

Synthetic Array Curves from Dual Induction Logs*

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Abstract

The traditional dual induction tool makes two apparent resistivity measurements at two different depths of investigations. In Weatherford's Simultaneous Triple Induction (STI) instrument, these are combined with an SFL to deliver three curves. Typical presentation of these measurements is by means of an enhanced resolution algorithm. However, it is more desirable to illustrate multiple depths of investigation curves with a variety of fixed depths of investigations. Based on the use of multiple frequencies at which the STI operates, we can derive an additional "synthetic" array logging response. This is achieved through a non-linear processing approach. Here, rigorous non-linear 2D modeling is used to forward model the induction tool response. The synthetic array curves are an improved version of the presentation of the traditional dual induction measurement at multiple frequencies by creating a "pseudo" array response. Usefulness and limitations of the method will also be discussed. We will show how synthetic array curves are generated through modeled examples and on field test examples. Combined use of multi-frequency data for traditional induction tools, e.g., the dual induction tools, has not been adequately addressed at least in published work. Our work shows that there is information untapped for in this area and with understanding of its limitations, more information on the near borehole region can be inferred than using the single frequency approach.

Description

The traditional dual induction tool records two apparent resistivity measurements at two different depths of investigation. In Weatherford's Simultaneous Triple Induction (STI) instrument, which is one of the induction services Weatherford provides, these are

combined with a Spherically Focused Log (SFL) to deliver three curves. Typical presentation of these measurements is by means of an enhanced resolution algorithm [Mitchell]. However, it is more desirable to illustrate a multitude of curves with a variety of fixed depths of investigation [Barber et al.]. Using the multiple frequencies at which the STI operates, one can derive a set of “synthetic” array logging responses to compliment the standard three-curve deliverable.

The frequency effect causes the induction response to change; even for the same tool transmitter-receiver spacing. Lower frequencies generally see deeper than higher frequencies. This is the physics on which the presented processing method is based. Examples of the frequency effect for Oil-Based Mud (OBM) and for Water-Based Mud (WBM) are shown in [Figure 1](#) and [Figure 2](#). In the OBM case, a resistive invasion profile is assumed. The curves plotted are geometrical factors. Note that these geometrical factors are skin effect corrected to the first order by assuming a homogeneous formation. As can be seen, the lower frequency (10 kHz; solid curves) indeed investigates a deeper area than the higher frequency (40 kHz; dotted curves). However, it must be admitted that the difference between high and low frequencies begins to diminish for shallow invasions. Similar observations can be made for the WBM case using a conductive invasion ([Figure 2](#)).

Application

The method is implemented by a nonlinear processing approach. A rigorous, nonlinear 2D modeling algorithm is used to forward model the induction tool response. The resulting synthetic array curves can be considered an improved version of the presentation of the traditional dual induction measurement at multiple frequencies through the creation of a “pseudo” array response. The frequency variation of the induction response is nonlinear in nature. Therefore, in order to take advantage of the information embedded in multi-frequency data, rigorous nonlinear modeling is most desired; often at the sacrifice of processing speed. In this work, a Numerical Mode Matching method [Chew et al.] is applied in modeling the multi-frequency induction response; the fastest known rigorous 2D modeling approach without resorting to questionable approximations.

The processing scheme is composed of two stages. The first stage is vertical processing (VPM) which enhances and matches the induction logs at two and four foot resolutions. This is accomplished with an improved Van Cittert method [Press et al.]. The second stage is a radial processing module (RPM), where a radial inversion is carried out and then the inverted radial profile is convolved with a set of pre-selected target functions to yield the fixed depth of investigation curves. The processing flowchart is shown in [Figure 3](#) and the target functions are given in [Figure 4](#). It has to be noted that the multi-frequency effect diminishes as formation resistivity goes up. This is to be expected, since at zero conductivity the skin effect (of any order) will disappear. For all practical purposes it can

be stated that at resistivities below 20 Ohmm, the multi-frequency approach works well. Above this Multi-Frequency Inversion Threshold (MFIT), interpolation and/or extrapolation is used to generate the fixed depth of investigation curves.

Results

Figure 5 shows a synthetic example of the new array processing technique. A 3-layer formation model and WBM are assumed (hole diameter 8 in.; mud resistivity 1 Ohmm; center bed invaded with diameter of invasion 60"; R_{xo} and R_t at 5 and 20 Ohmm). It is worth noting that the presented processing approach is inherently accounting for borehole effect, even in thin beds. This has never been achieved in traditional borehole correction methods. The processing generates 20 in., 30 in., 40 in., 60 in. and 80 in. curves at two and four feet resolution, respectively. The four foot resolution curve is particularly helpful when environmental noise in the measurement is prominent. Figure 6 depicts the same formation, processed with the legacy STI approach. The new processing approach provides a better insight into the formation profile.

In order to compare the two processing approaches in a real-life situation, measurements were made in a fiberglass-cased test well at Weatherford's R&D facility. Figure 7 shows the test well example. The agreement with the legacy resistivity measurement is excellent.

Significance

Combining the use of multi-frequency information for traditional induction tools, e.g., the dual induction tools, has yet to be adequately addressed in published work. This work shows that there is additional useful information present in multi-frequency measurement and, considering the inherent limitations, substantially more information about the near borehole region can be inferred; when compared to the use of single frequency data.

References

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Chew, W., S. Barone, B. Anderson, and C. Henessy, 1984, Diffraction of Axisymmetric Waves in a Borehole by Boundary Discontinuities: Geophysics, v. 49/10, p. 1586-1595.

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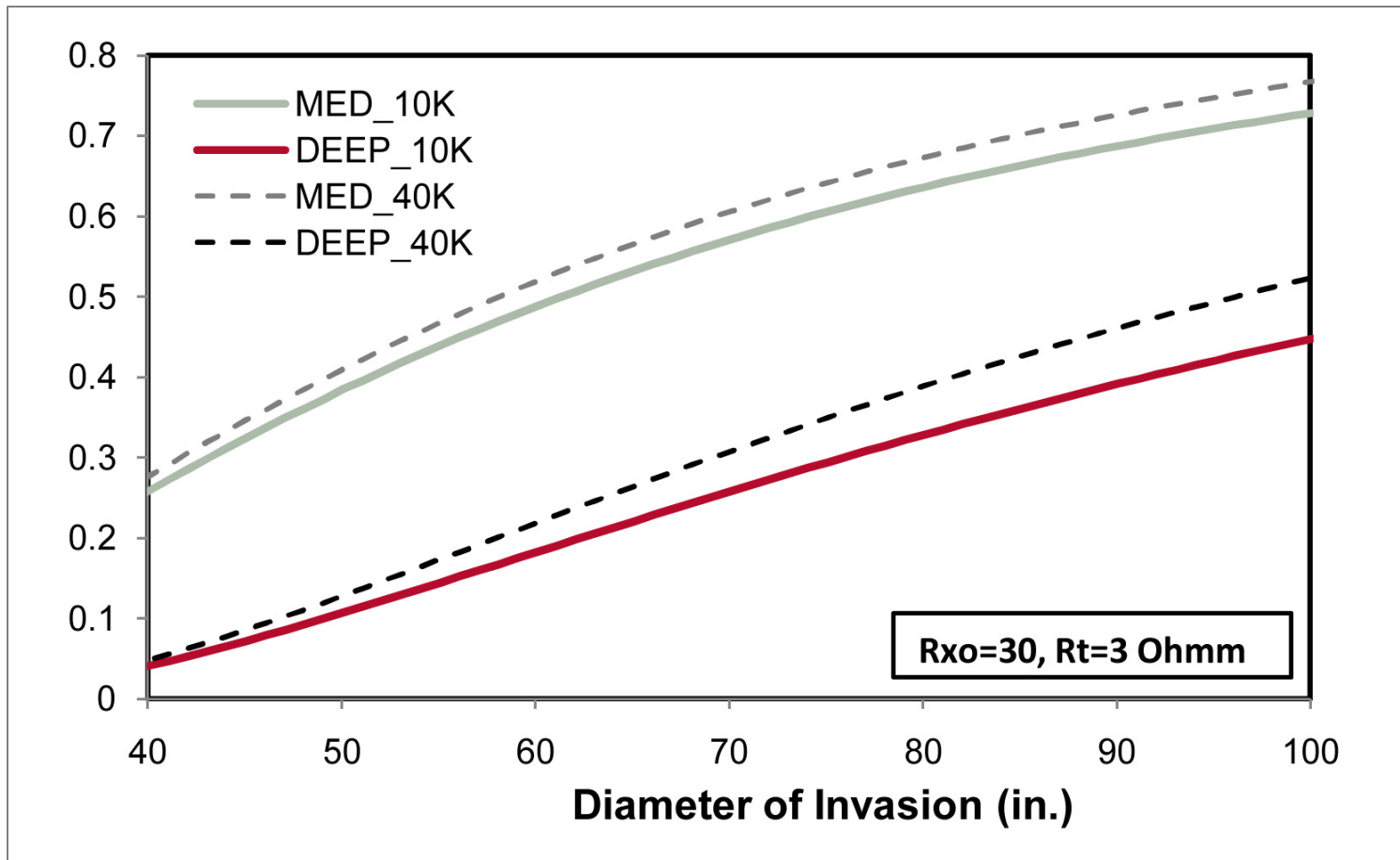


Figure 1. Multi-freq. effect in OBM.

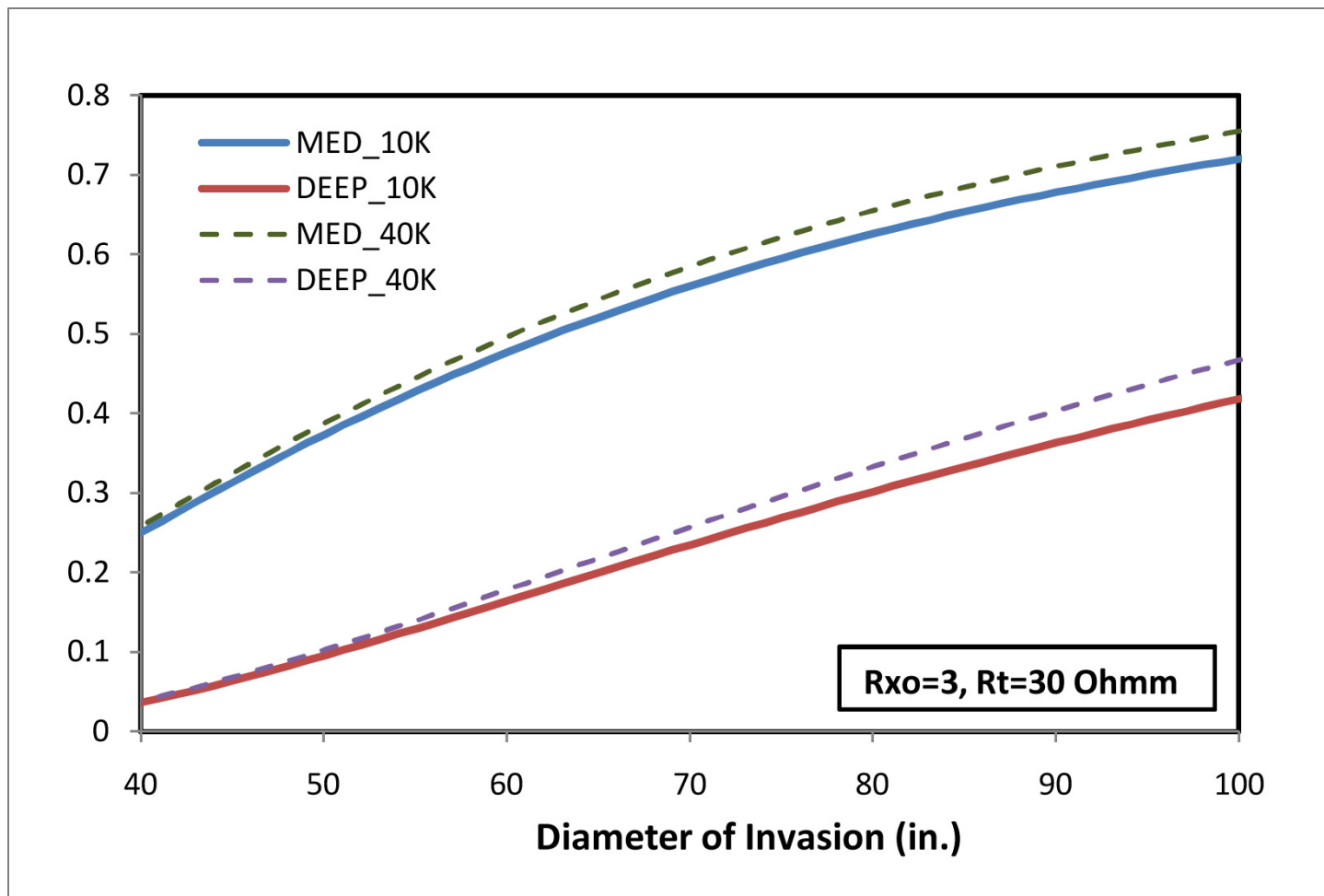


Figure 2. Multi-freq. effect in WBM.

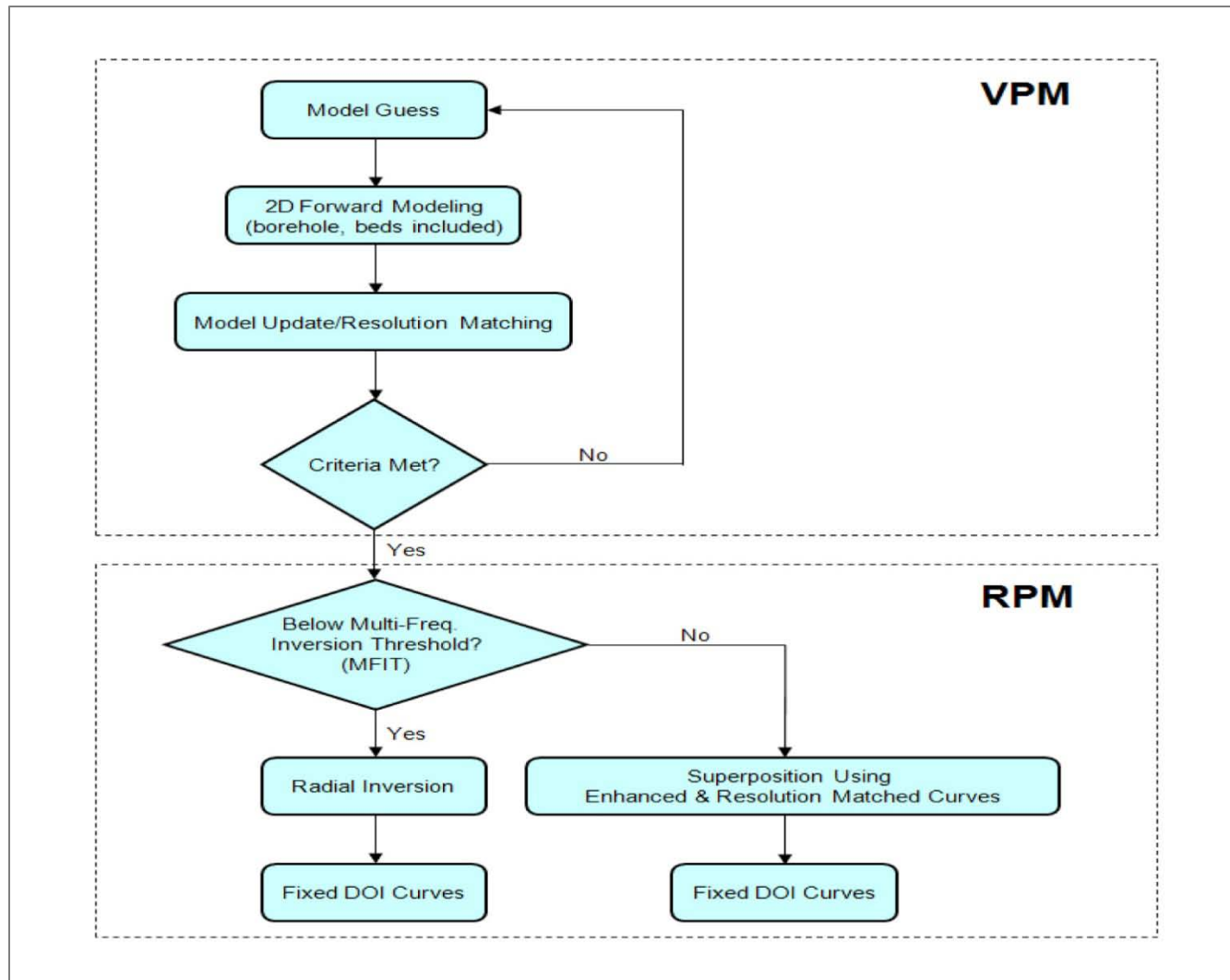


Figure 3. Process flowchart.

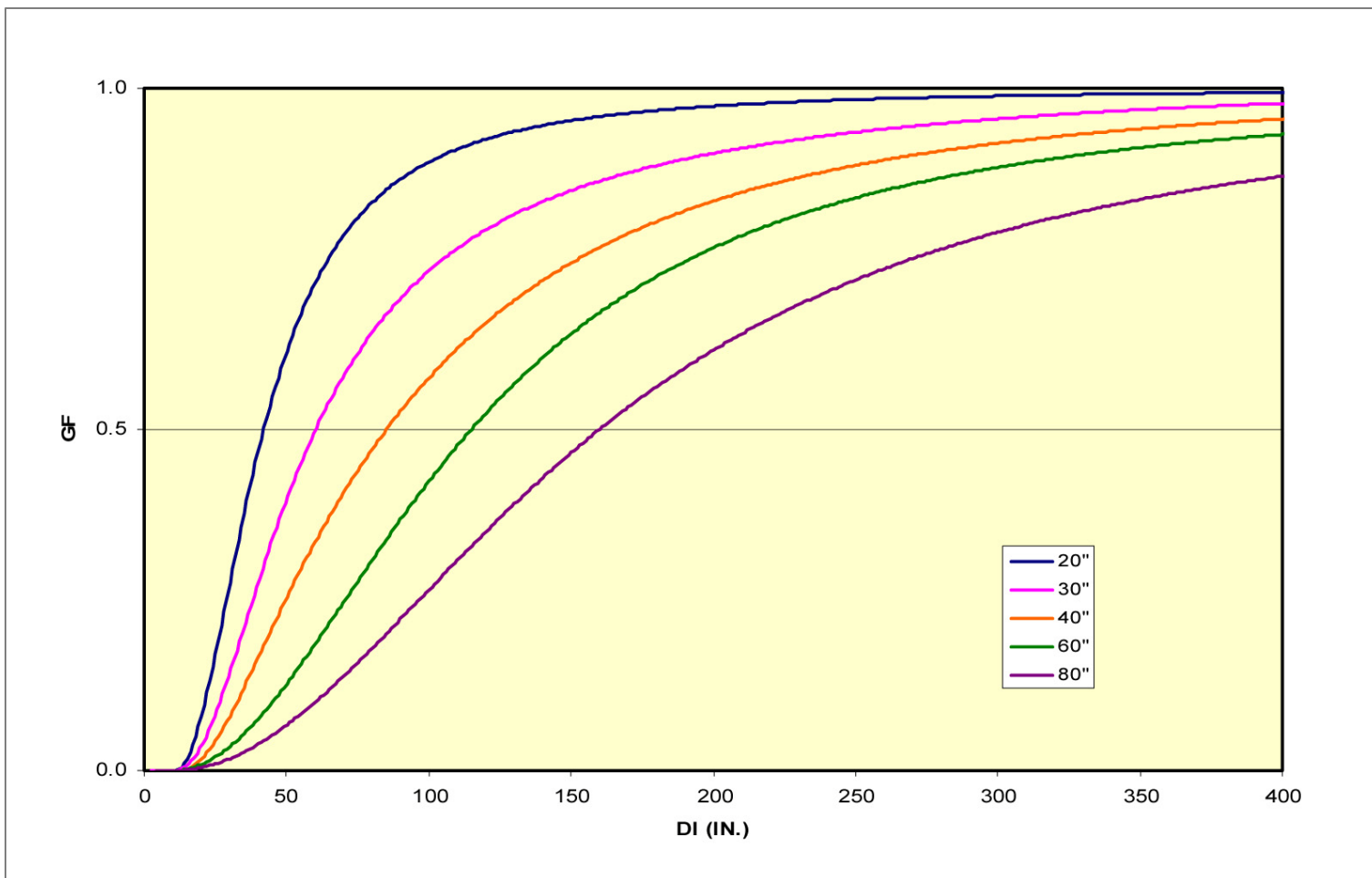


Figure 4. Target functions.

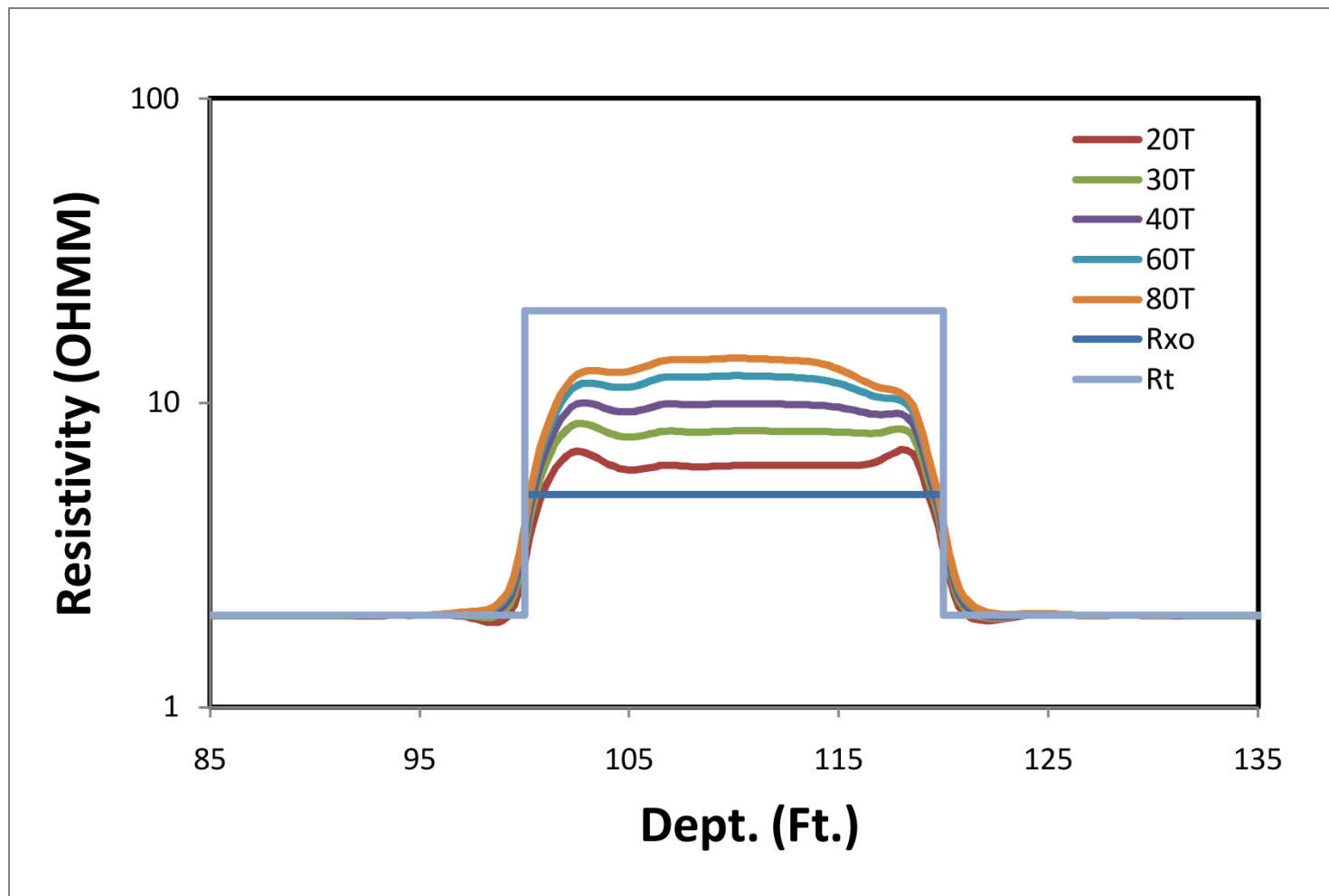


Figure 5. Synthetic model---the array processing.

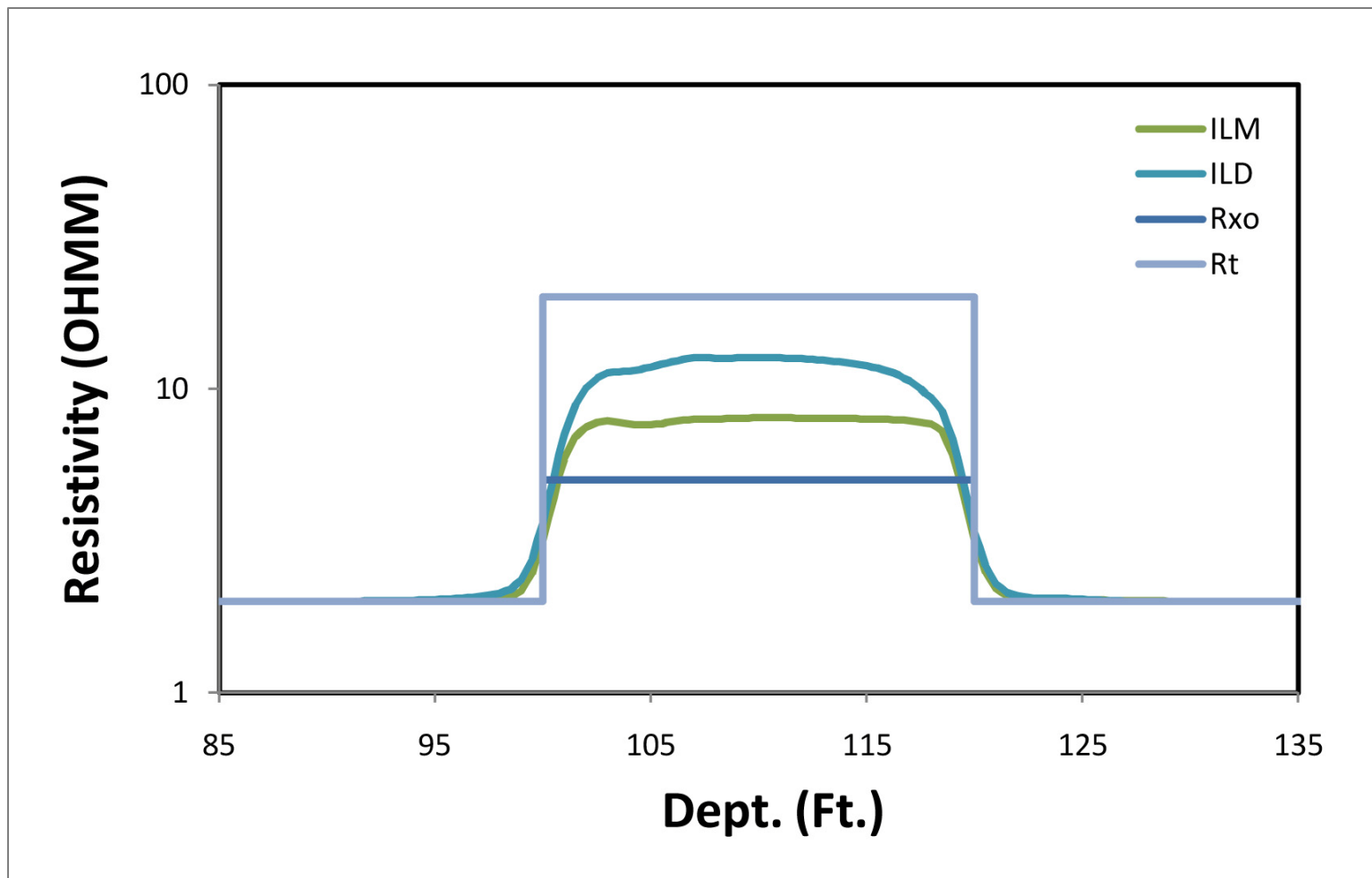


Figure 6. Synthetic model---the legacy processing.

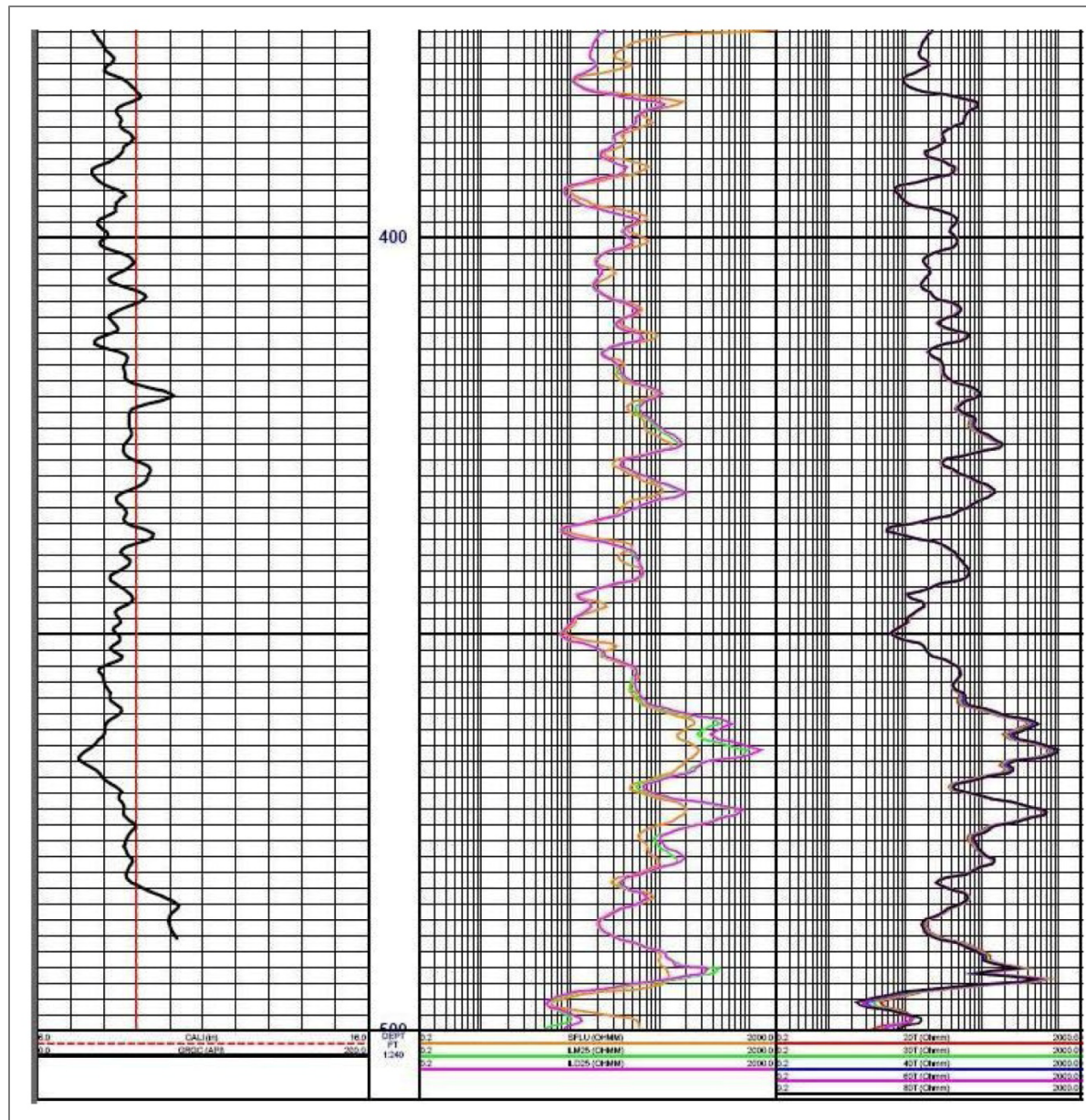


Figure 7. Test well example.