U.S. Department of Labor

Mine Safety and Health Administration
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Mine Waste and Geotechnical Engineering Division

February 2, 2007

MEMORANDUM FOR IRVING McCRAE
Contracting Officer, Acquisition Management Division
MSHA Headquarters, Arlington

THROUGH: STANLEY J. MICHALEK
Acting Chief, Mine Waste and Geotechnical Engineering Division

GEORGE H. GARDNER
Senior Civil Engineer, Mine Waste and Geotechnical Engineering Division

FROM: DARREN J. BLANK
Civil Engineer, Mine Waste and Geotechnical Engineering Division

SUBJECT: Summary of the Geophysical Void Detection Demonstration Project by Marshall Miller and Associates, Incorporated, (Account No. B2532531) Conducted at Clintwood Elkhorn Mining Company's Sassy No. 1 Mine, Mine I.D. No. 44-03010, Near Hurley, Buchanan County, Virginia

Marshall Miller and Associates have recently fulfilled their contract to demonstrate in-seam seismic technology for detecting underground mine workings. The demonstration project was conducted at Clintwood Elkhorn Coal Company's Sassy No. 1 Mine. I am the Contract Officer's Technical Representative (COTR) for this project. The purpose of this memo is to provide a general summary of the completed project and discuss the success of the geophysical results.

BACKGROUND

Marshall Miller and Associates was the prime contractor for this in-seam seismic demonstration project. Assistance in collecting and processing the seismic field data was provided by Dr. Mattias Imhof and his staff at the Virginia Polytechnic Institute and State University (Virginia Tech).

The in-seam seismic method was used from a surface outcrop in an attempt to locate both air- and water-filled mine workings within the Splashdown coal seam. The mine lies at an elevation of 1,110 feet above MSL at the portal entry and dips to the northwest to an elevation of 1,030 feet at the extent of the workings. The Splashdown seam is 30 inches thick and contains a 1-inch-thick parting in the middle of the seam. The mine roof consists of shale and the floor consists of clay. Prior to the test, the contractor obtained an accurate mine map and survey from the coal company, so distances from the outcrop to the underground mine workings were known.

After Marshall Miller was awarded the contract, a project kick-off meeting was held on November 8, 2004, to introduce the team members and to develop a process for reporting project milestones and invoicing for progress payments. Field work associated with the collection of data was completed on February 11, 2005. I was on site for the testing. On July 28, 2005, a meeting was held to discuss the status of the project and work that was anticipated for completion. The processing of the field data was completed and a draft project report was submitted on January 27, 2006. Following a technical review of the report, Marshall Miller revised the draft report and submitted what they considered to be a final project report on October 2, 2006. However, several comments pertaining to the review of the draft report were not adequately addressed in the document and typographical errors were found. Comments pertaining to the review of this report were contained in a letter to Marshall Miller dated October 27, 2006. Items contained in the letter were addressed in the revised final project report dated December 19, 2006. A hard and electronic copy of this report was mailed via overnight delivery to your attention on January 18, 2007. In a telephone conversation on January 19, 2007, you confirmed receipt of this information.

DEMONSTRATION OF IN-SEAM SEISMIC METHOD

The contractor performed two in-seam seismic surveys from the outcrop of the coal seam. In preparation for conducting the seismic surveys, the existing seam outcrop and bench were cleared of trees and brush to allow for placement of the seismic equipment. Two sections of the coal outcrop, each approximately 900 feet long, were excavated to remove weathered and loose coal. In the first in-seam seismic survey line (ISS Line 1), the researchers attempted to detect water-filled workings in the northwest corner of the mine that were located at a distance of approximately 1200 feet from the outcrop. The second in-seam seismic survey line (ISS Line 2) was located to the southeast of the first, and the researchers attempted to profile air-filled workings along the northwest mains that were located at a distance of approximately 800 feet from the outcrop. For a layout of the test, refer to figure 1.

In both tests, geophones were evenly spaced along the prepared coal seam outcrop to form a receiver array. The geophone model used is typically installed vertically, but the springs are stiff enough to permit horizontal installation without loss of data. The 100 Hz geophones used were mounted horizontally into the middle of the coal seam by drilling approximately 4-inch-deep pilot holes into the seam and driving the geophone spikes into the holes with a mallet. Seismic sources consisted of explosive charges which were positioned approximately midway between the geophones and were placed in 3-foot-deep holes drilled into the coal seam. For accuracy, survey instrumentation was used to position the geophones and source holes. Upon detonation of the explosive charge, channel waves propagated into the seam until their advancement was interrupted by a void, and the waves were reflected back to the outcrop.

The center piece of the seismic data acquisition system was the seismograph. The seismograph recorded the time histories of motion for each of the geophones, and was powered by a 12-volt car battery. A geophone cable was used to attach the seismograph to the geophones. Initiation of the seismic event was controlled by the blast control box. The blast control box was used to detonate the zero-delay blasting caps and explosive charge. The control box was also connected to the seismograph via a trigger cable to start the recording.

The ISS Line 1 consisted of an array of 60 geophones spaced on approximately 12-foot-centers. The explosive charges were grouped in pairs, with each pair approximately 12 feet apart, and the pairs were spaced 24 feet apart. Thirty-seven explosive charges were detonated, but only 35 provided usable readings. One charge was used as a background test and one was a misfire.

The ISS Line 2 also consisted of a 60-geophone array, but the geophones were spaced a little differently. The geophones were spaced on alternate centers of 14 and 16 feet. Forty-six explosive charges were placed on 30-foot centers and individually detonated. Of the 46 charges, only 37 provided usable recordings. One charge was used as a background test and the remaining charges did not trigger the recording device due to sensitivity problems in the geophone cable.

Separate transmission surveys were performed to estimate the velocity of channel waves within the coal seam and for computation of site-specific dispersion relationships required for processing the seismic data collected in ISS Lines No. 1 and 2. Two transmission surveys were performed. The first test was conducted with a distance of 515 feet between the source and receiver array, and the second test was performed with a distance of 682 feet between the source and receiver array. The seismic source was located within the mine wall along the west main entry. It was generated by striking a railroad spike placed in the coal seam 10 times for each test. Each strike was recorded separately. The receiver array for the transmission test consisted of 30 geophones placed in two staggered rows along the outcrop of the coal seam.

MODIFICATIONS TO ORIGINAL PROPOSAL

Due to unanticipated geologic and topographic conditions encountered during the field-work phase of the project, a couple of modifications to the proposal were required. The survey was performed in accordance with the procedures, but the ISS Line 1 had to be adjusted due to geologic and topographic conditions that were apparently not evident during the initial mapping. During the field preparation for ISS Line 1, a seam roll (a localized drop and then rise in the coal seam elevation over a short distance) was encountered at the eastern end of the proposed location. Additionally, the stability of the hillside above proposed location appeared to be questionable. Tension cracks were observed. Consequently, ISS Line 1 was shifted to the northwest to avoid the local geologic condition and hillside instability.

Modifications to the originally-proposed direct transmission test were also required. In the accepted proposal, Marshall Miller indicated that two 230-foot-deep boreholes would be drilled from the surface into the coal seam at each test site. The boreholes would have been used for placement of in-seam seismic sources to conduct transmission experiments in which the channel waves would propagate from the source directly to the seam receivers at the outcrop. According to Marshall Miller, the coal mine in the overlying Blair seam was reactivated and they were unable to initiate drilling and conduct the tests due to the haulage traffic. Mining operations were also reactivated in the Sassy No. 1 mine, and Marshall Miller indicated that they did not desire to drill into an active mine and set off an explosive seismic source. As an alternative, the transmission test was conducted as outlined in the previous section. It appeared that an accurate estimate of the channel wave velocity was determined through the transmission testing since the waves were readily identified on a plot of the gathered data.

DISCUSSION OF RESULTS

The data processing was performed by Virginia Tech under the guidance of Dr. Imhof at the campus facility in Blacksburg, Virginia. The raw data was initially compressed and the Multiple Filter Technique was used to identify the dispersive channel waves. The results from the transmission test were used to derive the dispersion relationship. Periodic power line noise was discovered in the data and was removed. After the data for ISS Line 1 was processed, the dispersive reflected channel wave arrival was visible at approximately 0.8 seconds. The researchers used conventional PreStack Depth

Migration to image the data. Using the seismic data processing software ProMax, the researchers stacked the results of all shots (35 for ISS Line 1 and 37 for ISS Line 2) to obtain the final images shown in figures 2 and 3.

ISS Line 1

In this survey, it appeared that the contractors were able to identify the presence of a void, although the specific location was approximate since the survey line was shifted northwest beyond the mine boundary. As shown in figure 4, the highlighted reflection data was located approximately 100 feet beyond the edge of the mine void and represents a shadow of the workings. The resultant shadow may be attributed to edge effects since the mine was located near the edge of the source and receiver array and because multiple surfaces for reflection existed. The report indicated that variations in the reflected channel waves were stacked during data processing and multiple diffracting reflections were merged into the single reflection event shown in figure 2. Further, it was suggested in the report that the inability to project a more definitive reflection boundary suggests that the mine workings are to one side and that the distance is no closer than the location shown in figure 4.

ISS Line 2

As shown in figure 5, the distance to the mine void changed along the seismic profile because the seismic survey line and the mine boundary were at an oblique angle. The distance from the southeast end of the survey line to the void was approximately 600 feet, but the distance increased to nearly 1200 feet at the northwest end of the survey line. As a result of the angle, much of the seismic energy at the greater distances was reflected away from the geophone receivers. Consequently, the eastern (right) side of the seismic line had higher density and more reliable data than the western (left) side. Additionally, 8 seismic sources were lost (did not trigger data collection) along the western side of the survey line. This created a situation where there were even fewer data points on the western side of the survey. Even though the data was not as dense along the west side of the array, Marshall Miller indicated that sufficient information was still obtained to define the profile of the mine void.

CONCLUSION

The demonstration project was unique since the test was performed along an exposed outcrop rather than attempting to position the seismic survey line along the ground surface or within the underground mine. By conducting the test in this manner, extreme relief in surface topography and areas of potentially dense vegetation may be avoided. However, preparation of the outcrop by removing loose material is required, and access may be limited which may make field testing difficult. This proved to be the case with the demonstration.

Several disadvantages exist with the application of the in-seam seismic method. Performing the seismic survey will have a major impact on mining operations since vibrations from machinery will contaminate the collected data. Testing would need to be performed when the mine is not operating. Another pitfall of the method is that any acoustical impedance contrast may be interpreted as a void when it may be just a cracked interface or other geologic anomaly. Also, detection of the closest void will likely mask any that may lie behind it. Further, it is extremely unlikely that the technique will be able to distinguish between air- and water-filled voids.

Marshall Miller achieved limited success in detecting mine voids with the in-seam seismic method. In ISS Line 1, they appeared to identify the presence of a void although its specific location was approximate due to the irregularly shaped mine works adjacent to the seismic survey line. In ISS Line 2, the reflection data corresponding to the location of the mine void did not appear to be unique. Based on the stacked reflection data presented in figures 3 and 5, it appeared that stronger reflections occurred at a distance of approximately 400 feet rather than the identified zone at approximately 600 feet. According to Marshall Miller, variations in the channel wave velocities due to the angle of the mine workings and geologic factors significantly impacted the accuracy in mapping the void.

The peer review team members were also skeptical of the results. Dr. Robert Hardage agreed that the zones identified in figures 2 and 3 were indeed mine reflections, but questioned whether the particular reflections would have been selected if the position of the void was not known. In a blind test, or when searching for an unmapped mine void, the non-uniqueness dilemma would have made selection of the identified zone very difficult. A peer reviewer from the U.S. Army Corps of Engineers stated that "both air-filled and water-filled voids were detected with moderate success," and Mr. Peter Michael indicated, "I'm not impressed with the reflected signal from Line 2." Mr. Michael also questioned whether the reflection signatures would have been selected if the location of the mine was not already known. In fact, he noted a clearer pattern in the reflection data for ISS Line 2 beyond the researcher's highlighted curve.

Based on the results of the demonstration project, it appears that Marshall Miller Associate's in-seam seismic method provided limited success in detecting voids and discontinuities in coal seams. At best, in-seam seismic testing may be used to compliment current drilling programs by utilizing the data to design a targeted drilling program to confirm the presence and contents of mine voids.

If you have any questions, please contact me.

cc: M.T. Hoch - Chief, PS&HTC
P. Retzer - TS

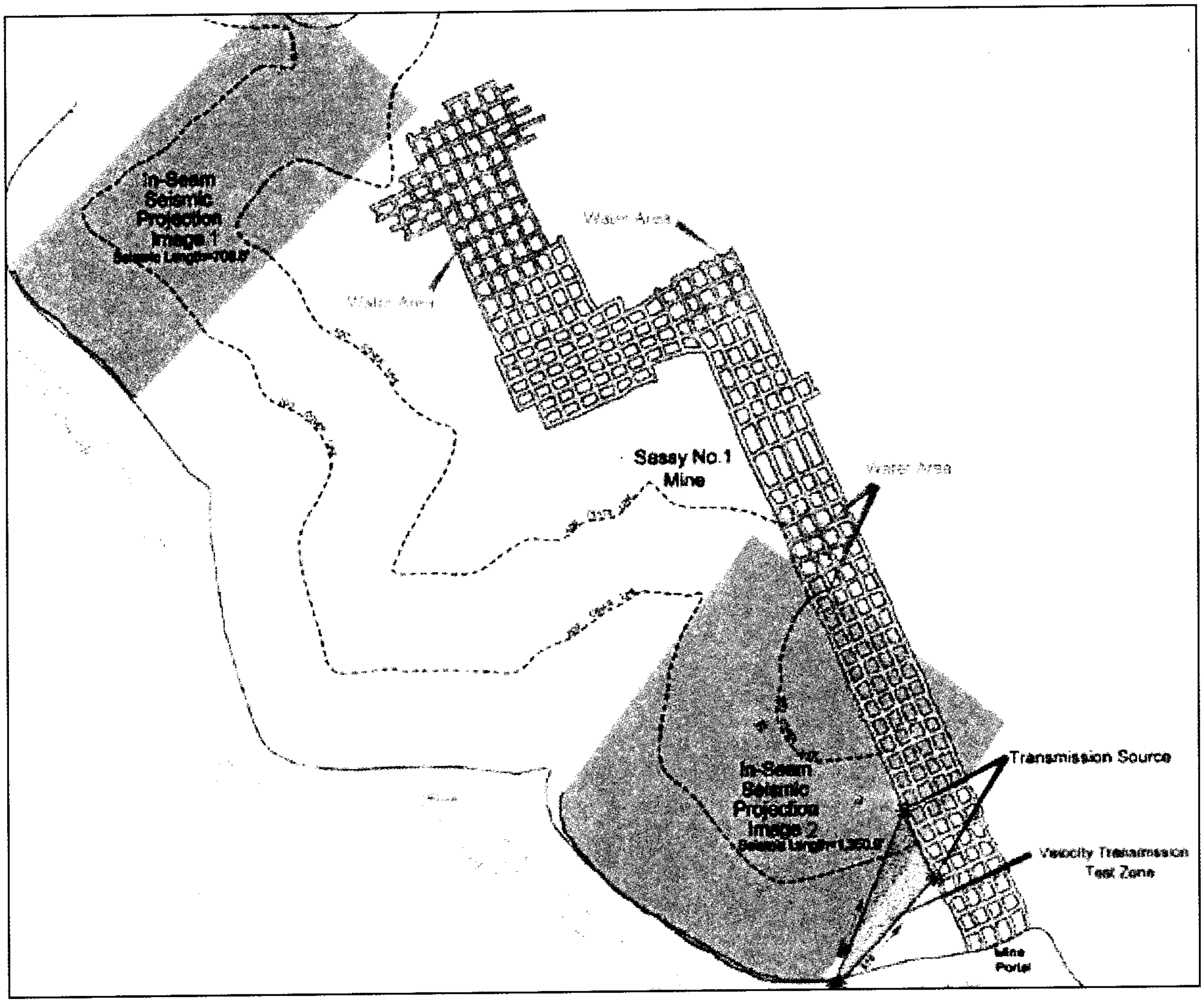

Figure 1: Plan view of the test layouts for ISS Lines 1 and 2. The ISS Line 1 is in the top of the figure and ISS Line 2 is at the bottom.

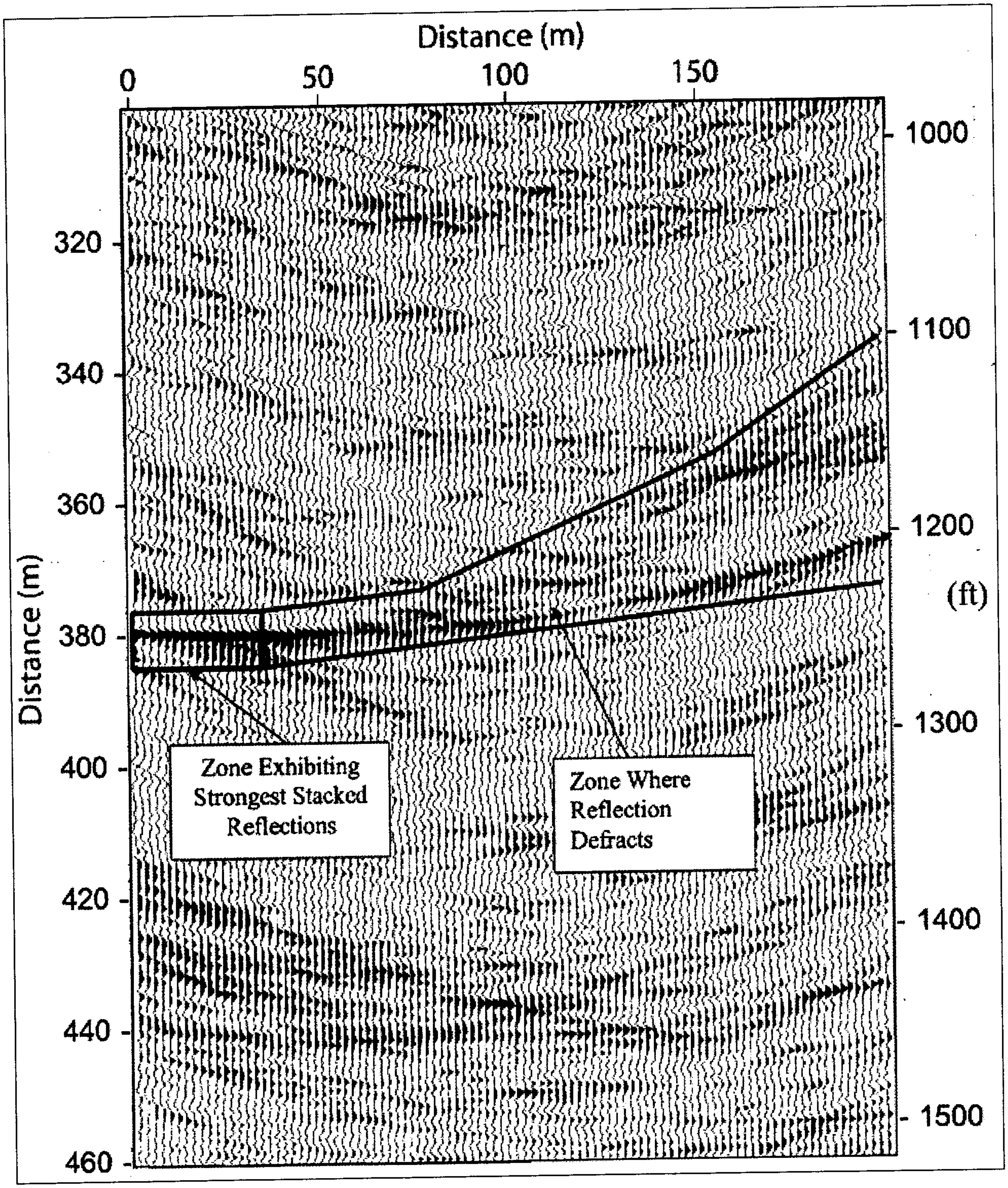

Figure 2: Stacked reflection images for ISS Line 1.

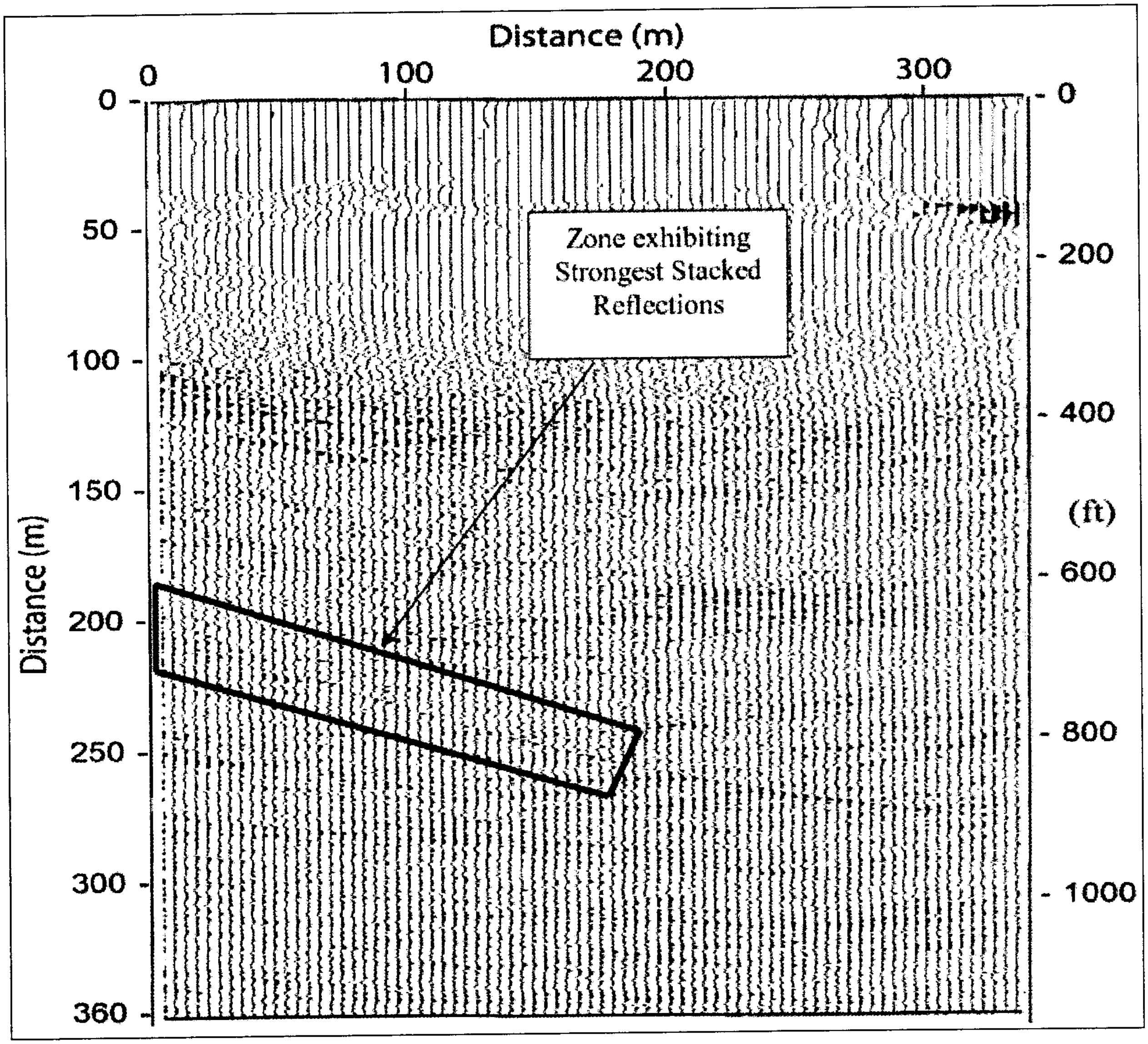

Figure 3: Stacked reflection images for ISS Line 2.

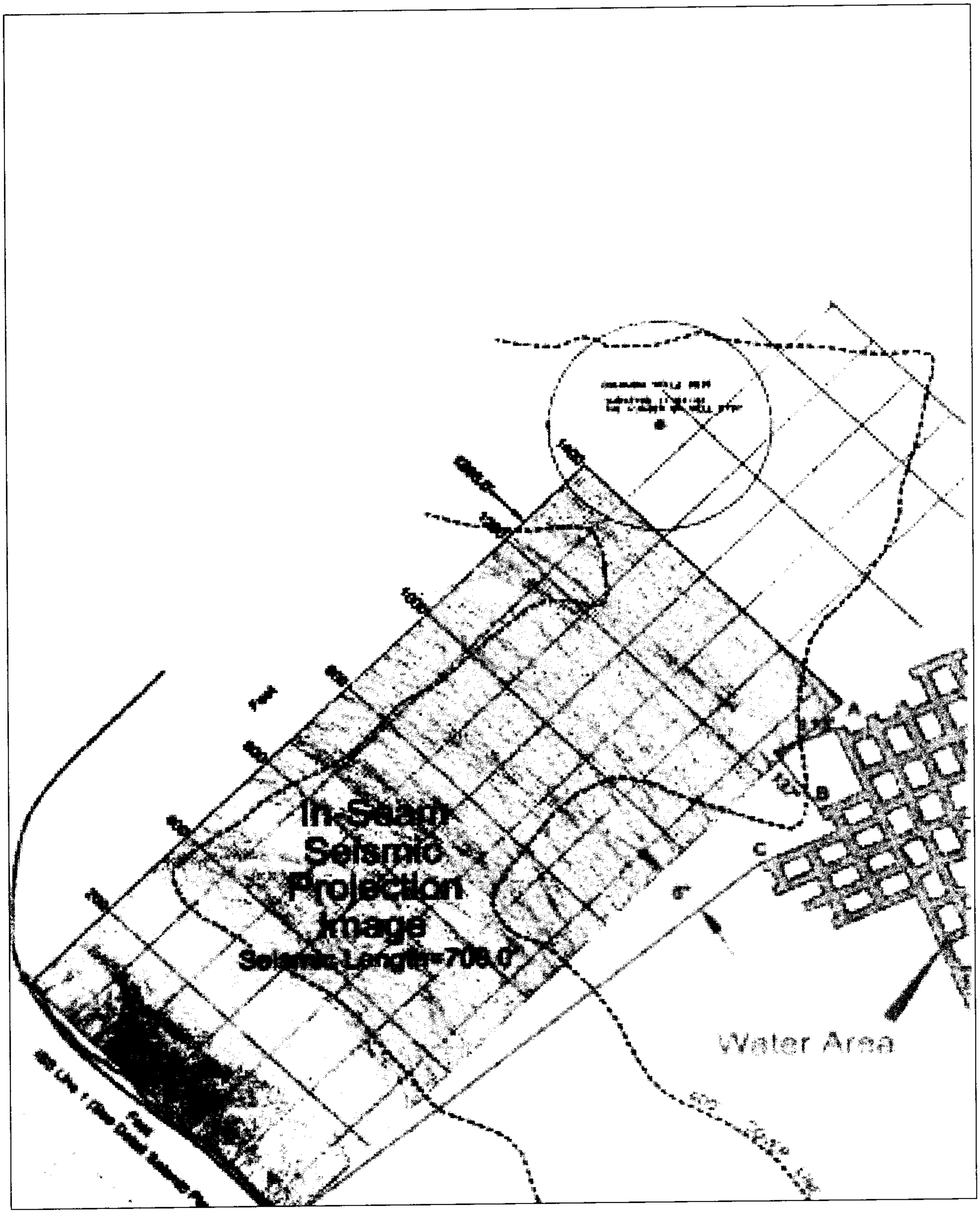

Figure 4: Full reflection image for ISS Line 1.

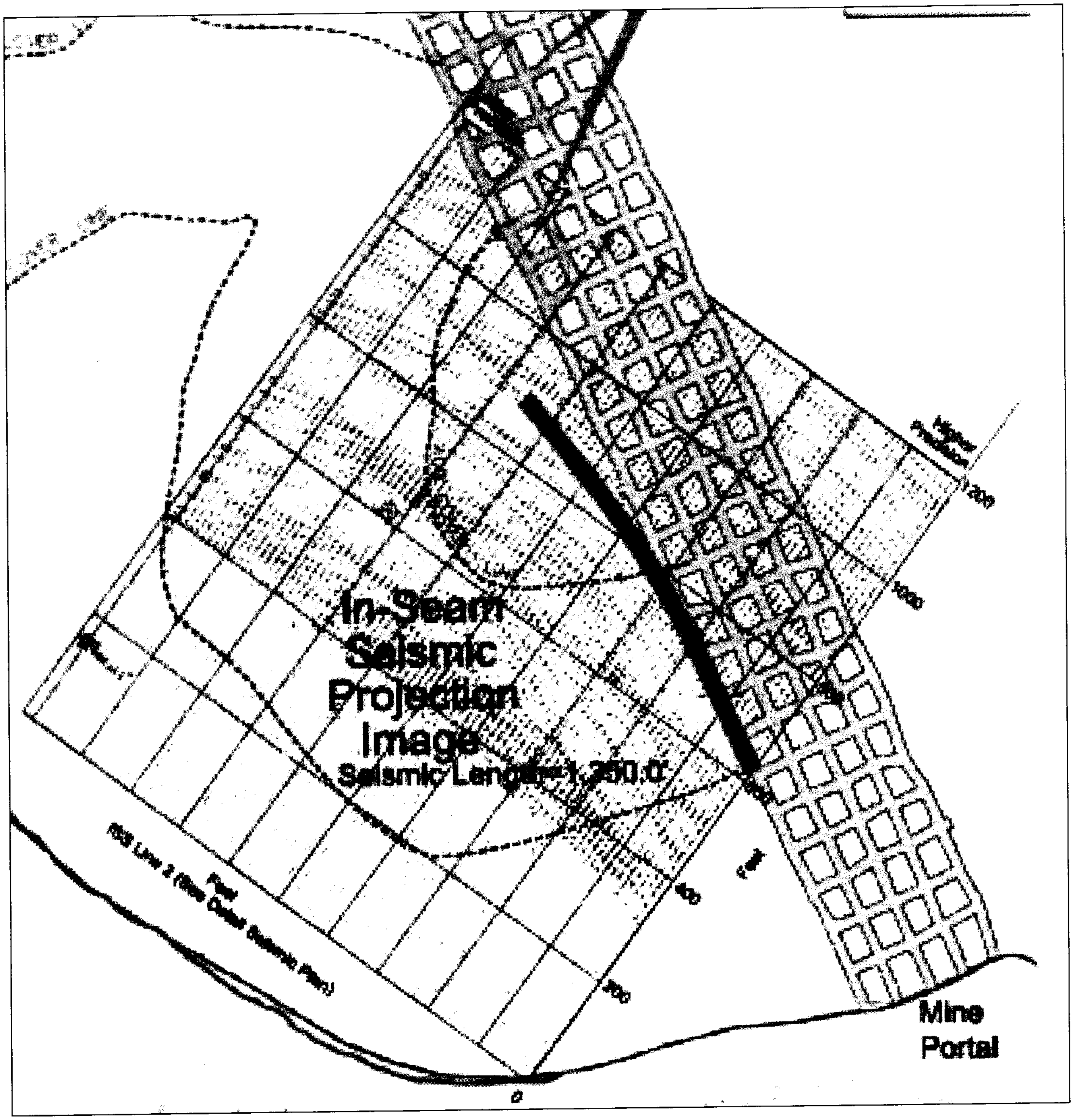

Figure 5: Full reflection image for ISS Line 2.