

## Short-Axis Orientation of Tandem Density Toolstrings in Inclined Wellbores Subject to Elongation

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### ABSTRACT

The drilling of boreholes in certain geographic regions is often significantly influenced by the presence of non-homogeneous in-situ stress fields. One commonly observed phenomena is the development of breakout in the axis of the hole parallel to the minimum horizontal stress direction. This typically results in elongated (elliptical) wellbores that are frequently rugose along the axis of elongation. Virtually all wireline-conveyed open hole density logging tools incorporate a mechanical caliper to ensure pad contact with the borehole wall. In elongated wellbores, poor density data is often acquired, as this design predisposes the tool to rotate into the long (rough) axis of the hole. Various short-axis running gear and tool configurations (for example, 90-degree bowsprings, 90-degree calipers and, more recently, dual or tandem-density toolstrings) have been utilized to improve density acquisition.

However, the industry has witnessed a steady increase in the proportion of wells being drilled directionally, and correspondently, the mounting realization that even fairly low wellbore inclinations (of 10-20 degrees) can render standard short-axis orientation tactics ineffective.

This paper seeks to analyze the behavior of tandem density toolstrings in directionally drilled wells, especially when subject to elongation. It also attempts to present a general methodology, as well as specific recommendations, for improving the acquisition of wireline density data in low to moderately inclined wells, even when they are drilled directionally along strike into the breakout or minimum horizontal stress direction. A number of log examples illustrate how standard density logging tools were successfully configured in an orthogonal arrangement, with related running gear, to restore consistent short-axis orientation, maximizing pad contact and increasing the probability of acquiring usable density data. Assuming that at least some portion of the wellbore is less rugose, the technique described affords more dependable density measurement in deviated wells.

### INTRODUCTION

Acquisition of valid bulk density log data in the foothills area of Alberta has been a recognized challenge since the introduction of gamma-gamma density logging technology in the 1960s. Over the years, various technological advances have limited the extent of the problem, but under certain circumstances it is still difficult (or impossible) to get a good bulk density log. For the most part, innovations have focused on trying to turn the toolstring in the hole so that the density skid consistently faces the short (and presumably smooth) axis of the hole.

A number of exploration and production companies active in Western Canada have made it a standard practice to run so-called “dual density” or “tandem density” tool configurations in the Foothills and Deep Basin areas. The intent is to increase the probability of acquiring valid density data. Overall, the strategy has worked. Recently, however, the number of wells drilled directionally has risen. The prevailing practice in deviated wellbores is to avoid running dual-density toolstrings or to close one tool if inclination appears to be interfering with data acquisition. Sometimes the data is just accepted “as is”. However, even at moderate inclinations, a significant increase in the incidence of density acquisition problems is observed. It is clear that improvement is needed with respect to bulk density logging in directional wellbores.

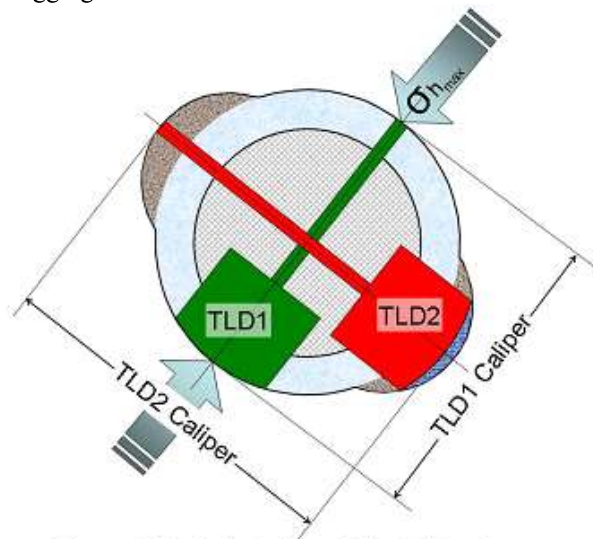


Figure 1. Typical dual density toolstring, in a vertical well with breakout

**IDENTIFICATION OF THE PROBLEM**

After logging over 100 wells in the Ansell-Galloway area of Alberta, many of them directionally, some degree of insight has been gained into the nature of the logging tool behavior. Figure 1 is a schematic of a typical dual-density toolstring in a vertical wellbore with breakout in one axis. The advantage of the dual-density tool configuration is obvious: although the measurements made by one of the tools may be affected by borehole breakout, the other density still acquires good data.

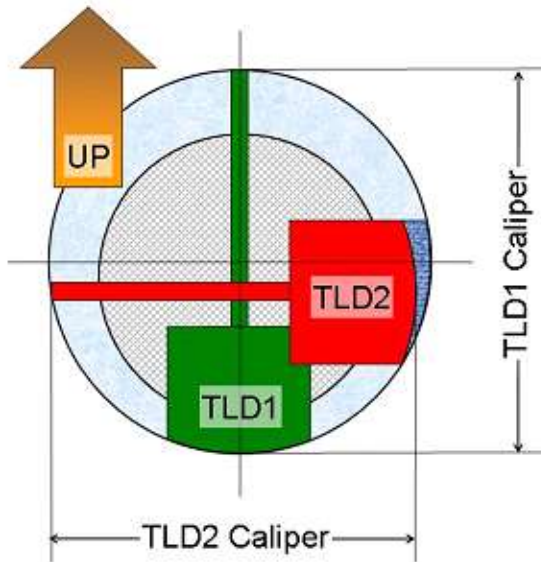


Figure 2. Typical dual density toolstring, inclined wellbore, no breakout

Figure 2 illustrates what happens with inclined wellbores. The important thing to note here is that, in deviated wells, there will be a tendency for one tool (TLD1) to turn into the low side of the hole. The weight of the toolstring tends to pull the other density tool (TLD2) towards the low side of the hole. Consequently, the TLD2 caliper makes an under-gauge measurement, and the density skid exhibits poor pad contact with the borehole wall, degrading the density measurement.

Figure 3a combines wellbore inclination with borehole breakout. Here TLD1 is oriented pad-down, but finds good hole and makes an acceptable measurement. TLD2 is affected by breakout and is also off-center in the hole. The resulting density measurement has reduced confidence (high density correction) and the caliper underestimates hole volume. However, as long as one tool is oriented toward the smaller axis of the

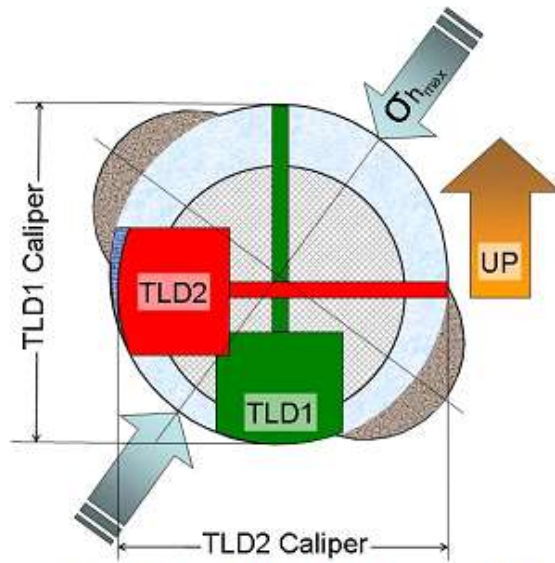


Figure 3a. Typical dual density toolstring, inclined wellbore with breakout, case 1

hole, there is a good chance that there will be sufficient pad contact to make a viable density measurement.

Figure 3b illustrates another possibility in an inclined wellbore with breakout. As inclination increases, the tools may display a tendency to “fight” each other to go pad-down. As a result, both may end up deployed across a chord of the wellbore. Both calipers will read under-gauge and neither tool will record trustworthy data. In such cases, it is generally preferable to run a single density tool, or close one density to allow the other to orient into the low side of the hole.

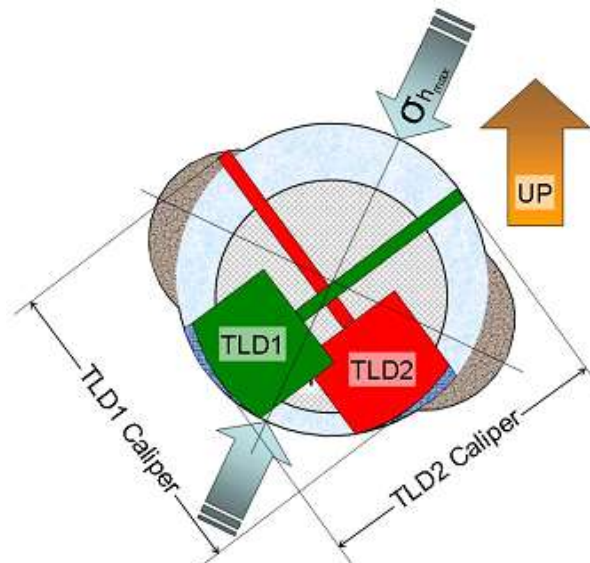


Figure 3b. Typical dual density toolstring, inclined wellbore with breakout, case 2

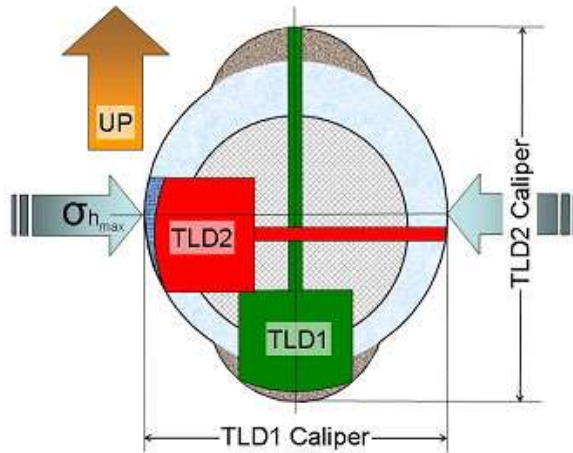


Figure 4. Typical dual density toolstring, inclined wellbore with breakout, drilled on strike

Figure 4 illustrates a situation in which it is doubtful that any useable data will be acquired by the typical tandem density toolstring. In this case, the well has been drilled in the direction of the least principal stress. One tool will go pad-down into the breakout and acquire bad density data. The other tool, although adjacent to smoother borehole wall, will exhibit poor pad contact, register an under-gauge caliper and record density data that will most likely be of diminished quality.

The scenarios presented in the schematic diagrams underscore the importance of toolstring position. In many cases, although one (or both) of the density skids may be facing “good” (smooth) hole, eccentricization of the toolstring causes poor pad contact and prevents reliable density measurement from being made.

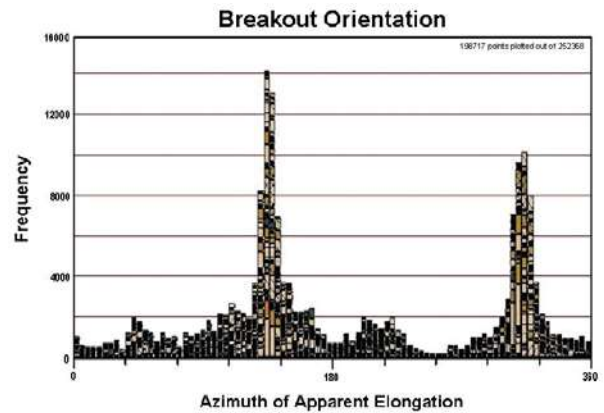
### LOG EXAMPLES AND DISCUSSION

The data presented herein deal with the implementation of a “Powered Positioning Caliper “ (PPC™) into a tandem density logging string, in such a manner as to support and center the upper density tool. This configuration has led to an increase in the proportion of useable density data acquired per well. Furthermore, because the PPC design records four independent radii and incorporates a relative bearing measurement, the configuration has yielded some valuable insights into the nature of tool behavior in deviated wellbores. Notably, it would appear that “centralization” of the toolstring (in the context of this document) is as important as trying to force or “lock” one density pad into the “good” side of the hole. In addition to improved bulk density measurements, the toolstring increases the accuracy of the calipers, yielding a more trustworthy calculation of hole volume.

Data from 28 wells were evaluated for this study. All were drilled with 200 mm bit size and oil-based drilling

fluid. Directionally, there was a broad sample of wellbore paths. Four of the wells were chosen as examples for this paper. One is an example of a dual density run without the PPC, for comparison. For deviated wells in the study area, the data indicates that the primary (lower) density tool usually faces toward the “down” direction (lower quadrant of the wellbore). For consistency, we will refer to the primary density as the “down-density”. The tool at 90-degrees will be referred to as the “side-density”. Note that the corresponding density measurements from the tools are RHOZ (from TLD1) and RHOZ2 (from TLD2). Although the HDRA measurement from the TLD density tool is not a conventional density correction, for our purposes it is considered an indicator of density quality analogous to DRHO.

By correlating apparent breakout (as determined from the relative correction between the density tools) with pad one azimuth, it was confirmed that wellbores in the area of study consistently exhibit ovality, with the direction of elongation being oriented in a NW-SE direction (see Fig. 5). This was expected, as was the fact that vertical wells drilled in the area tended to drift to the NE (into the dipping strata).



Referring to the log examples at the end of the paper, the log presentation used is intended to help understand the data with reference to the position of the toolstring in the hole. Track 1 is a correlation track, with gamma ray and ROP, as well as both of the density calipers. Track 2 is the resistivity data presented in conjunction with the gas detector readings. Next, a porosity track contains the sonic travel time, neutron porosity and the bulk density data from both tools. The final track shows the PPC calipers and directional data, including the relative bearing of the primary density pad and the deviation measurement from the neutron tool. Hole direction and inclination from MWD tools (if run) are presented as green tadpoles for comparison with the red tadpoles, which represent the inclination and azimuth of the down-density pad.

Light grey shading is used when the side-density correction is greater than the down-density correction. Light green shading is used where the down-density correction is greater than the side-density correction. The density and PPC calipers are shaded in a similar fashion. This shading scheme allows us to quickly identify the breakout axis, as green shading should correspond to breakout on the top and bottom of the hole (i.e. along the same azimuth as the hole deviation) and grey shading should represent breakout on the side of the hole (perpendicular to hole azimuth).

#### **Example #1 - Vertical Well**

Well #1 (see Fig. 6) was a vertical well that drifted a little to the NE. Throughout the zone of interest, breakout is visible on TLD2, which has assumed a NW-SE orientation. At first glance, this example appears to show a change in the breakout direction, with breakout occurring in one axis of the hole in the sand, and in the opposite (orthogonal) axis for the overlying shales. However, scrutiny of the orientation data reveals that the toolstring turns by almost 90 degrees coming out of the sand. Therefore, the side-density (TLD2) sees the breakout in the sand and the down-density (TLD1) sees the breakout in the shales. This example demonstrates how toolstring behavior is often unpredictable in response to varying borehole geometry. Nevertheless, for this well, the dual density configuration was successfully able to acquire good data throughout (most of) the zone of interest.

#### **Example #2 – Northwest Deviated Well**

Well #2 (see Fig. 7) was drilled to the NW with a bottom-hole inclination of about 10 degrees. No PPC was run and an LDS was used as the 90-degree density. The LDS caliper reads strongly under-gauge and it appears to be riding below the centerline of the hole, as reflected in the high LDS correction values. Some breakout can be seen on the down-density (TLD) at the top of the sand. Given the regional stress orientation and the path of the well, the good axis should have been the “side” of the hole. Without a PPC to support it, the LDS did not achieve good enough pad contact to capture reliable density data. Luckily, it would appear that the lower portion of this wellbore did not develop particularly strong breakout, as evidenced by the low correction readings seen from the TLD. On the other hand, in the zone of interest, the breakout on the low side is significant and, consequently, the TLD correction looks very poor. It is interesting to note that although HDRA (the “correction” from the TLD) appears to be worse than DRH (from the LDS) in the zone of interest, the resulting TLD density measurements appear to be more reasonable than those obtained from the LDS.

#### **Example #3 – Northwest Deviated Well**

In well #3 (see Fig. 8) the orientation data shows that the down-density (TLD1) has locked into the low side of the hole. As expected from the prevailing NW-SE breakout direction, the resultant data is of poor quality. However, the PPC is hoisting the side-density (TLD2) into good contact with the smooth axis of the hole, and the ensuing density data is quite good. This is an example where it seems unlikely that good density could have been acquired, even with tandem density tools, without the aid of the powered positioning calipers.

#### **Example #4 – Southeast Deviated Well**

This example (Fig. 9) was also drilled along strike, but to the southeast. It may be expected from the extent of the rugosity displayed on both the density and the PPC calipers that it would be very difficult for any density tool to acquire useable data in this well. The fact that the TLD2 caliper agrees with the corresponding PPC caliper confirms that the PPC is supporting the side-density sufficiently to allow for a good density measurement to be made. It is apparent from the acceptable HDRA2 readings that the side of the hole is where the tool needs to be positioned in order to make a good density measurement. Without the PPC, this would not have happened.

Examples #3 and #4 illustrate how use of the PPC has enabled more dependable acquisition of formation density data and afforded a better understanding of wellbore geometry in three dimensions. For the data set under study, it was found that most wells display breakout along one axis. As such, the density tool in that axis will not deliver accurate density readings. However, it will confirm the presence and magnitude of the breakout. The density tool in the opposite axis, more often than not, will offer a valid density measurement (or the best available).

On a number of occasions, experimentation was undertaken with opening only one of the density skids, to see if this would influence the path taken by the toolstring. Remarkably (or perhaps not so), it was found that, in most cases, the toolstring will lock into the same path on multiple passes, regardless of the wellbore inclination. In vertical wells, or wells with low inclinations (less than +/-3 degrees), tool orientation tends to be governed by the breakout axis. At higher deviations, gravity comes into play and the down-density (TLD1) tends to roll into a facedown attitude. This explains why moving the tool up and down in moderately inclined wells often fails to persuade the density tool to take the “good” axis.

In some cases, both axes of the hole exhibit deterioration and valid formation density data is

inaccessible. Running the PPC helps to deal with the troublesome question of whether good density data was even available. Knowing this, in itself, is useful information. In deviated wellbores, without the PPC, if both density calipers read under-gauge (as is often the case) then we are unsure as to whether there is breakout (or washout). When the PPC is run, the density tools are more likely to “see” the true hole geometry. Even so, despite the orthogonal orientation of the density calipers, they do not make simultaneous measurements at the same depth, and any inferences with regards to hole geometry are therefore subject to error due to tool rotation. The PPC, by contrast, measures four independent and instantaneous radii, providing very good verification of hole geometry.

It is interesting to note that some of the studied wells show very little breakout through the interval of interest. In other wells, the pay interval(s) appear to exhibit significant breakout (as opposed to washout) in both axes. A potential avenue for further investigation would be to check the production rates of these wells to see if there is any correlation between hole failure and inflow performance.

## CONCLUSIONS

Until recently, it would seem that the prevailing mindset for obtaining reliable density data in elongated wellbores has been to use mechanical means to forcibly lock one side of the toolstring into the long axis of the wellbore. Tandem density logging improves on this by adding another density skid at 90 degrees, with the expectation that one of the tools will encounter a smooth borehole wall. Logging companies have therefore designed toolstrings and running gear with an eye to accomplishing this end. For the most part, they have met with a good deal of success. Certainly, when logging vertical wells, the majority of the logging contractors operating in the Western Canadian Sedimentary Basin (WCSB) can field toolstrings that offer a reasonable probability of acquiring valid density data. However, when wellbores deviate (by accident or design) with inclinations as small as 3-4 degrees, the results obtained from these toolstrings can become somewhat hit-and-miss.

As regards the tandem density toolstrings currently available to the industry, at higher angles of deviation (greater than +/- 10 degrees) it may be more cost effective to stick with conventional, single-axis density tools. In wells drilled directionally along the orientation of the principal minimum stress, there may be very little chance of getting a reliable density from any of the commonly utilized tool combinations. In all wells evaluated so far, regardless of inclination or direction, the addition of certain hardware (such as the PPC) to aid in proper orientation/positioning of the toolstring

has increased the proportion of quality bulk density data acquired. Moreover, the understanding of the underlying conditions relating to the acquisition of the log data has been greatly enhanced.

The following recommendations are put forward towards increasing the probability of acquiring high quality density data in elongated, directional boreholes drilled through stressed formations. They apply for inclinations of up to 20 degrees in wells that exhibit elongation of the borehole (such as those along western flank of the WCSB), and especially if drilled along strike (into the minimum principal stress direction). The following strategy is proposed:

- 1) Run a toolstring that combines two density tools in an orthogonal orientation.
- 2) Configure the tools and related running gear in such a fashion as to emphasize centralization and support of the density tools in order to permit the density skids to deploy fully across the entire diameter of the wellbore, thereby optimizing contact with the borehole wall.

## ACKNOWLEDGMENTS

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## REFERENCES

Berger, Pierre and Leon Williams, 1993: Improved Formation Evaluation and Borehole Stability of Ovalized Wellbores, paper SPE 25322 presented at the SPE Asia Pacific Oil & Gas Conference, Singapore, February 8-10, 1993.

Cox, John W., 1983: Long Axis Orientation in Elongated Boreholes and Its Correlation with Rock Stress Data, paper "J" presented at the SPWLA 24TH Annual Logging Symposium, June 27-30, 1983.

Kimminau, S.J., and John Edwards, 1994: Tandem Density Logging in Rugose, Tectonically Stressed Boreholes, Oman, paper SPE 28408 presented at the SPE Annual Technical Conference and Exhibition, New Orleans, Louisiana, September 25-28, 1994.

## ABOUT THE AUTHORS

**Barry L Johnson**, P.Eng., is an independent consultant involved in the logging and evaluation industry. He specializes in wellsite logging supervision and log interpretation. After graduating from Engineering Physics at the University of Saskatchewan in 1975, he worked for a decade with Schlumberger in many capacities including field engineer, sales, operations management and senior log analyst. For the past 20 years, he has been involved in logging supervision and interpretation of land operations throughout Western Canada and the Northwest Territories as well as assignments offshore the Canadian East Coast and China.

**Harold S. Hovdebo** is a Senior Staff Petrophysicist for Husky Energy in Calgary, Alberta. He received a Bachelor of Geological Engineering degree from the University of Saskatchewan in 1983 and soon thereafter began a career as a logging engineer with a Canadian oilfield service company. He spent the next 20-plus years working in various logging-related positions, first domestically and then abroad. In 2005 he returned to Canada and joined Husky, where he is currently focused on logging operations and interpretation with the Deep Basin and Rainbow/Northwest Plains business units.

## Appendix – Logging Procedures and Operational Recommendations for Running Tandem Density Toolstrings

What follow are some practical procedures for consideration when running tandem density toolstrings:

- When using a "Powered Positioning Caliper" (PPC) or equivalent device, we recommend it be placed in the toolstring directly under the upper density tool, as close

to the density measurement skid as possible (see Fig. 10). In wells with higher inclination, it may be advantageous to incorporate more than one PPC into the toolstring (although this has not been investigated so far).

- Run the PPC with all arms extended at maximum pressure (full power, level 4) to ensure centralization of the side-density tool (TLD2).

- Exercise caution when interpreting relative bearing readings. The raw relative bearing is dependent upon the toolstring configuration. Our recommendation is to perform a relative bearing check with the toolstring hanging in the derrick.

- If logging passes off bottom do not show good density data, then try a repeat with only the down-facing density tool open (all other calipers closed). Changing the downhole forces acting on the tool may move it into a different orientation with better pad contact.

- It is advisable to make a minimum of three passes over the zone(s) of interest (if sufficiently close to the bottom of the well) to help wipe the hole and minimize the effect of any debris, as well as to verify any unexpected log responses. Two passes leave you in an either/or situation – a third pass should confirm one response or the other.

- When running tandem-density configurations, the use of same-generation density tools eliminates potential questions as to the source of any discrepancies between tools (i.e. there can no debate as to whether observed differences in tool response are related to tool type or caused by borehole geometry/tool attitude).

- When in smaller holes (e.g. 156 mm) 90-degree hardware cannot be run on the neutron, and a swivel head may help to limit tool rotation. It may be that a swivel head is helpful in any hole size. We have not endeavored to investigate the efficacy of the swivel so far, but we did log one well (outside the study area) using a dual-density toolstring with the PPC but without a swivel. The hole size was 156 mm and the toolstring exhibited rotation (normally related to cable torque) even though the wellbore inclination was in the order of 20 degrees.

- Initially, we were not sure of the influences on tool rotation. After reviewing the data from these wells, we are now of the opinion that, when the PPC is used and functioning correctly, borehole ovality caused by stress-induced breakout will tend to be the dominant factor affecting tool orientation.

- Logging tool orientation measurements are generally not reliable below about 2-3 degrees of inclination. This is a tool limitation and it is often noticeable when comparing MWD data with wireline. At higher angles,

the agreement on most wells was very good. On a few wells there may have been calibration issues.

- At very low deviations, the relative bearing may be influenced more by the attitude of the PPC in the toolstring than the actual borehole direction. Relative bearing is measured in the PPC, which is assumed to be centered in the hole. In reality, the PPC will not be positioned at the exact center of the hole. Fortunately, it is possible to use the four individual radii measured by PPC caliper arms to determine how far off center the tool is really located. Certain components of the toolstring (such as the sonic) are designed to be run centered in the wellbore. Others are meant to be eccentered (such as the resistivity and the density tools). Even with knuckle joints in the toolstring, the resulting moment influences on the PPC can pull either end of the tool out of alignment with the true borehole axis. So, if the wellbore inclination is very low, and especially in large or washed out holes, the PPC may actually end up leaning in a different direction than that of the wellbore (albeit only 1 or 2 degrees out of vertical). In such a case, the recorded PPC relative bearing will appear to be at odds with everything else the logging tools are telling us. This explains why we apparently observed breakout in the wrong axis in two vertically drilled wells. It is recommended that the individual radii from the PPC calipers arms be recorded to the log data files, as they may be an invaluable reference in such cases.

- An alternate service provider was used for a number of the evaluated wells. No equivalent of the PPC was available at the time of logging and, as may be expected, the data acquired suffered from poor pad contact in the deviated section of the hole. The density tools tend to read under-gauge in both axes, yielding a positive density correction of more than 50 kg/m<sup>3</sup> throughout the log. An extra run was performed in one well with additional offset joints in the tool string. The ensuing data was better, but still not optimal. Although the density measurements repeated well, the calipers remained under-gauge and correction was still quite high. The service company in question is presently working on potential solutions to better support and centralize the second density tool.

Figure 6. Log example #1

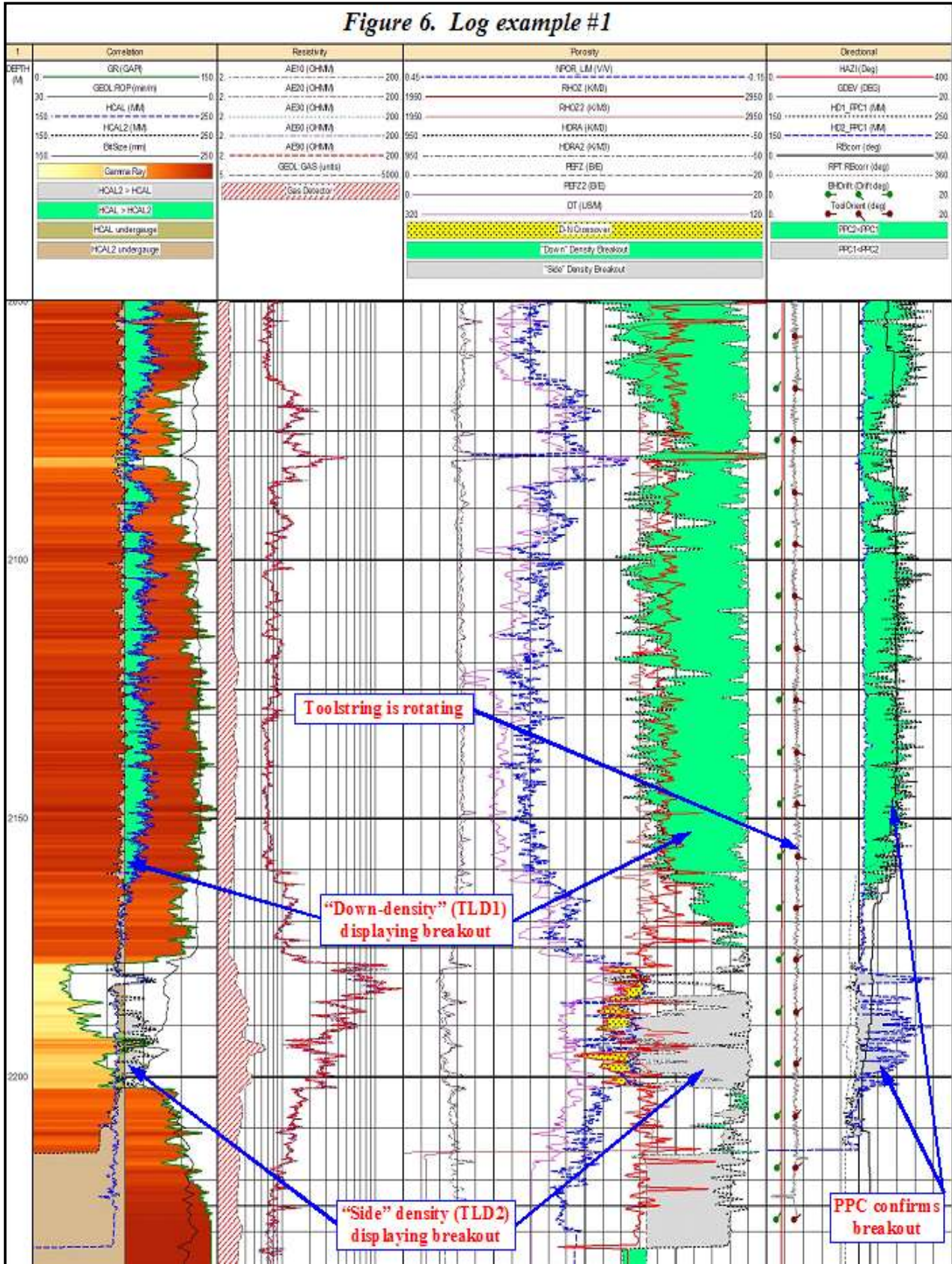


Figure 7. Log example #2

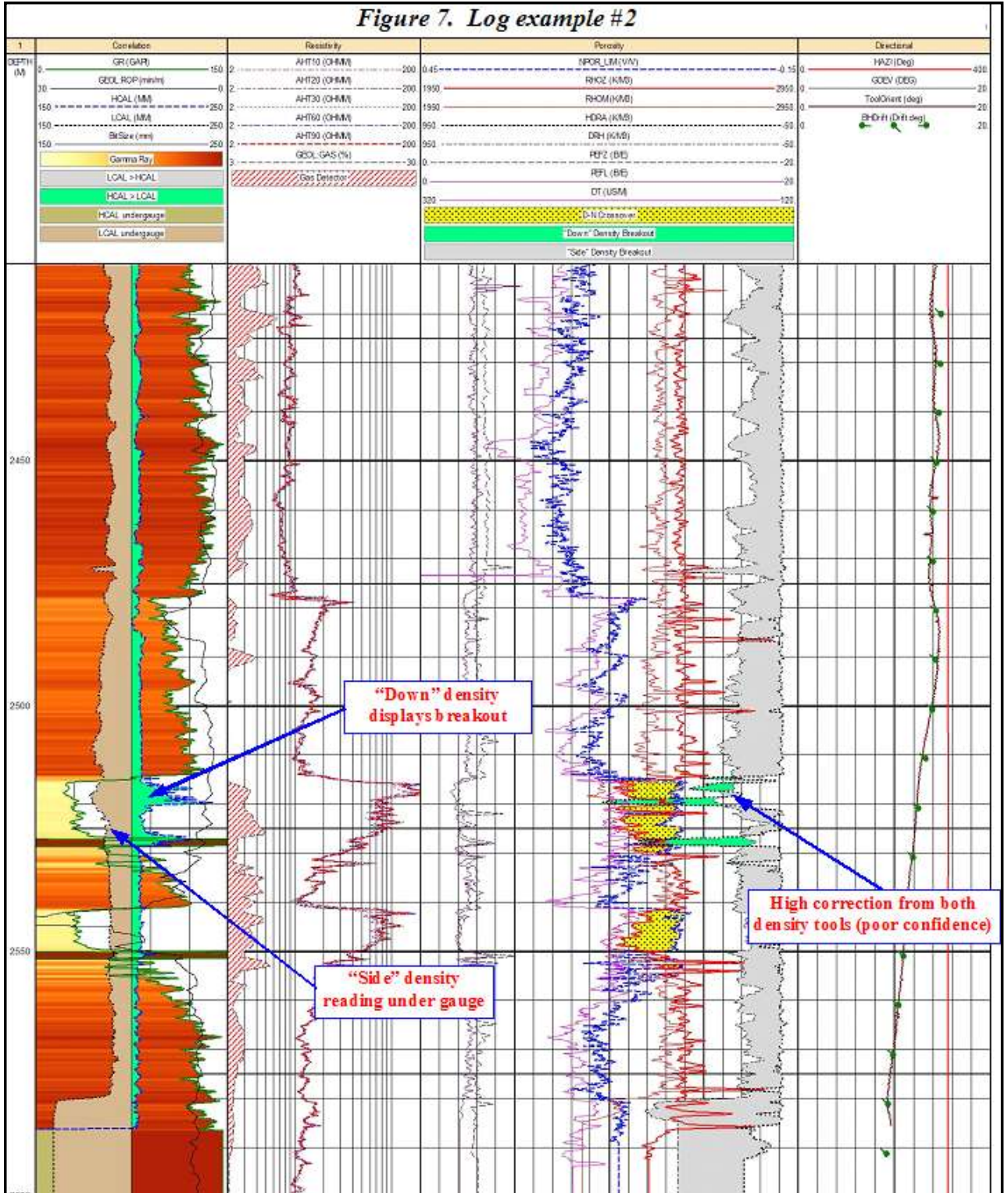


Figure 8. Log example #3

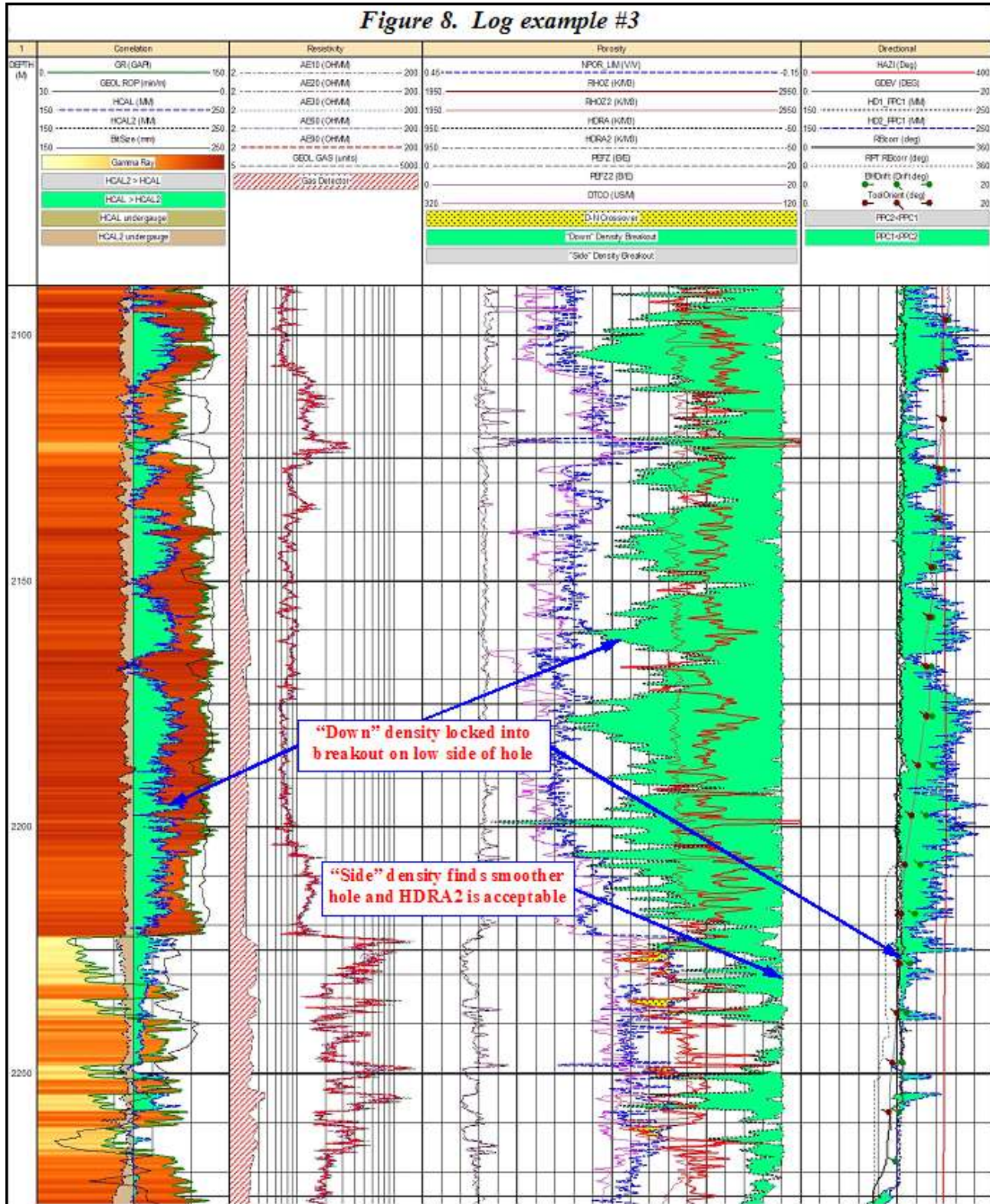


Figure 9. Log example #4

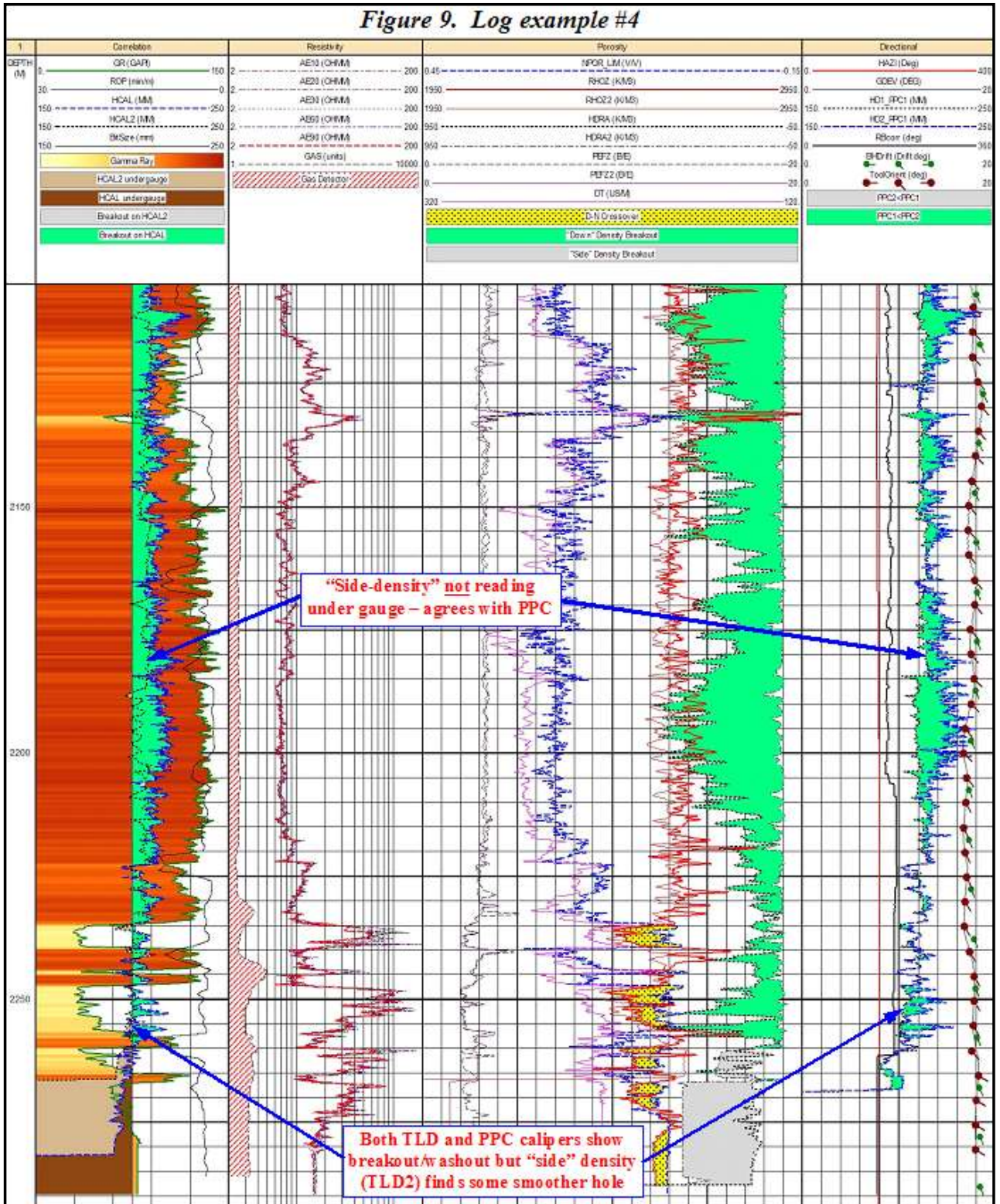


Figure 10. Typical Schlumberger Tandem Density Tool Strings with and without PPC™

