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REFRACTION SURVEYS AT THE SHELL
OIL COMPANY'S OIL SHALE PROJECT-
PICEANCE CREEK BASIN, COLORADO

July 1972

Prepared for the U.S. Atomic Energy Commission

Nevada Operations Office

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Earth Sciences
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LAS VEGAS,
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REFRACTION SURVEYS AT THE SHELL OIL COMPANY'S OIL SHALE PROJECT - PICEANCE CREEK BASIN, COLORADO

K. C. Bayer and R. Navarro

A refraction survey was made at the Shell Oil Company's oil shale project located 28.5 miles southeast of Rangely, Colorado. The thickness of the alluvium layer at the site ranged from 6 ft to 24 ft, with an average depth of 18 ft. The average propagational velocities of the low and high velocity layers were 1140 ft/sec (V_1) and 4640 ft/sec (V_2) respectively. The apparent dip of the $V_1 - V_2$ and $V_2 - V_3$ interfaces was less than 5 degrees in every instance.

1. INTRODUCTION

Seismic refraction surveys were conducted at the Colorado Oil Shale Project of the Shell Oil Company. The oil shale project is located on ten acres of land in the Piceance Creek Basin, leased by the Shell Oil Company from the Marathon Oil Company. Figure 1 shows the general location of the Shell Company installation. The surface elevation at the site is 6075 ft above sea level. The oil shale project is located 28.5 mi southeast of Rangely, Colorado, and 10.6 mi northeast of the proposed Project Rio Blanco site. The surveys were made during November 1971 by the Nevada Special Projects Party of the Earth Sciences Laboratories (ESL) for the U. S. Atomic Energy Commission's Nevada Operations Office (AEC/NV).

Data obtained from the surveys will be used as an aid for the prediction of structural behavior and ground motions resulting from Project Rio Blanco, currently scheduled for the latter part of 1972. Rio Blanco will be the first multiple-explosive Plowshare experiment to stimulate natural gas production from gas-bearing sandstones in the Piceance Creek Basin in Rio Blanco County, Colorado. The experiment will use three 30-kiloton explosives spaced vertically and detonated simultaneously in a single well-bore to fracture a thick section of gas-bearing sands.

Two previous projects, Gasbuggy and Rulison, were single-detonation Plowshare experiments to test the feasibility of stimulating natural gas production utilizing nuclear explosives. Gasbuggy was detonated in 1967 in the San Juan Basin, New Mexico. Rulison was detonated in 1969 in the Piceance Creek Basin, Colorado, about 35 mi southeast of the proposed Rio Blanco experimental site (fig. 1).

Many areas near the Rulison and Rio Blanco sites are covered with relatively thin alluvial layers which can sometimes cause ground motions to be amplified. The amount of amplification and the frequency at which it occurs depends, among other factors, on the thickness of the surface layers and the velocity contrast between the underlying layers (Davis and Murphy, 1967; Foote, et al., 1970).

In the previous two experiments, Projects Gasbuggy and Rulison, the ESL conducted shallow refraction surveys at locations of interest near the project sites and made measurements of ground motion and structural response resulting from the detonations (Navarro, 1968; Navarro and Wuollet, 1969; Weetman et al., 1969). The geophysical information obtained from the refraction surveys was correlated by John A. Blume and Associates Research Division (JABARD) with damage claims which resulted from the experiments (Blume, 1969). The resulting damage-prediction methods will be refined by JABARD for the Rio Blanco Project using the refraction data (Blume, 1969). The refraction data will also be used as input parameters by Environmental Research Corporation (ERC) to refine ground-motion prediction models (Foote et al., 1970). The ESL will make seismic measurement recordings of motions resulting from Project Rio Blanco. Depending on permission being granted by the Shell Oil Company, the plant will be one of more than ten sites to be instrumented with seismic systems for Project Rio Blanco.

This is the third in a series of three technical memoranda that presents the data obtained from the refraction surveys conducted in different parts of Colorado. The first memorandum gave the refraction survey data from Grand Valley, Silt, and the Equity Oil Company Plant (Navarro and King, 1972). The second presented the refraction survey data from Rifle (Navarro et al., 1972).

Figure 1. Map of northwest Colorado.

2. INSTRUMENTATION AND PROCEDURE

2.1 Instrumentation

The Bison signal enhancement seismograph, Model 1570B, was used in conducting the shallow refraction surveys at the Shell Oil Company oil shale project. The main components of the self-contained portable system are the electronic storage and display unit, a high-output geophone, a 10-lb hammer with impact switch, an aluminum striking plate, and associated cables.

The principle of operation rests on the idea that in-phase (coherent) seismic signals from successive hammer impacts at any individual hammer station are added together and stored within the electronic memory of the instrument. Extraneous vibrations from traffic, machines, wind, etc., arriving at random times (incoherent noise) will tend to cancel when summed (Bison, 1971).

The operator observes the summed signal at all times, and with the gain controls, can enhance the true seismic signal. Successive time measurements at increasing source-to-receiver distances can be interpreted in terms of seismic velocities and subsurface structure (see Appendix). The depth limit of penetration is controlled by the energy source (hammer impacts) used. The depth limit of penetration of the survey is equal to one-half the distance from the geophone to the energy source.

2.2 Procedure

The refraction survey site was selected in terms of relative sensitivity to possible frequency dependent amplification of ground motion resulting from the Rio Blanco Project. The procedure employed standard methods for surface seismic refraction investigations. The schematic diagram in the Appendix displays the refraction array of the hammer (source) impact positions, the seismic energy travel paths for a one-layer condition, and the graphical determination of layer velocities. Also, below the illustration is the equation used to determine depths. The terms as defined in the Appendix are used throughout this memorandum. Because of

the inherent inaccuracies in instrumentation and field techniques, the propagational velocities and depths from the table were rounded off throughout the text to the nearest 5 ft/sec and 1 ft, respectively.

The refraction lines were carefully conducted to prevent interference with the functions of the plant. They were also located in such a way that the elevation differences were minimal. Ten-foot spacings were used on all lines and reversed profiles were programed for each line. The refraction lines at each site were numbered in the order in which they were conducted and the abbreviation "RB" for Rio Blanco prefixed each number. In table 1 on the "traverse" column the directions of the refraction lines are given in the same order as the "forward" and "reversed" profiles were conducted. For example the RB-2 "S→N" is given which means the "forward" profile was started at the "south" end of the line while the "reversed" profile was begun at the "north" end of the line. The arrow indicates the direction in which the "forward" line was surveyed.

Refraction surveys were conducted on five different profiles; two lines (RB-1 and RB-2) traversing north-south and three lines (RB-3, RB-4, and RB-5) traversing east-west. Figure 2 is a generalized sketch of the oil shale plant showing the relative location of the refraction lines.

3. REFRACTION SURVEY RESULTS

Table 1 lists the apparent propagational velocities (V_1 , V_2 , and V_3), depths (D_1 and D_2), and dips of the refractor at the $V_1 - V_2$ and $V_2 - V_3$ velocity interface. The data are given for both the forward and reversed profiles. Figures 3 through 7 are the time-distance graphs and profiles of the five refraction lines (RB-1 through RB-5).

Line RB-1 could not be completed because of buried gas lines nearby. RB-2 was located on 3 to 4 ft of fill above the main area; and therefore, a three-layer condition was encountered. The intermediate layer of RB-2 had an average propagational velocity of 2350 ft/sec and an average thickness of 8 ft. The higher velocity layer (V_3) ranged from 7370 ft/sec to 12,900 ft/sec.

Table 1. Shell Oil Shale Plant Refraction Results

			FORWARD					REVERSED					
Line	Traverse ¹	Length of Line	V ₁	V ₂	D ₁	V ₃	D ₂	V ₁	V ₂	D ₁	V ₃	D ₂	Dip
		ft	ft/sec	ft/sec	ft	ft/sec	ft	ft/sec	ft/sec	ft	ft/sec	ft	deg. & min.
RB-1 ²	N→S	80	1335	-	-	-	-	1335	-	-	-	-	-
RB-2	S→N	100	1000	1935	6.2	12900	31.6	1051	2760	10.0	7370	24.2	2°25' ³ 4°13'
RB-3	W→E	90	976	4000	10.0	-	-	1110	4540	17.1	-	-	4°31'
RB-4	E→W	100	1075	5590	18.2	-	-	1088	4570	17.0	-	-	0°27'
RB-5	E→W	100	1325	4350	23.7	-	-	1110	4790	20.0	-	-	2°7'

¹Azimuth and direction the forward profile was surveyed.

Example: N→S (profile worked from north to south).

²Buried gas lines; survey could not be completed.

³2°25' = Dip first layer; 4°13' = dip second layer.

Abbreviations:

- V₁ = propagational velocity of the first layer, ft/sec
- V₂ = propagational velocity of the second layer, ft/sec
- V₃ = propagational velocity of the third layer, ft/sec
- D₁ = thickness of first layer, feet
- D₂ = thickness of second layer, feet
- Dip = dip of first layer unless otherwise noted
- EW or WE = east-west or west-east
- ft = feet
- ft/sec = feet per second
- NS or SN = north-south or south-north
- RB = Rio Blanco

Figure 2. Sketch of the Shell Oil Company oil shale project with refraction lines and low velocity layer isopach contours.

Figure 3. Time-distance profile of RB-1.

Figure 4. Time-distance graph and profile of RB-2.

Figure 5. Time-distance graph and profile of RB-3.

Figure 6. Time-distance graph and profile of RB-4.

Figure 7. Time-distance graph and profile of RB-5.

The average values of depth and the propagational velocities (V_1 and V_2) for RB-3 through RB-5 were 18 ft, 1140 ft/sec, and 4640 ft/sec, respectively. The thickness of the alluvium layer varies considerably as shown by the isopach contours of figure 2. The alluvium layer tends to be thicker to the northwest, as deep as 32 ft. The apparent dip of the $V_1 - V_2$ and $V_2 - V_3$ interface was found to be less than 5 degrees in every case.

4. ACKNOWLEDGMENTS

Special recognition is due the personnel of the Shell Oil Company concerned with the oil shale project in Colorado for their permission and assistance in conducting the refraction survey work.

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APPENDIX . SCHEMATIC REPRESENTATION OF THE PARAMETERS INVOLVED IN A SEISMIC REFRACTION SURVEY

$$D = \frac{X_c}{2} \sqrt{\frac{v_2 - v_1}{v_2 + v_1}}$$

WHERE D = DEPTH, FEET

X_c = CRITICAL DISTANCE POINT, FEET

v_1 = FIRST LAYERED PROPAGATIONAL VELOCITY, FEET/SEC.

v_2 = SECOND LAYERED PROPAGATIONAL VELOCITY, FEET/ SEC.

SCHEMATIC REPRESENTATION OF
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