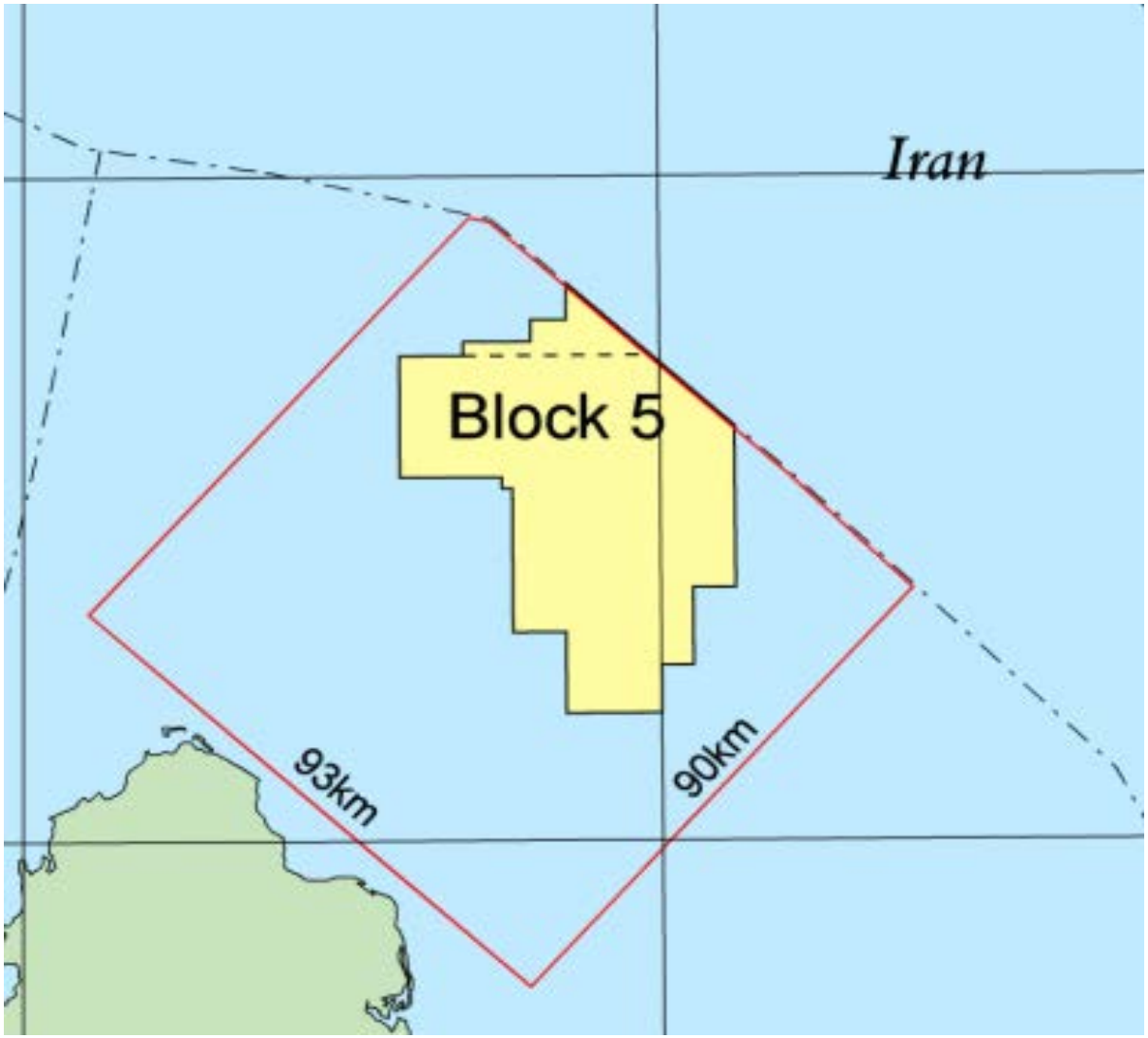
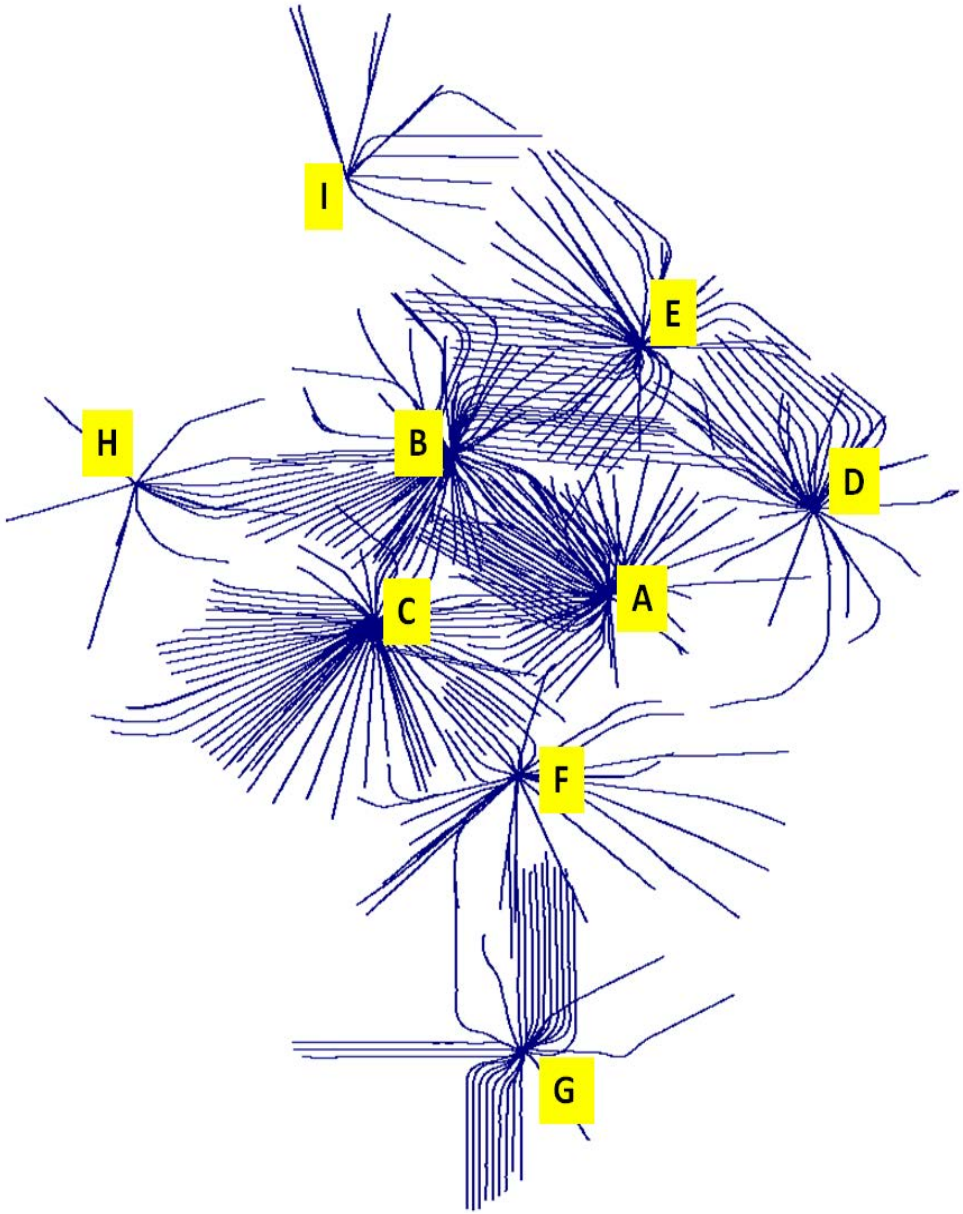
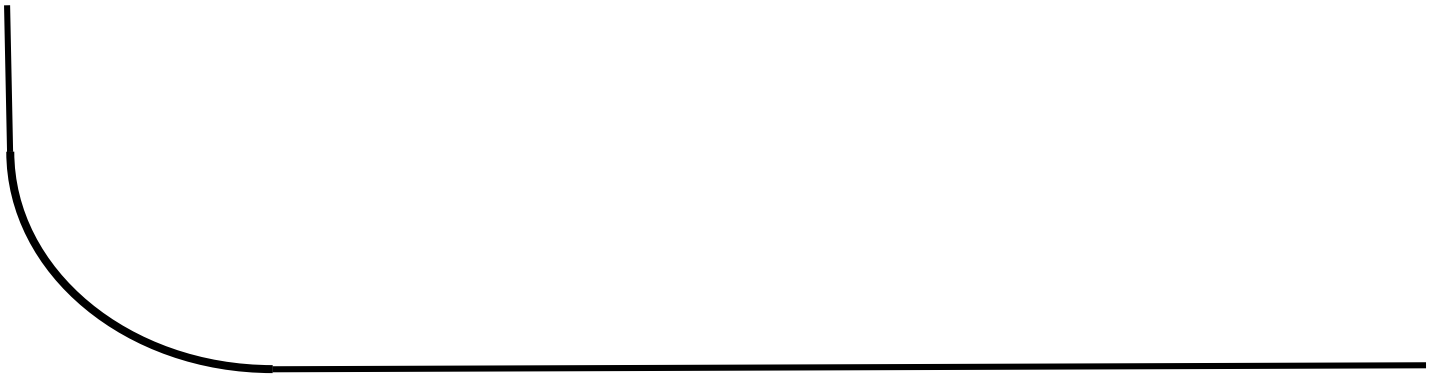
Combined use of MWD and gyro surveying to reduce wellbore positioning uncertainties

Simon McCulloch, Maersk Oil Qatar
Stefan Maus, Magnetic Variation Services LLC

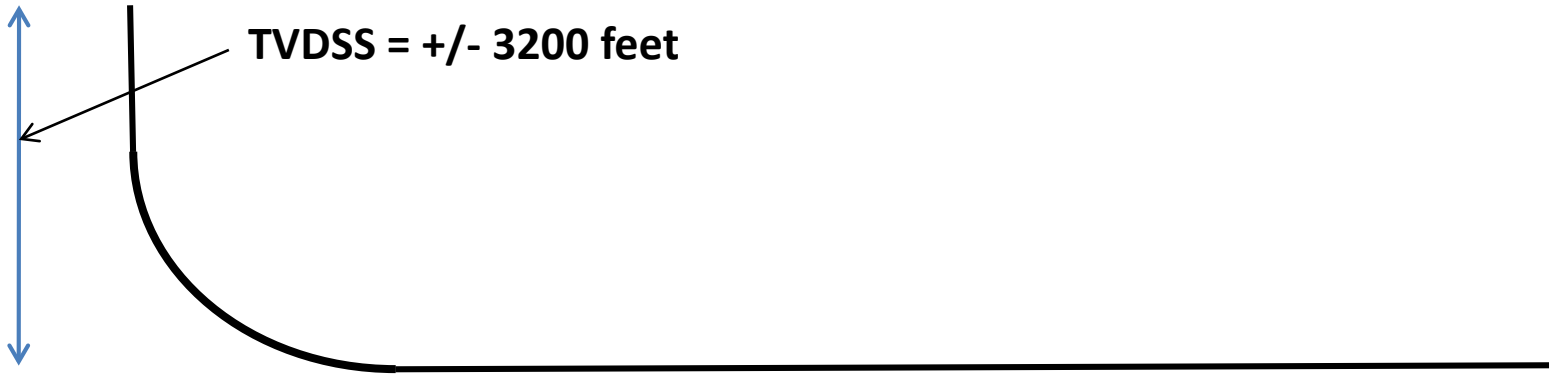

Iran
Block 5
93km
90km


I
E
H
B
D
A
C
F
G

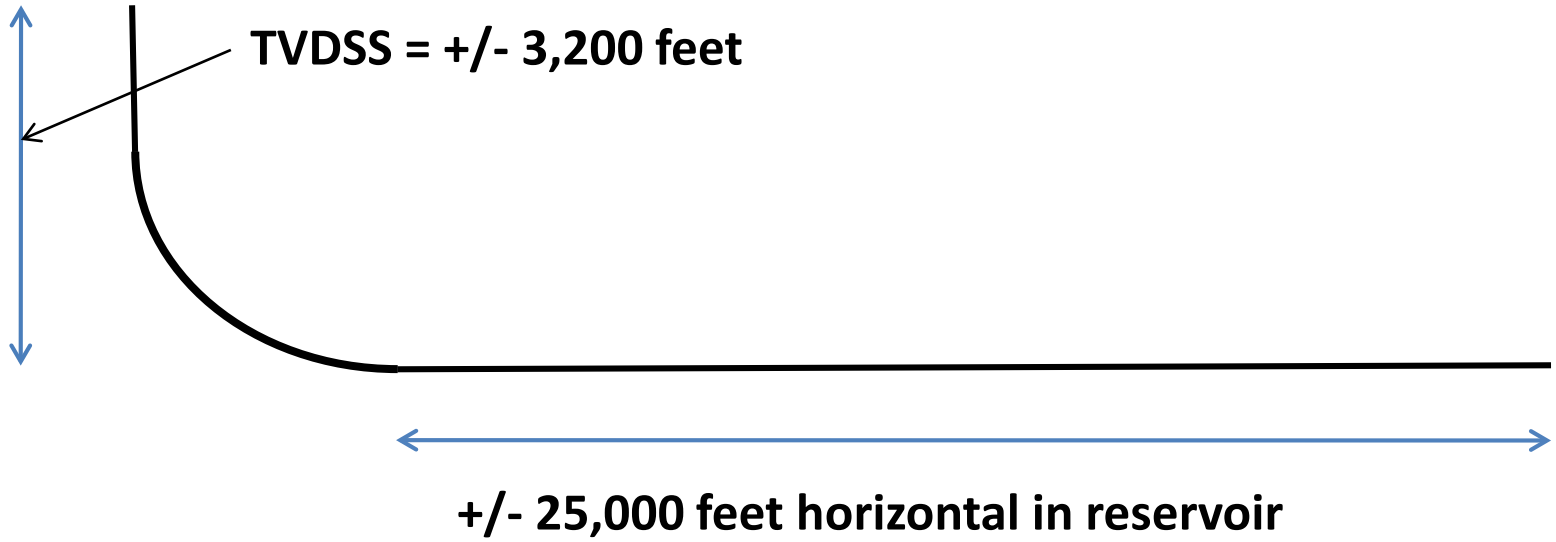
Typical MOQ Well



Typical MOQ Well



Typical MOQ Well



BGGM Example

Declination: **2.24° (Magnetic North is East of True North)**

Dip: **41.03°**

Total field: **43,950 nT**

Accuracy of BGGM (1-sigma)

Declination: +/- 0.39°

Dip: +/- 0.2°

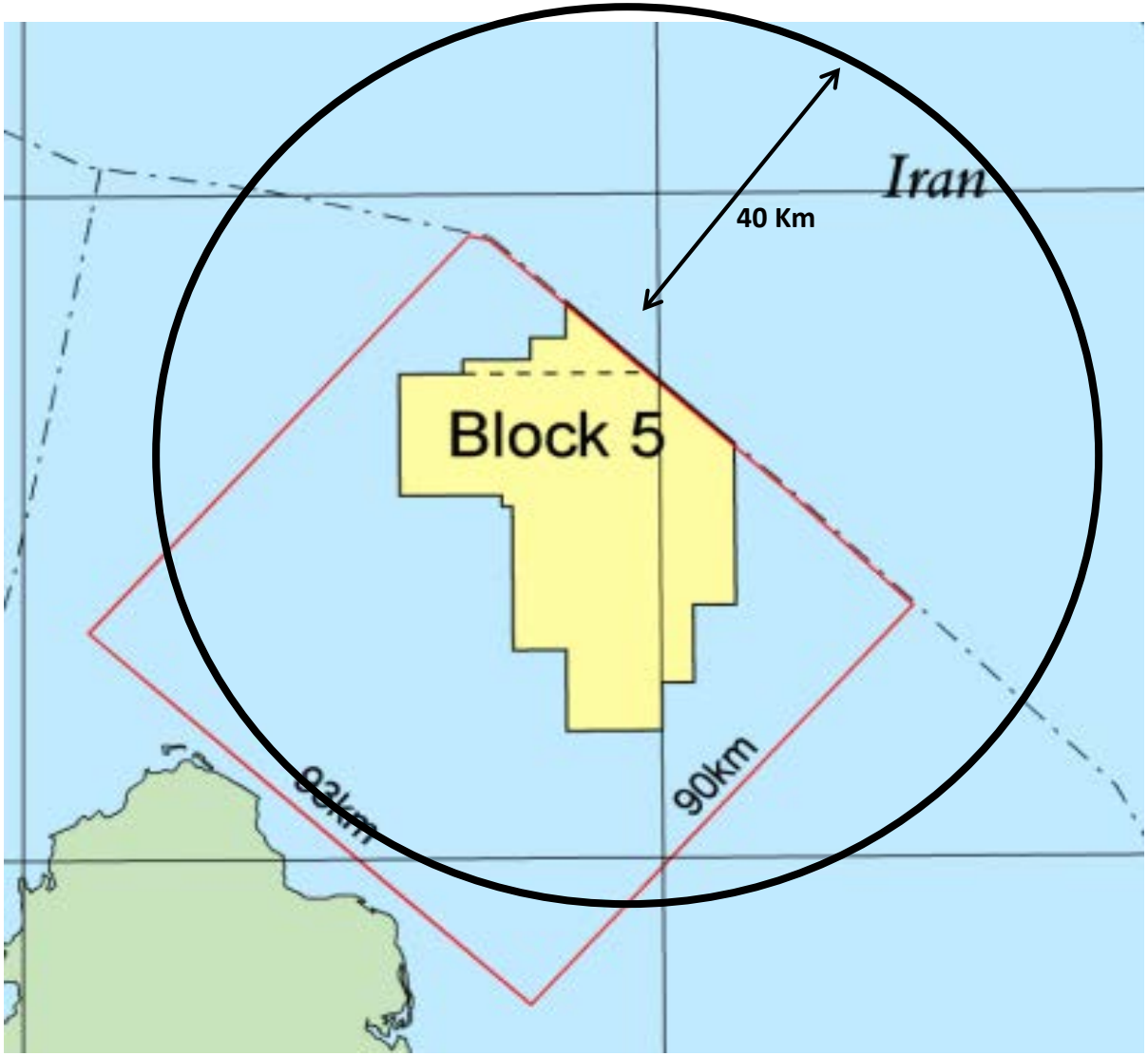
Total field: +/- 130 nT

Accuracy of BGGM Corrected by Aeromagnetic Anomaly Survey

Declination: +/- 0.15°

Dip: +/- 0.1°

Total field: +/- 60 nT


Iran
40 Km
Block 5
90km
93km

2007 Marine Magnetic Vector Survey

Declination correction: **-0.6°**

Dip correction: **+0.11°**

Total field correction: **-6nT**

BGGM Corrected by Marine Magnetic Vector Survey

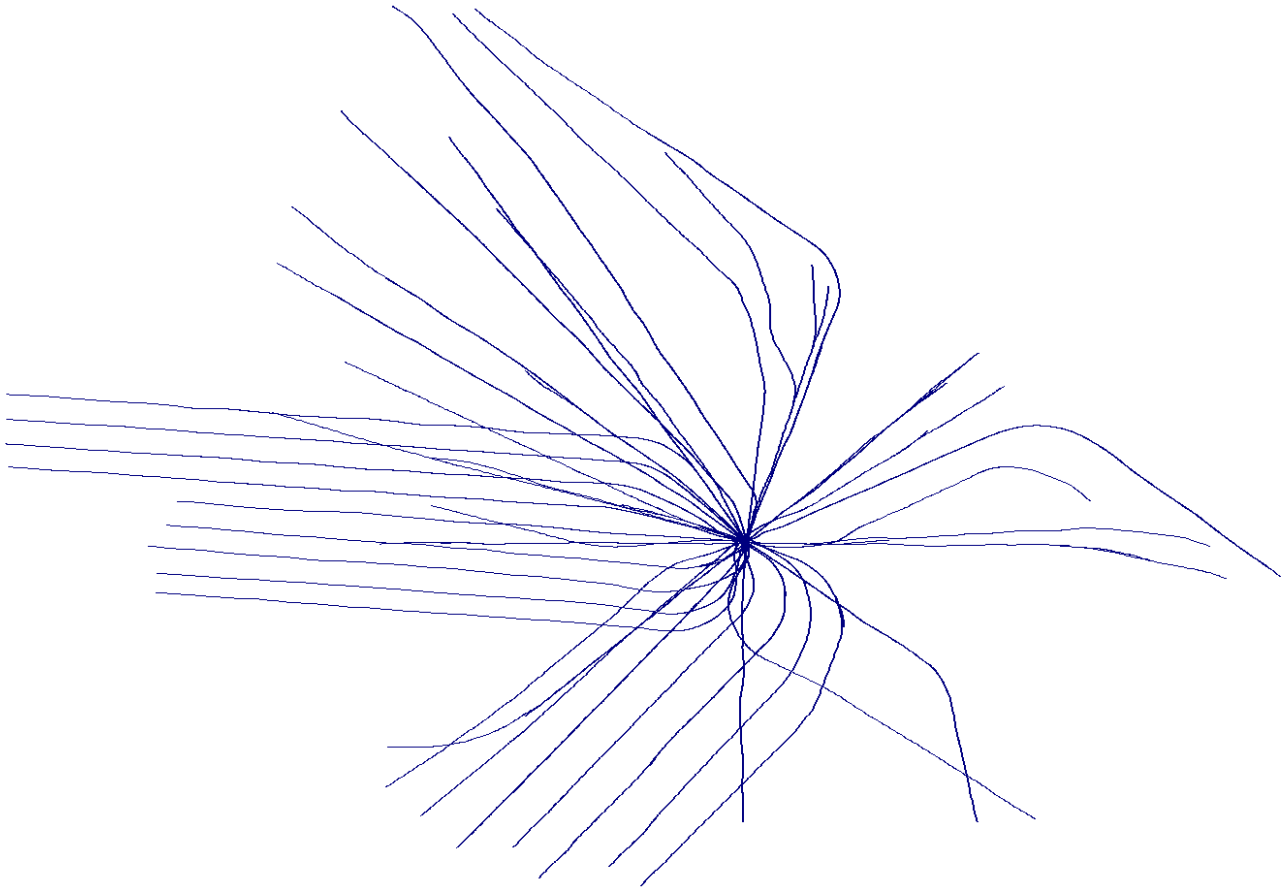
Declination: ~~**2.24°**~~ **1.64°**

Dip: ~~**41.03°**~~ **41.14°**

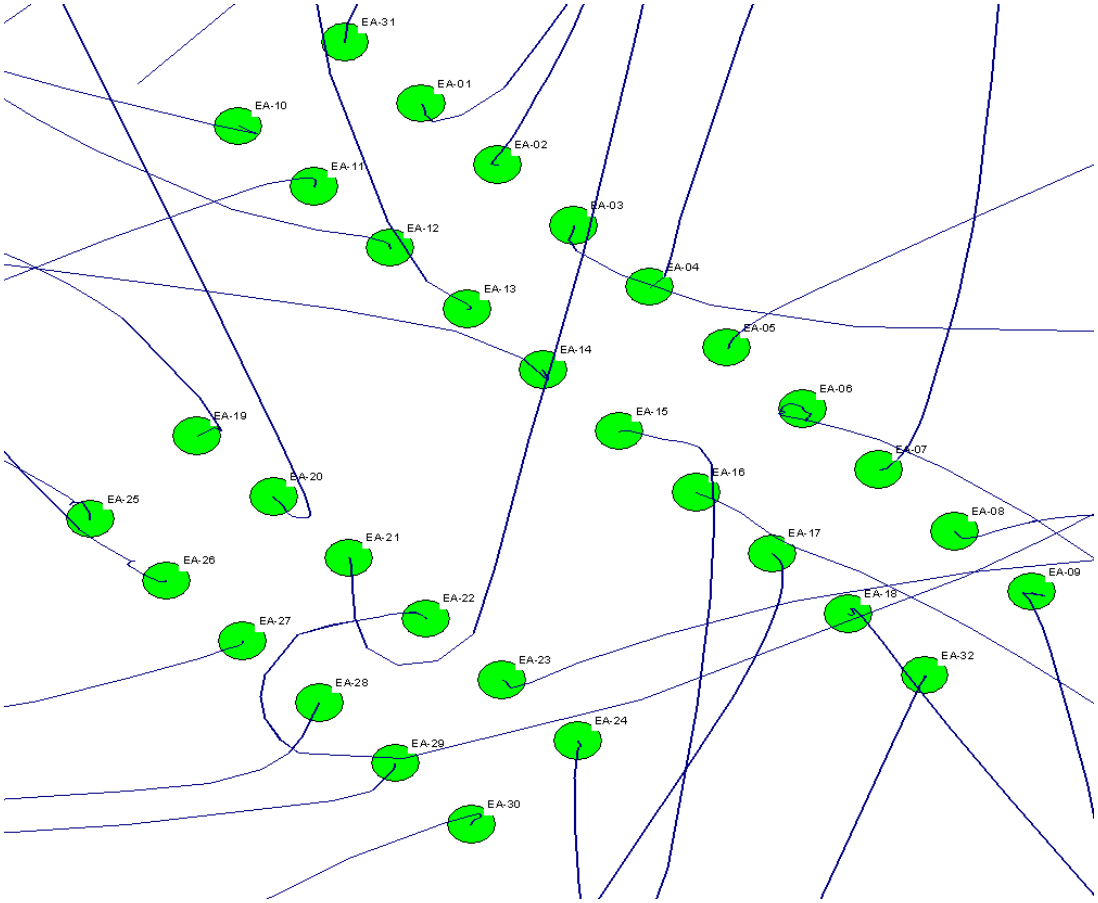
Total field: ~~**43,950 nT**~~ **43,944 nT**

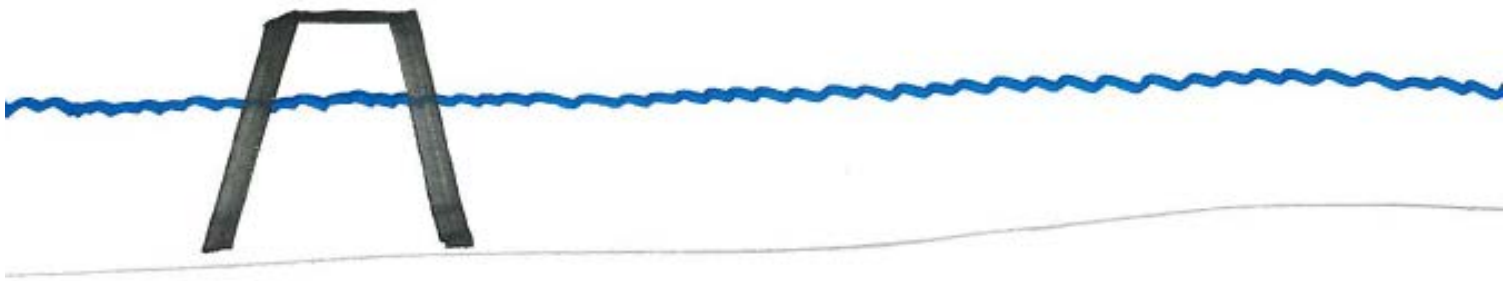
Well	# of Surveys	# Failing	Predicted BT	Average Measured BT	Difference	Predicted Dip	Average Dip	Difference
IA-14	5	0	43981	43880	-101.1	41.342	41.317	-0.025
IA-14A	138	0	43981	43979	-2.0	41.342	41.313	-0.029
BD-25	183	0	43961	43935	-26.1	41.22	41.204	-0.016
EA-08A	21	0	43977	44032	54.8	41.27	41.157	-0.113
EA-08B	153	0	43977	44040	62.9	41.27	41.125	-0.145
IA-17	33	0	43990	44013	23.0	41.354	41.388	0.034
IA-17A	77	0	43990	43990	-0.3	41.354	41.387	0.033
IA-17B	75	0	43990	43997	7.4	41.354	41.380	0.026
IA-24	68	0	43986	44051	64.8	41.349	41.272	-0.077
IA-24A	78	0	43986	44029	42.8	41.349	41.314	-0.035
IA-23B	74	0	43977	43986	9.1	41.337	41.231	-0.106
IA-23	31	0	43977	44010	33.0	41.337	41.202	-0.135
IA-23A	64	0	43977	43980	2.7	41.337	41.272	-0.065
BA-31A	134	0	43942	44013	70.5	41.194	41.219	0.025
BA-31B	100	0	43942	43931	-11.5	41.194	41.260	0.066
CA-35B	173	0	43930	43881	-48.6	41.11	41.037	-0.073
CA-36A	155	0	43927	43929	2.2	41.107	40.930	-0.177
EA-09	190	0	43987	43977	-9.8	41.271	41.263	-0.008
AB-25	102	0	43949	43982	33.2	41.139	41.031	-0.108
EA-17A	190	0	43979	43970	-9.5	41.257	41.240	-0.017
CA-38	178	1	43900	43706	-194.1	41.071	41.092	0.021
CA-32	224	0	43893	43730	-162.7	41.063	41.173	0.110
FA-02	16	0	43941	44049	107.9	41.081	40.960	-0.121
FA-02A	117	0	43941	43990	49.3	41.081	41.026	-0.055
AB-02	112	0	43953	44034	81.5	41.147	41.134	-0.013
BA-33	241	0	43965	43979	13.9	41.212	41.216	0.004
BA-35	262	4	43927	43990	63.4	41.159	41.150	-0.009
BA-32	180	0	43921	43967	45.9	41.153	41.171	0.018
CA-33	105	0	43910	43923	12.6	41.082	41.026	-0.056
FA-15	145	1	43929	43927	-2.1	41.06	40.949	-0.111
FA-15A	128	0	43929	43883	-45.8	41.06	40.970	-0.090
FA-13E	211	3	43938	43880	-58.1	41.075	41.026	-0.049
FA-13B	57	0	43929	43946	16.5	41.06	40.969	-0.091
FA-13C	162	5	43935	43937	2.3	41.069	41.001	-0.068
FA-13A	104	0	43929	43933	3.9	41.06	40.999	-0.061
GA-14	214	0	43911	43973	62.2	40.952	40.992	0.040
GA-12	131	0	43913	43802	-110.6	40.955	40.908	-0.047
BA-36	260	1	43947	44011	63.6	41.182	41.212	0.030
BA-37	23	0	43916	44038	121.7	41.146	41.092	-0.054
BA-37A	158	4	43916	43958	41.9	41.146	41.165	0.019
AB-30 ML1	111	1	43961	43813	-147.5	41.16	41.146	-0.014
AB-30 ML2	113	1	43963	43923	-40.3	41.164	41.089	-0.075
BA-38	181	0	43933	43977	44.3	41.165	41.209	0.044
FA-01A	92	0	43938	43927	-11.5	41.075	41.078	0.003
					-0.9			**-0.025**

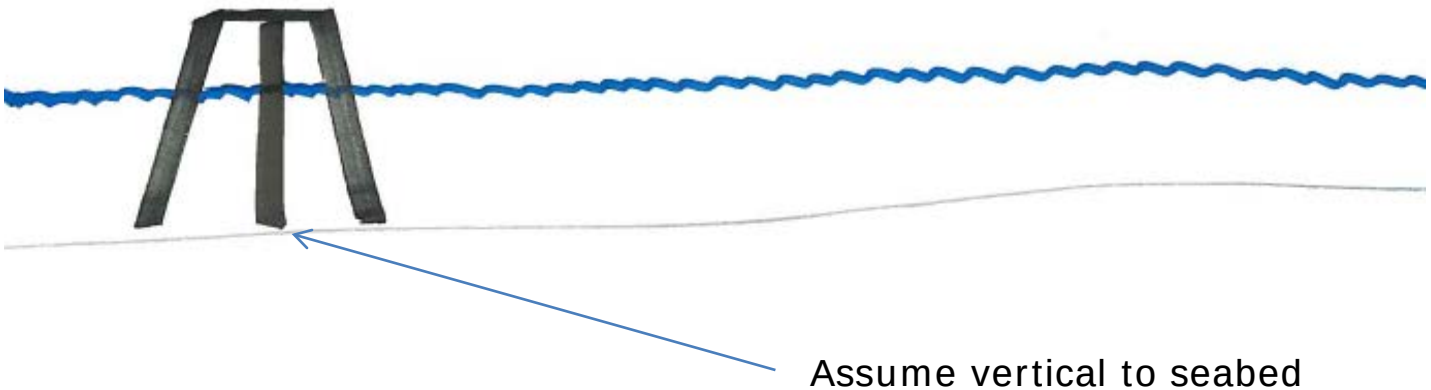
Typical Platform Spider Plot

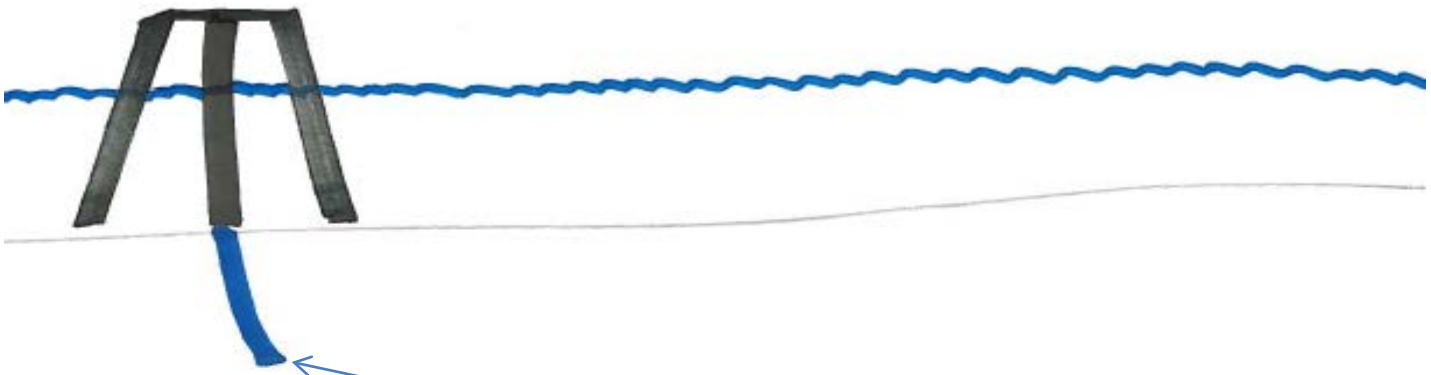


Typical Surface Location

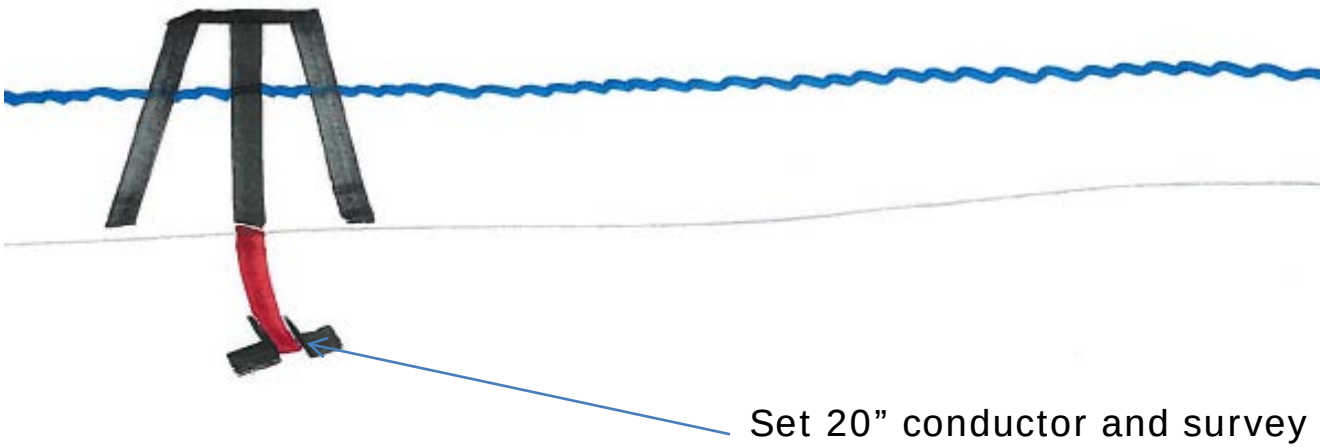




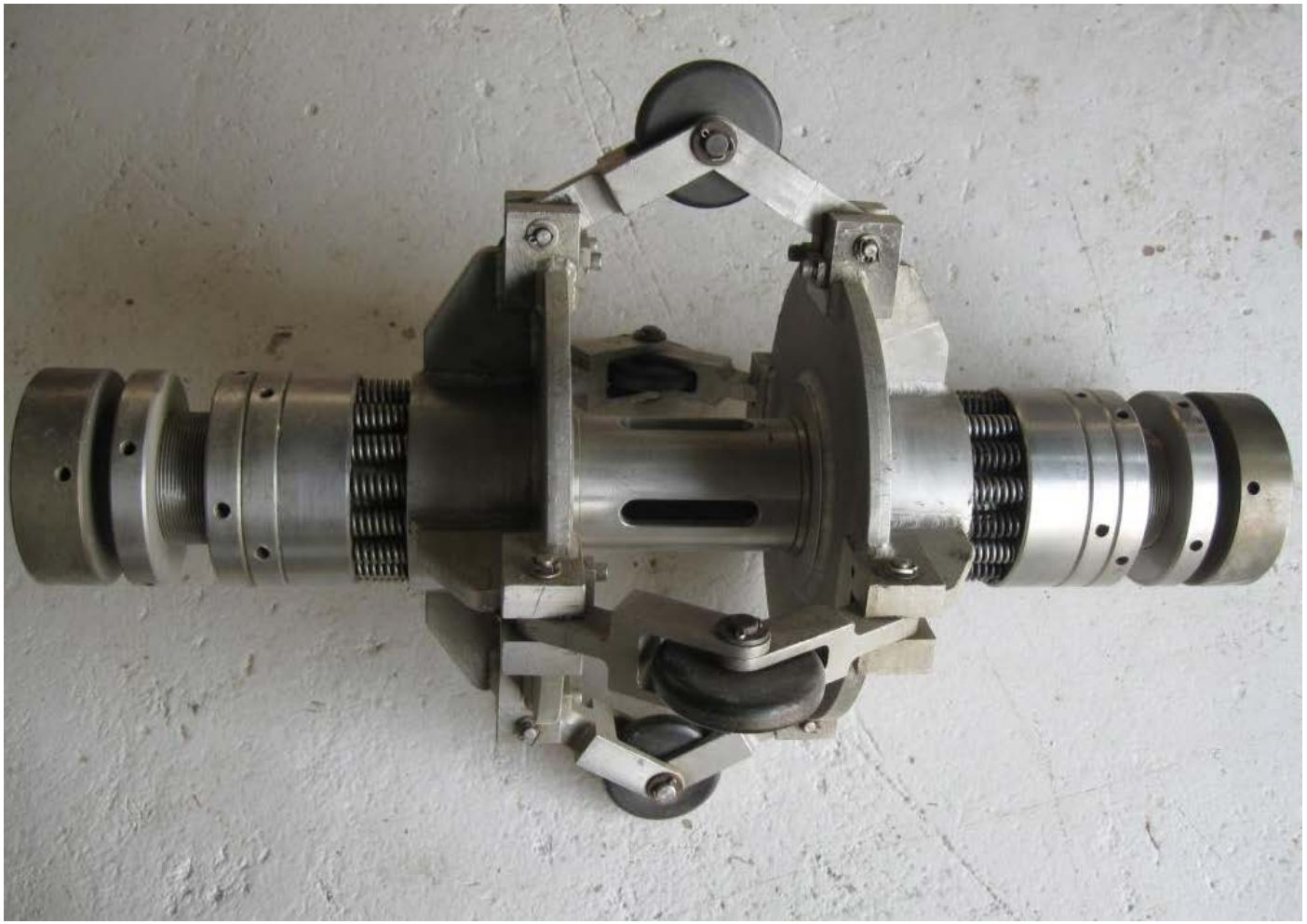

Assume vertical to seabed

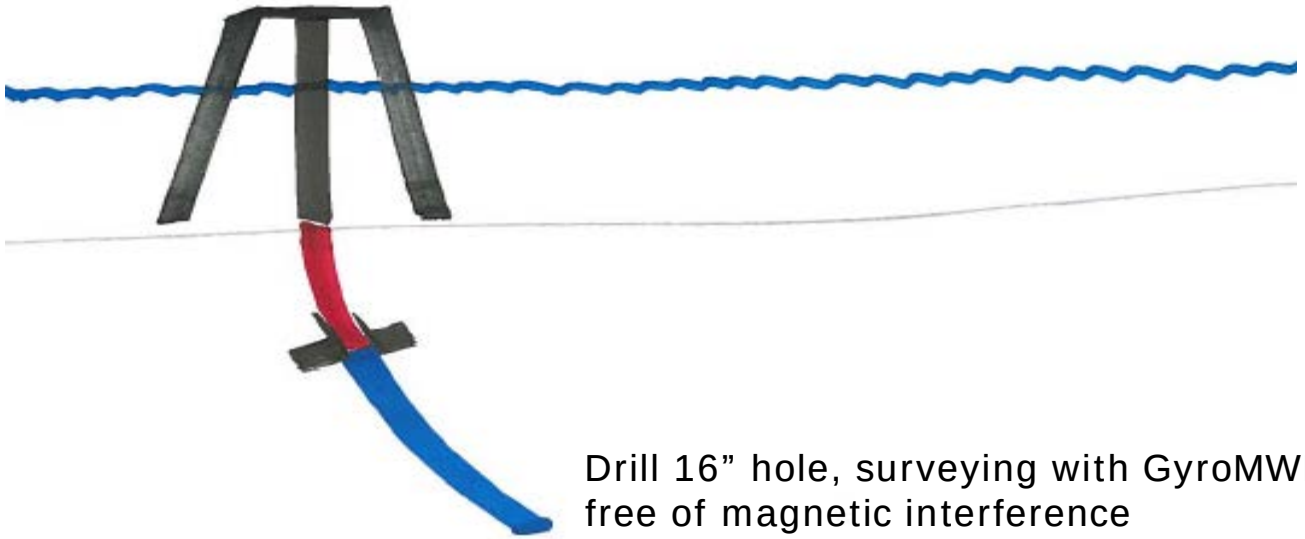


Drive conductor, or drill
26” hole to 600 feet
surveying with GyroMWD

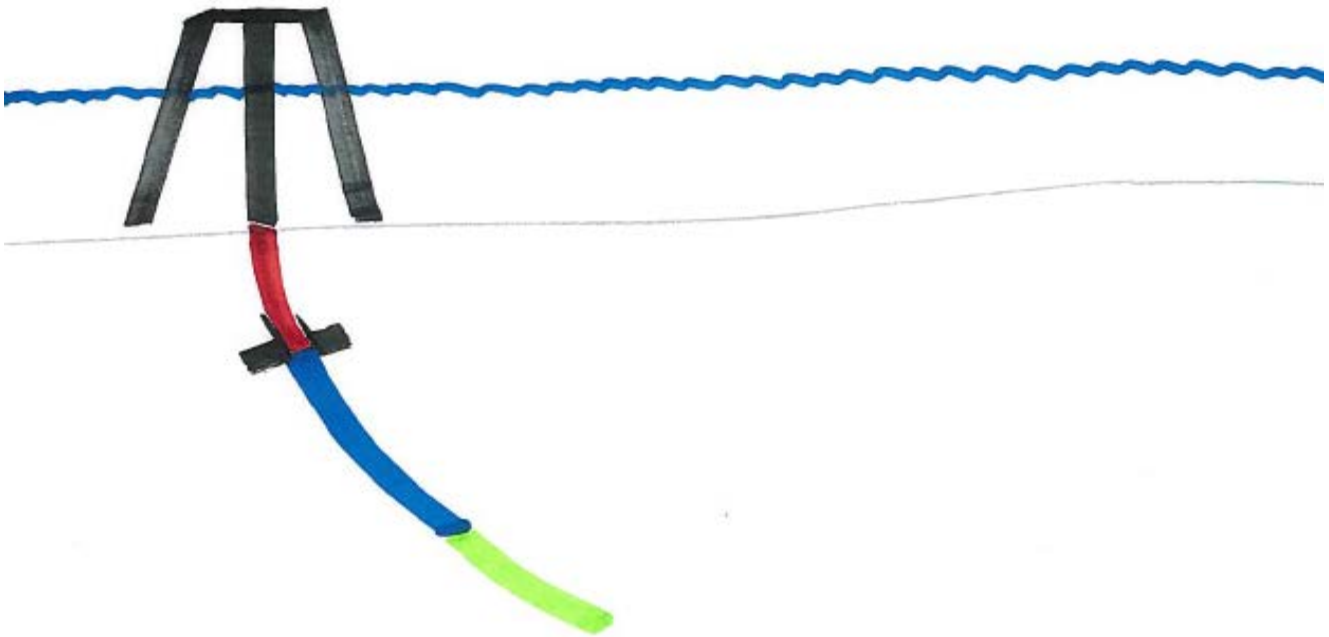

Set 20” conductor and survey
with wireline centroller gyro

Centroller

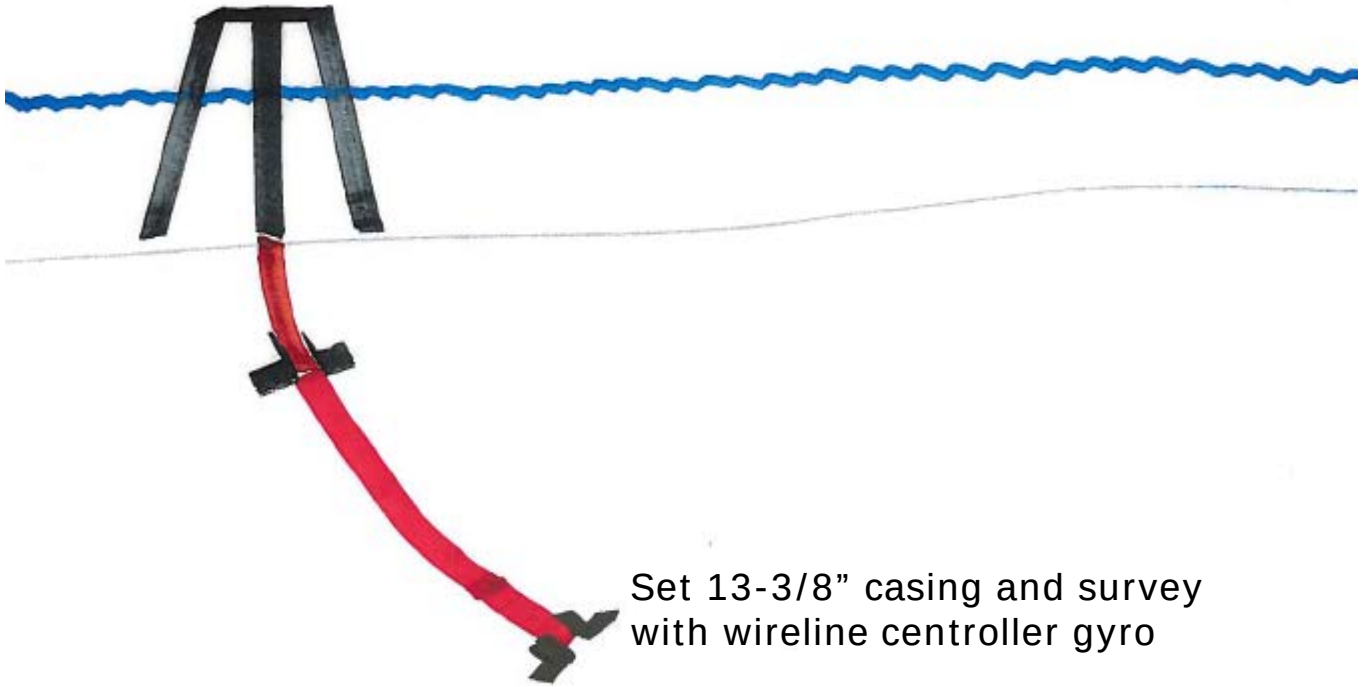




Drill 16” hole, surveying with GyroMWD until free of magnetic interference

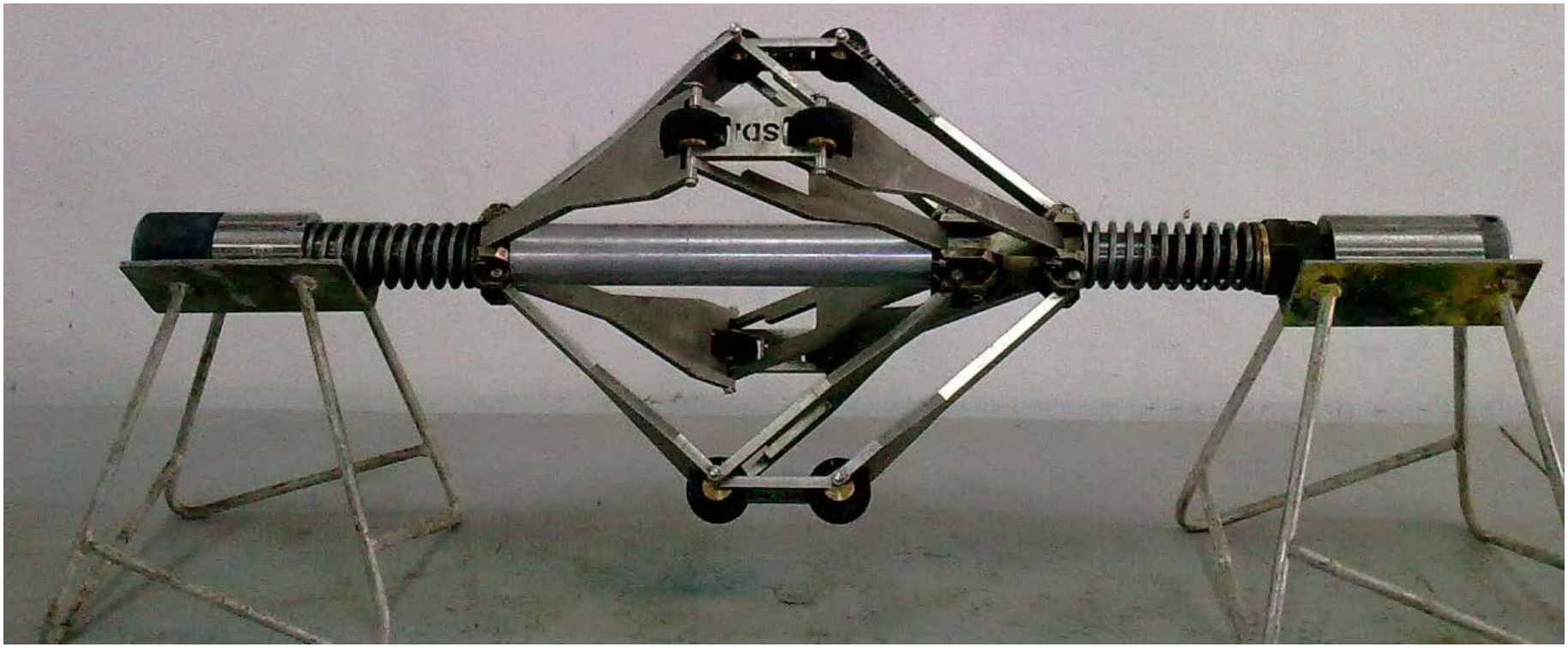


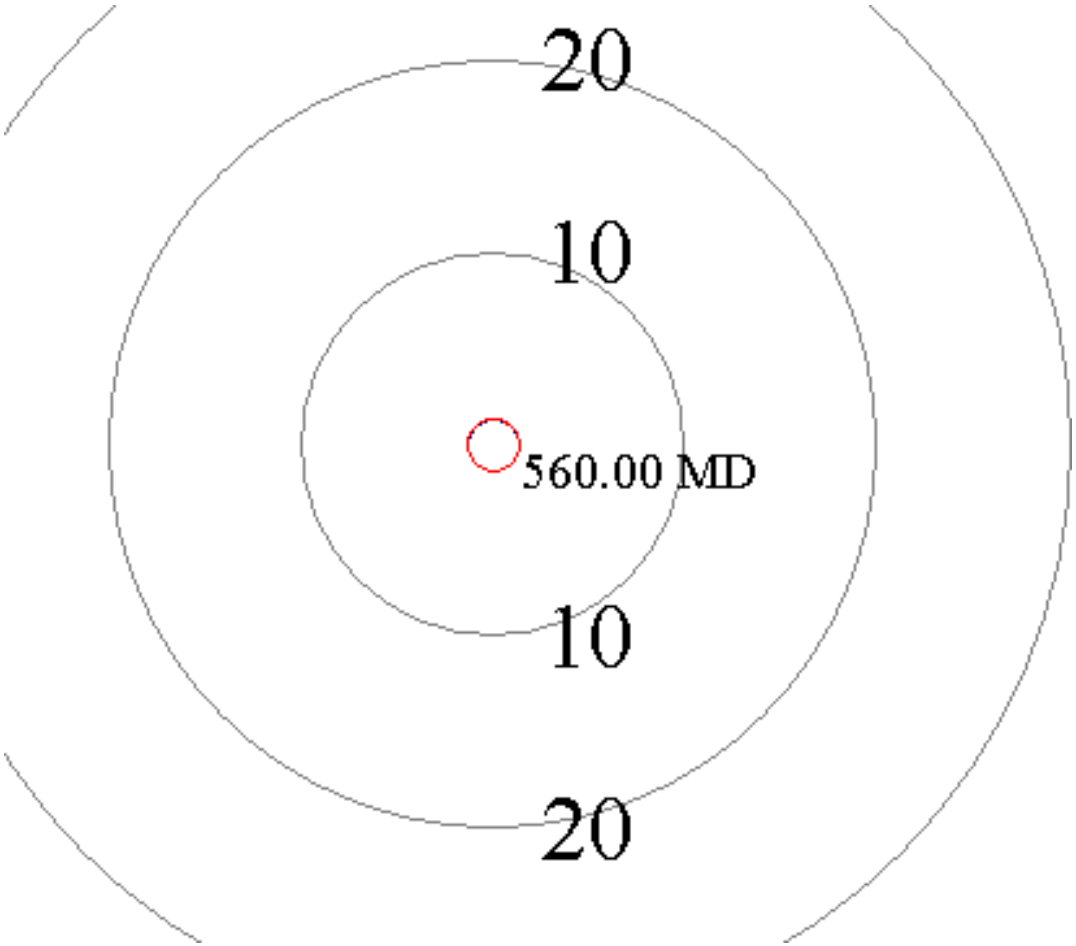
Drill 16” hole to TD at about 3,000 feet, surveying with magnetic MWD

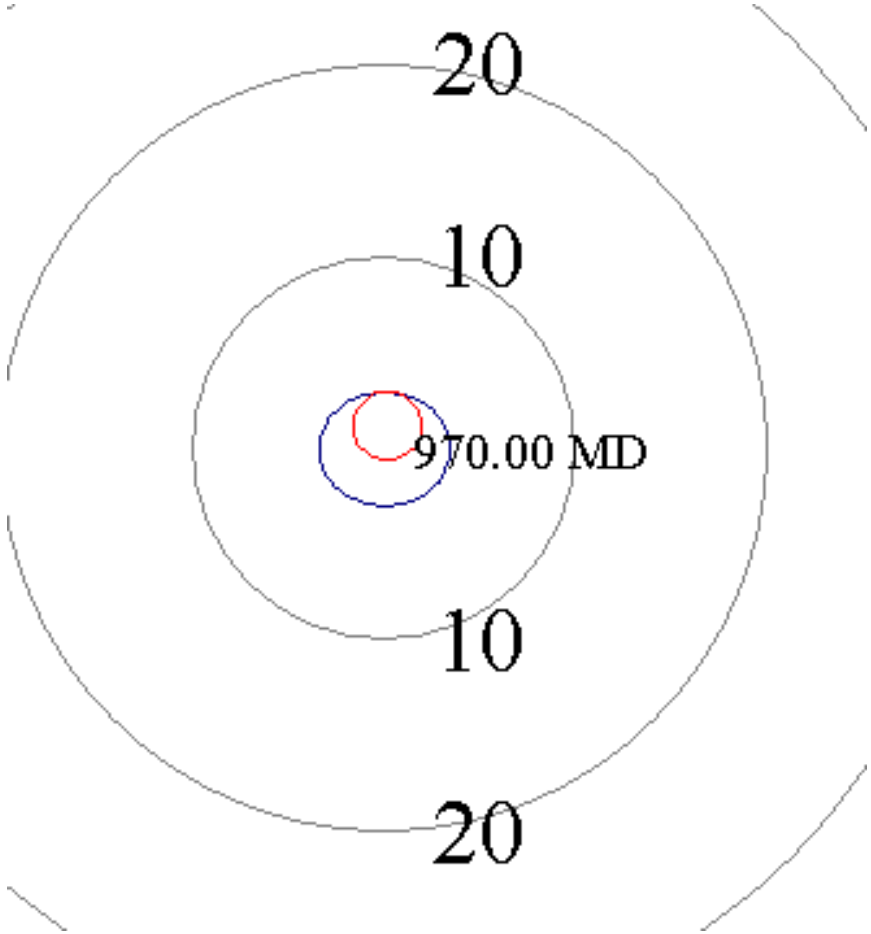


Set 13-3/8” casing and survey
with wireline centroller gyro

Centroller




20
10
560.00 MD
10
20


20
10
970.00 MD
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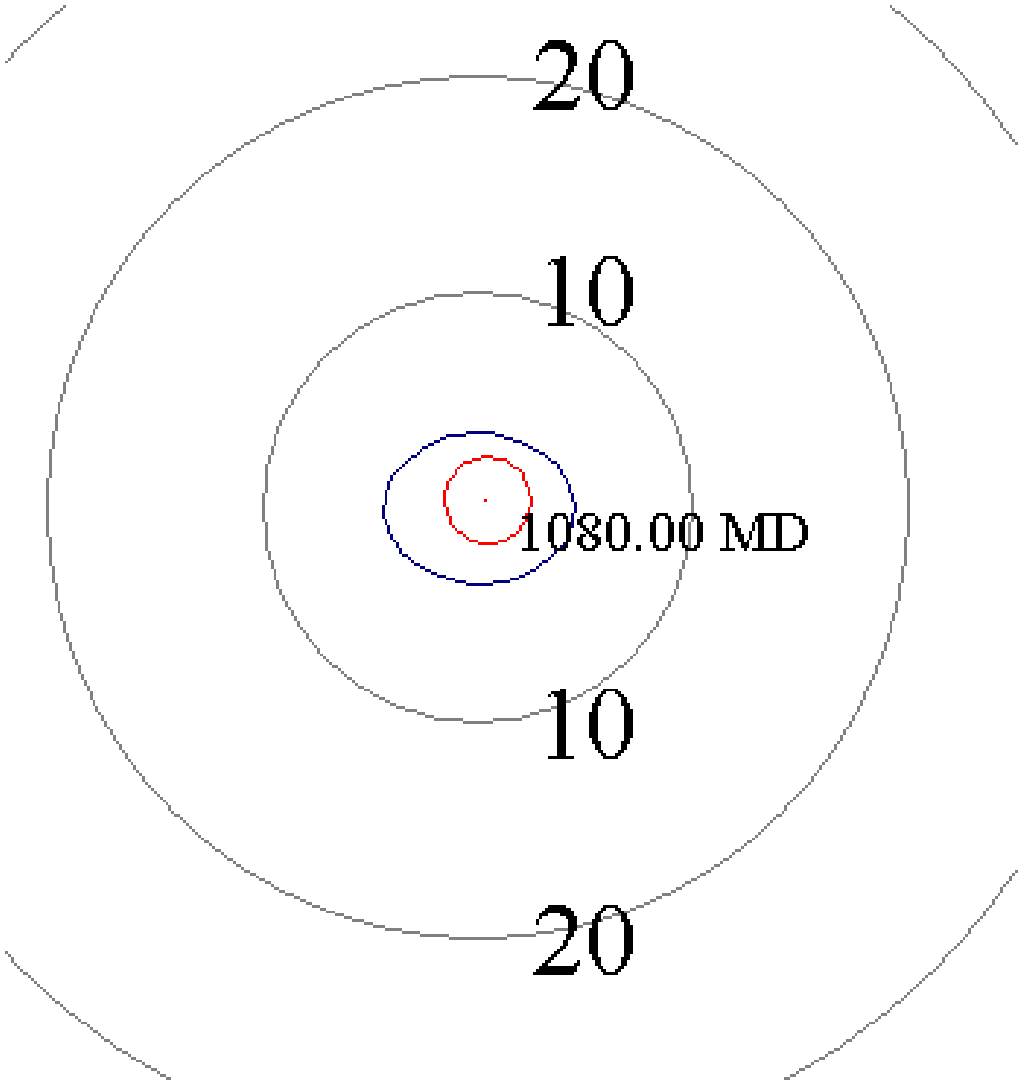
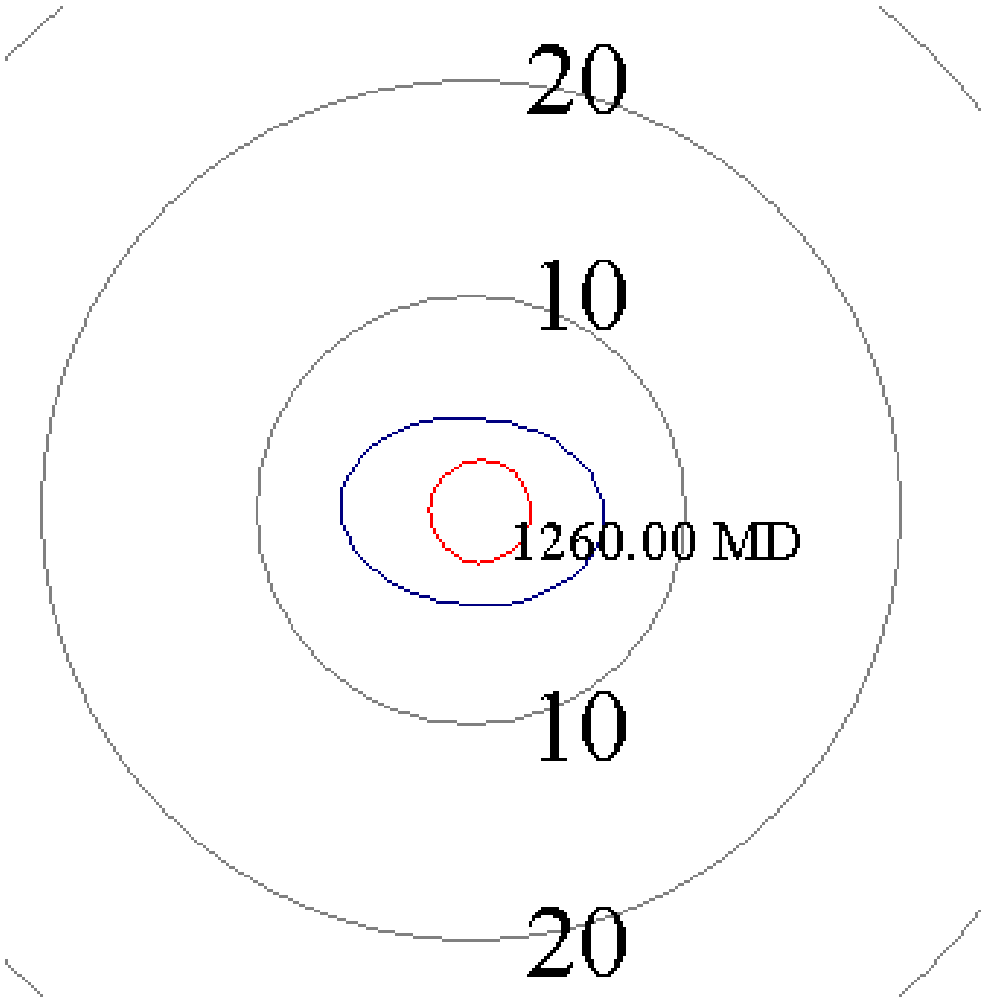
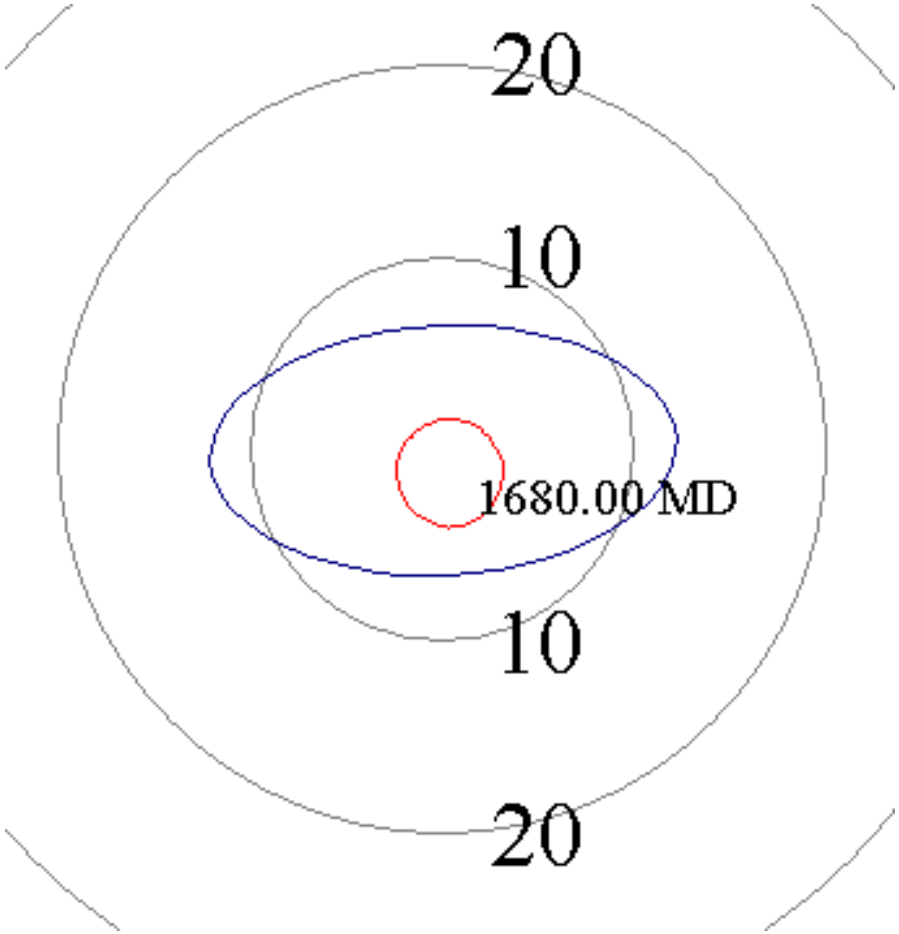
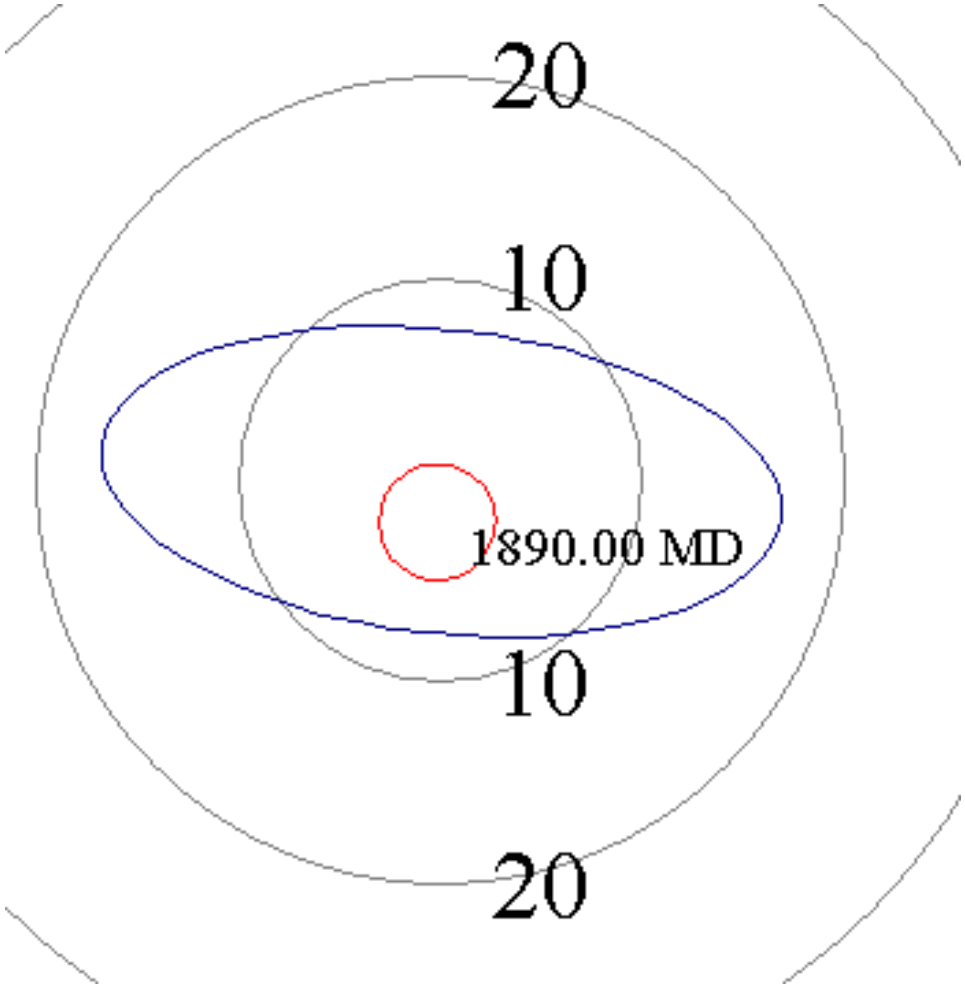
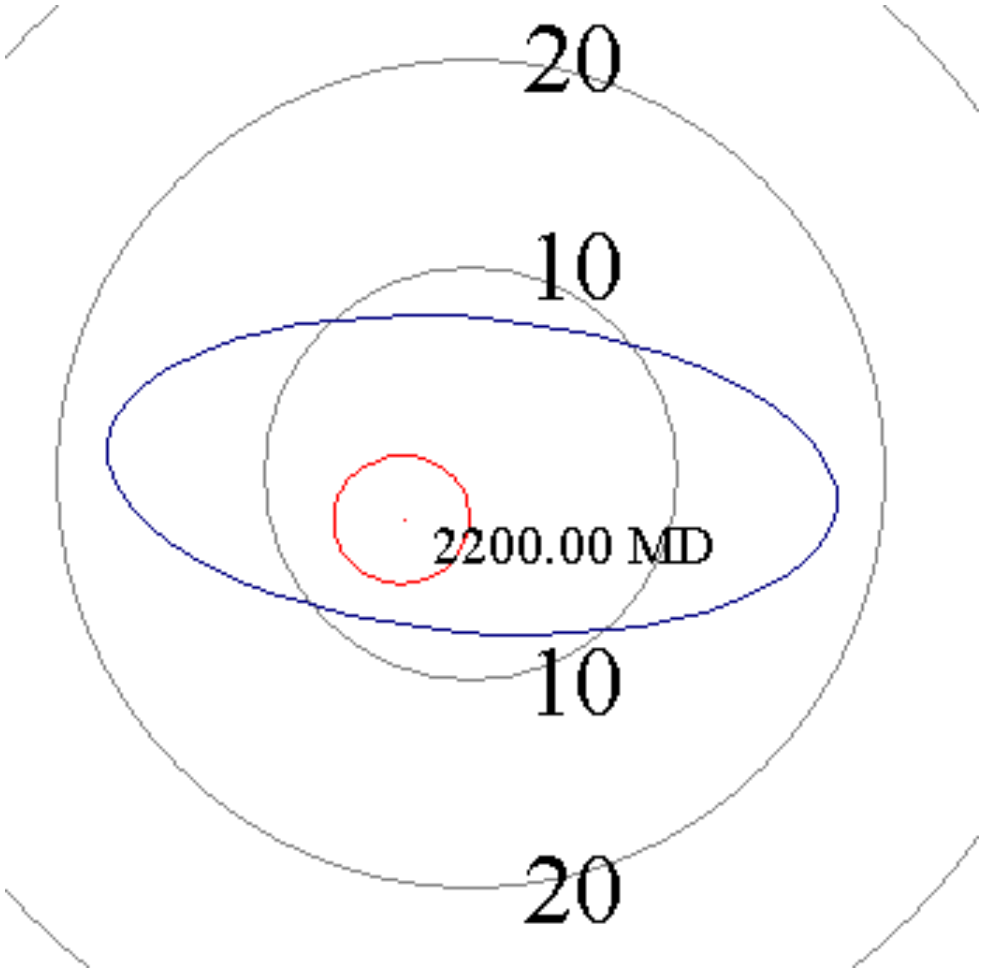
20


20
10
1080.00 MD
10
20


20
10
1260.00 MD
10
20


20
10
1680.00 MD
10
20


20
10
1890.00 MD
10
20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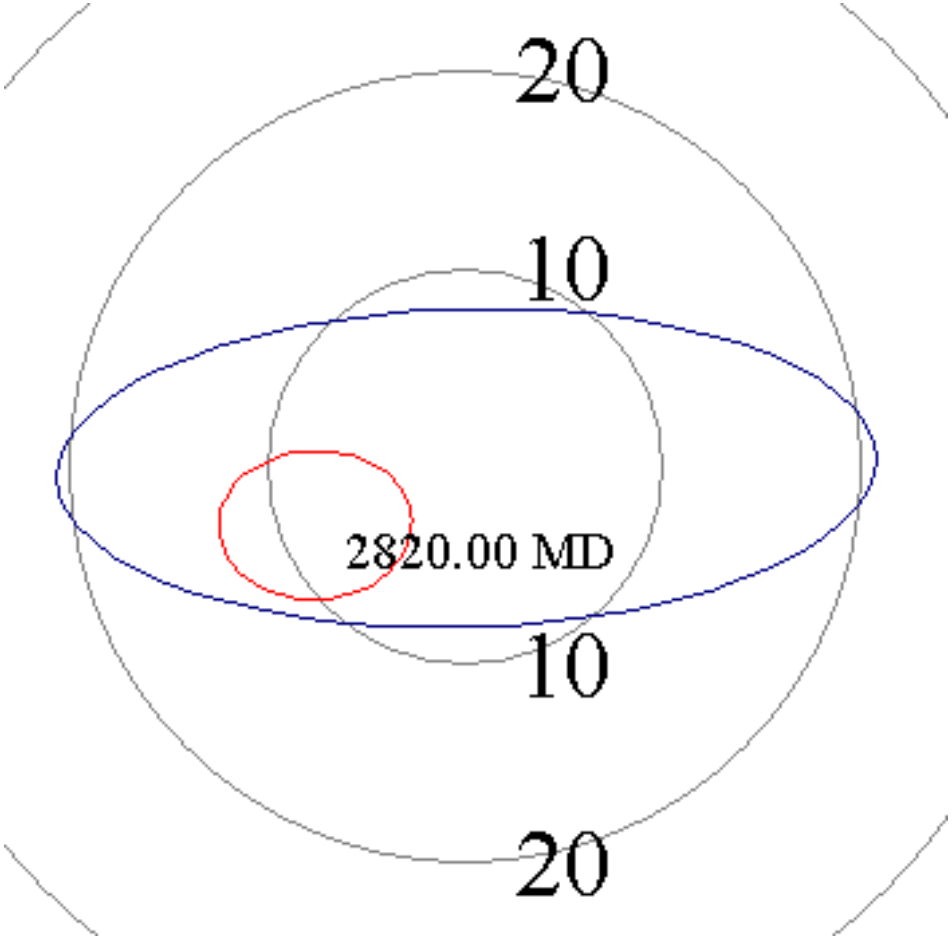
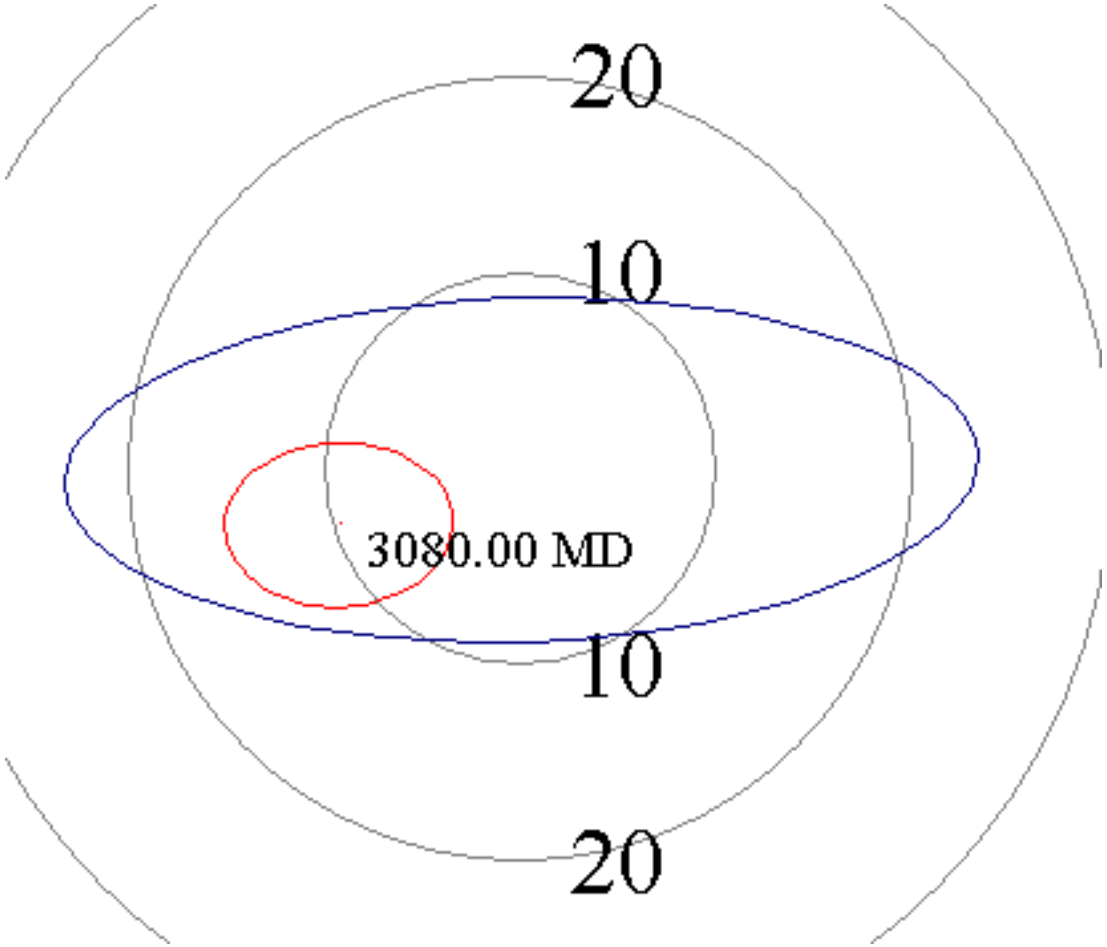
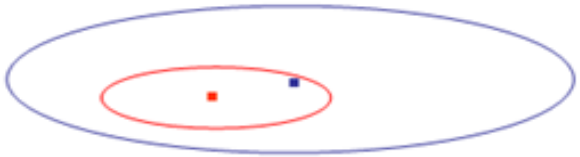
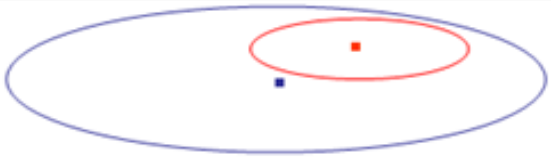
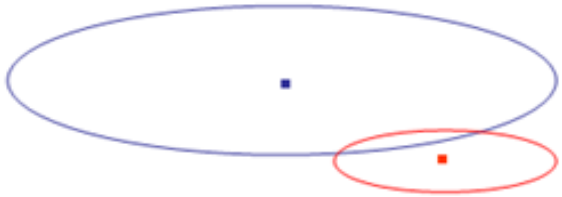
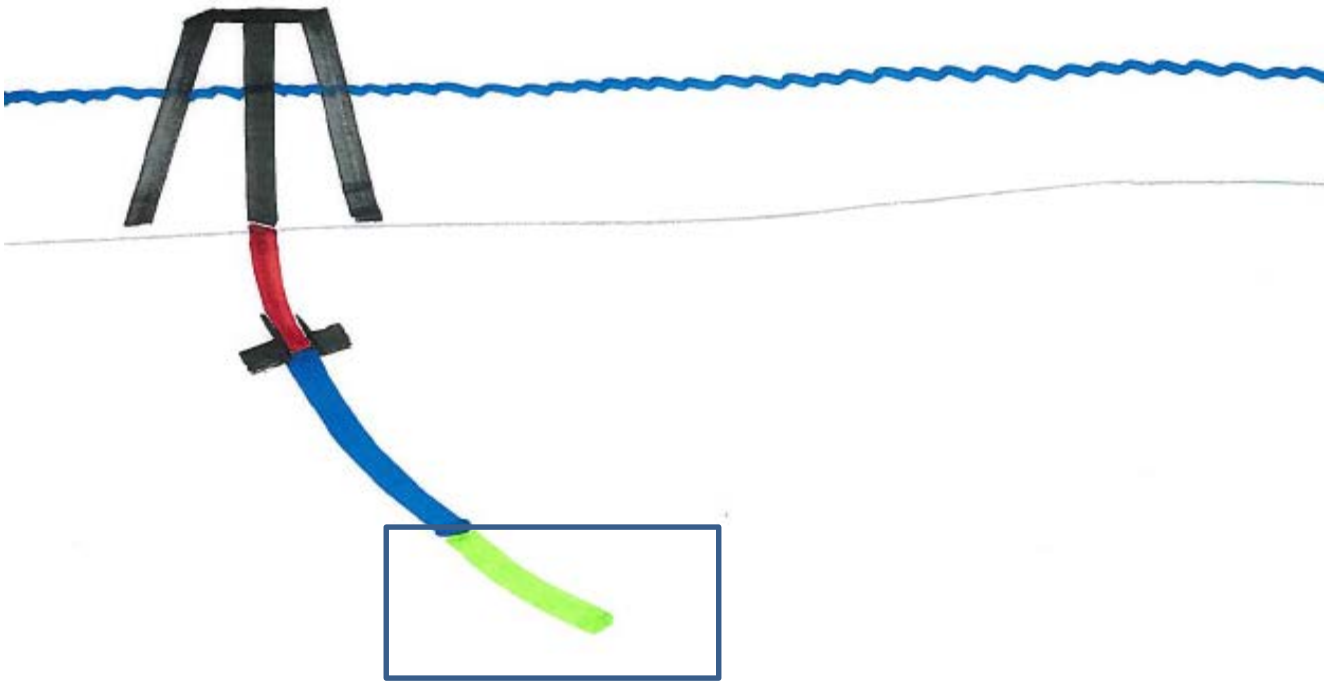
10
2200.00 MD
10
20

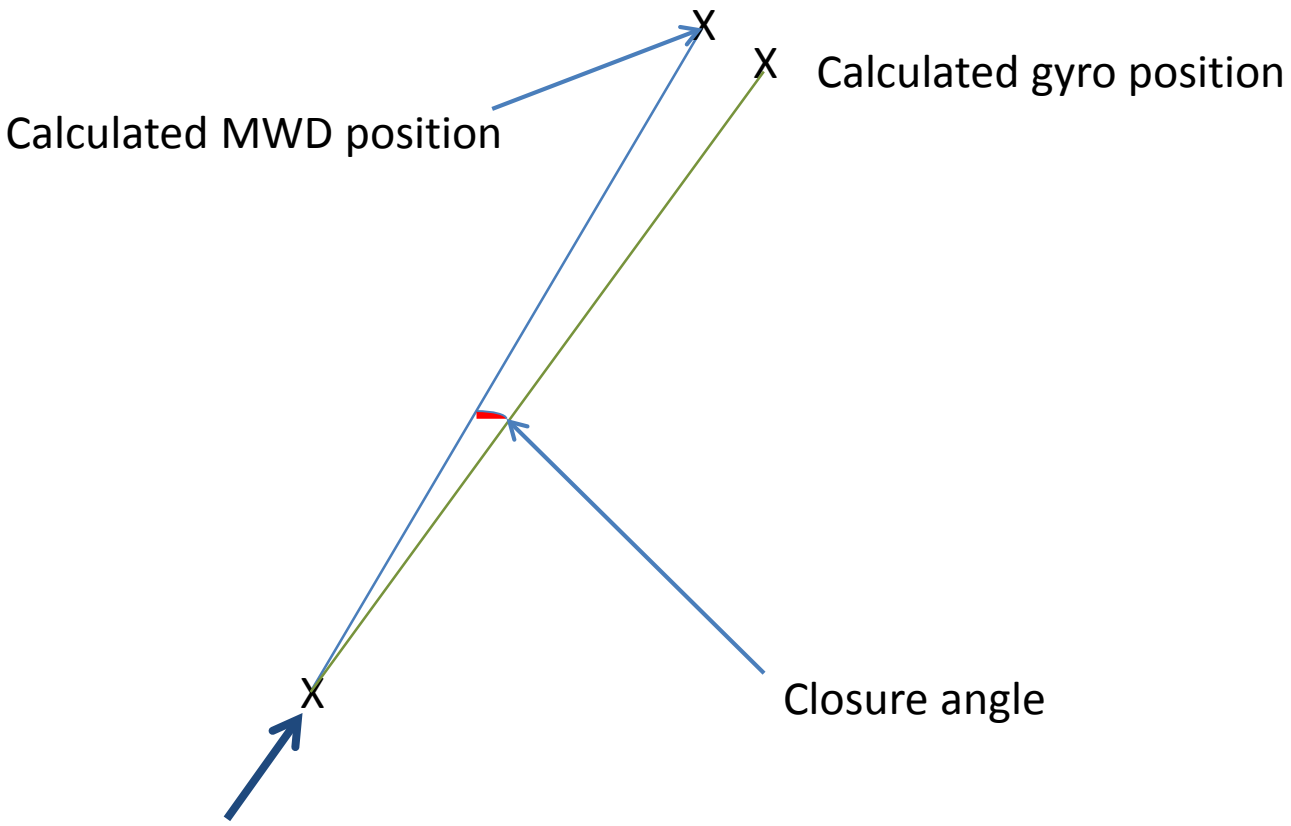

20
10
2820.00 MD
10
20


20
10
3080.00 MD
10
20

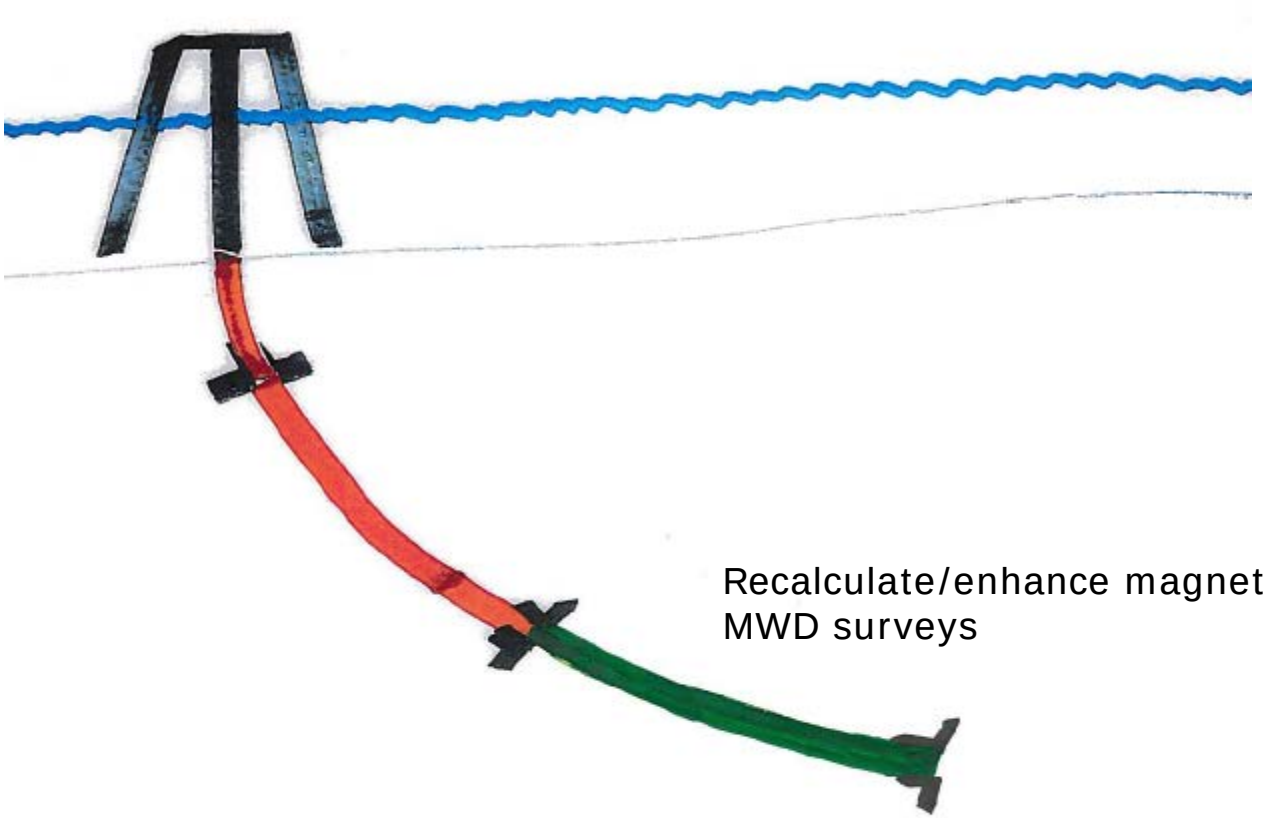
Level of Agreement	Description of Agreement Level	Pictorial Description of Agreement Level	Action
Very Good	MWD ellipse fully encompasses gyro ellipse and gyro ellipse encompasses centre of MWD ellipse.		No further investigation needed
Good	MWD ellipse fully encompasses gyro ellipse but gyro ellipse does not encompass centre of MWD ellipse.		No further investigation needed
Average	MWD ellipse does not fully encompass gyro ellipse but overlaps with it. The centre of the gyro ellipse lies inside the MWD ellipse.		No further investigation needed
Poor	MWD ellipse does not fully encompass gyro ellipse but overlaps with it. The centre of the gyro ellipse lies outside the MWD ellipse.		Investigate – if unresolved consider re-survey
Unacceptable	Ellipses do not overlap.		Probably re-survey immediately and investigate



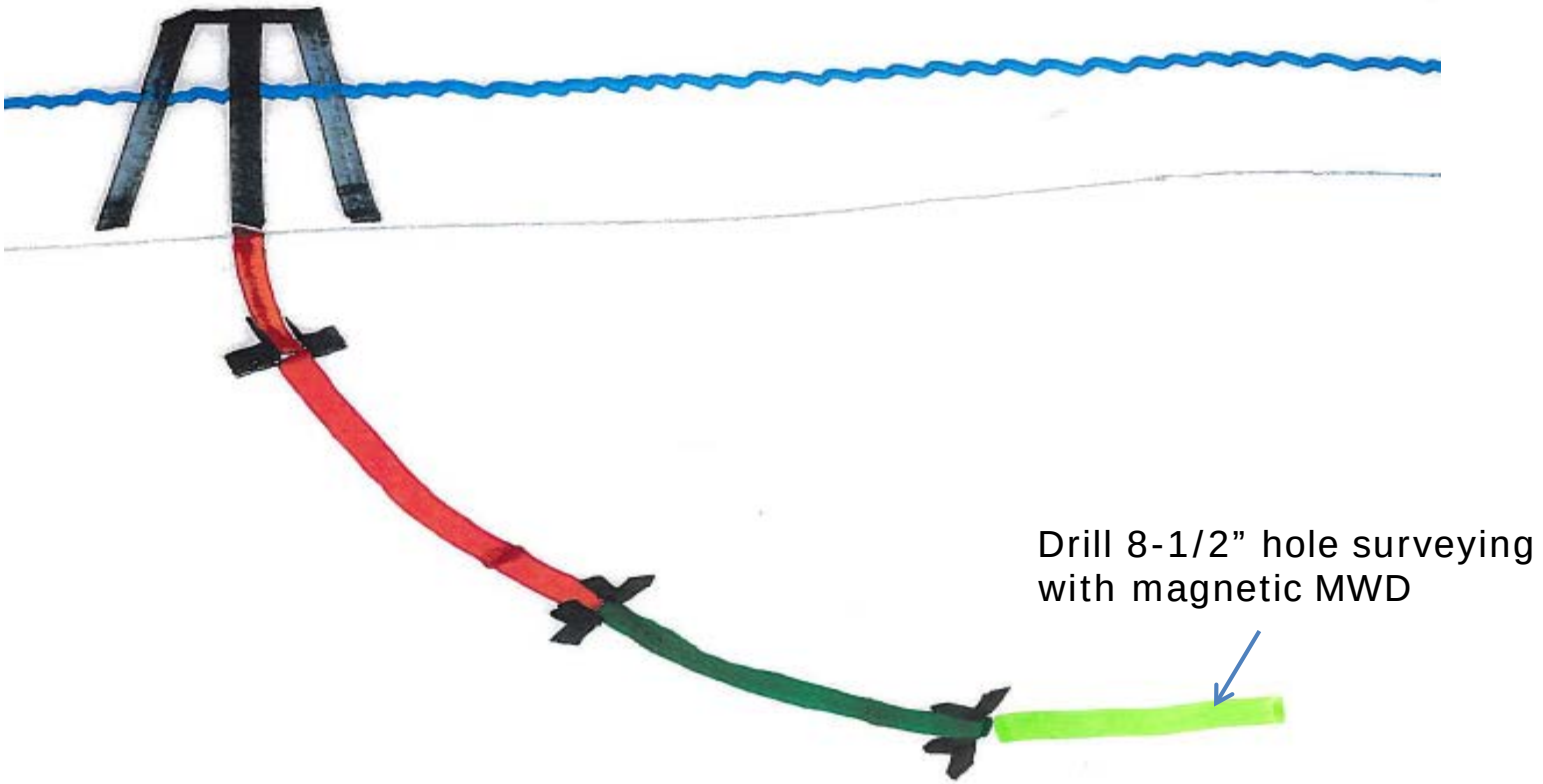
+/- 1,000 feet of comparison between magnetically clean MWD surveys and subsequent continuous gyro survey using centroller centralisation In 13-3/8" casing

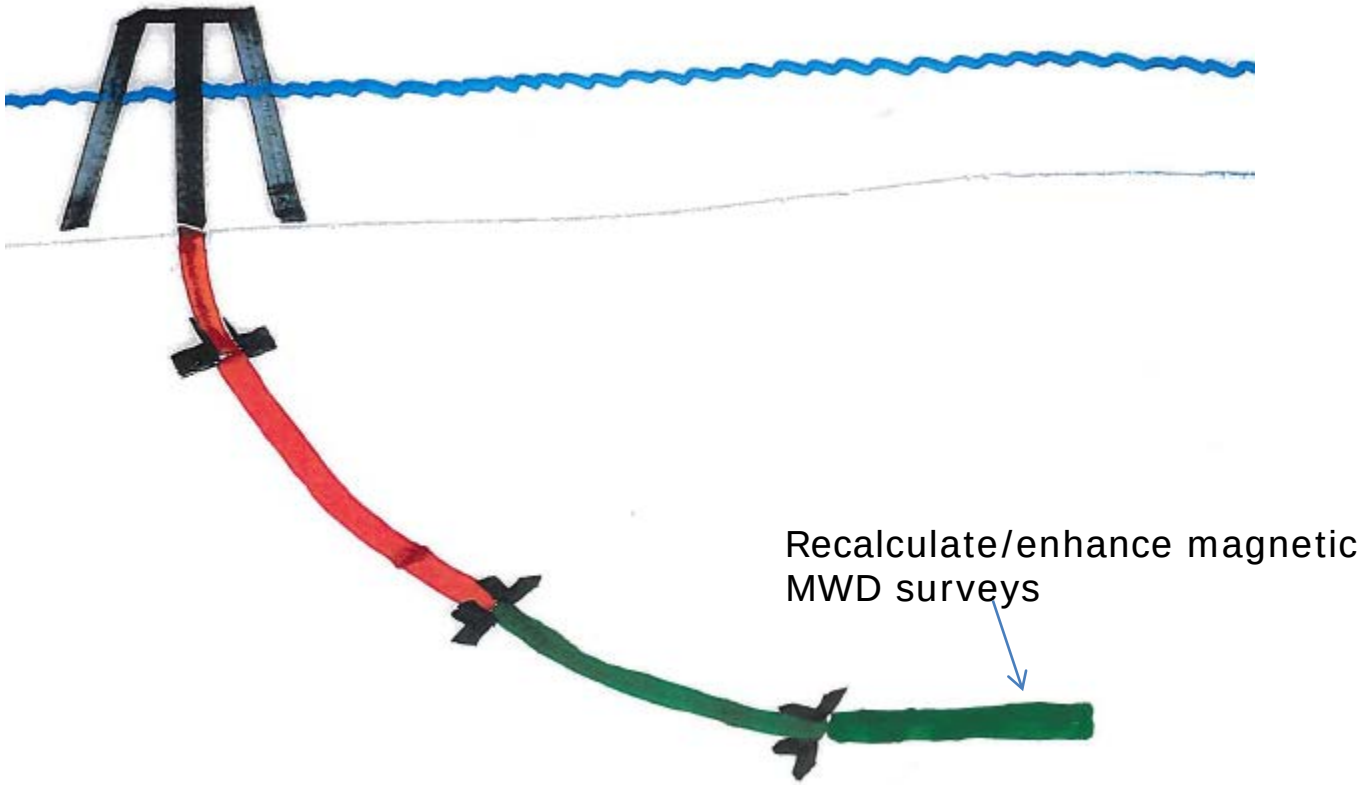


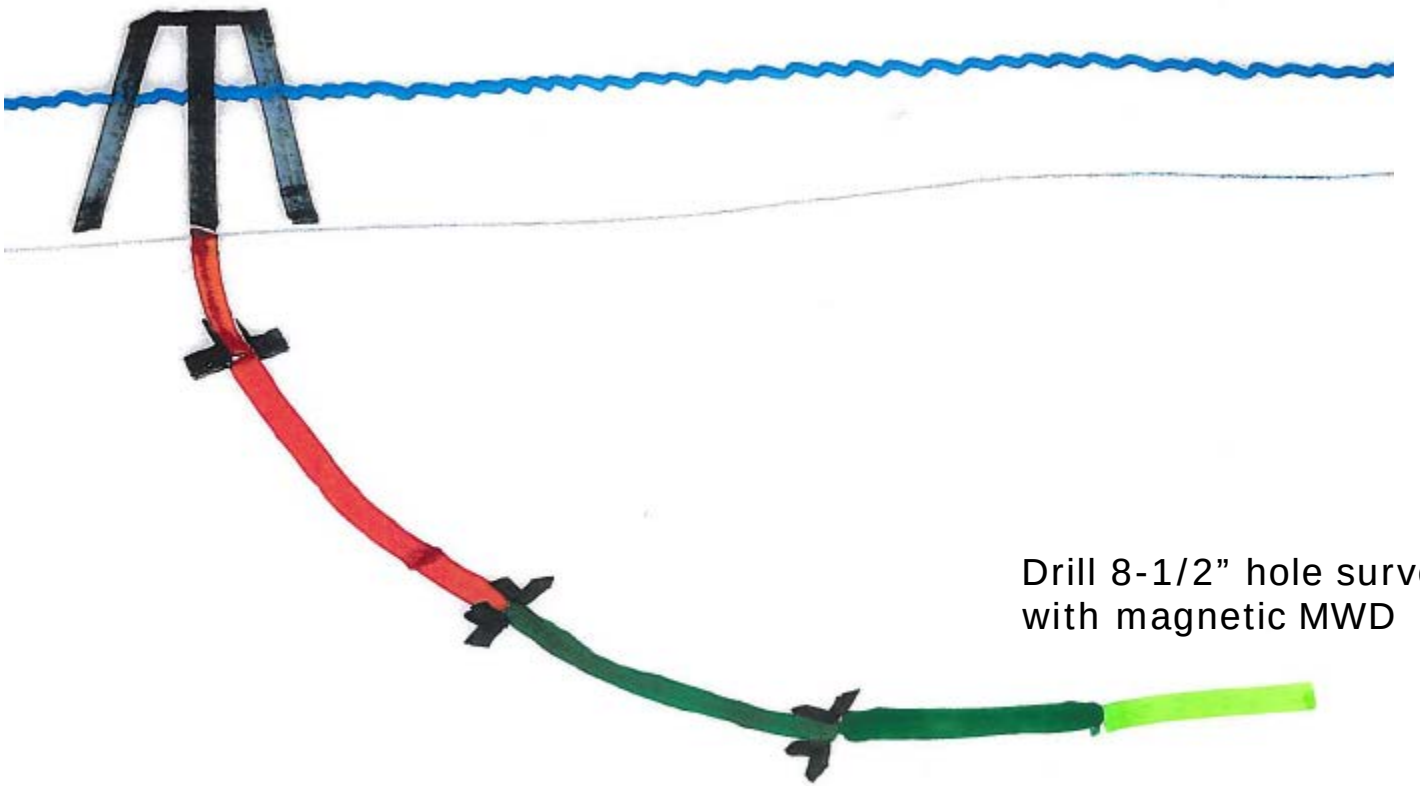
Common tie-in just before first clean MWD survey



Recalculate/enhance magnetic
MWD surveys


Drill 8-1/2” hole surveying
with magnetic MWD


Recalculate/enhance magnetic
MWD surveys



Drill 8-1/2” hole surveying
with magnetic MWD

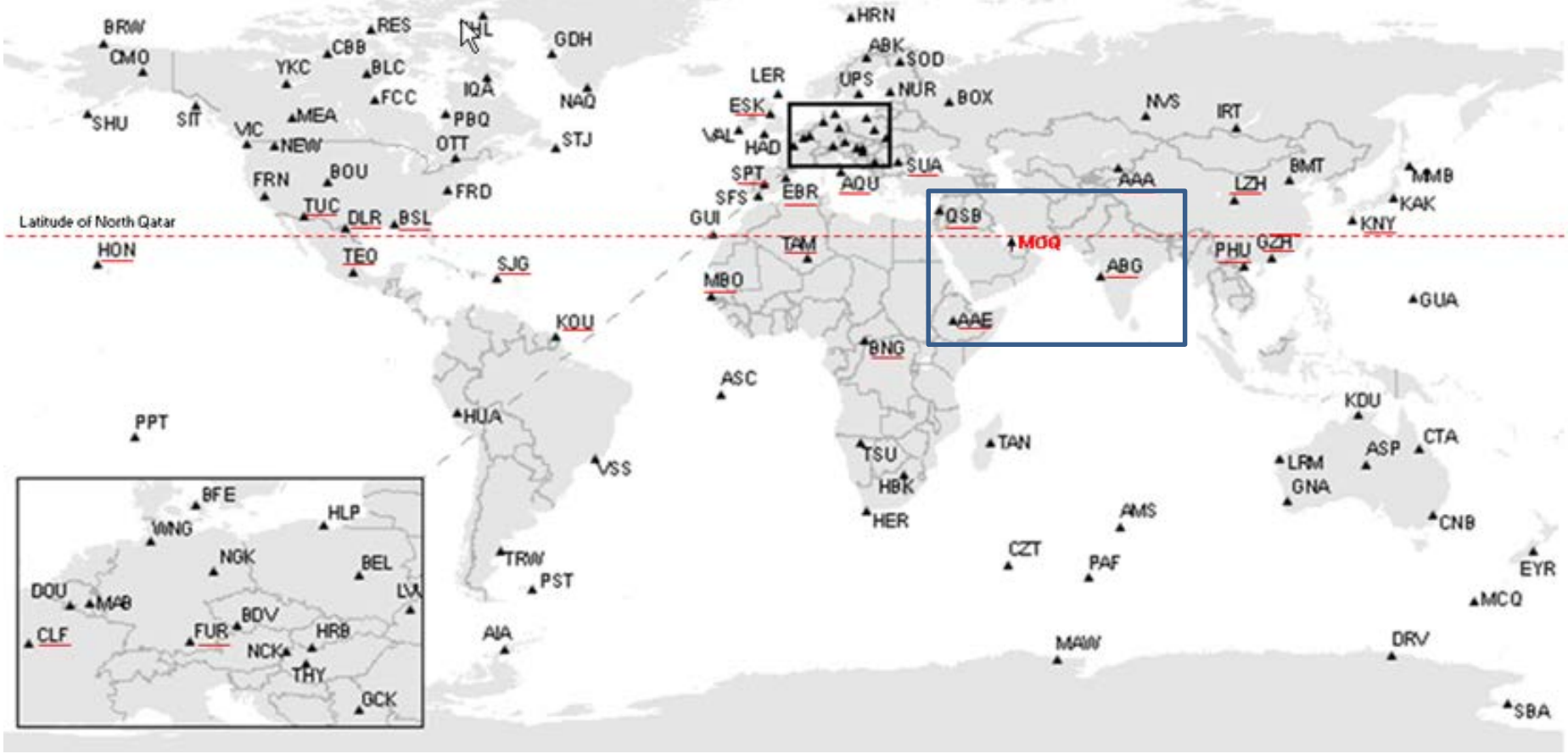
Survey Programme of Final Definitive Survey

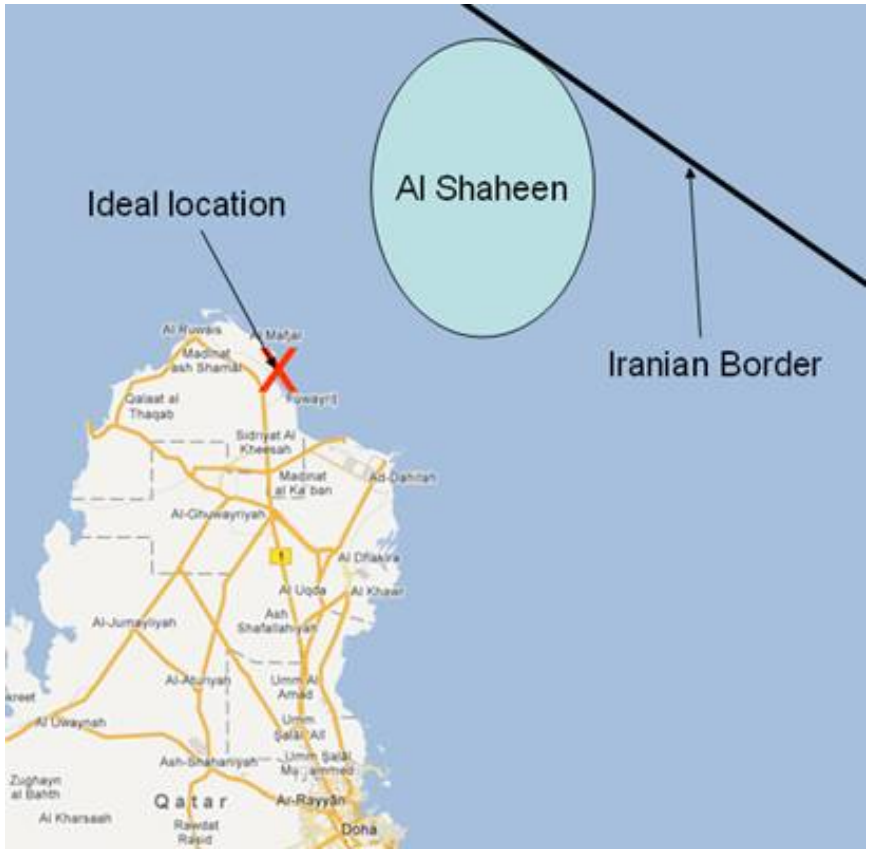
From (feet)	To (feet)	Survey Method	Error Model
0	300	Assumed vertical to bottom guide	Zero Error
300	600	Centroller survey of 20" conductor	SDC_CENT_20
600	3000	Centroller survey of 13-3/8" casing	SDC_CENT_13
3000	5000	Enhanced MWD in 12-1/4" hole	EnhancedMWD_12
5000	25000	Enhanced MWD in 8-1/2" hole	EnhancedMWD_8
25000	25080	Projection to TD	TD Projection

Survey Programme of Final Definitive Survey

From (feet)	To (feet)	Survey Method	Error Model	Validation Method
0	300	Assumed vertical to bottom guide	Zero Error	-
300	600	Centroller survey of 20" conductor	SDC_CENT_20	Acceptable agreement with other surveys in same interval
600	3000	Centroller survey of 13-3/8" casing	SDC_CENT_13	Acceptable agreement with other surveys in same interval
3000	5000	Enhanced MWD in 12-1/4" hole	EnhancedMWD_12	Recalculation/Correction/Validation by independent third party
5000	25000	Enhanced MWD in 8-1/2" hole	EnhancedMWD_8	Recalculation/Correction/Validation by independent third party
25000	25080	Projection to TD	TD Projection	-

Magnetic Measuring Stations

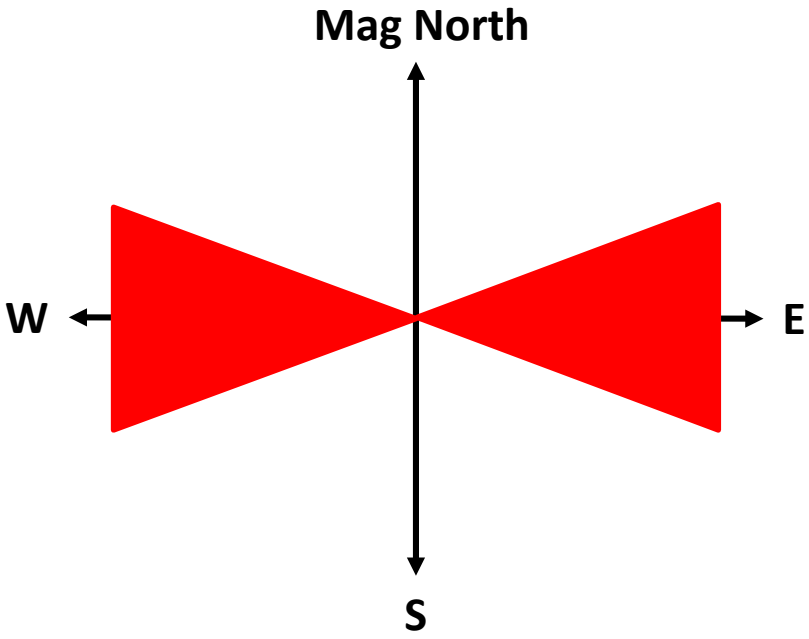



Ideal location
Al Shaheen
Iranian Border
Madinat ash Shamal
Qalaat al Thaqab
Madinat al Ka`ban
Al-Ghuwayriyah
Al Uqda
Al Khawr
Ash Shafallahiyah
Al-Jumayliyah
Al-Aruyah
Umm Al Amad
Al Uwaynah
Ash-Shahaniyah
Qatar
Ar-Rayyan
Doha
Al Kharsaah
Rawdat Rashid

MOQ Rules for the Application of an MSA Correction

At the Planning Stage

- **Never expect a successful MSA correction if the predominant direction of the planned horizontal hole is within +/- 30° of East/West**



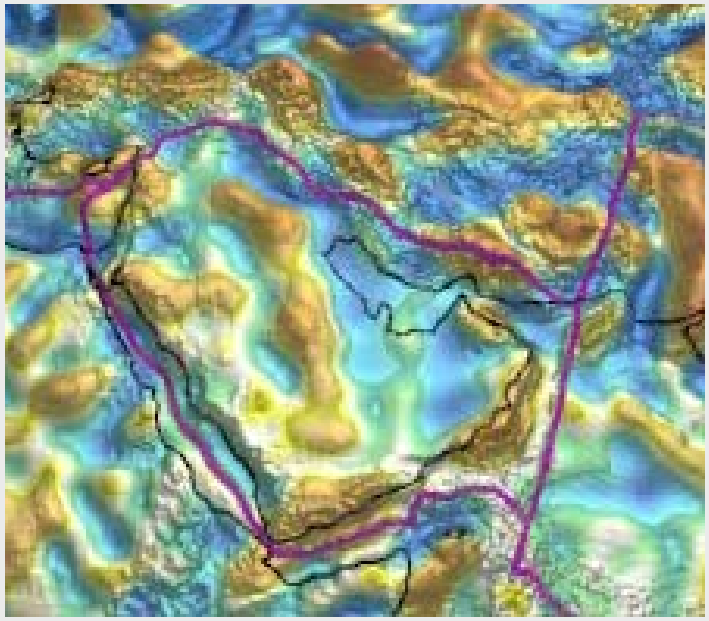
Once the BHA-run is complete and the raw data have been inspected

- Survey management company uses rules based on SPE/IADC 125677 Nyrnes, Torkildsen & Wilson

"Minimum Requirements for Multi-Station Analysis of MWD Magnetic Directional Surveys"

Part 2:
MWD Survey Analysis for Al Shaheen Field

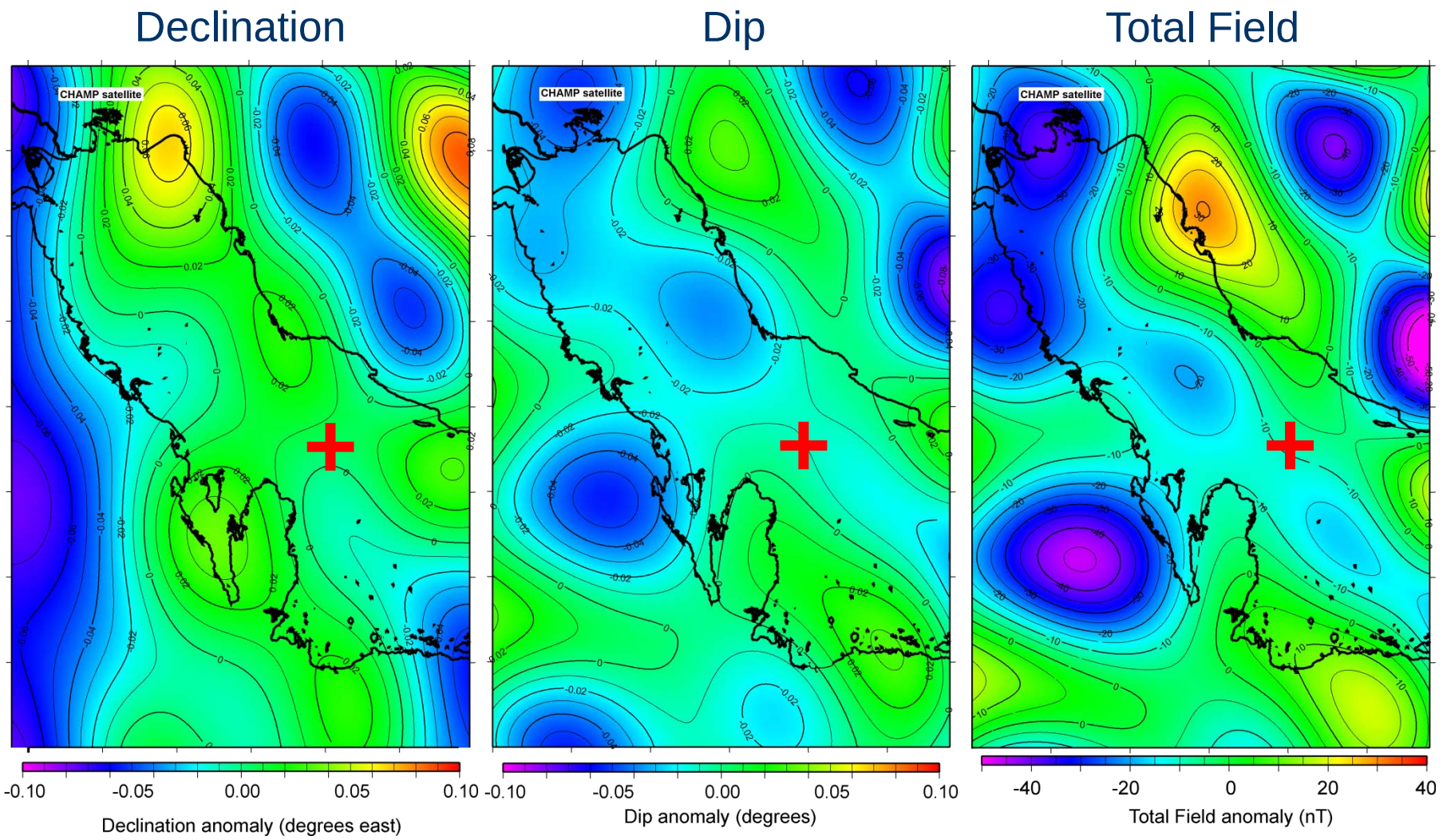
- Declination inferred from 16” well sections
- Total Field and Dip from 12.25” & 8.5” well sections



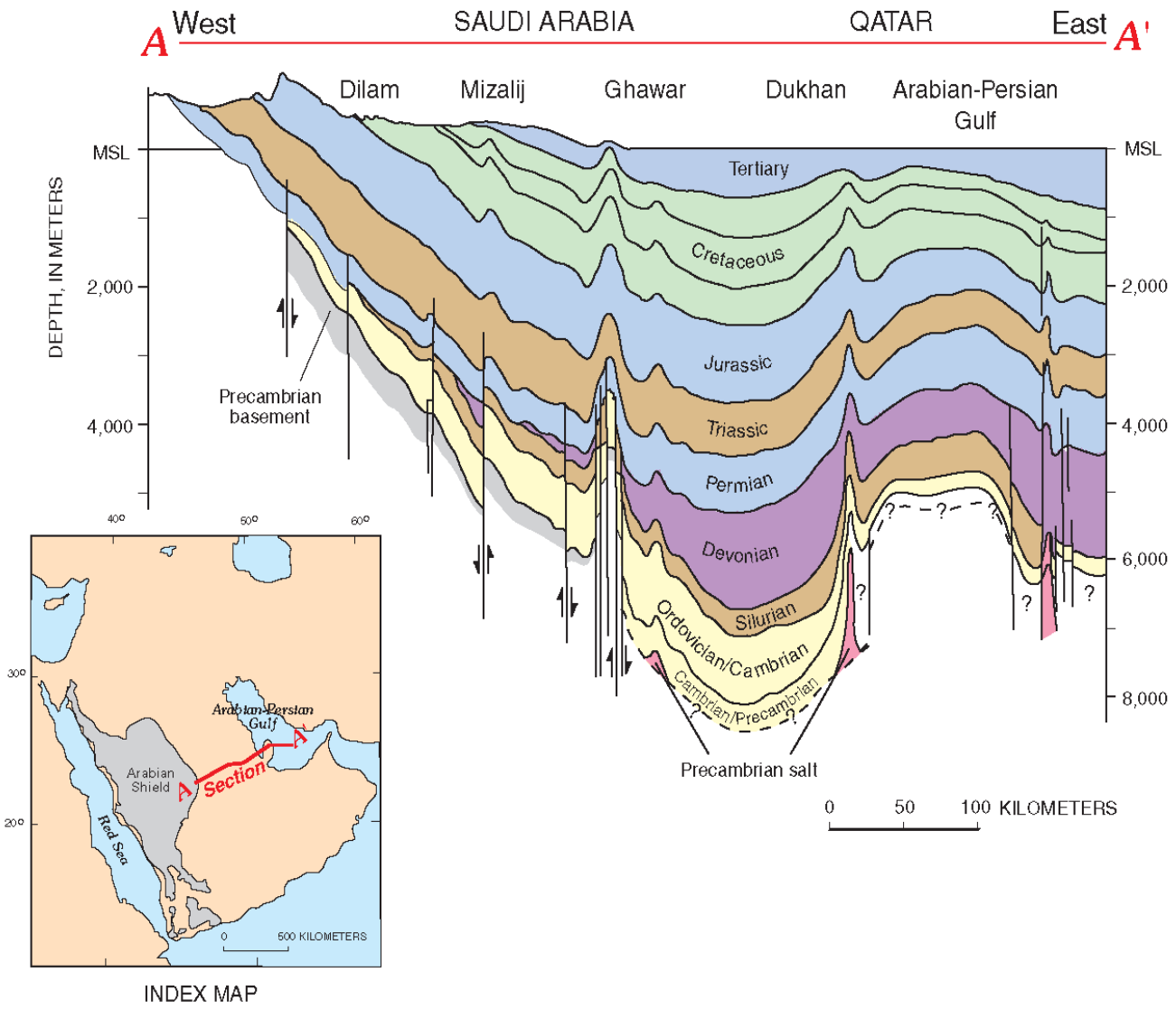
Simon McCulloch and Stefan Maus

37th Meeting of the ISCWSA, Paris, 8-Mar-2013

CHAMP satellite magnetic anomaly maps



Thickness of non-magnetic sediments



Summary of data used from 30 wells

Hole section / data type	BHA runs	MWD surveys
16” inch MWD surveys	28	182
16” Cazandra Multi-Station corrected MWD surveys	21	131
13⅜” Centroller Gyro runs	Interpolated well positions, every 25 ft	
12¼” MWD surveys	32	540
8½” MWD surveys	65	5408

Well azimuth from MWD readings

Coordinate system with z-axis pointed in the well bore direction (Sperry) :

$$G_{total} = \sqrt{G_x^2 + G_y^2 + G_z^2}$$

$$B_{total} = \sqrt{B_x^2 + B_y^2 + B_z^2}$$

$$B_{dip} = \text{asin}\left(\frac{G_x B_x + G_y B_y + G_z B_z}{G_{total} B_{total}}\right)$$

$$magnetic\ azimuth = \text{atan}\left(\frac{G_{total}\left(G_x B_y - G_y B_x\right)}{B_z\left(G_x^2 + G_y^2\right) - G_z\left(G_x B_x + G_y B_y\right)}\right)$$

Coordinate system with x-axis pointed in well bore direction (Schlumberger):

$$G_x \to G_z;\ G_y \to G_x;\ \ G_z \to G_y;\ B_x \to B_z;\ B_y \to B_x;\ \ B_z \to B_y;$$

MWD well azimuth **=** *magnetic azimuth* + *declination – grid convergence*

Gyro-derived well inclination and azimuth

- Input: final gyro-derived well paths
- Interpolated well path given at 25 ft intervals
- Cubic B-splines fit to well positions → continuous well path
- Take measured depth (MD) of MWD survey
- Compute inclination and azimuth by differencing the well path:

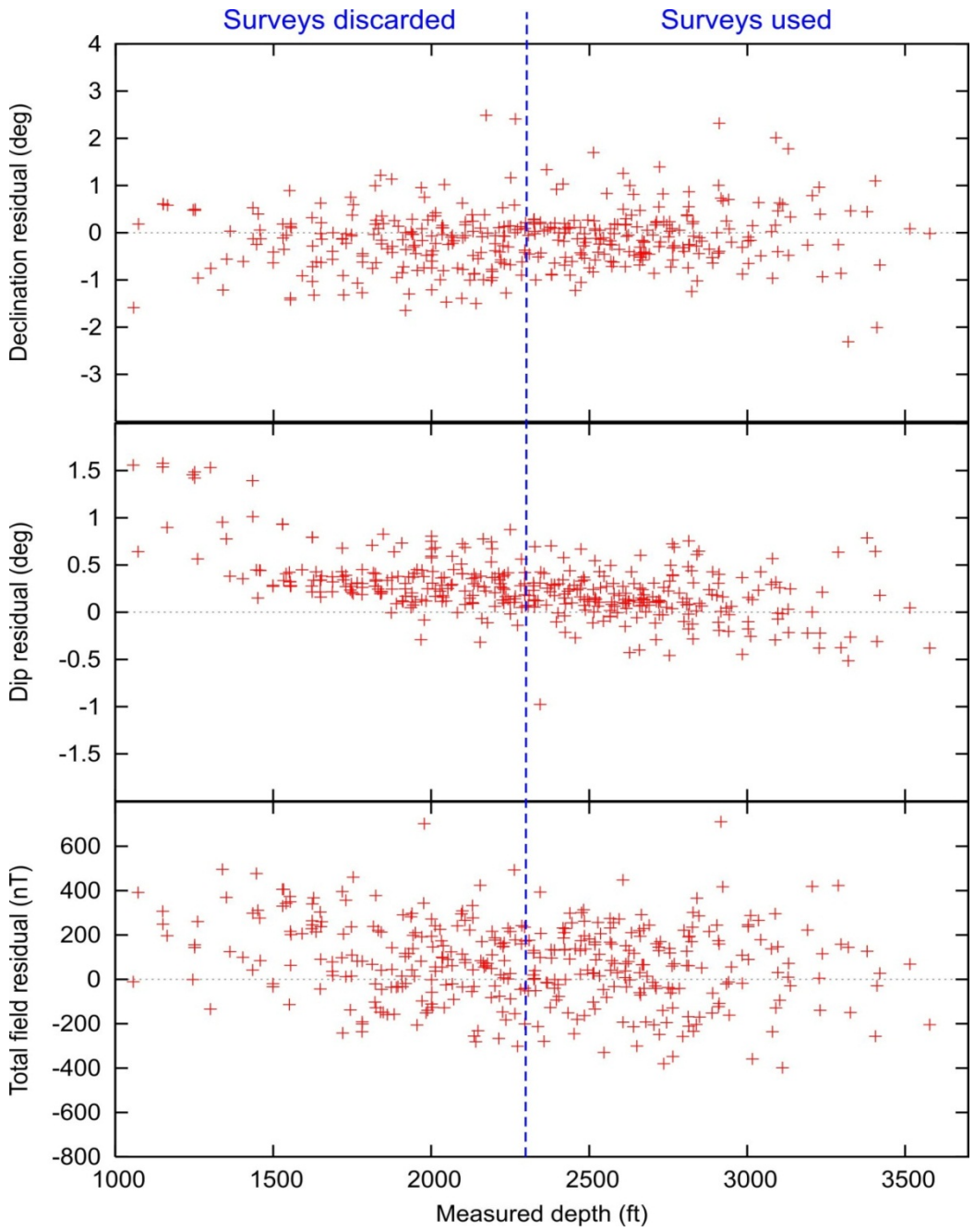
$$Gyro\ well\ inclination = \mathrm{acos}\left(\frac{\partial TVD(MD)}{\partial MD}\right)$$

$$Gyro\ well\ azimuth = \mathrm{atan}\left(\frac{\partial EW(MD)/\partial MD}{\partial NS(MD)/\partial MD}\right)$$

Finally:

Declination residual **=** *Gyro well azimuth* **–** *MWD well azimuth*

16” section: Residuals plotted against measured depth



Residual =

Gyro azimuth

– MWD azimuth

Declination anomaly at Al Shaheen

Residual against BGS Global Geomagnetic Model (BGGM) at well head

Method	Surveys	BHA runs	Declination anomaly
1) Raw MWD surveys	182	28	-0.05° ± 0.11°
2) Multi-station corrected azimuth	131	21	-0.05° ± 0.11°
3) MWD well path	183	28	-0.01° ± 0.10°

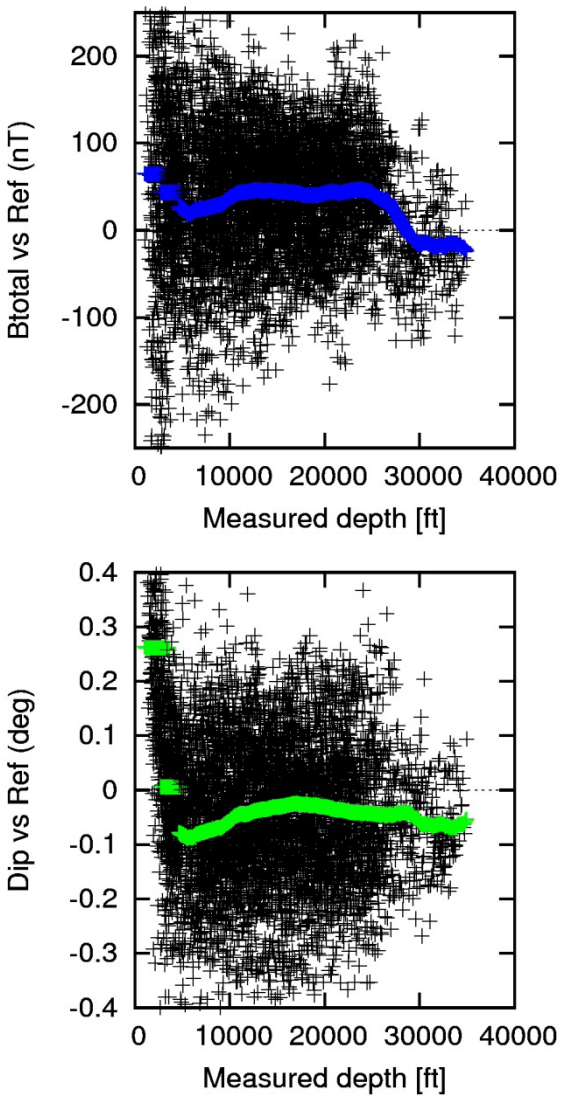
Residual against High Definition Geomagnetic Model (HDGM) at well head

Method	Surveys	BHA runs	Declination anomaly
1) Raw MWD surveys	182	28	-0.03° ± 0.11°
2) Multi-station corrected azimuth	131	21	-0.03° ± 0.11°
3) MWD well path	183	28	+0.01° ± 0.10°

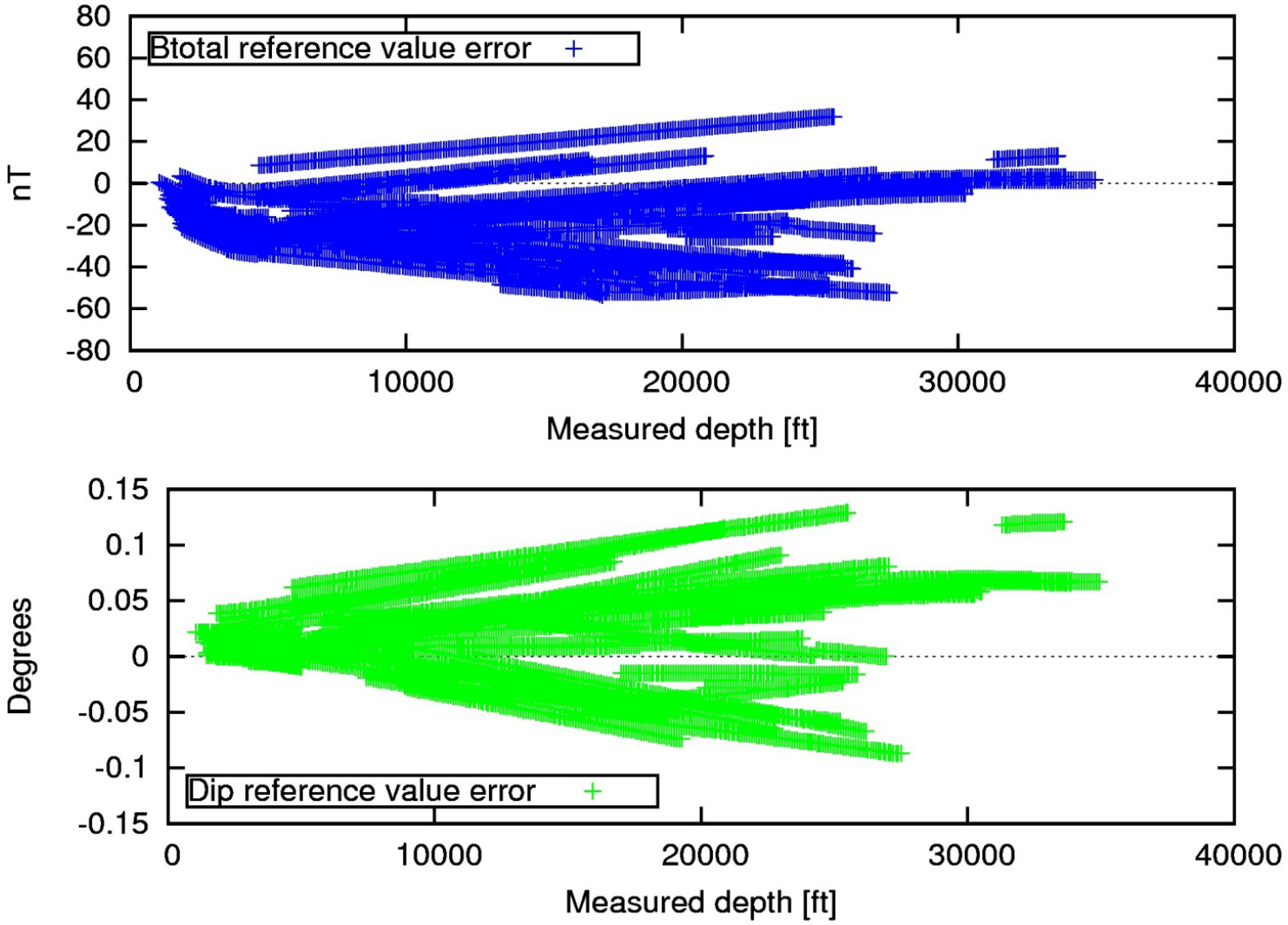
16”,12¼” & 8½”:

Total field and dip residuals plotted against measured depth

Using reference values at well head



Difference between geomagnetic reference field at well head and at survey location



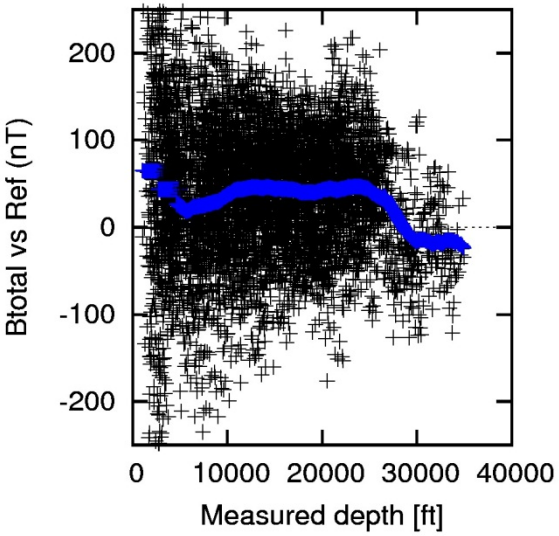
16”,12¼” & 8½”:

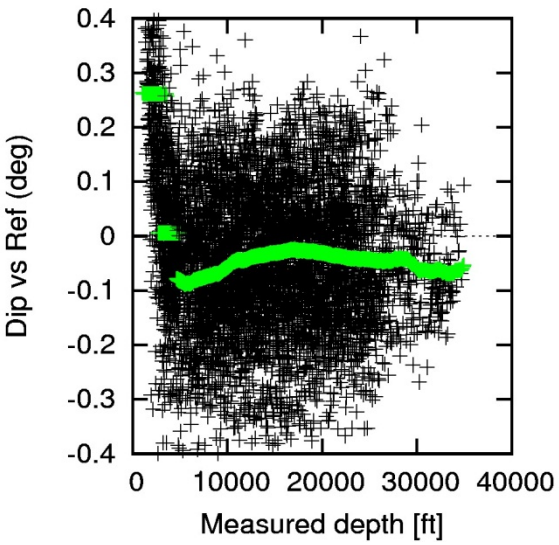
Total field and dip residuals plotted against measured depth

Mean residuals are close to zero

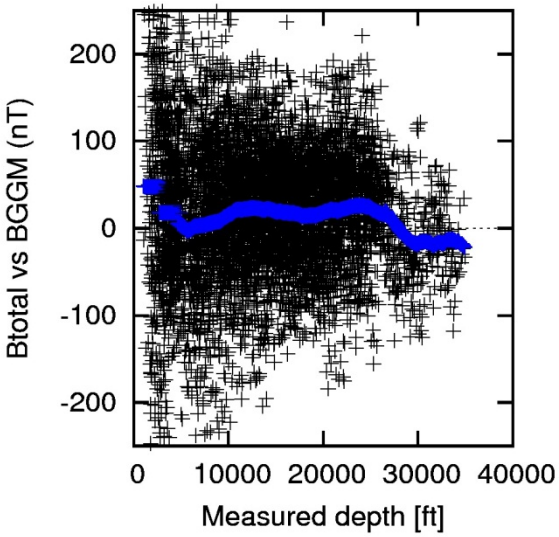
- **No crustal magnetic anomaly at Al Shaheen**

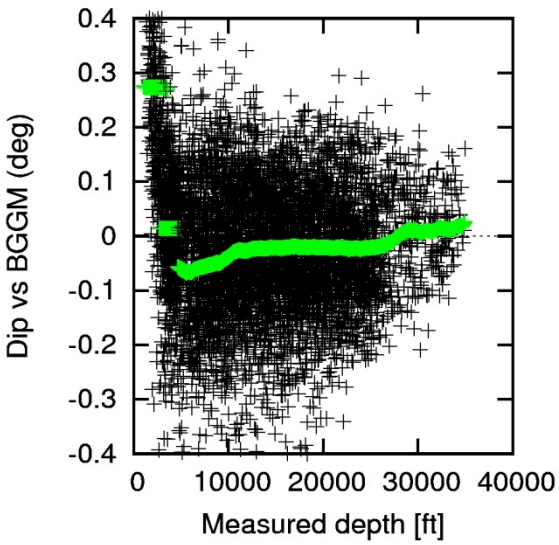
Using reference values at well head





Using reference values at survey





Resulting geomagnetic reference uncertainty (1σ)

Error source	Declination		Dip		Total field	
	bias	random	bias	random	bias	random
Main field	-	0.02°	-	0.03°	-	24 nT
Crustal field (this study)	-0.01°	0.10°	-0.03°	0.05°	15 nT	10 nT
Disturbance field	-	0.05°	-	0.06°	-	42 nT
Reference field at well head	-	0.02°	-0.02°	0.05°	22 nT	17 nT
Total 1-sigma uncertainty (with bias folded in)	**0.12°**		**0.11°**		**67 nT**	

For comparison:			
ISCWSA-2000 error model	0.39°	0.2°	130 nT

Total uncertainty of actual MWD surveys (not just the geomagnetic reference)

Standard deviation of the tool readings against the reference value.

Well section	MWD azimuth	Multi-station corrected azimuth	MWD Dip	MWD Total field
16 inch (below 2300 ft MD)	± 0.56°	± 0.43°	± 0.27°	± 170 nT
12¼ inch	Unknown	Unknown	± 0.14°	± 92 nT
8½ inch	Unknown	Unknown	± 0.13°	± 82 nT

Total uncertainties in the 12¼" and 8½" sections are about 50% lower than in 16" sections

→ azimuth uncertainty is about 0.3° for raw and 0.2° for multi-station-corrected azimuths?

Results

- No crustal magnetic anomaly at Al Shaheen
  - Supported by satellite data and MWD surveys
- Total uncertainty (1-sigma) of geomagnetic reference:

Declination	Dip	Total field
0.12°	0.11°	67 nT

Lessons Learned

- Continuous gyro surveys run on wireline through casing with centroller centralisation from surface to +/-60° inclination represent the best current means of surveying our wells to the depth of the 13-3/8” casing shoe.

- With enough good quality gyro and magnetic survey data, the uncertainty of the local magnetic field can be reduced.

- Independently check all reference data.

Combined use of MWD and gyro surveying to reduce wellbore positioning uncertainties

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Stefan Maus, Magnetic Variation Services LLC