Comparative Analysis of Five Different Magnetic Ranging Methods Used for Wellbore Intersections

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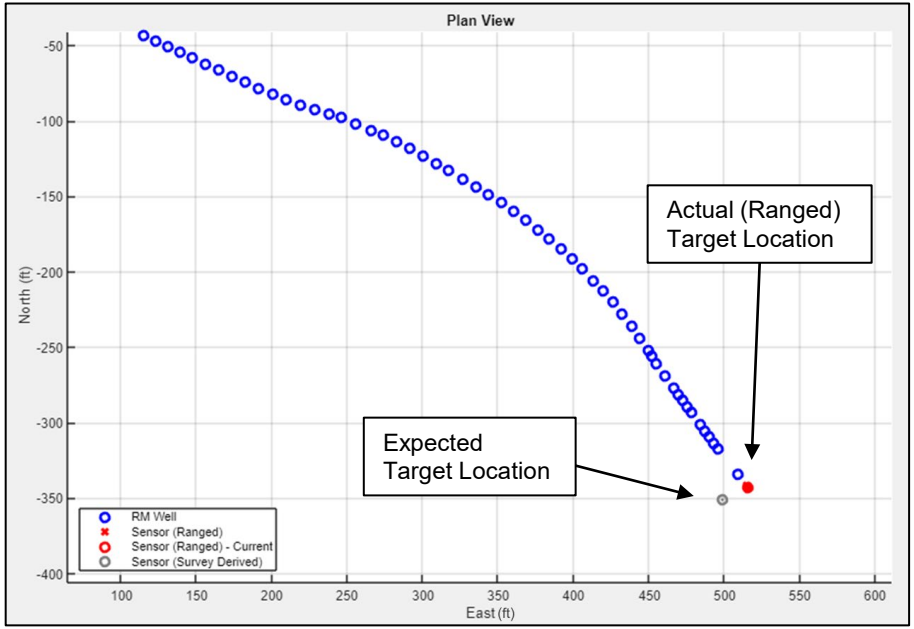
What is Ranging?

- Addresses conventional wellbore surveying uncertainty
- Identifies location of an offset wellbore relative to a reference wellbore
- Used to avoid unintentional collisions or purposefully twin and intersect wellbores




CAUTION
DON'T TRY
THIS AT HOME

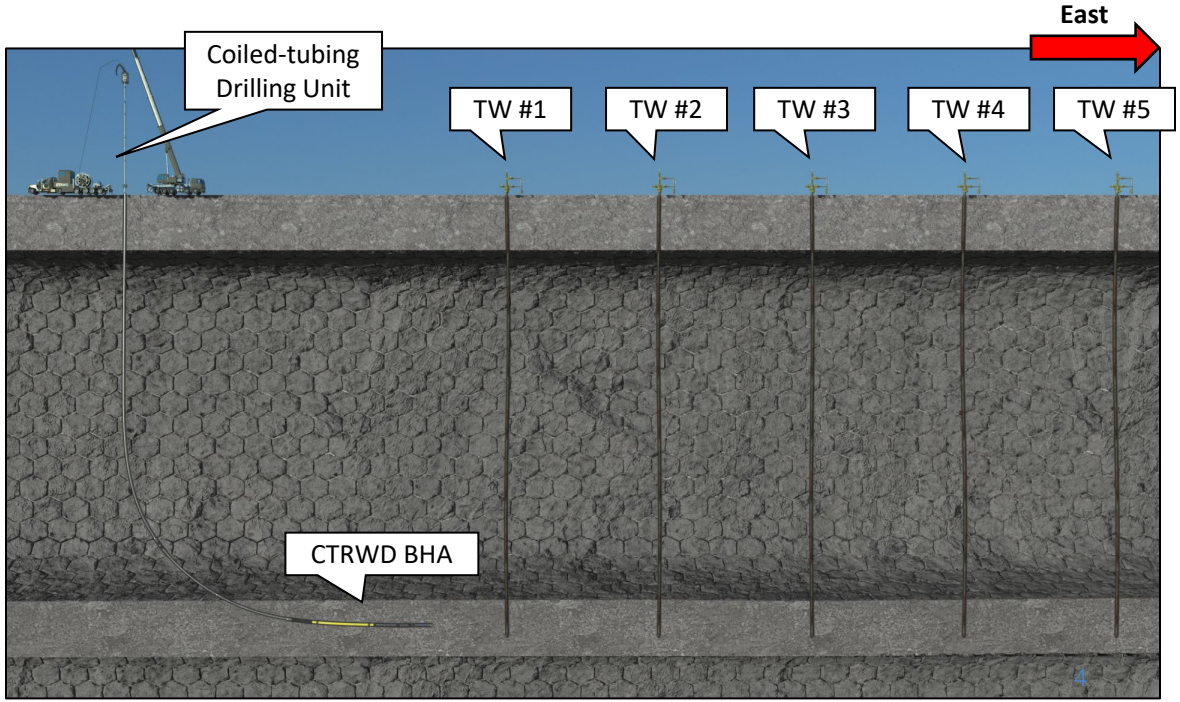
Case History – Coiled-Tubing Ranging While Drilling

Objectives:

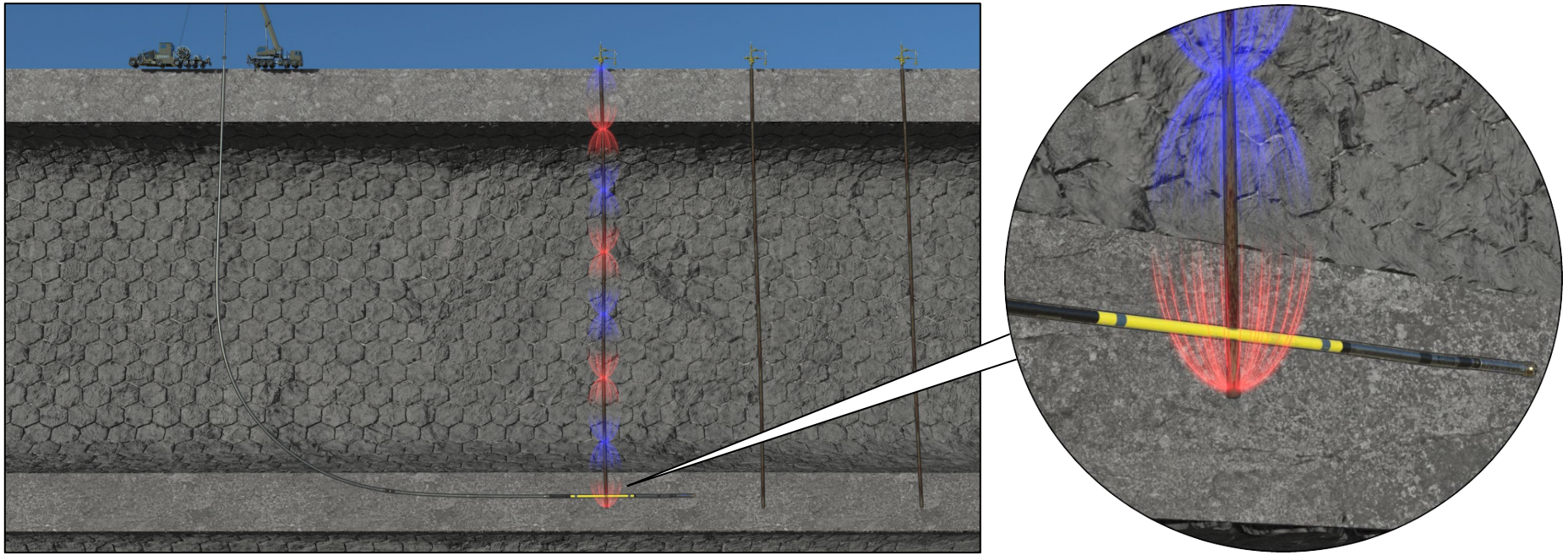
- Hydraulically connect five vertical cased wellbores with one horizontal
  - Drill close but not physically touch to avoid damaging the perforated target casing
- Unlock magnetic ranging superpowers and double-check, triple-check, and check again with all the tools in your ranging toolbox!
  - Passive ranging, surface DC & AC injection, novel CTRWD with downhole AC injection, rotating magnet

Challenges:

- Drilling horizontal east

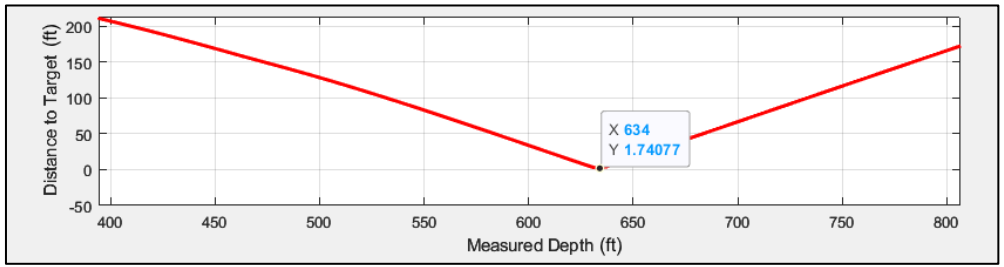


Well #1 – Passive Magnetic Ranging

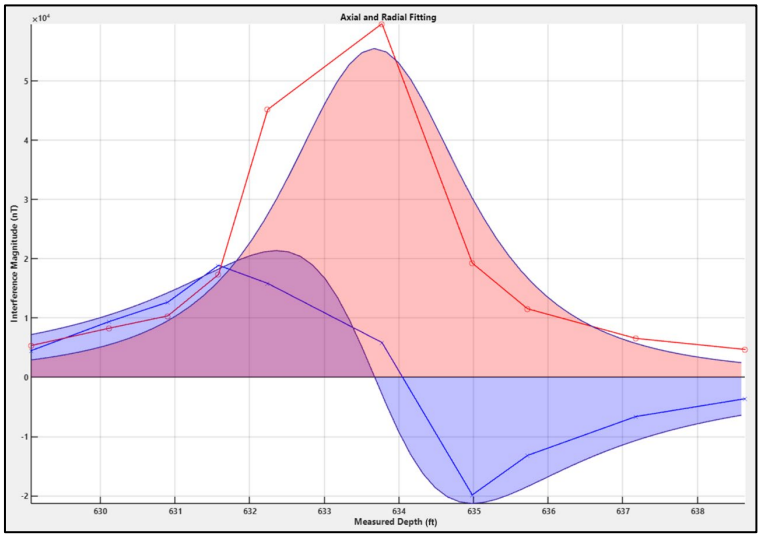


Well #1 – Passive Magnetic Ranging

- Strong passive signal ~60 000 nT
- Dominated by a nearby offset casing “monopole”
  - Simple theoretical monopole fit is used
- Passby at 633.67 ft. MD
- Minimum distance scan to target well after applying PMR results:
  - 1.74±0.4 ft.
  - 15.7±10.8 deg



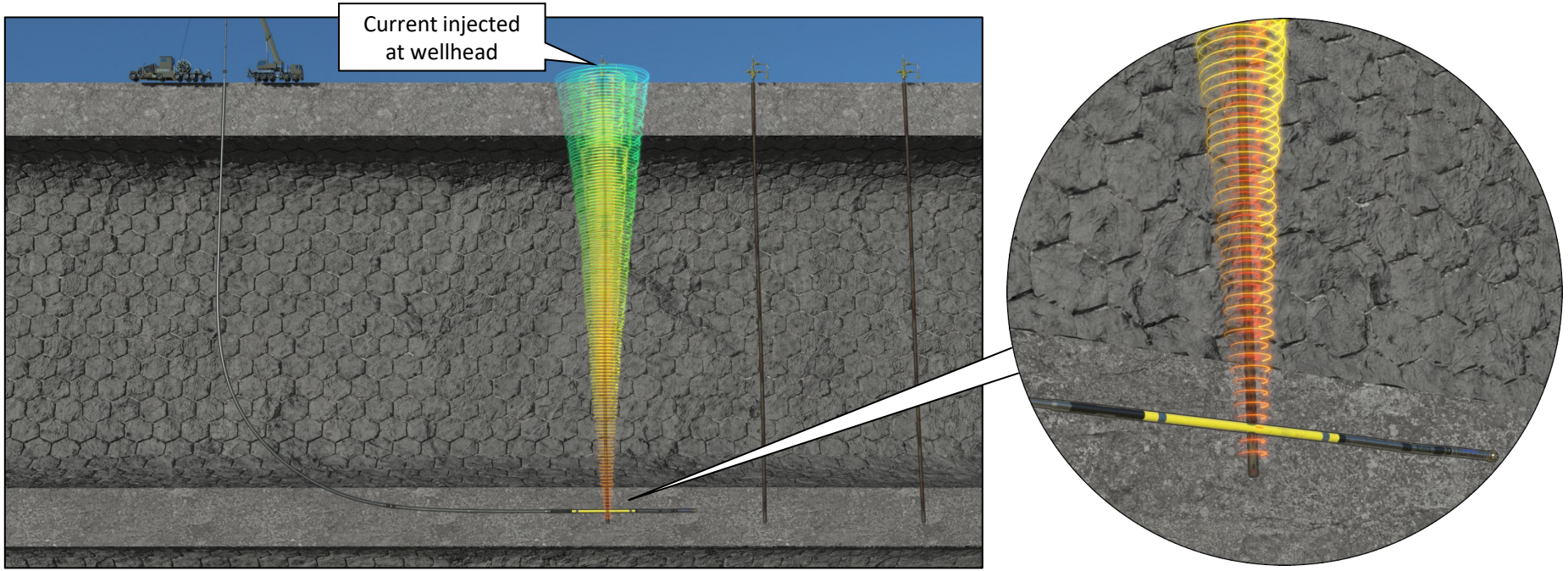
Theoretical Monopole Fit (PMR Method #1)



Distance and directions to pole

Peak Position (md)	633.67
Distance to Target	1.85
Highside to Target	-70.52
Azimuth to Target	15.70

Well #1 – Surface Current Injection



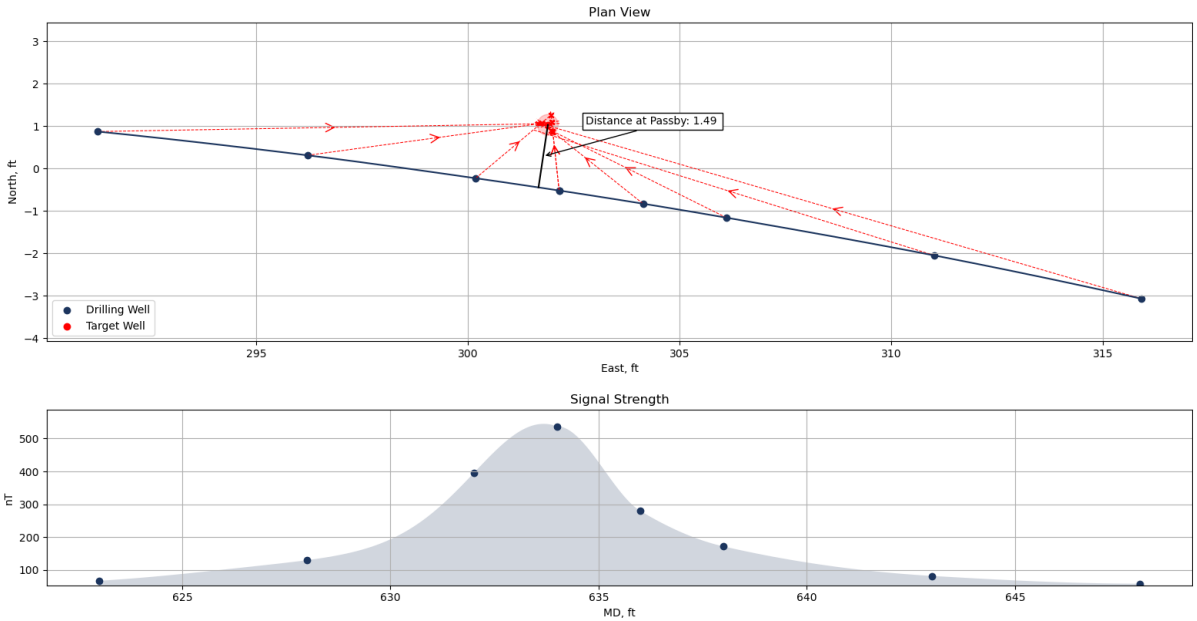
Well #1 – Surface Current Injection

Surface AC injection (picture on the right):

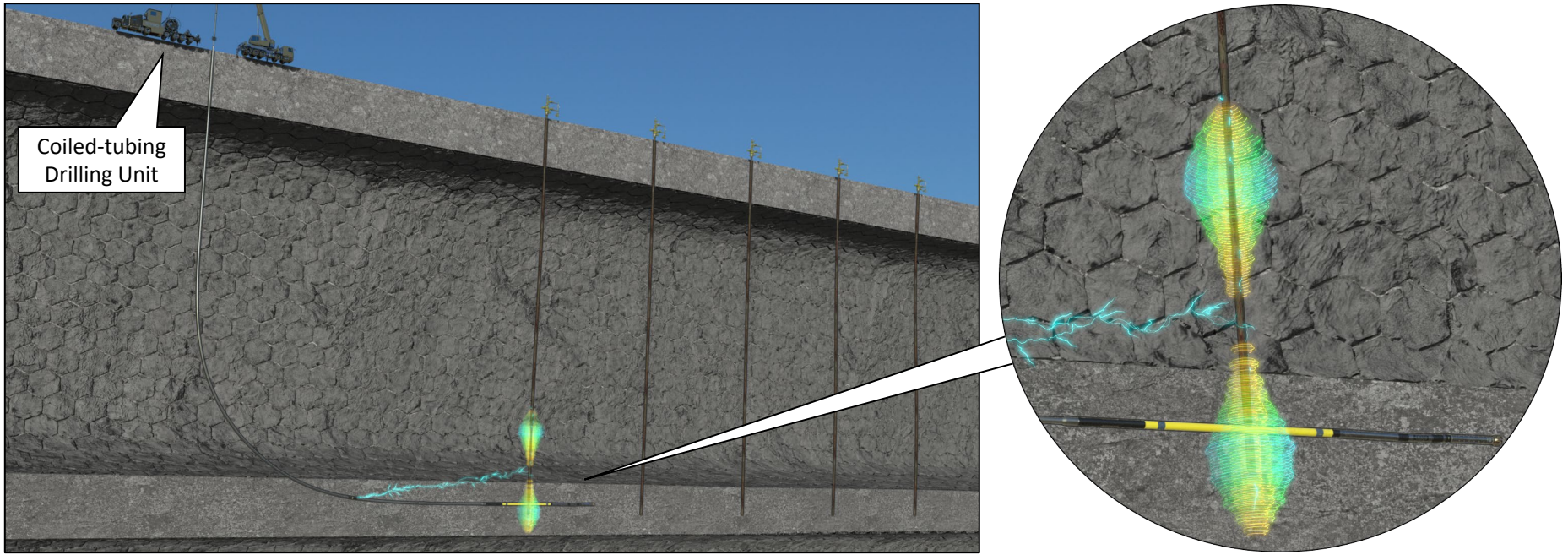
- Array of measurements collected
- Max. observed signal: 537.4 nT @ 634 ft. MD
- Passby @ 633.7 ft. MD
  - Distance to target: 1.49±0.16 ft.
  - Azimuth to target: 8.7±6.1 deg

Surface DC injection (picture not shown):

- Single measurement @ 633.5 ft. MD
  - Signal: 583.6 nT
  - Azimuth to target: 6.58±10.8 deg



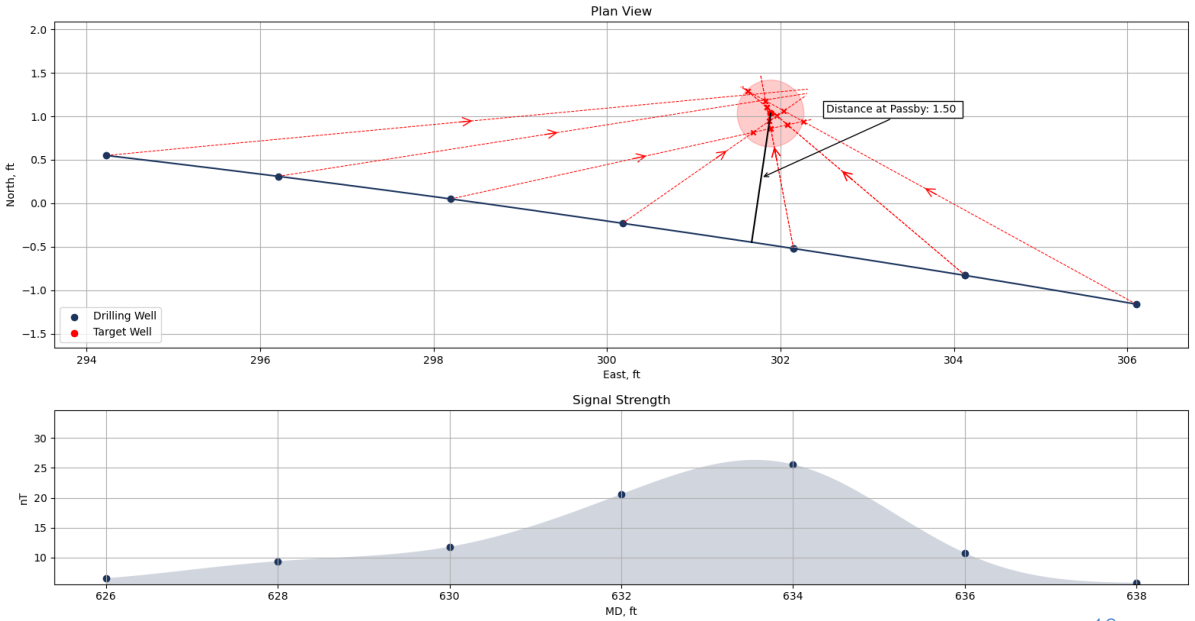
Well #1 – Novel CTRWD



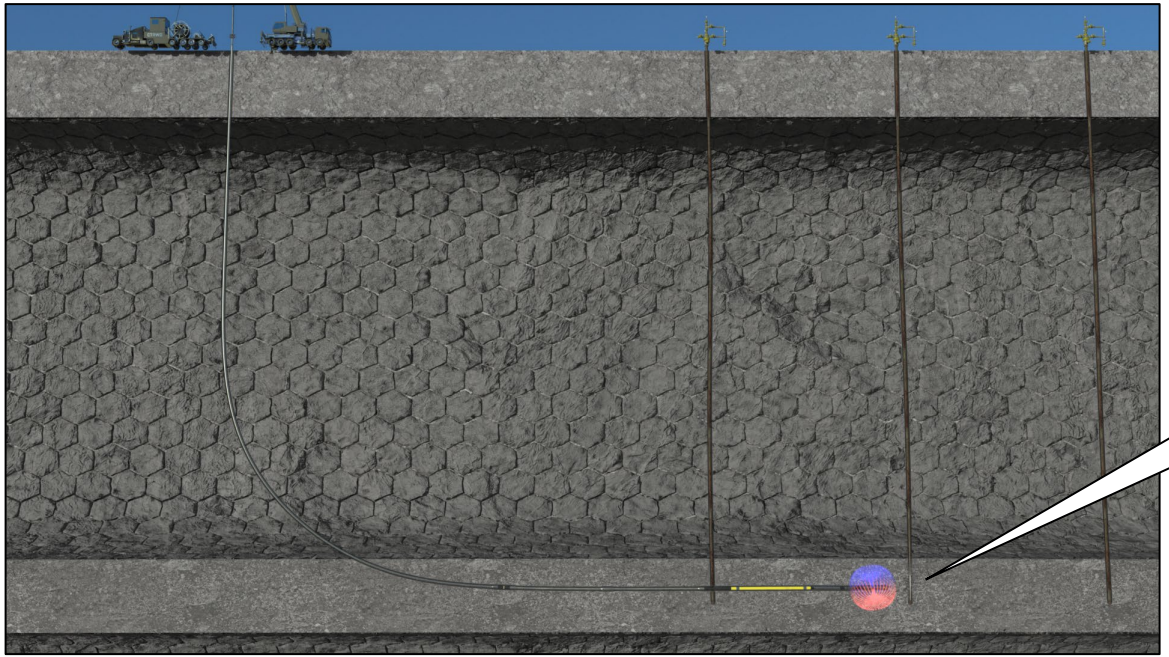
Well #1 – Novel CTRWD

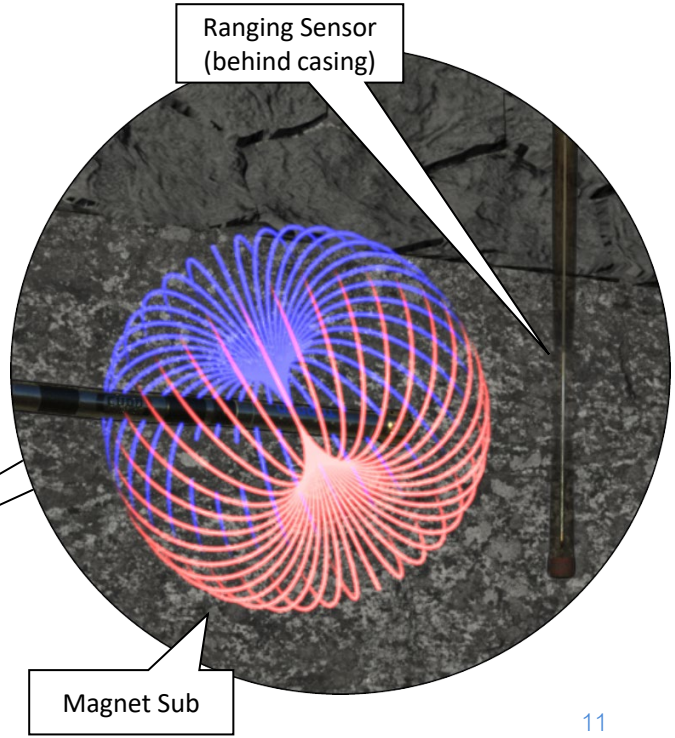
Downhole AC injection:

- Physical principle similar to traditional AMR
  - No access to the target well
  - Downhole formation current injection
- Current injection and sensor modules in the same coiled-tubing drilling BHA
  - No dedicated wireline runs
  - No time-consuming BHA trips
- Array of measurements collected
- Max. observed signal: 25.6 nT @ 634 ft. MD. Strong signal considering:
  - The worst possible geometry for downhole current injection
  - Salt formation
- Passby @ 633.7 ft. MD
  - Distance to target: 1.50±0.22 ft.
  - Azimuth to target: 8.5±8.3 deg



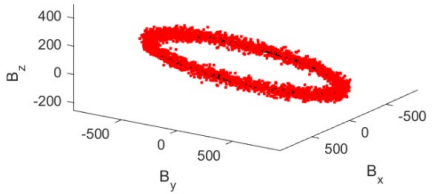
Well #2 – Rotating Magnet Ranging





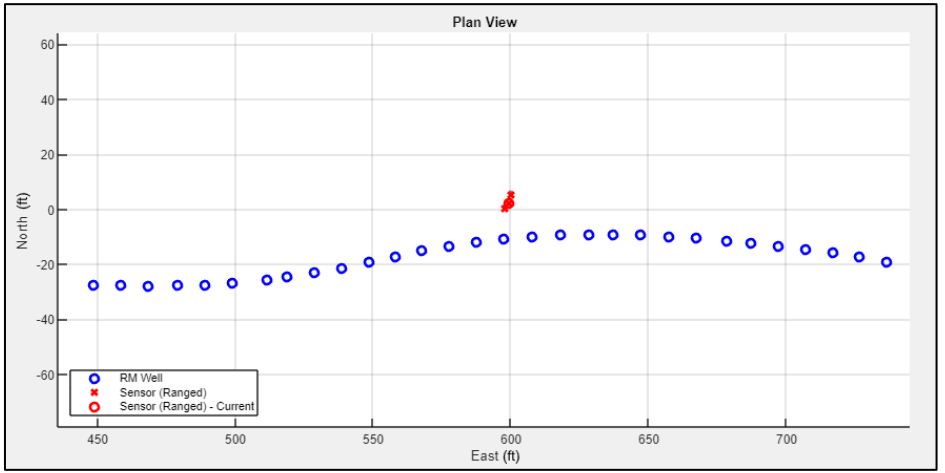
Well #2 – Rotating Magnet Ranging

- Ranging Sensor is in the cased vertical target well
  - Probe calibrated for known casing type
  - Integrated gyro for True North referencing
- Near-bit magnet sub is in the drilling BHA
- Signal from the rotating cross-dipole looks like an ellipse in Bxyz coordinates

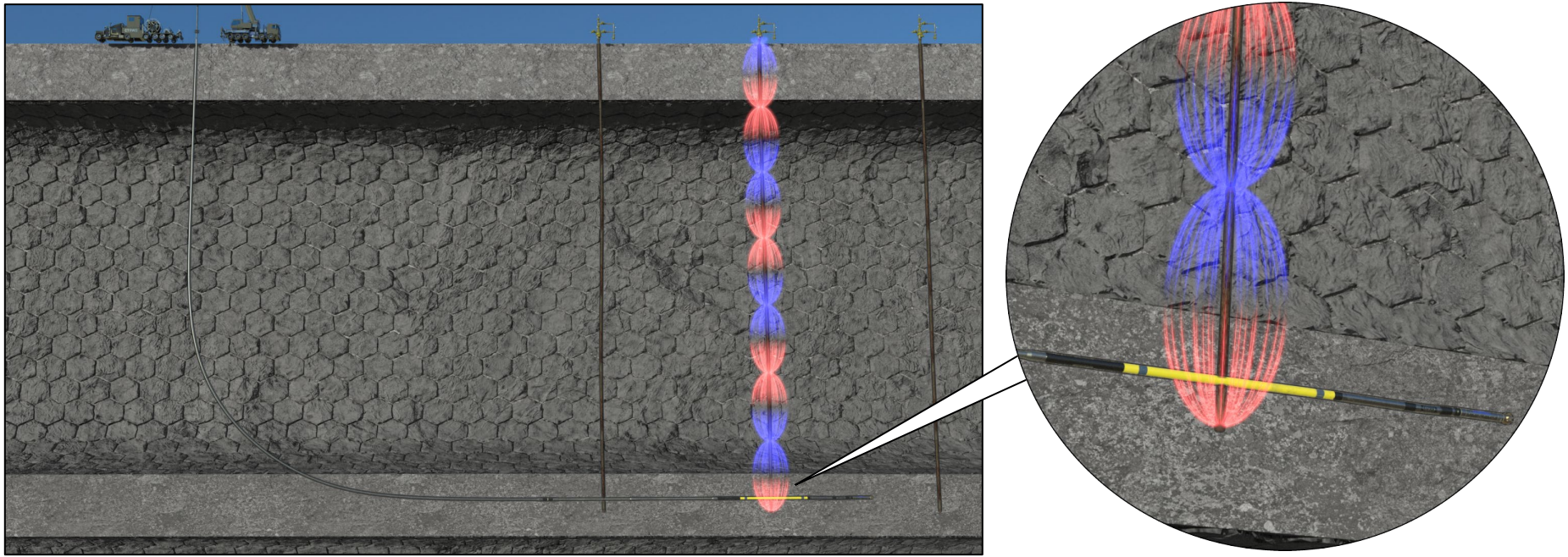


- Closest shot @ 938 ft. MD (distance to sensor 13.02 ft., minimum distance to target well 12.88±2.1 ft. @ 359.9±4.9 deg azimuth to target)

RM Depth	ΔN to Sensor	ΔE to Sensor	ΔTVD to Sensor	ΔHS to Sensor	ΔRS to Sensor	ΔAx to Sensor	Tot. Range
908	11.9751	26.9029	1.4108	0.8202	-6.9554	28.6427	29.4948
918	11.7454	17.7493	0.7218	0.7874	-8.9567	19.2963	21.2927
928	12.1063	8.4318	-0.1640	0.7874	-11.0236	9.7865	14.7638
938	12.8937	-0.0328	-1.7388	1.7717	-12.8609	1.0519	13.0249
948	15.0591	-9.2848	-1.0171	0.8530	-15.5840	-8.3928	17.7165



Well #2 – Passive Magnetic Ranging

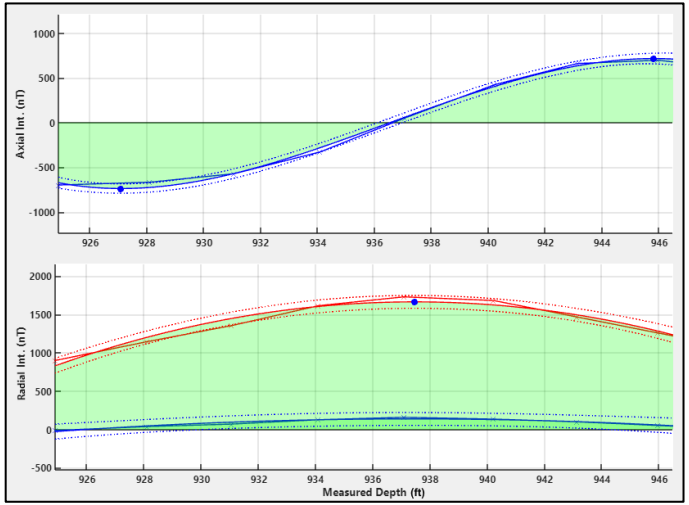


Well #2 – Passive Magnetic Ranging

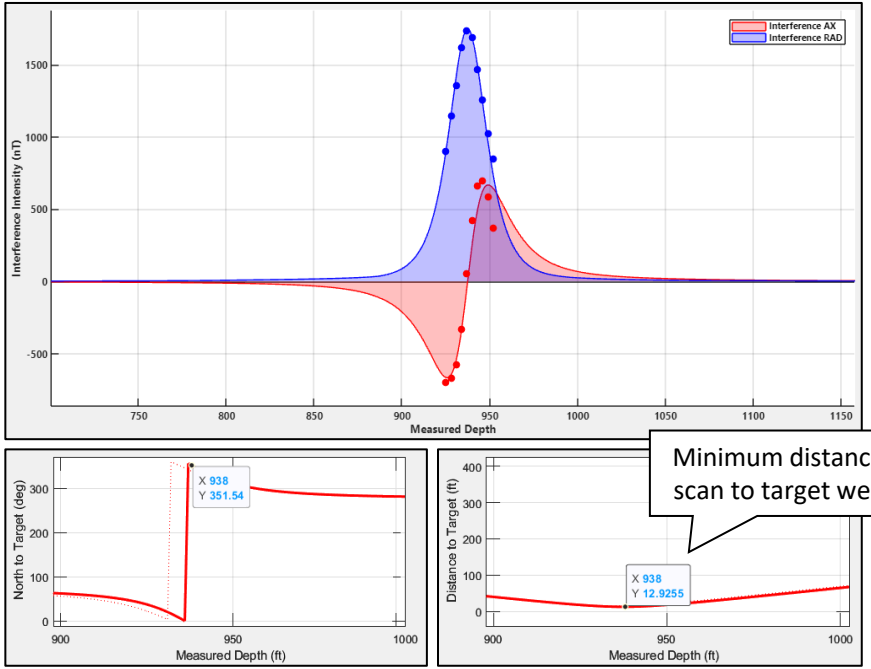
Signal Geometry Analysis (PMR Method #2)

Distance and directions to pole

Peak Position (md)	937.6
Distance to Target	13.23
Highside to Target	-95.15
Azimuth to Target	350.87



Theoretical Multi-Pole Fit (PMR Method #3)



Minimum distance scan to target well

Summary of Results

- Accumulating discrepancy between surveyed and ranged positions was discovered
  - Likely dominated by systematic azimuth error
  - +1.7 deg azimuth shift was applied
- Rotating Magnet was used for TW #3 – 5
- Hydraulic communication successfully achieved with all wells

- CTRWD method showed excellent correlation with other ranging techniques
  - Without access to the target
  - Without BHA trips and wireline runs
- Substantial signal in perpendicular geometry
  - The electrode is the furthest from the target
- Notoriously challenging formation (salt)

TW #1

Method	Source	Target Well Access	MD, ft (Passby)	Distance to Target, ft	Azimuth to Target, deg
CTRWD	Downhole formation current injection	Not required	633.7	1.5 *±0.2*	8.5 *±8.3*
Surface AC Injection	Casing excitation from surface using AC power	Required	633.7	1.5 *±0.2*	8.7 *±6.1*
Surface DC Injection	Casing excitation from surface using DC power	Required	633.5	N/A	6.6 *±10.8*
PMR	Residual target casing magnetization	Not required	633.7	1.7 *±0.4*	15.7 *±10.8*

TW #2

Method	Source	Target Well Access	MD, ft (Passby)	Distance to Target, ft	Azimuth to Target, deg
Rotating Magnet	Near-bit rotating dipole magnet	Required	938	12.9 *±2.1*	359.9 *±4.9*
PMR	Residual target casing magnetization	Not required	938	12.9 *±2.6*	351.5 *±10.8*

Appendix – Method Comparison

RANGING METHOD	APPLICATIONS	MINIMUM REQUIREMENTS	ADVANTAGES	LIMITATIONS
Coiled-Tubing Ranging While Drilling (CTRWD)	**Well intercepts, complex P&A, CCS**	**Coiled-tubing drilling unit with special ranging setup**	**Same physical principle, range and accuracy as standard AMR but while-drilling, access independent method, easily combined with other ranging techniques, no drilling rig, no dedicated BHA trips or wireline ranging runs**	**Hole size is currently limited to 6 ¼" or smaller, total depth is generally limited to 20,000 ft.**
Standard wireline AMR *(not shown on the slides)*	Well intercepts, complex P&A, relief wells	Magnetic field gradiometer in the drilling well, downhole current injection assembly, AC power supply, wireline unit (7-conductor)	Access independent active magnetic ranging method	Requires dedicated BHA trips and wireline ranging runs. Typically involves sensor being deployed in the open hole. May be susceptible to highly resistive formations like salt.
Passive magnetic ranging (PMR)	Collision avoidance, fish bypass, well intercepts, relief wells	MWD system capable of transmitting Bxyz and Gxyz data, residual offset casing magnetization, accurate reference well survey (for background field modeling and cancellation), accurate geomagnetic field model, Bxyz and Gxyz data at short MD interval (1 - 10m depending on distance to the target well).	No additional equipment required other than MWD system, no electrical continuity of the target required, not affected by formation or mud resistivity	Standard PMR relies on the presence of measurable magnetic poles. When distance to target well is greater than distance between these poles, fitting multiple theoretical poles into observed signal is required. Poor reference survey quality causes erroneous ranging results (solved with GWD). May be time consuming due to short measurement interval (solved with Definitive Dynamic Survey solution).
PMR with magnetized casing *(not shown on the slides)*	Twinning, SAGD, collision avoidance, well intercepts, relief wells	Magnetized casing, pole strength log, MWD system capable of transmitting Bxyz and Gxyz data, accurate reference well survey and geomagnetic model	Ranges comparable to active ranging, works in salt, no additional equipment required other than MWD system (not accounting for casing magnetization equipment)	Poor reference survey quality causes erroneous ranging results (solved with GWD). May be time consuming due to short measurement interval (solved with Definitive Dynamic Survey solution). Our experience suggests that strong casing magnetization should last at least 10 years but data beyond 10 years is sparse.
Surface current (DC & AC) injection	Collision avoidance, twinning, well intercepts	DC: MWD system capable of transmitting Bxyz and Gxyz data, DC power supply and ability to connect it to the target well casing. AC: requires special sensor and AC power supply	DC: Simple active magnetic ranging technique, standard MWD is used as a ranging sensor. AC: AC configuration typically yields superior range and accuracy.	Requires access to the target well. Direct casing injection is limited to shallow depth applications. Target casing must be electrically continuous.
Rotating magnet (RM)	Twinning, SAGD, collision avoidance, geothermal, CBM, well intersections	Special alternating magnetic field sensor in the offset well, magnet sub in the drilling well, wireline unit (mono-conductor)	One of the furthest range methods (when sensor is unshielded by steel casing), at-bit measurements, straightforward results, highly customizable method	Requires access to the target well. Requires pump-down or wireline tractor for high-angle applications.

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Proper planning and combination of ranging techniques are the keys to success!

Thank you! Questions?