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STRUCTURE OF THE BASINS AND RANGES, SOUTHWEST NEW MEXICO, AN INTERPRETATION OF SEISMIC VELOCITY SECTIONS

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INTRODUCTION

This report presents a geologic appraisal of seismic velocity sections that profile a total of 790 km in southwest New Mexico west of Las Cruces and south of Lordsburg and Deming. The present work outlines the contribution of these velocity sections to estimating areas favorable for mineral resource occurrences. Seismic refraction surveys are carried out with the initial goal of estimating the subsurface distribution of acoustic compressional velocity (Vp), which may ultimately be interpreted to provide information on lithology, geologic structure, and the occurrence of natural resources. The seismic sections presented here show velocity detail having dimensions of 100's to 1000's of meters to a depth of about 2.5 km, and across a net of traverses that profile most basins well as several ranges in the study area.

Figure 1 shows the location of the seismic refraction lines. The lines are designated 1, 2, 3, 4, 5, and 7; there is no line 6. The survey covers a broad swath of the southwest Basin and Range Province extending from the Arizona border eastward to the Rio Grande River, and from the Mexican border to about lat. 32° 30′ N. Lines 1, 3, and 7 traverse the axis of basins in roughly north-south directions; the remaining lines 2, 4, and 5 trend east-west and cross various ranges and basins.

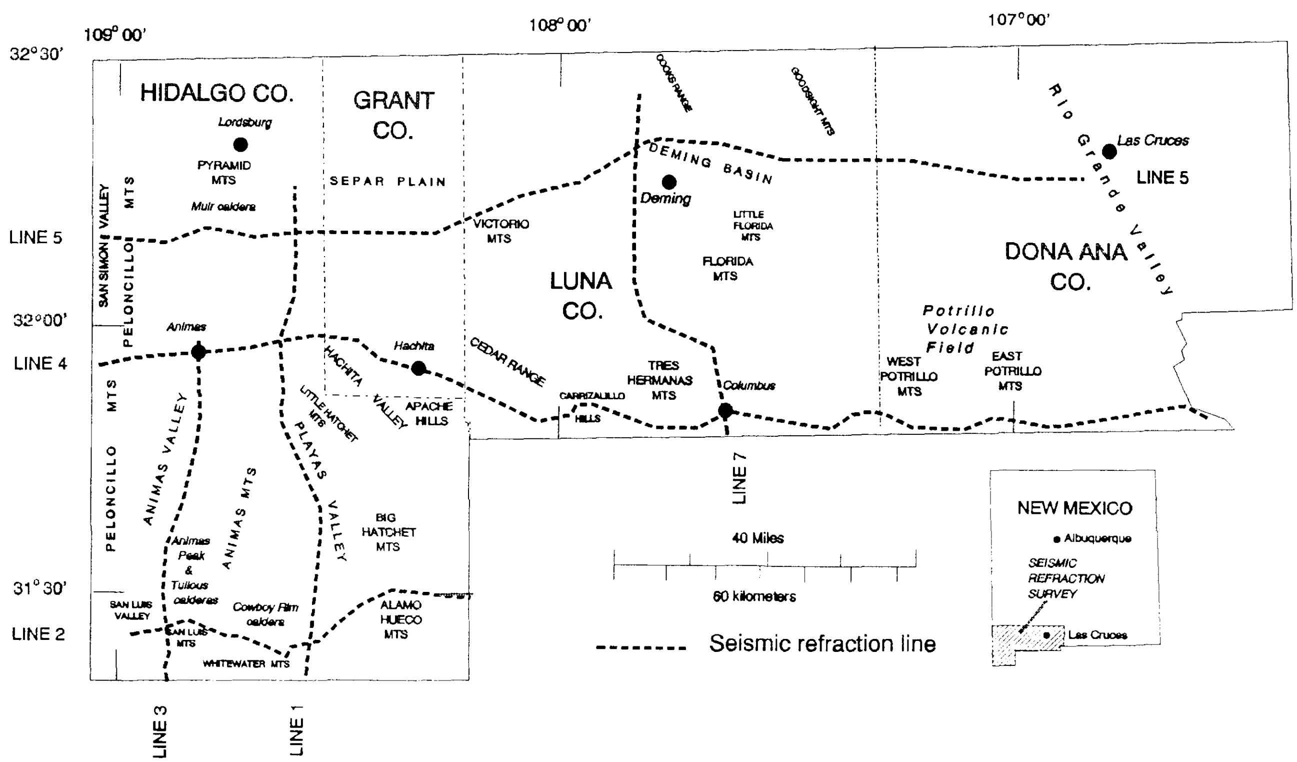

Figure 1 -- Location of seismic refraction lines in southwest New Mexico.

Seismic data that have been collected in this region include deep-crustal refraction traverses by university scientists and commercial seismic reflection profiles acquired for petroleum exploration. Results of deep-crustal refraction studies are reviewed to provide a regional setting for the higher resolution refraction data. Results from seismic reflection will not be discussed. Industry reflection data in the area are not generally available for non-proprietary use. The nearest reflection data publicly available are in the Socorro area, about 80 km north of the present study area (Brown and others, 1980). These data were acquired by the Consortium for Continental Reflection Profiling (COCORP), a public-supported research group, to investigate the possibility of magma beneath part of the Rio Grande valley.

Up to 1978 there were about 36 deep borings in the region of southwest New Mexico (Thompson and others, 1978). This drilling resulted mainly from an evaluation of petroleum potential of the Pedrogosa basin which is an extensive area of Paleozoic subsidence in Arizona, New Mexico, and Mexico that accumulated about three kilometers of Paleozoic sedimentary rock (Zeller, 1965; Thompson and others, 1978). Of these drill holes, 25 are close enough to the present seismic sections to provide correlations of velocity to lithology, and to provide an estimate of the errors associated with depth-to-interface interpretations. This information is summarized prior to considering the implications of the seismic sections in detail. The major portion of the report centers around two plates: Plate I shows seismic lines and selected drill hole locations superimposed on gravity contours, and Plate II shows velocity-sections with drill hole summaries. These plates provide the foundation for developing inferences on buried lithologic, structural, and mineral resources for the region.

DEEP SEISMIC CRUSTAL STUDIES

Seismic refraction data acquired for studying large features deep in the Earth's crust are reviewed by Braile and others (1989). Such regional seismic data penetrate through the Earth's crust and into the uppermost mantle, which in southwest New Mexico begins at a depth of about 30 km. Traverses intended for deep-crustal studies in this area are sparsely located, and their shotpoints and geophones are widely separated compared to the shallow crustal study of the present report. This prohibits detailed resolution of upper crustal features. However, the regional data provide a broad perspective of the crust which can be useful in understanding many of the shallow crustal features.

Sinno and others (1986) present three profiles that are within the vicinity of the region studied in this report. Figure 2 shows the location of these profiles and others in the southwest New Mexico as well. Figure 2 also shows a composite interpretation of crustal velocity for an east-west profile between lat.32° to 33° N. The model extends from long.109°00'W to east of the Rio Grande Valley at about long.104°30'W. This interpretation (fig.2) is based on merging results from the different traverses shown.

One of the deep crustal traverses is in the area of Deming to the Franklin Mountains (A-A' on figure 2; "Pipeline Road Line" of Sinno and others, 1986). This profile is within the area of the higher-resolution data that makes up the bulk of this report. This line shows the crystalline (basement) crust having a velocity (Vp) ranging from 5.9 km/sec at 1 to 2 km depth to 6.7 km/sec depth at the base of the crust. The "Pipeline Road Line", along with other lines were used to interpret mantle velocity as 7.7 km/sec beneath the Rio Grande area, and increasing both eastward and westward.

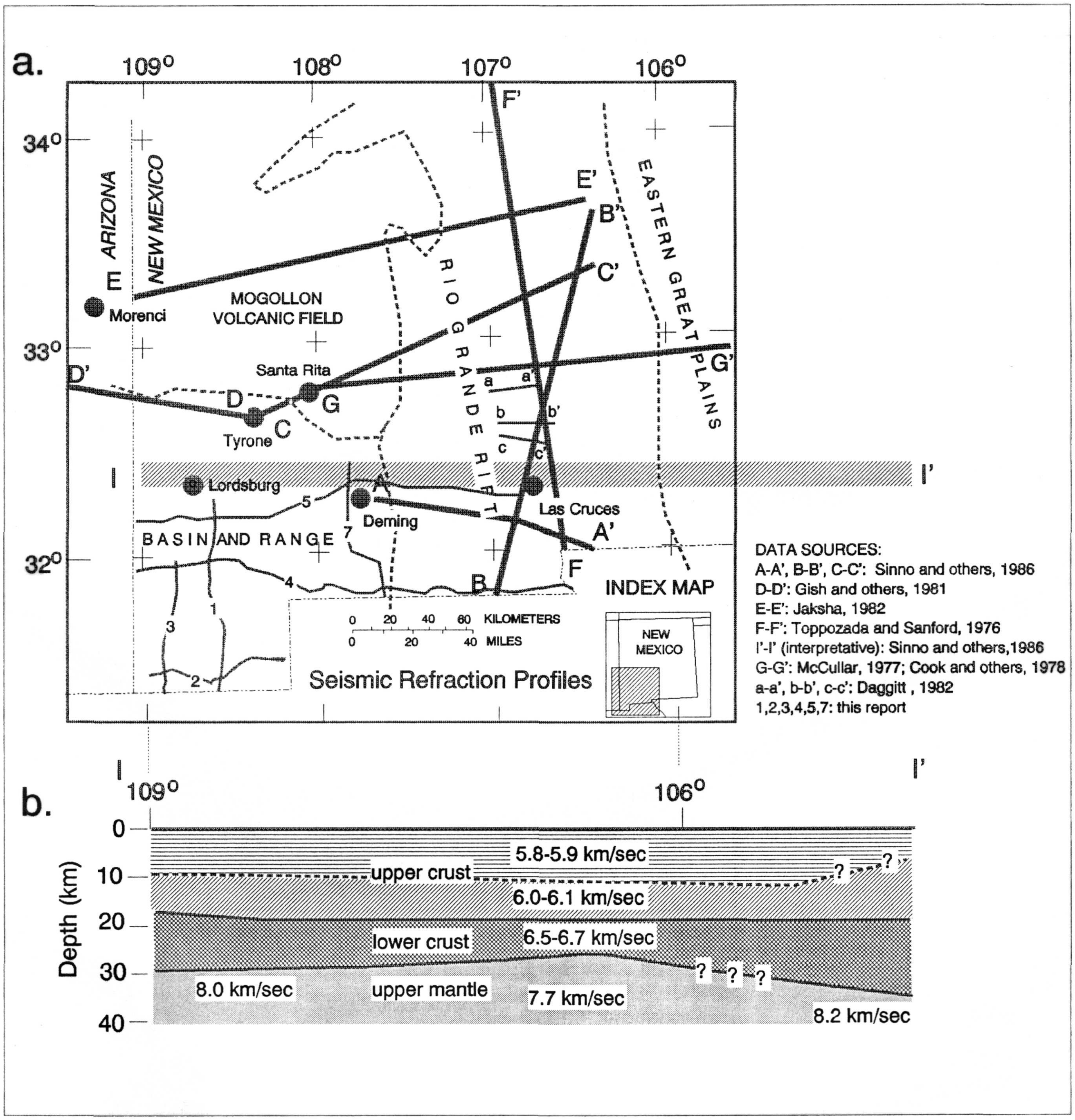

Figure 2 -- Seismic refraction studies in southwest New Mexico. **a)**-Location of deep-crustal seismic refraction profiles (lines A-A′, B-B′, C-C′, D-D′, E-E′, F-F′), upper-crustal refraction profiles (lines a-a′, b-b′, c-c′), and refraction profiles of the present study (lines 1, 2, 3,4, 5, 7). **b)**-Interpreted deep crustal velocity section along line I-I′ (Sinno and others, 1986).

West of the Rio Grande, mantle velocity is about 8.0 km/sec near lat.109°W (fig. 2: see fig. 18 of Sinno and others, 1986). The crustal thickness is interpreted to vary from 27 km in the Rio Grande river area to 30 km in the Basin and Range Province to the west. To the east the crust thickens to nearly 50 km.

One result from Sinno and others (1986) is that southern New Mexico appears to be underlain by a thin crust compared to the continental interior east of the Rio Grande area. The Rio Grande Valley is itself anomalous; it has a thinner, higher velocity crust, and lower velocity upper mantle compared with bordering areas. Sinno and others (1986) point out that low velocity mantle under the Rio Grande Valley may imply an underlaying thermal anomaly with possible incipient or active melting just below the crust; the higher velocity crust indicates mafic intrusions. This result supports the inference that the Rio Grande is a crustal rift; other studies have indicated that the Rio Grande Rift is a zone characterized by concentrated crustal faulting and magmatism that are associated with low electrical resistivity and high heat flow (Seager and Morgan, 1979), along with the seismic features just mentioned. The magmatism in the Rio Grande Rift coupled with faults to circulate heated water causes the geothermal resources known along the Rio Grande (Swanberg, 1979).

The overall thinner crust of southern New Mexico compared to more easterly parts of the continent is characteristic of the Basin and Range Province as a whole which includes southern Arizona and Nevada, as well as southwest New Mexico (Eaton, 1982). Eaton (1979, 1982) points out that the crustal characteristics of the Basin and Range result from widespread felsic magmatism in Mesozoic through mid-Tertiary time, one consequence of which was the development of a rich base and precious metal province.

Although deep-sensing refraction data provides a regional perspective of the tectonics involved in creation of geothermal and mineral resources of the southwest New Mexico, it does so with an imprecise focus on the details of the upper crust that are critical to locating areas favorable for mineral resources. For example, Emory Caldera, which is located about 50 km north of Deming (fig. 1) within the Mogollon Volcanic Field (Ericksen and others, 1970; Elston, 1984; McIntosh, 1992) does not produce a recognizable signature in a regional refraction model of line C-C′ (fig. 2; Sinno and others, 1986). Also, neither Bursum caldera nor the Mogollon Volcanic Field as a whole, are apparent in regional refraction velocity results for line E′-E′ (fig. 2; Jaksha, 1982). However, Jaksha (1982) points out a correlation of greater seismic refraction delay times with a gravity low over the volcanic field (Coney, 1976). Greater delay times and low gravity together indicate a depression of the subvolcanic crystalline basement beneath a thick volcanic section (Jaksha, 1982). Jaksha (1982) also identified reflectors near 21 km depth beneath the western part of the volcanic field and noted that these reflectors may represent melting in the middle crust. An alternative hypotheses, not mentioned by Jaksha (1982) but implicit from considerations of crustal magma intrusion and differentiation (Johnson, 1991), are that these reflections are from residual mafic sills related to earlier melting beneath the Mogollon volcanic field. Deep seismic data in southwest New Mexico acquired to date provide no evidence supporting or refuting the inference of an upper crustal silicic batholith (top at 3 to 10 km) (Coney, 1976) beneath this volcanic field or any of it′s calderas.

SEISMIC REFRACTION DATA

The seismic refraction lines in southwest new Mexico considered here were acquired by Geophysical Service, Inc. (GSI) in July, 1969, purchased by the U.S. Geological Survey (USGS) Water Resources Division (WRD) in New Mexico for hydrologic studies, and analyzed by Ackermann and Pankratz in 1981 (Ackermann and others, 1994). Inasmuch as data acquisition and processing are described by Ackermann and others (1994); only the salient points will be repeated here.

Data were acquired using a shotpoint interval of 3.2 km with two shots at each shotpoint for backward and forward recording; receivers were spaced at intervals of 201 m. Shotpoints were originally plotted at a scale of 1:12,000, but for USGS processing the shotpoints were replotted by hand at a scale of 1:250,000. The replotted shotpoint locations are estimated to be accurate to within about 300 m worst case. Inasmuch as the 1:250,000 plot could not be found for the present report, a photographically reduced version of the 1:250,000 map composite at scale of about 1:635,000 (Ackermann and others, 1994) was digitized and shotpoints replotted back to a scale of 1:250,000. The locations presented here include additional errors from digitization, possibly further degrading shotpoint location accuracy by 100 or 200 m. Plate I shows the present 1:250,000 map that includes complete Bouguer gravity contours, and selected drill-hole locations, as well as shotpoint locations.

To analyze the refracting horizons, analog records were picked for first arrival times. Data processing was based on reversed travel-time curves constructed as described Ackermann and others (1986). Depth-velocity sections were derived from a set of interactive computer programs detailed by Ackermann and others (1982, 1983) and reviewed by Ackermann and others (1994). Velocity is assumed to be isotropic and to increase vertically downward. A surface layer of variable thickness (seldom more than 150 m) and constant velocity of 0.85 km/sec was incorporated into all velocity sections. This layer was required to account for dry, porous, and unconsolidated rock or soil. The assigned velocity is considered typical of surface material in the region. This layer is too thin to be reliably identified on the plotted travel-time points because of the 200 m geophone spacing, thus the data provide poor constraints on its velocity.

Plate II shows the resulting velocity sections. Units are metric with velocity in km/sec. Horizontal variations in velocity are interpreted in blocks, typically 4 to 10 km in horizontal extent. Bounds of the blocks are indicated by near-horizontal lines defining the refracting horizons, and near-vertical lines between blocks of differing velocity. Velocity within a block is representative of the average velocity spanning the block. Where velocities changes are uncertain, dashed lines are drawn. Uncertainties arise because a unique solution is not inherent in seismic refraction data interpretation. Hidden layers (layers without clear travel-time segments) and velocity reversals contribute to the ambiguities in interpretation.

Seismic lines were segmented for processing convenience and were labeled (A,B, or East, West, etc.). Shotpoint numbers for each segment begin at 1. Each shotpoint had two consecutive numbers that code two shots at each location, one for recording in the forward direction from the shotpoint, the other for recording in the reverse direction. Where segments overlap, shotpoints have an additional number (or pair of numbers) representing the adjacent segment. Only one of the numbers for each shotpoint is shown on the sections and on the shotpoint map. Also, some shotpoint locations are left off of the map to avoid overcrowding. All shotpoint locations and shotpoint numbers are shown by Ackermann and others (1994).

RELIABILITY OF VELOCITY STRUCTURE

Reliability of the modeled velocity structure in interpreting lithology and depth of lithologic interfaces is examined here by considering consistency of models at line intersections, and correlations between seismic units and drill hole lithologic logs. One published sonic log in the study area is also considered as an aid to lithologic correlation but it turns out to be of little value.

Internal consistency in the seismic interpretation can be evaluated by inspecting the discrepancies at traverse intersections because lines were processed independently. There are insufficient data to provide statistical estimates of error, but qualitative comparisons are instructive. Five of the seven intersections are at locations where the velocity sections were well enough developed on both of the intersection lines to provide comparative data (intersections of lines 1 and 4, lines 1 and 5, lines 2 and 3, lines 3 and 4, lines 4 and 7, and lines 5 and 7). On the average, layer depths are consistent within about 50 m (averaging to about a 20-percent discrepancy), and velocity values correspond to within about 0.2 km/sec.

One study that provides insight into likely depth determination errors in seismic interpretation is found Zohdy and others (1974, p.77-78). They described a comparison of 97 seismic refraction depth determinations with drill-hole depths. The depths range up to 100 m in that study. Results showed that about 95-percent of data showed errors in depth determinations of 20-percent or less; the remaining errors range from 30- to 90-percent. The larger errors overestimated the depth; Zohdy and others (1974) presumed that this was because of unrecognized velocity reversals.

About 25 deep drill holes in southwest New Mexico that were drilled for geothermal and petroleum exploration are along the traverses of the present data (Plate I). Lithologic logs have been summarized for some these drill holes (Thompson and Bieberman, 1975; Thompson, 1977, 1981; Thompson and others, 1978; Gates and others, 1978; Foster, 1978, Zeller, 1965) and lithologic data from 14 of these drillholes are used to analyze a likely error for interpreted depths from the velocity sections. These data will be described later in this report. Generalized summaries of the logs are shown on Plate II.

Thompson (1977) published a sonic log for Drill hole KCM No.1

Forest Federal Well (H-6 on Plate I). This well is located in the Animas Mountains, 12 km west of line 1 and 16 km east of line 3 (Plate I). Figure 3 shows a simplified depth-velocity section based on the log shown in Thompson (1977). The vertical velocity-depth lines on figure 3 are estimated averages from the published log. Comparison of the velocities in Figure 3 to those on Plate II, show that the sonic-log values for drill hole KCM No.1 (fig. 3) are higher by 5- to 25-percent than that of the bulk of bedrock measured in the seismic refraction survey.

The higher velocities in the drill hole log are explainable by higher frequencies and smaller sample volume of sonic logs compared to surface refraction surveys. Sonic logs sample volumes measured in meters compared to surface refraction measurements that sample volumes across 10's of kilometers. Porosity lowers seismic velocity, and when sampling larger volumes it may be reasonably inferred that the fraction of pore space (related to faults and formation interfaces for instance) will increase and lower the bulk

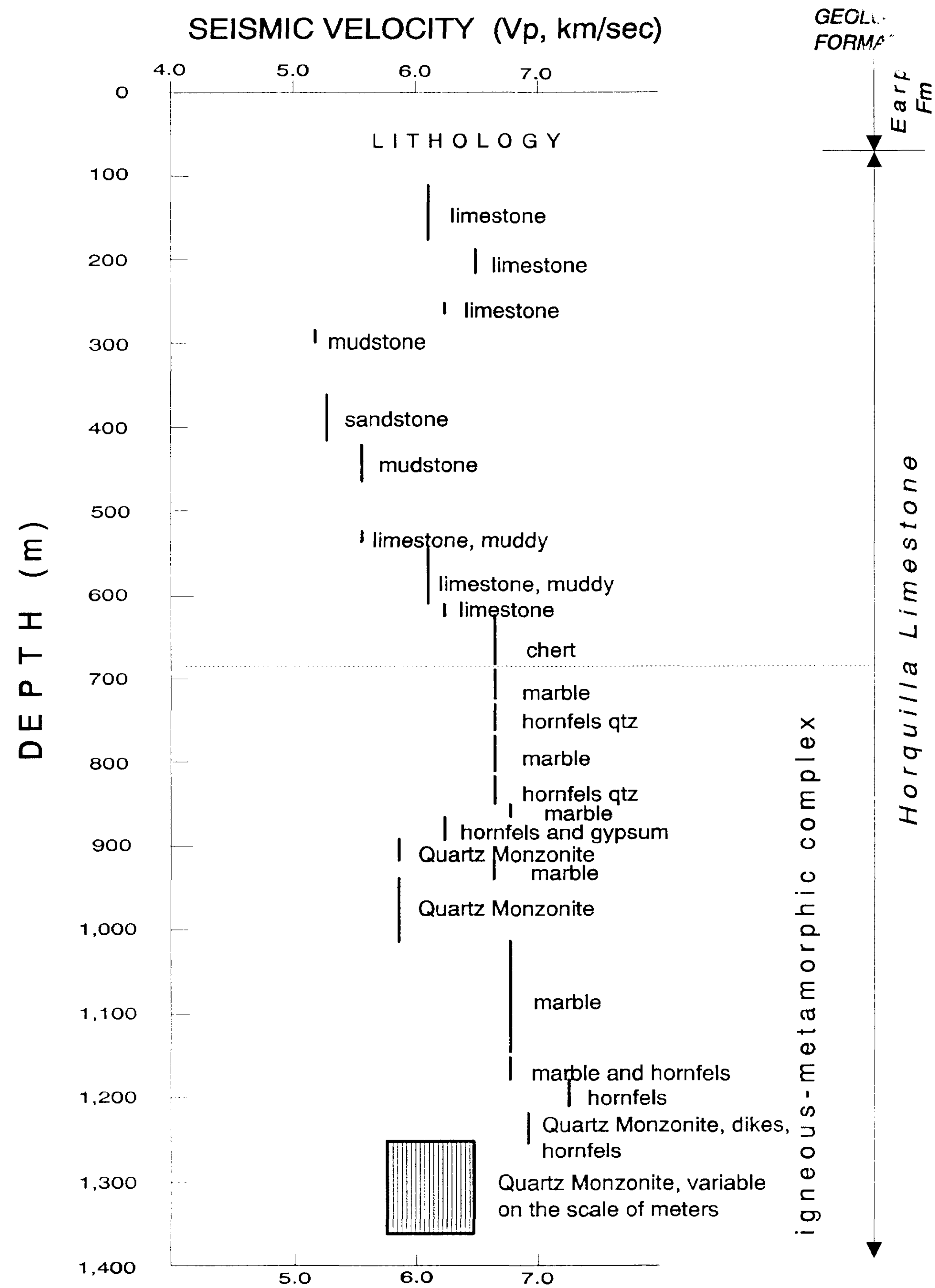

Figure 3 -- Seismic velocities from sonic log in KCM No.1 Forest Federal drill hole (Thompson, 1977). Vertical lines indicate average velocity for depth range shown; corresponding lithologic units are labeled. Box indicates velocity and depth range for quartz monzonite penetrated near the bottom of the drill hole. Velocities varied significantly on the scale of meters in this intrusion.

measured velocity. Sonic logs measure frequencies of the order 1,000's Hz compared to the refraction surveys which measure frequencies in the range from one to a few 10's Hz. Higher frequencies travel faster than lower frequencies, a phenomenon called dispersion (Telford and others, 1976, p.238). Such velocity differences have been studied in by De and others (1994). They have determined that sonic logs typically have velocities 2- to 4-percent higher than Vertical Seismic Profiling (VSP; surface to well) velocities. The decrease in velocity for refraction surveys versus sonic logs will be larger than that for VSP versus sonic logs because of greater distances, and lower frequencies involved in refraction surveys. The magnitude of the decrease cannot be reliably predicted, but it can be concluded that the raw sonic log for drill hole KCM No. 1 will not provide velocity-lithology correlations that are reasonable for the refraction velocities on the sections presented here.

CHARACTER OF THE SEISMIC VELOCITY SECTION

Acoustic compressional velocities (Vp) in the seismic sections of southwest New Mexico are placed into three layers that can be assigned lithologic significance using rock-velocity relationships (Diment, 1980; Christianson, 1989), drill-hole correlations and surficial geology. Lateral variations in the sections show that the layers often dip, are discontinuous, and may exhibit variable velocity. This lateral structure shows where bedrock and basement may be faulted or intruded, and thus favorable for mineral occurrences. Velocity variations, both horizontal and vertical, also provide information for making inferences about lithology and structure that affect hydrologic conditions.

The seismic sections show velocity ranging from about 2 to 6 km/sec. The various blocks resulting from the seismic interpretation seem to group into three to five "layers". A "layer" may have lateral variation among the blocks, but is used here in the sense that the lateral changes in velocity within a layer are typically less than vertical changes in velocity across layers. For the present description the two or three mid-level layers are considered as a single zone. This results in three significant layers numbered downward with layer one just below the uppermost layer or layer zero (a layer with assigned velocity of 0.85 km/sec representing the dry, loose, weathered, near surface materials).

Layer 1 (1.6 to 3.0 km/sec)

Layer 1, starting at 50 to 150 m depth beneath the surface zone and pinching out in mountain ranges, is believed to be a porous zone of unconsolidated to poorly consolidated gravel, alluvium, sand, clay and possibly thin layers of volcanic rock. Most of this material is probably Quaternary age. Where velocities are about 1.8 km/sec or greater, the layer is probably water saturated (Pankratz and others, 1978). Water can probably be extracted from rocks and loose material when porosity exceeds about 20-percent; this is where compressional velocity in unconsolidated sediments is less than about 3.0 km/sec (Zohdy and others, 1974, figure 63, p.83). Thus, shallow basin aquifers are likely where velocity in layer 1 ranges from about 2 to 3 km/sec. Layer 1 varies considerably in thickness, even in the central parts of basins. The thickness of this layer commonly ranges between 150 m to 400 m but reaches about 700 m in parts of Playas Valley (line 2), Hachita Valley (line 4), Animas Valley (line 5), and in Deming Basin (lines 5 and 6).

Layer 2 (2.7 to 4.5 km/sec)

Velocity sections of this report show two or three discrete layers between layer 1 and the deepest layer detected. For this report, these intermediate layers are grouped as layer 2. Different zones, or sub-layers, in this layer show velocity differences of about 0.6 km/sec, which is believed significant and resolvable, but specific lithologic correlations to the various velocity units in this layer would be equivocal. The velocity range in this layer will encompasses many rock types, and velocity changes may relate to compaction of some similar rock types as well. As a generalization, layer 2 most likely consists predominantly of Tertiary and Mesozoic clastic and volcanic rock and may include some porous, dirty limestones. Where seismic units have velocity values in the higher range for this layer (near 4 km/sec), the clastic units may have increased cementation, induration or welding (for volcanic rocks), all of which increase velocity (Diment, 1980; Christianson, 1989). An increased fraction of carbonate rocks will also increase velocity. Units having lower velocity near 3 km/sec may have porosity of about 10-percent or greater (Zohdy and others, 1974, p.83), which may be sufficient to form aquifers.

Layer 3 (seismic basement: 4.0 to 6.1 km/sec)

This is the deepest and highest velocity refracting horizon detected and forms the core of mountain ranges as well as the floor of basins. Layer 3, referred to as seismic basement, does not necessarily represent the geologic basement composed of igneous and metamorphic rock. The layer is composed chiefly of rock with velocities in the range of 4.0 to 5.1 km/sec that represents plutonic rock, metamorphic rock, strongly welded volcanic rock, carbonate or silica-cemented sedimentary rock. Units with velocities exceeding 5 km/sec probably represent rocks with low fracture densities and (in igneous or metamorphic rock) high mafic composition . Where this layer is shallow below valleys, uplifts or intrusions may be present that may present barriers to ground water flow and are possible targets for mineralized rock. Where layer 3 is undetected, such as in the southern Playas and Animas Valleys, there was insufficient distance between shotpoints and detectors to penetrate unusually thick deposits of Tertiary sedimentary and volcanic rock.

DRILL HOLE DATA

Table 1 lists drill holes that are within about 10 km of the seismic refraction lines. These bore holes are shown on Plate I. Published down-hole lithologic logs have been compared to the seismic velocity sections to gain insight into the velocity-lithology relationships and to investigate the accuracy of the present sections. Figure 4 shows the velocity ranges encountered in the present data for correlative geologic units. Also shown on figure 4 are the ranges of velocity observed in the sonic log of drill hole KCM No.1 (H-6, Plate I), located in the central part of the Animas Mountains, about 30 km from the nearest refraction line. Velocity-lithology correlations show a wide overlapping range that points out the need to treat lithological interpretations carefully. Data from the sonic log at drill hole H-6 were discussed previously when examining sources of error.

Figure 5 shows discrepancies in depths picked from the refraction data and from the logs of nearby drill holes. About 65-percent of the refraction depth determinations fall within the 20-percent discrepancy lines; about 90-percent of the points fall within a 25-percent discrepancy. Drill hole depths are from data presented by Thompson and Bieberman (1975), Thompson (1977), Thompson and others (1978), and Thompson (1981).

Table 1 - Drill holes near seismic lines in southwest New Mexico. Drill holes are ordered alphabetically for each County. Locations are shown on Plates I and II except Plate II does not show drill holes having brackets in columns "Seismic Line" and "Near Shotpoint(s)".

DRILL HOLE (References)* (All locations from reference R1)	MAP SYMBOL	SEISMIC LINE	NEAR SHOTPOINT(S)	TOTAL DEPTH (meters)
DONA ANA COUNTY				
Exxon Corp. #1 Mason Draw Fed. (R1)	D-1	[5]	[5-24 (C)]	3,642
Pure #1 Federal "H" (R1,R3,R4)	D-2	[4]	[4-35 (C,D)/4-8 (D)]	2,239
GRANT COUNTY				
Cockrell No.1 Coyote State (R1,R2,R3)	G-1	5	5-26 (A)/5-30 (A)	2,827
Wininger and Berry No.1 State (R1,R2)	G-2	4	4-30 (A)/1-34 (A)	454
HILDALGO COUNTY				
ARCO O & G #1 Fitzpatrick (R1)	H-8	[3]	[3-7 (A)]	3,290
Cockrell #1 N.M. State (R1)	H-10	[1]	[1-27 (A,B)]	942
Cockrell No. 1 State-1, 225 (R1,R2,R3)	H-5	1	1-19 (A)	1,222
Cockrell No.1 Playas State (R1,R2,R3)	H-4	1	1-23 (A)/1-25 (A)	2,156
Cockrell No.1 Pyramid Fed. (R1,R2,R3)	H-1	5	5-4 (A)	2,254
GTM Steam Reserve #55-7 N.M. (R1)	H-9	[5]	[5-4 (A)]	2,134
Humble No.1 State BA (R1,R2,R3)	H-7	2	1-11(E)	4,445
KCM No.1, Cochise St. A (R1,R2,R3)	H-3	1	1-33 (A,B)/1-34 (A,B)	1,800
KCM No.1 Forest Fed. (R1,R2,R4)	H-6	none	[Animas Mountains]	1,221
Powers No.1 State (R1,R2)	H-2	1	1-23 (B)	1,220
LUNA COUNTY				
Angelus Angelus #3 (R1)	L-7	[7]	[7-26 (B)]	1,881
Cockrell #1 Victorio (R1)	L-6	[4]	[4-12 (B)/4-14 (B)]	1,221
Cockrell No.1 State-1, 349 (R1,R2,R3)	L-1	5	[5-19 (B)/5-23 (B)]	2,248
Florida Bickford #3 (R1)	L-10	[7]	[7-14 (B)]	872
Florida State #1 (R1)	L-11	[7]	[7-14 (B)]	707
Guest and Wolfson No.1 Diana (R1,R2,R3)	L-3	5	5-15 (B)	2,412
MR Young Oil Co. #1 Bisbee Hills (R1)	L-8	[7]	[7-25 (A,B)]	2,183
Seville-Trident #1 Hurt Ranch (R1)	L-9	[7]	[7-12 (B)]	2,354
Skelly No. 1-A State C (R1,R2,R3)	L-4	4	[4-14 (C)]	2,876
Sunray Mid-Cont. No.1 Fed. R (R1,R2,R3)	L-5	4	4-16 (C)	2,016
Sycor Newton No.1 St. L-6, 350 (R1,R2)	L-2	5	5-15 (B)	3,069

***References:** R1-Bieberman and Chavez, undated, A-D; R2-Thompson, 1981; R3-Thompson, Tovar, and Conley, 1978; R4-Thompson, 1977; and R5-Thompson and Bieberman, 1975.

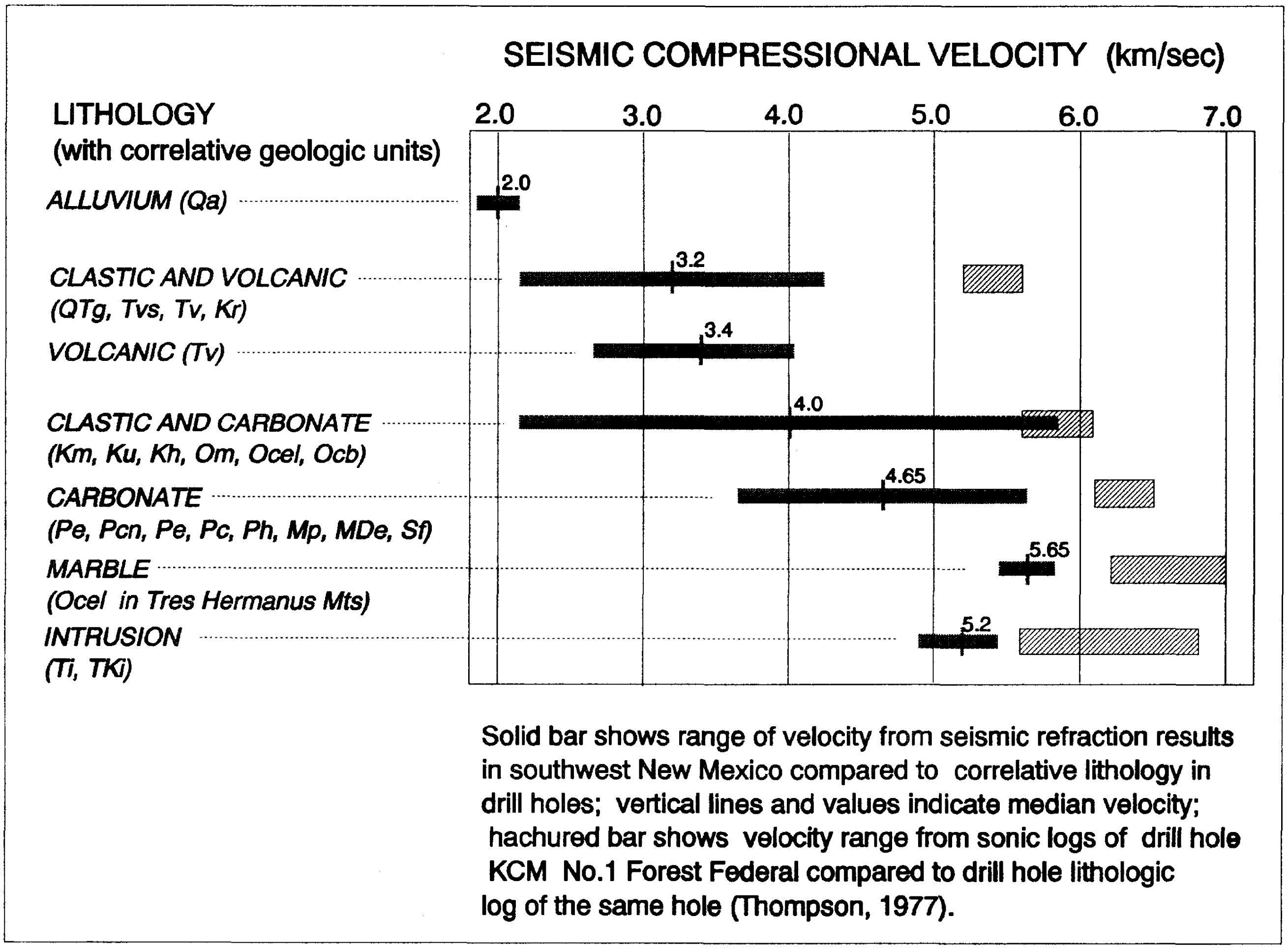

Figure 4 -- Correlation of seismic velocity measurements and lithology from drill hole logs in the southwest New Mexico. Solid lines from correlations of seismic refraction velocities with drill hole logs along survey lines; hachured bars from sonic log velocities in drill hole KCM No.1 Forest Federal (Thompson, 1977).

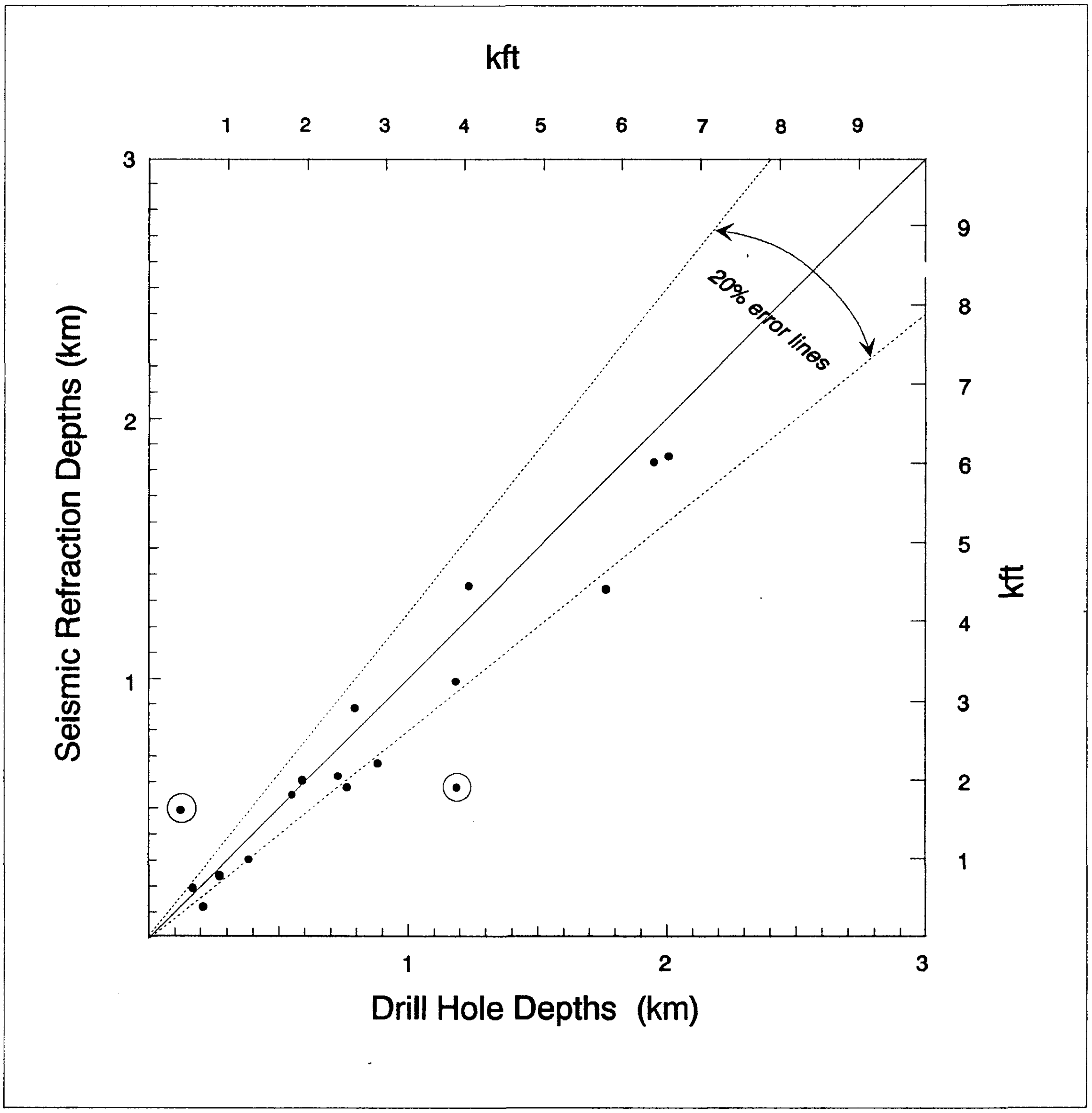

Figure 5 -- Comparison of depths to major lithologic contacts from seismic velocity sections and drill hole lithologic logs. Drill hole data reported by Thompson (1977, 1981) and Thompson and others, 1981).

Thompson (1981, p.9-13) discusses the drill holes, and uncertainties in the depths to formation tops. Thompson (1981) warns that the depths are preliminary because detailed stratigraphic studies for the drill holes were not completed at the time of his report. Many of the depths are based on drill hole cuttings. He does not analyze the errors, but uncertainty in the drill hole depths contributes to the discrepancies shown on figure 5. Drill holes were located at varying distances from the seismic refraction lines, and some discrepancy in depths can be attributed to local structures. An example of such structure is apparent in 3 drill holes (L-1, L-2, and L-3: Table 1, Plate I) that are within a radius of 5 km, and are all about 5 km from seismic line 5. Reported depths to the interface between Tertiary volcanic and sedimentary rock, and Permian Lobo (Abo) formation varies from 400 to 800 m among these drill holes. The seismic structure on line 5 that correlates to this interface is the break from 2.6 km/sec for the Tertiary rocks to 3.7 km/sec for the Permian rocks. This structure shows a dip that changes the interface depth from about 400 to 500 m in the vicinity of the drill holes.

BASIN DEPOSITS AND BEDROCK STRUCTURE

In the following discussion, locations are designated by shotpoint position for a particular line and segment of the line (Plates I and II). For instance, SP 1-12 (B) indicates line 1, SP 12, segment B. The segments of each line are shown with cross-sections on Plate II, which also shows shotpoints. Segments overlap at adjacent lines and although overlapping shotpoints have different numbers for each segment, only one of the numbers is used in this report. A shotpoint that is used for overlapping segments will be indicated by showing both segments in parentheses, such as 1-27 (A,B). On the map (Plate I), shotpoints are labeled but line segments are not indicated. Plates I and II should be used together to avoid possible confusion in locations based on the shotpoint nomenclature.

When the coincidence of gravity or magnetic anomalies to structure in the seismic velocity section is discussed, gravity anomalies are based on the complete Bouguer gravity map shown on Plate I and magnetic anomalies are from Cordell (1983). The gravity map is based on the compilation from Keller and Cordell (1983), with additional data provided by Chuck Heywood (Water Resources Division, USGS, personal communication, November 1994). Where gravity anomalies are quantified in milliGals (mGal), the values are relative to mean gravity usually taken from the inflection point of bounding gradients rather than peak-to-peak values.

Geological relationships discussed are based on a digital revision (Orin Anderson, New Mexico Bureau Mines and Mineral Resources, oral communication, Nov, 1994) of the New Mexico geologic map (Dane and Bachman, 1965; New Mexico Geological Society, 1982). Geologic units discussed with drill hole data are from Thompson (1977, 1981), Thompson and others (1981), Gates and others, (1978), and Zeller (1965) and are usually consistent with the geologic map units. The geologic units penetrated by the various drill holes are listed on Table 2.

Line 1 - Playas Valley

Line 1 traverses the Playas valley from south to north. The line consists of two segments (Plate II). Segment A includes SP 1-2 (A) to SP 1-31 (A,B); this segment crosses the eastern boundary of Cowboy Rim Caldera and up to the area of the Little Hatchet Mountains. Segment B includes SP 1-27 (A,B) to SP 1-33 (B); this segment extends to an area east of the Pyramid Mountains.

Table 2 -- List of geologic units encountered in drill holes near seismic refraction lines of southwest New Mexico. Map unit formation names and lithology based on geologic map described in separate chapter of this report. Drill hole units from Thompson and Bieberman (1975), Thompson (1977, 1981), and Thompson and others (1978).

Drill hole unit	Map unit	Formation name and lithology (minor or local lithologic components in parenthesis)
Qa	(Qa)	Alluvium, Quaternary
QTg	(QTg)	Gila Group - basin deposits, Quaternary-Tertiary
Tvs	(none)	Volcanic and sedimentary rock; Tertiary
Tv	(Tv)	Volcanic rock; Tertiary
Ti	(Ti)	Intrusive rock; Tertiary
TKv	(none)	Volcanic rock; Lower Tertiary-Upper Cretaceous
Ksv	(Ksv)	Sedimentary and volcanic rock; Cretaceous
Kr	(Ku)	Ringbone Shale - shale, conglomerate, sandstone; Upper Cretaceous
Km	(Kl)	Mojado Formation - sandstone, shale, (limestone, conglomerate); Lower Cretaceous
Ku	(Kl)	U-Bar Formation - limestone, (sandstone, shale); Lower Cretaceous
Kh	(Kl)	Hell-to-Finish Conglomerate - conglomerate, (shale, siltstone, sandstone); Lower Cretaceous
Pa	(Pa)	Lobo (Abo) Formation - limestone, conglomerate, siltstone, shale, sandstone; Lower Permian
Pcn	(PP)	Concha Formation - limestone; Lower Permian
Ps	(PP)	Sherrer Formation - siltstone, sandstone, quartzite; Lower Permian
Pe	(PP)	Epitaph Dolomite - dolomite (limestone, siltstone, marlstone); Lower Permian
Pc	(PP)	Colina Limestone - limestone; Lower Permian
Per	(PP)	Earp Formation - siltstone, marlstone, (limestone, mudstone); Lower Permian
Ph	(PP)	Horquilla Limestone - limestone, dolomite, widespread secondary porosity; Lower Permian - Upper Pennsylvanian
Mp	(M)	Paradise Formation - limestone, (shale, mudstone, sandstone, siltstone); Upper Mississippian
MDe	(MD)	Escabrosa Group - massive carbonates, commonly contact metamorphosed; Mississippian and Devonian
Dp	(D)	Percha Shale - shale, siltstone, sandstone; often metamorphosed into hornfels; Devonian
Sf	(SO)	Fusselman Dolomite - limestone, dolomite; vuggy and cavernous; marbleized in Tres Hermanas; Silurian
Om	(OC)	Montaya Group - sandstone, siltstone, dolomite, limestone; Upper to Middle Ordovician
Os	(none)	Simpson Formation - clastic rocks; Ordovician
OCel	(OC)	El Paso Formation - calcarious conglomerate, sandstone, chert, locally metamorphosed to marble; Ordovician-Cambrian
OCb	(OC)	Bliss Formation - sandstone, shale, siltstone, locally metamorphosed to quartzite; Ordovician-Cambrian
YX	(Y,X)	Undifferentiated crystalline rock, granite (metasedimentary rock); Proterozoic

In the area of Cowboy Rim caldera, SP 1-02 (A) to 1-15 (A), bedrock shows a nearly uniform velocity of about 4 km/sec throughout the penetrated depth range. In the Valley floor north of SP 1-15 (A), seismic basement (about 5 km/sec) is found at varying depths ranging from less than 0.2 km to about 1.5 km.

Cowboy Rim caldera

Seismic basement (4 to 6 km/sec) is not detected in the southern Playas Valley from near the Mexican border north to about SP 1-15 (A). This area is adjacent to the inferred east boundary of the Cowboy Rim caldera (Elston, 1984). Layer 1 has unusually high velocity (2.7 - 2.9 km/sec) for unconsolidated basin fill, and this layer may be lava or tuff or contain a significant portion of such rock. Layer 2 (3.2 to 4.4 km/sec) is probably welded tuff. The lack of seismic basement with velocity of 4.5 km/sec or greater, indicates a thickness of welded tuff exceeding 1.5 km. The area of this seismic feature is partially on the east flank of a 15-20 mGal gravity low.

The Cowboy Rim caldera is part of a cluster of middle Tertiary extrusive centers in southwest New Mexico and adjacent Arizona (Deal and others, 1978; Elston, 1984; Luedke, 1993). The area of this volcanism is generally marked by thick, large-volume ash-flow tuff, irregular magnetic intensity, and a broad gravity low. The diameter of this cluster, including adjacent calderas in Arizona and volcanic centers in Mexico, is about 120 km, or about 1/3 the diameter of the Mogollon Volcanic Field located about 120 km north. Individually, the calderas near this cluster do not have characteristic geophysical signatures in magnetic and gravity data. Seismic line 3 also crosses this volcanic rock.

The importance of these eruptive centers to the present work is that they mark areas of intense faulting, fracturing, intrusion, and long-lived or recurrent hydrothermal activity (often asynchronous with the major volcanic activity). They therefore have the potential to control mineral deposits of various types (Rytuba, 1981; Lipman, 1984; Elston, 1984).

Valley Floor

In the central part of Playas valley from SP 1-15 (A) to 1-25 (A), the seismic section shows elevated seismic basement (4.9-5.6 km/sec). This area is between Big Hatchet Peak on the east and Gillispie Mountain in the Animas Mountains on the west. The high seismic basement velocity (4.9-5.6 km/sec) requires a compact rock such as intrusive or metamorphic rock, silicified sedimentary or volcanic rock, or carbonate rock. Seismic basement is shallowest near SP 1-17 (A) where high velocity is found at about 700 m depth. High velocity rock deepens northward. Drill hole H-5 near SP 1-18 (A) indicates that the 5.6.km/sec rock corresponds to Permian Epitaph Dolomite here, and overlying 3.4-4.1 km/sec rock of the layer 2 corresponds to Tertiary and Quaternary clastic rock of the Gila Group. Gravity shows a 5 mGal high over this shallow carbonate rock. Basement velocities in this area are higher (4.9-5.6 km/sec) where basement is shallow (500-800 m depth) near drill hole H-5 beneath SP 1-17 (A). Possibly, there is silicified sedimentary and volcanic rocks or intrusives where velocities increase. The inferred thick section of volcanic rock (4 km/s) southward from SP 1-15 (A) and the abrupt change to shallow high velocity rock at SP 1-17 (A) suggest that the section may traverse the northern wall a buried caldera here.

Between SP 1-25 (A) and 1-32 (A,B), seismic basement (4.5 - 4.9 km/sec) shallows from about 1.5-km depth to a depth of 250-350 m. Basement shallowing is gentle from the south to SP 1-32 (A,B). Depth to basement increases abruptly north of SP 1-33 (A,B) where alluvium (2.4 km/sec layer 1) shows a thickness of about 300 m as far north as SP 1-17 (B). Seismic basement is modeled at about 400-m depth beneath SP 1-32 (A,B) to SP 1-33 (A,B), and is associated with a gravity high that extends eastward from Proterozoic through Cretaceous age outcrop in the northern end of the Animas Mountains; Paleozoic carbonate rocks dominant the outcrop pattern. The combined signature of seismic refraction and gravity is inferred to represent a ridge of Paleozoic rock extending beneath alluvium east or southeast from outcrop. Gravity suggests that this ridge might extend beneath much if not all of the Playas Valley.

South of the basement rise, drill hole H-4 near SP 1-25 (A) shows Permian Horquilla Limestone corresponding to 4 km/sec rock, and Mississippian-Devonian Escabrosa Group corresponding to 5 km/sec rock. On the north flank of the rise, drill hole H-3 near SP 1-34 and 1-33 (A,B) indicates that Cretaceous Mojado Formation (clastic and carbonate rock) corresponds to rock of velocity of 5 km/sec. However, the seismic basement dips steeply north beneath drill hole H-3 with 4 km/sec rock filling the lower part of the section to the north of 5 km/sec seismic basement. Considering uncertainties in the seismic modeling and shotpoint locations, the Mojado Formation may be correlative with 4 km/sec rock, and 5 km/sec rock is Paleozoic limestone.

At SP 1-25 (B), near the continental divide east of South Pyramid Peak, seismic basement (5 km/sec) rises to within 150 m of the surface. Layer 1 pinches out here, and layer 2 velocity (4 km/s) is higher than normal. Gravity shows a northwest-trending high here. Cretaceous and Tertiary volcanic rock outcrop in the nearby northwestern Coyote Hills area probably corresponds to the 4 km/sec rock in layer 2. Underlying 5 km/sec rock is believed to intrusions, metamorphic rock or carbonate rock. Gravity shows a prong of a high over this shallow seismic basement that culminates to the southwest over Winkler anticline in the Animas Mountains near drill hole H-6. Lithology beneath SP 1-25 (B) may be similar to that beneath drill hole H-6.

Line 2 - San Luis Valley through the Alamo Hueco Mountains

From the east flank of the Peloncillo Mountains, line 2 traverses eastward across the southern Animas Valley, also known as the San Luis Valley, the San Luis and Whitewater Mountains, the southern Playas Valley, and the Alamo Hueco Mountains. The line consists of 2 discontinuous segments. The western segment W includes SP 2-01 (W) through 2-24 (W). The eastern segment E includes SP 2-01 (E) through 2-23 (E). There is no overlap between segments, and the velocity section shows a gap in the Playas Valley where line 2 is intersected by line 1. The velocity section shows 5 km/sec seismic basement within about 300 m of the surface over most of the San Luis and Whitewater mountains, and the Alamo Hueco Mountains, as well as beneath bordering areas that extend into the topographic basins.

San Luis Valley

The east flank of the Peloncillo Mountains at SP 2-1 (W) to 2-6 (W) are underlain by about 100 m of weathered bedrock (layer 1, 2.4 km/sec) and 600 m of layer 2 (3.3-4.0 km/sec) rock. Seismic basement (5.0 km/sec) is at about 700 m depth at SP 2-1 (W), and deepens eastward to a depth of about 1.2 km at SP 2-6 (W). Alluvium, or weathered bedrock changes little in thickness in the interval from SP 2-1 (W) to 2-6 (W). The valley here is characterized by a moderate (4-6 mGal) gravity low that is most likely explained by constantly thin alluvium (2.2-2.4 km/sec) over a thickening section of layer 2 rock (0.8 to 1.0 km of 3.2 - 3.9 km/sec) rock. The latter is inferred to be volcanic tuff. The profile here traverses part of the Geronimo Trail caldera (Elston, 1984; Luedke, 1993). Alluvium (2.0-2.4 km/sec) is less than about 300 m thick across the entire valley.

San Luis and Whitewater Mountains

On the east side of the San Luis (southern Animas) valley, seismic basement at 4.7 to 5.0 km/sec rises to less than 100 m of the surface in the San Luis Mountains at SP 2-12 (W) and remains within 300-600 m depth across the San Luis and Whitewater Mountains to SP 2-22 (W). At SP 2-12 (W) the profile crosses mapped outcrop of basalt and rhyolite tuff. Here the seismic basement is overlain only by surface layer that represents weathered outcrop. Seismic basement deepens eastward, but is within 600 m of the surface as far east as SP-20 (W) in the Whitewater Mountains. Layer 2 bedrock (3.7 km/sec) is near the surface from SP-12 (W) to SP-16 (W); alluvium (2.4 km/sec) thickens on an eastward sloping pediment toward the Playas Valley.

Eastward from SP 2-12 (W), shallow (less than 700 m) seismic basement is found along the intersection of the Cowboy Rim caldera to the north and the San Luis caldera to the south (Elston, 1984; Luedke, 1993). Bedrock velocity, including seismic basement (4.8 to 5 km/sec) is inferred to be flows and welded tuff because intrusive or carbonate rock would probably have velocity of 5.5 km/sec or greater. The shallow seismic basement here is marked by a broad but unpronounced 5 mGal gravity low that further suggests that carbonates, intrusive, or metamorphic rock is not within a kilometer of the surface.

Southern Playas Valley

A gap in the velocity sections between the east and west segments of line 2 occurs over much of Playas Valley. East of this gap, the model shows that alluvial thickness is about 700 m between SP-1 (E) to SP-3 (E). Seismic basement (4.6 to 5.2 km/sec) rises to depths less than 350 m from SP 2-3 (E) to 2-11 (E) within the eastern edge of Playas valley. East from SP 2-9 (E), this profile skirts outcrop of Cretaceous rock. Cretaceous carbonate rock or well indurated sandstones or shales could have the modeled seismic velocities (3-4 km/sec) for bedrock here. However, the seismic basement rise near SP 2-3 (E) is associated with a 10-15 mGal gravity high, thus it seems likely that Cretaceous rock is thin and the seismic basement is comprised of Paleozoic rock such as comprises the Big Hatchet Mountains 8 km north. Drill hole H-7 confirms this inference.

North flank of the Alamo Hueco Mountains

Between SP 2-11 (E) and 2-13 (E), seismic basement drops from a depth of a about 30 m to 1.2 km. Seismic basement velocities here are 5 km/sec west of SP 2-11 (E), and except for a modeled 7 km/sec basement for a small block under SP 2-13 (E), basement velocities decrease by 0.3-0.5 km/sec east of SP 2-11 (E). The 7 km/sec block seems inconsistent with others modeled values in this refraction survey and is ignored. Capping rock east and west of SP 2-11 (E) has velocity from 3 to 4 km/sec and is believed to be the same lithology. Outcrop does not change across this seismic discontinuity and the gravity remains high. This suggests that the Cretaceous rock varies rapidly and significantly in thickness across SP 2-11 (E), probably due to faulting in Cretaceous or post-Cretaceous time.

East of SP 2-17 (E), the highest and deepest velocity modeled is 4.7 km/sec. This is interpreted as seismic basement of weak (fractured) or dirty (large fraction of silt and sandstone) carbonates. Alternatively, the lithology may belong to layer 2 as clastic sedimentary or volcanic rock. There is no clear choice between the alternatives, but seismic basement of 5 km/sec or more is missing and there is apparently an important lithologic change from the higher velocity basement west of SP 2-11 (E). SP 2-19 (E) is near a mapped normal fault that bounds Cretaceous rocks to the west and Tertiary andesitic rocks to the east. The mapped normal fault near SP 2-19 (E) is shown by an increase in thickness of alluvium (layer 1: 2 - 2.9 km/sec).

Velocity structure in the eastern Playas Valley and across the northern Alamo Hueco Mountains is complex but consistent with a probable east- or northeast-verging thrust of Paleozoic carbonates (about 5 km/sec) and Cretaceous rocks (3.3 to 4.0 km/sec) between SP 2-03 (E) and 2-11 (E) or 2-13 (E). Paleozoic rocks, inferred to be represented by the 4.9 to 5.0 km/sec velocity, are interpreted as the buried equivalent of rocks exposed in the Hatchet Mountains.

The proposed structure is in broad accord with the regional tectonic style of southwest New Mexico outlined by Drewes (1991), and the specific structural style shown by Drewes and others (1988) for the Big Hatchet Mountains just north of the Alamo Hueco Mountains. The change in velocities east of SP 2-11 (E) is interpreted as large-throw normal faulting synchronous or later than the thrust.

Line 3 - Animas Valley

Section 3 traverses north through the Animas valley, flanked by volcanic rocks derived from calderas in the Peloncillo Mountains to the west and the southern Animas mountains to the east (Elston, 1984; Luedke, 1993). The line is short, only 72 km long, and composed of a single segment from SP 3-31 on the south to SP 3-42 on the north.

Animas Peak and Tullous calderas

Line 3 is dominated by a 12-km wide velocity discontinuity buried beneath the valley floor northwest of Animas Peak. From SP 3-15 to 3-27, the upper part of layer 2 indicates doming over a higher-velocity core (4.3 km/sec). Adjacent lower-layer-2 rocks have velocity of 3.7-3.9 km/sec. Seismic basement of 4.5 km/sec or greater is not detected beneath the core. Furthermore, seismic basement bordering the core has velocity only of 4.6-5.1 km/sec. This seismic velocity pattern occurs over the nested Animas Peak and Tullous calderas (Elston, 1984; Luedke, 1993).

The region from SP 3-1 to SP 3-31 shows generally low gravity, both in and west of Animas Basin, but the seismic anomaly at SP 3-15 to 3-27 corresponds to a slight 4-6 mGal high within the broader low. The broad gravity low encloses several eruptive centers including several named calderas which are mostly inferred from reconnaissance mapping (Elston, 1984).

The 4.3 km/sec rock forming the core of the seismic structure is inferred from surrounding geology to be low-porosity, highly welded tuff relating to a center of explosive volcanism that left highly fractured, or no geologic basement throughout the depth of detection to about 1.5 km depth. The 4.3 km/sec rock may also contain seismically invisible dikes or small plutons, or itself be a fractured and altered intrusion. Low velocity seismic basement (4.6-4.8 km/sec) bordering the 4.3 km/sec core of the inferred volcanic center may indicate that welded tuff composes the seismic basement as well. If carbonate, metamorphic or igneous rock is present it is disturbed by fracturing. The configuration of seismic units adjacent to the 4.3 km/sec rock suggests lava or ash outflow units thickening toward the core. Also the thinned layer of sedimentary rocks above the core suggest that the inferred volcanic system might have been active during erosion of the bordering ranges. Seismic data support the inference and the location of an volcanic center, but do not distinguish between the Animas and Tullous nested calderas shown by Elston (1984) and Luedke (1993).

Seismic basement velocity increases by 0.2 km/sec north of SP 3-31 where gravity also increases. This may mark the northern boundary zone of the volcanic center.

Line 4 - San Simon Valley to the Rio Grande Valley

Seismic profile 4 crosses the structural grain of southwest New Mexico to provide a broad cross-section of the basin-range structure for the upper 1 to 2 km of the crust. The line is along New Mexico State Highway 9 through the towns of Animas and Hachita to Columbus; from Columbus to El Paso the line follows county roads close to the Mexican border. The larger ranges traversed are west of Columbus where the elevations range from 1,280 to 1,430 m. Although the profile crosses ranges at relatively low passes, or skirts the end of ranges, the uplifted basement rock is often clearly expressed. East of Columbus, the topography is a broad plain where the elevation traversed ranges from 1,220 to 1,280 m.

Outcrop is scarce east of Columbus, except across the Potrillo basalt field; nevertheless the velocity section shows significant buried relief in the seismic basement.

The velocity section has 4 segments: segment A extends from SP 4-01 (A) at the New Mexico border to 4-45 (A,B) near Hachita; segment B extends from SP 4-40 (A,B) by the Tres Hermanas Mountains to SP 4-44 (B,C), segment C extends from SP 4-42 (B,C) to 4-35 (C,D) near the East Potrillo Mountains, and segment D extends from SP 4-30 (C,D) to 4-34 (D) near the Rio Grande.

San Simon Valley to the Animas Mountains

Line 4 begins on the eastern San Simon Valley where alluvium (2.2-2.5 km/sec) is modeled with a thickness of about 460 m. The second layer (3.2 km/sec) is inferred to be sedimentary and volcanic rock about 790 m thick overlying seismic basement with velocity of about 5 km/sec. These seismic units dip away from the Peloncillo Mountains on the east.

Line 4 at SP 4-4 (A) to 4-6 (A) crosses the Peloncillo Mountains over Antelope pass, which is a subdued topographic saddle underlain by ash flow tuff. The seismic model here shows near surface rock of 3.2 to 4.2 km/sec and seismic basement (5.3 km/sec) within about 610 m of the surface on the eastern part of the pass. A 10 mGal gravity high coincides with the raised seismic basement.

Within the Animas valley at SP 4-10 (A), the model shows a deep and narrow depression in the seismic basement. This depression is characterized by about 360 m of alluvium (2.4 km/sec) plus about 1,600 m of inferred volcanic and sedimentary rock (3.0 km/sec) above 6.1 km/sec seismic basement. The depression is about 6 km wide and appears to have lower velocities throughout layers 1-3. Gravity shows a narrow low of about 15 mGal amplitude, which agrees qualitatively with the seismic model in indicating a thick sequence of low density rocks. There is a moderate-sized basalt field over and west of this depression. Interpretation of the depression will be discussed along with a similar graben-like feature located further east on this line at SP 4-8 (C).

Between SP 4-12 to 4-15 (A) near the town of Animas, seismic basement (4.8 km/sec) rises to less than 100 m below the surface. The area of this raised seismic basement is on a north-northwest trending gravity high, but topography here is deceiving. There are several low hills composed of tuff and lava such as found in the Animas and Pyramid Mountains, but the seismic rise is about 6 mi west of the crest of the north-south topographic-trend of the Pyramid and Animas mountains as marked by the continental divide.

At the continental divide near SP 4-18 (A), the seismic model shows more than 650 m of inferred alluvium (2.5 km/sec) and clastic sedimentary and volcanic rock (2.5 to 3.0 km/sec). Gravity here is low as well. These relations indicate a westward embayment of the Playas Basin in this area. The Playas basin, as defined by the seismic refraction model extends from SP 4-18 (A) to SP 4-26 (A) with an inferred alluvial thickness of 150 to 300 m.

Although the Playas Valley shows generally uniformly deep alluvium (150-300 m), it nevertheless has pronounced relief on the seismic basement (4.3 km/sec) and on the lower part of layer 2. At SP 4-22 (A), the seismic basement rises to within about 700 m of the surface whereas at both SP 4-16 (A) and 4-26 (A) seismic basement is at a depth of about 1200 m. This seismically defined relief peaks east of the continental divide and shows no corresponding topography. The peak of seismic basement rise is also associated with a 0.4-0.5 km/sec decrease in basement velocity. Gravity over the basement rise is a small high of less than 5 mGal and shows as an inflection in contours. This gravity anomaly is consistent with a deep and small density contrast. The seismic line from SP 4-18 (A) to SP 4-22 (A) is about 5 km south of the inferred boundary of the middle Tertiary aged Muir Caldera

(Elston, 1984; Luedke, 1993), and the seismic basement rise may be outflow units on the caldera wall.

Little Hatchet Mountains

An 8-km wide zone from SP 4-28 (A) to 4-34 (A) has seismic basement (4.7 km/sec) at about 300 m depth. This area also has a gravity high of about 10 mGal. The seismic basement is overlain by 4.1 km/sec rock at less than 50 m below the surface. Cretaceous and Tertiary volcanic and sedimentary rock outcrop in the nearby Little Hatchet Mountains and Coyote Hills together form a north-south trend crossed by line 4. Seismic basement corresponds to Cretaceous Mojado Formation (sandstone, shale, and limestone) in drill hole G-2.

In view of the gravity patterns, the seismic basement high centered near SP 4-30 (A) is interpreted to show the northwest continuation of the core of the Little Hatchet mountains and the tectonically related (Drewes, 1991) Sierra Rica mountains. The Little Hatchet Mountains and the Santa Rica Mountains show outcrop chiefly dominated by Cretaceous through Tertiary sedimentary and volcanic rock, with local Tertiary intrusions. Proterozoic and Paleozoic age rocks of these ranges are exposed only in their southern parts. The gravity high is part of a trend that does not encompass the Big Hatchet mountains, but instead is continuous with the Sierra Rica Mountains.

Hachita Valley, Apache Hills and Cedar Mountains

From SP 4-34 (A) to SP 4-18 (B) there is variable-thickness basin fill typically underlain by 1,000 to 1,500 m, of inferred clastic and volcanic rock (3-4 km/sec) with seismic basement (5-6 km/sec) ranging in depth from 1,500 to 1,900 m. The Hachita valley is traversed from SP 4-34 (A) to about 4-42 (A,B). The seismic section shows that alluvial fill in the Hachita Valley is less than 250 m thick. However, between SP 4-42 (A,B) and 4-8 (A,B) alluvium (2.4 km/sec) reaches a thickness of about 700 m. Alluvium thins to less than about 250 m east of SP 4-8 (B).

Gravity contours along this part of the seismic section form a 10 mGal low extending from Hachita to the Mexican border. Gravity here is chiefly influenced by the thick section of layer 2 and the deep basement so it does not reflect the variations in alluvial thickness inferred from seismic velocities.

Carrizalillo Hills-Cedar Mountains and Tres Hermanas Mountains

At SP 4-22 (B) between the Carrizalillo Hills and the Cedar Mountains there is a rise in seismic basement with 5.3 km/sec at 900 m depth and overlaying 4.6 km/sec rock within 150 m of the surface. The 4.6 km/sec rock in layer 2 may be volcanic and clastic rock, or fractured carbonate or plutonic rock. The Cedar range is composed of andesite faulted against rhyolite and mixed sedimentary rock. Rocks such as carbonate rocks that likely to have velocity exceeding 5 km/sec are mapped in the northwestern part of the range. Velocity in the section for the seismic basement (5.3 km/sec) suggests that Paleozoic carbonate rocks are present at a depth of 900 m. Fractured carbonate rocks and intrusions (4.6 km/sec) may rise to about 150 below the surface, but gravity forms a small 5 mGal high here that appears to make in likely that the 5.3 seismic basement is overlain chiefly by low-density volcanic rocks.

At SP 4-34 (B), the line crosses the southern edge of Tres Hermanas Mountains. Seismic basement (4.8 km/sec) approaches within 300 m of the surface. The Tres Hermanas Mountains are closer to line 7 and are discussed in the interpretation of line 7 in this report.

Gravity highs over both the Carrizalillo Hills-Cedar Range and the Tres Hermanas Mountains indicate subsurface continuity for at least 30 km northwest. Based on gravity contours and scattered outcrop, both of which form a correlative northwest trending zone, the Tres Hermanas Mountains appear to be structurally connected to the Victorio Mountains.

West of the Potrillo volcanic field

The seismic section from SP 4-42 (B,C) to 4-18 (C) defines a broad uplift of seismic basement (5.2-5.8 km/sec). There is a significant velocity reduction in the seismic velocity in this uplift at SP 4-8 (C) that will be discussed subsequently. High velocity rock (5.2 km/sec) is indicated within 500 m of the surface near SP 4-16 (C). The total relief in the seismic basement is about 800 m across this uplift.

Drill hole L-5, 2.5 km north of SP 4-16 (C), is the closest of two drill-holes into the uplift near it's peak; the second nearby drill hole, L-4, is about 9 km north-northwest of SP 4-14 (C). In drill hole L-5, Tertiary volcanic and sedimentary rock were reported to a depth of about 800 m below which Paleozoic rocks were found to about 2 km depth where Proterozoic rock was encountered at the bottom of the hole. Paleozoic carbonates were deeper in drill L-4.

A 5 mGal gravity high over the uplift peaks to the south of the seismic line, indicating that uplift shallows southward and that the discrepancy between the seismic model and the drill hole depths to carbonate rocks is related to geologic structure and not modeling error.

The uplift terminates near outcrop of basalt of the Potrillo lava field at SP 4-22 (C) where there are hills composed of Paleozoic and Cretaceous sedimentary rock and Tertiary intrusive rock. Outcrop and topography provide scant indication of a shallow bedrock structure. On the average, the top of this buried seismic basement uplift lies within 700 m of the surface, whereas seismic basement to the east and west is at more than 1,500 m depth, giving a total relief in the seismic basement of about 800 m.

On the western flank of the uplift, between SP 4-6 (C) and 4-12 (C), a velocity reduction suggests a narrow (4-8 km wide) graben-like structure that disrupts all seismic layers to a depth exceeding 2 km where it is underlain by 6.1 km/sec rock. 3.75 km/sec rock replaces normal seismic basement indicating that the graben formed after the uplift. Layer 2 above the graben shows a velocity reduction of 1-2 km/sec relative to adjoining rock at similar depth and the alluvial layer above the depression is thickened by 150-200 m. Normal faults mapped in the alluvium bound this graben on the east and west. This structure is anomalous in all seismically modeled layers, and extends to the surface. This suggests that the age of this graben is Quaternary or late-Tertiary. A 10-15 mGal gravity low over the graben extends about 20 km north-south.

Basement rifts

On line 4, pronounced seismic-velocity depressions are at SP 4-10 (A) just west of a basement rise near the town of Animas, and at about SP 4-8 (C) about 16 km west of Potrillo lava field.

These depressions show: 1) seismic basement dropping a kilometer or more, 2) high velocity basement (6.1 km/sec) on the floor of the structure, 3) relatively low velocities extending from basement to near the surface, 4) occurrence on seismically defined broad rises of relatively high-velocity basement (5 km/sec), 5) association with bordering Quaternary lava flows and, 6) coincidence with linear north-south-trending gravity lows.

The western depression is associated with a basement rise that includes the cores of the Peloncillo and Animas Mountains. The Peloncillo and Animas mountains are both composed largely of ash flow tuff, but just west of the depression is a Quaternary basalt field about 8 km wide and 16 km long that extends over much of the northern Animas Valley. The eastern depression is part of broad rise in seismic basement that is largely buried beneath a plain devoid of outcrop, but it is just west of a peak in the basement rise that is coincident with a gravity high. This gravity high is part of a regional high that characterizes the Potrillo lava field.

There are four explanations to consider: 1) grabens of basin and range development, 2) Keystone grabens capping an intrusion-driven uplift, 3) volcanic rift grabens, and 4) gross modeling error related to velocity inversions caused by surface or buried high-velocity layers. The fourth possibility cannot be thoroughly considered without reexamination of the processing and modeling which is beyond the scope of this paper. However, there is corroborative gravity signatures that appear to verify that the structures are present, thus modeling error will be neglected.

The structures in question are narrower than most typical basins, and the structures have a vertical, through-going velocity anomaly from the surface downward through the full extent of the modeled seismic section. Thus, the structures are synchronous, or younger than the chief elements of basin and range development. A further factor that is difficult to associate with a basin and range structure is the high-velocity floor of the two seismic depressions.

Although late basin-range style grabens, or keystone grabens of the type associated with magmatic, or pre-volcanic activity calderas are not eliminated, the seismic signature and surrounding geologic setting is more characteristic of volcanic rift depressions, possibly outliers to Rio Grande tectonism. The structures in question are consistent with basement uplifts at least partly composed of intermediate composition intrusive or extrusive rock. The structures are located on broad uplifts of relatively high (5.2 km/sec) velocity rock. The basal seismic velocity in these depressions are very high (6.1 km/sec) for the depth range of the survey, which suggests that the depressions are bottomed by rock more mafic than the surrounding uplift. Drill hole data indicates that the uplift at SP 4-16 (C) is in part composed of Paleozoic carbonate rock. Basal rock in the grabens may be mafic volcanic rocks.

Low velocity structure above the seismic basement indicates that the graben formed after the main phase of basin filling. The overlying capping may be partially eruptive debris or syn-tectonic alluvium. Nearby Quaternary basalt and geothermal waters in both cases suggest magmatism associated with graben formation. The depression in the Animas Valley is within the Lightning Dock geothermal area and 20 km south of the Lightning Dock hot wells. The depression bordering the Potrillo Mountains is within the Kilborne Hole geothermal area (Swanberg, 1979). The eastern depression bordering the Potrillo Mountains is within the traditional realm of the Rio Grande Rift system (Cordell, 1978; Swanberg, 1979). Numerous Quaternary lava fields throughout the southwest (see Reynolds, 1988 for Arizona) might also be related to shallow crustal rifting.

Low gravity over these structures is consistent with narrow, and moderately elongate north-south structures. Gravity places the orientation of the structure along a typical basin-range trend, which is parallel to the larger Rio Grande Rift. If the high-velocity base in these structures is residual melt (presumably a positive density contrast), it is not apparent in gravity. However a deep positive density contrast can be offset by the shallow negative density contrasts.

Potrillo lava field

Quaternary basalts of the Potrillo lava field outcrop from SP 4-22 (C) to 4-32 (C,D). These surface basalts are invisible in the velocity modeling. The basalt field appears to be underlain by about 300 m of alluvium and weathered rock (2 km/sec), 900 m of sedimentary and volcanic rock (2.9-3.7 km/sec), and seismic basement (4.5 km/sec) at a depth of about 1,100 m. Layers 1 and 2 are thickened relative to adjacent areas along profile, and they may include interbedded lava may form velocity inversions that may introduce errors in the velocity section. The seismic basement has relatively low-velocity (4.4 km/sec) that can be caused by a preponderance of clastic sedimentary rocks, fracturing, or thermal waters.

The Potrillo lava field is associated with a broad and variable gravity high that averages about 5 mGal above the surrounding area. The gravity high is broad and it probably results from a source deeper than the seismic velocity model. One of the larger gravity variations of the Potrillo lava field is an elongate 10 mGal low that is crossed by the seismic line at SP 4-24 (C) and 4-26 (C) where the seismic section indicates thickening layers 1 and 2. Enclosing this interpreted thickening of the clastic section are higher velocities at SP 4-18 (C) and 4-8 (D) which are both associated with gravity highs. SP 4-18 (C) is on the flank of the uplift discussed previously; the vicinity of SP 4-8 (D) is discussed below.

East Potrillo Mountains

At SP 4-8 (D) , seismic basement (5.9 km/sec) rises to within 600 m of the surface. A 12 km wide area encompassing the rise SP 4-32 (C,D) to SP 4-14 (D) shows a 1 km/sec velocity increase compared to the adjoining, deeper seismic basement. This high-velocity rise is located at the southern end of the East Potrillo Mountains, which are underlain by Paleozoic and Cretaceous rocks and intruded in the north by a Tertiary pluton. Seismic basement here is overlain by 400 m of 3.2-3.3 km/sec rock and about 200 m of alluvium (2.2 km/sec).

The high velocity rise centered on SP 4-8 (D) is marked by a gravity high of about 20 mGal trending north-northwest. The high is maximum one to two km west of the East Potrillo Mountains over the Tertiary intrusion. Higher velocity seismic basement of the seismic rise may be partially accounted for by dikes or plutons inasmuch as both gravity and seismic data indicate that much of the East Potrillo range may be underlain by shallow intrusive rock.

The refraction model east of SP 4-12 (D) shows a uniform alluvial layer 300-400 m thick. Layer 2 shows a normal velocity of 3.2-3.4 km/sec east to SP 4-18 (D) where the normal velocity is interrupted by an upward protrusion of 4.4 km/sec rock. East of SP 4-22 (D), layer 2 is composed of 3.4 to 4 km/sec rock to the end of the profile. Gravity is uniformly low over this area. Higher velocities locally present in layer two may be represent interbedded lavas, or distributed igneous dikes. The dikes or lava sills may be too thin and sparse to influence regional gravity, or to define individually in the seismic section.

Line 5 - Peloncillo Mountains to Rio Grande Valley

Line 5 starts on the east flank of Peloncillo Mountains, about 40 km north of line 4, and runs east parallel to line 4 across Animas Valley, the central part of Pyramid Mountains, and then east to highway US 10 near the village of Separ. Near Separ, line 5 turns northeasterly and follows close to US highway 10 to the Rio Grande Valley. Except for crossing the Pyramid Mountains, this traverse is across plains having scarce outcrop.

Velocity section 5 is numbered in three segments. Segment A runs from the eastern flank of Peloncillo Mountains (west edge of Animas Valley) at SP 5-01 (A) to Victorio Mountains at SP 5-45 (A,B). Segment B traverses from Victorio Mountains starting at SP 5-42 (A,B) to Little Florida Mountains at SP 5-40 (B,C). Segment C continues from 5-35 (B,C) to the Rio Grande at 5-44 (C).

<u>Animas Valley and Pyramid Mountains</u>

Line 5 starts its traverse of the Animas Valley on the east flank of Peloncillo Mountains. Strata in the Animas valley dip west as inferred from sub-layers within layer 2 with the greatest thickness of alluvium (2.1-2.6 km/sec) reaching 670 m on the western side of the valley. Maximum depth of seismic basement (4.8 km/sec) in the Animas basin is modeled at about 1,550 m. Seismic data indicates about one km of sedimentary and volcanic rocks (3.5-4.3 km/sec). Drill hole H-1, which is located about 1.2 km north of SP 5-4 (A), encountered about 580 m of Quaternary alluvium and gravel, then penetrated Tertiary volcanic rock to a depth of about 1,770 m, where Paleozoic rocks were encountered. Gravity contours indicate that the basin deepens rapidly northward in the vicinity of the seismic line which may accounts for the 200 m discrepancy between the depths to seismic basement and the depth to Paleozoic carbonate rocks recorded from drill hole H-1.

The central Pyramid Mountains are crossed at SP 5-10 (A) along the northern border of Muir caldera (Elston, 1984, Luedke, 1993). Seismic basement (4.6 km/sec) here is at 120- to 180-m depth with velocity typical of welded tuff or fractured intrusions. Seismic basement is capped by rock of 3.57 km/sec which is mapped as quartz latite to rhyolitic pyroclastic rocks. The core of the range forms a symmetrical rise, with flanking layers conformable to the seismic basement as indicated by the sub-layers of layer 2. These characteristics are consistent with this part of the range having been constructed by intrusion and volcanism.

Separ Plain

An alluvial plain is traversed from Pyramid to Victorio Mountains between SP 5-14 (A) and 5-5 (A,B). Alluvium (2.3-2.6 km/sec) thickens abruptly to about 300 m beneath SP 5-18 (A) and increases in thickness more gently eastward to about 500 m below SP 5-26 (A) to 5-36 (A). About 13 km west of Victorio Mountains near SP 5-38 (A), alluvium is abruptly thinned and shallows toward Victorio Mountains.

Outcrop is sparse from Pyramid to Victorio Mountains, but about 10 km south of SP 5-26 (A) are low hills composed of Tertiary rhyolite that form outliers of the Coyote Hills. Beneath Separ plain, seismic basement (5.5-5.6 km/sec) varies in depth from 1.6 to 2.3 km, being shallowest under SP 5-26 (A). This basement rise may identify an additional northwest extension of Little Hatchet Mountains uplift discussed with line 4 (south of Coyote Hills beneath SP 4-22 (A). An upward flexure in 3.4-4.2 km/sec rock of layer 2 beneath SP 5-22 (A), located about 5 km west of the basement rise, may relate to volcanic rock in the outliers of Coyote Hills.

Layer 1 ranges from 1.6-3.0 km/sec in this report and is usually interpreted as Quaternary basin fill consisting of alluvium and conglomerate. Generally, layer 1 has velocities closer to 2 km/sec rather than 3 km/sec. From SP 4-18 (A) 4-20 (A), layer 1 has velocity of 2.65 km/sec which is on the higher end of the range, and it may contain significant quantities of indurated sediment or porous rhyolitic rock. The latter seems to be the case, as lithology reported from drill hole G-1 located 5 km south of SP 4-28 (A) indicates volcanic rock from 110-600 m depth. Below the volcanic rock, Cretaceous Mojado Formation corresponds to 3.0 or 3.4 km/sec rock to about 1,950 m depth below which about 250 m of Cretaceous Ubar and Hell-to-Finish Conglomerate are found overlying Ordovician carbonates at about 2,200 m depth. Seismic basement (5.5 km/sec) at SP 5-28 (A) is at a depth of about 2,000 m. Drill hole G-1 penetrated Proterozoic rock from 2,615 m to 2,828 m.

<u>Victorio Mountains</u>

Line 5 traverses the northern flank of Victorio Mountains at SP 5-5 (B). Outcrop on this range consists of lower Paleozoic carbonate rocks, Cretaceous rocks, and Tertiary rocks. Tertiary strata are dominantly andesitic lava flows on the north and south flanks of the range.

Seismic basement velocity of the Victorio Mountains (4.6-4.8 km/sec) is congruous with carbonate or intrusive rocks. Beneath the east flank of the range between SP 5-7 (B) and 5-9 (B), a 5-km wide basement shelf (4.8 km/sec) may indicate a flanking fault block or intrusion. Seismic basement here is at about 640 m and overlain by 500-600 m of 2.9 and 3.7 km/sec rock. The 2.9 km/sec velocity strata is probably volcanic rock. East of the Victorio Mountains near SP 5-15 (B) and 5-19 (B), drill holes L-1 and L-2 show upper Permian (Lobo or Abo formation) mixed limestones and clastic rocks beginning at depths of 400 to 800 m and correspond to 3.7 km/sec rock. Paleozoic carbonate rocks in these drill hole are at depths near 2 km and correspond to the seismic basement (5.5 km/sec).

A gravity high of 10-20 mGal conforms with Victorio uplift as seen in the seismic section. High gravity extends about 8 km northwest and 20 km southeast of the Victorio mountains. This gravity anomaly is larger in extent than outcrop of Victorio Mountains with maximum amplitude located about 12 km southeast of the outcrop. Gravity and seismic data together show that most of the structure of Victorio range is buried beneath moderately thin cover. Inasmuch as the exposed part of the Victorio Range is mineralized, the geophysically defined shallowly buried structure may also be mineralized.

Deming basin

From the east flank of Victorio Mountains at SP 5-11 (B) to north of Deming near SP 5-35 (B), line 5 profiles a basin similar to that of Separ Plain. The thickest section of alluvium (2.4 km/sec, over 600 m) occurs from SP 5-23 (B) to 5-31 (B) under which seismic basement (4.8-5.5 km/sec) shallows gently eastward, varying from about 2,000 m east of Victorio Mountains uplift, to about 1,700 m beneath the Deming area. Layer 2 changes significantly near SP 5-23 (B). West of SP 5-23 (B), layer 2 (3.7 km/sec, about 1.5 km thick) corresponds to Permian Lobo formation (carbonate and clastic rocks) in drill hole L-1. East of SP 5-23 (B), velocity in layer 2 drops to 3.2 to 3.5 km/sec, and the layer thins to less than 1 km. This may signify that Tertiary or Cretaceous volcanic and sedimentary rocks form the upper part of a thinned layer 2 east of SP 5/23 (B). Small hills of Tertiary volcanic rock that are seen about 10 km north and south of the profile west of Deming (south of Line 5) have no signature in seismic section 5.

Little Florida and Goodsight Mountains

Eastward from Deming to Las Cruces, line 5 traverses a featureless alluvial plain. However, three areas of outcrop exist about 10 km laterally from line 5: Little Florida Mountains south of the line near SP 5-37 (B,C), Goodsight Mountains north of the line at about SP 5-17 (C), and Aden Hills (south) and Sleeping Lady Hills (north) of the line near SP 5-30 (C). These outcrops are Tertiary volcanic rock except in Little Florida Mountains which are composed of Proterozoic and lower Paleozoic rock overlain locally by Permian, Cretaceous, and Tertiary strata. Little Florida Mountains also display the only appreciable topography near the eastern part of line 5.

Seismic basement (4.5-5.2 km/sec) broadly rises between SP 5-35 (B,C) and SP 5-18 (C). Uplift is abrupt north of Little Florida Mountains rising 800 m from a depth of about 1,600 m. Eastward, seismic basement rises more slowly to culminate at SP 5-13 (C), south of Goodsight Mountains at a depth of about 300 m. Seismic basement velocity is highest (5.2 km/sec) south of Goodsight Range as well. The seismic section also shows anomalously high velocity rock in layer 2 (4.27 km/sec) and layer 1 (3.26 km/sec) over the higher parts of the basement rise indicating that about 100-200 m of Tertiary volcanic rocks are near the surface. These may be underlain by carbonate rocks which are possibly intruded at the depth of seismic basement (about 500 m on the average). A gravity high of 5-10 mGal coincides with this area. Gravity patterns indicate that this high-velocity uplift may trend southeast to the

East Potrillo Mountains where there is also anomalously high velocity seismic basement (discussed with line 4 at SP 4-8 (D)).

Eastward from SP 5-18 (C) to 5-38 (C), layer 1 velocity (2.5 to 3 km/sec) remains high and probably reflects volcanic rock. Layer 2 from about 200- to 1,000-m depth has 3.4 to 4.2 km/sec velocity signifying Tertiary or Cretaceous volcanic rock, sedimentary rock, or muddy carbonates. Seismic basement has unusually low velocity (4.7 km/sec) of uncertain composition. Seismic basement depth is about 1,200 m to SP 5-32 (C), where sharp upward and downward excursions most likely reflect faulting in Rio Grande valley. At SP 4-38 (C), seismic basement drops to a depth of about 1,800 m. Gravity here shows a steep gradient to a 10 mGal low. These characteristics are inferred to mark a major Rio Grande valley boundary fault. East of the inferred fault, layer 1 (1.89 km/sec) indicates an accumulation of 300 m of alluvium.

Line 7 - Tres Hermanas Mountains through the Deming Basin

Line 7 traverses from south to north making a broad curve to the west around Tres Hermanas Mountains (southwest of Florida Mountains), then continues north across the Deming basin to the vicinity of Cook's Range. Two segments comprise this line. Segment A on the south includes SP 7-01 (A) - 7-29 (A,B); segment B includes SP 7-25 (A,B) - 7-27 (B).

<u>Tres Hermanas Mountains</u>

Tres Hermanas mountains are composed of lower Paleozoic carbonate rocks, Tertiary intrusive rocks, and various overlying Tertiary sedimentary and volcanic rocks. Volcanic rocks predominate in outcrop over other Tertiary lithologies. Along the east side of the Tres Hermanas Mountains from SP 7-1 (A) to 7-11 (A), seismic basement (5.4-5.5 km/sec) is at about 1,100 m depth, overlain by layer 2 strata (3-4 km/sec) that is within 100 to 150 m of the surface. Seismic basement velocity is consistent with intrusive, metamorphic, or massive carbonate lithologies. The lower part of layer two (4.3 km/sec) in the seismic model is likely to be carbonate rocks although silicic or altered intrusives may be present. The upper part of layer 2 (3 km/sec) is inferred to be volcanic rocks correlative with outcrop on the north and south flanks of Tres Hermanas Mountains.

From SP 7-11 (A) to 7-23 (A), which runs northwest, basement is depressed to about 1,400-m depth on the average. Layer 2 is depressed in the same area and is overlain by about 300 m of inferred alluvium and volcanic rock (2.4-2.7 km/sec).

West of the Florida Mountains

From SP 7-23 (A) to 7-12 (B), a broad uplift of seismic basement is indicated on the depth-velocity section. This uplift peaks at SP 7-28 (A) where 5.2 km/sec rock is within 100 m of the surface. A one-kilometer thick platform of 4 km/sec rock continues north to 7-12 (B). The seismic line crosses a flat plain here, but is located about 20 km west of the Florida Mountains. Modeled basement uplift occurs on a northwest-trending gravity high (10 mGal) that connects outcrop of lower Paleozoic rock found in both Florida Mountains (east of the of the seismic line) and in Red Mountain (west of the seismic line). High velocity and outcrop east and west of this anomaly indicates that carbonate rocks form the upper kilometer of the uplift from SP 7-29 (A,B) to 7-12 (B). Crystalline basement of metamorphic or plutonic rock cannot be ruled out for parts of the uplift with velocity greater than 5 km/sec. Such velocity occurs throughout the core of the uplift, and is within 500 m of the surface for about 4 km south from SP 4-28 (A,B).

Deming basin

From SP 7-12 (B) to 7-20 (B), line 7 provides a north-south cross-section of the Deming basin. This basin is also traversed by east-west line 5. The latter, discussed earlier, defines a deep basin from SP 5-23 (B) to 5-30 (B,C). Lines 5 and 7 agree in defining the depth to seismic basement as 1.5 to 2 km, overlain by 500-700 m of alluvium (2.4-2.6 km/sec). Gravity over the Deming basin shows a northwest-trending low. The magnitude of the low is about 10 mGal near where crossed by line 7, and larger (more negative) northwest.

West of Cook's Range

Near SP 7-20 (B), seismic basement (4.7-4.9 km/sec) rises about 600 m. Layer 2 strata (3-4 km/s) rises in concordance with the seismic basement to within 50 to 200 m of the surface and remains shallow north of SP 7-22 (B). Except for a thin surface layer, velocities typical of alluvium (2.0-2.5 km/sec) disappear north of SP 7-22 (B). This structure is probably related to subsurface rocks extending westward from Goat Ridge, Flourite Ridge, and Cook's Range. The 3- to 4-km/sec rock is probably Cretaceous and Tertiary sedimentary and volcanic rock similar to that in nearby outcrop.

SUMMARY AND RESOURCE IMPLICATIONS

Seismic velocity sections discussed in this report provide insight into the structure of part of the Basin and Range Province in southwest New Mexico from the Mexican border north to about lat. 32° N and from Arizona to the Rio Grande Valley. Velocity structure is interpreted to a depth of about 3 km. Comparison of interfaces at profile cross-over points and comparison to drill hole logs indicate that the sections can be used to predict major lithologic interfaces with an accuracy of 15- to 20-percent, although discrepancies exceeding 50-percent were observed in two cases. Gravity highs corresponded well with areas of inferred uplift and gravity lows corresponded well with deep seismic basement. Thus gravity may be used qualitatively to extend the seismic interpretation outward from the lines. Gravity contours also indicate that part of the discrepancy between seismic depth determinations and depths from drill-hole lithologic logs can be related to structure between the drill hole and the seismic section.

There are three main seismic horizons in the seismic profiles, a wet, alluvial layer (1.6-3.0 km/sec), a layer of mixed sedimentary and volcanic lithologies (2.7-4.5 km/sec), and seismic basement (4.0 to 6.1 km/sec). The second horizon is composed of 2 to 3 seismic layers that show horizontal and vertical variations in clastic sedimentary rock, volcanic rock, and porous or muddy limestones. The seismic basement is mostly compact Paleozoic carbonate rock; igneous intrusive rock may be locally present.

Table 3 lists subsurface geologic environments as inferred from the seismic data, drill-correlations, and surficial geology.

Table 3 -- Summary of results inferred from seismic velocity sections. Shot-point locations indicated by line number, shotpoint number, and segment of line.

GEOGRAPHIC AREA	SHOT-POINT LOCATION	REMARKS
FEATURE		
THICK VOLCANIC DEPOSITS (3.7-4.6 km/sec)-seismic basement (about 5 km/sec) absent		
Playas Valley near Southern Animas-San Luis Mts	1-2(A) - 1-15(A)	Cowboy Rim Caldera-more than 1.5 km of volcanic rock
Southern Animas Valley	3-2 - 3-31	Rodeo Caldera-at least 1 km of volcanic rock-eruptive center at 3-15 - 3-27
Pyramid Mts	5-8(A) - 5-14(A)	Muir Caldera-4.6 km/sec volcanic-intrusive rock at depth of 100-300m
TECTONIC BASINS-thick alluvium (1.7-2.6 km/sec) and deep seismic basement (about 5 km/sec)		
Central Playas Valley	1-25(A) - 1-29(A)	300-m alluvim, 0.7-1.5 km to seismic basement
Northern Playas Valley	1-34(A,B) - 1-23(B)	300-m alluvium, 1.2 km to seismic basement
Hachita Valley	4-34(A) - 4-42(A,B)	200-m alluvium, 1.7 km to seismic basement
Apache Hills-Cedar Mountains Basin	4-42(A,B) - 4-9(B) 4-9(B) - 4-18(B) 4-26(B) - 4-32(B)	100-600-m alluvium, 1.1-1.7 km to seismic basement
Animas Valley	5-2(A) - 5-6(A)	400-m alluvium, 1.1 km to seismic basement
Separ Plain	5-14(A) - 5-42(A)	100-500-m alluvium, 1.9 km to seismic basement
Deming Basin	5-11(B) - 5-35(A,B) 7-11(A) - 7-25(A,B) 7-11(B) - 7-22(B)	100-500-m alluvium; 1.5 km to seismic basement
SHALLOW MESOZOIC AND PALEOZOIC ROCK (roughly 4-5 km/sec)-largely limestones and dolomites-Tertiary and Mesozoic volcanic rocks may have equivalent velocity although in many cases drill hole data substantiates the correlation as carbonate rocks		
Central Playas Valley	1-31(A) - 1-34(A,B) 1-23(B) - 1-27(B)	top at 200-700 m; relief and velocity of seismic basement indicates faulting and intrusion at 1-32(A,B) - 1-33(A,B) and at 1-23(B) - 1-27(B)
San Luis and Whitewater Mts	2-10(WEST) - 2-22(WEST)	top from near-surface to 300 m
Playas Valley near Alamo Hueco Mts	2-3(EAST) - 2-19(EAST)	top from near-surface to 300 m
Animas Valley	3-31 - 3-39	top at 300-500 m

Table 3 -- continued

FEATURE GEOGRAPHIC AREA	SHOT-POINT LOCATION	REMARKS
SHALLOW MESOZOIC AND PALEOZOIC ROCK (continued)		
Coyote Hills	4-26(A) - 4-34(A)	top at 300 m
Carrizalillo Hills	4-18(B)- 4-26(B)	top at 200-500 m
Peloncillo Mts	4-4(A) - 4-8(A)	top at 200-300 m
Tres Hermanas Mts area	4-34(B) - 4-38(B) 7-3(A) - 7-9(A)	top at 300-500 m
West Potrillo Mts	4-12(C) - 4-18(C)	top at 500-600 m
East Potrillo Mts	4-8(D) - 4-12(D)	top at 300-400 m; 3-4 km/sec rock within 500 m of surface east of 4-8(D)-suspected to be volcanic or clastic sedimentary rock east of 4-14(D)
East flank Victorio Mts	5-45(A,B) - 5-19(B)	top at 200-500 m
Goodsight Range	5-7(C) - 5-17(C)	top at 200-300 m believed to be volcanic rock (4.3 km/sec); rock at 300-700 m is probably carbonate rock (4.5-5.1 km/sec)
Little Florida Mts	7-28(A,B) - 7-12(B)	top within 300 m, less than 100 m at 7-28(A,B)
BASALTIC RIFTS-narrow, deep, grabens associated with basaltic volcanism and floored by 6 km/sec rock; low-velocity fill extends to surface indicating Quaternary age.		
Animas Valley area near village of Animas	4-8(A) - 4-12(A)	
West of West Potrillo Mts	4-6(C)- 4-12(C)	

The four geologic environments in the subsurface revealed in the seismic data (table 3) are: 1) thick volcanic deposits where there are more than 1.5 km of inferred volcanic rock, 2) tectonic basins characterized by a few to several hundred meters of inferred alluvium, and by seismic basement usually at a depth exceeding one kilometer, 3) areas underlain by shallow Mesozoic or Paleozoic rock where bedrock, usually seismic basement, is interpreted to be composed of limestones, possibly intruded, and within about 500 m the surface, and 4) areas where narrow, volcanic-associated grabens are interpreted as likely Quaternary basaltic rift zones.

Areas of inferred thick volcanic rock are located in the boot-heel region of New Mexico where a cluster of mid-Tertiary volcanic centers is known from geologic mapping. The seismic data in the southern Animas Valley are interpreted to indicate that a caldera structure extends beneath valley fill. This information allows extension of possible areas for volcanic hosted epithermal deposits.

The alluvial thickness in the tectonic basins, based on interpretation of seismic velocity, ranges from 200 to 600 m. The seismic basement (either geologic basement, or more likely lower Paleozoic carbonate sequences) is concluded to be at 1.2 to 1.9 km depth. These areas are important areas for potential water resources that exits in the alluvial section or in the upper part of layer 2 where velocities are less than about 3 km/sec. The tectonic basins are generally non-exploitable for mineral resources because of the thick overburden that covers any rock having the potential to be mineralized.

There are eleven areas of uplift where the depth to probable pre-Tertiary rock (4-5 km/sec) underlays less than 700 m of lower velocity overburden. In a few localities (Table 3) high-velocity rock is modeled at a depth of 100 to 200 m depth. Gravity was found to link the inferred uplifts to bordering ranges at distances of few 10's of kilometers. Based on correlation with nearby outcrop or drill holes, the composition of these uplifts is concluded to be Mesozoic or Paleozoic carbonate rock. Intrusions are possible in these rocks, but are not easily distinguished in seismic data. Under favorable economic circumstances, these areas are regarded as targets for exploration for a variety of mineral deposits including carbonate hosted veins, skarns, and porphyry deposits. Analysis of auxiliary data that has potential to define possible mineralization and alteration, particularly geochemical data, surface electrical surveys and aeromagnetic maps, will be crucial to define areas where exploration for and development of buried ore deposits may be likely and economical. There is potential for petroleum resources in these areas, as well in some parts of the deep tectonic basins. Thompson and others, (1978) and Thompson (1981) have summarized the prospects of petroleum resources in the study area; further analysis is not part of this report.

Along line 4, two seismic structures were found that indicated narrow zones of deep, high-velocity seismic basement overlain by low seismic velocities upward through layer 1. The areas are highlighted by gravity lows. Both areas adjoin Quaternary volcanic rocks, and are near known geothermal areas. These structures are interpreted as Quaternary grabens or rifts, and it is possible that these structures are related to fairly recent (2-5 ma) deep crustal faulting and associated crustal melting. The structures may form paths for present day upwelling of thermal waters.

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