[AV]K-Ar Dating of Authigenic Illites: Integrating Diagenetic History of the Mesaverde Group, Piceance Basin, NW Colorado*

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Abstract

Tight gas sands represent a significant portion of the U.S. domestic petroleum reserves. The ability to date diagenetic reactions that significantly influence reservoir quality will enhance our ability to characterize and produce these fields. Though diagenetic clays form only a small percent of the sandstone, they have a disproportionately large impact on reservoir properties because of their high surface-to-volume ratio. Using thin-section petrographic analysis, X-ray diffraction, scanning electron microscopy, and K-Ar dating, systematic trends in feldspar alteration, and illitization can be seen in the fluvial section of the Williams Fork Formation (upper Mesaverde), Piceance Basin, Colorado.

Samples taken from wells in Rulison and Parachute fields between 4500 to 7000 feet below surface were investigated for whole rock mineralogy and also treated to isolate the clay- sized fraction (<1µm). Illite from the extracted clays provide K-Ar ages for fifteen samples, revealing a linear increase in age from approximately 37 Ma to 55 Ma with depth. These ages incorporate two different types of diagenetic illite. The largest constituent, as determined by SEM microscopy, is a highly illitized, pore-lining, mixed layer illite/smectite; smaller quantities of later stage, pore-filling fibrous illite are also present. Samples with relatively high concentrations of fibrous pore-filling illite compared to MLIS exhibit age dates 4-7 Ma younger than those of the same depth with little to no fibrous pore-filling illite, corroborating the relative age relationship between the two illite polytypes based on petrographic observations.

The illite age dates correspond to entry into the calculated 100°C window during initial burial as determined by Crossey and Larsen (1992) and Johnson and Nuccio (1983). This temperature regime is often associated with a transition to highly ordered MLIS from early smectite (Lee, 1989) with water released from smectite creating overpressure conditions and aiding in the generation of hydrocarbons in nearby organic-rich stratum (Ko and Hesse, 1998). Ages recorded by illite K-Ar dating are approximately 20 Ma younger and correspond to a depth 4000 feet shallower than the maximum burial for the fluvial interval of the Williams Fork Formation, possibly indicating a mechanism for early over-pressurization and fracturing of this interval.

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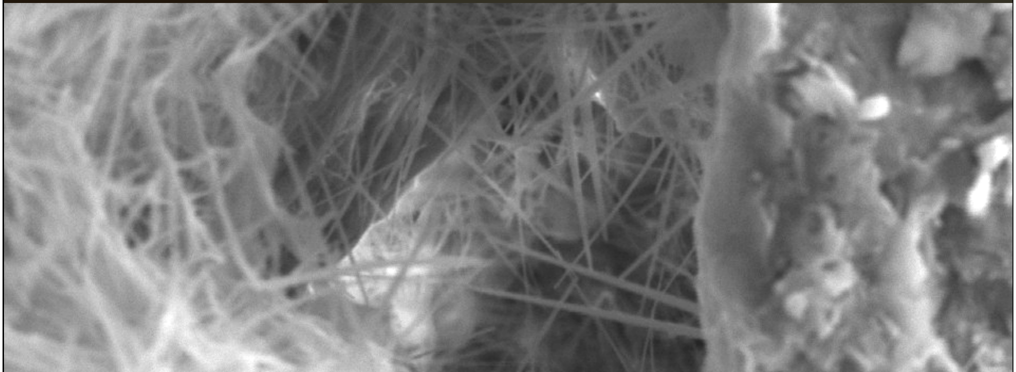
K-Ar Dating of Authigenic Illites:

Integrating Diagenetic History of the Mesaverde Group, Piceance Basin, NW Colorado



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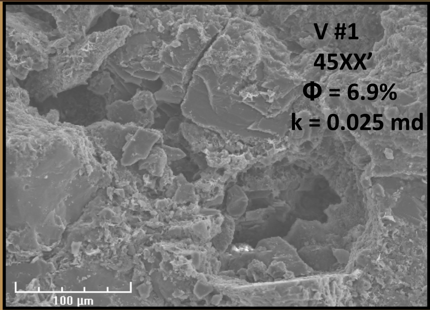
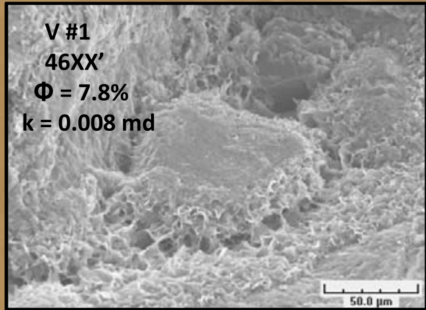
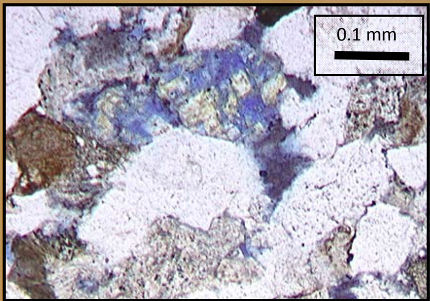
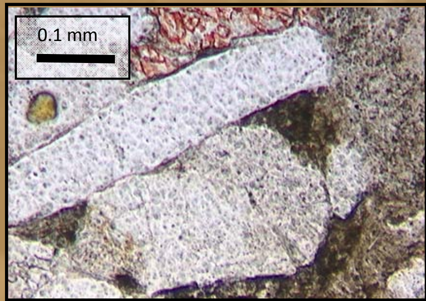
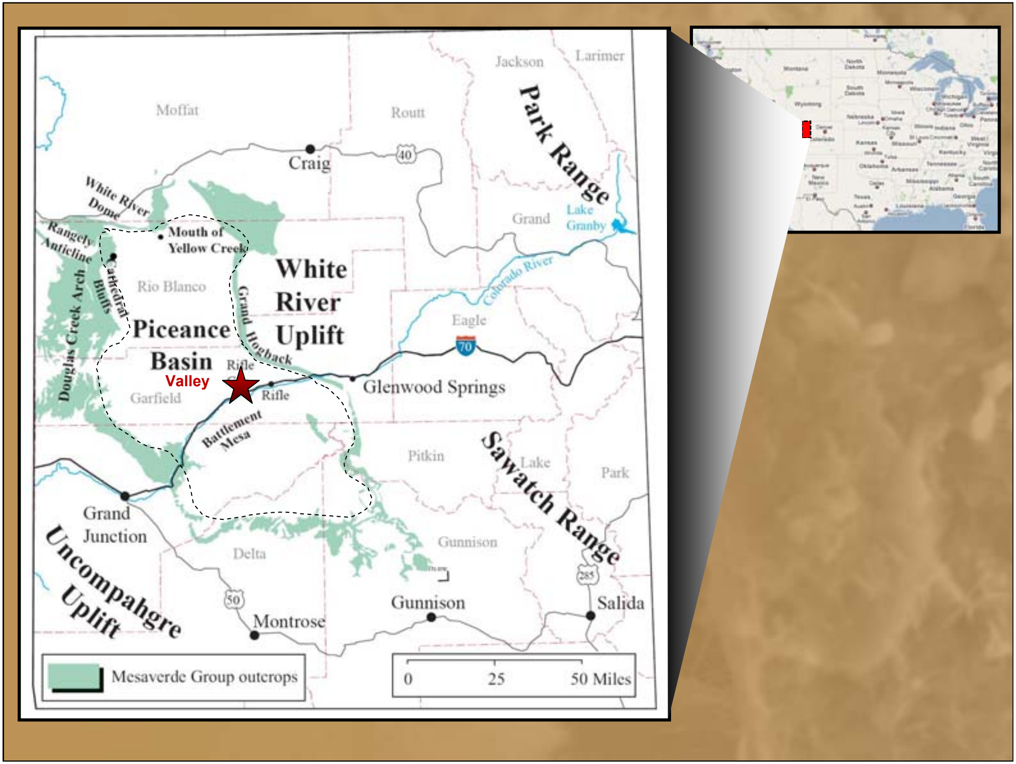
Diagenetic Influences on Reservoir Properties



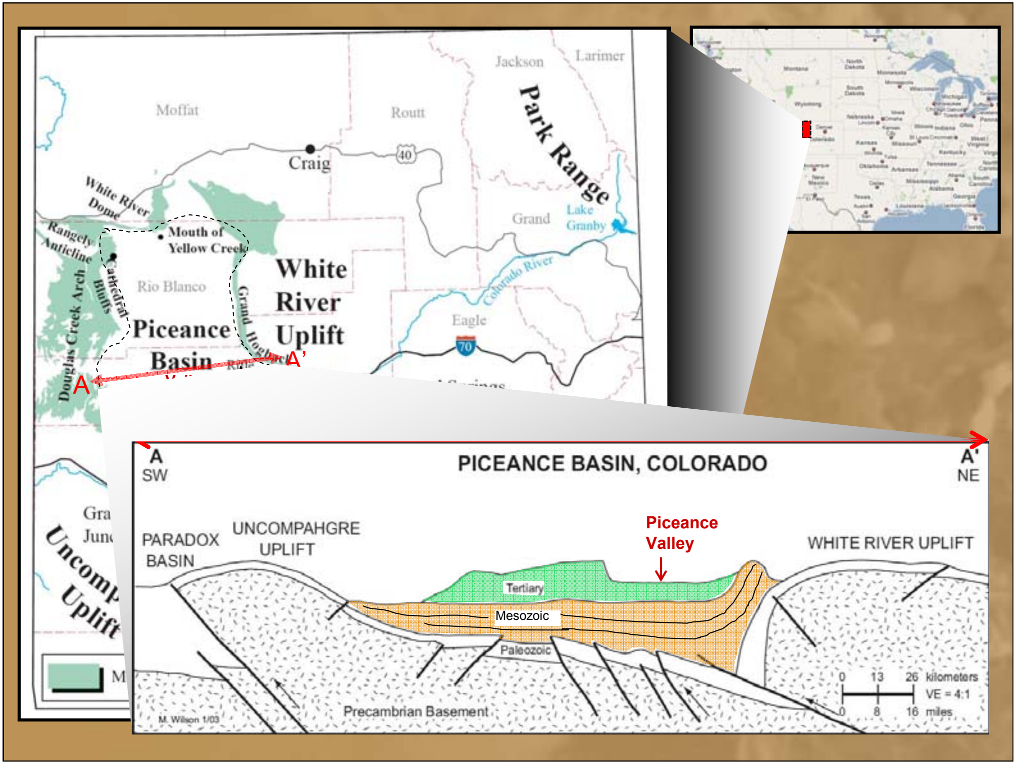








Moffat
Routt
Jackson
Larimer
Park Range
Craig
40
White River Dome
Rangely Anticline
Mouth of Yellow Creek
Cathedral Bluffs
Douglas Creek Arch
Rio Blanco
White River Uplift
Grand
Lake Granby
Colorado River
Grand Hogback
Piceance Basin
Eagle
70
Valley
Rifle
Garfield
Glenwood Springs
Battlement Mesa
Pitkin
Lake
Park
Sawatch Range
Grand Junction
Gunnison
Delta
Uncompahgre Uplift
50
Montrose
285
Salida
Mesaverde Group outcrops
0
25
50 Miles



Jackson
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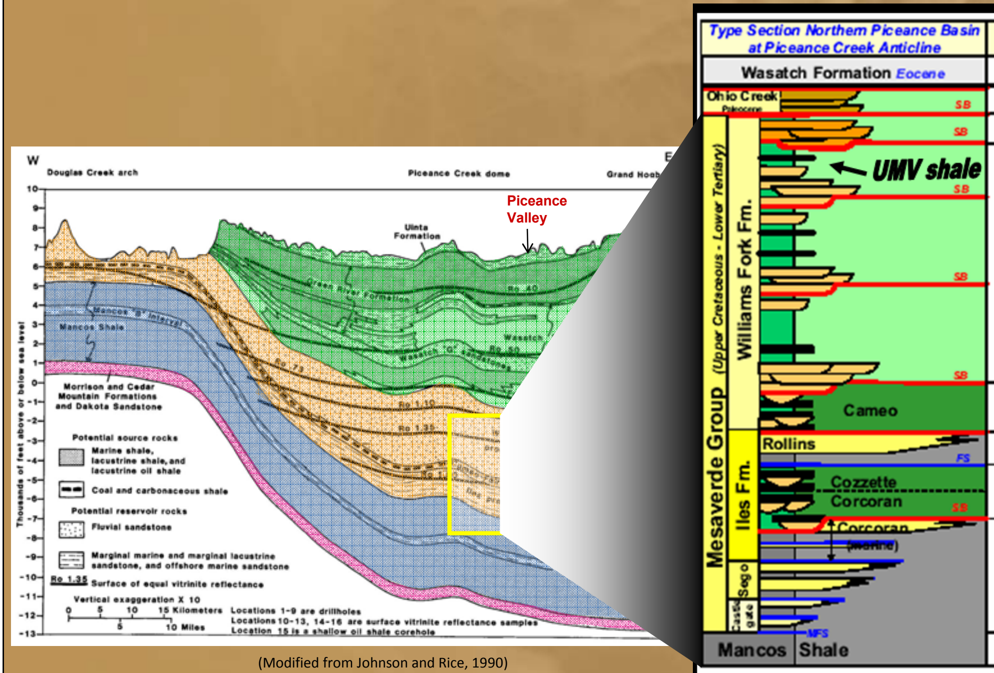
Colorado River
Eagle
70
A
A'
PICEANCE BASIN, COLORADO
SW
NE
PARADOX BASIN
UNCOMPAHGRE UPLIFT
Piceance Valley
WHITE RIVER UPLIFT
Tertiary
Mesozoic
Paleozoic
Precambrian Basement
M. Wilson 1/03
0 13 26 kilometers
0 8 16 miles
VE = 4:1

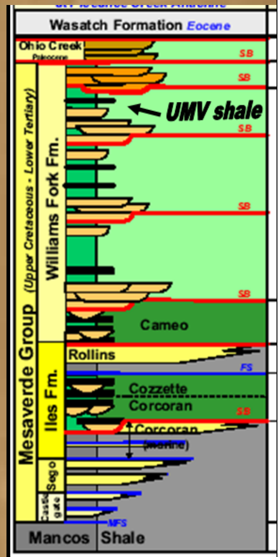


(Modified from Johnson and Rice, 1990)

(Modified from Patterson et al., 2003)

Artistic rendition of Late Cretaceous Interior Seaway

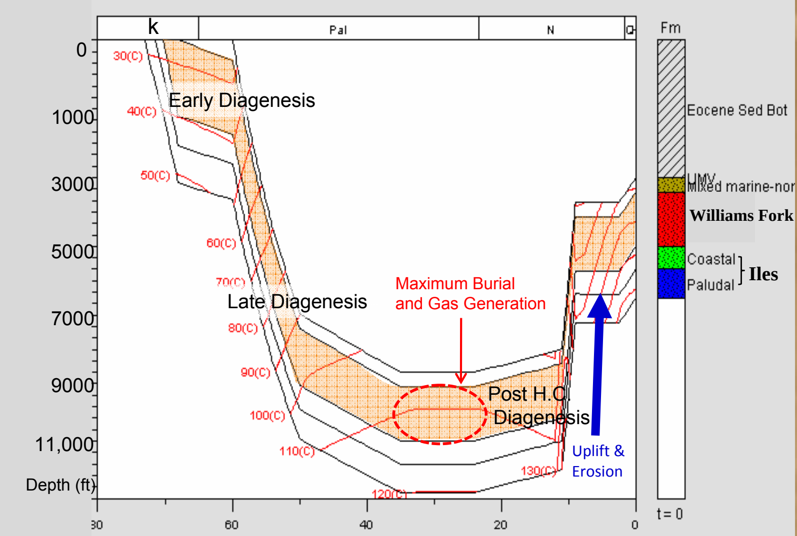
(From Cumella and Ostby, 2003 / Blakey, 2003)



(Modified from Patterson et al., 2003)

Presenter's Notes: The Maatrichtian Interior Seaway deposited the laterally extensive Mancos Shale above the Dakota formation, forming the base interval of hydrocarbon significant Mesaverde strata in the basin (figure 2). A regressive sequence of coastal deltaic sandstones, sourced from the Sevier Orogenic Belt, establish the Corcoran, Cozzette, and Rollins intervals of the Iles formation. The base of the Williams Fork is a coastal plain with meandering streams and the wide-ranging Cameo Coal. Moving up section, the Williams Fork becomes increasingly terrestrial with meandering and braided stream channels creating isolated lenticular sand bodies surrounded by shale. The Price Coal or "UMV" Shale forms a laterally extensive marker and is generally associated with the top of gas saturation in the Williams Fork (figure 3). Paleocene and Eocene age strata overlying the Mesa Verde are sourced from uplifts on the eastern edge of the basin and generally not considered economic in the Rulison area.

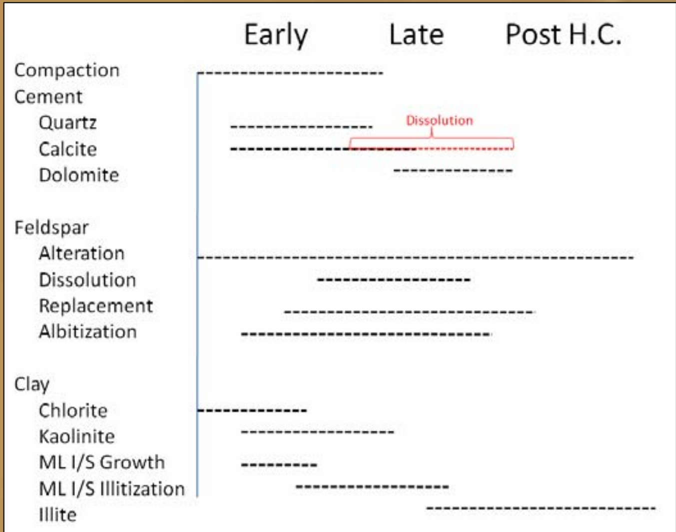
Burial history profile
MWX wells – Rulison Field



(after Crossey and Larsen,1992)

Generalized diagenetic sequence for the Williams Fork Formation

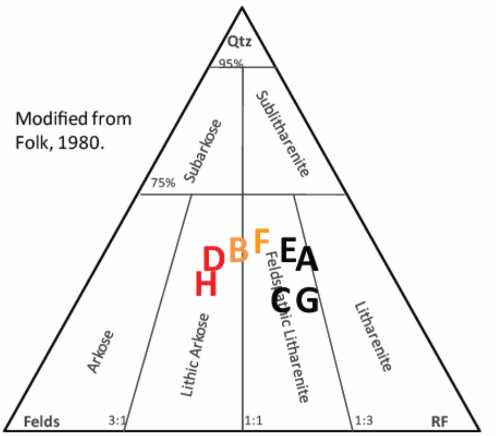
During burial, changes in depth/temperature resulted in specific mineral alterations and clay assemblages.



Presenter's Notes: So why is this important, there are two places that this material can

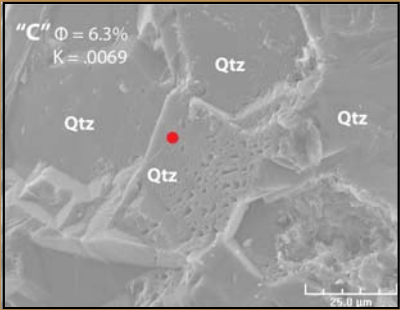
General Lithology

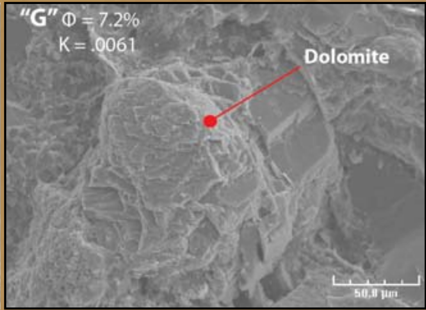
Interval	Porosity % (at 1200 psi)	Permability md (at 1200 psi)
A	**4.6**	**0.0061**
G	**7.2**	**0.0061**
C	**6.3**	**0.0069**
E	**7.7**	**0.0071**
B	**6.9**	**0.020**
F	**6.9**	**0.028**
D	**11.6**	**0.010**
H	**12.9**	**0.042**

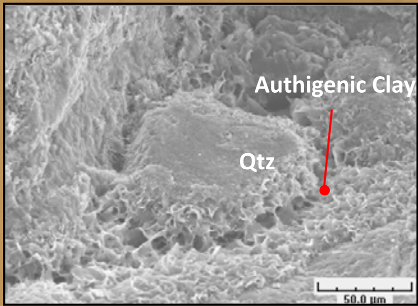


***Chert = Rock Fragments**

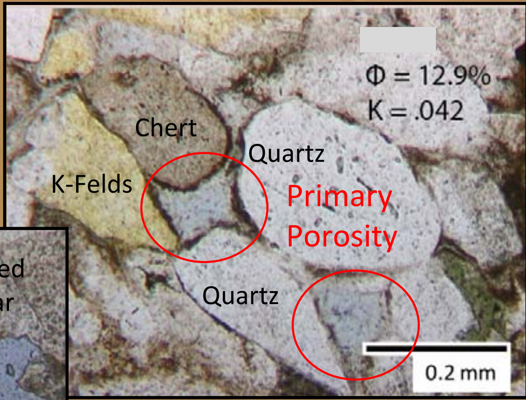
Cement Types:

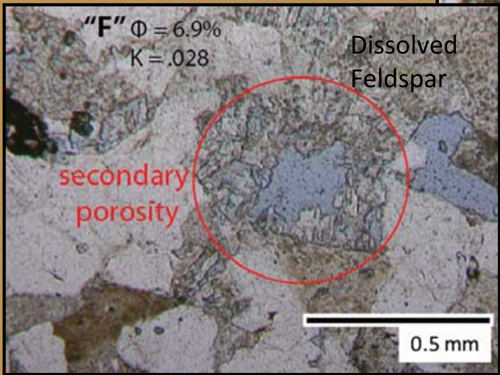




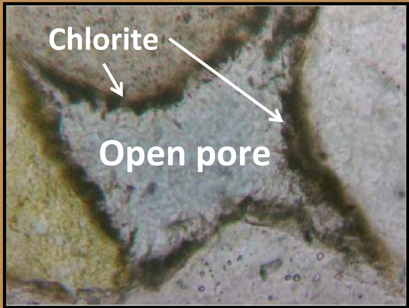


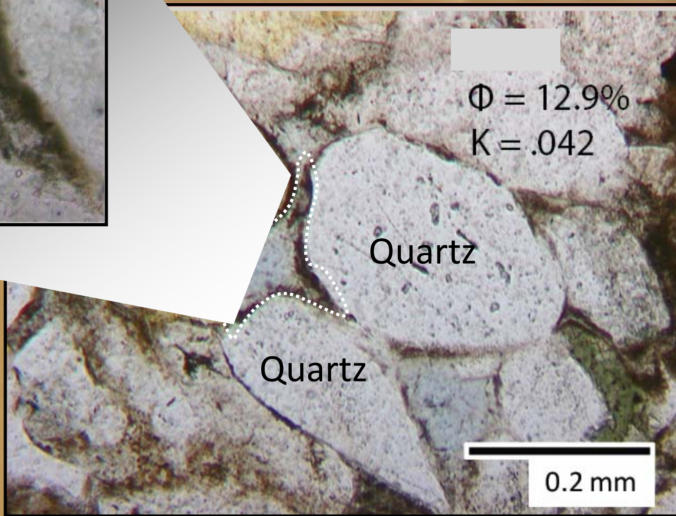
Porosity Types:





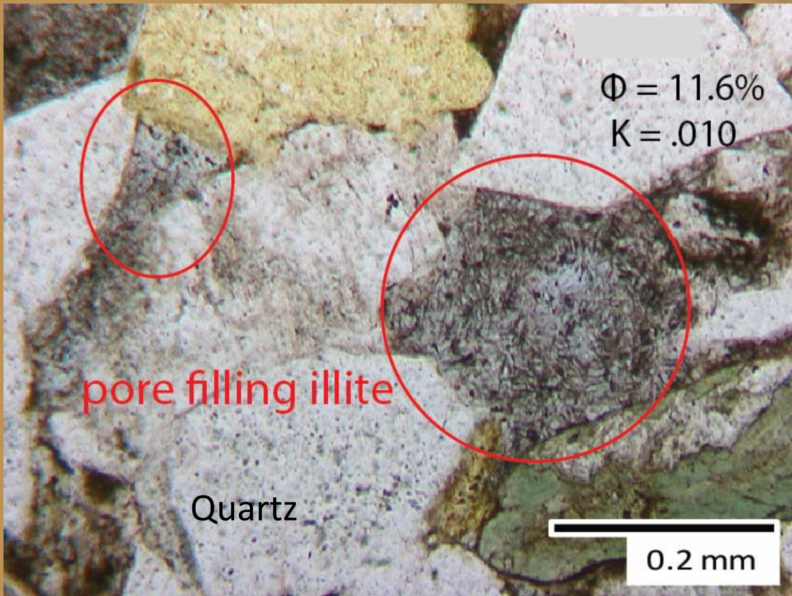
Pore-lining Clay



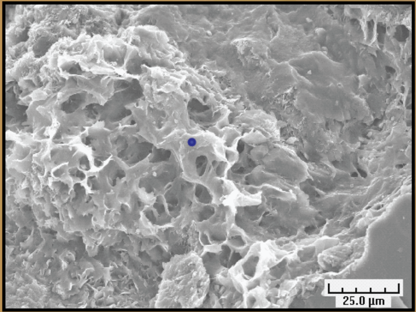


Chlorite grain coating around mostly open pore space

Pore-Filling Clay

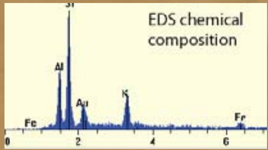


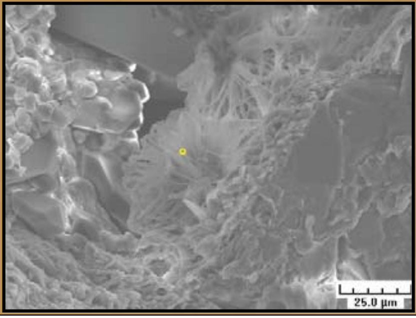
Illite polytypes found in the samples



2M1 – lath-like illite

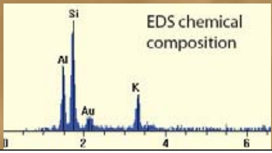
- Replacement of smectite = MLIS
- Smectite + K + Al → illite + Na + S
- Lower temp.
- Larger crystal size





1M – discrete fibrous illite

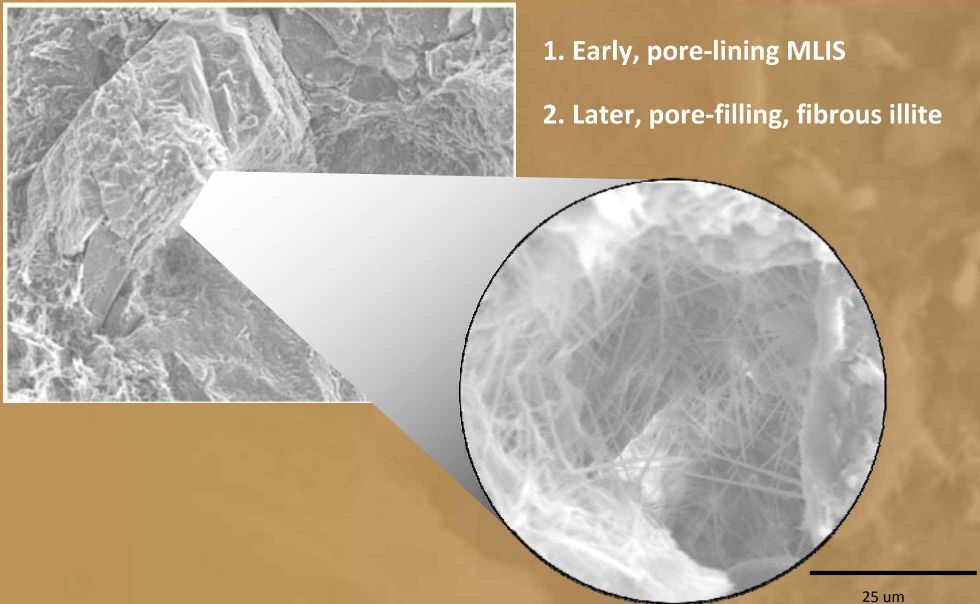
- Higher temperature
- Smaller crystal size
- Fluid super-saturation precipitation



Two Stages of Illite Growth

1. Early, pore-lining MLIS

2. Later, pore-filling, fibrous illite

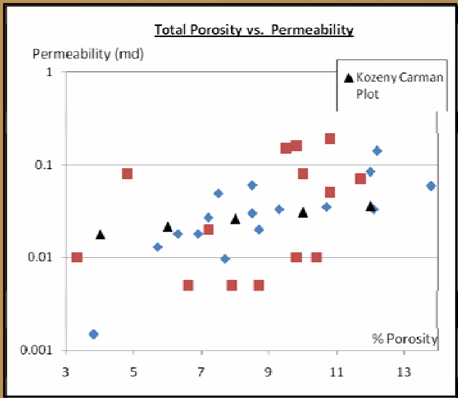


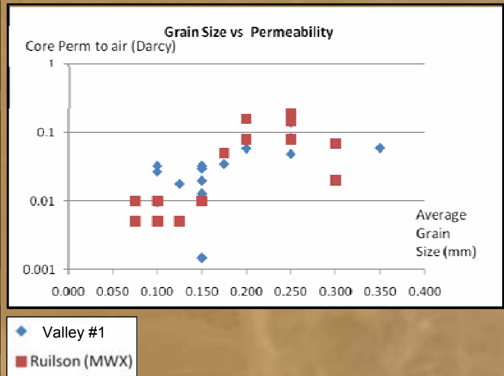
Influence of diagenetic alterations on porosity/permeability

Kozeny Carman Equation:

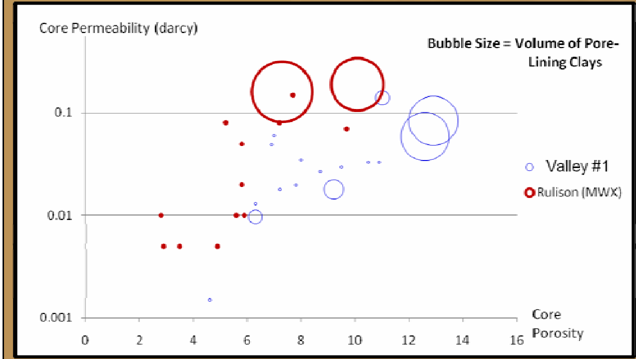
$$K = \frac{\emptyset^3}{CS_o^2(1-\emptyset^2)}$$

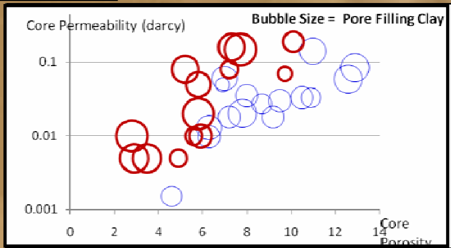
K = permeability, Φ = porosity
C = tortuosity
S_o = surface area per unit volume of solid phase





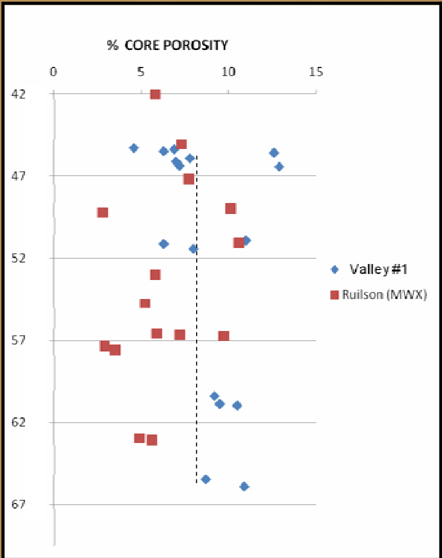
Influence of different clay types

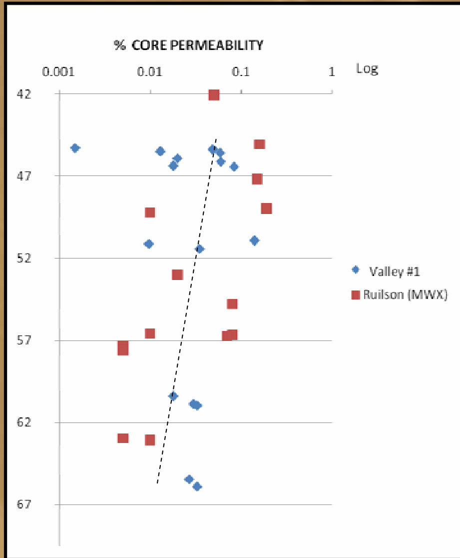




Porosity vs. Permeability

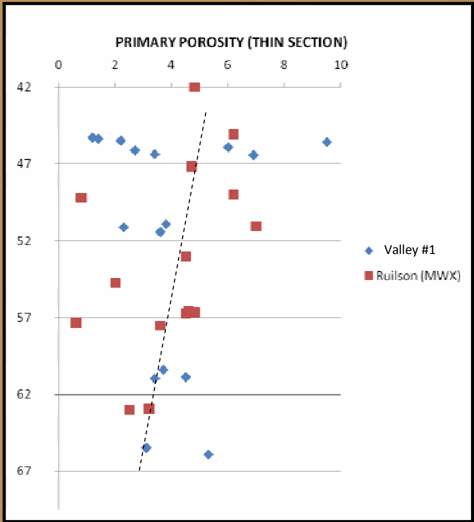
Porosity and Permeability vs. Depth

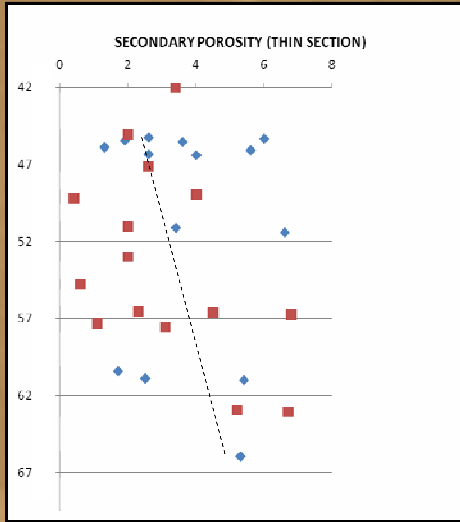




Primary vs. Secondary porosity

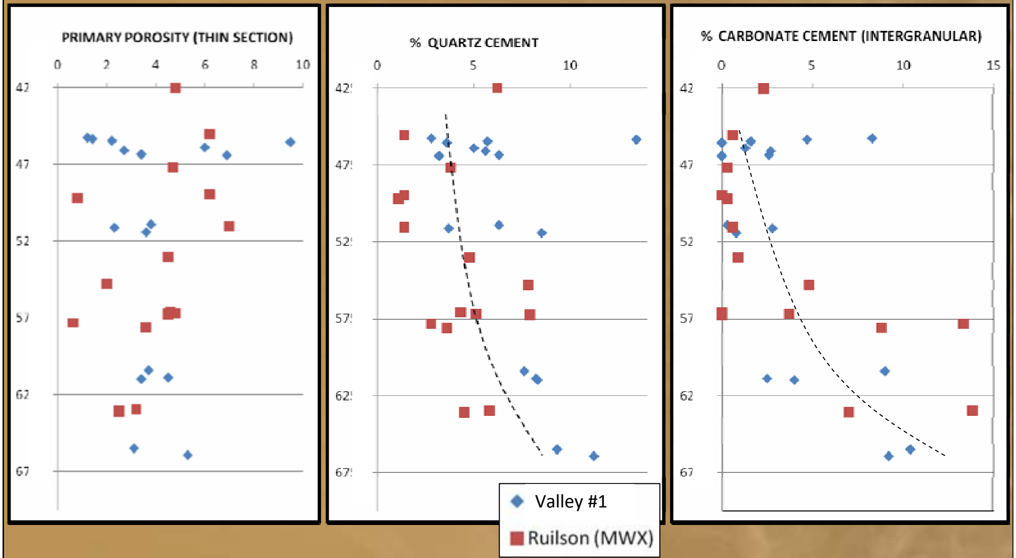
Change in dominant porosity “type” with Depth





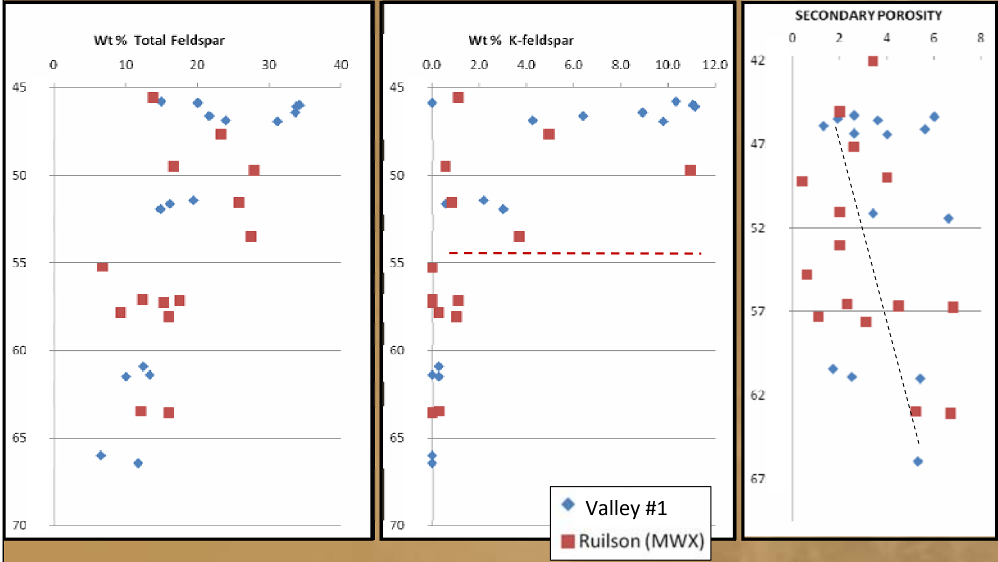
Intergranular Cement

Quartz and Carbonate Cement Increases with Depth



Feldspar Dissolution

Feldspar Decreases with Depth



What Happened to the K-Feldspar?

- $KAlSi_3O_8$ *(K-Feldspar)* + ⅔ H^+ →

  ⅔ K^+ + ⅓ $KAl_3Si_3O_{10}(OH)_2$ *(illite)* + 2 SiO_2 *(aq)*

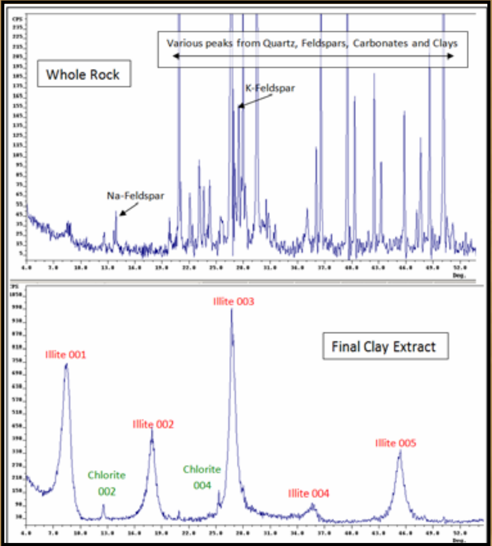
  4.5 K^+ + 8 Al^{+3} + smectite → illite + Na,Ca,Mg,Fe,Si

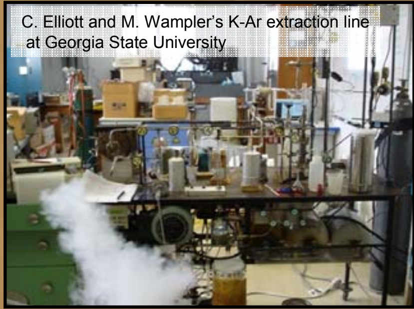
  and/or

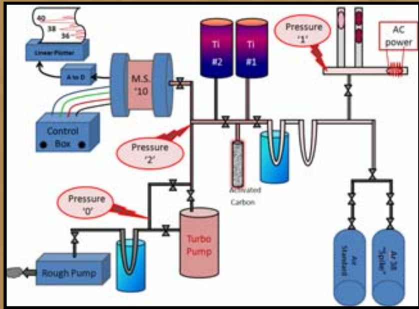
  4 K^+ + 1.6 smectite → illite + Na,Ca,Mg,Fe,Si

	K-feldspar wt%		Fib. Illite wt%		MLIS wt %		Kaolinite wt %		Chlorite wt %	
	SS	Shale	SS	Shale	SS	Shale	SS	Shale	SS	Shale
Upper fluvial	4.9	2.2	3.4	18.4	3.5	17.2	0	0.5	3.8	4.9
Lower fluvial	0.1	0.01	2.2	14.7	3.7	13.7	0	0.7	1.3	0.3

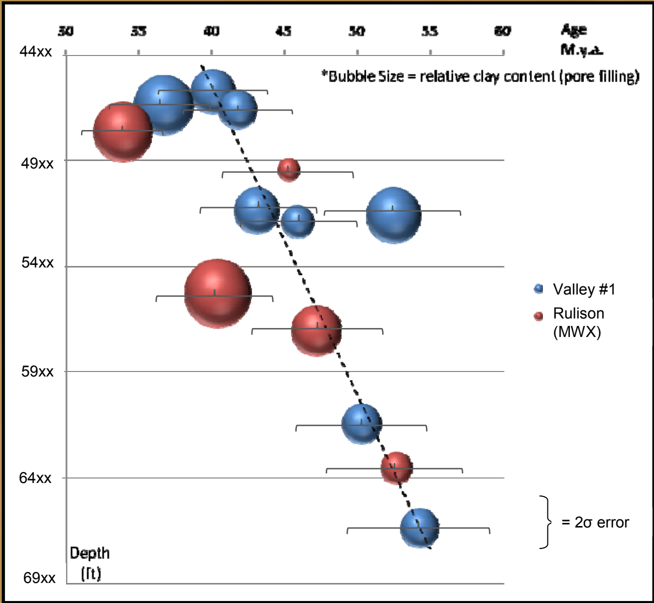
Clay Extraction and K-Ar Dating



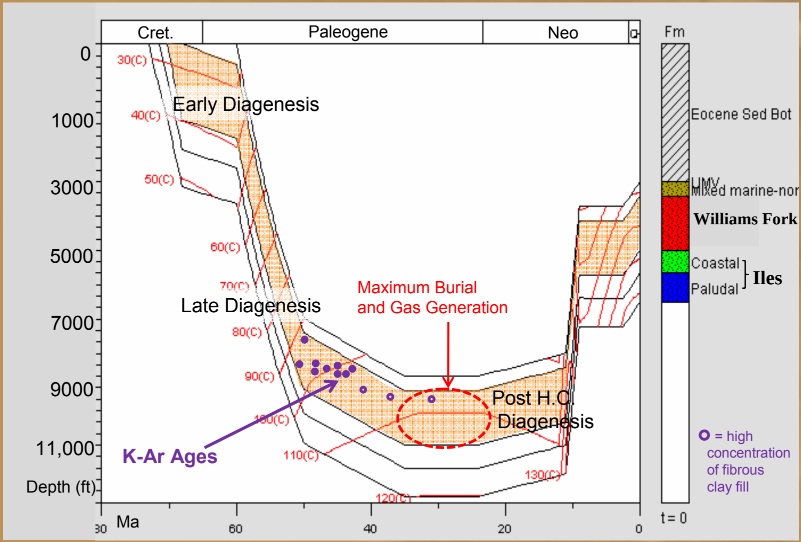




K-Ar Age Dating Results

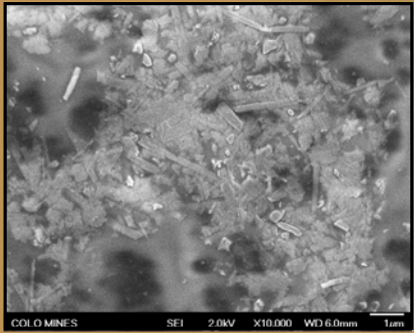


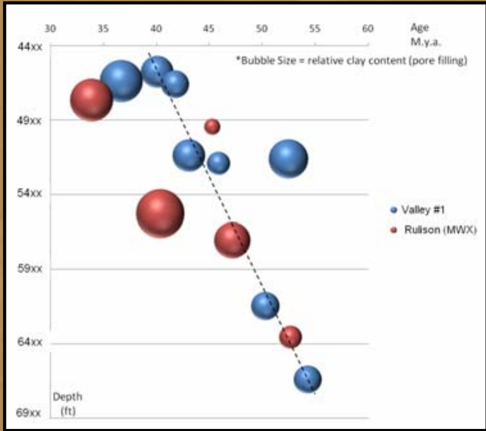
Burial history profile
MWX wells – Rulison Field

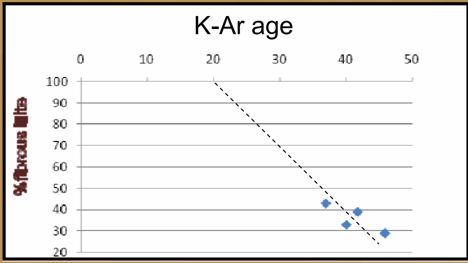


(after Crossey and Larsen,1992)

Clay Extract – age of fibrous illite component







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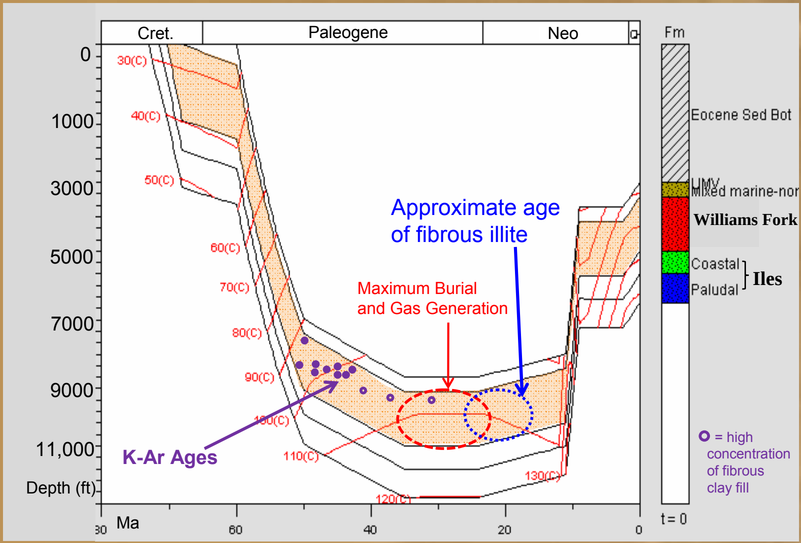
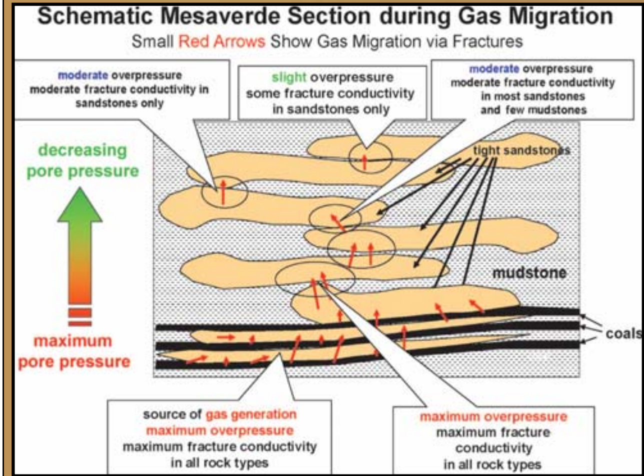
MWX wells – Rulison Field

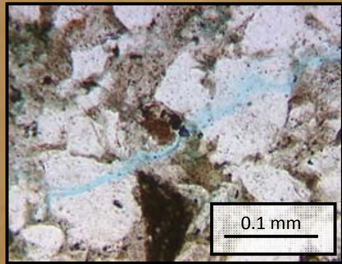


(after Crossey and Larsen,1992)

Fluid Movement Along Fractures
(Driven by Gas Charge)

MWX #1 at 5755'

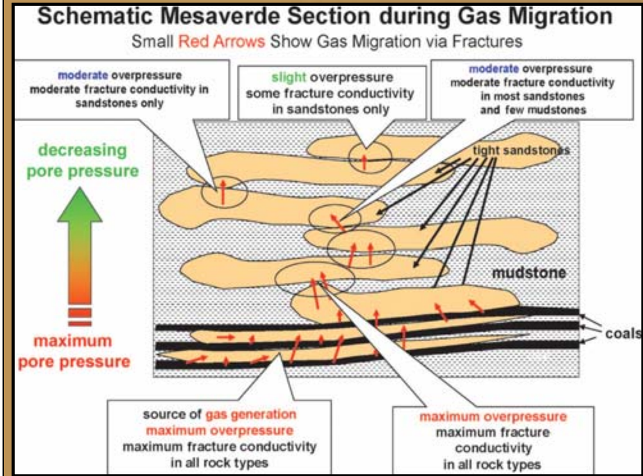


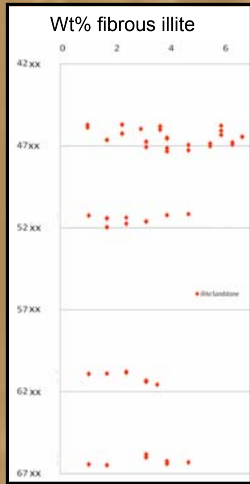


(from Cumella and Scheevel, 2008)

Fluid Movement Along Fractures

(Driven by Gas Charge)

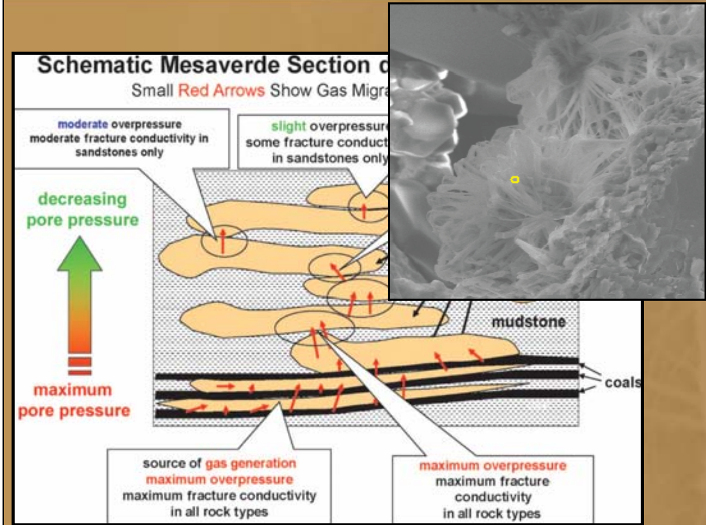


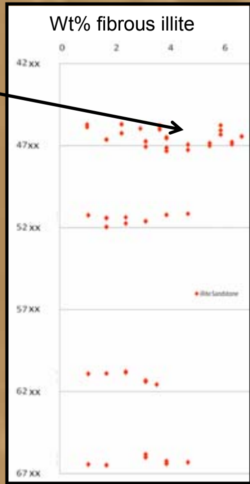


(from Cumella and Scheevel, 2008)

Fluid Movement Along Fractures

(Driven by Gas Charge)

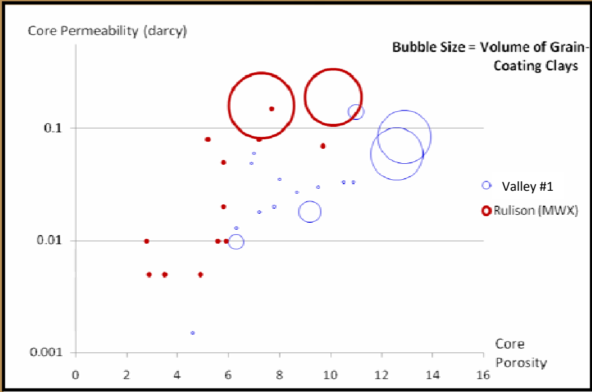


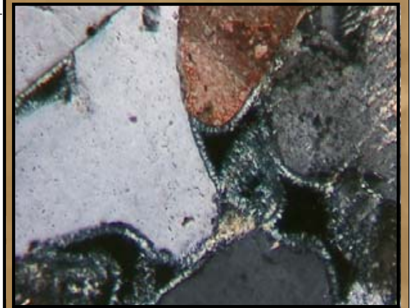


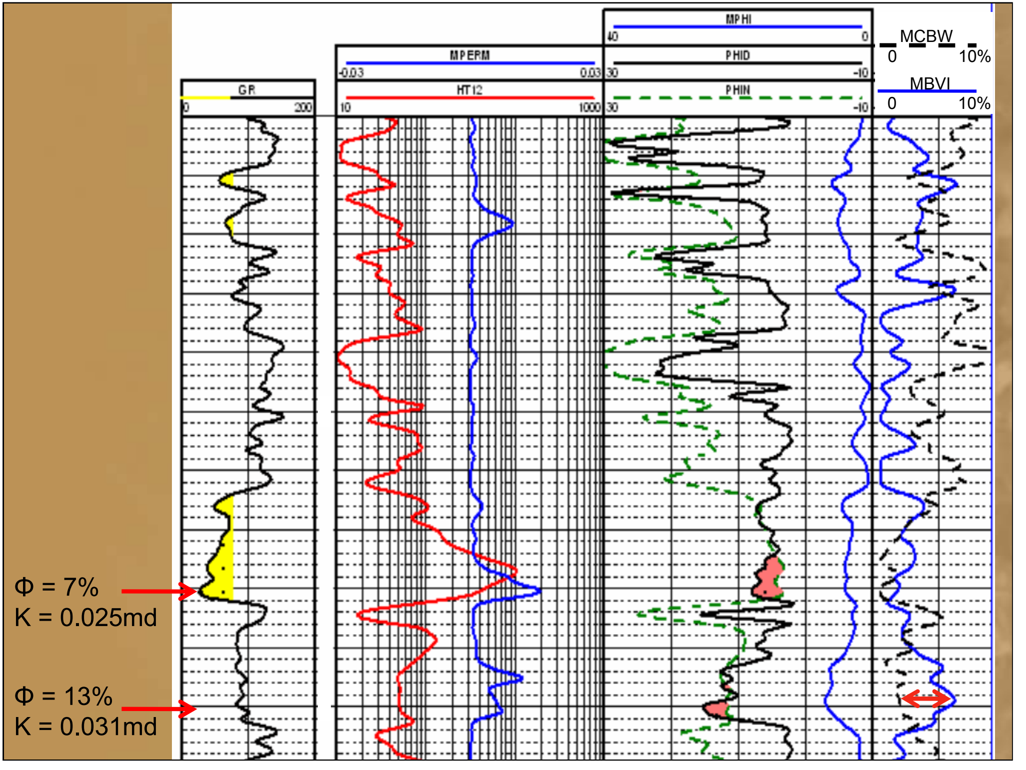
(from Cumella and Scheevel, 2008)

Diagenetic Influences on Reservoir Properties

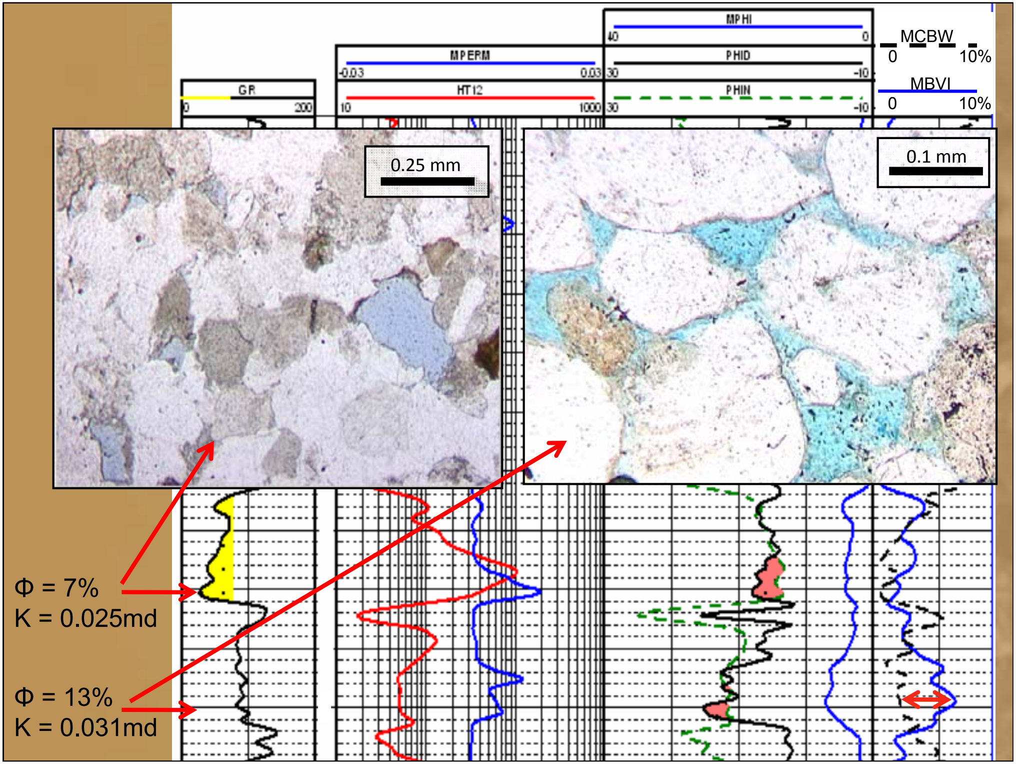
Grain Coating Clay (chlorite, illite) → increased porosity and permeability







Presenter's Notes: So why is this important, there are two places that this material can



Presenter's Notes: So why is this important, there are two places that this material can

Conclusions

- Primary porosity decreases with depth, while secondary porosity increases.
  Result: total porosity is essentially constant with respect to depth.

- Permeability decreases because porosity becomes more disconnected as intergranular pore space is filled with cement.

- K-Ar dates indicate:
  1. smectite illitization occurred during early burial in response to thermal alteration
  2. significant fibrous illite emplacement occurred concurrent with maximum gas generation in the Williams Fork.

- Authigenic clays have significant influence on reservoir properties
  - Pore-filling fibrous illite = decreased permeability
  - Grain-coating chlorite/illite = higher porosity/permeability
  - Petrophysics intended to characterize clays is useful in these sandstones

Thanks to:

The Reservoir Characterization Project

ExxonMobil

Williams

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