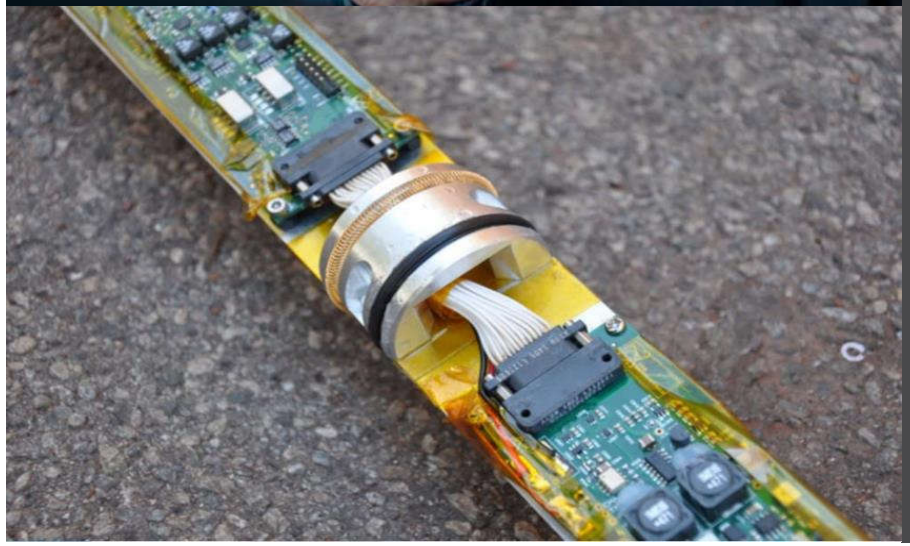
Borehole Magnetic Resonance

Economic Innovations

About Us



Qteq is a technology provider of innovative, integrated technical services and products to the georesources industry – across the oil and gas, groundwater, minerals and alternative energy sectors.

Our aim is to pioneer technologies that improve production in the georesources industry, increase sustainability in the hydrology sector and provide a positive environmental outcome for our customers.

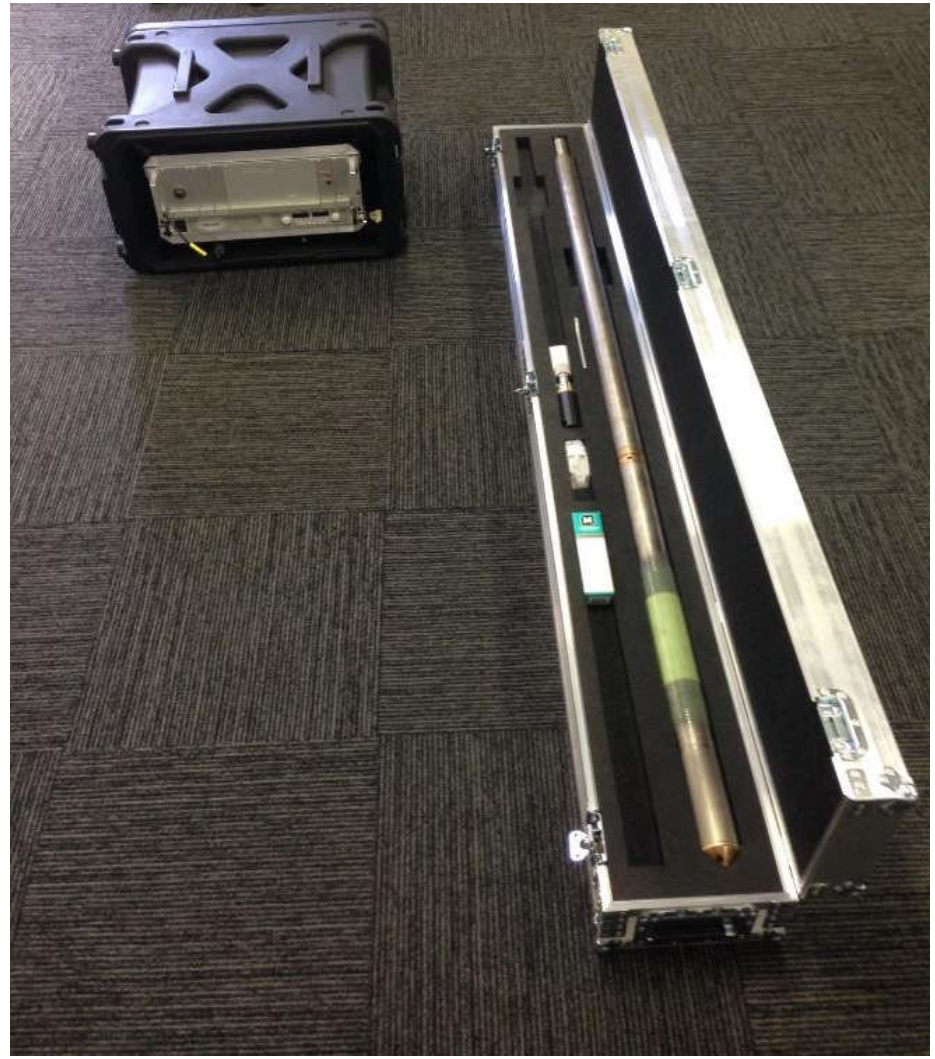
Measure, Monitor, Manage & Mitigate

Mission

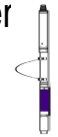
BMR Logging Equipment

Technical Specifications

Specifications		
Physical Dimensions		
Tool Diameter	60 mm	90 mm
Tool Length	2.01 m	2.16 m
Operating Pressure	200 bar	200 bar
Operating Temperature	100 °C	100 °C
Vertical Resolution	8 cm	10 cm
Diameter of Investigation	190 mm, 230 mm, 260 mm	360 mm
Echo Spacing (TE)	320 µs, 450 µs, 600 µs	500 µs
Wait Time (TW)	Multi	Multi
T2 Distribution	0.5xTE – 5 seconds	0.5xTE – 5 seconds
Porosity Range	0 – 100 pu	0 – 100 pu
Total Porosity Precision	2 pu – 2 level averaging	2 pu – 3 level averaging
Well Parameters		
Hole Sizes	75 – 216 mm	122 – 312 mm
Hole Condition	Open hole, Fiberglass or PVC casing	



Summary of commercially available BMR tools

	Qteq QL40 BMR-60	SLB MR Scanner 	SLB CMR Plus 	BHI MREX 	HAL MRIL 	WFT NMRT 	Vista Clara (40 mm OD – 133 mm tools)
Hole Size	**3 – 9 in**	5.8 – 14 in	6.5 – 14 in	5.8 – 14 in	5.8 – 12 in	7 - ? in	2 – 12.25 in
Temp & Press	**100 C, 3 Kpsi**	150 C, 20 Kpsi	175 C, 25 Kpsi	160 C, 20 Kpsi	175 C, 25 Kpsi	125 C, 11.6 Kpsi	60 C, 1.5 Kpsi
Salinity (Rm)	**< 0.01 Ohmm**	0.02 Ohmm	< 0.01 Ohmm	0.015 Ohmm	0.02 Ohmm	0.04 Ohmm	unknown
Size & Weight	**2.01 m, 19 kg**	9.8 m, 544 kg	4.3 m, 136 kg	7.3 m, 282 kg	15.8 m, 670 kg	6.7 m, 265 kg	1.5 – 4.2 m , (10-73 kg)
Echo spacing	**320 us**	350-600 us	200 us	400 us	600 us	800 us	700-2000 us
Logging Speed	**60-180 m/hr**	70 m/hr	168 m/hr	274 m/hr	183 m/hr	~180 m/hr	5-40 m/hr
Cable Type	**Standard 4 core**	Standard 7 core	Standard 7 core	Standard 7 core	Standard 7 core	Standard 7 core	Standard 4 core to 1000m
Crew Size	**1 person**	2-3 ppl	2-3 ppl	2-3 ppl	2-3 ppl	2-3 ppl	1-2 ppl

4

Logging Environments

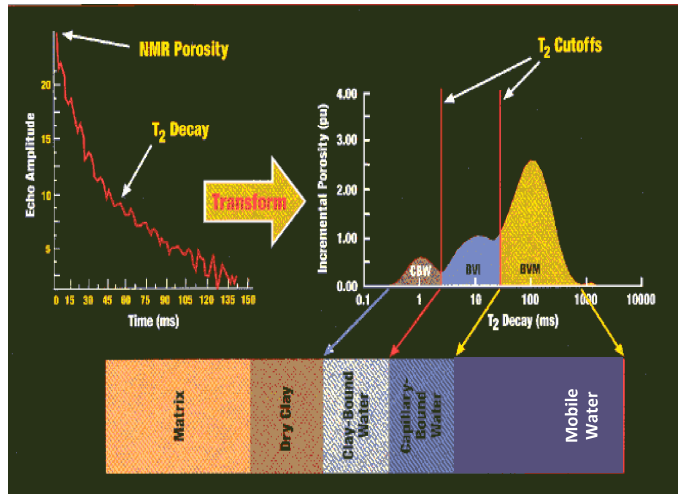
The BMR tool has been run in a wide variety of logging environments

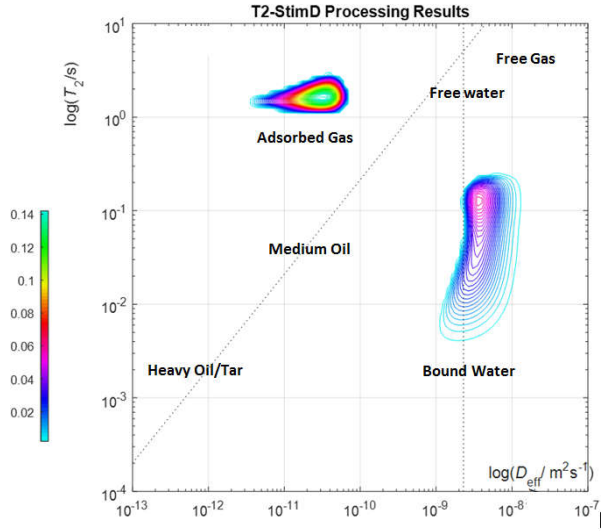
Hard Rock	In-Situ Recovery	Oil & Gas	Groundwater
Iron Ore	Potash	Coal Seam Gas	State Departments
Copper	Lithium		Water Corporations
Lead	Uranium		Agricultural Irrigation
Zinc			Local Council Water
Gold			
Diamond			
Platinum			
Coal			

In all of these situations, we are measuring only the water content in the pore space of the rock. The measurement is lithology independent and is free of chemical radiation sources.

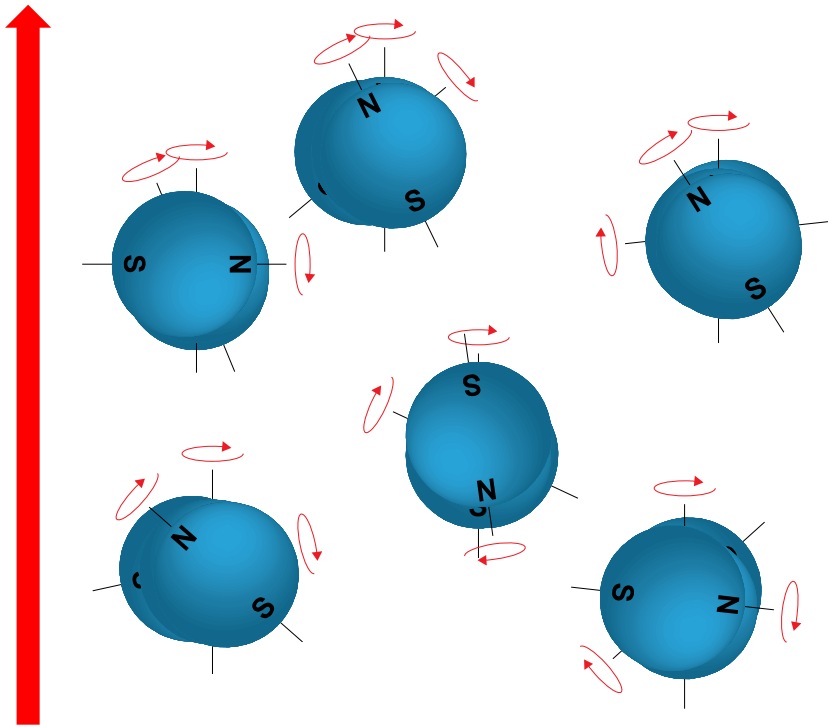
BMR Logging Answers

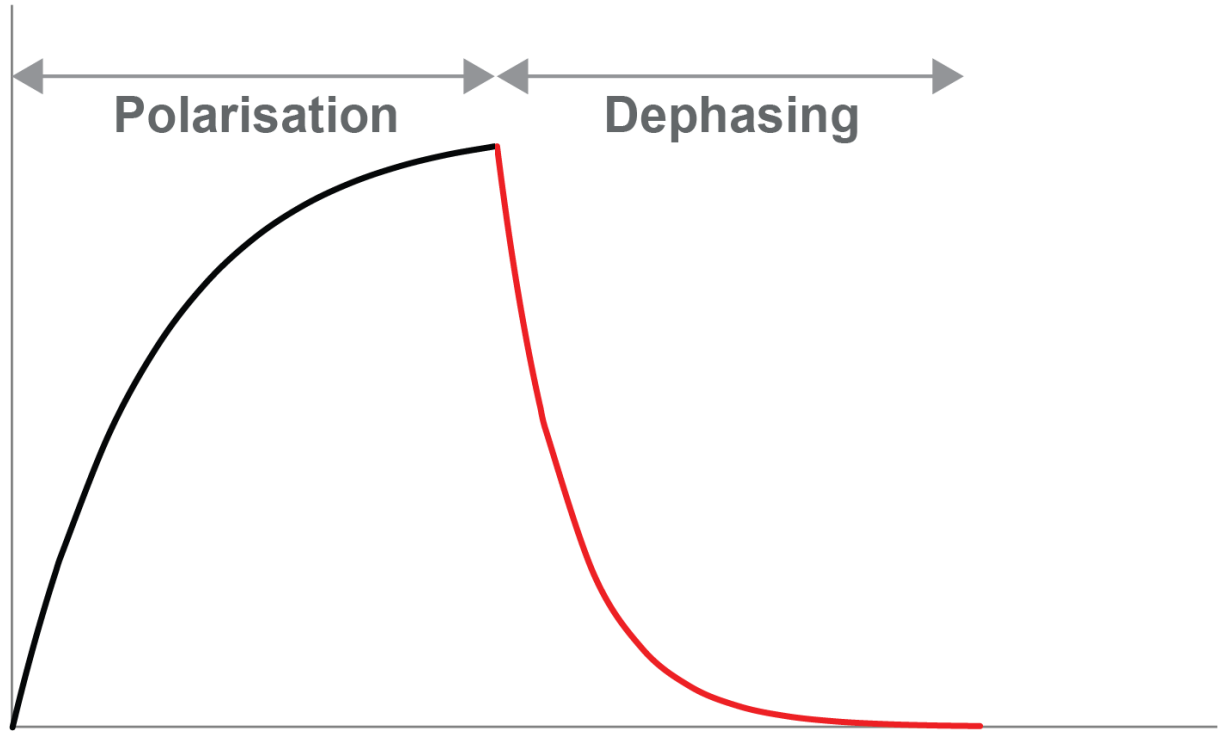
Measured Parameters	Computed Parameters
Total porosity	Permeability
Pore size distribution (PSD)	Dry weight density (need bulk density)
Free water porosity (specific yield)	Adsorbed and free gas content of coals
Capillary-bound porosity	Multi-mineral modelling (with other log suites)
Clay-bound porosity	





Magnetic Resonance

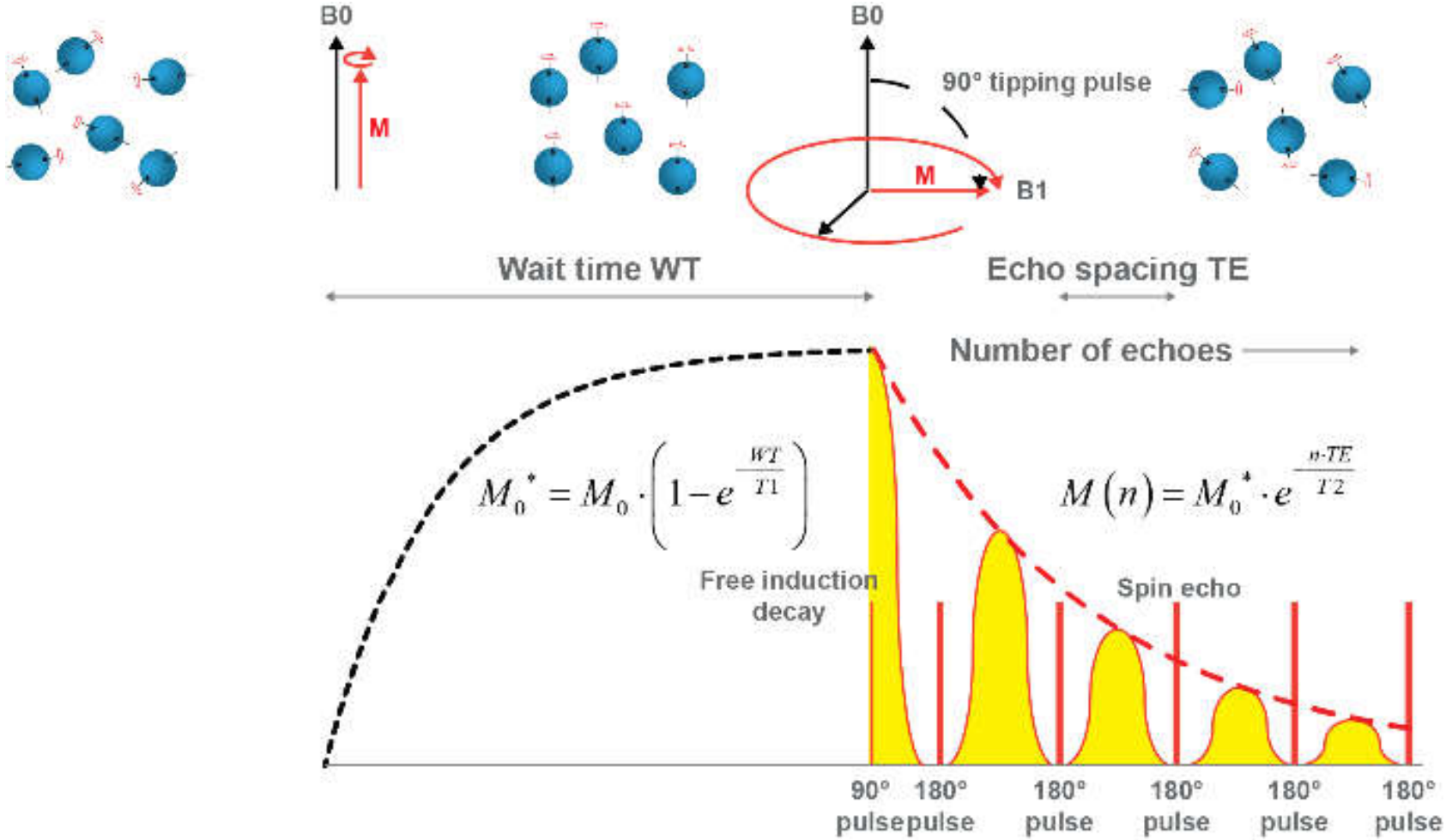




$$M(t) = M_0 \cdot \left(1 - e^{-\frac{t}{T1}}\right)$$

$$M(t) = M_0 \cdot e^{-\frac{t}{T2}}$$

The BMR Measurement



BMR Signal Processing

The amplitude decay is recorded in the time domain, and is inverted to produce a T_2 distribution

- T_2 distribution = Pore Size Distribution
- Sum of amplitudes = Total Porosity
- Total Porosity can be divided into Bound (BFV) and Free Water (FFV)
- A permeability estimate can be calculated

Echo spacing (TE)

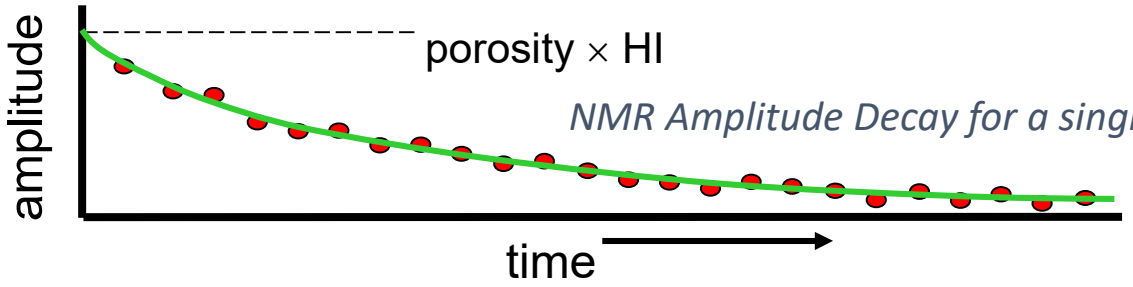
- Time between successive NMR echoes/RF pulses

Signal to noise ratio

- BMR inversions are very susceptible to noise in the early part of the decay data

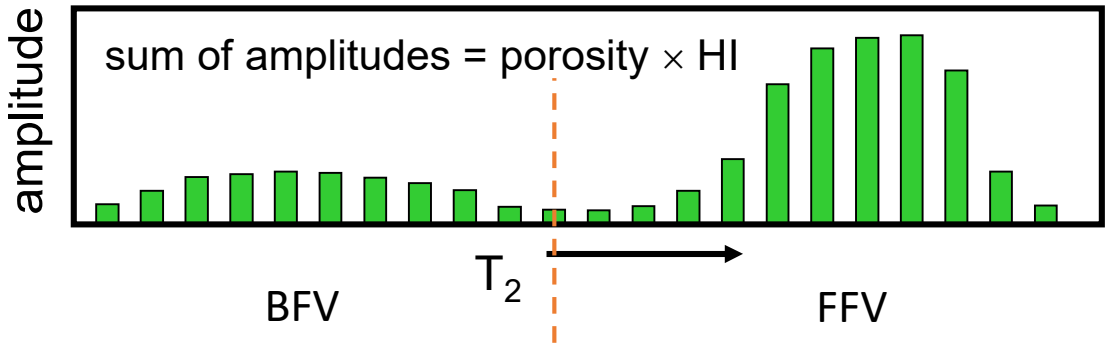
Continuous logging

- Requires a high SNR

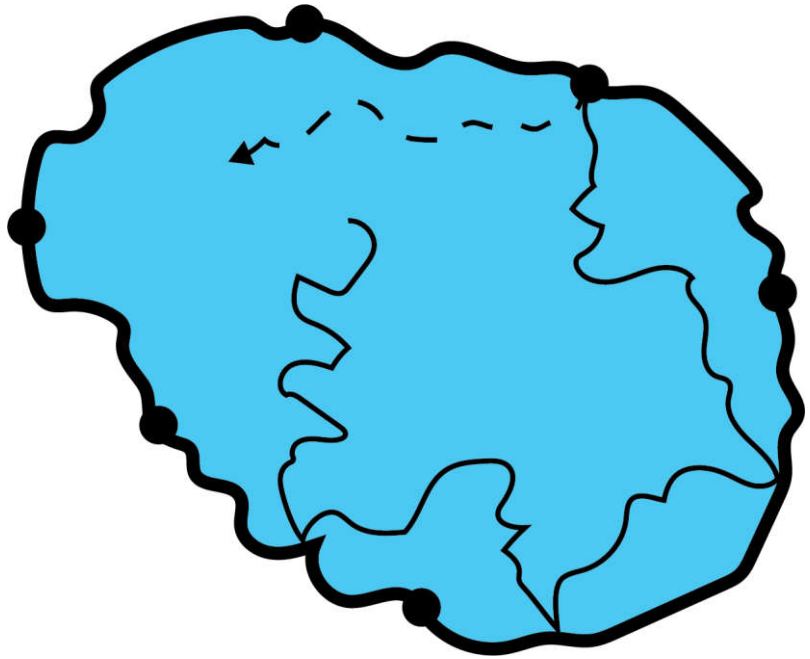


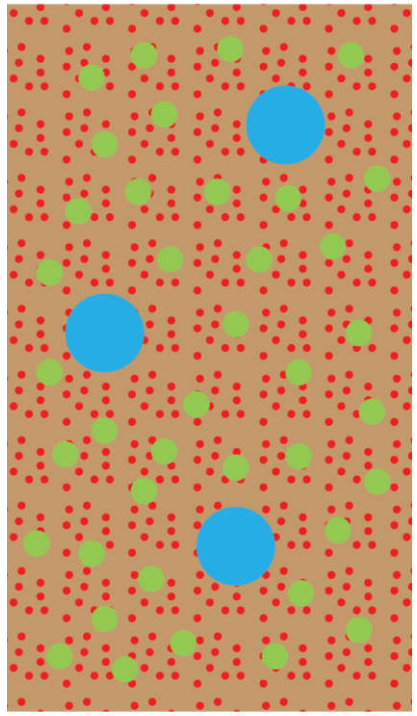
NMR Amplitude Decay for a single depth

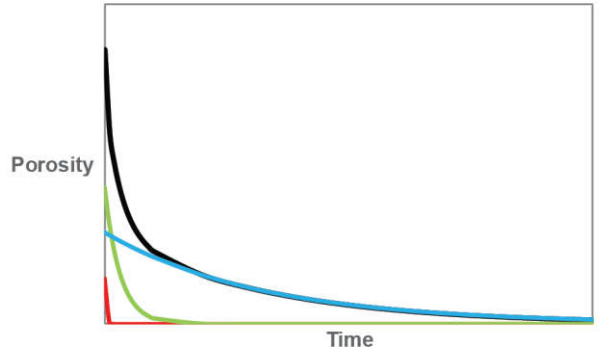
NMR T_2 Distribution for a single depth

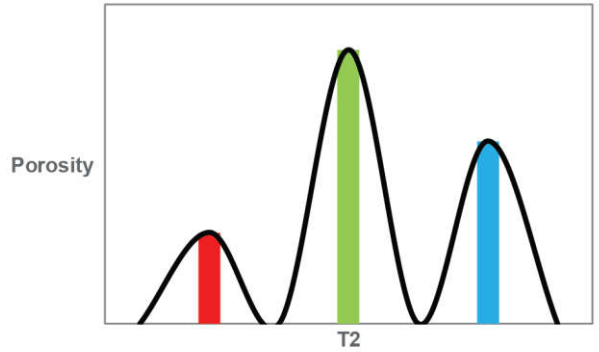


BMR and Pore Geometry

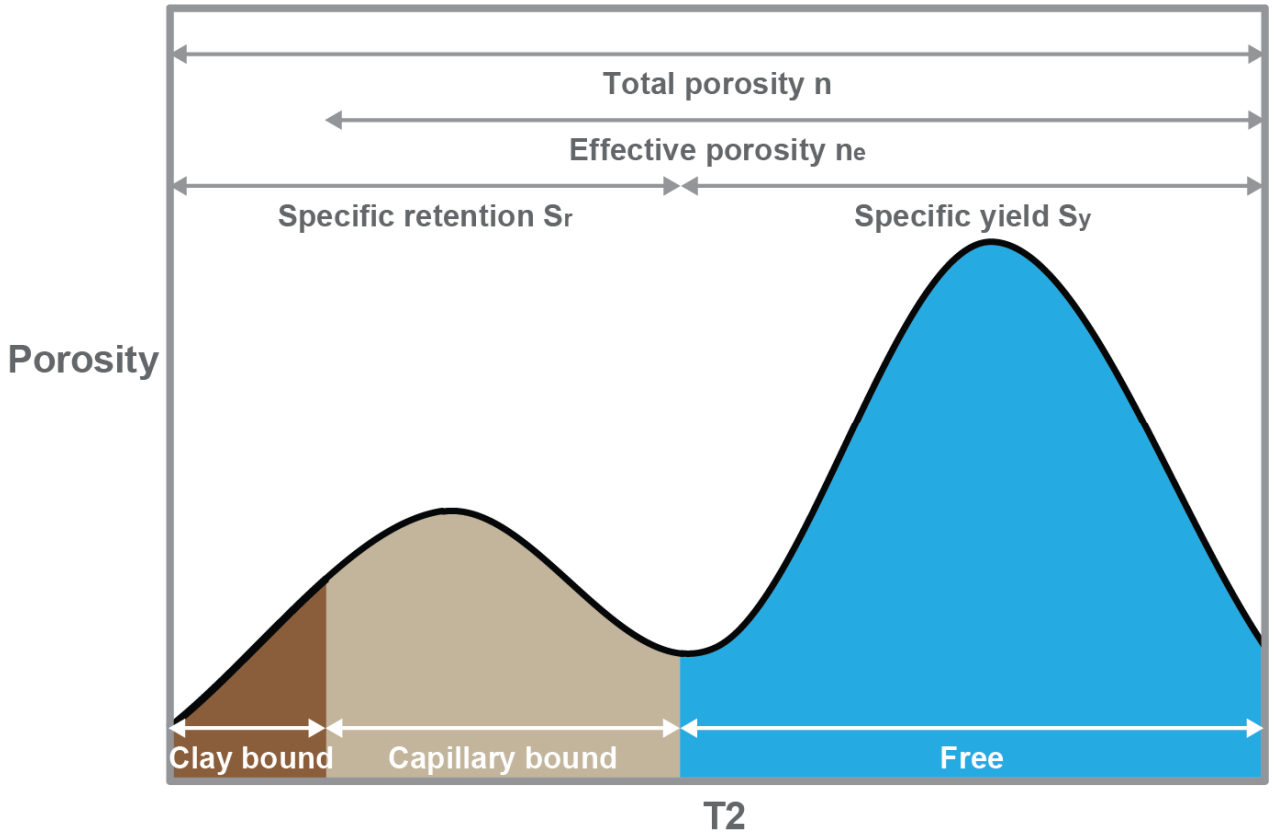








BMR and Hydrogeology



Permeability

$$k_{Timur-Coates} = a \cdot n^b \cdot \left(\frac{S_y}{S_r}\right)^c$$

$$k_{SDR} = a \cdot n^b \cdot {T2_{LM}}^c$$

Hydraulic conductivity

$$K = \frac{k \cdot \rho \cdot g}{\mu}$$

Transmissivity

$$T = K \cdot b$$

Hydrogeology Sources of Data

Parameter	Cores	Aquifer Tests	Well Tests	Geophysical Well Logs	BMR
Porosity	Yes			Yes	Yes
Specific Yield	Yes	Yes			Yes
Specific Retention	Yes	Yes			Yes
Permeability	Yes	Yes	Yes		Yes
Hydraulic Conductivity	Yes	Yes	Yes		Yes
Transmissivity	Yes	Yes	Yes		Yes
Specific Storage		Yes			
Compressibility	Yes				
Storativity		Yes			

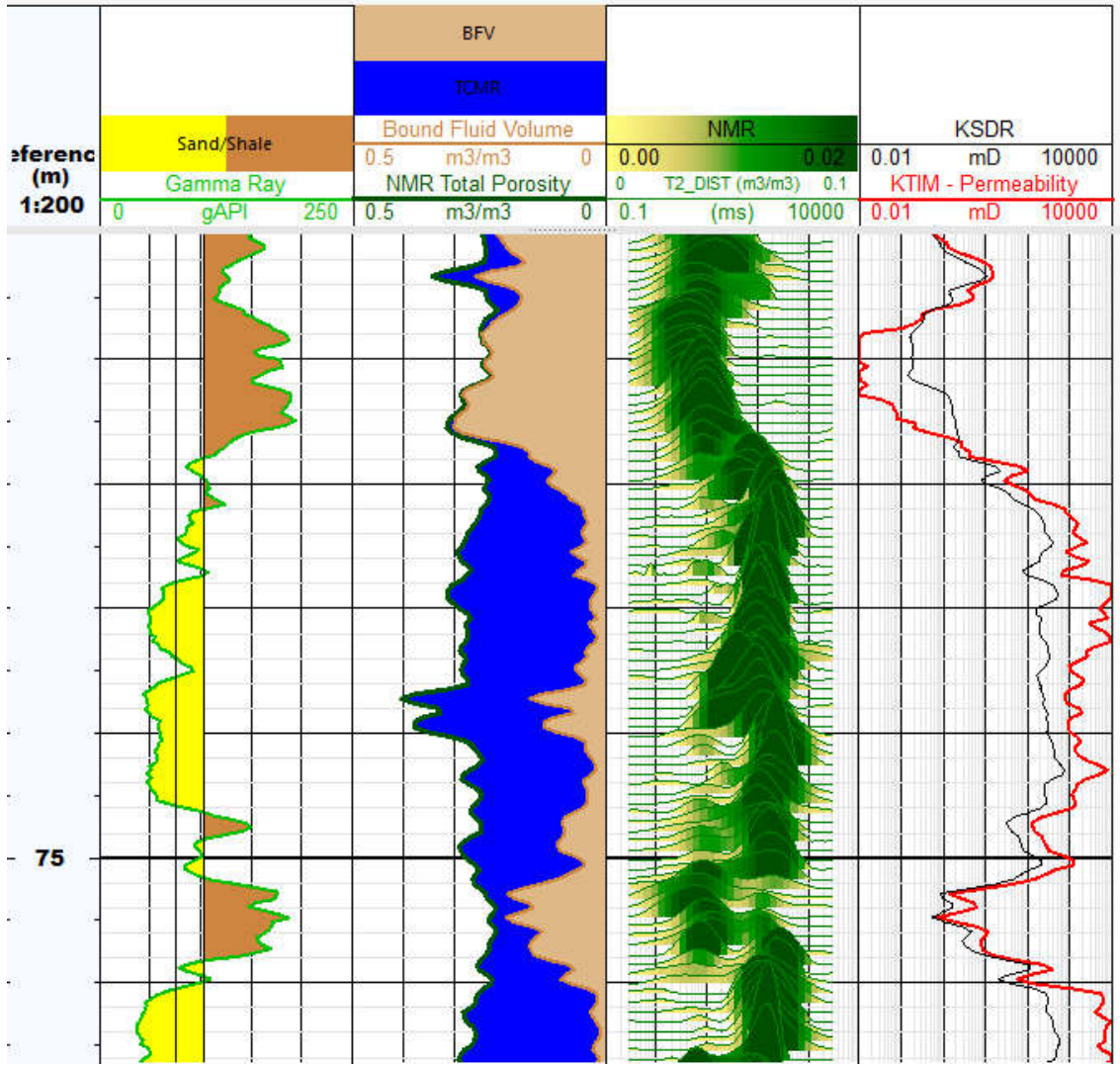
Applications

Metrology	Hydro	Resource Def	Geotech
• Dry bulk density • Dry weight matrix density • Materials handling and flow properties • Ore Blending – moisture content for crushers • Transport moisture limit	• Aquifer / aquitard characterisation • Replace pump / packer testing • Improve pump sizing and placement • Size screens • Assess water re-injection targets	• Clay typing • Multi-mineral models • Improved subsurface models • Grain size distribution	• Pit slope stability • Fluid and moisture content • Open and Closed fracture identification • Tailings Dams

Basic BMR Log

Shallow sandstone aquifer

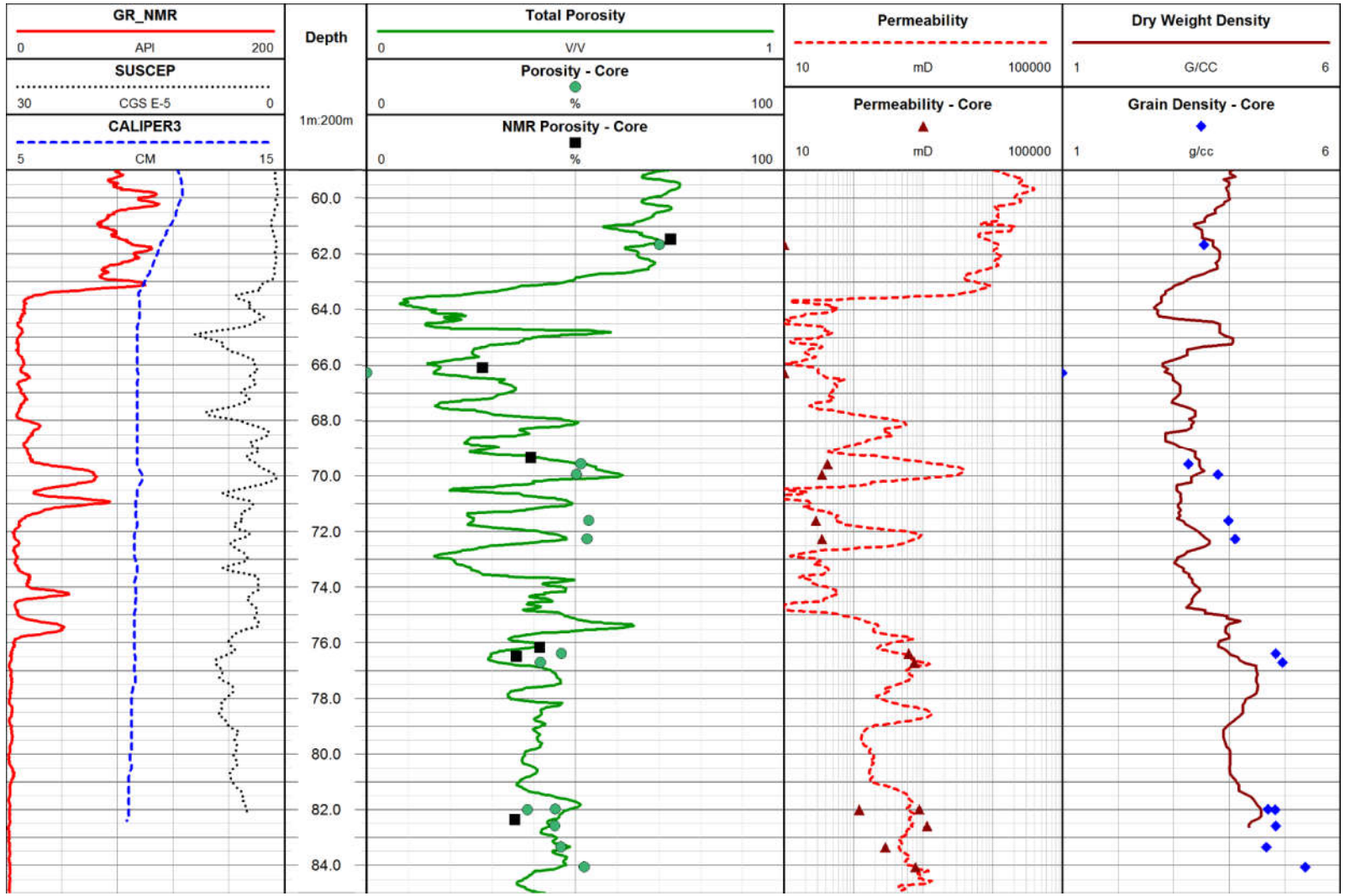
- NMR data is inverted to give a continuous T2 distribution for the logged interval
- T2 distribution readily interrogated to derive:
  - Total Porosity
  - Bound Fluid (specific retention)
  - Free Fluid (specific yield)
  - Permeability (hydraulic conductivity)
- Track 3 is the NMR T2 distribution, which represents a pore size distribution (small pores to the left, large pores to the right)



BMR in Banded Iron Formation (BIF)

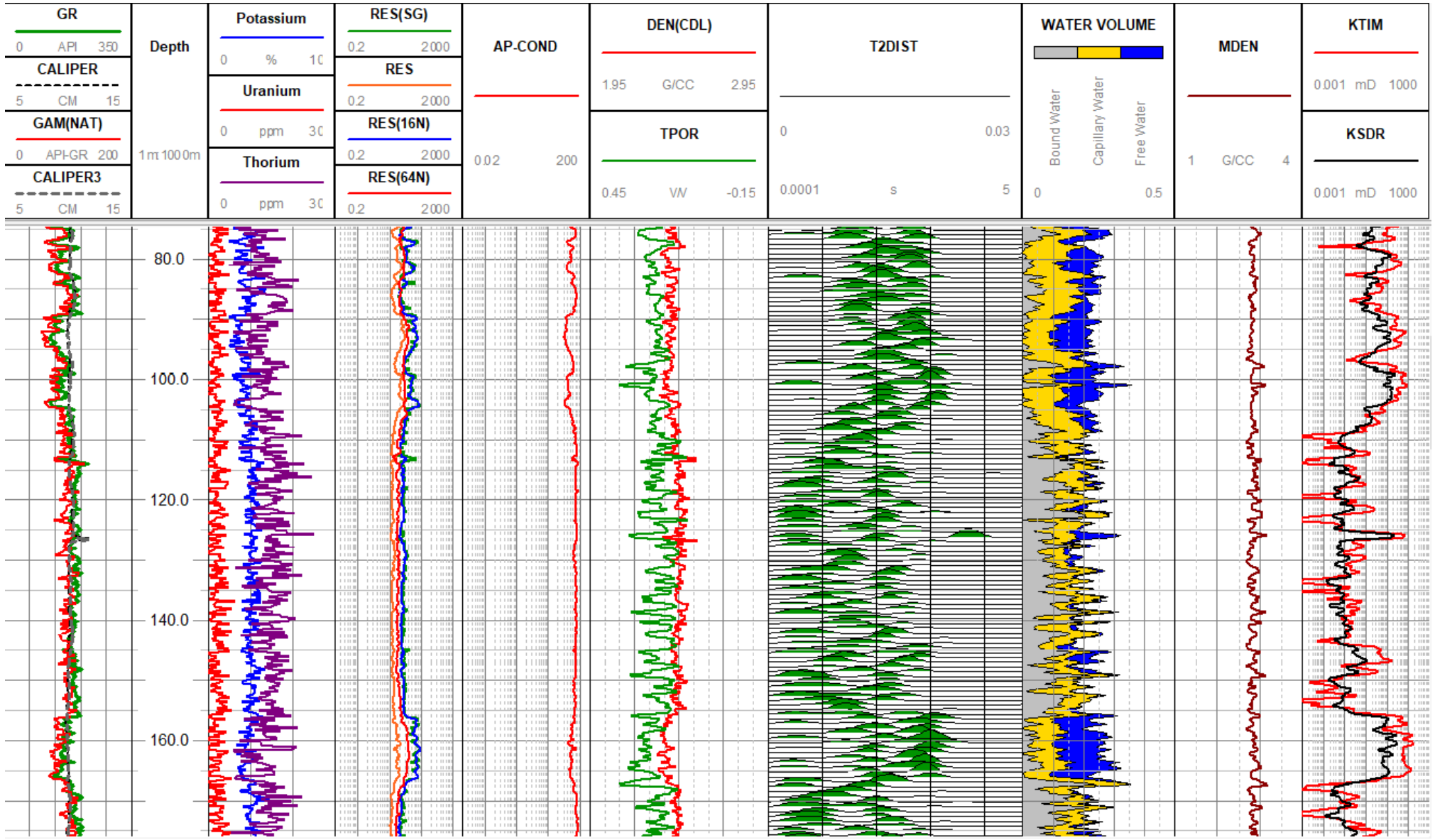
BIF BMR Logs

- BMR has been extensively tested in BIF formations with hundreds of logs performed
- This data was validated using core plugs measured in the laboratory



Case History

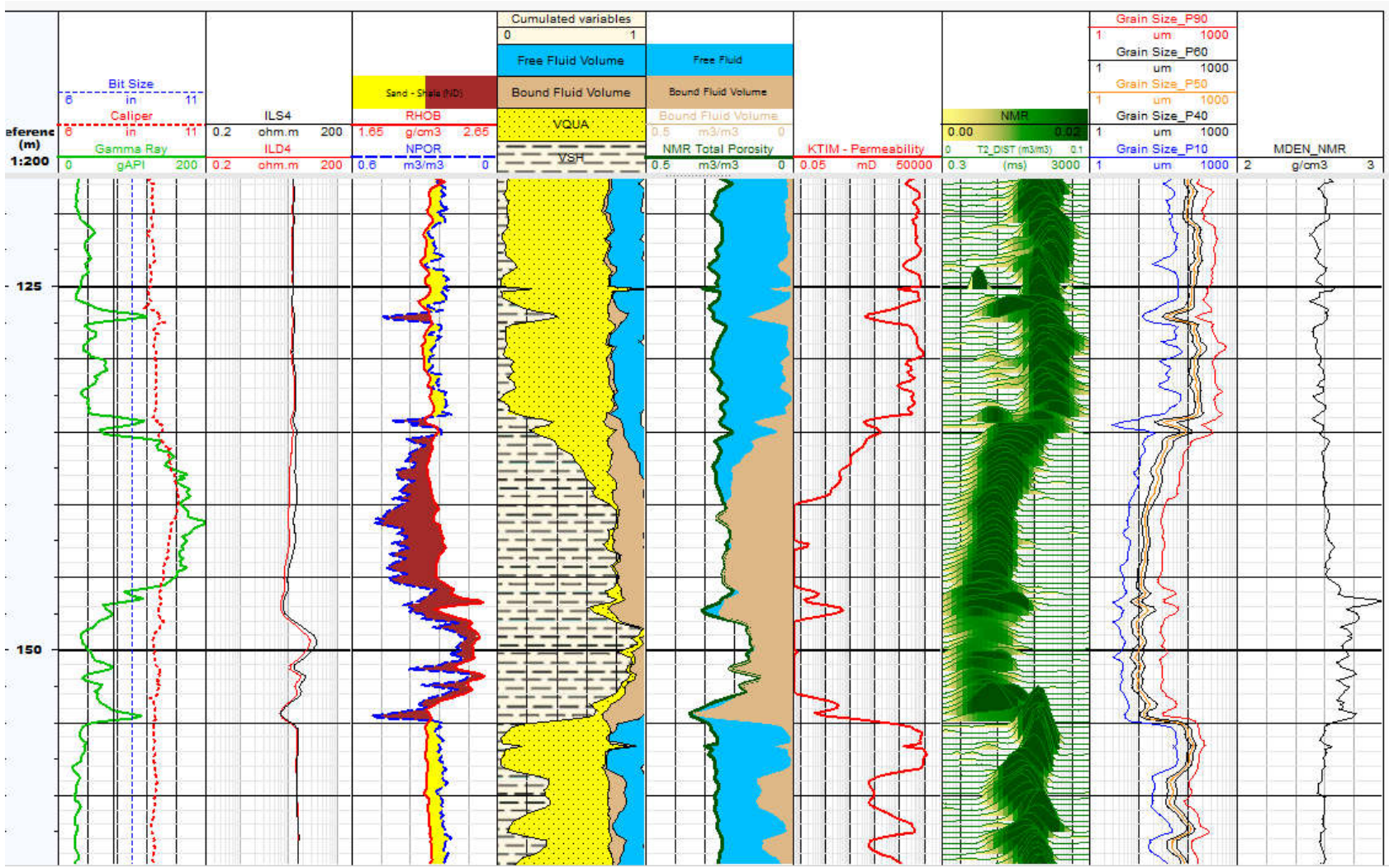
BMR in Carbonates



BMR Advanced Interpretation

Aquifer BMR Logs

- NMR can be integrated with conventional geophysical logs to expand on formation evaluation
  - Water conductivity/ salinity from BMR and resistivity
  - Matrix density from BMR and density
  - Grain size distribution with BMR and core
  - Multi-mineral lithological prediction with BMR and basic logs



De-watering

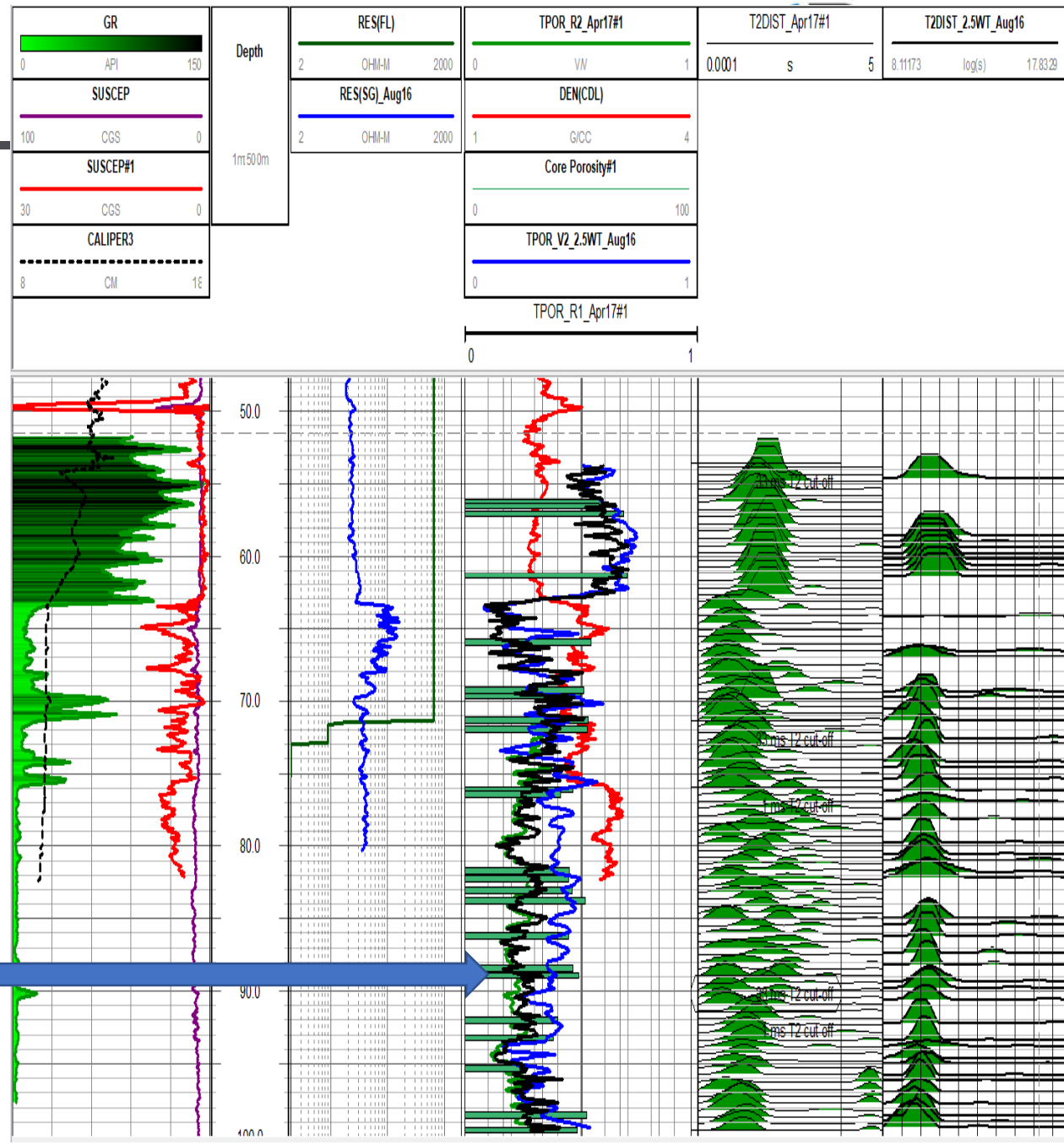
Logged in August 2016

Re-logged in April 2017, with repeat

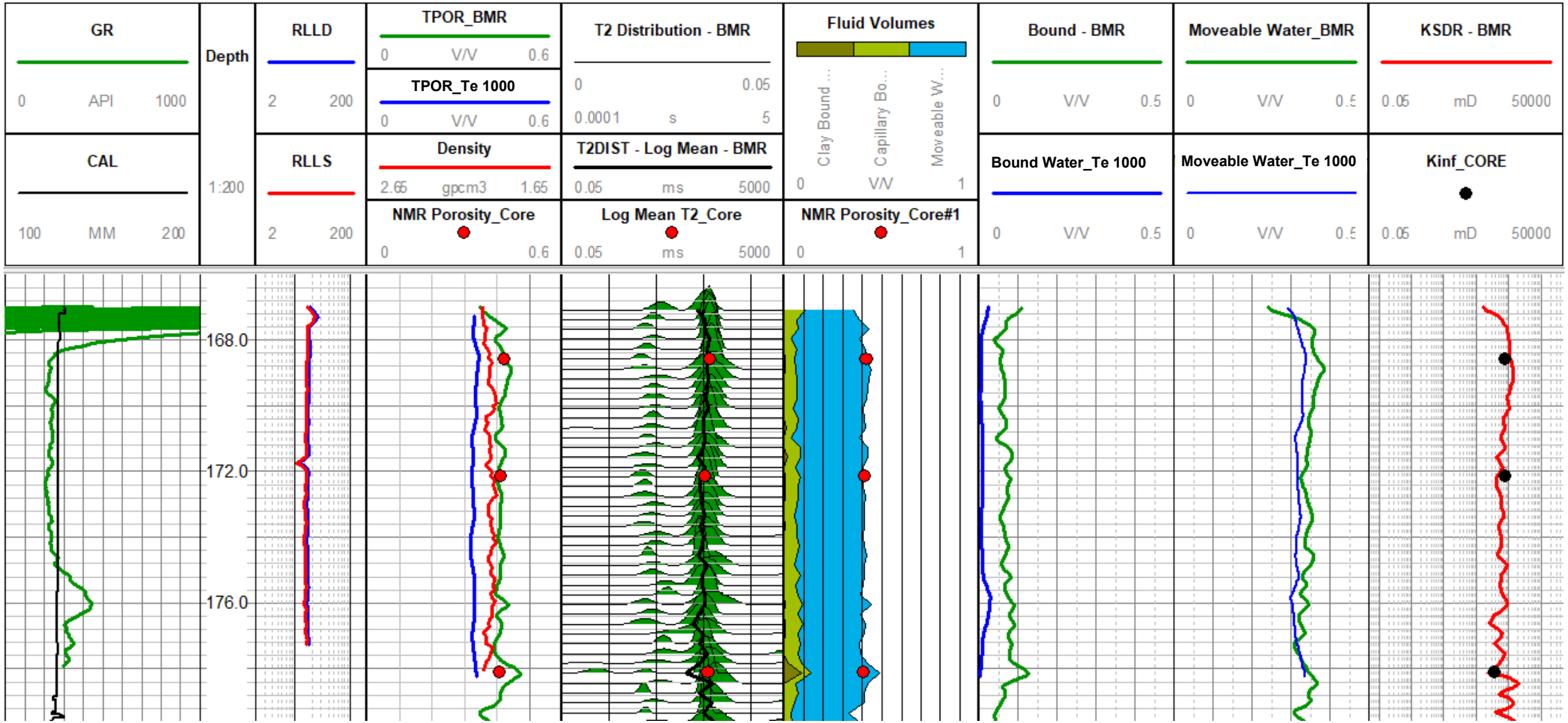
The T2 Dist shows a dewatering pattern – as the pore pressure is reduced, the pores expand and the T2Dist will spread out (lower S/V effects).

NOTE: preferential dewatering of higher permeability zones

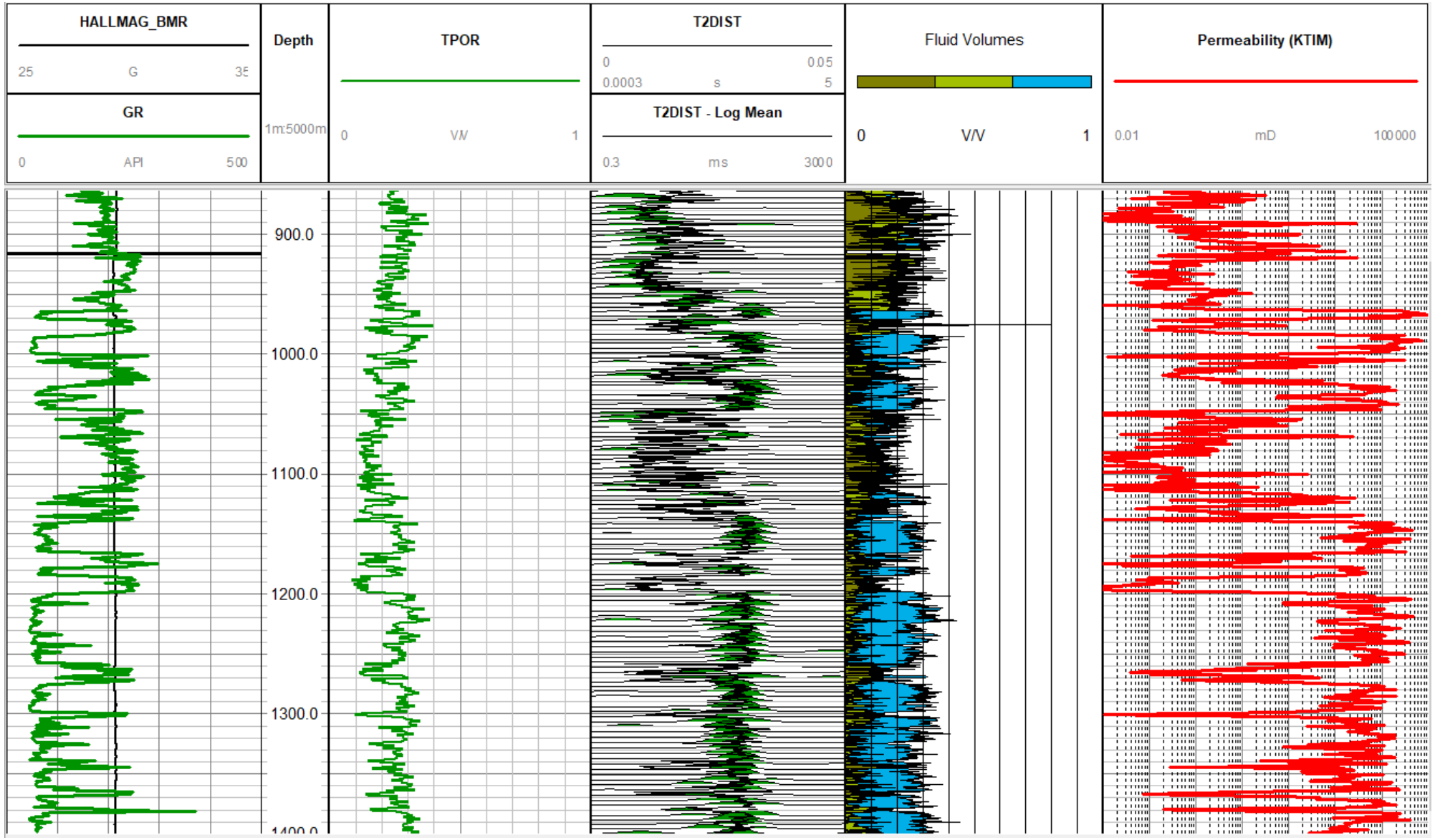
Quantification of de-watering …



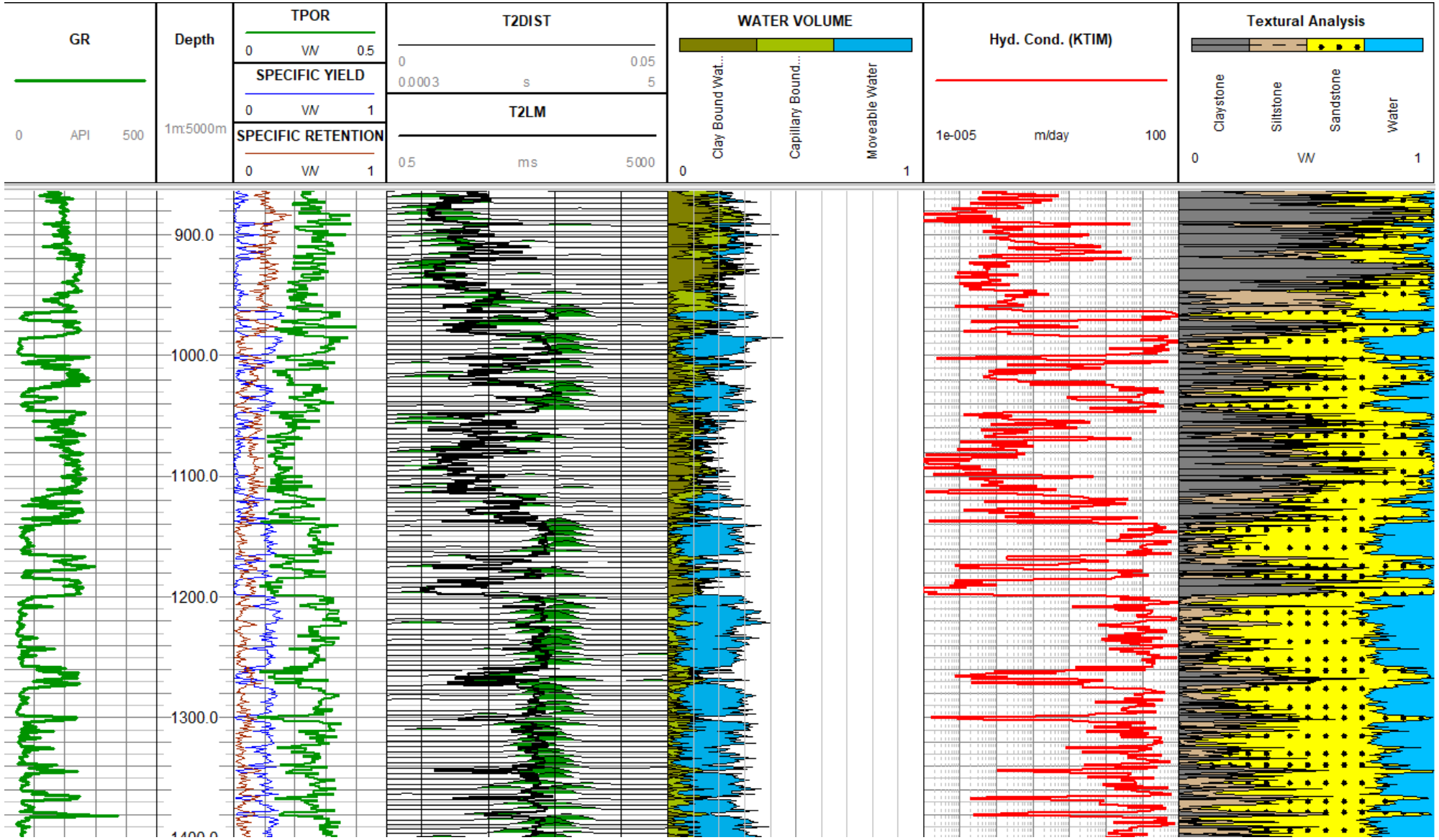
Comparison to Core data



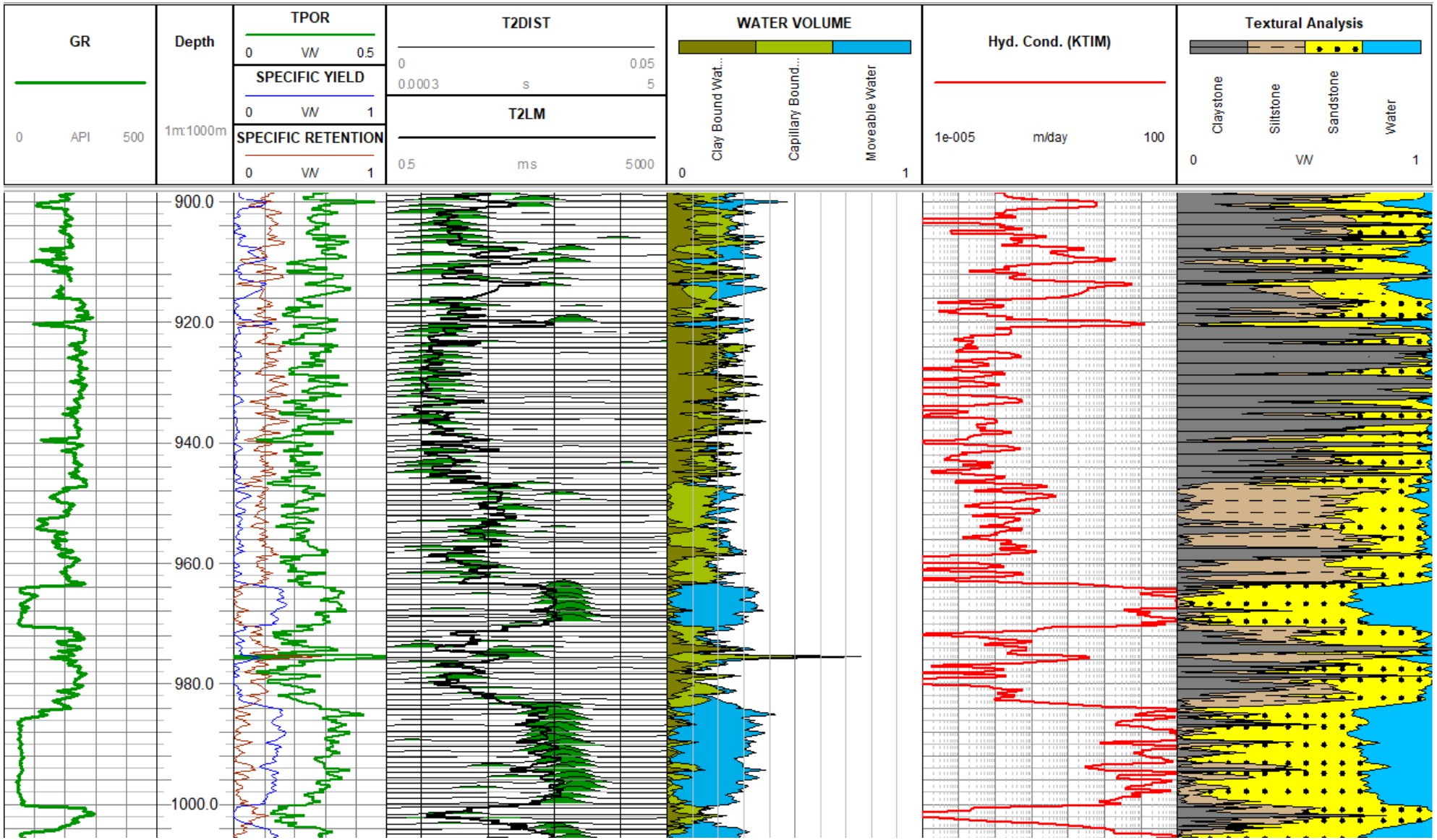
Water Corporation



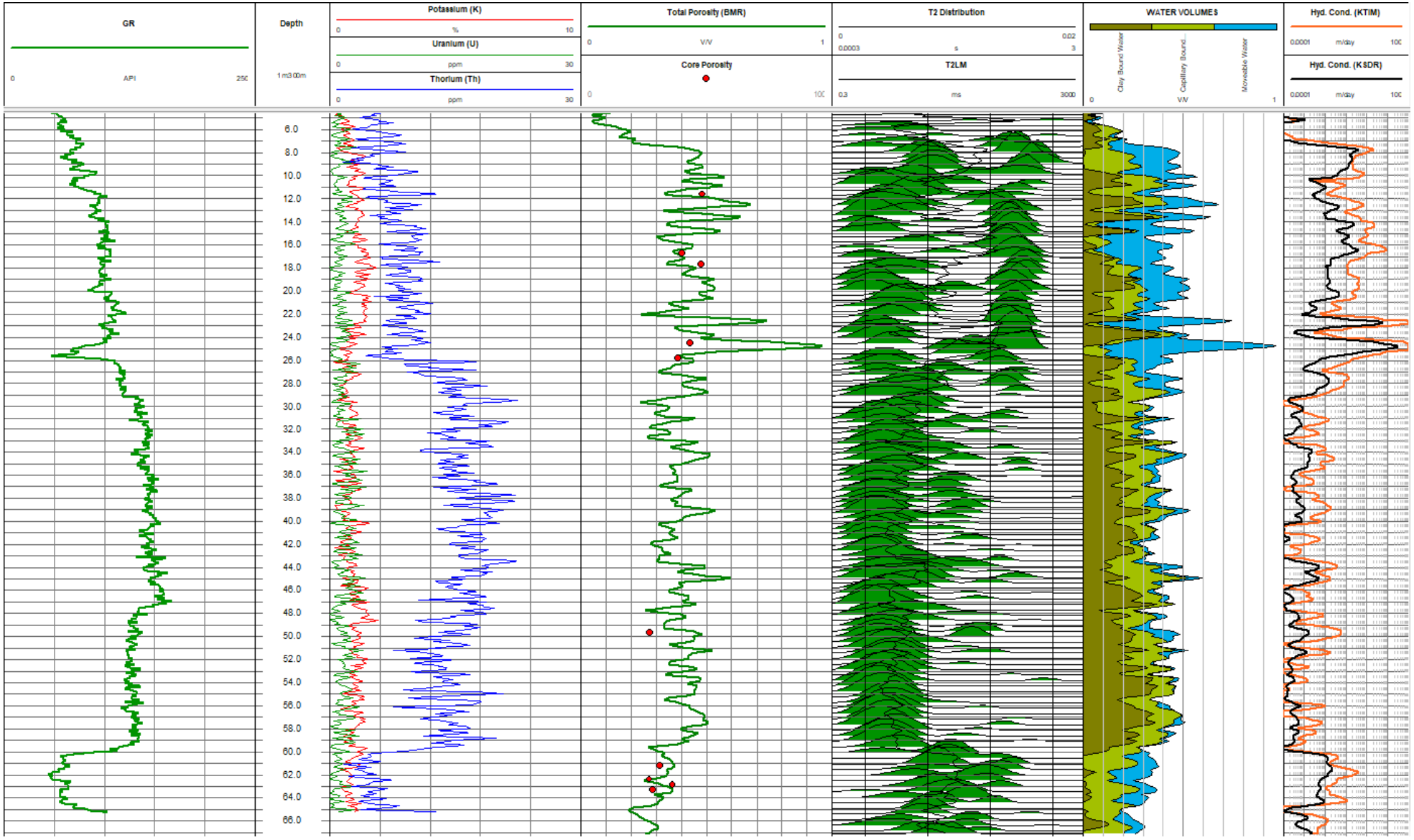
Water Corporation



Water Corporation



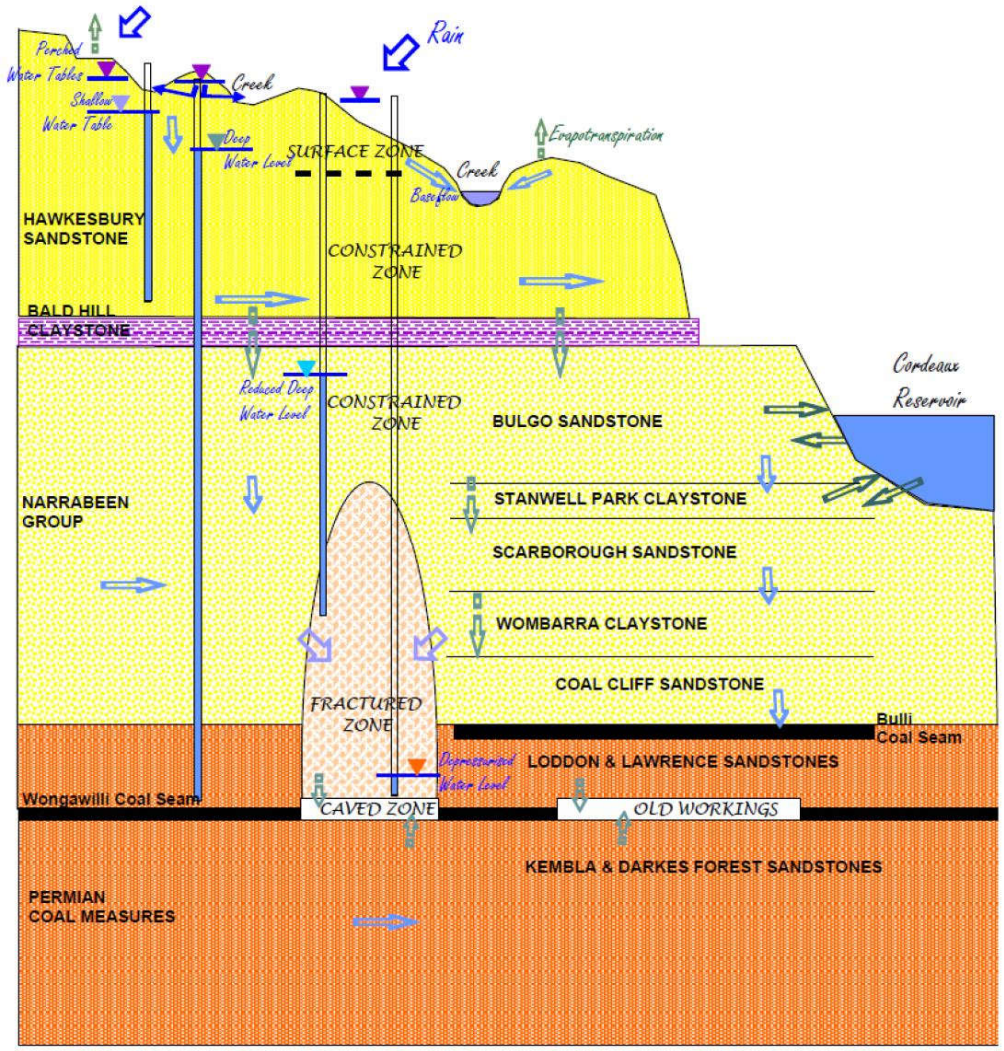
Potash



Study Area Geology and Hydrogeology

Two main groundwater systems exist in the area, a shallow system and a deep system separated by a major regional aquiclude

The deep groundwater system includes the coal measures sequence targeted by mining operations

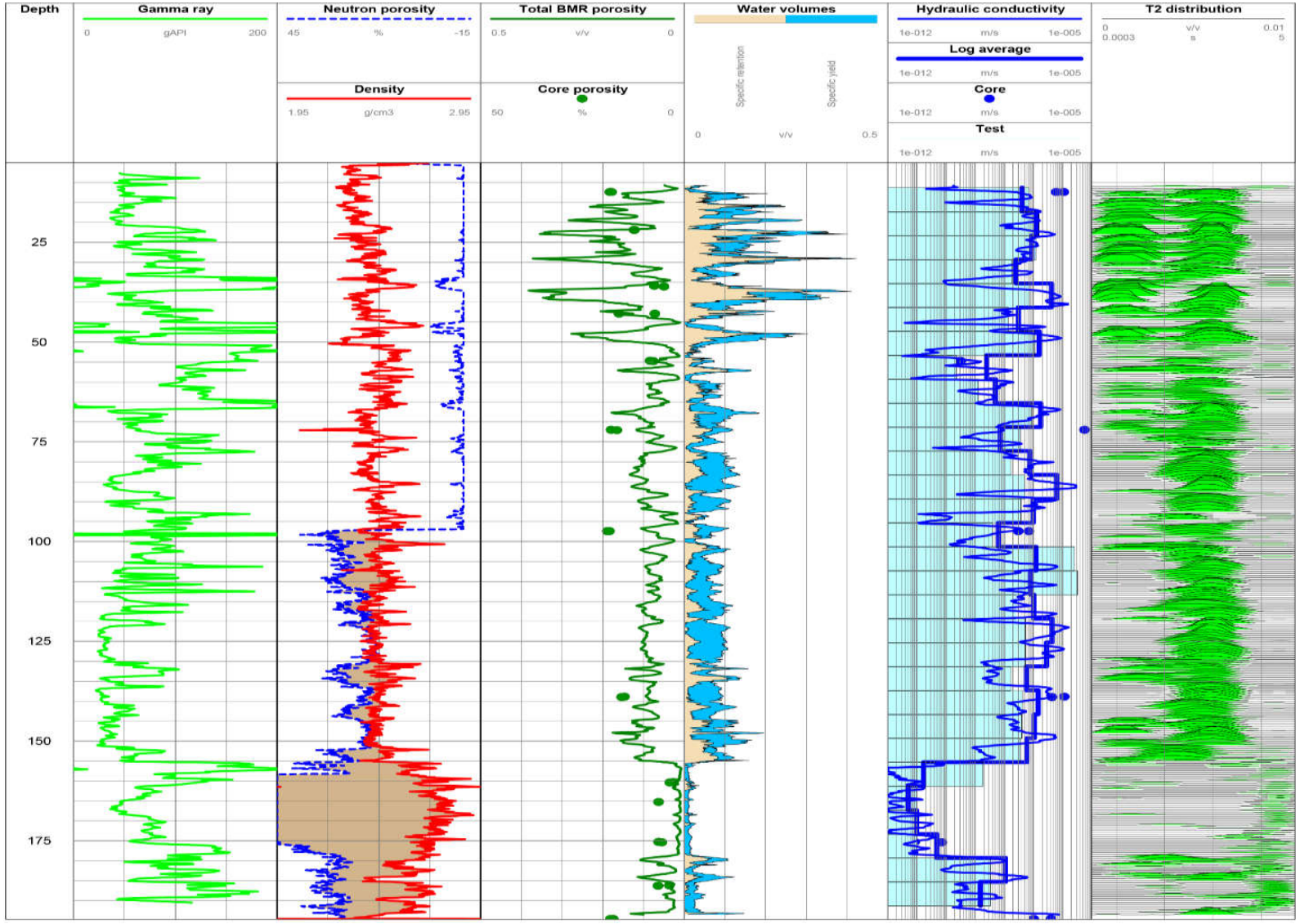


Source: Hydrosimulations 2015

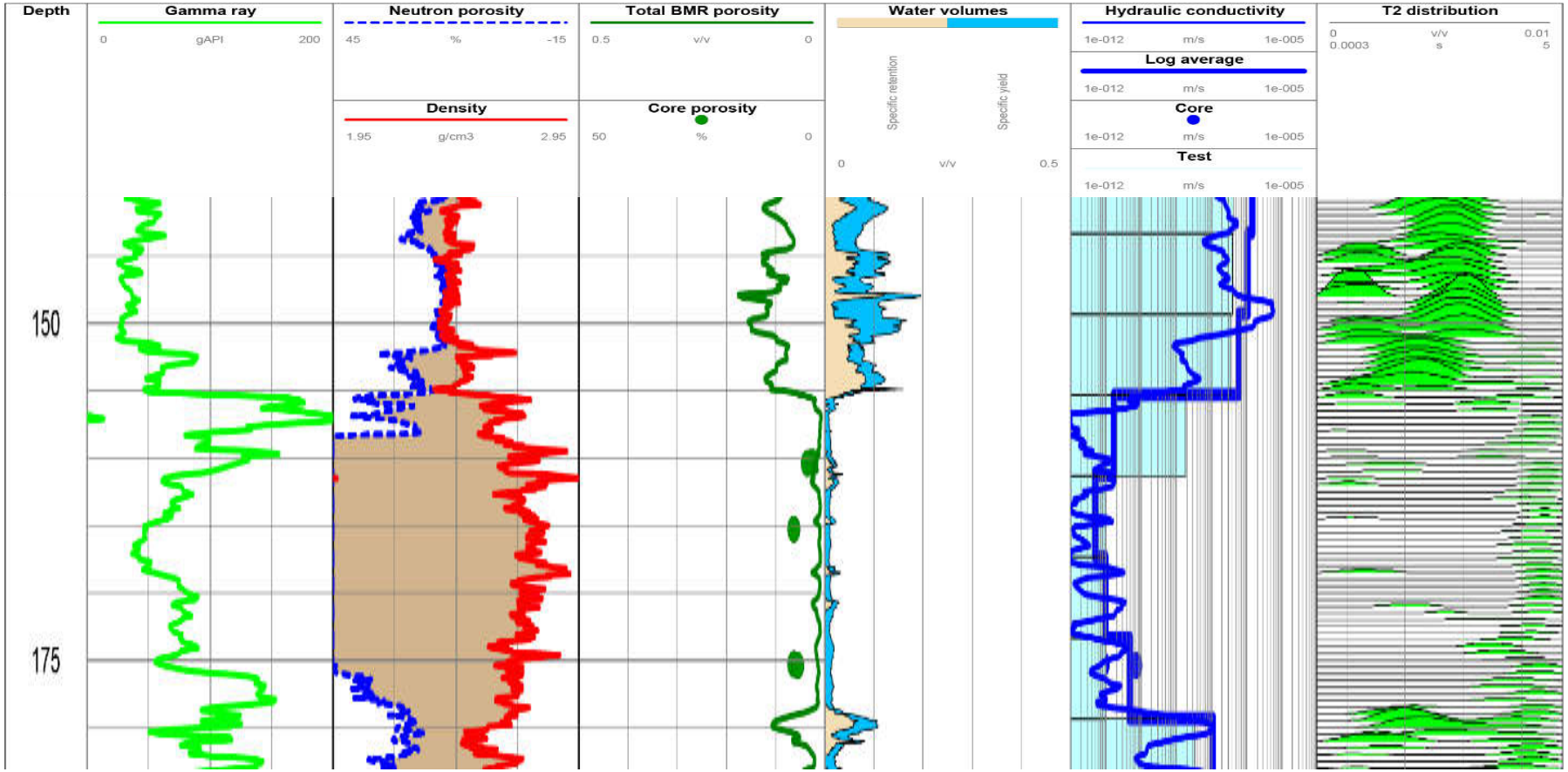
Study Data Sources

- **Core – storage and flow properties**
  - Discrete small-scale measurements
  - Weeks
- **Packer testing – flow properties**
  - Discrete interval measurements
  - Days
- **BMR logging – storage and flow properties**
  - Continuous small-scale measurements
  - Hours

Comparison of Results

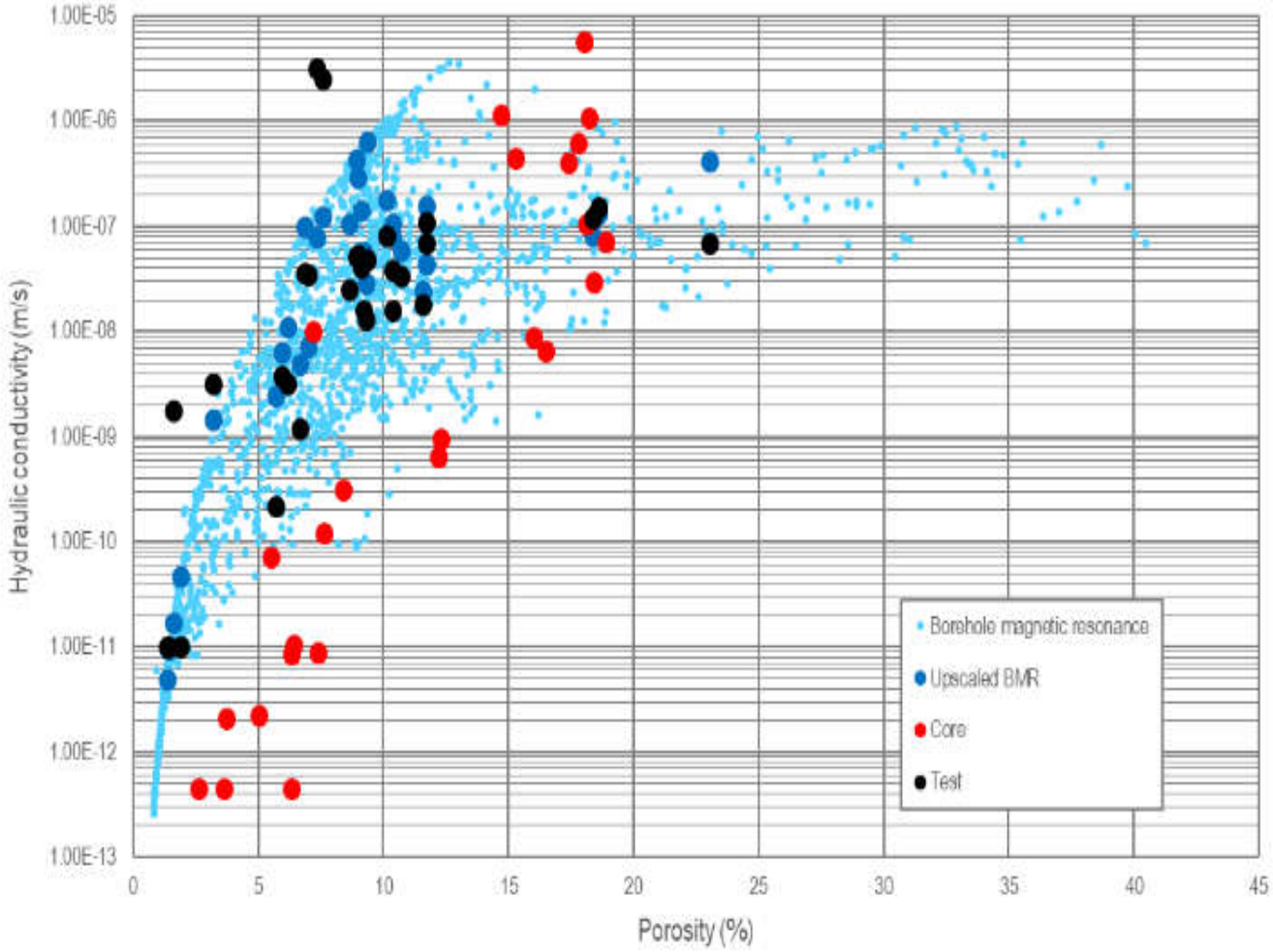


Fine Resolution



Conductivity v Porosity

Good correlation between pump test and upscaled BMR results



BMR v Packer Tests

	Horizontal hydraulic conductivity (m/s)	Vertical hydraulic conductivity (m/s)
Borehole magnetic resonance	1.38E-07	1.43E-10
Packer testing	2.81E-07	3.87E-09

Table 1: Comparison of borehole magnetic resonance and packer testing estimates of horizontal and vertical hydraulic conductivity.

Conclusions

- **BMR provides a unique framework for integration of other data**
- Sensitive to both storage (S_Y) and flow properties
- High-resolution but continuous coverage facilitates up-scaling
- Time-efficient and cost-effective
- **BMR improves the robustness and resolution of hydrogeological models**

Key Benefits of BMR Measurement

Measure

- Lithology Independent measure of TOTAL POROSITY
- Can divide total porosity into
  - Bound Water (Specific Retention)
  - Free Water (Specific Yield)

Calculate

- Can obtain continuous permeability / hydraulic conductivity log
- Grain size distribution

Cost Savings

- Reduces / replaces need for pump testing / packer tests
- Removes need for use of chemical sources (density / neutron)

Completely safe – no chemical sources, no radiation, no worries…