History of Hydrothermal Fluid Flow in the Midcontinent: A Key to Understanding the Origin and Distribution of Porosity*

Robert Goldstein[1] and Bradley King[1]

Search and Discovery Article #50958 (2014)**
Posted May 31, 2014

*Adapted from oral presentation given at Mississippian Lime Play Forum, Oklahoma City, Oklahoma, February 20, 2014

[1]University of Kansas, Lawrence, KS (gold@ku.edu)

Abstract

Ordovician, Mississippian, and Pennsylvanian strata in Kansas all show fracturing, megaquartz, silica dissolution, carbonate dissolu-tion, baroque dolomite, MVT minerals, and calcite after stylolitization. CL petrography, fluid inclusions, $^{87}Sr/^{86}Sr$, and $\delta^{18}O$ indicate hydrothermal fluid flow affected Ordovician-through-Pennsylvanian stratigraphic units.

The history is simplified into three phases of hydrothermal fluid flow (86-144ºC). All show evidence of thermal pulses, suggesting tectonic valving. Phase I was from brines near seawater salinity, interpreted as connate fluids migrating out of the Anadarko basin, likely during the Pennsylvanian or early Permian. Fluids were associated with gas, and precipitated megaquartz.

Phase II led to precipitation of baroque dolomite. Fluid inclusion data indicate high salinities (20 wt. %) and $^{87}Sr/^{86}Sr$ indicate advective fluid flow across long distances. $\delta^{18}O$ data indicate the Ordovician-Mississippian section acted as an aquifer in vertical communication, leading to warmer fluids and preferred flow towards the top of the Mississippian. The shale-rich Pennsylvanian section acted as a leaky confining unit. This phase of fluid flow was associated with oil migration and likely occurred late in the Permian or after.

The first two phases of hydrothermal fluid flow are associated with fracturing, silica dissolution and carbonate dissolution. Much of the porosity, typically assumed to originate from subaerial weathering, may have been generated by these late hydrothermal fluids. The fluids followed fracture systems and were concentrated along the tops of hydrothermal aquifers by stratigraphic discontinuities and temperature-controlled density differences. This model for hydrothermal porosity formation helps to explain the spatial variation in reser-voir quality in the Mississippian and leads to an enhanced model for locating the best producers.

Phase III of hydrothermal fluid flow was complex, and is recorded by calcite cements. Spatial variation of $\delta^{18}O$ and $^{87}Sr/^{86}Sr$ indicate cessation of advective fluid flow and initiation of localized vertical fluid flow, possibly directly from basement. A driver could be localized faulting and fracturing associated with Laramide or other deformation. Comparison of fluid inclusion temperature and salinity data to modern reservoir

conditions indicate that this phase clearly predates the current fluid flow and thermal regime, but played a part in evolution of the reservoir system.

Selected References

Gallardo, J.D., and D.D. Blackwell, 1999, Thermal structure of the Anadarko Basin: AAPG Bulletin, v. 83/2, p. 333-361.

Garven, G., S. Ge, M.A. Person, and D.A. Sverjensky, 1993, Genesis of stratabound ore deposits in the Midcontinent basins of North America; 1, The role of regional groundwater flow: American Journal of Science, v. 293/6, p. 497-568.

Miller, J.A., and C.L. Appel, 1997, Groundwater atlas of the United States, Kansas, Missouri, and Nebraska: USGS HA 730-D, 300 p.

Wojcik, K.M., M.E. MCKibben, R.H. Goldstein, and A.W. WALTON, 1994, History of diagenetic fluids in a distant foreland area, Middle and Upper Pennsylvanian, Cherokee Basin, Kansas, USA: Fluid inclusion evidence: Geochimica et Cosmochimica Acta, v. 58, p. 1175-1191.

History of hydrothermal fluid flow in the Midcontinent: A key to understanding the origin and distribution of porosity?

Robert H. Goldstein and Bradley D. King

KICC, University of Kansas, Department of Geology

Purpose

- Integrate petrographic and geochemical data to provide new insights into ancient fluid flow, thermal history, hydrocarbon migration, and origin of porosity
- Study Arbuckle through Pennsylvanian in Midcontinent to show three-stage evolution of hydrothermal system
- New conceptual model for hydrothermal fluid flow useful in predicting the distribution of porosity in the subsurface

Purpose

- Utility in predicting distribution of porosity
  - Investigate the paradigm that enhanced porosity in chert and carbonates is only related to subaerial weathering
  - Show that much of this porosity forms late, in association with hydrothermal fluid flow
  - If controlled by hydrothermal fluid flow, late timing, structural, and stratigraphic controls are key to reservoir properties

Study Area

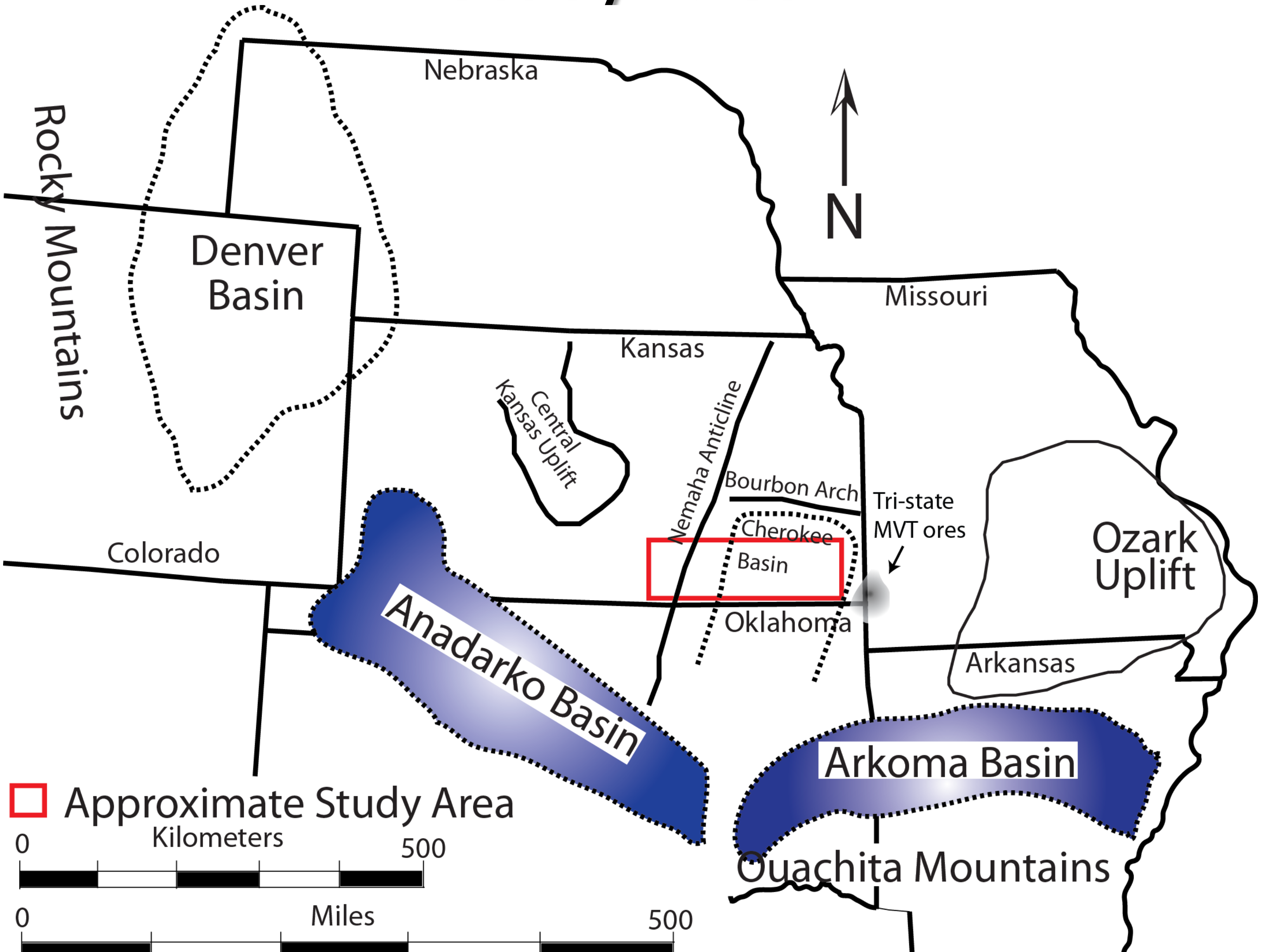
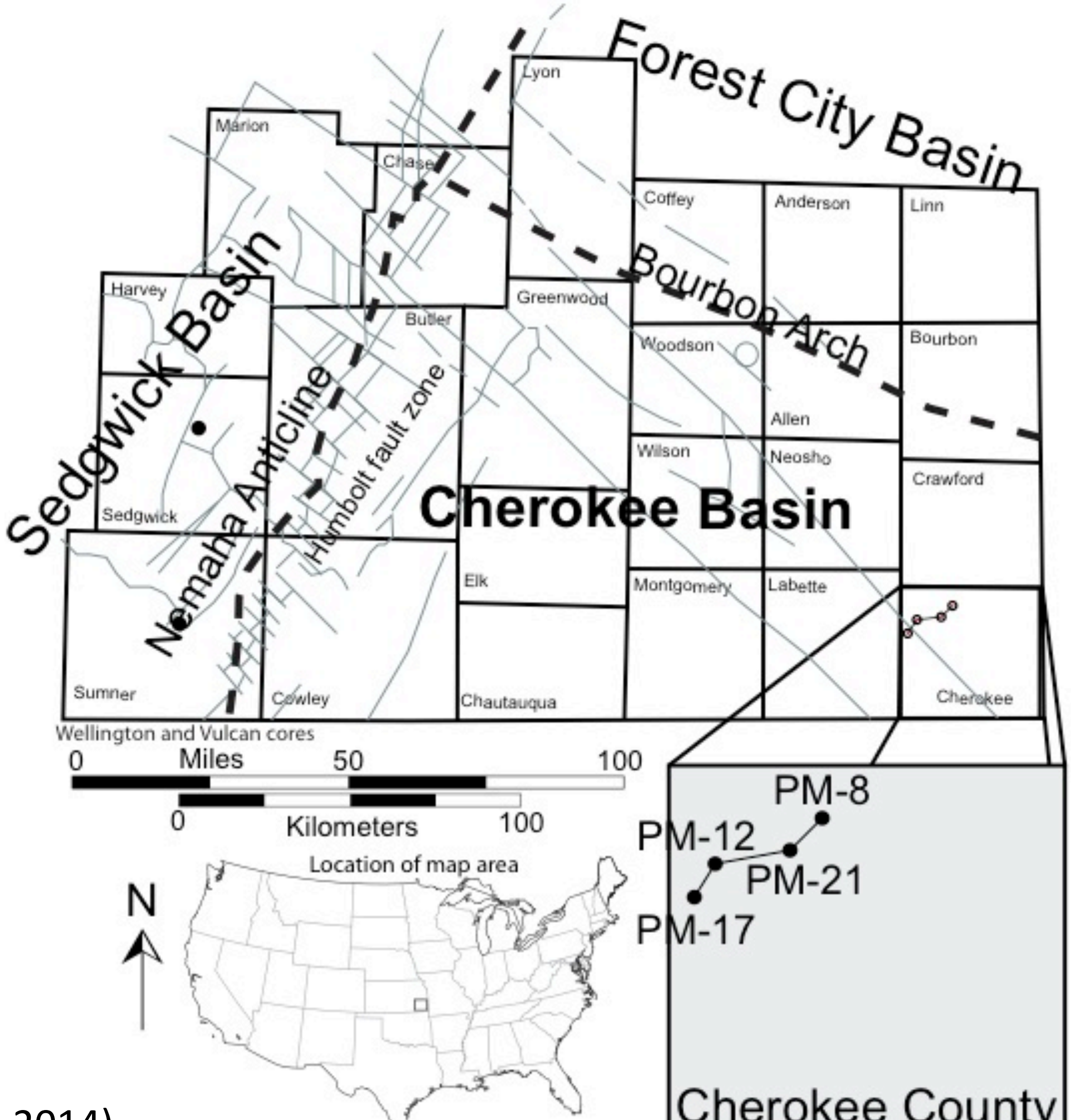
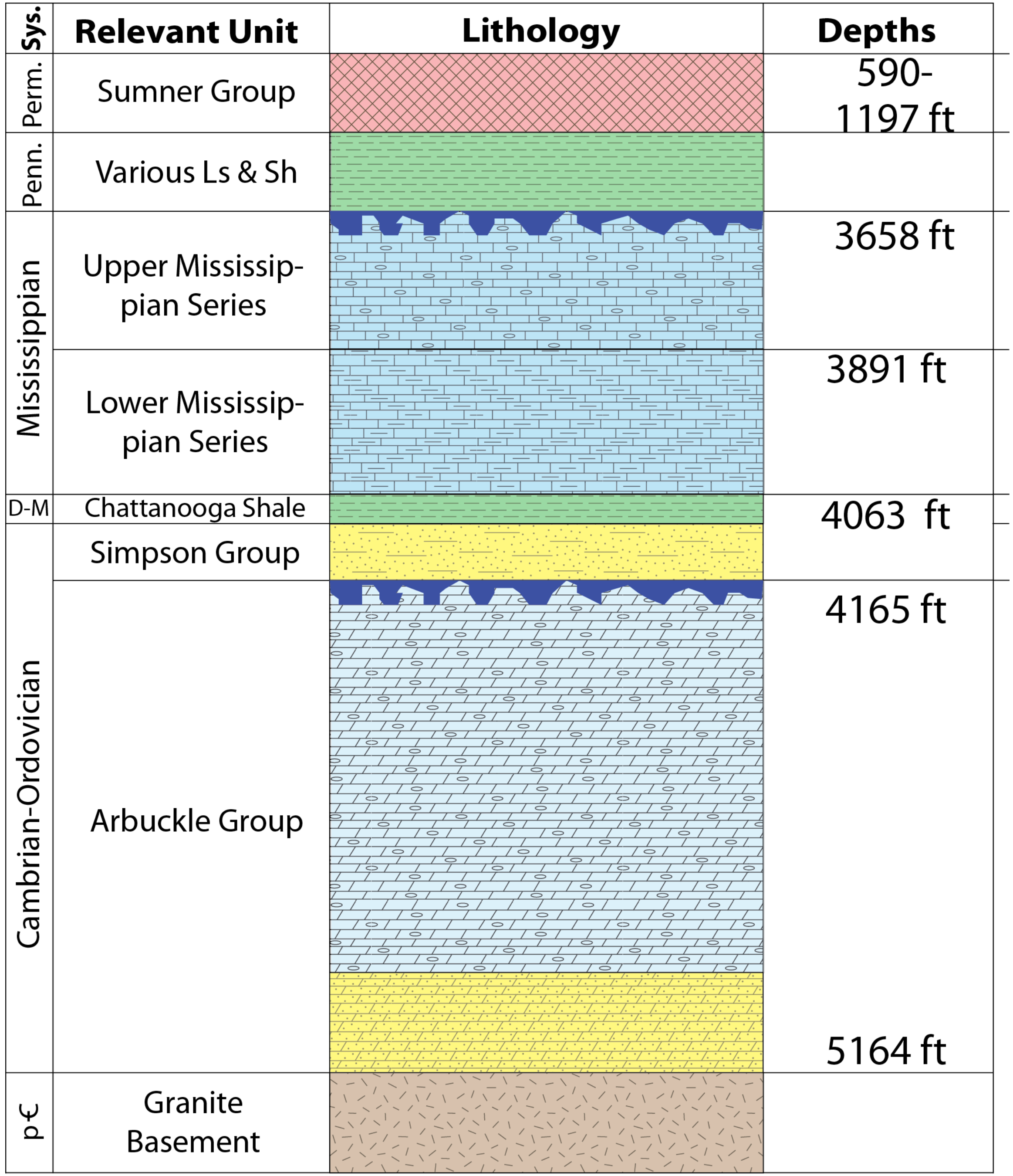


Image modified from Garven, 1993

Study Area

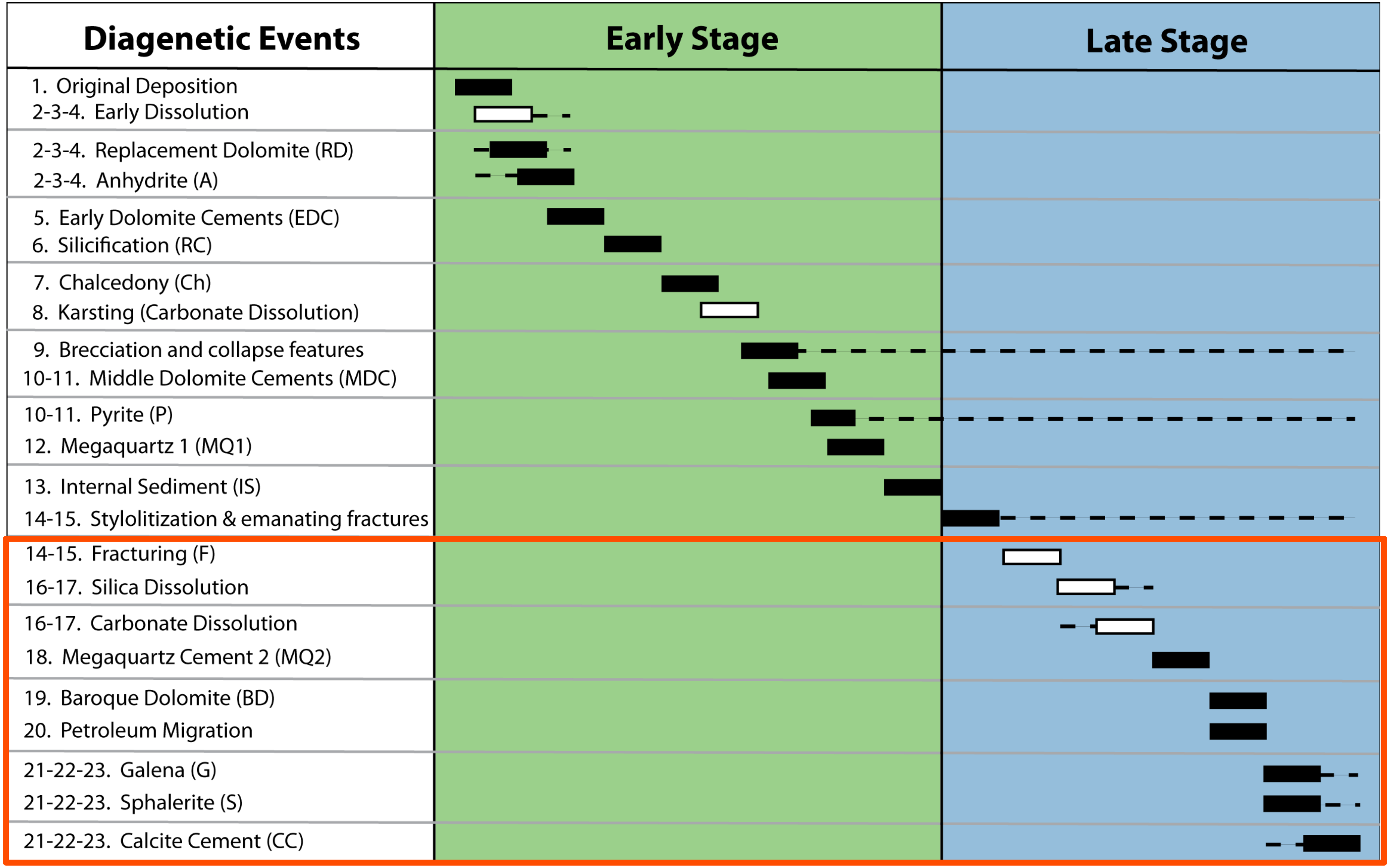


(Ramaker et al., 2014)

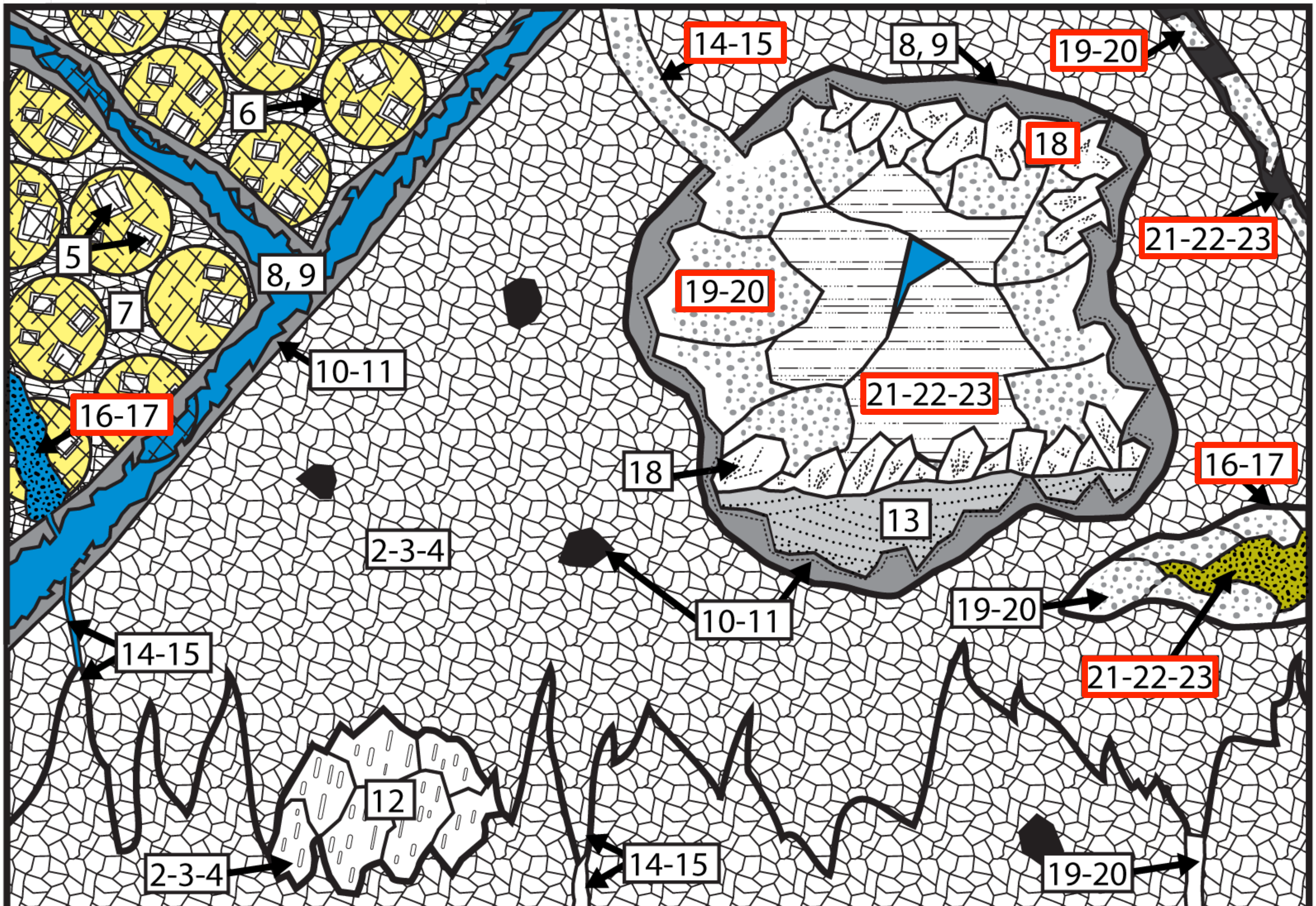

Sys.
Relevant Unit
Lithology
Depths
Perm.
Sumner Group
590-
1197 ft
Penn.
Various Ls & Sh
Mississippian
Upper Mississip-
pian Series
3658 ft
Lower Mississip-
pian Series
3891 ft
D-M
Chattanooga Shale
4063 ft
Cambrian-Ordovician
Simpson Group
Arbuckle Group
4165 ft
5164 ft
p€
Granite
Basement

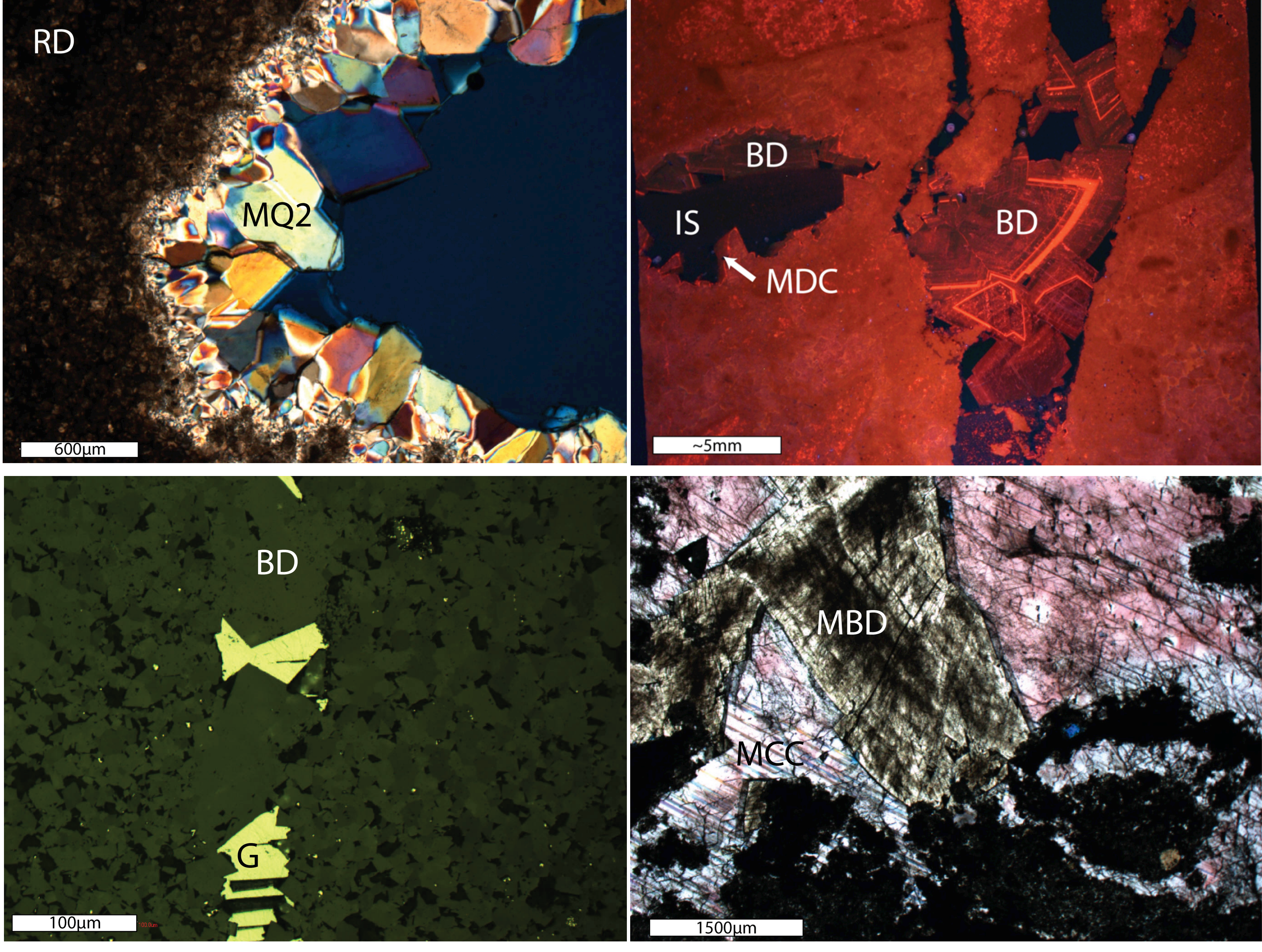
* Not to scale

Arbuckle Group Late Paragenesis

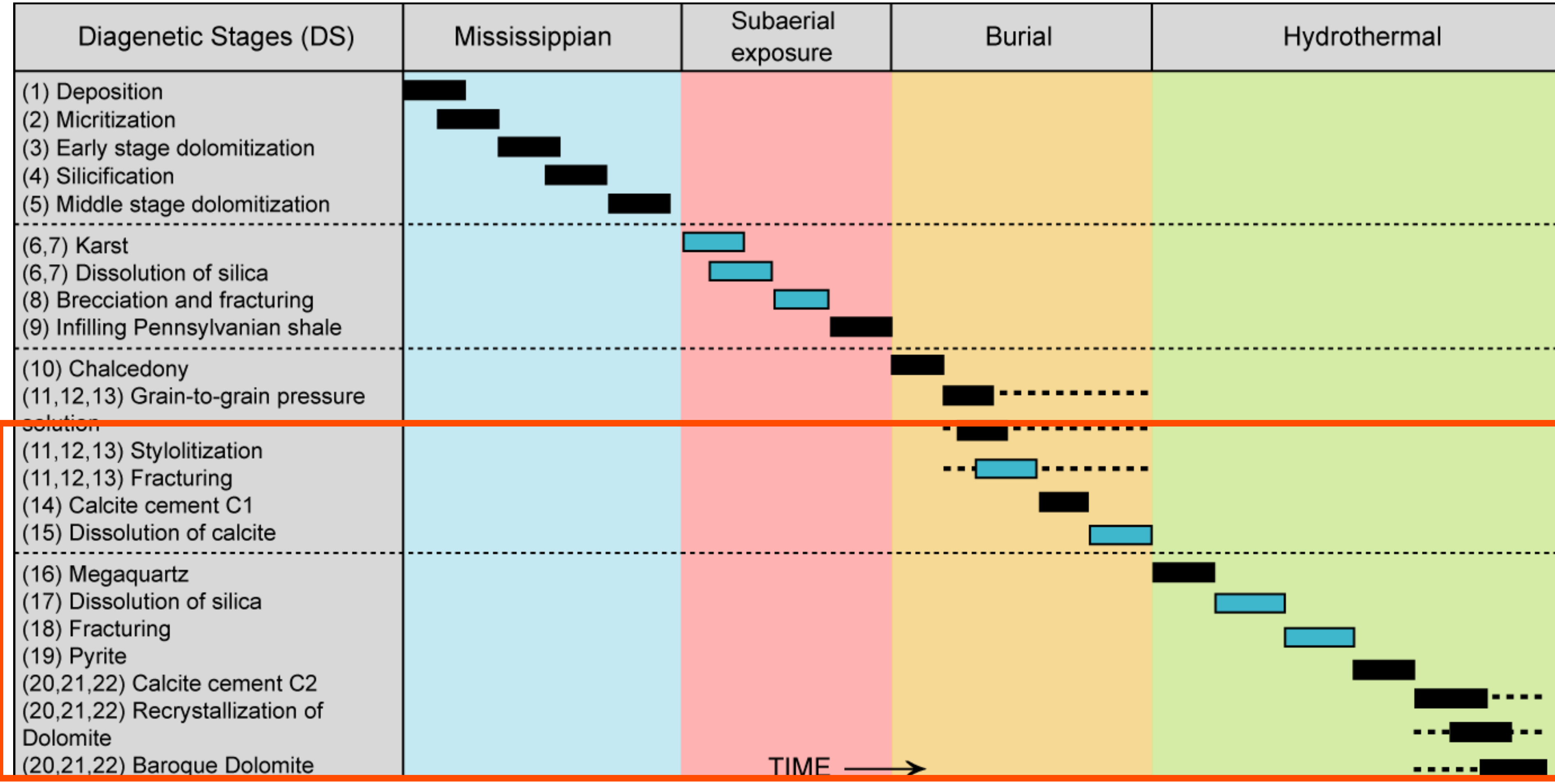


Arbuckle Group Ideal Paragenesis




RD
MQ2
600µm
BD
IS
MDC
BD
~5mm
BD
G
100µm
MBD
MCC
1500µm

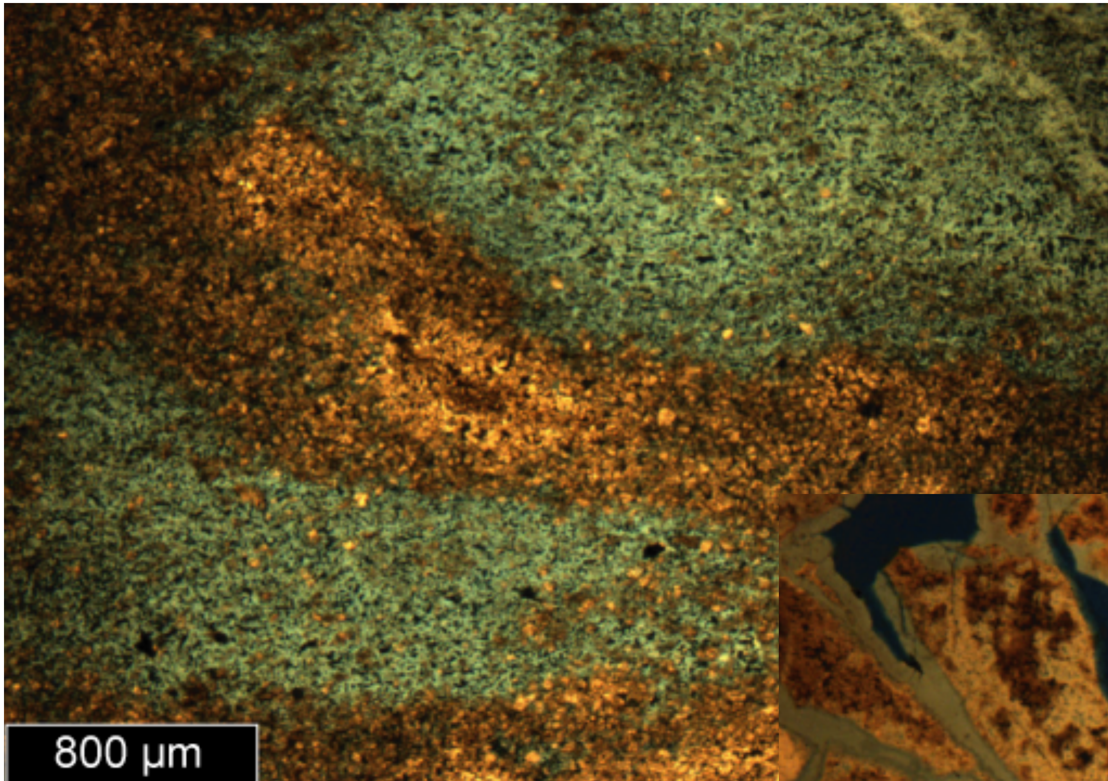
Mississippian Diagenetic History

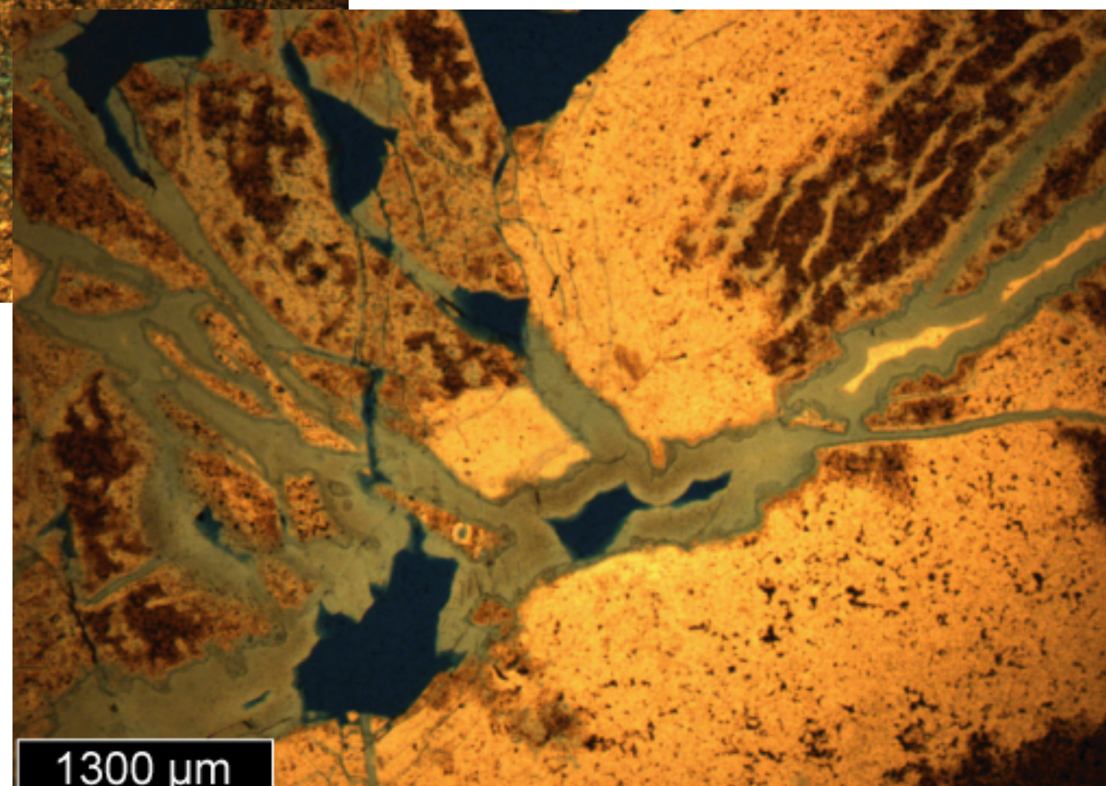


POROSITY DEVELOPMENT

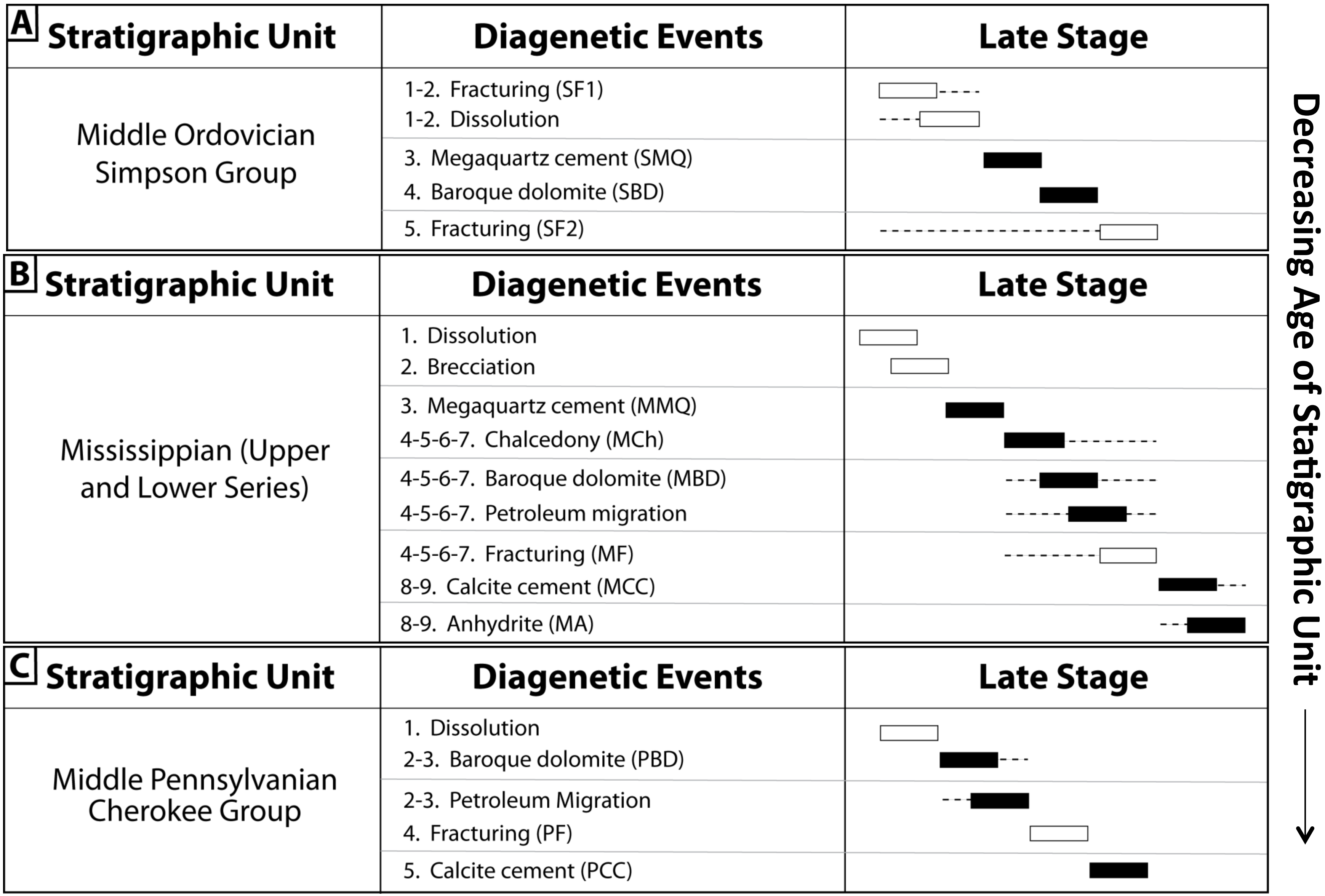
(Ramaker et al., 2014)

Porosity Enhancement in Silica Phases

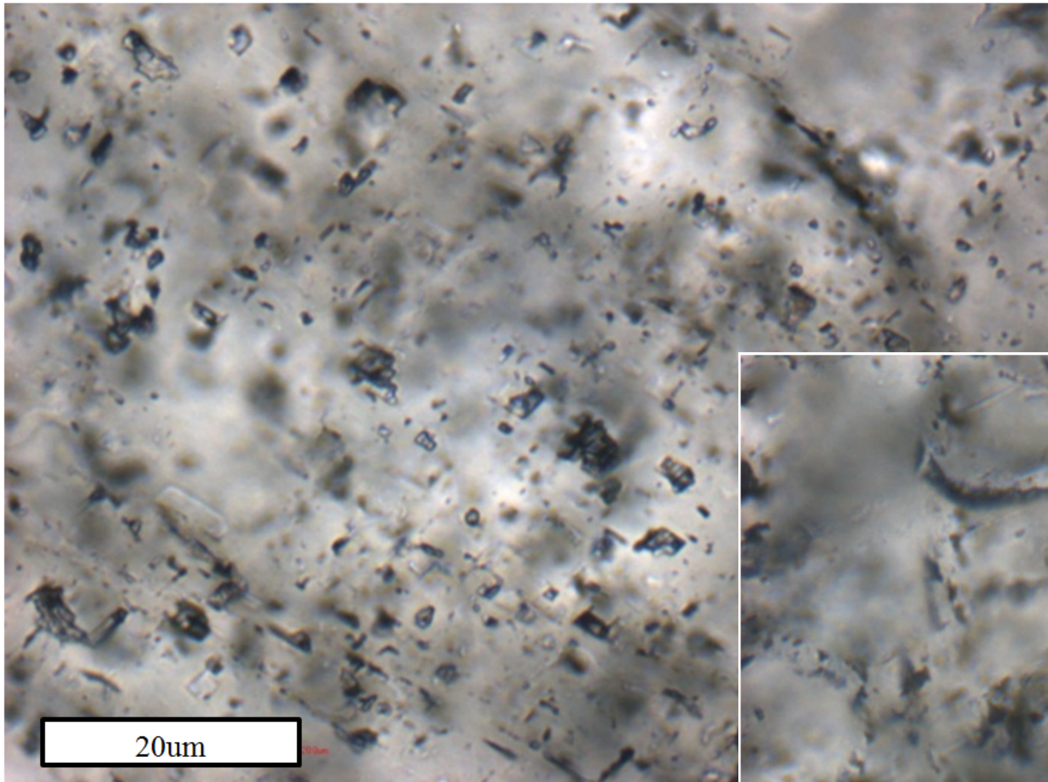




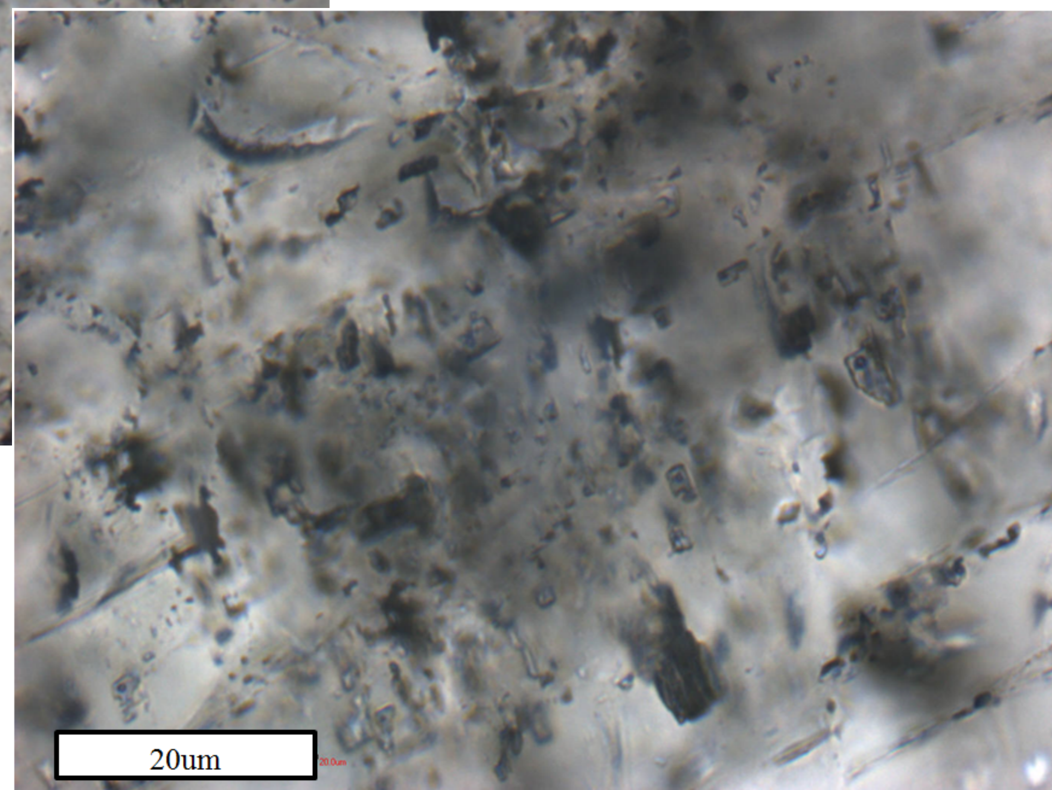
Similar Late-Stage Paragenesis in All Units



Fluid Inclusion Evidence for Hydrothermal Fluid

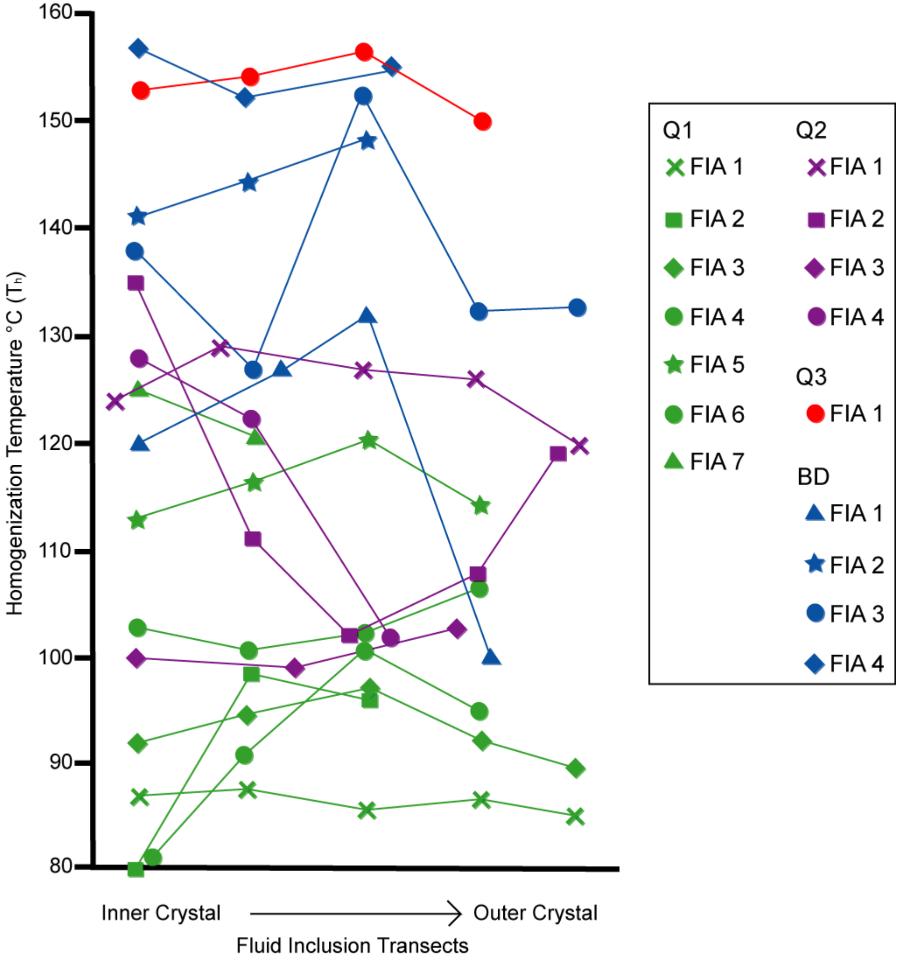


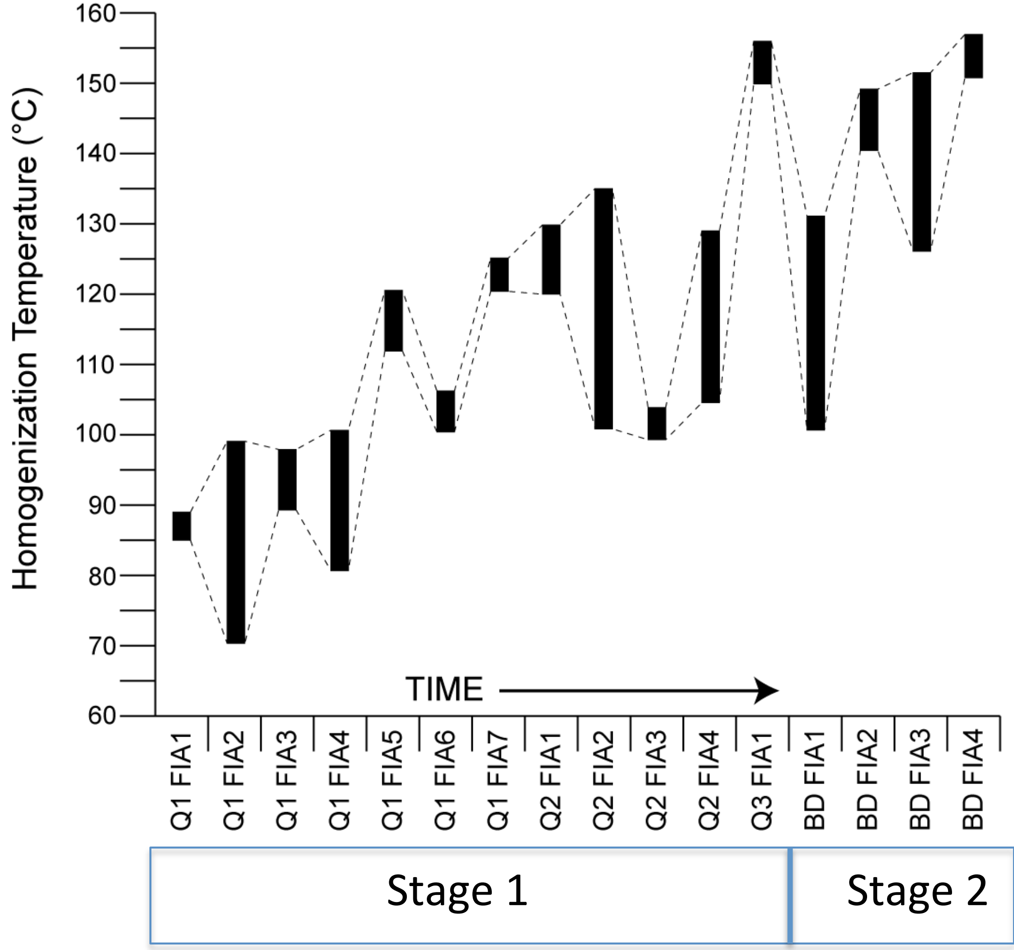
- Primary Fluid Inclusions in Arbuckle Baroque Dolomite



- Primary Fluid Inclusions in Mississippian Baroque Dolomite

Fluid Inclusion Evidence for Hydrothermal Conditions

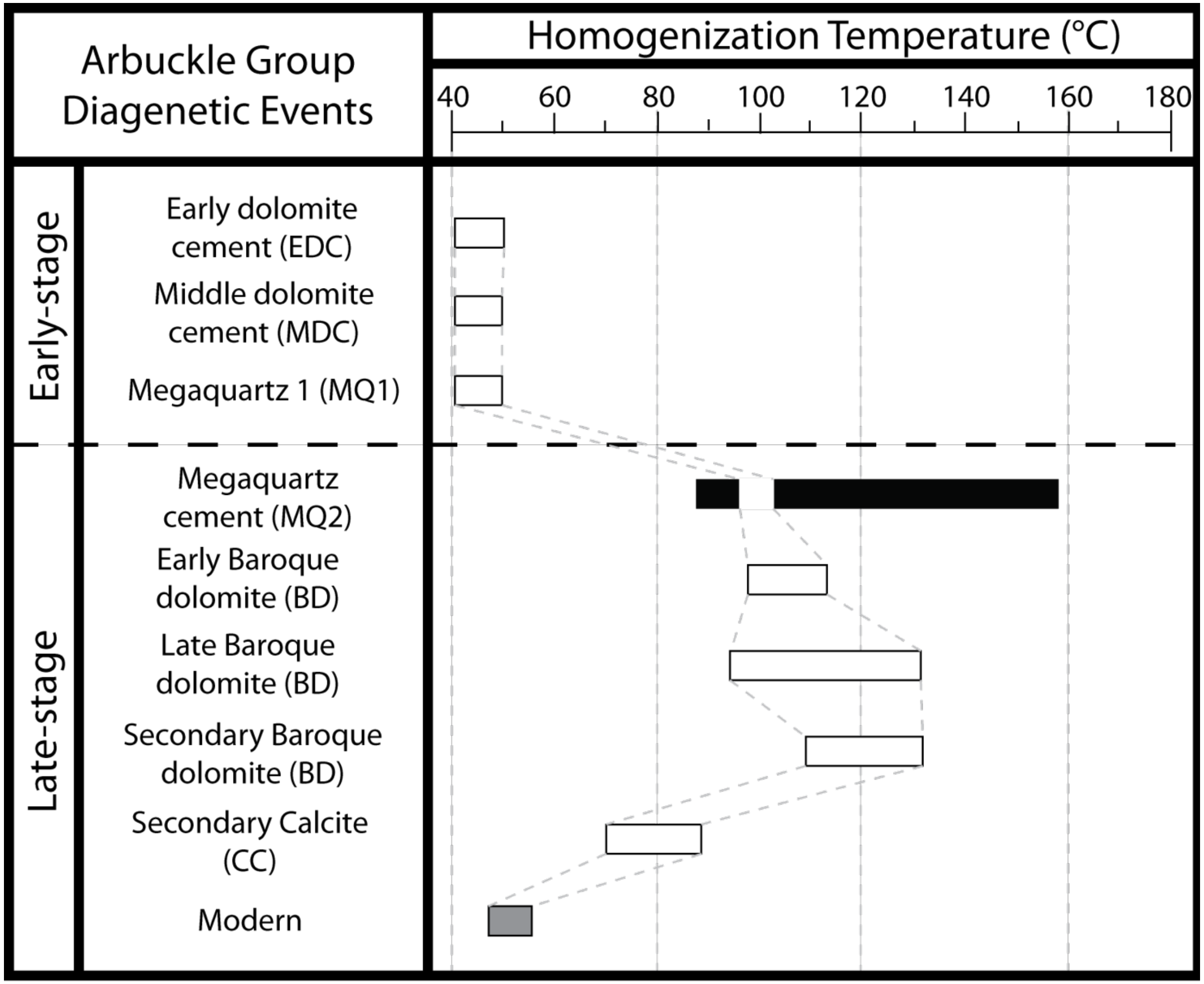


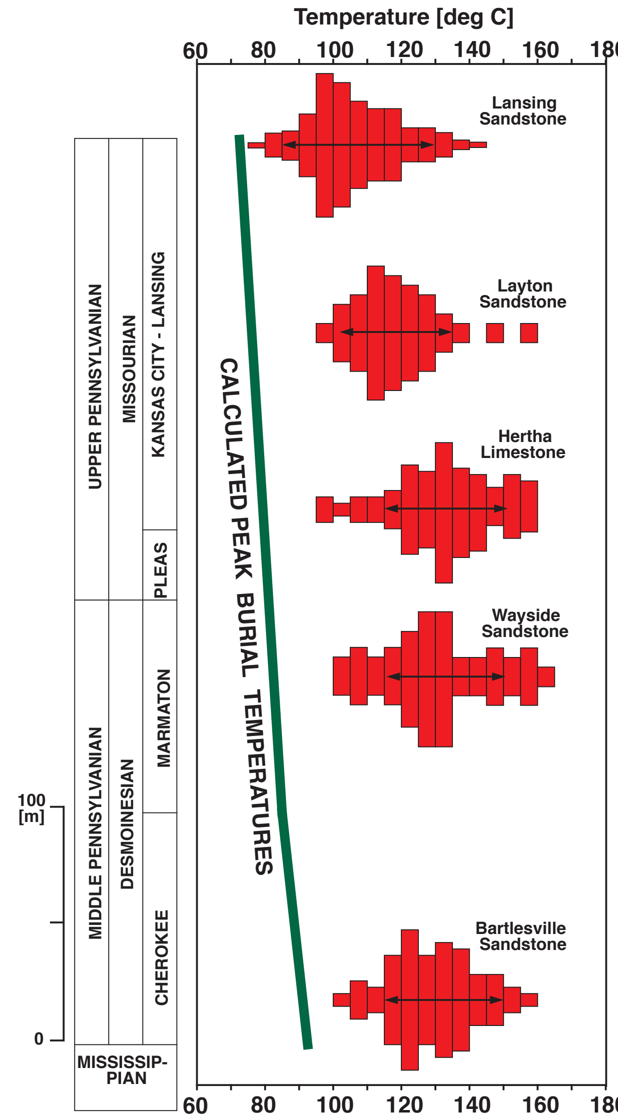


- Homogenization temperatures rise and fall through time – pulsed fluid flow

(Ramaker et al., 2014)

Evidence for Hydrothermal Flow



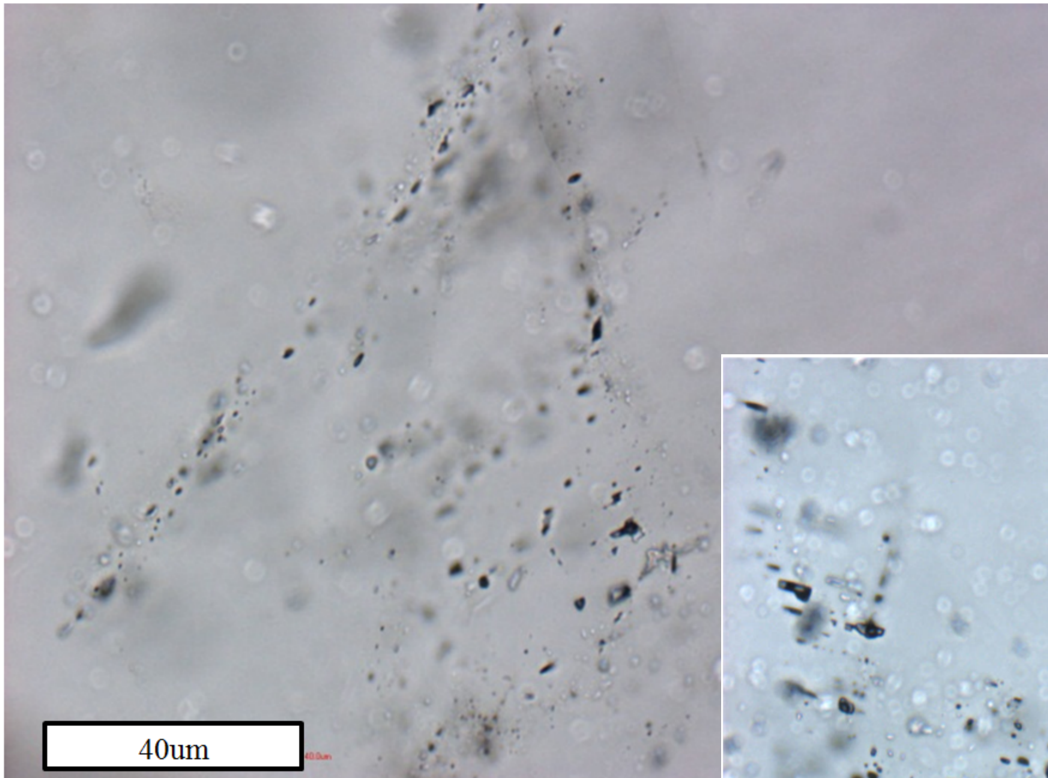


- Homogenization temperatures much higher than burial history allows
- Paleogeothermal gradients inconsistent with normal burial conductive heating

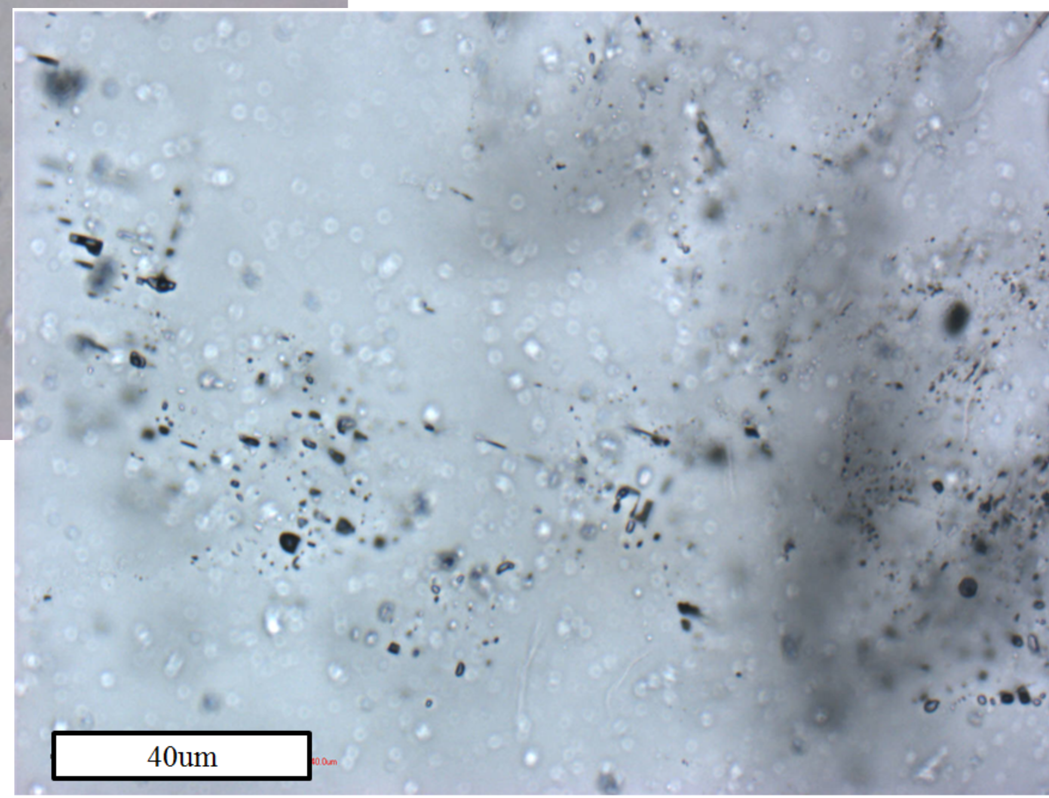
(Wojcik et al. 1994)

Stage 1 - Hydrothermal Flow

Megaquartz Cement

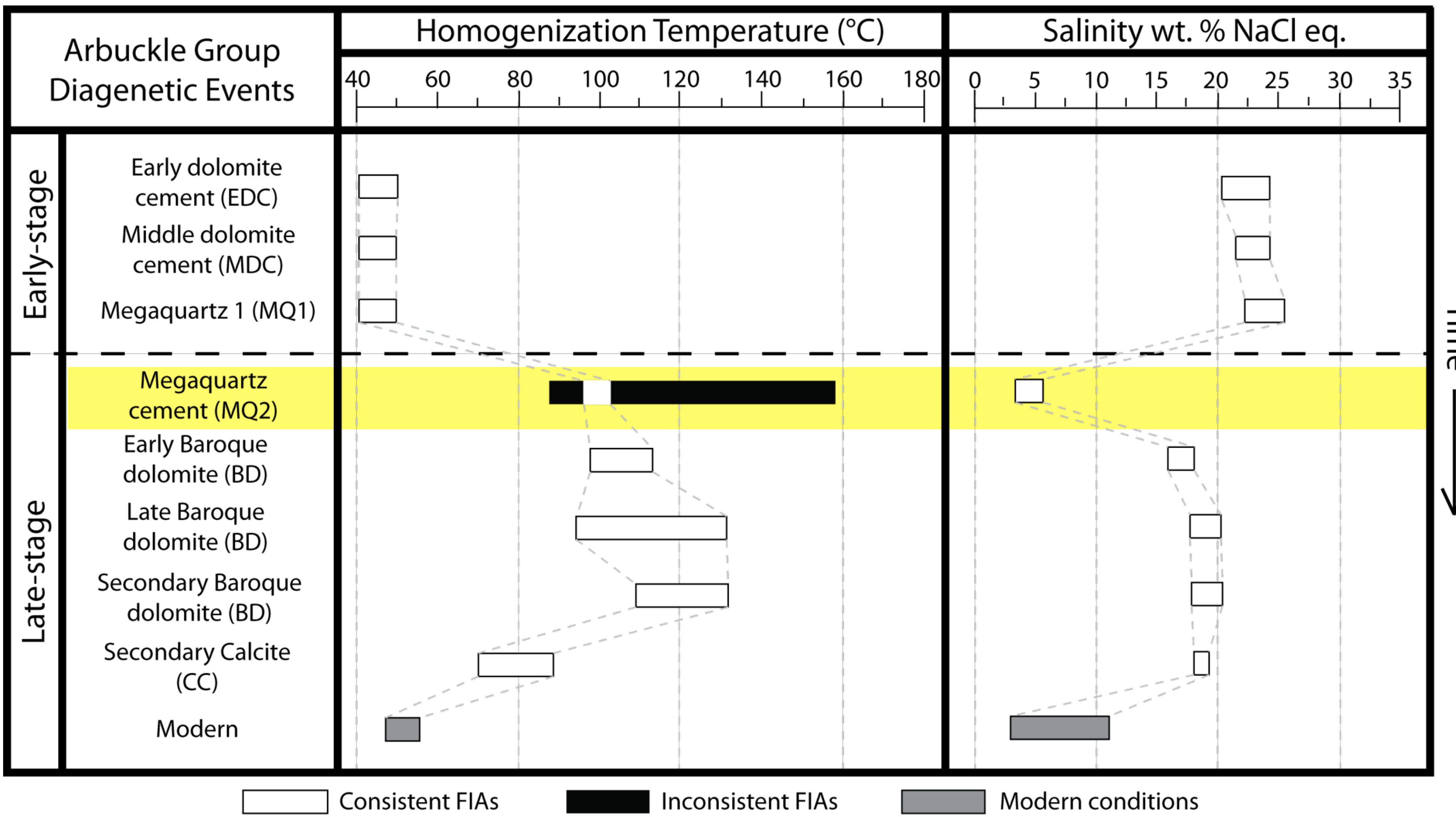


- Primary FIAs in Arbuckle Group MQ2 displaying heterogeneous entrapment with variable liquid-gas ratios in two-phase flincs



- Primary FIAs in Mississippian MMQ displaying heterogeneous entrapment with variable liquid-gas ratios in two-phase flincs

Stage 1 - Hydrothermal Flow



Stage 1 - Advective Fluid Flow - Megaquartz

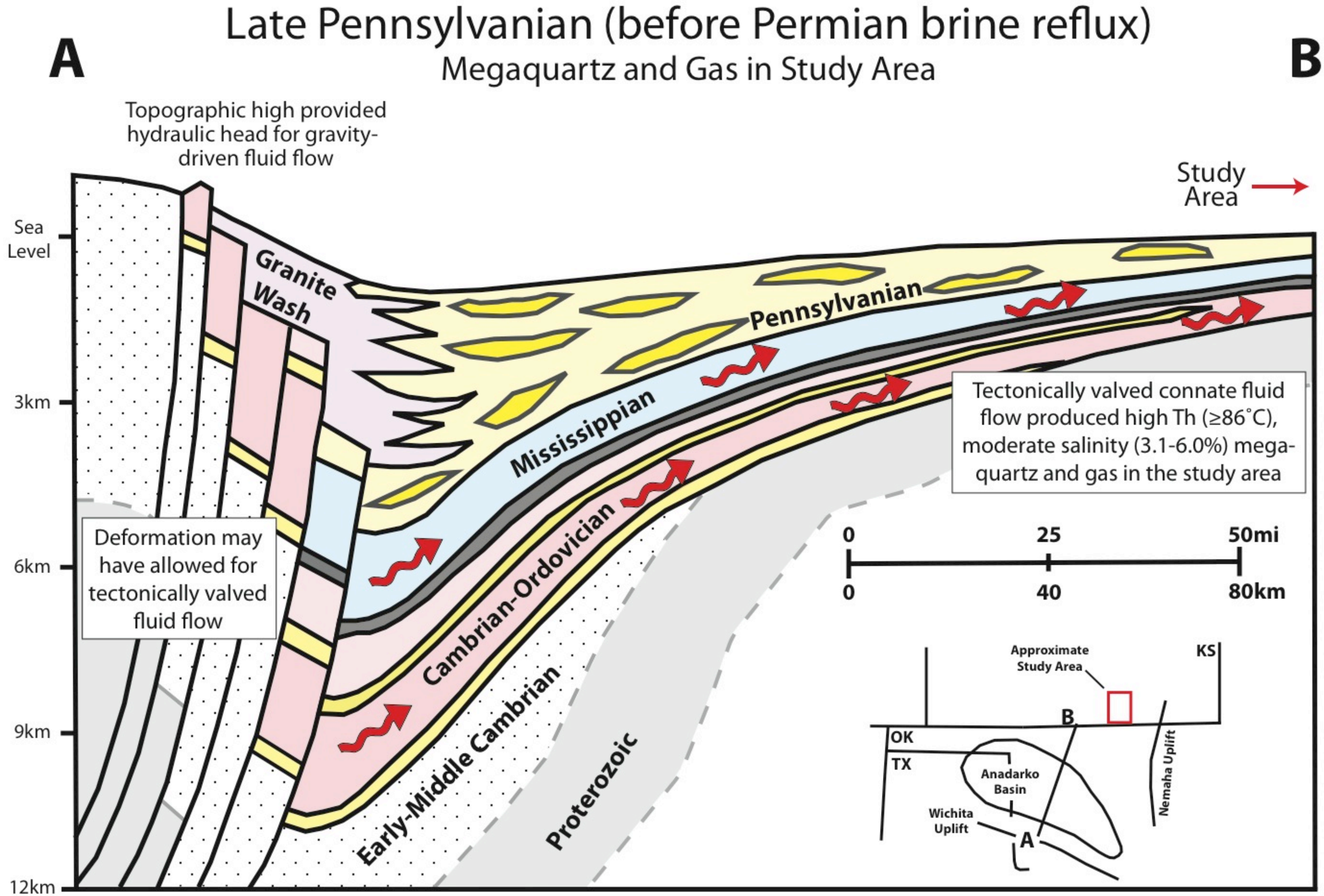
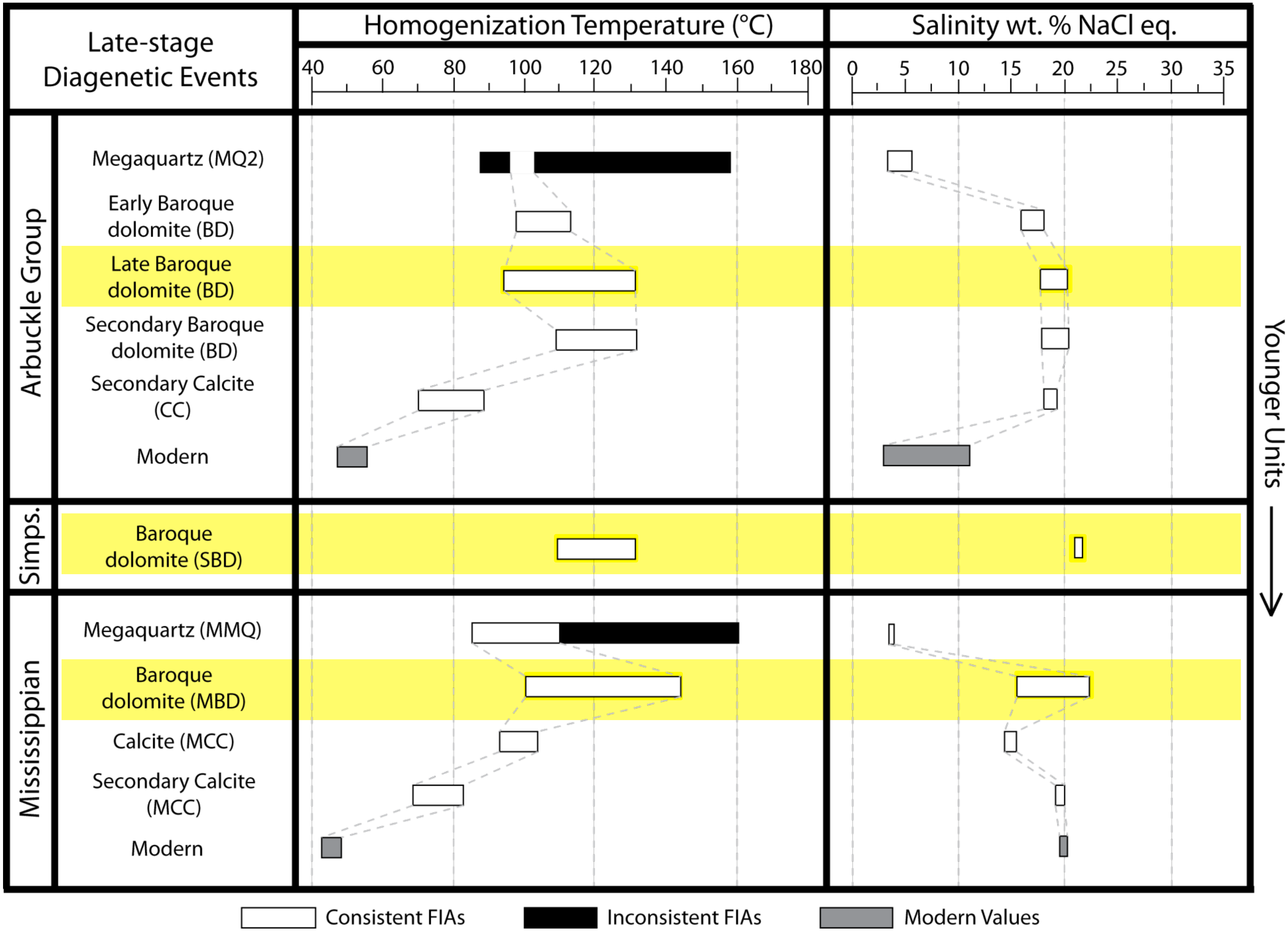


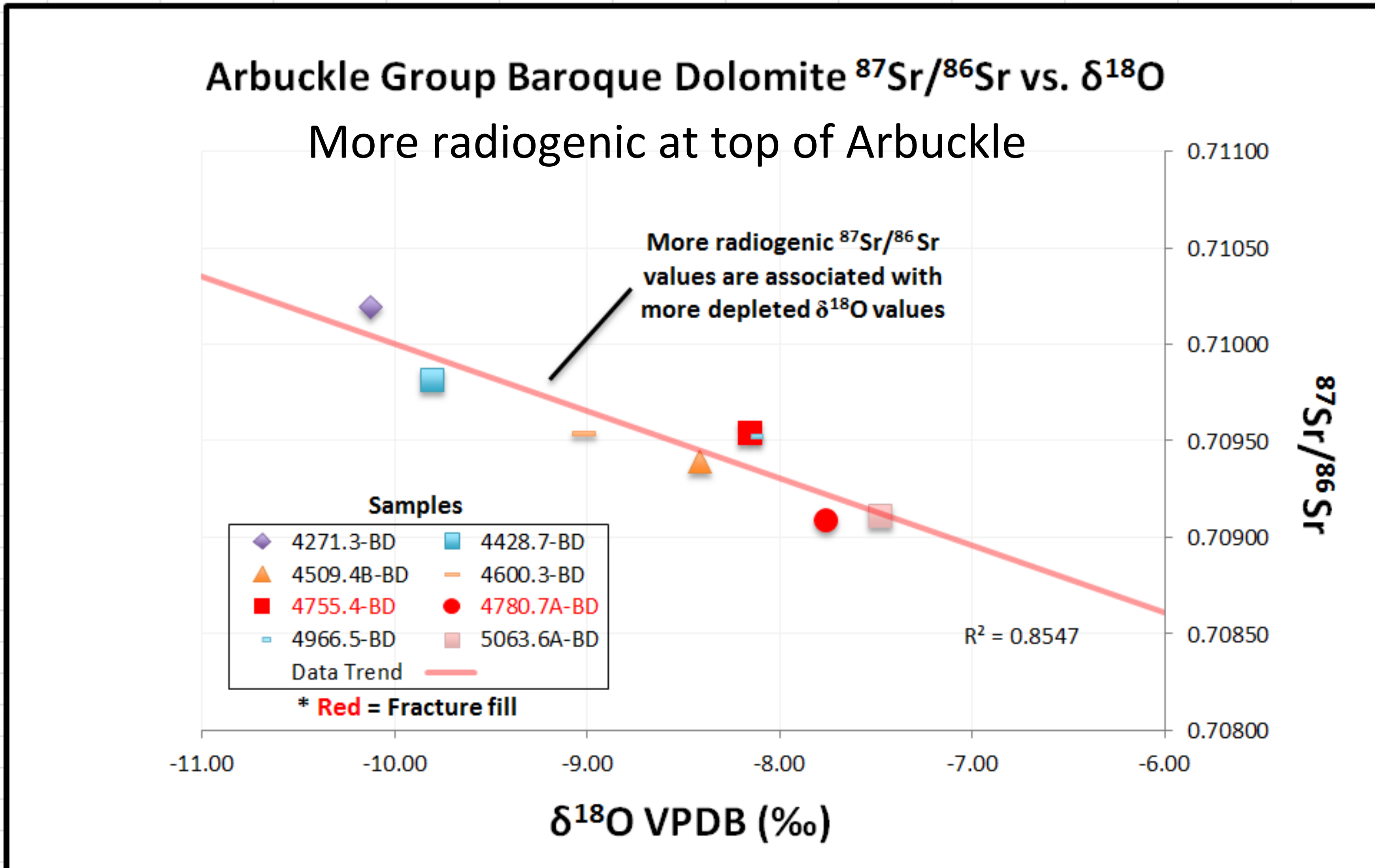
Image modified from Gallardo and Blackwell, 1999

Stage 2 - Hydrothermal Flow

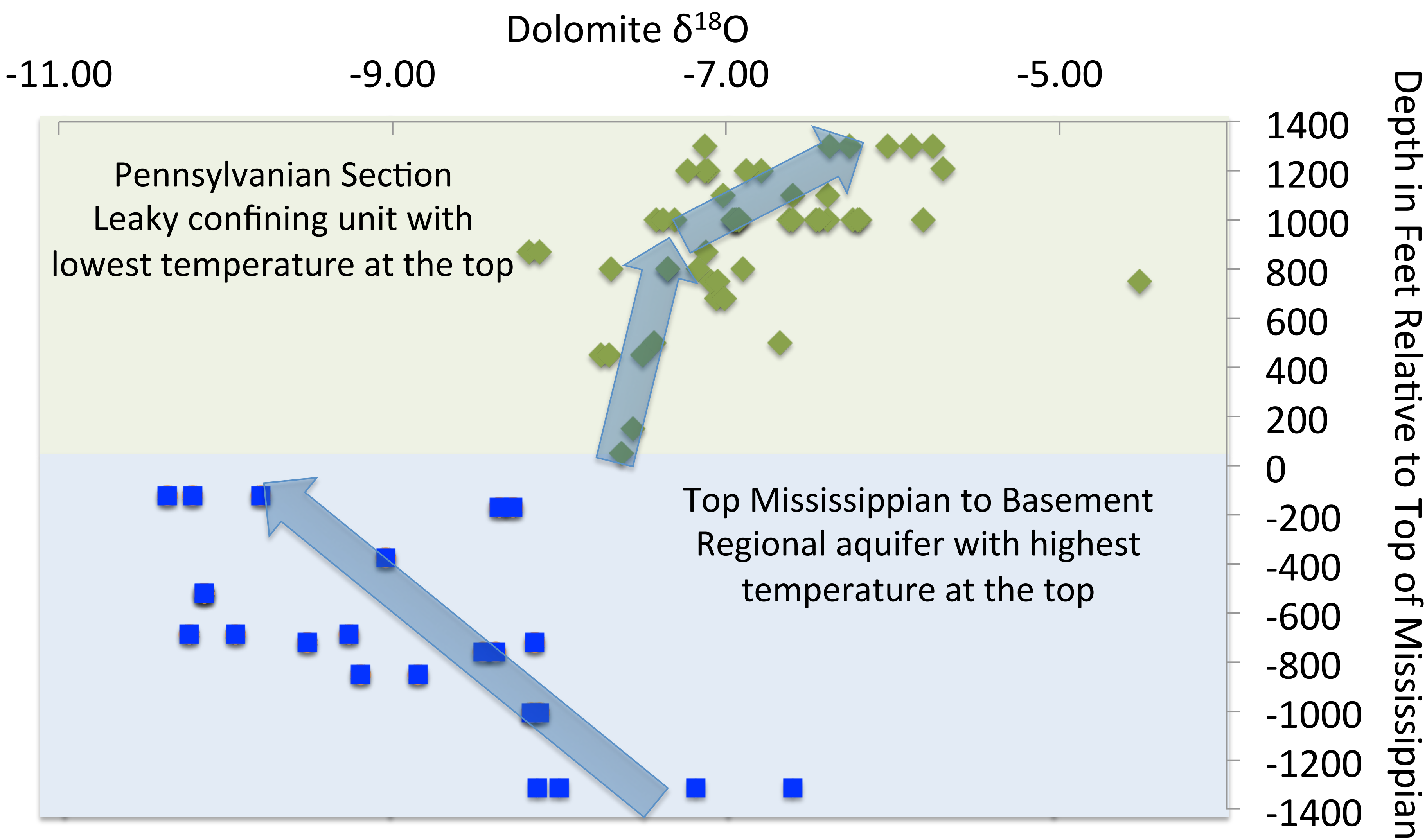


Arbuckle Dolomite – $^{87}Sr/^{86}Sr$ vs. Temp.

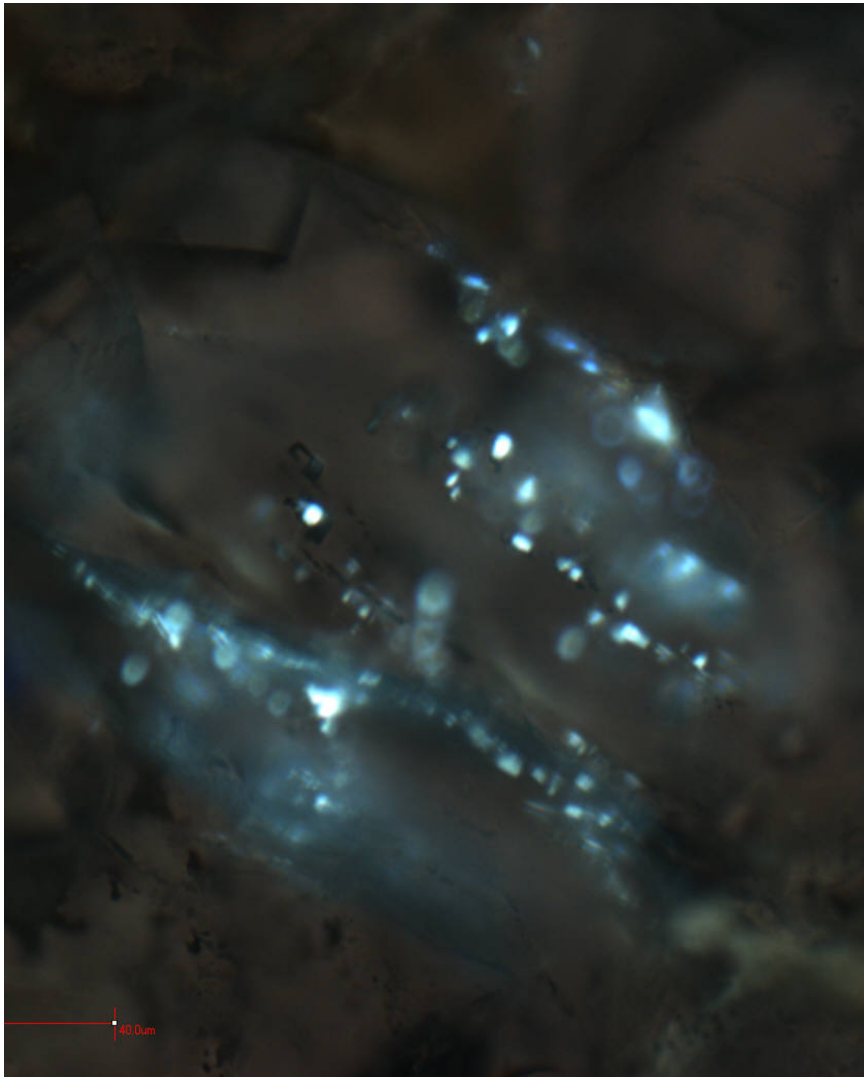
Radiogenic values, higher temp = less rock-water interaction with carbonates

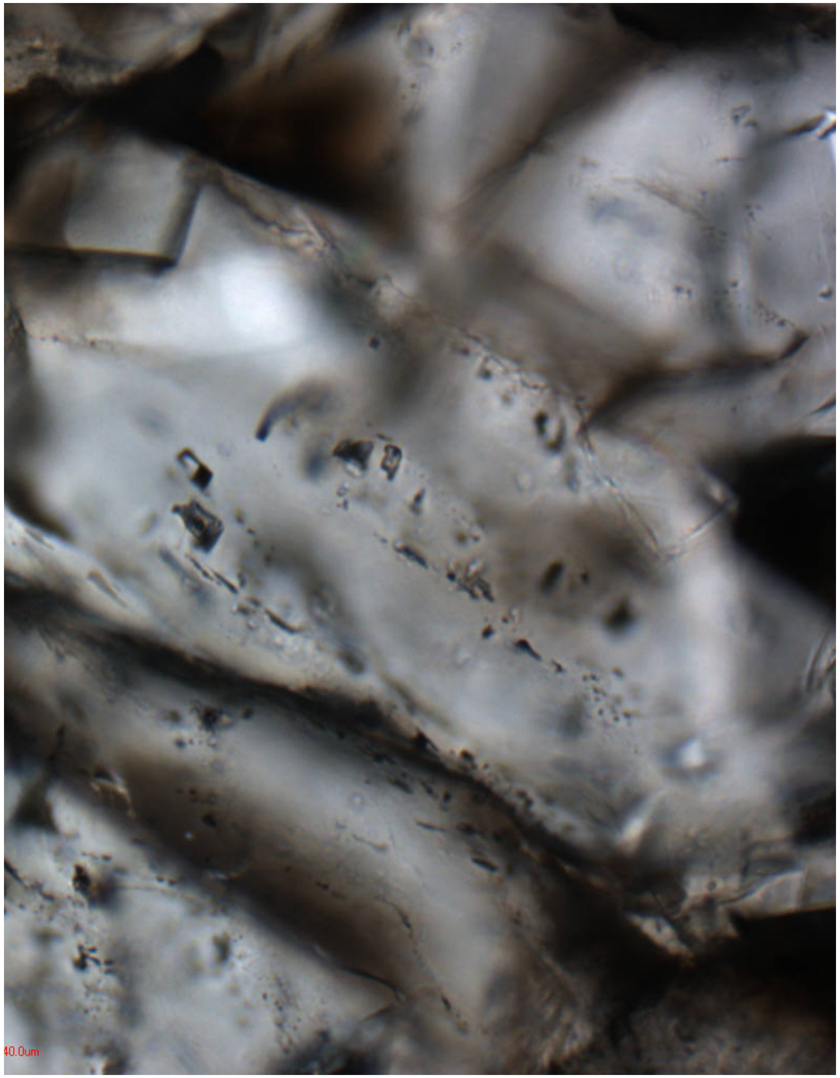


Thermal Structure During Stage 2 – Regional Fluid Flow



Oil Migration during Stage 2





Permian Reflux before or during Stage 2

Early-Mid Permian Time

High Salinity Reflux w/ Potential for Early Baroque Dolomite

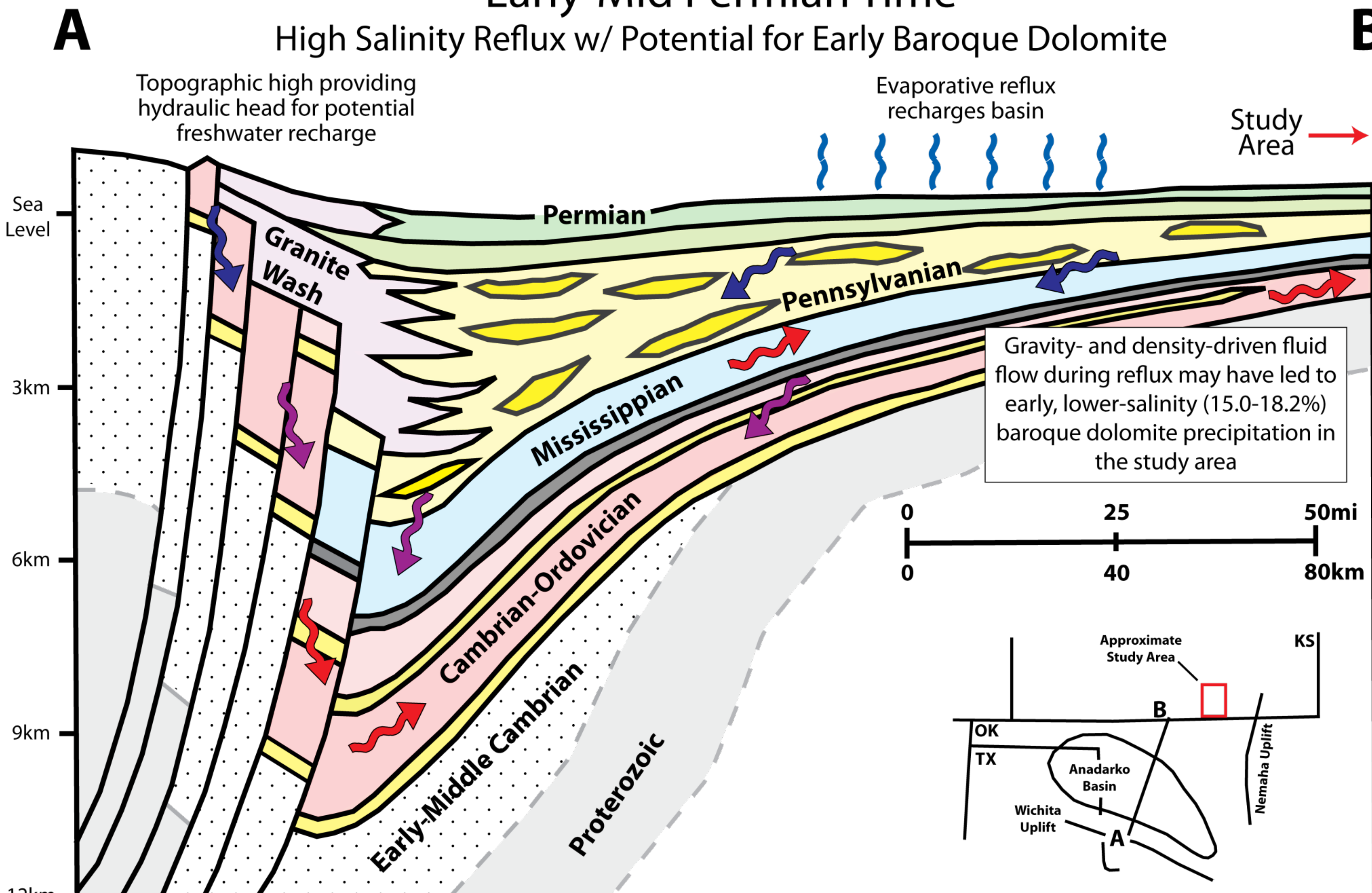


Image modified from Gallardo and Blackwell, 1999

Advective Fluid Flow – Stage 2

Early-Late Permian Time (after Permian brine reflux)

Baroque Dolomite and Oil in Study Area

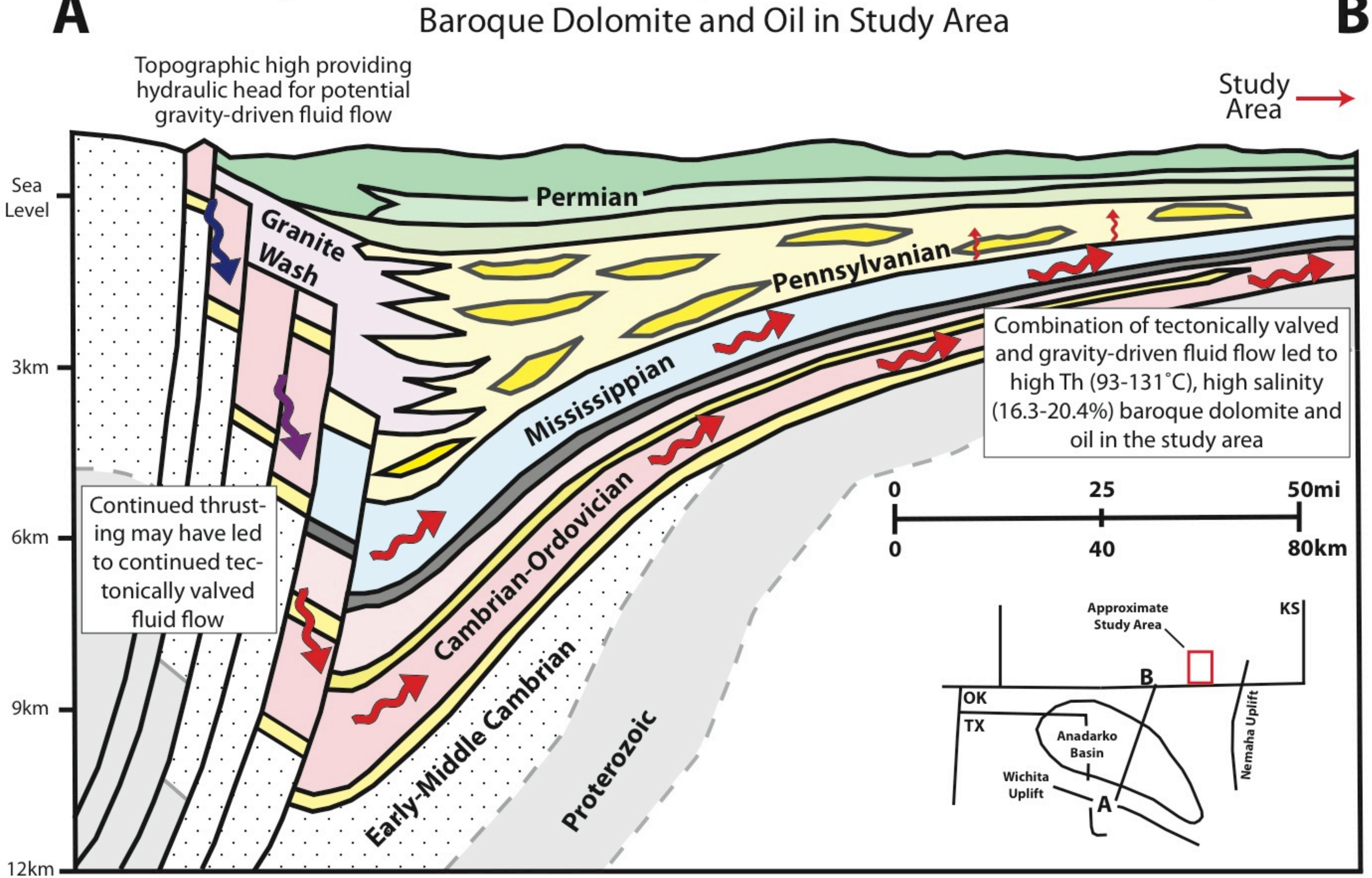


Image modified from Gallardo and Blackwell, 1999

Stage 2 – Warmer fluids at top of Aquifer

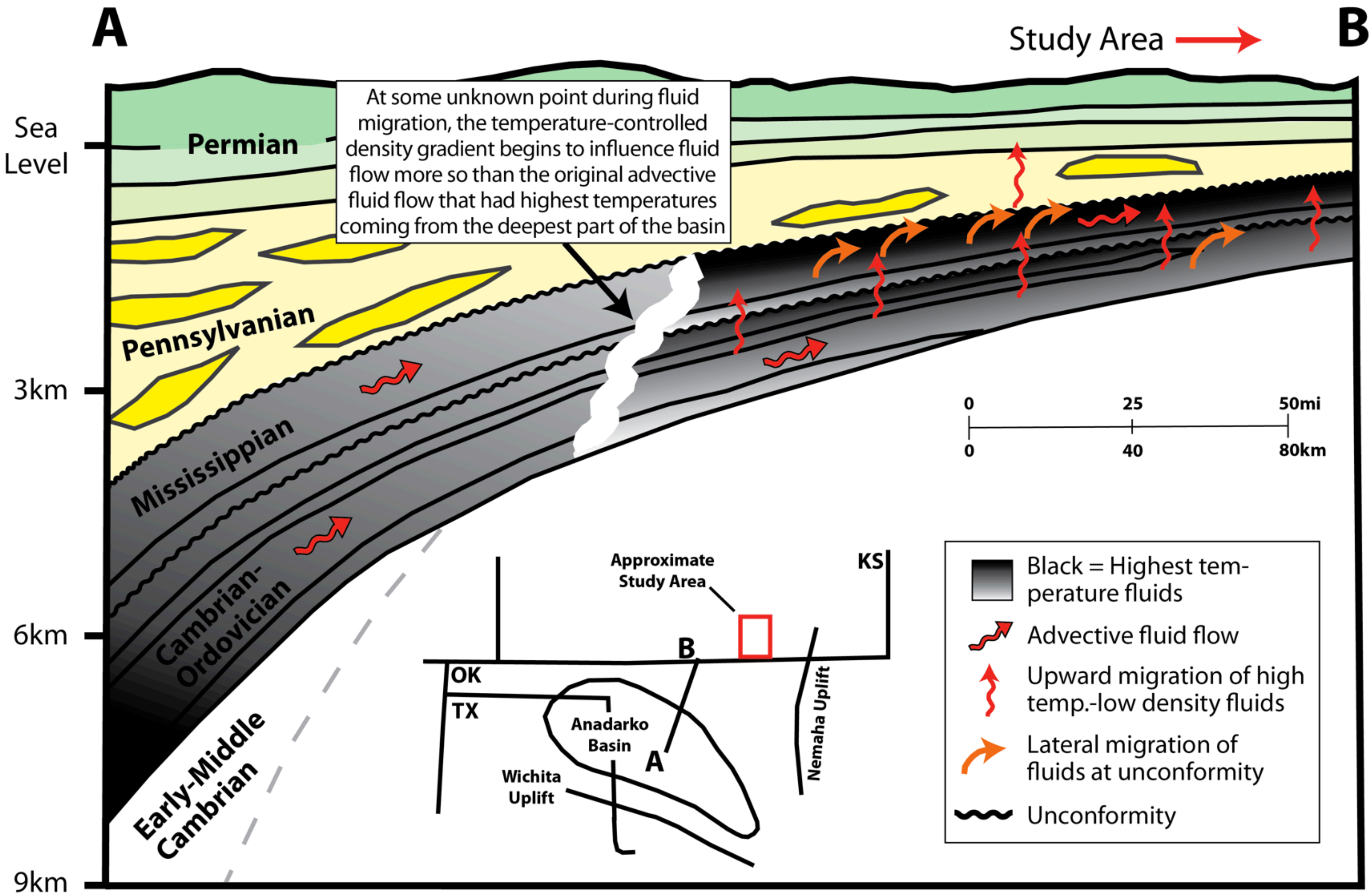
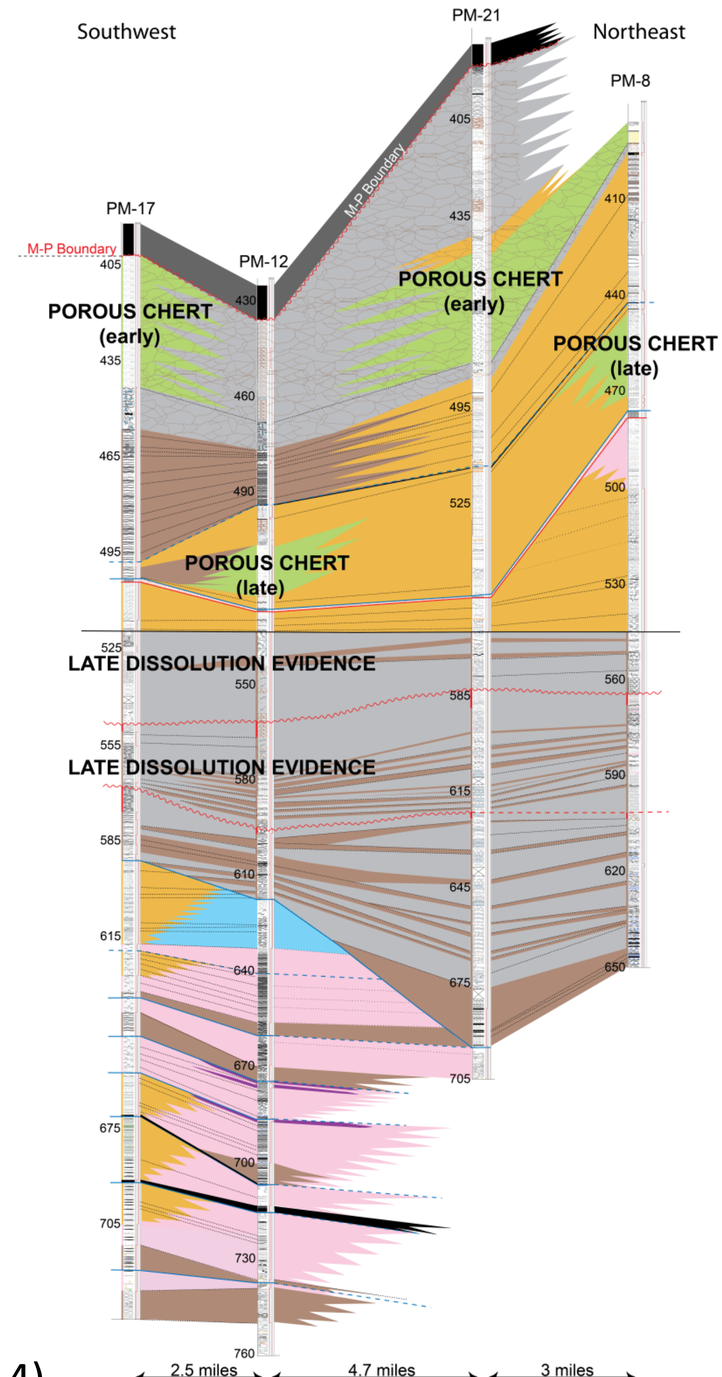


Image modified from Gallardo and Blackwell, 1999

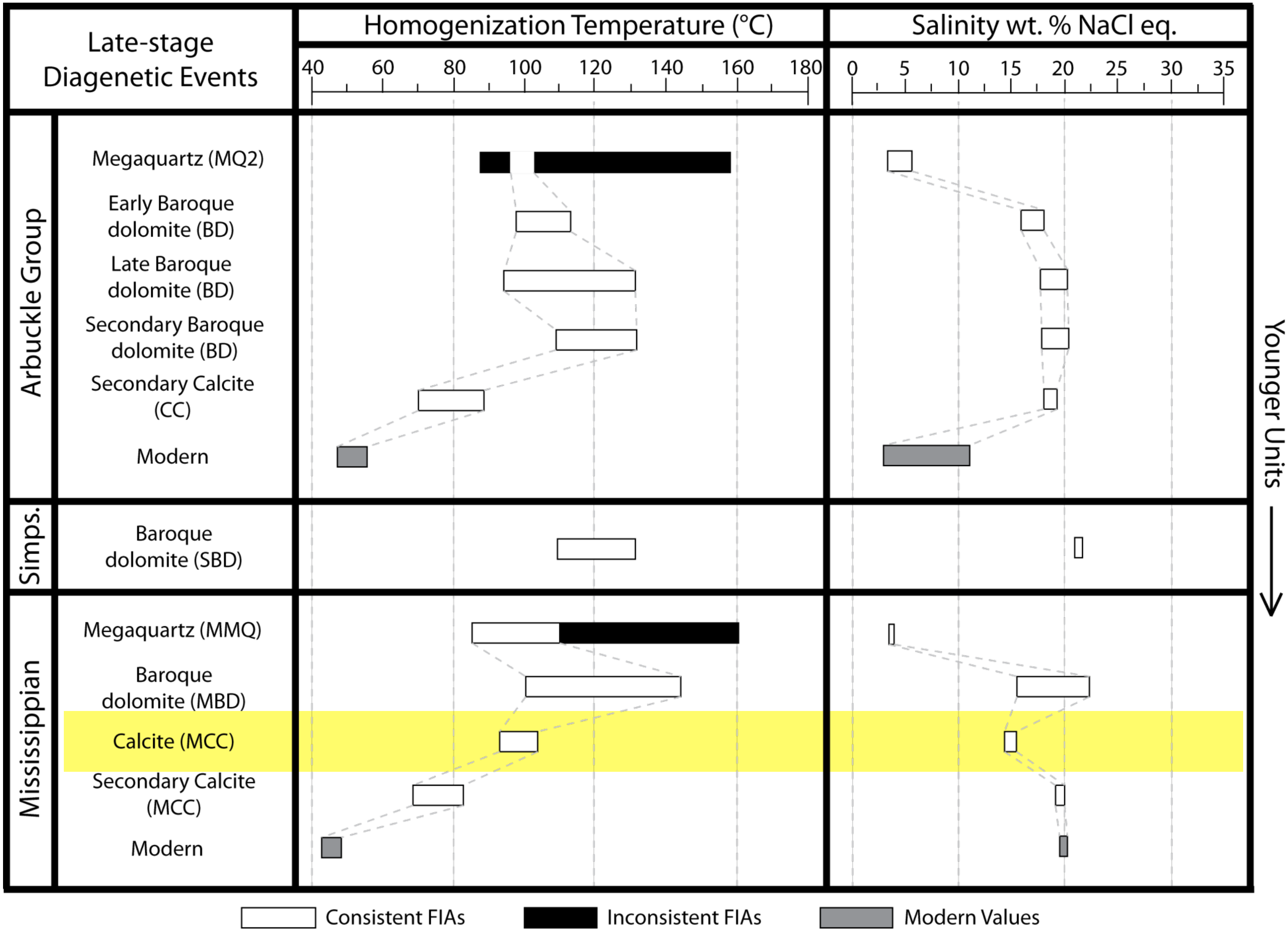
Stage 2 Discussion: Subaerial vs. Hydrothermal Porosity Enhancement in Chert

- NE cores contain 55% chert; 25% of which is porous
- SW cores (close to fault) contain 37% chert; 32% of which is porous
- Early dissolution is only in the uppermost 75 feet; hydrothermal alteration is seen 120 below M-P unconformity
- Hydrothermal advective flow, concentrated toward the top of the Arbuckle-Miss. aquifer and closely associated with fracture zones, enhanced porosity

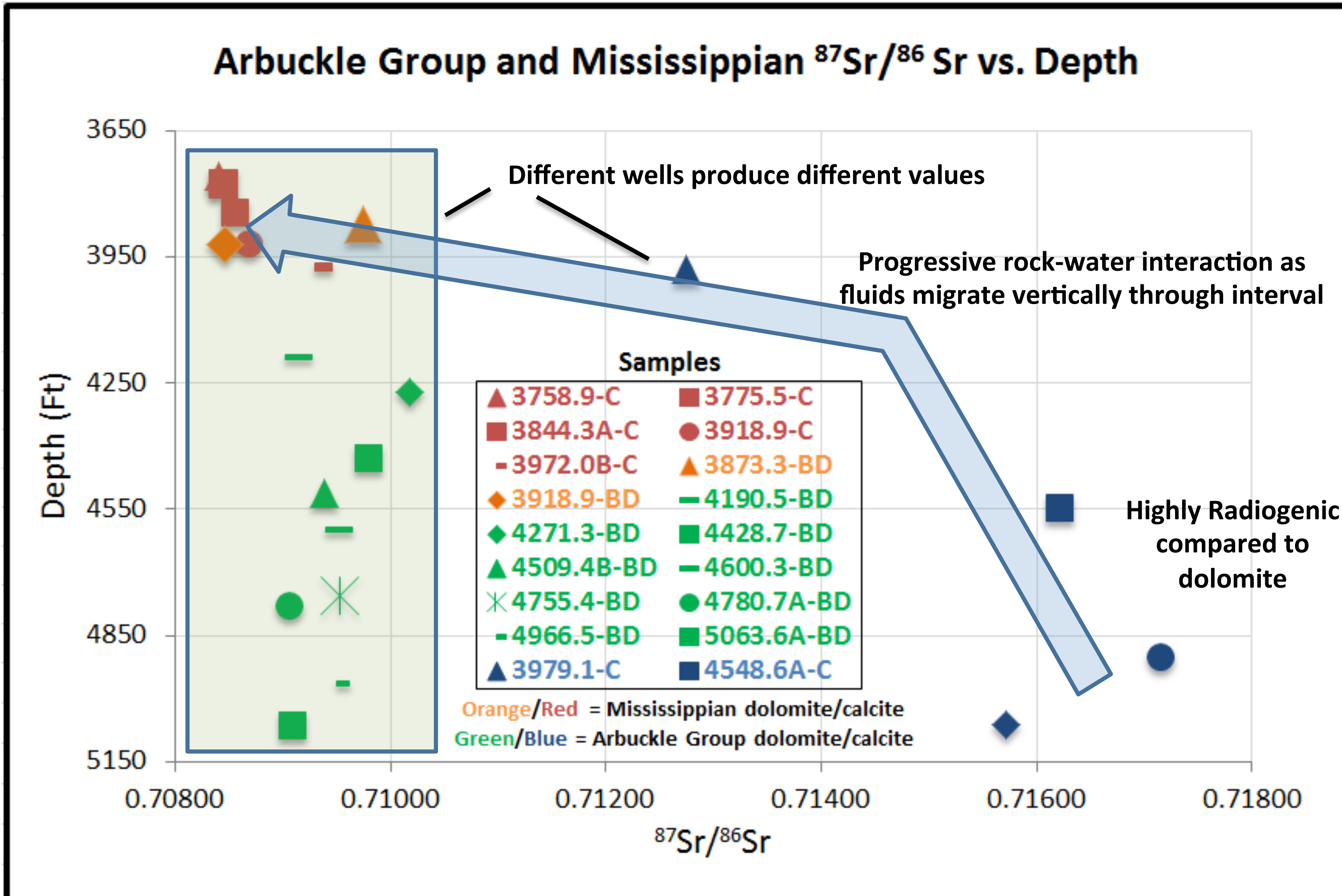


(Ramaker et al., 2014)

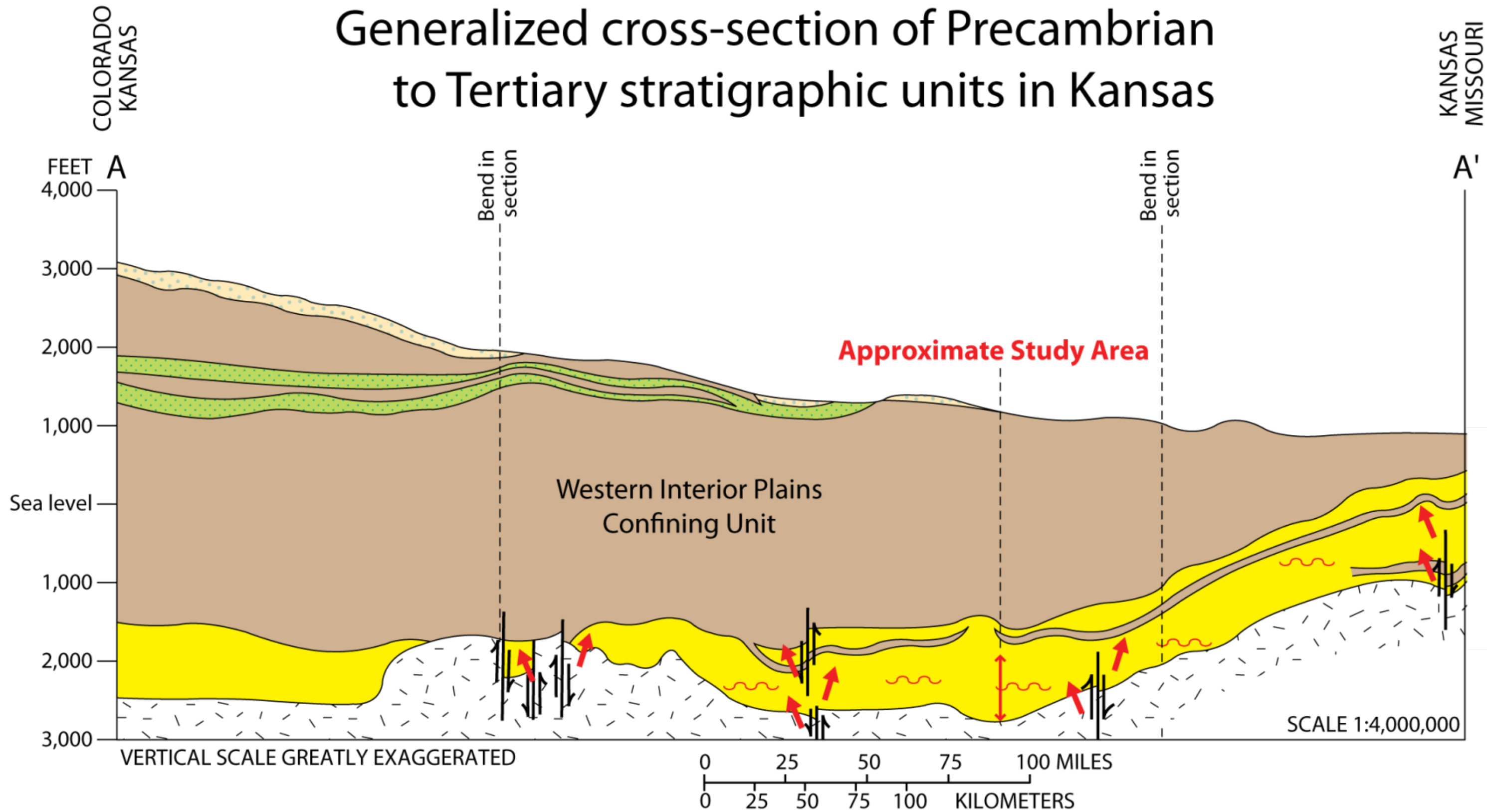
Stage 3 - Hydrothermal Flow



Stage 3 - Calcite $^{87}Sr/^{86}Sr$



Stage 3 - Fracture-Controlled Hydrothermal Fluid Flow and Calcite-Laramide?



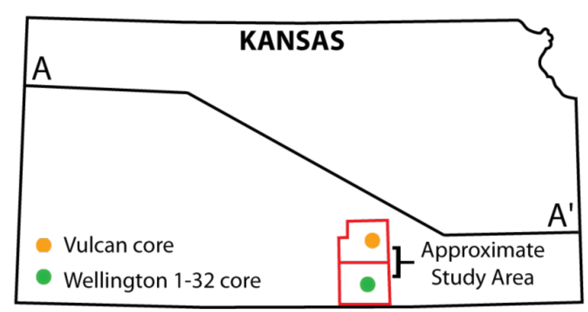


Image modified from Miller and Appel, 1997

Conclusions

- Three-stage evolution of hydrothermal systems
- Two stages of regional advective flow
  - Connate fluids + gas followed by concentrated brines + oil
  - Mississippian to Cambrian-Ordovician section acted as a regional aquifer and Pennsylvanian acted as a leaky confining unit.
  - In the regional aquifer cross-formational connections allowed lower density, warmer fluids to concentrate at the top of the aquifer, and this structure could be a very useful model for understanding porosity in oil-and-gas reservoirs
  - Reservoir porosity is partially controlled by hydrothermal fluid migration enhancing the porosity in areas where fractures and faults led to preferred hydrothermal fluid flow, especially close to the top of the regional aquifer

Conclusions

- Better porosity is related to late structure and stratigraphic control on fluid flow
- A third stage of hydrothermal fluid flow was localized by later (possibly Laramide) faults and fractures and led to localized hydrothermal systems
  - The impact of the third stage is as yet unknown, but clearly indicates localized vertical connections across reservoir units that allowed fluid flow
- All three stages clearly predate the modern fluid structure in the system

Details and data available from: KICC

Kansas Interdisciplinary Carbonates Consortium

Acknowledgements

- This project was largely completed as the Master's thesis research of Bradley King, which was supported by the U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL) under Grant Number DEFE0000002056. This project is managed and administered by the Kansas Geological Survey/KUCR, W. L. Watney, PI, and funded by DOE/NETL and cost-sharing partners
- Additional support was provided by the sponsors of the Kansas Interdisciplinary Carbonates Consortium (KICC)