Characterization of Geologic Anomalies
Through Horizontal Directional Drilling

Coal operators have begun to realize the exploration potential of data obtained from Horizontal Directional Drilling ("HDD"). Localized anomalies (for example channeling, splays, and faulting) with significant implications to mining are often un-detected with conventional vertical exploration drilling due to their erratic nature. Typically, high-density vertical exploration drilling patterns are necessary to reasonably map these anomalies for mine planning purposes. For some mine operators focused vertical exploration drilling is cost prohibitive or difficult to implement due to depth or environmental drilling restrictions (areas of the western U.S).

HDD data must be recorded accurately by an experienced and attentive drilling crew and plotted and interpreted by a qualified geologist that can interact with mine professionals to present useful interpretations of anomalies with this technique. In all cases where HDD is applied, as-mined data should be obtained to validate interpretations for future projections on the same property.

The HDD applications presented herein are deployed by REI Drilling, Inc. ("REI"), which since 1983 provides directional drilling services to the coal mining industry. REI currently operates a fleet of ten (10) underground longhole drilling units supported by professional geologic and mining engineering staff. REI is based in Salt Lake City, UT with offices in Virginia and can be reached at (877) 838-0534, or www.reidrilling.com.

Horizontal Directional Drilling

Advances in permissible downhole borehole survey technology in the 1990's has improved the accuracy of HDD performed for underground coal mining operations, and as a result, increased its application. Initially performed for development of in-seam boreholes for methane drainage, HDD is now routinely applied for geologic exploration, exploration of abandoned mine workings, and for the development of targeted boreholes into surrounding mine workings (underlying, overlying, or adjacent) for water transfer or water drainage (draining overlying abandoned workings in advance of longwall mining, for example).

For coal mining operations, HDD is performed with high thrust, permissible drills, downhole mud-motor drilling technology, and state-of-the-art borehole surveying equipment. Clean circulating fluid is pumped through drill rods at rates of 50 to 100 gpm at high pressures (1,000 psi), to power a hydraulic downhole motor which rotates a bit (typically 4 inches in diameter). Directional control is achieved by the use of a bent housing installed behind the bit. The orientation of the "bend" (typically 1 to 2 degrees) is monitored by the borehole survey system and is positioned by the operator through rotation of the drill rods. The bend and axial force produced by the drill (thrust) along the rods alter the track of the bit in a direction opposite to that of the bend. This also allows the development of multiple tangential boreholes (side-tracks).

Downhole magnetometers and accelerometers provide the drill operator with the azimuth and pitch of the drilling tools, in addition to the orientation of the bent housing. Steering is performed by the operator upon rationalization of the downhole data and orientation of the bent housing through rotation of the drill rods. Experienced directional drillers use plots of rationalized downhole data, drilling thrust, downhole drilling water pressures, circulation volumes, and cuttings to accurately steer boreholes in coal seams, or interburden, to distances in excess of 5,000 ft.

Seam Discontinuities

Seam discontinuities which compromise seam height, such as channeling, can be interpreted through the use of HDD within reasonable accuracies. The approach is to determine the seam height over an extended lateral length by physically contacting the mine roof at planned intervals. Once the total depth of the borehole is reached, tangential boreholes ("side-tracks") are developed to intercept the floor at locations that coincide with the roof contacts to provide a reasonable measure of coal thickness. Pending proper borehole planning, thickness measurements may be provided at intervals as frequent as 50 feet for a typical coal seam (6 ft). Although this technique relies on coinciding roof and floor contact points, the use of proper borehole surveying techniques, and interpretation of the roof and floor through drilling thrust, downhole water pressures and cuttings, REI has provided mine operators reasonable predictions of seam profile and the extent of post-depositional features which have been validated by subsequent mining.

Figure No. 1 presents the results of an HDD exploration program to determine the extent of a post-depositional channel system intercepted during gate-road development. In-place vertical drilling on this property indicated increasing seam height through projected longwall mining. However, when gate road development commenced, the Mine quickly encountered channeling that had scoured into the coal seam. Seam height at the gate-road face was three (3) ft and the mine was forced to cut sandstone roof with the continuous miner to advance the gate-road. The trend of the channel was unknown and the Mine was concerned that all three of the longwall panels planned in the vicinity could be affected, compromising this part of the reserve.

Initial exploration drilling was along the gate road projections (Borehole No. 1 as indicated on the Figure). REI drilled Borehole No. 1 to 1,000 ft bit depth, touching the roof at planned intervals of 100 ft. REI pulled the downhole equipment back and developed side-tracks to contact the floor near the vicinity of the roof touches. Through plotting and drill log interpretation, REI determined that the channeling had lifted off the coal seam within a hundred feet from the current face location. Figure 2 presents a detailed interpretation of seam height based on two data points separated by 100 ft.

REI developed a total of six (6) boreholes to determine the lateral extent and orientation of the sandstone body within the planned longwall panels in this mining district. Further drilling and seam height characterization determined that the channeling continued through three of the planned longwall panels. Figure 1 presents the isopachs derived from integrating the HDD results with as-mined and exploration data. Following interpretation of HDD information, the Mine elected to continue gate development and exploit this part of the reserve. As-mined surveys indicated that the seam heights determined from HDD exploration were consistently conservative but within 10 percent of as-mined measurements.

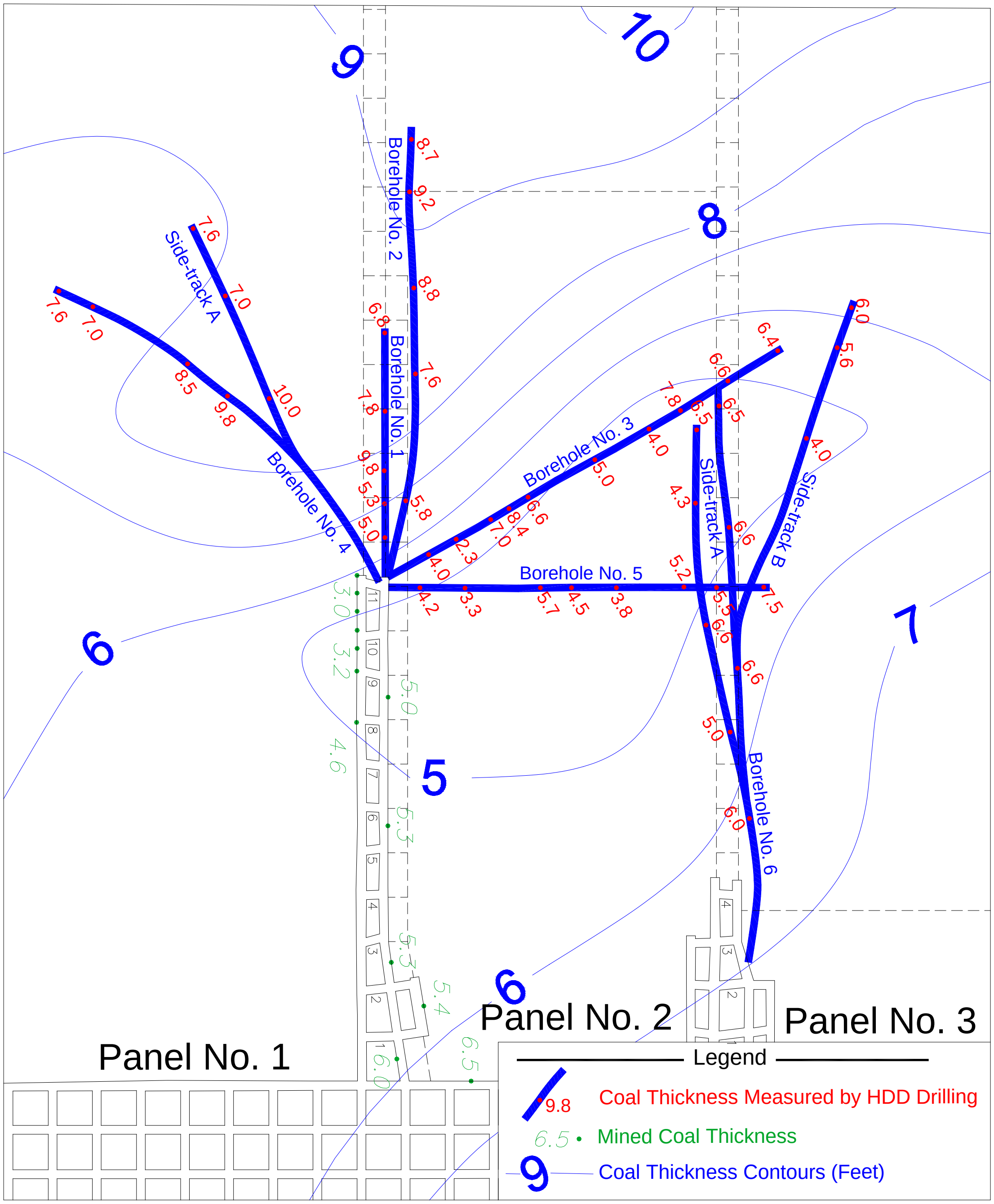

Figure No. 1: Plan view illustrating extent of coal thinning associated with post-depositional channeling as determined by HDD drilling to determine seam height. The anomaly affected three (3) longwall panels as indicated by the seam heights determined from drilling and the resulting isopachs.

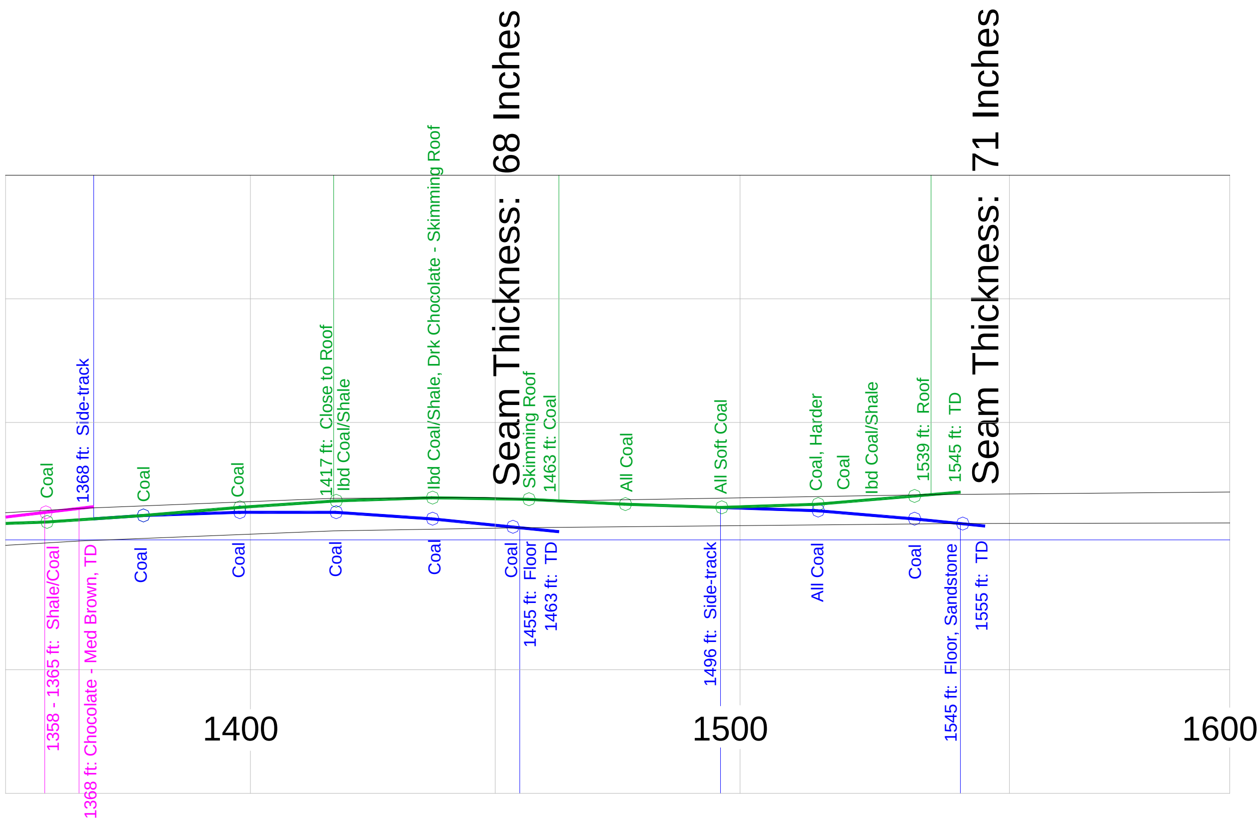

Figure No. 2: Profile view of the initial borehole (green) and side-tracking (blue) to determine seam height using horizontal directional drilling (HDD). Note the proximity of the floor touches relative to the roof touches and the level of detail ascertained from drilling logs and borehole survey data.

Fault Detection & Characterization

Concerns associated with mining into structural faults include determining the trend and lateral extent of the fault, the amount of offset, the volume of rock excavation required for mine-through, roof control impacts, and the potential emission of any associated water or methane. Be it gate-road development or longwall mining, advancing through an unexpected fault can require a significant, capital intensive effort.

HDD can be utilized to identify faults, quantify their characteristics and extent, and relieve associated water and gas. Properly performed borehole surveys and drilling logs provide information to derive projections of seam offset, the presence of fault gouge, and the lateral extent of faulting in advance of mining. Such information is invaluable as it provides a mine operator valuable time to revise mining plans, develop contingency plans, or derive fault interception plans.

The approach is to determine the location of the fault by ascertaining the continuity of coal during drilling. This is achieved through monitoring drilling thrust, downhole water pressures, change in circulation volumes, and cuttings. Where faults are encountered, carefully surveyed side-tracks placed into the roof, floor, or fault gouge, determine the orientation of the displacement and its magnitude. Side-tracks developed to further intercept the discontinuity along its lateral length characterize its extent.

Figure 3 illustrates a profile of a fault zone intercepted by REI in advance of gate entry developments. This fault zone, when intercepted by mining in an adjacent gateroad had produced a tremendous volume of water which significantly impeded mining development. Drilling indicated that the anticipated fault zone was further outby than anticipated, while exploratory side-tracks and associated drilling logs indicated that the fault was comprised of multiple “en echelon” step faults. REI projected that the offsets were four (4) and eleven (11) feet, respectively. Water production from encountering the fault was less than 50 gallons per minute, indicating that the interception from prior mining had discharged the fault zone. Based on the results derived from HDD exploration, the Mine elected to proceed with bleeder development and prepared rock excavation and gob disposal plans.

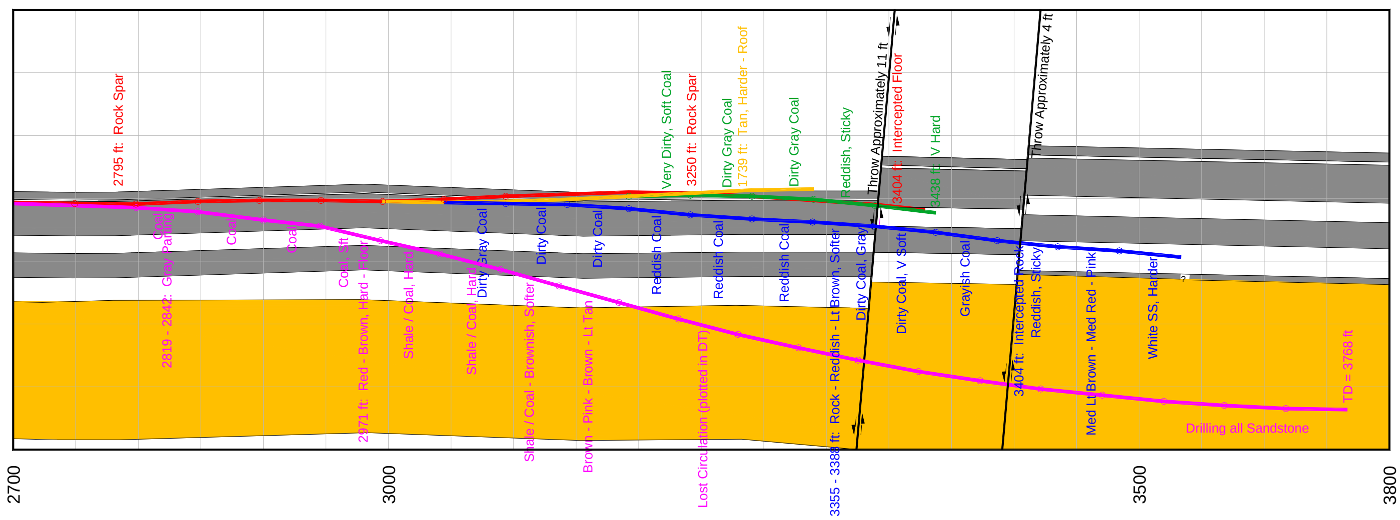

Figure No. 3: The profile presents the side-track drilling to determine the amount of offset from faulting. It was discovered that the fault had several “en echelon” or step faults which were projected to measure four (4) and eleven (11) ft, respectively.

Coal Burn

Coal Burn or “Clinker”, is common in western U.S. coal basins near outcrop. Burn characteristics include oxidized, or burned coal, which affects roof stability in proximate entries and condemns reserve areas. In some instances, oxidation is still active. From a mine planning perspective, burn is sporadic and unpredictable. REI has applied HDD to effectively determine the lateral extent of burn and identify active oxidation.

The HDD approach is to identify the contact between virgin coal and burn. Thrust, downhole water pressures, return volumes and cuttings are monitored while drilling. Clear indications of burn are reduced downhole drilling pressures, circulation loss, and a significant reduction in drilling thrust (weight on bit necessary to advance). The key to quantifying the extent of burn is planning for placement of strategic exploratory side-tracks during drilling of the initial borehole. Well placed side-tracks can map the lateral extent of burn and provide mine operators with the information necessary to define mine plans that will maximize coal recovery from reserves near burn.

Figure 4 illustrates the application of HDD to map coal burn between projected gate-road development and coal outcrop. The outcrop near the reserve had extensive coal burn, but the lateral extent of burn toward the interior of the reserve was unknown. The mine operator was concerned that burn encroached on the reserve and used HDD to map the burn prior to committing to development. Vertical drilling was out of the question as it required extensive permitting and had environmental implications.

The approach was to develop an exploration borehole along the azimuth of the Mine’s projected workings and flank the anticipated burn. During drilling, REI planned for placement of side-tracks to explore for the burn adjacent to the main borehole. As shown on Figure 4, no coal burn was intercepted during drilling of the main borehole. From the main borehole, REI explored tangentially, toward outcrop, with numerous side-tracks.

This effort identified the contact between virgin coal and burn along the length of the initial borehole. Side-tracking efforts were performed from inby to outby and required placement of mechanical packers after each interception with burn.

REI completed the effort and was able to provide the mine operator with the location of competent coal along the azimuth of projected developments, and the extent of burn relative to this line. This information was used by the mine operator to plan the development of this reserve.

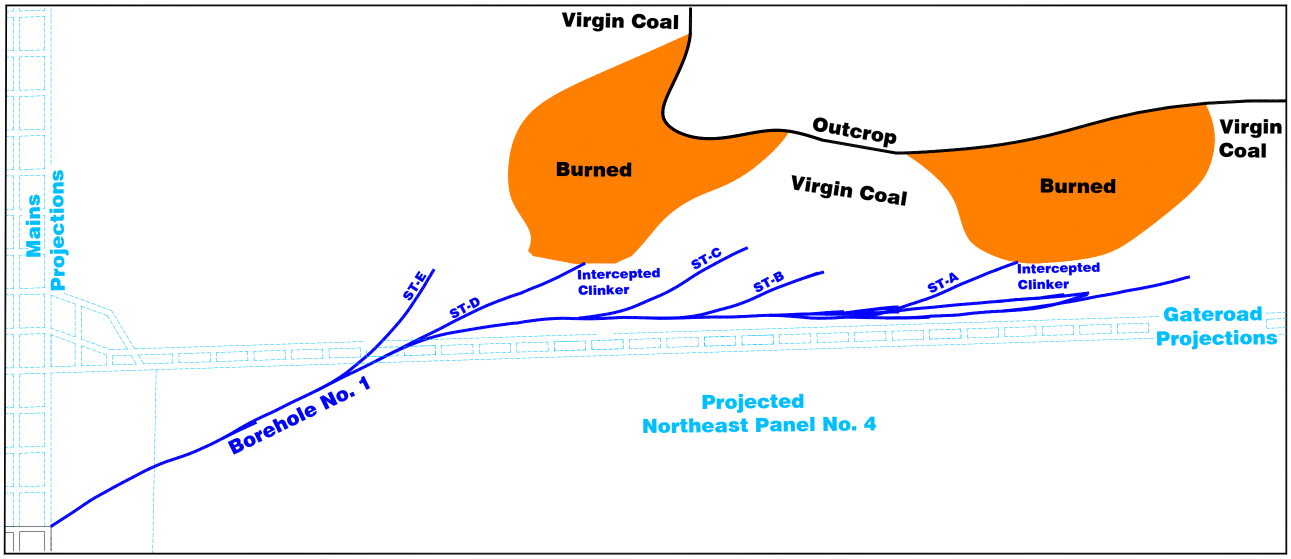

Figure No. 5: Plan view illustrating the directional drilling effort performed to characterize the extent of burn into the reserve. Note the exploration side-tracks developed from the main borehole to define the distance between competent coal, as verified by the main borehole, to the burn.

Intrusive Dikes

Igneous dikes are linear features associated with regional tectonic activity. However, dikes can be unpredictable in width. When coming in contact with coal seams, igneous intrusions produce a baked zone altering the coal to coke, and upgrade the rank of coal away from the intrusive / coal contact.

The main problem associated with dikes and longwall mining and conventional room and pillar mining is that they can be completely overlooked in exploration drilling programs. Geologic mapping from state, federal, or private sectors may not always be available or accurate, and geophysical surveying is very expensive.

When an unmapped dike is intercepted in longwall mining, particularly in a panel, it can stall production, damage equipment, and cause an operator to incur significant costs. Figure 6 presents an example where a longwall shearer encountered an igneous dike which increased in width across the face. Face drilling performed by the Mine (Figure 6) showed the dike to be extensive and potentially detrimental to the life of the panel. REI was called in to drill from the headgate to determine if the dike would retain its breadth inby of the longwall face. Over one weekend, REI mobilized from an adjacent mine, setup the equipment underground and drilled two boreholes through the dike which indicated that the intrusive body thinned away from the face (to 3 to 4 ft). Rapid drilling and interpretation of survey data and drilling characteristics (thrust and drilling fluid pressures) provided this mine operator the information necessary to continue mining the panel.

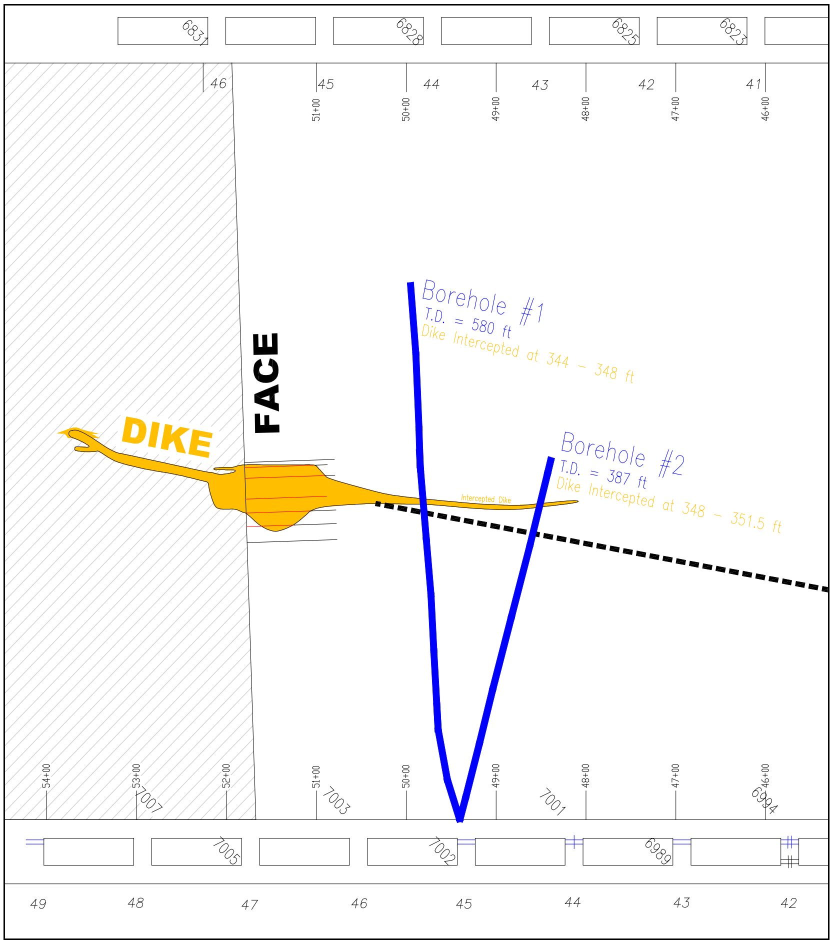

Figure No. 6: Plan view illustrating the directional drilling effort performed to characterize the extent of the igneous intrusion inby the longwall face. Note that face drilling indicated the dike was massive and extended inby.

Summary

HDD provides the coal mining industry with an effective and practical geological exploration tool. Applications by REI have established the approach for characterization of channeling, faults, coal burn, and intrusive anomalies. Other applications practiced by REI include core sample recovery from directionally drilled boreholes for characterization of mine roof or floor, partings, and coal, for the purposes of integrity planning (roof control) and determining coal quality. Applications include the use of geophysical instruments down-hole (natural gamma to characterize the immediate roof conditions in advance of mining), and experimentation with borehole radar. Future developments for HDD and its application to exploration focus on bringing geophysics to the bit face.