deepest burial (~7,000 ft) about 50 Ma ago and uplift started around 35 Ma (~3000 ft of uplift).

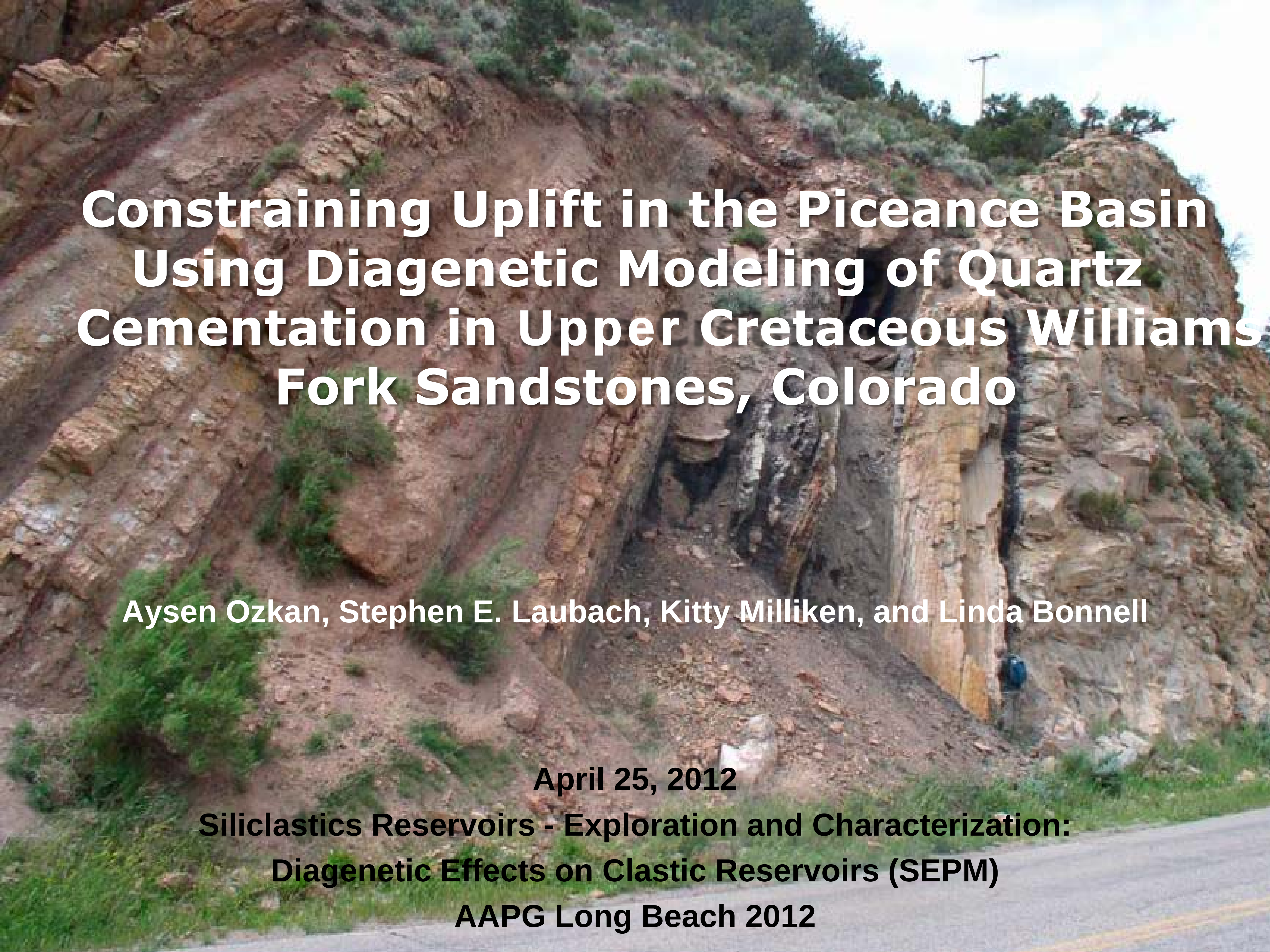
Using quartz cement, which is sensitive to temperatures reached and time spent in those temperature ranges, as a paleothermometer provides an independent estimate of amount of erosion. However, because finite pore space is available for quartz cementation; once porosity is entirely occluded this gauge is insensitive to further thermal exposure unless other pore space becomes available (secondary pores, fractures).

## Reference

Yurewicz, D. A., K. M. Bohacs, J. Kendall, R. E. Klimentidis, K. Kronmueller, M. E. Meurer, T. C. Ryan, and J. D. Yeakel, 2008, Controls on gas and water distribution, Mesaverde basin-centered gas play, Piceance Basin, Colorado, in S. P. Cumella, K. W. Shanley, and W. K. Camp, eds., Understanding, exploring, and developing tight-gas sands— 2005 Vail Hedberg Conference: AAPG Hedberg Series, no. 3, p. 105–136.

## Website

Blakey, R., 2011, Colorado Plateau Geosystems, Inc.: Web accessed 30 July 2012. http://cpgeosystems.com/index.html



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April 25, 2012

Siliclastics Reservoirs - Exploration and Characterization:

Diagenetic Effects on Clastic Reservoirs (SEPM)

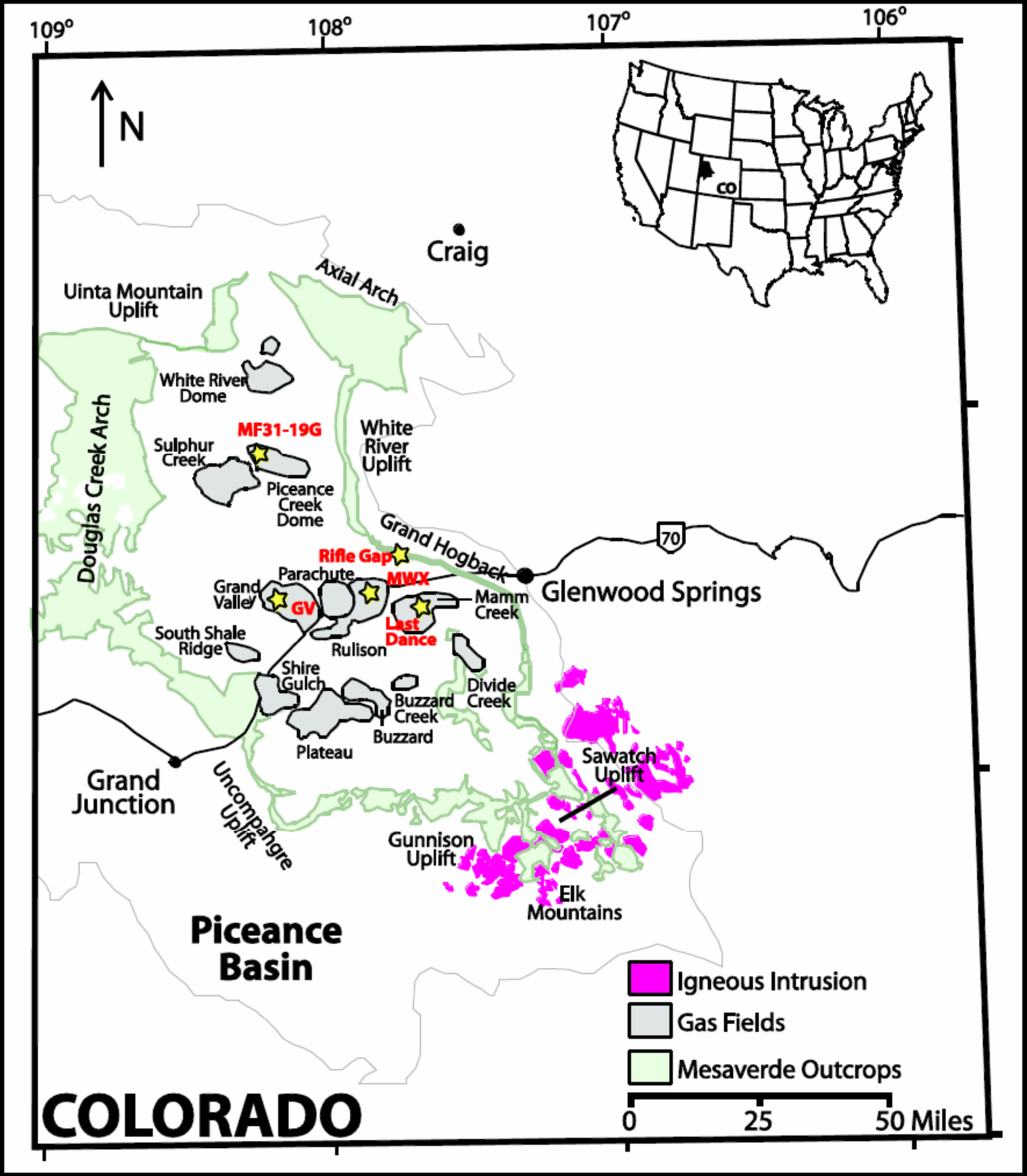
AAPG Long Beach 2012

# Outline



- Introduction
  - Structural Setting, Stratigraphy, Erosion debate
- Estimating the Erosion
  - Stratigraphy Approach
    - Stratigraphic Projections
    - Vitrinite Reflectance Extrapolation
  - Basin Modeling Approach
    - Burial History & Thermal History Inputs
  - Diagenetic Modeling Approach
    - Methodology
    - Petrography Input
    - Results
- Conclusions

# Study Locations

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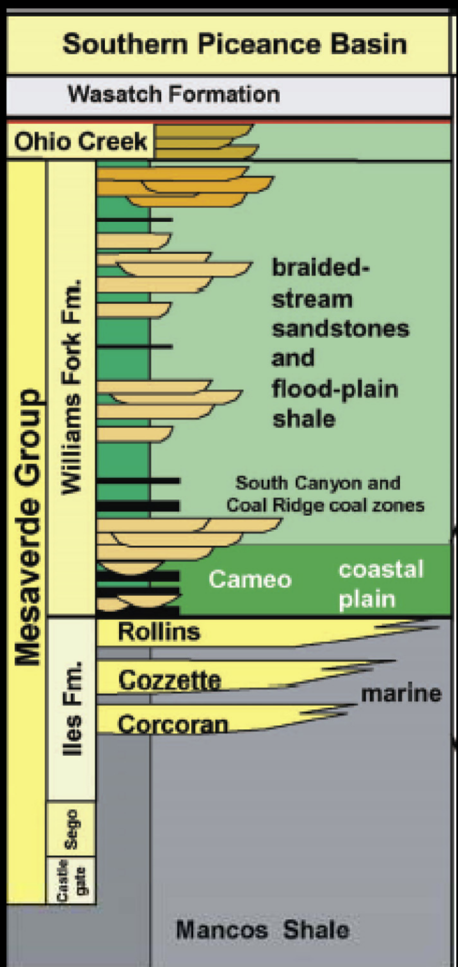
# Deposition of Mesaverde Sandstones Upper Cretaceous (~75Ma)

Source: Tectonic uplift / Sevier orogenic belt

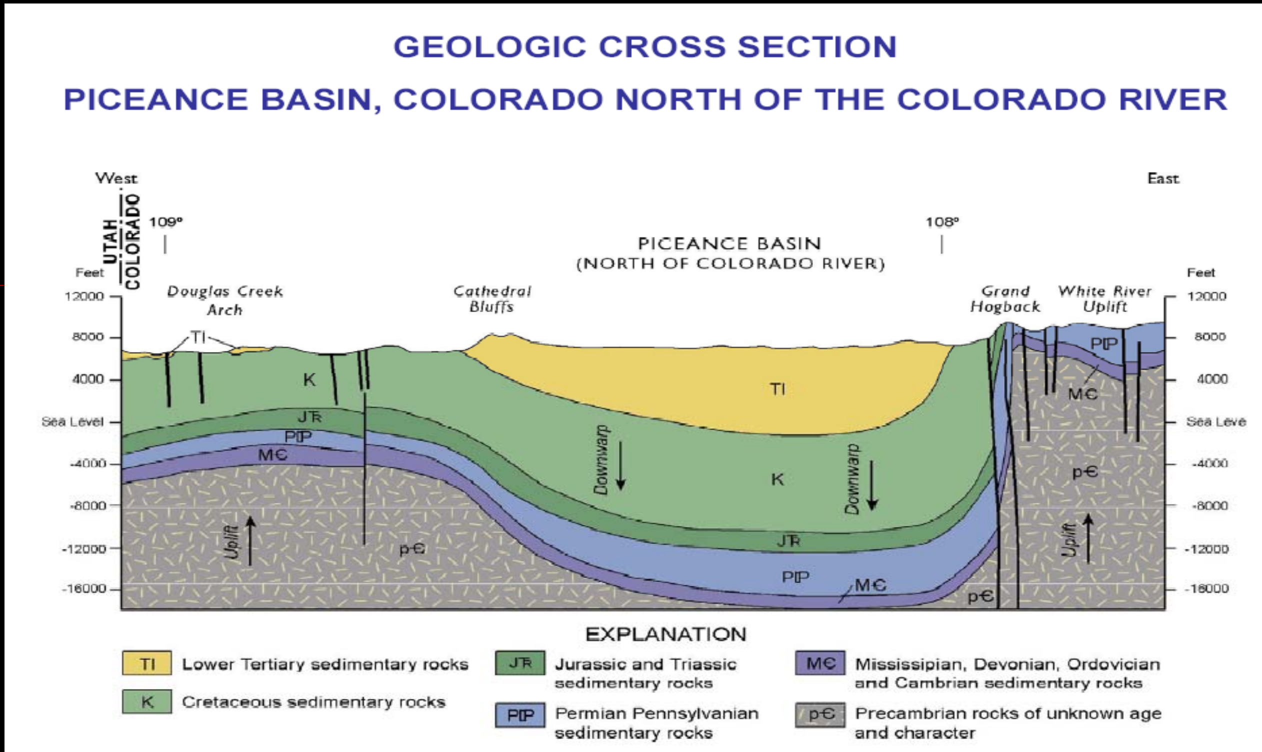


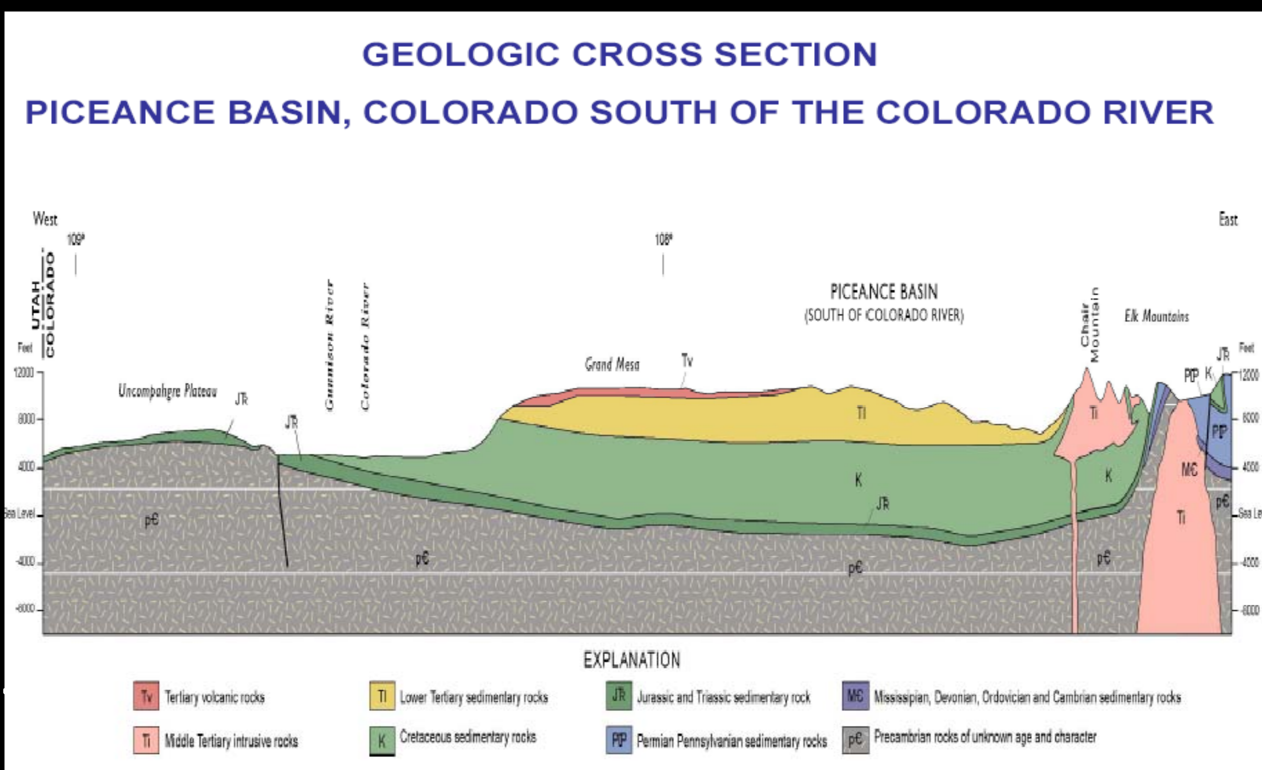

Yurewicz et al, 2008


Blakey, 2011

## Late Cretaceous Mesaverde Group

- Williams Fork Fm: shales, sandstones, & coals deposited on broad coastal plain
- Iles Fm: regressive, laterally continuous marine sandstone cycles separated by tongues of marine Mancos Shale




# Stratigraphy & Tectonics

- 10 Ma - Present: uplift & erosion
- 9.7 ± 0.5 Ma: Basaltic extrusions in central Piceance
- 34 to 29 Ma: Shallow intrusions in the SE Piceance
- 36 to 10 Ma: No evidence of deposition
- ~65-61 Ma to 36 Ma: Tertiary sedimentation. Max burial of Williams Fork during the Laramide orogeny
- 65 Ma: Nondeposition and subsidence
- 75 Ma to 65 Ma: Mesaverde deposition

http://water.state.co.us/pubs/presentations/nwgasforum100903.pdf

# Debate: Removed Tertiary Sediments

FRAC

- Apatite fission-track and thermal maturation studies suggest:
  - Deepest burial between 45 and 20 Ma in the Piceance
  - Post-Laramide uplift began ~10 Ma as the Colorado River system eroded large quantities of sediment.

- However, there is debate about the magnitude and pattern of this uplift.

- Estimates of erosion from literature using stratigraphy, vitrinite reflectance extrapolation, and basin modeling:
  - 3800 ft to 6100 ft for the MWX well
  - 3700 ft to 9167 ft for the MF31-19G well
  - 4400 ft near the Last Dance 43C-3-792 well

Can we constrain these estimations with diagenetic modeling?

# Estimation of Removed Overburden - Stratigraphic Approach

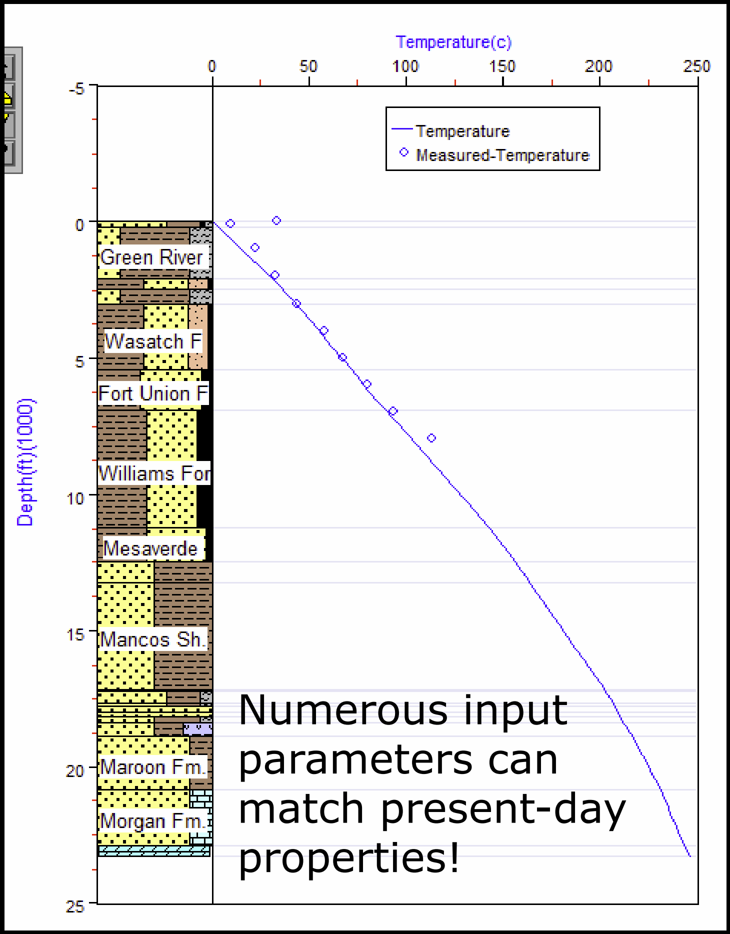
FRAC

1. <u>Stratigraphic projections</u> (geologic inference):
   - Assumption: missing Tertiary section was uniform in thickness and that differences in present-day topography represent differential erosion by the Colorado River system.

2. <u>Extrapolation of Ro vs. depth profiles</u> to Ro values of 0.2% and 0.3%
   - Assumption: Ro = 0.2% - 0.3% are believed to be Ro values for vitrinite near the surface in a basin that has <u>not</u> undergone erosion.

# Estimation of Removed Overburden - Basin Modeling Approach

3. Basin Modeling: Burial reconstructions are calibrated by adjusting input parameters so that predicted and observed present-day properties match.




Stratigraphy Inputs: Lithology, thickness, rock properties (TOC, HI, thermal conductivity)

Thermal Inputs:

- Bottom hole temperatures
- Vitrinite reflectance (sensitive to max Tº reached)
- Heat flow: radiogenic heat production from the crust & sediments, magmatic activity (S. Piceance), thickness of the lithosphere, burial

# Constraining the Burial History - Quartz Cement Modeling

FRAC

- Intergranular volume (IGV) and quartz cement abundance can provide valuable constraints on thermal and burial histories when combined with other thermal indicators.

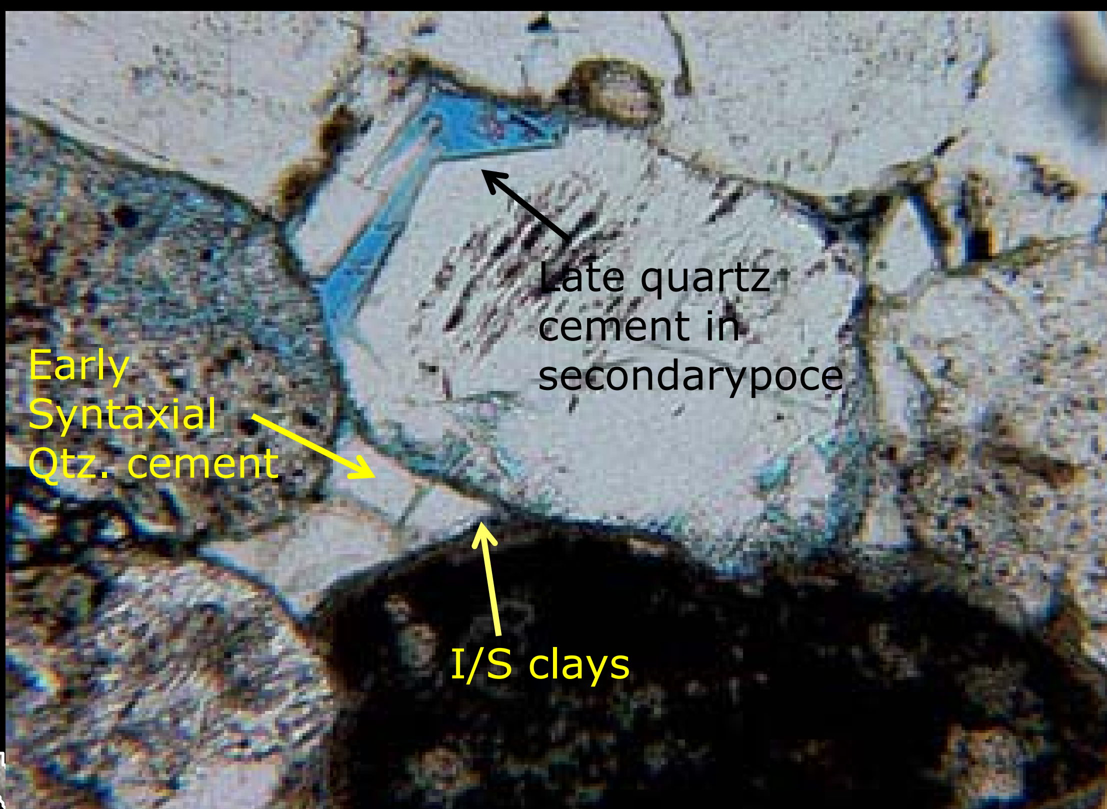
$$K = A_o\, e^{-Ea/RT}$$

K: Quartz precipitation rate (mole/cm2 s)
Ao: Pre-exponential or frequency factor
Ea: Activation energy (J/mol)
R: Gas constant (8.314 J/K mol)
T: Temperature (K)

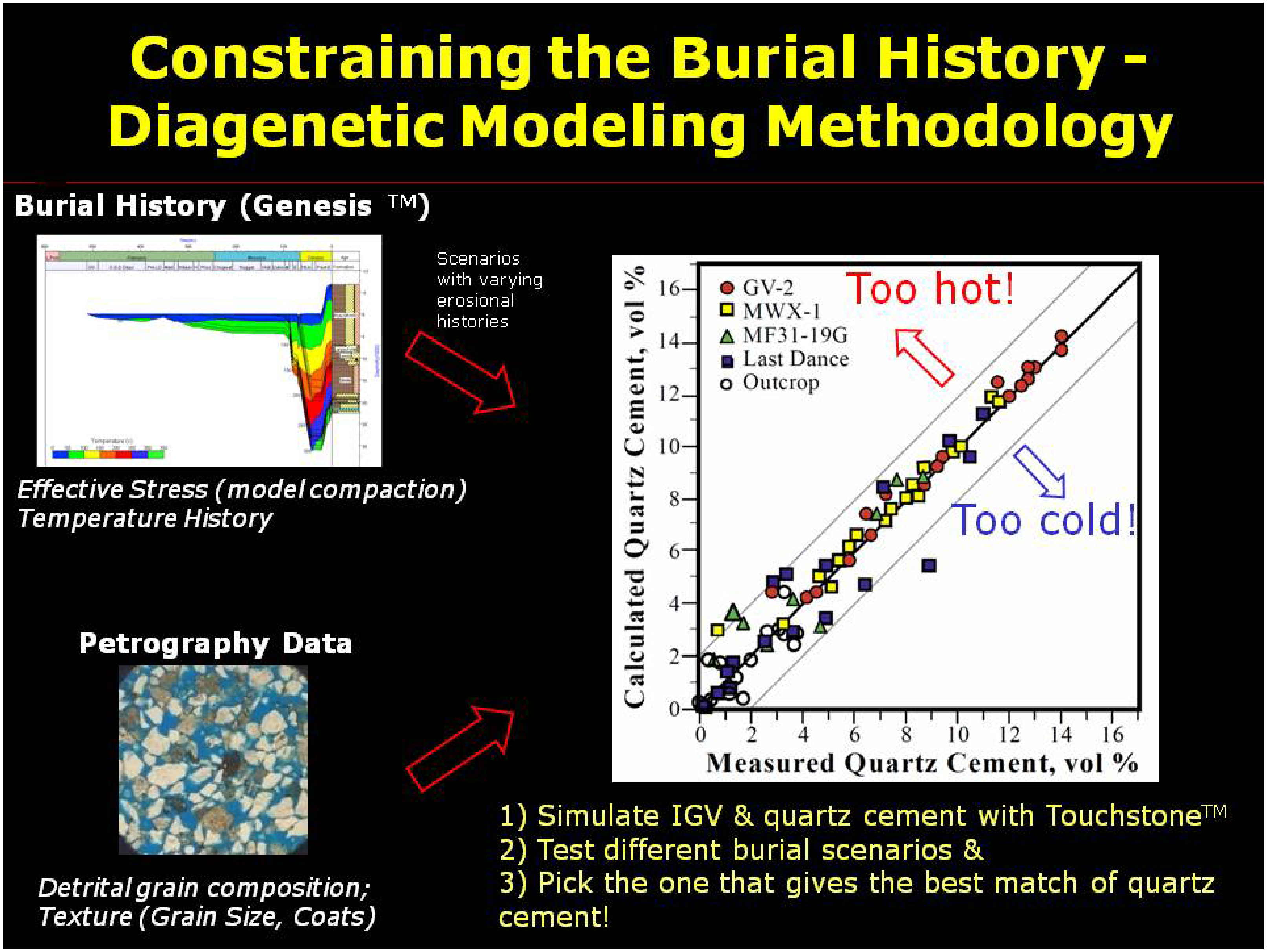
- Quartz cement is a valuable paleothermometer!
- Precipitation rates increase nearly exponentially with Tº & at a given Tº increases nearly linearly with time as long as nucleation sites are available.

# Constraining the Burial History - Quartz Cement Modeling

- Limitation: Finite pore space is available; once porosity is entirely occluded this gauge is insensitive to recording further thermal exposure!

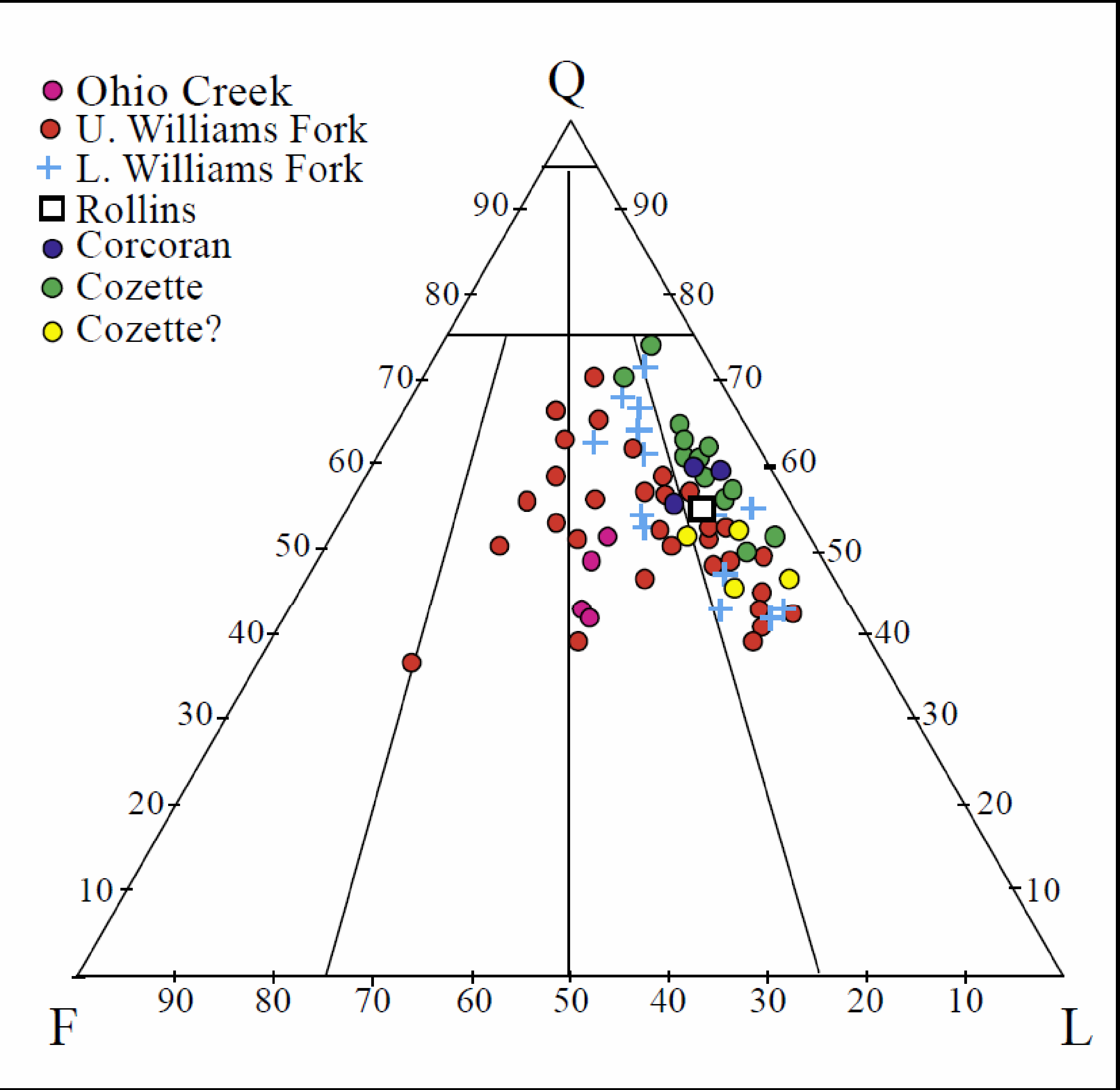



- Unless other pore space becomes available (secondary pores, fractures).



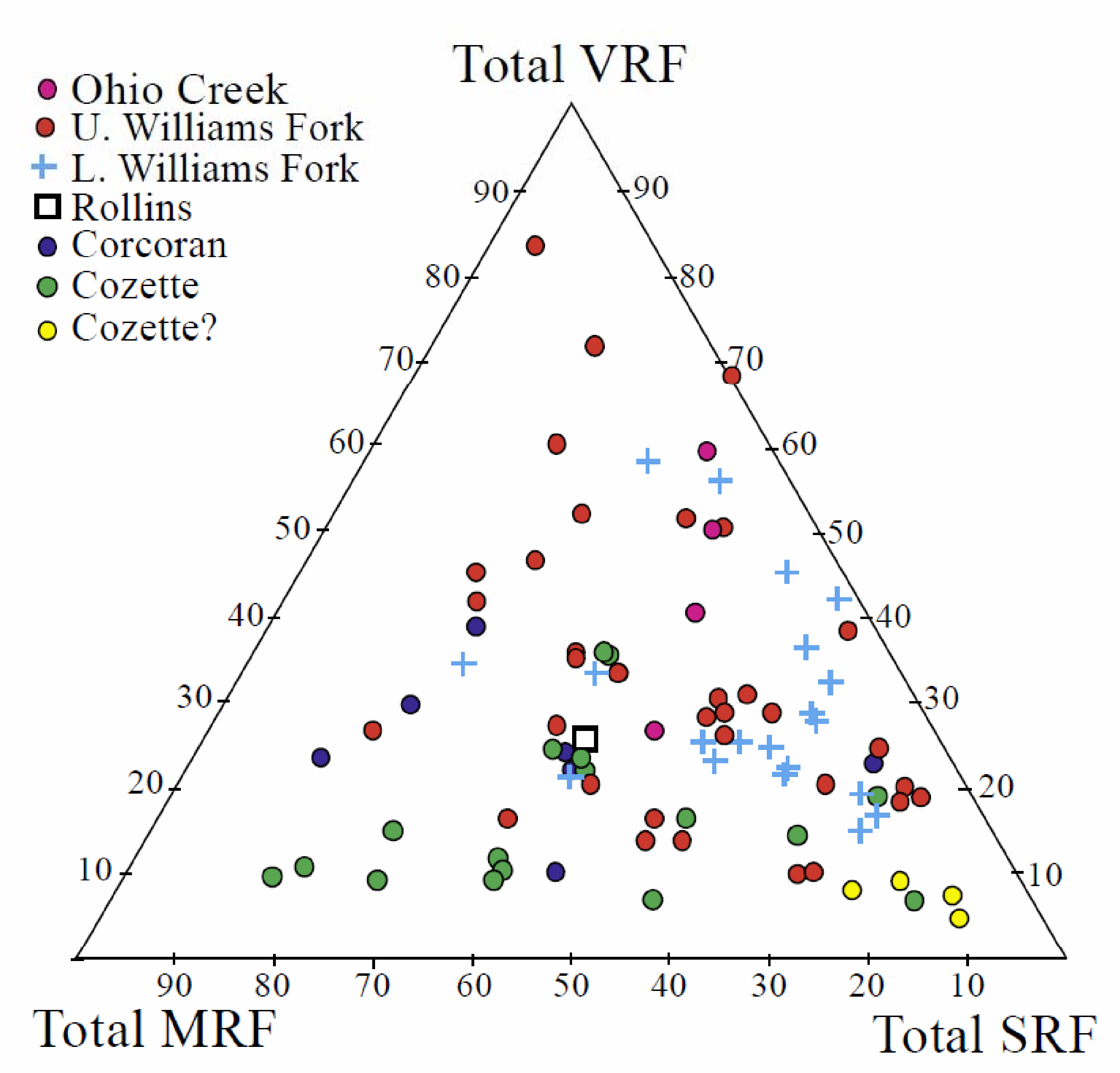

- Build basin models with varying erosional histories
- Simulate the quartz cement abundance by using identical parameter values for compaction and quartz cementation algorithms for all study locations.
- Test performance of the basin models on how well they can predict the amount of quartz cement in the sdstones
- Select the best-performing burial curves as representative burial reconstructions for the study areas
- I determined the maximum burial depth and amount of erosion from these representative curves.

# Petrography Input - Sandstone Composition



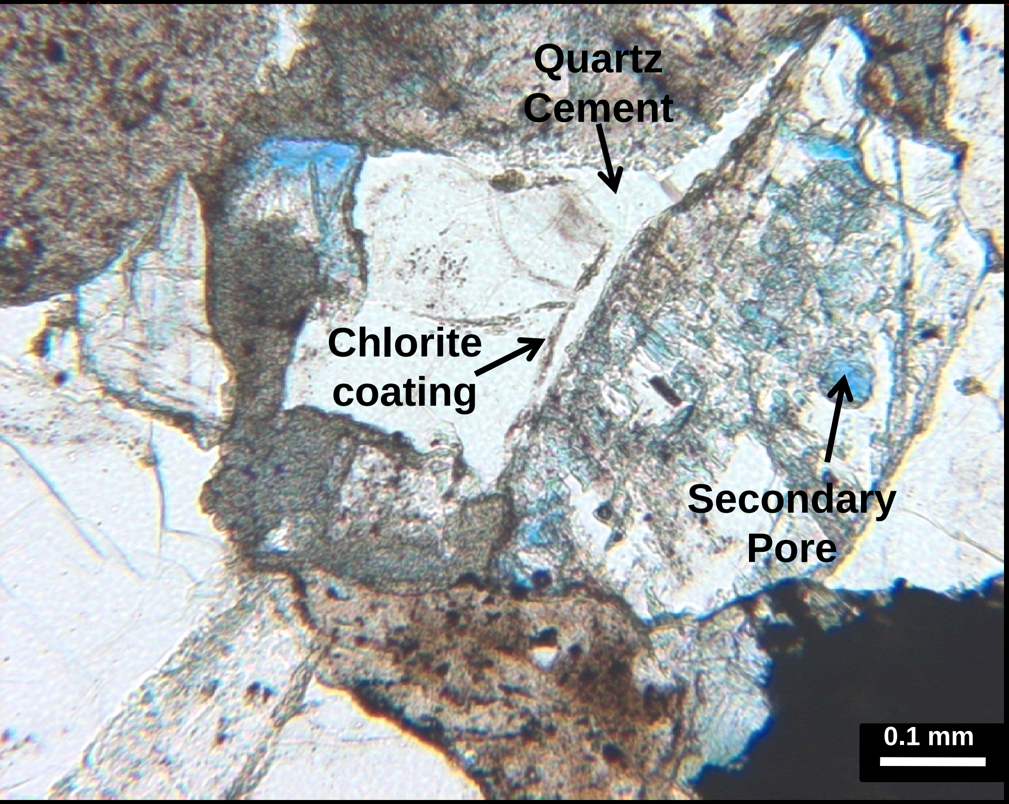
# Distribution of Rock Fragments





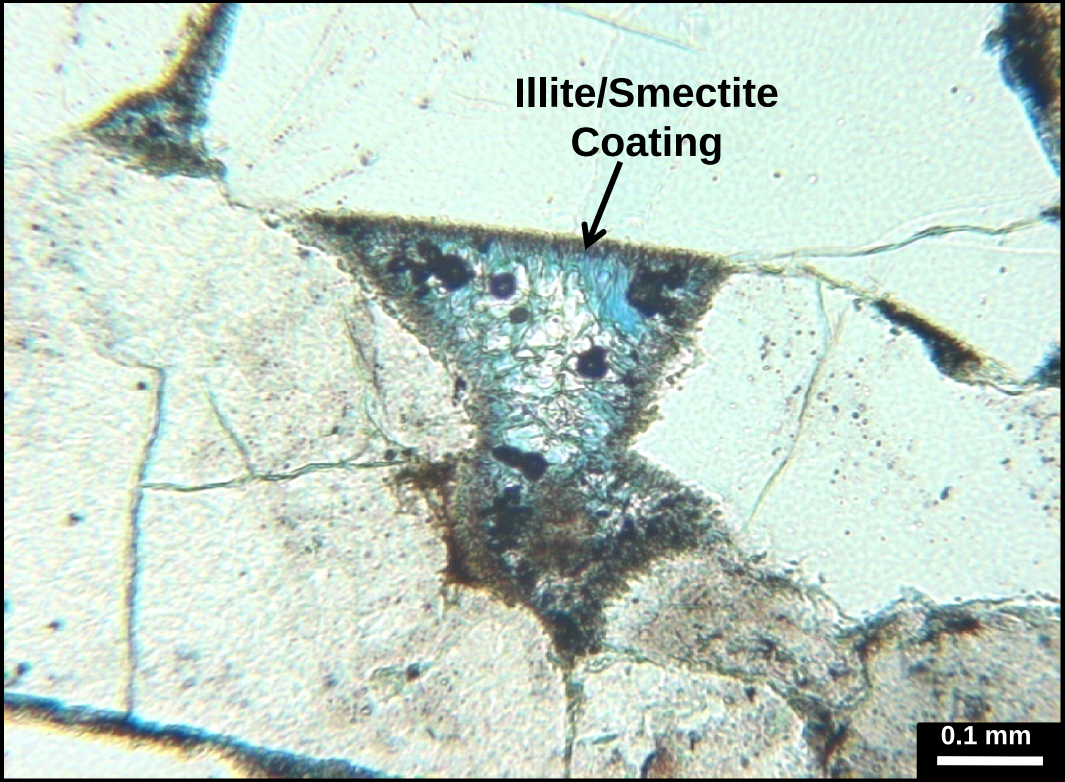

Provenance controls on diagenetic pathways & reservoir quality!

# Petrographic Input:
# Textural Data (Grain Size, Sorting, Coating)




Williams Fork 2809 ft

Nucleation sites for quartz cementation!




Williams Fork 4014.9 ft

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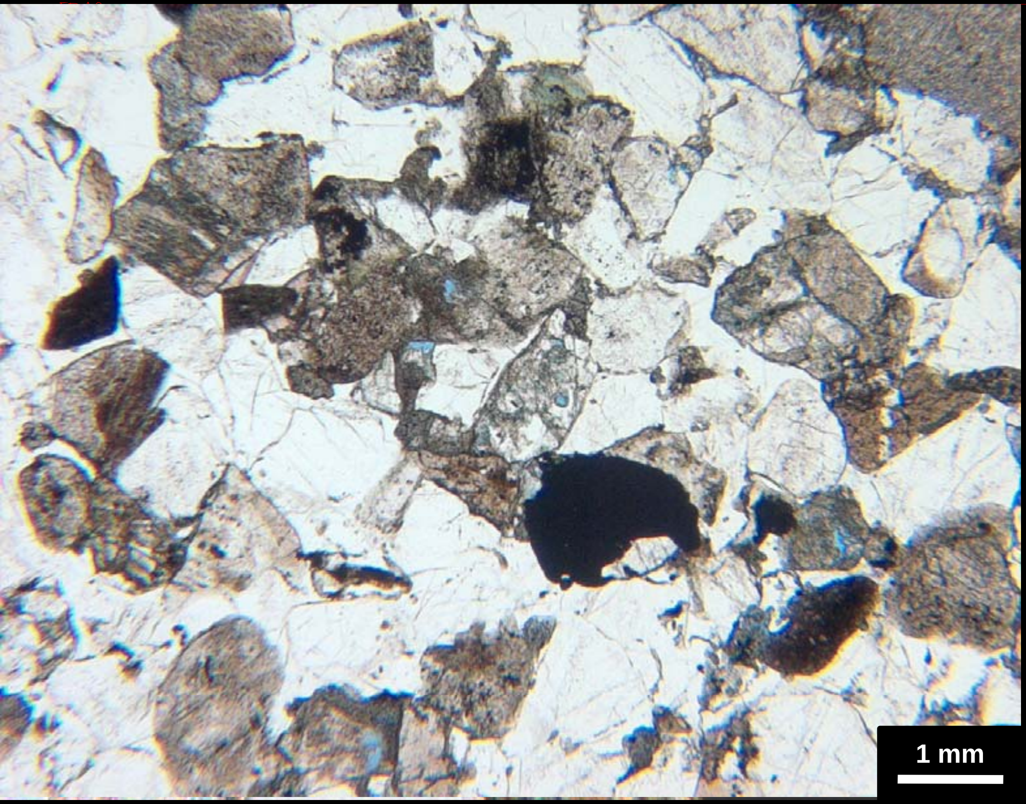
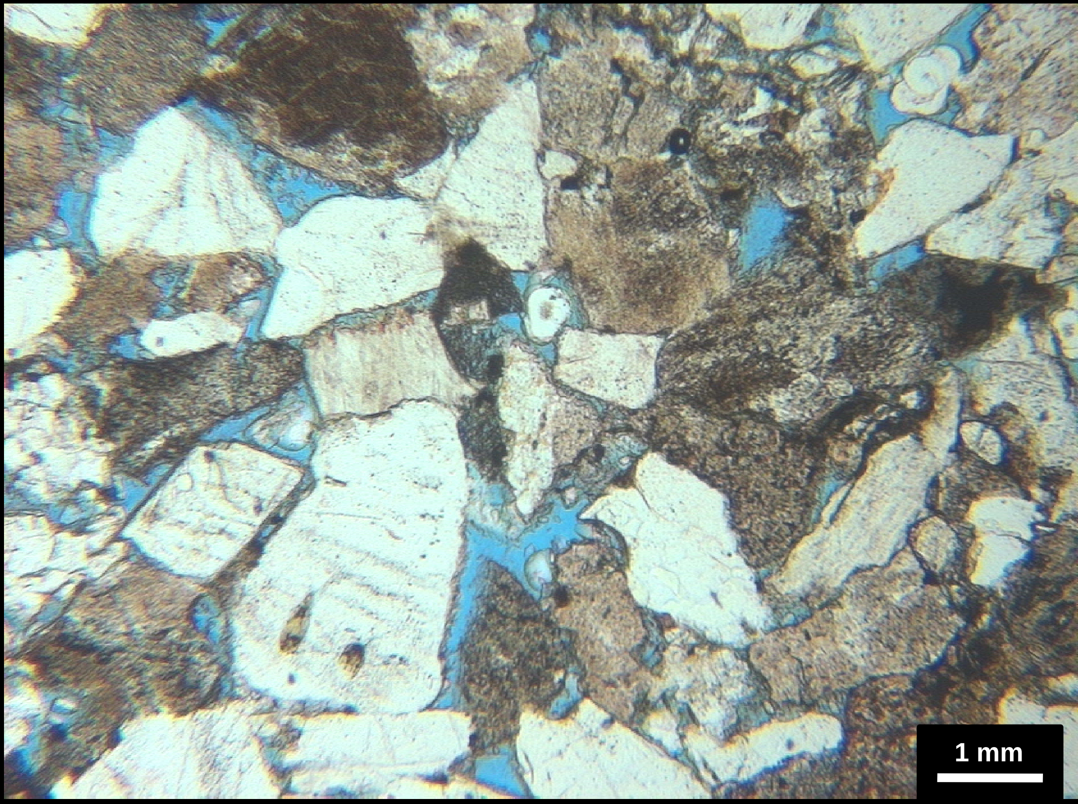
# Petrographic Input:
# Textural Data (Grain Size, Sorting, Coating)




Williams Fork 2809 ft

Nucleation sites for quartz cementation!

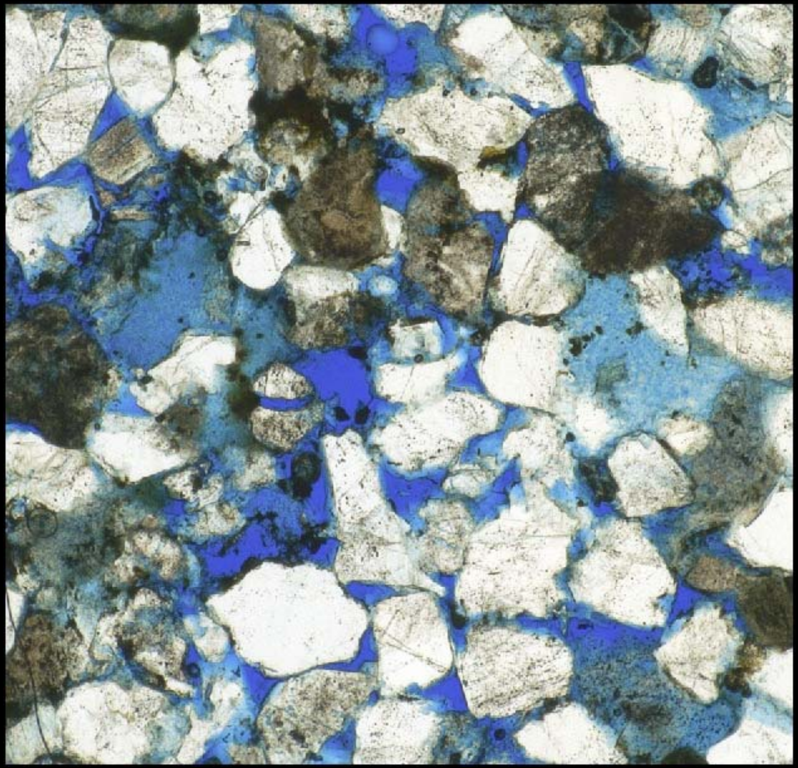



Williams Fork 4014.9 ft

# Comparison of Williams Fork Sandstones Outcrop vs. Subsurface Samples

FRAC

**WF7**



**18% pores**

0.5 mm

OUTCROP
90 °C

Cementation

**8% Quartz**
**3% Fe-dolomite**

**5736.8 ft**

**2% pores**

0.5 mm

SUBSURFACE
150 °C

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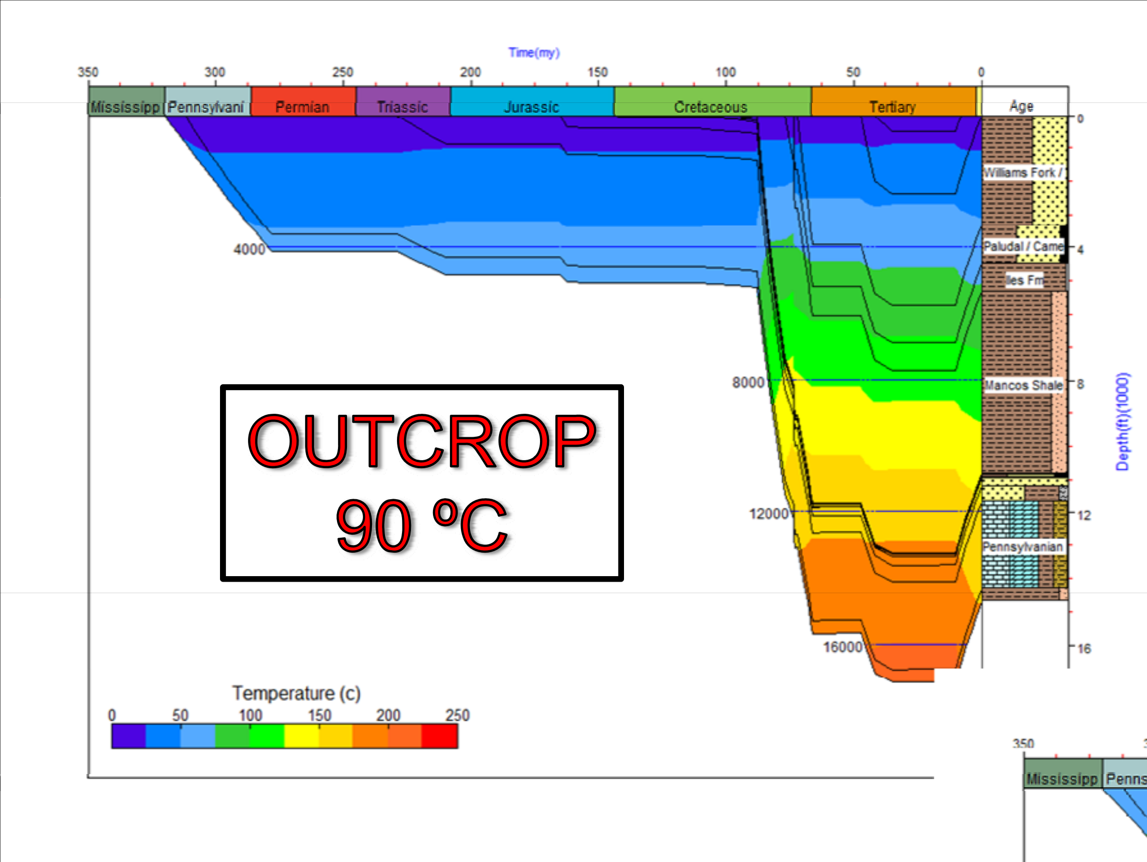
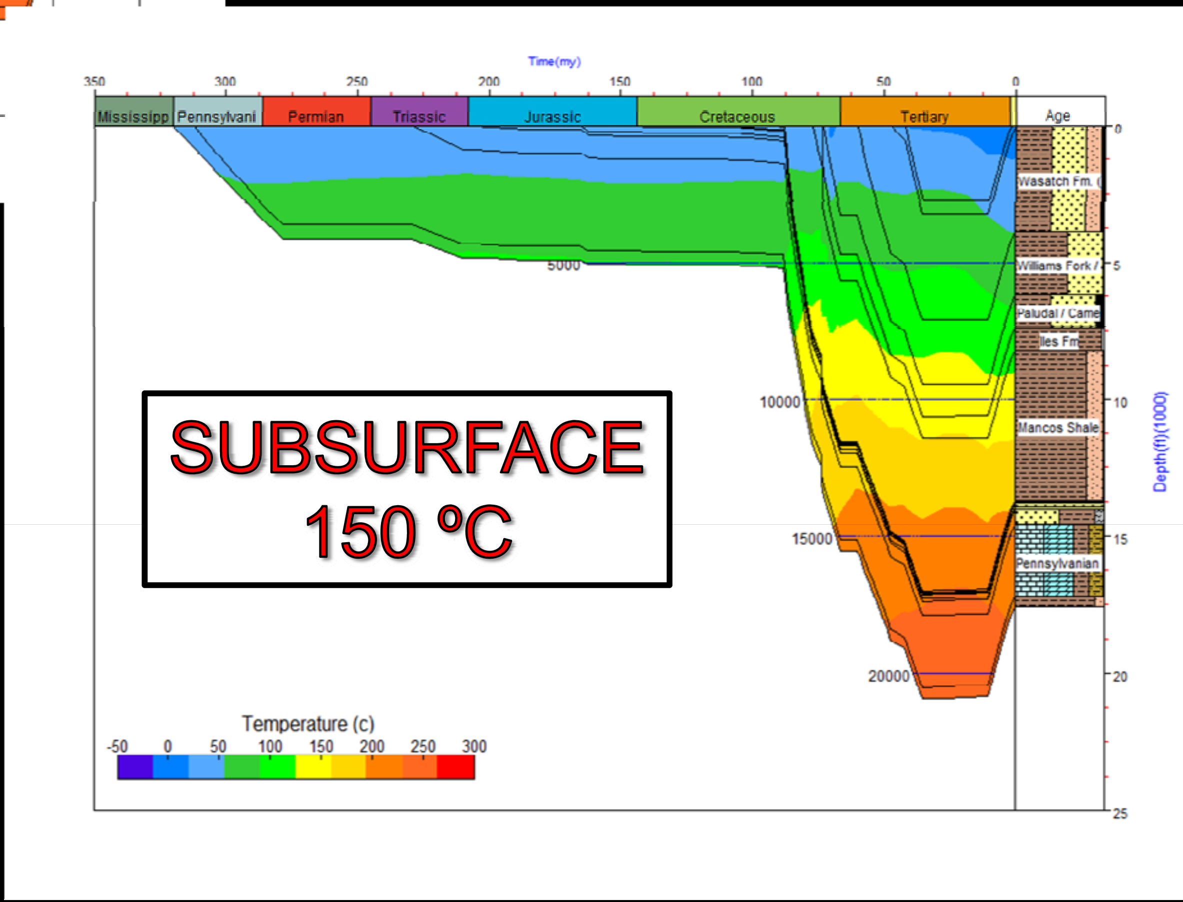
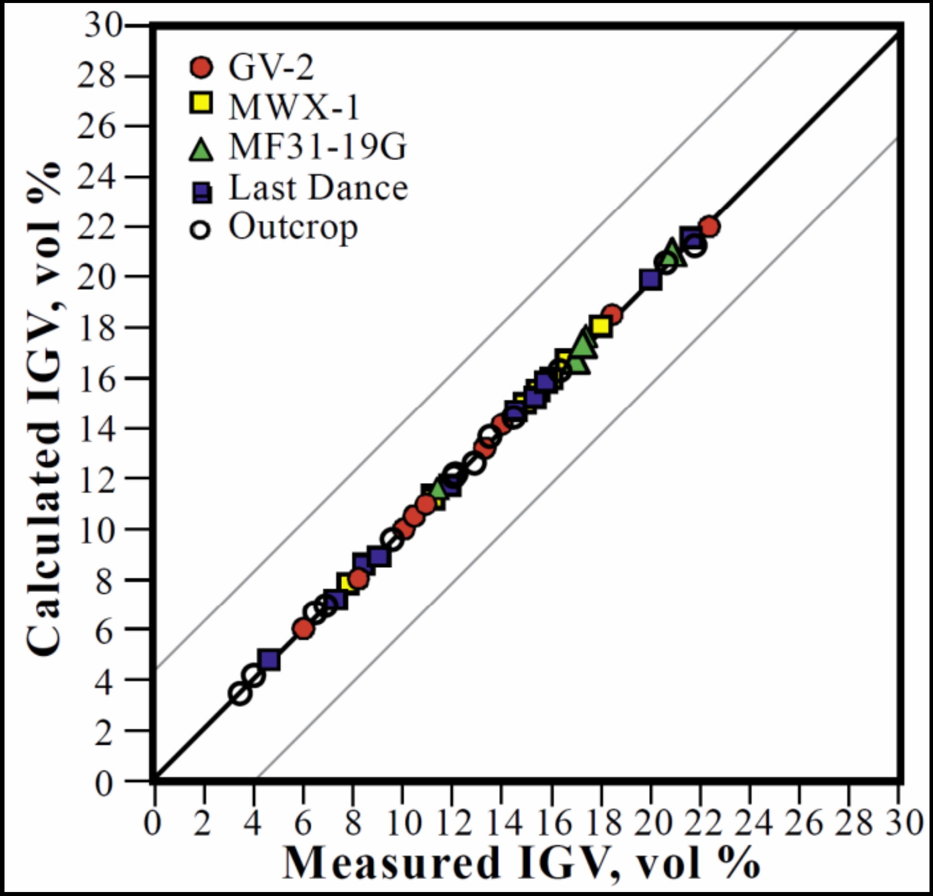
# 1D Basin Models – Genesis™

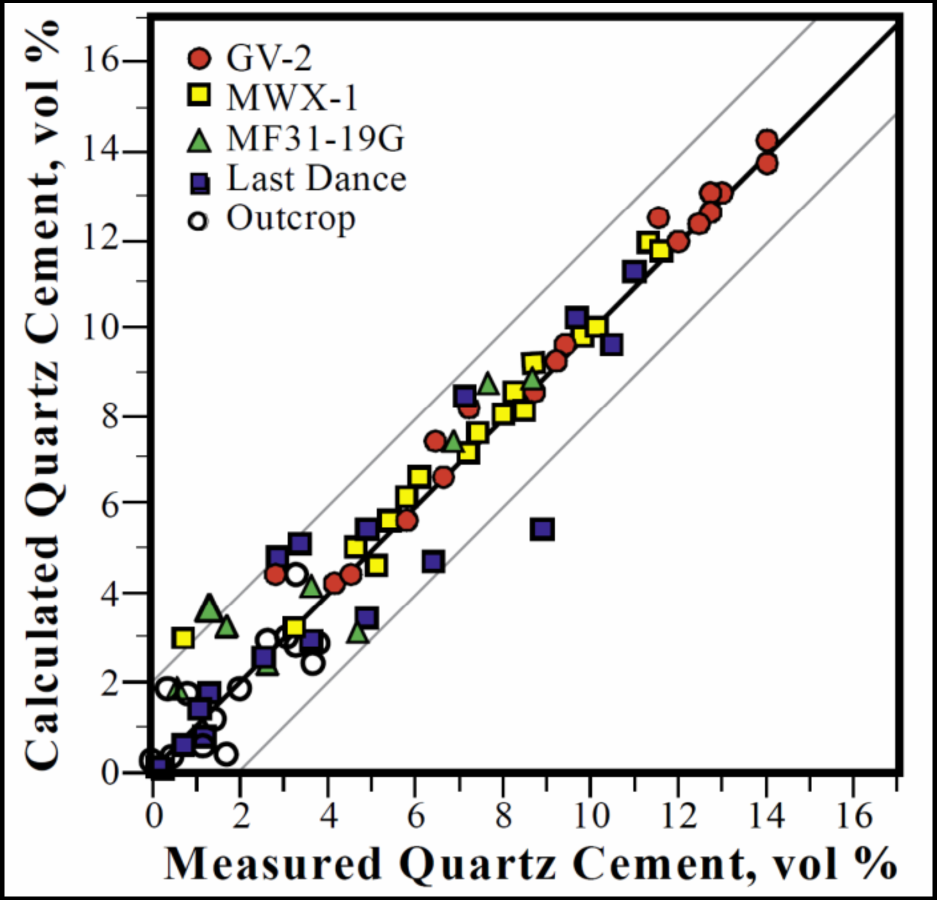



Maximum temperature reached at the base of Williams Fork (results from Genesis™)

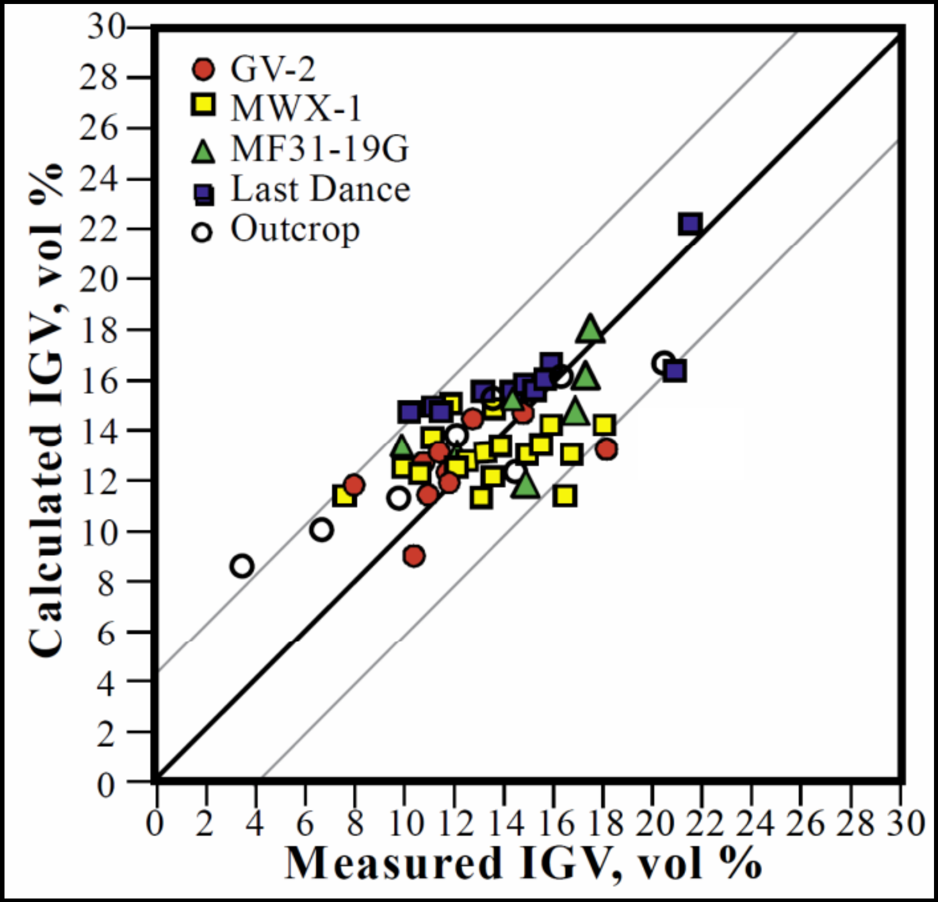
# Diagenetic Model Calibration
# Quartz Kinetics

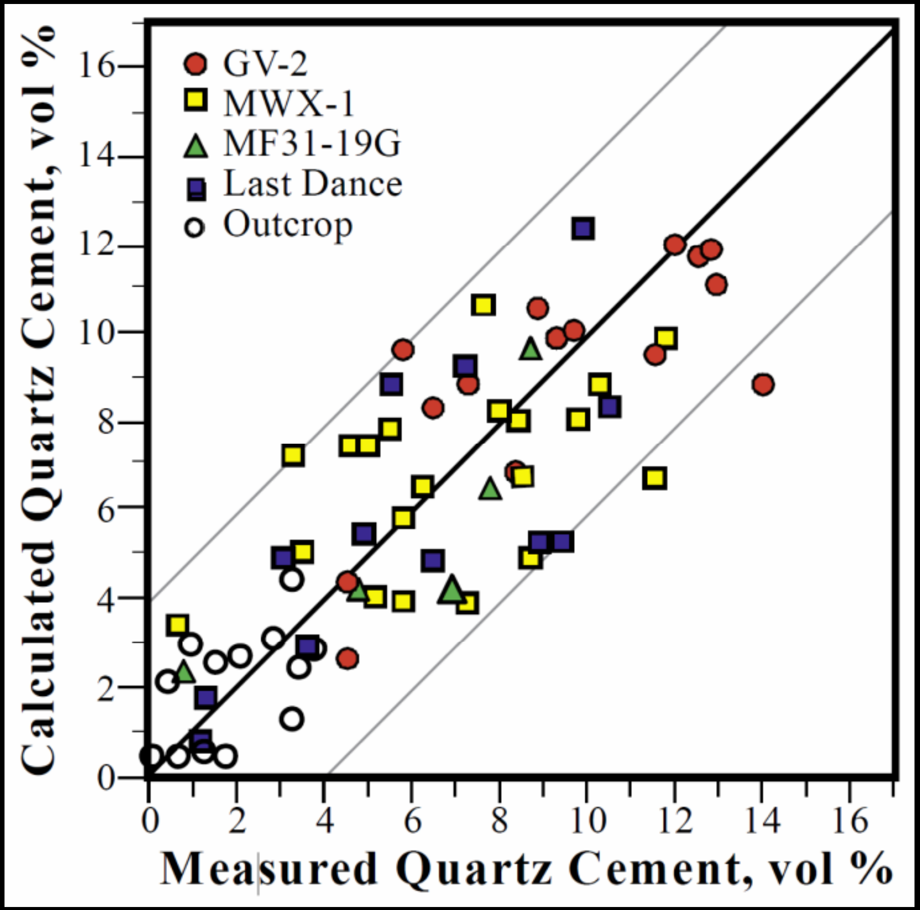



- **Identical parameter values for compaction and quartz cementation algorithms for all study locations**

# Diagenetic Model Calibration
# IGV & Quartz Cementation




- Tested multiple burial scenarios and the one that gives the best match of model results with present-day quartz cement abundance is selected as representative for burial reconstruction!

# Results

| | MWX-1 | MF31-19G (Mobil Oil, T52-19G) | Last Dance (O`Connell F11X-34P) | Outcrop Rifle Gap |
|---|---|---|---|---|
| **Nuccio and Roberts, 2003**<br>Basin models | 4700 ft | | | |
| **Nuccio and Johnson, 1992**<br>Ro-depth extrapolation to 0.2 -0.3% | 6100 ft Ro = 0.2%<br>3800 ft Ro = 0.3% | 7200 ft Ro = 0.2%<br>3700 ft Ro = 0.3% | | 3800 - 4000 ft (Harvey Gap, White River Uplift) |
| **Zhang et al, 2008**<br>Basin models by using Ro values estimated from pyrolysis analyses | | 9166 ft | | |
| **Kelley and Blackwell, 1990**<br>AFT | Max burial at 10 Ma | | | |
| **Johnson and Nuccio, 1986** | 4600 ft. | | | |
| **Barker, 1990**<br>Ro and FIs | 4600 ft | | | |
| **Bostick and Freeman, 1984**<br>Ro | 4000 – 5000 ft | | | |
| **Wilson et al., 1998**<br>AFT, Ro and FI | | | 4460 ft | |
| **This study**<br>Quartz cement Paleothermometer | 5147 – 5200 ft | 3157 ft | 5068- 5400 ft | 3000 ft |

# Conclusions

- Using quartz cement, which is sensitive to temperatures reached and time spent in those temperature ranges, as a paleothermometer provides an independent estimate of amount of erosion.

- However, because finite pore space is available for quartz cementation; once porosity is entirely occluded this gauge is insensitive to further thermal exposure.

# THANKS...

- GDL FOUNDATION
- FRACTURE RESEARCH & APPLICATION CONSORTIUM
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