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REGIONAL GRAVITY AND MAGNETIC ANOMALIES IN THE EASTERN SNAKE RIVER PLAIN, IDAHO

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Abstract.—Over the eastern Snake River Plain, the Bouguer gravity anomaly and the magnetic intensity are, in general, high. In detail, both the gravity and the magnetic anomalies are a complex of highs and lows, in contrast to the simpler anomalies over the western Snake River Plain. The broad gravity high associated with the eastern Snake River Plain cannot be produced by a dense mass at shallow depth under the plain, but must be produced either by a deep feature under the plain or by a broader, shallower feature extending well beyond the plain. The high could be produced by a thinning of the crust under the plain by 4.5 to 7 kilometers. The data suggest that the Cenozoic rocks of the plain are underlain by rocks that have density and magnetization similar to the density and magnetization of the pre-Cenozoic rocks north and south of the plain. The data do not suggest rifting of the upper crust such as is inferred for the western Snake River Plain. The plain is in approximate isostatic equilibrium with adjoining regions to the north and south and thus contrasts with the adjoining areas where the basin-and-range topography is not in isostatic equilibrium. The local gravity anomalies on the plain are probably produced by variations in the thickness of Cenozoic rocks, but the wavelength of the anomalies is about twice that of the basin-and-range structural features in areas adjoining the plain. The gravity expression of basin-and-range structural features does not extend far onto the plain. Magnetic anomalies on the plain are produced by Cenozoic volcanic rocks.

The Snake River Plain extends across southern Idaho in an arc about 550 kilometers long (fig. 1). Although the plain is a continuous physiographic feature, the gravity and magnetic anomalies over its eastern and western parts are significantly different. The western Snake River Plain is characterized by large but relatively simple gravity and magnetic anomalies. The dominant Bouguer gravity anomaly over the western Snake River Plain is an elongate high cresting in a series of en echelon closures along the axis of the plain, and the gross magnetic anomaly is a high along the southwestern edge of the plain and a low along the northeastern edge. Together, these magnetic features suggest a thick layer of magnetic material underlying the western part of the plain, and the gravity anomaly requires a large positive mass anomaly in the crust. A model for the western Snake River Plain previously presented (Mabey, 1976) demonstrated that the gravity and magnetic anomalies can be produced by variations in the thickness and physical properties of the upper crust and that no contribution from the lower crust or the upper mantle is required. Although several models can satisfy the measured anomalies over the western Snake River Plain, the data seem to require a very thin or perhaps completely rifted upper crust with a large volume of dense magnetic rock (presumably basalt) high in the crust.

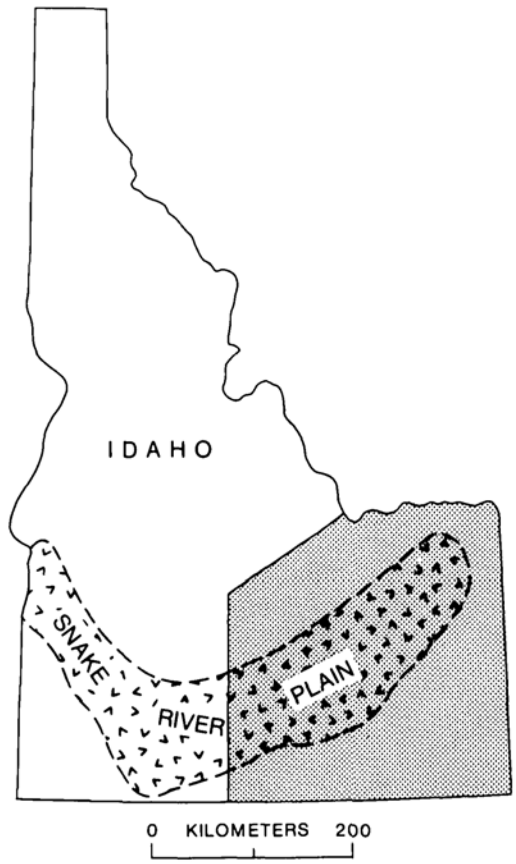

FIGURE 1.—Index map of Idaho showing Snake River Plain and area of study (stippled).

In contrast, the eastern Snake River Plain is an area of more complex gravity and magnetic anomalies. The amplitude of the regional Bouguer gravity high over the eastern plain is about half that over the western plain, and a series of highs and lows with differing trends are superimposed upon the regional high. The general level of magnetic intensity over the eastern plain is high, but the pattern is a complex of highs and lows. In this report, the gross features of the magnetic and gravity anomalies over the eastern Snake River Plain will be examined.

GRAVITY ANOMALIES

The regional Bouguer gravity map (fig. 2) illustrates the gravity high over the eastern Snake River Plain relative to the gravity features of the adjoining regions and also shows variations in patterns within the plain. In the area where the plain strikes approximately east, a pair of gravity highs are separated by a gravity low; these major gravity features trend approximately parallel to the axis of the plain. The northern of the two highs is an extension of the axial high that is the dominant gravity feature of the western Snake River Plain.

Where the Snake River Plain begins to trend northeast, major gravity features that trend northwest, approximately normal to the axis of the plain, are superimposed on the regional high centered over the plain. This pattern continues for about 90 km to the northeast. In the northeastern part of the plain, the trends of the gravity features are more arcuate.

Southeast and northwest of the eastern Snake River Plain, the dominant gravity anomalies are associated with basin-and-range structures; large lows are produced by low-density Cenozoic rocks that underlie the valleys. Individual gravity lows do not exceed about 70 km in length, and some are much shorter. In the area between Burley and Pocatello, the basin-and-range-type anomalies decrease in amplitude toward the edge of the Snake River Plain but apparently continue onto the plain as far as 15 km and then terminate abruptly. The single exception is the low in Arbon Valley south of the plain. Northward, this low swings to the northeast into the adjoining range and then turns northwest to continue across the plain to the Craters of the Moon (CM in fig. 2). Where this low crosses the southeastern edge of the plain the low is not coincident with the valley. These gravity data suggest that along this segment of the southeastern edge of the plain, the structural border of the plain is a few kilometers north of the physiographic edge of the plain and is deeply buried by the sedimentary and volcanic rocks of the plain that lap onto the north-plunging basin-and-range structural features.

For about 100 km east of Pocatello, the large gravity lows that occur in the major valleys terminate well south of the plain as does the major basin-and-range topography. Small relief structures that produce small gravity effects may extend to and across this segment of the border of the plain, but clearly the gravity expression of major basin-and-range structures does not. Farther east, the gravity low in Swan and Grand Valleys is not typical of anomalies associated with basin-and-range valleys. The valleys are very narrow, and the bounding gravity gradients extend into the adjoining ranges in a way that suggests that reverse faults may bound the valleys. Whatever the nature of this structure, the gravity expression terminates south of the border of the plain. A gravity low is produced by low-density sediments underlying Teton Valley to the northeast. Although Teton Valley is open to the north, the gravity low does not extend north of it.

Three basin-and-range valleys open onto the northwestern side of the eastern Snake River Plain. Large gravity lows occur in parts of each of these valleys; however, in each valley the largest lows occur well north of the plain. The low in Big Lost River Valley extends with diminished amplitude to the edge of the plain where it terminates. Just to the south, a small negative gravity feature continues the trend onto the plain and is bounded on the east by a gradient that suggests that the fault zone on the eastern side of Big Lost River Valley may extend into the plain. A low at the mouth of Little Lost River Valley arcs around the southern side of the hills east of Arco and becomes parallel to the edge of the plain. Where Birch Creek Valley broadens as it joins the plain, the gravity low in the valley follows the edge of the range to the west over outcropping Tertiary silicic volcanic rock. This low also terminates at the edge of the plain.

MAGNETIC ANOMALIES

The general magnetic high over the eastern Snake River Plain consists of a complex of local highs and lows (fig. 3). Extending west from Burley is the eastern end of the high that approximately coincides with the southern edge of the western Snake River Plain. This anomaly has been interpreted as indicating the southern edge of a thick, nearly flat layer of basalt, possibly of Miocene age (Mabey, 1976).

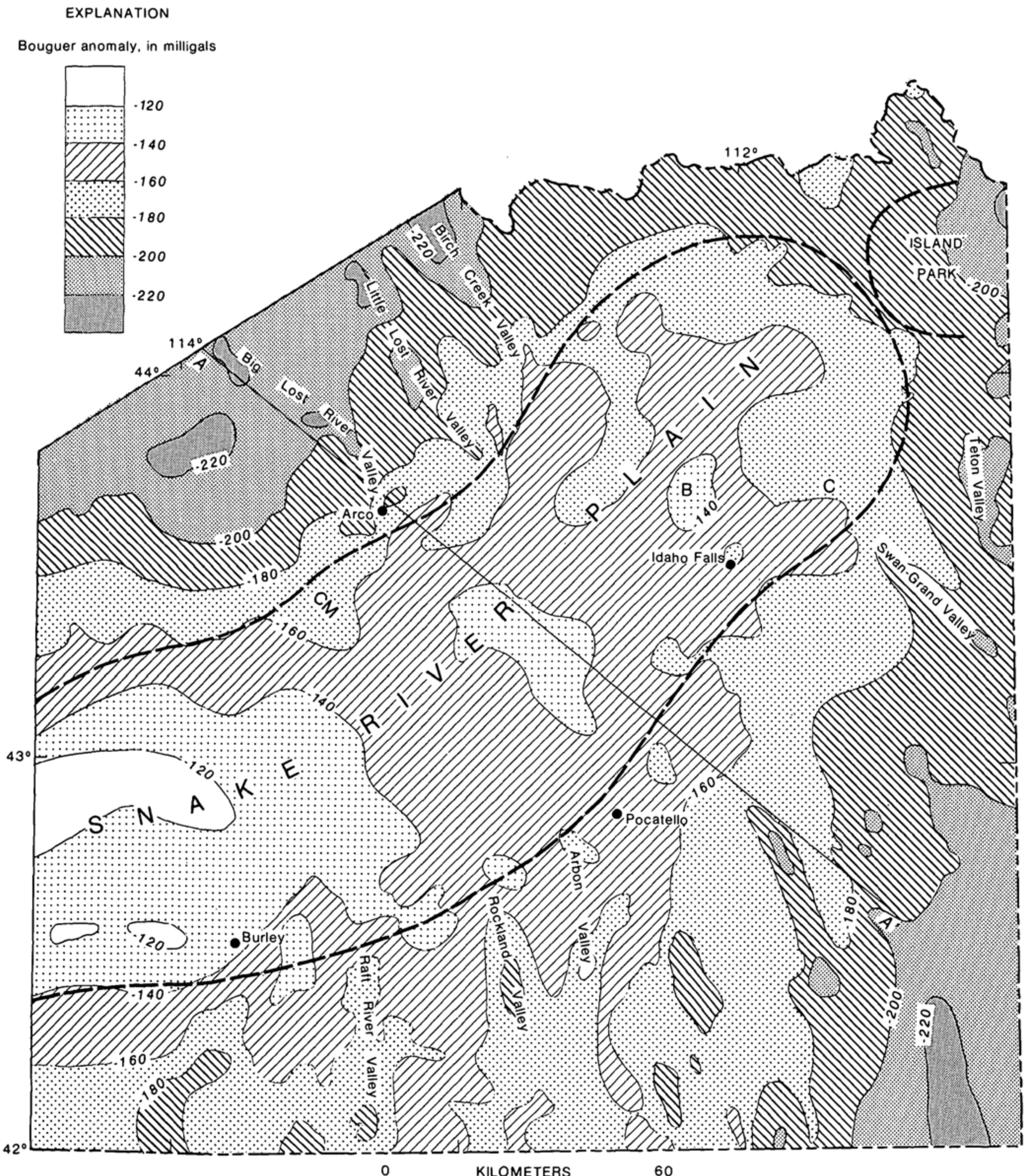

FIGURE 2.—Bouguer gravity anomaly map of southeastern Idaho generalized from Mabey and others (1974). Contour interval, 10 milligals. *A-A'* is the location of profile in figure 4. Dashed lines bound Snake River Plain and Island Park areas. CM, the Craters of the Moon; B and C, gravity highs.

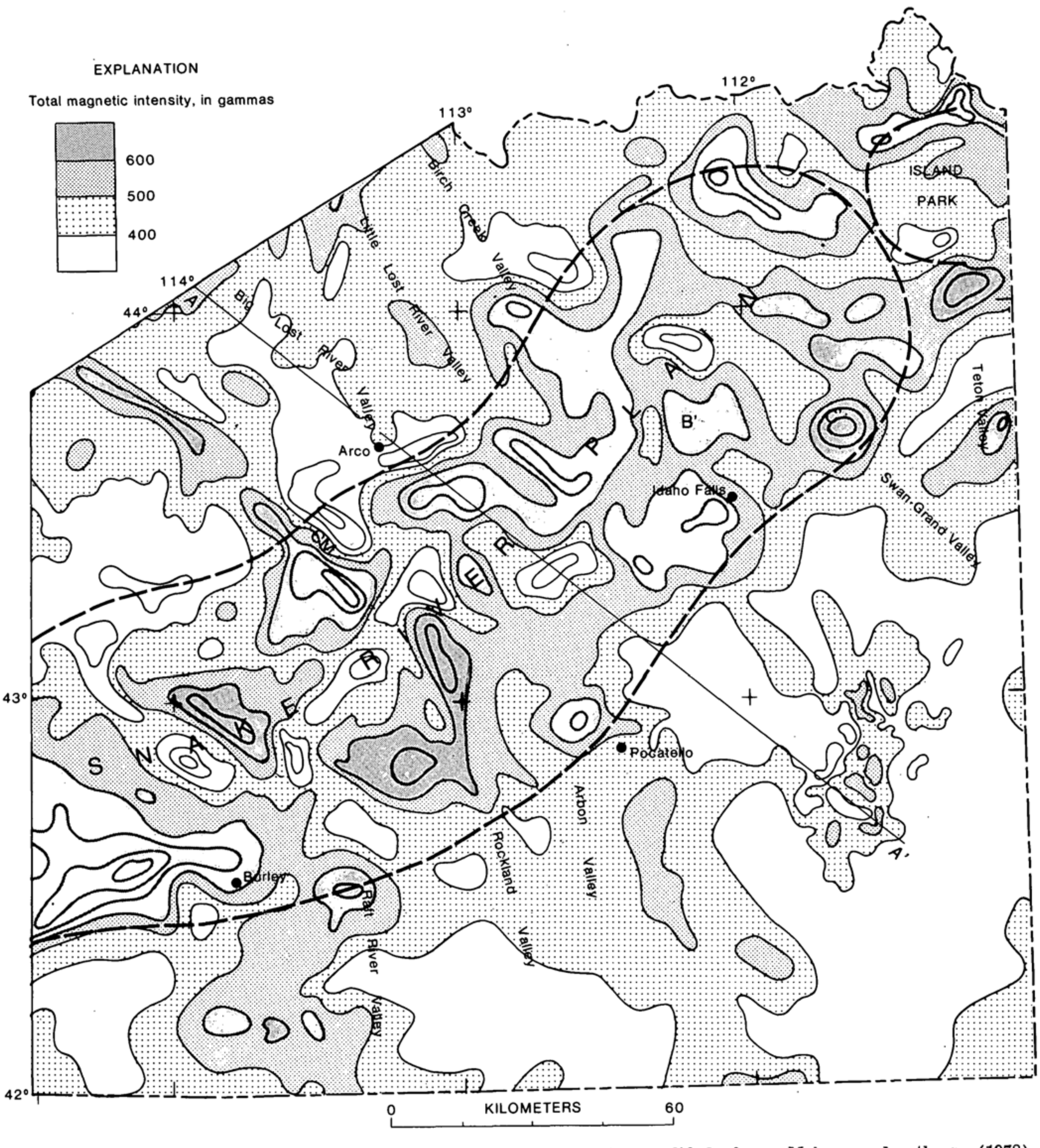

FIGURE 3.—Total intensity aeromagnetic map of southeastern Idaho modified from Mabey and others (1978). Flight elevations were 2750 to 3700 meters above sea level. Contour interval is 100 gammas relative to an arbitrary datum. *A-A'* is profile in figure 4. Dashed lines bound Snake River Plain and Island Park areas. CM, the Craters of the Moon; B' and C', magnetic highs.

Outside the plain, the magnetic intensity is, in general, low. Magnetic highs south of Burley and south of Pocatello are over outcrops of Precambrian rocks; however, the relation between outcropping Precambrian rocks and local magnetic anomalies is not clear. North of the plain, the anomaly that trends northwest about 40 km west of Arco apparently reflects an alinement of Tertiary intrusive rocks. The apparent continuation of this feature on the plain coincides in part with the Craters of the Moon (CM in fig. 3) but does not follow the Great Rift (Prinz, 1970) across the plain. The occurrence of three high-amplitude, approximately equidimensional magnetic highs along the southeastern margin of the plain suggests that these features may be related to the plain margin. All three occur where major valleys intersect the margin of the plain.

INTERPRETATION OF GRAVITY AND MAGNETIC ANOMALIES

The gravity anomaly over the eastern Snake River Plain can be separated into two components. The broad gravity high over the entire plain and extending well beyond the edge of the plain can be considered as a regional anomaly. About 40 km beyond the edge of the plain, the Bouger gravity values are increasing toward the plain by over 0.7 milligals per kilometer. This gradient is more than twice what could be produced by a near-surface dense mass confined to the area of the plain. The source of the regional gravity high either must be areally more extensive than the plain itself or must be deep under the plain; LaFehr and Pakiser (1962) also reached this conclusion. Within the plain and superimposed on the regional high are local gravity features that reflect mass anomalies underlying the plain at relatively shallow depths.

Over most of the eastern Snake River Plain, the Bouguer anomaly is only a few milligals higher than at the margins of the plain, and, in some areas of the plain, the anomaly is lower than at the margins. The residual gravity anomaly within the plain apparently is a complex low on the crest of the regional high. Such a low would be expected if the sedimentary and volcanic rocks of Cenozoic age within the Snake River depression had a density lower than that of average normal upper crustal rocks, and the local gravity relief would reflect the thickness and the lateral changes in density of the sedimentary and volcanic rocks. Because the gravity low over the plain produced by low-density Cenozoic rocks has an extent approximately coincident with the crest of the regional gravity high produced by the deeper structure under the plain, separation of the two features is difficult. Surface fitting to determine the regional high is not satisfactory because the calculated surface of the regional high would be significantly influenced by the superimposed broad low.

Figure 4 illustrates the gravity and magnetic anomaly across the plain where the best gravity control is available. The interpreted model, which will produce the total measured anomaly, assumes a simple deep structure producing the regional gravity high and a gravity low that reflects shallow Cenozoic rocks on the plain. The model attributes the regional anomaly to a thinning of the crust under the plain. The two major crustal layers on the southeastern side of the plain are assumed to be approximately the same thickness as those calculated by Willden (1965) from seismic refraction data obtained along a profile shot southeastward to Bear Lake from the American Falls reservoir, which is near the edge of the plain about 40 km southwest of the profile. An approximate match to the regional anomaly, as measured along the margin of the plain, can be obtained by thinning the total crust 7 km at the northwestern edge of the plain and 4.5 km at the southeastern edge. These values agree with LaFehr and Pakiser's (1962) interpretation of about 6 km of thinning. An additional thinning in the base of the crust is suggested near the southeastern end of the profile. Neither the gravity nor the magnetic data suggest that the pre-Cenozoic rocks underlying the plain are different from those to the north and south of the plain. Thus, rifting of the crust similar to that inferred for the western plain is not suggested for the eastern plain.

A major problem in interpreting the gravity anomalies within the plain is the estimation of the densities of the Cenozoic rocks that underlie the plain. The best information on physical properties of rocks in the area of the eastern Snake River Plain comes from studies done in the vicinity of the Idaho National Engineering Laboratory southeast of Arco. There the plain is underlain by the Pleistocene and Holocene Snake River Group, which consists of basalt flows interbedded with lake and stream deposits derived from the mountains to the north (Walker, 1964). Near the axis of the plain, the basalt is the dominant rock and the average bulk density is estimated to be about 2.65 grams per cubic centimeter. Near the margins of the plain, sediments predominate and their average density is probably about 2.2 g/cm^3. Thus, a large and systematic density increase in the section of interbedded basalts and

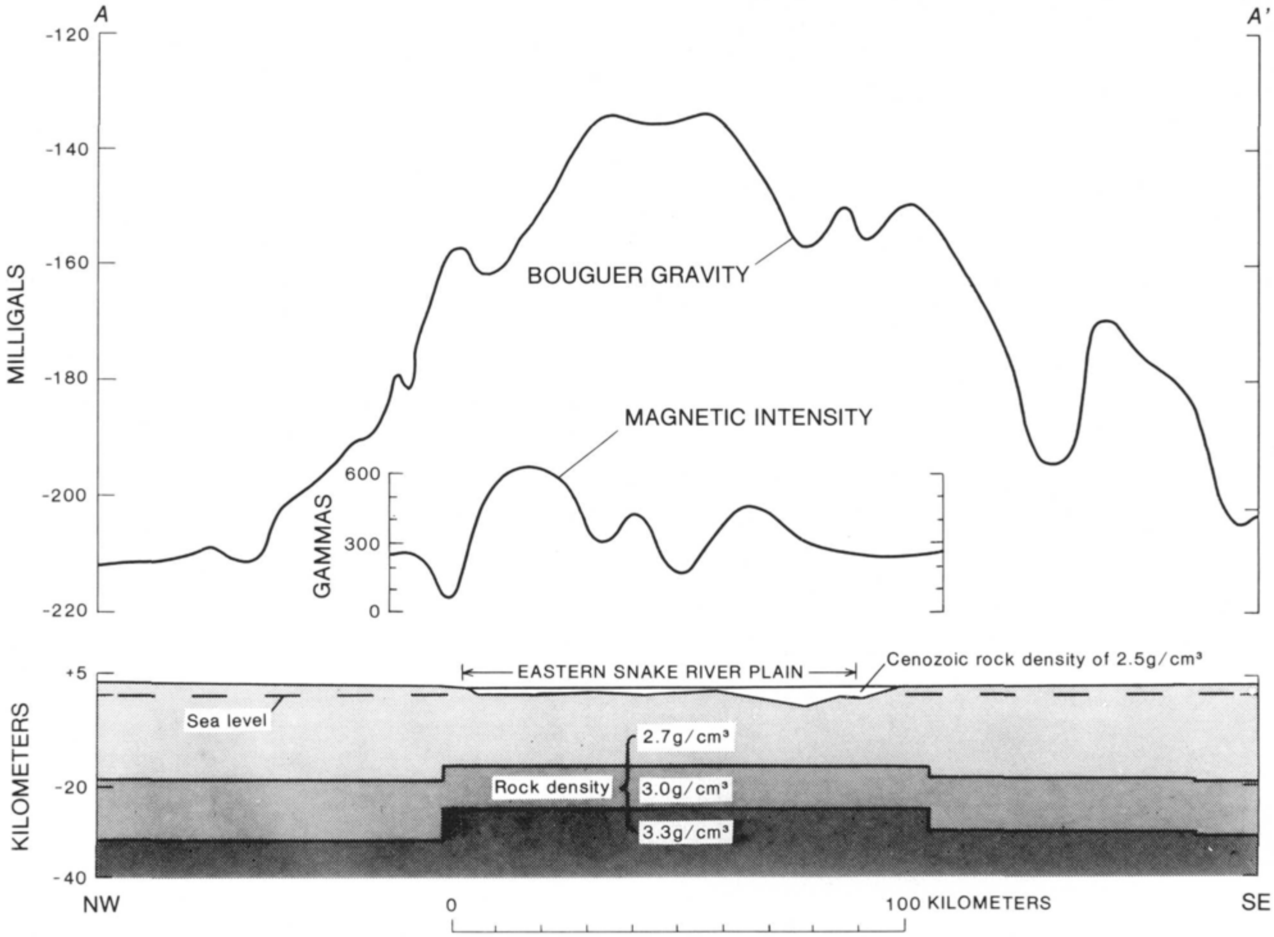

FIGURE 4.—Gravity and magnetic intensity profiles across the eastern Snake River Plain and a two-dimensional model that could produce the observed gravity anomaly. Location of profile is shown in figures 2 and 3.

sediments occurs laterally from the margin toward the axis of the plain. Underlying the basalt-sediment sequence and cropping out on both sides of the plain are Tertiary silicic volcanic rocks of unknown, but possibly great, thickness. These rocks have an average density of about 2.45 g/cm³ and thus are less dense than the basalt but more dense than the sediments of the overlying Snake River Group. The average density of the Cenozoic volcanic and sedimentary rocks is less than that of the pre-Tertiary rocks on both sides of the plain. The broad gravity low over the plain superimposed on the regional high undoubtedly, in large part, reflects the presence of these rocks.

The cause of the more local variations within this low over the plain is not always clear. The low gravity values near the edge of the plain east of Arco and southwest of Idaho Falls probably reflect depressions along the edge of the plain that contain thick Cenozoic sediments. LaFehr and Pakiser (1962) believed that the local gravity highs could be produced by variations in thickness of the basalt resulting from relief on the surface of underlying silicic volcanic rocks. If relief on the top of the silicic volcanic rocks reflects structure that also affects the underlying pre-Cenozoic rocks, the gravity anomaly produced by the density interface between the basalt and the silicic volcanic rocks would be opposite to the effect of the interface between the silicic volcanic rocks and the more dense pre-Cenozoic rocks. The local gravity highs in the eastern Snake River Plain more likely should be regarded as reflecting areas where Cenozoic rocks are thinned. As an approximation, a density contrast of -0.2 g/cm³ between the Cenozoic rocks and the older rocks was assumed in computing the model in figure 4. This contrast is a minimum value and is probably lower than the true average. Thus, the actual thickness of Cenozoic rocks is probably somewhat greater than that indicated on the profile and is perhaps substantially greater in some areas.

A gravity anomaly of about 10 mGal coincides with the rift at the Craters of the Moon. This low is alined with the low that trends across the plain from near the northern end of Arbon Valley. Karlo and Kosiur (1975) suggest that gravity lows may be characteristic of areas of recent volcanism in the eastern Snake River Plain and may reflect a thermal effect. If a general pattern exists between the gravity anomalies and centers of basalt eruption, it is a complex one and not readily apparent.

Throughout southeastern Idaho, free-air anomalies average about +30 mGal; isostatic anomalies are also positive (Woollard, 1966; Mabey, 1966; and Mabey and Oriel, 1970). This area of positive anomalies is part of a large region of average positive anomalies that covers much of Idaho, Wyoming, and Montana and is in sharp contrast to the Great Basin to the southwest where free-air and isostatic anomalies average near zero. Because free-air anomalies strongly reflect local surface relief, they must be used with great care. The problem is particularly serious in areas of basin-and-range topography because of the high local relief and because of the large majority of the gravity observations that are made in the valleys at elevations well below the average. Local gravity lows in the valleys further bias the average. Thus, in an area of high local relief, the averaging of values of free-air anomalies for all available gravity stations will not usually produce a correct value for the average free-air anomaly. An approximation of the average free-air anomaly can be computed by subtracting the difference between the average elevation and the elevation at the station multiplied by the Bouguer correction from the free-air anomaly value for a representative station (Mabey, 1966). Although the computed average free-air value will depend on the method of determining "average" elevation and on the density assumed in the Bouguer correction, the values are reasonable approximations. Free-air anomalies thus computed will reflect local mass anomalies in about the same way as do the Bouguer anomalies. However, free-air anomalies reflect to a much lower degree regional mass anomalies that are in isostatic equilibrium.

If the depression of the Snake River Plain represents a local isostatic response to a block of thinner crust, free-air anomaly values (assuming no local relief except that of the step at the plain boundary) would rise above zero as the plain was approached, would become negative on the plain, and would rise toward but not reach zero toward the center of the plain. Even if the plain were in perfect isostatic balance, the gravity effect of the thicker crust in the adjoining areas would keep the values on the plain negative. Unadjusted free-air and average free-air anomalies for the profile across the eastern Snake River Plain are shown in figure 5. The central part of the profile is along the axis of one of the largest local gravity highs on the eastern Snake River Plain, and profiles across the plain 20 km to the southwest or northwest would show free-air anomaly values 15–20 mGal lower at the same distance from the edge of the plain. Thus, values about 10 mGal lower are probably more representative for the area of the axial part of the regional gravity high and are indicated by the dashed line.

To compute the average free-air anomaly, the average elevation within 32 km of the gravity station was determined. In the areas of basin-and-range topography, this technique of averaging the elevations filters the local relief between the valleys and ranges. The size of the area for which the average is made usually is not critical. However, on the plain and near the margins of the plain, the averaging over circular areas smooths the linear topographic margin of the plain and thus alters its form as a topographic step. Because relief on the plain is low, the unadjusted free-air anomalies on the plain are not strongly influenced

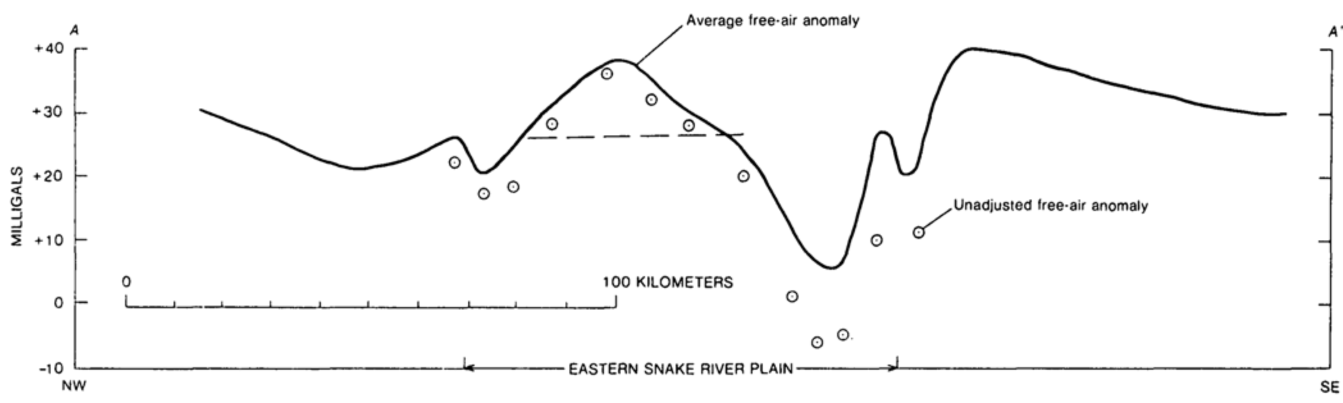

FIGURE 5.—Free-air gravity anomaly across the eastern Snake River Plain. Solid line values are adjusted to average elevation within 32 km of the observation. Dashed line is representative average free-air anomaly within 20 km of this part of the profile.

by local topography, and, near the margins of the plain, the unadjusted free-air values are more meaningful than the average values that are influenced by topography off the plain. A free-air anomaly comparable to the unadjusted values on the plain could be obtained for stations within 32 km of the plain by averaging elevations along a line through the station and parallel to the margin of the plain and adjusting the free-air anomaly values to this elevation. The adjusted values thus computed immediately northwest of the plain would be about 10 mGal higher than the average values based on elevations averaged over circular areas.

Regardless of how the average free-air anomalies across the eastern Snake River Plain are computed, the values determined over the plain are less positive than those in the adjoining areas. This observation is consistent with approximate isostatic balance of the plain relative to these areas. If a much more detailed definition of the free-air anomaly was obtained in the areas adjoining the plain, the data could be used to quantitatively study the isostatic compensation of the plain.

Thus, the free-air anomalies over the entire region are positive, and the Snake River Plain is in approximate isostatic balance with adjoining regions. This combination suggests that compensation of the plain is relatively shallow, whereas the entire region is held above the level of isostatic balance, perhaps by deeper dynamic forces.

If the gravity anomalies, in combination with surface topography, are accepted as indicators of the size and distribution of basin-and-range structures, several conclusions can be reached regarding the relation of these structures to the Snake River Plain. First, the relief of the basin-and-range structures decreases toward the plain and some features terminate before reaching it. Those that reach the plain apparently interact with the plain in a complex way; some extend a few kilometers onto the plain, whereas others terminate at the edge. In some areas, such as along the northwestern side of the plain east of Arco, the edge of the plain seems to coincide with a major bounding fault. In other areas, such as east of Burley, the rocks and structures from outside the plain dip under the volcanic and sedimentary rocks of the plain, but in those areas the gravity data suggest a fault paralleling the edge a few kilometers onto the plain.

The gravity anomalies within the eastern Snake River Plain do not have the same character as the anomalies in the regions of basin-and-range structure. The large gravity highs and lows within the plain are approximately twice as broad as those associated with the basin-and-range structures. Interpreted gravity lows adjoining the plain are apparently largely due to low-density Tertiary rocks underlying the Quaternary fill that covers the valley floors. In the valleys south and southeast of the plain, these low-density Tertiary rocks consist, in large part, of the Miocene and Pliocene Salt Lake Formation. The nature of these basins in which the Salt Lake Formation was deposited is not well understood. That the basins were much broader than the current basins is indicated by the presence of extensive Miocene and Pliocene deposits in the high parts of several of the ranges. Perhaps the gravity anomalies within the eastern Snake River Plain are reflecting the distribution of Tertiary rocks deposited or preserved in basins that were approximately twice the width of the current topographic basins in the basin-and-range areas. These younger basin-and-range structures do not seem to extend across the plain.

Although major volcanic features must exist under the cover of the youngest sedimentary and volcanic rocks that cover the eastern Snake River Plain, their expression is not readily apparent in the gravity anomalies. Large calderas, such as Long Valley, Calif., that contain thick piles of low-density sedimentary and volcanic rocks produce large negative gravity anomalies (Kane and others, 1976). The residual low in Long Valley is about 40 mGal, about half the amplitude of the total anomaly across the eastern Snake River Plain; and, if a negative anomaly of the size and extent of the Long Valley anomaly existed in the area of the eastern Snake River Plain, it would be apparent on the gravity map. However, not all large calderas produce large negative gravity anomalies. The Island Park caldera at the northeastern end of the Snake River Plain has no pronounced gravity expression. Some of the local gravity anomalies within the plain may relate to volcanic features underlying the plain; however, without supplemental information, the anomalies cannot, with confidence, be identified. Detailed geologic mapping combined with more detailed gravity surveys may reveal the relationship between the gravity anomalies and the volcanic features.

Although both the eastern Snake River Plain and the adjoining basin-and-range areas may reflect tension related to regional crustal spreading, the gravity data suggest that they represent different responses to what appear to be different strains. The individual basins and ranges are not in isostatic balance, and the differential load between them is supported by the strength of the lithosphere. In effect, they are superficial features, with the faults probably flattening with depth and, in general, not displacing any major deep density horizons. The structure of the eastern Snake River Plain, on the other hand, involves the total thickness of the crust and perhaps the upper mantle. The plain is in approximate isostatic balance with the adjoining regions, and the gravity data suggest that a major part of the compensating mass is at the base of the crust.

Very few earthquakes are occurring in the area of the eastern Snake River Plain, and few fault scarps are apparent except near the margins of the plain. Apparently any deformation that may now be occurring in the plain is not accompanied by major faulting. In contrast, recent fault scarps and numerous earthquakes occur both north and south of the plain. This absence of evidence of active faulting and the indication of isostatic balance for the plain relative to the adjoining regions indicate that the crust in the area of the plain is a zone of very low stress. Such a condition is consistent with the eastern Snake River Plain being an area of high thermal gradients.

The complex magnetic anomalies over the eastern Snake River Plain have sources within a few kilometers of the surface and, at least in large part, relate to the volcanic rock underlying the plain. Some of the magnetic anomalies correlate with surface features. For example, the high 30 km east of Burley is centered over a dome of basalt and the elongate high 25 km southwest of Arco is over the Craters of the Moon. Probably most, if not all, of the large magnetic anomalies are produced by variations in the thickness, relative abundance, and magnetism of the Cenozoic volcanic rocks, primarily the basalt and related intrusive complexes. The apparent absence of deep magnetic anomalies may be partly due to a relatively near surface Curie temperature under the plain.

The relationship between the local gravity and magnetic anomalies on the eastern Snake River Plain is complex, but a pattern seems to exist. All the closed magnetic lows on the plain are in the area of relative gravity highs. Also, areas of high magnetic intensity are more abundant in the area of relative gravity lows; this relationship holds best for the more extensive magnetic highs. This general relationship of magnetic lows with gravity highs and magnetic highs with gravity lows is consistent with the sources of the gravity highs being structural highs where the Cenozoic rocks are relatively thin and the magnetic highs reflecting areas where the Cenozoic rocks are thickest.

A notable exception to the above correlation occurs about 10 km northwest of Idaho Falls. Here coincident gravity B and magnetic B′ highs occur, thus suggesting a dense and magnetic rock mass in the subsurface. Similar paired anomalies C and C′ occur about 30 km northeast of Idaho Falls.

Profile *A-A′* illustrates the problem of correlating the gravity and magnetic anomalies. The magnetic high along the profile covers the northwestern three-fourths of the plain but does not extend to its southeastern edge. Probably basalt is not abundant in the Cenozoic rocks that produce the gravity low along this part of the southeastern margin of the plain. In the area of the gravity high near the center of the plain, the magnetic intensity is relatively low suggesting that the volcanic rocks are relatively thin.

Considerable evidence suggests that volcanic activity from Miocene to Quaternary time has migrated northeast along the present location of the Snake River Plain to the Yellowstone area (Eaton and others, 1975). Thus, the Yellowstone Plateau might be expected to evolve into an extension of the Snake River Plain. The low gravity and magnetic anomalies and the high elevation of the Yellowstone Plateau are exactly opposite to those of the high gravity and magnetic anomalies and low elevation of the eastern Snake River Plain. In Eaton and others (1975), it was suggested that the gravity low in the Yellowstone Plateau could reflect a large active magma chamber underlying the region. The shallow depth of the Curie isotherm and extensive hydrothermal alteration could account for the low magnetic intensity. If this magma chamber was to solidify without any major accompanying mass transfer, the resulting thermal contraction would produce a relative gravity high and topographic low similar to that of the Snake River Plain and basaltic volcanism would produce areas of high magnetic intensity. The northeastern part of the Snake River Plain may have developed over a complex of calderas, and the Island Park area may be a transitional phase between the Yellowstone Plateau and the Snake River Plain.

A topographic high is coincident with the axis of the eastern Snake River Plain. The gravity high down the axis of the plain and an approximately coincident subtle magnetic low trend suggest that Cenozoic rocks may be thinner along the axis of the plain than nearer the margins. If the topographic high along the axis was constructional, reflecting a thick pile of basalt, a magnetic high would be expected. The topography, gravity, and magnetic data suggest, but do not prove, that the margins of the plain have subsided more than the central part of the plain.

Any model of the eastern Snake River Plain based on an interpretation of the gravity and magnetic data alone should be considered as tentative. However, these data do provide significant constraints that will be useful in constructing more precise models as information from other geophysical surveys and deep drilling becomes available.

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