Coal, geophysics, U.S. power generation, and mine safety

LAWRENCE M. GOCHIOCO, GX Technology, Houston, Texas, U.S.

Nearly 96% of recent annual U.S. coal production is used as fuel in electric power generation. In fact, coal supplies nearly 51% of the nation's energy. Nuclear, natural gas, and hydroelectric—the next three fuels on the list—are responsible for 19.8%, 16.7%, and 6.9%, respectively. These statistics make it apparent that coal will continue to be of major importance in power generation in the U.S.

Internationally renowned energy investment banker Matt Simmons has written that coal must stay as one of primary sources of energy in the U.S. and might even be more important in the future because North American natural gas supply has peaked. Simmons' argument is that additional economic growth in the U.S. will require more electricity and the only way this can happen is through coal. "Whether coal can rise to this challenge will be an extremely important event to monitor," Simmons concluded.

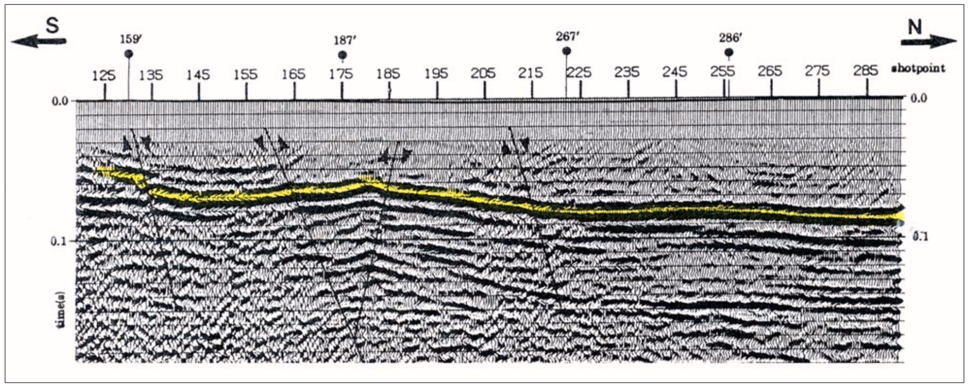

Figure 1. High-resolution 2D seismic data collected over a known fault zone area where four drillholes showed that seam elevation dropped significantly in the northward direction. The continuous coal seam reflection (yellow) is intersected by multiple faults, indicating extremely difficult underground mining conditions.

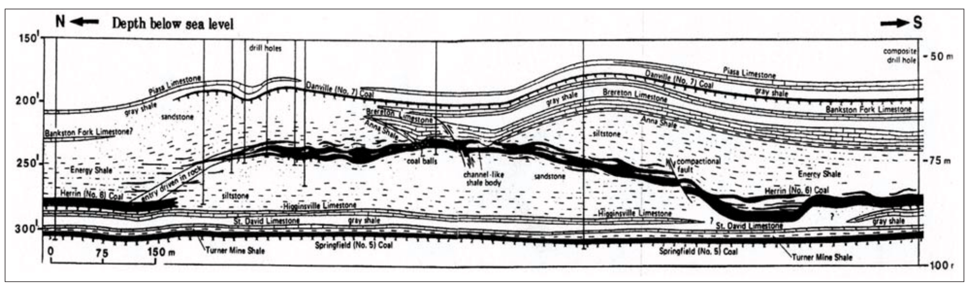

Figure 2. Geologic cross-section of a roll encountered in an underground coal mine.

Meeting Simmons' challenge. In my opinion, there are reasons to believe that the U.S. coal industry can meet this challenge...if, and this is the question in my mind, it takes advantage of advanced geophysical technologies.

Over the last 20 years, U.S. coal companies have increased productivity by adopting sophisticated extraction methods. In 1985, about 156 000 surface and underground miners produced approximately 838 million short tons of coal. However, in 2002, an estimated 1093 million short tons of coal were produced by a much smaller labor force—about 66 000 miners. Such improved productivity, coupled with lower accident rates, indicate the industry is able to reengineer itself to adjust to market conditions and demand.

In fact, over the last two decades, the U.S. coal industry has an impressive record of capital investment in downstream operations. This has led to improved mining methods via longwall, improved equipment monitoring via special sensors and computerized diagnostics that have resulted in longer service lives and less unscheduled maintenance activities, and the use of GPS to improve surface heavy equipment utilization and avoid accidents.

Other downstream developments are generally known as clean coal technologies (CCT). Scrubbers were developed for conventional coal-fired power plants to significantly reduce pollutants after coal is burned. Another is coal gasification, a new and different approach in which the pollutants are removed before the fuel is burned. In this process, coal is crushed and turned into a slurry-like product that is combined with oxygen and converted into synthetic gas. Such plants might cost about 50% more than conventional ones, but coal gasification plants can squeeze more electricity from a ton of coal than conventional coal-fired power plants and are projected to have lower maintenance costs.

However, despite the major improvements to their downstream sector, the coal industry has done little to upgrade its upstream side. For example, drilling is still the only exploration tool as coal seams are much shallower than petroleum reservoirs or structures. As such, exploration has a different meaning here than in the petroleum industry. Coal companies don't need to find more coal; there is plenty in already known basins. The U.S., in fact, has about 25% of the world's recoverable coal reserves. Ironically, coal companies need to "explore" for major geologic anomalies that can create adverse mining conditions. When unexpected geologic anomalies are encountered by drilling, companies currently just drill more (and more) holes, hoping that they can get a general idea or trend of the problem. This practice can be devastating to their bottom line especially when drilling completely misses them early in exploration drilling programs. When a longwall is down due to unexpected geologic anomaly encounters, the lost productivity can cost up to a $1 million per day. Therefore, you would think that mining companies would have a strong incentive to find and

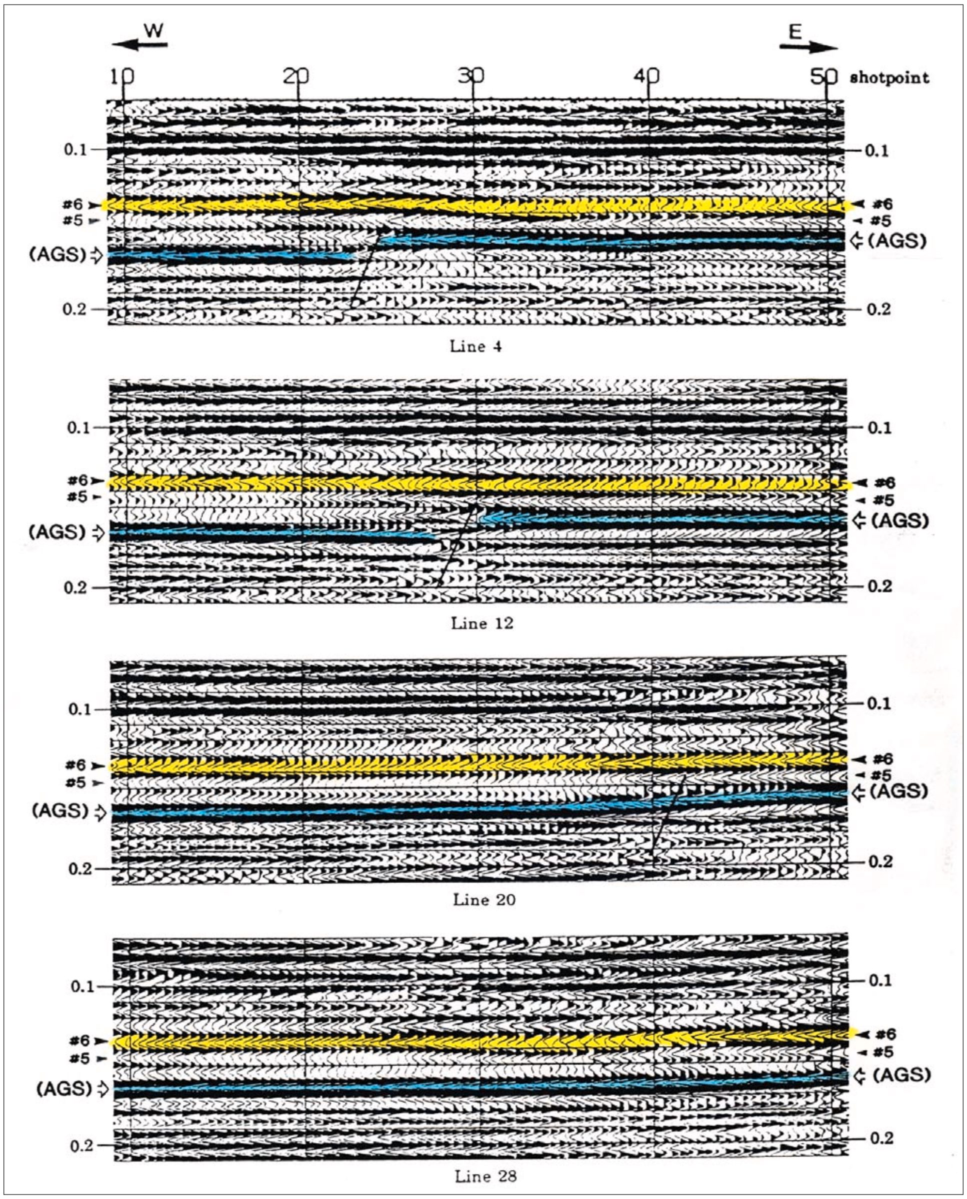

Figure 3. Four inline seismic sections, 240 ft apart, show the roll feature quickly meandered in a southeast direction beneath the 3D survey area.

map these geologic anomalies ahead of mine development. Unfortunately, they don't.

It has been demonstrated that 2D and/or 3D high-resolution surface seismic is effective (when properly employed) at gathering valuable subsurface information. For example, a company conducted a high-resolution 2D seismic survey over a reserve area that intersected four drillholes that revealed the depths to the top of the 6-ft coal seam to be 159, 187, 267, and 286 ft, respectively—indicating major faulting. The average spacing between the drillholes is 600 ft. Figure 1 is the seismic section over this interval and the coal seam reflection is highlighted in yellow. Through continuous subsurface profiling, the seismic data show the locations of detected major faulting. Without the seismic data, mine engineers would have been hard-pressed, and forced to drill many more holes, just to get a general idea of the fault zone. This would have eventually cost the company more capital and the resulting subsurface information would have had limited value.

Another example is presented to demonstrate the value of seismic profiling in detecting a complex stratigraphic feature, called a "roll." In coal mining, a roll is considered a small buried hill or geologic structure that exhibits a sudden change in seam elevation. Figure 2 shows the geologic cross-section of the actual roll being imaged. It lies at a depth of 800 ft, has a maximum vertical relief of 30 ft, and is about 500 ft wide. A high-resolution 3D seismic survey was conducted over its estimated location. Four parallel (inlines) seismic sections (240 ft apart) extracted from the 3D data volume are presented in Figure 3. The target (No. 6) coal seam averages 8 ft in thickness and is highlighted in yellow. The top seismic section (line 4) shows a subtle relief in time of 4-5 ms, indicating the anomalous roll. However, lines 12, 20, and 28 didn't show a similar temporal relief. Instead, amplitude anomalies beneath the target seam reflection are evident, resulting from increasing separation between the No. 6 seam and the 4-ft No. 5 seam. This phenomenon is an interference (constructive) reflection that proved a reliable indicator of the roll feature. Computer modeling and geostatistics processes, coupled with existing drillhole data as control points, were integrated to generate a 3D surface map of the roll feature.

In addition to actual mining operations, coal companies must comply with strict federal and state laws to minimize the impact of mining on the environment. Many challenges can be addressed by employing various geophysical methods (such as electrical resistivity, ground-penetrating radar, ground conductivity, magnetics, electromagnetics) to address site-specific problems.

Unfortunately, the potential of geophysical technology to ameliorate upstream problems appears to be one of the best kept technology secrets in U.S. coal mining history, although one company operated a multifaceted coal geophysics program successfully for nearly 15 years. High-resolution seismic surveys were routinely conducted years in advance of mine development to evaluate large reserve areas. Several mine plans were changed, and expensive "downtimes" were avoided because geologic anomalies were detected and confirmed by drilling in advance of the actual mining operations.

On 24 July, 2002, an underground mining accident occurred when a breakthrough occurred from an old abandoned water-filled mine flooded the QueCreek Mine in Pennsylvania (Figure 4), trapping nine coal miners for 77 hours before they were all safely rescued. The incident received international coverage and highlighted another major problem facing the coal industry—poorly documented

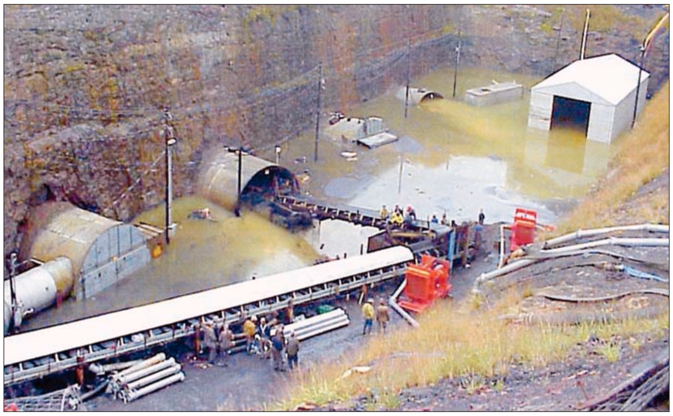

***Figure 4.** Flooded entrance to QueCreek Mine indicates the severity of the problem. Large capacity pumps (orange) were used to quickly drain the water before trapped miners were safely rescued.*

***Figure 5.** Mural depicting the rich mining history of the Appalachian coal basin which helped fuel the U.S. industrial revolution. Display case shows safety equipment used by miners in underground environments. (The painting is in a Pennsylvania Welcome Center near the border with West Virginia and is reprinted with permission).*

or unreliable maps of old mines. As a result of the QueCreek Mine incident, a U.S. government agency (MSHA) sponsored a symposium in 2003 to explore remote sensing technologies that can be used to detect mine voids. It was in this symposium that the industry's best kept technology secret was unveiled. (Full disclosure requires me to reveal that I once led this program.) The symposium also revealed that there are thousands of poorly documented abandoned mines worldwide. This is a serious global problem and innovative geophysical technologies will be needed to detect them.

Coalbed methane is another valuable resource, that (as the name implies) is associated with coal, and is another area where the use of applied geophysics can be very cost-effective. This will be discussed in a separate article.

Conclusion. Coal is a hydrocarbon that receives little publicity and the little publicity it does get is usually negative. Despite its reputation, coal is the largest fuel source for U.S. electric power generation. The world's highest energy-consuming nation fortunately has extensive coal reserves that can be counted on in times of energy instability and insecurity. Coal has a rich history (Figure 5) and was the key energy source that fueled the American industrial revolution from the 19th to early 20th centuries when it was displaced by oil. Research sponsored by the U.S. government on CCTs has paid off. Hundreds of coal-fired plants are emitting significantly less airborne pollutants than before and combustion waste is being recycled into construction materials. Research funding for CO_2 sequestration studies are under way.

The industry has done a good job in introducing modern technologies into the downstream side of the business over the last two decades, as evident by the increased tonnage produced by a smaller workforce. Despite these productivity gains, coal companies are often cash-strapped because of various complex issues. One of the most costly is encountering unexpected major geologic anomalies or poorly-documented abandoned mines during operations. In my opinion, these problems can be avoided if modern geophysical techniques are properly employed. There are case histories, some dating to the 1980s, that support this view.

So what is the problem? Why aren't U.S. coal companies employing more geophysics? In my opinion, coal company managers take a myopic view on its value because it is difficult to initially quantify and qualify the immediate benefits to the company. It is only after major problems have occurred that a second look is granted. But by then, it is too late because a sophisticated geophysics program can't be turned on like a light switch. The current high spot coal and methane gas prices are giving coal companies an opportunity to improve their bottom lines. But we all know that the energy business is cyclic. Thus, they should utilize this rare opportunity to strengthen their balance sheets and should start funding and focusing on the next generation of innovative upstream technologies...and the one which has a proven track record and the most potential is geophysics.

Suggested reading. "High-resolution 3D seismic survey over a coal mine reserve area in the U.S. — a case study" by Gochioco, (*Geophysics*, March 2000). "Assessing the coal resources of the United States" by Pierce (USGS FS-157-96). "Time-lapse seismic imaging of enhanced coalbed methane production: a numerical modeling study" by Richardson et al. (CREWES Research Report, 14, 17. 1-17.13). "Multicomponent 3D characterization of a coalbed methane reservoir" by Shuck et al. (*Geophysics*, 1996). "Shallow VSP work in the U.S. Appalachian coal basin" by Gochioco (*Geophysics*, 1998). "Coalbed methane—an untapped energy resource and an environmental concern" by Rice (USGS FS-019-97). "Advances in seismic reflection profiling in U.S. coal exploration" by Gochioco (*TLE*, 1991). TLE

Corresponding author: lgochioco@gxt.com