Impact of Hydrothermal Fluid Flow on Conventional and Unconventional Carbonate-Rich Reservoirs, Midcontinent USA*

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Abstract

Hydrothermal fluid flow in Ordovician, Mississippian, and Pennsylvanian reservoir rocks of the Midcontinent is partially responsible for generating the porosity in those reservoirs (Ramaker et al. 2014), as well as hydrocarbon migration and local thermal maturation. The hydrothermal fluid flow occurred in three late stages (King, 2013). Fluid flow was controlled by stratigraphic discontinuities, fault and fracture systems, and temperature-controlled density differences. These controls are critical for localization of some of the reservoirs in the Midcontinent.

Ordovician, Mississippian, and Pennsylvanian strata in Kansas all show fracturing, megaquartz, silica dissolution, carbonate dissolution, baroque dolomite, MVT minerals, and calcite after stylolitization. Cathodoluminescence 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 stages of hydrothermal fluid flow (86-144ºC). All show evidence of thermal pulses, suggesting tectonic valving.

Fluid inclusion data indicate *Stage 1* was from brines near seawater salinity, interpreted as connate fluids migrating out of the Anadarko and/or Arkoma basins, likely during the Pennsylvanian or Early Permian. Fluids were associated with a separate gas phase, and they precipitated megaquartz.

Stage 2 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 fluid flow toward the top of the Mississippian. The shale-rich Pennsylvanian section acted as a leaky confining unit. This stage of fluid flow was associated with oil migration and likely occurred late in the Permian or after.

Stage 3 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 out of the basement. Comparison of fluid inclusion temperature and salinity data to modern reservoir conditions indicates that this stage clearly predates the current fluid flow and thermal regime, but played a part in evolution of the reservoir system.

The first two stages 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 reservoir quality in the Mississippian and leads to an enhanced model for locating the best producers. The 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. 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. Better porosity is related to late structure and stratigraphic control on fluid flow.

For the third stage of hydrothermal fluid flow, further study is necessary. A driver could be localized faulting and fracturing associated with Laramide or other deformation. Fracturing and vertical fluid flow clearly could have had an impact on late hydrocarbon migration. As these systems are highly localized, their identification may be key in predicting location of some of the best producers.

References Cited

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

King, B.D., 2013, Fluid flow, thermal history, and diagenesis and the Cambrian-Ordovician Arbuckle Group and overlying units in south-central Kansas: University of Kansas unpublished M.S. Thesis, 288 p.

Miller, J. A., and C. L. Appel. 1997, Groundwater atlas of the United States, Kansas, Missouri, and Nebraska. U.S. Geological Survey Publication HA 730-D, website accessed March 22, 2015, http://pubs.usgs.gov/ha/ha730/ch_d/index.html.

Ramaker, E.N., R.H. Goldstein, E.K. Franseen, and W.L. Watney, 2014, What controls porosity in cherty fine-grained carbonates rocks? Impact of stratigraphy, unconformities, structural setting and hydrothermal fluid flow: Mississippian, southeast Kansas, *in* S. Agar and S. Geiger, editors, Fundamental Controls on Flow in Carbonates: Current Workflows to Emerging Technologies: Geological Society London SP v. 406, p. 179-208.

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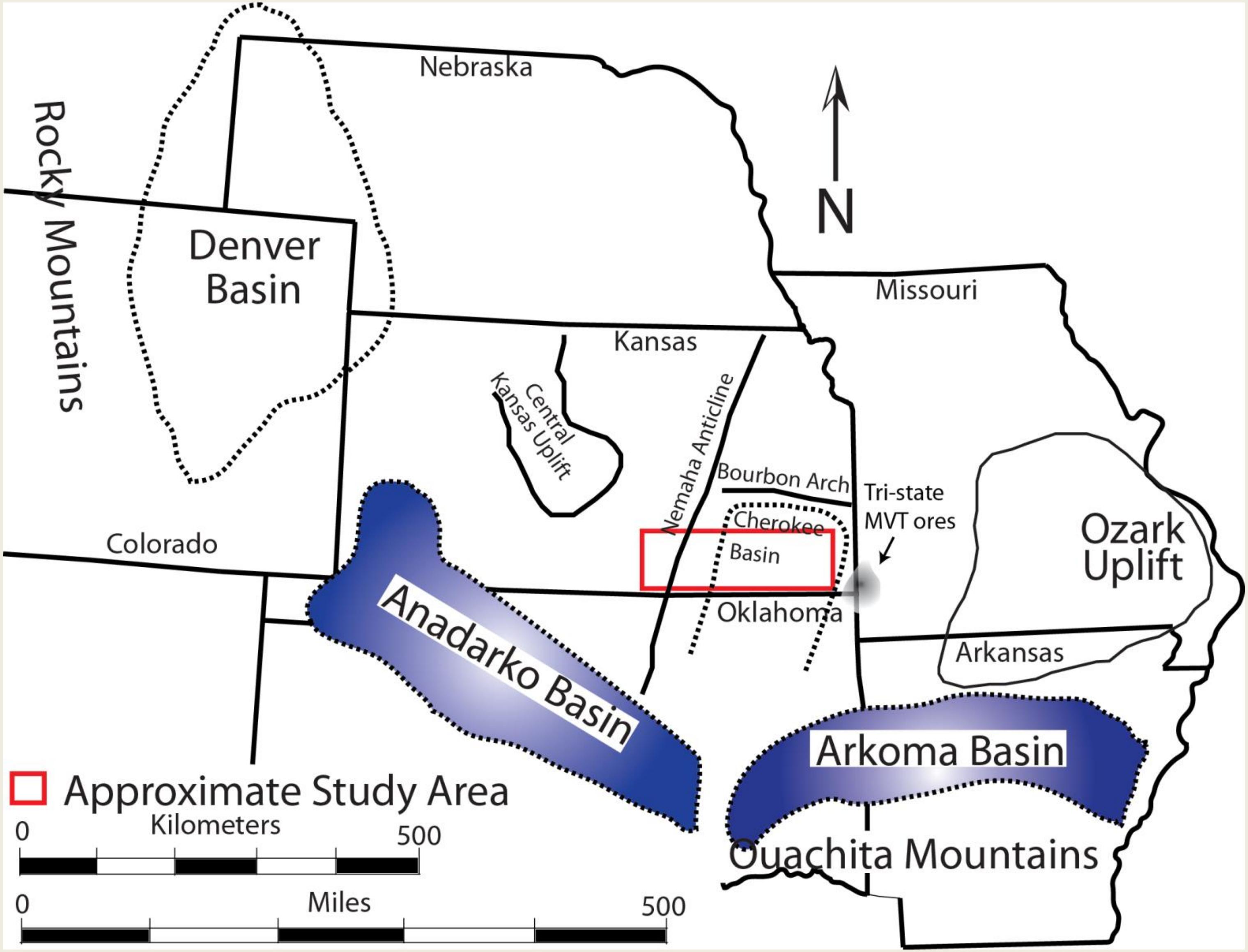
KICC

Kansas Interdisciplinary Carbonates Consortium

Purpose

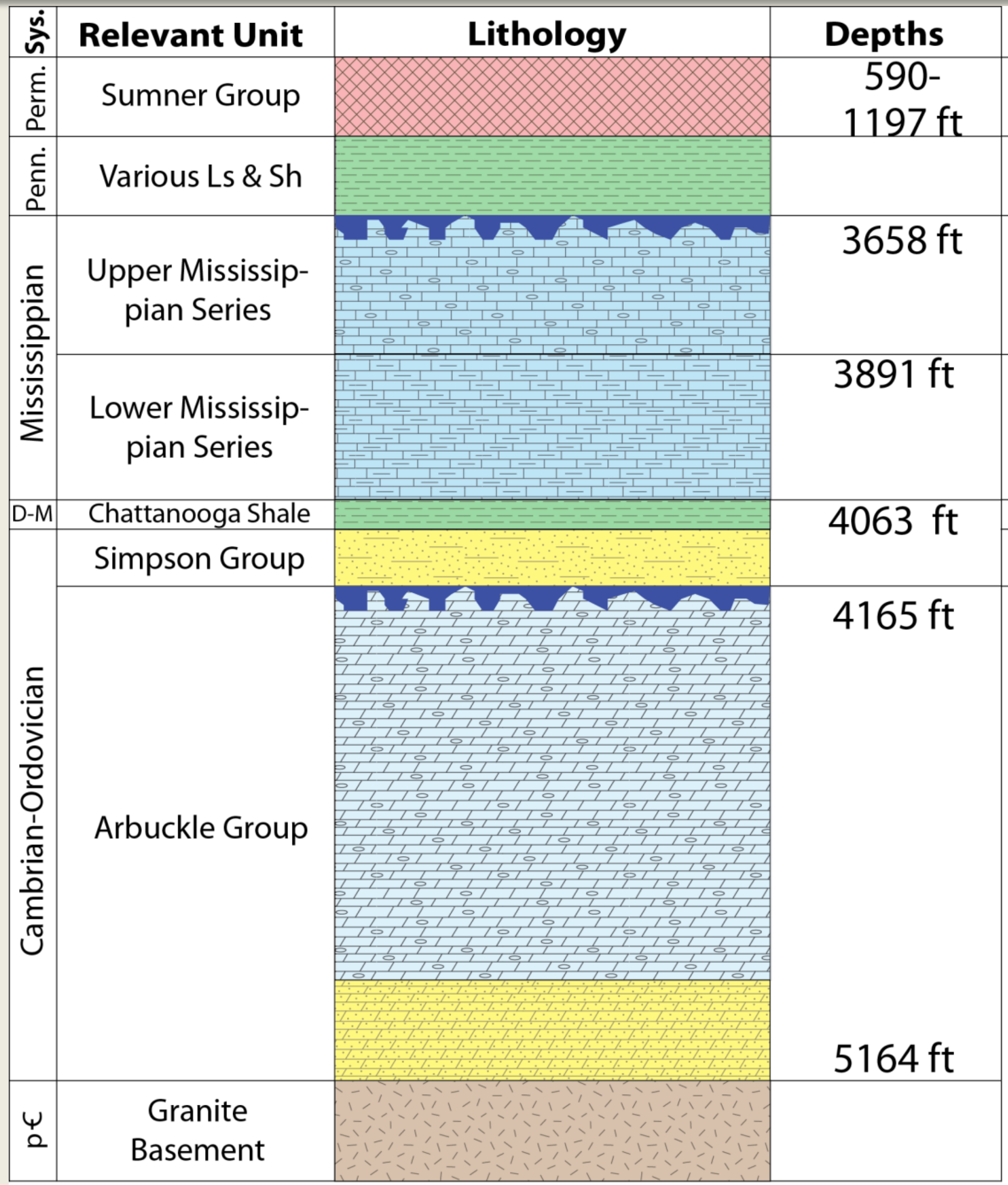
- Study of basement through Pennsylvanian in Midcontinent, USA, shows three-stage evolution of hydrothermal system
- Concentration of hydrothermal alteration immediately below unconformities caused by density-controlled advective fluid flow
- Study demonstrates that porosity associated with unconformities is much later than development of meteoric karst and caused by a predictable fluid distribution in hydrothermal aquifers

Study Area

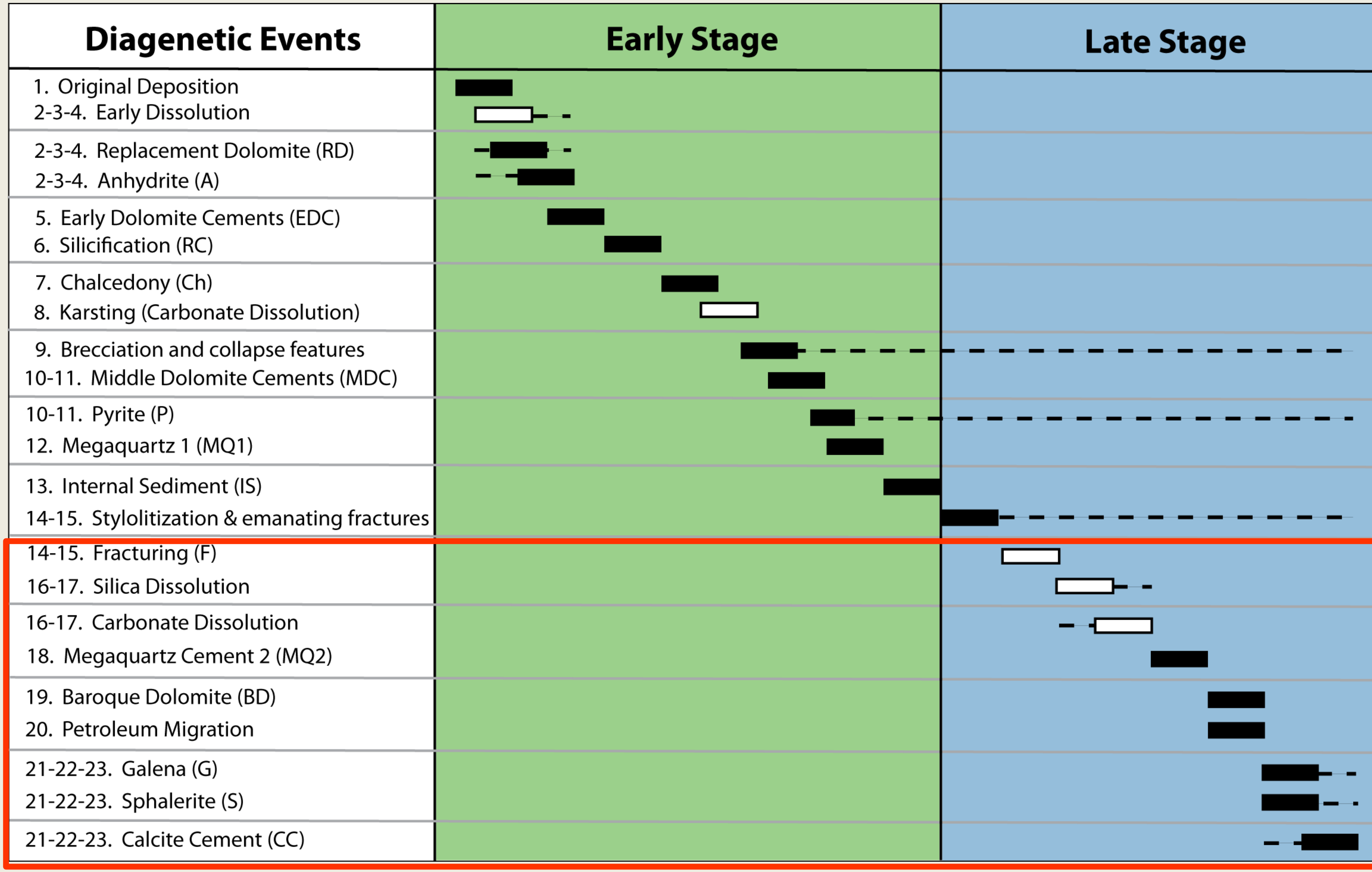


Nebraska
Rocky Mountains
Denver Basin
N
Missouri
Kansas
Central Kansas Uplift
Nemaha Anticline
Bourbon Arch
Tri-state MVT ores
Cherokee Basin
Colorado
Ozark Uplift
Oklahoma
Anadarko Basin
Arkansas
Arkoma Basin
Approximate Study Area
Kilometers
0
500
Ouachita Mountains
Miles
0
500

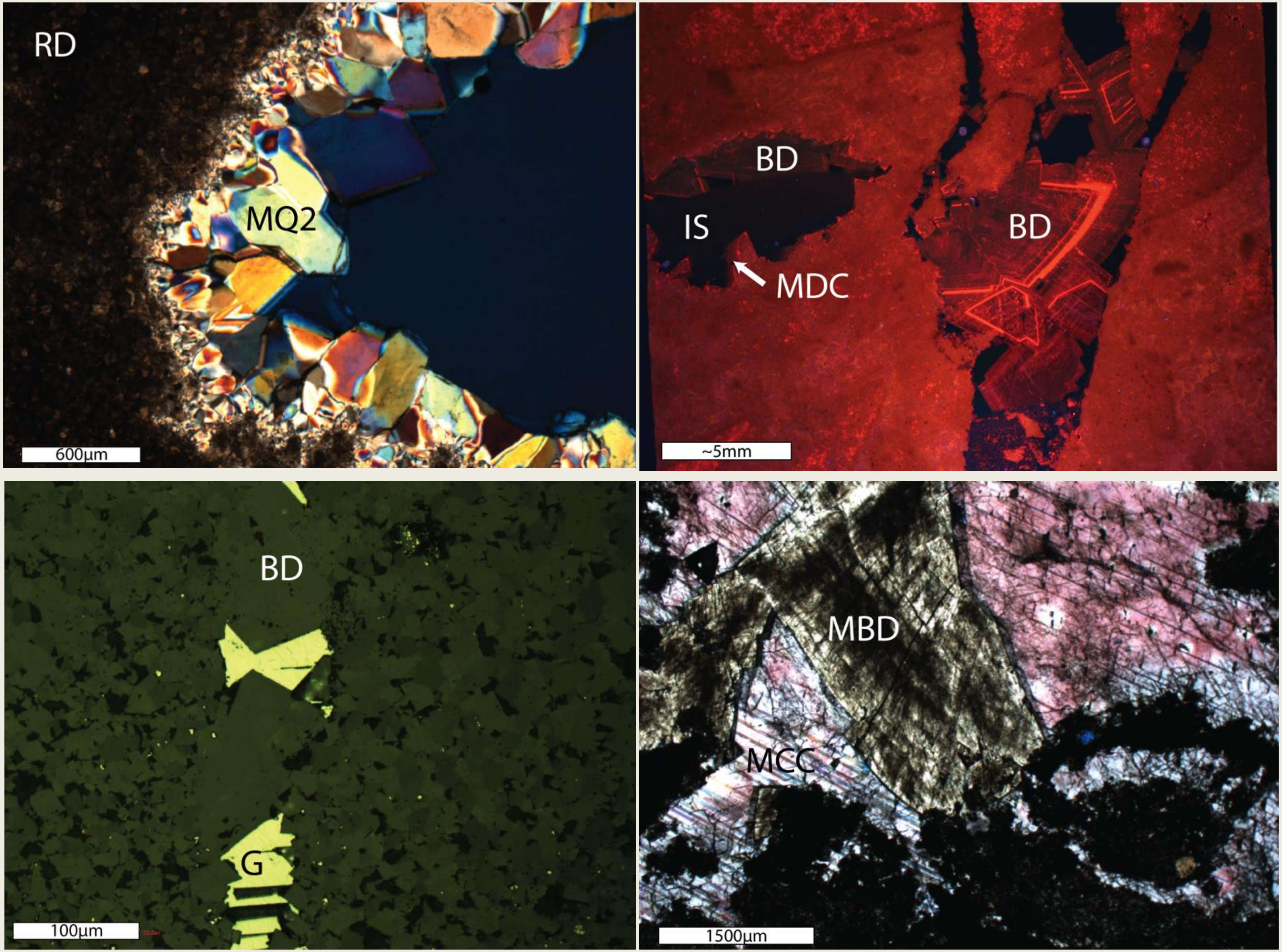
Stratigraphy



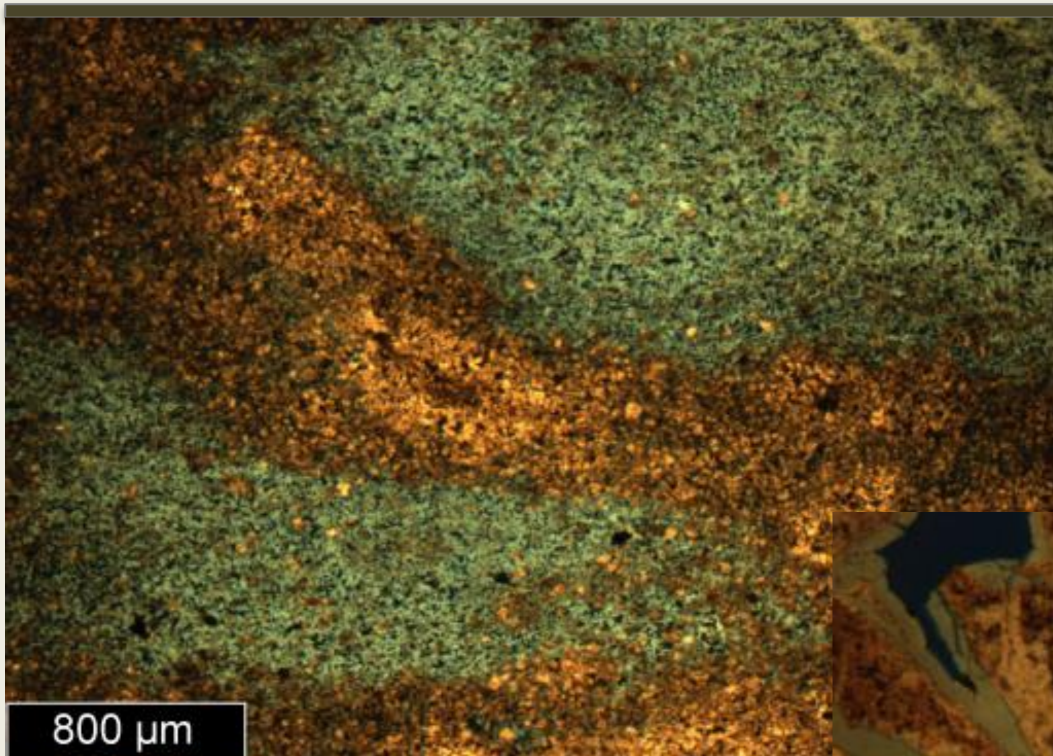
Arbuckle Group Late Paragenesis

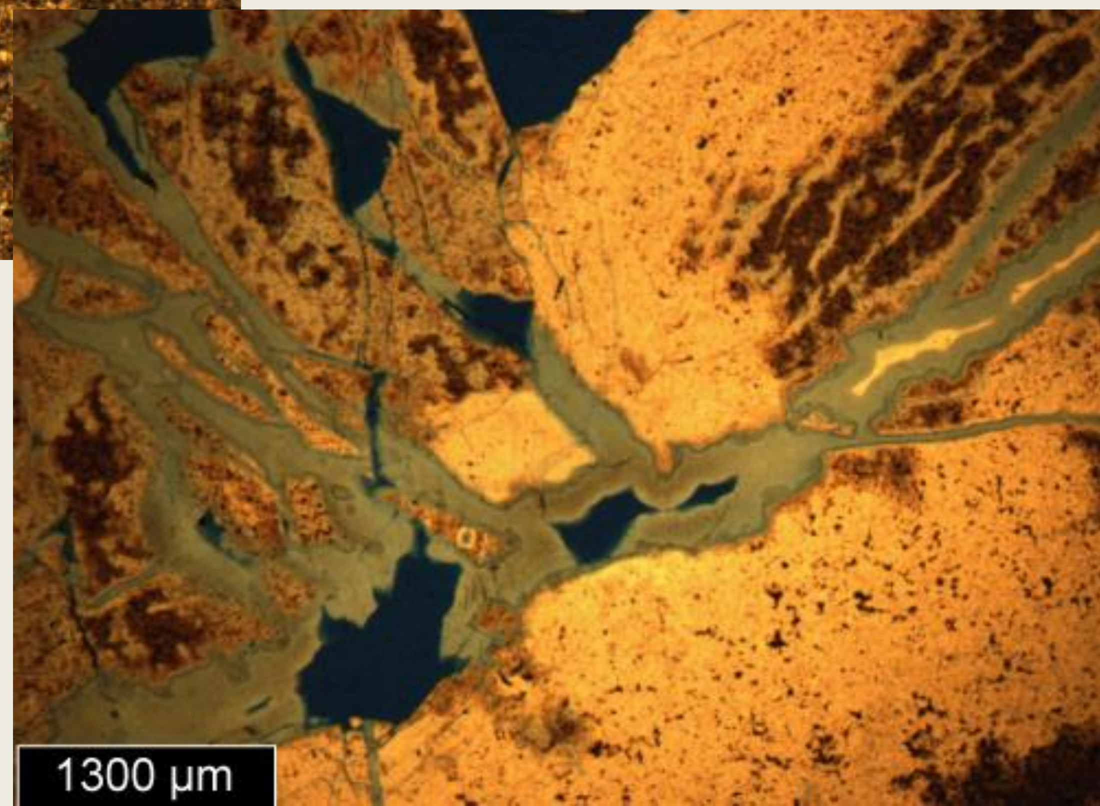


Late-Stage Paragenesis associated with fractures and porosity enhancement

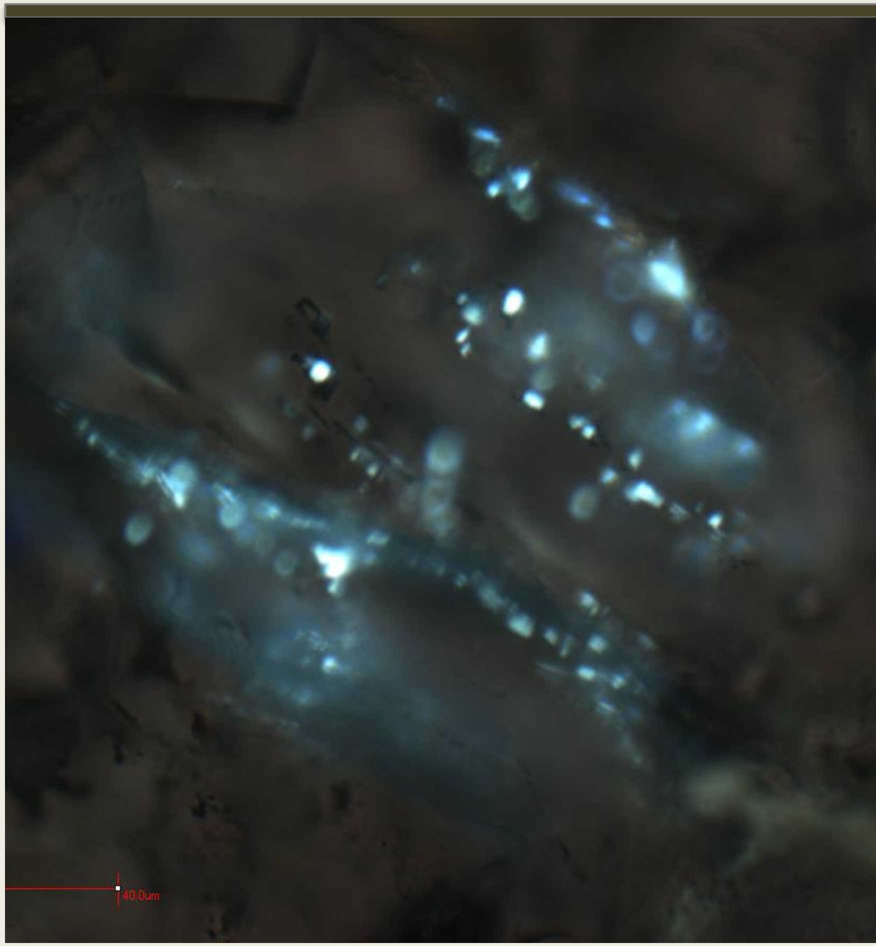


Porosity Enhancement in Silica Phases



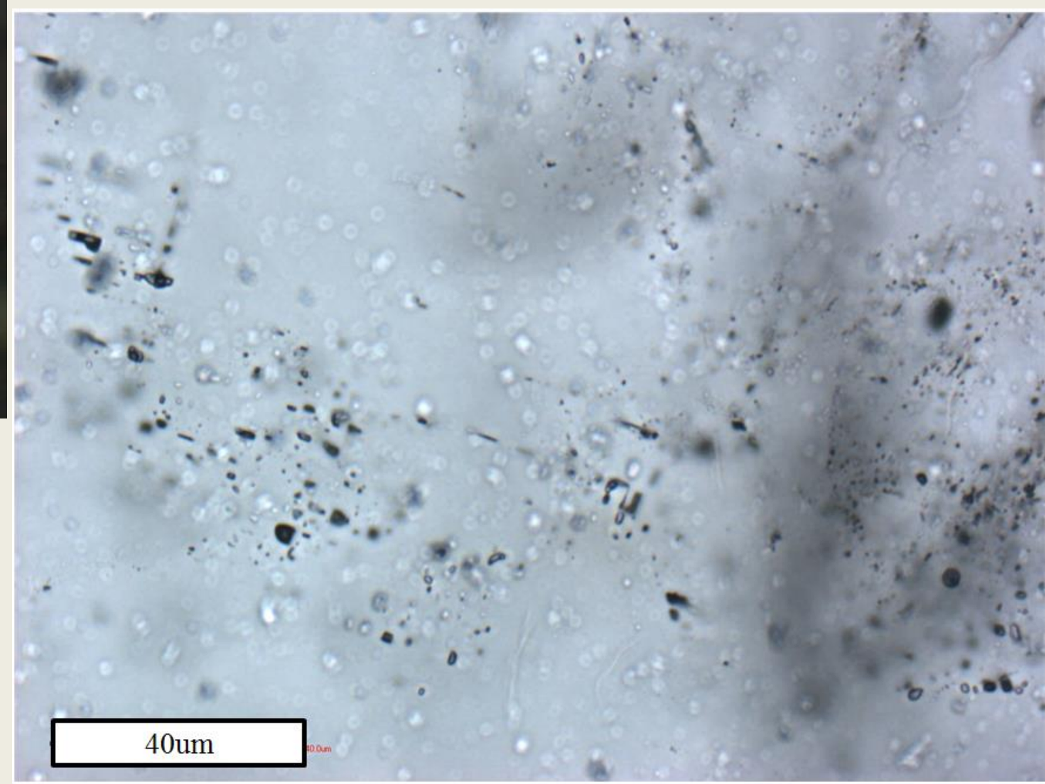


Late Mineral Phases - Hydrocarbon Migration

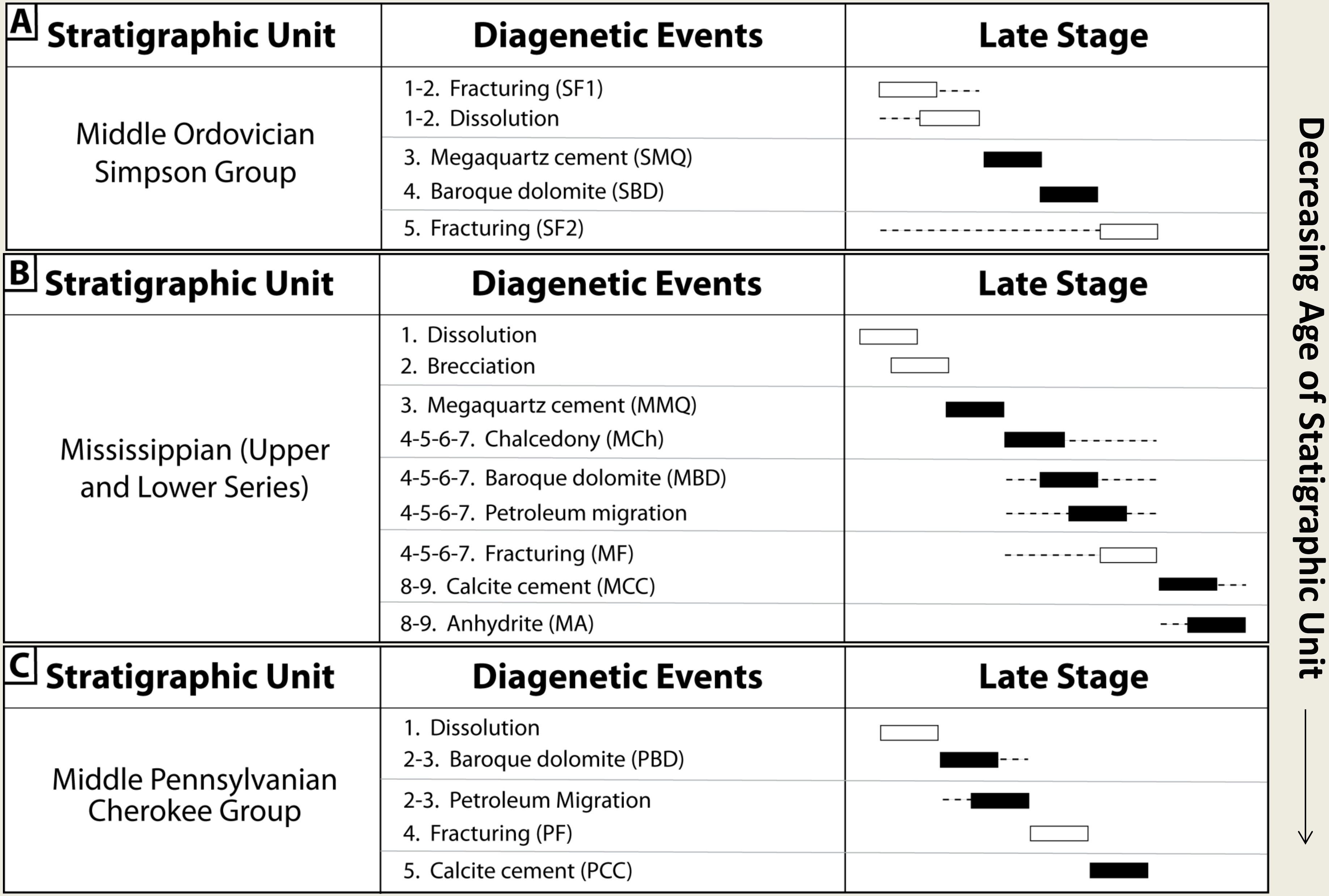


←Oil during baroque dolomite

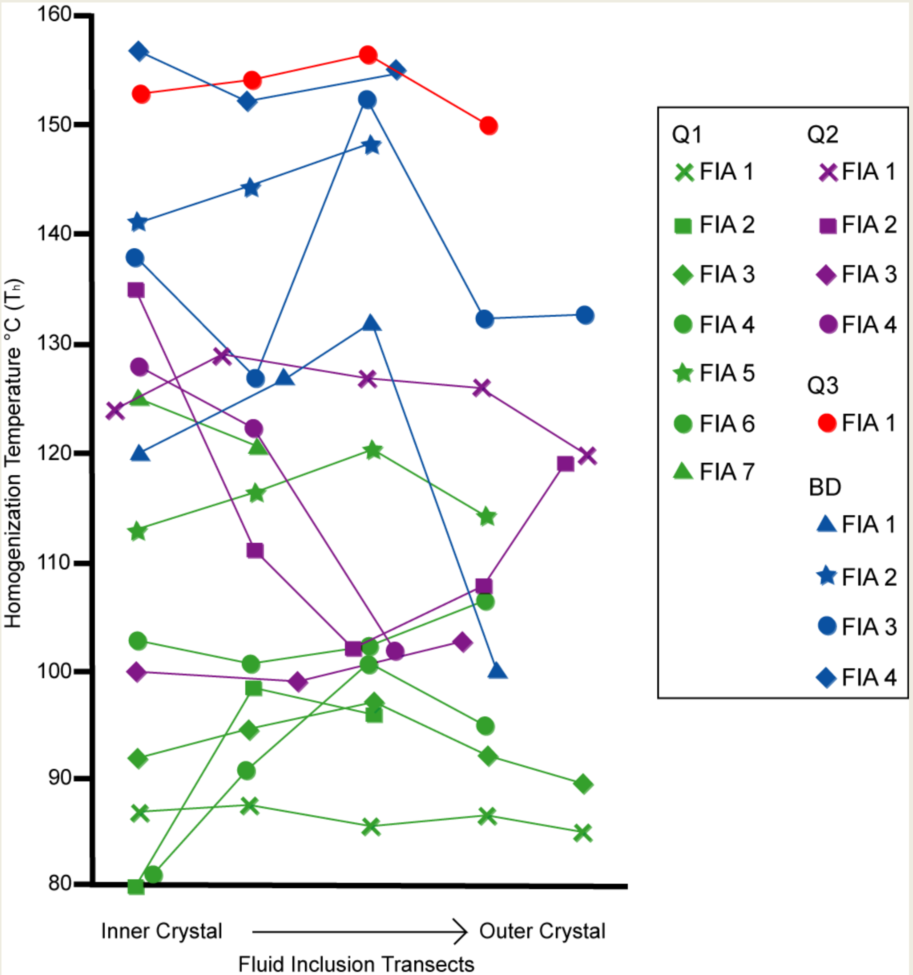
Gas during megaquartz→

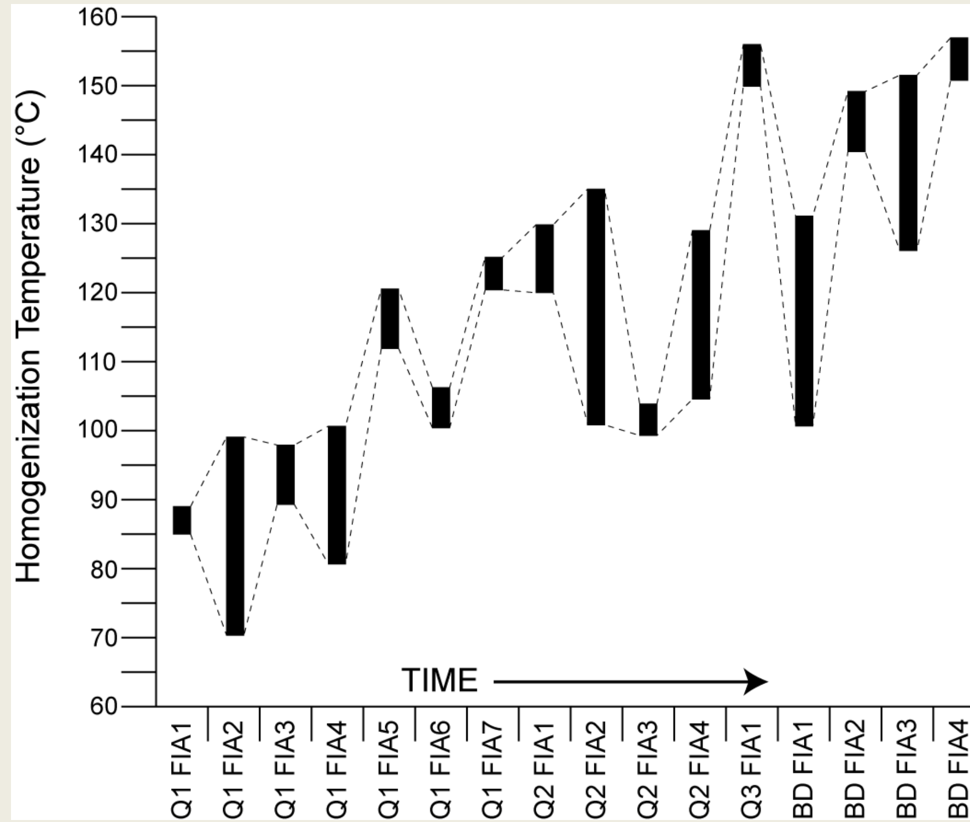


Similar Late-Stage Paragenesis in All Units



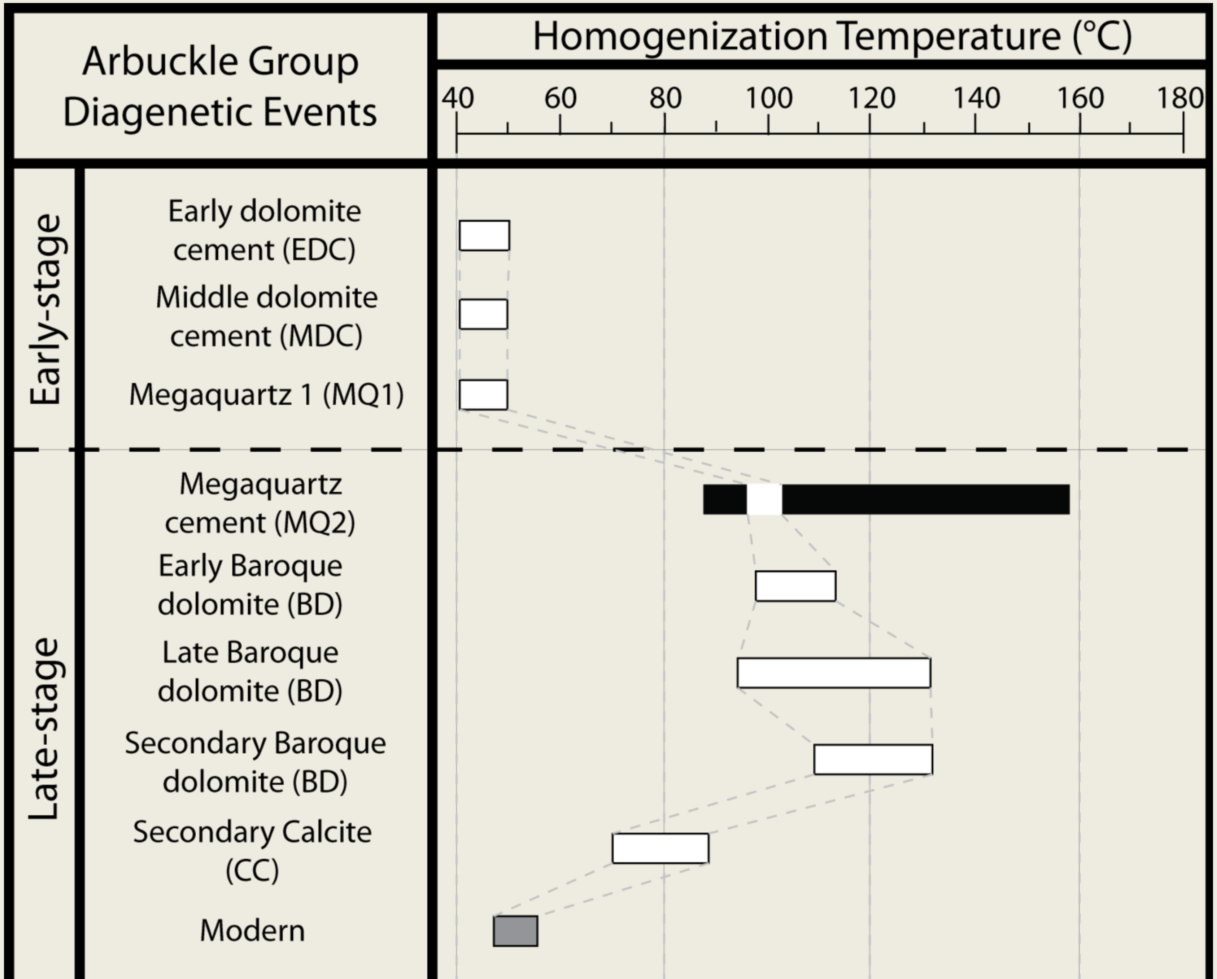
Fluid Inclusion Data – Hydrothermal

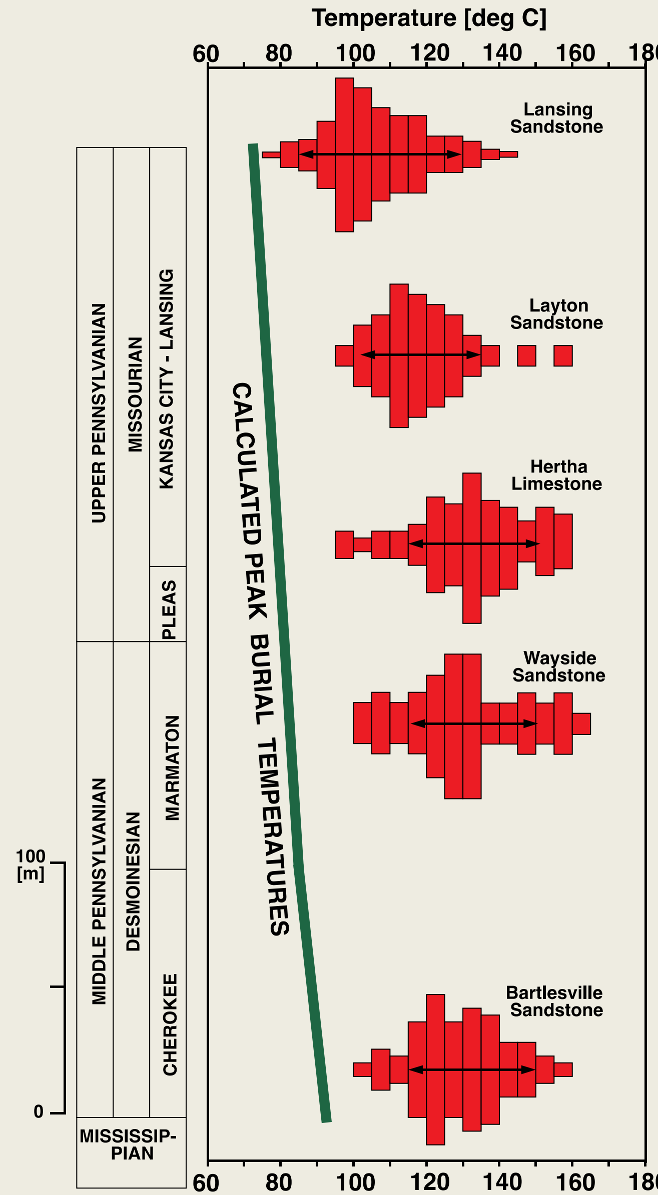




- Homogenization temperatures rise and fall through time - pulsed fluid flow

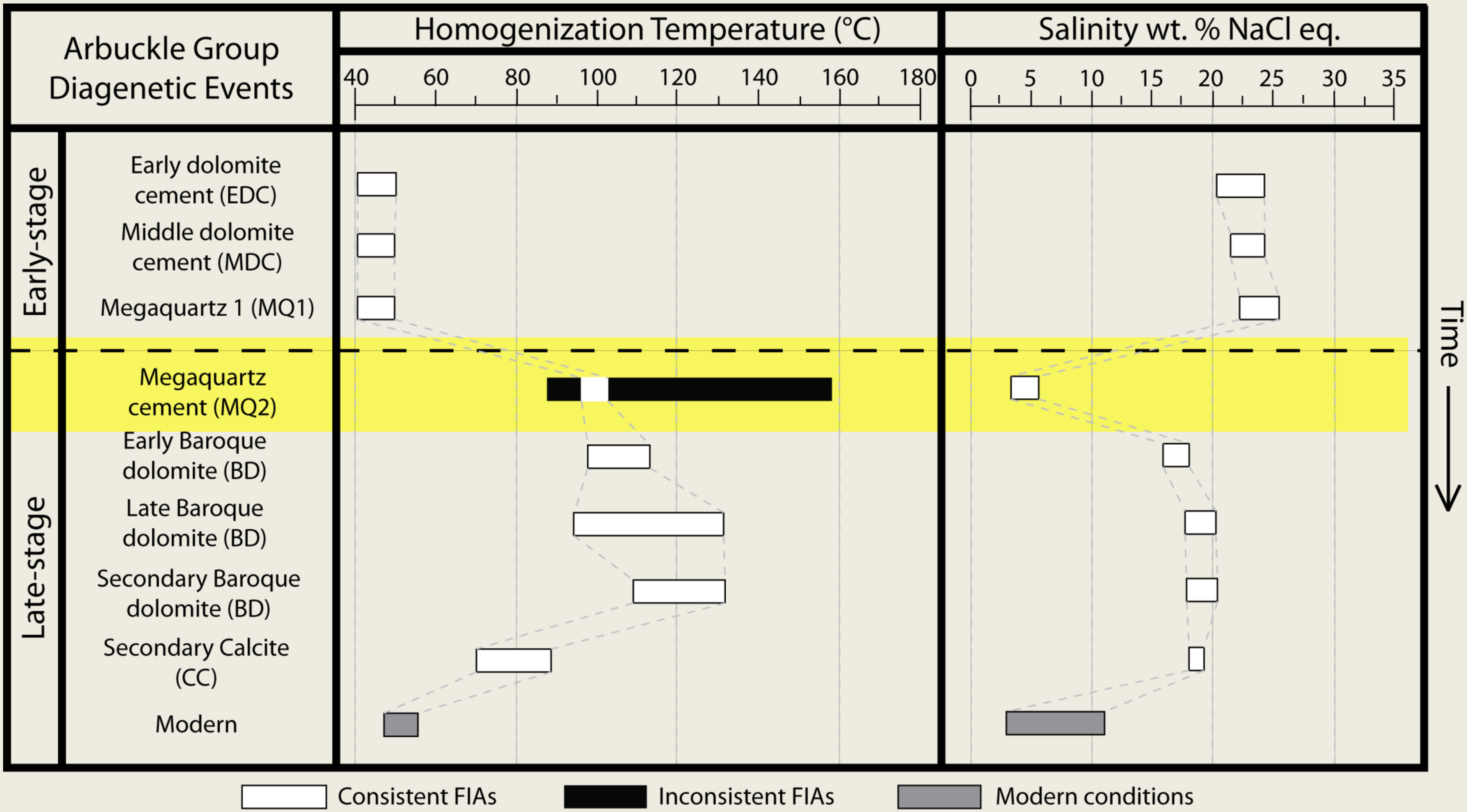
Fluid Inclusion Data – Hydrothermal





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

Stage 1 - Hydrothermal Flow



Stage 1 - Advective Fluid Flow - Megaquartz

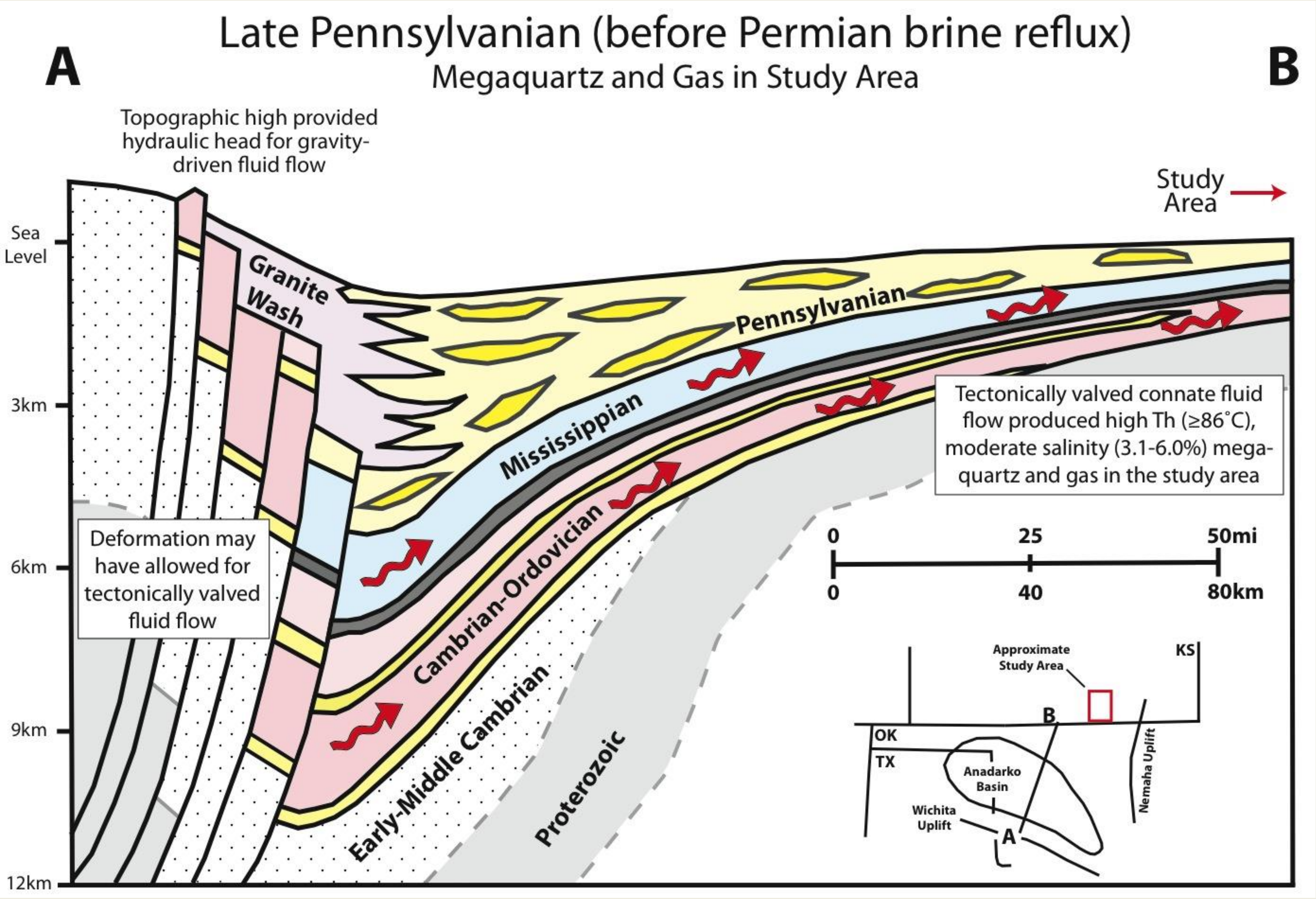
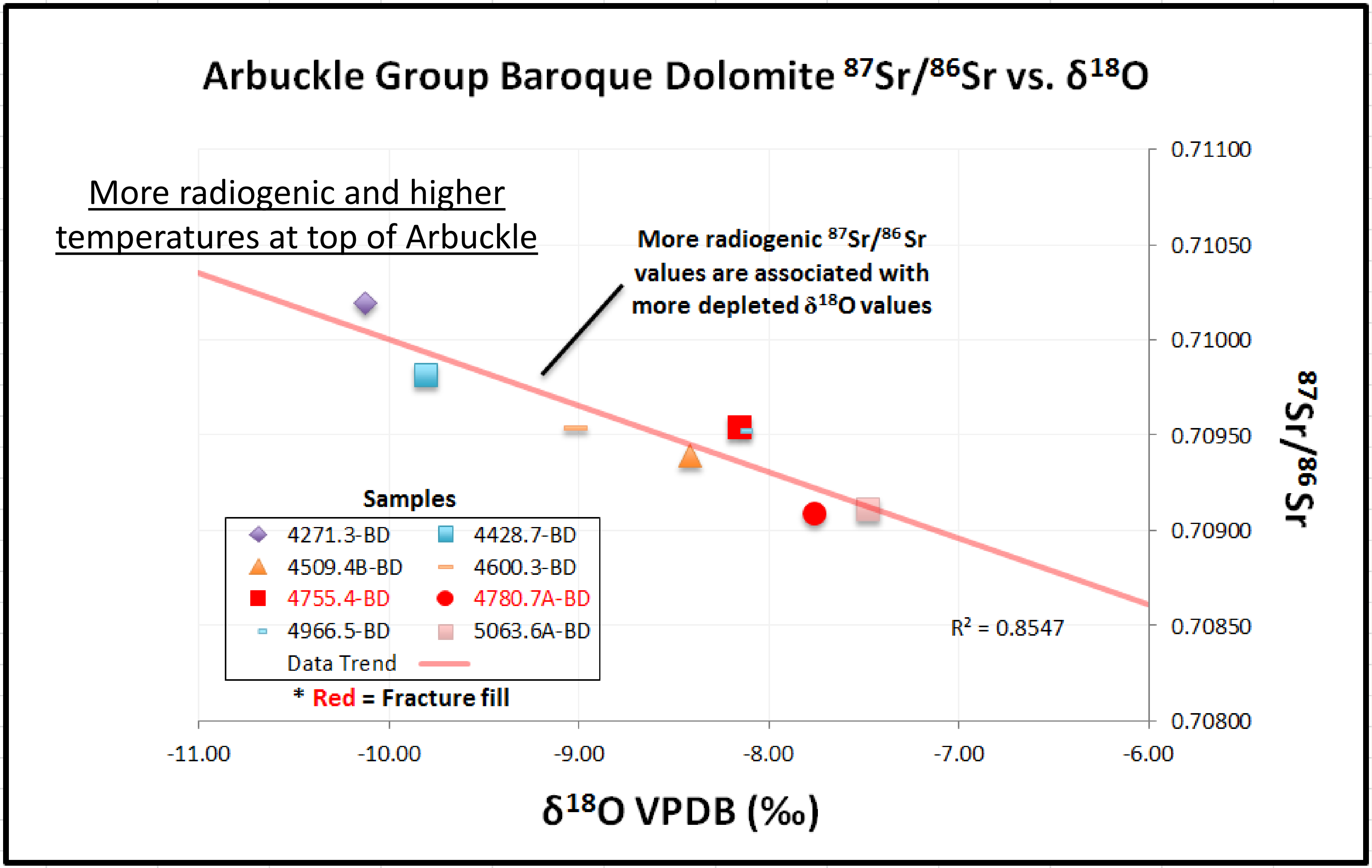


Image modified from Gallardo and Blackwell, 1999

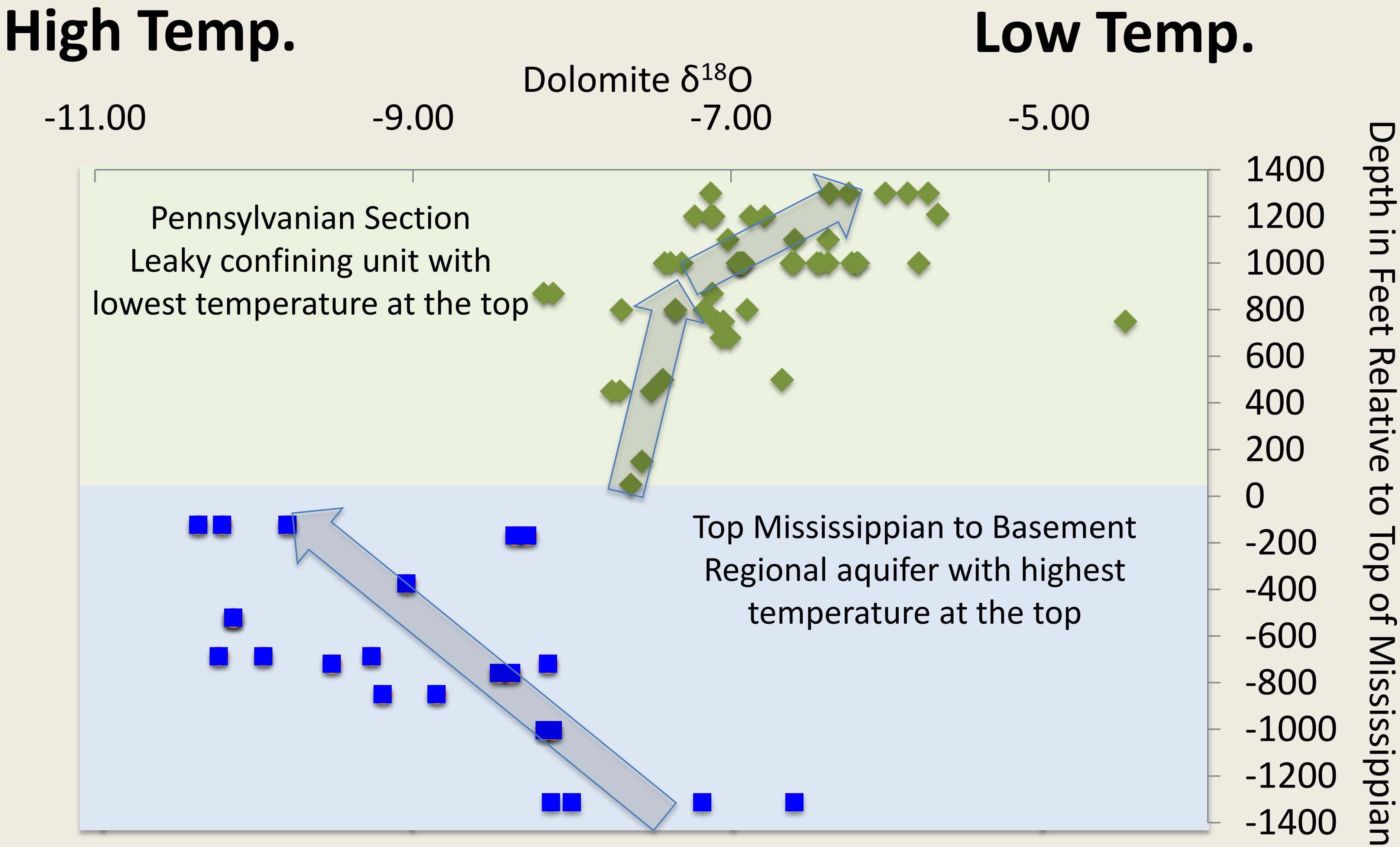
Stage 2 - Hydrothermal Flow

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

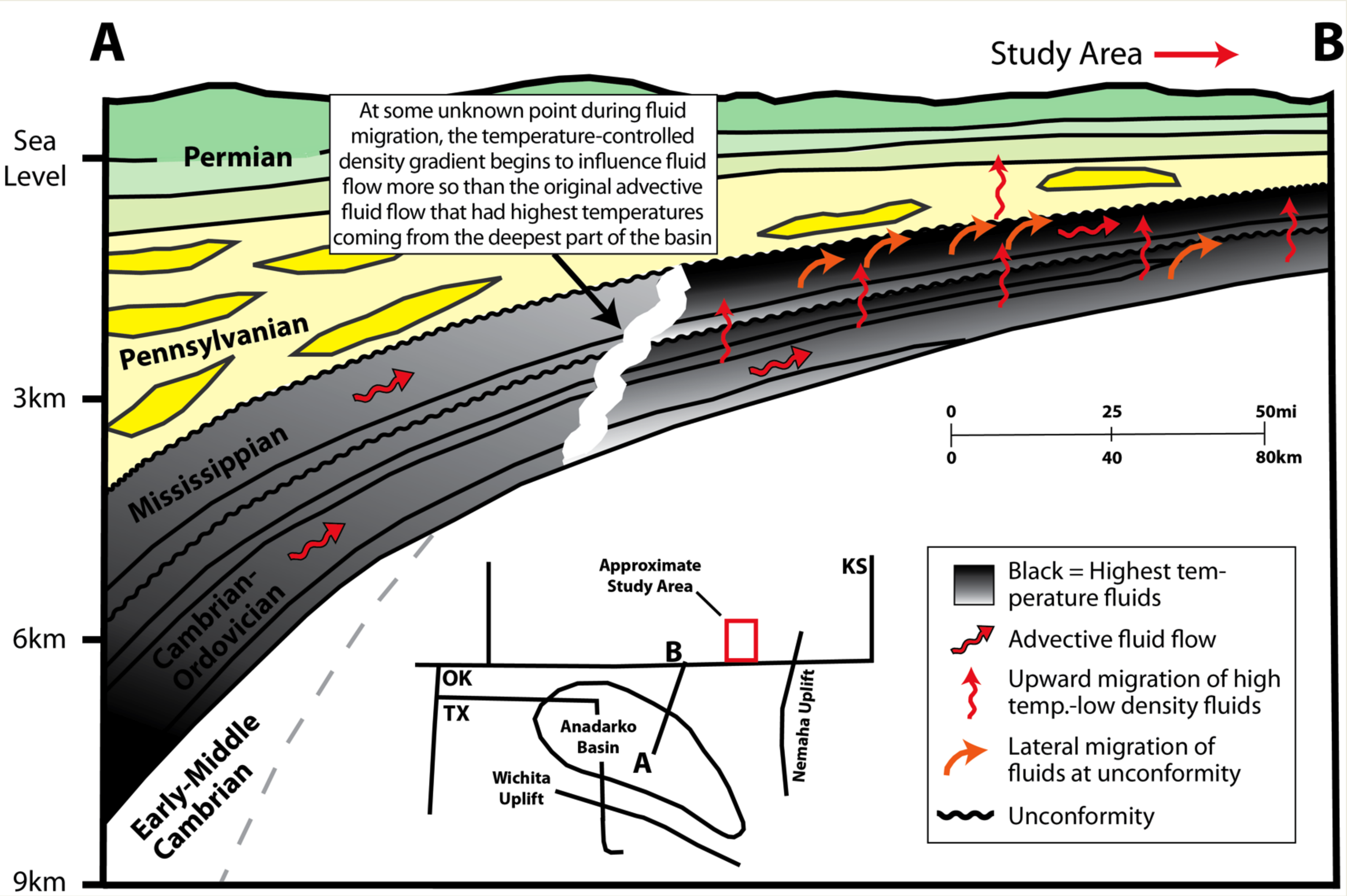


Radiogenic values, higher temp = less rock-water interaction with carbonates

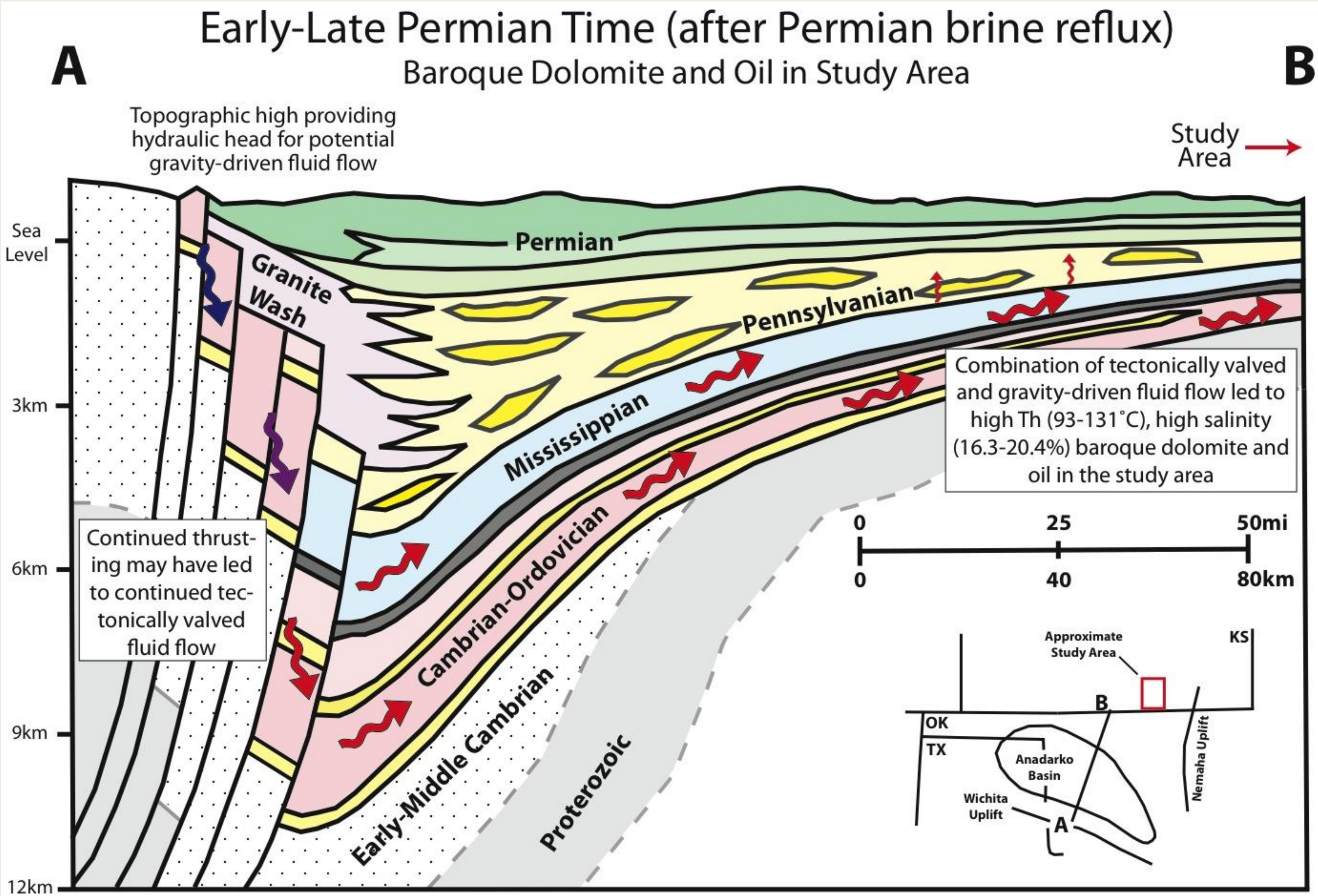
Thermal Structure - Stage 2 Regional Fluid Flow



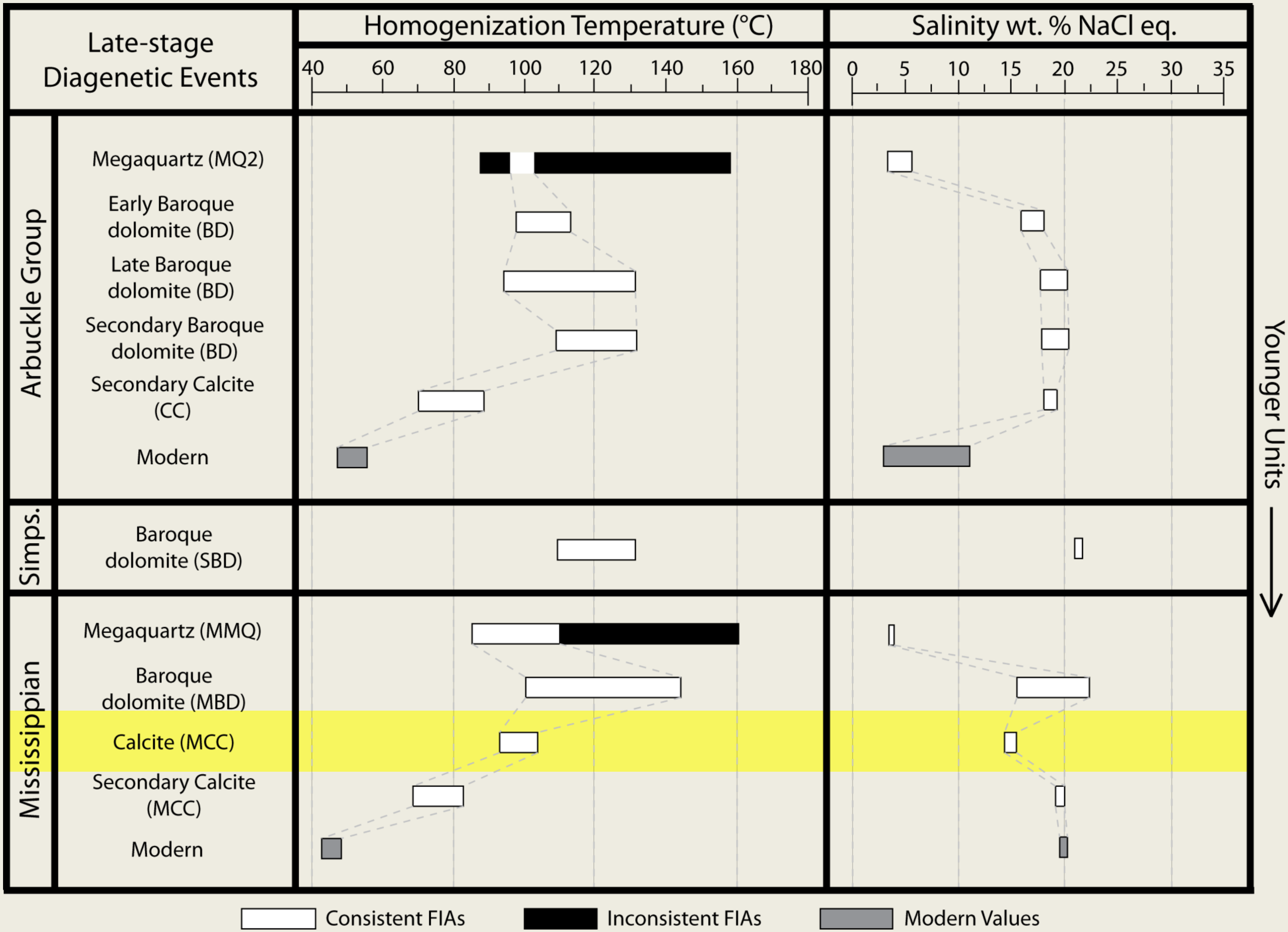
Stage 2 – Warmer fluids at top of Aquifer



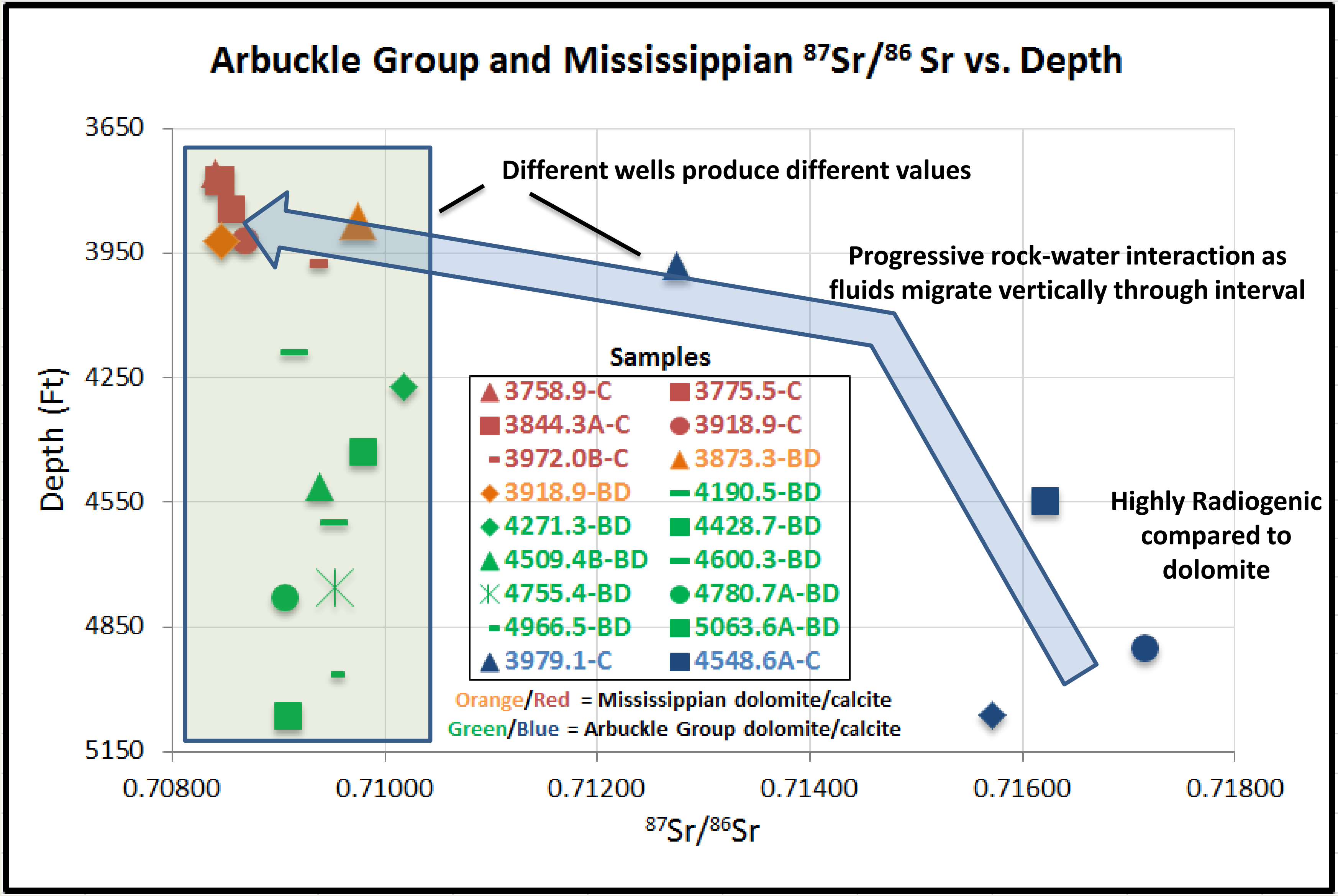
Advective Fluid Flow – Stage 2



Stage 3 - Hydrothermal Flow



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



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

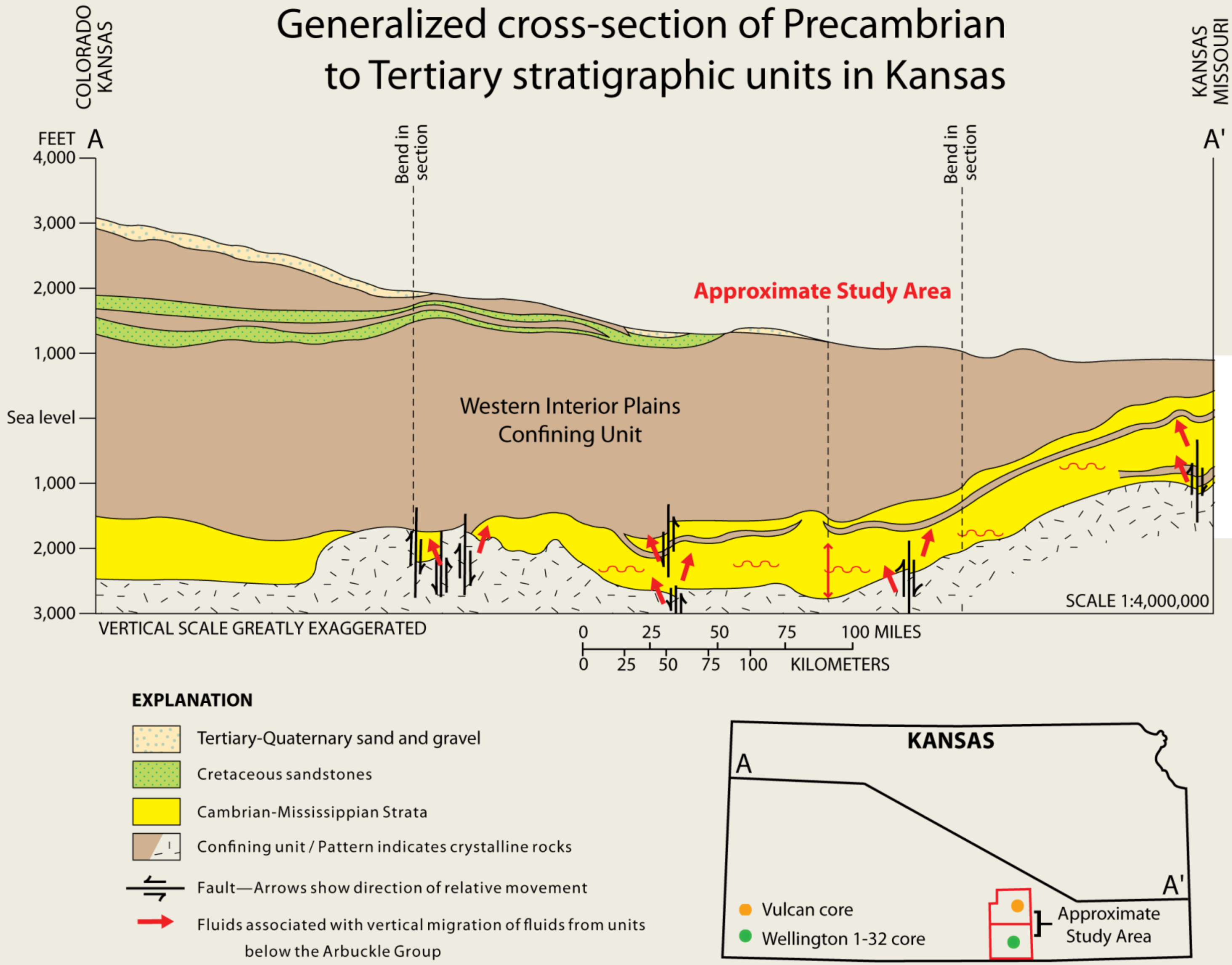


Image modified from Miller and Appel, 1997

Conclusions

- Three-stage evolution of hydrothermal systems
- Two stages of regional advective flow
  - 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, something predicted on the basis of density
- Better porosity is related to late structure and hydrothermal flow immediately below unconformity
- A third stage of hydrothermal fluid flow was localized by later (possibly Laramide) faults and fractures and led to localized hydrothermal systems