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Abstract

A time-term method of analyzing seismic refraction data was used to process 62 time-distance pairs observed on a 13 station seismic network from 10 shot points in and around Albuquerque Basin, New Mexico. The time terms derived from the analysis range from 1.50 seconds at the Albuquerque volcanoes down to -.047 seconds at the Albuquerque Seismological Laboratory. In a general way the time terms correlate with the geologic foundation beneath the site: Large values are calculated for stations and shots within the basin, intermediate values on consolidated sedimentary rocks and Tertiary intrusions, and the smallest on Precambrian outcrops. The P-wave (Pg) velocity in bedrock was found to be 6.0 ± .02 km/s. This falls approximately midway between higher velocities reported to the east and west of Albuquerque Basin and lower velocities reported to the north and south. These numbers will be valuable in future efforts to accurately locate shallow nearby earthquakes and for studies seeking to unravel seismic complexities deeper in the crust.

Introduction

The U.S. Geological Survey in cooperation with Los Alamos National Laboratory (LANL) and New Mexico Institute of Mining and Technology (NMT) operated a 13 station seismic network around and within the Albuquerque Basin for a 66-month period between 1976 and 1981 with the goal of mapping contemporary seismicity. In the course of this earthquake monitoring, explosions originating from nearby mining operations were routinely recorded, along with special shots set off for scientific research by the University of New Mexico, the U.S. Department of Defense, and LANL. These data were used to estimate some of the seismic parameters of the shallow crust beneath the network. This report gives an estimate for the P-wave velocity in the Precambrian basement (Pg) and the P-wave time terms (delay times) associated with each of the recording stations and shot sites along with the standard errors for the computed values. These numbers are important for the accurate location of earthquakes and for deducing structure at deeper levels in the crust. The delay times also are related simply to the thickness of the Phanerozoic section above the basement, or, where the site is already located on basement, they are related mainly to the amount of confining pressure in the rocks beneath the explosion or recording station.

Geology

The Albuquerque Basin is one of a number of northerly elongate crustal features that in aggregate make up the Rio Grande depression as identified by Bryan (1938) and described as the Rio Grande rift by Kelley (1952). The basin measures approximately 160 km long by 50 km in wide, and the surface of the basin floor is roughly 1.6 km above sea level. Parts of the basin probably began to form during the Laramide, but most of the features seen today are the result of Miocene and younger faulting and uplift. The basin is linked through bedrock constrictions to the Española Basin on the north and to the San Marcial Basin on the south. The uplifted eastern margin, fault blocks rotated to the east, consists of the Sandia–Manzano–Los Pinos Mountains. The less clearly defined western margin is composed of Ladron Peak, Lucero uplift, and the Puerco fault belt. Deep hydrocarbon test wells, seismic reflection profiles, and gravity/magnetic surveys in the basin reveal a highly faulted and irregular basin bottom. These studies tally closely with the geologic fabric seen directly in the uplifted margins (Kelley 1977). The basin seems truncated at its northern end by the Miocene–late Pleistocene Jemez Mountains and the Valles caldera. Olsen et al. (1986) reported on a seismic experiment for the Jemez Mountains that analyzed 290 ray paths and found the P-wave velocity in bedrock to be 5.86 ± .01 km/s. The southernmost part of the Albuquerque Basin is underlain by the northern edge of the Socorro Magma Body described by Sanford et al. (1977). Singer (1989) studied the entire crust beneath a seismic network centered on Socorro and from an analysis of 265 ray paths reported that the P-wave velocity in bedrock was best modeled as increasing from 5.71 km/s at the top of the Precambrian section to just under 6.0 km/s at approximately 10 km depth. This study fills the gap between the Valles caldera to the north and the contemporary magma injection proposed to the south of the basin.

Method

The time-term method of analyzing seismic refraction data was proposed by Scheidegger and Willmore (1957) and has been used successfully by many others. The method assumes that the travel time for the first arriving refracted signal from an explosion can be partitioned into 3 terms:

$$T = a + b + D/V \qquad (1)$$

Where:

- T is the shot to station travel time.
- a is the delay time associated with the receiver.
- b is the delay time associated with the shot.
- D/V is the time the signal spends traversing the high-speed refractor (distance divided by velocity).

Delay time is defined by Sheriff (1973) as the additional time taken for a wave to follow a trajectory to and along a buried marker over that which would have been taken to follow the same marker considered hypothetically to have been at the ground surface. It is synonymous with "time term" in this study.

An examination of equation (1) suggests that if the coordinates of the shots and stations are known, D can be calculated, and that if the shot origin time is known, T can be estimated from the arrival times. Figure 1 shows the arrangement of explosions and stations used in this study. There are 13 station time terms, 10 shot time terms, and 1 velocity [the a, b, and V in equation (1)] to be determined. If every station recorded every shot, 130 equations like (1) could be written, and there are only 24 unknowns so that the system of equations is over determined and has a solution. Multiple linear regression (Draper and Smith 1966) was used to estimate the unknowns, their associated standard errors, and the standard deviation of the solution (Murdock and Jaksha 1980). Berry and West (1966) discussed the errors associated with the time-term method and stated that the estimates should be taken as indicators of "goodness of fit" but not as accurate fiducial limit calculations.

The time-term method assumes a starting model that includes:

1. A high velocity layer that is constant beneath the study area.
2. Dip on the refractor surface is small.
3. Curvature on the refractor is small.
4. The velocity beneath the sites varies only with depth.

The method produces relative time terms unless a recording station and an explosion occupy the same site, in which case absolute values are calculated. In this study a station at the Occidental Mineral Corporation mine (OXM) recorded the first arrival from explosions at LANL shot points SP5 and SP6, and on the White Sands Missile Range (WSMR) a station at the site of DICE THROW recorded the shot at DISTANT RUNNER 2.

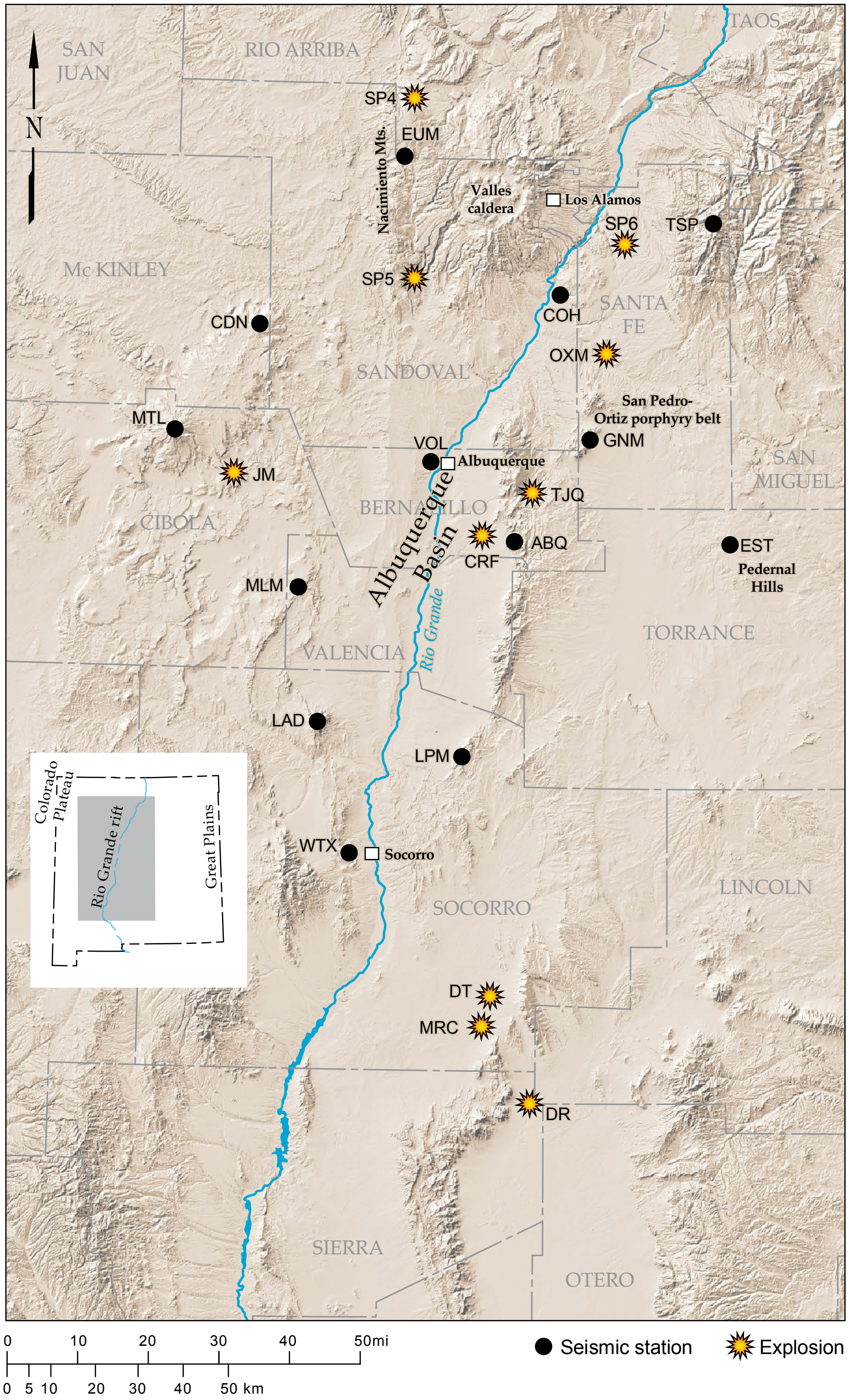

FIGURE 1—Plan view of the stations and shot points used in this study. A key to codes for seismograph stations and explosions is included in Tables 1 and 2.

Data and results

The origin times and coordinates for the explosions used in this study were usually provided by the organizations responsible for the blast. These parameters are very accurate, less than 1 second temporally and within a few meters geographically. In some cases the origin time was determined from a temporary station installed close to the explosion or from the nearest permanent station. In these cases the shot location was estimated from topographic maps, and the times and locations of these shots are thought to be correct to ± 1 second (time) and ± 500 m (position). These data are presented in Table 1. The locations of the permanent seismic stations along with their elevations are given in Table 2. A description of the instruments in the field (short period vertical sensors and radio telemetry) and at the recording site is given by Jaksha et al. (1977). The seismic data were recorded on 16 mm film displayed at 1 cm per second. Two analysts timed the refracted P-wave arrivals independently, and if the results varied by more than ± 100 ms the data were rejected. Shot to station distances were computed using DISTAZ, an unpublished computer program from the U.S. Geological Survey, Menlo Park, California. The data were then assembled into matrix algebra format and processed using a TI-89 calculator manufactured by Texas Instruments Inc.

Residuals for each ray path were calculated, and those with values greater than 200 ms, the estimate for our ability to read the seismograms, were reviewed, rejected, or both. These data are shown in Figure 2 and presented in tabular form in the Appendix. Distance constraints were used to look for aberrations associated with arrivals from shots too close (direct arrivals) or too far (a deeper refractor) from the stations. It was found that Pg appears as a first arrival in the range 10–150 km in and around the Albuquerque Basin and that its velocity is 6.0 ± .02 km/s. This result is in agreement with a refraction line partially in the basin analyzed by Olsen et al. (1979).

Estimates for the station and shot time terms are listed in Table 3. The standard error for the estimate is given along with the number of observations associated with each site. The standard deviation for the entire solution is 103 ms. The estimate for our ability to read the arrival times given above is 200 ms, so the solution appears to be well determined.

A modification to the method

The CRF (University of New Mexico Civil Engineering Research Facility) explosion was sited approximately 3 km west of the intersection of two extensive faults (Fig. 3) and roughly 5 km northwest of Hubbell Spring where a clearly defined fault scarp reveals a flat-lying strata of Triassic through Pennsylvanian rocks atop the Precambrian (Grant 1982). Kelley (1977) suggested that the north-trending, 58-km-long, normal, down-to-the-west Hubbell Spring fault might serve as the eastern boundary of the Albuquerque Basin in recent time and that the Hubbell bench separates the Manzano Mountains from the deeper basin to the west.

The Tijeras fault, active since the Precambrian and more than 80 km in length, was reactivated during extension associated with the Rio Grande rift. Movement involved left lateral and locally down-to-the-north normal slip (Abbott et al. 2004). Ander (1980) speculated that the Tijeras fault continued southwest across what is now the Albuquerque Basin.

TABLE 1—A listing of the shot point locations along with their associated code names, elevations, and date of explosion. UNM = University of New Mexico, WSMR = White Sands Missile Range, and LANL = Los Alamos National Laboratory.

Shot	Location	Latitude (N)	Longitude (W)	Elevation (km)	Date
CRF	UNM Civil Engineering Research	34.9600	106.5740	1.61	June 2, 1977
DT	WSMR DICE THROW	33.6790	106.5210	1.44	October 6, 1976
DR	WSMR DISTANT RUNNER 2	33.3810	106.3670	1.28	October 7, 1981
JM	Anaconda Minerals Co. Jackpile mine	35.1230	107.3722	1.87	July 2, 1980
MRC	WSMR MILLRACE	33.6211	106.4779	1.50	September 16, 1981
OXM	Occidental Minerals Corp. Oxymin mine	35.4611	106.1150	1.85	January 21, 1977
SP 4	LANL Research	36.1813	106.8277	2.02	September 25, 1981
SP 5	LANL Research	35.6503	106.7845	1.95	September 29, 1981
SP 6	LANL Research	35.7575	106.1408	2.03	September 29, 1981
TJQ	Ideal Cement Company Tijeras quarry	35.0625	106.3958	1.98	January 18, 1977

TABLE 2— A listing of the seismograph station locations along with the station code, and the station's elevation.

Station	Location	Latitude (N)	Longitude (W)	Elevation (km)
ABQ	Albuquerque Seismological Laboratory	34.9425	106.4575	1.85
CDN	Cerro Durazno	35.4547	107.3485	2.59
COH	Cochiti Dam	35.5802	106.3048	1.65
EST	Estancia	34.8703	105.7365	2.03
EUM	Eureka Mesa	36.0130	106.8438	2.75
GNM	Golden	35.2497	106.1927	2.42
LAD	Ladron Peak	34.4554	107.0317	1.74
LPM	Los Pinos Mountains	34.3077	106.6337	1.77
MLM	Mesa Lucero	34.8143	107.1450	2.09
MTL	Mt. Taylor	35.2517	107.6087	3.34
TSP	Tesuque Peak	35.7850	105.7817	3.43
VOL	Albuquerque volcanoes	35.1250	106.7675	1.74
WTX	Woods tunnel	34.0722	106.9458	1.56

In addition to these large faults to the east of CRF, two deep hydrocarbon test wells were drilled to the west of the site. The TransOcean Isleta No. 1 bottomed in the top of the Precambrian after 3.2 km (10,378 ft) of drilling, and the Shell Isleta No. 2 was completed after 6.5 km (21,266 ft), reportedly still in basin fill. Grant (1981) estimated, from stratigraphic relationships, that the Precambrian would be encountered at around 8 km.

These features were sketched onto the line A–B (Fig. 4) along with the stations at the Albuquerque Seismological Laboratory (ABQ), Mesa Lucero (MLM), and the CRF test location. The depth to the refractor beneath the CRF shot (4.6 km) was estimated using:

$$Z = (d)\,(Vo) \,/\, \cos ic \quad \text{(Nettleton 1940)} \qquad (2)$$

Where:

- Z is the depth to the high-speed refractor (km).
- d is the site delay time(s).
- Vo is the P-wave velocity in the surface layer (km/s).
- V_1 is the P-wave velocity in the high-speed refractor (km/s).
- ic is the critical angle to produce a refracted wave.
- $\sin i_c$ is Vo/V_1

The P-wave velocity in the surface layer (Vo) in the Albuquerque Basin was estimated to be 3.5 km/s using explosions at the Jackpile mine and CRF (Jaksha et al. 1981). An examination of Figure 4 suggests that seismic signals traveling east from the test site will have smaller delay times than those going west because the basin to the west is so much deeper. It makes geologic sense then to break the times from the CRF explosion into two groups with CRF-E (Table 3) being signals going east to ABQ and Estancia (EST) and CRF-W being signals going to most of the rest of the network. Handling the CRF shot in this way resulted in lowering the standard deviation of the solution from 132 ms to 103 ms.

Discussion

Velocity

The Albuquerque Basin is surrounded by terranes having different P-wave velocities in bedrock. East of the basin Stewart and Pakiser (1962) measured 6.14 km/s on the Great Plains, and to the south Singer (1989) found 5.7 km/s. Roller (1965) measured 6.2 km/s on

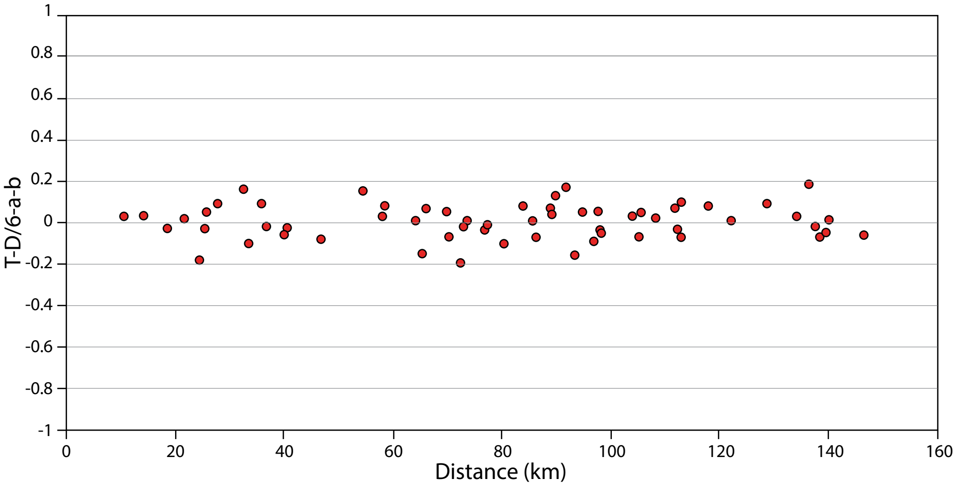

FIGURE 2—Travel time residuals for 62 data points used in the study, plotted as a function of distance.

the Colorado Plateau, and Olsen et al. (1986) report 5.86 km/s beneath the Valles caldera. The 6.0 km/s velocity found beneath this seismic network fits approximately into the mid-range of these previous investigations.

The velocities were plotted on the enhanced geothermal resource map (Blackwell et al. 2011; Fig. 5) that shows estimated temperature at 3.5 km depth, roughly where the refracted signals in this study traveled. The Rio Grande rift appears on this map as a terrane having a lowered Pg velocity along with a higher subsurface temperature compared to its neighbors to the east and west, and within the rift there exist areas of even lower Pg velocity and still higher temperatures, sometimes in the same place. The source for this heat has been imaged in the upper mantle and is centered beneath the rift axis (Wilson et al. 2005).

Time terms

In a general way the time terms determined from this study fall into three groups. Sites located within the Albuquerque Basin atop thick layers of Neogene material, Cochiti Dam (COH .712 s), Albuquerque volcanoes (VOL 1.50 s), and the two time terms for the Civil Engineering Research Facility, (CRF-E .699 s and CRF-W 1.18 s) exhibit large values. Two explosions sited on basin-filling sediments on the White Sands Missile Range and detonated by the U.S. Department of Defense to simulate blast effects on equipment and facilities have large time terms as well: DICE THROW (DT 1.04 s) and MILLRACE (MRC .557 s). Another shot in the series of tests, DISTANT RUNNER2 (DR .404 s), took place closer to bedrock as reflected by the smaller time term calculated for the site. The bedrock beneath the Albuquerque volcanoes (VOL 1.50 s) appears to be more than 6 km below the surface using equation (2).

Intermediate time-term numbers are associated with sites on Cretaceous and older sediments (sometimes flooded with young basalts) and at sites on or near Tertiary intrusive rocks. West of the Rio Grande the time terms increase from Mesa Lucero (MLM .326 s) to the Jackpile mine (JM .584 s) and Cerro del Durazno (CDN .685 s) as the Precambrian deepens going northwest into the San Juan Basin (Jaksha and Evans 1984). Unraveling the time term at the 4 m.y. volcano Mt. Taylor (MTL .489 s) with its high elevation (3.34 km at the MTL seismograph station) and composite accumulation of rock material erupted atop and intruded within the Cretaceous section (Crumpler 1982) will require a more detailed study than this. Note, however, that although its elevation is a bit less than Tesuque Peak (TSP) its time term is 119 ms larger. Mt. Taylor is likely built with rocks having lower P-wave velocity than those at Tesuque Peak. East of the Rio Grande, OXM and Golden (GNM), both sites located at mines in the San Pedro–Ortiz porphyry belt, have practically identical time terms.

TABLE 3—A listing of station and shot point time terms, standard error, number of observations, and the foundation material at the site (taken from the *New Mexico Geologic Highway Map*, Wilks 2005).

Site	No. of observations	Time term(s)	Standard error(s)	Foundation
ABQ	8	-.047	.06	Precambrian granite
CDN	4	.685	.07	Tertiary basalt
COH	2	.712	.09	Quaternary sediments
EST	3	.089	.09	Permian limestone
EUM	4	.142	.07	Precambrian rocks
GNM	3	.248	.07	Tertiary intrusive rocks
LAD	8	.199	.07	Precambrian metasediments and metavolcanics
LPM	6	.171	.06	Precambrian granite
MLM	7	.326	.06	Tertiary basalt
MTL	3	.489	.08	Tertiary volcanics
TSP	5	.369	.07	Precambrian rocks
VOL	2	1.50	.09	Quaternary basalt
WTX	4	.392	.07	Precambrian granite
CRF-E	2	.699	.09	Quaternary piedmont deposits
CRF-W	6	1.18	.06	Quaternary piedmont deposits
DT	6	1.04	.05	Quaternary alluvium
DR	3	.404	.06	Quaternary piedmont gravels
JM	8	.584	.05	Cretaceous sedimentary rocks
MRC	3	.557	.07	Quaternary alluvium
OXM	12	.246	.04	Tertiary intrusive rocks
SP4	2	.312	.09	
SP5	8	.379	.05	
SP6	5	.879	.06	
TJQ	9	.156	.05	Pennsylvanian limestone

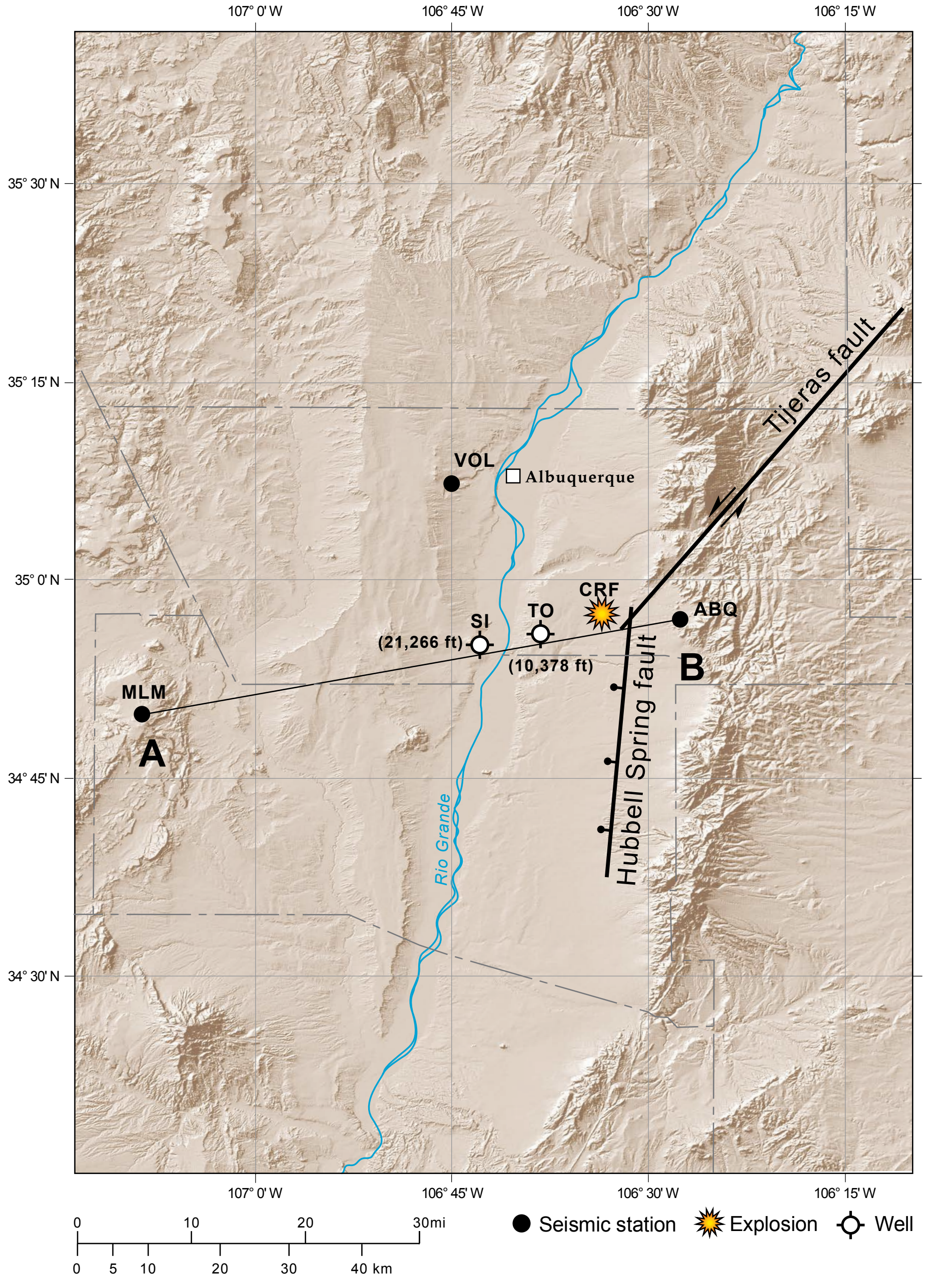

FIGURE 3—Location of the University of New Mexico **CRF** test site. **SI** is the position of the Shell Isleta No. 2 hydrocarbon test well. **TO** is the position of the TransOcean Isleta No. 1 hydrocarbon test well. Three seismograph stations are shown: **ABQ**, Albuquerque Seismological Laboratory; **VOL**, Albuquerque volcanoes; and **MLM**, Mesa Lucero.

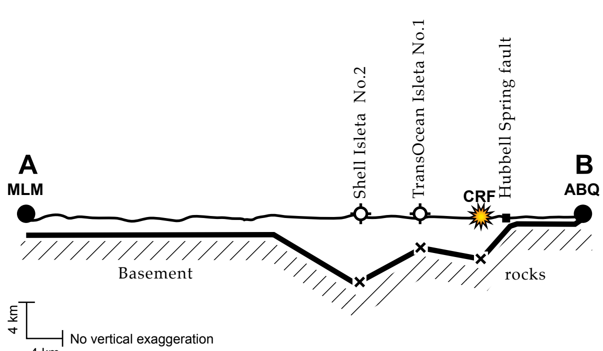

FIGURE 4—Cartoon cross section along line A–B on Figure 3.

Sites on or near Precambrian bedrock exhibit, as expected, the smallest time terms, and they range from -.047 s at ABQ to .369 s at TSP and .392 s at Wood's tunnel (WTX) located on the campus of New Mexico Institute of Mining and Technology in Socorro. The large number at TSP can be attributed partly to its high elevation, which at 3.43 km is almost 1.5 km higher than the average of the other seven sites that are on or very near to bedrock. The large time term at WTX (.392 s) seems incompatible with that determined by Singer (1989) who reported .06 s at the same site. The Pg velocities are different as well, 6.0 km/s and 5.7 km/s. His crustal model shows an increase in velocity with depth to approximately 10 km where "just under" 6.0 km/s is expected. Equation (2) can be employed along with the time term (.392 s) found in this study and Singer's crustal model to estimate the depth to the 6.0 km/s refractor. The average (5.7 + 6.0)/2 near-surface velocity (Vo) was used for the computation that yields 10.3 km for Z (the depth). The two studies appear to support one another very well at site WTX. The time terms for the quartet of stations on bedrock—ABQ, Ladron Peak (LAD .199 s), Los Pinos Mountains (LPM .171 s), and WTX—suggest that the high-speed refractor deepens substantially from north to south in this section of the Rio Grande rift.

This kind of confirmation was not possible with the LANL results (Olsen et al. 1986) as the Albuquerque Basin network had no stations in the Valles caldera. The higher refractor velocity found in this experiment would normally result in larger time terms at sites common to both studies, and larger numbers than they report are seen at TSP, SP4, and SP5. Eureka Mesa (EUM) and SP6 have smaller time terms in this experiment, however, so it's likely that the model assumptions used here are too simple to accurately reflect a very complicated subsurface basement structure (Ankeny et al. 1986) beneath the caldera.

Eureka Mesa (EUM .142 s) located in the Nacimiento Mountains and Estancia (EST .089 s) in the Pedernal Hills are both sited on prerift uplifts. The Pedernal Hills are a remnant of the Ancestral Rocky Mountains. The Tijeras quarry shot site (TJQ .156 s) has the smallest time term of the explosions used in this study.

The very small time term at ABQ is intriguing, and a few tests were carried out to explore for a possible explanation.

1. All ABQ readings were deleted from the data, then restored one at a time, and the entire set rerun with a single ABQ data point. This is a test for the time term being the result of one or a few travel times skewing the result. The velocity and time terms remained essentially unchanged with no ABQ data in the solution. When single ABQ readings were included in the computation the program will estimate a station time term but cannot calculate a standard error. The velocity and time terms of the rest of the sites are not affected by the inclusion of a single ABQ data point. Table 4 shows the results of this test. The travel times

from MILLRACE and OXM were deleted, based on the suspicion that the MILLRACE arrival might be from a deeper refractor (Pn) and that the OXM signal might have found a high velocity path to ABQ along the strike of the Tijeras fault. Rerunning the data resulted in an ABQ time term of .0002s and a standard deviation that changed from 103 ms to 101 ms. This "improvement" was judged to be spurious, and the two travel times were restored to the data.

2. An area of rock having velocity > 6.0 km/s beneath and around ABQ was modeled by subtracting 0.2 s from all travel times recorded by the station. This resulted in all parameters of the multiple linear regression remaining the same (time terms, velocity, standard error, standard deviation of solution) except for the ABQ time term, which decreased from -.047 s to -.247 s. This was interpreted to mean that the small time term could be caused, at least in part, by rocks having Pg > 6.0 km/s beneath and around the site.

3. ABQ was modeled as being updip from all the shots it recorded (a structural high) by adding 0.5 km to all of the shot-to-station distances. In the updip position the larger the offset distance the smaller the station delay time becomes. This test resulted in the ABQ time term changing from -.047 s to -.130 s and suggests that dip might play a role in the small ABQ number.

Conclusion

The P-wave velocity beneath the Albuquerque Basin seismic network is 6.0 ± .02 km/s, probably the most common value for this parameter worldwide. It is surrounded by terranes having different velocities, higher to the east and west, lower to the north and south.

TABLE 4—Test results from the multiple linear regression using only one ABQ data point.

Shot	ABQ time term(s)
CE	.04
DT	-.04
JM	.05
MRC	-.18
OXM	-.22
SP5	.05
SP6	.03
TJQ	.02

The time terms fall mainly into three groups:

1. Large (.557 s to 1.50 s) values are found associated with sites on Quaternary basin-fill deposits.
2. Intermediate (.246 s to .685 s) values are found at sites on consolidated sedimentary rocks (Cretaceous and older) and on or near Tertiary intrusive rocks.
3. Sites on or near Precambrian granite or metamorphic rocks have, on average, the smallest (-.047 s to .392 s) time terms.

These numbers will be useful in any future efforts to precisely locate shallow nearby earthquakes. In particular they will be helpful in estimating "station corrections" in the location procedure. An independent estimate of the P-wave velocity above the 6.0 km/s refractor has been made only for the basin-filling sediments. These time terms will become more relevant when Vo is known for all of the sites, at which time depth to the refractor can be estimated directly from the time terms.

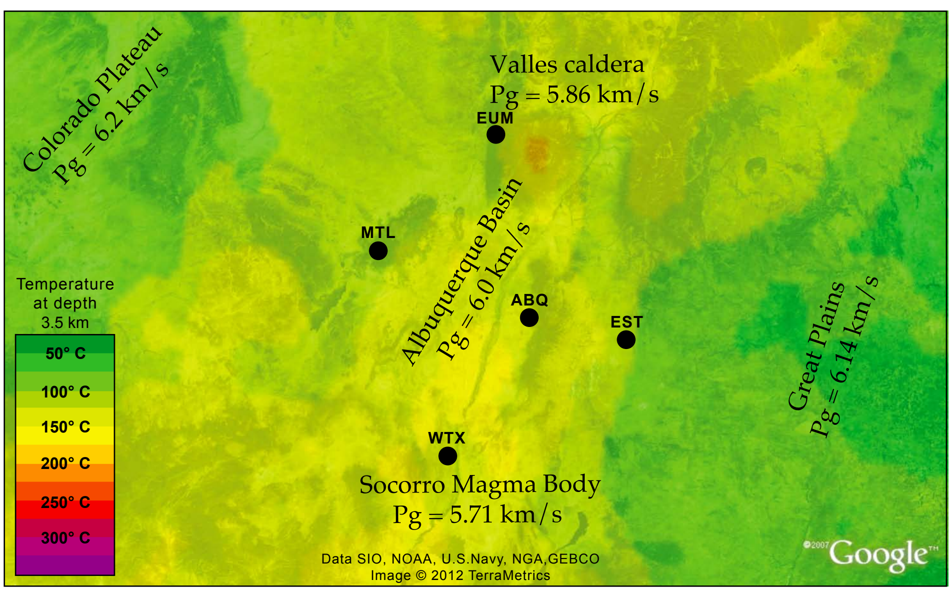

FIGURE 5—Enhanced geothermal resource map centered on the Albuquerque Basin. For reference the distance from **WTX** to **ABQ** is 107 km. The map shows estimated temperature at a depth of 3.5 km and is color coded from green (50°C) through orange (200°C) to purple (greater then 300°C). Google.org/EGS (Blackwell et al. 2011).

The very small time term at the U.S. Geological Survey Albuquerque Seismological Laboratory is interesting. This number is an order of magnitude smaller than any other station (or shot) in the experiment and suggests the site might be structurally high, be sited on rocks with P-wave velocity in excess of 6.0 km/s, or both.

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Bill and Joy Wrye allowed the author to search their ranch near Estancia to confirm the location of station EST.

The geometry of this network changed in 1982 when stations CDN, COH, EST, GNM, LAD, and VOL were redeployed to better monitor seismicity associated with the Socorro Magma Body. At that time A. R. Sanford, professor of geophysics at New Mexico Institute of Mining and Technology, encouraged the author to publish this research. He reasoned correctly that it would be unlikely to see 13 stations monitoring the Albuquerque Basin again in the foreseeable future.

Jane Love and the editorial staff at New Mexico Bureau of Geology and Mineral Resources improved every aspect of the manuscript from the title all the way to the final number of the Appendix.

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Appendix

Time-distance readings, time terms, and residuals.

Distance (km)	Time(s)	Station time term(s)	Shot time term(s)	Station code	Shot code	Residual(s)
97.01	16.92	0.685	0.156	CDN	TJQ	-0.09
113.06	19.07	0.142	0.156	EUM	TJQ	-0.07
27.87	5.14	0.248	0.156	GNM	TJQ	0.09
89.02	15.26	0.199	0.156	LAD	TJQ	0.07
86.47	14.67	0.171	0.156	LPM	TJQ	-0.07
73.74	12.78	0.326	0.156	MLM	TJQ	0.01
112.48	19.36	0.489	0.156	MTL	TJQ	-0.03
97.71	16.86	0.369	0.156	TSP	TJQ	0.05
111.98	19.66	0.685	0.246	CDN	OXM	0.07
21.71	4.6	0.712	0.246	COH	OXM	0.02
89.99	15.52	0.142	0.246	EUM	OXM	0.13
24.49	4.46	0.248	0.246	GNM	OXM	-0.12
139.61	23.66	0.199	0.246	LAD	OXM	-0.05
136.45	23.35	0.171	0.246	LPM	OXM	0.19
118.15	20.34	0.326	0.246	MLM	OXM	0.08
137.74	23.67	0.489	0.246	MTL	OXM	-0.02
46.95	8.36	0.369	0.246	TSP	OXM	-0.08
64.22	11.34	0.379	0.246	SP5	OXM	0.01

Distance (km)	Time(s)	Station time term(s)	Shot time term(s)	Station code	Shot code	Residual(s)
89.36	16.8	0.685	1.18	CDN	CRF-W	0.04
54.64	10.76	0.326	1.18	MLM	CRF-W	0.15
77.03	13.6	0.089	0.699	EST	CRF-E	-0.03
70	13.1	0.199	1.18	LAD	CRF-W	0.05
72.57	13.26	0.171	1.18	LPM	CRF-W	-0.19
25.43	6.89	1.5	1.18	VOL	CRF-W	-0.03
98.34	17.59	0.199	1.04	LAD	DT	-0.04
70.5	12.89	0.171	1.04	LPM	DT	-0.07
58.71	11.3	0.392	1.04	WTX	DT	0.08
35.95	7.52	0.403	1.04	DR	DT	0.09
36.86	7.39	0.685	0.584	CDN	JM	-0.02
108.33	18.91	0.248	0.584	GNM	JM	0.02
80.5	14.1	0.199	0.584	LAD	JM	-0.1
40.03	7.52	0.326	0.584	MLM	JM	-0.06
25.85	5.43	0.489	0.584	MTL	JM	0.05
128.78	22.02	0.089	0.379	EST	SP5	0.09
40.64	7.26	0.142	0.379	EUM	SP5	-0.03
134.21	22.98	0.199	0.379	LAD	SP5	0.03
98.36	17.05	0.326	0.379	MLM	SP5	-0.05
91.93	15.9	0.369	0.379	TSP	SP5	0.17
58.27	11.62	1.5	0.379	VOL	SP5	0.03
105.28	18.45	0.089	0.879	EST	SP6	-0.06
138.93	24.3	0.326	0.879	MLM	SP6	-0.06
32.63	6.85	0.369	0.879	TSP	SP6	0.16
134.32	23.02	0.199	0.404	LAD	DR	0.03
105.71	18.24	0.171	0.404	LPM	DR	0.05
93.57	16.23	0.392	0.404	WTX	DR	-0.16
18.7	3.54	0.142	0.312	EUM	SP4	-0.03
104.09	18.06	0.369	0.312	TSP	SP4	0.03
85.82	14.85	-0.047	0.584	ABQ	JM	0.01
83.92	14.4	-0.047	0.379	ABQ	SP5	0.08
94.94	16.71	-0.047	0.879	ABQ	SP6	0.05
14.4	2.54	-0.047	0.156	ABQ	TJQ	0.03
10.82	2.48	-0.047	0.699	ABQ	CRF-E	0.02
140.28	24.38	-0.047	1.04	ABQ	DT	0.01
65.44	10.96	-0.047	0.246	ABQ	OXM	-0.15
73.03	14.04	0.712	1.18	COH	CRF-W	-0.02
138.44	24.37	0.326	1.04	MLM	DT	-0.07
33.56	6.62	0.879	0.246	SP6	OXM	-0.1
113.1	19.7	0.171	0.584	LPM	JM	0.1
122.2	21.35	0.392	0.584	WTX	JM	0.01
66.18	12.05	0.392	0.557	WTX	MRC	0.07
77.51	13.64	0.171	0.557	LPM	MRC	-0.01
146.6	24.88	-0.047	0.557	ABQ	MRC	-0.06