ISCWSA #36

An unconventional tool for calculating wellpath position in high dogleg severity wells

James Hood,

Baker Hughes

Outline

- References
- Bending Moment – Definition and Measurement
- Bending Tool Face – Definition and Measurement
- Application Examples
  - Build and Turn RSS Section
  - Casing Exit with RSS
  - Examples from drilling challenging well paths
  - Example with drilling with conventional system
- Discussion and Outlook
- Conclusions

References For Further Investigation

IADC/SPE 79918 : Real-time BHA Bending Information Reduces Risk when Drilling Hard Interbedded Formations

SPE/ATCE 90794 : Continuous Borehole Curvature Estimates While Drilling Based on Downhole Bending Moment Measurements

SPE 93864 : Verification of an Advanced Analysis Model with Downhole Bending Moment Measurements

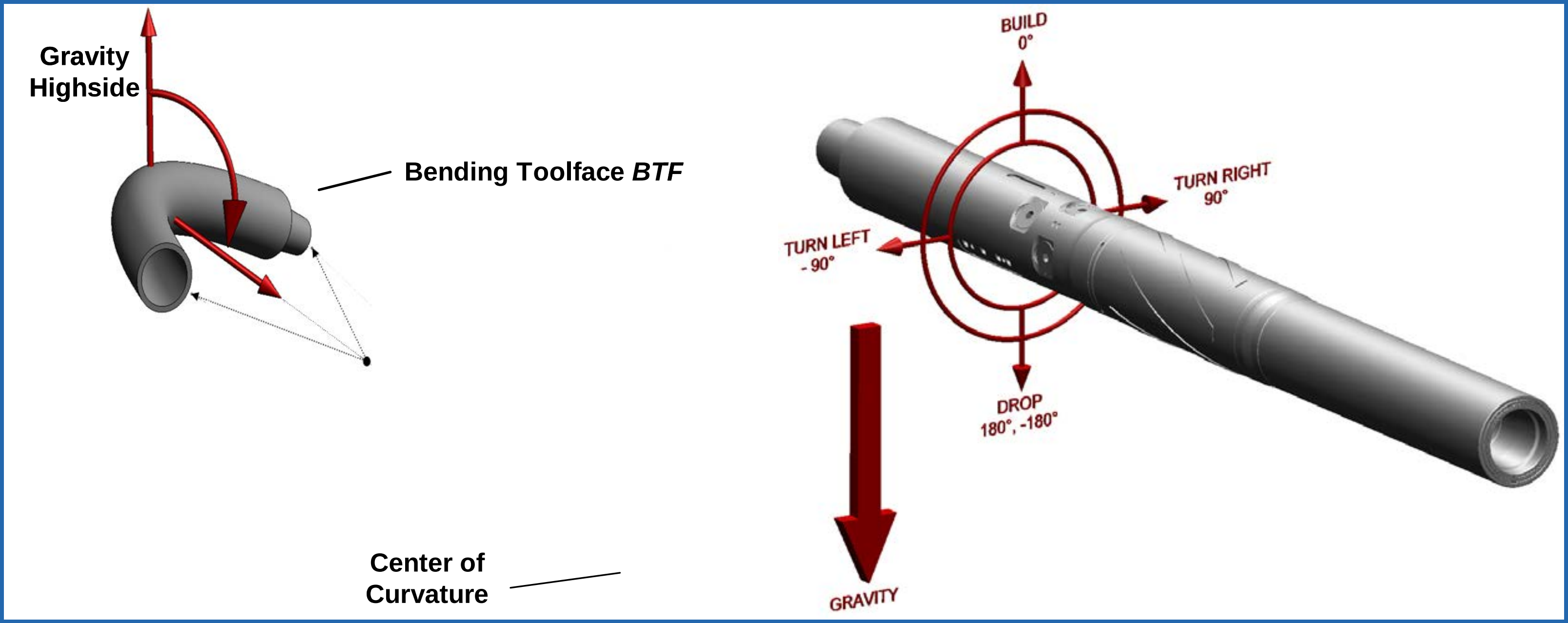
IADC/SPE 128520 : Real-Time Tool Face Information Reduces Directional Uncertainty and Risks in Difficult Sidetracks in the Gulf of Suez

IADC/SPE 128789 : Bending Tool Face Measurements While Drilling Delivers New Directional Information, Improved Directional Control

SPWLA 52nd Annual : Superior horizontal well placement yields impressive production increases in mature field by using multidiscipline approach combining deep azimuthal resistivity and continuous survey monitoring with downhole bending moment and bending tool-face measurement in_a rotary steerable drilling system

Bending Tool Face - Definition

- Continuous downhole bending moment measurements provide good estimates of local dogleg severity (SPE 90794, 2004)
    - Simple model: BHA curvature and hole curvature are same
    - Advanced model: Relationship calculated via mathematical BHA model (3D Finite Element Model) ➔ Today standard application
- Downhole tool processing enhanced to derive bending tool face w.r.t. gravity highside



Bending Moment (BM)

- Measurement in downhole BHA
  - Two independent strain gauge bridges → M_x, M_y
    - Sampled at 1000 Hz
  - Resulting bending moment $M = SQRT(M_x^2 + M_y^2)$
    - Recorded in memory every 5 seconds
    - MWD transmission to surface

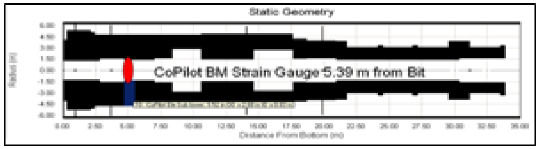
- BHA Curvature
  - Bending stiffness of BHA: EI
    - Young Modulus E
    - Moment of Inertia I of BHA cross section at point of measurement

Bending Tool Face - Definition

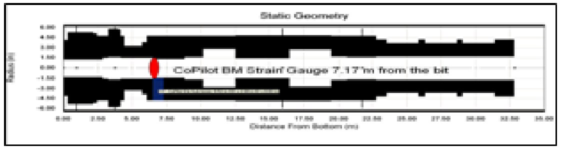
- **Algorithm Overview**
  - 2 independent bending strain gauge bridges ➔ *BM_x, BM_y*
  - 3-axis accelerometer and magnetometer in same tool
  - All sensors sampled simultaneously at 1000 Hz
  - Sliding case ➔ SPE 128520
  - Rotating case (challenging due to vibrations, stick/slip):
    - Advanced signal processing to derive azimuthal reference from magnetometer signals
    - Derive phase angle Φ_{accel} between accelerometer signals and azimuthal reference
    - Derive phase angle Φ_{bend} between bending moment signals and azimuthal reference
    - Obtain bending tool face as $BTF = \Phi_{bend} - \Phi_{accel}$

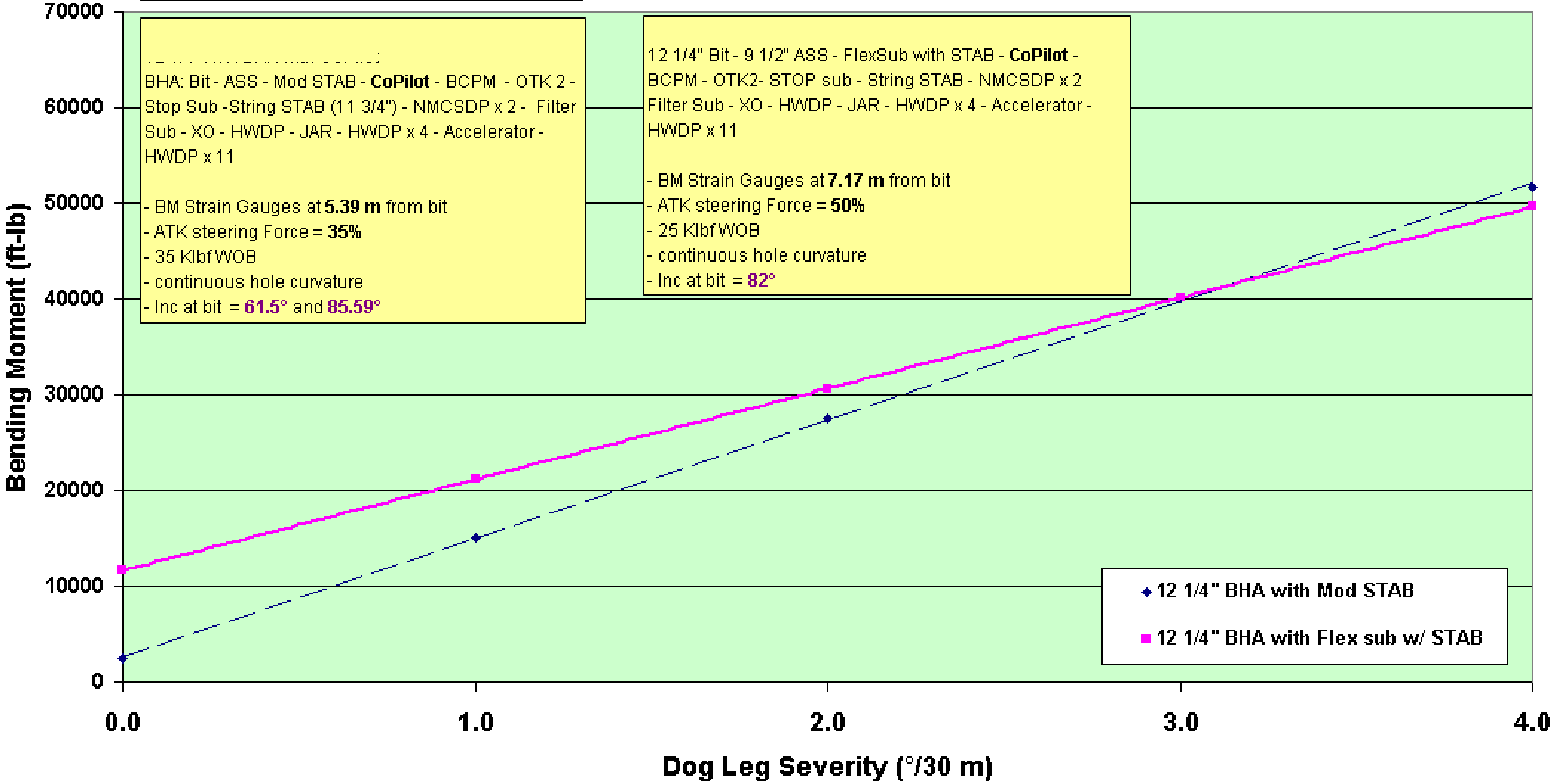
Build and Turn RSS Section

12 1/4" BHA: ASS - Mod STAB

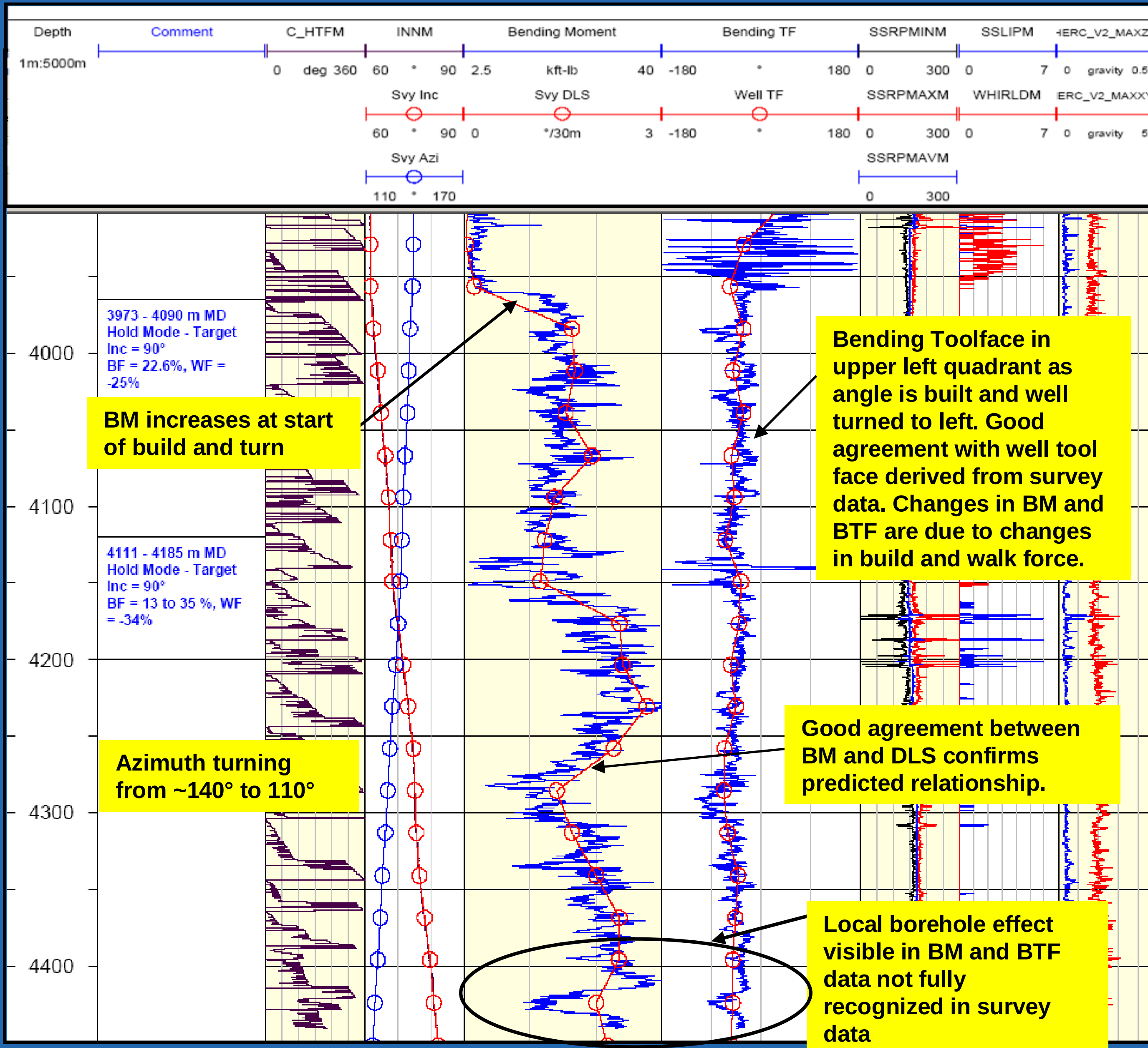


12 1/4" BHA: ASS - Flex sub w/ STAB





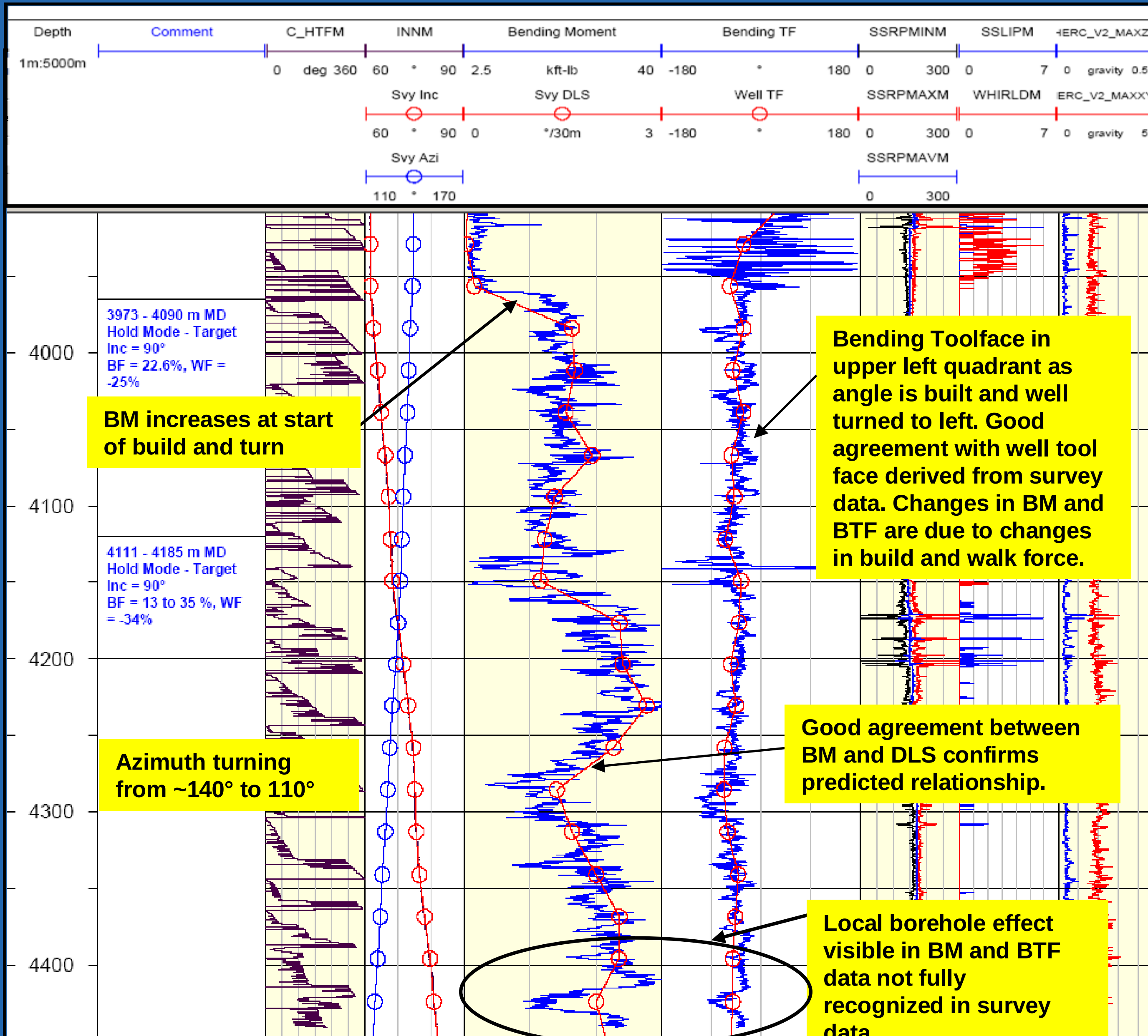
Build and Turn RSS Section



Recorded with 9 ½" tool in RSS BHA in 12 ¼" borehole

Bending moment measurement point 5.4 m behind the bit

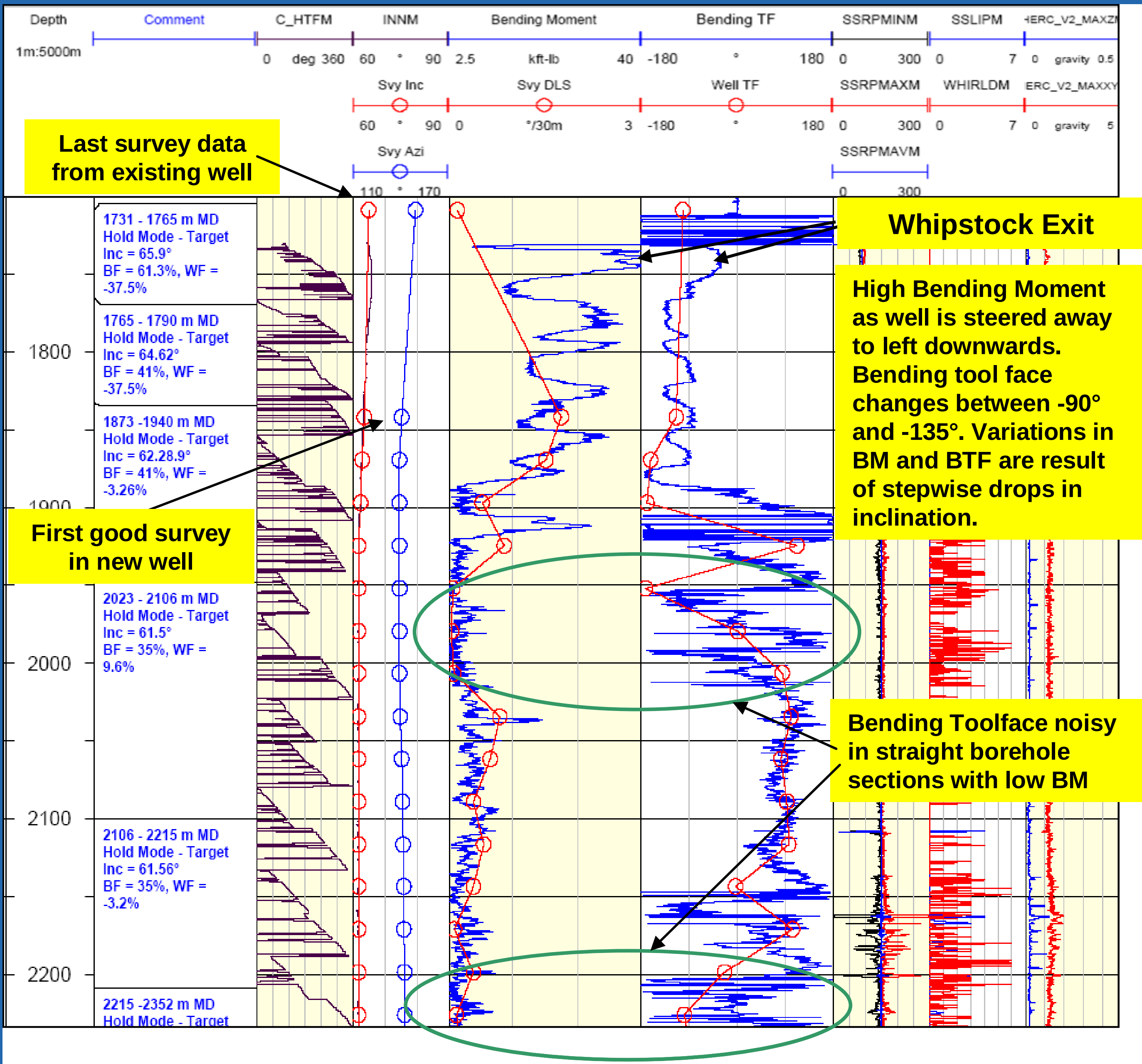
Build and Turn RSS Section



Recorded with 9 ½” tool in RSS BHA in 12 ¼” borehole

Bending moment measurement point 5.4 m behind the bit

Casing Exit with RSS



Recorded with 9 ½" tool in RSS BHA in 12 ¼" borehole

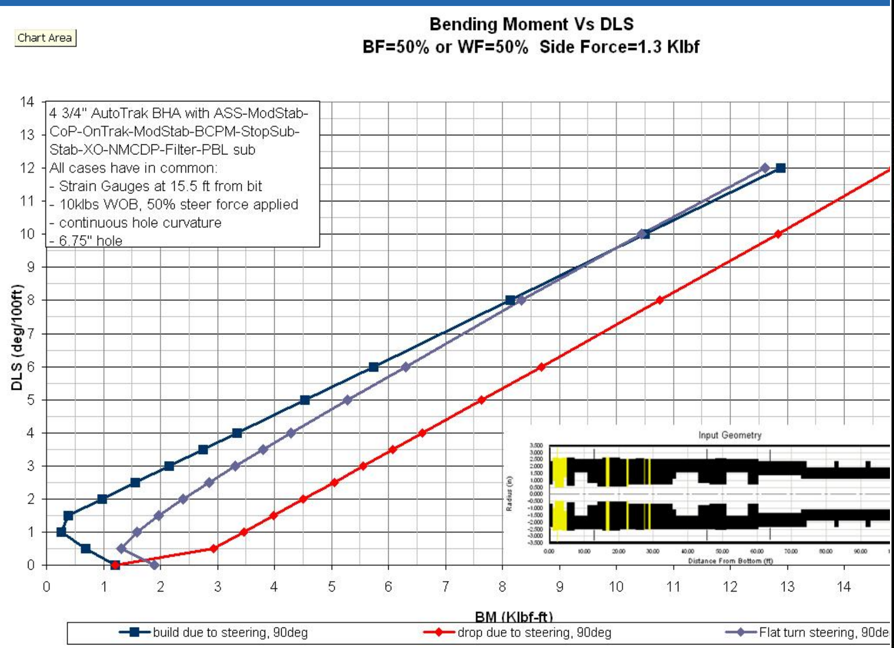
Bending moment measurement point 5.4 m behind the bit

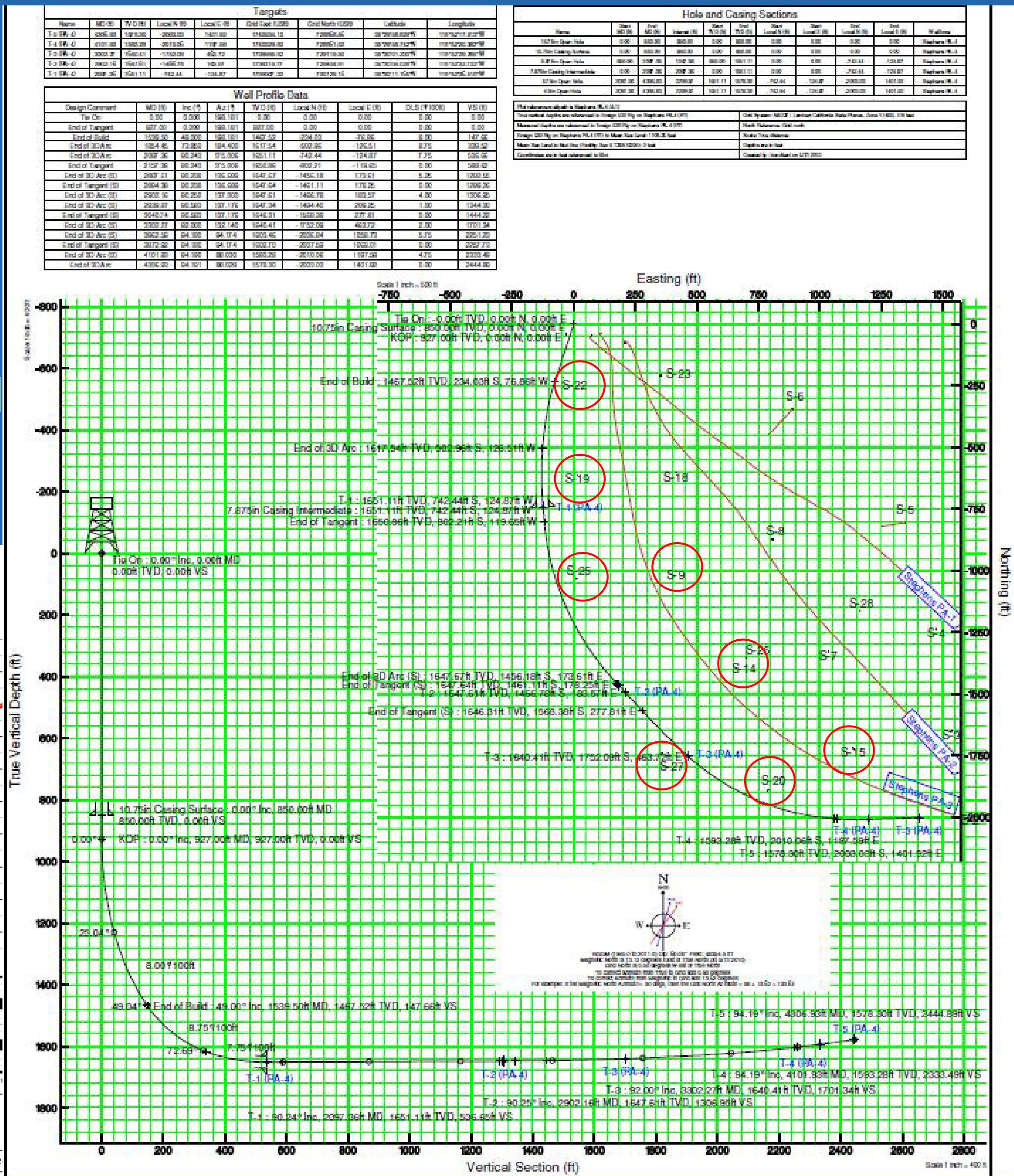
Real-time Benefits

- **Immediate confirmation of whipstock orientation**
- **Confirmation of well moving away from old wellbore ➔ reduction in steer force, no oversteering**

High Dog-Leg Left Turns Avoiding Well Bore Collision

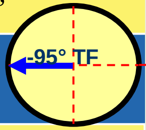
Bending Tool-face provides Rotary Steerable system with the close Azimuthal control. Drilling these Steering Challenges require the best possible well path with Rotary Steerable especially for (build & turn & flat turn wells) these demand close to the bit azimuthal control for well bore collision avoidance.





High Dog-Leg Left Turn control method

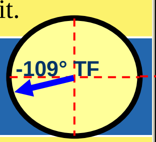
Smooth Turn left 5 deg/100'



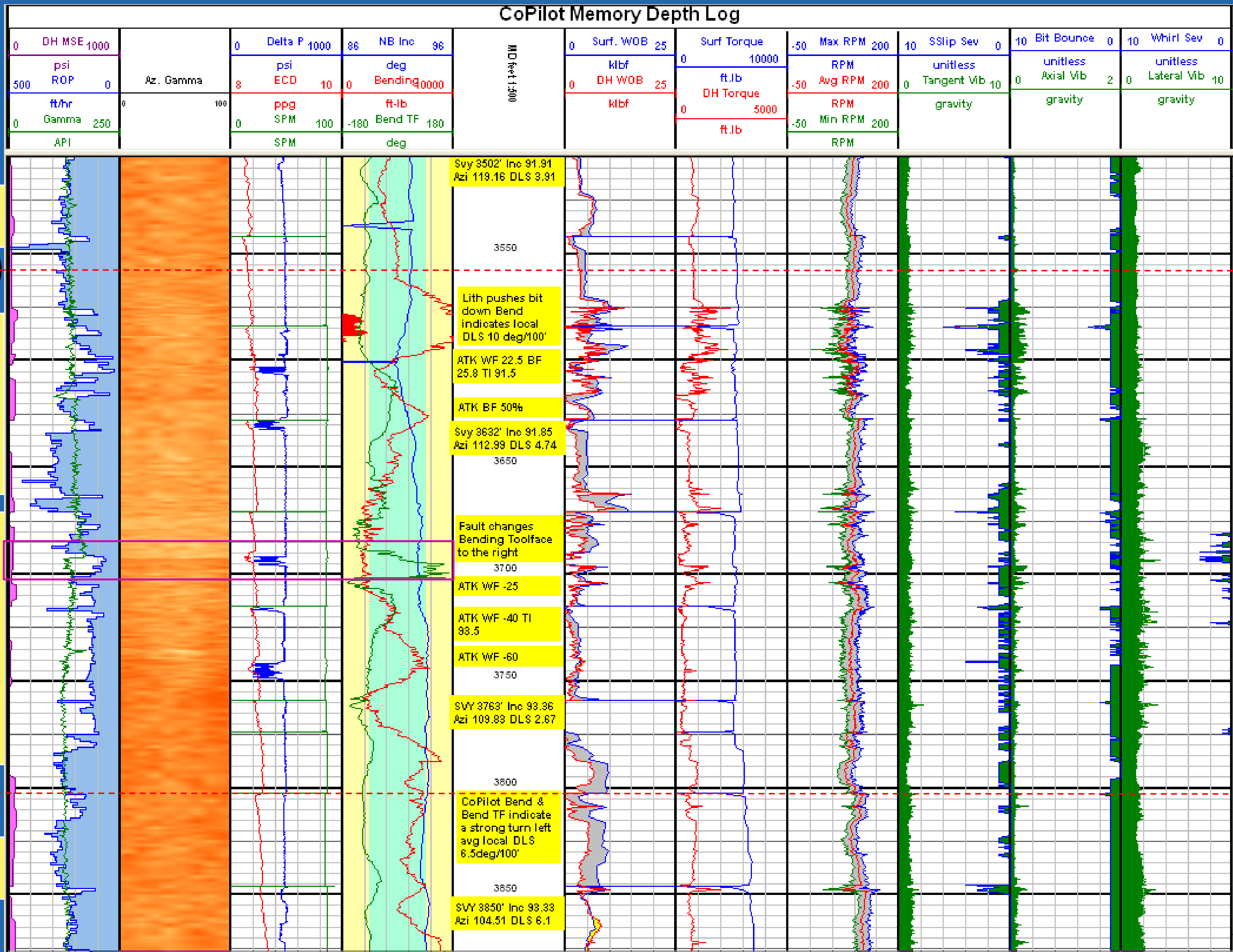
Drop 10 deg/100' rock hardness change cause drop due hardness on top Slow increase in target Inc & build force

Fault flips direction downlink

To increase left turn force continue to increase turn force based from CoPilots bending tool-face and bending moment info close to the bit.

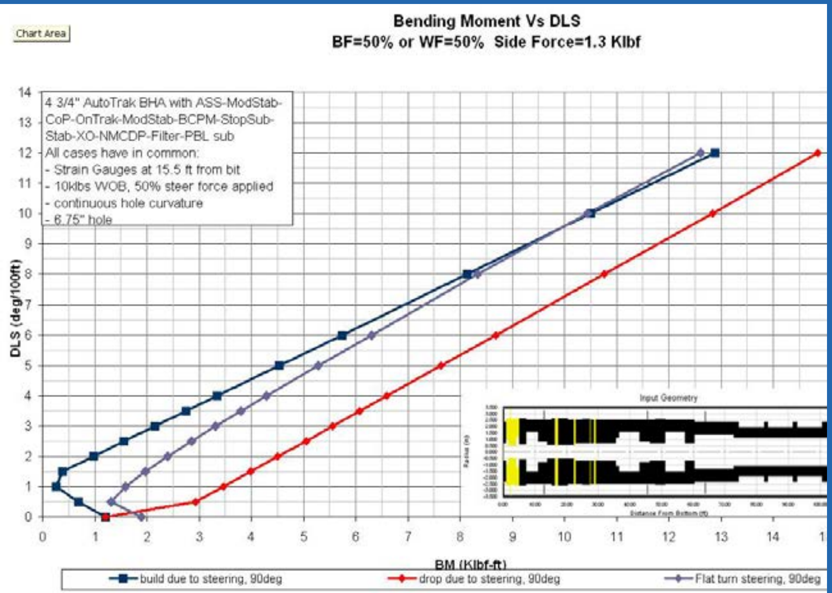


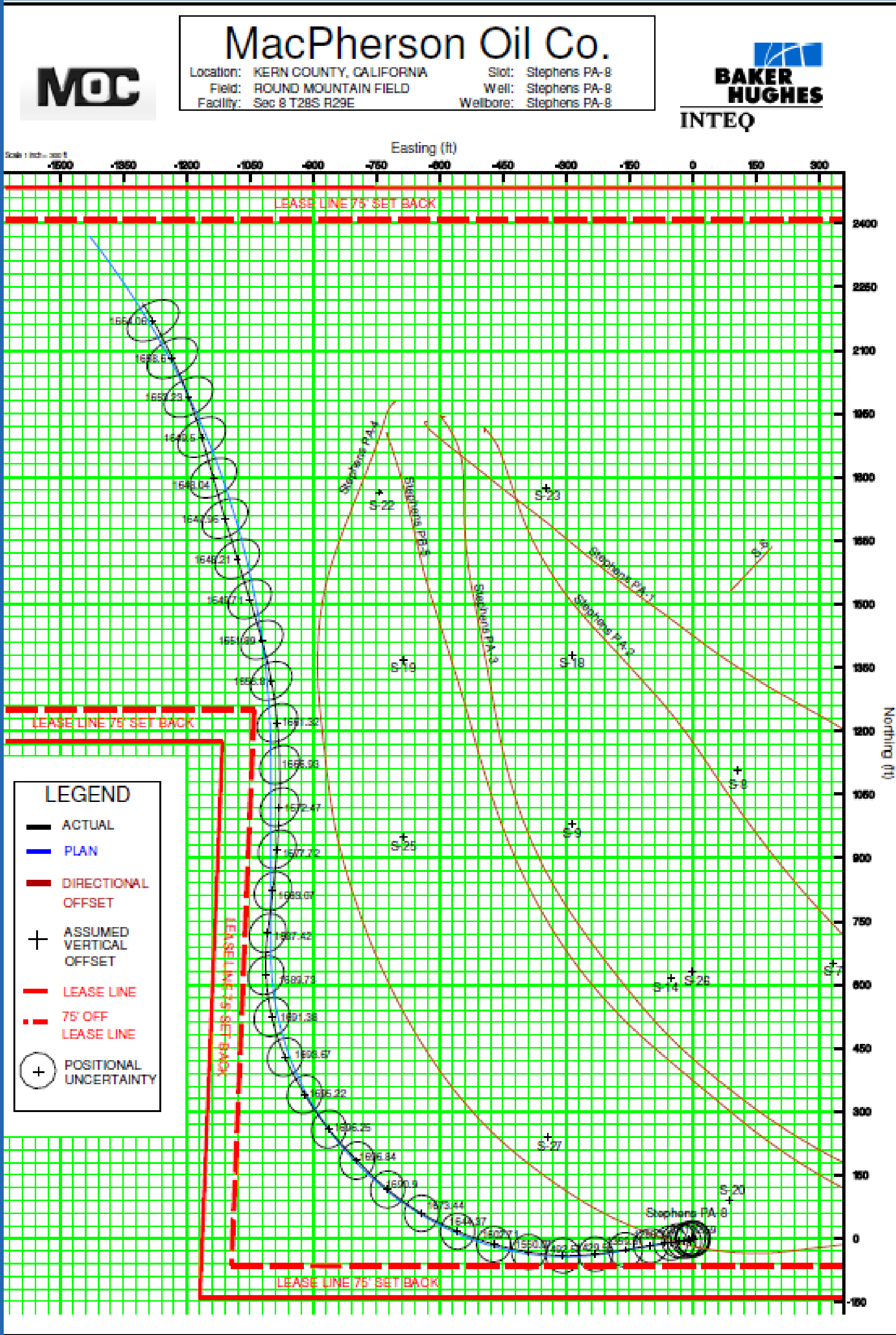
Smooth Turn left 6.5 deg/100'



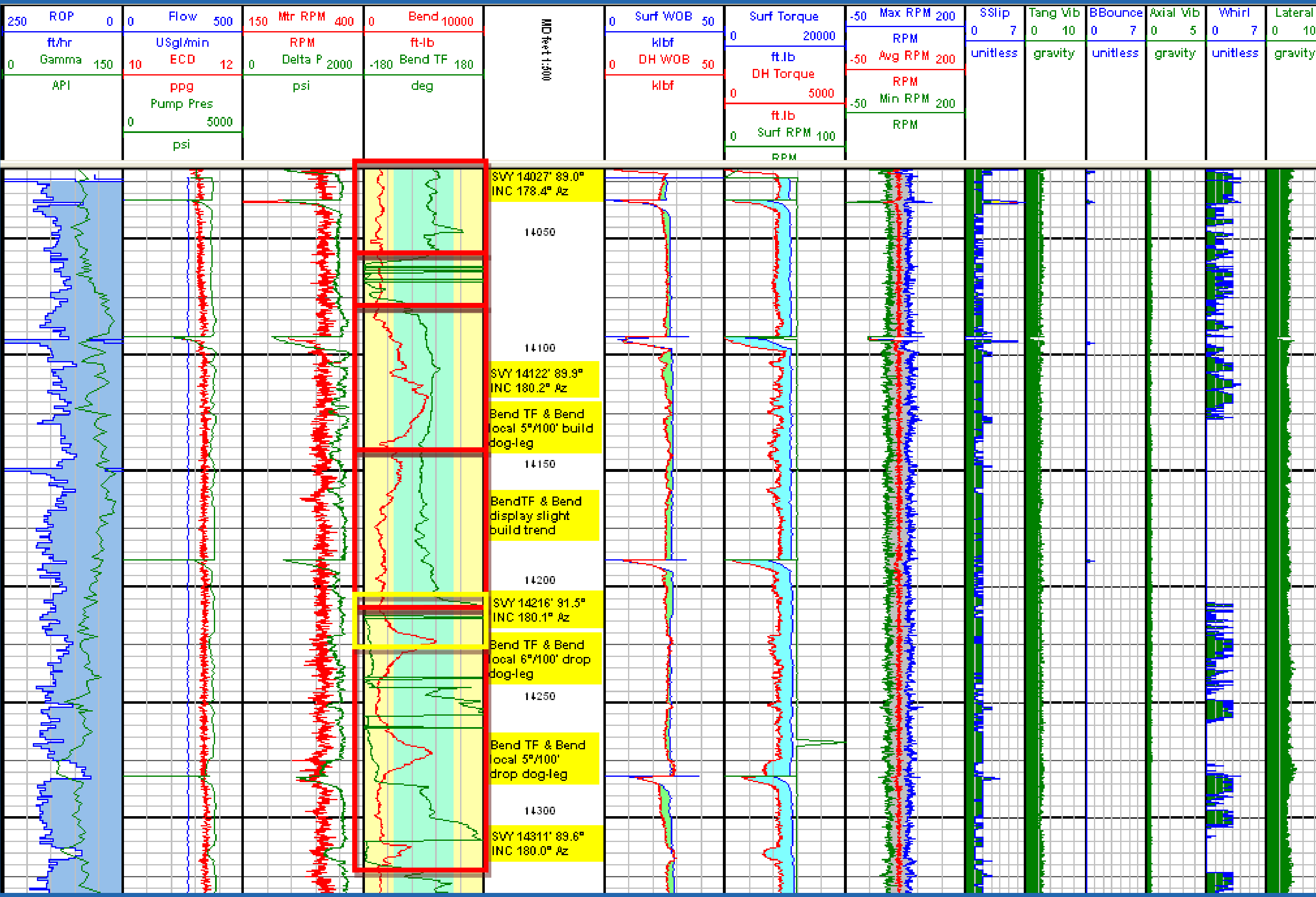
Trace Lease Line with Perfect Clearance

Bending Tool-face provides Rotary Steerable system with close Azimuthal control. Drilling these Steering Challenges require the best possible well path with Rotary Steerable especially for (build & turn & flat turn wells) these demand close to the bit azimuthal control for lease line avoidance with10 deg/100' flat turn.





Bending & Bending Toolface Information Prevents the Need for a Wellbore Correction Disregarding the Survey 25 feet Behind



14000 to 14057 ft bend toolface ID's a slight build trend w/slight right turn SVY @ 14122confirms

14058 to 14075 ft bend toolface ID's slight drop w/ slight left turn

14090 to 14140 ft bend toolface a mod build trend w/slight right turn

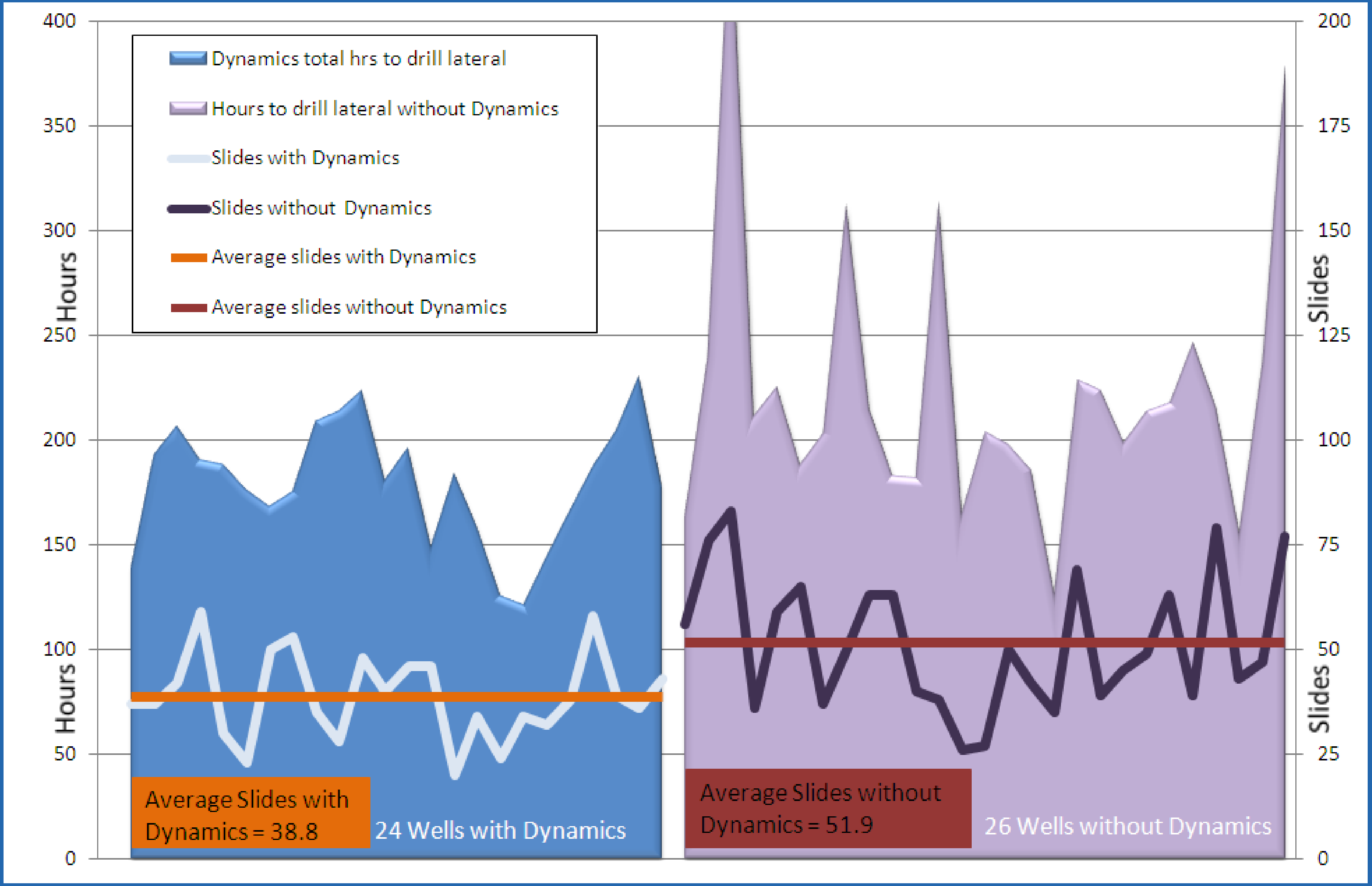
14140 to 14190 ft bend toolface a slight build trend w/slight left turn SVY at 14216 confirms

14216 Inc 91.5 deg demands a slide to drop Inc Bend Toolface ID's drop

14205 to 14320 ft Bend & bend toolface ID's a couple strong drop local dog-legs . SVY @14311 confirms

SPE -160121 - Information from a Downhole Dynamics Tool Provides Real-Time Answers for Optimization While Drilling 10,000 ft Laterals in the Middle Bakken Formation of the Williston Basin - James Hood

More Consistent Results With Dynamics Sub



SPE -160121 - Information from a Downhole Dynamics Tool Provides Real-Time Answers for Optimization While Drilling 10,000 ft Laterals in the Middle Bakken Formation of the Williston Basin - James Hood

Case History

Poster Page 1

Presented at Colorado Springs, CO 2011

SUPERIOR HORIZONTAL WELL PLACEMENT YIELDS IMPRESSIVE PRODUCTION INCREASE IN MATURE FIELD BY RESISTIVITY & CONTINUOUS SURVEY MONITORING USINGDOWN-HOLE BENDING MOMENT AND BENDING TOOL-

Jeffrey K. Vaughan, Vaughan Exploration, Inc. Ron Palmer, Macpherson Oil Co., Andres Benitez, Aaron Bowser, Adam Graham, Eric Hart, James Hood, Justin Long, Micheal

ABSTRACT

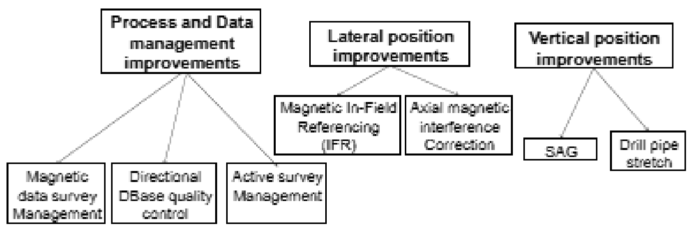
A recent project initiated to drill shallow horizontal wells in California, USA for Macpherson Oil Co. utilized a customized package of solutions and technologies that were developed to drill horizontal wells in the field while improving production. After completing one third of the initial horizontal development, the current production is the highest the field has seen in 72 years. Highly precise wellbore placement, in conjunction with robust real-time logging information were sighted as the primary reasons for the success of the operation thus far. To achieve optimized wellbore placement, the following processes were used:

1) Real-time three-dimensional reservoir navigation drilling systems helped to visualize and interpret the large volume of available information, reduce well-placement uncertainty, and estimate distance to bed boundaries with high confidence by using formation evaluation data such as azimuthal resistivity, gamma imaging, etc.
2) Deep-azimuthal resistivity service to provide formation evaluation information in three-dimensional reservoir navigation.
3) Economical usage of rotary steerable systems in a land-based application, with a smooth wellbore to facilitate completion.
4) Real-time continuous survey calculation while drilling using continuous down-hole bending moment and bending tool-face measurements for superior well placement with rotary steerable systems. this continuous down-hole survey measurement, unaffected by magnetic interference from nearby offset casing, helped place wells closer to offsets, maximizing the density of horizontal wellbores that can be drilled.
5) Real-time drilling dynamics for optimum drilling parameters to maximize steering efficiency and improve well placement
6) Introduction of new survey-management services to reduce wellbore uncertainty and increase room for more horizontal wells with more effective and efficient usage of the field and its future potential further development of the field will include the examination of technologies that are still at the inception stage but hold potential for development and execution in these operations.

The names of geological identifiers, formation information, and well names will be assigned arbitrary naming conventions.

Wellbore Placement and Enhancement

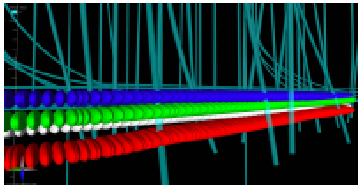
Enhanced Survey and wellbore placement clasification

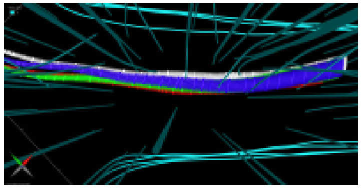


Cross Section view

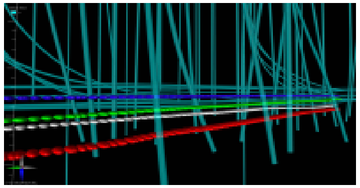
Top view

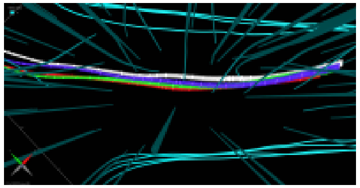
Ellipses uncertainty **without** survey enhancement corrections



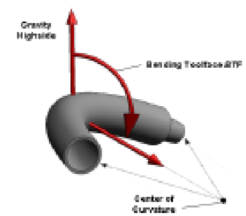


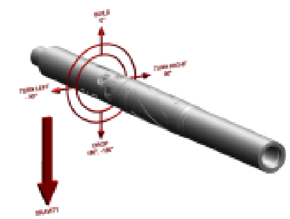
Ellipses uncertainty **with** survey enhancement corrections



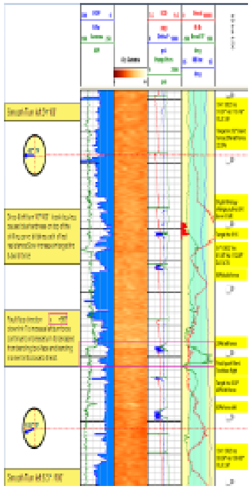


Directional Control Improvement using Down-hole Bending Moment and Bending Tool-face

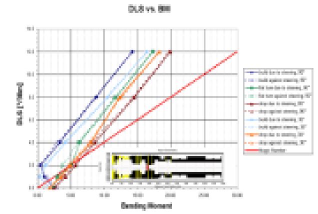




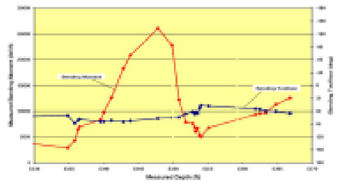
Drilling Dynamics Log



Dogleg severity and bending moment equivalency chart



Bending moment & Beniding Tool-face response Through a High Local Dogleg



Case History

Poster Page 2

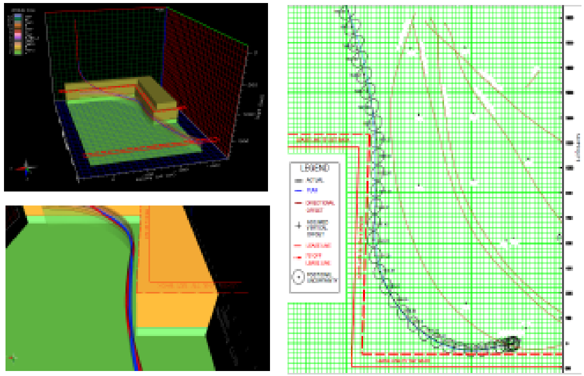
Presented at Colorado Springs, CO 2011

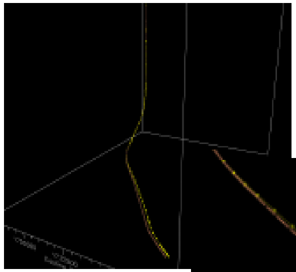
USING MULTIDISCIPLINED APPROACH COMBINING DEEP-AZIMUTHAL FACE MEASUREMENTS IN A ROTARY STEERABLE DRILLING SYSTEM

SPWLA-D-10-00036R1

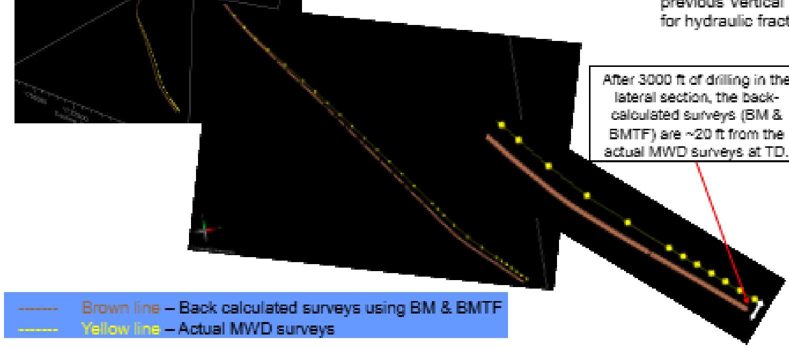
Vigil, Tandre Williams, Arash Aghassi, Baker Hughes Incorporated

Example of how the bending moment and the bending tool-face was used to control steering while drilling along lease lines

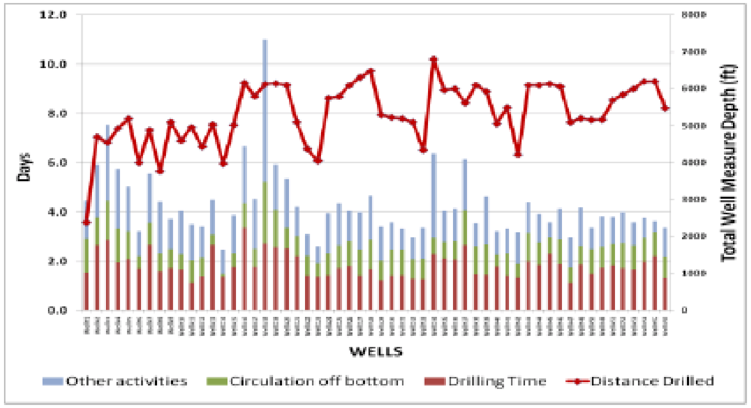




Example of well where bending moment (BM) and bending tool-face (BMTF) was used to back calculate survey and compared them with actual MWD surveys.



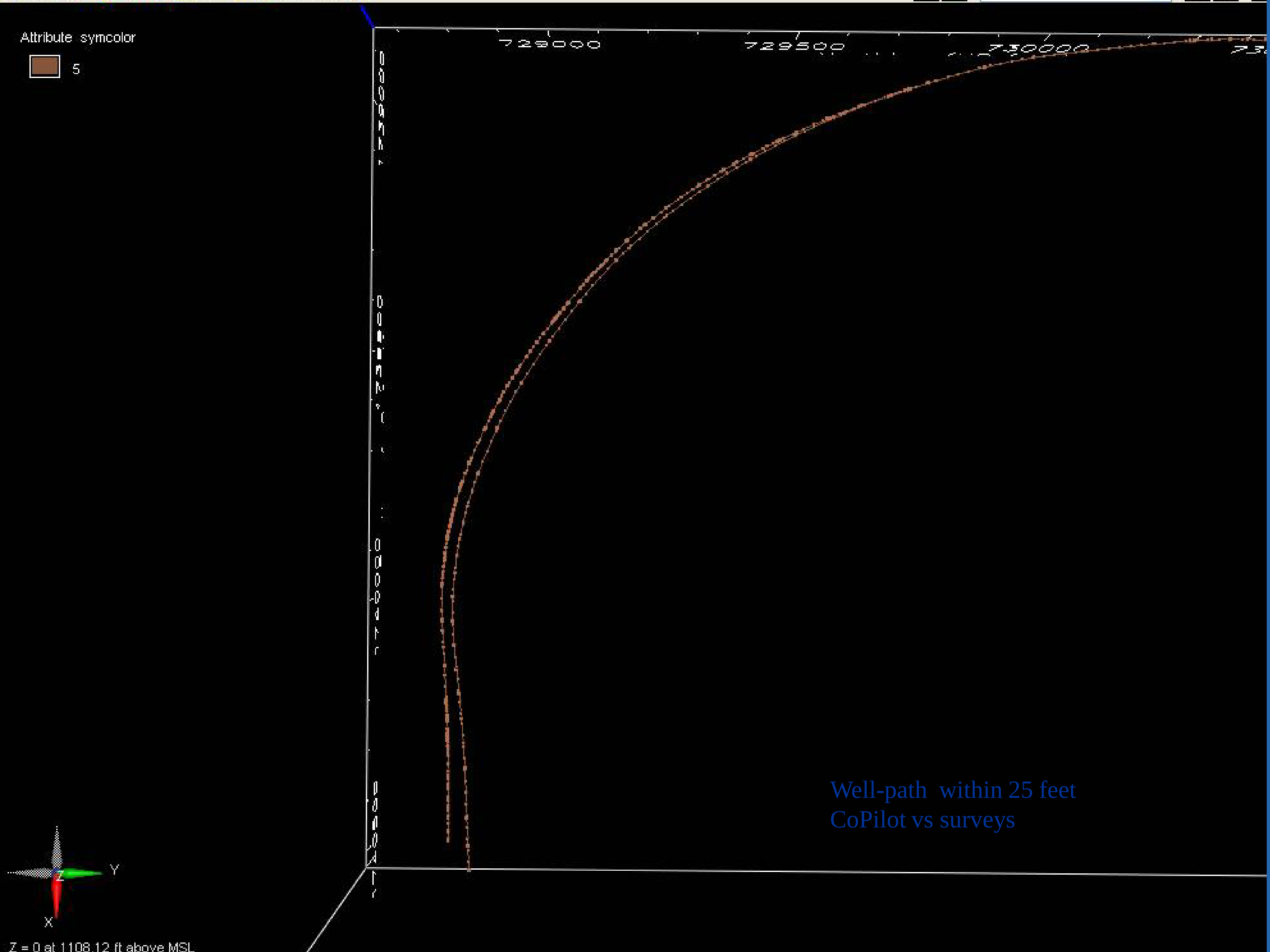
Drilling Performance

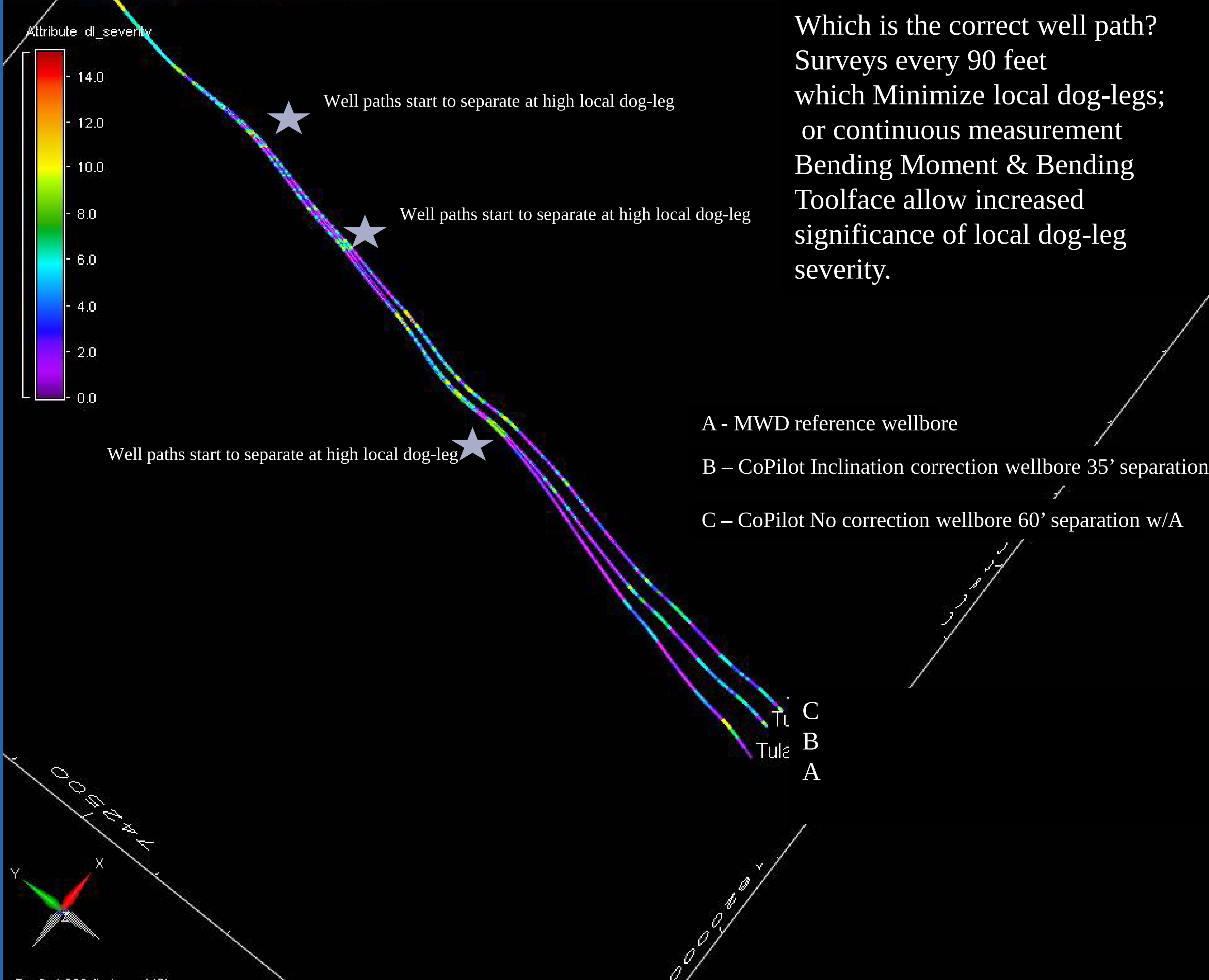


Many horizontal wells were drilled in this area since 2008. The chart above shows the overall performance of the directionally drilled portion. The average length of the horizontal wells was approximately 5,334 ft (1,626 m), and it took about 4.3 days on average to drill them. If we add drilling surface hole, completion, rig mobilization, etc. it takes about 8.5 days between the spud dates of two wells. This was approximately one day shorter than previous vertical drilling programs because the need for hydraulic fracture technology was eliminated.

CONCLUSION

the contrast in cost, it may often be the case that a careful, multi-faceted approach to in-field drilling applications provides the most long-term economic benefit when compared to typical vertical or near-vertical wellbore placement combined with limited reservoir contact. The technology now exists to better exploit known plays in dimensions that might not have been considered up to this point. It is forward thinking and careful consideration of all technologies available, past and present, that has enabled the revitalization of this project in such a grand fashion. Reservoir navigation services in resistive reservoirs can allow for better reservoir contact than ever possible prior to its inception. This can yield production results that not only justify, but necessitate its use. Survey data collection and correction, combined with proper modeling, can equip operators with the knowledge they need to confidently decrease well spacing in environments where high well density is desired. Combined with rotary steerable technology and measurement while drilling, this allows for exceedingly accurate wellbore placement. The addition of drilling dynamics tools, bending tool-face, and down-hole bending moment detection adds new degrees of accuracy and confidence to survey data and thusly, wellbore placement and optimization.


Attribute symcolor
5
729000
729500
730000
Y
Z
X
Z = 0 at 1108.12 ft above MSL
Well-path within 25 feet
CoPilot vs surveys



Which is the correct well path?
Surveys every 90 feet
which Minimize local dog-legs;
or continuous measurement
Bending Moment & Bending
Toolface allow increased
significance of local dog-leg
severity.
Attribute dl_severity
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
Well paths start to separate at high local dog-leg
Well paths start to separate at high local dog-leg
Well paths start to separate at high local dog-leg
A - MWD reference wellbore
B – CoPilot Inclination correction wellbore 35’ separation w/A
C – CoPilot No correction wellbore 60’ separation w/A
C
B
A
Y
X

Discussion and Outlook

- Directional Drillers have included bending tool face *BTF* information in their real-time decision making processes
- Mostly qualitative use of *BTF* information to improve directional control in special situations
  - Challenging wells with elevated risk of unwanted azimuth changes
  - Casing exits, open hole sidetracks
  - Redundancy in case of directional sensor failures
- More work necessary to use measurement in quantitative way
  - Indicator for survey quality and frequency
  - Derivation of interim survey stations w/ equations above e.g. in zones of magnetic interference
  - Reduction of azimuthal uncertainty with independent measurements

Conclusions

- Downhole bending moment measurement provides good estimate of dogleg severity
  - Direct estimate via bending stiffness
  - Calculation via BHA model depending on BHA design

- Continuous DLS estimates provide insight into local hole geometry between survey stations including
  - Local doglegs
  - Hole spiraling

  ➔ DLS estimates complement directional data set

Conclusions

- Theoretical analysis has demonstrated that well path calculation can be made based on dogleg severity *DLS* and well tool face *WTF* along well path

- Downhole bending tool face *BTF* complements bending moment *BM* in providing good estimates of dogleg severity and well tool face (build rate and walk rate)
  - Measurements made close to bit ➔ Improved directional control ➔ wellbore quality
  - Optimized execution of special operations

- More work necessary to fully explore potential of new measurements