LWD Interpretation Newsletter
Image Derived Density (IDD)

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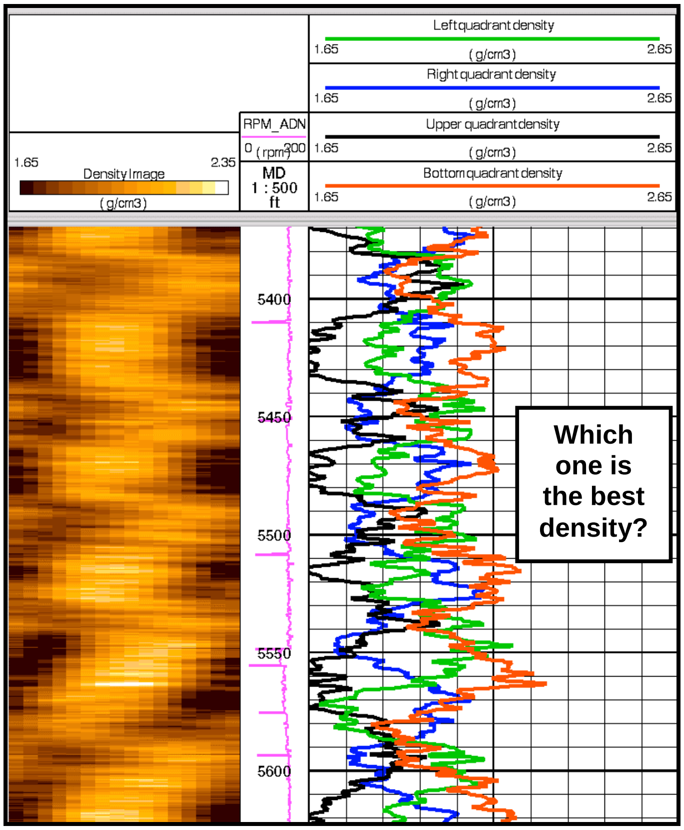


The Logging While Drilling (LWD) Azimuthal Density Neutron (ADN) tool measures the density of the formation in the borehole. When the borehole is deviated, the tool lies in contact with the formation by gravity. The measurements are carried out while drilling and rotating such as for each measured depth 16 values of the density are obtained. Those values can be displayed as an image of the borehole density. An average of the four bottom sector densities is taken to evaluate the formation density (Bulk Density Bottom, ROBB). However, the four-bottom sectors average may not always reflect the best density. Washouts, elliptical borehole and irregular tool paths (where "tool path" can be thought of as the area of closest proximity between tool and formation) are examples of more complicated density patterns. The goal of the Image Derived Density (IDD) is to improve the output density by extracting from the 16-density array the best possible value. The IDD processing is particularly useful for slick tools, but it can also improve data acquired with stabilized tools run in enlarged boreholes.

Theory

The IDD algorithm uses the bulk density image from an ADN to compute a single density. It identifies which sectors at each depth level provide the highest-quality density measurements and computes a density based on those sectors. By contrast, the bottom-quadrant bulk density (ROBB) is obtained by averaging the bulk density in the bottom four sectors. Due to motion of the tool in the borehole, these sectors may not yield the best density measurement (see example on the left). Hence, the density resulting from the IDD algorithm is generally more representative of the formation density than ROBB.

The algorithm consists of three steps:

Quality factor computation. For each depth level and sector, the short- (RSSC) and long-spacing bulk density (RLSC) and volumetric photoelectric factor (USC) are used to compute a quality factor. The quality factor is based on qualitative expectations and an empirical choice of parameters. Larger quality factors represent more accurate density measurements.

Tool path identification. As a function of depth, the centroid of the region of high-quality measurements defines a "tool path". The "tool path" can loosely be thought of as the path of closest approach of the tool to the formation. This path is computed from the quality factor at each depth level by a partial Fourier decomposition.

Density calculation. The density is computed at each depth level by averaging the bulk density (ROSC) over four sectors centered on the tool path. Fractional sectors are accounted for by linear interpolation. A special parameter (IDQT) allows the user to automatically toggle between the "tool path" density and the bottom quadrant density.

Quality factor computation. The quality factor is inspired by the spine-and-ribs approach, in which high-quality points lie near the spine. Consequently, it is parameterized by the apparent densities along and normal to the spine. For depth level i and sector α = 0, 1, 2, … 15, these densities are defined as

$$\rho_{i\alpha}^{\parallel} = \rho_{i\alpha}^{LS}$$

and

$$\rho_{i\alpha}^{\perp} = \rho_{i\alpha}^{LS} - \rho_{i\alpha}^{SS},$$

respectively. Here, $\rho_{i\alpha}^{LS}$ and $\rho_{i\alpha}^{SS}$ are the long- and short-spacing electron densities obtained from the corresponding bulk densities RLSC and RSSC by

$$\rho_{i\alpha}^{LS} = (\mathrm{RLSC} + 0.1883)/1.0704$$

and

$$\rho_{i\alpha}^{SS} = (\mathrm{RSSC} + 0.1883)/1.0704.$$

In addition, the apparent volumetric photoelectric factor $U_{i\alpha}$ stored in USC is used to indicate when the measured density is contaminated by high Pe mud.

The quality factor $Q_{i\alpha}$ at depth level i in sector α is defined as a product of a spine, a rib, and a U factor:

$$Q_{i\alpha} = F(\rho_{i\alpha}^{\parallel}; a_S, \Delta a_S, b_S, \Delta b_S) \times F(\rho_{i\alpha}^{\perp}; a_R, \Delta a_R, b_R, \Delta b_R) \\ \times F(U_{i\alpha}; a_U, \Delta a_U, b_U, \Delta b_U),$$

where F is a Fermi-type function (see figure on the right).

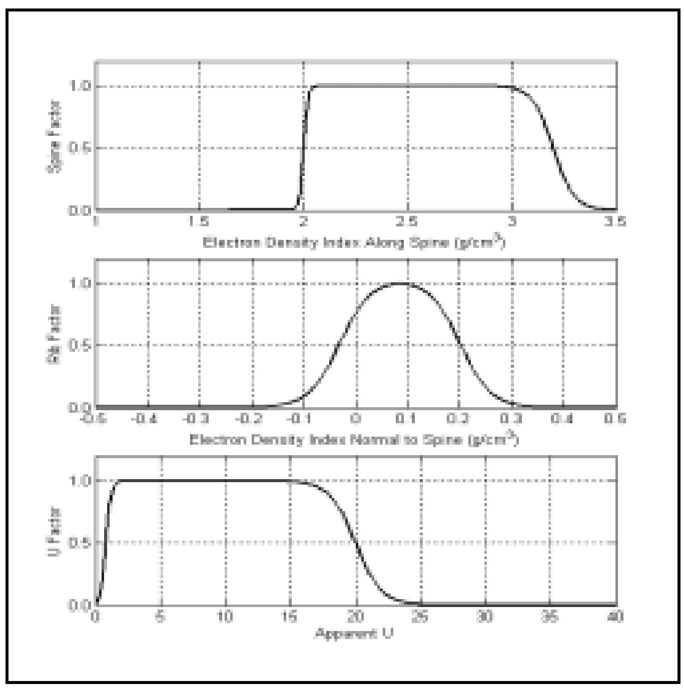
The individual factors have the following parameterizations:

The spine factor associates high-quality measurements with readings in the range of formation densities. It excludes low densities, which are more characteristic of the drilling fluid, and high densities, which are unphysical.

The rib factor connects high-quality measurements with small $\left|\rho_{i\alpha}^{\perp}\right|$. In the spine-and-ribs algorithm, $\rho_{i\alpha}^{\perp}$ is related to DRSC, the correction applied to RLSC to yield ROSC. Selecting small $\left|\rho_{i\alpha}^{\perp}\right|$ thus corresponds to situations that have generally low stand-off and correctable mud weight effects.

The U factor indicates high quality only when the measured U falls within values expected for a formation. Higher or lower values suggest that the measurement is contaminated by mud effects and is therefore of lower quality.

A graphic representation of the (provisional) spine, rib and U factors for ADN8 is presented below.



Path identification. Intuitively, the tool path at a given depth level is the centroid of the high-quality-factor region at that level. To make this idea quantitative and to reduce the effect of statistical noise, the centroid is obtained from a low-order Fourier expansion, so the effects of statistical noise (i.e., high-frequency components in the Fourier transform) are reduced.

According to this definition, the tool path is a continuous variable. This quantity is used in the density calculation and can be used to visualize the tool path (IDDP) on a density image.

Density calculation. At each depth level, the image-derived density is computed from the bulk density array (ROSC) by averaging it over an azimuth interval of width 4 sectors centered on path.

Combining logic. At this point, the software computes the IDD quality factor (QIDD), by averaging the quality factor along the tool path. A ROBB quality factor (QRBB) is obtained similarly, but for a path constantly centered at the bottom of the hole. Then, the normalized ratio of the two quality factors is computed as

$$IDQR = QRBB/(QRBB + QIDD).$$

where IDQR (Image Derived Quality Ratio) is a number between 0 and 1. Obviously, IDQR will be close to 0 when IDD is of better quality respect to ROBB, and closer to 1 when ROBB is better than IDD.

IDQT (Image Derived Quality Threshold) is a parameter specified by the user, and controls (together with the stabilizer size) what type of density (IDD or ROBB) is used to produce the Client's output IDRO (see "Processing").

An example of quality factor image (normalized to a 0 to 1 scale), tool path and image derived density is provided in Figure 1.

Range of applicability

There are situations where the use of the IDD is not recommended. An example is provided in Fig. 2, which shows the density image ROSC in track 4, the quality factor image in track 5, and the IDD and ROBB in track 1.

The tool (equipped with a full-gauge stabilizer) makes good contact all around the borehole. The quality factor is very similar for all sectors at any given depth, with no clear centroid. The slightest unbalance in the quality factor distribution is enough to drive the Fourier decomposition. As a result, the tool path wanders around the borehole erratically.

The situation is made worse by the presence of dipping beds. As the formation density is not homogeneous around the borehole, IDD is affected by what practically amounts to a variable depth offset. In such cases, ROBB is clearly a better option.

In general, for slick tools, or tools fitted with severely under-gauge stabilizers, IDD is the best answer. For a tool like ADN8 (that can only be run slick), IDD is the density of choice, and should always be of equal or better quality than ROBB.

For stabilized tools, it is up to the user to decide which one, between IDRO and ROBB (or RHOB, in vertical wells) provides the best answer. In some cases it may be necessary to combine the two logics in order to deliver a good log (see "Processing").

IDD is not an universal "fix" for all the issues that afflict density logs. It addresses the problem of a tool moving away from the bottom quadrant of the borehole, and it should be used accordingly. IDD can be used to extract a density log from badly oriented data (wrong "AngleX"). The algorithm cannot be used to repair data affected by problems such as spiraled borehole, sliding (!) and excessive standoff.

Processing

IDD is part of the commercial Ideal 7.1 baseline, and it automatically runs as part of the Recorded Mode data processing. A patch is also available for Ideal 7.0.

IDQT and ADN_SSIZ (ADN stabilizer size) are the parameters used by the algorithm. The software uses ADN_SSIZ value to determine whether the tool is stabilized or slick (for example: an ADN6C would be considered "slick" when ADN_SSIZ=6.93").

If the tool is stabilized, the following logic is used:

Quality threshold parameter (IDQT)	Image derived output (IDRO)
IDQT=2 (default)	IDRO=ROBB
IDQR lower then IDQT	IDRO=IDD
IDQR equal or higher then IDQT	IDRO=ROBB

Table 1: Combining logic for stabilized tools

In other words, when the tool is stabilized, IDD is used only when IDQR is less then IDQT.

If the tool is slick:

Quality threshold parameter (IDQT)	Image derived output (IDRO)
IDQT=2 (default)	IDRO=IDD
IDQR lower then IDQT	IDRO=IDD
IDQR equal or higher then IDQT	IDRO=ROBB

Table 2: Combining logic for slick tools

This means that IDD is always used, unless IDQR is greater than IDQT.

As previously mentioned, for some logs ROBB may be preferable to IDD, and there are situations where only a combination of the two is the best answer. Such would be the case of a fully stabilized tool in a washed-out hole, where ROBB and IDD are the density of choice in the good sections and in washouts, respectively. This is the case of the example shown in Fig. 3: an 8.5 in. well logged with a stabilized ADN6. The large washouts at the top of the borehole are better handled by IDD, while ROBB is preferred where the borehole is in gauge. The combined output IDRO was produced using an IDQT=0.4

Leaving IDQT at the default value ("2") disallows the combining logic. IDRO=ROBB for stabilized tools, and IDRO=IDD for slick tools.

The IDQT parameter is zonable, thus providing the flexibility necessary to handle complex situations (washouts, tool motion, dipping beds, etc.).
The same logic is used to derive IDDR (Image Derived Density Correction), IDU (Image Derived volumetric photoelectric factor) and IDPE Image Derived Photoelectric Factor).

Processing hints and QC

ADN8

The ADN8 is a slick tool, run in relatively large boreholes. The quality factor distribution is normally "pointed", with a well defined high-quality region. The Fourier transform has no problems deriving the correct tool path, and the IDD density is normally of equivalent (or better) quality with respect to ROBB. Therefore, the user should keep IDQT=2. An example of IDD applied to ADN8 data is provided in Fig. 1.

It is always recommendable to compare IDRO to ROBB. The tool path (IDDP) should be reasonable (riding the "crest" of the quality factor distribution) and stable.

ADN6 and 4 slick

Most of the considerations made for ADN8 are also valid for slick ADN6 and ADN4 tools. In most cases, IDD is preferable to ROBB. IDQT should be left at default value, at least for the first pass.

In small boreholes and light muds, even slick tools are sometimes able to measure good quality density all around the borehole. This might result into a relatively flat quality factor distribution, and consequent erratic tool path.

Verify that the tool path is stable, and compare IDRO against ROBB. In case of problems, check the IDQR average value in the troubled sections and re-process with IDQT set just below it.

ADN6 and 4 stabilized

A first pass should be made with IDQT left at the default value. ROBB would probably be the best answer for this type of configuration, unless the tool is fitted with an under-gauge stabilizer, or the borehole is seriously washed-out. If the tool has an under-gauge stabilizer, check the IDQR average value, and set IDQT above it. In case of washouts, check the IDQR value in the bad sections and set IDQT above it.

Vertical holes (all tools)

In theory, IDD should be better than ROBB in vertical holes. However, this particular situation has never been tested with real data, and should be approached with particular care.

Deliverables

The Ideal7.1 Recorded Mode processing produces the following outputs:

IDRO: Image Derived Density

IDDQ: Density Quality Factor Image **IDQS:** Density Quality Factor Image, scaled

IDDR: Image Derived Density Correction

IDDP: Tool Path

IDQR: Image Derived Quality Ratio

IDU: Image Derived Volumetric Phot. Eff.

IDPE: Image Derived Phot. Effect

QIDD: Tool Path Quality Factor

QRBB: Bottom Hole Quality Factor

IDQT: User Set Quality Threshold

Note: In sliding sections, IDRO and ROBB have the same value.

Note: for ADN8, the RHOB channel is set equal to IDRO. For ADN4 and ADN6, RHOB is still the average density.

GeoFrame

The IDD computation will also be implemented in the PrePlus module of GeoFrame.

All the Ideal IDD outputs can be displayed in GeoFrame using WellComposite Plus. The IDDP (tool path) channel, however, requires some attention. IDDP is expressed in terms of number of sectors that the tool “contact point” (path) has crossed from the beginning of the acquisition. Consequently, it can assume quite large values, either positive (clockwise rotation) or negative (anti-clockwise rotation). It is advisable to use the “shifted curve” option to display IDDP. The scale must be a multiple of 16 (-16-0, 0-16, 16-32, etc.).

3D Visualization

Displaying the scaled quality factor (IDQS) on a 3D representation of the borehole can be quite useful. WellEye, synchronized with the 2D viewer (Fig. 5), allows the user to easily identify ROBB issues related to tool motion, hence fixable with IDD.

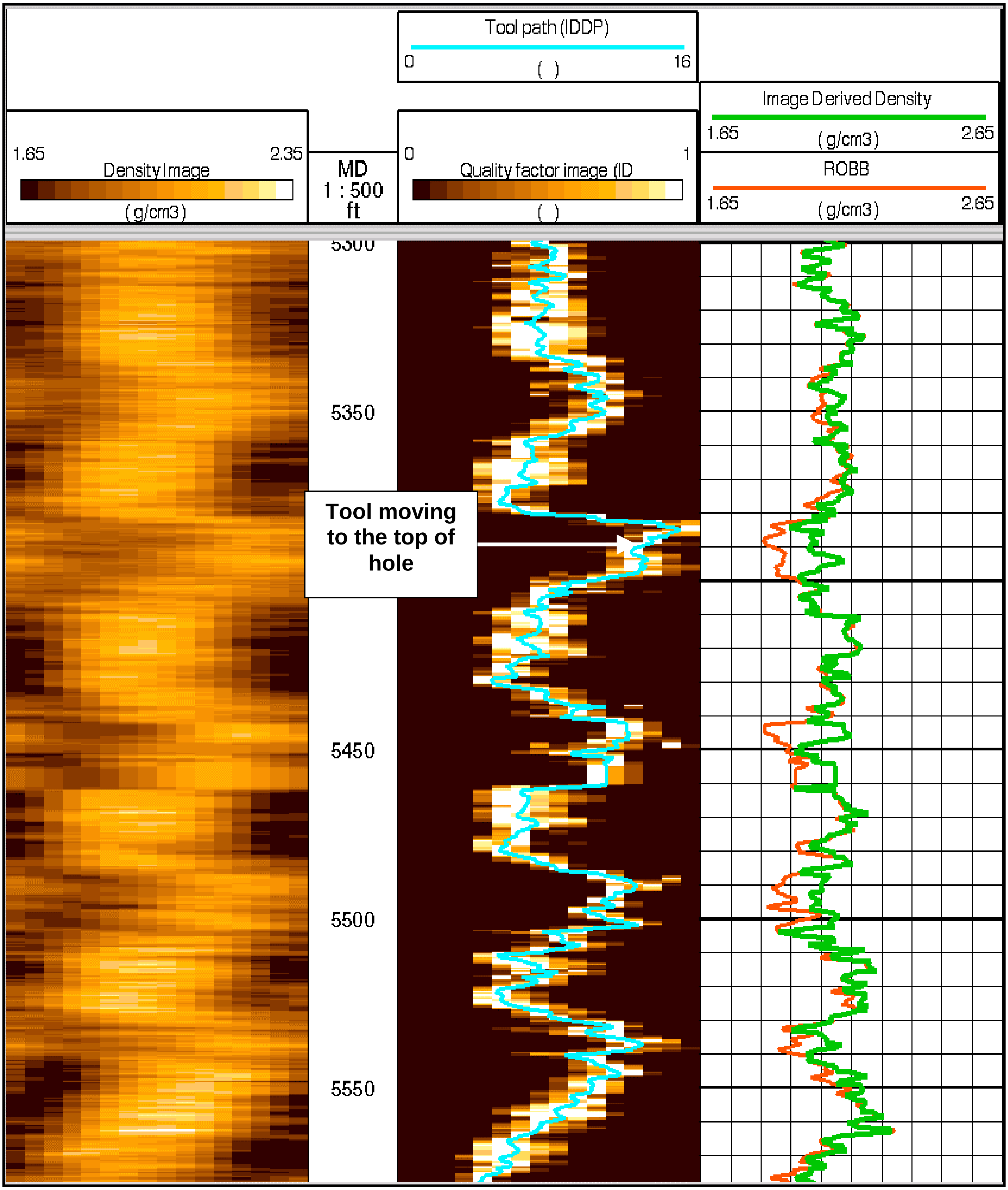


Figure 1: Example of IDD applied to ADN8 data (data not released)

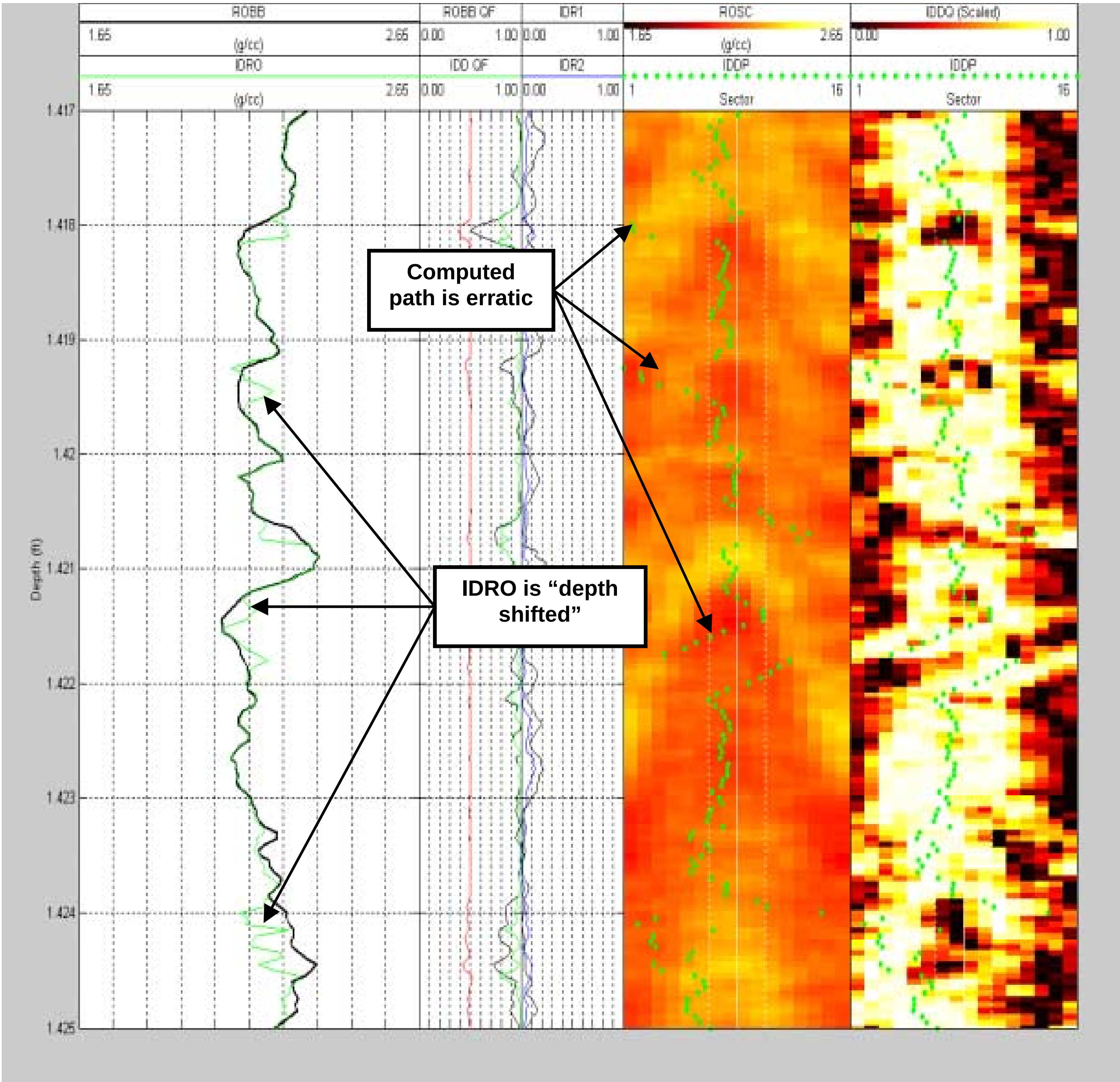


Figure 2: IDD should not be used when the tool is stabilized and the borehole is in gauge

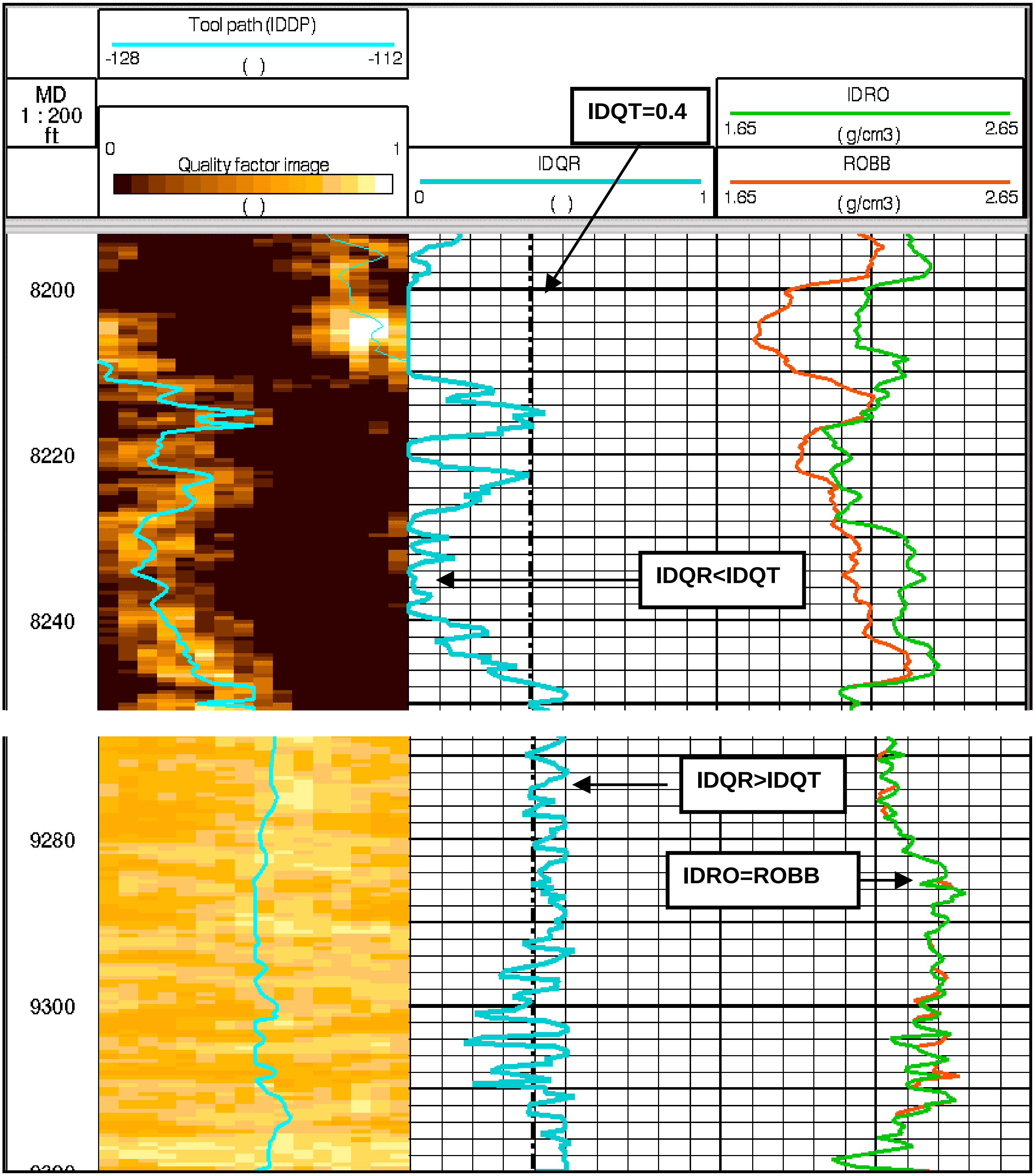


Figure 3: Combining logic for stabilized ADN6 (data not released)

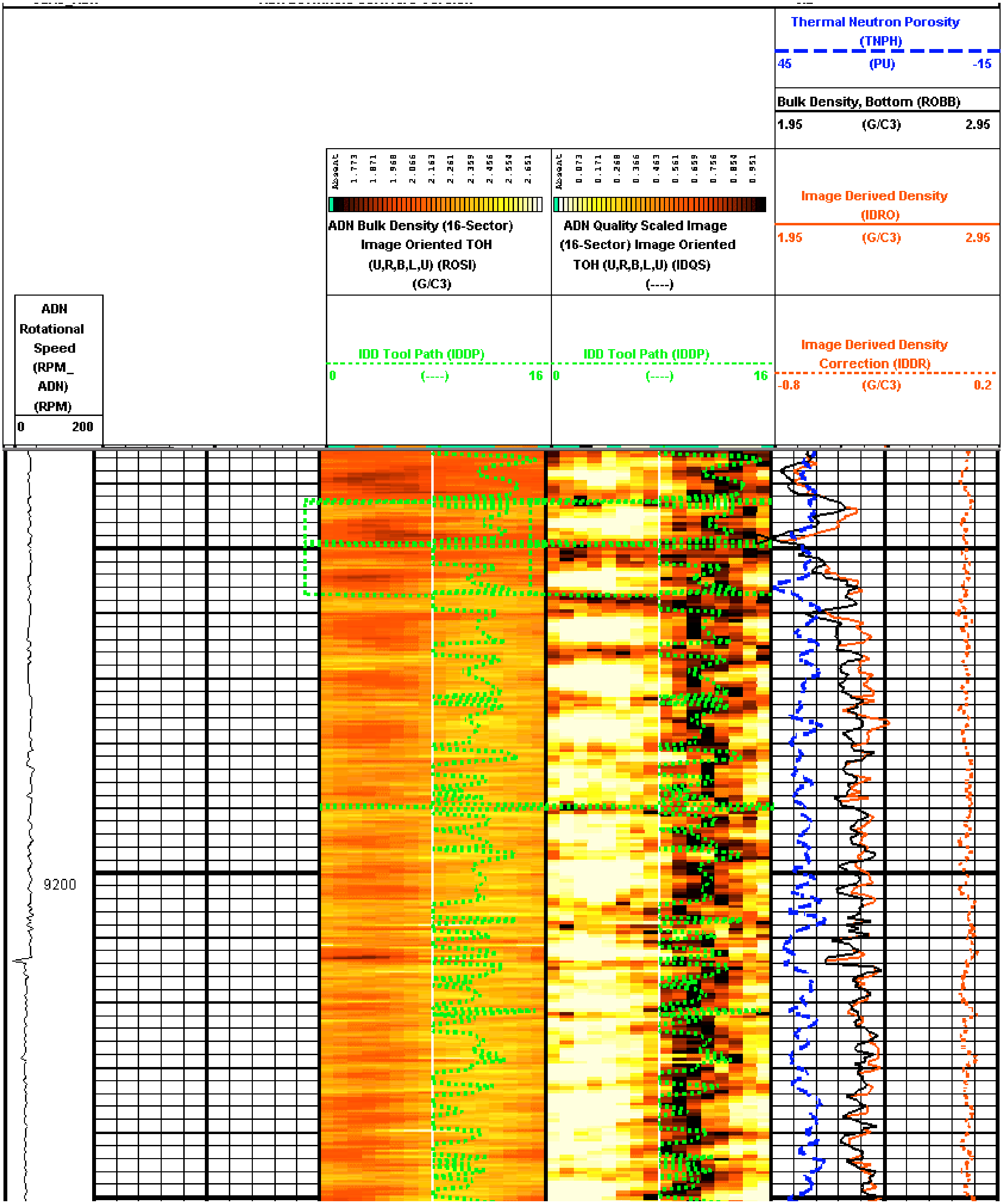


Figure 4: “ADNDenIDDImage” presentation in Ideal (data not released)

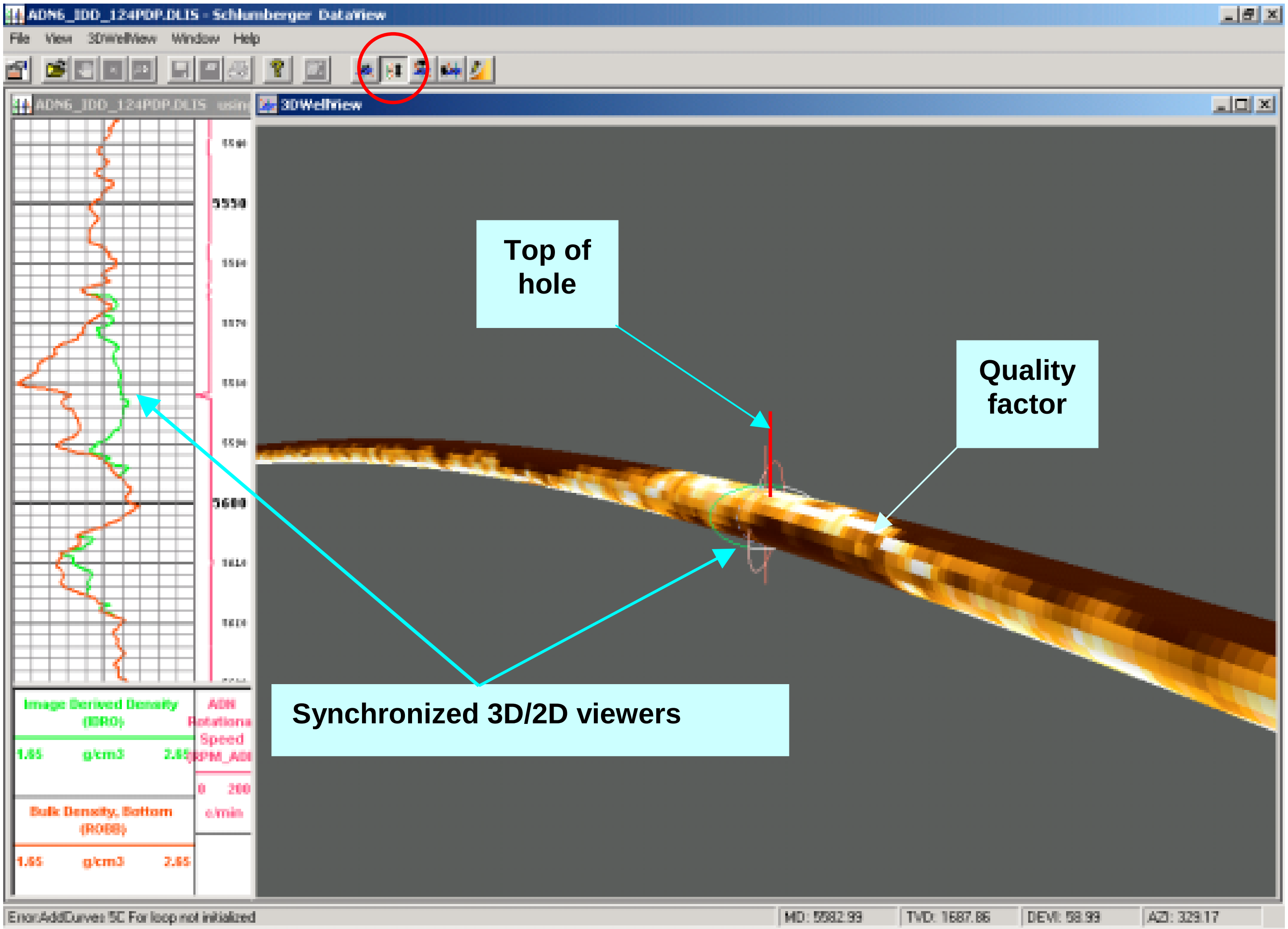


Figure 5: 3D visualization of quality factor (IDQS) distribution