First U-tube well connects horizontal wells

Dean Lee, Landmark Graphics Corp; Richard Hay, Fernando Brandao, Halliburton Sperry-Sun

ALTHOUGH WELLBORES HAVE been intersected before, both through planned intersections for well control and through unplanned wellbore collisions, they have not been intersected to join their wellpaths to effectively create one smooth continuous conduit from one surface location to another—until now.

PROJECT GOALS, OBJECTIVES

As with any trial or development of new technology, clear goals, objectives and expectations must be identified prior to design and implementation.

It was clear from the onset that this was to be a producing well, and, as such, sand control was a concern. The intersection of the two wellbores was strictly for science and had no value to the actual production of the originally planned wellbore.

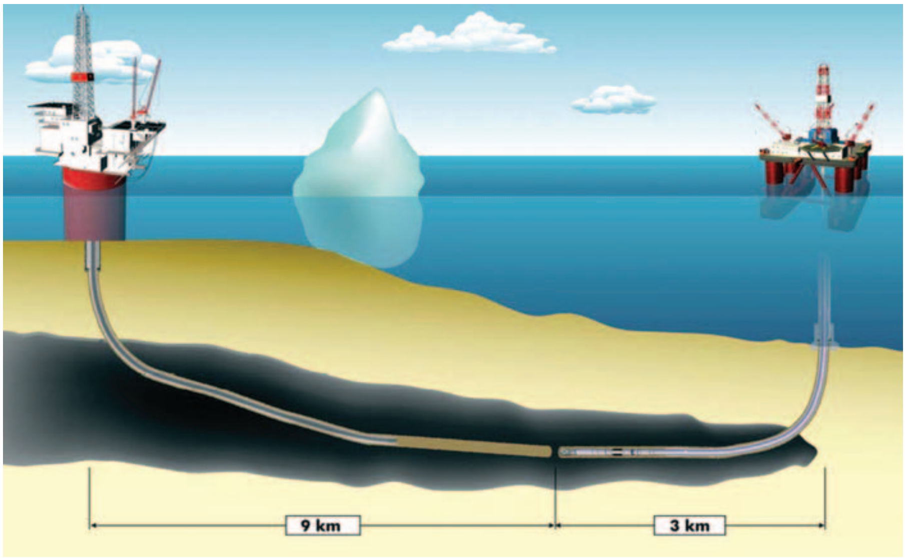
The value obtained was the knowledge of what could be accomplished so that future implementation of the technology could be considered for strategic planning purposes.

Following this line of thought, three goals of this project were laid out. The first was to apply current directional drilling technology to see if two horizontal wellbores could be intersected end to end.

Success was defined as intersecting the two wellbores with the drill bit and being able to enter the wellbore of the second well with the drilling assembly.

The second goal was to run standard steel casing through the intersection to prove that the two wellbores could be linked with solid tubulars. Success was defined as being able to run regular 7-in. casing through an 8 ¾-in. intersection point without getting the casing stuck in the hole.

The final goal was to join the two casing strings with a connection technique that eliminated sand production. It was agreed that the connection technique used on this first well would be as simple as possible. If this initial trial was successful, future work could be done on a more advanced connection technique.



Intersecting two horizontal wellbores end to end in harsh and hostile environments such as where icebergs scrape the ocean floor can result in safely recovering reserves by extending the length of already extended reach wells.

RESERVOIR DESCRIPTION

The location selected for the trial of this technology was on land in an unconsolidated sandstone reservoir only 195 m true vertical depth (TVD).

The original field development plan called for several horizontal wells to be drilled under a river running through the field. It was decided that one of these horizontal wells would be an excellent location to test the technology, as only one additional well would need to be drilled and connected to the currently planned well.

Since one well was already planned to be drilled from one side of the river, a second surface location was selected on the opposite side of the river approximately 430 m from each other.

TECHNOLOGY SELECTION

This project was created more so as a simulation of what could be done on a larger scale later. The intent was to prove it could be done using existing, reliable technology but in a new way.

Traditional river crossing drilling requires that the borehole enter at one surface location and drill back to surface at the second location. Since most of these holes are relatively short there is less concern about drag and the effects of gravity as the drilling rig has ample push to achieve the goal over such a short interval.

In addition, exiting on the surface with a borehole that has passed through a porous formation under pressure is not generally possible due to safety issues around blowout prevention.

The obvious additional benefit of using two surface locations instead of one is the effective distance possible between the two locations can be at least doubled as torque and drag limitations can be maximized for reach at both surface locations.

Since it was decided that drilling was to occur from two separate locations, the first decision made resulted in the method of survey measurement technique that was to be used to create the physical intersection between the two wellbores. This decision was, without a doubt, the single most important decision to be made. This project was a research project, and it would likely be difficult to get funding for a second attempt if this one failed.

Steam Assisted Gravity Drainage (SAGD) wells must be placed with great accuracy with respect to one another, so this was the most obvious survey ranging method to consider.

The ranging method developed for SAGD operations utilizes a wireline powered, tubing conveyed, magnetic field generating transmitter (solenoid) and a receiver (a specially adapted MWD survey system).

MOCK INTERSECTION TESTING

In order to prepare the directional driller and solenoid/MWD operator for the intersection, it was decided to simulate downhole conditions as closely as possible and conduct a mock intersection test at surface.

Conducting a mock intersection allowed the key operations personnel to practice their communication and decision making skills and gain some "intersection" drilling experience and confidence at the same time.

The tools were set up in the yard and calibrated before the mock test was to begin. The operators were then placed inside an MWD cabin and told to "make the intersection." After each survey taken, they would decide what directional correction needed to be made and two assistants would go outside and manually move the solenoid with respect to the MWD probe.

This scheme proved to be a very beneficial exercise, as there were several key learning points which contributed to the success of the project. For example, because the tools are reversed from their normal orientation to one another, the survey data is also reversed. However, with the flip of one switch in the software, most of this information is automatically corrected.

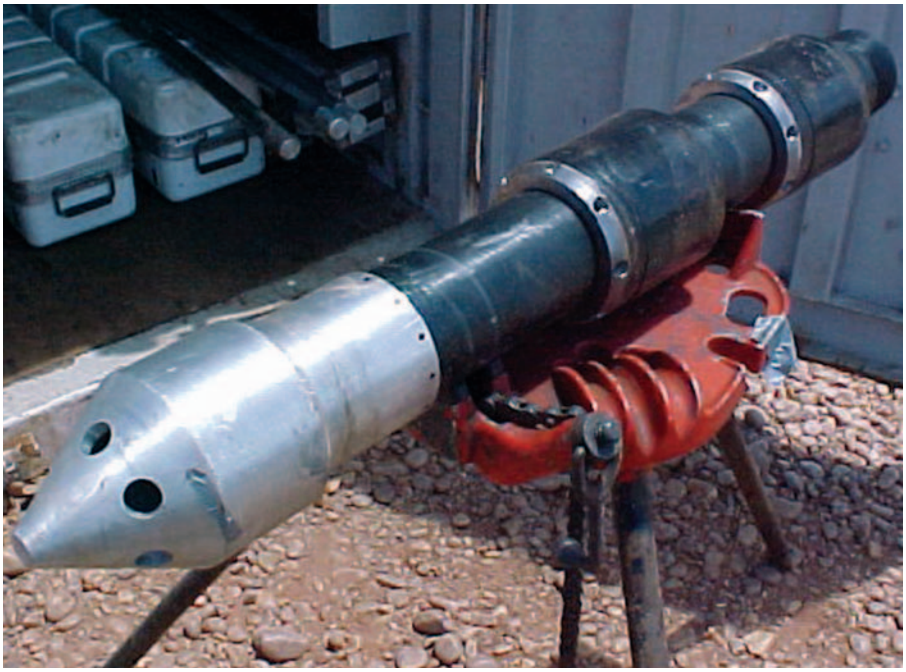
Potentially reversed survey data is not a problem as long as everyone is aware of the survey output and how it can be affected by the software and by the switches within the software.

However, if this simulation had not been run and the switch was inadvertently flipped during the actual drilling of the intersection, a failed attempt could have been the result. Learning about all these nuances ahead of time allowed us to put additional checks in place to prevent unknown problems.

WELL PLAN AND COMPLETION

Since several horizontal wells had already been drilled in this field, the directional well plan for these two wells was essentially the same as previous wells, with the same planned casing strings, of 9 ⅝-in. surface casing and 7-in. production casing/slotted liner.

The only difference was that the horizontal section of the wellbore would now be left open for an extended period of time while the second well was being drilled, and the slotted liner would be run after creating the intersection. The slotted liner would also be used to mechanically join the two wellbores.



The overlapping mechanical connection used to isolate any possible sand production duirng drilling and connectin of the wells was a needle nose guide shoe and washcup stinger assembly.

Since the connection method was a secondary objective of the intersection trial, it was kept as simple as possible. The overlapping mechanical connection used to isolate any possible sand production was simply a needle nosed guide shoe and washcup stinger assembly.

The length of time that the open-hole section was left open was a concern since the horizontal section was drilled in unconsolidated sand. Initial thoughts revolved around the temporary installation of a composite tubing string to ensure that the wellbore would remain open. The thought was that if the tubing became stuck, it could be drilled up and the intersection could still be completed successfully.

However, in the end, it was felt that the benefit of the composite tubing over regular steel tubing was not worth the risk of it breaking. Consequently, regular steel tubing was used as a conduit for pumping down the solenoid and the tubing was removed after the intersection was completed.

EXECUTION – WELL #1

The first well was drilled as per normal drilling operations in the field. However, it was requested that the well be drilled on as close to a straight azimuth as possible (N15°E), as the second well was planned to land directly over top of the first and then be dropped down for the intersection.

The first well was drilled to a depth of 80 m in 12 ¼-in. hole, and a 9 ⅝-in. casing string was run. The well was kicked off at 40 m in the 12 ¼-in. hole and the 9 5/8-in. casing shoe was landed at an inclination of approximately 16°.

After the 9 ⅝-in. casing was run and cemented, the shoe was drilled out with an 8 ¾-in. bit. The entire build section was then drilled with a dogleg severity of approximately 11–13° per 30 m. The well was landed at 90° at a TVD of about 195 m. After the build section was drilled, the BHA was pulled and the horizontal drilling assembly was installed. The horizontal section was then drilled to a total depth of 476 m.

This horizontal section was drilled an extra 30 m longer than required so that the solenoid could be placed in the toe (in a future operation) and help guide the second well into the correct position for the intersection.

After the horizontal leg was drilled, a combination of 7-in. slotted liner and 7-in. casing was run and cemented around the build section. The 7-in. casing shoe was landed at a measured depth of 318 m. The rest of the horizontal section was left open hole for the intersection.

A cement basket was positioned above the producing zone to keep the cement in the desired location. The casing was cemented as per plan, and the rig was moved to the second location.

A service rig was then moved over the first well to run the 2 ⅞-in. protective tubing for the solenoid. The rig was kept on standby while the second well was being drilled.

EXECUTION – WELL#2

The second well was drilled immediately following the first well to minimize the amount of time that the open hole in the first well would remain open.

The well plan was essentially the same as the first well, except that this well was drilled directly at the first well on an azimuth of N195°E,or 180° opposite the first well. The 12 ¼-in. hole was drilled to a depth of 80 m, and then a 9 ⅝-in. casing string was run. The well was kicked off at 40 m in the 12 ¼-in. hole and the 9 ⅝-in. casing shoe was landed at an inclination of approximately 21°.

After the 9 ⅝-in. casing was run and cemented, the shoe was drilled out with an 8 ¾-in. bit. The entire build section was then drilled with a standard MWD package until the angle was built to approximately 60° inclination, once again at a dogleg severity of about 11-13° per 30 m.

At this point the BHA was pulled out of the hole and the MWD ranging probe was made up, surface tested and run in the hole. At the same time, the 2 ⅞-in. tubing was run to TD in the first well, and the solenoid was pumped down on wireline to the end of the horizontal section inside the tubing so that it could be used to guide the final build section of this well.

The final buildup was made by guiding the drilling with the magnetic guidance system. It was immediately observed that a TVD correction of 0.5 m was necessary in order to correct the survey error between the two wells.

This correction was made and the drilling continued while referencing was done with the magnetic guidance system. Planning was done with directional drilling planning software. The magnetic guidance information was used to update the planning model throughout.

The targeted intersection was at the start of 55 m straight section that was at 87° in the target well (just past a high spot on the horizontal section). On the first attempted intersection, the well was landed at a slightly higher angle than the planned 88° inclination (it was actually 90° inclination) and 2 meters to the right side of the target well.

This error on inclination was largely due to the fact that the MWD probe was 16 m behind the bit, and the actual build rate was higher than projected at the landing point. This error meant that the target well was falling away at 87° inclination or diverging at an angle of 3°. This was not learned until the BHAs were changed and drilled another 16 m.

Being slightly to the right of the target well was a result of not being able to build and turn at the same time for fear of landing the well too low, and going into and out the other side of the target well. It was decided to get the entire angle built first, turn the well to get over the top of the target well and then angle down into it.

Unfortunately, since the target well was now falling away and the well had to turn the left to get back over it a large part of the available horizontal section was used, to get into a good position for the intersection.

Lessons Learned. The original plan was to drill directly over the target well and then slowly come down and intersect it from above. When this plan was tried on the first attempt, it was not known when the wellbore would collapse as the bit approached it. For this reason, the solenoid and 2 ⅞-in. tubing were installed and removed after every 18 m of drilled section when the bit was within 1.0 m of the target well.

This operation was very time consuming, and could have been conducted quicker by preparing for and using a side-entry sub in the tubing string. The tubing and solenoid could be moved back and forth together, without having to pull the solenoid completely out of the wellbore.

Alternatively, the solenoid could be run on coiled tubing to save time, however, modeling would be required to ensure that the coil could reach the intersection point in open hole. It may not be possible if smaller coiled tubing sizes are used, as they may reach lockup prior to reaching the end of the horizontal section.

Finally a borehole tractor could possibly be adapted that would run on wireline negating the need for the service rig and tubing string. By the time the well was lined up for the intersection, the intersection point ended up being where the inclination went from 93° to 87° in the first well.

This location for the intersection point complicated the intersection as the inclination had to be corrected accordingly to use projected inclinations for the intersection. As a result, the first attempted intersection crossed the target well 0.7 m above it.

As mentioned earlier, it was initially decided that it would be best to come directly over the top of the first well and slowly come down into it. For this reason, more attention was paid to the azimuth while drilling the first well, and there was less concern about the inclination.

This frame of mind proved to be an error in judgment and part of the learning experience associated with doing something for the first time. It is now known that the target wellbore should be drilled as straight as possible (both in azimuth and inclination) through the planned zone of intersection.

Improvement Possible. If possible, drilling both the first well and the second well should be done with near bit inclination measurement tools. This requisite will ensure that the last 100 m of the target well is drilled as straight as possible, and it will also solve any problems that could occur with having to project ahead during the landing and intersection operations while drilling the second well.

After the first attempt, it was decided to plug back and try to sidetrack the wellbore very close to the first intersection point. The reasoning was that the wells were very close together at this point, and it would be easier to intersect the target well.

An open-hole sidetrack was made, but, after a few more intersection well plans were made (done on the fly), it was soon discovered that the convergence angle required would be too high. There would be a very strong possibility of entering the target well and passing through it. Such passage would also complicate any further attempts farther up the hole, as the integrity of the first wellbore would have been compromised.

It was decided to abandon the intersection attempt at this position and sidetrack farther up the hole. Sidetracking uphole would allow for correction of both the initial landing and the direction of the well. It would also keep the intersection farther away from the casing shoe of the target well and give us more space to make a nice easy intersection point with a low convergence angle between the two wells.

The well was open hole sidetracked back at 238 m (73° inclination). It was then turned slightly so that it was at a convergence angle of approximately 4° with the target well. The well was then drilled to within 5-10 m of the planned intersection point.

At this point, with the probe at 292 m, the ranging surveys showed that the MWD probe was actually 1.7 m to the right and 0.59 m lower than the target well. Using the directional drilling program and projecting 16 m ahead to the bit (at 308 m), it was expected that the bit was about 0.55 m to the right and 0.0 m high of the target well, given the direction being drilled and the corrections made at that time.

It was therefore anticipated that the intersection would occur somewhere between a measured depth of 312-316 m. At this point the solenoid and the 2 ⅞-in. tubing were pulled from the target well so that the bit did not collide with them.

The well was then drilled another 6 m (measured depth of 314 m) and circulation was lost. The service rig on location over the target well immediately reported flow and shut in their well.

The BHA was then pushed downhole and the 8 ¾-in. bit entered the target well with 15,000 lbs slack off. It was pushed 4 m into the target well with slower circulation rates, confirming that the bit was in fact entering the target well and not sidetracking.

A connection was made and pumps were left off and the BHA was pushed another 3 m until it hung up. The pumps were turned back on at reduced circulation rates and the bit was worked downhole. Another connection was made and the bit was worked to a depth of 330 m very quickly. The well was then cleaned up prior to pulling out of hole.

MAKING CASING CONNECTION

The well was then logged with tubing conveyed logging tools, another cleanout trip was run, and the well was prepared for casing.

The guided bull nose shoe and washcup stinger assembly were made up to 10 m of 4 ½-in. tubing. This assembly was then made up to the bottom of the 7-in. slotted liner and casing string, and the casing string was run in the hole. The casing ran in the hole normally, and very little additional weight was noticed while passing through the intersection.

No indications of significant added weight meant that there was a nice smooth transition, with an actual convergence angle of about 4½-5° between the two wells.

The casing was pushed to TD, and the stinger was inserted 5 m inside the 7-in. casing shoe of the target well. The upper section of the casing was then cemented in place, as was also done on the first well.

FUTURE APPLICATIONS

Being able to drill and intersect boreholes toe-to-toe presents many new opportunities in well construction and field development design. While some of the following thoughts are big ideas, we believe them to be technologically possible today.

What's next for this method is to drill much larger U-tube spans, perhaps ultimately even a 10-20 km span between surface locations. The main limiting factors in drilling large U-tube segments in this manner is torque, drag, fracture gradient of the formation and the ability to sense the other well as you near the intersection point, to name a few. How to overcome all of these limitations is a subject in the future.

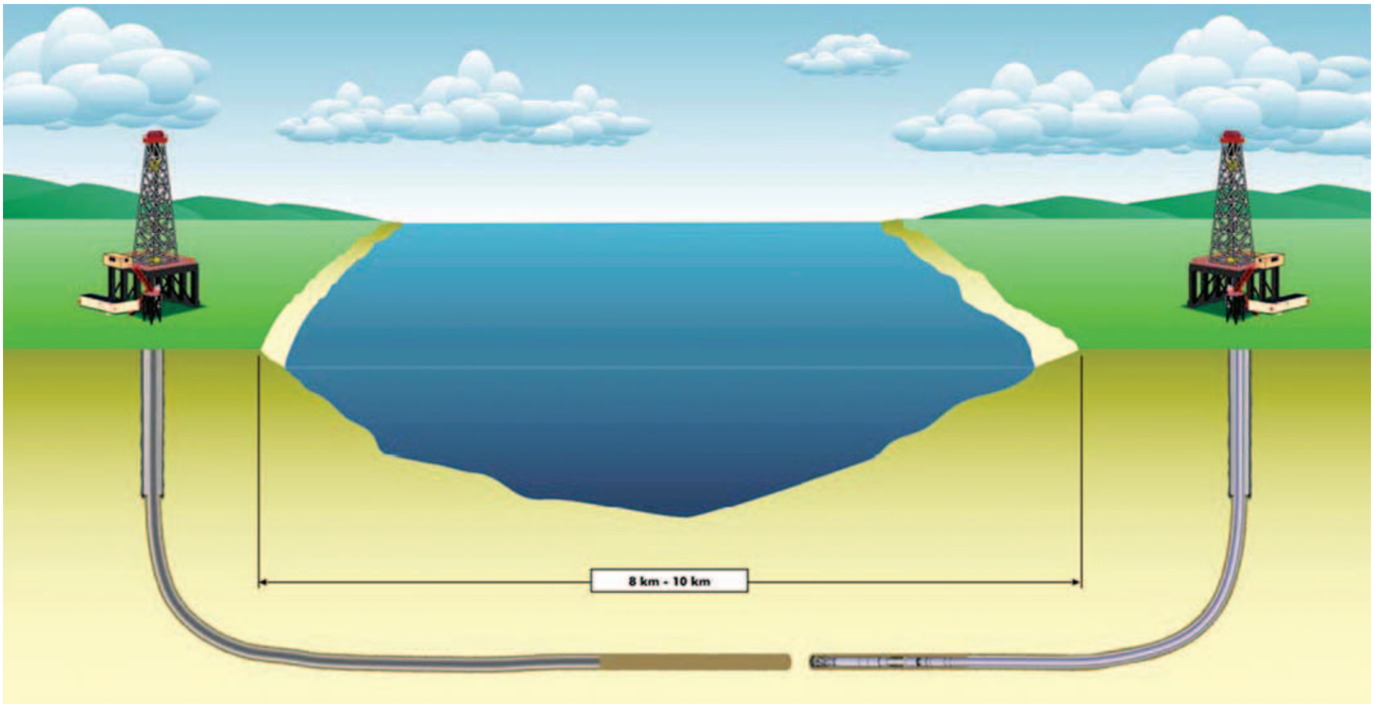
However, in general, today's ranging methods coupled with tightened surveying techniques and quality control can easily result in connecting boreholes together over such large spans. As the distances increase so will the complexity of the drilling and ranging program.

Drilling long distances for pipelines is now possible using this ranging method and conventional drilling technology. Taking it a step further, the composite coiled tubing technology is also a good candidate for super extended reach drilling.

The neutral buoyancy of the composite tubing eliminates the vast majority of drag in comparison to steel tubing and has its own downhole tractor to provide WOB. This composite coil system can drill distances measured in miles of hole. The drag forces can be as low as 138 times less than steel, essentially removing the drag concern from the equation.

One could also couple super extended-reach boreholes with expandable monobore liners. These liners could be positioned in place with the help of the tractor system referenced above then expanded to allow new segments to be drilled and lined well past existing technical limits of conventional well construction techniques.

To aid liner placement the liner can have drillable plugs that can seal an air/water mixture to allow the steel liner to be neutrally buoyant while being transferred to its placement point with the tractor.



Coonnecting wells end to end can address environmental concerns by eliminating access roads or installing subterranean pipelines in areas where a surface pipeline might interfere with migration routes or damage wildlife habitats. The above example illustrates the technology in river or gorge crossings.

In locations where icebergs scrape the ocean floor, such as the East coast of Canada in parts of the Grand Banks, subsea flowlines are at risk if they are laid down on the ocean floor. This danger all but eliminates subsea flowlines that can tie in step out wells to the existing platform. In these fields, additional reserves may be recovered by extending the length of the already extended reach wells.

Tying in surrounding satellite fields could also be achieved through the use of a subsurface pipeline and wellheads below the ocean floor. Daisy chaining these U-tubes together could be achieved using existing multi-lateral technologies.

Other locations in the world have very rugged shorelines where onshore facilities are high on cliffs or the route inland follows an environmentally sensitive shoreline. In these locations, bringing oil and gas to shore can be very challenging to do any other way.

A similar solution has already been implemented along the rugged coastline of Australia's Port Cambell National Park. A gas pipeline from BHP Billiton's Minerva gas field (12 km offshore) has been brought onto shore using a horizontal drilled wellbore.

Deep gorges on land or on the sea floor can be very problematic for a pipeline if not impossible to construct economically using conventional methods.

Pushing the envelope, other big opportunities might be to link the Chukchi Peninsula in Northeast Russia and the Seward Peninsula in Alaska. There has been talk of constructing a multi-billion dollar bridge for the purpose of connecting the two land masses to access Russian oil reserves but tunneling could be done at a fraction of the cost. Needless to say there is obviously no infrastructure built to these locations but the point is that the crossing may not be as expensive as conventional methods.

The concern over protecting our environment while producing reserves is in the forefront of planning for every responsible operator regardless of legislation.

Long-term access roads can be too costly to construct and maintain or the environmental impact of such a road might be prohibitive.

Subterranean pipelines can be used in environmentally sensitive areas where a surface pipeline might interfere with migration routes or damage habitat such as in the Arctic National Wildlife Refuge.

Such pipelines are also useful in politically hostile environments where even trench placed pipelines can be dug up and sabotaged.

It's much easier to defend pumping stations instead of an entire pipeline with this technique. Pumping stations set up along junction points in the U-tubes could be powered electrically or by natural gas. This results in a very small footprint, self-contained, pumping station. The pumping station might even be completely self-contained in the borehole.

It could be further covered over and hidden from view between maintenance intervals or with only a maintenance wellhead to service an ESP thereby reducing the surface footprint even further.

While wellbore intersections have occurred in the past, both intended and not, the ability to reliably connect two wellbores toe-to-toe opens the door to many new possibilities in well construction.

The practicality of connecting two boreholes together reliably using magnetic ranging technology has now been demonstrated and it is only a matter of time before we see more wells drilled in this manner, as the need arises. ■