Paper No. 194057

Paper Title: Eliminating Rig Time from MWD Surveying

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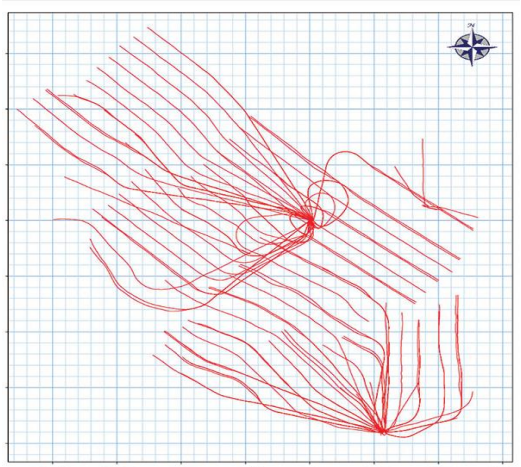
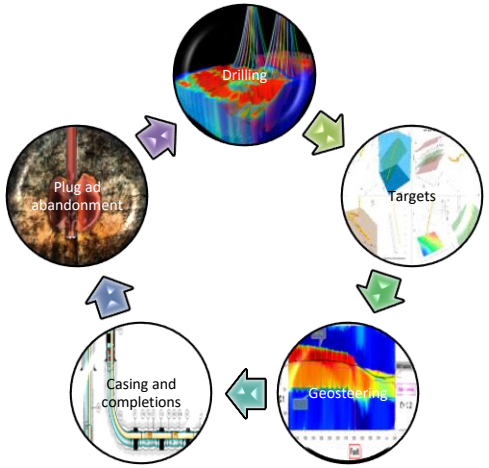
The Surveying Conundrum

- Geographically defines the wellbore
- Drilling safely
- Achieves geological Objectives
- Delivers engineering objectives

- Time consuming
- Increased pump cycles
- Reducing borehole quality
- Stuck pipe exposure





Measurement While Drilling — Current and Future

- MWD measurement
- 6 axis (3 accelerometers and 3 magnetometers)
- Robust reliable and auditable
- Survey taken when stationary
- Time penalty

- Continuous 6-axis surveying
- Definitive survey taken while drilling
- No “survey time”
- Reduced pump cycles
- Improved directional control

1979

2001

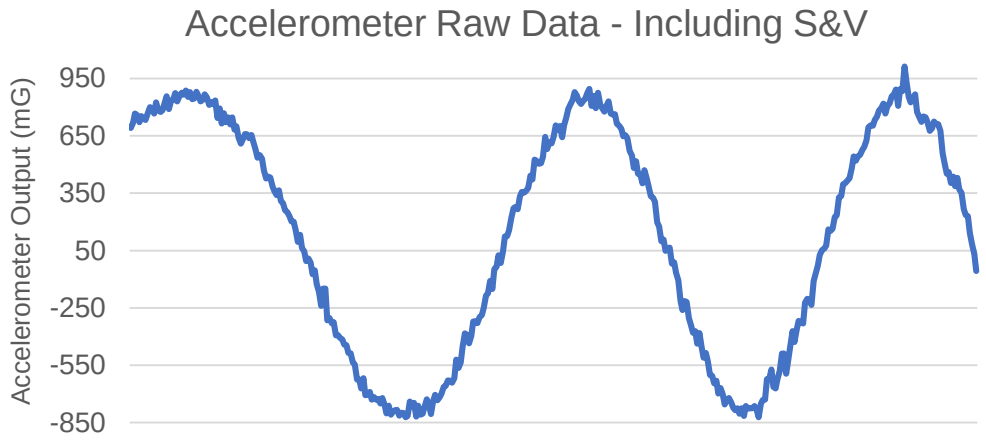
Continuous single-axis surveying
Improved trajectory control
Not definitive without static surveys

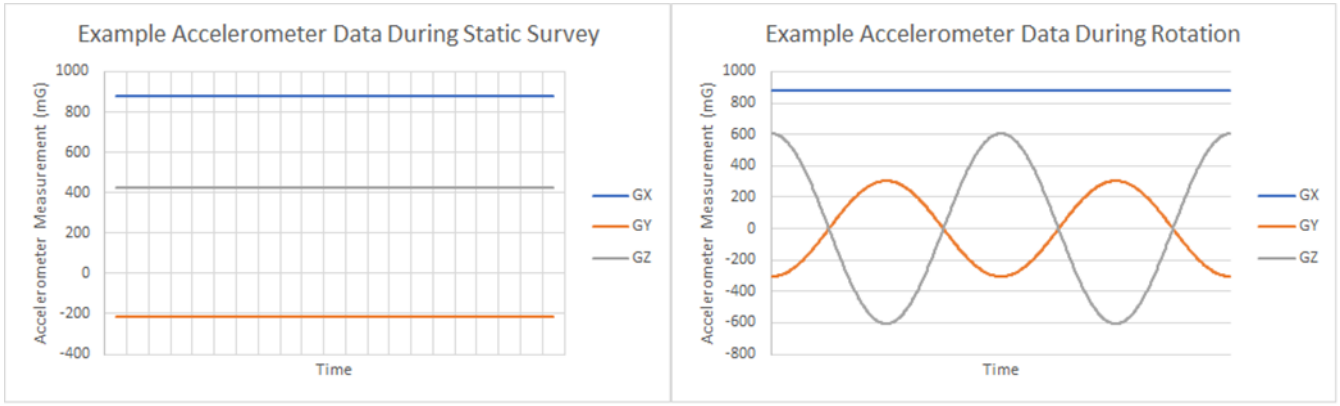
2019

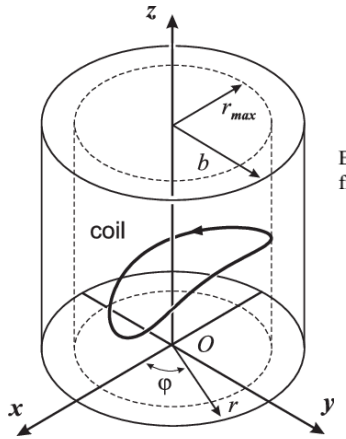
Continuous 6-Axis Surveys — Drilling Mode Surveys (DMS)

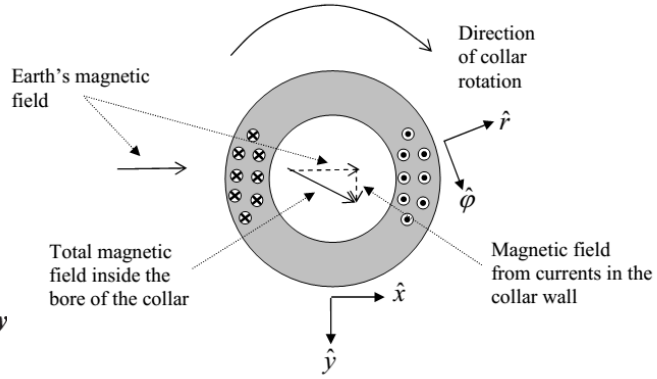
Continuous 6-axis surveying challenges

- Phase compensation
- Shock and vibration
- Eddy currents









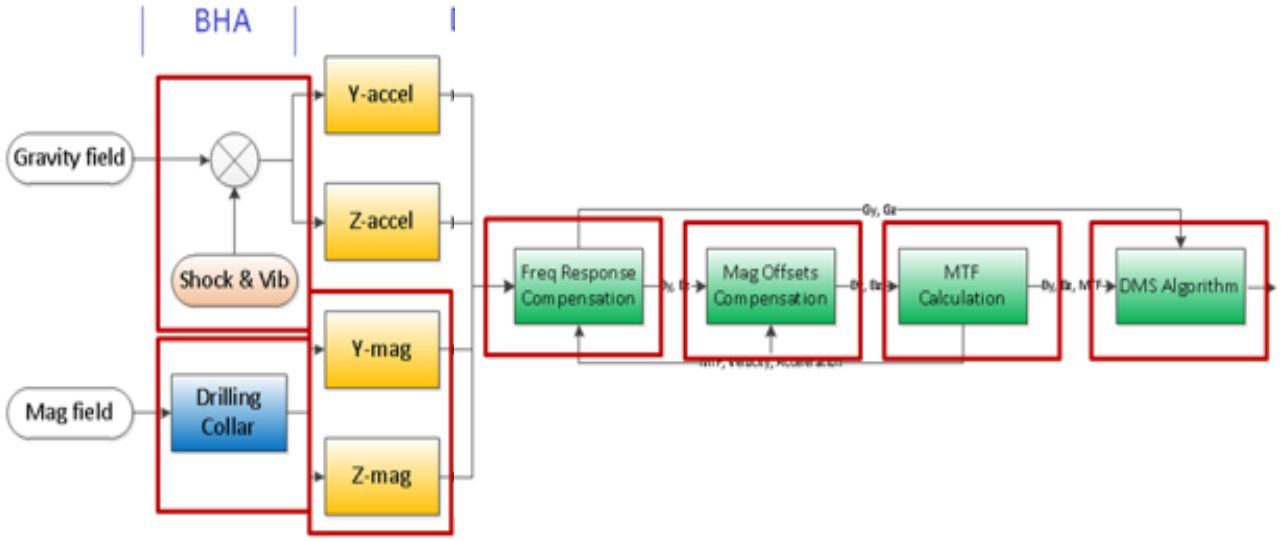
Continuous 6-Axis Surveys — Drilling Mode Survey Design Journey

Firmware

- Single correction for all errors
- Separating
  - Phase shift
  - Shock and vibration
  - Eddy current compensation

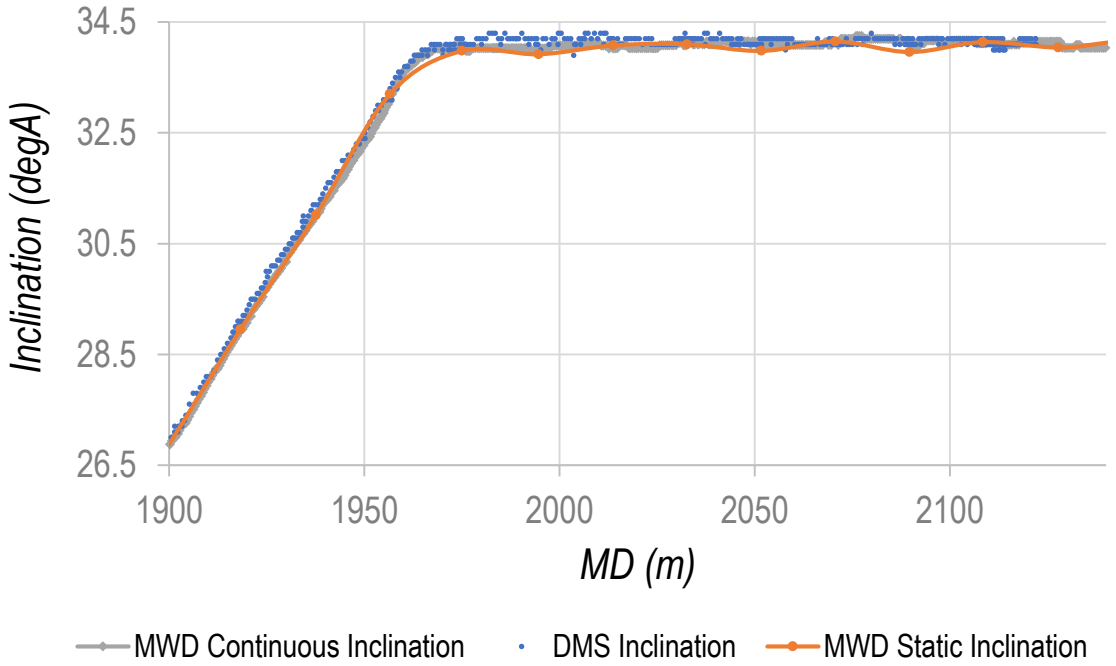
Hardware

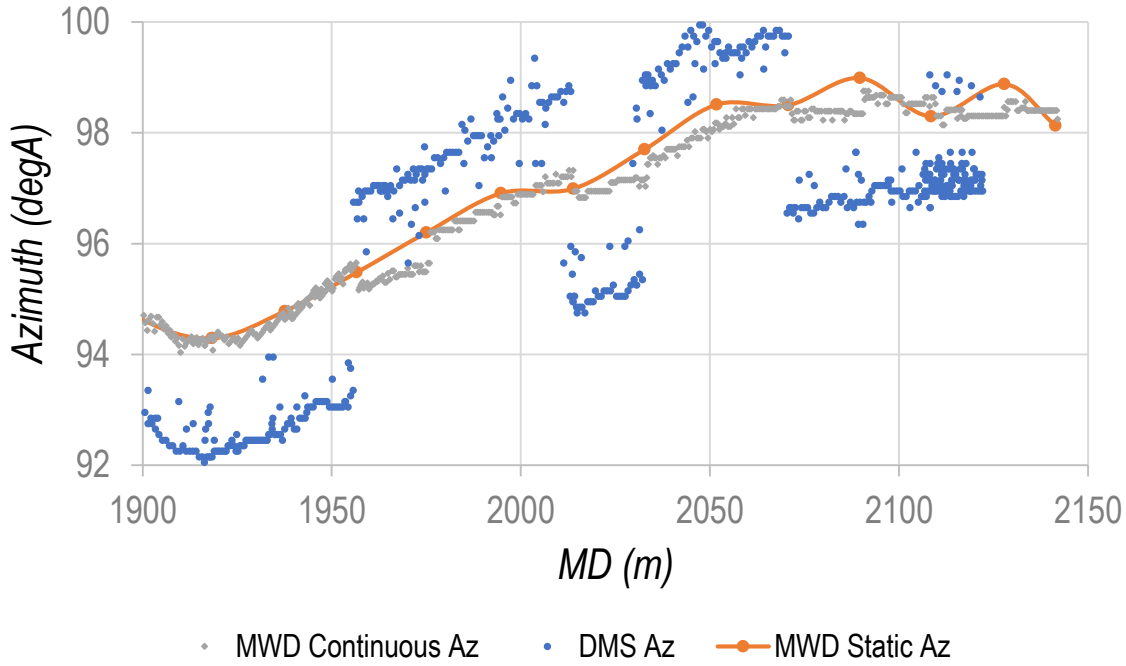
- Improve mag frequency response
- Accelerometers already capable



Continuous 6-Axis Surveys — Field Test Results

Example 1: EXP tool, early testing





Continuous 6-Axis Surveys — Testing the Theory

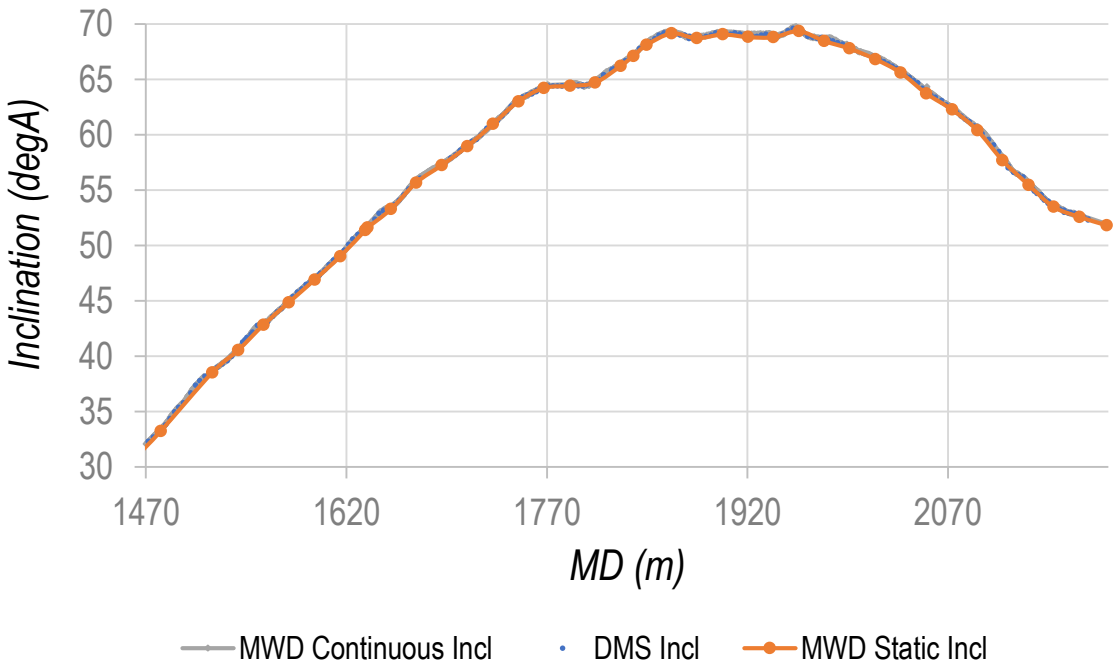
Spin Rig

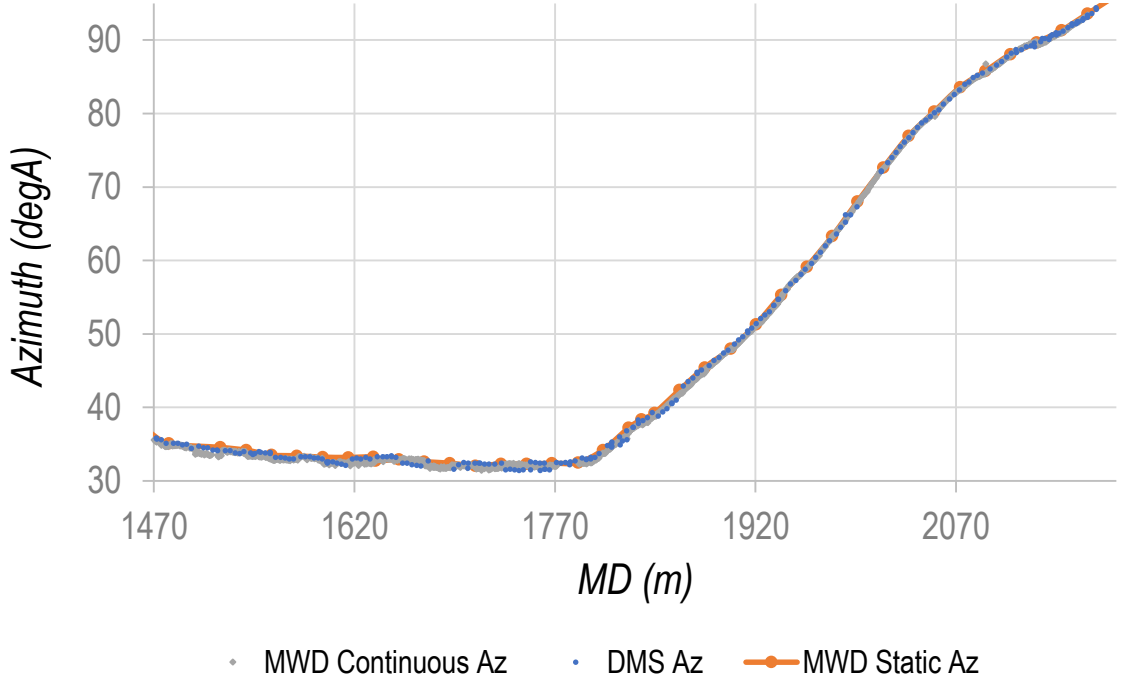
- Eliminate Eddy currents
- Magnetically clean environment
- 0 - 700RPM
- Worst case orientation
  - Attenuation 50 Incl 67 azi
  - Phase shift 67 Incl and 189 Azi

Static Survey					
	Azimuth	Inclination	Magnetic DIP	Total G	Total H
	153	68	66.9	1001.1	48502
Rotating Survey					
RPM	Azimuth	Inclination	Magnetic DIP	Total G	Total H
0	153	68	66.9	1001.1	48609
60	153	68	66.9	1001.1	48600
120	153.1	67.9	66.9	1001.2	48606
180	153.2	67.9	66.9	1001.3	48633
240	153.2	67.9	66.9	1001.3	48657
300	153.4	67.9	66.9	1001.3	48660
360	153.4	67.9	66.9	1001.3	48756

Continuous 6-Axis Surveys — Field Test Results

Example 2: EXP tool, modified firmware + 675 hole





Continuous 6-Axis Surveys — Error Modeling

Base case equivalence to MWD standard model

Term Name	Prop. Mode	Units	Magnitude	Depth Formula	Inclination Formula	Azimuth Formula
DRFR	Random	m	0.35	1	0	0
DSFS	Systematic	–	0.00056	MD	0	0
DSTG	Global	$1/m$	0.00000025	MD $*$ TVD	0	0
ABZ	Systematic	m/s^2	0.004	0	$-\sin(I)/G$	$\tan(\Theta)\sin(I)\sin(A_m)/G$
ASXY-TI1S	Systematic	–	0.0005	0	$\sin(I)\cos(I)/\sqrt{2}$	$-\tan(\Theta)\sin(I)\cos(I)\sin(A_m)/\sqrt{2}$
ASZ	Systematic	–	0.0005	0	$-\sin(I)\cos(I)$	$\tan(\Theta)\sin(I)\cos(I)\sin(A_m)$
AN1	Random	m/s^2	0.0088	0	0	$(1/\tan(I)-\cos(A_m)\tan(\Theta))/G$
AN2	Random	m/s^2	0.0088	0	$-\cos(I)/G$	$\cos(I)\sin(A_m)\tan(\Theta)/G$
ANZ	Random	m/s^2	0.0044	0	$-\sin(I)/G$	$\sin(I)\sin(A_m)\tan(\Theta)/G$
AAXY	Systematic	–	0.0015	0	$\sin(I)\cos(I)$	$-\sin(I)\cos(I)\sin(A_m)\tan(\Theta)$
MBZ	Systematic	nT	70	0	0	$-\sin(I)\sin(A_m)/(B\cos(\Theta))$
MSXY	Systematic	–	0.0016	0	0	$-B_{xy}(\cos(A_m)\sin(\alpha)+\cos(I)\sin(A_m)\cos(\alpha))/(\sqrt{2}B\cos(\Theta))$
MSZ	Systematic	–	0.0016	0	0	$-(\sin(I)\cos(A_m)+\tan(\Theta)\cos(I))\sin(I)\sin(A_m)$
AMXY	Systematic	–	0.0015	0	0	$(1-\cos^2(I))\sin(A_m)\cos(A_m)+\sin(I)\cos(I)\sin(A_m)\tan(\Theta)$
PSD	Systematic	deg	0.08	0	0	$\cos(I)-\sin(I)\cos(A_m)\tan(\Theta)$
DECG	Global	deg	0.36	0	0	1
DECR	Random	deg	0.1	0	0	1
DBHG	Global	deg·nT	5000	0	0	$1/(B\cos(\Theta))$
DBHR	Random	deg·nT	3000	0	0	$1/(B\cos(\Theta))$
AMIL	Systematic	nT	220	0	0	$\sin(I)\sin(A_m)/(B\cos(\Theta))$
SAG	Systematic	deg	0.2	0	$\sin(I)$	0
EDDY	Systematic	deg	0.06	0	0	$\cos(I)-\sin(I)\cos(A_m)\tan(\Theta)$
CA1	Random	m/s^2	0.0025	0	0	$(1/\tan(I)-\cos(A_m)\tan(\Theta))/G$
CA2	Random	m/s^2	0.0025	0	$-\cos(I)/G$	$\cos(I)\sin(A_m)\tan(\Theta)/G$
DSC	Random	deg	0.08	0	1	$1/\sin(I)$
XYM1	Systematic	deg	0.04	0	$\lvert\sin(I)\rvert$	0
XYM2	Systematic	deg	0.04	0	0	-1
XYM3	Systematic	deg	0.04	0	$\lvert\cos(I)\rvert\cos(A_t)$	$-\lvert\cos(I)\rvert\sin(A_t)/\sin(I)$
XYM4	Systematic	deg	0.04	0	$\lvert\cos(I)\rvert\sin(A_t)$	$\lvert\cos(I)\rvert\cos(A_t)/\sin(I)$

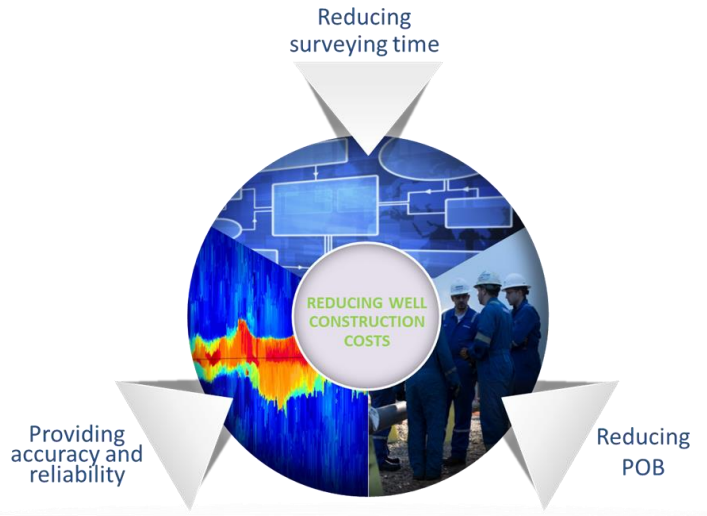
Further work and Conclusions

Further work

- Improve Magnetometer bandwidth
- Eddy current compensation testing
- More field tests

Conclusions

- Zero MWD rig time a big prize
- DMS surveys very promising
- Error model developed
- Possibilities to improve on static surveys



Acknowledgements / Thank You / Questions