Recent role of geophysics in U.S. coal and CBM development

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Ten years ago, some major U.S. oil companies began disposing of coal assets and properties because they were deemed not to be part of the core business. Passage of the Clean Air Act Amendment in 1990 kept commodity prices soft, and increasing government regulations likely contributed to their lack of interest. However, when natural gas prices surpassed $5/1000 ft^3 and reached an all-time high of about $10/1000 ft^3 in 2000, development and production of unconventional natural gas took on a frenzied pace.

Coalbed methane (CBM), once a scourge of mining operations, is now playing a key role in revitalizing the U.S. coal fields, resulting in increased exploration and development activities, even in the once-avoided high-sulfur gassy coal fields of the Appalachian and Illinois Basins. A few coal companies evolved into energy companies by expanding into natural gas production and power generation. Independents who had the foresight to develop their CBM resource since the early 1990s realized high returns on their investments because prospecting for CBM is largely low-cost and low-risk. CBM now accounts for about 7.5% of total domestic natural gas production. A recent U.S. Geological Survey (USGS) study indicates the country has more than 700 trillion ft^3 CBM in place, with perhaps 100 trillion ft^3 economically recoverable with existing technology.

The USGS estimates the United States has about 1.7 trillion tons of identified coal reserves. Because coal quality and recovery techniques vary from one basin to another, the recoverable reserve base is estimated at 286 billion tons. Domestic coal companies have been producing about 990 million metric tons of coal per year over the last five years. At this current rate of mining, the reserve base could last another 290 years. Figure 1 shows the five major coal-producing basins in the conterminous United States.

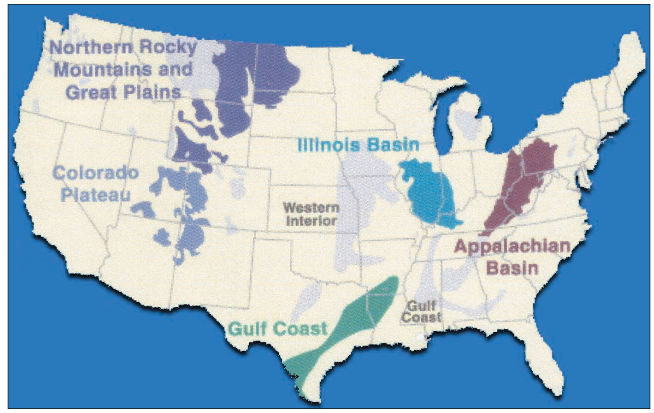

Figure 1. Major coal basins in the conterminous United States (courtesy of the USGS).

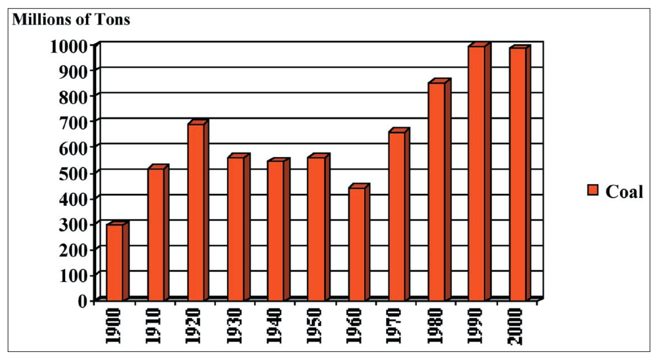

Figure 2. Annual U.S. coal production at a 10-year interval.

Electric power generation. The coal industry has a symbiotic relationship with the domestic utility industry. About 90% of the annual coal production is consumed by more than 600 coal-fired power plants to generate nearly 56% of total electricity demand in the United States. The remaining 10% of coal production is exported to European and Asian markets. Figure 2 shows the annual coal production at a 10-year interval in the last century. Despite negative perceptions about coal usage because of environmental concerns, the United States consumed record tonnages of coal in the last three decades.

Deregulation of the electricity market and the airborne emission regulations are shaping the future of coal usage. Under market deregulation, electric power plants no longer have captive markets, but will have to compete to sell their electricity to consumers at competitive prices. One area where utilities can continue to offer competitive prices is to use the lowest-cost fuel because they have to compete with newer and more efficient natural-gas-fired plants. Subsequently, coal companies were pressured to keep their costs down, resulting in the closing of the inefficient mines, which amounted to nearly half of the total.

Compliance with the 1990 Clean Air Act Amendment is the second factor shaping the future of domestic coal usage. The amendment set new federal regulations on sulfur dioxide emissions from coal-fired power plants. From 1973 to 1999, the amount of sulfur content in coal burned at power plants significantly declined from 2.35% to 1.0%, demonstrating the implementation of constructive measures such as better employment of mining and processing techniques at mine sites and clean coal technologies at power plants to reduce airborne pollutants.

Coalbed methane. When organic plant material decays and undergoes the coalification process, large quantities of methane gas are produced and stored within the seam. Because coal has such a large internal surface area, it can store up to seven times more methane gas than conventional natural gas reservoirs of equal rock volume. For over a century, mining operators had known the explosive risks of CBM in poorly vented underground mines. To minimize the risk, operators usually drill and hydrofrac the seam to release and vent the gas into the atmosphere before mining—a wasteful and environmentally unacceptable practice.

Early CBM field development began in the 1980s at the San Juan and Black Warrior Basins. The potential for capturing and using the gas has been recognized for decades. However, major disagreements as to "who actually owns" the mineral rights to the methane in coal located beneath a

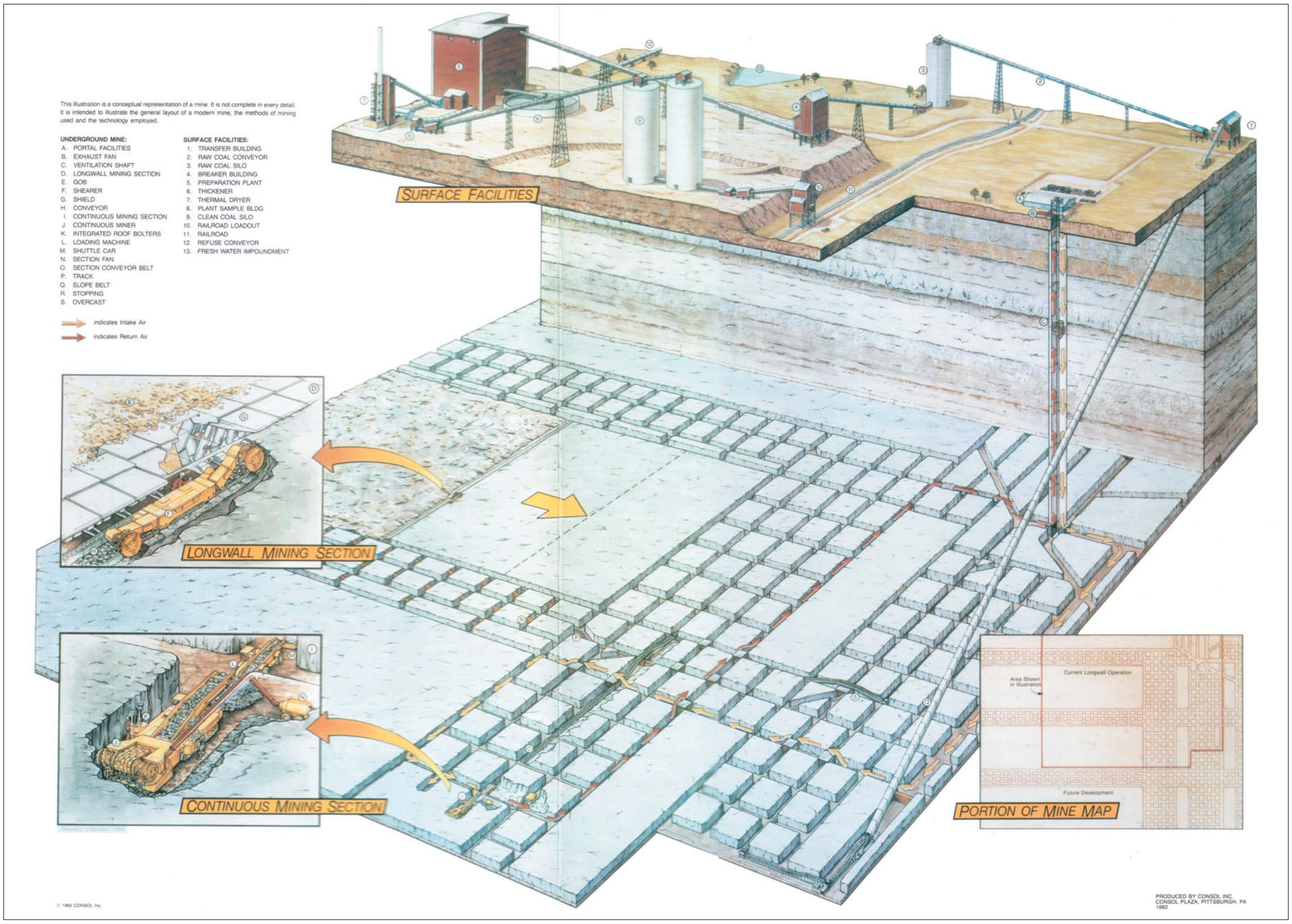

Figure 3. A typical underground longwall mining operation showing an intricate network of tunnels and surface processing facilities (courtesy of Consol Energy).

property and the ensuing lawsuits hindered development. It wasn't until the early 1990s that drafts of a comprehensive research, sanctioned by the National Research Center for Coal and Energy, resolved most of the uncertainties in CBM ownership. Thereafter, some coal companies formed partnerships with petroleum companies to help them develop the infrastructure needed to harness, transport (via pipelines), and deliver CBM to gas-fired power plants.

Another factor that contributed to maintaining interests in domestic coal was the U.S. Section 29 tax credit for unconventional gas sources. It provided incentives for companies to continually develop domestic CBM even though natural gas prices were soft at that time. When the tax credit expired, natural gas prices rose in the mid-1990s to help sustain its developmental momentum. Because most of the coal seams lie at shallow depths (<2000 ft) relative to typical natural gas prospects, development of CBM is usually low-cost and low-risk. Companies also found that CBM plays have a high reserve base on a per-well basis that can add a tremendous economic value to their bottom line. There are currently more than 8000 producing CBM wells in the country.

Role of geophysics. Because the locations of U.S. coal basins are well known, coal and energy companies do not need to find more reserves, but to improve extraction methods to increase productivity and safety. Longwall mining has proven to be the most productive underground mining method (Figure 3). Longwall panels are nominally 1000 ft wide and 8000-10 000 ft long. Longwall mines, however, require large reserve blocks to be level with uniform seam thickness. Any unexpected geologic anomaly encounters can create adverse mining conditions that could financially impact or cripple these mines.

High-resolution seismic surveying methods (Figure 4) have proven to be the most effective remote-sensing technique to detect potential geologic anomalies ahead of mining. As petroleum E&P seismic surveying techniques continued to improve, some of them were adopted and employed in U.S. coal fields in the 1980s. It started with simple 2D seismic lines, which eventually grew into 2D grids used to better map seam structures. Vertical seismic profiling and 3D seismic methods soon followed.

In the last 15 years, coal geophysics in the United States was largely employed in exploratory (upstream) activities. As the nation shifted into CBM resource development, advanced downstream geophysical methods were tested. Multicomponent 3D seismic and AVO analysis methods were employed in the San Juan Basin to characterize and model CBM reservoirs. Knowing the natural fracture system in coal (called cleats) is key to understanding ways to separate methane from coal, leading to higher CBM production. Test results proved that areas with large AVO gradients and large Poisson's ratio contrasts indicate zones of high-fracture densities in the reservoir. Analyses of shear-wave polarization, traveltimes, and reflection amplitudes also allowed the identification of zones of variable fracture density and direction. The effectiveness of these robust analytical tools is largely dependent on the quality of the multicomponent 3D seismic data.

Other geophysical methods such as electrical resistivity,

Figure 4. High-resolution surface seismic surveying in a northern Appalachian coal field.

ground conductivity, ground-probing radar, magnetometer, and borehole logging can also be employed because of the numerous challenges related to engineering and environmental issues associated with mining. Environmental geophysical investigations are often conducted to detect shallow mine-induced fractures along a dry streambed after being undermined. Once shallow fracture zones are detected, the stream would be remediated by having the detected fractures filled and grouted.

Saline water is produced in large volumes in the early stages of CBM development. To increase production, the saline water has to be pumped out and disposed of properly. The water is often reinjected into the subsurface rock formations or is allowed to flow into surface evaporation ponds. Mines typically have slurry ponds filled with tarry waste rife with heavy metals and chemicals left from cleaning and processing coal. These holding ponds and dams require both hydrological and geophysical solutions to provide real-time monitoring to detect potential leaks or seepage so that appropriate measures can be implemented to minimize environmental impacts from dam failures.

Geophysical technology addresses many of the complex conditions associated with coal mining and CBM development, but more often than not, corporate executives with minimal geophysical background question its value because it is difficult to initially quantify the immediate financial benefits. It is only after major problems have occurred, such as a longwall machine encountering unexpected major geologic anomalies or CBM production in wells suddenly dropped to become uneconomical, that a second look to the potential usefulness of geophysics is granted. The question is: "Can a coal or energy company afford more risk, which can adversely affect the bottom line, by not employing geophysical technologies?"

Suggested reading. "Seismic surveys for coal exploration and mine planning" by Gochioco (*TLE*, April 1990). "Coal and geophysics in the USA" by Gochioco (*TLE*, November 1994). "Assessing the coal resources of the United States" by Pierce (USGS FS-157-96, 1996). "Multicomponent 3D characterization of a coalbed methane reservoir" by Shuck et al. (GEOPHYSICS, March-April 1996). "3D AVO analysis and modeling applied to fracture detection in coalbed methane reservoirs" by Ramos and Davis (GEOPHYSICS, November-December 1997). "Coalbed Methane—an untapped energy resource and an environmental concern" by Rice (USGS FS-019-97). "Shallow VSP work in the US Appalachian coal basin" by Gochioco (GEOPHYSICS, May-June 1998). "High-resolution 3D seismic survey over a coal mine reserve area in the US—a case study" by Gochioco (GEOPHYSICS, May-June 2000). TLE

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