Improved Wireline Density Acquisition in Elongated, Directional Boreholes Drilled Through Stressed Formations of Western Canada

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Summary

Wells drilled in the WCSB, and particularly along the Alberta foothills, are influenced by the regional stress regime. In general, the minimum horizontal stress is oriented in a NW-SE direction, precipitating borehole breakout parallel to this trend2. The result is elongated (elliptical) wellbores that are frequently rugose along the axis of elongation. Density logging tools invariably incorporate a back-up caliper to maximize pad contact with the borehole wall. In elongated wellbores, poor density data is often acquired, as the tool design tends to "flip" the measurement section of the tool into the long (rough) axis of the hole. Various running gear and tool configurations (e.g. 90-degree bowsprings, 90-degree calipers and, more recently, "dual" or "tandem"-density toolstrings) have been utilized to improve density data acquisition, but deviated wellbores can render standard tactics ineffective.

This paper addresses methodology for improvement of the acquisition of wireline density data in low to moderately inclined wells (20 degrees or less), even when drilled directionally along strike into the "breakout" or minimum horizontal stress direction. Specifically, standard density logging tools were configured orthogonally, with related running gear, to maximize pad contact and increase the probability of acquiring high-quality density data. Assuming that at least some portion of the wellbore is less rugose, the technique described affords more reliable density measurements in deviated boreholes.

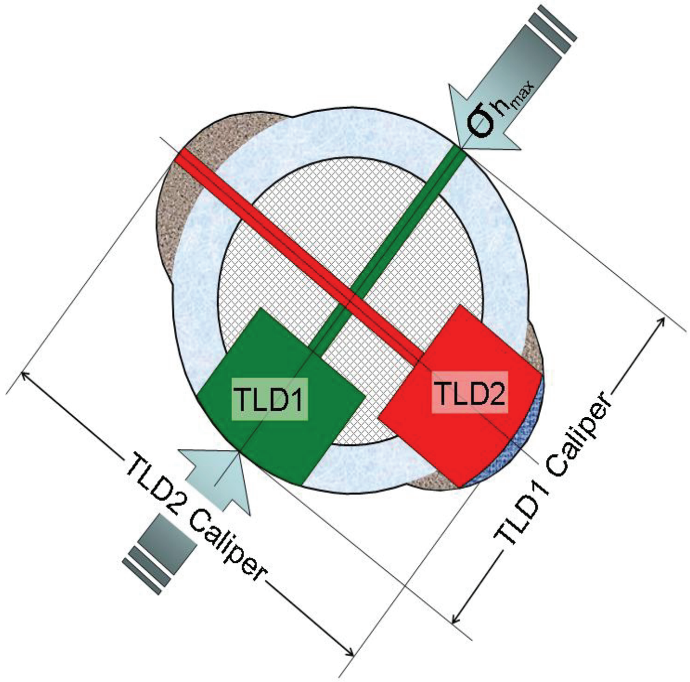

Figure 1: Typical dual density toolstring, in a vertical well with breakout

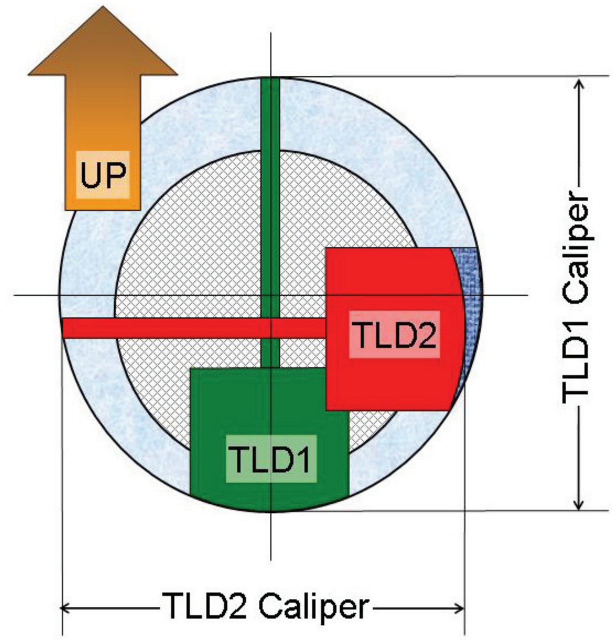

Figure 2: Typical dual density toolstring, inclined wellbore, no breakout

Introduction

Acquisition of valid bulk density log data in the foothills of Alberta has been a recognized challenge since the introduction of gamma-gamma density logging technology in the 1960s3. Various technological advances have limited the extent of the problem, For the most part, innovations have focused on trying to turn the toolstring so that the density skid consistently faces the short (and presumably, smooth) axis of the hole. As a standard practice, some exploration and production companies active in Western Canada run so-called "tandem-density" toolstrings in tectonically stressed areas. The intent is to increase the probability of acquiring valid density data. Generally, the strategy works fairly well. However, with the growing prevalence of directional drilling, density acquisition problems have increased, even at moderate inclinations. Clearly, there is room for improvement with respect to bulk density logging in directional wellbores.

The data presented herein deal with the implementation of a "Powered Positioning Caliper" (PPC) into the logging string, to support and center the upper density tool. This configuration has increased the proportion of useable density data acquired per well. Furthermore, because the PPC design records four independent radii and incorporates a relative bearing measurement, valuable insight into tool behaviour in deviated wells has been gained. 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.

Theory and Method

The advantages of the tandem-density toolstring are obvious. As illustrated in Fig. 1, measurements made by one density tool may be affected by borehole breakout (or washout), but the other density rides in the smooth side of the hole and acquires good data.

Data from 28 wells were evaluated for this study. All were drilled with 200 mm bit size and oil-based drilling fluid. There was a broad sample of wellbore trajectories. After logging the tandem-density toolstring in a sizeable number of inclined wells, we became aware of certain peculiar tool responses that are often observed. Figure 2 illustrates our interpretation of tandem-density behaviour in inclined boreholes, without considering breakout/washout. The important thing to note is that one tool (TLD1) will tend to turn into the low side of the hole. The weight of the toolstring then pulls the other density tool (TLD2) downwards. 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.

Figures 3a and 3b conceptualize two possibilities for inclined boreholes where there is ovality due to breakout (or washout). In Fig. 3a, TLD2 is off-center and running in broken-out hole. The resulting density measurement has reduced confidence (high density correction) and the caliper will underestimate hole volume. However, TLD1 is oriented pad down and finds good hole, yielding an acceptable density measurement. Figure 3b illustrates a different situation: as inclination increases, the tools may “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 may be 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 4 illustrates another situation for which it is doubtful that any useable data will be acquired by a tandem-density toolstring. In this case, the well has been drilled into the direction of the least horizontal stress. One tool will go pad-down into broken-out hole and acquire bad density data. The other tool, although adjacent to smoother borehole, will measure an under-gauge caliper and exhibit poor pad contact. The density data is likely to be of diminished quality.

The scenarios presented in these schematics underscore the importance of toolstring position. In many cases, although one (or both) of the density skids may, in fact, be facing “good” (smooth) hole, poor pad contact, due to eccentralization of the toolstring, will prevent reliable density measurements from being made.

Examples

Two wells have been chosen to establish the principal assertions of this investigation. Example #1 shows a tandem-density (TLD and LDS) run in an inclined borehole drilled along strike, without the benefit of the PPC. The lower density tool (TLD) is facing downwards into the breakout and records poor data. The other density tool (LDS), although facing smoother borehole, is partially compressed by the weight of the toolstring. The caliper reads under-gauge and correction is high. In this example, the standard tandem-density toolstring did not do a very good job of characterizing porosity in the interval of interest.

Example #2 presents data from a similar well, drilled on strike to the SE, at even greater inclination. In this well, a PPC was added to the toolstring. Note the agreement between the PPC calipers and the calipers of the density tools. Significantly, neither density caliper reads under-gauge. The PPC provides sufficient support for the toolstring, such that both density calipers are fully deployed and pad contact is optimal. As intended, one tool (TLD1) faces the rough side (long axis) of the borehole and acquires poor density data. However, the other tool (TLD2) is now making good contact with the smooth side of the hole and the resulting density measurement is of acceptable quality, as evidenced by the low density correction values. In this case, RHOZ is the less reliable measurement, displaying high density correction values. The more trustworthy RHOZ2 is actually reading lower density (higher porosity) and thus adds net pay to the zone of interest in this well.

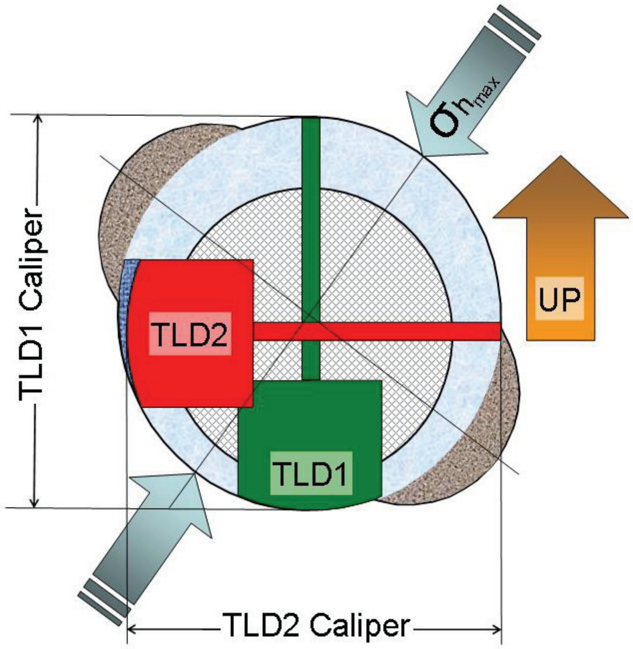

Figure 3a: Typical dual density toolstring, inclined wellbore with breakout, case 1

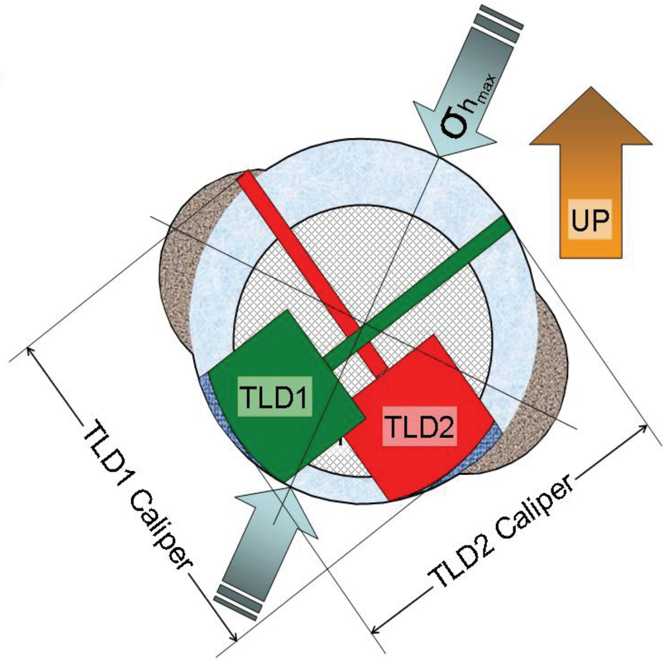

Figure 3b: Typical dual density toolstring, inclined wellbore with breakout, case 2

Conclusions

The prevailing mind-set for obtaining reliable density data in elongated wellbores is to use mechanical means to force the density tool into the short 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. However, with borehole inclinations as small as 3-4 degrees, the results obtained from such toolstrings can become somewhat hit-and-miss. Our findings suggest that this is due to eccentralization of the toolstring under it's own weight.

To remedy this, the following recommendations are advanced with regard to increasing the probability of acquiring high quality density data in elongated, directional boreholes drilled through stressed formations, especially when drilled along strike (into the minimum horizontal stress direction):

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.

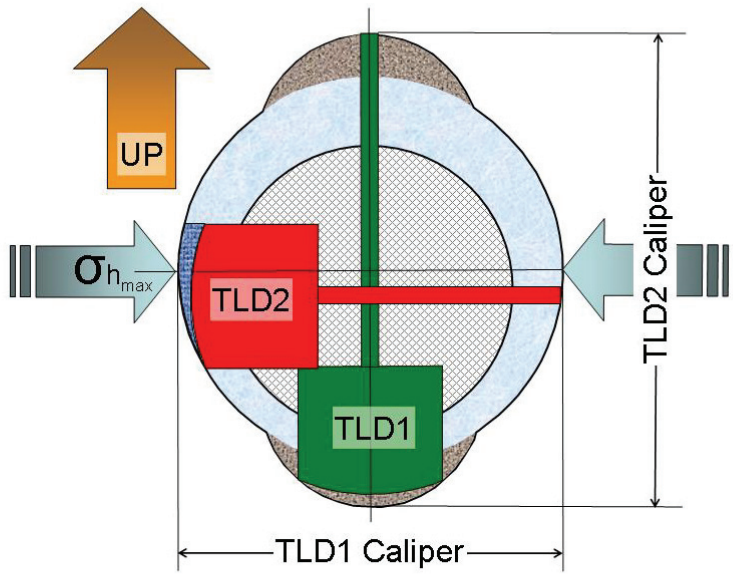

Figure 4: Typical dual density toolstring, inclined wellbore with breakout, drilled on strike

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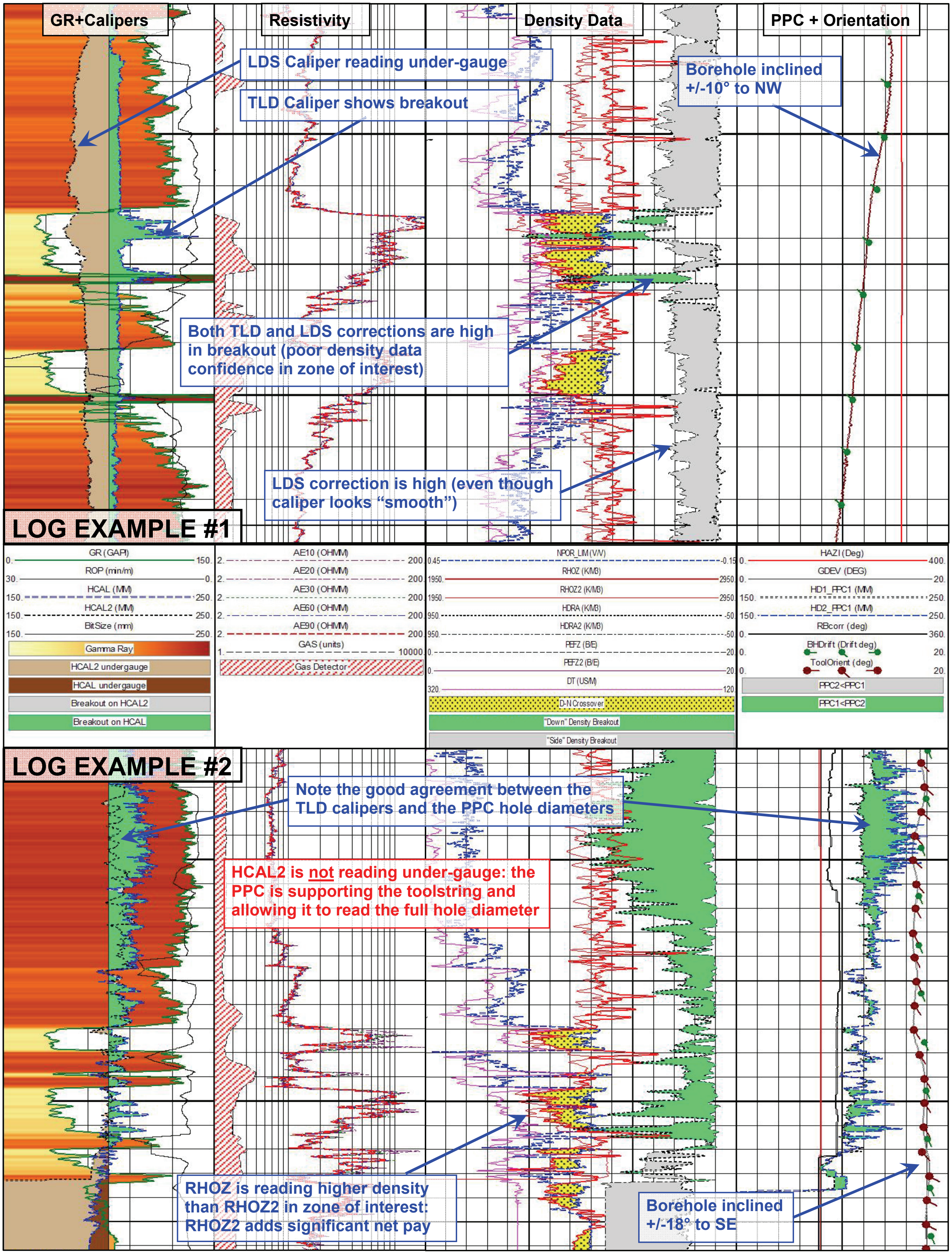
GR+Calipers
Resistivity
Density Data
PPC + Orientation
LDS Caliper reading under-gauge
TLD Caliper shows breakout
Borehole inclined +/-10° to NW
Both TLD and LDS corrections are high in breakout (poor density data confidence in zone of interest)
LDS correction is high (even though caliper looks “smooth”)
LOG EXAMPLE #1
GR (GAPI) 0. 150.
ROP (m/m) 30. 0.
HCAL (MM) 150. 250.
HCAL2 (MM) 150. 250.
BitSize (mm) 150. 250.
Gamma Ray
HCAL2 undergauge
HCAL undergauge
Breakout on HCAL2
Breakout on HCAL
AE10 (OHMM) 2. 200.
AE20 (OHMM) 2. 200.
AE30 (OHMM) 2. 200.
AE60 (OHMM) 2. 200.
AE90 (OHMM) 2. 200.
GAS (units) 1. 10000.
Gas Detector
NPOR_LIM (V/V) 0.45 -0.15
RHOZ (K/M3) 1950. 2950.
RHOZ2 (K/M3) 1950. 2950.
HDRA (K/M3) 950. -50.
HDRA2 (K/M3) 950. -50.
PEFZ (B/E) 0. 20.
PEFZ2 (B/E) 0. 20.
DT (US/M) 320. 120.
D-N Crossover
"Down" Density Breakout
"Side" Density Breakout
HAZI (Deg) 0. 400.
GDEV (DEG) 0. 20.
HD1_PPC1 (MM) 150. 250.
HD2_PPC1 (MM) 150. 250.
RBcorr (deg) 0. 360.
BHDrift (Drift deg) 0. 20.
ToolOrient (deg) 0. 20.
PPC2<PPC1
PPC1<PPC2
LOG EXAMPLE #2
Note the good agreement between the TLD calipers and the PPC hole diameters
HCAL2 is not reading under-gauge: the PPC is supporting the toolstring and allowing it to read the full hole diameter
RHOZ is reading higher density than RHOZ2 in zone of interest: RHOZ2 adds significant net pay
Borehole inclined +/-18° to SE