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# Reflection Seismic Experiments along a 2-mile profile at the Hanford Site, south-central Washington

Prepared for
Rockwell International Corp
Geoscience Group, Basalt Waste Isolation Project
Rockwell Hanford Operations
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Abstract

As part of the Basalt Waste Isolation Project, reflection seismic experiments were run along a 2-mile line at the Hanford Site in south-central Washington to determine the field parameters needed to acquire high resolution seismic data down to about 1000 ft.

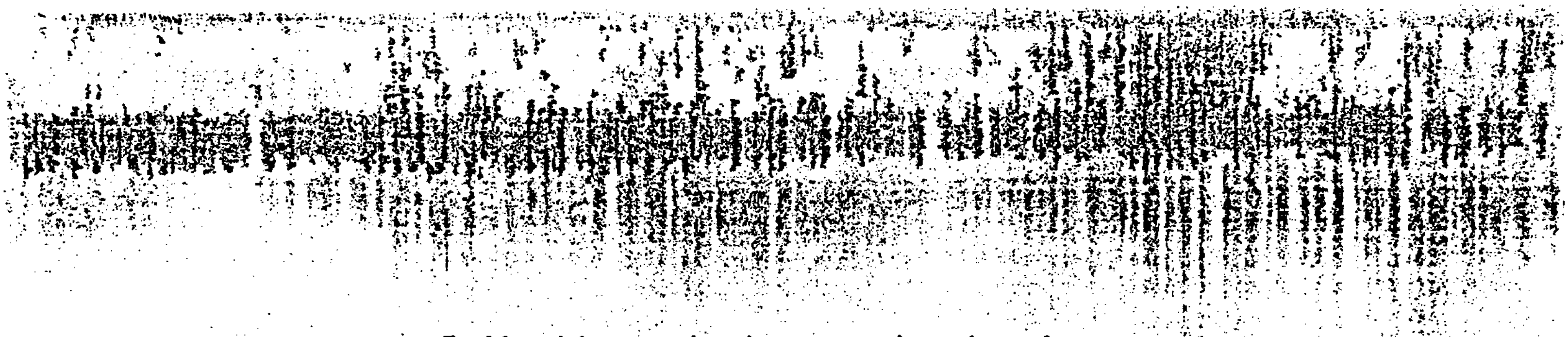
The experimental work was broken down into four parts: (1) noise walkaway tests, (2) shothole profiles, (3) a buried Primacord* profile, and (4) a land airgun profile.

Analyses of the noise spreads and experimental sections show that no high resolution data was acquired due to attenuation of high frequency signals both in a thick weathering layer and in poorly consolidated strata below.

Reflections from the top of the Elephant Mt. basalt and overlying formations were recorded on the shothole and airgun tests where the data was acquired in a narrow, long offset window outside the envelope of noise which contained a suite of low frequency direct arrivals, groundroll, and refracted arrivals.

Quality of the airgun test data was better than that of the long-offset shothole. Simple stratigraphic features were interpreted on the airgun section while the low frequency, narrowband shothole data precluded identifying significant structural or stratigraphic detail.

The land airgun is the most promising seismic source tested at the Hanford Site. Used with 96 channels recording from one geophone per trace at a 2 millisecond sample rate, the airgun could economically produce good quality sections.



# Reflection seismic experiments along a 2-mile profile at the Hanford Site, south-central Washington

Table of Contents

## List of Figures

Figures



## List of Plates

# I. INTRODUCTION

## A. AUTHORIZATION

The work was done by Walker Geophysical Company under contract number SA 5032 for Rockwell. Rockwell is under contract number DE-AC06-77RL01030 to the Department of Energy.

## B. PURPOSE

The purpose of the project was to ascertain the optimum field and processing parameters needed to produce high resolution seismic sections accurately mapping the upper 1000 ft of strata.

## C. DIVISION OF WORK AND RESPONSIBILITY

The work in this report was done by Cameron Walker, jr. of Walker Geophysical Co (WGC) in cooperation with Joseph Kunk, Rockwell.

The seismic data was acquired by WGC's crew no. 1-685, supervised by Cameron Walker, jr.

The data was processed by Digicon, Inc., Houston Processing Center under the supervision of Pedro Segura at the direction of Joseph Kunk and Cameron Walker.

Joseph Kunk received all field records, observer's reports, survey notes and line logs during the program. Test results, processed sections, and field tapes were delivered at the conclusion of the program.

## D. METHODS AND PROCEDURES

Test and production procedures were based on methods common to the seismic data acquisition industry. Source and receiver configurations were tested using both modified and standard noise walkaway techniques.

WGC acquired the shallow minihole and buried Primacord* test and production data under the direction of Rockwell. Land airgun noise walkaway and production surveys were directed by Rockwell and WGC. Conventional shothole noise walkaway test and production data were directed by WGC with the cooperation of Rockwell. An additional shothole noise walkaway test was run at the conclusion of the program under the direction of Rockwell.

## II. LOCATION

The Hanford Site is located northwest of Richland, Washington in the Pasco Basin of the Columbia Plateau Province (Figure 1).

The following geologic overview of the test area (Figure 2a) is paraphrased from the project's statement of work:

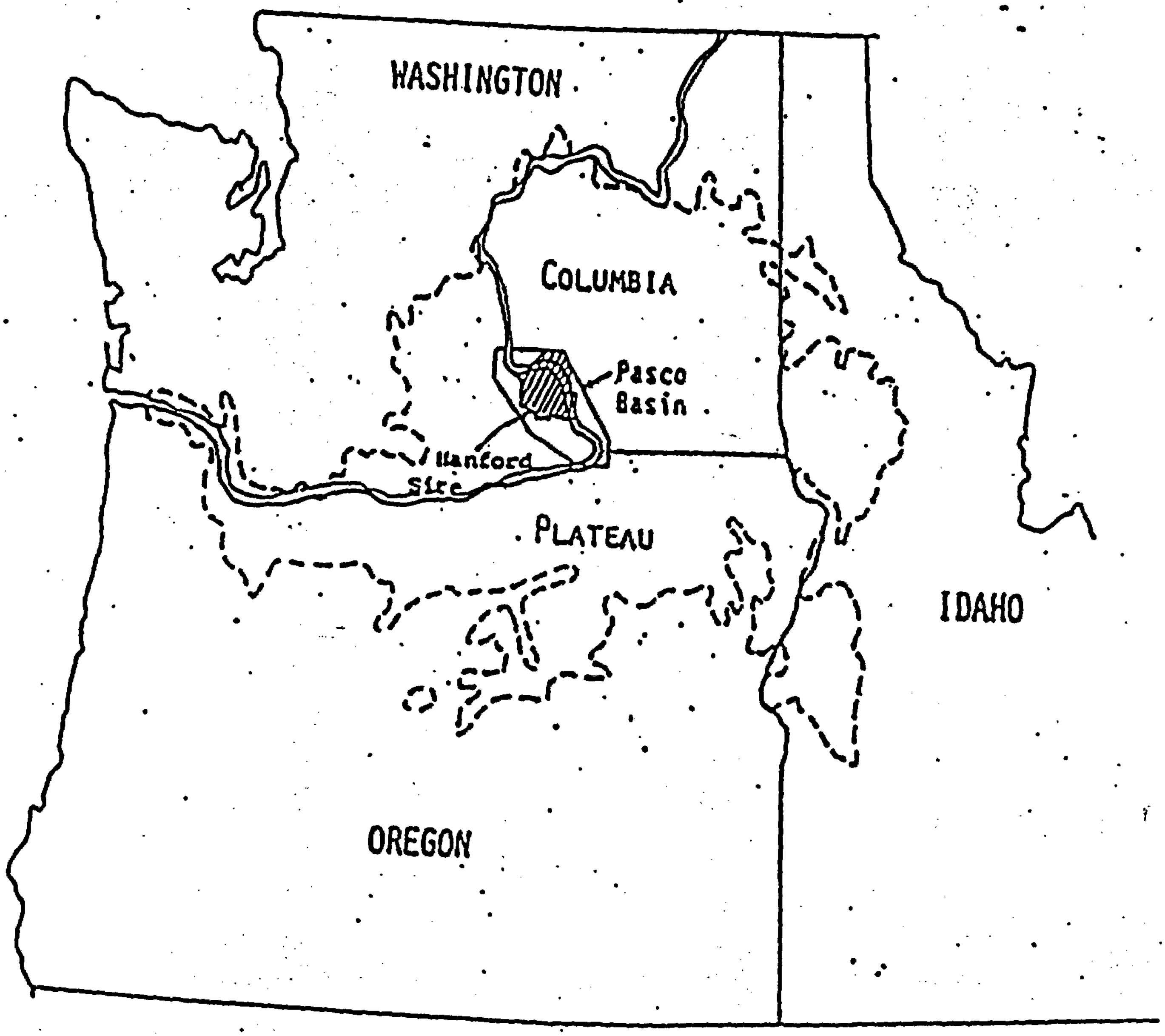
The geology of the Pasco Basin is divided into three general stratigraphic units; (1) the Columbia River Basalt Group, (2) the Ringold Formation, and (3) the Hanford Formation and Recent surficial units. The Miocene Columbia River Basalt Group is composed of many basalt flows, the uppermost flows separated by sedimentary beds. The Group is folded into a system of east-west trending anticlines and synclines. Directly overlying the basalt group is the Pliocene Ringold Formation composed of layers of sand, silt, clay and gravel of varying thicknesses and lateral extent. The gravels range up to eight inches in size and vary in degree of cementation. The Ringold Formation is overlain by Recent fluviatile and glaciofluviatile sediments consisting of sand and gravel. The stratigraphic nomenclature is given in Figure 3.

For detailed regional geology, refer to Caggiano (1983).

## III. FIELD PROCEDURES

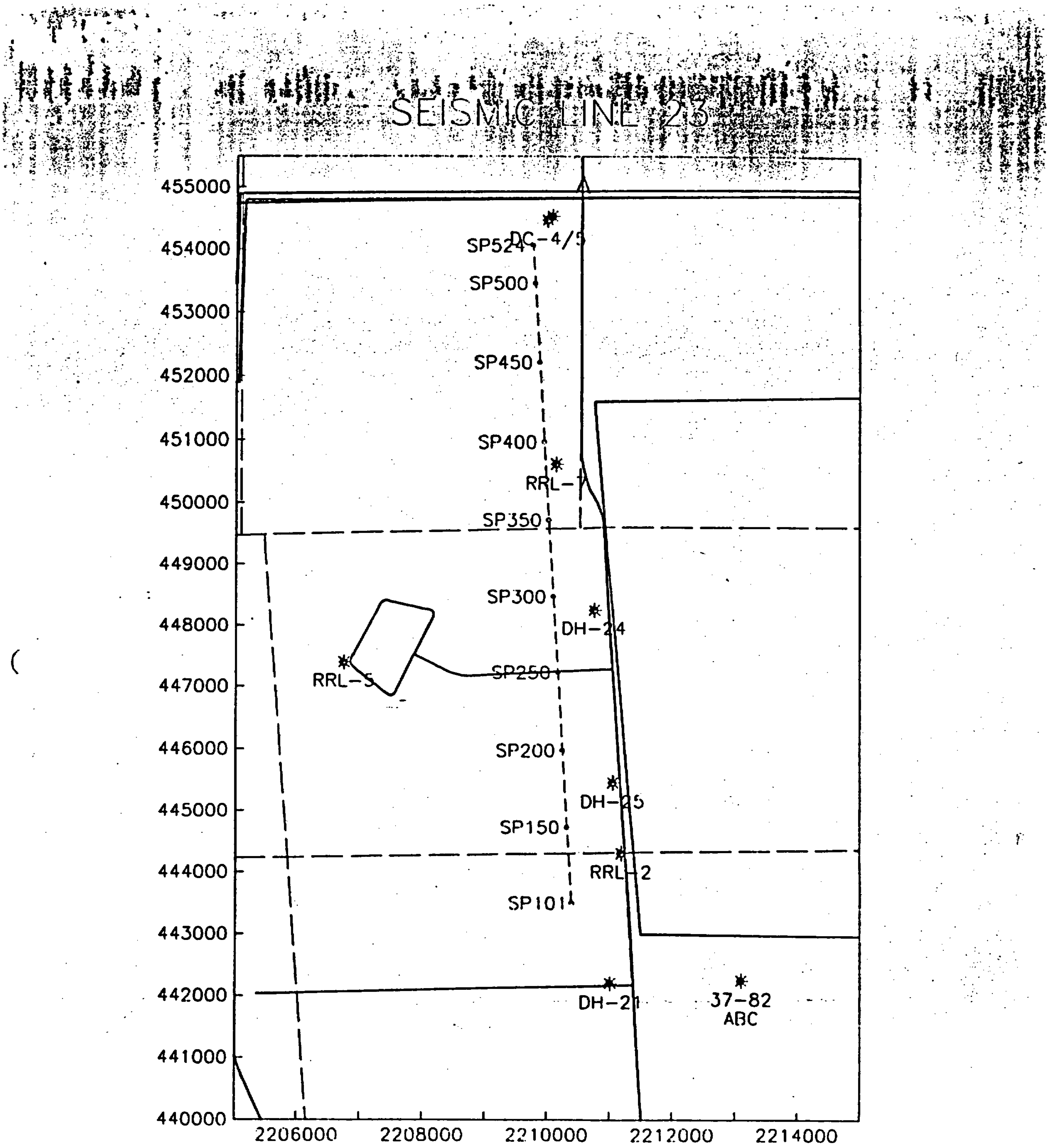
### A. INTRODUCTION

The seismic test program was divided into three catagories; (1) shothole, (2) buried Primacord*, and (3) surface source. The shothole work was furthur divided into two parts; (a) minihole pattern shooting, and (b) conventional shothole.



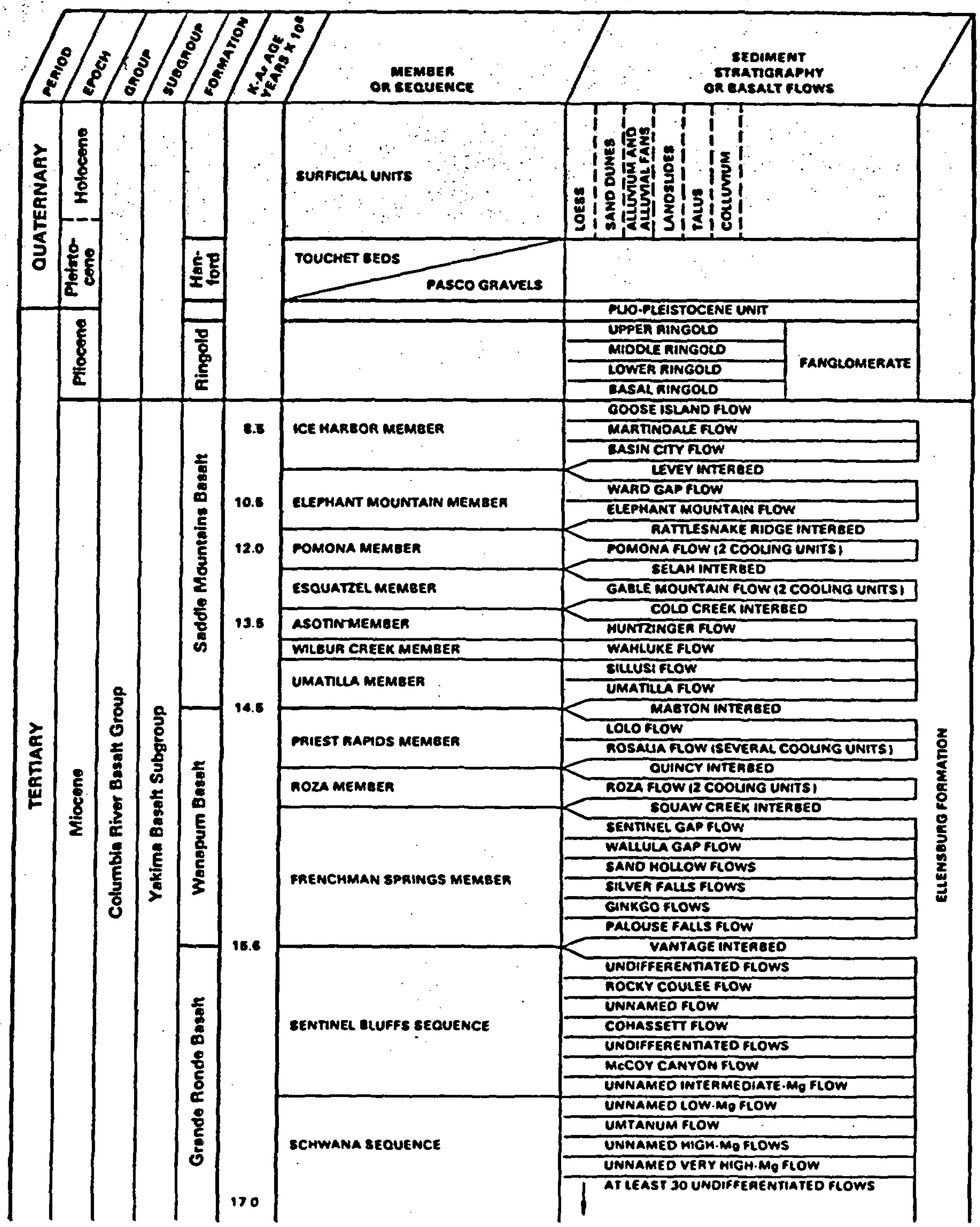

LOCATION MAP: HANFORD SITE AND PASCO BASIN

FIGURE 1



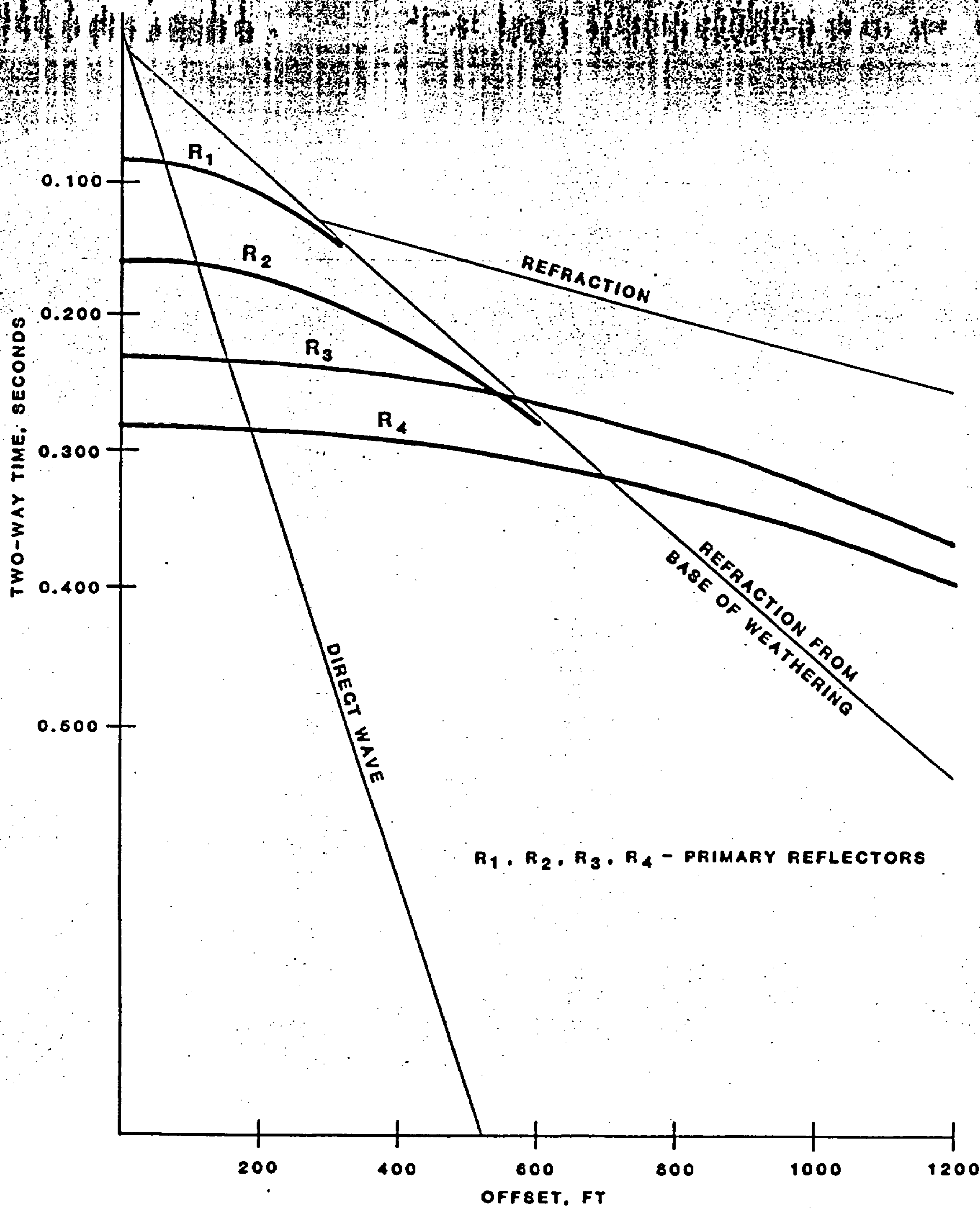

SEISMIC REFLECTION TEST LINE

FIGURE 2a



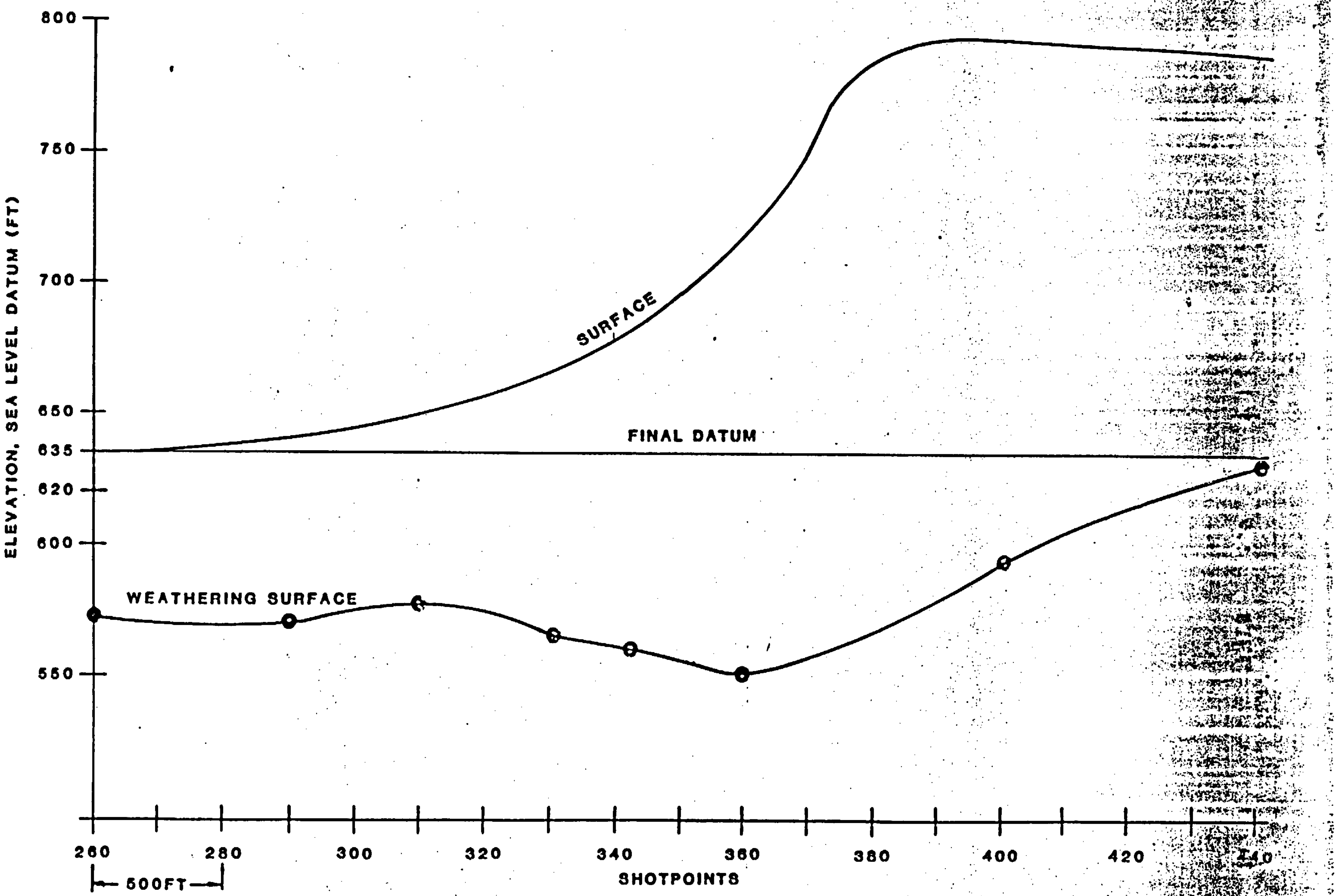

STRATIGRAPHIC NOMENCLATURE,
COLUMBIA RIVER BASALT GROUP,
PASCO BASIN

FIGURE 3




MODEL SEISMIC RECORD,
HANFORD SITE, SOUTH-CENTRAL WASHINGTON

FIGURE 6.




PROFILE OF SEISMIC WEATHERING

FIGURE 7

Originally, the program's objectives were to use high resolution field techniques to map the upper 1000 ft of section at Hanford. The first experiment was the minihole pattern shooting. As it became apparent from the field data that no reflections from the shallowest basalt flow (about 600 ft below the surface) were obtained with this method, Rockwell and WGC agreed to abandon the technique and experiment with conventional shooting.

The buried Primacord* test followed the minihole tests, but was a compromise survey using some conventional field methods and some geometry left over from the minihole survey.

The next test was a long-offset conventional shothole noise walkaway. It was followed immediately by a land airgun (surface source) noise walkaway survey and a series of tests to examine the effects of gun displacement, gun pressure, number of 'pops' per shotpoint, and recording filters on the character of the field records. The airgun production survey was run next.

The conventional shothole survey was run subsequently using long offsets but with a split-spread which spatially undersampled the profile. The purpose of the test was to demonstrate the necessity of recording data outside the envelope of noise, sacrificing the quality of the section.

An additional shothole noise walkaway was recorded using low-frequency receivers. The purpose of the test was to examine the noise envelope over a broader frequency band, and evaluate source and receiver arrays.

## B. SURVEY PARAMETERS

The following equipment was used for the program.

### Recording Instruments

Texas Instruments DFS V configured 56 channels at 1 millisecond sample rate

### Receivers

Mark Products L25E 40 Hz geophones; singles and arrays with 12 elements per string. Mark Products L10E 10 Hz geophones, 18 elements per string

## Ancillary Equipment

Input/Output Multi-source Processor

Shothole Drill

Mobile Drilling B-31 Auger Rig

Primacord Plow

Ditch Witch

Land Airgun

Bolt LSS 6B, 60 and 20 cubic inches

## Minihole test and production field parameters

Forty-nine shotholes 8 to 25 ft deep were drilled for the initial (Part I) testing of charge size, charge pattern, and receiver array dimensions and orientation at the south end of the test line, Line 23. Receiver spreads for the tests were 56 stations on 12.5 ft group spacing for the single 40 Hz geophone spread. Fourteen groups each of 40 Hz arrays, 12 elements per string in crossline, inline and grouped patterns all parallel to the near 14 groups of single geophones made up 56 channels for side-by-side comparisons. Subsurface coverage was 644 ft into the single phone spread and 381 ft into the arrays. Part I test data was recorded June 1, 1985.

### Minihole test spreads

```
   SP                          SP       56 single geophones
   *                           *oooooooooooooo......ooooooooo
station
  101                          125            132.5        153.5

                                oooooooooooooo X-line arrays

                                oooooooooooooo N-line arrays

                                oooooooooooooo Grouped arrays
```

LEGEND

oo geophone stations, 12.5 ft group interval

* shotpoint location

EXPLANATION

X-line array: crossline array with elements planted perpendicular to the seismic line

N-line array: inline array with elements planted parallel to the seismic line

Grouped array: array with elements planted close together

Part II of the minihole test was run at the north end of Line 23 on a gravel bar about 160 ft higher in elevation than the south end of the line. Thirty-six shotholes 8 to 20 ft deep were drilled for this test. Receiver layout was the same as Part I. Several parallel crossline arrays were connected in series to test 24-element arrays. Some shotholes had a water tamp to test coupling. Part II test data was recorded on June 6, 1985.

Recording filters for Parts I and II were 256 Hz hicuts at 70 dB/octave slope, and 60 Hz locuts tested 'out', and at 18 dB/octave and 36dB/octave slopes.

Production parameters were 40 Hz arrays, 12 elements per string in a crossline pattern with 2 ft element spacing and 25 ft group spacing. Shothole spacing was 12.5 ft on and between receiver groups. The spread was symmetrical split, 687.5-12.5-SP(0)-12.5-687.5 ft when shooting between receiver groups, and antisymmetrical split, 700-SP(0)-25-650 ft when shooting on station. Refer to the diagram below. Recording filters were 256 Hz hicuts with 70 dB/octave slope and 60 Hz locuts with 36 dB/octave slope. Charge size was 1/3 lb. Final section is shown on plate LINE 23M.

Minihole production spread

```
                         SP 128.5
                             *
  o o o o o o o o o o o o o o . . . . . . . o o o o o o o o
station              56 X-line arrays
  101                                                    156
```

LEGEND

o o geophone stations, 25 ft group interval

* shotpoint location

EXPLANATION

X-line array: crossline array with elements planted perpendicular to the seismic line

The rationale for the production parameters was that high resolution data would be obtained by maintaining a tight spread, keeping the arrays crossline to minimize filtering along the line while ameliorating any possible scattering, using a small charge, and filtering out low frequency noise with high-valued locut filters. Shooting on and between stations would improve the signal-to-noise ratio of the data through common-depth-point (CDP) stacking.

Minihole production statistics

Minihole production shotholes were nominally 12 ft deep on 12.5 ft centers. There were 644 shotpoints along the line from station 101 to 409. Drilling and recording were completed on June 24, 1985. Average drilling production was 40 shotholes per shift. Average loading and recording production was 129 shotholes per day; the low was 92, the high was 173.

Primacord* test and production field parameters

The Primacord* survey was begun with a configuration test. Receiver spreads were the same as those for the first minihole tests.

Primacord* test spread

```
ooooooooooooooooooo.................oooooooooooooo *****

station              56 single geophones
 221.5                                        242.5         249   274
                                                oooooooooooooo
                                                       X-line arrays
                                                oooooooooooooo
                                                       N-line arrays
                                                oooooooooooooo
                                                       Grouped arrays
```

Lengths of Primacord* varying from 5 to 25 ft buried about 30 inches deep, oriented perpendicular and parallel to the line were fired singly, in pairs and in arrays into first the spread of 56 single phones on 12.5 ft group spacing and then into the side-by-side configuration described above. Several water-tamp lines were tested for improved coupling.

Production parameters included the 40 Hz arrays, 12 elements per string in a crossline pattern with 2 ft element spacing on 25 ft group spacing. A single length of Primacord* 25 ft long was buried parallel to the line with the center of the cord on station. Shotpoint interval was 25 ft. From station 410 to 504, two additional 25 ft lengths were buried parallel to the line alongside the single length at each shotpoint. These two were fired together to increase source energy on the gravel bar. Three production spreads were used to experiment with offsets. From shotpoint 101 to 173, the spread was symmetrically split, 875-200-SP(0)-200-875 ft. From shotpoint 174 to 405, the spread was symmetrically split with an antisymmetric shotpoint gap, 875-375-SP(0)-25-875 ft. From shotpoint 406 to 504, the spread was symmetrically split with a shotpoint gap, 700-25-SP(0)-25-700 ft. Refer to the diagram below for a graphical description of the spreads. Recording filters were 256 Hz hicuts at 70 dB/octave slope and 60 Hz locuts at 18 dB/octave slope. Final section is shown on plate LINE 23P.

## Primacord* production spreads

```
                              SP 138
     o o o o . . . o o o o . . . * . . . o o o o o . . o o o
station              56 X-line arrays
    103                   130              146                  173

                                           SP 175
     o o o o o . . . o o o o o . . . . . . . * o o o . . o o
                     56 X-line arrays
    140                       160                   176         210

                              SP 406
     o o o o o . . . o o o . . o * o . . o o o o o . . o o o
                     56 X-line arrays
   378                           405 407                        434
```

**LEGEND**

o o  geophone stations, 25 ft group interval

*  shotpoint location

Production parameters were chosen to preserve as much of the high resolution field methods as possible. The minimum cord length, crossline arrays, and relatively tight spreads were maintained.

## Primacord* production statistics

The Primacord* survey was begun with a configuration test on June 26, 1985 and production was completed on June 30, 1985. There were 616 shotpoints plowed in; 41 pattern test shotpoints, and 575 production shotpoints. Average production shooting was 144 shotpoints per day; low of 118, high of 196.

## Land airgun test and production field parameters

The land airgun noise and receiver tests were run at both the south and north ends of line 23. Receiver spreads for the airgun tests were conventional for a noise walkaway. Fifty-six single 40 Hz geophones on 12.5 ft centers were shot into from a minimum of 25 ft to the near trace to a maximum of 2750 ft to the near trace. See plate COMPOSITE 23A. Then the 40 Hz arrays with 12 elements per string in an inline pattern 50 ft long on 25 ft group spacing were shot into from a maximum offset of 2000 ft to the near trace to test noise train attenuation.

At the south end of the line all tests were run with 256 Hz hicuts and locuts 'out'. At the north end of the line, only the arrays were shot into with the number of 'pops' per shotpoint varied, 27 Hz and 60 Hz locuts at 18 dB/octave slope tested, and gun pressure varied. A 20 in³ chamber was tested on July 13, 1985 at station 230.

**Land airgun noise walkaway test**

```
                     SP158.5    SP212.5      SP267.5
   56 single phones
   ooooooooo....oooooooo*      *      *      *      *
 station                      SP185        SP240
  130                157.5

                  56 N-line arrays
   o o o o o o o . .  o o o o o      *      *      *
  130                          185
```

Production parameters were shotpoints on 25 ft centers, group spacing 25 ft, array length of 50 ft, and an antisymmetrical split spread, 250--25-SP(0)-25-1150 ft. Gun pressure was 900 psi, chamber size 60 cubic inches. Ten 'pops' per shotpoint on silent running (compressor off, air accumulator charged between shotpoints) were summed in a Multisource Processor (I/O). Field filters were 256 Hz hicuts and 27 Hz locuts at 18 dB/octave slope. Final section is shown on plate LINE 23A.

**Land airgun production spread**

```
                              SP402
   o o o o o o o o o o . . . o o o * o o o o o o o o o o
 station            56 N-line arrays
  356                        401 403                 412
```

**LEGEND**

o o    geophone stations, 25 ft group interval

Production parameters were agreed upon after examining the noise walkaway data (COMPOSITE 23A). Shotpoint interval and group spacing were maintained at 25 ft to preserve as much shallow data as possible, while the spread was altered to an antisymmetric split to achieve long offset on one end. The locut filter was lowered to 27 Hz to increase bandwidth. Arrays were inline to attenuate some of the faster noise trains arriving at 2300 to 2600 ft/s.

## Airgun production statistics

The airgun field configuration tests were run on July 9 and 10, 1985. Production recording began on July 10 and was completed on July 13, 1985, averaging 121 shotpoints per day.

## Shothole test and production field parameters

The shothole noise walkaway survey was run at the south end of line 23. Fifty-six single phones on 12.5 ft centers were shot into from a maximum offset of 2750 ft. Then the 40 Hz arrays were laid out inline on 25 ft group spacing. Array length was 50 ft. Another walkaway was shot with a maximum offset to the near trace of 2063 ft. See plate COMPOSITE 23D. Recording filters were 180 Hz hicuts with 70 dB/octave slope and 27 Hz locuts 'out' for the single phone test and one array test, and 'in' for the final array test at 18 dB/octave slope (COMPOSITE 23D). Shothole depth was 19 ft, charge size 2 lbs.

### Shothole noise walkaway spreads

```
  56 single phones                    SP185    212.5  240  267.5
  ooooooooooo.........oooooooo         * *       *     *      *
station
 130                             157.5
  56 N-line arrays                        SP186
  o o o o o o . . . . o o o o o o o o *      *     *      *
  o o o o o o . . . . o o o o o o o o *      *     *      *
```

**LEGEND**

o o     geophone stations, 25 ft group interval

oo      geophone stations, 12.5 ft group interval

Shothole production field parameters were shotpoints on 50 ft centers, 50 ft inline 40 Hz arrays on 50 ft group spacing, 256 Hz hicut filters at 70 dB/octave slope and 27 Hz locuts with 18 dB/octave slope. Shothole depth was 18 ft, charge size 1 lb. Spread geometry was symmetrical split, 1400-50-SP(0)-50-1400 ft.

### Shothole production spread

```
    56 N-line arrays              SP 380
    o   o   o   o   o  .   .   o   *   o   .   .   o   o
station
   324                         378     382             436
```

**LEGEND**

o  o  geophone stations, 50 ft group interval

Production parameters were chosen after an analysis of the noise walkaway tests was made. Shotpoint and receiver spacing of 50 ft with a symmetrical split spread and shotpoint gap were picked to acquire as much data as possible outside the noise envelope, although at the expense of shallow events. The array length of 50 ft inline was used to attenuate some of the noise trains arriving at 2300 to 2600 ft/sec. The 27 Hz locut filters were used to increase the recording bandwidth. Shothole depth was about 18 ft, and charge size 1 lb. The shothole parameters were judged to be minimum depth and charge for the survey objectives of about 1000 ft. Final section is shown on plate LINE 23D.

### Shothole production statistics

The shothole noise walkaway survey was recorded on July 3, 1985. There were 11 shotpoints. The shothole production line was recorded on July 20, 1985. There were 105 shotpoints.

### Low frequency shothole noise walkaway test

The low frequency shothole noise walkaway test was run at the south end of line 23. Receivers for the test were Mark Products L10E 10 Hz geophone arrays, 18 elements per string. Three sets of 18 arrays were arranged parallel to the test line on 17.5 ft centers. Set 1 was grouped arrays at each of the 18 stations, Set 2 was 35 ft long arrays with 17.5 ft group interval, and Set 3 was 70 ft long arrays with 17.5 ft group interval. Maximum offset to the near trace was 2400 ft. There were 81 shotholes 19 ft deep arranged in patterns of 5, 3 and 1 at each of 9 shotpoints. Pattern holes were inline on 5 ft centers. Charge size was 1/2 lb per shothole. A noise walkaway display is shown on plate COMPOSITE 23K. See the diagram of the test spread below.

Low frequency shothole noise walkaway test spread

```
18 grouped arrays                         SP157     +600   +2400'
o o o o o o o o o o o o o o o o o o *....*....*...  ...*

18 N-line arrays, 35' array length
o o o o o o o o o o o o o o o o o o

18 N-line arrays, 70' array length
o o o o o o o o o o o o o o o o o o
```

LEGEND

O O — geophone stations, 17.5 ft intervals

* — shotpoint locations, every 300 ft from SP157 to 157+2400 ft

EXPLANATION

N-line array: inline array with elements planted parallel to the seismic line

The field parameters were selected to show the response of low frequency geophones at the Hanford Site.

## IV. DATA PROCESSING

### A. INTRODUCTION

The following standard data processing steps were used on all the production data acquired during the program.

1. Demultiplex
2. Spherical divergence correction
3. Trace editing
4. Datum statics
5. CDP gather
6. Mute
7. Preliminary velocity analysis
8. Brute stack
9. Residual statics correction
10. Final velocity analysis
11. Normal moveout correction
12. AGC normalization
13. Stack
14. Filter
15. Trace Equalization
16. Decon Test
17. F-k tests

Processing of the minihole data (23M) and the Primacord* data (23P) was done at the direction of Rockwell. Rockwell also directed the original processing of the airgun data (23A) and the shothole data (23D) to expedite an option to continue seismic work at the Hanford Site. The processing of these lines was done at 1 ms sample rate.

Final processing of the shothole data (23D) and reprocessing of the airgun data (23A) was done at the direction of Walker Geophysical. The processing of these two lines was done at 2 ms sample rate.

B. Processing analyses and results

Line 23M

Line 23M, the minihole production line, was processed in the sequence shown on plate 23M. Deconvolution filter tests were run, but did not improve the stack. These test displays, and amplitude spectra showing the bandpass of the data is in the data package under the heading 23M.

The final stacking velocities reveal some of the problems with the quality of the section. They are too slow at two-way times later than 100 milliseconds, suggesting that they are nearer shear wave velocities which are 1/2 to 1/3 P-wave velocities (Lash, 1980, 1985). In poorly consolidated rocks, Poisson's ratio may be as high as 0.45. Compare the velocity panels of 23M to 23D.

The datum statics replacement velocity of 2000 ft/s used may actually vary as much as 900 ft/s or 45%. The values for variable replacement velocities used on 23D and 23A were calculated from the field records of Line 23D. The results are shown in Figure 7.

Finally, the data was not properly muted to eliminate the envelope of noise. The effect of a proper mute is shown in the comparison between the original airgun stack (23A original) and the final airgun stack, Line 23A.

Line 23P

Line 23P, the Primacord* production line, was processed in the sequence shown on plate 23P. The same tests used on the minihole data were run on 23P, but no improvement was noted. These test displays may be found in the data package under the heading 23P.

All the processing parameters including velocity, datum statics and muting were exactly the same as those used for Line 23M. Refer to the critique on 23M.

The double shots at the north end of the line were included in the data proceessing.

## Line 23A

Line 23A, the airgun production line, was processed in the sequence shown on plate 23A. The preliminary section shown in the data package under the heading 23A Version 1 was processed exactly the same as Lines 23M and 23P.

A composite of the airgun noise walkaway test is shown on plate COMPOSITE 23A. Refraction and surgical mutes were designed to respectively eliminate refracted events and the noise envelope lying between about 800 ft/s and 2500 ft/s.

Datum statics replacement velocities used were calculated from the profile of weathering shown in Figure 7.

Final velocities for the restacked section were based on velocities selected from Line 23D. Further improvement could be effected on the final stack with more detailed velocity analysis over the portions of the line that extend beyond the limits of 23D, but more reprocessing would require a separate budget.

The improvement over the original stack was made through a combination of three steps; (1) the mutes, (2) the datum statics, and (3) the choice of stacking velocities.

## Line 23D

Line 23D, the shothole production line, was processed in the sequence shown on plate 23D. F-k filter tests were run, but no improvement to the data was apparent. The test displays are in the data package. The analyses that led up to the key choices for datum statics, mute patterns and stacking velocities to obtain a satisfactory brute stack were based on field record refraction picks, the noise walkaway data, and elementary modeling.

First arrivals were picked on every fifth record along the 23D profile. Depth of weathering was calculated and plotted in Figure 7.

Refraction and surgical mute patterns were constructed from the noise walkaway profile, COMPOSITE 23D. The mutes were applied to each shot record individually. First guess stacking velocities were used to apply moveout corrections to the walkaway to confirm the identification of events on the composite. The results are shown on plate COMPOSITE 23D(NMO). The refractions curve upward, reflections are flattened and the direct arrivals remain unchanged. The surgical mute was designed to remove all data arriving at 800 to 2500 ft/s.

The elementary seismic record model in Figure 6 was made with velocities to match events on COMPOSITE 23D. The envelope of noise lying between direct arrivals and the refraction from the base of weathering overrides the hyperbolic expression of shallow events. Stacking velocities are very slow, and critical distances are short early in the section. Events below 150 milliseconds are best seen as wide-angle reflections which can easily mislead the interpreter if there is mode conversion from P-waves to S-waves at long offsets (Lash, 1980,1983; Tatham et al, 1984; Zoeppritz, 1919). The refraction mute pattern was chosen to minimize the possibility of admitting mode-converted waves to the stack by attempting to limit the stack to data recorded at angles of incidence less than 35 degrees. Full fold, 2800%, was obtained at two-way time greater than 500 ms due to the mutes.

Final velocity analysis concentrated on the first 300 milliseconds of data. Velocity panels are shown on plate Line 23D. The data was sensitive to small changes in velocity on the order of a few hundreds of feet per second. Although the magnitude was small, the percentage change was significant due to the low velocities.

## V. INTERPRETATION

### A. INTRODUCTION

Interpretation of Line 23M is limited to the upper 100 milliseconds of the section. Lines 23A and 23D contain deeper events down to the Elephant Mt. basalt near 240 milliseconds and some unidentified reflections below. Line 23P has no continuous reflections to be interpreted.

### B. STRUCTURE AND STRATIGRAPHY

## Line 23M

The event colored in on plate Line 23M at approximately 95 milliseconds beginning at shotpoint 104 is interpreted to be the contact between the base of the Upper Ringold and the top of the Middle Ringold. The event can be traced to shotpoint 356 where the continuity disappears. The apparent dip on the contact beyond shotpoint 280 is probably unreliable because the datum statics correction was based on a constant replacement velocity of 2000 ft/s, but shown on Line 23D to be quite variable.

## Line 23A

Groupings of formations into sequences clarify the interpretation of the section by allowing the viewer to look first at gross features (major unconformities), then examine some detail within the groups (lithofacies). The sequence boundaries (yellow-blue, blue-red, red-green, and green-uncolored) are recognized by their amplitude and coherence, marking them as major unconformities. The zone colored yellow on plate Line 23A is interpreted as the contact between the top of the Elephant Mt. basalt and the bottom of the Basal Ringold. The blue zone above is the Lower and Basal Ringold formations. The Upper and Middle Ringold formations are colored red. The contact between the Upper Ringold and the Plio-Pleistocene unit is shown in green. The Hanford Formation/Plio-Pleistocene contact is uncolored and lies above the green line.

The top of the basalt has an apparent dip to the south along the line of about 30 milliseconds over 2 miles. Using an average velocity of 5200 ft/s obtained from the rms velocities on the section, we calculate the apparent dip to be roughly 40 ft/mi.

There are no discontinuities in the flow top, but a number of small irregularities along the profile deserve comment:

Between stations 258 and 328, the top of basalt appears to be in a depression suggesting a paleochannel. Within the Lower and Basal Ringold formations (blue) above this feature, there are discontinuous reflectors suggesting pinchouts and facies changes to be expected with channeling.

The high at station 418 is most likely an artifact of data processing where datum statics were inaccurate.

Low amplitude events between stations 370 and 400 above the top of basalt may be caused by inaccurate stacking velocity. The abrupt change in topography and in near-surface geology in this area accounts for the inconstant velocity.

The Lower and Basal Ringold (blue) shows a thickening over the interpreted paleochannel between stations 258 and 328. A reflector dipping to the south (crossing the 200 ms timing line at station 310) pinches out at station 258 within the Basal Ringold and may mark the top of a channel fill deposit. Similarly, two reflectors truncate at station 205 against the same reflector within the Basal Ringold.

The contact between the Lower and Middle Ringold (blue-red) is generally well-defined on the section, clearly suggesting an unconformity.

The contact between the Upper Ringold and the Plio-Pleistocene (red-green) on the other hand is not very well-defined. The probable causes are insufficient stacking velocity control and low fold (400% at 100 ms).

The Middle/Upper Ringold sequence thickens southward, picking up another reflector near station 300. The watertable may be the good reflector seen at 130 ms near station 310, continuous south to station 180 and traceable to the north end of the line.

The contact between the Plio-Pleistocene and the Hanford Formation (green-uncolored) is fair to poor, again due to insufficient stacking velocity control and low fold. Within the Hanford Formation, sequences of reflectors from stations 345 to 380 lie unconformably on the upper part of the Plio-Pleistocene.

In summary, the Elephant Mt. Basalt is present all along the test line and has an apparent dip of 40 ft/mi. A channel ran over the flow between stations 258 and 328, and fill deposits of the Basal Ringold lie unconformably on the basalt. Events within the mapping horizons (blue and red) show local unconformities, thickening and pinchouts. The sequence boundaries (yellow-blue, blue-red, red-green, and green-uncolored) are recognized by their amplitude and coherence, marking them as major unconformities.

Critique

An attempt to interpret the section using time-stratigraphic relations resulted in miscorrelation of lithofacies (jumped a leg). Specifically, when trying to maintain the time-sequence of events between the Plio-Pleistocene and the Elephant Mt. Basalt, this interpreter forced a leg jump at station 328. The section was reinterpreted by mapping sequences of "regional" unconformities, and the results are defensible.

Line 23D

The zone colored yellow on plate Line 23D is interpreted as the contact between the top of the Elephant Mt. basalt and the bottom of the Basal Ringold. The blue zone above is the Lower and Basal Ringold formations. The Upper and Middle Ringold formations are colored red. The contact between the Upper Ringold and the Plio-Pleistocene unit is shown in green. The Hanford Formation/Plio-Pleistocene contact is uncolored and lies above the green line.

The narrow-band, low frequency data does not easily reveal any significant information. From station 390 to 480, the top of basalt is poorly defined, and minor relief can be interpreted, but with little confidence. Events below the basalt are seen between stations 250 and 330. In comparison with the airgun data, there is not enough resolution to separate out stratigraphic events such as pinchouts. The data was instrumental in demonstrating the need for longer offset, establishing the range of stacking velocities for the first 300 milliseconds at Hanford, and characterizing Hanford for future seismic surveying.

Critique

The shothole data is bandlimited by attenuation, noise, and offset. In general, dry, unconsolidated overburden will attenuate high frequencies severly. The watertable along the test line is about 165 to 320 ft below the surface, so there is a long travelpath through lossy material.

Noise in the form of destructive interference (viz. Ghosting, Appendix) from deep shotholes in loose, dry sand and gravel bandlimit the data at frequencies inversely proportional to the uphole time ( $f \propto 1/2*t_{uh}$). Noise trains shown in the COMPOSITE plates override reflection data, and by far outweigh all other shotnoise.

The source wavelet at wide angles of incidence is stretched. Consequently, at the long offsets used on the shothole survey, the wavelet is lower frequency than desirable and contributed to the bandlimiting of the data.

## VI Conclusion

Analyses of the noise spreads and experimental work show that no high resolution data was acquired due to attenuation of high frequency signals both in a thick weathering layer and in poorly consolidated strata below.

Reflections from the top of the Elephant Mt. basalt and overlying formations were recorded on the shothole and airgun tests where the data was acquired in a narrow, long-offset window outside the envelope of noise which contained a suite of low frequency direct arrivals, groundroll, and refracted arrivals.

Quality of the airgun data was better than that of the long-offset shothole. Simple stratigraphic features could be interpreted on the airgun section while the low frequency, narrow-band shothole data precluded identifying any significant structural, or stratigraphic features other than the basalt horizon.

The land airgun is the most promising seismic source tested at the Hanford Site. Used with 96 channels recording from one geophone per trace at a 2 millisecond sample rate, the airgun could economically produce good quality sections.

## VII Recommendations

All programs should begin with a VSP (and VSP walkaway), and follow with a standard noise walkaway.

Production parameters should be changed to 96 channels at 2 millisecond sample rate. Due to the severe high frequency attenuation at the Hanford Site, I recommend that hicut filters be lowered to 180 or 128 Hz while the locuts remain near, but not equal to the natural frequency of the phones. This will improve the signal-to-noise ratio. Since the noise trains at Hanford are exceptionally dispersive, I recommend also the use of single phones per group. No significant noise cancellation was achieved during the 1985 tests with arrays of any dimension, nor was any inline or crossline scattering observed. Offset to the far trace should range to less than 150% of the depth of the target to guard against recording mode-converted waves (Lash, 1980,1985; Tatham et al, 1984; Zoeppritz, 1919).

The most economical source tested was the land airgun. Either the Betsy seisgun or dynamite refraction surveys would have to be run in conjunction with the land airgun source to provide weathering data for processing.

The data processing timetable should allow for the extra amount of analytical work needed to produce interpretable sections from Hanford. Particular attention should be given to processing and interpreting the noise walkaway before establishing the production field parameters. Production data should go through a set of "pre-processing" steps including hand (datum) statics from refraction data, $x^2$,$T^2$ plots, trace editing, and muting before running a brute stack..

## VIII. Bibliography

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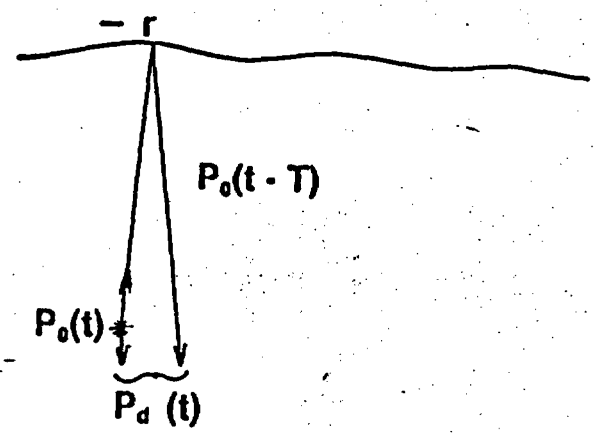
## Appendix II

### Ghosting

Attenuation by ghosting notches out the source signature amplitude spectrum at frequencies related to shot depth. Seismic waves radiate spherically from the shot at detonation. Those waves which travel upwards are reflected back down by a nearby reflector such as the Earth's surface. They sum constructively and destructively with the downward going signal that originated at the shotpoint augmenting and notching the source signature amplitude at some fundamental frequency and its harmonics. Shallow shotholes reduce the effects of ghosting by pushing the fundamental notch out to higher frequencies, broadening the amplitude spectrum.




If the traveltime for seismic waves from the source, $p_o(t)$, upwards to a reflector with reflection coefficient $-r$, and back to the source is T, the downgoing signal $p_d(t)$ will be given by

$$p_d(t) = p_o(t) - rp_o(t-T) \qquad (1)$$

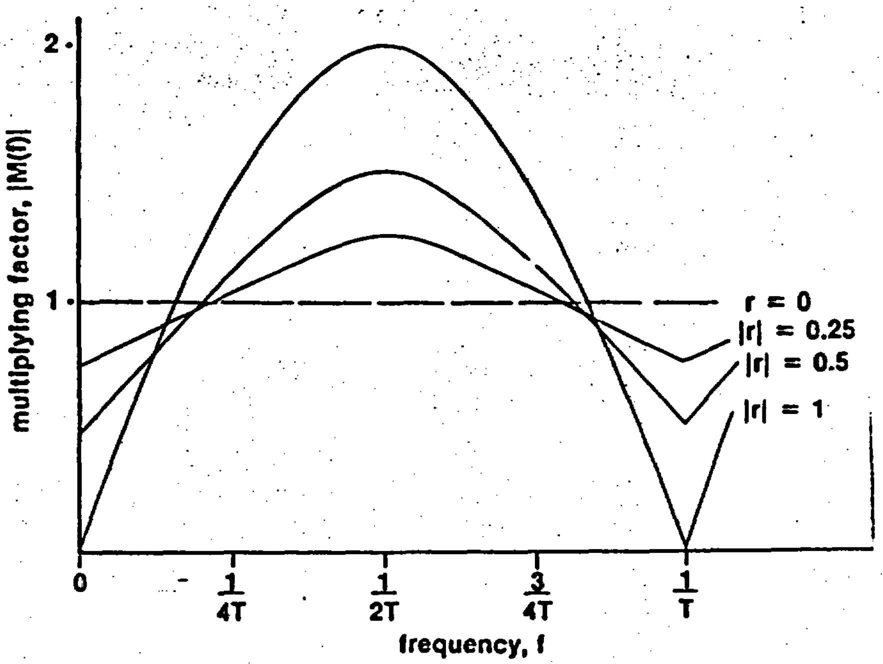
Its Fourier transform is

$$P_d(f) = P_o(f)[1-re^{-i2\pi fT}] \qquad (2)$$

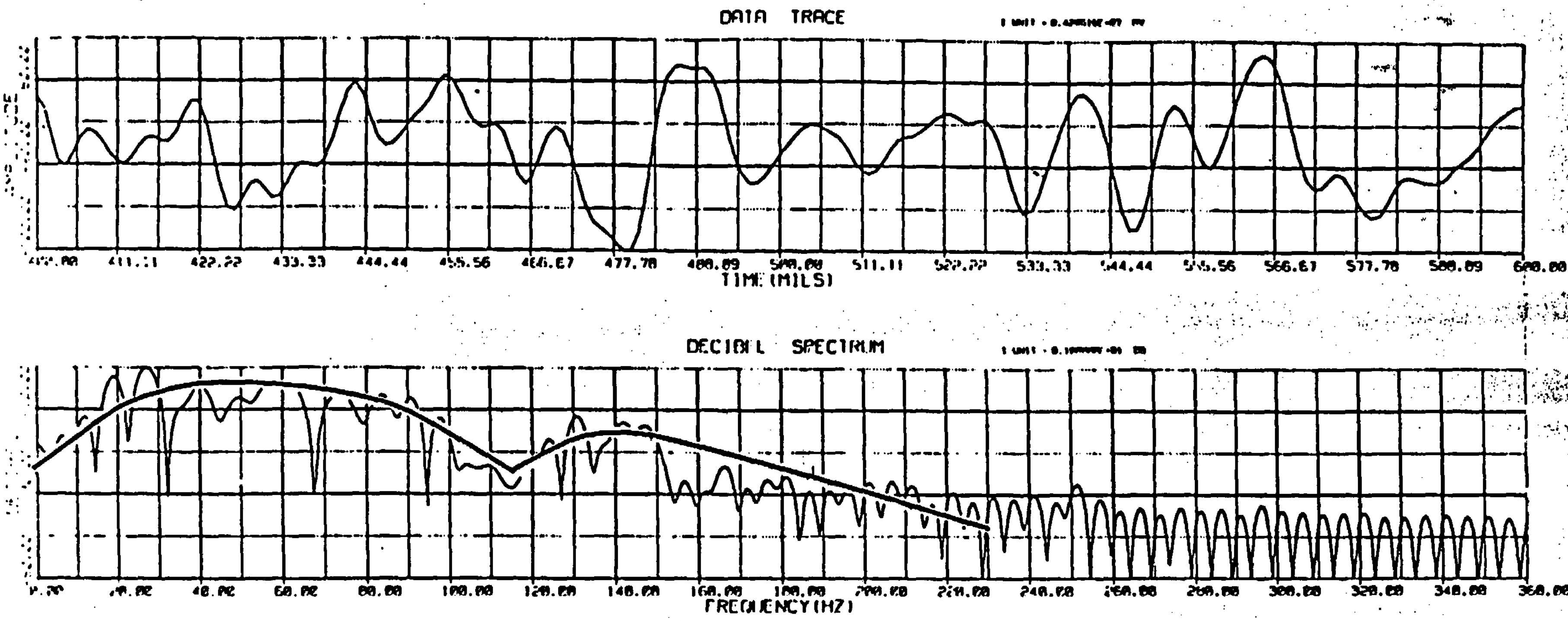
Rewriting (2),

$$P_d(f) = P_o(f)*M(f) \qquad (3)$$

Plotting M(f) for |r| = 1, 0.5, 0.25, and 0;




The plot shows that for large values of |r|, a nearby reflector affects the shape of the source signal spectrum. If the source is wideband, the spectrum near 1/T and its harmonics is severely attenuated. If T can be controlled (through shothole depth), the source spectrum can be augmented between 1/4T and 3/4T, (Walker, 1983).




The ghosting phenomenon bandlimits seismic data as shown in this amplitude spectrum of a trace from data acquired with 1/3rd pound dynamite. At detonation, seismic waves radiate spherically from the shot. Some of the waves which traveled upwards are reflected back down by a nearby reflector such as the earth's surface and they sum constructively and destructively with the downward going signal that originated at the shotpoint. At 114Hz, destructive interference has brought the amplitude down -30dB. The spectrum repeats itself and is about 40dB down at its first harmonic, 228Hz. Notches or ghosts occur also at 32Hz and its harmonics at 64Hz, 96Hz, and 128Hz. The dominant, high frequency ghost at 114Hz originates at the base of weathering, a low-velocity near-surface zone of severe attenuation just below which the shot is placed. The secondary, narrowband ghost at 32Hz and its harmonics are caused by ghosting from the ground surface, their fundamental frequency corresponding to uphole time, the traveltime of seismic waves from shotpoint to surface.

# Appendix II

## Data Package

## Data Package Contents

Line 23M

Shot displays: 101-222,223-315,316-350,89-127/AGC100
Production shots w/AGC
Production shots w/ no AGC
Field records
Spectrum analysis
First arrival picks
NMO gathers
Preliminary Velfans
Velfans: final; final with residual statics
Decon tests: no filter, no balance, after stack, with balance, with 51 pt
CDP gathers
Brute stacks: after Vstack, revised, 140-256
Mute tests
CVA's
Vstacked shots
Autocorrelation CDP 542
Stacks: every other CDP; final through CDP 1347; merged conventional; conventional; residual statics; with 60/180 filters; with refraction statics; with autostatics, filter and balance after stack; coherency
Filter tests
Composites; AGC 100;FFID 53,56,57,59
Residual statics: end of line; ASTAT;BSTAT

Line 23P

Field records
Velfans
CDP gathers
Demux FFID 755-795
Filter test
Decon test: nofilter, no balance
Brute stack
Final stack: residual statics

## Data Package Contents

**Line 23A**

Field records
Auxillary Demux
Spectrum analysis
Decon test: no filter, no balance; after stack
CDP gathers: w/residual statics; w/o residual statics
Composites: 1500 psi, 27 Hz locut; 900 psi, no locut; 900 psi, 27 Hz locut; 1500 psi, no locut; 1500 psi, 60 Hz locut.
Filter tests: CDP's 411-450; 850-889
Displays: every 25th shotpoint w/constant shift; shots
Velfans
Stacks: original residual; original residual w/higher velocities; original brute; new brute w/A filter; new brute w/D filter; new residuals; new velocities; static T; residual stack w/40 /18-85/18 filter; final stack.
Composite

**Line 23D**

Composite
Composite with NMO
Field records: scaled; w/mutes;
CVA's: after mutes; 275-295
CDP gathers: 275-295
Stacks: brute w/mutes, old and new velocities; w/100 Hz hicut; original and new residual statics; final
Mute test

**Line 23K**

Composite: 60 Hz locut; NMO, mute, AGC 200; 27Hz locut; locut out; locut w/18dB/oct slope
Field records

**Line 23**

Field elevations w/surveyor's notes