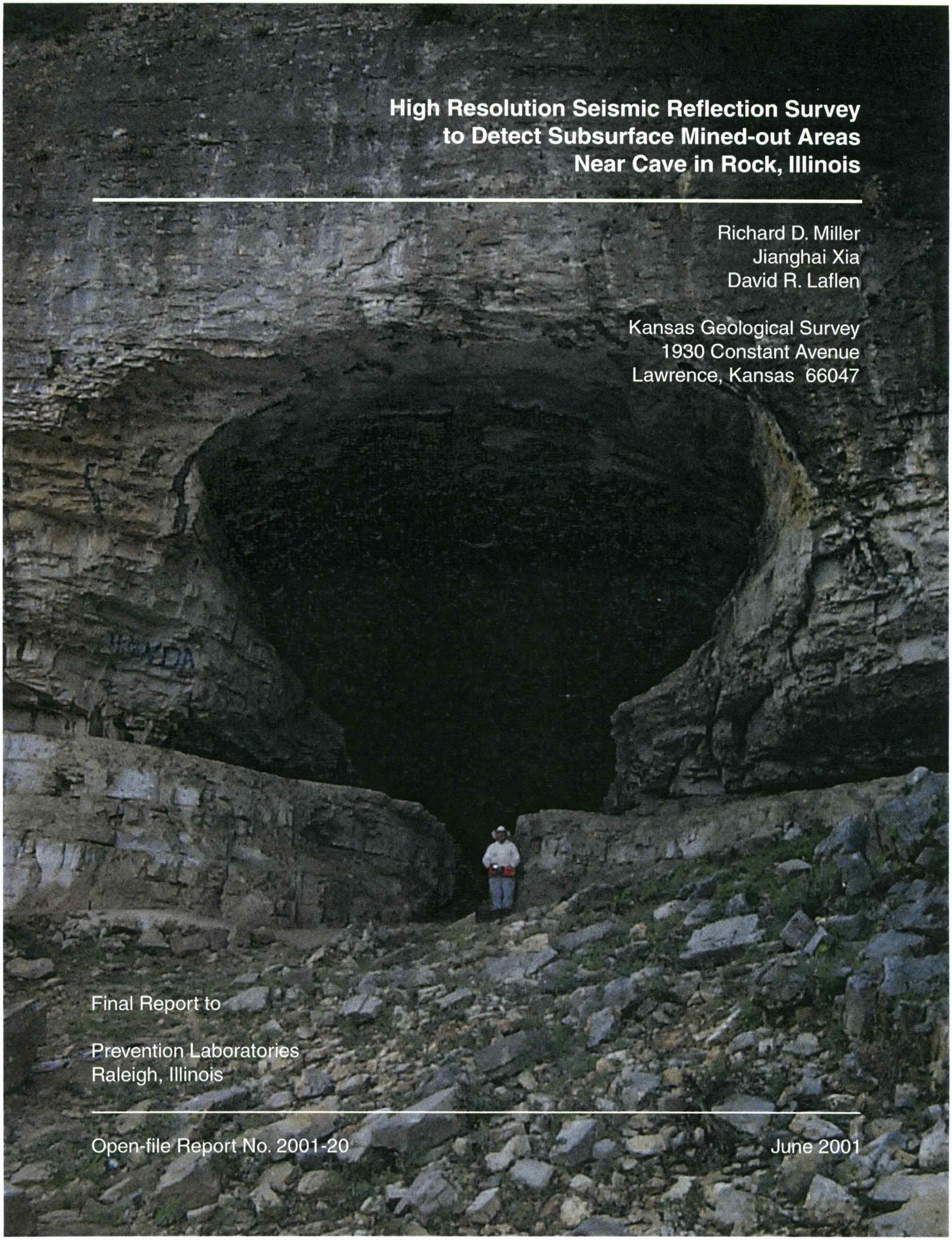

High Resolution Seismic Reflection Survey to Detect Subsurface Mined-out Areas Near Cave in Rock, Illinois

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Final Report to

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Project Summary

High resolution shear wave reflection profiling produced CMP stacked sections with features that are generally indicative of faults and/or factures. In this geologic setting these kinds of features could have easily provided the pathway for and therefore controlled the movement of mineralized fluids through the rocks and eventually acted as the host for the massive deposits of fluorspar, mined for decades through this part of southern Illinois. If geologic features of the type interpreted on these CMP sections have mineralized zones associated with them, they would have had a significant influence on local mining activities. It is therefore reasonable to suggest that if any byproducts of the mining process (drifts) exist in this area, they will be closely associated with these geologic features.

Scattered body and surface wave energy, offset in coherent events, wavelet attenuation, and hyperbolic arrivals (characteristic of diffractions) observed on stacked and some walkaway and shot gather sections are usually indicative of bed terminations, faulting, fracture systems, voids, and/or mine drifts. Considering all possible sources for these arrivals, the geology of this area, and available mine maps and historical information, specific locations along these profiles have been identified as reasonable candidates for drill investigations targeting old mineworks. Areas with the greatest potential for undermining will correlate to specific types of geologic features, which can be identified on seismic sections.

Acoustic characteristics observed in seismic data from this study are consistent with those observed in previous published work where high-resolution seismic reflection has been used to detect voids (Miller et al., 1990; Steeples and Miller, 1988; Miller et al., 1995; Miller et al., 1997). Considering the depth zones of interest (voids/mineworks) are below ground surface and the lack of a drill-confirmed void necessary for technique verification, it is not possible to suggest with complete confidence that any seismic patterns interpreted in these data are indicative of voids. It is, however, reasonable to interpret scattered, diffracted, and disturbed coherent energy arrivals as related to geologic features and/or conditions conducive to settings where mining might have taken place. It is possible diffracted/scattered energy is associated with old mine works and is therefore indicative of direct detection.

Introduction

Shallow, high-resolution seismic reflection represents a non-invasive method of imaging voids and faults in two and/or three dimensions. Shallow seismic reflection has effectively extended geometries and characteristics of faulted rock away from boreholes and surface exposures in previous applied research efforts. Enhancing vertical and horizontal resolution and signal-to-noise ratio has become a forefront area of applied shallow seismic reflection research and technique development. This applied research effort has emphasized both effective and accurate imaging of faults and voids potentially associated with mining that is known to be present in this general area, by optimizing resolution and signal-to-noise ratio. Step-by-step analysis and careful attention to detail and quality control clearly result in the highest resolution and signal-to-noise ratio possible at this site.

A properly designed and executed high-resolution seismic reflection survey may be capable of detecting and possibly delineating underground voids if surface and subsurface conditions are ideal. This study, which was concentrated in the southeastern tip of Illinois (Figure 1), used seismic reflection methods to detect (possibly directly but most likely indirectly) mine works in the fluorspar district of southern Illinois where mined-out areas were reported to be approximately 8 feet in height and extending as much as 150 feet laterally. Thus, although theoretically the height is significantly less than necessary for detection, the large lateral extent of these mined-out areas justified attempting to apply this technique to these targets. If these voids were directly detected, this effort would push ahead the practical limits of this method. On all three CMP profiles an interpretable seismic response was consistently observed that might correlate to geologic features that once were or currently are mineralized. The unique wave propagation characteristics (i.e., diffraction patterns and incoherent and discontinuous events) observed on the stacked seismic sections may be used to infer the existence of, and map the lateral extent of the mineralized zones. As stated in the proposal, there are no guarantees this method will directly or indirectly detect old mine workings in this geologic setting, and at this point it is not possible to confidently interpret the anomalous wave propagation characteristics without drill verification. Coherent scattered energy and offset incoherent events do provide a basis for inferring voids might be present directly beneath these profiles.

Five different sites were occupied during this study (Figure 1), each with uniquely different objectives: 1) initial walkaway test site was near area 471 where geology was defined by a series of previously drilled boreholes, 2) the downhole survey was conducted at a site about a

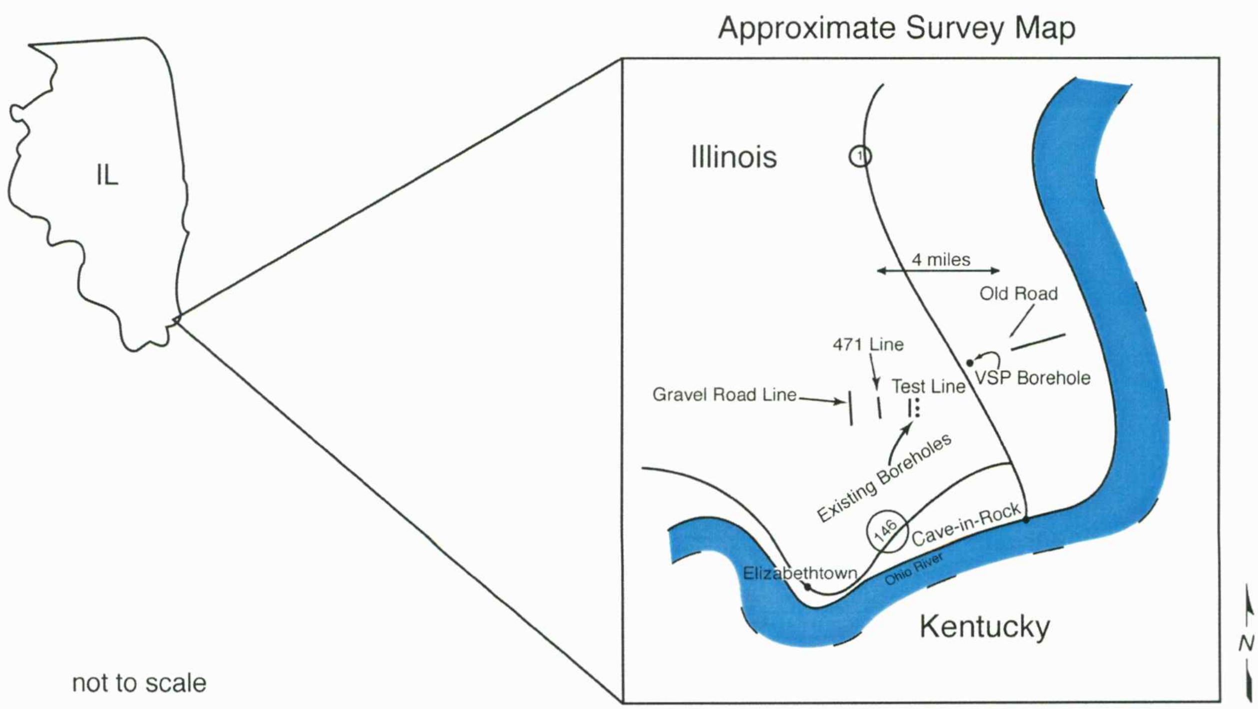

Figure 1. Site map with generalized location of various unique study sites.

quarter mile immediately east of the walkaway test area where a 400+ ft borehole was accessible, 3) the old road CMP profile was acquired along an abandoned road that ran approximately east/ west and was around a quarter mile north and east of the downhole survey site, 4) confirmation CMP data were acquired along a gravel road about ½ to 1 mile west of area 471, and 5) area 471 CMP line was acquired about a quarter mile west of the walkaway test area. None of the sites visited had drill-confirmed voids. Only the gravel road line had been proposed to have known mine voids running beneath it. A local man identifying himself as a former employee of the mining company provided location and orientation of the drifts relative to the gravel road line (westernmost profile). Inferences of void locations along the gravel road line are made based on interpretations of geologic features from the CMP section, which correlated to anomalies reasonably consistent with these purported locations and depths.

Increasing the number of seismic profiles originally proposed in phase 1 from two to three and expanding from a single test area to two different test areas was necessary to resolve access issues and to increase the opportunities to seismically investigate different mineralized zone characteristics with different near-surface conditions. This seismic reflection study focused on several specific as well as more general research objectives which included: 1) distinguishing mined areas from unmined areas, 2) identifying void areas at several different depth intervals (200 ft to over 350 ft), 3) mapping distinct stratigraphic layers and structural features related to the mineral deposits being mined in this area within the upper 1000 ft, 4) evaluating resolution potential (vertical and horizontal), 5) establishing optimum geometries and equipment, 6) near-surface variability and its effects on recorded data, 7) comparing the effectiveness of compressional vs. shear waves in detecting mined-out areas and lateral discontinuities in layers, and 8) necessary QC to eliminate artifacts and maximize data quality. Most of these objectives were met; however, without drill confirmation of interpreted seismic events it is not possible to appraise to what degree the primary goal—determining the utility of state-of-the-art shallow high resolution seismic reflection techniques to detect, delineate, and aerial map mineworks in this area—has been met.

After an extensive series of walkaway test, it was empirically confirmed that shear waves provide better resolution in this setting. VSP data were acquired and processed initially to establish a Vp to Vs ratio for the rock layers of interest. Considering the much slower seismic velocities of shear waves relative to compressional waves and the insensitivity of shear waves to material within the pore spaces of the rocks and voids, it was obvious during in-field analysis that shear waves should be the focus of any production test lines.

Proven high-resolution techniques were used to design data acquisition parameters and determine optimum equipment and methodologies (Steeples and Miller, 1990). Maximizing the resolution potential and signal-to-noise ratio was emphasized throughout this survey. Continuous common midpoint (CMP) profile lines were acquired using a conventional roll-along approach maintaining 96 live recording channels within the optimum offset (Hunter et al., 1984). The seismic source, geophone type, spread geometry, shots/point, and acquisition philosophy used to acquire the CMP profile lines were based on the results of walkaway noise tests and downhole survey.

Simulations designed to show the detectability, and in some cases, resolvability, of tunnels and voids have never been experimentally verified to the degree predicted by modeling (Rechtien et al., 1995). It is, therefore, only reasonable to suggest voids left from mining activities can be directly interpreted on high-resolution seismic reflection data only after ground truth verification of void seismic signatures. A "rule of thumb" for shallow void detection using seismic reflection methods suggests a minimum void diameter to depth ratio of 1 to 10 for direct detection. As stated in the proposal, based on this generally accepted axiom, a void 250 feet below the ground surface must be at least 25 feet in diameter for direct detection using surface seismic reflection methods. However, seismic wavetrain interference originating at features related to mineralization could be used to focus in on voids significantly smaller than theory predicts for direct detection.

Program Phases

Phase one (testing phase) included comparison tests of compressional and shear wave sources using a walk-away evaluation format and downhole VSP with ground truth provided by 3-C. The signal attributes were compared for the various seismic sources with general data characteristics used to provide a portion of the information necessary to evaluate the overall potential of high-resolution seismic reflection techniques to successfully achieve the objectives of this study. The downhole survey was critical to accurate event identification on walkaway gathers, acting as ground truth for confident velocity/depth determinations, preliminary event identification, and correlation of reflections with reflectors on the stacked sections. All walk-away tests, the downhole survey, and preliminary in-field data analysis were accomplished through the cooperative activities of Kansas Geological Survey personnel and Dr. John L. Sexton. It was determined that data of sufficient quality to meet the objectives of this survey could be obtained using the shear wave vibrator recorded into a 96-channel rolling spread with 4 ft receiver and 8 ft source spacing. Based on test data, specific parameter selections for acquisition and general parameter determinations for processing could be estimated, with sufficient confidence to justify the study moving on to phase two.

Phase two included the acquisition and processing of three common midpoint (CMP) profiles, one over a "known" mined-out area and two over areas suspected of being mined-out. The three profiles collected during phase two totaled over 3800 linear feet of profile. Originally, two profiles were proposed, each approximately 2000 feet in length. It was also originally suggested that 5 ft geophone group spacing and 10 ft source point spacing would be the likely station intervals, but after on-site testing the spacing was reduced to 4 ft receiver and 8 ft source. The resulting total number of shotpoint exceeds the number proposed for the number of field days budgeted. Success of this method in detecting voids of the type described here can only be fully appraised with drilling. Therefore, the study has not moved onto phase three as detailed in the proposal, pending agreement by both the KGS and Prevention Labs representatives that the method is providing accurate results.

Phase three of this program, if requested by Dr. Douglas of Prevention Labs or his authorized representative and agreed to by KGS staff, will involve the acquisition and processing of several profiles deployed in a 2½-D grid designed to delineate the aerial extent of the undermined region. This phase would commence at a mutually agreed upon time and would be dictated by the findings of phase two and associated confirmation drilling. Data for phase three, if initiated, will be acquired as part of a separate mobilization.

Geology and Target

The Cave in Rock fluorspar district is located in southeastern Illinois, a few miles north of the town of Cave in Rock on the Ohio River (Figure 1). The mineralized fluorspar deposits in this part of the fluorspar district generally occur as bedded replacement deposits rather than as the vein deposits prominent in the Rosiclare area. Mineralization along the contacts between formations (see stratigraphic column below) apparently occurred from solutions filling any openings or easily replaced zones; formation contacts seem most susceptible to this depositional process. Larger mineralized zones may include parallel deposits with an occasionally much shorter side branch, which, when combined with other short branches, may extend several hundred feet. Faults, often associated with these deposits, generally have offsets less than 10 feet.

The geology of the area approximately 1 mile north of the field site consists of approximately 20 feet of alluvium overlying a sequence of sandstone, limestone, and shale. A stratigraphic column at this site (hereafter called the main stratigraphic column site) possesses the following geologic sequence:

Depth (feet)		Unit	Thickness (feet)
		Alluvium	20
20		Tar Springs Sandstone	80
100		Glen Dean Limestone	60
160		Hardinsburg Sandstone	120
280		Haney Limestone	50
330		Frailey's Shale	100
430		Cypress Sandstone	55
485		Ridenhower Shale +Sandstone	30
515		Bethel Sandstone	70
585	1st Mine Level	Downey Bluff Limestone	30
615		Yankeetown Shale	15
630	2nd Mine Level(?)	Shelterville and Levias Limestone	30
660		Rosiclare Sandstone	20
680		St. Genevieve Limestone	150
700	3rd Mine Level (?)		
730		St. Louis Limestone	400
850	4th Mine Level(?)		

Although this site is a bit distant from the seismic lines, the geology is given to provide a regional viewpoint and for contrast to the geology of the areas where the seismic lines were located. Change in mine depth and therefore target depth over this very short distance is of particular interest and allows inference of dip or topography changes.

The first mine level near the location for which the stratigraphic column applies is approximately 585 feet deep. The mined out areas may average 6-8 feet high. Other *possible* mining levels are at depths of 630, 700, and 850 feet. These deeper mining levels are possible but not confirmed at this location. Clearly the mineralization has significant vertical movement across multiple competent rock boundaries. This is very likely indicative of fault or fracture control of vertical fluid movement. It is therefore reasonable to assume that where multi-layer mineral deposition is observed, such as at the stratigraphic column site, fault or fracture zones are likely acting as pathways and therefore strongly controlling the mining process.

Study Areas

Seismic Line 471

This area was selected based on its proximity to and confidence in the locations of known undermining, depth to the target, and site logistics. This site has a series of boreholes that trend approximately north/south with a well-defined subsurface geology. No mines have been encountered during drilling in this area, but old mineworks are mapped immediately north and west of the property line. The walkaway profiles were acquired along a segment connecting these 3 or 4 borings and approximately a quarter mile east of the seismic profile named "471." This pastured area possessed a rolling topography cut by drainage ditches and creeks.

Undermining is suspected in this area, but has never been confirmed. Mineralization is significantly shallower in the 471 area than observed at the previously described type section area. In the 471 area, which was the location of the first planned production seismic line, the first potential mine level is estimated to be at a depth of approximately 200 to 250 feet below ground surface. Unlike the previously described main stratigraphic column site, the near-surface geology at area 471 is characterized by a 15 ft thick residual soil layer overlying Frailey Shale. The entire upper portion of the section (alluvium down to and including the Haney Limestone) present at the type section site to the north is missing in the 471 area. Other possible mining levels at this site likely range between 300 to 400 feet below ground surface. The primary target was the first mining level.

The stratigraphic column for area 471, location of the walkaway tests, VSP, and production line 471 includes the following sequence:

Depth (Feet)	Unit	Thickness (feet)
	Residual soil	15
15	Frailey shale	35
50	Cypress sandstone	55
105	Ridenhower shale /ss	30
135	Bethel sandstone	70
205 1st Mine Level (200ft)	Downeys Bluff ls	30
235	Yankeetown shale	15
240 2nd Mine Level (245ft)	Shetlerville/Levias ss	45
285	Rosiclare sandstone	20
305	St. Genevieve ls	150

Old Road Seismic Line

Immediately north and east of the VSP site is an abandoned east/west road with known to have had mining activity just to the north. No drill data exists within a half mile of this location but, based on old mine maps, incursions from the north are possible and would cross beneath this road.

This production seismic profile was located approximately one mile south of the main stratigraphic column site and half to three-quarters of a mile east and north of the stratigraphic profile of area 471. The first mined-out zone at this location is expected to be at a depth of approximately 350 ft. The stratigraphic column at this site is expected to fall somewhere between the main stratigraphic column site and area 471 stratigraphic column, as previously discussed. The soil layer along this site was thin to non-existent in some areas. Limestone outcrops at low water crossing of creeks is likely the Haney Limestone. Residual soils are a sandy-clay, with road materials and organics present in the upper 3 ft. The old road had not been maintained for many decades and therefore was more a path through the timber than a road. Clearing of scrubs and sprouts and filling in ditches allowed the tractor-mounted vibrator to move down the line somewhat unimpeded. Data were acquired along a 1600 ft transect of the road which had several feet of rolling hill relief.

Gravel Road Seismic Line

With the critical need for ground truth, a profile along the first all-weather gravel road immediately west of area 471 was run that straddled two drifts reported by a former mining company employee to pass beneath the road at nearly right angles. The profile was acquired over a geologic setting that was stratigraphically similar to the other profiles. Based on regional dip it is likely that the first competent rock layers would have been either Frailey Shale or Haney Limestone. Even though this line is a bit further west than area 471, it is topographically higher and therefore, stratigraphically, rock units are likely about the same depth below ground surface.

The source and receivers occupied the gravel road or road ditch. The planting conditions were poor, but the source coupling was quite good. Based on personal communication (Dr. John Sexton), a pair of shafts runs beneath the road at or around station 180. The separation between these shafts was speculated to be several hundred feet. This line was about 1600 ft as well, with the speculated locations of the drifts in the middle of the profile. After this line was collected and the acquisition efforts moved to area 471, it was suggested that mine maps revealed another portion of the gravel road immediately south of the end of the gravel road line that was undermined as well. Data from the gravel road line did not extend far enough to image the portion of the subsurface where these mineworks would have been located.

Seismic Reflection Philosophy

Critical to the success of any high resolution seismic reflection program is the conscious and meticulous checking and verification that all parameters and procedures are appropriate for the enhancement of signal and attenuation of noise. Unequivocal identification and verification of reflections on shot gathers is not only necessary, it is mandatory for meaningful interpretations of shallow seismic data. Matching modeled normal moveout (NMO) curves based on borehole velocity information with reflection hyperbola interpreted on shot gathers is the most conclusive means to both verify and analyze reflections. This combination incorporates ground truth (borehole velocity), geometric curve fitting (forward and inverse modeling), and event identification directly from single-fold shot gather data. Data from this project has undergone rigorous verification techniques that include modeling, event verification, and cross comparisons of borehole and surface seismic.

Quality Control (QC)

QC is critical and was continuous throughout acquisition, processing, and interpretation of these data. Near-surface inconsistencies, vehicle noise, an extremely narrow and changing optimum recording window, and poor receiver coupling conditions required strict compliance with acquisition QC guidelines and meticulous monitoring of data, an absolutely essential aspect of the data acquisition. Based on subtle changes in the near-surface, minor adjustments to some parameters (e.g., source-to-near offset) were necessary to maintain the optimum recording window (Hunter et al., 1984). The seismograph CRT display was continuously monitored to insure the vibrator pilot trace maintained appropriate amplitude levels and frequency content. This monitoring process was necessary for every sweep of the vibrator to insure ground coupling was not compromised and to track operational consistency in the equipment.

Real-time graphical display of noise levels allowed for the continuous monitoring of cultural, air traffic, and vehicle traffic noise as well as cable-to-ground leakage and geophone plant quality. After each geophone was planted, it was checked to insure the cable-to-ground resistance was greater than 5000K ohms while individual geophone continuity was required to be within 5% of nominal string impedance (including consideration for cable offset). As well, each geophone underwent a modified tap and twist test. No shot was recorded if background noise voltage levels on active geophones were greater than 0.05 mV. The ability of the seismograph to real-time monitor noise levels, signal quality (through digital filtering), and unacceptable geophone plants as well as the roll switch's built-in earth leakage and continuity meters all but eliminated the chance a recorded shot was not maximized for the site and equipment.

Walkaway Testing and Vertical Seismic Profile (VSP): Phase One

Unique shallow data characteristics at this site demonstrated the utility of a good testing program. Pre-survey speculation about the optimum parameters and equipment proved to be only partially correct and demonstrated the critical need to have a sizable repertoire of acquisition equipment available for testing. A shallow seismic reflection program needs to be tuned for the acoustic and logistical conditions of the particular site. As previously stated, identification and confirmation of reflection hyperbola on walkaway noise tests was essential and best accomplished through mathematical curve fitting, matching to borehole-derived velocity structure, and observation of file-to-file consistency. Walkaway noise tests were designed to oversample the subsurface horizontally, with source-to-farthest-receiver-offset equivalent to or greater than the primary depth of interest. This approach allows all aspects of the full wave field (especially the reflections) to be thoroughly appraised.

The primary intent of these walkaway noise tests was to allow as meaningful a comparison of various source, receiver, and instrument settings and configurations as possible. Principally the evaluation criteria focused on each component or parameter that affected the signal-to-noise ratio and frequency content. Walkaway tests are ideally suited for the identification of individual events within the full wavefield. Phase velocity and wave types are two of the most important pieces of information extractable from walkaways. The relationship of velocity and wave type to spread geometries and offsets was completely analyzed and was the basis for the selection of acquisition parameters and equipment (Pullan and Hunter, 1990). Assumptions or partial analysis of key properties could have easily resulted in artifacts or improperly recorded data at this site. Processing of walkaway data for this study focused on trace organizing by offset and gain balancing to achieve spectral uniformity. Walkaway data from each source configuration or comparison parameter was preliminarily processed and analyzed in the field prior to acquisition geometry and equipment selections.

The evaluation/feasibility portion of the study (phase 1) allowed analysis of acoustic characteristics and, more generally, the reflection method, which in turn permitted accurate estimations of resolution and optimization of acquisition equipment and parameters. Walkaways consisted of source-to-receiver offsets ranging from 4 ft to approximately 480 ft (Figure 2). A total of 120 receivers were planted on a uniform 2 ft grid (Figure 2). Source testing included the 8-gauge auger gun (Healey et al., 1991) (requiring only class C explosives) (Figure 3), 50 cal downhole projectile (Figure 4), IVI Minivib w/mass transverse (Figure 5), 12 lb hammer and miniblock shear wave source (Figure 6). It was the intent of these comparisons to allow the optimization of the source, source configuration, and source geometry for the near-surface conditions, target depth, resolution requirements, and environmental constraints of this site. Each source was evaluated with as near equivalent conditions and parameters as possible. Experience with source testing (Miller et al., 1986; Miller et al., 1992; Miller et al., 1994; Doll et al., 1994) greatly enhanced both the quality and the efficiency of source evaluations at this site.

Custom built geophones used during the testing phase included triple 10 Hz Mark Products UltraPhones (U2) wired in series for compressional wave surveys (Figure 7) and single 14 Hz Geospace GS-11 transverse geophones for the shear wave surveys (Figure 8). These geophones provide optimal output for these coupling conditions and for the signal transmitted through this near-surface material. VSP data were recorded with a three-component hole lock, borehole geophone assembly that was lowered down the borehole and locked to the borehole walls by a mechanical spring-loaded arm electrically controlled from a control box on the surface

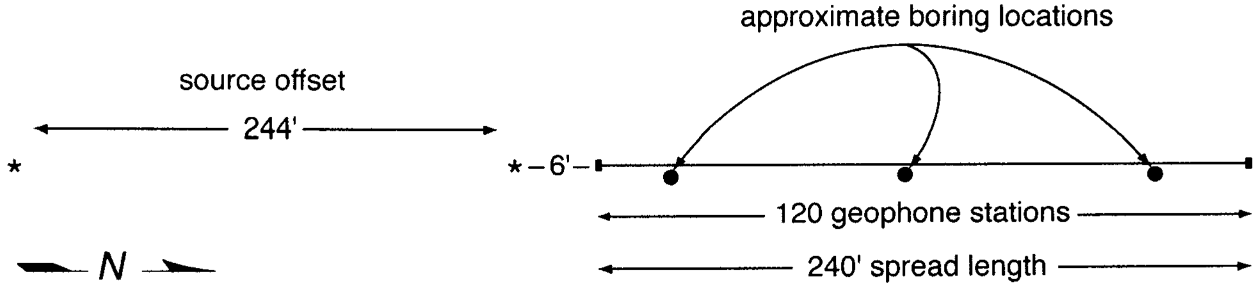

Figure 2. Diagram of walkaway testing source and receiver configuration.

Figure 3. Auger gun (12 gauge and 8 gauge).

Figure 4. Loading 50 caliber downhole seismic source with 750 grain projectile.

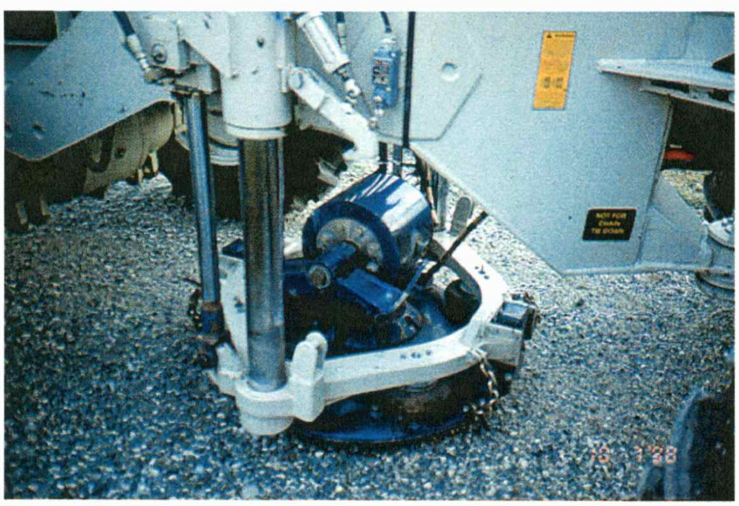

Figure 5. IVI Minivib in SH mass configuration.

Figure 6. Vehicle holding down shear wave block with steel endplates and teeth for ground coupling.

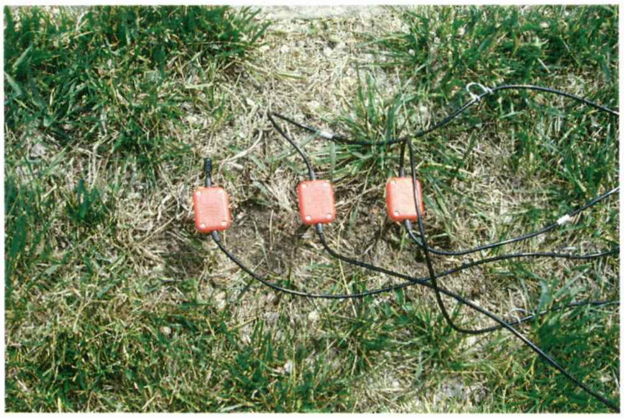

Figure 7. Triple 10 Hz UltraPhones planted in a 2 ft array.

Figure 8. 14 Hz shear wave geophone with level bubble.

(Figure 9). The need for a strong signal from geophones with a high spurious noise threshold is paramount, and from previous experience lower quality geophones would not have produced the desired output within the desired frequency band. A variety of receivers and sources were available for on-site experimenting but were not tested after the in-field analysis of initial signal characteristics from sources and receivers that were tested and eventually used for the CMP portion of the program. Pre-test estimations of data characteristics were consistent with actual findings and allowed for the optimization of the testing procedures.

All the data were recorded on a set of Geometrics StrataView seismographs (Figure 10). These PC-based seismographs possess a dynamic range sufficient to exceed the ground's ability to shake elastically. Only 96 channels of the system's available 240 channels were used during this study. This reduction in channel number was possible as a result of the field geometry and optimum recording window of the target reflections at this site. A "roll-along" switch was used to keep the 96 recording channels at a fixed distance from the source as the spread progressed along the survey line. Data were recorded on hard disk in SEG2 format and then transferred to CD, were it was saved in both SEG2 (native to the seismograph) and SEGY (an industry standard format) data format. The entire data set with digital field notes was then sent to Dr. John Sexton.

Shear wave data acquired from the walkaway spread using the vibrator provided an excellent look at the wavefield and its particular propagation nuances at this site (Figure 11). Since two source offsets were used, a slight suture where the two spreads were digitally joined is evident on the gathers. Offsets are, however, uniformly changing at each trace across the entire 480+ ft of spread length. Several features are of particular interest at this site. Probably one of the more pronounced features on this particular gather is the backscattering of surface waves that can be observed at about 700 msec of depth and about halfway across the section. Consistent in general characteristics with this backscattered event is another similar feature near the very northern edge (486 ft offset) of the gather at a depth of about 400 ft. This event is likely backscatter of the refraction or guided wave. These features are approximately beneath the same receiver station, just arriving at different times at different source offsets. Upon preliminary review of these features it is likely these are related to point or line source scattering. They could be indicative of fault, fractures, or voids. They do not appear to extend to the surface and, based

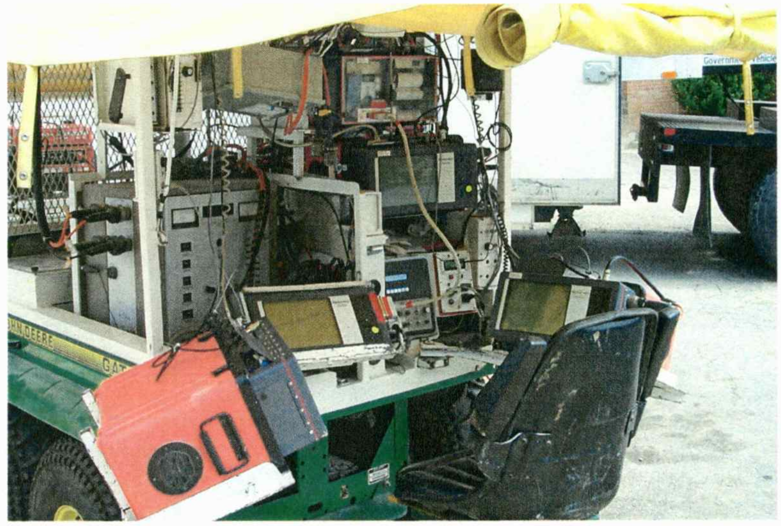

Figure 9. Three-component downhole geophone with band partially extended.

Figure 10. Four 60-channel Geometrics StrataViews networked with a 240-channel roll-along switch, IVI Vib controller, time break conditioners, line checker, VHF radio, and powered by six deep-cycle marine batteries.

on the apex of the diffraction-like hyperbola, are features with expression on the bedrock surface and likely extend downward from there.

Compressional wave data acquired during the walkaway tests included both the 8 gauge auger gun and 50 cal downhole as sources, with the auger gun providing data with the more preferred characteristics (Figure 12). Scattering phenomena observed on shear wave data is not evident on compressional wave data. Direct wave and refractions possess velocities in the 8,000 to 15,000-ft/sec range with no reflections easily interpretable. A strong Raleigh wave packet is obvious on the gather. This, coupled with the presence of several guided wave cycles and a strong air-coupled wave, inhibits the enhancement of reflected body waves. After significant preliminary processing it was not possible to identify high confidence reflections within the upper 100 to 150 msec. It is within this shallow time window that reflections from the upper 700 to 800 ft will occur at this site. With little or no reflected energy interpretable on this gather, and with the advantage shear wave reflection surveys have in terms of resolution potential, the emphasis of phase one shifted toward shear wave imaging.

Both the compressional and shear wave walkaway gathers possess very interesting dispersion phenomena arriving after the initial surface wave energy (Figures 11 and 12). At first blush there appear to be reflection hyperbolae coming asymptotic to the fundamental surface wave arrivals (Figure 13). These arrivals possess NMO velocities ranging from 400 to 600 ft/sec, values that are well within a reasonable range for unconsolidated shear wave velocities. It could be easily assumed that all arrivals before ground roll are mode converted compressional and

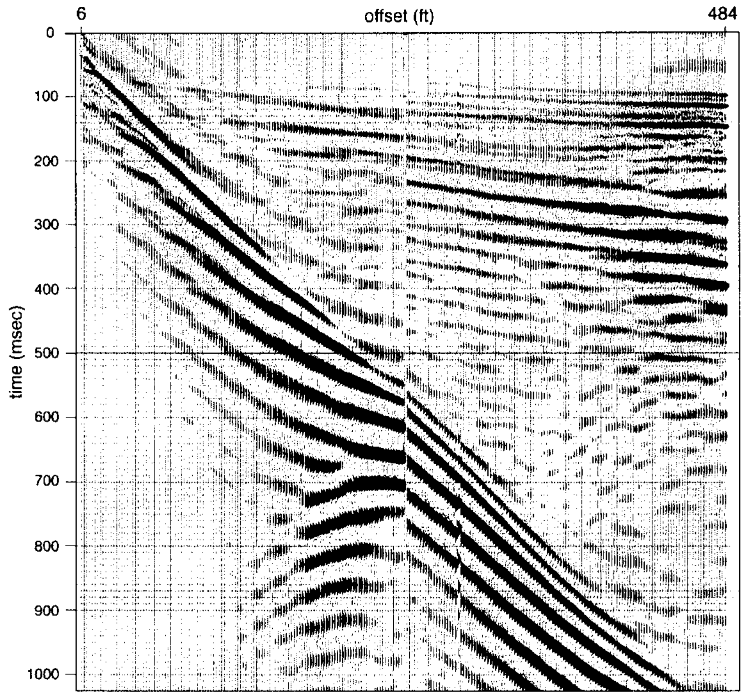

Figure 11. Walkaway shot gather of three sweeps from the shear wave vibrator vertically stacked. The scatter phenomena are easily interpreted on this seismogram.

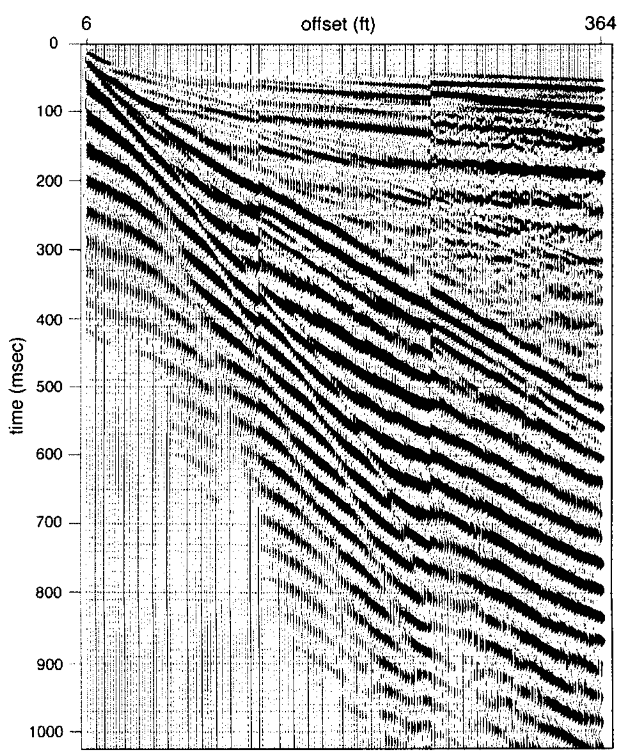

Figure 12. Compressional wave shot gather from the 8-gauge downhole gun.

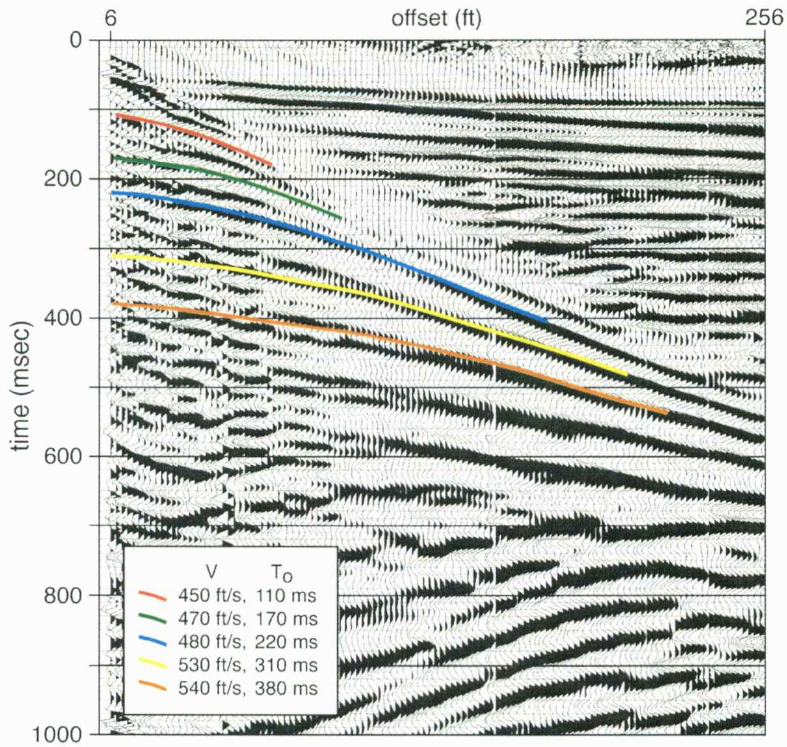

Figure 13. NMO velocity curves superimposed on the shot record.

these hyperbolic events are reflections and, with that interpretation, they become the focus of enhancement processing. If enhancement processed, they would stack coherently on CMP sections. This ground roll energy would result in coherent events within the upper 500 msec that would appear to represent about the first 400 to 500 ft of earth, but in reality have absolutely no correlation to the geology in that depth range at all. In reality these coherent events are stacked ground roll constrained completely to within the upper 15 ft. Interpretations based on sections composed in this fashion would be completely wrong with no relationship between the seismic images and the earth at the inferred depths.

Looking at these data a bit more skeptically (a practice that is always recommended for shallow high resolution seismic reflection data) and considering realistic velocities for this unconsolidated soil over a limestone, sandstone, and shale sequence, interval shear wave velocities below 15 ft should be in the range of 3000 to 9000 ft/sec. Considering the potentially very low unconsolidated shear velocity (as low as 200 ft/sec), average velocities for the upper 400 ft at this site should range from 1000 ft/sec or so in the upper 50 ft increasing to 2000 ft/sec around 250 ft and then up to 4000 ft/sec at depths around 500 ft. With this in mind, the apparent NMO velocity values for the hyperbolic events arriving after the fundamental surface wave cannot be reflections. Based on curve fitting of model hyperbola with the real data, real reflections from geologic interfaces within the upper 500 ft must be present beneath the high amplitude guided wave which are prevalent on the raw walkaway shot gather between the refractions and surface wave arrival (Figure 11). Processing to enhance the higher frequency and lower amplitude nature of reflected energy can most effectively be done in this shot gather format using a simple spectral balancing routine (band-limited spiking decon) (Figure 14). A series of hyperbolic events are evident on the spectral balanced version of the walkaway shot gather that would be consistent with the layered type of geology interpreted to be present beneath this site.

Model NMO curves generated as a best fit for the curved arrivals (potential reflections) on the spectral balance walkaway gather overlay the real data quite nicely (Figure 15). Based on these curves and their match to the real walkaway data only, it appears reflectors as shallow as 50 ft and as deep as 550 ft should be imageable at this site with this method and field configuration (Table 1). Using the model curves as the basis for selecting NMO velocity corrections on production gathers minimizes the possibility of mis-identifying surface waves as reflections on CMP stacked sections. From analysis of these test data, it is critical that all energy arriving at or after the fundamental mode surface wave be surgically muted to avoid interference with reflections.

Table 1

To (msec)	Vnmo (ft/sec)	depth (ft)
55	42	12
90	1750	80
125	2000	125
155	2500	195
187	3000	280
202	3500	355
246	4000	490

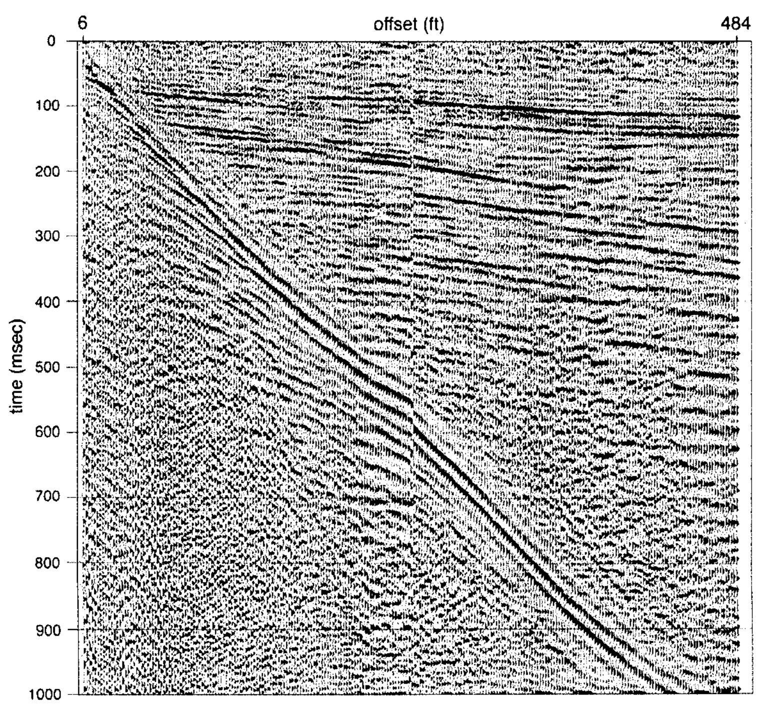

Figure 14. Walkaway shot gather spectral balanced to enhance all energy across the 15 Hz to 150 Hz sweep range.

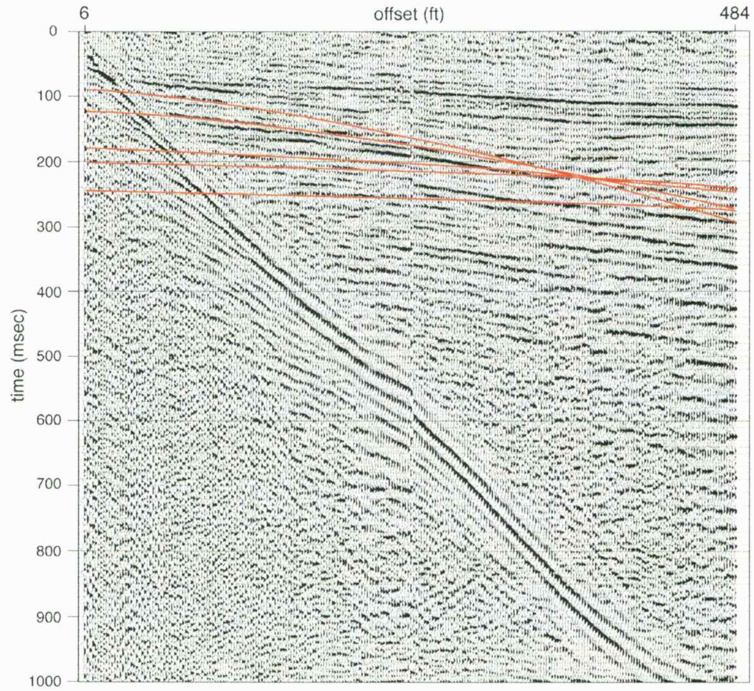

Figure 15. Figure 14 with model NMO curves superimposed onto gather. Depth and lithology interpretations are consistent with these arrivals (Table 1).

Confirmation and verification of the observations and interpretations of reflections, refractions, and surface wave energy can only be done with direct measurements in a borehole. By matching modeled NMO curves based on borehole velocity information with reflection hyperbola interpreted on shot gathers geology can be inferred with confidence. Since VSP data were acquired with a 3-component downhole receiver, even though a shear wave directional source was used, shear (Figure 16) and compressional (Figure 17) first arrivals can both be extracted from the recorded data. Analysis of the VSP data will be limited to first arrivals for this phase of the project. From first arrivals estimations of interval and average velocities as well as identification of some lithologic boundaries can be made from the VSP data with only minor processing. Based on these downhole data it is possible to correlate geology (derived from borehole logs) and associated mine depths to the two-way travel time and wiggle trace representation of the subsurface in this area (Table 2).

From calculations of long offset refraction/first arrival velocities on both compressional and shear wave data sets it is clear that mode conversions are occurring at the boundary between the residual soil and Frailey Shale (Figure 15). Long offset refraction velocities are approximately the same on both P and S walkaway gathers. Onset of first breaks is about double on the S as compared to the P at these longer (>300 ft) source-to-receiver distances. This is a characteristic of mode-converted energy that has been observed on shear wave refraction profiles when the orientation of the profiles has not been parallel to dip (Xia et al., 1999). With this observation, the final apparent discrepancy between in the seismic data relative to geology is resolved. In general, the Vp to Vs ratio is around 2 to 2.5 to 1 in the consolidated rocks and 5 to 6 to 1 in the unconsolidated sediments. Considering all the data—drilling, logs, seismic, and historical

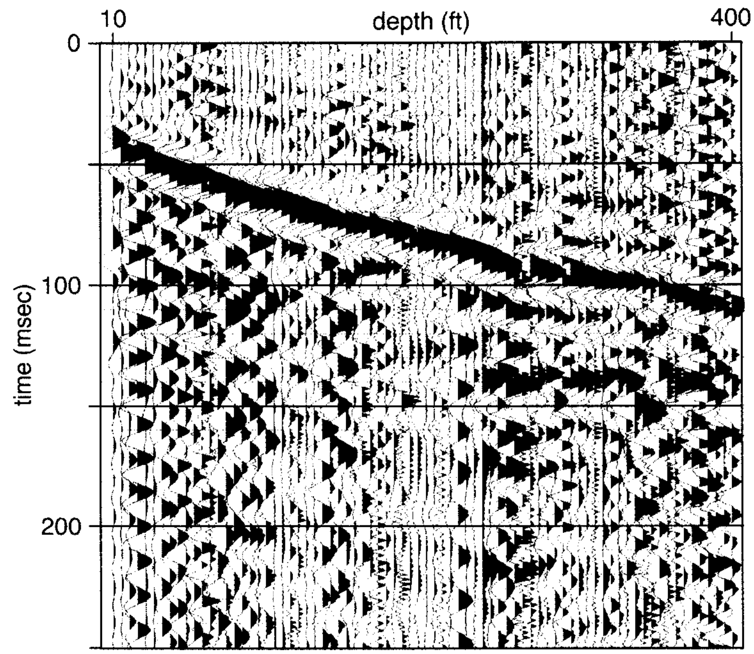

Figure 16. Shear wave uphole survey with coherent arrival direct source to downhole phone energy.

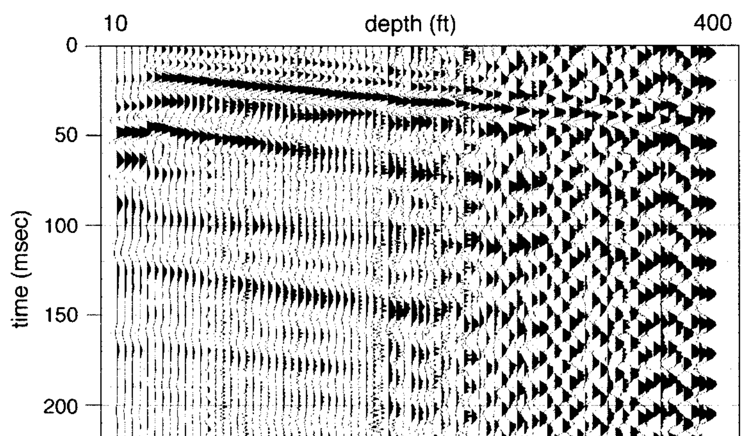

Figure 17. Compressional wave downhole data with high frequency, high amplitude first arrival source to geophone direct energy.

Table 2

Depth (ft)		Unit	Thickness (ft)	Vs (av)	To (ms)	Vs (int)
		Residual soil	15	300 ft/s		300
15		Frailey sh	35	375	70	4000
50		Cypress ss	55	1000	90	
105		Ridenhower sh/ss	30	1750	120	5700
135		Bethel ss	70	2075	130	
205	1st Mine	Downeys Bluff ls	30	2500	150	
235		Yankeetown sh	15	2950	162	
240	2nd Mine	Shetlerville/Levias ss	45	3000	164	6300
285		Rosiclare ss	20	3200	180	
305		St. Genevieve ls	150	3300	185	
455		Basal St. Gene. Ls		3950	230	

Correlations of Depth (ft), Unit, and Thickness (ft) were provided by Dr. John Sexton from an unknown source. Vs (av) is the average velocity calculated from the downhole survey. To (ms) is the vertical incident two-way reflection time to each of the indicated interfaces. Vs (int) is the interval velocity for the three major velocity changes within the upper 400 ft of the borehole as measured from downhole velocity curves.

records—shear wave reflection profiling has the greatest potential of detecting the geologic features or physical scars of the mining process in this area.

In summary, walkaway noise testing effectively evaluated the seismic characteristics and provided some basis for estimating potential of seismic reflection/diffraction surveying to detect mineworks in this geologic setting. Testing procedures and associated analysis was a critical component of this program and provided essential information, which acted as the basis for most acquisition and many processing and interpretation decisions. Evaluation of acoustic signature, optimum acquisition equipment and parameters, near-surface velocity structure, horizontal consistency in reflection character, general resolution potential, signal-to-noise ratio, and impact of cultural noise (i.e., jet aircraft, industrial facility, vehicle traffic, etc.) provides the basis for optimization of effort and resulting geologic information.

Common Midpoint (CMP) Profiling: Phase Two

The CMP profiling portion of this program was designed to sample an area with known mine voids and areas suspected to be undermined. If the voids known to exist possess a repeatable and hopefully unique seismic signature, then a template can be devised which allows the seismic characteristics of void areas to be used as reasonably good indicators of void in areas where no other evidence exists. Line locations and acquisition order was modified on a day-by-day basis as access was obtained and new information discovered. As previously indicated, a total of three field days were committed to the acquisition of three shear wave CMP profiles: one in a known undermined area and two in areas that, based on mine maps, were never undermined but suggest underground activity came very close to property boundaries.

The equipment and parameters used to acquire the CMP data was based on the results of individual walkaway tests performed and VSP profiles collected during phase 1. Data were recorded on a 240-channel (quad 60-channel machines networked), R60 Geometrics StrataView floating-point seismograph. To facilitate the most expedient acquisition possible while maintaining the highest data quality, a 240-channel roll-along switch was used to direct the 96 optimum receiver stations to the seismograph's recording channels (Figure 18). Parameters such as sampling interval and record length were determined based on vibroseis sweeps, dominant frequency and usable bandwidth of reflected energy, and velocity structure. A 1 msec sampling interval was used to record the 12,288 samples per recorded trace. The ground force pilot trace was recorded on seismograph channel 1 for future correlation with the 96 recorded data traces. Data were removed from the seismograph in SEG2 format and stored on CDs for permanent archival.

Horizontal orientation of the IVI Minivib mass (Figure 19) and single GS-11 14 Hz transverse mounted geophones produced and recorded, respectively, the shear wave energy (Figure 20). Data were recorded in uncorrelated format to permit maximum flexibility in future processing of these data. The sweep frequency range was 15 Hz to 150 Hz with all the energy being delivered in 10 sec through a linear upsweep. Unique to this study was an experimental high output value, which provided 4 times the peak force as conventional values across the frequency range of interest (Figure 21). To insure the spectra was accurately recorded, the single 14 Hz geophones were uniformly oriented in Sh mode and leveled to eliminate any parasitic resonance or spectral distortion from misalignment of mass and spring within the geophone assembly (Figure 22). Data possessed a dominant frequency of around 100 Hz and a useable bandwidth from 30 Hz to just over 130 Hz.

Data were acquired using a standard CMP roll technique with a constant source/receiver offset of 40 ft. Source locations were separated by 8 ft while receivers were located every 4 ft. This geometry resulted in CMP stacked profiles with a nominal 24-fold redundancy. The 4 ft geophone station spacing was settled on to optimize the number of traces sampling receivers within the optimum window. Data were acquired using an end-on source/receiver geometry configured to balance the need for near-offset reflections, thereby minimizing wide-angle effects while recording sufficiently longer offset traces to improve NMO velocity control. Source-to-nearest receiver offset was 40 ft with the maximum offset generally around 420 ft. This offset

Figure 18. Seismic recording system mounted on a 6-wheel John Deere Gator set up for roll-along recording on 96 channels.

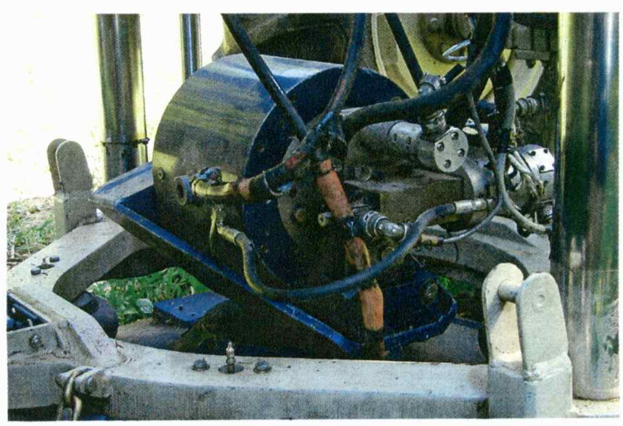

Figure 19. Closeup of mass with cylinder center representing the axis of motion.

Figure 20. Shear wave geophone with level bubble and transverse orientation.

Figure 21. Vibrator traversing down profile along western boundary of Area 471. Mass is oriented so first motion is transverse to the profile line.

Figure 22. Geophone planting procedure into a spattering of poison ivy plants.

range remained well within the span of offsets that can be dynamically time adjusted to vertical incidence and stacked with other offset traces without significantly distorting the stacked waveform (Miller, 1992).

Fine-tuning of the source and seismograph parameters was strongly influenced by the analysis of potential (using physical properties derived from the test data) versus required resolution (Miller et al., 1995), contrasted with maximizing signal-to-noise ratio. The ¼-wavelength criteria of Widess (1973) suggests the best vertical resolution for these 100 Hz dominant frequency reflections from a depth of around 400 ft and average velocity of about 4000 ft/sec is approximately 10 ft. Considering the reported height of the mined areas to be a maximum of 8 ft, direct detection is unlikely. Practical resolution axioms suggest it is unlikely voids small than 20 ft in diameter will be directly detected on CMP stacked sections (vertically incident traces) produced from these data. Horizontal resolution of production profiles is based on the radius of the Fresnel zone, a theoretical principle of optics. Radius of the first Fresnel zone is approximately 125 ft at 400 ft below ground surface along these profiles. This property of the seismic data suggests that any object at least 125 ft in diameter (lateral) might be laterally resolvable. All things considered, from a theoretical perspective these data possess good potential for detecting the mine voids, but it is very unlikely to impossible these voids could be fully resolved.

Data Processing

CMP lines were processed into final CMP stacked sections (two-way travel time) using commercial processing software (WinSeis) at KGS's Lawrence, Kansas, facility. The basic architecture and sequence of steps followed during the generation of the final stacked sections was similar to conventional petroleum exploration processing flows. Exceptions related to the meticulous QC necessary for generation of a finished stacked sections permits confident interpretation of shallow features and realization of full resolution potential of the data (Miller et al., 1989; 1990; Miller and Steeples, 1991) (Figure 23). The main distinctions between high resolution and conventional data processing are related to the emphasis placed on velocity analysis (Miller, 1992; Miller and Xia, 1998), lack of extensive wavelet processing, care and precision placed on muting (especially in this case the thorough removal of all ground roll), detailed step-by-step analysis of key parameters, constraints on statics operations (maximum shifts no greater than ¼ wavelength of the dominant reflection energy with correlation windows at least 10 times the dominant wavelength), and coincident iterative velocity and statics analysis.

Special emphasis was placed on all the analysis portions of the processing flow. It has been proven necessary and most effective to do velocity and spectral analysis on every CDP (Steeples and Miller, 1990). Many times variability in near-surface materials and/or conditions require changes in processing parameters over distances of less than 50 ft. To insure the highest quality geologically representative stacked section, velocity analysis of every CMP was necessary. In association with point-by-point analysis, care was taken to insure all coherent events interpreted on stacked sections were body waves (reflections or diffractions). Biasing processing parameters to enhance events interpreted as reflections that are actually ground roll was avoided at all cost. Differentiating reflections from direct wave, refractions, air wave, and ground roll in the early portion of a stacked section is an extremely difficult task and was not taken lightly (Steeples and Miller, 1990).

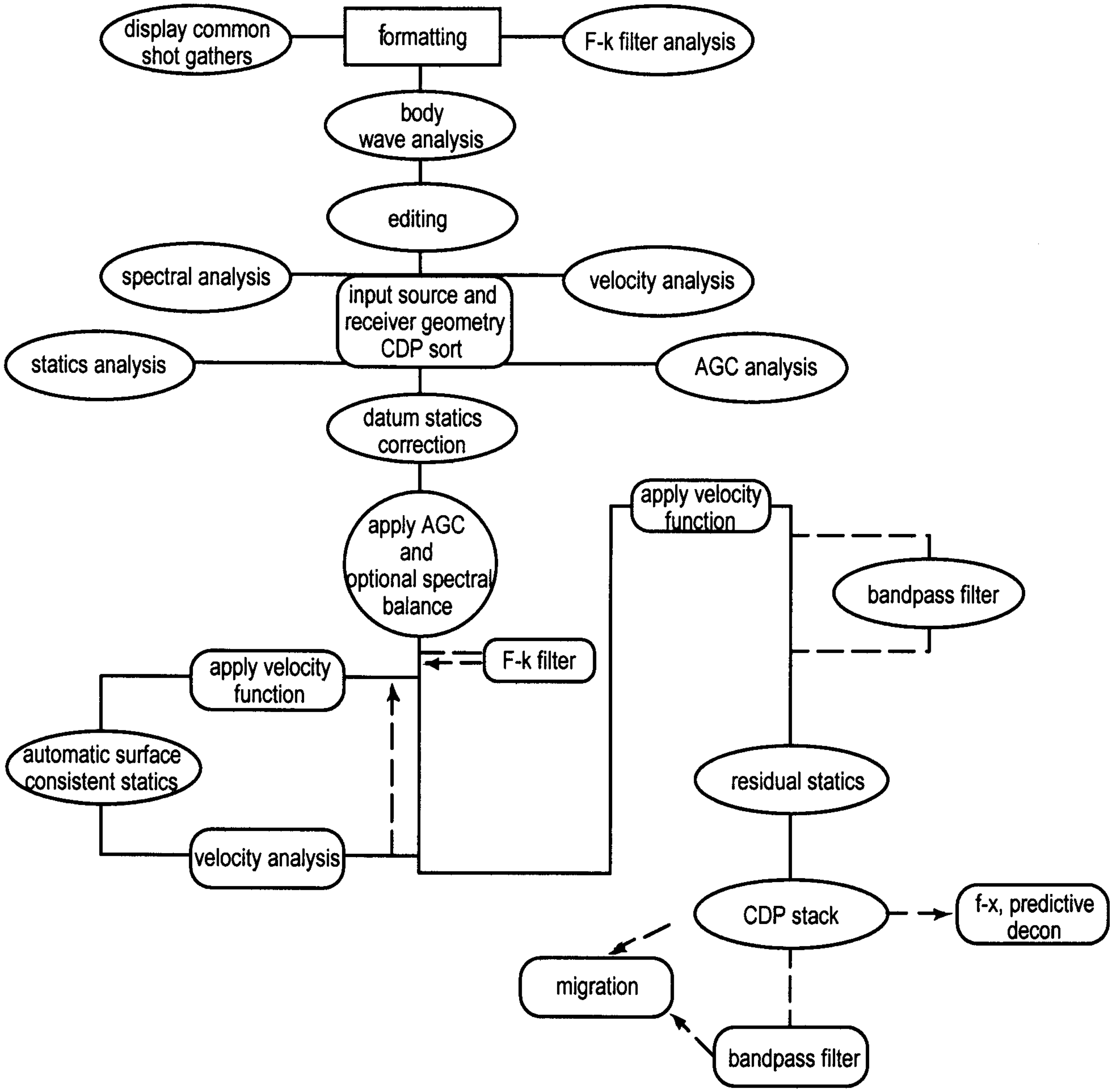

Figure 23. Generalized data processing flow.

This geologic setting provided for easy differentiation of dispersive ground roll from reflections arriving after the onset of the fundamental mode of surface waves. Shallow shear wave reflection profiling, in comparison to compressional wave surveys, requires a greater awareness of and ability to discriminate the many sources and associated forms coherent noise can take on shot gathers and the manifestation of that noise on CMP stacked sections. Shallow shear wave reflection surveying is an attractive alternative to compressional wave reflection surveys in some situations. This draw toward shear wave imaging is due in large part to the increased resolution potential at a given dominant reflection frequency, the polarized nature of the energy, insensitivity to pore materials, and the relationship of shear wave velocity to rigidity/stiffness of materials. Unlike compressional wave arrivals where reflections are the only coherent hyperbolic events, reflections and surface waves can appear hyperbolic on shear wave shot gathers (Figures 13 and 15). This unique difference should eliminate the complete confidence placed in unique interpretations of all hyperbolic events with a zero offset apex as reflections. Without careful attention to true measured velocities (ground truth) and complete removal of all energy arriving within the noise cone, Love waves will likely stack coherently on CMP sections. Interpretations made of stacked shear wave data which do not include sample shot gathers where reflection events are clearly identifiable either outside the noise cone or with unique spectral properties (higher frequency and consistent frequency) should not be considered legitimate and need to be assumed coherent noise.

CMP Sections Interpretation

Interpretations of events on these CMP stacked sections are based primarily on the correlation of seismic energy patterns with geologic features. From there, specific suggestions as the particular source of the seismic event are made with consideration for the mining and mineralization process in this area. There has been no attempt to identify lithology nor to correlate events on the stacked sections with velocity breaks on the VSP. All depth determinations have taken both the VSP and NMO velocity calculations into consideration. All coherent events related to anomalous zones are interpreted to highlight geometry. Anomalous zones are areas generally at the apex of the interpreted coherent events where the energy becomes more chaotic or possesses amplitude abnormalities. The stacked sections will be discussed in a scientifically procedurally correct fashion (i.e., first appraise the "type section" with known mine locations and then explore for voids in areas they are suspected).

Stacked sections presented in this report are annotated with CMP numbers along the X axis and two-way travel time along the Y axis (Figures 24-26, 28, 31, and 32). To establish the exact surface location a CMP number represents it is necessary to divide the CMP number by 2, hence the surface station number is double the CMP number. Intuitively, it is fairly obvious that each CMP stacked trace is half the receiver station spacing, making the spatial sampling along these profiles 2 ft. The two-way travel time is converted on the interpreted section to depth using NMO velocities, which as previously shown, correlate quite well to downhole derived velocities. Coherent events on the CMP stacked sections have been enhanced according to their geometric arrival patterns on the shot gathers, frequency, arrival time and offset, and trace-to-trace as well as shot-to-shot coherency.

West Gravel Road

The general character of events on the gravel road section is quite consistent with expectations for this geologic setting (Figure 24). Apparent dip on events seems to match the geologic setting (as implied by borehole data) and orientation of this profile. Considering the arrivals interpreted on the walkaway shot gather from near area 471, if coherent events obvious on this section are reflections, then this profile has successfully imagined reflectors deeper than 1200 ft. Quite apparent from a cursory glance at this section is a relatively isolated series of high angle events with an apparent north to south dip directly contrasting the more general section wide south to north dipping coherent events. Upon careful study of the various patterns present in these data, if events with the opposing dips are diffractions, and high frequency interference that appears to be associated with their apex is scattered energy, these would be excellent candidates to be fault related.

Interpretations of coherent events on this profile focused on characteristics associated with non-uniformity and point source energy spatially specific to the areas suggested to correlate with the mine drifts beneath the road (Figure 25). Diffraction events have been highlighted with red lines. The apex of these hyperbolic events is theoretically the source of the re-radiated energy and is interpreted here to represent the trace of a fault or fault zone. Green, linear highlights are interpreted to be scatter and are identified by their characteristic interference patterns and high angle slopes. Zones colored in yellow are areas with anomalous amplitudes or significant increases in the amount of chaotic energy arrivals. These yellow zones are centered in or around the fault zones and should be the primary target of any confirmation drilling program.

Several areas appear to be dominated by faults along this profile (Figure 25). Interpretation of diffractions, scatter, and anomalous energy zones along on this section are prevalent beneath CMP 4270 (equivalent to receiver station number 2135). If this location is directly over the old drift, it is several hundred feet further north than had been suggested by a local former mine worker, but skewed well within what would be considered reasonable considering the basis for determining the location of the drifts. It was suggested that a pair of drifts separated by as much as 200 ft passed beneath the road centered around station 2180 (CMP 4360). The most likely area on the seismic data that can be correlated to a mine void is around stations 2135 and 2240. If this does equate to the drifts suggested by the former mine worker, they would be separated by around 400 ft. If the drifts are in close proximity to each other, say on the order of 50 ft, then based on the lateral resolution they would be too close to distinguish on these data.

Faults and anomalous areas interpreted as related to mining and/or mineralization are primarily identified on the gravel road line by discontinuities in events and the apex of diffractions and energy scatters. These criteria are consistent with the expectations and interpretations of faults scatter observed throughout the scientific literature. Areas with the greatest potential for old mineworks to be present will be identified based on interpreted faults and anomalous areas possessing characteristics matching those observed on the gravel road line.

Using seismic characteristics as interpreted at CMP 4275 on the gravel road line, voids suspected but with no confirmation (none of these three profiles have confirmed void locations, confirmation requires drilling) will be identified on the other two CMP profiles. In general, diffraction curvatures should be consistent with the velocity structure, receiver spacing, and depth to the point source of the energy re-radiation.

<u>Old Road</u>

The variability encountered in the near surface along the old road profile had a significant impact on the overall data quality on the stacked section (Figure 26). A shallow coherent event is prominent at about 40 msec across most of the section. Based on frequency content and arrival characteristics, this event is likely a stacked refraction and should not be interpreted to possess the same meaning as a reflection from that time depth. Beneath that one coherent event

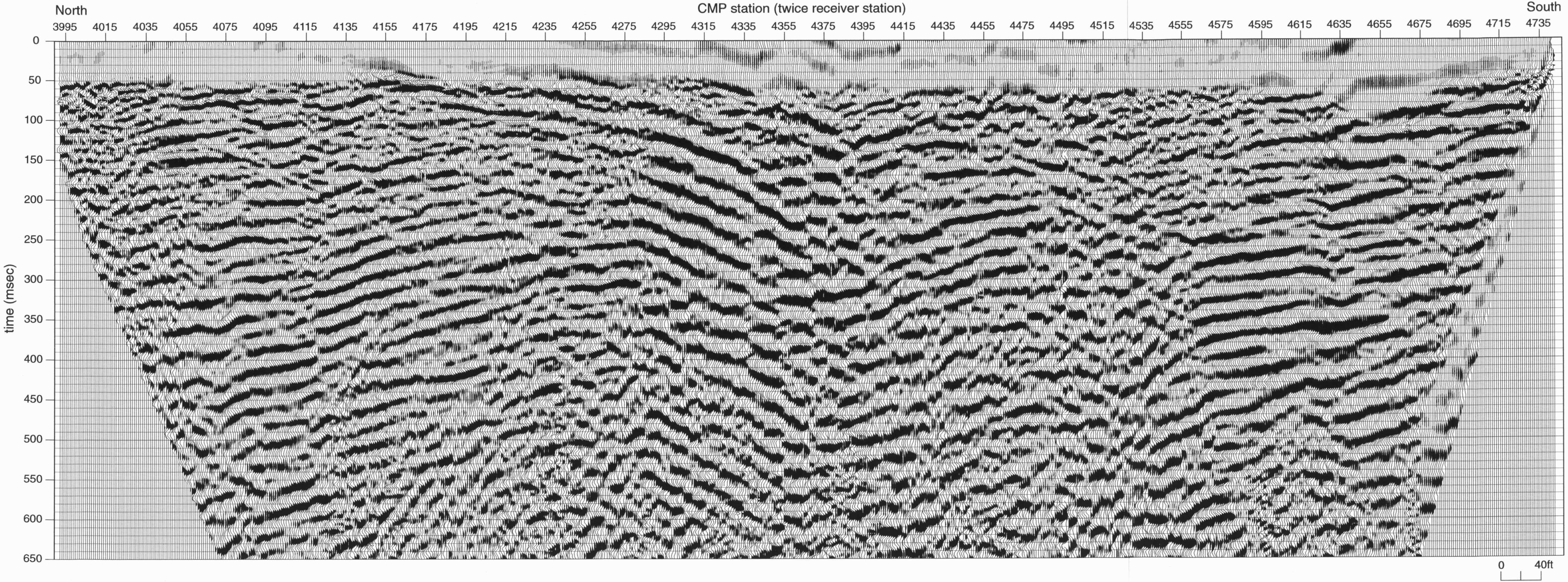

Figure 24. Uninterpreted CMP stack of West Gravel Road line.

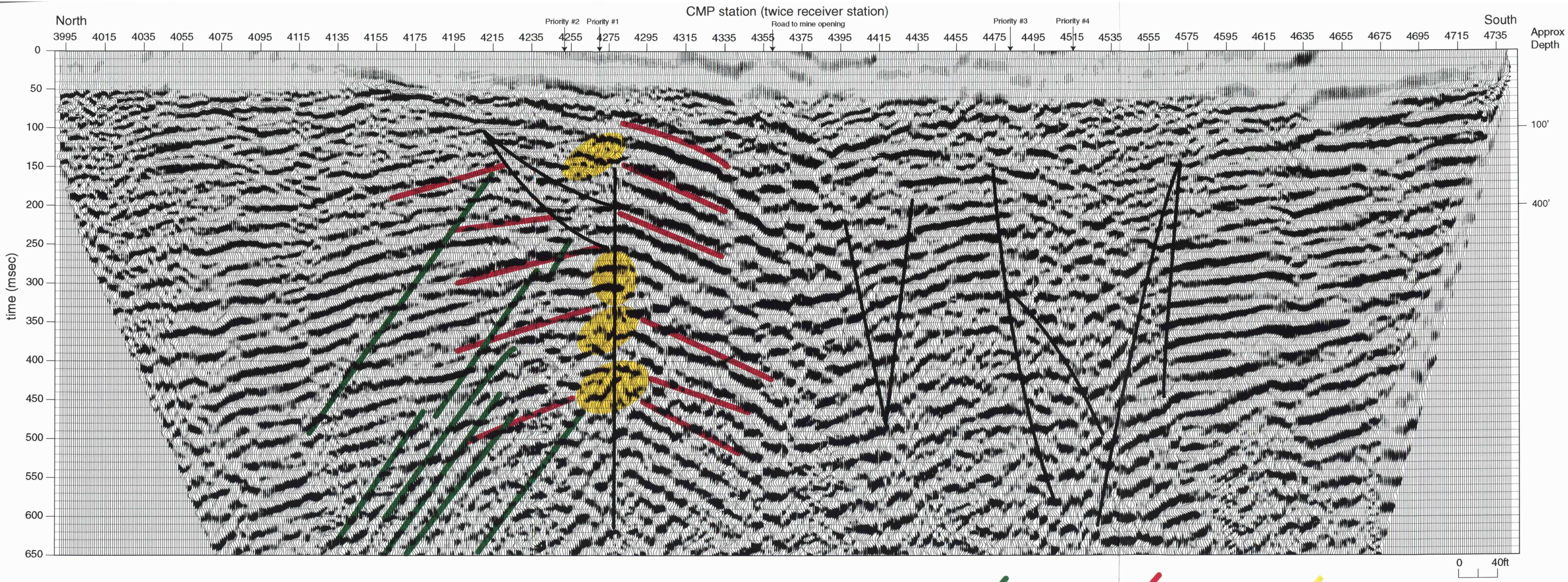

Figure 25. Interpreted CMP stack from West Gravel Road line. Suspected mine crossings are consistent with locations of faults and scatter zones. Yellow highlights are apex of diffraction that are also scatter or areas of chaotic energy returns.

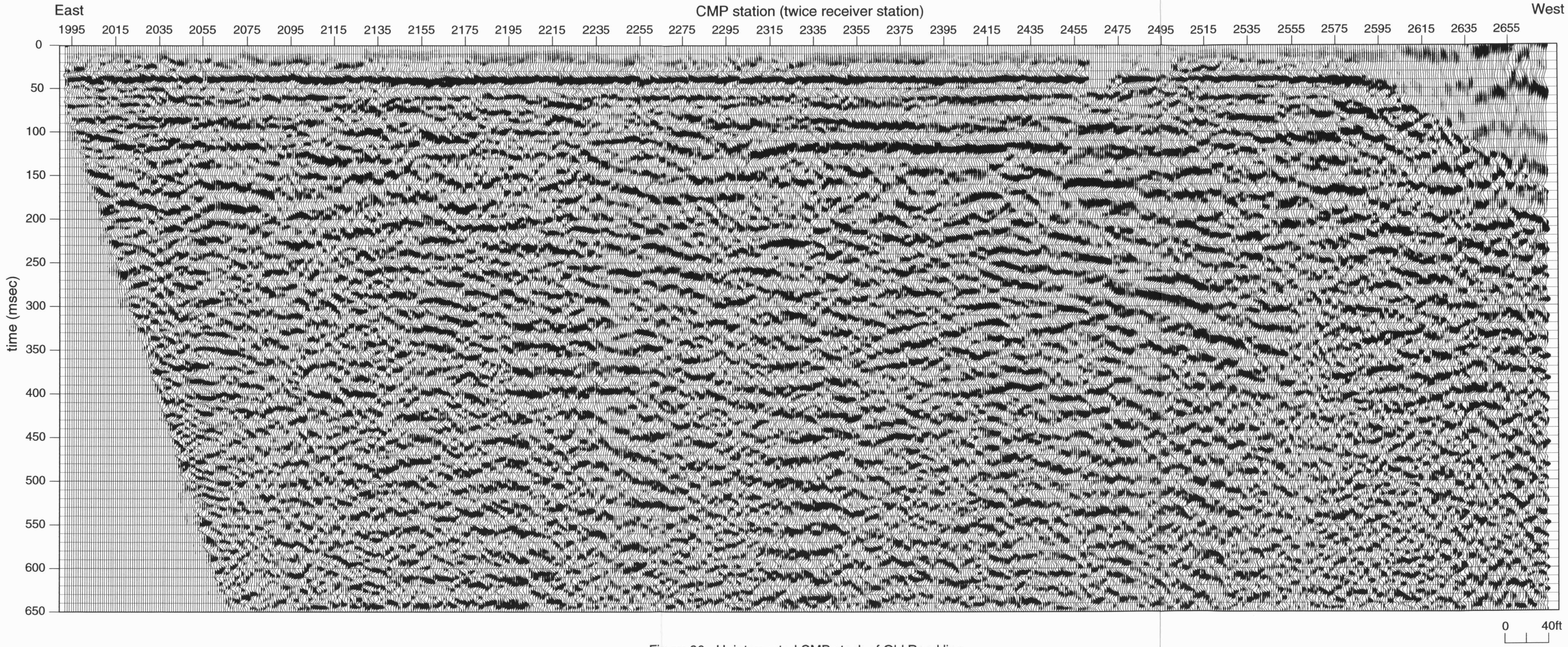

Figure 26. Uninterpreted CMP stack of Old Road line.

Figure 27. Shear wave waffle plate footprint.

is a section without much in the way of laterally continuous events as observed on the West Gravel Road line. Several reasons exist that might explain this difference. Clearly the near-surface soil layer is much thinner along the old road line in comparison to either the 471 area line or the gravel road line. In places along this profile the sandstone bedrock was exposed, forcing the vibrator to directly couple to hard rock. When using a shear wave vibrator, the waffle-style plate must penetrate the upper few inches of soil to completely adhere to the earth (Figure 27). A second difference between this profile and the gravel road line is its orientation to the regional dip. This line, considering the lithologic logs provided and the dip observed on the gravel road line, is a strike line. Depending on geologic particulars, it very well could be difficult along this transect to record events with coherency across distances greater than several hundred feet regardless of the near-surface conditions.

Places along the profile do exist where coherent events are present that could be reasonably interpreted as reflections (Figure 28). It is also possible to interpret several diffraction and energy scattering type arrivals prominent on the gravel road line that correlated reasonably well with the suggested locations of mine voids. With the lower signal-to-noise observed on this section in comparison to the gravel road line, the energy scatter identified by the green highlights on the gravel road line are not as prominent or interpretable with the degree of confidence here on the old road line that was possible on the gravel road line. Diffraction patterns can be interpreted in two unique places along this profile. The slope of the diffractions and their characteristics beneath CMP 2415 is quite similar to those observed on the gravel road line. This is not the case for the diffraction interpreted to have an apex around CMP 2225. This similarity makes interpretations of faults and associated anomalous zones much more convincing at 2415 than 2225, and hence the prioritization of confirmation boreholes.

Reflection events, if present, are related to lithology and structures associated with the contact of various geologic units. It was therefore not critical to interpret reflections nor was it necessary to correlate reflected energy with lithology. Diffractions, faults, and scattered energy in conjunction with velocity information provide the detection tools and pointers necessary to provide drill locations. The diffraction patterns, faults, and void areas interpreted on the western one-third of the profile overlay the same seismic patterns identified on the gravel road line. This strongly suggests that the features are similar in nature. It must be stated that the features

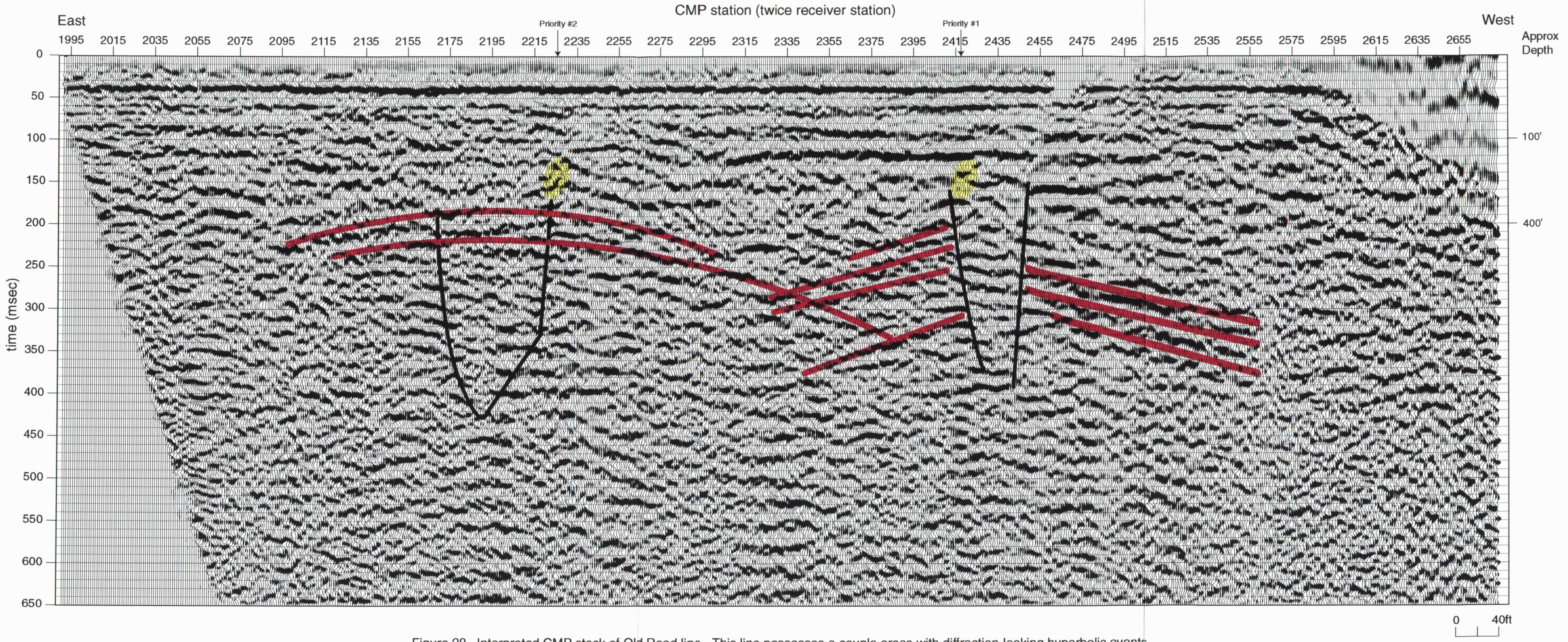

Figure 28. Interpreted CMP stack of Old Road line. This line possesses a couple areas with diffraction-looking hyperbolic events. Tracing the apex of these arrivals are likely zones of both mineralization and mining.

interpreted on these sections are consistent with the type of mineralization that went on in this area, but not necessarily indicative of voids. If mining was active beneath this profile at some time in the past, these features would have very likely guided mine activities.

Area 471

The seismic profile that passed through the 471 area was originally thought to cross an area with the greatest potential for traversing unmapped voids that are remnants of mining activities. The primary target area that was the original focus of this investigation is on the northern extreme of the 471 area profile and several hundred feet beyond the end of the profile. Unfortunately, the ground preparation necessary for this profile to extend sufficiently north to encounter the likely void areas with full fold and offset sections was not completed. The southern half of the profile was in a pasture which was mowed and provided no obstacles to acquisition of data (Figure 29). North of the pasture fence, however the line was not cleared and was infested with poison ivy (Figure 30). Since the seismic source was a tractor-style articulated vehicle, gaining access and therefore imaging the earth beneath the uncleared northern extreme of the profile was imperative. Hence, the portion of the 471 original profile that was actually acquired may have been undermined, but the potential was much less than just north of the pasture fence. Data that were acquired did not capture the optimum locations and therefore the primary target of this project. Extending the line would have provided valuable data in this search for unmapped voids.

Dipping events resembling those observed in proximity to the proposed mine drifts on the gravel road line are evident on this profile at about 350 msec and beneath CMP 2095 or so (Figure 31). If these events represent faults that have been mineralized and possibly mined, they are significantly further south than suspected from study of old mine maps. The general data quality is a bit better than the old road line, but the area interpreted to be indicative of faulting is much better defined on the old road line than on this section. Considering the orientation of this profile is approximately the same as the gravel road line, it is somewhat of a mystery as to why the observed coherent events don't have the prominent south-to-north dip observed less than a mile west along the gravel road line.

Figure 29. Moving along Area 471 line on the last day of the field program.

Figure 30. Field activities along Area 471 line.

Interpretation of events characteristic of faults as identified on the "type section" profile suggests the area with the highest probably of encountering mine remnants is beneath CMP 2135 (Figure 32). The anomalous zone beneath this station is consistent with the interpreted fault trace and is shallower than any observed on the other two lines. Some care must be taken that interpretations of event offset does not directly correlate with the stream cut that was near the center of this profile. It is possible that this stream could be fault controlled, but at the same time it could as produce static artifacts that resemble event offsets. Some of the diffraction looking events have curvature consistent with the easternmost fault zone interpreted on the old road line. Both of these areas are unique with respect to the diffraction and energy scattered zones compared to interpretations indicative of voids on the gravel road line. The strong events with apex around 2090 and 350 msec deep can be overlain by the diffraction events interpreted on the gravel road line with little or no mismatch.

Conclusion and Recommendations

The goal of this study was to image and resolve structural and stratigraphic features and characteristics directly or indirectly indicative of voids caused by mining in otherwise competent rock layers within the upper 200-400 feet. The results of this study were to include a thorough comparison of several high resolution seismic sources, an empirically based estimation of horizontal and vertical resolution potential, evaluation of interpretation confidence, determination of optimum recording parameters, and estimation of potential of this method to detect and delineate subsurface voids at 200+ ft in this near-surface setting. Actual results provided in this report match reasonably well with those originally proposed. Once confirmation drilling has been completed and drill findings compared to the seismic interpretations provided in this report, estimations of confidence can be made. Features interpreted as faults and anomalous zones were identified within the upper 500 ft at this site. Based on the supporting information available at this time, these features appear to be consistent with the expectations of potential void areas. Drilling is necessary to improve the interpretations and provide a measure of confidence.

In areas identified which possess seismic characteristic consistent with faults and indirectly related to void areas left from mining activities it is necessary to ground truth the seismic data interpretations. It would be prudent to first identify where the mine drifts are along the gravel road line. This information may well alter the interpretations of the other profiles prior to confirmation drilling. If the features, as interpreted, represent faults and anomalous zones where mining has taken place, then extending those correlations as has been done in this report to these areas without known mining activity is a legitimate process. If the voids turn out to correlate to some other less intuitive seismic characteristic, then that information would be extremely valuable in revising interpretation of the 471 area and old road lines. A reasonable drill program would target the following areas on the gravel road line in the following order:

1) CMP 4270
2) CMP 4250
3) CMP 4480
4) CMP 4515

Results from these borings will provide all the information necessary for confirming the present interpretations or improving those interpretations based on a new set of criteria. A second set of drill holes would target CMPs 2420 and 2230 on the old road line and CMPs 2130 and 2100 on the area 471 transect. These drill locations are prioritized on the sections and consistent with the seismic characteristics interpreted to be representative of the intersection of faults and anomalous zones.

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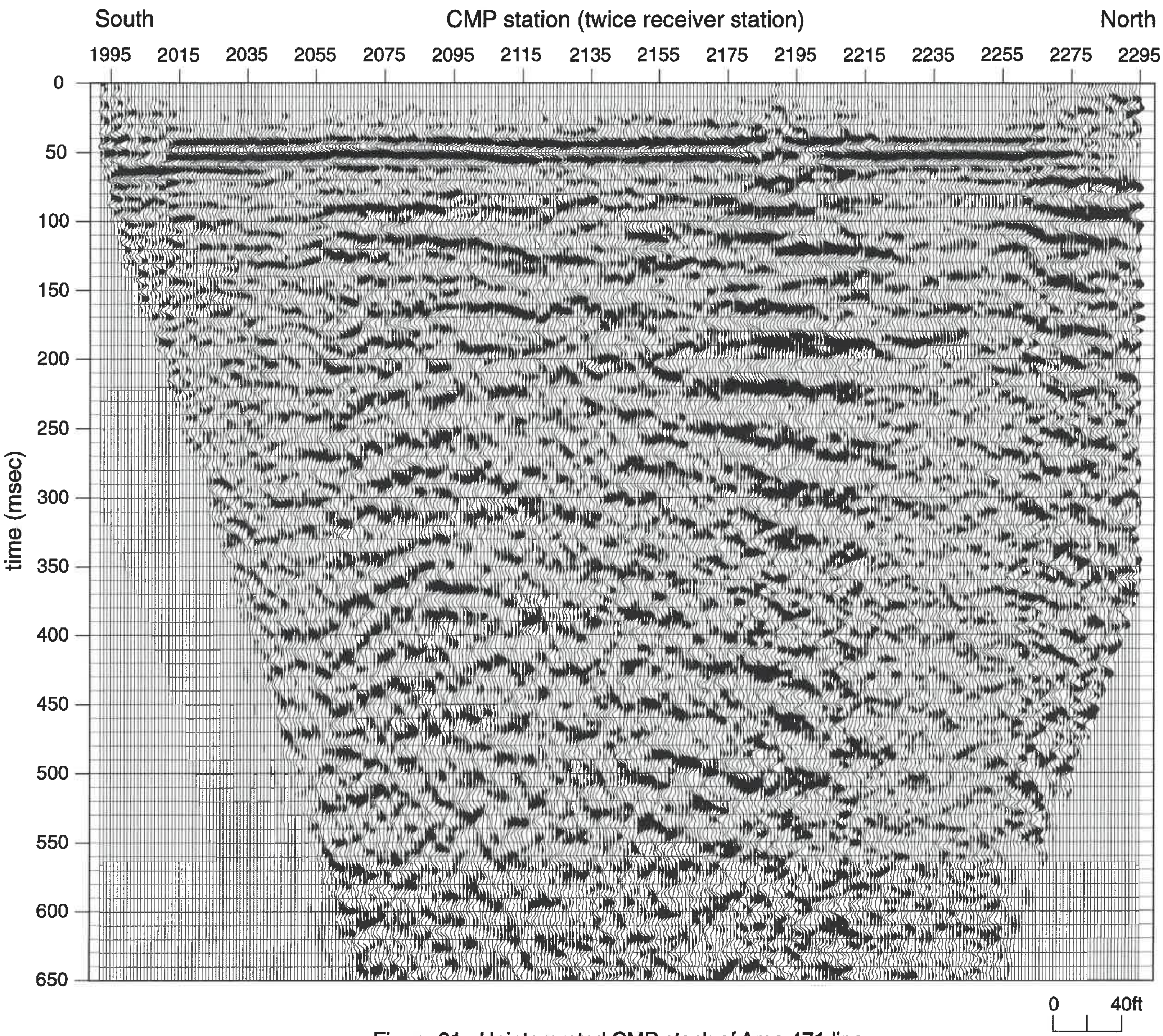

Figure 31. Uninterpreted CMP stack of Area 471 line.

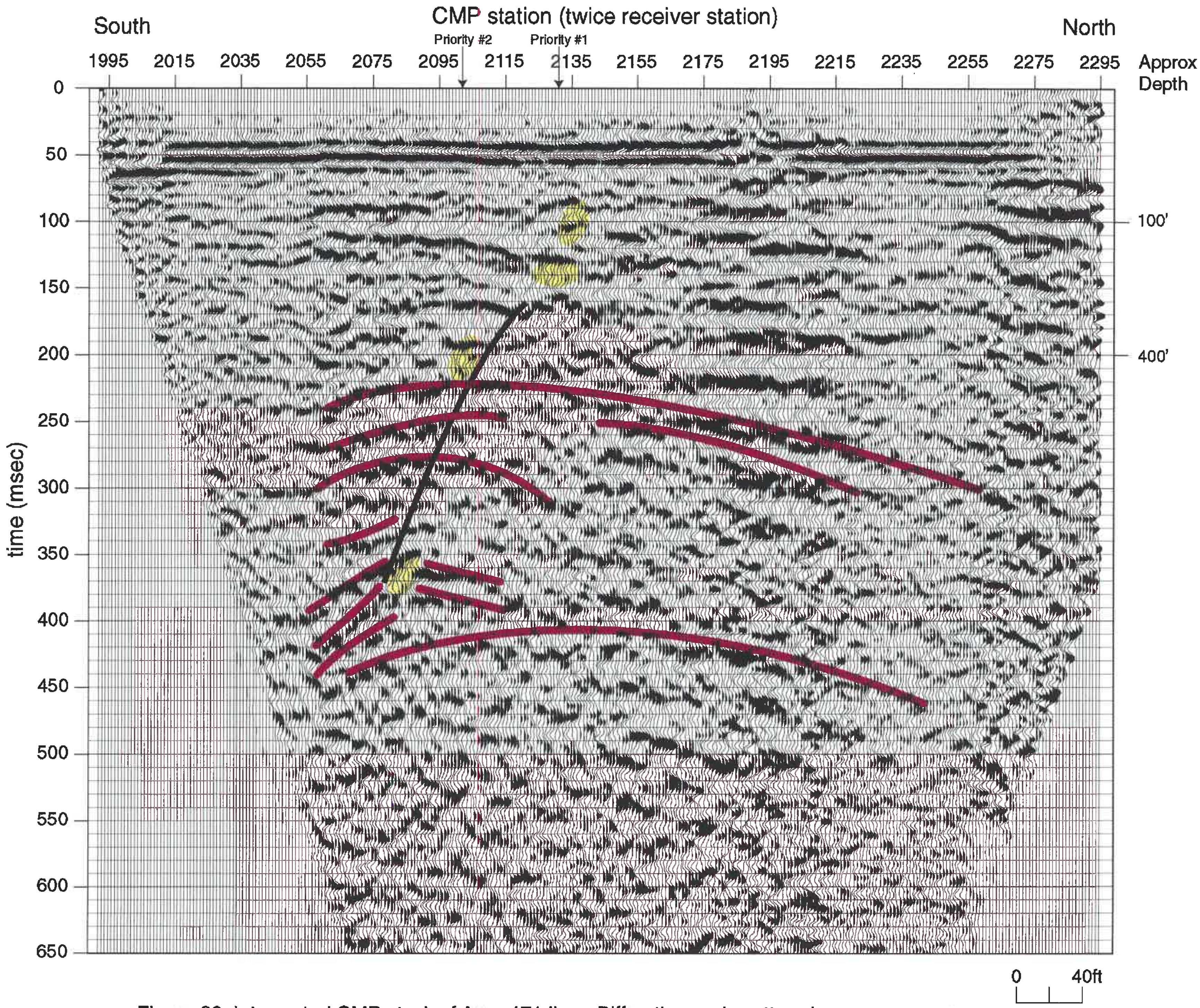

Figure 32. Interpreted CMP stack of Area 471 line. Diffraction and scattered energy appears to correlate to a fault lineament which marks the trace along which more chaotic, possibly mined-out areas exist.