Table 2: Depths to tops of formations penetrated by Test Well #2A.

Formation Top Depths (feet)		Formations and Members Test Well #2A
0		**Lakota Formation** – hole starts in Lakota sandstone.
139		**Morrison Formation**
234		**Sundance Formation**
	234	Redwater Shale Member Sundance Fm.
	580	LAK Member Sundance Fm.
	621	Hulett Sandstone Member Sundance Fm.
	644	Stockade Beaver Shale Mbr. Sundance Fm.
	740	Canyon Springs SS Mbr. of Sundance Fm.
754		**Spearfish Formation**
1394		**Minnekahta Limestone**
1432		**Opeche Shale**
1508		**Minnelusa Formation**
2370		**Madison Formation** (Pahasapa Limestone)
	2760	No samples 2760 to 2848 feet, air drilling wrecked shakers
2752		**Whitewood Dolomite and Winnipeg Formation**
2862		**Deadwood Formation**
2891		**Total depth** ending in Deadwood Formation

3 CONSTRUCTION

3.1 Drilling Equipment

The drilling equipment used for this project was Layne Christensen Company Rig No. 490 consisting of a Challenger 360 draw works and a Challenger 200 Derrick mounted on a triple-axle trailer with three 20,000-pound axles and a 4th pusher tag axle combination for a portable rotary drill rig combination. Photographs of the drilling rig and support equipment are shown in Appendix E.

3.1.1 Draw Works

The Challenger 360 draw works is equipped with a 10-foot elevated drill floor with a 200,000-pound floor capacity, 7 feet of under floor clearance and an IDECO 23-inch rotary table. On Test Well #2, the floor and rig were elevated one foot for flow line clearance to the mud pit in flooded reverse circulation configuration, providing an under floor clearance of 8-feet.

The Kelly drum and the hoisting drum on the double stacked drum rig were both 10-3/4" X 22-1/2 drums equipped with Wichita 24", 3-plate clutches and a PARMAC hydromatic twin disc water brake. LeBus grooving with 7/8-inch line (1-inch swaged

line) provided a single line pull of 36,000 pounds. A separate hydraulic wireline retrieval winch was equipped with 3000 feet of ¼-inch wireline for deviation measurements and other applications.

3.1.2 Derrick

The Challenger Model 200 derrick, with a top of crown height of 89 feet from ground level, was equipped with fluorescent derrick lighting and MD/TOTCO weight indicators. The working line was a Brewster 100-ton, 4-sheave traveling block and the drilling line was a McKissick 100-ton 4-sheave traveling block and hook combination with a rated hook load capacity of 200,000 pounds on 8 lines.

3.1.3 Power Unit

The power unit consisted of a Detroit Series 60, 540 horsepower diesel engine equipped with an Allison CLT5860 transmission with torque converter. The engine was housed in an enclosed engine compartment and equipped with a MAXIM silencer muffler and 100 gallons of on rig deck fuel storage.

3.1.4 Support Equipment

Support equipment included a 360-bbl portable mud pit plumbed for flooded reverse drilling. The mud pit was equipped with two shale shakers, fine mesh shale shaker screens for maximum solids removal, two desanders for solids removal, and a cyclone/gas buster. Two desilters were added for Test Well #2A as well as a smaller portable mud pit to catch cuttings and fluid from the shale shakers. The Challenger rig was equipped with an elevated, self-contained dog house; an 80-kW generator; a 300-amp welder; a 950-gallon diesel fuel storage tank with electric fueling pump; a hex Kelley and high-pressure swivel; a Bear automatic driller; a 15-horsepower Mission 2X3 mixing pump; a single-pen Geolograph for drilling rate; a 3 and 7 degree deviation survey tool and a Halliburton survey tool wire line. Other skid-mounted piston pumps and centrifugal pumps were added from time-to-time, as needed. The rig was wired with explosion proof electrical connections and was PASON ready equipped, although PASON services were not used.

Additional support equipment included a duplex pump for shallow cementing, an 1170-cfm Ingersoll Rand compressor for reverse circulation drilling, a 225-kW Cat generator to run the shale shakers and mud pit pumps, a field office trailer with separate sample analysis room and living quarters, a Magnum 90-kW (single phase) generator for the field office power and a Cat 430E 4X4 backhoe with front-loader bucket and forks. A second 900-cfm air compressor was added during drilling of Test Well #2A.

Two 400-bbl frac tanks were initially used for drilling operations and two more 400-bbl tanks were added later in drilling Test Wells #2 and #2A, to hold used drilling fluid until it was transported off-site for disposal. Various tractor-trailers and flatbed trailers were used to deliver equipment, casing, and drilling tools at various times. One Kenworth tractor was retained on site during drilling operations.

3.1.5 Air Package

The air package, used for direct air rotary drilling in the Madison aquifer strata, consisted of five compressors with a collective data-plate air capacity of 6,740 cfm and two 1600-psi boosters. The air compressor data-plate capacities were as follows:

Two	1350-CFM compressor	= 2700 CFM
One	1170-CFM compressor	= 1170 CFM
One	1070-CFM compressor	= 1070 CFM
Two	900-CFM compressors	= 1800 CFM
TOTAL RATED AIR VOLUME:		6740 CFM

The air compressors and boosters were connected through a common manifold that with valves to allow operation of individual compressors or combinations of compressors. Photo 1 shows the air compressors and boosters installed behind the drill rig.

Photo 2 shows a manifold used to direct compressed air from the five air compressors to the two boosters. Photo 3 shows the compressors and manifold with a light plant in the front, right foreground, blocking view of the connections to the two boosters out of sight to the right. Photo 4 shows the manifold used to connect high-pressure air from the boosters to the Kelly hose on the drill rig – two high-pressure steel lines coming in from the right from the 1600-psi boosters and a single high-pressure steel line going out left to the Kelly hose.

Photo 1: Five air compressors and two boosters for air rotary drilling.

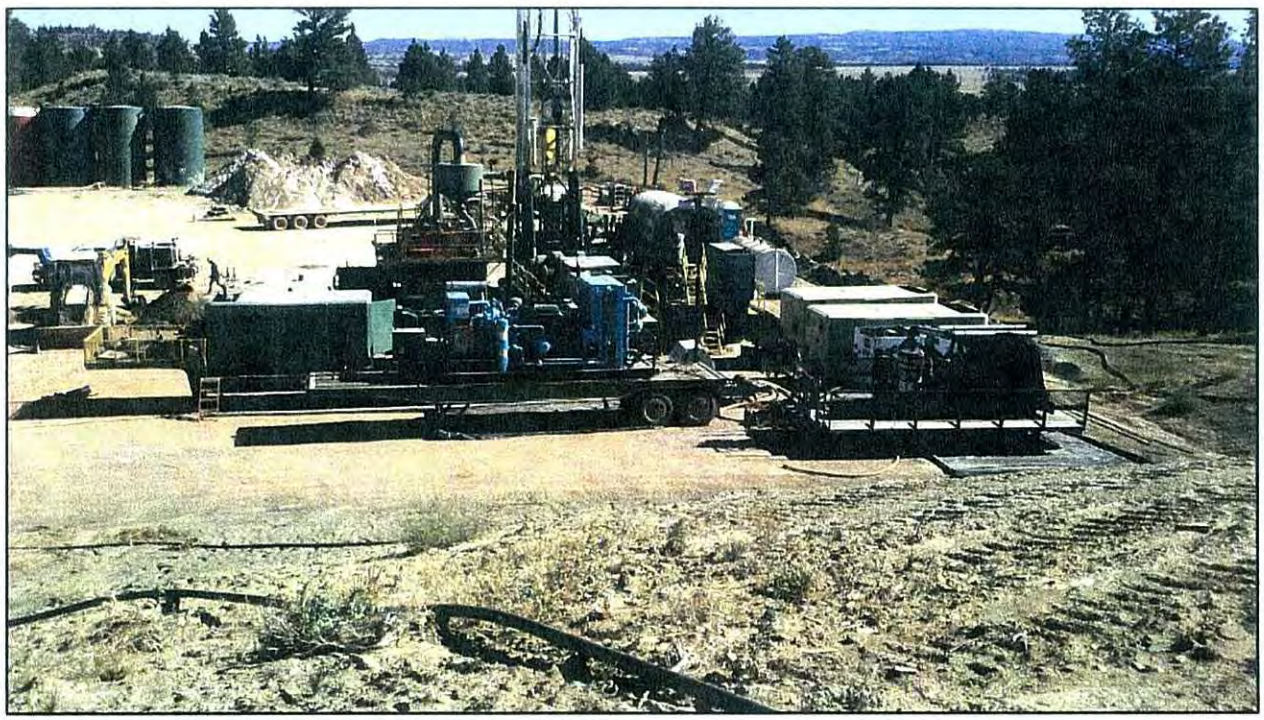


Photo 2: Manifold connecting compressors to boosters for air rotary drilling.

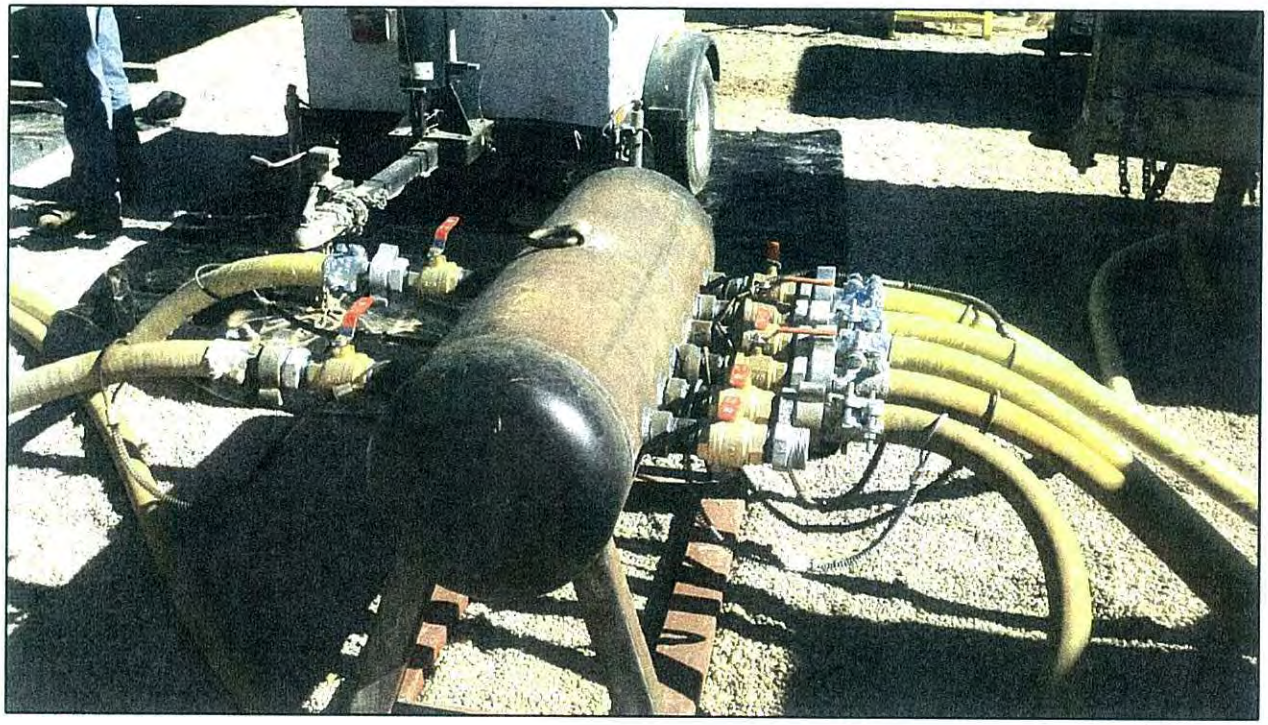
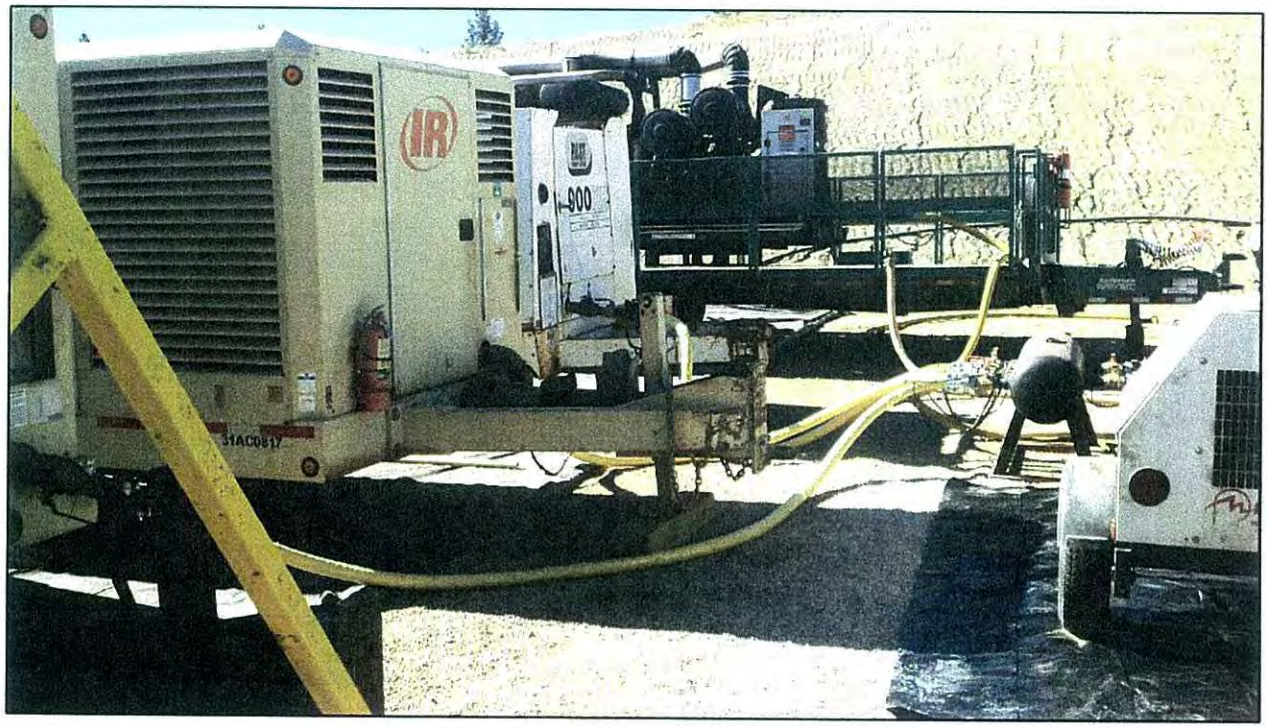


Photo 3: Compressors and manifold.



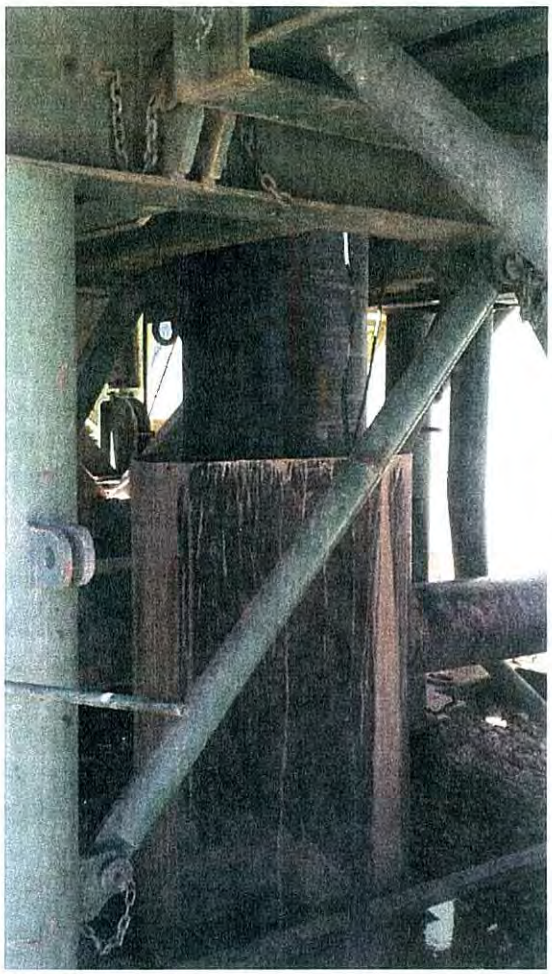


Photo 4 (below): Manifold used to direct air from boosters to Kelly hose on drill rig.

Photo 5 (left): View of surface conduit with mud pit line coming in from right and 24-inch casing hanging in hole.

3.2 Drilling Methods

The portions of the test wells to be cased were drilled with conventional flooded reverse drilling methods. Open hole in the Madison limestone was drilled with direct air rotary methods.

3.2.1 Flooded Reverse Method

Static fluid level in the portable mud put adjacent to the well was maintained between ground level and the top of the surface conduit. The surface conduit, as shown in Photo 5, extended high enough above the ground to allow a relatively full mud pit, but provide access to inspect drill bits and reamers above the surface conduit. Positive static pressure was maintained on the borehole with the drilling fluid level above the land surface. The static water level in the formation was subsequently determined to be 686 feet below land surface in the Madison aquifer and unknown for shallower water-bearing strata.

In flooded reverse drilling, the drilling fluid circulates from the mud pit, down the annulus between the drill pipe and the borehole wall. An airline is installed in the upper part of

the drill pipe and compressed air is injected through the swivel on the Kelly to displace drilling fluid out of the upper part of the drill pipe. This causes the fluid level in the drill pipe to be lower than that in the annulus outside the drill pipe, so fluid circulates through the drill bit, up through the drill pipe, carrying drill cuttings up the drill pipe to where they are discharged to a cyclone separator.

The cyclone directs the cuttings and drilling fluid into shale shakers there the cuttings are separated from the fluid. The shaker screens dump the cuttings overboard onto the ground or into an auxiliary pit where they can be removed with a backhoe. The drilling fluid is directed back to the main mud pit after the cuttings are removed by the shale shaker screens. Continuous injection of air into the upper part of the drill pipe pumps the system and maintains circulation. Standard mill tooth and carbide insert button tri-cone drill bits are used; however, they usually have their skirts cut off to allow large cuttings to pass through the center of the bit body and into the drill pipe.

Photo 6 shows the shale shakers dumping drill cuttings into a backhoe bucket. Photo 7 shows the shale shakers (orange equipment) mounted on the portable mud pit and dumping drill cuttings into an auxiliary mud pit. Photo 8 shows the auxiliary mud pit with the far end filling with drill cuttings from the shale shakers and the near end filling with saturated sand and silt in where it is discharged from the sand and silt separators that are used for solids control in the drilling fluid system. The auxiliary mud pit compartments shown in Photo 8 are cleaned periodically by means of a backhoe which moves the cuttings to a storage site on the drill pad.

Photo 6: Cyclone and shale shakers without auxiliary pit.

Photo 7: Shale shakers dumping samples into auxiliary pit.

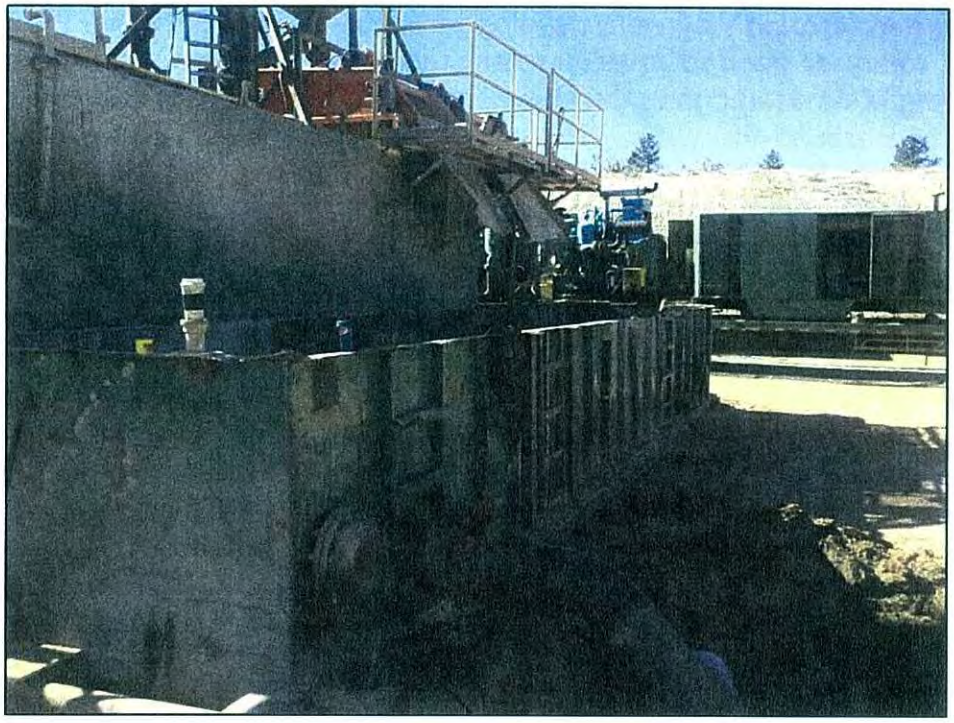
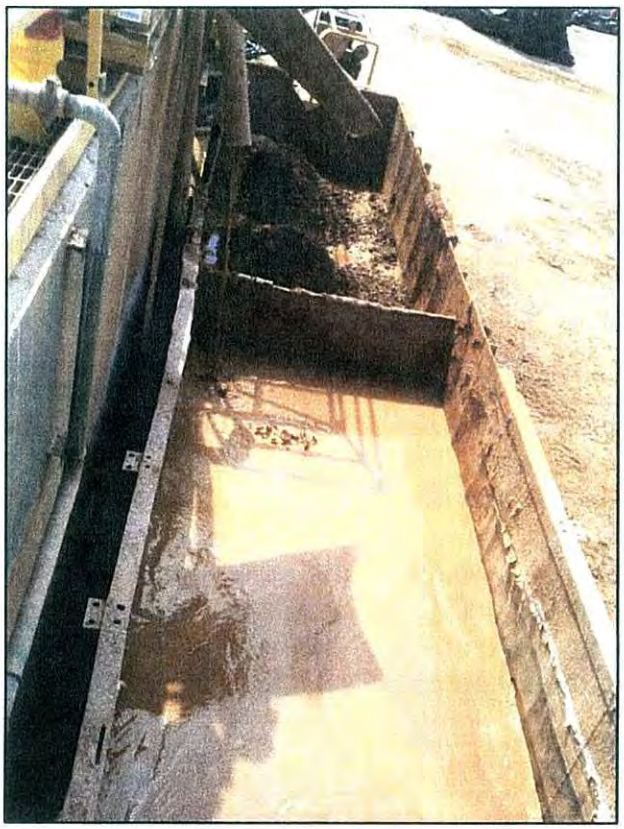


Photo 8 (left): Auxiliary mud pit with cuttings and sand and silt separator discharge.



3.2.2 Direct Air Rotary Method

The use of direct air rotary drilling for open hole in the Madison aquifer strata was selected for two reasons:

Discharge of formation water and drill cuttings from the hole during drilling would result in development of the production zones in the well while it was drilled. This would eliminate the need to develop the well after it was drilled with drilling mud.

Air rotary drilling would likely allow the borehole to penetrate the full thickness of the aquifer in conditions where mud rotary or flooded reverse rotary drilling would not be able to continue due to loss of circulation.

Reports of yield and drawdown tests of previously constructed Madison aquifer wells for the City of Gillette describe wells discharging large amounts of sediment and turbid water; even though they were developed with air lift pumping after they were drilled with direct rotary or flooded reverse rotary methods. The reports indicate that the air lift pumping rates used during development were not effective in cleaning up the productive formation around the wells. Therefore, a primary objective of direct air rotary drilling was to provide sufficient air lift capability to not only ensure that drill cuttings were removed from the advancing borehole during drilling, but that the rate of water pumped from the aquifer was sufficient to exceed potential pumping rates by test pumps after the well was completed. In order to meet these goals, the air package was designed with adequate pressure capability to air lift water from the bottom of the well, starting at static conditions.

The volume of compressed air required to accomplish the design goals was calculated with two different methods; volume based on minimum required up-hole flow velocity of 3000 ft/minute in 16-inch casing at the top of the well and volume based on kinetic energy requirements to lift drill cuttings and fluid out of the well. Both methods of calculating air requirements indicated that a 6000 cfm flow of compressed air was suitable for the anticipated drilling conditions. Estimates of probable static water levels in the Madison aquifer, based on the existing well field and the local geology, indicated a minimum air pressure of 1350 psi was required for the air package. Based on the foregoing requirements, the previously described air package with a data-plate capacity of 6740 cfm was provided, including two 1600-psi boosters. The use of two boosters was necessary to provide the required volume of 6000 cfm at the 1350-psi operating pressure.

3.3 Drilling Fluids

Drilling fluids for flooded reverse drilling consisted of conventional gel/polymer water-based drilling fluid. The design parameters for the drilling fluid system were to maintain water loss at 12 mL/30 seconds for most of the formation and as low as 8 mL/30 sec for the soft shales in the uppermost 700 to 800 feet of the borehole. Associated design parameters were to maintain mud weight at generally less than 9.0 lb/gal and Marsh funnel fluid viscosity at 36 to 40 seconds per liter.

The Daily Driller's Reports on Disc 1 provided with this report, contain a record of the drilling fluid additives used during the project, including drilling gel, regular and low viscosity polymer and pH control with soda ash. The reports also indicate the drilling fluid Marsh funnel viscosity, weight and water loss at approximately four-hour intervals. The records reflect the influence of dissolving natural clays in the uppermost 800 feet of strata which tend to increase the viscosity and weight of the drilling fluid. The records for Test Well #2 reflect difficulty controlling the drilling properties at the beginning of the project. Immediately after this problem was corrected, the well lost circulation and control of drilling fluid properties was not an option as an attempt was made to drill with formation water.

Control of drilling fluid properties during construction of Test Well #2A was given close attention and results were much better than in the abandoned hole. A polymer designed for clay encapsulation was not initially applied in the drilling fluid and this fact is reflected in fluid weights of 9.0 to 9.4 lb/gal and water loss exceeding 12 mL/30 sec in the uppermost few hundred feet of borehole.

Subsequent addition of a low viscosity, clay inhibiting polymer brought the fluid properties closer to the desired parameters; however, penetration of calcium-rich gypsum and anhydrite intimately interbedded into the Spearfish strata resulted in considerable reaction between the drill cuttings and the drilling fluid below a depth of about 750 feet. In general, repeated pumping off of used mud to be replaced with new drilling fluid containing additional gel and polymer was necessary to keep fluid weight at about 9.2 lb/gal or less and water loss down to about 12 mL/30 sec with frequent excursions in the range of 12 to 15 mL/30 sec occurring before mud was pumped off and new mud mixed. As shown on the Daily Driller's Reports on Disc 1, large amounts of soda ash were required to condition the mud. Soda ash is regarded as a pH-control additive; however, its real importance is to provide enough sodium cations in the drilling fluid to ensure that cation-exchange sites on the drilling gel clay are occupied by sodium, rather than by calcium from the formation. If calcium dominates the cation exchange sites on the colloids in the drilling fluid, the fluid weight and viscosity become unmanageable and the mud must be replaced with new mud. Therefore, large amounts of soda ash were used in the drilling fluid for Test Well #2A to prevent calcium from the gypsum and anhydrite in the Spearfish Formation from overwhelming the fluid system and degrading the drilling mud properties. Even so, it was necessary to frequently pump off used mud and replace it with new product.

The drilling fluid for direct air rotary drilling was compressed air. Additives such as water or foam were not used with the compressed air because of the difficulty of attempting to inject fluid into the compressed air stream at high pressures.

3.4 Construction History

3.4.1 Road Construction

Construction of an access road and 300 foot by 300 foot drilling pads at two test well sites began with staking of the alignment and mobilization of equipment on October 4, 2011. Pioneering of the road began on October 5, 2011 and on October 6, 2011, grading of the Test Well #2 site began as well as stockpiling of base course hauled from Sundance, Wyoming. Installation of culverts began on October 10 and installation of a cattle guard and silt fences began on October 11, 2011. Rough grading of Site #2 was completed on October 12, and grading with a road grader began while road base was completed from the highway to the south boundary of Section 36. Laying of road base continued into Section 36 beginning October 12, and by October 17, graveling of Site #2 with road base began while the Caterpillar dozer and scraper were moved to Site #1 to begin rough grading of the drill pad. Laying of road base continued and graveling of Site #1 started October 22 and was finished October 24, 2011. Base course was finished to Site #1 on October 26, 2011, completing the road construction effort.

Layne Christensen began staging drilling equipment along State Highway 14 on October 18, 2011, so the equipment would be ready to mobilize to a drill pad when road construction and drill pad construction were completed. A Layne Christensen caisson rig arrived on site on October 19, 2011 to begin drilling rat hole for surface conduit, concurrent with on-going road and pad construction.

3.4.2 Test Well #2

A summary history of drilling and abandonment of Test Well #2 is set forth below.

3.4.2.1 36-Inch Surface Conduit

At Test Well #2, a caisson rig drilled a 42-inch diameter auger hole to auger refusal on hard bedrock at 19 feet below the drill pad surface on October 19, 2011. A large-diameter coring rig was used to drill core hole into the hard siltstone at the top of the Fall River Formation siltstone unit from 19 feet to a depth of 34 feet. Surface conduit 40-feet long, consisting of 36-inch O.D., 0.375-inch wall steel casing, was installed in the 42-inch open hole with 6 feet of casing sticking up above the ground surface. The surface conduit was cemented into the 42-inch diameter hole on October 21, 2011, with 5 to 6 yards of 14.8 lb/gal, six gallon per sack, Portland cement.

Photo 9: Fall River siltstone in surface conduit core hole for Test Well #2.

3.4.2.2 24-Inch Surface Casing

All depths recorded on Daily Drilling Reports, geological logs, geophysical logs, and construction logs for Test Well #2 are based on depth below the Kelly bushing (depth KB), as required by the specifications for this project. The Kelly bushing was 9.7 feet above ground level. Accordingly, depth below ground level (BGL) can be determined by subtracting 9.7 feet from all depths given as depth KB. This protocol was changed at Test Well #2A, where all depths are recorded as depth below ground level (BGL). The change to depth BGL was made because the Layne crews were used to working with all depths expressed as BGL, and using depth KB, contrary to their normal procedures, was causing confusion in recording drill pipe tallies, casing tallies and drilling depth. Accordingly, in the descriptions of casings and construction history below, depths for Test Well #2 are consistently expressed as depth KB whereas those for Test Well #2A are consistently expressed as depth BGL in all of the Daily Drilling Reports and supporting documents for the wells.

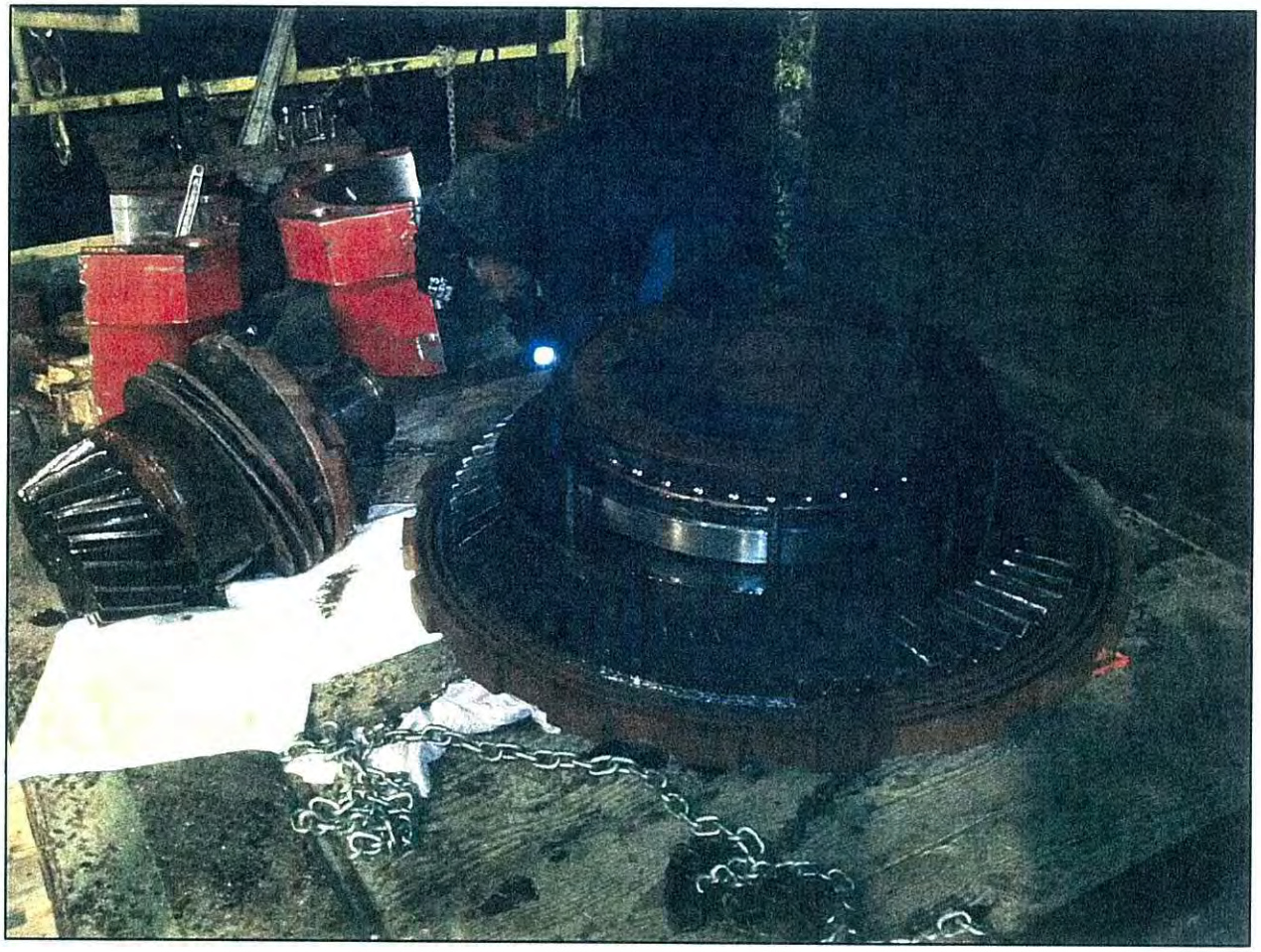
The 24-inch surface casing in Test Well #2 consists of 0.375-inch wall thickness casing installed to a depth of 70 feet below ground level (BGL).

The components of the Challenger 360/200 rig were mobilized to Test Well #2 from October 18 through October 20, 2011 and rigging up commenced. The 300-barrel (bbl) mud pit was set up first and water hauling and mixing of mud followed while the remainder of the drilling equipment was rigged. Layne Christensen had rebuilt the main hydraulic pump for the drill rig prior to starting this job. When an attempt was made to raise the derrick, the new pump was not working properly. It was ultimately returned to Denver where it had been rebuilt and where it was found to be improperly assembled by the pump service company. Rigging up was completed by 5:00 p.m. on October 26, 2011, including mixing of mud. A 17.5-inch long mill tooth lead bit and 32-inch long mill tooth reamer were assembled and hung in the surface conduit below the rig floor. The 23-inch IDECO rotary table was installed on the floor and the drive line connected.

At 8:00 p.m. on October 26, 2011, drilling of 32-inch diameter borehole for the surface casing began. The intention was to drill a short distance with the reamer on the assembly to keep the lead bit centered in the hole. After a hole was established in the center of the surface conduit, the reamer would be removed and pilot hole would be drilled for surface casing.

After one foot of drilling, it was evident that something was wrong with the gears in the IDECO rotary table. This was a surprise because the rotary table was new, having just been assembled in Houston and installed on the rig for this project. Drilling was stopped and the Layne Christensen driller began diagnosing the problem, starting with inspection of the driveline. Various attempts were made to correct the problem, but the table continued to exhibit distress when operated, indicating the ring and pinion gears in the table were not set correctly.

Photo 10: Ring and pinion gear for IDECO 23-inch rotary table.



Layne Christensen flew in an equipment repair specialist from Houston who disassembled and reassembled the rotary table several times, finally concluding that the pinion gear did not have the same helical pattern as the helical teeth on the ring gear. A search for a new pinion gear was initiated, but finding one that matched the ring gear was difficult. A new gear was eventually found and installed and the tool string was assembled to drill 14.75-inch pilot hole, starting in the hole centered in the surface conduit earlier when the 32-inch reamer was on the tool assembly.

Drilling of 14.75-inch pilot hole commenced at 1:00 a.m. on November 1, 2011. A deviation survey was performed at 120 feet and determined 0.25 degrees of inclination (the Daily Drilling Report Form records 0.5 degrees because of a misunderstanding in how to read the instrument). The pilot hole was stopped at the direction of the Morrison-Maierle Chief Geologist at 147 feet KB at 8:00 p.m. on November 1, 2011. The Kelley bushing was 9.7 feet above ground level so all depths KB must be corrected to depth below ground level (BGL) by subtracting 9.7 feet from the KB depth. The tools were tripped out of the hole and reassembled with a 17.5-inch lead bit and a 32-inch reamer. Reaming of 32-inch hole began at 2:30 a.m. on November 2, 2011 and was

completed at a depth of 80 feet KB at 12:00 noon on November 2, 2011, stopping in the hard sandstone of the lower Lakota Formation where the surface casing sitting on the bottom of the hole would have a foundation with high compressive strength for bearing loads in the future.

Surface casing consisting of 24-inch outside diameter, 0.375-inch wall, steel casing was installed to a nominal depth of 80 feet KB and excess length on the 82-foot length of casing was cut off. A total of 6 cubic yards of 14.8-lb/gal, 6-gal/sack neat cement grout with 2 percent calcium chloride was pumped through a tremie pipe into the annulus between the 24-inch casing and 32-inch borehole on November 3, 2011 with returns observed, but not measured, at the surface. Pumping of grout was completed by 8:15 a.m. on that date and after the cement had set for 24 hours, the top of the cement in the annulus was measured at 27 feet KB and inside the casing at 52 feet KB. The tops to the cement account for the 6 cubic yards pumped plus the observed overrun.

3.4.2.3 16-Inch Pumping Chamber (Abandoned)

Test Well #2 was designed for installation of 16-inch casing in 22-inch borehole to a depth of 1850 feet to provide a chamber for a production pump. However, loss of circulation followed by loss of the drilling tools resulted in abandonment of this hole before the 16-inch casing was installed.

The 28 feet of cement inside the 24-inch surface casing was drilled out beginning at 5:00 a.m. on November 4, 2011; starting at 52 feet KB with a 14.75-inch diameter long tooth mill bit lead and a 22-inch diameter long tooth mill bit reamer.

After penetration of the Redwater Shale Member of the Sundance Formation at 250 feet, mud weight and viscosity began to rise due to dissolution of natural clay into the drilling fluid. Weighted mud was pumped off and water added at 311 feet, keeping mud weight around 9.1 to 9.2 lb/gal with 37 to 42 second Marsh funnel viscosity. The rate of penetration (ROP) became progressively slower until it was less than one foot per hour at 427 feet KB at 5:00 a.m. on November 8, 2011. The tools were tripped out and the bit and reamer were found to be completely encased in hard clay such that the tri-cones on the bits were not turning. The bit and reamer exhibited very little wear. A 2-pound hammer and a chisel were required to remove the compacted clay from the bit and reamer.

A 14.75 inch long tooth mill bit was tripped back into the hole without a reamer and drilling of 14.75-inch pilot hole began at 427 feet KB at 2:00 p.m. on November 8, 2011. The bit was replaced with a similar bit at 1115 feet KB. Pilot-hole drilling continued until 1:00 a.m. on November 19, 2011 when circulation was lost in the 14.75-inch pilot hole at a depth of 1585 feet KB in sandstone in the upper Minnelusa. Lost circulation material consisting of Baroid N-Seal was mixed and circulation was restored. The bottom of the hole contained 20 feet of backfill when circulation was restored and drilling new pilot hole resumed at 1585 feet KB at 1:00 a.m. on November 21, 2011.

At 1626 feet KB, circulation was lost again at 11:30 p.m. on November 21, 2011. A mixture of 400 bbl of LCM was flowed into the borehole at an average rate exceeding 1,300 gpm and disappeared under a vacuum the entire time, without bringing the fluid level up to where it could be observed. This indicated the presence of a relatively large, open fracture. The geolograph record indicated the last foot of penetration took place in less than one minute compared to the 10-feet per hour ROP in the preceding 10 feet, suggesting a vertical fracture.

In order to make progress through the forthcoming Thanksgiving holiday, a decision was made to resume reaming the hole to 22-inch diameter, starting at 427 feet KB. The bottom of the hole was filled with 10 feet of pea gravel followed by a backfill of pure 3/8-inch hole plug (bentonite chips). Circulation was reestablished, and reaming of the hole to 22-inch diameter began at 427 feet at 11:00 a.m. on November 23, 2011 with a 17.5-inch long tooth mill bit lead and a 22-inch long tooth mill bit reamer. Reaming continued until 8:50 p.m. on December 2, 2011 when a flange on the U-joints on the driveshaft to the rotary table broke with reaming at a depth of 1408 feet KB. Circulation was continued while a new part was obtained and installed, and reaming resumed at 1408 feet KB at 1:00 p.m. on December 3, 2011.

At approximately 10:00 a.m. on December 4, at a reaming depth of 1452 feet KB, the bit and reamer were tripped out of the hole and replaced with a 16-inch long tooth mill bit lead and a 22-inch button bit reamer. Reaming continued until 8:45 p.m. on December 6, 2011 when circulation was lost at 1589 ft KB, as the reamer above the lead bit passed through the former zone of lost circulation.

After mixing and circulating 350 bbl of polymer gel with N-Seal LCM, the fluid level was reestablished. The coupler on the shaft to the jet mixer broke and drilling was delayed until the mixer was made operational. Reaming resumed at 1589 feet KB at 8:00 a.m. on December 7, 2011 and continued to 1608 feet where pea gravel previously dumped in the well began returning to the surface in the drill cuttings and the pit began to lose a foot or two of water at a time as the top of the gravel backfill column would take water, then plug off, then open up as it was penetrated by the drill bit. This continued to 1622 ft KB when all the fluid in the mud pit (300 -350 bbl) was lost to the borehole at 2:35 p.m. An attempt to plug the lost circulation with polymer gell and LCM was not successful and washing eight 50-pound bags of 3/8-inch bentonite chips (Hole Plug) into the hole did not help.

Following the latter loss of circulation, repeated attempts were made to restore circulation by applying LCM (N-Seal) in gel/polymer mud. Although the borehole was filled with fluid for short periods of time, resumption of drilling resulted in almost immediate loss of circulation.

At 5:10 a.m. on December 11, 2011, 200 sacks of 14.8-lb/gal cement with 3% calcium chloride and 3/4-lb/sack cellophane flakes (Flowtroll) were displaced through a tremie pipe from 1626 feet back up the hole. The top of the plug was tagged at 1561 feet KB, indicating that with true hole size of 22 inches, about 92 cubic feet of cement column

was absent, presumably because the cement went into the fractured formation. The volume of drilling mud required to return fluid to the surface was essentially equal to the borehole volume, causing the driller to erroneously conclude that the borehole was empty of fluid to the top of the cement plug. This supported the incorrect conclusion that the static water level in the hole was very deep or absent, such that drilling with formation water was not an option.

After tripping tools into the hole, backfill on top of the cement plug was encountered at 1488 feet at 1:00 a.m. on December 12, 2011. The backfill included LCM and other materials displaced off the bottom of the borehole by the cement plug. The bit encountered the top of the cement plug at 1522 feet, indicating that the depth of 1561 feet measured with the tremie pipe was incorrect due to a miscount of the tremie pipe in the hole. The cement plug was drilled out by 5:00 a.m. on December 13, 2011 at which time circulation was lost. The crew was sent to Belle Fourche for more LCM and two pills of 400 bbl and 300 bbl, respectively, were flowed into the borehole, including 192 sacks of N-Seal. This restored circulation and on December 14, 2011, the hole was advanced from 1628 to 1631 feet at which depth circulation was lost at 4:30 a.m.

The drill pipe was tripped out and tremie pipe tripped in by 10:45 p.m. for cementing. Cementing began at 11:05 p.m. and was completed at 11:30 p.m. with another hot plug of 14.8-lb/gal Type III cement with 3% calcium chloride and 3/4-lb/sack flocell. The top of the hot plug was tagged at 1532 feet KB at 3:30 a.m. December 15, 2011.

Drilling cement plug began at 10:00 a.m. December 15, 2011. The bottom of the plug was drilled out at 2:30 a.m. on December 16, 2011 at which time circulation was lost. One pill of LCM was mixed and flowed into the hole at 5:30 a.m. with no returns to the surface. Mike Kaczmarek, Chief Geologist for Morrison-Maierle arrived at 6:30 p.m. with a sonic sounder to measure the fluid level in the drill pipe and borehole. By that time the hole was rigged for another cement plug and by 9:00 p.m., 200 sacks of the hot plug mix used before had been displaced into the borehole. The top of the hot plug was tagged at 1517 feet KB at 1:30 a.m. on December 17, 2011. Tools were tripped in and reaming backfill above the hot plug began at 1:00 p.m. at 1420 feet KB. Backfill contained a large amount of LCM displaced off bottom of the borehole by cement. The top of the hot plug was penetrated at 7:30 p.m. at 1520 feet KB.

The cement plug was drilled out at 1:50 p.m. on December 18, 2011 at 1630 feet KB, penetrating shale backfill to 1631 feet KB. As drilling new hole resumed at 1631 feet KB, circulation was lost before reaching 1632 feet KB. The mud pit drained out in seven minutes at average rate of 1,350 gpm. The sonic sounder was used to determine that the water level inside and outside the drill pipe was 708 feet BGL. Until this time, the airline in the drill pipe had been no more than 500 feet deep. Verifying the formation water level of approximately 700 feet opened the possibility of drilling with formation water, and the air line was extended to 960 feet KB, providing a flow of 113 gpm from the formation. The airline pipe was too small and caused considerable friction loss expressed as backpressure. Formation water was used to drill through four feet of backfill to 1631 feet KB by midnight, December 18, 2011.

In the early morning hours of December 19, 2011, the hole was advanced from 1631 to 1633 feet KB using formation water; however, the flow of water was insufficient to clean the drill pipe of the larger cuttings, up to 2 inches or more in mean size, and the drill pipe gradually became plugged. The drill pipe was tripped out and cleaned and tripped back in with the airline extended to 1000 feet KB. A flow of 160 gpm was obtained from the formation with the increased airline depth and with an increase in airline diameter to 2 inchs. Drilling resumed at 5:30 p.m. on December 20, 2011 on backfill at 1610 feet KB. Reaming backfill continued until 8:00 a.m. on December 21, 2011 when drilling of new hole began at 1633 feet KB. The formation was producing about 138.5 gpm from the fracture in the Minnelusa, according to mud pit volumetric measurements made with a pressure transducer in the mud pit.

By December 22, 2011, the hole was advanced to 1696 feet KB whereupon the flow of water into the drill pipe was plugged off by backfill sloughing off the upper part of the borehole and falling on top of the bit. If the drill pipe was lifted up and rotated, flow was reestablished, but when an attempt was made to drill, the flow into the drill pipe ceased. Drilling stopped at 11:45 a.m. on December 22, 2011 and the tools were tripped out of the hole, preparatory to the crew departing the site for the Christmas holiday.

The borehole was not filled with drilling fluid on December 22, 2011 and the fluid remained at static (approximately 700 feet BGL) until work resumed on December 27, 2011. On December 27, 2011, a 2 or 3-foot bridge of caved material was encountered at 759 feet KB. Another bridge of caved material was encountered at 1160 feet KB and was drilled out, ending at 1271 feet KB at 5:00 p.m. on December 28, 2011. Open hole was found from 1271 feet to 1547 feet KB. The borehole below 1571 feet KB was filled with caved backfill. Reaming of backfill reached 1623 feet KB by 9:30 a.m. on December 29, 2011, when the mud pit began to drain into the borehole.

After the backfill in the borehole was removed to a depth of 1623 feet, the rate at which backfill was falling into the borehole from the shale above 800 feet was essentially equal to the rate at which backfill could be removed, using the flow of formation water up through the backfill. Small advances in removing backfill would be made, followed by abrupt loss of progress to caving of shale above 800 feet or by the need to pull the bit and reamer up to prevent plugging on the outside of the drill pipe due to material falling in faster than it could be removed with the limited flow of water produced from the formation. Various mixtures of drilling fluid and changes in tools were made without any lasting success in overcoming the influx of caving material.

Reaming backfill out of existing borehole advanced to 1636 feet KB at 7:00 p.m. on January 3, 2012, with no increase in flow of formation water. Reaming advanced to 1656 feet KB by 9:30 a.m. on January 4, 2012. Just before 12:45 p.m. on January 4, 2012, caved material above the reamer partially stopped the flow of water to the bit and drill pipe. The driller stopped and circulated out a large volume of backfill until no sediments were coming up the drill pipe; however, the flow of water to the drill pipe remained restricted by the caved material outside the drill pipe.

The drill pipe was pulled back one Kelly bar length to 1632 feet KB following which material collapsed onto the tools, locking them in the hole at 1:34 p.m., making it impossible to rotate the bit or pull it up or down. The driller worked to free the stuck drill pipe, ultimately pulling up to 240,000 pounds while rocking the bit forward and reverse with the rotary table. Lowering the tools allowed more caving and the bit would not come up. Adding water to hole increased the weight on the tools, indicating circulation was plugged off by caved material and the reamer and caved material are acting like a piston in the borehole. The tools finally became free at about 4:30 p.m. and were tripped out of the hole, with all pipe laid down by 2:00 a.m. on January 5, 2012.

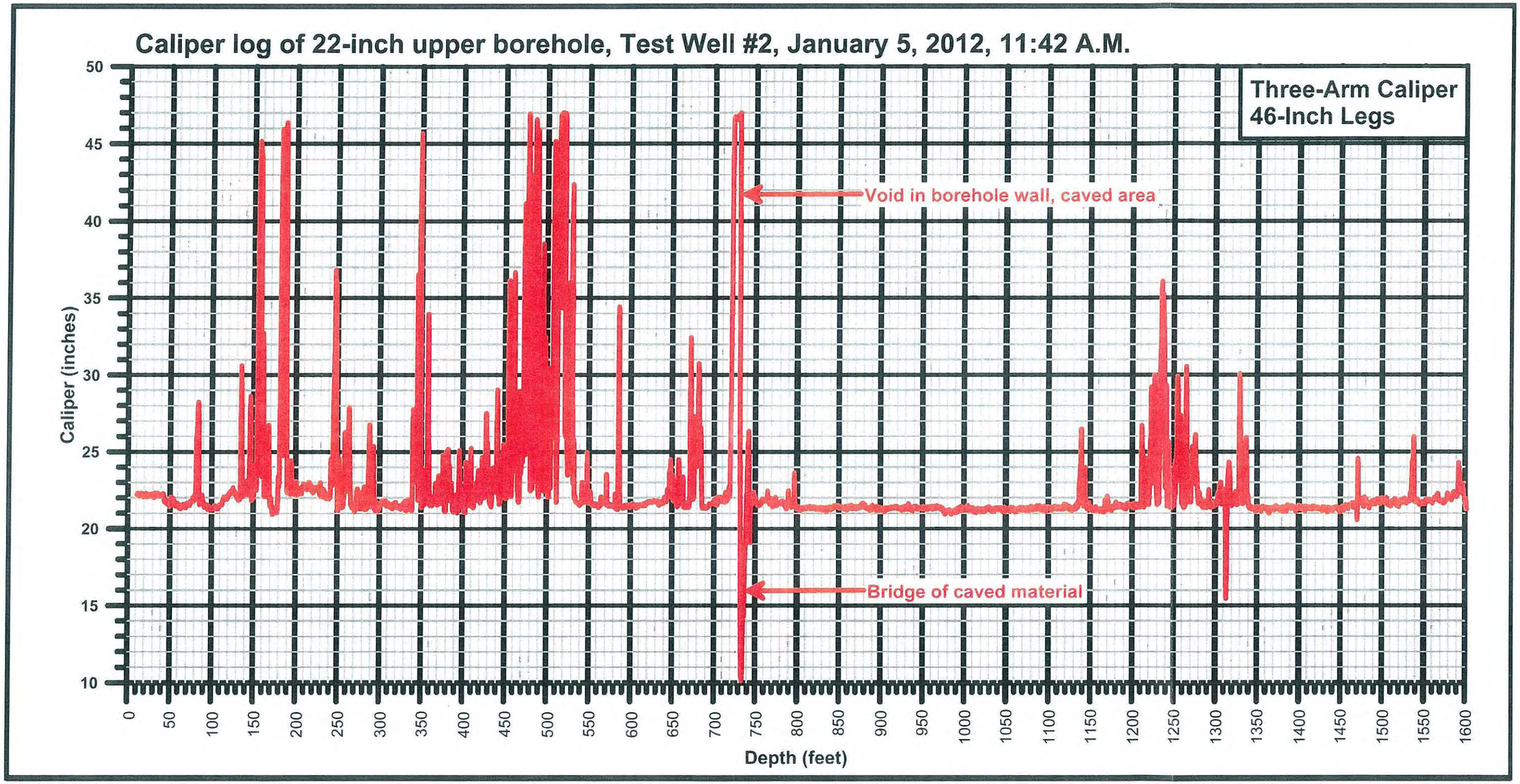
At approximately 7:30 a.m. on January 5, 2012, a caliper tool was lowered into the hole and encountered a bridge of caved material at 1133 feet KB. Attempts were made for about half an hour to drop the tool through the bridge at which time material caved in and raised the top of the bridge from 1133 feet KB to 1129 feet KB. The caliper was used to log borehole diameter from the top of the bridge back to the surface. The caliper was equipped with 34-inch arms which proved to be too short to reach the borehole walls in quite a number of places in the shale in the Sundance and Morrison Formations above 750 feet.

The borehole was flooded with about 540 bbl of water at more than 1,300 gpm while the loggers went to Gillette for longer caliper arms. The caliper tool equipped with 46-inch arms went to the top of the backfill at 1607 feet KB. While coming up the hole, the tool hit a bridge of caved material at 732 to 740 feet KB; however, the wireline pulled the tool through the bridge with no problem. The caliper log indicated many portions of borehole larger in diameter than 46-inch caliper arms in the area above 750 feet KB in the Sundance and Morrison Formations, as shown on Figure 4.

The caliper log (Figure 4) indicated unstable borehole above 750 feet KB and one area of unstable mudstone in the Spearfish Formation from 1210 to 1340 feet KB as well. Options to stabilize the upper borehole included lining it with 20-inch casing or spotting hot plugs in the caving zones to stabilize them with cement. Installation of 20-inch casing in 22-inch nominal diameter borehole offered a real risk that the casing could not be installed to the necessary depth below 750 feet KB, so installation of hot plugs in the unstable intervals was selected to stabilize the borehole.

The drilling operation remained on standby until 1900 hrs on January 6, 2012 when the tripping of tremie pipe back into the hole began. The tremie pipe encountered a hard bridge at 722 feet at about midnight and was tripped out because the end of it was slotted for cementing and could not be used to wash through the bridge. The tremie pipe was tripped back in with a bare end, reaching the top of the bridged material at 8:45 a.m. on January 7, 2012. The tremie pipe was pressured up to as much as 800 to 1000 psi, with the flow passing through the bridge most of the time. Dropping the tremie pipe two or three feet onto the plug burrowed it through large, hard fragments of rock in the bridge, penetrating about four feet of material before breaking through into open hole.

Figure 4: Caliper log of 22-inch upper borehole, COG Test Well #2 on January 5, 2012, prior to attempt to stabilize hole with cement.



The top of caved backfill was tagged at 1605 feet and the tremie pipe was pulled back to 1600 feet KB. Water was circulated through the tremie pipe followed by 200 sacks of 14.8-lb/gal Type III cement with 2% calcium chloride and 1/2 lb/sack flocell. The tubing was displaced with 8 bbl of water at 12:30 p.m. and eight joints tubing were pulled and laid down. The top of the hot plug was tagged at 1502 feet KB at 2000 hrs after which 72-second viscosity mud was used to displace the hole from the hot plug up. After the hole was displaced with mud, the rig was on standby while circulating the hole, waiting for contract modifications.

Circulating 70 to 72-second mud on standby continued until 6:00 p.m. on January 10, 2012, 800 bbls of fresh water was displaced into the hole and the fluid remaining in the hole was circulated to balance the hole. At 5:00 a.m. on January 11, 2012, the hole remained slightly overbalanced with 30 to 40 gpm flowing out of the tremie pipe, when the crew started tripping the tremie pipe out of the hole. The overbalanced condition was interpreted to be the result of viscous mud draining out of the enlarged portions of the borehole above 750 feet.

Following removal of viscous drilling fluid and obtaining equal fluid weight in the borehole except for heavy fluid draining out of the enlarged portions of borehole, cement hot plugs alternating with pea gravel backfill were installed in the borehole to stabilize the caving zones. The hot plug and gravel backfill sequence was as follows:

Surface to 106 feet	Open hole
106 to 762 feet	1905 sacks 14.8 lb/gal cement
762 to 806 feet	caved backfill
806 to 1185 feet	pea gravel
1185 to 1354 feet	405 sacks 14.8 lb/gal cement
1354 to 1482 feet	pea gravel
1482 to 1502 feet	caved backfill
1502 to 1605 feet	200 sacks 14.8 lb/gal cement

The tops of cement plugs, pea gravel backfill, and caved backfill were tagged with either tremmie pipe or drill pipe as the borehole was plugged and backfilled. Attempts were made to drill and circulate out caved backfill, but the rate of backfill caving often equaled the rate at which it could be removed, resulting in some backfill remaining in the hole. The last of the cement was pumped ending 12:54 p.m. on January 15, 2012.

Drilling out of the cement plugs and backfill installed to stabilize the borehole began at 7:00 a.m. on January 16, 2012. Drilling proceeded routinely; however, by the time a depth of 708 feet was reached at 9:30 a.m. on January 18, 2012, the driller was encountering bridges of caved and somewhat soft cement at 227 to 240 feet and three other bridges between 240 and 460 feet and a thick bridge of backfill from 460 to 600 feet, indicating stabilization of the borehole was not successful.

On January 19, 2012, at 3:00 p.m. at a depth of 888 feet, the drill pipe was inadvertently separated by unscrewing a tool joint at 210 feet KB. Attempts to reconnect the tool string were not initially successful and a series of events followed this incident that terminated with loss of a significant part of the tool string in the borehole and permanent abandonment of the well.

After the separation of the drill string, a centering tool was built and the tool string was reconnected by 12:40 p.m. on January 20, 2012. The tools were stuck at this time, but with various attempts at high-pressure circulation, the tools came up 1.5 feet on the morning of January 21, 2012, and early in the morning of January 22, 2012, the night tour pulled the tool string up to 680 feet KB. On January 26, 2012, after considerable effort with high-pressure circulation and other methods, a free-point tool was used to determine that the drill pipe was stuck between 545 and 550 feet KB. By 11:00 p.m. January 26, 2012, the free-point tool was used to turn out of the tool joint at a depth of 520 feet KB and the drill pipe above that depth was tripped out of the hole. This left the bit and reamer assembly, a short sub, four 11-inch diameter drill collars, another sub and one drill pipe in the hole.

By 8:45 p.m. on January 28, 2012, a drill string with a bumper sub was connected to the lost tools and an attempt was made to bump them back down the hole as part of an effort to free them. This effort continued until late in the evening of January 30, 2012, when the bumper sub tool string was tripped out. On January 31, 2012, with technical assistance from the Weatherford Company, jars were attached to the stuck tools. The jars were applied with over-pull up to 180,000 pounds (with two pulls at 250K to 260K due to an errant line scale). The jars were applied through 3:10 p.m. on February 1, 2012, when the tool string with the jars was tripped out of the hole, leaving the stuck drill string in place plus one additional drill pipe for a total of four drill collars and two 6-inch drill pipes.

Pioneer Wireline tagged the drill bit at 701 feet KB (indicating an extra drill rod was omitted from the original tally when fishing started), and at 10:50 p.m. on February 3, 2012, the drill collar was shot off at 696 feet KB, about one foot above the reamer. Attempts to pull the two 6-inch drill pipe and four 11-inch drill collars were unsuccessful. On February 4, 2012, Pioneer Wireline attempted to conduct a second shot to severe the tools; however, 20 feet of fill was encountered in the drill string and no shot was performed. The crew continued pulling back on the tools until Layne management could reassess the situation on Monday, February 6, 2012. At 10:00 a.m., February 6, 2012, the decision was made to abandon the hole. Basic Energy Services pumped 240 sacks of 14.8 lb/gal cement with 3% chloride from 672 feet KB. The top of the plug was tagged at 6:10 p.m. at 430 feet KB. The drilling mud was circulated out of the hole with clear water and the well was backfilled with pea gravel to 120 feet KB. Another 50-sack hot plug was pumped in the well on February 7, 2012 and tagged at 95 feet KB. The rig was rigged down and moved off the hole and the remaining well was backfilled with pea gravel from 95 to 31 feet BGL and with a 50/50 mixture of pea gravel and 3/8-inch hole plug from 31 to 10 feet, BGL.

On February 8, 2012, after completing the pea gravel and hole plug backfill, the area around the well head was excavated to bedrock at a depth of 8 feet BGL, and the conductor and casing are cut off approximately 6 feet BGL. The excavation was then backfilled with fill compacted in 8-inch lifts, consisting of a 50/50 mixture of native soils and bentonite chips.

3.4.3 Test Well #2A

A summary history of drilling, completion and testing of Test Well #2A is set forth below.

3.4.3.1 36-Inch Surface Conduit

After the problems with lost circulation at Test Well #2, a decision was made to install 24-inch surface casing in Test Well #2A to stabilize the upper formation if lost circulation was experienced while drilling below 1500 feet. A depth of 1500 feet was targeted for the 24-inch casing which would be hung on the surface conduit until it was cemented into the borehole. Therefore, the surface conduit had to be adequate to support the weight of the anticipated 1500 feet of 24-inch surface casing. Based on these considerations, surface conduit consisting of 0.375-inch wall thickness, 36-inch outside diameter steel casing was installed in 42-inch borehole to a depth of 71 feet in the lower Lakota Formation sandstone at Test Well #2A on 5/30/2012 through 6/6/2012. The surface conduit was cemented with 21 cubic yards of 10-bag, 8-inch slump Portland cement displaced through a tremmie pipe from the bottom of the annulus to the land surface by positive emplacement, utilizing the services of Campbell County Concrete and Pete Lien & Sons, Inc. Pumping Service on 6/7/2012.

3.4.3.2 24-Inch Surface Casing

All depths recorded on Daily Drilling Reports, geological logs, geophysical logs, and construction logs for Test Well #2A are based on depth below ground level (BGL). The depth BGL was used on Test Well #2A (compared to depth KB on Test Well #2) because the Layne crews were used to working with all depths expressed as BGL, and using depth KB, contrary to their normal procedures, was causing confusion in recording drill pipe tallies, casing tallies and drilling depth.

The surface casing in Test Well #2A consists of 0.500-inch wall thickness casing installed in 32-inch borehole to a depth of 1484 feet BGL. The 32-inch borehole was drilled in two passes, starting at midnight of June 16, 2012 with a 14-3/4 inch button bit. The jets were removed from the button bit and the skirts cut out to allow maximum opening for cuttings to enter the drill pipe through the drill bit for flooded reverse circulation drilling. Inclinometer surveys of deviation in the 14-3/4 inch pilot hole were completed as follows:

195 ft	0.5 degrees
300 ft	0.5 degrees
441 ft	0.5 degrees
570 ft	0.5 degrees
661 ft	0.5 degrees

760 ft	0.5 degrees plus
860 ft	0.25 degrees plus
977 ft	0.25 degrees
1068 ft	0.25 degrees
1150 ft	0.25 degrees
1240 ft	0.25 degrees
1340 ft	0.5 degrees
1440 ft	0.5 degrees

Photo 11: 32-inch reamer.

The inclinometer tool was a 3.5-degree tool; however, the metal discs in the tool were for a 7-degree tool. Accordingly, each 1-degree graduation on the discs actually measured 0.5 degrees of inclination. Thus, it was possible to interpolate between the graduations to 0.25-degree increments.

Drilling of pilot hole continued without event until 10:00 a.m. on July 7, 2012 when loss of fluid started to occur at 1529 feet BGL with the mud pit fluid level declining about six-inches per hour. The pilot hole was stopped at 1529 feet BGL and the tools tripped out to reenter with a 14-3/4 inch lead bit and a 22-inch diameter, five-cone reamer. The lead bit and reamer were medium-tooth, button bits with chisel inserts. The skirts were retained on the lead bit; however, the jets were open. Reaming to a 32-inch borehole diameter started at 6:00 a.m. on July 9, 2012 at a depth of 80 feet BGL. During drilling

Photo 12: 32-inch reamer with 17-1/2 inch lead bit.

of the pilot hole and reaming of the pilot hole to 32-inch diameter, the drilling bits and reamers were inspected regularly, initially every 60 hours and, later, at 75-hour intervals after some experience with wear at 60 hour intervals.

At 654 feet, on July 16, 2012, the lead bit was replaced with a 14-3/4 inch long mill tooth bit from which the jets and skirts were removed. On July 20, 2012, at a 32-inch hole depth of 743 feet BGL, the tools were tripped out and the 14-3/4 inch lead bit was replaced with a 17-1/2 inch long mill tooth lead bit with open jets because the smaller lead bit was not getting enough resistance in the pilot hole to turn, and the absence of cone rotation was causing the bit to plug with cuttings such that reverse circulation was cut off. Reaming of the 14-3/4 inch pilot hole continued with the 17-1/2 inch lead bit and 32-inch reamer without significant incident, with normal pauses for rig service and repair of support equipment. At the end of a 75-hour inspection trip, with 32-inch hole reamed to 1250 feet BGL, the four 8000-lb 11-inch drill collars in use were sent to a machine shop in Casper for resurfacing of the faces on the joints, which were becoming galled and exhibited scores and burrs. Resurfacing was required because it was very difficult to break the galled joints on the collars. Reaming resumed at 6:00 p.m. on August 1, 2012, and continued to a total depth of 1510 feet BGL of 32-inch hole at 3:30 p.m. on August 7, 2012.

Inclinometer surveys of deviation in the 32-inch hole were completed as follows:

755 ft	0.5 degrees
850 ft	0.25 degrees
935 ft	0.5 degrees
1000 ft	0.25 degrees
1055 ft	0.5 degrees
1160 ft	0.5 degrees plus
1217 ft	0.5 degrees plus
1278 ft	0.5 degrees
1640 ft	0.5 degrees
1730 ft	0.4 degrees

After tripping out of the hole on August 7, 2012, downhole logging was completed by 11:30 a.m. and 24-inch, 0.500-inch wall thickness steel casing with welded joints and pipe-round centralizers at 80-foot intervals was run into the hole. The 24-inch casing was hung on the 36-inch surface conduit at a total depth of 1484 feet BGL. The casing hanger consisted of eight 12-inch by 12-inch, one-inch thick, steel plates welded on the 24-inch casing at each 45 degrees of circumference and welded into slots cut into the 36-inch steel conduit. The casing was landed on the hanger at 8:00 p.m. on August 9, 2012.

On August 10, 2012, Basic Energy Services arrived on site and began hooking up to the cementing pipe which had been installed through a Bradenhead to a depth of 1480 feet. The cementing pipe consisted of 2-7/8 inch drill pipe. Cementing started at 12:05 p.m. The lead cement consisted of 1200 sacks of 12.0 lb/gal cement with a slurry yield of

2.64 cubic feet per sack (ft^3/sk), displaced by 2:45 p.m., and the tail cement consisted of 460 sacks of 14.8 lb/gal cement with slurry yield of 1.38 ft^3/sack displaced between 2:45 and 3:00 p.m.

Photo 13: Installation of 24-inch surface casing at Test Well #2A.

At about 2:35 p.m., while pumping was in progress, a small leak developed in the packing on the Bradenhead, raising the question as to how much fluid leaked out of the casing during cementing. The leakage of fluid out of the casing would potentially allow some cement to displace upwards into the casing, thus leaving the top of the cement in the casing at an unknown depth, potentially high enough to cement the lower end of the cementing pipe into the casing. The estimate of fluid lost was less than three barrels, not enough to affect the cementing pipe, and the leak stopped when pumping of cement stopped, but the depth to cement in the casing remained a concern, as only 25 feet of cement pipe could be pulled back without releasing pressure in the Bradenhead.

With the latter issues in mind, 10 barrels of water were displaced through the cementing pipe at 3:20 p.m., after giving the cement 20 minutes to start to set up. The pressure in the Bradenhead was 252 psi after pumping ceased and until pressure was released at 3:45 p.m. When the valve on the cement pipe was opened, the 252-psi pressure was released with a flow of about three gallons of water. Likewise, when the valve on the Bradenhead was opened, the annulus between the cement pipe and the 24-inch casing flowed less than two or three gallons of water, indicating the cement was not moving in the annulus. Subsequently, the cement inside the 24-inch casing was tagged at a depth

Photo 14: Fabricating casing hanger for 24-inch surface casing.

Photo 15: 24-inch casing hanging on 36-inch surface conduit.

Photo 16: Tubing packed off by Bradenhead installed on 24-inch casing.

of 1456 feet BGL and a cement bond log (CBL) run at mid-morning on August 13, 2012, approximately 68 hours after cement displacement stopped, exhibited an excellent, void-free bond between the cement and the pipe.

Photo 17: Cement pumper connected to tubing in Bradenhead.

Photo 18: Small leak in Bradenhead packing box.

3.4.3.3 Test Well #2A 16-Inch Pumping Chamber

Offset hole Test Well #2A was completed with 16-inch casing installed to 1850 feet.

On 8/14/2012, a 22-inch, tri-cone button bit was tripped into the hole through the 24-inch surface casing and tagged fill in the hole at 1431 feet. The bit was circulated down to cement backfill in the hole at 1458 feet and drilling began. Cement was drilled out from 1458 to 1486 feet and backfill to 1510 feet. Drilling continued until 1612 feet at 9:00 a.m. on 8/16/2012 when cracks in the Kelly bar required repair. Drilling resumed at noon on 8/17/2012, after the Kelly bar was repaired, wrapped with insulation, and cooled. On 8/19/2012, at 6:30 a.m. and 1660 feet, the flange and bolts on the main driveline to the rotary table broke. Drilling resumed at 9:00 p.m. on 8/20/2012 with the 22-inch bit.

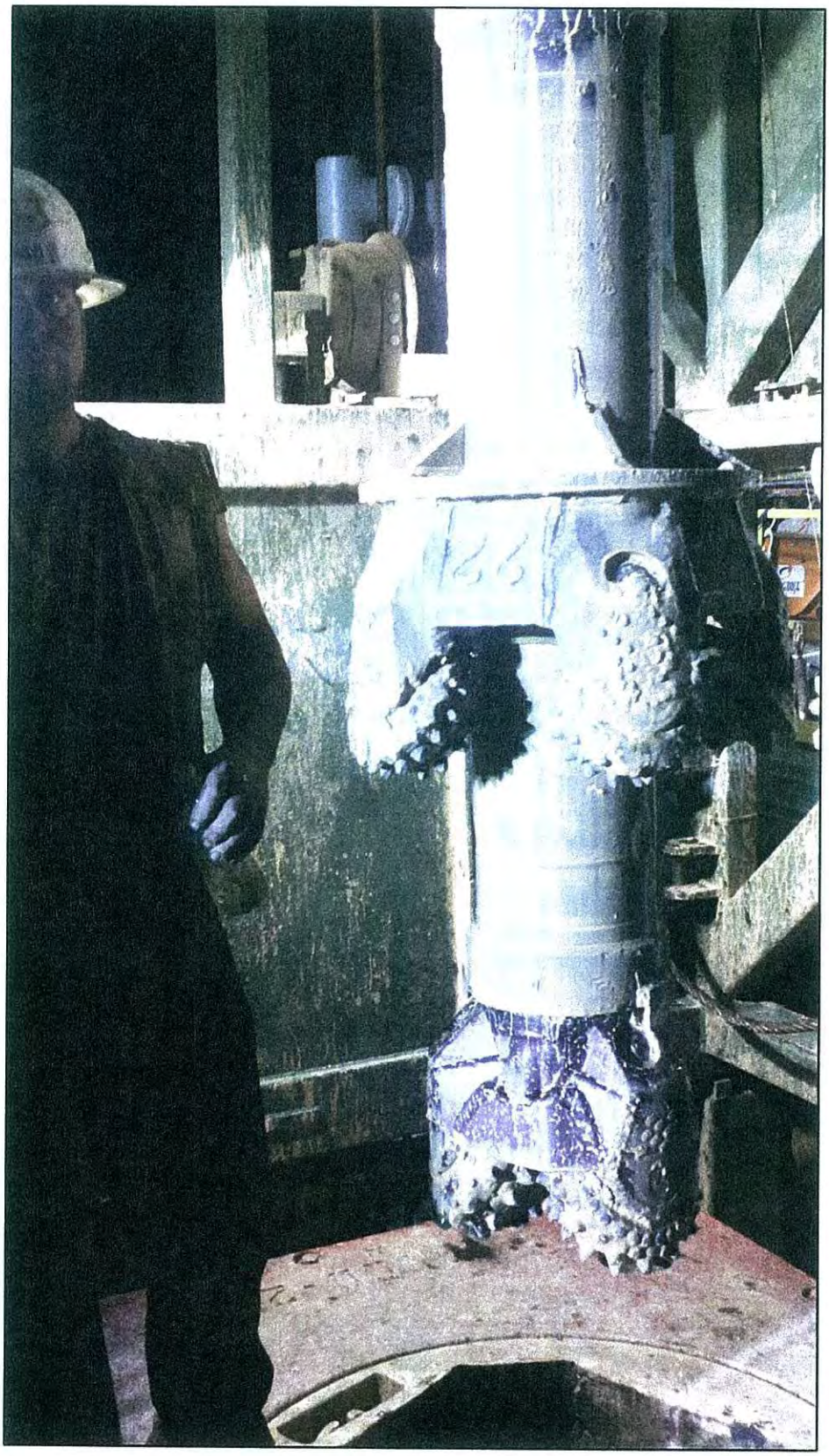
At 5:30 a.m. on 8/22/2012, at a depth of 1702 feet, the drill bit was tripped out of the hole for the first bit inspection. Drilling resumed at 6:00 p.m. that day and continued through midnight 8/25/2012, with the drilling rate decreasing to between 1 to 1.5 feet per hour in some intervals and 2 to 3 feet per hour in others. At midnight 8/25/2012, the bit was tripped out for inspection and found to have a loose bearing. A new bit was obtained from Denver and drilling resumed at 1805 feet at 1:30 a.m. on 8/26/2012. The new bit was a 22-inch medium-tooth, chisel-point button bit.

The rate of progress with this bit decreased to one-half foot per hour and at 1811 feet and 10:00 p.m. on 8/27/2012, the crew began tripping the bit out of the hole. At 3:30 a.m. on 8/28/2012, the crew experienced trouble disconnecting the tool joint on the third drill collar and the standing tong line and sheave for the standing tong line used to disconnect tool joints broke. All of the crew were in their proper positions and no one was hurt by the flailing cable when it broke. The drill bit was found to be out of gauge with 75 percent wear on the buttons and one bearing loose. The bit would not break loose on the tool joint collar.

By 8:00 p.m., a welder was building a bit box to assist in removing the 22-inch bit which was too tight to be removed from the tool joint with the tongs. In addition, the crew was waiting on a new sub to attach a 14-3/4 inch lead button bit below a 22-inch button reamer in an attempt to increase the rate of penetration. At 8:00 a.m. on 8/31/2012, drilling resumed with the new lead bit and 22-inch reamer. A tight spot beginning at 1490 feet was reamed until the bit plugged with loose cuttings at 1701 feet at 8:00 p.m. on 8/31/2012. The lead bit and reamer were replaced with a 22-inch mill bit and the hole was cleaned to 1811 feet by 10:30 a.m. on 9/1/2012. The 22-inch bit penetrated through loose, bridged material at 1701 feet and found 15 feet of soft backfill in the bottom of the hole. An attempt to drill new hole in hard silicic rock at 1811 feet resulted in less than one foot of progress and one broken tooth on the new mill-tooth bit.

The 22-inch mill tooth bit was replaced with a 14-3/4 lead button bit and 22-inch five cone button bit reamer. It was necessary to ream under-gauge hole from 1707 to 1812

Photo 19: 22-inch reamer with buttons and 14-3/4 inch lead button bit.



feet from midnight 9/1/2012 to 7:00 a.m. 9/2/2012. From 7:00 to 9:00 a.m., the lead bit and 22-inch reamer combination advanced the hole from 1812 to 1816 feet. With the length of sub and lead bit below the reamer, this meant the 22-inch reamer only cut about one foot of new 22-inch hole in two hours. The tools were tripped out and some of the buttons on the outside row of the reamer cones were found broken off from reaming the out-of-gauge hole from 1707 to 1812 feet.

The lead bit and reamer were replaced with a 14-3/4 inch button bit and drilling of 14-3/4 inch pilot hole began at 1816 feet at 8:00 p.m. on 9/2/2012. At a depth of 1869 feet at 10:30 a.m. on 9/4/2012, the Kelly bar was leaking severely through cracks and the driller decided to trip out of the hole to repair the Kelly bar. At this time, it was found that the main hydraulic pump on the rig would not deliver enough pressure to lift the tools out of the hole. Circulation was maintained while a new pump was obtained and installed. A new pump was installed by 2:00 a.m. on 9/5/2012; however, the pump was still not delivering hydraulic pressure to the rig. Further diagnostics determined that the clutch pack on the PTO that drives the pump was worn out and the probable cause of wear was a faulty air-activated valve that engages the clutch pack. Parts were delivered to the site at 11:00 a.m. on 9/6/2012 and the rig was up and running by 2:00 p.m. The tools were tripped out and the Kelly bar was removed and repaired by welding the cracks. After cooling in insulation, the Kelly bar was installed.

After Kelly bar repairs were made, it was necessary to slip and remove cable on the main working winch that had reached the 400-ton-mile criteria for removal. During this work, it was necessary to replace a broken spring found in the brake band for the main winch. The brake was necessary for operation of the winch to hold the tool loads. On 9/7/2012, repairs were complete and reaming of the pilot hole resumed at 11:30 p.m. with a 14-3/4 inch mill lead bit and a 22-inch button reamer at 1816 feet. Reaming was completed with the bottom of the 22-inch hole at 1868 feet at 8:00 a.m. on 9/10/2012. After tripping out of the hole, changing the cable on the trip blocks, and obtaining geophysical logs of the open borehole, the crew began running 16-inch casing at 10:30 p.m. on 9/10/2012.

The casing consisted of 16-inch steel casing in random 40s (approximately 39 to 42 foot lengths) with 0.500-inch wall thickness, an inside diameter of 15.000 inches and butt-welded joints. The casing was installed to 1850 feet BGL by 3:30 a.m. on 9/12/2012. The casing included a 16-inch float shoe installed with a 10-foot piece of blank casing used as a guide below the shoe and 4-1/2 inch x-hole pipe was stabbed into the shoe and nippled up for circulation by 10:00 a.m. Cementing by Basic Energy began at approximately 10:30 a.m. A total of 580 sacks of 14.8-lb/gal cement (143 bbl) was pumped at 500 psi followed by 17 bbls of clean water to flush the x-hole pipe. Pumping of cement was complete by 11:20 a.m. on 9/12/2012. The 580-sack cement job included 30 percent overrun of the caliper log volume for the hole, which in fact was essentially true-hole size volume. The cement bond log (CBL) appeared good but was indeterminate as to exact top of cement in the 1300-1320 feet range.

3.4.3.4 10-3/4 Inch Casing to Top of Madison

At 9:00 p.m. on 9/14/2012, the crew began tripping tools into the 16-inch casing. Drilling with a 14-3/4 inch button bit began at 7:00 a.m. on 9/15/2012 at 1869 feet. A total depth of 2390 feet was obtained at 3:00 p.m. on 9/21/2012 with the top of the Madison strata penetrated at 2370 feet, as determined from drill cutting samples. After tripping out and obtaining geophysical logs of the hole, the crew began running 10-3/4 inch casing at 10:00 a.m. on 9/22/2012. As shown in Photo 20, the bottom of the casing consisted of an 18-foot joint of casing into which castellated teeth were cut to sit into the

Photo 20: Bottom end of 18-foot long 10-3/4 inch casing guide for float shoe.

bottom of the hole and help prevent the casing from turning when drill pipe was turned out of the back off sub.

Photo 21 shows the casing used as a guide below the cementing shoe (float shoe) with windows cut into it so cement can be displaced up the outside of the casing, even if the bottom of the 10-3/4 inch casing is plugged by sediment at the bottom of the casing.

The float show (cement shoe) is the silver device welded on the left end of the guide casing in Photo 21.

Photo 21: Float shoe and cementing windows in guide section of 10-3/4 inch casing.

Photo 22 shows the left-hand thread (LHT) back-off sub used at the top of the 10-3/4 inch casing section so that the drill pipe used to lower the 10-3/4 inch casing can be rotated backward and screwed off of the casing.

Photo 22: 10-inch back-off sub for 10-3/4 inch casing.

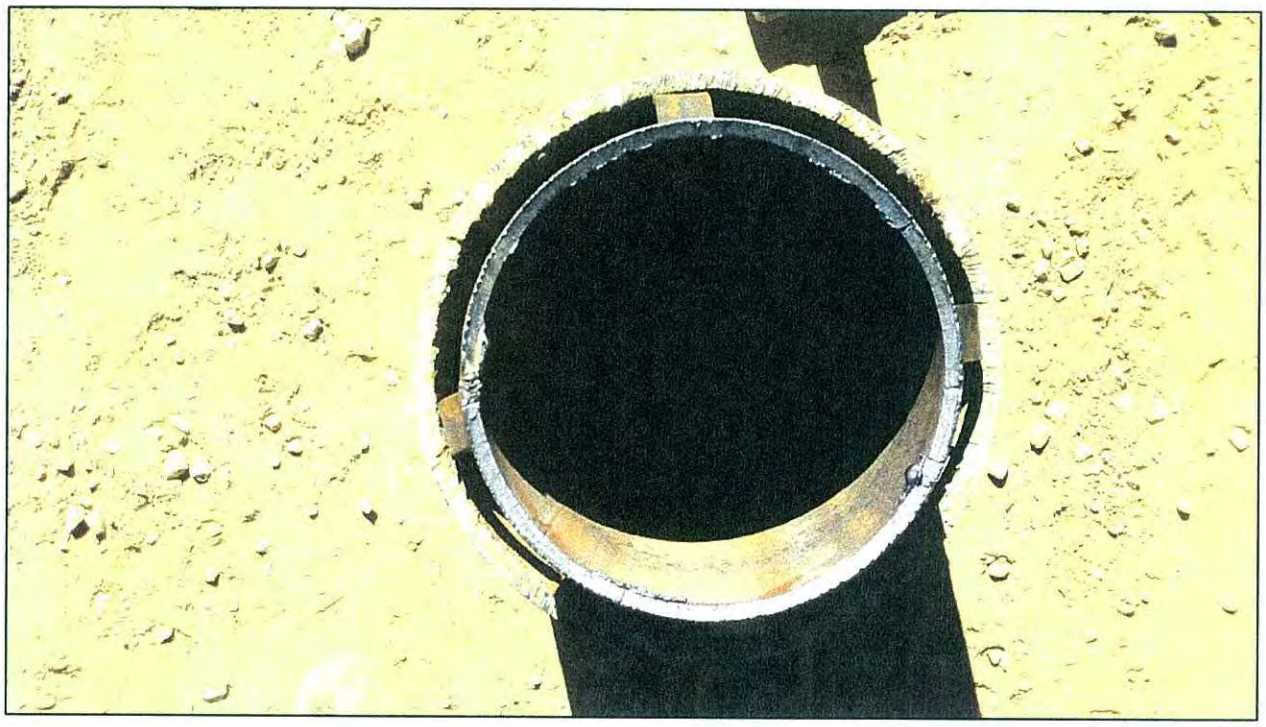
Photo 23 shows the LHT adaptor used to attach drill pipe to the 10-3/4 inch casing. Photos 24 and 25 show a mockup of how the 10-3/4 inch casing is centralized in the 16-inch casing with centralizers that are fabricated for high strength so that they will not be crushed during installation. Photo 26 shows the top of the cement shoe being welded to the bottom of the 10-3/4 inch casing string as the casing is installed. Note the ¾-inch steel lugs used to support the casing on the elevator clamp.

The 590-feet long 10-3/4 inch casing assembly was lowered with the LHT adaptor and back-off sub to a depth where the top of the back off sub was at 1795 feet, overlapping the 16-inch casing by 55 feet, and the bottom of the 10-3/4 inch casing was at 2385 feet. The cement shoe was at 2367 feet with 18 feet of guide casing below the cementing shoe. It was necessary that the casing sit on the bottom of the hole for operation of the back off sub and LHT adaptor. The total length of the casing was calculated to provide 50 feet of overlap with the 16-inch casing; however, the casing stopped on five feet of fill in the hole, five feet above the depth that would provide 50

Photo 23: LHT adaptor for 10-inch back-off sub.

Photo 24: Centralizers for 10-3/4 inch casing inside 16-inch casing.

Photo 25: Mockup of centralizers for 10-3/4 inch casing inside 16-inch casing.



feet of overlap; thus the final overlap was 55 feet. The position of the float shoe in the casing was based on the drill pipe tally and selected so that the top of the drill pipe used to stab into the float shoe for cementing would be reasonably near to the floor of the drill rig for safety and convenience in connecting the cementing hose and valve to the drill pipe.

Based on the foregoing considerations, the final configuration of the 10-3/4 inch casing for installation and cementing was as follows:

10.75-inch casing length:	590.00 ft	
6-inch drill pipe length:	1806.12 ft	
Total casing and drill pipe:	2396.12 ft	
Stickup above ground level:	11.08 ft	
Depth to bottom of casing:	**2385.04 ft BGL**	**TOP CASING 1795 FT BGL**
End of casing to float shoe:	18.00 ft	
Depth to bottom of float shoe:	2367.04 ft BGL	
Bottom of float shoe to window:	4.00 ft	
Depth to first cementing window:	2371.04 ft BGL	

Photo 26: Welding cement shoe to bottom of production casing.

Neutral weight observed on the line scale for turning out of the back off shoe was 30,000 pounds. The casing was landed at 11:50 p.m. on 9/22/2012 and the rotary table was used to turn the LHT adaptor off the back off shoe. The 4-1/2 inch x-hole drill pipe used for cementing was tripped in and stabbed into the cementing shoe by 10:30 a.m. on 9/23/2012. Cementing by Basic Energy consisted of 310 sacks (75 bbl) of 14.8-lb/gal cement preceded by 25 bbl clean water and followed by 25 bbl water to displace the cement out of the 2388 feet of 3-inch I.D. x-hole tubing. Cementing was completed before noon on 9/23/2012. A cement bond log performed 10/4/2012 indicated a successful cement job.

3.4.3.5 9-7/8 Inch Open Hole in Madison Aquifer

The well design called for open-hole completion in the Madison aquifer strata. The goal of the open-hole completion was to penetrate the full thickness of the Madison strata in order to determine the water-bearing characteristics of the Madison rock at depth and to maximize the potential yield from the aquifer.

3.4.3.5.1 Air Rotary Drilling

The open hole completion consisted of 9-7/8 open hole drilled through the Madison strata with direct air rotary drilling. The air package is described in section 3.1.5 Air Package of this report and the philosophy behind the use of direct air rotary drilling is discussed in section 3.2.2 Direct Air Rotary Method of this report.

All reconfiguration of the drilling rig for air rotary drilling was completed by 10/1/2012. Modifications included sealing the 16-inch well head with a rotating well head as shown in Photos 27 and 28. Photo 29 shows the seat of the rotating well head on top of the 16-inch casing and a horizontal 16-inch pipe to convey compressed air, drill cuttings and water from the 16-inch well casing to the cyclone on top of the mud pit and shale shakers during drilling. Photo 30 shows the 16-inch steel pipe from the well head to the cyclone.

Photo 31 shows the cyclone with 8-inch discharge pipes to the two shale shakers (orange equipment) as well as a 16-inch steel vent added to the top of the cyclone lid to route compressed air and water under pressure back into the mud pit. The mud pit was connected to an auxiliary mud pit by a 16-inch line. The auxiliary mud pit was drained by a 10-inch steel line buried in the drill pad to direct water to the point of discharge under the WYPDES. The auxiliary mud pit is shown on Photos 7 and 8. Photo 32 shows construction of the 10-inch dump line from the auxiliary mud pit to the edge of the drilling pad. The 10-inch dump line was equipped with a 10-inch butterfly valve so that the line could be closed and the time for fluid in the mud pit to rise between two marks 12-inches apart in the pit could be used to calculate the volumetric rate of air lift discharge during drilling and air lift development of the well.

Initial unloading of the fluid in the well was accomplished in stages with water initially unloaded from 601 feet at 7:00 p.m. on 10/1/2012. Although the water exerted noticeable force on the cyclone and vent tube bracing, the system worked well and the hole was then unloaded from 1009 feet, ultimately finding that 2700 cfm of air was required at that depth and essentially no inflow to the well. The air boosters provided pressure as needed and worked throughout the project on an on-demand basis. The hole was then unloaded from 1511 feet.

After unloading the hole, drilling of new hole at 2389 feet (depth at which cleaning out of cement and fill ended) began at 6:00 a.m. on 10/2/2012 and proceeded at an average rate of penetration of 8 ft/hr. The open hole began to yield water almost immediately with the early discharge rate of 50 gpm observed in the first 10 to 15 feet of borehole penetrating the aquifer. By midnight on 10/2/2012, at a depth of 2461 feet, the borehole yield was 248 gpm.

Photo 27: Seat and seal for rotating well head to shut in compressed air.

Photo 28: Seal engaged and locked on rotating well head.

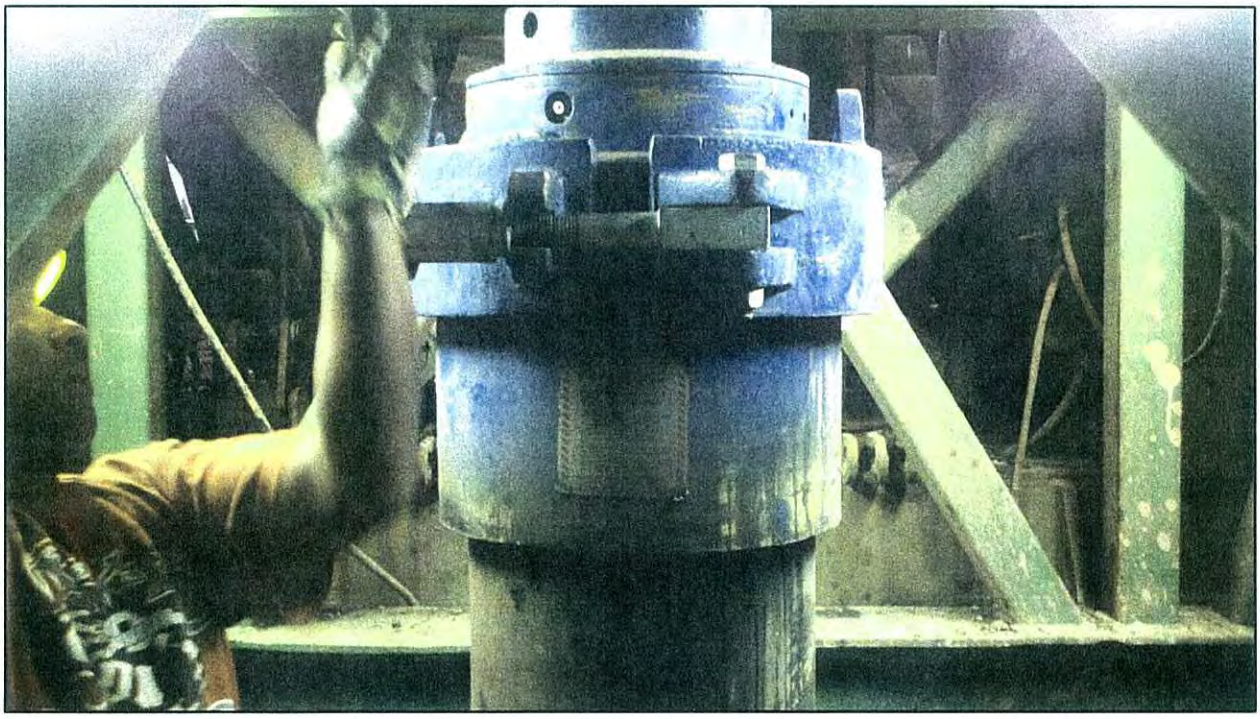


Photo 29: 16-inch steel diversion line to cyclone.

Photo 30: 16-inch steel diversion line to cyclone.

Photo 31: Cyclone on mud pit with 10-inch inlet pipe from site, 8-inch discharge pipes to shale shakers on bottom and 16-inch vent pipe on top.

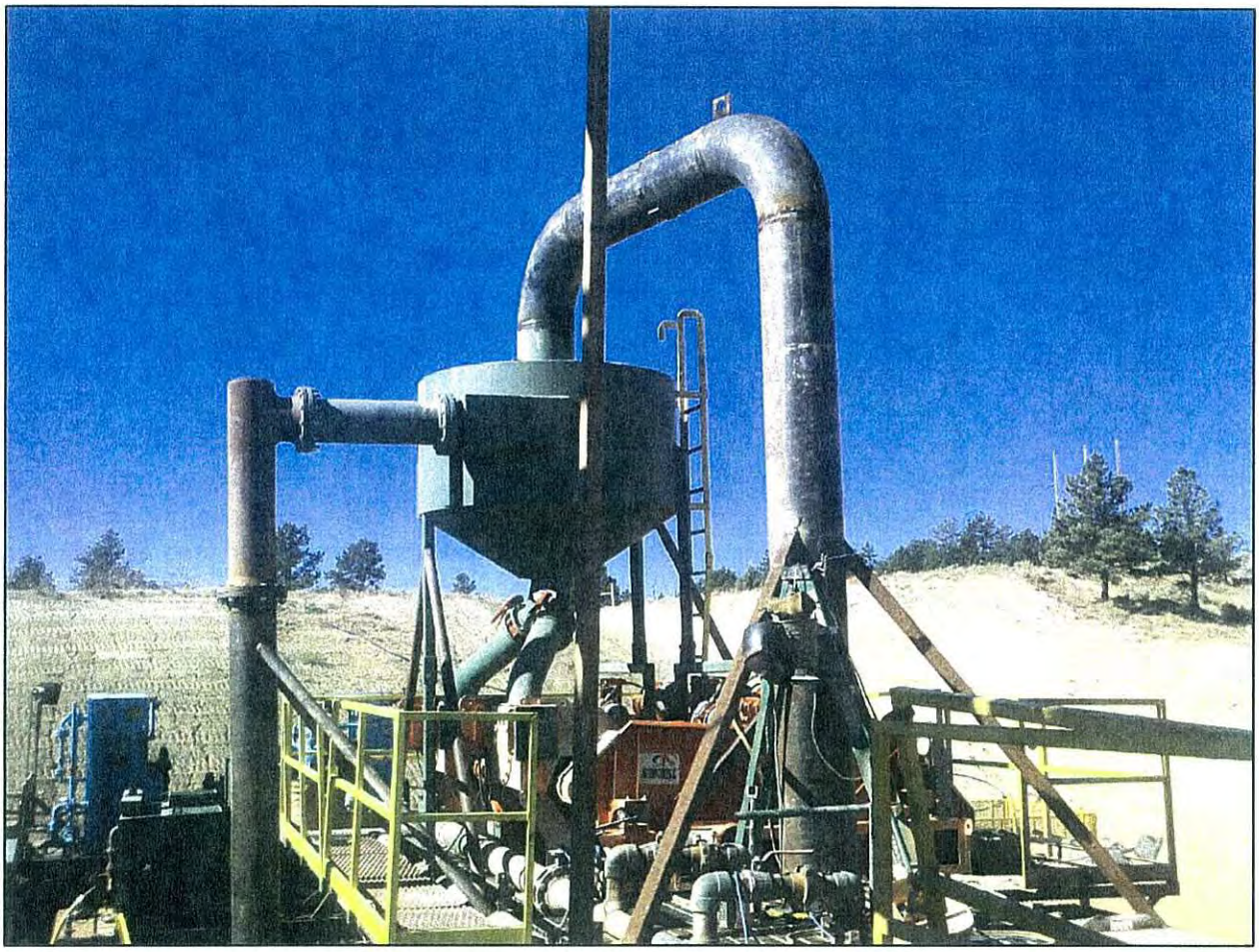


Photo 32: 10-inch dump line for air rotary drilling and pumping tests.

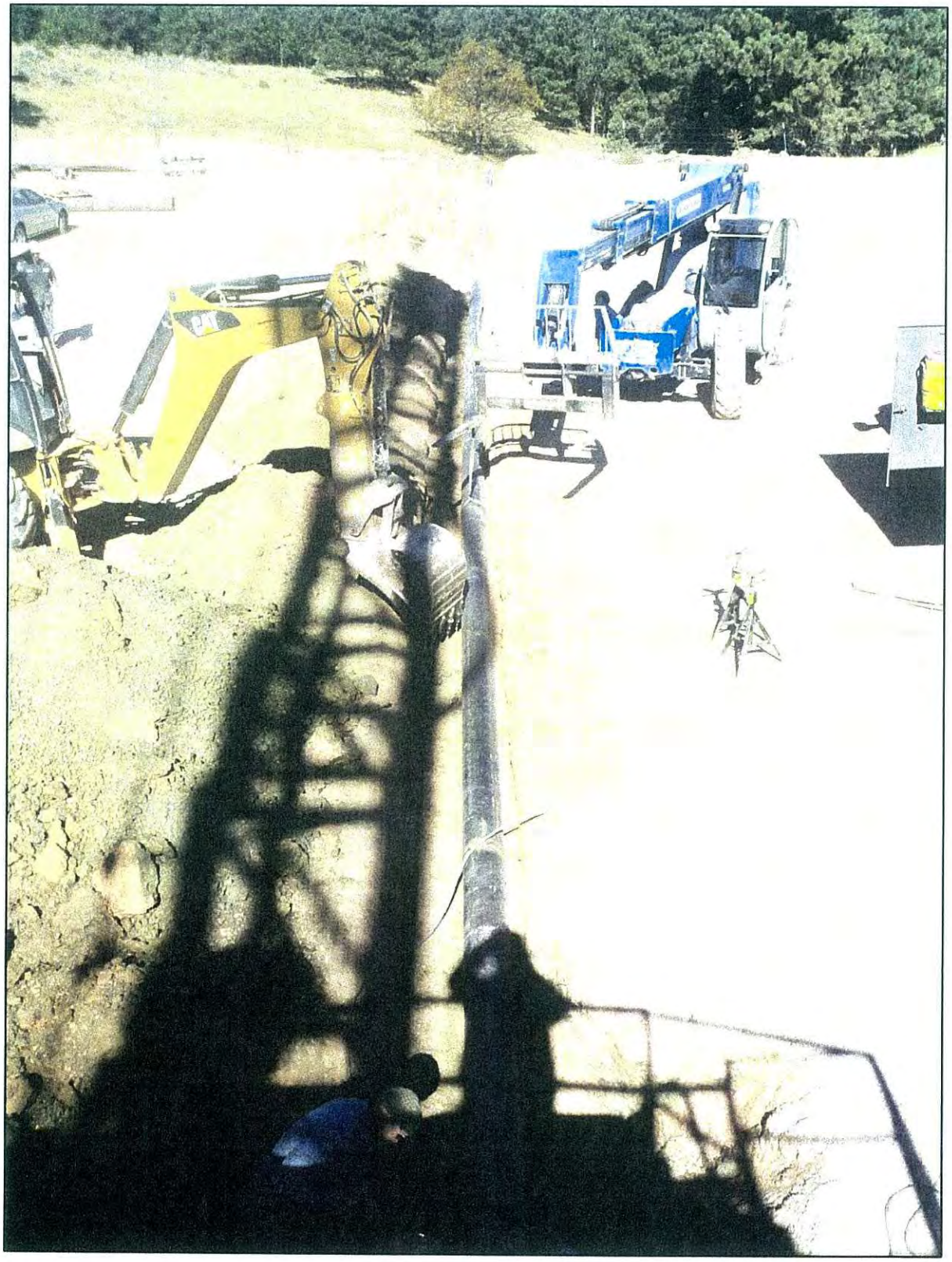
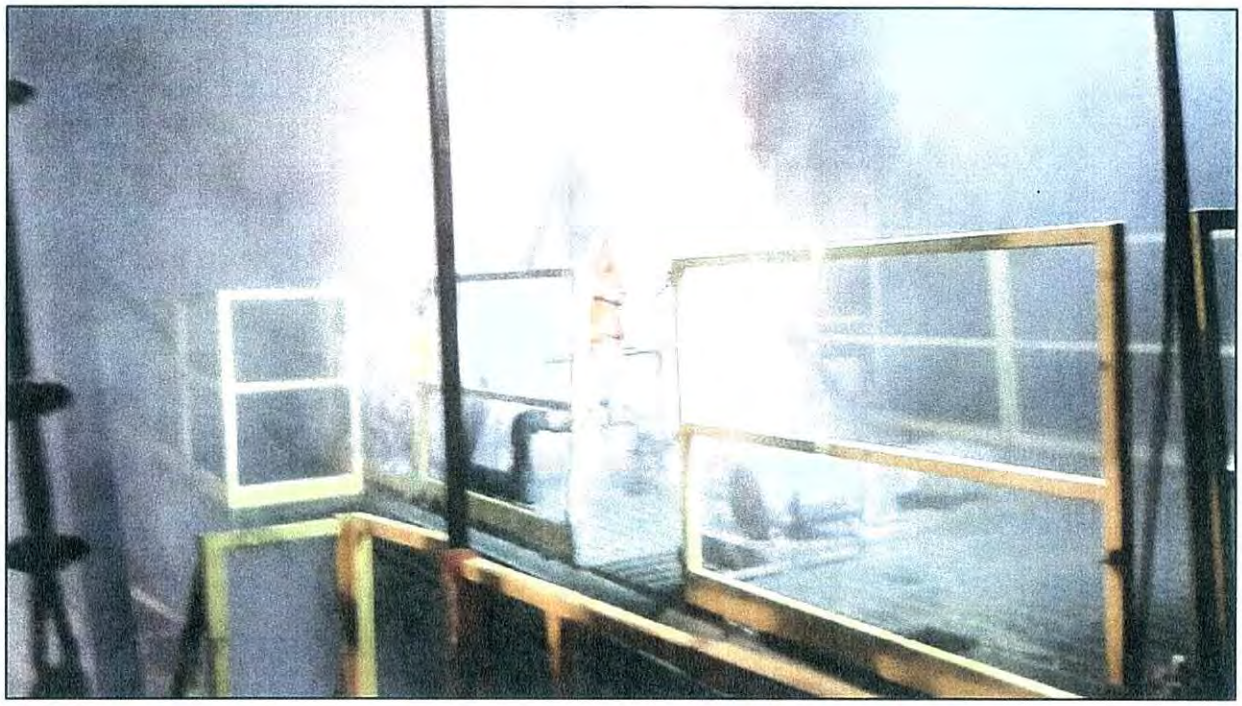


Photo 33: Night operation 10/2/2012 with fog off warm water obscuring cyclone.



At approximately 10:00 a.m. on 10/4/2012, at a depth of 2766 feet with an air lift discharge rate of 800 gpm during drilling, the water hammer effect from the surge of water entering the cyclone during unloading of the hole exceeded the pressure limits of the ½-inch thick steel wall cyclone and the top blew off the cyclone.

At the onset of air rotary drilling, a buffer zone was established around the mud pit and cyclone and personnel were not allowed to be within the buffer zone while compressed air was discharged through the cyclone. When the lid was blown off the cyclone, one of the rig hands was standing on the floor of the drill rig, at the edge of the buffer zone, using his cell phone to record video of the cyclone in operation. The following four photographs were copied from the cell phone video, each photograph representing a successive frame in the video and attesting to the separation of the lid from the cyclone in a split second. The four sequential video frames show the 16-inch vent pipe remaining attached to the lid and bending away from the cyclone under the force of the water hammer event, anchoring the lid, and preventing it from being launched into the air.

Less attention-getting in the sequence of photographs is the effect of the water hammer on the shale shakers. Photo 35 shows the initial leakage of water under pressure around the bottom of the 8-inch discharge pipes where they discharge into the Possum belly on each shaker. In Photo 34, the back of the possum belly is vertical and nearly lined up with the vertical yellow guard rail. In Photos 34 through 36, the rotation of the possum bellies to the left, and away from the shale shakers is evident in the changing alignment between the possum bellies and the guard rail.

Photo 34: Intact cyclone with plumbing.

Photo 35: Initial cyclone failure.

Photo 38 shows the top of the orange shale shakers with the gray possum belly bodies pushed back away from the shakers. This is evident in the tilt of the electrical switch panel and the separation of the 8-inch discharge pipes from the top of the possum bellies.

Not evident in Photo 38 is the fact that the internal frames for the shaker screens have been bent down. Photo 39 shows how the displacement of the 16-inch vent pipe from vertical buckled the floor grate and upper frame of the mud pit. Photo 40 shows the edge of the metal lid and the somewhat meager weld that broke under the pressure of the water hammer surge.

Photo 36: Second video frame.

Photo 37: Third video frame.

The care exercised by the Layne Christensen Drilling Company in establishing a safety zone around the cyclone during the energy intensive air lift unloading of the well and air rotary drilling prevented any injuries during this incident. Although the possibility of pressure surge breaking part of the discharge plumbing was recognized and planned for by establishing a safety zone around the equipment, the burst cyclone made it evident that an alternative approach was necessary and that the discharge system for this type of air rotary drilling required a new design.

Photo 38: Damaged shale shakers.

Photo 39: Buckled mud pit floor grate around 16-inch vent pipe.

Photo 40: Edge of ½-inch thick steel cyclone lid and broken weld.

Photo 41: Cyclone lid after failure caused by surge pressure.

In the interim, the discharge line to the cyclone and mud pit was routed directly to the 10-inch discharge line and the mud pit and cyclone were eliminated from the discharge system. This meant that drill cuttings were discharged directly through and from the 10-inch dump line, at high velocity, and collection of samples had to take place at the end of the dump line. It also eliminated any realistic possibility of measuring the air lift discharge from the well after the cyclone and mud pits were bypassed. Photos 42 and 43 are frames from a video of unloading the well with compressed air after the rate of inflow to the borehole resulted in a relatively long column of water above the drill bit when air lifting was stopped to add a drill pipe.

In Photo 42, air injected through the drill bit at the bottom of the hole is building a bubble of air that is displacing the water column up the hole and will displace all of the water out of the hole. Photo 42 shows the initial flow of water to the surface. Photo 43 shows a mixture of air and water discharged from the well after the water column is completely displaced and air rotary drilling is in progress.

The conditions shown in Photo 43 are those prevailing during air rotary drilling, when the well was yielding 800 gpm or more during drilling. This type of discharge was initiated at night, after the cyclone and mud pit were bypassed, and drill cutting samples were not collected from the formidable stream of high-pressure air, water and cuttings until daylight conditions prevailed. The end of the discharge pipe was in a steep slope lined with vinyl and was undercut such that it was necessary for a person to lean out over a four-foot drop while supporting themselves with one arm while carefully skimming the bottom of the discharge stream with a strainer held in the other hand. This was a somewhat daunting thing to do at night, when this type of discharge was first initiated, and no attempt was made to collect drill cutting samples from this jet of air and water until daylight, when sampling resumed. Consequently, no drill cutting samples were collected in the 2760- to 2848-foot interval.

3.4.3.5.2 Air Lift Discharge Rate

Figure 5 shows the air lift yield of the Madison strata increased over the 40-hour period of air lift pumping of the borehole as it was advanced from the bottom of the 10-3/4 inch casing at 2385 feet to a total depth of 2766 feet where the cyclone burst and volumetric measurements of the air lift yield ceased. This relationship reflects a steady increase in well yield as the amount of aquifer strata penetrated by the borehole increased, plus the fact that drilling progress was relatively steady.

The air lift yield versus length of open borehole is a linear relationship with the yield increasing about two gallons per minute per foot of new borehole. The data scatter is the result of variables affecting the air lift yield rate including variations in air pressure, unloading recovered water column in the borehole between adding drill pipes, timing of tool joint additions, and drill cuttings loads.

Photo 42: Water column starting to discharge out of well as displaced by air bubble.

Photo 43: Air and water mixture after water column displaced out of well.

The yield per foot of borehole remained constant at about two gallons per minute per foot of aquifer strata penetrated as shown by Figure 7. The relationship is yield per foot

of borehole versus length of open borehole; however, the reciprocal relationship is plotted on Figure 7 for the convenience of presentation of an easily viewed chart. Figure 7 shows length of open borehole (length of open hole in Madison aquifer strata) plotted versus air lift yield per foot. The total borehole depth at each volumetric measurement of discharge rate is annotated beside the data points on the plot. As shown on Figure 6, the borehole produced 2.08 gpm per foot of borehole, with scatter around the line of regression reducing the coefficient of determination, R-squared, to 0.879994.

The foregoing conclusion is verified by Figure 6 which shows the air lift yield during drilling plotted versus the length of open borehole penetrating the aquifer strata down to 2766 feet, before failure of the cyclone separator.

The nature of the data scatter is clear on Figure 7 where the yield per foot of hole clusters into three or four distinct alignments of decreasing yield per foot with increased length of open hole (increased depth). The physical significance of these relationships is evident in the depth annotations which show that as the depth of the borehole increased, yield per foot decreased; however, the relationship reverts back to larger yield per foot at three distinct times. The relatively abrupt changes back to a higher yield per foot are associated with times when drilling and airlift pumping were paused momentarily to make repairs to the drill rig or to air lines. The principal factor that restored the yield per foot was recovery of drawdown in the aquifer during brief periods when drilling and air lift pumping ceased momentarily. The principal factor causing yield per foot of borehole to decrease was the effect of increasing drawdown in the aquifer and associated change in the percent of the drill pipe (air pipe) submerged. Other variables included how many compressors were in operation and short periods of recovery while new drill pipe was added to the tool string every 30 feet. For example, Figure 7 shows a yield per foot exceeding 6 gpm/ft at 2420 feet with values of 2.50 gpm/ft and 1.81 gpm/ft at the same depth.

The differences in yield per foot of borehole at this depth reflect the effect of unloading the borehole with a partial versus full water column. The apparent well yield per foot of borehole was high when a full water column was discharged into the mud pit where the volumetric measurements were conducted and it was low after the borehole storage effect ceased. The anomalously high value of 6.05 gpm/ft reflects unloading a full borehole whereas the low value of 1.81 gpm/ft represents the actual yield per foot without borehole storage effects. The decrease from 1.18 gpm/ft at a depth of 2420 feet to 1.20 gpm/ft at a depth of 2452 feet is gradual and reflects the effect of drawdown of pressure in the aquifer, even as the length of open hole increased. All of the air lift discharge data are for the formation during drilling, before hydraulic fracturing of the well with hydrochloric acid.

3.4.3.6 Identification of Bottom of Madison Aquifer Strata

Figure 8 is a reproduction of a portion of the downhole geophysical logs of the open hole below the 10-3/4 inch casing in Test Well #2A. The two upper tracks are the short and long normal resistivity logs (short normal is solid line; long normal is dashed line).

Figure 5: Air lift yield versus air lift pumping time (drilling time).

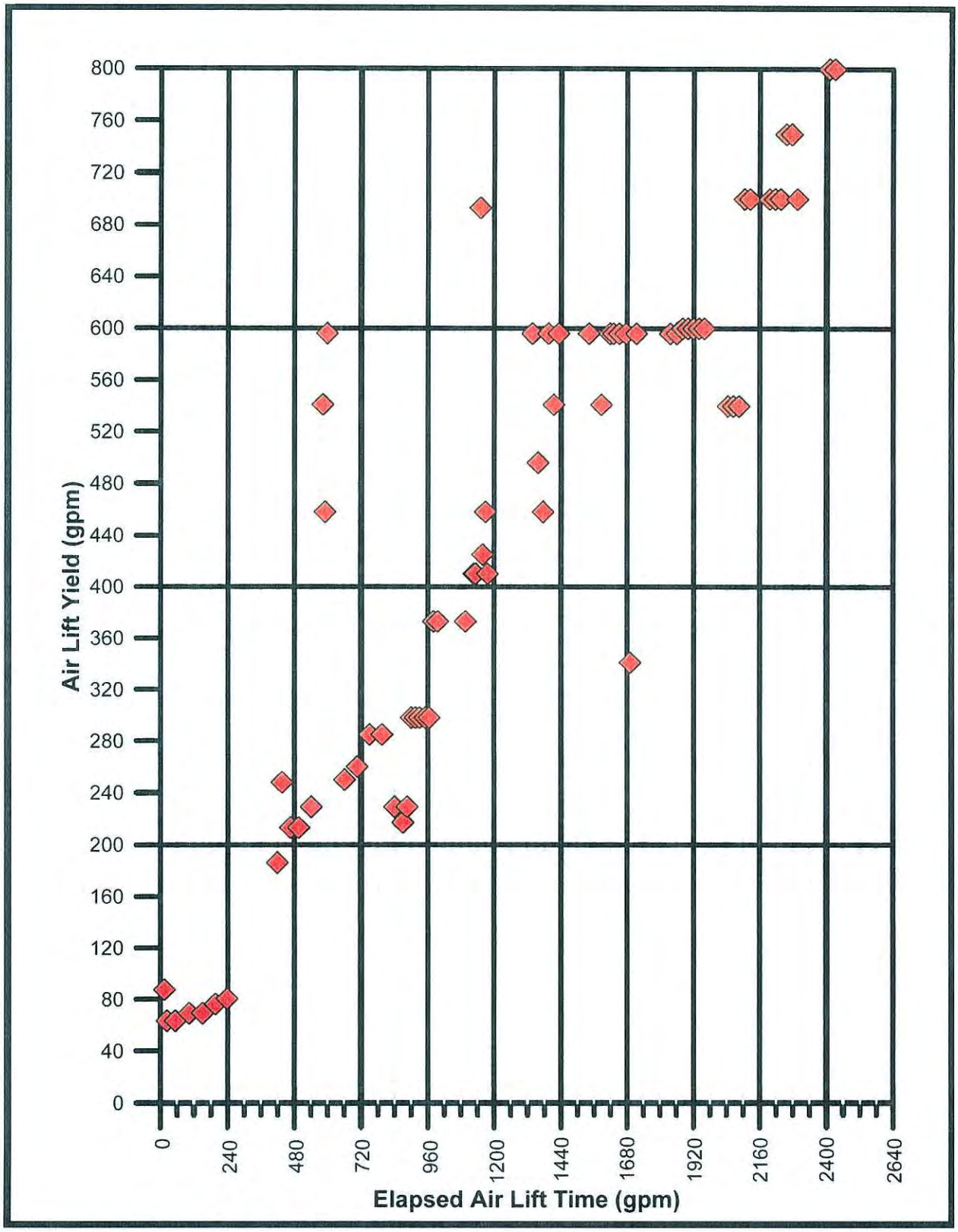


Figure 6: Air lift yield versus length of open borehole.

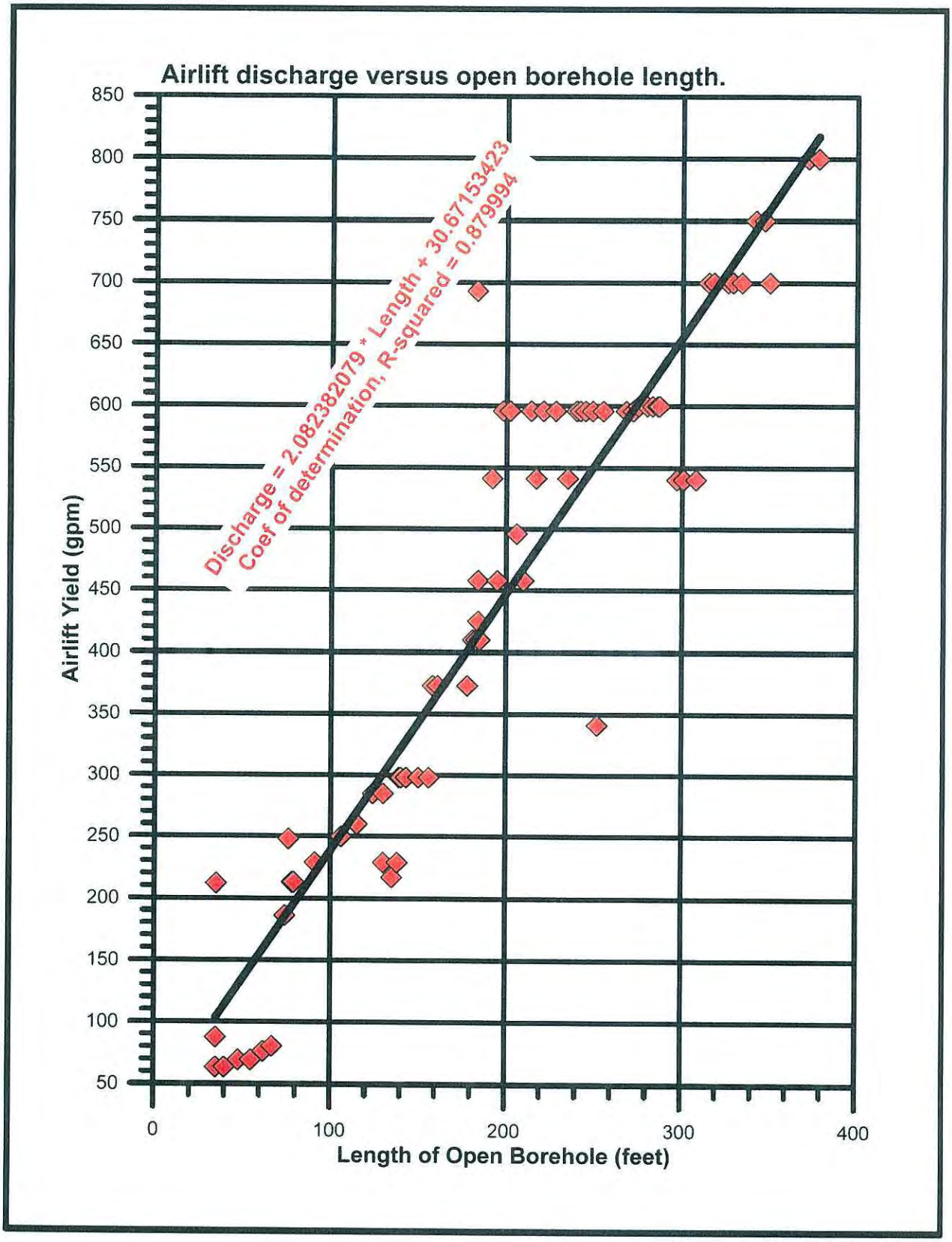
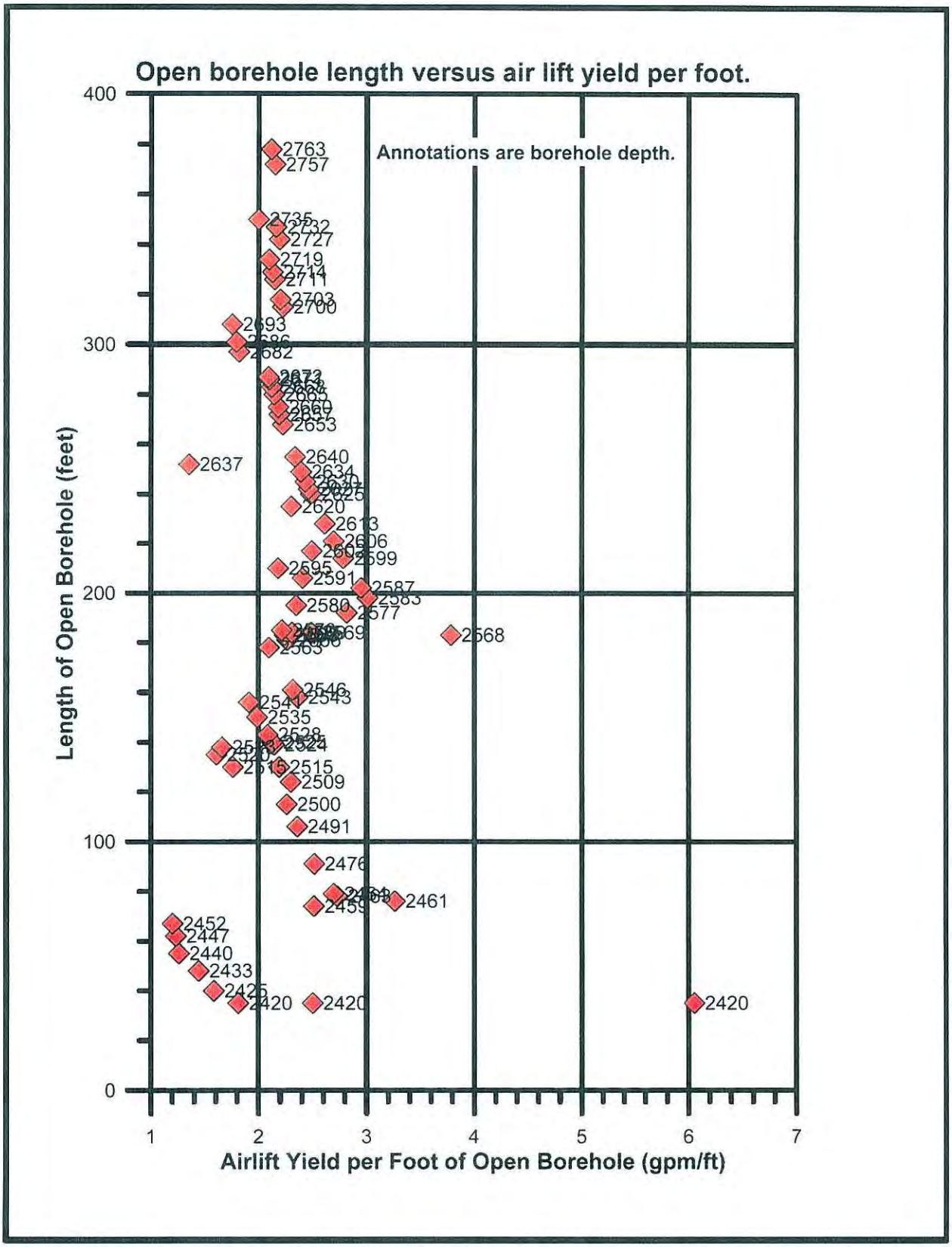


Figure 7: Air lift yield per foot of borehole versus length of open borehole.

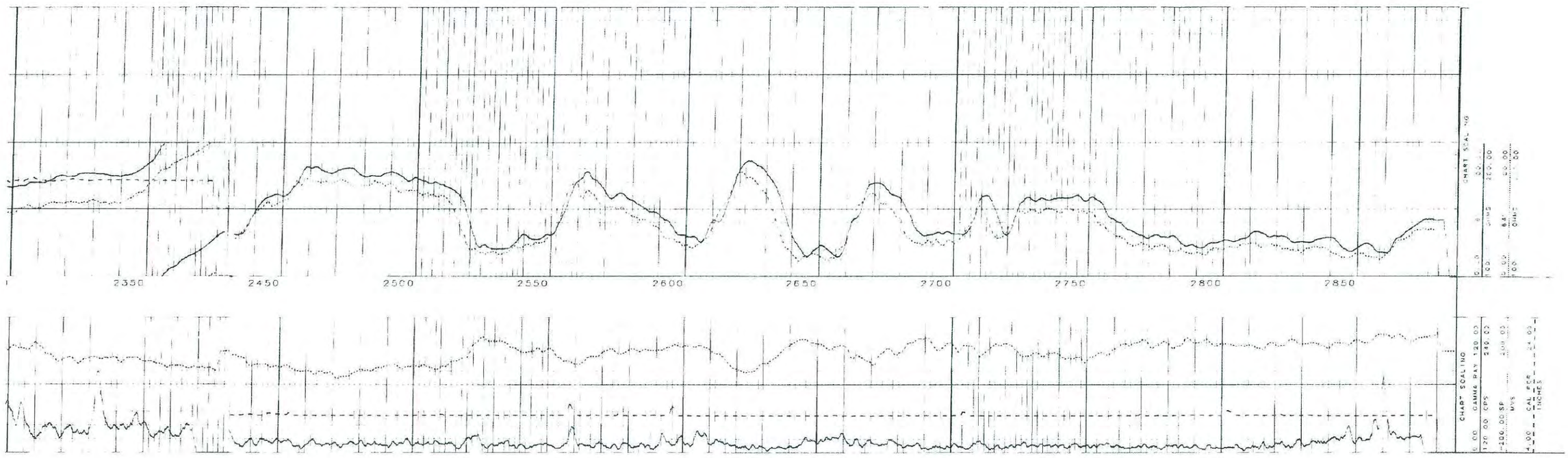


The top of the Madison strata was identified at 2370 feet from drill cutting samples observed as they came over the shale shaker and the rate of penetration on the geolograph log, so the top is identified within one foot. A good electric log of the interval between 2350 and 2450 feet is not available. This is because 14-3/4 inch diameter hole was logged with a total depth of 2390 feet, with good results obtained to 2350 or 2360 feet, as shown below. A new log was performed in 9-7/8 inch diameter open hole below 10-3/4 inch casing set to 2385 feet. The log below cuts off the information between 2385 and 2432 feet, where the two logs were spliced together. Thus, the top of the Madison is not shown on the log on Figure 8.

No drill cutting samples were collected from 2760 to 2848 feet, because the air rotary discharge bypassed the shale shakers and samples were not collected from the high-pressure stream of water and cuttings until daylight, when it was relatively safe to approach the discharge pipe. Accordingly, the bottom of the Madison aquifer strata cannot be identified from the drill cuttings, because it is somewhere in the interval that was not sampled. A drill cutting sample collected while the borehole advanced from 2848 to 2849 feet consisted entirely of porous, medium gray dolosparite consistent with the Whitewood Dolomite. Drill cutting samples in the 2850 – 2860 foot interval contain hard green shale typical of the Winnipeg Formation.

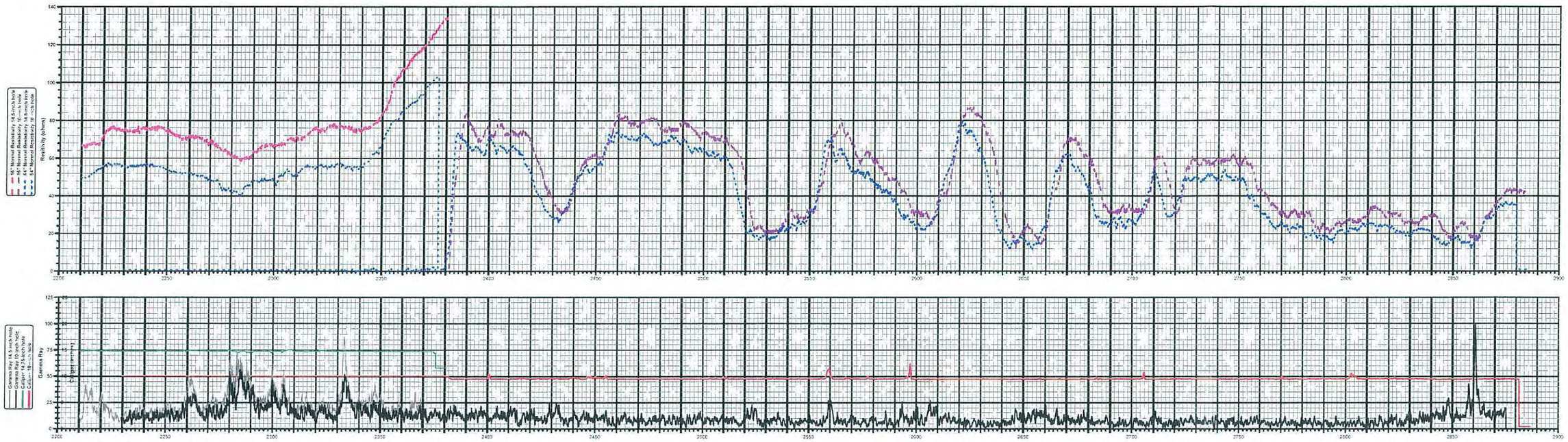
The short and long normal (16" and 64") logs below show relatively high electrical resistivity values in the formation down to 2752 feet, then a distinct decrease in resistivity to the top of the Deadwood quartzite at 2862 feet, the top of which was verified with drill cutting samples. The porous dolomite from 2848 to 2849 feet is in the interval of relatively low resistivity that starts at 2752 feet. Accordingly, the bottom of the Madison strata is set at the last area of high resistivity values at 2752 feet and the interval of relatively low resistivity from 2752 feet to 2862 feet is assigned to the Whitewood Dolomite and the Winnipeg Formation. This designation of formation intervals, based on electrical resistivity logs, is somewhat arbitrary because some of the low resistivity interval could include low permeability strata of the lowermost Madison Group. Stratigraphic questions aside, the interval assigned to the Madison aquifer based on drill cuttings and geophysical logs is the most productive part of the carbonate strata sequence at this site and is certainly the principle Madison aquifer production zone penetrated by this well. Figure 9 is a plot of the digital data from the logs of the 14-3/4 and 9-7/8 open holes at the top of the Madison. The plot was developed to determine if the raw logger data provided any better overlap of the two logs than shown on the logger plot reproduced in Figure 8. Figure 9 shows that there is no overlap of the logger data due to the truncation of the logs by the bottom of the 14-3/4 inch hole and by the 10-inch casing when the 9-7/8 inch hole was logged. It is clear on Figures 8 and 9 that the Minnelusa strata above the Madison exhibits equally large resistivity values as the Madison with some effect on absolute resistivity values due to the change in borehole diameters.

Figure 8: Short and long normal resistivity logs of open hole in Madison aquifer and underlying strata.



MADISON AQUIFER STRATA FROM 2370 TO 2752 FEET BGL

Figure 9: Digital data for Figure 8 logs plotted independently for top of Madison interpretation.



3.5 Borehole, Casing and Cement Summary

A summary of borehole, casing and cement used for completion of Test Well #2A is provided on Table 3:

Table 3: Summary of borehole, casing and cement for Test Well #2A.

Depth Interval (feet)	Nominal Borehole Diameter (inches)	Casing O.D. (inches)	Casing Wall Thickness (inches)	Cementing and Completion
0- 71	42	36	0.375	21 cubic yards of 10-bag, 8-inch slump, Portland cement.
71-1529 71-1510 0-1484	14-3/4 32 32	Pilot hole Borehole 24	 0.500	Install Bradenhead with 2-7/8 drill pipe to 1480 ft; pump 1200 sacks (564 bbl) 12.0 lb/gal lead cement; pump 460 sacks (113 bbl) 14.8-lb/gal tail cement, wait 20 minutes, pull drill pipe back 25 feet in Bradenhead and displace pipe with 10 bbl water
1510-1816 1816-1869 1816-1868 0-1850	22 14-3/4 22 22	Borehole Pilot hole Borehole 16	 0.500	Bottom of 16-inch float shoe at 1840 ft with 4-1/2 inch x-hole drill pipe stabbed in; pumped 580 sacks (143 bbl) of 14.8-lb/gal cement followed by displacement of drill pipe with 17 bbl of water.
1869-2390 1795-2385	14-3/4 14-3/4	Borehole 10-3/4	 0.375	Bottom of 10-inch float shoe at 2367 ft with 4-1/2 inch x-hole drill pipe stabbed in; pumped 25 bbl clean water, 310 sacks (75 bbl) of 14.8-lb/gal followed by 25 bbl clear water
2390-2891	9-7/8	Open hole	No casing	Hydraulically fracture open hole section starting with 383 bbl clear water at up to 1028 psi, follow with 708 bbl chlorine water; 37 bbl clean water; 674 bbl 15% hydro-chloric acid at 67 bbl/min and up to 888 psi; 51 bbl clean water; and 140 bbl chorine water on vacuum, flush hoses with 54 bbl clean water on vacuum.

3.6 Plumbness and Alignment

Drift and deviation of completed Test Well #2A were determined by a gyroscopic drift and deviation survey conducted on 10/26/2012. Most companies offering drift and deviation services operate the equipment in either cased hole or inside drill pipe, but not in open hole where there is a risk of losing the equipment. Accordingly, the service company providing the survey, Gyrodata Incorporated, Casper,Wyoming, would not operate the downhole survey instrument in open hole below the well casing, so the survey is limited to the cased portion of the well, with measurements ending at a depth of 2375 feet.

Measurements were taken at 10-foot increments from surface to the bottom of the 16-inch diameter casing, with the last measurement in 16-inch casing at 1785 feet. Measurements in the 10-inch casing begin at 1850 feet and were taken in 50-foot increments with the last 50-foot increment at 2350 feet and a final measurement at 2375 feet.

Figure 10 is a polar view of the well drift and deviation. The polar view is a view directly down the theoretical vertical axis of a plumb and straight well. The polar view shows that the well departs from the vertical, with the 2375-foot measurement ending 9.49 feet from the vertical axis on a bearing of 324.3 degrees from grid north. In addition to the departure from vertical, the separation between the trace of the well on the polar view and a plane drawn through the origin of the plot and the last point on the survey, at 2375 feet, shows the departure of the well from straight along that plane of survey. The 9.49-foot departure from vertical is very small and the well is reasonably straight with one excursion from the generally straight trend centered on the 1000-foot depth.

Figure 11 is a view of the drift and deviation projected onto a plane drawn through the center of the well at the land surface and the last point on the survey at 2375 feet depth. The maximum departure from vertical on this plane of project, 9.49 feet, is shown as well as the departure from vertical on this plane for each point on the drift and deviation survey. Considering that the plot has a horizontal to vertical exaggeration factor of 90:1 (one inch on the vertical axis is equal to 90 times more feet than one inch on the horizontal axis), the plot reflects very little departure from vertical and a reasonably straight well in this plane.

Figures 12 and 13 show the drift and deviation in the east-to-west and north-to-south planes, respectively. The maximum departure from vertical in the east-to-west plane is 5.54 feet and the well is reasonably straight. The maximum departure from vertical in the north-to-south plane is 7.71 feet and the well exhibits an increase in the departure from vertical beginning at about 1100 feet.

Figure 14 compares the departure from vertical in the plane of drift to a 1-degree constant departure from vertical, which is the limit of the amount of drift allowable in the specifications for the well. As shown on Figure 14, the measured drift is less than one quarter of the allowable drift.

Figure 10: Polar view of Test Well #2A drift and deviation.

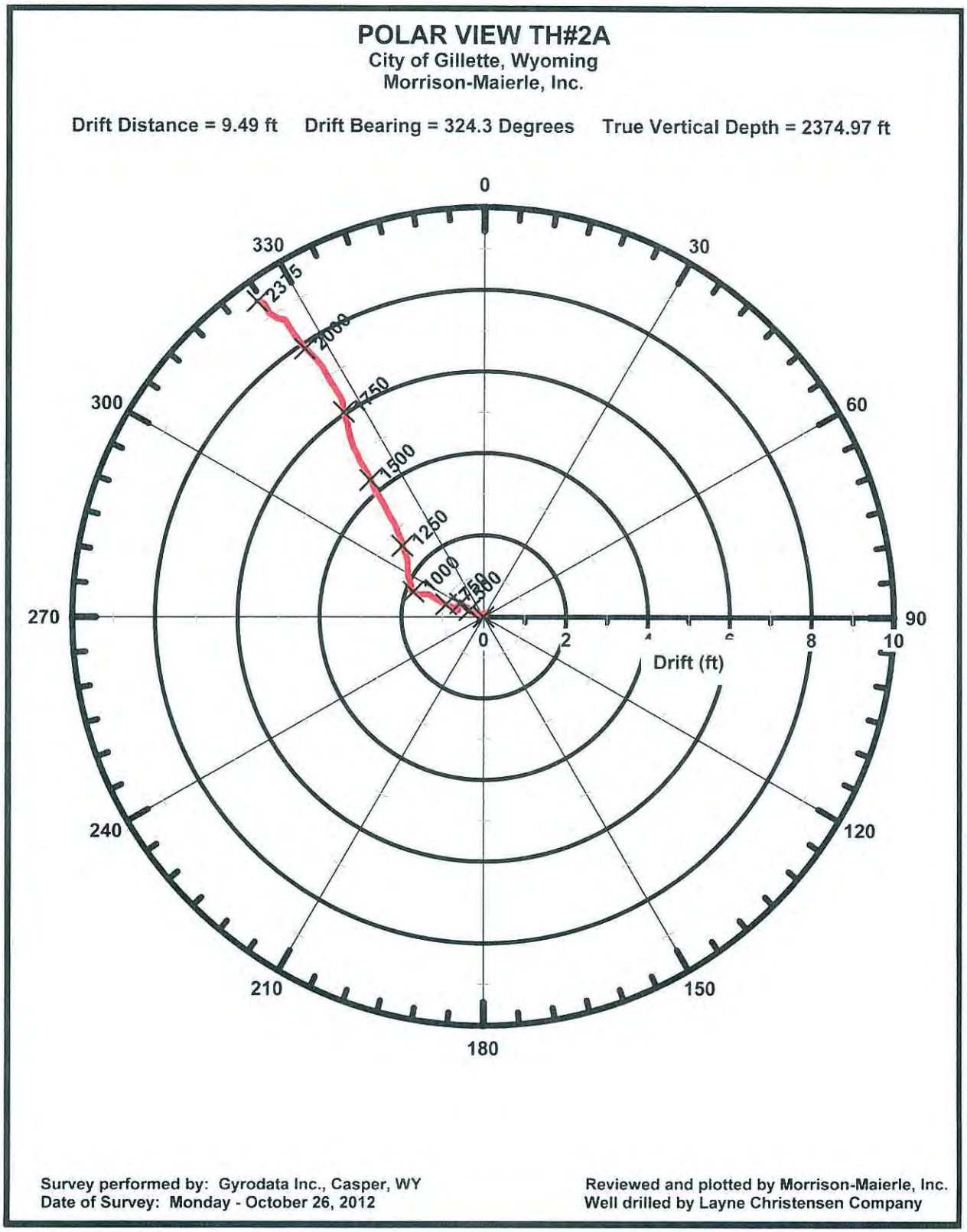


Figure 11: Drift and deviation in the plane of drift.

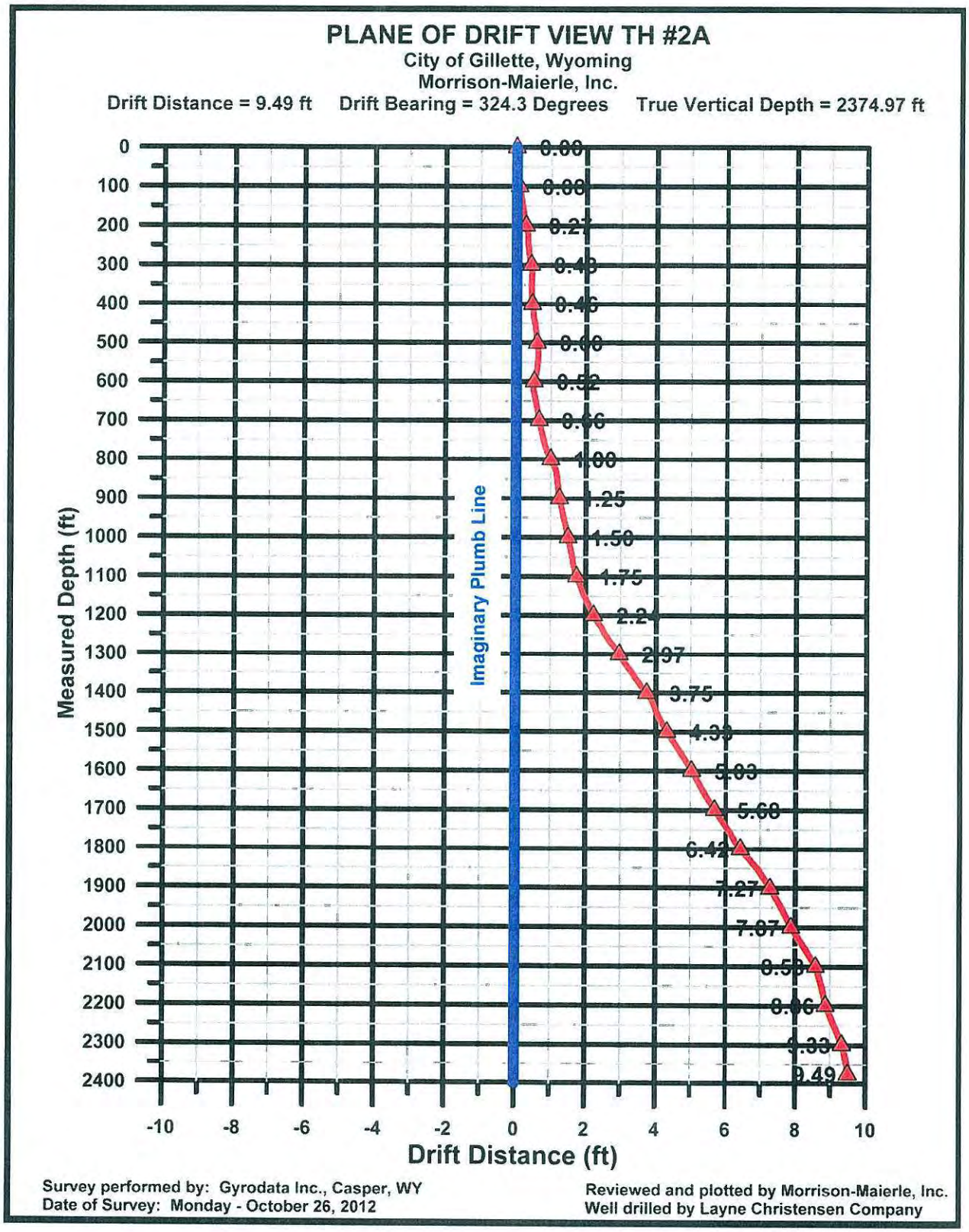


Figure 12: Drift and deviation in the east-west plane of view.

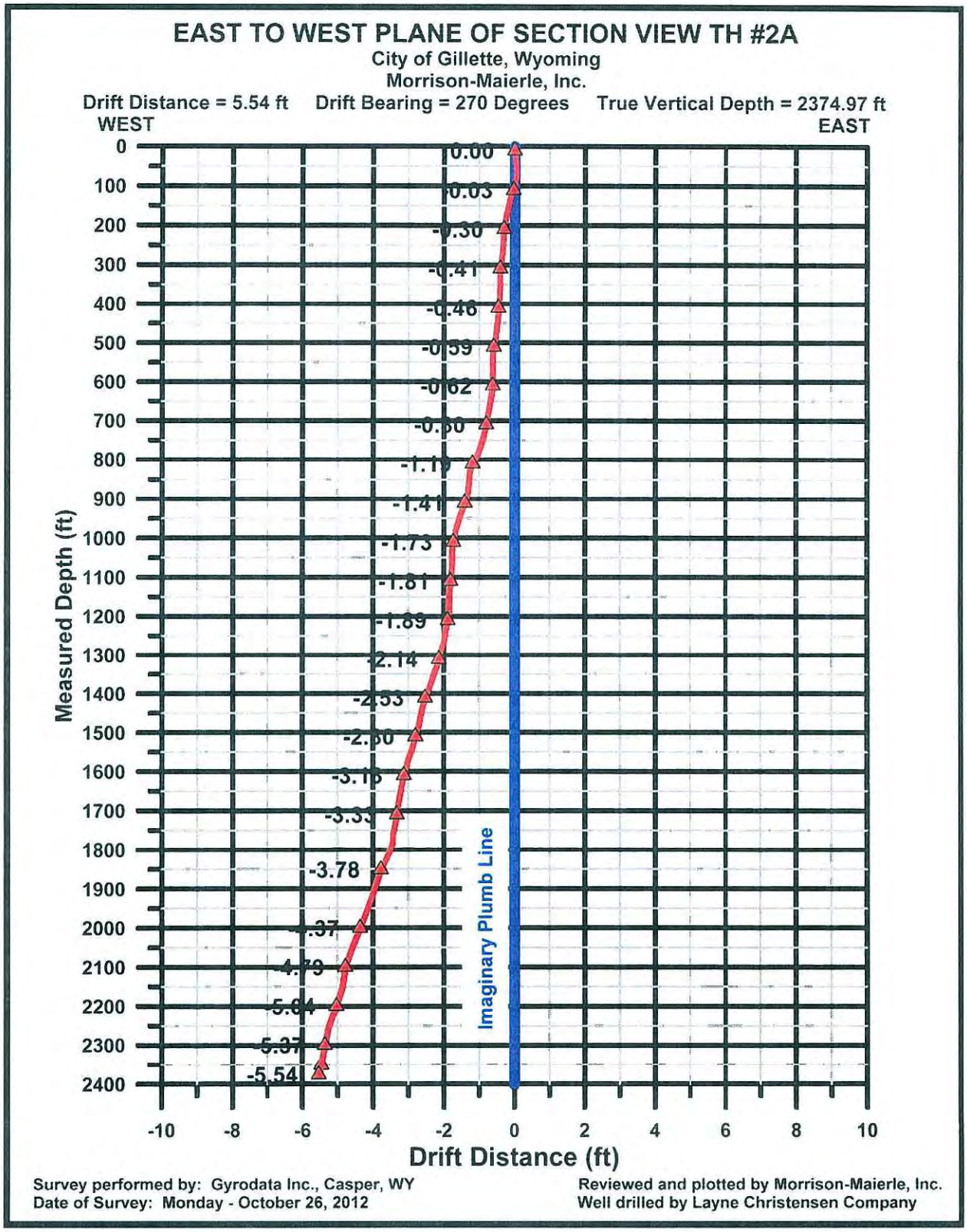


Figure 13: Drift and deviation in the north-south plane of view.

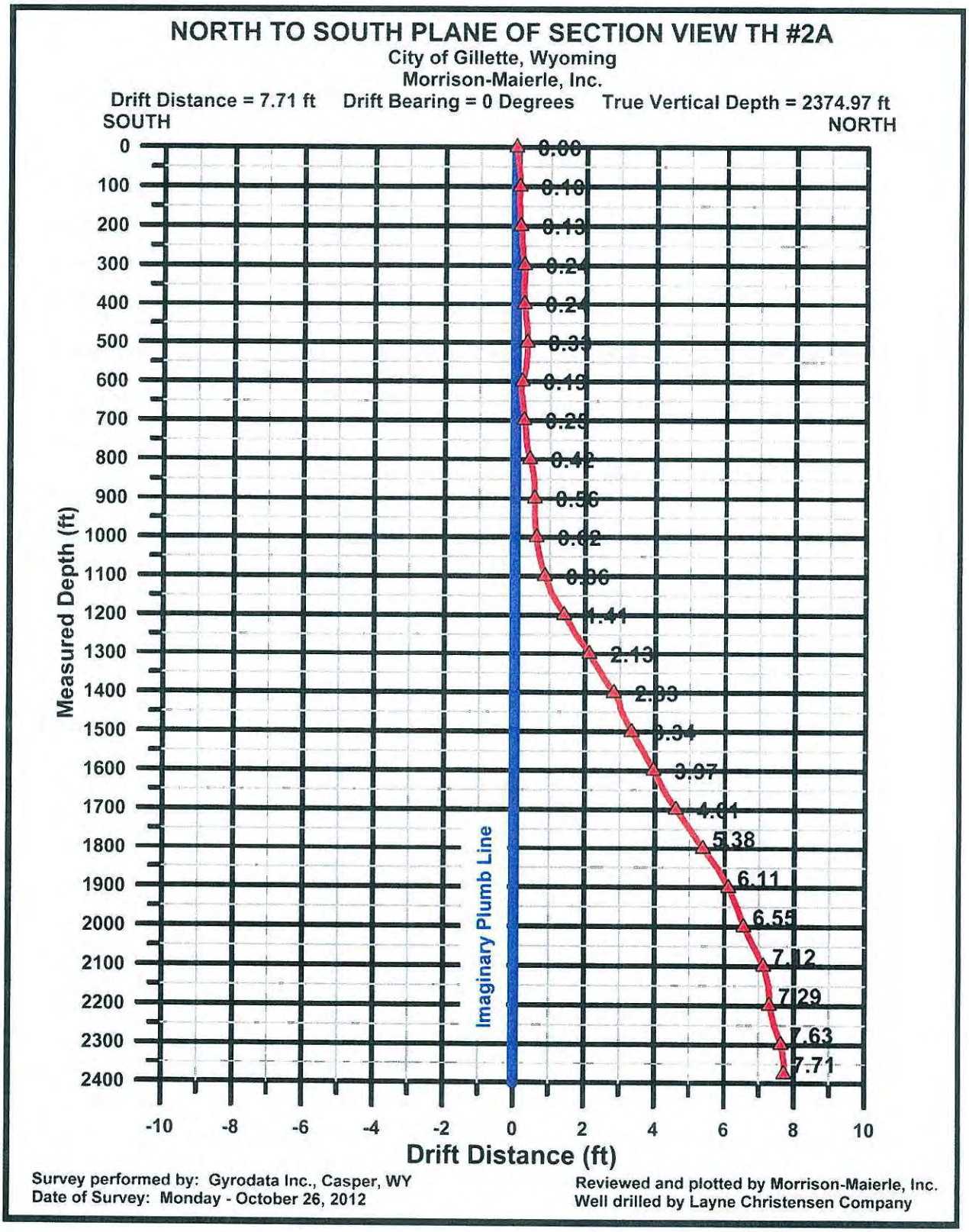


Figure 14: Drift and deviation compared to allowable 1-degree drift.

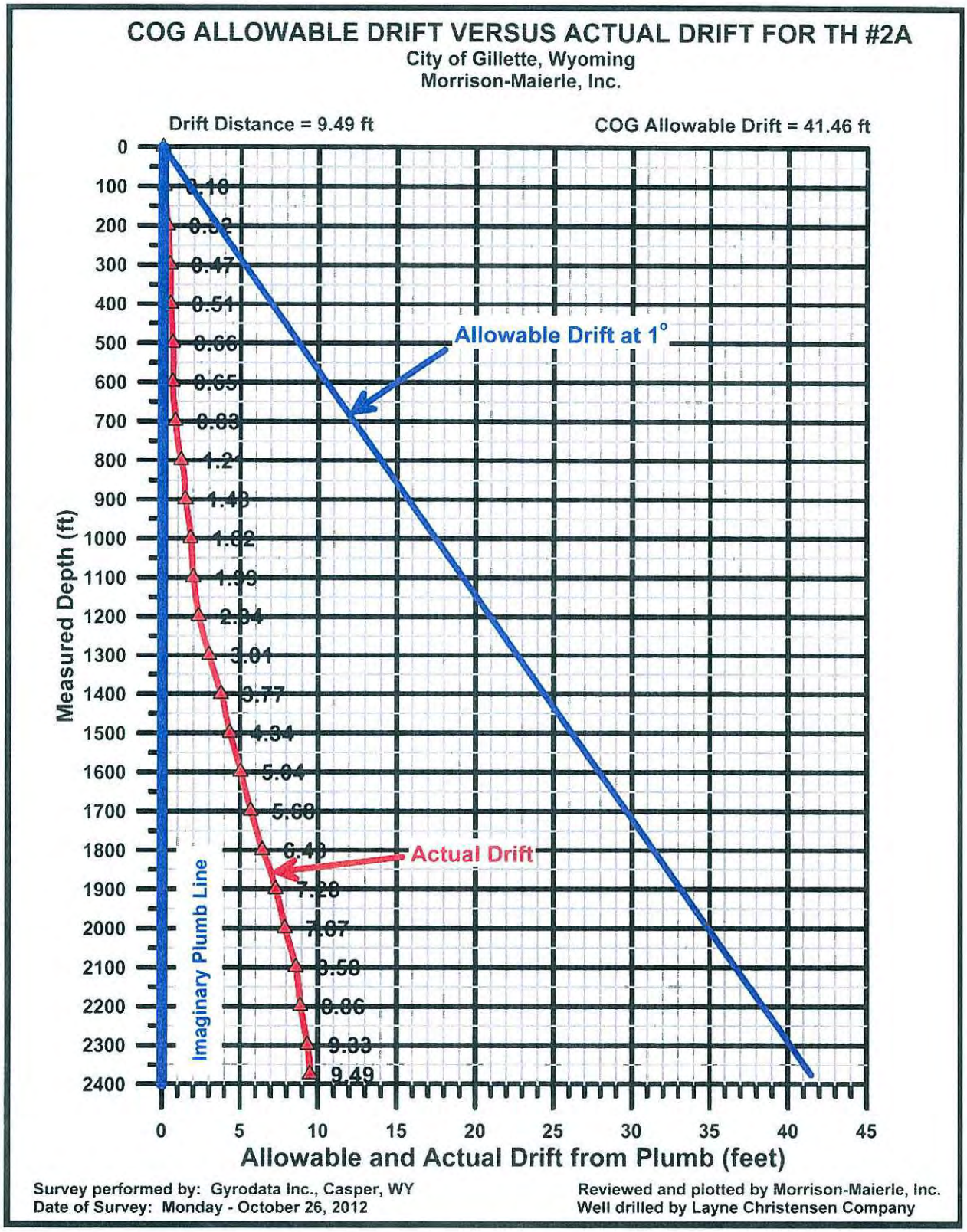


Figure 15: Three-dimensional projection view of drift and deviation.

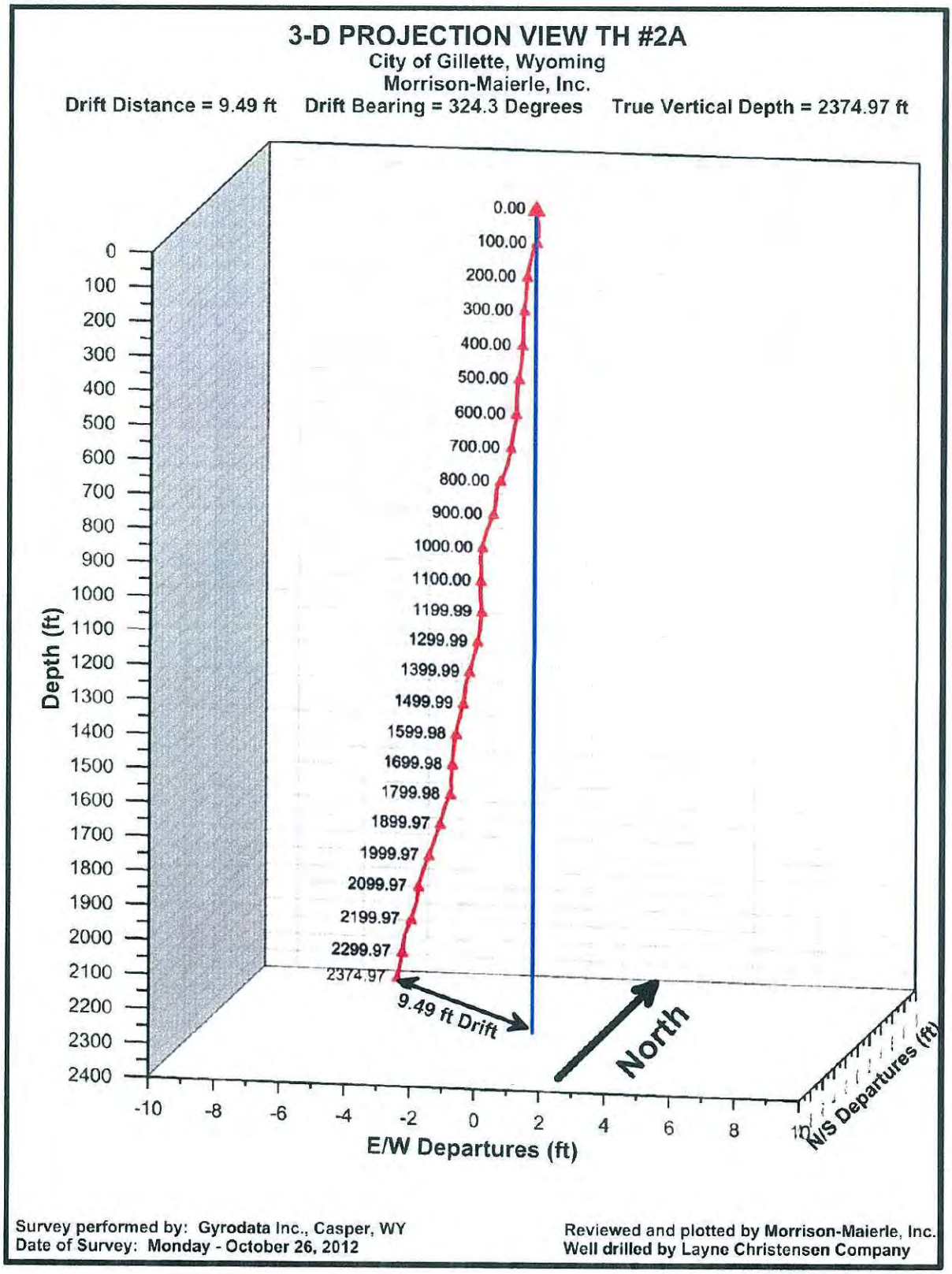


Figure 15 is a three-dimensional projection of the drift and deviation survey data compared to an imaginary plumb line representing a straight and plumb well.

The drift and deviation data on Figures 10 and 13 show that the departure of the well from straight and plumb in the 1000 to 1100-foot depth interval presents an area where pump column will rub against the casing. This conclusion was verified during test pumping of the well when PVC standpipes clamped to the pump column were deformed enough to make installation and removal of 0.75-inch diameter pressure transducers and their 0.25-inch cables difficult because the PVC pipes were compressed between the pump column and the well casing. The casing deviation in this area does not prevent the well from being used with submersible pumps; however, it indicates that only submersible pumps, not line shaft pumps, should be used in the well and the electrical motor cable to the submersible pump motor should be armored to prevent insulation from being rubbed off the wire in this part of the well.

4 DEVELOPMENT BY HYDRAULIC FRACTURING WITH ACID

A stepped rate pumping test of Test Well #2A conducted on October 21, 2012, resulted in nearly 540 feet of drawdown after three hours of pumping at 510 gpm and 21 minutes of pumping at 650 gpm. The results of this pumping test indicated the well yield was not adequate to provide the long-term design yield of 1400 gpm which was the target for this well. Accordingly, the decision was made to stimulate the well yield by hydraulically fracturing the Madison rock strata with concentrated hydrochloric acid; a process colloquially referred to as an "acid frac".

On 11/13/2012, Test Well #2A was hydraulically fractured with 15% hydrochloric acid to improve the hydraulic performance and, therefore, the yield of the well. The acid treatment to stimulate well production was provided by Basic Energy Services, using pumps and a control truck provided by Maverick Stimulation Company, LLC, of Fort Logan, CO. On 11/12/2012, an initial effort to stimulate the well was aborted when the packer failed to inflate, due to erroneous information about the inflation pressure required to seal the packer against the 10-3/4 steel casing. Because of that incident, an initial 383 bbl (16,086 gallons) of fresh water were injected into the Madison on the morning of 11/13/2012, prior to fracturing the well with acid, in order to test the packer and the acid-injection pumping equipment.

4.1 Acid-Fracturing Equipment

A Baski inflatable packer was set in the 10-3/4 inch well casing at a depth of 1951 feet. The packer was installed on 7-inch oilfield tubing with an allowable pressure rating of 1200 psi. The packer was inflated to 1500 psi with water applied with a small, high-pressure pump through stainless steel tubing (Photo 44), independent of the 7-inch tubing. In order to obtain the specified minimum injection rate and pressure of 2800 gpm (66.7 bbl/min) at 1200 psi, it was necessary to use five pumper trucks (Photo 45), each de-rated to operate at 2,000 hp for this project. Fresh water and chlorine water were stored in on-site frac tanks and connected to a mixing truck (Photo 46). The mixing truck was in turn connected to a manifold (Photos 47