PRELIMINARY DRAFT

# Milestone SP3B6AM4

## REPORT: RESULTS OF VSP ANALYSIS IN P#1

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## REPORT: RESULTS OF VSP ANALYSIS IN P#1

WBS 1.2.3.11.2 Surface Geophysics

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## 1. Introduction

In November 1997, a multicomponent, multioffset Vertical Seismic Profile (VSP) experiment was carried out by Lawrence Berkeley National Laboratory (LBNL) at borehole UE25P#1 (also referred to as P#1 or P-1 in this report). The purpose of this survey was to identify seismic reflection energy from the Paleozoic (Pz) surface that could be processed to image local structure and faulting, and if possible, correlate the results with the REG-3 seismic reflection line to obtain a more regional depth to Paleozoic estimate.

Of the four VSP sites collected, two provided good Pz reflections. The VSP data was successfully matched with the REG-3 data to provide a good estimate to the top of Pz within about 2,000 feet of the well. However, due to the poorly known velocity structure away from the well and possible large offsets in the Pz, tracing the Pz much further from the well proved difficult, and only rough depth estimates can be given.



## 2. Data Status Including QA Status

The raw field data were delivered to the Yucca Mountain Project in November 1997 as qualified (Q) data. The Technical Data Information Form (TDIF) 306616 was submitted and Data Tracking Number (DTN) LB980130123112.001 was assigned.



The geologic model presented in this paper is from ISM 2.1 (Clayton 1998) and is not yet qualified. We used this model because the latest qualified model ISM 2.0 (Clayton et al. 1997) contains a mislocated Paintbrush Canyon Fault at P#1 (see page 35 of Clayton et al. 1997 for a discussion of this deficiency). The cross sections shown here are for reference only, and were not used in the modeling of the data.

The two software packages used to process the data were Focus v4.1 and Seislink v3.2, both of which have been qualified. Also, the regional seismic line REG-3 from Brocher et al. (1996) has been qualified.

## 3. Data Acquisition

A standard VSP uses a seismic source on the surface, and records ground motion from a borehole seismic sensor at various depths in a well (usually equally spaced in depth). This standard configuration was used at well P#1. Four separate VSP surveys were acquired, each one having a unique source location (Figure 1a). Figure 1b shows a cross-section of the Geologic Model ISM 2.1 (Clayton 1998) along REG-3 for the CDP's shown in Figure 1a. Different source locations provide measurement of the seismic wavefield in different spatial planes (the planes containing the source and borehole). The P#1 VSP used a vibroseis source. Two Failing P-wave vibroseis trucks were used together at each source location. The vibroseis source signal is a controlled swept frequency signal (similar to a radar chirp) compressed into an equivalent pulse by correlation (done with Focus v4.1

during data processing). The source sweep parameters were chosen using initial field tests to determine the frequency content that would propagate to the Paleozoic at P#1. A number of sweeps were recorded at each source/sensor level to be "stacked" to improve signal-to-noise ratios. We typically recorded 4 sets of 8 sweeps (the sets of 8 were stacked in the field, giving 4 recordings available for post survey editing). This relatively large number of sweeps is indicative of the poor seismic wave propagation characteristics of the Yucca Mountain region. The source sweep parameters used were:

Start Frequency=8 Hz; End Frequency= 64 Hz; Sweep Length= 10 s; Sweep Taper= 0.2 s.

The sensors used were LBNL's wall-locking 3-component accelerometers in a five-level string with 40 foot spacing between sensors. The multi-level sensor string allowed more data recording in a given time period than standard single level wall-locking sensors. The recorded data were digitized downhole and telemetered to a Century Recording System (Seis-Well) using 16 bit recording with variable gain. The recording parameters were:

Total Record Time =13 s; Sample Rate = 1 ms; Low Cut Filter = None; High Cut Filter = 250 Hz.



Data were recorded at four source sites with surveyed locations shown in Table 1. Source Site 1 was near the well and primarily designed to develop a velocity model using nearly vertical wave

Table 1. Surveyed Locations of Source Sites



| Nevada Central State Plane Coordinates For VSP Sites At UE25 P#1 | | | | |
|---|---|---|---|---|
| Sites | Easting (ft) | Northing (ft) | Elevation (ft) | Distance (ft) |
| UE25 P#1 | 571484.439 | 756172.553 | 3655.443 | ------------ |
| Site 1 | 570991.923 | 756251.462 | 3660.420 | 498.931 |
| Site 2 | 572265.017 | 756942.649 | 3640.488 | 1096.812 |
| Site 3 | 573191.650 | 758430.494 | 3609.545 | 2831.462 |
| Site 4 | 570003.802 | 756735.050 | 3696.932 | 1584.309 |

propagation. Data at Site 1 were recorded from 5,800 ft. to 1,440 ft at 40 intervals. We would like to have recorded as shallow as possible to give a complete velocity model to the surface, but above 1,440 ft the well casing was too large a diameter for our sensors to lock in the borehole. Some 20-ft sensor intervals were recorded to investigate the possible gain from closer spacing, but field analysis determined that the 20-ft. intervals were not necessary because the frequency content of the data appeared to be much larger than the 20-ft spacing. Data at Sites 2, 3 and 4 were recorded with the goal of imaging Paleozoic reflectivity (as well as shallower reflectivity). We therefore recorded only a few levels below the Paleozoic interface. At Site 2 data was recorded from 4,200 ft to 1,840 ft. At Sites 3 and 4, data were recorded from 4,400 to 1,440 ft. The data quality is generally fair to good, due the relatively large number of sweeps. Occasionally, one of the sensors in the 5-level string experienced a telemetry problem and the data were not recorded at that one level. However, since we typically had 4 or more sets of sweeps at each level, this intermittent problem resulted in only four missing 40-ft depth levels at Site 3: 1,960, 2,160, 2,360, and 2,560 ft. These are much higher in the well than the Paleozoic and did not impact the goals of the survey. During data processing, these data levels were interpolated from adjacent depth levels to create a constant 40-ft interval throughout.

## 4. Data Processing

The initial processing of the data started with the raw Vibroseis field data in SEG-Y format. These data were read and processed by the software package Focus v4.1, which has been qualified under the software QA program. The first step was to correlate the data with the recorded Vibroseis sweep on the auxiliary channel of each recorded shot. Each shot was edited by inspection to remove bad traces, sorted by depth in the well, and then summed for each depth level. A 500-ms automatic gain control (AGC) was applied to balance the trace amplitudes. Figures 2a-d show the VSP data at each site.

The processing continued with the software package Seislink v3.2, which has been qualified under the software QA program. A frequency-wavenumber (F-K) filter was applied to each site to remove the downgoing energy and retain the reflected energy, which is of interest in this study. A 500-ms automatic gain control (AGC) was applied to balance the trace amplitudes, and the data were shifted by the amount of the first arrival time at each level. This was done to transform the data to two-way travel time; in this kind of display, the reflected energy should be nearly flat. Figures 3a-d show the reflected energy at each site. Also shown along the depth scale are the geologic units encountered in the well. As can be seen in Figure 3b for Site 2 for example, a nearly flat reflector arrives at the expected depth of the Paleozoic (Pz) interface in the well, thus linking this reflection to the top of Pz. This correlation is also strong at Site 4 (Figure 3d), weaker at Site 3 (Figure 3c), and weakest at Site 1; hardly any coherent reflections of the Pz occur at this depth for Site 1 (Figure 3a).



The next major step in the processing is the VSP/CDP (Common Depth Point) mapping. This is a projection of the reflection events from recorded time to depth-offset location using ray paths traced through a velocity model. This was done in Seislink v3.2, based on a flat layered model. The starting interval velocities for this model were taken from the check shot velocity survey at P#1 that was reported in Table 11 (this data is not qualified and was not used in any reprocessing of the data) of Brocher et al. (1996). From this starting model, the velocities were adjusted to fit the first arrival times at each depth. A comparison and discussion of velocities is contained in Appendix A. The CDP transformed data for each site is shown in Figures 4a-d. The geologic model is included for comparison; the structure and/or faulting was not used in the velocity modeling.

Only the vertical component of the data are shown here. An attempt was made to rotate the sensor data in order to enhance the energy of the reflected data around the Pz. The results in all cases degraded the existing Pz signal and did not add to the continuity of this reflector. Thus, gaps or breaks in the Pz are not due to bending rays distributing energy on other components, but due to actual disruptions or change in reflection properties of this reflector.

## 5. Interpretation of VSP Data

Figure 1b shows the geologic cross section along the REG-3 CDP locations shown in Figure 1a. The depth to the top of the Paleozoic in this model is based on the gravity data from Majer et al. (1996). This interface was modified to tie to known faults, with most of the downward offset of the basement assigned to the Paintbrush Canyon Fault. At the location of Borehole P#1. the basement was encountered at a depth of 4,080 feet.

The vertical components of the total wavefields are presented in Figure 2a-d. The data collection for the nearest offset (Figure 2a) spanned the longest depth interval from 1,440 ft to 5,800 ft. Consequently the geophones are located from the Prow Pass to the Paleozoic basement. The relatively constant moveout of the P-wave between 1,440 ft and 4,200 ft indicates a relative constant P-wave velocity within these formations. Below this depth interval, the flattening in slope indicates the transition to the basement with a faster P-wave velocity. The data shown at Site 2 was recorded between

1,840 ft and 4,200 ft only (Figure 2b). As for Site 1, the first arrival is visible over the entire depth range, revealing a similar flattening of the slope in the traces of the dataset at about 4,000 ft. The two farthest offsets (2c, 2d) reveal a different character. The offsets are so long that the P-waves associated with the shallow arrivals incident almost horizontally, and don't produce large amplitudes on the vertical components. Instead, small amplitudes visible prior to the arrival times of the direct P wave indicate refracted waves that may originate at interfaces within the Prow Pass formation. This effect is most visible for the farthest offset in Figure 2d.

After removal of the downgoing wavefield, the reflected energy becomes apparent in the seismogram sections. Figure 3a reveals the reflected wavefield of the data collected at Site 1. The geologic units are indicated in the upper part of the seismogram section according to the depth range indicated on top of the figure. The expected onset of the reflection off the Paleozoic basement is indicated by the vertical arrow. It is evident that no strong reflection in the vicinity of the well is present at this depth, although a weak noncoherent event can be seen at the depth level of the basement. In contrast Figure 3b shows a strong reflection event at the expected depth range, indicating the top of the basement at a depth of 4,080 ft between Site 2 and the borehole. The data collected from Site 3 (Figure 3c) shows weak reflections at the intersection of the basement with the well, but stronger reflected amplitudes farther away from the well. Figure 3d, finally, shows a strong basement reflection in the data collected from Site 4. This appears to be the strongest and most coherent reflection off the basement in the current data set.



The CDP mapping transforms the reflected data from a time-depth section into an offset-depth section. The results are presented in Figure 4a-d. These figures show cross sections of the geologic model along lines between the source location and the borehole, flanked by the corresponding CDP maps for direct comparison. The offset between Site 1 and the borehole was the shortest (499 ft), and consequently the CDP map reveals the shortest lateral image (250 ft), as the CDP mapped interfaces extend only half the distance from the well to the source location. The CDP map in Figure 4a reveals no clear reflections off the basement, and thus it can't be determine whether the geologic model is in accordance with the VSP data between the borehole and a distance 250 feet towards Site 1. The lack of coherent reflected seismic amplitudes for near-offset geometries is a common feature at Yucca Mountain, and was also observed during the VSP studies in UE-25 UZ-16 (Feighner et al. 1997), and during the processing of the regional seismic surface survey. The CDP map related to Site 2 is given in Figure 4b. According to the strong reflections in Figure 3b, the mapping produces a wavelet coinciding with the position of the reflector in the geologic model. The broadening of the wavelet is caused by the loss of high frequency energy while the elastic waves propagate from the source to the basement and back to the receivers in the borehole. The wavelet associated with the reflection has been marked by brackets. The map for Site 3 indicates similar results. The energy that reflected off the basement, increasing in amplitude away from the well (Figure 3c), is now visible as a weak reflector close to the position of P#1, which shows good coherence between a distance of 200 ft and 800 ft away from the well (indicated by brackets). It can be assumed that the interface of the basement is horizontal over this distance.



The data collected from Site 4 is finally mapped in Figure 4d. Similar to the previous results, the reflection is evident as a coherent wavelet covering the distance from the well to 600 ft toward Site 4. Referring to the geologic model, it can be seen that only the part west of the Paintbrush Canyon Fault seems to correspond to this depth. However, because the reflection is coherent over the entire extent of 600 ft, and because the CDP mapping would produce noncoherent reflection events if the reflector were subhorizontal, it is suggested that the downward throw of the Paleozoic basement to the west of the Paintbrush Canyon Fault (as indicated in the geological model) is exaggerated. It is more likely that the basement west of the fault continues at the same depth level as on its eastern side. However, this interpretation can only be supported out to 600 ft from the well, as this distance represents the limit in lateral resolution.

Thus it can be summarized that the seismic reflections off the Paleozoic basement are found at three of the four investigated VSP sites. The interface of the Prow Pass formation to the basement seems to be constant over the area at a depth of about 4080 ft (at the position of P#1) which translates into an elevation of -425 ft.

## 6. Comparison of VSP Data to Regional Seismic Line REG-3

A subsection of the surface reflection data along the regional line REG-3 is presented in Figure 5. Shown are the final CDP gathers from Brocher et al. (1996), just before final stacking. The data consist of three neighboring CDP gathers centered around Borehole P#1, located at Gather # 673. The gathers are not stacked, and therefore each trace represents a reflection off the same subsurface area with increasing offset between source and receiver. In addition, a static shift has been applied to the data to shift it to the surface elevation at P#1, to facilitate the comparison to Site 1. The arrows point at a reflector that arrives at about the same time as the expected arrival time of the Paleozoic reflector from Figure 3a. It is evident that a reflection off the basement is visible in the data for offset greater than 2,500 ft. This confirms the problems of coherent seismic reflections for near vertical wave incidence as mentioned above.



To compare the VSP with the surface seismic reflection results, the VSP CDP maps of Sites 2 and 4 are displayed next to the stacked surface CDP gathers that cover the same offset from the well as the VSP CDP maps. The comparison is presented in Figure 6. In this figure, only the offsets greater than 2,500 feet have been used in the REG-3 stack in order to enhance the signal-to-noise ratio. The stacked time data is then converted to depth using the velocity function determined at Site 1 (see Appendix A). The left side shows the comparison between the VSP map for Site 4 and the CDP gathers starting at P#1 and extending to a distance of 660 ft at CDP #657. These two lines run parallel as shown in Figure 1a. The most significant difference is the frequency content between the two data sets. The low frequency content of the surface seismic data is caused by the longer travel distance of the elastic waves compared to the VSP data, since they have to propagate back to the surface and thus are more strongly attenuated. Reflection maps show a relative good match for the Site 4 lines. While the difference in frequency content makes a direct comparison difficult. However, it is clear that the two wavelets relate to the same structure in the subsurface. The right side of Figure 6 shows the comparison between the Site 2 VSP CDP map and the CDP Gathers #673-683 of the regional line to the southeast of P#1. Referring to Figure 1a, it can be seen that these two CDP lines, although in close proximity, strike about 60 degrees to each other. As a consequence, the match between the two maps is not as good as for the previous site. The reflection in the surface data appears shallower than in the VSP data, and reveals a slight updip away from P#1, while no clear indication of a dip is evident in the VSP CDP map. However, the comparison strongly suggests that the selected reflections in the regional surface data relate to the same basement reflections as identified in the VSP data.



The reprocessed results of the surface seismic CDP sections within a distance of 2,000 ft to either side of P#1 are presented in Figures 7a-b. This distance represents the section of the regional line as shown in Figure 1a. The geologic model (multicolored image) is overlain by the processed data (red and blue amplitudes). Figure 7a shows the CDP data that were mapped to depth using the velocities as determined from the first arrivals at Site 1, with the white line representing the interpretation of the basement reflection. It is evident from the data that to the west of the Paintbrush Canyon Fault, the basement reflection does not drop down to the depth level indicated by the present geologic model. However, since the CDP depth mapping is an imaging technique that does not reproduce the correct dip of possible reflectors, the CDP data are depth migrated (see Appendix A) and presented in Figure 7b. It can be seen that after migration, the smooth and continuous character of the reflector changes to a set of interrupted piecewise flat reflectors at different depths. Similar to the CDP depth section, the reflector to the west of the Paintbrush Canyon Fault appears at shallower depths than the geologic model suggests. This result supports the findings of the VSP CDP mapping, presented in Figure 4d, that suggested a continuation of the basement interface at constant depth across the Paintbrush Canyon Fault to the west of P#1.

The present findings, based on the VSP CDP mapping and the reprocessing of the surface data between CDP's #625 and #722 indicate that a throw of more than 1,500 ft across the Paintbrush Canyon Fault at basement depth level, as indicated in the present geologic model, cannot be supported. The results indicate a slight step down (~100 ft) at P#1 across the fault and a slight overall dip of the Pz to the west.

## 7. Conclusions

The major conclusions of this report are based on qualified data and software. They are:

- Four VSP datasets were collected at P#1, with offsets ranging from 500 to 2,800 feet. There were considerable variations in the strength of the Pz reflections at each site. The best sites were 2 and 4, which showed the Pz to be continuous and nearly flat 600 feet to the northwest and 200 feet to the northeast of P#1.

- Near vertical reflections of P-wave energy reveal few coherent amplitudes.

- The VSP Pz reflection data were matched to the REG-3 seismic line CDP data, providing a reasonable fit. The REG-3 data showed a strong coherent reflector at the Pz, but with a longer wavelength and greater westward dip than the VSP data. The migrated REG-3 data shows a possible fault of the Pz at P#1 with a small offset of about 100 feet. The Pz was traced within 2000 feet of the well and revealed numerous offsets in the surface with generally westward dipping interfaces.

- There is no indication that a large offset exists in the Paleozoic at P#1 (as shown in ISM 2.1). A better model for the top of the Pz basement near P#1 is a continuous, slightly westward dipping interface with a slight step across the Paintbrush Canyon Fault at P#1.

## 8. Appendix A: Interpretation of Paleozoic Along REG-3 Seismic Line

An attempt is made in this section to extend the estimate of the top of Paleozoic (Pz) across the entire REG-3 seismic line (Figure A1). As shown in the previous section, the Pz can be traced with some confidence about 2000 feet east and west of the well. However, there are two serious limitations in trying to trace the Pz interface further away from P#1. The first limitation is estimating the correct velocity structure. This is important for the migration and depth conversion of the data. The best estimate of the changing velocity structure is the stacking velocities along the line from Brocher et al. (1996) (hereafter referred to as Brocher). We will use these velocities, but we will rescale them to match the observed velocities from Site 1. The second limitation is large offsets in the Pz surface. The Pz does seem to have a distinctive signal near P#1; however, if large offsets greater than the wavelength of this signal (about 750 feet) occur, then multiple interpretations must be given, since it becomes difficult to determine if the correct wavelet is being traced. This is especially true beneath Yucca Mountain, where there are a number of sub-parallel reflectors at different depths. A geologic cross section from ISM 2.1 is shown in Figure A2 for reference.

We first compare the velocities of the check shot reported by Brocher and Site 1. This comparison is shown in Figure A3a as the root-mean squared (rms) velocity versus two-way travel time from the surface of P#1. There is good comparison in the velocity structure down to the Pz interface (at about 800 ms) and then the Site 1 velocities are about 7% faster in the Pz. This confirms the velocity structure to a few percent down the length of the 5,900 foot well.

Next, Site 1 velocity is compared to the stacking velocities used by Brocher near P#1 in Figure A3b. The stacking velocities are about 10% slower than the actual measured values from Site 1. Thus, the stacking velocities will be scaled by 110% during our depth conversion. In Brocher's paper, 80% of the stacking velocities were used for depth conversion, which results in velocities that were 30% slower than the observed values at P#1. This will turn out to be the biggest difference between our interpretation and Brocher's. Since our study uses faster velocities, the depth scale is stretched and the same reflectors appear deeper than in Brocher's interpretation. However, the faster velocities will map the identified Pz reflector to the correct depth in the well. We also assume that this 110% factor is constant across the line, which, for lack of other information, seems reasonable at this time.

The reprocessing of Brocher's data will start with the final CDP gathers, which are corrected for normal moveout, muted, corrected for residual statics, and datum corrected to 5000 feet. Only the offsets greater than 2,500 feet are stacked, bandpass filtered between 5-10-40-60 Hz, followed by automatic gain control with a 500-ms window, and a final 7-trace mixing to increase coherency. This time section was then converted to depth using 110% of the smooth stacking velocities (as shown in Figure A4). We also performed a post-stack migration using different percentages of the smooth stacking velocities from 50% to 100%. By inspection, the migration velocity of 60% of the smoothed stacking velocities was found to give the best result, as faster velocities tended to defocus the seismic images at P#1. Brocher found a migration velocity of 70% to give the best image. This migrated time section was then converted to depth using 110% of the smooth stacking velocities (Figure A5).

In Figure A6, we present an interpretation of the Pz traced away from P#1, generally following the trend in the data. In this figure, we tended to pick the shallowest possible reflector that may be the top of Pz. The result is that the picked Pz is shallower to the east and west of P#1 than at the borehole, with the major downward offset near the Bow Ridge Fault (compare with Figure A2). This interpretation generally agrees with the recent gravity inversion of Lane Johnson (personal communication, Jan. 1998).

In Figure A7 another interpretation of the Pz is presented, with the emphasis on picking the deepest possible Pz interface. In this figure, the largest offset occurs just west of the Midway Valley Fault (compare with Figure A2). The Pz could also be about 1,500 feet deeper on the eastern portion of the line. The estimates vary greatly in these two models, but without another known Pz depth point for control (especially beneath Yucca Mountain), the uncertainty will likely remain large.

## 9. References

Brocher, T.M., Hart P.E., Hunter W.C. , and Langenheim V.E. 1996, *Hybrid-source Seismic Reflection Profiling across Yucca Mountain, Nevada: Regional Lines 2 and 3*, USGS-OFR-96-28, MOL.19970310.0094, GS960108314211.002 (Q), USGS, Denver, Colorando, 110.

Clayton, R.W. 1998, *Geologic Model ISM 2.1*, personal communication. Not Qualified.

Clayton, R.W., Zelinski W.P., and Rautman C.A. 1997, *ISM2.0: A 3D Geologic Framework and Integrated Site Model of Yucca Mountain*, Report prepared by the Civilian Radioactive Waste Management System, Management and Operating Contractor to the U.S. Department of Energy, M&O Document Identifier B00000000-01717-5700-00004 Rev 00. MOL. 19970728.0283.

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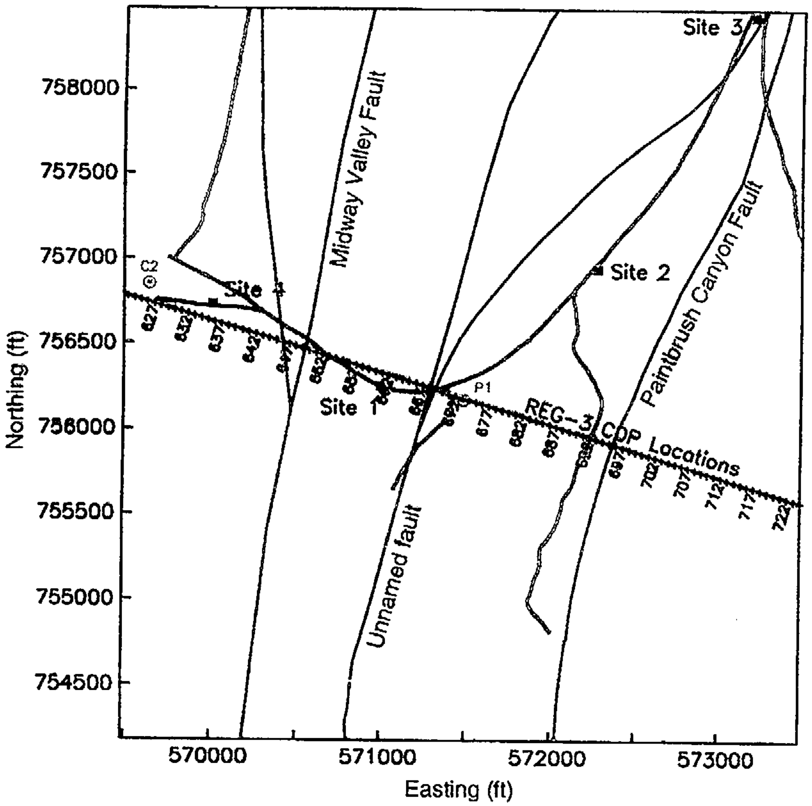



Figure 1a. Location of four VSP source locations (Sites 1 - 4) in relation to the P#1 well. Red faults are from the Geologic Model ISM 2.1 from Clayton (1998) and blue lines are roads. The CDP locations are from the regional seismic line REG-3 by Brocher et al. (1996). "Unnamed fault" is given this name as a reference in this paper.

## Geologic Cross-section Along REG-3

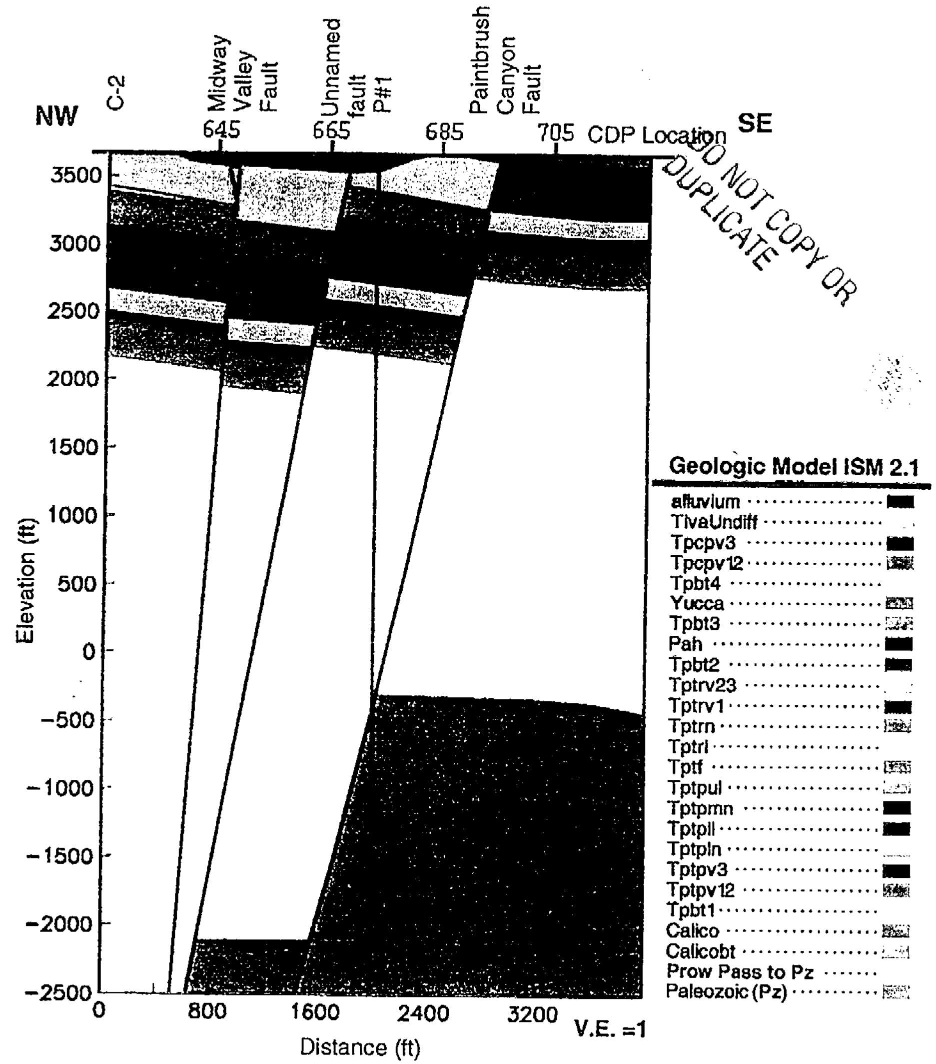



Figure 1b. Geologic cross-section from ISM 2.1 (Clayton, 1998) along REG-3 for CDP's shown in Figure 1a. In this model, the deeper units below the Prow Pass were not subdivided and are shown here in yellow.

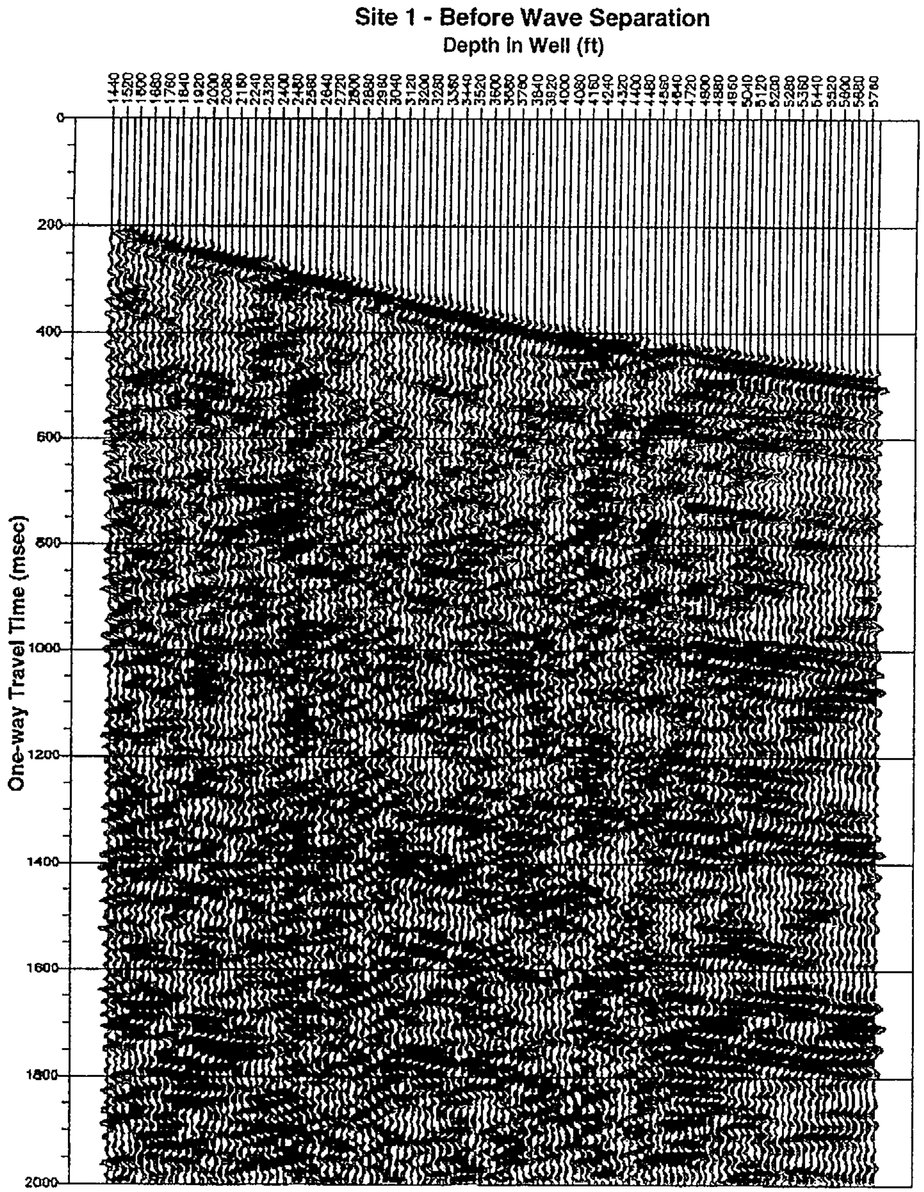



Figure 2a. Site 1 VSP data containing both downgoing and reflected energy.

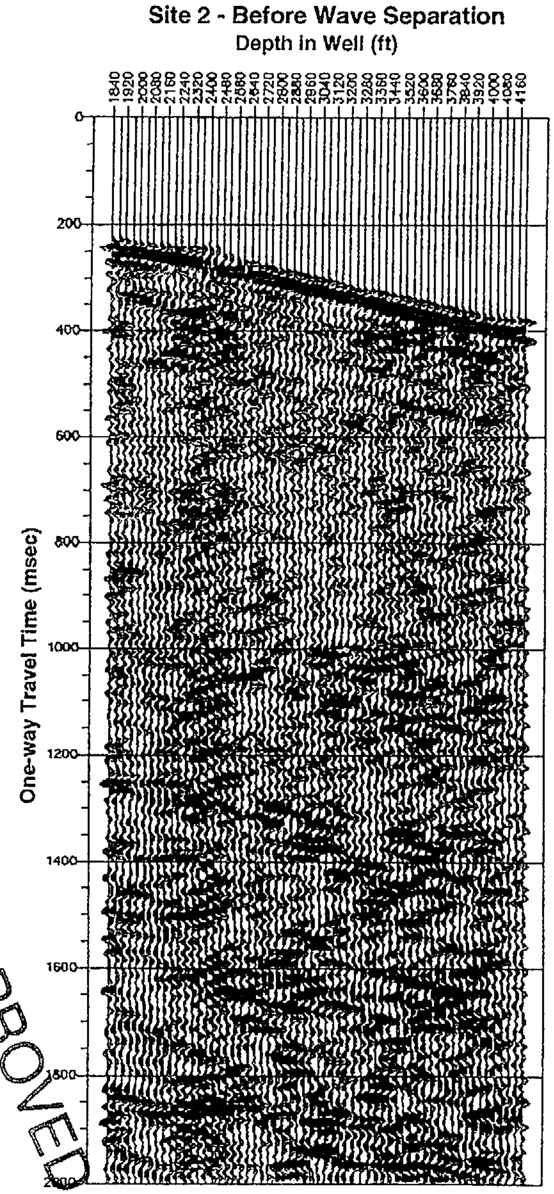



Figure 2b. Site 2 VSP data containing both downgoing and reflected energy.

## Site 3 - Before Wave Separation

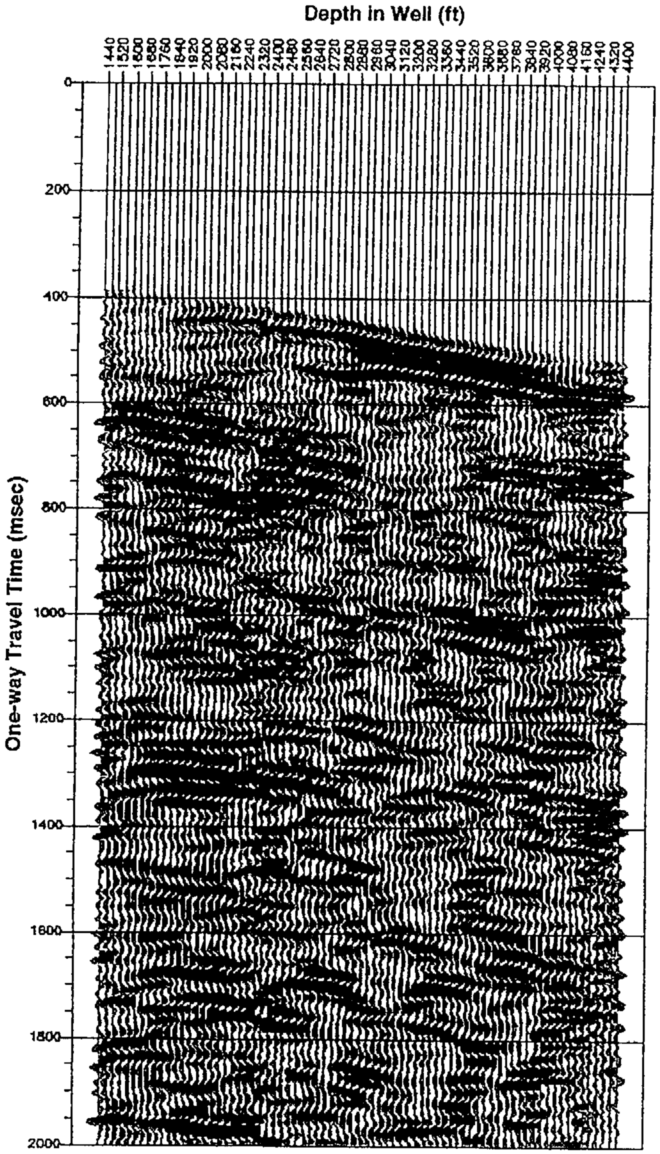



Figure 2c. Site 3 VSP data containing both downgoing and reflected energy.

## Site 4 - Before Wave Separation

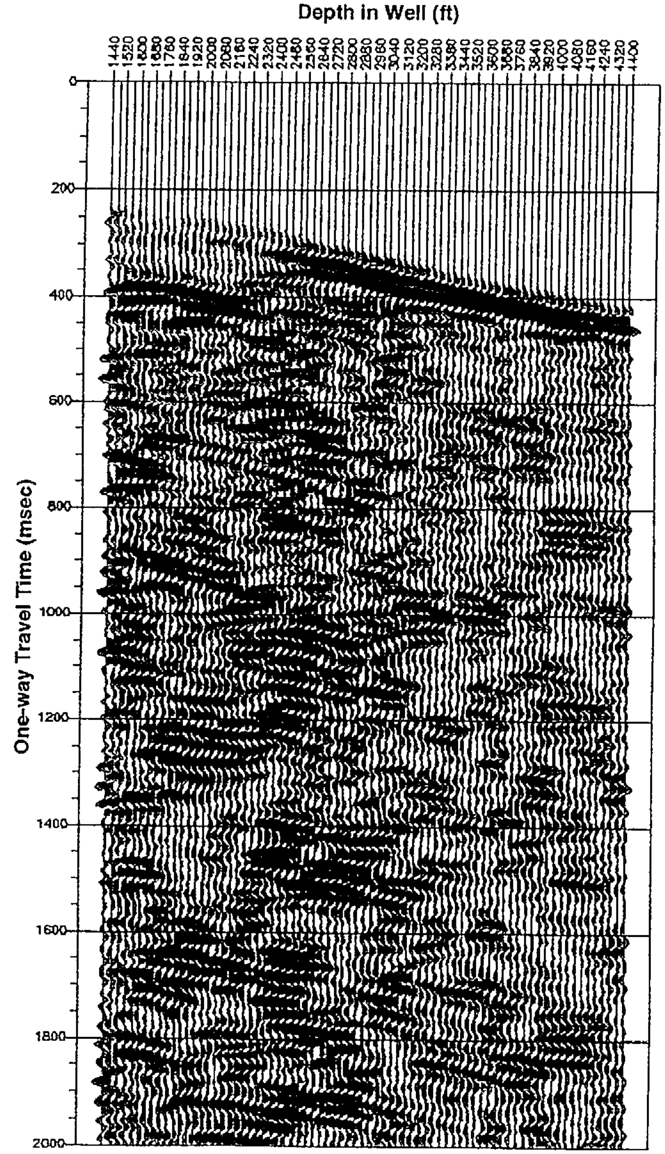



Figure 2d. Site 4 VSP data containing both downgoing and reflected energy.

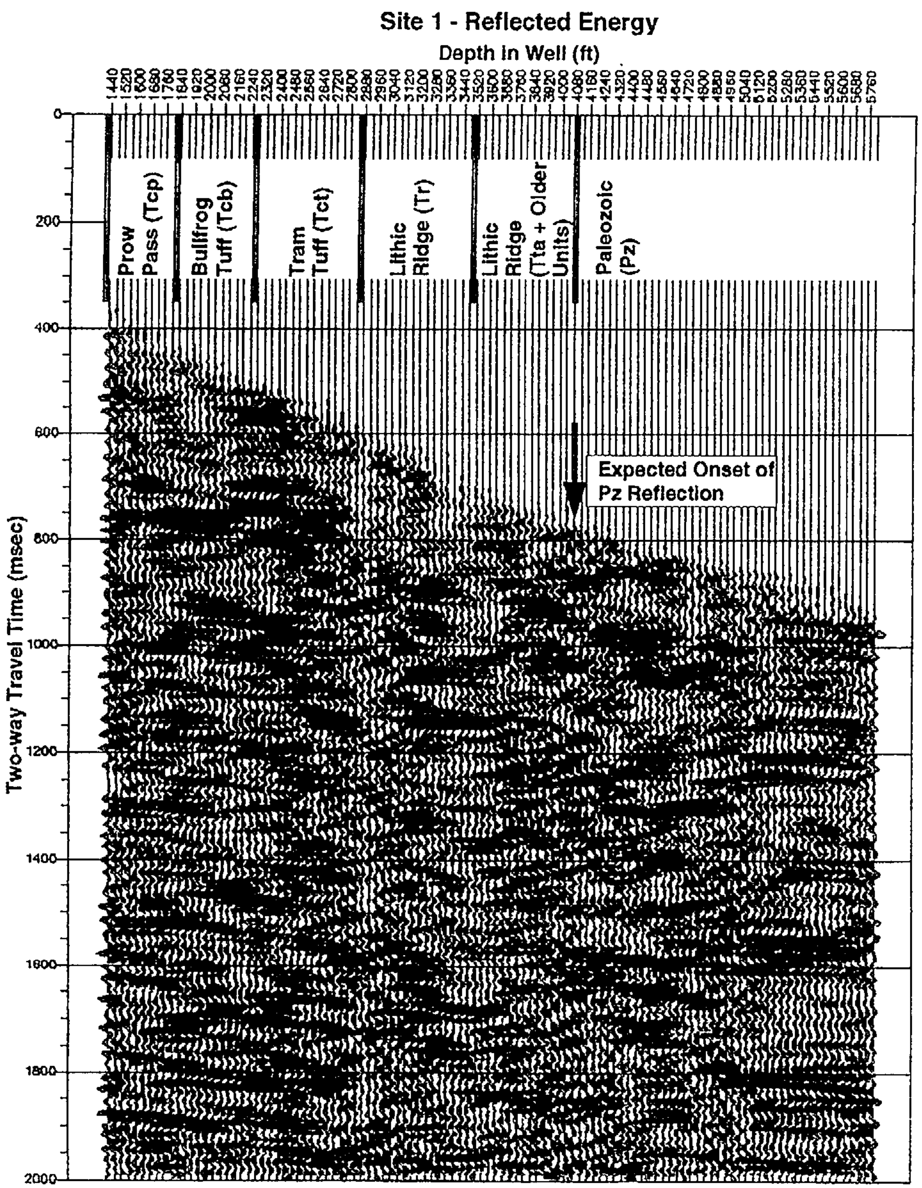



Figure 3a. Site 1 reflected energy after F-K filtering of downgoing energy. There are no strong Paleozoic reflections at the known depth of the Pz in the well.

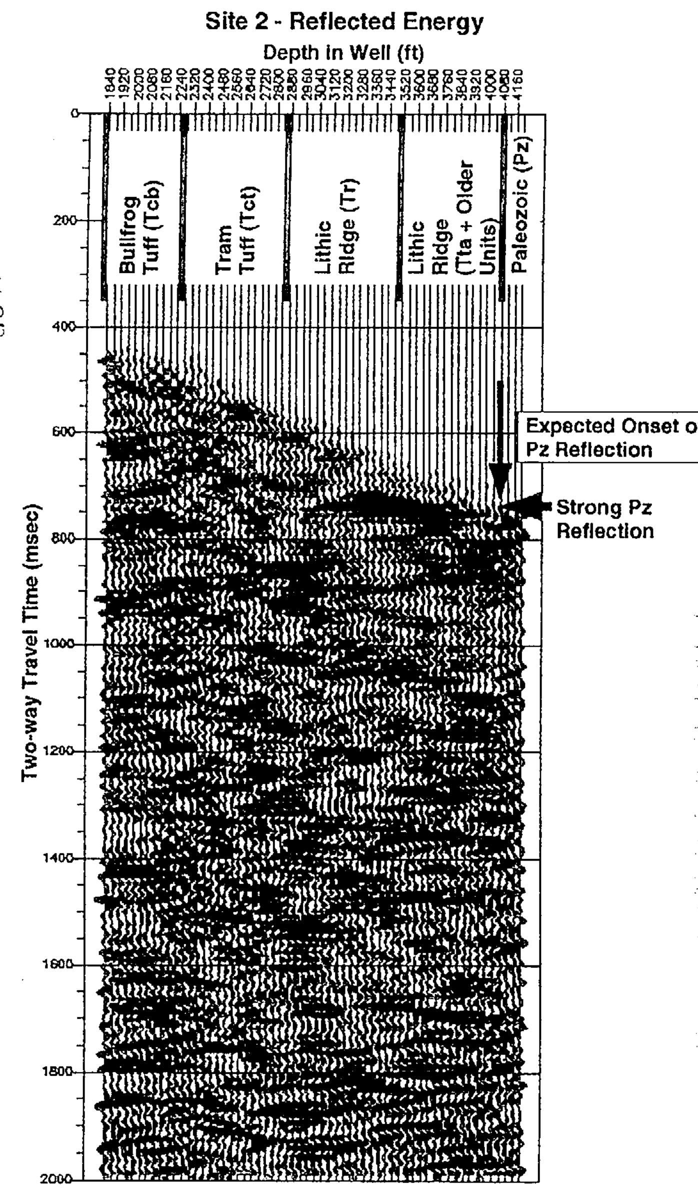



Figure 3b. Site 2 reflected energy after F-K filtering of downgoing energy. The strong reflector intersects the well at the depth of the Paleozoic.

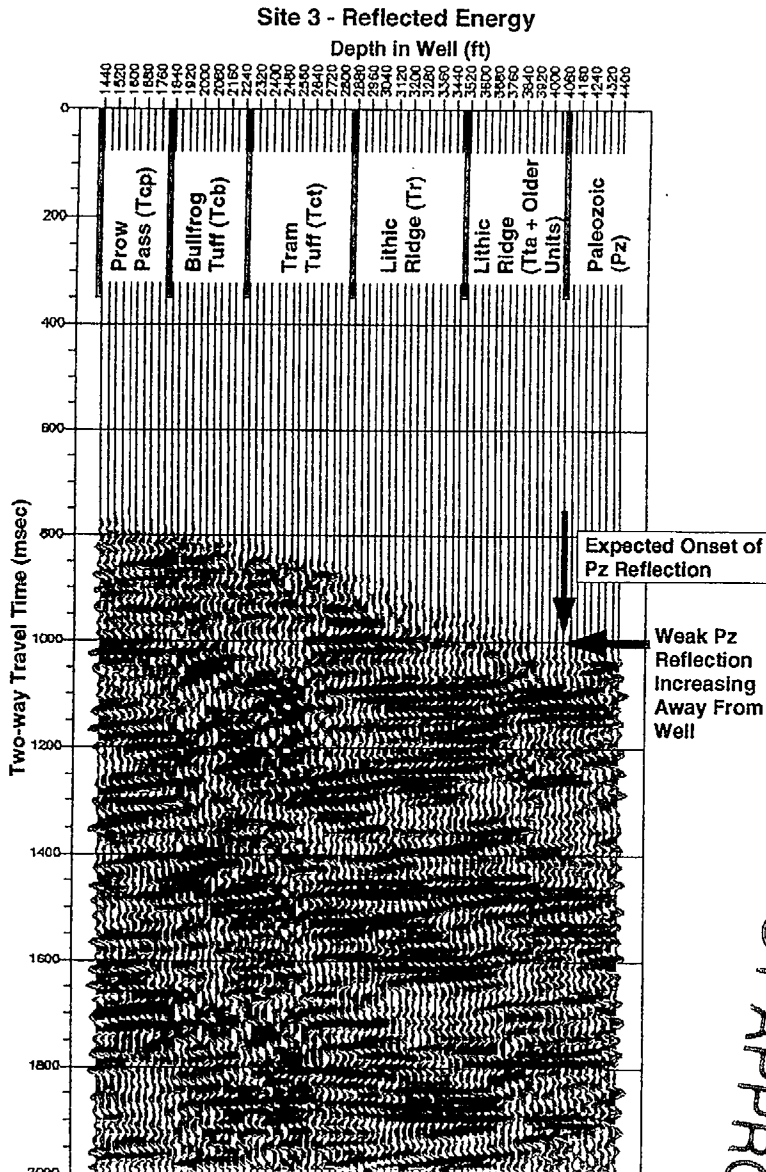



Figure 3c. Site 3 reflected energy after F-K filtering of the downgoing energy. A weak reflector appears at about the correct time away from the well.

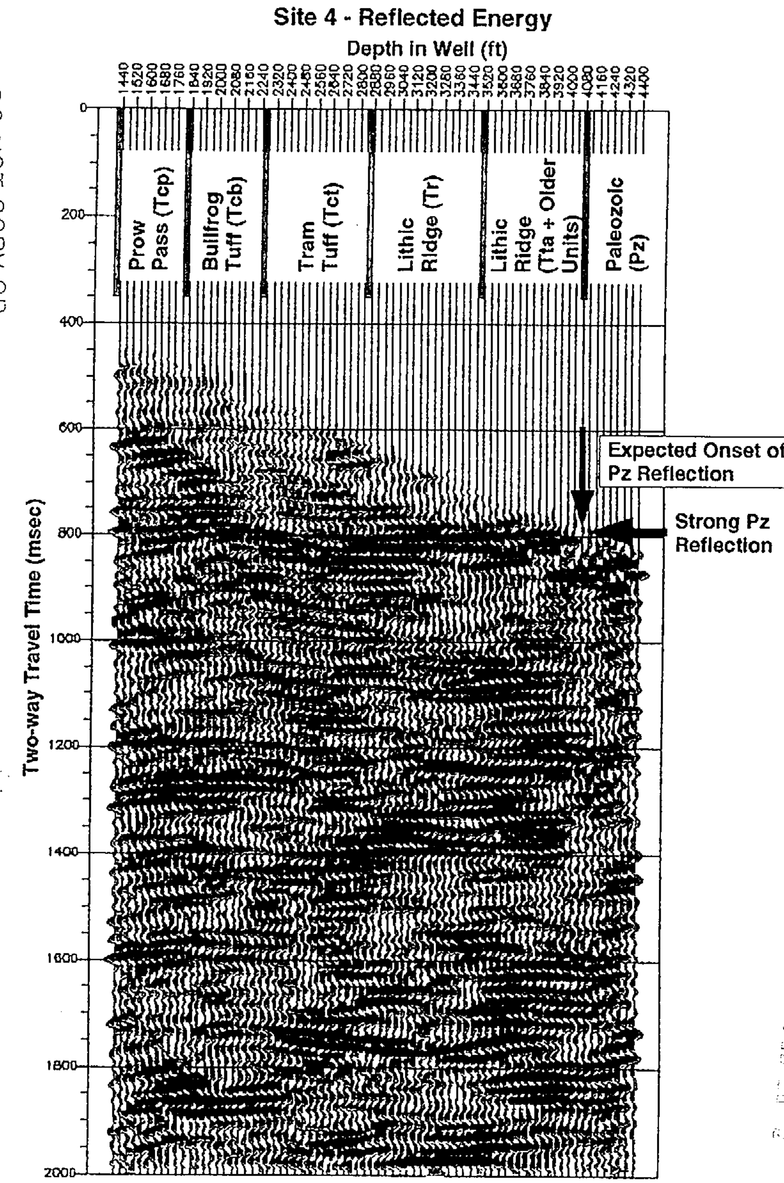



Figure 3d. Site 4 reflected energy after F-K filtering of downgoing energy. A strong reflector appears at the depth in the well corresponding to the Paleozoic.

## Site 1 - CDP Transform

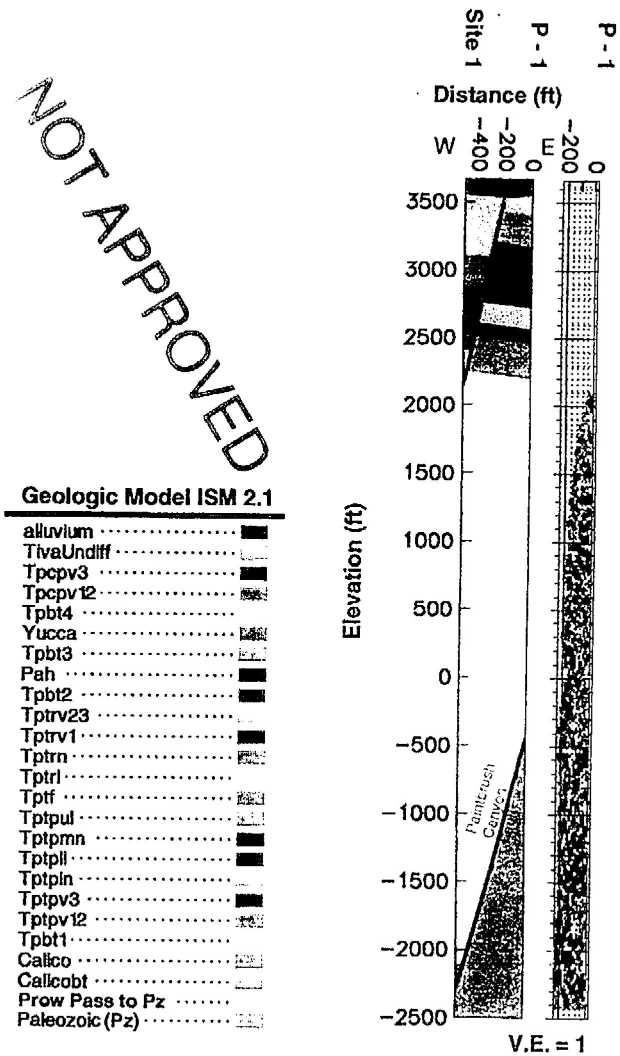



Figure 4a. Site 1 CDP mapping of reflected energy. Geologic model is shown for comparison. Pz reflection is not apparent.

## Site 2 - CDP Transform

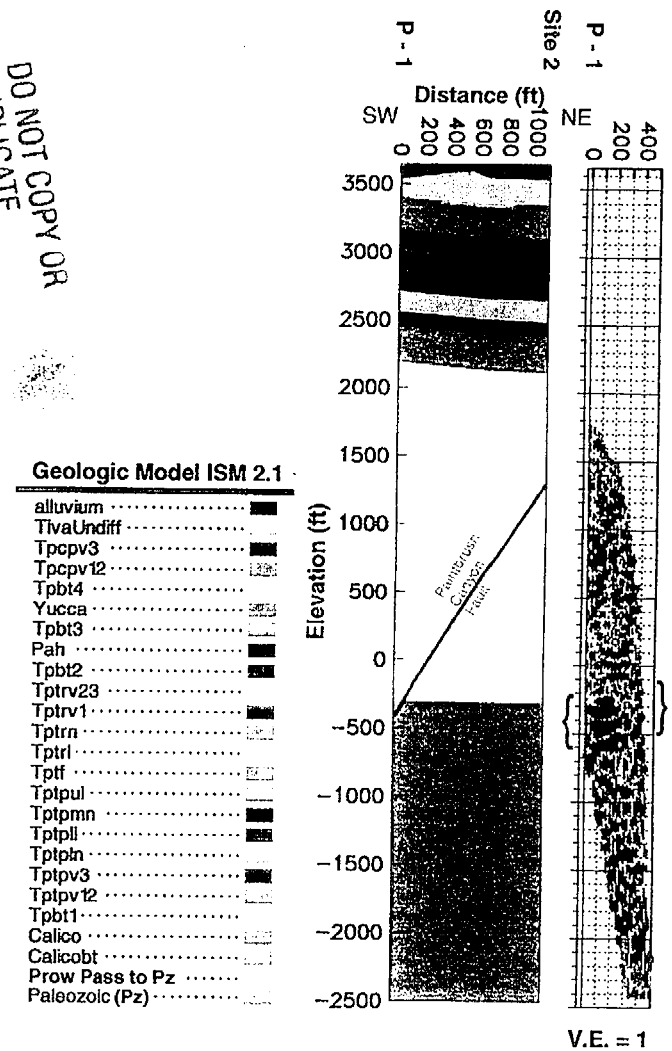



Figure 4b. Site 2 CDP mapping of the reflected energy. Geologic model is shown for comparison. Pz reflector (in brackets) is continuous for about 200 feet northeast of the well.

Site 3 - CDP Transform



Site 4 - CDP Transform

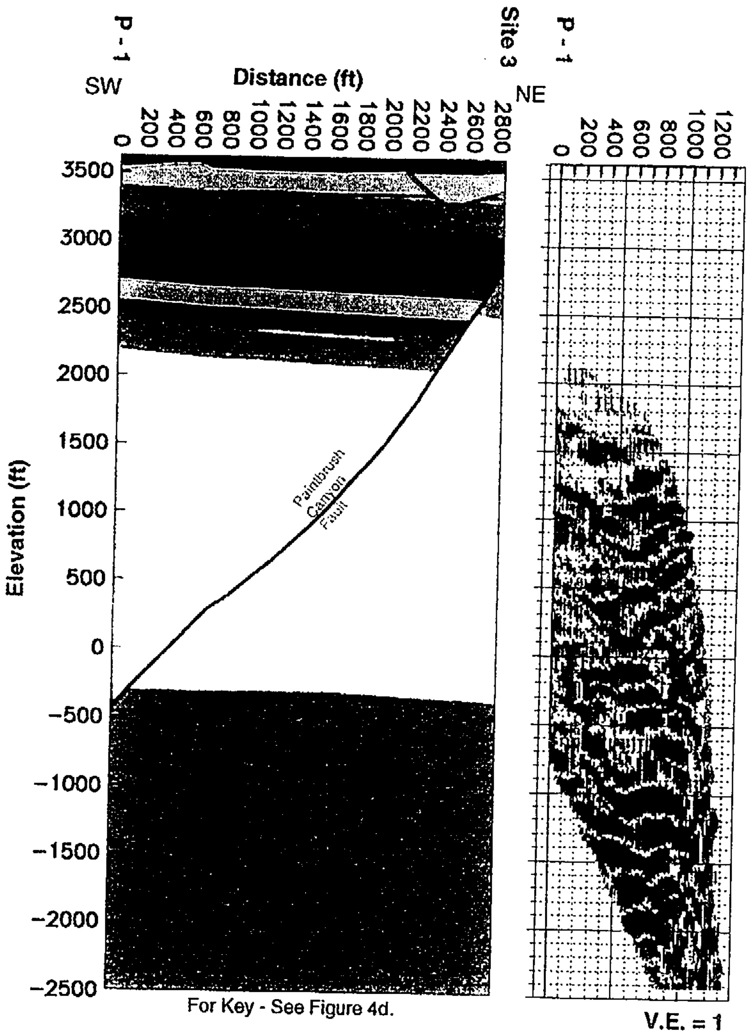



Figure 4c. Site 3 CDP mapping of thr reflected energy. Geologic model is shown for comparison. Pz reflector (in brackets) is weaker and may be slighly higher in the section away from the well.

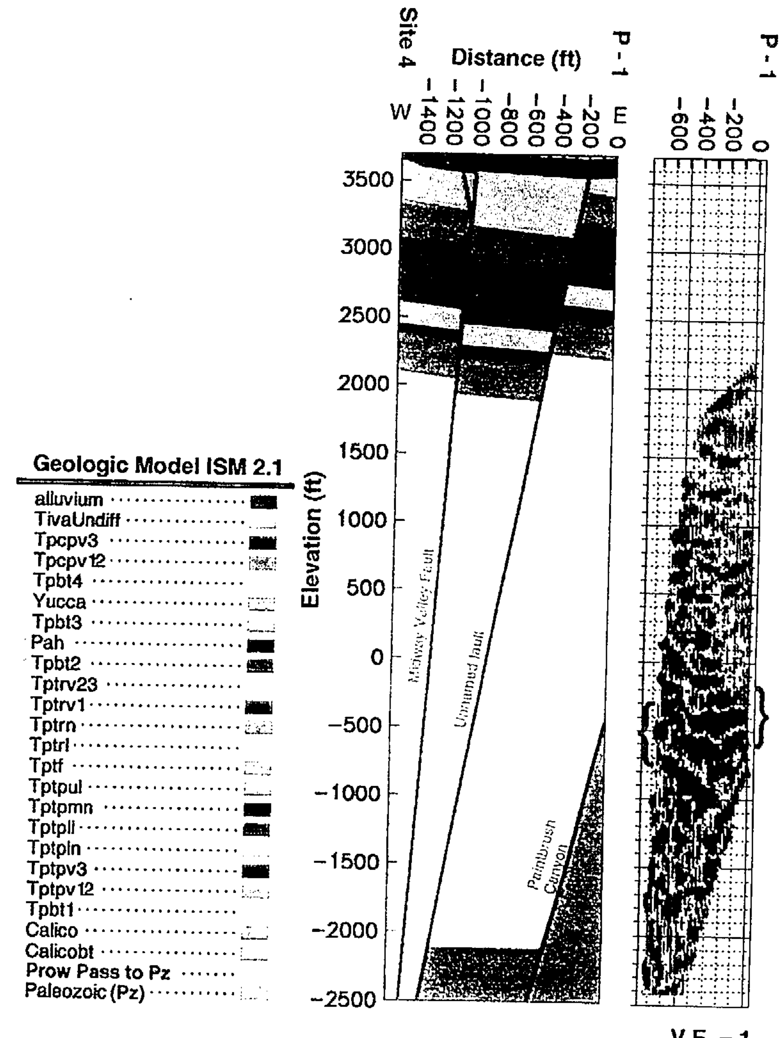



Figure 4d. Site 4 CDP mapping of the reflected energy. Geologic model is shown for comparison. Pz reflector (in brackets) appears to be continuous and nearly flat 500 feet west of the well, with possible faulting or westward dip beyond.

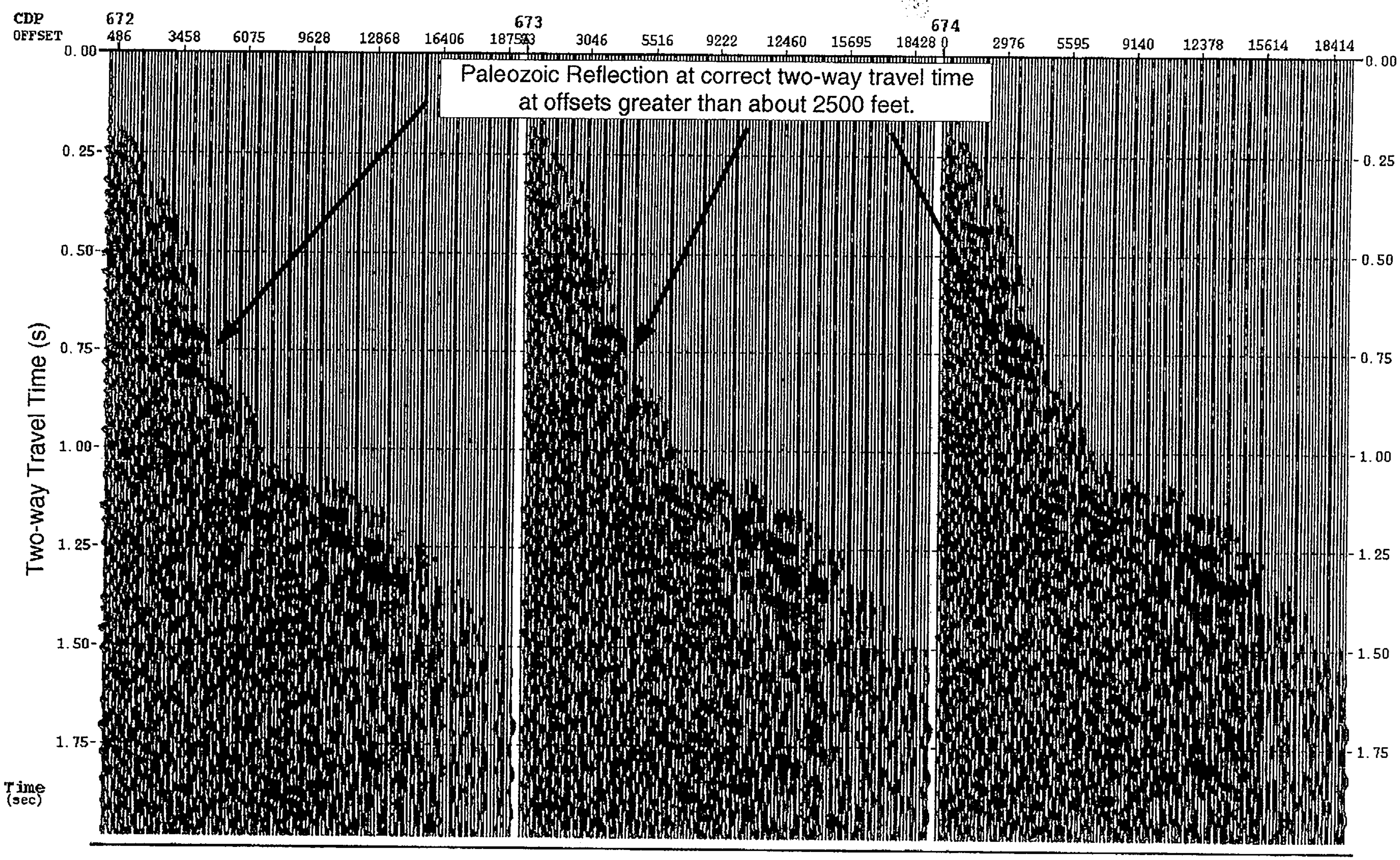
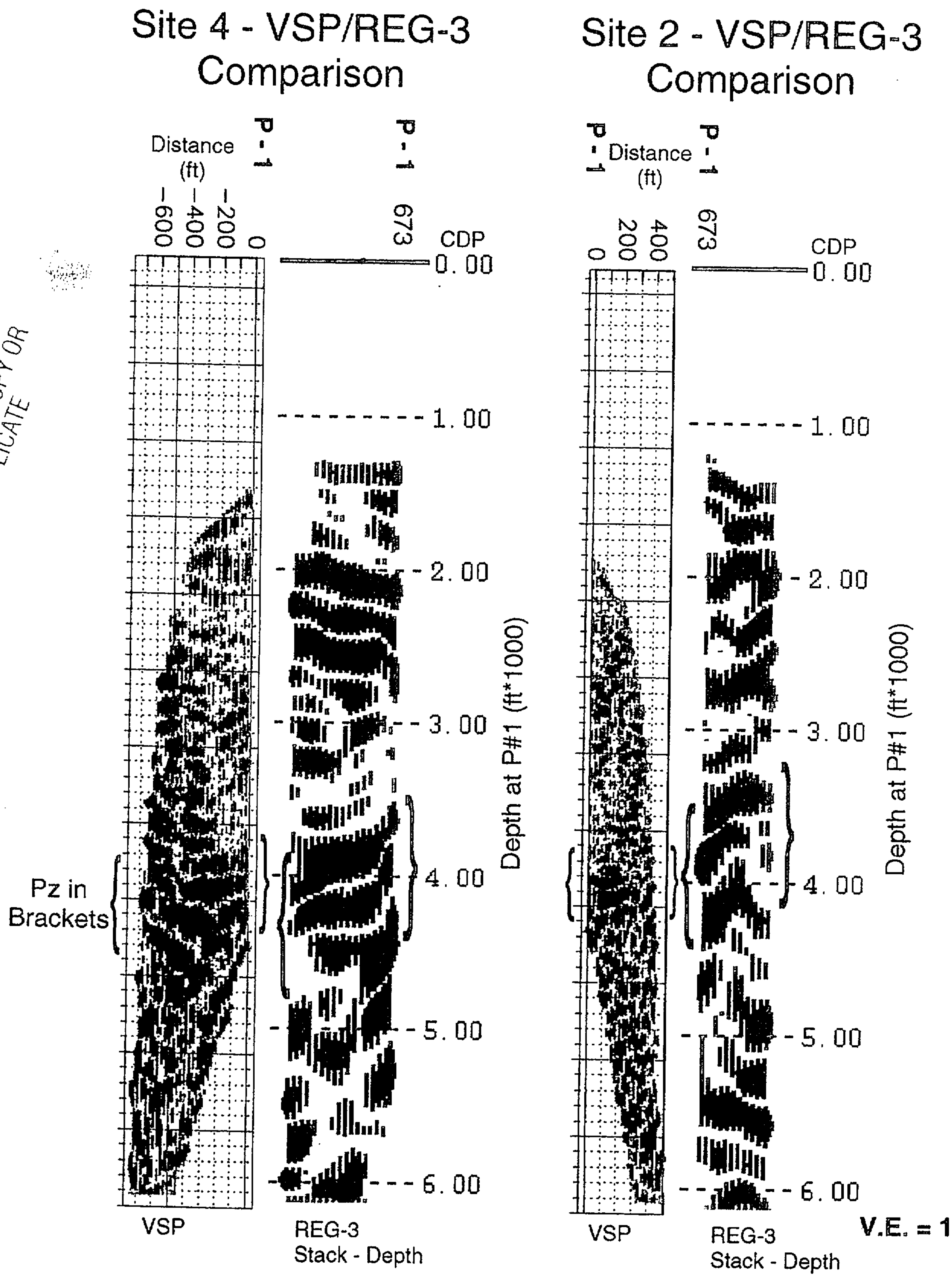



Figure 5. Three CDP gathers (672-674) from REG-3 seismic line. Well P#1 is at CDP 673. Data has been shifted to the surface elevation of P#1 (3655 feet) using a replacement velocity of 5000 ft/s. A reflection can be seen at the expected two-way travel time of the Paleozoic.








Fiugre 6. Comparison of the VSP data and REG-3 reflection data for Sites 2 and 4. The REG-3 reflected data shows a slightly greater westward dip at both sites and appears higher in the section at Site 2.

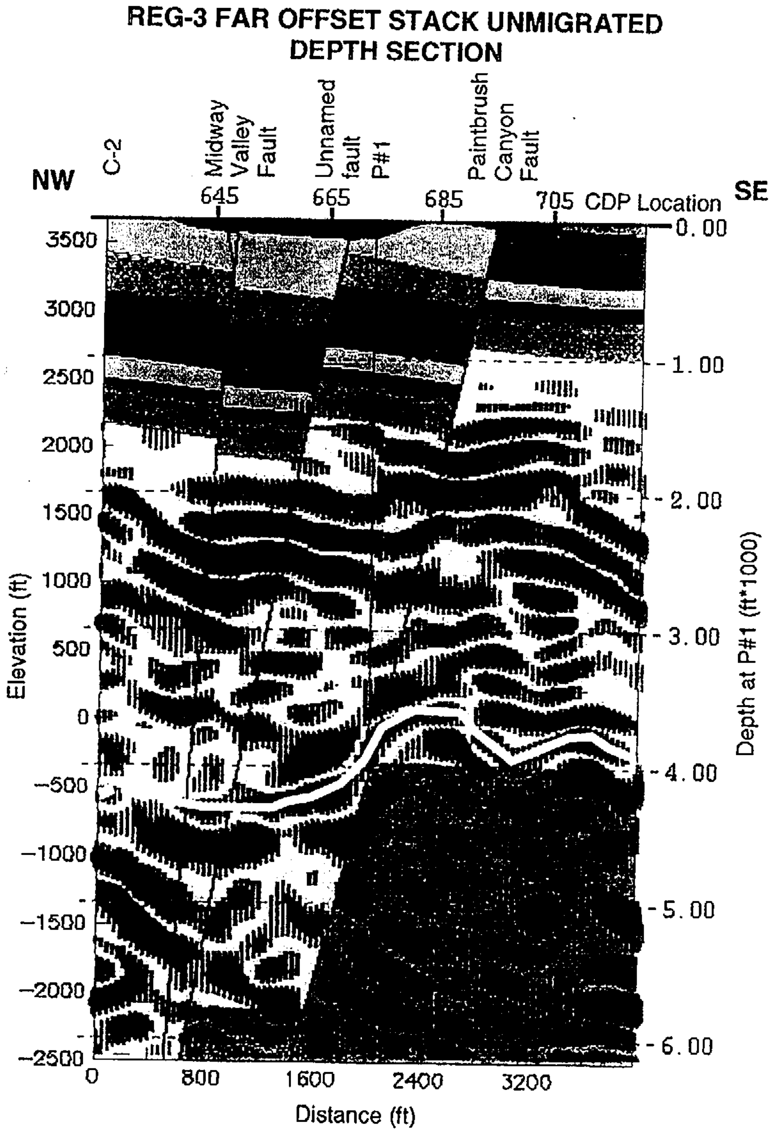



Figure 7a. REG-3 stacked depth section within 2000 feet of either side of P#1. Geologic model is shown for reference. Top of Pz (shown as white line) appears offset at P#1 with undulations to the east and generally flat to the west. The migrated data is shown in Figure 7b, from which offsets can be determined.

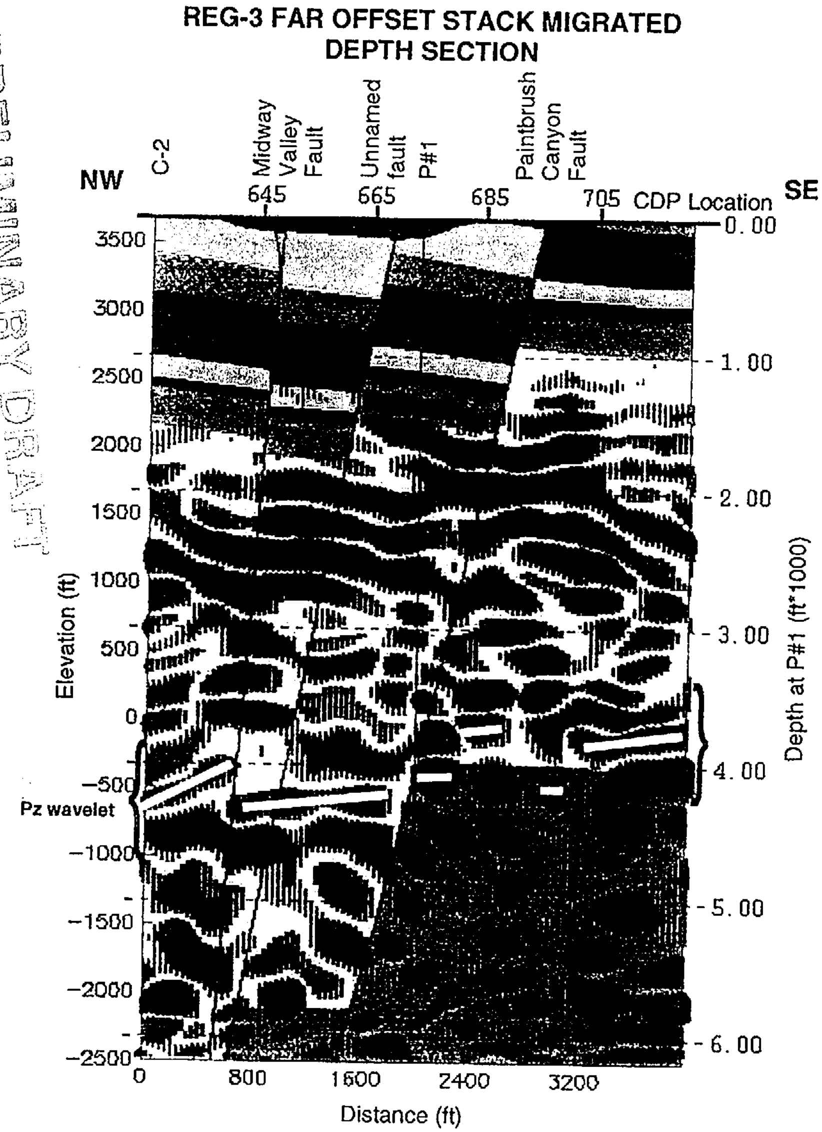



Figure 7b. REG-3 migrated depth section within 2000 feet of either side of P#1. Geologic model is shown for reference. Top of Pz (shown as white line) appears offset at P#1 about 100 feet and appears disrupted by other faults to the east and west with offsets generally in the range of 200 to 400 feet.

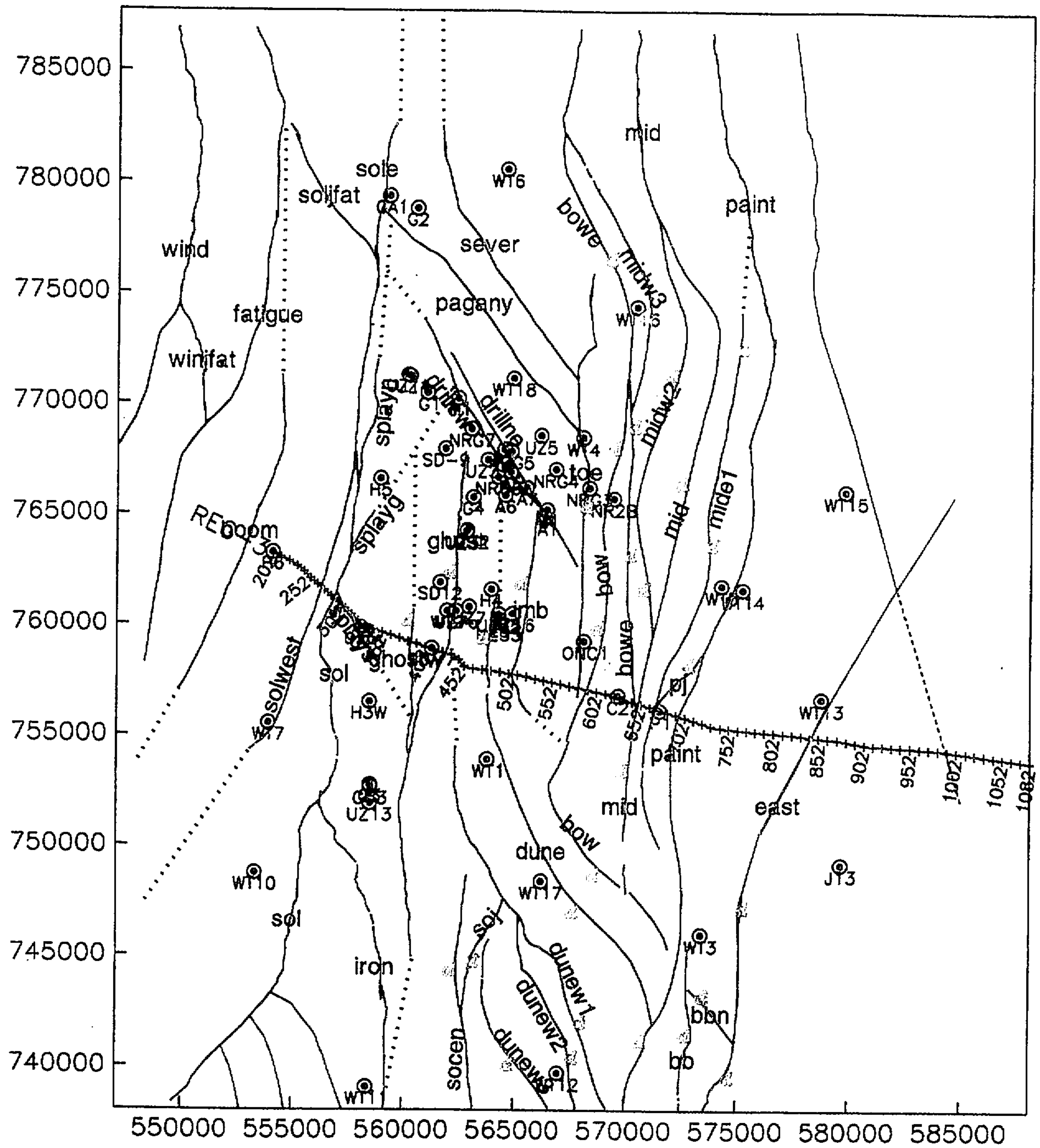



Figure A1. The ISM 2.1 surface fault traces (Clayton, 1998) with REG-3 CDP locations and boreholes.

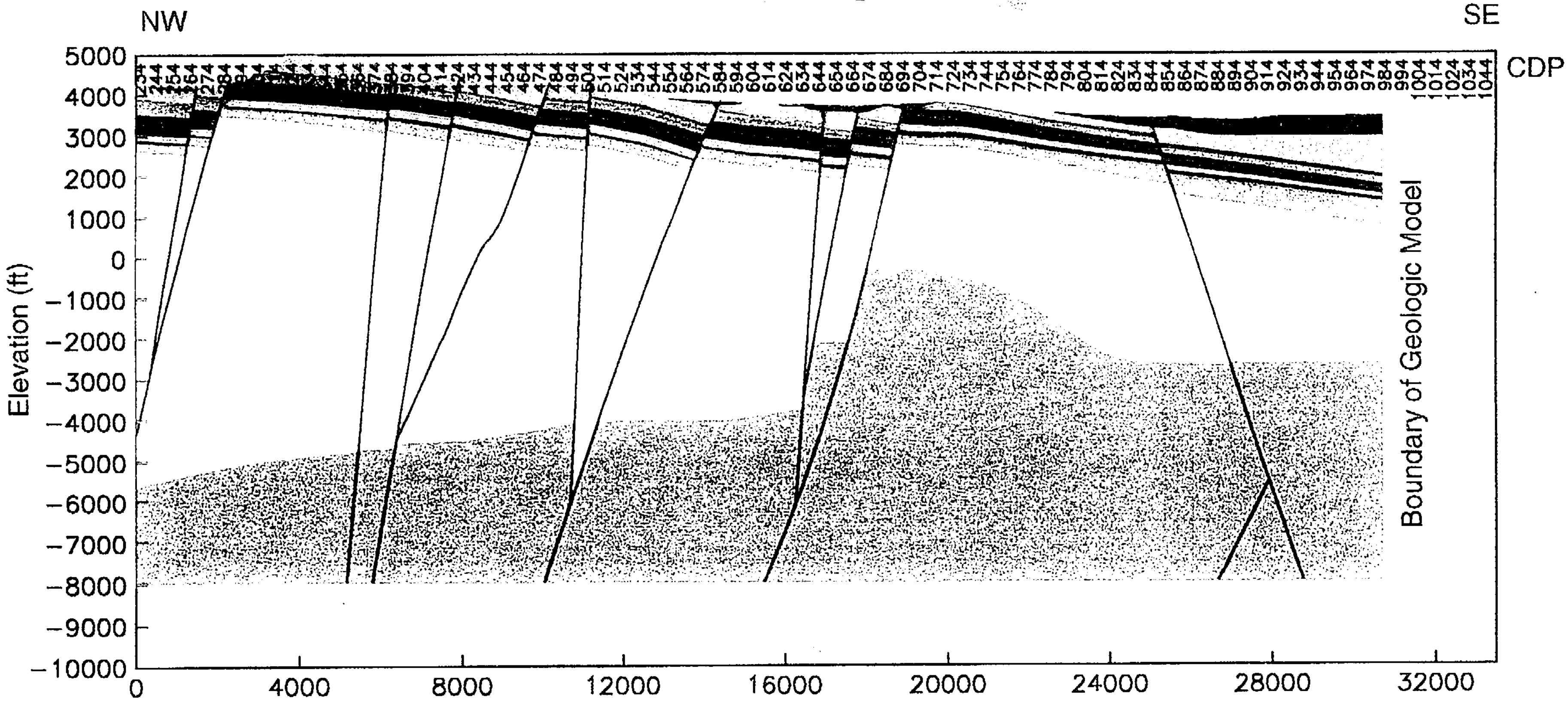



Figure A2. Cross-section of ISM 2.1 along REG-3 CDP locations. Key can be found in Figure 1b.

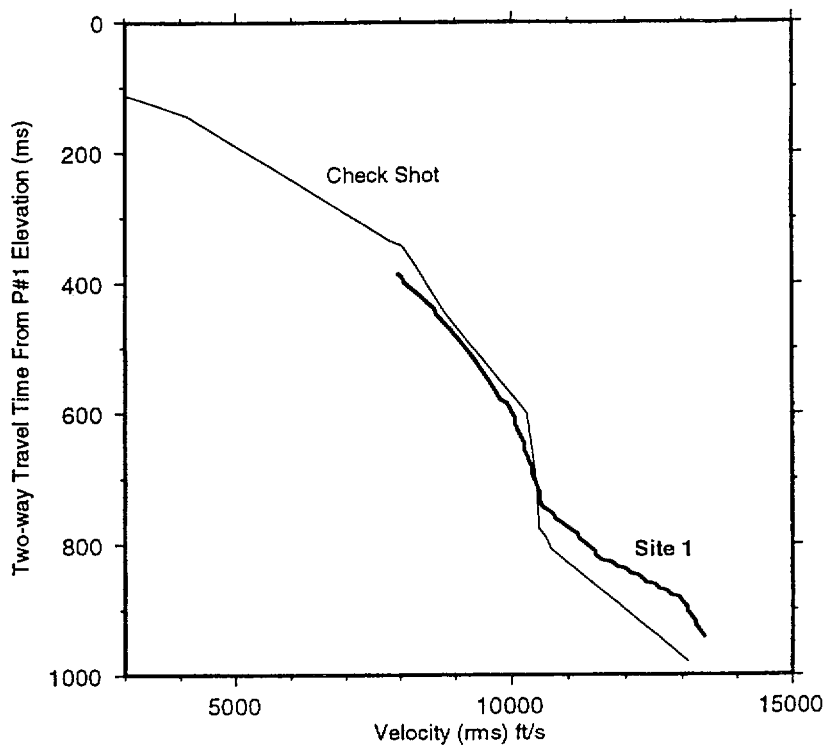



Figure A3a. Comparison of check shot velocity survey from Brocher et al. (1996) and that calculated at Site 1.

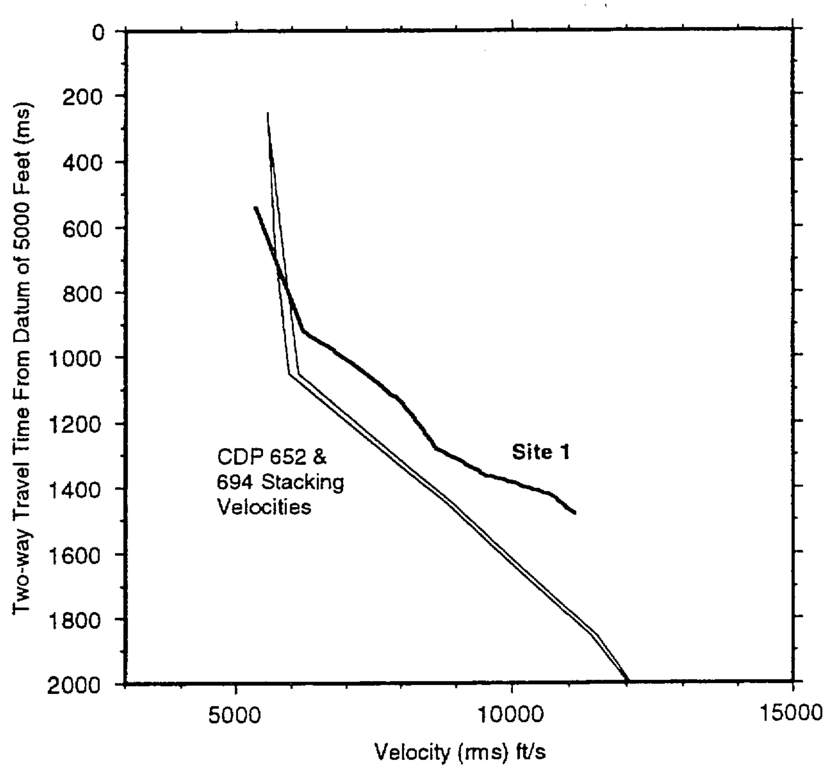



Figure A3b. Comparison of stacking velocities near P#1 from Brocher et al. (1996) and that calculated from Site 1. Data is referenced to the processing datum of 5000 feet.

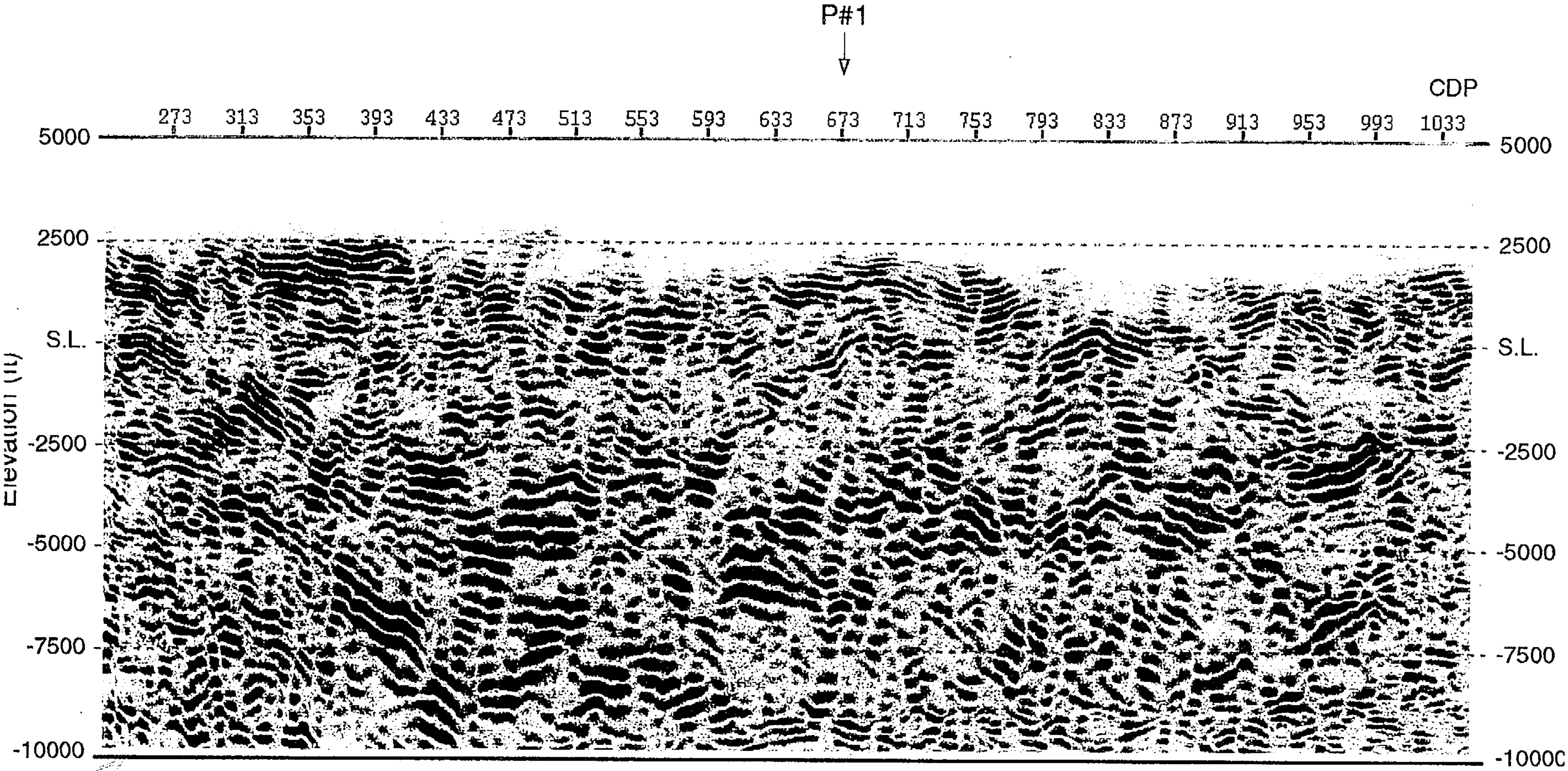



Figure A4. REG-3 Far-offset Final Stack converted to depth.

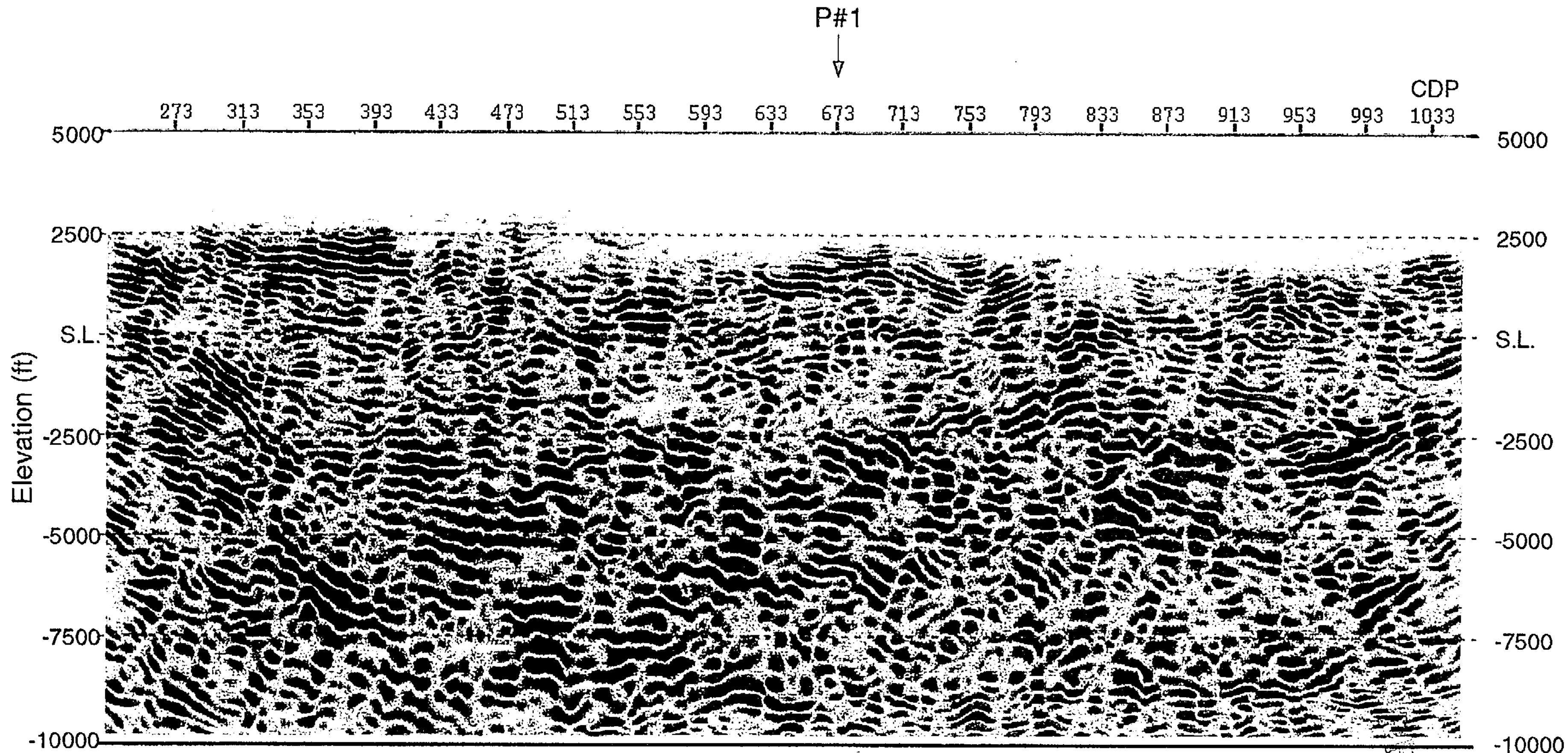



Figure A5. REG-3 far-offset migrated section converted to depth.

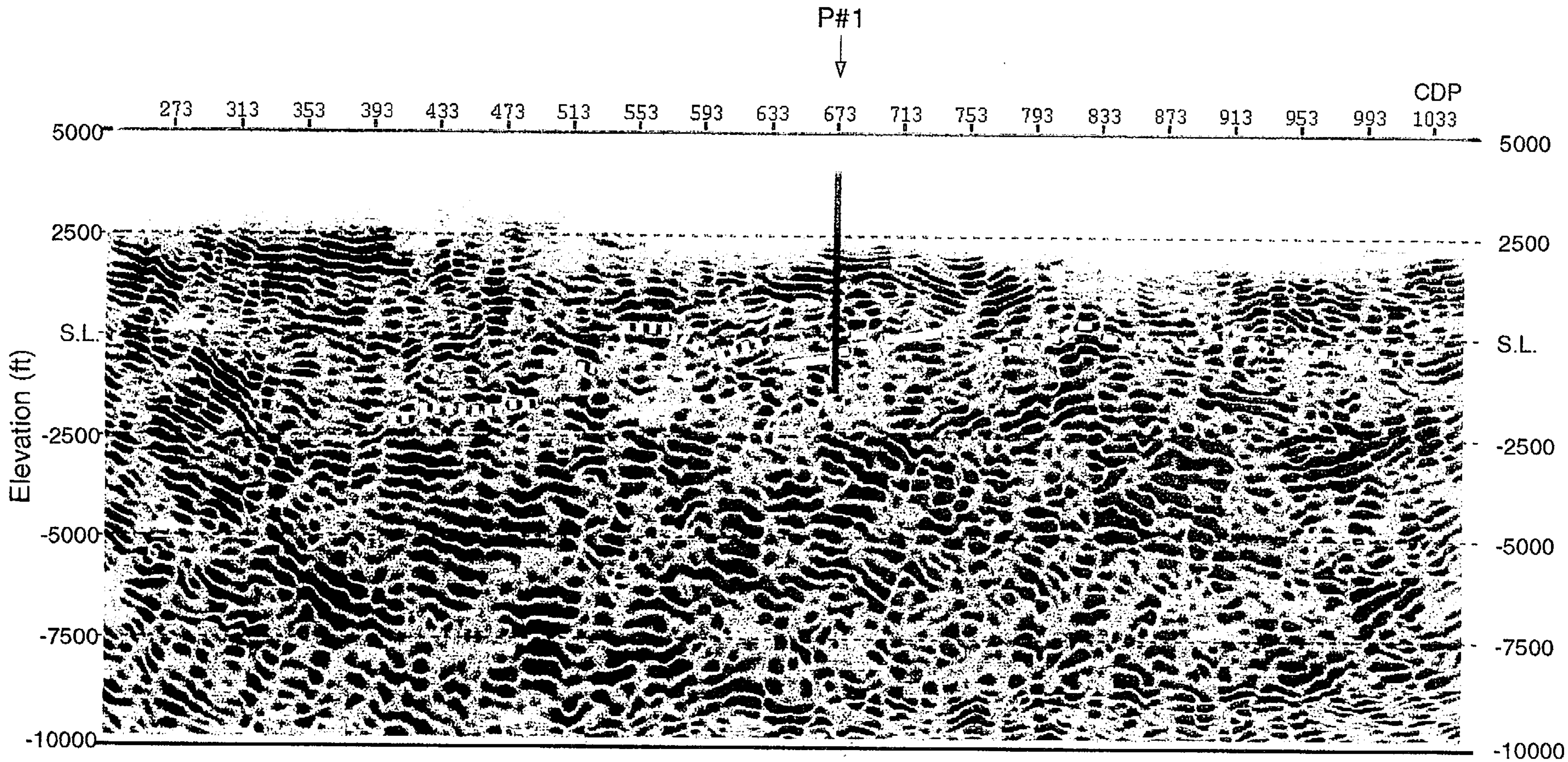





Figure A6. Interpretation of depth to Pz following shallower wavelets. This interpretation is more consistant with the gravity inversion results which indicate a higher basement east and west of P#1 and downward offset at Bow Ridge Fault.

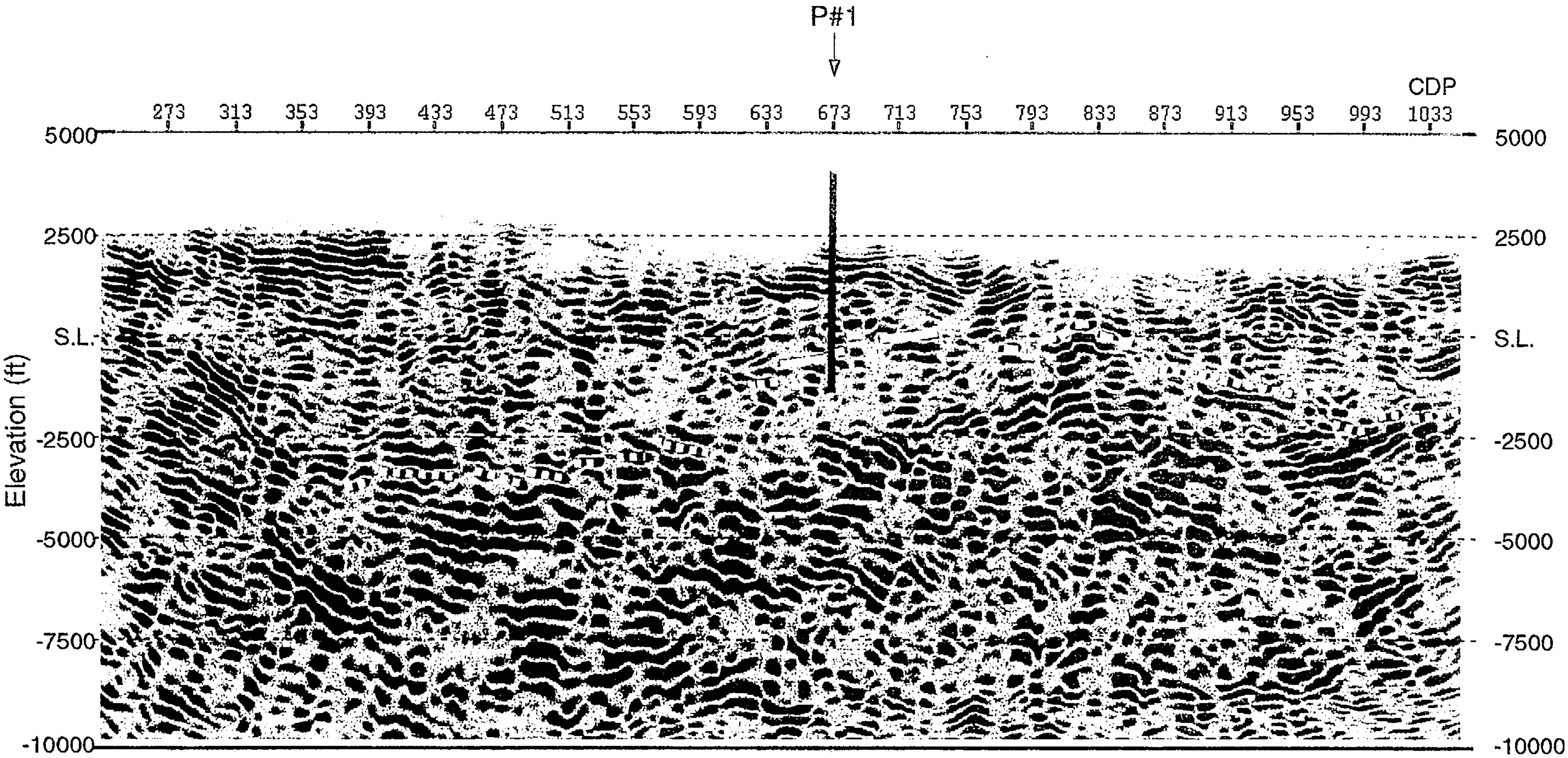





Figure A7. Another interpretation to the depth of Pz following deeper wavelets. In this model, most of the downward offset occurs near the Midway Valley Fault.

## DRAFT DISCLAIMER

This contractor document was prepared for the U.S. Department of Energy (DOE), but has not undergone programmatic, policy, or publication review, and is provided for information only. The document provides preliminary information that may change based on new information or analysis, and is not intended for publication or wide distribution; it is a lower level contractor document that may or may not directly contribute to a published DOE report. Although this document has undergone technical reviews at the contractor organization, it has not undergone a DOE policy review. Therefore, the views and opinions of authors expressed do not necessarily state or reflect those of the DOE. However, in the interest of the rapid transfer of information, we are providing this document for your information.

DATE: 1/6/97

TO: Ron Smith
CC: Larry Hayes
FROM: [redacted] T. GRANT
SUBJECT: Review of FY 1997 Baseline L4 Deliverable -- m/s SPT23LM4
M/S SPT23MM4

Please review the attached deliverable against the its criteria/description (also attached), provide an "FYI" courtesy copy of the deliverable to your DOE counterpart, fill out the next section of this form, and then forward the deliverable and this form back to me by 1/9/97 (i.e., within 3 working days). Thank you.

→ COPY SENT TO M. TYNAN

---

*(This section to be filled out by Technical Lead)*

- I have discussed this deliverable with my DOE counterpart:
  YES ____ NO ____

- Acceptance / rejection decision (please check one):
  - [initials] → X I accept this deliverable as satisfying the criteria
  - 8-8-97 ___ I reject this deliverable back to originator with required changes (which are specified under "Comments" below)
  - (X) I accept this deliverable "conditionally" and specify that it be held pending receipt from originator of information required to resolve rejection.

- Comments: Deliverable accepted 8-8-97 as meeting all required criteria. This package contains milestones SPT23LM4 and SPT23MM4

- Signature & today's date: Daniel J. Soeder 8-8-97

---

*(This section to be filled out by [redacted]) T. GRANT*

Date when SPO rec'd deliverable: 30-DEC-96
Date deliverable given to Technical Lead (TL): 6-JAN-97
Date when TL acceptance/rejection decision rec'd: ________
(if applicable:) Date deliverable returned to originator: ________

BERKELEY LAB

EARTH SCIENCES DIVISION

December 30, 1996

Larry R. Hayes
Scientific Programs Operations
M&O/TRW
MS 423/SU-427
101 Convention Center Drive
Las Vegas, NV 89109

QA:N/A

6.2.8 2/1/97

WBS: 1.2.3.11.2

SUBJECT: Level 4 Milestone ~~SP24LM4~~ SPT23LM4, "Regional Seismic Reflection Profile, Re: Processing Decision" by E.L. Majer

Enclosed, please find a copy of the above letter report entitled "Regional Seismic Reflection Profile, Re: Processing Decision" In accordance with YAP 5.1Q, this report fulfills Level 4 Milestone ~~SP24LM~~4. SPT23LM4 VF 1/2/97

Per YMP-LBNL-QIP 6. 1, technical reviews were performed by Y. Tsang and G.S. Bodvarsson and a quality assurance review was performed by D. Mangold. No technical data have resulted from this deliverable.

Sincerely,

Gudmundur S. Bodvarsson
Head, Nuclear Waste Department
Earth Science Division

GSB/mef

enclosure

cc: E.L. Majer
N. Biggar
RPC

ERNEST ORLANDO LAWRENCE BERKELEY NATIONAL LABORATORY

ONE CYCLOTRON ROAD | BERKELEY, CALIFORNIA 94720 | TEL: 510.486.7071 | FAX: 510.486.5686

Milestone: SPT 23LM4

Regional Seismic Reflection Profile

Re: Processing Decision

E.L. Majer, Lawrence Berkeley National Laboratory

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In the absence of Dr. David Okaya, Dr. James Rector of the University of California at Berkeley was asked to provide an assessment of the likelihood of improving the image with a different course of reprocessing.

Several areas of concern were noted; the low stacking velocities required to provide apparent reflections, and the large amount of "smiles" in the migrated sections. The data quality are poor in certain areas (e.g. over Yucca Mountain) and fair to good in certain other areas, such as the western edge of Crater Flats. A two phase approval was recommended, using existing reflectivity from UZ-16 and WT-2, model expected velocities and interfaces to determine realistic stacking velocities. Also, perform more detailed statics (refraction) and velocity studies in difficult areas. Also, it was suggested that a detailed migration image study be performed. With these suggestions however, it was not expected to have a dramatic effect on the outcome, but one may achieve a more accurate level of confidence in the data.

Therefore we recommend that we proceed with the approved suggestions of a modeling reprocessing strategy with the option of focusing on modeling if the reprocessing suggestion is yielding little improvement. Suggestions of Dr. David Okaya will be also considered when he completes his evaluations.

# MILESTONE DATA SHEET

**Last Updated:**

| | | | |
|---|---|---|---|
| **Milestone ID:** | SPT23MM4 | **Title:** | Modeling of Geophysical Data for Yucca Mountain |
| **M/S Level:** | 4 | **Responsible Org:** | LBNL |
| **Old FY95 WBS:** | | **PI:** | Maier |
| **FY97 WBS:** | 1.2.3.11.2 | **M+O Tech Lead:** | Smith |
| **FY97 Summary Acct:** | TR3B2FB2 | **DOE Counterpart:** | |

**Baseline/Target:** 03-Apr-97 **PACS Forecast:** **Mgr's Forecast:**

**Actual Finish:** 03-Apr-97

**Criteria:**

If the December decision milestone is to reprocess the regional seismic line, this April milestone will meet Criteria "A", below. If the December decision is that reprocessing would not add additional value to the Project, the April milestone will meet Criteria "B" below.

A: This milestone will be satisfied by a report containing a new seismic section of the regional line, and an explanation of the processing sequence. A copy of the reprcessed data will be annotated with interpreted major reflectors, seismic disruptions that could be interpreted as faults, as well as locations of the merging of data from intersecting seismic lines, and the intersection of the line with major mapped surface faults.

B: This milestone will be satisfied by the completion of a report describing the results of modeling geophysical data collected at Yucca Mountain. It will describe the modeling of seismic reflection data to investigate their time and amplitude consistency of the 3-D geologic framework model. Results of modeling potential field data will also be presented to determine the consistency of the total geophysics data set. The sensitivity of modeling results to selection of rock material properties will be discussed as well as implications for confidence in 3-D rock properties models. The report will describe the modeling methods used, the results of the investigation, the assumptions and data that were used, and the limitations of the approach.

For both A and B:

This deliverable shall be prepared in accordance with OCRWM approved quality assurance procedures implementing requirements of the Quality Assurance Requirements Description. The product shall be developed on the basis of the best technical data, including both Q and non-Q data. The Q status of data used and cited in the report shall be appropriately noted. Stratigraphic nomenclature used shall be consistent with the Reference Information Base section 1.12 (a): Stratigraphy-Geologic Lithologic Stratigraphy. Within the report's Reference Section, references to data used in the report shall include record Accession Numbers or Data Tracking Numbers when available. Technical data contained within the deliverable and not already incorporated in the Geographic Nodal Information Study and Evaluation System (GENISES) shall be submitted for incorporation into the GENISES in accordance with YAP-SIII.3Q. Verification of technical data submittal compliance shall be demonstrated by including as part of the deliverable: 1) a copy of the Technical Data Information Form generated identifying the data in the Automated Technical Data Tracking system, and 2) a copy of the transmittal letter attached to the technical data transmittal to the GENISES Administrator.

**Criteria Last Updated:**

**Status:**

**Status Last Updated:**

**Earned Value Status:** 0 **EV Status Updated:**

BERKELEY LAB

Earth Sciences Division

April 1, 1997

Larry R. Hayes
Scientific Programs Operations
1180 Town Center Drive
MS 423/1265
Las Vegas, Nevada 89134

WBS: 1.2.3.11.2

ATTN. Terry A. Grant, Planning and Performance

SUBJECT: In accordance with YAP 5.1Q, Level 4 Milestone SPT23MM4: "Completion of Regional Seismic Reflection Profile Reprocessing Part 2: Modeling of Seismic Reflection Profiles from Yucca Mountain", by E. L. Majer, M.A. Feighner, and T. Daley. Ernest L. Majer, PI.

Enclosed, please find a copy of the above analysis report entitled "Completion of Regional Seismic Reflection Profile Reprocessing Part 2: Modeling of Seismic Reflection Profiles from Yucca Mountain". This report fulfills Level 4 Milestone SPT23MM4. This report summarizes the evaluation and modeling of the regional seismic lines as well as modeling of the repository seismic lines.

Per YMP-LBNL-QIP-6. 1, technical reviews were performed by J. Peterson and D. Vasco, and a quality assurance review was performed by D. Mangold. Since no technical data have resulted from this deliverable, no technical data information form is included in this submittal.

Sincerely,

Gudmundur S. Bodvarsson
Head, Nuclear Waste Department
Earth Sciences Division

GSB/mhc

Enclosure:

cc: N. E. Bigger
R. C. Quittmeyer
G. S. Bodvarsson
E. J. Majer
M. Feighner
T. Daley
RPC

Ernest Orlando Lawrence Berkeley National Laboratory
One Cyclotron Road | Berkeley, California 94720 | Tel: 510.486.7071 | Fax: 510.486.5686