Advancing Reservoir Performance

Nuclear Magnetic Resonance

A Refresher !

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By
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Outline

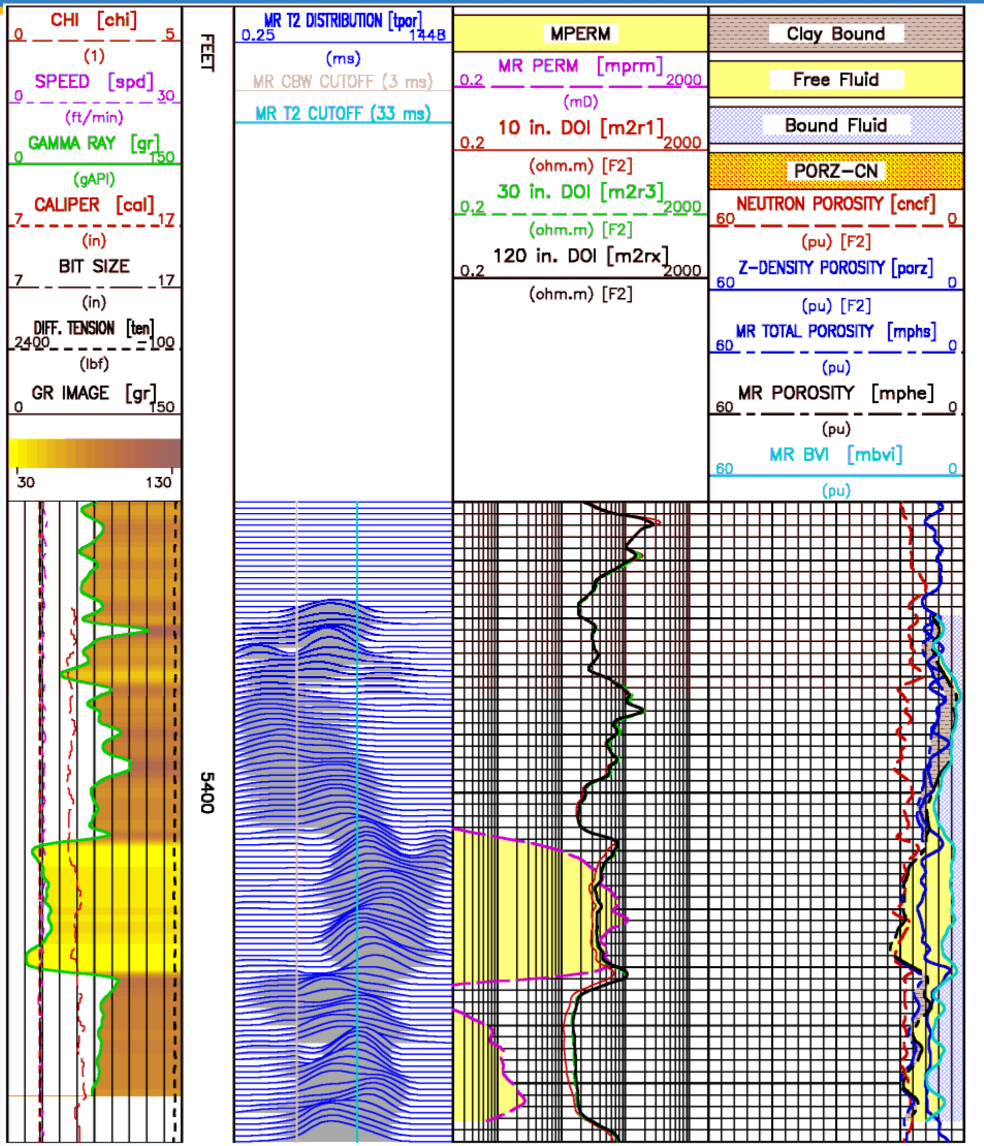
- Introduction
- Field Print(s): a starting point
- NMR Porosity & Permeability
- Controls on ‘relaxation’
- Differing spectra & interpretation
- 2D NMR:
  - Fluid typing for gas
  - Fluid typing for oil

NMR Field Prints

Standard NMR Print – A revision

A fundemental ‘corner-stone’ of NMR is the:

- **Relaxation spectrum**
  - The area underneath the spectrum indicates porosity.
  - The position of the peaks from left to right indicates the time taken for that porosity to ‘relax’.
  - Generally the spectrum has been optimised for porosity determination.



There are other types of spectra – check what type you are viewing

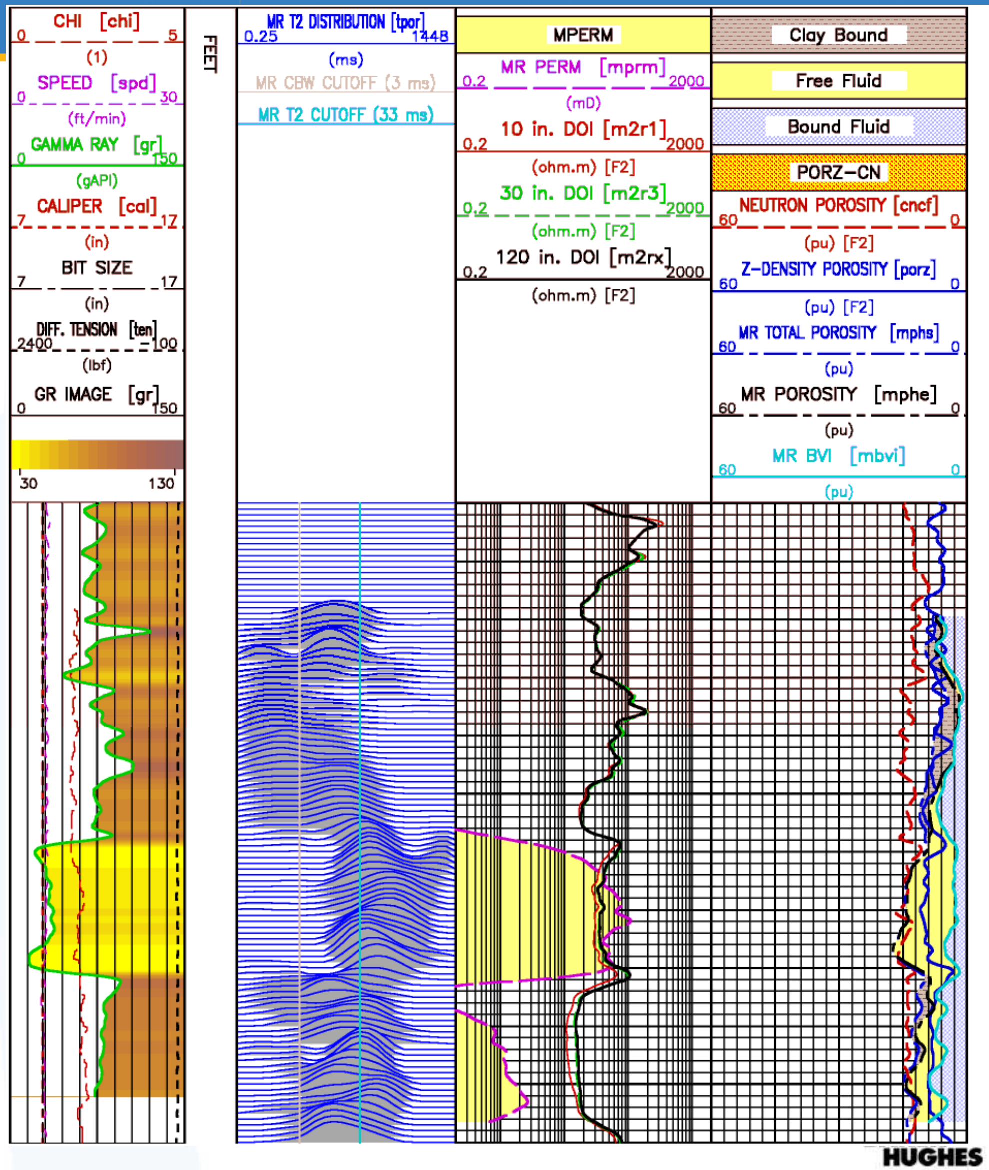
Spectra can be generated from subsets of the recorded NMR data.

Spectra interpretation varies between low-gradient and high-gradient tools

Standard MREX Field Print (PoroPorm +)

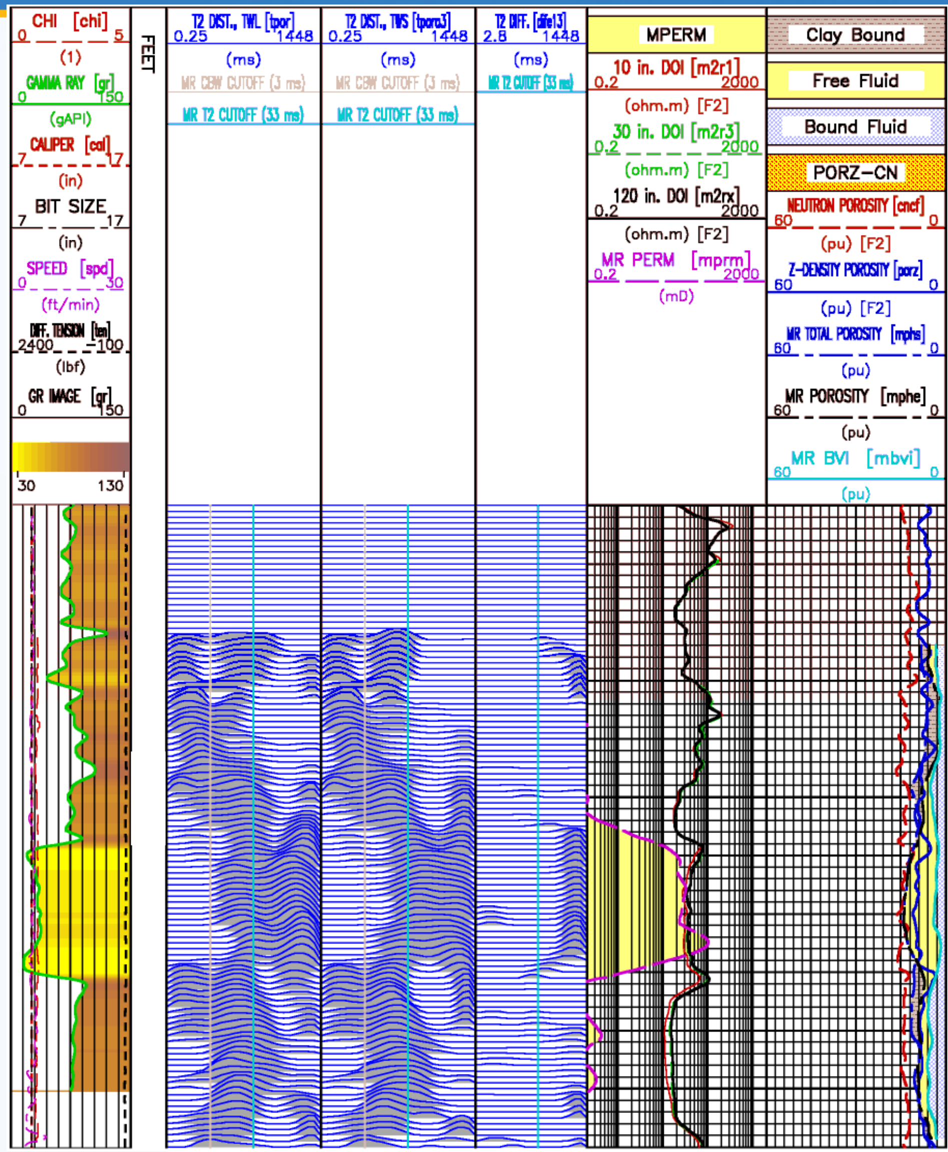
- **CBW, BVI, BVM, ϕ_e, ϕ_t and k_{NMR}**
- **Bound water field print will NOT show; BVM, ϕ_e, ϕ_t and k_{NMR}**
- **Porosity distribution based on chosen cutoffs such as:**
  CBW 3 ms and BVI/BVM 33 ms
- **k_{NMR} based on Coates equation with chosen c, m and n**
  (use as a relative permeability indicator)
- **Underestimation of BVM, ϕ_e, ϕ_t and k_{NMR} in oil/gas zones if HI effect is significant**

  - to account for HI by phase we need to analyze the NMR data for fluid content via 2D-NMR techniques.



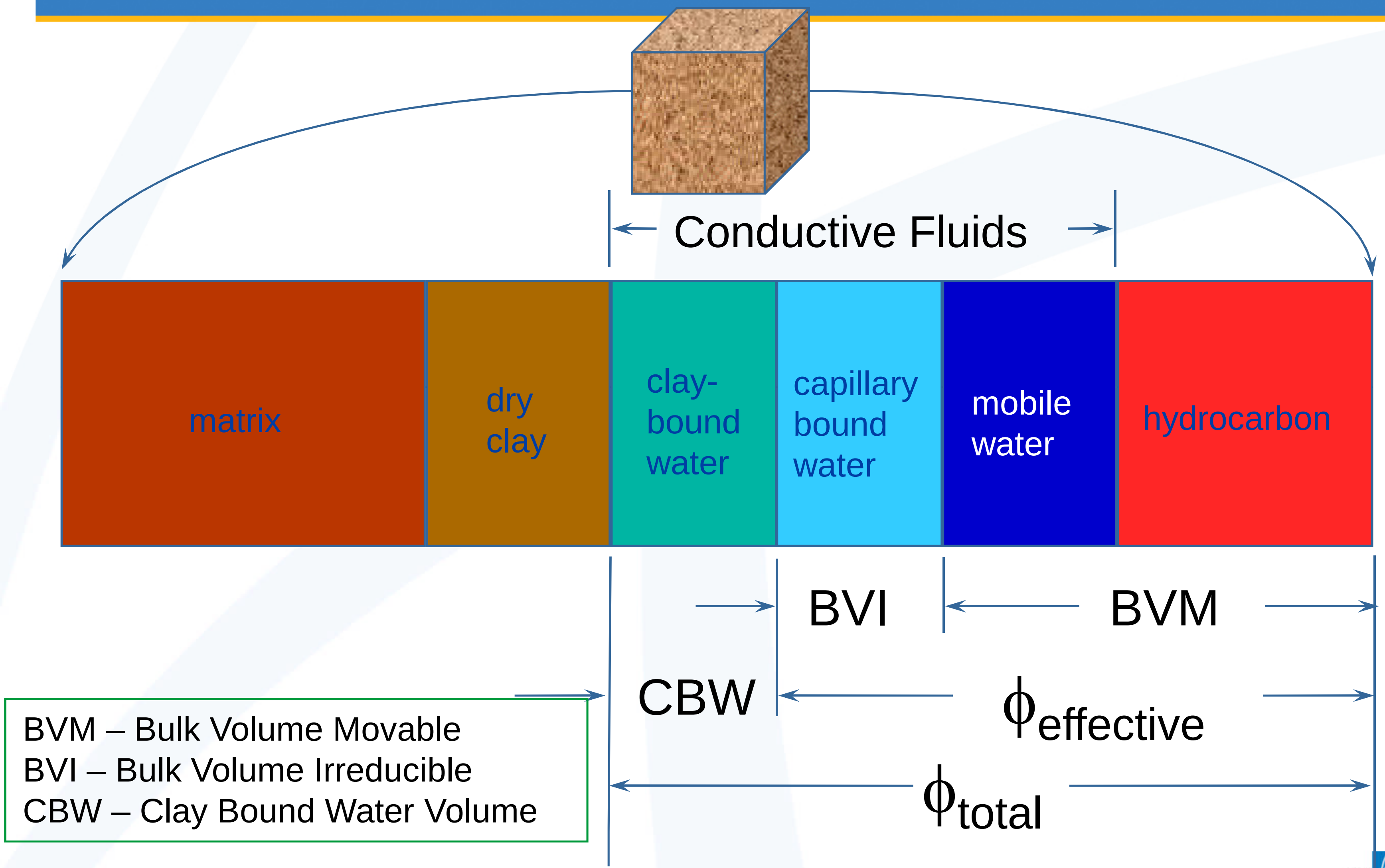
PoroPerm + Gas Field Deliverable

- CBW, BVI, BVM, ϕ_e, ϕ_t, and k_{NMR}
- Porosity distribution based on chosen cutoffs such as:
  CBW 3 ms and BVI 33 ms
- k_{NMR} based on Coates equation with chosen C, m, and n
- Underestimation of BVM, ϕ_e, ϕ_t and k_{NMR} in gas zones if HI effect is significant
- T_2 spectra for long and short TW and the differential spectrum
  - Highlights intervals with gas in the flushed zone due to insufficient polarization of gas with short TW



NMR Porosity & Permeability Models

Magnetic Resonance Porosity Model



MR Permeability - k_{NMR}

Two models in use

Coates-Timur Model :

$$k_{NMR} = \left(\frac{\phi_{NMR}}{C} \right)^m \bullet \left(\frac{BVM}{BVI} \right)^n$$

SDR Model:

$$k_{NMR} = C \bullet \left(\phi_{NMR} \right)^m \bullet \left(T_{2\ Geo.\ Mean} \right)^n$$

Where assumed default parameters are: C =10, m = 4 & n = 2

Note: k_{NMR} is an estimate of permeability based on a model. For accuracy k_{NMR} should be calibrated to local reservoir data.

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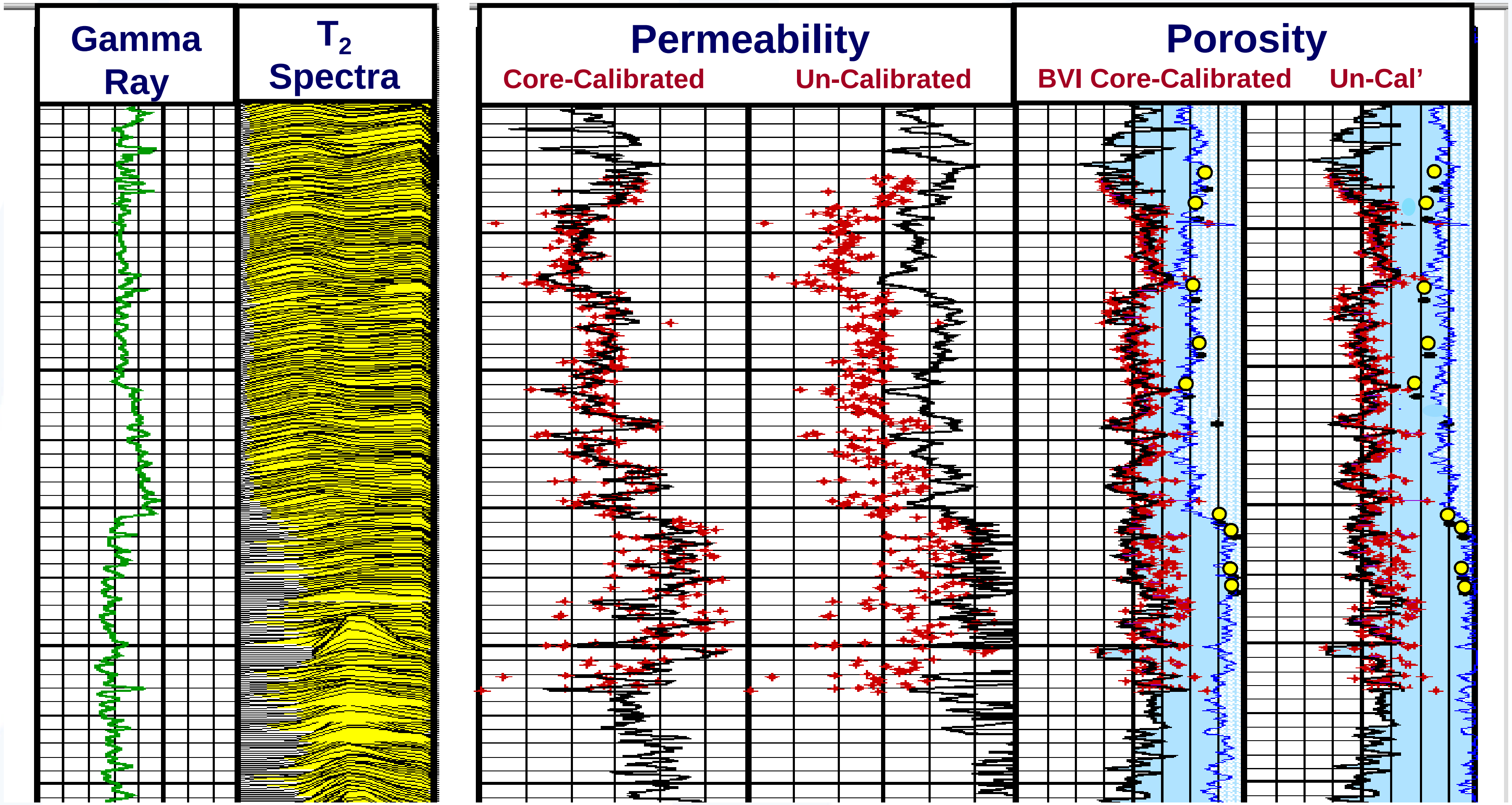
Core Calibrated MR Analysis Results
Cross-Well Prediction – Well B

T_2 Cutoff = 80 ms

$$k = \left(\frac{\phi_{NMR}}{10.91}\right)^4 \bullet \left(\frac{BVM}{BVI}\right)^{1.73}$$



NMR Controls on relaxation

MR Relaxation

- 2 types of MR relaxation
  - T_1 relaxation – longitudinal relaxation
    - Time constant for the net magnetization to align with the static magnetic field
  - T_2 relaxation – transverse relaxation- T_2 decay rate
    - Time constant for the echo train to decay
- T_1 & T_2 contain information on pore sizes and fluid properties

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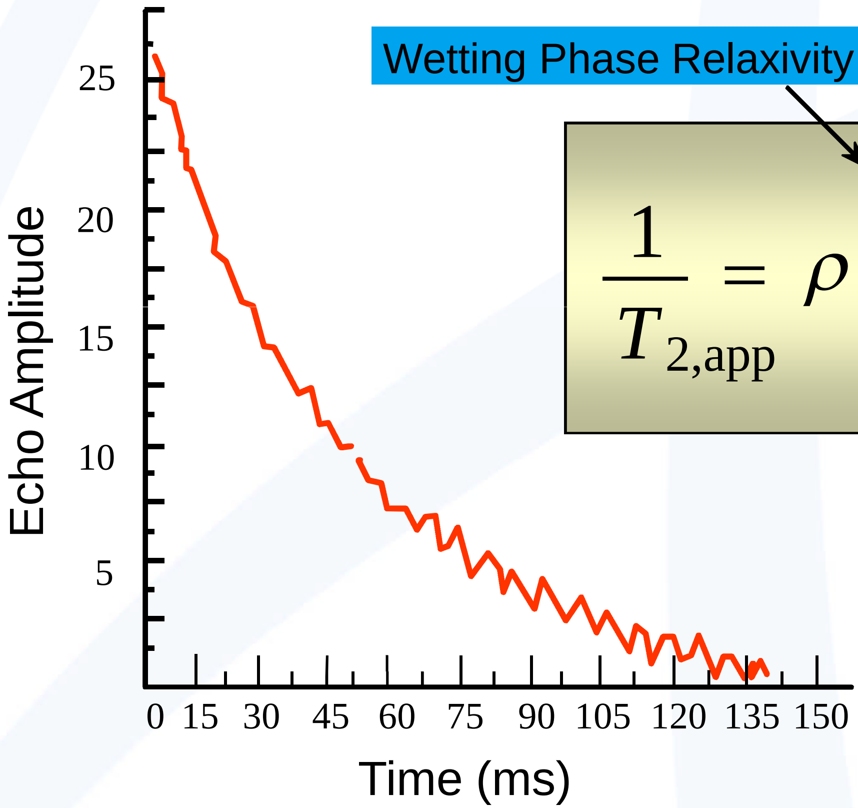
Controls on Relaxation - T_2 Decay



Wetting Phase Relaxivity

Non-wetting Phase Relaxivity

$$\frac{1}{T_{2,app}} = \rho \frac{S}{V} + \frac{1}{T_{2b}} + \frac{1}{T_{2D}}$$

Kenyon, 1992, Klienberg *et al* 1994, & Coates *et al* 1999 (and references therein)

Controls on Relaxation - T_2 Decay

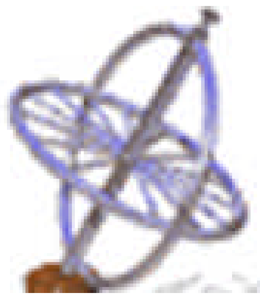
$$\frac{1}{T_{2,app}} = \rho \frac{S}{V} + \frac{1}{T_{2b}} + \frac{1}{T_{2D}}$$

$T_{2,D}$ – This is called the ‘diffusion’ T_2, and occurs in the presence of a magnetic gradient. This is a property of the free fluid that may be manipulated by the MR acquisition sequence.
Diffusion – the ability of the molecule to move.

$T_{2,app} = T_{2,log}$ – This is the T_2 that is measured by the logging tool. Historically is was referred to as simply T_2. With the latest generation of MR tools it is good practice to the subscript ‘app’ or ‘log’ for clarity.

Surface relaxivity; a function of pore-size and grain surface.

$T_{2,b} = T_{2,bulk} = T_{2,int}$ – This is called the ‘bulk’ or ‘intrinsic’ T_2. This is an inherent property of the free fluid and it is used to identify and quantify the fluid type and volume.



Controls on Relaxation - Gradient

$$\frac{1}{T_{2,app}} = \rho\frac{S}{V} + \frac{1}{T_{2b}} + \frac{1}{T_{2D}}$$

$$\frac{1}{T_{2,int}} = \rho\frac{S}{V} + \frac{1}{T_{2b}} + \frac{1}{T_{2D}}$$

T_2 apparent is recorded by gradient NMR tools e.g. MReX tool.

It is NOT recorded by the gradient-less tools e.g. MagTrak, which does not employ a gradient. Thus cannot determine T_{2D}.

Low gradient/No gradient tools e.g.

MagTrak measures **T_2 intrinsic.**

MReX also measures $T_{2,int}$ and can manipulate the magnetic gradient to determine properties of the fluids.

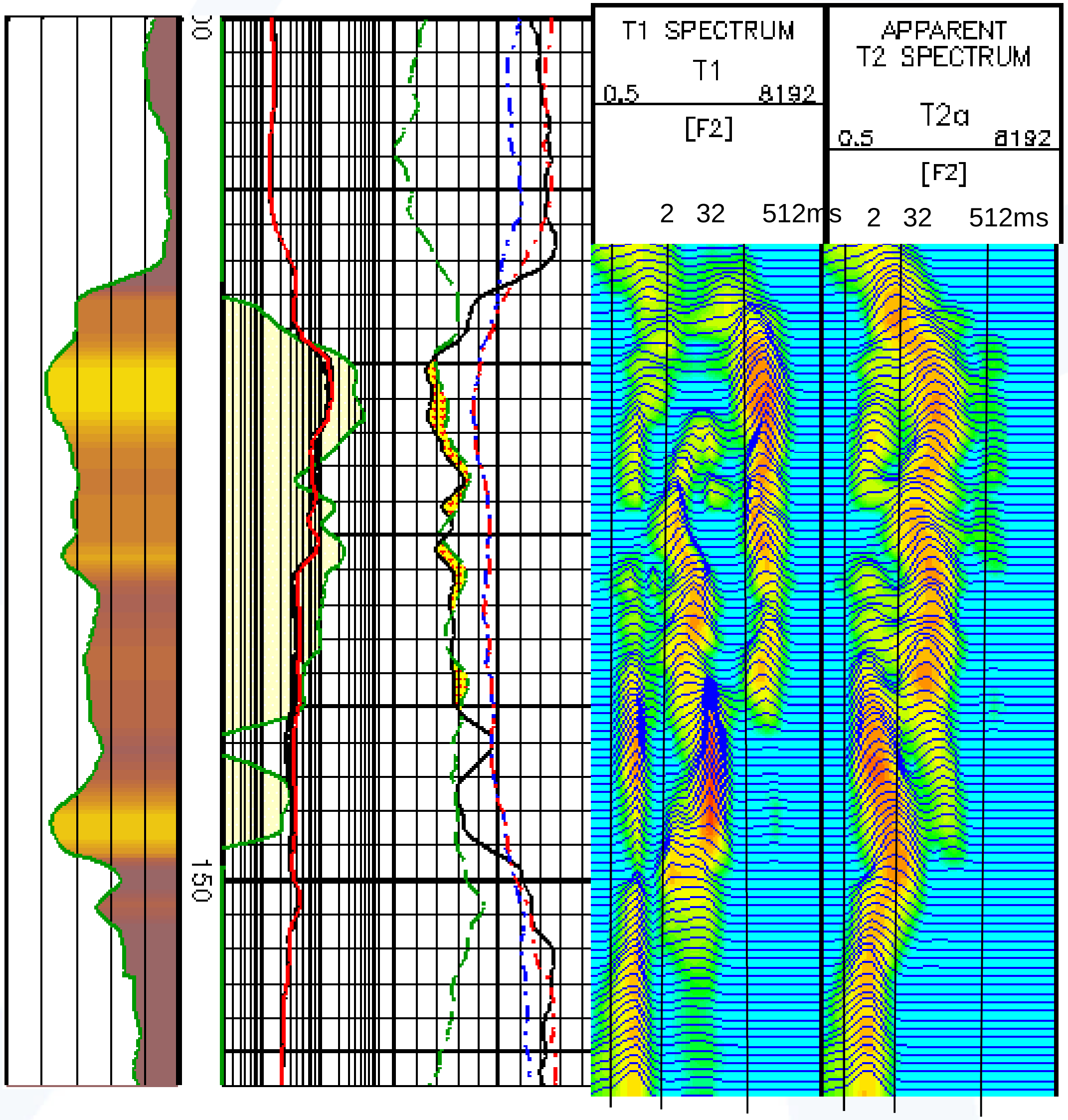
NMR Properties of Typical Reservoir Fluids

Fluid	T_1 (ms)	$T_{2,a}$ (ms)*	Typical $T_1/T_{2,a}$	Viscosity (cp)	$D \cdot 10^{-9}$ (m^2/s)
Brine	1 – 2,000	1 – 500	2	0.2 – 0.8	1.8 – 7
Oil	1 – 3,000	1 – 2,000	2	0.2 – 1000	0.0015 – 7.6
Gas	3,000 – 4,000	30 – 500	16	0.011 – 0.014	80 - 100

* Gradient tool

NMR Differing Spectra

Differing Spectra Types T1 and T2



Two types of spectra are commonly displayed:

T_1 – spectrum
T_2 – spectrum
(of which there are several types)

Other spectra:
T_2 TWS
T_2 TWL
Differential spectra
Diffusion spectra

Comparing spectra can provide valuable information: for instance the example opposite indicates the presence of gas.

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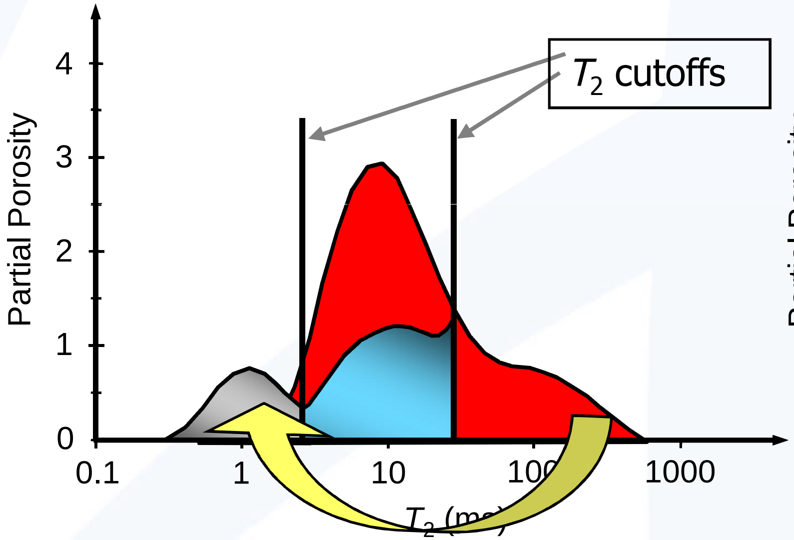
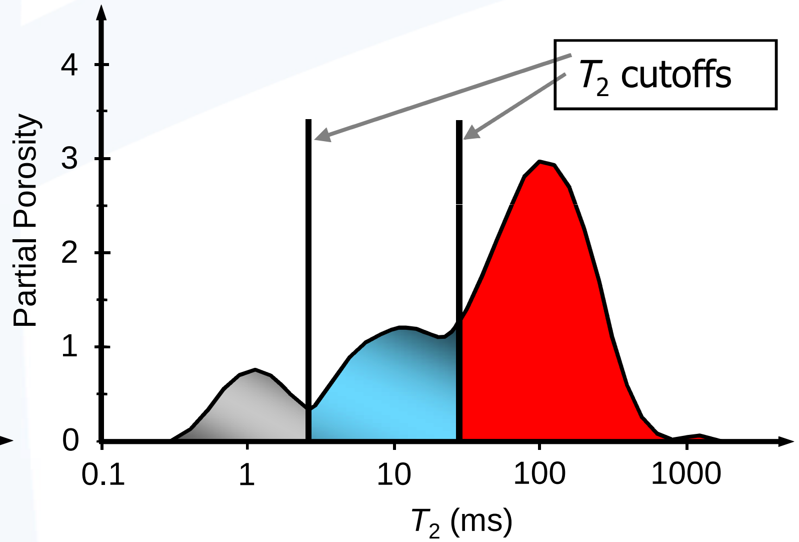
T2 Spectra: Gradient control ~ which type is yours?

High Gradient



Low Gradient

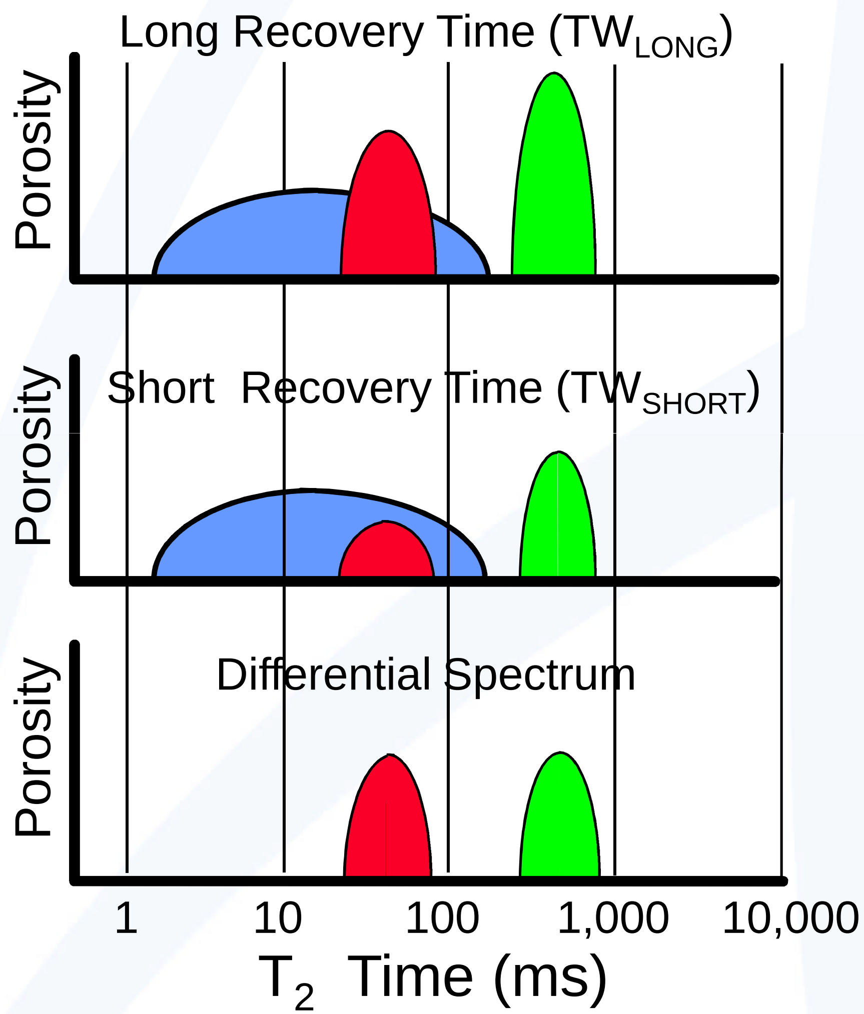


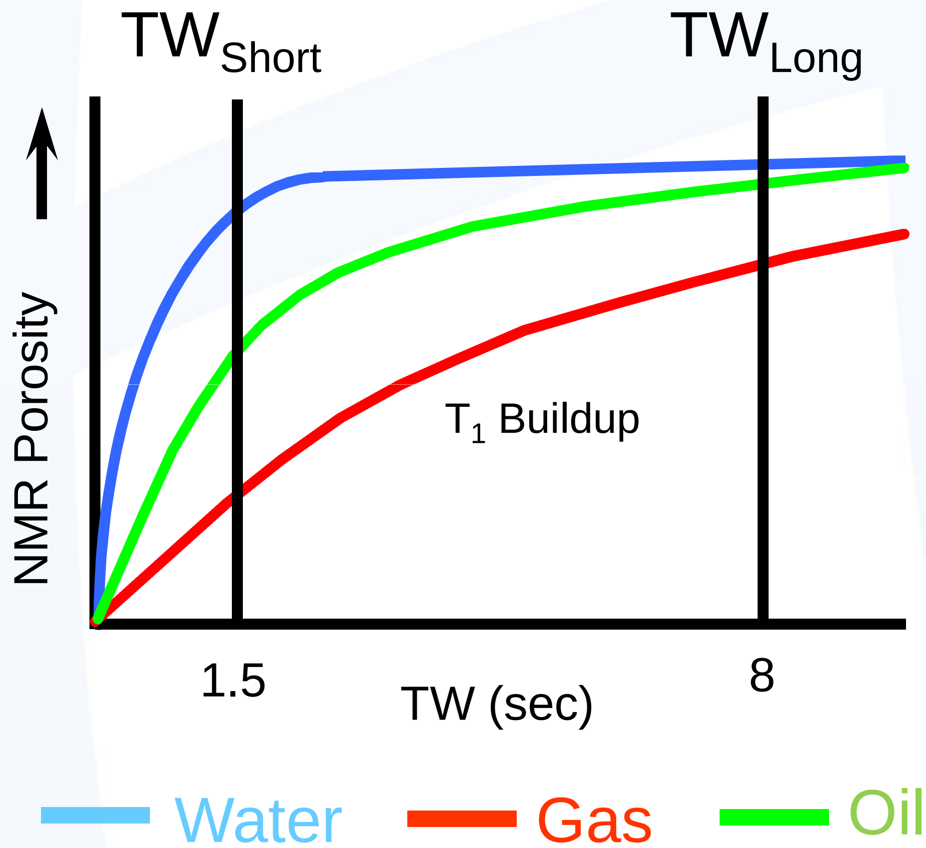
Diffusion Effect

No Diffusion Effect

Note the diffusion effect is greatest for gas, but can also occur to a lesser extent in light oil and rarer water.

Differing Spectra: Differential Spectrum





Gas Identification

- CBW, BVI, BVM, ϕ_e, ϕ_t, and k_{NMR}
- Porosity distribution based on chosen cutoffs such as:
  CBW 3 ms and BVI 33 ms
- k_{NMR} based on Coates equation with chosen C, m, and n
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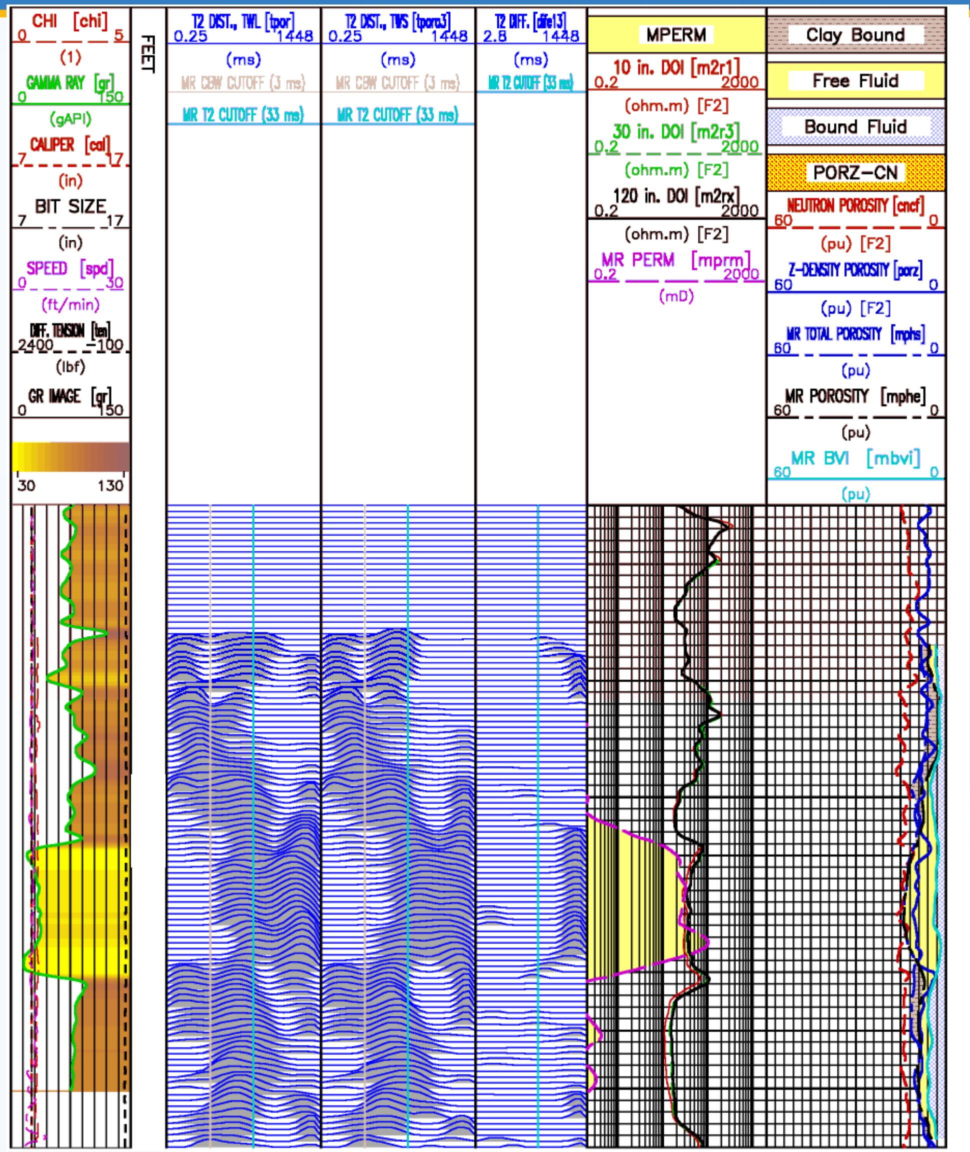
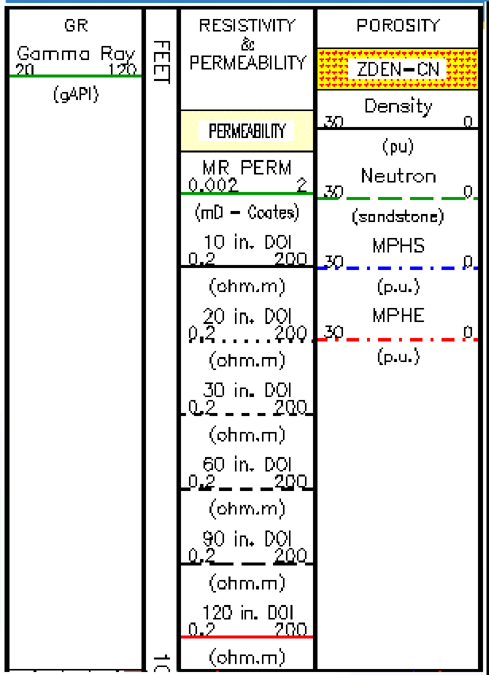
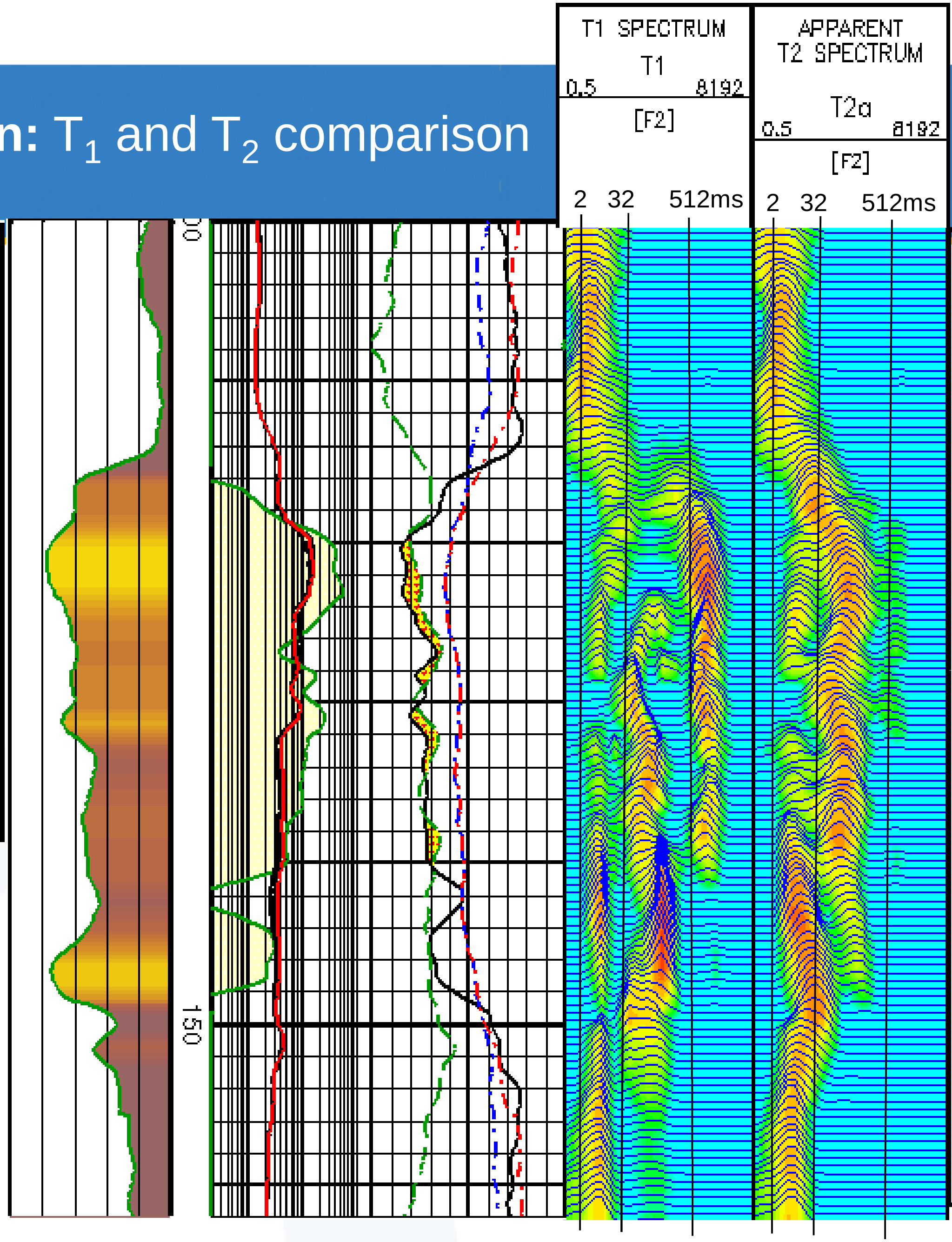


Gas Identification: T$_1$ and T$_2$ comparison





Answers?

1) Is the reservoir gas bearing & why?
2) If so does the gas occur throughout?
3) Is there moveable water?
4) Compare the MReX porosities versus the density measurement, what do you observe, why may this occur?

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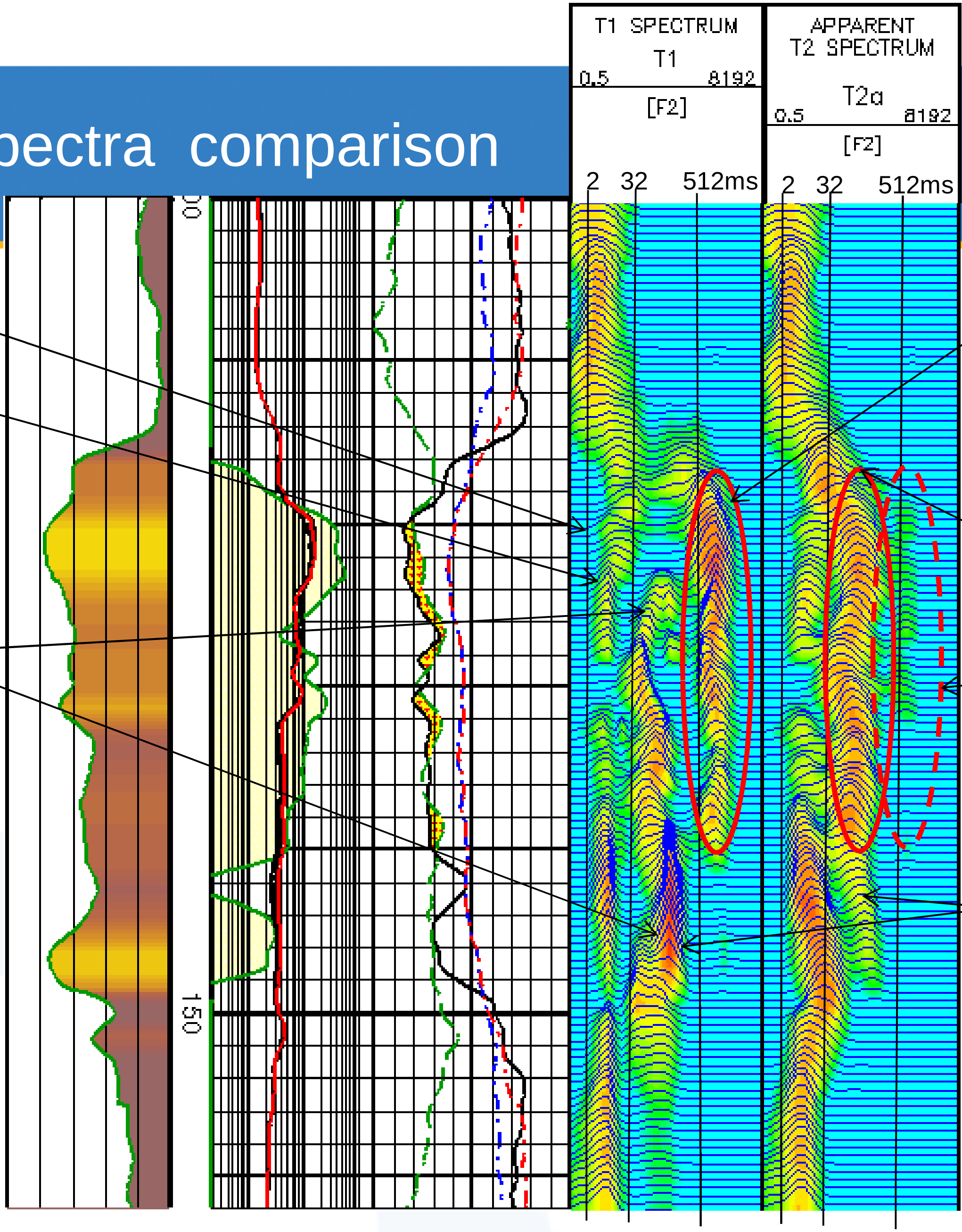
T_1 and T_2 spectra comparison

Reservoir has limited clay bound water

Reservoir has common irreducible fluids

'Short' T_1 signal not characteristic of the gas or oil so far identified. In the absence of any heavy oil phases; probable moveable water. Signal decreases in abundance upwards.

T_1 and T_2 spectra are NOT Hydrogen Index corrected. Thus in the presence of light hydrocarbon depending on the reservoir temperature and pressure, NMR porosities will 'undercall' density/neutron measurements



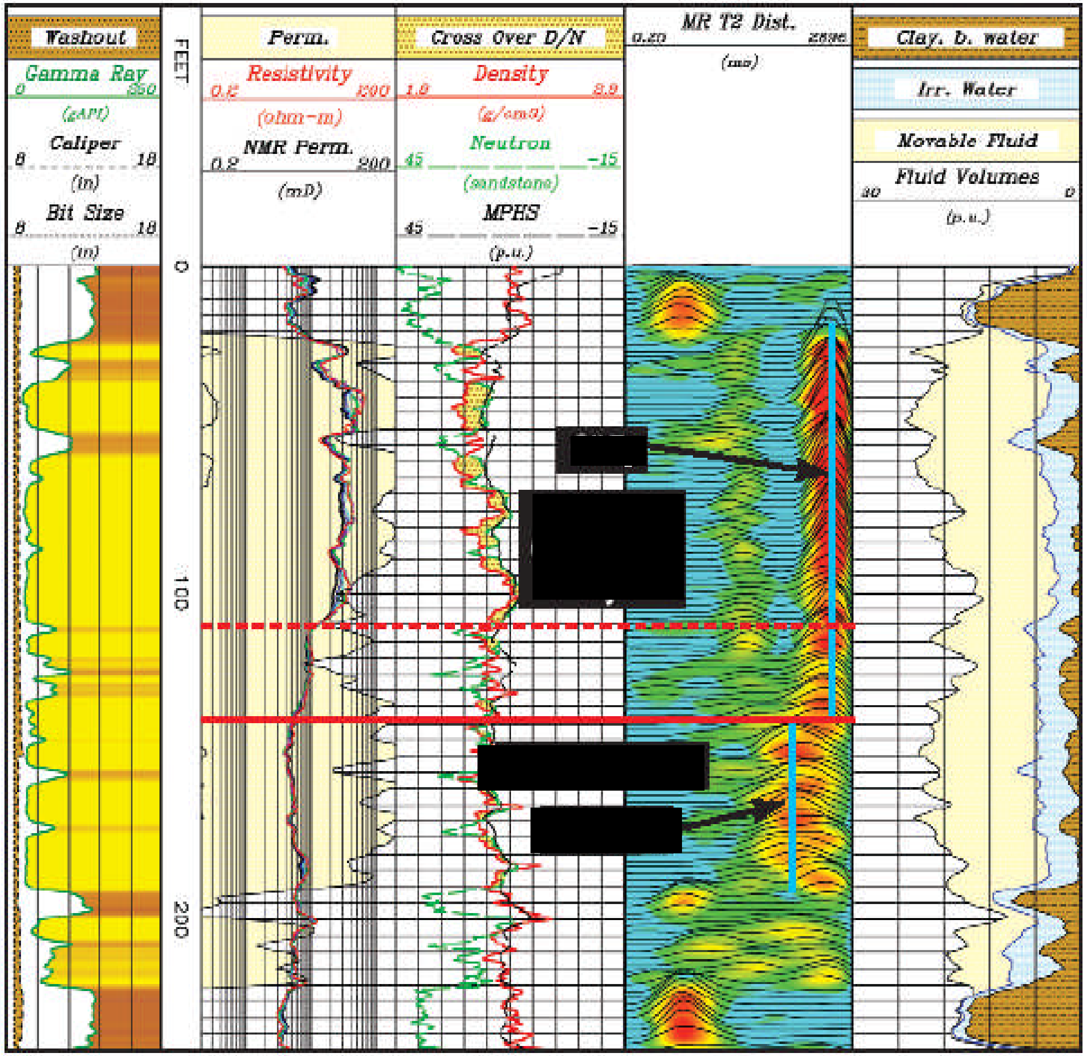
On T_1 spectrum slow relaxing components could represent Oil, OBMF or Gas.

Proportion of signal on T_2 'moves' to left and occupies 30 – 500ms portion of spectrum compared to T_1, therefore Gas. Gas $T_1 >> T_2$

Corresponding reduction of late T_2 signal

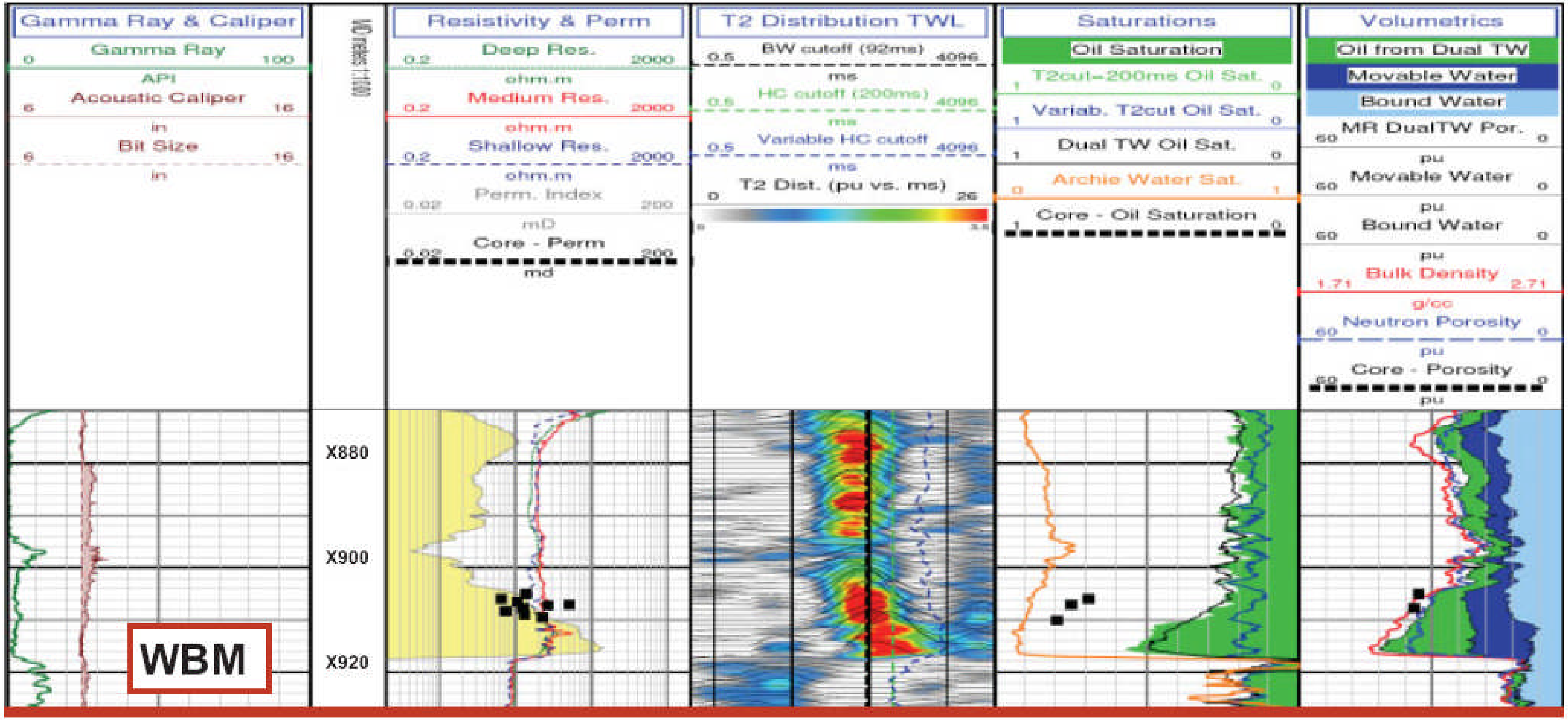
Limited change ($T_1 = T_2$)
No Gas in lower sandstone.

Example of a T2 spectrum: Quiz

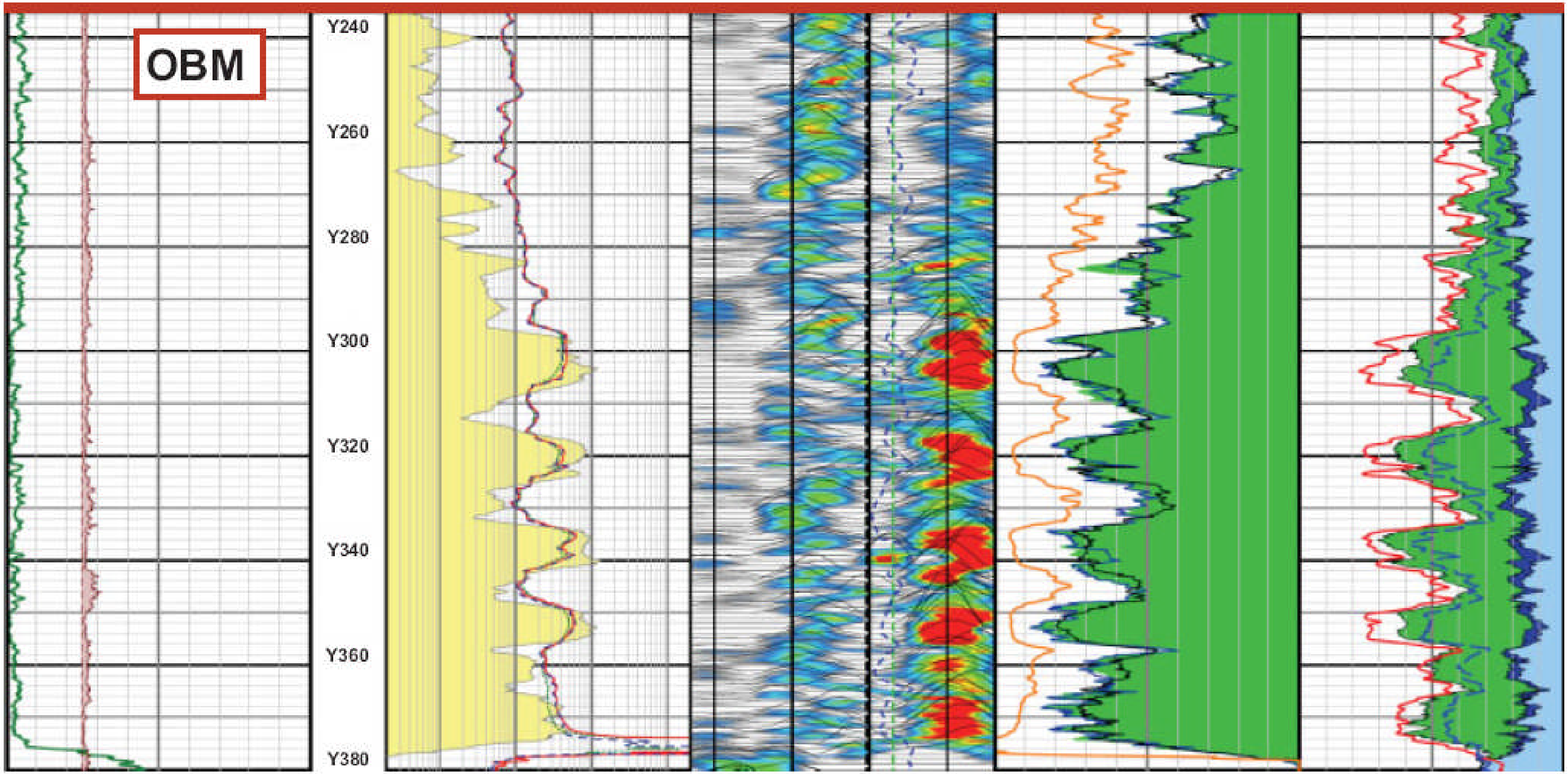


What can you identify?

Oil identification - Simple Analysis of MagTrak T_2



Simple Analysis of MagTrak T_2



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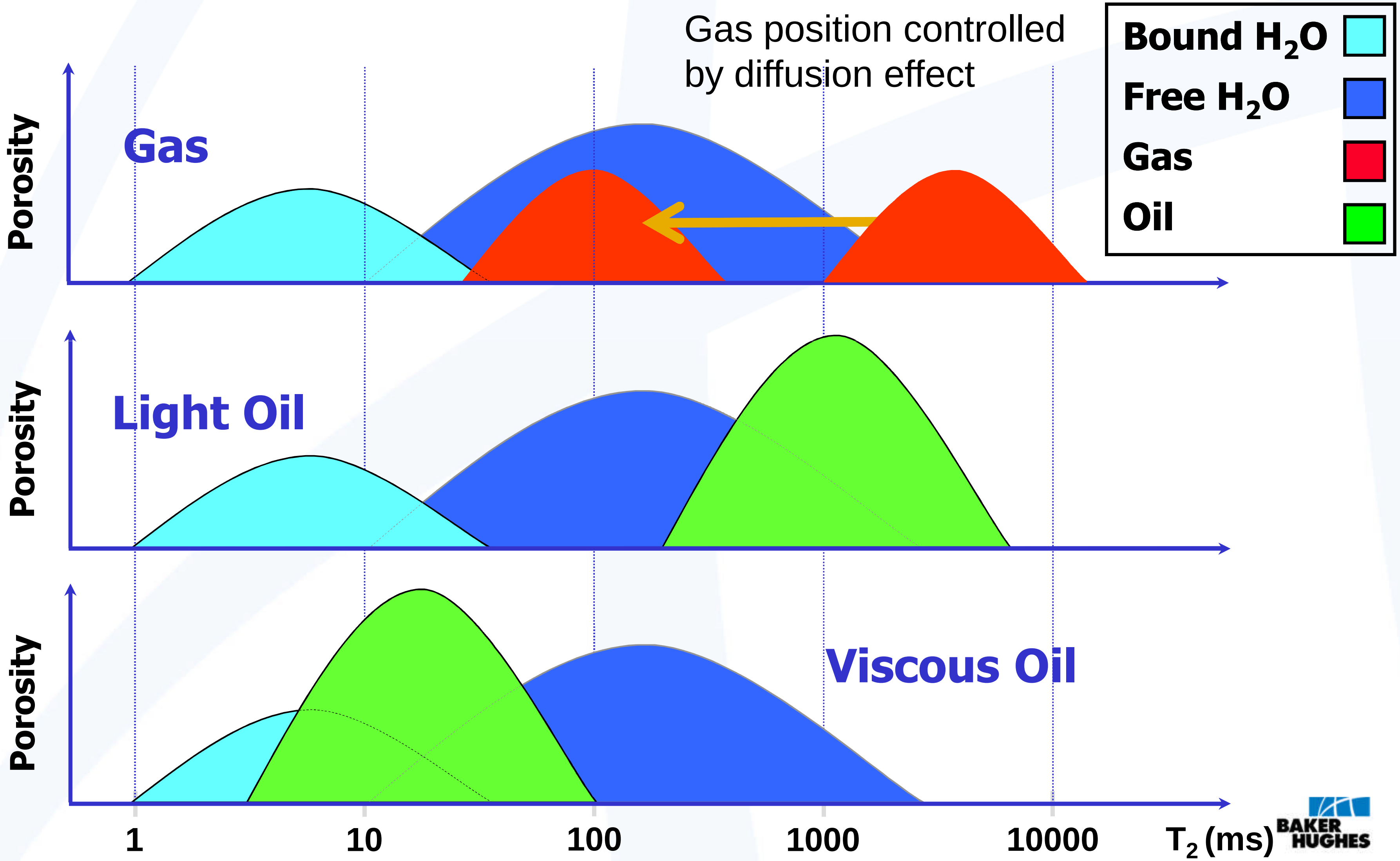
Fluid Identification: T_2 Analysis Challenges



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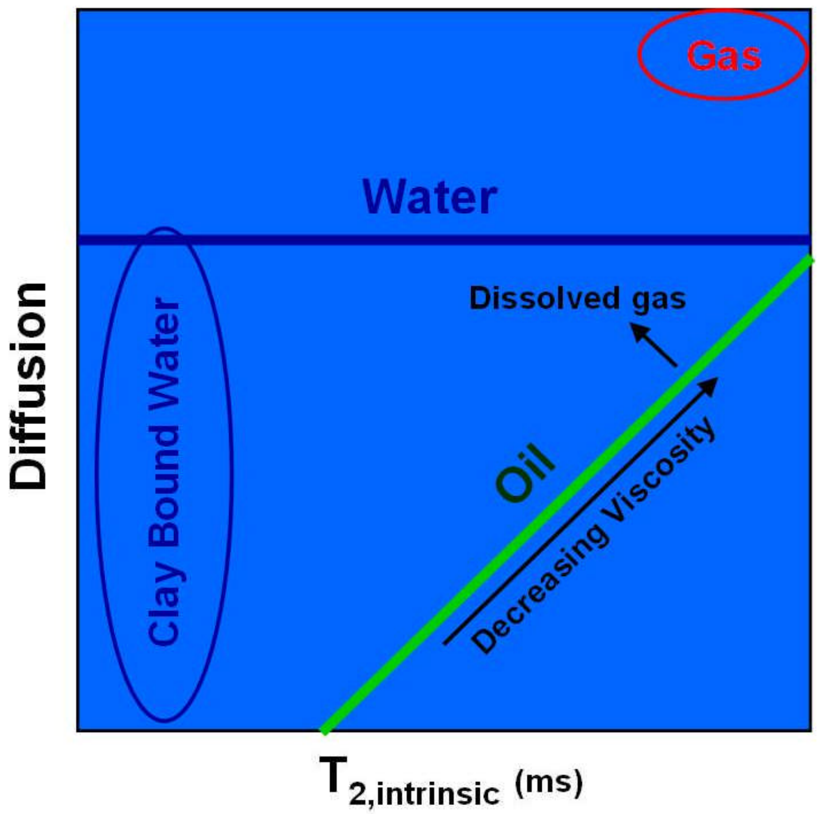
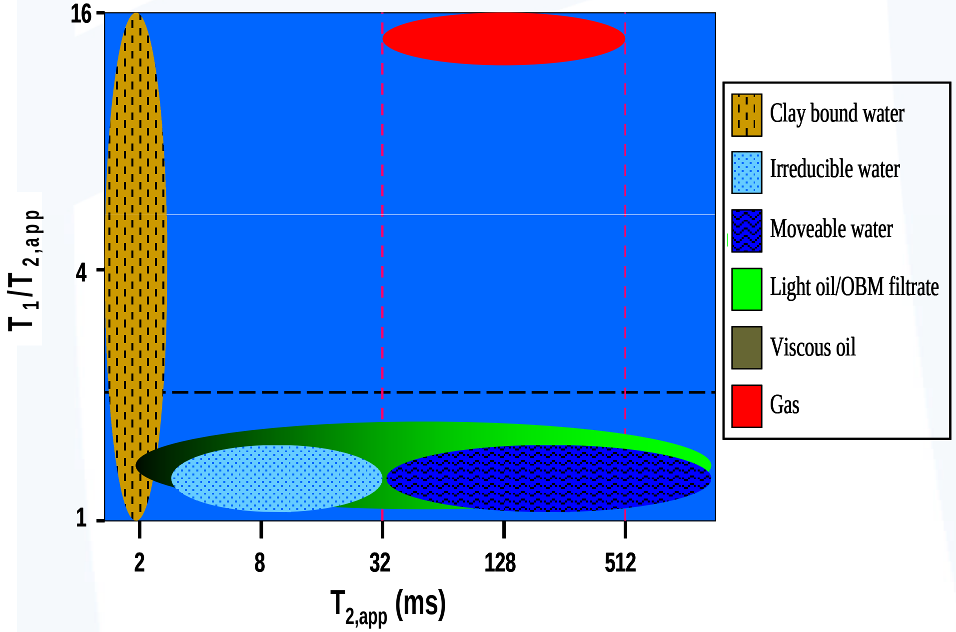
2D NMR

2D NMR Fluid Identification: D -T_2 & R-T_2

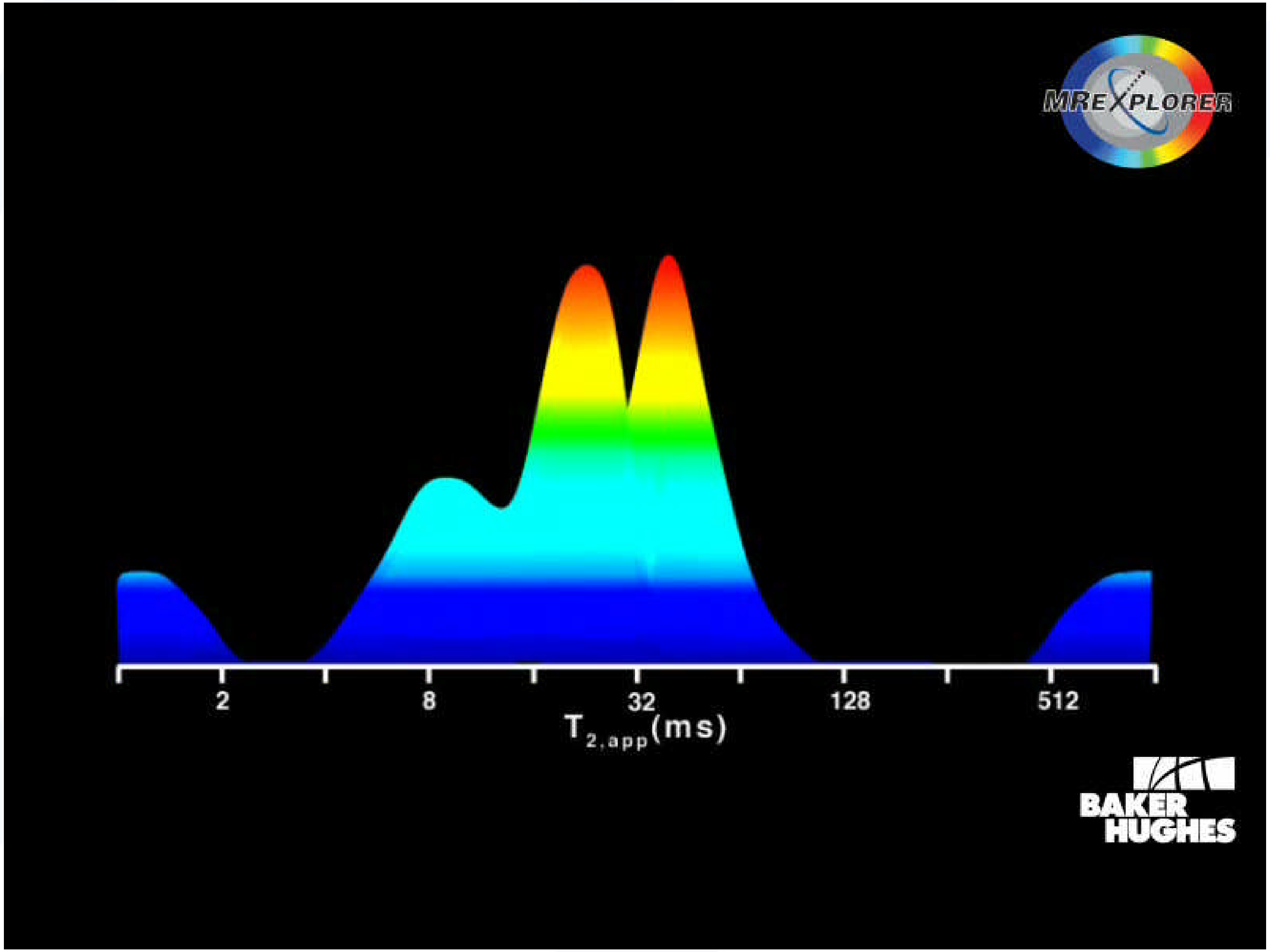
D-T_2
Used for Oil & Gas



R-T_2
Used for Gas



2D R-T_2 NMR Video



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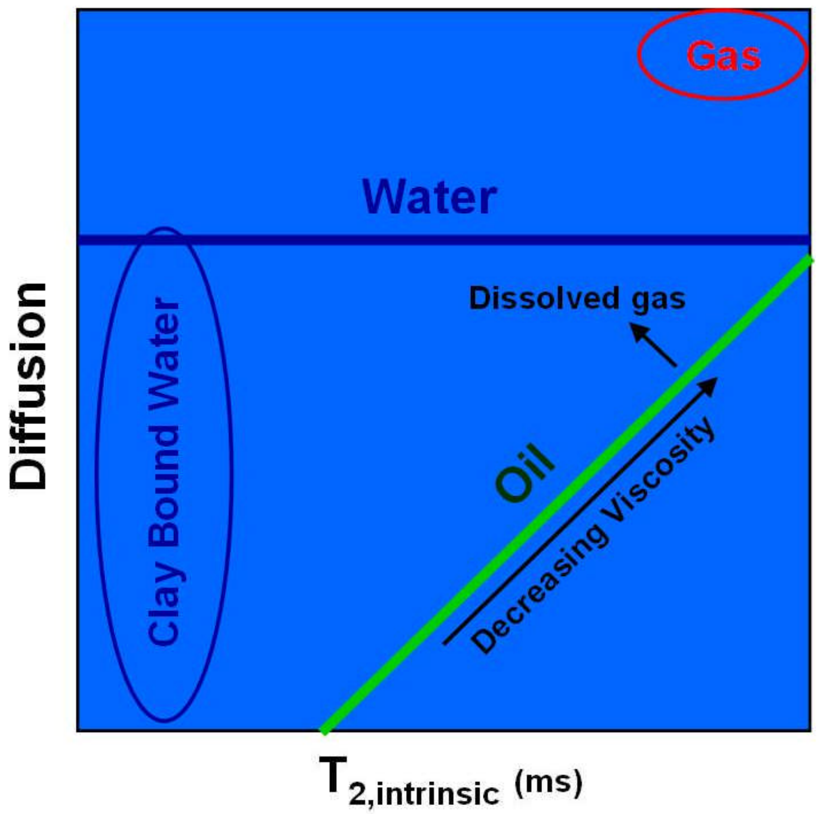
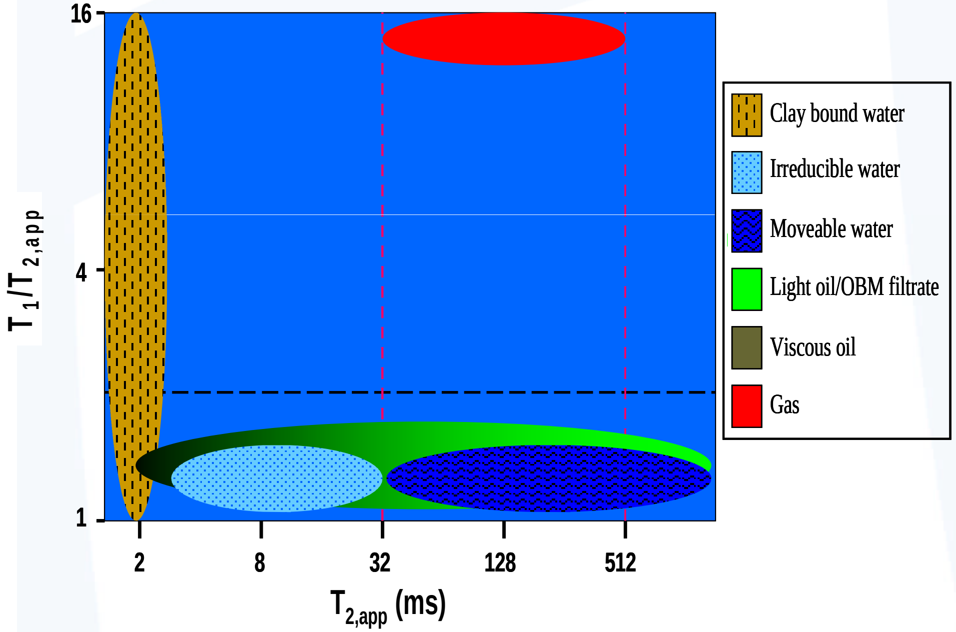
2D NMR Fluid Identification: D -T_2 & R-T_2

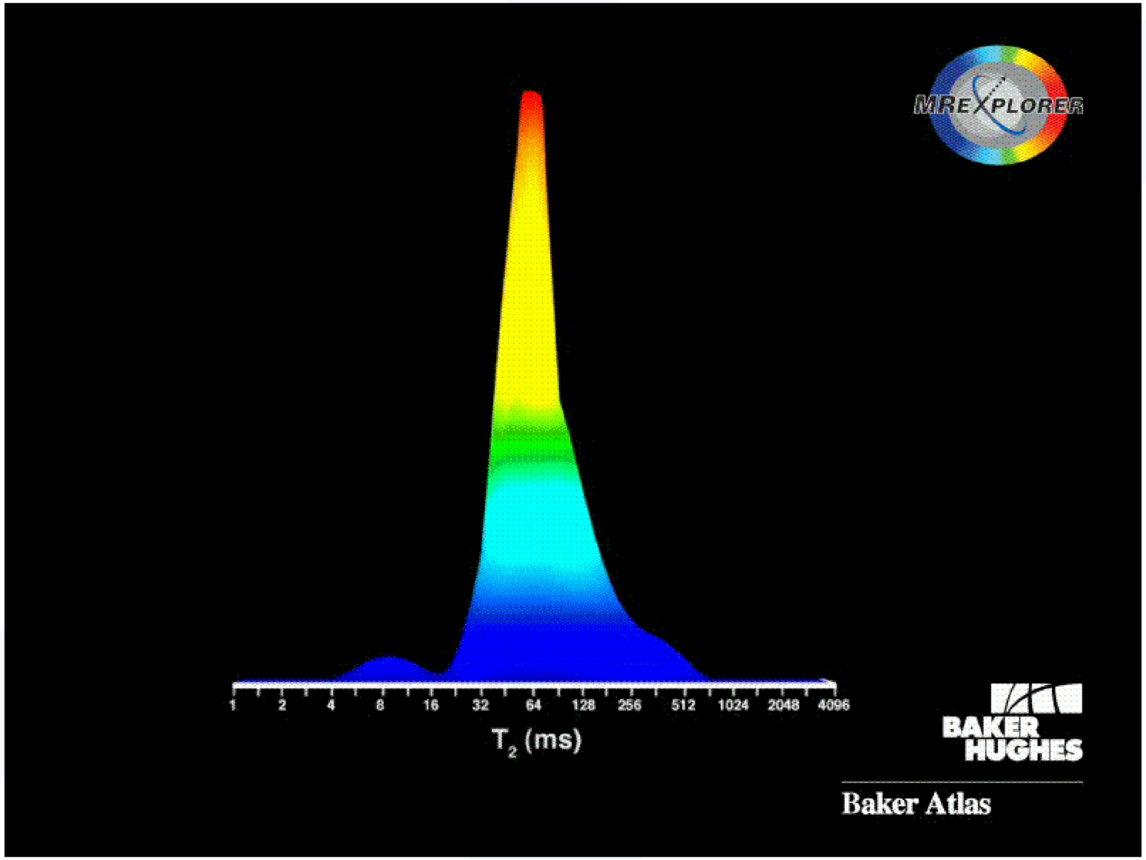
D-T_2
Used for Oil & Gas



R-T_2
Used for Gas



D-T_2 animation



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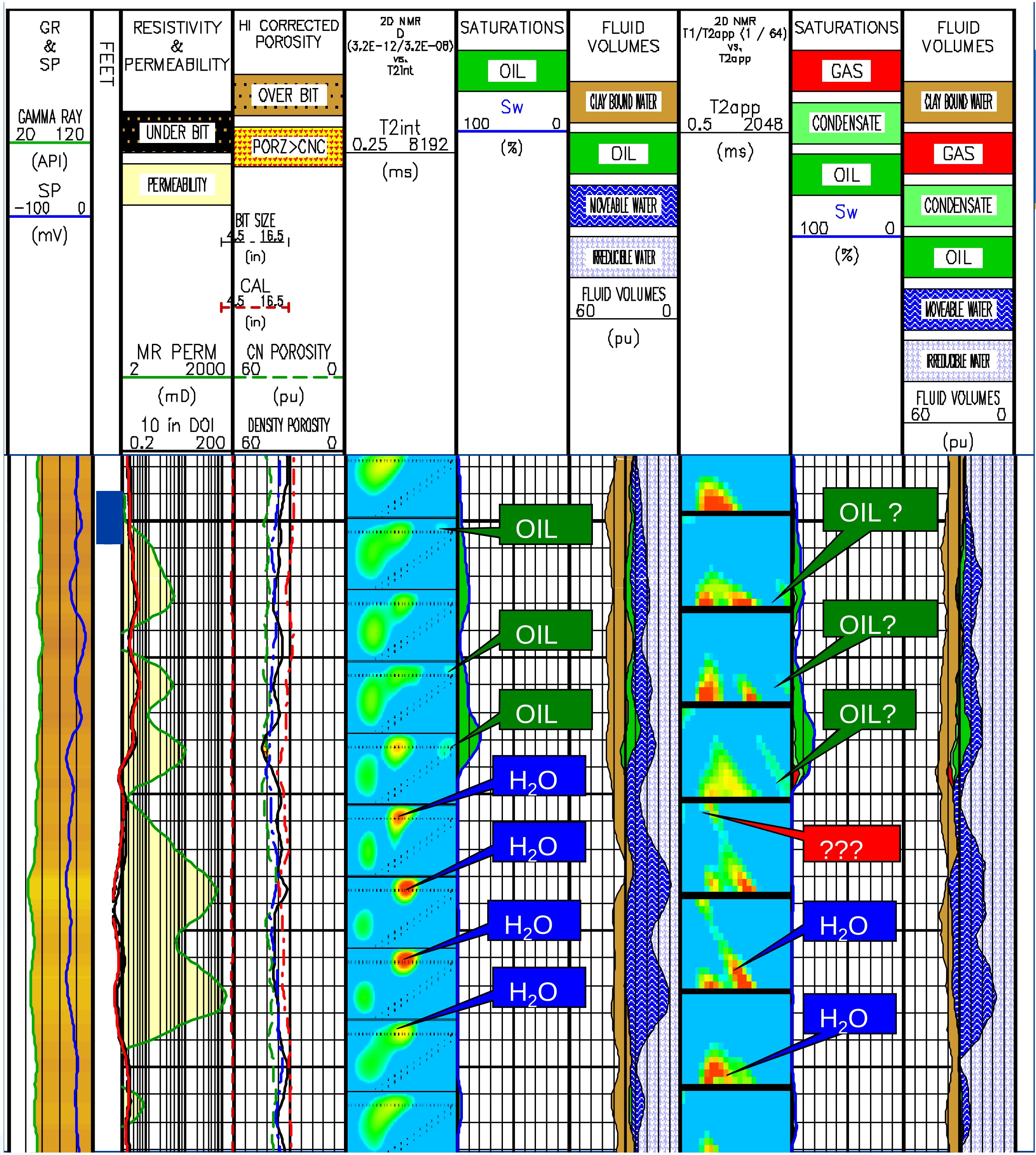

Oil Reservoir & WBM

Example illustrating MREX 2NMR techniques across OWC in a laminated reservoir

- Saturation determinations were made using 2DNMR techniques

- Water based mud filtrate invasion is responsible for moveable water shown in upper (oil) section

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Summary

- NMR can provide multiple spectra types.
- Differing Spectra provide differing and useful information.
- Understand how the spectra was acquired, before starting to interpret them.
- Confirmation of visual interpretation of the spectra by 2D NMR fluid typing or other sources of information.
- Permeability is calculated not measured.

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