NMR Gas Relaxation Signature for Organic Shale Reservoir Rocks

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A powerful application of NMR logging is to identify gas in conventional reservoirs. NMR logging methods have the potential in organic shale reservoirs not to just identify the presence of gas but to provide significant quantitative information. Because of the nature of shale gas reservoir rocks NMR logging can acting as a stand-alone logging tool accurately estimate the total number of moles of free hydrocarbon gas in the reservoir, parse the total free gas into gas stored in the organic pores, and that stored in the inorganic pores, and provide a reservoir dependent correlation to the amount of adsorbed gas. This though can only be done if the signature of methane in the NMR relaxation spectrum is understood.

The NMR logging relaxation signature of methane in an ordinary sandstone reservoir is a very poor guide to the relaxation of methane in a shale gas reservoir rock. In a standard reservoir NMR logging measurements respond to the fluid distribution in the invaded zone. That is in a zone that is high in water saturation, where, gas being the non-wetting fluid, the gas saturation is considerably below its insitu reservoir value, and the gas exists only in the centers of the larger pores. Because of this the gas relaxes only due to its bulk fluid relaxation properties for T_1 relaxation, and for T_2 relaxation it relaxes by the parallel processes of bulk relaxation and de-phasing due to molecular diffusion in the logging tool's magnet field gradient. This produces characteristic T_1 relaxation times of several seconds and characteristic T_2 relaxation times on the order of 50 ms. Gas can then be identified as fluid the has a long T_1 time and a short T_2 time. It can also be identified by its behavior when the echo spacing in the CPMG sequence used to acquire the T_2 relaxation is varied as the diffusion induced relaxation time is proportional to the inverse of the square of the echo spacing. The conditions necessary for gas to behave in this way all fail in shale gas reservoirs.

It is now understood from SEM studies on ion-milled samples that a significant portion of the free gas is stored in pores contained in the organic material that generated oil and gas. Those pores have never contained water and being organic are hydrophobic. Therefore they are gas wet relative to water. The pores visible on the SEM images have a size on the order of 10 nm. Calculations based on the surface area from methane adsorption produce comparable or smaller pore sizes depending on assumptions. The small pore sizes and gas wettability imply that very strong capillary forces will prevent water based mud filtrate from displacing the gas in the organic pores. That is any NMR measurement will detect all the gas in the organic pores.

Because the organic pores are nano-meter size and the organic volumes they are contained in have extents on the order of microns there is limited volume available for diffusion so relaxation due to diffusion in a gradient magnetic field will be strongly suppressed. The organic material the pores are in though can relax the methane by surface relaxation through the mechanism of dipole-dipole interaction between the hydrogen in the methane and the hydrogen in the organic material. Because of paramagnetic impurities in the organic material that relaxation mode may also act to relax the methane. So the methane in the organic pores will have a strong surface relaxation and limited diffusion relaxation unlike methane in the invaded zone of ordinary reservoirs.

Methane may also be located in pores in the inorganic rock fabric. Those pores would also be small so diffusion mediated relaxation will also be suppressed. The pores could be water wet, or have fractional wettability. In either case water would be expected to be a stronger wetting fluid than gas. Under these conditions in a zone invaded by water based mud filtrate the gas would be in part displaced from the inorganic pores, and the remaining gas should relax slower, probably with a T_1 relaxation on the order of seconds. Modeling studies done for reservoir simulation indicate that the very low permeabilities of the shale gas reservoir rocks produce a very shallow invaded zone. NMR logging tools exist that have variable depths of investigation. Using this feature, measurements could be made in the invaded zone and in a zone that has insitu reservoir saturation. This set of measurements would provide both the total gas in the reservoir and a parsing of the gas into that contained in the organic pores and that in the inorganic pores.

The gas in the inorganic pores at insitu reservoir conditions most likely does not relax as a bulk gas. It has been shown in published laboratory studies that the NMR relaxation of gas in any rock that has low water saturation is dominated by surface relaxation. This combined with the suppression of diffusion-mediated relaxation implies that standard gas identification methods would not identify the gas contained in these pores.

An extensive laboratory study on the NMR relaxation of gas saturated organic shale gas samples is currently being conducted at The University of Oklahoma. The water in the samples investigated relaxes very fast. The spectral region of primary relaxation has a mode of roughly 1 ms. A typical T_2 water relaxation spectrum for a preserved sample is shown in figure 1. The T_2 relaxation of the gas in the samples is also fast with the mode of its primary spectral relaxation region being roughly at 10 ms. An example of a gas T_2 relaxation spectrum is shown in figure 2. The small amount of gas relaxing at its bulk relaxation rate is gas in the visible stress release cracks produced by the coring process. Unlike the case for logging tools, the measuring instrument magnet did not have a gradient.

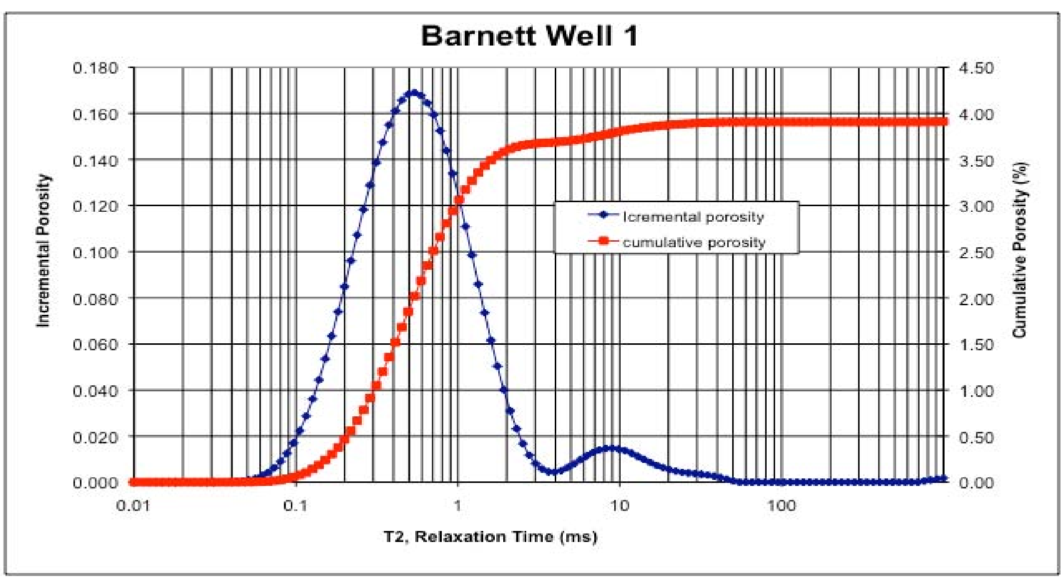

***Figure 1**. Water cumulative and incremental NMR T_2 relaxation spectra from a preserved state sample.*

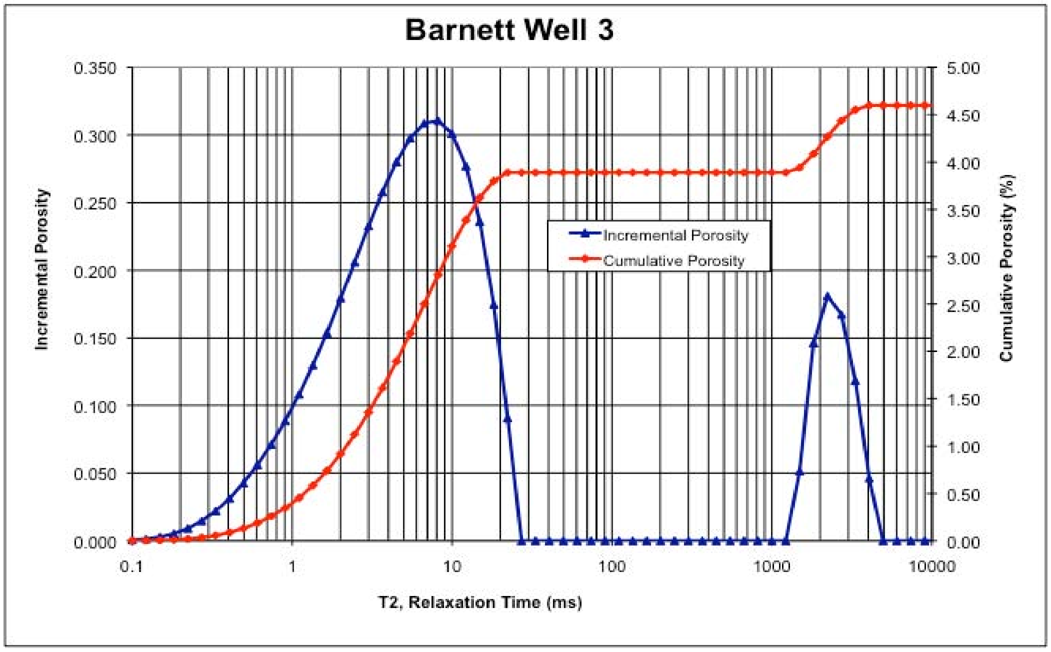

Figure 2. *The NMR T2 cumulative and incremental methane relaxation spectra for the same sample shown in figure 1. The gas was at 4000 psi pore pressure. The water signal was subtracted from the NMR measurement made on the gas saturated preserved sample to get this plot. The signal at about two seconds is from gas in stress relief cracks. The measurement was made without an external magnet field gradient.*