Regional Gravity Survey Along the Central and Southern Wasatch Front Utah

By KENNETH L. COOK *and* JOSEPH W. BERG, JR.

GEOPHYSICAL FIELD INVESTIGATIONS

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A correlation of gravity data with regional geologic structures

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GEOPHYSICAL FIELD INVESTIGATIONS

REGIONAL GRAVITY SURVEY ALONG THE CENTRAL AND SOUTHERN WASATCH FRONT, UTAH

By Kenneth L. Cook and Joseph W. Berg, Jr.

ABSTRACT

A regional gravity survey was made from June to August 1954 in Salt Lake and Utah Counties, Utah. Gravity measurements were made at 1,100 stations in an area of about 5,000 square miles, and the results were compiled as a Bouguer gravity anomaly map with a contour interval of 2 milligals.

Past tectonic activity in the region has been great, and the regional gravity patterns reflect the present contrasts in the crust that are the product of several orogenies. A gravity high occurs over the ancient northern Utah highland in the Antelope Island area. The gravity data give no evidence that the Uinta arch extends west of the Wasatch front. Steep gravity gradients corresponding with Basin and Range faults occur along parts of the Wasatch fault zone on the west margin of the Wasatch Range; along a continuous fault zone 60 miles in length on the west margin of the Oquirrh Mountains, Boulter Ridge, and East Tintic Mountains; and along the newly discovered Utah Lake fault zone east of West Mountain and the Lake Mountains. A gravity high corresponds with the great fault block comprising the Oquirrh Mountains, Boulter Ridge, and the northern part of the East Tintic Mountains.

The gravity data indicate that in the valley areas between this fault block and the Wasatch fault block, an intermont trough (designated by us as the Wasatch structural trough) more than 100 miles in length comprises a great belt of grabens and smaller fault blocks whose dislocations are varied and more complex than previously realized. Several large block fragments lying just west of the Wasatch block have apparently dropped deeper than some other fragments, as if slipping into a great crevasse. From north to south, the major grabens are the Farmington, Jordan Valley, Utah Valley, and Juab Valley grabens. The major fault-block spurs are the eastern part of the Traverse Mountains and the spur in the Santaquin area.

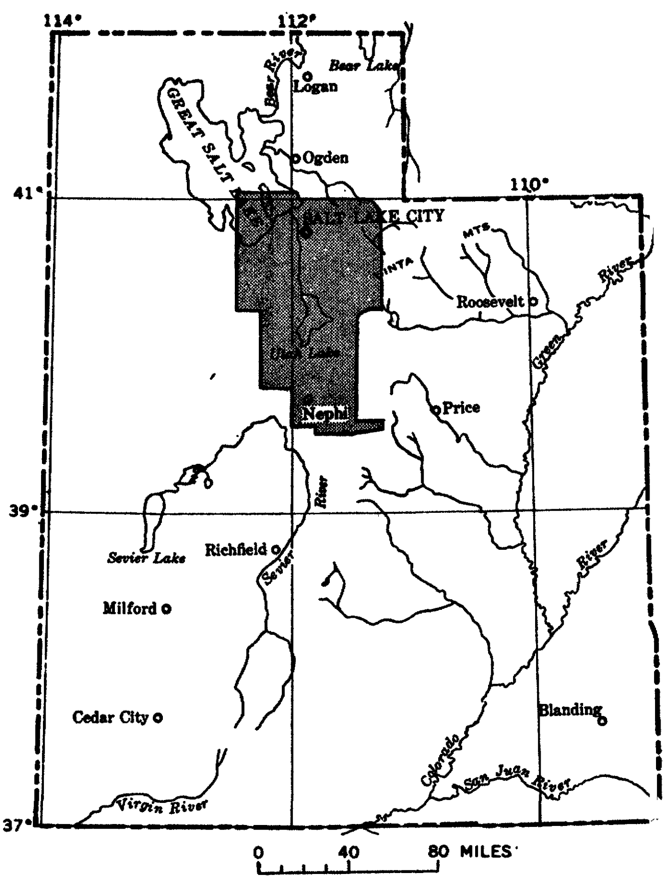

Figure 32.—Index map of Utah showing area covered by regional gravity survey.

INTRODUCTION

During June to August 1954, a regional gravity survey was made in Salt Lake and Utah Counties, Utah (fig. 32), as part of a broad geophysical study of the Basin and Range province. The survey extended from latitudes 39°30′ N. to 41°00′ N. and from longitudes 111°15′ W. to 112°30′ W.

The principal topographic features of this area are the northward-trending Wasatch Range; a northward-trending mountain belt comprising the Oquirrh Mountains, Boulter Ridge, and East Tintic Mountains; and the eastward-trending Traverse Mountains, which extend between the Wasatch Range and the Oquirrh Mountains and which are bisected by the Jordan River in a water gap designated the Jordan Narrows (pl. 13). The Traverse Mountains separate Utah Valley on the south from Jordan Valley on the north. Utah Lake, a fresh-water lake that covers a large area in the central part of the surveyed region, empties its overflow water into the Jordan River, which flows northward into Great Salt Lake.

The principal mining and industrial centers of the State of Utah are in this area. The ore for nearly one-third of the new copper produced in the United States is mined and milled here. As in most of the semiarid West, water is one of the principal factors that will determine the capacity of this area for industrial growth.

The survey was made to determine, insofar as possible, the regional lithology and structure of the underlying rocks. Although many parts of the general region covered by the survey have been mapped geologically, most of the area is covered with valley fill that has obscured many of the regional geologic ties and trends. It was hoped that the gravity survey would assist in delineating the main structural geologic trends in the parts that are hidden and perhaps provide helpful information incident to ground-water and mineral-deposit studies currently being made in the region.

ACKNOWLEDGMENTS

E. T. Cannon, D. L. Endsley, and G. H. Turner assisted in the fieldwork and compilation of the data. For helpful suggestions and discussions incident to the interpretation of the gravity anomalies, we are indebted to A. J. Eardley and R. E. Marsell, of the University of Utah, and to M. D. Crittenden and H. T. Morris, of the U.S. Geological Survey. The many sources of the published data for the regional geologic map accompanying this report are indicated by asterisks (*) in the bibliography. H. T. Morris furnished some unpublished data on faults in the Boulter Ridge and East Tintic Mountains areas.

FIELD OBSERVATIONS AND TECHNIQUES

A Frost gravimeter with double thermostatic control and a sensitivity of 0.0729 milligal per dial division was used throughout the survey. A total of 1,100 gravity stations were occupied over the 5,000 square miles covered by the survey. In addition, about 350 gravimeter readings were taken at base stations and at previously occupied stations to furnish gravity control. A total of 9 base stations were established, and 1 U.S. Coast and Geodetic Survey pendulum station was occupied.

To provide a relatively accurate base of reference for the gravity values, each gravimeter base station was tied to one or more nearby base stations by alternating two or more pairs of gravimeter readings. One of the base stations was similarly tied accurately to the U.S. Coast and Geodetic Survey pendulum station.

The elevations of all the stations were taken from the elevations given at bench marks and road intersections on the topographic quadrangle maps of the U.S. Geological Survey. Because the topographic map coverage in most of the surveyed area is recent, the elevations at most of the stations occupied are believed to be correct within 1 foot in the valley areas and within 4 feet in the mountain areas.

Most of the gravity readings were taken in the valleys. In the valleys between Provo and Farmington, the survey was made on a 2-mile grid in general or on a 1-mile grid in areas of pronounced gravity anomalies. In the valleys between Provo and Nephi, the survey was made on a 2-mile grid. In the mountainous areas, only a relatively few measurements were made because of rather poor topographic control and the inaccessibility of these areas; the traverses, therefore, were of the large-scale reconnaissance type.

REDUCTION OF DATA

The instrument readings were corrected for drift; latitude corrections were also made. A total elevation correction factor of 0.06 milligal per foot, which includes the Bouguer correction for a density of 2.67 g per cm.^{3} (grams per cubic centimeter) and the free-air correction, was used.

The datum for the reductions was mean sea level. The reference for observed absolute gravity was the U.S. Coast and Geodetic Survey pendulum station 49, established in 1894 in the Temple Grounds in Salt Lake City. The simple Bouguer anomaly value for this station was taken as −183 milligals; [1] the values of all the other gravity stations of the survey are in reference to this value.

Terrain corrections were carried out to and including zone *K* (6.1 miles) on Hammer's (1939) zone chart for about 220 of the 1,100 gravity stations. These 220 key stations were carefully selected so that their corrections could be contoured on a map from which the terrain corrections of the remaining stations could then be obtained by interpolation. An average density of 2.67 g per cm.^{3} was assumed for the rocks in the surveyed region. The expansion charts for Hammer's terrain correction tables were used for computing the terrain correction in areas of great topographic relief, as, for example, for most stations adjacent to the Wasatch front. The range of the terrain corrections was great because of the rugged topography in the mountains and the relative broadness of the flat valleys. The largest terrain correction, in American Fork Canyon where the canyon walls rise precipitously to a height of 2,500 feet

[1] The complete Bouguer anomaly value, which includes the effect of topography within a radius of about 100 miles from the station, is −179 milligals for this pendulum station (Duerksen, 1949, p. 8). As the U.S. Coast and Geodetic Survey terrain correction out to 100 miles is 4 milligals for this station, the simple Bouguer anomaly, which omits the effect of topography, is taken as −183 milligals.

above the narrow canyon floor within a horizontal distance of 1 mile, was 25 milligals. The terrain corrections for about 110 stations in the central part of the floors of Jordan and Utah Valleys were less than 0.1 milligal, and were considered negligible. The gravity effect of the topography in zones beyond K, for which corrections were not made, probably manifests itself in some areas within the surveyed region, but is too small to alter significantly the observed regional gravity anomalies.

No isostatic corrections were applied to the data.

Plate 13 gives the Bouguer anomalies, which were obtained by adding the terrain corrections to the simple Bouguer anomaly values. The contour interval is 2 milligals. The accuracy of the Bouguer anomaly values for individual gravity stations given on the map depends on whether the terrain corrections for the stations were computed from the zone chart or interpolated from the terrain-correction contour map. Gravity stations for which terrain corrections were obtained with the zone chart are indicated on the map with an appropriate symbol and are believed accurate within half a milligal. Gravity stations for which terrain corrections were obtained by interpolation from the terrain-correction contour map are believed accurate within half a milligal in the central part of the floors of the large valleys, where all terrain corrections are small, and within a few milligals in the deep canyon areas in the mountains, where all terrain corrections are relatively large. Though the interpolation procedure results in less accuracy for individual stations in the deep canyon areas in the mountains, a judicious choice of the stations for which terrain corrections are made with the zone chart in these bedrock areas results in establishing sufficiently accurate values of the total gravity relief for interpretation work in regional studies.

The Bouguer gravity values in the high plateaus and mountainous regions of the West are strongly negative in comparison with the Bouguer gravity values at or near sea level. The gravity value is said to decrease when the negative number becomes more negative and to increase when it becomes less negative.

The geologic data shown on plate 13 were assembled largely from published sources, which are marked with asterisks (*) in the bibliography, and from the following unpublished master of science theses: R. E. Marsell, "Geology of the Jordan Narrows Region, Traverse Mountains, Utah," University of Utah, 1932, 113 p.; and Siegfried Muessig, "Geologic Map of a Part of Long Ridge, Utah," Ohio State University, 1951.

REGIONAL GRAVITY PATTERNS AND REGIONAL GEOLOGY

The region covered by the gravity survey lies along the eastern margin of the Basin and Range province and within the system of great structural trenches of central Utah (Eardley, 1951, p. 475, 496). Tectonic activity in the region has been intense, and the resulting complexities of the regional structure have not yet been completely deciphered. The Great Basin orogeny is superimposed on Laramide and older structures; the regional gravity patterns observed today, therefore, reflect density contrasts in the crust that are the final product of all these orogenies.

The imprint of the Basin and Range orogeny on the gravity patterns is greater than that of the earlier orogenies because it was profound as well as more recent. A Basin and Range fault, which is one of the principal geologic structures of the region, gives a recognizable gravity anomaly provided a sufficient density contrast exists between the rocks on either side of the fault, and provided the throw of the fault is sufficiently large. These two requirements are fulfilled in many areas. The throws of many Basin and Range faults are as much as several thousand feet or more; and large density contrasts of 0.4 to 0.6 g per cm^3. exist in many areas where a down-faulted block of the Basin and Range type was covered continuously with valley fill as faulting continued. The interpretation of gravity data over Basin and Range faults is complicated somewhat by the fact that earlier structural systems generally exert little or no regional control on the course or the throw of the faults, which cut across rocks of contrasting denisities, and the prefaulted surface of the region had a topographic relief of at least 3,000 feet in places (Eardley, 1951, p. 496; 1933b, p. 243).

The gravity manifestations of the pre-Basin and Range orogenies and variations of density contrasts within the basement complex are found in some areas.

LARAMIDE AND OLDER STRUCTURES

NORTHERN UTAH HIGHLAND

The highest gravity values recorded, about −130 milligals, occur on Antelope Island in the northwest corner of the area surveyed. The bedrock there consists of older Precambrian gneisses and schists which form a part of the ancient northern Utah highland of Eardley (1939, p. 1286; 1944, pl. 3). This positive structural element came into existence late in Precambrian time and persisted through parts of Paleozoic and Mesozoic time, during which it had a marked effect on structures. The highland area is believed to be about 50 miles in its longest horizontal dimension. Crystalline rocks that were once a part of this structure form most of the Wasatch block from City Creek to Farmington Creek, but the Bouguer gravity values in this area are about 40 milligals less than on Antelope Island. These lower gravity values probably are caused by density contracts within the basement complex. Whether some of the effect is isostatic in origin, is not yet known.

The gravity contours on Antelope Island, as inferred from the small amount of gravity data that could be readily obtained in this area, approximately follow the foliation. The steep gravity gradient along the western end of the causeway between Antelope Island and the mainland indicates a northward-trending fault, downthrown on the east, along the southeastern margin of Antelope Island. The curving gravity contours along the shore of the mainland southeast and east of the south tip of Antelope Island indicate irregularities in the buried bedrock surface, which may be of either erosional or fault-block origin. In the mainland area, the Byrd-Frost, Inc., well (BF 1, pl. 13) bottomed at a total depth of 1,916 feet in material reported as Lake Bonneville (Hansen and Scoville, 1955, p. 54–55). The well coincides with the crest of a southward-trending gravity ridge, but we do not know whether the location of the well, which was drilled in 1951, was based on gravity data.

UINTA ARCH

The surveyed area includes the junction of the eastward-trending anticlinal structure of the Uinta arch and the northward-trending structure of the Wasatch Range. The axis of the Uinta arch intersects the Wasatch front in Little Willow Canyon, which lies north of Little Cottonwood Canyon (M. D. Crittenden, 1956, written communication). A regional gravity high of 10 to 15 milligals is shown by Lyons (1950, p. 34–35) over the Uinta Mountains, which lie for the most part east of plate 13. A single curving gravity traverse across the arch between Wanship and a point on Daniels Creek east of Wallsburg shows a gravity high of about 7 milligals at the gravity station several miles east of Bald Mountain that correlates rather well (within 2 miles) with the known approximate location of the western part of the axis of the Uinta arch (Williams, N.C., 1953). The present regional gravity data give no evidence that the Uinta arch extends west of the Wasatch front, as previously reported apparently on the basis of meager gravity data (probably U.S. Coast and Geodetic Survey pendulum stations) in this area (Lyons, 1950, p. 36). It should be emphasized, however, that the gravity effect of the faulting in and adjacent to the Wasatch fault zone is sufficiently great to obscure the relatively small gravity anomaly apparently associated with the Uinta arch near its western extremity.

BASIN AND RANGE STRUCTURES

WASATCH FAULT ZONE

The Wasatch fault system, one of the most striking structural features of the Salt Lake area, forms the face of the Wasatch Range for a distance of about 150 miles. Only the southern 100 miles from Nephi to Farmington are covered by this survey (pl. 13). The Wasatch fault is a typical Basin and Range normal fault, dipping 50°–70° W., and having a vertical displacement ranging from 1,000 to 6,000 feet (Eardley, 1951, p. 479; 1939; 1944). Like most faults of comparable length, it consists of a series of individual faults with a braided or branching pattern. In some areas most of the displacement seems to have been concentrated on one fault or in a narrow zone; when such displacements are large and result in a great thickness of Cenozoic rock in contact with older rock, as between Pleasant Grove and Springville, a steep gravity gradient is found close to the mountain front.

The more gentle gravity gradients along the Wasatch fault zone, such as those observed on the east margin of Jordan Valley for most of the distance between the mouth of Big Cottonwood Canyon and Becks Hot Springs, are in an area where the displacement beneath the valley fill is probably distributed over a wide zone along northwestward-trending step faults downthrown to the west and southwest and en echelon (Pack, 1926, p. 403) rather than along a single master fault of large displacement. There is a striking correspondence in this area between the northwestward trend of the gravity contours and the northwestward trend of the step faults as mapped in the outcrops to the east and southeast (Crittenden and others, 1952). Starting from the mouth of Big Cottonwood Canyon, the trend of the gravity contours indicates that one branch of the Wasatch fault zone trends first north-northwest through the Holladay area, then northward to a point about 1½ miles north of Sugar House, and then northwestward to join the branch of the Warm Springs fault extending south-southeast of Becks Hot Springs. The broad gravity nose in the area where Mill Creek emerges from the Wasach front corresponds with the area where a bedrock pediment at shallow depth beneath the valley fill extends for a distance of a mile or more from the mountain front; here the range front is regarded as a faultline erosion scarp (Crittenden and others, 1952, p. 29).

FEATURES OF THE WASATCH STRUCTURAL TROUGH

Several grabens of great size and displacement are indicated by the oval-shaped gravity lows over the downthrown blocks west of the Wasatch fault. The coincidence of these gravity lows with the areas of known deep fill indicates that they are caused by the density contrast of the dense bedrock of the mountains with less dense alluvium, lake beds, and tuffaceous sediments that underlie the valleys. The sharp gravity gradients along the margins of the valleys testify that marginal faults exist there. Along some of the segments of the peripheral areas of the valleys, the faults were mapped geologically many years before the gravity survey; many of these faults, which are shown on plate 13, correspond with the steep gravity gradients. Along other segments, the continuation of already-known faults can be readily inferred from the gravity gradients. Along still other segments, particularly in the alluvium-covered areas where few or no faults have been previously mapped geologically, the gravity gradients indicate newly discovered faults.

The grabens are separated by gravity saddles, which, in general, coincide with fault-block spurs which themselves have also been downfaulted relative to the adjoining mountain block; but the grabens were displaced downward farther than the fault-block spurs.

It will be demonstrated that the system of grabens, with the intervening fault-block spurs, together constitute a northward-trending structural trough which lies just west of the Wasatch front and extends for 100 miles along the front. The feature is designated for convenience in this paper as the "Wasatch structural trough." Gilbert (1928, p. 33) first recognized the possibility of such a trough, though he visualized it for the Juab Valley and Utah Valley areas only. We will adopt his general thesis and apply it more widespread to the entire area immediately adjacent to the Wasatch front.

FARMINGTON GRABEN

As used in this report, a graben is defined as "a block, generally long compared to its width, that has been downthrown along faults relative to the rocks on either side"; and a horst is defined as "a block * * *, generally long compared to its width, that has been uplifted along faults relative to the rocks on either side" (Howell, 1957, p. 127, 140). It will be noted that these definitions make no restrictions as to the amount of vertical displacement of the bounding faults. In this report use of the terms "graben" or "horst" is generally restricted to those blocks where bounding faults—or segments thereof—have been mapped, or where the gravity data indicate the possibility of a bounding fault in the alluvium-covered or geologically unsurveyed area. In a few areas where the existence of a bounding fault is inferred from gravity data only, the feature is still called a graben or horst. In still other areas, a feature may be referred to as a basin, with the realization that later work may establish the structure as a graben.

The Farmington graben is indicated by a narrow elongate gravity low that extends from Becks Hot Springs northward toward Farmington. Though only the south and east sides of the low are covered by this survey, it has an apparent closure in this area of 16 milligals. The graben is bounded on the east by the Wasatch escarpment, and by the Warm Springs fault, which is believed to have been active in Recent time. The steep linear gradient on the southwest edge of the gravity low indicates that the graben probably is bounded by a buried east-facing bedrock scarp on this side also.

The thickness of the valley fill in the Farmington graben area is unknown—but exceeds 3,500 feet. Five wells have been drilled, the deepest 3,525 feet, but none penetrated rocks older than Tertiary. The Gerald H. Anderson well, DH 3 on plate 13, bottomed at a depth of 3,525 feet in rock that was logged as Tertiary (Hanson and Scoville, 1955, p. 26–27). The Guffey and Galey well, DH 1, bottomed at a depth of 2,000 feet in lake beds. The Gerald H. Anderson well, DH 2 (which was slightly offset from DH 3), and Hickey 1 and 2 bottomed at depths of 1,390 feet, 3,000 feet, and 2,060 feet, respectively, and failed to enter pre-Tertiary rocks.

JORDAN VALLEY GRABEN

Jordan Valley is interpreted as a graben. The evidence of the bounding faults is based on published geologic data along the east, south, and southwest segments of the graben and on geophysical data elsewhere. The Jordan Valley graben, as indicated by the gravity contours, is about 25 miles in length and 16 miles in maximum width. The northern part, which extends from Murray to the vicinity of Becks Hot Springs, is narrow and more constricted. The southern part is characterized by a broad gravity low, with a closure of about 8 milligals, extending from Herriman to Draper.

Many test wells within the Jordan Valley area confirm the relatively great thickness of the valley fill. The small amount of gravity closure makes it doubtful, however, that the valley fill in Jordan Valley is as thick as that in the Farmington area or in Utah Valley. Along the extreme northwestern margin of the gravity minimum, the Western Petroleum Co. well, WP 1, about 2 miles west-southwest of Becks Hot Springs, bottomed at a total depth of 1,832 feet (1,985(?) feet, according to Hansen and Scoville, 1955, p. 54–55) in Tertiary rocks; marl, volcanic ash, and tuff were penetrated in the well, and a 2½-foot bed of tuff was reported at a depth of 1,308 feet (Eardley and Haas, 1936, p. 73–74).

Along the northeastern margin of the gravity minimum, several wells drilled in or near Salt Lake City to moderate depths (up to 1,170 feet) did not penetrate rocks older than Tertiary. Salt Lake City well SLC 1 entered Tertiary beds at a depth of 750 feet at 6th South and State Street, well SLC 2 bottomed in Tertiary rocks at a depth of 1,170 feet at 9th South and 4th West Street, and well SLC 3 entered Tertiary rocks at a depth of 464 feet at 4th Avenue and Canyon Road (Marsell and Jones, 1955a, p. 116). Wells SLC 4 (23d South and between 2d and 3d East), SLC 5 (28th South and West Temple), and SLC 6 (33d South and 5th East) bottomed at depths of 875, 1,083, and 1,005 feet, respectively, in unconsolidated rock (B. F. Lofgren, U.S. Geological Survey, 1955, written communication). The Tower Petroleum Co. well TP 1, near 33d South and Highland Drive, penetrated chiefly alluvial fan debris and bottomed in unconsolidated rock; the total depth of the hole is reported as 930 feet by Hansen and Scoville (1955, p. 54–55) and 500 feet by Eardley and Hass (1936, p. 74).

Along the eastern margin of the gravity minimum, the Metropolitan Water District of Salt Lake City well, MWD 1, about 1 mile west of the Wasatch fault zone opposite the mouth of Little Cottonwood Canyon, penetrated only glacial outwash gravels and sands to a total depth of 1,027 feet (Marsell and Jones, 1955a, p. 117; R. E. Marsell, 1960, oral communication). Along the northern flanks of the lowest center within the gravity minimum, the sugar factory well at West Jordan, which was driven to a depth of about 1,900 feet, did not reach the bottom of the valley fill (Schneider, 1925, p. 31).

Along the southeastern margin of the gravity minimum, the American Smelting & Refining well ASR 1, located about 1 mile southeast of Draper and about half a mile west of the Wasatch fault at the foot of the Lone Peak salient, entered andesite at a depth of 390 feet and continued in andesite to a total depth of 818 feet without penetrating pre-Tertiary rock.

Along the southern margin of the gravity minimum, two wells penetrated andesite, but did not reach pre-Tertiary rock. Utah State Prison farm well PF 1 entered andesite at a depth of 707 feet and continued in andesite to a total depth of 825 feet. Well ASR 2, about a quarter of a mile southeast of this well, entered andesite at a depth of 370 feet and continued in andesite to a total depth of 940 feet. The andesite penetrated in these valley wells is apparently similar to the andesite exposed on the Traverse Mountains. In the Utah State Prison farm area, the quartzite of the Oquirrh formation is exposed in places, as, for example, in the Rideout quarry and in the area about a quarter of a mile east of the Utah State Prison grounds. Well PF 2, just within the east edge of the prison grounds, is reported to have penetrated quartzite at a depth of 300 feet and bottomed in quartzite at a total depth of 335 feet. Much of the gravity gradient in this area occurs over the quartzite of the Oquirrh formation rather than over the alluvium.

The Jordan Valley graben is bounded on the east by the Wasatch fault zone. The curving character of the fault and the gravity contours in this area have already been noted.

On the west, the Jordan Valley graben is interpreted to be bounded by a fault zone which extends southward through the Granger area, then follows a curving course through the Bacchus area and finally southward through the Copperton and Lark areas. The fault zone is interpreted to follow the curving, steep gravity gradient in this area. To date (1958), the existence of faulting along the steep gravity gradient has been confirmed in the Bacchus-Copperton-Lark area only, where a major northward-trending fault was mapped by L. W. Slentz.[2] Just to the east of this fault, there is a northward-trending belt about 3 miles wide, of Harkers fanglomerate of Slentz (1955), which is probably the subaerial accumulation resulting from large-scale block faulting which began in late Pliocene time (Eardley, 1955, p. 39). The belt of fanglomerate terminates abruptly south of Bacchus,[3] where the trend of the fault zone inferred from the steep gravity gradient changes abruptly from north to east. Additional evidence that eastward-trending faults exist in the Bacchus area is found in the bottom of the Bacchus pit, where two small areas of tufa are alined along an eastward direction (L. W. Slentz, 1955, oral communication).[4]

The southeastward-trending gravity nose extending several miles east of Magna to the vicinity of Granger corresponds with a bedrock pediment of Paleozoic rocks and late Tertiary sediments and tuffs that extends at shallow depth beneath a thin veneer of Pleistocene lake sediments and Recent alluvium far out into Jordan

[2] Slentz, L. W., 1955, Tertiary Salt Lake group in the Great Salt Lake basin, unpublished Ph. D. dissertation, Utah Univ., pl. 17. Keith (1905) also recognized possible faults in the Lark area.

[3] Slentz, L. W., op. cit., pl. 17.

[4] Since this manuscript was completed, additional evidence of Basin and Range faulting is afforded by the report that the ground water in the Bacchus area is warm. The temperature of the water is 68° F in a spring about half a mile northwest of the Bacchus pit and 56° F in a well about 1 mile due east of Bacchus. (I. W. Marine, U.S. Geological Survey, 1960, oral communication).

Valley (Marsell and Jones, 1955b). The late Tertiary sediments and tuffs are also probably thin in this area. Paleozoic rocks crop out at the east edge of Magna at a point (marked "X" on pl. 13) about 2 miles east of the Oquirrh Mountains proper, and wells have entered Paleozoic rocks at shallow depth elsewhere in the Magna area (R. E. Marsell, 1955, oral communication). Tertiary tuffs are exposed in the Bacchus pit. The east edge of this bedrock pediment probably is formed by the northward-trending fault or fault zone in the vicinity of Granger that coincides with the steep gravity gradient. Evidence for such a fault is afforded by the presence of warm water in wells in the Granger area (R. E. Marsell, 1955, oral communication).[5] This same fault zone probably forms the west edge of the Jordan Valley graben; furthermore, it apparently extends northward to the northern extremity of the area shown on plate 13, where it joins the fault system on the west edge of the Farmington graben.

The Jordan Valley graben is terminated on the south by an eastward-trending fault zone along the north edge of the Traverse Mountains. Gilbert (1928, fig. 12; p. 29) postulated a fault in this area, and regarded the best indication of the position of the fault to be along the group of warm springs in the Utah State Prison area. These springs lie about midway down the gravity slope in this area, and the postulated fault here probably causes some of the gravity gradient. There is an inconsistency, however, in the relation between the location of the steep gravity gradient and the inferred fault in this area, in comparison with the relation between the location of the corresponding gravity gradient and the existence of quartzite outcrops of the Oquirrh formation in the valley about one mile northeast of the warm springs. The quartzite outcrops occur farther north along the gravity slope than might be expected. This fact may be due partly to the intense brecciation of the quartzite, which is probably related to overthrusting in Cretaceous time. The density of the brecciated quartzite is perhaps as low as the andesite known to underlie the alluvium 2 miles east of the quartzite outcrops. The zone of intense brecciation is believed to extend eastward to the area of Corner Creek. This creek lies at or near the intersection of two faults with the Wasatch fault system: the Charleston fault, a tremendous overthrust of Cretaceous age; and the Deer Creek fault, a normal fault of probable middle Tertiary age, which probably coincides in large part with the Charleston thrust from the Traverse Mountains to American Fork Canyon (Crittenden and others, 1952, p. 30). The Basin and Range faulting along the Wasatch fault zone east of Corner Creek apparently followed for a short distance the already-established lines of weakness to give the present 4½-mile offset north of Alpine.

On the basis of topographic evidence alone, we have interpreted a fault scarp along the front of Steep Mountain about 1½ miles south of the warm springs at Utah State Prison. As in the Mill Creek area, however, there is no gravity manifestation of this fault along the bedrock pediment because quartzite is faulted against quartzite.

Abundant evidence indicates that the faults in and around the Jordan Valley are still active. Fresh scarps cutting moraines and lake terraces at the mouth of Big and Little Cottonwood Canyons attest to the recency of movements in those areas. Minor earthquake tremors felt principally in the western and southwestern part of Salt Lake City (Williams and Tapper, 1953) may be due to displacements on some of the inferred faults in that area.

The smaller individual gravity lows within the main gravity basin of Jordan Valley suggest that subsidiary fault blocks within the main graben have been displaced differentially, though similar gravity effects could be caused by prefaulting relief or by horizontal variations in the density of the basin fill. The small closure gravity low in the southern part of Salt Lake City is separated from the broad gravity low in the Herriman-Draper area by a low gravity ridge in the northern part of Murray. The small gravity low in the area northeast of Copperton probably is caused by a small block that has dropped deeper than its surroundings. This period of local block faulting northeast of Copperton probably preceded the formation of Harkers fanglomerate of Slentz because no major displacement of the Harkers has been observed in this area.

UTAH VALLEY GRABEN

The Utah Valley graben, which lies in a sharp reentrant in the Wasatch Range that coincides with Utah Valley, is indicated by the longest and most pronounced gravity low observed during the survey. The anomaly is strikingly narrow, and extends with northerly trend for a distance of about 30 miles from the Salem area, where it is more than 10 miles wide, to the Alpine area, where it is only about 5 miles wide. The center of the

[5] Since this manuscript was completed, a study of the temperatures of the ground water in many wells in Jordan Valley has revealed a strikingly narrow (about 1 mile in width), northward-trending isothermal high area, which extends mainly along the 112°00′ longitude line from a point about 2 miles west of the center of Granger northward for a distance of about 6 miles; farther north, the anomalously high temperature area persists and broadens somewhat. (I. W. Marine, U.S. Geological Survey, 1960, oral communication). The temperatures of the ground water within the high temperature area near Granger exceed 70° F. in several wells; the highest temperature recorded was 83° F. The isothermal high zone in effect coincides with the steepest part of the gravity gradient in this area and thus gives added support to the interpretation of a major northward-trending Basin and Range fault zone here.

gravity low, with a closure of about 22 milligals, lies 6 miles northwest of the city of Spanish Fork. The graben is bounded on the east by a nearly straightline segment of the Wasatch fault zone, which has been mapped in this area as extending continuously from Alpine to Springville (Hunt and others, 1953, pl. 1). The correspondence of the steep gravity gradient and the known fault in this area has already been noted. The graben is bounded on the west by the newly discovered Utah Lake fault zone, which is described below as extending from Santaquin to Saratoga Springs along the eastern margin of West Mountain and the Lake Mountains. The graben is bounded on the southeast by the Wasatch fault zone, which bends abrubtly southwestward in the area southeast of Springville to conform with the similarly abrupt bend in the Wasatch Range. The direction of the contours along the gravity gradient in the area south of Springville corresponds with that of the known fault zone. At the mouth of Santaquin Canyon and in Payson Canyon, an east-west zone of weakness that existed before Basin and Range faulting is indicated by east-west faults mapped by Eardley (1933a, p. 379, 388); thus, some of the Basin and Range faulting along the southern margin of the Utah Valley graben apparently developed along this zone of weakness. The graben is bounded on the north—in part at least—by an eastward-trending fault having a downthrow to the south, which has been mapped along the southern margin of the Traverse Mountains (Hunt and others, 1953, pl. 1).

The detailed mechanism and patterns of the displacements at the ends of a graben of this type are beyond the scope of this paper. It is noteworthy, however, that east-west faults which are transverse to the main northerly trend of the graben are clearly demonstrated at either end of the Utah Valley graben.

The deepest boring in Utah Valley is a water well at the Geneva steel plant west of Orem, which bottomed at a depth of 830 feet in unconsolidated beds regarded as Tertiary (?) in age (Hunt and others, 1953, p. 14, 37, 85). The gravity data suggest that the Cenozoic rocks beneath the center of the graben probably extend to a depth of at least several thousand feet.

JUAB VALLEY GRABEN

Juab Valley, a long narrow valley that lies at the north between Mount Nebo and Long Ridge, is interpreted provisionally to be a graben. It is marked by an almost coincident gravity anomaly with a possible closure of 18 milligals and a length of at least 27 miles. The valley is bounded on the east by a fault zone which is known to extend on the east side of the valley as far south as Nephi (Eardley, 1933a map), and which is inferred to extend to Levan (Butler and others, 1920, pl. 4). To our knowledge, no fault is known to extend along the east margin of Long Ridge and the West Hills. A fault is inferred here, however, on the basis of the analogy of this anomaly with that in Utah Valley, together with the striking similarity of the gravity gradients on either side of the Juab Valley gravity low, especially in the area of the West Hills.

The thickness of the valley fill in Juab Valley in the Mount Nebo area is known from drilling to exceed 2,000 feet in places (Eardley, 1933b, p. 245).

UTAH LAKE FAULT ZONE

The newly discovered Utah Lake fault zone is indicated by the remarkably continuous set of steep gravity gradients that extend along the west side of Utah Lake from the vicinity of Santaquin and Payson through Saratoga Springs. Though the detailed configuration of all the central part must be inferred, because no readings were taken on the lake, enough stations were available around the edges so that the general form of the anomaly is clearly established. In the vicinity of Pelican Point, for example, a gravity decrease of about 50 milligals exists over a horizontal distance of about 5 miles; this constitutes one of the largest fault-type anomalies obtained to date (1958) in the entire Basin and Range province. The form of the gravity gradients, together with what is known of the adjoining mountain blocks, leaves little doubt that the gravity data are an expression of buried fault scarps that mark the west side of the Utah Valley graben.

A gravity profile across the southwestern part of Utah Valley indicates that two distinct northward-striking faults probably are concealed. One begins near Santaquin in line with a fault that bounds one of the mountain blocks to the south (Eardley, 1933a, map) and extends almost due north through Holladay Springs and the thermal springs near Lincoln Point; the fact that the vertical displacement of the concealed fault north of Santaquin is of opposite sense from that exposed east and south of Santaquin suggests either a hinge action or east-west cross faulting in this area. A major east-west cross fault is shown here by Andrews and Hunt (1948). A second concealed northward-striking fault, 2 to 3 miles to the east of the one just described, apparently begins near Payson and extends north past the mouth of Spanish Fork.

At the northwest edge of the lake northeast of Saratoga Springs, there are two distinct steepenings of the gravity gradients 1 to 2 miles apart. One is along the trend which continues northwest into the western part of the Traverse Mountains; the other is on the trend which swings northeast toward Alpine. The possible connection between these features and those at the south end of the lake—in which, if true, an inner deeper graben could be postulated within an outer shallower one—must remain conjectural until additional data are available over Utah Lake.

The interpretation of the steep gravity gradients along the west edge of Utah Lake as faults is supported by abundant geologic evidence. Beginning at the south, the warm waters of Holladay Springs emerge about 1½ miles northeast of Santaquin; normal faults, downthrown to the east, are inferred along scarps on the east margin of West Mountain (Eaton, 1929, p. 77–78); a thermal spring occurs above the low-water level of Utah Lake half a mile northeast of Lincoln Point (Richardson, 1906; Eaton, 1929, p. 78; R. E. Marsell, 1955, oral communication, who visited the spring during the low-water season of 1935); a normal fault, downthrown to the east with a displacement of at least 250 feet, has been mapped in the Pelican Hills on the east margin of the Lake Mountains (Bullock, 1951, p. 21); and, finally, a probable major fault, which is indicated by a series of thermal springs, including Saratoga Springs, along the western and northwestern shores of Utah Lake, probably terminates the eastern margin of a pediment extending eastward from the Lake Mountains fault block (Bullock, 1951, p. 41; Hunt and others, 1953, p. 89).

On the basis of the gravity data, the Utah Lake fault zone is believed to project into the Jordan Narrows area, where northwestward-trending faults were found by Marsell[6] and Slentz (1955, fig. 5), and into the Traverse Mountains area west of Jordan Narrows, where extensive volcanic rocks are exposed. Several volcanic vents or plugs apparently occur within a restricted zone along or near the inferred fault zone. The plugs include South Mountain, Step Mountain, and two other unnamed volcanic vents nearby. The volcanic material probably found egress through fractures genetically related to the formation of the Utah Lake fault zone. The volcanic activity is regarded as late Eocene (post-Wasatch) or Oligocene (Gilluly, 1932, p. 66), but the dating of the faulting is not exact enough to prove the suggested genetic relation.

FAULT-BLOCK SPURS

The individual grabens along the Wasatch structural trough are separated by low but distinct gravity saddles in the areas of Becks Hot Springs, the Traverse Mountains, and near Santaquin. Each of these saddles coincides closely with a well-developed bedrock spur or salient that projects from the adjoining Wasatch Range block. It has been suggested (Gilbert, 1928, p. 67) that these spurs represent blocks that became separated from the adjoining mountain mass and lodged at an intermediate level between it and the sunken valley block. The bedrock that is commonly exposed in the spurs serves as an important key in the study of the fault movements, and thus aids in interpreting the gravity data. Because the spurs are bedrock like the adjoining mountain, the gravity values there tend to be much higher than over the grabens.

The gravity saddle over the Traverse Mountains is confined principally to the area east of Jordan Narrows, which Gilbert (1928, p. 27) designated the Traverse spur. There is geologic evidence that faulting has occurred along the north, east, and south margins of the Traverse spur. The downward displacement of the east margin of this block probably occurred along the fault in the Corner Creek area at the junction of the Traverse Mountains and the Lone Peak salient. The three abandoned channels of Corner Creek that now lie high up on the fault scarp and entrenched in the granite indicate that some of this faulting is rather recent. The northwestward-trending gravity contours over that part of the Traverse Mountains lying west of Jordan Narrows indicates a structural feature. The feature is perhaps an "early" fault of the Basin and Range orogeny which presumably later became "sealed"; for, according to Gilluly (1928, p. 1121), geologic evidence indicates that the movements of the entire crest of the Traverse Mountains—both its east and west segments—during the more recent episodes of Basin and Range faulting probably were in unison, and involved a tilting of some 4° to the east and southeast.

The surface of the Traverse Mountains is subdued and mature (Marsell, 1953). The down faulting in the adjacent graben areas must have proceeded to a greater extent than the down faulting of the Traverse spur. High prefaulting relief may also have accentuated the present topographic relief of the Traverse spur.

The Salt Lake salient, an area of moderately high topographic relief lying just northeast of Salt Lake City, is apparently part of the upthrown Wasatch block. No known structural or physiographic evidence of the Wasatch fault crossing the salient was noted by Schneider (Eardley, 1939, p. 1299), although Gilbert there mapped the Wasatch fault as unbroken and designated the area as a spur. Gilbert mapped the fault there largely by analogy with the other spurs and with "mental reservation, for the evidence is not complete" (Gilbert, 1928, p. 23). A fault of post-Almy (Paleocene) and pre-Knight (Eocene) age, downthrown to the west and alined with the mountain front, was mapped by Crittenden and others (1952, p. 29); but

[6] Marsell, R. E., 1932, Geology of the Jordan Narrows region, unpublished master of science thesis, Univ. Utah Library, p. 50.

this faulting antedates that generally regarded as Basin and Range faulting. The Weber Valley surface rises unbroken along the crest of the Salt Lake salient from its tip near Becks Hot Springs to the crest of the Wasatch Range north of City Creek, and gives proof that no major recent faulting has occurred (Eardley, 1944, pl. 8). The salient was apparently decapitated at Becks Hot Springs by the Warm Springs fault, which is one of the principal faults of the Wasatch fault zone in this area (Thomas and Nelson, 1948). The gravity saddle here indicates that the down-faulted ridge of the salient still stands as a topographic high in the buried basement west of Becks Hot Springs. The Western Petroleum Co. well WP 1, about 2 miles west-southwest of Becks Hot Springs and apparently south of the buried crest, was drilled to a total depth of 1,985 (?) feet (Hansen and Scoville, 1955, p. 54–55), but failed to penetrate rocks older than Tertiary. It should be noted that rocks older than Tertiary are exposed at the west tip of the Salt Lake salient.

A gravity saddle and gravity high exist in the area near Santaquin. The ridges that constitute the adjoining spur are small northward-trending "fault-block ranges" separated by faults having a downthrow to the west (Gilbert, 1928, p. 31, 33). Because their trends are parallel to the Wasatch Range, Gilbert regarded them as a type distinct from the other spurs of the Wasatch. As stated on page 82, one of the major northward-trending faults east of Santaquin (Eardley, 1933a, map) extends directly toward the westernmost of the Utah Lake steep gravity gradients, but the two faults are of opposite displacement. The east-west fault south of Payson apparently forms the north margin of the Santaquin spur, but its other margins are not well defined.

SUMMARY OF STRUCTURAL FEATURES

The Wasatch structural trough extends for at least 100 miles along the Wasatch front and consists of a system of grabens, with intervening fault-block spurs. All the blocks have been faulted downward relative to the main Wasatch Range fault block, but with different amounts of throw and tilt. Some blocks were lodged at intermediate height as if pinned in between other blocks, in a manner analogous to the kingpin in a mason's arch. These are designated fault-block spurs.

The grabens along the Wasatch structural trough are as follows: The Farmington, Jordan Valley, Utah Valley, and Juab Valley. The fault-block spurs are—the eastern part of the Traverse Mountains and the spur in the Santaquin area.

GOSHEN VALLEY BASIN

An elongate valley in the vicinity of Goshen seems to be a continuation of the southwest arm of Utah Lake. It contains a gravity low with a closure of about 6 milligals centered a mile or more west of Goshen. The southeast edge of the basin is bounded by the Long Ridge fault, which is marked by thermal springs east of Goshen. A gravity gradient occurs along the fault. Similar faults were reported by Eaton (1929, p. 78) west and southwest of West Mountain. The gravity gradient along the southwestern margin of West Mountain gives support to the fault in this area. The lack of any strong gravity gradient in the area lying just west of the northern half of West Mountain indicates that here the alluvium is probably thin; yet it does not preclude the possibility that a bounding fault exists along the west margin of West Mountain. If this fault exists, then West Mountain is a horst, as postulated by Eaton. The zone of steep gravity slopes west of Elberta suggests that the basin may be a graben bounded by faults on this side also. No Recent faults have been mapped along the west margin of the basin, but they may be obscured in this area by the widespread lava.

OQUIRRH-BOULTER-TINTIC FAULT BLOCK

The Oquirrh Mountains, Boulter Ridge, and East Tintic Mountains together form an irregular and more or less continuous fault block which probably extends from the Buckhorn Mountain area on the south to the north tip of the Oquirrh Mountains on the north and is bounded on the west by the Oquirrh-Boulter-Tintic fault zone, and on the east in part at least, by the Utah Lake fault zone. A gravity high lies over the block. The north and south termini may require revision when additional gravity data and geologic control are available in critical areas, such as the northern third of the Oquirrh Mountains and the southern part of the East Tintic Mountains. As Loughlin considered the East Tintic Mountains to be a composite fault block (Lindgren and Loughlin, 1919, p. 16), the Oquirrh-Boulter-Tintic fault block may be found to extend to the south end of the East Tintic Mountains. The Oquirrh-Boulter-Tintic fault block probably is a horst that is tilted eastward. In the area lying roughly within the −180-milligal contour that skirts the block, except for the northern third of the Oquirrh Mountains, the relatively small gravity relief indicates that this block probably has remained virtually as a single tectonic unit during the period of the Basin and Range orogeny.

The gravity trends at the northern part of the Oquirrh-Boulter-Tintic block, though based on sparse gravity data, have important geologic implications. In contrast with their northerly trend along the southern part of the Oquirrh Mountains, the gravity contours that cross the Oquirrh Mountains near Dry Fork in the Bingham Canyon area correspond with an east-west fault zone that has a throw of many thousands of feet in this area (Emmons, 1905, p. 22). To the north of this fault zone and throughout the remaining northern part of the Oquirrh Mountains, the eastward-trending gravity contours, such as those observed between Bacchus and Garfield, must continue westward across the Oquirrh Mountains. This easterly gravity trend corresponds with the east-west structural geologic trends that characterize this part of the range, in contrast to the northwesterly trends to the south (Emmons, 1905, p. 22–23).

At the north tip of the Oquirrh Mountains, just west of Garfield, the northward gravity decrease of about 10 milligals in 1 mile along a trend a little north of east corresponds well with a fault scarp with the same trend in this area (Emmons, 1905, p. 23). In the area north of Garfield, however, the gravity anomaly indicating this fault diminishes eastward and gives way to a strong local anomaly trending north.

OQUIRRH-BOULTER-TINTIC FAULT ZONE

The Oquirrh-Boulter-Tintic fault zone forms the west margin of the Oquirrh-Boulter-Tintic fault block. The fault zone comprises an irregular and probably discontinuous series of major faults that extend with a northerly trend for a distance of at least 60 miles along the west fronts of the Oquirrh Mountains, Boulter Ridge, and East Tintic Mountains. It is marked by almost continuous steep gravity gradients of about 10 milligals per mile. The total gravity relief over the fault zone is 10 to 20 milligals, though a somewhat greater relief may be found when the valleys to the west are completely surveyed.

The north segment of the fault zone, though not covered in the present survey because of lack of topographic control, was traced by Gilbert (1890) for more than 4 miles southward from the north end of the Oquirrh Mountains and was interpreted by him as a Basin and Range fault that was continuous with the fault at Ophir Creek. Gilluly (1928, p. 1104) concluded from his detailed work in the Stockton and Fairfield quadrangles that the entire west front of the Oquirrh Mountains was bounded by a Basin and Range fault. Butler mapped an inferred fault as continuous along the western margins of Boulter Ridge and the East Tintic Mountains (Butler and others, 1920, pl. 4). Loughlin recognized the possibility of block faulting at the north end of Tintic Valley (Lindgren and Loughlin, 1919, p. 16). The fault zone in the Stockton quadrangle comprises a series of steeply dipping (ranging from 40° W. to 64° W. and averaging 57° W.) normal faults in steplike and en echelon arrangement downthrown to the west (Gilluly, 1932, p. 69). The displacement of the Lakes of Killarney fault is estimated by Gilluly as 1,000 to 3,500 feet in different places along the fault. The average displacement on the fault zone as a whole in the Stockton quadrangle is at least 3,000 feet and may be more than 5,000 feet; it is possible that additional step faults are concealed beneath the alluvium (Gilluly, 1932, p. 85, 87).

CEDAR VALLEY BASIN

Cedar Valley, a broad alluvial basin, lies in the interior of the Oquirrh-Boulter-Tintic block. It is marked by an irregular gravity low with a closure of about 6 milligals. The Church of Jesus Christ of Latter Day Saints well LDS 1 in the northern, and presumably deeper, part penetrated 1,250 feet of unconsolidated valley fill without reaching bedrock; the total depth to bedrock is unknown. A fault with a throw of about 500 feet has been recognized along the east edge of Cedar Valley (Bullock, 1951, p. 29), but no faults have been mapped on the west side. Bullock (1951, p. 43) recognized Cedar Valley as a "structural valley" that presumably resulted largely from downwarping locally accentuated by faulting. There is a possibility, however, that future geologic work in Cedar Valley may establish it as a graben.

TINTIC VALLEY GRABEN

Tintic Valley, lying just west of the Oquirrh-Boulter-Tintic fault zone, is marked by a sharp gravity low with a closure of at least 4 milligals. Fault scarps on the north and east sides of the valley, recognized by Loughlin (Lindgren and Loughlin, 1919, p. 16) and Butler (1920, pl. 4), are marked by a striking gravity gradient of more than 20 milligals. The valley is interpreted by us to be a graben, though faulting has not yet (1958) been proved on the west side of the valley.

SANPETE VALLEY

Only a limited part of the upper Sanpete Valley, in the area north of Wales, was covered by reconnaissance with a few gravity stations. A gravity low occurs along Silver Creek in this area. Sanpete Valley is structural in origin (Spieker, 1949, p. 4), but we do not know whether geologic evidence for a graben in the upper part of the valley has been established. A fault, apparently downthrown to the east, extends with northward trend for a distance of 1½ miles along the western margin of Sanpete Valley about 2 miles north of Wales (Spieker, 1949, map).

AGE OF FAULTING

Nolan (1943, p. 183) believes that the best conclusion possible from available information is that block faulting, as a process in the Basin and Range province, probably began in early Oligocene time and has been more or less continuous ever since. Topographically expressed faults, however, probably date back only to late Pliocene or early Pleistocene, though earlier movements may have occurred along them (Nolan, 1943, p. 184).

The gravity map shows some features that are caused by density irregularities which probably originated as fractures in the earth's crust during the earliest episode of the Basin and Range orogeny. The main fractures that border the Oquirrh-Boulter-Tintic fault block probably were developed at this time. Along the Utah Lake fault zone, the faults outlining the Lake Mountains are also believed to have formed during the early part of the Basin and Range orogeny (Bullock, 1951, p. 37).

The extent to which some of the density irregularities existed along the main rupture lines prior to the Basin and Range orogeny is not known. Certain evidence, however, indicates that the fault movements of the Basin and Range orogeny in some areas occurred along previously existing structural lines. For example, some of the structural lines along the Oquirrh-Boulter-Tintic fault zone probably were formed earlier than the Basin and Range orogeny; movement along the West Mercur fault, which follows the zone, is believed to have been as early as pre-Miocene or possibly pre-Wasatch time (Gilluly, 1928, p. 1117).

It is recognized that certain segments of these earliest Basin and Range faults may have later become inactive, and that two or more formerly separate fault blocks may later have moved in unison. The inferred "early" Basin and Range fault extending along the west edge of Utah Lake (Bullock, 1951, p. 37) and through the South Mountain and Step Mountain areas is believed by us to be of this type. In the Jordan Narrows area, this fault probably became inactive, so that the whole Traverse Mountains moved as a block in unison and tilted about 4° to the east and southeast (Gilluly, 1928, p. 1121).

Although the gravity data cannot give the age of the faulting as such, the data serve to emphasize key areas where geologic fieldwork can be undertaken to help decipher the age relations between the various fault blocks.

INTERRELATIONS OF THE FAULT BLOCKS

The dislocated fault blocks present in the mapped area include grabens, horsts, and down-faulted spurs that are faulted and tilted differently with respect to each other. Although their interrelations are complex, some generalizations can be made.

The similar rock types of the Traverse Mountains, Lake Mountains (a horst), and West Mountain (a horst) and the almost uniform elevation of the crests of these mountains appear to be significant. These facts suggest that, during the Basin and Range faulting following the erosion of the "Traverse Mountains surface" (Eardley, 1955, fig. 9), these blocks may have stood relatively stationary with respect to the main Oquirrh-Boulter-Tintic block. The Cedar Valley and Goshen Valley basins and the Utah Valley and Jordan Valley grabens were dislocated downward relative to the "stationary" blocks; but additional geologic data are needed to establish this relation. The horsts were not entirely stationary, however; the Lake Mountains horst, for example, was tilted southward (Bullock, 1951, p. 37), and the Traverse Mountains block was tilted east and southeast.

The greatest displacements to any of the blocks occurred just west of the Wasatch Mountains block. The blocks involved include the Farmington, Jordan Valley, Utah Valley, and Juab Valley grabens. Each of these large fragments broke from the descending valley block on the west side of the Wasatch block and dropped below the level of the block, as if slipping into a great crevasse. Other fragments broken from the descending valley block on the west side of the Wasatch block were lodged at intermediate height, and now constitute spurs of the Wasatch Range. The net result is the Wasatch structural trough, which comprises an elaborate compound of many blocks with prevalent north-south trend, which lie between the Wasatch block and the Oquirrh-Boulter-Tintic block. The floor of the trough is highly irregular, and is formed by the tops of the blocks, in some places buried beneath thick alluvium and rocks of Tertiary age and in other places rising exceptionally high to form the tops of the exposed spurs. All these blocks, however, have been dislocated downward relative to the Wasatch block, but with varying amounts of throw and tilt. The fault-block spurs apparently became wedged in during the dislocation process, and they remained at a higher elevation than the adjoining blocks.

Gilbert (1928, p. 33, 62) first recognized the possibility of this intermont trough, and our gravity work has helped to corroborate his original view by supplying many additional details.

SUMMARY AND CONCLUSIONS

The gravity anomalies observed reflect density contrasts in the earth's crust that are a product of both old and young orogenies. Some effects of crustal changes that took place before the Basin and Range orogeny are noted. A gravity high exists over the ancient northern Utah highland in the Antelope Island area. Sparse data indicate a small gravity high over the Uinta arch in the Wallsburg area that conforms with the known axis of the arch, but the gravity data give no evidence that the Uinta arch extends west of the Wasatch front.

Steep gravity gradients of 10 milligals or more per mile are found over the Basin and Range faults, where alluvium and rocks of Tertiary age, which lie in the valleys, are faulted against bedrock of Paleozoic age or older. The continuity of gravity trends between thermal springs and other areas of known faults permit the charting of many previously unmapped Basin and Range faults. The existence of steep gravity gradients over valley alluvium, away from the mountain fronts—in some places as much as 2 or 3 miles from the fronts—indicate newly discovered concealed faults, some of which are postulated to have vertical throws of at least several thousand feet. Steep gravity gradients corresponding with Basin and Range faults occur along parts of the Wasatch fault zone on the west margin of the Wasatch Mountains; along a continuous fault zone 60 miles in length on the west margin of the Oquirrh Mountains, Boulter Ridge, and East Tintic Mountains; and along the Utah Lake fault zone east of West Mountain and the Lake Mountains.

The gravity data have delineated a large number of fault blocks in the area, some large and some small, that have been displaced in various ways relative to one another. Geologic data show that some are tilted eastward or southeastward. The gravity data indicate that the principal vertical displacement of the blocks has occurred along a northerly trend just west of the Wasatch fault zone. Here, for at least 100 miles along the zone just west of the Wasatch front, there exists an intermont trough—here designated as the Wasatch structural trough—which comprises a belt of grabens and smaller fault blocks whose dislocations are varied and more complex than previously realized. The floor of the trough, which lies between the Wasatch block and the Oquirrh-Boulter-Tintic block, is highly irregular, and is formed by the tops of the blocks, in some places buried beneath thick alluvium and rocks of Tertiary age, and in other places rising exceptionally high to form the tops of the exposed fault-block spurs. All these blocks were displaced downward relative to the Wasatch Mountains block; some dropped deeper as if slipping into a great crevasse. Some fragments were wedged in between other blocks and remained lodged at intermediate height. In the main, the gravity results corroborate the findings and viewpoints of Gilbert (1928).

DESCRIPTION AND VALUES OF GRAVITY BASE STATIONS

The descriptions of several of the important gravity base stations used in the present survey are given below. The accompanying value is the gravity reading at the designated station, in milligals, relative to the reading at the U.S. Coast and Geodetic Survey pendulum station 49, located in the Temple Grounds in Salt Lake City and established in 1894 (Duerkson, 1949, p. 8). The value shown is the algebraic quantity "base station value minus pendulum station value."

	Milligals
American Fork Canyon base station. The station is at the gateway of the South Fork Ranger Station in line with and 7 ft northeast of the northeast base of the sign reading "South Fork Ranger Station." (Timpanogos Cave, Utah, quadrangle.)	—161.18
Big Cottonwood Canyon base station. The station is 5 ft east of a 2 ft rock monument which is located about 12 ft southeast of U.S. Forest Ranger telephone pole labeled "140." The pole is about 300 ft northwest of ranger station and 150 ft southwest of bridge across Big Cottonwood Creek at entrance to the Spruces picnic ground in Big Cottonwood Canyon. (Mount Aire, Utah, quadrangle.)	—214.65
Jordan Narrows base station. The station is 5 ft east of a 2-ft monument of concrete blocks located 15 ft west of the center of an unimproved road. The monument is 50 ft north of the first bend in this unimproved road, which enters Highway 91 from the west in the "Point of the Mountain" area at a point located 0.35 mile north of the Salt Lake-Utah County line. (Jordan Narrows, Utah, quadrangle.)	—69.72
Liberty Park base station. The station is located 12 ft due north of the center of a large 3-forked boxelder tree. The tree is 100 ft north and 150 ft west of a large outdoor stone fireplace, which, in turn, is about 150 ft southwest of the Liberty Park horseshoe pitching pits. Liberty Park is located at 9th South Street and 6th East Street, Salt Lake City. (Sugar House, Utah, quadrangle.)	—2.70
Payson base station 1. The station is 10 ft west and 10 ft north of the southwest corner of the Payson Junior High School building located at about 250 South Main Street, Payson, Utah. (Spanish Fork, Utah, quadrangle.)	—10[illegible].10
Payson base station 2. The station is located in Payson Canyon at the northwest tip of the entrance to the Utah National Parks Council area; the station is 21 ft east and 5 ft north of the U.S. Geological Survey bench mark (5,608 ft) in a stone monument and 3.9 ft below the top of the bench mark. (Santaquin Peak, Utah, quadrangle.)	—16[illegible].18

	Milligals
Payson base station 3	—217.45

The station is located in Payson Canyon in a clearing west of Nebo Loop Road; the station is 5 ft south of the sign reading "Payson Canyon Winter Sports Area." (Santaquin Peak, Utah, quadrangle.)

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