UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

RESULTS AND INTERPRETATION OF GEOPHYSICAL STUDIES NEAR THE PICACHO FAULT, SOUTH-CENTRAL ARIZONA

BY

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This report is preliminary and has not been reviewed or edited for conformity with Geological Survey standards.

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Abstract

Earth fissuring attributed to ground-water withdrawal occurs throughout south-central Arizona. A large zone of active fissures is located near Picacho, Arizona on the eastern rim of a large subsidence bowl. The main fissure has been named the Picacho fault. During February and March 1977, approximately 6.5 km of seismic-refraction lines were run across the Picacho fault to investigate subsurface conditions down to the crystalline basement. In addition, two lines of close-spaced gravity stations were made across the fault. The gross geologic features inferred from the gravity data agree with the seismic interpretations.

Six layers were interpreted from the seismic refraction data: three layers of unconsolidated alluvium, two of denser rock of varying porosity, and the basement rock.

Three significant basement faults were identified. These faults appear to lie almost directly beneath the surface fissures. Abrupt slope changes in the alluvial layers and an abrupt velocity change in the denser compacted sediments seem to be related spatially to the surface fissures. In addition there are lateral velocity differences within the basement fault blocks.

In the overlying sediments a facies change in a 3.0-km/sec layer is suggested by the abrupt lateral velocity increase from 3.0 km/sec to 3.7 km/sec. This apparent facies change may in fact represent a fault plane extending upwards from the westernmost basement fault. This fault plane may even extend farther into the unconsolidated overlying sediments, inferred from basinward increases in slope, subtle basinward decreases in velocity, and a basinward elevation decrease in the top of the zone of saturation.

Introduction

Examples of surface faulting[1] possibly related to ground-water withdrawal from unconsolidated sediments have been recognized in several areas in the United States (Van Siclen, 1967; Rogers, 1967; Clark and others, 1978a; Holzer, 1978a, b; Holzer and others, 1979). For most of these examples, the specific mechanism of faulting, if the modern movement is indeed man-induced, and subsurface conditions at the faults have not been studied in detail. As a consequence, why such faulting occurs or what subsurface conditions are conducive to its occurrence is not understood.

The Picacho fault is the main fissure in the zone of fissures located 5 km east of Picacho, Arizona, on the western slopes of the Picacho Mountains. In order to investigate subsurface conditions beneath one of these faults and to seek data that would contribute to the understanding of mechanisms for such faulting, a geophysical and drilling program at the Picacho fault was conducted. This report describes and interprets the results from the geophysical program. Results from the drilling program are published in U.S. Geological Survey Open-File Report 78-1016 (Holzer, 1978a).

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[1] Surface faulting is used here to characterize failure of the land surface characterized by points at the land surface on opposite sides of the failure plane moving parallel to the failure plane.

The Picacho fault, east of Picacho in south-central Arizona (fig. 1), was selected for detailed investigation because arguments have been made for a relation between modern fault offset and ground-water withdrawal (Holzer and others, 1979). These arguments, were based principally on geodetic data. Very little was known about detailed subsurface hydrologic and geologic conditions beneath the surface fault, although Schumann and Poland (1971, p. 299-300) implied, on the basis of a regional gravity survey, that the surface fault might be underlain by "buried fault scarp." Pierce (1976) also suggested that the eastern margin of the Picacho basin, along which the modern faulting occurs, is bounded by a preexisting fault zone.

The Picacho fault at the surface consists of a 15.8- km-long scarp that ranges from 0.2 to 0.6 m high (Holzer and others, 1979). The geodetic data indicate that the modern faulting is high-angle and normal (Holzer and Thatcher, 1979). The fault occurs near the eastern margin of the Eloy-Picacho subsidence bowl, at the center of which more than 3.8 m of subsidence has been caused by ground-water-level declines (Laney and others, 1978). The subsidence bowl is restricted to an alluvial basin containing unconsolidated sediments bounded by the crystalline basement that crops out discontinuously around the basin. The hydrogeology of the basin was described by Hardt and Cattany (1965).

In February and March 1977, the U.S. Geological Survey conducted seismic-refraction and gravity surveys across the zone of earth fissures near Picacho. Five seismic-refraction spreads were run across and perpendicular to the zone of fissures.

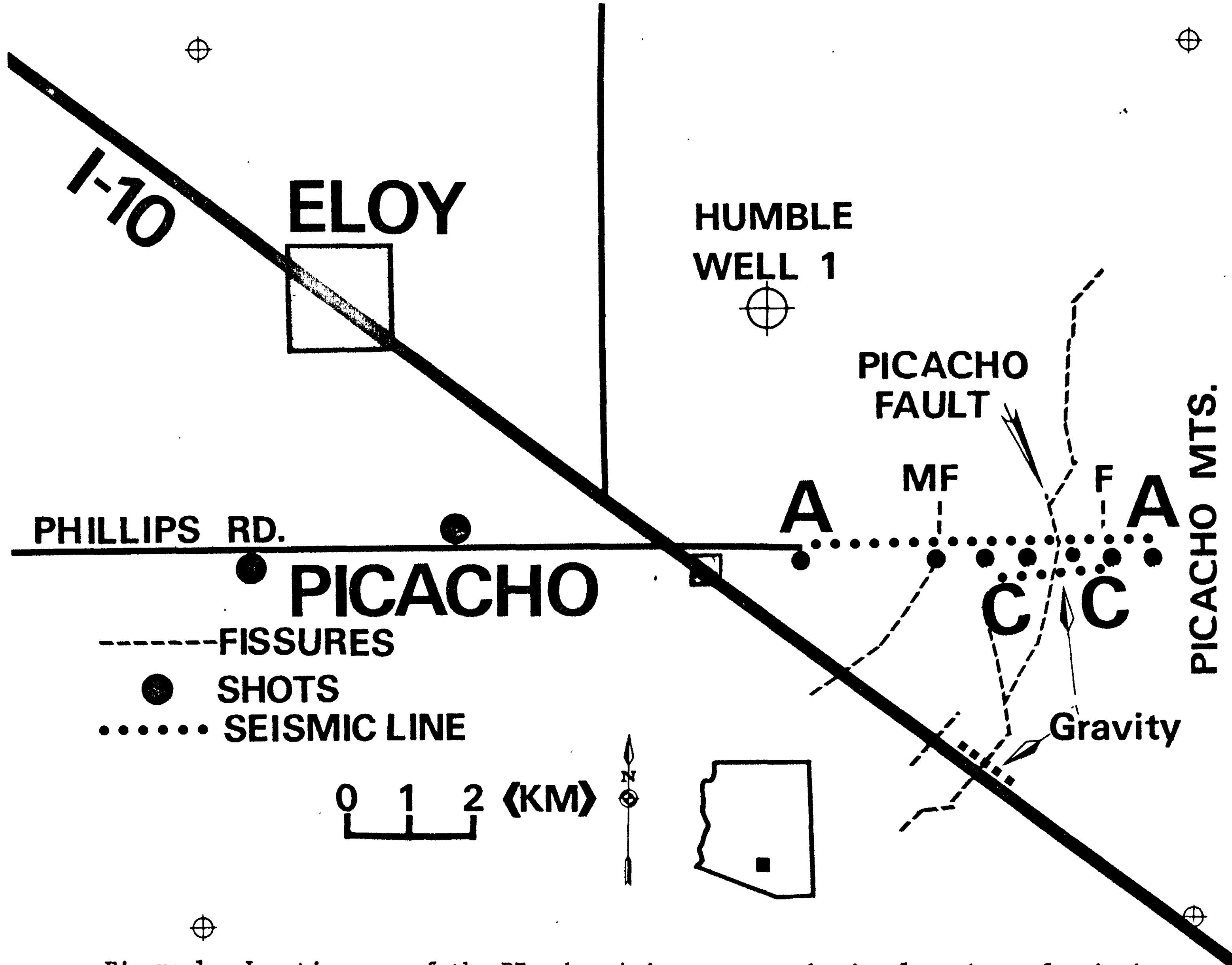

Figure 1.--Location map of the PIcacho, Arizona, area showing locations of seismic lines AA and CC, the more distinctive fissures, and shot locations for line AA.

Two end-to-end 2.76-km-long spreads (AA in figure 1), consisting of 24 geophones each at 120 m separation, were shot to map the basement structure. These spreads will be referred to as the Phillips Road spreads, because they lie along the extension of Phillips Road eastward from Picacho.

A high-resolution seismic-refraction line consisting of three spreads was recorded along a U.S. Bureau of Reclamation geodetic survey line. Each spread was 345 m long and consisted of 24 geophones at 15-m spacing. These spreads (CC in figure 1), referred to as the Crack spreads, focused on the alluvial layers. Numerous shot points, shown in figure 2, were used to provide reverse coverage from many layers. High-velocity explosives were used for all shots; accurate timing was accomplished using a radio shot system. Gravity was measured at 60-m spacing along the seismic lines, with the spacing shortened to 30 m near the fissures. Well-log information from the Humble O&R Well #1, 3.8 km north of the spreads, indicates Precambrian gneiss at a depth of 3011 m (Scurlock, 1973). This information, coupled with outcropping basement on the slopes of the Picacho Mountain 6200 m to the east, indicates a possible basement slope of nearly 30°. On the basis of this information, several distant offset shots west of Picacho were recorded by the Phillips Road spreads in order to map a possible steeply dipping basement horizon (fig. 2).

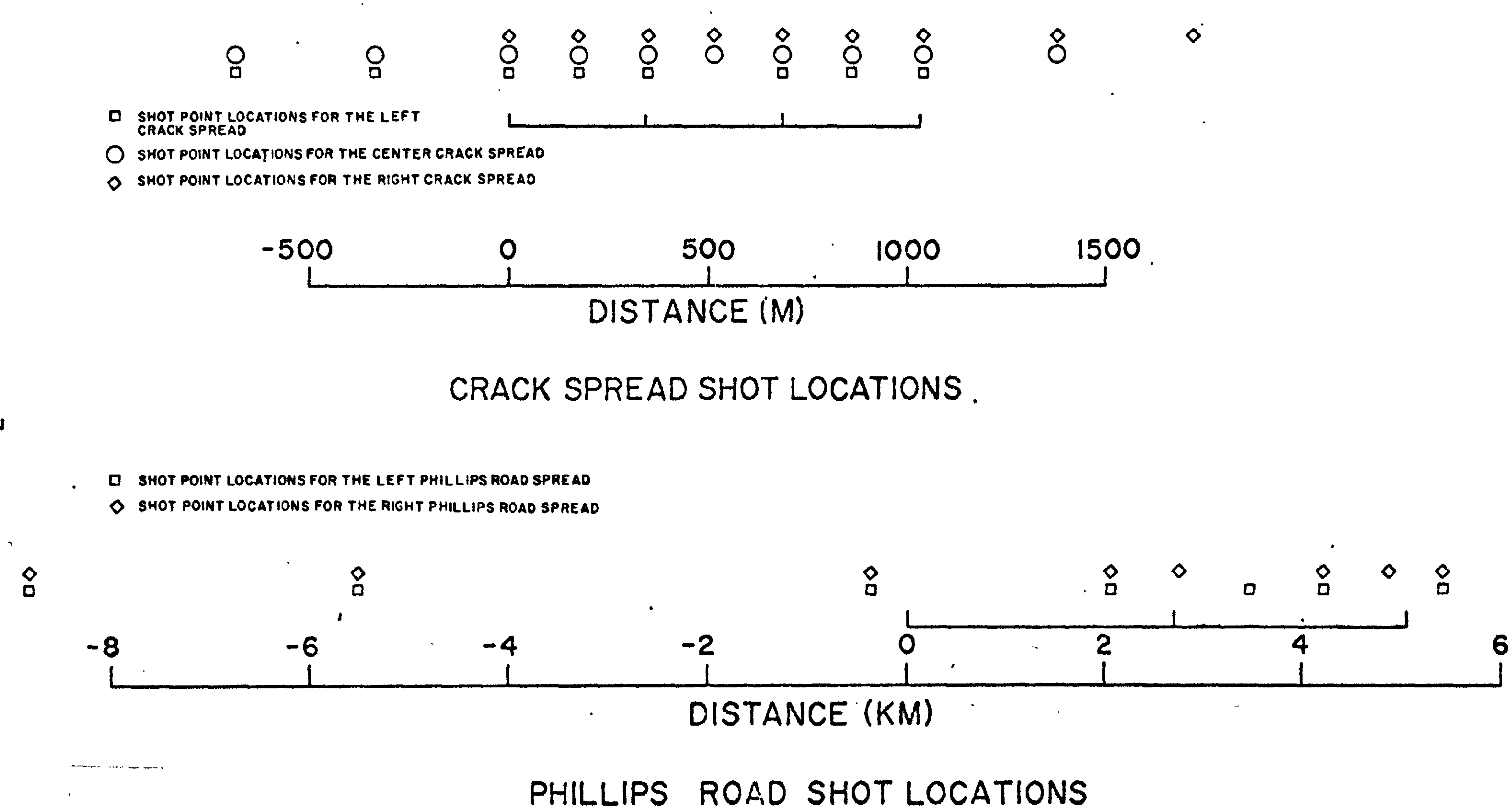

Figure 2.--Shot-point locations for the Phillips Road and Crack spreads, illustrating the large number of shots for each spread.

Interpretation of the Seismic-Refraction Data

Interpretation of the Phillips Road spreads (fig. 3) shows the expected westward-dipping trend in all of the layers. Because of the relatively large shot and geophone spacings for these spreads, only gross features are detectable except in the bottom layer, the crystalline basement. Using an interactive computer program recently developed by Ackermann, horizontal velocity variations along the basement layer were computed. Basement velocities generally range between 4.4- and 6.2-km/sec. Interpretation of the refraction data suggests three high-angle normal faults with offsets ranging from 50 m to 125 m. The shallow easternmost basement fault approximately underlies some newly mapped fissures at the mountain front, suggesting a genetic relationship between the fissures and this fault. The central fault lies several hundred meters upslope from the Picacho fault surface trace. The westernmost interpreted fault lies downslope several hundred meters from the Picacho fault surface trace. It seems to have a lower velocity zone, 4.4-km/sec associated with it, on the downthrown side, suggesting a related zone of fracturing (fig. 3). This basement fault is approximately 500 m below the top of the zone of saturation (top of 2.0-km/sec layer), probably too deep to be directly responsible for the Picacho fault, which is a surface feature. However, interpretation of the higher resolution refraction data from the Crack spreads suggests that this fault may project upwards into the 3.0 km/sec layer.

The interpretation of Crack-spread data resulted in good control as deep as the 3.0 km/sec layer. This layer exhibits a lateral velocity change, shown in figure 4. A number of interesting features occur near the Picacho fault

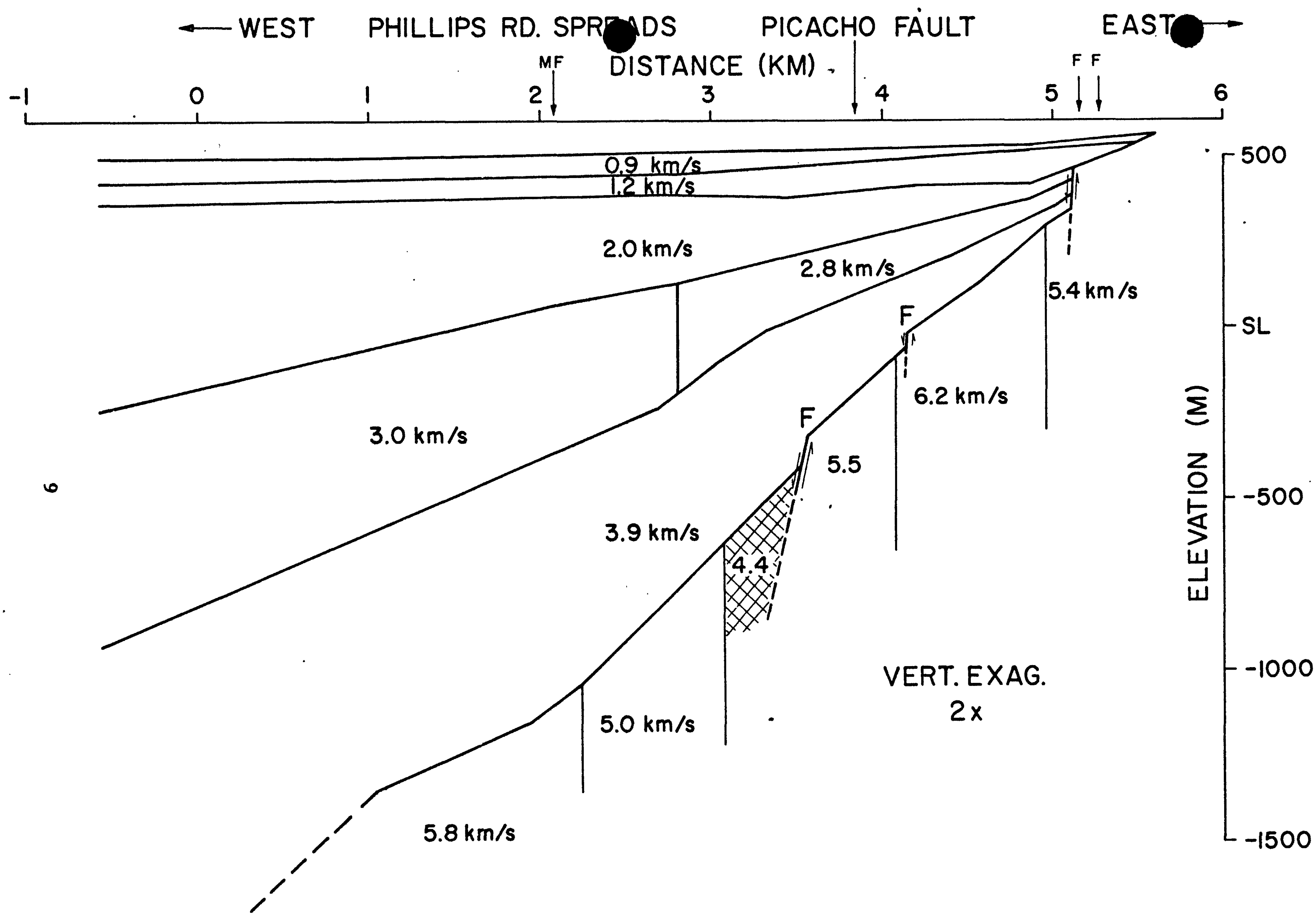

Figure 3.--Seismic velocity model derived from the Phillips Road spreads. Surface traces of the mapped fissures are labeled MF, F, and Picacho fault. Three high angle normal faults are indicated in the basement layer. The cross-hatched zone may represent fractured rock.

surface trace:

1. An abrupt change in thickness of the 0.85-km/sec layer, accompanied by an abrupt change of slope and a slight velocity change of the 1.1-km/sec layer, upslope of the Picacho fault.

2. An abrupt change of slope and a slight velocity change of the 2.0-km/sec layer. This layer is associated with the top of the zone of saturation as determined from neutron drill-hole logs (Holzer, 1978a).

3. An apparent facies change where denser compacted sediments of velocity 3.7-km/sec and greater abut more porous sediments of velocity 3.0 km/sec. The top of this layer undergoes a slope change with the inflection point just downslope from the Picacho fault.

The apparent facies change (fig. 4) in the 3.0- km/sec layer overlies the westernmost basement fault, and hence it may represent the projection of this fault into the overlying sedimentary beds. Furthermore, this faulting may extend upward to within 20 m of the surface, as manifested by the lateral changes in the 0.85-km/sec to 2.0-km/sec layers. Such a fault, if present, would not coincide with the fault interpreted by Holzer (1978a) from the drilling information, but is several hundred meters upslope.

Even though the Picacho fault as seen on the surface does not exactly coincide with all of the seismic features interpreted here, we believe that their near coincidence infers a genetic relationship. When one scans horizontally across the cross sections (figs. 3 and 4) beneath the Picacho fault, an unusually large number of eastward velocity increases are apparent.

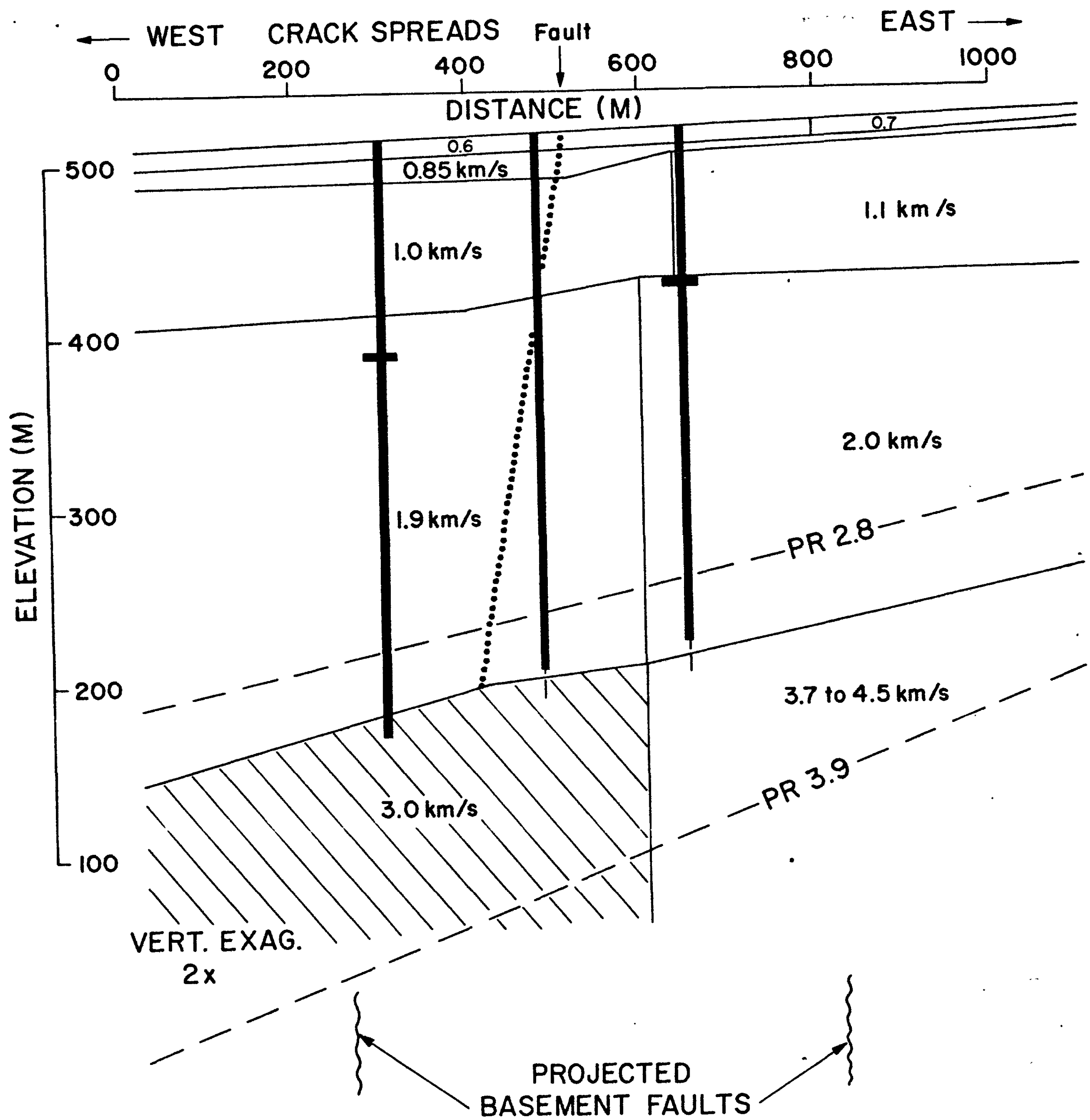

Figure 4.--Seismic velocity model derived from the Crack spreads. The vertical black lines represent the drill holes. Hard rock was encountered at the bottom of each. The horizontal bars represent the top of the zone of saturation. The fault postulated by Holzer is indicated by the dotted line. Dashed lines represent the projection of the 3.8-km/sec and 3.9-km/sec layers from Figure 3. Projection of the basement fault locations is also shown.

Although some of these increases are slight, when combined, a strong case can be made for a basinward zone of abrupt decreasing porosity at this location.

Gravity Data Interpretation

Detailed Bouguer gravity profiles across the Picacho fault are shown in figure 5. The two profiles show a hint of a very small local gravity high over the fault zone. Two models which would satisfy the gravity high are shown as a dike-like feature (body 2) and a square body (body 1) in the lower panel. We conclude that the gravity shows no pronounced indication of the fault zone and that the apparent anomaly can be attributed to noise.

Figure 6 shows the gravity derived along the USBR line from the Picacho Mountains to I-10. The flat residual curve west of the Picacho fault indicates excellent agreement between the seismic and gravity models. However, the increase in magnitude of the residual gravity curve east of the Picacho fault may be interpreted as indicating a step, a gradual offset, or a basinward decrease in the density of some lower layer. The velocity change of 3.0 km/sec to 3.7 km/sec in layer 5 (not used in calculating the gravity model) may account for some or all of this discrepancy. The abrupt drop of the residual curve at the far right end of the profile can be interpreted to being caused by a basement shelf extending westward under sedimentary cover as far as 500 m from its nearest outcrop. This shelf is beyond the eastern end of the seismic spreads.

Acknowledgments

The authors wish to express their appreciation to the many local people in the area around Picacho for their interest in the project and their cooperation in permitting use of the land for shot holes and spread locations.

DETAILED BOUGUER ANOMALY PROFILES ACROSS FISSURE ZONE

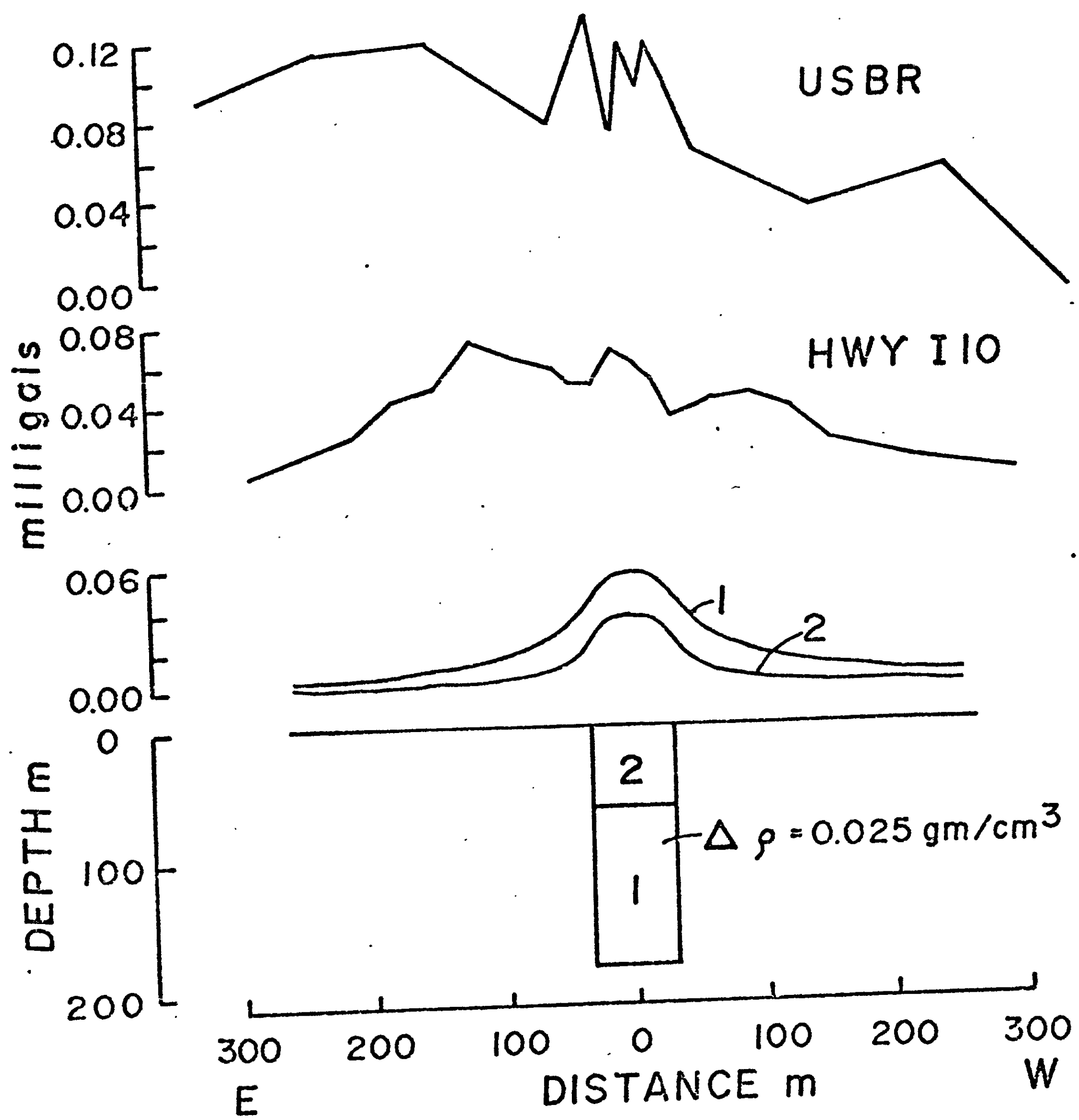

Figure 5.--Detailed Bouguer anomaly profiles across the fissure zone with two possible models. The upper profile extends along CC in Figure 2 to I-10. The lower is along I-10.

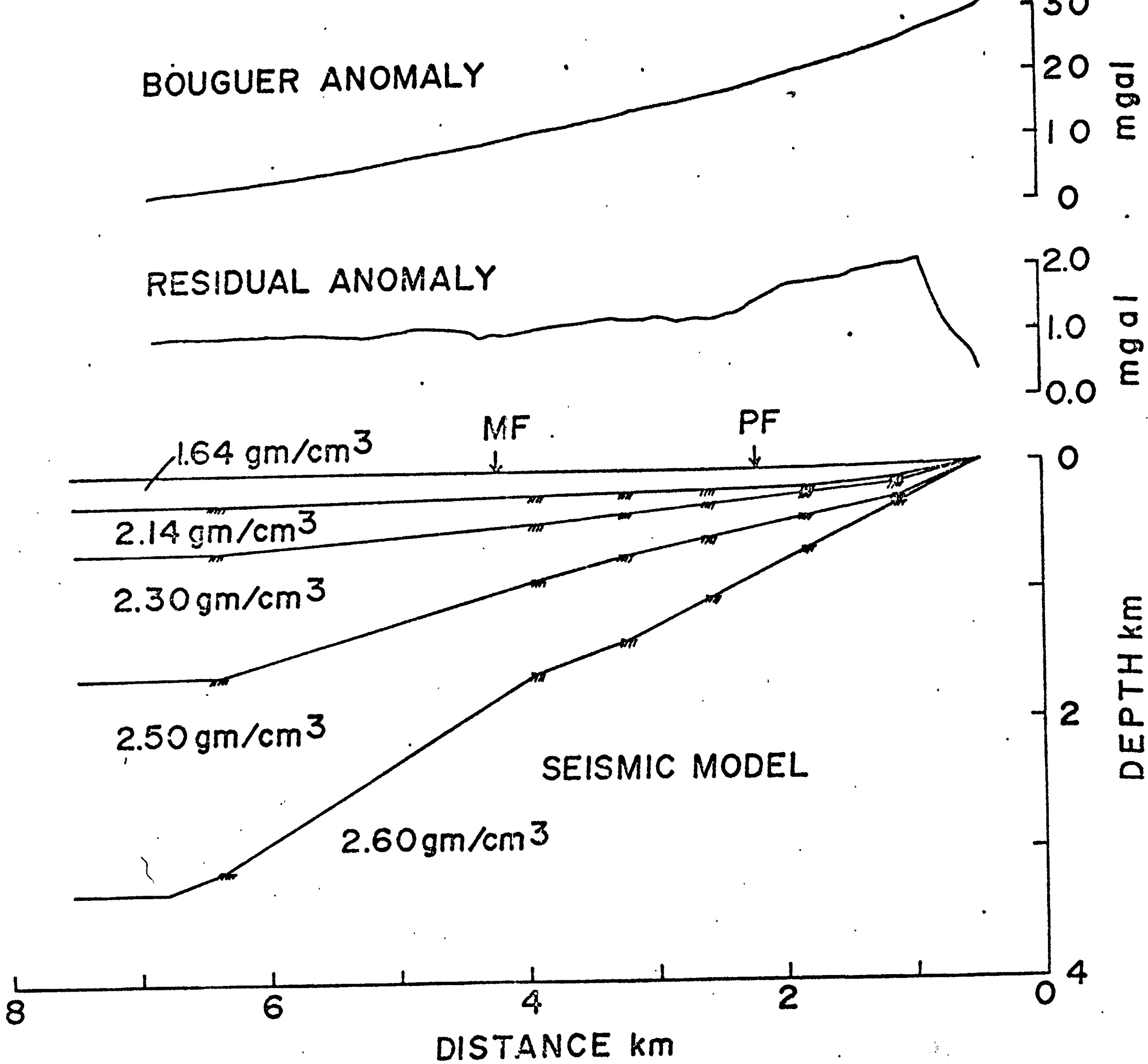

Figure 6.--Complete Bouguer anomaly and the residual calculated by substracting the effect of the 2-D model shown. Densities of the top two layers and the basement were obtained from measured samples. Other densities were calculated from seismic velocities using the Nape-Drake curve (Grant and West, 1965).

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