Gravity Study of the San Gabriel Mountains,

California

By

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Abstract

A gravity study of the San Gabriel Mountains was made. A map of Bouguer anomalies in the area was completed and a profile across the mountains was taken. Calculations of the crustal thickness beneath the Los Angeles basin, the San Gabriel Mountains, and the Mojave Desert were made using the sin x/x method and a method described by Bott. These calculations indicate that there is a crustal thinning under the San Gabriel Mountains to 27 km. Values of 35 and 38 km were obtained for the Los Angeles basin and the Mojave Desert respectively. These results correspond quite closely to seismic determinations of the crustal thickness in this area. They indicate that forces originating in the mantle were important in the uplift of the San Gabriel Mountains.

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Introduction

Geologic Setting. The San Gabriel Mountains are an intricately faulted block of pre-Tertiary intrusive and metamorphic rocks. They are characterized by an extremely rough topography with many V-shaped canyons. They are a part of the Transverse Range province of Southern California. The axis of the range runs almost directly east-west for sixty miles from San Bernardino to San Fernando. The maximum width of the mountains is about twenty miles. The San Gabriel Mountains are bounded by three major fault zones -- the San Andreas on the northeast, the Sierra Madre on the south, and the Soledad on the northwest. They are bordered by the Mojave Desert on the north, and Los Angeles Basin on the south, the San Bernardino Mountains on the east, and the Santa Susana Mountains, Santa Monica Mountains, and Sierra Pelona on the west. They were uplifted to their present height during Pleistocene time.

Geophysical Survey. A map of Bouguer Anomolies was compiled from gravity readings taken in the mountains themselves, The Mojave Desert, the Los Angeles Basin, and the Sierra Pelona. The primary purpose of the investigation was to determine the crustal structure beneath the San Gabriel Mountains, which have little effect on the marked regional gravity trend in the area due to seaward thinning of the earth's crust.

Geology

Rocks. The oldest rocks in the San Gabriel Mountains are a series of metamorphosed sedimentary strata. Miller (1934) has designated this series as the Placerita Formation and has given them a pre-Cambrian Age. They crop out in a very limited area near Placerita Canyon in the southwestern part of the range, but are present as inclusions in the complex rocks (San Gabriel Formation) which form much of the western section of the mountains. They are composed of various kinds of schists, quartzites, and crystalline limestones.

Another old series of metamorphosed sediments crops out in the eastern section of the San Gabriel Mountains. This has been called the Pelona Schist and is composed of quartz-albite schist. Miller (1934) believes this series to be younger than the Placerita Formation (late pre-Cambrian or early Paleozoic) because it is less metamorphosed and has not been lit-par-lit injected by granite.

Another pre-Cambrian formation present in the San Gabriel Mountains has been designated by Miller (1934) as the San Gabriel Formation. It is an intimate mixture of granite, metadiorite, metasediments, and dikes of diorite and granodiorite. Its composition is generally granodiorite. It crops out extensively in the western part of the mountains.

One of the most interesting formations in this range is a large anorthosite massif which is present in the northwest portion of the mountains. Most of the massif is composed almost purely of andesine, but there are also facies ranging through gabbroic anorthosite to almost pure titaniferous magnetite. Neurerberg and Gottfried (1954) have dated the anorthosite as 930 ± 90 million years old using lead alpha activity measurements. This confirms Miller's

belief that the Placerita and San Gabrial Formations are pre-Cambrian, because contacts between the anorthosite and San Gabriel show the anorthosite to be younger. It also raises an interesting question because a pegmatitic granite intrusion, presumably Lowe granodiorite, in the anorthosite was dated at 810 ± 80 million years. Miller did not believe that there was any igneous activity in the area between the intrusion of the anorthosite and Jurassic time. Miller postulated that the massif was a thickset laccolith or batholith increasing in width upward which shouldered its way through the San Gabriel Formation. The massif is also interesting geophysically because there is a large mass excess apparently associated with it.

The only other extensively developed pre-Tertiary formation in the western San Gabriel Mountains has been called the Lowe granodiorite by Miller (1934). Its most common facies is porphyritic. Miller believes that the granodiorite is Jurassic in age, based on correlation with similar formations in neighboring areas.

Alf (1948) describes a section at the southeastern tip of the San Gabriel Mountains. It includes (from youngest to oldest) -- pyroxene dioritic gneiss, undifferentiated metamorphics composed primarily of quartzite and crystalline limestone of probable Paleozoic age, gneiss and mylonite, and quartz dioritic gneiss.

All of the formations described above are mapped on Plate 2. There is no detailed description of the rocks in much of the east-central San Gabriel Mountains. However, some extension of Miller's (1934) map has been made into this area. The extensions are indicated as questionable.

Tertiary and Quaternary formations are present along the margins of the San Gabriel Mountains. Some of the more significant ones will be described. The Martinez Formation, which lies between the San Andreas and San Jacinto Faults, is described by Noble (1954). It consists of over 6000 feet of marine shales, arkosic sandstone, and conglomerate of Paleocene age. The Punchbowl Formation outcrops near the southeastern tip of the mountains and consists of up to 8000 feet of conglomeratic sandstone with some shale and limestone. It is of late Miocene age. The Vasquez formation (Jahns and Muehlberger, 1954) consists of up to 12,500 feet of conglomerate, breccia, and sandstone. It lies just north of the Saledad Fault. The Saugus Formation (Howell, 1954) crops out south of the San Gabriel Fault near the western tip of the mountains. It consists of over 7800 feet of arkosic sandstone and conglomerate and is late Pliocene to early Pleistocene in age. A thick sequence of sediments and volcanic flows crops out north of the center of the mountains. It is over 8000 feet thick and is of Miocene age (Miller, 1934).

Structure. The San Gabriel Mountains can be regarded as a gigantic horst which has been transected by countless fault and shear zones. Several of the major faults will be considered.

The major fault in the area is the San Andreas Fault, which runs along the northeast margin of the mountains. It is essentially vertical and movements along it have been right lateral strike slip. It has existed since pre-Tertiary time and there are displacements of older rocks up to a few hundred miles (Mabey, 1960). A movement of thirty miles since Miocene time is indicated by displaced sediments (Noble, 1954).

Intimately associated with the San Andreas Fault is the San Jacinto Fault, which runs parallel to and is separated from the San Andreas Fault by two to four miles along most of the San Gabriel Mountains. Movements along it have also been strike slip.

The oldest fault in the San Gabriel Mountains is the Vincent Thrust Fault. It runs a sinuous course through some of the highest country in the mountains, near the eastern end. It is a thrust fault and commonly dips southeastward at angles less than 45°. It marks the contact between the Pelona schist and younger plutonic rocks and is at least Mesozoic in age (Noble, 1954).

The San Gabriel Fault traverses the entire range in an essentially east-west direction from three to eight miles north of the mountain front. It dips steeply northward. Movements have been left-lateral strike slip up to 2 1/2 miles in areas northwest of the mountains (Oakeshott, 1954). It has existed since late Miocene, possibly since Upper Eocene or Oligocene, time. It butts against the San Jacinto Fault.

The Soledad Fault runs along the northwest margin of the mountains. It is a northerly dipping normal fault. It has not been active since Lower Miocene time. It butts against the San Andreas Fault (Jahns and Muehlberger, 1954).

The southern front of the San Gabriel Mountains is defined by the Sierra Madre Fault Zone. It is a complex group of branching and enechelon faults. Dips range from steeply south to moderately north and movement has been thrust faulting (Bailey and Jahns, 1954).

Miller (1934) postulated that the San Gabriel Mountains existed as a positive area throughout Tertiary time. By the end of Pliocene

time.the mountain area had been eroded to a peneplain. In early

Quaternary time, the present mountain mass began to rise and

has continued to do so until the present. They are still rising

at a rate of about 20 inches per century (Noble, 1954). Strong

lateral (north-south to northeast-southwest) pressure has been

an important factor in these movements (Miller, 1934). Movement

in the San Andreas, San Gabriel and Sierra Madre fault zones has

been high-angle thrust falting. Miller also states that vertical

forces must have been present during this time.

Gravity Anomalies

Areal Features. Plate 1 is a map of Bouguer anomalies plus 1000 milligals for the region. The contour interval is 5 milligals.

The most striking feature of the map is the regional gradient which extends from the San Andreas falt zone southwest across the mapped area and then across the Los Angeles basin. Gravity increases along this line, probably due to thinning of the earth's crust.

The San Gabriel Mountains seem to have little effect on this regional trend. Except for the extreme western portion of the range contours run roughly parallel to the San Andreas fault zone. The positive gradient across the range is steeper than the regional gradient. The western section of the mountain is dominated by a gravity high, centered over the anorthosite massif described earlier.

The Mojave Desert is a region of extremely uniform gravity in the area mapped. Except for isolated sedimentary troughs, the gravity anomalies lie between -95 and -110 milligals over most of this region. There is no significant regional trend, although contours near the San Andreas falt tend to run parallel to it.

The gravity high associated with the anorthosite body in the San Gabriel Mountains extends northward into the Sierra Pelona. These mountains are composed primarily of Pelona schist. There is a gravity low west of the San Gabriel Mountains, probably due to the extremely thick sedimentary sequence in the Ventura Basin.

There are two areas mapped which have extremely large gravity gradients. Just southwest of the western tip of the San Gabriel Mountains there is a positive southward gradient of up to 6 milligals per mile, due to a transition from the low associated with the

Ventura Basin to a high which is centered near the eastern edge of

the Santa Monica Mountains, where basement rocks are extensively exposed.

The second large gravity gradient is centered on the San Jacinto

fault just south of San Bernardino. It has a positive gradient south-

westward of up to 10 milligals per mile. It lies along a contact

between Jurassic granite and Pliocene sedimentary rocks.

Profiles. Two profiles were made and are shown with their

geologic sections on Plate 3. The first extends from San Pedro across

the Los Angeles Basin and San Gabriel Mountains to the Mojave Desert.

Its trace is shown (A-A') on Plate 1 and Figure 5. The gravity values

in the Los Angeles Basin were taken from a paper by Mc Culloh (1960).

Figure 1 is a contour map from this paper. It is believed possible

to treat the anomalies on the profile as two dimensional with

limited exceptions. In the San Gabriel Mountains the profile runs

almost normal to the gravity contours which are quite uniform on

each side of it. It crosses through the center of an area of extremely

low gravity relief in the Mojave Desert. From San Pedro to the

central Los Angeles Basin the profile runs normal to the contours.

In all these areas the profile can be regarded as a good represen-

tation of a two dimensional structure. From the central Los Angeles

Basin to the southern face of the San Gabriels there is a negative

gravity gradient southeastward across the profile. The gravity values

in this section may be slightly higher than they should be in making

a two dimensional interpretation. The second profile was taken across

the gravity high present in the western San Gabriel Mountains and
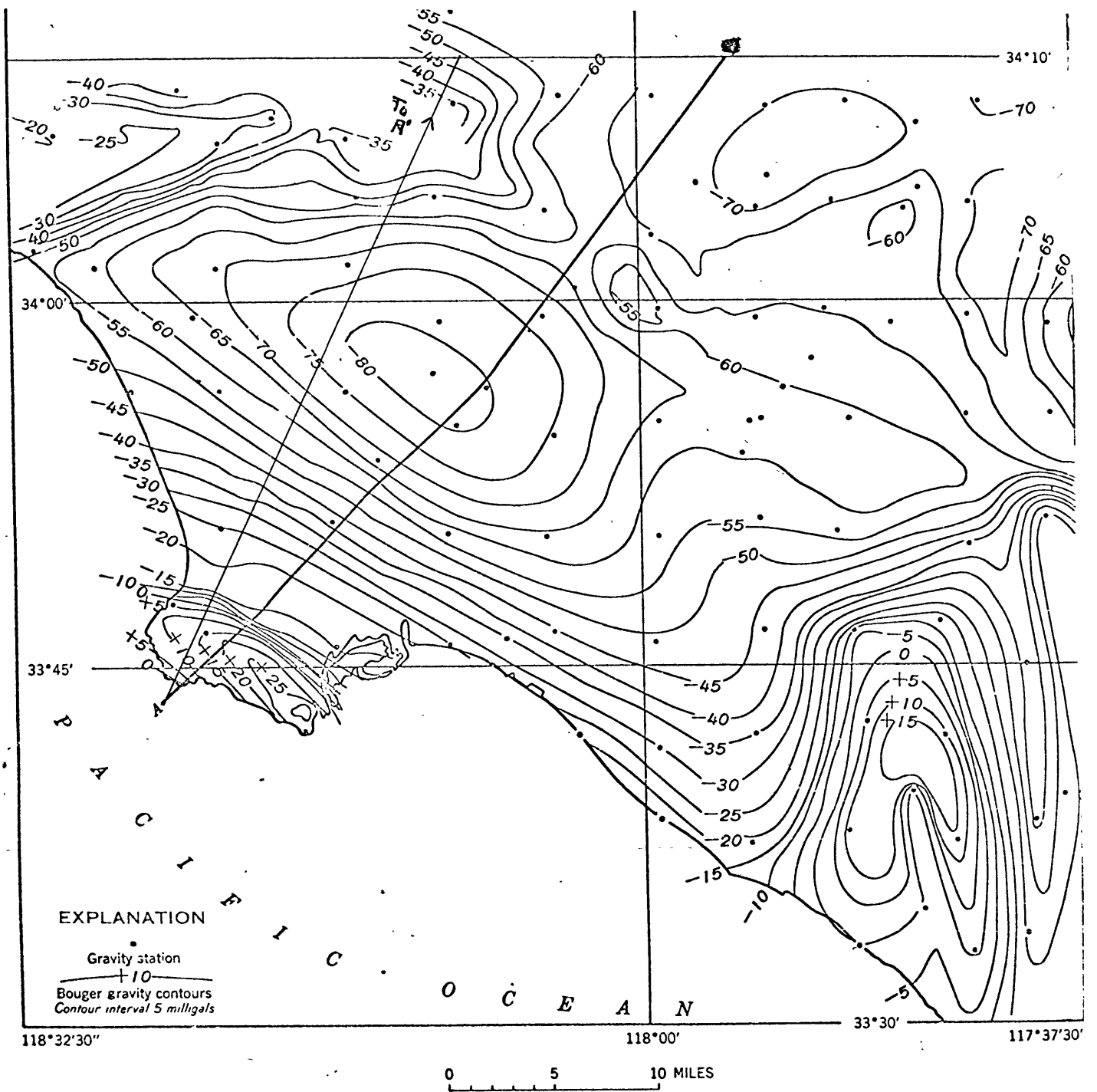
Figure 1.

Bouguer anomalies in the Los Angeles basin.

the Sierra Pelona. Its trace is shown (B-B') on Plate 1. The values

on this profile should give a valid two dimensional interpretation

with the exception of those near the southern end. In this area

there is a large positive gravity gradient eastward across the profile.

The values in this section of the profile are probably slightly too

high.

Computations. The gravity values along the profiles were

used to compute the crustal thickness beneath the profile (A-A')

by two different methods. The first was the sin x/ x method. This

method involves a calculation of the mass variation at a given depth

necessary to produce the observed gravity profile. Assuming a certain

density contrast between the crust and the mantle, it is then possible

to calculate the variations in crustal thickness along the profile.

The density contrast was assumed to be $0.3gm/cm^3$. A typical profile

is shown in Figure 2. The surface along which masses were calculated

has a depth of 27 kilometers.

The second computation was based on a method described by

Bott (1950). It provides a picture of relative, rather than absolute,

thickness. This method involves the division of the profile into a set

of two dimensional strips. A regionally corrected gravity value for

the center point of each strip is determined and an initial estimate

of the thickness of each block is made from these values with an

assumed density contrast $(0.3gm/cm^3)$. These thicknesses are then

altered in a series of iterations until the calculated gravity effect

closely matches the observed profile. The results of this computation

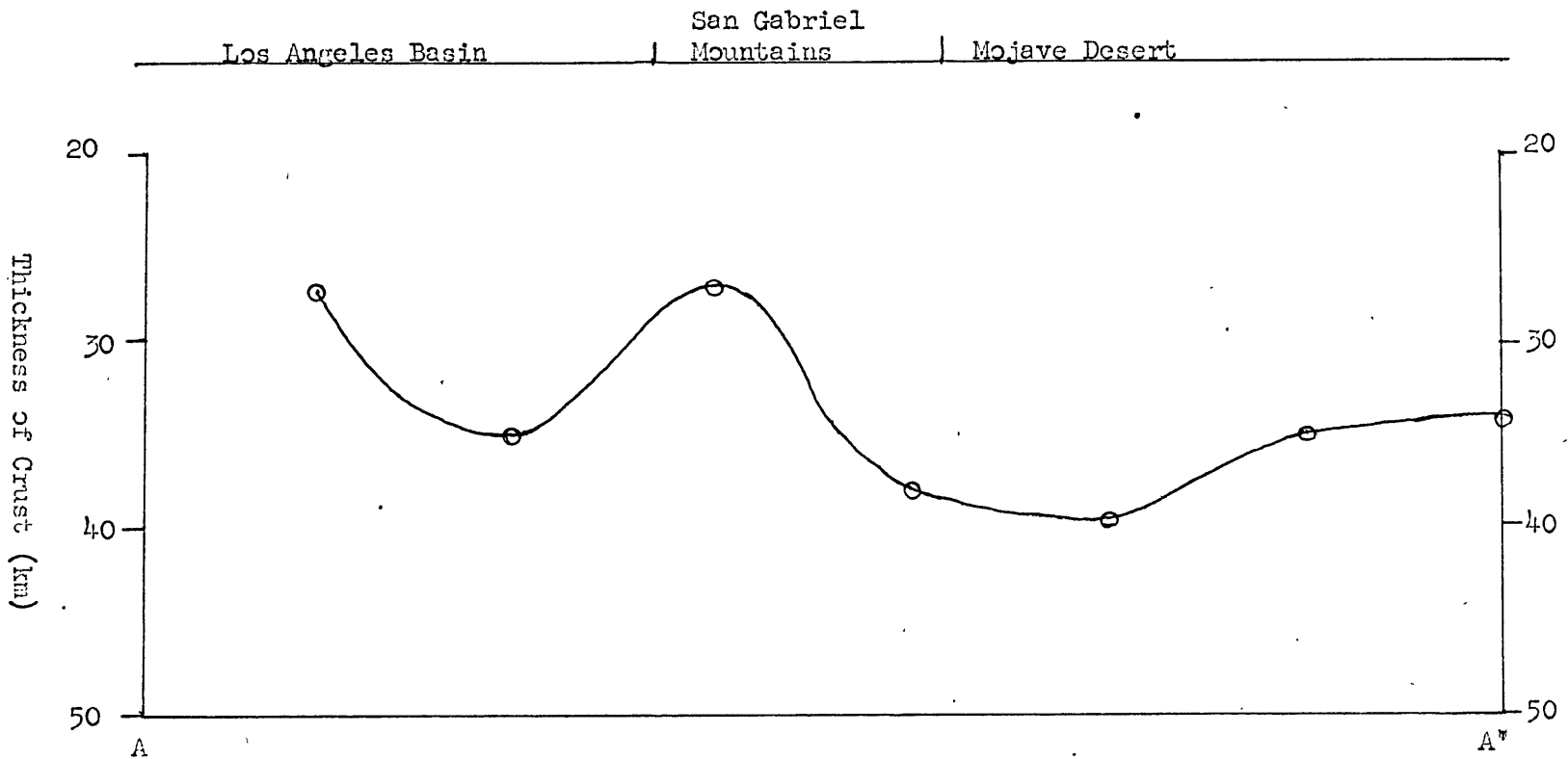are shown in Figure 3. Except for the two points at each end of the

Figure 2.
Crustal profile using sin x/x method.   Horizontal scale - 1:1,000,000.
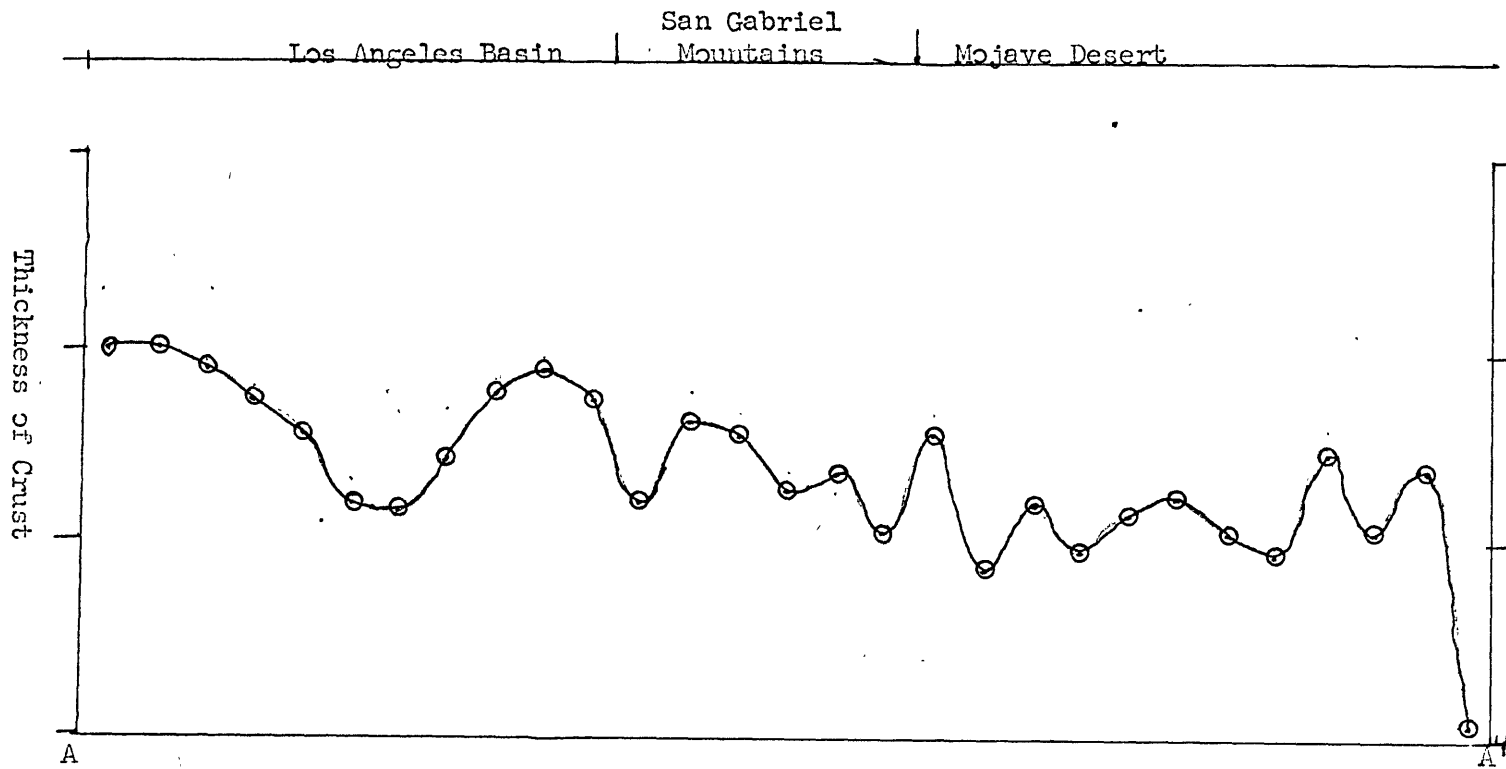
Figure 3.

Crustal profile using Bott's method. Horizontal scale - 1:1,000,000. The thicknesses are only relative.

of the profile the calculated gravity value is within one milligal
of the observed. Although the calculated thickness is very erratic,
its general structure is quite simular to that obtained by the
sin x/ x method.

Both calculations indicate that there is an anti-root
associated with the San Gabriel Mountains. The relief of this feature
is 11 kilometers. This may be slightly exaggerated due to the un-
realistically high gravity values southwest of the mountains which
were mentioned earlier. However, its existence as a feature of
considerable magnitude seems established. The trough to the south-
west is associated with the Los Angeles Basin.

Comparisons. Figure 4 shows the results of seismic work done
by Roller and Healy (1960). Figure 5 shows a trace of their profile
and profile A-A'. Although the general crustal structure in this
figure is simular to that calculated by the sin x/ x method, there
is a major discrepancy in the actual depths of the two models. Figure
5 shows the anti-root to have a relief of only 5 kilometers. Their
model also shows the crustal thickness under the Mojave near point A'
to be 27 kilometers. This discrepancy may be partially due to hetero-
geneties in the crustal structure since this point is near the beginning
of crustal thickening associated with the San Andreas fault, but the
difference seems too large to be wholly accounted for in this manner.
The gravity trough to the northeast of the San Gabriel Mountains has
a depth of 38 kilometers by the sin x/ x method and 37 kilometers by
the seismic method. The seismic model gives a thickness of 40 kilometers
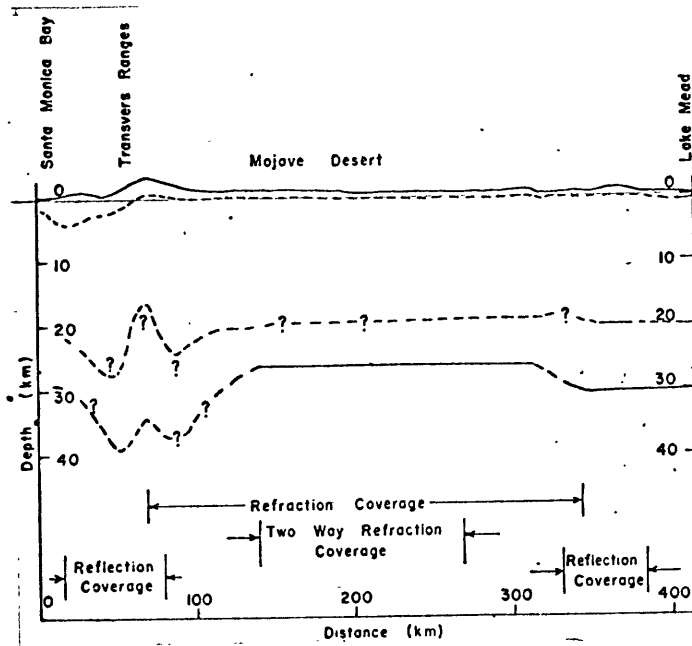under the Los Angeles Basin, and the gravity one gives 35 kilometers.

Figure 4.
Crustal thickness from Santa Monica Bay to Lake Mead from seismic data.
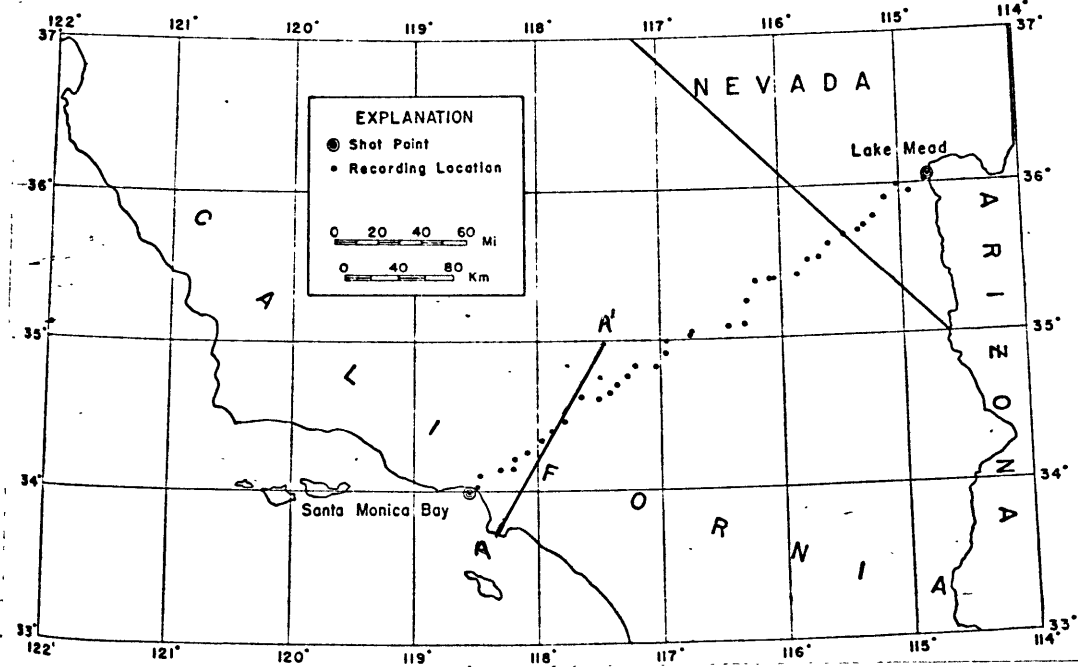

Figure 5.
Traces of seismic profile and gravity profile A-A'.

Another large difference in thickness is present at the western end
of the profiles - 27 kilometers for sin x/ x and 35 kilometers for
seismic. This difference may be partially due to seaward crustal
thinning since the gravith profile extends further west than the
seismic, but again the whole difference cannot be explained in this way.
Thus the gravity and seismic models agree in their general structure,
but differ in actual thickness, especially near the end points and in
the central San Gabriel Mountains. The end point differences may be
due to the method used in calculating the sin x/ x profile. The
gravity values at the end points were continued outward without change,
which in the southwest would make the calculated crustal thickness
thinner than it should be. The effect of this at the northeast end is
not clear. The two values given for the San Gabriel anti-root might
be regarded as upper and lower limits of its relief.

McCulloh (1960) postulated a thickness of 30 kilometers in
the central Los Angeles Basin. This figure appears to be seriously
in error. He also postulated that the Mohorovicic discontinuity
slopes uniformly across the basin and flattens on either side of it.
This also appears to be incorrect.

Conclusions

The San Gabriel Mountains are a mass of pre-Cretaceous crystalline rocks which were uplifted most recently by high-angle thrust faulting initiated in early Quaternary time. The uplift is still continuing presently. Strong lateral pressure was an important factor in the mountain building. Gravity data indicate that vertical forces initiated in the mantle were also important, because there is a large upwarping of the Mohorovicic discontinuity beneath the mountains.

One possible explanation of the cause of these mantle forces suggests itself. The deposition of 3 kilometers of sediment in the Los Angeles Basin during Pliocene and Pleistocene time resulted in displacement of a corresponding thickness of mantle material. The San Gabriel Mountains offered an easy outlet for this material since there was already established along its margins a well developed fauly system. The mantle material moved under the San Gabriel Mountains and displaced them upward. This theory is admittedly highly speculative, but accounts for the crustal structure beneath the Los Angeles Basin and San Gabriel Mountains, and is supported by the fact that the Soledad Fault has been inactive since Miocene time.

Bibliography

Alf, R.M., "A Mylonite Belt in the Southeastern San Gabriel Mountains, California", Geol. Soc. of America Bulletin, Vol. 59, 1948, pp.1101-1119.

Bailey, T.L. and Jahns, R.H., "Geology of the Transverse Range Province, California", Calif. Div. of Mines Bulletin 170, Chapter 2, 1954, pp. 83-105.

Bott, M.H.P., "The Use of Rapid Digital Computing Methods for Direct Gravity Interpretation of Sedimentary Basins", Geophysical Journal, Vol. 3, 1960, pp. 63-67.

Howell, B.F., "Geology of the Little Tujunga Area, Los Angeles County," Calif. Div. of Mines Bulletin 170, Map Sheet 10, 1954.

Jahns, R.H. and Muehlberger, W.R., "Geology of the Soledad Basin, Los Angeles County", Calif. Div. of Mines Bulletin 170, Map Sheet 6, 1954.

Mabey, D.R., "Gravity Survey of the Western Mojave Desert, California", U.S.G.S. Professional Paper 316-D, 1960, pp. 51-70.

McCulloh, T.H., "Gravity Variations and the Geology of the Los Angeles Basin of California", U.S.G.S. Professional Paper 400-B, 1960, pp. 320-325.

Miller, W.J., "Geology of the Western San Gabriel Mountains of California", Pub. of U.C.L.A. in Math. and Physical Sciences, Vol. 1, 1934, 83 p.

Neuerberg, G.J. and Gottfried, David, "Age Determinations of the San Gabriel Anorthosite Massif, California," Geol. Soc. of America Bull., Vol. 65, 1954, p. 465.

Noble, L.F., "San Andreas Fault Zone from Soledad Pass to Cajon Pass, California", Calif. Div. of Mines Bulletin 170, Chapter 4, 1954, pp. 37-50.

Oakeshott, G.B., "Geology of the Western San Gabriel Mountains, Los Angeles County", Calif. Div. of Mines Bulletin 170, Map Sheet 9, 1954.

Roller, J.C. and Healy, J.H., "Seismic Refraction Measurements of Crustal Structure between Santa Monica Bay and Lake Mead", Journal of Geophysical Research, Vol. 68, 1963, pp. 5837-5849.