Seismic surveys for coal exploration and mine planning

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The US coal industry is undergoing dramatic changes to meet the challenges of a keenly competitive fuels market. Many of these changes involve the application of innovative technology to increase productivity without sacrificing safety. A prime example is longwall mining, which is becoming the accepted method because it allows large blocks of coal to be mined very efficiently.

Longwall mining utilizes an integrated system of roof support, coal cutting, and transportation. Hydraulically-driven shields support the roof; a shearer traverses the entire width of the face and cuts the coal; the coal is then transported from the face by a chain conveyor system that runs adjacent to the face and supports (and guides) the shearer (Figure 1). Longwall panels are 600-1000 ft wide and several thousand feet long. Mine plans may include more than 20 longwall panels.

It is reasonable to expect the shift to capital-intensive longwall mining to bring an increased use of geophysics in coal exploration because it can obtain, at very low cost, geologic information necessary for efficient mine planning. Longwall mining machinery is large, heavy and difficult to maneuver underground, so determining the correct location of good coal areas, a task often made much easier with geophysical data, is essential to high productivity. Other valuable uses of geophysical data include:

- Detection of coal seam anomalies, like sandstone washouts and faults, which may halt the advance of the longwall face in mid-panel and cause lengthy, costly delays.
- Avoidance of nonproductive zones because digging through rock rapidly wears out expensive equipment designed for mining coal.

Geophysical exploration in the coal industry differs from that for petroleum because the latter usually searches virgin areas or frontiers for potential structure or stratigraphic traps of oil and gas. Conversely, in the United States (which has one of the largest coal reserves in the world), the objective of coal exploration is not so much to find coal whose existence is already known but to make it cheaper to mine.

Drilling is the traditional and still the most common method used in coal exploration. Most coal companies rely heavily on drillhole data to evaluate their mine properties. However, this method is frequently expensive and offers only limited spatial information (drillholes are, on the average, about 2000 ft apart).

Surface seismic surveys, on the other hand, provide a continuous subsurface profile at considerably less cost. For example, a one mile-by-two mile area may require, for initial investigation, a minimum of 15 drillholes (Figure 2). A seismic survey, using only five boreholes for correlation, would generate more than 4000 data points and likely yield detailed information about complex faulting systems as well as mapping the course and meander of paleochannels (Figure 3).

When Continental Oil Company (Conoco) acquired Consolidation Coal Company (Consol) in 1966, an effort was initiated to adapt oil field technology to coal-mining problems. In the mid-1970s, continued difficulites caused research in utilizing seismic reflection techniques for coal-mining applications.

Currently, Consol is the only US coal company that maintains a seismic crew. This crew typically conducts shallow, high-resolution surveys. The crew can average about a mile of seismic surveying daily. (When the survey is significantly larger than normal, Conoco usually augments this crew by furnishing a recording truck, vibroseis unit, and experienced personnel.)

The density of bituminous coal is about 1.35 g/cm^3, and its *P*-wave velocity about 7500 ft/s. The surrounding rocks (like shales, sandy shales, and sandstones) have average densities of 2.1-2.6 g/cm^3 and corresponding *P*-wave velocities of 9000-15 000 ft/s. This contrast makes the coal seam a good seismic reflector.

A coal seismic section is shown in Figure 4. The coal seam reflection is indicated as well as four exploratory drillholes (7A, 7B, 7C, 7D). All four drillholes encountered seam thickness of 9-11 ft. The seismic data show the coal seam reflection (predominant frequency about 125 Hz, average depth of 800 ft) to be robust and continuous from SP-38 to SP-186, indicating no seam interruptions or disturbances. A seam thickness averaging about 10 ft is expected over this interval.

Surface seismic surveys can, in addition, image deeper subsurface structures below the drill bit (which normally stops at seam depth). These data are valuable because geologic structures beneath the seam may affect seam thickness and elevation. The seismic data in Figure 4 show a well-defined lens-shaped body beneath the coal seam between SP-88 and SP-160. It does not appear to have affected the seam thickness but may produce changes in seam elevation.

Another benefit from a seismic investigation is detection of paleochannels (courses of ancient rivers that eroded part or all of a coal seam and, often, adjacent layers of rock). Complete erosion of the seam is commonly called a washout, and early detection of washouts can make a mine safer and more productive.

Figure 5 is part of a seismic section from a survey, conducted over preexisting mine works, to detect channel-induced washouts in the area. Development entries are located beneath SP-90 to SP-107. The underground workings affected the bottom reflection signature between SP-93 and SP-103 where changes in seismic attributes were observed. The seismic reflection returned to its normal character from SP-104 to SP-116.5, indicating an undisturbed uniformly thick coal seam. A broadening of the seismic wavelet with smaller reflection amplitudes between SP-117 and SP-125 suggests an area of relatively smaller acoustic impedance contrasts. Thus, it is likely that a sandstone washout occurs in this interval. A similar event lies between SP-129 and SP-132. A hole

Figure 1. Miner operates the longwall where the shearer cuts the coal while the shields support the roof.

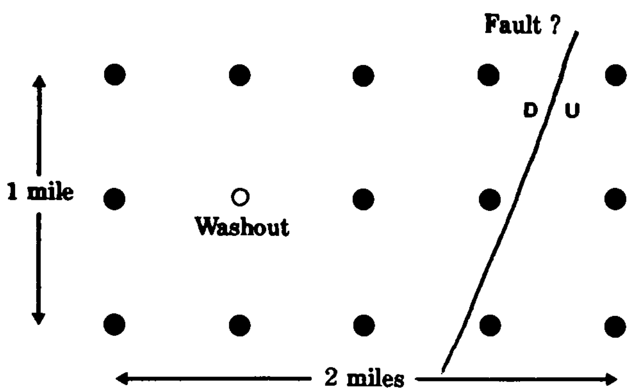

Figure 2. Geologic information based on drillhole data showing washout and suspected fault.

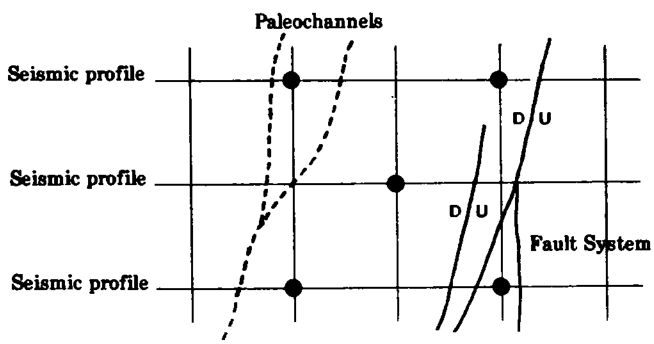

Figure 3. New geologic interpretation based on seismic and drill hole data showing paleochannels and fault system.

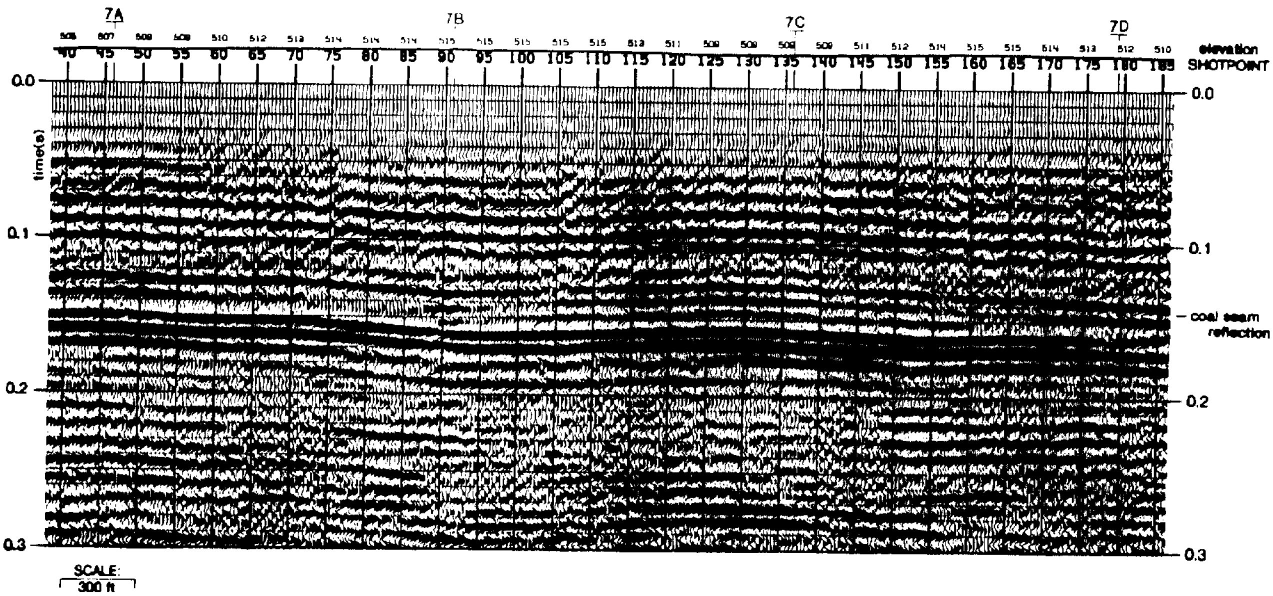

Figure 4. Seismic section of a survey conducted to investigate seam anomalies between drillholes.

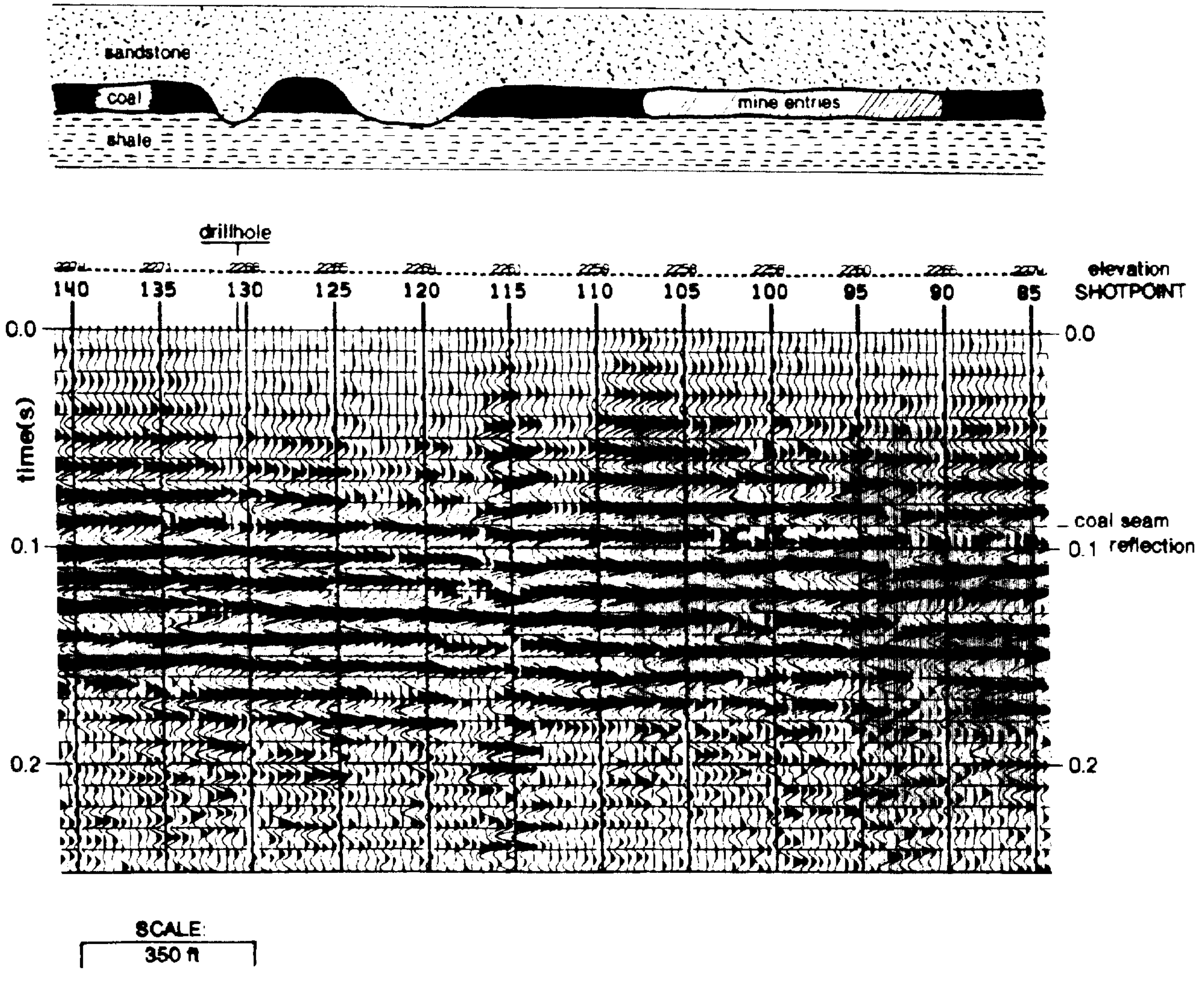

Figure 5. Seismic section of a survey conducted to investigate sandstone washouts.

was drilled at SP-130.5 after the seismic program was completed and encountered sandstone instead of coal. A small geologic cross section with an exaggerated vertical scale, built from available drillhole and seismic data, is shown above the section and indicates intervals where sandstone channels may have eroded the coal seam.

The Conoco prototype high-frequency vibroseis unit was used as the source for both surveys.

Such combined high-resolution seismic and drilling programs have proved a cost-effective, appropriate technique for Consol's coal exploration. Successful surface surveys have pinpointed the location of potential seam anomalies; washouts caused by the course and meander of paleochannels; faults; and areas of seam thinning or splitting. Areas of good coal have also been identified which might, otherwise, have been left unexploited. Postseismic drilling is recommended to confirm some seismic interpretations. Seismic surveying can also complement the exploration drilling program by targeting specific areas for additional drilling for evaluation of coal quality and reserves.

The success of a surface seismic program is constrained by accessibility to study areas and resolution limitations inherent in the method. Even though surface seismic can detect small faults with vertical displacements on the order of seam thickness, the data do not yet allow accurate estimation of the throw of the fault. However, the widths of detected paleochannels and washouts are close approximations of the actual anomalies. Despite the constraints, the information provided by these estimates is very valuable to coal companies. It is better that they respond in advance to geophysically-detected anomalies than after encountering them at the longwall face during mining. When access problems prevent surface surveys, in-seam seismics—a technique in which shots and receivers are placed in the coal seam, with the seam acting as a wave guide—are a possibility. British, German, and Australian mine operators have utilized in-seam seismic surveys for more than 10 years; the US coal industry, though, is just beginning to investigate its potential.

Consol is also exploring possible uses of other seismic techniques very common in petroleum exploration—vertical seismic profiling, interwell seismic surveying and/or crosshole tomography—for coal-mining applications.

The magnitude of Consol's seismic projects has grown dramatically since 1986. The continued growth of the seismic program has caused a need to integrate various geophysical and geologic data sets. This in turn implies that computer workstations are playing a major role in interpretation. LE

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