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Gravity survey in the western Snake River Plain, Idaho -- A progress report

by

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Gravity survey in the western Snake River Plain, Idaho--A progress report

Abstract

From June 24 through August 16, 1960, a regional gravity survey was made in 3,600 square miles of the Snake River Plain in southwestern Idaho. Six hundred and seventy-two gravity stations were established between latitudes 42°30'N and 43°30'N and between longitudes 114°15'W and 116°15'W at an average density of one station per 5.4 square miles. The data were reduced to simple-Bouguer gravity by standard methods and plotted as a gravity contour map.

Three major anomalies were defined by the survey; two 30-mile long, *en echelon* gravity highs with amplitudes of 15 and 50 milligals, and one elongated gravity low with an amplitude of -10 milligals. A two-dimensional graticule analysis suggests that the highs are caused by vertical slabs of dense rock (probably basalt), the largest about 4 miles wide, about 30 miles long, and extending from about 1,000 feet (0.3 kilometer) below sea level to about 66,000 feet (20 kilometers) below sea level. A possible geological interpretation is that the vertical slabs are large, *en echelon*, basalt-filled fissures or zones of fissures in the earth's crust. The gravity low is attributed to an alluvium-filled trough about 5,000 feet (1.5 kilometers) deep.

Introduction

This progress report describes a regional gravity survey of part of the western Snake River Plain, Idaho. The survey was established to define the gravity field over the Snake River Plain as an aid in determining the structure and composition of the underlying crust.

The 1960 field work is a continuation of the survey started in 1959 in cooperation with the Geophysics Department, Colorado School of Mines (Baldwin and Hill, 1960; Baldwin, 1960). Two immediate objectives in the field were 1) to define further gravity anomalies suggested by the 1959 survey, and 2) to search out and define any new gravity anomalies. The field party of D. P. Hill and J. J. Jacobson worked under the supervision of L. C. Pakiser. Professor Paul Rogers of the Colorado School of Mines Geophysics Department acted in an advisory capacity.

Geography

The surveyed area covers parts of Blaine, Camas, Elmore, Lincoln, Owyhee, and Twin Falls counties in southwestern Idaho. Gravity stations were established between latitudes 42°30'N and 43°30'N and longitudes 114°15'W and 116°15'W (fig. 1). U. S. Highway 30 is the main transcontinental road through the region; it closely follows the Snake River in a southeasterly direction through the center of the surveyed area. The larger towns in the area are Twin Falls, Glenns Ferry, Jerome, Buhl, Gooding, Fairfield, and Wendell.

The southern half of the survey is in the Snake River Plain, a broad, relatively flat lava plain forming a belt across southern Idaho. In the area of the survey, the plain is 40 to 60 miles wide, trends west-northwest, and averages about 3,000 feet above sea level. It is bounded on the south by the Owyhee Mountains (not included in the survey) and on the north by the Mount Bennett Hills. The Snake River flows the length of the plain, cutting a deep narrow canyon through accumulated lava beds and carving badlands through the softer Tertiary and Quaternary lake beds. On either side of the Snake River the plain is characterized by broad lava flats interspersed with buttes and badlands. The latter features rarely show more than 300 feet of relief. Maximum relief in the plain is about 1,000 feet.

The northern half of the survey includes the Mount Bennett Hills and Camas Prairie. The Mount Bennett Hills create an east-trending barrier between Camas Prairie and the Snake River Plain. The highest peak in the hills, Mount Bennett, rises 7,465 feet above sea level. Camas Prairie, the northernmost feature covered by the survey, is about 17 miles long and 8 to 10 miles wide. The prairie is bounded on the north by the Soldier Mountains, which rise to elevations of about 10,000 feet above sea level.

Most of the area is semi-arid, receiving essentially all its moisture during the winter. The principal vegetative cover is sagebrush and cheat grass. Pine trees and aspen groves are found on the higher mountain slopes.

Geology

The oldest exposed rocks in the region of the survey are the Cretaceous igneous rocks of the Idaho batholith. These rocks crop out in the Soldier Mountains north of Camas Prairie and in a few isolated inliers on the northern slopes of the Mount Bennett Hills. The highlands to the north and south of the Snake River are composed essentially of upper Miocene and lower Pliocene silicic volcanic rocks. A veneer of middle Pliocene age Banbury basalts covers the silicic volcanic rocks in some of the lower elevations. The central part of the Snake River Plain - a collapse structure, or graben - is filled with Pliocene and Pleistocene sedimentary rocks and a few interbedded basalt flows of the Idaho group to a depth of at least 3,000 feet (H. E. Malde and H. A. Powers, 1960, written communication). Subsidence of the graben has taken place along fault zones striking northwest in the western Snake River Plain and northeast in the eastern Snake River Plain. Recent basalt flows of the Snake River group have covered parts of the plain as far west as Bliss.

Previous work

Bonini and Lavin (1957) conducted a regional gravity survey over southern Idaho and southwestern Montana. Their work outlined an elongated gravity high along the Snake River Plain.

The initial work in the present study (Baldwin and Hill, 1960; Baldwin, 1960) defined two *en echelon* gravity highs trending northwest in the Boise-Mountain Home area of the western Snake River Plain. A third gravity high, apparently related to the other two, was suggested by a line of stations extending south of the main survey along Idaho State Highway 51.

Field methods and computations

Field work in 1960 extended from June 24 through August 16. During this period, 672 gravity stations-- including seven base stations --were established over an area of about 3,600 square miles. The average station density for the survey is one gravity station per 5.4 square miles.

The entire 1960 survey was done using Worden gravity meter E-134. The meter has a constant of 0.4836 milligals per dial division and a range of about 800 dial divisions. As work progressed, it became evident that the drift was to a great extent a function of the ambient temperature. On cool, overcast days the drift for a 4-hour period would range from 0.0 to 0.4 dial divisions. On warmer days the drift for a similar period would be as much as 0.9 to 1.0 dial divisions. The most severe drift usually corresponded to large changes in the ambient temperature. The instrument readings invariably drifted up throughout the survey.

Horizontal and vertical control for the survey was taken from U. S. Geological Survey 7 1/2- and 15-minute quadrangle series of topographic maps; Army Map Service 1:250,000 sheets; and U. S. Coast and Geodetic Survey, U. S. Geological Survey, and Idaho State Highway bench-mark descriptions. About 93 percent of the gravity stations were established from spot elevations published on the 7 1/2- and 15-minute maps. Eight stations were established from spot elevations given on the 1:250,000 sheets. The remainder of the stations were located by the various bench-mark descriptions. Spot elevations published on the Geological Survey's 7 1/2- and 15-minute maps, as well as all bench marks are accurate to within 2 feet. Spot elevations on the 1:250,000 sheets are probably accurate to within 10 feet. In a few instances where spot-elevation coverage was sparse, unchecked photogrammetrically determined elevations (brown on the maps) and points of uncertain location were used. These stations may be off in elevation as much as 10 feet.

The 1960 gravity net is tied to five base stations established in 1959 by Baldwin and Hill. New base stations were set by making readings from three separate base stations. A new base was considered established if the three readings differed by less than 0.2 milligal. A series of new stations was set by the single loop method in which the same base is read at the beginning and end of a loop. A loop contained an average of 11 new gravity stations, two repeated readings, and the initial and final base readings. One of the repeated readings was taken on a station in a previous loop as a tie, the other was repeated within the loop as a check on instrument drift. The maximum allowable difference between any two repeated readings was set at 0.4 milligal. Most loops were run in four to five hours. In Camas Prairie, however, time, terrain, and distance considerations made it more practical to take eight hours for a single loop. Two ties and two repeats were made in each of these longer loops. The authors alternated reading the meter and recording data. The meter was read by the same person for a complete loop; the other person recorded data and drove the vehicle. These duties were usually switched at the beginning of a new loop. Data recorded in the field were 1) instrument reading, 2) time of reading, 3) station elevation, and 4) a written description of the station location along with the location spotted on a map.

The data were reduced to observed gravity at the end of each field day. This procedure permitted a continuous check to be made on the accuracy of the survey. Computations were based on the assumption that instrument drift was linear between the initial and final base readings of a loop. Reduction of data to simple-Bouguer gravity was made at the end of each week. Latitude corrections for the stations were read from curves based on the table of values of theoretical gravity from The International Gravity Formula given by Nettleton (1940, p. 139-143). The latitude (and later the longitude) of each station was measured to the nearest two seconds from 7 1/2- and 15-minute maps and to the nearest five seconds from the 1:250,000 maps. The combined free air and slab (Bouguer) correction was referred to sea level and computed for an assumed density of 2.67 g per cm^3--giving a correction factor of 0.06 milligal per foot. All computations were carried to 0.01 milligal to reduce the rounding error. The resulting Bouguer gravity was plotted on a rough field map as a guide for directing further field work. No terrain corrections have been added because the significant anomalies are large with respect to the expected terrain effects.

A histogram showing the frequency distribution of differences in repeat readings made during the survey was compiled (fig. 2). Out of 123 repeated readings 58 percent differ by 0.1 dial division (0.07 milligal) or less, 75 percent differ by 0.2 dial divisions (0.12 milligal) or less. All repeated differ by less than 0.26 milligals. The average difference of the repeated readings is 0.1 dial divisions or 0.08 milligal. Included with this report are the data for each gravity station established in 1960. (See two sheets in pocket.)

Results

Description of anomalies

The results of the survey are represented by a Bouguer-gravity contour map plotted at a two-milligal contour interval and on a scale of 1:250,000 (fig. 1). Two gravity highs, one gravity low, and several minor anomalies are defined by the map.

Major anomalies

The most conspicuous feature on the contour map is an elongated gravity high about 30 miles long and 10 miles wide trending west-northwest across the center of the map. The axis of the high extends from a point approximately five miles northeast of Wendell to a point about two miles east of Glenns Ferry. The amplitude of the anomaly is approximately 50 milligals and it has a maximum Bouguer gravity value of -85 milligals. Gradients on the sides of the anomaly are as much as six to eight milligals per mile. The steepest gradients are found on the northeast side. This anomaly is slightly offset from the easternmost high defined by the 1959 survey. The maxima of the two highs are separated in the vicinity of Glenns Ferry by a low of about 10 milligals.

A second elongated gravity high is located about 35 miles southwest of the high just described. The axis of this high can be followed from a point 10 miles south of where the Bruneau River enters the Snake, southeast to a point about 12 miles east of where the east and west forks of the Bruneau River join. The high is also about 30 miles long and 10 miles wide, but has amplitude of only 20 milligals. The steepest gradients associated with this anomaly are about 6 milligals per mile and are found on its southwestern side. This gravity high is parallel to, and on the southwestern side of the easternmost high found in 1959.

The two gravity highs defined by the map form an en echelon pattern, the axis of the larger high being offset to the northeast from the smaller by about 20 miles. Apparently this is a continuation of the en echelon relationship shown by the two gravity highs defined in the survey by Baldwin and Hill (1960); and Baldwin (1960).

An elongated gravity low is defined by the contours in the northern part of the map over Camas Prairie. The axis of this anomaly extends from a point about 5 miles northeast of Hill City, through Fairfield, and on to a point about 18 miles farther east, giving a total length of nearly 30 miles. With the assumed regional gravity subtracted, the amplitude of the anomaly is found to range between about 13 milligals in the vicinity of Fairfield to about 17 milligals in a kidney-shaped gravity minimum 6 miles east-northeast of Fairfield. Gradients range from two milligals per mile to five milligals per mile; the steepest gradients are associated with the kidney-shaped minimum. Terrain corrections applied in this area will tend to increase the amplitude of the negative anomaly because the added effects will be largest in the surrounding mountains.

Regional trends and minor anomalies

A strong west-northwest trend of the gravity contours is evident over the entire western portion of the map. This trend is essentially parallel to the three major anomalies, the general boundaries of the western Snake River Plain, and most of the mapped faults in the area (Malde, 1959). East of longitude 114°45'W, the trend begins to swing to the northeast in accord with the general direction of the boundaries of the eastern Snake River Plain. The regional gravity drops off from the major gravity high into the Idaho batholith to the north at a gradient of about 40 milligals in 27 miles and to the south toward the Owyhee Mountains at a gradient of 18 milligals in 15 miles. Of particular note is the suggestion of a linear anomaly at the eastern edge of the map that trends northeast at a rather sharp angle to the axis of the major gravity high.

Of the minor anomalies, one of the most interesting is a small, elliptical gravity high on the southern side of the Thousand Springs, southwest of Wendell at 114°49'W and 42°43'30"N. The gravity contours show a closure of four milligals and an areal extent of about 2 1/2 square miles. Subtraction of the regional gradient would probably shift the center of the anomaly to the south about a mile and increase its closure to about 8 milligals. The entire area is covered by a lava flow and gives no hint as to the source of the anomaly. The shape of this small high suggests that the anomalous body might be approximated by a vertical cylinder; this in turn suggests a lava neck or plug. The small spur on the southern flank of the second gravity high may be the result of a similar feature.

Toward the eastern edge of Camas Prairie, between Fairfield and Bellvue, there is a comma-shaped gravity high that fits around the northeastern end of the Camas Prairie low. It is about 10 miles long, 5 miles wide, and has an amplitude of 8 to 10 milligals. The total relief between the high and the adjacent low is about 18 milligals in a distance of 4 miles. This high seems to be associated with the flows of the Snake River basalt and other local volcanic features.

Most other minor anomalies show closures of two milligals or less and are associated with the Mount Bennett Hills or the badlands south of the river. These anomalies are probably caused by a combination of local density variations and terrain effects.

Preliminary interpretation

To set bounds on the amount and probable distribution of material causing the major anomalies, a two-dimensional interpretation has been made along profiles A-A' and B-B' (fig. 1). This interpretation is based on the following assumptions and controlling factors:

1) A two-dimensional analysis requires that the feature analyzed be approximated by a body with infinite dimensions normal to the profile. The three major gravity anomalies have been assumed to fit this requirement.

2) A density contrast of 0.3 g per cu^3 is used for the hypothetical bodies causing the anomalous highs. This is based on an assumed background density of 2.67 g per cu^3 (the conventional assumed density of crustal material) and an estimated density of 3.0 g per cu^3 for the material forming the anomalous body (presumably basalt). The density contrast for the gravity low is assumed to be -0.4 g per cm^3, the average density difference between alluvial material and granite.

3) The major gravity highs occur over the Pliocene and Pleistocene Idaho group of sedimentary rocks. These deposits form a relatively low-density mass consisting essentially of poorly consolidated sandstones and silts. Test drilling and field geology indicate that these deposits are at least 3,000 feet thick in the vicinity of the highs (H. E. Malde and H. A. Powers, 1960, written communication). This places the tops of the anomaly causing bodies at least 3,000 feet below the surface.

4) The prominent *en echelon* pattern of the elongated gravity highs suggests that the anomaly causing bodies are structurally controlled, possibly by *en echelon* faults or fissures.

5) A smooth curve has been drawn through what appears to be a regional gravity trend (figs. 3 and 4). For this interpretation, the assumed regional trend has been attributed to deep crustal -- probably isostatic -- effects and therefore subtracted in the analysis of the anomalies.

The interpretation was based on calculations made with a graticule similar to that designed by D. G. Skeels as described in Dobrin (1952, p. 98). The graticule was constructed so that each trapezoidal compartment covering the body contributed 1.17 ($\Delta\rho$) milligal toward the total vertical component attraction at the point being considered; $\Delta\rho$ is the density contrast in g per cm^3.

Profile A-A'

Profile A-A' is a line 70 miles long that trends N18°E; it forms the perpendicular bisector to the axis of the anomalous high and intersects the axis of the Camas Prairie low at an angle of 68°. The south end of the profile is located approximately at latitude 42°36'N and longitude 115°11'W. The assumed regional Bouguer gravity is about -145 milligals in the vicinity of the high and drops off toward the Camas Prairie low and the Sawtooth Mountains at a gradient of 2 milligals per mile. The gravity high sits on the regional trend as a slightly skewed, bell-shaped curve with a relative amplitude of 50 milligals. Maximum gradients are 7 1/2 and 6 milligals per mile on the north and south sides of the high, respectively. The maximum point of the anomaly is located about 1 mile southwest of the Snake River as measured along the profile. The Camas Prairie low forms a broad U-shaped curve with respect to the regional trend. The amplitude of the low in this cross section is about 5 milligals.

The generalized shape of the body causing the gravity high is interpreted as being a vertical slab about 4 1/2 miles wide, 30 miles long, and extending from about 1,000 feet (0.3 kilometers) below sea level to a depth of 66,000 feet (20 kilometers) below sea level (fig. 3). The gravity low in the Camas Prairie vicinity is attributed to an alluvium-filled trough about 5,000 (1.5 kilometers) deep.

Profile B-B'

Profile B-B' trends N.34°E., is 26 miles long, and bisects the axis of the smaller high at right angles. Latitude 42°32'N and longitude 115°59'W locate the southern end of this profile. The regional gradient is assumed to be linear between the simple Bouguer values of -160 and -120 milligals at the south and north ends of the profile, respectively. The anomaly has an amplitude of 20 milligals above the regional gradient.

The similar character of the two gravity highs has led to similar interpretations for each. Thus this smaller anomaly has also been attributed to a body in the general shape of a vertical slab (fig. 4). In this interpretation the slab is about 3 miles wide, 30 miles long, and extends from 8,000 feet (2.4 kilometers) to nearly 24,000 feet (7.3 kilometers) below sea level.

Conclusions

Various alternative interpretations are possible depending on the initial assumptions. For example, isostatic corrections along profile A-A' may show that the regional gravity is actually quite different than has been assumed for this interpretation. It is conceivable that the regional curve in profile A-A' has less amplitude or is even essentially flat. If this is the case, the anomalous body will be larger and probably considerably broader near the surface than is shown in figure 3.

Several geological hypotheses have been offered in explanation of the gravity highs. The most important of these are:

1) The Snake River Plain is a broad downwarp that has been filled with extensive basalt flows.

2) The plain is a collapse structure bounded by faults with large vertical displacements. As subsidence progressed, lava flows filled the depression resulting in thick accumulations of basalt.

3) Crustal stresses have caused large <u>en echelon</u> fissures under the Snake River Plain. These fissures have been injected with basalt.

In light of the interpretation presented in this paper, the authors place most credence in the last of the above possibilities. Further study may show, however, that the anomalies are actually due to some combination of the second and third hypotheses.

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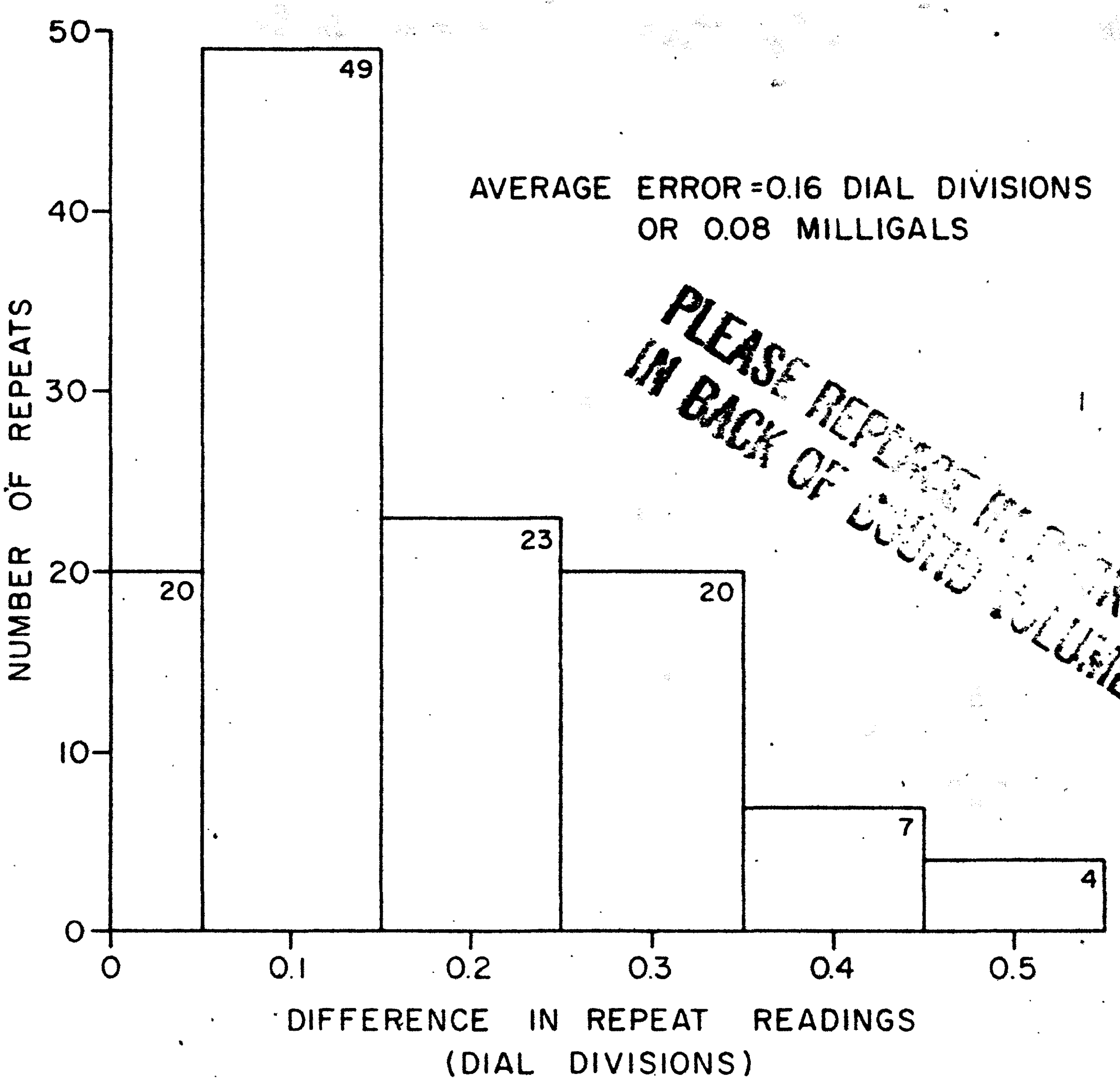

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Figure 2.— Histogram of repeat readings

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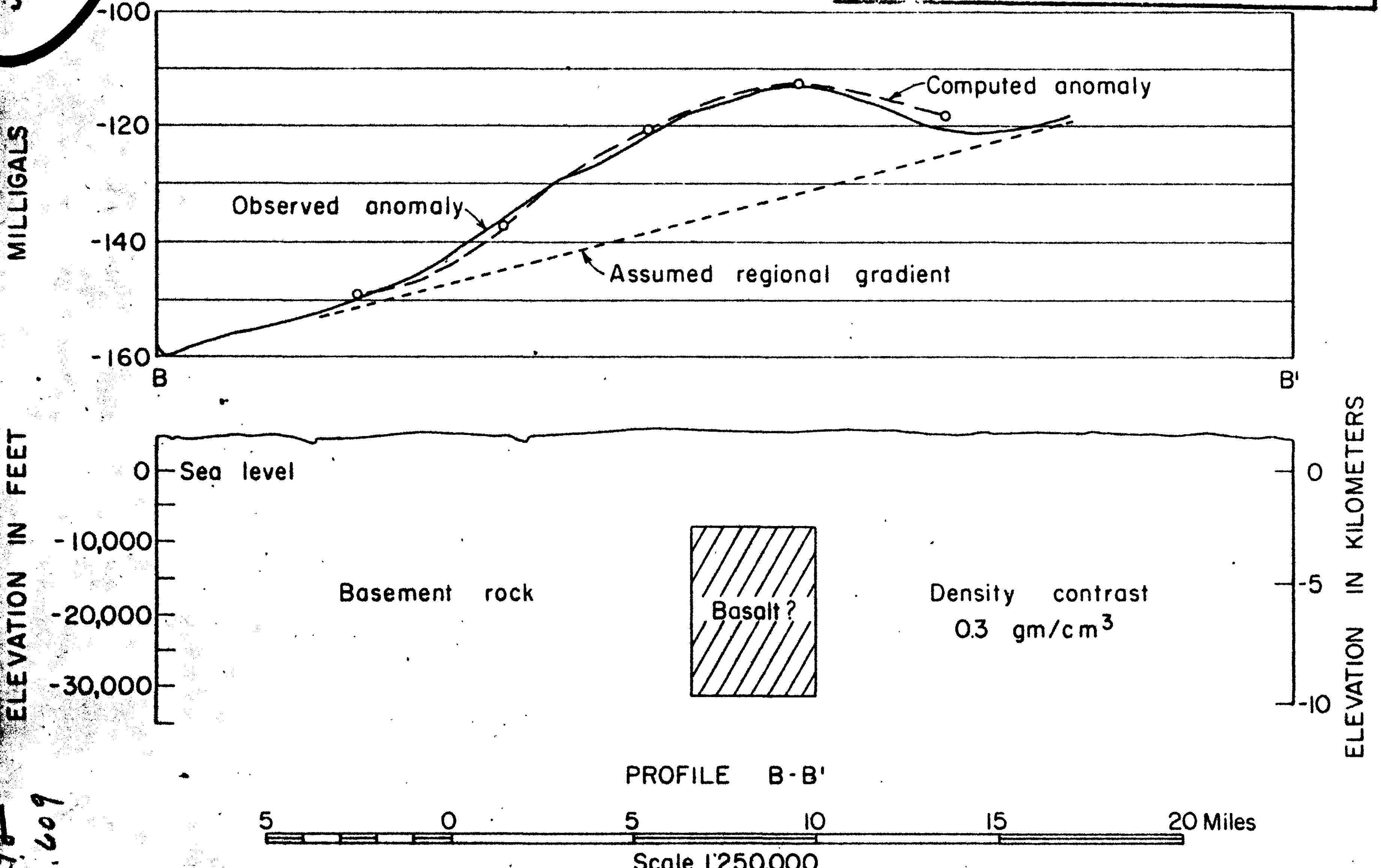

Figure 4. — Interpretive section profile B-B', Snake River Plain, Idaho

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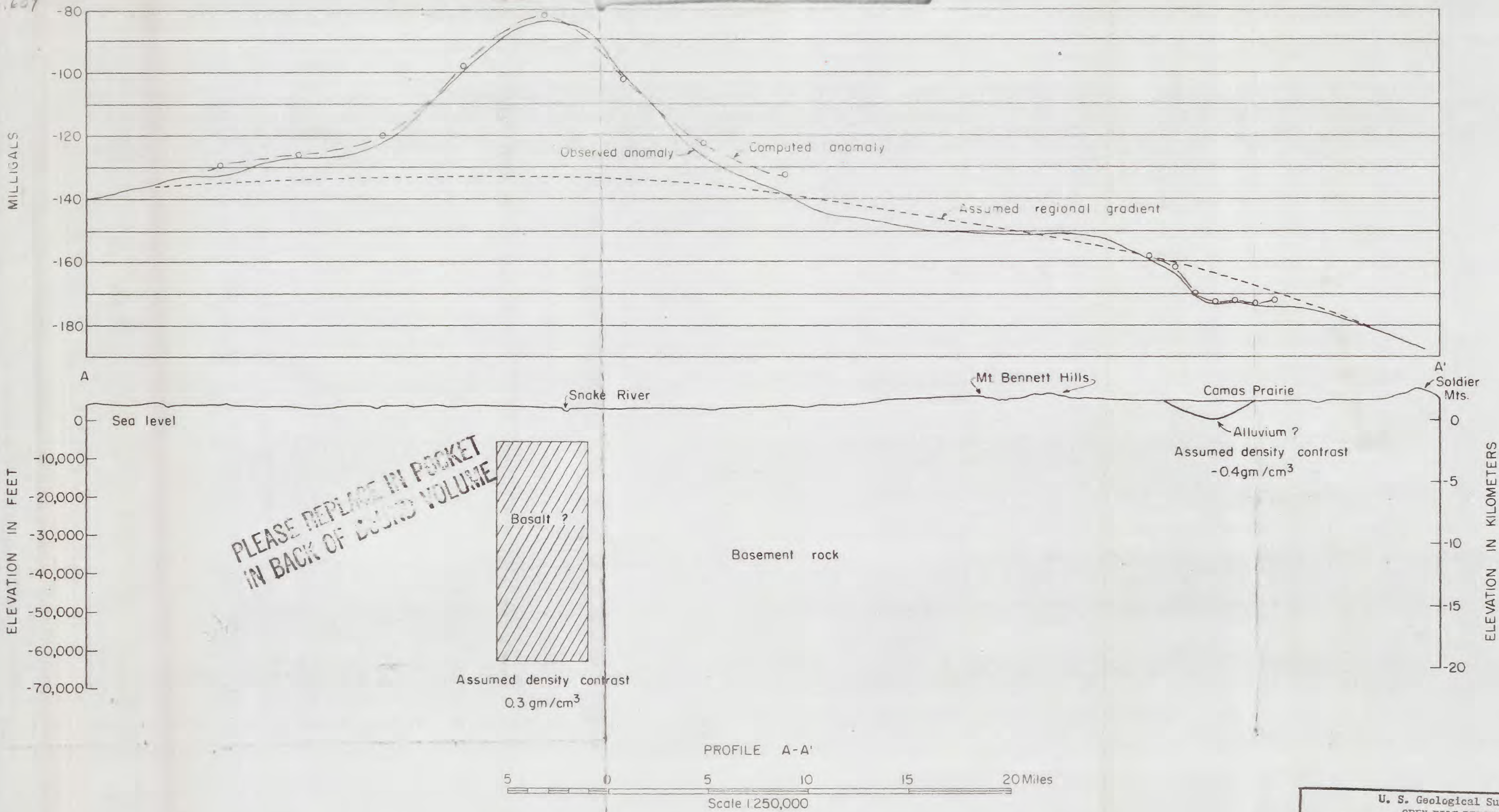

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Figure 3.— Interpretive section profile A-A', Snake River Plain, Idaho

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