Wellbore Positioning For Intersection Wells

Pete Clark
CVX ETC D&C DEU DD SME
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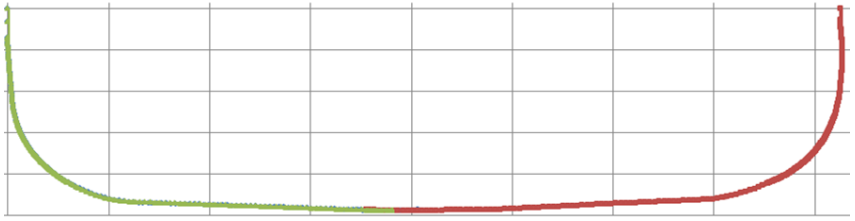
Agenda

- Intersection Well Phases
- Intersection Geometry
- Detection Tunnel & Technology
- NM Shuffle
- Geometric Well Design & TC plot
- Traversing & closing workflow
- Incidence Angle & Toolface steering
- Communication
- Survey Program & Survey Management
- MWD QC
- DLS management
- Conclusion

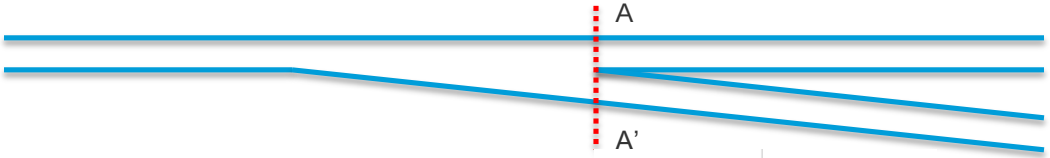


Intersection Well Phases

- Navigation
  - Objective ; deliver sufficient proximity for detection
- Detection
  - Objective ; enumerate relative position
  - Decision point – commit to running casing
- Traverse & close
  - Objective ; track offset well while drilling to intersection zone
- Intersection
  - Objective ; Full bore intersection, incidence angle < 3°, Free running drillstring, Intersect from below

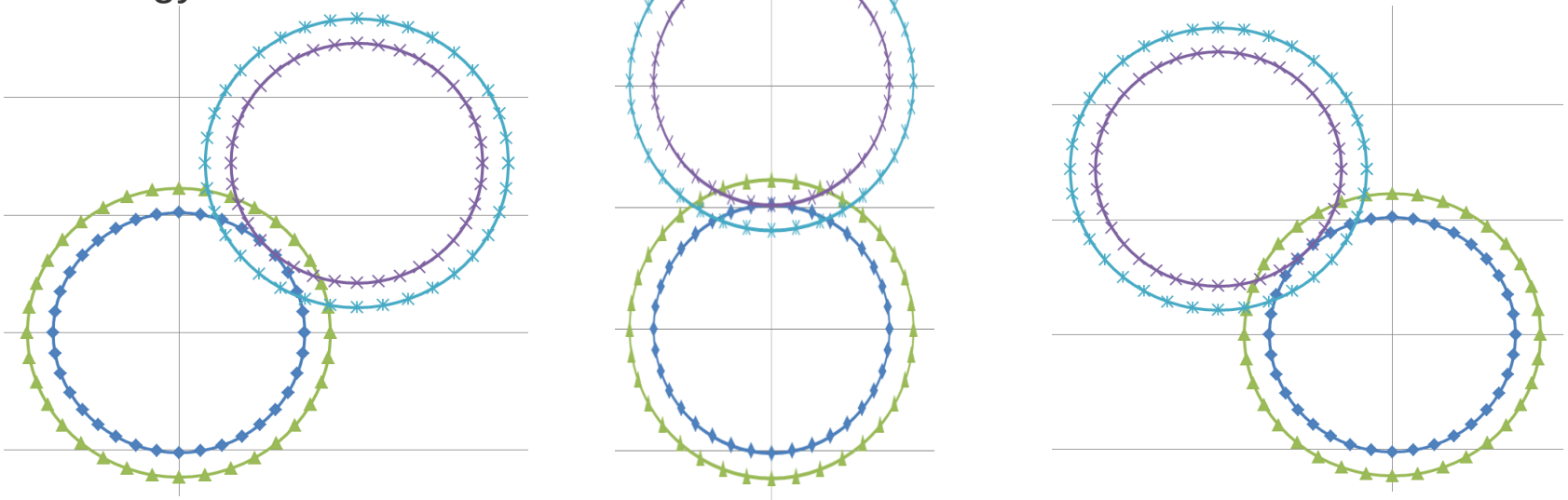
Intersection Geometry

- For conventional hydrocarbon wells “start with the end in mind”
  - Lay out a landing zone on offset well; flat & straight
  - Reference well intersecting from below



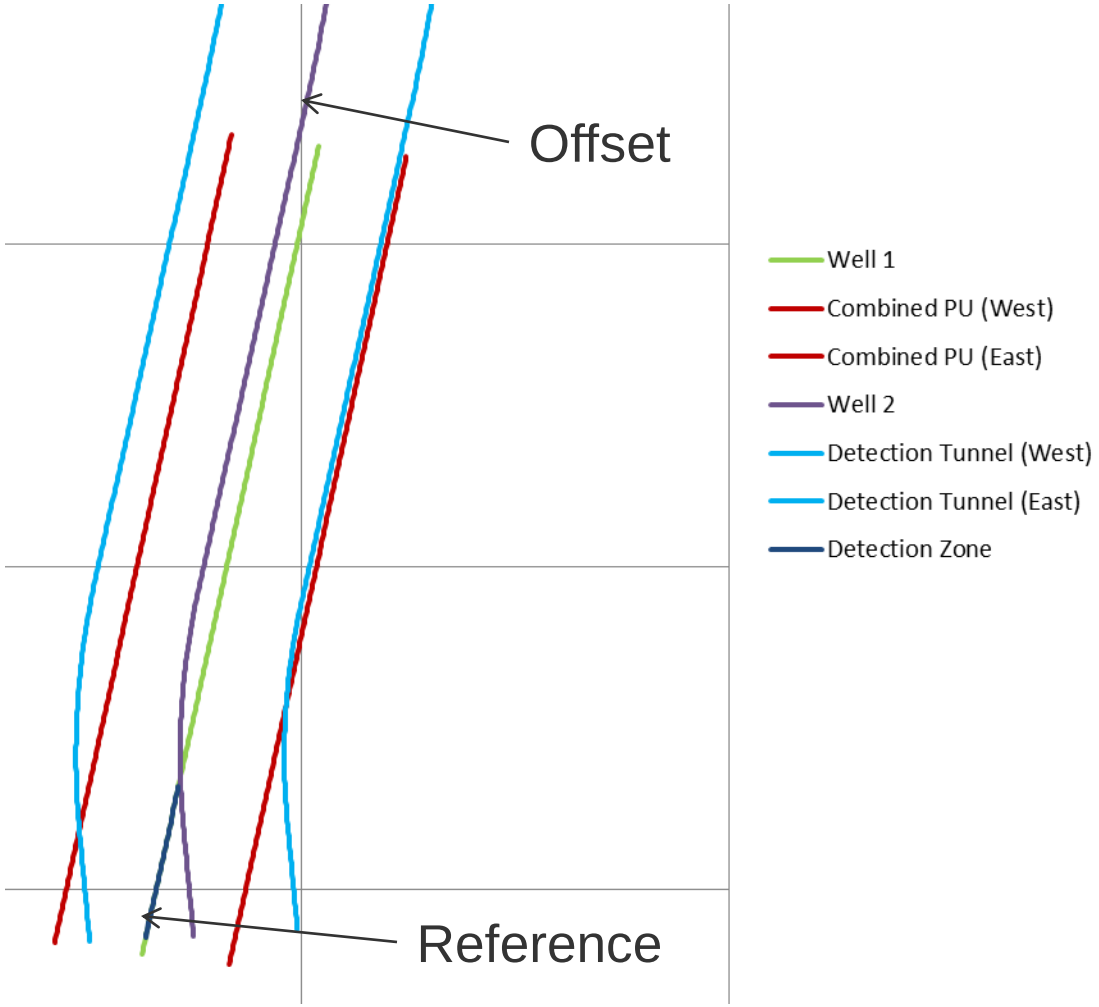
Incidence ≤ 3°

  - Geology at intersection



Detection Tunnel

- Detection limitations
  - Relative ranging tool's detection limit
    - Greater than or equal to combined positional uncertainty
  - Directional capability to meet landing zone
  - Detection and Positional Uncertainty may have larger lateral range than radial

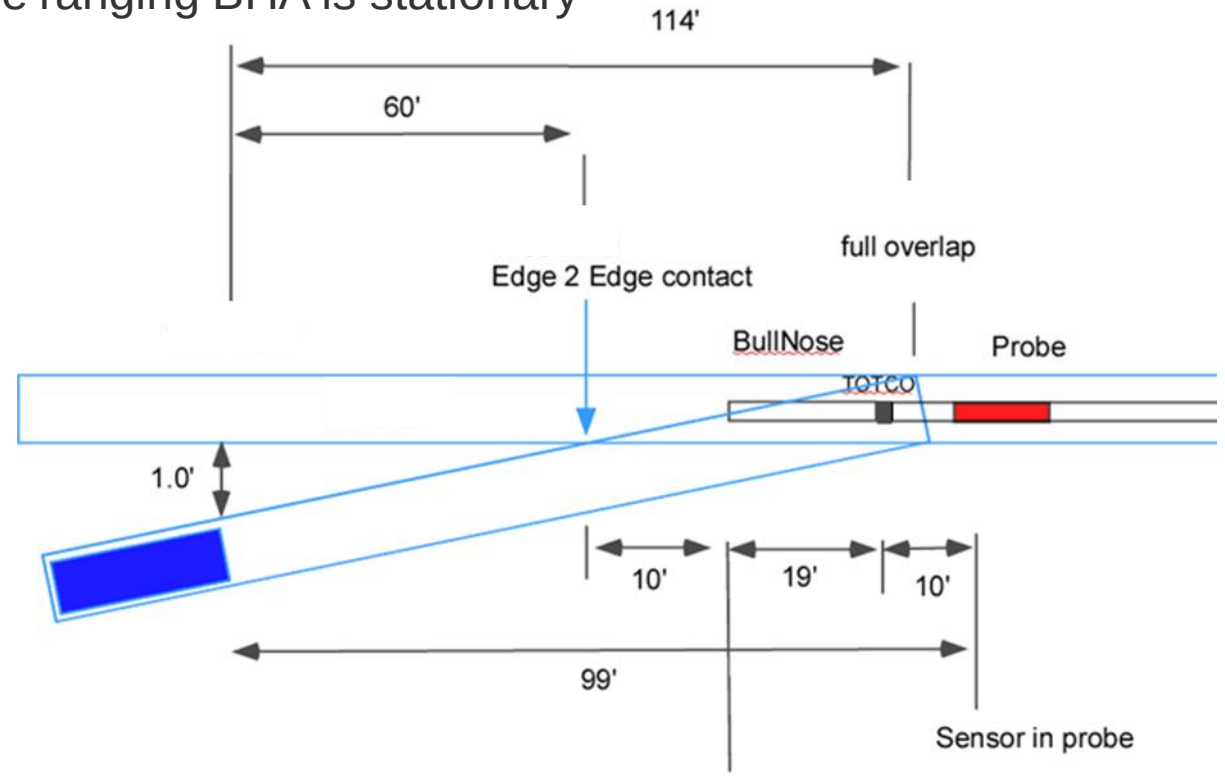


Detection Technology

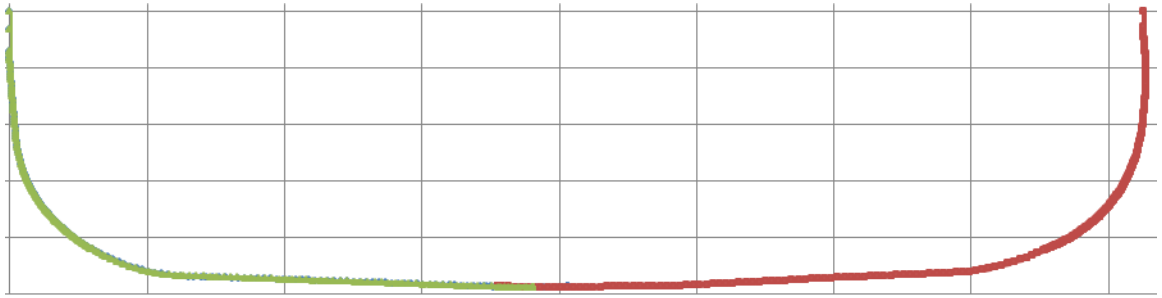
- Active magnetic ranging
  - “Access Dependent”
  - Could use rotational magnetic field generated from a rare earth magnet
  - Detected by a tri-axial magnetometer
- Magnet sub in reference well BHA
  - Placement can depend on objective
- Wireline conveyed magnetometer tool in offset well
  - Pumpdown
  - Optimally placed in NM
  - Must know position; MD => interpolated wellbore position

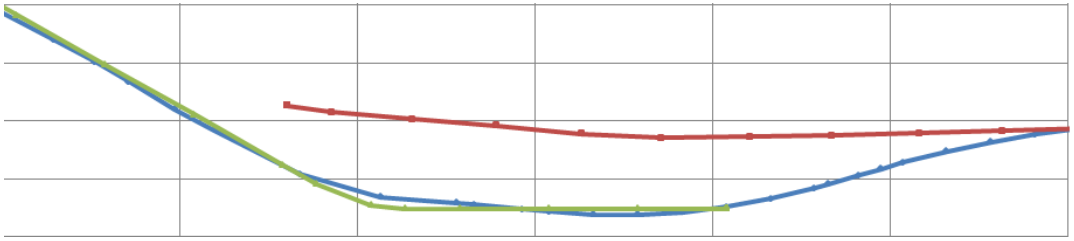
Non-Mag Shuffle

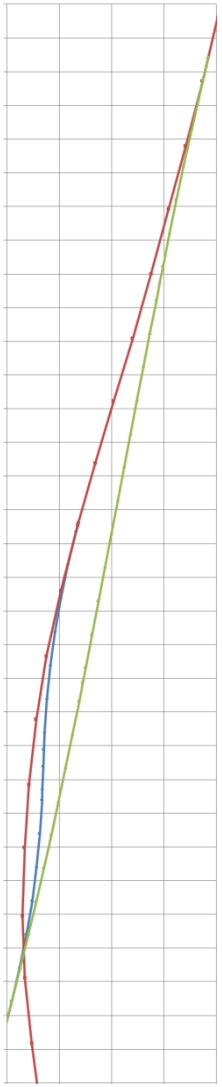
- NM to track drilling of reference wellbore
  - Reposition probe on wireline
  - While ranging BHA is stationary

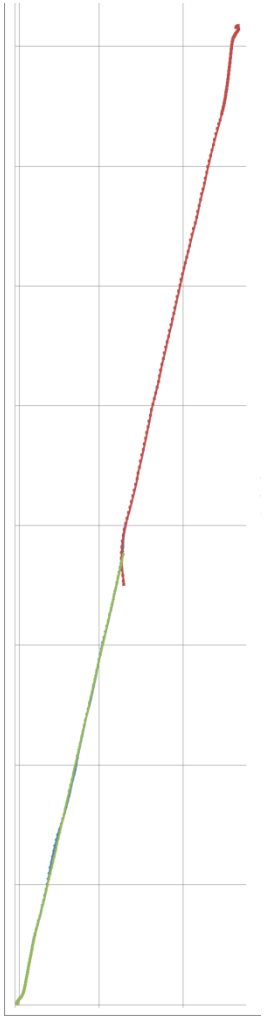


Geometric Well Design





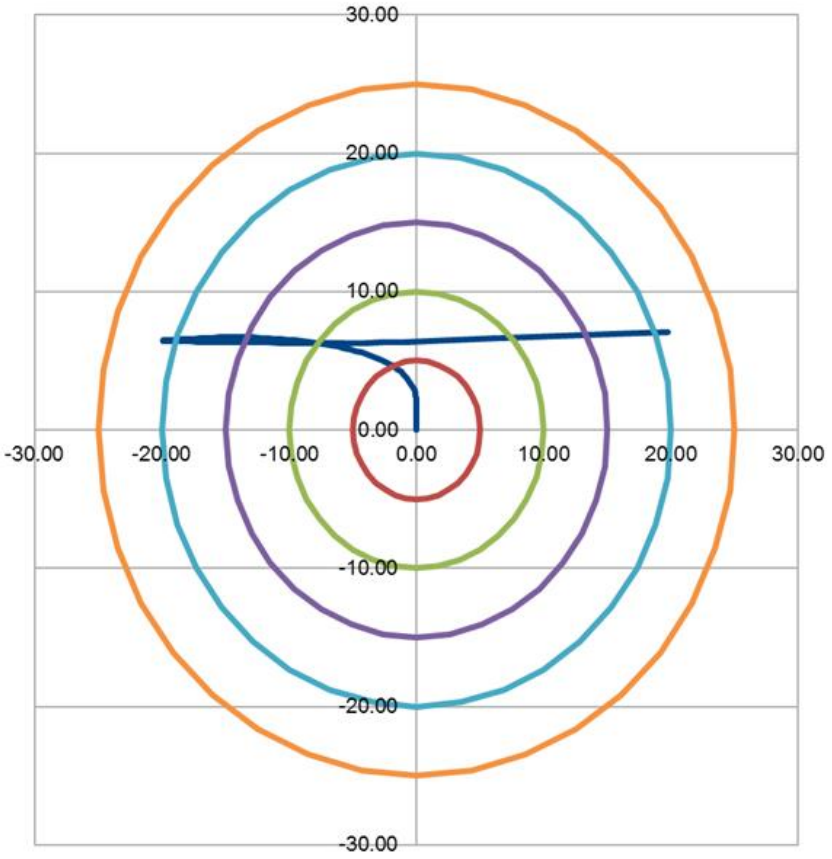




- Diametrically opposed horizontals
  - Reference well drills deeper than offset
  - Crossing in plan view prior to intersection

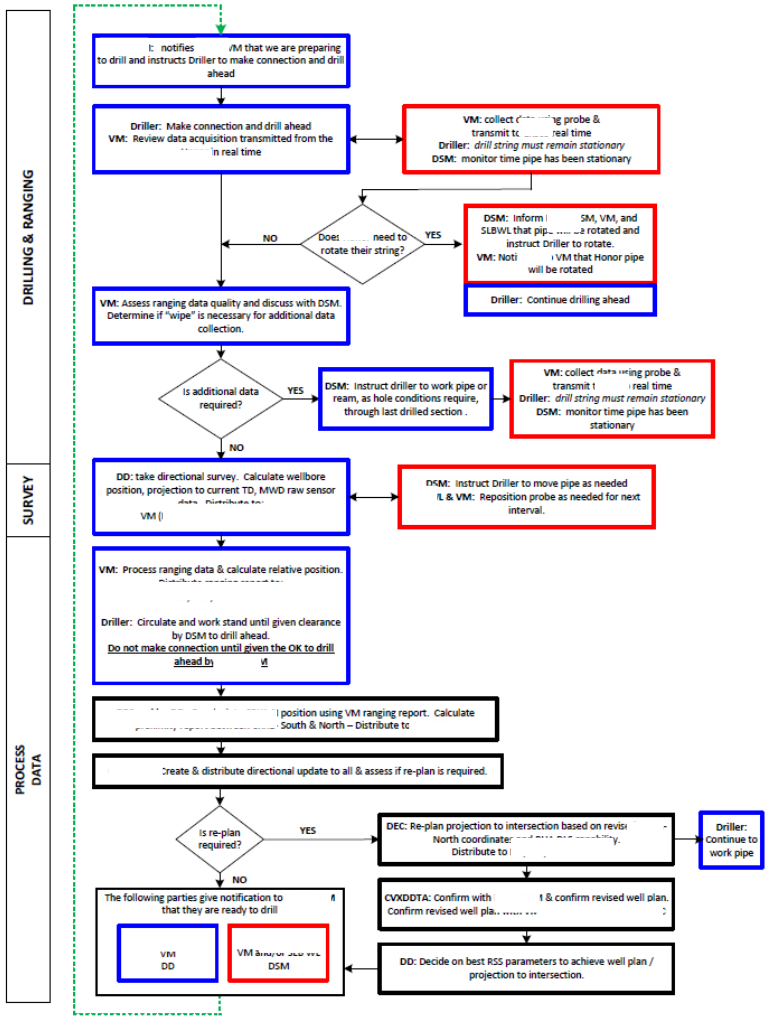
Travelling Cylinder - Highside

- As reference well proceeds
  - Offset to right
  - Directly over
    - Drillstring in both wellbores
    - Consider C-C minus hole size
  - To left
  - Directly over and tracking azimuth
    - Inclination control is only requirement
  - Intersect from below
    - Appears as if offset drops



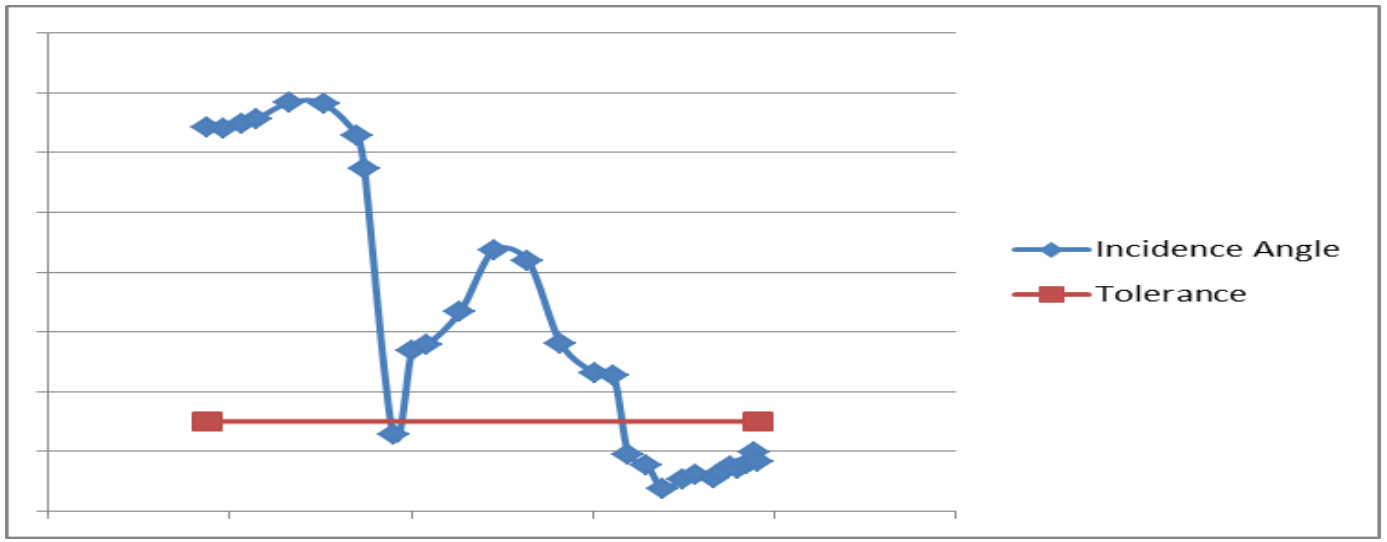
Traversing & Closing workflow

- Simultaneous Operations on two rigs
  - Ops decision making
  - Temporal components
    - Drilling & Planning
    - Survey
    - Processing Data
  - Relative positioning
    - Acquire magnetic data while drilling
    - Calculate reference wellbore position and attitude
    - Calculate probe position
    - Move offset wellbore
    - Recalculate directional well plan



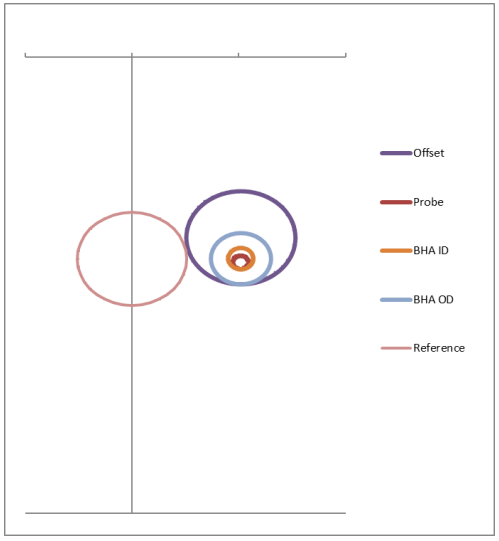
Incidence Angle

- Incidence Angle = ArcCosine(NrNo + ErEo + VrVo)
  - Where $Nr^2+Er^2+Vr^2=1$ and $No^2+Eo^2+Vo^2=1$ and
  - North = Sine(inclination) x Cosine(azimuth)
  - East = Sine(inclination) x Sine(azimuth)
  - TVD = Cosine(inclination)

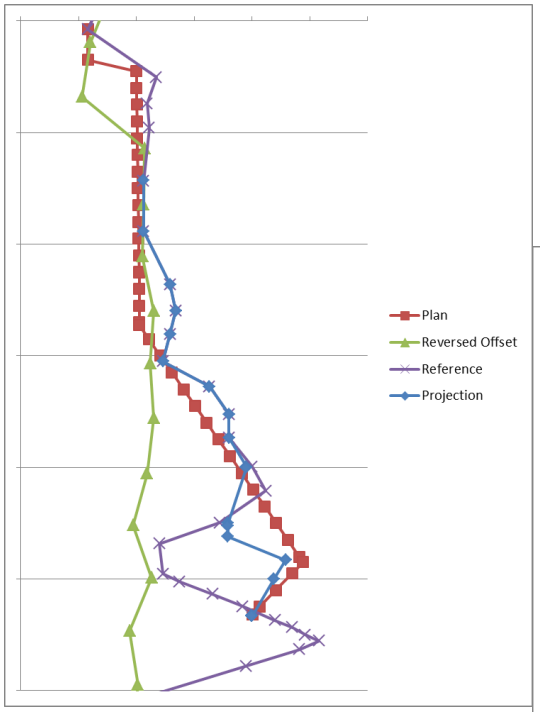


Toolface steering

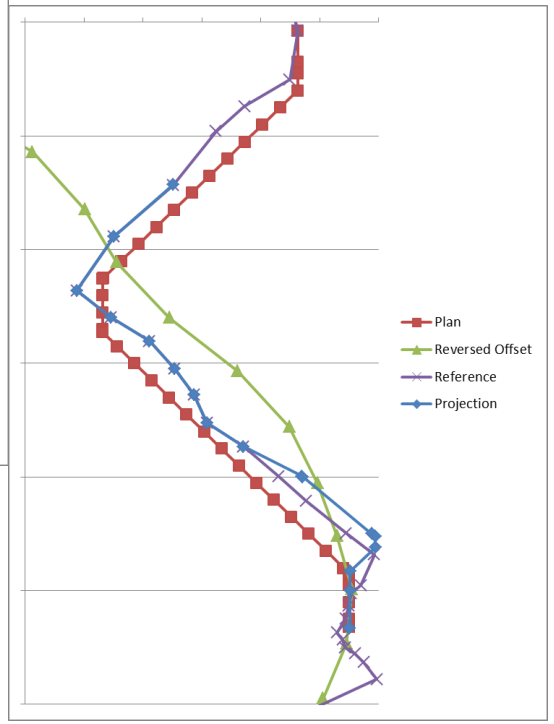
- Manage incidence angle, relative attitude & relative position
  - Low incidence was held
  - Success is steering down to intersect with wellbore above



Inclination



Azimuth

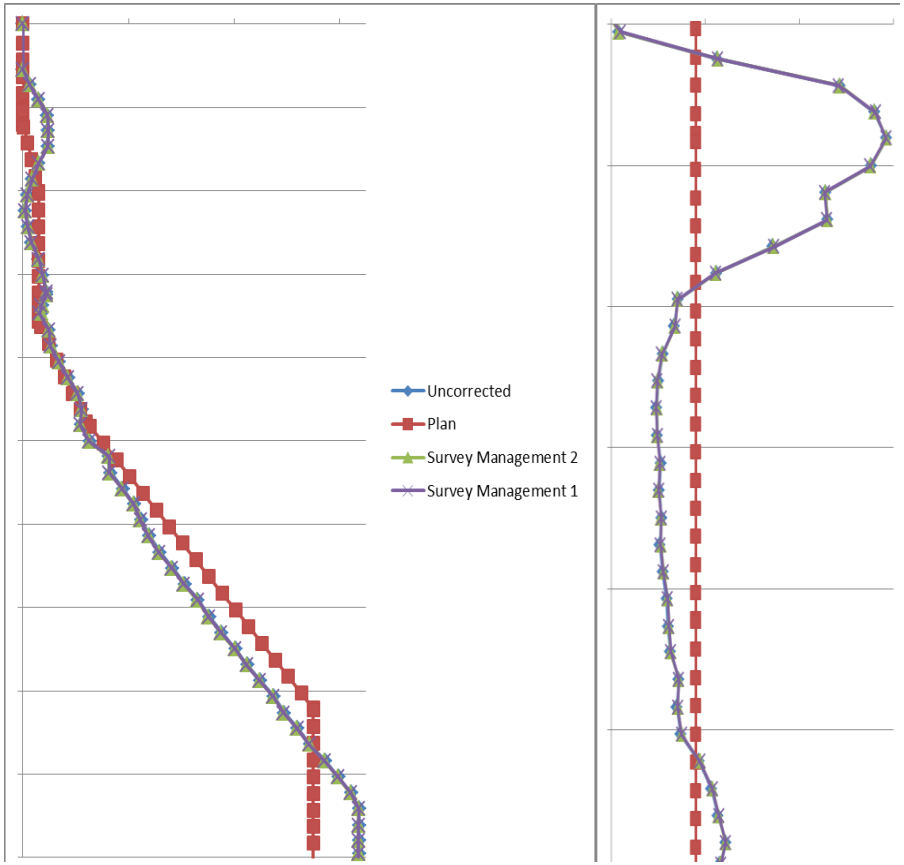


Communication & Workflow

- Weekly operations, planning & business partner conference calls
  - Agenda, minutes & action items
- eMail update while drilling – updated position & QC
  - Visual information & actions
- Workflow
  - Declination & Convergence averaged for wellbore
  - Pass rigsite QC, aggregate daily and send to survey management 1
  - Survey management 1 – apply correction & sent to survey management 2
  - Survey management 2 - Apply correction & sent to survey management 1
  - Default – Use Survey management 1

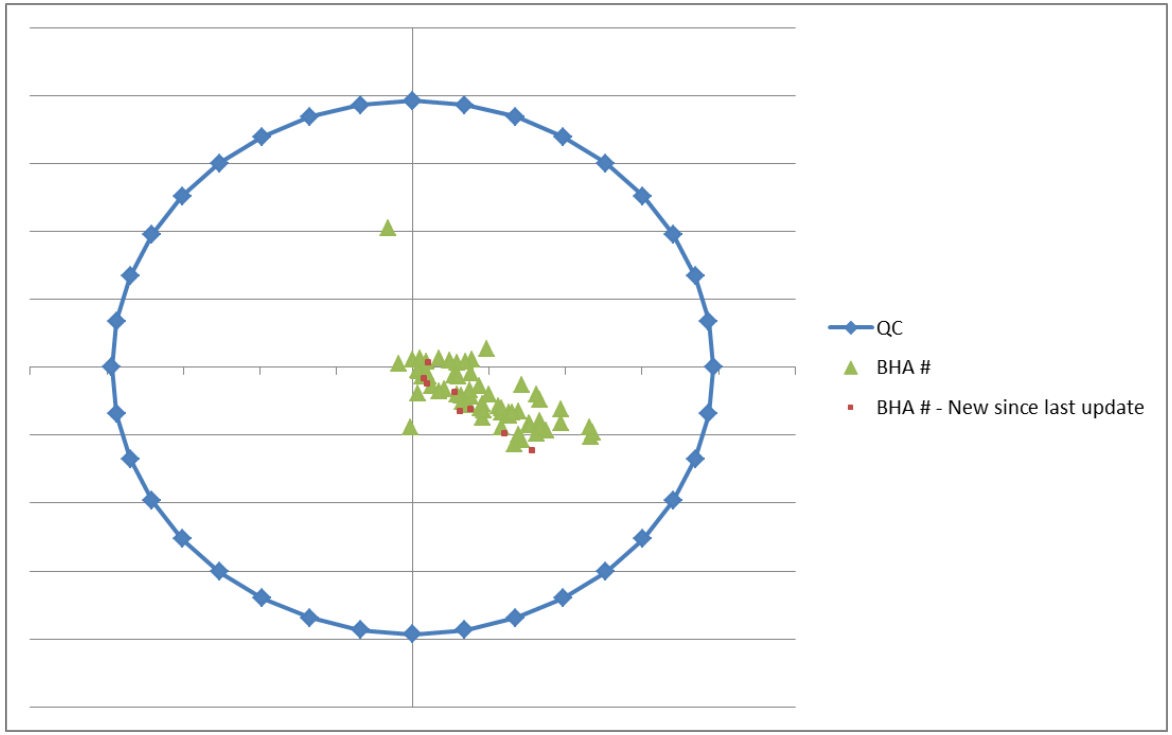
Survey Program & Double Survey Management

- Project risk
  - Unable to detect
- Detection zone
  - Does not require most accurate wellbore position
- Survey program
  - In-Field Reference
  - Multi-Station Correction
  - BHA SAG
  - Redundancy check
- Double Survey Management



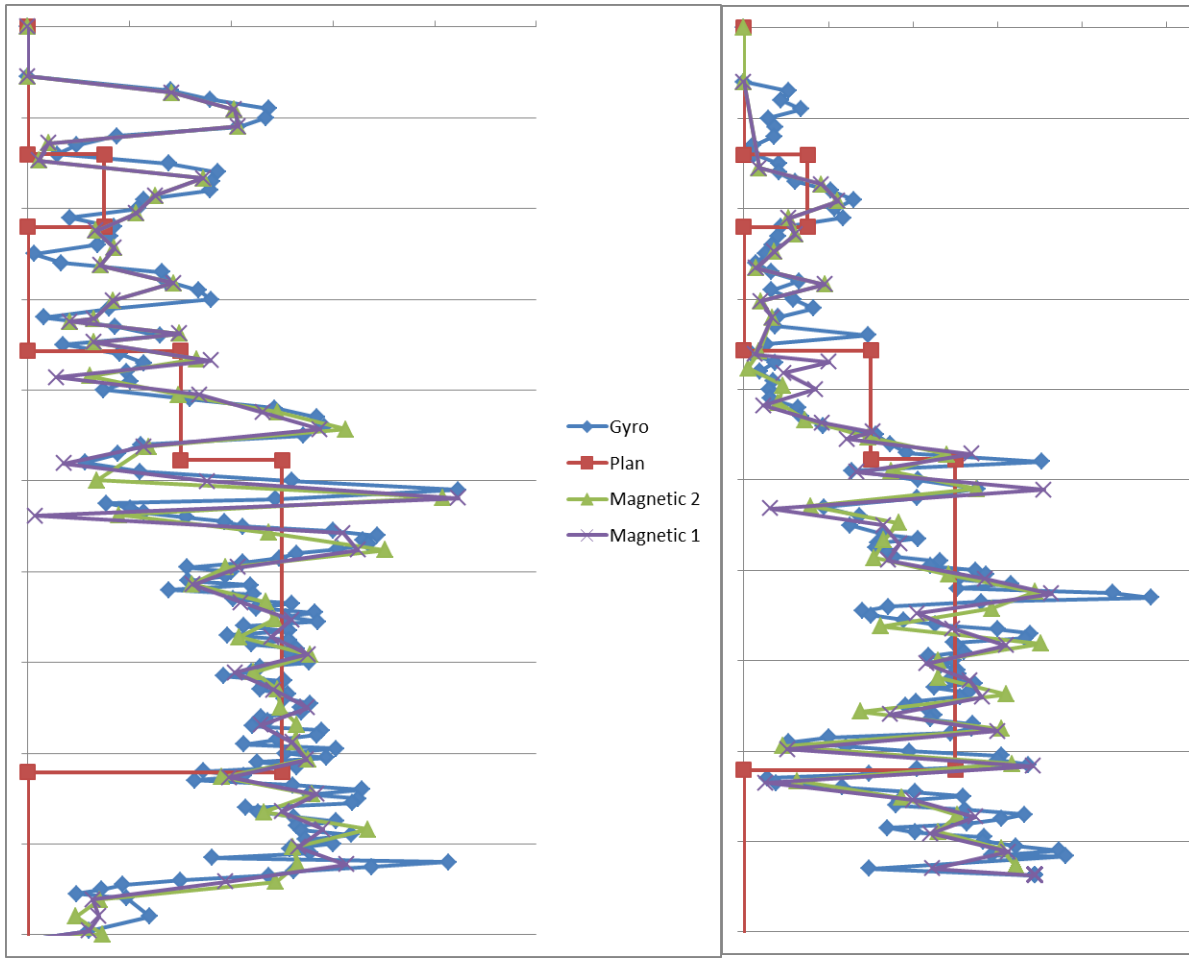
MWD QC

- Visual QC using Bdip acceptance
  - Plot of delta measured & expected total mag field v. (delta measured & expected dip angle) x total mag field
  - Identify acceptable outliers



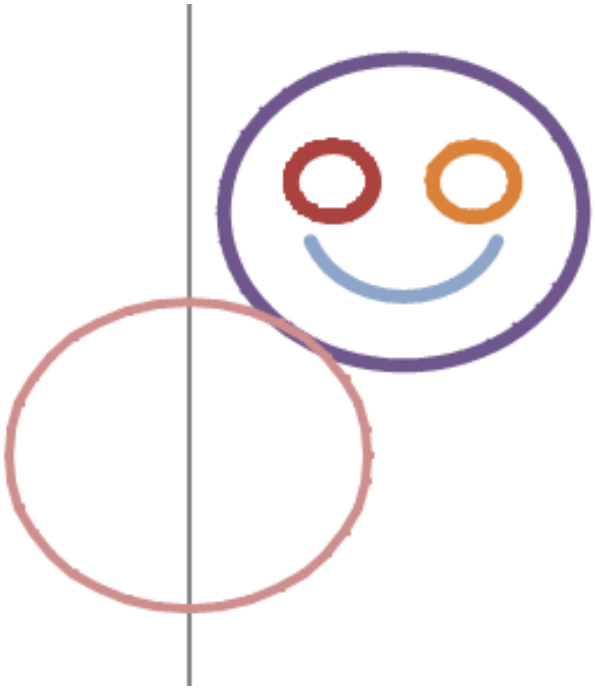
DLS

- DLS Management
- Repeatable
  - Casing & Open Hole
  - Multiple tools



Conclusion

Technology available – required careful planning – software / process integration required



Better lucky than good…