



# Pad Drilling Using Magnetic MWD

Managing Magnetic Interference from  
nearby casing

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# MWD Surveying in Top-Hole Section

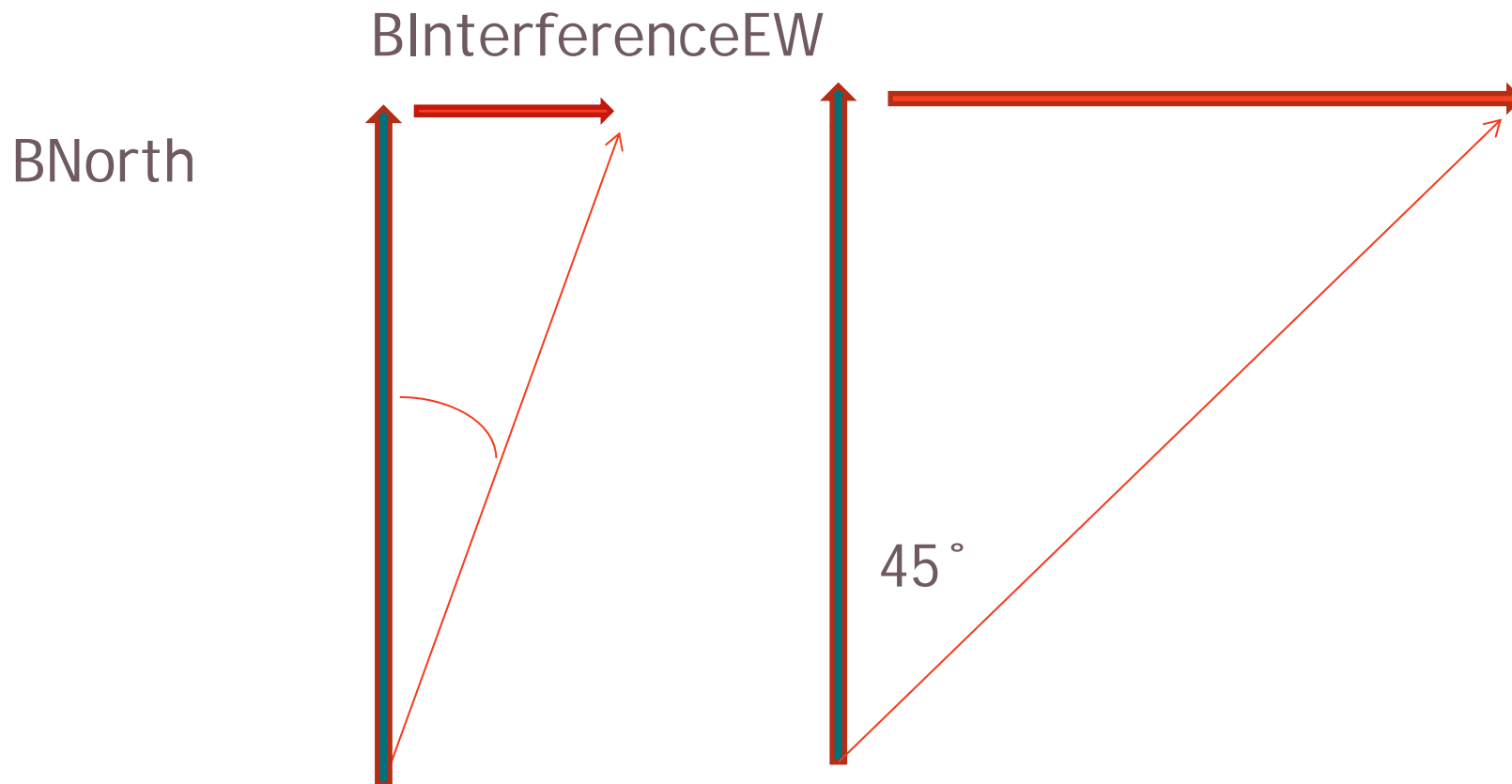
- Common practice is to use gyro surveys (gyroMWD or single shot wireline) when close to nearby steel casing.
- Distance varies with operator and/or contractor. Typically gyros are specified to 20-50 feet, or when MWD fails QC limits.
- Magnetic interference from nearby wells changes the apparent azimuth measured by magnetic tools.
- The interference cannot be measured with a single survey shot but it can be estimated using several survey shots at different depths.
- The azimuth error can be estimated.
- The effect is to make the Ellipse of Uncertainty (EoU) larger.
- Magnetic Interference does not effect the measured inclination.
- In near-vertical wells azimuth errors have small effect on position.

# How External Magnetic interference changes Azimuth

- Only the horizontal part of the measured field is used to determine the azimuth between the tool Z-axis and apparent magnetic north.
- External interference changes the direction to apparent magnetic north.
- Only the EW component of interference changes this angle.
  - THIS CANNOT BE MEASURED WITH A STANDARD MWD TOOL
- Only the NS component changes the magnitude of BH.
- The Azimuth change is  $A \tan(EW_{interference}/BH_{ref})$
- Interference  $<$  BH will change the measured azimuth by  $<45$  degrees.
- Interference  $>$  BH can potentially swing azimuth by 180 degrees.
- At low inclination the change in wellbore position is minimal.
  - At 1 degree inc a 1 degree azi error  $\Rightarrow$  0.3 ft BHL change/1000 ft.

# How External Magnetic Interference changes Azimuth

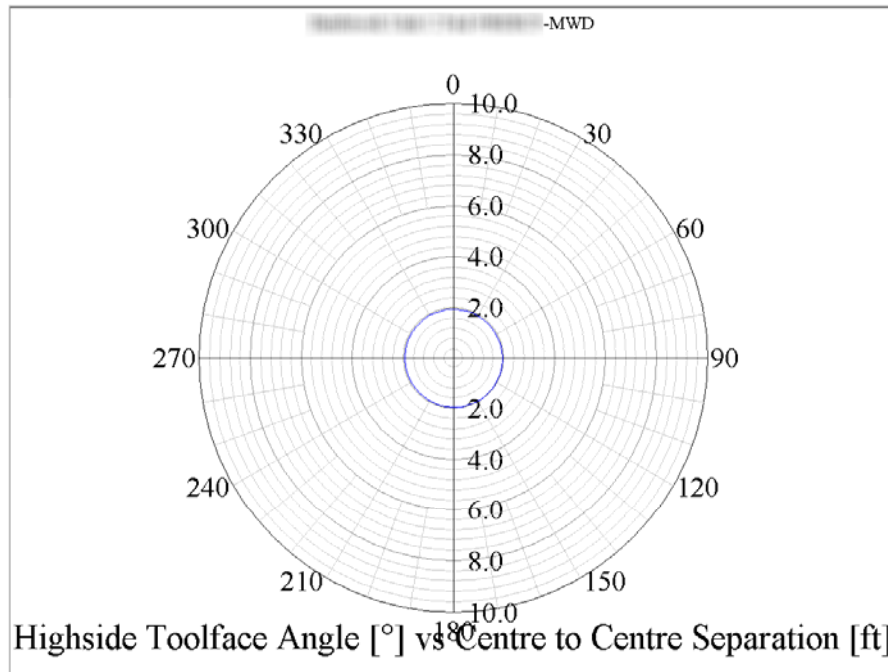
- This shows how magnetic interference swings the apparent declination. The angle of change is  $\text{ATan}(B_{\text{Interference}}/B_{\text{North}})$



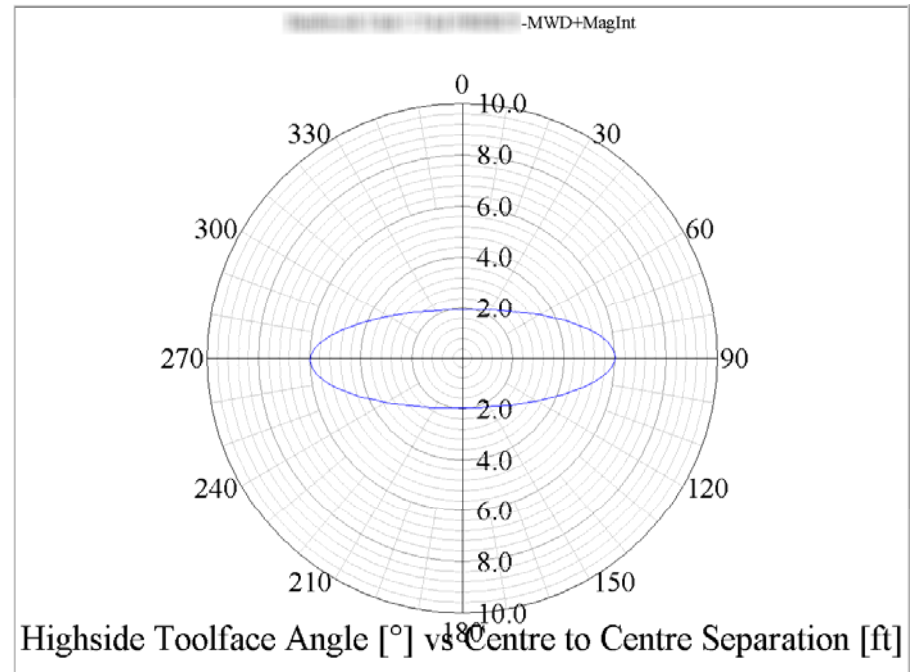
# Considerations using Magnetic MWD near existing steel casing

- The inclination measurement is OK.
- The azimuth has reduced accuracy. It takes a very large amount of interference ( $\sim BH$ ) to change the azimuth more than 45 degrees.
- In near vertical wells typical of top hole drilling, small errors in azimuth do not make much change in bottom hole position.
- Additional interference can be tolerated if the IPM used to plan the ellipse size is designed for this.
- Typical MWD ellipse size at 1000 ft in a low angle ( $<5$  degrees) well is  $\sim\pm 3$  feet
- Typical ellipse size with 2000 nT interference is  $\sim\pm 6$  feet (2X)
- With careful planning these larger ellipses can be accommodated.

# Examples of Ellipse Size Changes (Landmark Compass)



Standard MWD IPM  
Depth Slice at 1000 Ft.

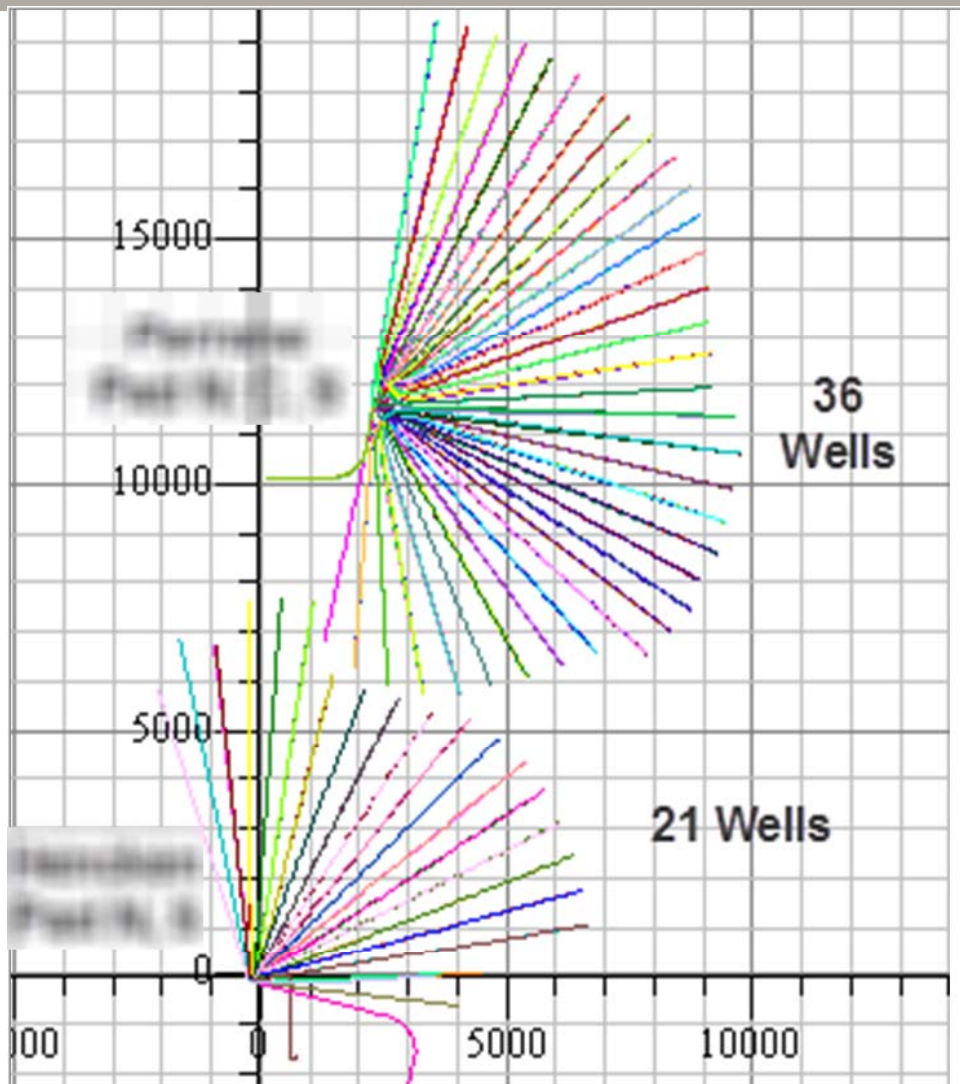


MWD+Magnetic Interference  
(2000 nT or 7.5 degrees)

# Multi-Well Pad Project Planning

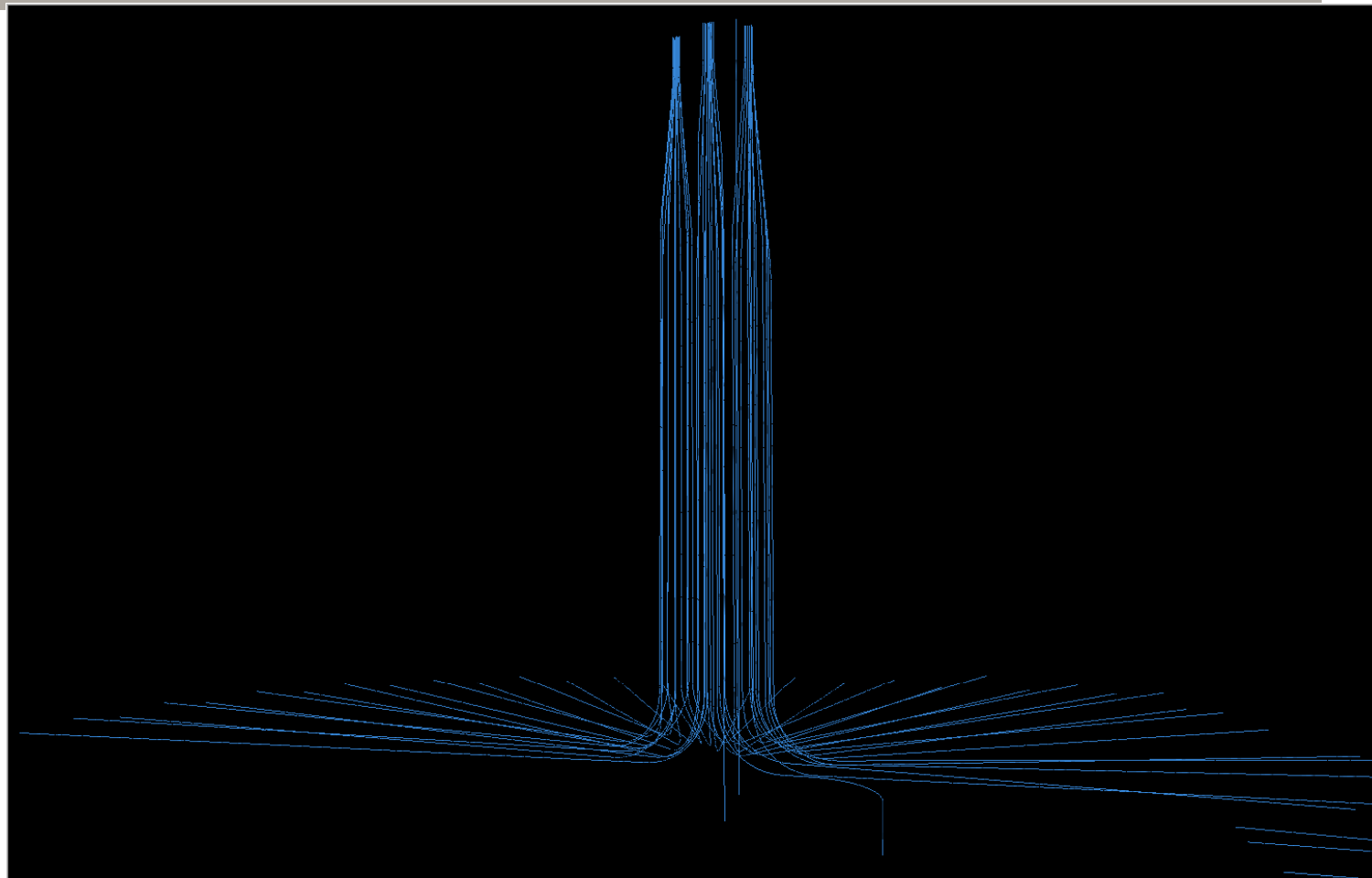
- A multi-well pad project was originally planned to use gyro while drilling until a separation of >30 ft was reached. Well to Well spacing was 17 ft.
- With careful design of the magnetic survey program and using appropriate Instrument Performance Models (IPM or toolcode) these wells were drilled with magnetic MWD.
- Magnetic interference was expected and planned for by designing an IPM that accounted for the extra azimuth error.
- MWD Limits were increased to 2000 nT in any direction for any shot.
- The Ellipses of Uncertainty (EOUs) were larger in the top hole section. Increase was from  $\sim\pm 3$  feet to  $\sim\pm 5$  feet at 1000 ft.
- Magnetic MWD is less expensive, faster, and more reliable than gyro measurements.
- Project was completed without need for gyro surveys except for confirmation.
- There was no compromise in standard anti-collision ( $SF > 2.0$ ) rules.

# Spider plot overview of entire project.

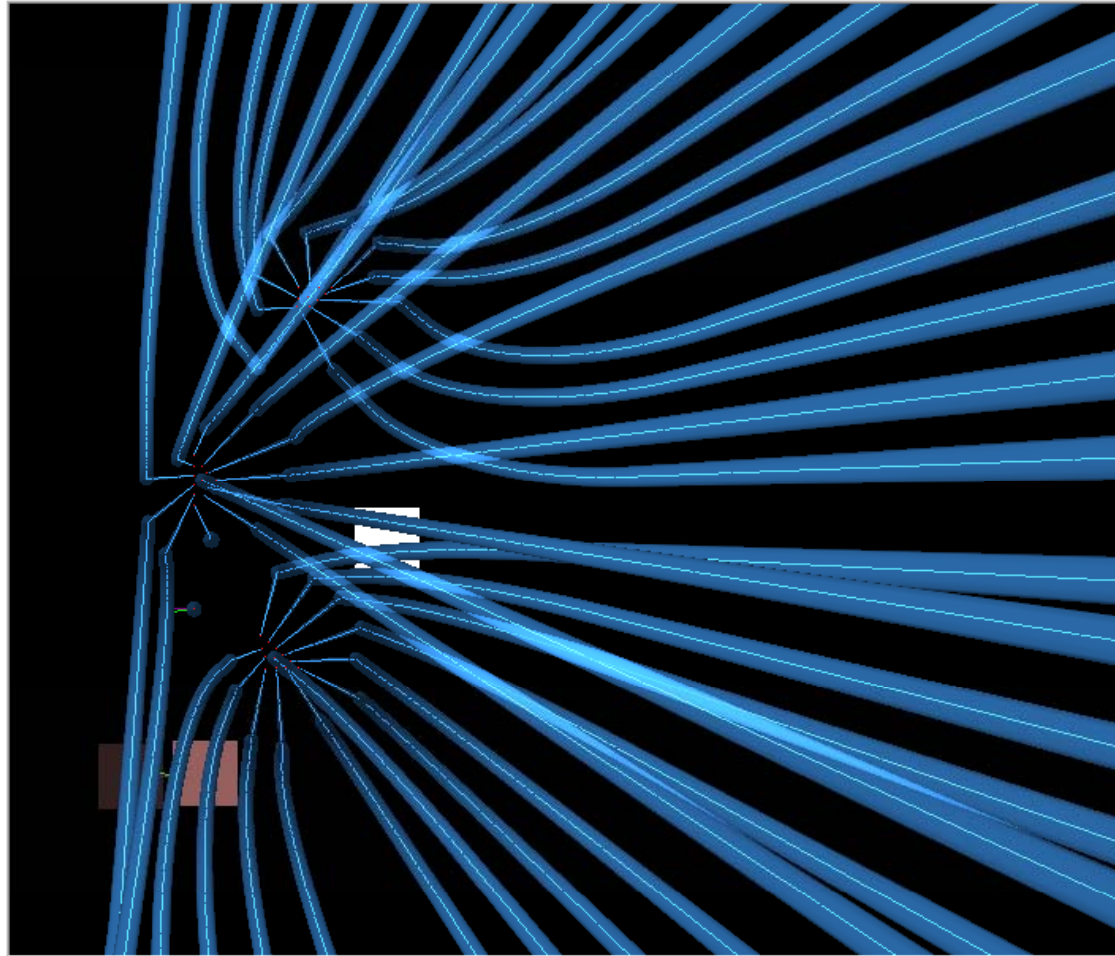




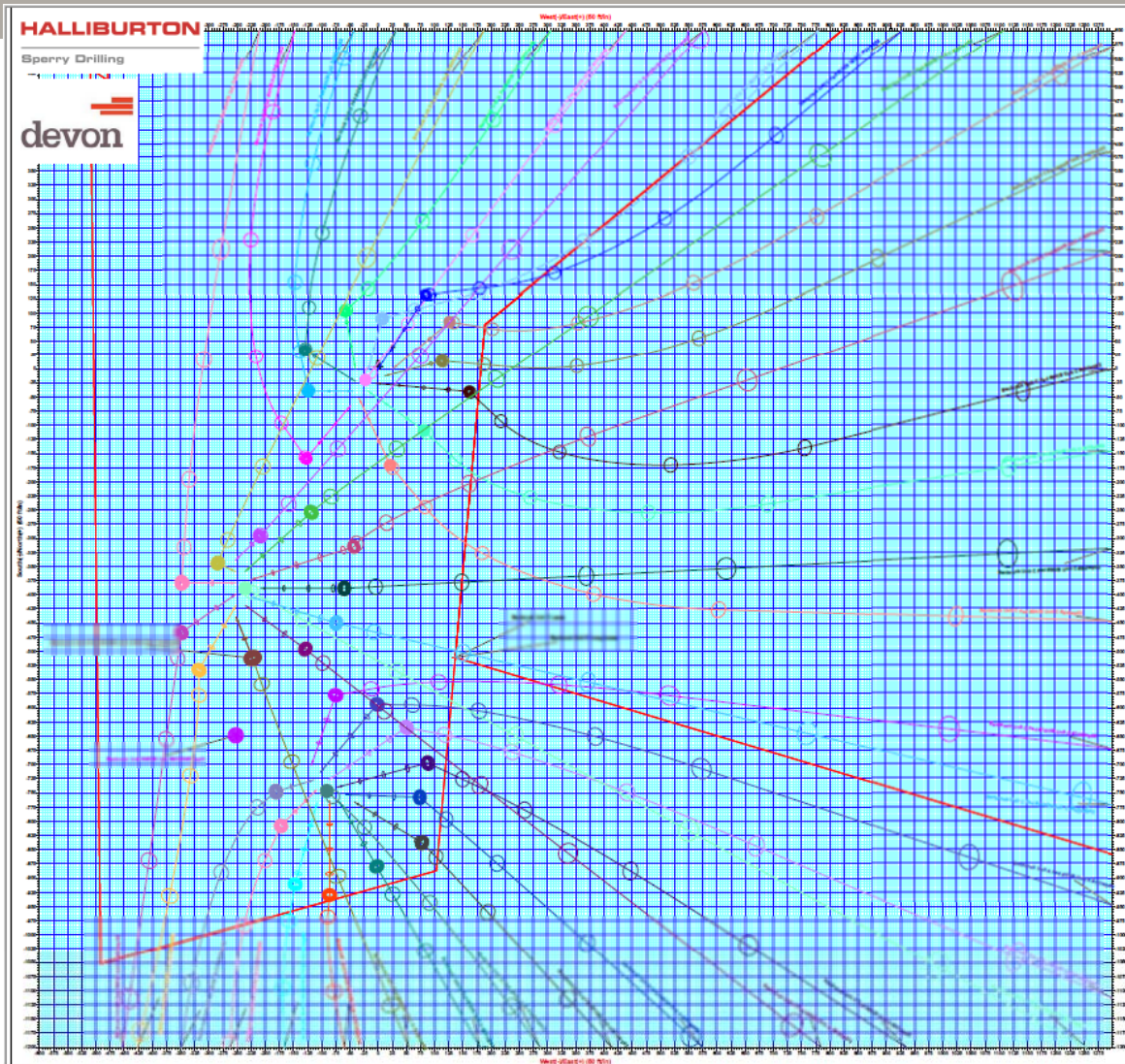
# 3D view of wellplans for north site (3 pads)



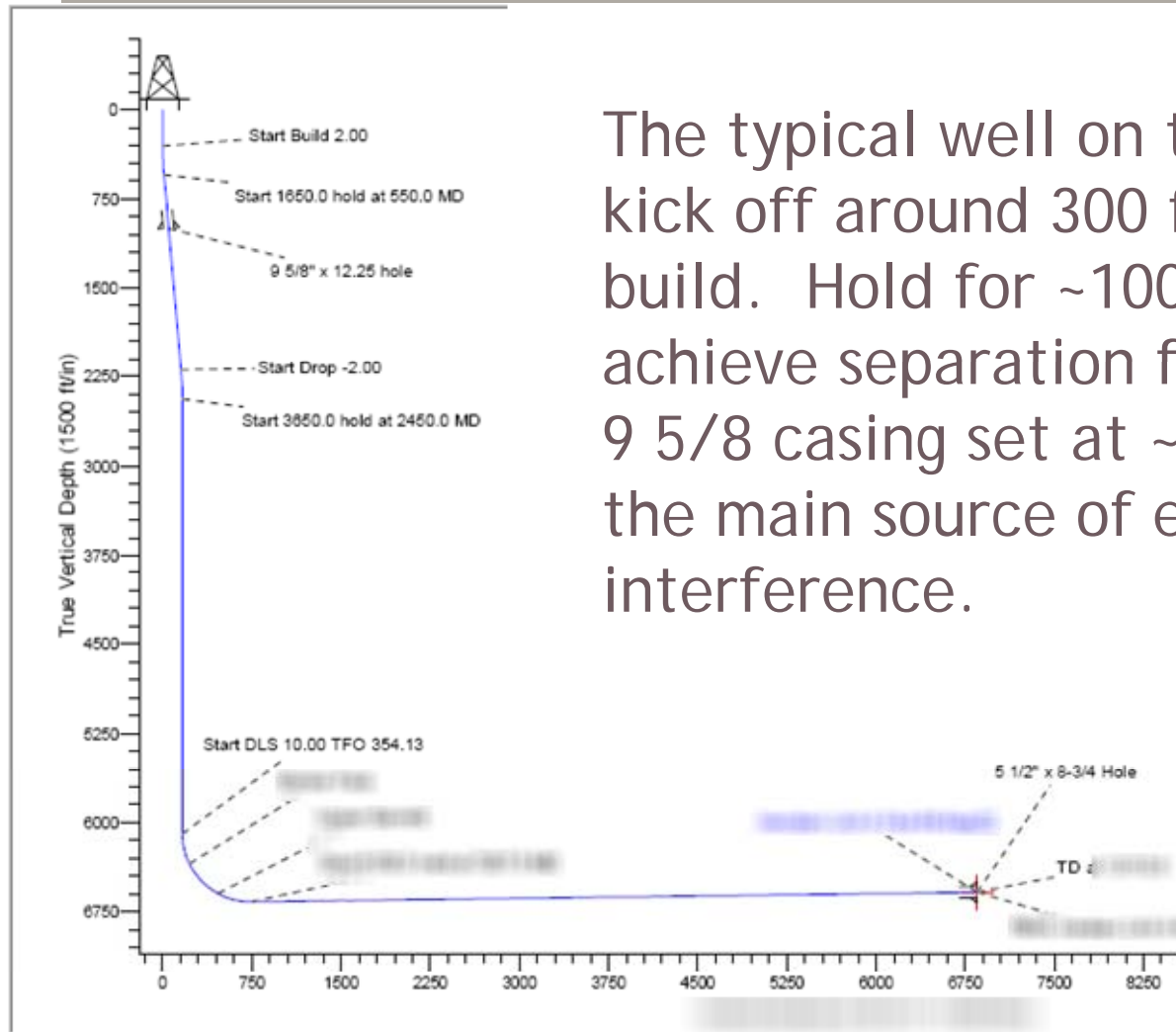
# Northern Site showing Error Ellipses (3 pads designed for simOps)



# Northern Site showing Error Ellipses (3 pads designed for simOps)

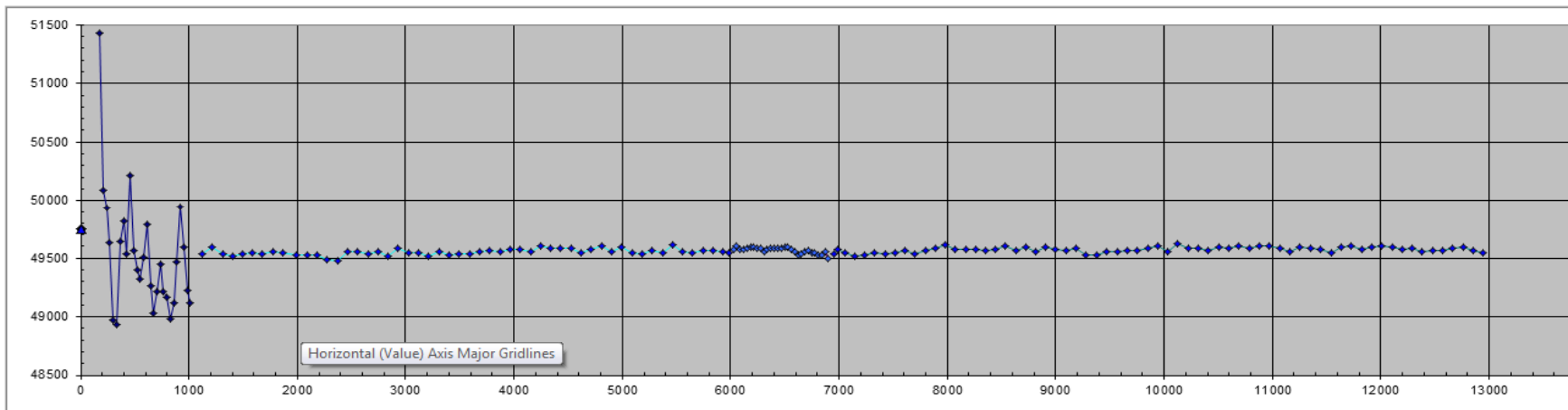
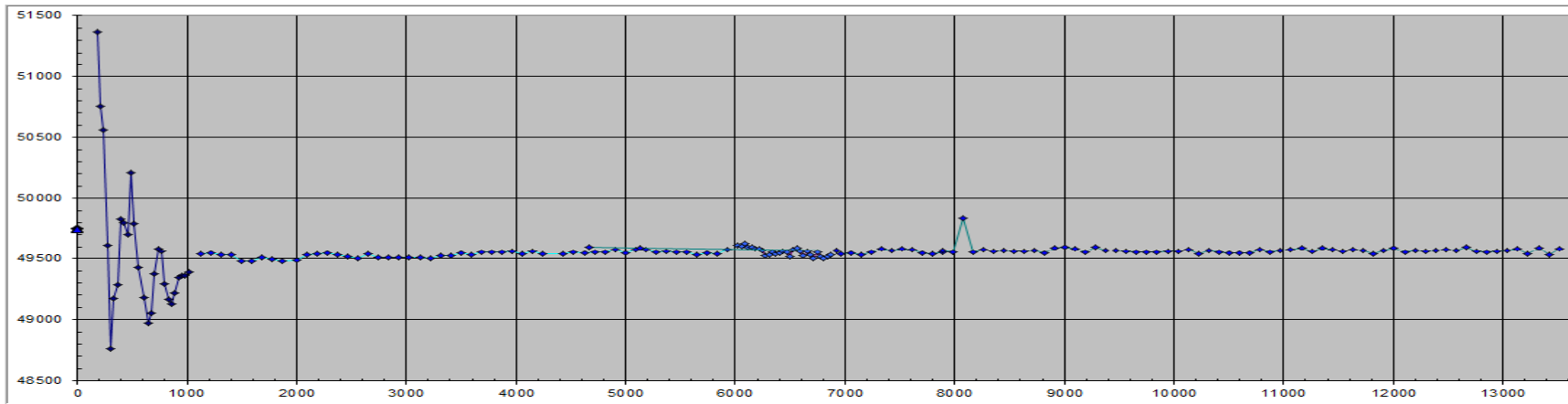


# Typical well profile



The typical well on this project would kick off around 300 ft with a 2°/100 ft build. Hold for ~1000-1500 ft. to achieve separation from nearby wells. 9 5/8 casing set at ~1000 ft. This was the main source of external magnetic interference.

# Typical magnetic (BTotal) Profiles (after correction for DSI)



# Magnetic MWD Survey Overview

- The survey tool reports Gx, Gy, Gz, and Bx, By, Bz.
- From this is calculated Inclination (accelerometers only), Azimuth, and toolface angle.
- QC info reported is GTotal, BTotal, and Magnetic Dip Angle. Alternatively BH (horizontal) and BV (vertical) magnetic field and/or BTotalDip  $\sim = (\text{sqrt}(\text{sumsq}(\text{deltaBH}, \text{deltaBV})))$
- Only the horizontal component of B is used in calculating azimuth. Vertical magnetic interference does not change azimuth.
- Only the E-W component of the horizontal interference changes the azimuth
- Only the N-S component of the horizontal interference field changes the measured BTotal and Magnetic Dip angle.
- Azimuth changes are caused by horizontal EW interference which cannot be detected. This shows up as azimuth error.

# The conundrum of measuring external magnetic interference

- **The PROBLEM:**

- Only the EW horizontal component of magnetic interference causes azimuth errors
- Only the NS horizontal and vertical components can be measured using Btotal and Dip QC Measures.

- **A SOLUTION:**

- Use Vertical component to estimate total horizontal field
- BH and BV are about the same when averaged over several shots
- The QC limits apply to the shots as a group, not individual shots. BV defines an “envelope” of interference.

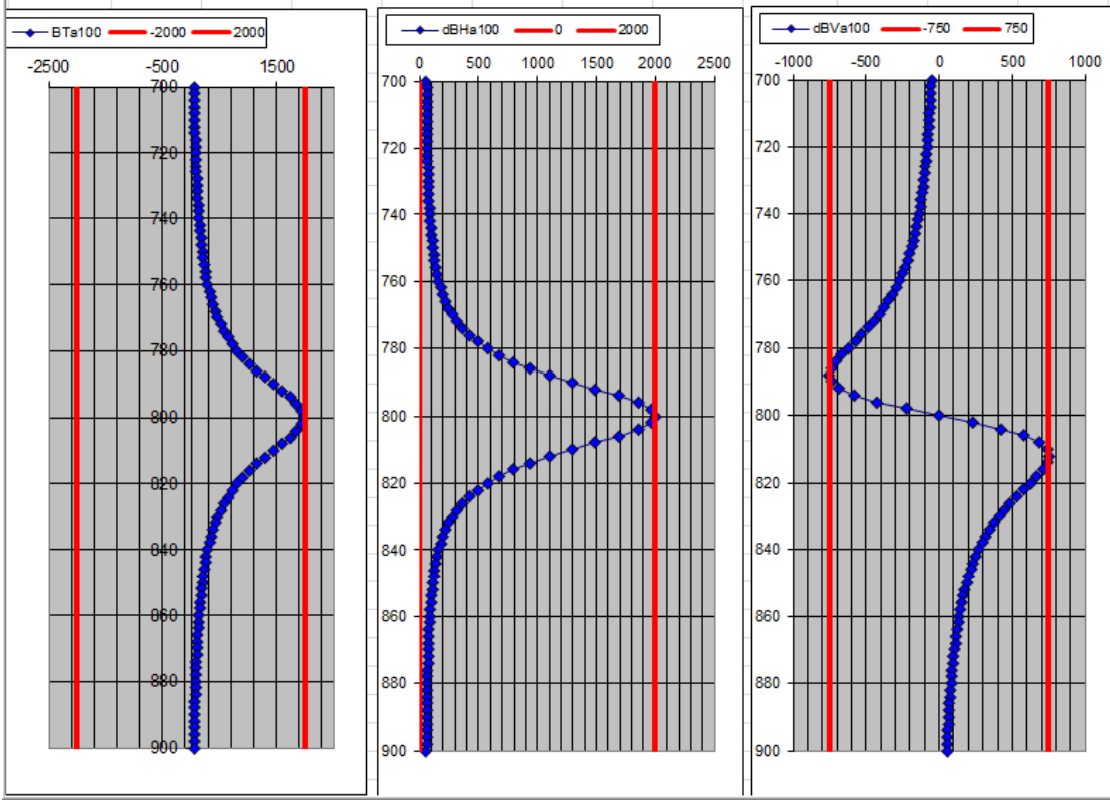
# How to model casing magnetics

- A simple model is as a string of dipole “bar magnets” joined end to end
- Any source field can be modeled using monopoles
- The pole strength is variable
- Sources of magnetization:
  - Magnetic inspection (at factory or onsite)
  - Contact with magnetized collars and drillpipe
  - Mechanical stresses/shock in a magnetic field
- Steel will distort the earth’s field to some extent.
  - Earth’s field of ~0.5 Oersted by itself is not enough to permanently magnetize most steel
- Proper degaussing can minimize the problems.
- Few MPI contractors can degauss large parts.



# Theoretical Magnetic field due to a monopole

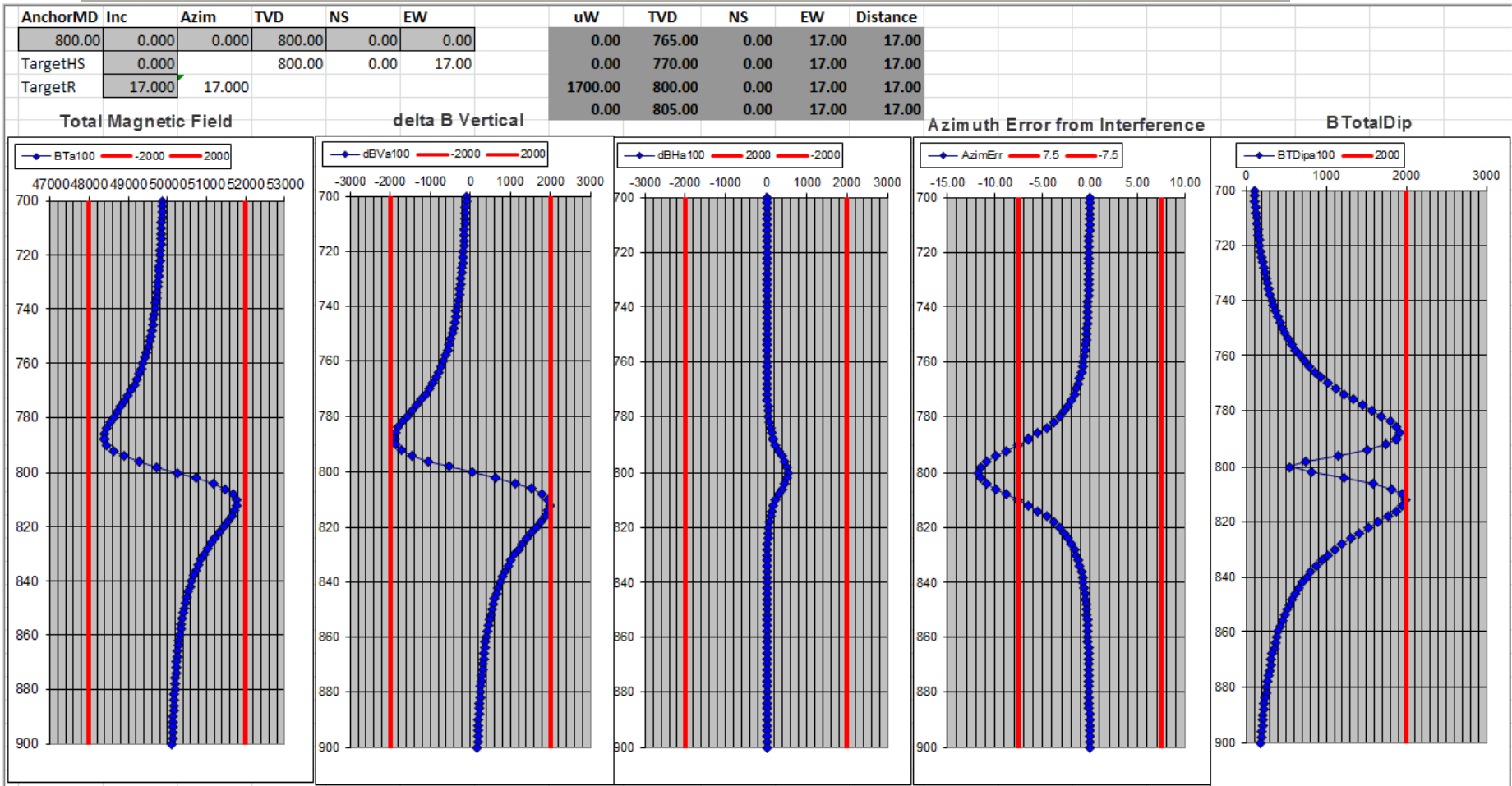
AnchorMD	Inc	Azim	TVD	NS	EW	uW	TVD	NS	EW	Distance
800.00	0.000	0.000	800.00	0.00	0.00	0.00	766.00	17.00	0.00	17.00
TargetHS	17.000		800.00	17.00	0.00	0.00	771.00	17.00	0.00	17.00
TargetR	0.000	17.000				0.00	795.00	17.00	0.00	17.00
						650.00	800.00	17.00	0.00	17.00



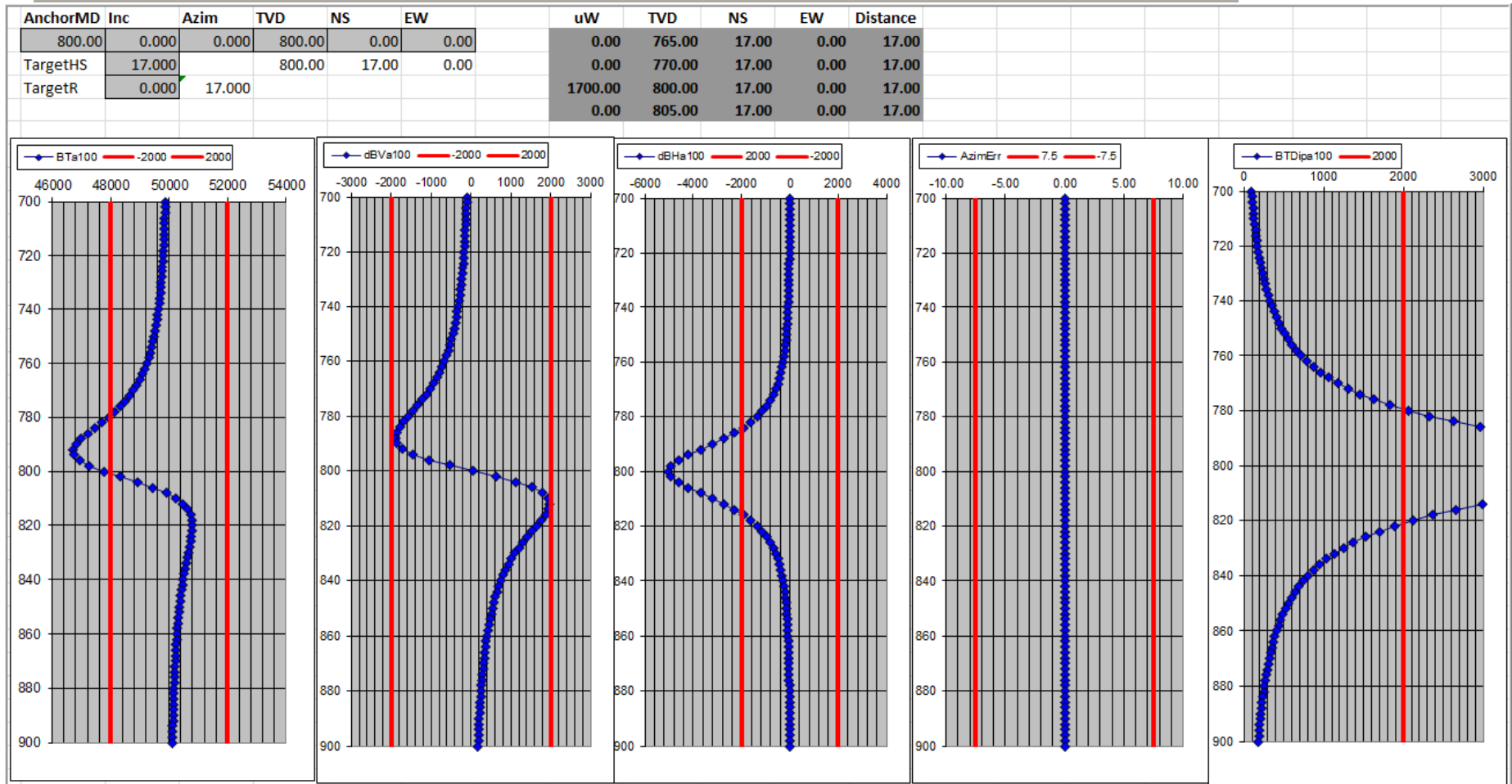
This plot shows the theoretical field (B<sub>Total</sub>, B<sub>H</sub>, and B<sub>V</sub>) from a magnetic monopole of 650 micro-Webers (uW) in a near-vertical well at a distance of 17 feet. Earth's field is not included. This is not direction dependent.

Note B<sub>Vertical</sub> (peak) is only about 1/3 of B<sub>horizontal</sub> (peak).

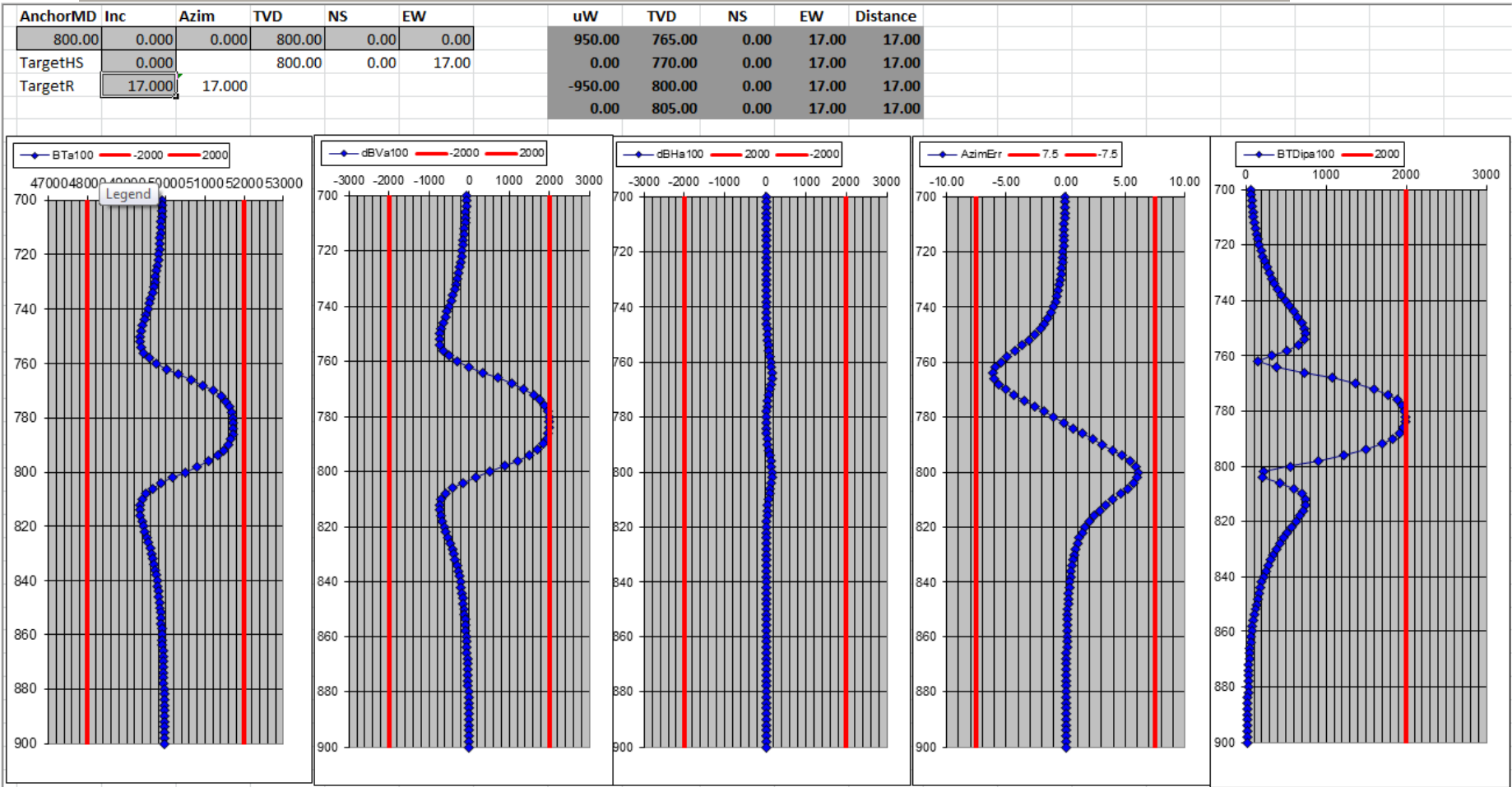
# Simulated Measured field from a 1700 uW Monopole due east in a near-vertical well



# Simulated Measured field from a 1700 uW monopole due North. No azimuth Error.

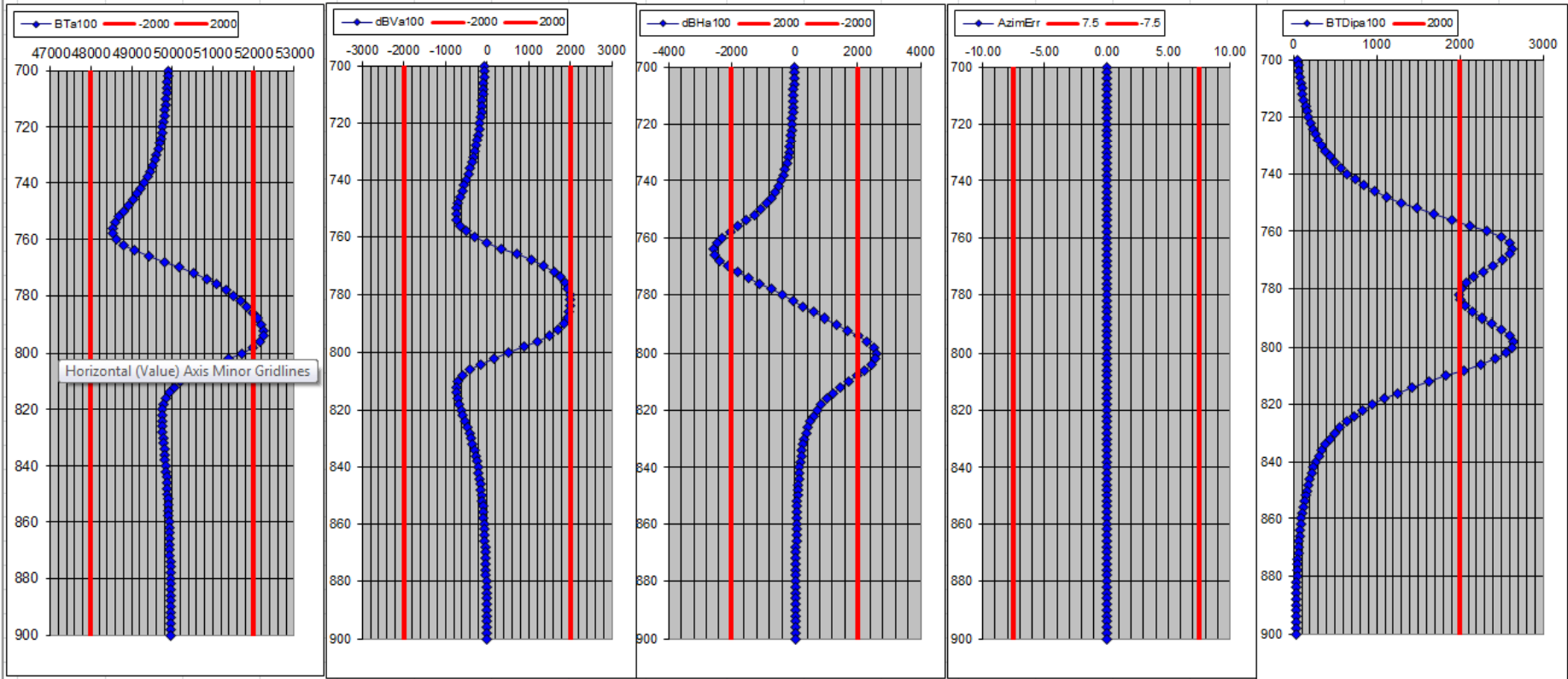


# Simulated Measured field: Dipole Due East - almost no measured dBH, Max azimuth error



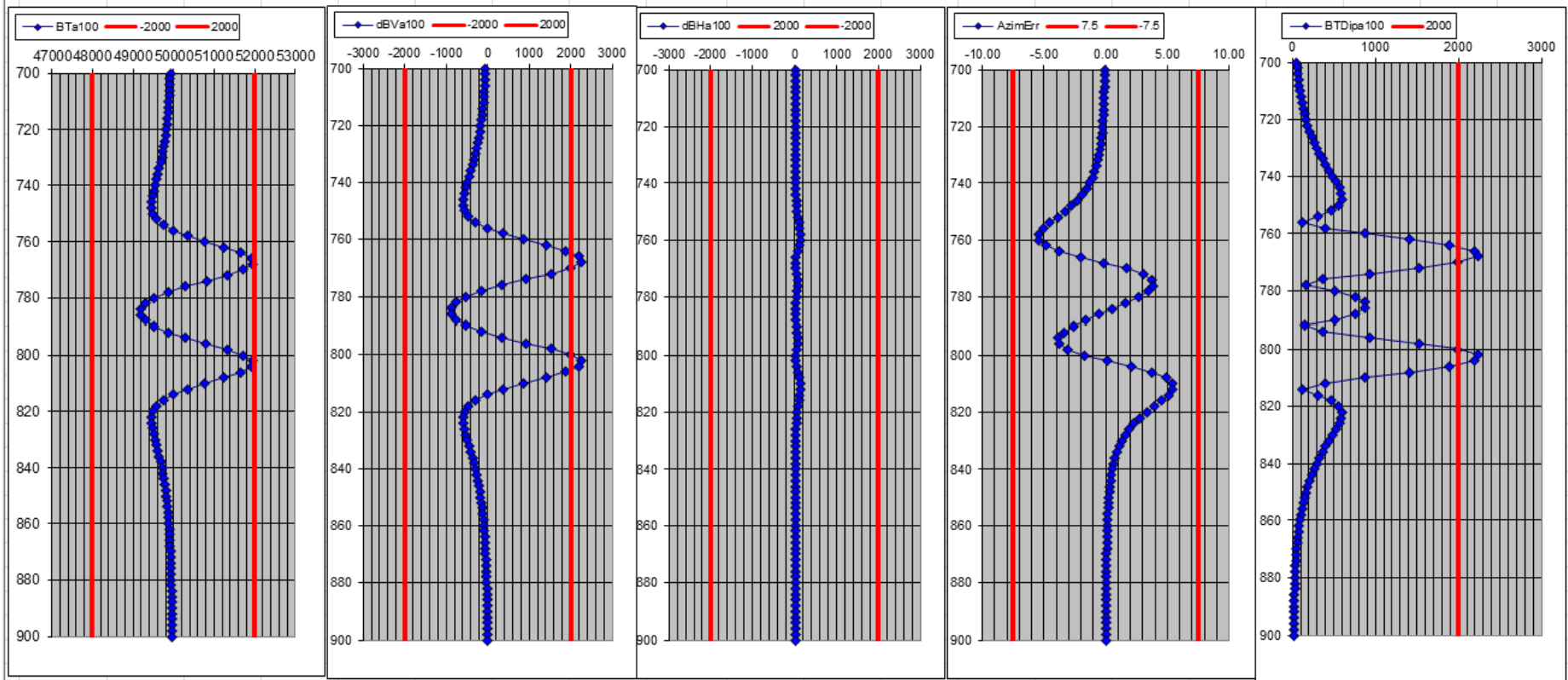
# Simulated Measured field: Dipole Due North - Max Measured delta BH No Azimuth Error

AnchorMD	Inc	Azim	TVD	NS	EW	uW	TVD	NS	EW	Distance
800.00	0.000	0.000	800.00	0.00	0.00	950.00	765.00	17.00	0.00	17.00
TargetHS	17.000		800.00	17.00	0.00	0.00	770.00	17.00	0.00	17.00
TargetR	0.000	17.000				-950	800.00	17.00	0.00	17.00
						0.00	805.00	17.00	0.00	17.00



# Simulated Measured Field from Two Dipoles end to end - Due East

AnchorMD	Inc	Azim	TVD	NS	EW	uW	TVD	NS	EW	Distance
800.00	0.000	0.000	800.00	0.00	0.00	3000.00	765.00	0.00	17.00	17.00
TargetHS	0.000		800.00	0.00	17.00	-3000.00	770.00	0.00	17.00	17.00
TargetR	17.000	17.000				3000.00	800.00	0.00	17.00	17.00
						-3000.00	805.00	0.00	17.00	17.00



## Conclusions from mathematical modeling

- If a 2000 nT limit on BVertical or BTotaldip is not exceeded, worst case azimuth errors are < 7.5 degrees.
- Close-spaced survey shots must be taken to confidently measure the maximum magnetic interference.
- When the plan is made with an IPM specifying 7.5 degrees azimuth error, MWD QC is OK with up to 2000 nT (max) of interference.
- BTotalDip is a convenient single measure of the interference. It is approximately the vector sum of deltaBH and deltaBV or  $\sqrt{\text{sumSq}(\text{dBH}, \text{dBV})}$
- The same errors can be expected in Magnetic Toolface for kickoffs.
- The method could be expanded to a limit of +/- 45 degrees error (correct quadrant) even with 12,000 nT of measured interference.
- This is for mid-continent latitudes with reference BH ~ 23,000 nT

# Why this model is very conservative

- The average  $\Delta BV$  is about the same as  $\Delta BH$ , not  $1/3$
- Azimuth swing from BH of 2000 nT at mid-latitudes is about 5 degrees, not 7.5
- There are an equal number of positive and negative poles (Maxwell's 2<sup>nd</sup> law - there are no monopoles). The average effect over a large number of survey shots is zero.
- The IPM is applied over the entire section, but the maximum effect is seen over only a few shots.
- The assumptions used were worst-case, but an IPM is intended to represent 1 standard deviation.



# IPM File Changes (Compass): There is no standard term for external interference

```

11 #Name Vector Tie-On Unit Value Formula
12 dref e r m 0.35 1.0
13 dsf e s - 0.00056 tmd
14 dst e g im 2.5e-007 tmd*tvd
15 w_12 n n - 1 sin(inc)
16 w_34 n n - 1 sqrt(1-(w_12)^2)
17 mxy1 i s d 0.06 w_12
18 mxy2 l s d 0.06 w_12
19 mxy3 i s d 0.06 cos(azi)*w_34
20 mxy3 l s d 0.06 -sin(azi)*w_34
21 mxy4 i s d 0.06 sin(azi)*w_34
22 mxy4 l s d 0.06 cos(azi)*w_34
23 sag i s d 0.2 (sin(inc))
24 azr a g d 0.15 1.0
25 azrr a r d 0.125 1.0
26 dbhr a r dnt 1500 1.0/(mtot*cos(dip))
27 azm a s d 0.25 1.0
28 amid a s d 0.6 sin(inc)*sin(azm)
29 azic a s d 2.5 1.0
30 azir a r d 5 1.0
31 abx i s - 0.004 (-cos(inc)*sin(tfo))/gtot
32 abx l s - 0.004 ((cos(inc)*sin(azm)*sin(tfo)-cos(azm)*cos(tfo))*tan(dip)*sin(inc)+cos(tfo)*cos(inc))/gtot
33 aby i s - 0.004 (-cos(inc)*cos(tfo))/gtot
34 aby l s - 0.004 ((cos(inc)*sin(azm)*cos(tfo)+cos(azm)*sin(tfo))*tan(dip)*sin(inc)-sin(tfo)*cos(inc))/gtot
35 abz i s - 0.004 (-sin(inc))/gtot
36 abz a s - 0.004 (tan(dip)*sin(inc)*sin(azm))/gtot
37 asx i s - 0.0005 (sin(inc)*cos(inc)*(sin(tfo))^2)
38 asx a s - 0.0005 (-tan(dip)*sin(inc)*(cos(inc)*sin(azm)*sin(tfo)-cos(azm)*cos(tfo))+cos(inc)*cos(tfo))*s
39 asy i s - 0.0005 (sin(inc)*cos(inc)*(cos(tfo))^2)
40 asy a s - 0.0005 (-tan(dip)*sin(inc)*(cos(inc)*sin(azm)*cos(tfo)+cos(azm)*sin(tfo))-cos(inc)*sin(tfo))*c
41 asz i s - 0.0005 (-sin(inc)*cos(inc))
42 asz a s - 0.0005 (tan(dip)*sin(inc)*cos(inc)*sin(azm))
43 mbx a s nt 70 (cos(azm)*cos(tfo)-cos(inc)*sin(azm)*sin(tfo))/(mtot*cos(dip))
44 mby a s nt 70 (-cos(azm)*sin(tfo)+cos(inc)*sin(azm)*cos(tfo))/(mtot*cos(dip))
45 mbz a s nt 70 (-sin(inc)*sin(azm))/(mtot*cos(dip))
46 msx a s - 0.0016 (cos(inc)*cos(azm)*sin(tfo)-tan(dip)*sin(inc)*sin(tfo)+sin(azm)*cos(tfo))*(cos(azm)*cos(
47 msy a s - 0.0016 (-cos(inc)*cos(azm)*cos(tfo)-tan(dip)*sin(inc)*cos(tfo)-sin(azm)*sin(tfo))*(cos(azm)*si
48 msz a s - 0.0016 (-sin(inc)*cos(azm)+tan(dip)*cos(inc))*sin(inc)*sin(azm))
49

```

# IPM File Changes (Compass)

```
12 dref e r m 0.35 1.0
13 dsf e s - 0.00056 tmd
14 dst e g im 2.5e-007 tmd*tvd
15 w_12 n n - 1 sin(inc)
16 w_34 n n - 1 sqrt(1-(w_12)^2)
17 mxy1 i s d 0.06 w_12
18 mxy2 l s d 0.06 w_12
19 mxy3 i s d 0.06 cos(azi)*w_34
20 mxy3 l s d 0.06 -sin(azi)*w_34
21 mxy4 i s d 0.06 sin(azi)*w_34
22 mxy4 l s d 0.06 cos(azi)*w_34
23 sag i s d 0.2 (sin(inc))
24 azr a g d 0.15 1.0
25 azrr a r d 0.125 1.0
26 dbhr a r dnt 1500 1.0/(mtot*cos(dip))
27 azm a s d 0.25 1.0
28 amid a s d 0.6 sin(inc)*sin(azm)
29 azic a s d 2.5 1.0
30 azir a r d 5 1.0
31 abx i s - 0.004 (-cos(inc)*sin(tfo))/gtot
```

# IPM File Changes (Compass)

```
23 sag i s d 0.2 (sin(inc))
24 azr a g d 0.15 1.0
25 azrr a r d 0.125 1.0
26 dbhr a r dnt 1500 1.0/(mtot*cos(dip))
27 azm a s d 0.25 1.0
28 amid a s d 0.6 sin(inc)*sin(azm)
29 azic a s d 2.5 1.0
30 azir a r d 5 1.0
```

24 azr a g d 0.36 1.0	24 azr a g d 0.15 1.0
25 dbh a g dnt 5000 1.0/(mtot*cos(dip))	25 azrr a r d 0.125 1.0
26 azm a s d 0.25 1.0	26 dbhr a r dnt 1500 1.0/(mtot*cos(dip))
27 amid a s d 0.6 sin(inc)*sin(azm)	27 azm a s d 0.25 1.0
	28 amid a s d 0.6 sin(inc)*sin(azm)
	29 azic a s d 2.5 1.0
	30 azir a r d 5 1.0

# Recommendations

- Don't drill near live wells.
- Casing should be degaussed before running to minimize interference with nearby wells. This can be done at the factory or onsite. A low-frequency degaussing method is recommended.
- Drillstring interference (in the Bz direction) must be subtracted. This should be a constant value. This can be minimized by proper degaussing of motors and subs after magnetic inspection.
- Interference from rig and/or conductor can be expected within 2-300 feet from end of conductor. This is usually before KOP.
- Don't use single station Z-axis correction methods when there is external interference.
- Even if gyro surveys are used, monitor magnetics for unexpected close approaches. Measured interference > 2000 nT is a warning sign.

# Thanks & Credits to

- Anne Holmes, Halliburton / Sperry Drilling
- Steve Grindrod, Copegrove Development
- Mark Mitchell, now with BHP (Previously Devon Energy)
- Shelly Grabb, Devon Energy
- Srinivas Karri Reddy ("Reddy"), Halliburton / Sperry Drilling
- Tony Williams, Halliburton / Sperry Drilling
- Shaun St. Louis, Pete Schiermeier, Halliburton / Sperry Drilling
- Jim Towle, Scientific Drilling
- The Industry Steering Committee for Wellbore Survey Accuracy (ISCWSA.org = SPE WPTS) and its members.
- Many others especially those who shared their work through SPE technical papers.

# Frequently Asked Questions

Q: Why would you choose to use a less accurate survey method?

A: The correct survey choice is the least expensive method that meets the project objectives.

Q: Why was 2000 nT chosen for a QC limit? Why 7.5 degrees error?

A: 2000 nT was a limit that few if any surveys were expected to fail, so a gyro would not be required. 7.5 degrees of error gave ellipse sizes that could be easily accommodated in the planning stages. This generous ellipse size gave an extra margin for errors.

Q: Can this be used at higher latitudes?

A: The ratio of QC limits to azimuth error would need to be calculated for a different value of BHorizontal.

Q: Isn't this dangerous?

A: Not more than usual, as the ellipse separations were planned for these large ellipses. The nearby wells were not pressured.

# Frequently Asked Questions

Q: Can this be used at closer well to well spacing?

A: Each situation requires analysis of the expected interference and appropriate QC values with corresponding ellipse sizes. These values for closer spacing would probably result in some surveys failing QC.

Q: Doesn't the "natural" magnetism of the casing (or motor, or drill pipe) come back after degaussing?

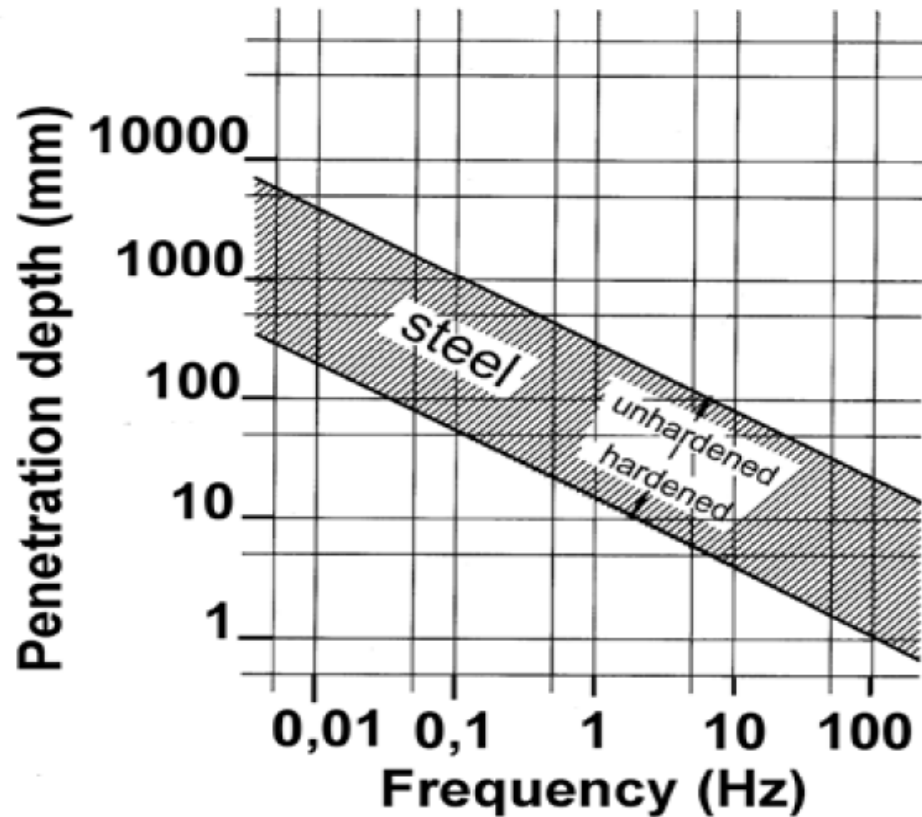
A: Not if degaussing is done properly and the internal fields in the steel (that cannot be measured) are reduced to near zero. See the following slide and the degaussing theory at <http://www.vallon-degaussing.com/products.lasso?a=degaussing>

Q: What about Drillstring Interference (in the vertical direction for a near-vertical well)?

A: Either reduce DSI by degaussing or use of sufficient non-mag spacing, or apply a constant (not varying from shot to shot) correction for DSI.

For more info contact [Neil.Bergstrom@dvn.com](mailto:Neil.Bergstrom@dvn.com)

# Degaussing Frequency



Penetration depth of eddy current

Line frequency (50 or 60 Hz) does not penetrate a large part. Lower frequency and/or higher fields (amp-turns) are required

Chart Used with permission from Vallon-Degaussing.com