PSConditions of Quartz Cementation in Mt. Simon Sandstone: Evidence from in situ Microanalysis of Oxygen Isotopes*

Anthony D. Pollington[1], Reinhard Kozdon[1], Takayuki Ushikubo[1], Noriko T. Kita[1], and John W. Valley[1]

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[1]WiscSIMS Lab, Department of Geoscience, University of Wisconsin, Madison, WI (apolling@geology.wisc.edu)

Abstract

Samples of the Mt. Simon Formation have been analyzed in situ for oxygen isotope ratio ($\delta^{18}O$, 10µm and 3µm spots) from three depth intervals in Illinois Basin cores as well as outcrop samples from Wisconsin. Diagenetic cements account for a major fraction of the intergranular volume of many samples. Almost all core samples contain quartz cements that occlude between 30 and >90% of the original porosity, while overgrowths in outcrop samples are quartz and feldspar which fill between 0 and 50% of original porosity. This reduction in porosity has a significant effect on permeability and reservoir quality. The $\delta^{18}O$ of diagenetic quartz cements allows estimation of the variability in precipitation temperature, if $\delta^{18}O$ (fluid) is known. Alternatively, changes in fluid source can be detected if thermal history is known.

Values of $\delta^{18}O$ of detrital and pore-filling quartz were measured on an IMS-1280 ion microprobe. $\delta^{18}O$ values for the detrital quartz are similar across all depths ($9.8 \pm 4.2‰_{VSMOW}$) consistent with a source dominated by igneous rocks. The quartz cements are distinctly higher in $\delta^{18}O$ than detrital grains and define a trend to lower values deeper in the basin (from 27.9 to 15.6‰ for the latest cement in each overgrowth). In a fluid-dominated system, the lower values are expected for quartz precipitated under warmer conditions, suggesting that the decrease in $\delta^{18}O$ down-dip in the basin is largely dominated by increasing burial temperature.

In addition to the basin-wide trend to lower $\delta^{18}O$ values with increasing depth, most individual overgrowths show a trend of decreasing $\delta^{18}O$ from early to late quartz growth. This suggests that cement growth started early in the burial history, continued while rocks were heated during burial, and ceased before unroofing and basin uplift. $\delta^{18}O$ zonation was measured in 84 overgrowths. Most overgrowths show a decrease in $\delta^{18}O$, on average by 2.1‰ (max. = 8.7‰), as growth proceeded. If $\delta^{18}O$ (H_2O) = -3‰ for a fluid-dominated system, this indicates that cements grew from 30-160ºC consistent with published temperatures from fluid inclusions and vitrinite reflectance in the Illinois Basin.

These results indicate that the majority of quartz cements formed in the Mount Simon sandstone during burial and heating. There is no evidence in these samples of later quartz cementation or cross-cutting cements.

References

Chen, Z., L.R. Riciputi, C.I. Mora, and N.S. Fishman, 2001, Regional fluid migration in the Illinois basin: Evidence from in situ oxygen isotope analysis of authigenic K-feldspar and quartz from the Mount Simon Sandstone: Geology, v. 29, p. 1067-1070.

Clayton R.N., J.R. O’Neil, and T.K. Mayeda, 1972, Oxygen isotope exchange between quartz and water: Journal of Geophysical Research, v. 77, p. 3057–3067.

Friedman, I. and J.R. O’Neil, 1977, Compilation of stable isotope fractionation factors of geochemical interest: USGS Professional Paper 440-KK.

Kelly, J.L., B. Fu, N.T. Kita, and J.W. Valley, 2007, Optically continuous silcrete quartz cements of the St. Peter Sandstone: High precision oxygen isotope analysis by ion microprobe: Geochimica et Cosmochimica Acta., v. 71, p. 3812-3832.

Mai, H. and R.H. Dott, 1985, A subsurface study of the St. Peter Sandstone in southern and eastern Wisconsin: Wisconsin Geological and Natural History Survey, Information Circular 47, p. 26.

Valley, J.W. and N.T. Kita, 2009, In situ oxygen isotope geochemistry by ion microprobe, *in* M. Fayek, editor, MAC Short Course: Secondary Ion Mass Spectrometry in the Earth Sciences, v 41, p. 19-63.

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Abstract

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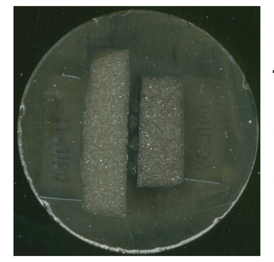
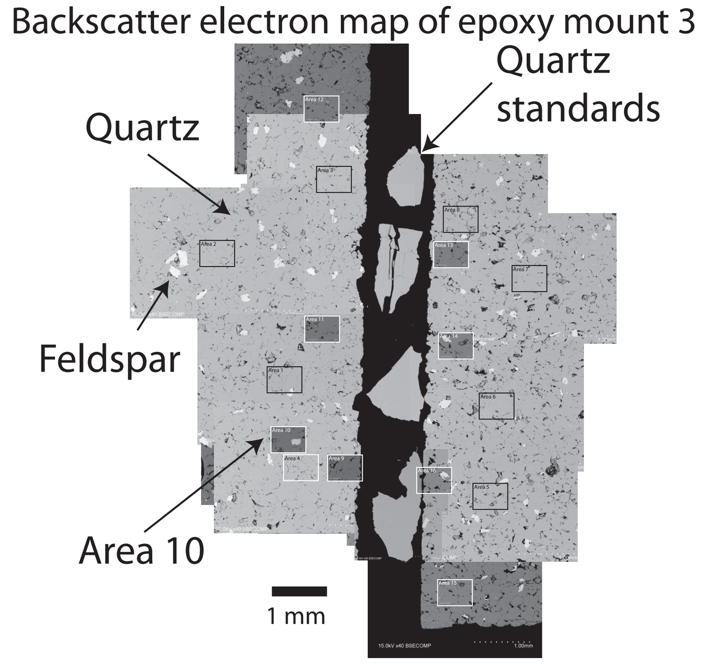
Sample Preparation



Two rock chips are mounted in a one inch epoxy round with quartz standards in the center

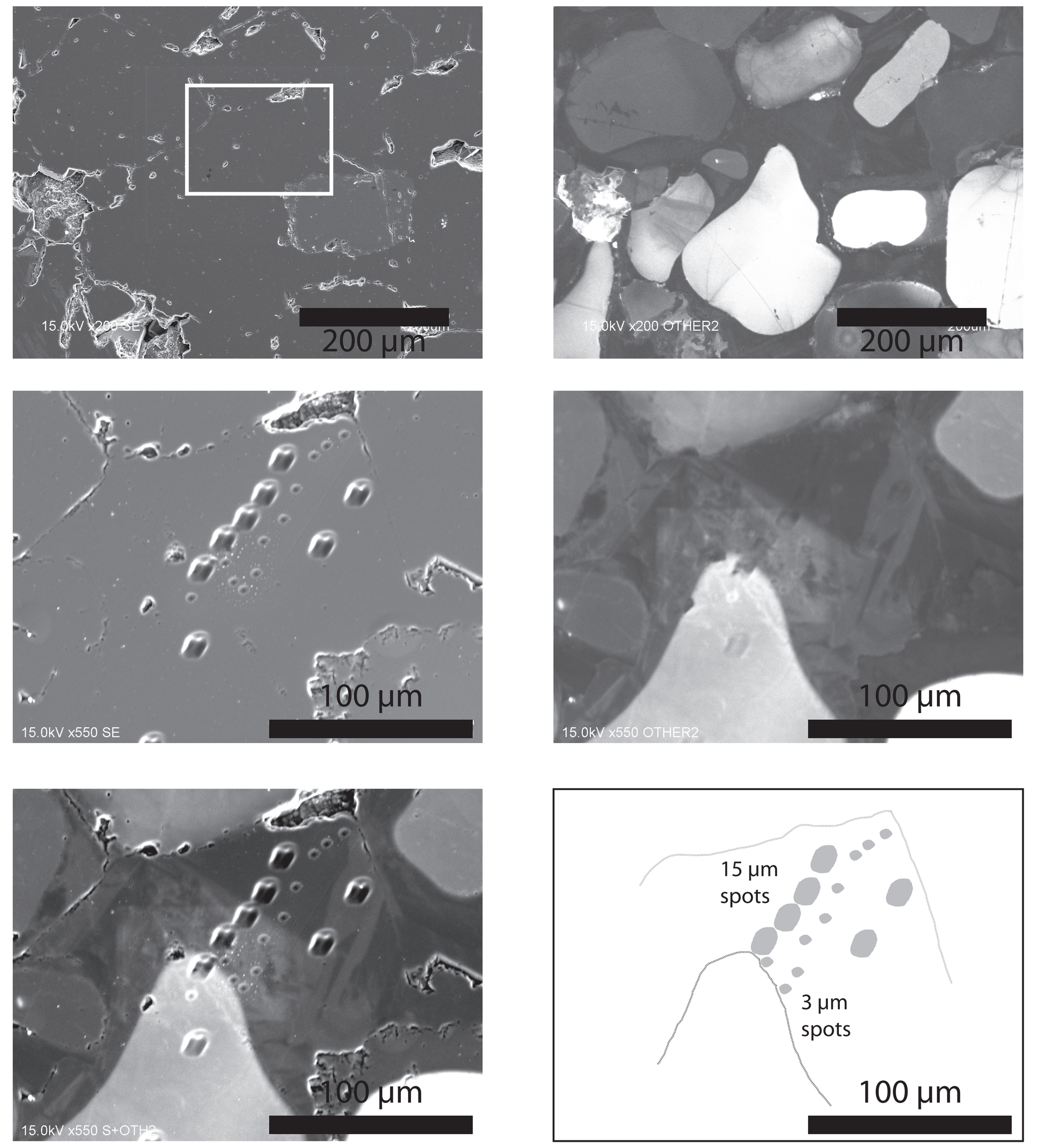
Backscatter electron map of epoxy mount 3



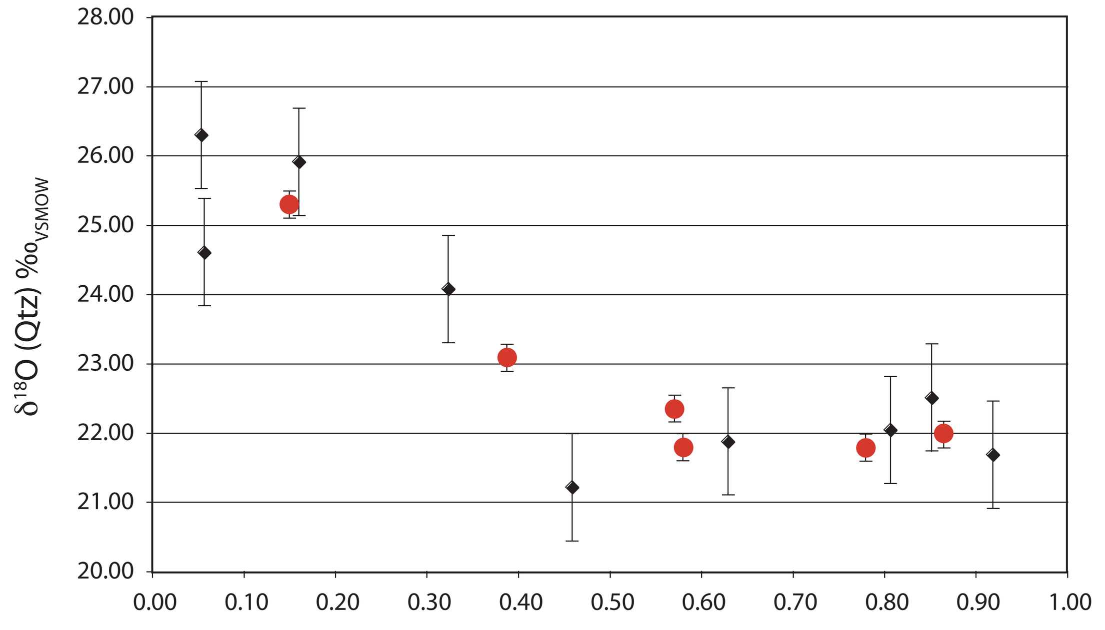
09IL-41 (1982 m, 6503 ft) | 09IL-39 (1980 m, 6499 ft)

See Kelly et al. (2007) and Valley and Kita (2009) for technique description

Scanning Electron Microscope images of Area 10, Mount 3

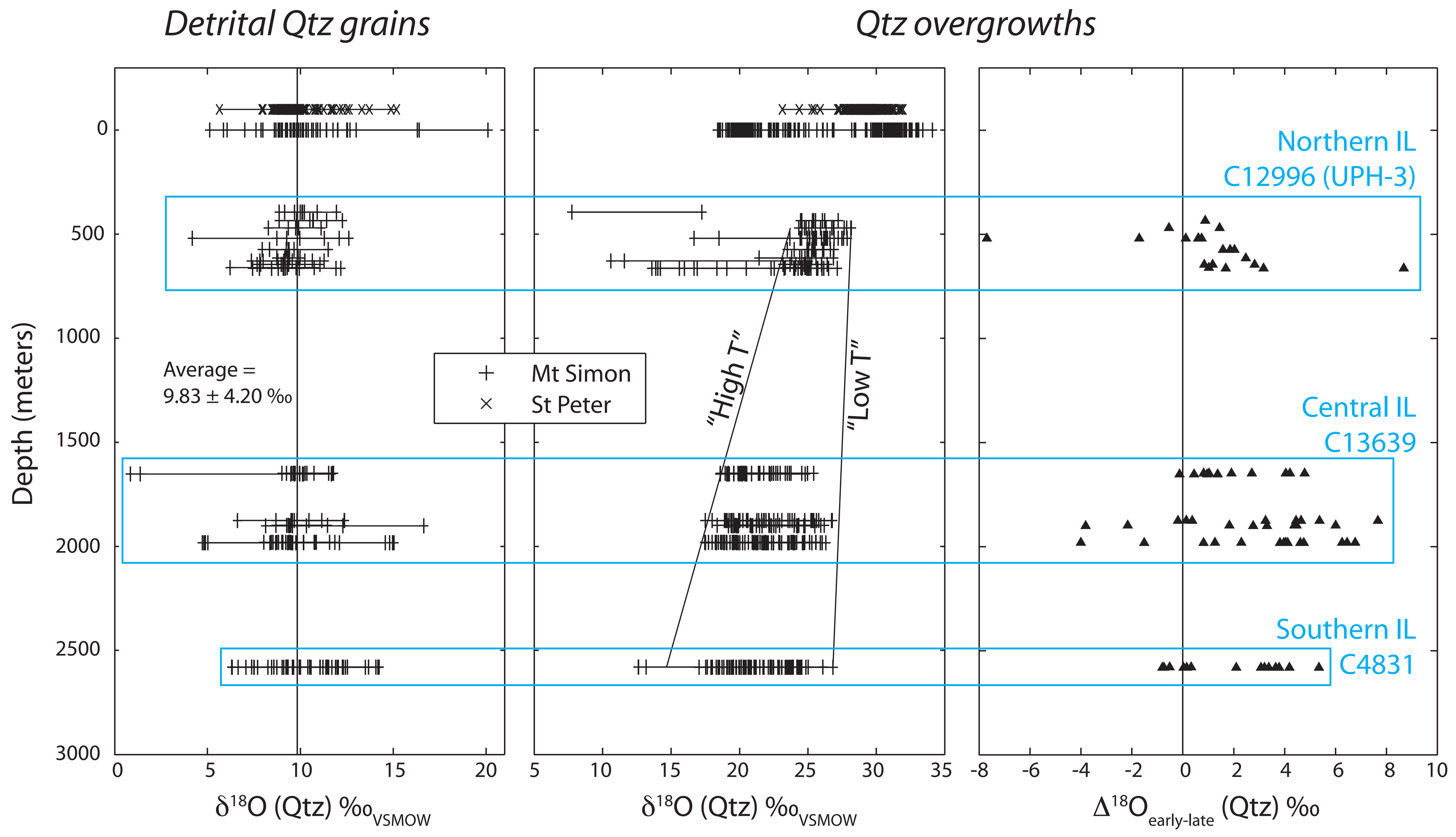


Oxygen isotope results for traverse in Area 10, Mount 3



Large red dots represent 15 μm spots, black diamonds represent 3 μm spots
Error bars are $2\sigma_{SD}$

Basin wide trends in oxygen isotope values



Oxygen isotope values for detrital quartz and quartz cement. The values for detrital quartz are consistent with a source dominated by Precambrian igneous quartz. The $\delta^{18}O$ values for quartz cement are much higher due to growth at low temperatures. The highest values occur in samples from the Wisconsin Arch, where there has never been more than ~1 km burial (Mai and Dott, 1985). Samples from deeper in cores from the Illinois Basin have lower values as well as greater variability. Most overgrowths are zoned in $\delta^{18}O$, with values near the detrital grain highest and generally decreasing as cement growth proceeds. $\Delta^{18}O$ is the value of the spot closest to the detrital grain minus the value of the spot farthest away and indicates that the majority of overgrowths decrease in value. The "High T" line is calculated assuming a constant $\delta^{18}O$ (H_2O) of -3 ‰$_{VSMOW}$, a constant paleogeothermal gradient of 30ºC/km, 1 km of uplift and 20ºC at the surface.

Isotope Fractionation

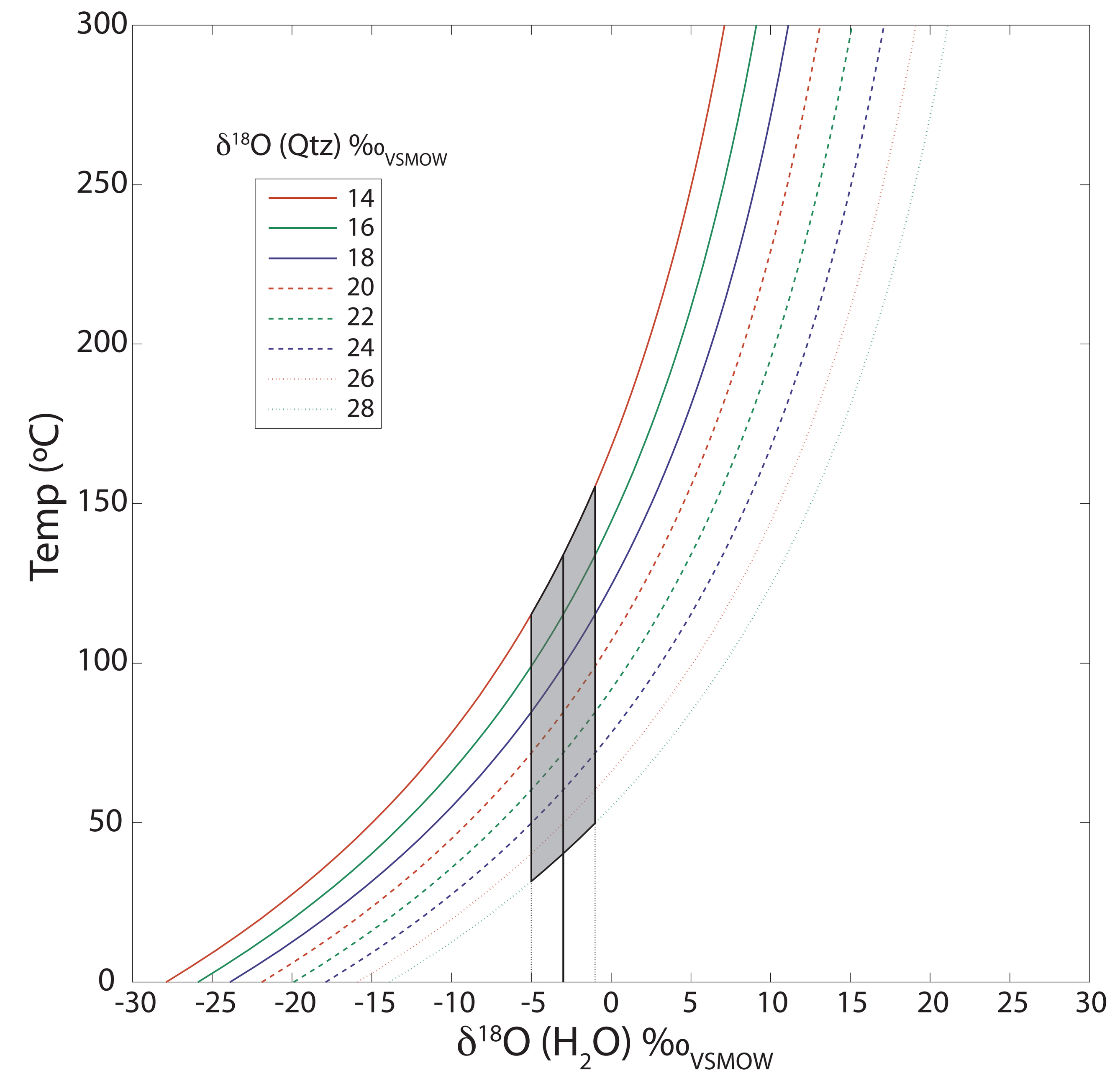
The $\delta^{18}O$ value of a quartz overgrowth precipitating in equilibrium from a fluid in a system with a high water-rock ratio is a function of the temperature at which it precipitates and the $\delta^{18}O$ of the fluid. Using calibrations of $\delta^{18}O$ versus temperature it is possible to calculate cement temperatures with an assumed constant fluid, or to use assumed temperatures and calculate a fluid composition. These results are useful in determining whether cements grew in response to fluid flow or variable temperature due to burial.

Calibration of Clayton et al., 1972*:

$$\Delta_{Qtz\text{-}H2O} = \delta^{18}O\,(Qtz) - \delta^{18}O\,(H_2O) = \frac{3.38 \times 10^6}{T^2} - 2.90$$

*See Friedman and O'Neil (1977)

Water $\delta^{18}O$ vs. temperature



Calculated curves for quartz in equilibrium with water for a range of temperature and fluid values. Gray box indicates range in temperature calculated for a $\delta^{18}O$ (H_2O) of -3 ± 2 ‰. The total range of temperatures in this box is from 33ºC to 161ºC, which corresponds well with the 30ºC/km gradient assumed for growth of the heaviest overgrowths.

Conclusions

Values of $\delta^{18}O$ (Qtz) measured in syntaxial quartz overgrowths from the Mt. Simon Sandstone in the Illinois Basin indicate that cements began to grow at near-surface, low-temperature conditions. Cements continued to grow during burial and heating and record this history. The variability of $\delta^{18}O$(Qtz) can be explained simply with heating due to burial and does not require isothermal modification of pore fluid composition as proposed by Chen et al. (2001).

References

Chen, Z., Riciputi, L. R., Mora, C. I., Fishman, N. S.(2001) Regional fluid migration in the Illinois basin: Evidence from in situ oxygen isotope analysis of authigenic K-feldspar and quartz from the Mount Simon Sandstone. *Geology.* **29**, 1067-1070.

Clayton R. N., O'Neil J. R. and Mayeda T. K. (1972) Oxygen isotope exchange between quartz and water. *J. Geophys. Res.* **77**, 3057–3067.

Friedman, I. and O'Neil, J. R. (1977) Compilation of stable isotope fractionation factors of geochemical interest. USGS professional paper 440-KK

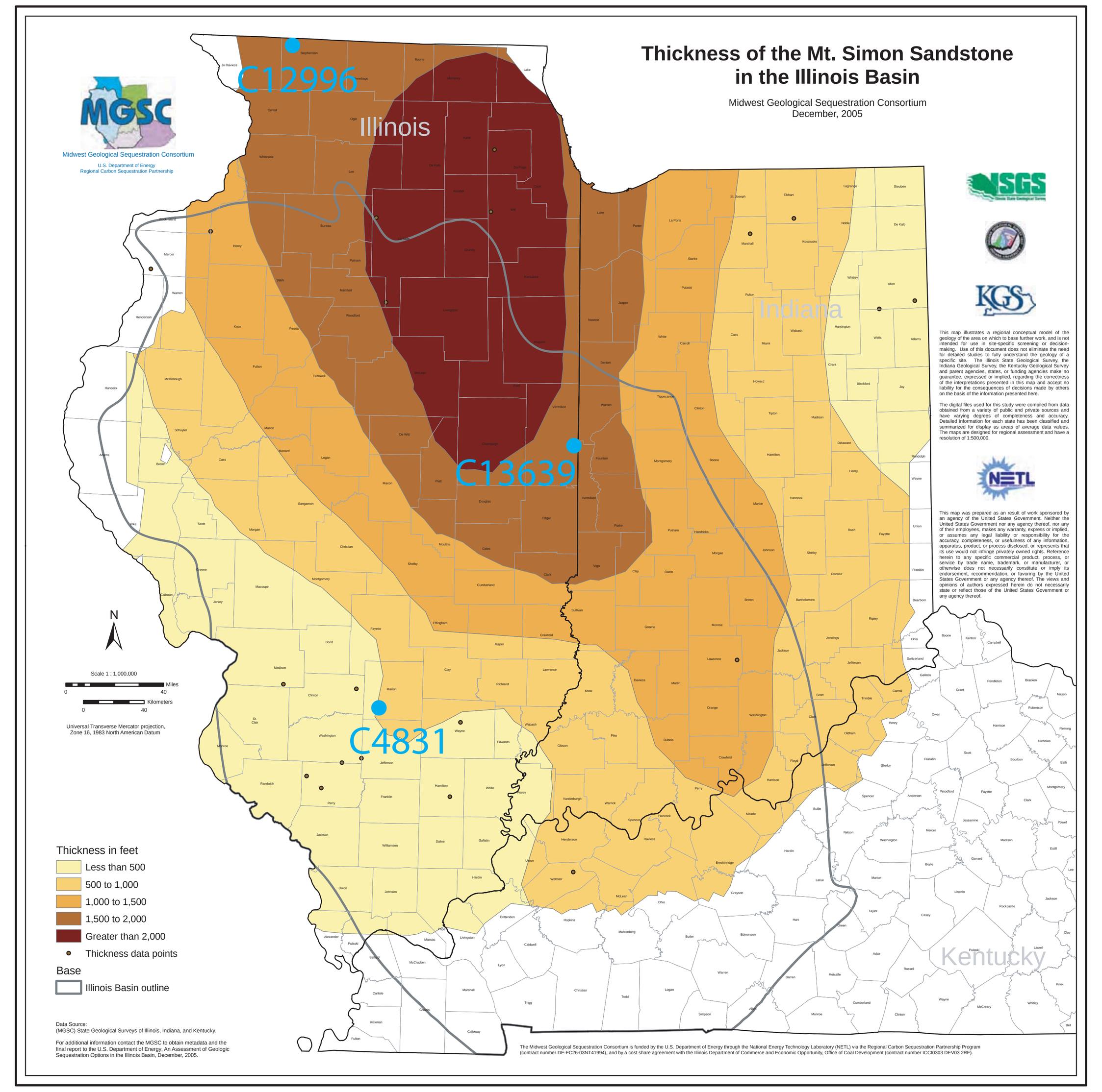
Kelly, J. L., Fu, B., Kita, N. T., Valley, J. W. (2007) Optically continuous silcrete quartz cements of the St. Peter Sandstone: High precision oxygen isotope analysis by ion microprobe. *Geochim. et Cosmochim. Acta.* **71**, 3812-3832.

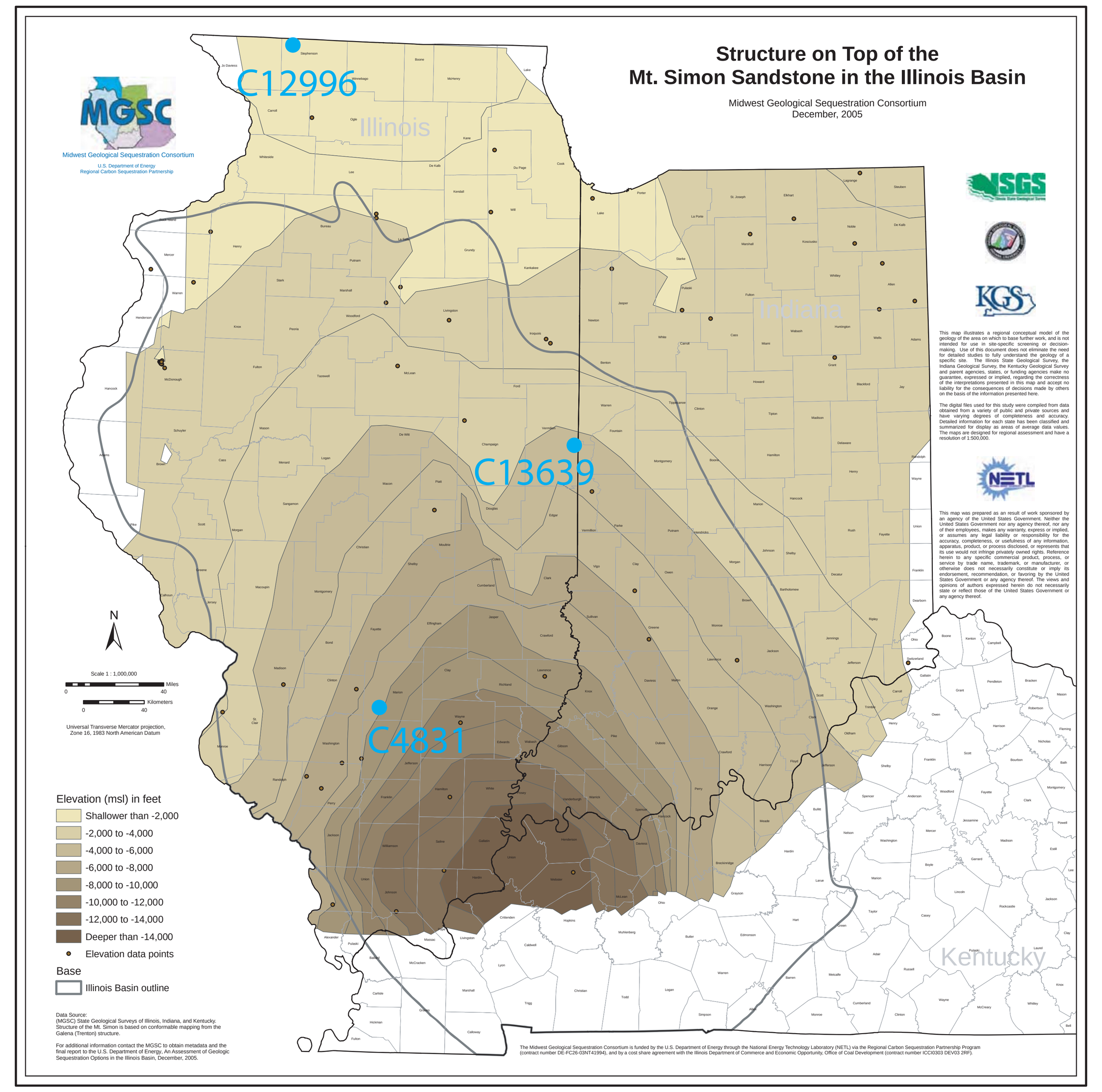
Mai H. and Dott, Jr., R. H. (1985) A subsurface study of the St. Peter Sandstone in southern and eastern Wisconsin. *Wisc. Geol. Nat. Hist. Surv. Info. Circ. 47*, p. 26.

Valley, J. W. and Kita, N. T. (2009) *In situ* Oxygen Isotope Geochemistry by Ion Microprobe, In: Fayek M. (ed) MAC Short Course: Secondary Ion Mass Spectrometry in the Earth Sciences, v 41, 19-63

Maps of Illinois Basin from MGSC

Blue circles are locations of cores used in this study





C12996

Gamma ray and Neutron logs of core C12996 (UPH-3) Purple lines indicate locations of some of the samples used in this study

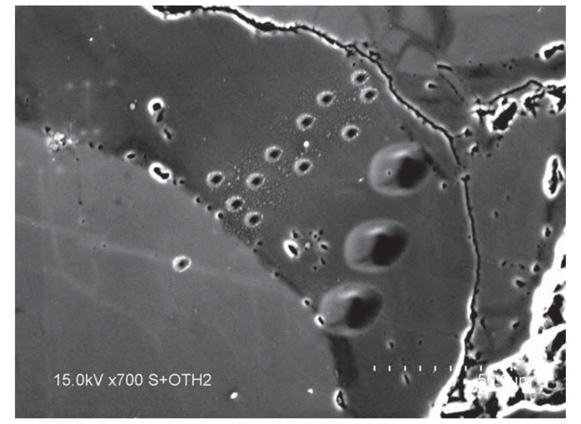
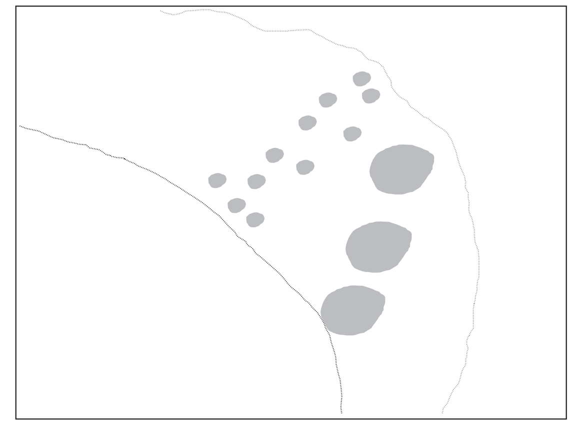
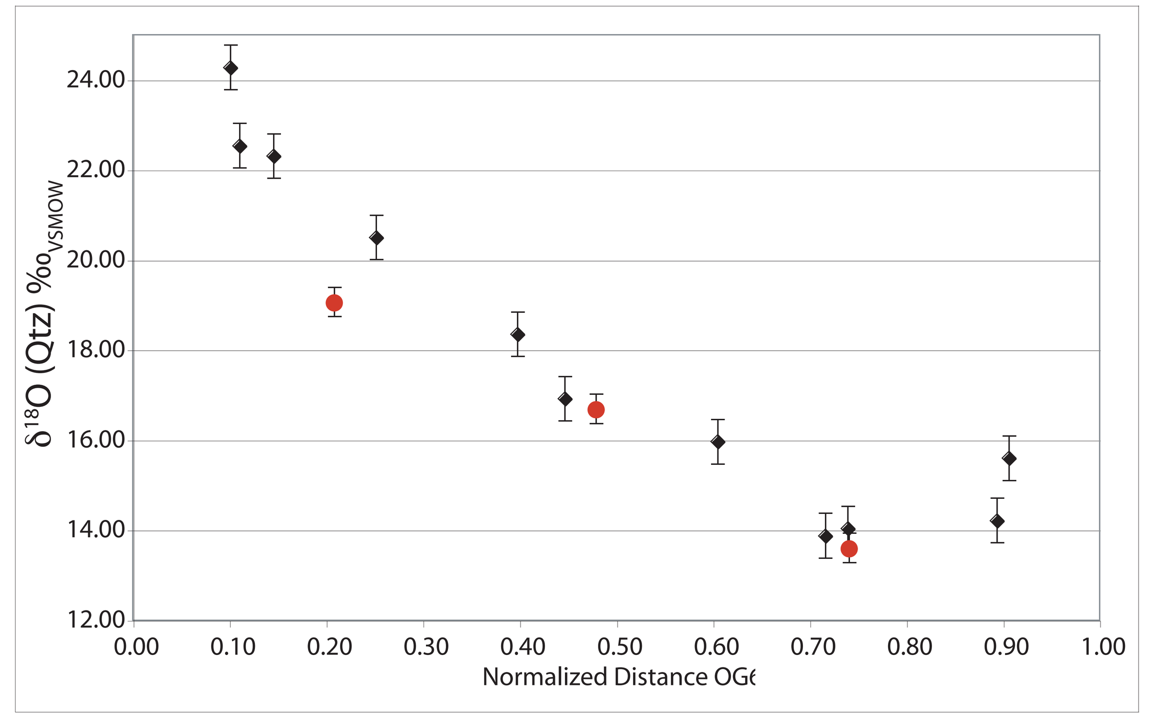
Break in log (1600'-1800')

Multi-spot traverses. Large spots are 15 μm and are represented by red dots on graphs. Small spots are 3 μm and are represented by black diamonds on graphs.

C12996

09IL-29 663 m, 2176.6 feet

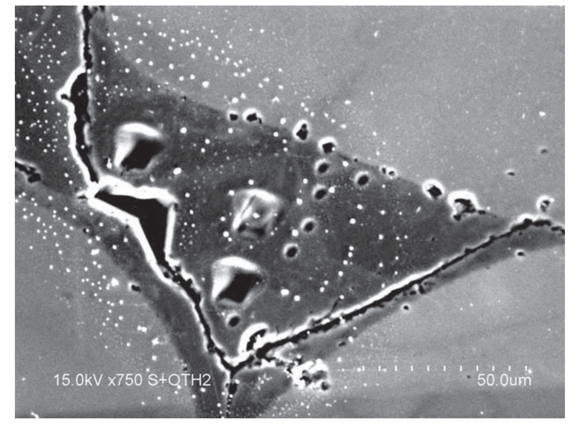
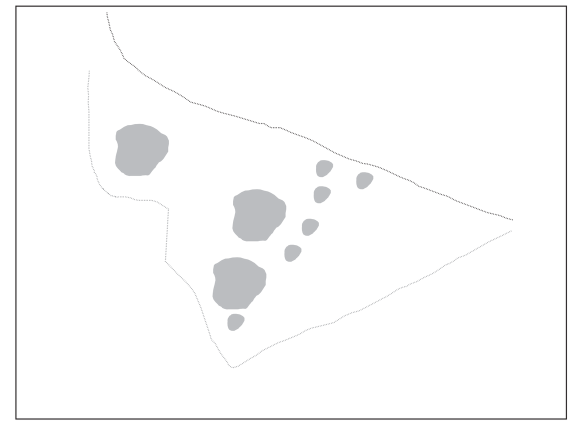
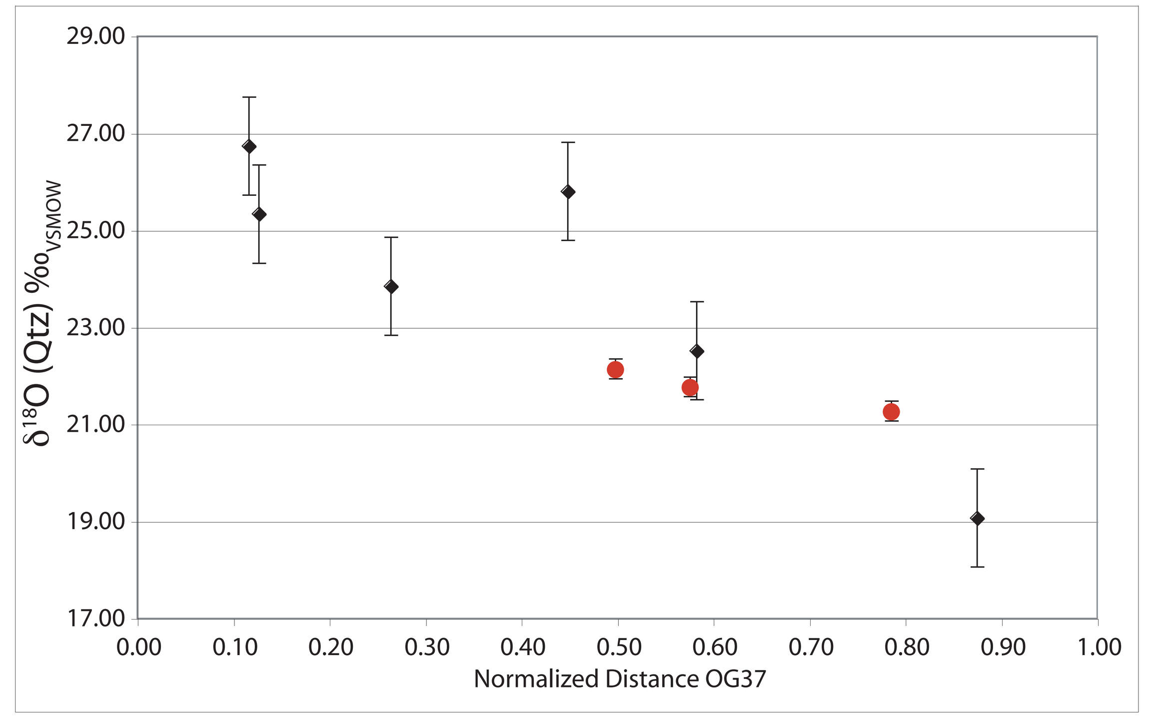
$\Delta^{18}O_{early-late} = 8.68‰$

C13639

09IL-35 1876 m, 6154.5 feet

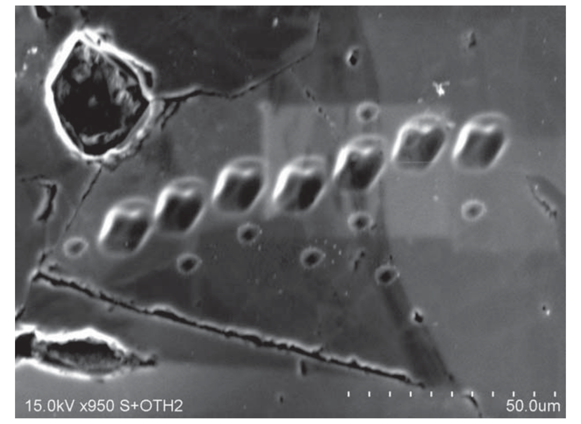
$\Delta^{18}O_{early-late} = 7.66‰$

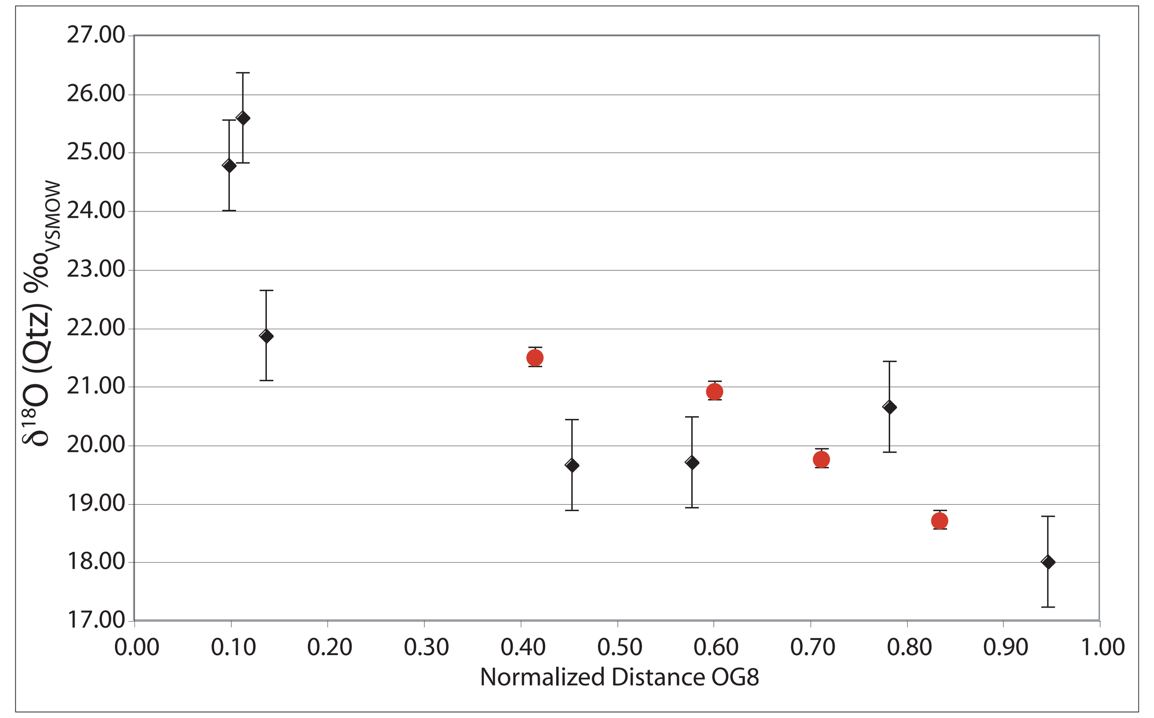




C13639

09IL-39 1981 m, 6499 feet

$\Delta^{18}O_{early-late} = 6.77‰$





C4831

09IL-50 2581 m, 8468.8 feet

$\Delta^{18}O_{early-late} = 3.78‰$