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Final Report

1985 REPOSITORY SURFACE FACILITY SEISMIC SURVEY

Yucca Mountain Area, NTS, Nye County, Nevada

November 20, 1985

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I. Summary - During August, 1985, a shallow seismic survey was carried out in the site vicinity of the proposed repository surface facility near Exile Hill in the Yucca Mountain area of the Nevada Test Site, Nye County, Nevada (see Figure 1). The survey included 2.03 miles of shallow seismic reflection lines, 16,500 ft of shallow primary wave refraction lines, 3,900 ft of shallow shear wave refraction lines and primary and shear wave downhole surveys in four shallow drill holes in the area (see Enclosure No.1). The purpose of the project was to attempt to obtain information regarding the shallow geologic structure of the area (reflection lines) and the engineering characteristics of the materials at shallow depths (velocity surveys, including refraction and downhole data).

The survey appears to have been successful, yielding results compatible with other geological and geophysical evidence, as well as adding new information. The following conclusions appear to be justified:

A. Primary wave velocities in the Tiva Canyon tuff are much lower than those measured in the laboratory, strongly suggesting intense fracturing in all parts of the study area except the west side of Exile Hill. The mean alluvial velocity is about 3,300 ft/sec and the mean Tiva Canyon velocity is about 4,500 ft/sec. Energy transmission east of drill hole RF-11 is very poor.

B. Because the observed velocity ranges for alluvium, reworked tuff and Tiva Canyon tuff overlap, it does not appear possible to recognize a given formation or lithology definitively on the basis of its velocity.

C. Shallow refractors near drill holes in the area east of Exile Hill appear to be in the lower part of the alluvium, except at drill hole RF-11, where the observed refractor is apparently in Tiva Canyon. Poor first arrivals and poor reciprocal times make these refractor depths approximate only.

D. Roughly north-south bands of alternating higher and

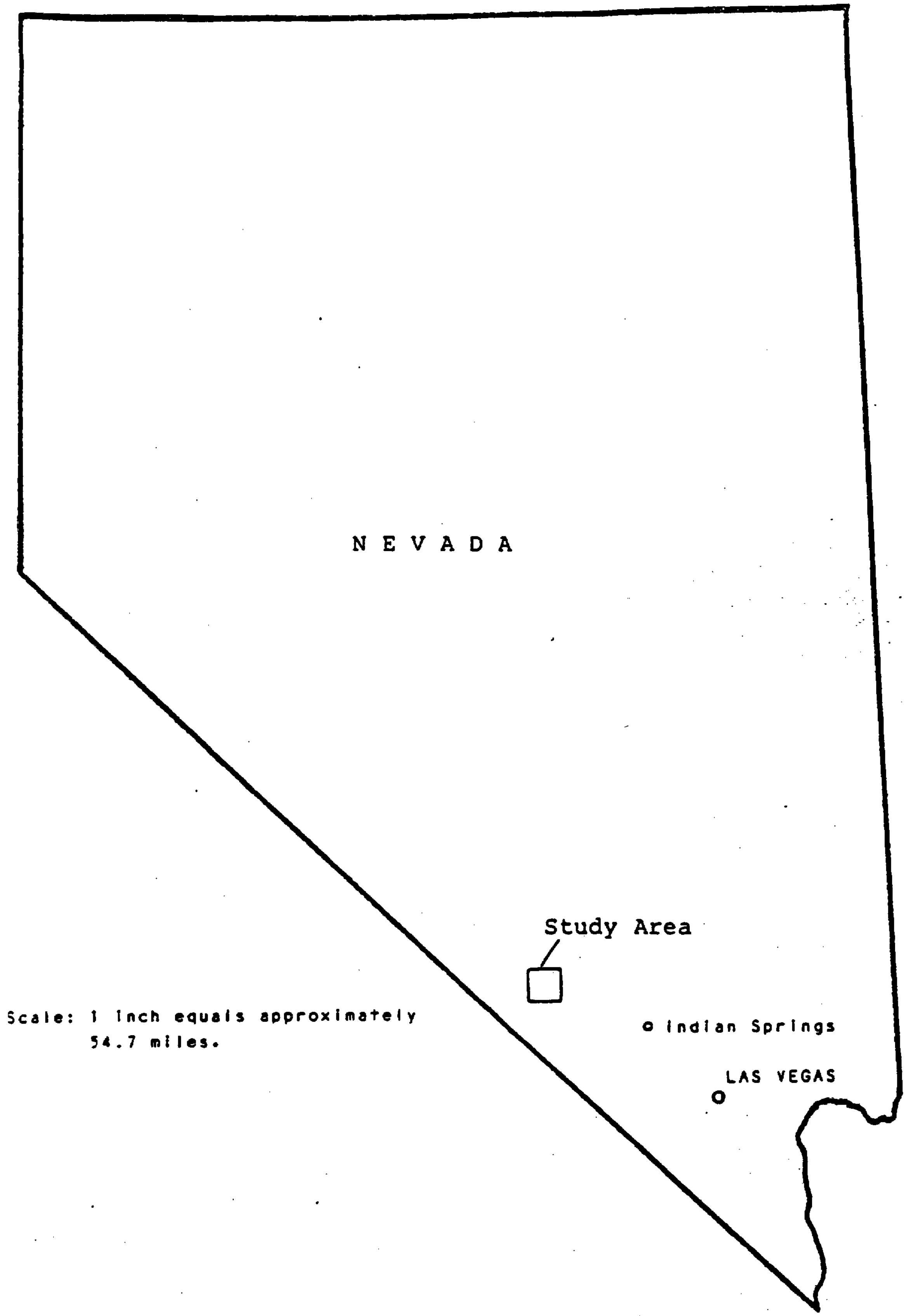

Figure 1. Study Area location, Repository Surface Facility Seismic Survey, 1985, Nevada Test Site, Nye County, Nevada.

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lower refraction velocities east of Exile Hill may reflect:

(1) local structurally high or low trends or buried hills and valleys,

(2) zones of greater or lesser fracturing,

(3) zones of varying alluvial composition, or

(4) some combination of these.

E. Poisson's Ratio, as determined from refraction and downhole surveys, appears to vary widely, but the calculated mean for the alluvium is 0.286 and the mean for the Tiva Canyon is 0.319.

F. The rocks inder the west side of Exile Hill may be less fractured than elsewhere in the area.

G. The shallow reflection lines east of Exile Hill seem to indicate gentle dips of less than ten degrees, cut by numerous faults.

H. Reflection data suggest that an area possibly free of shallow faulting may exist along line RSFS-12 in the north central part of the area.

I. Reflection suggests that some at least of the faults east of Exile Hill strike north-northeast, possibly including those bounding the Midway Valley structural high, which may be a horst 300-700 ft wide.

The following steps in further investigation of the geological and engineering characteristics of the repository surface facility site are recommended for consideration:

A. A detailed gravity survey east of Exile Hill to attempt to trace the Midway Valley high and other major faults and fault blocks.

B. Drilling of the apparent velocity highs and lows east of Exile Hill to determine their nature and confirm or refute the validity of the reflection data.

C. If drilling (B., above) confirms the reflection evidence, a detailed reflection survey in the northern part of the area east of Exile Hill in an effort to find an unfaulted block large enough for the largest building planned.

II. Introduction -

A. Scope of Study - The August, 1985, shallow seismic survey in the proposed site area for the repository surface facility near Exile Hill, Yucca Mountain area, NTS, Nevada, was planned both to evaluate seismic techniques new to the area and to obtain information on the shallow geological structure and material velocities of the area. The project included the recording of shallow reflection lines, primary and shear wave shallow refraction lines, and primary and shear wave downhole surveys in previously-drilled boreholes.

The field work began on August 5, 1985, and was completed on August 28, 1985. During this interval five days were lost to equipment breakdown. No time was lost to weather, although on several days wind velocities became almost high enough to preclude refraction recording.

Five reflection lines were recorded, totaling 2.03 miles in length. Ten refraction lines, mostly using 300 ft spreads, were surveyed with primary waves for a total length of 16,500 ft. Three shear wave refraction lines totaled 3,900 ft in length. Four drill holes were surveyed using surface source and downhole receiver, with both primary and shear waves.

B. Description of Area and Seismic Lines - Enclosure No. 1 is a location map showing the various seismic lines and drill holes. Exile Hill is shown by topographic formline contours. The individual lines and downhole surveys, with their lengths and dates of recording, are listed in a box at the lower left-hand corner. Because some of the lines were coincident in position, color coding is used for clarification. For example, Lines RSFS-1 (reflection), RSFS-2 (refraction, 300 ft spreads), RSFS-5 (shear wave refraction) and RSFS-15 (refraction, 600 ft spreads) were all recorded along the same line on the ground.

The dominant feature of the project area is Exile Hill, an approximately north-south ridge roughly a mile long and 150 ft high as viewed from the east. On the west, Exile Hill is separated from the foothills of Yucca Mountain by a high, narrow valley about a quarter mile wide. Exile Hill itself is rocky and steep on its east side. East of Exile Hill the ground slopes away gently to the southeast, and is cut by one major and several minor southeast-flowing arroyos or intermittent streams. The area is arid, with less than five inches of precipitation per year. The vegetation consists of scattered to dense desert bushes and bunchgrass. In summer, the weather is generally clear, dry and hot, with maxima usually in the range of 95-105 degrees F, occasional high winds and rare thunderstorms.

Geologically the area falls within the Basin and Range province. A thick section of pre-Tertiary strata (mostly Paleozoic carbonates, shales and sandstones), which had earlier been strongly folded and thrust, was covered by Tertiary explosive volcanics before being intensely faulted in the late

Tertiary and Quaternary Basin and Range orogeny characterized by normal faulting and basalt eruptions. In this area the dominant structural and geomorphic grain is north-south, though north of Exile Hill the east side of Yucca Mountain shows a strong northwest canyon development, possibly related to faulting with that trend.

Exile Hill is an east-tilted fault block bounded on the west by the large Bow Ridge fault, apparently a normal fault downthrown to the west. At the surface of Exile Hill beds of the Miocene Tiva Canyon tuff are exposed, dipping eastward at about twenty to twenty-five degrees. This dip rate has been projected under the alluviated valley to the east, but drilling in the valley has shown the Tiva Canyon tuff to be much shallower than this projection. Repeated faulting, upthrown to the east, has been postulated as the mechanism by which this failure to deepen occurs. One worker, Robert Scott of the U. S. Geological Survey, has shown that in exposures to the west (Yucca Mountain) many small, closely spaced, imbricate normal faults upthrown to the east cut the Tertiary volcanics.

C. Purpose of Study - The purposes of the survey were to obtain information on the shallow geologic structure of the area (reflection lines) and on the primary and shear wave velocities of the shallow rocks (refraction and downhole surveys). Both types of information are needed in order to plan and design effectively the buildings and ramped tunnel for the proposed repository surface facility.

III. Reflection Seismic Survey -

A. Lines Recorded - Five reflection lines were surveyed as part of the project. These are listed and shown on the location map (Enclosure No. 1).

Line RSFS-1 was recorded from east to west in the valley east of Exile Hill, and was continued as far up the steep east side of the hill as the seismic truck could negotiate successfully. The line had been originally planned to run directly east-west, but had to be canted east-northeast in order to cross the large arroyo near the east end of the line. Line RSFS-1 is 111 profiles or 3,696 ft long.

Line RSFS-10 was recorded from east to west in the southern part of the valley area east of Exile Hill. This line is 92 profiles or 3,069 ft long.

Line RSFS-12 was recorded from east to west in the northern part of the valley east of Exile Hill and is 72 profiles or 2,409 ft long.

Lines RSFS-9 and RSFS-16 were recorded across the narrow valley west of Exile Hill. Because of the steepness of the valley sides, it was not possible to record a single line completely across the valley. Instead, Line RSFS-9 started at the center of the valley and proceeded eastward to the crest of Exile Hill. Line RSFS-16 started at the same point in the center of the valley and proceeded westward. Lines RSFS-9 and RSFS-16 thus form a line 50 profiles or 1,716 ft long.

B. Field Method - Because the seismic reflection system used is relatively new and unconventional, it was hoped that it might prove more effective in the Yucca Mountain area than more conventional techniques tried earlier.

Conventional modern reflection seismic systems rely heavily on large receiver and source arrays to obtain useable seismic data. This approach has been developed over many years to satisfy the needs of large petroleum companies, who are mainly looking for major geologic structures at considerable depth. The data requirements of the repository surface facility project, however, are diametrically opposite; the geologists and engineers concerned with this project need information on much smaller, shallower geologic structures. The seismic reflection system used for the present survey, in contrast, was specifically designed for investigation of shallow, small-scale geological features, such as shallow faults and fault blocks.

The best shallow seismic reflection data the writer has seen from onshore and offshore in 35 years' experience have been recorded using a short spread, short group interval, short receiver group arrays, and a weak point source with moderate common depth point multiplicity. The system used in the present survey was designed to incorporate these characteristics. Also included in the system characteristics are high mobility, low visibility profile, low cost and minimal environmental impact.

The seismic energy source used is a patented "soft" dropped weight consisting of a heavy leather bag containing 500 lbs of lead birdshot. This weight is dropped freefall 6-1/2 ft (2 m) to the ground. It does not bounce, and produces an unusually clean, constant and repeatable pulse of wide frequency content (5-140 Hz, with peak amplitude at 30-35 Hz). This wide frequency spectrum has often proven to be of great importance in obtaining useable data in difficult areas.

The receiver array consists of six groups of geophones with group centers located at distances of 66, 131, 197, 262, 328 and 394 ft (20, 40, 60, 80, 100 and 120 m) behind the weight drop impact point. Each group is made up of five Mark Products GL-21 gimbal-mounted self-orienting 10 Hz drag geophones spaced 13 ft (4 m) apart inline for a group length of 66 ft (20 m). The six groups are attached to two cables towed behind the seismic truck. This "landstreamer" arrangement produces relatively constant source and receiver geometry.

The recording instruments are a six-channel E. G. & G. Geometrics Nimbus ES1210F system with frequency filters and G724S digital recorder. For the repository surface facility survey all reflection lines were recorded for one second after impact at one millisecond sample rate, except for Line RSFS-16, which was accidentally recorded for one half second at one half millisecond sample rate (the normal refraction recording parameters). The recording filter used is out-60 Hz with notch filters in.

In practice this system is a one-vehicle operation, though two vehicles are normally taken to the field for safety reasons. The field crew usually consists of two persons, an instrument operator and a weight-drop operator. The rough surface and brush of the present survey area, however, required the use of a third crew member to check the seating of the geophones.

Recordings (both analog and digital) are taken at 33 ft (10 m) intervals along each reflection line. This drop point spacing, combined with the 66 ft (20 m) receiver group intervals, yields 600% (six-fold) common depth point data. The 33 ft distances between recording positions are chained during recording of the lines, and every tenth drop position (i.e., drop points 10, 20, 30 and so on) is monumented with a wooden stake (marked with the line and drop point number) driven in the ground. The monumented positions are normally surveyed by plane table and alidade after completion of the project recording, but in this case the client elected to have the line ends and intersections surveyed by a third party. Intermediate elevations were taken from the U. S. G. S. metric topographic contour sheets, adjusted 10 ft up to tie the elevations from the ground survey at common points.

The field recording sequence is as follows. At the beginning of a line the cables (with geophones) are removed from the truck, attached to hooks under the rear bumper of the truck, and straightened out by driving the truck forward. The truck is positioned with the weight ("shot bag") located over the selected beginning point and the impact trigger switch placed on the ground under the shot bag. On a signal from the instrument operator, the weight-drop operator releases the shot bag. When the weight strikes the trigger switch, the seismograph is triggered and records the outputs of the six receiver groups in memory for the time interval selected (one second in this case, except in the instance noted earlier). The instrument operator then observes the recorded data on the monitor CRT screen; if he is not satisfied he may call for one or more additional drops to be summed in the memory of the seismograph, or he may erase the recorded data and start over. When the instrument operator is satisfied with the record as displayed on the CRT, he takes both analog (paper) and digital (cassette tape) recordings, notes the position on his report form, and signals the weight drop operator to move up. The weight operator has meanwhile picked up the weight by electric winch. When signaled to move up, he hands the end of fiberglass surveyor's tape to the instrument operator and walks forward, marking an advance of 33 ft (measured by the tape) with a pin flag stuck in the ground. The instrument operator then drives the truck forward to the new position, trying to stop even with the pin flag. On the next sequence, the weight drop operator adjusts for small stopping inaccuracies to prevent cumulative distance error. This recording sequence continues to the end of the line, where an end of line stake is emplaced, the weight and cables picked up, and the operation moved to the next location.

The first drop point on a line is designated position 1, the next 2, and so on. The cable and weight geometry are such that at position 1, data are obtained at positions 0, -1, -2, -3, -4 and -5. As the recording advances the common depth point multiplicity increases, so that at position -5 it is 100%; at -4, 200%; at -3, 300%; at -2, 400%; at -1, 500% and at position 0 it reaches full stack or 600%. At the far or finishing end of the line, the stack also tapers off over the last five traces. For example, if the last record is at position 100, at position 94 the multiplicity is 600%; at 95, 500%; at 96, 400%; at 97, 300%; at 98, 200% and at 99, 100%. There is, of course, no subsurface coverage directly under the last drop position (in this example, there is no subsurface coverage under position 100).

At the end of the day the field notes, paper records and digital cassettes are delivered to the computer operator, who begins the data processing sequence.

C. <u>Digital Data Processing</u> - Because of the unique and unconventional nature of this seismic system, special data processing techniques are needed which are very different from those normally used by data processing centers dealing with data recorded by more conventional systems. For example, conventional seismic data are usually 48 or more channels, recorded multiplexed on 9-track reel-to-reel tape; the data from this system are six channels, recorded sequentially on digital cassettes. Few processing centers are equipped to read such cassettes and transfer them to a computer. Further, two of the most important and time-consuming steps in the processing of conventional data--normal moveout removal and deconvolution--are made unnecessary by the characteristics of the system. On the other hand, another processing step which is necessary to successful processing of short spread, weak source onshore data (F-K filter before CDP stack) has been in the past regarded as heresy by many processors of conventional data and is only now gaining acceptance among major oil companies.

To provide appropriate processing for data recorded by this system, it thus became both desireable and necessary to write processing software specifically designed for the purpose. At present all processing is done on IBM PC microcomputers. The sequence used for the repository surface facility survey reflection data is as follows:

(1) Transcription (via serial port) from the 3M DC-100A digital cassettes to mini-floppy diskettes, with concomitant resampling to 2 ms sample rate. At this stage the record files are named R1, R2, R3 and so on to correspond to the field record notation, and are written as integers in pseudosequential format.

(2) Reformatting to true random access format with resampling to 4 ms sample rate.

(3) Quality verification and editing. This is generally done by displaying and examining the records on the computer monitor.

(4) Calculation (from the refraction breaks) of weathering velocity, weathering depth and subweathering or replacement velocity. If the refraction breaks are strong and clear, this can be done on the computer screen; in more difficult cases, such as the present study, paper record plots are made to allow more careful study of the refraction breaks. Figure 2 shows examples of paper plots of raw reflection data.

(5) Calculation of datum corrections is done using the elevations determined by surveying or from topographic maps, the weathering velocity, subweathering velocity, the weathering depth calculated from the refraction breaks, and the replacement or correction velocity (taken as the rounded-off mean of the subweathering velocities measured). For the present survey, the weathering velocity used is 2,300 ft/sec, except for Lines RSFS-9 and RSFS-16, where there was no measurable weathering. The replacement or correction velocity is 3,100 ft/sec for RSFS-1 (the first line) and 3,400 ft/sec for the remainder of the reflection lines. The datum or reference plane (to which all

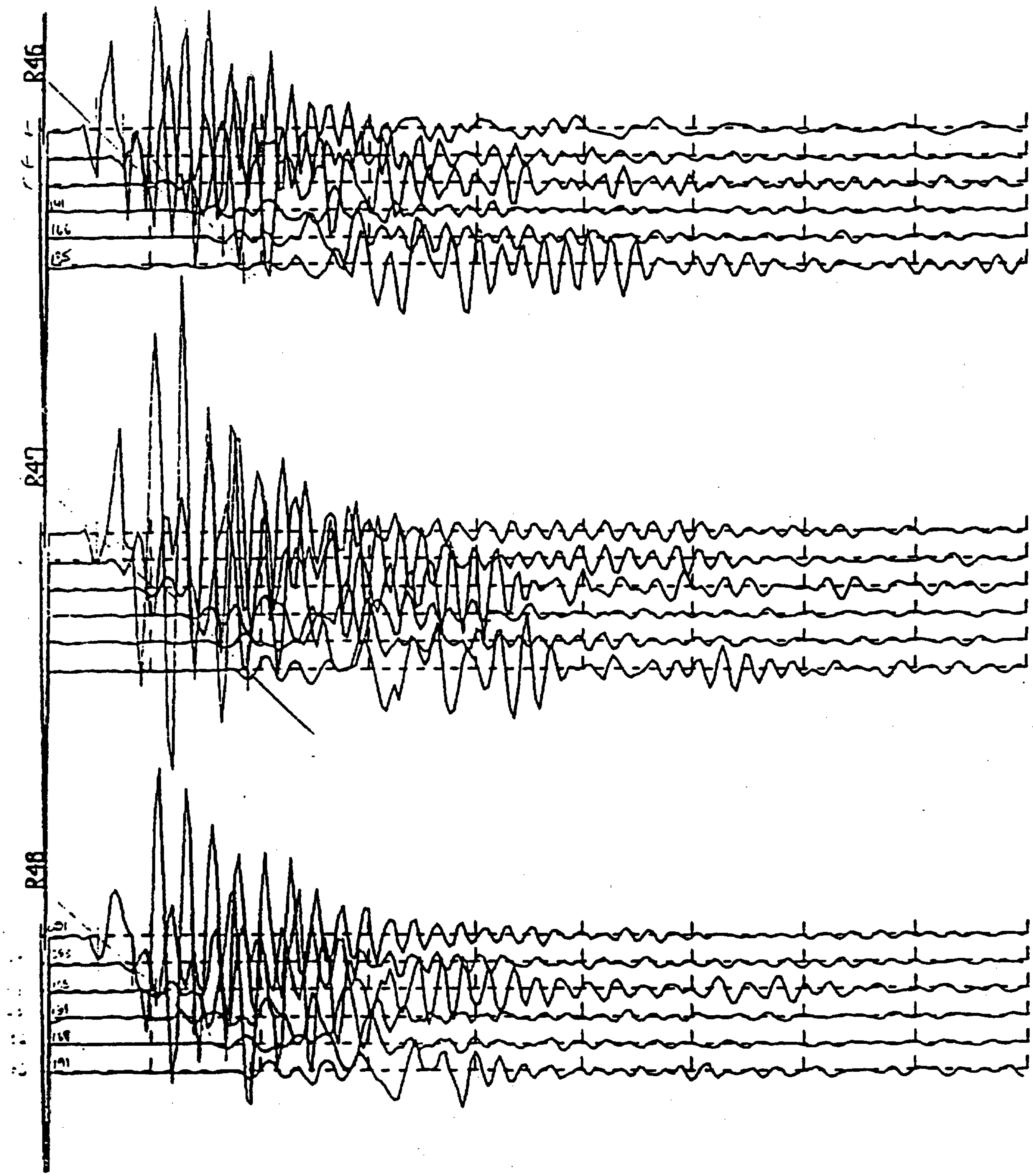

Figure 2. Example of raw data plots as used for weathering determinations for datum corrections. Line RSFS-12, Repository Surface Facility seismic survey, 1985.

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reflection data were corrected) is 3,700 ft above mean sea level.

(6) While the datum corrections are being computed, an F-K or velocity filter is being applied to the edited records. This is the single most important step in making short spread, weak source data useable, especially in a difficult area such as the repository surface facility site. The problem is that the coherent surface and near-surface noise, such as refraction breaks, various types of groundroll and air wave, are of the order of ten times greater in amplitude than the desired reflection signals. The purpose of the velocity filter is to remove these types of coherent noise. In this case all signals of apparent velocity slower than 16,500 ft/sec were rejected, and all signals faster than that were retained. The retained signals should include all reflections from beds which dip up to about 20 degrees. A comparison of Figure 3, which shows Line RSFS-12 as stacked without velocity or fan filter before stacking, with Figure 4, which shows the same line as stacked after application of the velocity filter, demonstrates the effectiveness of this process. Figure 3 is very noisy and shows little or no coherent signal lineups which may be bedding-plane reflections; figure 4, in contrast, shows numerous events which may be bedding plane reflections. As has been shown by Hans Ackerman of the U. S. G. S., F-K filtering can produce lineups or apparent events from random noise. The interpreter must, therefore, attempt to recognize and reject random lineups by recognizing geologically coherent events--i.e., those which show similarity up and down the record section as well as showing some measure of continuity along the section.

The importance of this processing step, in the writer's opinion, cannot be overemphasized. If this technology had been common practice when the 1980 Colorado School of Mines survey in the Exile Hill area was carried out, the results of that survey might have been useable, provided the near traces only (offset less than 600 ft) had been used. As mentioned earlier, however, the application of a velocity filter before stack is only now coming into widespread useage. In 1980 it was not likely even to have been tried.

(7) The next step in the data processing for the repository surface facility survey reflection lines is 600% common depth point stacking. In this step six different seismic traces which followed different paths to a common reflecting point in the subsurface are added together to produce one summed or stacked trace. The number of output or stacked traces resulting from this step is one-sixth the number of input traces. Common depth point stacking has become a generally accepted practice in reflection seismic during the last 20 years, and is considered to yield a substantial improvement in data quality.

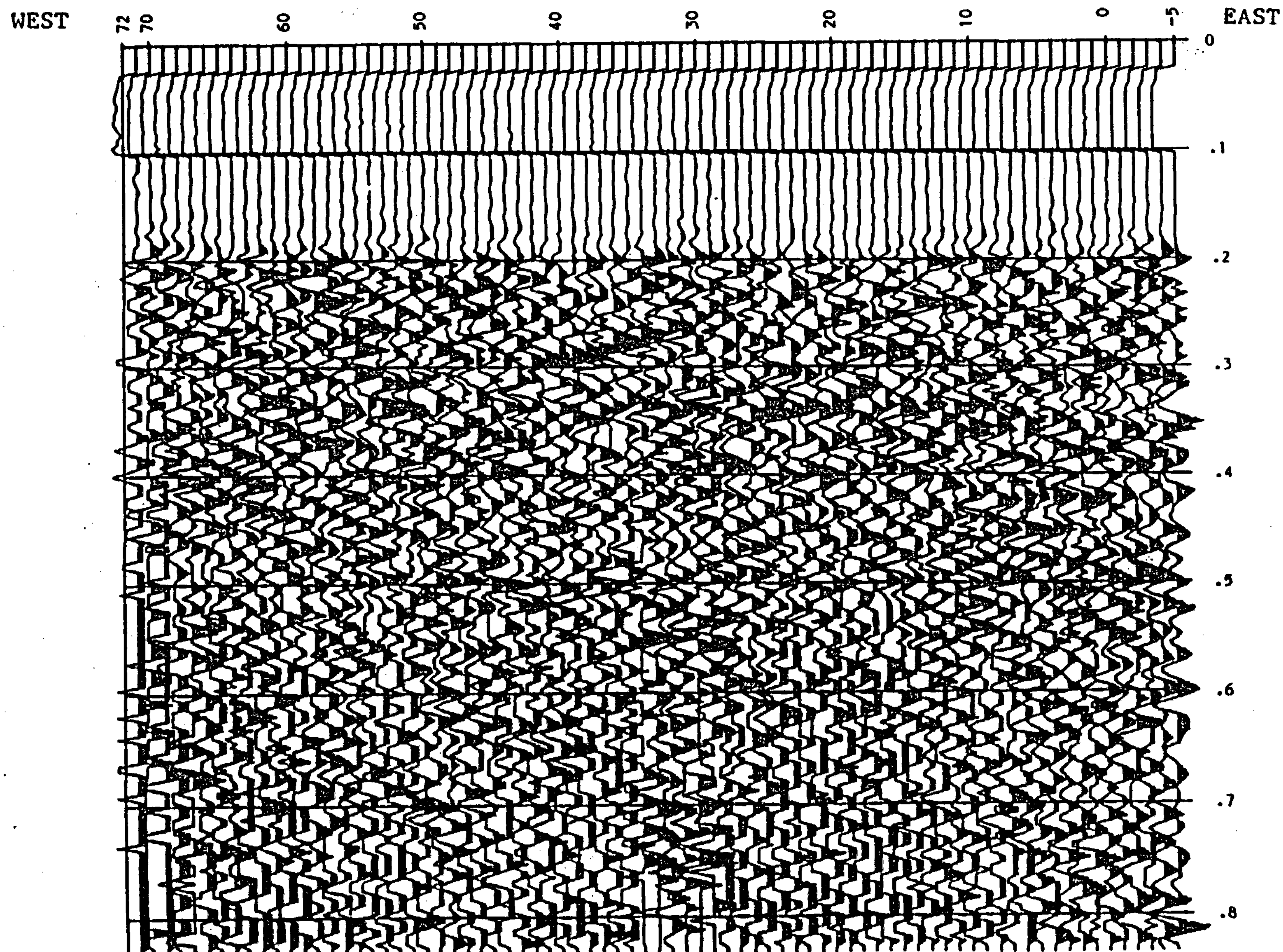

Figure 3. Reflection line RSFS-12, 600% CDP stacked section without velocity filter before stack. Stack valid only between 0.01 and 0.8 seconds. Repository Surface Facility seismic survey, Nye County, Nevada.

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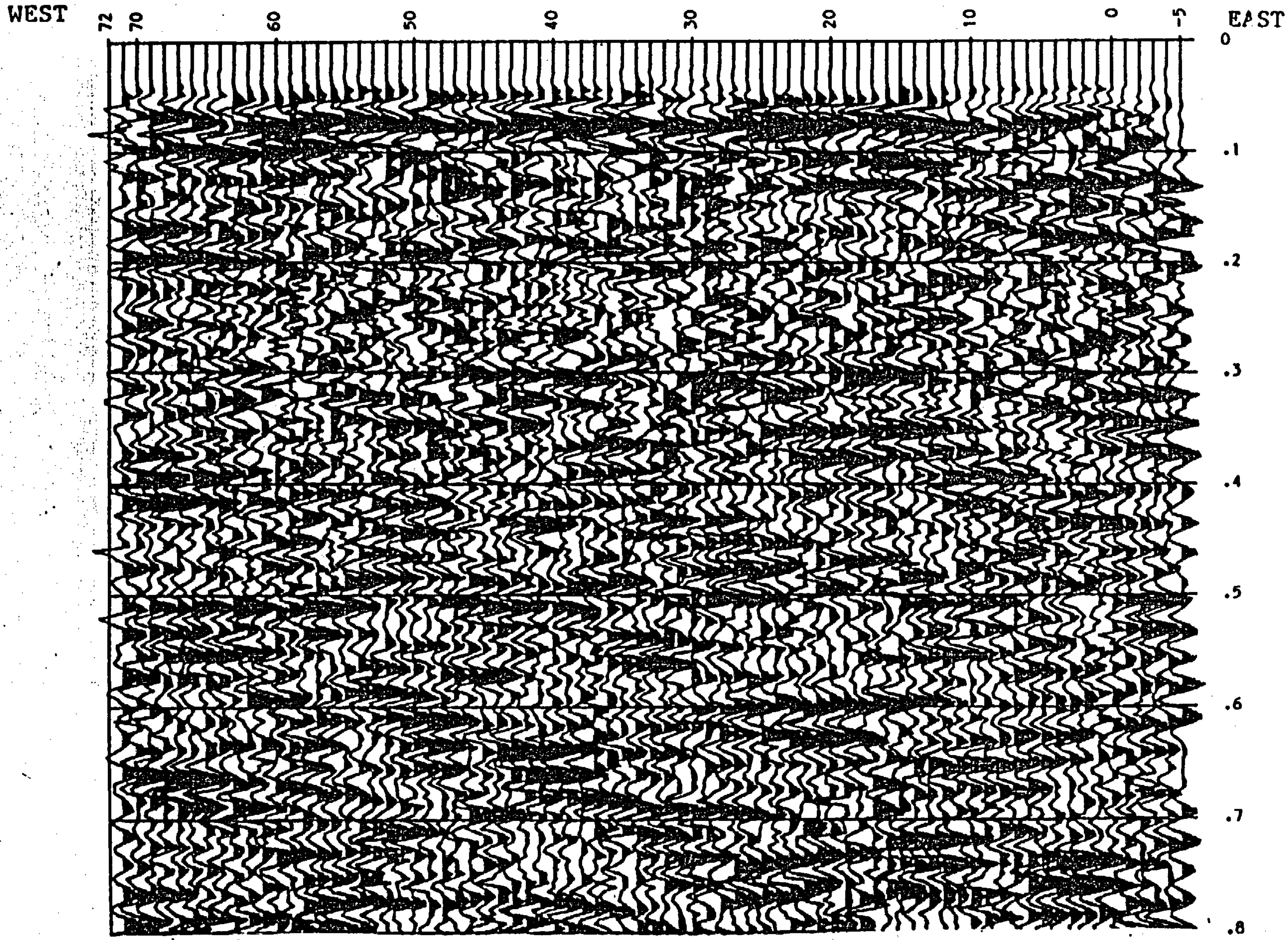

Figure 4. Reflection line RSFS-12, 600% common depth point stack section after velocity filter. No frequency filtering applied after recording filters. Repository Surface Facility seismic survey, Nye County, Nevada.

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(8) Application of the datum corrections calculated earlier is done at this point, after completion of the common depth point stacking. For shallow reflection surveys such as this the datum or reference plane used is commonly selected to be above ground level, to avoid excessive loss of very shallow data. In the case of the present survey, the datum selected is 3,700 ft above sea level; this is at the east base of Exile Hill, so that in most of the area the datum is above ground level.

(9) A dip filter is next applied. This filter recognizes and enhances events or possible reflections which are coherent over nine successive traces of the stacked data, advancing one trace at a time. The filter recognizes an event as coherent over nine traces and adds it at its mean amplitude back to the unfiltered data at the position of the central trace of the nine being filtered. Coherent events thus are doubled in amplitude, while the background noise remains unchanged. The range of dips examined for coherency and enhanced in this case is the same as that used in the pre-stack velocity filter, from about 20 degrees in one direction to about 20 degrees in the other. Comparison of Figure 4 (Line RSFS-12, after stacking but before datum correction and dip filter) with Figure 5 (RSFS-12, after datum correction and dip filter) will show the effect of this step.

(10) Migration in time is commonly applied at this stage. It was in fact carried out on the data from the present survey, but is felt to have been beneficial only in the case of Line RSFS-9, where it appears to have clarified somewhat the position of the Bow Ridge fault.

(11) Bandpass frequency filtering of the data normally precedes the making of the final plot of a seismic line. Selection of the pass band to be used includes making a filter comparison sequence using one-octave passbands--usually 5-10 Hz, 10-20 Hz, 15-30 Hz, 20-40 Hz, 25-50 Hz, 30-60 Hz, 35-70 Hz, 40-80 Hz, 50-100 Hz and 60-120 Hz. Enclosure No. 2 shows the filter comparisons made for one of the lines (RSFS-12). The 5-10 Hz and 60-120 Hz displays showed no coherent data and are not included. A one or two octave passband is then selected which shows the highest signal-to-noise ratio and is used for final filtering of the data. In some cases time-variant filtering is used, usually to enhance higher frequency events at shallow depth and lower frequency events at greater depth. On occasion spectral whitening is used before the final filtering to bring up weak higher or lower frequencies. The decision was made not to apply further frequency filtering to Lines RSFS-9 and RSFS-16.

(12) Slow AGC or automatic gain control is generally applied at this point. The purpose of this is to adjust the overall amplitude of the data to counter the signal

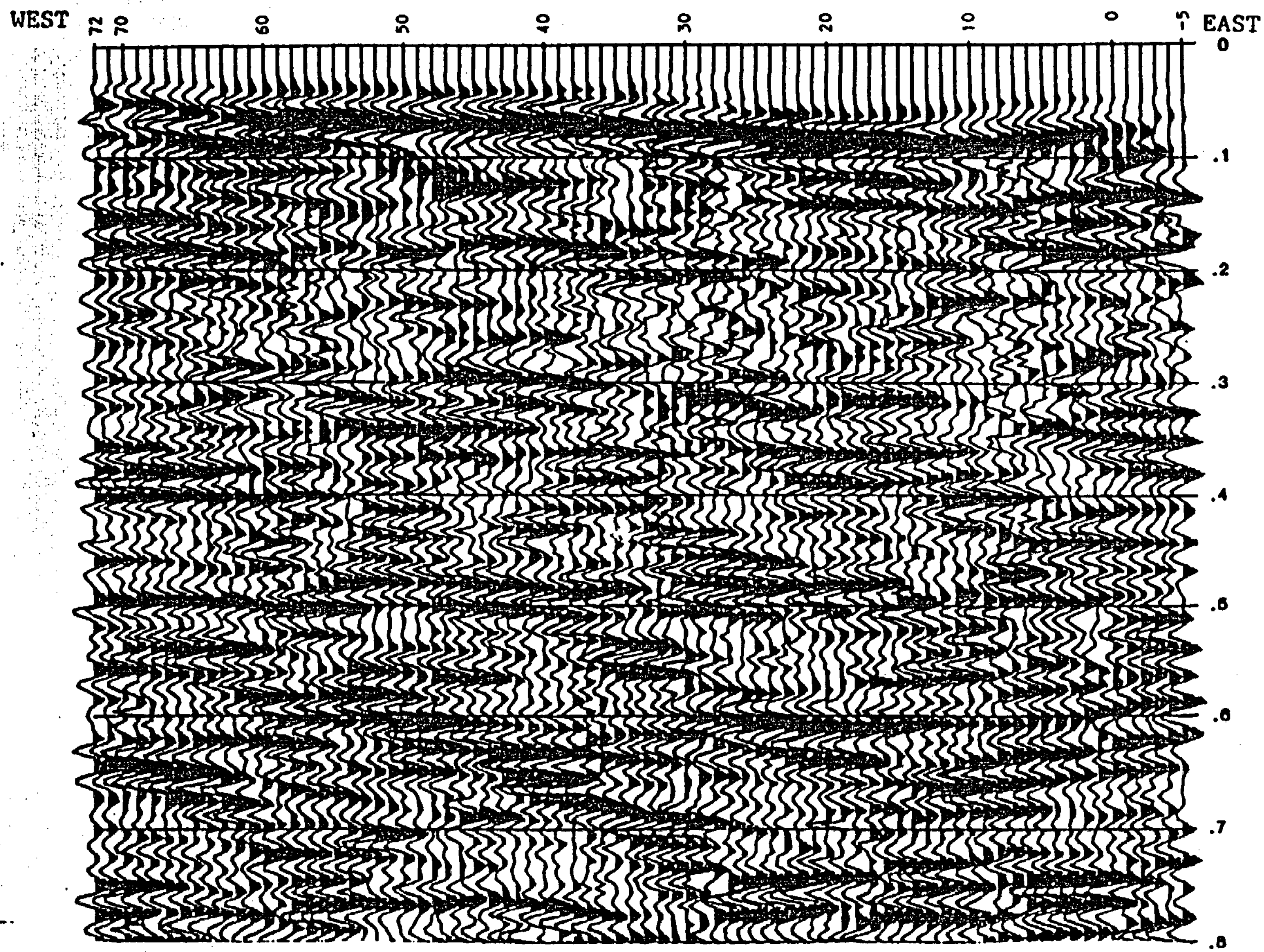

Figure 5. Reflection line RSFS-12, 600% common depth point stack section, velocity filter before stack, datum corrections and dip filter. No frequency filters applied after recording filters. Repository Surface Facility seismic survey, Nye County, Nevada.

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amplitude decrease with time and depth. In this case the amplitude sensing gate used is 0.200 second.

(13) Plotting a variable area and wiggle trace (VA/WT) record section of the final data. This is done at a standard scale of 7.5 inches/second, with a trace separation of 0.094 inch (equal to 33 ft on the ground).

D. Results - Enclosures Nos. 3 through 7 are the final 600% stacked record sections for the reflection lines recorded in this survey. Enclosure No. 8 is the time migrated section for Line RSFS-9, mentioned earlier. Lines RSFS-9 and RSFS-16 are regarded as of fair quality, Lines RSFS-1 and RSFS-12 are regarded as of poor quality, and Line RSFS-10 as of very poor quality. The data are "ringy", which is characteristic of data produced by this system in the absence of strong reflectors.

E. Interpretation - All the reflection lines recorded as part of the project show seismic events interpreted as likely to be bedding plane reflections to a maximum depth of 1,000 to 1,200 ft. A selection of these is colored yellow on the enclosed interpreted reflection sections (Enclosures Nos. 9 through 14). These events were chosen on the bases of (1) event standout, (2) lateral continuity (along the sections) and (3) vertical geological coherence.

In general, the selected events on the seismic sections east of Exile Hill show gentle dips (less than ten degrees). These seismic dips, which appear likely to be real (see Enclosures Nos. 9 and 11), are much lower than expected from the surface exposures on Exile Hill and the cores in the drill holes. This will be discussed in Section VI, Integration of Results.

Also shown on the interpreted sections are possible seismic faults (steep green lines). These were recognized on the bases of (1) discontinuity of possible reflections and (2) deflections of possible reflections. Most of these appear to be small faults which seem to die out with depth and evidently are upthrown to the east. Three of the larger faults may be correlatable from one line to another; this suggested correlation is shown on Enclosure No. 15. These faults, if correctly interpreted, appear to strike north-northeast.

Some of the interpreted faults show stronger suggestion of recent movement than others; examples of this are the small faults at about positions 6 and 44 on Line RSFS-12 (see Enclosure No. 11). This suggestion of recent movement is taken from apparent displacement of the shallowest possible reflection, which may come from near the base of the alluvium.

The reflection lines across the narrow valley west of Exile Hill exhibit particularly clear seismic fault evidence. Line RSFS-9 (Enclosures Nos. 13 and 14) appears to show the Bow Ridge fault clearly, apparently as a steep, down to the west normal fault. The throw of this fault, as suggested by a possible reflection between 0.2 and 0.3 second (perhaps 500 ft depth) may be of the order of 200 ft. In addition, Line RSFS-9 suggests that there may be significant drag (i.e., flat to gentle west dip) on either side of the fault, increasing the total displacement to perhaps 250 ft. Further west, Line RSFS-16 suggests a near-surface fault at about position 13, a west-dipping normal fault of small displacement at about position 3, and a near vertical, down to the west fault at greater depth near position 5. The total displacement across the valley west of Exile Hill may thus be of the order of 300 ft.

The largest apparently unfaulted shallow block shown on the reflection lines as interpreted lies between positions 8 and 27 on Line RSFS-12. This block appears to be unfaulted for a width of about 600 ft.

IV. Refraction Seismic Surveys (primary and shear wave) -

A. Lines Recorded - The primary (compression) wave refraction lines recorded include Lines RSFS-ØA, ØB, 2, 3, 4, 11, 13, and 14 (using 300 ft spreads) and Lines RSFS-7 and 15 (using 600 ft spreads). The shear wave refraction lines include RSFS-5, 6 and 8, all using 300 ft spreads. The locations of all these lines are shown by Enclosure No. 1.

B. Field Methods -

(1) Primary wave refraction - For very shallow (less than 100 ft depth) information, the field layout used is a 300 ft reversed spread. The seismic truck is positioned with the weight (shot bag) suspended over one end of the spread and single receivers (Mark Products 8 Hz refraction geophones) are emplaced at distances of 50, 100, 150, 200, 250 and 300 ft from the position of the weight. The geophones were generally buried, during the present survey, to reduce wind noise. The weight is then dropped and a half-second recording taken. After examination of the resulting record, the operator may decide to add more drops. When the operator decides that more drops will not further improve the record, a geophone is positioned exactly where the bag has just been dropped, and the seismic truck moved to the other end of the 300 ft spread. The far geophone (that is, the one which is 300 ft from the first drop point) is removed and the weight positioned to fall where the geophone had been. In this way, the profile can be reversed, i.e., the travel path from the second drop point to the far geophone is (or should be) the same as the travel path from the first drop point to the then far geophone. Because the two travel paths should be the same, the travel times in the opposite directions (reciprocal times) should be the same. This constitutes a very powerful tool in evaluating the reliability of refraction results, as well as being necessary for some of the better refraction analysis techniques.

After the change is made from one end of the spread to the other, the weight is dropped again and the record examined. As before, if the instrument operator feels it is advisable, several drops may be summed. The two records from the opposite ends of the spread are then examined and compared with regard to reciprocal times. If the reciprocal times are more than 5 milliseconds different, the second position should be redropped and rerecorded after the far geophone is checked for position, seating, and polarity. In previous surveys elsewhere, this procedure has generally been successful in reducing reciprocal time differences to acceptable limits. The fact that it did not work in many cases in the Exile Hill area almost has to be due to the cause suggested by Hans Ackerman of the U. S. Geological Survey--greater attenuation and loss of first arrival energy in one direction than in the other.

When both ends of a refraction spread have been recorded, the spread is moved forward half its length and repeated. The purpose of this is to try to ensure reasonably continuous refractor coverage.

For 600 ft profiles, which can be hoped to detect good refractors to a depth of 150-200 ft, the procedure used is more complex. The 300 ft receiver array (still with 50 ft geophone spacing) is laid out in one half--say the west half--of the 600 ft profile length and records taken with the weight dropped at first one end and then the other of the 600 ft profile. The 300 ft receiver array is then moved to the center 300 ft of the 600 ft profile and records taken with the weight dropped at each end of the 600 ft profile. Finally the 300 ft receiver array is moved to the other end--again, say the east end--of the 600 ft profile and records taken with the weight dropped at each end of the 600 ft profile. The purpose of this overlapping system is to allow construction of a 600 ft reversed time-distance plot which can be made, by adjusting back from the reciprocal times, into a continuous 600 ft profile.

(2) Shear wave refraction - The receiver arrays used are the same as the 300 ft primary wave refraction spreads, except, of course, that horizontal geophones are used. The energy source used consists of a heavy metal frame made of four inch drill stem and a truck parked on each end of the frame, all aligned parallel to the direction of the receiver cable. A steel riser or bulkhead, attached to the frame between the two trucks is struck repeatedly on one side (say on the south side for an east-west line) until the instrument operator feels that the record, as observed on the CRT of the seismograph, is of satisfactory amplitude. A recording is then taken (analog and digital), the seismograph's memory cleared, and the bulkhead struck on the opposite side (again, say on the north side for an east-west line). After the record appears satisfactory to the instrument operator a second recording is taken. In this fashion, horizontally polarized shear waves, polarized in first one direction and then the other, are generated. Ten to sixteen blows of the sledgehammer on each side of the bulkhead were used for the present survey.

Digital as well as analog recordings one half second in length were taken for all shear wave recordings of this survey. Initially, only analog recordings were taken for primary wave refraction profiles. The problem of weak first arrivals, however, became apparent as the project progressed, so after RSFS-4 all primary wave refraction data were recorded digitally also, to allow later amplification of the records.

C. <u>Analog and Digital Data Processing</u> - The 300 ft primary wave refraction data were analyzed by the following procedure.

First, reciprocal (reversed) record pairs were examined and an attempt made to pick (recognize and mark) the first energy arrival on each trace of both records. The two records were then compared to see if the same refractions appeared to be present on both. In many instances this showed that a deepest refraction recognized on one record had not been recognized on the record from the opposite direction or that on the stronger record the deepest event had been picked a cycle earlier than on the weaker record. In such cases attempts were then made to recognize the deep refraction on the weaker record, sometimes including step-by-step digital amplification of the weaker record. When it was felt that the picks were as good as possible the reciprocal times were compared, and if they were different, as they usually were, the times of all traces on the record with the shorter reciprocal times were increased by the amount necessary to make the reciprocal times equal. This step was based on the observation, based on experimentation in the field, that small reciprocal time differences seemed to be source-point dependent. That is, softer soil at the drop-point appears to cause delays of up to 10 ms in the triggering of the seismograph, resulting in shorter measured travel times; thus the longer travel time appears likely to be more nearly correct.

After picking of the first arrivals, the picks were timed and separated into apparent different refractions. A common condition was that the nearest trace appeared to show the direct arrival through the first or surface layer; the next two traces evidently showed a refraction from a deeper second layer; and the three far traces showed a refraction from a still deeper third layer. In a number of cases only the direct wave and a single deeper layer refraction were indicated.

The distance-time data pairs for each refraction recognized on each record were then entered into a computer program called LNFT, which fits an inverse velocity line by the method of least squares to each set of distance-time data pairs. The output of this program is the velocity, zero-distance time intercept, and quality indicator of the line fitted. These data were then entered into a program called ZBYTØ, which solves for the depths of refractors by the zero-distance time intercept method. The velocity used for the first or surface layer was taken as the rounded-off mean of the velocities derived from acceptable near-trace first arrivals for the entire line. The velocities used for the second layer (and if present, third layer) refractions were taken from the LNFT output.

The deepest refraction detected on each reversed profile was then analyzed by a wavefront-reconstruction method which requires that a single velocity be assigned for all overlying material. This overburden velocity was determined for each line by taking the per foot mean of all the ZBYTØ solutions for the surface layer and second layer (where three layers appear to be present).

Finally, the results of the ZBYTØ and wavefront-reconstruction solutions for each line were summarized in graphic form on depth sections at a scale of one inch equals 100 ft.

The 600 ft profile data, after being picked and timed, were plotted on time-distance charts. The far spread data were adjusted to equal reciprocal times by adding the reciprocal time difference to all the traces of the record with the shorter reciprocal time. The center spreads were then adjusted so that their receiver positions common with the far spreads had the same arrival times. The near spreads were in turn adjusted to the center spreads in the same manner. From this point the procedure followed was the same as for the 300 ft profiles.

The shear wave refraction data were picked not in pairs but in sets of four--that is, two records of opposite SH polarity for each end of reversed profiles. First arrivals of shear wave energy were recognized by comparing the two records of opposite polarity from one end of a profile and looking for the first divergency of opposite polarity. After picking of apparent shear wave first arrivals was completed, the reciprocal times were compared to give an idea of data reliability. The resulting distance-time pairs, separated into sets apparently representing different refractions, were then entered into LNFT to obtain shear wave velocities.

D. Results - Enclosures Nos. 16, 17 and 18 are the depth sections derived from the primary wave refraction data. Note that excessive miss-ties (greater than 10 ft) between adjacent wavefront-reconstruction solutions (solid depth lines) are common, though less so on Lines RSFS-3 and RSFS-13 than on the other lines.

Table I summarizes the primary wave and shear wave velocities derived from the refraction and downhole data. Some of the shear wave data, including those of Line RSFS-8, were incompatible with the primary wave data and could not be used.

E. Interpretation - The difficulty of obtaining satisfactory reciprocal times, probably because of loss of first arrival energy as pointed out by Hans Ackerman of the U. S. G. S., makes most of the individual depth solutions of questionable accuracy. [redacted] The velocity information obtained is in close agreement with the velocity results of the earlier U. S. G. S. refraction survey, which used longer spreads and explosive energy source, lending considerable support and credibility to both surveys. The refraction data from both the U. S. G. S. refraction survey and the present study, though not reliable in the normal sense of being able to follow specific bedding plane refractors, nevertheless have yielded a great deal of information regarding the main purpose of the two surveys--the material properties of the rocks in the area of the repository surface facility and tunnel.

A plot of locations where refractions (primary wave) have

TABLE I

SUMMARY OF PRIMARY AND SHEAR WAVE VELOCITIES

Alluvium (Including Reworked Tuff)

	Vp	Vs	Vs/Vp	Poisson's Ratio
RSFS-2, 5	3301	1702	0.516	0.319
RSFS-2, 5	3623	1821	0.503	0.331
RSFS-2, 5	3378	1771	0.524	0.310
RSFS-2, 5	3049	1897	0.622	0.184
RF-3	3240	2075	0.640	0.152
RF-3B	3350	2050	0.611	0.201
RF-9	3850	1700	0.441	0.379
RF-10	2500	1375	0.550	0.283
Means	3286	1799	0.547	0.286

Tiva Canyon Tuff

	Vp	Vs	Vs/Vp	Poisson's Ratio
RSFS-2, 5	4399	2413	0.549	0.285
RSFS-2, 5	4348	2189	0.503	0.330
RSFS-3, 6	5137	2270	0.442	0.379
RSFS-3, 6	4981	2563	0.515	0.320
RSFS-3, 6	3465	2172	0.627	0.176
RSFS-3, 6	4319	2462	0.570	0.259
RF-9	4265	1963	0.460	0.366
RF-10	5297	2651	0.500	0.333
Means	4526	2335	0.516	0.319

velocities greater than 4,000 ft/sec suggests that there are zones of higher and lower velocity in the shallow subsurface of the area (see Enclosure No. 19). These show a roughly north-south orientation.

The following conclusions seem merited:

(1) The difficulty of obtaining satisfactory reciprocal times in the area, plus the common miss-ties between depth solutions, indicate that no consistent, continuous refractor is present within the area to a depth of about 100 ft. The U. S. G. S. refraction survey results show that this condition persists to much greater depth.

(2) The very low velocities measured both by this survey and the U. S. G. S. study indicate that except under the west side of Exile Hill the rocks, especially the tuffs of the Tiva Canyon, are very highly fractured and weathered.

(3) The Poisson's Ratio values calculated for both the alluvium and the Tiva Canyon from the refraction data show wide variation but in the mean are typical of non-coherent, loose material.

(4) Zones of comparatively higher and lower measured refraction velocities east of Exile Hill (Enclosure No. 19) may represent uplifted or downdropped zones such as horsts and grabens or buried hills and valleys, zones of lesser or greater fracturing, zones of varying alluvial composition, or some combination of these.

z (5) The rocks under the west side of Exile Hill, in the vicinity of the Bow Ridge fault, appear to be much less fractured and weathered than under the rest of the area, perhaps because the presence of the fault has allowed release of stress which might otherwise have caused fracturing and small-scale faulting.

(6) Line RSFS-13, which shows more coherence between successive depth solutions, may suggest that there has been less recent tectonic disturbance in the northern part of the area east of Exile Hill.

V. Downhole Seismic Surveys (Primary and Shear Wave) -

A. Drillholes Surveyed - Four drill holes east of Exile Hill were surveyed. These are RF-3, RF-3B, RF-9 and RF-10 (see Location Map, Enclosure No. 1). RF-3 and RF-3B, being close together, are regarded as more or less one survey. The upper part of RF-3B could not be surveyed because the casing is too large in diameter for the downhole geophone packer.

B. Field Methods - The downhole surveys utilized the same seismic energy sources as the surface refraction surveys, placed at a distance of 32 ft from the well head. Two source positions per drill hole were used, at approximately right angles. At all but the shallowest geophone positions, repeated weight drops and sledgehammer blows were necessary.

The same seismograph was used for the downhole surveys as had been used for the reflection and refraction surveys. Analog and digital recordings 0.2 second in length were taken.

A three-axial downhole geophone supplied by the Bison Corporation was used. This geophone used an inflatable rubber packer to hold it in position against the side of the hole (casing). The output of the vertical receiver was put on trace one of the records (top trace of record) and the signals of the two horizontal axis receivers were put on traces three and five. The orientations of the two horizontal receivers were not known.

C. Analog and Digital Data Processing - The downhole primary wave (weight drop) records were picked on the trace corresponding to the vertical geophone. The first arrivals weakened rapidly with increasing depth, so that corrections back to first arrivals had to be made. In some cases digital amplification had to be used. The travel distances used were slant distances (square root of sum of squares of downhole depth and horizontal offset).

The shear wave data were picked by comparing the two opposite-polarity records from the same depth and position and looking for the first arrival of opposite-polarity energy on the two horizontal phone traces. This procedure worked better than reversing the polarity of one of the two traces and adding them to cancel primary wave energy and enhance shear wave energy (program SHRAD). The trace (corresponding to a horizontal phone) which showed more clearly the reversal of polarity associated with horizontally-polarized shear waves was used. This usually gave a more reasonable shear wave velocity than did the other geophone, presumably due to better orientation. As with the primary wave data, the slant distance was used to convert measured travel times to velocities.

The vertical geophone output also showed reversed polarity on the two shear wave records from a given depth and position, presumably indicating generation of a strong SV wave.

D. Results - Figures 6, 7 and 8 show the results of the downhole surveys.

Drill hole RF-3 (Figure 6), though drilled below 300 ft, could not be surveyed below 155 ft because the hole was plugged by mud or debris. Consequently the survey could not reach the Tiva Canyon, though it did reach the top of the reworked tuff. Note that the primary wave velocities (Vp) as measured from the east and south source positions for RF-3B cross over at about 55 ft of depth. This may be because below this depth the first cycle of the primary wave with the source to the south could not be recognized and consequently the calculated velocities may be too low. In any case, the primary wave velocities increase down to a depth of about 75 ft and then become almost constant below that depth. The shear wave results show greater agreement between the velocities measured with the source in the two directions. The calculated Poisson's Ratio, as determined from the two directions, differs greatly below 55 ft, perhaps because of the possible loss of the first cycle of primary wave energy below that depth with the source to the south.

The results of the survey in RF-9 (Figure 7) are more satisfactory. Both the primary and shear wave plots show a relatively rapid increase in velocity down to about 45 ft depth and then increase much less rapidly below that. The calculated Poisson's Ratio stays fairly constant but very high below about 25 ft depth.

Figure 8 shows the results of the survey in RF-10. The deepest (53 ft) recording with the primary wave source to the north is very questionable and leads to a very large difference in the Poisson's Ratio at that depth. Both the primary and shear wave velocities appear to increase down to about 15 ft and then decrease to about 35 ft (near the top of the Tiva Canyon), below which depth they increase again. Note that the calculated Poisson's Ratio values here are much lower than at RF-9 (Figure 7).

E. Interpretation - As with the refraction data, questions regarding recognition of first arrivals of energy allow only the most general interpretation and conclusions. The conclusions deemed worth drawing are:

(1) The velocities measured are in keeping with the velocities measured by both the present refraction study and the earlier U. S. G. S. refraction survey; they are very low and may be interpreted as indicating intense fracturing and deep weathering.

(2) The Poisson's Ratios calculated are generally high, except perhaps at the bottom of RF-10, and are more suggestive of a loose aggregate than rock, even in the Tiva Canyon.

(3) In all three drill holes, a significant change in

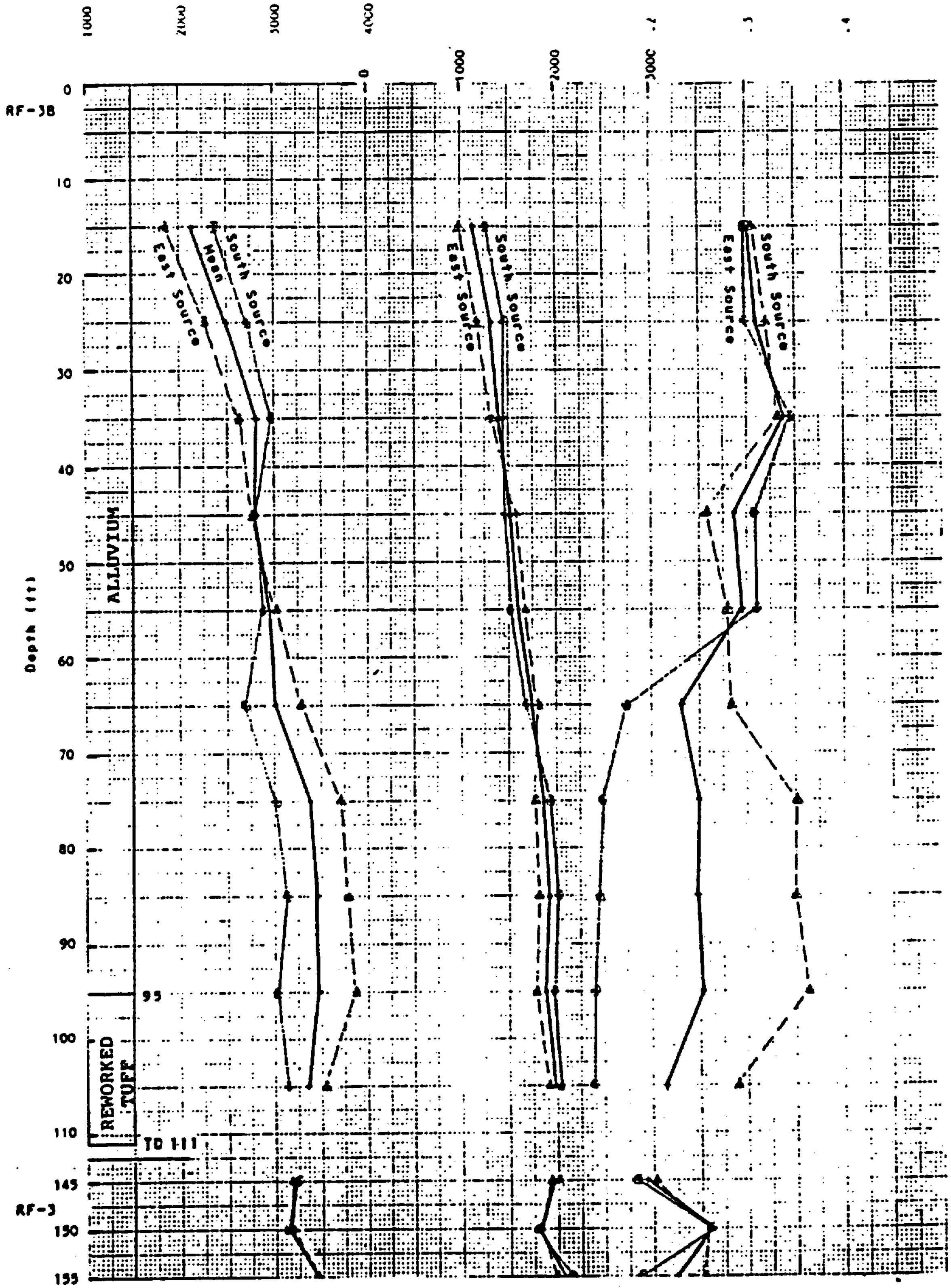


Figure 6.

SANDIA NATIONAL LABORATORIES

REPOSITORY SURFACE FACILITY SEISMIC SURVEY
Yucca Mountain Area, Nye County, Nevada

DOWNHOLE VELOCITY SURVEY - PRIMARY AND SHEAR WAVES

Drill Holes RF-3B and RF-3

November 3, 1985 **Charles B. Reynolds & Assoc.**

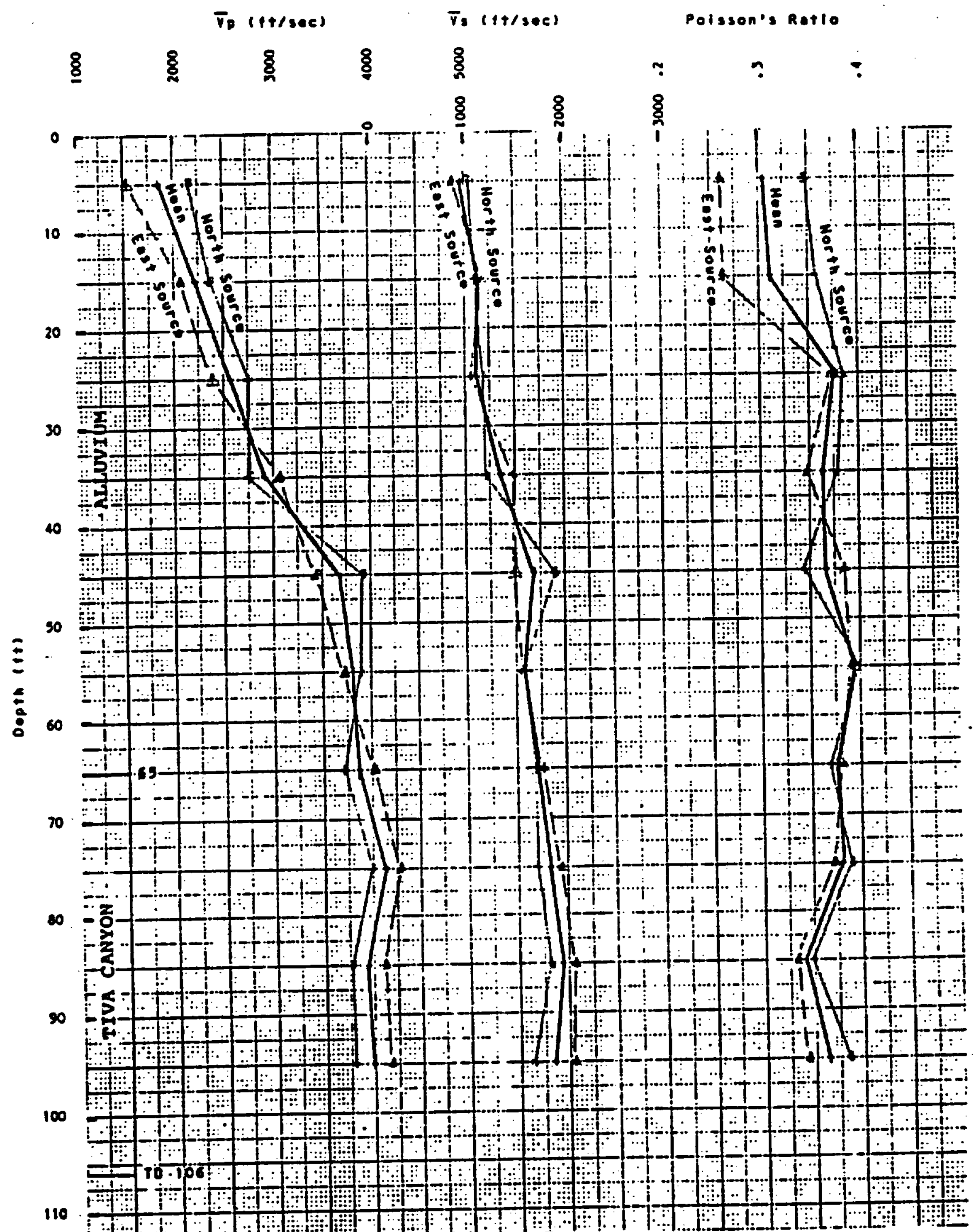


Figure 7.

SANDIA NATIONAL LABORATORIES

REPOSITORY SURFACE FACILITY SEISMIC SURVEY

Yucca Mountain Area, Nye County, Nevada

DOWNHOLE VELOCITY SURVEY - PRIMARY AND SHEAR WAVES

Drill Hole RF-9

November 3, 1985 Charles B. Reynolds & Assoc.

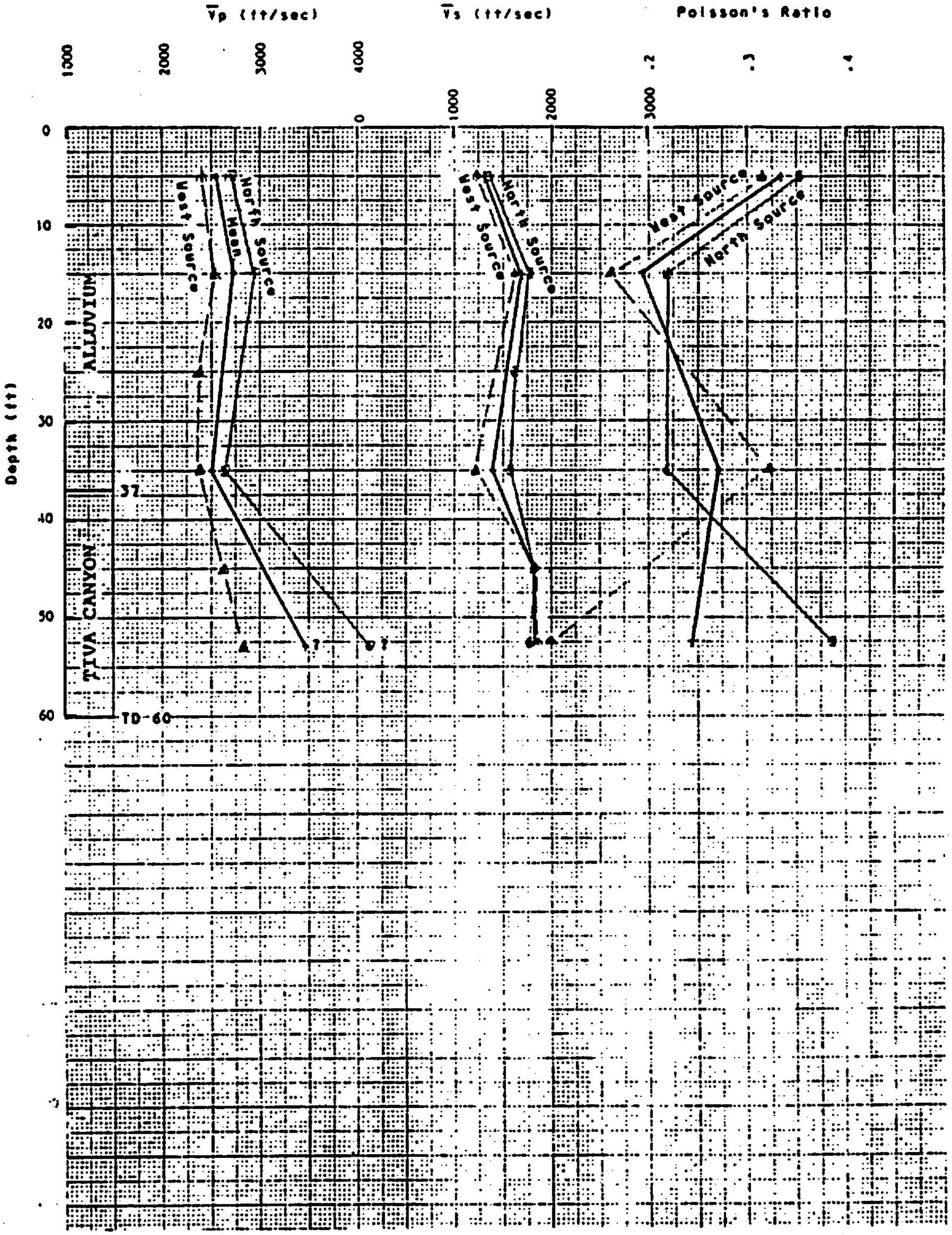


Figure 8.

SANDIA NATIONAL LABORATORIES

REPOSITORY SURFACE FACILITY SEISMIC SURVEY
Yucca Mountain Area, Nye County, Nevada

DOWNHOLE VELOCITY SURVEY - PRIMARY AND SHEAR WAVES

Drill Hole RF-10

November 3, 1985 Charles B. Reynolds & Assoc.

velocity appears to occur in the alluvium, about 20 ft above its base.

(4) The Tiva Canyon may be less fractured and may have more of the character of rock in RF-10 than in RF-9.

VI. Integration of Results of Reflection, Refraction and Downhole Surveys - Discussion -

The sum of the geophysical evidence from this project seems to be internally coherent, with the various lines of evidence in good general agreement. Further, there is good agreement with evidence from surface geology, drilling results, the U. S. G. S. refraction survey, and indirectly, a U. S. G. S. gravity profile south of the area.

Both the present refraction study and the previous U. S. G. S. refraction survey clearly indicate that to a considerable depth the rocks of the area, except for those under the west side of Exile Hill, are intensely fractured and weathered, with material properties more like a loose aggregate than coherent rock. The downhole surveys, especially in RF-9, indicate the same condition in the tuffs of the Tiva Canyon. The cores recovered from the Tiva Canyon in drill holes east of Exile Hill have shown extensive fracturing, weathering and faulting. The downhole surveys show an apparent slowing of the downward increase of velocity within the alluvium, about 20 ft above its base. The zone above this apparent slowing might well be a refractor within the alluvium; this fits with the fact that the principal refractor on the refraction line nearest each of the drill holes (except RF-11) calculates to be above the base of the alluvium, not at the top of the Tiva Canyon or Rainier Mesa. This may at least in part explain the apparent discontinuous nature of the refractor(s) east of Exile Hill, in that discontinuous refractors are not uncommon in alluvium.

The material properties of the alluvium and Tiva Canyon, as estimated from the velocity studies (including refraction and downhole surveys) are summarized by Table I. The mean Poisson's Ratios for both the alluvium and Tiva Canyon are thought likely to be approximately correct, and are very high.

Surface geologic studies in the vicinity, particularly by Robert Scott of the U. S. G. S., have indicated considerable development of closely spaced faults of small normal displacement, as well as less common faults of greater displacement. The very small-displacement faults might in fact be part of the fracturing which produces the very low velocities observed in the area. They might also help explain, if they are listric in nature, the apparent discrepancy between the dips observed in cores east of Exile Hill (20-25 degrees) and the lower dips suggested by the seismic reflection lines (less than 10 degrees). That is, the internal bedding of small fault blocks could be tilted more than the overall dip of the unit, which is what reflection could be hoped to see. The reflection lines east of Exile Hill suggest numerous, repeated faults upthrown to the east; which is in agreement with the evidence from drilling and surface geology.

The only one of the three larger faults interpreted east of Exile Hill (see Enclosures Nos. 9, 10, 11 and 15) for which there is evidence other than reflection is the one near position 51 on

RSFS-12, 79 on RSFS-1 and 73 on RSFS-10. Drill hole RF-9, west of this fault, ran nearly 200 ft higher than RF-3, which was east of the fault. The writer tentatively interprets this fault as a very steep, nearly vertical reverse fault. The fault may have been vertical or even steeply east-dipping at time of formation, and since rotated by uplift of Exile Hill. This fault, incidentally, shows more clearly on lower frequency playbacks, as does the structure of the east edge of the Exile Hill block (see 15-30 Hz display of Enclosure No. 2).

The central interpreted fault (near position 20 on RSFS-10, 40 on RSFS-1 and below 30 on RSFS-12) appears to be upthrown to the east and to become steeper northward. Its displacement, if interpreted correctly, would be perhaps 50 ft or less. The correlation across it, however, is by no means unambiguous, so the displacement could be greater.

The most easterly of the three interpreted larger faults (position 20 on RSFS-1 and about 14 on RSFS-10) appears to be a curved normal fault down to the east. Its displacement, as interpreted on RSFS-1, may be of the order of 50-100 ft.

The best of the reflection data were recorded in the narrow valley west of Exile Hill (Lines RSFS-9 and RSFS-16, forming one line). The refraction data suggest that the rocks on the west side of Exile Hill may be less fractured and weathered than east of the hill. The blurring of velocity and density boundaries by fracturing and weathering may explain at least in part why the reflection data east of Exile Hill are poorer. The greater thickness of alluvium east of the hill may also be a factor.

The writer interprets Lines RSFS-9 and RSFS-16 as suggesting perhaps 200-250 ft of displacement, up to the east, on the Bow Ridge fault and the other faults suggested by the reflection data west of Exile Hill. In addition, about 50 ft of drag on the upthrown side of the Bow Ridge fault is suggested, ~~giving perhaps~~ 250-300 ft of apparent total displacement between the ~~east side of Exile Hill and the west side of the narrow valley~~. This is in reasonably close agreement with the estimate of 300-400 ft made on the basis of surface geology.

The apparent zones of relatively higher refraction velocity east of Exile Hill (Enclosure No. 19) seem to correspond reasonably well with apparent shallow structural highs and buried hills on the reflection lines. For example, the apparent velocity high more or less along Line RSFS-14 (see Enclosure No. 18) seems to coincide approximately with an apparent shallow horst on Lines RSFS-12 and RSFS-1 and a relatively high fault block on RSFS-10 as well as possible buried hills on RSFS-12 and RSFS-10. The lower velocity zones east and west of this relatively high velocity zone coincide approximately with structurally lower shallow fault blocks suggested by reflection. Further east, apparent velocity highs on the east end of RSFS-1 and near the east end of RSFS-10 appear to correspond reasonably well to suggested local structural highs and buried hills on these reflection lines and perhaps at the extreme east end of RSFS-12. This last apparent velocity high appears to correspond to the east side of the "concealed fault" of Lipman and McKay (1965, GQ-439), which some distance further south appears to have a gravity expression, as shown by David Ponce of the U. S. G. S.

Enclosure No. 20 is a structure section, A-A', constructed east-west along reflection lines RSFS-1, RSFS-9 and RSFS-16, using surface geologic, drill hole and reflection seismic data. The location of Section A-A' is shown by Enclosure No. 15. The most striking difference between this interpretation and previous sections is the down-to-the-east high angle reverse fault between RF-9 and RF-3. The middle-depth seismic phantom of Section A-A', plotted on a "conceptual projection, subsurface geology" section across the area, from Scott and Bonk, U. S. G. S. OFR-84-494, is shown by Figure 9. Comparison of the seismic phantom and one of the conceptual marker horizons of Scott and Bonk shows considerable similarity except at the east end of Section A-A' (east of the high fault block). Greater throw on the most easterly fault (down to the east) may account for this difference. The horst interpreted between about positions 20 and 40 on Lines RSFS-1 (Enclosure No. 9) may be the Midway Valley structural high.

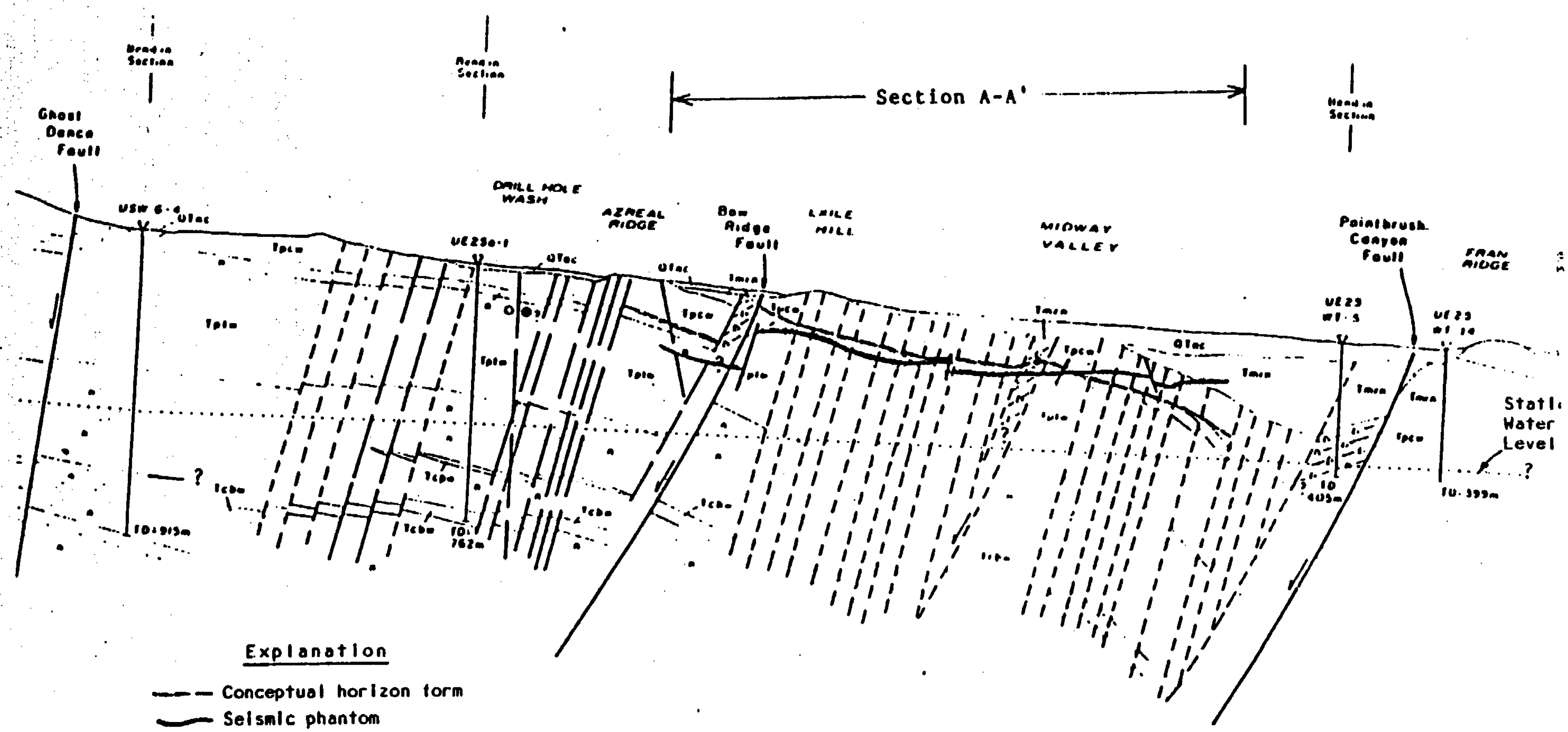


Figure 9. Conceptual projection, subsurface structure - from Scott and Bonk, USGS OFR-84-494, showing comparison of their conceptual horizon form with a seismic phantom from Section A-A' of this report. Scale: one inch equals 1547 feet.

VII. Geological Conclusions -

A. The rocks of the area, except for the west side of Exile Hill, appear to be intensely fractured and weathered, to the point that they seem to have the velocities and material properties of loose aggregate, and transmit refraction energy very poorly.

B. Bedding plane reflections appear to be present east of Exile Hill, so that though the rocks resemble loose aggregate in their material properties, they may still retain their overall bedded form.

C. The reflection data east of Exile Hill suggest that the overall dip of the beds may be lower than in exposures on Exile Hill or in cores from the drill holes; this may support the concept by Robert Scott of many small faults, possibly listric, cutting the beds and upthrown to the east, on a scale too small to be seen by seismic.

D. The reflection data east of Exile Hill are interpreted as suggesting numerous faults, mostly upthrown to the east, including some which appear to persist to as much as 1,000 ft of depth.

E. The Midway Valley structural high appears to be a horst 300-700 ft wide, as interpreted from the reflection data.

F. The refraction data suggest north-south zones of relatively higher or lower velocity east of Exile Hill. Comparison of these to reflection data suggests they may represent shallow zones of relatively uplifted or downdropped blocks. The higher velocity (uplifted?) zones may also be less fractured and weathered. They could also be caused by variations in shallow (probably alluvial) composition.

G. The reflection data east of Exile Hill suggest that most of the faults present trend roughly north-northeast. However, since all the reflection lines run east-west, this may be more apparent than real.

H. The evidence of velocity indicates that the rocks under the west side of Exile Hill and the east side of the narrow valley may be much less broken (except for the Bow Ridge fault) than elsewhere.

I. The total displacement across the Bow Ridge fault system may be about 250-300 ft, including significant drag along the fault.

J. An unfaulted block approximately 600 ft wide may be present in the northeastern part of the area (positions 8 to 27 on RSFS-12).

VIII. Recommendations - The following suggestions are offered for consideration with regard to further geological and geophysical investigations in the repository surface facility area:

A. A detailed gravity survey east of Exile Hill should be considered, with station spacing of the order of 100 meters, to attempt to trace the Midway Valley high and the larger faults and fault blocks.

B. Drilling of the apparent velocity highs and lows east of Exile Hill should be considered to determine their nature and to determine whether the gentle dips interpreted from the reflection seismic are correct. All holes should be logged with gamma ray tools to facilitate correlation between holes, and all cores should be oriented. Suggested drill locations are at positions 2, 22, 46 and 63 on Line RSFS-1.

C. If drilling (B., above) confirms the reflection evidence, a detailed reflection survey in the northern half of the area east of Exile Hill should be considered in an effort to find an unfaulted block large enough for the largest building planned.

Respectfully submitted,

Charles B Reynolds

Charles B. Reynolds
Registered Geophysicist (Calif.)
Certified Professional Geologist

Appendix A - Quality Assurance Program

(1) Field Checks include continuous, twice daily and daily tests.

Continuous or frequent checks include:

(a) Each reflection receiver group is wired in series, so that if one receiver goes out, the whole group fails and the failure is detected with the next recording as a dead trace.

(b) The resistance of each reflection receiver group is checked after each second or third recording by means of an ohmmeter built into the seismograph. In the case of refraction, the resistance of each geophone is checked before the recording of each profile.

(c) Each analog (paper) record is examined for proper appearance and lack of abnormalities immediately after being recorded. This will normally prevent reversed traces, dead traces and clipping (memory overload).

(d) At each recording position the instrument operator observes the time-variant noise output of the geophones by use of the seismograph's noise monitor function.

(e) For this survey a third crew member was added to allow the instrument operator to have the seating of the reflection geophones to be checked if he observed wind noises or other time-variant noise, such as might be caused by a geophone in an unstable position (e.g., lying on vegetation or a loose rock).

(f) The ambient noise level (usually wind) was high enough during this survey that the geophones were generally buried.

(g) In refraction recording, after one crew member has planted and connected geophones another crew member checks them for polarity and planting. This is color-coded; the red connector always goes toward the starting end of the line; and during this survey the crew added color-coding to the connection positions (takeouts) on the cables.

(h) If refraction reciprocal times are more different than about 5 ms, the second position is redropped and rerecorded after checking geophone positions, polarity and planting. This usually suffices to reduce reciprocal times differences to less than 5 ms; in the present case it did not. The second record at the second position was generally identical to the first.

(i) Periodic rerecording of a record (i.e., clearing the seismograph, dropping again and recording again) to allow comparison and thus checking of repeatability.

(j) The battery voltage is checked frequently, by means of the seismograph's built-in voltmeter, to prevent data loss due to low voltage.

Twice daily checks include:

(a) Playback from the digital recorder of a newly recorded digital recording, to allow comparison with the paper monitor record, to insure proper functioning of the digital recorder and correct digital I-O connections between the seismograph and the recorder.

(b) Physical examination by a crew member of all geophones and cables to check that protective wrappings, electrical connections and bail screws (reflection) are intact.

Daily tests include:

(a) All tests recommended (for the seismograph and its components as well as the digital recorder) by the manufacturer, E. G. & G. Geometrics, Sunnyvale, California.

(b) Daily tests are made of frequency, phase and amplitude response of all seismograph channels plus timing accuracy by use of a new special testing device custom-made for us by the seismograph manufacturer, E. G. & G. Geometrics. Use of this device caused the discovery that the seismograph does not record 1,000 samples per second as advertised and shown on the panel, but instead records 1,024 samples per second. Consequently, all time measurements are uniformly off by 2.4%, which fortunately is well within the accuracy limits of this survey. More importantly, use of the tester allows a daily check that the frequency, phase and amplitude response plus timing accuracy of the seismograph have not changed. Digital recording of the test record, plus playback from the recorder and comparison to the paper test records, also provides a check on the recorder's accuracy.

(c) A geophone response test is made by bunching the geophones tightly and either dropping the weight (refraction geophones) or striking the bed of the truck with a sledgehammer (reflection phones in back of truck). Though perfect copy on all traces can rarely be achieved under field conditions, the bunch test normally will reveal if a geophone (refraction) or group (reflection) is significantly out of phase.

(d) The digital recordings were played back and examined by the computer operator for quality, normally the night recordings were made. This was done by displaying the digital recordings on the monitor of an IBM PC portable microcomputer. This led to the first day's reflection recording (on Line RSFS-1) being redone the next day because one trace on each record (channel 5) was intermittently unsatisfactory. It also showed that RSFS-16, the shortest reflection line, which was recorded on the last day and was not checked before leaving the area, was recorded for one half second rather than one second.

(2) Data Processing Checks

(a) All digital recordings of reflection records are plotted on paper to allow examination of the data and to check that editing (i.e., removal of obvious noise bursts) is adequate.

(b) Intermediate plots of processed data are standard (e.g., after common depth point stacking and before datum corrections). In the present case, the plot after datum corrections led to the discovery that the datum corrections had been inadvertently doubled (by giving the computer twice the correct sample interval), so that the datum corrections were redone.

(c) All plots are carefully examined for data drop-outs or trace shifts. For this survey, only one plot had to be redone because of a trace shift.

(d) In interpretation, reflection events regarded as being likely to be bedding plane reflections must pass the test of geologic coherence--that is, they must be related to events above and below in a manner consistent with geologic experience.

Appendix B - Equipment Used

A list of the major items of equipment used in the survey includes:

(1) One Dodge one-ton Powerwagon all-wheel drive truck, equipped with dual battery system and A-frame and electric winch for lifting and dropping the seismic weight (see Figure B-1).

(2) One Ford Bronco four-wheel drive vehicle as backup car (safety measure).

(3) One 500 lb "soft" weight to be dropped as a seismic energy source. Covered by U. S. Patent No. 4,124,090 (Charles B. Reynolds and Associates, Inc.). Licensees--Compagnie General de Geophysique, Paris, France, and Developmental Geophysics, Inc., Shawnee, Oklahoma.

(4) One E. G. & G. Geometrics Nimbus ES1210F seismograph with G724S digital cassette recorder.

(5) One "landstreamer" cable fitted with 30 Mark Products 10 Hz GL-21 gimbal-mounted self-orienting drag geophones (see Figure B-1).

(6) Two 400 ft refraction cables, each with seven takeouts spaced 50 ft apart, double-ended.

(7) Fourteen Mark Products 8 Hz vertical refraction phones, tripod mounted.

(8) Seven Mark Products 8 Hz horizontal refraction geophones, spike mounted.

(9) One IBM PC portable microcomputer, 256 K, with two mini-floppy diskette drives and one J & M Systems 15 MB hard disk.

(10) One Radio Shack Printer-Plotter.

(11) Assorted connecting cables, tools, battery chargers, electric testers and drafting equipment.

(12) One three-axis downhole geophone with inflatable packer, supplied by Bison Instruments.

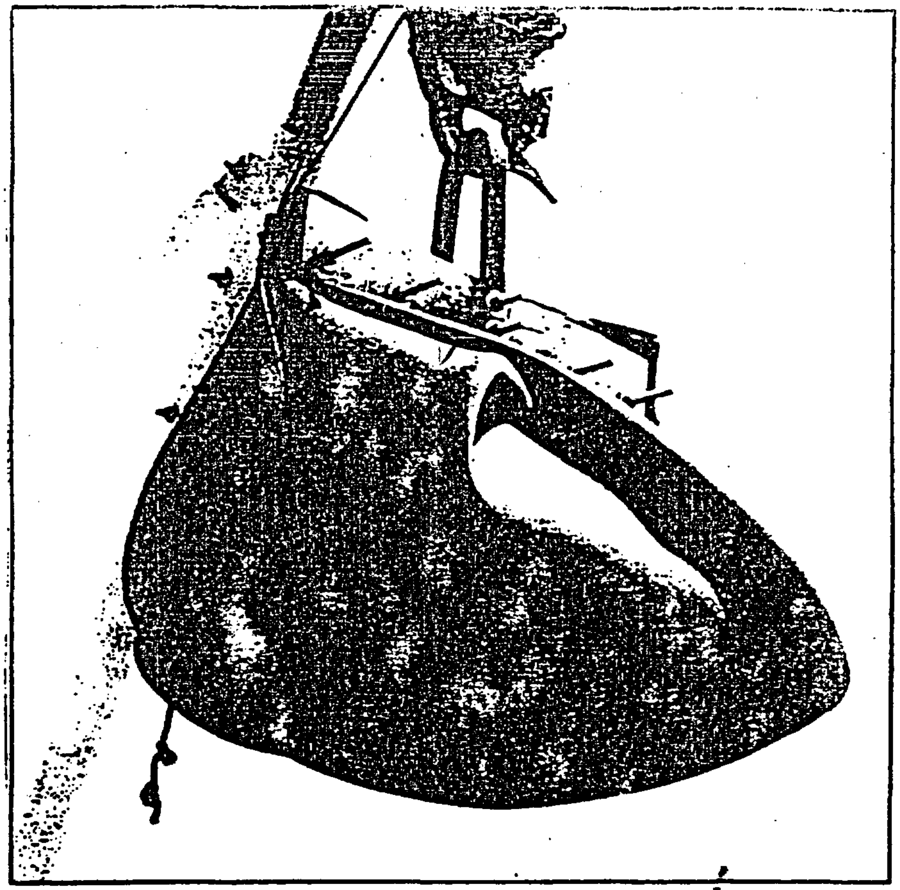


Figure B-1(a). "Soft" weight seismic energy source. Heavy leather bag containing 500 pounds of lead birdshot, dropped 6.5 feet (2m) freefall to ground.

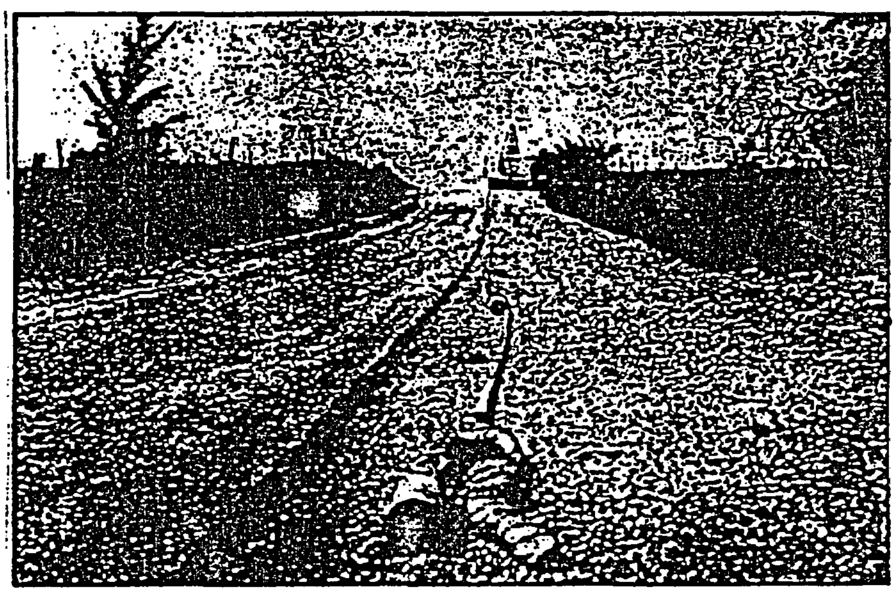


Figure B-1(b). Reflection "landstreamer" cables fitted with Mark Products GL-21 gimbal-mounted self-oriented drag geophones.

Figure B-1. Seismic equipment used in Repository Surface Facility seismic survey, 1985. Nevada Test Site, Nye County, Nevada. Photos from AAPG Explorer, Sept. 1985.

CHARLES B. REYNOLDS & ASSOCIATES
CONSULTING GEOPHYSICISTS & GEOLOGISTS
4409 SAN ANDRES AVE. NE, ALBUQUERQUE, NEW MEXICO 87110

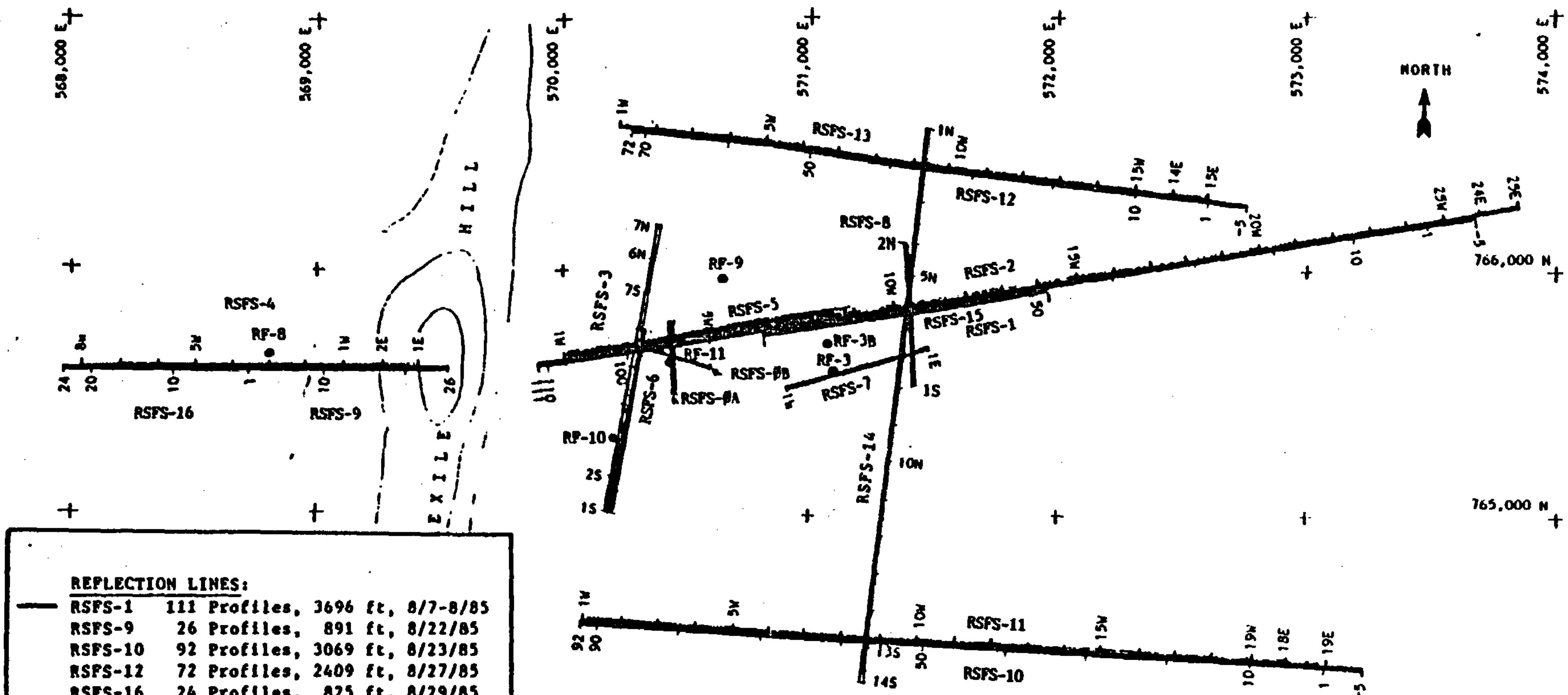
SANDIA NATIONAL LABORATORIES

FINAL REPORT - ENCLOSURES 1 THRU 20

1985 REPOSITORY SURFACE FACILITY SEISMIC SURVEY

YUCCA MOUNTAIN AREA, NTS, NYE COUNTY, NEVADA

NOVEMBER 20, 1985



REFLECTION LINES:

RSFS-1	111 Profiles,	3696 ft,	8/7-8/85
RSFS-9	26 Profiles,	891 ft,	8/22/85
RSFS-10	92 Profiles,	3069 ft,	8/23/85
RSFS-12	72 Profiles,	2409 ft,	8/27/85
RSFS-16	24 Profiles,	825 ft,	8/29/85

PRIMARY WAVE REFRACTION LINES:

-300 ft Spreads-

RSFS-ØA	1 Profile,	300 ft,	8/5/85
RSFS-ØB	1 Profile,	300 ft,	8/5/85
RSFS-2	25 Profiles,	3900 ft,	8/9/85
RSFS-3	7 Profiles,	1200 ft,	8/10/85
RSFS-4	8 Profiles,	1350 ft,	8/10/85
RSFS-11	19 Profiles,	3000 ft,	8/21/85
RSFS-13	15 Profiles,	1200 ft,	8/26/85
RSFS-14	14 Profiles,	2250 ft,	8/28/85

-600 ft Spreads-

RSFS-7	1 Profile,	600 ft,	8/21/85
RSFS-15	2 Profiles,	1200 ft,	8/28/85

SHEAR WAVE REFRACTION LINES:

RSFS-5	7 Profiles,	2100 ft,	8/12-13/85
RSFS-6	4 Profiles,	1200 ft,	8/13/85
RSFS-8	2 Profiles,	600 ft,	8/22/85

DOWNHOLE SURVEYS (Primary and Shear):

RF-3	155 ft,	8/25/85
RF-3B	105 ft,	8/24-25/85
RF-9	105 ft,	8/20,24/85
RF-10	53 ft,	8/20/85

SANDIA NATIONAL LABORATORIES

REPOSITORY SURFACE FACILITY SEISMIC SURVEY
Yucca Mountain Area, Nye County, Nevada

LOCATION OF SEISMIC SURVEY LINES AND DRILL HOLES

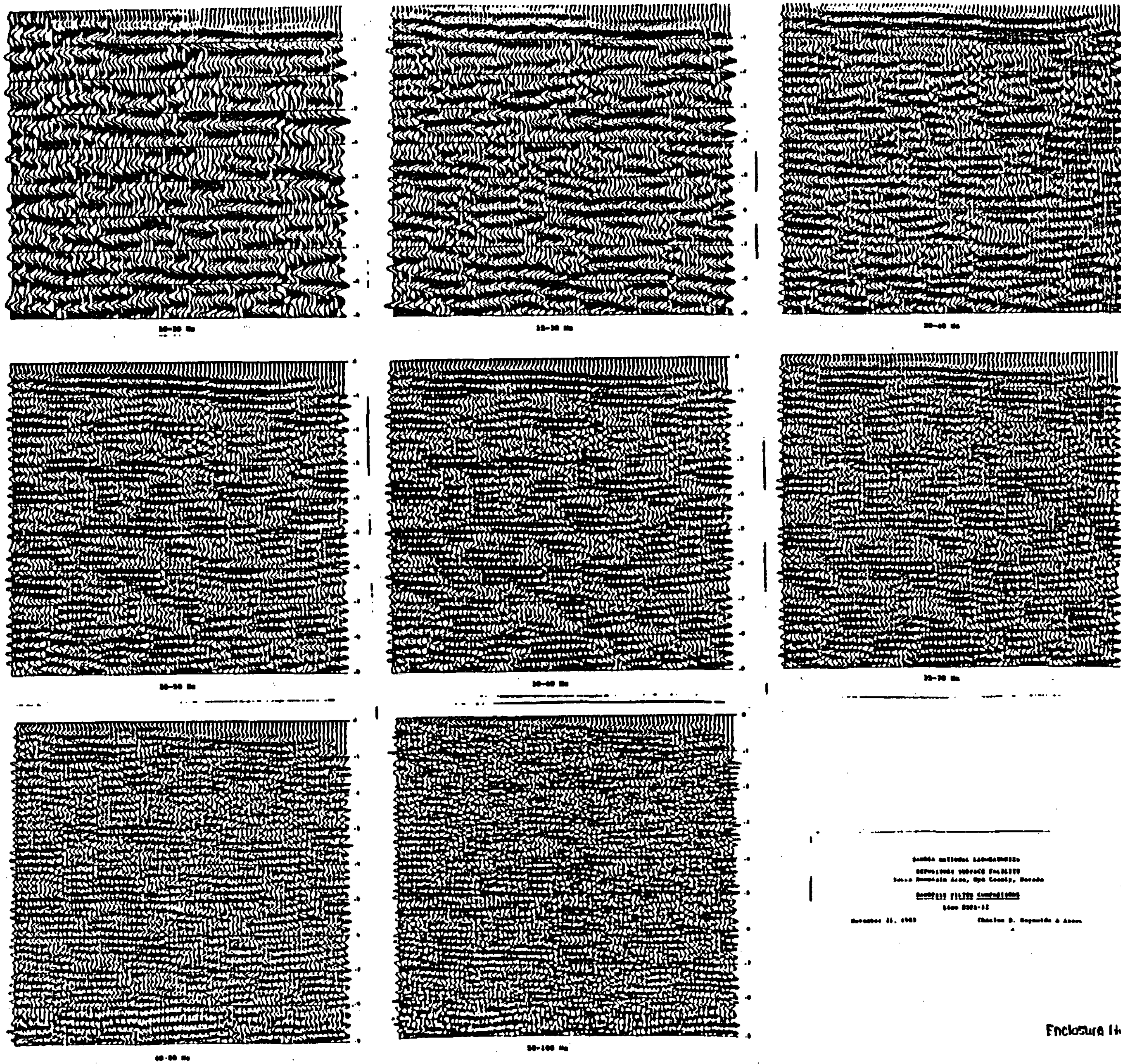
Scale

0 500 1000 1500 Feet

Coordinates: 1,000-foot grid, Nevada State Plane Coordinate System.

October 15, 1985 Charles B. Reynolds & Associates

Enclosure No. 1



SANDIA NATIONAL LABORATORIES

REPOSITORY SURFACE FACILITY
Yucca Mountain Area, Nye County, Nevada

BANDPASS FILTER COMPARISONS

Line [illegible]

[illegible] Charles B. Reynolds & Assoc.

Enclosure No. [illegible]

SANDIA NATIONAL LABORATORIES

LINE RSFS 1 R1-R111
YUCCA MTN AREA NEVAQA
FINAL 600% SECTION

FIELD PARAMETERS

RECORDED BY: HS DATE RECORDED: 8/8/85 INSTRUMENTS: EG&G ES1210F
GAIN MODE: FIXED FIELD FILTER: OUT-60HZ 60HZ NOTCH FILTER: IN
RECORD LENGTH: 1 SEC SAMPLE RATE: 4 MS

SPREAD

TYPE: END OVER CDP FOLD: 6 NO. GROUPS: 6
DIR. PROGRESS: E-W NEAR GRP CTR: 66 FT FAR GRP CTR: 394 FT
SEISES/GRP: 5 @ 13 FT.INLINE GROUP INTERVAL: 66 FT

ENERGY

SOURCE: 500 LB WT DRP SP ARRAY: POINT SP INTERVAL: 33 FT
SP OFFSET: 0 DROPS/SP: 1-2

PROCESSING SEQUENCE

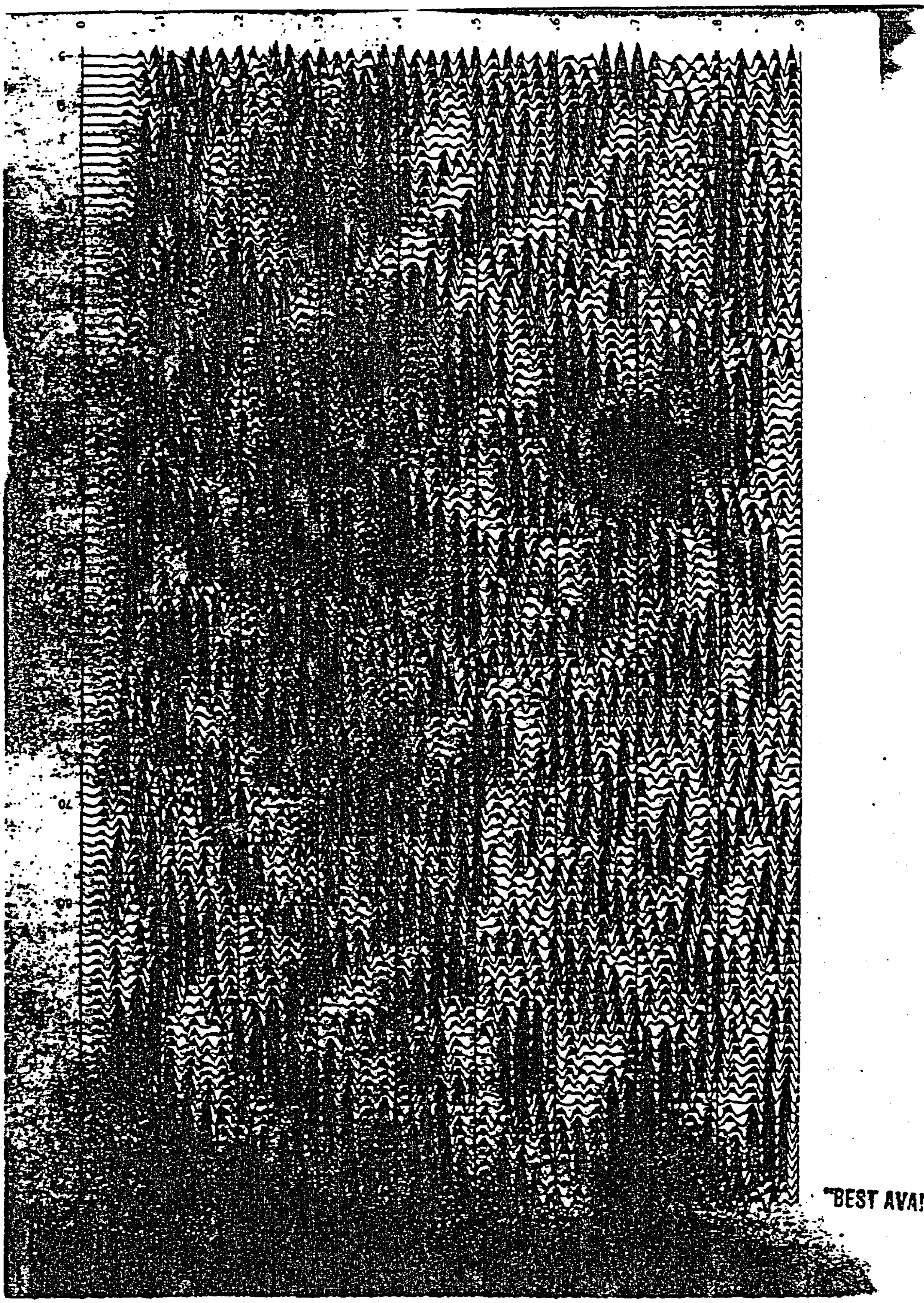
(1) TRANSCR	(2) QUAL VERIF	(3) EDIT
(4) WX DETERM	(5) FAN	(6) STK 600%
(7) DTM CORRN	(8) DIPFIL	(9) FILTER 40-80 HZ
(10) SLOW AGC	(11) PLOT VA/WT	(12)

PLOTTER DISPLAY

HORIZ.SCALE: 33 FT/TR POLARITY: POS. VERT.SCALE: 7.5 IN/SEC
WX. VEL.: 2300 FT/SEC DATUM: +3700 FT CORRN. VEL.: 3100 FT/SEC

CHARLES B. REYNOLDS & ASSOC., INC.

Enclosure No. 3



SANDIA NATIONAL LABORATORIES

LINE RSIFS 16 R1-R92
YUCCA MTN AREA NEVADA
FINAL 600% SECTION

FIELD PARAMETERS

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GAIN MODE: FIXED   FIELD FILTER: OUT-60HZ   60HZ NOTCH FILTER: IN
RECCRD LENGTH: 1 SEC   SAMPLE RATE: 4 MS

SPREAD

TYPE: END OVER   CDP FOLD: 6   NO. GROUPS: 6
DIR. PROGRESS: E-W   NEAR GRP CTR: 66 FT   FAR GRP CTR: 394 FT
SEISES/GRP: 5 @ 13 FT.INLINE   GROUP INTERVAL: 66 FT

ENERGY

SOURCE: 500 LB WT DRP   SP ARRAY: POINT   SP INTERVAL: 33 FT
SP OFFSET: 0   DROPS/SP: 1-2

PROCESSING SEQUENCE

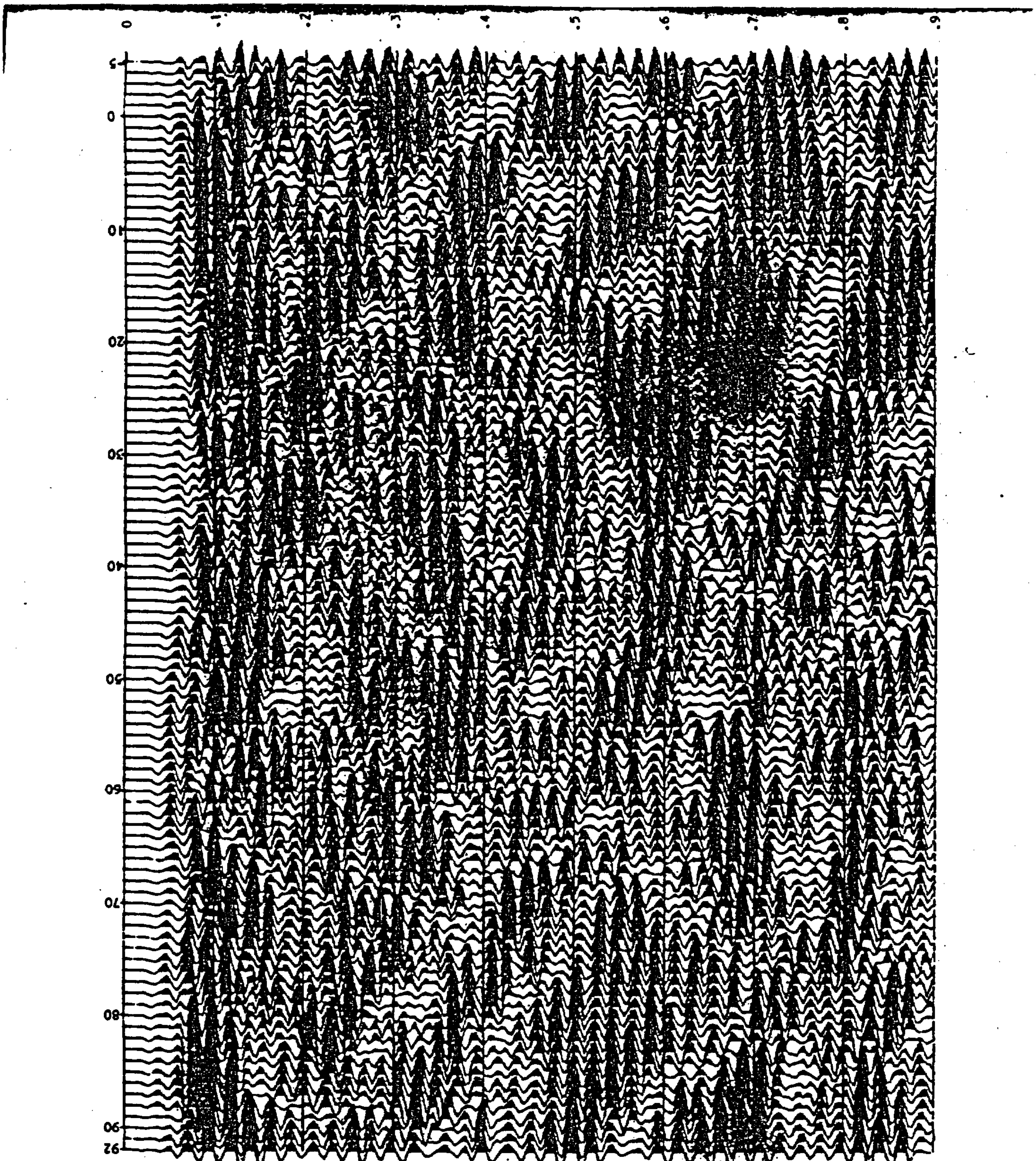
(1) TRANSCR	(2) QUAL VERIF	(3) EDIT
(4) WX DETERM	(5) FAN	(6) STK 600%
(7) DTM CORRN	(8) DIPFIL	(9) FILTER 40-80 HZ
(10) SLOW AGC	(11) PLOT VA/WT	(12)

PLOTTER DISPLAY

HORIZ.SCALE: 33 FT/TR   POLARITY: POS.   VERT.SCALE: 7.5 IN/SEC
WX. VEL.: 2300 FT/SEC   DATUM: +3700 FT   CORRN. VEL.: 3400 FT/SEC

CHARLES B. REYNOLDS & ASSOC., INC.

Enclosure No. 4



SANDIA NATIONAL LABORATORIES

LINE RSFS 12 R1-R22
YUCCA MTN AREA NEVADA
FINAL 600% SECTION

FIELD PARAMETERS

RECORDED BY: HS DATE RECORDED: 8/27/85 INSTRUMENTS: EG&G ES1210F
GAIN MODE: FIXED FIELD FILTER: OUT-60HZ 60HZ NOTCH FILTER: IN
RECORD LENGTH: 1 SEC SAMPLE RATE: 4 MS

SPREAD

TYPE: END OVER CDP FOLD: 6 NO. GROUPS: 6
DIR. PROGRESS: E-W NEAR GRP CTR: 66 FT FAR GRP CTR: 394 FT
SEISES/GRP: 5 @ 13 FT.INLINE GROUP INTERVAL: 66 FT

ENERGY

SOURCE: 500 LB WT DRP SP ARRAY: POINT SP INTERVAL: 33 FT
SP OFFSET: 0 DROPS/SP: 1-2

PROCESSING SEQUENCE

(1) TRANSCR (2) QUAL VERIF (3) EDIT
(4) WX DETERM (5) FAN (6) STK 600%
(7) DTM CORRN (8) DIPFIL (9) FILTER 40-80 HZ
(10) SLOW AGC (11) PLOT VA/WT (12)

PLOTTER DISPLAY

HORIZ.SCALE: 33 FT/TR POLARITY: POS. VERT.SCALE: 7.5 IN/SEC
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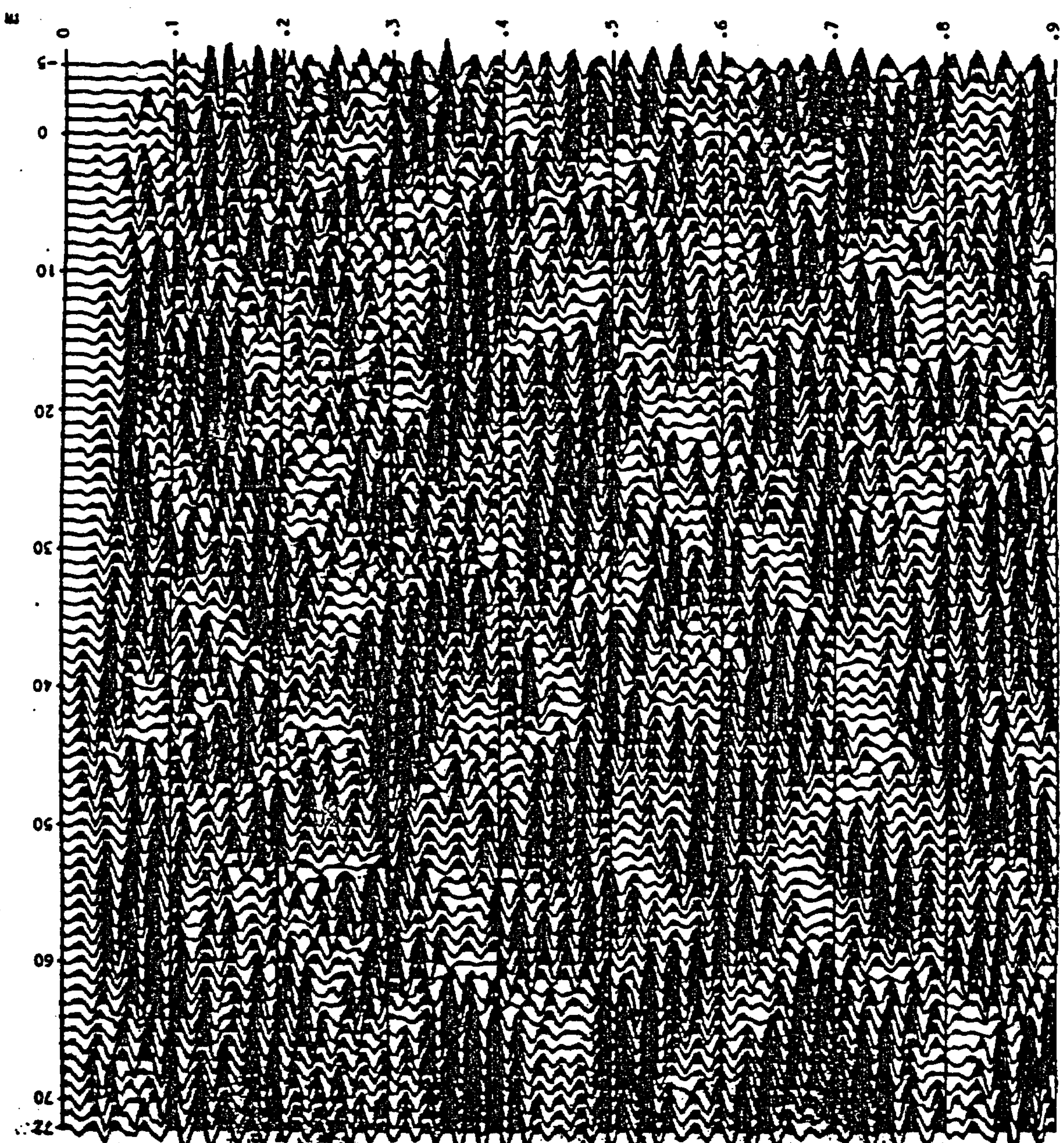
CHARLES B. REYNOLDS & ASSOC., INC.

Enclosure No. 5



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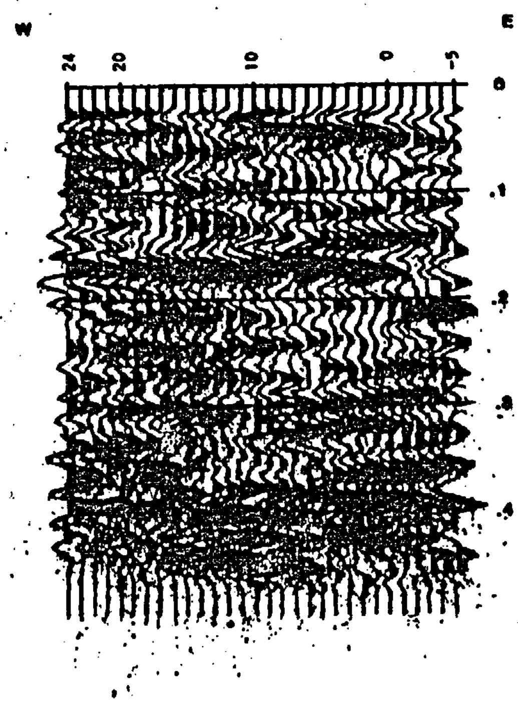

SANDIA NATIONAL LABORATORIES

LINE RSFS 16 R1-R24
YUCCA MTN AREA NEVADA
FINAL 600% SECTION

FIELD PARAMETERS

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GAIN MODE: FIXED FIELD FILTER: OUT-60HZ 60HZ NOTCH FILTER: IN
RECORD LENGTH: 0.5 SEC SAMPLE RATE: 4 MS

SPREAD

TYPE: END OVER CDP FOLD: 6 NO. GROUPS: 6
DIR. PROGRESS: E-W NEAR GRP CTR: 66 FT FAR GRP CTR: 394 FT
SEISES/GRP: 5 @ 13 FT.INLINE GROUP INTERVAL: 66 FT

ENERGY

SOURCE: 500 LB WT DRP SP ARRAY: POINT SP INTERVAL: 33 FT
SP OFFSET: 0 DROPS/SP: 1-2

PROCESSING SEQUENCE

(1) TRANSCR	(2) QUAL VERIF	(3) EDIT
(4) WX DETERM	(5) FAN	(6) STK 600%
(7) DTM CORRN	(8) DIPFIL	(9) SLOW AGC
(10) PLOT VA/WT	(11)	(12)

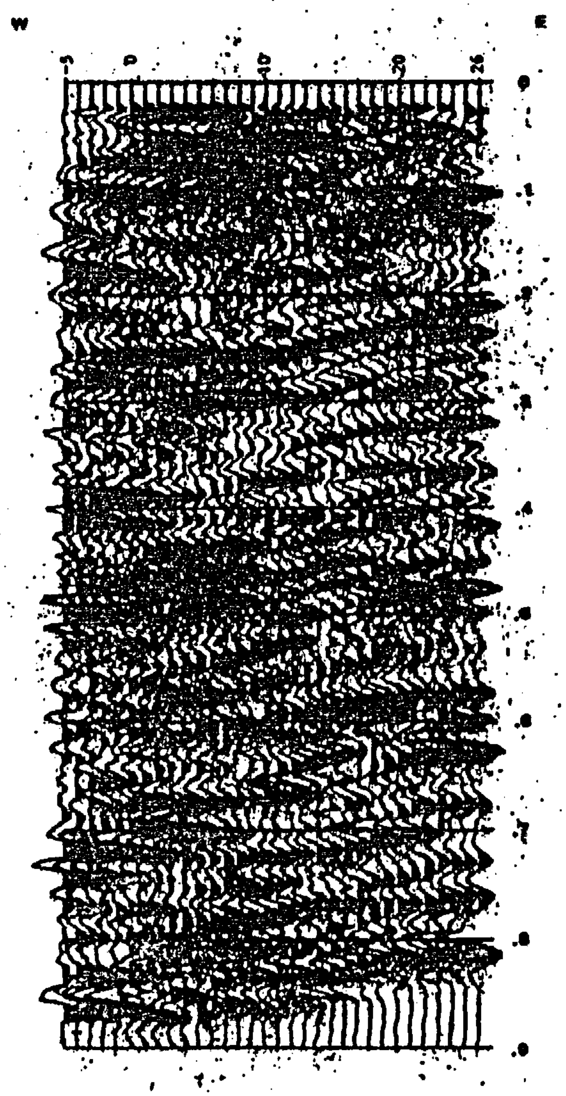
PLOTTER DISPLAY

HORIZ.SCALE: 33 FT/TR POLARITY: POS. VERT.SCALE: 7.5 IN/SEC
WX. VEL.: NONE DATUM: +3700 FT CORRN. VEL.: 3400 FT/SEC

CHARLES B. REYNOLDS & ASSOC., INC.

Enclosure No. 6

"BEST AVAILABLE COPY"



SANDIA NATIONAL LABORATORIES

LINE RSFS 9 R1-R26
YUCCA MTN AREA NEVADA
FINAL 600% SECTION

FIELD PARAMETERS

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GAIN MODE: FIXED | FIELD FILTER: OUT-60HZ | 60HZ NOTCH FILTER: IN
RECORD LENGTH: 1 SEC | SAMPLE RATE: 4 MS

SPREAD

TYPE: END OVER | CDP FOLD: 6 | NO. GROUPS: 6
DIR. PROGRESS: W-E | NEAR GRP CTR: 66 FT | FAR GRP CTR: 394 FT
SEISES/GRP: 5 @ 13 FT. INLINE | GROUP INTERVAL: 66 FT

ENERGY

SOURCE: 500 LB WT DRP | SP ARRAY: POINT | SP INTERVAL: 33 FT
SP OFFSET: 0 | DROPS/SP: 1-2

PROCESSING SEQUENCE

(1) TRANSCR | (2) QUAL VERIF | (3) EDIT
(4) NX DETERM | (5) FAN | (6) STK 600%
(7) DTM CORRN | (8) DIPFIL | (9) SLOW AGC
(10) PLOT VA/WT | (11) | (12)

PLOTTER DISPLAY

HORIZ.SCALE: 33 FT/TR | POLARITY: POS. | VERT.SCALE: 7.5 IN/SEC
NX. VEL.: NONE | DATUM: +3700 FT | CORRN. VEL.: 3400 FT/SEC

CHARLES B. REYNOLDS & ASSOC., INC.

Enclosure No. 7

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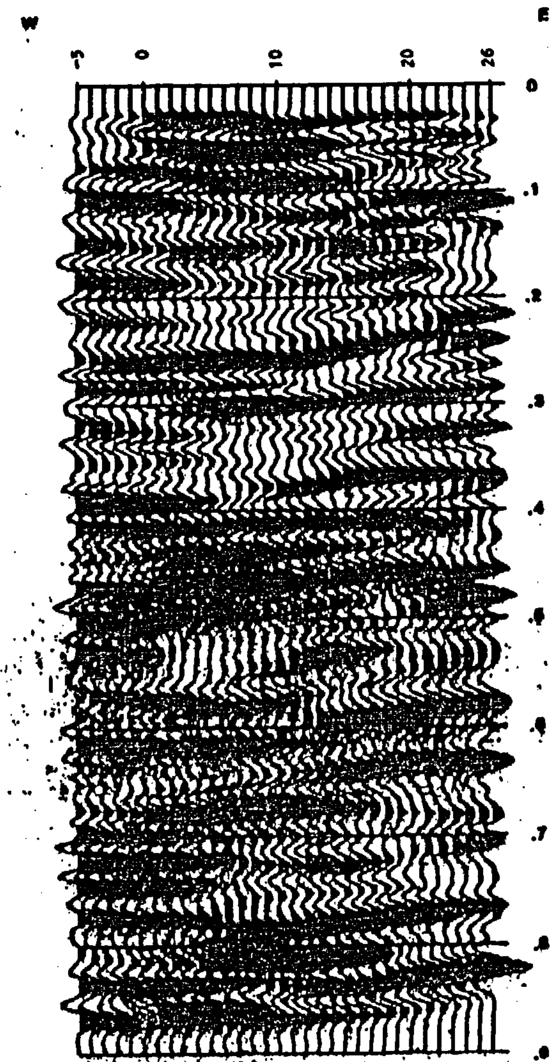

SANDIA NATIONAL LABORATORIES

LINE RSFS 9 R1-R26
YUCCA MTN AREA NEVADA
FINAL 600% MIGRATED SECTION

FIELD PARAMETERS
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GAIN MODE: FIXED   FIELD FILTER: OUT-60HZ   60HZ NOTCH FILTER: IN
RECORD LENGTH: 1 SEC   SAMPLE RATE: 4 MS

SPREAD
TYPE: END OVER   CDP FOLD: 6   NO. GROUPS: 6
DIR. PROGRESS: W-E   NEAR GRP CTR: 66 FT   FAR GRP CTR: 394 FT
SEISES/GRP: 5 @ 13 FT.INLINE   GROUP INTERVAL: 66 FT

ENERGY
SOURCE: 500 LB WT DRP   SP ARRAY: POINT   SP INTERVAL: 33 FT
SP OFFSET: 0   DROPS/SP: 1-2

PROCESSING SEQUENCE
(1) TRANSCR   (2) QUAL VERIF   (3) EDIT
(4) HX DETERM   (5) FAN   (6) STK 600%
(7) DTM CORRN   (8) DIPFIL   (9) DIPPIC
(10) TIMIGR   (11) SLOW AGC   (12) PLOT VA/WT

PLOTTER DISPLAY
HORIZ.SCALE: 33 FT/TR   POLARITY: POS.   VERT.SCALE: 7.5 IN/SEC
HX. VEL.: NONE   DATUM: +3700 FT   CORRN. VEL.: 3400 FT/SEC

CHARLES B. REYNOLDS & ASSOC., INC.

Enclosure No. 8

SANDIA NATIONAL LABORATORIES

LINE RSFS 3 R1-R111
YUCCA MTN AREA NEVADA
FINAL 600% SECTION

FIELD PARAMETERS

RECORDED BY: HS DATE RECORDED: 8/8/85 INSTRUMENTS: EG&G ES1210F
GAIN MODE: FIXED FIELD FILTER: OUT-60HZ 60HZ NOTCH FILTER: IN
RECORD LENGTH: 1 SEC SAMPLE RATE: 4 MS

SPREAD

TYPE: END OVER CDP FOLD: 6 NO. GROUPS: 6
DIR. PROGRESS: E-W NEAR GRP CTR: 66 FT FAR GRP CTR: 394 FT
SEISES/GRP: 5 @ 13 FT.INLINE GROUP INTERVAL: 66 FT

ENERGY

SOURCE: 500 LB WT DRP SP ARRAY: POINT SP INTERVAL: 33 FT
SP OFFSET: 0 DROPS/SP: 1-2

PROCESSING SEQUENCE

(1) TRANSCR	(2) QUAL VERIF	(3) EDIT
(4) WX DETERM	(5) FAN	(6) STK 600%
(7) DTM CORRN	(8) DIPFIL	(9) FILTER 40-80 HZ
(10) SLOW AGC	(11) PLOT VA/WT	(12)

PLOTTER DISPLAY

HORIZ.SCALE: 33 FT/TR POLARITY: POS. VERT.SCALE: 7.5 IN/SEC
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CHARLES B. REYNOLDS & ASSOC., INC.

Enclosure No. 9

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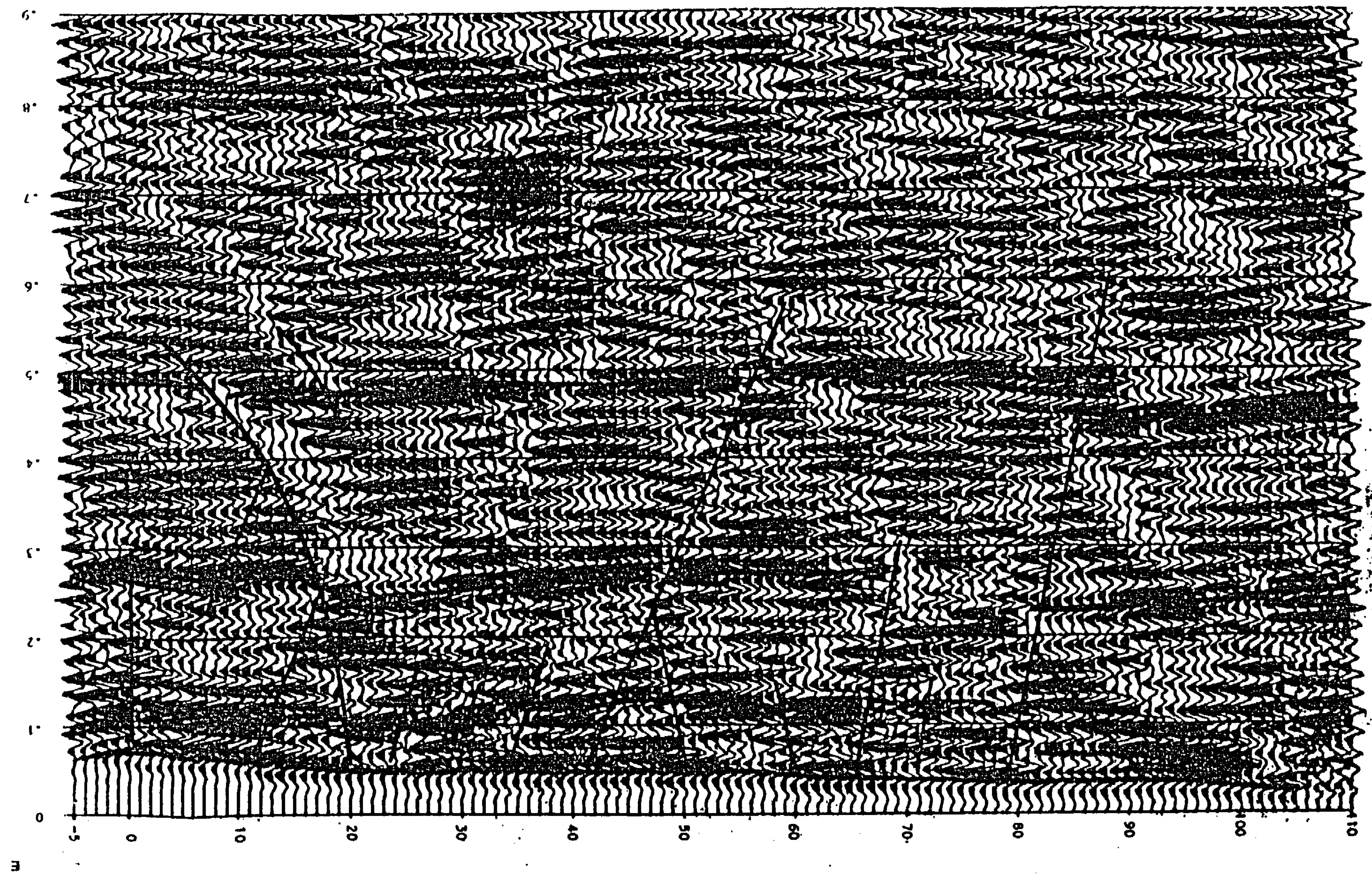

SANDIA NATIONAL LABORATORIES

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YUCCA MTN AREA NEVADA
FINAL 600% SECTION

FIELD PARAMETERS

RECORDED BY: HS — DATE RECORDED: 8/23/85 — INSTRUMENTS: EG&G 2401
GAIN MODE: FIXED — FIELD FILTER: OUT-60HZ — 60HZ NOTCH FILTER: IN
RECORD LENGTH: 1 SEC — SAMPLE RATE: 4 MS

SPREAD

TYPE: END OVER — CDP FOLD: 6 — NO. GROUPS: 6
DIR. PROGRESS: E-W — NEAR GRP CTR: 66 FT — FAR GRP CTR: 594 FT
SEISES/GRP: 5 @ 13 FT.INLINE — GROUP INTERVAL: 66 FT

ENERGY

SOURCE: 500 LB WT DRP — SP ARRAY: POINT — SP INTERVAL: 33 FT
SP OFFSET: 0 — DROPS/SP: 1-2

PROCESSING SEQUENCE

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(7) DTM CORRN	(8) DIPFIL	(9) FILTER 40-80 HZ
(10) SLOW AGC	(11) PLOT VA/WT	(12)

PLOTTER DISPLAY

HORIZ.SCALE: 33 FT/TR — POLARITY: POS. — VERT.SCALE: 7.5 IN/SEC
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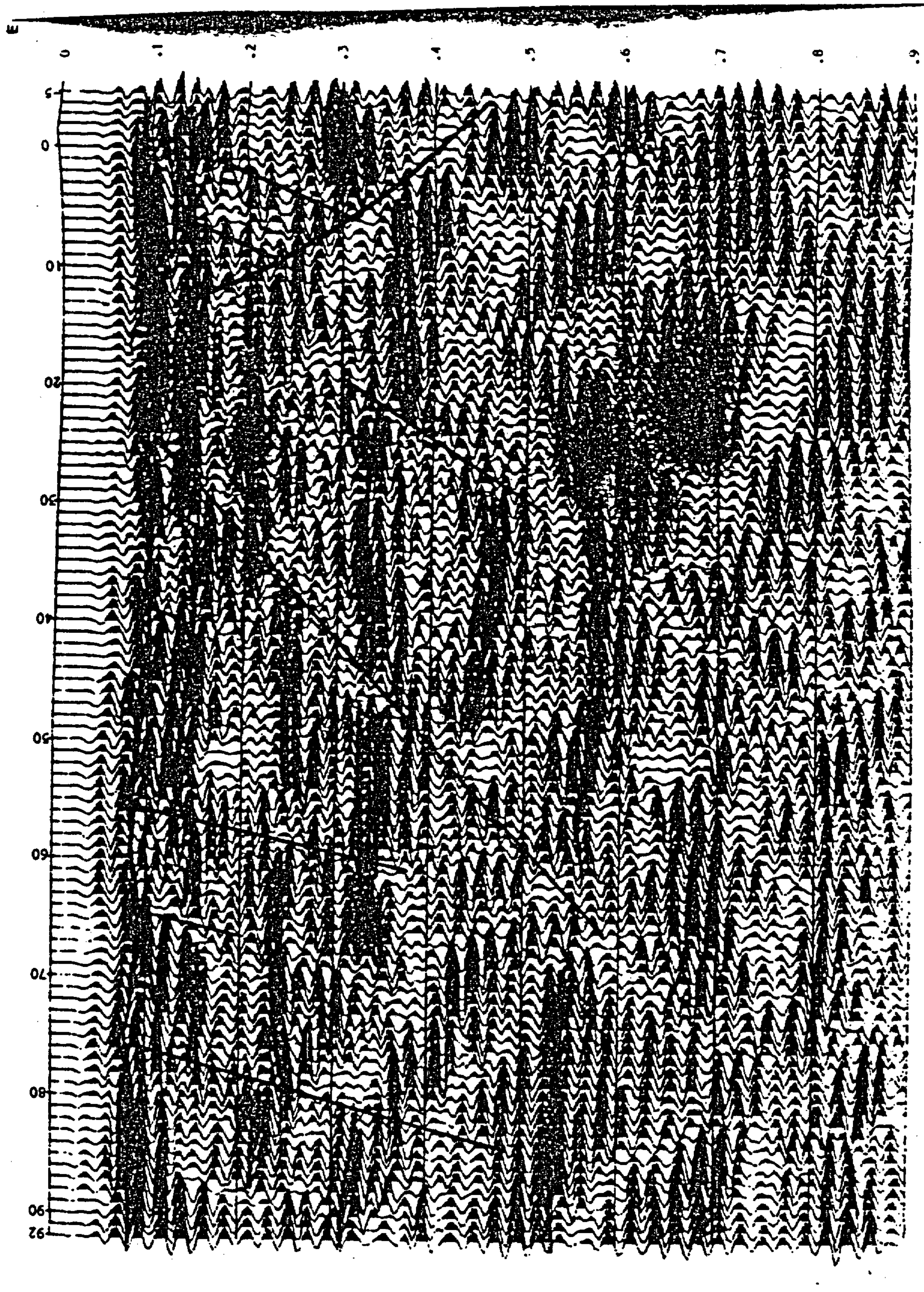
CHARLES B. REYNOLDS & ASSOC., INC.

Enclosure No. 10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SANDIA NATIONAL LABORATORIES

LINE RSFS 12 R1-R72

YUCCA MTN AREA NEVADA

FINAL 600% SECTION

FIELD PARAMETERS

RECORDED BY: HS   DATE RECORDED: 8/27/85   INSTRUMENTS: EG&G ES1210F

GAIN MODE: FIXED   FIELD FILTER: OUT-60HZ   60HZ NOTCH FILTER: IN

RECORD LENGTH: 1 SEC   SAMPLE RATE: 4 MS

SPREAD

TYPE: END OVER   CDP FOLD: 6   NO. GROUPS: 6

DIR. PROGRESS: E-W   NEAR GRP CTR: 66 FT   FAR GRP CTR: 394 FT

SEISES/GRP: 5 @ 13 FT.INLINE   GROUP INTERVAL: 66 FT

ENERGY

SOURCE: 500 LB WT DRP   SP ARRAY: POINT   SP INTERVAL: 33 FT

SP OFFSET: 0   DROPS/SP: 1-2

PROCESSING SEQUENCE

(1) TRANSCR	(2) QUAL VERIF	(3) EDIT
(4) WX DETERM	(5) FAN	(6) STK 600%
(7) DTM CORRN	(8) DIPFIL	(9) FILTER 40-80 HZ
(10) SLOW AGC	(11) PLOT VA/WT	(12)

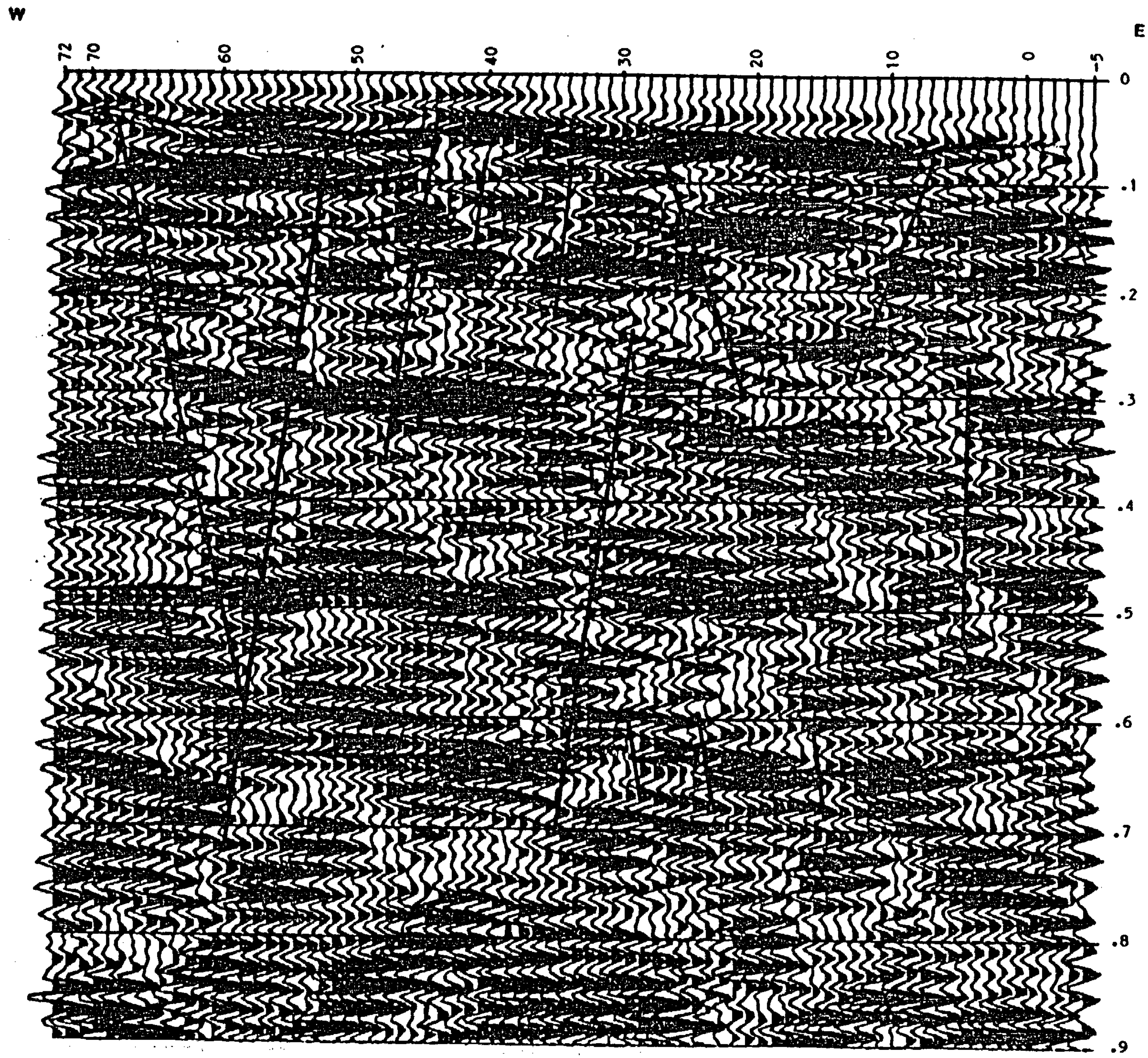
PLOTTER DISPLAY

HORIZ.SCALE: 33 FT/TR   POLARITY: POS.   VERT.SCALE: 7.5 IN/SEC

WX. VEL.: 2300 FT/SEC   DATUM: +3700 FT   CORRN. VEL.: 3400 FT/SEC

CHARLES B. REYNOLDS & ASSOC., INC.

Enclosure No. 11



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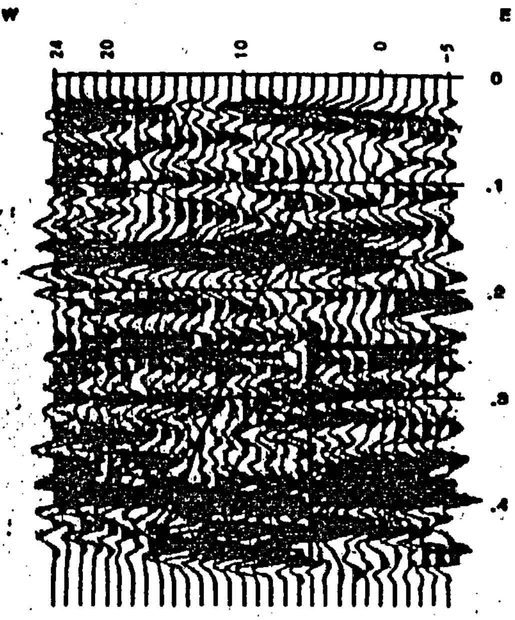


SANDIA NATIONAL LABORATORIES

LINE RSFS 16 R1—R24
YUCCA MTN AREA NEVADA
FINAL 600% SECTION

FIELD PARAMETERS

RECORDED BY: HB
DATE RECORDED: 8/29/85
INSTRUMENTS: EG&G ES1210F
GAIN MODE: FIXED
FIELD FILTER: OUT-60HZ
60HZ NOTCH FILTER: IN
RECORD LENGTH: 0.5 SEC
SAMPLE RATE: 4 MS

SPREAD

TYPE: END OVER
CDP FOLD: 6
NO. GROUPS: 6
DIR. PROGRESS: E-W
NEAR GRP CTR: 66 FT
FAR GRP CTR: 394 FT
SEISES/GRP: 5 @ 13 FT.INLINE
GROUP INTERVAL: 66 FT

ENERGY

SOURCE: 500 LB WT DRP
SP ARRAY: POINT
SP INTERVAL: 33 FT
SP OFFSET: 0
DROPS/SP: 1-2

PROCESSING SEQUENCE

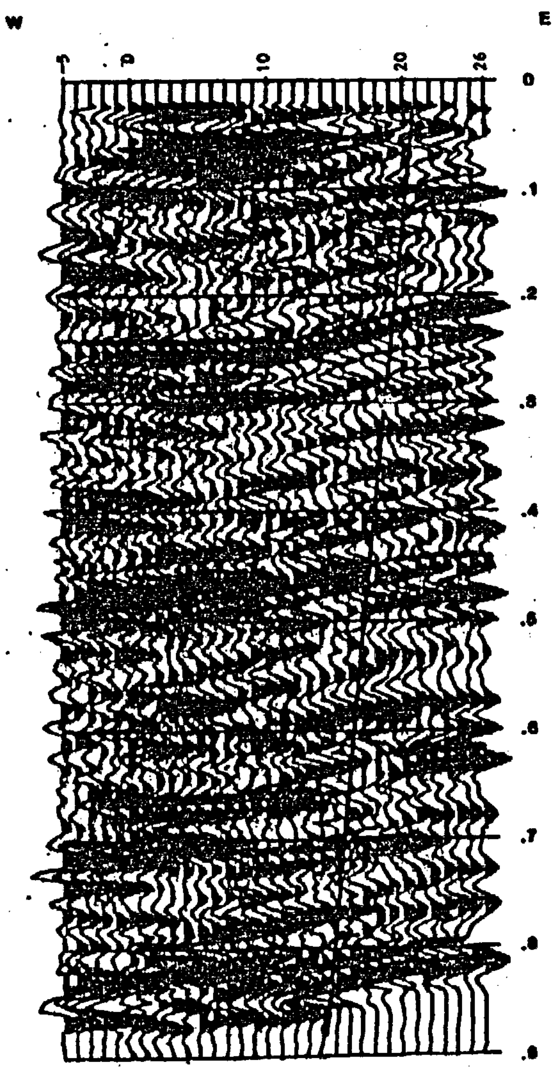
(1) TRANSCR
(2) QUAL VERIF
(3) EDIT
(4) WX DETERM
(5) FAN
(6) STK 600%
(7) DTM CORRN
(8) DIPFIL
(9) SLOW AGC
(10) PLOT VA/WT
(11)
(12)

PLOTTER DISPLAY

HORIZ.SCALE: 33 FT/TR
POLARITY: POS.
VERT.SCALE: 7.5 IN/SEC
WX. VEL.: NONE
DATUM: +3700 FT
CORRN. VEL.: 3400 FT/SEC

CHARLES B. REYNOLDS & ASSOC., INC.

Enclosure No. 12



SANDIA NATIONAL LABORATORIES

LINE RSIFS 9 R1-R26
YUCCA MTN AREA NEVADA
FINAL 600X SECTION

FIELD PARAMETERS

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GAIN MODE: FIXED — FIELD FILTER: OUT-60HZ — 60HZ NOTCH FILTER: IN
RECORD LENGTH: 1 SEC — SAMPLE RATE: 4 MS

SPREAD

TYPE: END OVER — CDP FOLD: 4 — NO. GROUPS: 6
DIR. PROGRESS: W-E — NEAR GRP CTR: 66 FT — FAR GRP CTR: 394 FT
SEISES/GRP: 5 @ 13 FT.INLINE — GROUP INTERVAL: 66 FT

ENERGY

SOURCE: 500 LB WT DRP — SP ARRAY: POINT — SP INTERVAL: 33 FT
SP OFFSET: 0 — DROPS/SP: 1-2

PROCESSING SEQUENCE

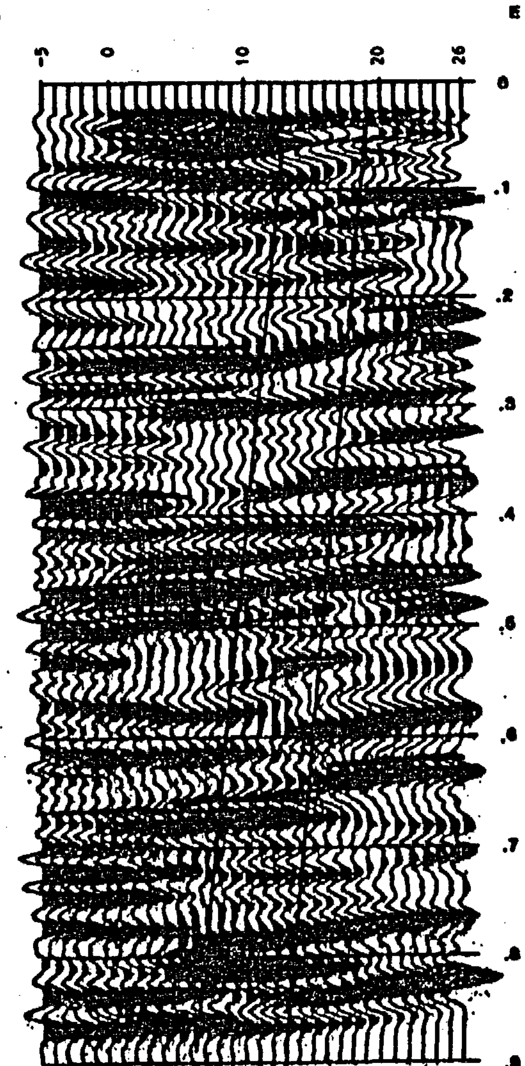
(1) TRANSCR	(2) QUAL VERIF	(3) EDIT
(4) WX DETERM	(5) FAN	(6) STK 600X
(7) DTM CORRN	(8) DIPFIL	(9) SLOW AGC
(10) PLOT VA/WT	(11)	(12)

PLOTTER DISPLAY

HORIZ.SCALE: 33 FT/TR — POLARITY: POS. — VERT.SCALE: 7.5 IN/SEC
WX. VEL.: NONE — DATUM: +3700 FT — CORRN. VEL.: 3400 FT/SEC

CHARLES B. REYNOLDS & ASSOC., INC.

Enclosure No. 13



SANDIA NATIONAL LABORATORIES

LINE RSFS 9 R1-R26
YUCCA MTN AREA NEVADA
FINAL 600% MIGRATED SECTION

FIELD PARAMETERS

RECORDED BY: HS   DATE RECORDED: 8/22/85   INSTRUMENTS: EG&G ES1210F
GAIN MODE: FIXED   FIELD FILTER: OUT-60HZ   60HZ NOTCH FILTER: IN
RECORD LENGTH: 1 SEC   SAMPLE RATE: 4 MS

SPREAD

TYPE: END OVER   CDP FOLD: 6   NO. GROUPS: 6
DIR. PROGRESS: W-E   NEAR GRP CTR: 66 FT   FAR GRP CTR: 394 FT
SEISES/GRP: 5 @ 13 FT.INLINE   GROUP INTERVAL: 66 FT

ENERGY

SOURCE: 500 LB WT DRP   SP ARRAY: POINT   SP INTERVAL: 33 FT
SP OFFSET: 0   DROPS/SP: 1-2

PROCESSING SEQUENCE

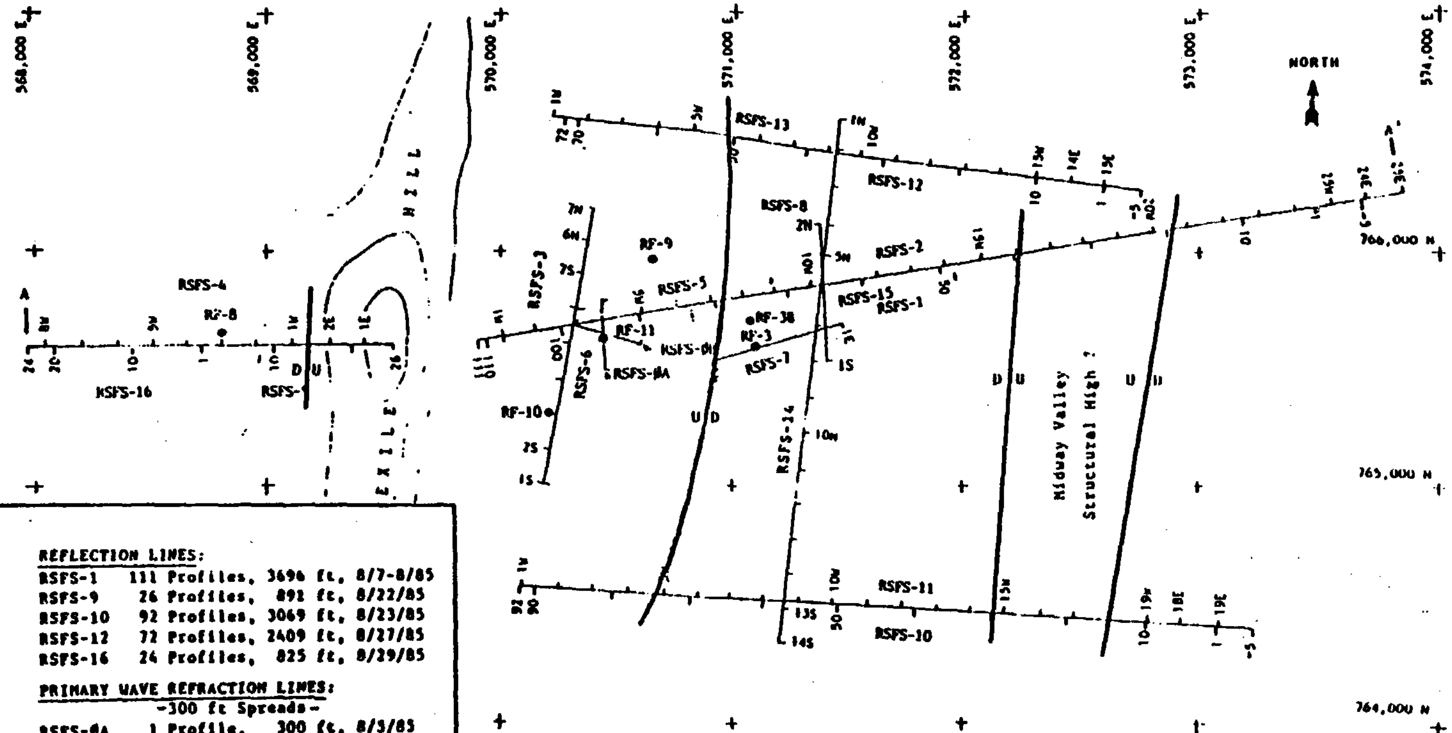
(1) TRANSCR   (2) QUAL VERIF   (3) EDIT
(4) WX DETERM   (5) FAN   (6) STK 600%
(7) DTM CORRN   (8) DIPFIL   (9) DIPPIC
(10) TIMIGR   (11) SLOW AGC   (12) PLOT VA/WT

PLOTTER DISPLAY

HORIZ.SCALE: 33 FT/TR   POLARITY: POS.   VERT.SCALE: 7.5 IN/SEC
WX. VEL.: NONE   DATUM: +3700 FT   CORRN. VEL.: 3400 FT/SEC

CHARLES B. REYNOLDS & ASSOC., INC.

Enclosure No. 14



REFLECTION LINES:

RSFS-1	111 Profiles,	3696 ft,	8/7-8/85
RSFS-9	26 Profiles,	891 ft,	8/22/85
RSFS-10	92 Profiles,	3069 ft,	8/23/85
RSFS-12	72 Profiles,	2409 ft,	8/27/85
RSFS-16	24 Profiles,	825 ft,	8/29/85

PRIMARY WAVE REFRACTION LINES:

-300 ft Spreads-

RSFS-ØA	1 Profile,	300 ft,	8/5/85
RSFS-ØB	1 Profile,	300 ft,	8/5/85
RSFS-2	25 Profiles,	3900 ft,	8/9/85
RSFS-3	7 Profiles,	1200 ft,	8/10/85
RSFS-4	8 Profiles,	1350 ft,	8/10/85
RSFS-11	19 Profiles,	3000 ft,	8/21/85
RSFS-13	15 Profiles,	1200 ft,	8/26/85
RSFS-14	14 Profiles,	2250 ft,	8/28/85

-600 ft Spreads-

RSFS-7	1 Profile,	600 ft,	8/21/85
RSFS-15	2 Profiles,	1200 ft,	8/28/85

SHEAR WAVE REFRACTION LINES:

RSFS-5	7 Profiles,	2100 ft,	8/12-13/85
RSFS-6	4 Profiles,	1200 ft,	8/13/85
RSFS-8	2 Profiles,	600 ft,	8/22/85

DOWNHOLE SURVEYS (Primary and Shear):

RF-3	155 ft,	8/25/85
RF-3B	105 ft,	8/24-25/85
RF-9	105 ft,	8/20,24/85
RF-10	53 ft,	8/20/85

SANDIA NATIONAL LABORATORIES

REPOSITORY SURFACE FACILITY SEISMIC SURVEY
Tucca Mountain Area, Nye County, Nevada

PRINCIPAL FAULTS INTERPRETED FROM REFLECTION DATA

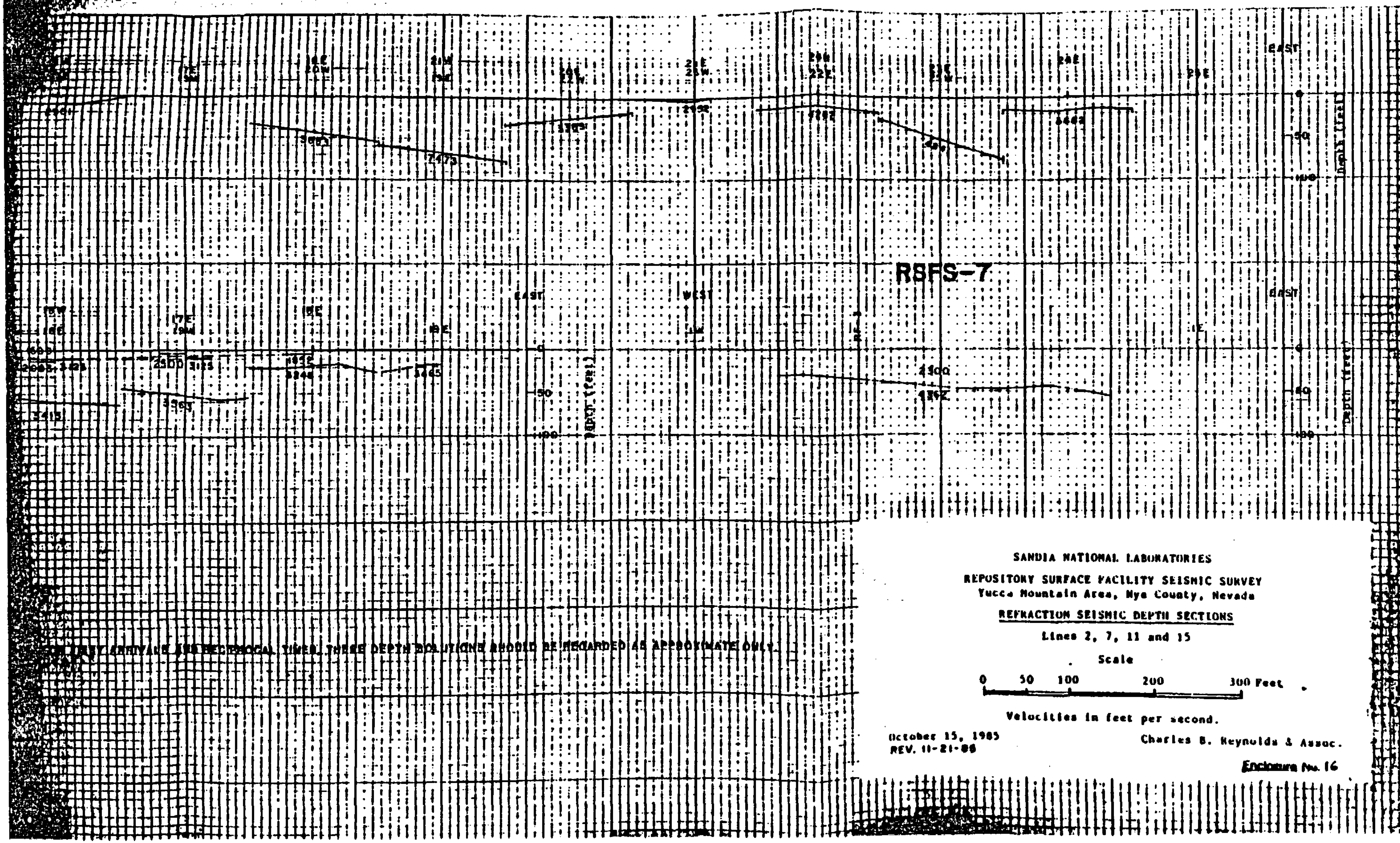
Scale
0 500 1000 1500 Feet

Coordinates: 1,000-foot grid, Nevada State Plane Coordinate System.

November 21, 1985

Charles B. Reynolds & Associates

Enclosure No. 15



SANDIA NATIONAL LABORATORIES

REPOSITORY SURFACE FACILITY SEISMIC SURVEY
Yucca Mountain Area, Nye County, Nevada

REFRACTION SEISMIC DEPTH SECTIONS

Lines 2, 7, 11 and 15

Scale

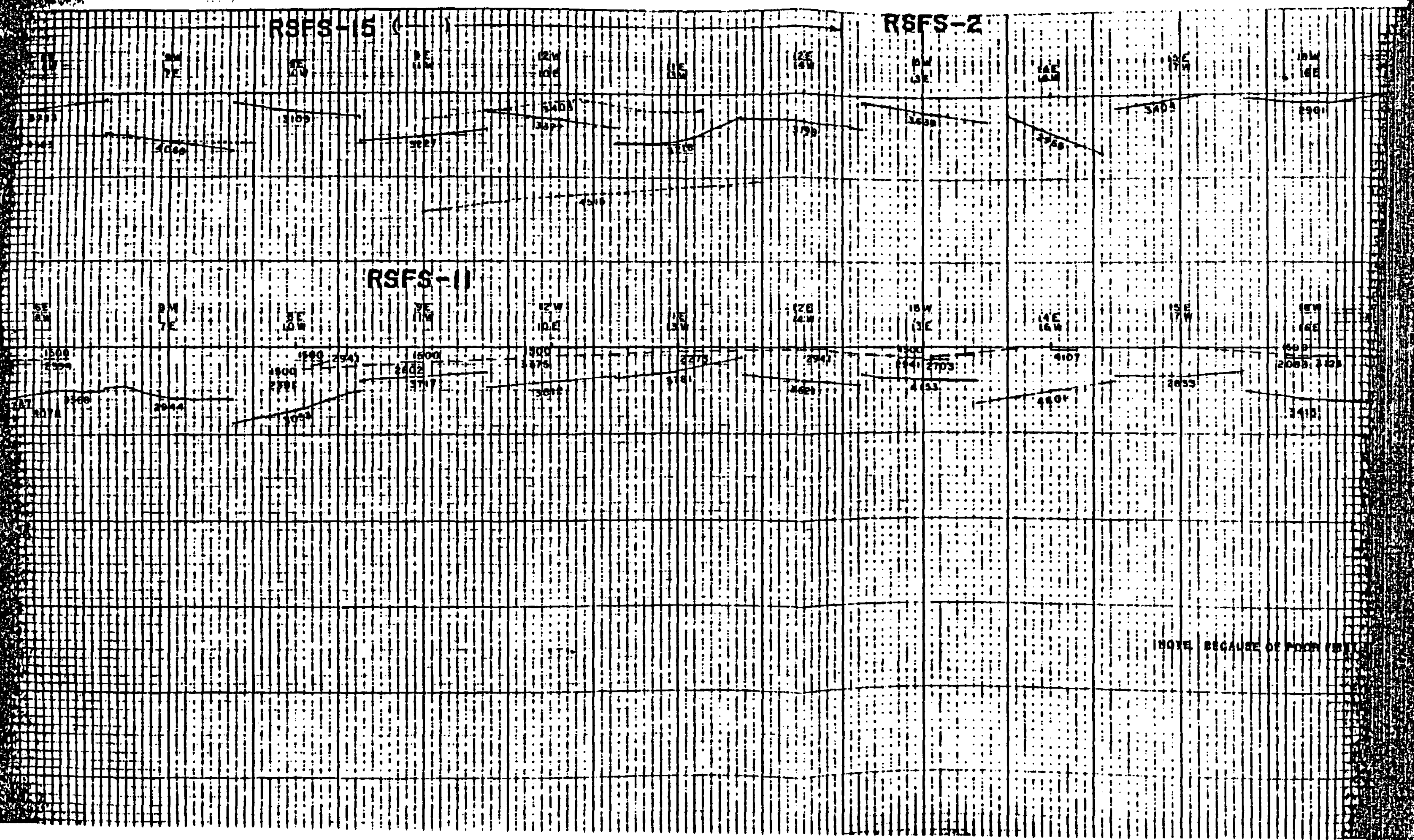
0 50 100 200 300 Feet

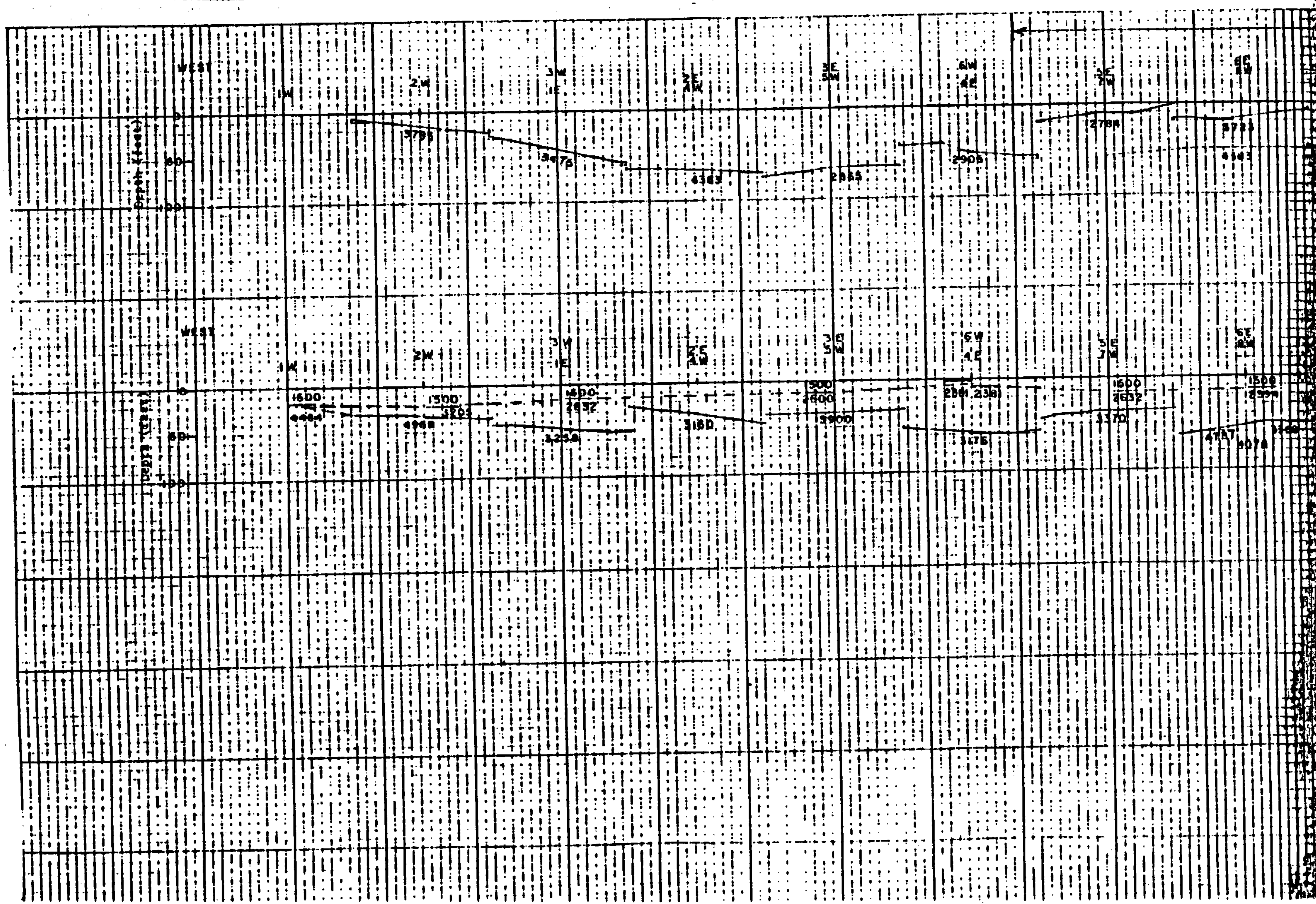
Velocities in feet per second.

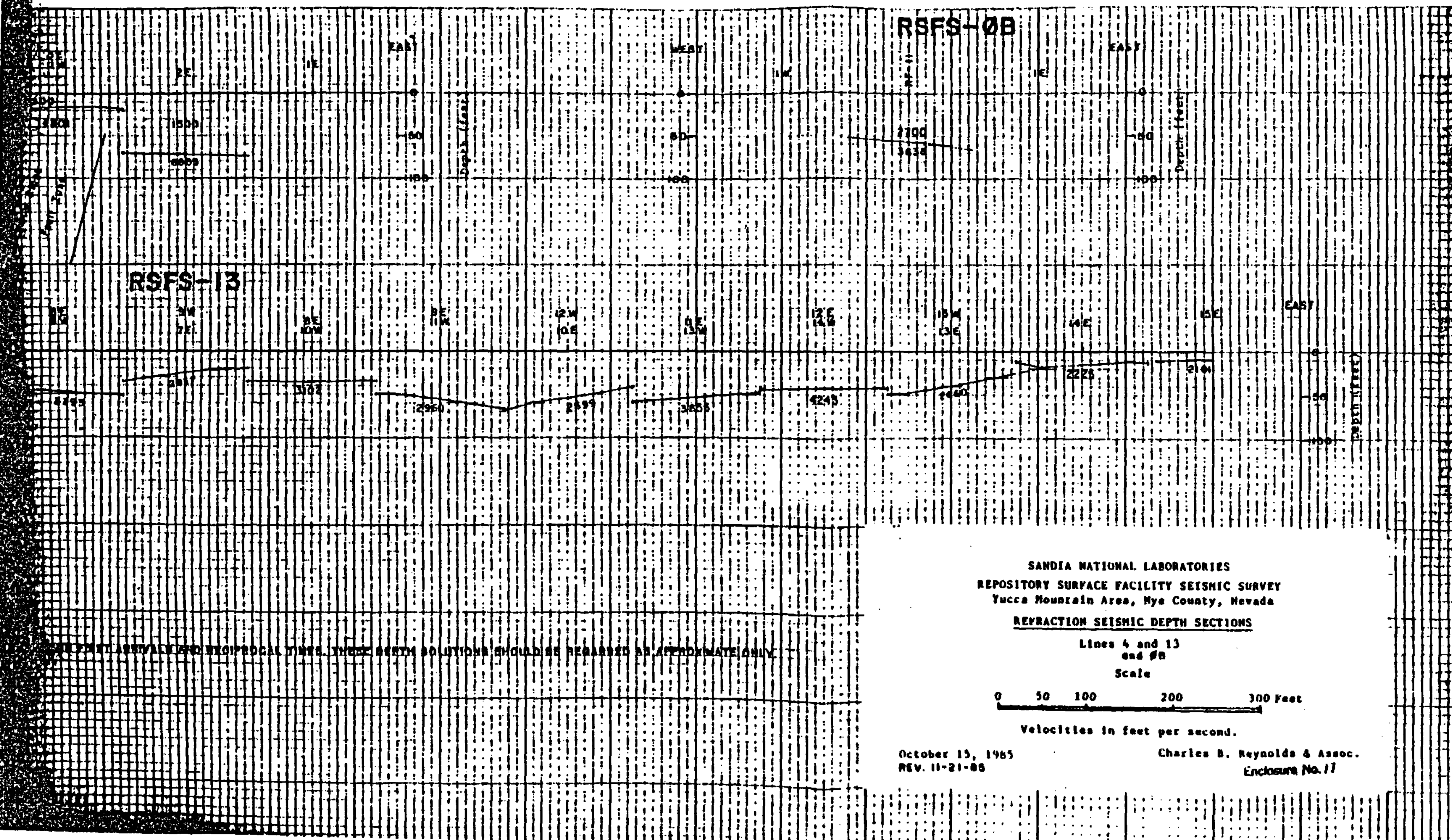
October 15, 1985
REV. 11-21-86

Charles B. Reynolds & Assoc.

Enclosure No. 16


RSFS-15
RSFS-2
RSFS-11
NOTE: BECAUSE OF POOR


WEST
1W
2W
3W
1E
2E
4W
3E
5W
6W
4E
5E
7W
6E
8W
WEST
1W
2W
3W
1E
2E
4W
3E
5W
6W
4E
5E
7W
6E
8W



SANDIA NATIONAL LABORATORIES

REPOSITORY SURFACE FACILITY SEISMIC SURVEY
Yucca Mountain Area, Nye County, Nevada

REFRACTION SEISMIC DEPTH SECTIONS

Lines 4 and 13
and ØB

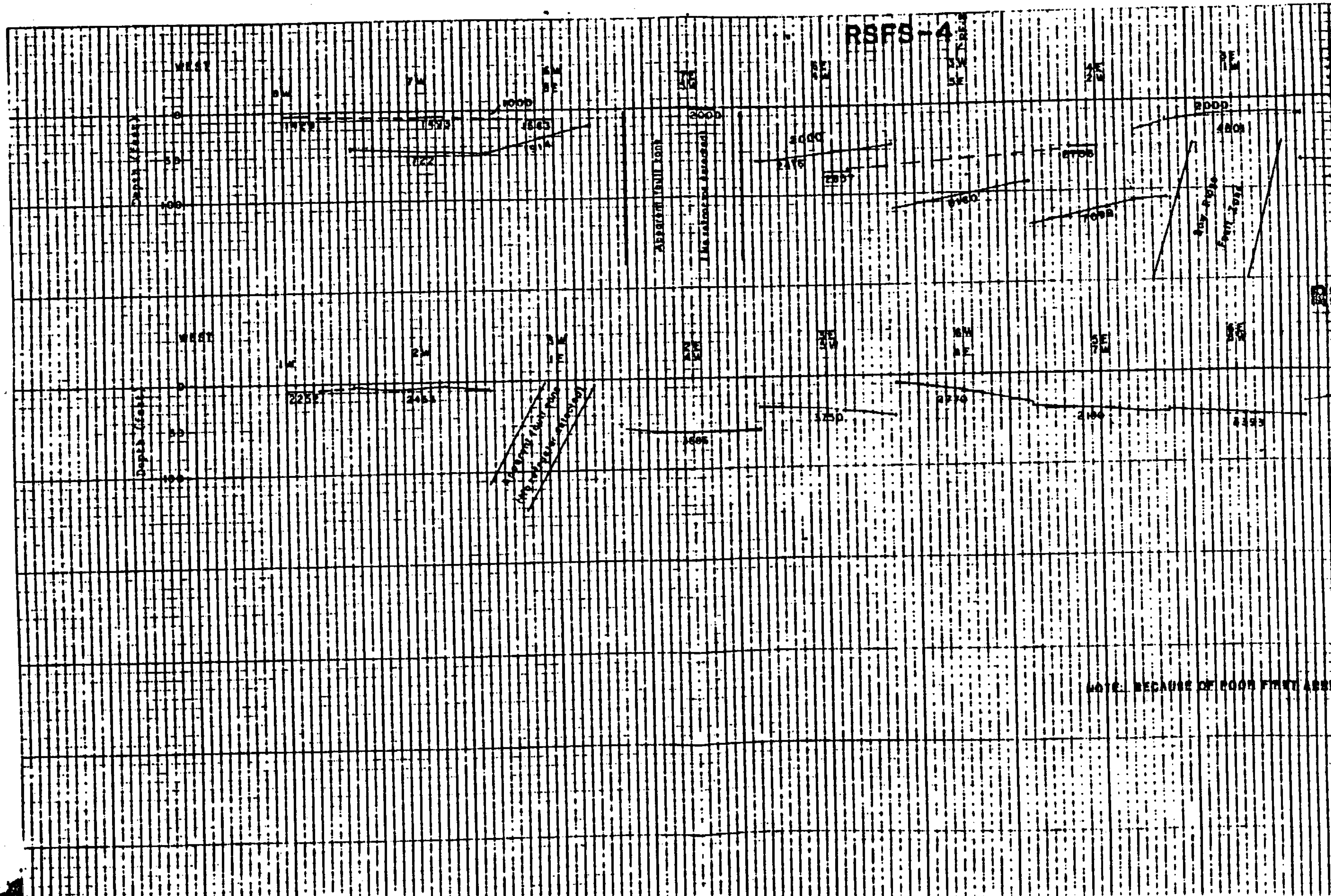
Scale

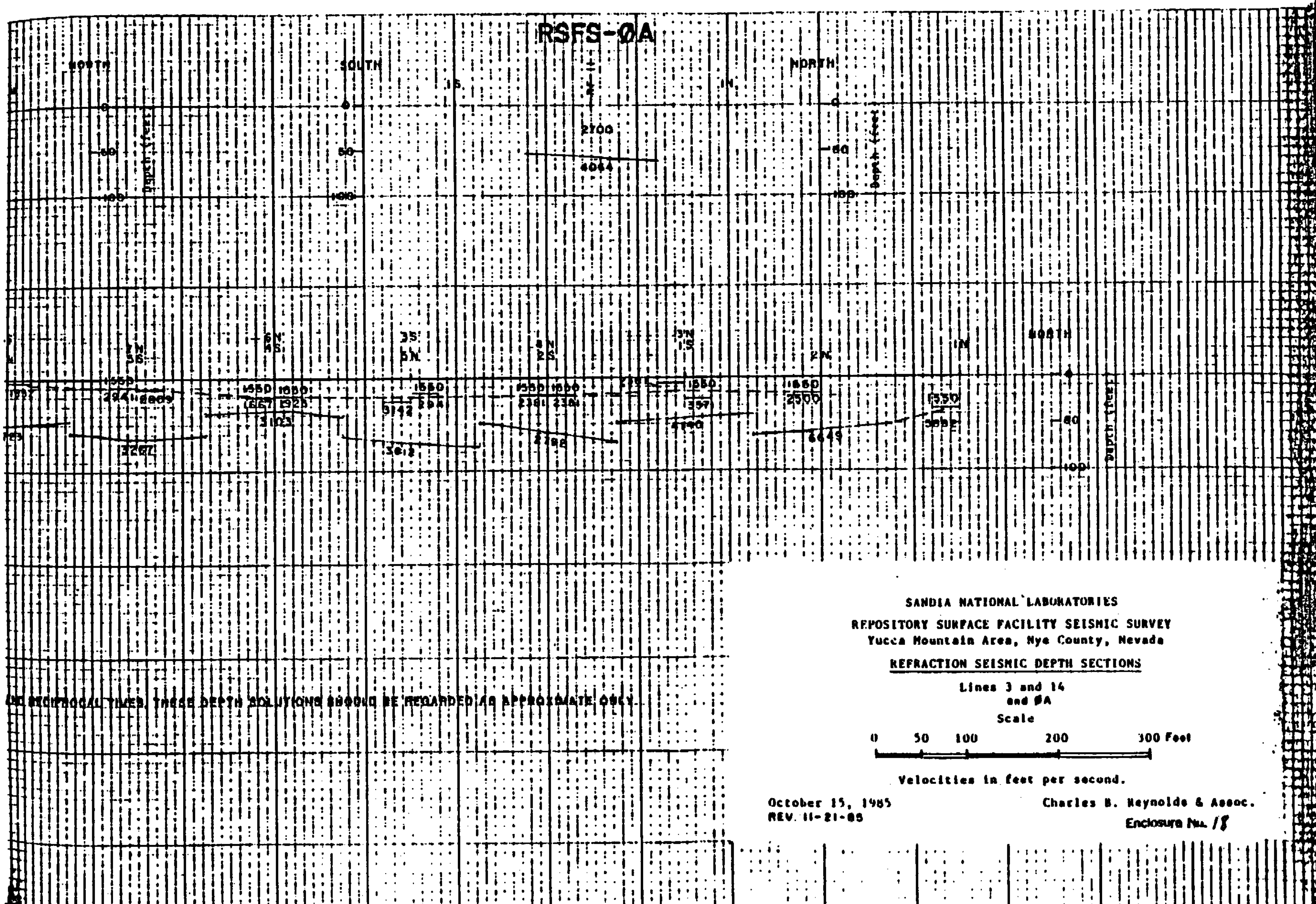
0 50 100 200 300 Feet

Velocities in feet per second.

October 15, 1985
REV. 11-21-85

Charles B. Reynolds & Assoc.
Enclosure No. 17


RSFS-4
WEST
Depth (feet)
0
50
100
Abyssal (Bull Run)
2000
3000
WEST
1
2253
2454
1605
NOTE: BECAUSE OF POOR



SANDIA NATIONAL LABORATORIES

REPOSITORY SURFACE FACILITY SEISMIC SURVEY
Yucca Mountain Area, Nye County, Nevada

REFRACTION SEISMIC DEPTH SECTIONS

Lines 3 and 14
and ØA

Scale

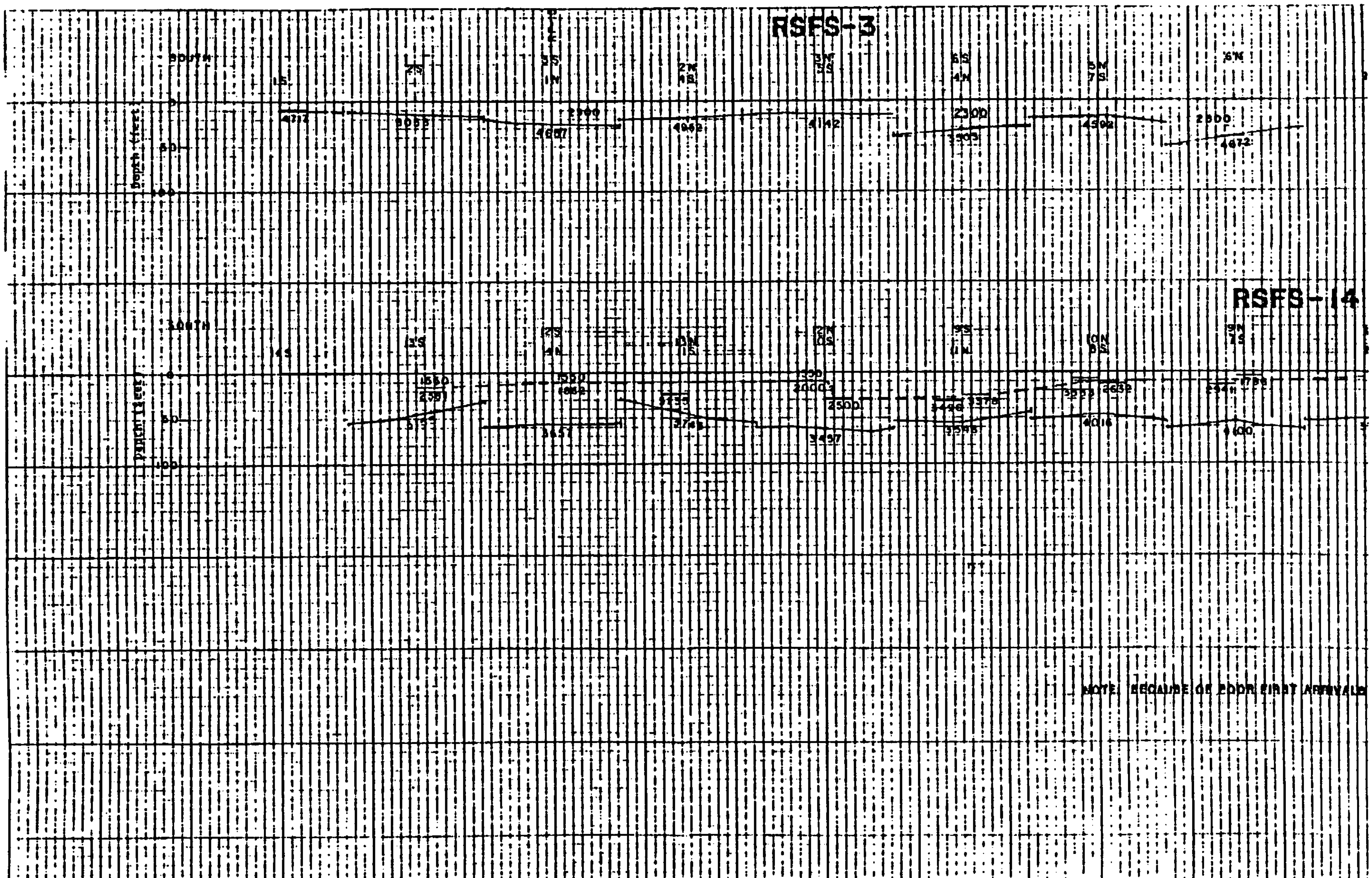
0 50 100 200 300 Feet

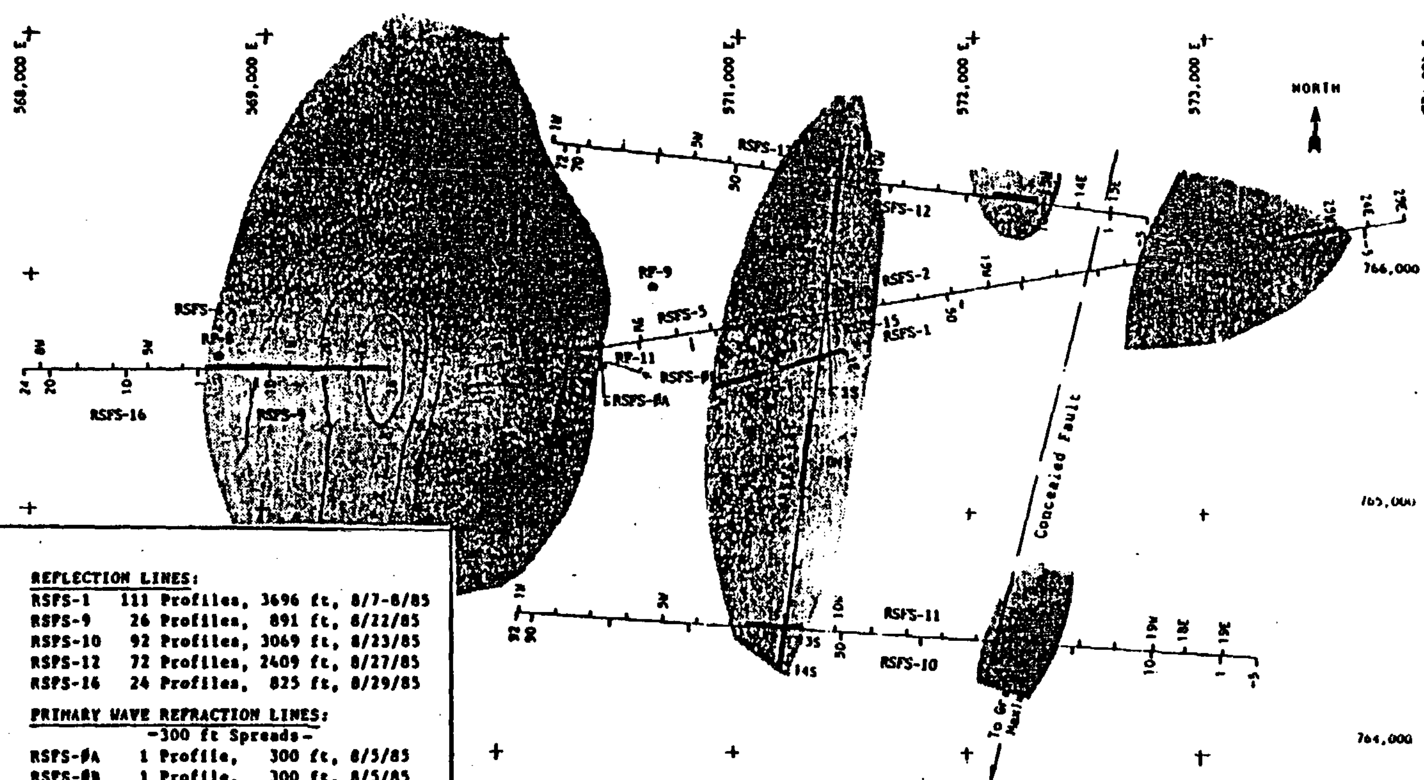
Velocities in feet per second.

October 15, 1985
REV. 11-21-85

Charles B. Reynolds & Assoc.

Enclosure No. 18


RSFS-3
SOUTH
Depth (feet)
0
50
100
4142
2300
4592
2600
4672
RSFS-14
SOUTH
Depth (feet)
0
50
100
2500
3497
4016
4600
NOTE: BECAUSE OF POOR FIRST ARRIVALS



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RF-9	105 ft,	8/20,24/85
RF-10	53 ft,	8/20/85

EXPLANATION

Measured velocity greater than 4,000 ft/sec

Apparent zone of velocity greater than 4,000 ft/sec

SANDIA NATIONAL LABORATORIES

REPOSITORY SURFACE FACILITY SEISMIC SURVEY
Yucca Mountain Area, Nye County, Nevada

LOCATION OF LOCAL HIGHER REFRACTION VELOCITY ZONES

Scale

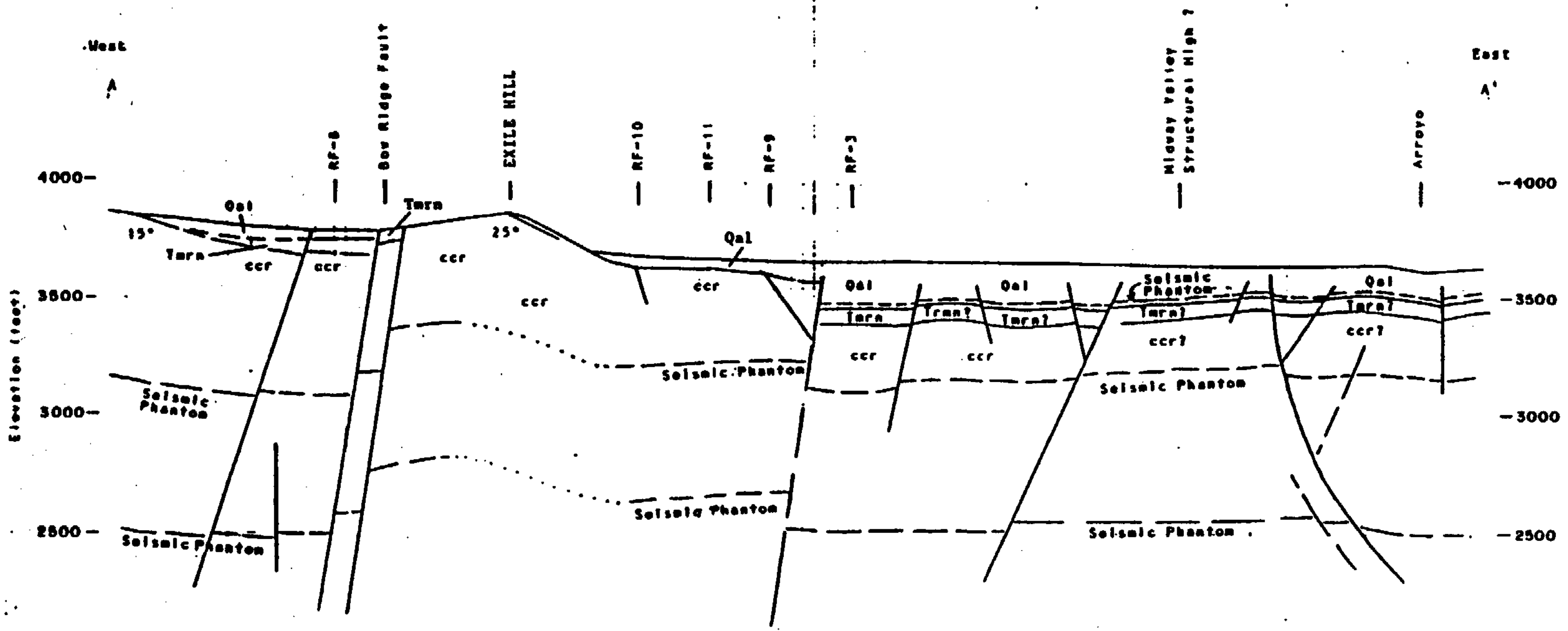
0 500 1000 1500 Feet

Coordinates: 1,000-foot grid, Nevada State Plane Coordinate System.

November 20, 1985

Charles B. Reynolds & Associ

Enclosure No 14



EXPLANATION

Qal Quaternary alluvium
Tmrn Rainier Mesa tuff
ccr Tiva Canyon tuff

SANDIA NATIONAL LABORATORIES

REPOSITORY SURFACE FACILITY SEISMIC SURVEY
Yucca Mountain Area, Nye County, Nevada

STRUCTURE SECTION A - A'

Based on Surface Geology, Drill Hole and Reflection Seismic Data

Scale: one inch equals 500 feet

November 21, 1985 Charles B. Reynolds & Assoc.

Enclosure No 20