RESULTS OF GRAVITY MEASUREMENTS
IN SOUTHERN CALIFORNIA

Thesis by

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Summary

The various types of instruments for gravity measurements are briefly discussed. The theory of an inverted pendulum of the "Holweck-Lejay" type with an elastic mounting at its base is given, and an instrument of this design, ninety times as sensitive to differences in gravity as an ordinary pendulum, is described. The theory of the interpretation of gravity data is discussed. The results of gravity observations along a profile across the Los Angeles Basin and San Gabriel Mountains are given. From this data together with geologic data and that obtained from a reflection seismograph survey, a hypothetical structure section along the profile is constructed.

The outstanding features of this section are the presence of a basin of Tertiary sediments about thirty thousand feet deep, and the increasing predominance of relatively lighter rocks under the San Gabriel Mountains and Mojave Desert. This last feature is in accord with the concept of "regional isostatic compensation".

INTRODUCTION

The geologist in his study of the deformation of the earth's crust is often handicapped by a lack of information concerning the structure and distribution of rocks at depth. The development of oil well drilling and the application of modern geophysical methods promises to make such data more easily available. In Southern California, a number of circumstances make the region an interesting one for the use of geophysical methods. The surface geology and geologic history are reasonably well known. The occurrence of oil in the Los Angeles Basin has led to extensive drilling and detailed information concerning the upper few thousand feet of sediments.

However, the events of Tertiary geologic history have occurred on a scale that places much interesting information beyond the reach of drilling. During Tertiary time the area of the Los Angeles Basin has been depressed several miles with a correspondingly large accumulation of sediments. To the north the San Gabriel Mountains have been considerably uplifted, resulting in an imposing mass of crystalline rocks facing out on this deep basin of sediments. The recency and magnitude of the deformation make the region one of special interest for a study of the deformation of the earth's crust.

To determine the structure of the basin and the thickness of sediments accumulated. Drs. J. P. Buwalda and B. Gutenberg have recently completed a reflection seismograph profile across the Los Angeles Basin. It has been the purpose of the following research to supplement these results, if possible, by a series of gravity measurements along the same profile and an extension of the profile across the San Gabriel Mountains. From this data an attempt has been made to secure some information concerning the densities of the rocks at depth, and accordingly a clue as to the nature of the rocks and the degree of approach to isostatic equilibrium in this region.

PART I.

INSTRUMENTS FOR MEASURING GRAVITY

There are three essentially different alternative methods for the measurement of the intensity of gravity. The first of these makes use of the definition of force in Newton's law of motion that the rate of change of momentum produced in a body is proportional to the force acting on it. The second method consists of comparing the force of gravity with some other force such as the elastic force of a spring, the pressure of a gas, or an electrostatic or electromagnetic force. The third possibility consists of a combination of these two methods. The three methods are illustrated diagrammatically in figure 1.

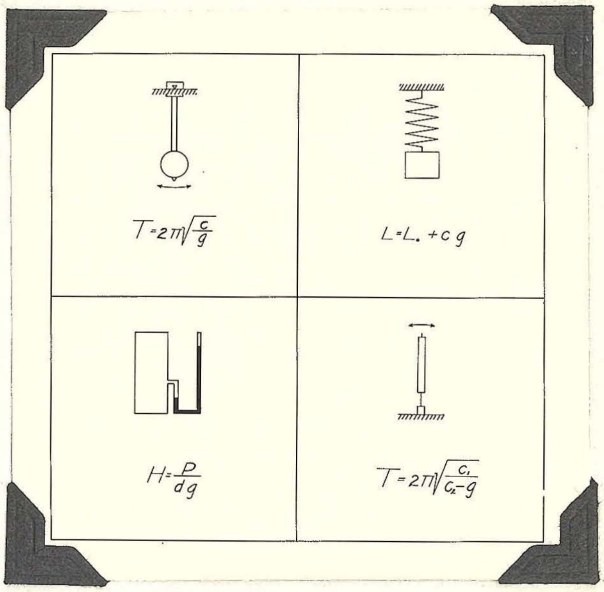


Figure 1 (a) (b) (c) (d)

The first of these is the classical one, and is the basis for the use of the common pendulum in determining gravity. Although the pendulum is probably the most reliable of all the types of instruments for precise gravity measurements, the relatively long time required for observations makes its use laborious and expensive. Since the period is inversely proportional to the square root of the value of gravity, (figure 1 a), it must be measured to an accuracy of one part in two million in order to determine g with an accuracy of one part in a million, which is the accuracy commonly desired. Previously this meant that the pendulum must be allowed to swing for a number of hours. Even with modern precise methods of timing by using radio time signals from a base station, at least an hour is necessary for a single measurement.

The present interest in using gravity data for locating and outlining larger scale geologic structures has created a demand for more rapid methods of measurement. As a result a number of instruments of the type shown diagrammatically in figure 1 (b) have been constructed, with varying degrees of success. In this type of instrument use is made of the fact that small changes in g produce corresponding changes in the length of the spring. The chief experimental difficulties are encountered in constructing a satisfactory and sufficiently precise means for measuring the extrmely small changes in the length of the spring; in avoiding the effects of ground vibration, since the instrument acts as a seismometer; and in carefully thermostating the instrument to avoid effects of changes in temperature.

An instrument of the type shown in figure 1 (c) consisting of a column of mercury supported by gas pressure has been constructed and operated with some success. Here the chief difficulty is first in determining the height of the column of mercury with sufficient precision, and second in elaborately thermostating and compensating the instrument against the effects of changes in temperature, since it is essentially a very sensitive gas thermometer.

So far as is known, no instrument depending on the comparison of gravity with electrostatic or electromagnetic forces has been successfully constructed.

An instrument of the third type combining the first two methods has been devised by two French scientists, MM. F. Holweck and P. Lejay. This instrument, illustrated in figure 1 (d) consists of an inverted pendulum swinging on a spring suspension at its base. As will be shown later, the period of oscillation is inversely proportional to the square root of the difference between a constant c_2, depending on the physical properties of the pendulum, and g. By constructing the pendulum so that the difference between c_2 and g is sufficiently small, the change in period can be made as sensitive as desired to changes in g. Hence the time required for an observation can be greatly reduced from that required for the ordinary type of pendulum. A pendulum of the Holweck-Lejay type requiring one minute for an observation has been constructed by the author, and in the following pages, the theory of the apparatus is discussed in detail.

PART II.

THEORY OF THE HOLWECK-LEJAY PENDULUM

Derivation of the equation of motion

Let:

(x,y) be the coordinates of the central line of the spring; (x_1,y_1) of the upper end of the spring, and (x_o,y_o) of the center of mass of the pendulum.

$\bar{I}$, $\bar{J}$, $\bar{K}$, be unit vectors in the X,Y,Z, directions.

θ be the inclination of the pendulum from the vertical, reckoned positive when x_o is positive (the pendulum being supposed to swing in the XY plane).

f be the distance from (x_1,y_1) to (x_o, y_o).

m be the mass of the pendulum and I the moment of inertia about an axis through the center of mass parallel to Z.

e be the thickness of the spring (assumed to be rectangular in cross section), h the width, c the length.

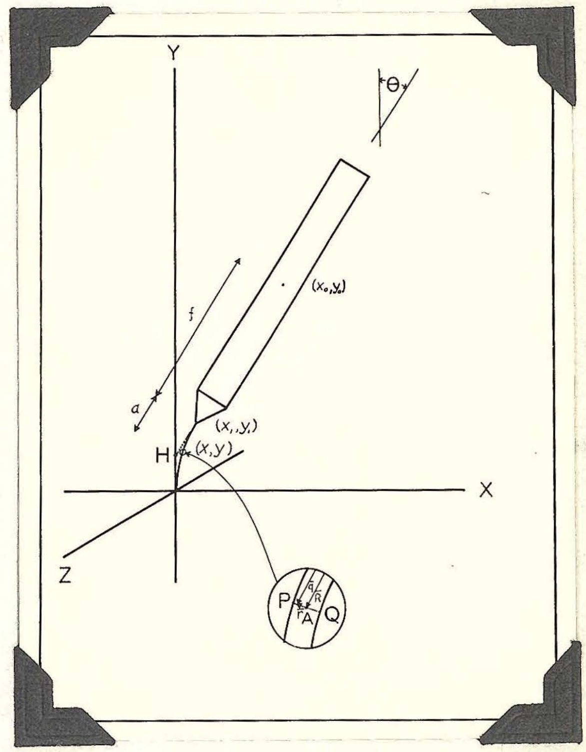


Figure 2

E be Young's modulus for the spring material,

$$B = \frac{E\,e^3\,h}{12}$$

the flexural rigidity, and

$$u = c\sqrt{\frac{mg}{B}} = \sqrt{\frac{12\,m\,g\,c^2}{E\,e^3 h}}$$

$\bar{R}$ be a vector from the center of mass to the point A at the center of any cross section PQ of the spring, $\bar{q}$ a vector from the center of mass to the center of an element of area

$$ds = h\,de,$$

and $\bar{r}$ a vector from A to the center of ds.

$\bar{S}\,ds = \bar{S}\,h\,de$ the stress acting on the area ds.

Then the total force exerted on the pendulum across section PQ will be

$$\bar{F} = \int_0^e \bar{S}\,h\,de$$

The moment of forces acting across this section about point A will be

$$\bar{M} = \int_0^e \bar{r}\times\bar{S}\,h\,de$$

The total moment of forces acting on the pendulum (stresses on PQ and gravity on the mass of the pendulum) about the center of mass will be (the moment of the attraction of gravity being zero about the center of mass),

$$\bar{L} = \int_0^e \bar{q}\times\bar{S}\,h\,de$$

$$= \int_0^e (\bar{R} + \bar{r})\times\bar{S}\,h\,de$$

$$= \bar{R}\times\bar{F} + \bar{M}$$

Since the acceleration of the center of mass is equal to the total force acting on the mass,

$$\bar{F} - mg\bar{J} = m\ddot{x}_o\bar{I} + m\ddot{y}_o\bar{J}$$

or since $\ddot{y}_o$ may be neglected as compared with g

$$\bar{F} = m\ddot{x}_o\bar{I} + mg\bar{J}$$

If the spring is thin as compared with its length we may use the "Bernoulli-Eulerian" theorem concerning the flexure of beams, namely

$$\bar{M} = B\frac{d^2x}{dy^2}\bar{K}$$

Substituting these values in the expression for $\bar{L}$ and noting that

$$\bar{R} = (x - x_o)\bar{I} + (y - y_o)\bar{J}$$

we get

$$\bar{L} = mg(x - x_o) - m\ddot{x}_o(y - y_o) + B\frac{d^2x}{dy^2}$$

Since $\bar{L}$ is also equal to the rate of change of angular momentum about the center of mass, we have

$$- I\ddot{\theta} = mg(x - x_o) - m\ddot{x}_o(y - y_o) + B\frac{d^2x}{dy^2}$$

or

$$\frac{d^2x}{dy^2} = W + Uy - n^2x$$

where

$$W = \frac{mgx_o - I\ddot{\theta} - m\ddot{x}_oy_o}{B}$$

$$U = \frac{m\ddot{x}_o}{B}$$

$$n^2 = \frac{mg}{B}$$

Integrating this equation and introducing the boundary conditions that x and $\frac{dx}{dy}$ vanish with y, we get the equation for the flexure of the spring

$$x = \frac{(1 - \cos ny)W}{n^2} + \frac{(ny - \sin ny)U}{n^3}$$

$$\frac{dx}{dy} = \frac{(\sin ny)W}{n} + \frac{(1 - \cos ny)U}{n^2}$$

Placing y equal to c and writing u for nc,

$$x_1 = \frac{(1 - \cos u)Wc^2}{u^2} + \frac{(u - \sin u)Uc^3}{u^3}$$

$$\tan \theta = \frac{(\sin u)Wc}{u} + \frac{(1 - \cos u)Uc^2}{u^2}$$

Replacing W, U, and n by their respective values and noting that for small motions $x_0 = x_1 + f\theta$ approximately, we have two linear second order differential equations in x_1 and θ. These equations can be solved giving expressions for x_1 and θ as functions of time and depending upon initial conditions. In general, it appears that the pendulum may execute a rather complicated type of motion. J. Haag[1] has investigated the effect of initial conditions and found in order that x and θ vary synchronously with simple harmonic motion, the pendulum must be started from rest by a horizontal impulse applied at the center of mass. We shall assume here that the pendulum has been started under these conditions, and derive an expression for the period of the motion.

1. See bibliography at the end of the thesis.

For small motions, the distance from x_1, y_1 to H, the intercept of the extended axis of the pendulum with the Y axis, is

$$a = \frac{x_1}{\theta} \quad \text{approximately}$$

$$= \frac{(1 - \cos u)uc + \frac{(u - \sin u)c^2 U}{W}}{(\sin u)u^2 + \frac{(1 - \cos u)ucU}{W}}$$

A comparison of the order of magnitudes of the various terms for the cases in which we are interested shows that the second terms in both the numerator and denominator may be neglected without introducing any appreciable error. Then

$$a = Gc$$

where

$$G = \frac{(1 - \cos u)}{(u \sin u)}$$

Since G is independent of θ, it is apparent that the pendulum swings essentially as though pivoted at point H, the spring bending in such a manner that the extended axis of the pendulum mass passes very nearly through H at all times. Then for small motions

$$x_o = (f + a)\theta$$

$$\ddot{x}_o = (f + a)\ddot{\theta}$$

Substituting these terms in the expressions for θ, W, and U and combining and rearranging terms, we get

$$\ddot{\theta}\left[k^2 - c^2(G - 0.5)^2\right] + \theta gc\left(\frac{\cot u}{u} - \frac{f}{c}\right) = 0$$

where $$mk^2 = I + m(f + \frac{c}{2})^2,$$

the moment of inertia of the pendulum about the midpoint of the spring.

Hence the period of oscillation for small amplitudes is

$$T = 2\pi\sqrt{\frac{k^2 - c^2(G - 0.5)^2}{gc(\frac{\cot u}{u} - \frac{f}{c})}}$$

As will be shown later, if the length of the spring is short compared with the length of the pendulum, u is considerably less than one and (cot u)/u may be replaced by the first two terms of its rapidly converging series expansion

$$\frac{\cot u}{u} = \frac{1}{u^2} - \frac{1}{3} - \frac{u^2}{45} - \frac{2\,u^4}{945} - \dots$$

Also in this case $c^2(G - 0.5)^2$ is negligible compared with k^2, and the expression for the period assumes the more simple form

$$T = 2\pi\sqrt{\frac{mk^2}{\frac{B}{c} - mg(f + \frac{c}{3})}}$$

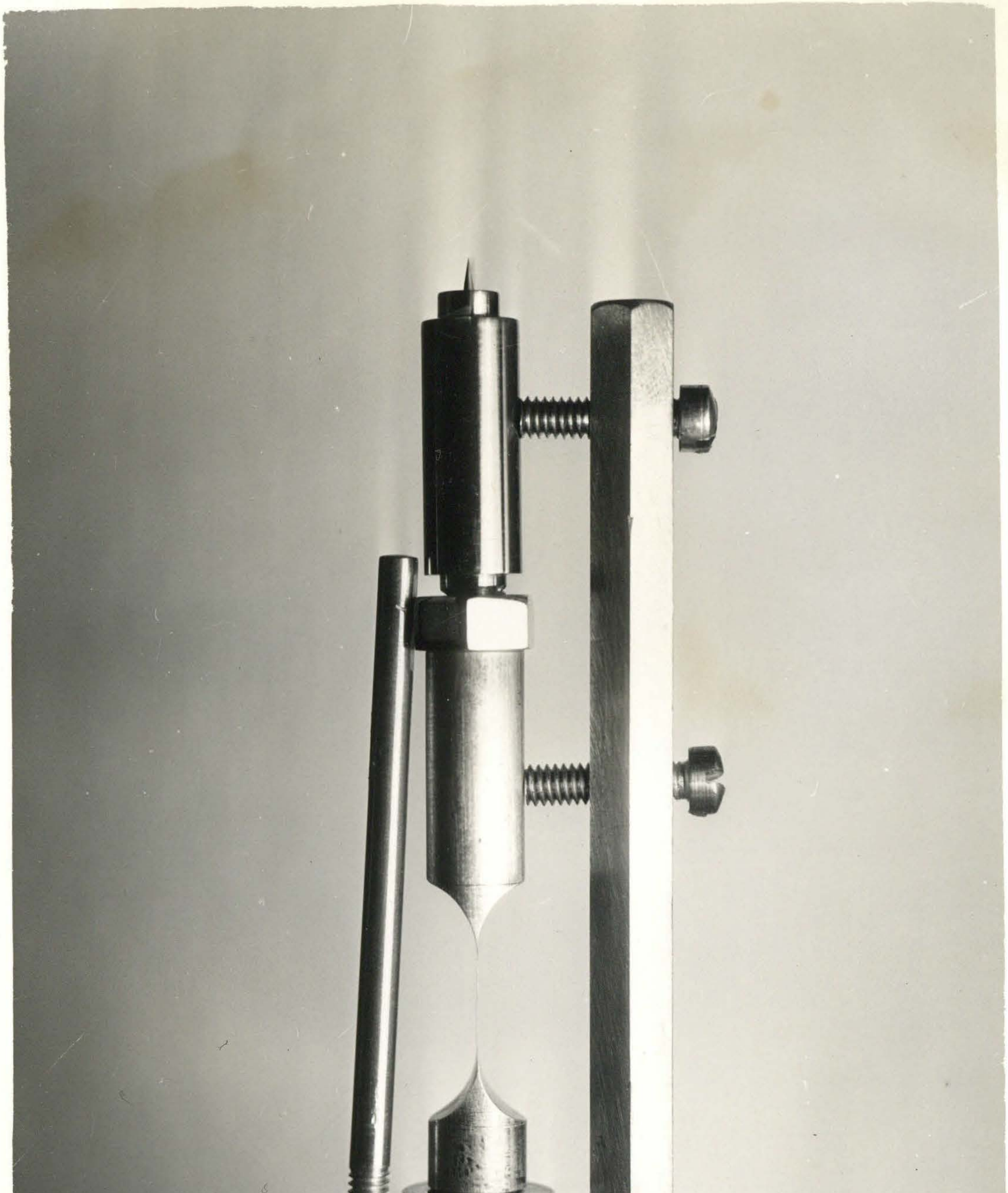
Application of theory to the design of the instrument

From either of the two formulae for the period of motion, it is apparent that to make the period very sensitive to small changes in gravity, $\frac{B}{c}$ must be made to approach $mg(f + \frac{c}{3})$ in value, or $\frac{\cot u}{u}$ to approach $\frac{f}{c}$ in value. This may be accomplished either by increasing the mass and length of the pendulum, or by decreasing the spring stiffness until the desired sensitivity is obtained. The latter alternative may be accomplished either by lengthening the spring, or by decreasing the thickness, or both. The following considerations show that the most desirable procedure is to make the spring short and thin rather than long and thick. The theory of stability of beams predicts that the spring will buckle under the weight of the pendulum mass if u becomes equal to $\frac{\pi}{2}$, and that the smaller u is, the less will be the tendency to buckle. Therefore it is obviously desirable to keep u as small as possible, or accordingly $\frac{\cot u}{u}$ as large as possible. This means that $\frac{f}{c}$ should be as large as possible, or that the length of the spring should be small compared with the length of the pendulum.

Theoretically it would be possible to attain any desired sensitivity by properly adjusting the dimensions of the instrument. However, with increasing sensitivity difficulties are encountered due to the effect of ground vibrations and extreme sensitivity to slight tilting of the instrument support. Also the period becomes increasingly long and difficult to measure accurately, the motion damps down rapidly, and the pendulum may acquire a tendency to fall over against its stops.

PLATE I.

Holweck-Lejay pendulum; one and one half times actual sise



PART III.

DESCRIPTION OF THE INSTRUMENT

A pendulum of the Holweck-Lejay type constructed by the ahthor is shown in plate I and the relevant dimensions in figure 3. As finally adjusted, it has a period of about four seconds and a sensitivity to changes in gravity about ninety times as great as that of the ordinary pendulum.

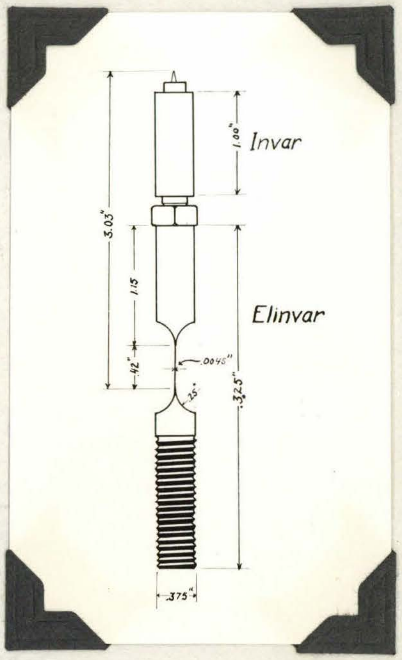


Figure 3

Construction of the pendulum

The most critical part of the pendulum is the spring. In the first models constructed, the spring consisted of a flat strip of metal clamped between tightly fitting jaws at its upper and lower ends. This arrangement proved unsatisfactory. The damping of the motion was excessive, reducing the amplitude to half value in about twenty seconds. The pendulum was also erratic in behaviour, failing to return to the rest position, and showing large and irregular changes in period. The trouble was apparently due to a slight slipping of the spring between its supports.

In order to overcome this difficulty, the spring and its supports were machined out of a single piece of metal. Considerable mechanical precision was necessary to produde an element accurately symmetrical and almost paper thin in its center portion. The successful construction of the spring was due to the skill and patience of Mr. G. W. Sherburne and mechanics of the Astrophysics machine shop.

The period and sensitivity of the pendulum were adjusted by means of a metal bob threaded into the upper spring support, and secured by a lock nut.

Materials used in the construction of the pendulum

To reduce the effects of temperature changes the spring was constructed of the Fe-Ni-Cr alloy "elinvar"[1] possessing a relatively small thermo-elastic coefficient, and the bob of the Fe-Ni alloy "invar"[1] which has an almost negligible thermal-expansion coefficient. The thermoelastic coefficient of the elinvar was not as small as might be desired, the period of the instrument changing by about minus eighty two parts in a hundred thousand per degree centigrade at 15° C. This change is equivalent to that produced by a change of -18.6 milligals in g (1 milligal = .001 cm/sec^2, hereafter written mgal). Assuming that this change in period is mainly due to increase in spring stiffness, it is equivalent to a change in spring stiffness of minus nineteen parts in a million per degree centigrade. The negative sign of the thermal-coefficient is rather unusual, since it is opposite to that for most metals.

1. Obtained from the R. Y. Ferner Co., Room 930 Investment Building, Washington, D. C.

Heat treatment of the spring

When the pendulum was first assembled, its damping was undesirably high, and the period showed a progressive decrease with time. In order to decrease the damping and stabilize the elastic properties of the spring, the pendulum was subjected to a series of heat treatments consisting of keeping the spring in an electric oven at about 150° C. for a week or more. After a series of five treatments, the behaviour of the spring was noticeably improved. The motion in air was damped to half amplitude in ninety seconds as compared with forty seconds before, and the period of the instrument assumed a more nearly constant value. Considerable care had to be taken not to strain the spring beyond its elastic limit after a heat treatment, since in this case the spring resumed its previous behaviour.

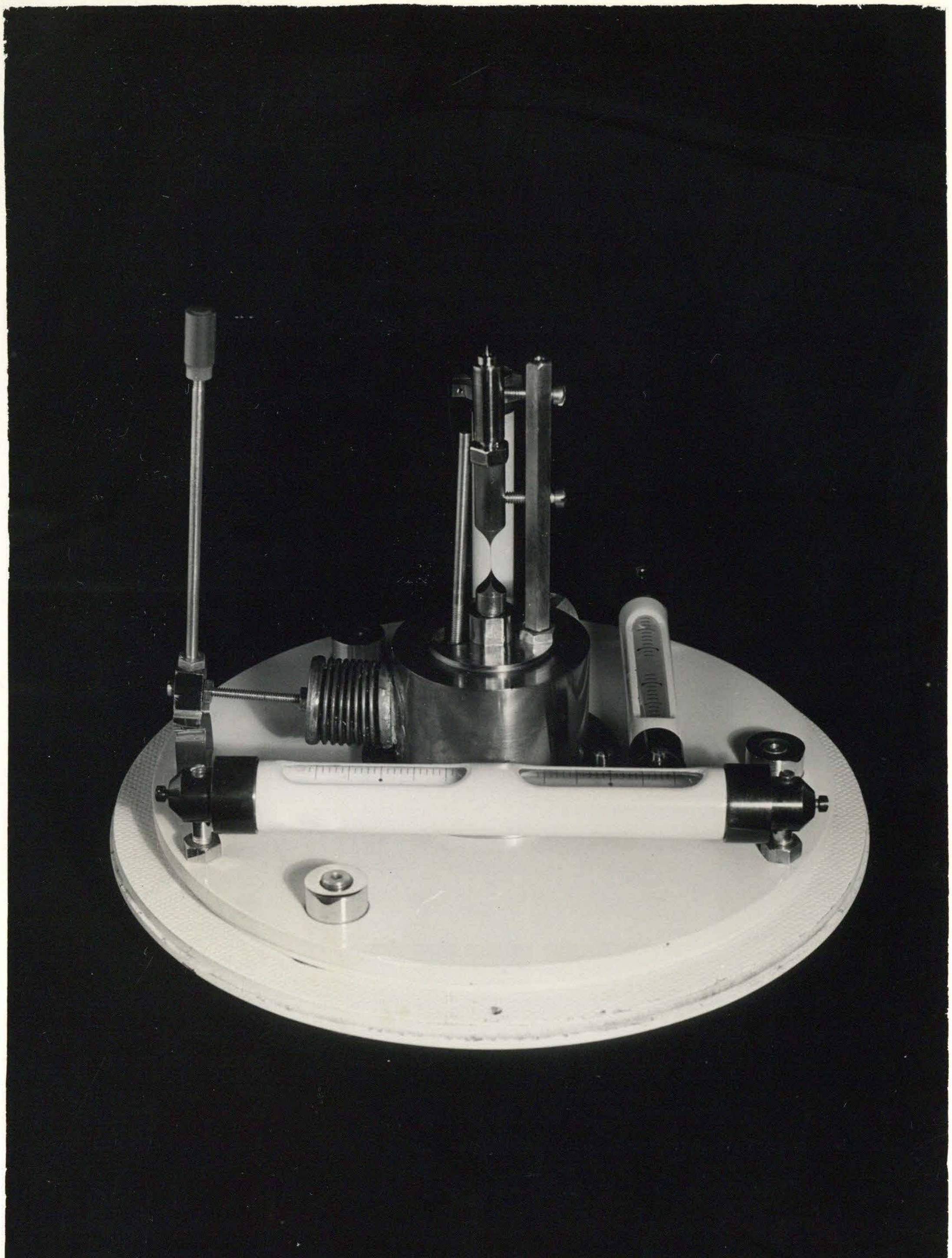
Apparently the undesirable properties of the spring were due to microscopic cleavages or fractures developed during the machining and working of the metal. Subsequently release of residual stresses probably occurred in the metal, with the processes being accelerated and carried to completion at 150° C.

Mounting of the pendulum

The instrument is shown partly assembled in plate II. The lower end of the pendulum spring is secured in a steel block which in turn is fastened to a steel base plate, provided with level vials, leveling screws, etc. In order to further reduce the damping, the pendulum is enclosed in a small glass bell jar (not shown in the photograph) which is evacuated to a pressure of about

PLATE II.

Instrument with cover and microscope removed.



10^{-4} mm. of Hg. For pressures greater than about 10^{-3} mm. of Hg the damping is practically independent of pressure, with reduction to half amplitude in ninety seconds. For pressures lower than this the damping drops off rapidly to reduction to half amplitude in about one hundred and forty seconds. This damping is partly due to internal dissipation of energy in the spring and partly to energy being imparted to motion of the ground and supports of the instrument.

The mechanism for clamping the pendulum in its evacuated chamber during transportation is adjusted externally through a vacuum tight "sylphon" bellow.

Adjustment of level vials

The period of the pendulum is a maximum when it is in an approximately vertical position. The effects on the period of slight inclinations from the vertical are then a minimum. This optimum position was found by systematically measuring the period for various positions of the base plate, and noting when it had its maximum value. The level bubbles were then approximately centered for this position, and the scale readings noted. The leveling in the plane of vibration of the pendulum is very critical, since an inclination of the base plate of 1" of arc causes 90" inclination of the pendulum. The instrument is first approximately leveled in this plane by means of a level vial having a sensitivity of one-tenth inch scale division per 17" of arc. The final leveling is done to within 1" of arc by the use of a microscope focused on the pendulum.

PLATE III.

The complete instrument

The leveling in the plane perpendicular to the plane of vibration is much less critical, and an accuracy of 30" is more than sufficient.

Heat insulation of the instrument

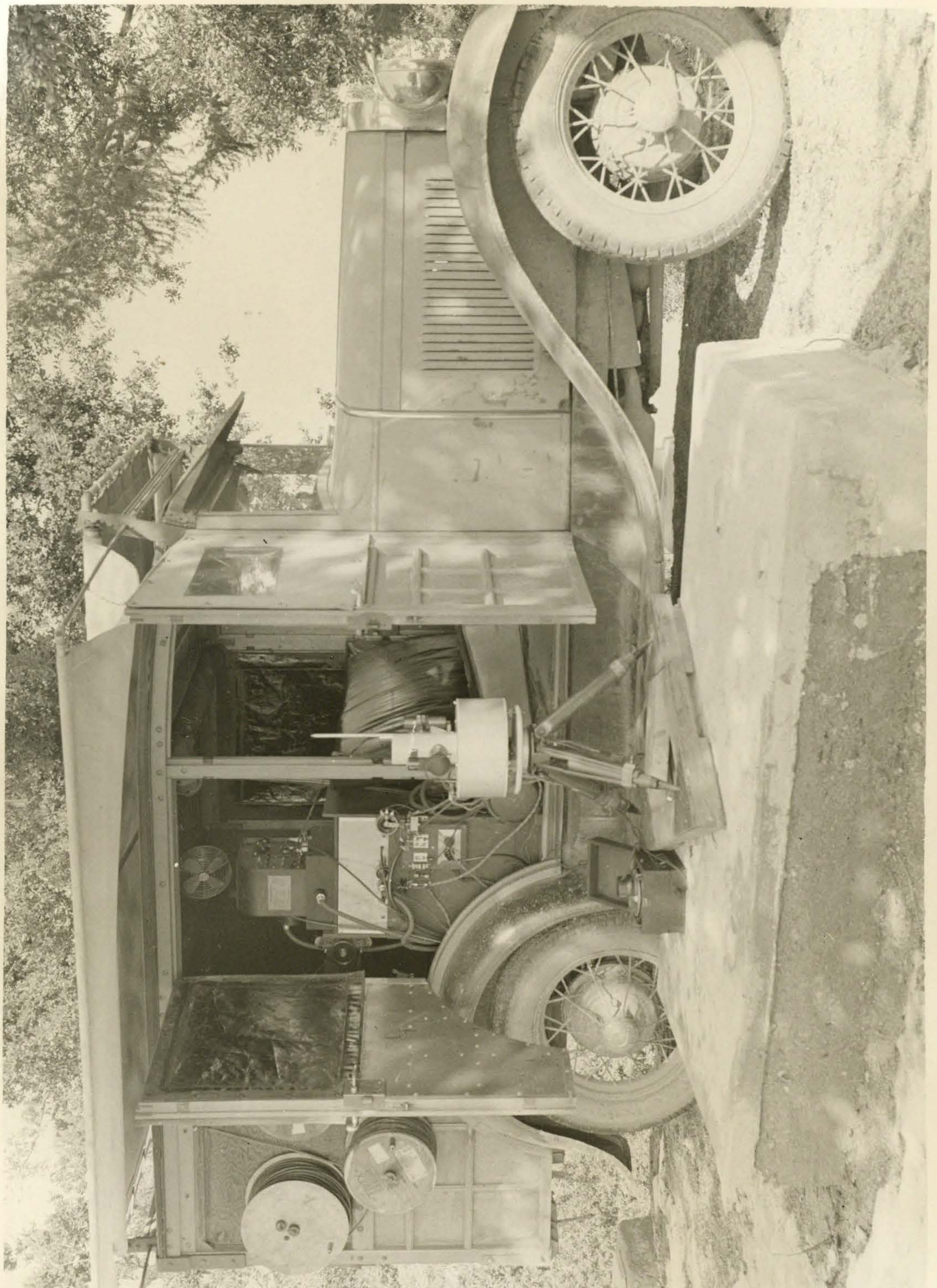
As previously mentioned the period of the pendulum has a temperature coefficient equivalent to a change in g of about -19 mgals per degree centigrade at 15° C. In addition, because of the relatively small heat conductivity of the thin spring and large heat capacity of the pendulum mass, appreciable temperature gradients may exist in the spring. Especially if the temperature of the base plate is changing rapidly, there may be a considerable lag in the mean spring temperature, and differences as great as one or two degrees centigrade may exist between it and that of the base plate. This condition, of course, considerably increases the uncertainty of the temperature corrections. It would be desirable to thermostat the instrument, holding the temperature constant to within a few tenths of a degree C. However, because of the inconveniemce of doing this in the field with only storage batteries as a source of power, an attempt was made to insulate the instrument and make allowances for the thermal hysteresis as will be explained later. The instrument is surrounded by a protective case, lined with cork and filled with sawdust. The exterior is painted white and the metal parts plated to present good reflecting surfaces. A thermometer graduated to 0.1° C. is used to read the temperature of the base plate. The complete instrument, with its protective cover is shown in plate III.

Observation and timing of the pendulum

A low power microscope (48 mm. objective, 15x ocular) is mounted on the base plate and focused on a small pointer at the top of the pendulum bob. The position of the pointer is read on a graduated ocular micrometer disc. Because of the relatively rapid damping of the pendulum motion, it is necessary to limit the time of observation to one or two minutes and measure the initial and final times to an accuracy of ± .005 second. This is accomplished by the use of a photoelectric cell and photographic recording. A light beam passing through the microscope objective is focused on the pendulum pointer in its center position. The interruption of this light beam normally falling on a photoelectric cell produces a small impulse which is amplified and recorded by an oscillograph. The reflection seismograph equipment of the California Institute of Technology was used for this purpose. The oscillogram has four traces, and is conveniently marked by timing lines every .01 of a second. The half second ticks of a chronometer are picked up with a microphone, amplified, and recorded on the same record. An electric contact on the second hand of the chronometer provides a ~~good~~ mark once every minute, and a hand switch is provided for recording the time when the pendulum motion has a certain amplitude.

PLATE IV.

Apparatus in place for an observation.



PART IV.

FIELD MEASUREMENTS AND DATA

Setting up of the instrument.

Since the instrument is very sensitive to slight tilting, it is necessary to provide a substantial structure on which to place the instruments during field observations. The instrument is mounted on a rigid, short legged tripod commonly used for mine and tunnel surveying. The tripod in turn is placed on a wooden triangle faced with steel plates, which prevent the tripod legs from spreading or sinking into the ground. It is necessary for the observer to keep his feet off the ground during a measurement, since even the shifting of weight from one foot to another is sufficient to cause a slight displacement of the ground and noticeable tilting of the instrument. In practice the instrument is set up next to the geophysical truck as shown in plates III and IV, and adjusted by the observer sitting in the car. In this manner it is possible to keep the base plate level to within a few seconds of arc if the tripod is resting on reasonably firm ground. On windy days some trouble is encountered due to vibration of the ground and instrument.

Method of observation

After the base plate has been leveled, the pendulum is started swinging with a half amplitude of fifteen microscope scale divisions (about 62' of arc). Shortly before the amplitude is reduced to thirteen divisions (45') the oscillograph camera is started and allowed to run for eight or ten seconds, in which time four or five impulses from the photoelectric cell are recorded. When the amplitude reaches thirteen divisions a mark is placed on the record by means of the hand switch. The time of starting the pendulum is chosen so as to insure the minute signal falling within the period of recording. Shortly before the elapse of sixty seconds the camera is again started and four or five more impulses recorded. The initial time for the swing with an amplitude of thirteen scale divisions is determined by plotting the times of the impulses and graphically determining the mean. In this way the effect of the light beam being slightly uncentered is eliminated. The same procedure is applied to determine the final time after fifteen swings (about sixty one seconds later). These times are corrected to chronometer time by means of the half second chronometer impulses on the record. The difference between the corrected initial and final times is denoted by T_{15}. The entire time required for setting up the pendulum, making several determinations of T_{15}, and replacing the equipment in the truck is about twenty five minutes if the photographic records are not developed in the field.

Temperature and inclination corrections

In order to take into account the effects of thermal hysteresis previously discussed, an observation was taken at a base station at the beginning and end of a series of runs. Also, if possible, the same series of stations were occupied twice in the same day. An accurate record of the temperature was kept, and from the results of repeating observations and checking in at the base station, it was possible to roughly estimate the mean spring temperature. From this estimated temperature, T_{15} was reduced to its value for 20° C. by means of the formula

$$\Delta T_{15} = +0.050(t - 20.00) \text{ sec.},$$

where t is the estimated mean spring temperature. Because of the uncertainty of this temperature, errors as great as 10 mgals or more may have been introduced.

The correction for slight inclination from the vertical position is usually not great. It amounts to

$$\Delta T_{15} = +.015\, n^2 \text{ sec.},$$

where n is the inclination in ocular micrometer divisions (1 division equals 3' 28" of arc) of the pendulum from its vertical position. In most cases the correction was negligible.

On two occasions it was found necessary to add a "drift correction" of 0.015 seconds to T_{15} in order to bring it to its average value at Pasadena.

It is quite important to always calculate T_{15} from the same initial amplitude (thirteen scale divisions in the present series of measurements) since the period depends markedly on the amplitude of motion. By taking the initial time one complete swing late or early, an error of about 11 mgals in the calculated value of g is introduced.

Calibration of the instrument

The instrument was calibrated by determining the difference in period between Pasadena and Mount Wilson. The data are given in Appendix A. At that time T_{30} (time for 30 swings) was determined rather than T_{15}, but the data can be easily adapted to the T_{15} base. The difference in T_{30} between Pasadena and Mount Wilson was 1.78 seconds, and the difference in gravity 323 mgals (determined by the United States Coast and Geodetic Survey). Using these data and the expression for the period of the instrument

$$T = 2\pi\sqrt{\frac{c1}{c2 - g}}$$

the following formula (approximate) may be derived

$$\Delta g = 355\left(1 - \frac{3}{2}\frac{\Delta T15}{61}\right)\Delta T_{15} \text{ mgals}$$

where Δg is the algebraic difference in g between a given station and Pasadena, and ΔT_{15} the algebraic difference in T_{15} between the two stations.

This corresponds to a sensitivity about 90 times as great as that of an ordinary pendulum, which is in fair agreement with the value 85 calculated from the period and dimensions of the instrument by means of the theory previously given.

Results of field observations

Measurements were made with the pendulum at sixteen stations, four of which had previously been occupied by the United States Coast and Geogetic Survey, and the remaining 12 along a profile across the Los Angeles Basin and San Gabriel Mountains. The latitudes, longitudes, elevations, and values of g for the stations are tabulated in appendix B. The locations of the stations are plotted on plate VII (back pocket of thesis). The observed values of T_{15}, temperature and inclination corrections, drift corrections, corrected values of T'_{15}, the weighted means, and corresponding values of g[1] are tabulated in appendix A.

Stations #3 to #9 to inclusive were repeated a number of times, and are probably accurate to $\pm$ 5 mgals. The remaining stations #10 to #18 (excluding Palmdale previously determined by the U.S.C. &G.S.) are less reliable, and some of the stations may have errors of $\pm$ 10 mgals or possibly greater.

1. Based on the 1933 value for the Washington, D. C. base station of the U.S.C.&G.S. Pasadena #3 value is taken as 979.578 cm/sec^2.

PART V

INTERPRETATION AND GEOLOGICAL SIGNIFICANCE OF THE DATA

Principles involved in the interpretation of the data.

The basis for the interpretation of the data is Newton's inverse square law of gravitational attraction. The problem of calculating the attraction of a given distribution of mass is straightforward and the solution uniquely determined. However. the inverse problem of determining the distribution of mass within a given region,

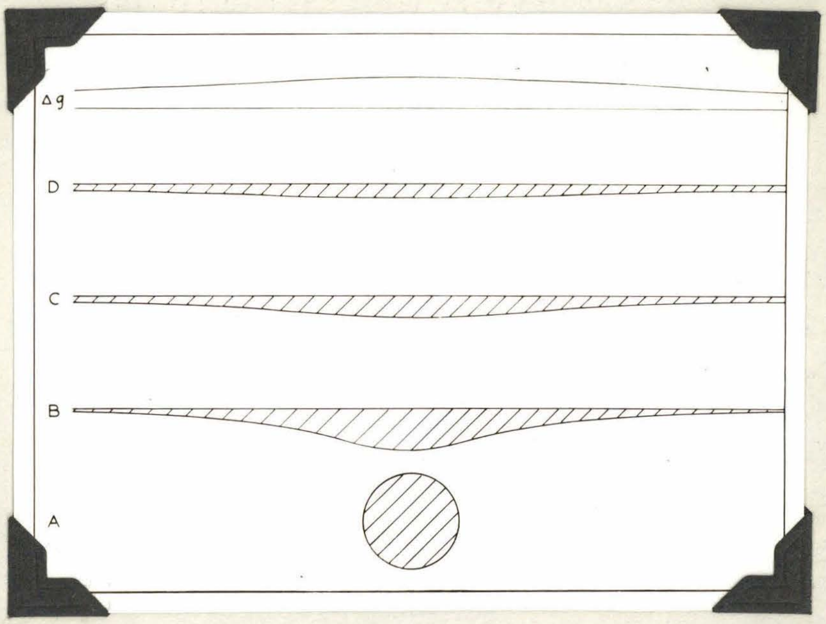


Figure 4

when the gravitational field is known outside the region, has no unique solution. If no restrictions are placed on the density of the attracting matter, there are always an infinite number of mass configurations which will produce identical external fields and therefore sââisfy the data equally well.

The chief difficulty arises from the fact that any distribution of mass, or any part of the distribution, may be replaced by a surface layer of proper surface density on any closed surface surrounding the mass, without effecting the field outside that surface. As an example of this difficulty, a simple hypothetical example is shown in figure 4. The Δg curve shown at the top represents the vertical component of attraction of a long cylinder located at depth A beneath the surface of the ground. At depths B, C, and D are shown distributions of mass which have essentially the same gravitational attraction at the surface as the cylinder. Moreover these distributions are only a few of an infinite number of similar ones which will satisfy the Δg curve equally well. Obviously it is not possible to determine from the gravity data alone which, if any, of the assumed distributions is the actual one. The difficulty which arises frequently is whether given data shall be accounted for by a deep distribution of limited horizontal extent, or by a shallower distribution of greater horizontal extent. The difficulty is further increased by the experimental errors of observation, and the limited data usually available.

However, if it is possible to place sufficient restrictions on the assumed densities of the attracting matter, the lack of uniqueness of solutions largely disappears. Ordinarily in the application of gravity methods to geological problems, it is legitimate as an approximation to assume continuous distributions of mass with the density constant, or varying more or less uniformly in any particular type of rock. In this case many of the solutions mathematically possible may be rejected as artificial and untenable.

Although gravity data by itself is not sufficient to completely and uniquely determine subterranean distributions of mass, when used in conjunction with geologic and other geophysical data it often serves a useful purpose. First it presents a number of possible solutions to the problem, from which it may be possible to select the correct one by use of other evidence, and secondly it serves as a check to eliminate assumptions incompatible with the gravity data.

Methods of Interpretation

The method commonly used in interpreting gravity data is to assume a hypothetical distribution of matter and compare the values of gravity calculated for this model with the observed values. Then by a process of cut and try and recalculation, the model is altered until the discrepancy between observed and computed values disappears.

In the present case, the hypothetical model is built up in the following way. If the earth were an ideal rotating ellipsoid in mechanical equilibrium, that is with its internal surfaces of equal density coinciding with its equipotential surfaces, the value of gravity on its surface (hereafter called the ideal reference ellipsoid) would be given very closely by the ~~next~~ formula.

$$\gamma_o = \gamma_e(1 + a \sin^2 \phi - b \sin^2 2\phi)$$

where γ_e, a, b, are constants, and ϕ the latitude. The values of these constants chosen by the International Geodetic and Geophysical

Union as best fitting existing geodetic and gravity data are given in the following formula

$$\gamma_o = 978.049(1 + 0.0052884 \sin^2 \phi - 0.0000059 \sin^2 2\phi)$$

In the following discussion, γ_o is computed from this International formula, but adjusted to the 1933 value of gravity at the U.S.C.&G.S. Washington base station.

At any limited height h (in feet) above the surface of this hypothetical earth the value of gravity would be

$$\gamma = \gamma_o - 0.0000941\ h \quad \text{cm/sec}^2.$$

Now imagine the land masses of the actual earth to be superimposed on the model, and the ocean basins scooped out and filled with water. The new value of gravity would be

$$\gamma'' = \gamma_o - 0.0000941\ h + \Delta g_t$$

where Δg_t is the attraction of the last added material.

The difference, $g - \gamma'' = \Delta g_H$ (commonly called the Bouguer Anomaly), between the observed values of g and γ'' computed for the model is then to be accounted for by the heterogeneous distribution of densities within the actual earth, and which remains to be superimposed on the model earth. The problem thus resolves itself into finding the distribution of mass which will account for the Δg_H term.

The work of geodesists and geophysicists tends to show that the heterogeneity of the earth is largely confined to its outermost portions, possibly to the upper fifty or one hundred miles. The first few thousand feet of the earth's crust is extremely heterogeneous, as is evident from its intricate and complicated geologic structure.

Also on a large scale there are distinct differences in the rocks of the continental and oceanic areas. The rocks of the continents are lighter than those of the ocean basins.

The extensive invesitgations of Hayford and Bowie and others of the U.S.C.&.G.S. have shown that the Bouger anomalies can be largely accounted for by the assumption of "isostatic compensation", that is that the excess of mass of the topography above sea level is compensated for by underlying rocks lighter than those of lower areas. Most Geologists are in accord that the continental areas are layers of light rock more or less "floating" in the heavier rocks of the substratum and ocean basins. However, as to the details of density distribution there are more diverse opinions. In order to throw further light on the problem, itis desirable to cover any given region with a closer net of gravity stations than is usually possible in the study of large areas of continental size.

Results in Southern California.

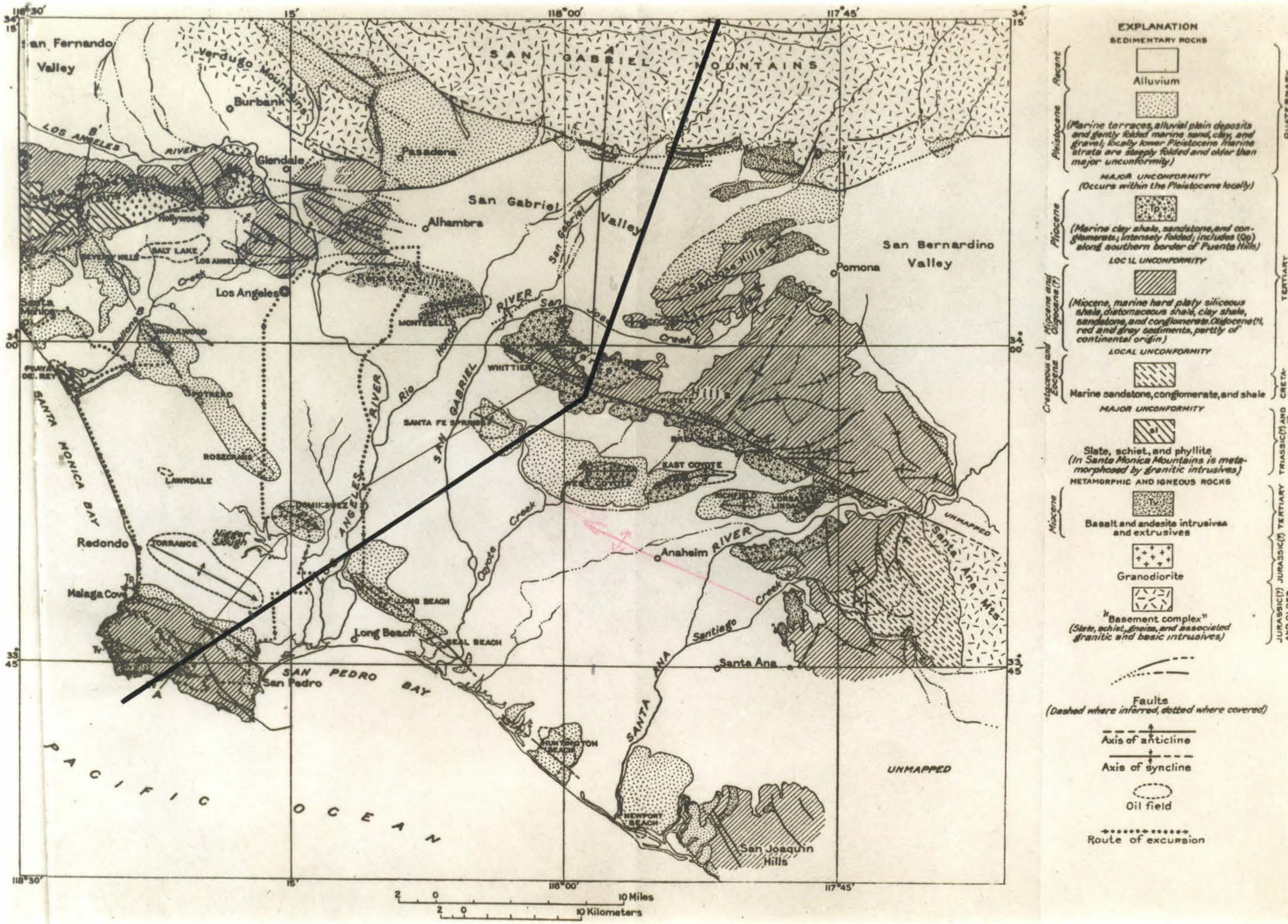
The assumption of isostasy has been remarkably successful in accounting for the Bouger anomalies taken as a whole, but in certain regions there are appreciable isostatic anomalies. In his book "Isostasy"[1], Bowie in 1927 suggested that the lack of agreement between calculated and observed values of g in the Los Angeles Basin could be attributed at least in part to the accumulation of Cenozoic sediments of relatively low density.

The occurrence of a considerable thickness of Tertiary sediments in the Los Angeles Basin has of course long been known to geologists, and estimates of the thickness by them have ranged

1. Pages 99, 164-172. See bibliography.

PLATE V.

Map showing route of reflection seismograph and gravity profiles. Base map taken from the Southern California Handbook of the XVI International Geological congress.


EXPLANATION
SEDIMENTARY ROCKS
Recent
Alluvium
Pleistocene
(Marine terraces, alluvial plain deposits and gently folded marine sand, clay, and gravel; locally lower Pleistocene marine strata are steeply folded and older than major unconformity)
QUATERNARY
MAJOR UNCONFORMITY
(Occurs within the Pleistocene locally)
Pliocene
(Marine clay shale, sandstone, and conglomerate; intensely folded; includes (Qp) along southern border of Puente Hills)
LOCAL UNCONFORMITY
Miocene and Oligocene(?)
(Miocene, marine hard platy siliceous shale, diatomaceous shale, clay shale, sandstone, and conglomerate. Oligocene(?), red and gray sediments, partly of continental origin)
TERTIARY
LOCAL UNCONFORMITY
Cretaceous and Eocene
Marine sandstone, conglomerate, and shale
CRETACEOUS
MAJOR UNCONFORMITY
Slate, schist, and phyllite
(In Santa Monica Mountains is metamorphosed by granitic intrusives)
TRIASSIC(?) AND JURASSIC(?)
METAMORPHIC AND IGNEOUS ROCKS
Miocene
Basalt and andesite intrusives and extrusives
TERTIARY
Granodiorite
JURASSIC(?)
"Basement complex"
(Slate, schist, gneiss, and associated granitic and basic intrusives)
JURASSIC(?) AND OLDER
Faults
(Dashed where inferred, dotted where covered)
Axis of anticline
Axis of syncline
Oil field
Route of excursion
San Fernando Valley
Verdugo Mountains
SAN GABRIEL MOUNTAINS
Burbank
Glendale
Pasadena
LOS ANGELES RIVER
Hollywood
SALT LAKE
Los Angeles
Alhambra
San Gabriel Valley
San Bernardino Valley
Pomona
MONTEBELLO
WHITTIER
Rio Hondo
SAN GABRIEL RIVER
SANTA FE SPRINGS
PUENTE HILLS
EAST COYOTE
Coyote Creek
INGLEWOOD
PLAYA DEL REY
POTRERO
ROSECRANS
LAWNDALE
DOMINGUEZ
SANTA MONICA BAY
Redondo
TORRANCE
Nigger Slough
Malaga Cove
Long Beach
LONG BEACH
SEAL BEACH
San Pedro
SAN PEDRO BAY
Anaheim
SANTA ANA RIVER
Santiago Creek
Santa Ana
Santa Ana Mts
UNMAPPED
HUNTINGTON BEACH
NEWPORT BEACH
San Joaquin Hills
PACIFIC OCEAN
118°30′
15′
118°00′
117°45′
34° 15′
34° 00′
33° 45′
10 Miles
10 Kilometers

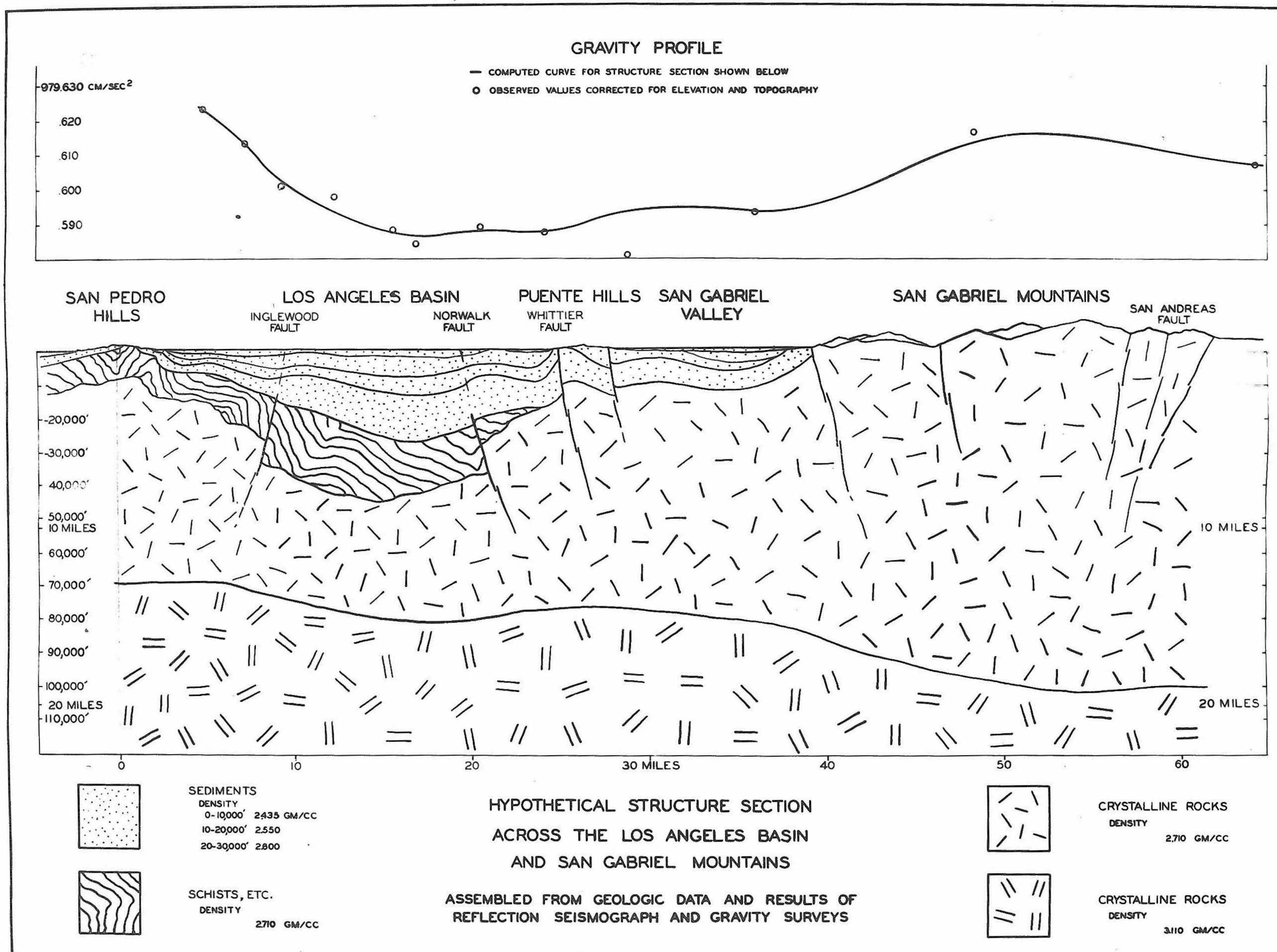
from fifteen thousand to fifty thousand feet. In the summer of 1931, Drs. B. Gutenberg, H. O. Wood, and J. P. Buwalda did some preliminary reflection seismograph work in the Los Angeles Basin[1]. In 1934 Drs. Gutenberg and Buwalda completed a reflection seismograph profile across the Los Angeles Basin and San Gabriel Valley approximately along the route shown in plate V.[2]

Some very interesting results were obtained. A number of reflections were recorded at each station, with the latest reflections coming from greater and greater depths as the center of the basin was approached. Also at the Inglewood and Norwalk faults marked discontinuities were encountered, with the deepest reflections suddenly dropping off from about a twenty or twenty five thousand foot depth on each side of the basin to much greater depths reaching forty five thousand feet in the center of the basin.

The question arises whether the Tertiary and possibly Cretaceous sediments of the basin are forty five thousand feet thick, or whether the deepest reflections are from the contact between rocks of the Fransican (Jurassic) and related formations and the crystalline "basement complex" rocks known to underly the region of Southern California. The gravity data tend to favor the latter alternative. In plate VI a hypothetical structure section is shown along the profile shown in plate V and its extension across the San Gabriel Mountains to the Mojave Desert. The plate is more or less self-explanatory, with a basin of sediments about thirty thousand feet deep in its deepest portion; next ten to twenty thousand feet of slates, schists,

1. "Experiments Testing Seismographic Methods etc." See Bibliography
2. Results presented at the thirty fourth annual meeting of the Geological Society of America, Cordilleran Section, Stanford University, 1935.

PLATE VI.



HYPOTHETICAL STRUCTURE SECTION
ACROSS THE LOS ANGELES BASIN
AND SAN GABRIEL MOUNTAINS

ASSEMBLED FROM GEOLOGIC DATA AND RESULTS OF
REFLECTION SEISMOGRAPH AND GRAVITY SURVEYS

and related metamorphic rocks, similar to those exposed in the Santa Monica Mountains, San Pedro Hills, and Santa Ana Mountains, and with their lower contact conforming roughly to the results of the reflection seismograph data; then a layer of variable thickness of crystalline "basement complex" rocks, resting in turn on denser and more basic rocks shown at the bottom of the section.

In the top half of the plate are shown the values of gravity calculated for the section, and the observed values (corrected for elevation and topography). Except for one point (station #14) the agreement between the obverved and calculated values is well within the limits of experimental error (about five to ~~10~~ ten mgals). The calculated values were computed by the **formula**

$$g_c = \gamma_o + \Delta g_H'$$

where $\Delta g_H'$ is the contribution due to the deficiency of density (as compared with that of the "basement complex") of the sediments, and of the projection of lighter crystalline rocks into the denser rocks below seventy thousand feet, with an added arbitrary constant, as explained in appendix C. The attraction Δg_H was computed by using a template placed on the structure section, and counting the squares over each area of different density, and for each gravity station. The process amounted to a graphical integration. The section was treated as a two dimensional one (that is, with infinite extent in a direction normal to the section), and the "basement complex" layer was assumed to extend infinitely with a thickness of seventy thousand feet to the left of the diagram and of one hundred and five thousand feet to the right of the diagram. These assumptions, while not strictly corresponding to reality, greatly simplify computations, and are justified because of the limited amount of data available.

In the calculations it was of course necessary to assume densities for the different rock types. The assumed values are shown with the symbols for the rock types at the bottom of plate VI. The density of 2.710 gm/cc assumed for the "basement complex" is based on the mean of the densities determined for fifty specimens collected mainly from the San Gabriel Mountains. The Franciscan and related rocks were assumed to have the same density because of the lack of more definite information. The mean density for eleven oil well core samples all taken from Tertiary sediments, and furnished by Mr. Edward Lynton of the Standard Oil Company of California, was 2.35 gm/cc. On the basis of this figure, the density of the first ten thousand feet of sediments was taken as 2.435 gm/cc, allowing a small increase due to compaction and water content in situ. For the sediments between ten and twenty thousand foot depths, a density of 2.550 gm/cc was assumed, and below twenty thousand feet, 2.600 gm/cc. For the density of sediments above sea level a density of 2.30 was assumed. For the lowermost crystalline rocks a density of 3.110 gm/cc was assumed.

The structure section must not be considered as anything but hypothetical. It may possibly resemble the true section in its broader features. However, in many respects it is undoubtedly over-simplified and inaccurate. The assumption of homogeneous densities in the various rock types can only be regarded as a first approximation to the complexity and heterogeneity actually existing. Because of the lack of uniqueness of solution previously discussed and the relatively large experimental errors, there is no assurance that other sections could not be assumed which would fit the gravity data equally well and satisfy the requirements of geologic plausibility. Specifically the assumed shape and depth of the sedimentary basin could be altered somewhat by assuming different densities. The boundary between the light and heavy crystalline rocks could be placed at lesser or greater depths by broadening or accentuating respectively its irregularities. The layer of "basement complex" rocks might be replaced by several layers of different densities, or again by a single layer of constant thickness, but with decreasing density in the direction of the San Gabriel Mountains.

However, there are limits to the variations possible, and certain general conclusions may be stated. First, the maximum thickness of the Tertiary sediments in the Los Angeles Basin may be somewhat greater or less than thirty thousand feet, but probably not as great as forty five thousand feet. Secondly, the increasing elevation of the land surface is isostatically compensated, at least in a qualitative and regional way.

If a speculative digression is permissible, one of the interesting points concerning the structure section of plate VI (which is drawn with equal horizontal and vertical scales) is that features such as the San Gabriel Mountains, which appear to tower above the observer when viewed from the ground, are relatively insignificant irregularities on the surface of the earth's crust. The mechanical behaviour of rocks under conditions existing at depth is very incompletely known, but it is probably a reasonable assumption that they have appreciable strength down to a depth of fifteen or twenty miles. Since the height of the surface inequalities is quite small compared with this thickness, the shearing stresses required for their support are relatively small, and hence the more local irregularities of limited horizontal extent wouldnot be expected to be isostatically compensated. However, surface undulations of large horizontal extent would be expected to cause broad warping and adjustment of the crust with resulting isostatic compensation on a regional scale. This is the old problem of regional versus local isostatic compensation.

It would seem in the present case that the surface irregularities represented by the San Gabriel Mountains and the Los Angeles Basin are largely due to the failure by shortening of the earth's crust under the action of horizontal compression, that these features may be partially compensated by local adjustments at depth, but that the most important adjustments have been on a broader scale. More specifically, the region owes its general elevation above sea level to the increasing thickness of a layer of light rocks, or its equivalent, while the San Gabriel Mountains and Los Angeles Basin are irregularities supported largely by the strength of the upper parts of the earth's crust. This opinion is, of course, only a speculation.

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APPENDIX A.

Calibration of Instrument

Record	T_{30}	Temperature Correction to 57.50°F	Inclination Correction	T'_{30}	Weight	
3B	122.43	+.05	+.01	122.49	1	Pasadena
C	.29	+.07	+.07	.43	1	
D	.42	+.07	+.01	.50	1	
E	.69	-.20	+.00	.49	1	
G	.47	-.10	+.05	.42	1	
H	.51	-.03	+.00	.48	1	

Mean $122.47 \pm .03$ sec.

$g = 979.578$ cm/sec^2.

Record	T_{30}	Temperature Correction	Inclination Correction	T'_{30}	Weight	
4A	120.62	+.07	+.00	120.69	1	Mt. Wilson
B	.67	+.03	+.01	.71	1	
C	.61	+.00	+.05	.66	1	
D	.70	-.02	+.01	.69	1	

Mean $120.69 \pm .01$ sec.

$g = 979.255$ cm/sec^2.

Record	T_{15}	Drift Correction	Temperature Correction to 20° C.	Inclination Correction	T'_{15}	Weight
3J	61.105		-0.19	+.035	60.950	1/4
K	.155		-0.22	+.002	.935	1/4
L	.025		-0.20	+.015	.840	1/2
M	.075		-0.20	+.001	.875	1
N	60.995		-0.11	+.004	.890	1
O	.995		-0.11	+.004	.885	1
O'	.995		-0.11	+.004	.885	1
P	61.166	+.015	-0.32	+.000	.860	1/2
Q	.150	+.015	-0.32	+.000	.845	1/4
Q'	.140	+.015	-0.32	+.000	.835	1/4
U	60.905		-0.02	+.002	.885	1
V	.860		-0.02	+.035	.875	1
W	.860		-0.02	+.035	.875	1
X	.570		+0.31	+.015	.895	1
Y	.550		+0.31	+.021	.880	1
Z	.550		+0.31	+.015	.875	1
AA	61.025		-0.11	+.000	.915	1
AB	60.960		-0.11	+.000	.850	1
AC	.975		-0.11	+.000	.860	1

Mean 60.881 ± .010 sec.

$g = 979.578 \text{ cm/sec}^2$

5A	61.145		-0.29	+.000	60.855	1
B	.140		-0.29	+.000	.850	1
C	60.990		-0.19	+.000	.800	1
D	61.040		-0.19	+.000	.850	1
E	60.960		-0.07	+.000	.890	1
F	60.955		-0.07	+.000	.885	1
F'	.945		-0.07	+.000	.875	1
G	.960		-0.09	+.000	.870	1
H	.955		-0.09	+.000	.865	1
H'	.940		-0.09	+.000	..850	1

Mean: 60.857 ± .015 sec.

$g = 979.569 \text{ cm/sec}^2$.

Record	T_{15}	Drift Correction	Temperature Correction to 20° C.	Inclination Correction	T'_{15}	Weight
6C	60.065		−0.19	+.010	60.885	1
D	.085		−0.19	+.000	.895	1
G	.950		−0.05	+.000	.900	1
H	.955		−0.05	+.000	.905	1
J	.980		−0.07	+.005	.915	1
K	.945		−0.07	+.005	.880	1/2
K'	.950		−0.07	+.005	.885	1/2
N	.935	+.015	−0.05	+.000	.900	1/4
O	.925	+.015	−0.05	+.000	.890	1/4

Mean 60.897 ± .010 sec.

g = 979.584 cm/sec^2.

7A	61.170		−0.18	+.035	61.025	1
B	.200		−0.18	+.005	.025	1
C	60.985	+.015	−0.02	+.0000	60.980	1
D	61.015	+.015	−0.02	+.000	61.010	1
E	.065	+.015	−0.09	+.000	60.990	1
F	.065	+.015	−0.09	+.000	.990	1

Mean 61.003 ± .015 sec.

g = 979.621

8A	60.930		−0.04	+.000	60.890	1
B	.920		−0.04	+.000	.880	1
B'	.920		−0.04	+.000	.880	1
C	.965		−0.07	+.000	.895	1
D	.965		−0.07	+.000	.895	1
D'	.945		−0.07	+.000	.875	1

Mean 60.886 ± .010

g = 979.580 cm/sec^2

9A	60.997		−0.06	+.000	60.935	1
B	.947		−0.06	+.000	.885	1
B'	.950		−0.06	+.000	.890	1
C	.970		−0.08	+.000	.890	1
D	.940		−0.08	+.010	.870	1

Mean 60.894 ± .015 sec.

g = 979.583 cm/sec^2.

Record	T_{15}	Drift Correction	Temperature Correction to 20° C.	Inclination Correction	T'_{15}	Weight
10A	61.135	+.015	-.31	.000	60.840	1/8
B	.190	+.015	-.31	+.005	.900	1/4
C	.010	+.015	-.07	.000	.955	2
D	60.955	+.015	-.07	.000	.900	1/4
				Mean	60.938 ± .030 sec.	
					g = 979.599 cm/sec².	
11A	61.140	+.015	-.21	.000	60.945	1/2
B	.120	+.015	-.21	.000	.925	1/4
B'	.110	+.015	-.21	.000	.915	1/4
C	.045	+.015	-.07	.000	.990	1
D	.040	+.015	-.07	.000	.985	1
				Mean	60.970 ± .030 sec.	
					g = 979.610 cm/sec².	
12A	61.060	+.015	-.12	+.010	60.965	1/3
B	.020	+.015	-.12	+.010	.925	1/3
B'	.035	+.015	-.12	+.010	.940	1/3
C	.055	+.015	-.07	+.005	61.005	1
D	.090	+.015	-.07	+.010	.045	1
				Mean	60.998 ± .035 sec.	
					g = 979.620 cm/sec².	
13A	60.940	+.015	-.02	.000	60.935	1
B	.915	+.015	-.02	.000	.910	1
B'	.930	+.015	-.02	.000	.925	1
				Mean	60.923 ± .010 sec.	
					g = 979.593 cm/sec²	
14A	60.715		+.12	.000	60.835	1
B	.710		+.12	.000	.830	1
C	.710		+.12	.000	.830	1
				Mean	60.832 ± .002 sec.	
					g = 979.560 cm/sec²	

Record	T_{15}	Drift Correction	Temperature Correction to 20° C.	Inclination Correction	T'_{15}	Weight
15A	60.580		+.27	.000	60.850	1
B	.550		+.27	.000	.820	1
C	.535		+.27	.000	.805	1/2
				Mean	60.829 ± .015 sec.	
				g =	979.559 cm/sec^2.	
16A	60.460		+.13	+.005	60.595	1
B	.445		+.13	.000	.575	1
C	.425		+.13	.000	.555	1
D	.305		+.27	.000	.575	1
E	.320		+.27	.000	.590	1
F	.305		+.27	.000	.575	1
G	.210		+.34	.000	.550	1
H	.250		+.34	.000	.590	1
I	.265		+.34	.000	.605	1
				Mean	60.579 ± .015 sec.	
				g =	979.467 cm/sec^2.	
17A	60.110		+.33	.000	60.440	1
B	.030		+.33	.000	.360	1/2
C	.065		+.33	.000	.395	1
				Mean	60.406 ± .030 sec.	
				g =	979.404 cm/sec^2.	
18A	60.740		-.12	.000	60.620	1
B	.715		-.12	.000	.595	1
C	.720		-.12	.000	.600	1
				Mean	60.605 ± .010 sec.	
				g =	979.479 cm/sec^2.	

APPENDIX B.

Location of Stations

Station	g	Longitude	Latitude	Elevation	Location
3	979.578	118°07.59'	34°08.20'	756'	Pasadena, Calif. Inst. of Technology, parking lot between Astrophysics and West Bridge buildings.
4	979.255	118°03.4'	34°13.4'	5,610±'	Mt. Wilson, interferometer pier used in Michelson's determination of the velocity of light.
5	979.569	117°59.15'	33°56.18'	277'	Santa Fe Ave., 300' west of First Ave.
6	979.584	118°06.47'	33°51.54'	53'	Palo Verde Ave., 200' north of First St. (Orangethorpe Ave.).
7	979.621	118°11.55'	33°46.41'	35'	Long Beach, intersection of alleys 250' northwest of Fifth and Pine
8	979.580	118°05.08'	33°52.40'	58'	Artesia Ave., 900' west of Pioneer Blvd. (Norwalk to Puente road).
9	979.583	118°02.24'	33°54.47'	88'	Road 0.5 mile west of Valley View Ave., 1800' north of Santa Fe tracks.
10	979.599	118°12.77'	33°49.85'	29'	200' south of Carson St., 2900' west of Los Angeles River.
11	979.610	118°14.72'	33°49.27'	26'	1200' south of 223 St. (Wilmington St.), 150' west of Wilmington Ave.
12	979.620	118°17.08'	33°48.42'	18'	400' southwest of intersection of Figueroa St. and Long Beach-Redondo Rd.
13	979.593	118°09.90'	33°50.86'	54'	900' northeast of intersection of Cherry and San Antonio Avenues.

Station	g	Longitude	Latitude	Elevation	Location.
14	979.560	117°57.70'	34°00.76' .663	327'	Hacienda Blvd., (Hudson Rd.) 800' south of Union Pacific Tracks.
15	979.559	117°54.38'	34°06.42' .671	521'	Bonita Ave., 100' east of Azusa Ave.
16	979.467	118°07.00'	34°34.76' .710	2,657'	Palmdale, 25' south of Southern Pacific Depot.
17	979.404	117°45.88'	34°29.93' .703	3,410'	Palmdale-Victorville Highway, one mile north of Larga Vista.
18	979.479	117°50.62'	34°15.80' .684	2,270'	450' north of junction of the north fork of the San Gabriel River and Bichota Creek.

APPENDIX C

REDUCTION OF GRAVITY DATA

Corrections for elevation and topography.

As explained in the text of the thesis, the effect of the elevation of a station on the value of gravity is given by

$$\Delta\gamma_0 = - 0.0000941 \text{ h cm/sec}^2$$

where h is the elevation of the station (measured in feet) above the ideal reference ellipsoid. However, the elevation of a station as determined by leveling operations is referred to the geoid (the equipotential surface coinciding with mean sea level). In the ideal earth the two surfaces coincide, but in the actual earth, because of the heterogeneous distribution of mass, the two do not coincide. The most recent geodetic work suggests that the undulations of the geoid above and below the reference ellipsoid amount to about one hundred meters at most and are broad in horizontal extent. Hence for the limited region being studied, the amount of undulation may be regarded as an unknown, but a practically constant quantity over the length of the profile. Hence in place of h we may use the elevation e of the station, and add an arbitrary constant to the calculated values of g at all stations to bring the calculated and observed values into agreement.

Stations #5 to #15 are located on the very flat terraine of the Los Angeles coastal plain, and the San Gabriel Valley. Hence the attraction of topography within a few hundred miles of each station is essentially the same as that of an infinite horizontal slab of material of the same thickness and density as the rocks below the station down to sea level. The attraction of topography and crustal heterogeneities outside of this range is essentially the same for all stations and may hence be taken care of by the addition of an arbitrary constant. Assuming a density of 2.30 gm/cc for the rocks above sea level (mainly Quaternary sediments), we get the following simple formula for Δg_t

$$\Delta g_t = 0.0000294 \, e \quad cm/sec^2,$$

where e = elevation in feet above sea level.

Hence, for these stations, the values plotted on plate VI as "observed values corrected for elevation and topography", are given by

$$g' = g_{obs} + 0.0000941 \, e - 0.0000294 \, e$$

$$= g_{obs} + 0.0000647 \, e \ cm/sec^2.$$

At stations # 17 and #18, a density of 2.71 gm/cc was used in place of 2.30 gm/cc, and account was taken of the more rugged topography.

Calculation of computed gravity curve.

As explained on page 27 of the text, the object in the interpretation of gravity data is to find a distribution of mass which will account for the Bouger anomalies,

$$\Delta g_H = g - \gamma''.$$

In the study of large areas, where gravity stations are widely spaced, it is customary to assume some relatively simple form of isostatic compensation whose attraction can be conveniently calculated. In this case the calculated attractions do not in general agree completely with the Bouger anomalies. The discrepancy is called the "isostatic anomaly", which of course depends on the particular type of isostatic compensation assumed.

In the present case where a relatively small region is being studied, and the gravity stations are reasonably close together, a somewhat different procedure was used. By cut and try, the structure section was altered until the attraction due to the heterogeneity agreed with the Bouger anomaly, Δg_H, within the limits of experimental error. The values plotted in the "computed curve" of plate VI are given by

$$g_c = \gamma_o + \Delta g_H'$$

where $\Delta g_H'$ is the contribution due to the deficiency (compared with 2.710 gm/cc) of density in the sedimentary basin, and the projection of rocks of density 2.710 gm/cc below seventy thousand feet, replacing rocks of density 3.110 gm/cc. In addition an arbitrary constant, +0.042 cm/sec^2, is included in $\Delta g_H'$ at all stations in order to bring the observed and calculated values into agreement.

The observed and computed values of gravity and other data are tabulated on the following page.

Station	g_{obs}	γ_o	$\Delta\gamma + \Delta g_t$	γ''	$\Delta g_H = g - \gamma''$	$\Delta g_H'$	$g_c = \gamma_o + \Delta g_H'$	$g' = g_{obs} - \Delta\gamma - \Delta g_t$	$g' - g_c$
12	979.620	979.645	-.001	979.644	-.024	-.024	979.621	979.621	0.000
11	.610	.646	-.002	.644	-.034	-.034	.612	.612	0.000
10	.599	.647	-.002	.645	-.046	-.045	.602	.601	-0.001
13	.593	.648	-.004	.644	-.051	-.055	.593	.597	+0.004
6	.584	.649	-.004	.645	-.061	-.062	.587	.588	+.001
8	.580	.650	-.004	.646	-.066	-.064	.586	.584	-.002
9	.583	.653	-.006	.647	-.064	-.065	.588	.589	+.001
5	.569	.656	-.018	.638	-.069	-.069	.587	.587	.000
14	.560	.662	-.021	.641	-.081	-.068	.594	.581	-0.013
15	.559	.670	-0.034	.636	-.077	-.077	.593	.593	0.000
18	.479	.684	-.139	.545	-.066	-.069	.615	.618	+0.003
17	.404	.704	-.0203	.501	-.097	-.097	.607	.607	0.000

Where Mt. Wilson g_o''