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HIGH-RESOLUTION SEISMIC SURVEY TO MAP PALEOCHANNELS IN AN UNDERGROUND COAL MINE[1]

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ABSTRACT

Shallow seismic reflection techniques were used to detect and map paleochannels in an underground coal mine where paleochannels have completely eroded the coal seam. This erosion of the coal seam is commonly called a washout. The early detection of washout areas would help in the development of a safe and productive mine. The Conoco prototype high-frequency Vibroseis* unit was utilized as the seismic source and was found to be effective for this application. Anomalous signatures in the coal-seam reflection indicating thin and/or absent coal observed on the seismic sections suggested the course and meander of the main channel structure and its associated distributaries. Postseismic drilling and subsequent underground mine development has confirmed some of the geophysical interpretations.

INTRODUCTION

Reflection seismology is one of several technologies that the Research & Development Department of Consolidation Coal Company (Consol) uses to assist the operating department in making Consol mines safe and productive (Kennedy, 1989). Seismic surveys augment the exploratory drilling program of the company in evaluating coal reserves and detecting seam anomalies that may create adverse mining conditions that are difficult to detect by drilling (Gochioco, 1990). The most common seam anomalies that pose potential mining problems are faults (Gochioco and Cotten, 1989) and washouts. The objectives of the seismic survey described in this paper were to detect sandstone washouts in an unmined reserve and to determine the likely course and meander of the main channel structure and its associated distributaries.

Mining in and near washout areas may encounter adverse conditions because of unstable, slickensided roof rock. Slickensides, which are common around the margins of many channels, are formed by differential slippage as sand, peat and mud compact unevenly. Roof stability under channel deposits varies greatly. Some sandstones are tightly cemented and make a solid roof. Other sandstones and some sandy or silty shales are brittle, thinly laminated, and very difficult to support. Where sandstone overlies shale in the roof, the shale may separate easily from the irregular, often slickensided, base of the sandstone. Potentially poor roof conditions may require longer bolts and additional roof support to stabilize the roof. Another potential mining problem associated with paleochannels is wet working conditions. Depending on the permeability of the sandstone, water inflow and seepage into the mine may require pumping the water out creating unwanted additional maintenance work on the pumps. Moreover, mining through sandstone channels causes more wear on mining equipment designed for mining softer coal. Therefore, it is important to detect sandstone washouts in advance of mine development so that a safe and productive mine design can be developed.

At a Consol mine located in the Appalachia basin, a sandstone channel of undetermined width was blocking the development of the northern reserve area (see Figure 1). The main channel structure had previously halted the

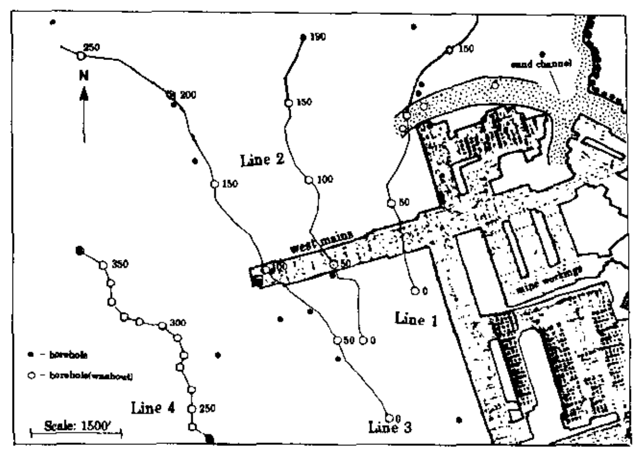

Fig. 1. Map of underground coal mine showing extent of mine workings.

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*Vibroseis is a trademark of Conoco Ltd.

advance of underground mine workings on the east side of the channel. The mine workings clearly show the boundary of the geologic disturbance. Additional exploratory drilling provided limited information about the width, extend and direction of this paleochannel. Development of the west mains was halted because of exceptionally thick seam splits and a sandstone which had scoured the top of the seam. A high-resolution seismic survey was proposed to delineate the channel structure in the mine property.

Geologic Conditions – Setting

A paleochannel is the course of an ancient river that eroded part or all of a coal seam, often including adjacent layers of rock. Seam thinning and complete erosion of the coal seam is commonly called a washout. To understand why washouts are encountered in coal mines, consider when the coal seam was a peat swamp. Shown in Figure 2 is a schematic diagram with typical geologic features found near the mouths of large rivers on coastal plains. The river meandered through the flatland, influencing the deposition of the peat and associated sediments. Coal is usually thicker along the channel because swamps bordering the river received a steady supply of nutrients and vegetation flourished. Areas away from the channel frequently dried out, which inhibited plant growth as well as peat development. Periodic flooding produced splits in the peat bed near the river from overbank or crevasse-splay deposits (see Figure 3). Splits are layers of shale (occasionally siltstone or sandstone) from a few centimetres to less than two metres thick which represent sediments washed into the swamp during floods (Nelson, 1983).

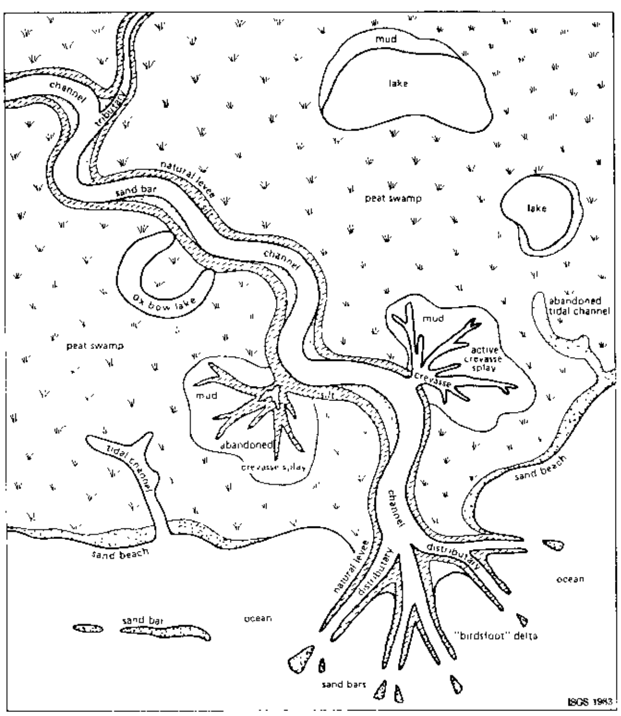

Fig. 2. Schematic diagram showing typical geologic features found near the mouths of large rivers in coastal plains.

The bituminous coal at the Consol mine is of the mid-Carboniferous period. The coal was deposited as peat in regions subjected to nonuniform rates of sedimentation. It was controlled, for the most part, by the interaction of migrating depositional environments. These migrations reflect directly rates of sediment influx, discharge of the associated rivers, and the nature of pre-existing substrata (e.g., sand, clay, bedrock, etc.). Mine maps from other nearby mature coal mines located in the Appalachia basin indicate an extensive paleodrainage system in the region. The drainage is established on alluvial silts and shales overlying an older buried peat. This drainage system incises the thin detrital cover (amounting to less than two metres) and impinges on and partly erodes the underlying peat. This erosional feature is also observed in nearby mines. Local unconformities where coal is absent or thin are due to channel scouring from the overlying sandstone. The depth to the seam beneath the valleys ranges from 120 to 170 m while the average depth of the seam along the ridges is 275 m; the average seam thickness is 2 m.

Field Procedures and Data Processing

The Conoco prototype high-frequency Vibroseis unit (Chapman et al., 1981) and recording truck were utilized in this project. The surface seismic survey employed the common-depth-point (CDP) method. The receiver group interval was 10 m and each record was composed of 24 channels. The shotpoint interval was the same as the receiver group interval resulting in a maximum stacking fold of 12. Field acquisition parameters were designed to optimize the imaging of the target coal seam horizon (Ziolkowski and Lerwill, 1979; Knapp and Steeples, 1986). Table 1 shows the field parameters utilized in this project.

Source: Conoco prototype high-frequency Vibroseis
Receiver: 40-Hz geophone array
Sample Rate: 1 ms
Record Length: 13 s
Sweep Length: 12 s
Sweep Frequency: 60-240 Hz, linear
Shotpoint interval: 10 m
Receiver group interval: 10 m
No. of channels: 24
Maximum fold: 12

Table 1. Field acquisition parameters.

Data processing was conducted in Library, Pennsylvania, through a network in which VAX computers are linked to Conoco mainframe computers (CRAY and VAX) in Ponca City, Oklahoma. Conoco seismic software programs were used to process the data and the processing sequence is presented in Table 2. A seismic interactive interpretation work station, based on a 32-bit microcomputer, was utilized in the interpretation process (Gochioco, 1989a). Sonic logs were gathered in selected drill holes along survey lines to assist in predicting the estimated two-way traveltime of the seismic wavelet reflected from the coal seam horizon. The work station was used to digitize the sonic logs in order to generate synthetic seismograms for subsequent correlation to the processed seismic sections. A 100-Hz Ricker wavelet was utilized in generating a synthetic seismogram and is shown in Figure 4. The coal seam being mined is indicated at the 122-m (400-ft) mark.

1. Edit bad traces
2. Elevation statics
3. Front-end mute
4. Zero-phase band-pass filter
5. Trace amplitude expansion
6. Spectral analysis
7. Deconvolution
8. Common-depth-point (CDP) sort
9. Velocity analysis
10. Surface-consistent statics
11. Zero-phase band-pass filter
12. Common-depth-point (CDP) stack
13. Zero-phase band-pass filter
14. Automatic gain control (AGC) scale
15. FK migration

Table 2. Seismic data processing flow chart.

Results and Interpretation

The frequency bandwidth of the seismic data ranges from 60 to 240 Hz. The reflected wavelet from the coal seam horizon has a predominant frequency of about 100 Hz. Using an interval velocity of 2500 m/s for bituminous coal, the standard resolution, defined as one-quarter of the predominant wavelength, is approximately 6 m. Even though the average seam thickness is only 2 m, the acoustic properties of coal (density ~1.35 Mg/m^3) have small values, creating a net acoustic impedance low with the immediate roof and floor rocks, thus causing a seismic reflection (Koefoed and de Voogh, 1980). Ruter and Schepers (1978) reported that coal seams as thin as 1/50 of the predominant wavelength can cause a distinct reflection. Widess (1973) stated that the reflection amplitude may contain information on the thickness of thin beds, to thinner than one-quarter of the predominant wavelength. That is why it is essential to study the signature of the seismic wavelet associated with the target coal seam. Washouts produce a distinct anomalous signature in the coal-seam reflection where frequency and amplitude attributes of the wavelet change. Complex trace attribute displays highlight these anomalies to enhance the interpretation process (Gochioco, 1989b).

Seismic survey Line 2 is located on top of a ridge where the depth of the target coal seam ranged from 275 to 290 m beneath the surface. A portion of the seismic section of Line 2 is shown in Figure 5. The reflection associated with the coal seam horizon is indicated. The coal-seam reflection is robust and continuous from SP-80 to SP-97, indicating normal seam thickness. The first evidence of a disturbance associated with potential seam thinning and/or channel-induced washout was detected between SP-97.5 and SP-102 where broadening of the seismic wavelet is observed. The coal-seam reflection returns to its normal character at SP-103 and is continuous up to SP-144. The weak coal-seam reflection centred at SP-118 may be due to recording problems rather than detecting a geologic disturbance. Another anomalous structure was detected between SP-145 and SP-153. The poor coal-seam reflection indicated smaller acoustic impedance contrasts, suggesting that seam thinning and/or a washout may have occurred over these intervals. The coal-seam reflection returns to its normal character and is continuous from SP-154 to SP-175, indicating uniform seam thickness. Two boreholes were drilled

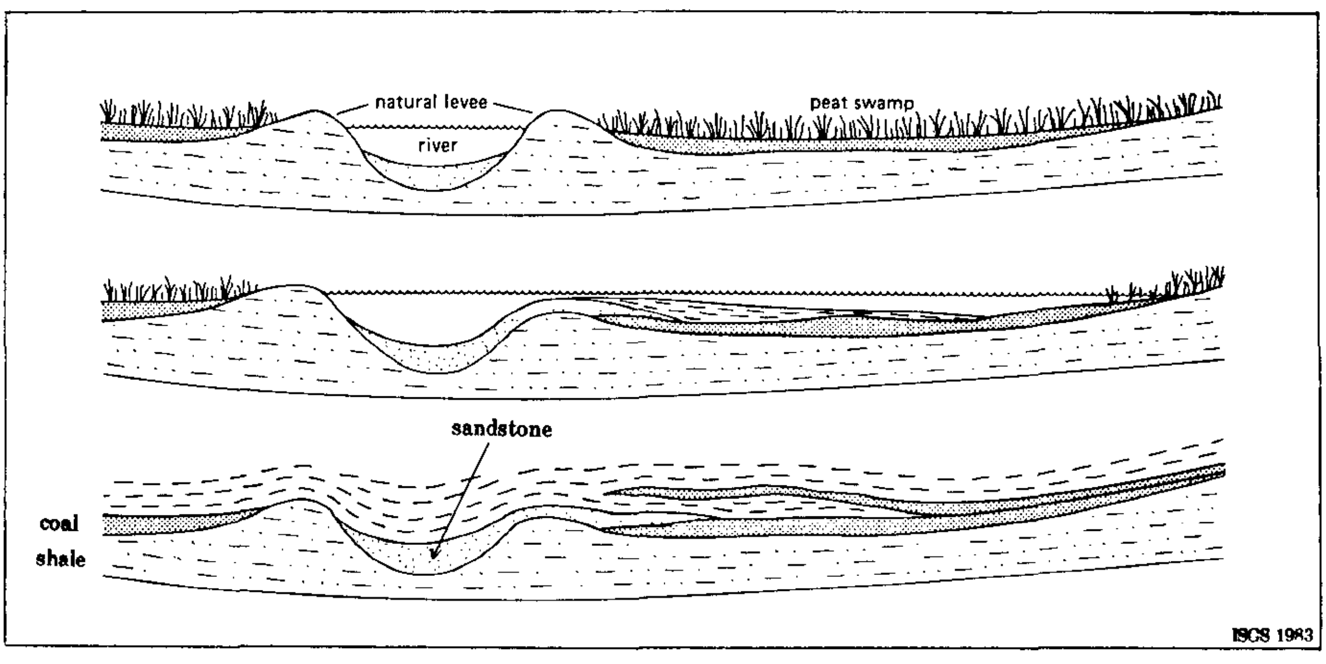

Fig. 3. Schematic diagram showing how periodic flooding produced splits in the seam near the river from overbank or crevasse-splay deposits.

after the survey to confirm the seismic interpretation along Line 2. The hole drilled at SP-99 encountered no coal while the other hole drilled at SP-138 revealed a normal seam thickness.

Seismic data were gathered along Line 3 over pre-existing mine works and the survey line was extended to the reserve area to detect channel-induced washouts. Figure 6 shows a portion of the seismic section of Line 3. The underground mine workings affected the bottom reflection signature between SP-93 and SP-103 where changes in seismic attributes were observed. The development entries are located beneath SP-90 to SP-107 of the survey line. The coal-seam reflection returned to its normal character from SP-104 to SP-116.5, indicating an undisturbed, uniformly thick coal

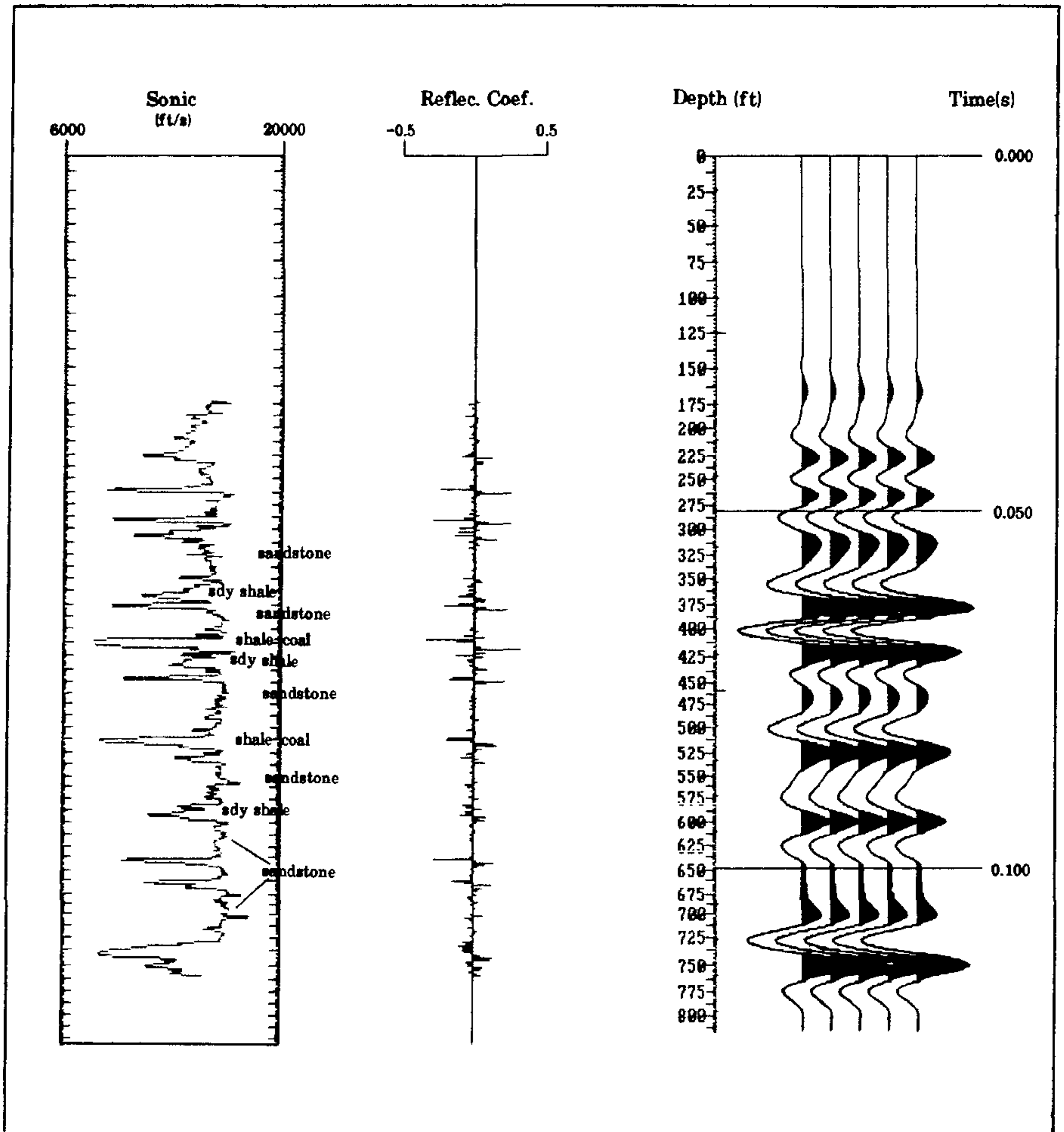

Fig. 4. Synthetic seismogram generated from a sonic log from a borehole near seismic Line 1, utilizing a 100-Hz Ricker wavelet. Key reflectors are indicated.

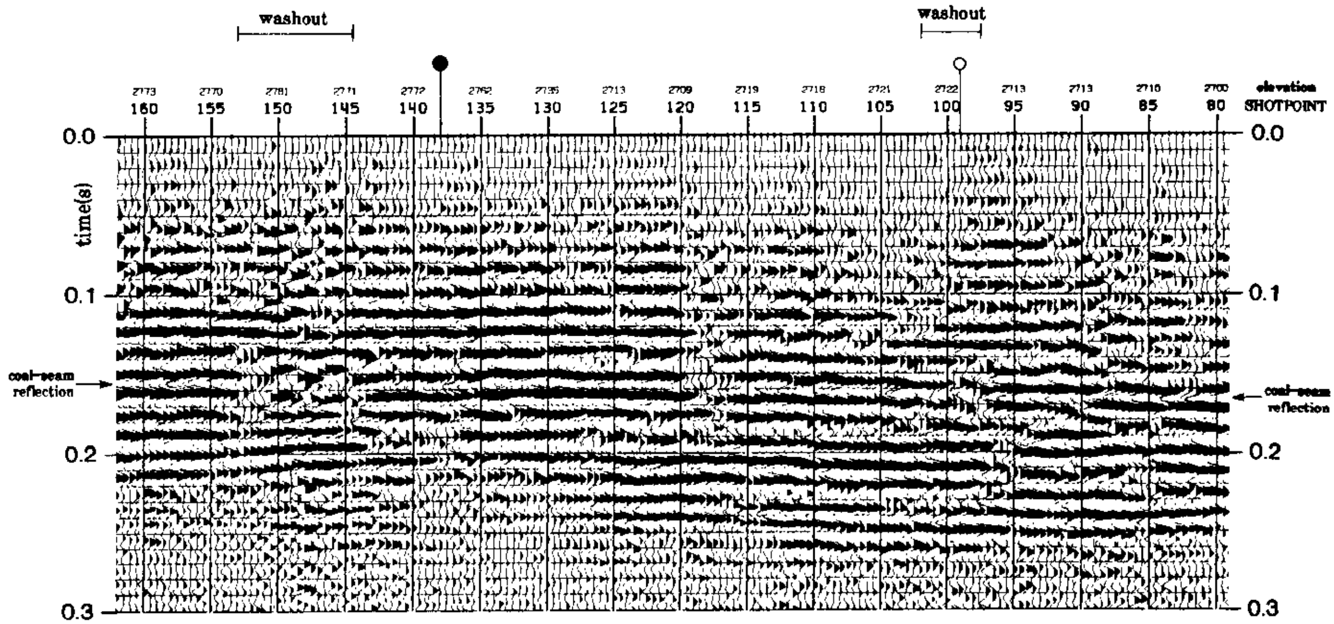

Fig. 5. Seismic section of Line 2.

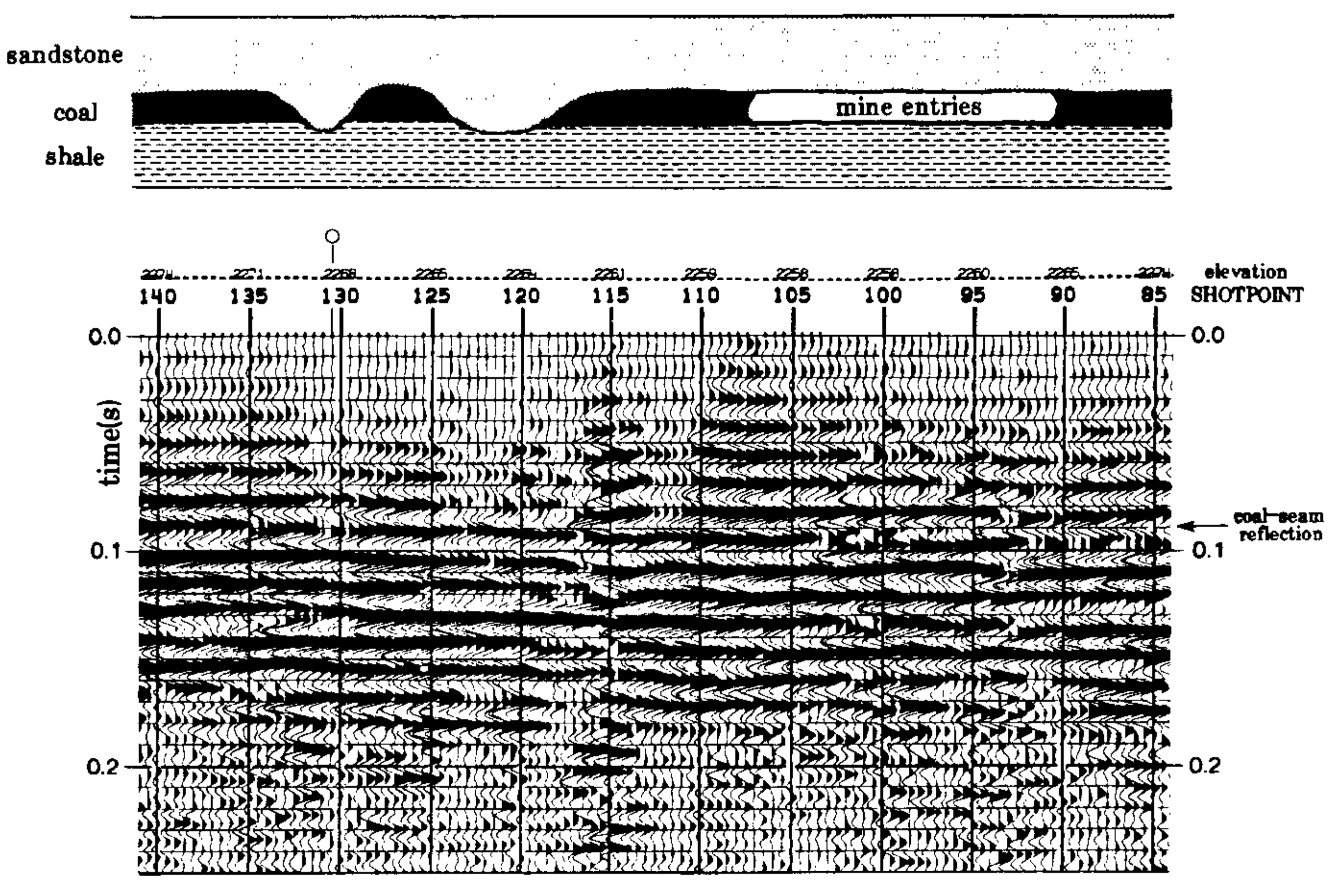

Fig. 6. Seismic section of Line 3.

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

Figure 7 shows the northern portion of the seismic section of Line 4. The reflection associated with the target coal seam horizon is indicated. The coal-seam reflection is robust and continuous from SP-280 to SP-295. However, the reflection signature begins to diminish from SP-296 to SP-300 and undergoes a phase change. The anomalous signature indicates possible seam thinning before it is completely eroded by sandstone between SP-297 and SP-304. From SP-305 to SP-313, the coal-seam reflection is robust and continuous indicating uniform seam thickness. The broadening of the seismic wavelet centred at SP-315 suggests possible thinning and/or washout of the coal seam at this location. Another potential washout was detected between SP-338 and SP-342 where the amplitude of the coal-seam reflection diminished considerably. The robust reflections outside these intervals suggest good coal areas.

By integrating all the interpreted channel-induced anomalies from the four seismic sections, the likely course, extent and meander of paleochannels in the mine was suggested as shown in Figure 8. The main channel structure interpreted beneath Line 2 may have split into two distributaries which appear to head on a nearly straight course toward Line 4.

Underground observations at the western edge of the west mains revealed unusual splits in the seam coupled with the sandstone scouring the top of the seam indicating the close proximity of a paleochannel. This information assisted in the interpretation of the likely meander of the southernmost paleochannel. Utilizing the information provided by geophysical and geological data, mine personnel drove the north mains by undermining the sandstone washout detected beneath Line 1 (see Figure 8). The seismic data indicated a 105-m disturbed area, while mine personnel undermined about 120 m of shale.

Conclusions

The high-resolution seismic reflection technique was able to detect washouts in an underground coal mine associated with paleochannels that eroded portions of a peat swamp. Based on the interpretation of the seismic and drillhole data, the likely course of the main channel structure and its associated distributaries in the mine property was mapped, as shown in Figure 8. Postseismic drilling and subsequent mine development confirmed some of the interpretations. Moreover, seismic surveying compliments the exploration drilling program by targeting specific areas for additional drilling to investigate the interpreted anomalies. Useful information provided by such survey can assist mining engineers in directing the development of reserves away from the detected and interpreted anomalies. Also, Vibroseis proved to be reliable energy source for this project and should be effective for shallow seismic exploration applied to the mining industry.

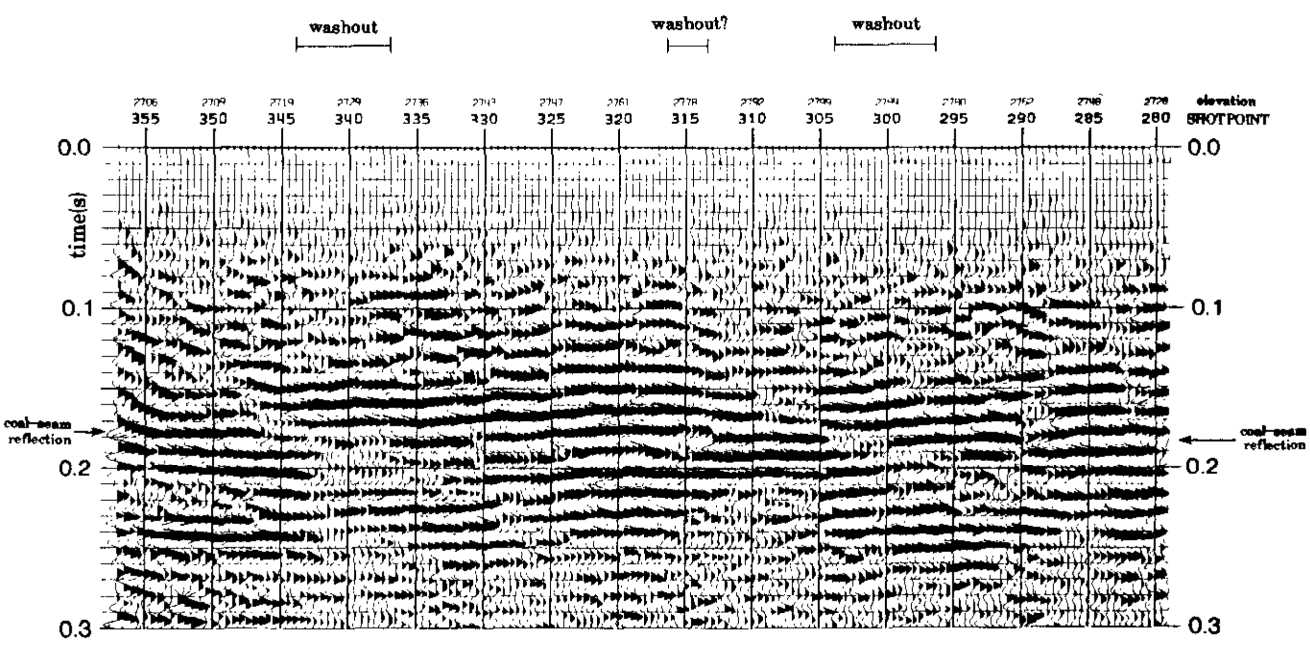

Fig. 7. Seismic section of Line 4.

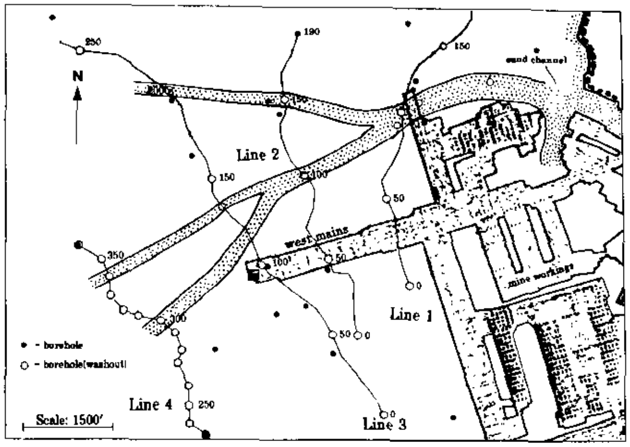

Fig. 8. Map showing geophysical interpretation of paleochannels in the mine property.

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