Directional Drilling for Methane Drainage and Exploration in Advance of Mining

Recent Advances and Applications

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Significant advances in directional drilling systems during the last two decades has lead to the maturation of a technology that can currently provide the coal mining industry with a large range of methane drainage options and provide the ability to better identify and understand geological and mining conditions in advance of mining. In-mine borehole steering conducted in the 1970's with single shot camera survey systems and borehole pitch control stabilizers has been replaced in the 1990's with systems comprised of permissible downhole measurement while drilling instrumentation, high thrust drilling equipment, powerful downhole motors, and high strength drill tubing. Operators have successfully coupled these systems with hydraulic fracturing to increase wellbore connectivity in low permeability coals for methane drainage, and to de-stress massive roof conditions in advance of longwall mining.

This article presents recent advances in directional drilling systems, and reviews its many applications, including in-seam methane drainage, gob gas drainage, commercial coalbed methane recovery, detection of abandoned mine workings, identification of discontinuities in advance of mining, determination of coal, roof, and floor characteristics, and de-stressing. Directional drilling applications described herein are deployed by REI Drilling, Inc., a leader in the coal mining directional drilling services industry.

Recent Advances in Directional Drilling Systems Equipment

Recent advances in permissible in-mine directional drilling systems have substantially increased drilling rates, depths, and borehole placement accuracy. These advances have effectively reduced directional drilling costs and increased the opportunities for use of this technique in the coal mining industry.

Clearly, developments in permissible tools that can quickly provide downhole location and tool face orientation information to the driller at high accuracy have had a tremendous impact. A prime example is the "DDM MECCA", an electronic drill navigation system manufactured by Advanced Mining Technologies Pty. Limited of Australia. The DDM MECCA, equipped with tri-axis geometric sensors located behind the downhole motor, sends survey information up the drill steel at high baud rates through a modular cable assembly to an uphole control system.

The DDM MECCA substantially decreases survey time relative to single shot borehole systems (single shots are pumped down the drill steel and then retrieved for interpretation). Depending on depth of borehole, the single shot process can take up to 45 minutes. With the DDM MECCA, directional drillers have achieved world record directional drilling production rates in excess of 1,600 ft in one shift. Typical directional drilling rates are greater than 300 ft per shift, depending on conditions. Directional drilling accuracy achieved by operators with single shot instruments is typically +/- 1 degrees in azimuth and +/- 0.5 in pitch. With the DDM MECCA, operators have achieved accuracies of better than +/- 0.5 degrees in azimuth and +/- 0.2 degrees in pitch. In terms of borehole placement in plan, this corresponds to better than +/- 26 ft over a distance of 3,000 ft.

Figure 1. Uphole DDM MECCA unit manufactured by Advanced Mining Technologies PTY LTD, NSW, Australia.

Recent advances in streamlining the modular cable assembly installed into drill rods for operation with the DDM MECCA have reduced hydraulic losses. Coupled with high performance wireline drill rods, the system enables directional drillers to develop even longer boreholes.

Finned centralizers now hold and insulate brass conductors in the drill rods reducing fluid pressure losses by approximately 30 percent compared to earlier single centralizer models. This Advanced Mining Technologies innovation provides for increased fluid pressure downhole for opertion of the motor at greater depths. Typical downhole motors require between 50 to 80 gpm of drilling fluid at 400 to 500 psi at maximum torque (up to 250 ft-lbs).

New high performance wireline rod manufactured by Boart Longyear, Salt Lake City, Utah, USA, with a reverse flank thread design provides much higher strength without changes in dimension or rod weight compared to conventional wireline tubing. The RQ™ product manufactured by Boart Longyear has a depth rating 90 percent higher than conventional wireline rod. Figure 2 shows the streamlined DDM MECCA inserts in REI Drilling, Inc.'s high performance wireline rod. This configuration enables the development of boreholes to distances greater than 5,000 ft.

Application of Directional Drilling Systems for In-Mine Methane Recovery

Advances in directional drilling systems technology provides gassy mining operations a new range of methane drainage possibilities. Long, directionally steered in-seam boreholes can effectively reduce in-situ gas contents of large coal volumes in advance of mining in low to high permeability coals. With longhole drilling capabilities, drillers can effectively drain coals in the mining, or any underlying or overlying level.

Figure 2. REI Drilling, Inc.'s high performance drill rod with streamlined DDM MECCA inserts.

Figure 3 graphically illustrates the in-situ gas content reduction from 368 ft^3/ton (11.5 m^3/t) to an average of 240 ft^3/ton (7.5 m^3/t) achieved with 1,640 ft (500 m) in-seam boreholes in a low permeability (0.2 md) coal seam after two years as predicted by reservoir modeling studies. REI Drilling, Inc. effectively uses reservoir simulation techniques to determine borehole spacing and degasification time requirements for specific geologic and reservoir conditions.

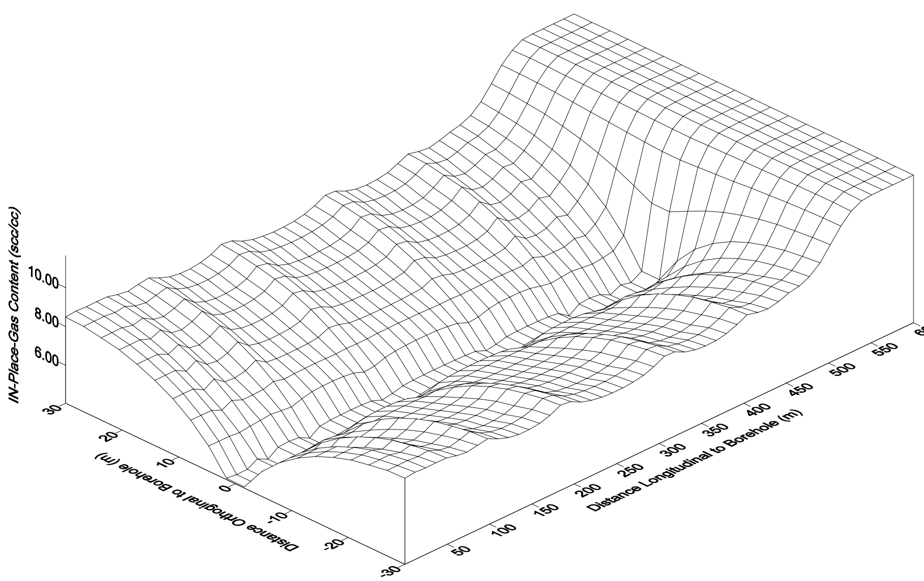

Figure 3. Graphical presentation of reduction in in-situ gas content achieved with 1,640 ft (500 m) in-seam boreholes in a low permeability coal seam.

In areas where vertical gob wells cannot be deployed, and in multi-level mining operations where cross-measures or superjacent gob gas recovery techniques are ineffective or too costly to apply, drillers can directionally steer horizontal gob boreholes up over future longwall panels. This creates low pressure sinks which can draw gob gas generated from overlying sources.

Other methane drainage options include targeting boreholes to drain sealed areas, charged faults and fissures in advance of mining, and overlying or underlying gas bearing formations, such as sandstones.

Considerations

As with any other degasification technique, engineers must determine whether directional drilling for drainage is applicable to the system of mining, consider site geological and reservoir conditions, and address logistical issues.

Longwall mining has significant impacts on overlying and underlying strata, breaking up vertical permeability barriers that separate gas bearing formations from mine workings. Gob gas recovery systems are suitable for such conditions. Effective gob gas drainage designs consider the stress distribution in the gob, distances to gas bearing strata, the geomechanical characteristics of this strata and how longwall mining impacts upon this strata, including gob ventilation systems. Geomechanical characteristics of lithologies, including coal seams is relevant for assessing drillability and borehole stability. Frequency and type of geologic discontinuties, including stress orientations, affect borehole stability, and dictate permeability anisotropy. With knowledge of these conditions designers can plan borehole location and orientations to maximize methane drainage benefits. In-situ gas contents, natural fracture and cleat permeability, and desorption characteristics determine times required for in-seam methane drainage and borehole spacing. Size of entries, availability of utilities, and mining schedules all impact upon the availability of drilling locations at an active coal mine.

The following are examples of applications of directional drilling for methane drainage.

Shielding Gate Entry Developments in Mexico

In-seam boreholes have had a significant impact on the development of gate entries in advance of longwall mining at Minerales Monclova S.A. de C.V.'s mining operations in the state of Coahuila in northern Mexico. Because of high cleat and natural fracture permeability (in excess of 30 milli-darcy as measured by REI DRILLING, INC. reservoir tests), in-seam boreholes rapidly shield gate entry development activity from methane emissions and allow significant increases in coal production. This is illustrated on Figure 4 which presents methane emissions (1000 cubic meters per day) and section advance rates (10's of meters per month) during development of the 2 West gate entries prior to and after REI DRILLING, INC. developed an 2,900 ft in-seam shield borehole. The figure indicates that after deployment of the borehole, methane emissions into the entry decreased by 30 percent in two months, enabling MIMOSA to reduce ventilation requirements to the section by an equal amount, and increase mining advance rates by 78 percent.

According to Minerales Monclova's mine engineer Ing. Jose Ruben Ponce, "we could not have achieved our increased coal production objectives without a program of in-seam degasification." REI Drilling, Inc. has directionally drilled in excess of 85,000 ft of in-seam borehole at four of Minerales Monclova's five longwall operations between 1992 and 2000.

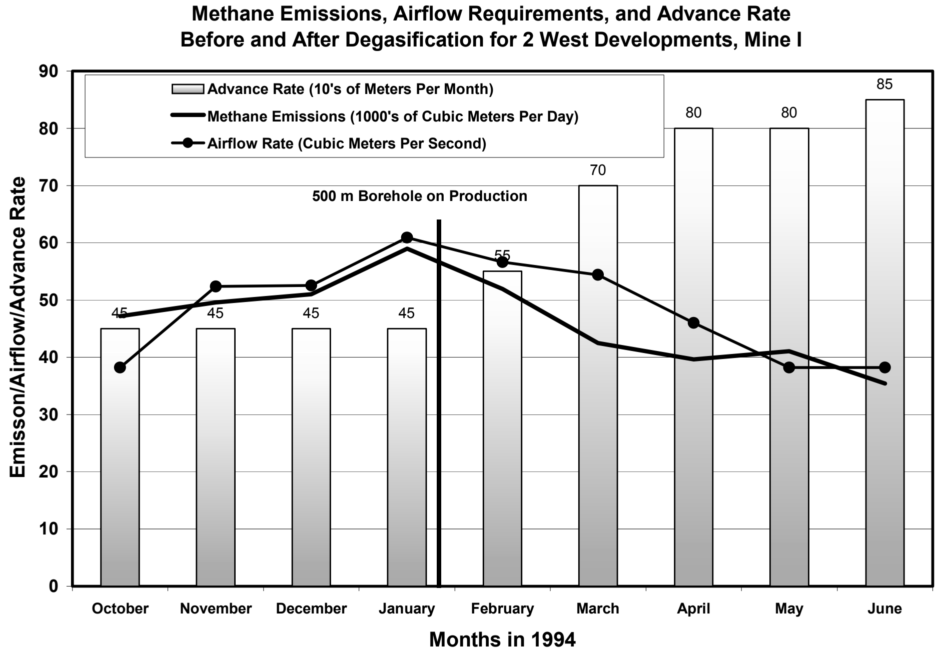

Figure 4. Methane emissions and section advance rates for the 2 West gate entries prior to and after development of a methane drainage shield borehole at one of Minerales Monclova's mines in northern Mexico.

Horizontal Gob Boreholes for Deep Multi-Level Mines in Eastern Europe

At some mines in the Upper Silesian coal basin in Poland and the Czech Republic, coal exploitation is conducted at deep mining levels (greater than 2,000 ft) using multi-level longwall mining techniques. Many of these operations exploit coals with high in-situ gas contents (greater than 400 ft^3/ton) and low permeability (between 0.1 and 1 md). Because of the presence of overlying and underlying gas bearing strata, these mines encounter high gob gas emissions during longwall mining. Most mines employ cross-measure boreholes, but in deeper and gassier conditions they drill multiple gob boreholes from overlying galleries which in some cases are constructed specifically in thin coal seams, or rock. In this case, and where galleries are developed strictly for methane drainage, directional drilling can provide a cost effective alternative. Directional drillers can develop horizontal gob boreholes in advance of longwall mining up over the coal seam from the mining level. These boreholes target areas below the nearest overlying gas source seam and are placed in the fracture zone, above the rubble zone of the gob. This system was first applied in Japan and was tested by REI Drilling, Inc. in the U.S. at the Cambria 33 Mine in Pennsylvania as shown on Figure 5, and applied through a United Nations administered greenhouse gas reduction program, to mines in China. REI Drilling, Inc. tests in the U.S. showed that this system can attain capture efficiencies greater than that of cross-measure boreholes.

Recovering Pipeline Quality Gas for Commercial Sale at the Soldier Canyon Mine

REI Drilling, Inc. effectively used directional drilling technology to commercially recover coalbed methane in advance of mining from low permeability coals at the Soldier Canyon Mine near Price, Utah, for a 10 year period. REI Drilling, Inc. directionally drilled over 490,000 ft of borehole in two seams at this room and pillar mine. The measured in-situ gas contents were greater than 225 ft^3/ton, and permeability measurements indicated a tight cleat and natural fracture system (permeability of less than 0.5 md). Because the mine was a room

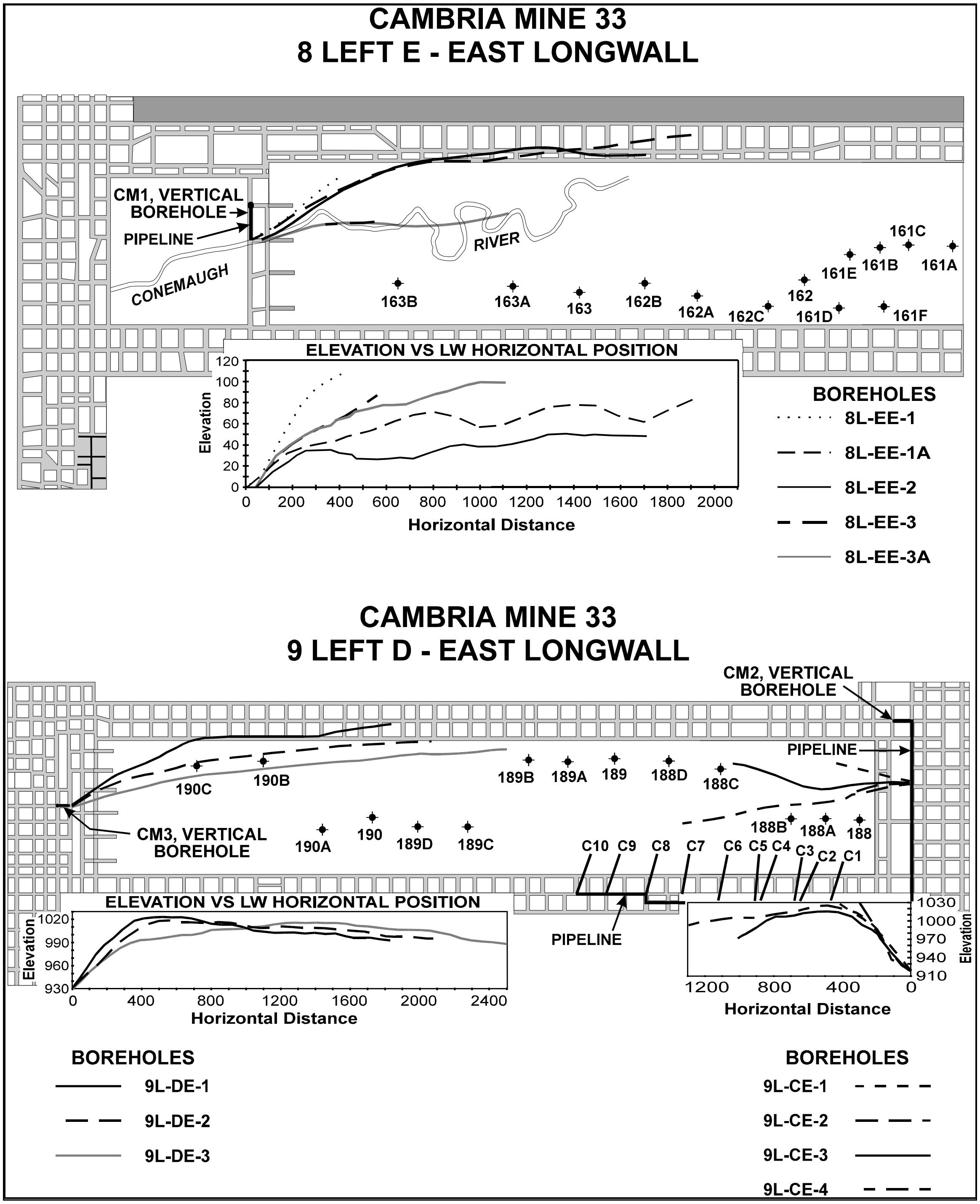

Figure 5. Horizontal gob boreholes implemented by REI Drilling, Inc. at the Cambria 33 Mine.

and pillar operation it offered extensive access to virgin coals that could be drained significantly in advance of mining. Effective reductions of in-situ gas contents were obtained from boreholes drilled 3 years in advance of mining (up to 60 percent). REI Drilling, Inc. recovered between 1 to 1.5 MMCFD of pipeline quality gas per day from this operation and commercialized the gas after minimal processing by injection into a nearby natural gas pipeline. Figure 6 illustrates the post-drilling wellhead water separation, and monitoring and safety system implemented by REI Drilling, Inc. at each borehole. An extensive network of underground pipeline with a safety integrity system collected the gas for transport to surface via vertical wells connected to a surface installed rotary screw compressor.

Figure 6. Post drilling water separation and safety and monitoring system implemented by REI Drilling, Inc. at boreholes at the Soldier Canyon Mine.

Application of Directional Drilling Systems for Exploration in Advance of Mining

The ability to steer and install boreholes at great distances with high accuracy makes directional drilling invaluable for coal mining exploration projects. The following presents some innovative applications of directional drilling implemented by REI Drilling, Inc. at various coal mining operations.

Verifying the Location of Abandoned Workings in Eastern U.S. Coal Mines

Mining regions that have had extensive activity, such as the Appalachian coal fields in the U.S., have incomplete archives and cannot accurately specify the location of old mining workings. In this region, auger mining, or drift mining from outcrops has been extensive and modern mining operations must navigate away from these potentially water-filled workings. U.S. Mine Safety and Health Administration (MSHA) guidelines require that mines developing near old works drill at frequent intervals from developments to ensure that the new workings are driven sufficiently away from the abandoned ones. Rather than drive entries and then determine distance, the Hutchinson Branch Mine in West Virginia contracted REI Drilling, Inc. to directionally drill between projected entries and abandoned workings. To verify placement accuracy, REI Drilling, Inc. drilled tangential legs into the projected entries for later interception by mining. REI Drilling, Inc. did not intercept any old workings in the corridor between workings, and later mining verified borehole placement accuracy of 7.5 ft at a distance of 1,160 ft.

Identifying Seam Structure and Discontinuities by Physical Detection in Advance of Mining

By definition, in-seam methane drainage and exploration drilling requires maintaining the borehole in the seam. The use of a bent housing for steering results in the drill operator periodically intersecting the roof or floor to verify seam position. Plotting the profile of the borehole from downhole surveys and driller logs, provides the mining operation with an indication of coal seam structure.

Any discontinuities intercepted during drilling, such as faults, palaeochannels, intrusions, etc., are detected by monitoring drilling fluid pressures, changes in thrust, vibration, rate of penetration, and inspection of cuttings. Because of the high placement accuracy achieved with the DDM MECCA, particularly in profile, directional drilling can determine the thickness of coal seams and normal fault displacements with reasonable precision. By physically touching the roof and then the floor, and using borehole surveys, directional drilling can typically determine coal seam thickness within 1 ft for an 8 ft seam, depending on conditions. Figure 7 illustrates the profile of coal seam derived from an exploration borehole drilled by REI Drilling, Inc. Determination of fault displacement and seam thickness was an important part of the project.

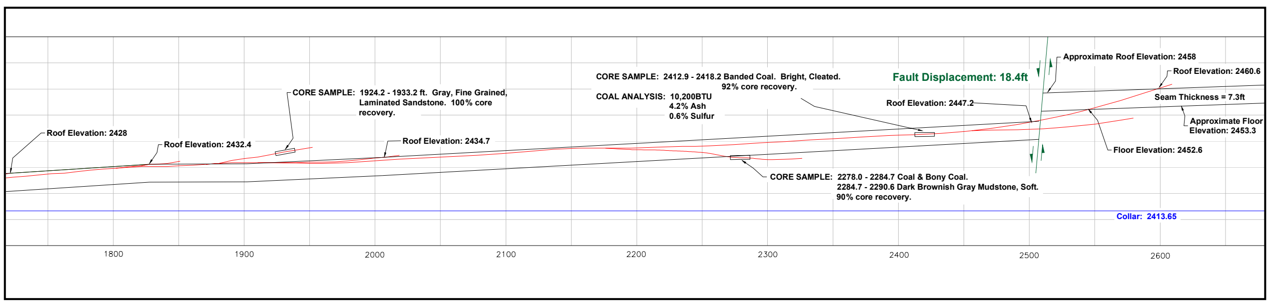

Figure 7. Coal seam structure determined in advance of mining by directional drilling.

Coring and geophysical logging from directionally drilled boreholes at Cape Breton Development Company's Subsea Mines in Canada

REI Drilling, Inc. performed exploratory drilling at two sub-Atlantic mines operated by Cape Breton Development Corporation (CBDC) in Nova Scotia, Canada. The project involved directional drilling in advance of future longwall workings to detect roof lithologies and seam thickness. Mine geologists correlated roof stability and rockburst conditions with immediate roof composition. The program involved drilling multiple tangential boreholes from in-seam, up into the roof and down into the floor. REI Drilling, Inc.'s innovative Motorcore^{TM} system retrieves intact coal and roof cores up to 10 ft in length from directionally drilled boreholes for geological inspection. Figure 8 presents core retrieved from coal-roof contacts at distances of up to 1,500 ft in advance of mining.

Through an alliance with geophysics firm, REI Drilling, Inc. deployed a modified natural gamma logging system through its drill rods at the CBDC mines to correlate gamma response with driller logs and cores. "The system worked perfectly" according to site geologist Steve Forgeron, "gamma logging minimized the amount of directional coring we needed to do in horizontal boreholes". The in-seam directional drilling exploration program has provided invaluable information in advance of mining, and at substantially lower costs than a comparable barge deployed vertical drilling program.

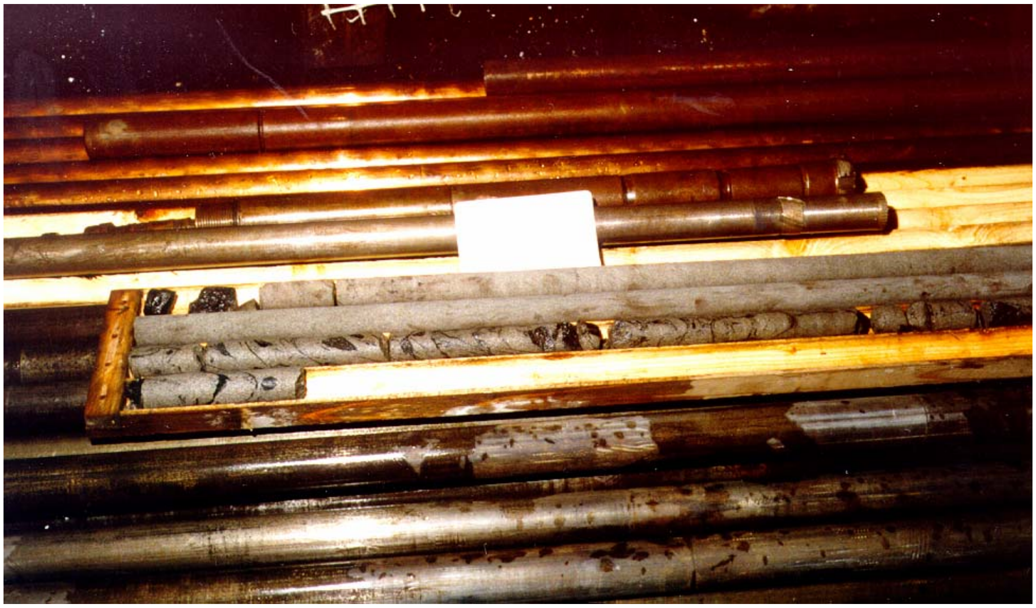

Figure 8. Cores of coal and roof contact retrieved by REI Drilling, Inc. in advance of mining at Cape Breton Development Corporation Mines in Nova Scotia, Canada.

Use of Ground Penetrating Radar to Characterize Coal Seam Structure in Advance of Mining

REI Drilling, Inc. experimented with ground penetrating radar with geophysical firms to image coal seam structure and discontinuities in advance of mining through directionally drilled boreholes. To date these entities have successfully imaged directionally drilled boreholes in coal seams as long as 400 ft using non-permissible equipment with regulatory approval. Experimental data to date indicates that ground penetrating radar can determine coal seam thickness in advance of mining with reasonable accuracy. Coupled with geophysical instruments, an imaging tool with the ability to also determine coal quality is being pursued.

Hydraulically Fracturing Directionally Drilled Boreholes

Using a straddle packer, illustrated on Figure 9, REI Drilling, Inc. has hydraulically fractured in-seam directionally drilled boreholes to increase wellbore connectivity to natural fractures and cleats for methane drainage in tight coal seams. REI Drilling, Inc. also successfully applied this technique in the U.S. at the Lynch 37 Mine in Kentucky, to fracture a massive sandstone roof in advance of longwall mining. Other potential applications include in-seam de-stressing in advance of mining, and reducing comminution and cutting requirements in hard coals.

Figure 9. Straddle packer used by REI Drilling, Inc. to hydraulically fracture directionally drilled boreholes at the Soldier Canyon Mine.

Conclusions

With modern state-of-the-art technology, in-mine directional drilling provides the coal mining industry with effective and practical options for methane drainage and exploration in advance of mining. Applications by REI Drilling, Inc. in North America have established the benefits of the methodology for mine gas control, coal mine methane commercialization, and mine planning.

A measurement and imaging system that can also provide coal quality information while drilling will further increase the value of directional drilling to the international underground coal mining industry. This challenge is currently being addressed by the authors.

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