Geologic Characterization Report

Appendix E

GEOLOGIC CHARACTERIZATION REPORT

APPENDIX E

SEISMIC DATA REPROCESSING

EBASCO SERVICES

For U.S. DOE-Rocky Flats Plant

July 31, 1991

EG&G ROCKY FLATS

SEISMIC DATA REPROCESSING

CONTRACT DEAC04-87AL32896
TASK 536948PB

FINAL REPORT
November 30, 1989

Prepared by:
EBASCO SERVICES INCORPORATED

For:
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DENVER, COLORADO

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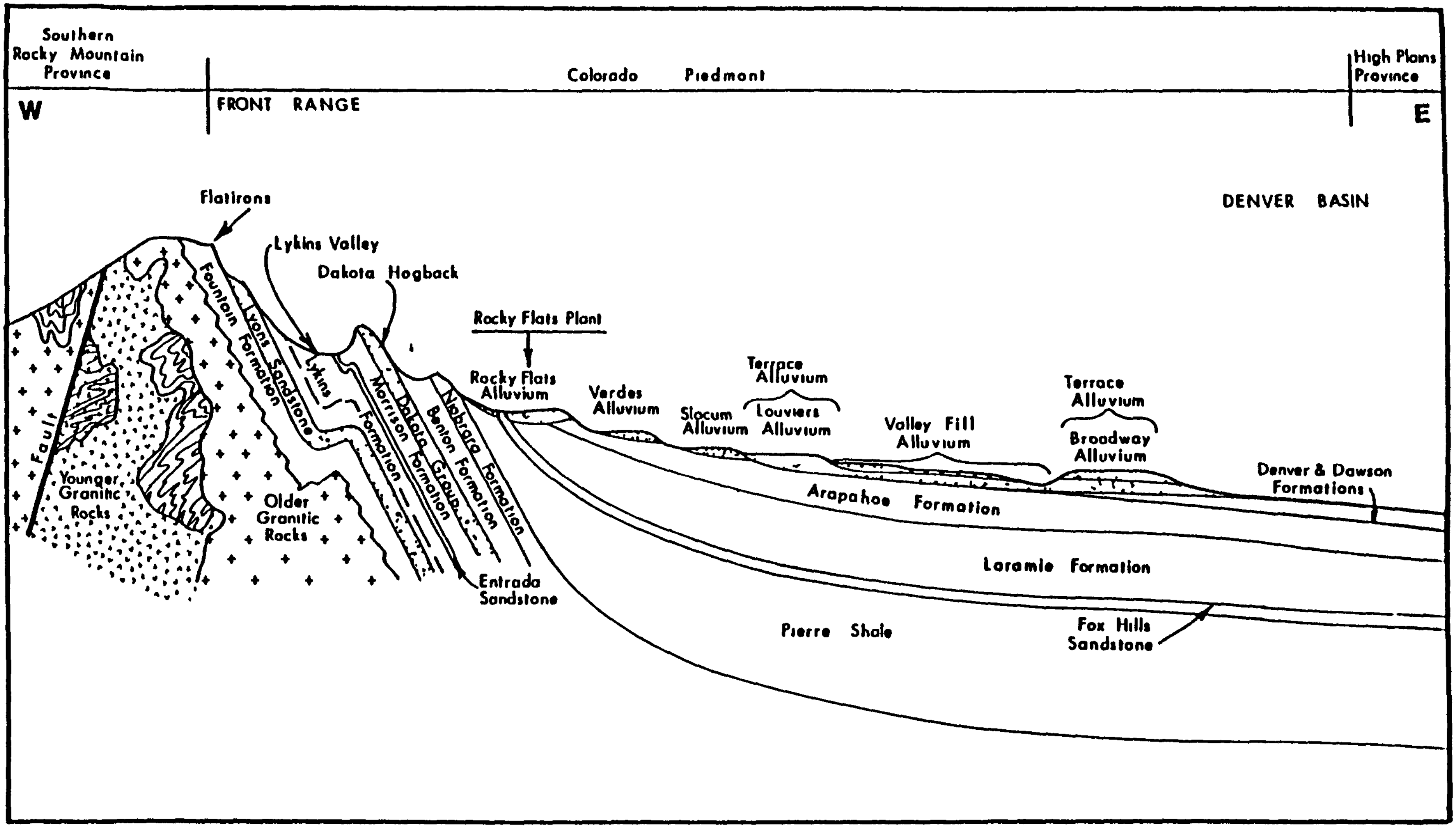
1.0 INTRODUCTION

Ebasco Services was contracted to reprocess approximately 13 miles of seismic data in an attempt to characterize the hydrogeology of the Rocky Flats Plant. The primary objective of the seismic reprocessing was to enhance the shallow data, which will provide more accurate information on the hydrogeological parameters affecting the Rocky Flats Plant. The reprocessed seismic data will be integrated with the geologic data obtained from drill hole cores. Reprocessed seismic data will also be compared to, and where possible integrated with, the shallow high resolution reflection data obtained by EBASCO within the Rocky Flats Plant boundaries (Rockwell, 1989).

Surficial materials at the Rocky Flats Plant consist of the Rocky Flats Alluvium, which is a poorly sorted Quaternary deposit of cobbles, pebbles, and gravel in a sandy clay matrix, ranging in thickness from 3 to 45 feet (ft). The Rocky Flats Alluvium is an important factor in controlling near-surface groundwater flow. Bedrock at the Rocky Flats Plant consists of the Cretaceous Arapahoe Formation (Weimer, 1973), which is comprised of complex fluvial/deltaic claystones with interbedded sandstones and siltstones. The Cretaceous Laramie Formation underlies the Arapahoe, and is considered bedrock where the Arapahoe Formation is not present (Spencer, 1961). The Laramie Formation is comprised of brackish and fresh water claystones, lenticular sandstones, and coal beds (Spencer, 1961). Stratigraphic and structural features present in the Arapahoe and/or Laramie Formation may influence the movement of groundwater from the Rocky Flats Plant. A generalized cross-section of the Front Range is presented in Figure 1.

The seismic data to be reprocessed was obtained by EBASCO from the Colorado School of Mines (CSM). The field data was acquired in 1975-76 under the direction of Dr. Tom Davis, who conducted the program to determine the nature of the Golden Fault Zone in the Vicinity of the Rocky Flats Plant (Davis, 1976). The results of the reprocessed seismic data are presented in this report.



(after: Boulder County Planning Commission, 1983 and Scott, 1960)

Not To Scale

Figure 1
Generalized East-West Cross Section
Front Range to Denver Basin

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2.0 1975-76 CSM SEISMIC PROJECT

2.1 DATA ACQUISITION

The Vibroseis* system of data acquisition was utilized by CSM. Field data acquisition parameters chosen for the survey consisted of the following:

Frequency	48-8 Hz downsweep (8 seconds)
Channels	24
Group interval	200 or 300 ft
Source interval	400 or 600 ft
Geophones per group	15
Recording period	Variable
Instrument	Texas Instruments Digital Field System (DFS) 10000
Source pattern	27 sweeps over 10 ft

Seismic lines were positioned with reference to a USGS topographic map of the Rocky Flats Plant area (Louisville Quadrangle). No formal topographic surveying procedures were utilized to locate the seismic lines with reference to an existing monument or a specific coordinate system. Vibrating points (VPs) were drawn on the topographic map by CSM geophysicists to represent the line sequence and direction (Figure 2).

2.2 DATA PROCESSING

A copy of an original processing sequence form completed for the CSM Phoenix minicomputer is shown in Figures 3-1 and 3-2. The Phoenix system typified the 'state of the art' seismic data processing technology in the early 1970's. The processing sequence corresponds to seismic line "Pluto I", and is a representative example of the processing conducted on the 1975-76 seismic lines. The processing sequence includes demultiplexing, summing, cross-correlation, and stacking (Davis, 1976). Stacking velocities were obtained by CSM upon examination of the sonic log from the Tom Jordan Marshall Lake Well, located north of the Rocky Flats Plant.

* Trademark of Continental Oil Company

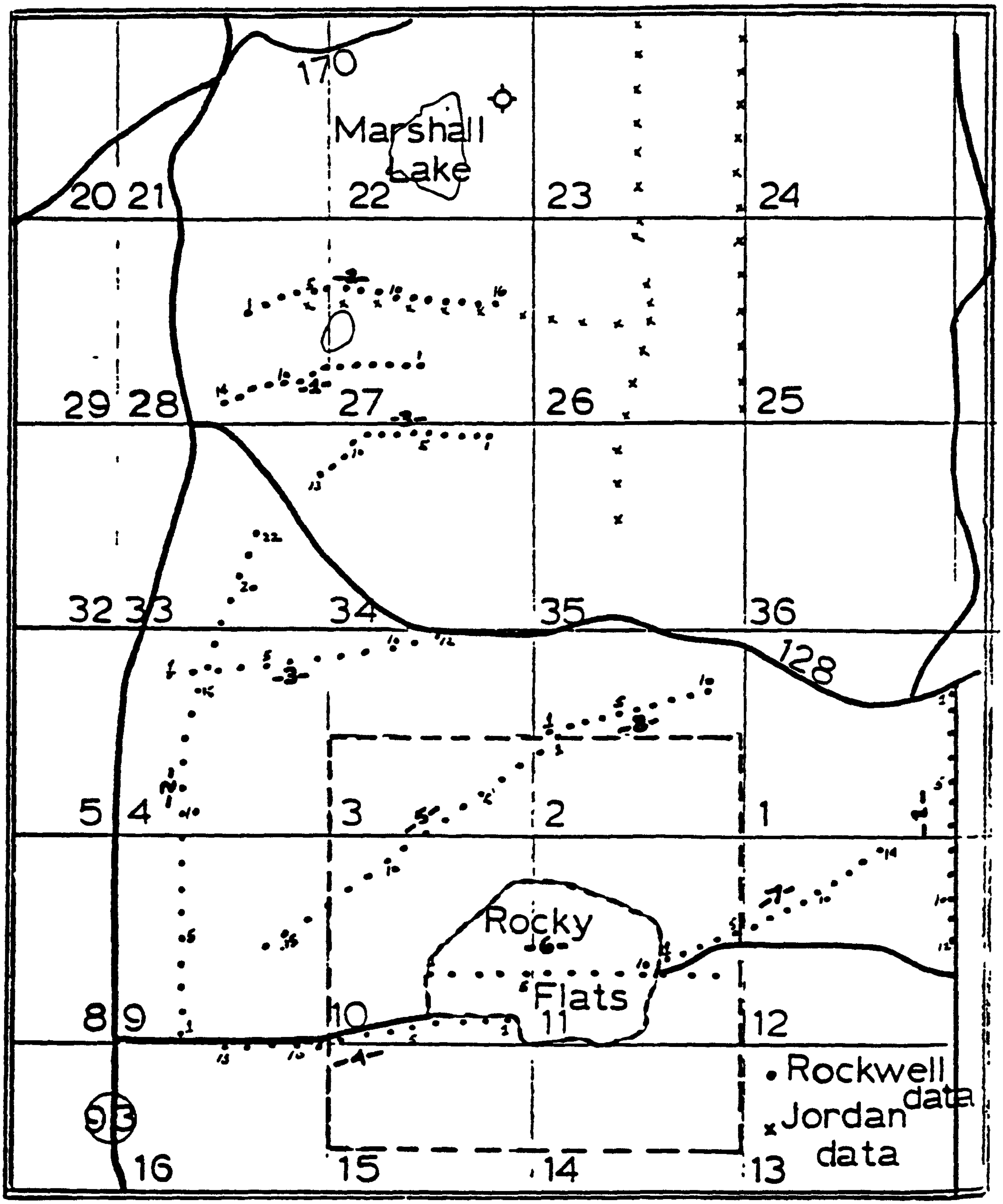


Figure 2
1975-76 CSM Seismic Project Line Location

EBASCO

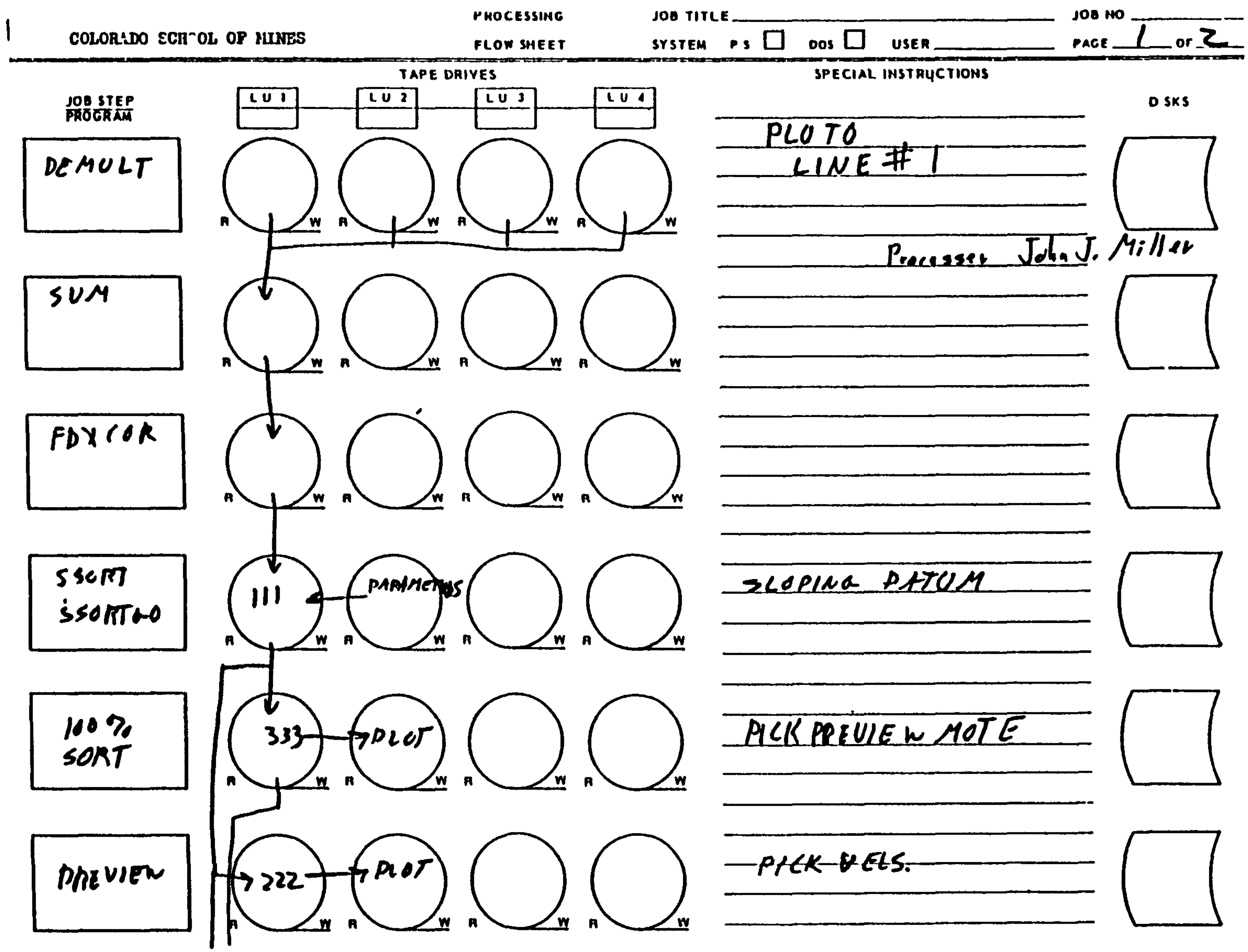


Figure 3-1

1975-76 CSM Seismic Project Data Processing Sequence

EBASCO

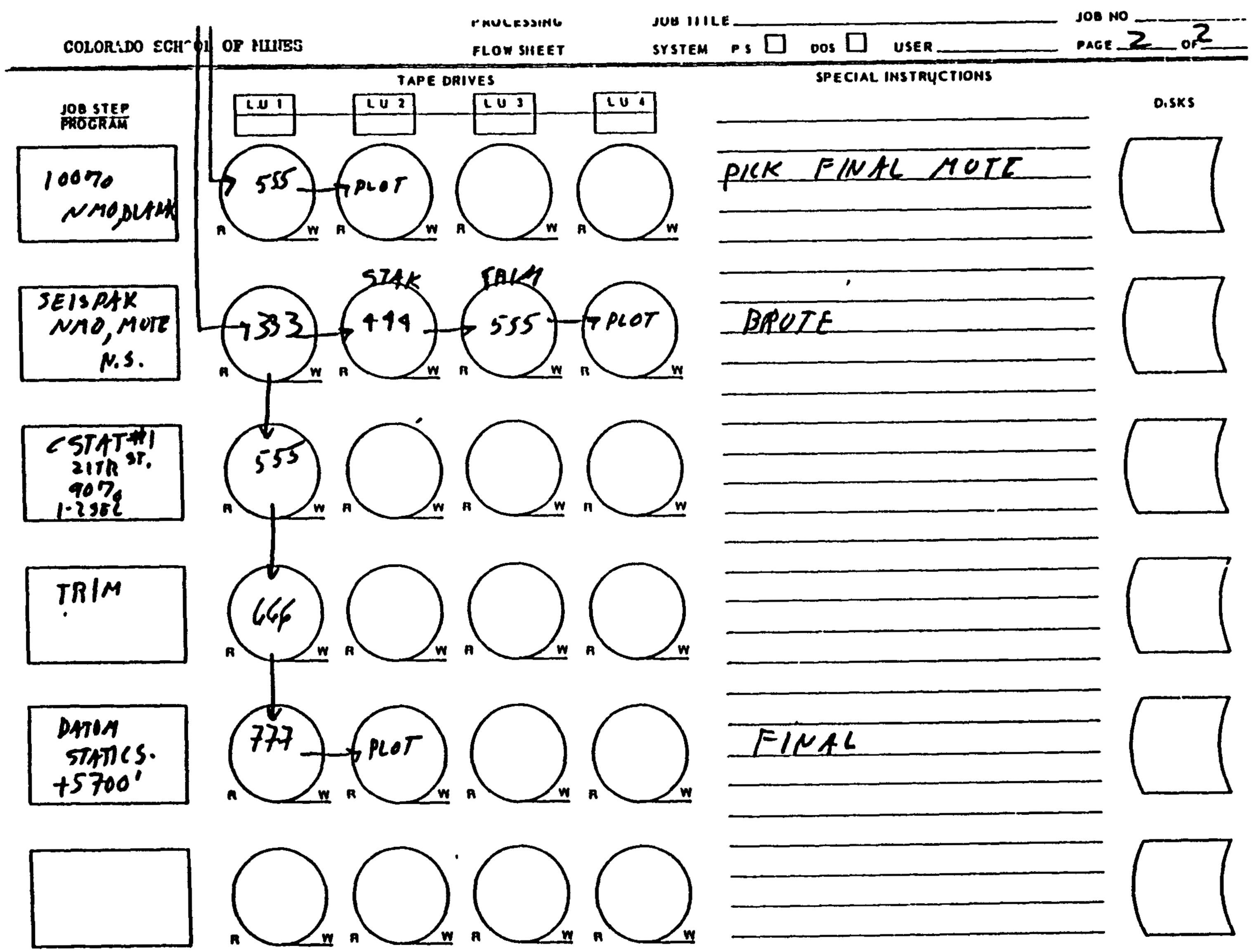


Figure 3-2
1975-76 CSM Seismic Project Data Processing Sequence

EBASCO

2.3 DATA INTERPRETATION

The 1975-76 CSM Seismic Project was reviewed in the report "Rocky Flats Reflection Seismic Project" by T.L. Davis, April 6, 1976. A copy of the report is included in Appendix I. Although each seismic line was not comprehensively reviewed, major geological contacts and interpreted faults were indicated on the seismic sections (Figure 4)

3.0 1989 REPROCESSING PROJECT

3.1 PROCUREMENT OF 1975-76 SEISMIC DATA

The procurement of the 1975-76 CSM Seismic Program data (digital tapes, field records, field notes) did not go as smoothly as anticipated. This was due to several events which were concurrent with the commencement of the reprocessing project:

- o Dr. Tom Davis was unavailable as a source of information
- o 1975-76 CSM Seismic Project Information was limited
- o No field data tapes were available.

In early September 1989, additional relevant data on the 1975-76 CSM Seismic Project (processing sequences, shooting geometries, observer's notes) were presented to EBASCO by Dr. Tom Davis. Although the additional information assisted EBASCO, information was unavailable on the following·

- o Lines 7 and 8 (aka Rocky Flats 2 and Rocky Flats 1): No field data tape(s) or archived data tape(s) was located
- o Lines 3 and 4 (aka Pluto 3 and Pluto 4): No file folders with pertinent data acquisition information were located. Lines 3 and 4 are archived on tape as final sections (there are no sum and cross correlation records).

Considerable time and effort were expended by EBASCO in an attempt to organize, correlate, and evaluate the available 1975-76 CSM Seismic Project data and accompanying information. The scope and time frame of the current reprocessing project did not allow for additional time and effort to be expended on tasks such as information and data tape searches, personal interviews, and general project inquiries. Available information on the 1975-76 CSM Seismic Project was sometimes incomplete and confusing, therefore, the

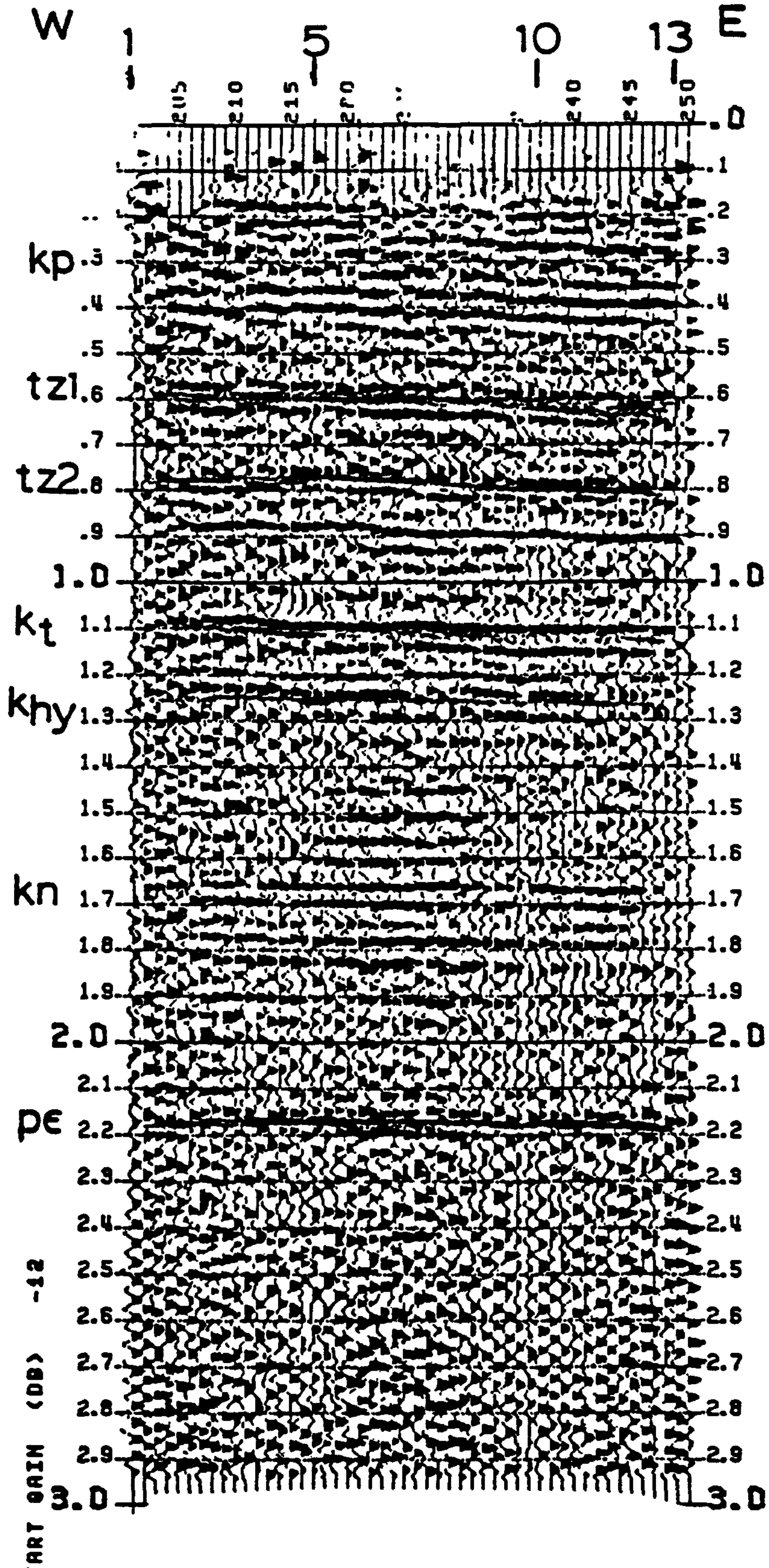


Figure 4
1975-76 Seismic Project
Rocky Flats Line 6

EBASCO

reprocessed seismic sections were interpreted with caution, and should be utilized accordingly. Seismic lines 3, 4, 7, and 8 were not reprocessed due to the lack of available information. The CSM file folders for lines 5 (aka Pluto 5) and 6 (aka Central Avenue) contained adequate shot geometry information, therefore, these seismic lines were reprocessed and the results are presented as part of this report.

3.2 DATA REPROCESSING

The 1975-76 CSM seismic data were reprocessed in an attempt to:

- o Enhance the shallow data for hydrogeological characterization of the Rocky Flats Plant area
- o Integrate the data with the core re-logging project
- o Identify subsurface structure(s) which may be indicative of faulting.

As previously mentioned, lines 5 and 6 were the only seismic lines reprocessed. The reprocessing analyst determined that the first 56 milliseconds (ms) on the archived data tape is masked with header information from the CSM Phoenix processor. Hence, there is no data in this interval. The reprocessing sequence implemented by the data processing center is shown on Plates 1-8

A noise reduction algorithm was used on the seismic data. The 'radon transform' algorithm effectively improves the signal-to-noise ratio of low fold common depth point (CDP) data while preserving reflection characteristics. As CDP fold increases, the radon transform algorithm becomes less of a factor for improving the signal-to-noise ratio.

3 3 REPROCESSED DATA INTERPRETATION

The reprocessed seismic sections are shown on Plates 1-4. Due to the interest in the shallow data, four additional seismic sections were generated, Plates 4-8 represent the 0 to 0.5 second interval of the seismic sections.

3.3.1 Line 5 and 6 Shallow

There are several factors which influence the interpretation of the shallow data:

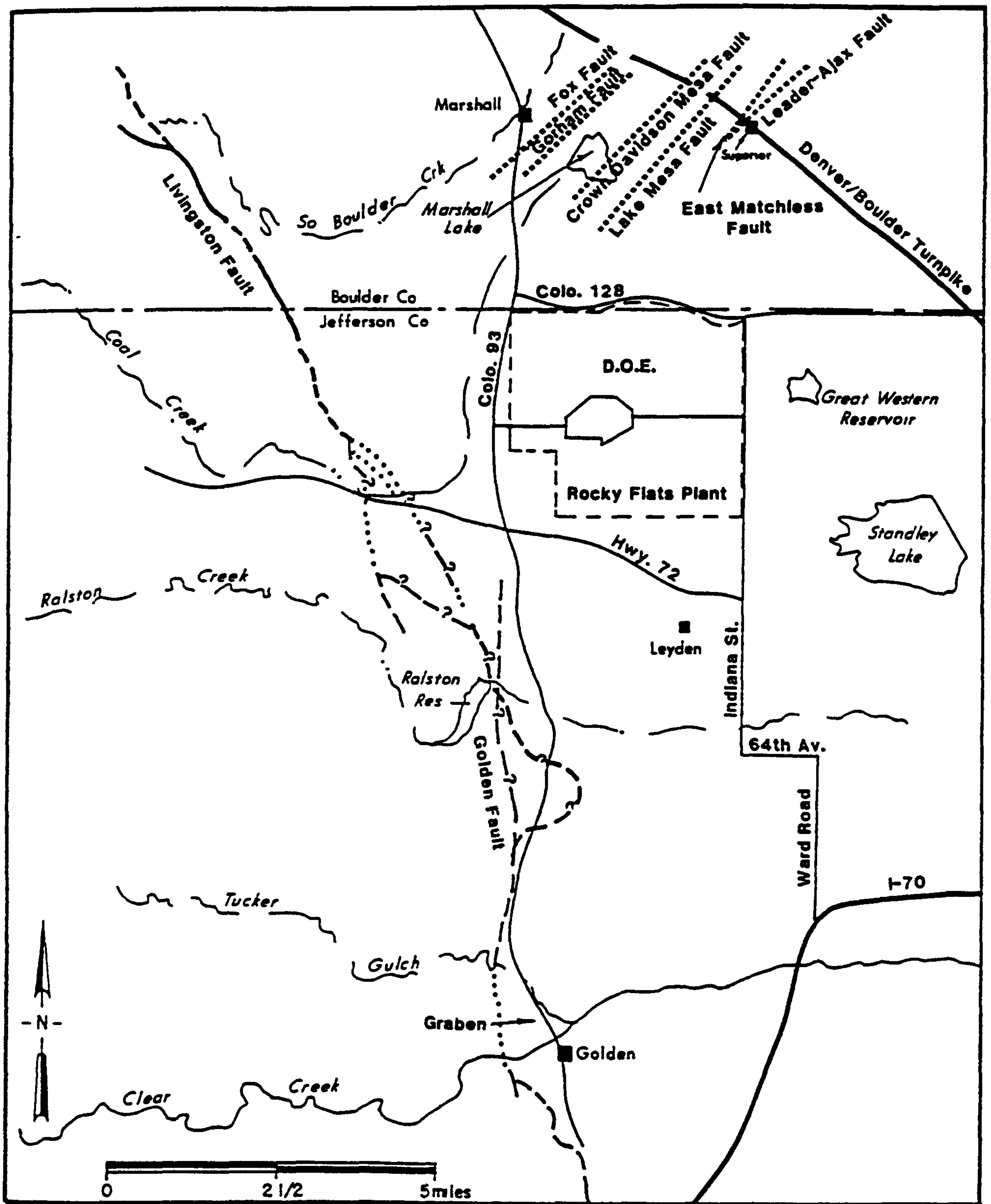
- o The data acquisition parameters for the 1975-76 CSM Seismic Program were chosen to investigate relatively deep (>300 ft) geologic structures
- o The low frequency content of the 1975-76 data are not representative of subtle characteristics in the near surface geology
- o The sampling rate of 4ms for the 1975-76 program is not conducive to optimumly delineating near surface geological features.

Although seismic field acquisition parameters were designed for imaging deeper geologic features, anomalous zones in the lower Laramie Formation may be the seismic expression of a stratigraphic facies change or possible fault zone(s). The results presented by Rockwell (1989) support a possible facies change, and borehole geophysical data near the Rocky Flats Plant may exhibit low angle thrust fault(s) are present near the base of the Laramie Formation. The presence of fault zone(s) is also possible as evidenced by the deeper fault structures on lines 5 and 6

3.3.2 Line 5 and 6 Deep

Deeper seismic reflection events (greater than 0.5 second) indicate a possible fault(s) on lines 5 and 6. A thrust fault emanating at the west end of the seismic section on Line 6 (Plate 1) at 1.13 seconds cuts upward through the upper Cretaceous section and flattens at vibrating point 118. A thrust fault is also present on Line 5 (Plate 3), emanating near vibrating point 114 at 1.18 seconds and diminishing in the upper Cretaceous section near vibrating point 108 at 0 9 seconds. The fault dip angles are 30 to 40 degrees (assuming an average velocity of approximately 7,000-9,000 ft per second). It is difficult to determine the three dimensional character of the interpreted fault system without additional seismic and/or borehole data. Based on our geophysical experience, the faults present on Lines 5 and 6 are part of an interconnected thrust fault system. Ken Kittleson has presented strong evidence in favor of the thrust fault theory in his document entitled "Decollement Faulting in the Northwest Portion of the Denver Basin, Colorado". Several fault locations near the Rocky Flats Plant area are shown in Figure 5.

The thrust fault(s) present on lines 5 and 6 is not clearly defined in the original CSM processing. The absence of the thrust fault(s) is most likely due to differences in processing algorithms for the calculation of statics. The original processing used "trim" statics with a



(after: Van Horn, 1972, Sheridan and others, 1967, Wells, 1967, and Spencer, 1961)

Figure 5

Fault Locations Between Golden and Marshall, Colorado (excluding Eggleston Fault)

EBASCO

deep time gate. This algorithm forces an alignment of coherent reflection events within the gate. The reprocessing sequence used a variety of modern static algorithms including surface consistent statics. These modern methods attempt to calculate static corrections using near surface solutions, thus preserving deeper structural features.

4.0 CONCLUSIONS

The reprocessed seismic data (specifically Line 5; inferred fault between 230 - 280 ms) and borehole geophysical data near the Rocky Flats Plant exhibit characteristics which may be indicative of relatively shallow thrust fault structure(s). These shallow thrust fault structure(s) may affect the morphology of the Cretaceous Laramie and Arapahoe strata, thus creating potential pathways for the downward migration of contaminants into deeper groundwater aquifers.

The deeper thrust fault structure(s) evident on lines 5 and 6 do not appreciably affect the shallow hydrologic system, although they do represent possible evidence thrust fault(s) ocurred in the history of Colorado Front Range geology.

It is recommended that additional seismic reflection data be acqured at the Rocky Flats Plant based upon the reprocessed seismic data. The seismic aquisition parameters should be designed to investigate the 300 - 800 ft depth zone.

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ROCKY FLATS REFLECTION SEISMIC PROJECT

by

T. L. Davis

Department of Geophysics
Colorado School of Mines
Golden, Colorado

Tom Davis

Tom Davis
April 6, 1976

OBJECTIVE

The purpose of this project was to investigate the possible existence of faults in the vicinity of the U.S. Atomic Energy Commission's Rocky Flats Plant.

INVESTIGATION PROCEDURE

During the time interval December 9-28, 1975 and February 1 through April 1, 1976, Rockwell International Inc., operator of the Rocky Flats Plant, contracted and financed the acquisition, processing and interpretation of 15 miles of seismic reflection data in the vicinity of the Rocky Flats Plant. The survey was performed through the Geophysics Fund Inc., under the direction of Tom Davis of the Department of Geophysics of the Colorado School of Mines.

The VIBROSEIS (trademark of Continental Oil Company) system of data acquisition was used throughout the project. The seismic source involved a truck-mounted servo-hydraulic vibrator which was made to sweep at a constant amplitude over a linear range of frequencies during a fixed period of time. Throughout the survey a 48 - 8 Hertz downsweep was used extending over an 8-second duration. Data was recorded for 11 seconds from the time of sweep initiation. The process by which the signal is recovered is similar to that of the chirp radar method. Field records from this seismic source show no discernible reflection information because the seismic pulse is spread over several seconds. The data must be computer cross-correlated with the original sweep of frequencies before reflection information may be viewed. The signal generated by this source was recorded by a 24-channel digital field system DFS-10000. The source pattern at each vibrator point (vp) consisted of 27 sweeps spaced over 10-foot intervals. Distance between source points (vps) varied from line to line but was either 400 or 600 feet. The receiver pattern consisted of 15 geophones stretched over 200 feet. Information during each vibration was recorded by 24 sets of these geophone arrays. The spacing between the geophone groups varied from line to line but was either 200 or 300 feet. Data acquired was processed on the Geophysics Department's Phoenix minicomputer. A standard processing sequence of demultiplexing, summing, cross-correlating, and stacking was performed.

Seismic data was acquired in the general vicinity of the Rocky Flats Plant (lines 1-8) and Eggleston Reservoir north of Highway 128 (lines 1-3) as shown in Figure 1. These lines were located according to topographic considerations with the specific geologic objective in mind. One line traversed the entire extent of the plant (line 6). The ecological advantage of the VIBROSEIS technique was demonstrated throughout the project but most important during the Central Avenue traverse.

INTERPRETATION

Geologically, the Rock Flats Plant is situated as depicted in Figure 2. A stratigraphic column is illustrated in Figure 3. The Rocky Flats (Figures 4-11) and Eggleston (Figures 12-14) seismic lines were interpreted as shown. The data quality facilitated the interpretation. In addition, the seismic data was tied to the Tom Jordan Marshall Lake Well (22-1S-70W) for horizon control and subsurface velocity information. A synthetic seismogram (Figure 15) run from the sonic log in the well enabled a good seismic-well tie. Seismic data made available by Tom Jordan (Davis, 1974) was tied directly to the Rocky Flats data. Two maps (Figures 16 and 17) were prepared on the Top and Base of the Pierre Shale respectively.

The maps and related seismic sections illustrate that two types of fault systems are present in the Rocky Flats area. One fault system is locally restricted to the Upper Pierre Shale and Laramie-Fox Hills sections. It is depositional in nature and related in a growth fault manner documented by Davis (1974) and Weimer (1973). An associated basement-controlled fault system exists on the western and southern extremity of the shallow growth fault system. The basement-controlled fault system localized deposition of the Upper Pierre Shale and Laramie-Fox Hills intervals. Sedimentation rates and thickness accumulations were greatest within the downfaulted graben area to the north of the Rocky Flats Plant. The basement-controlled faults to the west and north of the Rocky Flats Plant exhibit a growth history as well. Displacement at the Niobrara level is approximately 150-200 feet whereas displacement at the Top of the Pierre is in the order of 50-75 feet. The Precambrian basement configuration conforms to the Top of the Niobrara structure map. It is located approximately 4000 feet beneath the Niobrara horizon. Displacements on the basement across the basement-controlled faults appears to be in the order of 300-350 feet. Displacement varies with lateral position on the basement-related faults as well. The north-south fault has more displacement than the northeast trending fault. In addition the north-south trending fault has more displacement in the southern portion of the map area than it has in the north; ie., the fault dies out to the north. The northeast trending fault has more displacement in the southwest and displacement diminishes in a northeasterly direction.

SUMMARY

Interpretation of 15 miles of seismic reflection data in the vicinity of the Rocky Flats Plan reveals:

a. Two distinct but associated fault systems exist in the area. A basement-controlled graben area to the north of the Rocky Flats Plant localized sedimentation in the form of a depocenter throughout Late Cretaceous time. Associated penecontemporaneous growth faulting exists in this graben area. These faults are northeast trending and do not trend into the plant area.

b. The Rocky Flats Plant is located on the stable, upthrown, horst block south of the graben area north of Highway 128. There is no evidence for shallow, penecontemporaneous, growth faults within this basic structural element. The structural block on which the plant is located is flanked one mile to the west and north by two basement-controlled faults which fault the entire sedimentary section. Near-surface displacement on these faults is in the order of 50 feet.

c. No faults exist within the immediate area of the Rocky Flats Plant.

REFERENCES

Davis, T. L., 1974, Seismic investigation of Late Cretaceous faulting along the East Flank of the Central Front Range, Colorado: Ph.D. Thesis 1681, Colorado School of Mines

Weimer, R. J., 1973, A guide to Uppermost Cretaceous stratigraphy, Central Front Range, Colorado: deltaic sedimentation, growth faulting, and Early Laramide crustal movement: Mtn. Geologist, v. 10, no. 3, p. 53-97

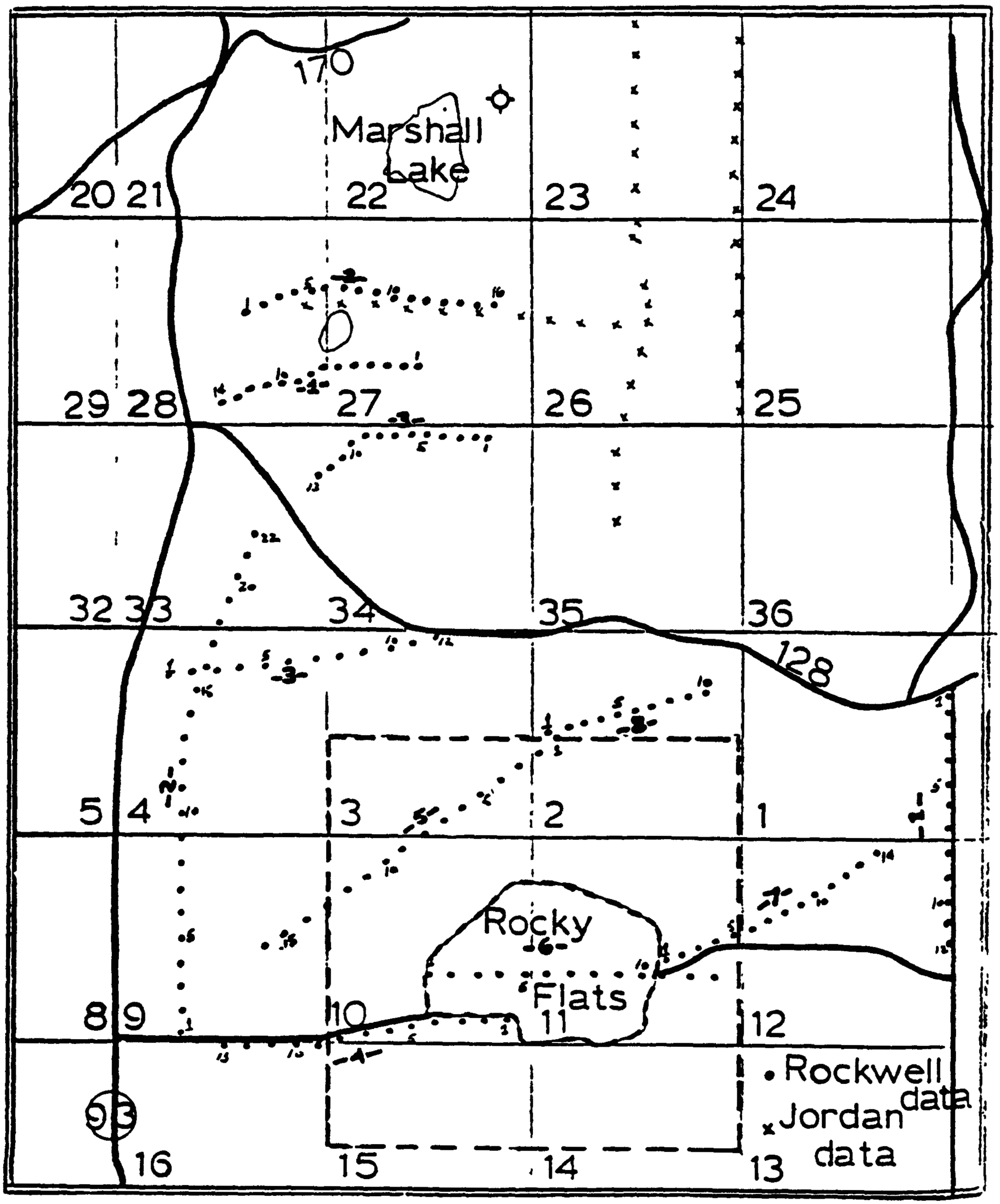


FIGURE 1. Seismic line location map

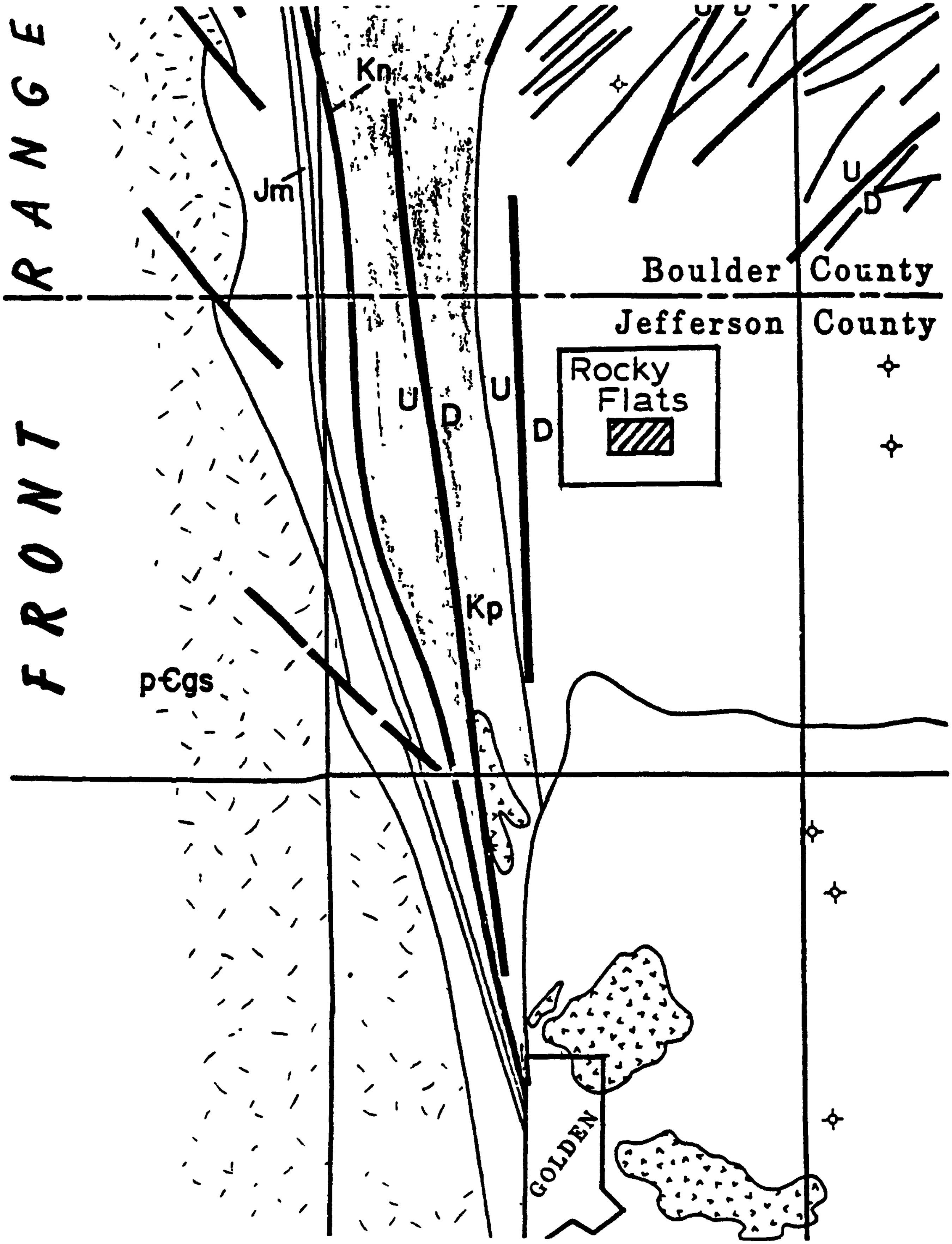


FIGURE 2. Tectonic map of Rocky Flats area

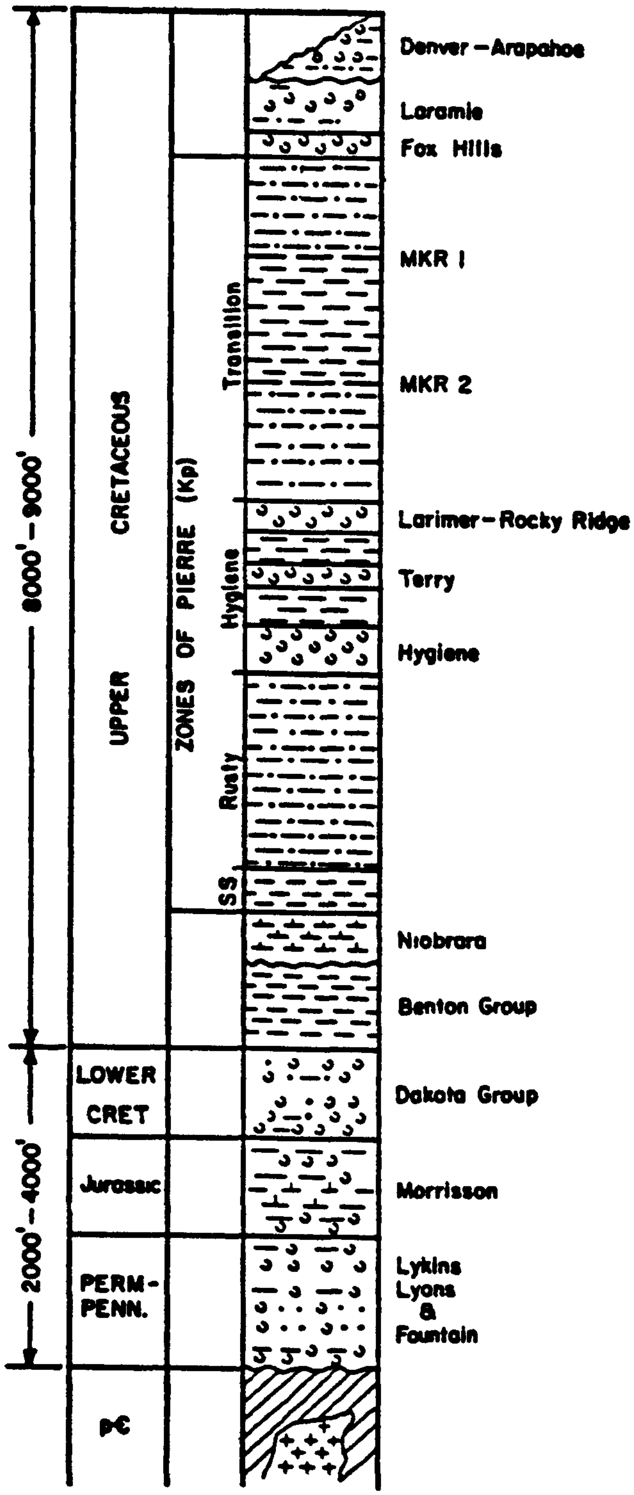
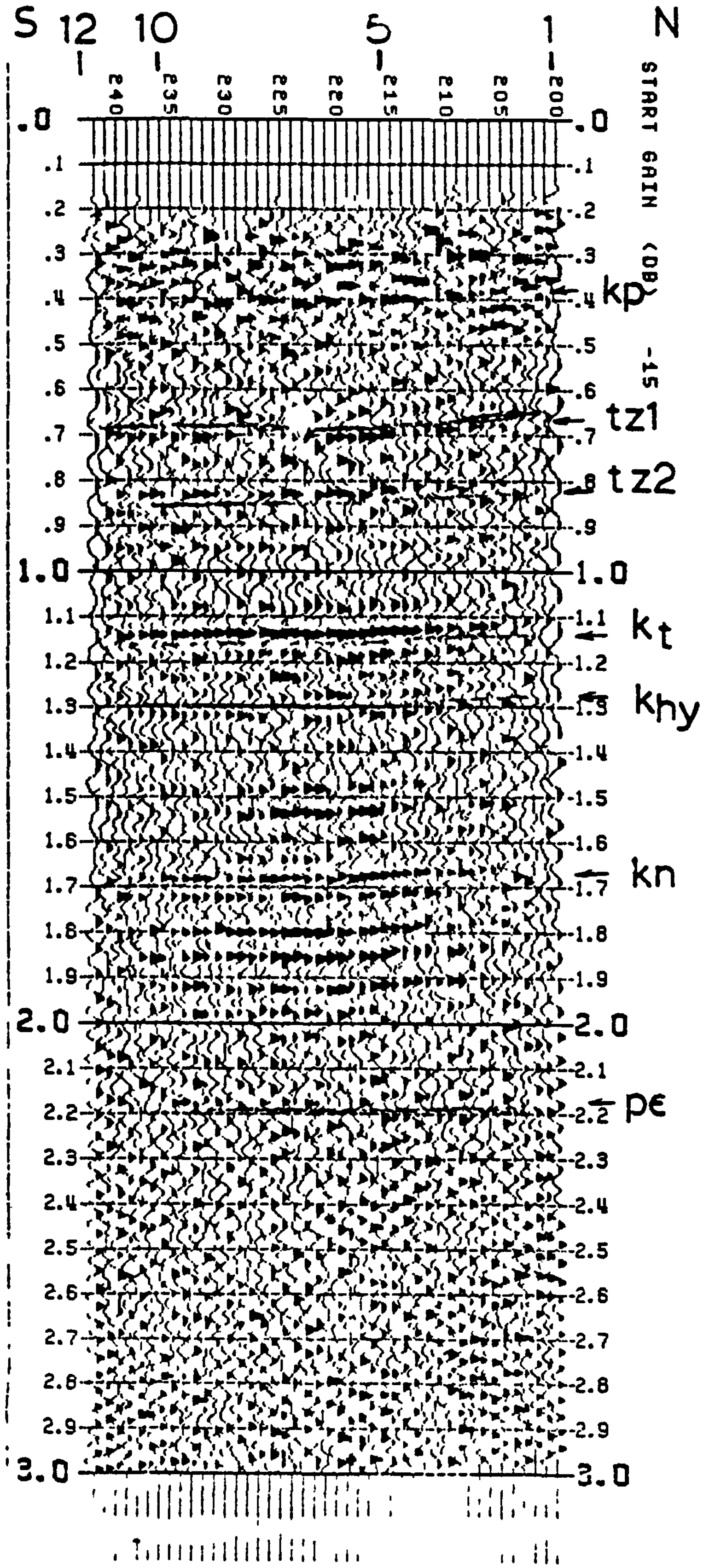


FIGURE 3. Stratigraphic column



LINE 1
FINAL
DATUM = +5700'
V_R = 8000 ft/s

FIGURE 4. Rocky Flats line 1

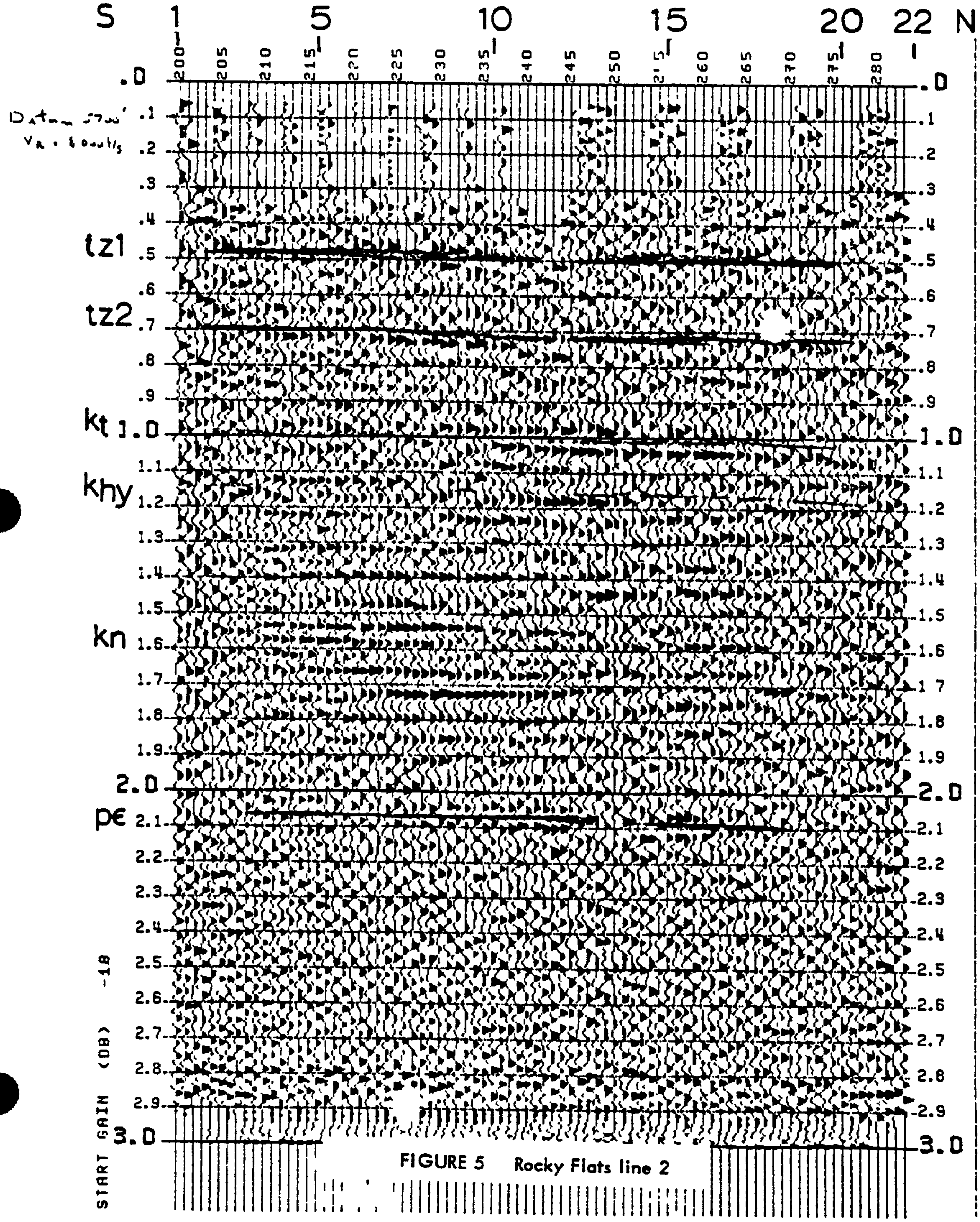


FIGURE 5 Rocky Flats line 2

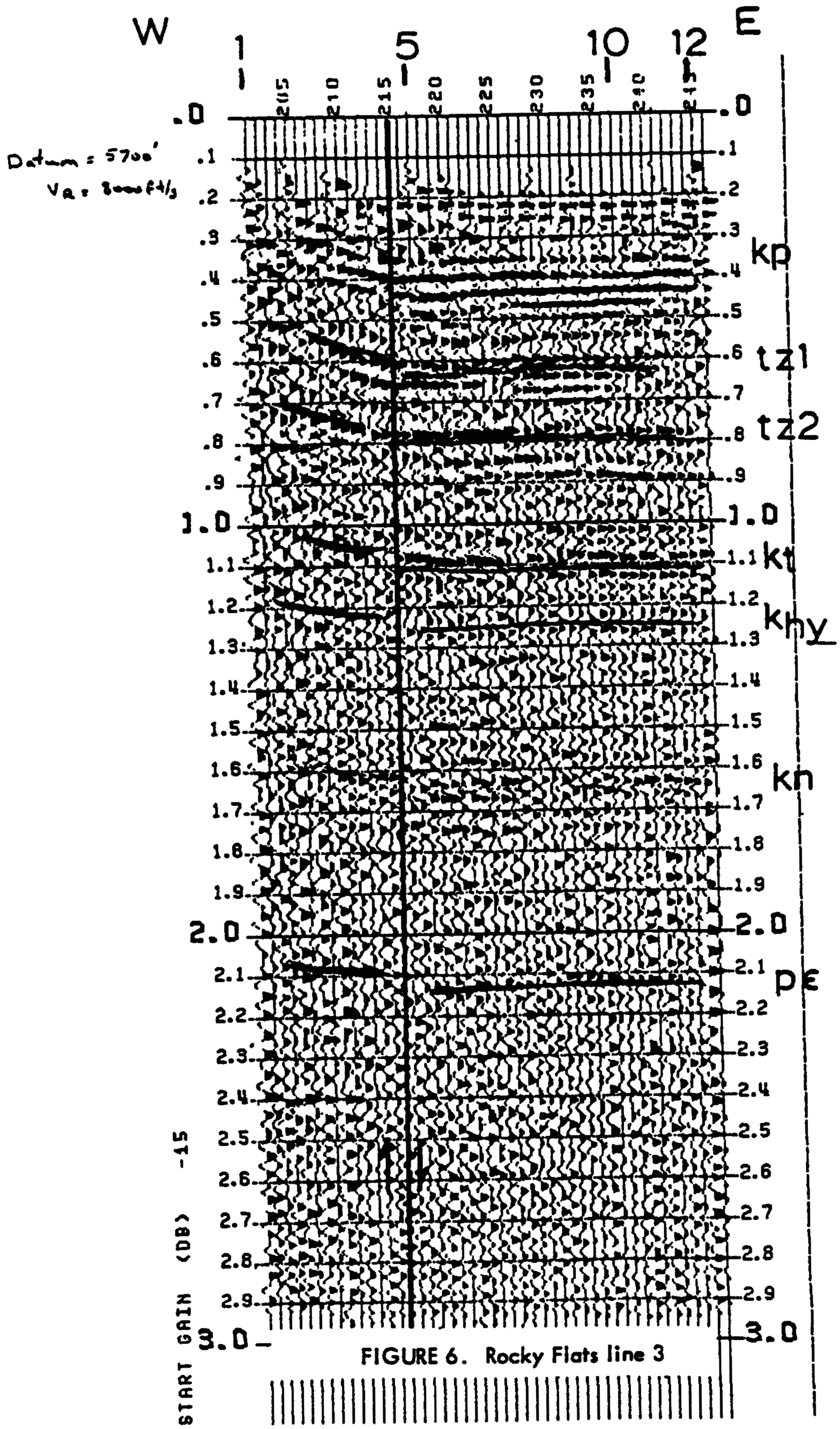


FIGURE 6. Rocky Flats line 3

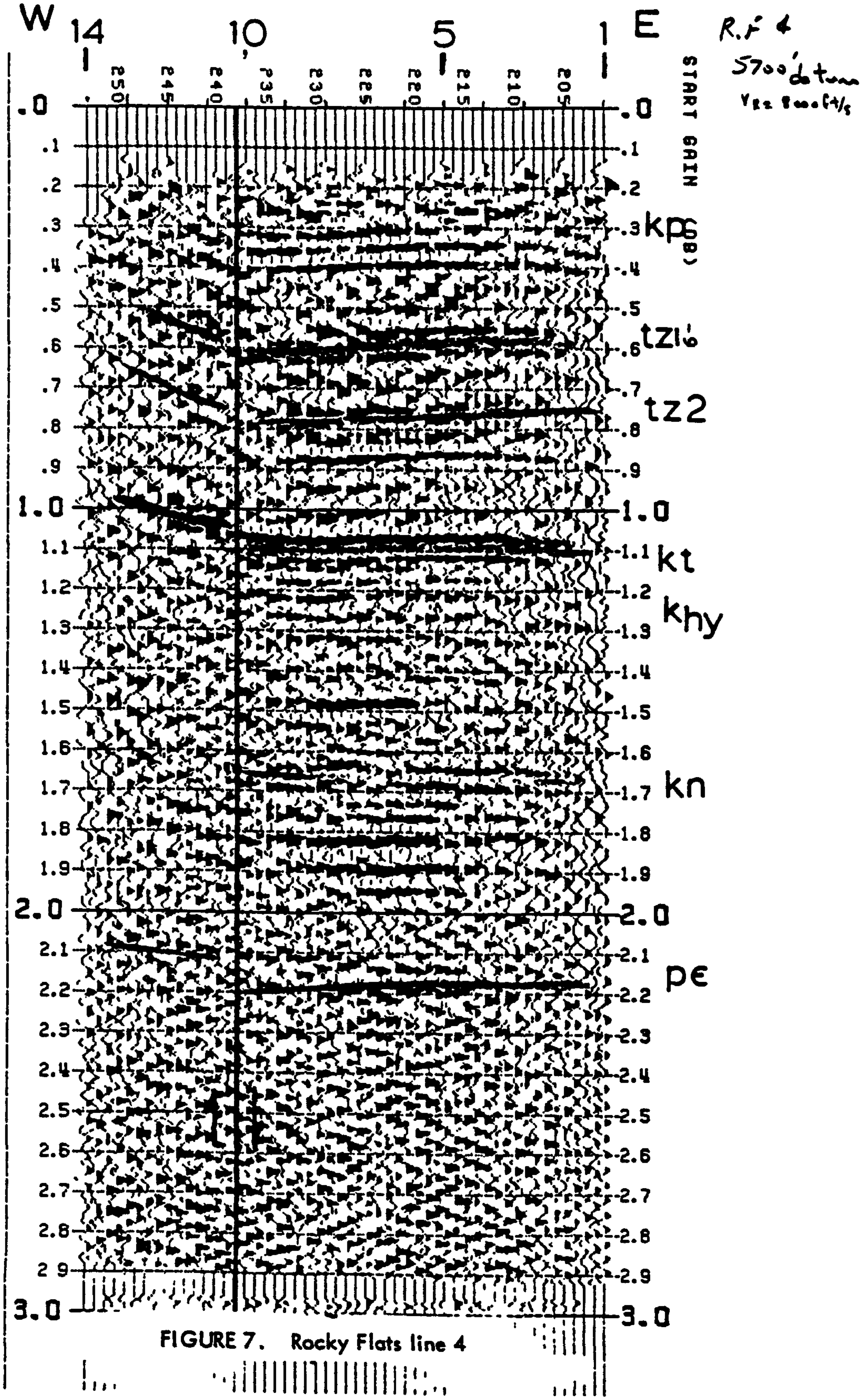
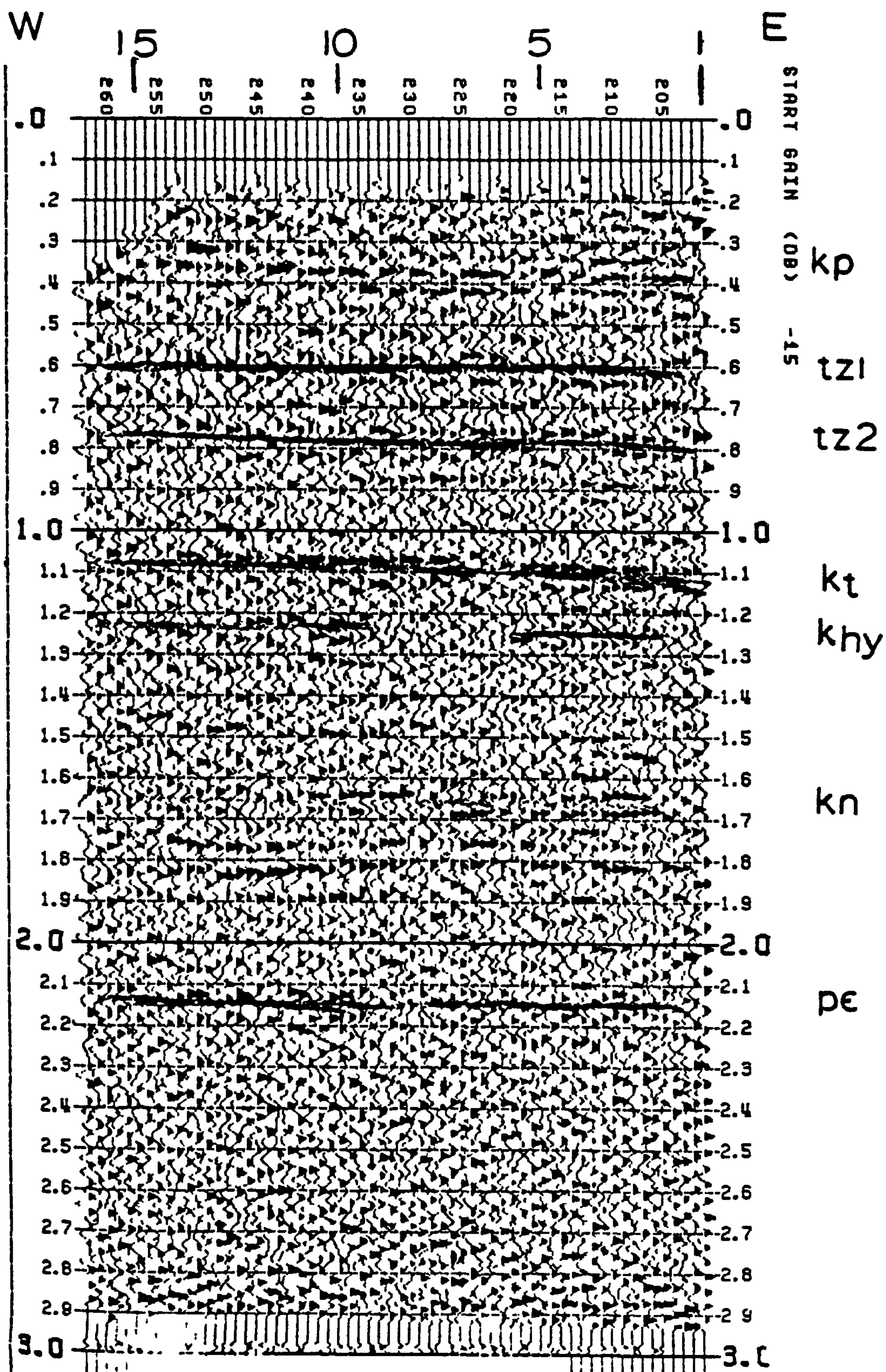


FIGURE 7. Rocky Flats line 4



datum = 5700'
V_R = 8000 ft/s

FIGURE 8. Rocky Flats line 5

FINAL
CENTRAL AV
+5700' datum
V_R = 8000 f/s

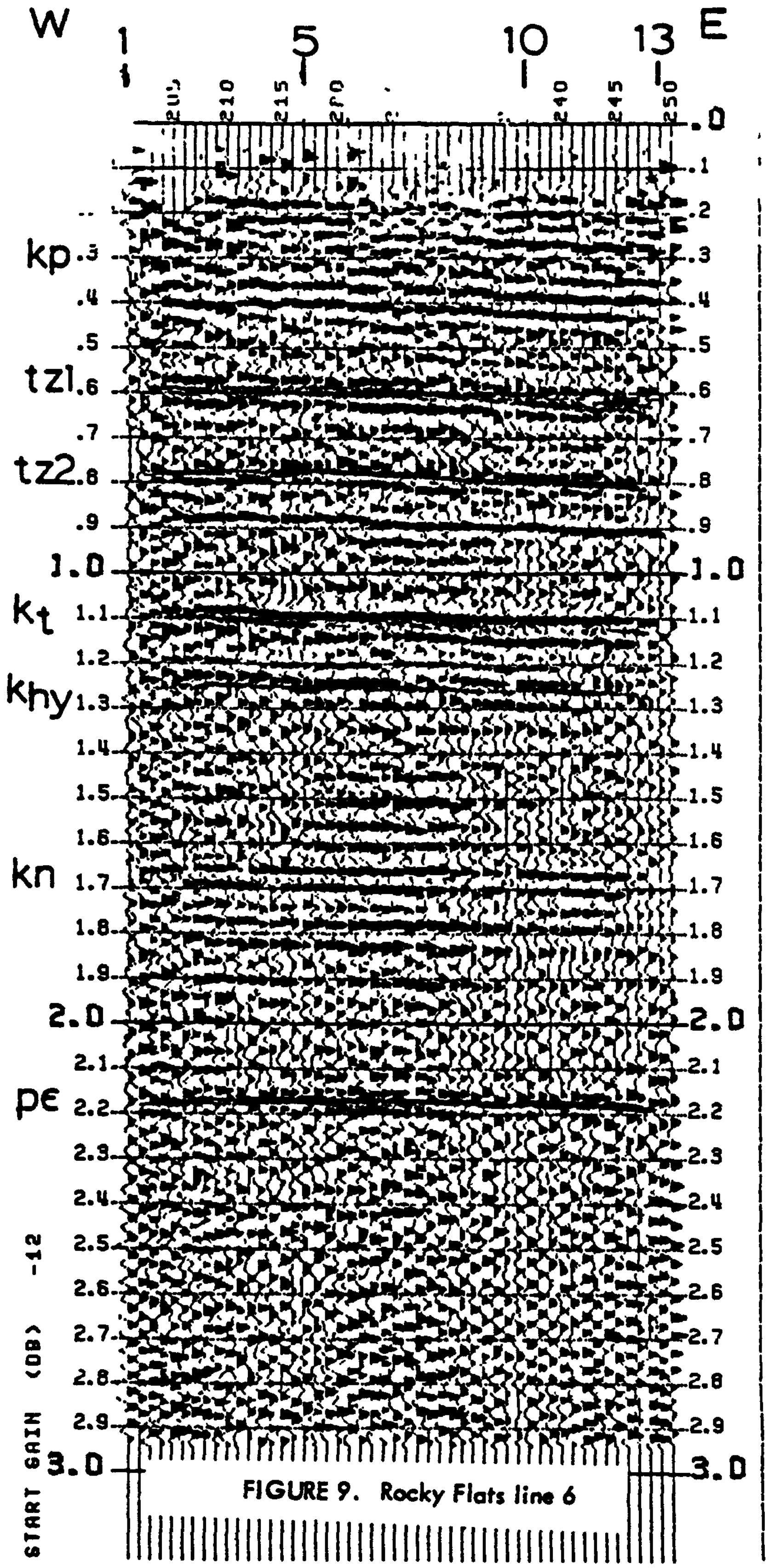


FIGURE 9. Rocky Flats line 6

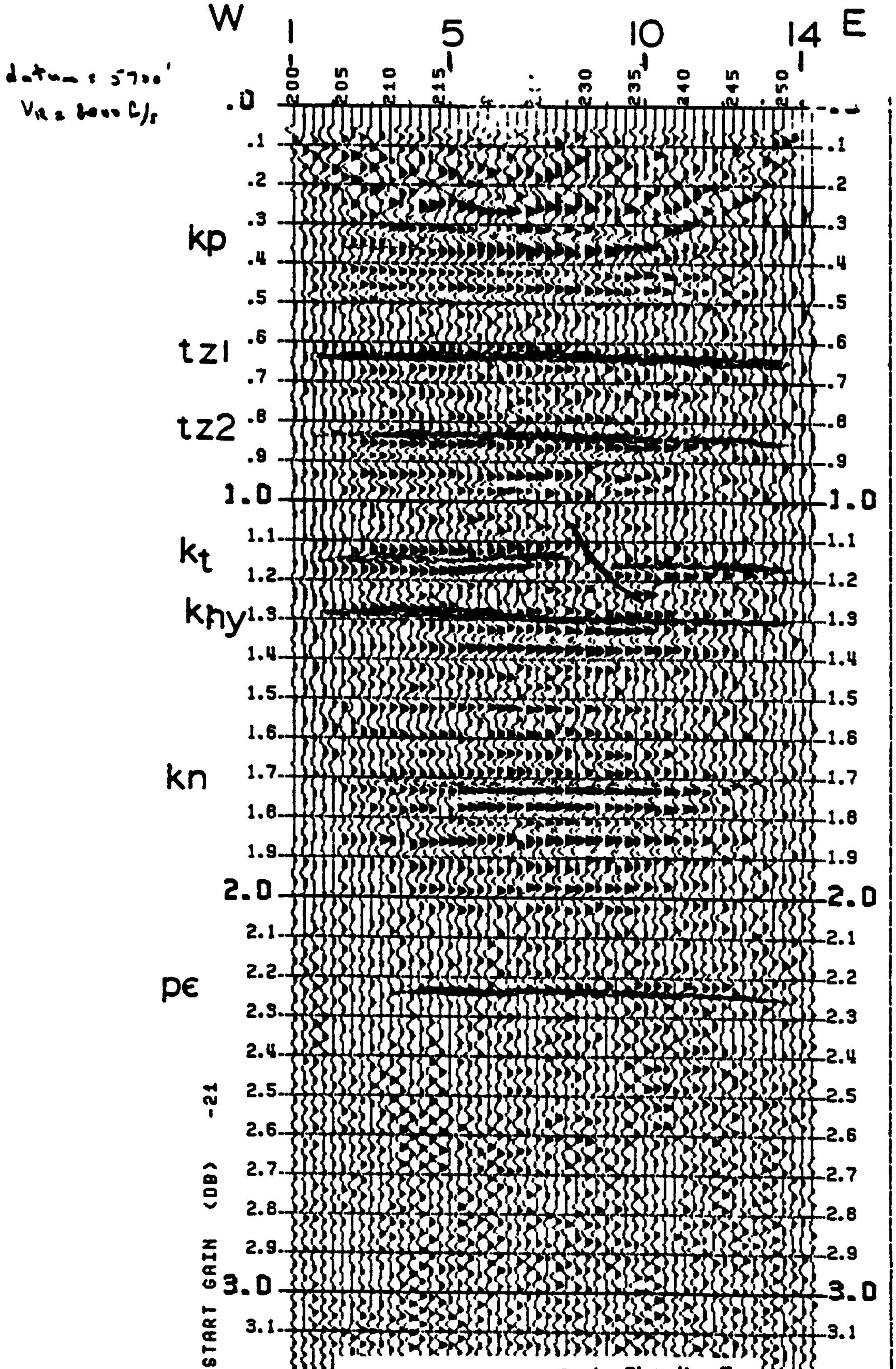
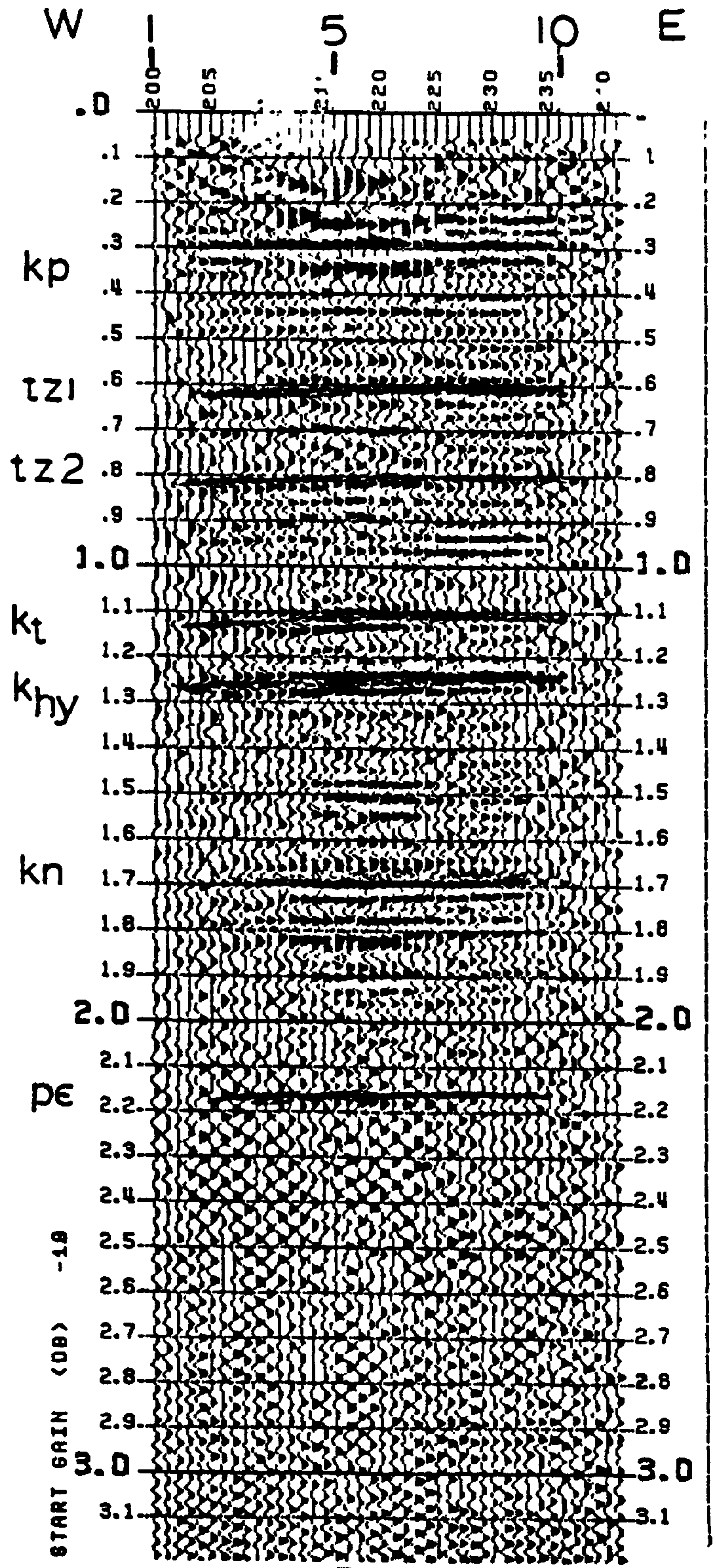


FIGURE 10. Rocky Flats line 7

datum = 5700'
V_R = 8000 ft/s



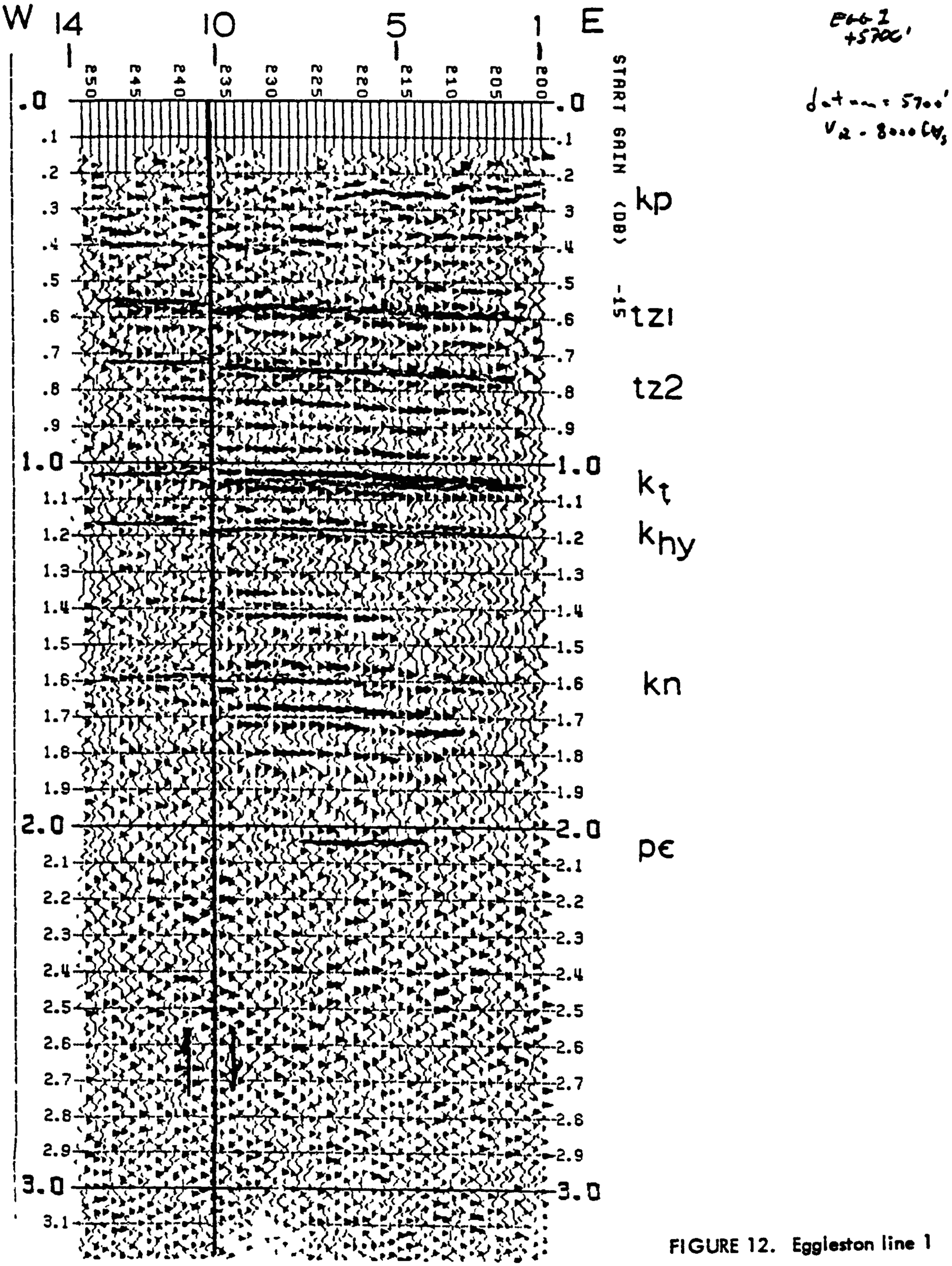


FIGURE 12. Eggleston line 1

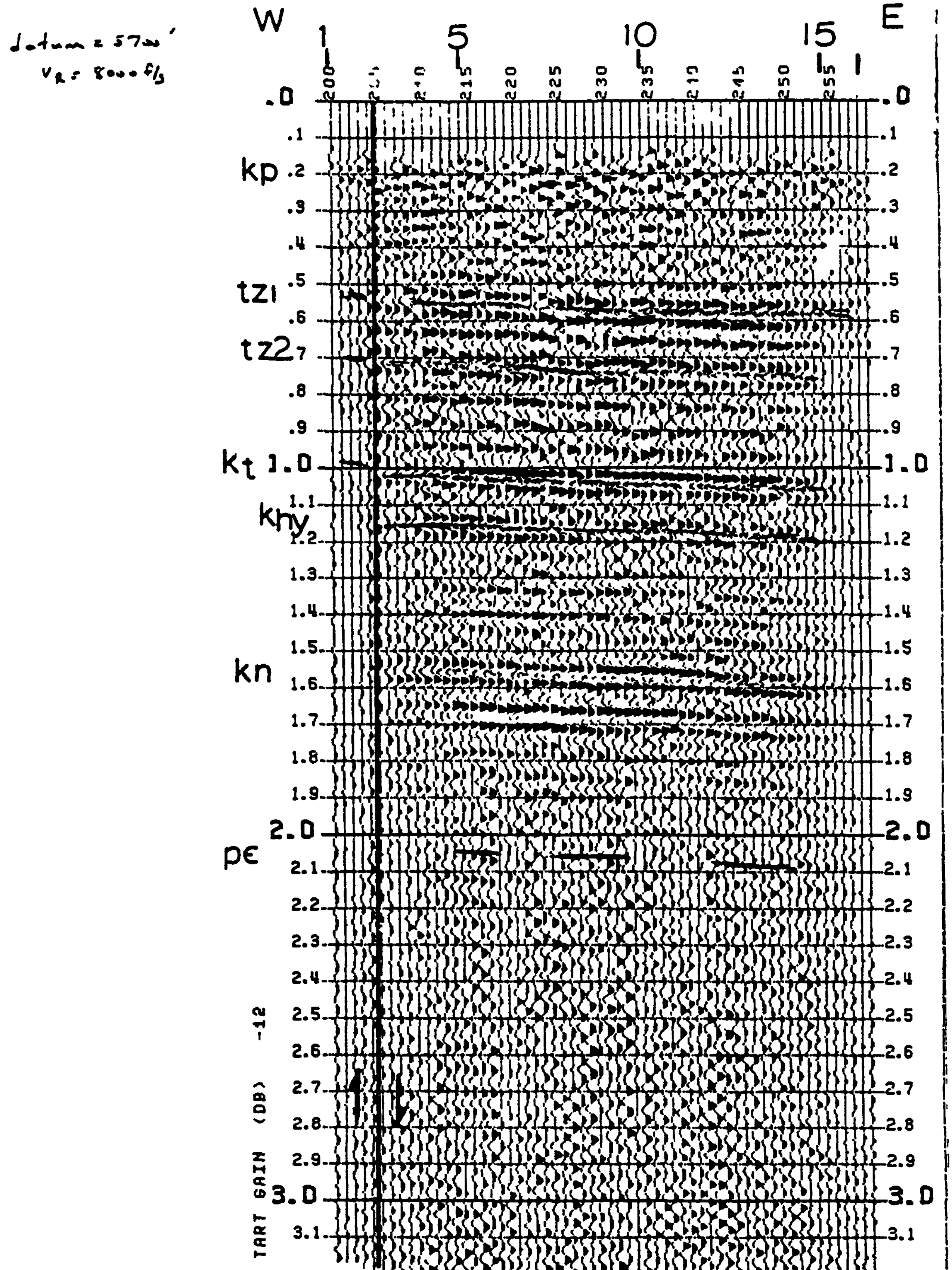


FIGURE 13. Eggleston line 2

EGG 3,
5700'

datum = 5700'
V_R = 8000 ft/s

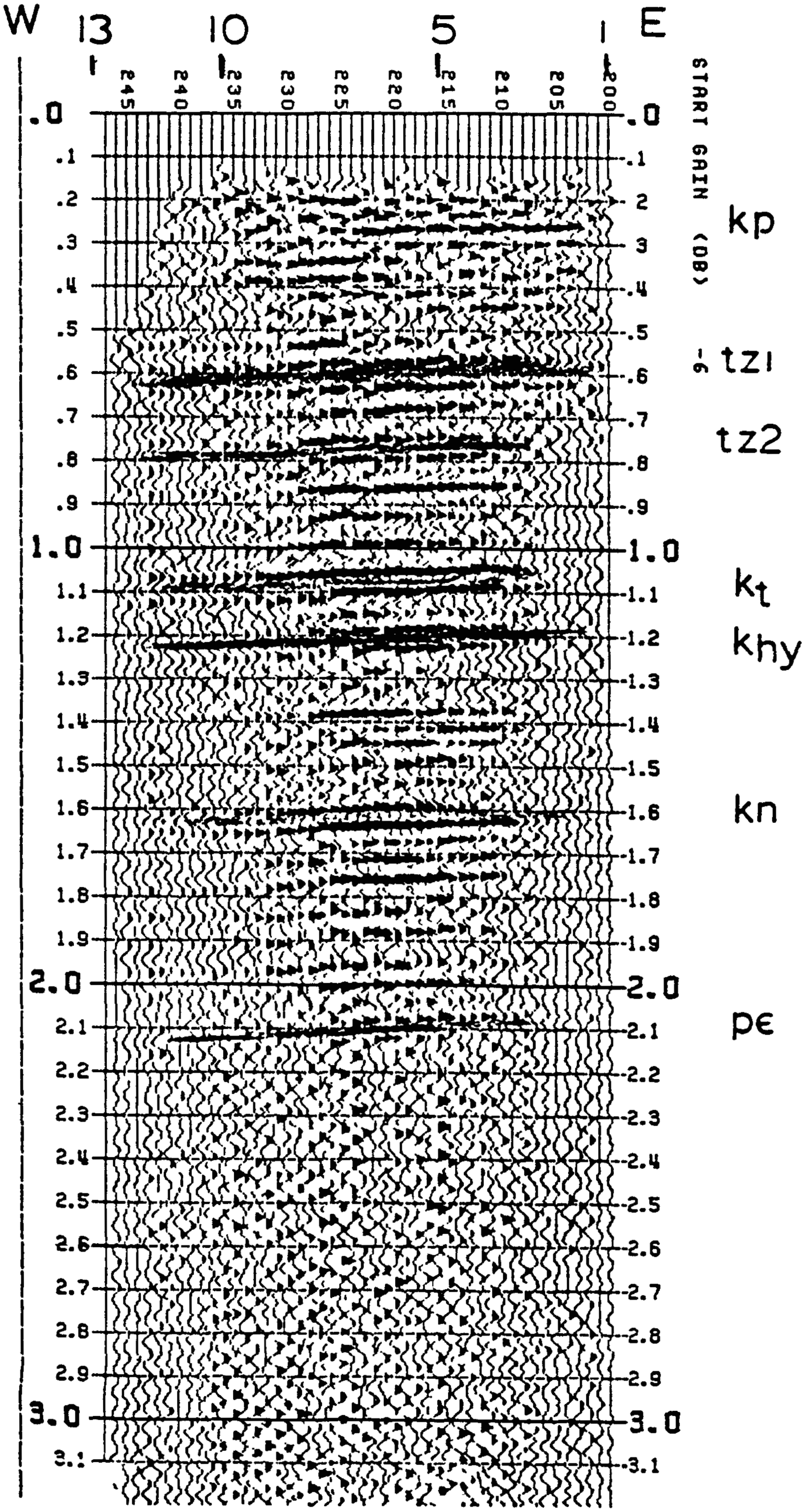


FIGURE 14 Eggleston line 3

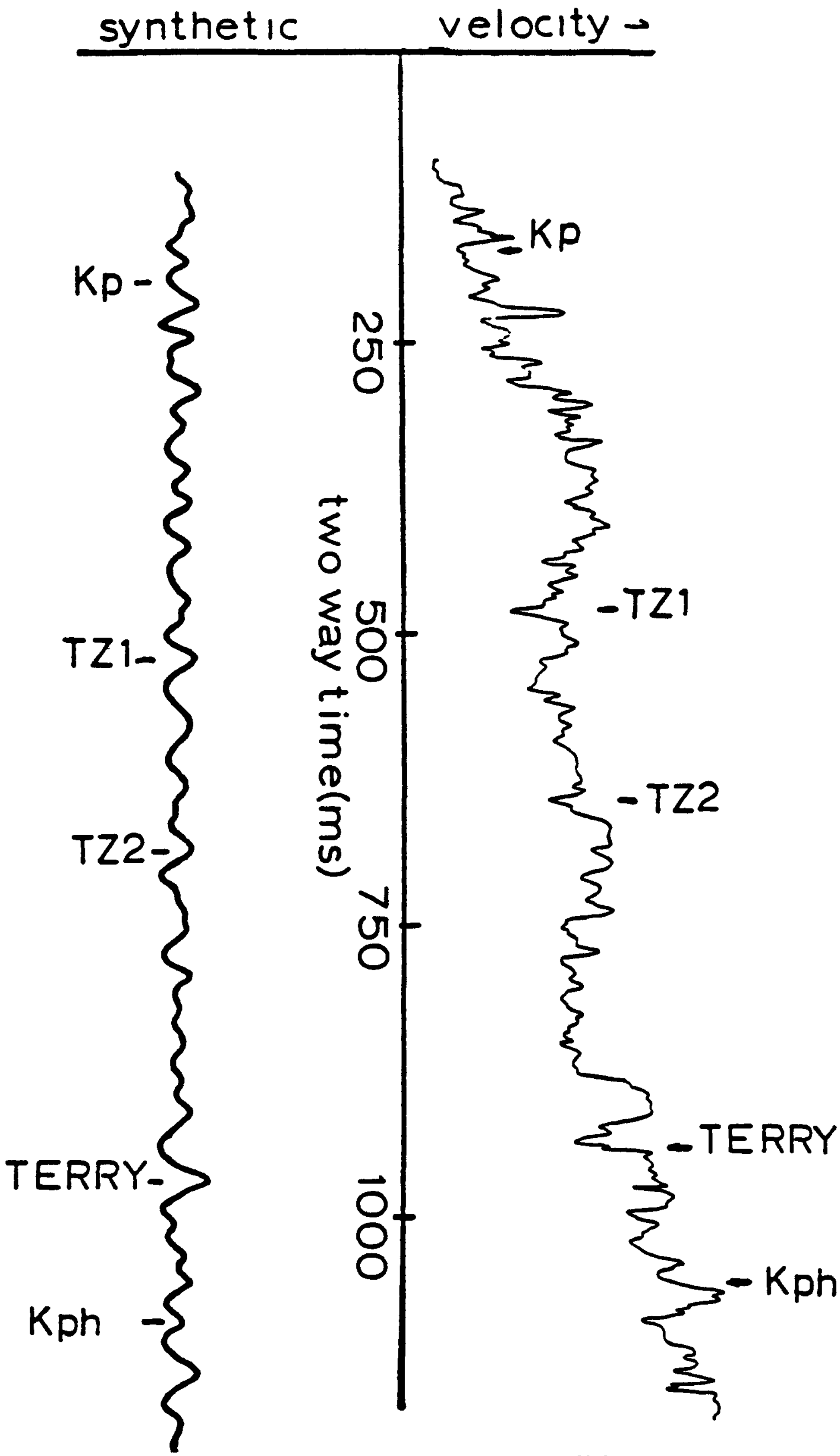


FIGURE 15. Synthetic seismogram from well 22-1S-70W

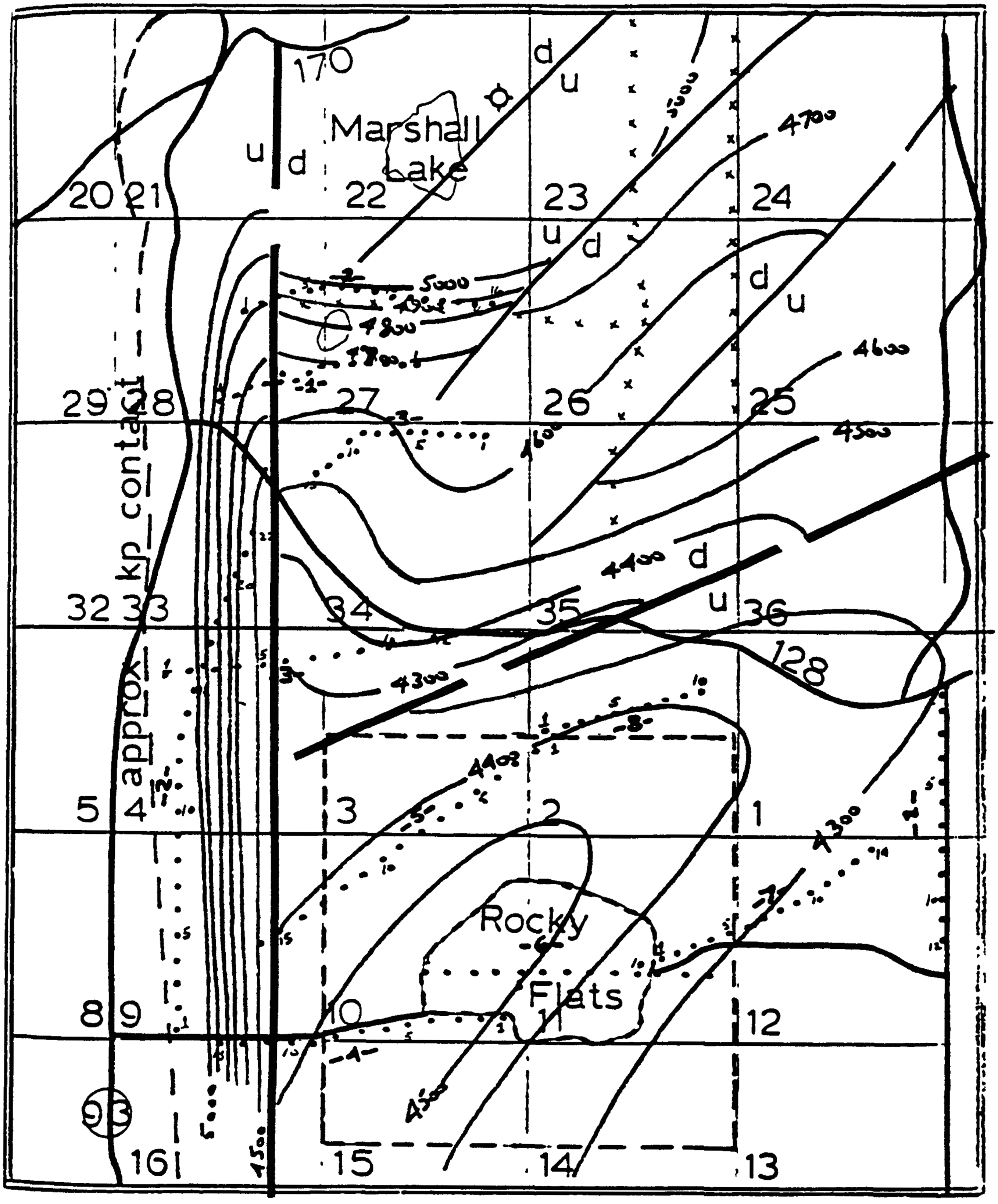
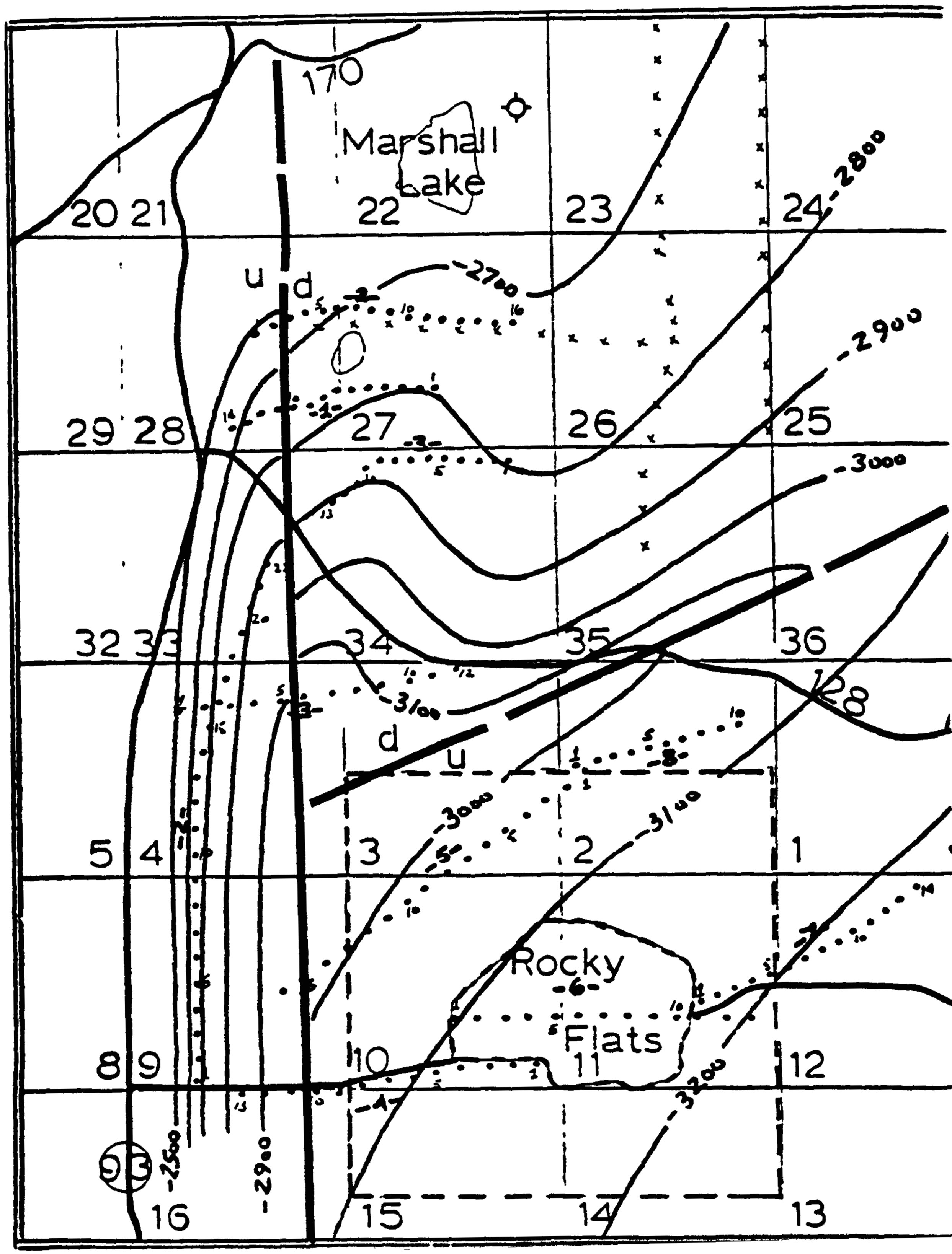


FIGURE 16 Structure contour map on the Top of the Pierre Shale (conversion velocity is 7500 ft/sec).



170
Marshall Lake
20 21
22
23
24
-2800
u
d
-2700
-2900
29 28
27
26
25
-3000
32 33
34
35
36
128
-3100
d
u
-3000
-3100
5 4
3
2
1
Rocky
Flats
8 9
10
11
12
-3200
93
-2500
-2900
16
15
14
13

GLOSSARY

A selection of relevant geophysical terms extracted from
Encyclopedic Dictionary of Exploration Geophysics (Sheriff, 1984),
Applied Geophysics (Telford et al., 1976),
Geophysical Prospecting (Dobrin and Savit, 1988), and others.

ACCELEROMETER - A geophone whose output is proportional to the acceleration of earth particles. For example, a moving coil geophone, with velocity response proportional to frequency (as may be the case below the natural frequency) operates as an accelerometer.

ACOUSTIC IMPEDANCE - Seismic velocity multiplied by density. Reflection coefficient at normal incidence depends on changes in acoustic impedance.

ACOUSTIC LOGGING - A borehole logging survey which will display any of several aspects of seismic-wave propagation, i.e., a sonic, amplitude, character or 3D-log.

AIR WAVE - Energy from the shot which travels in the air at the velocity of sound: V = 1051 + 1.1F ft/s, where F = Fahrenheit temperature, or V = 331.5 + 0.607C m/s, where C = Celsius temperature.

ALIAS - Data in sampled form have an ambiguity where there are fewer than two samples per cycle. This creates a situation where an input signal at one frequency appears to have another frequency at the output of the system. Half of the frequency of sampling is called the folding or Nyquist frequency, f_N, and a frequency larger than this, $f_N + Y$, appears to have the smaller frequency $f_N - Y$. To avoid this ambiguity, frequencies above the Nyquist frequency must be removed by an anti-alias filter before the sampling. Otherwise the system will react as if the spectral characteristics were folded back at the Nyquist frequency. Thus, for a system sampled over 4 msec, or 250 times per second, the Nyquist frequency is 125 cps; if, for example, 50 cps is within the pass band, then 200 cps will also be passed if an anti-alias filter is not used, appearing upon output to have a 50 cps frequency. The pass bands obtained by folding about the Nyquist frequency are also called "alias bands," "side lobes," and "secondary lobes." Aliasing is an inherent property of all sampling systems and applies to digital seismic recording and also to the sampling which is done by the separate elements of geophone and shotpoint arrays.

ANALOG - (1) A continuous physical variable (such as voltage or rotation) which bears a direct relationship (usually linear) to another variable (such as earth motion) so that one is proportional to the other. (2) Continuous, as opposed to discrete or digital.

ANOMALY - A deviation from uniformity in physical properties, often of exploration interest. For example, a travel time anomaly, Bouguer anomaly, free-air anomaly.

APPARENT VELOCITY - (1) The phase velocity which a wavefront appears to have along a line of geophones. (2) The inverse of the slope of a time-distance curve.

ATTENUATION - A reduction in amplitude or energy caused by the physical characteristics of the transmitting media or system. Usually includes geometric effects such as the decrease in amplitude of a wave with increasing distance from a source. Also used for instrumental reduction effects such as might be produced by passage through a filter.

AUTOMATIC GAIN CONTROL (AGC) - A system in which the output amplitude is used for automatic control of the gain of a seismic amplifier, usually individual for each channel, although multi-channel devices are sometimes used.

BEDROCK - Any solid rock, such as may be exposed at the surface of the earth or overlain by unconsolidated material.

BODY WAVES - P-waves and S-waves, which travel through the body of a medium, as opposed to surface waves..

CABLE - The assembly of electrical conductors used to connect the geophone groups to the recording instrument.

CAPACITANCE - The ratio of charge (Q in coulombs) on a capacitor to the potential across it (V in volts) is the capacitance (C in farads):

$$C = Q/V$$

CHANNEL - (1) A single series of interconnected devices through which geophysical data can flow from sources to recorder. Most seismic systems are 24 channel, allowing the simultaneous recording of energy from 24 groups of geophones. (2) A localized elongated geological feature resulting from present or past drainage or water action; often presents a weathering problems. (3) An allocated portion of the radio-frequency spectrum.

CHANNEL WAVE - An elastic wave propagated in a layer of lower velocity than those on either side of it. Energy is largely prevented from escaping from the channel because of repeated total reflection at the channel boundaries or because rays which tend to escape are bent back toward the channel by the increasing velocity away from it in either direction.

CHARACTER - (1) The recognizable aspect of a seismic event, usually in the waveform, which distinguishes it from other events. Usually a frequency or phasing effect, often not defined precisely and hence dependent upon subjective judgment. (2) A single letter, numeral, or special symbol in a processing system.

COMMON DEPTH POINT (CDP) - The situation where the same portion of subsurface produces reflections at different offset distances on several profiles.

COMPRESSIONAL WAVE - An elastic body wave in which particle motion is in the direction of propagation. (Same as P-waves, longitudinal wave, dilation wave).

CONVERTED WAVE - A wave which is converted from longitudinal to transverse, or vice versa, upon reflection or refraction at oblique incidence from an interface.

CRITICAL ANGLE - Angle of incidence, q_c, for which the refracted ray grazes the surface of contact between two media (of velocities V_1 and V_2):

$$\sin q_c = V_1/V_2$$

CRITICAL DISTANCE - (1) The offset at which the reflection time equals the refraction time; that is, the offset for which the reflection occurs at the critical angle (see Sheriff, 1984 p. 45). (2) Sometimes incorrectly used for crossover distance, the offset at which a refracted event becomes the first break.

CROSSFEED - Interference resulting from the unintentional pickup of information or noise on one channel from another channel. Also crosstalk.

CROSS-HOLE METHOD - Technique for measuring in situ compressional (p) and/or shear (s) wave velocities by recording transit times from a source within one borehole to receivers at the same elevation in one or more other boreholes. Sources may be explosive or directional to enhance either P- or S-wave generation.

CROSS SECTION - A plot of seismic events.

DATUM - (1) The arbitrary reference level to which measurements are corrected. (2) The surface from which seismic reflection times or depths are counted, corrections having been made for local topographic and/or weathering variations. (3) The reference level for elevation measurements, often sea level.

DELAY TIME - (1) In refraction work, the additional time required for a wave to follow a trajectory to and along a buried marker over that which would have been required to follow the same marker considered hypothetically to be at the ground surface or at a reference level. Normally, delay time exists separately under a source and under a detector; and is dependent upon the depth of the marker at wave incidence and emergence points. Shot delay time plus geophone delay time equals intercept time (See Dobrin, 1988 p. 472). (2) Delay produced by a filter.

DIELECTRIC CONSTANT - A measure of the capacity of a material to store charge when an electric field is applied. It is the dimensionless ratio of the capacitivity (or permittivity, the ratio of the electrical displacement to the electric field strength) of the material to that of free space.

DIFFRACTION - (1) Scattered energy which emanates from an abrupt irregularity of rock type, particularly common where faults cut reflecting interfaces. The diffracted energy shows greater curvature than a reflection (except in certain cases where there are buried foci), although not necessarily as much as the curve of maximum convexity. It frequently blends with a reflection and obscures the fault location or becomes confused with dip. (2) Interference produced by scattering at edges. (3) The phenomenon by which energy is transmitted laterally along a wave crest. When a portion of a wave train is interrupted by a barrier, diffraction allows waves to propagate into the region of the barrier's geometric shadow.

DIGITAL - Representation of quantities in discrete units. A digital system is one in which the information is contained and manipulated as a series of discrete numbers as opposed to an analog system, in which the information is represented by a continuous flow of the quantity constituting the signal.

DOWN-HOLE METHOD - Technique for measurement of in situ compressional and shear wave velocities utilizing a seismic source at ground surface and a clamped triaxial geophone at depth in a borehole. Shear wave energy is often enhanced by use of directional sources such as striking the ends of a weighted plank.

END LINE - Shotpoints that are shot near the end of the spread.

FIRST BREAK - The first recorded signal attributable to seismic wave travel from a known source. First breaks on reflection records are used for information about the weathering. Refraction work is based principally on the first breaks, although secondary (later) refraction arrivals are also used. Also first arrival.

FOLD - The multiplicity of common-midpoint data. Where the midpoint is the same for 12 offset distances, e.g., the stack is referred to as "12-fold".

FREQUENCY DOMAIN: - A representation in which frequency is the independent variable; the Fourier transform variable when transforming from time.

GAIN - An increase (or change) in signal amplitude (or power) from one point in a circuit or system to another, often from system input to output.

GALVANOMETER - A part of a seismic camera consisting of a coil suspended in a constant magnetic field. The coil rotates through an angle proportional to the electrical current flowing through the coil. A small mirror on the coil reflects a light beam, which exhibits a visual record of the galvanometer rotation.

GEOPHONE - The instrument used to convert seismic energy into electrical voltage. Same as seismometer.

GEOPHONE STATION - Point of location of a geophone on a spread, expressed in engineering notation as 1+75 taken from 0+00 at the beginning of the line.

GROUP VELOCITY - The velocity with which most of the energy in a wave train travels. In dispersive media where velocity varies with frequency, the wave train changes shape as it progresses so that individual wave crests appear to travel at a different velocity (the phase velocity) than the overall energy as approximately enclosed by the envelope of the wave train. The velocity of the envelope is the group velocity. Same as dispersion.

HYDROPHONE - (Pressure detector) A detector which is sensitive to variations in pressure, as opposed to a geophone which is sensitive to particle motion. Used when the detector can be placed below a few feet of water, as in marine or marsh or as a well seismometer. The frequency response of the hydrophone depends on its depth beneath the surface.

IMPEDANCE - The apparent resistance to the flow of alternating current, analogous to resistance in a dc circuit. Impedance is (in general) complex, of magnitude Z with a phase angle g. These can be expressed in terms of resistance R (in ohms), inductive reactance X_L = 2pL, and capacitive reactance X_c = 1/2pnC:

$$Z = [R^2 + (X_L - X_C)^{2}]^{1/2}$$
$$g = \tan^{-1}[(X_L - X_C)/R].$$

Z is in ohms when frequency n is in hertz, L is inductance in henrys, and C is capacitance in farads.

IN-LINE OFFSET - A spread which is shot from a shotpoint which is separated (offset) from the nearest active point on the spread by an appreciable distance (more than a few hundred feet) along the line of spread.

INPHASE - Electrical signal with the same phase angle as that of the exciting signal or comparison signal.

LEAD - An electrical conductor for connecting electrical devices. Geophones are connected to cables at the takeouts via leads on the geophones.

LINE - A series of profiles shot in line.

LOVE WAVE - A surface seismic channel wave associated with a surface layer which has rigidity, characterized by horizontal motion perpendicular to the direction of propagation with no vertical motion.

LOW-VELOCITY LAYER - A near-surface belt of very low-velocity material often abbreviated LVL; also called weathering.

MAGNETIC PERMEABILITY - The ratio of the magnetic induction B to the inducing field strengh H: denoted by the symbol m:

$$m = B/moH$$

mo is the permeability of free space = $4p10^{-7}$ weber/ampere meter or (henrys/meter) in SI system, and 1 gauss/oersted in the cgs system, so that the permeability m is dimensionless. The quantity mmo is sometimes considered the permeability (especially in the cgs system).

MIS-TIE - (1) The time difference obtained on carrying a reflection, phantom, or some other measured quantity around a loop; or the difference of the values at identical points on intersecting lines or loops. (2) In refraction shooting, the time difference from reversed profiles which gives erroneous depth and dip calculations.

MULTIPLE - Seismic energy which has been reflected more than once. Same as long-path multiple, short path multiple, peg-leg multiple, and ghost.

MULTIPLEX - A process which permits transmitting several channels of information over a single channel without crossfeed. Usually different input channels are sampled in sequence at regular intervals and the samples are fed into a single output channel; digital seismic tapes are multiplexed in this way. Multiplexing can also be done by using different carrier frequencies for different information channels and in other ways.

NOISE - (1) Any undesired signal; a disturbance which does not represent any part of a message from a specified source. (2) Sometimes restricted to energy which is random. (3) Seismic energy which is not resolvable as reflections. In this sense noise includes microseisms, shot-generated noise, tape-modulation noise, harmonic distortions, etc. Sometimes divided into coherent noise (including non-reflection coherent events) and random noise (including wind noise, instrument noise, and all other energy which is non-coherent). To the extent that noise is random, it can be attenuated by a factor of n by compositing n signals from independent measurements. (4) Sometimes restricted to seismic energy not derived from the shot explosion. (5) Disturbances in observed data due to more or less random inhomogeneities in surface and near surface material.

NOISE SURVEY - A mapping of ambient, continuous seismic noise levels within a given frequency band. As some geothermal reservoirs are a source of short-period seismic energy, this technique is a useful tool for detecting such reservoirs. Also called ground noise survey.

OBSERVER - The geophysicist in charge of recording and overall field operations on a seismic crew.

ON-LINE - Shotpoints that are shot at any point on a spread other than at the ends of the spread.

OSCILLOGRAPH - An instrument that renders visible a curve representing the time variations of electric phenomena.

OSCILLOSCOPE - A type of oscillograph that visually displays an electrical wave on the screen of a cathode ray tube type.

PERMITTIVITY - Capacitivity (q.v.) of a three-dimensional material, such as a dielectric. Relative permittivity is the dimensionless ratio of the permittivity of a material to that of free space; it is also called the dielectric constant.

PHASE VELOCITY - The velocity with which any given phase (such as a trough or a wave of single frequency) travels; may differ from group velocity because of dispersion.

PLANT - The manner in which a geophone is placed on or in the earth; the coupling to the ground.

PROFILE - The series of measurements made from several shotpoints into a recording spread from which a seismic data cross section or profile can be constructed.

PROFILING - A geophysical survey in which the measuring system is moved about an area (often along a line) with the objective of determining how measurements vary with location. Specifically, a resistivity, IP, or electromagnetic field method wherein a fixed electrode or antenna array is moved progressively along a traverse to create a horizontal profile of the apparent resistivity.

RADAR - A system in which short electromagnetic waves are transmitted and the energy scattered back by reflecting objects is detected. Acronym for "radio detection and ranging." Ships use radar to help "see" other ships, buoys, shorelines, etc. Beacons sometimes provide distinctive targets. Radar is used in aircraft navigation (see Doppler-radar), in positioning, and in remote sensing.

RADIO FREQUENCY - A frequency above 3kHz. Radio frequencies are subdivided into bands.

RAYLEIGH WAVE - A seismic wave propagated along the free surface of a semiinfinate medium. The particle motion near the surface is elliptical and retrograde, in the vertical plane containing the direction of propogation.

RAYPATH - A line everywhere perpendicular to wavefronts (in isotropic media). The path which a seismic wave takes.

REFLECTION SURVEY - A survey of geologic structure using measurements made of arrival time of events attributed to seismic waves which have been reflected from interfaces where the acoustic impedance changes.

RESOLUTION - The ability to separate two features which are very close together.

SEISMIC AMPLIFIER - An electronic device used to increase the electrical amplitude of a seismic signal. (See geophone)

SEISMIC CAMERA - A recording oscillograph used to produce a visible pattern of electrical signals to make a seismic record.

SEISMIC VELOCITY - The rate of propagation of a seismic wave through a medium.

SEISMOGRAM - A seismic record.

SHEAR WAVE - A body wave in which the particle motion is perpendicular to the direction of propagation. (Same as S-wave, equivoluminal, transverse wave).

SHOOTER - The qualified, licensed individual (powderman) in charge of all shotpoint operations and explosives handling on a seismic crew.

SHOT DEPTH - The distance down the hole from the surface to the explosive charge, often measured with loading poles. With small charges the shot depth is measured to the center or bottom of the charge, but with large charges the distances to both the top and bottom of the column of explosives are usually given.

SHOT INSTANT - (Time Break (TB), Zero Time) - The time at which a shot is detonated.

SHOTPOINT - Point of location of the energy source used in generating a particular seismogram. Expressed either sequentially for a line (i.e. SP 3) or in engineering notation (i.e. SP 3+00).

SIGNAL ENHANCEMENT - A hardware development utilized in seismographs and resistivity systems to improve signal-to-noise ratio by real-time adding (stacking) successive waveforms from the same source point and thereby discriminating against random noise.

SIGNAL-TO-NOISE RATIO SOUNDING- The energy (or sometimes amplitude) divided by all remaining energy (noise) at the time; abbreviated S/N.

SOUNDING _ Measuring a property as a function of depth; a depth probe or expander. Especially a series of electrical resistivity readings made with successively greater electrode spacing while maintaining one point in the array fixed, thus giving resistivity-versus-depth information (assuming horizontal layering); electric drilling, probing, VES (vertical electric sounding).

SPREAD - The layout of geophone groups from which data from a single shot are recorded simultaneously.

STONELEY WAVE - A type of seismic wave propagated along an interface.

SURFACE WAVE - Energy which travels along or near the surface (ground roll).

TAKEOUT - A connection point to a multiconductor cable where geophones can be connected.

TIME BREAK (TB)- The mark on a seismic record which indicates the shot instant or the time at which the seismic wave was generated.

TIME DOMAIN - 1. Expression of a variable as a function of time, as opposed to its expression as a function of frequency (frequency domain). Processing can be done using time as the variable, i.e., "in the time domain". For example, convolving involves taking values at successive time intervals, multiplying by appropriate constants, and recombining; this is equivalent to filtering through frequency-selective circuitry. It is also equivalent to Fourier transforming, multiplying the amplitude spectra, and adding the phase spectra ("in the frequency domain"), and then inverse-Fourier transforming.

2. Time-domain induced polarization is called the pulse method (q.v.)

TOMOGRAPHY - The reconstruction of an object from a set of its projections. Tomographic techniques are utilized in medical physics as well as in cross-borehole electromagnetic and seismic transmission surveys.

TRACE - A record of one seismic channel. This channel may contain one or more geophones. A trace is made by a galvanometer.

UPHOLE METHOD- Also called the Meissner technique, a method of reconstructing wave front diagrams by shooting at several depths and recording on a full surface spread of geophones. Derived wavefront diagrams yield a true picture of wavepaths and, therefore, layering in the subsurface.

WAVE TRAIN - (1) The sum of a series of propagating wave fronts emanating from a single source. (2) The complex wave form observed in a seismogram obtained from an explosive source.

NOTICE

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Normal Polarity

Fiche location: A-SW-M3

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Fiche location: A-SW-M3

EBASCO ENVIRONMENTAL, INC.

CENTRAL AVENUE
LINE 6

FINAL STACK
NORMAL POLARITY

W → E

SPS: 101 - 125
COUNTY: JEFFERSON   STATE: COLORADO
DATUM: 5900 FT V_c : 8000 FT/SEC

FIELD PARAMETERS

RECORD LENGTH:	3 SEC	DATE SHOT:	1975/76
SAMPLE INTERVAL:	4 ms	SOURCE INTERVAL:	600 FT
SOURCE TYPE:	VIBROSEIS	GROUP INTERVAL:	300 FT
SWEEP FREQUENCY:	48 - 8 Hz	COVERAGE:	1200%
SOURCE LAYOUT:	27 SWEEPS/10 FT	GEOPHONE TYPE:	
FIELD FILTER:		GEOPHONE LAYOUT:	15 PHONES/200 FT

NORMAL TRACE SPREAD IS 24 CHANNELS SHOT THROUGH THE CABLE

DISPLAY PARAMETERS

TRACES/INCH 6   INCHES/SECOND 10

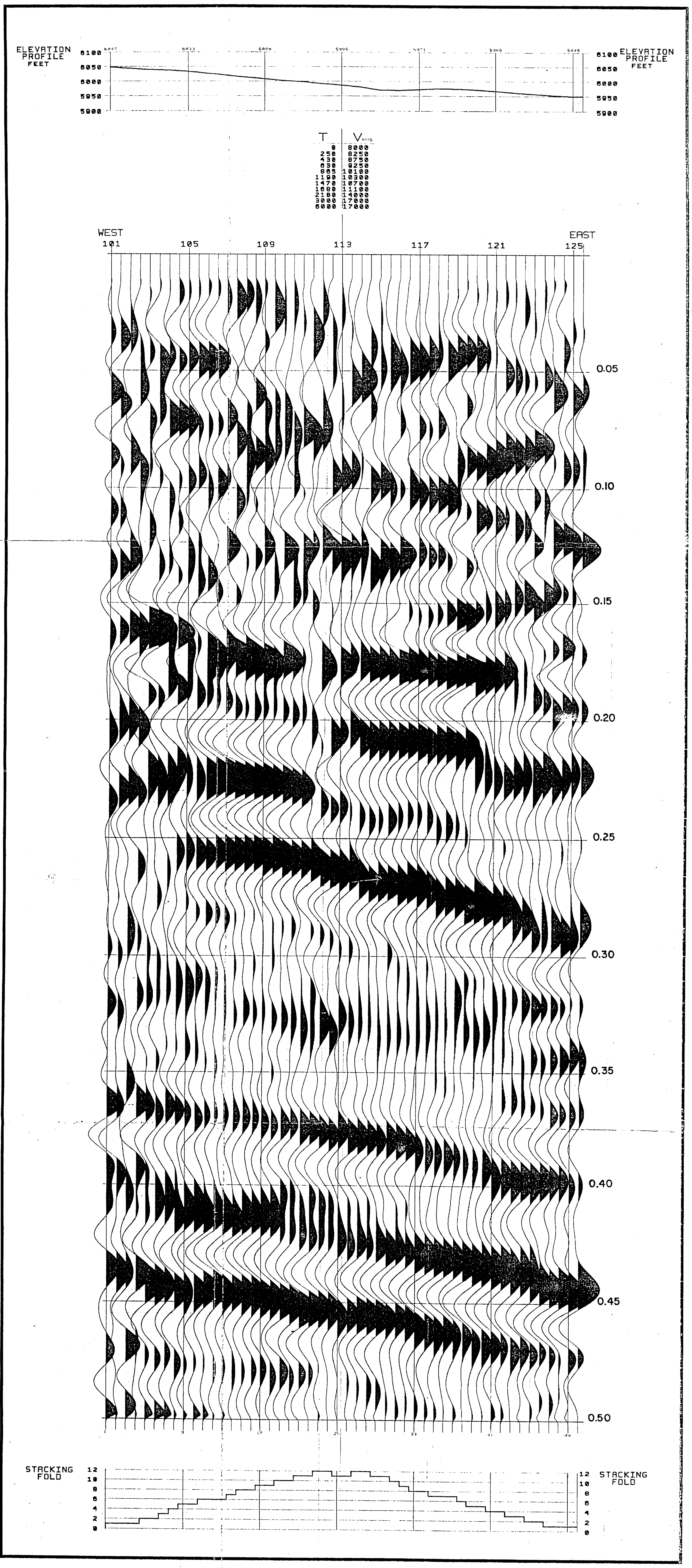
PROCESSING PARAMETERS

1. DEMULTIPLEX, SUM, AND CORRELATION AT AN EARLIER DATE
2. FORMAT CONVERSION
3. GEOMETRY APPLICATION
4. DECONVOLUTION - SURFACE CONSISTENT
   Operator Length: 130 ms
   Prewhitening: .1%
5. STRUCTURE STATICS - ELEVATION CORRECTIONS
   Datum 5900 FT
   Correctional Velocity 8000 FT/SEC
6. PRELIMINARY VELOCITY ANALYSIS
7. STATICS - AUTOMATIC SURFACE CONSISTENT
8. FREQUENCY DOMAIN SPECTRAL BALANCING
9. TRACE EQUALIZATION
   500 ms AGC
10. FINAL VELOCITY ANALYSIS
11. NORMAL MOVEOUT
12. STATICS - AUTOMATIC SURFACE CONSISTENT
13. STATICS - CDP CROSS CORRELATION
14. NOISE SUPPRESSION VIA RADON TRANSFORM (INVEST)
15. FIRST BREAK SUPPRESSION MUTE
16. STACK 1200%
17. FILTER - DIGITAL BANDPASS
   Pass Band: 6/10 - 43/53 Hz
18. TRACE EQUALIZATION
   Time Variant AGC: 150 ms 0.0 - .25 SEC
   500 ms .25 - .75 SEC
   750 ms .75 - 3.0 SEC

VECTOR

SEISMIC DATA PROCESSING INC.
Denver, Colorado

DATE PROCESSED: OCTOBER, 1989



EBASCO ENVIRONMENTAL, INC.

CENTRAL AVENUE
LINE 6

FINAL STACK
NORMAL POLARITY

W → E

SPS: 101 - 125
COUNTY: JEFFERSON STATE: COLORADO
DATUM: 5900 FT V_c : 8000 FT/SEC

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SAMPLE INTERVAL:	4 ms	SOURCE INTERVAL:	600 FT
SOURCE TYPE:	VIBROSEIS	GROUP INTERVAL:	300 FT
SWEEP FREQUENCY:	40 - 8 Hz	COVERAGE:	1200%
SOURCE LAYOUT:	27 SWEEPS/10 FT	GEOPHONE TYPE:	
FIELD FILTER:		GEOPHONE LAYOUT:	15 PHONES/200 FT

NORMAL TRACE SPREAD IS 24 CHANNELS SHOT THROUGH THE CABLE

DISPLAY PARAMETERS

TRACES/INCH 6 INCHES/SECOND 40

PROCESSING PARAMETERS

1. DEMULTIPLEX, SUM, AND CORRELATION AT AN EARLIER DATE
2. FORMAT CONVERSION
3. GEOMETRY APPLICATION
4. DECONVOLUTION - SURFACE CONSISTENT
   Operator Length: 130 ms
   Prewhitening: .1%
5. STRUCTURE STATICS - ELEVATION CORRECTIONS
   Datum 5900 FT
   Correctional Velocity 8000 FT/SEC
6. PRELIMINARY VELOCITY ANALYSIS
7. STATICS - AUTOMATIC SURFACE CONSISTENT
8. FREQUENCY DOMAIN SPECTRAL BALANCING
9. TRACE EQUALIZATION
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10. FINAL VELOCITY ANALYSIS
11. NORMAL MOVEOUT
12. STATICS - AUTOMATIC SURFACE CONSISTENT
13. STATICS - CDP CROSS CORRELATION
14. NOISE SUPPRESSION VIA RADON TRANSFORM (INVEST)
15. FIRST BREAK SUPPRESSION MUTE
16. STACK 1200%
17. FILTER - DIGITAL BANDPASS
    Pass Band: 6/10 - 43/53 Hz
18. TRACE EQUALIZATION
    Time Variant AGC: 150 ms 0.0 - .25 SEC
    500 ms .25 - .75 SEC
    750 ms .75 - 3.0 SEC

VECTOR

SEISMIC DATA PROCESSING INC.
Denver, Colorado

DATE PROCESSED: OCTOBER, 1989

EBASCO ENVIRONMENTAL, INC.

CENTRAL AVENUE
LINE 6

FINAL STACK
REVERSE POLARITY

W → E

SPS: 101 - 125

COUNTY: JEFFERSON   STATE: COLORADO
DATUM: 5900 FT V_c : 8000 FT/SEC

FIELD PARAMETERS

RECORD LENGTH:	3 SEC	DATE SHOT:	1975/76
SAMPLE INTERVAL:	4 ms	SOURCE INTERVAL:	600 FT
SOURCE TYPE:	VIBROSEIS	GROUP INTERVAL:	300 FT
SWEEP FREQUENCY:	40 - 8 Hz	COVERAGE:	1200%
SOURCE LAYOUT:	27 SWEEPS/10 FT	GEOPHONE TYPE:	
FIELD FILTER:		GEOPHONE LAYOUT:	15 PHONES/200 FT

NORMAL TRACE SPREAD IS 24 CHANNELS SHOT THROUGH THE CABLE

DISPLAY PARAMETERS

TRACES/INCH 6   INCHES/SECOND 10

PROCESSING PARAMETERS

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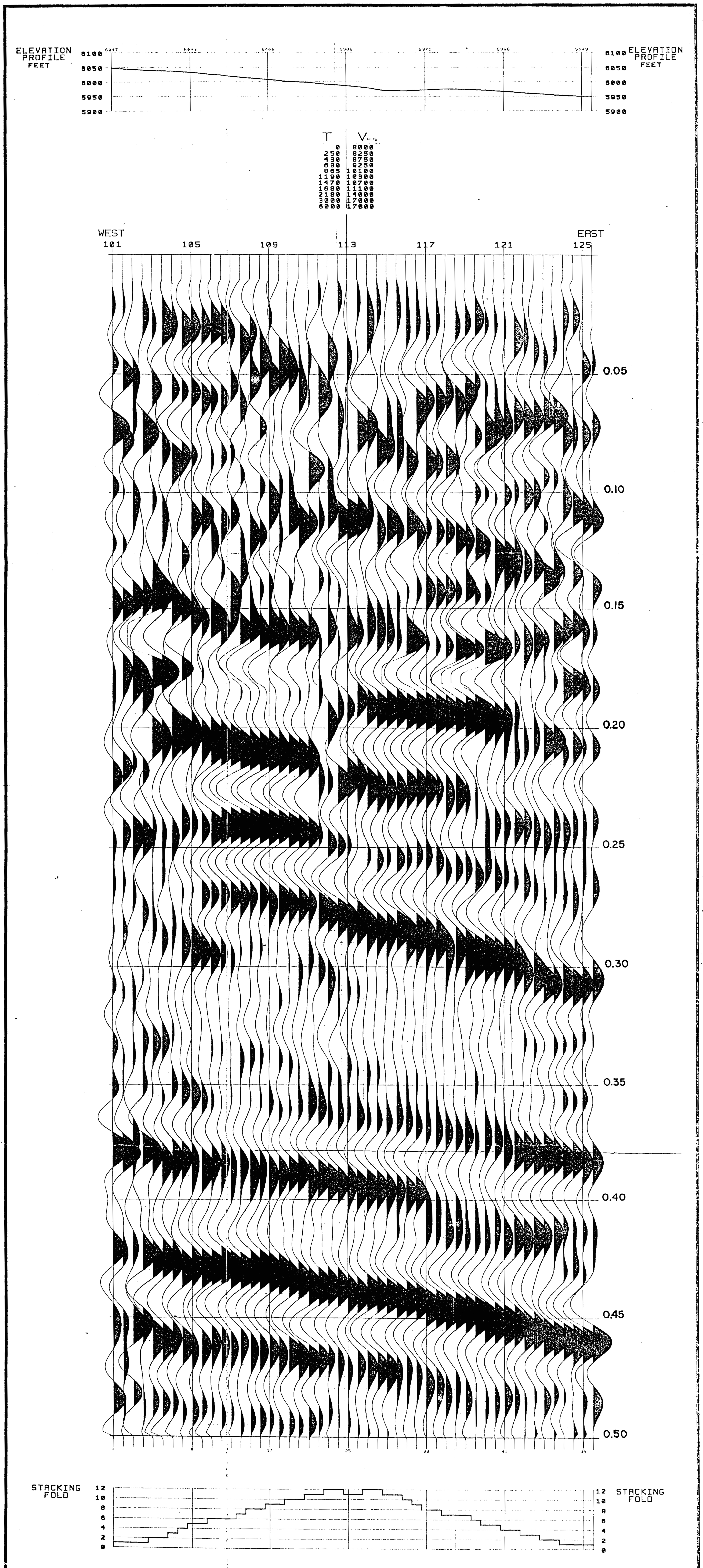

EBASCO ENVIRONMENTAL, INC.

CENTRAL AVENUE
LINE 6

FINAL STACK
REVERSE POLARITY

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NORMAL TRACE SPREAD IS 24 CHANNELS SHOT THROUGH THE CABLE

DISPLAY PARAMETERS

TRACES/INCH 6 INCHES/SECOND 40

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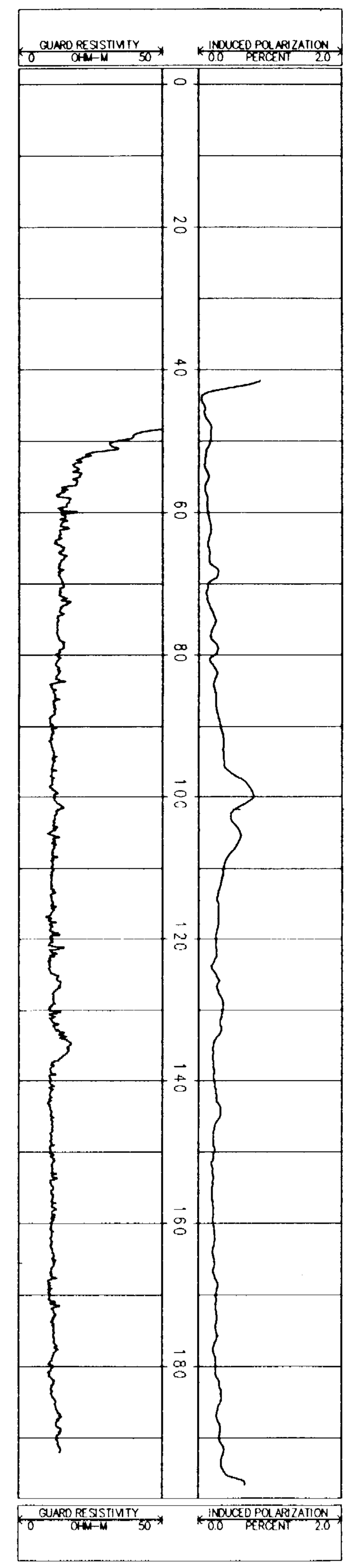
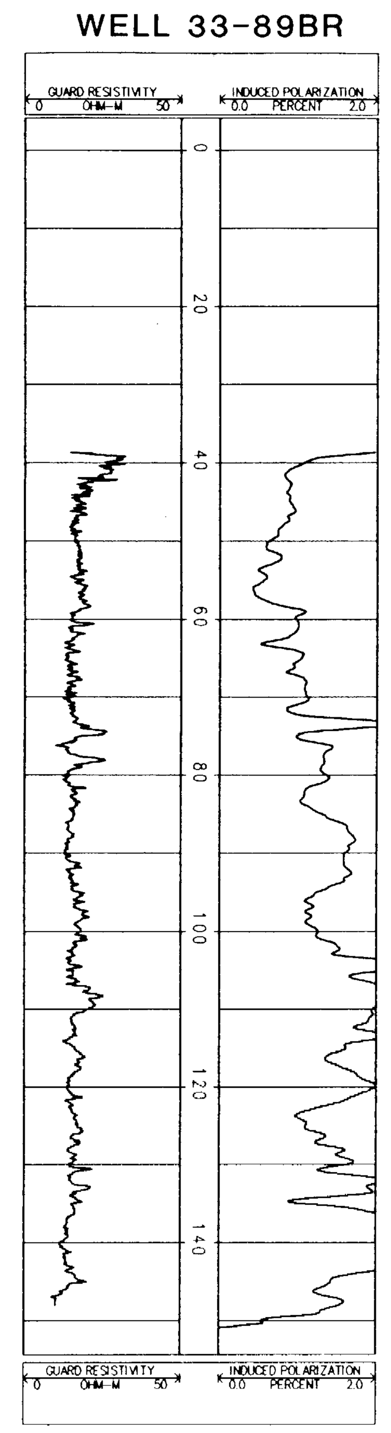
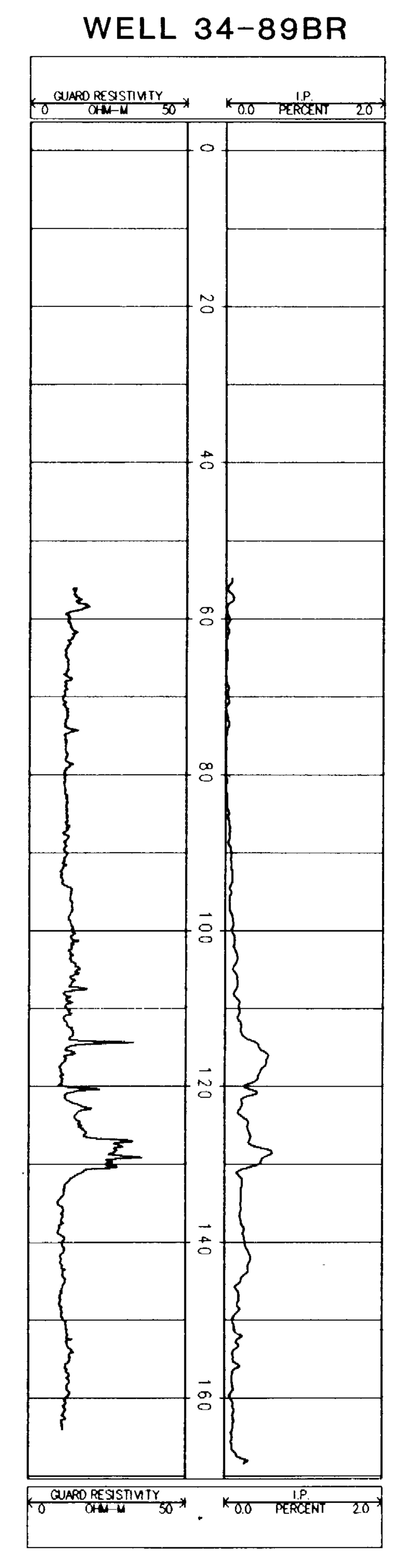






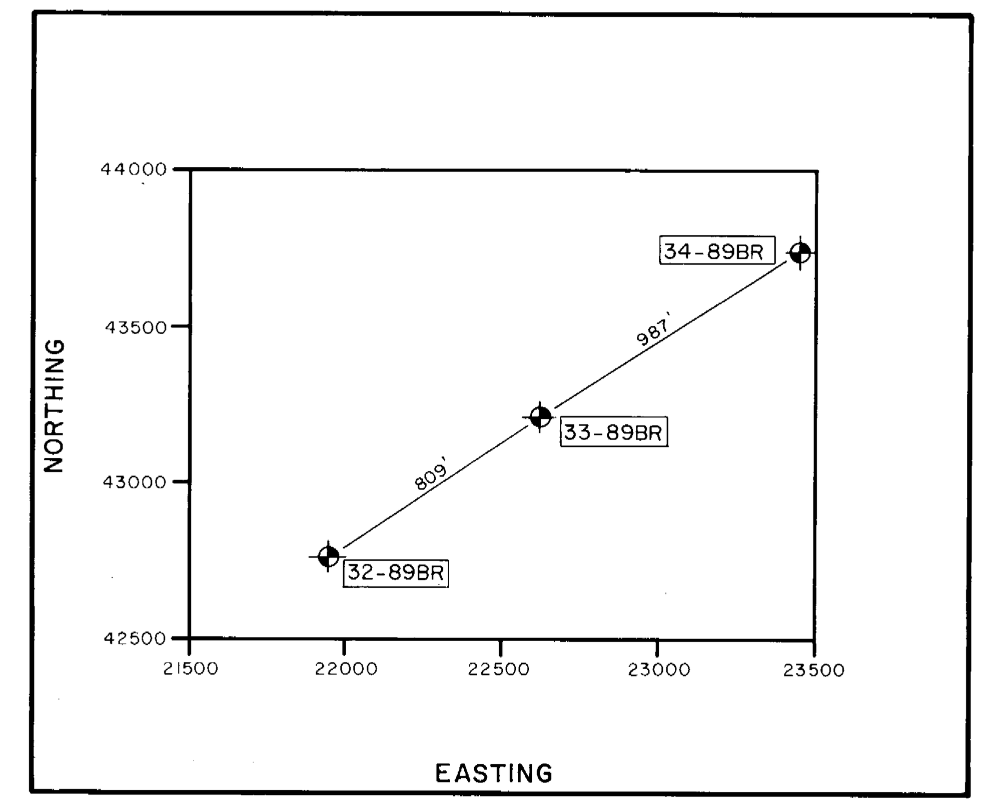


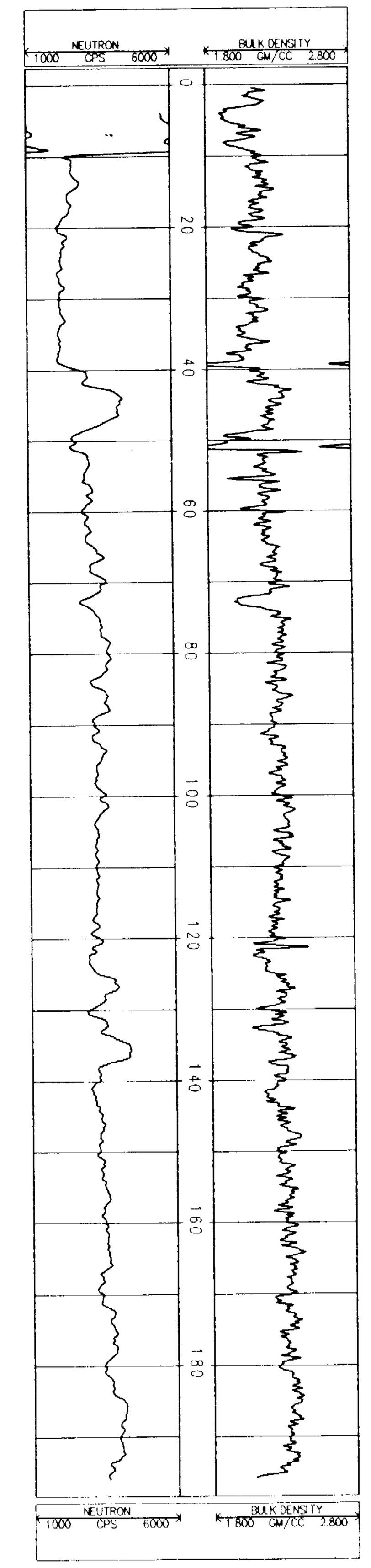
PLATE NO. 5

ROCKWELL INTERNATIONAL
ROCKY FLATS PLANT - GOLDEN, COLORADO
WELLS 32-89BR, 33-89BR, 34-89BR
GUARD RESISTIVITY - I.P. COMPARISON

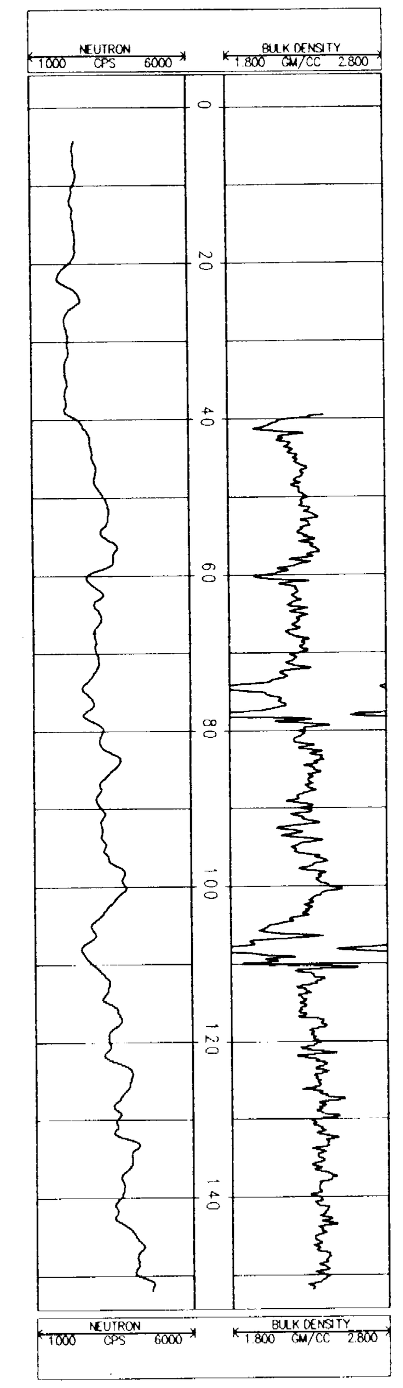
ENGINEERS: Roy F. Weston
Lakewood, Colorado

COLOG INC.
Golden, Colorado

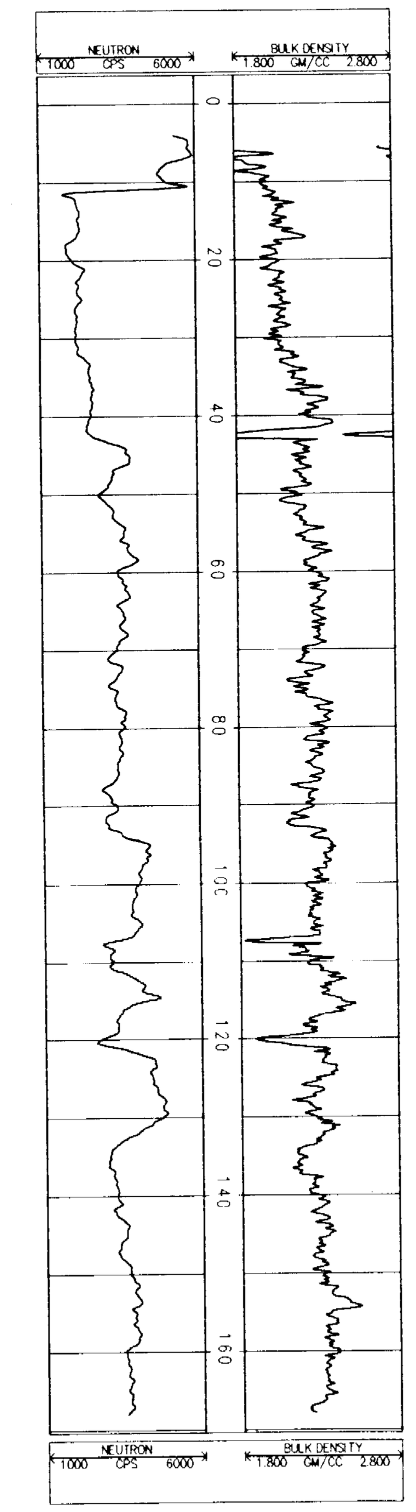
WELL 32-89BR



WELL 33-89BR



WELL 34-89BR



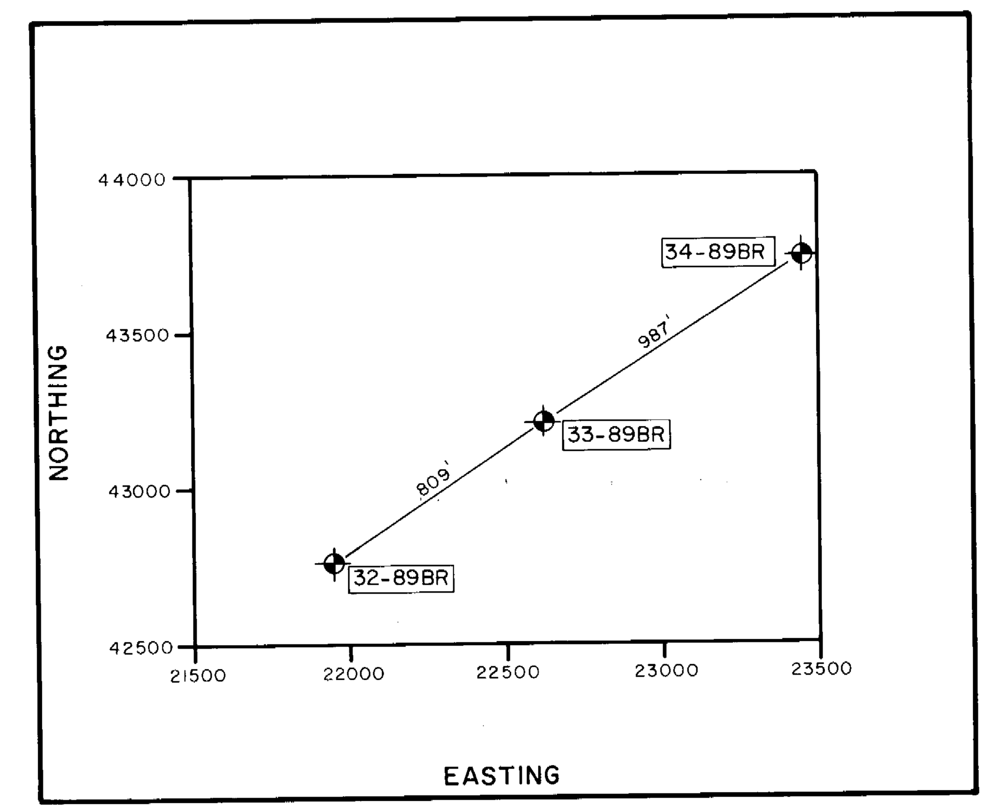
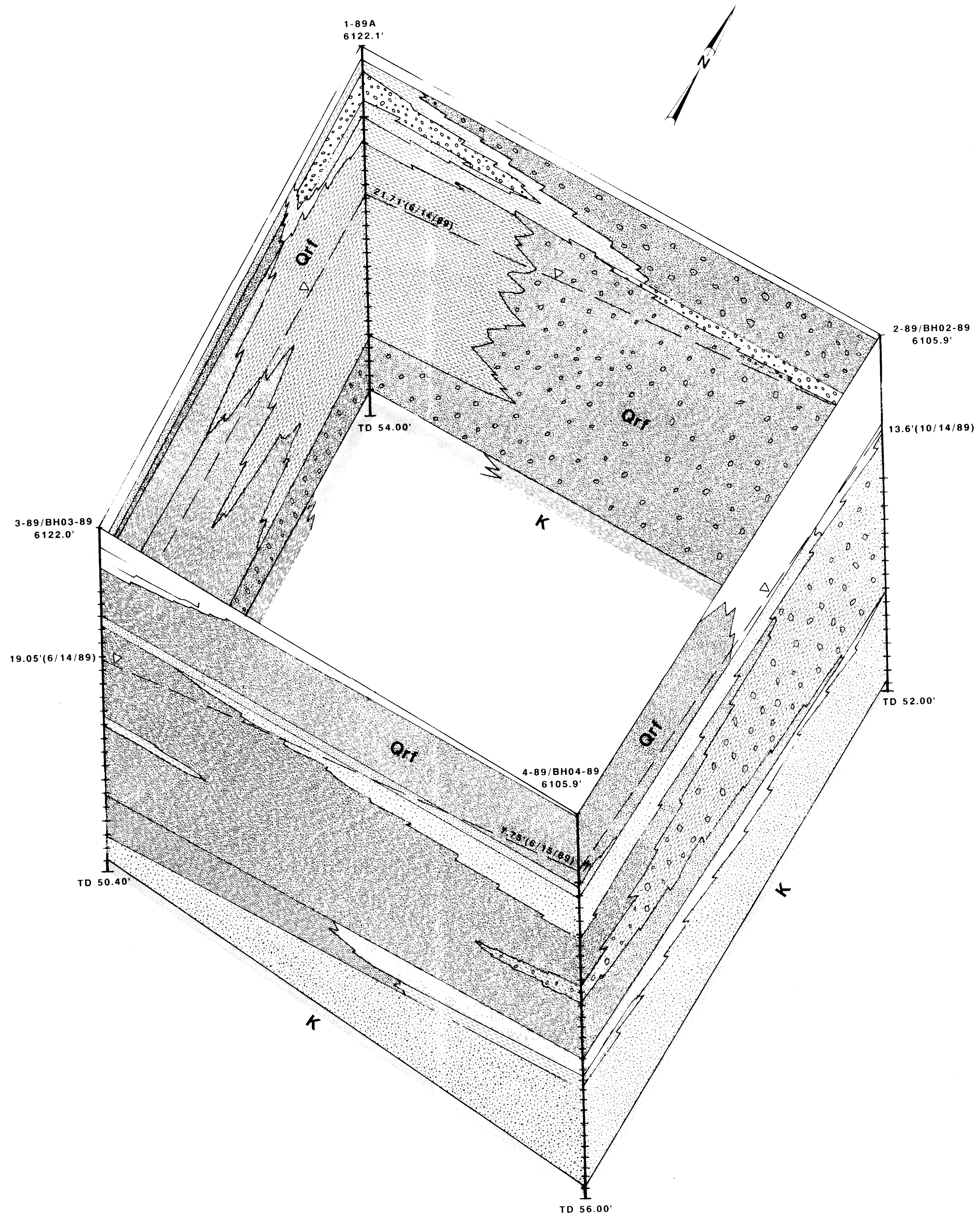


PLATE NO. 4

ROCKWELL INTERNATIONAL
ROCKY FLATS PLANT - GOLDEN, COLORADO
WELLS 32-89BR, 33-89BR, 34-89BR
NEUTRON - DENSITY COMPARISON

ENGINEERS: Roy F. Weston
Lakewood, Colorado

COLOG INC.
Golden, Colorado



EXPLANATION

2-87/BH3-87 Well/Borehole Identification
5930.56' Ground Surface Elevation (Surveyed)

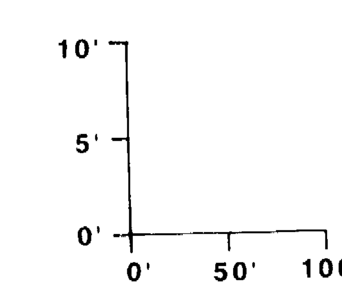
Water Level (Measured / /)
Geologic Contact (Querried where inferred. Dashed where approximately located.)
Screened Interval

TD 16.00' Total Depth Drilled

QUATERNARY
Qt Terrace
Qd Disturbed Ground
Qc Colluvium
Qrf Rocky Flats Alluvium
Qal Alluvium

CRETACEOUS
K Undiferentiated Cretaceous Claystone
Kss Undiferentiated Cretaceous Sandstone

Clay
Clayey Sand or Sandy Clay
Cobbles and/or Gravel
Sand and Sandstone
Sand and Gravel
Silt or Siltstone
Claystone



SCALE

Vertical Exaggeration 10x

WESTON MANAGERS DESIGNERS/CONSULTANTS
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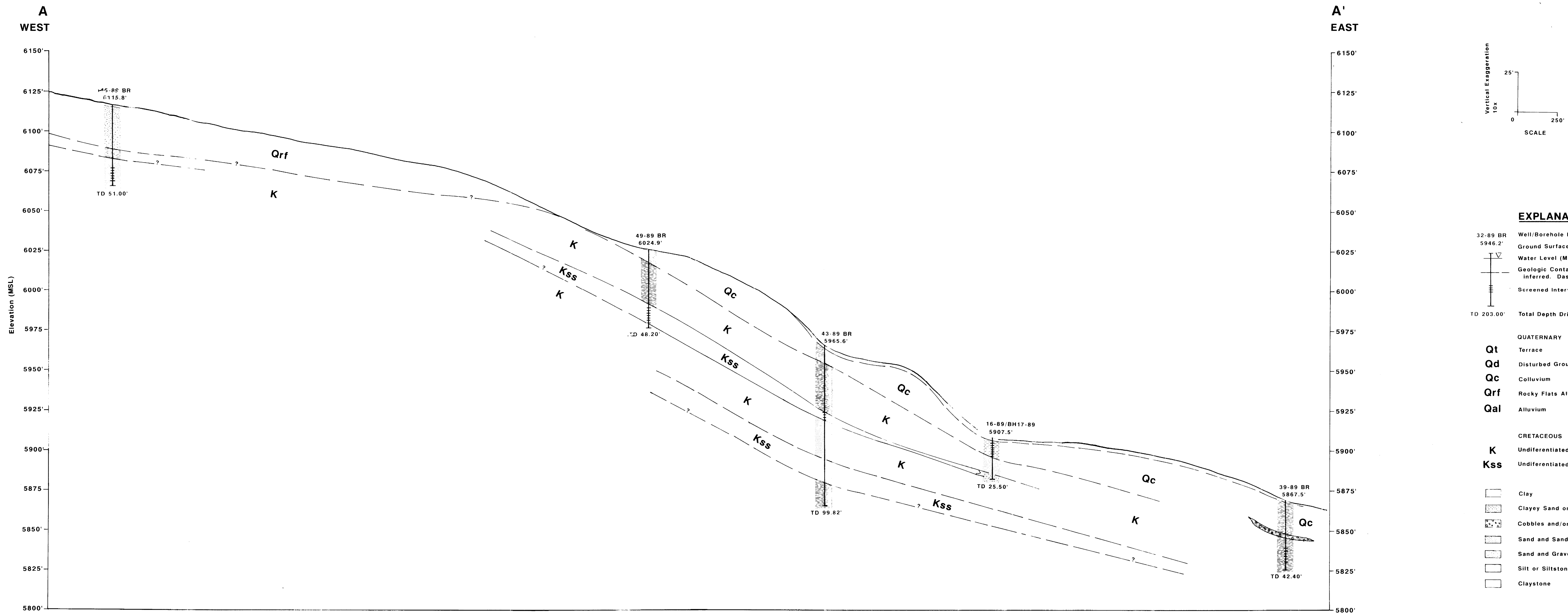
ROCKWELL INTERNATIONAL
Rocky Flats Plant
Golden, Colorado

Plate 3

Background Geochemical Characterization Report

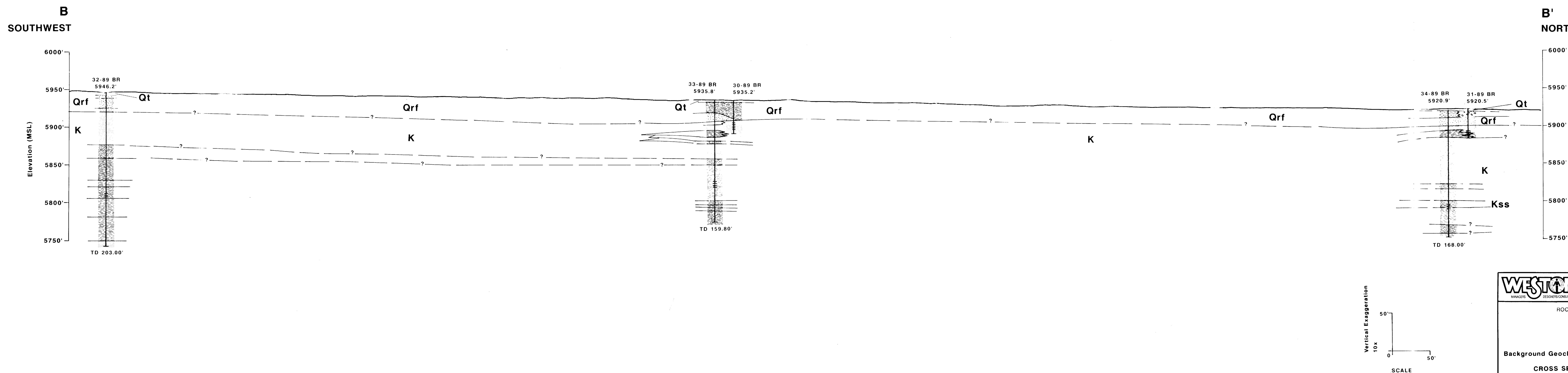
FENCE DIAGRAM

October, 1989



EXPLANATION

32-89 BR	Well/Borehole Identification
5946.2'	Ground Surface Elevation (Surveyed)
▽	Water Level (Measured / /)
– –	Geologic Contact (Querried where inferred. Dashed where approximately located.)
	Screened Interval
TD 203.00'	Total Depth Drilled
	QUATERNARY
Qt	Terrace
Qd	Disturbed Ground
Qc	Colluvium
Qrf	Rocky Flats Alluvium
Qal	Alluvium
	CRETACEOUS
K	Undifferentiated Cretaceous Claystone
Kss	Undifferentiated Cretaceous Sandstone
	Clay
	Clayey Sand or Sandy Clay
	Cobbles and/or Gravel
	Sand and Sandstone
	Sand and Gravel
	Silt or Siltstone
	Claystone



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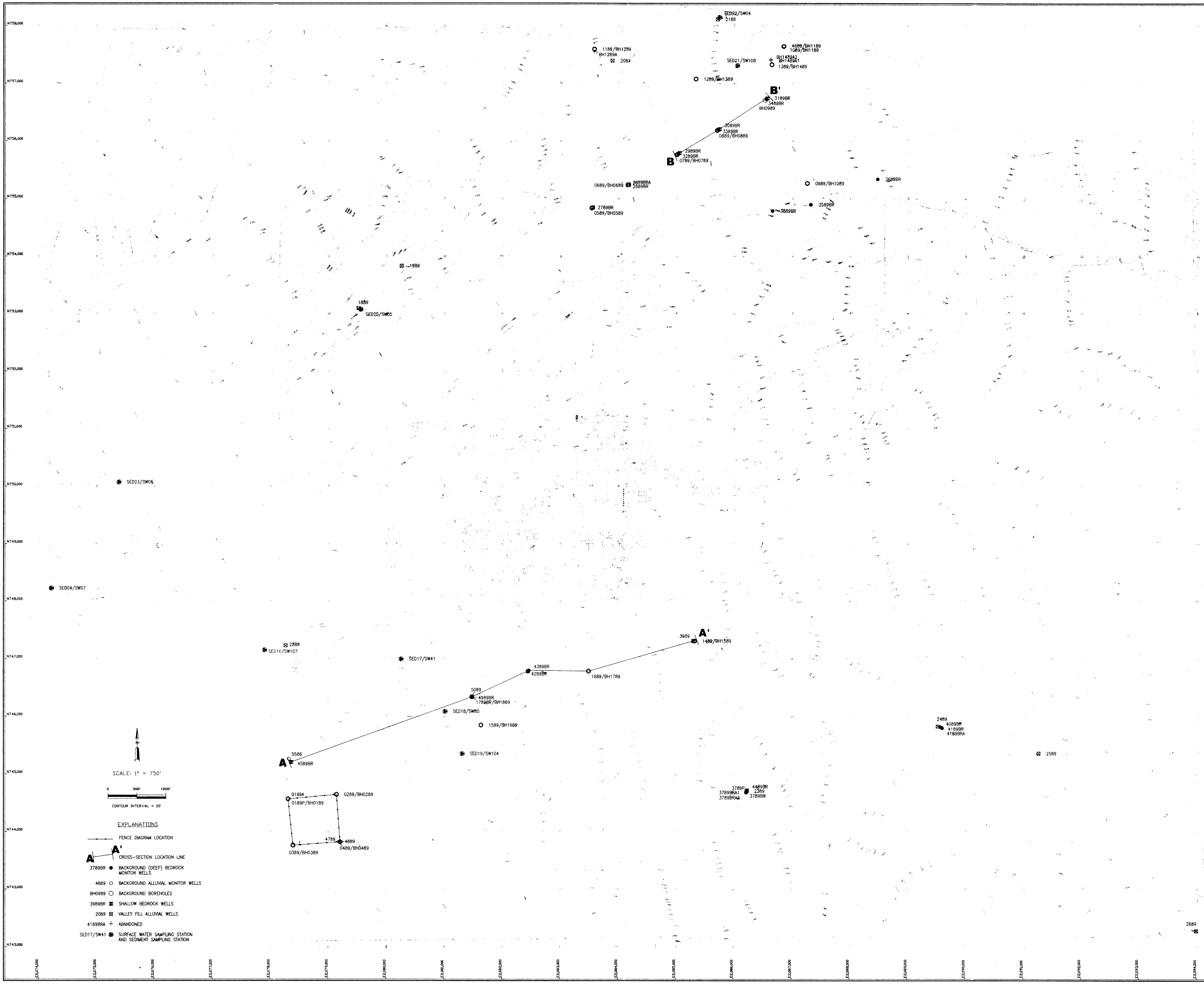
Rocky Flats Plant
Golden, Colorado

Plate 2

Background Geochemical Characterization Report

CROSS SECTIONS A-A' and B-B'

October, 1989



NO. | DATE | REVISION

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ROCKWELL INTERNATIONAL
Rocky Flats Plant
Golden, Colorado

Plate 1

1989 BACKGROUND SURFACE WATER, SEDIMENT, BOREHOLE, MONITOR WELL LOCATIONS, AND CROSS-SECTION LOCATION LINES

RF750A-092889XB