



Schlumberger



HRLA High-Resolution Laterolog Array Tool



Improving the
accuracy of R_t

Applications

- Resistivity determination in conductive mud systems
- Thin-bed evaluation
- Invasion characterization for permeability indication
- Water saturation determination
- Identification of fluid contacts

Benefits and Features

- Bridleless operations save rig time and improve logging efficiency.
- All currents return to tool body, eliminating Groningen and other voltage reference effects.
- Data measured from common central electrode using multiple frequencies give simultaneous measurements that are naturally resolution-matched and depth-aligned.
- Arrays are actively focused using both software and hardware, reducing shoulder-bed sensitivity and enhancing thin-bed definition.
- Five resistivity measurements, each with increasing depth of investigation, give a clear indication of invasion.
- Tool operates without auxiliary current, enabling combination with other formation evaluation tools that require special power, such as the FMI* Fullbore Formation Microlmager tool.
- Advanced 2D processing improves R_t accuracy and enhances reserves estimates.

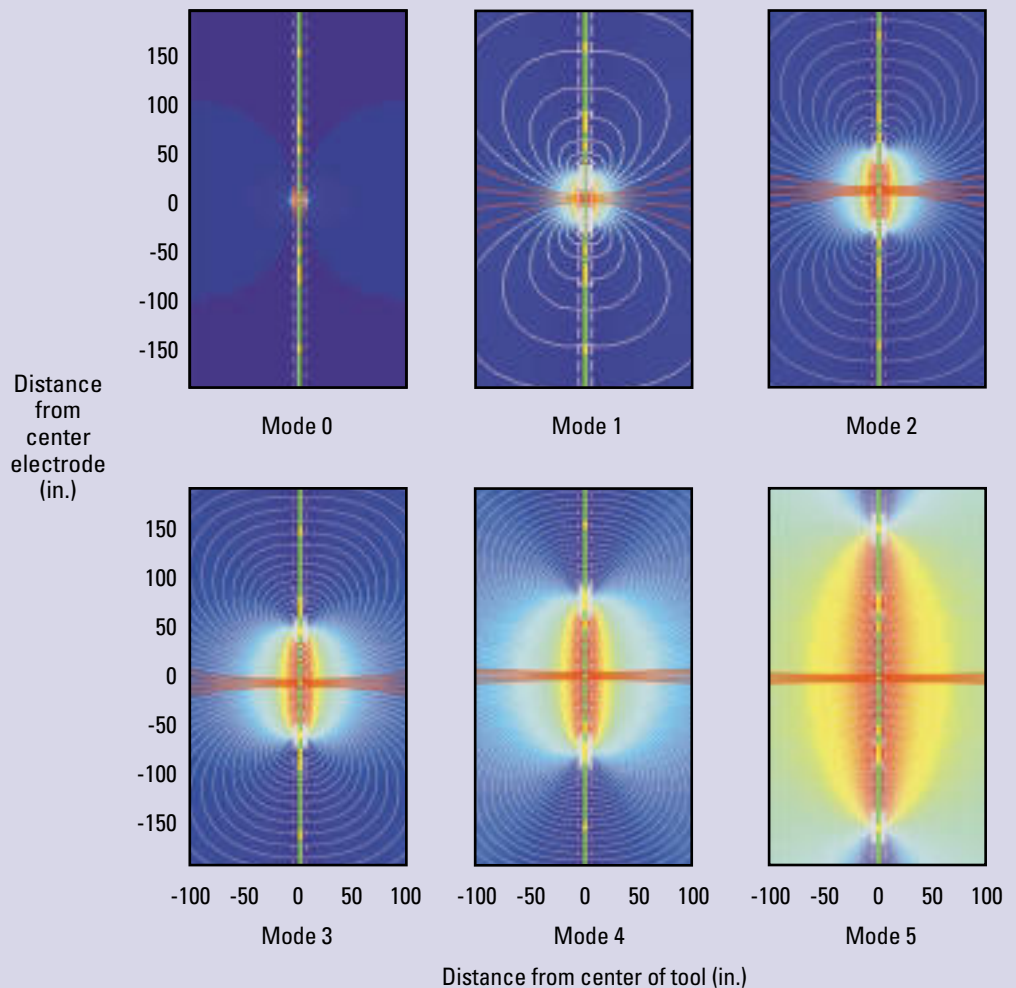
Focused array technology

The HRLA* High-Resolution Laterolog Array tool attacks the difficult task of resolving true formation resistivity (R_t) in thinly bedded and deeply invaded formations by providing five independent, actively focused, depth- and resolution-matched measurements. These measurements, together with a 2D earth model and inversion scheme, simultaneously account for borehole, shoulder-bed and invasion effects, yielding a more accurate, more robust R_t —critical for identifying and estimating reserves. The array spacing is optimized to obtain the maximum amount of information about the invasion profile, thereby improving resistivity estimations. The unique feature of bridleless operations improves wellsite efficiency, and the absence of the surface current return and the tool's through-wired design offer unprecedented combinability.

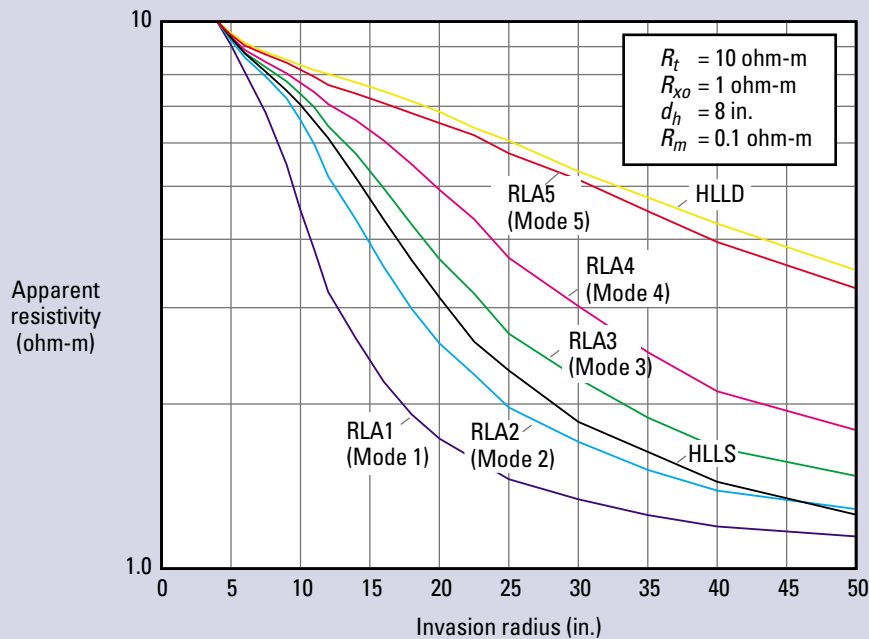
Wellsite benefits—clear answers for quick decisions

Optimal array focusing, enhanced by the symmetric HRLA tool design, ensures all signals are measured at exactly the same time and same tool position. This focusing helps avoid horns and oscillations produced by irregular tool motion and ensures the measurements are depth aligned. The tool delivers an array of five resistivities, each with increasing depth of investigation. This resistivity profile, in conjunction with the improved quality of the HRLA measurements, provides the necessary elements to affect a robust 1D inversion at the wellsite. This inversion assumes radial resistivity variation and an infinitely thick bed to produce a true formation resistivity, R_t , an invaded zone resistivity, R_{xo} , and a diameter of invasion, d_i .

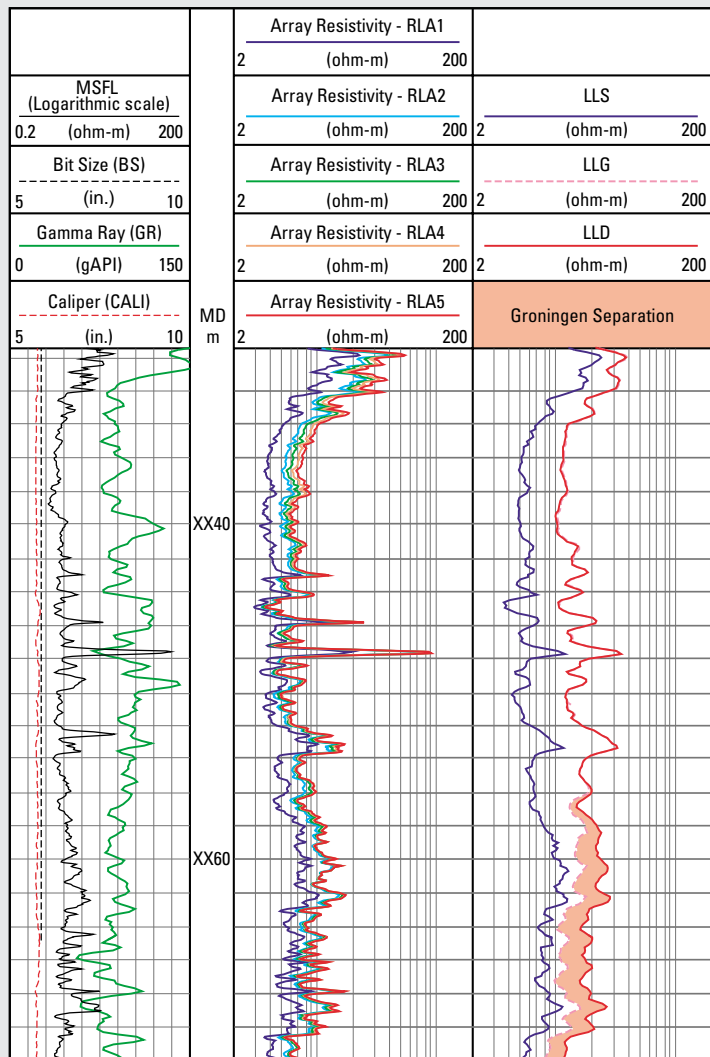
Mode 0 is used to measure mud resistivity. Modes 1 through 5 are used to measure formation resistivities at different depths from the borehole. The red lines are the measure currents, and the white lines are the focusing currents.



Plot of HRLA and HALS resistivities versus depth of mud filtrate invasion. RLA5 from the HRLA tool is comparable to HLLD from the HALS tool.



Comparison of HRLA and DLL* Dual Laterolog resistivity field data showing improved resolution and the absence of Groningen effect on the HRLA response. Microresistivity is presented in the left track to confirm the high-resolution HRLA data.



Depth of investigation

The HRLA tool operates using six different modes. The shallowest mode, Mode 0, is primarily sensitive to the borehole and is used to estimate mud resistivity, R_m . The array spacing is designed to supply the most information possible about the invasion profile. The plot at left compares the Platform Express* resistivity measurements from the HALS High-Resolution Azimuthal Laterolog sonde and the resistivities from the HRLA tool. The borehole-corrected HALS deep resistivity (HLLD) compares well with the Mode-5 response from the HRLA array measurement, while the HALS shallow resistivity (HLLS) is intermediate between the Mode-2 and Mode-3 HRLA responses. The additional HRLA resistivity measurements identify resistivity changes resulting from invasion.

Reduced shoulder-bed effects

HRLA wellsite data, significantly less affected by shoulder beds than traditional laterolog measurements, allow quick, reliable interpretations. Active focusing and multifrequency operation, together with the symmetric tool design, reduce the sensitivity to the shoulder-bed effect that often complicates dual laterolog interpretations. Since hardware focusing is subject to physical limitations, the HRLA tool also employs software focusing, which uses mathematical superposition of signals to ensure the focusing conditions are respected and rectifies any voltage imbalances.

No reference effects

The HRLA tool design eliminates voltage reference effects because all the current returns to the body of the tool, permitting unambiguous formation evaluation. Traditional laterolog measurements use a current return at surface that requires the logging cable be electrically isolated from the tool by use of a long insulating bridle. A shift in the deep-resistivity measurement, called the Groningen effect, arises when high-resistivity formation layers force currents returning to the surface electrode into the borehole. An artificially high formation resistivity results, and therefore incorrect saturation estimates (log at left). Long tool strings and drillpipe-conveyed logging have a similar effect. Since the HRLA tool design returns the current to the tool body, a bridle is no longer required, and voltage reference effects are eliminated. This design feature has the added benefit of reduced rig-up time, anywhere from 15 to 45 minutes per job, as well as improved combinability and reliability.

Clear invasion profile

In thin beds, where deeper measurements tend to degrade in both depth of investigation and vertical resolution, the HRLA service provides an array of measurements that present a clear invasion profile. The shallow readings improve the radial sensitivity to resistivity change, which results in greater curve separation in an invaded zone. With no reference effects and only minimal shoulder-bed effects, the five resistivity measurements reduce ambiguity and improve interpretations.

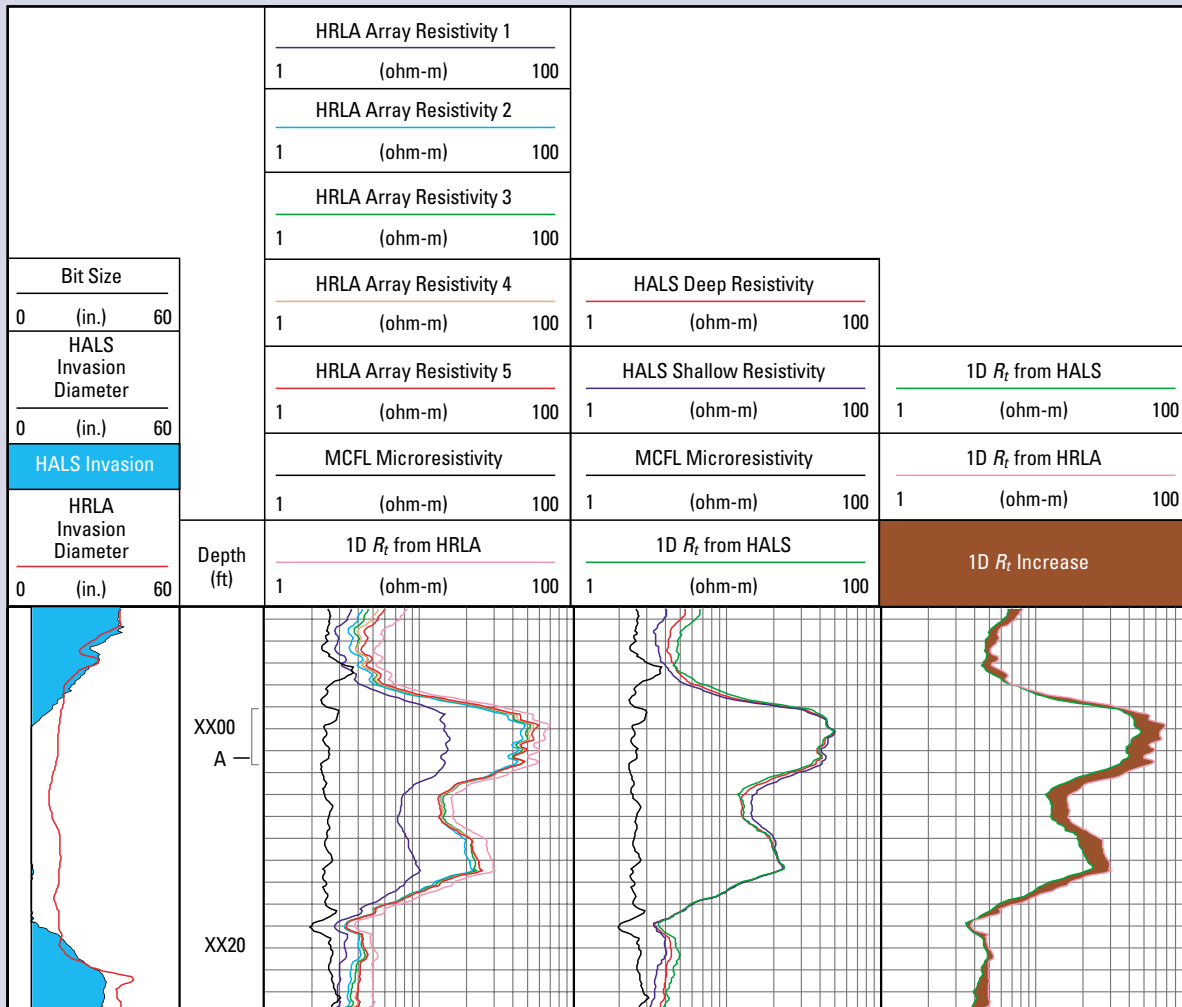
The wellsite example shown below compares 1D R_t and d_i from HRLA and traditional

dual laterolog data. The laterolog curves are out of sequence as a result of shoulder-bed effect. Because the input data are inconsistent with the 1D formation model, R_t is set equal to the deep reading of the laterolog and the d_i is forced to bit size, indicating no formation invasion. The additional information from the HRLA resistivity data allows a realistic estimate of d_i , which in turn allows invasion corrections to be applied to find a more accurate R_t . For the peak around XX00 ft, the R_t is 45% higher, resulting in a 16% overall increase in reserves estimates over the interval.

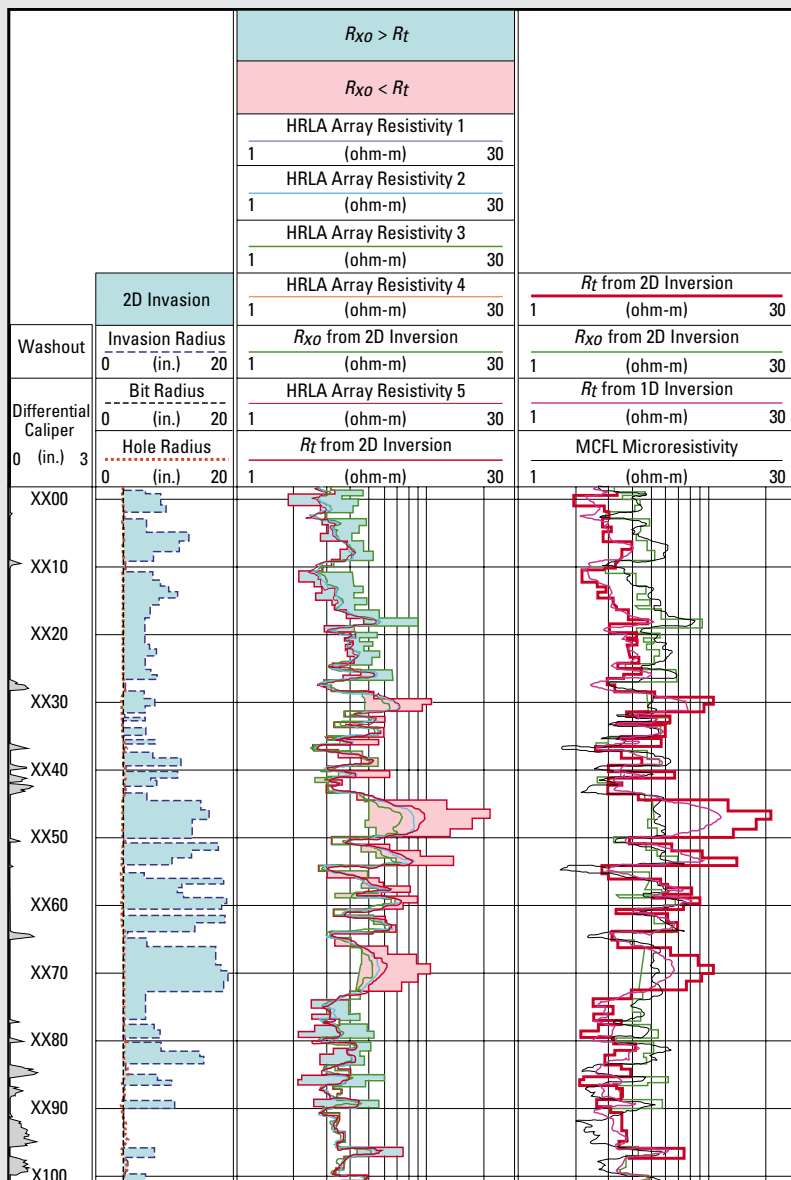
Improved combinability

The HRLA tool is compatible and combinable with a host of Schlumberger logging tools, giving improved wellsite efficiency. The combination of the AIT* Array Induction Imager and HRLA tools yields complementary data for quantification of complex resistivity environments. The new HRLA tool design eliminates the need for auxiliary power, allowing combinations with services such as the FMI and CMR* Combinable Magnetic Resonance tools, which require special power. In addition, use of the HRLA real-time invasion analysis streamlines formation pressure sampling operations.

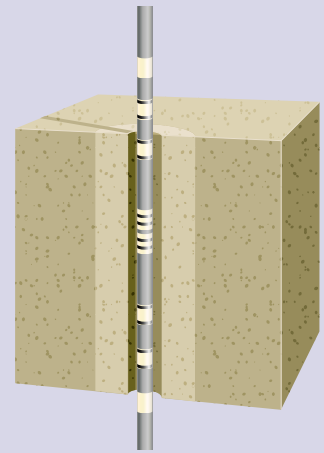
Comparison of HRLA and HALS data showing reduced shoulder-bed effect and improved characterization of invasion, which led to a better R_t after the 1D inversion. The real-time 1D inversion facilitates quick decisions.



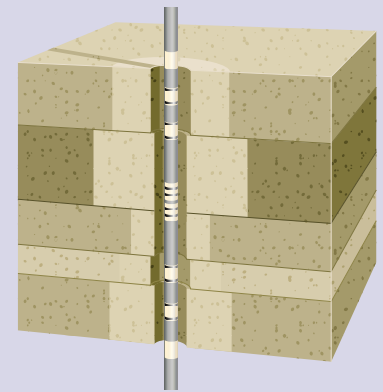
Comparison of raw log, field 1D inversion and 2D inversion. Note the many thin zones across this 100-ft interval.



Formation model used for the 1D inversion. The only variable is the amount of invasion.



Formation model used for the 2D inversion. This model allows for variations in hole size, zone thickness and the amount of invasion.



Advanced 2D inversion—improving the accuracy of R_t

More accurate representation of the formation and borehole environment means more accurate R_t estimates, especially in thinly bedded formations. The HRLA tool not only provides a coherent array of measurements, but the improved quality of these measurements and the additional information about the invaded zone allow advanced 2D inversion processing. The 2D formation model simultaneously accounts for all 2D effects, including those from the wellbore (caves) and from vertical (shoulder-bed) and radial (invasion) resistivity variations. The 2D inversion process begins with the information-rich

raw HRLA data. First, layers are defined through inflection-point segmentation, and a “first guess” is made for the initial formation parameters: R_t , R_{XO} and d_i . The program then computes the tool response in the theoretical formation and compares it to the actual response. The formation parameters are updated, and after successive iterations an acceptable match is found. This mathematical inversion technique, used with a 2D formation model, yields a more accurate R_t and therefore a more accurate saturation estimate.

On the log above, the 2D inverted R_t and R_{XO} are shown in track 3 with the raw HRLA curves. The red shading indicates normal

invasion ($R_{XO} < R_t$); the green indicates reversed invasion ($R_{XO} > R_t$). In track 4, the 2D inverted resistivities R_t (red) and R_{XO} (green) are compared with the 1D inverted formation resistivity R_t (magenta) and the R_{XO} (black) from the Platform Express MCFL MicroCylindrically Focused Tool. The 2D inversion shows a significant increase in R_t obtained in thin beds—such as those between XX30 and XX70 ft—over the 1D inversion results. A good match between the 2D inversion-derived R_{XO} and the one independently obtained from the MCFL measurement adds confidence to the inversion results.

HRLA Tool Specifications

Physical Characteristics	
Tool diameter	3½ in.
Tool length	24.1 ft
Tool weight	394 lbm
Environmental Limitations	
Maximum temperature	300°F [150°C]
Maximum pressure	15,000 psi
Shocks and vibrations	2000 shocks of 250 g for 2 ms, LWD qualification standards
Minimum borehole diameter	≥ 5 in. (4¾ in. under certain borehole conditions)
Maximum borehole diameter	≤ 16 in. (≤ 12 in. preferred)
Maximum dogleg severity	50°/100 ft in 8.5-in. borehole
Measurement Performance (8-in. borehole)	
Resistivity range ($R_m = 1$)	0.2–100,000 ohm-m
Resistivity range ($R_m = 0.02$)	0.2–20,000 ohm-m
Depth of investigation	50 in. (median response at 10/1 R_t/R_{xo} contrast)
Vertical resolution	12 in.
Sampling rate	2 in. at 3600 ft/hr logging speed