Innovation in Horizontal Wells Petrophysical Evaluation, A Case Study from Kuwait*

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Abstract

The oil industry has been dealing with logging data based on a vertical hole geometry for decades. In a vertical hole, usually the deep resistivity measurement is often used as Rt for saturation calculation. This is true in most cases unless we are crossing a bed boundary or we have a very deep mud filtrate invasion. In a horizontal hole, several factors are affecting the formation resistivity measurements. One factor to mention here is the adjacent bed resistivity effect. Moreover, when the well trajectory is cutting a bed boundary at a high angle, polarization horns are affecting the measurement and causing severe noise that masks the formation true resistivity.

Introduction

The oil industry has been dealing with logging data based on a vertical hole geometry for decades. In a vertical hole, usually the deep resistivity measurement is often used as Rt for saturation calculation. This is true in most cases unless we are crossing a bed boundary or we have a very deep mud filtrate invasion. In a horizontal hole, several factors are affecting the formation resistivity measurements. One factor to mention here is the adjacent bed resistivity effect. Moreover, when the well trajectory is cutting a bed boundary at a high angle, polarization horns are affecting the measurement and causing severe noise that masks the formation true resistivity.

The Problem

Recently, one horizontal well in North Kuwait had severe issues with resistivity (Figure 1). In the heel part of the hole, resistivity measurements were behaving as expected and the formation true resistivity was easy to get. Approaching the lower side of the hole, severe noise and horns were present with high occurrence making the evaluation of true formation resistivity unreachable.

Figure 2 shows the resistivity response across the same formation when drilled with two different angles. The first one is the pilot hole drilled with 64 deg. deviation and the second one is the lateral deviated hole drilled with 80 deg. deviation. As shown in Figure 2, at 64 deg. deviation, the measurement is only suffering horn effect at the formation interface with shale above and below. At higher angle (80 deg.), the resistivity is useless and cannot be used for proper formation evaluation.

The Solution

A new Logging While Drilling (LWD) technique was introduced to KOC in order to overcome the resistivity anomalous response. The new technique was based on measuring the formation capture cross section SIGMA (Σ) and using that for water saturation computation. Σ has been used for several decades as a reservoir monitoring technique to monitor hydrocarbon depletion with very good results worldwide as shown in Figure 3. Of course, measuring Σ in cased hole environments has its own uncertainties such as the presence of both casing and cement. However, in cased hole environment, usually the mud filtrate disappears after certain time of production. Wireline introduced measuring Σ in open hole several years ago. Unfortunately, in open hole environments, mud filtrate invasion plays a big role in affecting the Σ reading. Therefore, it is a bit risky to use Σ from Wireline tools to calculate water saturation Sw.

Σ Measurement with LWD Technology

The LWD tool is usually positioned behind the motor or Rotary Steerable tool. The distance from the tool different measure points to the bit is usually in the range of 25 to 30 feet. Therefore, the LWD tool will be passing by the drilled formation after approximately 30 minutes assuming rate of penetration of 50 to 60 ft/hr. Σ measured by LWD will not suffer from the mud filtrate invasion as the one measured by Wireline. In this case, it can be used with great confidence to calculate water saturation Sw. Moreover, Σ measured by LWD can be considered a base log for future reservoir monitoring activity.

Processing Results

The EcoScope* was acquired while drilling the drain hole of one of the wells in North Kuwait. EcoView* software was used in real time to process the data and the results were delivered to KOC twice a day. Kuwait Oil Company (KOC) was impressed by the different tool outputs. Figure 4 shows the processing results of water saturation using Sigma that was done by KOC.

The KOC processing results using Σ showed more realistic values of irreducible water saturation (Swirr). This is a very important result since this is used to calculate formation mobility using KOC built in equations. The calculated formation mobility was needed for the Inflow Control Device (ICD) design.

UltraSonic Caliper Recording while Pulling Out of Hole

The UltraSonic caliper was recorded during pulling out of the hole after drilling (Figure 5). The information was very useful to KOC to see the latest hole conditions before running the completion. The caliper helped KOC to position the inflatable packers in the right depth.

Time Lapse Σ

Σ was also recorded while pulling out of the hole and was compared to the drilling pass Σ. If oil base mud is used in drilling a reservoir, a time-lapse comparison between drilling Σ and recording while pulling out of the hole will reveal any water movement. The time-lapse Σ comparison did not reveal any water movement. Therefore, most of the water present in the formation is bound. Figure 6 illustrates the comparison.

Spectroscopy Analysis

Figure 7 illustrates the spectroscopy analysis results. Across some intervals, the clay content from EcoView* was more accurate than GR curve. This indicated the presence of radioactive sand or approaching shale layer from top or bottom.

Sourceless Density

Sourceless density (Figure 8) was evaluated and a comparison with the standard density showed very good agreement. This can be used in the future to encourage KOC to use Sourceless density/neutron for problematic wells.

Well Placement

Distance to Boundary Deep Resistivity mapping technology was used to stay in the reservoir sand (Figure 9). The formation structural dip and the reservoir thickness vary from the Pilot hole and facies changes were encountered. The LWD Density Image coupled with distance to Boundary information from PeriScope allowed to place 1,230 feet of train hole in the best part of 12-ft thick reservoir.

The real time information brought better understanding on the geometry of the sand body as the decision to call out for TD was based real time interpretation due to the reservoir pinching that saved cost by avoiding drilling out of the target and hole stability issues that could be associated with that.

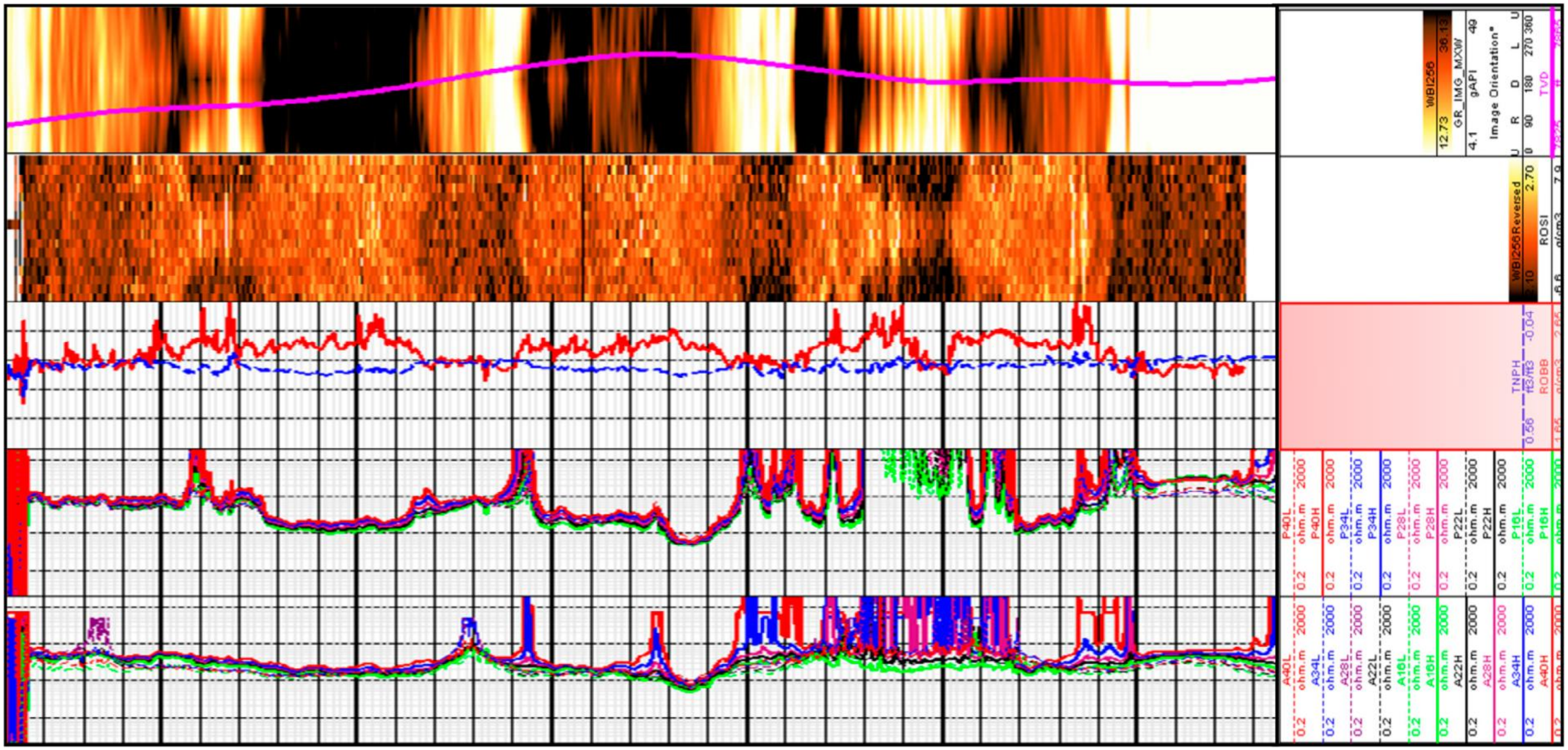

Figure 1. Strange resistivity behavior in a horizontal well in North Kuwait.

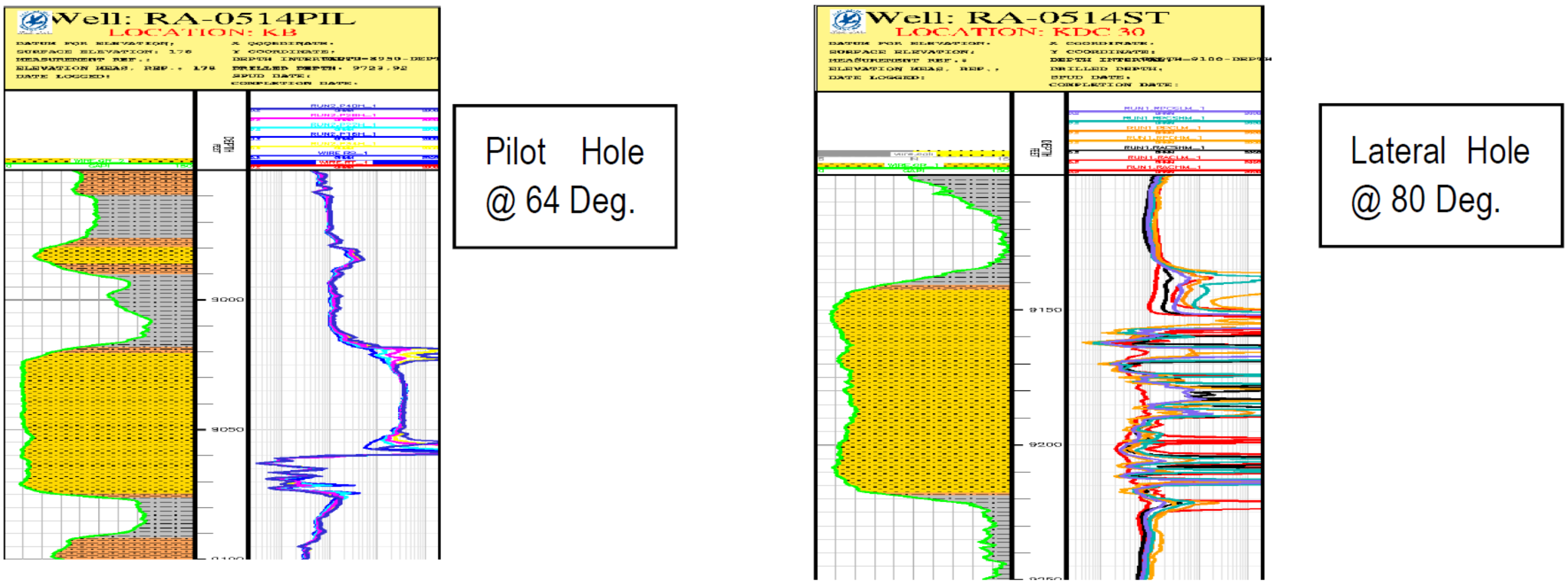

Figure 2. Another example of resistivity behavior with changing deviation.

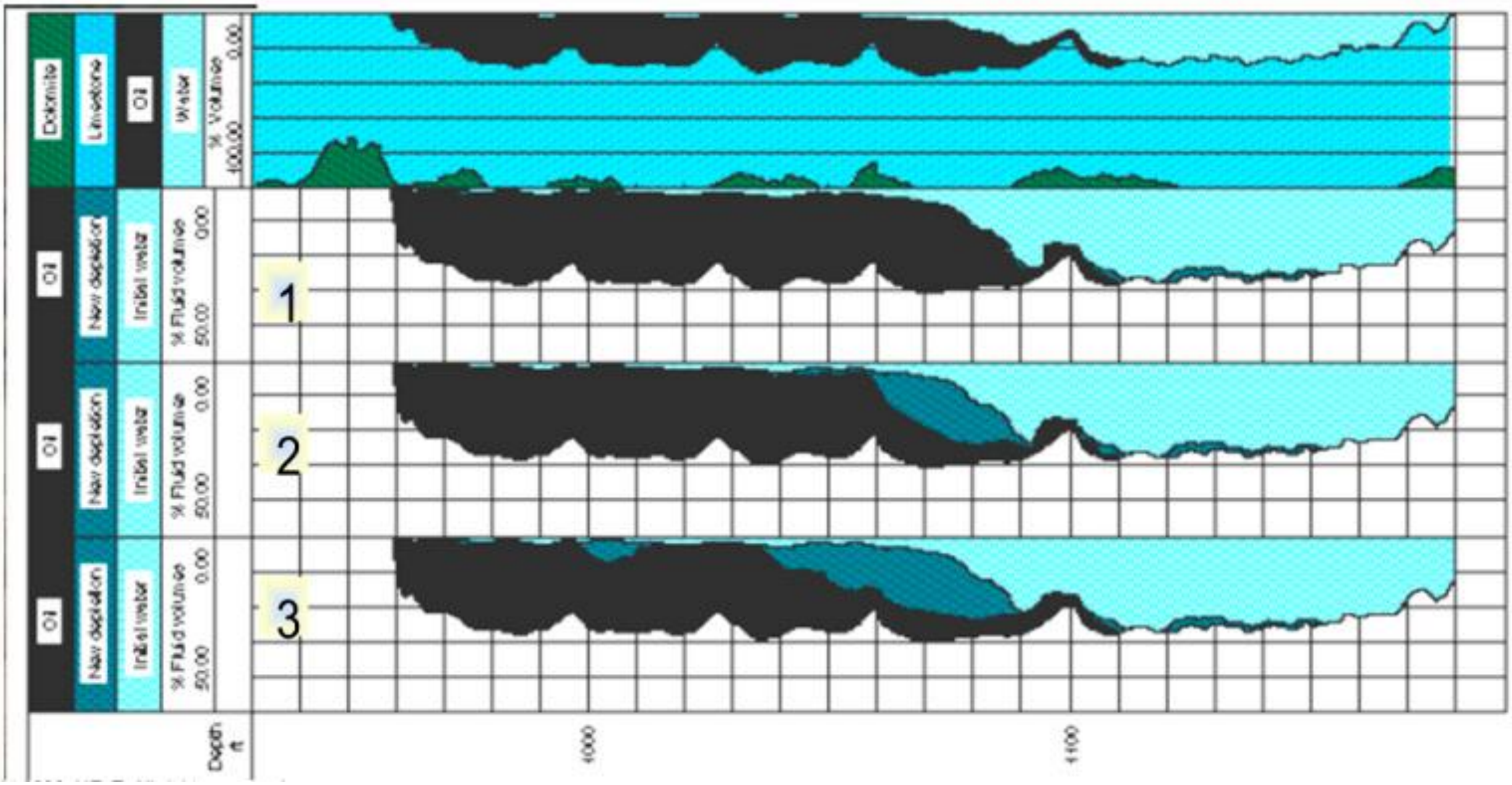

Figure 3. An example of SIGMA time-lapse technique in cased hole.

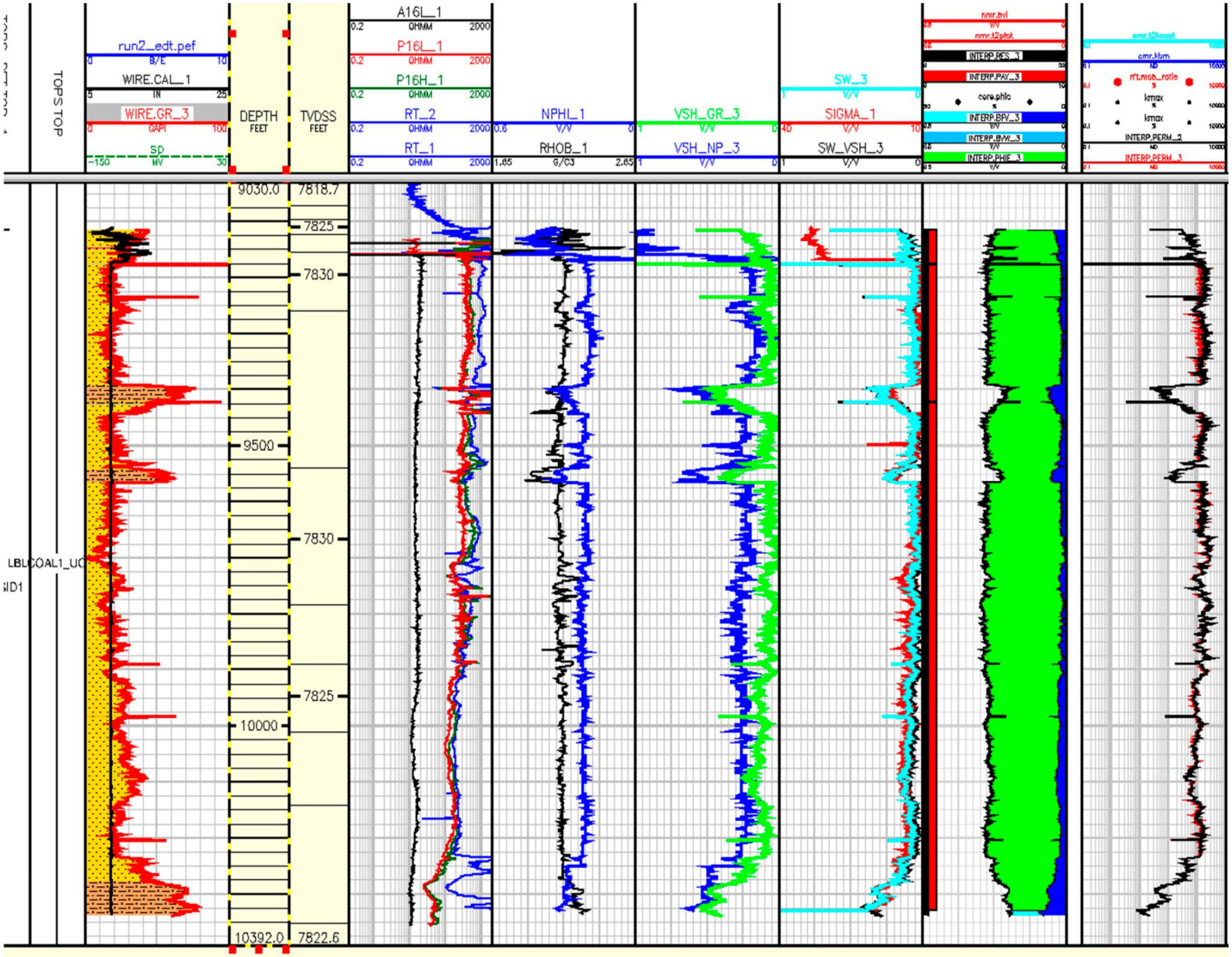

Figure 4. KOC data processing results using Σ.

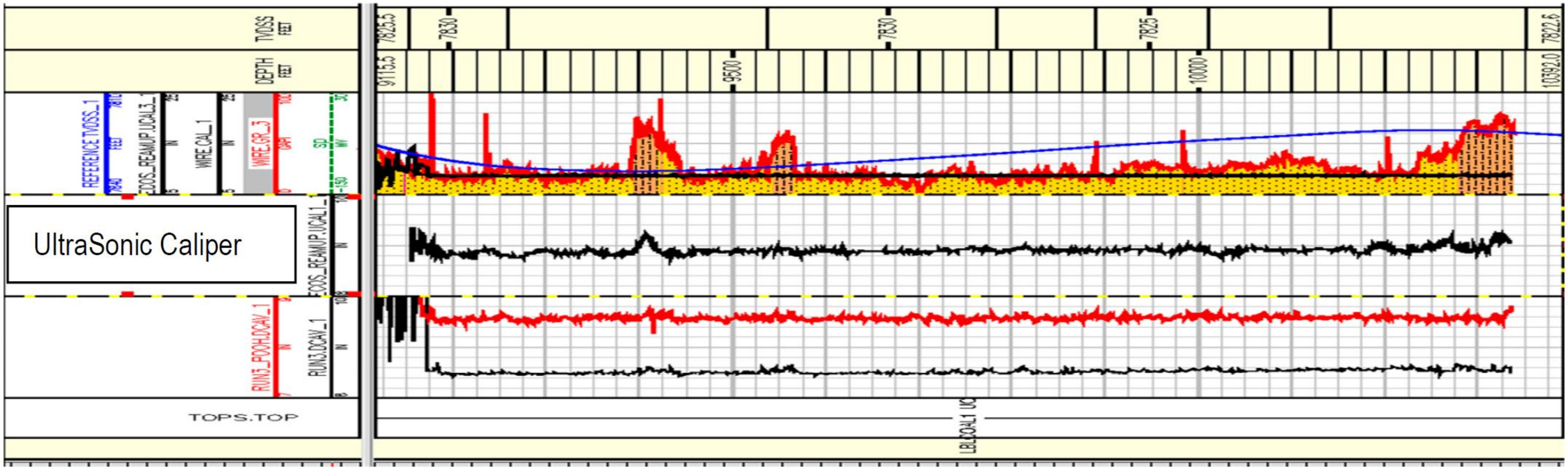

Figure 5. Ultrasonic caliper recording during pulling out of the hole.

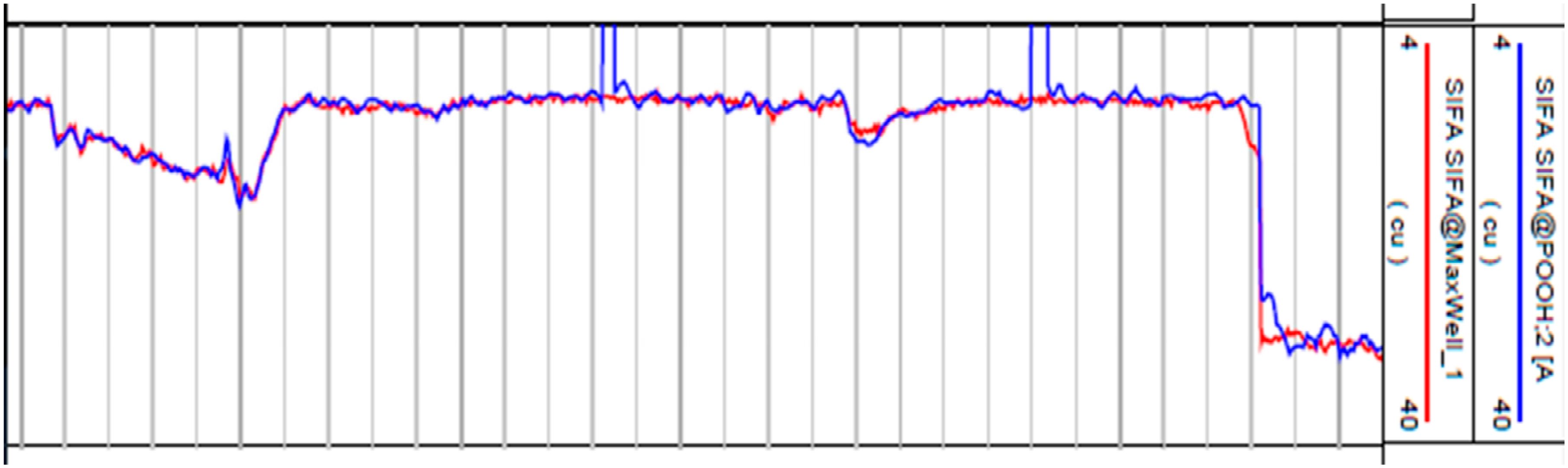

Figure 6. Time-lapse Σ results.

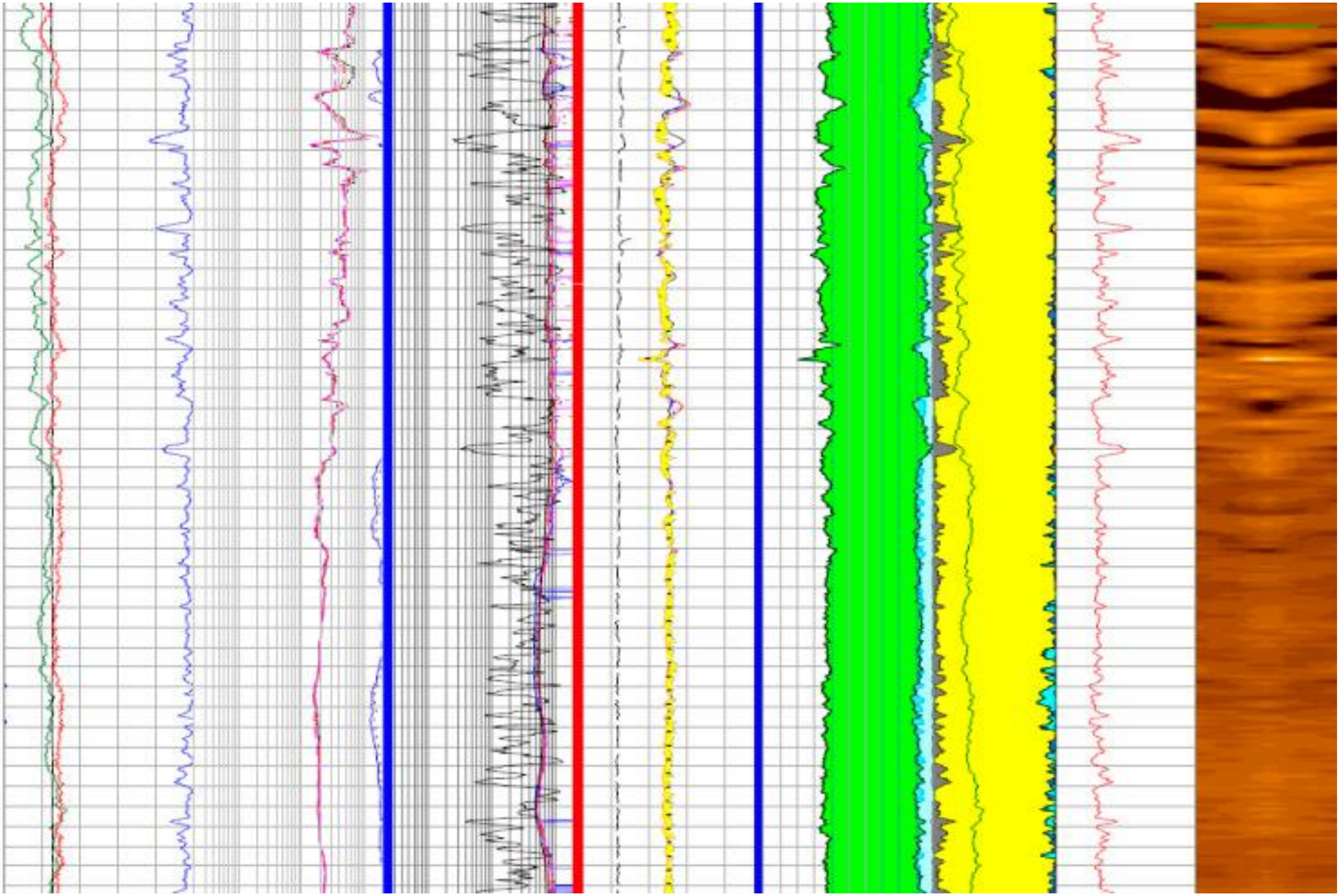

Figure 7. Spectroscopy analysis results.

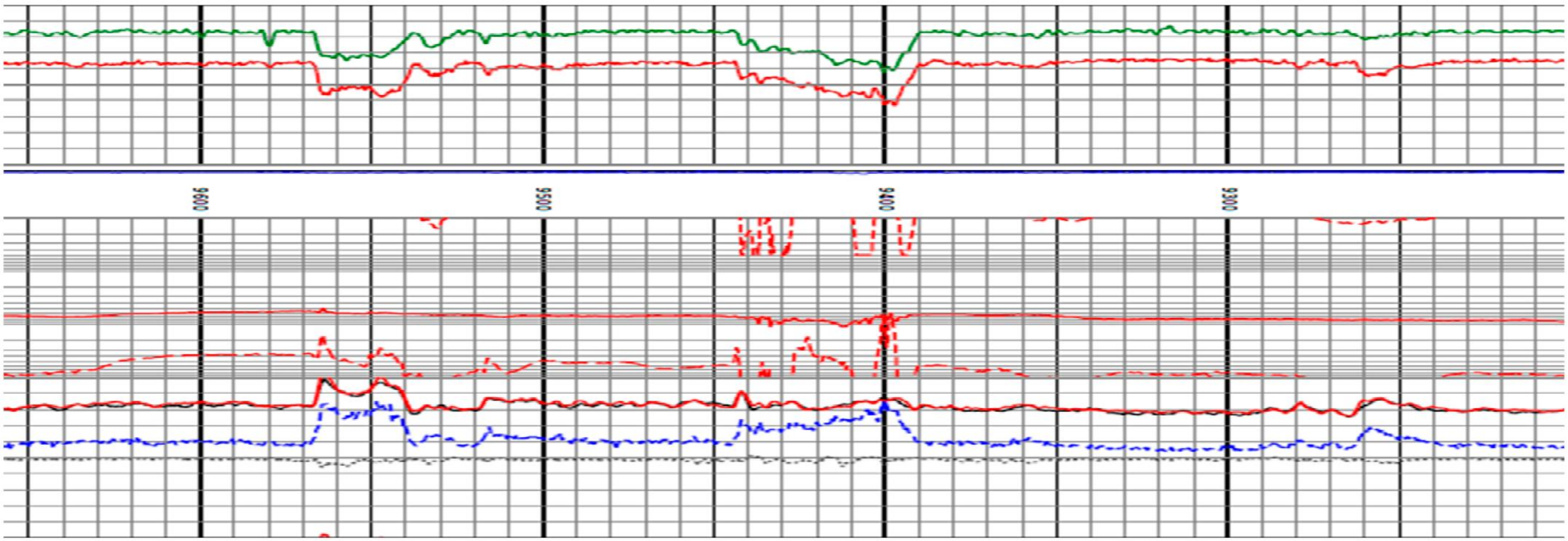

Figure 8. Sourceless density comparison with standard density.

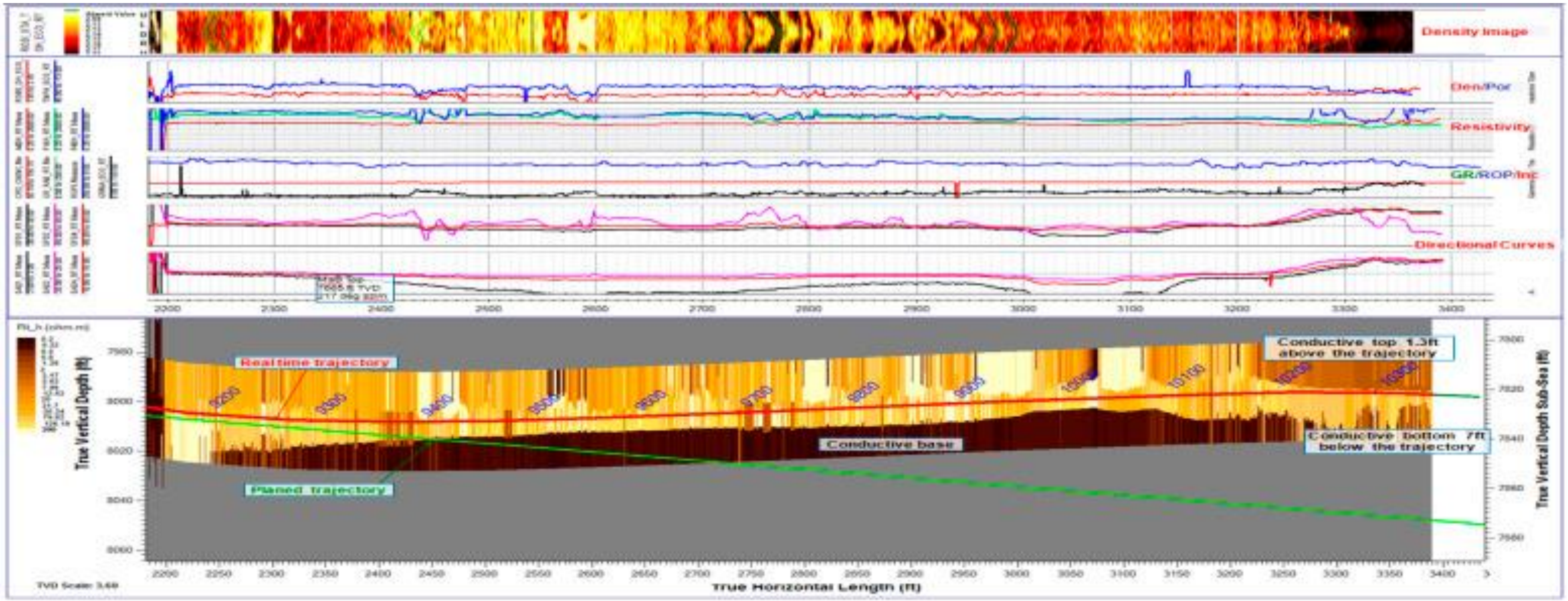

Figure 9. Final distance to boundary inversion result.