Organic Shale NMR and What It Means for Logs*

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Conclusions

- Brine is mainly in water-wet pores.
- Methane is mainly in gas-wet pores.
- Surface relaxivity dominates both signals.
- No evidence exists that methane will occupy pore space that holds water.
- NMR gas porosity is equal at least to free-gas porosity.
- Water saturation is 30 to 45 %.
- Diffusion will have only minor effect on primary part of methane T_2 spectrum.
- NMR T_1 log spectrum will not show methane at bulk relaxation time.

References

Sigal, R., and E. Odusina, 2011, Laboratory NMR Measurements on Methane Saturated Barnett Shale Samples: MPGE, University of Oklahoma, Petrophysics.

Straley, C., 1997, An Experimental Investigation of Methane in Rock Materials: SPWLA 38th Annual Logging Symposium, Paper AA, 14 p.

Winkler, M., J.J. Freeman, E. Quint, and M. Caputi, 2006, Evaluating Tight Gas Reservoirs with NMR – The Perception, The Reality and How to Make It Work: SPWLA 47th Annual Logging Symposium, Paper BB, 9 p.

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Good and Bad news

- Good News
  - The NMR log porosity contains a contribution from almost all to all the free gas in a shale gas reservoir.
  - The gas distribution may be able to be used to estimate adsorbed gas.
- Bad News
  - Gas signal probably cannot be extracted from standard NMR log
  - Using standard processing to identify gas signal will give incorrect answer.

Ordinary Reservoirs

- Pore walls not gas wetting
- Measurement made in invaded zone
- Relatively large pores
- Surface relaxation dominated by paramagnetic minerals
- Implies for T_2 measurement
  - High-wetting fluid saturation
  - Gas in centers of pores
  - Diffusion coefficient is approximately bulk value
  - $1/T_{gas} = 1/T_{bulk} + 1/T_{diffusion}$
  - Logging tools have magnetic field gradient so that T_2 gas is about equal to $T_{diffusion}$.

If Previous Slide Incorrect

Low water saturation
- Gas can have surface relaxation mode
  - Straley (SPWLA 38, 1997)
  - Winkler et al. (SPWLA 47, 2006)
- Diffusion may be less important

Small pores
- Diffusion coefficient not bulk value

Organic pores
- Small
- Pore walls hydrophobic
- Probably no water invasion
- Surface relaxation component
- Relaxation may not be dominated by paramagnetic minerals
- Relaxation could be temperature-dependent
- Adsorbed gas

Organic Shales

- Some to most porosity in organic materials
- Small pores
- Possibly very limited invasion from water-based mud
  - Low permeability
  - Organic pores hydrophobic

Organic Pores

- Organic Porosity
  - SEM images show high porosity in some organic material
  - Petrophysical calculations give roughly 20 to 50% organic porosity.
- Pore Size
  - SEM 1-100 nm range very roughly
  - Surface to volume estimate
    - Barnett
    - Langmuir isotherm
    - Gas volume
    - Effective pore size on order of 2-20 nm.

Diffusion

- Zones of organic material from SEM on order of microns.

- Methane diffusion distance in 1 ms
  - Methane bulk diffusion constant
  - 4000 psi, 355°C
  - 10,000 nm =10 μ
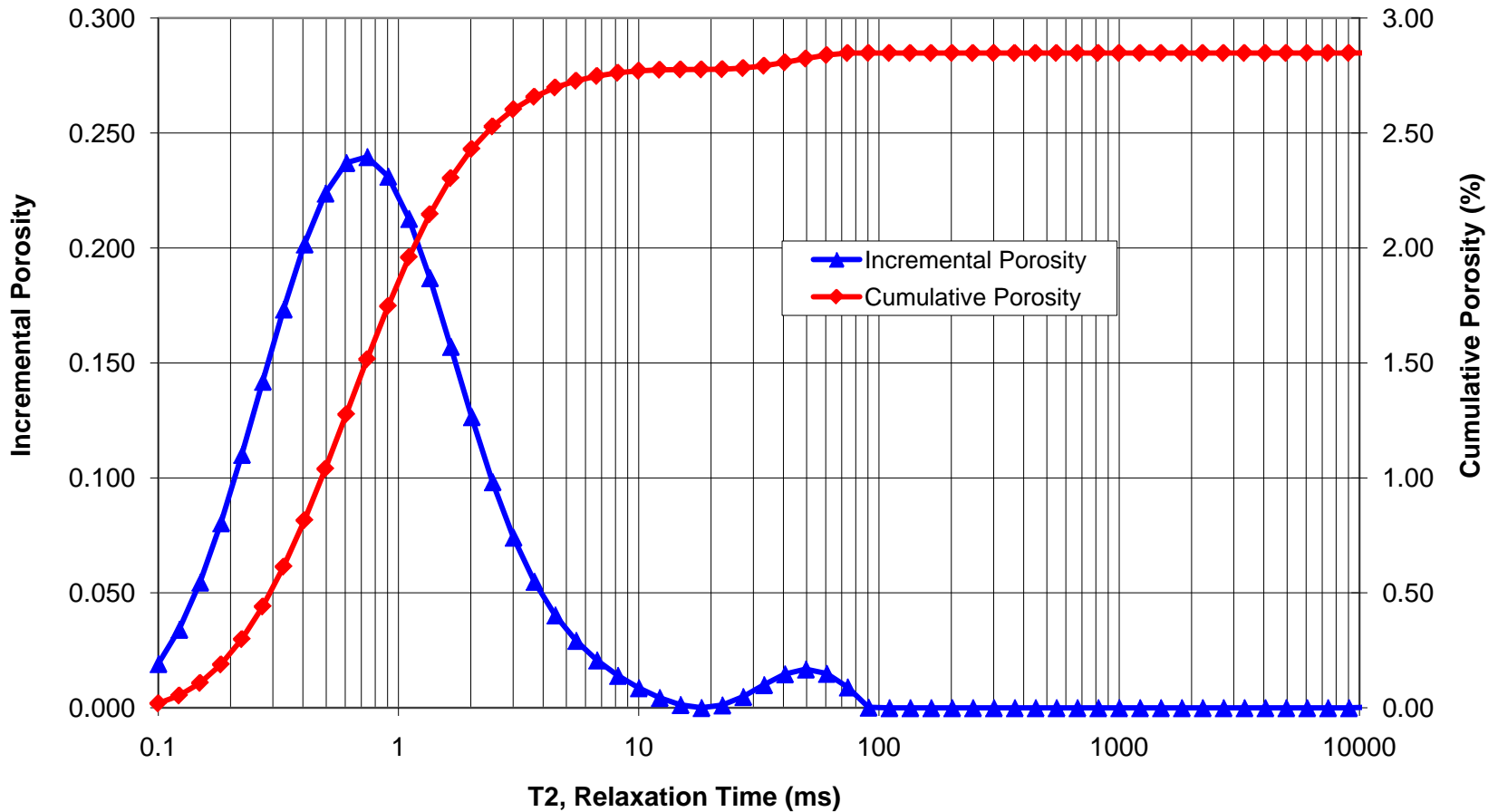
Lab Measurements

Barnett samples

Room temperature
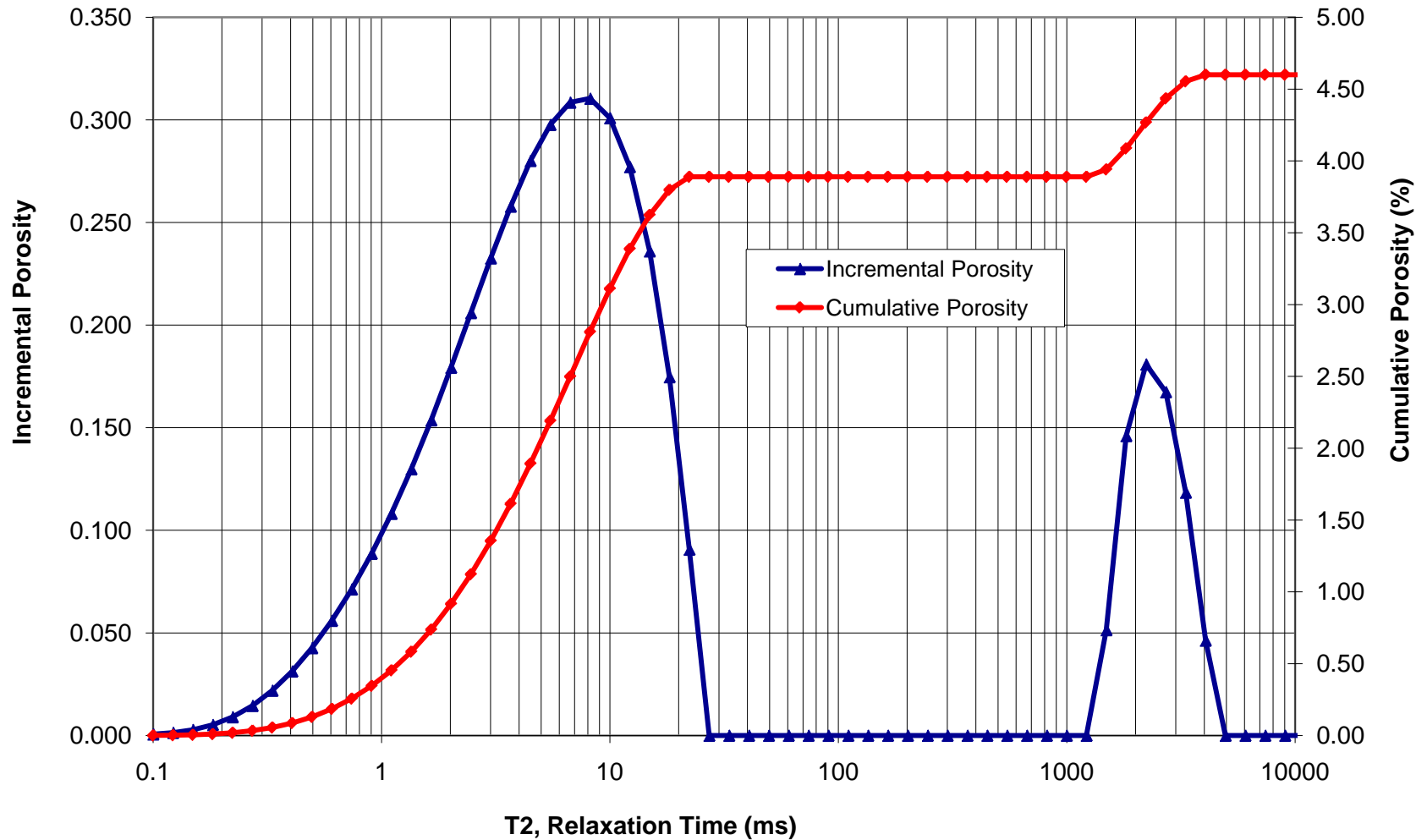
5000 psi confining pressure

4000 psi pore pressure

Preserved State No Methane T$_2$ Response
No External Magnetic Field Gradient

Barnett Well 3

Methane T$_2$ Response Barnett Preserved State
No External Magnetic Field Gradient

Barnett Well 3

Sample #	NMR Gas Porosity (%)	NMR Water Porosity (%)	He Porosity (%)	Water Saturation (%)	State
Well 1 6366.78	4.06	3.52	7.16	46.4	P
Well 1 6366.58	4.10	2.86	6.26	41.1	P
Well 1 6454.95	4.50	1.74	6.61	27.9	P
Well 2 7529.6	5.98	2.57	6.24	26.9	P
Well 2 7433	4.95	2.92	8.45	37.1	P
Well 3 7259	3.47	1.02	7		U
Well 3 7508	3.92	3.18	8		U
Well 3 7591	4.72	1.67	9		U
Well 3 7621	3.61	1.56	7		U
Well 3 7694	2.7	1.56	6		U

Observations

- Dominate brine response less than 1 ms.
- Usually brine has secondary mode
- At room temperature dominate gas response in 1-20 ms range
- About 10% of gas response comes in at bulk decay rate for methane. This is gas in stress release cracks.
- Unpreserved samples have no more gas porosity than preserved samples.

Conclusions

- Brine is mainly in water-wet pores
- Methane mainly in gas-wet pores
- Surface relaxivity dominates both signals
- No evidence that methane will occupy pore space that holds water
- NMR gas porosity at least equal to free-gas porosity
- Water saturation 30 to 45 %
- Diffusion will have only minor effect on primary part of methane T_2 spectrum
- NMR T_1 log spectrum will not show methane at bulk relaxation time.

Open Questions

- Amount of adsorbed gas in NMR gas porosity.

- Restricted diffusivity value.

- Best way to separate gas and brine in logging signal.

- The effect of temperature on gas relaxivity.

- How typical is Barnett NMR?

Selected Reference

Laboratory NMR Measurements on Methane Saturated Barnett Shale Samples, Richard Sigal and Elijah Odusina, MPGE, University of Oklahoma, Petrophysics 2011