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PRELIMINARY RESULTS OF A SEISMIC REFLECTION STUDY IN THE MITCHELL BUTTE QUADRANGLE, OREGON

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Introduction

In September 1974 personnel of the Geophysics Group of Oregon State University, the Department of Earth Sciences of Portland State University, and the Department of Geology of the University of Oregon conducted a geophysical survey of the Vale, Oregon Known Geothermal Resource Area.

Seismic reflection measurements were made during the survey to test the ability of the seismic reflection techniques to provide information on subsurface structure in volcanic areas where geothermal resources commonly occur, to provide seismic velocity and structural constraints for contemporary and continuing gravity and magnetic studies of the area, and to develop new techniques of geophysical exploration for geothermal resources particularly applicable to very complex volcanic terrane. This brief report outlines the preliminary results of the analysis of the seismic reflection measurements made during the survey.

Figure 1 shows the location of four seismic reflection arrays deployed sequentially during the survey. The bars show the location and orientation of the 13,000-foot arrays and the small circles indicate the shot points (SP). A series of charges detonated in cased drill holes 30 feet deep at each shot-point permitted testing of different filter and gain settings.

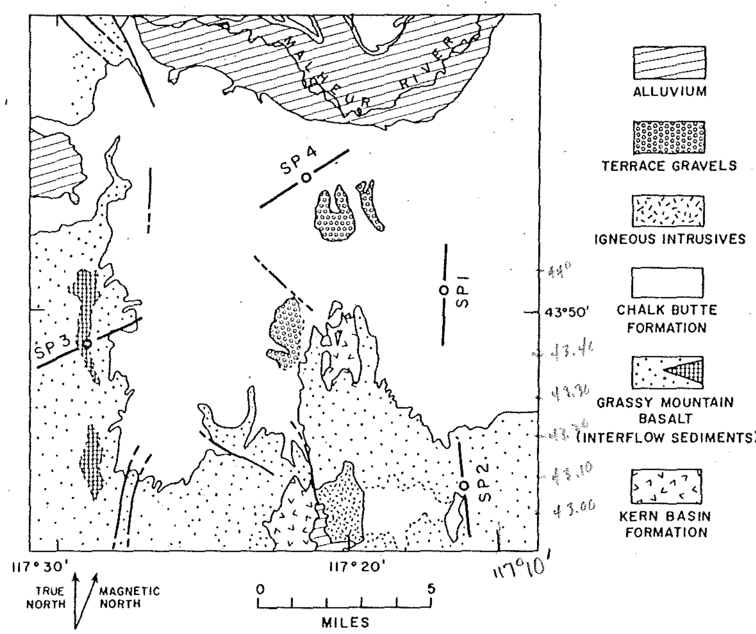

Figure 1. Generalized geologic map of study area near Vale, Oregon showing location of shot points (SP) and seismic array orientations. (Map after Corcoran and others, 1962)

Shallow Refraction Data

Seismic reflection techniques include methods of data reduction which identify both refraction and reflection events present on the records (e.g., Grant and West, 1965). The first arrivals at a sufficient distance from shot points represent critically refracted compressional waves or "head waves." Because instrument gains were high during the field measurements it was possible in most cases to pick refraction arrivals on the original records.

Figure 2 shows plots of time of first arrival versus distance from the shot point for the four seismic lines and the surface topography along the seismic reflection array. Time corrections for topography were not made in this preliminary analysis because data on seismic velocity and variations in thickness of the near-surface weathered zone were not available. The data points plotted in Figure 2, however, are very nearly linear. Analysis of the refraction data in Figure 2 gives the subsurface layer thicknesses and velocities listed in Table 1.

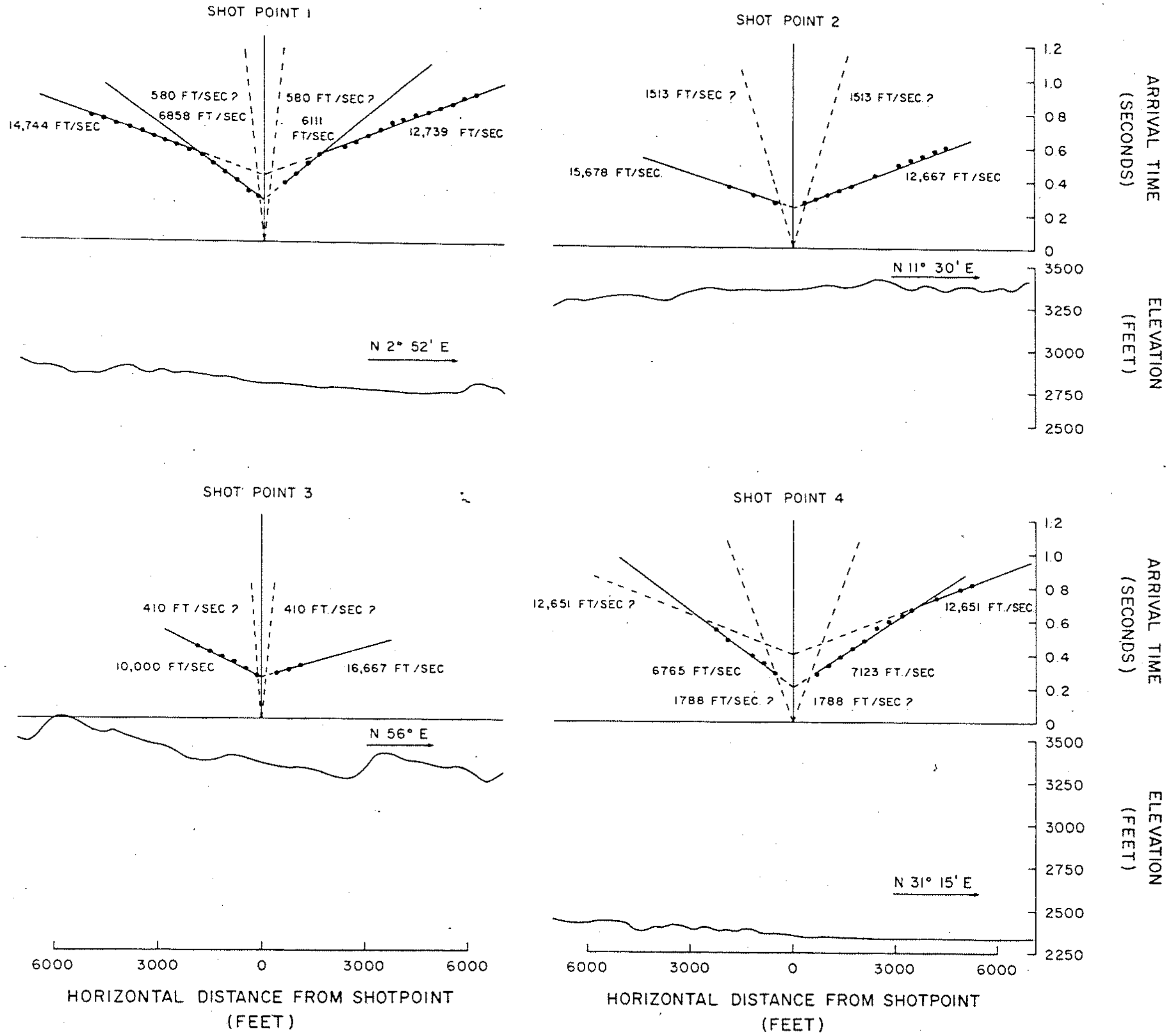

Figure 2. Topography and travel-time curves along seismic reflection lines 1, 2, 3 and 4. Points along the T-T curves represent first arrivals of refracted waves.

Table 1. Layer velocities and thickness from seismic refraction measurements

	Layer	Velocity ft/sec	Thickness ft
Line 1	1	580	70
	2	6,463	540
	3	13,664	-
Line 2	1	1,513	183
	2	14,011	-
Line 3	1	410	50
	2	12,500	-
Line 4	1	1,788	199
	2	6,939	767
	3	12,651	-

The first layer in each case is the thin zone of weathered material at the surface. On all records the first motion of the trace nearest the shot point results from a refraction at the interface immediately below this zone (Figure 2). Thus, the direct wave from the shot through the weathered zone was not recorded as a first arrival. It was necessary, therefore, to estimate the velocity of the weathered zone by extrapolating the travel-time curve from the value at the closest geophone to time zero. The reciprocal of the slope of this line provides an upper limit to the velocity of the weathered zone. Because calculated thicknesses are directly related to calculated velocities, the thicknesses shown for the first layer represent maximum estimates. On lines 2 and 4, for example, the calculated maximum thickness of the weathered zone is 200 feet but the actual thickness may be considerably less.

Velocities calculated for the weathered layer are extremely low. Lester (1932) and Domenico (1974) discuss low velocities observed in loose unconsolidated material above the water table. They verify by theory and actual observation that velocities less than that of sound waves in air (1,180 ft/sec) are possible in loose material containing air in a free state. The amount of air can be less than 1 percent of the total material and still produce the velocities calculated for the surface layer in this study. This is consistent with the near-surface soil conditions during the field study.

Below the weathered zone velocities expected for consolidated materials are observed. On lines 1 and 4, layer 2 has a velocity between 6,000 and 7,000 ft/sec. This is a typical velocity observed in lithified sediments. Below this and immediately below the weathered zone on lines 2 and 3, velocities from 12,000 to 14,000 ft/sec appear abruptly. It seems apparent that these higher velocities represent the basalt which crops out on lines 2 and 3 (see Figure 1).

On line 1, 70 feet of weathered material and 540 feet of sediment overlie the basalt. An analysis of measurements of the Earth's total magnetic field made along the reflection array indicate a surface source along lines 2 and 3 and suggest a depth to magnetic basement of 500 to 700 feet along line 1. The total 610 feet of sediment on line 1 calculated from the refraction data is in good agreement with the depth calculated from the magnetic data.

Though data quality is poor, reflection events are present and are indicated by dots on the records. The change in curvature from one hyperbola to a later one

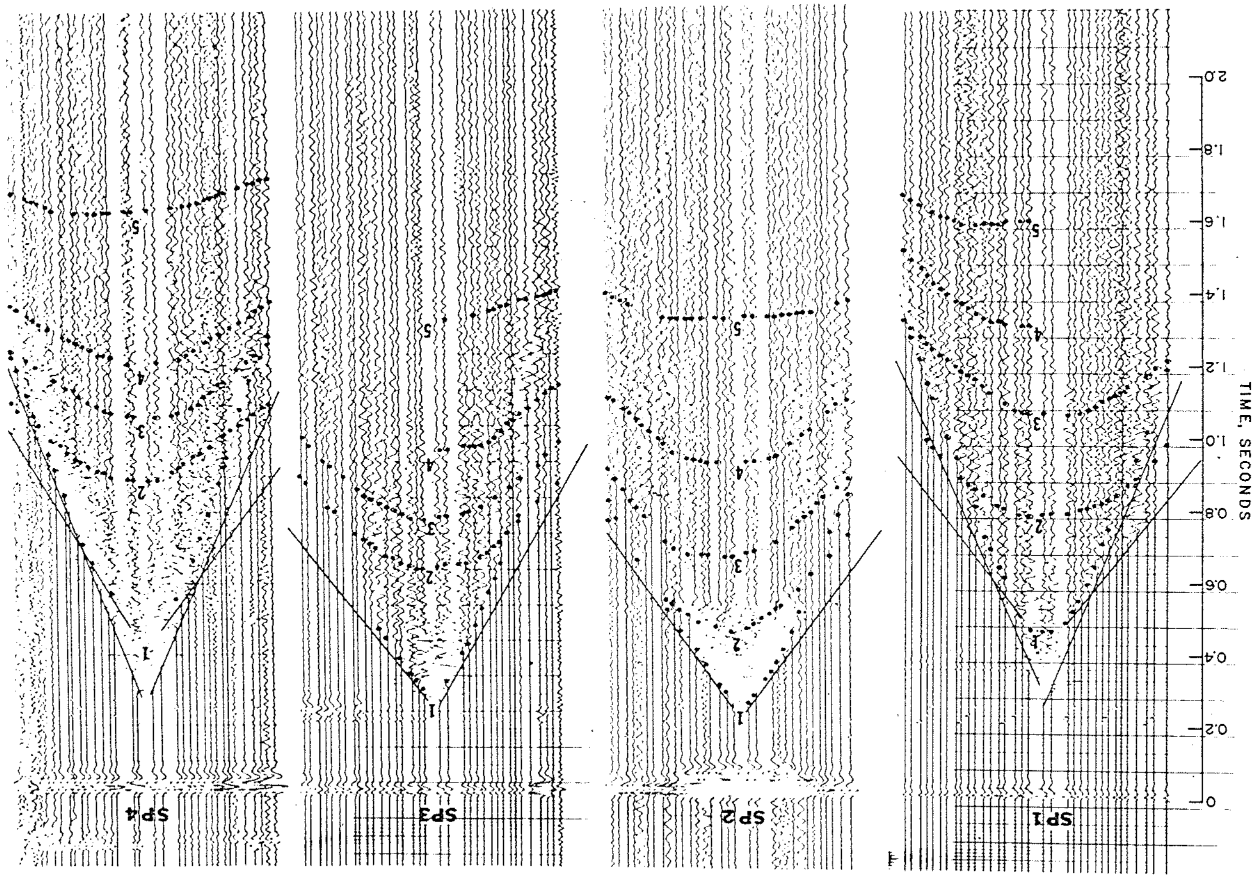

Figure 3. Filtered reflection records obtained at SP 1, 2, 3, and 4. Solid lines represent refracted arrivals and dots represent arrivals of reflected waves.

is a function of the average velocity and thickness of material between the corresponding reflecting interfaces. The interval velocities and thicknesses were estimated using the T^2-X^2 technique (see Grant and West, 1965, p. 141-148). In most instances, it was possible to trace hyperbolas across both sides of the records. Interval velocities and thicknesses were calculated from both sides of the record for the same interval and then averaged. When, because of lack of coherent reflections, it was not possible to extend a hyperbola to both sides of the record, only the interpretable side of the record was used (e.g., see reflectors 4 and 5 on shot point 1). The five reflection events which are consistent for all four shot points are identified by dots in Figure 3.

Table 2 shows results of the analysis of the reflection records. Interval A is the interval between reflectors 1 and 2, B is between 2 and 3, C is between 3 and 4, and D is between reflectors 4 and 5. The calculated velocities of each of the intervals are correlatable from shot point to shot point. The cross sections shown in Figures 4, 5, and 6 use calculated thicknesses for each interval. Refraction evidence discussed earlier was used for the upper layers on each line. The approximate bottom to the weathered zone is shown by a wavy line just below the surface on each section. Dips in each instance are low, and thicknesses between shot points are consistent.

Table 2. Interval velocities and layer thicknesses from seismic reflection measurements

	Velocities (ft/sec)			
	Interval			
	A	B	C	D
Line 1	14,028	7,193	8,772	25,000
Line 2	12,415	9,283	9,176	22,491
Line 3	11,430	8,229	8,375	18,344
Line 4	14,225	8,151	8,586	19,230

	Thicknesses (ft)			
	A	B	C	D
Line 1	2,168	1,035	1,101	3,600
Line 2	1,220	823	1,266	4,376
Line 3	2,110	568	770	3,320
Line 4	2,670	793	773	3,809

The marked contrast of velocities between intervals has definite lithologic implications. Table 3 shows a suggested relation between the seismic intervals discussed here and the stratigraphic sequence of Corcoran and others (1962) for the Mitchell Butte quadrangle.

It is emphasized that not all reflectors chosen in this investigation are contacts between geologic formations. Velocities calculated are interval velocities and are therefore an average of a large thickness of material. Formations mentioned which are predominantly sediment also may contain thin interbedded basalts. These basalts presumably have velocities much higher than the surrounding sediment. The entire

Table 3. Seismic velocity intervals and suggested lithology

Interval	Approx. velocity (ft/sec)	Approx. thickness (ft)	Suggested lithology	Stratigraphic sequence*
Layer 2 from refraction on lines 1 and 4	6-7,000	At least 750	Sediment	Chalk Butte Fm.
A	11-14,000	2-3,000	Basalt	Grassy Mtn. Basalt
B and C	7-9,000	$1\frac{1}{2}$-2,000	Sediment	Kern Basin Fm. Deer Butte Fm.
D	18-25,000	3-4,000	Basalt	Owyhee Basalt
				Sucker Creek Fm.

* From Corcoran and others 1962

formation, however, will show an average velocity close to that of sediment. Likewise, basalt formations with thin interbedded sediments will have a velocity characteristic of basalt when large thicknesses are considered. These interbedded layers are important, though, because they represent sharp changes in lithology and are therefore capable of producing strong reflections. This implies that reflectors may represent sharp lithologic changes within geologic formations and are not necessarily the actual contacts between geologic formations.

Figure 1 is a portion of the geologic map of the Mitchell Butte quadrangle compiled by Corcoran and others (1962). The four seismic reflection lines have been added to the map. Lines 1 and 4 rest upon Chalk Butte sediments whereas older Grassy Mountain Basalt is at the surface on line 2 and 3. Generally, beds at the surface near the lines dip in a northeasterly direction toward the Snake River Basin.

The three cross sections (Figures 4, 5, and 6) are in good agreement with an extrapolation downward of the surface geology. In Figure 4 it is seen that material with a seismic velocity of 12,415 ft/sec (i.e., basalt) crops out on line 2 and shows an apparent dip of about 3.3° to the north. On line 1 about 600 feet of sediment overlies the basalt. Figure 4 shows that the sediment at the surface on line 1 has an apparent dip of approximately 1.8° in a northwesterly direction toward line 4. Since the geologic map shows that the center of line 4 is approximately on strike with the center of line 1, this low apparent dip is reasonable. Basalt with a seismic velocity of 11,430 ft/sec is seen at the surface on line 3. Figure 6 shows that this basalt has an apparent northeasterly dip of approximately 2.4° toward line 4. Again, this is in agreement with the geologic map.

Below the Chalk Butte sediments and the Grassy Mountain Basalt, correlations on the three cross sections all tend to indicate that the low dip toward the Snake River Basin continues. Below about 2,500 feet of Grassy Mountain Basalt, approximately 2,000 feet of lower-velocity material is encountered. This interval probably represents the Kern Basin and Deer Butte Formations, which are both predominantly sediment.

The deepest interval investigated consists of approximately 4,000 feet of very high-velocity material (approximately 20,000 ft/sec). Following the stratigraphic sequence outlined by Corcoran and others (1962), this material corresponds to the Owyhee Basalt. The reflection representing the bottom of this interval (reflector 5)

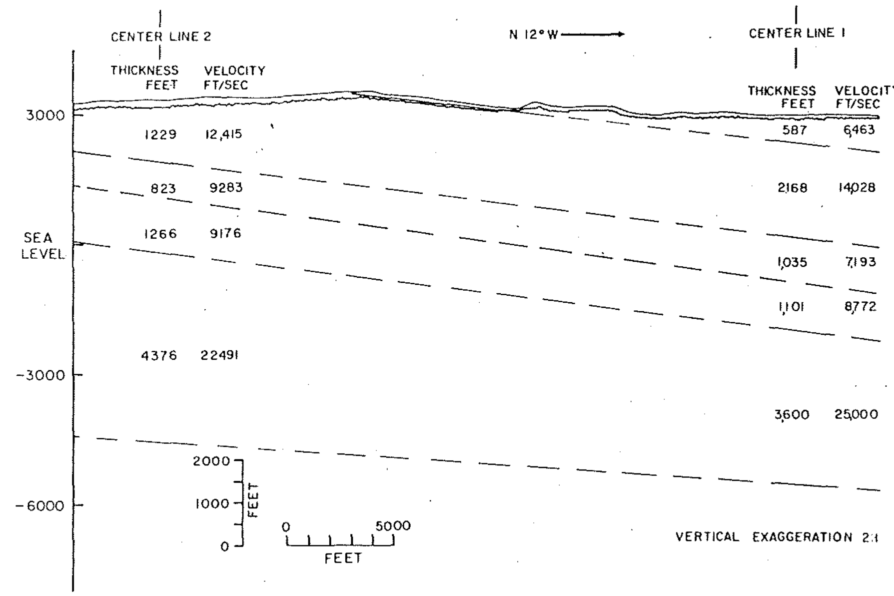

Figure 4. Cross section showing seismic velocities and thicknesses calculated for SP 1 and SP 2.

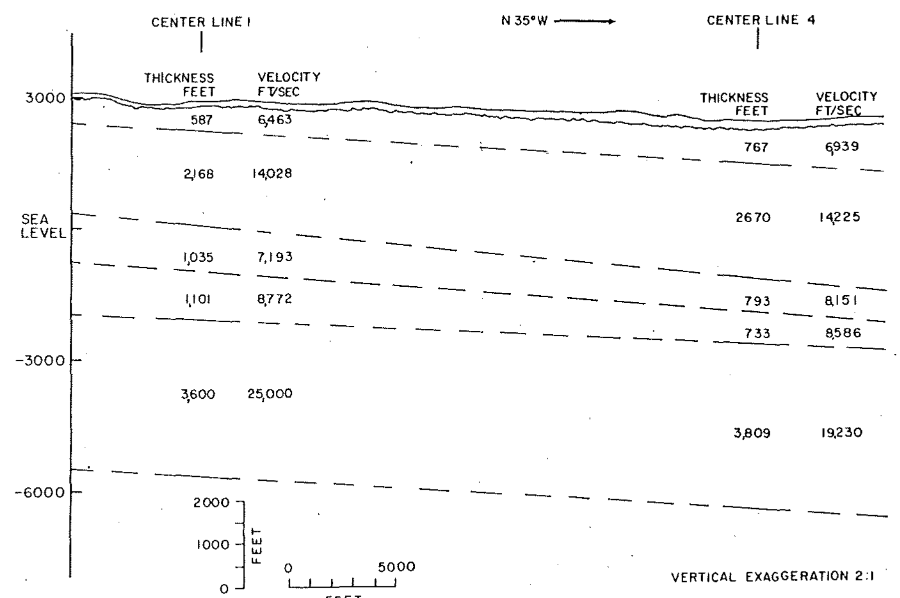

Figure 5. Cross section showing seismic velocities and thicknesses calculated for SP 1 and SP 4.

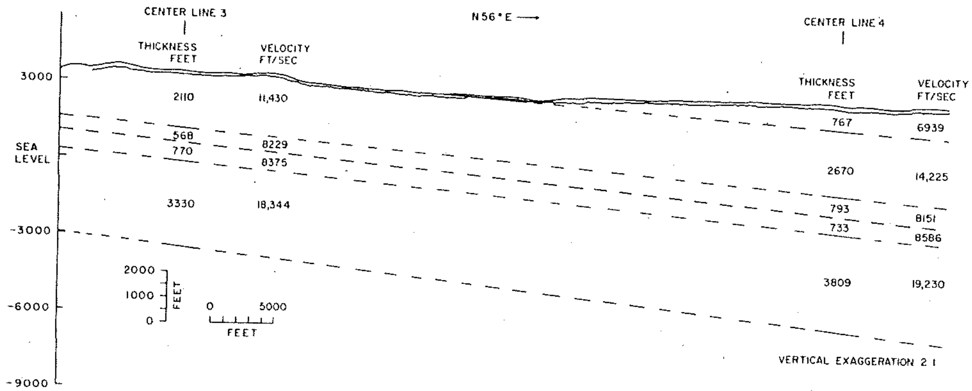

Figure 6. Cross section showing seismic velocities and thicknesses calculated for SP 3 and SP 4.

is very distinct on reflection records 1, 2, and 4. Such a strong reflection is expected in going from massive basalt flows to the underlying sediments of the Sucker Creek Formation. Reflector 5 is therefore believed to be near the top of the Sucker Creek Formation. This puts the limit to the seismic section for this study at a depth of about 9,000 feet.

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