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**Seismic Reconnaissance of the
Los Alamos Scientific Laboratory's
Dry Hot Rock Geothermal Project Area**

by

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SEISMIC RECONNAISSANCE OF THE LOS ALAMOS SCIENTIFIC LABORATORY'S

DRY HOT ROCK GEOTHERMAL PROJECT AREA

by

P. R. Kintzinger and F. G. West

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ABSTRACT

Active seismic methods using high-explosive sources and nondestructive energy sources were used to determine seismic velocities, signal detectability, and subsurface geologic structure in the vicinity of the Los Alamos Scientific Laboratory's (LASL) Dry Hot Rock Geothermal Project area. Positions of several faults have been determined. A synthetic seismogram has been created that shows good agreement with recorded reflection records taken near exploratory borehole GT-2.

INTRODUCTION

Active seismic methods using high-explosive sources, vibrator-generated wave trains of controlled frequencies (Vibroseis*) and impulse-generated wave trains (Dinoseis**), were used to determine seismic velocities and signal detectability, and to delineate subsurface geologic features in the vicinity of the LASL Dry Hot Rock Geothermal Project area. The project area is 3 km (2 miles) west of the ring fault zone associated with the Valles Caldera in the Jemez Mountains of northern New Mexico. Site location is NE 1/4, Sec 13, T19N, R2E NMPM. Land-surface elevation is 2648.7 m (8690 ft).

GT-2 was drilled to a depth of 2932 m (9619 ft) and EE-1 was drilled to a depth of 3064 m (10,053 ft) using drilling procedures and equipment typical of hard-rock drilling. Details of the drilling project are summarized by Pettitt.^{1,2}

GEOLOGY

Faults associated with the Rio Grande rift valley are thought to be the locus of former volcanic activity in the area.³ One group of faults, the Jemez Springs fault zone, is about 5 km (3.1 miles) southeast of the site. The Jemez-Nacimiento

Mountains area has been structurally active to varying degrees since Precambrian time. Structural activity after the last eruption from the Valles Caldera is evident along the Jemez Springs fault zone, the closest known fault being the Virgin Canyon fault.⁴ Drilling information and geophysical logs suggest that fracture zones with unknown displacement were encountered in GT-2.⁵

GT-2 penetrated 137 m (449 ft) of volcanics, 238 m (780 ft) of Permian red beds and 355 m (1165 ft) of Pennsylvanian-Mississippian shales and limestones, before encountering granite at 732 m (2402 ft).⁶ The crystalline Precambrian rocks include granites, granodiorites, monzonites, biotite schist, and amphibolite. The textures range from fine- to coarse-grained and the colors from pink to black.⁵

REFLECTION SEISMIC SURVEY

A reconnaissance reflection seismic survey was done to delineate subsurface geologic features in the vicinity of GT-2 and EE-1 during June and July 1974. Three geophone sensor lines were designed to give reflection data over regions of geologic interest, with a total of 9448 m (30,996 ft) of data developed as shown on the location map, Fig. 1. Field work and interpretation were done by J. W. Cooksley Company.

*Trademark of Continental Oil Company.

**Trademark of Atlantic Richfield Oil Corporation.

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Fig. 1. Seismic reflection lines location map, Fenton Hill Geothermal Project area (scale: 1:32,000).

Geophone spacing of 50 m (164 ft) was used for the survey. At each sensor station a group of six induction-type geophones connected in a parallel series was deployed. The geophones were critically damped for a 7.5-Hz signal and had nearly flat spectral response above 7.5 Hz. Geophones in each group, spaced at 6.1-m (20-ft) intervals--30.5-m (100-ft) group length--could be deployed in various configurations to maximize signal-to-noise ratio for a particular site. During this investigation a circular group pattern was used exclusively in order to accommodate the different shot-point locations and various directions of incidence of seismic energy.

Data were recorded digitally on a Texas Instruments DFS/10,000 seismograph system using a 21-track magnetic tape. The DFS/10,000 is a 24-channel "ganged" gain system, and allows several options for control of the amplifier gains and for band-pass filtering during data recording. During this investigation, an automatic gain control (AGC) recording option was employed in which the amplifier output levels of four operator-selected data channels were averaged and fed back to the gain-control system. The gain-control system then set all amplifier gain levels so that the average four-channel signal level would remain within the dynamic range of the system. The DFS/10,000 system has a maximum dynamic range of 100 dB (5 orders of magnitude) and a maximum gain of 120 dB (amplification of 10^6 times in amplitude).

During the initial phase of the field work, Line 1 was run along the bottom of Lake Fork Canyon utilizing colinear shot points. Experimentation was conducted utilizing various shooting and recording parameters. Data were recorded at various initial and final gains and with filter band passes of various widths to determine the optimum filtering for signal-to-noise enhancement. It was discovered at this time that severe high-amplitude "ground roll" or surface waves emanating from the shot points were overdriving the seismograph's range and causing the gain-control system to reduce the recording levels. As the amplitude of these surface waves could not be sufficiently filtered out during recording, it was decided at this time to modify the shot-sensor geometry and resort to broadside shooting in which the sensor line was run on top of Lake Fork Mesa while the shot points would remain along the bottom of Lake Fork Canyon. The topography of the ground and the

separation of shots and sensors were very effective in attenuating surface waves and allowed the gain-control system to respond to the desired reflected energy.

Through the use of the above-mentioned shooting geometry, a series of 11 reflection-point lines (RPL) was developed forming a continuous seismic profile under Lake Fork Mesa (see RPL 2A on the seismic reflection lines map, Fig. 2). In addition to these, three shot points were employed on the southern arm of the mesa to develop an additional line of reflection points forming a second seismic profile near the eastern end of Sensor Line 2 (see RPL 2B, Fig. 2).

Upon completion of the above work, Sensor Line 3 was deployed in the vicinity of geothermal test hole GT-2 for the purpose of obtaining areal reflection coverage. This was accomplished through the use of 10 shot points spaced at 100- to 200-m (328- to 656-ft) intervals normal to, and on either side of, the sensor line. Four additional shot points were employed along the bottom of Lake Fork Canyon to give extended coverage to the area previously developed.

A final sensor line of 24 stations was deployed in the western end of Lake Fork Canyon, and two shot points were used to give overlapping reflection coverage in this region.

Data Processing

Initial processing consisted of applying corrections to the data to account for the shot point-sensor geometry and for surface topography of the site. The first correction, termed normal moveout (NMO), is designed to allow for the variation in path length (and therefore travel time) between arrivals at sensors near and distant from the shot points. The second correction is termed the static correction and corrects for elevation differences between the sensors and the shot points. All sensor-station data are reduced to a datum elevation, using line-survey data. During this initial processing additional frequency filtering was applied, and through trial of numerous band-pass windows an optimum window was defined which gave the best signal-to-noise ratio. The optimum band pass was then employed during further processing.

One of the processing techniques that was applied to the data in this investigation was deconvolution. The deconvolution process is an attempt to reconstruct what is termed an impulse seismogram. When a dynamite

Fig. 2. Seismic reflection lines LASL geothermal site (scale: 1:32,000).

charge is detonated its reaction duration is a fraction of a millisecond, and ideally it would impart elastic waves into the ground containing nearly equal amplitudes of the component frequencies between 0 and 300 Hz (the maximum band pass of the seismograph system). In reality, the ground does not transmit part of the high-frequency energy, which is lost to shearing and inelastic processes in the ground. In effect, the ground acts as a low-pass filter. The process of deconvolution attempts to restore equal importance to all frequencies represented in the shot impulse over the broadest possible band width. This in effect reconstructs a seismogram as it would appear if the shot were a true impulse containing equal amplitudes of all frequency components. It is an inverse filter process which attempts to restore the transmission losses in the ground. The general result of this processing is an overall increase in the high-frequency content of the seismic signal and a sharpening of the reflected events.

Noise-rejection filtering, also termed velocity filtering, is a processing technique which diminishes coherent seismic energy with a large horizontal component and passes energy with a predominantly vertical component. The effect of this process is to eliminate "noise" such as late-arrival refractions and diffractions which move horizontally along the sensor line and interfere with the vertically traveling reflections arriving at the sensors. Time sections for Line 2 (see Figs. 3 and 4), with and without noise-rejection processing, have been included in this report for comparison. The seismic-geologic interpretations have utilized almost exclusively the noise-filtered data.

After the processed time sections of the data were constructed, a set of time-domain templates was constructed depicting the configuration of strong coherent events (see time-domain templates, Figs. 3-5). These have been reproduced in transparent form, allowing them to be overlain on the processed time sections for comparison. Using a computer program, the discontinuities on the templates were converted from time to depth and plotted as depth profiles. This conversion utilized a velocity function developed during processing and from calculations performed on downhole velocity logs of drill hole GT-2.⁵

The velocity function represents the root-mean-square (RMS) velocity experienced by a seismic wave

TABLE I
VELOCITY FUNCTION

Two-Way Travel Time (s)	RMS Velocity (m/s)	RMS Velocity (ft/s)
0.1	457	1,500
0.2	610	2,000
0.3	914	3,000
0.4	1219	4,000
0.6	1524	5,000
1.0	1829	6,000
1.2	2438	8,000
1.5	3048	10,000
2.0	4572	15,000

of a given two-way travel time on the time-domain sections. The depth of each digitized time point is found by computing a velocity corresponding to its travel time and multiplying half the travel time by this velocity value. The velocity function employed during data processing and depth conversion is given in Table I. Final geologic interpretation was completed employing the depth section of each reflection-point line (see depth sections, Figs. 6-8).

Interpretation

The text that follows concerns the geologic interpretation of seismic data referring to the data contained in Figs. 6-8 of seismic sections accompanying this report. In Figs. 3-5, the interpretational procedure has been illustrated through the use of transparent overlays on the seismic data sections, and the interpreted geologic significance of the events shown is demonstrated on the depth sections in Figs. 6-8 which follow these overlays.

In general, data from this site were characterized by a predominance of strong, continuous, and near-horizontal events in the upper portions of the time-domain sections, while events of a dipping, curved, and usually discontinuous nature predominate in the lower portions of the sections. Particularly on the Line 2 reflection-point lines (RPL), there is a discrete transition between these two regions. This time of transition has been interpreted as the unconformity between the Paleozoic sedimentary section and the Precambrian granitic basement. On the Line 3 data, this transition is somewhat vague on some reflection-point lines. Numerous curved and discontinuous events are observed below this unconformity

Fig. 3. Time-domain sections, Line 2, without noise rejection.

LINE 2B TIME DOMAIN TEMPLATE

LINE 2A TIME DOMAIN TEMPLATE

F&M CONCEPTS, INC.	
F&M CONCEPTS COMPANY	
PROJECT LINE 2	CONTRACT NO. 2-1
FIELD PARAMETERS	
RECORDING BY F&M CONCEPTS COMPANY ENERGY SOURCE SYNTHETIC	
PROCESSING PARAMETERS	
COVERAGE 100 PER CENT S&D BECS 2 MS SPPS RATE SPTLN 8000 FT SPTLN VELOCITY 10000 FT/SEC FILTERING 0.5-100 SEC DECONVOLUTION 0.5-100 SEC OPERATOR LENGTH 800 MS PRECISE TIME 10 MS FILTER TIME VARIANT S&D-DIR 80-90 MS S&D-SID 80-90 MS	
DISPLAY PARAMETERS	
HORIZ. SCALE 2 IN/IN VERT. SCALE 10 IN/SEC POLARITY CODE LEFT+ RIGHT-	
FILE NO. 2-1	DATE COMPLETED NOV 1978

Fig. 3. Time-domain sections, Line 2, without noise rejection.

LINE 2B TIME DOMAIN TEMPLATE

LINE 2A TIME DOMAIN TEMPLATE

GEOSPEC AND GEOSYS CONCEPTS, INC.	
F.O.M. CONSOLE COMPANY	
NAME	CONSOLE BBS
LINE	2
FIELD PARAMETERS	
RECORDED	GEOSYS
BY	F.O.M. CONSOLE COMPANY
SOURCE	SYNTHETIC
PROCESSING PARAMETERS	
COVERAGE	100 PER CENT
S&S SECS	8 MS S&S, RATE
DATA	8000 FT
DATA VELOCITY	10000 FT/SEC
AUTOWAVE	PLACING
RECONVOLUTION	0.0-1.0 SEC
OPERATOR LENGTH	800 MS
PREDICTIVE TIME	10 MS
FILTER	TIME VARIANT
S&S-S&S	80-80 HZ
S&S-S&S	80-80 HZ
PLATE RECONV. SYSTEM	0.0-1.0 SEC
DATA	0.0-1.0 SEC
NOISE REJECTION FILTER	
SYSTEM PARAMETERS	
HORIZ. SCALE	1 IN/20
VERT. SCALE	10 IN/SEC
POLARITY CODE	LEFT: RIGHT
END NO.	1000
DATE COMPLETED	APRIL 1978

Fig. 4. Time-domain sections, Line 2, with noise rejection.

Fig. 5a. Time-domain sections, Line 3.

Fig. 5a. Time-domain sections, Line 3.

Fig. 5b. Time-domain sections, Line 3.

Fig. 5b. Time-domain sections, Line 3.

LINE 2B DEPTH SECTION

LINE 2A DEPTH SECTION

Fig. 6. Depth sections, Line 2 (ft).

Fig. 7. Depth sections, Line 3 (ft).

Fig. 8. Depth sections, Line 3 (ft).

and some may represent intrusive contacts within the granite or zones of magmatic segregation or metamorphism. There is one such event on both RPL 3-5 and 3-6 at a depth of about 1000 m (3281 ft), dipping to the south. This event may correlate with a zone of increased drilling rate indicated on downhole logs of test hole GT-2 at a depth of about 930 m (3050 ft).

Systems of short events aligned along diagonal patterns in the granite may be related to diffracted waves whose horizontal component has been enhanced by the velocity filtering process. These diffractions may be related to faulting in the granite or adjacent Paleozoic units (see next section).

Above the Precambrian unconformity, a set of strong and continuous events delineates the lower section of the Madera and Sandia Formations. Above this region the Abo Formation (Permian) and Upper Madera Formations exhibit a general lack of continuous events. Due to the shooting geometry employed, large angles of incidence of the seismic waves were encountered (angles greater than the critical refraction angle) for shallow geologic units; hence few reflection events were recorded for times less than 0.3 s on any but the near-normal incidence traces of RPL 3-5 and 3-6. For this reason the base of the Bandelier Tuff and the upper portions of the Abo Formation have incomplete reflection coverage.

The interpretation of faulting on seismic sections is characterized by the presence of three possible indicators: (1) offsets in otherwise continuous events; (2) truncation of a sequence of events along a common boundary; and (3) diffracted waves whose origins occur along a common source line.

The offsetting and/or truncation of events along a boundary are straightforward indicators for faulting. The occurrence of diffracted waves is an indirect indicator from which the presence of a fault may be inferred. Diffracted waves originate at the edges of truncated seismic reflectors or at any abrupt horizontal lithologic variation having dimensions on the order of the wave length of the seismic energy. When a set of diffracted waves is observed to have originated along a common line, it may be inferred that the sources are the edges of fault-truncated seismic reflectors.

Conclusions

A geologic model, based on the results of the seismic interpretation and correlation with drill

hole data, is depicted on the depth sections. Faults are shown by solid lines with the inferred displacement indicated. Faults depicted by dashed lines are inferred or approximately located.

Two predominant faults shown on RPLS 2A and 2B, and the left-hand fault shown on RPLS 3-6 and 3-10, have been located on the generalized geologic map of the west rim of the Valles Caldera to indicate possible regional correlation (see Fig. 9). The strike of the north-northeast-trending fault was determined by its location on RPLS 2A and 2B. It is shown extending to the north due to the apparent correlations with a surface lineament, with the previously mapped ring fault to the north, and with the location of the San Antonio hot springs.

The strike of the faults indicated on RPLS 3-6 and 3-10 is nearly east-west and the projected dip to the south infers that the surface expression of one of these faults may be related to the canyon immediately north of Lake Fork Mesa. The projected surface trend of this fault is also indicated on the generalized geologic map.

This east-west fault with surface trend mapped to the north of GT-2 and EE-1 could very well be the source of some of the fracture zones encountered in GT-2 and EE-1. It is also possible that the faults shown below Lines 2-6 and 2-2 on the depth sections in Fig. 6 have been intersected by the boreholes.

In conclusion, the seismic data indicate the presence of a gentle easterly dip to the surface of the Precambrian granite and indicates its origin is, at least in part, structural. Faulting appears restricted to the granite in general, but shows offsetting of beds at least as young as Pennsylvanian in the case of four faults. The Pennsylvanian Sandia Formation also appears to be thinning to the west on RPL 2A in support of the trends cited in a Los Alamos Scientific Laboratory report by W. D. Purtymun.⁷

DOWNHOLE VELOCITY SURVEY AND SEISMIC STATION CALIBRATION

Seismic measurements were made by Birdwell Division of Seismograph Service Corporation to provide a downhole-geophone velocity survey of the GT-2 borehole and to calibrate the area within a ring of seismic stations surrounding GT-2 so as to provide an input for a seismic location program whose purpose is to utilize seismic signals from the growth of a large (approximately 1-km-diam) hydraulic fracture

Fig. 9. Generalized geologic map of LASL geothermal site (scale: 1:166667).

REFERENCES

1. *Geologic Map of the Jemez Mountains, New Mexico*, by R. L. Smith, R. A. Bailey and C. S. Ross, 1970.
2. *Geology of the Jemez Plateau West of the Valles Caldera*, by William D. Purtymun, 1973.

TABLE II
TRAVEL TIMES FOR STATION CALIBRATION

Station Number	Geophone		Travel Times (s)	Vibroseis Location Relative to Downhole Geophone X+ = East, Y+ = North, Z+ = Up							
	Depth, GT-2			Delta X		Delta Y		Delta Z		Slant Dist.	
	(m)	(ft)		(m)	(ft)	(m)	(ft)	(m)	(ft)	(m)	(ft)
Q-1	1371.3	4499	0.4790	204.1	670	830.9	2726	1380.8	4530	1624.4	5329
	1591.0	5223	0.537	213.6	701	827.3	2714	1601.5	5254	1815.1	5955
	1812.3	5946	0.536	229.3	752	820.7	2693	1821.8	5977	2011.3	6599
Q-2	1371.3	4499	0.428	755.8	2480	224.0	735	1321.3	4335	1538.6	5048
	1591.0	5223	—	765.3	2511	220.4	723	1542.0	5059	1735.5	5694
	1812.3	5946	0.492 ^a	781.0	2562	213.8	702	1762.4	5782	1939.5	6363
Q-3	1371.3	4499	0.485	476.3	1563	- 641.3	-2104	1352.4	4437	1570.7	5153
	1591.0	5223	0.510	485.8	1594	- 644.9	-2116	1573.1	5161	1768.2	5801
	1812.3	5946	0.537	501.5	1645	- 651.5	-2137	1793.5	5884	1972.9	6473
Q-4	1371.3	4499	0.455	- 489.9	-1607	- 618.8	-2030	1357.0	4452	1569.8	5152
	1591.0	5223	0.485 ^a	- 480.4	-1576	- 622.3	-2042	1577.7	5176	1762.7	5783
	1812.3	5946	0.515	- 464.7	-1525	- 628.9	-2063	1798.1	5899	1960.7	6433
Q-5	1371.3	4499	0.437	- 687.7	-2256	- 188.4	- 618	1354.6	4444	1530.8	5022
	1591.0	5223	0.466	- 678.2	-2225	- 192.0	- 630	1575.2	5168	1725.7	5662
	1812.3	5946	0.559	- 662.6	-2174	- 198.6	- 651	1795.6	5891	1924.2	6313
Q-6	1371.3	4499	0.417 ^a	60.0	197	113.4	372	1377.1	4518	1383.1	4538
	1591.0	5223	0.454 ^a	69.5	228	109.8	360	1597.8	5242	1603.1	5259
	1812.3	5946	0.492 ^a	85.1	279	103.2	339	1818.2	5965	1823.1	5981
Q-7	1371.3	4499	?	- 43.4	- 142	49.7	163	1372.5	4503	1374.1	4508
	1591.0	5223	?	- 33.9	- 111	46.1	151	1593.2	5227	1594.3	5230
	1812.3	5946	0.507	- 18.2	- 60	39.5	130	1813.6	5950	1814.1	5952
Q-8	1371.3	4499	0.364 ^a	38.0	125	32.0	105	1371.9	4501	1372.8	4504
	1591.0	5223	0.480 ^a	47.5	156	28.4	93	1592.6	5225	1593.6	5228
	1812.3	5946	0.508 ^a	63.2	207	21.8	72	1813.0	5948	1814.2	5952
Q-9	1371.3	4499	0.562	875.0	2871	1259.7	4133	1385.7	4546	2067.0	6782
	1591.0	5223	0.579	884.5	2902	1256.2	4121	1606.3	5270	2222.7	7292
	1812.3	5946	0.605	900.2	2953	1249.6	4100	1826.7	5993	2389.3	7839
J-7	1371.3	4499	0.544	- 696.9	-2286	-1221.0	-4006	1318.6	4326	1927.5	6324
	1591.0	5223	0.565	- 687.4	-2255	-1224.6	-4018	1539.3	5050	2083.6	6836
	1812.3	5946	0.591	- 671.7	-2204	-1231.2	-4039	1759.6	5773	2250.2	7383
J-8	1371.3	4499	0.543	-1062.9	-3487	- 823.0	-2700	1346.0	4416	1902.3	6241
	1591.0	5223	0.557	-1053.4	-3456	- 826.5	-2712	1566.7	5140	2060.9	6762
	1812.3	5946	—	-1037.8	-3405	- 833.1	-2733	1787.1	5863	2228.2	7310
J-9	1371.3	4499	0.540	-1350.7	-4431	-1310.7	-4300	1326.5	4352	2302.6	7554
	1591.0	5223	0.585	-1341.2	-4400	-1314.2	-4312	1547.2	5076	2433.0	7982
	1812.3	5946	?	-1325.5	-4349	-1320.8	-4333	1767.6	5799	2574.1	8445
J-11	1371.3	4499	—	-1156.8	-3795	310.0	1017	1228.4	4030	1715.6	5629
	1591.0	5223	0.470	-1147.3	-3764	306.4	1005	1449.0	4754	1873.4	6147
	1812.3	5946	—	-1131.6	-3713	299.8	984	1669.4	5477	2039.0	6690

^aTimes from initial field record.

TABLE III
DOWNHOLE GEOPHONE VELOCITY SURVEY, GT-2

Measured Depth		True Depth		Travel Time (s)
(m)	(ft)	(m)	(ft)	
780.0	2559	780.0	2559	0.326
780.6	2561	780.6	2561	0.325
851.6	2794	851.6	2794	0.337
914.4	3000	914.4	3000	?
1005.8	3300	1005.5	3299	0.363
1158.2	3800	1157.9	3799	0.387
1310.9	4301	1310.6	4300	0.411
1462.4	4798	1461.8	4796	0.437
1615.7	5301	1615.1	5299	0.461
1767.8	5800	1766.6	5796	0.487
1921.2	6303	1919.6	6298	0.514

in order to determine size and orientation of the fracture. Vibroseis signals from most of the Q-22 seismic stations and several of the LASL Group J-9 stations were detected at three depths by a geophone in GT-2: 1372 m, 1593 m, and 1814 m (4500 ft, 5225 ft, and 5950 ft). Separate Vibroseis excitations were used for each level in the hole. (Some J-9 calibrations could not be completed due to failure of the clutch on the LASL logging van which was being used to lower the Birdwell geophone in the hole.)

Table II lists travel times for each travel-time calibration and lists the north-south, east-west vertical distances and slant distances of seismic-source stations from the geophone locations in GT-2. It should be noted here that, due to drift of the hole, geophone locations at the 1372-m, 1593-m, and 1814-m (4500-ft, 5225-ft, and 5950-ft) measured depths are all northwest of the surface location of GT-2.⁸ Travel times marked "a" were field picks by the operator, for those cases in which the final tabulation from Birdwell did not list travel times.

For the downhole-geophone velocity survey of GT-2, the vibrator was stationed 16.5 m (45 ft) north-northwest of the borehole. Table III lists the one-way travel times determined by the survey.

The corrected continuous-velocity log (CVL)⁵ was used for velocity data from 109.7 m (360 ft) to 1926.3 m (6320 ft) below ground level, with a gap from 548.6 m (1800 ft) to 774.8 m (2542 ft). The CVL log is a measurement of interval times. The

deviation slope changes between the log data and geophone data were held to near 16.4 $\mu\text{s/m}$ (5 $\mu\text{s/ft}$), so as not to introduce drastic velocity contrasts into the finished log.

The density log⁵ was used to provide input for the synthetic velocity log. The assumption is made that the density is proportional to the Δt (interval time) of a given formation type and can be applied to this problem as long as no anomalous conditions such as salt beds exist in the area of investigation. Using density-log input, approximate values representative of Δt were determined. These values were summed by depth increments to obtain an integrated pseudo-total travel time. From this total travel time a time-depth relation was obtained at each geophone level. The differences between these time-depth values and the geophone data were compared graphically to determine the logical points at which breaks in the overall slope of the deviation curve could be made. The interval times between slope changes are the basis for control points that are entered into a computer program that adjusts numerical values of the first estimate Δt to the geophone data. The output of this program is the synthetic velocity log (or Δt log).

Interval velocities from the synthetic velocity log are used as input data to obtain a synthetic seismogram, Fig. 10. For this purpose, only primary reflections were computed. The nature of the lithology involved suggests that interbed multiples should not be a problem. Although care was taken in placing the slope breaks during production of the synthetic velocity log, these points sometimes may create artificial velocity interfaces which could result in artificial reflected waves being shown on the synthetic seismogram.

The filter used for the synthetic seismogram is a Klauder wave with a peak frequency of 30 Hz. This is a wave form equivalent to a Vibroseis auto-correlation pulse.

Figure 11 shows a comparison of the synthetic seismogram and the signals recorded after stacking several signals detected by a 12-geophone array located about 61 m (200 ft) southeast of GT-2. The geophones were connected in parallel on a single input to the accumulating oscilloscope. Geophones were spaced so as to achieve surface noise cancellation. The seismic source was a Dinoseis.

Fig. 11. Synthetic seismogram and recorded seismic signals near GT-2.

Conclusions

Although the seismic survey was of reconnaissance nature and good data were difficult to obtain, the results were useful in several aspects. Field techniques for enhancement of the data were determined, such as broadside shooting and stacked multiple recording, which can be used if a detailed seismic survey of the site is deemed necessary in the future. Variations in recorded travel times from seismic stations at various azimuths around GT-2 may be due to elastic anisotropy, formation dip, and changes in formation thicknesses due to faults, some of which have been mapped by the reflection seismic survey. The faults mapped appear to have a relatively minor displacement compared to other known faults in the area. The amount and quality of the seismic data is such that only the general attitude of the faults can be determined. The synthetic seismogram shows good agreement for reflections from the surface of the granite and below on the Dinoseis source reflection record near GT-2.

REFERENCES

1. R. A. Pettitt, "Planning, Drilling, and Logging of Geothermal Test Hole GT-2, Phase I," Los Alamos Scientific Laboratory report LA-5819-PR (January 1975).
2. R. A. Pettitt, "Testing, Drilling, and Logging of Geothermal Test Hole GT-2, Phase II," Los Alamos Scientific Laboratory report LA-5897-PR (March 1975).
3. C. S. Ross, R. L. Smith, and R. A. Bailey, "Outline of the Geology of the Jemez Mountains, New Mexico," 12th Field Conf. N. M. Geol. Soc., 139-143 (1961).
4. D. B. Slemmons, "Fault Activity and Seismicity near the Los Alamos Scientific Laboratory Geothermal Test Site, Jemez Mountains, New Mexico," Los Alamos Scientific Laboratory report LA-5911-MS (April 1975).
5. F. G. West, P. R. Kintzinger, and A. W. Laughlin, "Geophysical Logging in Los Alamos Scientific Laboratory Geothermal Test Hole No. 2," Los Alamos Scientific Laboratory report LA-6112-MS (November 1975).
6. W. D. Purtyman, F. G. West, and R. A. Pettitt, "Geology of Geothermal Test Hole GT-2 Fenton Hill Site, July 1974," Los Alamos Scientific Laboratory report LA-5780-MS (November 1974).
7. W. D. Purtyman, "Geology of the Jemez Plateau West of Valles Caldera," Los Alamos Scientific Laboratory report LA-5124-MS (February 1973).
8. D. Helleckson, Eastman Whipstock, unpublished data, 1975.