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Multi Field Evaluation of T_2 Distributions and T_1-T_2 2D Maps

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Abstract

Objectives/Scope

Low field NMR instruments (~2MHz) are popular for use in petrophysics labs as they compare favorably, and reliably, to NMR logs done downhole. The lower field also reduces the issue of high magnetic susceptibility of core samples as compared to higher field instruments. However, higher field instruments present several distinct advantages including faster scan times for a given signal to noise ratio (SNR), and superior detection of short relaxation elements due to their shift to longer relaxation times. For these reasons, higher field instruments have become more popular in recent years for use in core analysis. However, very little investigation has been done on the validity of comparing NMR data recorded with low field instruments and to data recorded with higher field NMR. This paper looks to fill this void.

Methods

This paper will include T_2 measurements and T_1-T_2 maps of bulk fluid (doped H_2O), as well as sandstone , carbonate and shale plugs at three different field strengths (2 MHz, 12 MHz and 23 MHz). T_2 NMR is a multiexponential decay that is dependent on pore size. T_1-T_2 maps are a two-dimensional measurement where fluids within a core sample are discriminated based on their relative viscosities. For these reasons, it is important to understand how T_2 distributions and T_1-T_2 maps will vary with field strength. Without this understanding T_2 distributions and T_1-T_2 maps recorded on the same sample could be interpreted differently when recorded at various fields.

Results

For all samples tested, the higher magnetic field decreased the scan time for the same SNR for both T_2 and T_1-T_2 measurements. For example, for the shale sample a T_1-T_2 map with a SNR of 165 took 2895 mins at

2 MHz but only 4.5 mins at 23 MHz. This corresponds to 645X decrease of scan time. The higher field also increases the separation between water and light hydrocarbons from heavier components in T_1-T_2 maps. It was found that for all samples T_2 distributions can shift to both shorter and longer values with increasing magnetic field. This makes interpreting T_2 distributions recorded at different fields difficult.

Applications

With the increase in prevalence of higher field NMR instruments, there is now plenty of NMR core analysis data taken at various magnetic fields being recorded in labs throughout the petrophysics industry. This paper has shown how T_2 measurements and T_1-T_2 maps on standard samples compare at 2, 12 and 20 MHz. We hope this work can be used throughout the industry as calibration when comparing measurements at various fields.

Introduction

Traditionally, low field NMR instruments (~2MHz) have been popular for use in petrophysics laboratories as they compare favorably, and reliably, to NMR logs [Coates et. al.] done downhole in the field. In addition, the lower field also reduces the issue of high magnetic susceptibility of core samples as compared to higher field instruments. However, higher field instruments present several distinct advantages including faster scan times for a given SNR, and superior detection of short relaxation elements due to their shift to longer relaxation times. The shift to longer relaxation times [Meiboom and Gill] is of particular advantage for shale type work due to the notoriously tight nature of shale pores and their short relaxivity.

Higher field instruments have become more popular in recent years for use in core analysis. As instruments operating at different fields become more prevalent, it is important to understand how T_2 distributions and T_1-T_2 maps will vary with field strength. Without this understanding T_2 distributions and T_1-T_2 maps recorded on the same sample could be interpreted differently when recorded at various fields.

Theory and/or Methods

The methodology for this work utilizes NMR instruments operating at three different magnetic field strengths and thus three different proton resonant frequencies, namely 2 MHz, 12 MHz and 23 MHz. The reason for choosing these is simply their availability in our lab. As was mentioned earlier, 2MHz NMR has been a favorite in the industry for a long time due to its compatibility with logging tools. NMR at 12 MHz has gained popularity because it drastically speeds up measurement time and has 3D imaging capabilities (MRI). 23 MHz offers even faster measurement time making it more suitable for small or low porosity samples. Four different samples were selected for this study, bulk water sample, sandstone, shale and carbonate rock core plug sample. NMR T_2 and T_1-T_2 [Song et. al.] data was acquired on each sample (except carbonate, T_1-T_2 data was not acquired for this sample) using all three instruments. To make the comparison of datasets easier, data was acquired using the same pulse sequence parameters on all instruments. Pulse sequence parameters are shown in Table 1. To further help with the analysis, all samples were scanned as many times as it was required to achieve SNR parity amongst the three instruments or get as close as possible to SNR parity.

Sample	Bulk Fluid		Sandstone		Shale		Carbonate
Test	T_2	T_1-T_2	T_2	T_1-T_2	T_2	T_1-T_2	T_2
Pulse Sequence	CPMG	IR-CPMG	CPMG	IR-CPMG	CPMG	IR-CPMG	CPMG
Tau (us)	50	50	50	50	50	50	50
RD (ms)	1125	1125	2250	2250	750	750	1500
# Echoes	7500	7500	15000	15000	5000	5000	10000
# T_1 Steps	N/A	30	N/A	30	N/A	30	N/A

Table 1 – Pulse sequence parameters.

Results

Summary of all conducted tests is provided in Table 1, showcasing the most interesting test results. From the data, it is obvious that the higher field instruments significantly reduce the scan time required to reach the same SNR.

Sample	Field	Test	Volume (ml)	SNR	Scan Time (mins)
Bulk Fluid	2 MHz	T_2	6.31	4767	51.0
		T_1-T_2	6.35	4418	1440
	12 MHz	T_2	5.94	5805	1.5
		T_1-T_2	6.15	4812	33.0
	20 MHz	T_2	6.67	4844	0.18
		T_1-T_2	6.67	4415	4.9
Shale	2 MHz	T_2	0.280	181.5	105.0
		T_1-T_2	0.258	165.6	2895
	12 MHz	T_2	0.284	189.4	0.72
		T_1-T_2	0.289	179	22.0
	20 MHz	T_2	0.291	181.5	0.12
		T_1-T_2	0.291	165.	4.5
Sandstone	2 MHz	T_2	2.54	884	63.5
		T_1-T_2	2.59	808	1597
	12 MHz	T_2	2.60	1033	0.62
		T_1-T_2	2.70	1355	32.7
	20 MHz	T_2	2.64	881	0.4
		T_1-T_2	2.65	768	480.6
Carbonate	2 MHz	T_2	0.334	240	160
	12 MHz	T_2	0.338	251	1.35
	20 MHz	T_2	0.354	245	0.28

Table 2 - The observed volume, SNR and scan time for each sample studied.

Additionally, representative T_2 and T_1-T_2 data is shown in Figures 1-4. In Figure 1, the big takeaway is that T_2 relaxation time of the bulk fluid (doped H_2O) increases as a function of field strength. In the T_2 data, the T_2 peak shifts from 60 ms to 90 ms to 110 ms for field strengths of 2 MHz, 12MHz and 23 MHz respectively. Similar trend is noticed in T_1-T_2 maps where T_2 values shift accordingly but no change is noticed in T_1 data as a function of field strength.

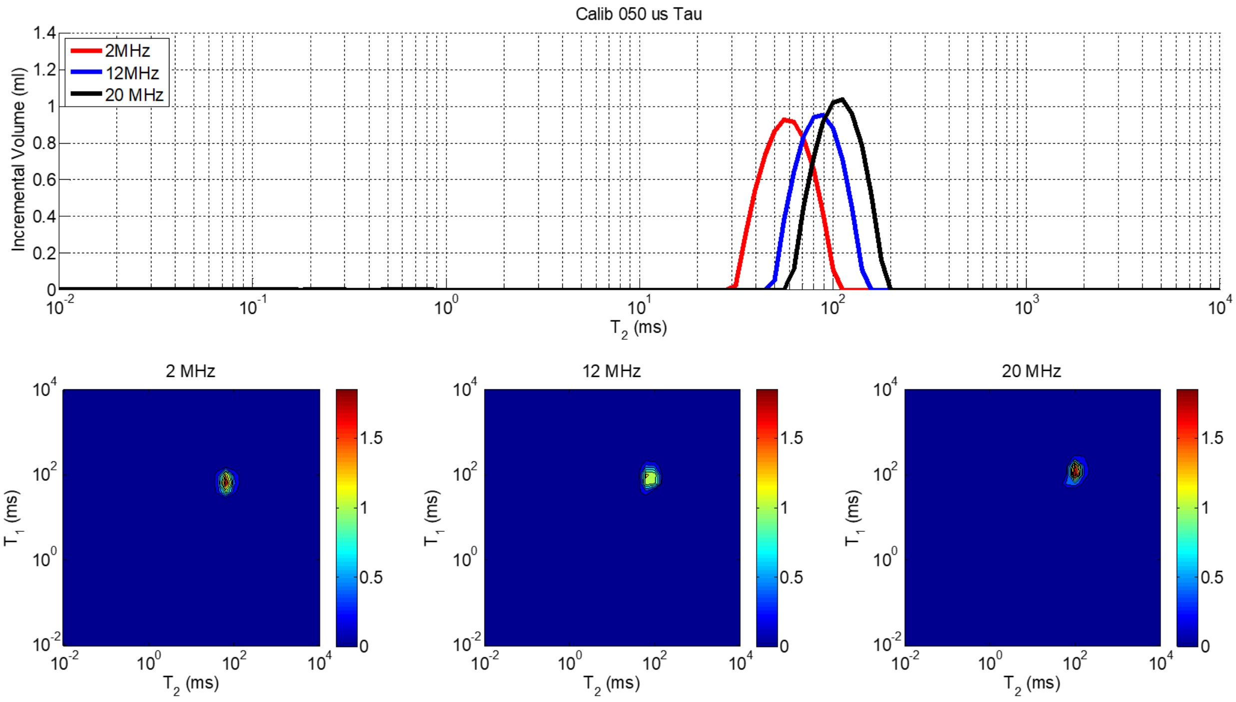

Figure 1 – T_2 distributions and T_1-T_2 maps for bulk fluid sample.

In Figure 2, T_2 and T_1-T_2 NMR data is displayed for the shale sample. T_2 distribution once again shifts to the right as the field strength increases, however there does not appear to be as much of a shift between 12 MHz and 20 MHz as we might expect from the bulk water data. The shift is also evident in the T_1-T_2 data.

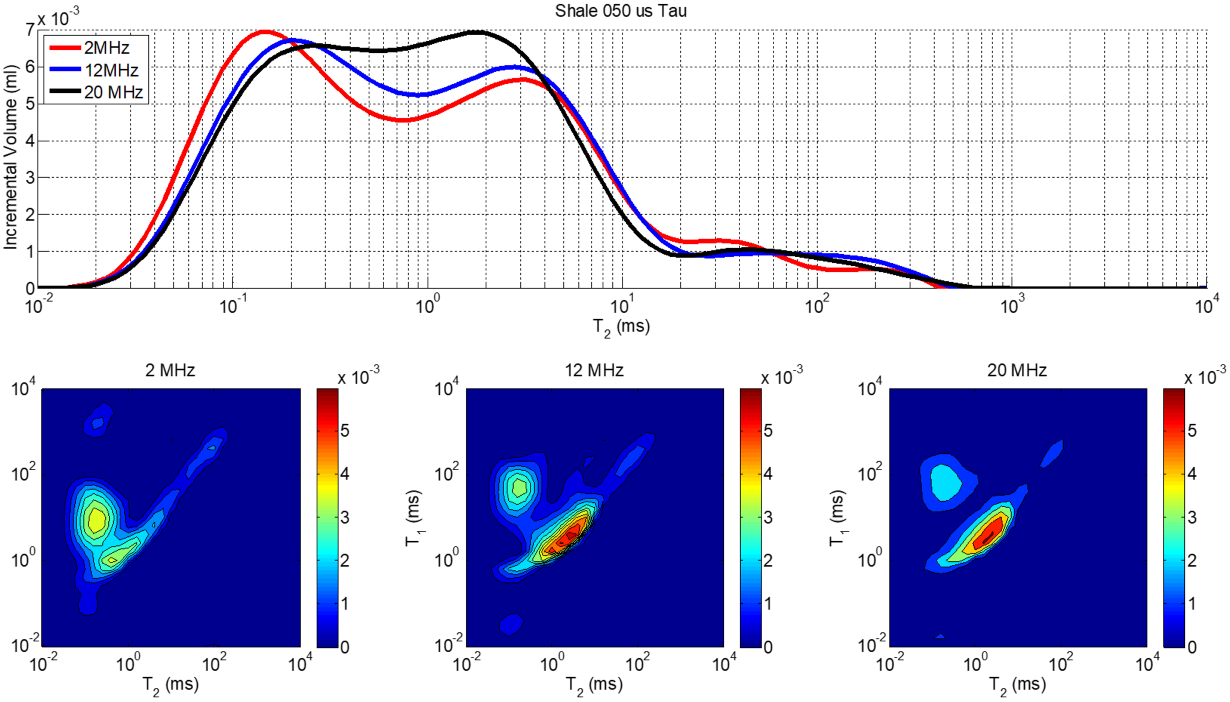

Figure 2 - T_2 distributions and T_1-T_2 maps for shale sample.

Figure 3 shows the T_2 distributions and T_1-T_2 maps measured for the sandstone sample. As with both the bulk fluid and shale samples the T_2 distribution shifted to longer values. This is obvious from the size of the peak near 0.15 ms which decreases as the field strength is increased. A similar shift to higher values is also seen along the T_2 axis for the T_1-T_2 maps (Figure 3 – lower panel).

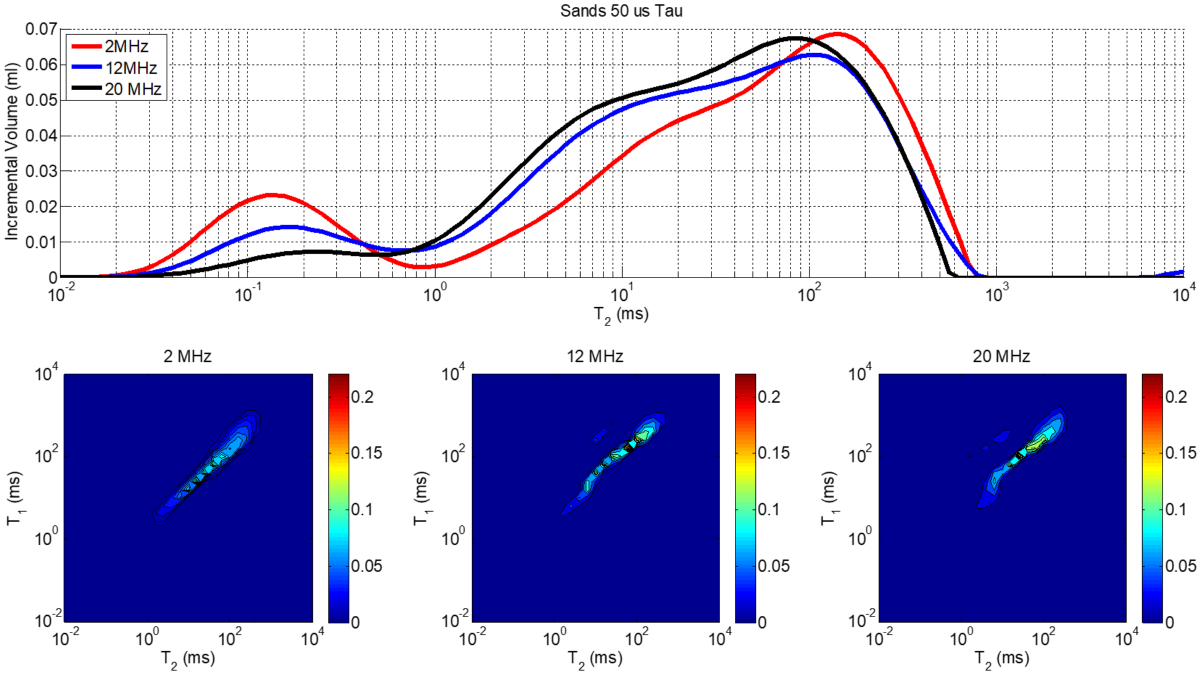

Figure 3 - T_2 distributions and T_1-T_2 maps for sandstone sample.

T_2 distributions for the carbonate sample are shown in Figure 4. Shift to the longer T_2 values at higher field is obvious at the short T_2 peak but the longer T_2 peak shift is more complicated.

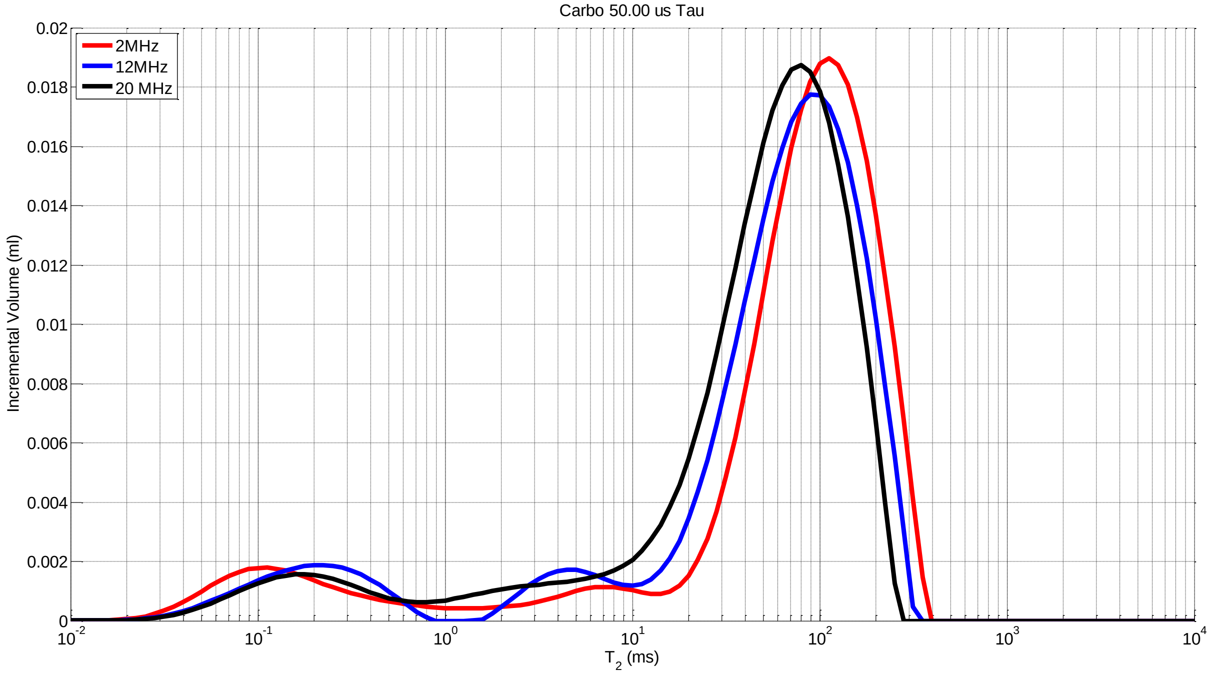

Figure 4 - T_2 distributions for carbonate sample.

Discussion

The most obvious advantage in moving to higher field NMR instruments is time savings. For example, for the bulk sample, the T_1-T_2 map took 1440 mins at 2 MHz but only 4.9 mins at 23 MHz. That is a 288x reduction in scan time. The advantage of obtaining a high SNR in a reasonable amount of time is amplified in shale samples because these samples often have low porosities leading to low amount of signal. Another advantage for using higher field on shales is the T_2 shift to longer relaxation times. Shales often have most of NMR T_2 signal at very short T_2's where it can be challenging to detect the signal before it decays. Using higher field NMR extends the lifetime of the signal making it easier to detect. These advantages translate to T_1-T_2 maps. Combined with a higher SNR on T_1-T_2 maps, higher field NMR enhances peak separation in the map making it easier to interpret the map for fluid typing purposes [Kausik et. al.]. This is nicely illustrated in Figure 2 where the peak separation in T_1-T_2 is more obvious at higher field. For the shale sample a T_1-T_2 map with a SNR of 165 took 2895 mins at 2 MHz but only 4.5 mins at 23 MHz. This corresponds to 645X decrease of scan time which is even larger than the decrease in time for bulk fluid measurement and can be attributed to an increase in detectable NMR signal on the short T_2 end. For the sandstone dataset similar T_2 shift is observed especially at the short T_2 end (Figure 3). As the data is shifted from short to long T_2 region, the fitting routine [Butler et. al.] gives more weight to the shorter components in the long T_2 region because they become more prevalent at higher field. As a result, although there is an overall shift in T_2 to the right at higher field, the red trace (2 MHz) at long T_2 appears a little longer than the other two and may cause some confusion at a first glance. The carbonate sample T_2 data (Figure 4) appears more complicated. While at short T_2 end of the spectrum, the shift to longer T_2 with higher field is obvious, this may not be true for the longer T_2 part of the spectrum, or at least further investigation would be required.

Conclusions

It is clear that NMR measurements done at higher field offer some advantages. These advantages are most noticeable with a jump from 2 MHz to 12 MHz whereas it seems there are diminishing returns when going from 12 MHz to 23 MHz. Switching from low field to higher field NMR allows much faster data acquisition and can help with data analysis and interpretation, especially on unconventional samples. In general, T_2 relaxation times are expected to be longer at higher field. This means that some signal which was not detectable at 2 MHz can be detected at higher field. Although more signal is usually a good thing, it can sometimes complicate data analysis when comparing low field to higher field NMR data.

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