MONITORING GEOTHERMAL WELLS: FROM HT DIRECTIONAL, PRESSURE AND TEMPERATURE WHILE DRILLING TO ADVANCED CASING INTEGRITY SERVICES.

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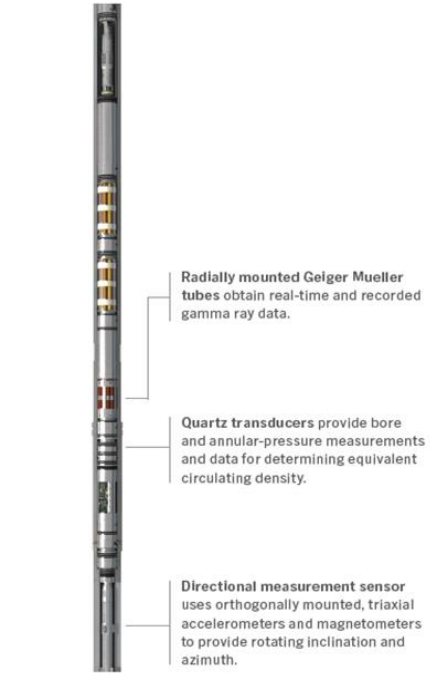
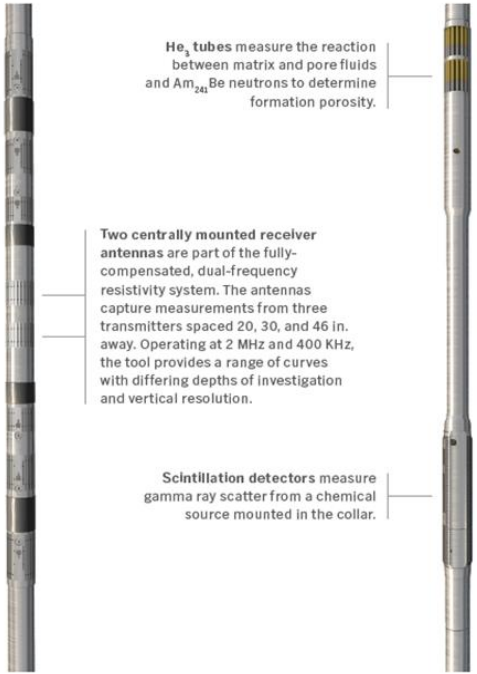
ULTRA-HIGH RATED LOGGING-WHILE-DRILLING (LWD) TOOLS

Rated 200°C temperature (210°C survivor), including directional, pressure-while-drilling, gamma ray, resistivity, porosity and density measurements.
The tools were originally developed for the Gulf of Thailand, one of the most challenging drilling environments on Earth.
Used as well in North Sea fields and in the deepest producing gas field in the Dutch North Sea, with temperatures exceeding 356°F (180°C) and pressures of 14,500 psi (1,000 bar).



HeatWave Extreme MWD Sensor



HeatWave Extreme MFR™ Multifrequency Resistivity Sensor

HeatWave Extreme Density and TNP™ Thermal Neutron Porosity Sensor

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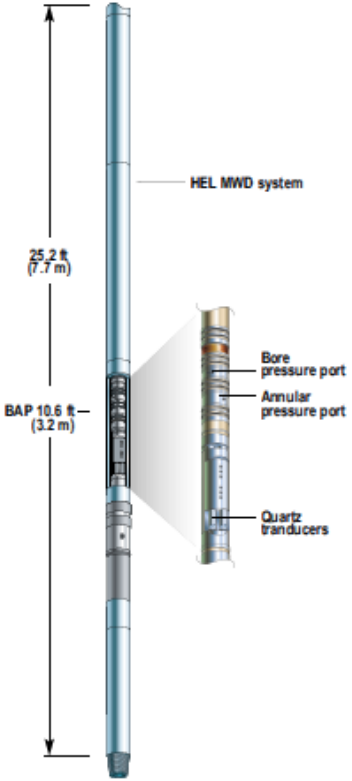
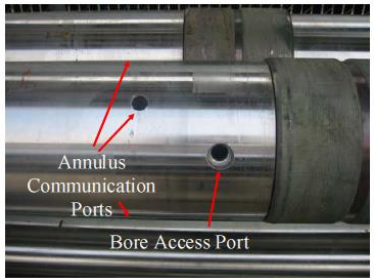
HEL™ MWD SYSTEM BORE/ANNULAR PRESSURE (BAP™)

- Quartz sensors
- HP/HT: 200°C and 30000 psi (2060 bar)
- Pressure Resolution: 1 psi (0.07 bar)
- Pressure Accuracy: +/- 7.5 psi (+/- 0.5 bar)
- Temperature resolution: 1°C
- Temperature accuracy: +/- 0.5°C
- Battery-powered tool





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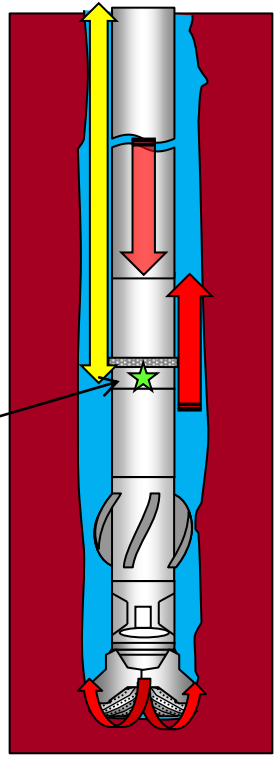
WHAT DOES BAP MEASURE?

Annular Pressure (AP) in yellow:
Temperature and hydrostatic density of the mud column plus frictional losses in the annulus from the pressure sensor to surface to monitor EMW and ECD.

BAP sensor measure point



Continuous pressure and temperature and Max and Min values during pump off in real time

Bore Pressure (BP) in red:
hydrostatic density of the mud column plus frictional losses through the BHA below the pressure sensor (i.e. PDM motor, LWD, etc.), pressure drop through the bit and frictional pressure losses in the annulus from the bit to the surface.

Differential Pressure (DP) = BP - AP:
difference in pressure between the bore and annulus pressure gauges which provides the pressure across the BHA and through the bit and is used to monitor motor performance, blockage at the bit, washout in the lower BHA, and evaluating where pack-off is occurring.

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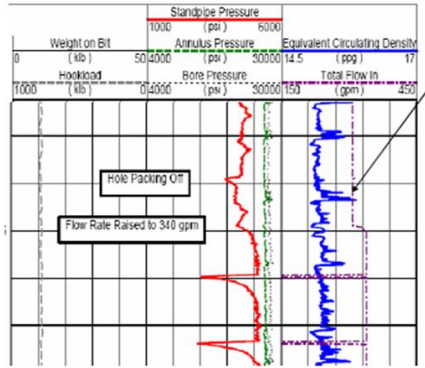
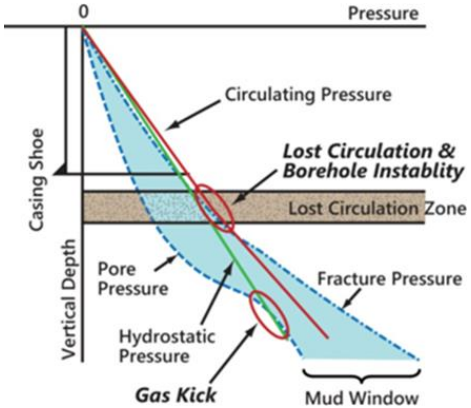
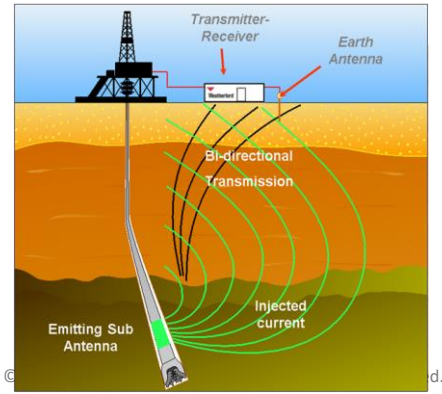
APPLICATIONS

- Monitor hole cleaning, cuttings transport, and barite sag.
- Provide critical information where a narrow window exists between pore pressure and formation fracture pressure.
- Improve drilling efficiency by providing accurate leak-off and formation integrity test information.
- Early detector of shallow water flows, kicks, and discriminates influxes/weeping.
- Optimize the tripping procedures and monitor motor performance.
- Underbalanced drilling or total losses: the BAP can be combined with electro-magnetic (EM) telemetry.



Note the erratic readings for ECD. This is signifying that the hole is packing off due to cuttings build up.





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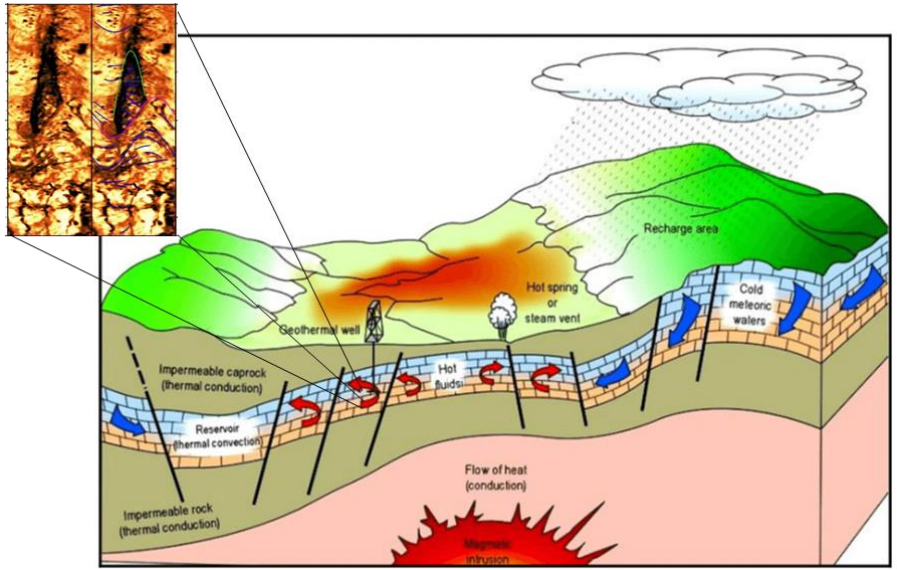
APPLICATION CASES

A combination of mud motor (PDM), MWD and BAP (pressure while drilling sensor), was used in some high enthalpy (>200°C) deviated geothermal wells.
Acquired data was analyzed: some interesting pressure and temperature behavior were observed, and possible specific applications were highlighted.



Schematic model of a fracture driven geothermal system (modified from the web).

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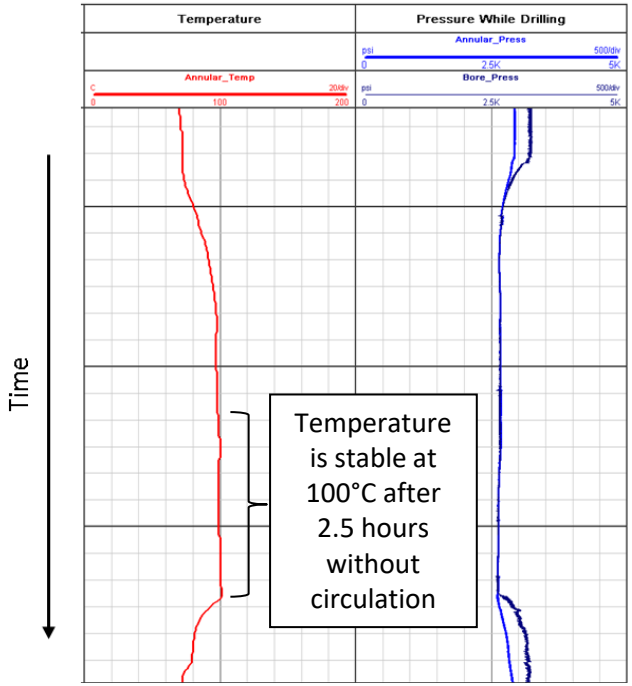
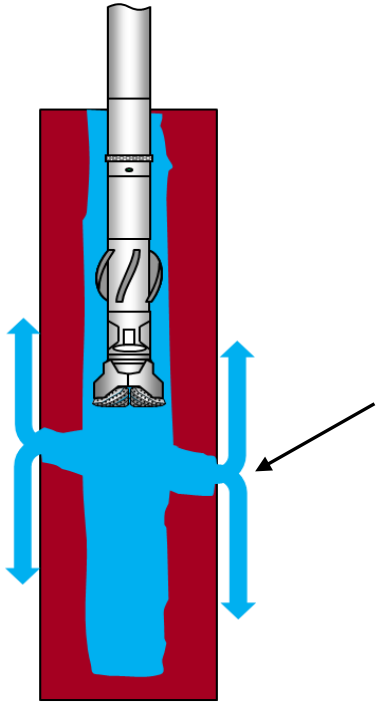
OPEN SYSTEM: after a pump off period the temperature is stable. The lack of temperature increase is interpreted as a more effective cooling effect on the reservoir, related to the presence of highly injective and connected fractures intercepted during drilling. This “open” system allows to cool a larger volume of the reservoir during drilling and circulation in the annulus.





Open fracture with flowing cold mud to cool the reservoir

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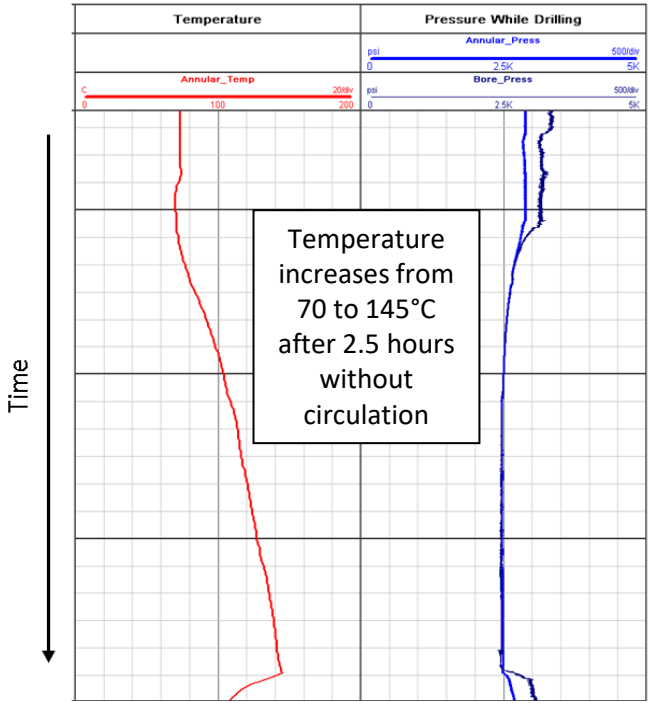
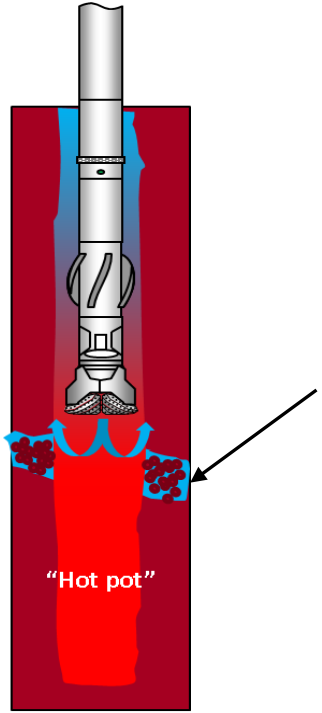
CLOSED SYSTEM ("HOT POT"): in absence of fractures the well is like a "hot pot" of water. We are not able to effectively decrease the temperature, which then increases during pump off controlled by the heating gradient. Going deeper it can also indicate that fracture had been closed by cuttings.





Close fracture (or no fracture) with lack of flow of cold mud to cool the reservoir.

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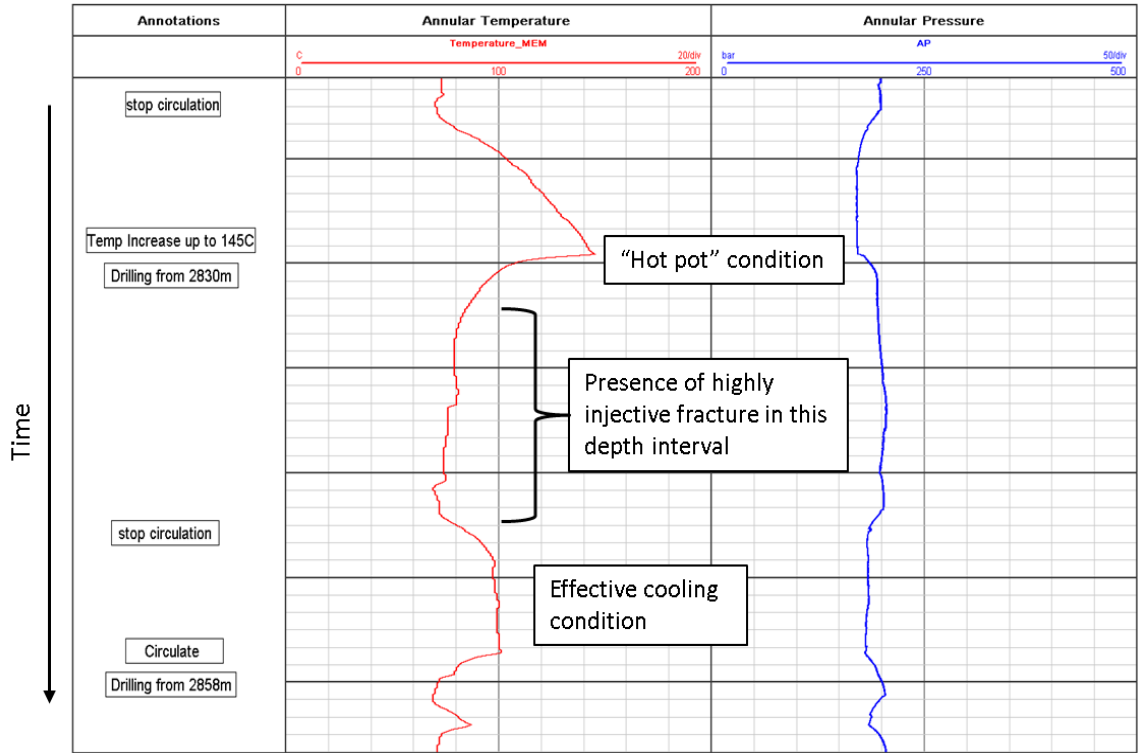
OBSERVATIONS

- We can interpret the depth position of the fracture looking at the boundary between the two conditions.
- In a “hot pot” situation it is needed to monitor and plan the trip in hole of motor and MWD to avoid temperature related damage.
- Understanding the system and active losses position will help to plan casing run and cement job.



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SecureView®

Well Integrity Evaluation (Tubulars and Cement Inspection)

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SECUREVIEW®

- Visualize a cased-hole well in **just one trip**
- Complete **casing and cement** evaluation service
- High-definition and **high-resolution** logs of inner casing, outer casing, cement strength and cement bond quality
- Proprietary software, processing algorithms, sophisticated reporting and **interactive 3D** data presentation formats

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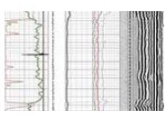
CEMENT INSPECTION

Ultrasonic Scanner (UltraView):

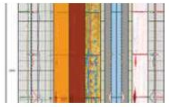
- 360° coverage, high-resolution acoustic impedance imager
- Identifies channels in the cement map as small as 5°
- 7 different size heads with 3 ultrasonic transducers extend tool's application to most of the API casings sizes (4.5 up to 20'')
- Foam and light cement analysis
- Fluids identification (liquid / gas) behind the casing
- Real-time dedicated wellbore fluid measurement

Conventional Cement Bond Tool (BondView):

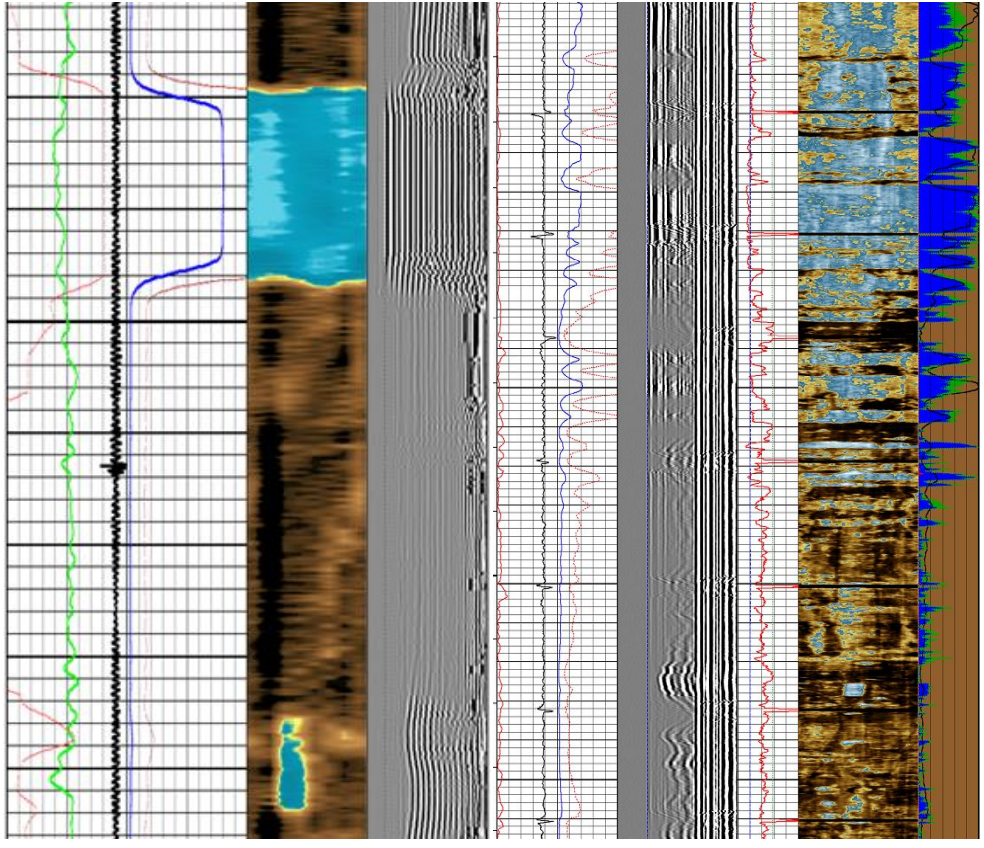
- Cement-to-casing bond assessment
- Cement-to-formation bond assessment
- The short length and light weight of CBT tool help to eliminate problems associated with inadequate centralization in deviated wellbores
- Azimuthal amplitude map for cement channeling identification from conventional CBL tool (Sector Bond Tool)
- 4.5-13-3/8'' casing size range



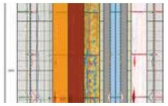
BondView® Tool



UltraView® Tool



CASING INSPECTION



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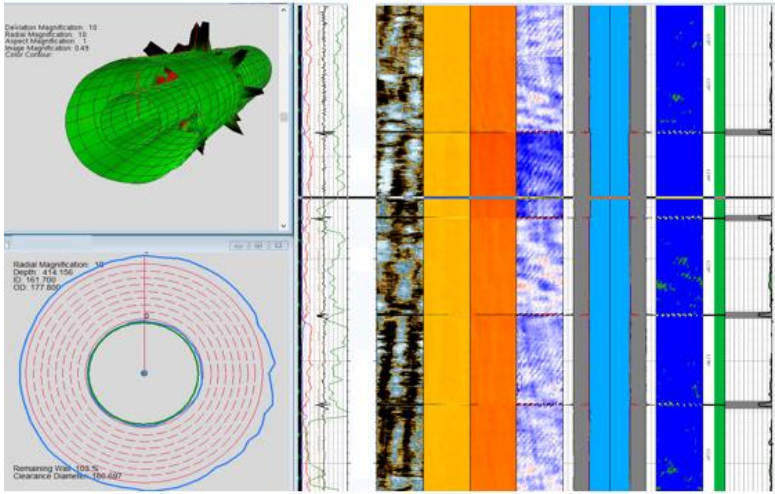
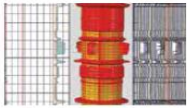
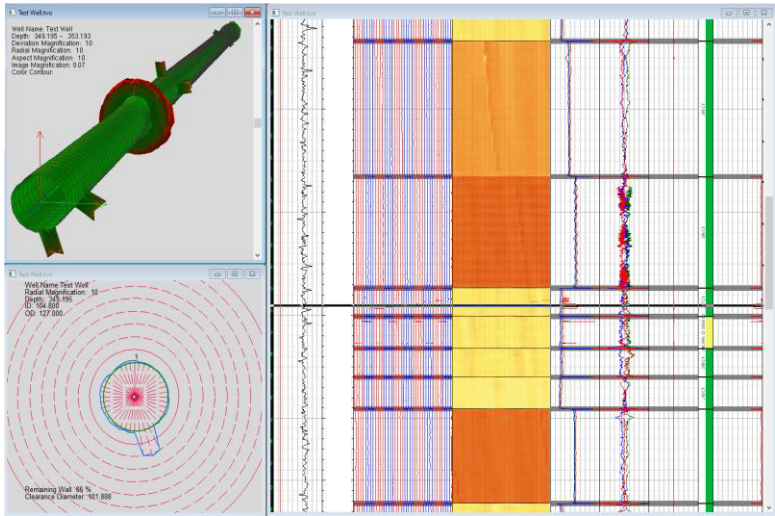


Ultrasonic Scanner (UltraView):

- 360° casing coverage
- Monitoring internal wear, thickness, corrosion, deformation, ovality
- Locating internal and external casing defects
- High-resolution imaging (Casing Thickness and Inner Casing Diameter maps)

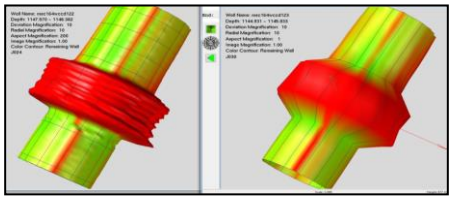


CalView® Tool



Multifinger Casing Caliper (CalView):

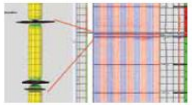
- Locating scale, wax, or other deposits in downhole tubulars
- Internal casing corrosion monitoring (e.g., wear from drilling operations)
- The highest resolution multisensory caliper tool on the market with a sampling rate x10 times the industry standard (2.5mm)
- Real-time proprietary tool eccentricity correction
- 4.5-22.0’’ casing size range



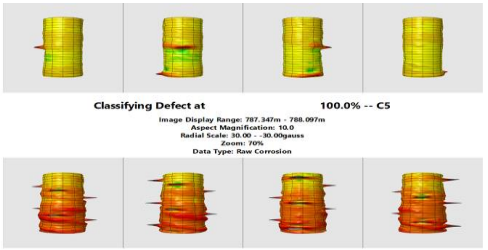
CASING INSPECTION

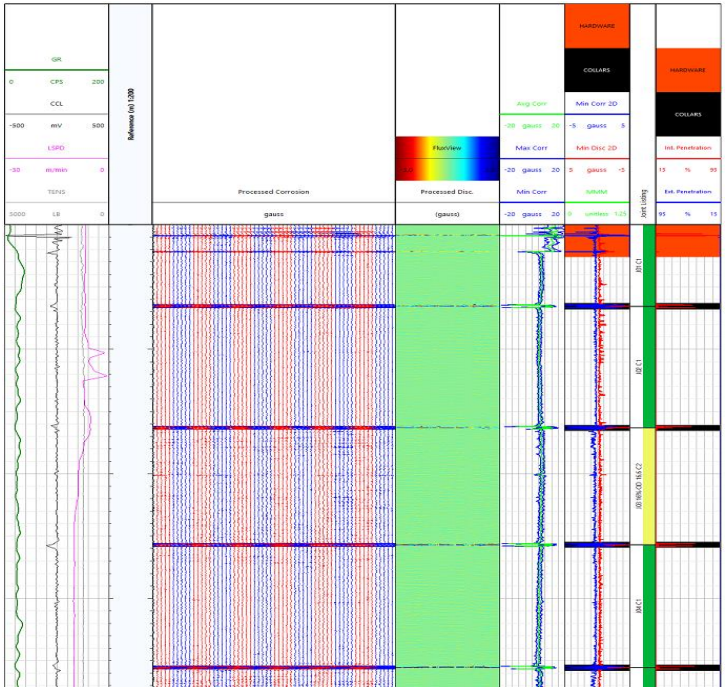
Magnetic Flux Leakage (FluxView):

- Determination of penetration percentage
- Geometry of internal and external casing defects
- Long-term, time-lapse corrosion monitoring for production, storage and injection wells
- Location and identification of casing hardware
- Evaluation of perforation performance
- Identification of casing weight or grade change
- Analysis of the internal and external casing damage using 360° coverage Hall-Effect sensors and magnetic flux technology
- 4.5-10-3/4’’ casing size range



FluxView® Tool





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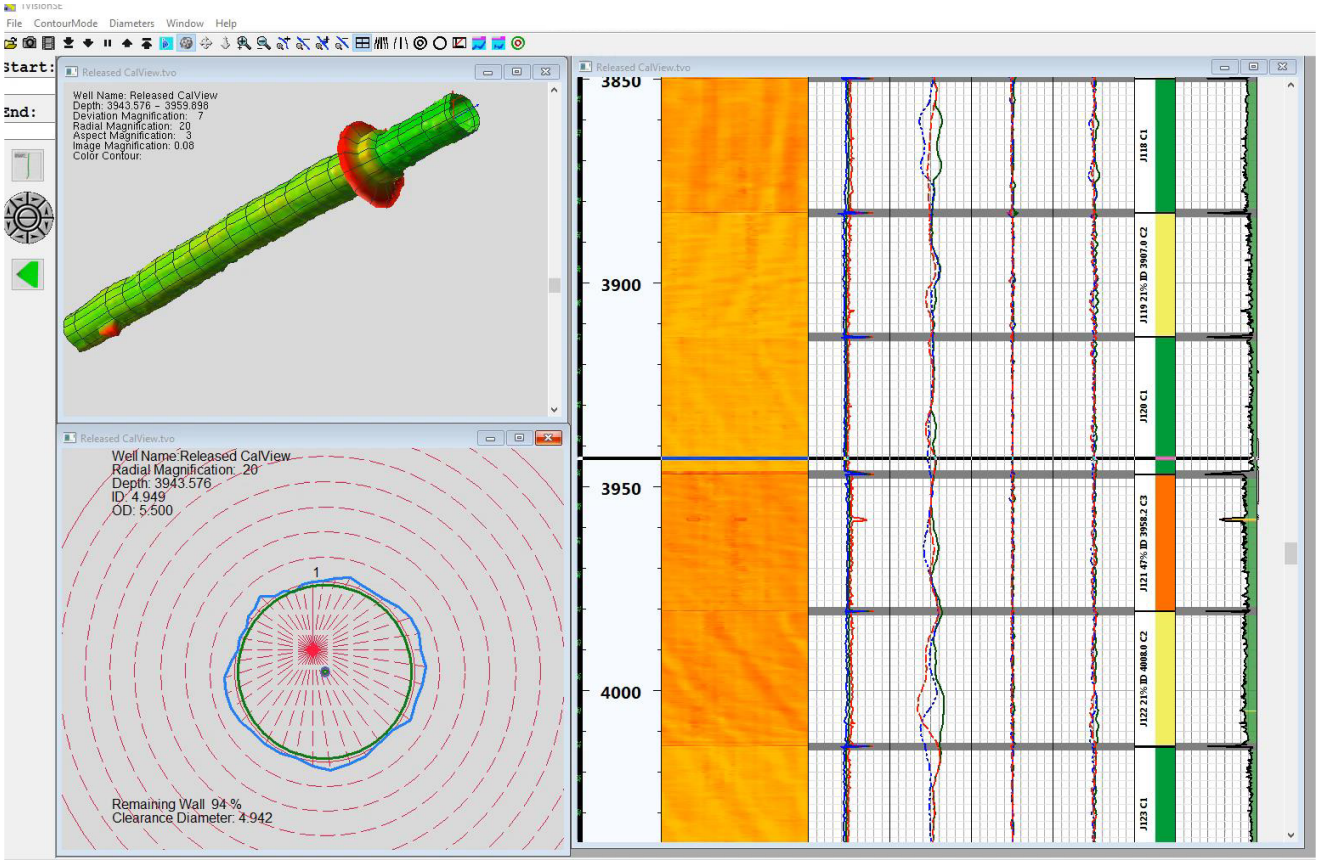
CALVIEW – 3D TVISION EXAMPLE



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