CHARACTERIZING LONGWALL COAL MINE SUBSIDENCE WITH HIGH RESOLUTION SEISMIC REFLECTION

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Abstract

As part of an Illinois mine subsidence initiative, the U. S. Bureau of Mines has conducted high-resolution, seismic-reflection surveys at a coal mine site in southern Illinois. Premine and postmine surveys conducted above longwall panels consisted of common-depth-point (CDP) data collection. Drill core and sonic logs from a nearby borehole, and mine maps were used in the interpretation of the data.

Processed sections show a number of interesting features which may aid in characterizing subsurface subsidence. The mined and unmined areas at these sites are clearly discernable, and seismic signatures associated with fracture zones and voids can be interpreted. In addition, reflection events from subsided areas have been identified which corroborate recently advanced theories of bridging potential of the overburden. This report concludes that a CDP, high-resolution, seismic-reflection method is an effective research tool for identifying changes in overburden due to high-extraction mining.

Introduction

Surface subsidence caused by longwall coal mining operations in southern Illinois often has detrimental effects on the landscape as well as cultural structures and activities. Researchers at the U. S. Bureau of Mines have been attempting to characterize subsidence events in order to develop prediction technologies that will help alleviate some of the effects of mining. In order to do this effectively, various surface and downhole measurements have been made, including the monitoring of surface elevation changes and lithologic and geophysical borehole logging. In addition, it was felt that the use of a high-resolution, seismic-reflection method might enhance the existing body of subsurface information and help to support conclusions of previous subsidence studies.

Several studies have been made to determine the effectiveness of seismic-reflection methods for identifying changes in overburden due to high-extraction coal mining. Rudenko et al., (1989) mapped the position of a longwall mine face during mining from P- and S- wave velocities obtained in seismic-reflection surveys. While velocity changes were complex, a slight P-wave increase occurred ahead of the longwall face and major decreases in both P- and S-wave velocity behind it. The velocity decreases were attributed to enhanced fracturing and tension behind the mine face. He and Wilson (1989) observed velocity decreases over mined-out zones using common-offset seismic-reflection profiling, and Wilson et al., (1988) identified zones of abnormal P-wave absorption over the edges of longwall mines. Miller and Steeples (1991) used a high-resolution, P-wave reflection method to evaluate the possible reactivation of subsidence caused by cavities in a thin coal seam at a depth of 7 meters. Carpenter and Booth (1992) also used common-offset seismic reflection over a longwall panel. They interpreted disruption of the reflections as due to fracturing of a limestone bed at a depth of 38 meters, which was 12 meters below the bedrock surface. In premine planning to help predict roof instability, areas of low-sulfur coal and geologic disturbances, Henson and Sexton (1991) used high-resolution, seismic-reflection data to supplement closely-spaced yet inadequate borehole data.

The fieldwork for this study was conducted near the town of West Frankfort in Franklin County, Illinois (Figure 1). In this part of the Illinois basin there are two seams from which coal is mined, the Herrin No. 6 and the Springfield No. 7, both of which are members of the Pennsylvanian age Carbondale Formation. The Franklin County site is a longwall mining operation in the Herrin No.6 seam at a depth of about 160 meters. In the seam, chain pillars were developed for mining longwall panels which were 244 meters wide (Figure 2). The overburden geology consists of alternating units of coal, siltstone, shales and limestones, with the coal and the overburden cut by sandstone channels. These units were identified and logged from a cored borehole located near the survey line.

Rock Mass Classification

The U. S. Bureau of Mines utilizes a commercially-available computer spreadsheet in combination with Bieniawski's Rock Mass Rating (RMR) system to characterize the geology overlying high-extraction coal mines (Siekmeier et al., 1992). An RMR value is computed for each bed based on the lithology, thickness, and engineering properties, which are determined from borehole logs, laboratory tests and field studies. The deformation modulus is then computed for each bed using an empirical relationship and the RMR value. This modulus, and other parameters based on overburden geology and mine geometry is used to compute the bending stiffness and bridging potential of each bed (Figure 3).

Subsurface displacements have been measured over seven longwall panels in Illinois using Time Domain Reflectometry (TDR) (Bauer et al., 1991; Dowding et al., 1988). Basically, a coaxial cable is grouted into a borehole drilled from the surface to the coal seam. A TDR cable tester is connected to the cable and a voltage pulse sent down the cable. At every location where there is a change in the cable geometry, a reflection is sent back to the cable tester where the waveform is displayed and recorded. The shape and magnitude of the waveform is directly related to the type and magnitude of cable damage. Based on laboratory correlations, it is possible to distinguish shear deformation from tensile deformation and to quantify shear displacement (Dowding et al., 1988).

Figure 3 shows TDR signatures that were recorded for a cable grouted into the borehole indicated in Figure 2. The signatures were recorded as the longwall face approached and advanced past the hole location. When the face was 31 meters from the hole, the TDR signature at a depth of 66 meters is characteristic of shearing. This depth corresponds to a 0.9-meter-thick bed of dark gray shale. Shearing continued, and ultimately the shear displacement was greater than 0.025-meter which resulted in shear failure of the cable. The TDR signatures also indicate shear deformation at many other depths (30, 47, 66, 95, 120, and 136 meters).

When stiffness and bridging potential for each bed are plotted next to the TDR signatures, it is possible to interpret the overburden response (Figure 3). The thicker shale and siltstone beds have capacity to "bridge" for a period of hours as the underlying rock material consolidated. The mining rate was approximately 8 meters per day.

The current model used to envision the overburden includes a zone of block caving near the mine overlain by a zone of strata separation and fracturing that eventually transitions to a near-surface zone of laminated beam bending (O'Connor and Dowding, 1992). The laminated beam thicknesses considered feasible are 44, 56, and 66 meters (Figure 3). These thicknesses correspond with the three different bedding planes in the vicinity of the final TDR cable length (47 meters). The bottom of this beam is separated from the lower bed and should act as a very strong reflector of seismic energy, providing an additional basis for interpretations of the processed seismic sections.

Seismic Data Collection And Processing

High-resolution, seismic-reflection surveys conducted at this site employed the 12-fold, common-depth-point (CDP) method (Dobrin, 1976). A 24-channel engineering seismograph with signal enhancement, analog filtering and multiple record storage capabilities was used for data recording. The seismic energy source was a nondestructive, mechanical weight dropping device, and the receivers used were 60 Hertz land geophones. A portable microcomputer allowed data collected to be transferred in the field to floppy disk storage for later processing.

Preliminary to data collection, a series of recordings known as noise tests were made to determine seismic source and receiver offset, station spacing and recording instrument parameters. Analysis of these tests resulted in a 91.4 meter source to receiver offset with geophones and shotpoints spaced at 3 meters. Analog low-cut filters up to 128 Hertz were used during much of the data recording.

At each source station, the weight was usually dropped 8 times, with the seismic energy from each drop being stacked together by the seismograph to form a single 24-channel record. The source and 24-channel geophone spread were then advanced 3 meters to record data for the next station. Proceeding in this manner, the premine survey line consisted of 130 shotpoints covering approximately 383 meters in the subsurface, while the postmine survey line consisted of 158 shotpoints covering approximately 468 meters in the subsurface.

The 12-fold, seismic-reflection data from these surveys were processed into seismic sections using a commercially-available, microcomputer-based software package. It was found that a relatively minimal amount of data processing was required to produce reasonable and interpretable seismic sections. After bad or extremely noisy data traces were edited from the data sets, the data were filtered using a 100 to 250 Hertz digital bandpass filter. The data sets were then sorted into common-depth-point gathers and stacked into section form using an RMS velocity of approximately 2,300 meters per second.

Results And Interpretation

Drill core and sonic logs from a borehole near the survey line were used to determine formation thicknesses and depths to lithologic contacts. Using the velocity through each rock formation, the total two-way traveltime can be determined for each lithologic unit. Figure 4 shows a plot of velocity and two-way traveltime for each formation and cumulative two-way traveltime versus depth. These traveltimes are used to identify observed reflections in the processed seismic sections and to assign a depth value to these reflections. This traveltime depth relationship provides a very useful basis for interpreting the processed seismic sections.

The processed seismic reflection section for the premine survey line is shown in figure 5. The location of the south chain pillar is shown which separates unmined coal to the north from a portion of a previously-mined panel to the south. The location of the logged borehole (DDH) is shown in the unmined part of the section and seismic reflection events in this area are identified which correspond closely with borehole log information (Figure 4). Data in the zone from surface location C to D shows some complexity which could be due to a buried channel or to a facies change in the overburden.

In the previously mined part of the section, from surface locations A to B, a strong reflection event having negative polarity at 57 milliseconds is interpreted as the bottom of a thick siltstone and shale unit at approximately 66 meters below the surface. Beneath this event, coherent reflections are not found, which suggests a scattering or attenuation of seismic energy at this depth. At surface location B this reflection shows a vertical displacement due in part to the presence of a high-angle fracture zone, and in part to a probable lateral seismic velocity change in the subsided area. This interpretation agrees well with a possible laminated beam thickness of 66 meters. Siekmeier et al., (1992) indicate that the maximum deflection of an elastic unsupported beam would be 1.35 meters, which agrees well with the maximum measured subsidence of 1.31 meters.

The processed seismic-reflection section for the postmine survey line is shown in figure 6. In order to achieve a longer survey line, the direction that the postmine data were collected was opposite to the direction of premine data collection. As a result, the processed section is displayed in reverse with respect to the north-south orientation. The locations of two chain pillars are shown on either side of a recently-mined longwall panel. At the southern end of the section, part of the previously-mined longwall panel is seen again, while north of surface location A, no mining has taken place.

Throughout most of the recently-mined central portion of the section, a strong negatively polarized reflection event is once again present. Near the logged borehole it occurs at a depth greater than 60 meters below the surface, in good agreement with possible laminated beam thicknesses in this area. The event tends to lose strength and continuity to the north of the borehole where some deeper reflections seem to be better developed. This may be an indication that the overburden in the northern part of the panel had not completely subsided at the time the postmine survey data were collected. On the other hand, lateral velocity variations due to facies changes, or the presence of buried channels in the overburden, may be obscuring reflection details in this area.

Conclusions

High-resolution, seismic-reflection methods have provided important information to help characterize subsurface subsidence over longwall coal mining operations in southern Illinois. In seismic-reflection work in general, the most effective data collection, processing and interpretation results when adequate borehole sonic and lithologic logs are available. In areas where subsidence over longwall mining has taken place, however, it is also necessary to interpret seismic reflection data in the light of recently developed concepts of bridging potential and laminated-beam formation in overburden rock. This report concludes that the CDP high-resolution, seismic-reflection method is an effective research tool for identifying major changes in overburden due to high-extraction mining.

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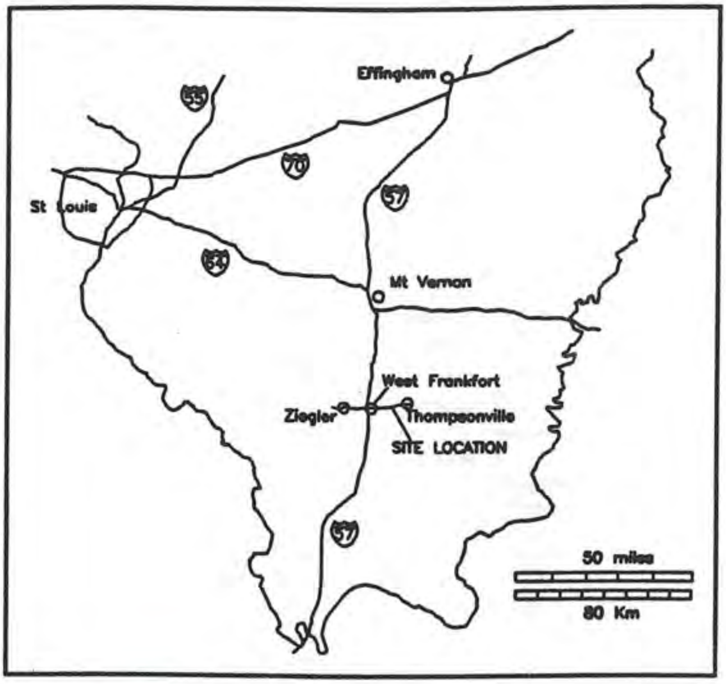

Figure 1.-Site location.

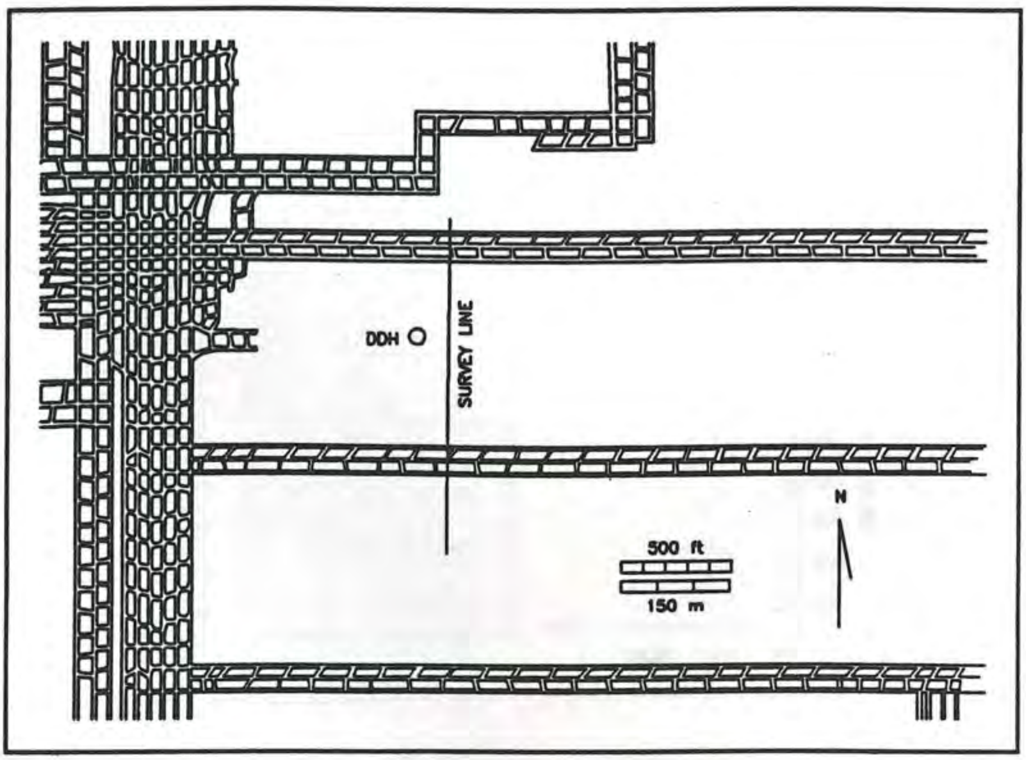

Figure 2.-Seismic line location.

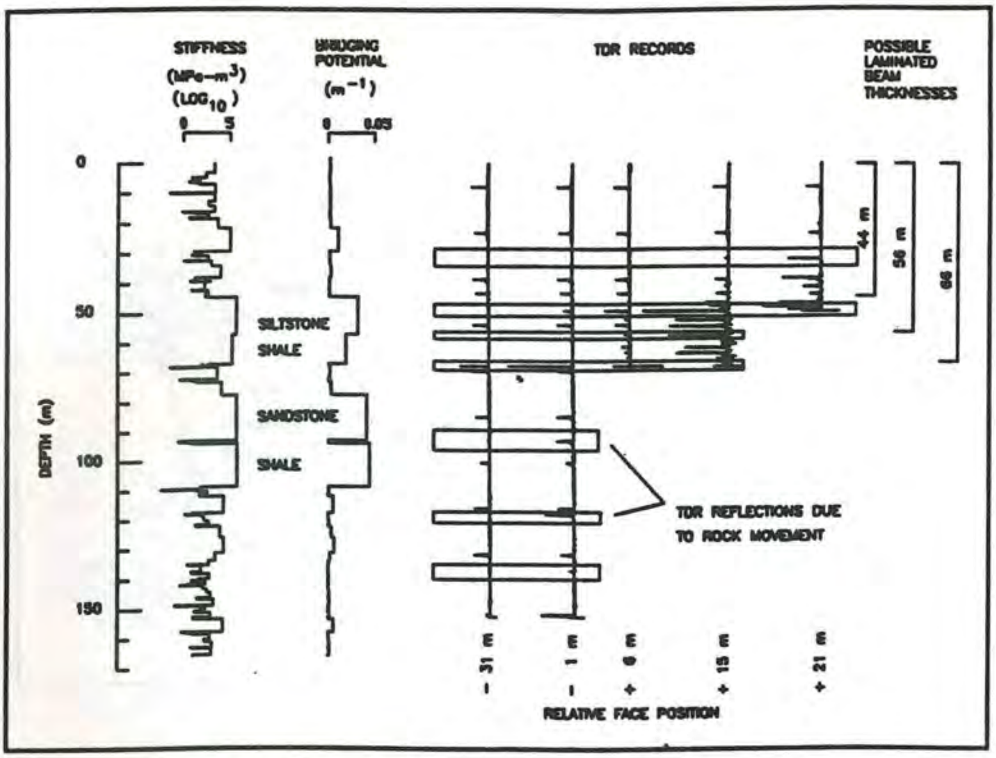

Figure 3.-Stiffness, bridging potential, TDR records, and possible laminated beam thicknesses.

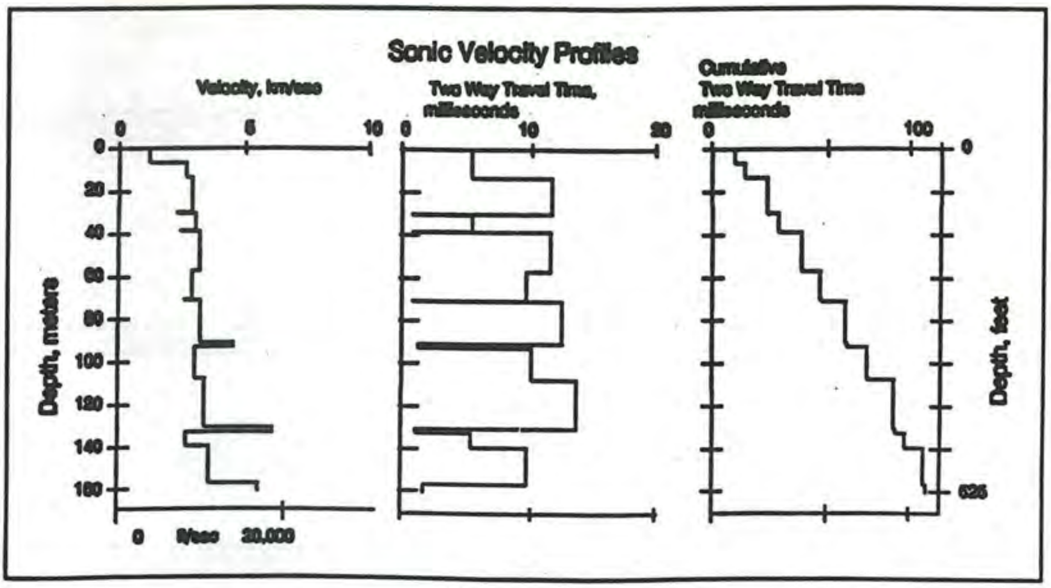

Figure 4.-Sonic velocity profile with two-way traveltime profiles.

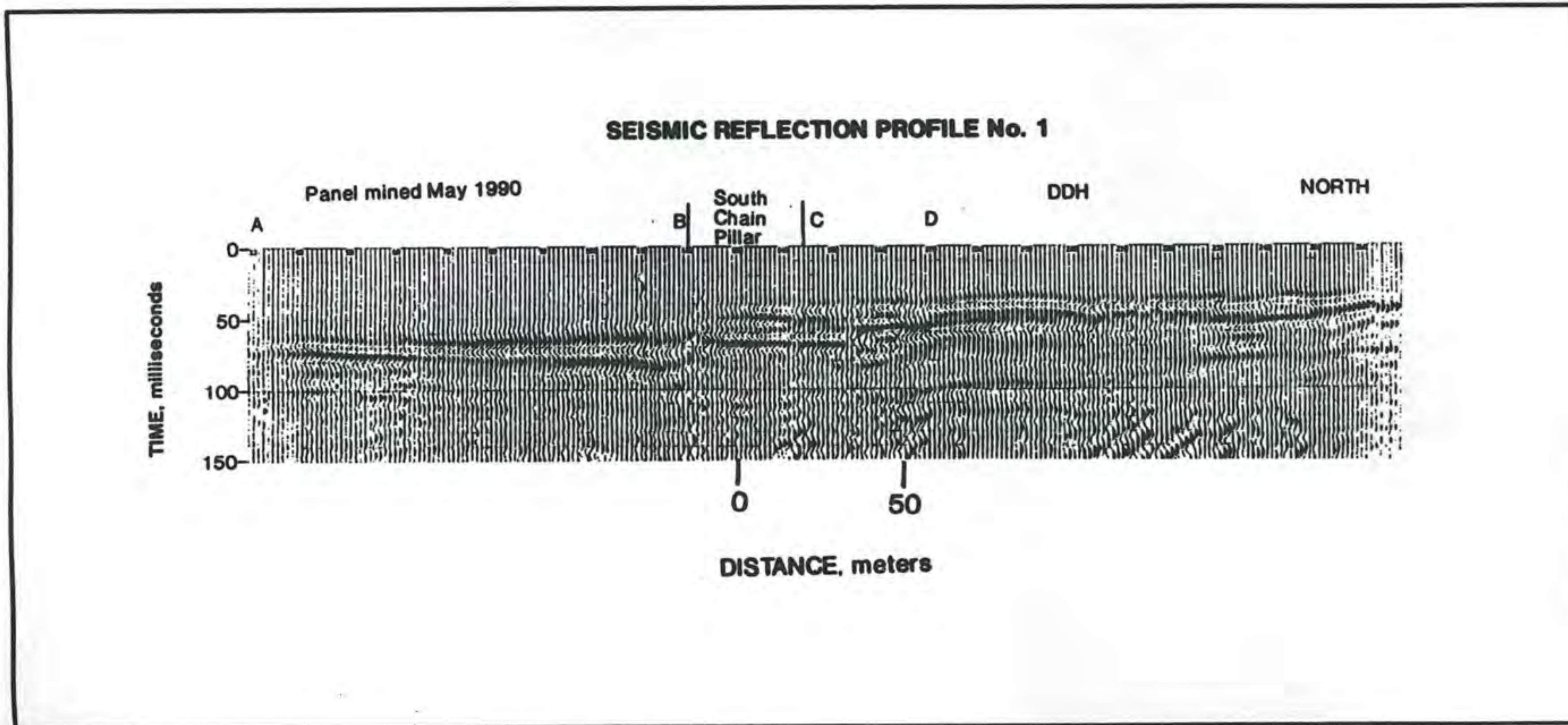

Figure 5.-Seismic reflection profile over unmined panel.

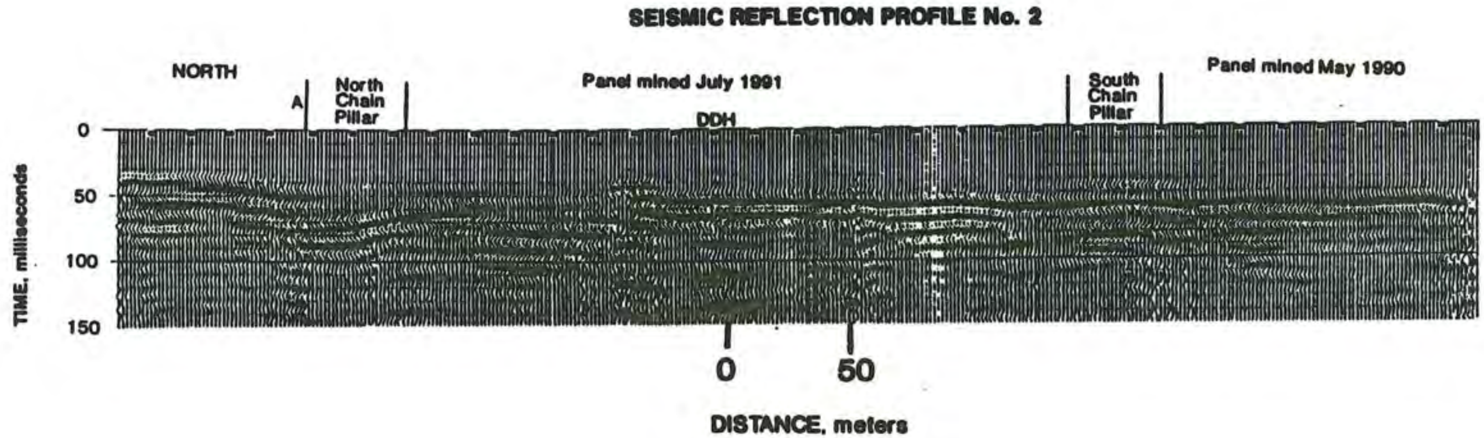

Figure 6.-Seismic reflection profile over mined panel.

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