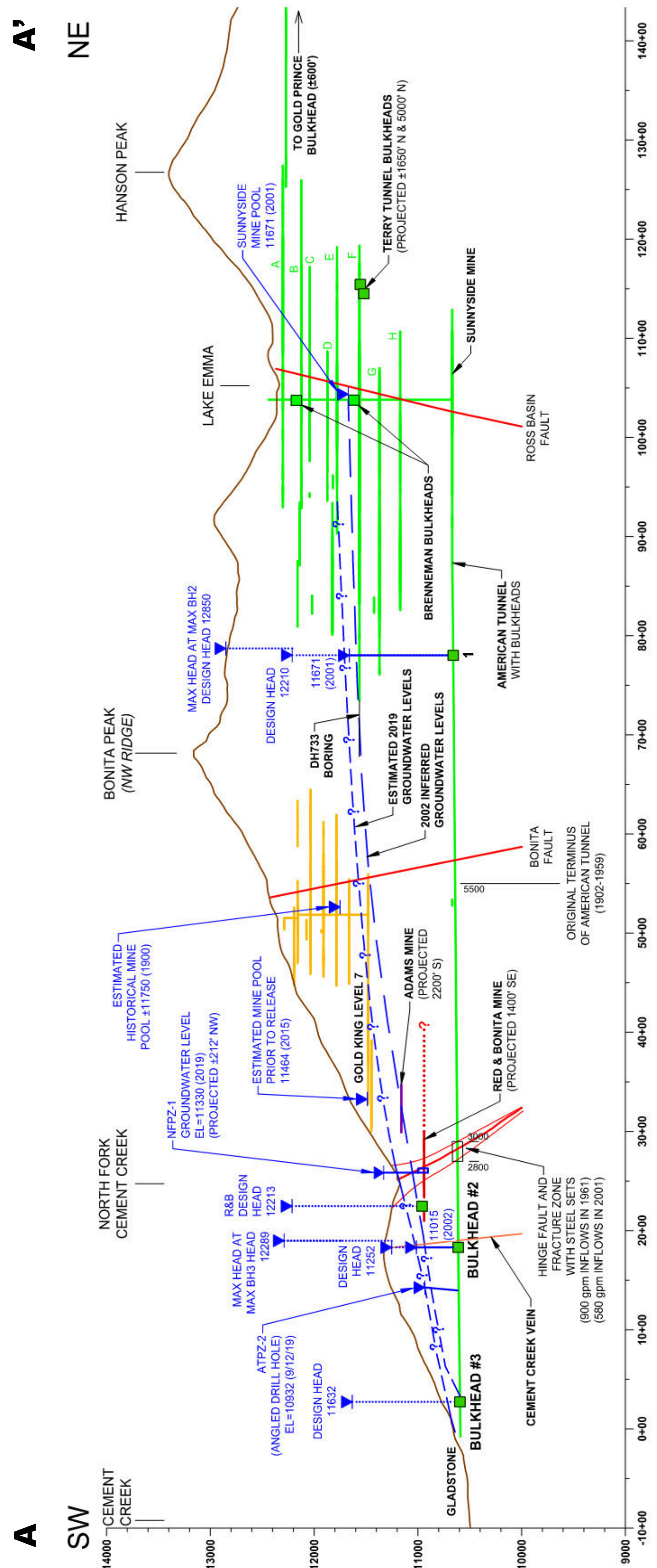


FIGURE 2. Bonita Peak Mining District Hydrogeologic Cross Section

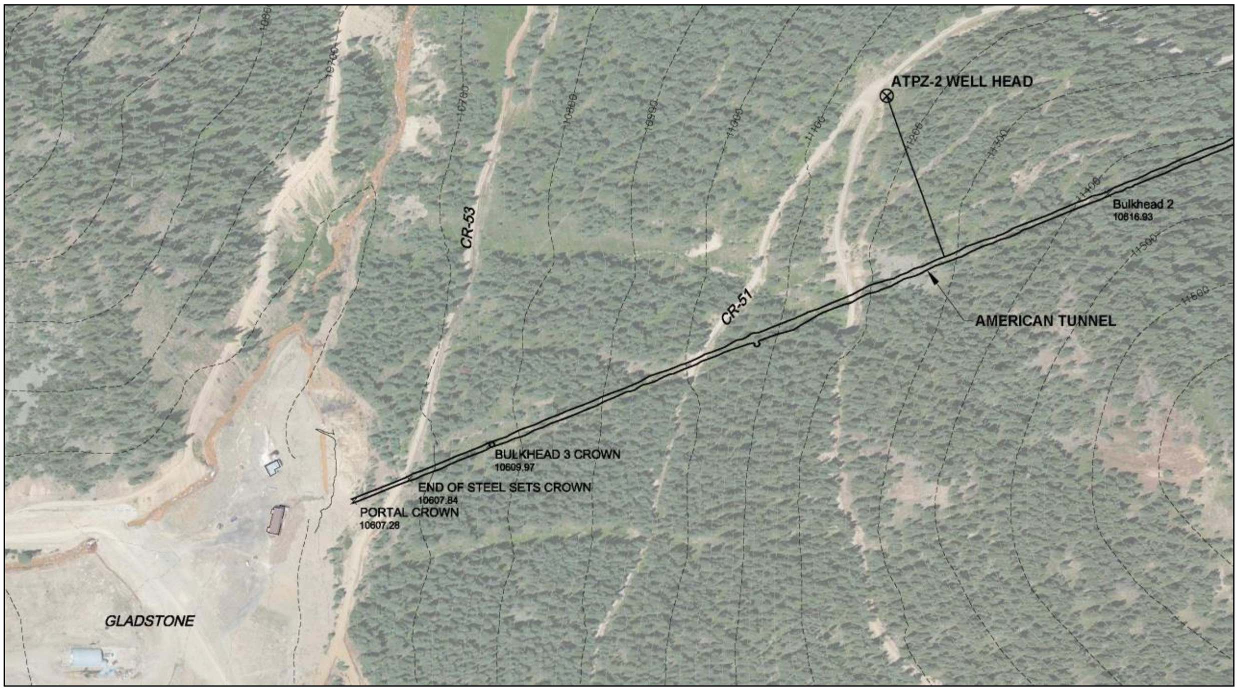


FIGURE 3. Aerial View of the American Tunnel and ATPZ-2

Figure 4 is a regional geologic cross section after Burbank and Luedke (1969, Plate 6) of the Bonita Peak Mining District, showing the approximate location of ATPZ-2. This figure shows ATPZ-2 extending through the Upper Burns Formation. The Burns Formation has been defined differently over the years; some define it as a Tertiary-aged sequence of latitic tuffs and intermediate lava flows erupted from the Silverton Caldera (Koch, 1990, Burbank and Luedke, 1969) while others define it as porphyritic andesite to rhyolite flows (Yager and Bove, 2002). Based on our observations during drilling, the rock consists primarily of intensely fractured porphyritic andesite flows, and locally latitic ash flow tuffs. Quartz-sericite-pyrite (propylitic) alteration was disseminated throughout the rock, increasing near faults and deeper into the borehole. Historically, these quartz-sericite-pyrite veins were locally mined for both precious and base metals, including gold, silver, lead, copper, zinc, iron, manganese, and titanium. (Burbank and Luedke, 1969).

METHODS

Prior to active drilling and construction, our team performed extensive digitization of old mining maps (Blood and Grose, 1968). In addition, construction reports listed as-built coordinates for the bulkheads, but in the Sunnyside Mine survey grid. To convert these data to State Plane coordinates, surveyors from ITC Resources had to locate historical mine grid base points in the high alpine environment. Using the maps, bulkhead coordinates, and a current high-accuracy conventional survey of the first 380 feet of the tunnel portal downstream of Bulkhead #3, our team determined the most likely alignment of the rest of the American Tunnel. However, digitization and interpretation of older hand-drawn maps invariably introduces a degree of uncertainty. The slope of the American Tunnel was reported variously as between 0.5 percent and 1 percent, and the targeted well location was 1,500 feet into the tunnel from the portal. Thus, the tunnel centerline (axis) elevation at the proposed intercept location was estimated between elevation 10,605 and 10,624 feet; representing a target zone up to 20 feet high. Based on additional hand-drawn records from upstream shafts and bulkheads, as well as experience with older tunnels excavated in the late 1800s and early 1900s, when the American Tunnel was initially advanced, our team determined the likely incline of the tunnel was closer to 1 percent in this section and we refined the target zone accordingly.

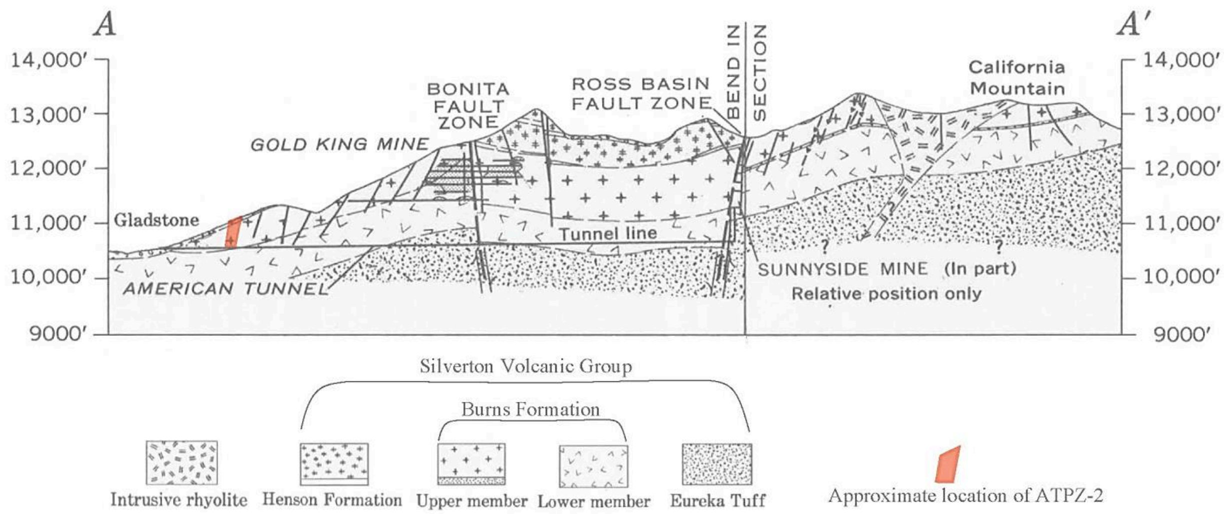


FIGURE 4. Regional Geologic Cross Section (after Burbank and Luedke, 1969)

Due to historic landmarks, land ownership, and challenging steep terrain directly above the proposed intercept of the tunnel, the drill pad had to be located to the northwest of the tunnel alignment. This required the borehole to be inclined downward at approximately 52 degrees from horizontal to intercept the tunnel. Due to the length of the proposed borehole (about 650 feet), it was recognized that conventional drilling techniques would not be sufficient to guarantee interception of the tunnel target. The target zone measured about 12 feet vertically, and conventional rock coring equipment could reasonably be expected to wander 50 feet or more (±10 degrees) over the length of the borehole. Accordingly, a drilling team with the ability to drill and steer the borehole to the intercept location, to an accuracy of 3 feet in any given direction, was solicited. The Godbe and IDS team brought both conventional rock coring expertise and steering capability to the project.

Drilling and Steering

In early July 2019, the field team was mobilized, and drilling began on July 11, 2019. The first step was to drill and grout (1:1 neat) HWT casing in place for the first 50 feet. Due to an error in the initial grout mixture (the mix was batched with excess water and did not properly cure) the HWT casing was over drilled using PWT rods to 47 feet. The PWT casing was grouted in place around the HWT casing (Fig. 5). This robust casing combination, together with a blow off preventor, provided insurance against any artesian groundwater conditions. Drilling then continued with HQ-sized triple-tube wireline coring techniques.

Surveying of the borehole commenced at 114 feet. A mix of downhole surveying equipment and techniques was utilized throughout the advancement of the borehole. A total of four gyroscopic surveys were performed by IDS at strategic intervals within the borehole. The results were used to refine appropriate steering/alignment correction intervals during drilling. As the gyroscopic surveys added to project costs and caused some delays, an EZ-Shot magnetic electronic survey tool was used by IDS at 20-foot intervals to confirm borehole dip and orientation on an ongoing basis.

The Rock Quality Designation (RQD) of the borehole averaged 13.7 percent. The rock was intensely fractured to rubblized throughout. In faulted zones, the drilling yielded run lengths of less than 1 foot to 3 feet with RQDs of zero. Consistent use of the EZ-Shot survey tool, paired with close coordination with the drill rig operator, allowed the team to keep the borehole on track. The Godbe drill operator used short core run lengths, reduced down pressure, and careful management of circulation fluid to maintain the borehole trajectory. Despite the challenges of drilling in such poor-quality rock, ongoing survey results indicated the borehole remained true to within about 1 degree of the target trajectory, a testament to the Godbe drill rig operator's skill.

At a borehole depth of 465 feet, it was determined that the borehole had deviated about 1 to 2 degrees upward from the proposed trajectory, which, if not corrected, could result in a deviation outside of the 3-foot target zone. The team determined that directional drilling techniques would increase the borehole accuracy and the likelihood of intercepting the tunnel. At this depth, however, the rock quality was greatly reduced due to extensive fracturing, faulting and alteration. After extensive discussion, to safeguard the integrity of the borehole and the steering equipment, the HQ-sized drill rods were grouted into place and converted into borehole casing to 465 feet borehole depth. Thereafter, NQ drilling equipment was used to advance the borehole, with the NQ core barrel fitting neatly inside the HQ drill-rod casing. Additionally, drilling mud was added to the circulation fluid to support the borehole as it progressed.

The steering tool consisted of an NQ-sized full-faced bit attached to an angled motor and three beryllium-titanium alloy BQ-sized drill rods at the end of a regular BQ-sized drill-rod string. The beryllium-titanium alloy rods allowed the EZ-shot survey tool to be used within the drill string. The steel of conventional drill rods prevents precise azimuth readings.

The initial steering operations occurred over an interval of 20 feet with the angled motor set at an angle of 0.71 degrees. The angle of the motor does not necessarily indicate the resulting angle of borehole deviation, as the success of steering depends on the rock type and competency. The intent was to slightly deepen (downward) the borehole trajectory to aim more directly for the center of the target zone. Due to the full-face bit required for steering the borehole, no sampling of the rock occurred within this interval. Following steering operations, the steered portion of the borehole was reamed out with a step bit to clean the borehole and allow reintroduction of the conventional NQ wireline coring bit to advance the borehole. Standard NQ-sized wireline coring was performed for another 20 feet, at which point the borehole was resurveyed. A second 20-foot steering interval was drilled with the same 0.71 degree motor angle. The necessity of a second 20-foot-long steering interval arose from an over-correction during the first interval of directional drilling. While directional drilling is an incredible tool in the geotechnical engineer's arsenal, it does pose challenges and shortfalls. Surveying with the directional tooling can only be performed 10 feet back from the drill bit, leading to uncertainty about how much the borehole trajectory is actually deviating until steering operations have continued for at least 20 feet.

After gyroscopically surveying the borehole, subsequent to the second steering interval, it was decided for the purposes of intercepting the tunnel, that the directional drilling should continue with the angled motor set at a diminished angle of 0.20 degrees. Directional drilling at the diminished motor angle was utilized for an additional 60-foot-long interval to a depth of 614 feet. Concerns regarding the potential to damage or lose the expensive directional drilling equipment within the abandoned tunnel zone led to an abundance of caution, and the directional drilling assembly was removed from the borehole at a depth of 614 feet. The remaining drilling was performed with an NQ-sized tri-cone button bit until the tunnel was intercepted.

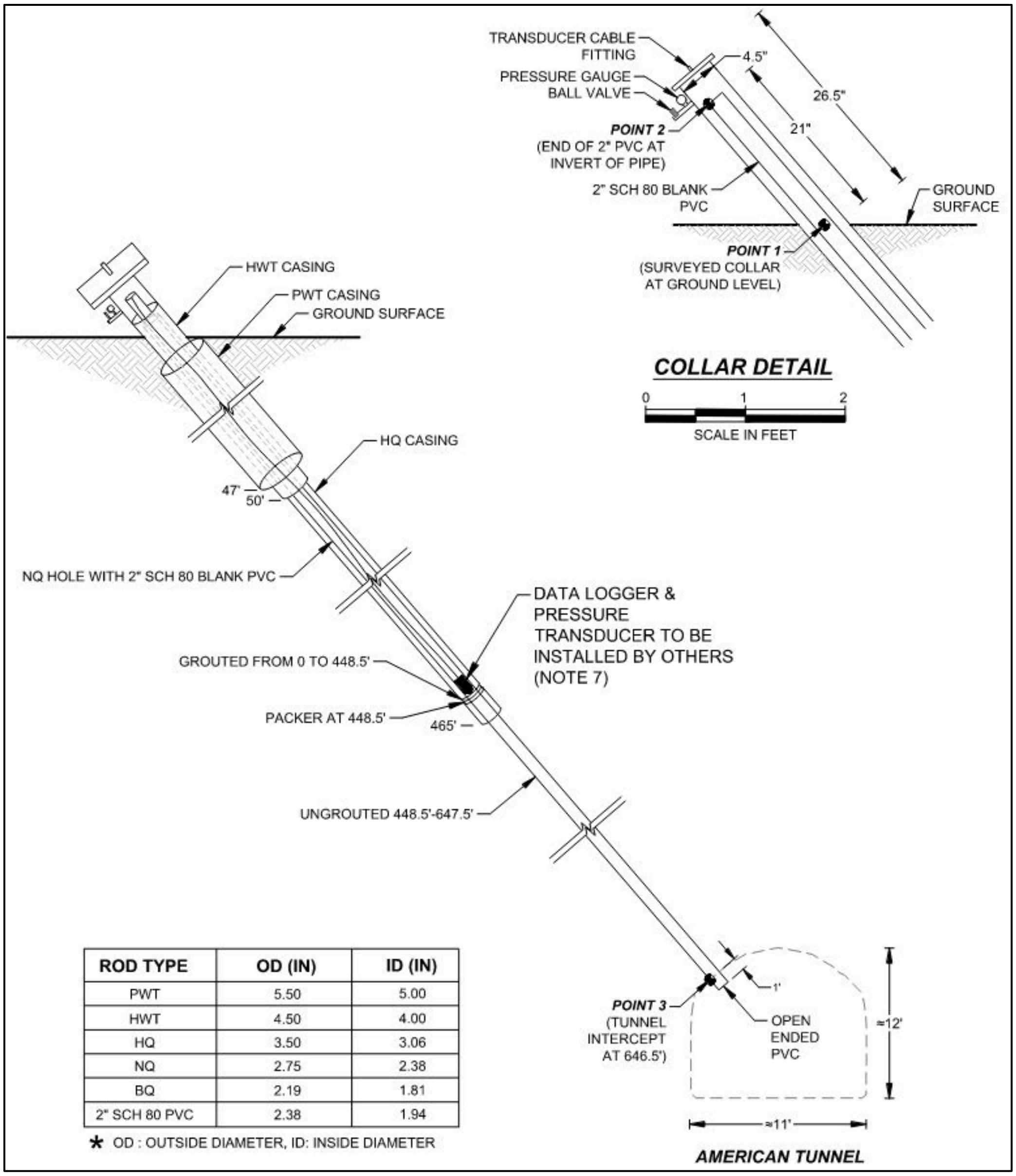
The American Tunnel was successfully intercepted on August 17, 2019, at a borehole depth of 646.5 feet, when the Godbe drill rig operator noticed a rapid decrease in the circulation fluid pressure and the torque on the drill bit. This indicated that there was a loss of fluid circulation in the borehole and a loss of friction at the bit, indicating the drill bit had penetrated a void within the tunnel. To further confirm the intercept of the tunnel, the drill stem was advanced into the American Tunnel to probe the extent of the void space. A total of about 4 feet of void space was encountered before resistance was noted by the drill rig operator. Based on this information, and the documented approximate 11-foot width of the American Tunnel, we surmised the borehole had intercepted the rib (sidewall) of the American Tunnel. The resistance at the bottom of the void was either the tunnel invert or a pile of debris (possibly roof fall) within the tunnel.

Well Completion

After the successful interception of the American Tunnel, a monitoring well was installed in the borehole. The well was constructed of two-inch-diameter Schedule 80 blank polyvinyl chloride (PVC) pipe. No screened interval was installed, as the intent of the well is to directly measure the groundwater levels and obtain water quality samples from inside the American Tunnel.

The NQ drill stem was removed from the borehole and the PVC pipe was advanced into the borehole. In order to grout the monitoring well PVC into place, a donut packer fitting was installed along the PVC well string within the HQ casing at a depth of 448.5 feet. As the monitoring well PVC pipes were procured before field operations in 20-foot lengths with threaded connections, the donut packer had to be installed at a joint between two PVC sections, which limited placement options. The donut packer was installed as deep as possible inside the HQ rod casing to allow for a tight seal against the inner HQ rod wall. The remaining PVC pipe below 448.5 feet was installed ungrouted within the open borehole and into the American Tunnel. Grout was pumped into the HQ rods, outside of the solid PVC monitoring well pipes, using the drill rig's fluid circulation system. Grout was placed in three lifts, and each lift was allowed to cure for 24 hours prior to additional grout placement or well construction.

After the PVC pipe was grouted and the well head attached, the well development was performed. Two casing volumes (125 gallons) were pumped from the well using a portable bladder pump temporarily suspended below the ground water level within the well. The well was deemed to be complete on August 23, 2019. In November 2019, a vibrating wire piezometer and a low flow bladder pump were installed in the well to allow for ongoing monitoring of groundwater levels within the American Tunnel, and for future water sampling events. The well head was also modified to allow for these instruments to be easily accessed during the winter, when snowpack at the well's surface location (the drill pad) can exceed 15 feet. The completed monitoring well and well head (collar) as-built drawing is shown on Figure 5, and a photograph of the well head is shown on Photograph 1.



ROD TYPE	OD (IN)	ID (IN)
PWT	5.50	5.00
HWT	4.50	4.00
HQ	3.50	3.06
NQ	2.75	2.38
BQ	2.19	1.81
2" SCH 80 PVC	2.38	1.94

FIGURE 5. ATPZ-2 Well and Well Head Collar Details

DISCUSSION

The process of completing ATPZ-2 required collaboration between numerous geologists and engineers, drilling personnel, CAD professionals, and onsite personnel. Successful execution of the project required the integration of historic hand-drawn mine maps, modern survey data, conventional drilling techniques, and precise borehole steering techniques.

A considerable challenge of this project was the quality of the rock encountered during the drilling to develop ATPZ-2. The average RQD of the cored sections of the borehole was 13.7 percent. The rock was intensely fractured to rubblized. The rubblization predominantly occurred in numerous fault zones along the borehole. The intensely fractured nature of the rock induced an average run length of 2.75 feet. Concern arose for the integrity of the borehole since its downward angle (~52 degrees) could increase the chance of borehole collapse. As such, precautionary casing of the upper two-thirds of the borehole by grouting the HQ-sized drill rods in-place was a prudent field decision.

PHOTOGRAPH 1. ATPZ-2 Well Head with Protective Bollards and Instrumentation Enclosures

In the preliminary stages of digitization and plans, the faults within the American Tunnel were projected onto the alignment of the borehole. This showed three fault zones possibly intersecting the path of the borehole. Based on the core retrieved from the borehole, particularly the fractured/altered zones encountered during drilling, the fault projection exercise was accurate to within about 30 feet as shown on Figure 6.

Groundwater and Bulk Heads

The measured groundwater level in ATPZ-2 (Figure 6) is consistent with estimates prepared prior to the construction of this monitoring well. The average groundwater level measured in ATPZ-2 (Elevation 10,935 feet) is approximately 24 feet below the originally estimated groundwater level elevation of 10,959 feet.

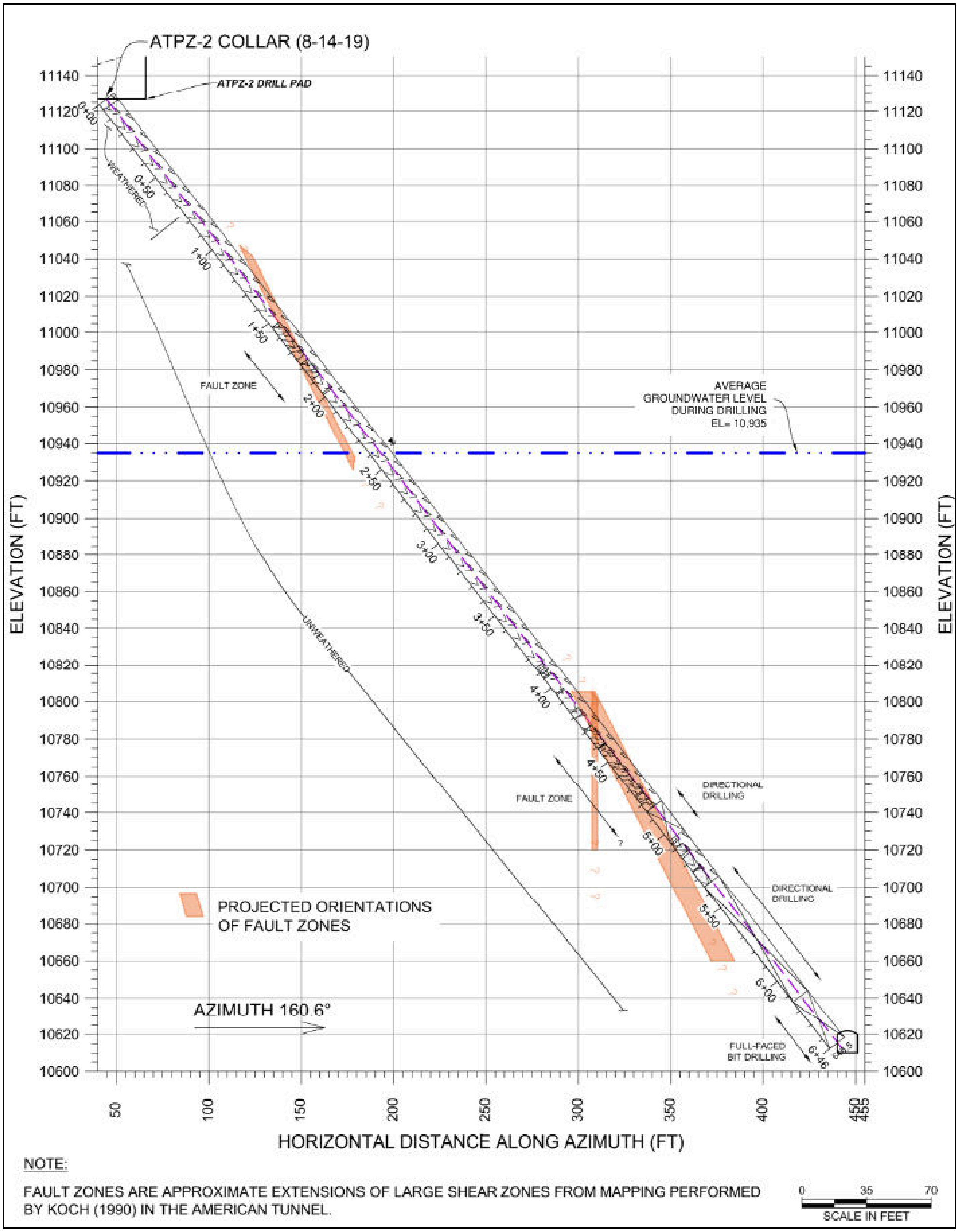


FIGURE 6. ATPZ-2 Borehole Log with Projected Fault Zones

The key groundwater observation was that the elevation of the groundwater encountered during drilling of the overlying rock essentially matched the elevation head of the water in the American Tunnel measured after drilling intercepted the tunnel. This suggests that the American Tunnel is the primary driver of the groundwater level in this area. Due to the highly fractured nature of this rock, the groundwater table is likely hydrologically connected for some distance near the tunnel. The groundwater within the rock mass surrounding the American Tunnel, and within the tunnel itself, is not under artesian pressure and will likely not become artesian unless other factors change in the surrounding area and connected mine workings.

The primary motivation for constructing ATPZ-2 was the concern for the pressures being contained behind Bulkhead #3. By intercepting and recording the groundwater pressure(s) in the American Tunnel, we were able to determine that the existing groundwater pressure on the bulkhead amounted to 32 percent of the original pressure considered in the design of Bulkhead #3. Thus, Bulkhead #3 can withstand additional groundwater pressure due to other changes in the local mine workings and associated hydrologic regime. In other words, the surrounding mines can now be considered for bulkhead closures, and the groundwater pressure(s) behind Bulkhead #3 can be closely monitored via ATPZ-2.

CONCLUSIONS

The completion of the American Tunnel Piezometer No. 2 was a feat of teamwork, experience and ingenuity. Combining conventional wireline coring techniques with directional drilling techniques provides a unique and powerful tool for drilling accurate boreholes over long distances. While an experienced, skilled wireline drill rig operator can achieve an extremely accurate borehole trajectory, the introduction of a steerable drill bit assembly and downhole surveying during drilling can provide additional targeting accuracy, particularly when attempting to intercept a small target zone at considerable depth.

By intersecting the American Tunnel and constructing a monitoring well that intercepts the tunnel, the groundwater pressure contained behind Bulkhead #3 can be effectively monitored, and the water quality within the tunnel can be directly sampled and tested. With this new groundwater pressure monitoring capability, other mines in the region can now be considered for bulkhead closures.

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Avalanche Impacts to Lake City, Colorado, Ute-Ulay and Hidden Treasure Dams

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ABSTRACT

During late winter of 2018–2019, Hinsdale County (and other areas of Colorado) experienced unprecedented avalanche activity. Massive avalanches numbering in the hundreds impacted the two main drainages in Hinsdale County. These were avalanches of historic proportions that shaved the forests and soil down to bedrock, resulting in massive amounts of debris being deposited in county waterways, leading to potential of flooding and debris flow within the town of Lake City. Governor Polis issued emergency declarations due to severe weather, including one on May 6, 2019, for Hinsdale County avalanche debris and flood risk mitigation and preparedness efforts. Henson Creek posed the primary risk for flooding of Lake City. Two historic concrete dams related to mining activity in the 1880s and early 1900s occur along Henson Creek. These are the Ute-Ulay and Hidden Treasure Dams. Analysis of the dams and the potential impacts from debris led to the partial removal of the Hidden Treasure Dam. In addition, concern about debris-flow flooding potentially impacting Lake City led to an initial evaluation of locations for debris-flow barriers. Ultimately, the natural draining characteristics of the debris/ice mix led to a “no-action” decision for debris-flow barriers.

INTRODUCTION

Historic snowfall in Colorado during the winter of 2018-19 produced extreme avalanche events in March greater than any previously recorded in Colorado. Many hundreds of avalanches impacted Henson Creek and the Lake Fork of the Gunnison River, the two drainages whose confluence is at the south end of Lake City, the largest town in Hinsdale County. Typically, the avalanches ran along established avalanche paths but also along wider and longer areas, carving through mature timber, shaving the soil and vegetation down to bedrock, and creating high-impact features on the other side of the valley. In some cases, the avalanches carved new routes in areas where avalanches were not previously known to run. The resulting debris fields covered the drainages at the base of the avalanches with a morass of trees, soil, and debris packed in snow and ice. This river basin includes the areas of Hinsdale County and Lake City, whose locations are shown in Figure 1.

HISTORIC SNOWPACK

The Colorado Avalanche Information Center (CAIC) indicated that the above-average snowfall in October provided the layer that sheared later in March, during the massive avalanches in that month. This type of heavy October snowfall event is not typical but when it happens, it provides a weak layer that can shear under stress from the water weight of later snowfall events. By February, the snowfall was resulting in high water contents with many