A More Efficient Design For Closed Loop Geothermal Magnetic Ranging

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Abstract

With the geothermal space seeing renewed interest in the broader desire to reduce our carbon footprint globally, new and refreshed methods to target this energy stream are being explored. One refreshed method seeing much interest globally due to its ability to be installed essentially anywhere temperatures can be found is Advanced Geothermal Systems or commonly known as Closed Loop Geothermal.

Amongst the typical geothermal drilling challenges such as high temperatures, high vibration in hard and abrasive rocks and significant losses drilling through naturally fractured reservoir. Closed Loop also requires incredibly precise wellbore placement to ensure two or more wellbores can physically connect to create a continuous fluid conduit.

A critical technology to deliver these well types which typically has only been needed for specialized applications is Magnetic Ranging. This presentation will explore different well types that have been explored within the closed loop geothermal space, the current technology landscape of magnetic ranging technologies, which current technologies are most suitable for closed loop geothermal, unique challenges to execute Closed Loop geothermal projects and the technical hurdles to tailor Magnetic Ranging technologies to overcome these challenges. The authors will also introduce a new technology that has been developed to address these challenges to improve the operational efficiency while drilling closed loop geothermal wellbores.

The authors aim to give the readers a better understanding of what is required to achieve these types of projects, the limitations that need to be considered in the planning stages and what the current technology landscape entails.

Introduction

Traditional survey measurements utilized by directional companies globally utilize either a magnetic compass or gyro compass techniques. These methods tie back to a known surveyed point on surface, from this point onwards each discrete survey's errors compound with the previous survey (Figure #1). Regardless of how accurate the survey is, a wellbores position is left with growing uncertainty with increasing measured depth.

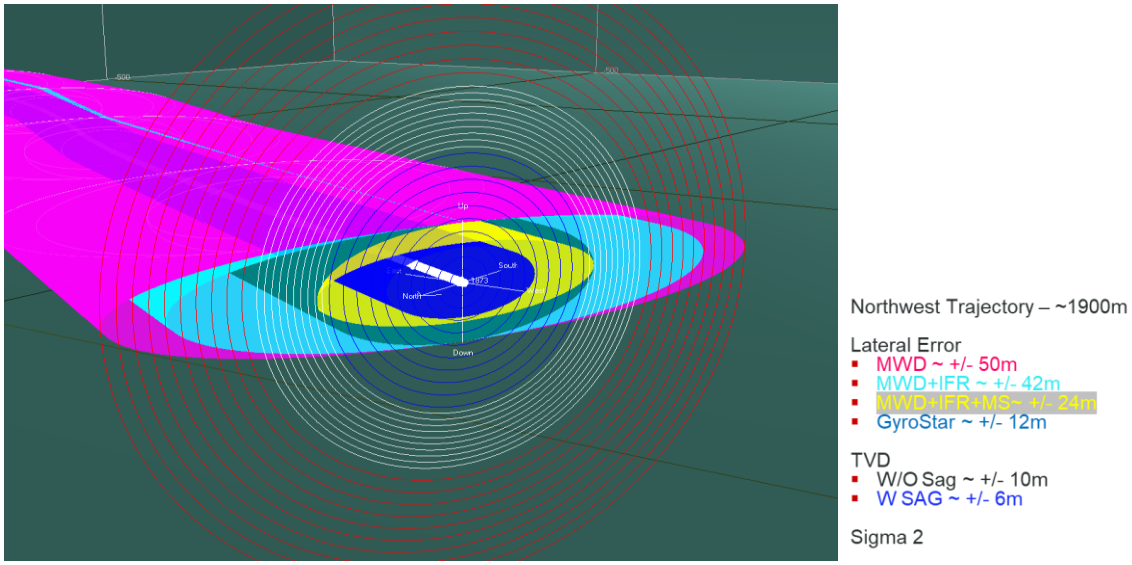


Figure 1: Survey Uncertainty with various instrument performance models (IPM), example is from Western Canada

Magnetic Ranging technology at its core fills a need in the industry where positional uncertainty is required beyond these conventional survey methods. This is essential when the compounded errors present with Measurement While Drilling or Gyro While Drilling surveys are not sufficiently accurate to achieve the objectives of the wellbore.

Magnetic ranging utilizes magnetic fields—either natural or induced—to determine the relative position between two or more wellbores. This technique has become essential in high-density drilling environments, relief well operations, plug and abandonment (P&A), Steam Assisted Gravity Drainage, and now, geothermal applications.

Principles of Magnetic Ranging

There are three fundamental steps in the magnetic ranging process, these are magnetic field generation, detection and finally positional determination.

Magnetic field generation for the purposes of magnetic ranging take advantage of long-established principles used across many industries in various methods (Figure 2). These methods are excitation of a casing string or wire by the active application of current to a wire inside or outside casing, current into an electromagnet/solenoid, deployed rare earth magnets or utilization of remnant magnetic fields present in ferrous objects (Lost Drill pipe, casing strings, etc.)

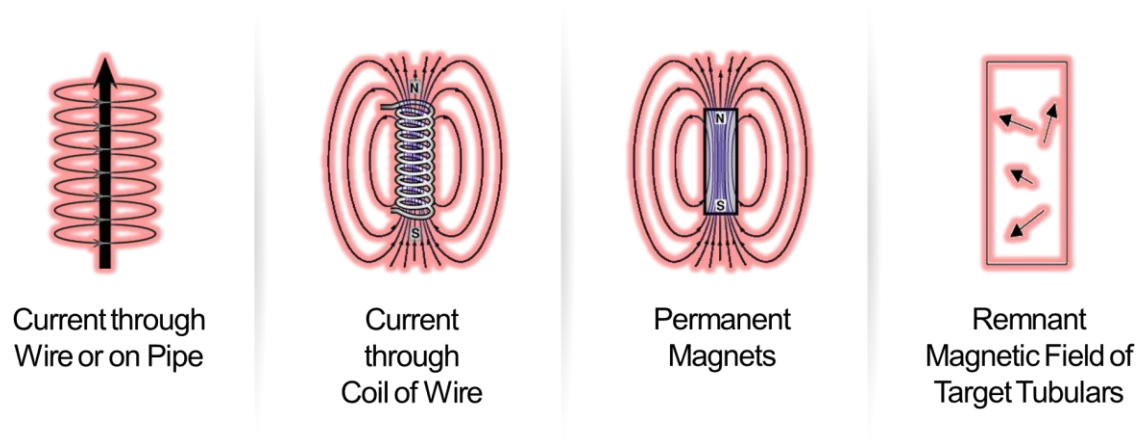


Figure 2: Method of generating a magnetic field for ranging purposes.

Depending on the method used to generate the magnetic field, the method to detect can vary. If the source strength of the magnetic field is known or assumed a little as a single triaxial magnetometer can be utilized, whereas if the magnetic field is being actively generated but field strength at a discrete depth is unknown a series of magnetometers at a known distance (gradiometers) can be utilized (Figure 3).

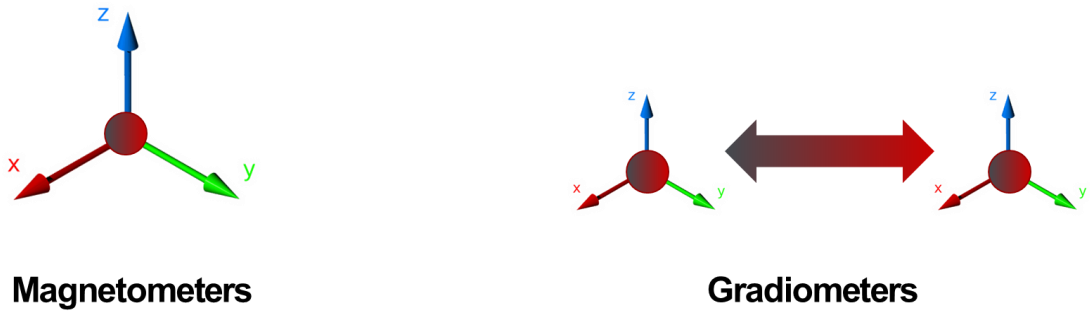


Figure 3: Methods of detection of a magnetic field

Once the field is generated and detected the data can be analyzed to determine the distance and direction to target determination. This processing and analysis create a direct measurement between the drilling well and a reference well, removing the uncertainty present with conventional survey techniques.

Applications

The most common applications for magnetic ranging across all industries are where the above-mentioned survey uncertainty is not enough to achieve the required objectives of the wellbore. This can also be exacerbated by the presence of steel from offset wellbores affecting the magnetic compass. Applications can include wellbore avoidance (e.g., Steam Assisted Gravity Drainage (SAGD), infills and re-drills of failed parent wellbores), interceptions (e.g., relief wells, complex Plug and Abandonments, river crossings for pipelines and utilities).

Technology Classification

Now that the basics of magnetic ranging have been established, it's possible to delve into the details of how the discrete methods are deployed. Depending on the application, different tools can be deployed into either the target well (Access Dependent) or deployed into the drilling well (Access Independent). Access Dependent methods are typically less complex than independent methods.

Access Dependent methods include deployed cables, solenoid and rare earth magnet approaches (Figure 4).

Deployed cables require placing a wireline into the target well and a sensor deployed on the MWD string into the drilled well. As a current is applied to the wireline, a field is generated perpendicular to the wire and detected with the sensor deployed into the drill string on the drilling well.

Solenoid ranging tools are deployed into the target well via wireline with or without tractors, or coil tubing. As current is applied to the solenoid, the steel core is saturated, and a steady magnetic field is created in an arc from the north to south poles of the solenoid. This polarity on the solenoid can be reversed to determine the signal amplitudes. A simple MWD magnetometer on the Bottom Hole Assembly (BHA) can be utilized to pick up the signal generated by the solenoid field.

Rare earth magnet ranging method uses a series of rare earth magnets installed into the sub that is mounted on the drilling bottom hole assembly. As the sub is rotated continuously with drill string rotation or via the downhole mud motor, an alternating magnetic field is generated. A sensor is deployed into the target well that is design specifically to measure the magnetic field generated by the spinning sub.

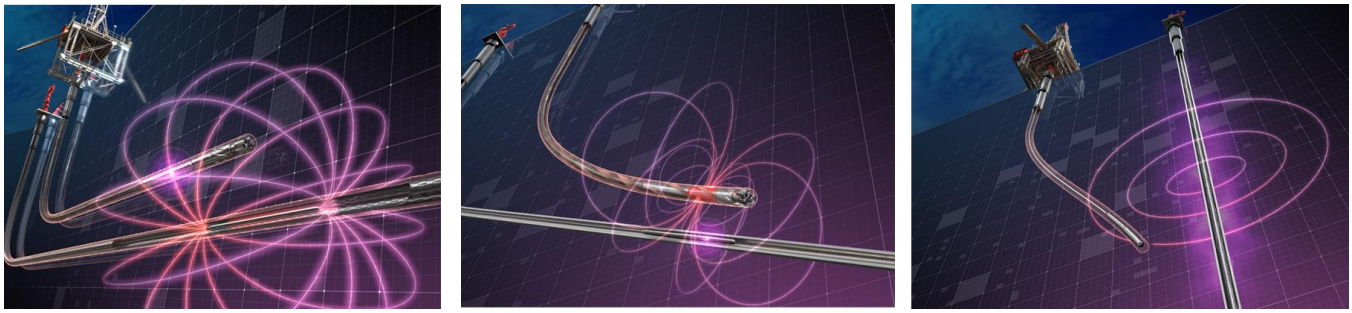


Figure 4: Access Dependent Ranging Methods

Access dependent methods (Figure 5) rely upon injecting current onto a target well either through surface excitation where you have access to the target well on surface to inject current or via downhole excitation an assembly is run into your drilling well and current is transmitted down a wire, into the formation to excite the target well. Both methods utilize a gradiometer-based measurement system that can be either mounted into the BHA or deployed via wireline in the drilling well.

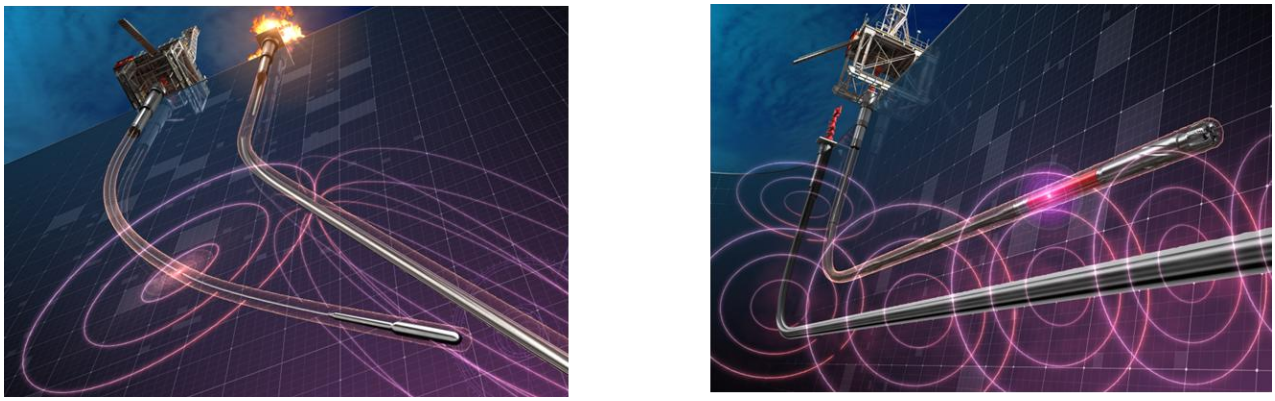


Figure 5: Access Independent ranging methods

Geothermal Ranging Development

As the push for a carbon free world grows, geothermal is a natural avenue to explore given that is a baseload capable renewable power source. Within that closed loop geothermal presents a possibility to have geothermal deployed nearly anywhere there is hot rock.

Closed loop geothermal does present some unique challenges however, especially related to the wellbore placement requirements and the precision required to perform the downhole interceptions. Some of the challenges are, most apparently that two BHA with rigs on two locations can “talk” to each other to determine relative distance and direction, significantly larger range (65m minimum down to intercept depth) than is commonly achieved with existing tools, remove need for wireline conveyance, and compatible and minimal to no impact on steerable assemblies. When one looks at the available technology for magnetic ranging it becomes clear that a tool requiring wireline deployment would be the most robust platform to build out a solution and this comes with significant operational costs to deploy.

To determine the most suitable magnetic ranging method for closed loop geothermal applications, a detailed comparison was conducted between two leading approaches: the Solenoid-based system and the Rare Earth Magnet-based system. Each method offers distinct advantages and limitations across several technical and operational dimensions.

The Solenoid approach offers precise control over magnetic field generation through active excitation, enabling frequency tuning and improved signal-to-noise performance. Its integration into the rotary steerable system (RSS) allows for seamless operation without interfering with

steering or sensor performance. Additionally, solenoids are thermally robust and already proven in high-temperature downhole environments.

In contrast, the Rare Earth Magnet approach is mechanically simpler and does not require downhole power, but it lacks reliable signal modulation capabilities and is more susceptible to interference. Its performance degrades at elevated temperatures, and it can require wireline deployment of the receiver, increasing operational complexity and cost.

Analyzing the suite of potential solutions that could be developed to address this efficiency problem, two technological paths stand out most clearly. The Solenoid and Rare Earth magnet approach have the strongest merits. Both methods have their own discrete advantages and limitations (Table 1)

Table 1: Unique characteristics of Solenoid and Rare Earth ranging methods.

Criteria	**Solenoid Approach**	**Rare Earth Magnet Approach**
Signal Generation	Active, controllable AC/DC excitation	Passive, continuous field from rotating magnets
Signal Modulation	Frequency-selectable, supports noise cancellation	Fixed frequency, complex noise rejection required
Integration with BHA	Modular integration into RSS, minimal sensor interference	Constant field may interfere with sensors; affected by BHA dynamics
Thermal Performance	High-temperature capable; proven in LWD tools and high temperature applications	NdFeB magnets degrade at high temperatures; SmCo needed for higher temps but are lower strength
Power Requirements	Uses RSS power; excitation only during ranging	No power required for transmitter; receiver requires wireline
Operational Complexity	No wireline needed; downhole processing reduces surface data handling	Challenging to remove wireline for downhole processing
Measurement Range	Up to 120 meters demonstrated	Commonly up to 80 meters
Accuracy	High precision with low-noise MWD receivers	Lower precision; affected by BHA motion and formation noise
Suitability for Geothermal	Ideal for long laterals and precise interception in closed loop systems	Well suited if operational challenges can be overcome

To the development team, it was apparent that the solenoid approach was a favourable design as the most complex problem had already been solved and well understood with the legacy suite of tools, downhole processing. This left the real challenge to be development of a BHA mounted and powered solenoid at a scale that could be used for magnetic ranging. Downhole solenoids are used quite frequently in Logging While Drilling (LWD) resistivity tool development such that the Technical Readiness Level (TRL) was already quite high. Concept sketch in figure 7 below.

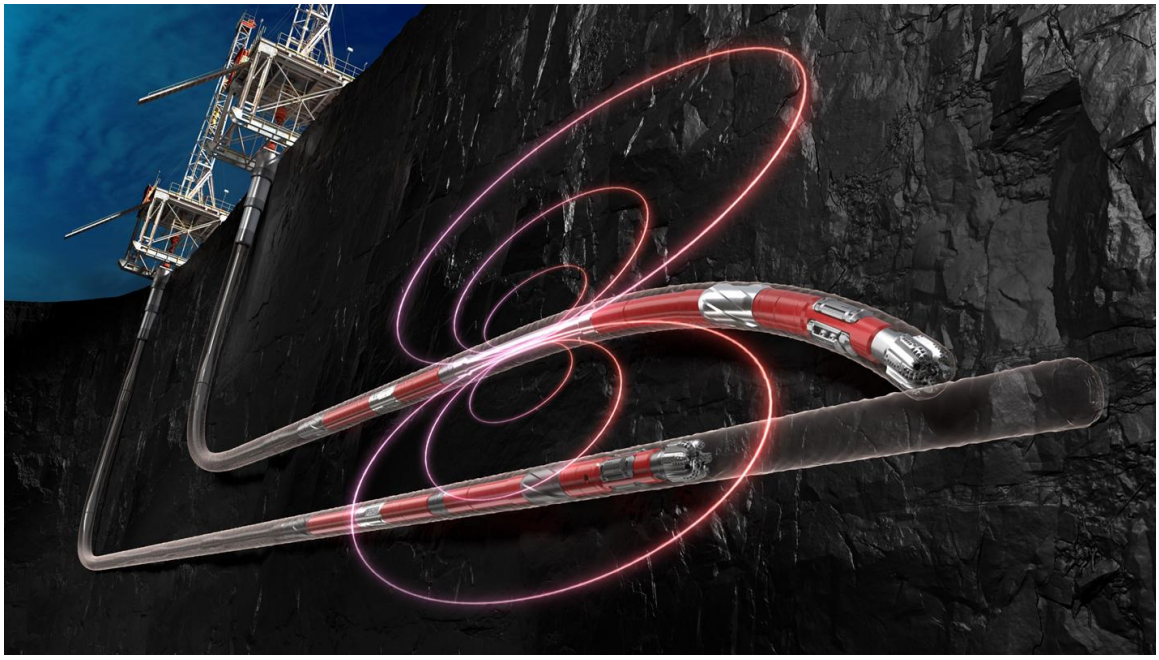


Figure 6: Illustration of Geothermal Ranging technology

As closed loop geothermal efficiency increases with longer lateral length, rotary steerable systems (RSS) are or will be deployed on most development projects. Enabling the development team to utilize excess power supply from the RSS tool to divert to powering a solenoid when a ranging measurement is necessary. This removed a major barrier from the solenoid approach to achieving overall objectives.

Additionally, given the modular design of the companies RSS tool, a solenoid design could be inserted into the RSS tool without impact on the overall steering performance and with little to no impact on sensor readings as excitation of the coil only occurs at ranging stations. This prevents a potential for sensor interference that can't be easily rectified with a rotary magnet design that will be creating a field while drilling.

The development team also had at their disposal a new generation of MWD receiver, with very low noise electronics. This design coupled with a selectable frequency for an AC excitation from the transmitter allows for very effective noise cancellation and signal detection with signals down into the less than one nanotesla range.

Overall system block diagram is illustrated in figure 8 below.

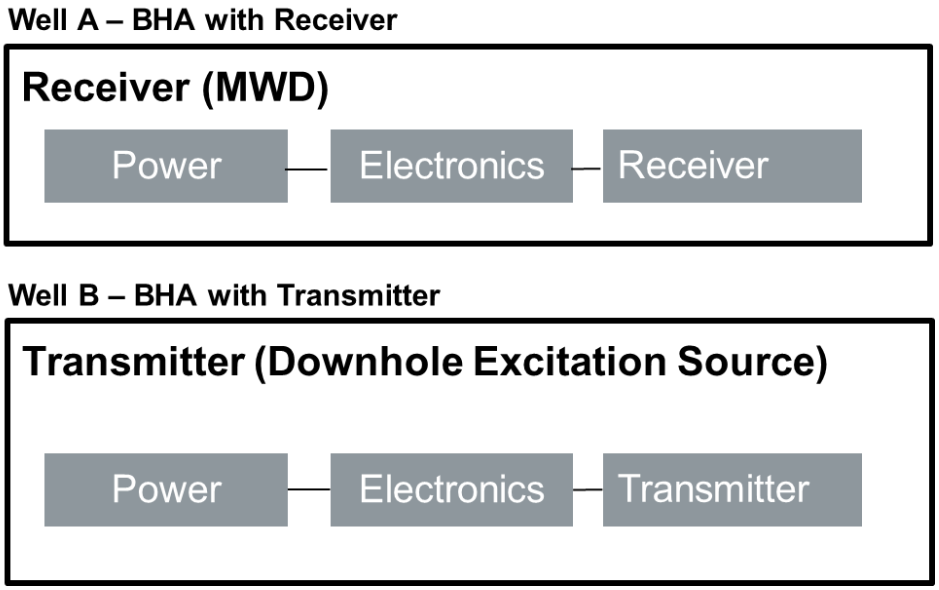


Figure 7: Block Diagram of the Geothermal Ranging System

Field Trials and Results

Field trials at the research facility validated the solenoid-based system would achieve the key objectives, that two BHA's could measure relative to each other, achieve the desired range requirements, and be able to process the data downhole. Field testing was able to determine that the maximum is in the order of 120m as demonstrated in the plot in figure 9 & 10 below.

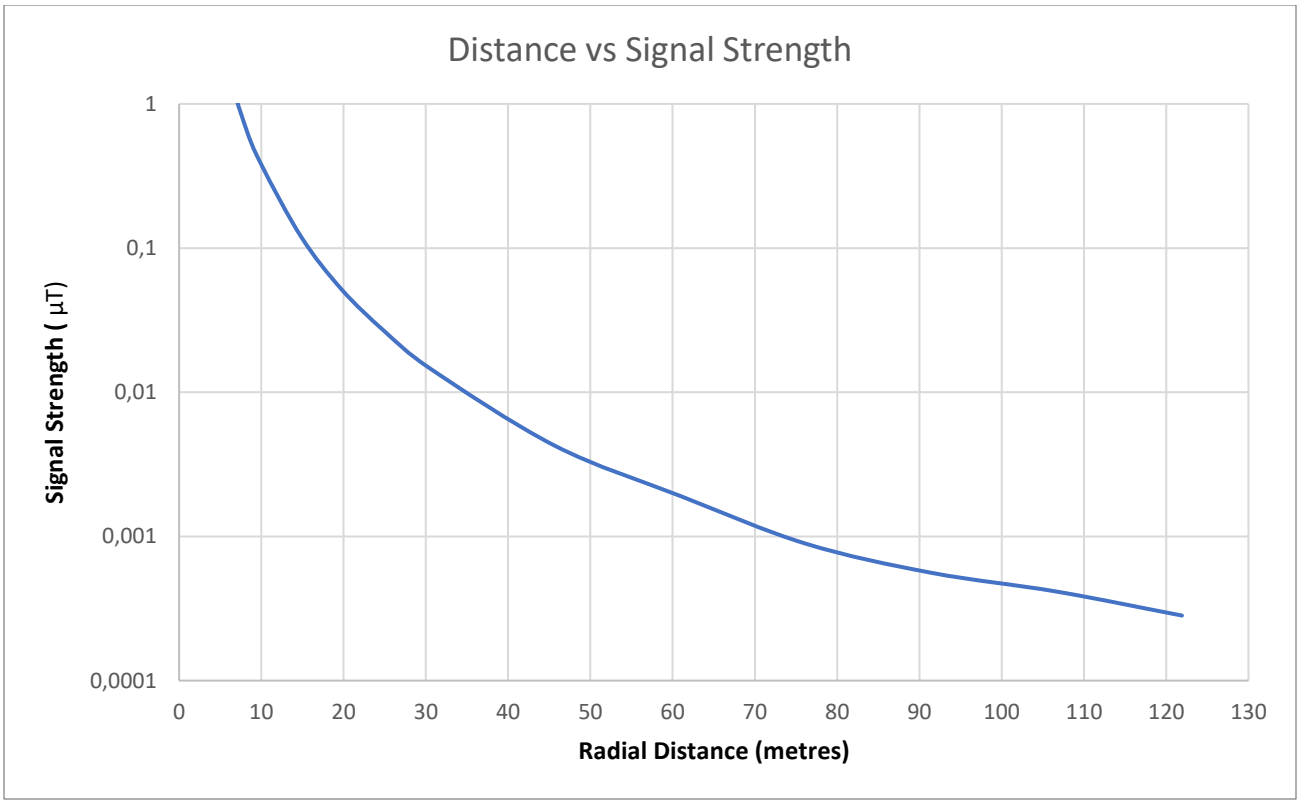


Figure 8: Plot showing the signal strength decay over a distance



Figure 9: Collar housing the BHA mounted solenoid

Once system functionality had been established, a test well was planned to test system capabilities in real world conditions. The system was deployed at the companies drilling test facility in Texas. A well profile was planned to test the range and steering capabilities of the

system as well as to get as close as possible without intercepting to avoid well control issues in the test facility. The test facility has three slots, however, due to the inability to have two rigs collocated in the test facility the BHA contained both transmit and receive functionality and transmit and receive functionality was placed on a wireline BHA in the offsetting target wellbore.

In slot A, a wireline unit was rigged up that was able to deploy a solenoid transmitter (MGT) capable of AC and DC transmission and an AC receiver.

In slot B, a drilling rig was spotted that had the ability to transmit from the solenoid (Geothermal Ranging) and also receive with the MWD (BaseStar) system.

As drilling progressed throughout the planned interval, ranging shots were alternating between the different combinations of systems. This allowed the team to understand any relative differences between the results and comparison relative to the MWD surveys from the respective wellbores. As the ranging system changes, the target well shifted from the drilling well to the target well and vice versa, this results in an equal "shift" but in the opposite direction. This is demonstrated on the plots below showing the surveyed and ranged position on the plots below (Figures 11, 12, & 13)

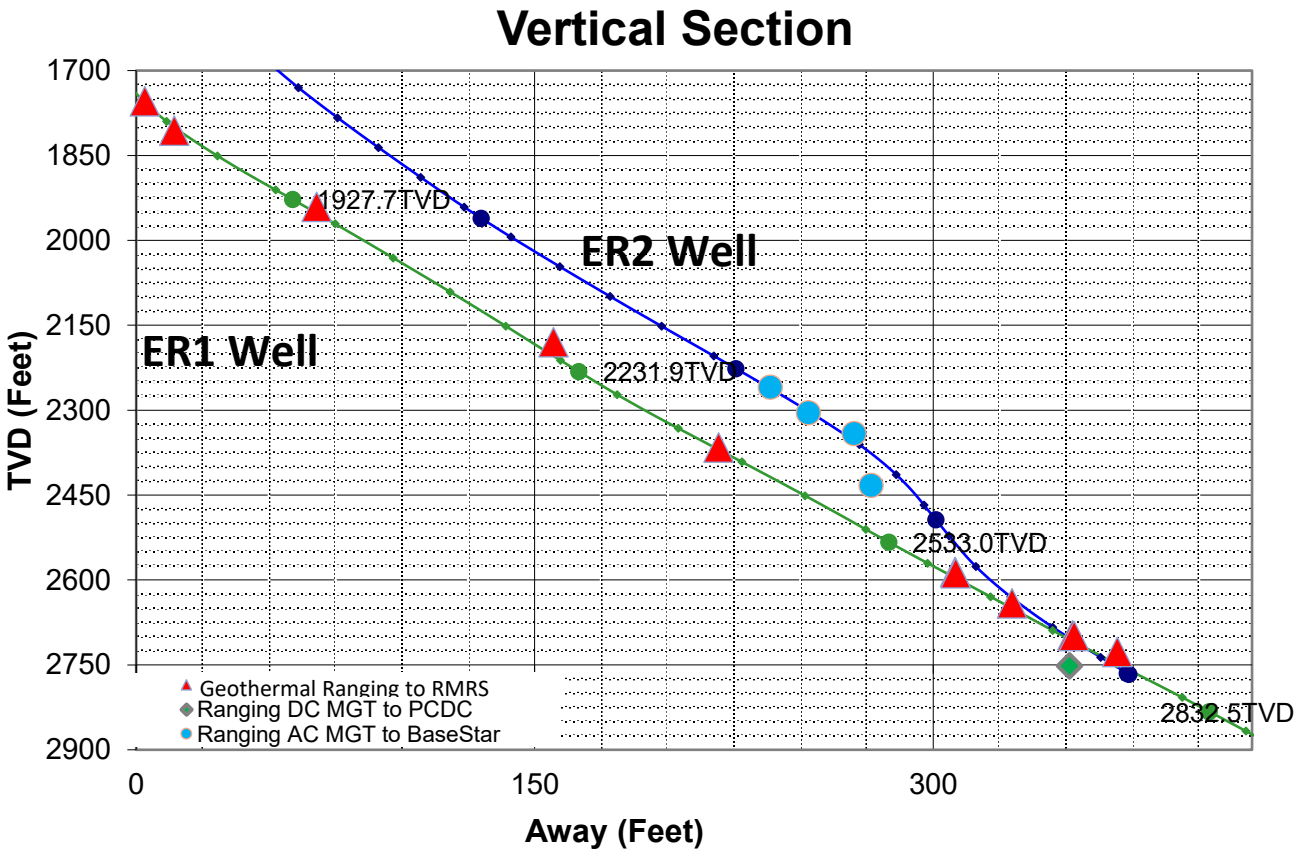


Figure 10: Vertical Section vs TVD plot from Test Well

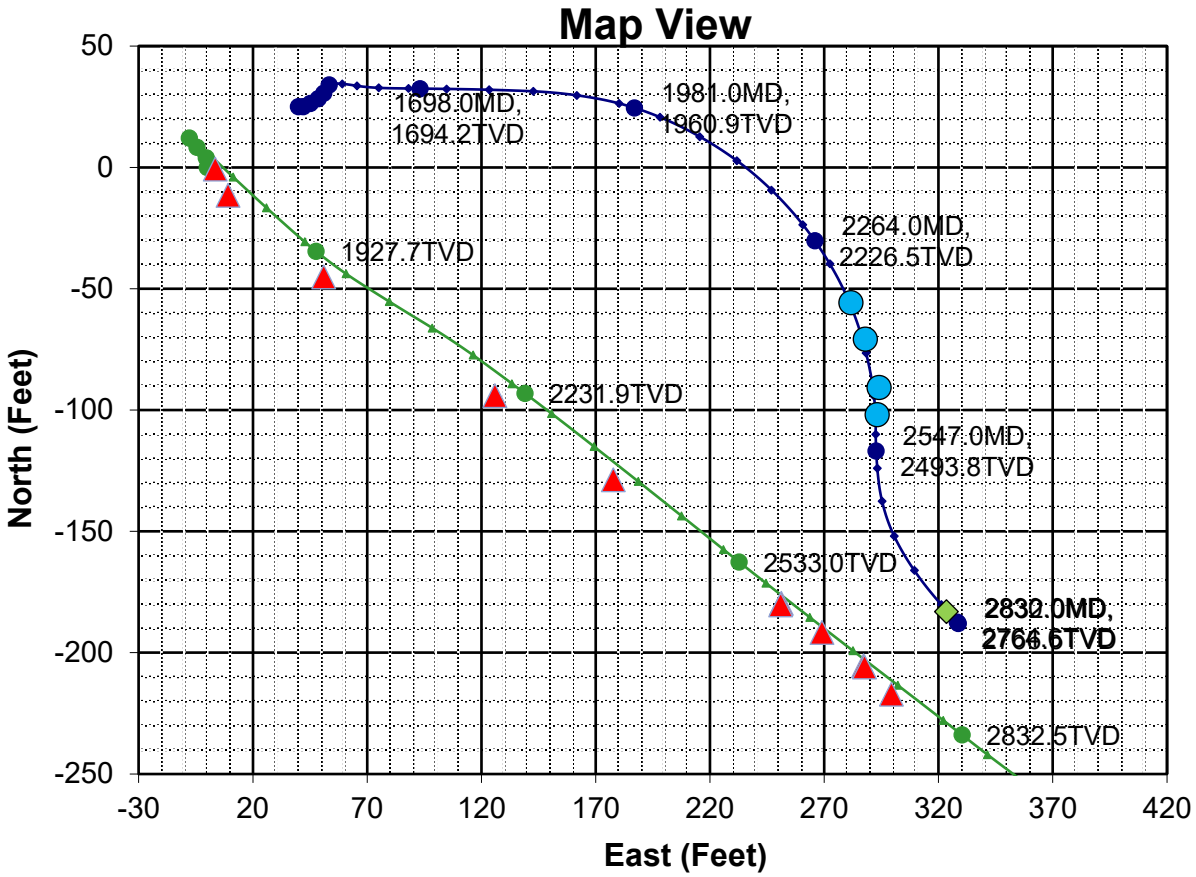


Figure 11: Plan View (Eastings vs Northing) Plot from the Test Well

When looking at the ranging data discretely, all systems provided data that agreed with each other along with agreement to the various MWD surveys relative to each other. This increases confidence in the results of all systems and further supports the data collection methodology used during the validation test.

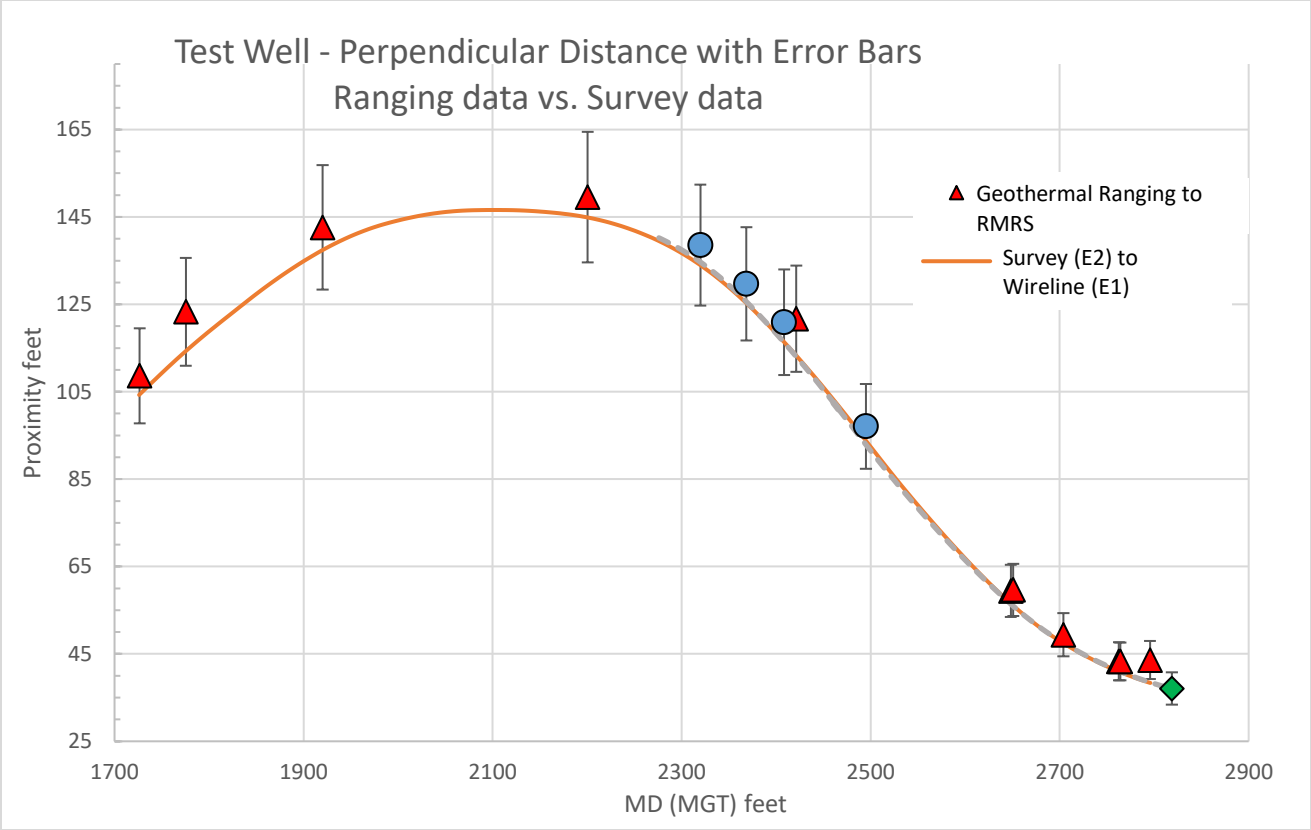


Figure 12: Proximity vs Measured Depth plot from Test Well

Through the field trial, the team was able to successfully demonstrate the system capabilities, accuracy and time requirements to achieve a ranging shot. The range capabilities of the system were verified in a real-world environment and provided correlation and validation between multiple ranging systems. The well was drilled to less than 30' interception depth without any significant issues.

Conclusion

The development and successful field validation of a solenoid-based magnetic ranging system marks a significant advancement in enabling precise wellbore placement for closed loop geothermal applications. By integrating the solenoid transmitter into the rotary steerable system (RSS) and leveraging downhole processing with low-noise MWD receivers, the system overcomes key limitations of traditional ranging methods—such as limited range, reliance on wireline deployment, and sensitivity to bottom hole assembly (BHA) dynamics.

Field trials demonstrated that the system could achieve accurate, real-time relative positioning between two wellbores at distances up to 120 meters, with strong agreement across multiple ranging configurations and MWD surveys. This innovation not only enhances operational efficiency and safety but also supports the broader deployment of closed loop geothermal

systems in diverse geological settings, contributing to the global push for carbon-free, baseload-capable energy solutions.

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