WBS 1.2.3.11.2 LBL Surface-Based Geophysical Testing

LBL Principal Investigator - Ernest L. Majer

Narrative of work performed

Objective of Work/Background

The work involved in the detection and mapping of lithology, structure, faults, and fractures at Yucca Mountain using surface geophysics is divided into four basic tasks, high resolution seismic imaging using surface reflection and VSP, gravity, electrical, and magnetics. LBL is responsible for the seismic, gravity, and electrical work in FY 95, and the USGS is responsible for some additional gravity and all of the magnetic work. LBL is also working with the USGS to synthesize the data into a geophysical model that will be used to constrain the geologic and site scale models. In FY 94, three seismic reflection profiles were acquired in the region of the wells WT2, (line Yucca-1, or Line-1, starting east of UZ16 and running up the road past WT2), NRG6 (line Yucca-2, or Line-2, starting at NRG7 and running down the road in Drill Hole Wash past NRG6 to the edge of the corporation yard) and a line along the crest of Yucca Mountain starting at UZ6 and extending approximately 3000 feet north along the crest road towards H-5 (line Yucca-3, or Line -3). Detailed VSP's, multicomponent using P-, and S-wave sources, were also acquired in WT-2 and NRG-6 to constrain and aid in the interpretation of the seismic reflection. The principal reason for the work was to image from the near surface to at least the repository horizon and below if possible. The objective was to provide information on faulting/fracturing and structure/lithology to provide input to ESF design activities. In addition these data would also provide information on geologic structure for input and control of the three-D site rock characteristics model. From this work the following conclusions were made:

Line 1

1. It seems that we have traversed a zone of faulting in this line that extends from just west of UZ-16 to the Ghost Dance Fault.

2. As seen in the VSP data and results, significant faulting extends to depth. No

conclusions on dip or final extent of faulting can could be reached from this set of data.

3. The interpretation indicates that the direction of dip of structure and faulting is consistent with known values.

Line 2

1. The reflections are discontinuous and indicate cross faulting along the line to a considerable depth, this is consistent with the VSP results at NRG-6

2. The complexity of faulting along Line 2 is greater than along Line 1, however, this may due to the oblique angle at which each line was run relative to the main structure.

In general we were pleasantly surprised on the ability of the seismic reflection methods to image the subsurface. Care must be taken to properly set survey parameters and in the processing of the data. It appears that in the region of these two lines there is significant faulting extending to well below the repository horizon. From the preliminary application and processing of the data, however, care must be taken not to over interpret the data or draw too strong a conclusion about the subsurface until greater experience and validation of the seismic reflection is obtained. There were also gravity data acquired along the WT-2 UZ-16 line by the USGS that confirmed the major faults detected by the seismic survey, and led to the conclusion that gravity data would be useful in the geophysical characterization effort.

Because of these conclusions and success, a larger scale seismic and gravity program was planned for FY 95, based on the work in FY 94. However, the work did show that the seismic and gravity data alone could not determine the hydrologic nature of the faults. For this reason the magnetic and electrical work were added for FY 95. Past electrical work at Yucca Mt. had mixed success at best. The Tuff is very resistive and difficult to resolve structure in using electrical methods. However, a new approach of using continuous profiling magnetotellurics (MT) could possibly resolve important conductive features. The approach is similar to seismic reflection, in that a continuous profile of stations at relatively close spacing (50 to 100 meters, which is close for MT) is acquired. Recent advances in interpretation and inversion methods have allowed this approach to be performed.

The approach in the MT work is to perform a preliminary profile on 2 kilometers of Line 3, Figure 1, across the Ghost dance fault region to determine its sensitivity and resolution. At that point a decision will be made on where to use the methodology. The technique is very expensive (two to three times the cost of seismic coverage) and its use may not be justified in the same quantity as the seismic reflection. However, over critical features as the Ghost Dance fault and the sharp water table gradient, it may provide critical information on hydrogeologic parameters.

FY 95 Plans

The plan for FY 95 was to perform high resolution seismic reflection on Lines 1, 2, 3, 4, 5, 6, 7, 7a, (short cross line perpendicular to the Yucca Wash faulting) 8, 9, 12. These lines sample a variety of geologic conditions and features of interest to the project. In addition four short lines on the pad of UZ-7a would be acquired at very high resolution (1 meter group spacing, using a hammer source) to determine the detailed fault structure in this region, hopefully to a depth of at least 500 meters, i.e., Lines 13, 13a, 14, and 14a, Figure 1. The electrical work would start on Line 3, across the Ghost Dance Fault region to determine the MT sensitivity and resolution. Depending upon the results of this line, the MT method may be employeed on some, or all of the other lines on which seismic was run. Gravity was to be run on all lines shown in Figure 1, (except on Lines 7, which has already been run) and on the regional seismic lines acquired by the USGS. Magnetic data was also scheduled to be collected on all lines in Figure 1 by the USGS. The schedule was to have all gravity and seismic data acquired by the end of February, 1995, and the MT acquired on Line 3 by the end of January, 1995.

Progress to Date:

<u>OB3B2L95A South and North-South ESF Alignment, Gravity, Electrical, and Seismic (Lines 1, 10, and 11)</u>

- All Gravity and Magnetic data has been acquired on Lines 1, 10, and 11. The USGS is processing the magnetic data, see Appendix 1 for the results of the Gravity data. (see next section for an explanation of electrical work)

OB3B2L95B Repository Region, Gravity, Electrical, and Seismic
(Lines 2, 3, 4, 5, 6, 7, 7a, 8, 9, 12, 13, 13a, 14, 14a)

- All seismic reflection data has been collected on all lines. Magnetic and gravity data has been collected on all lines except for lines 13, 13a, 14, and 14a, which no gravity and magnetic acquisition were planned.

- MT was collected on 2 kilometers of line 3 across the Ghost dance fault. Both controlled and natural source measurements were made with two horizontal (N-S and E-W oriented coils) sets of receivers. The frequency range varied from 10 hertz (natural source) to 20,000 hertz for the controlled source. From the preliminary in-field processing, the Ghost Dance Fault does show up as an electrical anomaly. However after further processing the data were very noisy due to equipment problems and weather difficulties. A second attempt at acquisition is planned for May in which different electrodes (copper sulfate filled clay pots versus iron rods) will be used to improve the signal to noise ratio. In addition vertical component electrodes will also be used to give better resolution on the location of vertical features (faults)
- See Appendix 1 and 2 for the results of the gravity and seismic data processing efforts.

OB3B2L95C Gravity on Regional Seismic Lines

- All gravity collection was completed on the regional seismic lines. see Appendix 1 for a discussion of the results. The data were acquired at 100 meters intervals along these lines.

Quality Assurance and Training

- All reading assignments were completed and QA reviews completed. As a result of the QA surveillance performed on the seismic field work three issues were identified and corrected.

Operations

Changes in Future Plans:

- All seismic and gravity data acquisition is proceeding on schedule or ahead of schedule. The electrical work is behind schedule due to difficulty in obtaining the data, i.e., equipment problems and the high surface resistivity of the ground at Yucca Mt. Lines 3 and 4 will be extended to the east to tie to line 6. Gravity and Seismic will be carried out on these portions of the lines. In addition two seismic and gravity lines will be acquired in the Rock Valley area in the vicinity of Little Skull Mt.

Problem areas:

- The surveying has lagged behind the geophysical work. This is delaying the processing of the seismic and gravity data. We are also awaiting topographic information from EG&G to perform the final processing on the gravity data.

YUCCA MOUNTAIN
SITE CHARACTERIZATION PROJECT

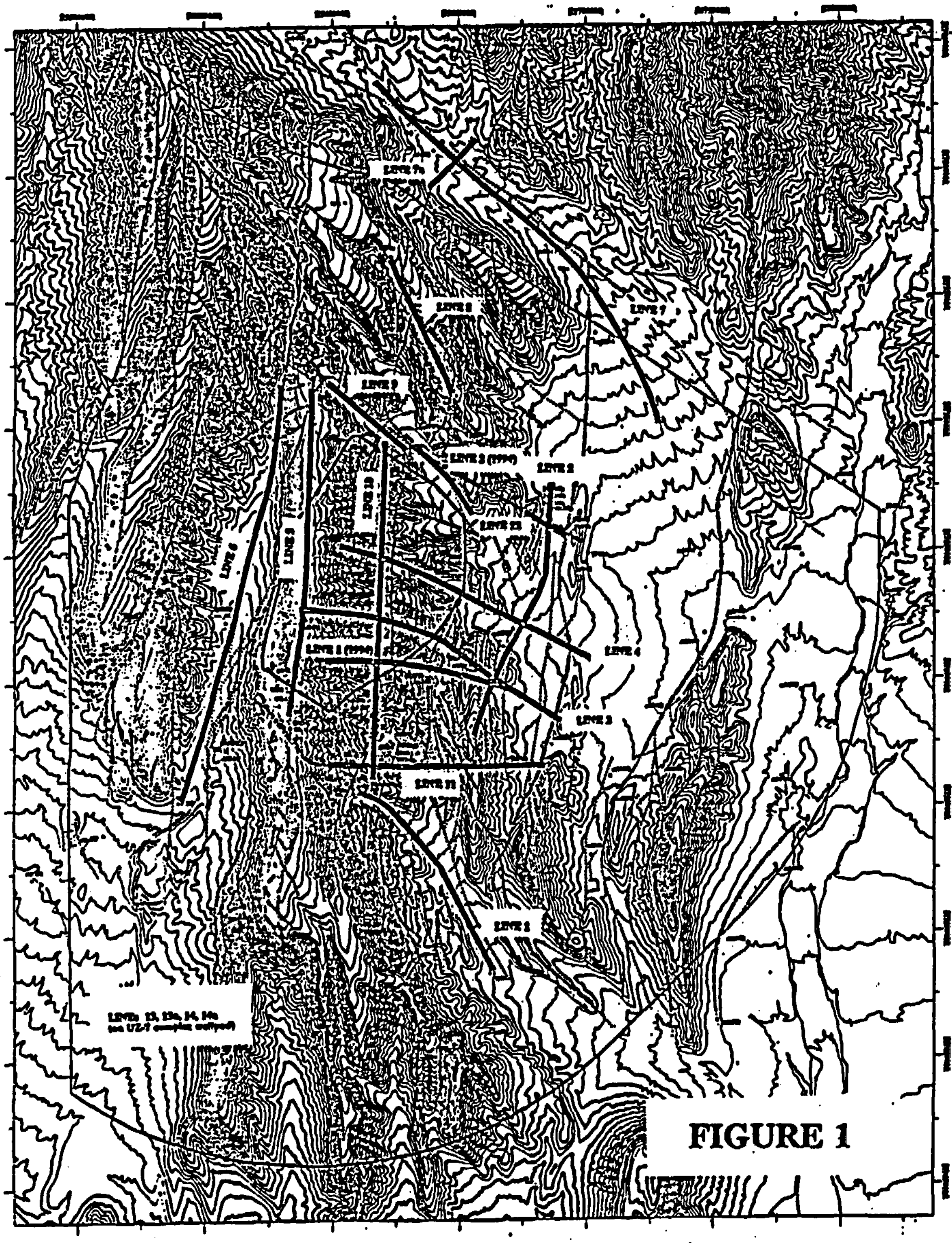


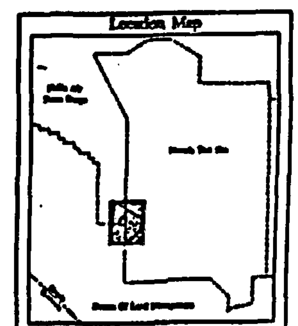
FIGURE 1

Faults

Legend

- Existing Borehole
- Planned Borehole
- Fault
- Inferred Fault
- Concealed Fault
- Fault Scarp
- Fault That Cuts Alluvium
- Dike Intruded Along Fault
- Fault Indicated by Aeromagnetic Anomaly
- Fracture
- Facture Set
- ESF Ramp
- Potential Repository Outline
- Conceptual Controlled Area Boundary

Contour Interval Is 40 Feet



Appendix 1 - Gravity Measurements at Yucca Mountain

Introduction

This appendix describes the initial phase of a surface gravity survey performed by Lawrence Berkeley Laboratory (LBL) at Yucca Mountain. This work was performed as part of the site characterization effort for the potential high-level nuclear waste repository. The objective was to provide regional and detailed gravity coverage both within the proposed repository area and in the area surrounding Yucca Mountain. This work is meant to complement the other geophysical surveys currently being conducted and has as primary goals the broad interpretation of geologic substructure, the delineation and interpretation of faults and fault systems, and the nature of recent movement along such faults.

This report describes the procedures used in the collection of the gravity data and the subsequent processing of the acquired data. Only minor attention is given to the interpretation of the processed data; the principal reason being that at the present time the available topographic data is insufficient for complete processing. Detailed interpretation of the gravity data and comparisons with other geophysical data will be presented in a later report.

Equipment and Calibration

The vertical acceleration of gravity was measured with two LaCoste and Romberg Model G gravity meters. The serial numbers of these meters are 244 and 531. The meters were read manually for all of the data collected in this project.

The meter calibration factors for the general region that includes Yucca Mountain were determined on the basis of four different runs on the Charleston Peak gravity calibration loop (Ponce and Oliver, 1981). The results of these calibration runs are contained in Tables 1 and 2. The mean values shown in these tables were obtained as maximum likelihood estimates of the average of the four individual runs. These mean values were used in the reduction of all the data collected as part of this project.

All gravity measurements were tied to the absolute gravity station MERCA, which is located in the U.S. Geological Survey Core Library building in Mercury, Nevada (Zumberge et al., 1988). The value of gravity at floor level which was used for this station was:

$$g = 979518.874 \ mgal$$

Each day of gravity measurements began and ended with a reading at this station, which served as the base station for all gravity measurements for this project.

Data Acquisition Procedures

The two gravity meters were operated in tandem for all of the survey lines. The meters were used in a leap frog fashion along the lines with the measurement at a minimum of every tenth station being duplicated by both meters. This provided redundancy in at least 10% of the readings and helped identify any possible tears or discontinuities in the data. All key points, such as the beginning and ending stations on all survey lines and the first and last stations for each day, were always read with both meters.

Data Reduction Procedures

After the removal of the effects of the solid earth tides, a drift correction was estimated for each meter for each day. This correction was based on all stations which had been occupied more than once by the same meter in the same day and assumed that the drift was linear in time. The drift rate was estimated with a least squares procedure using a weighting factor proportional to the time duration between two measurements at the same station. This calculated drift, which typically had a maximum value of less than 0.05 mgals, was then removed from the readings for that day.

After correction for solid earth tides and meter drift, all measurements were referenced to the value at the base station MERCA. The data collected with the two meters were then combined for each station where gravity had been measured more than once. For these stations a mean and standard error was obtained and the mean value used in all further calculations for that station. The standard errors were used to detect any errors in the reading or recording of the data.

A standard free air gravity anomaly was then estimated by removing the effects of gravity on a reference ellipsoid and the elevation of the station. A Bouguer anomaly was also calculated by assuming a density of 2.67 gm/cm^3 below an elevation of 900 *meters* and a density of 2.10 gm/cm^3 above an elevation of 900 *meters*. This use of two densities was an attempt to take account of the fact that the rocks near the surface in the vicinity of Yucca Mountain are known to have densities that are less than the average value for the crust. Later analyses of these data will incorporate a more complete Bouguer correction.

The data have not yet been corrected for topographic effects. These will be calculated when topographic data for the Yucca Mountain region becomes available.

Gravity Data Acquired

To date gravity data have been collected for 14 lines, which includes 2 regional lines and 12 lines at the repository. Survey data for the positions of the stations have been received for 7 of these lines and preliminary data reduction has been completed for these lines. Survey data for the other 7 lines have still not been received, so no preliminary processing has been attempted. Terrain corrections and complete Bouguer anomalies have not been calculated for any of the lines. The list of the lines where gravity data have been collected and the present status of processing is contained in Table 3.

The details of the gravity measurement procedures for the 14 lines mentioned above are given in Table 4. To date about 4240 gravity measurements have been made in this project.

Preliminary Results

Figures are included that contain preliminary plots of elevation and both free air and Bouguer gravity anomalies along 5 of the lines. These include regional lines 2 and 3 which traverse Yucca Mountain. Regional line 2 starts over 20 km to the west in Amargosa Valley and extends east of the crest of Yucca Mountain. Regional line 3 starts west of the crest of Yucca Mountain and extends east about 10 km into Midway Valley. A preliminary interpretation of the regional lines suggests significant displacements on faults both to the west and east of Yucca Mountain. Repository lines 4, 9, and 12 all lie within the Yucca Mountain area. The repository lines have small offsets

Table 3.

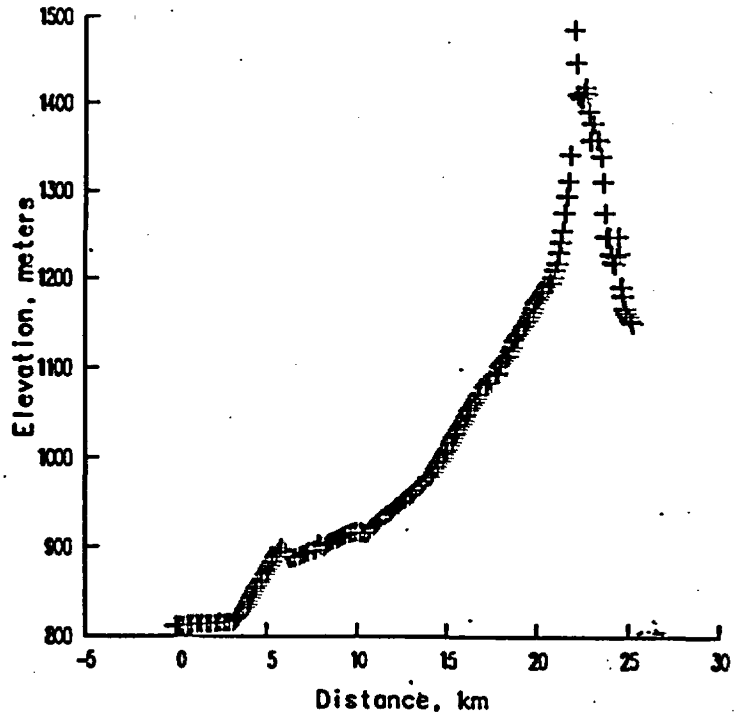
Line Number	Survey Data Collected	Complete Processing	Partial Processing	Processing Status
Reg. 2	yes	no	yes	Awaiting terrain data and correction
Reg. 3	yes	no	yes	Awaiting terrain data and correction
Rep. 1	no	no	no	Awaiting survey data; processing
Rep. 2	yes	no	yes	Awaiting terrain data and correction
Rep. 3	yes	no	yes	Awaiting terrain data and correction
Rep. 4	yes	no	yes	Awaiting terrain data and correction
Rep. 5	no	no	no	Awaiting survey data; processing
Rep. 6	no	no	no	Awaiting survey data; processing
Rep. 7a	no	no	no	Awaiting survey data; processing
Rep. 8	no	no	no	Awaiting survey data; processing
Rep. 9	yes	no	yes	Awaiting terrain data and correction
Rep. 10	no	no	no	Awaiting survey data; processing
Rep. 11	no	no	no	Awaiting survey data; processing
Rep. 12	yes	no	yes	Awaiting terrain data and correction

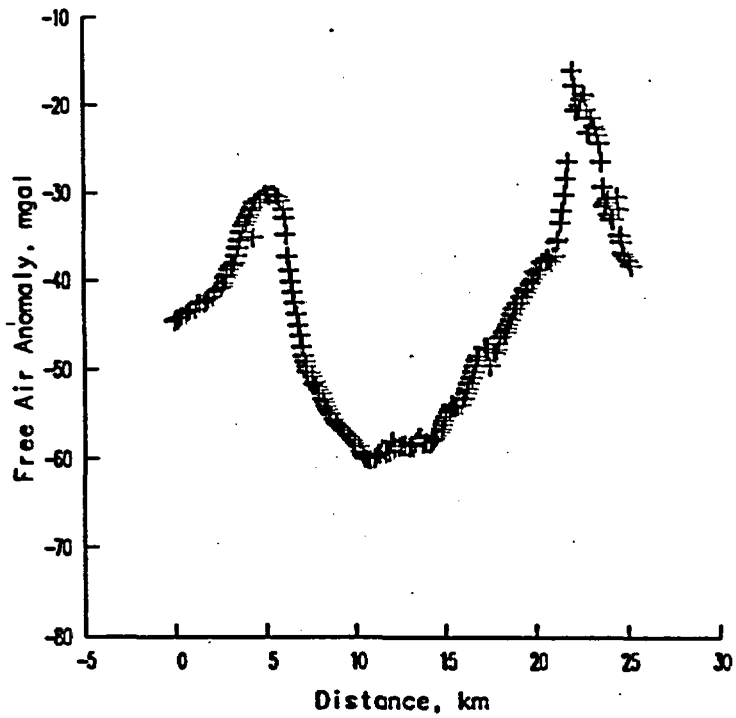
Fig. 2. Gravity line processing parameters. Chart details the present level of processing completed for a given line. Partial processing indicates that the gravity data has been reduced and Bouger corrected with no terrain correction having been applied. Complete processing indicates that the data has additionally been corrected for terrain effects. The level of processing depends heavily on the availability of both survey data (station coordinates; elevation) and digital topographic data. For those lines where survey data has yet to be collected, no level of processing has been undertaken. In all cases, digital topographic data has yet to be supplied and therefore no complete processing has been performed at this time.

Table 4.

Line Number	Line Length	Number of Stations	Station Interval	Measurement Interval	Date Collected
Reg. 2	25,825 m	1033	25 m	100 m	12/2/94-12/6/94
Reg. 3	11,025 m	441	25 m	100 m	12/8/94-12/9/94
Rep. 1	3,168 m	264	12 m	48 m	2/3/95-2/4/95
Rep. 2	2,604 m	217	12 m	48 m	2/1/95
Rep. 3	3,804 m	317	12 m	48 m	2/1/95-2/295
Rep. 4	4,032 m	336	12 m	48 m	2/4/95-2/6/95
Rep. 5	4,656 m	388	12 m	48 m	2/2/95-2/3/95
Rep. 6	5,088 m	424	12 m	48 m	2/14/95
Rep. 7a	372 m	31	12 m	48 m	2/13/95
Rep. 8	2,856 m	238	12 m	48 m	2/15/95
Rep. 9	1,164 m	97	12 m	48 m	2/4/95
Rep. 10	4,650 m	93	50 m	50 m	2/22/95-2/23/95.
Rep. 11	7,750 m	155	50 m	50 m	2/15/95-2/16/95
Rep. 12	624 m	208	3 m	24 m	2/14/95-2/15/95

Fig. 1. Gravity line data paramenters. Chart details those lines currently under consideration within the repository area and the outlying regional area. Note that the measurement interval within the repository area varies slightly for lines 10 and 11. These lines were surveyed only using gravimetric means; no seismic reflection data has been gathered along them.





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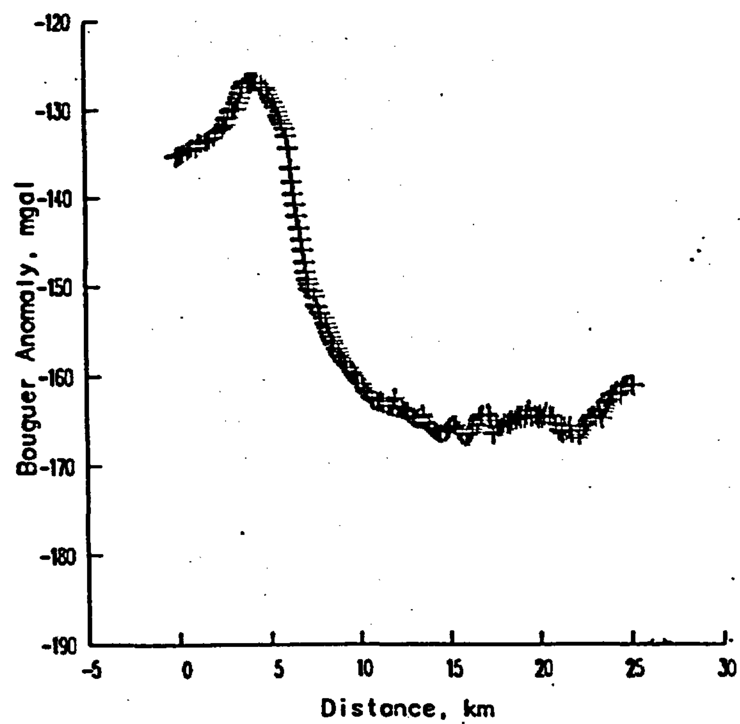
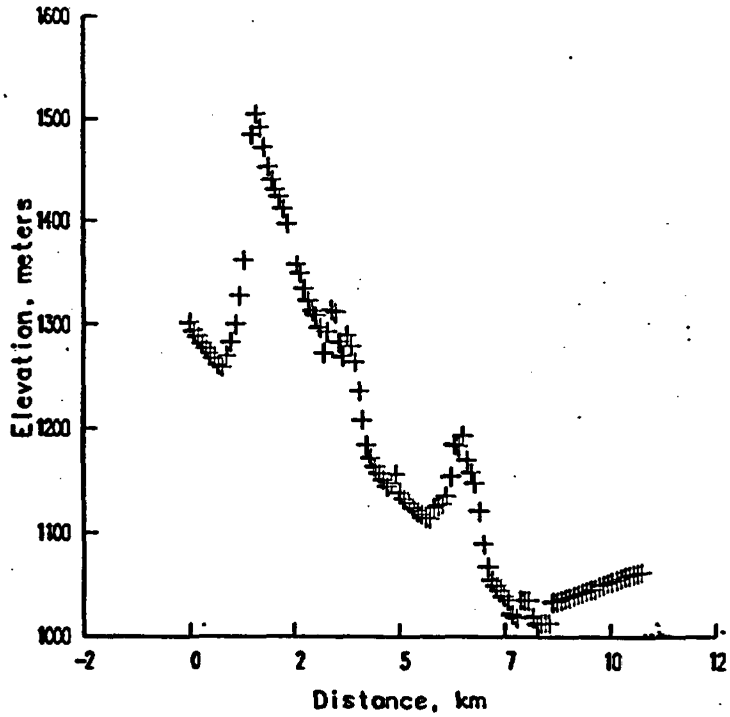
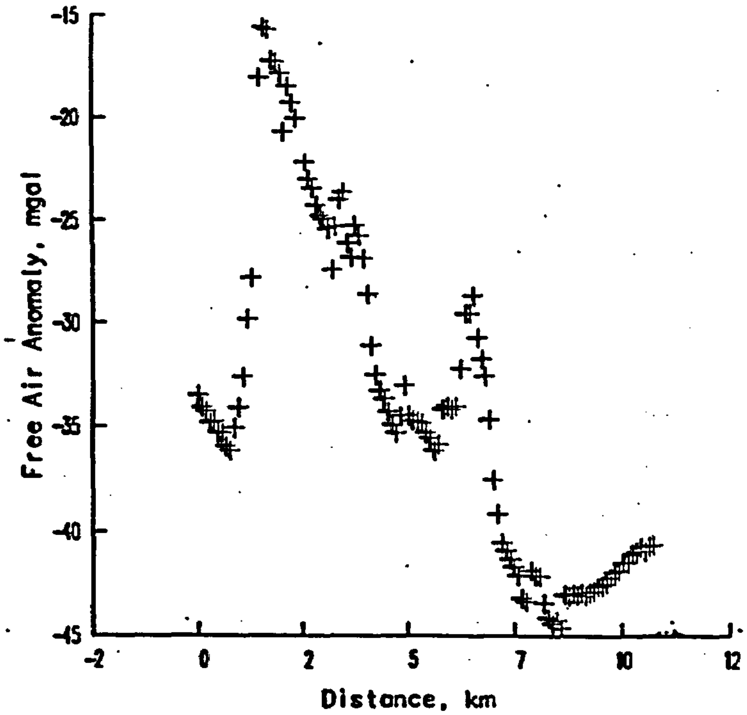
Regional Line 2

This is the longest of the lines, traversing NE from the edge of the Amargosa Valley, past Black Butte, traversing Crater Flat and Solitario Canyon, and across Yucca Mountain.

The Bouguer anomaly drops dramatically (by about 20 mgal) after about 5 km, indicative of a near surface density change. The overall Bouguer drop in this region corresponds to the entrance into Crater Flat, a deep sedimentary valley.







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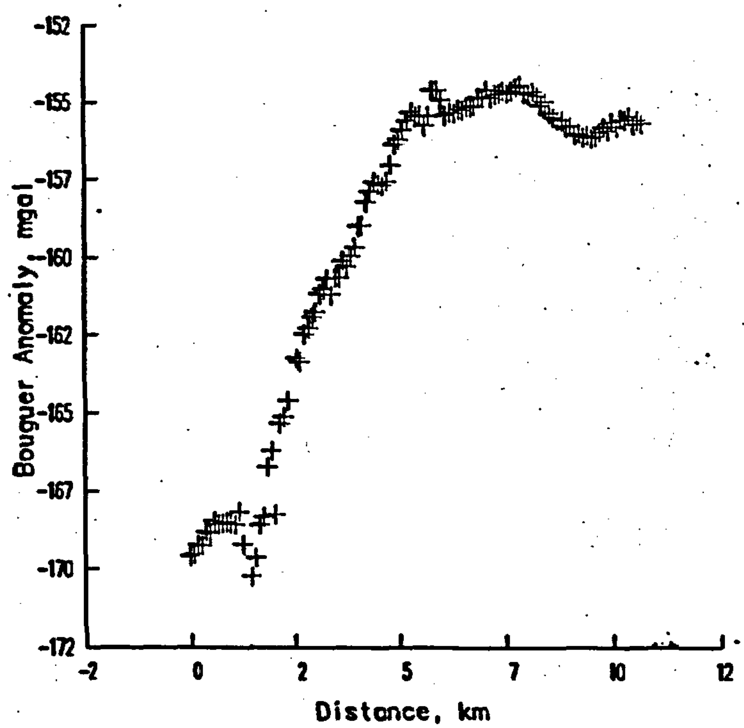
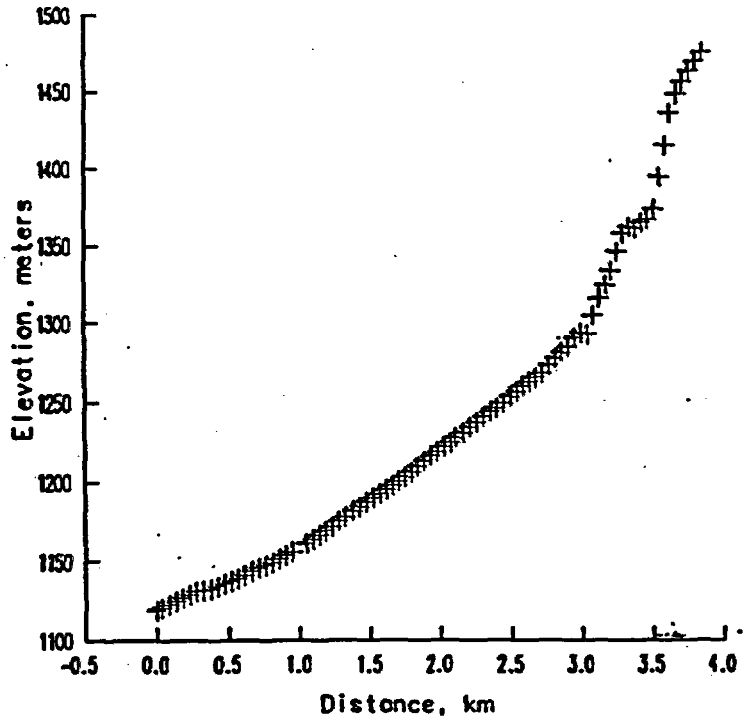
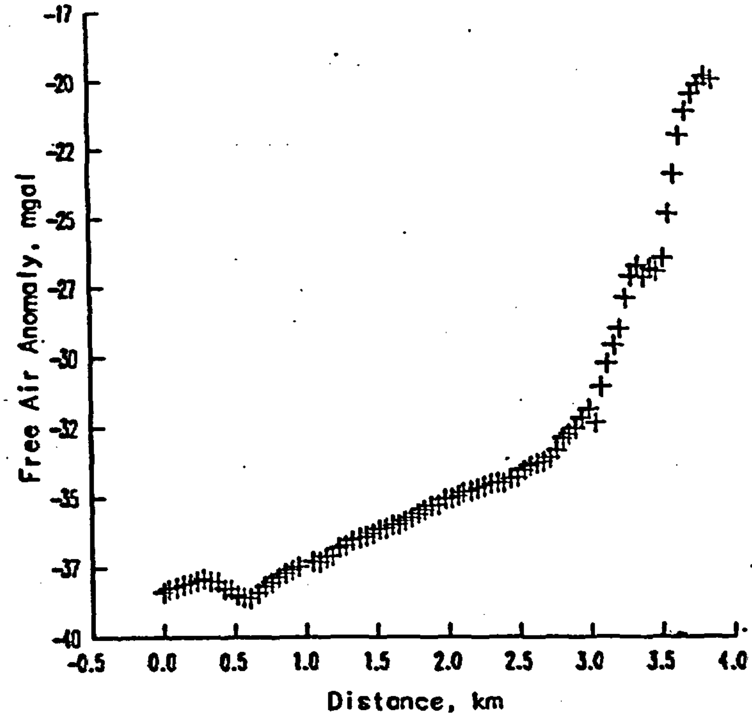


Regional Line 3
This line crosses over Yucca Mountain from Solitario Canyon and extends far to the East into Midway Valley.





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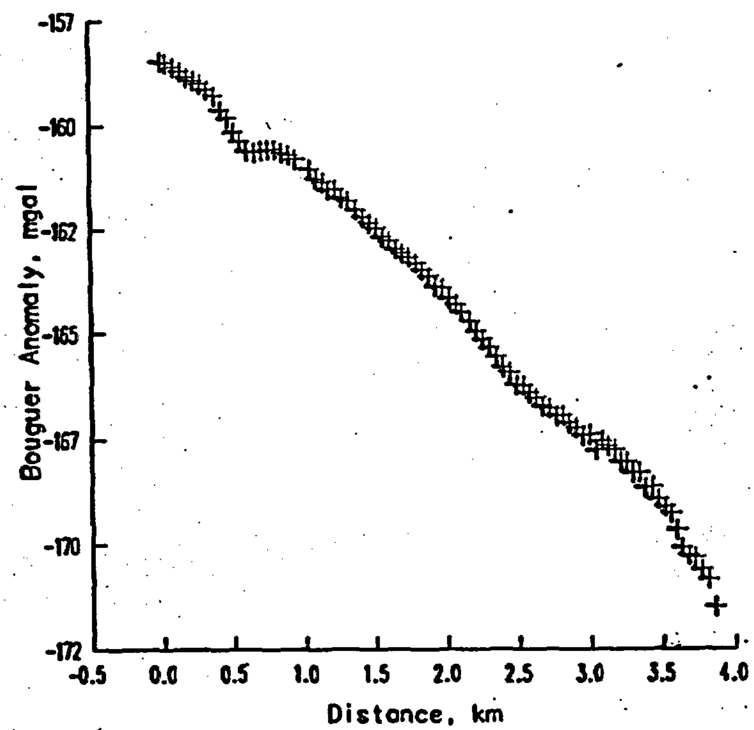
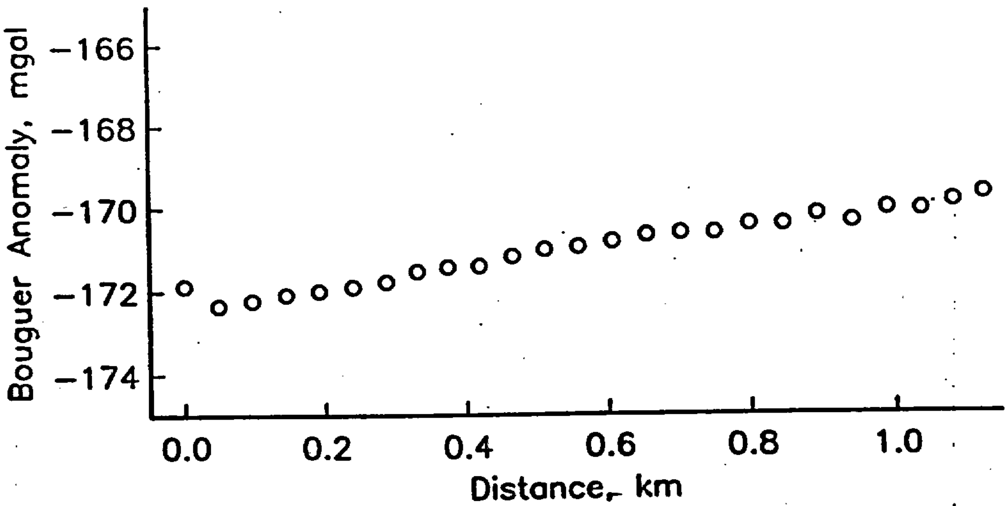
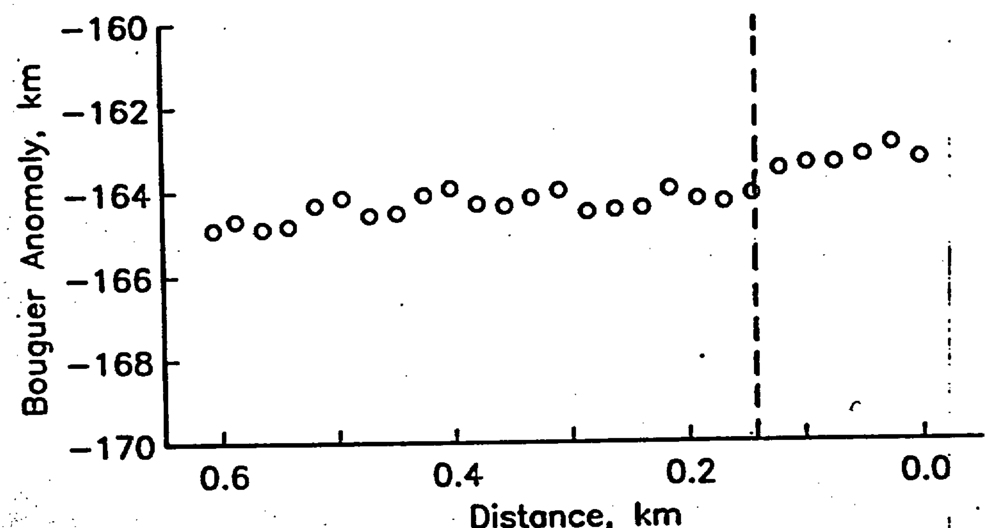


Repository Line 4

This line traverses SE from the top of Yucca Mountain. The most interesting feature is the upward Bouguer anomaly shift at 3.1 km and back down at about 3.6 km.



Repository Line 9



Repository Line 12

Repository lines 9 & 12

These are short lines with 48 m station spacing. line 9 traverses SE and line 9 almost due South. The dashed line shows where the Bowridge fault is believed to lie. There is a shift of about 0.9 mgal just to the right of this line.

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Appendix 2 - High Resolution Seismic Reflection Measurements at Yucca Mountain

Introduction

The seismic data were collected using a 144 channel 24-bit seismograph, (OYO-DAS-1). The geophones groups were at 12 meter intervals with 6 equally spaced vertical 30 hertz geophones. Up to 240 geophone groups were laid out at a time. However in order to focus at a shallower depth, on Line 12 the spacing was 3 meters, and on lines 13, 13a, 14, and 14a the spacing was 1 meter. The source used on the 12 meter spacing lines was a Bison EWG-4 which has 30,000 ft-lbs of force. It is an accelerated weight drop source with two large "rubber bands" accelerating a weight onto a steel plate. The primary power of the spectra of the signals from this impact source was in the 30 to 120 hertz range for most depths of penetration. Except for lines 13, 13a, 14, 14a, and 12, (two seconds of data) three seconds of data were acquired on all lines using 8 to 12 shots per shot point. Good signal was recored in most areas up to 2 seconds depth (approximately 10,000 to 15,000 feet depending on the velocity) and in many areas up to the full three seconds (15,000 to 20,000 feet). The shot points were at 24 meter intervals, but in areas at the end of the lines, and over known features of interest (such as the Ghost Dance fault) the shot points were at every 12 meters. The fold of the data was a designed maximum of 72, however due to some crooked line segments it was higher over certain areas. On line 6 a vibroseis was used in order to compare to the impact source. No significant difference in the data quality was noticed, therefore due to its lower cost of operation, the impact source was adopted for use. This appendix describes the processing of the seismic reflection to date.

Table 1 gives the present status of the seismic reflection work. As can be seen all data has been collected that had been planned in the initial phase of the 95 field work. The processing is proceeding as soon as the survey data is received from RS&N. As can also be seen from Table 1, we are still awaiting survey data on many of the lines.

Much of our initial efforts have been focused on the very high resolution lines (12, 13, 13a, 14, and 14a) and on lines near or over the proposed ramp alignment (line 9). These lines will be discussed here, although Line 9 was not designed to be a shallow focused line (its shot and group spacing was 12 meters, it was processed with the goal of imaging the first 100 meters to 300 meters.

Line 12

Line 9 was shot with 3 meter group and shot intervals in order to improve the resolution of the shallow structure. As can be seen from Figure 1. in the main body of the report, line 12 was directly over the north ramp, starting at the top of Exile Hill and extending down the hill to the top of the next ridge. The length of the line was determined by the extent of area cleared for access. Two sources were used, a sledge hammer striking the ground and the EWG-4. Figure 1 in this appendix gives some examples of the shot gathers. The hammer source gave high frequency, and less surface noise, but the high power of the EWG-4 gave better results. Figures 2 and 3 are examples of the EWG-4 shot gathers. Figure 4 is a spectrum of the data. As can be seen in Figure 4, most of the data lie in the 30 to 120 hertz range. This held true for every source used in all of the work, i.e., the near surface at Yucca Mt. in general limits the energy content of the data. Table 2 shows the processing steps used to produce the subsequent figures. A considerable effort went into determining the proper move out and lateral velocity functions to be used. It is clear that rapid near surface lateral velocity changes are controlling our ability to image the detail of the shallow structure. This is particularly true in areas of sedimentary fill and faults. Figures 5 through 8 show the processed data in increasing stages of interpretation. As can be seen, the Bow Ridge Fault as well as other features are quite evident. The image in these figures is a distorted view of the subsurface. Presently we are reprocessing the data using detailed statics (refraction) in an attempt to correct for the large lateral velocity changes. We are also finding that the near surface velocity is slower than expected. (approximately 1000 m/sec versus expected of 1500 to 2000 m/sec.) The correct application of statics should improve the image. Figure 9 shows the gravity at the same scale as the seismic results in Figures 5 through 8. It is interesting to note that the gravity shows a number of variations along the line, in addition to the Bow Ridge fault. Again, as soon as we receive the topographic data from EG&G we can complete the processing and interpretation of the gravity data.

Line 9

Line 9 was shot with 12 meter shot and receiver intervals. Line 9 was designed to look deeper, possibly for structure associated with the water table gradient. However, at the present time we have been trying to pull out as much shallow structure as possible. Figures 10 through 14 show the various interpretation stages of Line 9. This line although showing some faulting, does not show as much faulting as Line 12. The gravity data also indicate less lateral change as well (Figure 15). In this area we are roughly parallel to the fault structure which may account for the lack of structure. In any case we are also in the process of carrying out detailed statics corrections which should improve quality of the image.

Lines on the UZ-7a Pad.

In order to resolve in as much detail as possible we carried out a survey on th newly completed pad of UZ 7-a using a hammer and plate at one meter intervals. Six geophones per group were also used. The processing effort has been considerable, and similar to the approach being taken on lines 12 and 9. However, this is in the same area as the WT-2 VSP carried out last year and we have good depth to velocity control. The geometry of the survey was two lines approximately 100 meters long running east-west across the pad (Lines 13 and 14), and two shorter lines 50 meters running north south across the pad. The east-west lines were laid out to cross the Ghost Dance Fault (GDF) and the north-south lines were laid out to have one to the east and one to the west of the GDF.

The processing is continuing on these set of lines, but we have complete images on Lines 13 and 14, and partial images on 13a, the line to the west of the GDF. As can be seen in Figure 16 the GDF shows up as a disrupted zone of reflectors. This line was laid out very close to the cut in the hill for the UZ-7a pad and it was clear where the "fault" was. The data from Lines 13 and 14 seem to indicate that the GDF may split or that there is another cross cutting fault through this area. In Figure 17 two clear faults show up. The geometry of the two lines relative to one another was that CDP 181 on Line 14 was due north of CDP 331 on Line 13. Also Line 13 was not exactly parallel to Line 14, but striking about 15 degrees SE from Line 14. If this geometry is taken into account, then the fault to the left on Line 14 (Figure 17) is the GDF. This also assumes that the GDF does not change direction in the 30 meters between the two lines. However, Figure 18 is interesting in that there is a definite fault in the center of the section. Line 13a intersects Line 13 at CDP 288, and Line 14 at CDP 215. (see Figures 16 and 17). The faults on Line 13a is only a few meters wide but still obvious. (The dipping events from the top left of Figure 18 to the to the bottom right of Figure 18 are artifacts of the processing) For the geometry to make sense there must be either a cross cutting fault, or the GDF splits or changes direction. In any case the UZ-7a pad which was designed to investigate the GDF structure, seems to be in the middle of a series of cross cutting nearly vertical faults that extend to several thousand feet. It also should be remembered that the exaggeration in the horizontal scale is over 10:1. Thus, any dip noted in these figures is actually much more.

TABLE 1

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Seismic Reflection Status

Line	Collection Complete	Surveying Complete	Geometry Application	Data Editing/ Processing	Brute Stack (Constant velocity)	Final Stack*
1	2/95					
2	12/94	1/12/95	1/18/95	1/18/95-1/20/95	1/22/95	1/27/95
3	12/94	3/95	4/20/95	4/20/95-present		
4	1/95	3/22/95				
5	2/95					
6	2/95					
7, 7a	1/95					
8	1/95					
9	1/95	3/12/95	3/27/95	3/27/95-3/28/95	3/29/95	4/3/95
12	1/95	2/2/95	2/10/95	2/10/95-3/23/95	3/24/95	3/31/95
13, 13a	2/95	2/15/95	3/1/95	3/1/95-4/1/95	4/10/95	4/21/95
14,14a	2/95	2/15/95	4/10/95	4/10/95-4/10/95	4/14/95	4/17/95

*All "final stacks" may need an additional re-processing as interpretation proceeds.

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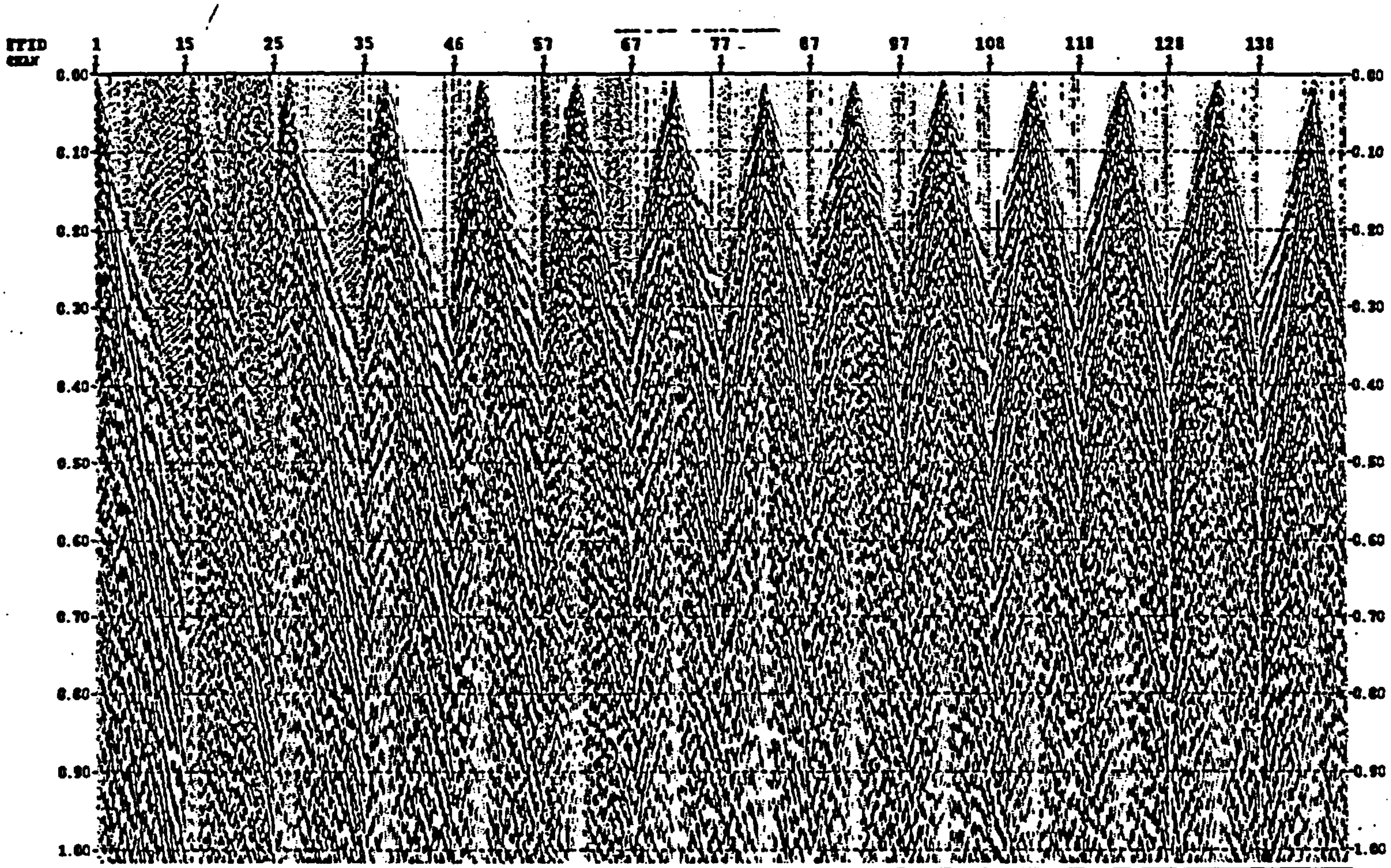

FIGURE 1

Example shot gathers from seismic line YMP-12. Note that shot #15 (FFID = 15) had a sledge hammer source, while the other shots in this figure used the EWG-4 source.

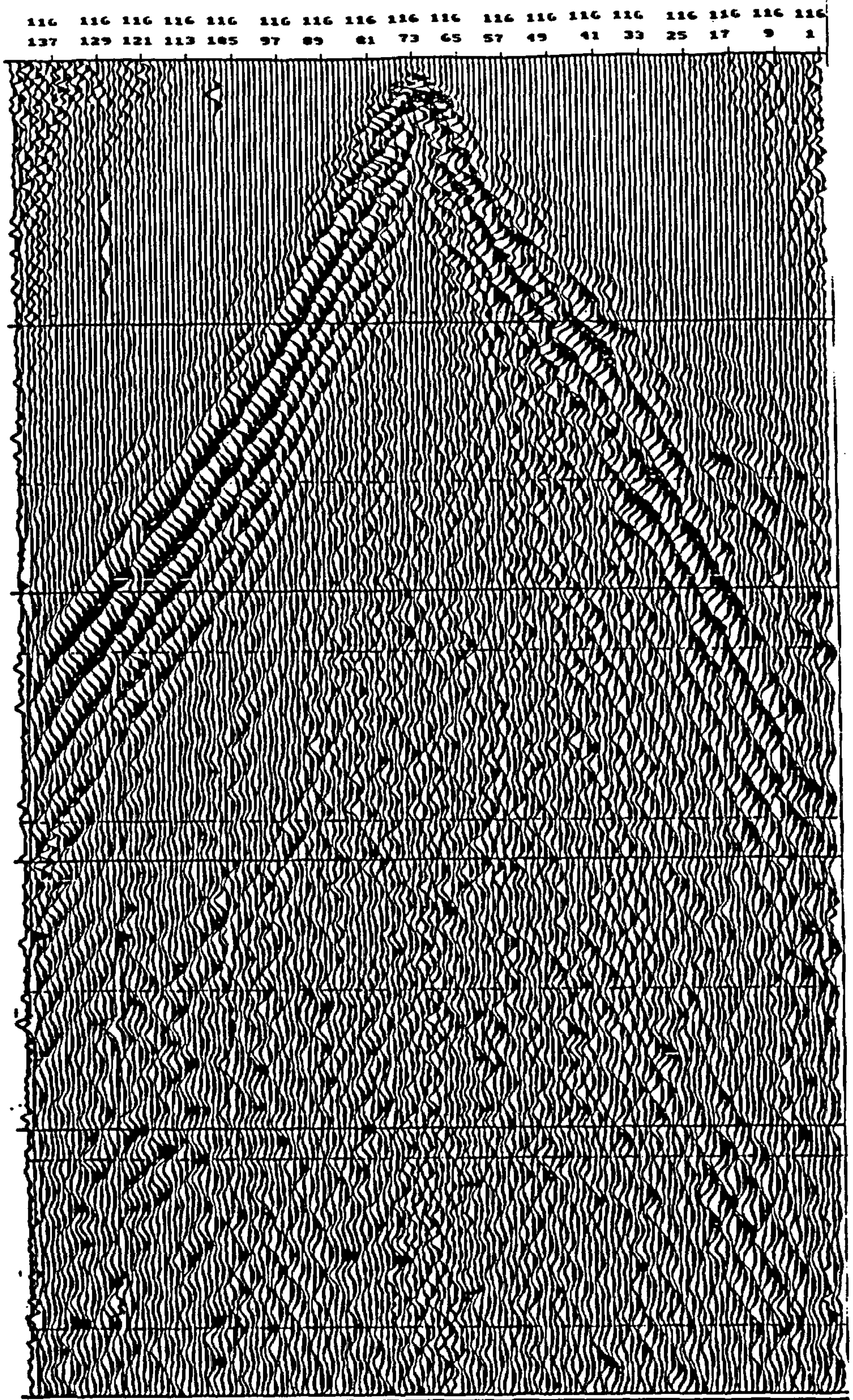

FIGURE 2

Example shot gather from seismic line YMP-12. Shot #116, 144 channels with AGC, 1 second of data is displayed.

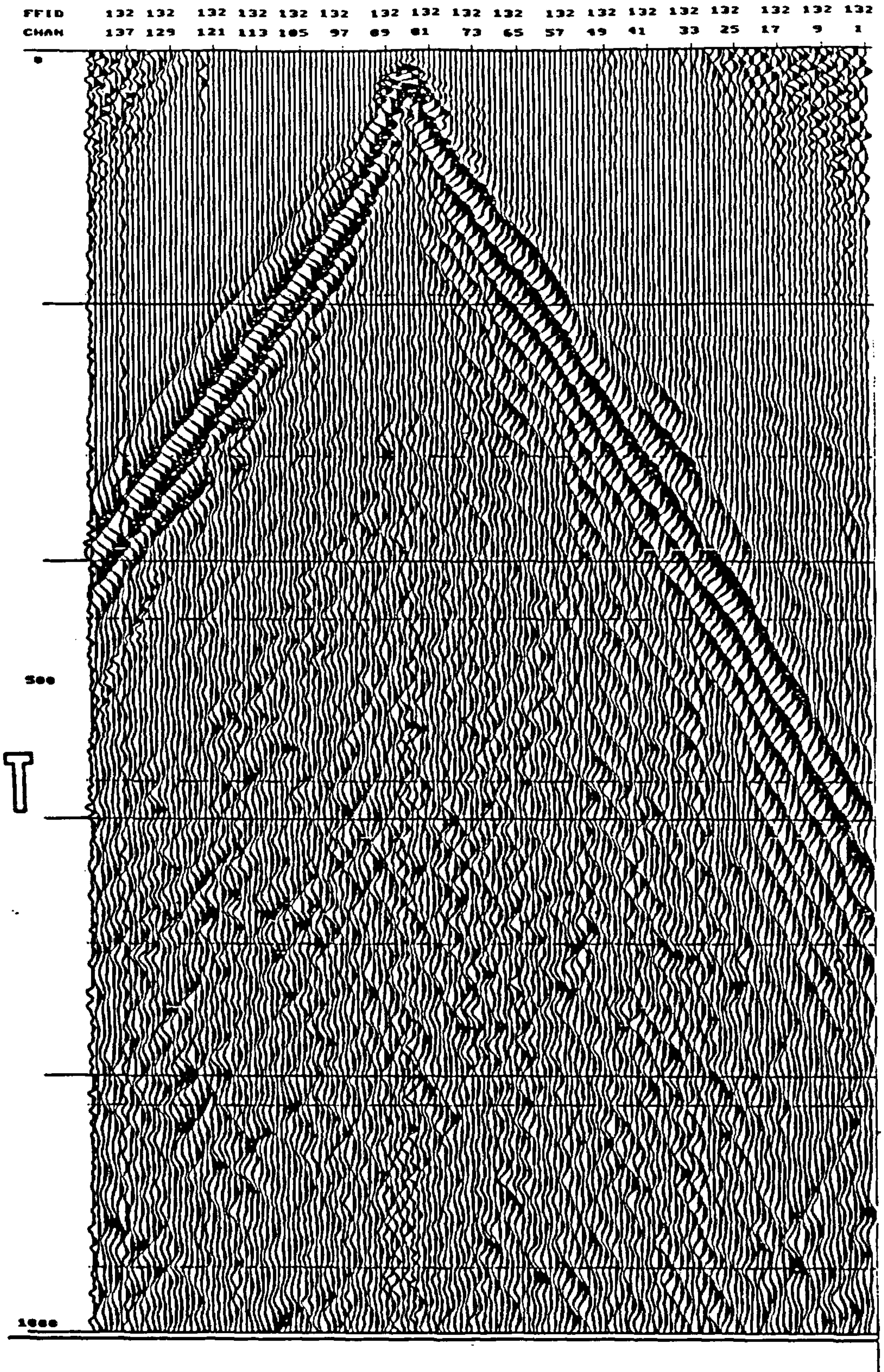

FIGURE 3

Example shot gather from seismic line YMP-12. Shot #132, 144 channels with AGC, 1 second of data is displayed.

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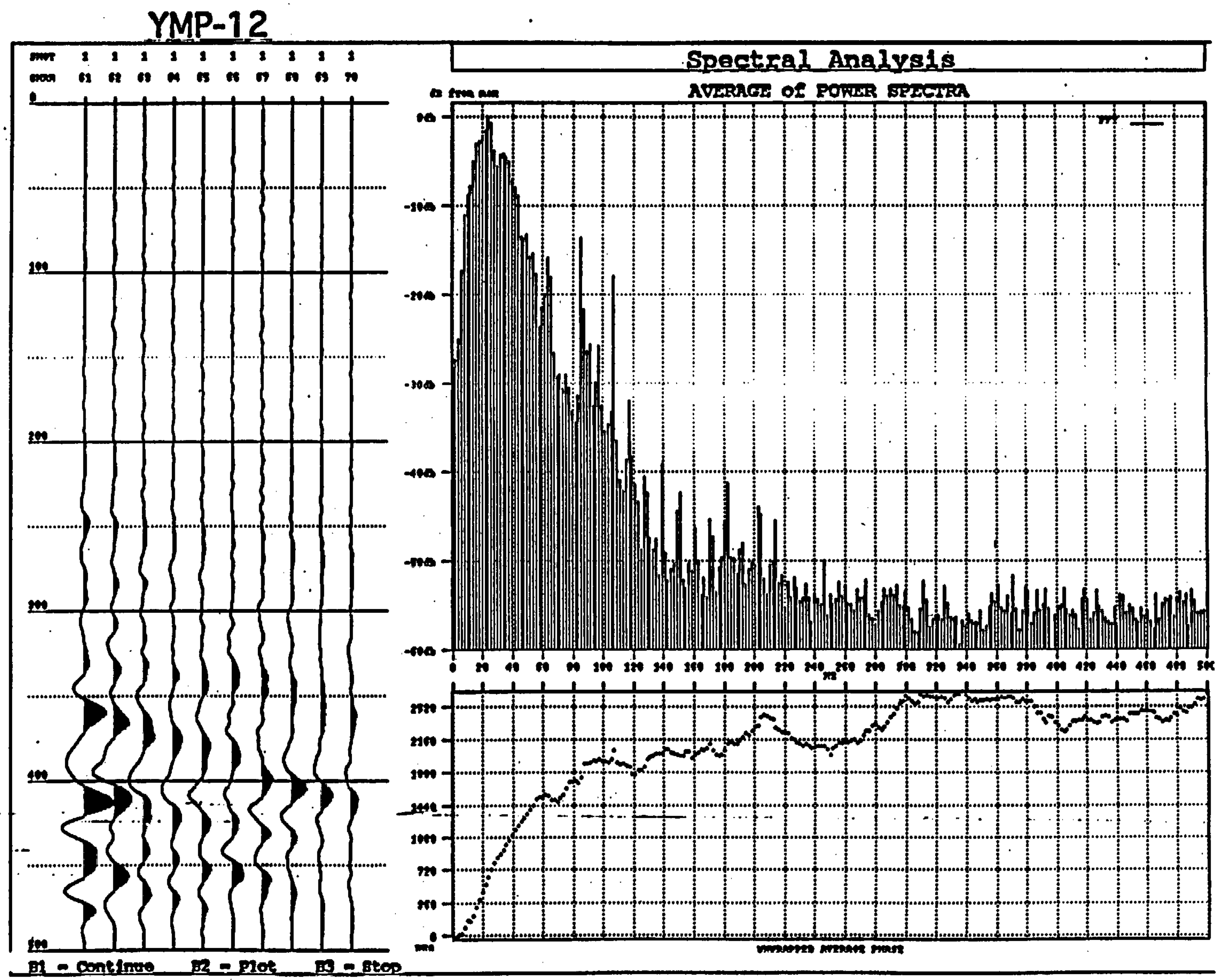

FIGURE 4

TABLE 2

Processing Steps for Lines: YMP12 and YMP9

A. Pre-processing

- Conversion of "segd" format field tapes to "segy" format for subsequent processing.
- Plotting of raw shot gathers for visual editing and quality assessment
- Application of field geometry and elevations.
- Spectral analysis for frequency bandwidth estimation.
- Band-pass filtering
- Predictive deconvolution (more significant for YMP9)
- Trace muting to first arrivals.
- Air-wave muting/attenuation

B. Processing

- Sorting to CDP gathers
- Constant velocity stacks (1000 ft/sec to 15000 ft/sec) for velocity estimation.
- Stacking.
- F-X deconvolution.
- Predictive deconvolution.
- Filtering.
- Depth conversion using velocities from NRG-6.
- AGC

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at positions which seem to correlate with several mapped faults in the Yucca Mountain area.

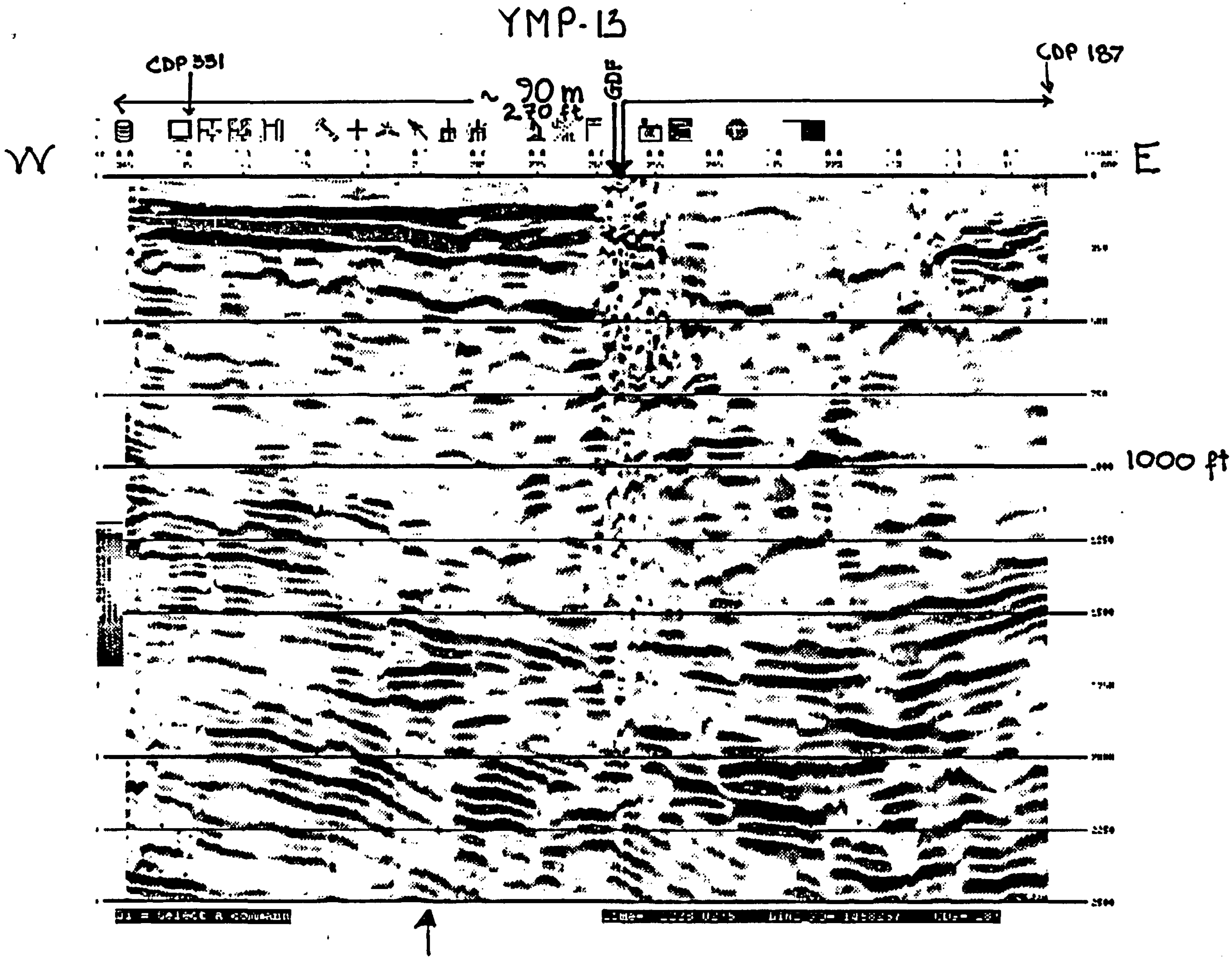
References

Ponce, D. A., and H. W. Oliver, Charleston Peak gravity calibration loop, Nevada, U.S. Geological Survey Open File Report 81-985, 20 p., 1981.

Zumberge, M. A., R. N. Harris, H. W. Oliver, G. S. Sasagawa, and D. A. Ponce, Preliminary results of absolute and high-precision gravity measurements at the Nevada Test Site and vicinity, Nevada, U.S. Geological Survey Open File Report 88-242, 29 p., 1988.

Table 1. Calibration Runs for Meter 244				
No.	Date m/d/y	Drift mgal	Factor	Standard Error
1	12/01/94	-0.011	1.000705	0.000058
2	12/10/94	0.018	1.000810	0.000159
3	01/31/95	0.006	1.000745	0.000128
4	02/24/95	0.068	1.000806	0.000064
	Mean		1.000754	0.000039

Table 2. Calibration Runs for Meter 531				
No.	Date m/d/y	Drift mgal	Factor	Standard Error
1	12/01/94	-0.071	1.000570	0.000074
2	12/10/94	0.002	1.000559	0.000057
3	01/31/95	0.148	1.000631	0.000096
4	02/24/95	0.437	1.000439	0.000231
	Mean		1.000571	0.000040



13A

FIGURE 16

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YMP-14

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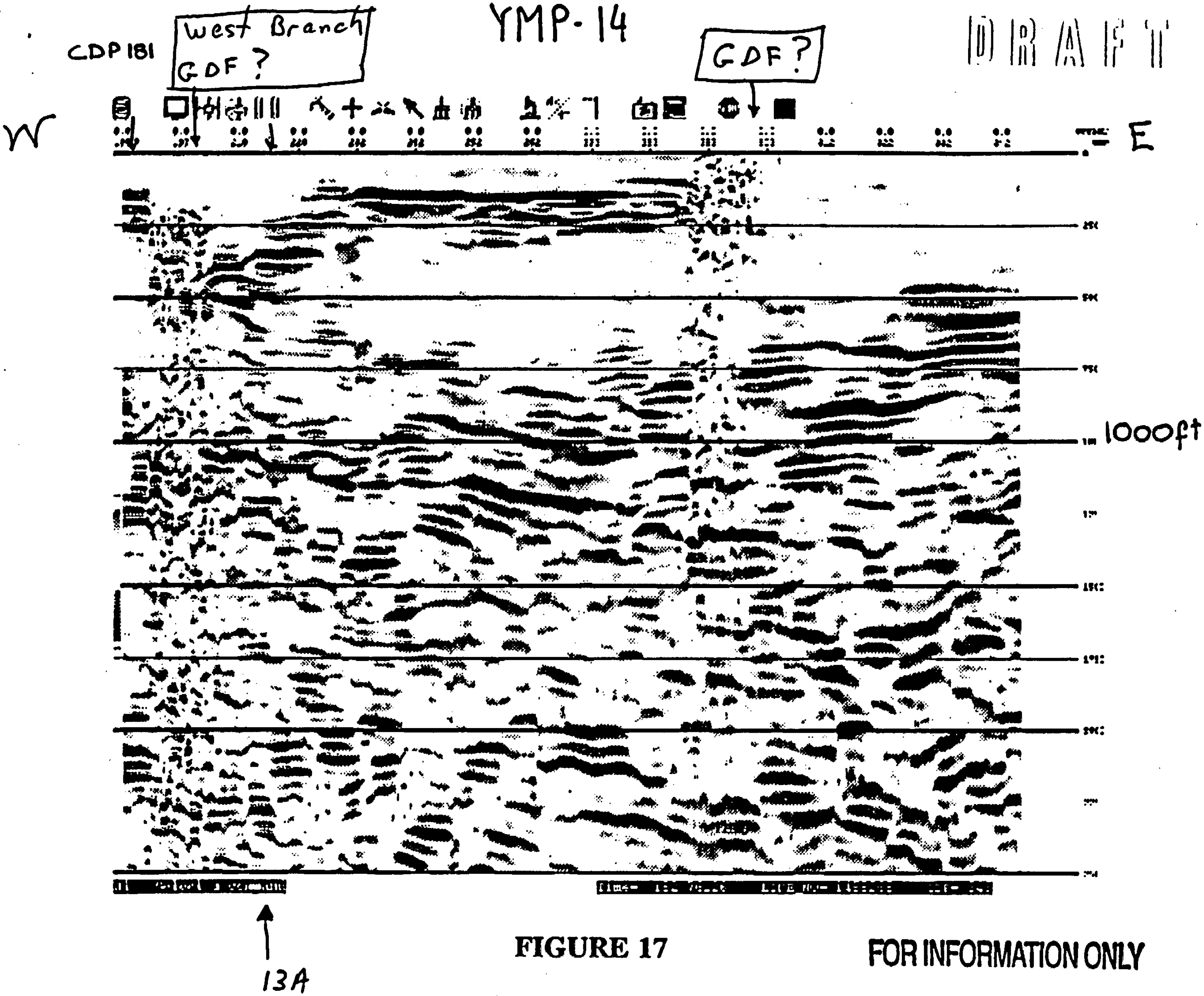

FIGURE 17

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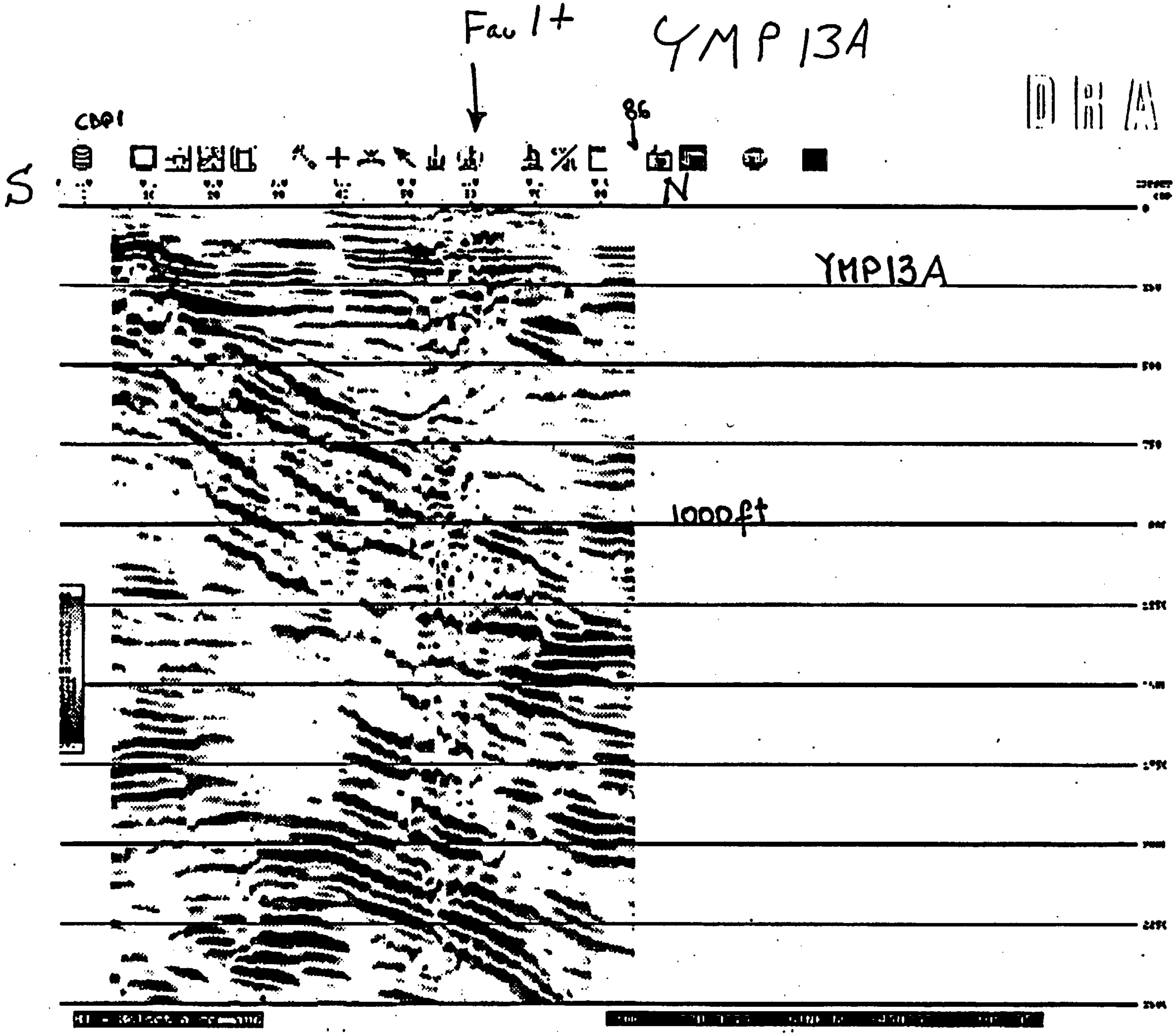

FIGURE 18

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Milestone 3GGU540M

PROVISIONAL RESULTS of SEISMIC REFLECTION PROFILING AT CRATER FLAT AND YUCCA MOUNTAIN

by Thomas M. Brocher and W. Clay Hunter
U.S. Geological Survey

May 1995

INTRODUCTION

This memorandum is a status report describing progress by the U.S. Geological Survey and subcontractor in regional seismic reflection profiling under milestone 3GGU540M [Provisional Results: Seismic Reflection Profiles]. The processing contractor is Texseis, Inc., of Houston, Texas. The results (from so-called regional Lines 2 and 3 across Crater Flat and Yucca Mountain) described here reflect intermediate-stage processing of the seismic data set and reflect only inclusion of the surface data sources. No deep explosive-source data have been incorporated at this stage of processing. Our provisional interpretations are based only on those reflections which appear significant at this stage of partial processing and on existing well control. To avoid over-interpretation, we have specifically avoided discussion of known (surface-mapped) features from which reflections do not appear at this stage of processing or for which there is no well control. Our final interpreted stacks will incorporate information from independent studies. The data provided herein have not received complete technical and quality checks and, therefore, are considered to be preliminary. Interpretations herein are also preliminary and have not been considered for approval by the Director of the U.S. Geological Survey, and must therefore not be released to the public.

As reflected in Project Accounting and Control System (PACS) documents controlling this work, milestone 3GGU540M shall be met when a memorandum containing provisional results of the work and status and availability of associated data has been submitted to DOE-YMSCO. This milestone requires intermediate-depth preliminary images and a provisional depth-converted interpretive section, but final images and depth conversions, as well as borehole-to-seismic correlations, are planned for a later milestone.

General objectives of the regional seismic reflection profiling include acquisition of images to describe the boundary between the Tertiary and underlying Paleozoic rocks and to evaluate the presence of a postulated west-dipping subhorizontal detachment surface beneath Yucca Mountain and possible magmatic centers in the lower crust. Hybrid seismic sources (including vibrators, surface-mounted explosive [Poulter] charges, and conventional shallow minihole explosions) were used for data collection in response to environmental, operational, and topographic constraints. Interpretations derived from the seismic reflection profiling will feed to investigations of probabilistic seismic hazards and probabilistic volcanic hazards, and this work may help to discriminate alternate models of tectonic setting for the Yucca Mountain region. In addition, we describe here the preliminary results of calculated synthetic seismograms from available well logs which will contribute to interpretation of these reflection results. We emphasize that depth conversions are provisional only, and extensive additional processing must be completed for calculation of final depth-converted stacks.

STATUS OF SEISMIC REFLECTION DATA

Review of the regional seismic reflection data is underway under USGS-QMP-3.04, current revision. Review is expected to be completed by the end of May, 1995. Data packages are being assembled. The review of data will contribute to constraints on eventual interpretation and will also allow evaluation of the results of data processing in terms of anticipated potential image quality.

Status of Archive Arrangements

Discussions are underway with USGS-YMPB and YMSCO data managers to identify the optimum archiving method for these large (gigabytes) seismic data sets. A back-up copy of the field-recorded industry-standard SEG-D format has been made on 8-mm tape cartridges. Original field records (SEG-D format) and a copy of all data records (in industry-standard transfer format SEG-Y) exist on 9-track, 12-inch tape reels. We are investigating alternative methods of long-term storage, since the tape media are known to be somewhat unstable. Stability and data-integrity issues suggest storage on CD-ROM format, but this step is unresolved at this time.

Status of location map and digital location information

USGS has obtained complete digital location information from the surveyors working under the acquisition contract (Northern Geophysical of America, Englewood, Colorado). Location maps have also been provided at a scale of 1:24,000 by the contractor. These will be contained in the data package being prepared. The location data have been shared with investigators acquiring gravity and magnetic data coincident to the seismic profiles.

Status of Magnetic/Gravity Data collected from Seismic Lines 2 and 3

1. Magnetic Data *(details provided by D. Ponce, USGS)*

Collection of magnetic data was conducted by USGS-YMPB staff and completed in February 1995. Data sources include coincident ground magnetic stations with maximum spacing of 25 m and average spacing of 10 m along the 23 miles of seismic profile, offset ground magnetic traverses (same spacing) from Amargosa Desert to drill hole USW VH-1, and aeromagnetic coverage for the remainder of the lines. Data reduction is underway, scheduled for completion 31July95, and currently on schedule. Preliminary correlation of magnetic results and seismic profile has begun with consideration of intermediate seismic stacks by the team working on magnetic data. The data review package is in preparation. Processing is complete and modeling is underway.

2. Gravity Data *(details provided by E. Majer, Lawrence Berkeley Laboratory)*

Collection of gravity data along the seismic reflection profiles was conducted by staff from Lawrence Berkeley Laboratory and completed in December 1994. Data sources include coincident gravity stations at 100-m spacing along the 23 miles of seismic profile. Data reduction is underway with Bouguer corrections. Further work awaits terrain data from EG&G to complete the processing. Data review is complete, and the data package is being assembled. Preliminary correlation of gravity results and the seismic profile has begun with consideration of intermediate seismic stacks by the team working on gravity data. After receipt of the terrain data, processing will be completed and modeling initiated.

SEISMIC DATA PROCESSING

Data acquired along Lines 2 and 3 shown in this report have been processed to an intermediate level by Texseis, Inc., Houston, Texas, using ProMAX release 5.1 and 6.0 seismic reflection data-processing software. A standard data-processing flow was used, as detailed in Table 1. This flow included demultiplexing data from SEG-D and conversion to SEG-Y format, vibrator correlation and compensation filter for the vibrator data to match the explosion data, trace edit, sort to common-depth point (CDP) geometry, constant velocity stacks for brute functions, refraction statics, F-K filter (after normal moveout to flatten reflection events), surface-consistent amplitude corrections and deconvolution, iterative velocity analysis, surface-consistent residual statics, top mute, CDP stack, post-stack deconvolution, post-stack bandpass time-variant filtering, automatic gain control (AGC), and display.

Table 1. Data Processing Scheme for Regional Seismic Reflection Lines 2 and 3

Processing Step	Description
SEG-D to SEG-Y Conversion:	Demultiplex all four sources
Separate Sources:	Vibroseis Data Cross-correlate zero phase Design compensation filter from sweep Apply compensation filter Deep-hole dynamite data Tape output 0 to 8 seconds Tape output 0 to 20 seconds Apply uphole correction Poulter Data Minihole dynamite data
Merge all sources	Use 0 to 8 s deep-hole dynamite
Build and apply geometry	
Trace edit	
Constant velocity stacks	For Brute Stack Velocity Functions
Refraction Statics	Pick first breaks using absolute offsets of 1000 to 5000 ft and all sources Calculate solution using 5000 ft datum and 8000 ft/s replacement velocity
F-K Filter	Apply NMO (brute functions) correction Apply and save AGC F-K rejection filter +/- 5000 ft/s Remove AGC Remove NMO correction
CDP Sort	Account for crooked line geometry
Surface consistent amplitude	Calculate and apply correction
Surface Consistent Cascaded Deconvolution	
Velocity Analysis	
Surface Consistent Residual Statics	
Top Mute	Calculate and apply
Spherical Divergence Recovery	
IVA Velocity Analysis	Iterative semblance analysis
Surface Consistent Residual Statics	
CDP Stack	
Post-stack adaptive Deconvolution	
Bandpass Time Variant Filter	5/10-50/70 Hz - 0-3.5 s 5/10-30/50 Hz - 4.0-8.0 s
1000 ms AGU	
Shift to Flat Datum	5000 ft
Stack Display	
Post-stack migration	
Pre-stack migration	

A provisional depth conversion of the stacked sections was performed using available intermediate-level stacking velocities, which are now known to be erroneous (too high) along parts of Line 2 in the Amargosa Desert and southwestern end of Crater Flat. Preliminary velocities were picked using constant-velocity stacks; velocity analyses were subsequently performed at 0.3-mi (0.5-km) intervals evenly spaced along each of the regional profiles. Estimated depths given below are relative to the datum of 5000 ft (1524 m) above sea level. We expect that these depth estimates will be revised in the final depth conversion.

Fold varied on each line. The nominal fold for Line 2 was 60, although beneath the crest of Yucca Mountain the fold exceeded 90. The nominal fold of Line 3 was 125. Fold ramped up and off the ends of both lines for 3 km.

PROVISIONAL INTERPRETATION OF REGIONAL SEISMIC LINES

Stacks representing intermediate-level processing for Lines 2 and 3 are shown as time sections in Figures 1 and 2. Both are displayed with a final datum of 5000 ft (1524 m), although a floating datum was used for the velocity analysis during data processing. Provisional depth conversions (in thousands of feet) of these intermediate stacks are also shown on Figures 3 and 4. (Vertical exaggeration [VE] is identified on all figures and varies from 1.6:1 to 4:1.) Images of shallow structure beneath and adjacent to Yucca Mountain require more extensive processing and are not considered in this report of partial results. Care should be taken in interpretation of apparent reflections which may be artifacts of incomplete processing and/or the hybrid sources used in this experiment.

Line 2

Line 2 shows a variety of reflection events as shallow as 0.2 seconds (s) two-way travel time (twtt) and as deep as 8 s twtt. The largest-amplitude reflections on the section are located within Crater Flat (stations 400 to 700) at depths between 7000 and 12,000 ft below datum (corresponding to two-way travel time between 1.6 and 2.5 s). The reflections dip towards each other and define a near-symmetrical structure of basinal form beneath Crater Flat. These prominent reflections are provisionally interpreted as the Tertiary/Paleozoic boundary due to their large amplitude and low frequency. The deepest part of the basin, at station 500, is estimated to be as much as 3.3 to 3.6 km deep. Similar reflections beneath the eastern flank of Yucca Mountain, at a depth near 3000 ft below datum (0.8 s twtt), are also provisionally interpreted as the Tertiary/Paleozoic boundary or as reflection from a Tertiary horizon just above the Tertiary/Paleozoic contact, based on well control (described below) at drill hole UE-25 p#1 and corroborating reflections from Line 3. Drill hole USW H-4 (station 1079), however, bottomed in the Tertiary Tram Tuff at about 4000 ft, suggesting that reflections above that depth occur within the Tertiary section.

Between stations 700 and 1001 the Tertiary/Paleozoic boundary is not sharply imaged in the intermediate stack. Based on existing isostatic gravity anomaly data, however, we tentatively identify a discontinuous, undulatory, low-frequency reflection at about 8000 ft (1.8 to 1.9 s twtt) below datum as the Tertiary/Paleozoic boundary. At this stage of the processing, we are uncertain whether the disrupted character of the reflection results from true geologic processes such as closely spaced normal faults, or whether this character results from data-processing artifacts associated with the strong topographic relief of the west flank of Yucca Mountain. If our interpretation of the depth to the Tertiary/Paleozoic boundary is correct, then prominent reflections at station 781 and at station 970, between 2000 and 2500 ft below datum, are produced within the Tertiary section.

A series of reflections from the inferred Tertiary fill within Crater Flat can also be recognized from 2000 to 12,000 ft below datum. With time the apparent depocenter in Crater Flat has shifted to the southwest, approaching Bare Mountain, such that the shallowest reflection events define a more asymmetrical subbasin within Crater Flat bounded by the Bare Mountain Fault and up to 3500 to 4000 ft deep. West-dipping reflections from this subbasin project to the surface in the vicinity of drill hole USW VH-1 (station 645). A series of steeply east-dipping events extending from the surface to a depth of 7000 ft below datum (2 s twtt; station 410) may represent several faults, perhaps including the Bare Mountain Fault. West-dipping reflections in the basin of Crater Flat appear to truncate against the east-dipping events, which may include the Bare Mountain Fault. This explanation would suggest a half-graben beneath western Crater Flat (stations 321 to 701). Crater Flat is underlain at a depth of 12,500 ft (2.9 s twtt) below datum by a subhorizontal, gently east-dipping reflection which may represent as-yet unexplained stratigraphic/structural boundaries within the Paleozoic section or, alternatively, a detachment surface. We acknowledge that postulated detachments near Yucca Mountain, if detachments exist, are typically expected to be much deeper (at depths of 10 to 15 km) than this reflection.

Other preliminary images have also been interpreted from these stacks. An east-dipping reflection beneath the western flank of Yucca Mountain at 10,000 ft below datum (1.4 s twtt) is also imaged on Line 3 in the same geographical location. Discontinuous subhorizontal lower crustal reflections below about 5 s twtt (corresponding to approximately 15 km depth) can be seen only on the southwestern end of Line 2 (stations 101 to 410). No reflections from the lower crust can be observed northeast approximately from station 410 on this stack, possible limitations of these surface-sourced data. Final processing will include deep-hole explosive sources which may resolve these questions.

Line 3

Line 3 also images a number of reflection events, to depths as great as 20,000 ft below datum (3 s twtt). A prominent, somewhat discontinuous reflection which subparallels the topography at about 2500 to 6000 ft (0.6 to 1.1 s twtt) subsurface beneath Yucca Mountain (stations 180 to 520) is at or above the apparent Tertiary/Paleozoic contact. (Well control at UE-25 p#1 [station 337] indicates that the interpreted Paleozoic contact is at approximately 4000 ft; our provisional interpretation [fig. 4] shows this reflection at about 4000 ft as well.) This reflection displays significant structural relief (a few hundreds of meters) along the line. At this point in processing, however, we have not attempted to correlate mapped faults with these offsets. A steeply east-dipping reflection (stations 121 to 181) imaged directly beneath the western flank of Yucca Mountain, at 5000 to 7000 ft below datum (1.2 to 1.3 s twtt), may represent either a down-dropped and tilted segment of the Tertiary/Paleozoic contact or a thrust fault within Paleozoic rocks. On the eastern end of the line, a series of reflections extends beneath Jackass Flats in the vicinity of Fortymile Wash (station 451). The most prominent of these events, at 6000 to 7000 ft (1.4 s twtt), dips gently west and extends across Fortymile Wash without significant offset. A gently east-dipping Tertiary section up to 5000 ft thick is inferred in the vicinity of Fortymile Wash at station 450.

Additional constraints may be offered at this stage of processing. No reflection events below 20,000 ft (3.1 s twtt) can be identified in the intermediate stack for Line 3. Shallow reflection events on Line 3, along the top of the data between stations 101 and 440, may represent data processing artifacts and are not interpreted here as primary reflections.

General Comments

Lines 2 and 3 tie about 600 m east of the crest of Yucca Mountain, and in that location, both lines show a reflection at 3000 ft below datum (0.6 to 0.7 s) inferred to represent either the Tertiary/Paleozoic contact or a Tertiary horizon close to the Tertiary/Paleozoic contact. (The two lines tie at station 1027 on Line 2 and station 191 on Line 3.) The close match of this reflection on both lines suggests that it is a true primary reflection, as Line 2 in that region was acquired using Poulter charges whereas that part of Line 3 was acquired using vibrator sources. Further, this close corroboration of apparent events suggests that our hybrid seismic sources, demanded by environmental, topographic and operational constraints, do in fact provide useful data.

WELL LOGS

Reasonably complete digital borehole compensated (DBC) density logs are available for seven wells along Lines 2 and 3 (table 2). These density logs contain a gap at the top of individual wells, yet on average cover more than 90% of the each well. Incomplete digital velocity logs (PVEL) are also available for four of these wells, including USW VH-1, USW H-6, USW H-4, and UE-25 p#1. As noted by Nelson and others (1991), velocity logs can only be acquired in a liquid-filled borehole and the water table is deep in the vicinity of Yucca Mountain, leading to large intervals at the top of the wells which could not be logged with the velocity tool. Both logs were used to generate synthetic, vertical-incidence seismograms using modules LOGINIT and LOGPROC of the DISCO, Version 9.0, borehole log-processing software.

As previously noted, all the velocity logs lack substantial amounts of data at the top of the well, contain gaps within the logs, and in total lack data for between 25 and 68% of each well (table 3). To calculate synthetic seismograms, however, it is necessary to have complete logs for both density and velocity, as null values in either would generate spurious seismic reflections. Gaps in the velocity logs were filled using interpolations from the more complete density logs. Comparison of observed density and velocity values for the four wells for which both logs are available revealed that Lindseth's formula [velocity = 3460/(1.0-0.308(Density))] yielded a more accurate prediction of velocity from density than Gardner's formula [velocity = $(\text{Density}/0.23)^4$]. (Both empirical formulas are embodied in the DISCO software; velocities are given in ft/s, and densities are given in gm/cm^3.) We therefore filled gaps in the velocity logs using Lindseth's formula.

Table 2. Well Ties to Regional Seismic Reflection Lines 2 and 3*

Well	Northing	Easting	Line, Sta. No.	Projection	Azimuth**
USW VH-1	743355.5	533625.9	2, 646	130	SE, 153°
USW WT-7	755569.8	553891.3	2, 938	150	NW, 309°
USW UZ-6	759731	558325	2, 1009	1112	NNW, 338
USW H-4	761643.6	563911.1	2, 1079	1050	N, 350°
UE-25 UZ-16	760535	564857	2, 1088	215	S, 170°
USW H-6	763298.9	554074.9	3, 101	67	N, 004°
UE-25 p#1	756171.2	571484.5	3, 337	9	S, 197°

* Compiled from Nelson and others (1991) and field Observer's Log, seismic data acquisition, by Northern Geophysical of America (contracted to the USGS), October/November 1994.

**Azimuth from seismic line to well, measured clockwise from north.

Table 3. Digital Well Log Data for Synthetic Seismograms*

Well Name	Density Log Coverage (ft)	Velocity Log Coverage (ft)	Percent Density Log Missing	Percent Velocity Log Missing	Two-way Travel Time to Base of Log (s)
UE-25 p#1	37-5910	1267-5900	4	25	0.83
USW H-6	312-3980	1907-3975	8	48	0.94
USW VH-1	50-2449	801-2477	9	60	0.46
USW H-4	59-4003	2583-4004	20	68	0.79
USW UZ-6	325-1856	None	17	100	0.46
UE-25 UZ#16	40-1676	None	3	100	0.37
USW WT-7	53-1589	None	3	100	0.33

* Modified from Nelson and others, 1991.

The density logs from the vicinity of Yucca Mountain suffer from two major problems (Nelson and others, 1991). First, the density tool compensation algorithm does not work well in air-filled boreholes above the water table, yielding noisy logs and consequently noisy calculated velocity logs. Second, at depth intervals in which the hole is rugose, the density tool may become separated from the rock wall and provide spuriously low density values. For the wells analyzed here, such intervals commonly correspond to zones where the caliper values become atypically large, indicating a wide borehole. This second problem was related to constraints against use of drilling fluids above the water table. Thus, both problems are restricted to the intervals of holes above the water table; below the water table there are relatively few problems with the density logs.

Due to these problems, all the well logs required substantial editing prior to the calculation of synthetic seismograms. The density logs were first desampled to a one-ft sample interval from the original 0.5-ft sample interval, extrapolated to the surface, and then used to interpolate missing portions of the velocity logs from Lindseth's formula. For wells USW UZ-6, UE-25 UZ#16, and USW WT-7, Lindseth's formula was used to generate the entire velocity log from the existing density log. Where velocity and density logs both contained gaps, both of these values were linearly interpolated across the gaps in the logs. Where the gravity log existed, as for UE-25 p#1, it was used to predict density values missing from the DBC log. (Gravity logs were obtained in some holes using a downhole gravity meter [Nelson and others, 1991].) Densities less than 1.0 gm/cm^3 were increased to a minimum of 1.3 gm/cm^3, and corresponding velocities less than 5000 ft/s were increased to a minimum of 6000 ft/s. Similarly, above the water table, and except for the Tertiary basalt section of USW VH-1, densities above 2.5 gm/cm^3 were reset to 2.5 gm/cm^3, and their corresponding velocities were reset to 12,000 ft/s. In some cases, the velocities in gaps calculated from Lindseth's formula were increased by hand in order to better match velocity values on either side of the gaps.

The final edited well logs were converted to integer ASCII values and copied to the DISCO system. The final logs contain depth in integer feet, velocity in ft/s, and density in kg/m^3. The module LOGINIT was used to read the logs into the YUCCA project name area from disk. The module LOGPROC was used to calculate a sonic well log, impedance log, a reflection coefficient series, and a primary reflection series from the input velocity and density log. A 30-Hz Ricker wavelet (defined in the filtering module FIL and chosen for consistency with the 10 to 50 Hz vibrator frequency bandwidth) was used to filter the primary reflection series.

Synthetic seismograms for the shallow holes VH-1, UZ-6, UZ#16, and WT-7 provide information above 0.46 s twtt (table 3). Synthetics for p#1, H-6, and H-4 yield information above 0.94 s twtt (table 3). Given the uncertainty in the density and velocity at the top of the logs, it probably unwise to attribute much significance to the strong reflections produced by the assumed velocities and densities at the top of the logs. Similarly, it is probably unwise to over-interpret the synthetics in the zones where velocities are interpolated solely from the density. Density logs for WT-7 and UZ-6 are similar and predict a reflection from near the base of the log at the contact between the Calico Hills Formation and the Prow Pass Tuff of the Crater Flat Group.

The synthetics show reflections produced at intervals where both density and velocity logs exist. The synthetic for p#1 reveals a reflection from 0.76 s just above the apparent pre-Tertiary/Tertiary boundary. A very large-amplitude reflection is produced at 0.04 s twtt in VH-1 by a high-density, high-velocity Tertiary basalt layer. Reflections from within the Tertiary section are generated as deep as 0.4 s in VH-1. A low-velocity layer in H-6 at about 2000 ft produces a reflection at about 0.52 s; however, the reality of these apparent low velocities in H-6 are uncertain given that they occur over an interval in which there is a large excursion in the caliper log (Nelson and others, 1991).

CONCLUSIONS

Stacks produced from intermediate processing of the regional seismic reflection data obtained across Crater Flat and Yucca Mountain provide promising provisional images of subsurface features and suggest that our hybrid-source data acquisition will provide useful interpretations. A discontinuous but probable image of the Tertiary/Paleozoic boundary appears in the stacks from both lines, clearly defining the basin in Crater Flat. The apparent Tertiary/Paleozoic boundary under the eastern flank of Yucca Mountain exhibits significant structural relief and is subparallel to surface topography. A series of steeply east-dipping reflection events occur on the east side of Bare Mountain and may represent several normal faults, including the Bare Mountain Fault. A deeper, discontinuous subhorizontal reflection which may be traced under much of Line 2 appears significant and may represent unexplained stratigraphic/structural boundaries within the Paleozoic section or a possible detachment surface. An east-dipping reflection under western Yucca Mountain appears on both Lines 2 and 3 (acquired with different seismic-energy sources) and is provisionally interpreted as either a segment of tilted and down-dropped Tertiary/Paleozoic contact or as a thrust fault in Paleozoic strata. A strong reflection event extending across Fortymile Wash is not offset.

REFERENCES

Nelson, P.H., Muller, D.C, Schimschal, Ulrich, and Kibler, J.E., 1991, Geophysical logs and core measurements from forty boreholes at Yucca Mountain, Nevada: U.S. Geological Survey Geophysical Investigations Map *GP-1001*, 64 p., 10 sheets.

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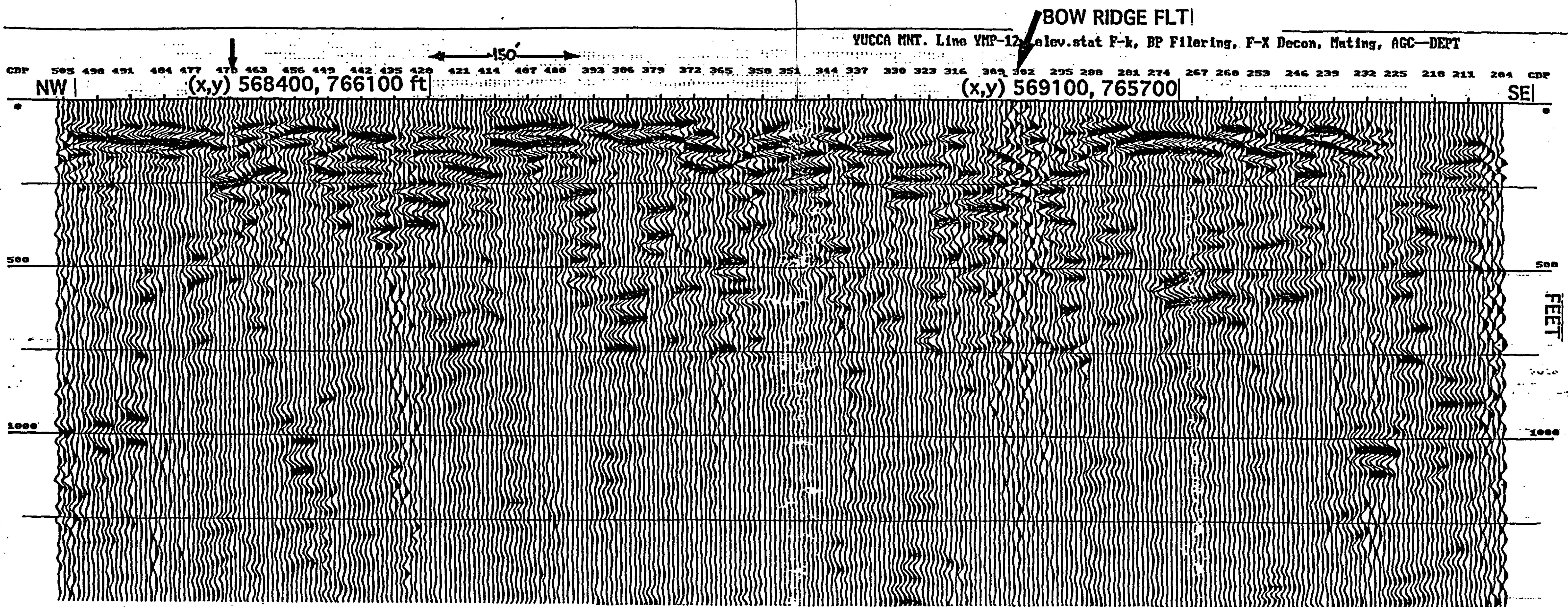
ANSTEC APERTURE CARD

Also Available on Aperture Card

FIGURE 5



CDP seismic section of line YMP-12. Processing includes elevation statics, datum statics, muting, band-pass filter, F-X decon., and AGC. Arrows and x-y locations indicate approximate location of previously mapped faults.

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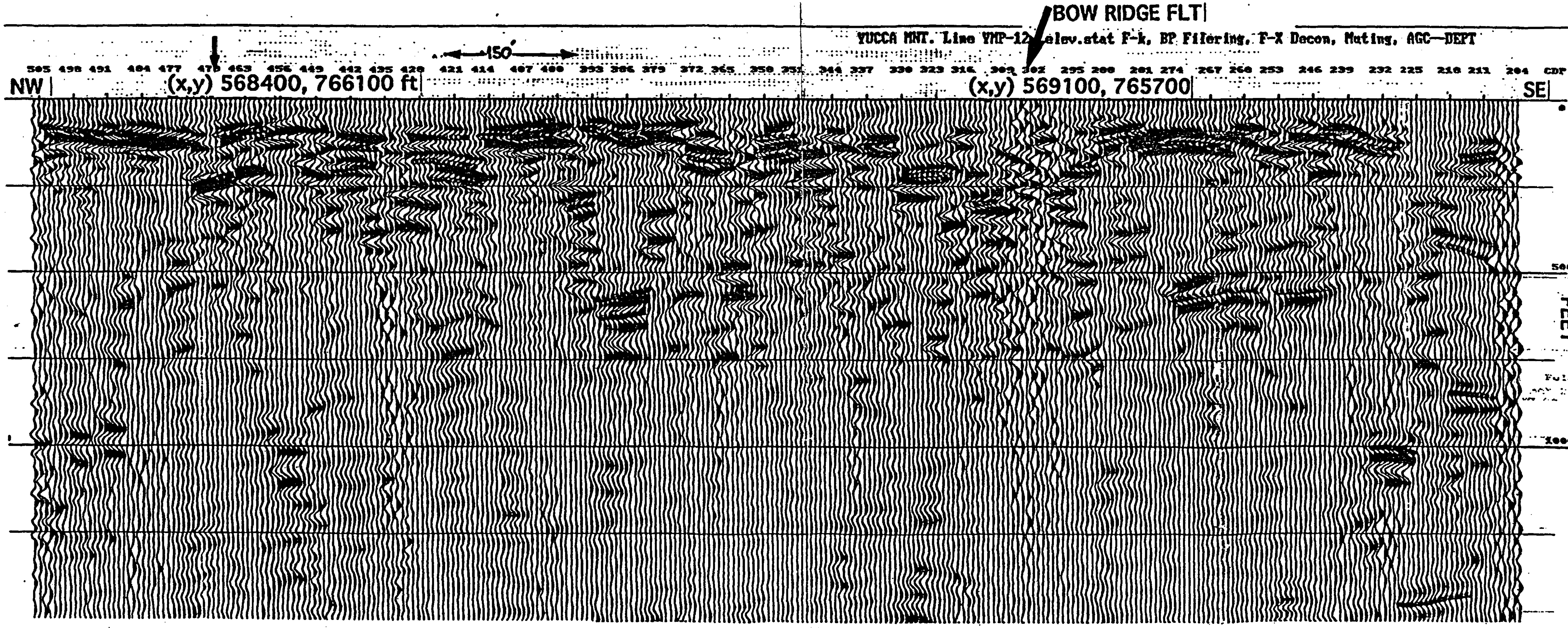
FIGURE 6



CDP seismic section of line YMP-12. Several reflection events have been highlighted in red for interpretation and to indicated lateral continuity of reflection events. Processing includes elevation statics, datum statics, muting, band-pass filter, F-X decon., and AGC. Arrows and x-y locations indicate approximate location of previously mapped faults.

FIGURE 7

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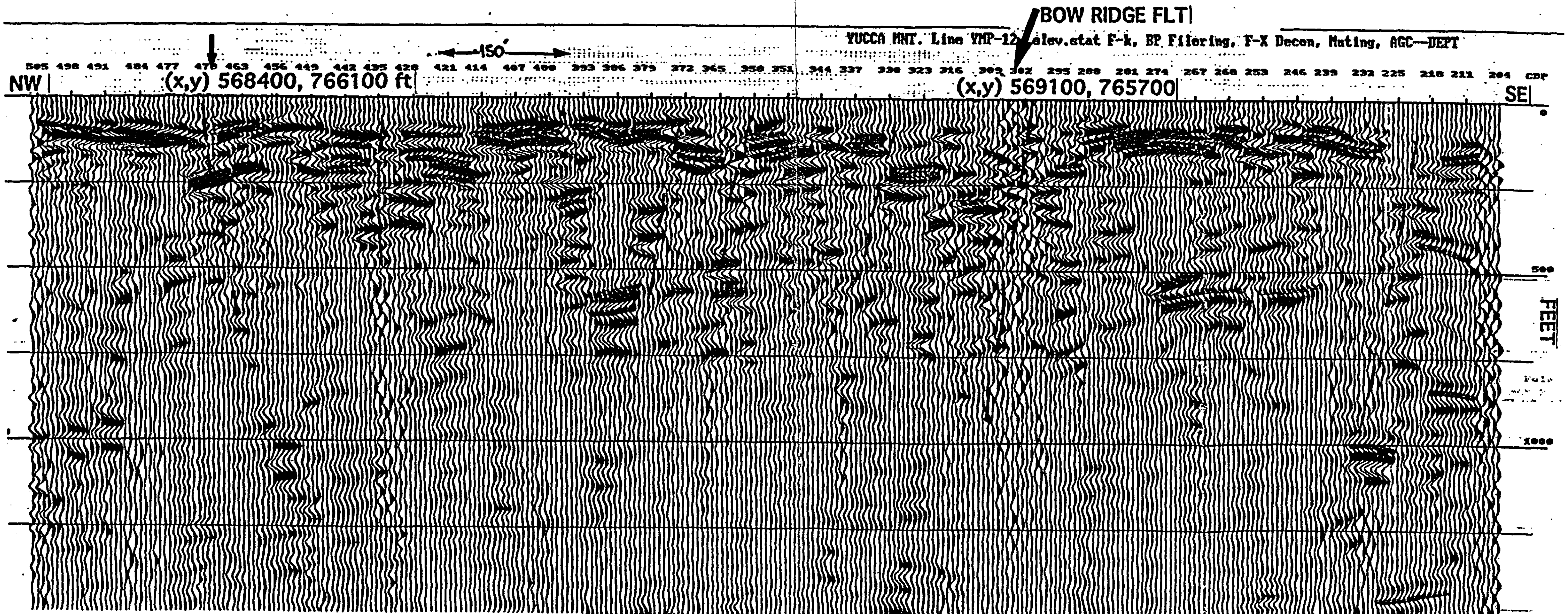

CDP seismic section of line YMP-12. Blue dashed lines are possible fault interpretations. Note that the lack of lateral continuity of reflection events limits the estimate accuracy of fault location and dip. Several reflection events have been highlighted in red for interpretation and to indicated lateral continuity of reflection events. Processing includes elevation statics, datum statics, muting, band-pass filter, F-X decon., and AGC. Arrows and x-y locations indicate approximate location of

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FIGURE 8

CDP seismic depth section of line YMP-12. Overlay is geologic section from preliminary unreviewed data for the North Ramp, which we believe to be from the USGS computer assisted stratigraphic model (v 1.0) released in Dec. 1993. This overlay is intended to illustrate the general geologic setting, and it is not intended to be a detailed (or up-to-date) interpretation. Processing of seismic section includes elevation statics, datum statics, muting, band-pass filter, F-X decon., and AGC. Arrows and x-y locations indicate approximate location of previously mapped faults. Seismic datum (depth = 0) is 3800 ft elevation.

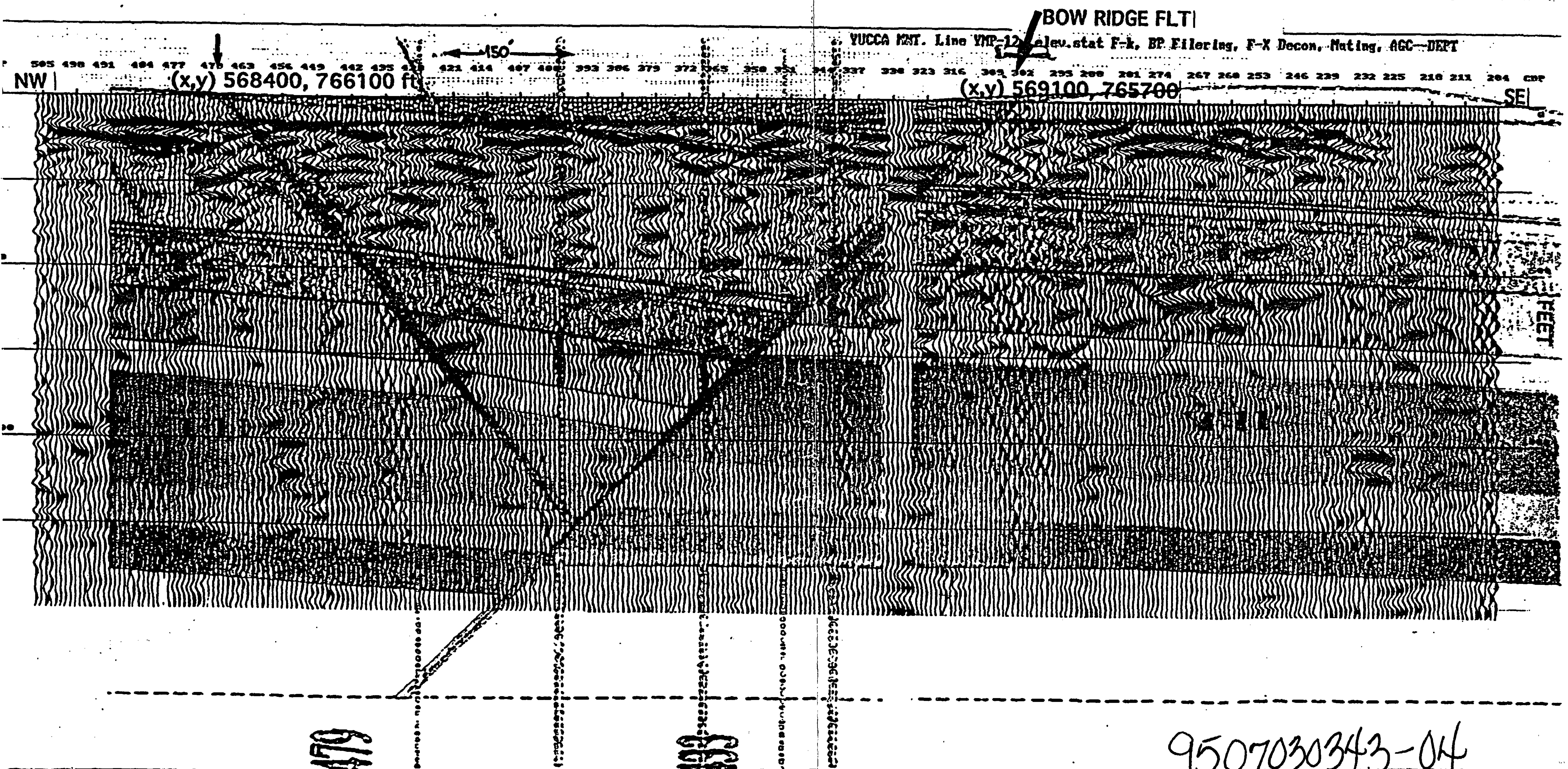

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FIGURE 9

Gravity survey line YMP-G12. Data is Bouguer anomaly, locations are at seismic line YMP-12 stations. Approximate location of the Bow Ridge Fault is labeled BRF. Horizontal scale is matched to seismic line YMP-12.

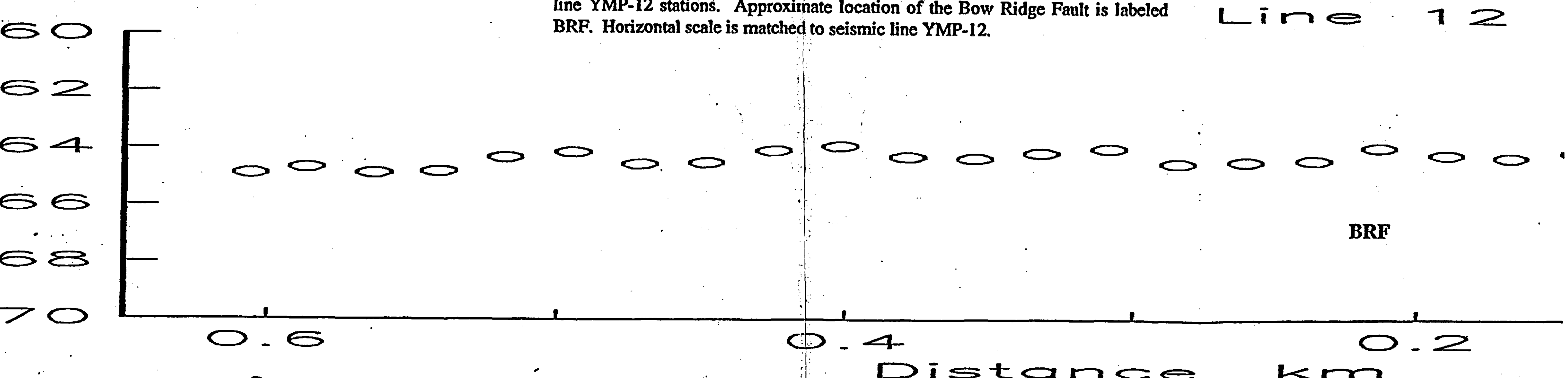

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FIGURE 10

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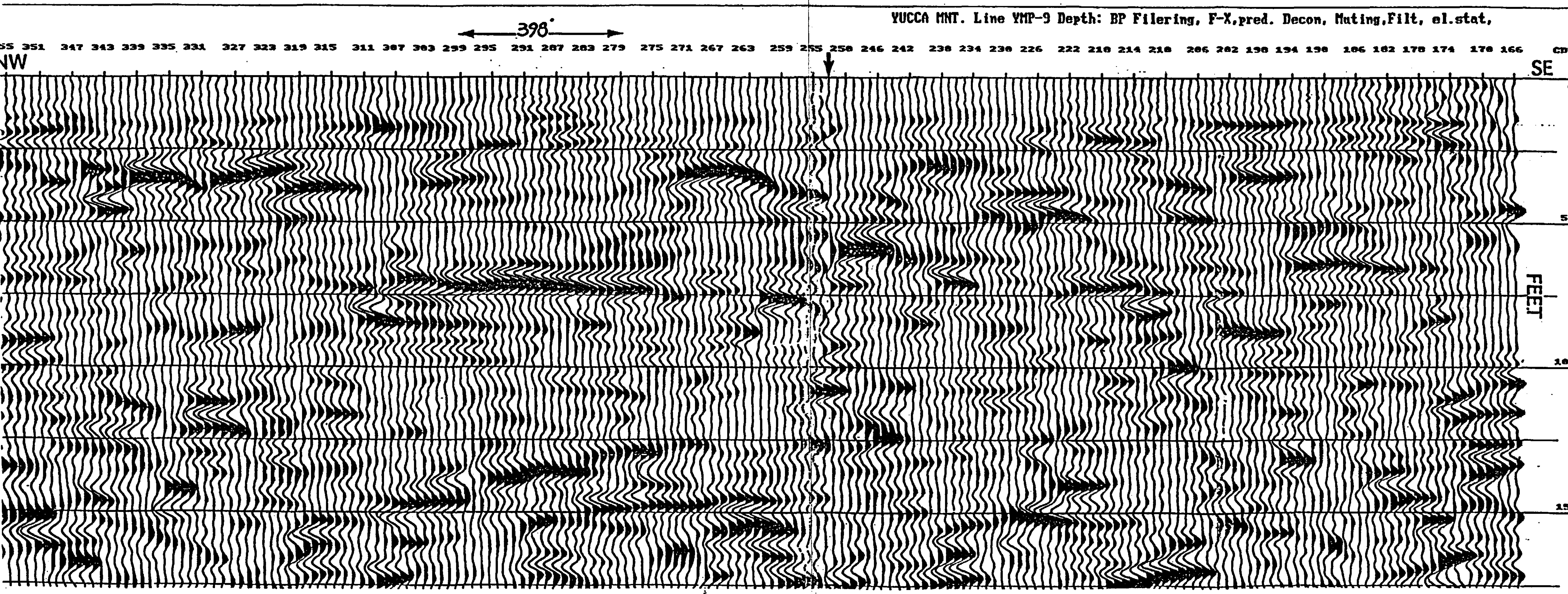

CDP seismic section of line YMP-9. Processing includes elevation statics, datum statics, muting, band-pass filter, F-X decon., and AGC. Arrow indicates approximate location of previously mapped faults. The depth lines are every 250 ft. Seismic datum (depth = 0) is 4227 ft. elevation.

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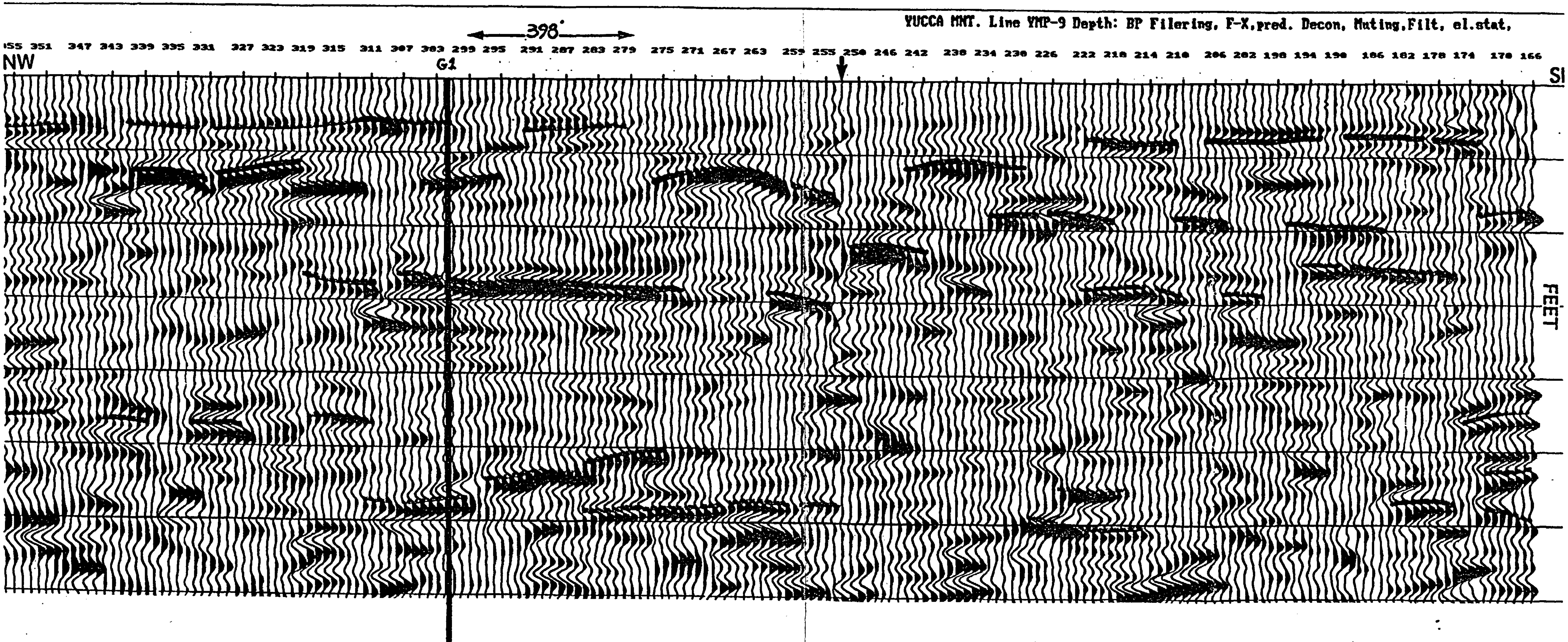
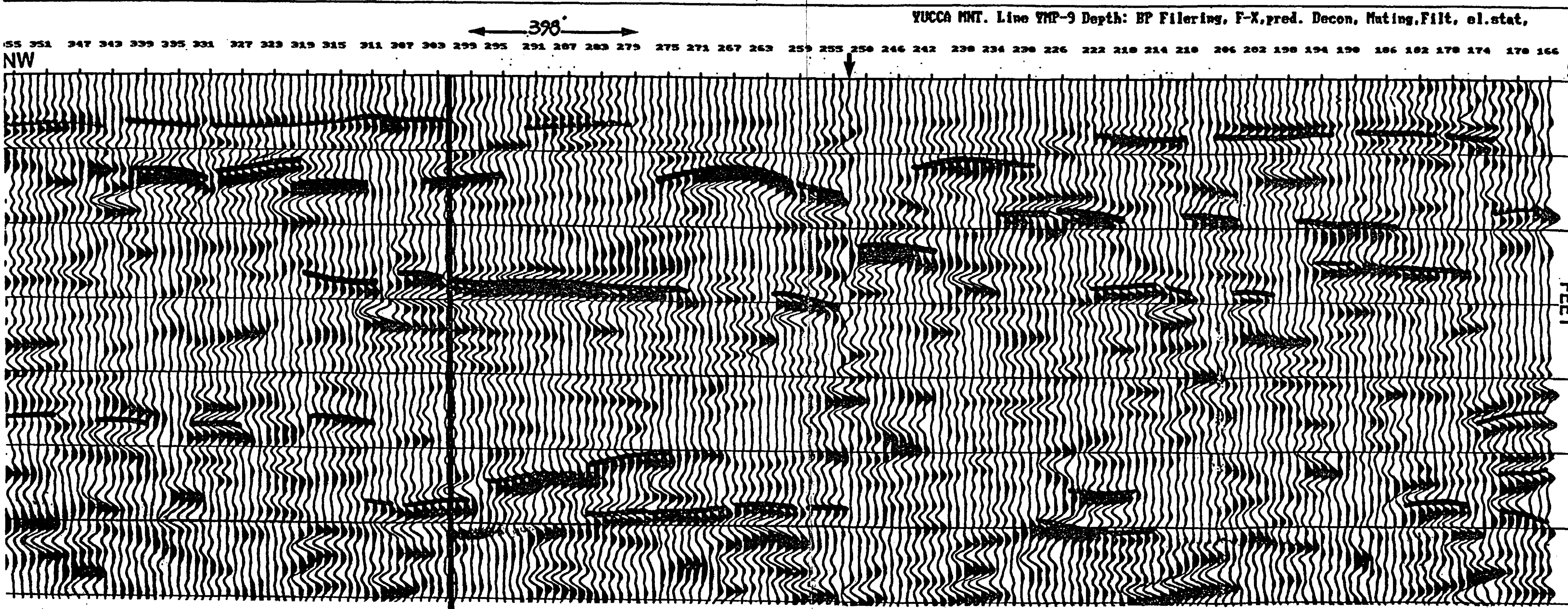
FIGURE 11 DRAFT



CDP seismic section of line YMP-9. Several reflection events have been highlighted in red for interpretation and to indicated lateral continuity of reflection events. The trace of well G-1 is projected onto the section. The depth lines are every 250 ft. Processing includes elevation statics, datum statics, muting, band-pass filter, F-X decon., and AGC. Arrow indicates approximate location of previously mapped faults. The depth lines are every 250 ft. Seismic datum (depth = 0) is 4227 ft. elevation.

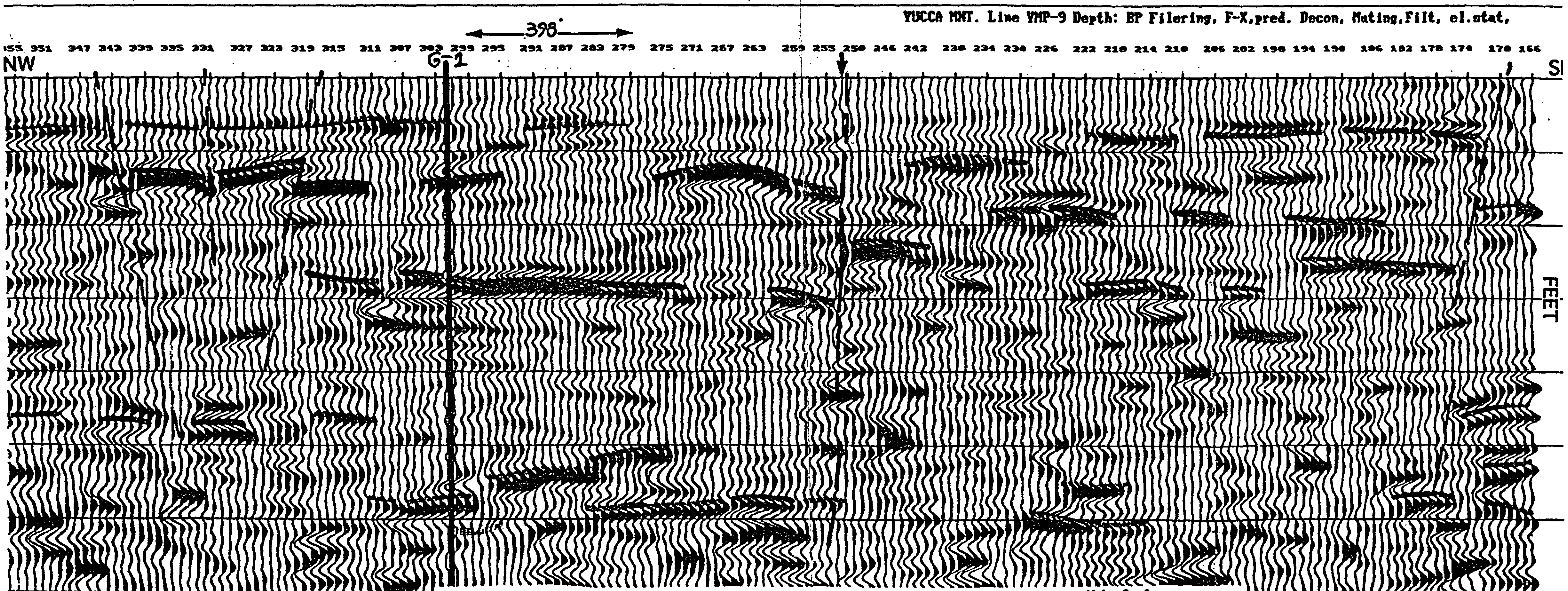
FIGURE 12

DRAFT



CDP seismic section of line YMP-9. The Topopah Spring Tuff and Calico Hills Formation are colored in yellow and pink, respectively with depths guided by nearby well data and seismic reflectivity. Several reflection events have been highlighted in red for interpretation and to indicated lateral continuity of reflection events. The trace of well G-1 is projected onto the section. The depth lines are every 250 ft. Processing includes elevation statics, datum statics, muting, band-pass filter, F-X decon., and AGC. Arrow indicates approximate location of previously mapped faults. The depth lines are every 250 ft. Seismic datum (depth = 0) is 4227 ft. elevation.

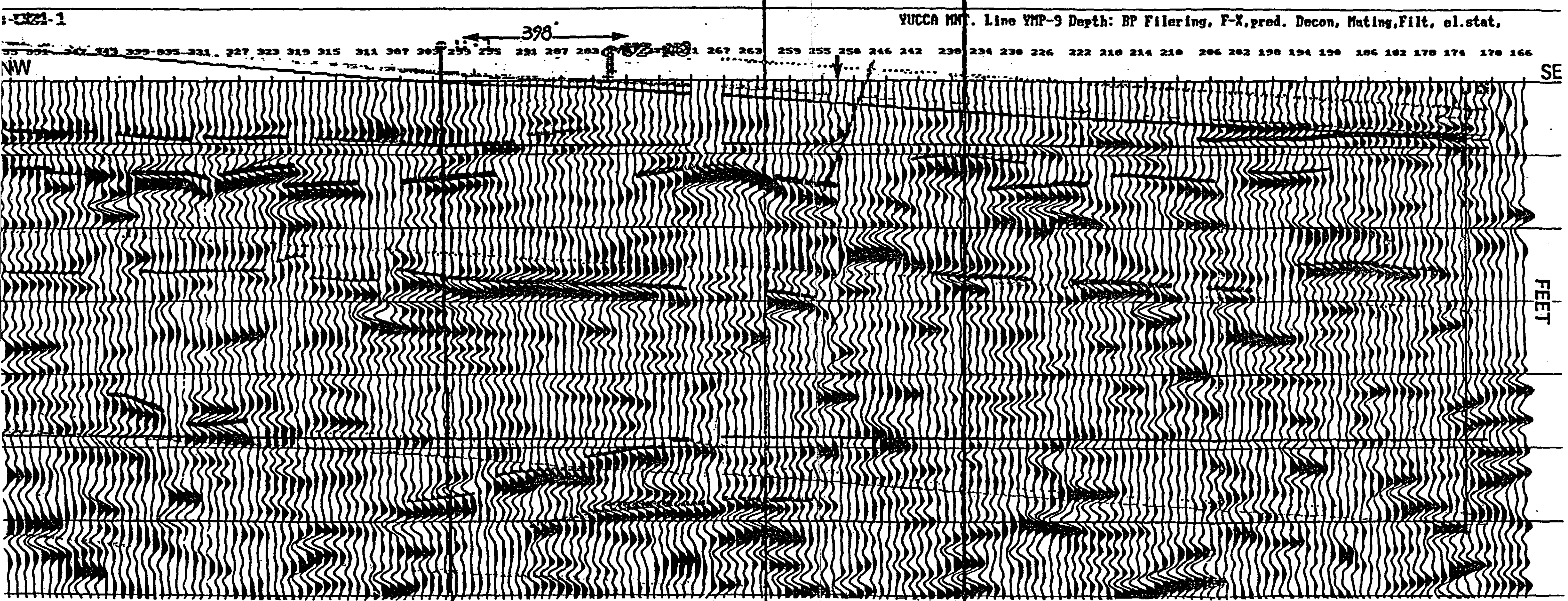
FIGURE 13 DRAFT FOR INFORMATION ONLY



CDP seismic section of line YMP-9. Blue dashed lines represent possible fault interpretations. Note that the lack of lateral continuity of reflection events limits the estimate accuracy of fault location and dip. The Topopah Spring Tuff and Calico Hills Formation are colored in yellow and pink, respectively with depths guided by nearby well data and seismic reflectivity. Several reflection events have been highlighted in red for interpretation and to indicated lateral continuity of reflection events. The trace of well G-1 is projected onto the section. The depth lines are every 250 ft. Processing includes elevation statics, datum statics, muting, band-pass filter, F-X decon., and AGC. Arrow indicates approximate location of previously mapped faults. The depth lines are every 250 ft. Seismic datum (depth = 0) is 4227 ft. elevation.

FIGURE 14

CDP seismic section of line YMP-9. Geologic overlay is from "Distribution of lithostratigraphic units within the central block of Yucca Mountain, Nevada, Version 2.0", USGS Yucca Mountain branch, Rock Characteristics Section, August 1994. The trace of well G-1 is projected onto the section. The depth lines are every 250 ft. Processing includes elevation statics, datum statics, muting, band-pass filter, F-X decon., and AGC. Arrow indicates approximate location of previously mapped faults. The depth lines are every 250 ft. Seismic datum (depth = 0) is 4227 ft. elevation.



Line 2 Intermediate-Stack

Depth-Converted

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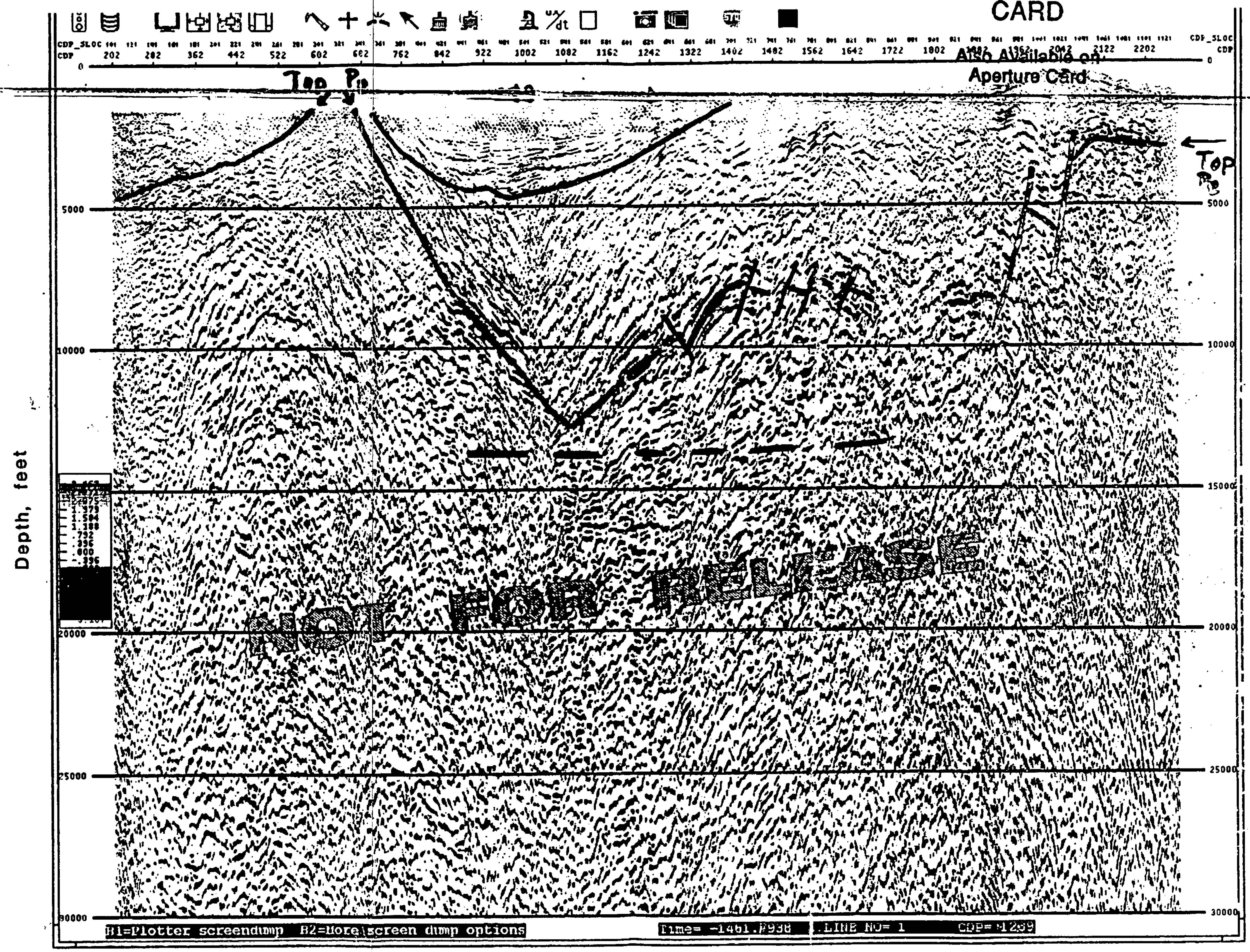

Figure 3

VE 4:1

USGS/YMPB

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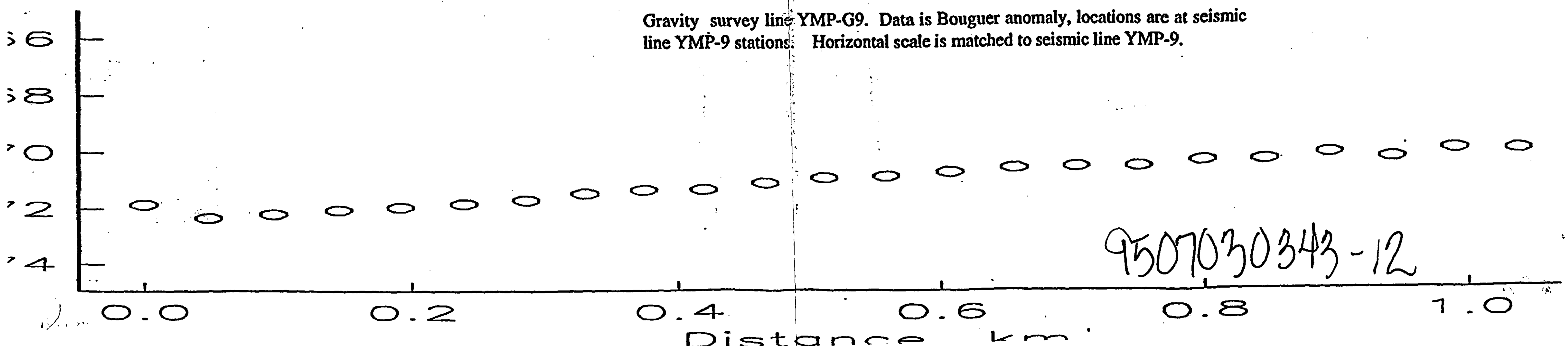
FIGURE 15

Gravity survey line YMP-G9. Data is Bouguer anomaly, locations are at seismic line YMP-9 stations. Horizontal scale is matched to seismic line YMP-9.



SW

Line 2 Intermediate-Stack

NE

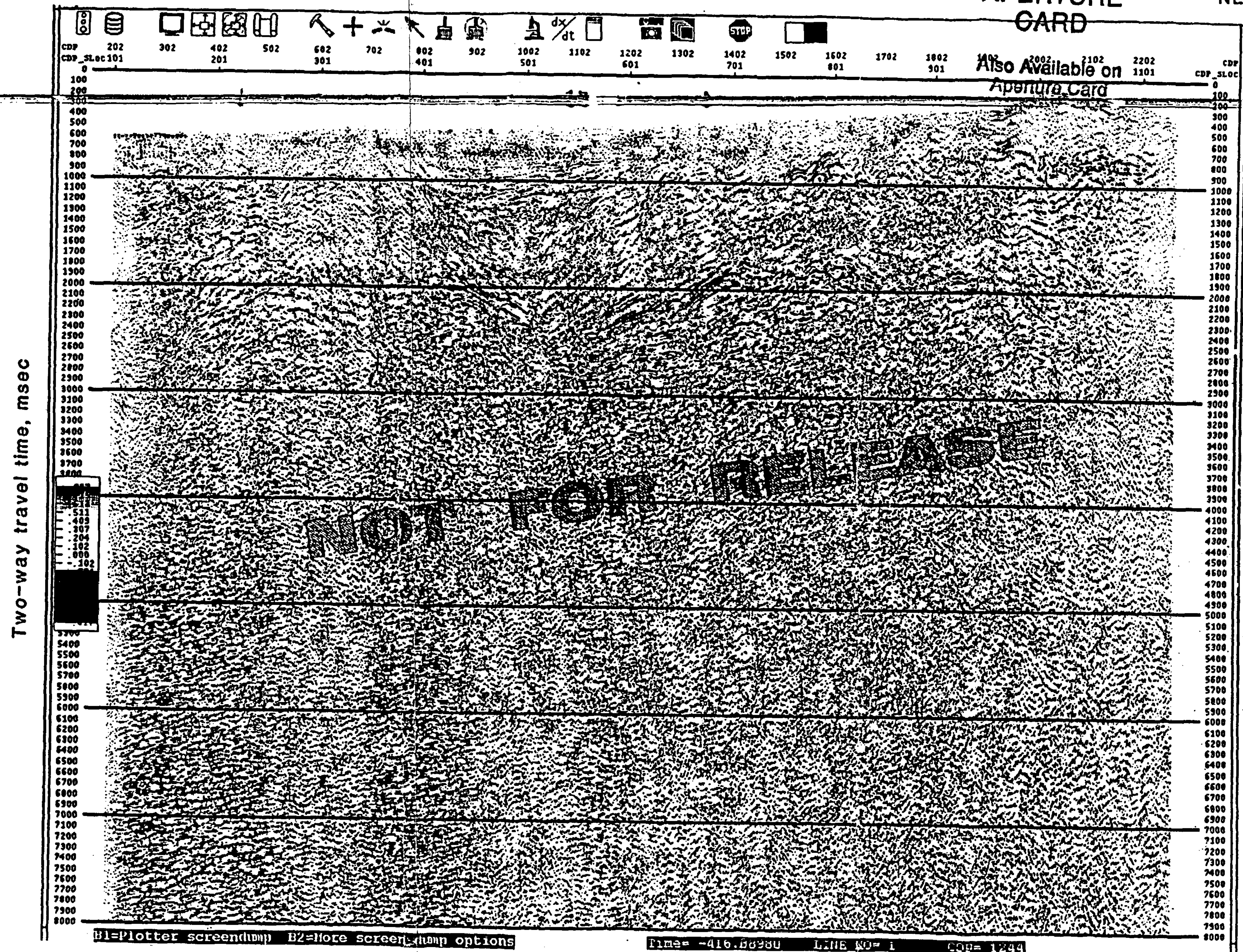


Figure 1

VE 1.6:1

USGS/YMPB

Line 3 - Intermediate Stack

Depth-Converted

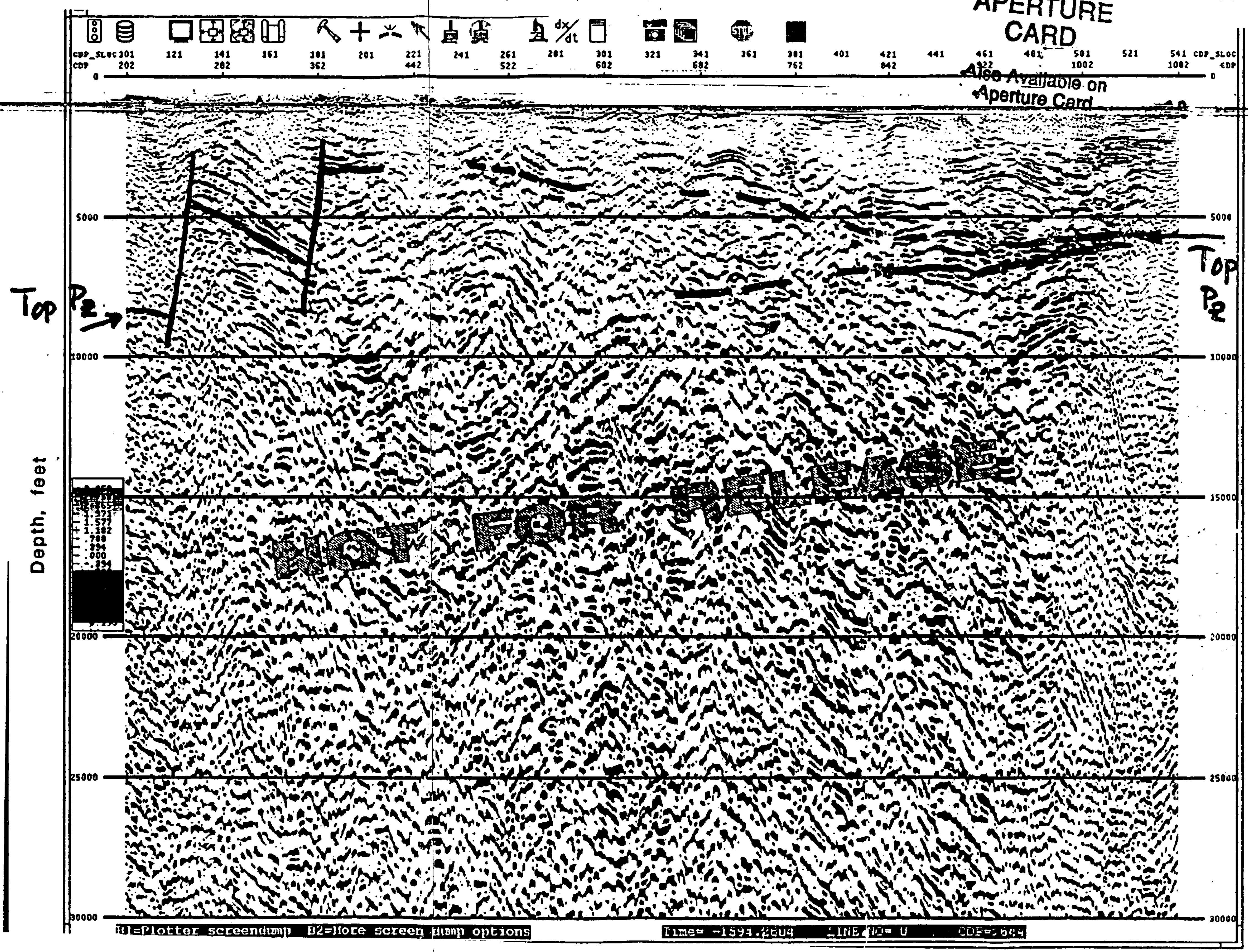


Figure 4

VE 2:1

USGS/YMPB

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West | Line 3 - Intermediate Stack | East

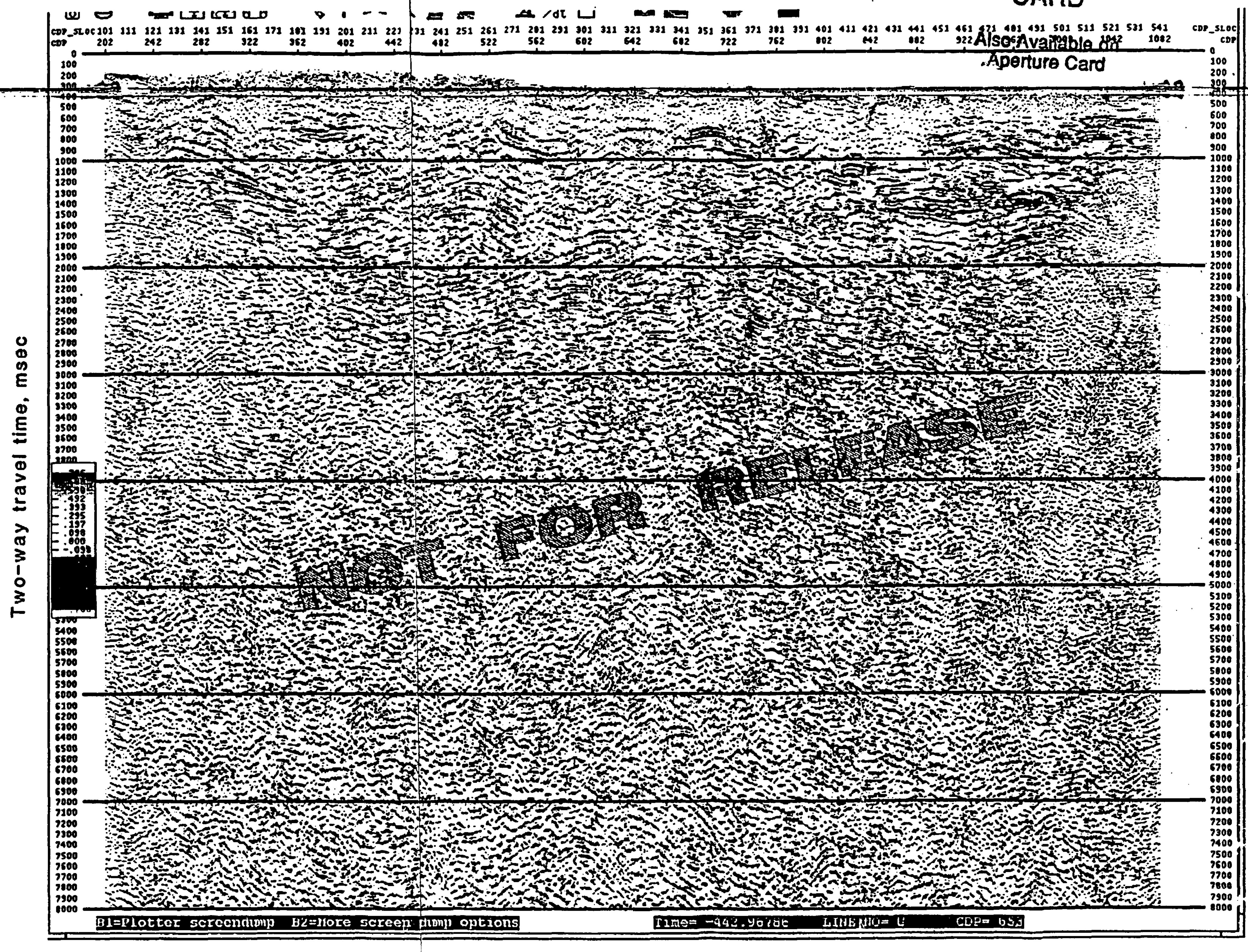

Figure 2

VE 1.5:1

USGS/YMPB

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