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CENOZOIC-FILL-THICKNESS ESTIMATES FROM P-WAVE DELAYS IN THE JORNADA DEL MUERTO AND PALOMAS BASINS

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Abstract—P-wave delay times in the Jornada del Muerto Basin indicate that the maximum thickness of Cenozoic basin fill is 3.6 km. This thickness is reached in the southern part of the basin and diminishes to the north to about 1.4 km. In addition, there seem to be no major east–west faults in the basin north of the north end of the Doña Ana Mountains. The Palomas Basin has a maximum thickness of 2.3 km; little else can be determined about the basin from this study.

INTRODUCTION

A number of seismic-refraction lines has been recently recorded within the Rio Grande rift to determine its crustal structure (Fig. 1). In crustal-structure studies, the delays in P-wave arrival times associated with smaller structures such as the Palomas and Jornada del Muerto Basins are considered to be noise which is dealt with by geologic corrections. However, these delays can be used to estimate the thickness of sediments within these basins. P-wave-delay times yield information similar to gravity data except that the quantity of interest is P-wave velocity rather than density. Delay-time anomalies have the opposite sense of gravity anomalies in that low-density materials which produce negative gravity anomalies usually have low P-wave velocities and, therefore, produce positive delay-time anomalies and vice versa.

Four seismic-refraction lines which traverse the Palomas and Jornada del Muerto Basins were available for this study. The first three are short segments recorded in the southern part of the Jornada del Muerto to investigate possible anomalous travel times associated with San Diego Mountain (Daggett 1982). The last is a refraction line extending from the Tyrone copper mine to the Distant Runner shot, a large chemical explosion detonated by the military in the Tularosa Basin just south of Mockingbird Gap (Sinno et al. in press). Having shot points on both ends, this line is reversed and crosses both the Jornada del Muerto and Palomas Basins. In addition to the P-wave delay times, residual-gravity profiles were constructed along these seismic profiles to illustrate the correlation between delay time and gravity anomalies and to facilitate comparisons with the detailed gravity results presented by Gilmer et al. (this guidebook).

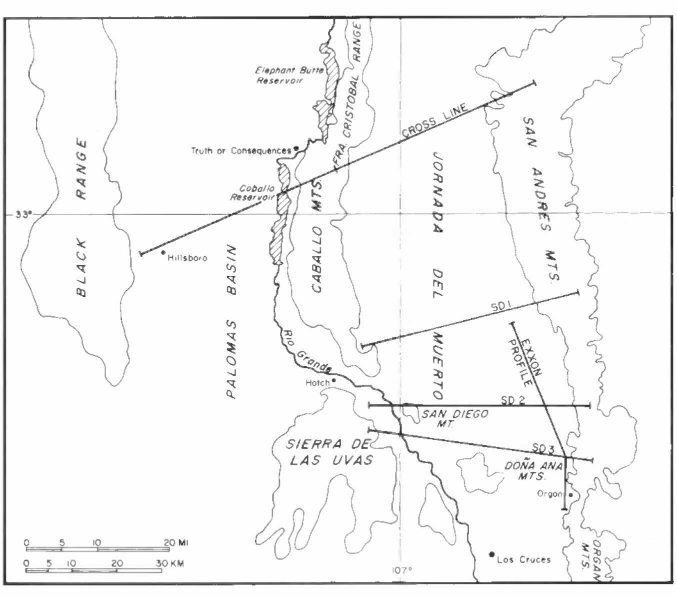

FIGURE 1—Index map of profiles discussed in this paper. Exxon profile is discussed by Keller et al. (this guidebook).

P-WAVE DELAY TIMES

P-wave delay-time sections across the Palomas and Jornada del Muerto Basins were constructed by first removing the geological corrections which were applied to the refraction data by Daggett (1982) and Sinno et al. (in press). The sections were then plotted at a greatly expanded time scale. Calculated travel times for an average earth model were drawn across these sections as a line of reference from which to measure delay times. The difference between the calculated travel time and actual travel time is the delay time, which may be either positive or negative. If the delay time is negative, it indicates that the upper layer of the earth is thinner or faster than assumed in the model. In this study, positive delays due to variations in the thickness of basin fill were of primary interest. These delays were modeled by using independent measurements to estimate P-wave velocities within the basin and making simple travel-time calculations. Fig. 2 illustrates the geometry of two rays: one with and one without a delay due to basin fill. Although the results are similar to those obtained by the analysis of gravity anomalies, a major difference is that P-wave delay times average a smaller portion of the subsurface.

The earth model used throughout this paper is an average obtained from the models of Daggett (1982) and Sinno et al. (in press). This model consists of a 2.4 km thick layer of high-velocity (5.5 km/s) Paleozoic and Mesozoic sedimentary rocks overlying a higher-velocity (6.04 km/s) granitic basement. The seismic sections were reduced to a velocity of 6.04 km/s so that head waves traveling along the basement (Pg arrivals) appear horizontal in time. A thickness of 2.4 km of Paleozoic sedimentary rocks whose P-wave velocity is 5.5 km/s would delay the Pg arrivals by 0.36 seconds. On the sections from the Distant Runner explosion in the Tularosa Basin an additional 0.4 second delay was added to compensate for the thick Cenozoic sedimentary section present. At 160 km on the sections extending from the Tyrone shot point, the Pg arrival is no longer the first arrival. At this point, the Moho refraction (the Pn arrival) with an apparent velocity of 7.61 km/s becomes the first arrival and delay times are measured from it.

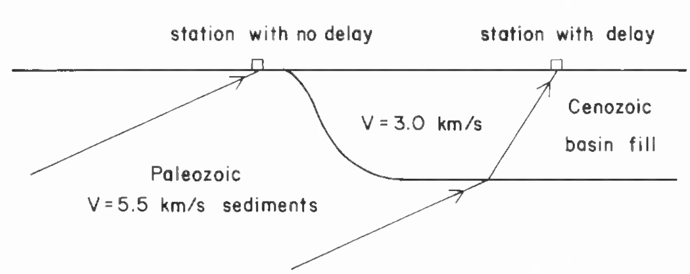

FIGURE 2—Differences in ray-path geometry for seismic stations with and without delays incurred in Cenozoic basin fill.

INTERPRETATION OF DELAY TIMES AND RESIDUAL GRAVITY

On profile SD1 (Fig. 3), the delays do not vary significantly until the east end of the line. However, the maximum delay time of 0.3 seconds and minimum residual gravity are reached at approximately 142 km from the Tyrone shot pont. Seismic-reflection results (Keller et al. in this guidebook) indicate that the Cenozoic basin fill has an average P-wave velocity of 3.0 km/s. Using this value, the maximum calculated depth to the top of the Mesozoic is 1.4 km. It can also be seen that the basin does not thin substantially until approximately 10 km from the Paleozoic outcrops in the San Andres Mountains. The basin fill consists of Love Ranch Conglomerate, Tertiary volcanics, and Santa Fe Group alluvium (Seager & Mack in press). Conglomerate and alluvium generally have P-wave velocities of 1.5–2.5 km/s, while volcanics have velocities of 4.0 km/s or greater (Birch 1966). Therefore, depending on the various thicknesses of the units involved, the velocity, and hence the depth of the basin fill, may vary from the calculated values. However, the good agreement between seismic, gravity, and drilling results suggests the calculated values are generally valid.

On profile SD2 (Fig. 4), the first seismogram is from a station just east of San Diego Mountain where the basin fill is of about the same thickness as along the SD1 profile. Farther east of San Diego Mountain the basin fill increases to a thickness of 3.6 km and then thins eastward to the San Andres Mountains. While maximum delay time on this profile occurs at approximately 147 km, the minimum residual gravity occurs at 137 km. This difference may be due to high-density material within the basement which is not sampled by the P-waves, as well as due to raypath geometry.

The basin beneath the SD3 profile (Fig. 5) has the same shape as beneath SD2, but the first seismogram is on Paleozoic sedimentary rocks. From the Paleozoic rocks, the basin thickens to 3.0 km just northeast of the Doña Ana Mountains and then thins towards the San Andres Mountains. Along the SD3 profile the gravity does not mirror

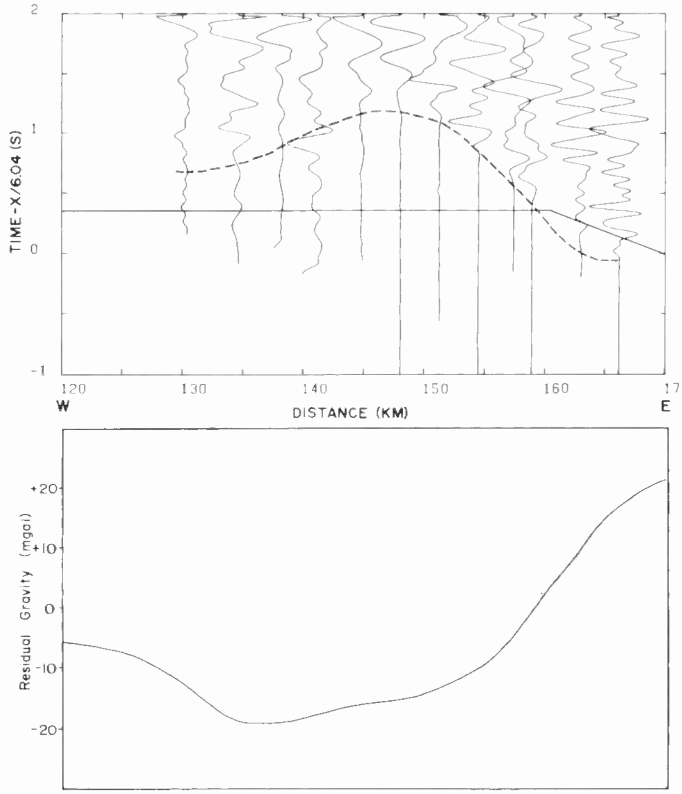

FIGURE 4—Profile SD2 with seismic section above residual gravity. Distances are measured from Tyrone copper mine. Solid line across the section is time at which first arrivals should occur in absence of local structure. Dashed line is time at which first arrivals actually occur.

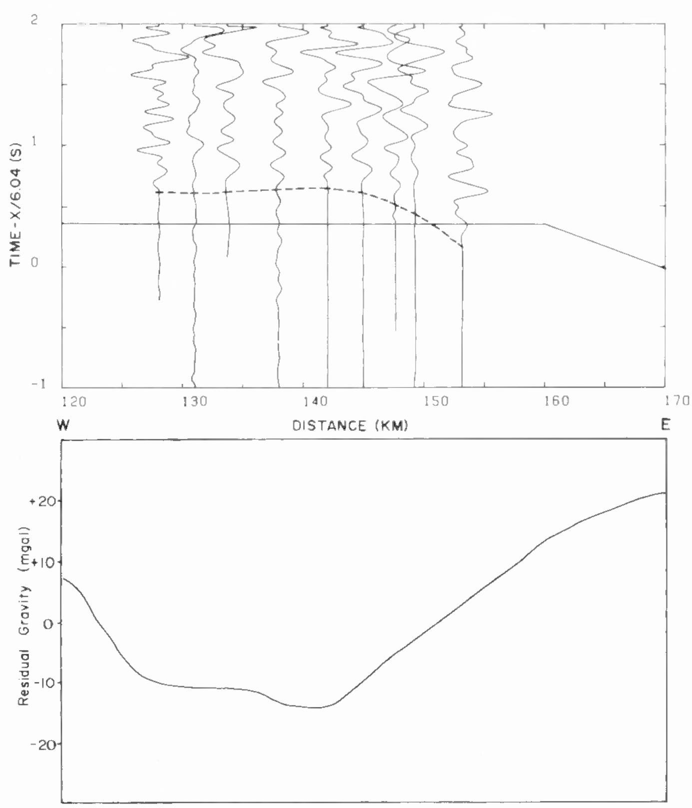

FIGURE 3—Profile SD1 with seismic section above residual gravity. Distances are measured from Tyrone copper mine. Solid line across the section is time at which first arrivals should occur in absence of local structure. Dashed line is time at which first arrivals actually occur.

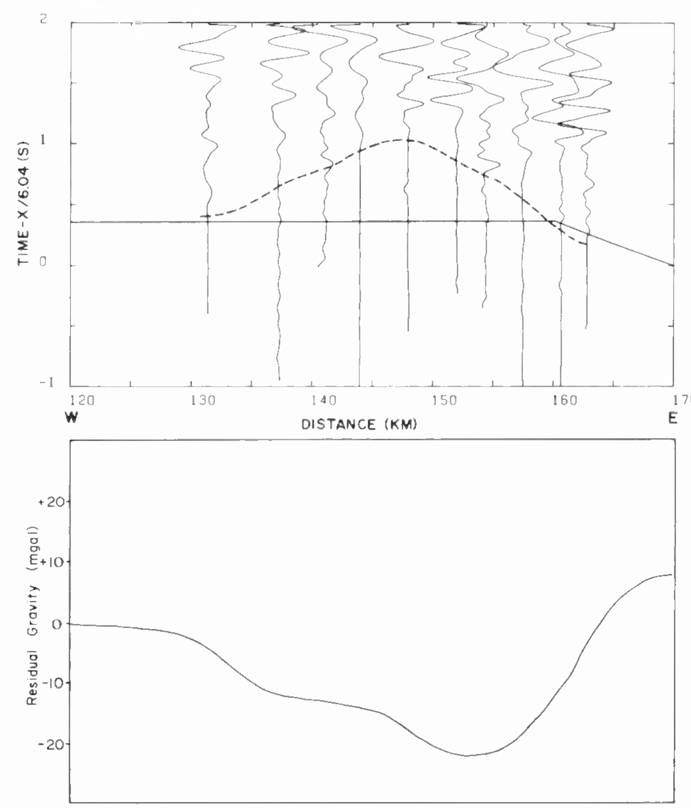

FIGURE 5—Profile SD3 with seismic section above residual gravity. Distances are measured from Tyrone copper mine. Solid line across the section is time at which first arrivals should occur in absence of local structure. Dashed line is time at which first arrivals actually occur.

the delay-time profile as it should between 135 and 145 km from the Tyrone shot point. The gravity in this area is increased by high-density material beneath the Doña Ana Mountains, which is not sampled by rays coming through the basin to the receivers along the profile. This high-density material may be basement due to the Rio Grande uplift of Seager & Mack (in press).

The reversed refraction profile (the Cross Line) of Sinno et al. (in press) has been divided into two parts. The dividing line is in the Caballo Mountains 120 km from the Tyrone shot point. The eastern portion of the profile (Fig. 6) crosses the Jornada del Muerto Basin and the western portion (Fig. 7) crosses the Palomas Basin. Since the refraction line was reversed, there are also two sections from the Distant Runner shot which correspond to the sections from the Tyrone shot point. One of these sections extends from 33 to 83 km from the Distant Runner shot (Fig. 6), and the other one extends from 83 to 133 km from the Distant Runner shot (Fig. 7). The maximum delay time for the section across the Jornada del Muerto is 0.3 second, which corresponds to a maximum depth of basin fill of 1.4 km, with the basin thinning rapidly eastward and slowly westward. A noticeable feature of the seismic section is the skewing of the maximum delay time eastward on the section from the Tyrone shot and westward on the section from the Distant Runner shot. This offset is due to the fact that the eastward traveling rays from the Tyrone shot point emerge from basement and Paleozoic–Mesozoic section at a point west of the receiver. The opposite is true for rays from the Distant Runner shot. The residual gravity does not mirror the delay times as well as would be expected. This variation is due to a large, high-density mass in the basement. This mass produces a large, north–south-trending gravity high shown on the maps of Gilmer et al. (this guidebook).

On the western part of the Cross Line (Fig. 7), which crosses the Palomas Basin south of Truth or Consequences, the same type of skewed anomalies are found as in the Jornada del Muerto. The maximum delay

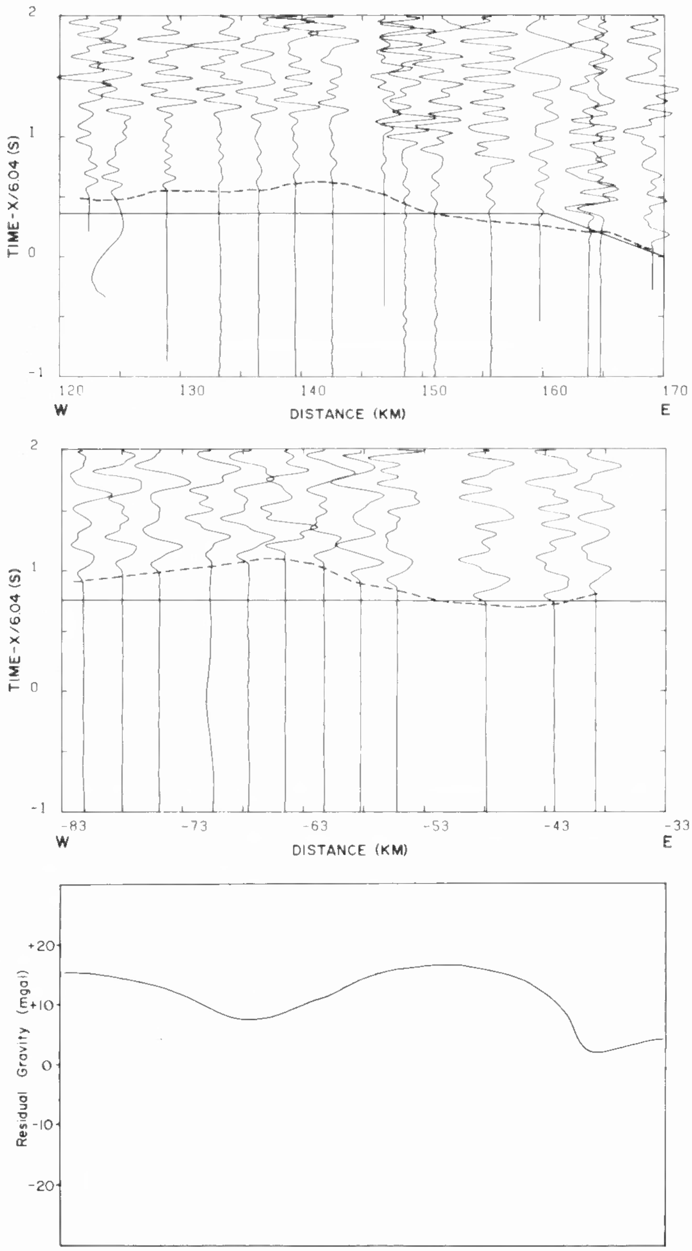

FIGURE 6—Eastern half of Cross Line profile with both seismic sections above residual gravity. Negative distances indicate shot was to the right and is distance from Distant Runner shot. Solid line across section is time at which first arrivals should occur in absence of local structure. Dashed line is time at which first arrivals actually occur.

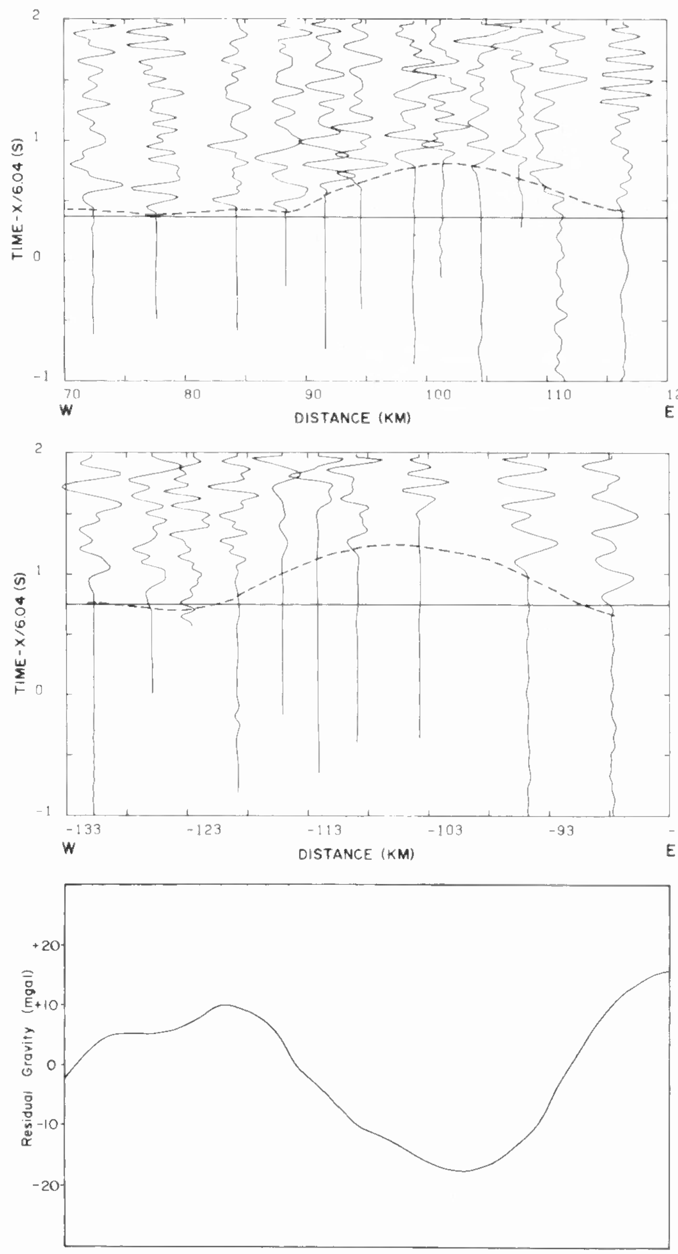

FIGURE 7—Western half of Cross Line profile with both seismic sections above residual gravity. Negative distances indicate shot was to the right and is distance from the Distant Runner shot. Solid line across section is time at which first arrivals should occur in absence of local structure. Dashed line is time at which first arrivals actually occur.

time of 0.5 second corresponds to 2.3 km of Cenozoic fill in the Palomas Basin. In this case, the residual gravity mirrors the delay times reasonably well.

CONCLUSIONS

The Jornada del Muerto has a thick (at least 3.0 km) sequence of Cenozoic basin fill in its southern end just north of the Doña Ana Mountains. This fill is interpreted as representing a foreland basin filled with conglomerates of the Love Ranch Formation that were derived from the Rio Grande uplift (Seager & Mack in press), as well as thick early and late rift-basin fill. It should be noted that individual thicknesses of these units cannot be determined by this method. Of the 10 seismograms of the SD3 profile only the first and possibly the last two seismograms have delay times interpretable as corresponding to a raypath which includes the Rio Grande uplift. Similarities between the SD2 and SD3 profiles and the lack of a steep gradient in the Bouguer gravity field between SD2 and SD3 (Gilmer et al. in this guidebook) indicate that no major fault exists between SD2 and SD3. This in turn indicates that the Rio Grande uplift lies along the western margin of the Jornada del Muerto at least as far south as the northern Doña Ana Mountains before extending eastward to the Bear Peak fault zone in the San Andres Mountains. Farther north (SD1 and Cross Line; Fig. 1), the Jornada del Muerto Basin has a relatively thin fill of Cenozoic sediments (1.4 km) which include Laramide basin fill, mid-Tertiary volcaniclastics, and late Tertiary Sante Fe Group, and is deeper on the west side than on the east side.

The Palomas Basin, on the other hand, is not as deep as the southern part of the Jornada del Muerto, its maximum depth (2.3 km) occurring about 5 km west of Interstate 25. Since only one profile across the Palomas Basin is available, little can be said about the nature of the Rio Grande uplift beneath the Palomas Basin. However, from the shape and size of the delay time and gravity anomalies one would infer that if the Rio Grande uplift extended into this area, it was faulted and downdropped during the formation of the Palomas Basin.

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