

# Anatomy of a Ballooning Borehole using PWD™ tool

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## Abstract

Borehole ballooning has often been mistaken in the field for an influx of formation fluid. This misdiagnosis often leads to unwarranted well control procedures that can be costly. The new down-hole annular Pressure-While-Drilling™ (PWD™) tool is able to help diagnose whether the well is flowing or if borehole ballooning is taking place. This paper shows PWD information collected from a recent deepwater Gulf of Mexico well that was suffering from borehole ballooning.

## Borehole Ballooning

The phenomenon variously called borehole ballooning, breathing, or loss/gain is the result of slow mud losses while drilling ahead followed by mud returns after the pumps have been turned off, such as during a connection or flow check. Usually any flows during these periods are cause for concern as they may be due to an influx of formation water, liquid hydrocarbons, or gas. Any influx from the formation can result in a well control problem, the magnitude of which is dependent on its volume and composition. However, if the flow is due to mud returns, well control is not an issue. The question is: how does one know unequivocally if it is an influx, or mud that was lost while drilling flowing back into the wellbore?

To be safe, the suspected influx can be circulated out under choke, but this is time consuming and also wasteful, particularly if the influx is only returning mud. The normal cure is to increase the mud weight and ensure an adequate overbalance in the absence of circulation. If the mud weight is increased and the influx is only mud, the situation will get progressively worse with a rise in mud weight and therefore equivalent circulating density (ECD). Mud losses will continue and eventually the fracture propagation pressure will be exceeded, resulting in total losses. The PWD offers a means to help determine whether it is an influx or returning mud, soon after the pit gain takes place.

The term "ballooning" originally implied that the wellbore diameter expands when circulation is started due to the additional ECD and contracted when circulation was stopped<sup>1,2,3</sup>. This explained the observed mud losses and gains and gave the analogy to blowing up and deflating a balloon. Some operators call this phenomenon breathing, i.e. the well takes (inhales) and returns (exhales) mud in response to turning the pumps on and off. Others call it loss/gain due to the observed mud losses and gains. It now seems more likely that

the phenomenon is due to fractures being opened and closed by the annular pressure fluctuations resulting from mud circulation and non-circulation<sup>4,5,6</sup>. Unfortunately the name 'ballooning' has stuck.

Mud losses while circulating are required for ballooning to occur but these are partial and not total. Small losses that are continuous while drilling ahead may not easily be detected but can accumulate to a sizeable volume over a long drilling time. The losses must be into fractures that are contained within a limited fracture network and with little or no fluid leak-off into porosity. When the pumps are stopped, the annular pressure will fall and mud lost to these fractures will flow back into the well bore. Such returns are more noticeable than the losses since the return occurs rapidly and during a period when no flow is expected.

## PWD Evidence for ballooning

When ballooning occurs the recorded PWD response during the pump shut down period is diagnostic in that the pressure will fall sharply when the pumps are turned off, but at some point, the pressure will decay slowly to the static level due to mud flow from the loss zone. The static level will be reached when the mud return flow stops if the pumps are off long enough. The rate of the pressure decay should be related to the return flow rate and it seems that it should be possible to predict the flow back volume from the pressure decay curve. In any event the pressure will eventually reach and then remain at the static level until the pumps are restarted.

Once the pumps are restarted, the annular pressure should return to the level it was at before the pumps were turned off, assuming the flow rate is the same before and after the shutdown. There may be some delay in reaching the former pressure level (and ECD) as the fracture network is being recharged. In this case not all the mud being pumped is coming up the wellbore at first. Some of the mud is refilling the system of fractures and being stored until the next time the pumps are turned off.

Figure 1 shows the pressure changes during a normal connection, in this case in the 8-1/2" interval of the case Gulf of Mexico well. The mud in use was a 15.70 lb/gal synthetic oil-based. In this case, the stand was drilled down to 16856 ft, then reamed once before the pumps were turned off. During

the pumps off interval the pit gained approximately 30 bbl, a normal flow from the lines when circulation is stopped. The pumps were turned on again about 23 minutes later. When the pumps were turned off, there was a sharp pressure drop to near the static level. When the pumps were restarted, the pressure rose just as sharply to the level prior to reaming the pipe. This 'square well' profile is characteristic of a normal connection with no signs of ballooning or flow. The equivalent mud weight (EMW) at selected points is shown on the figure. The EMW before and after the connection are the same at 16.26 lb/gal. Reaming up and down caused a swab to 16.14 lb/gal and surge to 16.32 lb/gal before the pumps were stopped. The EMW dropped to 15.92 lb/gal and stayed at that level except for two times when the pipe was moved slightly. Once the pumps were turned on again, the EMW quickly increased back to 16.25 lb/gal, the same as before the connection. Note that on Fig. 1 the effective downhole mud density is approximately 0.22 lb/gal higher than that reported going in. The difference between the surface and downhole densities is due to the effect of temperature and pressure on the mud in the borehole.

Fig. 2 shows the connection at a depth of 16679 ft. The mud weight had been raised to 15.9 lb/gal at this point and the ECD was 16.48 lb/gal, the swab and surge upon reaming up and down were similar to the previous example. When the pumps were turned off the EMW fell sharply to 16.16 lb/gal and then fell more gradually over the next 20 minutes to a near static level of about 16.11 lb/gal. When the pumps were restarted, the EMW rose quickly back to 16.47 lb/gal, essentially the level prior to the connection. There were no reports of at this time, although the well was giving back 45 bbls, 10 bbls more than previously.

Fig. 3 shows a connection at 17230 ft where ballooning was reported. From the ECD as the stand was drilled down of 16.42 lb/gal, when pumps were stopped the EMW fell rapidly to 16.37 lb/gal and then gradually to 16.13 lb/gal just before the pumps were restarted. After restarting the pumps, the EMW eventually increased to 16.40 lb/gal, or nearly the same as prior to the connection, but took more than 15 minutes even with a slightly higher flow rate. Ballooning was reported at this depth and flow checks experienced returns of  $\pm 85$  bbls. The gradual fall in pressure to the static level shown in Fig. 3 is indicative of returning mudflow with the pumps off. The return mudflow prevents the pressure from falling rapidly to the static level as shown in the pre-ballooning well in Fig. 1.

Fig. 4 shows a connection at 17696 ft where ballooning was severe just before a major lost circulation event. Here the slow build up to the drilling ECD is obvious and can be observed with the real-time PWD data. Also, the pressure does not reach static equilibrium during the 8-minute pumps off period.

How do the ballooning cases in Figs. 2, 3 & 4 compare with a formation influx? Unpublished PWD observations of

influxes and kicks have shown that with a weighted mud (and ballooning always occurs with a weighted mud close the fracture pressure) an influx will always be of a lower density than the drilling fluid, and in the case of gas of a much lower density. Therefore a drop in EMW characterizes the PWD data during an influx whether circulating, while static, or during tripping. The magnitude of this drop depends on the relative densities of the influx and mud and the influx volume. In ballooning well the ECD always eventually goes back up to the same ECD as was observed before the static period. In Fig. 4, had the pit gain been caused by an influx during the connection then the ECD would not have increased back up to 16.45 lb/gal but would have been somewhat less.

Looking at Fig. 2, the connections before ballooning was reported/observed on the rig raises questions about the shape of the initial section of the pumps off portion of this pressure vs. time curve. There is definite curvature in this section of the plot. This may be due to mud return flow that is overlooked or too small to be detected. If this is true, the onset of ballooning might be able to be detected via the PWD before it becomes apparent on the rig floor. During ballooning (Figs. 3 & 4) the PWD signature is distinct with a curved pressure decline when pumps are stopped and a slow curved pressure increase after pumps are restarted. In addition, on the decline curve there is typically a break in slope (Fig. 3) which is interpreted to be the fracture closure pressure similar to that interpreted in many leak-off tests (LOT's) when pumping is halted.

## Ballooning case well, 12-1/4" section

The 11-3/4" shoe of this Gulf of Mexico well was set at 10204 ft. The essentially vertical 12-1/4" interval was drilled with synthetic oil-based mud and a bi-centred bit. The PWD sensor was located some 22.50 ft behind the bit. No LOT data for this section was recorded with the PWD. A summary of the PWD data at connections is shown in Fig. 5.

Drilling proceeded uneventfully down to 11320 ft at which time mud losses were first reported with an ECD of 16.18 lb/gal. The mud weight was being increased rapidly at the time from 15.1 to 15.7 lb/gal. Before this the PWD had shown the typical "square-well" shape at connections of the non-ballooning well. After the losses were initiated signs that the well started ballooning show up on the plots, although no returns were reported at this time only losses. Attempts were made to regain circulation by staging the pumps and pumping lost circulation material (LCM).

Ultimately the pipe was pulled to the shoe wet, and with the hole taking fluid. The average EMW at each of the 13 connections on the short trip was 15.98 lb/gal. This is above the static level shown in the 11327 ft-connection plot and about the same level as the fracture closure pressure seen at this depth.

Once at the shoe, the surface mud weight was lowered to 15.5 lb/gal and circulated around. The pipe was then run back to bottom. The EMW averaged 15.84 lb/gal on the trip back to bottom. A LCM pill was then pumped around the bit, the pipe pulled to 10660 ft and 15.5 lb/gal mud circulated around.

The pipe was then washed to bottom and logged with MWD to find the loss zone. The resistivity log indicated this to be between 11245 and 11250 ft. The seven connection plots while washing down from 11686 to 11234 ft all show the “square-well” shape seen previously for these connections. When the connection at 11327 ft was reached, the hole was circulated and the riser flushed. The hole took 10 bbl of mud and then returned 10 bbl during a 25-minute flow check. The pressure/EMW plot showed evidence of mudflow back with a break in the EMW/time curve at about 15.72 lb/gal.

Drilling proceeded to 11558 ft. The two connections below 11327 ft show curvature in the pressure/EMW response when the pumps were turned off but there were no reports of mud losses or gains. After reaching 11588 ft, 52 bbls of mud were recovered during a 30-minute flow check. When circulation resumed the well took a reported 52 bbl of mud before equilibrium was regained.

During drilling to the next connection at 11600 ft, another 35 bbl were lost. This mud was recovered during the connection. Mud was again lost while drilling the next stand down which was regained when the pumps were turned off after reaching 11691 ft. It was decided that at this point the well was ballooning.

From 11691 to 12215 ft drilling proceeded without incident. No mud losses or returns were reported although the pressure/EMW plots show that ballooning was occurring.

A short trip to the shoe was made after reaching 12515 ft and circulating bottoms up. The pipe had to be pumped out because of swabbing, although in retrospect it was probably only ballooning. On the trip back to bottom, no fill was found.

Drilling proceeded to the connection at 12885 ft with no mention of mud losses or gains although there still was a signature on the pressure/EMW plots. When drilling resumed below 12885 ft the mud weight was increased from 15.5 to 15.7 lb/gal. At 12932 ft, with the heavier mud 1/3 of the way up the annulus, losses occurred. The maximum EMW was 15.97 lb/gal. The pipe was pumped out to the shoe with continued losses and then tripped out to the rig floor. The mud weight was reduced to 15.5 lb/gal at the shoe but circulation could not be fully regained.

Based on PWD logs it appears that a further trip was made back in the hole in an attempt to cure the losses with 15.5 lb/gal mud weight in but with no luck. Before drilling resumed

the mud weight in was lowered to 15.2 lb/gal. The static EMW at the connection at 12995 ft was 15.53 lb/gal versus 15.82 lb/gal prior to losing circulation. The pressure/EMW plots for the connections from 12995 to 13454 ft are more of the “square-well” type than any of the connections and flow checks between 11327 and 12885 ft. This lower section was drilled without incident and demonstrates that the swabbing observed tripping out at 12515 ft could not have been due to an influx.

The hole was drilled on to the next casing point at 15423 ft using the lower 15.1 lb/gal mud weight where there were no reported losses or gains. Below 12932 ft, the ECD did not reach the level at which fractures higher in the hole were apparently opening and closing (approximately 15.8 lb/gal).

## Ballooning case well, 8-1/2” section

The 9-5/8” shoe of this Gulf of Mexico well was set at 15423 ft. The interval was slightly deviated (maximum angle 13°). The PWD sensor was located some 53.54 ft behind the bit down to 17320 ft and 25.25 ft for the remainder of the section. A summary of the PWD data is shown in Fig. 5.

A LOT was taken after drilling out the shoe at 15423 ft (Fig. 7). This was taken to up to a downhole EMW of 17.51 lb/gal without any apparent leak-off. A second pair of LOT’s was taken at 15616 ft. These apparently show a leak-off that suggests a fracture pressure of around 16.45 lb/gal. Subsequent events while drilling the 8-1/2” section show that mud losses were sustained around or slightly higher than this pressure.

Drilling proceeded rather uneventfully down to 16868 ft at which time ballooning was first reported. Again, retrospectively, ballooning was observed from the curved pressure decay on the EMW as high as 16690 ft when the ECD had increased to 16.52 lb/gal. During a flow check at 16877 ft, some 84 bbls of mud were recovered. During the next four connections, mud returns of ±85 bbls were reported. Each of the pressure/EMW plots for these connections, show strong evidence of flow after the pumps were turned off.

On the connection after drilling to 17485 ft, 170 bbl of mud were recovered within one hour. The flow back slowed to 1 bpm at the end of the hour. Again, the ECD had increased to 16.52 lb/gal.

After drilling to 17553 ft and cutting back the mud weight from 15.9 to 15.8 lb/gal, a flow check resulted in mud returns of 110 bbls in 45 minutes with the flow rate slowing to less than 1 bpm at the end of this time period. Although the mud weight had been lowered the ECD remained high, probably due to an increase in ROP and cuttings load.

At 17919 ft, a drilling break was observed with reduced

returns at surface. When the pumps were stopped, 70 bbl of mud were regained in one hour. An attempt was made to regain circulation by staging up the pumps but at 250 gpm, losses resumed. Additional mud was lost on the trip out. Several days later, after tripping back to bottom, the mud weight was again lowered this time to 15.6 lb/gal.

The ballooning in the 8-1/2" hole section was larger in magnitude than in the previous 12-1/4" hole section. Part of the reason may be that in the smaller hole, the difference between the ECD and the static EMW was considerably larger than in the bigger hole (0.33 vs. 0.17 lb/gal). The higher circulating pressure drop makes it more difficult to remain above the pore pressure when static and below the fracture pressure when circulating.

The reduction in mud weight after 17919 ft, resulted in circulating densities (16.23 to 16.28 lb/gal) below the fracture closure density (16.32 to 16.42 lb/gal) seen higher in the hole, but some mud flow back still seemed to be taking place. The lower ECD, however, was about on par with what appeared to be a possible fracture opening/closing seen at densities of 16.25 lb/gal in the two connections just prior to the connection at 16878 ft when ballooning was first reported. The speculation is that the initial indications may have set the tone for the future connections. It is possible that if the mud weight had been lower initially, ballooning may not have occurred from 16868 ft on down. There was never any indication of an influx of formation fluids in this section down to 18300 ft and indications are that a lower mud weight could have been used in the interval, possibly avoiding ballooning any the costly rig time to deal with the problems that did arise.

## Conclusions

A number of conclusions can be drawn from the preceding discussion of ballooning:

1. Ballooning is caused by mud losses during drilling and subsequent mud returns of equal volume when the pumps are turned off. The losses are confined within a limited fracture network in which little to no fluid leak-off into porosity is possible.

2. Return mud flow will slow the pressure decline to the static level when the pumps are initially turned off.
3. Mud losses will slow the return to the ECD level observed before the connection/flow check after the pumps are turned on again.
4. The ECD before and after the connection/flow check will be the same, assuming the pump rate and rotary speed are the same. A lower ECD after the pumps are restarted is indicative of an influx.
5. The downhole pressure response to turning the pumps off and on during a connection or a flow check is diagnostic for ballooning. A real-time PWD tool measures this and can allow for correct decisions to be made.

## Nomenclature

Pressure-While-Drilling™ and PWD™ are trademarks of Halliburton Energy Services, Inc.

*ECD* = Equivalent Circulating Density, lb/gal

*EMW* = Equivalent Mud Weight, lb/gal

*FIT* = Formation Integrity Test

*LOT* = Leak-off Test

## References

1. Gill, J.A. "Charge shales: Self-induced pore pressures. *IADC/SPE Drilling Technology Conf., Dallas, Feb. 9, 1986.*
2. Gill, J.A. "Well logs real true pressures where drilling responses fail. *Oil & Gas Journal* **41**, March 16, 1987.
3. Gill, J.A. "How borehole ballooning alters drilling responses. *Oil & Gas Journal* **43**, March 13, 1989.
4. Bowman, G.R. 'Borehole ballooning in response to Gill' *Oil & Gas Journal* **43**, Apr 10, 1989
5. Holbrook, P. 'Debate on borehole ballooning in response to Gill' *Oil & Gas Journal* **43**, June 12, 1989.
6. Aadnøy, B.S. Evaluation of borehole ballooning in deep wells. In: *Modern Well Design*. Balkema, 1996.

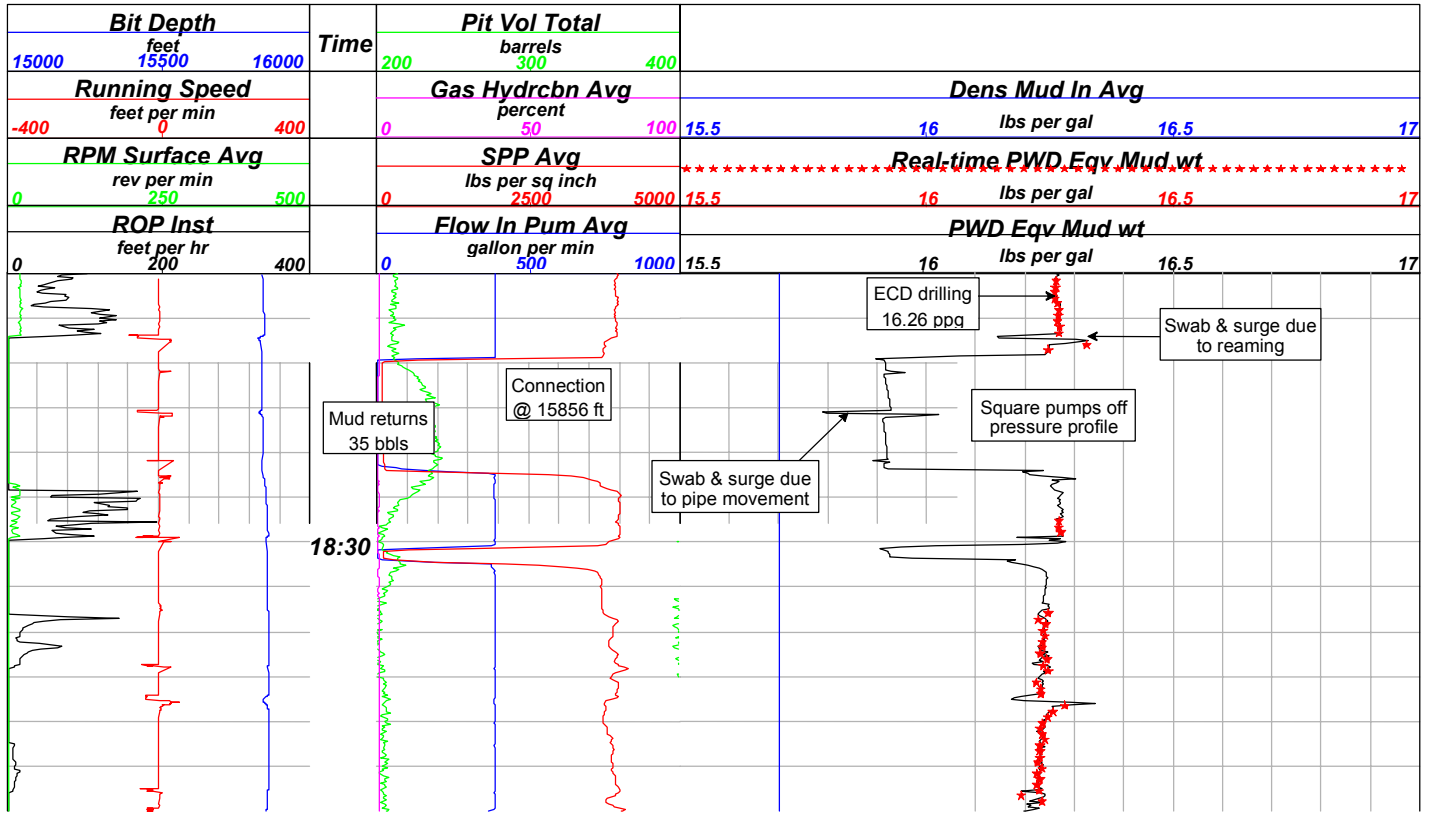


Fig. 1. Pre-ballooning connection in the 8-1/2" section. This has the normal "square-well" signature.

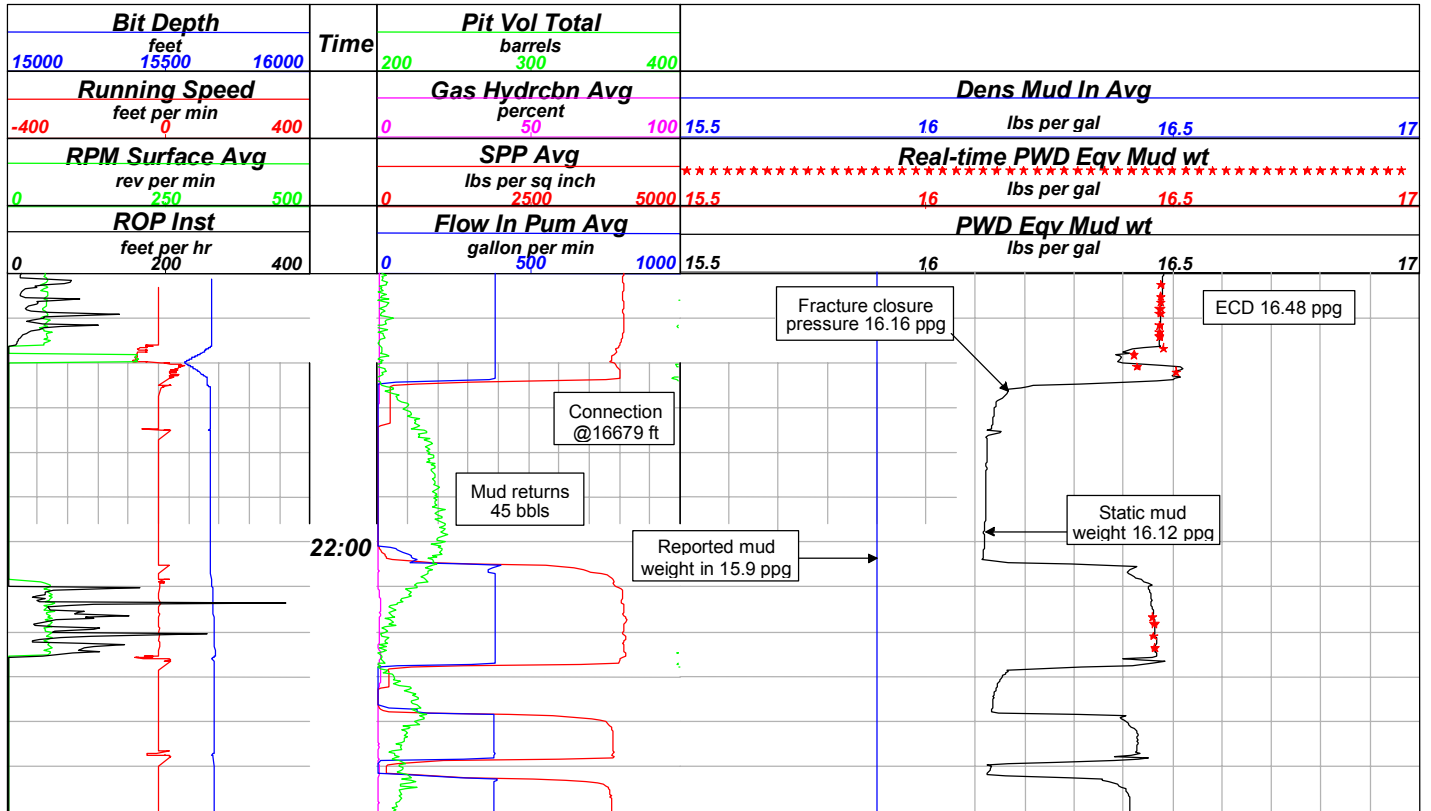


Fig. 2. Start of ballooning in the 8-1/2" section. Early indications of ballooning seen with the PWD but not noticed at surface.

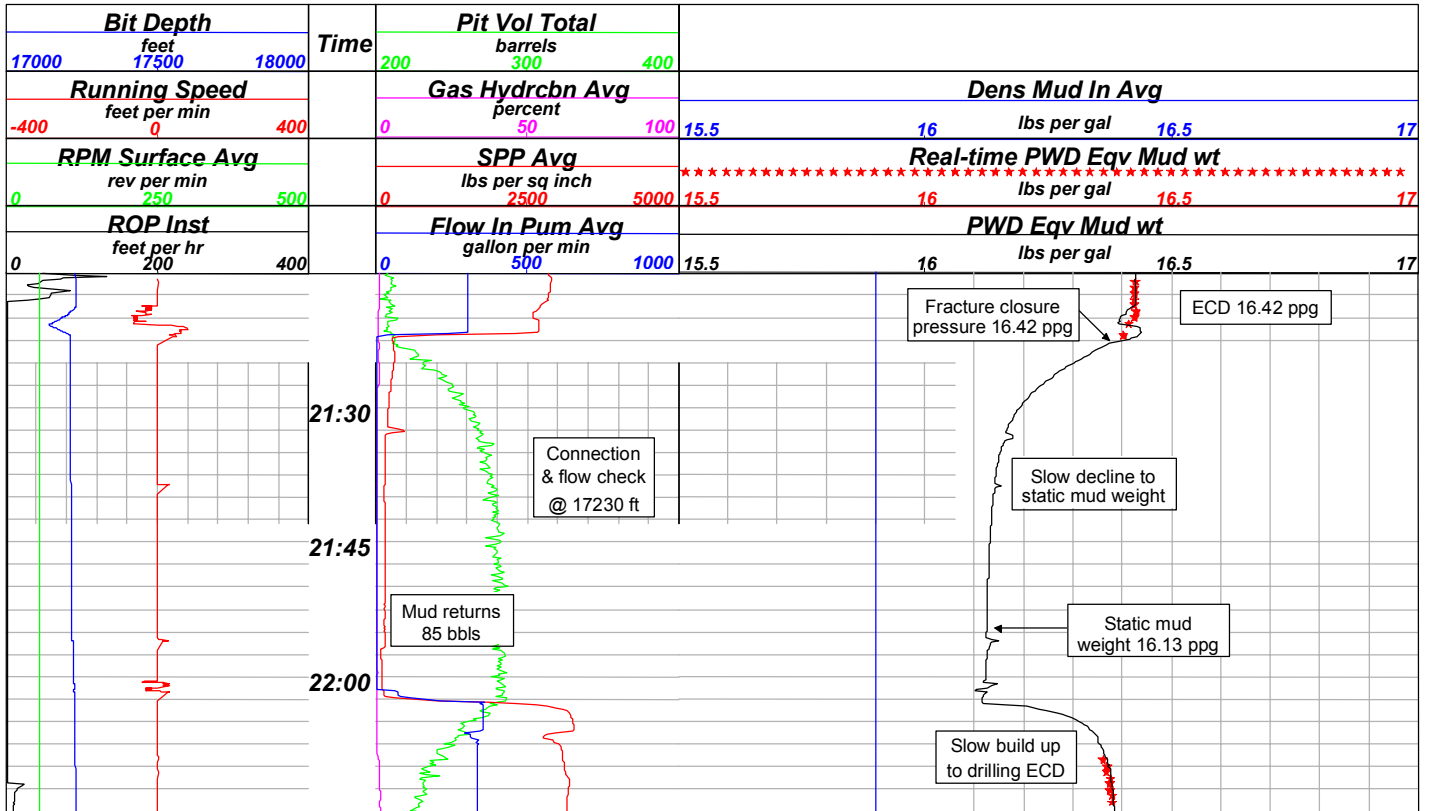


Fig. 3. Ballooning in the 8-1/2" section. Severe ballooning characterized by slow pressure decline and build up curves.

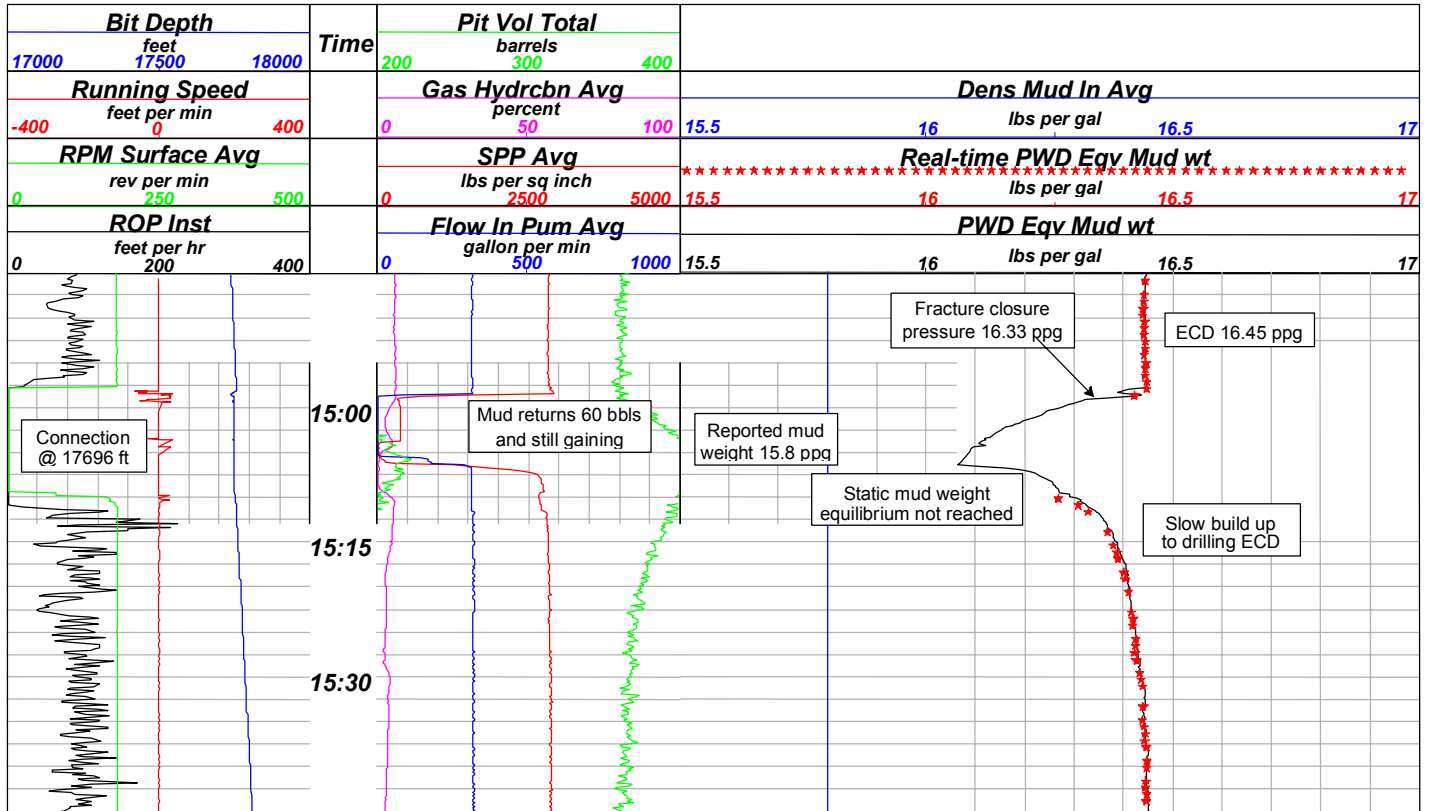


Fig. 4. Ballooning just before severe lost circulation in the 8-1/2". Here the quick connection does not allow static equilibrium to take place.

	<b>Reported Mud Weight In</b>			
	15	15.5	16	16.5
	<i>lbs per gal</i>			
	<b>PWD Fracture Closure Pressure</b>			
	15	15.5	16	16.5
	<i>lbs per gal</i>			
	<b>PWD ECD Avg</b>			
	15	15.5	16	16.5
	<i>lbs per gal</i>			
<b>MD</b> <b>ft</b>	<b>PWD Static Mud Weight</b>			
	15	15.5	16	16.5
	<i>lbs per gal</i>			

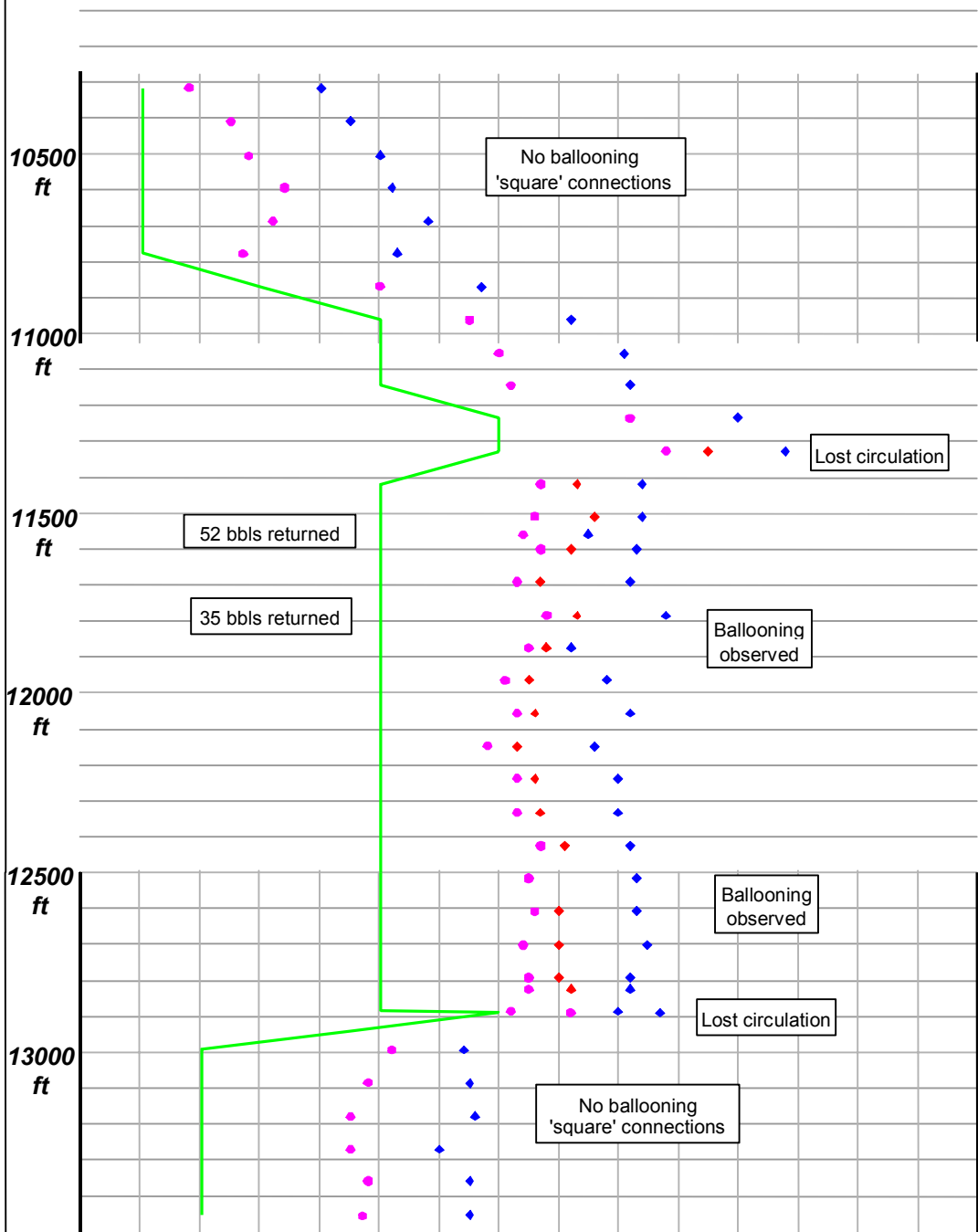


Fig. 5. Summary 12-1/4" section

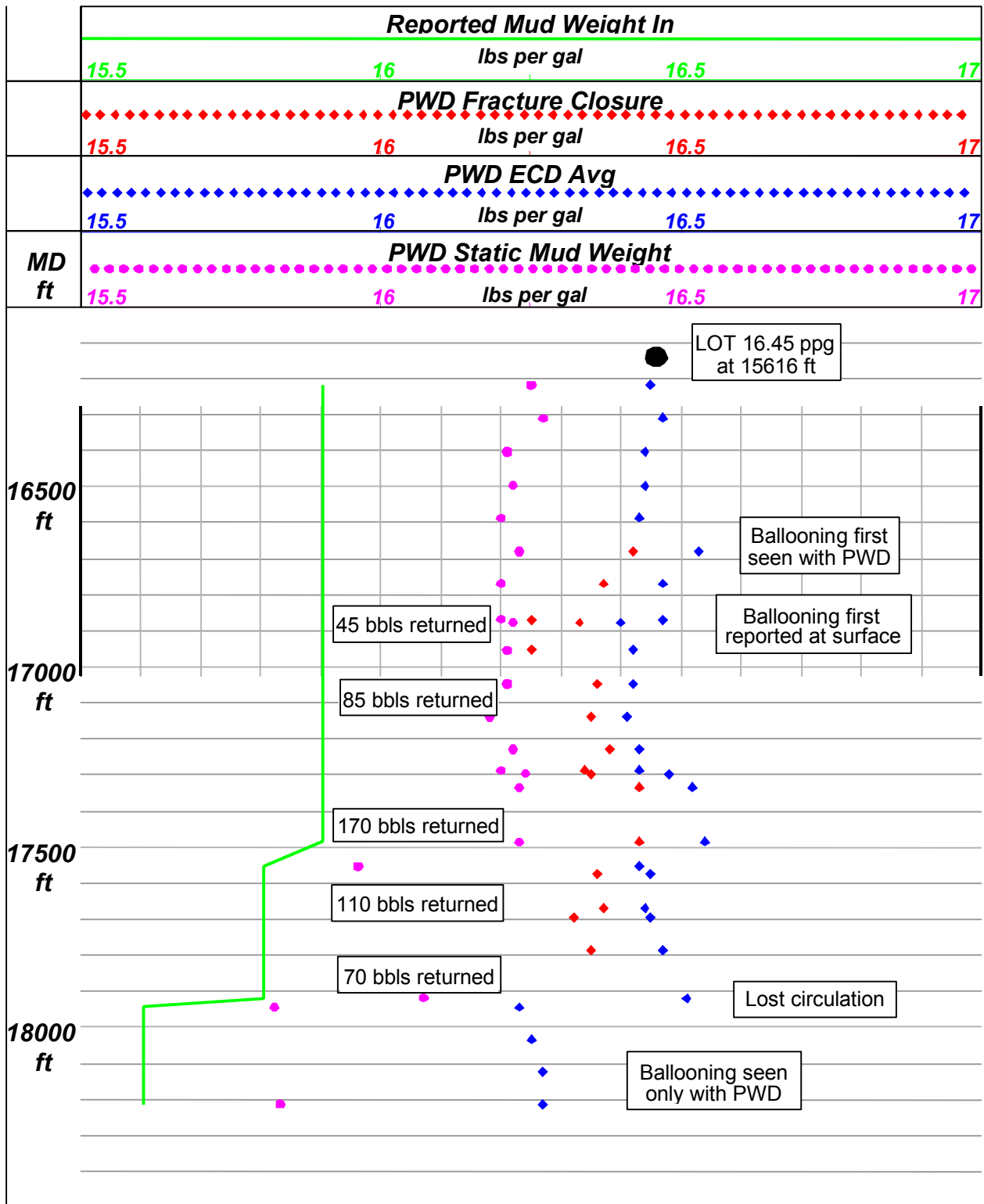


Fig. 6. Summary 8-1/2" Section

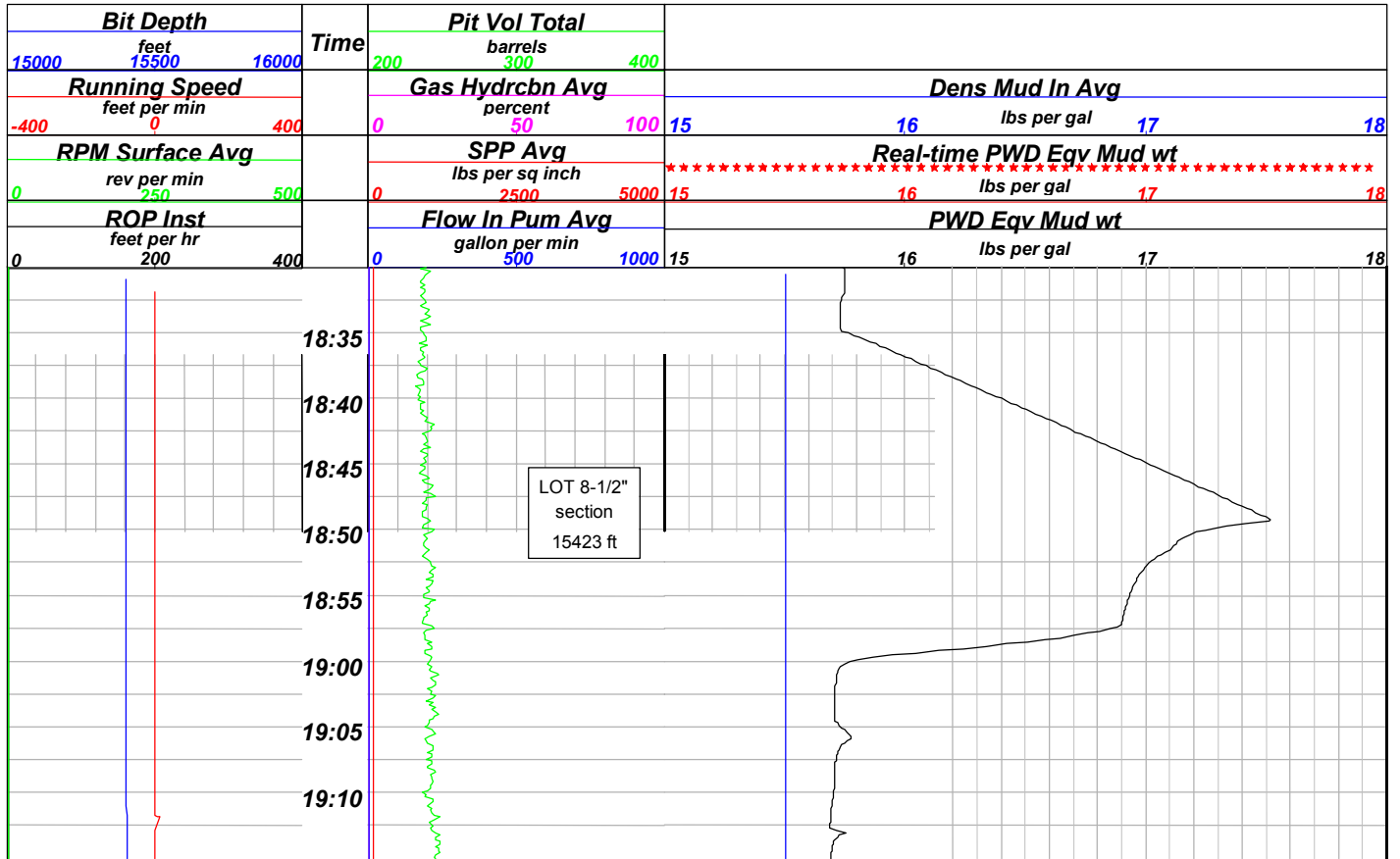


Fig.7. First LOT1 in the 8-1/2" section below the shoe at 15423 ft.

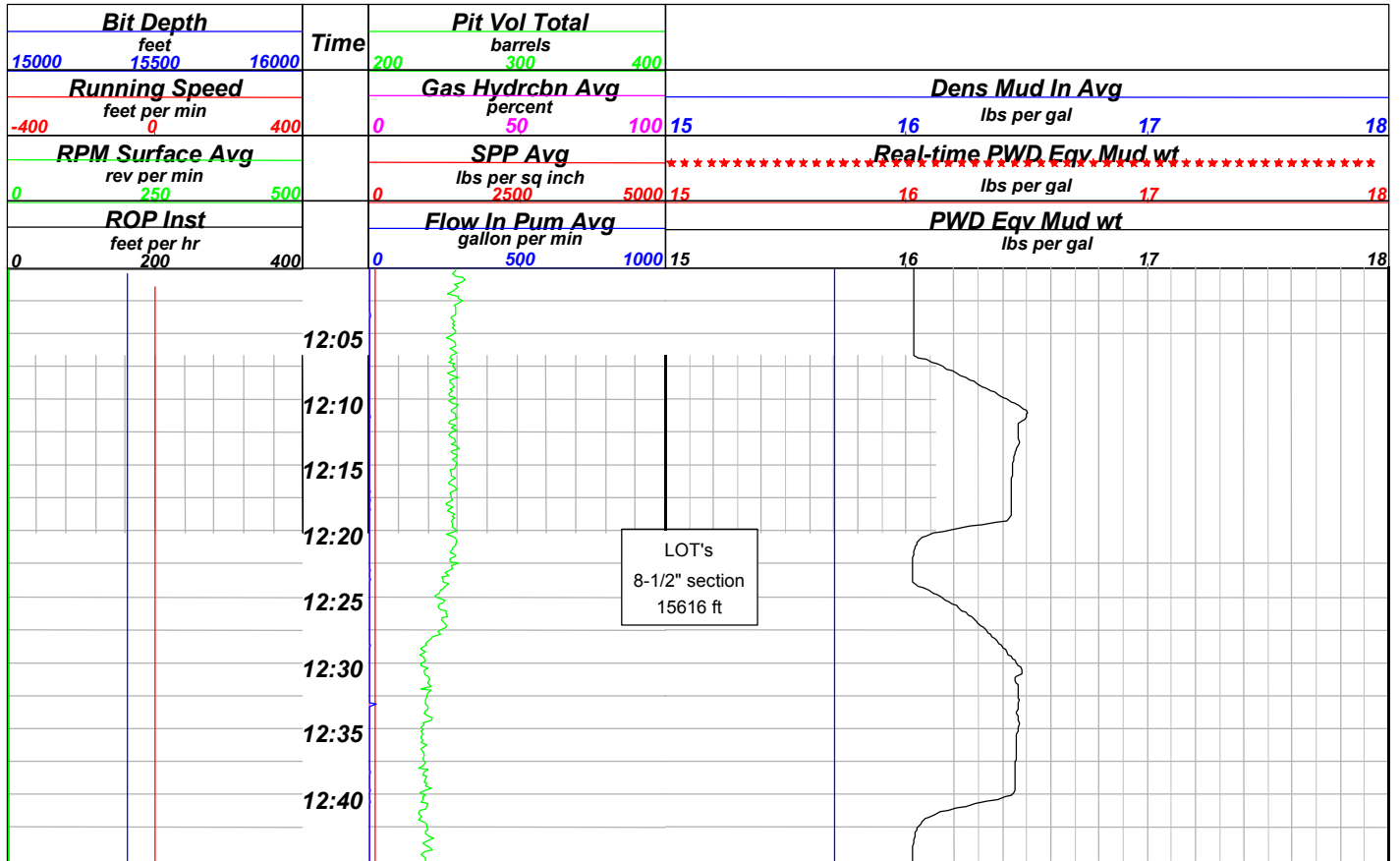


Fig. 8. Second LOT in the 8-1/2" section after drilling to 15616 ft.