Reducing Sample Heating During NMR Measurements

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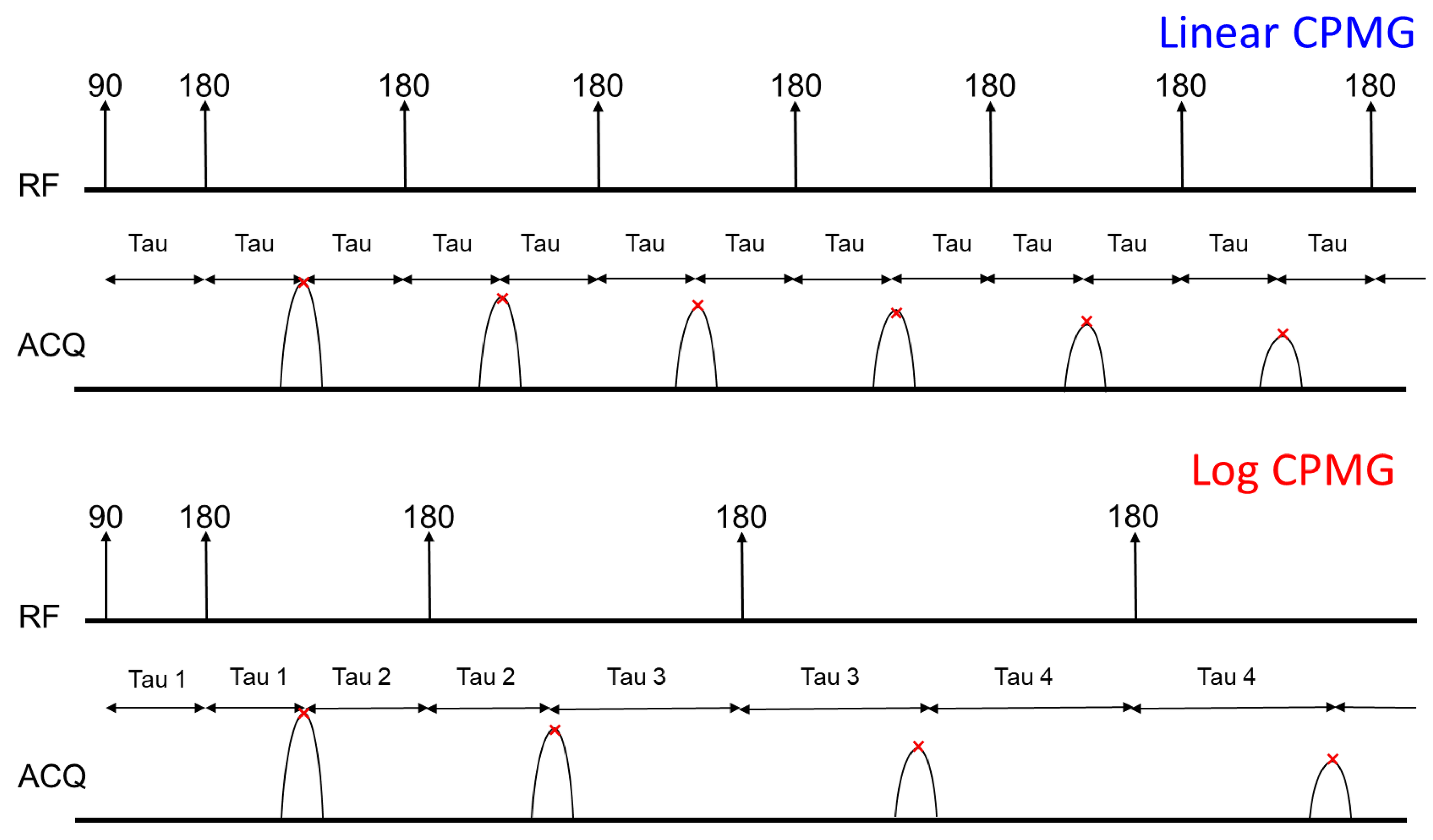
CPMG Pulse Sequence And Sample Heating

- The pore size (or T_2) distribution is probably the most important measurement in NMR core analysis. It is employed to derive porosity of core samples as well as used as the basis of other measurements such as wettability determination, NMR log calibration and bound vs. free fluid determination.
- The T_2 distribution is derived from the Carr-Purcell-Meiboom-Gill (CPMG) NMR pulse sequence.
- The CPMG sequence employs many RF pulses (linearly spaced), each of which deposit energy into the sample. This can lead heating of the sample, which can lead to a reduction in NMR signal, which can lead to inaccuracies in porosity determination.
- In general, the NMR signal decreases 0.3% per degree Celsius increase in sample temperature.
- One method to avoid sample heating by the CPMG pulse sequence is to employ a sequence where the RF pulses are spaced logarithmically. This maintains the accuracy needed to probe the T_2 decay while reducing the number of RF pulses impinging on the sample.
- We have implemented these logarithmically spaced CPMG sequences and will show that these sequences still accurately reproduce the NMR-measurements for all samples while eliminating sample heating.

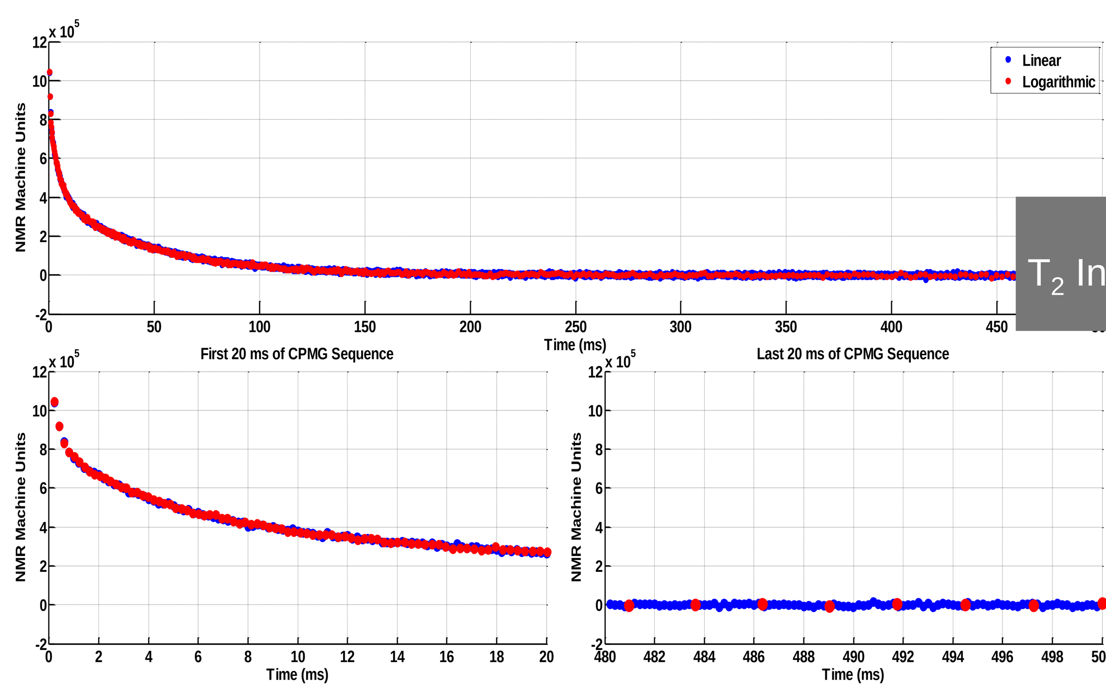
Log Vs. Linear CPMG



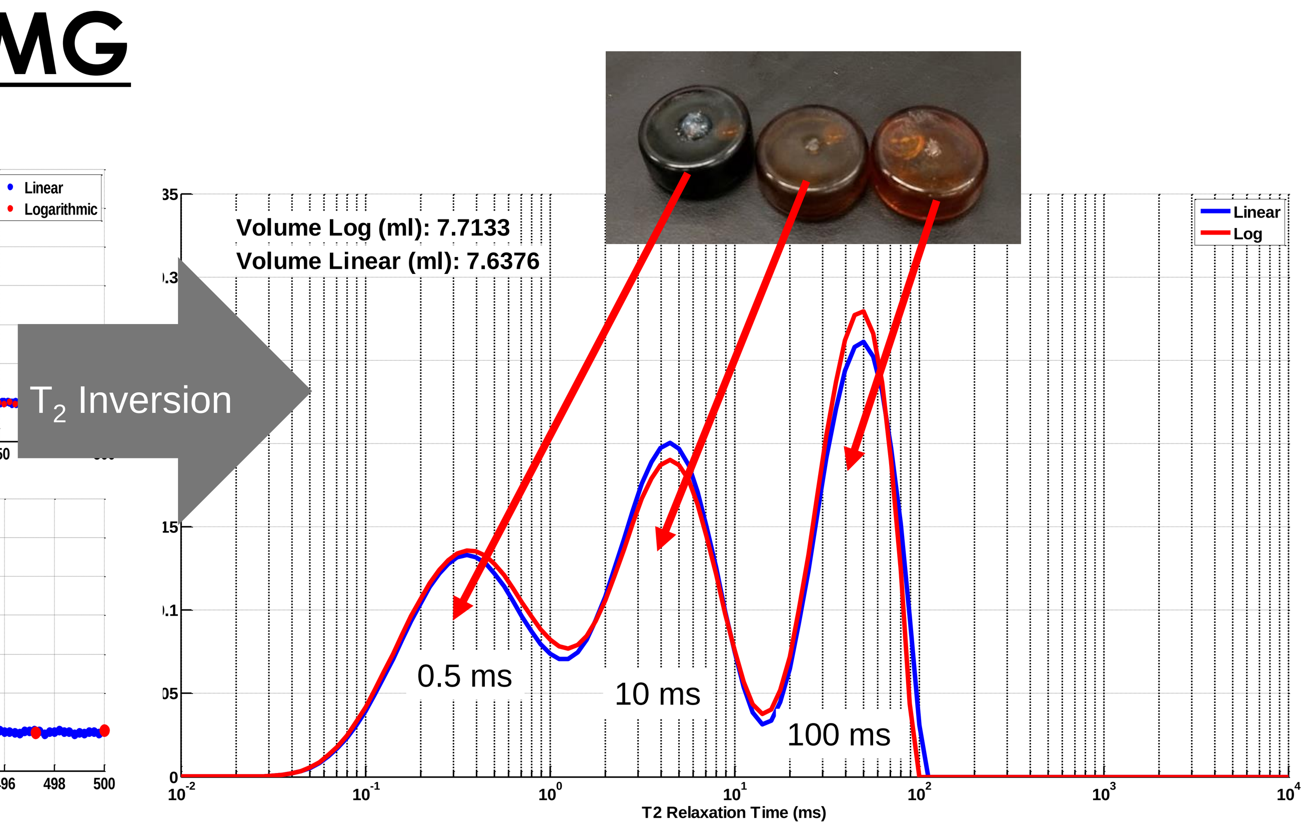
Accuracy Log Vs. Linear CPMG

- The first experiment compared data derived from log and linear CPMG sequences for the same sample.
- Sample consisted of three glass cylinders filled with 2% KCl brine doped with $CuSO_4$. Different $CuSO_4$ concentrations give different peak T_2 values.

NMR Parameters	Log Spaced CPMG	Linear Spaced CPMG
Tau (µs)	Log spaced between 100→1380	100
Number of Echoes	512	2500
Max T_2 (ms)	100	100
Recycle Delay (s)	0.5	0.5
Number of Scans	16	16
P90 (µs)	11.22	11.22
P180 (µs)	22.42	22.42
NMR Resonance (MHz)	2.457	2.457

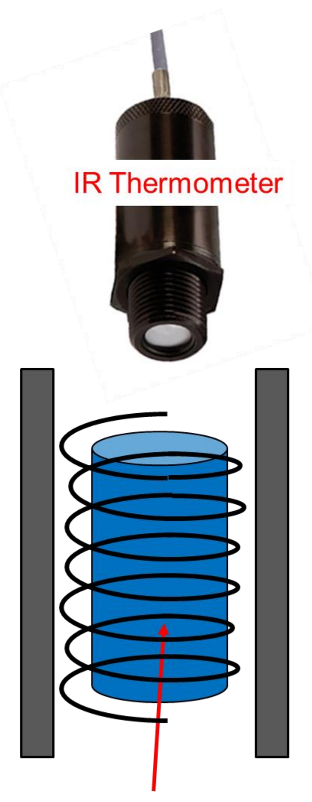


Raw CPMG Data



T_2 Distributions

Quantify Heating By Linear CPMG Sequence

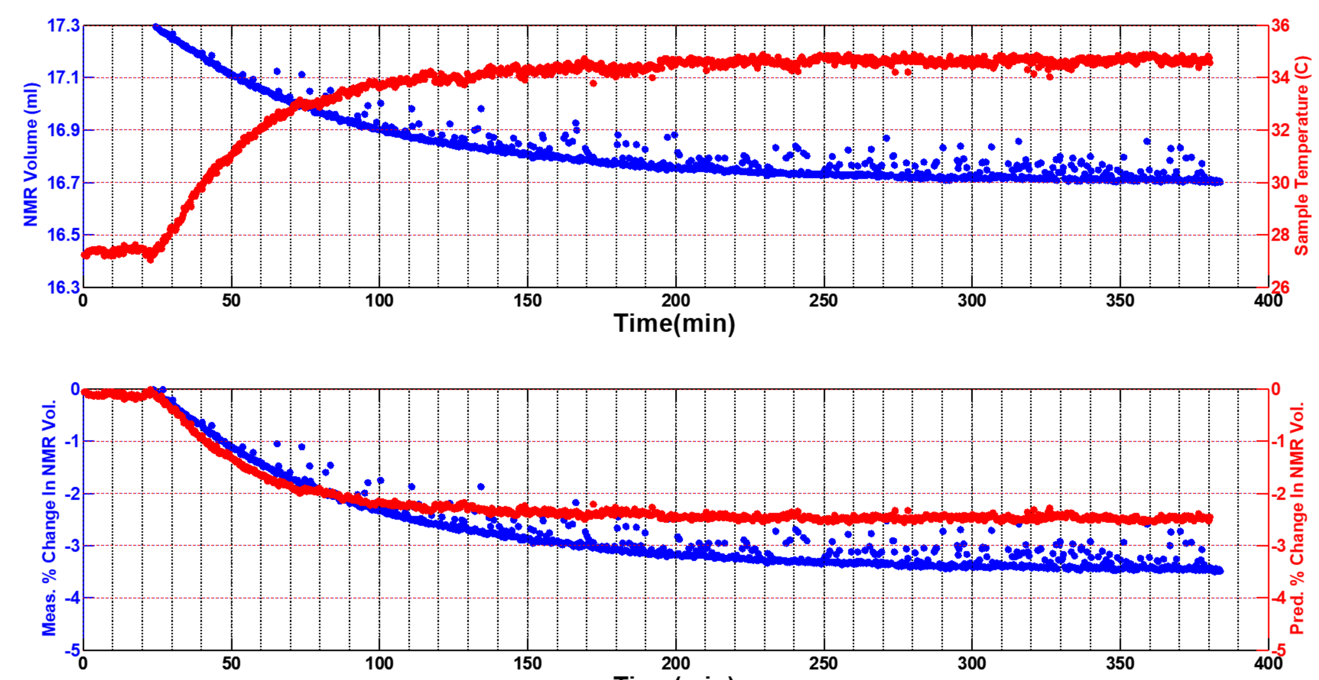


- The second set of experiments calibrated the change in NMR signal to the temperature change of the sample.
- This was accomplished using an IR thermometer placed directly above a sealed calibration sample in the magnet.
- Temperature converted to predicted NMR signal using ratio of temperature to macroscopic magnetization.
- The volume of the calibration sample was also monitored periodically using a linear spaced tau CPMG sequence.
- CPMG sequence placed in loop. Each time through loop the CPMG sequence ran 16 times, averaged the T_2 decay, produced the T_2 distribution and retrieved the volume of the sample.

NMR Parameters - Linear Spaced CPMG	
Tau (µs)	50
Number of Echoes	5000
Max T_2 (ms)	100
Recycle Delay (s)	0.75
Number of Scans	16
Number of Meas.	1000

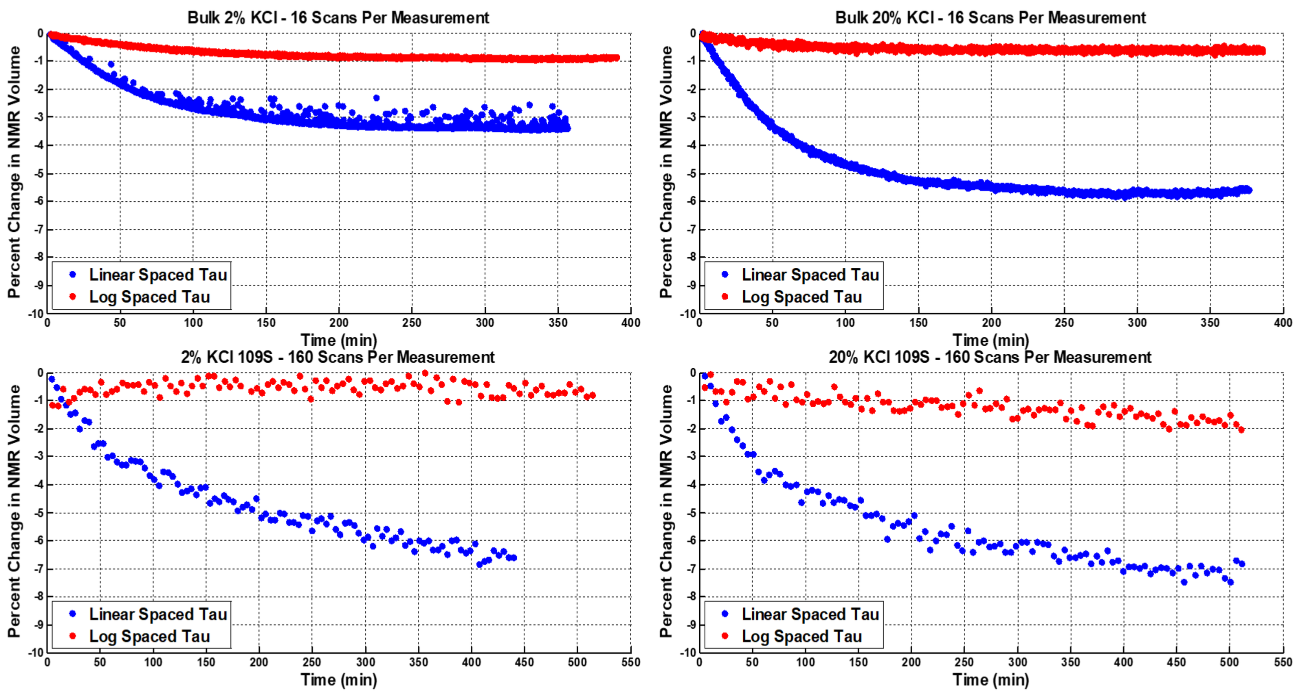
Ratio Macroscopic Magnetization To Temperature

$$\frac{M_{35^\circ C}}{M_{28^\circ C}} = \frac{\frac{N\gamma^2 \hbar I(I+1)}{6\pi k(273.15+35)}}{\frac{N\gamma^2 \hbar I(I+1)}{6\pi k(273.15+28)}} = \frac{301.15}{308.15} = 0.977$$



Change In NMR Signal Temperature Vs. CPMG

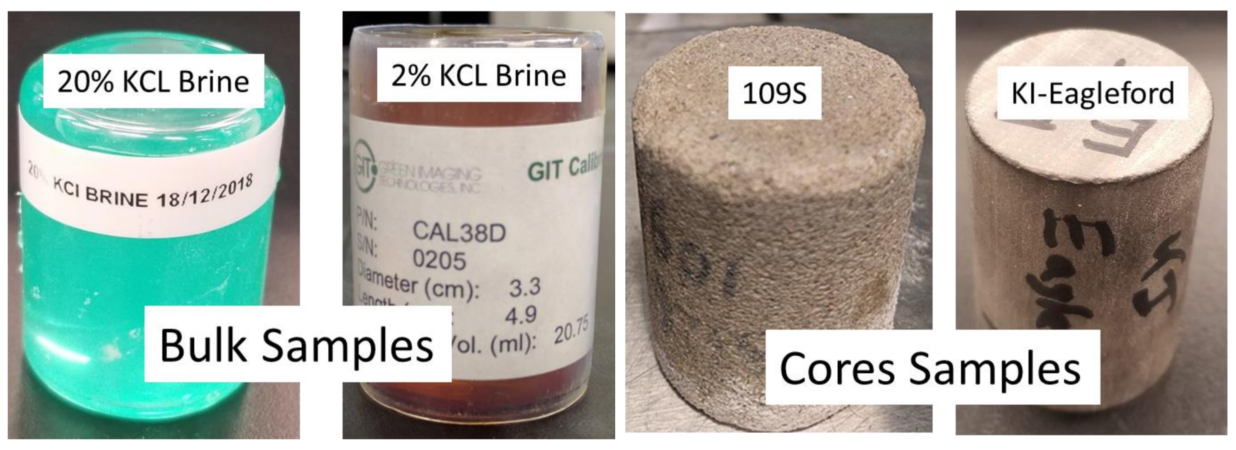
Log Vs. Linear CPMG Heating

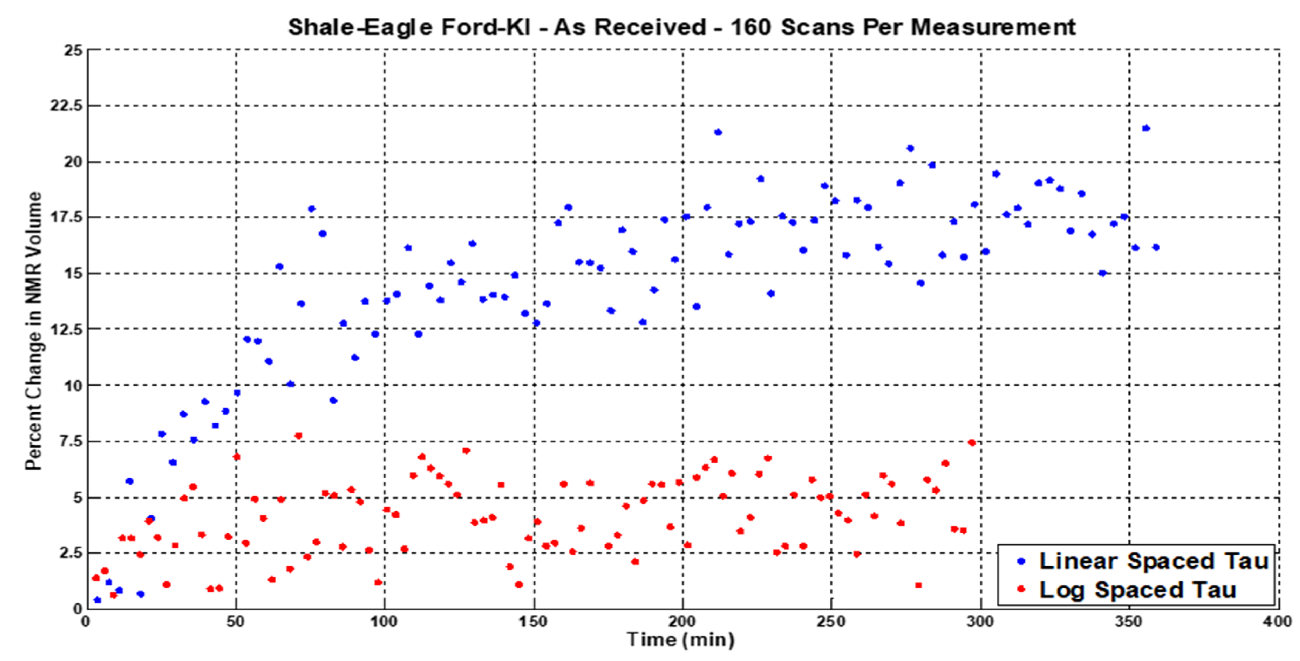


- The effect of heating by log and linear CPMG sequences was tested using both bulk brine (upper panels in above figure) and saturated core samples (lower panels in above figure).
- The effect of salinity was also explored (2% KCl vs 20% KCl) for both saturated core and bulk samples.
- The heating was greatly reduced when the log CPMG sequence was employed versus the linear CPMG sequence.

NMR Parameters	Bulk KCl Samples (2% and 20%)		KCl Saturated 109S Sandstone (2% and 20%) and Shale Eagle Ford – KI (As Received)	
CPMG	Log	Linear	Log	Linear
Tau (µs)	Log spaced 50→1795	50	Log spaced 50→1795	50
# of Echoes	512	5000	512	5000
Max T_2 (ms)	100	100	100	100
Recycle Delay(s)	0.75	0.75	0.75	0.75
# of Scans	16	16	160	160
# of Meas.	1000	1000	100	100

Samples Tested





- The effect of heating by log and linear CPMG sequences was also explored for an as received shale sample.
- As shown in the above figure,the log sequence greatly reduces the effects of sample heating.
- For the shale sample, the observed volume increases with temperature because the residual hydrocarbons in the shale sample liquefy as the temperature is increased. At lower temperatures, the hydrocarbons are solid and their T_2 relaxations are too short to be observed.

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