

# **PS Placement Matters: Improving Survey Accuracy by Using Continuous Directional Data and Drilling Parameter Settings\***

**Ed Stockhausen<sup>1</sup>, Richard Ball<sup>1</sup>, Pete Clark<sup>1</sup>, Richard Mongan<sup>1</sup>, and Philip Rice<sup>1</sup>**

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## **Abstract**

Traditional directional surveys used in the determining wellbore position are based on a minimum-curvature calculation method. This method assumes that a constant smooth curve exists between each of the stationary directional survey points, and is the current standard industry-wide. However, it is outdated since it totally ignores modern continuous survey measurements and/or any directional drilling parameters changes made between the stationary survey points. Previously published papers, have discussed the value of the continuous survey data to identify instances that occur while drilling in which the minimum curvature assumption is invalid and results in gross positional errors. Further, it was shown how these can lead to the accumulation of significant TVD and positional error. However, these papers fall short in providing a methodology for combining this data into a final industry accepted definitive positional survey. The authors propose a new method, the Continuous Directional Enhancement Method (CDEM), which combines the available continuous directional survey measurements and steering parameter setting changes with the stationary survey data to create a new hybrid and more accurate survey. When geologists and geosteers use CDEM in real-time, it can result in optimally landed wells in the correct lobe and/or relative to fluid or gas contacts. The method also greatly aids in the proactive steering of the lateral section of horizontal wells within the target zone. As part of the methodology, the continuous survey data streams are collected and filtered in real-time to remove noise and to determine directional tendencies. This may include both near-bit and continuous MWD inclination and sometimes azimuth data. By adding the directional steering parameters, such as gravity tool-face and steering force (when running Rotary Steerable Systems), it is possible to predict the inclination and azimuth at the bit and on an ongoing bases provide a real-time trajectory to the bit. Additionally, the CDEM method provides for a constant monitoring of directional drilling tendencies and is used to identify changes in tendencies that result from directional parameter setting changes and/or from changes in lithology. In several instances, severe deflections were identified early, which exceeded the recommended maximum doglegs severity for rotating the MWD/LWD tool through and drilling was stop in order to evaluate the potential risk to cause a tool failure. In several cases, it was decided to back up and sidetrack rather than drill ahead. Overall, the CDEM adds value and understanding across disciplines, providing for better communication between drilling and geology. Also it enables accurate well placement, more accurate dip calculations, a better understanding of borehole tortuosity and torque and drag - all leading to significant increase in NPV. In this paper, we will fully describe the CDEM methodology and workflow, presenting several case history examples of the successful application in the placement of multiple horizontal wells.

### **References Cited**

Lesso, W.G., I.M. Cooper, M. and Chau, 2001, Continuous Direction and Inclination Measurements Revolutionize Real-Time Directional Drilling Decision-Making: IADC/SPE 67752 presented at the IADC/SPE Drilling Conference, Amsterdam, The Netherlands, 27 Feb – 1 Mar 2001.

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# Improving Survey Accuracy by Using Continuous Directional Data and Drilling Parameter Settings

By: Ed Stockhausen, Richard Ball, Pete Clark, Richard Mongan, and Philip Rice (Chevron)

**ABSTRACT:**

Traditional directional surveys used in determining wellbore position are based on a minimum-curvature calculation method. This method assumes that a constant smooth curve exists between each of the stationary directional survey points, and is the current standard industry-wide. However, it is outdated, since it totally ignores modern continuous survey measurements and/or any directional drilling parameters changes made between the stationary survey points.

Previously published papers, have discussed the value of the continuous survey data to identify instances that occur while drilling in which the minimum curvature assumption is invalid and results in gross positional errors. Further, it was shown how these can lead to the accumulation of significant TVD and positional errors.

These papers fall short in providing a methodology for combining this data into a final industry accepted definitive positional survey. The authors propose a new method, the Continuous Directional Enhancement Method (CDEM), which combines the available continuous directional survey measurements and steering parameter setting changes with the stationary survey data to create a new hybrid and more accurate survey. When CDEM is used in real-time by geologists and geosteerers, it can result in optimally landed wells in the correct lobe and/or correctly positioned relative to fluid or gas contacts. The method also greatly aids in the proactive steering of the lateral section of horizontal wells within the target zone.

As part of the methodology, the continuous survey data streams are collected and filtered in real-time to remove noise and to determine directional tendencies. This may include both near-bit and continuous MWD inclination and sometimes azimuth data. By adding the directional steering parameters, such as gravity tool-face and steering force (when running Rotary Steerable Systems), it is possible to predict the inclination and azimuth at the bit and on an ongoing basis provide a real-time trajectory to the bit.

Additionally, the CDEM method provides for a constant monitoring of directional drilling tendencies and is used to identify changes in these tendencies that result from directional parameter setting changes and/or from changes in lithology. In several instances, severe deflections were identified early, which exceeded the recommended maximum dogleg severity for rotating the MWD/LWD tool through, drilling was stopped in order to evaluate the potential risk to cause a tool failure. In several cases, it was decided to back up and sidetrack rather than drill ahead.

Overall, the CDEM adds value and understanding across disciplines, providing for better communication between drilling and geology. Also it enables accurate well placement, more accurate dip calculations, a better understanding of borehole tortuosity and torque and drag – culminating in a significant increase in NPV. In this paper (poster), we will fully describe the CDEM methodology and workflow, presenting several case history examples of the successful application in the placement of multiple horizontal wells.

**Directional Drilling Overview and Key Terms:**

In the case of drilling with positive displacement motors (PDM's) with bent housings, directional work is accomplished by pointing/orienting the motor in the desired direction and proceeding to pump mud through the motor - causing the bit to spin and then to begin to drill new formation as weight is added to the bit. This is known as **slide drilling**, in that only the bit is spinning/rotating while drilling. When the drilling mode is changed to a rotary drilling mode, **rotate drilling**, the entire drill string is made to rotate by the rig at the surface, generally resulting in a straighter section being achieved in the wellbore. This is often referred to as a **tangent section**.

The direction the motor and bit is pointing is known as the **tool-face setting**. At low inclination, below approximately 8 degrees, a magnetic tool-face angle is used (set). When directionally drilling with inclinations greater than approximately 8 degrees, a gravity tool-face setting/orientation is used. **Dogleg severity** is a measure of the total change in direction from one point along the wellbore to the next; it is most often defined in terms of degrees/100 feet or degrees/30 meters.

**Current State: Utilizes the Assumption of Minimum Curvature**

The current industry standard practice for determining wellbore position uses a calculation method called **Minimum Curvature**. **This method assumes and fits a single constant curve-rate arc between the stationary survey points**, irrespective of any and all directional drilling mode changes that were applied or lithology changes that occurred over the interval between the survey points. It has also become a common practice in the industry, with the advent of top-drive drilling rigs, to only take stationary surveys once per stand (3 joints of drillpipe), which provides a survey point once per approximately every 96 feet (29 meters) of measured depth while drilling. Most of the modern MWD drilling systems these days however, provide at least some **continuous inclination data** (and sometimes **continuous azimuth data**), plus other drilling parameter mode setting change data, which **proves that the minimum curvature assumption is invalid in many cases**.

**Accumulation of Positional Errors:**

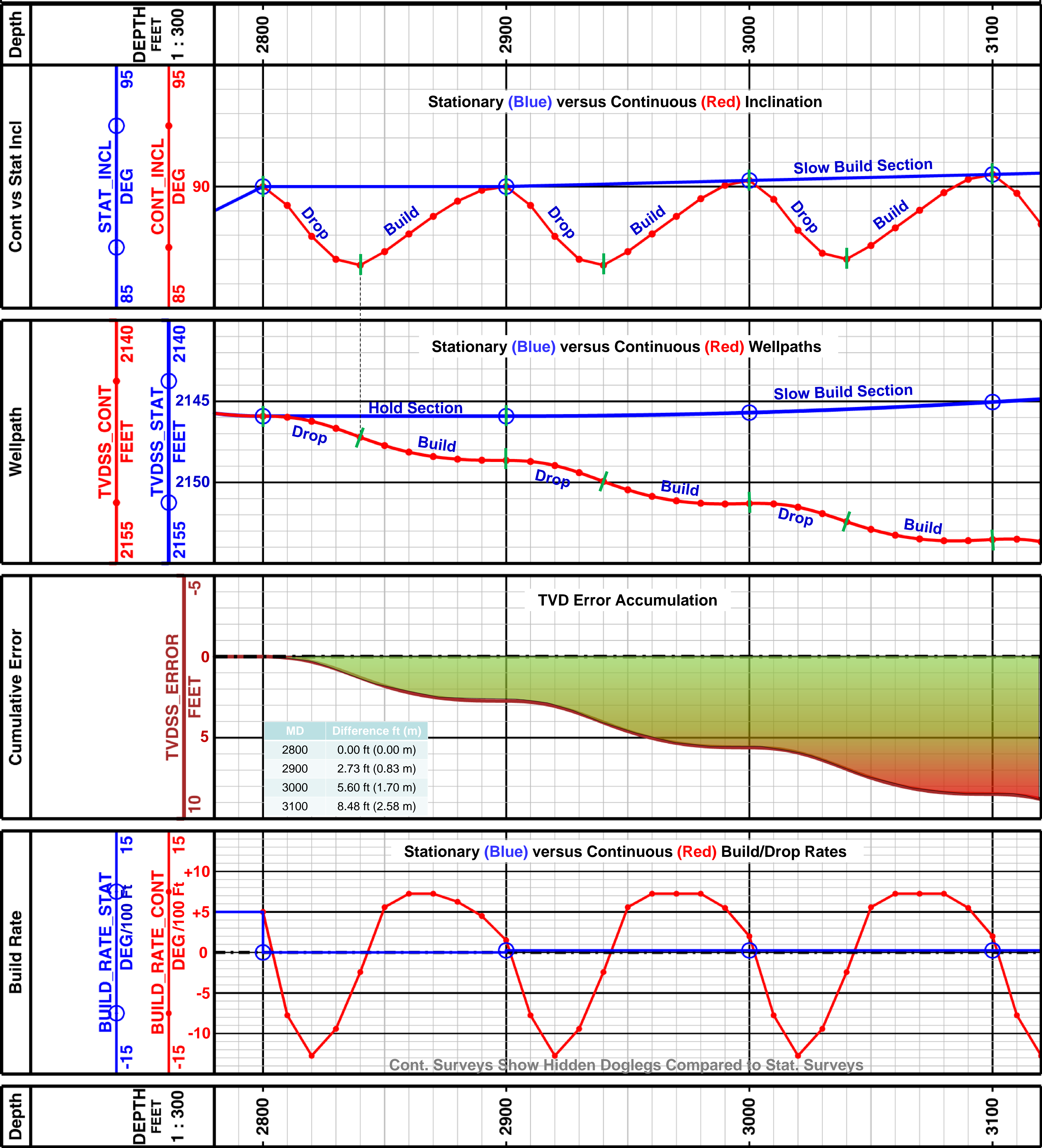
Gross positional errors begin to accumulate along the length of a wellbore any time the actual wellpath trajectory does not match the calculated wellpath trajectory. The areas in which these errors occur can be identified by plotting the continuous survey data against the stationary surveys and looking for places in which there is a separation between the curves connecting the points together. The larger the separation between the curves, the greater the error over that interval.

By monitoring the drilling parameter setting changes along with the continuous survey measurements, one can predict and determine whether or not a gross survey error occurred over the survey interval being evaluated. Additionally combining the continuous survey data with drilling parameter setting data aids in determining if the continuous data is reasonable by visually examining the data for outliers or if a major deflection occurred as a result of the wellbore intersecting a hard or soft geologic feature.

The example to the right highlights how stationary survey data and continuous survey data represent a well path in two very different trajectories. While this data set is generated, it represents real world situations the authors have encountered in fields, basins and countries worldwide (i.e. Angola, Nigeria, Norway, United States, Venezuela, etc.). While these directional errors may seem trivial due to the small scale they represent, when modern day target windows, artificial lift safe operating deviation windows, and proximity to water and gas contacts are considered, the accumulation of these errors can have serious economic impacts.

## Comparing Stationary (Blue) Versus Continuous (Red) Survey Data

### Highlights TVD Error Accumulation and Hidden Doglegs



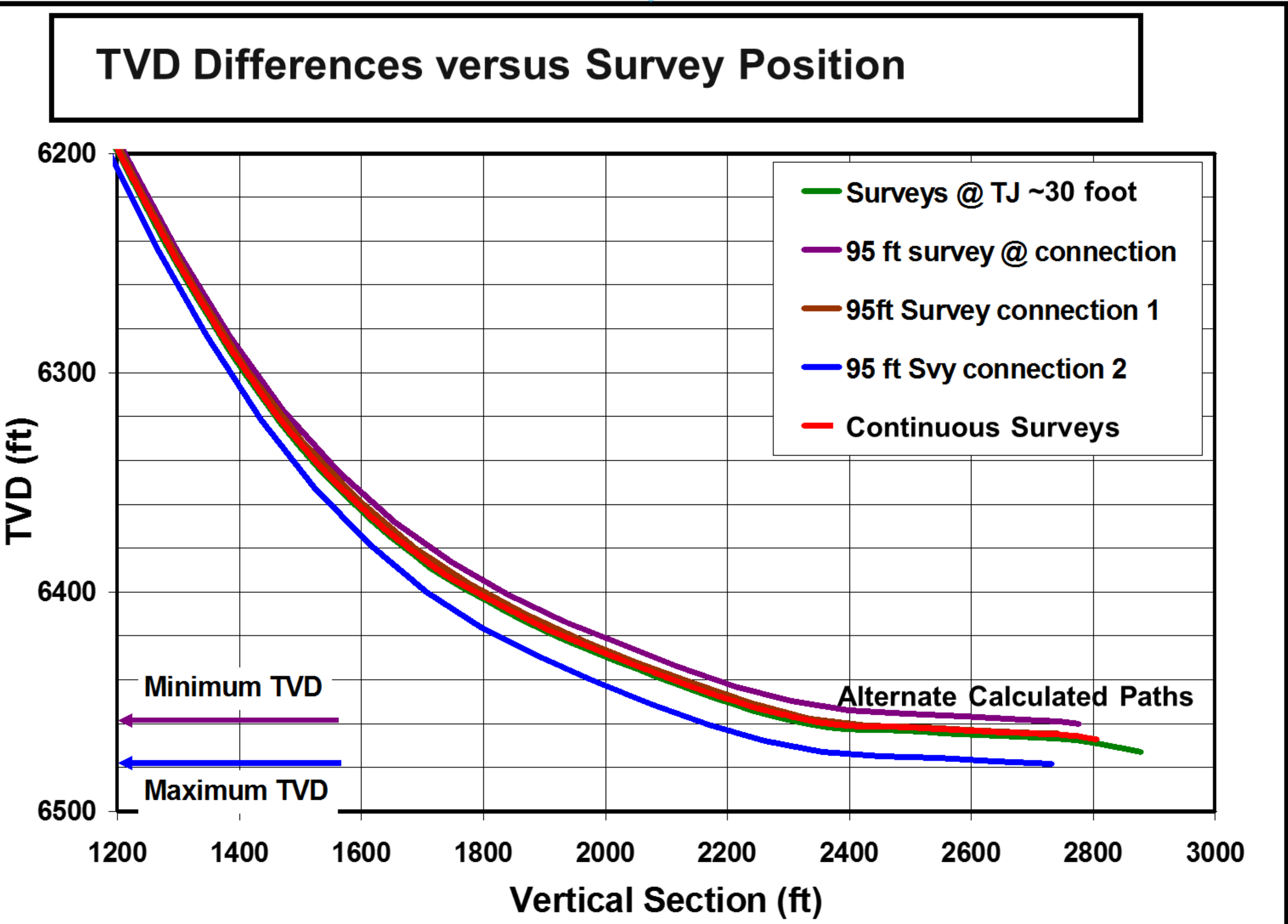
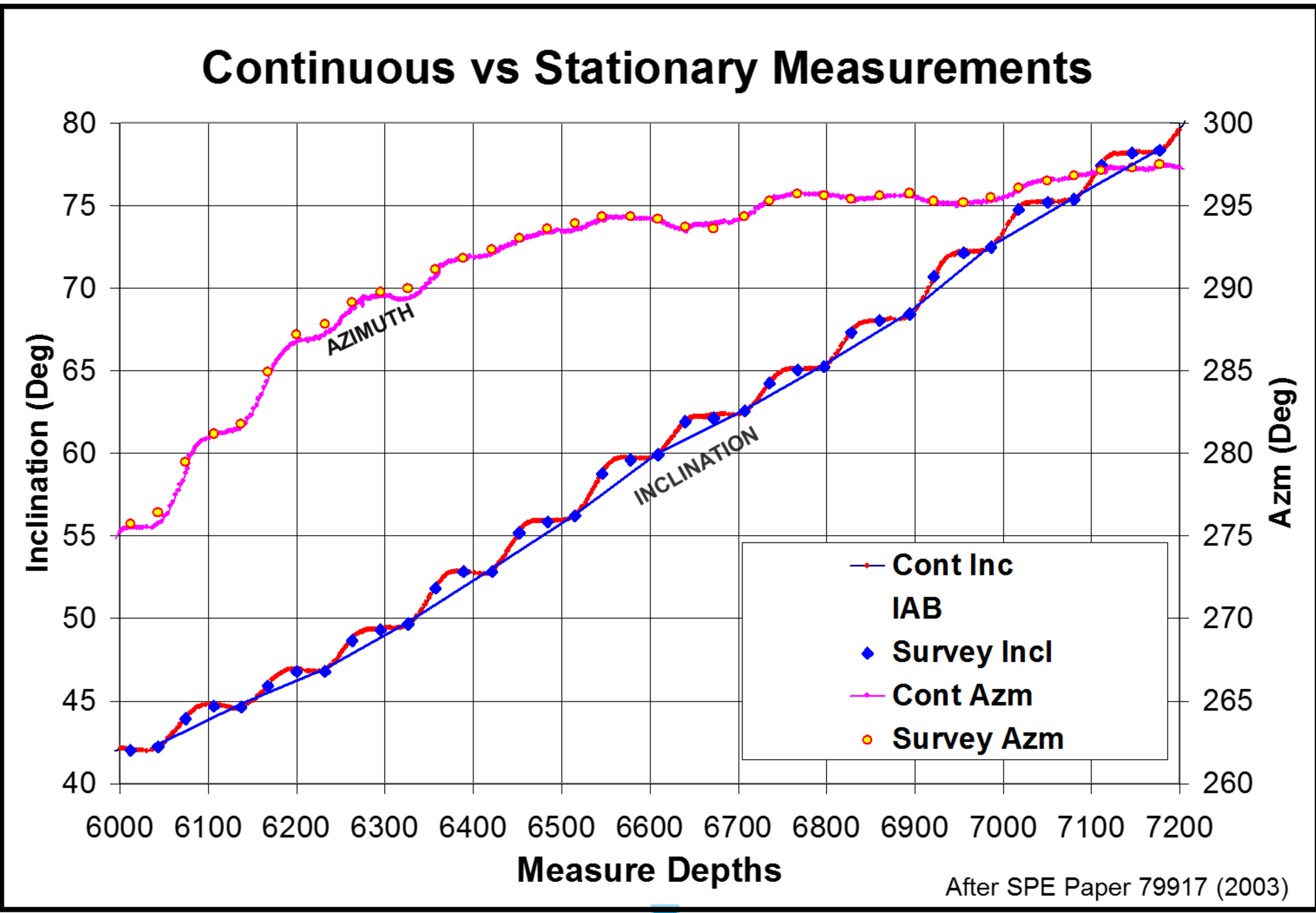


Improving Survey Accuracy by Using Continuous Directional Data and Drilling Parameter Settings

Survey Error Accumulation versus Relative Survey Position and Frequency

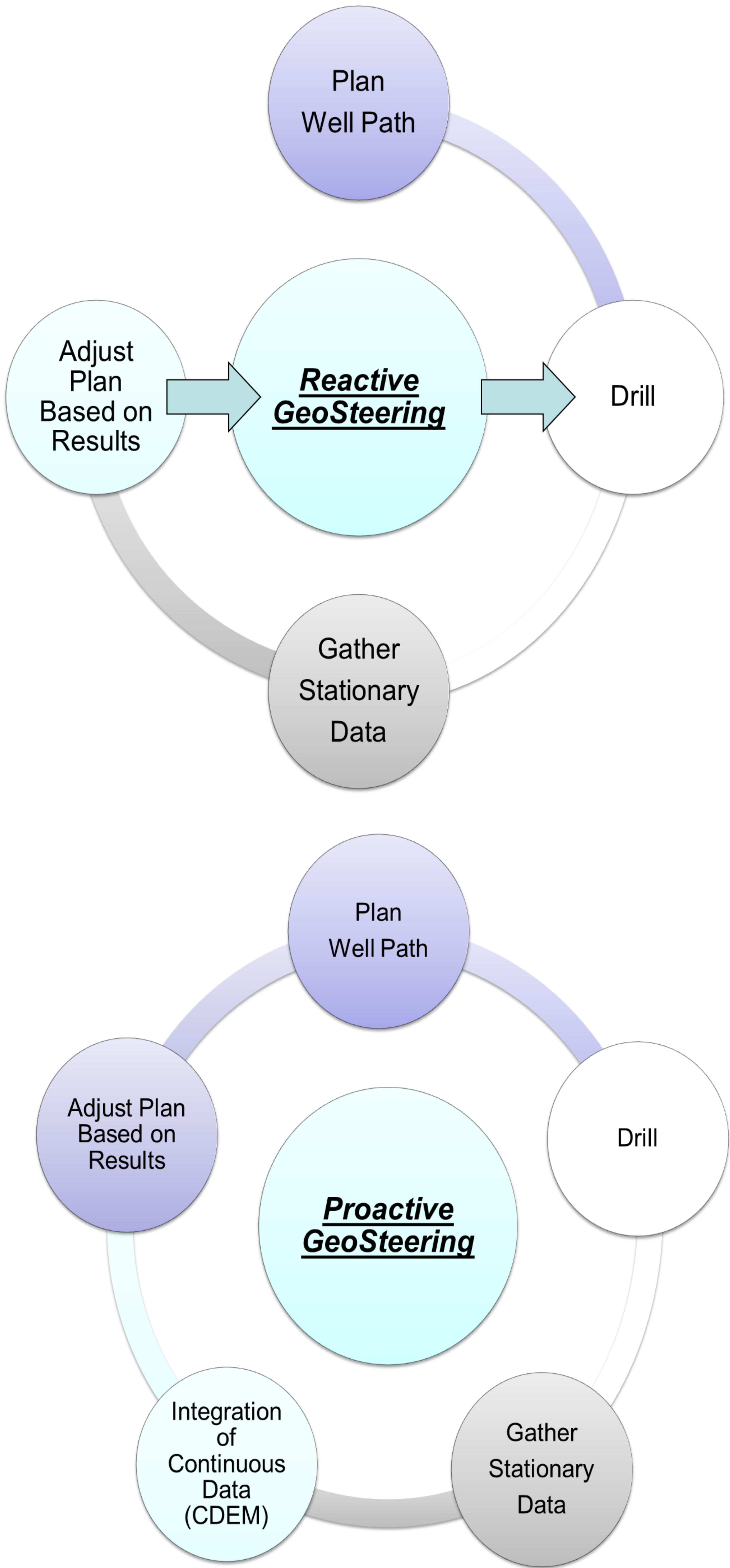
Advantages of use CDEM in Landing Horizontal Wells:

- 90-foot surveys can result in +/-25 feet TVD Errors
- 30-foot surveys minimize errors but adds cost through rig time
- CDEM corrected surveys match surveys in both TVD and X, Y position without adding cost



The CDEM Survey Evaluation and Monitoring Process is an Important Part of Proactive Geosteering

Reactive / Proactive Geosteering

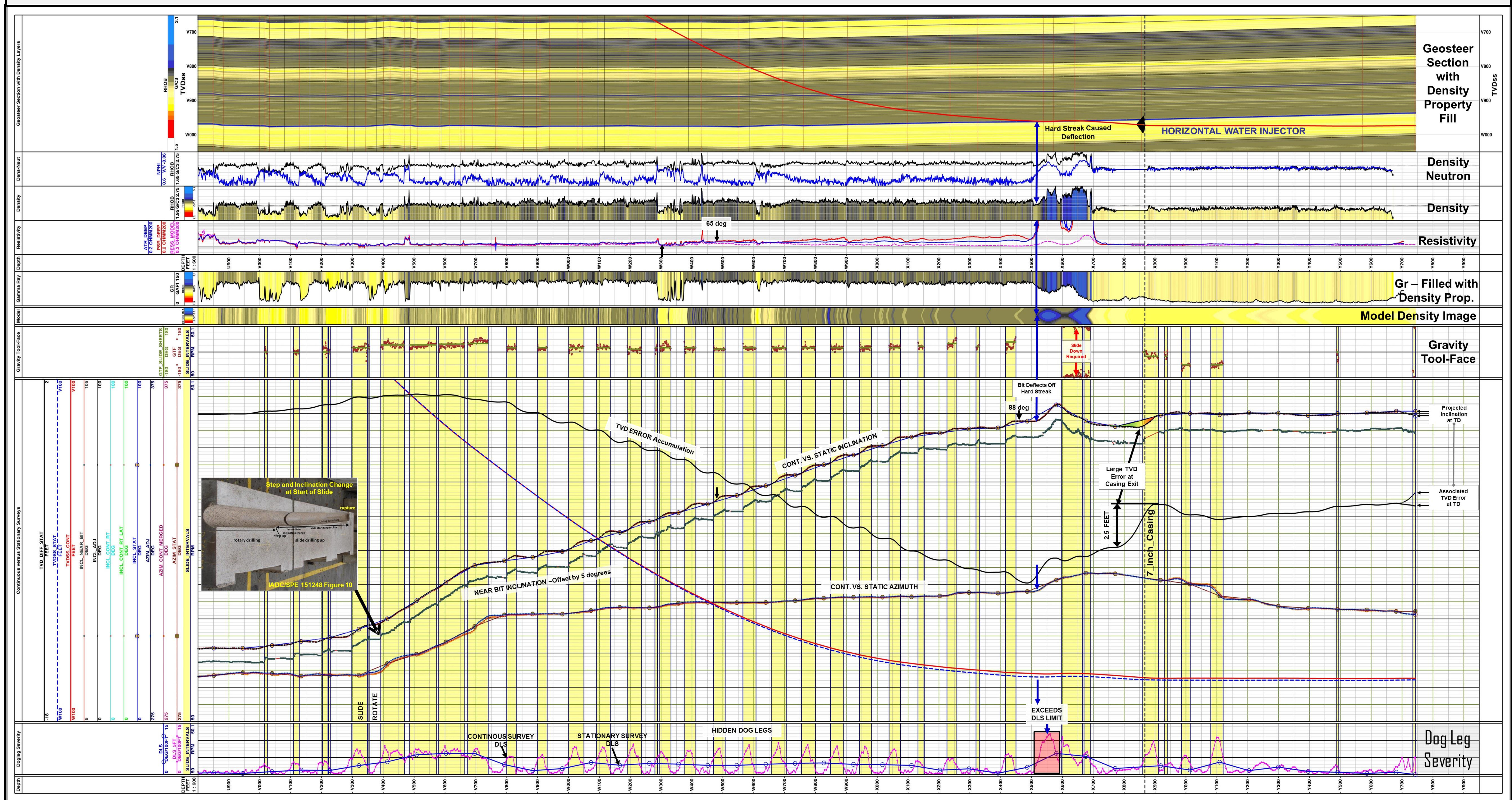




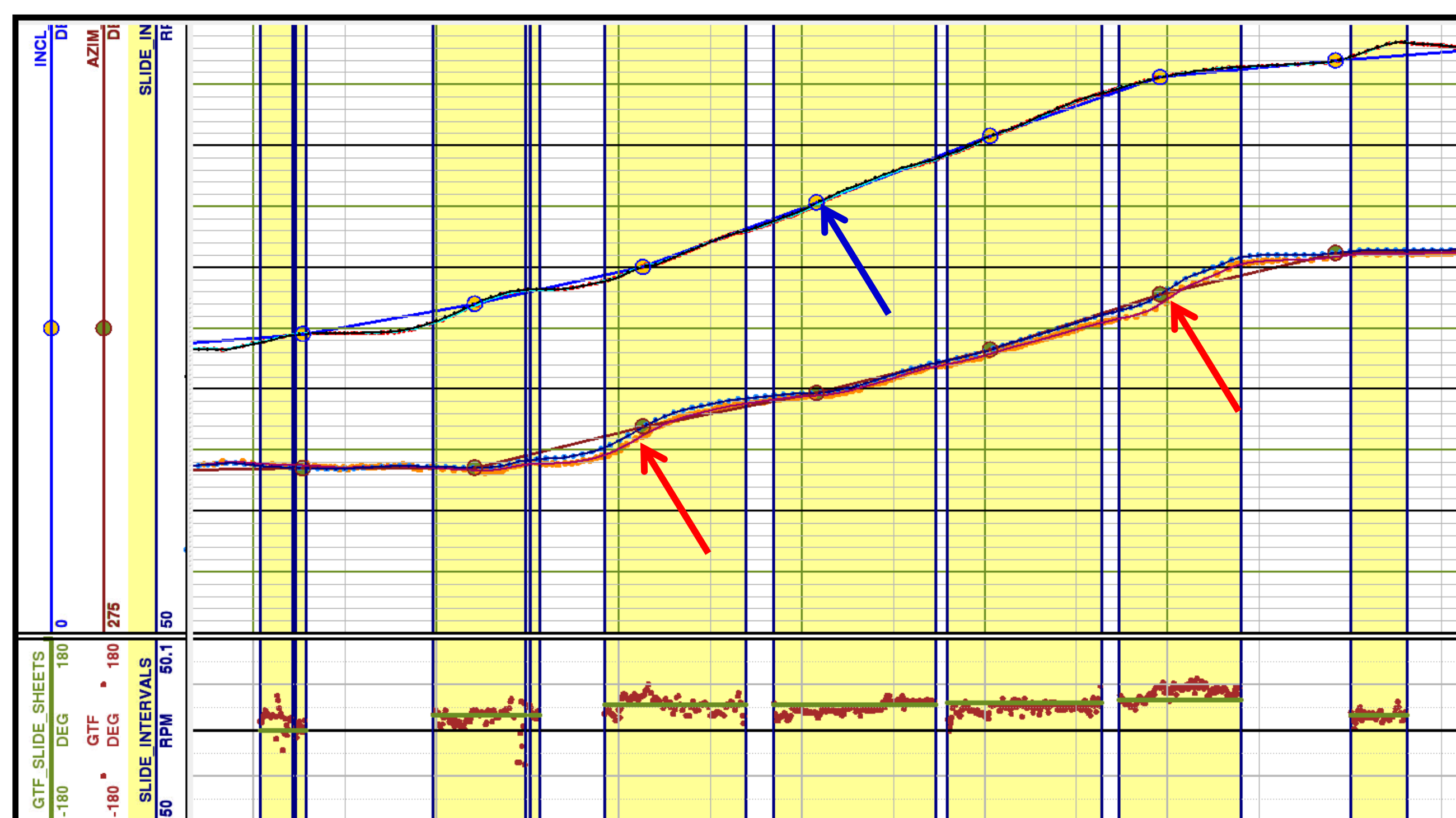
# Improving Survey Accuracy by Using Continuous Directional Data and Drilling Parameter Settings

## Applied Continuous Directional Enhancement Method (CDEM) Workflow

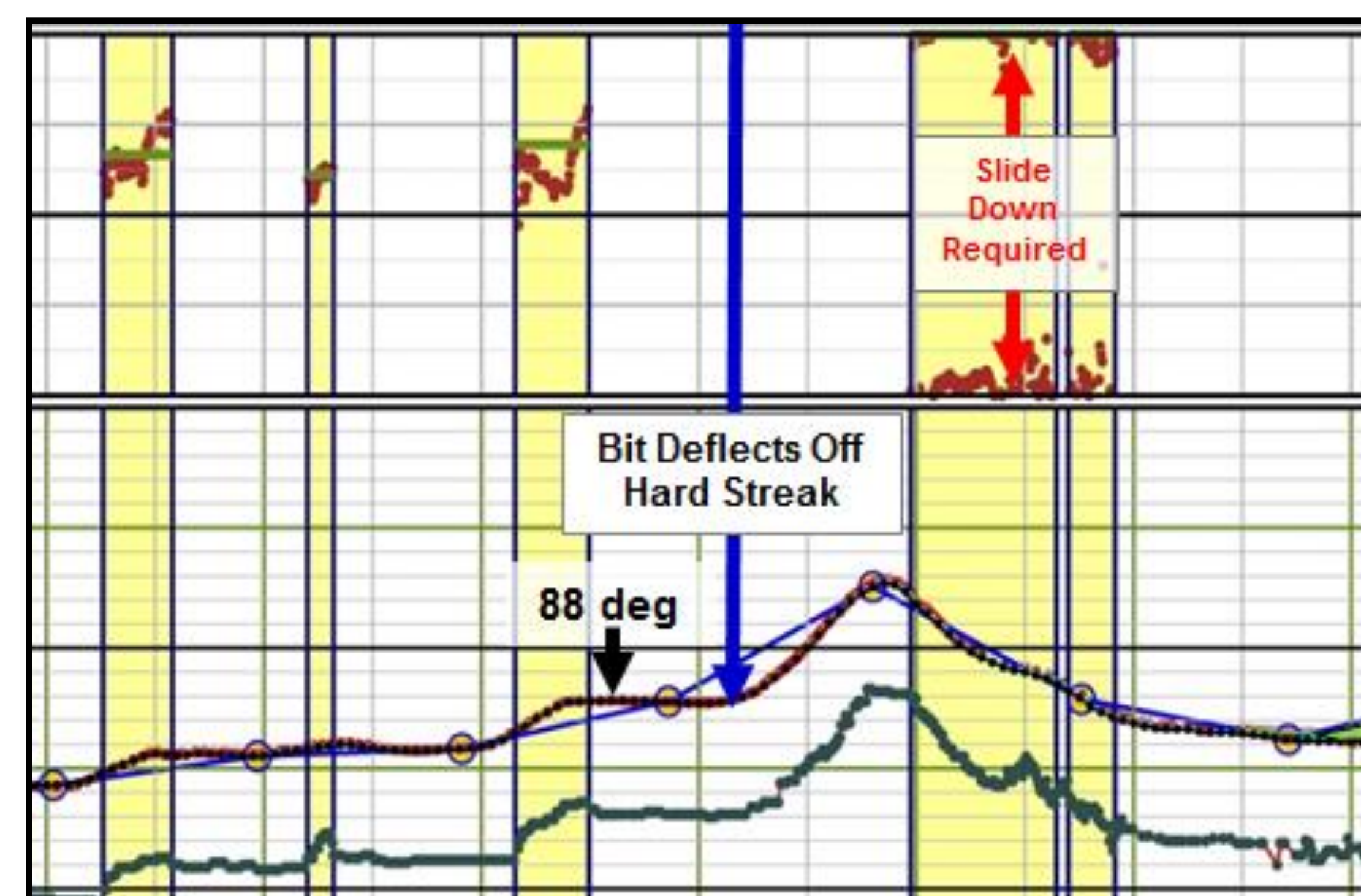
### Example Horizontal Well Drilled with PDM Motors and Slide – Rotate Directional Drilling Modes



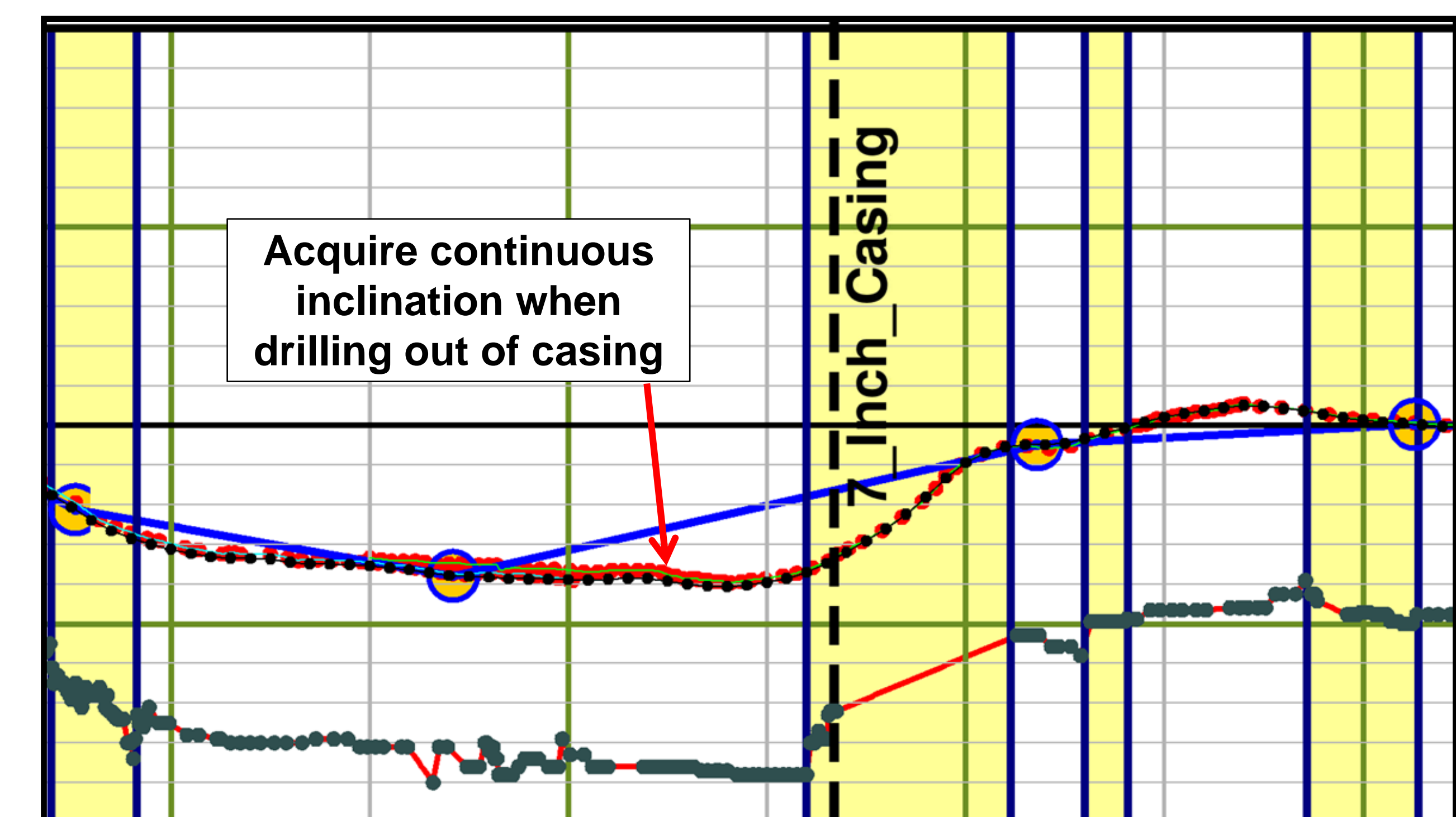
### Fitting and Adjusting Cont. Data to Stat. Data



### Beware of Hard Streaks



### Best Practice for Casing Exits





Continuous Directional Enhancement Method (CDEM) Workflow

Results in Significant Increases in NPV

Gather

QC

Create Best Fit Curve

Adjust

Utilize

Plot Continuous survey data and despike data, removing extreme values

Snap - rotate best fit line through the continuous survey data to the stationary surveys

Load directional path plan and import stationary and continuous survey data in real-time.

Create Best Fit curve through continuous data, use tendency analysis and drilling parameters to fill gaps in data.

Monitor and continuously project ahead in real time, proactively communicating with the directional driller and drilling team to make steering adjustments and identify early extreme doglegs.

Consider Using CDEM to Enhance Accuracy

The advent and subsequent evolution of MWD technologies, brought in part by the recent ‘Shale’ drilling boom, is now providing more data in real time than anytime in the past. The authors believe using the following parameters, which are provided by modern MWD systems will greatly enhance directional survey accuracy and confidence: 1) continuous inclination and azimuth data, 2) gravity and magnetic tool-face data 3) RPM data to identify slide vs. rotate modes, or 4) Rotary Steerable Systems (RSS) steering setting modes.

Changing the industry standard to combined stationary surveys and continuous directional data will provide a robust method for significantly reducing directional positioning errors and to provide early warning of excessive doglegs before they lead to MWD tool failures. In order to accomplish the goal of establishing a workflow the authors propose a method called the Continuous Directional Enhancement Method (CDEM). This method combines the available continuous directional survey measurements and steering parameter setting changes with the stationary survey data to create a new hybrid and more accurate survey.

Evaluating and Making Adjustment for Directional Drilling Tendencies

In order to achieve the desired directional plan, the directional driller needs to continuously evaluate the directional tendency of the bottom hole assembly (bha) in both oriented/sliding mode and in neutral/rotating mode. This is often accomplished by taking additional “check shot” surveys, which are often not reported. A second method for determining the directional tendencies of a bha is described in Lesso’s 2001 SPE paper, which uses continuous survey data – thus reducing the need for wasting rig-time to taking check shots.

Based on this tendency analysis, the directional driller will plan how long to slide and what tool-face setting is needed to meet the directional plan in the build section when drilling with a motor. The same principles also applies when drilling with a RSS system. In this case the directional driller needs to decide on the steering parameter and desired tool-face settings to send down to the bha via a down link.

When drilling a long straight sections (tangent sections), or when drilling the lateral section of a horizontal well, some directional work is often required to correct for build, drop, and/or walking tendencies. In these cases, small nudges (short slides) may be necessary when drilling with a motor or a small steering force at a particular tool-face setting may be needed with a rotary steerable system. The small nudges can result in a 1 to 2-foot or more TVD error in each case.

The Need for Real-time Monitoring and Projecting to the Bit

With knowledge learned from the directional tendency analysis, it is then possible to project ahead and to predict both the inclination and azimuth at the bit. In order to do this, one needs to determine which drilling mode is being applied, what gravity tool-face was settings were achieved or what the predicted current estimated build/drop/walk rate is in rotary mode, and for how long each was applied.

As a well gets closer to becoming bed parallel, close monitoring is very of the continuous survey data is important. This is particularly true in formations that have tight hard layers at the top or base or distributed through the targeted interval. It has been found that it often takes a 4 to 6 degree attack angle for the bit to cut down or up through a tight streak. Each hard stringer encountered often results in a diffraction or deflection of the bit. At too low of an incidence/attack angle, a major deflection can occur, producing a severe localized dogleg, which can lead to an MWD tool failure and/or the well trajectory being knocked off the plan.

This can be seen in the example well, when the bit was approaching the top of the targeted formation. In this case, the bit encountered a hard calcite cemented layer when drilling at 88 degrees of inclination. The bit was deflected upwards to 93 degrees of inclination. In this case, it was lucky that we had a near-bit inclination tool. The event was recognized and the bha was turned down and a slide interval was added and was able to break through to land the well in the top of the targeted reservoir.

Conclusion

Using workflows and methods described in this poster, the CDEM methodology, will provide the user a significantly more accurate wellbore positional survey and will result in better well placement within the targeted reservoir. It will also reduce the number of MWD tool failures and result in a significant improvement in Net Present Value (NPV) for your drilling projects.

Acknowledgements:

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References:

Lesso, W.G., Cooper, I.M. and Chau, M.: "Continuous Direction and Inclination Measurements Revolutionize Real-Time Directional Drilling Decision-Making", paper IADC/SPE 67752 presented at the IADC/SPE Drilling Conference, Amsterdam, The Netherlands, 27 Feb – 1 Mar 2001.

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