Value of Logging While Drilling Data

Examples from Gas Fields

Society of Petroleum Engineers

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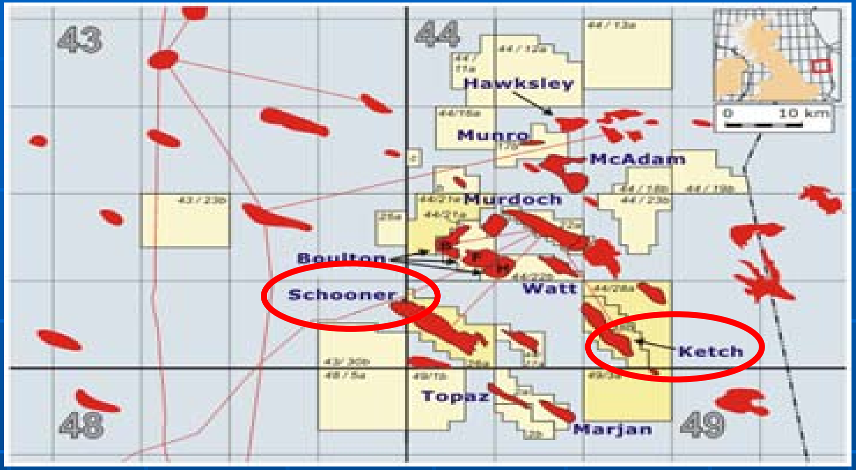
Value of LWD Data

- Examples of…..
  - Fracture Identification, density and orientation
  - Formation Pressure
    - Compartments
    - Depletion
    - Pore Pressure
  - Well Placement
    - LWD sensors to stay in the reservoir

What is the Formation Pressure?

- Important in Gas Fields.
  - Gradient
  - Absolute Pressure
  - Depletion
  - Injection
  - Compartments
  - Connectivity

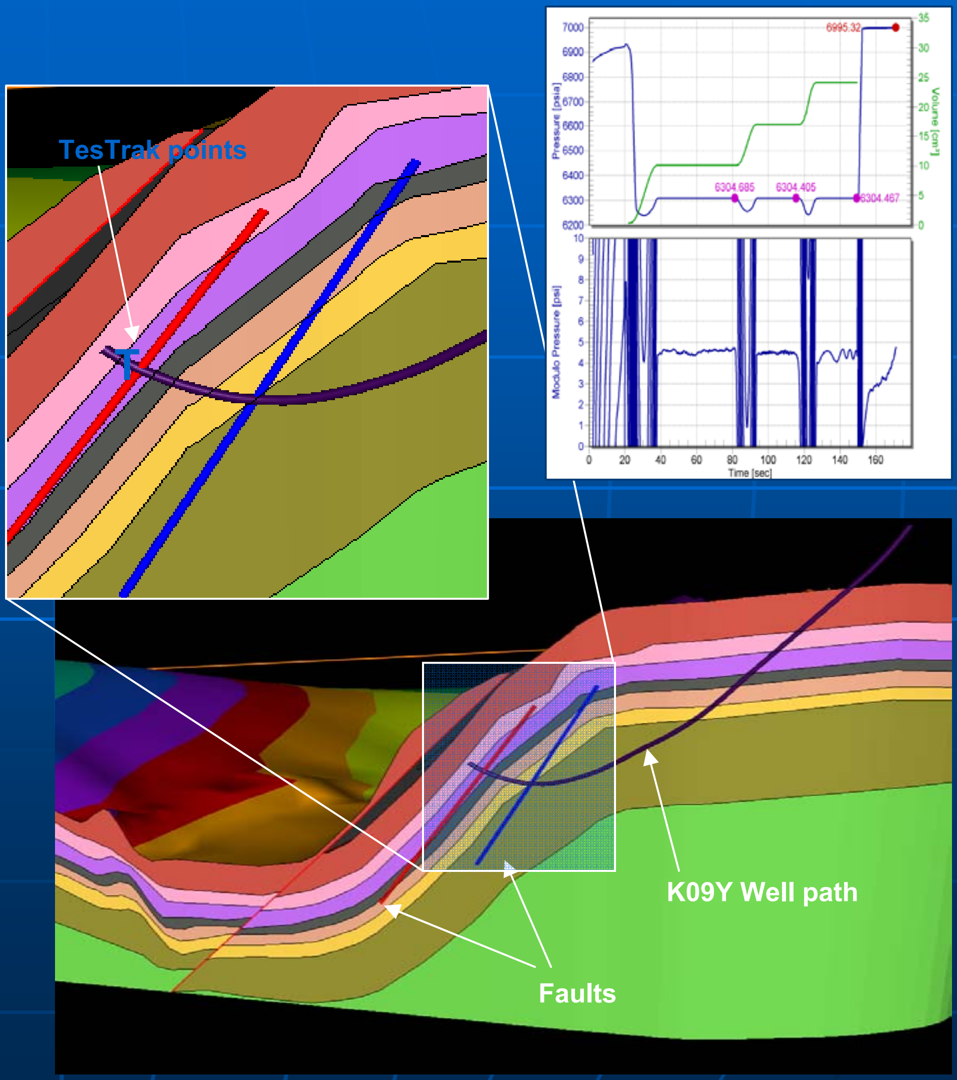
Formation Pressure
Case History – Southern North Sea



- The South North Sea (SNS) contains dry gas-charged Carboniferous (Westphalian) age sandstones
- Stacked, multi-storey fluvial channel belts, encased in overbank shales
- Gas source are Carboniferous coal measures
- Sealed above by Zechstein evaporites
- Ketch and Schooner fields first gas production in 1997, depletion is expected

Formation Pressure Data- SNS

- ***Well Data***
  - Location: Southern North Sea
  - Date: May 2007
  - Hole Size: 6-in. from 14,650ft to 17,747ft
  - Well Type: Directional well building from 66° to 104°
  - Formation: Carboniferous Ketch and Cleaver Formation
- ***Objectives***
  - Complete directional build and hold the tangent through the boundary fault to explore the adjacent fault block
  - LWD used to obtain pressure data from selected sands, indicating if the sands were depleted or virgin
  - Obtain enough data to prove whether communication had occurred between the reservoir sections
  - 4¾-in. Motor and LWD used
- ***Results***
  - Successful tests were taken on three BHA runs in all the reservoir sections
  - delivered accurate formation pressure in real-time
  - Test results allowed good interpretation of the reservoir formation pressure structure in both fault blocks



* Reg. U.S. Pat & TM Office

Formation Pressure Testing in 6” hole

With real-time mobility measurements

Well Data

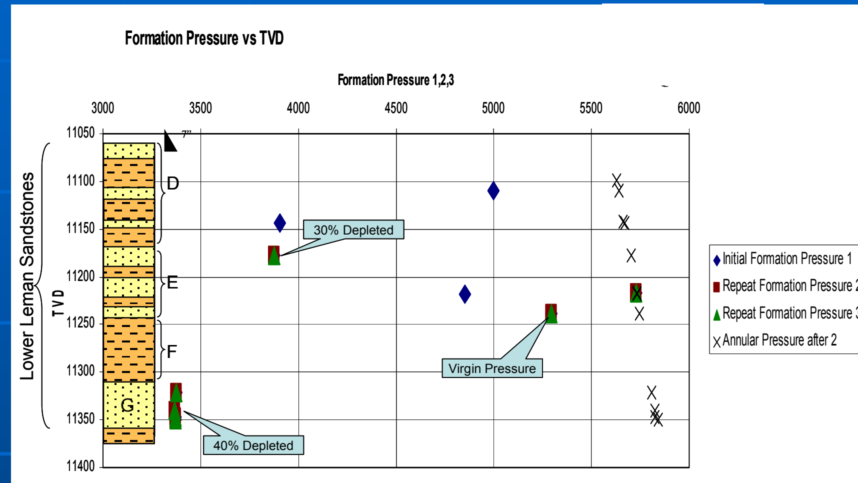
- Location: UK Southern North Sea
- Date: December 2005
- Hole Size: 6”
- Well Type: directional well with initial 3° DLS building to horizontal across a potentially depleted section
- Formation: Leman Sandstone and Carboniferous sequences

Objectives

- 1st Deployment of 4 ¾” TesTrak worldwide
- Obtain Formation Pressure and Mobility While Drilling
  - Measure formation pressure in Leman sands
  - Determine reservoir depletion
  - Provide mobility of the formation

Results

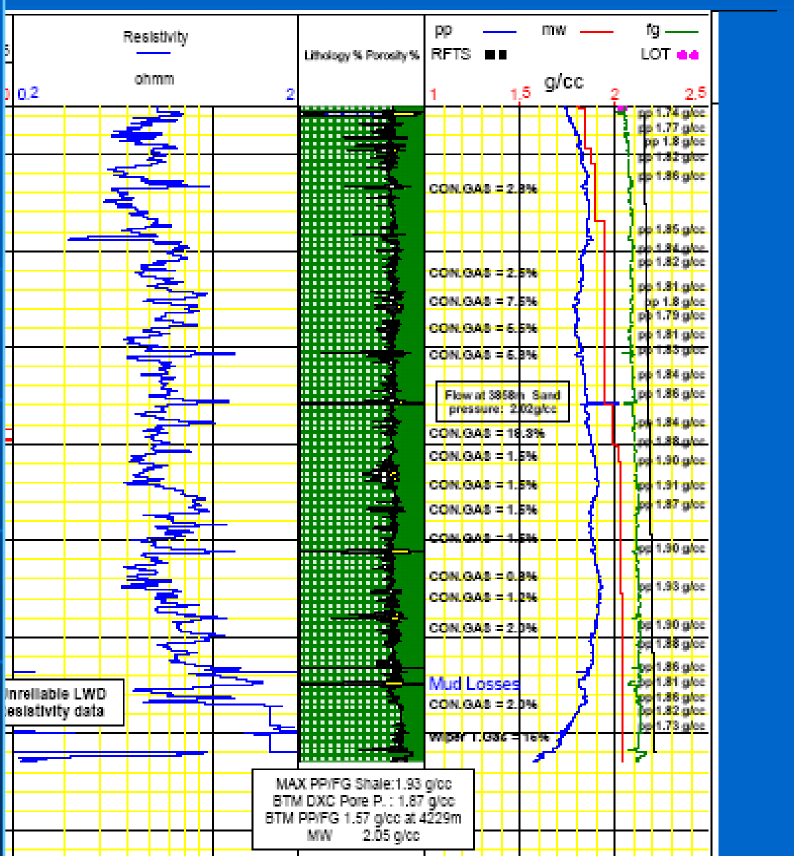
- All objectives achieved
- All tests taken over one run, 48.9 hr circulation
- 11 good seals (5 very tight tests ie. < 0.1 mD/cP) and 1 no seal
- All tests transmitted to surface in real time



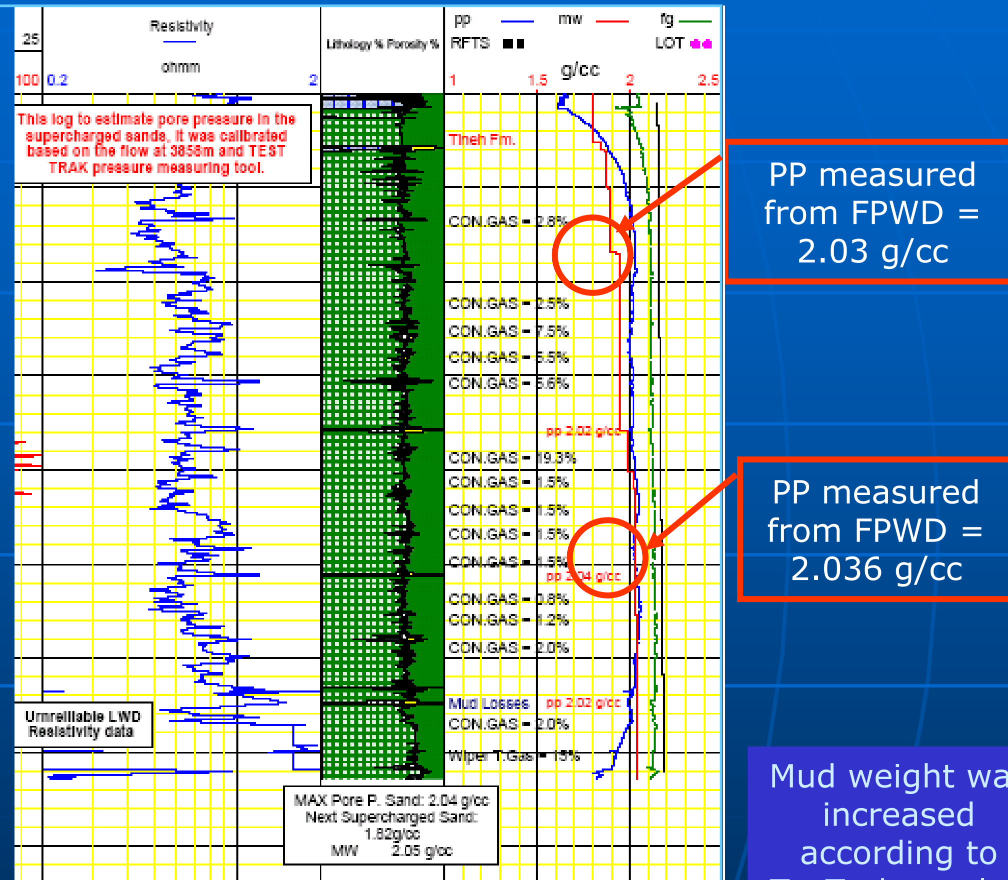
TesTrak Formation Pressure Test Depth		Initial Formation Pressure	Repeat Formation Pressure	Repeat Formation Pressure	Mobility
MD	TVD	1	2	3	Best Test
ft	ft	psia	psia	psia	mD/cp
15402.00	11347.12	3370.25	3370.02	3369.91	156.28
15341.00	11339.82	3368.02	3367.79	3367.67	149.94
15187.00	11321.20	3376.90	3376.44	3376.38	8.66
14773.00	11239.15	5296.91	5296.51	5296.34	6.58
14711.00	11217.79	4851.31	0.00	0.00	TIGHT
14707.00	11216.34	5730.36	5730.65	5729.60	No SEAL
14606.00	11178.02	3875.89	3875.72	3875.60	44.97
14518.00	11143.49	3904.19	0.00	0.00	TIGHT
14516.00	11142.70	631.33	0.00	0.00	TIGHT
14433.00	11110.12	4998.71	0.00	0.00	TIGHT
14405.00	11099.15	1148.20	0.00	0.00	TIGHT
15429.00	11350.29	3370.71	3370.99	3370.54	42.16

Calibrated Pore Pressure Prediction

Pore Pressure prediction re-calibration with LWD data



Before LWD calibration
Max PP shale 1.93 g/cc
Bottomhole PP 1.57 g/cc

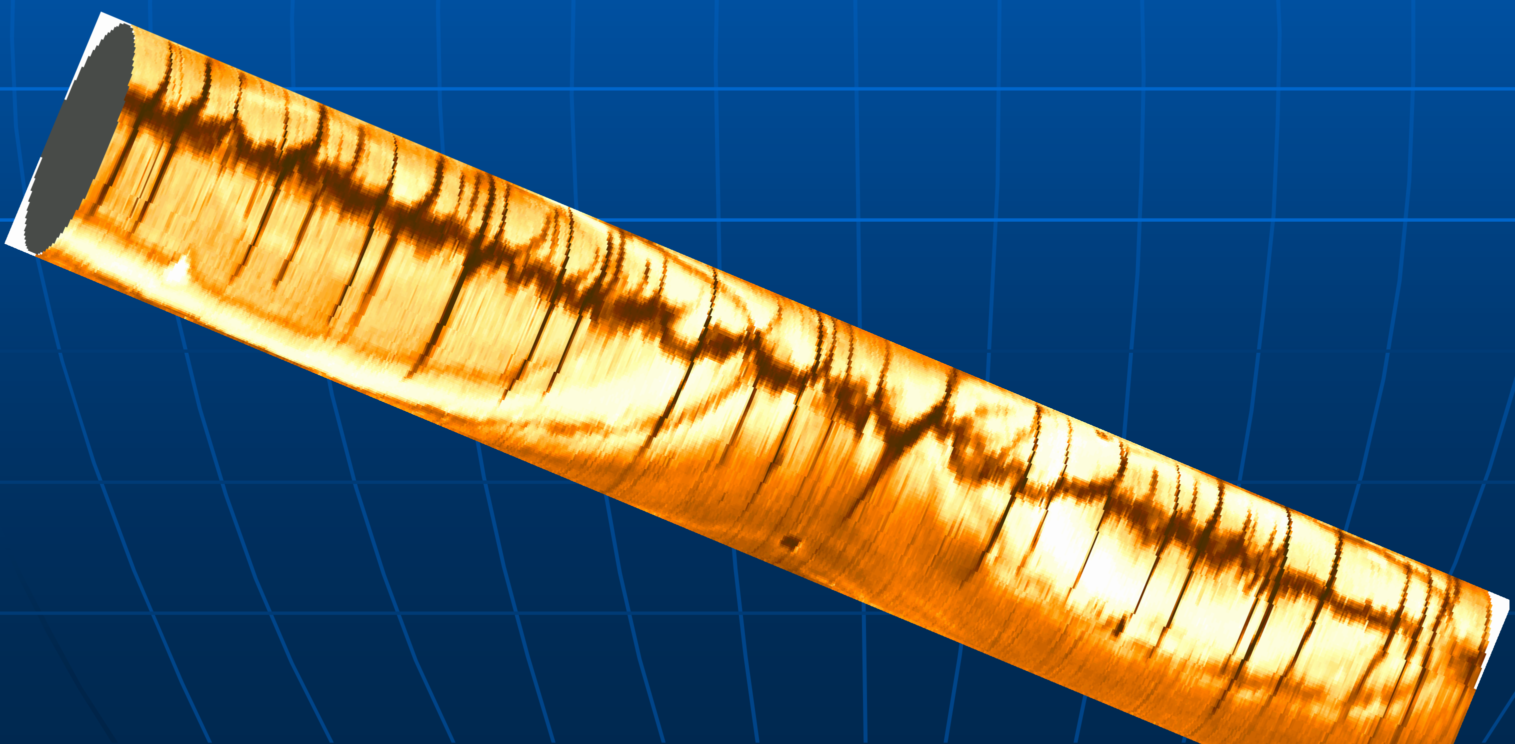


After LWD calibration
Max PP sand 2.04 g/cc
Bottomhole PP 1.82g/cc

Mud weight was increased according to TesTrak results. Successfully drilled ahead.

Fracture identification, Density and Orientation

- Resistivity imaging
- Shallow reading
- High Resolution



Fractured Shale Reservoir

Steeply dipping calcite-filled fractures

Images For perforations selection

Objective

- Identify reservoir variability in horizontal well
- Identify zones of hydraulic fracture networks
- Pick perforations to best stimulate untreated rock

Induced fractures

- Don’t normally transverse borehole
- Vertical well showed most induced fractures NE-SW

Conductive hydraulic fractures

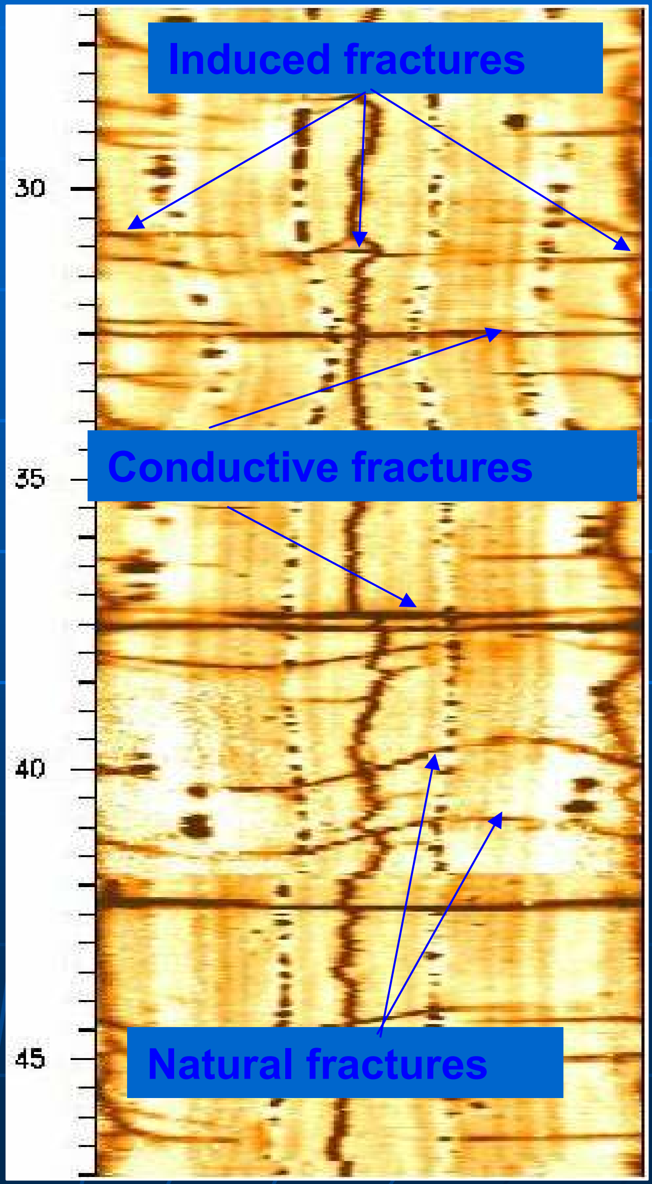
- Hydraulic fractures from offset well
- Transverse the entire bore hole

Natural fractures

- Activated by stimulation
- Different strike NW-SE

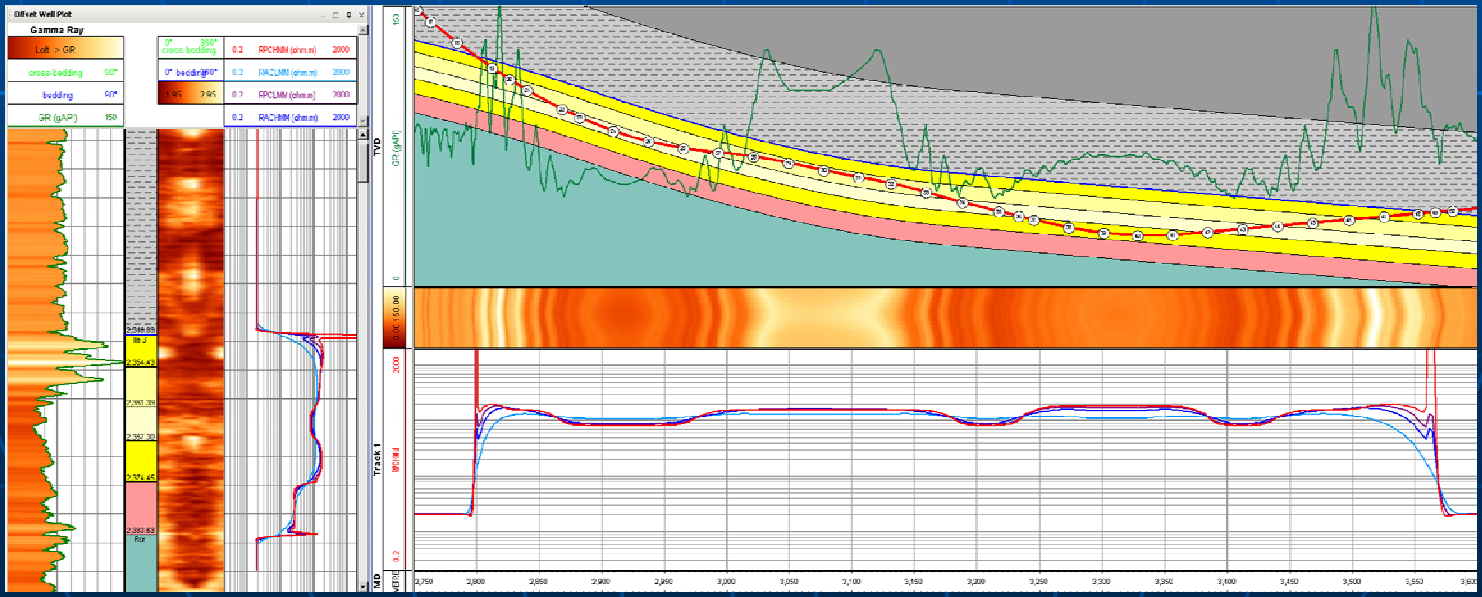
Conclusion

- Information used to pick perforations
- Stimulate intervals that have not been treated
- More effective stimulation dollars
- Increased production



Reservoir Navigation – putting the well in the optimal place!

- Staying fixed distance above water contact
- Staying within 1 m of top of reservoir
- Staying within sweeter zone of reservoir

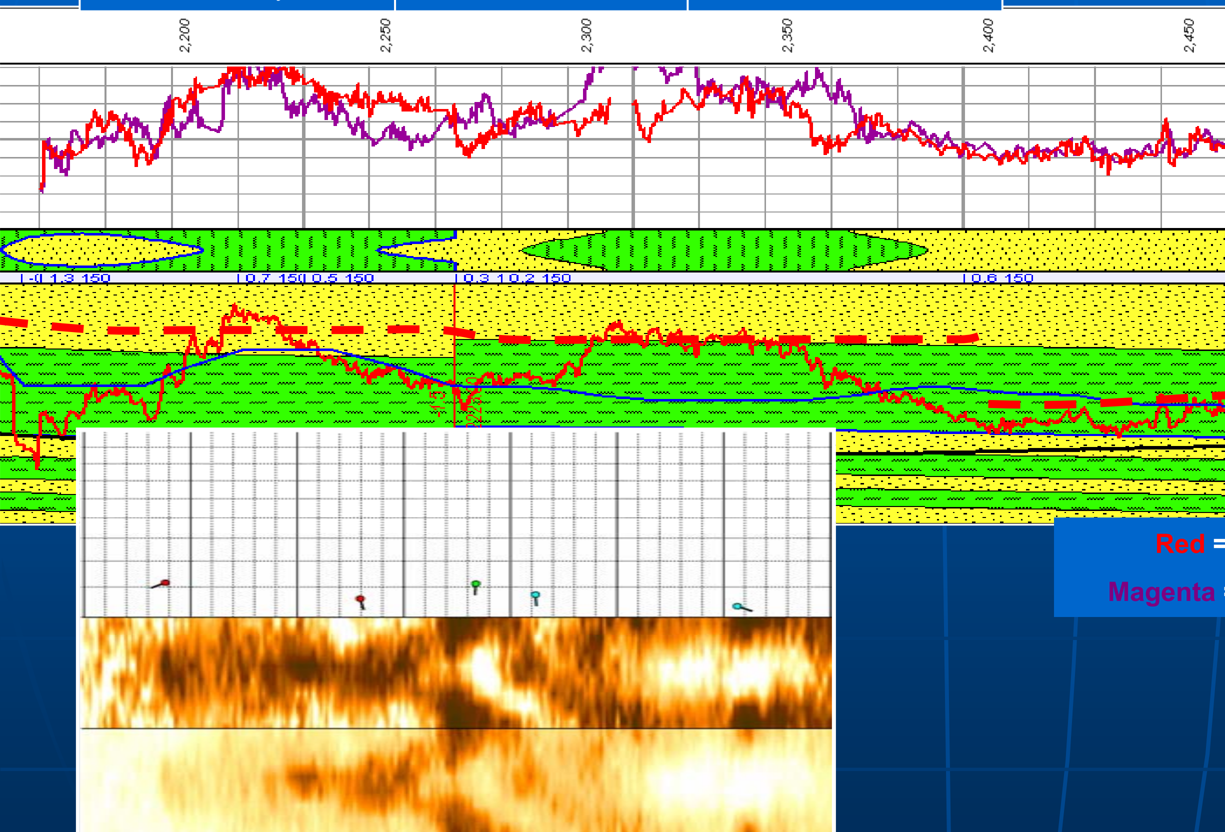


Simple Well Placement – gamma ray

Up gamma values indicates upper shale boundary

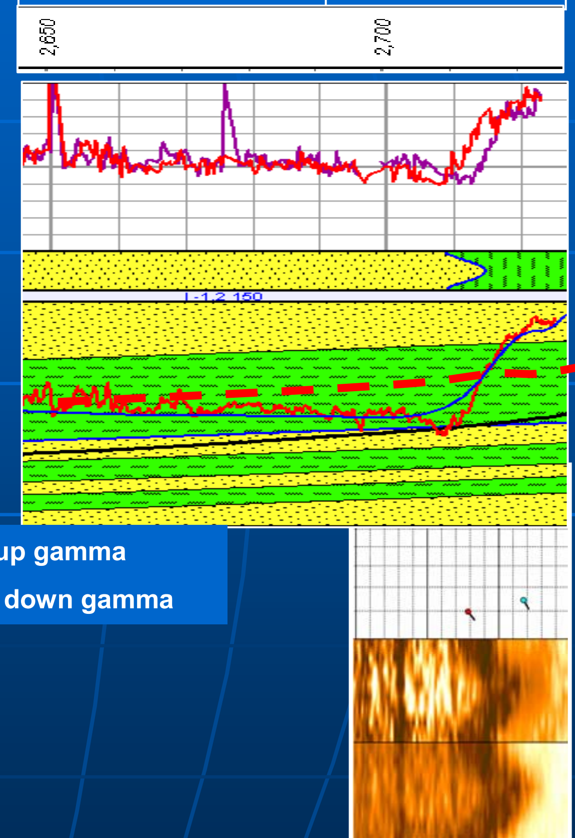
Sudden crossover of up/down gamma indicates small fault

Down gamma shows shale below wellpath so build inclination



Increase inclination to build to top of target sand

Confirm bed exit geometry with gamma



Red = up gamma

Magenta = down gamma

- Improved net-to-gross, with 88% of the horizontal section in the target sand
- Without up/down gamma different steering decisions would have been made, reducing NTG

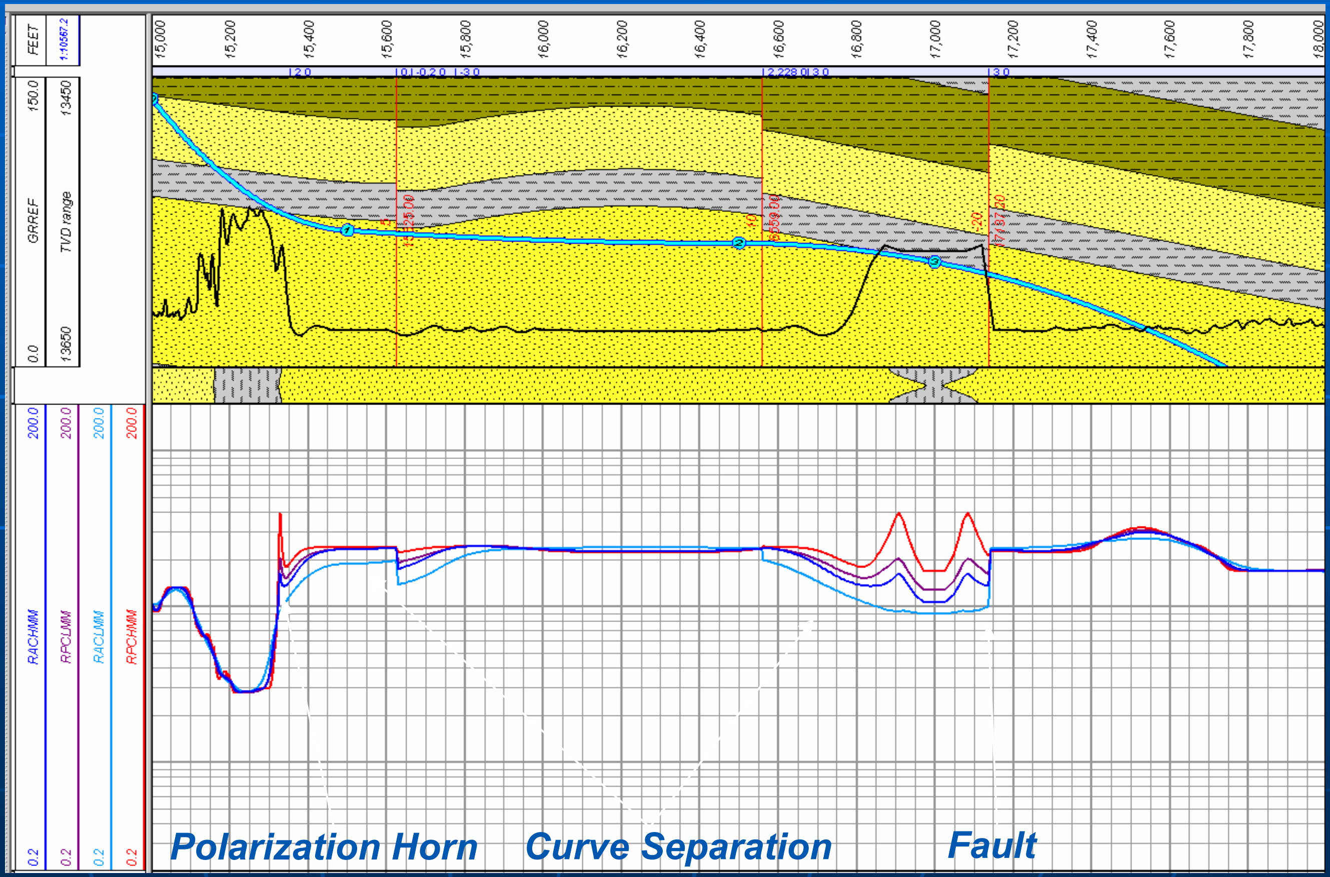
Propagation Resistivity
unique responses in horizontal wells

Responses

- **Curve Separation**
- **Resistivity Phase Dip**
- **Polarization Horns**

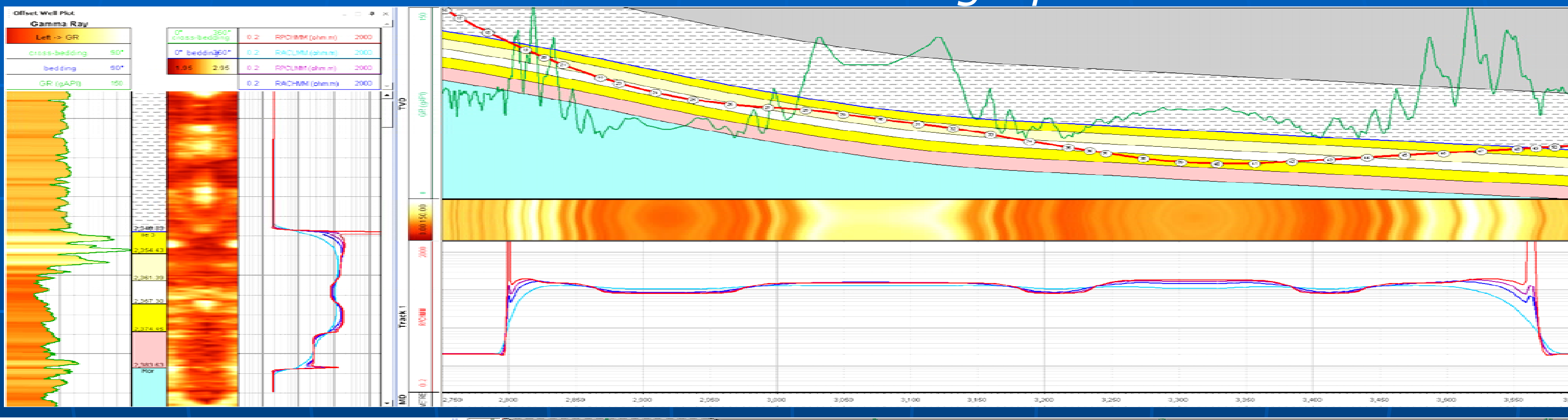
Other factors to consider:

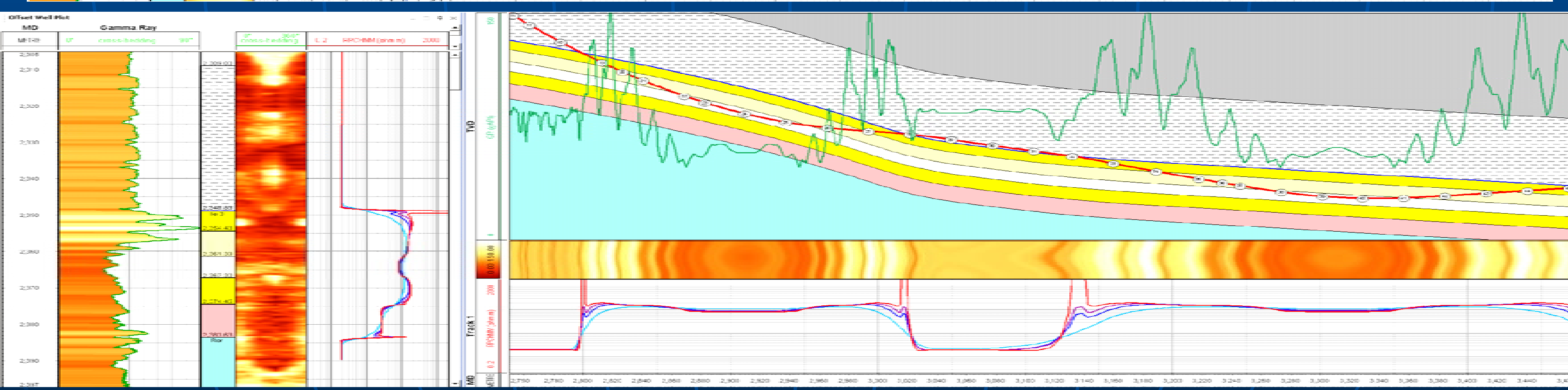
- **Anisotropy**
- **Dielectrics**
- **Borehole effects (skin effect)**
- **Eccentricity**
- **Invasion**
- **Thin**
- **beds**



Optimising Well Placement
Importance of modelling

- *Pre-well predictive response modelling*
  - *Offset data converted to True Stratigraphic Thickness*

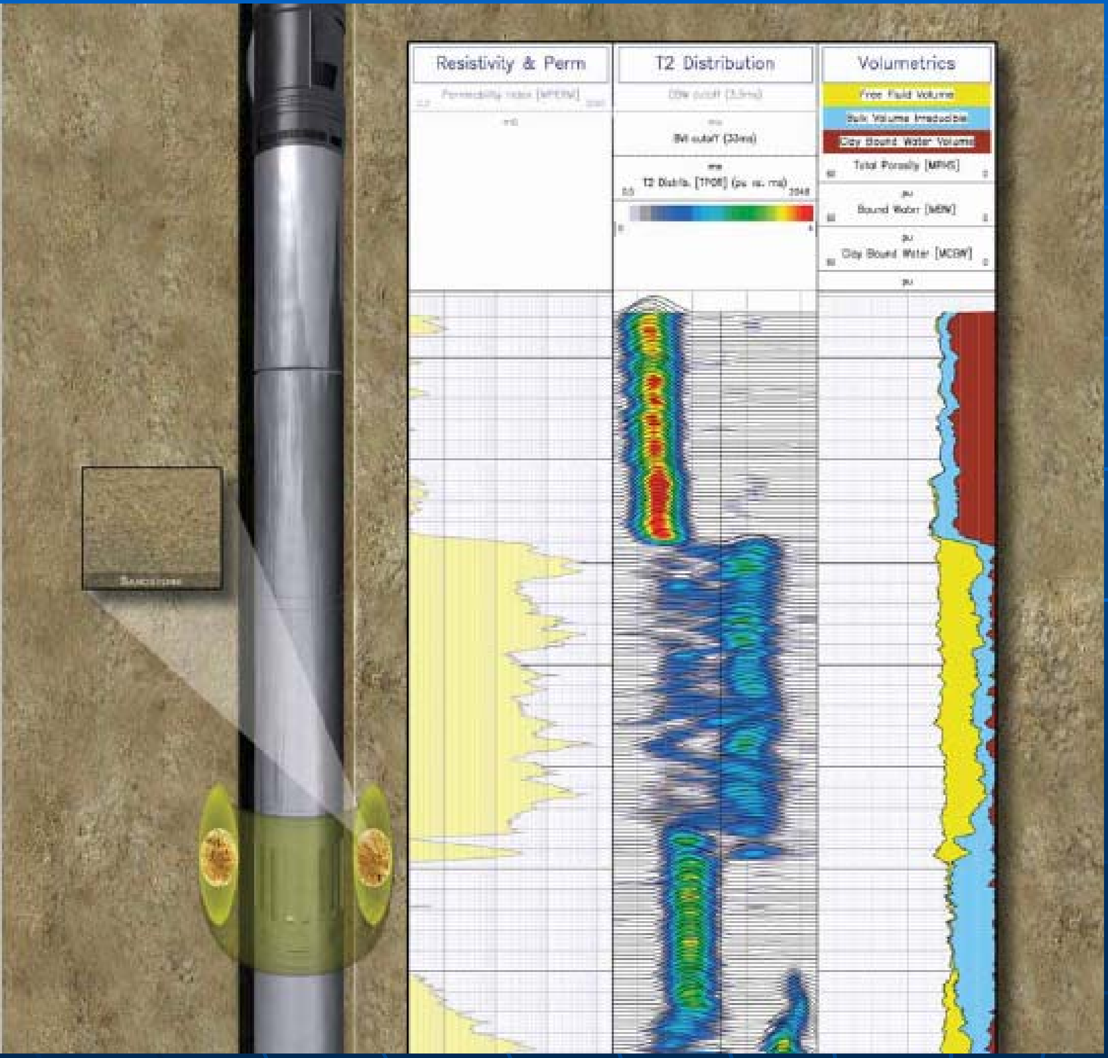




Optimising Well Placement

Model versus Reality

LWD Magnetic Resonance



- Direct measurement of fluid filled porosity (HI)
  - Independent of lithology
  - No radio-active source
- Estimate of movable fluid volume
- Permeability estimation
- Fluid typing
- Irreducible water saturation
- Clay/shale volume

Optimising Well Placement: Using Magnetic Resonance

Well Data

- Location: Italy, Po plain, Ripalta 61
- Hole Size: 8 ½" Highly Inclined
- Well Type: Development for gas storage
- Formation: Sand –silt – shale, depleted gas

Objectives

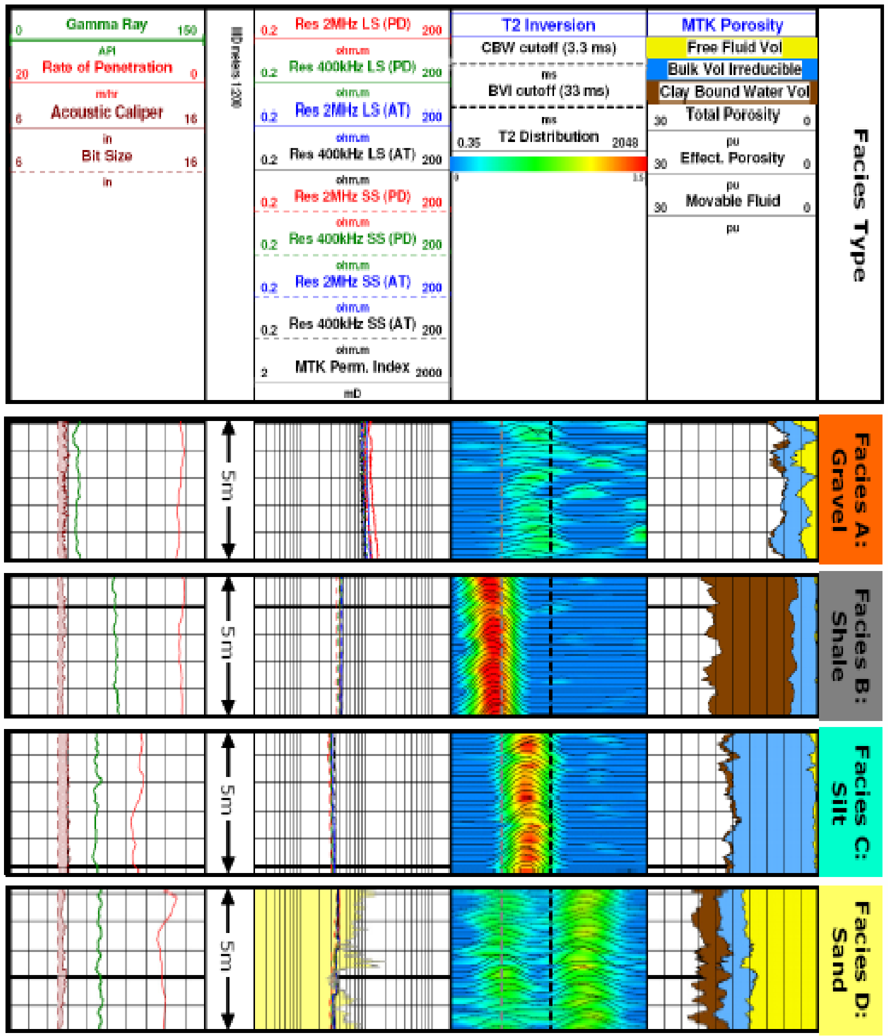
- Delineate permeable and non-permeable zones for optimum gas storage
- Characterize complex formation
  - ⇨ GR affected by mica
  - ⇨ Very poor resistivity contrast
  - ⇨ No DENSITY and POROSITY due to LIH risk

INTEQ Solution

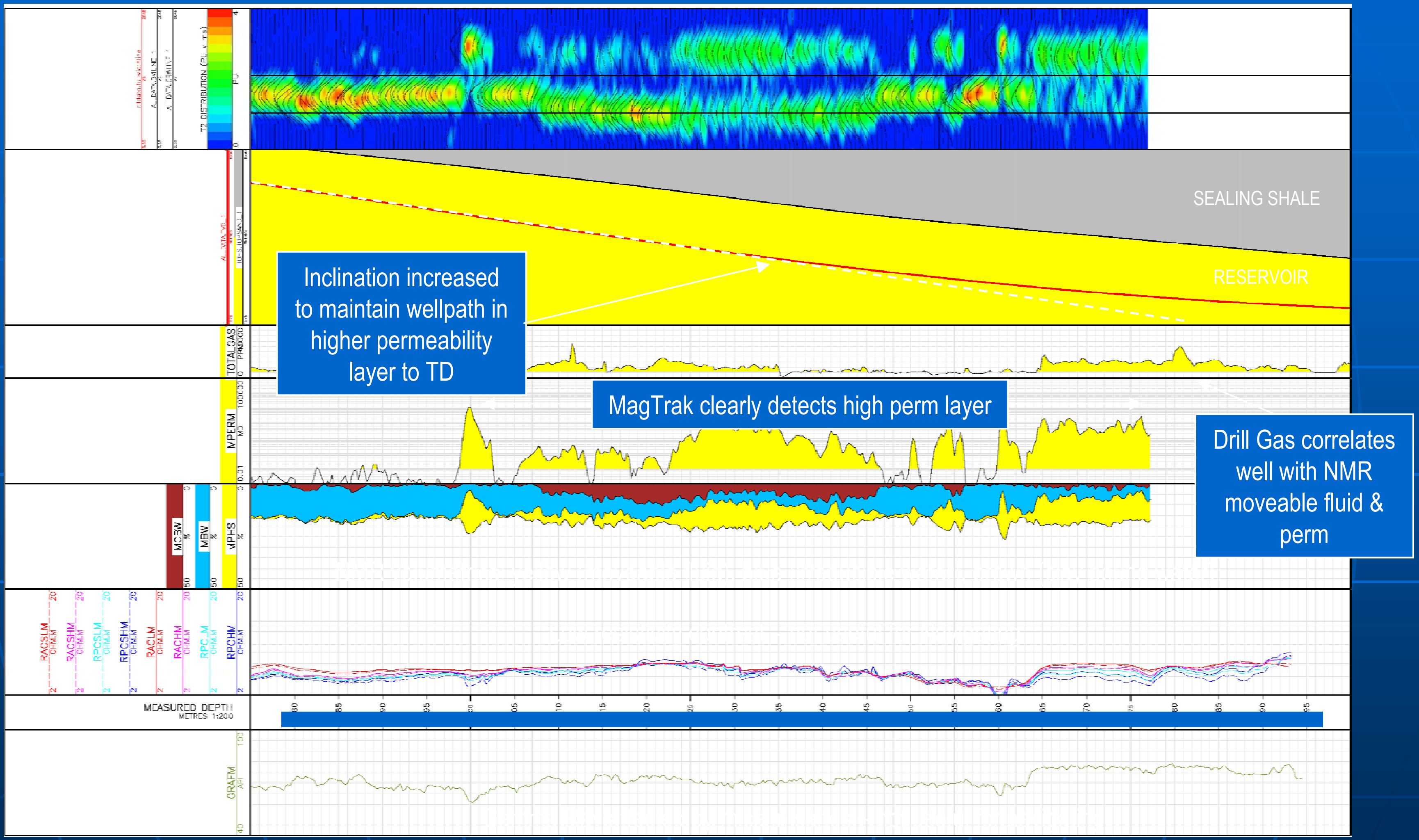
- MagTrak in combination with AutoTrak, Resitivity, Gamma and Drilling Dynamics service

Results—Answers While Drilling

- Accurate source-free porosity is determined with high vertical resolution
- Clear delineation of shale, silt, and sand zones by characteristic T2 signatures
- Geosteering was optimized by MR real-time data, while GR and Resistivity were not suitable
- The drillpath in high perm zones was maximized by MR real-time data increasing the pay by 32%



Steering on Permeability index



Summary

- Logging While Drilling data
  - Drill wells with less risk
  - Stay in the reservoir longer
  - Better evaluation of reservoir