GEOPHYSICAL STUDY OF THE SALTON TROUGH
OF SOUTHERN CALIFORNIA

Thesis by

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In Partial Fulfillment of the Requirements

For the Degree of

Doctor of Philosophy

California Institute of Technology

Pasadena, California

1964

(Submitted May 7, 1964)

ACKNOWLEDGMENTS

The author gratefully acknowledges Frank Press and Clarence R. Allen for their advice and suggestions throughout this entire study. Robert L. Kovach kindly made available all of this gravity and seismic data in the Colorado Delta region. G. P. Woollard supplied regional gravity maps of southern California and Arizona. Martin F. Kane made available his terrain correction program. C. W. Jennings released preliminary field maps of the San Bernardino and Needles quadrangles. C. E. Corbato supplied information on the gravimeter calibration loop.

The oil companies of California supplied helpful information on their wells and released some geophysical data. The Standard Oil Company of California supplied a grant-in-aid for the seismic field work. I am indebted to Drs. Lucien La Coste of La Coste and Romberg for supplying the underwater gravimeter, and to Aerial Control, Inc. and Pacific Air Industries for the use of their Tellurometers. A. Ibrahim and L. Teng assisted with the seismic field program.

I am especially indebted to Elaine E. Biehler for assistance with all phases of the field study and for doing much of the tedious work in the gravity reductions.

This study was supported by National Science Foundation Grant G-19778 and by the American Petroleum Institute.

ABSTRACT

More than 2300 gravity observations were made in the northern end of the Salton trough, including an underwater gravity survey of the Salton Sea. 400 gravity observations by Kovach are used to extend the gravity map southward and 700 gravity observations from oil companies and Woollard are used for part of the regional control. A complete Bouguer anomaly map of the California portion of the Salton trough area shows that the general trend of the isogal contours is parallel to the over-all northwest trend of the tectonic pattern. The contours northeast of the Coachella Valley trend east parallel to the Transverse Range structure. The Coachella Valley and Borrego sink are associated with gravity lows, the Salton volcanic domes with a gravity maximum, and the Peninsular Ranges with a gravity minimum. The anomalous mass of the Salton volcanic domes is 6 to 7 km deep with a radius of 3.5 to 4.5 km based on the "half-width" interpretation of a sphere. Due to uncertainties arising from contemporaneous metamorphism of the sediments and the ambiquity in the regional gravity field a detailed interpretation was not attempted.

All of the major fault zones are associated with small gravity lows. A series of these small lows southeast along the projected trace of the Banning-Mission Creek fault may indicate continuation of faulting toward Yuma, Arizona. The steep gravity gradient across this fault in

the Coachella Valley can be explained by a steep contact between crystalline rock and sediments which exceed 4 km thickness in the Indio-Mecca area.

Seismic refraction profiles were established at Thousand Palms, Truckhaven, Frink, and Westmorland. These give depths to basement of 4350, 5540, 7340, and 18,300 ft respectively. The Westmorland profile establishes the depth to basement near the center of the trough.

Regional gravity studies indicate that much of the gravity low over the Peninsular Ranges can be explained by a thickening of the crust from 29 to 33 km. The Imperial Valley, with over 5.5 km of sediments, is anomalously associated with a broad gravity high. This is interpreted in terms of a thinning crust under the valley possibly to a depth of 21 km, relative to 29 km at San Diego. The crustal structure of the Imperial Valley is probably the northward continuation of the structure of the Gulf of California and may represent the initial stages of an alteration from continental to oceanic type section by rifting and northwest movement of the Baja California peninsula and western California relative to the stable area northeast of the San Andreas fault system.

INTRODUCTION

One of the most striking topographic and tectonic features of southern California is the Salton trough. This structural depression is the northward continuation of the Gulf of California and extends from the Mexican tidelands at the head of the Gulf to San Gorgonio Pass, 80 miles east of Los Angeles (Figure 1). The Salton trough is an area of diverse geological complexities such as major faulting, thick sedimentary deposits, recent volcanism and potential petroleum reservoirs, all of which have correspondingly interesting geophysical expressions of local and regional importance.

The study of the earth's gravity field and its associated anomalies has proven extremely useful in delineating the geological structure of this area. To investigate, on a local scale, the subsurface geological structures within the valley and its basement it is necessary to resort to detailed geophysical methods. But in order to interpret the gravity anomalies associated with the trough and the complex crustal structure beneath such a tectonically active area a much larger region must be studied to establish the regional gravity field. For these reasons a detailed gravity study based on a one mile grid and four seismic refraction profiles were established within the northern portion of the trough and the gravity observations were continued on a regional basis eastward to the Colorado River and westward to the Pacific Ocean. Although the regional gravity coverage to the west and the detailed gravity data in the south are somewhat incomplete, they nevertheless indicate some interesting results.

Several gravity maps are presented in this report (figure 2). The major portion of the gravity study is based on a complete Bouguer anomaly map of the Salton trough of California and parts of the Peninsular Ranges and Mojave Desert province (figure 20). Because of the lack of good topographic maps and elevation control for the Mexican observations by Kovach (1962) it is not practical to make a complete Bouguer map of this area. A simple Bouguer map of the entire Salton trough area which includes all of the observations of Kovach between 33° north latitude and the head of the Gulf and most of the observations by Biehler between 33° and 34° 15' is in press (Biehler _et al._, 1964) and is reproduced as figure 24.

For a study of the crustal structure a generalized regional Bouguer map for all of southern California and the continental shelf south of 34° 15' was prepared from the data of Harrison (1960a, 1960b), Mabey (1960), McCulloh (1957, 1960), Press (1960), and Woollard (1963, 1964) (figure 22). The gravity interpretation of the Coachella Valley is based on a complete Bouguer anomaly map using a varying Bouguer density, a basement regional

Bouguer map, and a residual Bouguer map (figure 23). A generalized geologic map of the area covered by the complete Bouguer anomaly map was prepared from fault maps of Allen, the Geologic Map of California (1955, 1962, 1964), Dibblee(1954), and Crowell (1962). All of the seismic profiles and well data are also shown on this map (figure 20).

REGIONAL GEOLOGIC SETTING

Physiography

The Gulf of California is a relatively narrow structural depression less than 100 miles wide and over 700 miles long. Although the Gulf terminates 60 miles south of the international border the characteristic structural depression continues for 240 miles northwest from the headwaters of the Gulf to San Gorgonio Pass. This northern segment of the Gulf of California structural province, called the Salton trough, is marked by a broad flat alluviated valley with an area of 10,000 square miles, of which 2,000 square miles lie below sea level. The Colorado River delta south of the international border rises to a height of 40 to 50 feet above sea level, forming a natural dam which prevents this sink from being inundated by the sea water of the Gulf of California.

Geophysically and physiographically the Salton trough can be divided into five units: the Coachella Valley, Salton Sea, Borrego Sink, Imperial Valley, and the Colorado River delta proper. The Coachella Valley extends southeast from San Gorgonio Pass to the north end of the Salton Sea. It is the narrowest segment of the Salton trough with an average width of less than 15 miles. The borders of the Coachella Valley are well defined on the southwest by the San Jacinto and Santa Rosa mountains of the Peninsular Range province and on the northeast by the Little

San Bernardino and Orocopia mountains of the Transverse Range province. The mountains which border the Coachella Valley have an average elevation which is approximately 1500 feet higher than their counterparts to the southeast which form the borders of the Imperial Valley. As the Coachella Valley narrows in the northwest the average elevation of the bordering ranges increases until at San Gorgonio Pass where the two highest peaks of southern California, San Gorgonio mountain and San Jacinto Peak, form the borders of the pass, there is 10,000 feet of relief in a few miles.

The Salton Sea is located in the transition zone between the narrow Coachella Valley in the north and the broad Imperial Valley in the south. This topographic center of the Salton trough is covered by a large man-made inland lake approximately 35 miles long and 10 to 15 miles wide, which forms a sink for all of the drainage in the area. The surface of the sea is presently 234 feet below sea level with a maximum measured depth of 44 feet. Prior to the flooding of the sink this area was a broad flat sandy playa which at one time formed the bottom of an ancient fresh-water lake. Thus, if it had not been for the disastrous inundation of the area in 1905-1907 by the accidental diversion of the Colorado River, the exposed land area of the Salton trough would have been only 4 feet higher than Death Valley. The Salton trough is still the second lowest land area in the United States. It is interesting to note that the maximum and minimum elevations and width of the two valleys are almost equal. At Death Valley (Mabey, 1963) with an average width of 10 miles the maximum elevation is 11,049 feet and the minimum is -282 feet. The regional Bouguer gravity values are similar as is the Bouguer anomaly across the valleys. Although these valleys are in two different tectonic settings, this may be an indication of a much deeper common crustal environment.

South of the Salton Sea lies the broad Imperial Valley, bounded by the Chocolate and Cargo Muchacho mountains on the northeast and by the Peninsular Ranges on the southwest. The borders of the Imperial Valley, however, are not as clearly defined as those of the Coachella Valley. Along the southwest margin are several fault-controlled hills of crystalline rock within the valley. In the southeast the bordering mountains gradually decrease in relief until at Yuma, Arizona, the eastward extent of the valley is poorly defined.

Within the Imperial Valley and southwest of the Chocolate and Cargo Muchacho mountains is a narrow northwest-trending band of low ridges called the Sand Hills or Algodones dunes. They are an almost unbroken mass of sand 45 miles long and 4 to 8 miles wide, which has been studied geologically by Norris and Norris (1961).

Four volcanic domes protrude over 100 feet above the valley floor at the south end of the Salton Sea. The northeast dome, Mullet Island, is now partially submerged in the Salton Sea. Associated with these domes are extensive hot springs activity and potential geothermal reservoirs.

The Colorado River delta proper designates that area in Mexico between the Imperial Valley on the north and the head of the Gulf in the south. This area is daily receiving large quantities of sediments from the Colorado River. The Colorado River has digressed many times across this cone, at times emptying into the Salton sink and then returning to the Gulf of California.

The Borrego and Clark valleys west of the Salton Sea are similar to the narrow Coachella Valley in the north, although the average elevation of the valley floor is considerably higher. These valleys are also fault-controlled and contain thick sedimentary deposits.

The geological, geophysical, and structural implications of these physiographic units will be discussed elsewhere.

Regional Tectonics

The general trend of the major faults in the Peninsular Ranges and Salton trough indicate that the surface expression of the Salton trough is not of a simple rift valley marked by parallel breaks along the borders of a dropped block. The general fault trend cuts obliquely across the axis of the Gulf and this northern extension. On the basis of topography it appears that this fault pattern is continued on the floor of the Gulf.

The predominate displacement along these major faults is right-handed strike slip and may be as great as 150 to 300 miles (Crowell, 1962). The narrowing and termination of the Salton trough at its northern end are caused by truncation and conflict between northwest-trending faults of the San Andreas system and east-trending faults of the Transverse Range province.

At about the mid point of the Gulf of California south of Tiburon Island, seismic evidence indicates a transition from continental to oceanic structures (Phillips, 1963). It is in this area also that the gravity anomalies become positive (Harrison and Spiess, 1959, 1963). It may be that the Gulf floor is undergoing a gradual transition from continental to oceanic type crust by the gradual rifting and northwest movement of Baja relative to the Mexican mainland with the emplacement of more basic material into the upper portion of the crust along zones of weakness. A similar mechanism has been suggested by Girdler (1964) for the formation of the Red Sea rift. This may also account for the absence of a negative anomaly across the Imperial Valley and the existence of such volcanic surface expression as Cerro Prieto, Pinacate volcanic field, and the Salton Volcanic Domes.

Historical Geology

The geology of the Salton trough has been studied by Dibblee (1954), Tarbet (1944, 1951), Woodard (1961), Durham and Allison (1961) and Downs and Woodard (1961). The Peninsular Range province west of the Salton trough has been studied by Jahns (1954), Larsen (1948), Merriam (1958), Beal (1948). The geology of the mountains to the north and east of the trough is covered by Bailey and Jahns (1954), Rogers (1961) and Crowell (1962). Only a brief summary of the rock types is given here.

A stratigraphic section for the Cenozoic sedimentary rocks of the Coachella Valley as given by Dibblee (1954) is shown in figure 3. Similar sections for the Imperial Valley have also been published (Dibblee, 1954). The detailed stratigraphy of the Salton trough is incompletely known. The geologic samples from the few deep wells within the trough are not easily interpreted stratigraphically. Most of the columnar sections are based on exposures in the western side of the Imperial Valley and the eastern side of the Coachella Valley. One of the most economically important stratigraphic units is the Imperial formation which in places is over 3000 feet thick. This formation was deposited under marine conditions during early Pliocene time and probably represents a major marine incursion of the Gulf. It is thought to contain potential petroleum reserves. Following this marine incursion there has been intermittent and interfingering deposition from the Colorado River, alluvial fans, and occasional marine inundations by the Gulf waters. The possibility of large continuous horizontal displacements along the major strike-slip faults certainly adds much complexity to stratigraphic correlation within the Cenozoic section.

The crystalline rock types of the Peninsular Ranges are primarily granitic intrusives of the Southern California batholith probably of Mid-Cretaceous age. In places large remnants of older sedimentary rocks now metamorphosed are observed. The crystalline rocks of the ranges east of the trough comprise more diverse igneous, metamorphic and volcanic types.

GEOPHYSICAL STUDY

Previous Geophysical Work

The earliest geophysical studies in the Salton trough were undertaken by Soske (1935), who made 13 vertical and horizontal magnetic traverses across the Banning-Mission Creek fault. A vertical magnetic intensity survey of the Salton Volcanic Domes was reported by Kelley and Soske (1936).

Four gravity pendulum stations were established in this area in 1939 by the U. S. Coast and Geodetic Survey (Duerksen, 1949). These stations are located at Mecca, Niland, El Centro, and Palomar Mountain, California. An additional pendulum station had been established in 1910 at Yuma, Arizona. The principal facts for these observations along with the values obtained from reoccupations at several of these stations are given in Appendix C.

A transcontinental gravity profile along U. S. Highway 80, which crosses the Imperial Valley and terminates at San Diego, shows that the gravity high anomalously associated with the Imperial Valley can be traced into southern Arizona (Woollard, 1962). A regional Bouguer anomaly map of southern California and Arizona indicates the gross aspects of the gravity field (Woollard, 1964). Nettleton <u>et al</u>., (1960) made a test flight of an airborne gravity meter across the Salton Sea area and compared the free air anomalies to Woollard's gravity stations. A gravity profile from Cuyamaca Lake, California to Beatty, Nevada crosses the northern end of the Coachella Valley and exhibits the steep gravity gradient across the front of the San Jacinto Mountains (Press, 1960).

The most important geophysical investigation of the Colorado Delta region was made by Kovach (Kovach et al, 1962), in which all of the seismic data and most of the gravity observations south of latitude 33° were discussed. Since the present investigation is closely related to this work,all of the seismic data is summarized here. The gravity observations by Kovach were used to extend the complete Bouguer map southward to the Mexican border.

Many extensive detailed geophysical studies in the Salton trough have been made by the oil companies. Because of the active interest in this area for possible petroleum reservoirs it is understandable that none of this data has been published.

A simple Bouguer anomaly map of the entire northern portion of the Gulf of California structural province based on a contour interval of 5 milligals and including the geophysical work in the south and the area covered in this report is in press (Biehler et al 1964).

Seismic Field Methods

In order to establish control on the sedimentary thickness in the northern Imperial and Coachella Valleys four partially reversed seismic refraction profiles were shot. Their locations were chosen on the basis of geologic desirability, shot hole locations, and accessibility. The agricultural development in both the Coachella and Imperial Valleys makes it extremely difficult to conduct any extensive seismic program within these areas. The danger of artesian water in the northeast Imperial Valley prohibits the use of deep shot holes or large explosive charges. These are some of the reasons for not obtaining complete reversal information on the profiles. Permission to undertake seismic studies in the Salton Sea was requested but not granted. This still remains one of the most interesting areas in which to obtain seismic data. The seismic field work was carried out during March 1963 by the Seismological Laboratory of the California Institute of Technology.

An attempt was made to use two separate recording systems for each shot. However, because of several mechanical failures this was not always possible. Both systems used a 1400 foot spread with 8 geophones 200 feet apart. One recording setup (designated Unit R) consisted of United Geophysical low frequency refraction amplifiers and Houston Technical Laboratories two-cycle geophones; the other (designated Unit P) was an S.I.E. portable seismic system package.

Shot holes were drilled either by hand-auger or a shot hole rig contracted from Partain Exploration Company. For shot point to detector distances up to 12,000 feet, with the exception of the Thousand Palms profile, excellent records could be obtained with 5 to 20 lbs of Vibrogel 3 in 10 to 15 foot holes. For greater distances 30 to 70 lbs of explosives at 30 to 60 feet were used. For the most distant shot on the Westmorland-north profile (shot point to detector 100,000 ft) 3 holes 120 feet deep with 120 lbs in each supplied ample energy.

Because of the difficulty in locating shot holes it was necessary in most cases to keep the shot point fixed and to move the spread. This necessitates shooting at both ends of a profile to obtain reversal information. For several shots on the Westmorland and Truckhaven profile the shot point was moved, giving some dip information.

The average depth of penetration was greater than 0.3 of the shot point to detector distance.

Seismic Interpretation

The arrival times of most first arrivals could easily be read to 0.01 seconds. Where ambiguity exists in the first arrival, it is noted in the discussion of the individual profiles. All major secondary arrivals were also read. Because of the shallow depths of the shots and relatively flat terrain along the spreads, it was not necessary to correct the raw travel times.

Conventional time-distance plots for each profile were made and time-intercept methods used in the interpretation. In most cases the reversal information is incomplete. Interpretation was then made assuming horizontal layers.

The shot number and recording unit code are shown at the farthest ends of each spread. The shot points were located at the ends of the profiles except where otherwise designated. In these cases the shot point to detector distance was plotted as if the shot point was at one end of the profile.

The location of the refraction profiles along with the 6 profiles previously established by Kovach (1962) are shown in Figure 4. The travel time plots and calculated sections are shown in figure 7 to 10. A summary of the seismic velocities and depths for all 10 profiles is given in Table 1 and Table 2.

The high velocity layer (>17,000 ft/sec) is interpreted as basement complex composed of intrusive and metamorphic rocks. The intermediate velocity layers (7,000-15,000 ft/sec) are probably Tertiary sediments with increasing velocity with increasing depth of burial. The lower velocity layers are Recent and Pleistocene sediments.

That the 15,000 ft/sec layer is not basement rocks is demonstrated by the two deep wells which penetrated this layer and reportedly were still in sediments. Two seismic crossections (Biehler et al, 1964) correlate the velocity layers across the Imperial Valley and along the axis of the trough (figure 5 and 6)

In view of the diversity of basement rock types which crop out along the borders of the Salton trough the variation in basement velocities from 17,000 (5.2 km) to 21,000 ft/sec (6.4 km) is not surprising. There is however, a remarkable correlation between profiles of the lower velocity layering. On the basis of limited subsurface well data this seismic layering does not appear to have any known stratigraphic significance. The Grube-Engebretson well penetrated four of these seismic layers and reported the entire section 12,300 ft section as Plio-Pleistocene Borrego formation.

This apparent seismic layering may well be due to compaction of the sedimentary section which would be quite similar throughout the trough. This is substantiated by the absence of any high velocity sedimentary layers (15,000 ft/sec) where the total thickness is less than 10,000 feet. Alternatively this may be due to a combination of compaction and pinch out of a sedimentary unit. The discontinuity in depth between the Stone well and that of the Thousand Palms profile is not as significant as it appears in figure 6 because the Stone well is closer to the axis of the trough and over a thicker sedimentary section as indicated by the gravity data (figure 23).

Table 1 Seismic Layer Velocities

Profile	V_o	V_1	V_2	V_3	V_4	V_5	V_6
Thousand Palms	2100	5900		7900	11,000		17,900
Truckhaven	1300	5470		7600	12,100		17,650
Frink	900	6100	6800	10,000	13,800		17,700
Westmorland-North	840	5590	6420	8900	12,350	15,400	21,000
Plaster City-North	1500		6940				19,230
Superstition Hills		5650	7020	7920	10,700	14,200	
E. Highline Canal	1200	5750	7620	8580	12,500		18,180
Coachella Canal	2270	6270	7300	8770	11,050		20,000
Glamis-Ogilby	3720		6970				18,520
Mexican Border	1500	6070	7580	8520	11,930	15,475	
Average Velocity	1700	5850	7080	8525	11,930	15,025	18,775

Table 2 Seismic Layer Thickness

Profile	h_o	h_1	h_2	h_3	h_4	h_5	h Total
Thousand Palms	100	1000		850	2400		4350
Truckhaven	40	400		2800	2300		5540
Frink	50	490	1500	1400	3900		7340
Westmorland-North	10	600	1800	3200	3900	8800	18,310
Plaster City-North	134		2620				2754
Superstition Hills*	45	700	1150	3945	3295		9135
E. Highline Canal	40	1426	3184	855	4645		10,150
Coachella Canal	77	1315	1450	2460	4070		9372
Glamis-Ogilby	407		1790				2197
Mexican Border*	50	1595	1670	3890	4500		11,705
Average Thickness	95	940	1895	2425	3625	8800	

*Average Thickness Used for Dipping Layers.

Westmorland Profile

This is the longest profile shot in the Salton trough and for the first time establishes the depth to basement near the center of the valley (Figure 7). The recordings were made along the east-west road which is one mile north of and parallel to U. S. Highway 99 near Westmorland. All distances are referred to the primary shot point on the west side of U. S. 99 (33° 03.64' N. Lat, 115° 43.50' W. Long).

The 840 ft/sec arrivals are observed as secondary events and give a calculated depth of only 10 feet. This layer was assumed constant and horizontal. Shot points 2 and 3 where 1000 ft and 2500 ft respectively west of shot point 1. No "shingling" of the 5680 ft/sec arrivals indicates little or no dip to this layer in this area. Strong secondary arrivals are observed from this layer along the entire profile. The corresponding 5,500 ft/sec velocity on the reversal is based entirely on secondary arrivals and may indicate a very small dip in that direction. The 8750 ft/sec arrivals also appear as strong multiple refractions with double and triple the intercept time. The 12,250 ft/sec arrivals were fair and the 15,150 ft/sec arrivals were weak. Some minor structure in this layer is indicated by the offset in arrivals at 45,000 feet. It was not possible due to logistic problems to obtain recordings between 55,000 and 90,000 feet. Another layer may exist but on the basis of other velocity sections in the valley it is not likely. The slightly higher apparent velocity of basement may be due to a westerly dip which is contrary to what would be expected from the synclinal structure of the trough, and the shallow easterly dips of the upper layers. Using the available reversal information the depth to basement is 18,300 feet. If the basement is projected easterly with the same shallow dip characteristic of the upper layers, the depth to basement is about 19,400 feet beneath the center of the valley.

The close correlation of these seismic layers with those elsewhere in the valley and the clean basement arrivals suggests that the contemporaneous metamorphism of the sediment around the Salton Volcanic Domes (White et al, 1963) is a localized phenomena.

Frink Profile

The recordings for this profile were made along State Highway 111 on the east side of the Salton Sea. All distances are measured from a point east of Frink (33^{0} 21.7 N. Lat., 115^{0} 38.4' W. Long.). The profile extends southeast from Frink, through Wister, to Mundo Siding. Because of problems involved in shooting at the southern end of the profile a complete reversal could not be made. All of the reverse points had to be obtained from hand-augered shot holes. Two interpretations of the profile are shown in Figure 8. The first interpretation assumes horizontal layers and uses only the well-established portion of the profile. This gives a basement depth of 7300 feet. The reversal interpretation was calculated by two methods. The first method is based on the best fit to the 8 points from shot 12P, which gives apparent basement velocity of 17,400 ft/sec. and a depth to basement at the center of the profile of 7,200 ft. The second method is based on the apparent velocity using the reverse point and shot 12P. This gives a higher apparent velocity of 19,800 ft/sec, and increases the dip of the basement contact but has negligible effect on the total depth to basement at the center of the profile (7,400 ft.). Thus all three interpretations give a basement depth of 7000-7500 foot near Wister, with possibly a slightly decreasing basement depth in the northwest. For both reversal interpretations a 900 ft/sec, and 6,100 ft/sec velocity layers were assumed.

If the linear surface trace or the Banning-Mission creek fault is projected southeast it would lie to the southwest of this profile. This may account for the rather shallow depth to basement as compared to 18,000 ft at Westmorland. The similarity of this seismic section with the other profiles and the existence of clear consistent basement arrivals for 15,000 feet limits the northward extent of the proposed metamorphic effects of the Salton Volcanic Domes.

Truckhaven Profile

This unreversed profile parallels U. S. Highway 99 on the west side of the Salton Sea. The zero point is located at 33° 14.7' N. Lat., 115° 56.3' W. Long. (Figure 9). All of the shot points except 1,2, and 8 were located at this point. Shot points 1 and 2 were 2000 feet northwest of this point and shot point 8 was 10,000 feet southeast. The arrivals from these shots were plotted from the zero point using the shot point to detector distance.

There is some indication of faulting near the middle of the profile where the first arrivals lie along the 12,100 ft/sec layer. It is difficult to say if those points associated with shots 9P and 10P are basement arrivals or possibly a 15,000 ft/sec layer. However, nowhere in the Salton trough is a 15,000 ft/sec layer observed at such shallow depths as are indicated here. On this basis these arrivals are placed on the basement line. The data is insufficient to place accurate limits on the depth or extent of this minor structure.

A slight dip is indicated by the en échelon pattern of the arrivals from shots 8P and 8R but this could be the result of complex structure between the zero point and SP 8. Making a straightforward interpretation of horizontal layers gives a basement depth of 5,500 feet. The Pure Oil Company, Truckhaven well was drilled to basement approximately 2 miles southeast of this profile probably within the zone of faulting to a depth of 6,100 feet which is in good agreement with the seismic evidence.

Thousand Palms Profile

This profile was recorded along the frontage road which parallels the Indio freeway (U.S. 99) on the northeast. The town of Thousand Palms is located about in the middle of the spread. It was extremely difficult to obtain satisfactory records on this profile because of traffic noise along the heavily traveled freeway. Also, the shot point on the northwest end of the profile was located in the sandy bottom of the Whitewater River wash which had exceedingly poor coupling for seismic energy. Several attempts were made to obtain basement arrivals along the reverse line by shooting 150 pounds at 90 feet. None of these produced usable records. This may be due to complex basement structure near the northwest shot point; however, the recording units were split such that one should receive basement refractions and the other an intermediate layer (13R, 13P) and both had extremely weak signals. That there is a fairly level basement section between 15,000 and 30,000 feet from the zero shot point in the southeast is indicated by the collinearity of arrivals from shots (7,8) and 4 which were 2500 feet apart. Also the upper layers determined by the reversal interpretation have approximately equal apparent velocity.

The depth to basement obtained by assuming horizontal layers is 4350 feet. The Stone well about 4 miles to the northeast was drilled to 7468 feet from a point 1500 feet above sea level and did not penetrate basement. The gravity data indicates a thickening sedimentary section in the direction of the Stone well. However, because of the proximity to the Banning fault the basement structure in this area is undoubtedly very complex. The magnetic data of Soske (1935) indicates that the seismic profile is along a magnetic high which may represent an uplifted block of basement.

Gravity Field Methods

During the period of August, 1961 to February, 1964 approximately 2500 gravity stations were established in the Coachella and Imperial Valleys and the surrounding area. An additional 180 underwater gravity readings were made in the Salton Sea. Readings were taken along all roads and trails accessible with a four-wheel-drive vehicle. Several stations were established on foot traverses into inaccessible areas to provide additional coverage, including a traverse to San Jacinto Peak. The stations were established on a one-mile grid within the valleys and a one-mile spacing on all profiles along the surrounding mountain roads. In addition gravity lines were extended as far east as Blythe, California, and gravity data was obtained westward to the Pacific Ocean to establish regional control. Wherever possible the gravity stations were selectively placed in order to avoid large inner zone terrain effects which could not be calculated from the scale and contour interval of the maps being used.

Gravimeter Calibration

A Master Model III Worden gravimeter No. 533 was used to establish most of the land stations. A calibration constant of 0.52295 milligals per dial division was determined by reading the gravimeter over a previously established calibration loop from the pendulum station and Woollard base station at the California Institute of Technology to the pendulum station at Mount Wilson Observatory. There is an observed gravity difference of over 324 milligals between these two stations, which is almost equivalent to a full scale reading on the gravimeter. This permitted the calibration constant to be determined to ±0.00003 milligals per dial division (see Appendix A for detailed description of stations and observed gravity). The calibration of the meter was checked along this base loop several times during the course of the survey to determine if there were any changes in the calibration constant. No differences in the calibration within the observable error were detected. During the latter part of the survey the meter was fitted with a direct-digit reading dial in order to increase its sensitivity and range. The new calibration constant obtained over the calibration loop was in agreement with that obtained by tilt-table methods of Texas Instruments.

For the foot traverse to San Jacinto Peak a Worden Prospector Model gravimeter No. 416 was used because of its ease of packing. The calibration constant of 0.54852 (milligals/dial division) for this meter was also obtained from the calibration loop.

A La Coste - Romberg underwater gravimeter Model No. HD-3 was used to establish all of the underwater stations in the Salton Sea. A calibration constant of 0.1058 milligals per scale division was established by La Coste and Romberg Inc.

The Worden gravimeter readings are reproducible to within 0.1 dial division or a reading error of ±0.05 milligals. The La Coste underwater gravimeter under normal conditions was reproducible to 0.1 dial divisions or a reading accuracy of 0.01 milligals. The La Coste meter, however, is not a null reading instrument because such a meter would be very unstable in soft bottom muds and underwater conditions. A gravity reading is produced by a combination of a direct reading dial and the measurement of a slope of a record trace which corresponds to the drift from center of the balance. Under normal conditions this slope can be determined precisely. If the bottom becomes very soft or if there is considerable surface disturbance the trace is no longer a straight line, and the true slope is somewhat incoherent. Even under the worse conditions encountered the reading accuracy was still better than ±0.05 milligals.

Base Stations

The entire gravity survey was tied into a Woollard base station at California Institue of Technology in Pasadena (Behrendt and Woollard, 1961). This was done by making several direct loops between Pasadena, Pomona, Banning and Indio, California. From these points direct ties were made to secondary base stations scattered throughout the area. These secondary bases were inturn all tied into each other so that an entire network was established with a maximum error of closure of 0.05 milligals. All of the secondary base stations in this area which were established by California oil companies had to be adjusted to coincide with the Woollard reference base at C.I.T. and because of a known error in the calibration constant of the meter used by some to establish these stations. It is believed that the maximum error in observed gravity throughout the entire network of primary and secondary base stations is less than 0.1 milligals relative to Pasadena.

The underwater stations were tied into the land network at Salton City, California by reading the La Coste gravimeter on the dock and then tieing this point into a secondary base station at Truckhaven, California. For a description of the primary and secondary base stations along with their observed gravity values see Appendix B.

Station Location

All of the gravity stations were located on U.S.G.S topographic maps; the major portion are on $7\frac{1}{2}$ minute quadrangles, the remainder on 15 minute quadrangles. The advanced sheets for the northeast section of the area were used for stations in that vicinity. Most of the maps are recent and very accurate and it is believed that most of the stations are located to within 50 feet when placed near intersections or some easily recognizable point on the maps. Some of the canyon and mountain stations are along jeep trails or in dry washes and may be in error by two hundred feet, as they were located primarily by a calibrated survey speedometer and topographic correlation. All of the latitude and longitudes of the stations were picked to 0.0001 degrees. The majority of the land stations have a location error less than ±0.02 milligals and all are less than ±0.05 milligals.

The first water stations were located using three Tellurometers. These electronic surveying instruments (Poling, 1961) have an easily obtainable accuracy of better than 50 feet in ten miles. Two instruments were placed on the shore at points such that the intersection of the distance arcs were close to 90 degrees to produce maximum accuracy. The third Tellurometer was placed on the boat and used as the master station. With this method the water stations were accurately located to within fifty feet.

Due to the extremely high temperatures during the day it was impossible to use the Tellurometers continuously without burning out certain components. As a result the next group of stations were located by the intersection of two transit sights on the boat from the shore. Some of these stations may be in error by 200 feet. During the latter part of the water survey the stations were located by an east-west transit line and two Tellurometers, one at the transit station and the other on the boat. Thus a straight course could be navigated and the distance from a fixed land station continuously monitored. This method was found to be most satisfactory of all. As a check on the accuracy of location during this latter part an additional transit station was established on the shore to give an extra sight on the boat at approximately right angles. In all cases the locations established by using the two transit sights or one transit and the Tellurometers were in good agreement within the plotting accuracy of the maps.

Due to visibility limitations of the transit some of the last stations on the long east-west lines had to be established by dead reckoning, and sailing a course in line with the previous wake which remained visible for several minutes on calm days. The boat was anchored in order to make all measurements. The location error of most of the water stations is probably about 0.08 mgal with some stations in error by as much as 0.15 mgal.

Elevation Control

About 70 percent of the stations were established on bench marks or points of known elevations given on the topographic maps. Elevations of the remaining stations were interpolated from the contour maps when the contour interval was less than ten feet or by the use of two Wallace and Tiernan altimeters, tied to points of known elevations. As a rule in order to remove the fluctuations in barometric pressure there is usually an altimeter reading at a benchmark or useful elevation every twenty minutes except in some extremely difficult canyons and along the foot traverse to San Jacinto Peak. These stations elevations were established by removing the effect of barometric pressure variations and then multiplying by the current dial division constant. Everywhere these elevations agreed with those of the topographic maps to within its reading accuracy. In fact several lines were established over areas of known elevations and this method applied to determine the elevations from the altimeters alone. These agreed everywhere to within three feet of the true elevations. The altimeters were read at every station regardless of whether it had a known elevation or not, thus one could determine a dial factor for each traverse. Most of the stations are believed to have elevations correct to 5 feet with most of the stations having errors of less than a foot. A maximum error due to the elevation would be 0.3 mgal and most less than 0.06 mgal.

Whenever barometric leveling was necessary, care was taken to reoccupy a known elevation immediately as soon as any noticeable changes in atmospheric pressure took place, such as thunderstorms or high winds. The elevations for the water stations were determined by lead line measurements from the boat using a tape measure and a 3 pound weight and reading the elevations to the nearest half foot. The surface of the Salton Sea at the time of the survey was -233.5 feet below sea level (Littlefield, 1963) according to the records of the gauging station at the Salton Sea test base maintained by the U.S.C.G.S. Due to drift of the tape from a straight line, bottom mud, and surface irregularities it is believed that all of the water stations have depths correct to 2 feet giving a maximum error of 0.15 milligals.

Gravity Reduction

Latitude Correction

Theoretical sea level gravity was calculated by the computer in the terrain correction and gravity reduction program using the international gravity formula for the reference spheroid:

$$\text{Theo.G.} = 978.049(1+0.0052884\sin^2\theta - 0.00000059\sin^2 2\theta) \quad (1)$$

where θ is the station latitude and Theo.G. is in gals.

Drift Correction

The effects of earth tides and instrumental drift were removed by calculating a drift curve based on reoccupations throughout a given field period. In most cases no more than two hours elapsed between reoccupations. The total drift was very low and almost constant at 0.05 milligals/hour. The meter was read each night and morning at the same base station so a continuous drift curve could be plotted.

Free Air Correction

The least uncertain of the reduction factors is the free air correction. This correction is based on the formula for the normal vertical gradient of gravity.

$$FA = \frac{2\,g\,h}{Ro}\left(1 - \frac{3}{2}\frac{h}{Ro} + \cdots\right) \tag{2}$$

where g is the average gravity value, Ro the average radius of curvature, and h the height above the geoid. In practice the factor 2gh/Ro is taken as constant with

$$FA = 0.09406h \text{ milligals} \quad h \text{ in feet} \tag{3}$$

and the second term is neglected.

Except in areas of high elevation the second term is small. For h = 3000 ft, only 0.07 milligals, h = 6500 ft, 0.3 milligals, for San Jacinto Peak (10,804 ft) 0.8 milligals. A much more serious error can arise from the deflexion of the vertical by a mountain mass which causes the actual curvature 1/R, which should be used, to differ considerably from the mean radius of curvature

1/Ro. This can increase both the free air and Bouguer anomaly by several milligals. A more complete discussion of this effect is given by Heiskanen (1958). Because of the difficulties in obtaining the actual curvature and to avoid confusion the free air reduction was based on equation (5), however, this effect is noted as a possible source of error for the mountain stations, and probably does not exceed 5 milligals. This, however, has very little effect on the interpretations in this report because the detailed interpretations use only the stations with low elevations; and the regional interpretation is based on averages over wide areas.

Terrain Corrections

The calculation of terrain corrections is probably the most tedious and time consuming part of gravity reductions. A Fortran program was written for an IBM 7090 digital computer which eliminates much of the task. The program essentially follows the methods outlined by Kane (1962) although his program was written for a Dataron 220. The use of the 7090 with its larger memory capacity and increased speed is much more suitable for the problem. For areas about one degree square it is not necessary to produce a magnetic tape for the input data. The program also has the added option of doing the complete gravity reduction with up to three density functions for the elevation and mass correction. The program was checked against several hand computed corrections and the difference was always within ±0.05 milligals. As an additional check an inclined plane was digitized by approximating with one kilometer blocks and agreed within 5 °/0 of the value which can be calculated exactly.

The input to the program consists of a digitixed topographic map in one kilometer squares, the latitude and longitude of the point for which a terrain correction is to be computed and the meter reading and inner zone correction if total gravity reductions is desired.

One of the major advantages of this system besides a considerable savings in time is the internal consistency of the corrections.

The system used here corrects for the terrain effect within a 40 km square with the station at the center, omitting the innermost 2 km square.

This is approximately equivalent to the C to K zones of the Hayford-Bowie charts (Swick, 1942) or the middle of zone G to middle of zone M of the Hammer (1939) charts.

The inner zone terrain correction for the 2 km square about the station has been calculated by several methods, depending on the nature of the near-station topography. Where the terrain is irregular the most commonly used technique was the application of a modified Hammer chart.

Zones A to F of the Hammer charts lie entirely within the area omitted by the computer calculation of the outer zone terrain correction and therefore can be used directly in the inner zone calculation. The G zone, however, lies part within and part without the 2 km boundary. This zone cannot be eliminated or included in its entirety for this would underestimate or overestimate respectively the terrain effect. Therefore a new zone was created which is called the G' zone. The inner radius and number of compartments of this zone are the same as the Hammer G zone. Because the contribution to the total terrain correction of any one compartment of the Hammer charts is a function of the area enclosed by the compartment, its distance from the station, and the relief the outer radius was established by calculating the radius of a circle which would enclose an equivalent area to that of the omitted 2 km square. This gives $R_2 = 1.2533$ km.

Tables were then calculated for the terrain effect of one compartment at 10 foot increments of averaged relief. using the formula for a segment of a hollow vertical cylinder at a point on the axis in the plane of one end of the cylinder.

$$g = 2\pi G\rho(R_2 - R_1 + (R_1^2 + h^2)^{\frac{1}{2}} - (R_2^2 + h^2)^{\frac{1}{2}})/n \quad (4)$$

where: R_1=inner radius (0.8949 km) ρ=density (2.67 g/cm^3)

R_2=outer radius (1.2533 km) h=height (kilometers)

G =gravitational constant (6.673)

n = number of compartments (12)

In the application of these terrain correction charts care must be exercised that a boundary between the compartments coincide with a contour line of the station elevation. This will minimize errors in the averaging of terrain. For it is total relief which effects the terrain correction, not average relief.

It was also found more convenient to have the terrain effect of the C to F zones tabulated in increments of 5 or 10 feet of relief rather than by hundredths of a milligal as originally done by Hammer. The table of corrections for these zones and the G' zone is given in Appendix D.

If the topography surrounding the station was a smooth, regular slope the inclined plane formula of Sandberg (1958) was used to calculate the inner zone terrain correction. This method was very useful along the sides of the trough. Because the corrections calculated by Sandberg used the normal Hammer zone radii, it was necessary to calculate the correction for the G' zone radius from the inclined plane formula.

$$TR = 2\, G\rho\, R\, (\pi - 2 \cos\theta\, K(\sin\theta)) \qquad (5)$$

From Table 3 it can be seen that the application of the terrain correction has little effect on the data for the Imperial Valley. In the Coachella Valley, however, the terrain corrections increase both the gradient along the borders of the valley and the total anomaly across

Table 3 Sample Terrain Corrections in the Salton Trough Area

Type Area	Location	Inner Zone Terr. Corr.	Outer Zone Terr. Corr.	Total Terr. Corr.
Central Imperial Valley	El Centro	0.00	0.00	0.00
Western Imperial Valley	Coyote Wells	0.03	0.75	0.78
Eastern Imperial Valley	Glamis	0.00	0.09	0.09
Central Coachella Valley	Indio	0.00	0.74	0.74
Western Coachella Valley	La Quinta	0.57	3.11	3.68
Eastern Coachella Valley	106-Fargo	0.34	2.89	3.23
San Gorgonio Pass	Cabazon	0.08	4.47	4.55
Peninsular Range	Warner Springs	0.18	1.73	1.91
Transverse Range	Joshua Tree	0.49	1.07	1.56
	San Jacinto Peak	10.83	60.43	71.26

Terrain corrections in milligals.

the valley. Failure to make terrain corrections in this area would amount to 3 milligals in the observed anomaly or about 350 meters of sediments with a density contrast 0.2 g/cm^3. The effect of terrain corrections can also be seen by comparing the simple Bouguer anomaly map (Figure24) with the complete Bouguer anomaly map (Figure 20).

The estimated accuracy of the total terrain correction is 10% or about 0.1 milligals for valley stations and 0.3 for most others.

Bouguer Correction

In areas of great relief and varying surficial rock density it is difficult if not impossible to make an accurate Bouguer correction. Within the Salton trough and surrounding areas there is over 11,000 feet of relief and a wide range of surface rock densities ranging from less than 1.9 g/cm^3 to more than 2.90 g/cm^3. It is customary in regional gravity surveys to use the average density value for surficial crustal rocks - 2.67 g/cm^3 - in the Bouguer reduction. That this method can introduce systematic errors into the gravity map has been demonstrated by Vajk (1956). He suggests the use of varying densities in the Bouguer reduction if the surface rock densities are known. A recent paper by Grant and Elsaharty (1962) uses a method which minimizes the correlation between Bouguer anomaly and topography.

Neither of these methods seem practical to use in this study because of insufficient surface density information, large relief, and varying station spacing in the mountains.

The question of what is the most appropriate density to be used in the Bouguer reduction can best be answered by first determining what is the effect to be studied. For studies on a local scale involving intrabasin anomalies the most appropriate density would be that of the surface sediments. However for regional crustal studies the most appropriate density is the average surficial crustal rock density 2.67 g/cm^3. For this reason two Bouguer corrections have been calculated and are listed as BA(1) and BA(2). The mass correction for BA(1) is obtained from

$$h(0.01277D_1) + (h-s)\ (0.01277Dw) \qquad (6)$$

for stations with $h \leq HC$ and by

$$HC(0.01277D_2) + (h-HC)\ (0.01277D_2) \qquad (7)$$

for stations with $h > HC$, where h is the elevation of the station, D_1 and D_2 are average surface densities, D_w is the density of sea water, s is the elevation of the Salton Sea, and HC is some arbitrary height above sea level. For BA(1), D_1=2.0 g/cm^3, D_2=2.67 g/cm^3, s=-233.5 ft, D_W=1.03 g/cm^3 for all water stations and 0.00 for all land stations, and HC = 1000 ft.

The mass correction for BA(2) is obtained from equation (6) for all stations regardless of elevation, with $D_1 = 2.67$ g/cm^3, $s = -233.5$ ft, $D_w = 1.03$ or 0.00g/cm^3 for water or land stations respectively.

Let us look at the meaning of these two mass corrections. For land stations in the case of BA(1) these equations become:

$$\text{for } h \leq 1000'$$

$$h(0.01277 \cdot 2.00) \tag{8}$$

$$\text{for } h > 1000'$$

$$1000(0.01277 \cdot 2.00) + (h - 1000)(0.01277 \cdot 2.67) \tag{9}$$

Equation (8) is just the correction for an infinite slab of material of density 2.00 g/cm^3 from $g_s = 2\pi G \rho h$, $2\pi G = 0.01277$ for ρ in g/cm^3, and h in feet.

Equation (9) corrects for 1000 ft of material with density 2.0 and the remainder with a density of 2.67. This is based on the fact that the average elevation of the contact between crystalline rocks and sedimentary rocks is approximately 1000 feet in the Salton trough. For stations with h positive the correction is subtracted from the observed gravity. For stations with h negative the correction is added. This in effect fills up the area below sea level with 2.00 density material. For all water stations ($h \leq -233.5$ ft) the correction is:

$$h(0.01277 \cdot 2.00) + (h + 233.5)(0.01277 \cdot 1.03) \tag{10}$$

where the second term accounts for the attraction of the slab of water above the station.

For BA(2) the corrections are similar except 2.67 is used for all land stations regardless of h.

Both of these corrections have been used in parts of this study. The regional map and the complete Bouguer map are based on BA (2). For investigation of the residual anomalies and intrabasin anomalies of the Coachella Valley a combination of BA (1) and BA (2) was used. The effect of these corrections on the anomalies is discussed elsewhere.

Errors arising from the Bouguer correction through the use of erroneous density can be minimized by the judicious selection of the datum elevation. The datum elevation should be somewhere between that of the lowest and highest station, and not necessarily at sea level. Since it is customary in regional studies to compare sea level Bouguer anomalies, a constant factor can be added to account for the difference between datum and sea level. Figure 11 gives the distribution of all of the gravity observations in the Salton trough region for 100 foot increments. Although the station elevations range from -278 feet to 10,804 feet, 57 % of the observations are within ± 300 feet of sea level. With a median of 154 feet. Thus the datum selected here was sea level. Had the median been significantly different from sea level slightly greater accuracy could be obtained by using the median elevation for a datum as done by Corbato (1963).

Before proceeding with the interpretation of the Bouguer anomalies it should be emphasized that contrary to statements in many geophysical texts the application of the elevation, mass, and topographic corrections does not mean that the gravity anomaly at the datum level is obtained for this would equate Bouguer correction to downward continuation. The difference in areas of high elevation, with local anomalies of the vertical gradient, and density changes above the datum can amount to several tens of milligals. For a discussion and example of this effect see Appendix E where the reduced Bouguer gravity anomaly over an ideal mountain range is calculated and compared to that of the "true" anomaly.

Reduction Accuracy

Aside from errors introduced by using an incorrect density in the Bouguer reduction it is estimated that most of the valley stations are accurate to $\pm$ 0.5 milligals and most mountain stations are accurate to ± 0.8 milligals. Considering the error in the terrain, correction would raise these values to 0.6 and 1.1 milligals respectively. The observed gravity values are accurate to ± 0.1, ± 0.2 milligals respectively.

Gravity Interpretation

Relation of Free Air Anomalies to Surface Elevation

The relation of surface elevation to free air anomalies has been studied by Woollard (1962), Heiskanen and Vening Meinesz (1958). Woollard has shown that the regional free air anomalies tend to average zero with markedly positive values in the mountains and negative values in the valleys. It is easy to show that this relation would hold even if there were complete local isostatic compensation. For example, the gravity effect at the center of a sediment filled basin 25 kilometers wide and 4 kilometers deep with a density contrast of 0.3 g/cm^3 is approximately 4 times that from a compensating anti-root at a depth of 30 km. A similar effect holds for a mountain mass see Appendix E. However, large departures from this relation are significant.

The average station free air anomaly and average station elevation for the Salton trough area are shown in Figure 12. These values were obtained by averaging the free air anomaly and elevation for all gravity observations within 20 km squares (Table 4). The average station free air anomaly for this area is -35 milligals, which is not unexpected considering that 60 to 70 % of the observations were made in the valley. Aside from the near-linear correlation of free air anomalies and elevation (which parallels closely that given by Heiskanen), it is interesting to investigate the points of maximum departure from this trend. An inspection of Table 4 shows that all of the points with free air anomalies of around -80 milligals and low elevations are associated with the

the Coachella Valley. Such a large negative free air anomaly must indicate a considerable mass deficiency. The effect of the low density sediments could not account for more than half of this anomaly. Thus the remaining anomaly of about -40 milligals must be accounted for in the crust or upper mantle. Complete local compensation of a narrow structural feature such as the Coachella Valley would not be expected. Thus the valley should have little or no anti-root contributing any positive effect. Instead the free air anomaly indicates that there is regional compensation of the area as a whole. The point at +86 milligals and close to 4000 feet of average elevation is located over the highest portion of the southern Peninsular Ranges and probably indicates lack of complete isostatic compensation in this area.

Relation of Bouguer Anomalies to Surface Elevation

In doing a study on the relation of Bouguer anomalies to surface elevation it is very easy to bias the relation by the means which data is obtained. Normally in any gravity survey the average elevation of gravity stations in a given area is not representative of the true elevation of the area. In areas of high relief the average station elevation can differ by 2000 feet or more from the true regional elevation, the former is invariably less than the latter. This is simply because most gravity observations are made along roads which usually follow the lower elevations. Few observations are made on mountain peaks and slopes. The use of the airborne gravimeter for geodetic and regional studies will remove this error. This error is also a source of scatter in the points of the free air anomaly relation previously discussed.

One method of reducing this effect is by using an average based on a final contour map. This is a time consuming and laborious task. A method was devised for a digital computer which essentially produces a digitized grid of gravity values from a weighted sampling of all observations within a given area.

An averaging of these values within a given area and the use of digitized topographic maps essentially removes the station bias.

Figure 13 is a plot of these regional Bouguer anomalies and regional elevation. The regional elevations (see Table 5) were obtained by averaging the digitized topographic map values, for 20 kilometer squares, used in the terrain correction program. Thus each average value represents 400 one kilometer topographic squares. The regional Bouguer anomalies were obtained for the same 20 kilometer squares by averaging the computed Bouguer values developed on a 4 x 2 kilometer spacing (Figure 27). These values are given in Table 6. This plot (Figure 13) gives almost double the elevation for a given Bouguer anomaly that is predicted by Woollard's curve.

The best linear fit has a slope of 15 milligals per 1000 feet. Comparing this plot with Figure 14 which is based directly on station values a somewhat less coherent relation and smaller slope (12 milligals/1000 ft) is observed as anticipated.

The scatter can be reduced further through the application of geologic corrections for the near surface anomalous masses or restricting the plot only to those points on crystalline rock outcrops.

The plots presented here are only construed to hold for southern California and to demonstrate the methods used in obtaining more meaningful and coherent relations of gravity anomalies and surface elevations. The application of these methods to data on a continental scale would produce more general relations.

When dealing with relief of several thousand feet it is easy to show that the correlation of Bouguer anomalies to surface elevations cannot be removed by using any geologically reasonable Bouguer reduction density. The average crustal rock density of 2.67 g/cm^3 used in this study is a minimum for average crystalline rocks. The average density of crystalline and basement rocks for the United States is greater than 2.74 (Woollard, 1962), but increasing the Bouguer density only tends to increase the topographic correlation.

Density-Depth Relation and Well Data

In order to make reasonable interpretations of the intra-basin anomalies, knowledge of the relation of density to depth for the sediments must be assembled. Despite the number of wells drilled in the Salton trough only a limited number of density measurements are available. A plot of density measurements on drill cores from 5 wells in the Salton trough are given in Figure 15. The density samples from the Salton Volcanic Domes area are not included because of the possibility of alteration. The large scatter in the points is not unexpected considering the diversity of rock types sampled; however, a general increase of density with depth is obvious. Woollard's curves for Miocene and Eocene sediments and Corbato's curve for Tertiary sediments of the San Fernando Valley are included for comparison. The Miocene curve is considerably lower than the well data indicates. The average density of the well samples is 2.40 g/cm^3 The average density from the Miocene curve over the same interval is 2.31 g/cm^3. Both Corbato's Tertiary and Woollard's Eocene curves fit the data fairly well in general shape and average density, 2.41 and 2.44 g/cm^3 respectively. The limited density depth data does not permit a greater refinement of the relation.

Over 70 wells have been drilled in the Salton trough area in search of oil, gas, or steam. To date there are no producing oil wells in the trough, but there is good indication of a potential geothermal source. The deepest well in the trough was drilled southeast of Brawley by the Standard Oil Company of California to a depth of 13,442 feet. No wells have been drilled to basement in the center of the trough but there are several basement wells along the flanks of the trough. The deepest basement well is the Texas Company, Browne Well with a depth of 7806 feet. Most of these wells have been used as anchor points in approximating the gravity effect of the Imperial Valley sediments as discussed later.

Before proceeding with the interpretation of the gravity anomalies it is instructive to investigate this effect of increasing density with depth on the calculated gravity anomaly. It will be shown that it is difficult to make accurate depth dterminations in sedimentary basins where the thickness of sediments is greater than 3 km. because of uncertainties in the residual anomaly and in the density-depth relations.

Consider a rectangular basin 15 km wide and 5.5 km deep which is approximated by two dimensional slabs 0.5 km thick and of decreasing density contrast from top to bottom as given in Table 7 with three sets of density contrasts D_1, D_2, D_3. The gravity anomaly for each of these 11 slabs for the three density contrasts is given in Figures 16, 17, 18. The sum of these 11 slabs for each density is given by the three curves of Figure 19. Fifty percent of the total gravity anomaly is accounted for by the top two layers or a total thickness of 1 km, 80 percent by the top 5 layers, and 90 percent by the top 6 layers. In most field situations it is impossible to determine the residual anomaly to better than 10 percent. Thus for most deep Tertiary basins doubling the thickness of sediments from 3 to 6 km only increases the observed anomaly by approximately the error in obtaining a residual anomaly. Similar results are obtained for a wedge shaped basin 25 km wide at the top and narrowing to 3 km at a depth of 5.5 km with even a greater percentage of the anomaly arising from the upper layers. Although this effect makes the accurate interpretation of the basin hazardous it is extremely helpful in making regional crustal or basement calculations. Most of the basement wells have been drilled along the borders of the trough providing some depth control in the critical upper 7000 to 8000 feet. The seismic data supplements this information and adds control for the deeper portions. This permits the approximate computation of the effect of the sediments which can be removed from the observed gravity to produce a regional map. This is discussed later in this report

Table 7

Assumed Density Variation With Depth for Sample Basin

Depth	D_1	D_2	D_3
0			
	0.38	0.43	0.48
.5			
	0.29	0.34	0.39
1.0			
	0.24	0.29	0.34
1.5			
	0.17	0.22	0.27
2.0			
	0.13	0.18	0.23
2.5			
	0.08	0.13	0.18
3.0			
	0.05	0.10	0.15
3.5			
	0.02	0.07	0.12
4.0			
	0.00	0.05	0.10
4.5			
	0.00	0.04	0.09
5.0			
	0.00	0.02	0.07
5.5			

Density Contrast (g/cm^3)

Depth in Kilometers

with regard to the interpretation of the regional anomalies.

Another approach to the problem of density-depth relations is to use the seismic data and velocity density curves. From Tables 1 and 2 the average velocity and thickness for the correlated layers can be obtained. Then using the velocity density curves of Woollard (1962), density can be assigned and the density contrast calculated (Table 8). These results are in reasonable agreement with those obtained from the density-depth relations.

The Complete Bouguer Anomaly Map

A complete Bouguer anomaly map of the California half of the Salton trough and surrounding area, based on a Bouguer density of 2.67 g/cm^3 and a contour interval of 2 milligals is presented in figure 20 as an overlay for the generalized geologic map (Figure 21). The general northwest trend of the Bouguer gravity contours in the Salton trough and Peninsular Ranges is a reflection of the major tectonic pattern of this area. Northeast of the Coachella Valley the east-west trend of the contours reflects the tectonic pattern of the Transverse Ranges. In the region northeast and southeast of Desert Center the gravity control is widely scattered and it is hazardous to place much emphasis on the anomalies. The contouring was continued in this area only for regional purposes, but even on a regional basis in an area of such varying

Table 8 Average Velocity-Density-Depth Relations

Layer	Thickness (Feet)	Depth (Feet)	Velocity Ft/sec	Density g/cm^3	$\Delta\rho$ g/cm^3
0	95	48	1700	1.6	1.15
1	940	565	5850	2.0	0.75
2	1895	1973	7100	2.15	0.60
3	2425	4142	8500	2.35	0.40
4	3625	7167	11,900	2.55	0.20
5	8800	13,380	15,000	2.65	0.10
6	- Basement -		18,800	2.75	0.00

surface geology prominent distortions are created in the gravity field. Nevertheless this apparent random pattern of gravity highs and lows appears to be characteristic of the Mojave Desert province (Mabey, 1960). In this province the gravity minimum and maximum are closely associated with the basins and ranges. Where the east-west trend of the Transverse Ranges is transformed into the Mojave Desert pattern is not clear because of the lack of data in the Dale Lake-Coxcomb Mountains area. It is in this area, however, that the surface trend of the Transverse Ranges is terminated, which is in general agreement with the gravity data.

One of the most striking features of the complete Bouguer map is the steep gravity gradient along the northeast side of the Coachella Valley which is associated with the surface trace of the Banning-Mission Creek fault. This steep gradient dies out to the southeast along with the last surficial evidence of the fault near the northeast embayment of the Salton Sea. In this area the fault zone is marked by a narrow elongated gravity low on the northeast side of the fault, which is one of a series of small gravity lows extending along a line, parallel to the extended surface trace, toward Yuma, Arizona. More detailed gravity coverage along this southern portion will probably indicate an even closer relation. This correlation which was not observed previously (Kovach et al, 1962; Biehler et al, 1964) is the result of added detailed gravity coverage in parts of this area and a smaller contour interval than used on the simple Bouguer gravity map (Figure 24).

This correlation of gravity lows and faulting is also observed along the Blue Cut, San Jacinto, and Elsinore fault zones. Starting with the gravity low associated with the sediment-filled valley at Hemet in the northwest gravity minimum are observed along the entire trace of the San Jacinto fault southeast into the Imperial Valley. The gravity lows extending from Warner Springs to the Mexican Border are associated with the Elsinore fault zone. The narrow elongated east-west trending low in the Transverse Range north of Indio is associated with the Blue Cut-Pinto Basin fault. In most cases the major gravity minimums of more than 8 milligals are associated with fault-controlled sediment-filled basins. However even within the crystalline rocks smaller minimums are observed. This may result from a lower average density of the rocks within fault zones.

The complete Bouguer anomalies range from a low of 882 milligals (actually -118 milligals; 1000 milligals have been added to all readings) 3 miles west of Desert Hot Springs to a high of 984 (-16) milligals west of Yuma, Arizona at the southeast corner of the map. This gravity difference of over 100 milligals in 220 kilometers is an indication of the magnitude of regional gradients in the area. In order to make an accurate interpretation of such "local" features as the Coachella Valley minimum and the Salton Volcanic Domes maximum it is necessary to remove the regional effects. Before proceeding with the interpretation of these local anomalies let us investigate the regional trends and their origins. It will be shown that the apparent lack of a large negative anomaly across the Imperial Valley is partly the result of regional crustal complications.

Regional Bouguer Anomalies - Crustal Structure

Valuable knowledge of the crustal structure of an area can be obtained from a study of the regional gravity anomalies. It must be made clear in the beginning that the terms regional anomalies and local anomalies are purely relative, depending on the extent of the survey. The regional anomaly of one investigation may be the local anomaly of another. In the interpretation of most "local anomalies" there is usually present at least two separate "regional" effects, which are treated as one and removed by subtracting a straight line or smooth curve from the observed anomaly. Little or no attention is given to the origins of these regional gradients which may be near-surface features such as a change in basement rock types or deep-seated features such as changes in crustal density or thickness. If a sufficiently large area has been investigated these two regional effects may be separated. However, regional anomalies resulting from systematic changes in near surface density over large areas cannot be distinguished from deeper sources.

In the present study gravity data has been obtained over 55,000 square kilometers. It is obvious that broad scale variations in the earth's crustal structure whether from changes in density or thickness will be detected by the gravity field. Minor regional changes from near surface density variations will appear as perturbations on the crustal regional. To clearly illustrate this consider a simple case of a sediment-filled basin with granitic rocks on one side and metamorphic rocks on the other, with the geologic contact somewhere below the sediments and the whole area above a crustal section which is thickening in the direction of the granite. Here the regional gradient is primarily caused by the change in densities across the valley and secondarily from the sloping Moho. The effect of the deeper source however will be observed over a broader area and ideally can be separated from the near surface regional gradient.

Near-surface regional anomalies and true local anomalies tend to obscure the effect of the crust on the gravity field. Thus one must use some form of filter system to remove these anomalies, in order to study crustal structure. Two methods were used in attacking this problem which yielded similar results. The first method was a straightforward averaging of all the gravity observations within 20 kilometer squares of Universal Transverse Mercator coordinates. A 20 kilometer square was selected because it is about the maximum extent in width of any local anomaly present in the area. The north-south orientation of the squares was selected because this cuts across the predominant northwest trend of the contours. A three dimensional plot of this data is given in Figure 25 where the average Bouguer gravity value is plotted vertically at the center of the square from which it was obtained. These points have been connected to form a regional gravity surface. Note particularly the orientation of the diagram; the nearest corner is at San Gorgonio Pass - the farthest at Yuma, Arizona. It is evident from this figure that there is a steep gradient associated with the northwest portion of the area, the Imperial Valley is a broad positive, and the Peninsular Ranges persist as a minimum after passing through a saddle point into the southwest.

Because the gravity observations are not uniformly distributed over the area (for example, the station density in the Coachella Valley is considerably higher than in the Transverse Ranges) a bias will be introduced into any simple averaging. Also this method only produces discreet regional values 20 kilometers apart rather than a smooth function. These problems were eliminated by writing a computer program which produces a digitized complete Bouguer anomaly gravity map on a 4 x 2 km grid (Figures 30,27) based on the gravity observations which are weighted according to their distance from the point at which the field is to be calculated. This greatly reduces any station density effect and permits the calculation of regional anomaly maps.

The regional anomaly value at a point is calculated by averaging the digitized Bouguer anomaly values around the edge of a 40 kilometer square. Thus any local gravity effects in the vicinity of the station are removed. This method produces a regional gravity map which covers an area 20 kilometers less on each side than the input Bouguer map. These values can then be contoured either by hand (Figure 22) or by machine (Figure 26). The portion of the regional gravity map outlined is that covered by the machine map and probably represents a reasonable approximation of the regional gravity field. The local divergences seen on the computer map near the edges are due to insufficient regional data to establish regional continuity. These areas have been smoothed in the hand contouring.

On the basis of the gradients involved, the size of the area used in the averaging process, and the extent of the regional gravity trends, the major features of this regional gravity map indicate crustal structure. This does not imply that the small closures of 1 and 2 milligals and the minor curves in the contours seen in Figure 26 have significance but that the continuous decrease in gravity values to the northwest and west does. The northwest-southeast trend which is so pronounced in the complete Bouguer anomaly map is preserved over the southern Peninsular Ranges. However, in the northwest where the highest peaks of the Transverse Ranges are adjacent to the highest peaks of the Peninsular Ranges the regional contours cut across the northwest-southeast trend of the Peninsular Ranges and the east-west trend of the Transverse Ranges. This is an indication of regional isostatic compensation of the area as a whole instead of complete local compensation of each unit, either by increasing crustal thickness (Airy), decreasing crustal density (Pratt) or both (Airy, Heiskanen). As had been observed by previous investigators (Woollard, 1959) and discussed previously there is a close correlation between regional Boughuer anomalies and topography. The lowest regional values are associated with the highest topography, the highest regional values are associated with the low lying Imperial Valley.

The regional Bouguer anomaly in the San Gorgonio Pass area is about -100 milligals. From the relationship between Bouguer anomaly and crustal thickness this would indicate a depth to the mantle of 40 kilometers (Woollard 1959). The average elevation in this area (Table 5) is 2 km above sea level. Assuming a surface density of 2.7 g/cm^3 and a crust - mantle density contrast of 0.45 g/cm^3, a 12 kilometer root would be needed for isostatic equilibrium if the isopiestic level is taken as the base of the crust. Alternatively, an average crustal density 0.15 g/cm^3 less is required for equilibrium assuming a 35 kilometer crust. Because part of the isostatic compensation undoubtedly arises from a portion of the upper mantle, these values are only intended as guides.

The regional gravity values decrease by 65 milligals between the Imperial Valley and San Gorgonio Pass. If this is to be explained in terms of crustal thickening assuming a density contrast of 0.45 g/cm^3 a change of 3 or 4 kilometers is all that is needed. The actual change, however, is probably considerably greater than this because the crust in this area cannot be assumed to be infinite horizontal plates, 0.45 g/cm^3 is close to the upper limit of density contrast between crust and mantle rocks, and no account has been made in this regional interpretation for the thick sedimentary section of the Imperial Valley. Taking these effects into account could easily increase this figure four fold. Let us now look into the effect of the sediments in the Imperial Valley on the regional gravity.

One of the most interesting problems in the interpretation of the gravity data in the Salton trough is the apparent lack of any large negative anomaly across the Imperial Valley (Figure 20, Figure 5, Figure 6). In spite of the fact that there is a thickness of over 18,000 feet of sediments in the valley, a gravity profile and the regional anomalies demonstrate that there is a broad positive anomaly associated with the center of the trough in this area. From seismic refraction and well data a general configuration of the basement can be assembled. (Figure 5). There is little correlation between the increasing depth to basement and the observed Bouguer anomalies. It is clear from the density-depth relations that this cannot be due to compaction phenomena alone because if the basin is only 3.5 km deep a -40 milligal anomaly should still be observed. Thus one must look elsewhere for an explanation. A possible solution to this enigma is associated with crustal thinning or increased crustal density. The evidence for this will now be discussed.

The width of the Salton trough is fairly constant at 80 to 100 km from the head of the Gulf of California northwest to the middle of the Salton Sea. In this area the trough narrows abruptly to less than 25 km and a large negative Bouguer anomaly of -40 milligals appears across the Coachella Valley. This anomaly continues throughout the entire length of the southern portion of the Coachella Valley and to a lesser degree northward to San Gorgonio Pass. As discussed later this anomaly can be explained by approximately 12,000 feet of sediments. It should also be noted that in the area where the trough narrows abruptly there is also a rapid increase in the regional gradient.

It could be argued that this negative Bouguer anomaly in the Coachella Valley is the result of a thicker sedimentary section here as compared to the Imperial Valley or that there is a large decrease in the basement rock densities in the northwest. It can be shown that neither of these explanations are probable.

The first argument can be dismissed on this basis: It has been shown previously that because of the increase of density with depth most of the gravity anomaly in thick sedimentary basins arises from the upper 10,000 feet of sediments, which have an average density of less than 2.40 g/cm^3. The average density from 10,000 to 20,000 feet is about 2.62 g/cm^3. Thus doubling the thickness of the sediments would only increase the magnitude of the negative Bouguer anomaly by 5 to 10 milligals. Since there is no negative anomaly across the Imperial Valley region north of the border and a known sedimentary thickness of 18,000 feet there would have to be an impossibly great depth of sediments in the northwest, to explain this relative decrease of the anomaly.

There is no systematic decrease in the density of exposed crystalline rocks on either side of the trough between the southeast and the northwest. The rock types which have been encountered in wells in the valley are similar to those exposed on the edges of the valley. Thus it can be argued that the basement rock types of the valley floor are similar to those exposed on the sides and therefore there should be no systematic decrease in basement densities if it is not observed along the borders of the trough. Also the seismic velocity of the basement rocks in the Coachella Valley is close to that of the Imperial Valley at similar depths of burial.

A plausible explanation to this problem can be obtained by looking at the regional anomalies along a curved profile from the continental shelf through San Diego to Blythe (Figure 28). The profile has been curved so that it is approximately perpendicular to the regional contours (Figure 22). If the gravity anomaly of a sedimentary basin 80 km wide and 5.5 km deep as determined approximately by seismic refraction (Figure 5) is added to this curve, a broad positive anomaly is observed across the Imperial Valley. The dashed contours on the regional gravity map approximate the gravity anomaly of the Imperial Valley sediments. Interpreting this profile on a regional basis for variations in Moho depths using a density contrast of 0.45 g/cm^3 yields a crust which thickens from 29 km (relative) at the coast to 34 km under the Peninsular Ranges and then shoals to 21 km under the Imperial Valley. From here northeast the crust thickens until a depth of 31 km is reached northeast toward Blythe. The depths given are all relative to a value chosen at the coast, but the relative thicknesses are not altered much by this choice. These depths are also effected by the selected density contrast (0.45 g/cm^3). This is based on the density associated with the crustal and mantle velocities as given by Shor (1958). The depths of Moho westward from San Diego agree with the seismic refraction depths calculated by Shor. The interpretation of a gravity profile from San Diego to Yuma, Arizona by Kovach et al. (1962) is somewhat distorted because it crosses the Imperial Valley at an oblique angle to the regional trend. For example the anchor point at Pilot Knob on the east, where the gravity values are 980 milligals, has its regional counterpart in the south west over the Sierra de Los Cucapas. A gravity profile across this portion of the Colorado delta indicates a negative anomaly of 30 milligals which is 15 to 20 milligals less than would be expected. As shown previously 30 milligals can be explained by less than 11,000 feet of sediments. The seismic profile by Kovach parallel to the Mexican border indicates a minimum depth to basement of at least 15,400 feet. Thus the crustal complexities beneath the Imperial Valley extend southward under the Colorado Delta region and into the Gulf of California.

The Imperial Valley is not the only sediment filled basin which has a relative positive anomaly associated with a great sedimentary thickness. In fact it appears to be the rule rather than the exception, provided that the basin is at least 80 kilometers wide. The wider the basin the more pronounced the gravity high. A positive gravity anomaly is observed in the San Joaquin Valley in northern California (Ivanhoe, 1957). Seismic refraction measurements by the U.S.G.S. indicate a shoaling Moho, possibly as shallow as 20 km (Pakiser, 1964). This is also substantiated by the seismic P wave anomaly (Press and Biehler, 1964) and the magnetic anomaly (Soske, 1935). Gravity studies in Argentina have shown that gravity maxima of +20 milligals are associated with the Rio Salado (300 km wide) and the San Jorge basin (200 km wide) despite known sedimentary thicknesses in access of 14,000 feet (Martin, 1954). Geophysical studies across the Red Sea trough by Girdler (1964) also indicate a positive gravity anomaly across the rift zone.

A gravity profile across the Gulf of California based on the gravity observations of Fett (1955) in the vicinity of Tiburon Island shows a marked positive anomaly as well as positive Bouguer anomaly values across the Gulf. The gravity observations of Harrison and Spiess (1963) clearly indicate that this gravity positive continues south along the entire length of the Gulf with a positive anomaly greater than 100 milligals at La Paz. The crustal complexities under the Imperial Valley are undoubtedly the northern continuation of this feature but to a lesser extent.

The seismic refraction work of Phillips (1963) in the northern end of the Gulf of California places a minimum depth to Moho of 18 kilometers near the head of the Gulf. Considering the small change in regional Bouguer gravity values between Tiburon Island in the south and the Imperial Valley in the north there is probably little change in crustal thickness in this area. On the basis of the regional gravity values there appears to be a considerable increase in the crustal thickness northward toward San Gorgonio Pass.

Unfortunately the gravity data available in Mexico is all located on the west side of the trough, and it may be that a positive anomaly is associated with the trough for the entire length. Even regional gravity values in southern Arizona are sparse but there is some indication of small negative and slightly positive Bougher gravity values along U. S. 80 through Aztec and Mohawk. Future gravity work is planned in this area to investigate the eastern extent of the anomaly.

It is possible that instead of a gradual bowing of the crust under the Imperial Valley there is a discontinuity in the Moho, along the sides of the valley. Such a discontinuity could arise along the major breaks of the fault systems, which may, considering their length, reasonably be assumed to have depths of crustal thickness. This could account for the fact that a structural feature the size of the Imperial Valley has an effect on the crust-mantle boundary.

A thinning crust under the Imperial Valley which is postulated here can also be accounted for by an increase density of the upper portion of the crust by basic intrusions from below. The absence of any large magnetic anomaly across the valley, however, indicates that if such is the case the masses must be relatively deep or their magnetic anomaly greatly reduced by the thick sedimentary deposits.

Regardless of how this gravity anomaly is explained-either by crustal thinning or increase density the anomalous mass must be extensive and at intracrustal depths. The regional gradients and the presence of a positive regional anomaly in the Imperial Valley make accurate depth determinations in this area on the basis of gravity data alone extremely difficult.

Salton Volcanic Domes

The large gravity high at the southern terminus of the Salton Sea coincides with the Salton Volcanic Domes (See also Figure 29). This area is one of the most promising geothermal prospects in California and is currently being actively explored as a potential economic source of geothermal power. Numerous shallow wells were drilled in this area between 1932 and 1954 to develop a carbon dioxide gas field which is now abandoned. A summary of the history of exploration in this area is given by McNitt (1963), which is already somewhat out of date. Eight exploratory steam wells have now been drilled with depths of 5000 to 8100 feet. The location and depths of these wells are shown in Figure 21. All of these wells have high heat flows with temperatures around 270^{o} C at 3000 feet, which is more than 5 times higher than encountered in other wells in Tertiary basins of California and 4 times larger than elsewhere in the Salton trough.

Prior to this gravity study the only published geophysical data was a vertical intensity magnetic survey (Kelley and Soske, 1936). Most of the geological information from the recent exploratory wells is not yet available for publication. Some of the most important geologic and geochemical information has been published by White (1963). This study indicates that the sediments in the vicinity of the domes are being metamorphosed at relatively shallow depths. The density of 5 well samples from this area was determined by White and have since been remeasured and added to by McCulloh (1963). The values obtained are given in Table 9.

Although this density information is very limited, it does indicate complexities in the interpretation of the geophysical anomalies. The saturated bulk densities above 4900 feet are not significantly different from other well samples in the Salton trough, but outside the thermal area. The samples below 4900 feet are 0.2 to 0.6 g/cm^3

Table 9

Drill Core Densities From O'Neil Geothermal Wells

Depth	Dry Bulk Density g/cm^3	Saturated Bulk Density g/cm^3
4477-94	2.35	
4477	2.35	2.47
4484	2.40	2.53
4662		2.52
4917-23	2.87	
4917	3.00	3.18
4923	2.50	2.62

higher and if extensive, would produce a considerable gravity anomaly. However, the Western Geothermal well on the south flank of the gravity high does not show any indication of alteration or metamorphism as reported for the O'Neil wells on the east side of the gravity high. This clearly demonstrates the hazards in interpreting the gravity data in terms of a simple igneous - sediment contrast.

Although a rigorous quantitative interpretation of the gravity anomaly is not warranted at this time because of the lack of reasonable density-depth control and sufficient constraints on the body, certain limitations can be placed on the subsurface shape and lateral extent of the anomalous mass. The term "anomalous mass" does not necessarily infer the shape of the crystalline intrusive rocks but only the volume of density contrast, which may well be gradational because of decreasing metamorphism of the sediments and increasing depth to the heat source toward the periphery of the geothermal area.

Although the surface expression of volcanic activity appears to be along a line trending northeast, the gravity anomaly indicates an approximately circular mass distribution at depth, which is centered about Red Island and may continue northwest under the Salton Sea. This distribution is substantiated by the limited thermal and magnetic data. All of the wells drilled within the closure of the gravity anomaly report very high temperatures with a decrease outward from the center. The Sardi well immediately south of the closure did not encounter particularly high temperatures.

The magnetic anomaly map (Kelley and Soske, 1936) shows a broad positive anomaly of several hundred gammas which has a common center and shape with the gravity anomaly. The magnetics also indicate very sharp local circular positive anomalies of 900 - 1000 gammas over the surface outcrops of each of the domes. This indicates that these exposed domes are approximately narrow horizontal cylinders which extend downward to a larger crystalline mass at depths at least as great as 5000 feet. No similar local gravity anomaly is associated with the surface outcrop of the individual domes either because of the station spacing or lack of density contrasts.

The contrasts in magentic properties between the volcanic rocks of the domes and the sediments is many times larger than the corresponding density contrast and resulting gravity effect. Surface samples of the volcanic rocks have densities of 2.3 g/cm^3. Thus the density contrast between the volcanics and sediments is easily removed at shallow depths by sediment compaction and metamorphic effects.

The relatively low gravity and magnetic gradients and broadness of these anomalies probably indicate the anomalous mass is fairly deep and extensive. It is possible to explain the gravity anomaly alone by a systematic decrease in the density of the sediments outward from the center of the anomaly. This would produce both a broad anomaly and low gradients. However, it is doubtful that such a configuration would explain the broad positive magnetic anomaly because hydrothermal alteration of the magnetite to pyrite in the sediments would result in a lowering of their susceptibility and a decrease in the vertical magnetic intensity. Re-orientation and remnant magnetization effects need not be considered here because of the recent age of volcanism. That the magma of the intrusive mass must be crystallized at least in the upper part is indicated by the presence of the magnetic anomaly. A molten mass above the Curie point would lose its magnetic effect.

Applying the half width method (Nettleton, 1940) to this anomaly one obtains $X_{\frac{1}{2}} = 5$ km and the depth to the center of a buried sphere is:

$$Z = 1.305\ X_{\frac{1}{2}}$$

$$Z = 6.5\ \text{km}$$

If the maximum value of the anomaly is taken as

$$g = 13 \text{ milligals}$$

Then from the attraction of sphere above its center

$$g = \frac{4}{3}\pi \; G \rho R^3/z^2$$

where ρ is the density contrast in g/cm^3, R is the radius, and

$$\rho R^3 = g z^2/27.9 = 20.4$$

Solutions of which are:

ρ g/cm^3	R km
0.1	5.9
0.2	4.7
0.3	4.1
0.4	3.7
0.5	3.4
0.6	3.2
1.0	2.7

The more likely densities of 0.2 to 0.5 yields spherical body 3.5 to 4.5 kilometers in radius with a center 6.5 km deep.

The Westmorland seismic profile indicates a sedimentary thickness of over 18,000 feet (5.5 km) nine miles south of the Volcanic Domes. The Frink profile on the northeast side of the projected trace of the Banning-Mission Creek fault gives a basement depth of 7200 feet (2.5 km). But the Bouguer gravity at both profiles is equal.

Thus the problem of removing regional effects is again quite complex and could produce fair size variations for any calculated shape. It should be indicated that neither the Westmorland nor the Frink or Holtville profiles showed any striking anomalous velocities for the sediments or basement rocks. The apparent continuation of the gravity high southeast into the Imperial Valley may be indicative of higher density rocks intruded into the upper layers of the crust or a crustal thinning as discussed elsewhere. On the basis of lack of any seismic anomalies, the localization of the gravity maximum, the absence of any similar magnetic anomalies south of the buttes and the lower well temperatures encountered it is believed that the potential economic geothermal reserves are limited to the area about the south end of the Salton Sea.

Coachella Valley

The most pronounced gravity anomaly of the Bouguer anomaly map is the large gravity minima associated with the Coachella Valley. The northeast border of the valley is marked by a steep linear gravity gradient which coincides with the surface trace of the Banning-Mission Creek fault. The gravity gradient on the southwest side of the Coachella Valley is not as steep nor as linear and is not associated with any known fault trace. At the southern end of the Coachella Valley the Bouguer anomaly becomes less negative and the steep gravity gradient associated with the faulting on the northeast dies out, the contours swing sharply across the Salton Sea as the effect of the positive gravity anomaly associated with the Salton Volcanic Domes increases. As previously discussed there is no similar gravity low associated with sediments in the Imperial Valley.

The detail of the gravity coverage in the Coachella Valley warrants a complete gravity interpretation. The elevation of the valley floor in the vicinity of Indio is at sea level. From here to the Salton Sea there is a gradual decrease in elevation of 230 feet. From Indio northwest to San Gorgonio Pass there is a more rapid increase to almost 1000 feet. Thus for doing a detailed interpretation of the Coachella Valley the complete Bouguer map (Figure 20) based on a Bouguer density of 2.67 is not appropriate. A false regional gradient will be produced from the north end of the valley to south. The gravity values at the north end reduced with 2.67 are about 6-8 milligals too low. For this reason a complete Bouguer anomaly map based on varying density from 2.0 to 2.67 for the valley and mountain stations respectively was prepared and is shown in Figure 23. A comparison of this Bouguer map with that of Figure 20 shows that although the over-all picture is much the same, the gravity values at the north have been increased and several small anomalies along the Banning fault are delineated.

From the gravity values on bedrock outcrops along both sides of the valley a basement regional Bouguer map was constructed. This regional gravity was then removed from the complete Bouguer map and a residual map produced.

The residual map shows an elongated closure in the Indio-Mecca area. At Indio there appears to be a steepening of the gravity gradients on both sides of the valley (See Figure 20) and the residual map shows a rapid decrease in the Bouguer anomaly at this point. The closure to south may or may not be a real phenomena, because of the difficulty in determining regional values south of here and in the area of Travertine Rock. On the basis of the Bouguer map alone the difference between the center of the valley gravity values and those on crystalline rock is 10 milligals more at Mecca than at the southern end of the valley, which tends to substantiate this closure. The northern closure of the basin at Desert Hot Springs in fairly well controlled although there is a notable lack of gravity information in the northwest extension of the valley toward San Gorgonio Pass. Further work is planned in this area.

A small ridge of high gravity west of the Stone well may indicate an anticlinal structure beneath Edom Hill.

From this residual map 7 gravity profiles were constructed along lines A to G, digitized at one kilometer intervals, and interpreted using an automatic two dimensional computer program patterned after Bott(1960).

The basement profiles were computed using a single density contrast of 0.35 g/cm^3. These are shown without vertical exaggeration on the generalized gravity map. The very rapid increase in the thickness of sediments along the fault is obvious and probably indicates a near vertical step in the basement of 12,000 feet or more. A maximum sedimentary thickness of 4.7 km (15,500 feet) is obtained on the Mecca profile BB' . The gravity profile which crosses the Thousand Palms refraction profile agrees within 200 feet of the basement depth determine seismically. The profile north of here gives a depth of 6200 feet below the Stone well which was drilled to a depth of 5970 feet below sea level. This agreement justifies the use of a single density contrast for the interpretation, however basing a gravity interpretation on a single density contrast for thick sedimentary basins is very hazardous as shown previously. But because of the complete lack of any density-depth control in the Coachella Valley a more rigorous interpretation is not justified. Where the residual Bouguer anomalies exceed 20 to 25 milligals the basement depths given probably indicate a minimum. Where the residual anomaly is less than 20 milligals toward the northern end of the valley, the basement depths represent maximums. In this case, however, the effect of the finiteness of the anomalous body is to underestimate the true depth of basement which is a compensating factor to that previously mentioned from the single density contrast. The gravity profiles indicate that the basin is somewhat assymetrical with the deepest portion along the southwest side of the Banning and Banning-Mission Creek faults.

<u>Borrego Sink and Lower Borrego Valley</u>

The 12 milligal gravity low at Borrego Springs is associated with the Cenozoic sediments of Borrego Sink. Superficially the gravity data indicate that this sink is a closed structural basin which extends probably as a syncline eastward toward Truckhaven. This eastward extension is interesting because it cuts across the northwest trends of the San Jacinto fault zone. The gravity high immediately south of this structure is associated on the west end with exposed crystalline rocks within the fault zone near Ocotillo. This high also trends east-west. Several exploratory wells have been drilled along the eastern nose of this uplift. Standard Oil Company South Lands Well was drilled 4531 ft to basement. A well southwest of the maximum and just north of the highway bottomed in basement at 3912 feet. No exploratory wells have been drilled in Borrego Sink.

There is a steep east-west regional gradient across the Borrego area as can be seen from the regional map and the gravity values on basement outcrops. Just west of Borrego Springs the crystalline rocks are associated with gravity values of 930. Coyote Mountain, and exposed crystalline mass northwest of Borrego Springs has values of 942 milligals. Farther east they increase to 950 at Ocotillo, to more than 966 along the unexposed basement high, and probably, after accounting for 6000 feet of sediment at Truckhaven, to values greater than 980. Removal of this regional gradient will extend the gravity low associated with the syncline eastward toward Truckhaven, giving it the appearance of a narrow trough like structure instead of a syncline plunging toward Borrego Sink. Thus the residual gravity would indicate a 12-20 milligal low extending from Borrego Sink toward the Salton Sea, indicating a gradual increase in basement from about 4000 feet at Borrego to 6000 to 7000 feet at Truckhaven. This clearly demonstrates the erroneous results which can be obtained by trying to interpret the complete Bouguer map

Twenty-five miles southeast of Borrego Springs is a broad gravity minimum at lower Borrego Valley. The very steep gradient southwest of this low is the result of faulting along the front of the Fish Creek Mountains. The low is bounded on the north by the gravity maximum associated with the basement uplift previously discussed. The saddle point to the northwest probably represents a true basement ridge which separates Borrego Sink from lower Borrego Valley. Here, as with the Borrego Sink syncline, removal of the regional trends would open the apparent gravity closure on east side of the valley into the main portion of the Salton trough. The 20 milligal residual anomaly across this valley can be explained by approximately 5000 to 6000 feet of sediments with a gradually deepening basement to the east and southeast and a shallowing toward the northwest. At the northwest the basement probably shallows to less than 1000 feet before deepening toward Borrego Springs.

CONCLUSIONS

A study of the earth's gravity field has proven very useful in delineating the major structural trends of the Salton trough. Regional gravity studies indicate a gravity low associated with the Peninsular Ranges and a broad positive anomaly with the Imperial Valley. Applying a geologic correction to the Bouguer gravity for the thick sediments of the Imperial Valley increases this positive anomaly. An explanation for this effect is a shoaling of the mantle to 21 kilometers or alternatively an increase in the density of the crust by intrusion of more basic rocks from below. The geophysical evidence indicates that the crustal complexities present under the Imperial Valley and Colorado Delta region are a northward extension of the crustal structure associated with the Gulf of California. The seismic evidence and Bouguer gravity anomalies across the southern portion of the Gulf indicate an oceanic type section which is probably a continuation of the east Pacific rise. The crustal structure becomes more continental as one goes northward from the Tiburon Island area. At the head of the Gulf a minimum depth to Moho of 18 kilometers was determined by Phillips (1963). It is believed that this shallow Moho continues under most of the Imperial Valley. Little or no shoaling is present under the narrow

Coachella Valley. The relations observed here are very similar to those studied by Girdler (1964) for the Red Sea and Gulf of Aqaba region. It may well be that within the Gulf of California structural province the continental crust of the northern half is being altered into oceanic type structure by rifting and northwest movement of the western land mass from the continental portion.

The gravity minimum over the Peninsular Ranges cannot be explained wholly by a decrease in the density of the upper crustal section without some crustal thickening. An increase in Moho from 29 kilometers at San Diego to 33 kilometers at the center of the minimum explains all but 15 to 20 milligals of this low. This residual anomaly is probably the result of lower density of the intrusive rocks as compared to a normal continental crustal section. The occurrence of gravity minima with granitic intrusive bodies appears to be a world-wide relation. However, it is impossible to explain all 90 milligals by this effect alone. The average elevation for the southern Peninsular Ranges is about one kilometer. For complete isostatic compensation at the Moho this would require a 6 kilometer root assuming that there is no mass deficiency below sea level until the crust mantle boundary is reached. This may indicate that these ranges are undercompensated. However, the presence of 6 kilometers of lower density intrusive rock with a density contrast of 0.15 g/cm^3 in the upper portion of the crust would restore isostatic balance with only a 4 kilometer root as previously calculated.

The major fault zones in the Salton trough are associated with small gravity lows. The Banning-Mission Creek fault is delineated by a continuous steep gravity gradient along the exposed trace in the Coachella Valley. Faulting probably continues along its trace southeast to Yuma as indicated by a series of small elongated gravity lows which were not previously delineated (Biehler et al, 1964). Considering the magnitude of these lows they can easily be missed without detailed coverage. For example the small gravity low north of Westmorland is along the extended trace of the Imperial fault. More detailed gravity coverage in the southern Imperial Valley would probably indicate similar anomalies along the buried fault traces.

Detailed gravity studies of the Coachella Valley indicate a gradual thickening of the sediments from San Gorgonio Pass to north of Indio where depths of 6000 feet are calculated. Southward the depth of the basement increases more rapidly to depths of 12,000 to 15,000 feet near Mecca. This thickness of sediments continues under the entire length of the Salton Sea, gradually thickening southward. At Westmorland seismic evidence indicates

18,000 feet of sediments, which is the deepest determination of basement in the Salton trough. The sediments probably increase in thickness toward the Mexican border where depths of 22,000 feet or greater are predicted. Sediment thicknesses of 6,000 to 4,000 feet extend from Truckhaven westward to Borrego Springs along a narrow trough. The Coachella Valley south of Indio is assymetric with the greatest thickness of sediments along the Banning fault, which on the basis of the steep gravity gradients indicates a steep contact.

The anomalous gravity field of the Salton Volcanic Domes is associated with a magnetic high and the area of high geothermal temperatures. A broad anomalous mass with a center 6 to 7 kilometers deep and a radius of 3.5 to 4.5 kilometers fits the gravity data. The seismic, gravity, and magnetic evidence indicates this is probably a localized phenomena and does not extend throughout the valley at least within the upper 5 to 6 kilometers. Limited subsurface data makes a complete rigorous interpretation at this time unwarranted.

Because of the complexities arising from crustal structure beneath the Imperial Valley it is difficult to use the gravity data alone to accurately estimate basement depths. Also it was shown that in deep sedimentary basins with more than 5 kilometers of deposits it is difficult to resolve the basement depth because of compaction effects in the sediments even if the residual anomaly can be determined precisely. However, it is impossible to account for the lack of a large negative anomaly with the Imperial Valley by compaction of the sediments, because a gravity low in excess of -40 milligals should still be observed. The intracrustal complexities present under the southern half of Salton trough would also effect any regional magnetic anomalies making the use of such a method to predict basement depths hazardous. The determination of basement depths in the Imperial Valley by seismic refraction appears to be the most reliable.

A Moho determination by seismic refraction within the southern portion of the Salton trough would add a much needed constraint to the geophysical interpretation and greatly reduce the ambiquity in the gravity study. It is evident, however, that the structural complications of this portion of the Salton trough involve the entire crust.

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FIGURE CAPTIONS

FIGURE 1 Index map of the Salton trough showing names of principal faults. Stippling indicates pre-Tertiary crystalline rocks.

FIGURE 2 Index to gravity maps.

FIGURE 3 Columnar section for northeastern Coachella Valley, Reproduced from Dibblee (1954).

FIGURE 4 Index map of Salton trough showing locations of seismic profiles and cross-section lines A-B (Figure 6) and C-D (Figure 5).

FIGURE 5 Seismic cross-section and simple Bouguer gravity profile along line C-D of Figure 4. Numbers indicate velocities in km/sec.

FIGURE 6 Seismic cross-section and simple Bouguer gravity profile along line A-B of Figure 4. Numbers indicate velocities in km/sec.

FIGURE 7 Westmorland-North seismic refraction profile.

FIGURE 8 Frink seismic refraction profile.

FIGURE 9 Truckhaven seismic refraction profile.

FIGURE 10 Thousand Palms seismic refraction profile.

FIGURE 11 Distribution of gravity station elevations for 100 foot increments. Note change in scale at right end of figure.

FIGURE 12 Relation of average station free air anomalies to average station elevation.

FIGURE 13 Relation of regional Bouguer anomalies and regional elevations. Based on machine computed complete Bouguer anomaly map.

FIGURE 14 Relation of average station Bouguer anomalies and average station elevation.

FIGURE 15 Density-depth relations of Tertiary sediments, after Woollard (1962) and Corbato (1963).

FIGURE 16 Gravity anomalies from 11 slabs of basin 1.

FIGURE 17 Gravity anomalies from 11 slabs of basin 2.

FIGURE 29 Complete Bouguer anomalies of the Salton volcanic domes. Computer contouring at 2 milligals. Gravity contour over domes is 980 milligals. See enclosed area Figure 30.

FIGURE 30 Computer contouring of complete Bouguer anomalies. Contour interval 2 milligals, 10 milligal contours left blank. Enclosed area is enlarged in Figure 29.

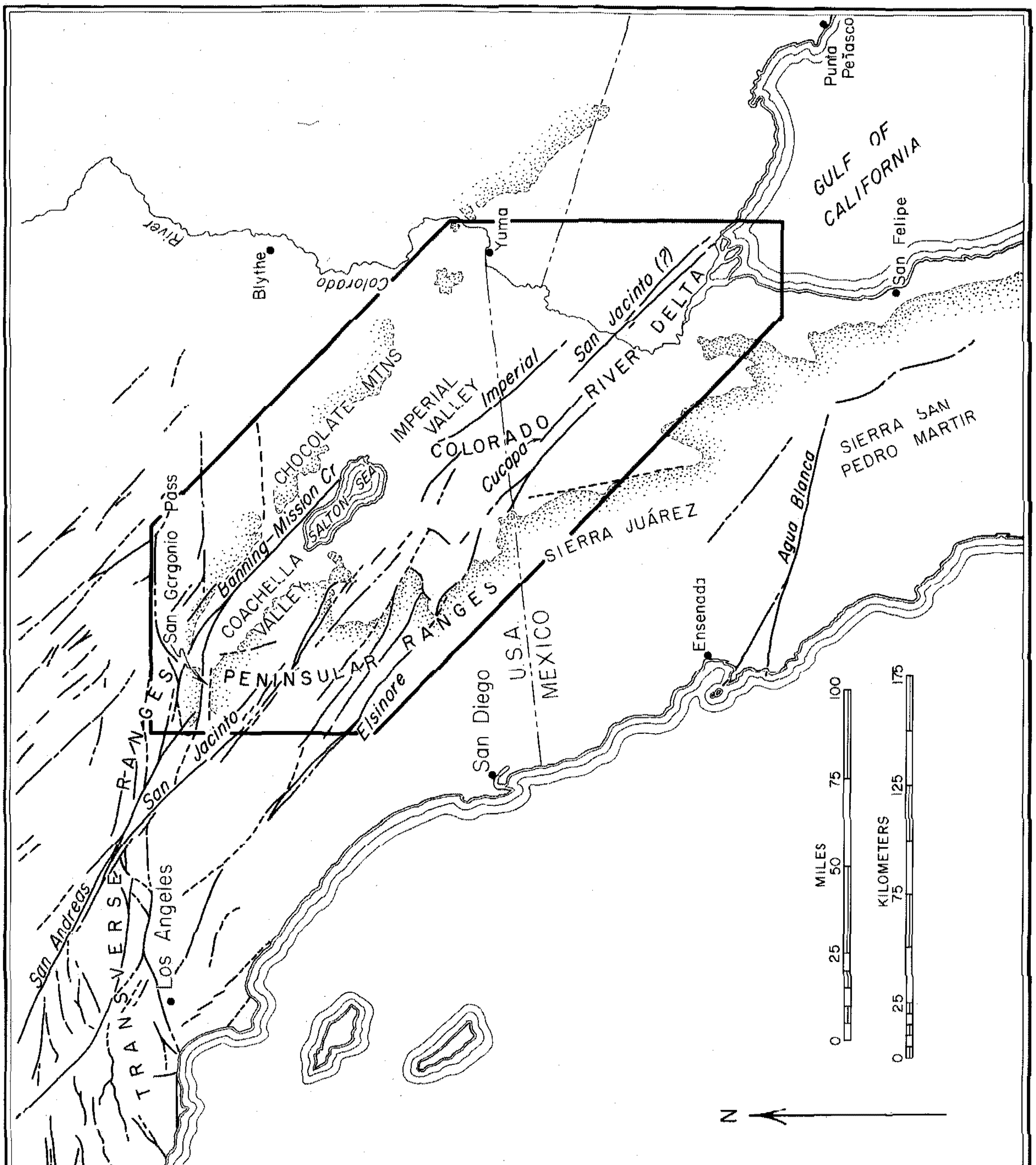

FIGURE 1. Index map of the Salton trough showing names of principal faults. Stippling indicates pre-Tertiary crystalline rocks.

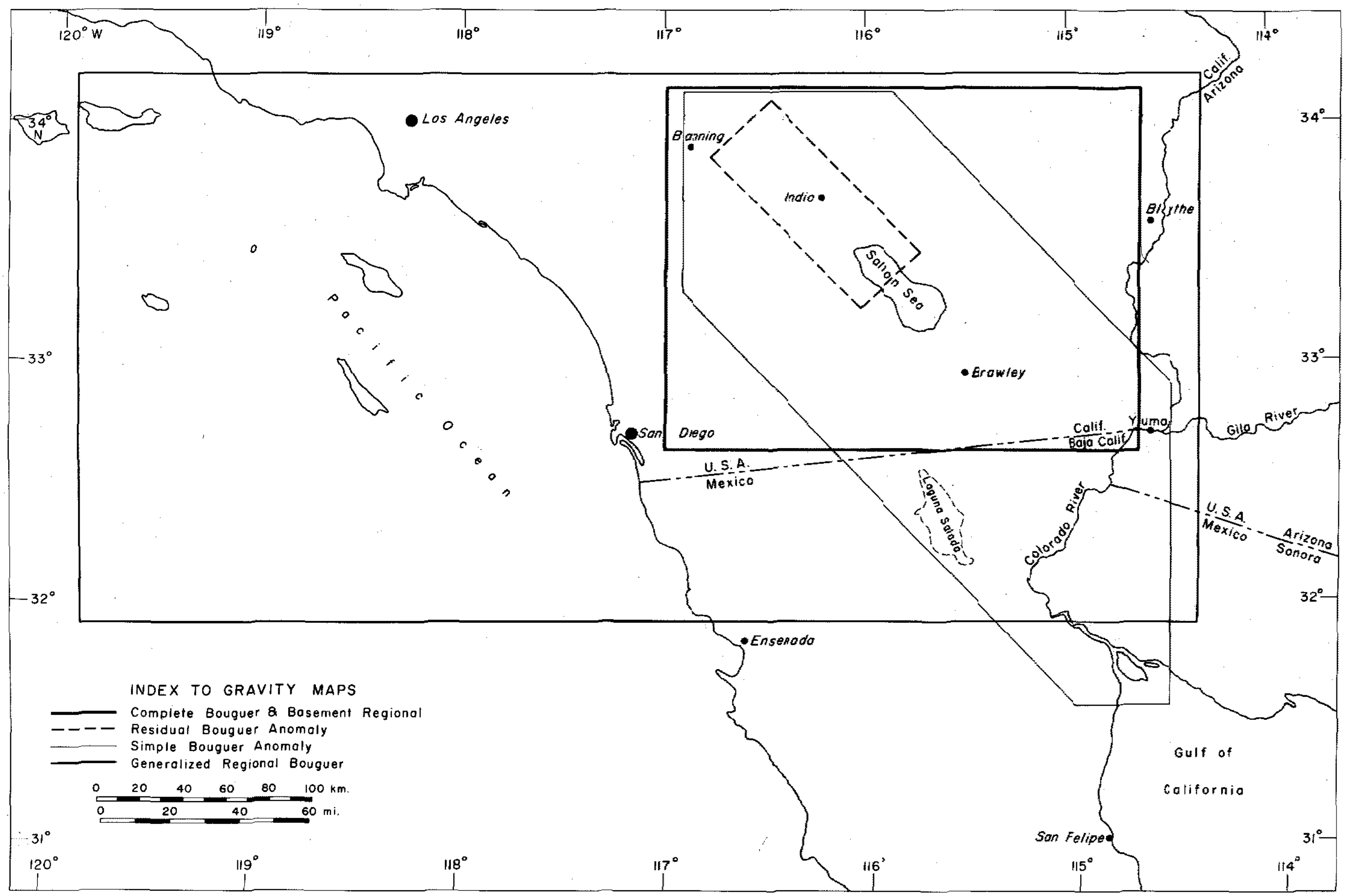

FIGURE 2. Index to gravity maps.

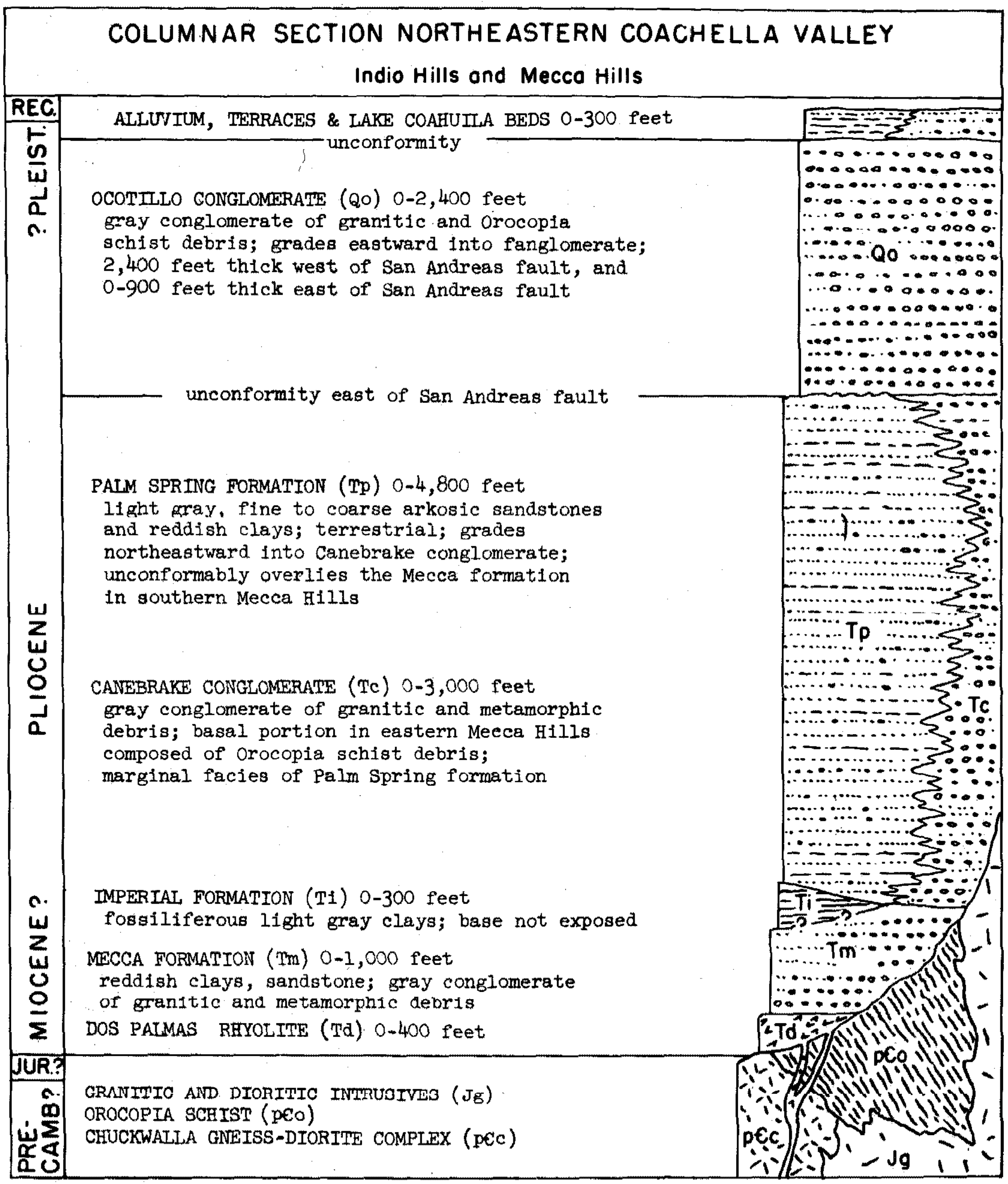

FIGURE 3. Columnar section for northeastern Coachella Valley.
Reproduced from Dibblee (1954)

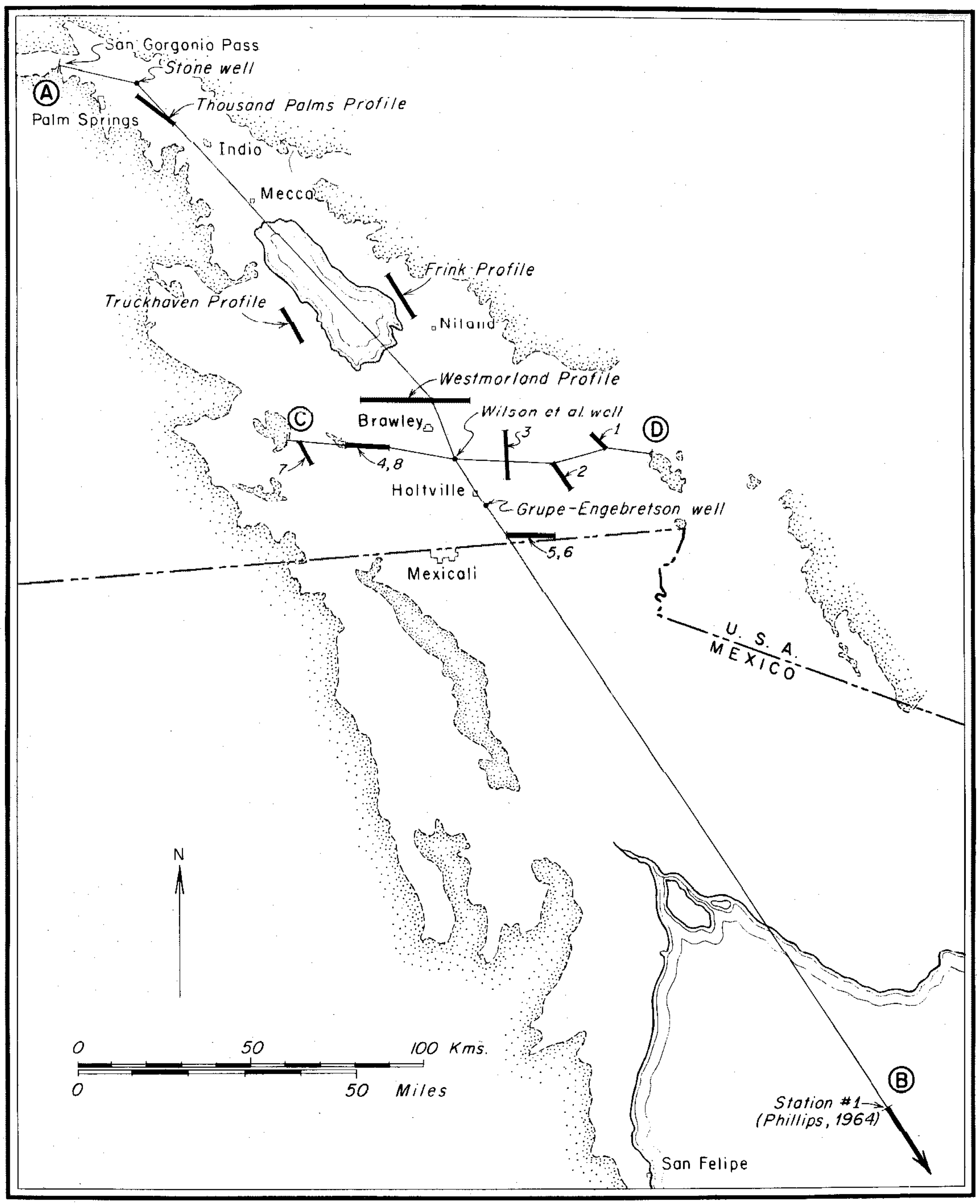

FIGURE 4. Index map of Salton trough showing locations of seismic profiles and cross-section lines A-B (Figure 6) and C-D (Figure 5).

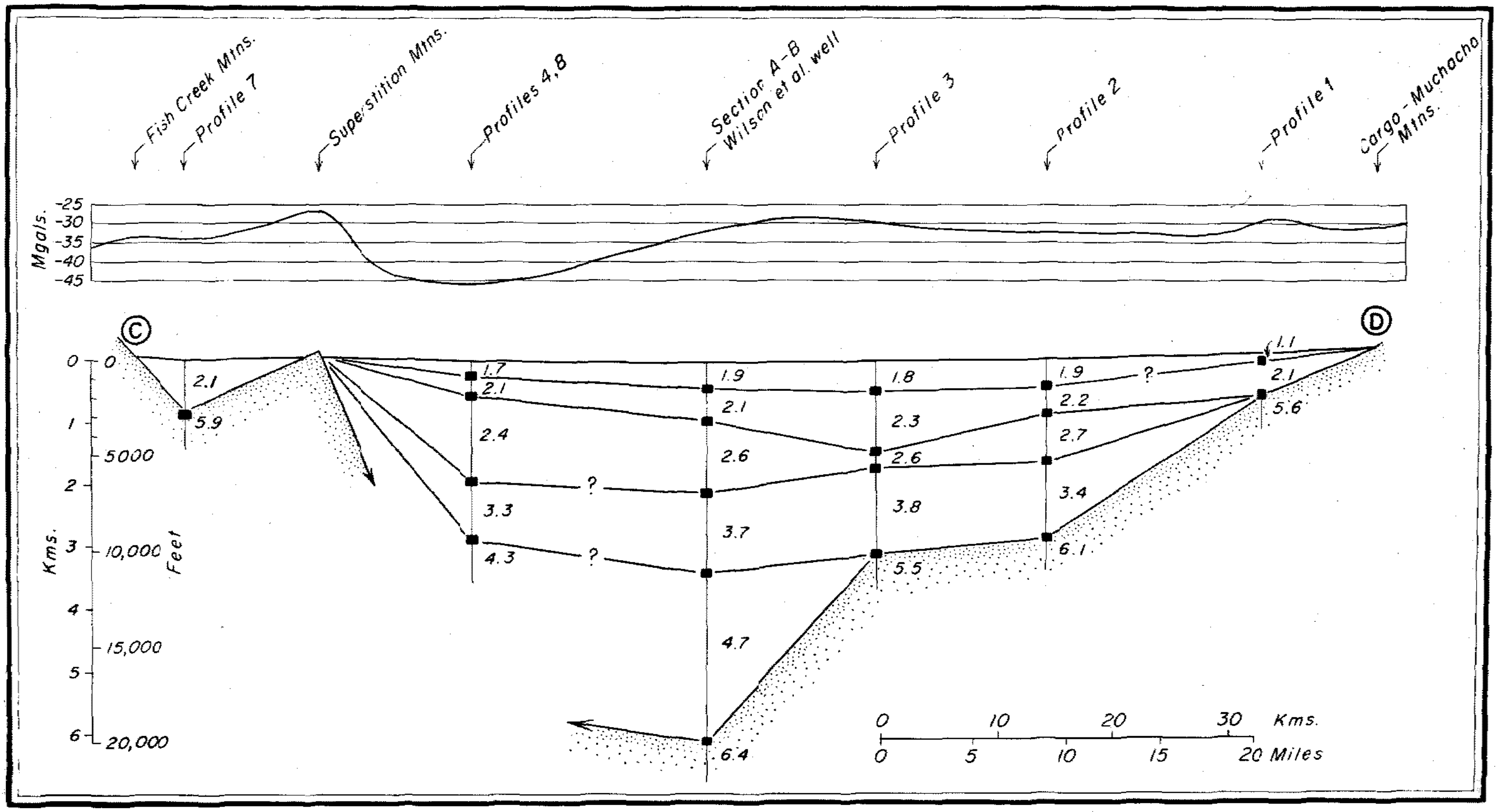

FIGURE 5. Seismic cross-section and simple Bouguer gravity profile along line C-D of Figure 4. Numbers indicate velocities in km/sec.

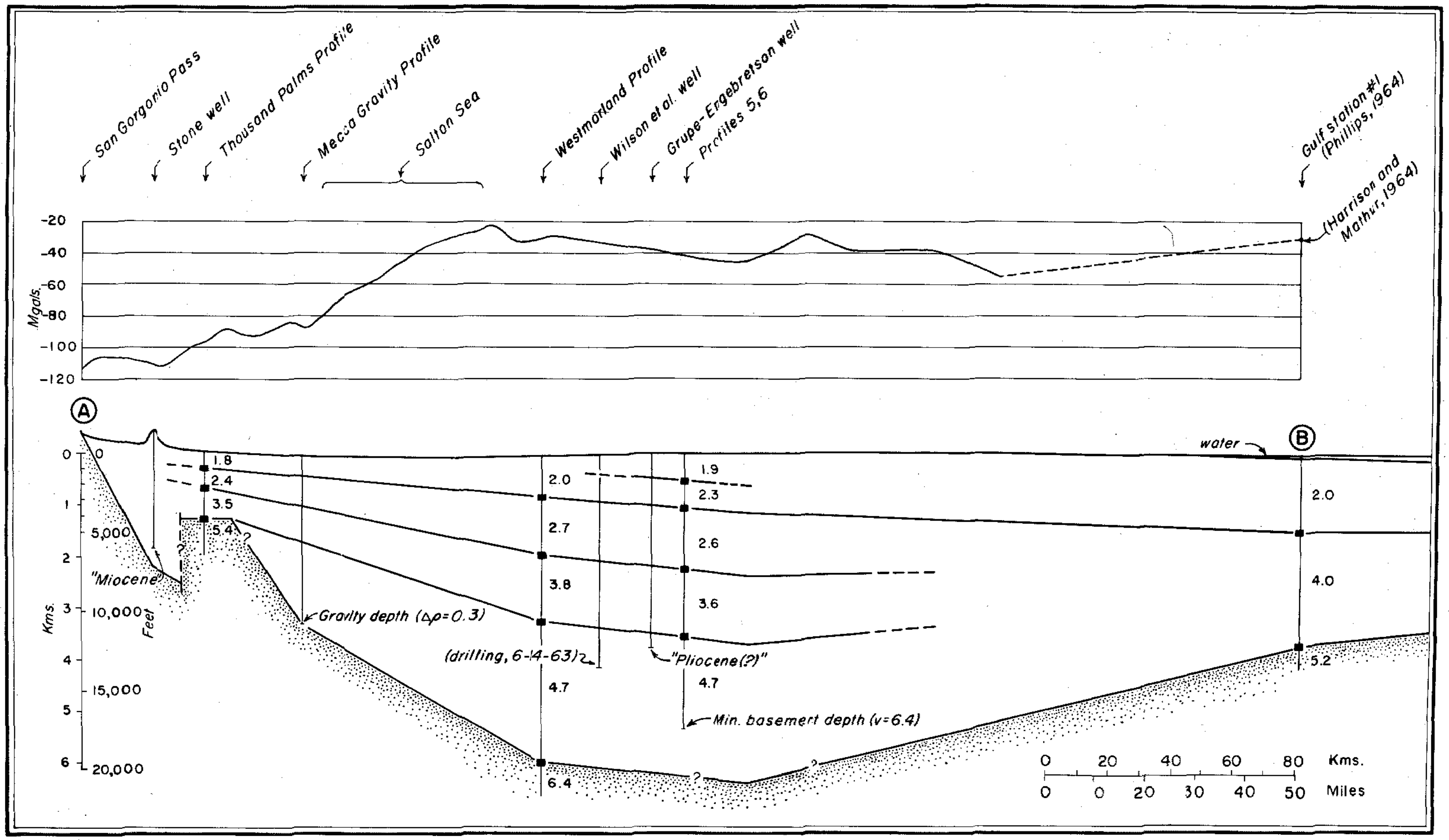

FIGURE 6. Seismic cross-section and simple Bouguer gravity profile along line A-B of Figure 4. Numbers indicate velocities in km/sec.

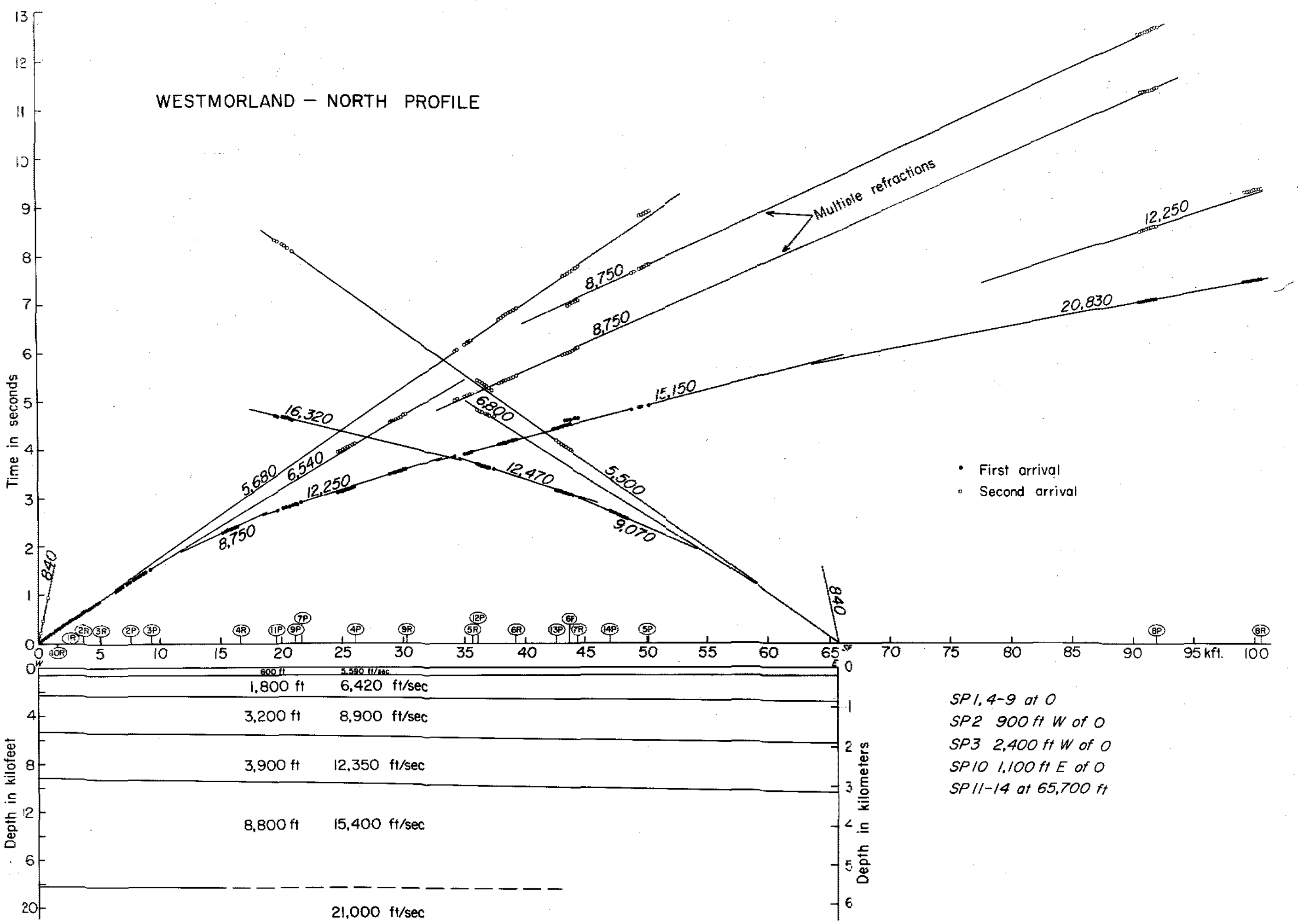

FIGURE 7. Westmorland-North seismic refraction profile.

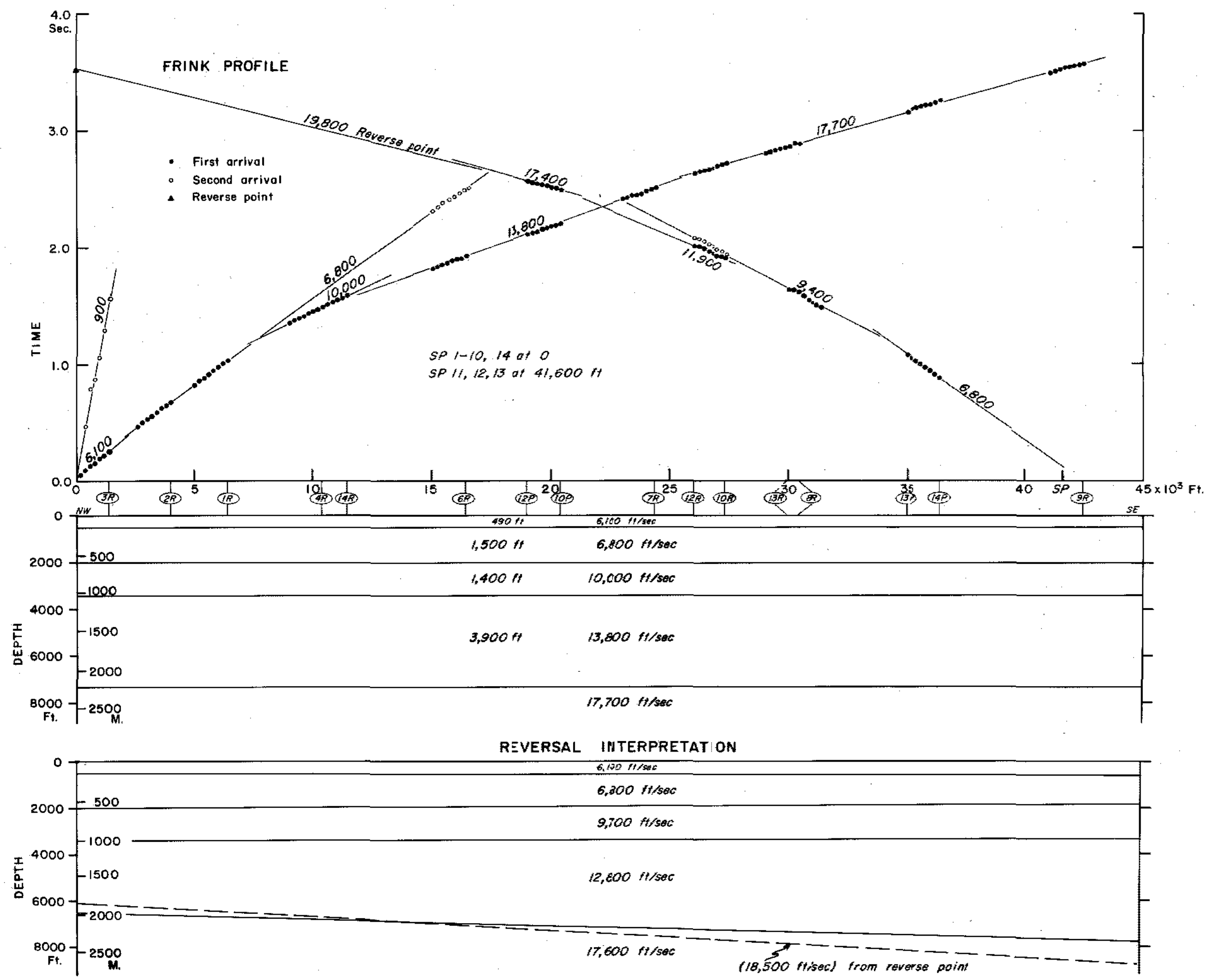

FIGURE 8. Frink seismic refraction profile.

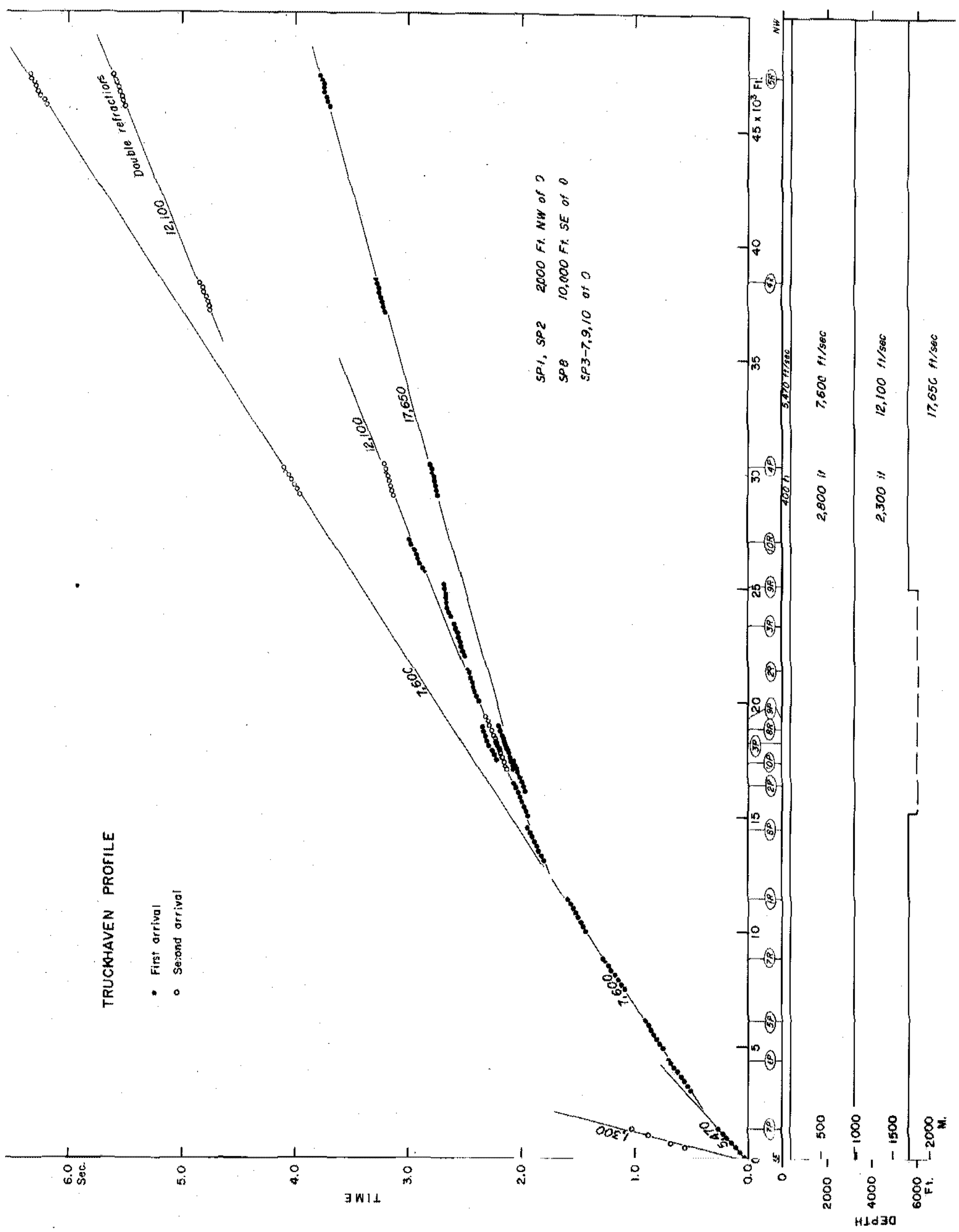

FIGURE 9. Truckhaven seismic refraction profile.

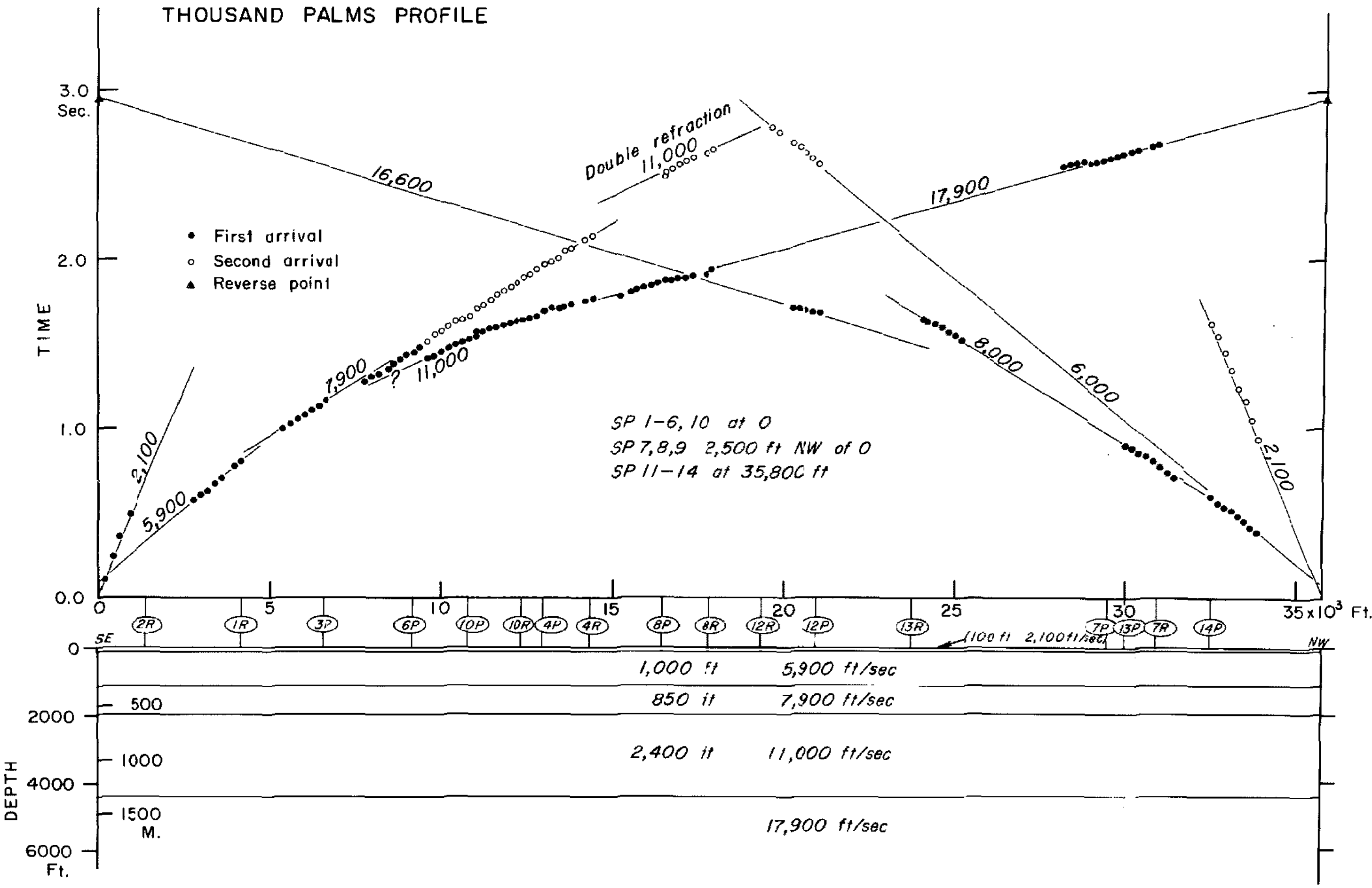

FIGURE 10. Thousand Palms seismic refraction profile.

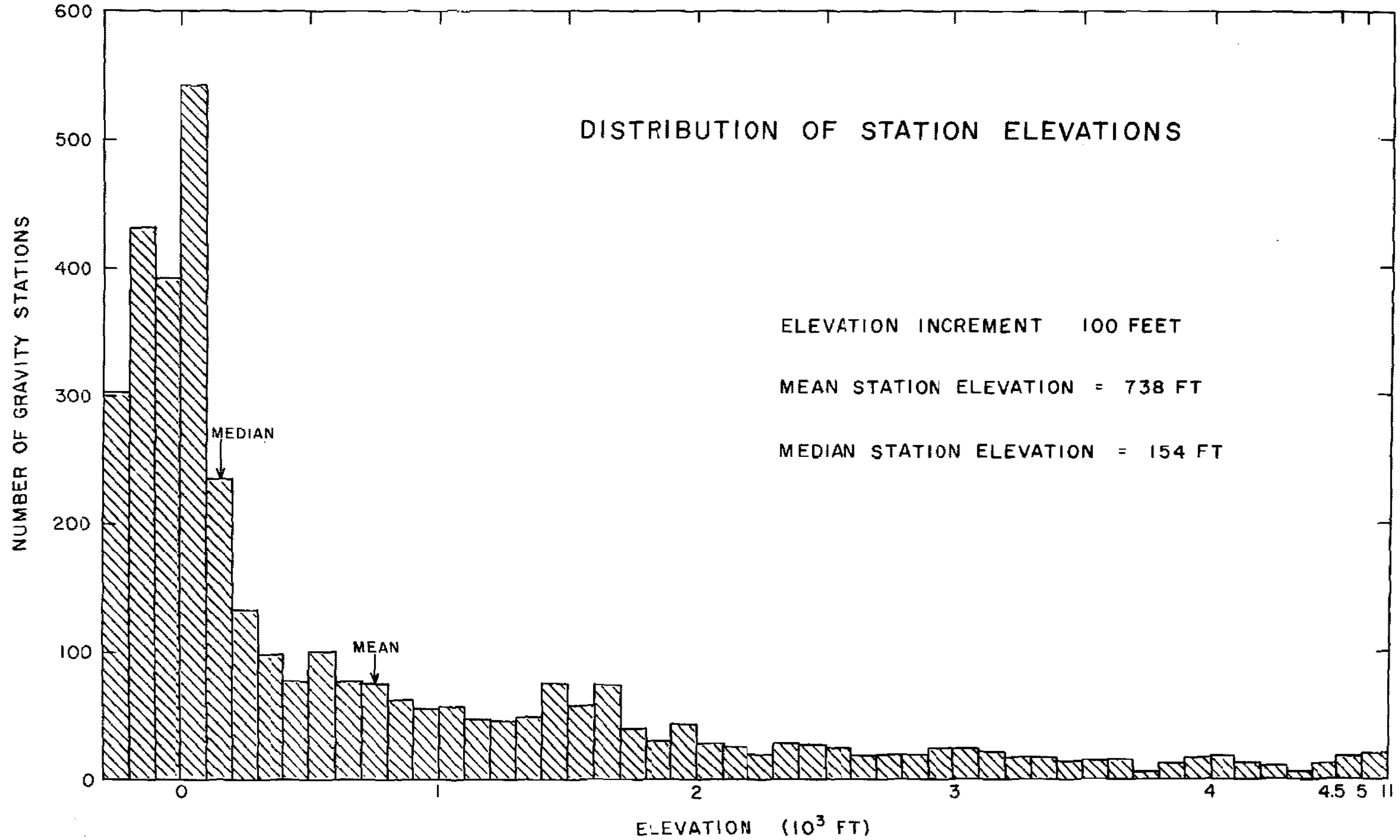

FIGURE 11. Distribution of gravity station elevations for 100 foot increments. Note change in scale at right end of figure.

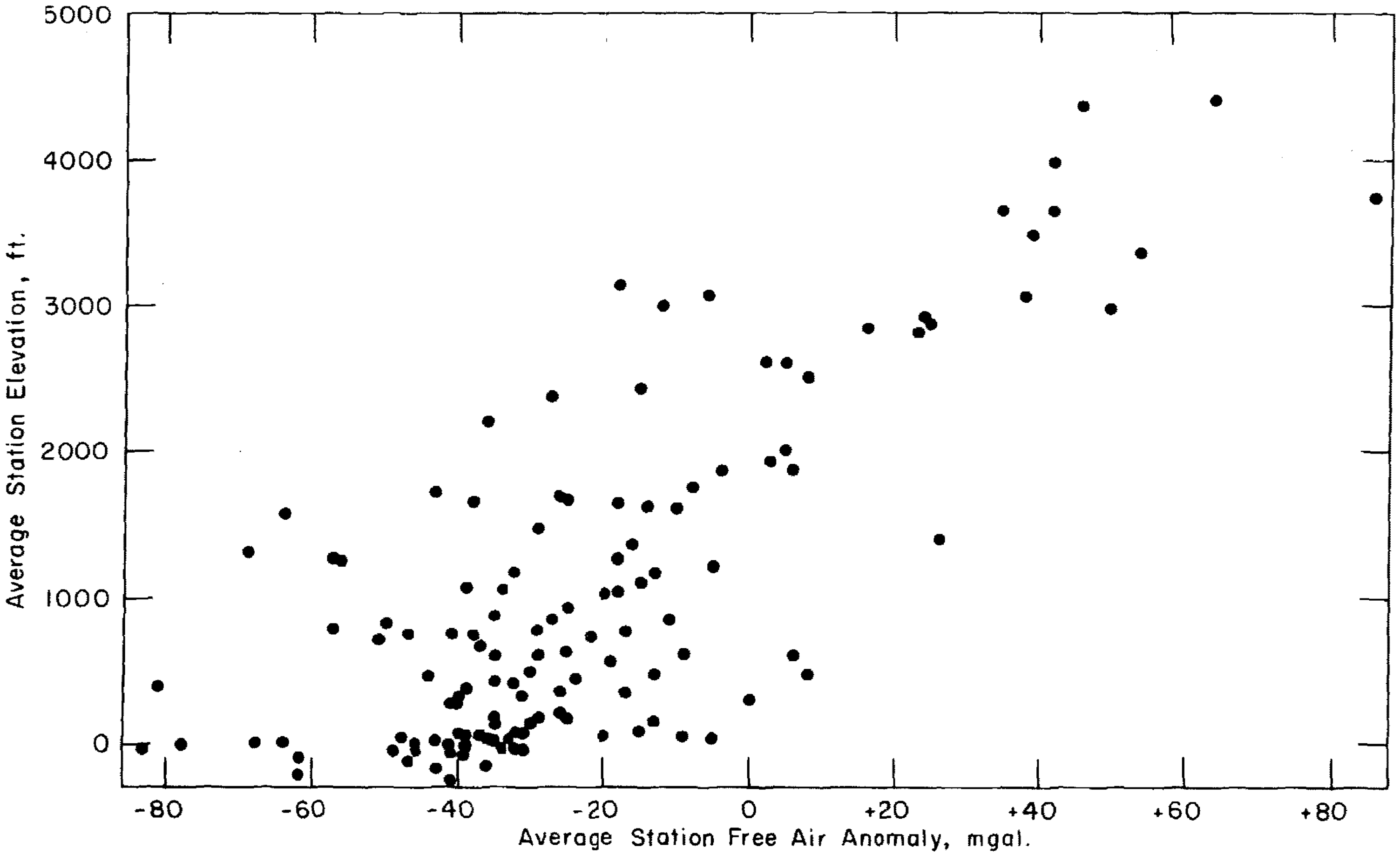

FIGURE 12. Relation of average station free air anomalies to average station elevation.

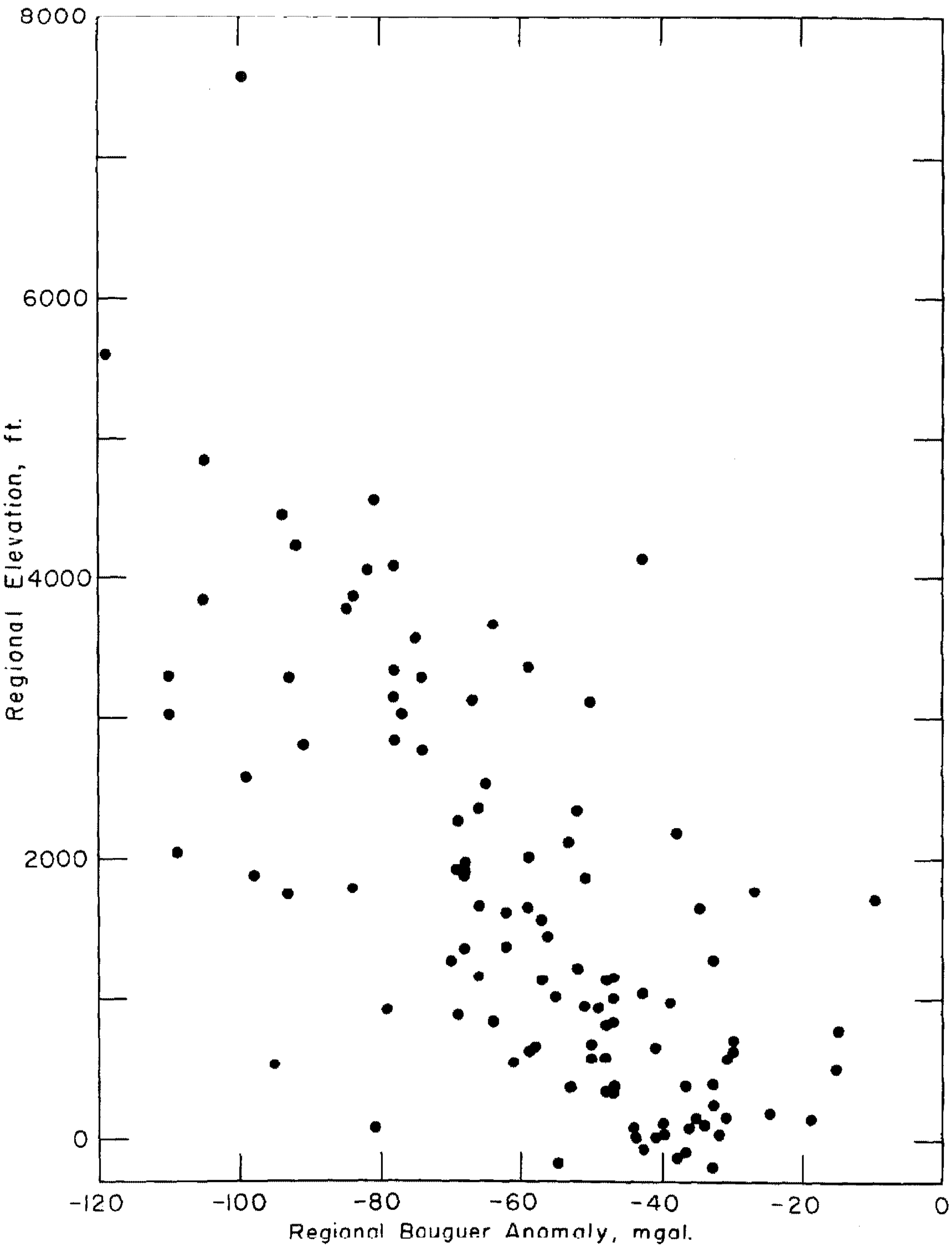

FIGURE 13. Relation of regional Bouguer anomalies and regional elevations. Based on machine computed complete Bouguer anomaly map.

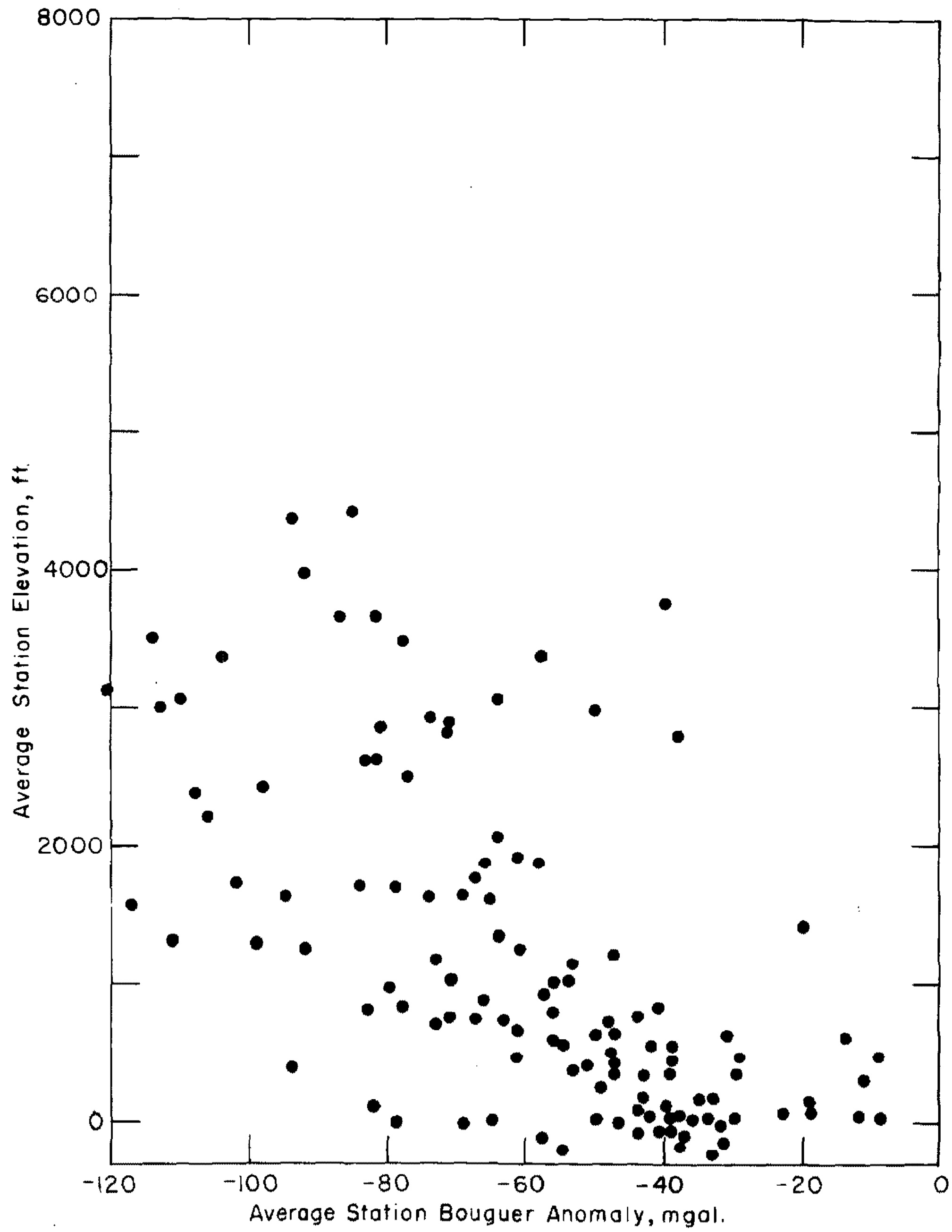

FIGURE 14. Relation of average station Bouguer anomalies and average station elevation.

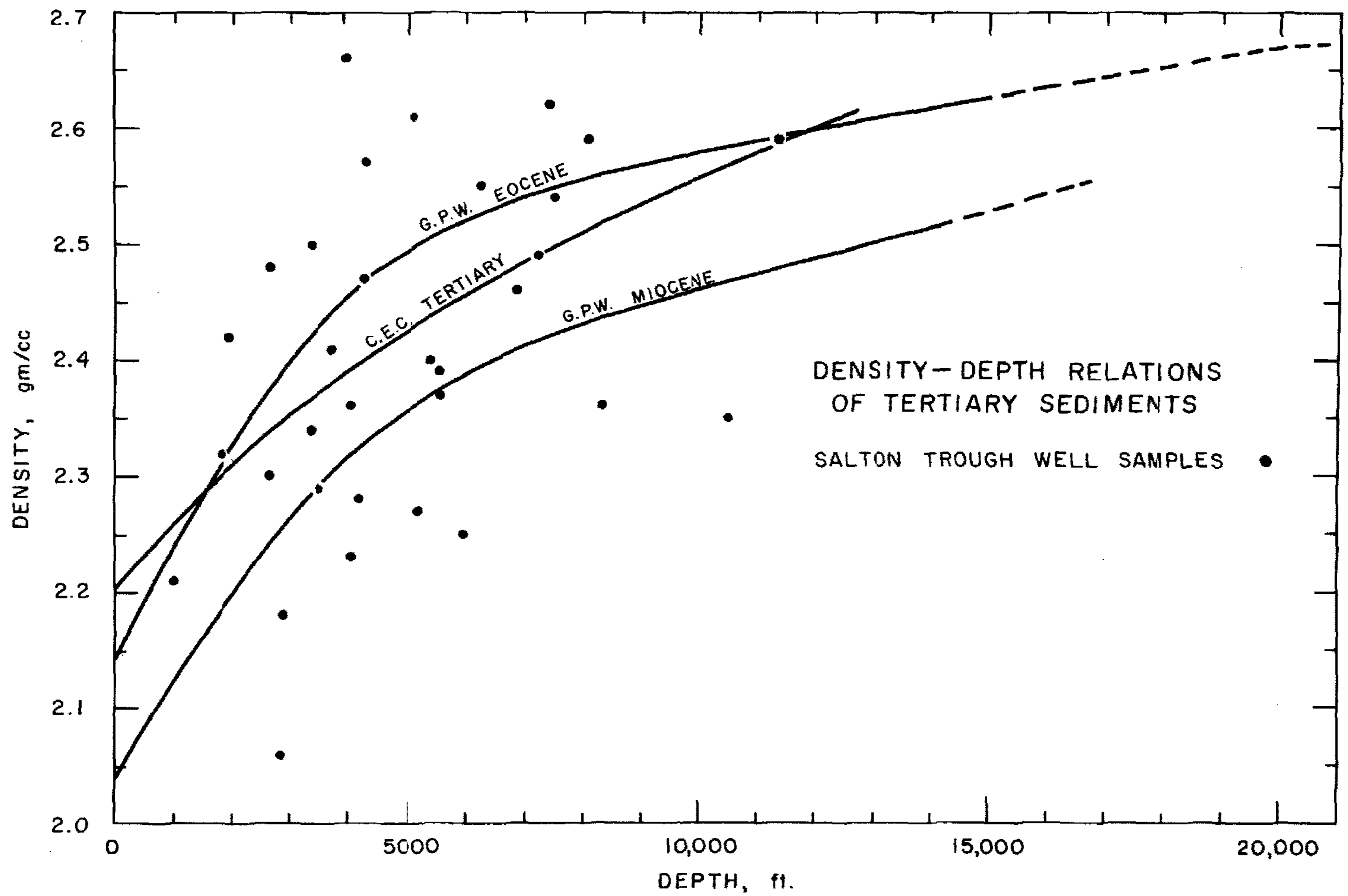

FIGURE 15. Density-depth relations of Tertiary sediments, after Woollard (1962) and Corbato (1963).

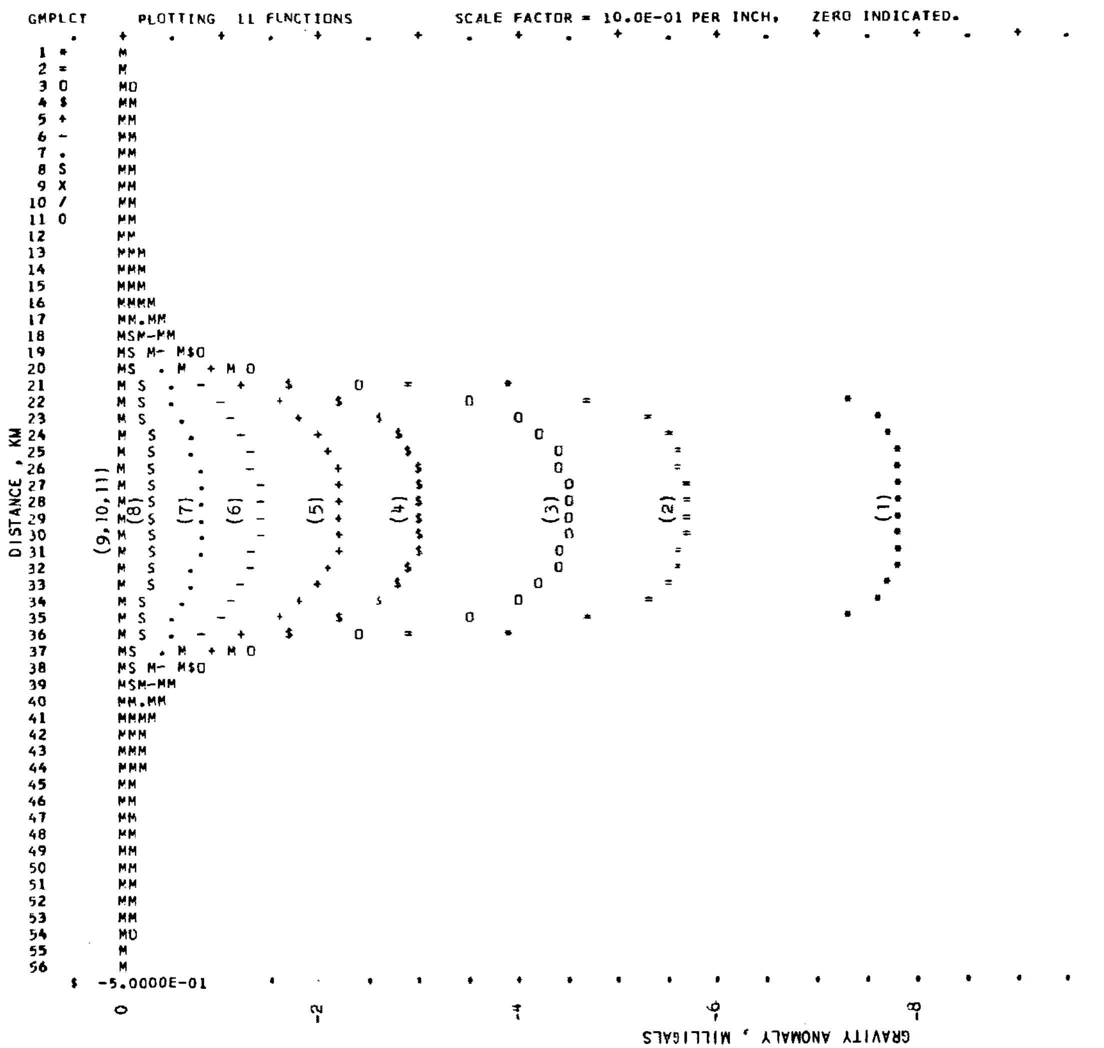

FIGURE 16. GRAVITY ANOMALIES FROM 11 SLABS OF BASIN 1.
M indicates coincidence of two or more points.

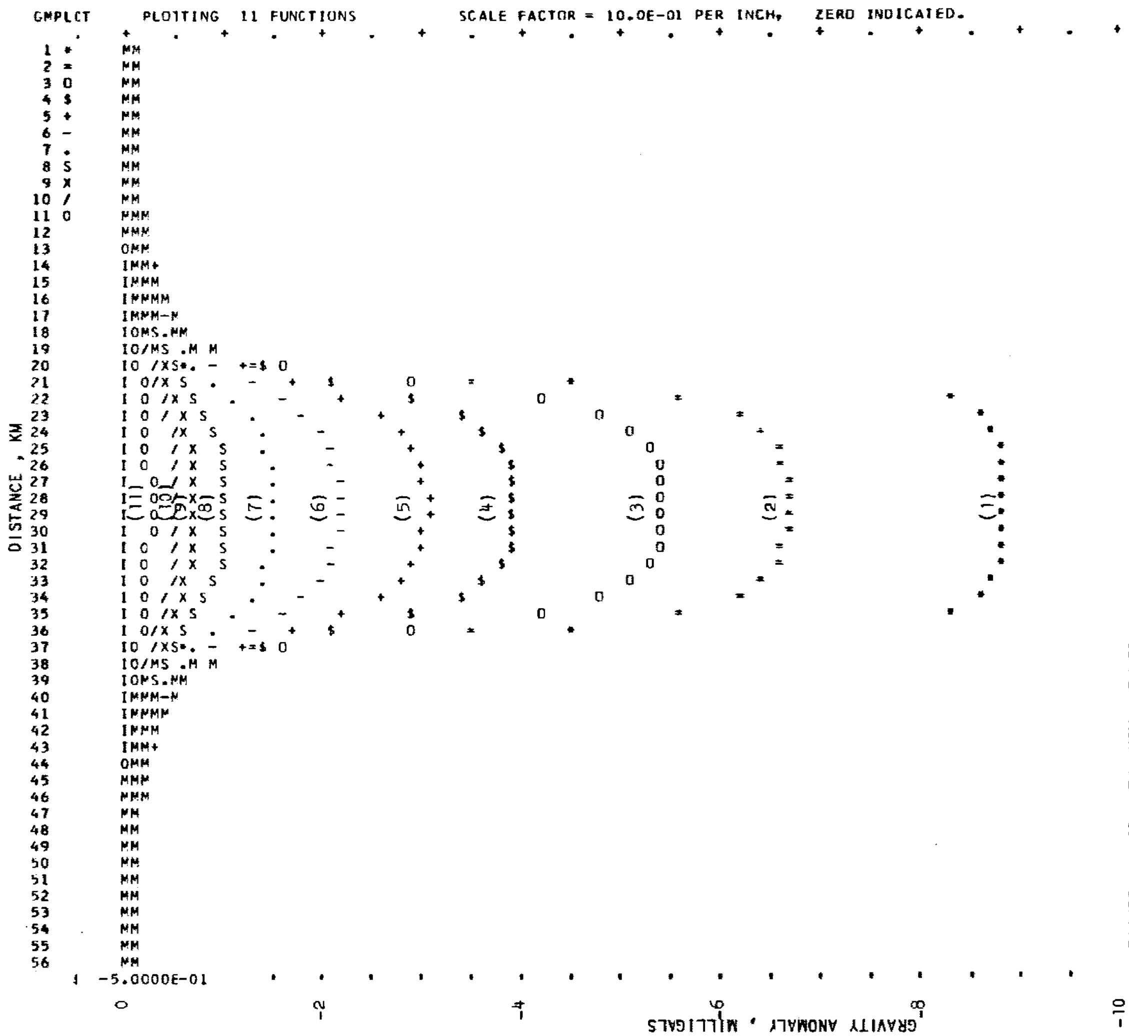

FIGURE 17. GRAVITY ANOMALIES FROM 11 SLABS OF BASIN 2.

M indicates coincidence of two or more points.

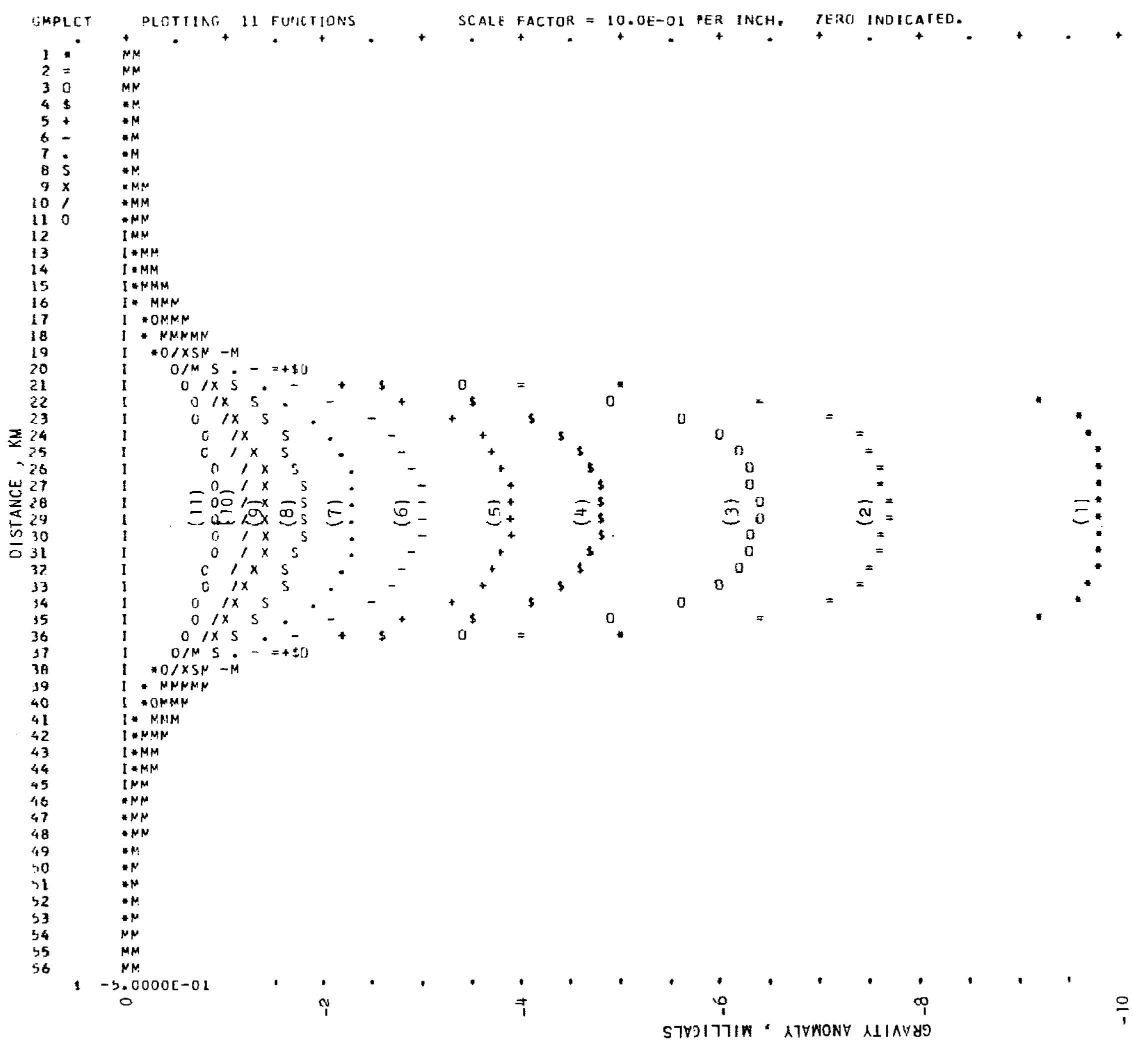

FIGURE 18. GRAVITY ANOMALIES FROM 11 SLABS OF BASIN 3

M indicates coincidence of two or more points.

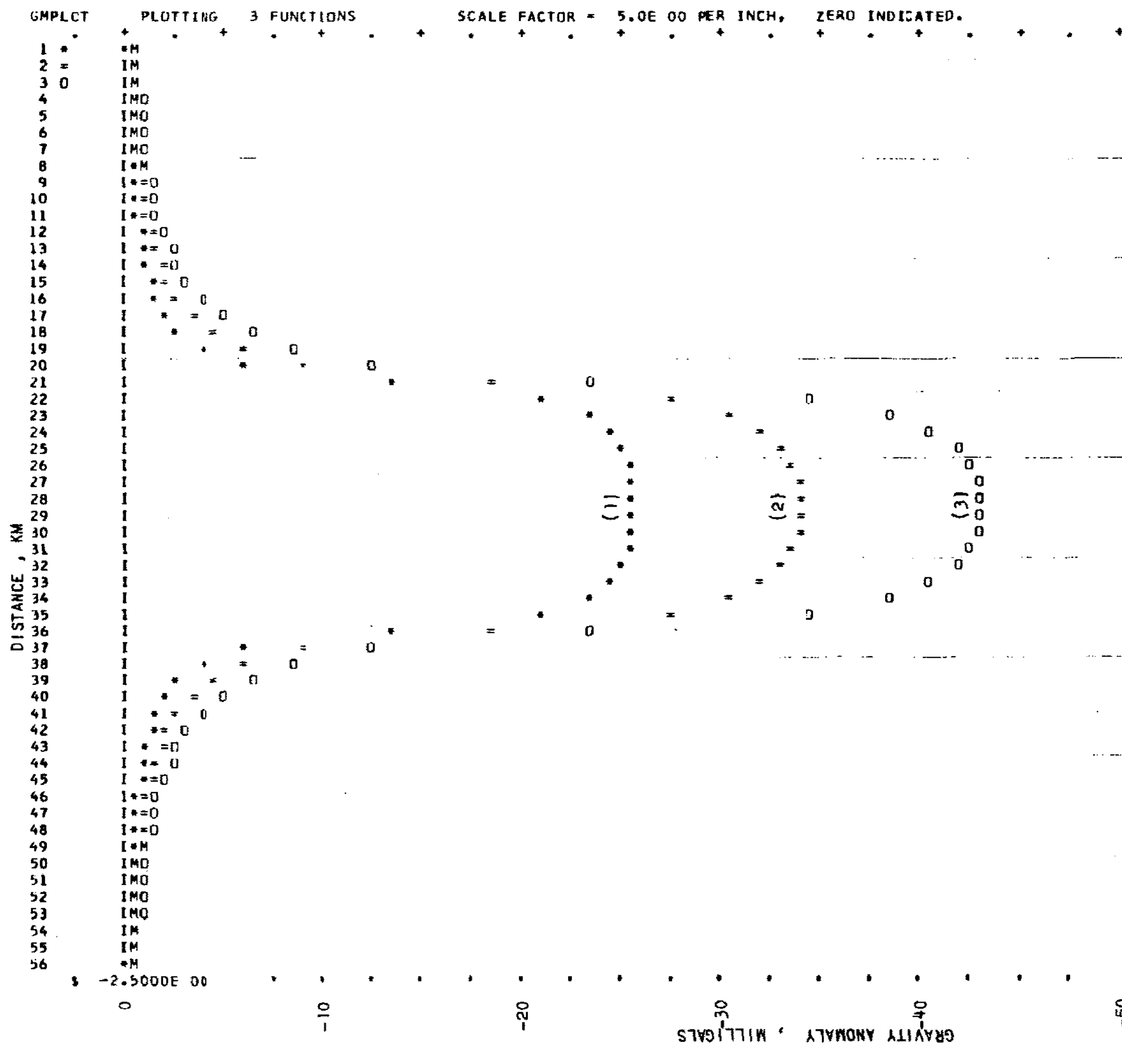

FIGURE 19. TOTAL GRAVITY ANOMALY FOR BASINS 1, 2, and 3. SUM OF 11 SLABS

M indicates coincidence of two or more points

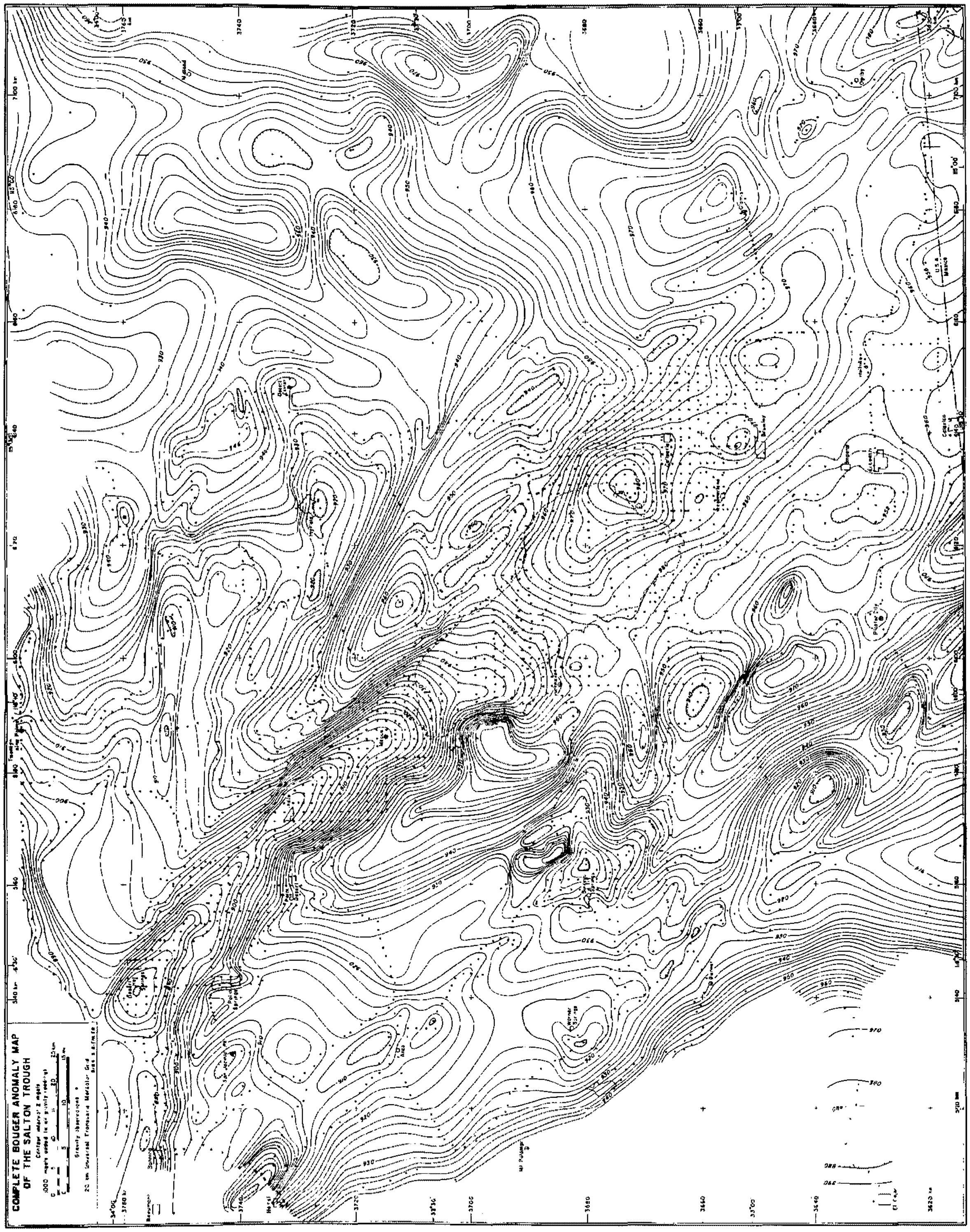

FIGURE 20.

FIGURE 21. Stippling indicates pre-Tertiary crystalline rocks. Seismic profiles with depths to basement(solid)or lowest layer(open) Wells shown with depth to bottom. Basement wells solid.

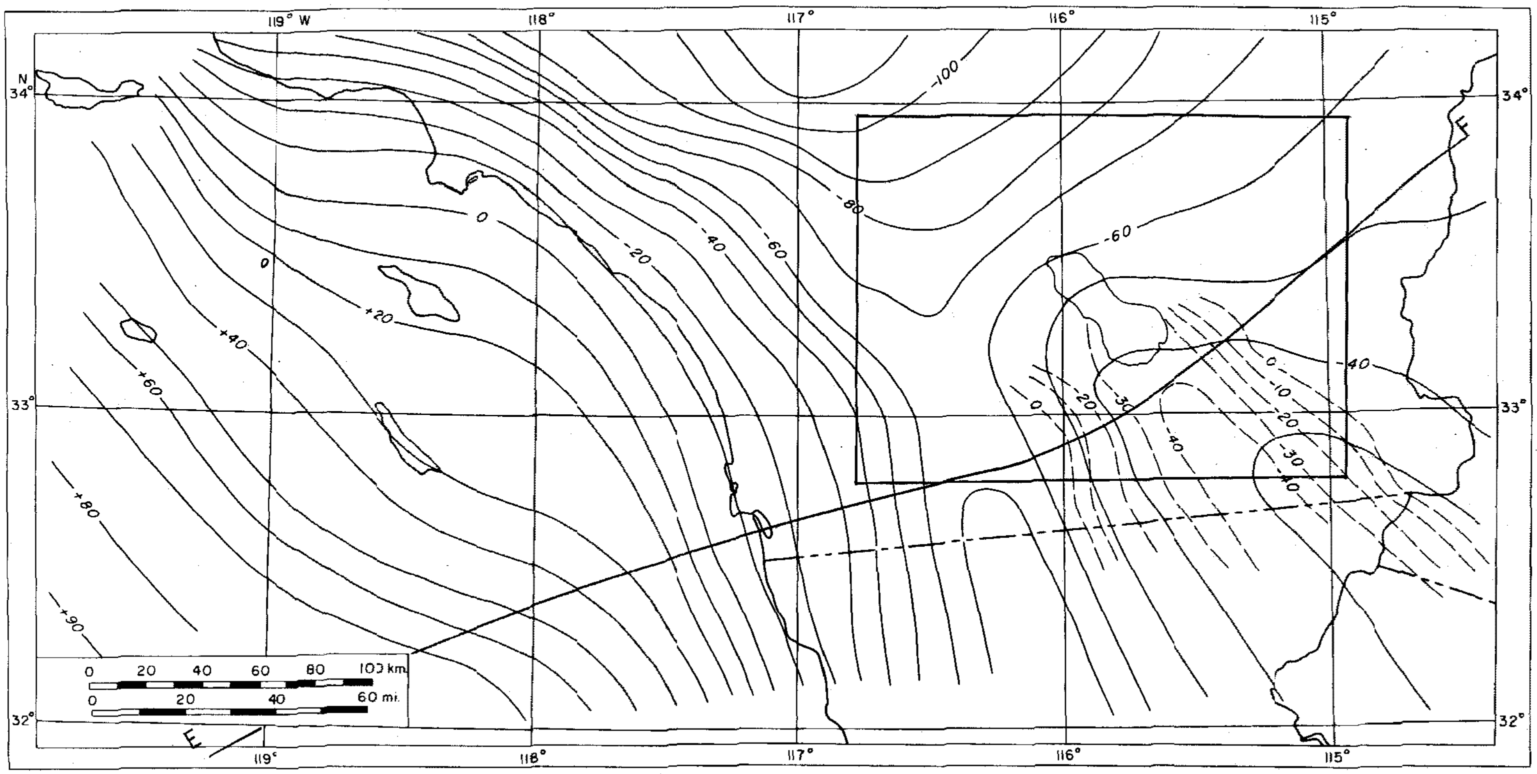

FIGURE 22. Regional Bouguer anomaly map of southern California. Contour interval 10 mgal. Enclosed area is covered by computer map (Figure 26). Regional gravity profile shown by line E - F (Figure 28). Dashed contours represent approximate gravity anomaly of Imperial Valley sediments.

GRAVITY INTERPRETATION OF THE COACHELLA VALLEY.

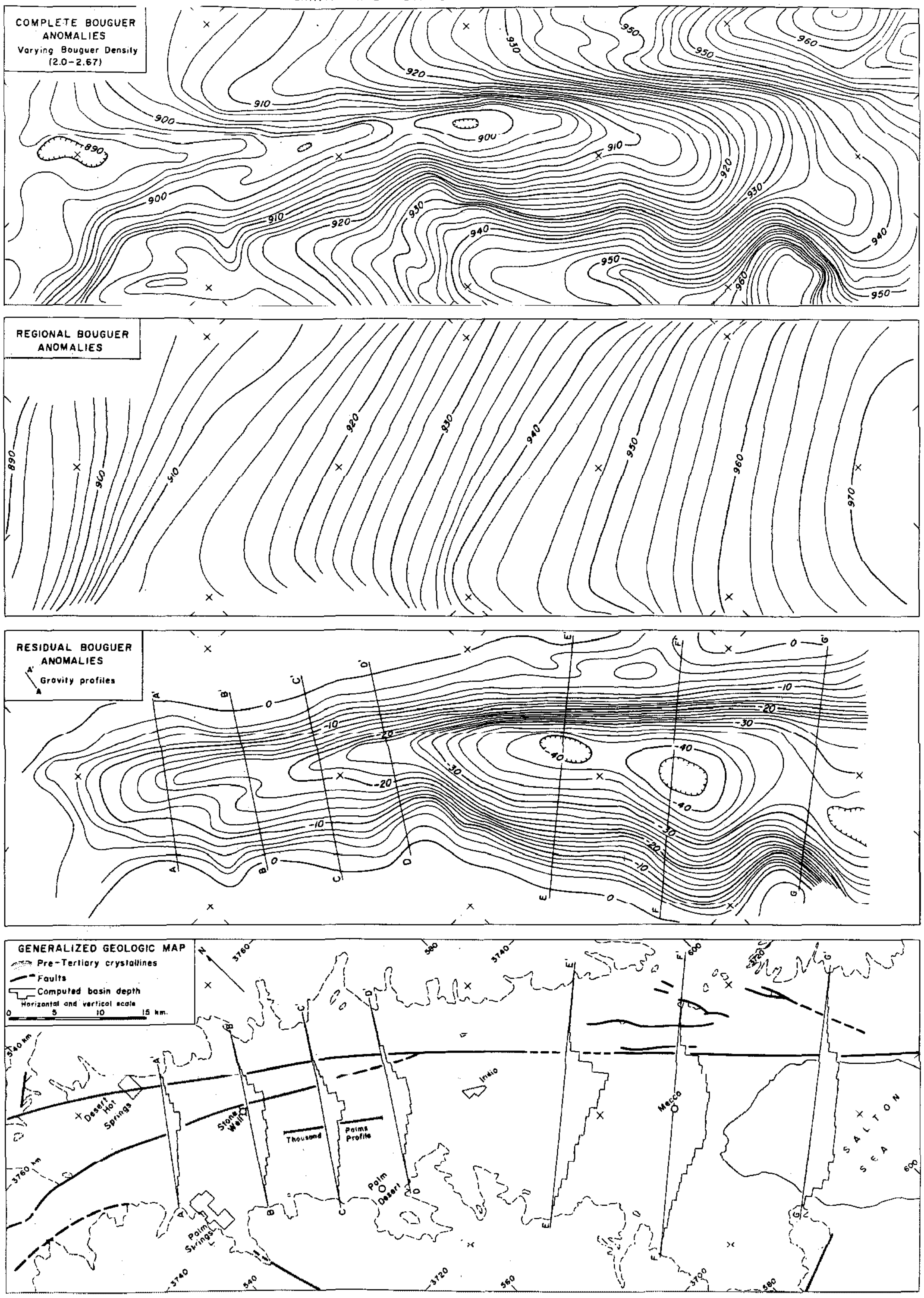

FIGURE 23.

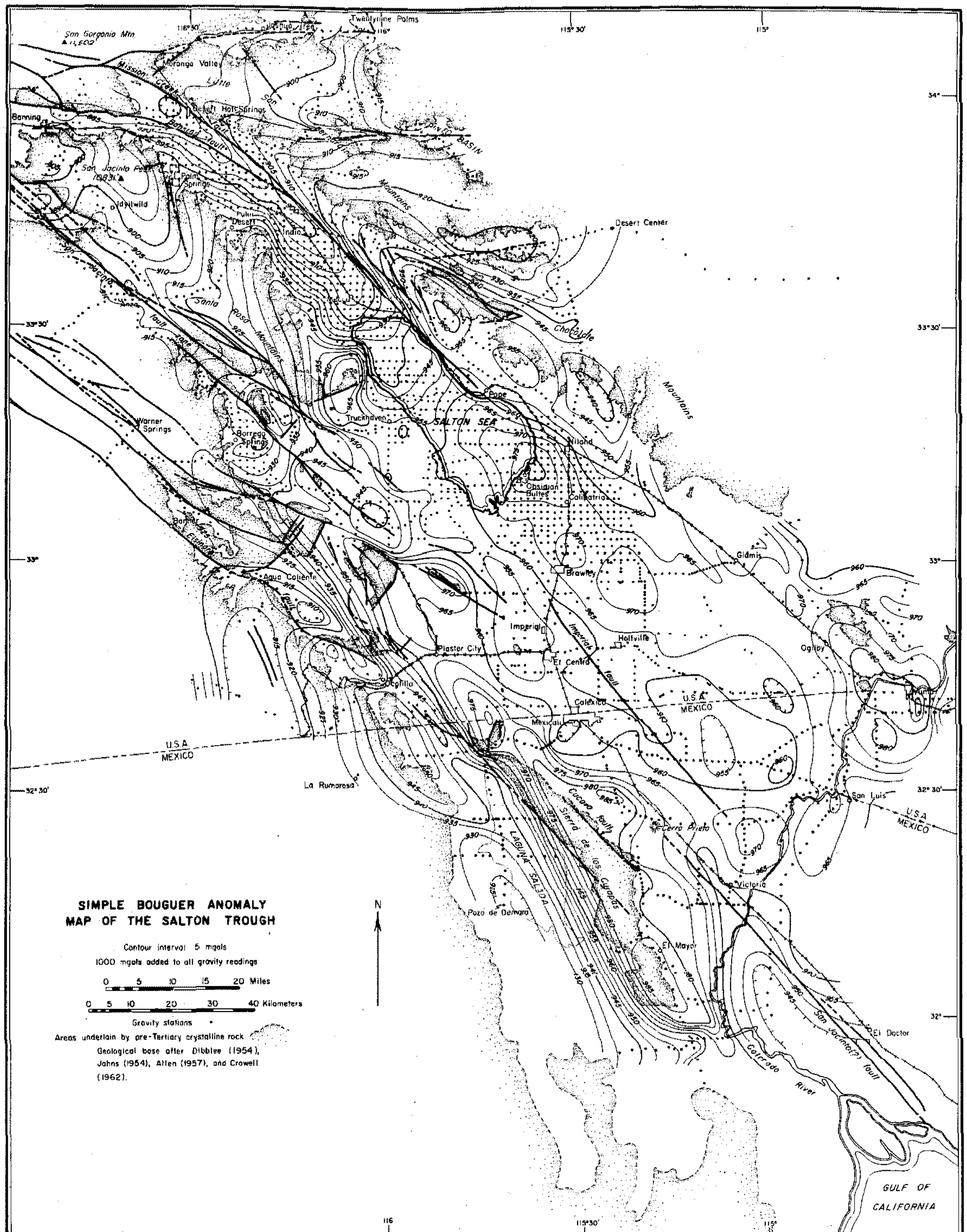

FIGURE 24. Simple Bouguer map of the Salton trough (Biehler et al, 1964)

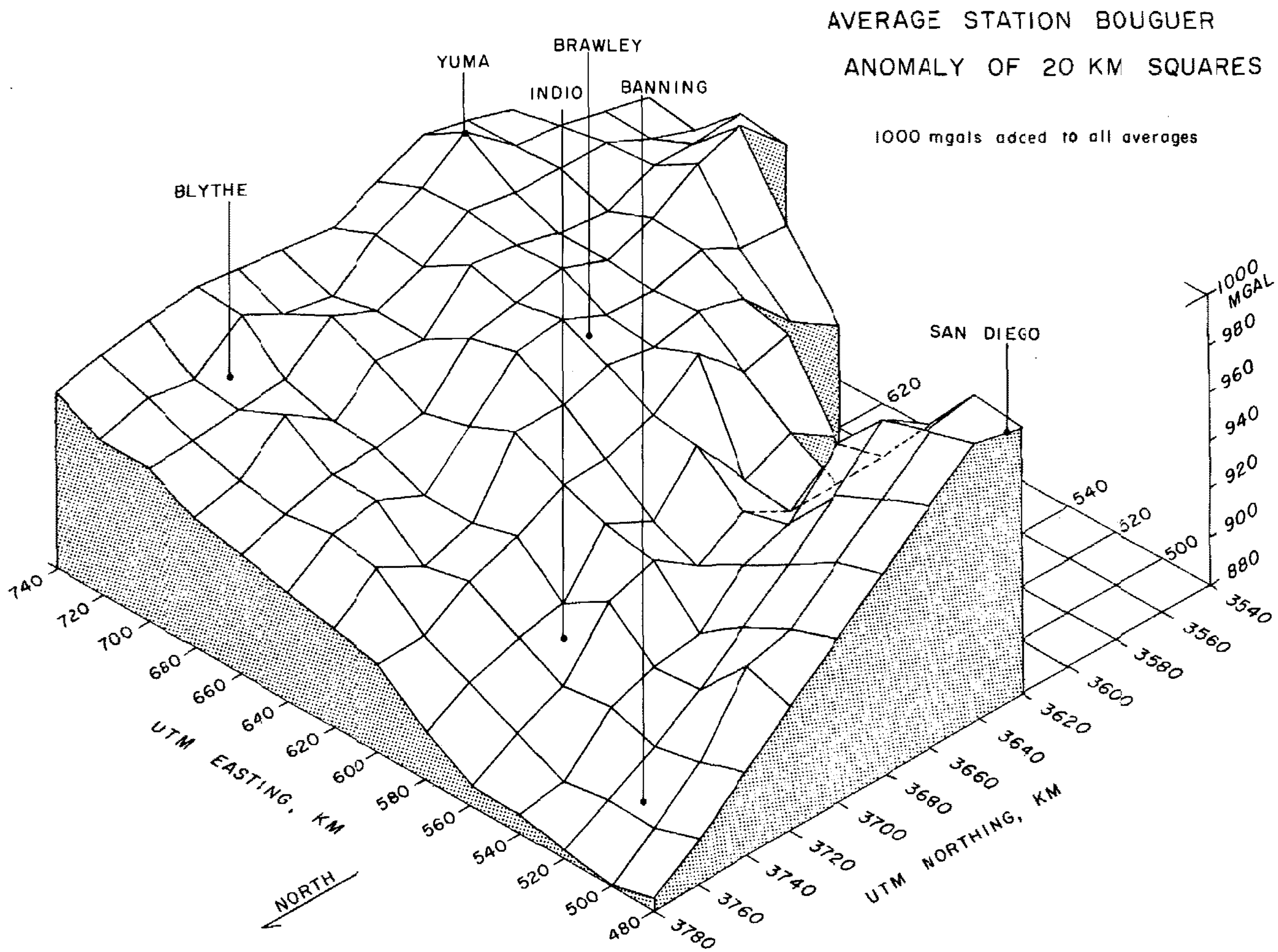

FIGURE 25. Average station Bouguer anomalies for 20 km squares.

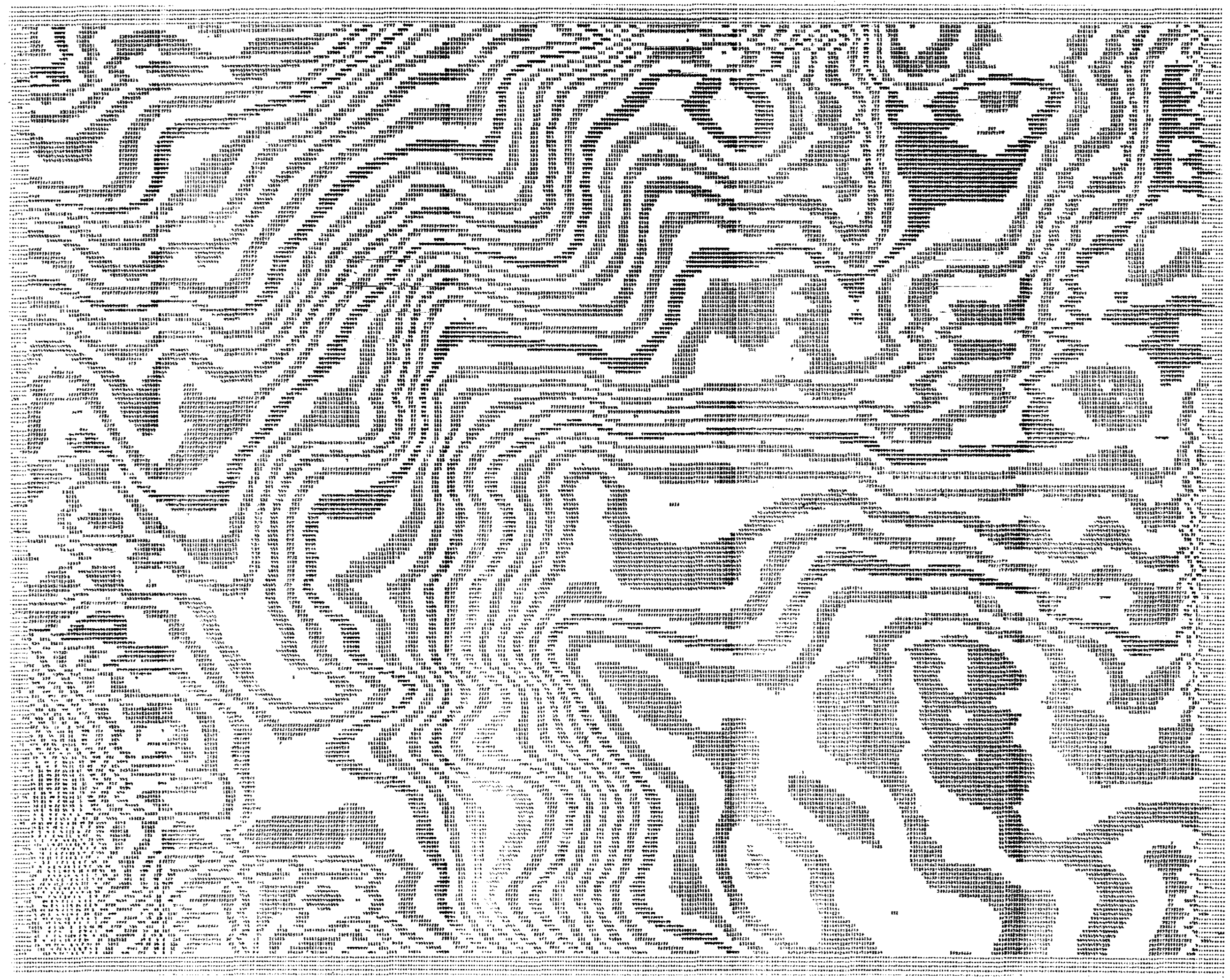

FIGURE 26. Computer contouring of the regional Bouguer anomalies. Contour interval 1 milligal, even numbered contours left blank. Contour value at northwest corner = 887 mgal (-113 mgal). 1000 mgal added to all contours.

BOUGUER ANOMALY GRAVITY MAP BY PARABOLIC INTERPOLATION OF THE SALTON TROUGH AREA OF SOUTHERN CALIFORNIA SHEET 1
SCALE. 1 INCH = 4.0 KM

	(500.0)	.	.	.	.	(520.0)	.	.	.	.	(540.0)
3740.	895.9	889.4	902.1	901.9	905.9	906.8	908.3	903.2	905.1	915.9	913.4
	67,20	81,20	107,20	122,20	130,20	142,20	160,20	168,20	173,20	202,20	223,20
.	900.8	890.9	894.3	899.1	906.2	907.8	908.1	906.9	910.5	914.1	914.4
	74,20	89,20	65,15	124,20	134,20	141,20	155,20	156,20	165,20	189,20	103,15
3736.	914.0	903.4	886.5	892.2	901.8	907.2	908.6	910.2	911.7	913.7	913.8
	59,20	75,20	58,15	110,20	120,20	129,20	130,20	137,20	144,20	152,20	186,20
.	916.8	901.0	889.9	898.0	905.7	908.6	911.3	914.2	912.7	914.5	913.3
	63,20	48,15	62,15	105,20	112,20	110,20	46,15	117,20	129,20	150,20	181,20
3732.	927.8	918.8	902.3	899.0	905.8	907.5	911.1	913.2	913.9	913.5	915.9
	52,20	65,20	81,20	90,20	100,20	101,20	102,20	108,20	111,20	129,20	162,20
.	929.3	916.0	911.8	906.5	908.6	909.9	913.2	913.0	913.1	914.9	918.5
	53,20	70,20	84,20	94,20	100,20	101,20	101,20	97,20	114,20	141,20	152,20
3728.	936.6	925.7	917.6	911.9	911.9	911.3	911.1	912.4	912.5	913.4	917.0
	49,20	56,20	77,20	85,20	102,20	103,20	94,20	86,20	90,20	119,20	140,20
.	933.4	927.7	918.8	916.2	913.6	912.3	912.3	912.7	912.7	914.7	919.4
	52,20	59,20	78,20	93,20	104,20	101,20	81,20	84,20	98,20	124,20	138,20
3724.	935.6	935.3	929.4	920.8	917.3	913.9	912.4	912.3	912.1	913.8	916.5
	48,20	55,20	68,20	88,20	97,20	103,20	88,20	82,20	83,20	99,20	119,20
.	933.5	935.9	927.6	921.3	917.1	913.4	911.7	911.1	913.3	915.1	919.5
	48,20	63,20	78,20	90,20	98,20	88,20	82,20	82,20	82,20	96,20	112,20
3720.	923.5	931.7	938.0	926.5	920.8	915.9	912.7	910.7	910.6	914.1	917.1
	42,20	56,20	68,20	82,20	91,20	85,20	86,20	77,20	76,20	81,20	89,20
.	927.5	936.2	932.4	925.0	919.0	914.8	912.2	909.4	911.1	916.1	921.0
	46,20	63,20	75,20	86,20	77,20	80,20	78,20	72,20	72,20	75,20	79,20
3716.	943.6	937.4	935.6	928.4	922.7	917.4	913.9	909.4	907.3	912.9	917.4
	34,20	51,20	69,20	74,20	73,20	82,20	82,20	50,15	70,20	69,20	67,20
.	938.1	938.5	932.6	925.5	920.5	916.3	913.4	910.5	908.6	914.5	921.3
	40,20	49,20	61,20	63,20	78,20	78,20	78,20	67,20	68,20	47,15	69,20
3712.	938.8	939.9	936.9	929.7	922.9	918.9	915.9	913.2	912.2	910.7	917.6
	22,20	40,20	44,20	49,20	68,20	77,20	81,20	78,20	67,20	67,20	66,20
.	938.6	939.6	934.7	926.1	921.2	917.8	915.3	912.6	912.6	913.4	920.8
	24,20	34,20	45,20	50,20	71,20	76,20	80,20	78,20	64,20	67,20	68,20
3708.	938.3	941.8	938.2	930.5	923.9	919.4	917.2	913.9	911.2	912.1	916.8
	20,20	26,20	39,20	47,20	58,20	68,20	74,20	78,20	78,20	68,20	69,20
.	946.1	942.2	934.6	926.1	922.1	918.4	916.5	911.7	911.2	913.9	917.1
	23,20	28,20	41,20	49,20	58,20	68,20	76,20	75,20	77,20	73,20	66,20
3704.	946.4	945.4	938.5	931.0	926.0	920.9	918.7	914.1	910.9	911.6	916.2
	20,20	26,20	32,20	43,20	54,20	58,20	71,20	75,20	80,20	79,20	46,15
.	946.0	943.6	937.4	930.1	925.2	921.2	917.9	912.7	911.1	915.5	917.8
	21,20	26,20	31,20	42,20	55,20	62,20	74,20	79,20	87,20	78,20	67,20
3700.	945.8	950.0	945.3	938.0	931.2	925.5	921.6	917.0	912.4	913.9	918.2
	18,20	24,20	29,20	33,20	43,20	56,20	65,20	74,20	87,20	87,20	76,20
.	958.0	954.9	946.8	936.4	930.9	926.3	921.9	917.1	914.0	918.3	920.9
	20,20	26,20	31,20	33,20	46,20	59,20	68,20	82,20	85,20	76,20	77,20
3696.	-0.0	966.4	955.8	944.3	935.0	930.8	926.1	922.4	918.8	919.3	921.5
	5,15	27,20	27,20	32,20	36,20	48,20	61,20	72,20	85,20	76,20	73,20
.	-0.0	965.1	951.7	940.2	932.0	928.8	924.6	922.3	921.1	922.2	922.7
	0,10	23,20	27,20	33,20	43,20	53,20	65,20	78,20	76,20	81,20	93,20
3692.	-0.0	-0.0	957.9	945.8	937.0	930.8	927.1	924.0	921.2	920.1	922.4
	2,15	0,10	25,20	30,20	38,20	46,20	53,20	66,20	74,20	74,20	95,20
.	-0.0	-0.0	950.5	946.8	938.2	929.3	926.1	923.0	918.6	919.2	923.1
	3,15	0,10	26,20	36,20	43,20	46,20	57,20	65,20	78,20	94,20	118,20
3688.	-0.0	-0.0	-0.0	957.8	948.1	936.0	926.8	925.6	920.2	917.4	919.2
	0,15	2,15	0,10	30,20	41,20	45,20	47,20	51,20	78,20	86,20	113,20
.	-0.0	-0.0	968.3	957.2	943.2	931.8	923.6	928.0	918.0	917.5	921.8
	0,15	0,15	25,20	39,20	43,20	45,20	47,20	57,20	81,20	112,20	133,20
3684.	-0.0	-0.0	-0.0	965.4	949.2	936.0	924.3	918.5	916.4	918.7	918.1
	0,20	0,15	0,15	32,20	38,20	42,20	46,20	54,20	67,20	95,20	127,20
.	-0.0	-0.0	976.6	955.6	941.5	929.4	921.4	916.5	918.1	917.8	920.0
	0,20	0,15	25,20	36,20	42,20	45,20	53,20	61,20	77,20	115,20	141,20
3680.	-0.0	-0.0	-0.0	966.7	949.9	938.5	929.0	921.0	913.9	917.6	918.8
	0,20	0,20	0,15	30,20	38,20	45,20	52,20	60,20	74,20	93,20	133,20
.	-0.0	-0.0	-0.0	959.8	950.4	939.6	928.7	920.8	916.2	919.2	920.1
	0,20	2,20	1,15	33,20	40,20	47,20	58,20	72,20	83,20	114,20	167,20
3676.	-0.0	-0.0	-0.0	-0.0	966.3	952.1	937.9	926.9	919.3	919.7	919.9
	0,20	1,20	5,20	2,15	35,20	45,20	54,20	68,20	79,20	95,20	133,20
.	-0.0	-0.0	-0.0	982.2	964.0	947.0	934.8	926.5	922.3	922.4	921.1
	0,20	2,20	1,15	25,20	40,20	49,20	64,20	77,20	87,20	110,20	86,15
3672.	-0.0	-0.0	-0.0	-0.0	970.8	958.6	943.7	935.1	927.7	925.5	921.5
	0,20	1,20	5,20	2,15	31,20	42,20	55,20	47,15	83,20	94,20	125,20
.	-0.0	-0.0	-0.0	-0.0	975.0	960.4	946.9	936.0	930.3	924.0	923.3
	0,20	2,20	1,15	5,15	34,20	48,20	62,20	77,20	91,20	107,20	145,20
3668.	-0.0	-0.0	-0.0	-0.0	-0.0	982.8	963.7	948.9	938.9	930.0	925.1
	0,20	0,20	3,20	2,15	0,10	39,20	52,20	69,20	83,20	97,20	124,20
.	-0.0	-0.0	-0.0	-0.0	-0.0	983.6	962.2	950.1	939.5	930.2	925.7
	1,20	1,20	0,15	3,15	0,10	43,20	59,20	76,20	89,20	106,20	132,20

FIGURE 27. Computer digitized complete Bouguer anomalies on a 4 x 2 km grid. Top number is Bouguer anomaly, bottom numbers are stations used and radius of interpolation.

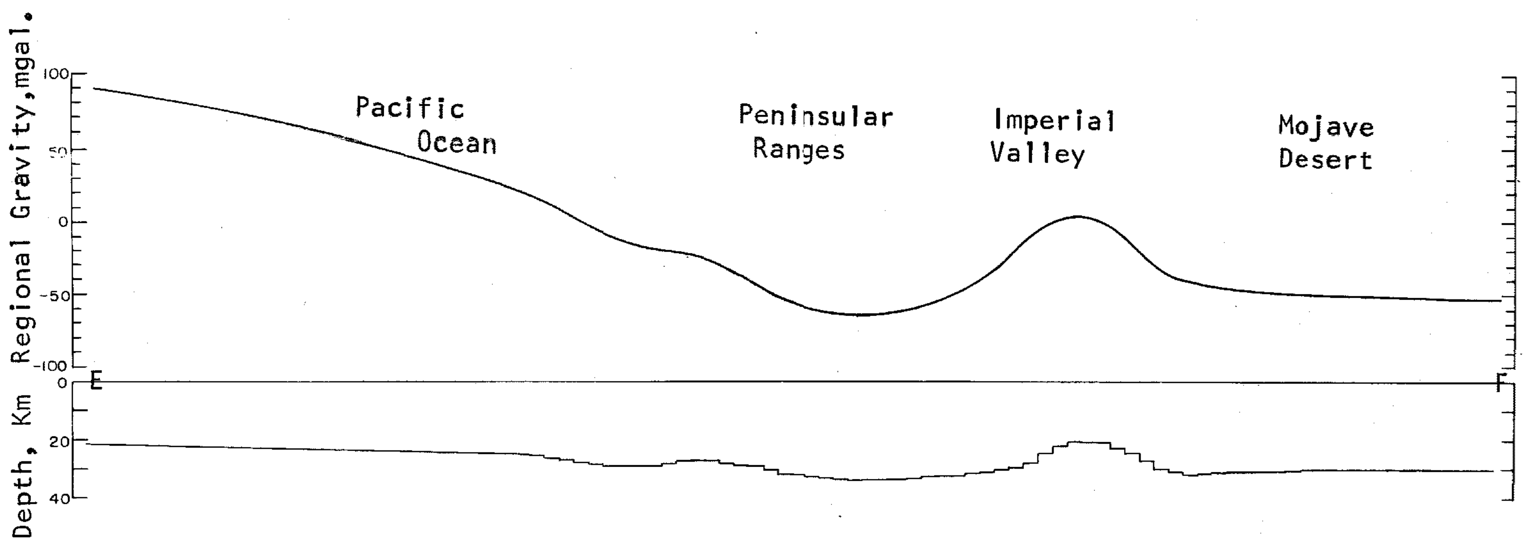

FIGURE 28. Regional gravity profile along line E-F (Figure 22) and crustal interpretation assuming a density contrast of 0.35 g/cm^3.

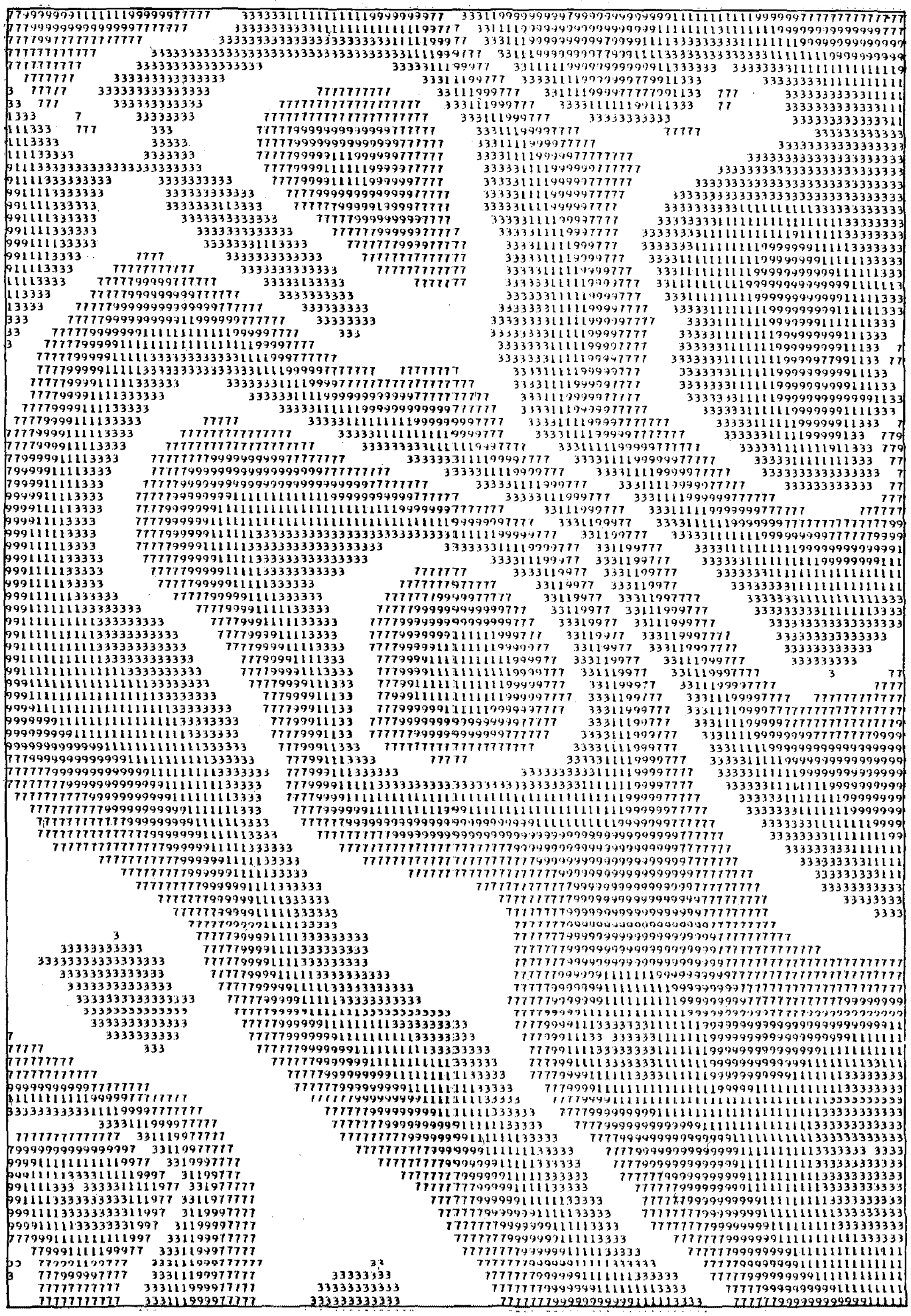

FIGURE 29. Complete Bouguer anomalies of the Salton volcanic domes. Computer contouring at 2 mgal. 10 mgal contour left blank.

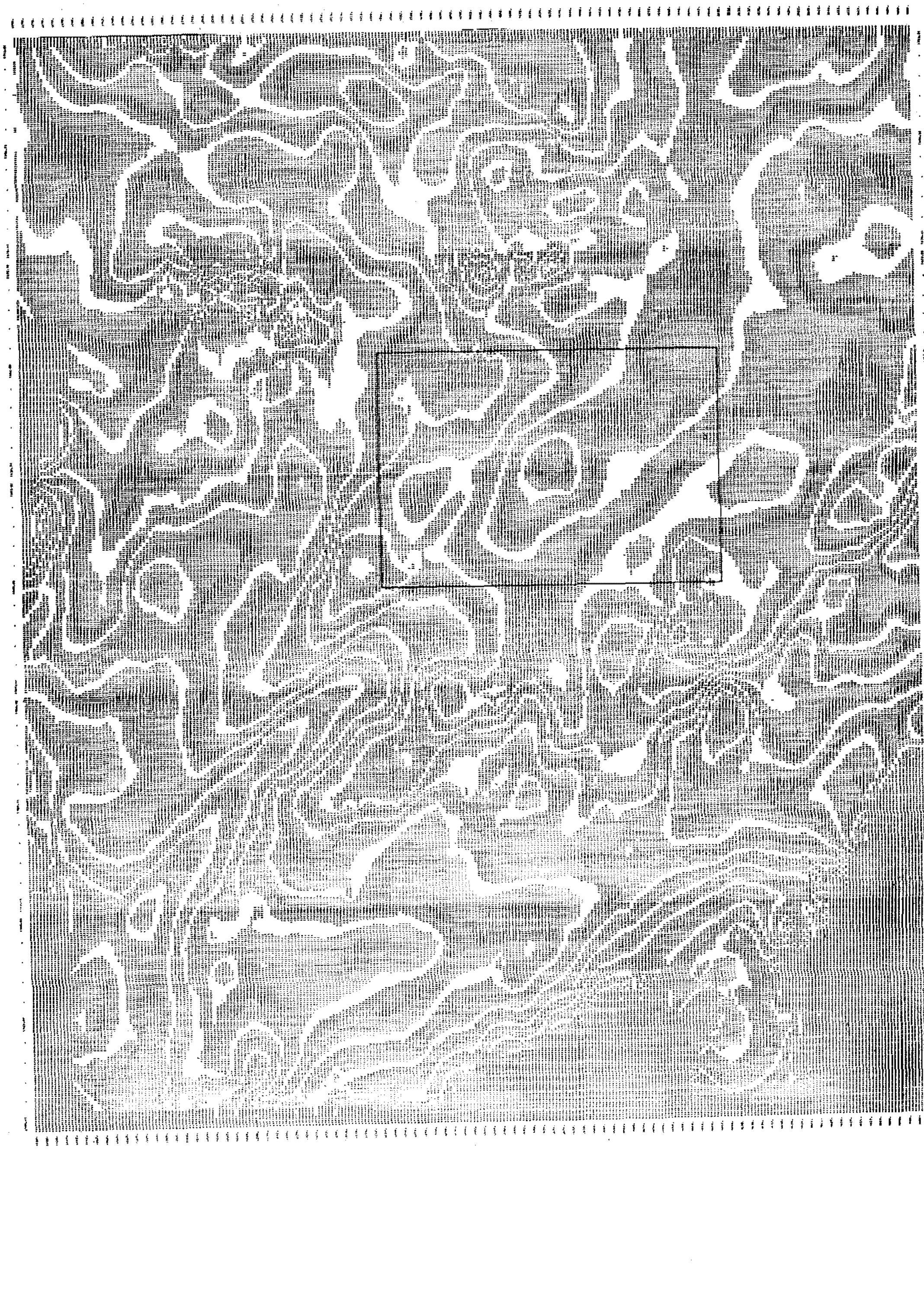

FIGURE 30. Computer contouring of complete Bouguer anomalies

TABLE 4.

AVERAGE STATION VALUES FOR 20 KILOMETER SQUARES

	450	470	490	510	530	550	570	590	610	630	650	670	690	710	730	750
3810																
	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	
	0	0	0	0	0	0	0	0	0	0	0	0	0	1183	0	
	0	0	0	0	0	0	0	0	0	0	0	0	0	-32	0	
	0	0	0	0	0	0	0	0	0	0	0	0	0	935	0	
	0	0	0	0	0	0	0	0	0	0	0	0	0	927	0	
3790																
	0	2	1	0	6	17	24	23	6	0	2	6	1	3	3	
	0	1573	3127	0	2994	3068	2434	1692	1462	0	1057	747	927	1024	623	
	0	-64	-18	0	-12	-6	-15	-26	-29	0	-34	-41	-25	-20	-25	
	0	891	888	0	896	898	911	924	929	0	938	939	951	952	958	
	0	883	879	0	887	889	902	916	920	0	929	933	943	944	353	
3770																
	0	1	6	48	89	39	36	21	35	6	3	4	3	0	1	
	0	1723	2386	2206	1310	1276	3984	2608	1608	1372	888	1174	858	0	323	
	0	-43	-27	-36	-69	-57	42	5	-10	-16	-35	-13	-27	0	-31	
	0	906	901	902	897	910	916	926	944	945	942	955	950	0	960	
	0	898	892	894	889	901	908	917	935	936	934	947	943	0	957	
3750																
	0	0	27	41	45	128	67	23	40	45	2	4	1	2	0	
	0	0	1668	4373	1259	396	799	2911	2503	1264	780	606	781	409	0	
	0	0	-38	40	-56	-61	-57	24	8	-16	-29	-55	-17	-32	0	
	0	0	914	915	913	909	921	935	932	947	951	949	963	957	0	
	0	0	905	906	908	906	917	926	923	939	944	944	956	953	0	
3730																
	0	0	7	25	23	46	139	79	31	34	3	8	9	6	2	
	0	0	2056	3657	4404	713	-32	743	1636	1620	681	475	424	272	499	
	0	0	5	35	64	-51	-83	-38	-18	-14	-37	-44	-35	-40	-30	
	0	0	945	922	926	930	918	941	935	939	945	943	953	952	956	
	0	0	936	913	915	927	918	937	926	931	939	939	949	949	952	
3710																
	0	0	3	21	24	15	60	112	78	21	12	2	7	3	0	
	0	0	1922	2816	2611	1081	-98	-212	-43	1038	1878	1220	553	241	0	
	0	0	3	23	2	-39	-62	-62	-46	-18	6	-5	-19	-40	0	
	0	0	947	937	927	936	941	943	955	952	951	961	966	953	0	
	0	0	939	929	918	928	942	945	956	946	942	953	961	951	0	
3690																
	0	0	0	13	36	102	66	97	69	138	21	0	6	1	0	
	0	0	0	2886	3490	757	574	-119	-253	-69	609	0	737	386	0	
	0	0	0	25	39	-47	-35	-47	-41	-41	-29	0	-22	-39	0	
	0	0	0	937	930	935	950	955	965	960	954	0	958	951	0	
	0	0	0	929	922	929	945	956	967	961	950	0	952	947	0	
3670																
	0	0	0	1	32	58	53	66	88	155	70	25	6	1	1	
	0	0	0	2985	3065	1884	280	-49	-176	-151	27	350	856	440	352	
	0	0	0	50	38	-4	-41	-49	-43	-36	-33	-17	-11	-24	-34	
	0	0	0	958	944	942	952	951	961	967	965	973	966	964	956	
	0	0	0	950	936	934	949	952	962	968	965	970	959	961	953	
3650																
	0	5	5	6	8	17	14	12	31	36	51	13	16	10	3	
	0	300	609	1403	3749	1680	824	169	5	-91	10	186	475	619	359	
	0	-0	6	26	86	-25	-50	-29	-43	-39	-31	-26	-13	-9	-26	
	0	992	991	987	969	930	929	966	956	962	968	968	974	974	964	
	0	989	986	980	960	921	922	965	956	963	968	967	970	969	961	
3630																
	0	10	3	0	2	7	25	37	40	37	35	20	30	46	11	
	0	36	484	0	3377	3656	1751	328	-7	-13	36	120	172	144	197	
	0	-9	8	0	54	42	-8	-40	-39	-41	-36	-35	-25	-13	-26	
	0	907	776	0	750	926	741	751	960	959	962	961	970	983	968	
	0	988	991	0	942	918	933	948	960	959	962	960	968	981	966	
3610																
	0	0	0	0	0	0	4	8	19	19	44	28	52	9	0	
	0	0	0	0	0	0	2845	1102	72	15	36	57	84	135	0	
	0	0	0	0	0	0	16	-15	-40	-35	-32	-39	-31	-30	0	
	0	0	0	0	0	0	928	952	958	964	966	959	966	965	0	
	0	0	0	0	0	0	919	946	957	964	966	958	966	964	0	
3590																
	0	0	0	0	0	0	0	1	27	2	23	33	9	1	0	
	0	0	0	0	0	0	0	3	-0	-0	48	44	73	186	0	
	0	0	0	0	0	0	0	-68	-64	-46	-20	-31	-32	-35	0	
	0	0	0	0	0	0	0	931	935	953	978	967	965	959	0	
	0	0	0	0	0	0	0	931	935	953	977	966	965	957	0	
3570																
	0	0	0	0	0	0	0	0	1	0	23	17	5	0	0	
	0	0	0	0	0	0	0	0	-0	0	86	40	47	0	0	
	0	0	0	0	0	0	0	0	-78	0	-15	-40	-37	0	0	
	0	0	0	0	0	0	0	0	921	0	982	958	961	0	0	
	0	0	0	0	0	0	0	0	921	0	981	958	961	0	0	
3550																
	0	0	0	0	0	0	0	0	0	0	19	19	1	2	0	
	0	0	0	0	0	0	0	0	0	0	22	18	57	39	0	
	0	0	0	0	0	0	0	0	0	0	-37	-36	-39	-48	0	
	0	0	0	0	0	0	0	0	0	0	962	962	959	950	0	
	0	0	0	0	0	0	0	0	0	0	962	962	958	950	0	
3530																
	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	
	0	0	0	0	0	0	0	0	0	0	0	37	0	0	0	
	0	0	0	0	0	0	0	0	0	0	0	-5	0	0	0	
	0	0	0	0	0	0	0	0	0	0	0	993	0	0	0	
	0	0	0	0	0	0	0	0	0	0	0	993	0	0	0	
3510																

TNSTA = 3587.

AELEV = 738.

AFAA = -35.

ABA(1) = 944.

ABA(2) = 941.

TABLE 5.

AVERAGE ELEVATION OF 20 KILOMETER SQUARES OF THE SALTON TROUGH AREA, SOUTHERN CALIFORNIA

	470–490	490–510	510–530	530–550	550–570	570–590	590–610	610–630	630–650	650–670	670–690	690–710	710–730
3810–3790	4280	5518	4935	3708	2729	2355	2300	1459	801	1174	1151	2335	1384
3790–3770	3017	5598	7756	4816	3282	2575	1777	1728	1868	1155	820	1388	1095
3770–3750	1782	3003	3831	2026	3292	4210	2818	1884	1647	1360	1447	990	976
3750–3730	1555	1869	4457	2803	511	1913	3332	2763	1641	640	1129	929	837
3730–3710	1439	1919	3788	4575	2364	74	1135	1900	1982	1605	512	559	310
3710–3690	1132	2119	3559	4016	3106	1211	-173	379	1563	2011	1155	623	357
3690–3670	671	1639	3365	4096	1285	688	-91	-199	4	1033	1280	803	521
3670–3650	532	1072	2199	3684	2536	944	32	-131	-147	146	699	1003	566
3650–3630	343	782	1763	4123	3148	888	368	10	-97	25	236	568	516
3630–3610	94	493	1702	3114	3849	2263	564	93	0	36	103	157	146
3610–3590	8	421	1351	2379	3027	3282	2329	387	382	20	95	99	181

TABLE 6.

AVERAGE BOUGUER ANOMALIES OF 20 KILOMETER SQUARES OF THE SALTON TROUGH, SOUTHERN CALIFORNIA

	450–470	470–490	490–510	510–530	530–550	550–570	570–590	590–610	610–630	630–650	650–670	670–690	690–710	710–730	730–750
3810–3790															
3790–3770			881	900	895	890	901	916	907	949	934	936	938	945	
3770–3750			890	895	891	907	908	922	932	934	932	944	945	961	
3750–3730			902	906	909	905	921	922	926	941	942	952	951	953	
3730–3710			931	915	919	934	919	943	932	932	938	939	952	953	
3710–3690			947	925	918	933	948	945	955	943	941	953	959	947	
3690–3670			965	941	922	930	950	957	967	956	957	967	952	941	
3670–3650			0	962	936	935	949	952	962	968	965	970	953	952	
3650–3630			985	973	957	922	931	967	957	963	968	967	969	970	
3630–3610			985	990	950	916	931	950	964	959	960	960	969	981	
3610–3590			0	0	0	923	926	948	967	963	959	956	966	975	

AVERAGE BOUGUER ANOMALY =942.

APPENDIX A

U.C.L.A. - Mt. Wilson Calibration Range*

Instrument: LaCoste and Romberg gravity meter DL-1

Dates: January 28, 1958; May 14, 1958; May 18, 1958; April 20, 1962

Gravity values: (corrected for earth tides and meter drift; mean of four runs ± standard error of the mean)

UCLA	0.00	
Cal Tech	-18.79	± 0.02 milligals
Vista	-75.32	0.02
Angeles	-117.47	0.02
Clear Creek	-199.27	0.03
Red Box	-263.21	0.03
Michelson	-342.72	0.03
Cloudburst	-418.99	(1 run only)
Dawson	-480.79	(1 run only)

Station Descriptions: Approx. elevation

UCLA--On floor of room 1275, Geology Building

Cal Tech--Top of outside steps, SW corner of Mudd Hall (near intersection of Wilson and California) . . . . 755'

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*After C. E. Corbato, 1963.

All of the following stations (except Michelson) are along the Angeles Crest Highway.

Station Descriptions:

	Miles from Foothill Blvd.	Approx. elevation
Vista--On water meter cover (level with curb) 85' S of center line Vista del Valle and Angeles Crest Highway.	1.0	1665'
Angeles--On asphalt 2' E of base of sign "Angeles Crest Ranger Station-Angeles National Forest".	3.6	2290'
Clear Creek--On cement curb 4' S of drinking fountain at SE corner of garage building, Cleer Creek Ranger Station . .	10.2	3640'
Red Box--In front of door on porch of Red Box Ranger Station.	15.3	4640'
Michelson--On Michelson Pier Mt. Wilson Observatory	20.5	5630'

Station Descriptions:	Miles from Foothill Blvd.	Approx. elevation
Cloudburst--On pavement of parking recess (S side of road) 4' N of highway marker, Cloudburst Summit	34.1	7018'
Dawson--On top of rock culvert wall at corner near highway marker D-254+77, on E side of road about 300' SW of Dawson Summit.	46.4	7885'

APPENDIX B

Base Stations

Banning - Located on U.S.B.M. J 71 on the east side of the road to Idyllwild near the intersection of the Idyllwild road and the southern frontage road of the Indio freeway. B.M. is 32 feet east of the center line of the Idyllwild road at the east edge of the sidewalk, and 98 feet north of the north rail of the main track. The concrete post projects 0.3 feet above the gound and is tilted at an angle of 20°.

elevation = 2326'
observed gravity = 979405.67 mgal.

Indio - Over U.S.B.M. H 588 at the Roosevelt School, at the intersection of State Highway 111 and Towne Avenue, 11.6 feet northwest of the north corner of the school, 39.5 feet south of the center line of the highway, 12.0 feet east of the northwest corner of a fence surrounding the school, 1.6 feet north of the side of the fence, about level with the highway, and set in the top of a concrete post about 0.3 feet underground, but accessible through a hole in the asphalt sidewalk.

elevation = -15'
observed gravity = 979537.14 mgal.

Desert Center - On the cement porch of the Desert Center store about 3 feet below U.S B.M. G 132. The B.M. is set vertically in the north face of the store 2 feet west of the main entrance.

elevation = 902'
observed gravity = 979515.65 mgal.

Brawley - Located at the south city limit of Brawley about 100 feet west of U.S. 99 on Canal Street. The setup was made on the south side of the street 12 feet north of the second power line pole off the highway. A metal tag stamped

894 is nailed on the pole.

elevation = -105'
observed gravity = 979546.45 mgal.

APPENDIX C

Pendulum Stations

Pend. Sta. No.	Location	Observed Gravity Pend. Value	Observed Gravity Gravimeter
Calif.			
314	Pasadena	979.577	979.5796
315	Mt. Wilson	979.253	979.2542
1019	Mecca	979.552	979.5516
1020	Nilano	979.573	
1021	El Centro	979.513	
1022	Palomar Mtn.	979.237	
1023	Pomona, 1939	979.548	979.5498
Ariz.			
65	Yuma	979.532	

APPENDIX D

Terrain Correction Table for Inclined Plane - G'zone

h = maximum elevation difference in feet.

T_1= terrain correction x 10^{-2} m/gal for terrain density 2.0 g/cm^3.

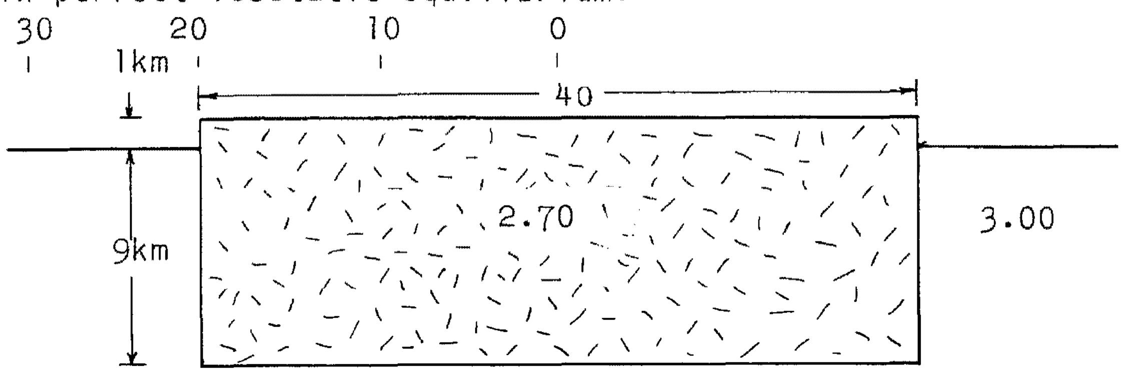
T_2= terrain correction x 10^{-2} m/gal for terrain density 2.67 g/cm^3.

h	T_1	T_2	h	T_1	T_2
0	.0	.0	200	7.4	9.9
10	.0	.0	210	8.1	10.9
20	.0	.0	220	8.9	11.9
30	.1	.2	230	9.8	13.0
40	.2	.3	240	10.6	14.2
50	.4	.6	250	11.5	15.4
60	.6	.8	260	12.5	16.7
70	.9	1.2	270	13.5	18.0
80	1.1	1.5	280	14.5	19.3
90	1.5	2.0	290	15.5	20.7
100	1.8	2.4	300	16.6	22.2
110	2.2	2.9	310	17.7	23.7
120	2.6	3.5	320	18.9	25.2
130	3.1	4.1	330	20.1	26.8
140	3.6	4.8	340	21.3	28.5
150	4.1	5.5	350	22.6	30.2
160	4.7	6.3	360	23.9	31.9
170	5.3	7.1	370	25.2	33.7
180	6.0	8.0	380	26.6	35.6
190	6.6	8.9	390	28.0	37.4

APPENDIX E

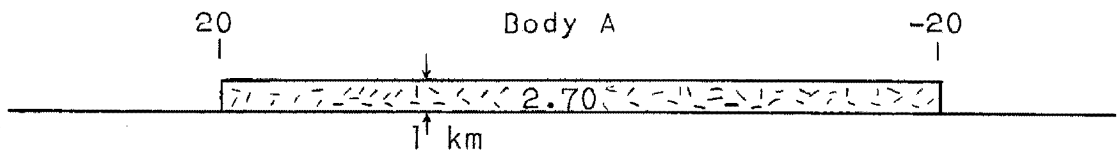
Bouguer Reduction Problem

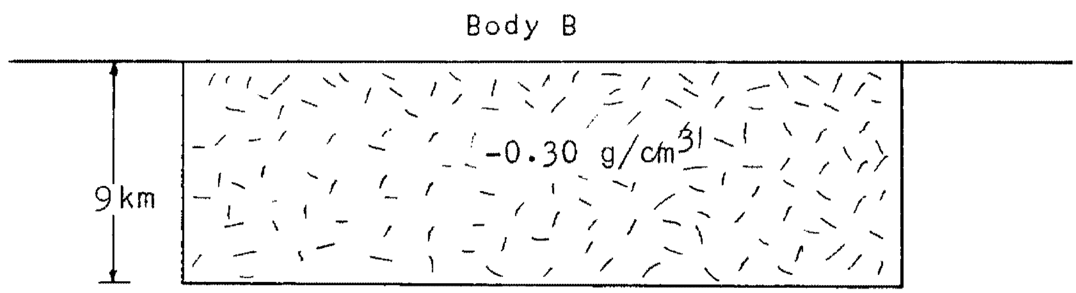
Consider a two dimensional north-south mountain range at the equator of a homogeneous earth which rises 1 km above sea level. The density contrast between the mountain and the surrounding crust is -0.30 g/cm^3 and the block is in perfect isostatic equilibrium.



An east-west gravity survey is made along the equator across the mountain range. What is the observed gravity, the free air anomaly and complete Bouguer anomaly? How does the complete Bouguer anomaly compare with the anomaly from the reduced mass of the mountain below sea level? For the purpose of this study gravity observations are started 80 km west of the west edge of the body and are made at 10 km intervals up to 10 km west of the body and then at 2 km intervals across the range to its center. The observed gravity far from the range is assumed to be equal to the theoretical sea level gravity at the equator. The vertical gradient of gravity is assumed constant at 308.6 mgal/km.

The observed gravity can be calculated for the points up to the west edge of the body by considering the attraction of the following two mass distributions:



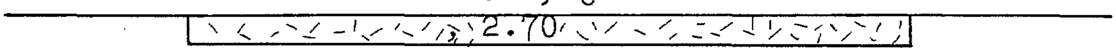


The sum of the gravity effect of body A and body B gives the total effect of the mountain range at points along sea level and outside of the range. The relative observed values for body A, and body B, and their sum are given below.

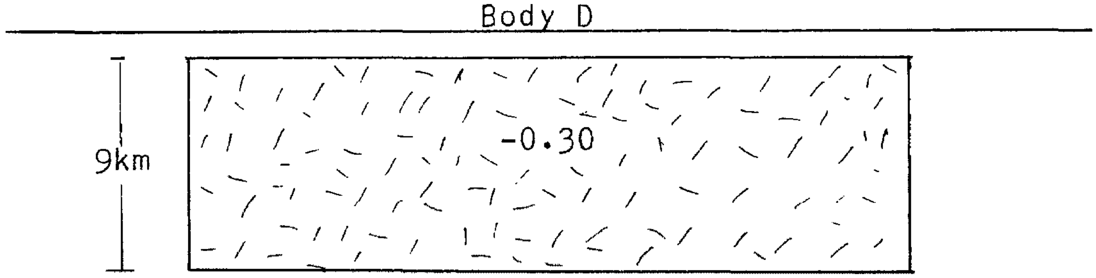
Distance	Body A	Body B	Total
100	- 0.09	- 0.66	- 0.75
90	- 0.09	- 0.84	- 0.93
80	- 0.12	- 1.08	- 1.20
70	- 0.15	- 1.44	- 1.59
60	- 0.24	- 2.01	- 2.25
50	- 0.34	- 3.02	- 3.36
40	- 0.60	- 5.16	- 5.76
30	- 1.44	- 11.30	- 12.74
28	- 1.87	- 13.96	- 15.83
26	- 2.60	- 17.75	- 20.35
24	- 4.05	- 23.44	- 27.49
22	- 8.24	- 32.65	- 40.89
20	- 56.15	- 52.58	-108.73

The gravity effect for points on top of the mountain can be calculated by summing the attraction of the following two mass distributions.

Body C



Body D



The sum of the gravity anomalies of body C and body D gives the total anomaly for points on top of the mountain. The relative gravity values for body C , body D, and their sum are given below.

Distance	Body C	Body D	Total
20	+ 56.15	- 51.70	4.45
18	+104.06	- 67.07	37.00
16	+108.25	- 76.47	31.78
14	+109.69	- 82.50	27.19
12	+110.40	- 86.55	23.84
10	+110.81	- 89.39	21.46
8	+111.06	- 91.29	19.77
6	+111.23	- 92.62	18.60
4	+111.33	- 93.49	17.83
2	+111.39	- 93.99	17.40
0	+111.40	- 94.15	17.26

The total gravity values given in the previous two tables are essentially the free air anomalies. This anomaly is positive over the mountain range and negative elsewhere. This is because no account has been made for the extra mass above sea level and below the mountain stations and the mountain root for the sea level stations. The Bouguer correction is 0 for the sea level stations and equal to the attraction of an infinite 1 km slab of density 2.70 g/cm^3 (-113.21 milligals) for the mountain stations. The simple Bouguer values which are given in the following table are all negative with a minimum over the edge of the mountain. Now the terrain correction is applied and the complete Bouguer anomalies calculated. This moves the minimum from the edge to the center of the mountain range. The complete Bouguer anomalies are now compared to the gravity anomaly of body B (the mountain with the mass above sea level removed). The difference is obviously 0.0 milligals up to the mountain edge, but within the mountain range the Bouguer anomaly underestimates body B by 3 to 5 milligals. If an interpretation of the Bouguer anomalies is attempted the thickness of the root will be less than actually present by approximately 0.36 km and of different shape.

Distance	F.A.A.	S.B.A.	C.B.A.	Body B	Diff.
100	- 0.75	- 0.75	- 0.66	- 0.66	0.00
90	- 0.93	- 0.93	- 0.84	- 0.84	0.00
80	- 1.20	- 1.20	- 1.08	- 1.08	0.00
70	- 1.59	- 1.59	- 1.44	- 1.44	0.00
60	- 2.25	- 2.25	- 2.01	- 2.01	0.00
50	- 3.36	- 3.36	- 3.02	- 3.02	0.00
40	- 5.76	- 5.76	- 5.16	- 5.16	0.00
30	- 12.74	- 12.74	- 11.30	- 11.30	0.00
28	- 15.83	- 15.83	- 13.96	- 13.96	0.00
26	- 20.35	- 20.35	- 17.75	- 17.75	0.00
24	- 27.49	- 27.49	- 23.44	- 23.44	0.00
22	- 40.89	- 40.89	- 32.65	- 32.65	0.00
20L	-108.73	-108.73	- 52.58	- 52.58	0.00
20U	4.45	-108.73	- 51.69	- 52.58	0.89
18	37.00	- 76.12	- 66.98	- 72.49	5.50
16	31.78	- 81.44	- 76.47	- 81.64	5.16
14	27.19	- 86.03	- 82.50	- 87.23	4.74
12	23.84	- 89.36	- 86.55	- 90.86	4.32
10	21.46	- 91.76	- 89.37	- 93.35	3.99
8	19.77	- 93.44	- 91.29	- 95.04	3.75
6	18.60	- 94.58	- 92.61	- 96.19	3.57
4	17.83	- 95.39	- 93.51	- 96.94	3.51
2	17.40	- 95.78	- 93.96	- 97.36	3.39
0	17.26	- 95.96	- 94.14	- 97.50	3.36