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Gravity Measurements between Hazen and Austin, Nevada: A Study of Basin-Range Structure

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Abstract—From the pendulum base stations at Mystic and Truckee, California, a line of gravimeter stations, with side loops, was extended eastward through Hazen, Fallon, Eastgate, and Austin, Nevada, crossing the area displaced by faults in 1954. Regionally, the Bouguer anomaly is about −160 mgal from Hazen eastward through Fallon to the Stillwater Range. Farther east the values decrease to −215 mgal near Austin, a change that can be accounted for by isostatic compensation for the increase in average elevation of about 1700 ft. Low-density sedimentary and volcanic debris is abundant enough in the intermontane basins and in parts of the mountains to make the average density of the whole elevated land mass abnormally low with respect to the conventional value, 2.7 g/cc. Consequently, 10 to 15 pct of the compensation for this high region is in the superficial materials themselves. The Basin Ranges show no evidence of being individually compensated.

Locally, each of the basins has a negative Bouguer anomaly relative to the adjacent ranges, reflecting thick sedimentary and volcanic fill. Dixie and Fairview Valleys, in the area displaced by faults in 1954, are characterized by local negative anomalies of about 30 mgal, indicating that these valleys contain several thousand feet of lightweight Cenozic sediments and that their bedrock floors lie below sea level. The 1954 faulting is thus only the latest of many displacements that produced not only the visible topographic relief of 5000 ft but also a buried relief of comparable magnitude.

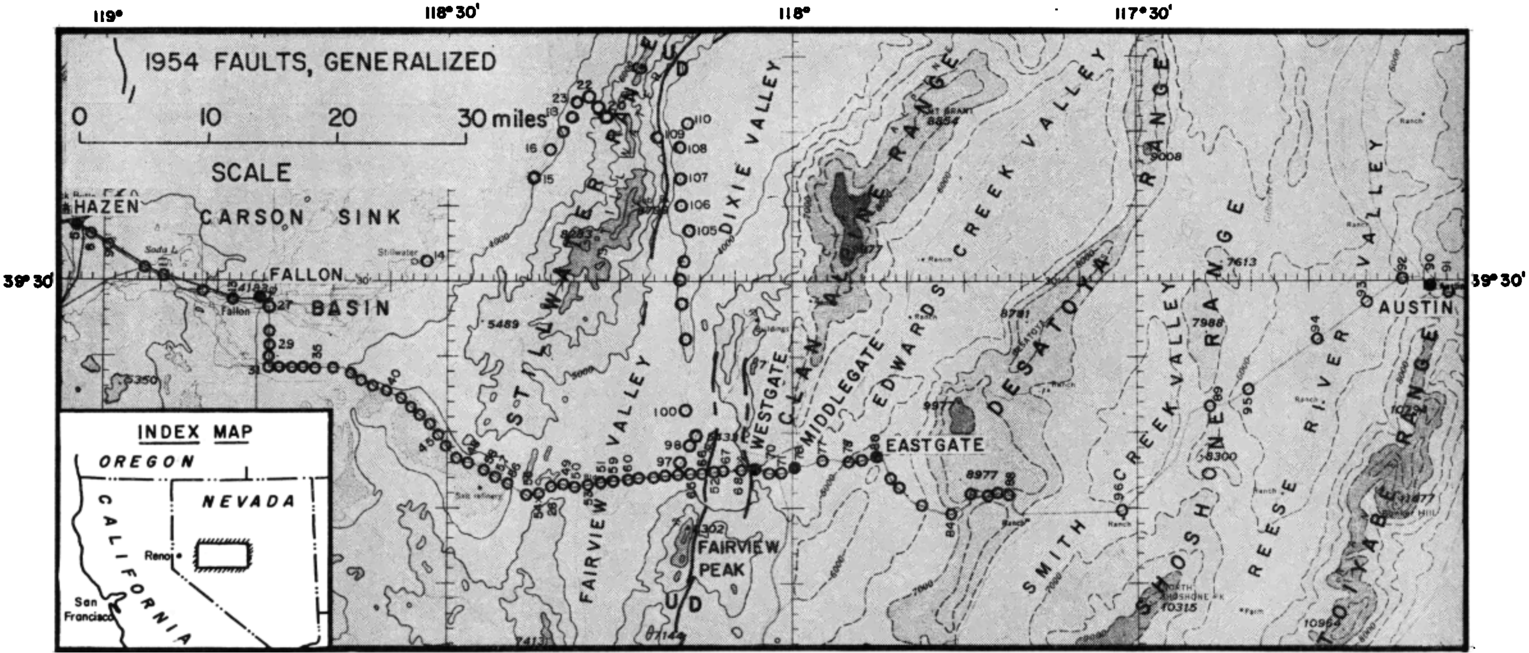
Romney's [1957] seismic studies of the 1954 faulting and *Whitten's* [1957] geodetic measurements agree with direct observations of fault surfaces to indicate a horizontal extension of about 5 ft normal to the trace of the fault. Independent of a strike-slip component of faulting, the region is expanding in area. If the total structural relief was produced by displacements comparable to that of 1954, the extension across Dixie and Fairview Valleys amounts to about 1½ mi in roughly 15 million years, and if this is taken as a fair sample of the Basin and Range Province, the rate of distension in the Province is about 1 ft/century, a rate well within that of historical fault displacements.

At the time of the 1954 faulting, the Bouguer gravity anomaly either did not change or decreased algebraically by an amount no greater than 1.0 mgal.

Introduction—The region under study lies in the Basin and Range Province in west-central Nevada and includes an area broken by faults in 1954 (Fig. 1).

Gravity measurements were undertaken to aid in understanding the structural history. Fault movements associated with the earthquakes of December 16, 1954, provide a dynamic demonstration of basin and range structures in the making. From July to December a series of earthquakes shook a large area centered east of Fallon, and two main shocks on December 16 were accompanied by surface breaks extending discontinuously for sixty miles in a northerly direction and having displacements of several feet [*Slemmons*, 1957]. The region is advantageous for study because it is crossed by a first-order triangulation net and a first-order line of levels, and also because the 1954 movements have been accurately measured by re-surveying [*Whitten*, 1957]. But the 1954 movements are only the latest of a long series of displacements during the latter part of the Cenozoic era, and gravity data help to determine the total displacement by indicating the thickness of light-weight fill in the basins. Structural movements in the Basin and Range Province are of special interest because the region is broken up by normal faults and, unlike many mountain regions, appears to be undergoing distension.

Gravity data also give an indication of the degree of regional and local isostatic balance, a matter of great interest because of its bearing on the problem of how isostatic compensation is



Base from USC & GS

FIG. 1—Map of gravity stations, Hazen to Austin, Nevada

maintained as a broad region is raised to a high elevation. Another question that was investigated is whether a measurable change in gravity took place as a result of sudden shifting of masses during the faulting in 1954.

Gravity measurements—Gravity measurements were made in the summer of 1956 with Stanford's North American gravimeter operating with a sensitivity of 0.1263 mgal per scale division. The primary base station for all readings is the pendulum station of the U. S. Coast and Geodetic Survey at Mystic, California [*Duerksen*, 1949]. Another pendulum station, at Truckee, California, was tied to the Mystic station by gravimeter readings (Station 75, appendix). The pendulum determinations are stated only to the nearest mgal, but relative measurements by gravimeter are made to the hundredth of a mgal; hence the base value at Mystic, which is given as 979,630 mgal, was assumed to be 979,630.00 mgal.

The Bouguer anomaly as used in this paper is determined (in mgal) as:

$$\underset{\substack{\text{Gravity}\\ \text{at Mystic, US}\\ \text{C \& GS}}}{g_{Mv}} + \underset{\substack{\text{Observed}\\ \text{difference}\\ \text{from Mystic}}}{g_d} + \underset{\substack{\text{Elevation and}\\ \text{simple Bouguer}\\ \text{corrections; } h \text{ is}\\ \text{altitude in ft}}}{0.05998\,h} - \underset{\substack{\text{Theoretical}\\ \text{gravity at}\\ \text{sea level}}}{g_0}$$

Combined corrections for tidal variation and instrument drift were made by returning to a previously occupied station about every two hours during each day. These corrections, which are incorporated in the 'observed difference from Mystic,' amount to roughly the expected tidal variation; the instrument itself was very stable. Terrain corrections were not made because no topographic maps are available for part of the region surveyed. Terrain corrections to a radius of 13.6 mi made by C. H. Sandberg in a similar region in western Nevada amounted to only about 2 mgal at most of the stations and a maximum of 10 mgal at one station [*Thompson* and *Sandberg*, 1958].

The precision of the field measurements is estimated to be within 0.1 mgal, assuming that the calibration constant of the instrument is correct within 0.1 pct. The calibration constant, originally determined by the Stanolind Oil and Gas Company, Tulsa, Oklahoma, was checked against other instruments, against the difference in observed gravity between pendulum stations, and against the change with elevation in a tall building; these measurements all agree in showing that the calibration constant is correct to better than 0.2 pct. Elevations of nearly all of the stations are known within 0.1 ft because the stations are at bench marks; hence elevation corrections have a precision of 0.01 mgal. A density of 2.67 g/cc was used in making the Bouguer correction, following the standard practice of the Coast and Geodetic Survey. The actual average density of pre-Cenozoic rocks that crop out in the mountains is probably within the range 2.6–2.8 g/cc. *Birch* [1950, p. 608] found an average of 2.67 in the Front Range of Colorado, and *Thompson* and *Sandberg* [1958] found densities within the stated range in western Nevada. The Cenozoic rocks, on the other hand, are generally much less dense.

Most of the gravity determinations were made with the instrument set up either directly over, or within a few feet of, permanent bench marks. Where the station was not directly over a bench mark, the elevation was determined from the bench mark by means of a hand level. Station locations are shown in Figure 1 and data are tabulated in the appendix.

Regional gravity and isostasy—The Bouguer anomaly averages −160 mgal in the western part of the area (Fig. 2) and −215 mgal in the eastern part. The change in anomaly from west to east, −55 mgal, indicates that an added slab of rock of density 2.67 g/cc and 1600 ft thick can be supported isostatically. The actual increase in average altitude over the same distance is estimated from topographic maps to be 1700 ft, which is in reasonably close agreement. The broad variations in Bouguer anomaly are thus related to isostatic compensation. Further support for this conclusion is provided by reconnaissance measurements which were extended westward from the area of Figures 1 and 2 to connect with a previously studied area near the Sierra Nevada, [*Thompson* and *Sandberg*, 1958]. In the regional picture that emerges, the basin of Carson Sink forms a gravity high and topographic low; westward toward the Sierra and eastward toward the higher Basin Ranges, the Bouguer anomaly grows more negative as the average altitude increases. This inverse relation between the Bouguer anomaly and the altitude of the land is the normal condition to be expected wherever compensation exists.

Although the pattern of the anomalies indi-

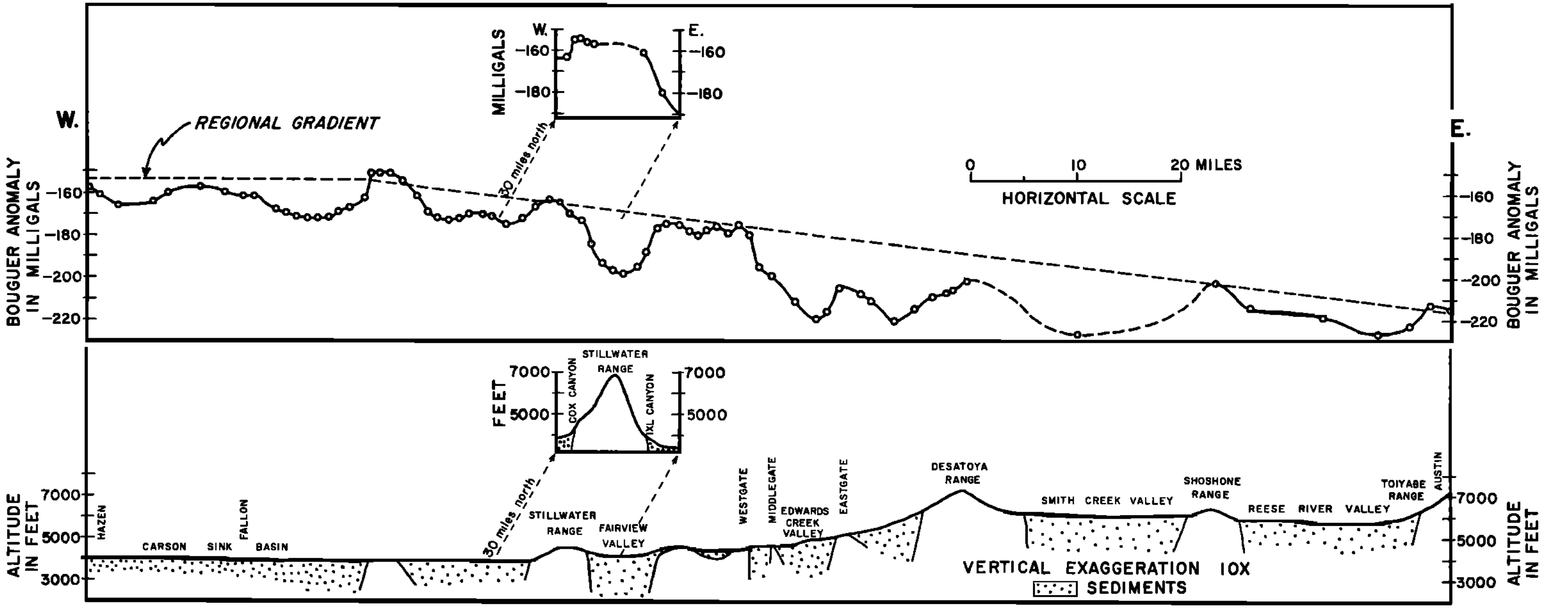


FIG. 2—Gravity profile and section, Hazen to Austin, Nevada

cates an approximation to regional isostatic balance, the average Bouguer anomaly appears to be roughly 10 pct larger than required for exact compensation. Stated in another way, the free-air anomaly averages about −20 mgal and is positive only at a few stations in the higher parts of the mountains. Part of this discrepancy may be attributed to a lack of terrain corrections and part to the (negative) attraction of compensating material of low density under the higher mountains lying east and west of the area, but negative isostatic anomalies at the pendulum stations in Nevada [*Duerksen*, 1949] suggest that these effects are not sufficient to explain all the discrepancy. Over-compensation sufficient to support topography a few hundred feet higher throughout the region is one possible interpretation. In any case the departure from regional compensation is small; compensation can safely be estimated at 100 pct ± 10 pct.

Apart from the degree of compensation is the interesting problem of the depth and form of the compensating material. Part of the compensation in this region, perhaps 10 pct to 15 pct of the total, must be in the uppermost part of the crust. That conclusion follows from the large amount of low density material in the basins (and parts of the mountains) as discussed in this paper. Probably more than half of the material above sea level is sedimentary debris and volcanic debris of low density. Assuming that half the material above sea level has an average density of 2.2 g/cc (Table 1) and the other half is rock of average density 2.7 g/cc, the average of all the material above sea level is approximately 2.4 g/cc. The difference between this average and 2.67 g/cc, the value assumed in computing the Bouguer anomaly, is 0.3 g/cc, an amount sufficient to account for 10 pct of the Bouguer anomaly. But the low-density material also extends below sea level in some of the basins, and it may possibly account for as much as 15 pct of the anomaly, on the average. Viewed another way, the upper part of the crust is less dense than usual and thus requires less compensating material at depth to support a given surface altitude.

The remainder (major part) of the compensation is probably not entirely effected by unusually light rocks within the crust, because this would require a density contrast of nearly 0.2 g/cc throughout the entire thickness of the crust. Variation in crustal thickness is generally thought to account for the compensation, but variations within the mantle are an additional possibility [*Tatel* and *Tuve*, 1955, p. 50].

Compensation and structure of basin ranges—No evidence of local compensation of the ranges can be found in the gravity data (Fig. 2). Ranges should show local negative Bouguer anomalies if they are compensated. ('Local anomaly' as used here refers to the anomaly in the ranges relative to that in the adjacent lowlands; the meaning is identical with the residual anomaly of exploration geophysics except that the residual anomaly is usually computed for much smaller areas.) In contrast to the regional picture, in which the Bouguer anomaly varies inversely with altitude and indicates compensation, the anomaly varies locally directly with altitude. It may be argued that use of a larger density than 2.67 g/cc for computing the Bouguer anomaly in the ranges would make the local anomalies negative. In order to make them negative, however, an improbably large density must be assumed. For example, on the west side of the Desatoya Range, where the anomaly varies directly with altitude, a density greater than 3.3 g/cc would be required in order to reverse the gradient of the anomaly, but such a large density is absurd. The rocks exposed in the range are light-weight rhyolite tuffs, and the anomaly is interpreted as indicating thinning of the tuffs toward the axis of the range.

Elsewhere in western Nevada, parts of the basins are free of sediments and a direct comparison of Bouguer anomalies in the ranges with those in sediment-free basins also fails to show local compensation [*Thompson* and *Sandberg*, 1958].

A lack of local compensation rules out any hypothesis of structural history that requires the formation of compensating roots beneath the ranges. For instance, a hypothesis of compressional folding and local thickening of the crust, followed by isostatic uplift of the thickened parts into ranges, is not in accord with the gravity picture. Four models that do accord with the gravity data are shown diagrammatically in Figure 3, which is not intended to portray the real structure but only to help define the permissible limits of interpretation of the gravity data. In (a) of Figure 3 the whole crust is shown as if warped by compressive deformation; regional compensa-

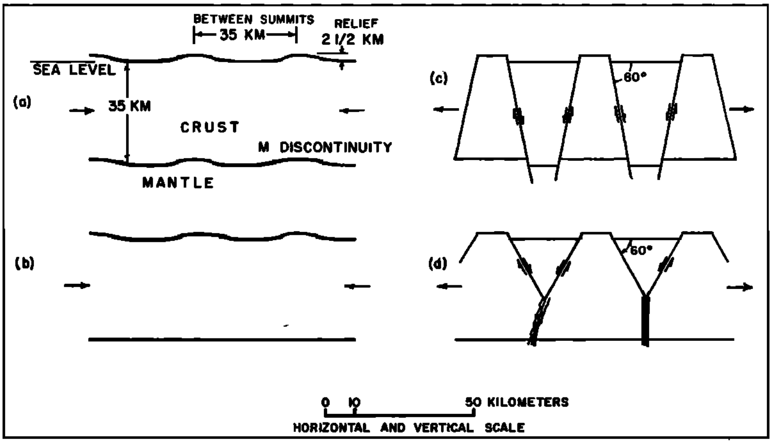


FIG. 3—Simplified models permitted by gravity data; horizontal arrows represent compression, (a) and (b), or extension, (c) and (d)

tion may be maintained, but the individual ranges are supported by the strength of the crust and are not locally compensated. The slight downwarp, (root) at the base of the crust below each basin is too small and too far below the surface to be readily detected in the gravity measurements; therefore the structure shown in Figure 3(b), in which only the upper part of the crust is deformed, is a reasonable alternative. In (c) of Figure 3 the crust is shown as if broken up by normal faults resulting from extension (with or without strike-slip components of movement). The mountain blocks have risen toward buoyant equilibrium and the valley blocks have sunk; they approach what *Vening Meinesz* [1948] has called crustal shear isostatic compensation. The 'roots' are again beneath the basins but are too small and too deep to be detected gravimetrically (except in larger structures than these, in areas uncomplicated by near-surface variations). Consequently, the structure illustrated by Figure 3(d), in which only the upper part of the crust is faulted, is an acceptable alternative. In Figure 3(d) the lower part of the crust is assumed to be extended plastically or to be dilated by igneous intrusions. Inasmuch as warped or tilted strata and normal faults with dips of about 60° are known features of the region, Figure 3(d) with the addition of shallow tilting and warping may best represent the actual structure.

Concealed structure of the basins—Local negative anomalies are associated with all the basins (Fig. 2). The anomaly relief is about 30 mgal at Fairview Valley and 40 mgal near Westgate. Gradients are so steep that the anomalous masses must be shallow; they cannot, for instance, lie at the base of the earth's crust. The maximum gradient is about 20 mgal/mi; according to the formulation of *Bott* and *Smith* [1958, p. 3], the maximum depth to the top of the anomalous mass would be about one mile. These local anomalies are interpreted as caused by low-density fill of sedimentary and volcanic material in the basins.

TABLE 1—*Density of rocks*

Rock	Measured range in density (Water-saturated rock)
Sedimentary rocks, Cenozoic	1.7–2.5 g/cc
Volcanic rocks, Cenozoic	
Pyroclastic rocks	1.8–2.6
Flows	2.2–2.8
Granite rocks, Mesozoic and Cenozoic	2.62–2.67
Metamorphic rocks, Mesozoic	2.7–2.8

Table 1 shows a summary of about 50 laboratory measurements of density made on rocks similar to those in the area under study [*Thompson* and *Sandberg*, 1958]. The important point is the large contrast between Cenozoic sedimentary and volcanic rocks and the older rocks. The maximum difference is approximately 1 g/cc and the average about 0.5 g/cc. This figure is rough but is certainly correct within a factor of two.

In Figure 2 a regional gradient is drawn by connecting gravity values of bedrock stations in the Stillwater Range, in the Toiyabe Range, and at Westgate; the other ranges are covered by Cenozoic volcanic rocks, which with minor exceptions have lower density than the pre-Cenozoic bedrock. The western end of the regional gradient is projected on the basis of bedrock stations that lie west of the area shown on Figure 2.

Using 0.5 g/cc as the most probable density contrast, one can readily compute the approximate thickness of fill in the basins. Carson Sink Basin (west side of Figs. 1 and 2) shows a local negative anomaly of 3 to 18 mgal. Thus the basin, although very wide, contains a maximum of only about 3000 ft of sediments along the line of the survey. West of Fallon the sediments appear to be only a few hundred feet thick. A spur of the Stillwater Range 12 mi east of Fallon bounds the basin. The spur is covered by basalt and the abrupt positive anomaly associated with it suggests that the basalt is not a single thin flow but is hundreds of feet thick. Alternatively, thin basalt may be underlain by bedrock of high density. Between the spur and the Stillwater Range is another basin, and the gravity data in that basin indicate a thickness of sediments of about 2000 ft.

The local gravity anomaly on the eastern side of the Stillwater Range is two to three times that on the western side, indicating a great thickness of low density material to the east, in Fairview Valley. These relations hold, not only on the main profile of Figure 2, but also on the short profile taken across the range 30 mi farther north (see inset above the Stillwater Range).

Fairview Valley is of special interest because of the 1954 fault movements (Fig. 1). Figure 4 shows the gravity measurements across Fairview Valley; the plotted points are the same as in Figure 2. Below the gravity profile in Figure 4 is a geologic section that is capable of explaining the gravity anomaly. The curve computed from the section and corrected for the regional gradient is shown by the solid line. The shape of the basin floor in cross section may be interpreted as representing step-faulting or alternatively as representing warping, as shown here. Or if we assume that the density contrast is smaller near the edges of the basin—as it is on the surface today because the center is occupied by low-density playa silts and the margins by gravels—the gravity data permit a simple flat-bottomed graben. The outstanding thing about this section is the depth of the fill, about 5000 ft. The highest peaks in the adjacent ranges rise roughly another 5000 ft above the basin, making a total structural relief of 2 mi in a basin only 7 mi wide. We shall return to a discussion of this basin in connection with the fault movements.

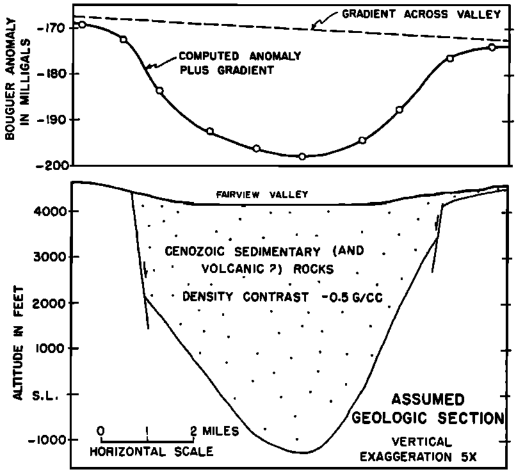


FIG. 4—Gravity profile and section across Fairview Valley

From Fairview Valley to Westgate, where the gravity line crosses the 1954 faults, the anomaly indicates no more than a few hundred feet of sediments; the shallow bedrock in that area is part of the buried northern extension of Fairview Peak and of the southern extension of the Clan Alpine Range. Beyond Westgate the anomaly curve drops sharply and is interpreted as indicating a fault or faults with a downthrow to the east of more than 2000 ft. Volcanic rocks crop out at Middlegate but they have only slight influence on the gravity. In this area *Axelrod* [1956, p. 182–188 and Fig. 10] describes a 3000-ft section of silicic volcanic rocks of Cenozoic age overlain by a 3500-ft sedimentary section, the whole dipping 10° to 40° eastward. His description (p. 184) seems to permit the alternative interpretation of major intertonguing of the volcanic and sedimentary rocks, with the former mainly in the mountains and the latter mainly in the basins. The total thickness, 6500 ft, is in good agreement with the local gravity anomaly, which amounts to −40 mgal, and with the assumption of a negative density contrast of 0.5 g/cc for both the sediments and the volcanics. Axelrod interprets the west side of Middlegate Hills as bounded by a major fault with downthrow to the west, but the gravity data indicate either that the fault is small or that there is little density contrast between the volcanic and the sedimentary rocks. On the other hand, the gravity data suggest a large fault with downthrow to the west at Eastgate, where volcanic rocks are again brought to the surface.

Between the Desatoya and Shoshone Ranges, both of which are covered by volcanic rocks of low density, Smith Creek Valley shows a local negative anomaly that suggests about 2000 ft of sedimentary material in the valley. The gravity high near the axis of the Desatoya Range probably indicates thinning of the volcanic cover toward the axis. The Reese River Valley contains an estimated 1500 to 3000 ft of sediments, and a fault boundary is suggested at the east side by the fairly steep gravity gradient.

Granitic bedrock crops out in the Toiyabe Range near Austin. In the whole distance between Westgate and Austin, low-density volcanic rocks and sediments are the only materials exposed, and from the positions of the contacts relative to the gravity anomaly, Cenozoic sediments and volcanics are estimated to contribute about equally to the local negative anomalies.

Gravity before and after 1954 faulting—The possibility of gravity changes accompanying the 1954 faulting remains to be considered. The 1954 faults generally follow the borders of the large basins, but where the main gravity profile crosses them, the faults depart from the usual habit and follow the margins of the small basin between Fairview Valley and Westgate. The west side of the small basin dropped a maximum of about 5 ft [*Whitten*, 1957, p. 324]. A movement of that magnitude, assuming that it is accompanied by no density changes in underlying rocks, should cause an increase of observed gravity amounting to the sum of the free-air and Bouguer corrections for an elevation difference of 5 ft. This increase should be 0.3 mgal. On the other hand, the Bouguer anomalies before and after faulting, each reduced to the elevation at the time of measurement, should show a difference only if masses have been redistributed or densities changed below the surface. Comparison of precise surveys before and after faulting may thus yield information on such changes.

The Standard Oil Company of California furnished data on a survey made previous to the 1954 faulting. Two of their base stations were reoccupied during the present survey and all data were reduced to the same base. The Bouguer anomalies from the Stillwater Range to Westgate were then compared. The largest uncertainty is in the location of the earlier stations, which, excepting the base stations, were not at permanent landmarks. In spite of this uncertainty, the two sets of data agree within 0.5 mgal. In the downfaulted block, two stations show Bouguer anomalies 0.2 and 0.5 mgal more negative after the faulting, and other stations agree within 0.1 mgal. As the uncertainty is also about 0.5 mgal, we can only conclude that the Bouguer anomaly either did not change or else decreased algebraically by an amount no greater than 1.0 mgal. If the anomaly in fact decreased, the most likely of several possible explanations is a slight decrease in density of shallow material in the disturbed zone.

Distension accompanying 1954 and earlier deformation—The total structural relief at Dixie and Fairview Valleys is roughly the sum of the topographic relief, about a mile, and the buried relief, another mile, making a total of two miles. Large horizontal distension, normal to the trend of the valleys, is also required. If the basin is bounded by faults dipping 60° (the angle shown in the section, Fig. 4), without major warping of the strata, the extension normal to the strike amounts to about a mile on each side of the basin, a total extension of two miles. If the faults dip 70°, the extension amounts to about a mile and a half.

Of this large deformation the last part, which took place in 1954, is known most accurately because of seismic and geodetic measurements. Figure 5 summarizes the horizontal displacements determined by the U. S. Coast and Geodetic Survey from triangulation before and after the

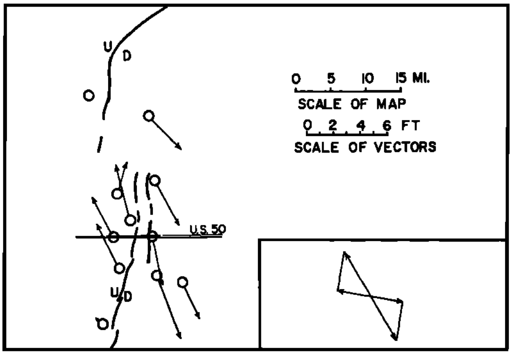


Fig. 5—Horizontal movements close to the faults (after Whitten)

1954 faulting [*Whitten*, 1957]. Epicenters of the two large earthquakes, which occurred in succession four minutes apart, were determined by *Romney* [1957] to lie about 35 mi from each other, one near the northern and one near the southern edge of Figure 5. He estimated the focal depths from the time interval $pP - P$ to be 15 km for the southern earthquake and 40 km for the northern. In Figure 5 the vectors indicate displacement of triangulation points relative to points about 40 mi east and west of the faults, which had no displacement relative to each other. On the average, from any point at the fault, points on opposite sides moved away to the northwest and southeast (Fig. 5, inset). The component of extension normal to the fault trace (horizontal component of dip slip) is 5 ft.

Dip of the 1954 faults can be determined in three ways, and the agreement among the results verifies the measurements of extension. First, the vertical and horizontal components of dip slip can be used to determine dip. The vertical displacement is 7 ft in Dixie Valley [*Whitten*, 1957] and is also 7 ft where the fault is in bedrock east of Fairview Peak [*Slemmons*, 1957, p. 360]; where U. S. Highway 50 crosses the fault zone the sum of displacements on oppositely facing faults is also 7 ft [*Whitten*, 1957, p. 324]. If 7 ft is taken as an average vertical displacement and 5 ft as the average extension, tangent of the dip is 7/5 and the dip is 55°. A second measure of the dip is provided by seismic first-motion observations. By this method *Romney* [1957] determined a dip of 62° at the southern focus. The third measure, direct observation, shows dips in bedrock of 55 to 75° [*Slemmons*, 1957]. Agreement among these three determinations of dip is reasonably good.

The close correspondence of dip and direction of motion at the surface with the same quantities determined at the focus of the first earthquake [*Romney*, 1957] is of special importance to an understanding of the mechanics of deformation. The focal depth of 15 km, coupled with the agreement just mentioned, implies that the fault or fault zone extends continuously from the surface to a depth greater than 15 km and that therefore a large fraction of the total thickness of the earth's crust is being deformed in the same manner. The probable depth of the second earthquake was even greater, 40 km [*Romney*, 1957]. Faulting observed at the surface would therefore seem to represent the type of deformation prevailing throughout most of the thickness of the earth's crust; the whole crust is undergoing extension. Of the four diagrams in Figure 3, 3(d) would come closest to fitting the facts.

One note of caution must be mentioned in regard to the focal depths. Romney's data on the epicentral locations, focal depths, and fault dips are not entirely self-consistent. The two epicenters lie close to the surface trace of the fault, whereas they should lie 9 and 23 km east of the trace if the foci are 15 and 40 km deep and if the fault dips 60°. Since the epicentral locations are not likely to be in error by as much as 9 and 23 km, the discrepancy casts doubt either on the focal depths or else on the continuity of the fault zone at a dip of 60°. The easiest escape from this dilemma is to assume that the phase that Romney tentatively identified as pP was in reality some other phase and that the foci were near the surface. Alternatively, the fault zone might be nearly vertical, although individual faults at the surface and at the focus dip 60° eastward.

A crude test of the depth of deformation can be made by analyzing the volume of the structural depression as related to the amount of extension. The cross-sectional area of the 1954 depression at U. S. Highway 50 [*Whitten*, 1957, p. 324] is approximately 6000 m^2. Uniform extension of 1.5 m (5 ft) to a depth of only 4 km would create a void large enough to account for the depression; if the potential void was triangular in cross-section, with a width of 1.5 m at the surface tapering downward to zero, the total depth would still be only 8 km. A similar calculation for the total deformation can be made as follows. The cross-sectional area of the fill in Figure 4 is approximately 13 km^2 and this amount must be at least doubled to include the relief between the surface of the fill and the mountain tops. On this basis the total extension of 2.4 km (1.5 mi) would require a triangular void roughly 20 km deep. None of these estimates are nearly as large as the larger of the two focal depths in question.

Rate of distension in the Basin and Range Province—The data indicate that the region of Dixie and Fairview Valleys has been distended in a nearly east-west direction about a mile and a half. If we assume that each of the principal basins between the Sierra Nevada and the Wasatch Mountains has been deformed this much on the average, the total distension amounts

TABLE 2—*Historic faults*

Location	Date	Estimated east-west component of extension (ft); dip, if unknown, is assumed to be 60°	Reference
Owens Valley, Calif.	1872	13	Hobbs [1910]
Pleasant Valley, Nev.	1915	13	Page [1935]
Cedar Mountain, Nev.	1932		Gianella and Callaghan [1934]
Excelsior Mountains, Nev.	1934	0.1	Callaghan and Gianella [1935]
Fort Sage Mountains, Calif.	1950	0.4	Gianella [1957]
Fallon, Nev.	1954	1	Tocher [1956]
Dixie Valley-Fairview Peak, Nev.	1954	5	Whitten [1957]

to 30 mi or 5 pct. And if the deformation took place in the last 15 million years, as suggested by the geologic history (deformation of Miocene-Pliocene and younger rocks), the rate is 2 mi/million years or only 1 ft/century. The rate of extension indicated by several fault movements within historic times appears to be at least 1 ft/century (Table 2). The faults listed in Table 2 lie in a north-south belt about 250 mi long. For at least this distance the data are consistent with an extension of 1 ft or more in the last hundred years. Prehistoric Quaternary faults are also numerous; they strongly suggest that the historic rate of deformation is not abnormally high.

It is recognized that tilted and warped blocks, which are a characteristic feature of the region, may absorb all or a part of the extension that occurs by faulting. No evidence for this view can be found in the geodetic measurements across the 1954 fault zone, however, although the valley block was tilted at that time. As *Whitten* [1957, p. 323] lucidly stated, blocks on opposite sides of the fault zone "are not only shearing but also pulling apart, creating a void that explains the lowering of the Valley adjacent to these faults." Probably expansion of tilted blocks by internal disruption along many minor faults is sufficient to balance any apparent contraction due to the tilt. The geodetic measurements are consistent with the elastic rebound theory of faulting, and we must conclude that a large region is undergoing slow distension, which from time to time results in breaks like those of 1954.

Strike-slip displacement—Throughout this paper, the strike-slip component of fault displacement has been neglected, for the interpretations presented are entirely independent of the strike-slip component. Strike-slip movement does not change the area of any given region, but any component of dip slip on non-vertical faults must result in a change of area. This fact is of cardinal importance in the search for basic causes and processes. If the area is expanding, as it seems to be, the often expressed idea that basin-range structure is the superficial result of horizontal compression in the deeper crust can hardly be correct.

It is not yet clear how fundamental the strike-slip component of the 1954 faults may be. Any normal fault that varies in strike should have a strike-slip component of displacement on some of its segments. In agreement with this, the southern part of the 1954 fault zone shows clear evidence of a large right-lateral component, but the northern part exhibits almost pure dip slip. The geodetic measurements also indicate that uniform displacement of the blocks east and west of the faults would produce little or no strike slip on the northern part of the fault, which trends northeast (Fig. 5). Throughout their extent the fault surfaces have a dip characteristic of normal faults, rather than the vertical dip to be expected of strike-slip faults on mechnical principles [*Anderson,* 1951; *Hubbert,* 1951].

It is also interesting to note that the seismically determined direction of displacement at the second epicenter should have been dip slip to agree with the surface evidence but could not be established because motion was still continuing from the first earthquake.

Strike-slip displacement, if it has a significant pattern in the Basin and Range Province, is an additional important key to the mechanics of the deformation. In the Dixie-Fairview region, the geodetic displacement vectors lie along a line that is not normal to the average trend of the basins and ranges; an average right-lateral component of displacement is indicated. If the geodetic measurements are representative of deformation in a larger part of the Basin and Range Province, the entire region is undergoing right lateral deformation in addition to distension.

Summary of conclusions—Gravity measurements show that the region is approximately in isostatic balance, but the possibility of slight overcompensation is not excluded. Sedimentary and volcanic material that occupies a large volume in the basins and in parts of the mountains has a low density and accounts for roughly 10 to 15 pct of the average Bouguer anomaly. Consequently the compensation for this high region is partly in the superficial materials themselves. Although the area is regionally compensated, the gravity data provide no evidence for compensation of individual basins or ranges.

Large negative anomalies are associated with all the basins and indicate great thicknesses of sedimentary and volcanic fill. Fairview and Dixie Valleys contain more than 5000 ft of fill and Edwards Creek Valley more than 6000 ft.

The Bouguer anomaly in the area downfaulted in 1954 either did not change during the faulting or else decreased algebraically by an amount no greater than 1.0 mgal.

Distension of 5 ft in 1954, measured in a direction normal to the strike of the faults, is the latest increment of a total distension that amounts to about $1\frac{1}{2}$ mi in 15 million years. If this small region is a fair sample of the Basin and Range Province, the total distension in the province is 30 mi in 15 million years and the rate of distension is about 1 ft/century, an amount well within the rate indicated by historical fault movements.

The analysis presented is independent of a strike-slip component of displacement, which occurred on only part of the fault zone, but a component of strike slip along the average trend of the ranges is an added factor. A hypothesis of deep-seated horizontal compression as a mechanism of origin of basin-range structures is not compatible with the implied expansion of area, nor does strike-slip displacement explain the expansion.

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Appendix

Gravity Stations between Hazen and Austin, Nevada, 1956.
Base is USC & GS pendulum station at Mystic, California.

Sta. No.	Bench Mark	Latitude North	Elevation of Instrument Feet	Observed Gravity Milligals	Int. Formula Gravity Milligals	Bouguer Anomaly Milligals
4	(Mystic)	39° 27.1′	5152.4	979, 630.00	980, 131.8	−192.8
5	B48	33.5	4002.0	744.80	141.3	−156.5
7	T47	28.75	3964.6	735.44	134.3	−161.1
8	A48	33.05	4005.2	740.05	140.7	−160.5
9	Z47	32.30	4031.2	732.07	139.6	−165.8
10	L321	30.86	4026.7	732.09	137.4	−163.8
11	F388	30.25	4017.4	736.07	136.5	−159.5
12	V47	29.45	4000.5	738.81	135.3	−156.6
13	U47*	28.82	3976.1	736.45	134.4	−159.5
14		31.15	3898.0	739.10	137.8	−164.9
15	F389	37.0	3939.3	748.82	146.5	−161.4
16	K389	38.7	3948.1	745.18	149.0	−168.1
17	L389	40.0	3954.4	754.12	150.9	−159.6
18	M389	40.9	3946.0	755.98	152.2	−159.6
19	R387	41.3	5014.2	695.66	152.8	−156.4
20	5288′	41.0	5282.0	678.89	152.4	−156.8
21	M387	41.7	4778.3	712.26	153.4	−154.6
22	P387	42.0	4210.7	746.48	153.9	−154.9
23	3978′	41.8	3970.7	752.33	153.6	−163.2
26	Y46	16.6	4610.2	670.76	116.4	−169.2
27	Q47	28.3	3956.8	735.38	133.7	−161.0
28	P47	26.8	3955.0	726.95	131.4	−167.3
29	A388	25.9	3950.2	724.18	130.1	−169.0
30	N47	25.0	3949.7	721.18	128.8	−170.8
31	B388	24.1	3941.4	719.61	127.4	−171.4
32	M47	24.1	3933.5	720.15	127.4	−171.4
33	J297	24.1	3928.9	721.49	127.4	−170.3
34	L47	24.1	3928.3	723.22	127.4	−168.6
35	Q383	24.1	3925.3	725.56	127.4	−166.4
36	R383	24.15	3925.6	730.40	127.5	−161.7
37	T383	23.5	3963.9	738.67	126.5	−150.1
38	H47	23.25	3938.7	739.81	126.2	−150.2
39	U383	22.8	3955.4	737.97	125.5	−150.3
40	3964′	22.47	3958.2	733.73	125.0	−153.9
41	3	21.9	3942.2	726.05	124.2	−161.7
42	F47	21.43	3924.7	719.99	123.5	−168.2
43	N383*	20.9	3923.3	716.15	122.8	−171.4
44	E47*	20.23	3922.5	714.29	121.7	−172.2
45	G383*	19.5	3916.6	714.15	120.6	−171.6
46	H383	18.9	3914.5	715.47	119.8	−169.6
47	V383*	18.0	3918.3	713.51	118.4	−169.9
48	X383*	17.8	3903.9	713.40	118.1	−170.6
49	Z382*	16.4	4459.5	676.13	116.1	−172.5
50	X46	16.3	4274.3	676.12	115.9	−183.5
51	W46	16.7	4154.5	671.27	116.5	−196.1
52	S46	17.2	4391.5	676.80	117.3	−177.1

APPENDIX—(Continued)

Sta. No.	Bench Mark	Latitude North	Elevation of Instrument Feet	Observed Gravity Milligals	Int. Formula Gravity Milligals	Bouguer Anomaly Milligals
53	Y382	39° 16.7	4167.0	979,674.19	980,116.5	−192.4
54	E383*	16.3	4570.2	677.79	115.9	−164.0
55	Z46	16.0	4375.2	690.62	115.5	−162.5
56	A47	16.1	4063.4	707.13	115.6	−165.8
57	B47	16.8	3804.7	711.27	116.7	−171.3
58	Y383*	17.3	3896.4	709.34	117.4	−174.4
59	T382*	16.9	4149.0	670.18	116.9	−197.9
60	V46	17.0	4188.5	671.57	117.0	−194.3
61	U382	17.0	4284.9	672.57	117.0	−187.5
62	4431′	17.0	4423.8	675.61	117.0	−176.1
63	U46 AZI*	17.1	4557.8	670.03	117.1	−173.7
64	V382*	17.1	4596.3	666.65	117.1	−174.8
65	T46	17.2	4564.5	666.18	117.3	−177.4
66	W382	17.2	4423.7	672.84	117.3	−179.2
67	X382*	17.3	4435.8	676.06	117.4	−175.3
68	R46	17.4	4469.7	671.16	117.6	−178.4
69	D383*	17.4	4532.7	671.13	117.6	−174.6
70	Q46	17.3	4590.0	663.06	117.4	−179.1
71	Q130	17.3	4623.5	645.69	117.4	−194.4
75	(Truckee)	19.6	5889.4	583.07	120.8	−184.3
76	P46	17.5	4667.4	639.52	117.7	−198.3
77	N46	18.0	4782.3	620.98	118.4	−210.6
78	M46	18.0	5017.5	598.45	118.4	−219.1
79	A383	18.5	5029.8	602.92	119.1	−214.5
80	L46	18.5	5110.5	608.29	119.1	−204.3
81	K46*	17.0	5333.6	589.94	117.0	−207.2
82	S388*	17.0	5410.3	581.64	117.0	−210.9
83	Q388	17.5	5726.0	554.36	117.7	−220.0
84	T388*	17.0	6100.6	536.79	117.0	−214.4
85	V388*	17.5	6585.5	514.03	117.7	−208.8
86	F385*	17.0	6968.0	492.41	117.0	−206.7
87	G385*	17.0	7187.3	480.56	117.0	−205.4
88	E385	16.0	7301.2	476.67	115.5	−201.0
89	A935X..	22.0	6431.2	536.62	124.3	−202.0
90	R63	30.0	6573.7	529.02	136.1	−212.9
91	Q385*	29.5	7179.9	489.90	135.4	−214.9
92	B384	30.5	5998.3	554.32	136.8	−222.8
93	H45*	29.5	5739.7	564.83	135.4	−226.4
94	J384*	26.5	5743.3	567.67	130.9	−218.8
95	P45	23.0	5967.3	553.90	125.8	−214.0
96	X45	14.5	6096.7	521.23	113.3	−226.5
97	A386	17.9	4461.9	675.70	118.3	−175.0
98	C386	19.1	4342.5	682.23	120.0	−177.4
99	4250′	19.7	4243.1	688.76	120.9	−177.7
100	F386*	21.2	4180.6	700.32	123.2	−172.2
101	L386	25.9	3998.1	709.85	130.1	−180.5
102	P386	28.3	3900.3	716.48	133.6	−183.2
103	R386*	29.9	3831.8	722.78	136.0	−183.4
104	T386	31.4	3784.1	723.07	138.2	−188.2
105	V386*	33.3	3701.7	726.17	141.0	−193.8
106	X386	34.9′	3620.3	736.31	143.4	−190.0
107	2386*	36.7	3581.2	754.64	146.0	−176.6
108	D387*	38.7	3531.1	758.96	149.0	−178.3
109	E387*	39.6	4028.8	747.74	150.3	−161.0
110	B387	39° 40.4	3482.4	979,761.09	980,151.5	−181.6

* Station was a few feet from bench mark; elevation determined from bench mark by hand level.