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Geophysical Ore Guides Along the Colorado Mineral Belt*

By

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This report is preliminary and has not been edited or reviewed for conformity with U.S. Geological Survey standards.

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Abstract

A 30-50-mgal gravity low trends northeast along the Colorado mineral belt between Monarch Pass and Breckenridge, Colorado. The low is probably caused by a silicic Tertiary batholith of lower density than adjacent Precambrian crystalline rocks. Many major mining districts associated with silicic Tertiary intrusives are near the axis of the low.

Positive and negative aeromagnetic anomalies are present over the larger silicic Tertiary intrusive bodies. A good correlation exists between the magnetic lows and zones of altered, mineralized porphyry. Apparently, original magnetite in the silicic porphyries has been altered to relatively nonmagnetic pyrite or iron oxides.

The regional gravity low aids in defining the limits of the mineral belt, and the magnetic lows over the porphyries indicate specific alteration zones and the possibility of associated mineral deposits.

Introduction

During 1961-66, the U.S. Geological Survey conducted gravity and aeromagnetic surveys in the Leadville-Salida region, Colorado, across the Colorado mineral belt with its association of Tertiary porphyry intrusives and wide variety of mineral deposits. These surveys were made to determine the tectonic setting of the mineral belt, to aid in outlining Precambrian structural and lithologic trends, and to aid in understanding the tectonic setting of the upper Arkansas Valley which is on the same trend as the San Luis Valley, a northern segment of the Rio Grande trough.

The data and interpretations presented in this report are preliminary, and this report should be regarded as a progress report.

One of the major aspects of the investigation has been demonstration of the usefulness of gravity and magnetic data in defining a mineralized province. In some respects, the gravity and magnetic maps have been "calibrated" along this segment of the Colorado mineral belt where the geology is relatively well known. Some guidelines have been gained which may aid in interpretation of gravity and magnetic data when used as exploration tools in areas where the geology is incompletely known.

Surveys were made over the Sawatch Range, east of the Arkansas and Eagle Rivers, and over the southern Gore, Tenmile, and Mosquito Ranges, and the Arkansas Hills, all elements of the Park Range west of the Arkansas and Eagle Rivers (fig. 1). Surveys were also made over the western part of South Park. More than 1,000 gravity stations have been established in the region by vehicle and foot traverse. Aeromagnetic surveys were flown along east-west lines spaced 2 miles apart. The aircraft flew at an elevation of 14,500 feet above sea level.

Acknowledgments.--Interpretations presented here are the outgrowth of many discussions with colleagues in the U.S. Geological Survey. I am especially indebted to Ogden Tweto, who formulated the geophysical program. Maurice Brock, Fred Barker, R. E. Van Alstine, R. B. Taylor, Priestley Toulmin, M. G. Dings, C. S. Robinson, C. T. Wrucke, M. H. Bergendahl, Robert Pearson, H. G. Wilshire, and J. C. Behrendt, all with the Geological Survey, contributed data and ideas to this investigation.

Regional geology

The following discussion of regional geology is taken largely from reports by Tweto and Sims (1963) and Dings and Robinson (1957).

Regionally, the Sawatch Range and Park Range, including the Mosquito-Tenmile Range, form a major north-trending faulted anticline which has a core of Precambrian crystalline rocks. Paleozoic and Mesozoic sedimentary rocks rest on the flanks of the major anticline. Along the axis of the anticline a major graben--the upper Arkansas Valley--formed along en echelon Tertiary faults. Large Precambrian shear zones, including the Homestake and Independence Pass shear zones, trend northeast across the region.

The Precambrian core of the ranges includes granitic to quartz monzonitic and granodioritic intrusive masses and a variety of quartzo-feldspathic gneisses and amphibole gneisses. These rocks have a wide range of densities and magnetic properties, discussed in subsequent sections. Paleozoic carbonate and clastic rocks, ranging from 1,000 to more than 5,000 feet in thickness, are preserved on the flanks of the major anticline (Tweto and Sims, 1963, p. 1006-1008) and in small, faulted synclinal masses in the Garfield 15-minute quadrangle in the southwest part of the surveyed area (Dings and Robinson, 1957, p. 8). Mesozoic sedimentary rocks are present in South Park and in the region west of Monarch Pass. Cenozoic sedimentary rocks are present in South Park and along the Upper Arkansas Valley (Van Alstine and Lewis, 1960; Stark and others, 1949).

Tertiary intrusive rocks range from granitic to dioritic, but most are porphyritic quartz monzonites. They include large composite batholithic masses, such as the Mount Princeton batholith (Dings and Robinson, 1957, p. 25-27) and small stocks, plugs, dikes, and swarms of sills (Tweto and Sims, 1963, p. 992; Tweto, 1958, 1960). Tertiary volcanic rocks range from rhyolite to andesite and basalt. These Tertiary igneous rocks are distributed in a zone that trends generally north and northeast across the area. Some of the larger igneous masses are shown on figures 1 and 2.

Crawford (1924) proposed that the Colorado mineral belt is underlain by a batholithic mass, whereas others suggested independent sources for the Tertiary igneous intrusions (see Tweto and Sims, 1963, p. 1010-1011). Tweto and Sims (1963) have shown how the belt of Tertiary intrusive bodies was apparently controlled by major Precambrian shear zones.

Gravity anomalies

The generalized Bouguer anomaly map of the region (fig. 2) is incomplete in that data south of lat 39° have been only partly corrected for terrain effects; corrections from Hammer's zone H to 166.7 km have been applied. Terrain corrections are complete in the Leadville 30-minute quadrangle, north of lat 39°. Even though the contours are generalized, they portray the main gravitational features of the region.

The dominant gravity anomaly of the region is the huge gravity low of 30-50 mgal (milligals) that trends northeast across the northern part of the area and about north-south in the southern part of the area. Of special interpretive significance is the spatial correlation that exists between closed gravity lows and the Mount Princeton porphyry batholith and the Twin Lakes porphyry stock. Such a good positional correlation of gravity lows with silicic Tertiary intrusive masses indicates that these masses are the most probable cause of the lows. In the northern part of the area, the northeast-trending segment of the gravity low coincides with the greatest concentration of smaller intrusive masses.

Because the regional gravity low cuts indiscriminately across the mountain ranges and across a variety of Precambrian lithologic units, and because of the close correlation of lows with the Mount Princeton and Twin Lakes intrusions, most of the regional low is inferred to be caused by a relatively shallow but largely concealed Tertiary batholith of low density, as proposed by Crawford (1924). Superimposed on the regional low is a more local low in the Twin Lakes-Leadville area which is caused by the thick low-density fill in the Upper Arkansas Valley.

To test the hypothesis that the regional low is, indeed, caused by a silicic batholith, several factors must be evaluated. First, are the Tertiary silicic porphyries significantly less dense than the average Precambrian rock which they intrude? Second, what volume of light rocks is required to produce the observed gravity anomaly? Third, what mass distribution at depth will yield a computed gravity anomaly that matches the observed anomaly, both in amplitude and in steepness of gradient on the flanks of the anomaly? As an alternate interpretation, is it geologically and physically plausible that the anomaly can be caused by local crustal thickening?

Densities of Tertiary silicic porphyries and Precambrian granitic and metamorphic rocks are shown on figure 3. The average density of 64 samples of Tertiary porphyry is 2.65 g per cm^3, of 35 samples of Precambrian granitic rocks it is 2.70 g per cm^3, and of 46 samples of Precambrian metamorphic rocks it is 2.79 g per cm^3. The average density of all samples of Precambrian rocks is 2.74 g per cm^3. Thus an average density contrast of about 0.09 (0.1) g per cm^3 exists between the Precambrian crystalline rocks and the Tertiary silicic porphyries.

To test whether a shallow batholithic mass of low density can cause the regional gravity low, a gravity profile from the northern end of the Sawatch Range, across the area between Leadville and Climax, to the edge of South Park was selected for analysis (figs. 4 and 5). This profile crosses the anomaly where glacial and alluvial deposits are negligible and where the anomaly can be approximated by a "two-dimensional" model. As shown in figure 5, a greatly simplified model of a batholithic mass yields a computed profile which approximately matches the observed profile, in both amplitude and gradient. The small discrepancies between computed gravitational effects of the model and the observed profile could be eliminated by making relatively slight changes in density contrast or configuration of the deep-seated mass.

The steep gravity gradients on the flank of the regional gravity anomaly are believed to preclude a deep intracrustal or subcrustal source for most of the anomaly. If a root 10 km long, 20 km wide, with a density contrast of -0.3 g per cm^3 extends downward below a crust 30 km thick, the anomaly at the surface is only -5 to -7 mgal measured from a point over the center of the root to a point 30 km from the center of the root. Exceedingly large density contrasts between crust and mantle would be required to cause the 30-50-mgal anomaly observed at the surface.

The calculations indicate that a shallow batholithic mass is probably present at depth. This mass, whose apex is within 2,000-5,000 feet of the surface, has a density contrast of -0.1^2 g per cm^3, an average width of 15 miles, and it extends to great depth (on the order of 40,000 feet below sea level). These results, plus the close coincidence of large local gravity lows over the Twin Lakes and Mount Princeton porphyry masses, constitute strong evidence that the Colorado mineral belt is, indeed, underlain by a batholithic mass. The physical continuity of the anomaly in areas where few or no Tertiary intrusive rocks are exposed indicates that the batholithic mass is virtually continuous at depth from near Monarch Pass to Breckenridge. If these interpretations are correct, then most of the major mining districts, including Leadville, Climax, and Breckenridge, are located over the apical region of the batholith. The many small plutons in the northern part of the area may be regarded as apophyses from the top of the main batholithic mass.

Although most productive mining districts of the region are within the gravity low, some, especially the Gilman district, are located along the margins just north of the surveyed area.

The local gravity low over the valley fill south and west of Leadville is difficult to isolate because it is a local low superimposed on the regional low. If one assumes that regional Bouguer anomalies over bedrock decrease linearly from -315 mgal, at a point between Leadville and Climax, to -330 mgal over the Twin Lakes pluton, then a residual gravity low of 10-15 mgal may be present over the fill in the central part of the valley. Such an anomaly could be caused by as much as 5,000 feet of valley fill if a density contrast of -0.3 g per cm^3 exists between fill and bedrock. Determination of the thickness of fill is extremely important, as bedrock in the area between Leadville and Twin Lakes is regarded as a potential mineralized area along the apex of the postulated shallow batholith. Deep drill holes or detailed seismic profiles are required for reliable estimates of depth of fill.

Aeromagnetic anomalies

All of the crystalline rocks of the region, both Precambrian and Tertiary, are magnetic in varying degree. The range in magnetization of the Precambrian rocks is about the same as for the Tertiary porphyries. This fact and the extreme topographic relief of the area introduce major interpretive problems, but some correlations and interpretations of the magnetic data can be made with relative confidence.

A generalized geologic and aeromagnetic map of the Leadville 30-minute quadrangle is shown on figure 6. The prominent magnetic high over the Mosquito Range and Arkansas Hills is caused by a coarse porphyritic biotite quartz monzonite. This is not an unexpected result, as evidence is gradually accumulating that many such "granitic" Precambrian rocks in Colorado, Utah, and Wyoming are moderately to highly magnetic (Case, 1966, p. 1432). A biotite gneiss sequence in the northwestern part of the area is apparently more magnetic than a calcareous gneiss sequence southeast of the Homestake shear zone.

Magnetic contours apparently reflect the Homestake shear zone by a steepened gradient, and one may infer from the magnetic data that the shear zone continues northeast beneath the cover of sedimentary rocks, beyond the edge of the exposed Precambrian.

In the Leadville quadrangle, the Climax and Leadville mining districts are located in magnetic lows or in magnetically flat areas. The best evidence that low levels of magnetic intensity may be due to alteration accompanying mineralization is found to the south in the Garfield quadrangle.

Figure 7 is a generalized geologic and aeromagnetic map of the Garfield 15-minute quadrangle. The geology may be briefly summarized as follows: a part of the Mount Princeton porphyry batholith, in the central and northeastern part of the quadrangle, intrudes a complex of Precambrian rocks and the sequqnce of Paleozoic sedimentary rocks.

Local faulted and mineralized inliers of Paleozoic rocks are present around the south and west margins of the batholith, and the Paleozoic and Mesozoic rocks form the west flank of the major regional anticline in the western part of the quadrangle. Tertiary volcanic rocks, predominantly andesitic, are preserved in the southern part of the batholith area (Dings and Robinson, 1957, pl. 1).

A prominent magnetic high trends north along the western part of the batholith, indicating that the porphyry is locally magnetic. Another high in the northeastern part of the area indicates moderate magnetization of the batholith. Most of the measured magnetic susceptibilities of the porphyry are in the range of $2\text{-}4 \times 10^{-3}$ cgs units. In other words, they are moderately magnetic. Many of the "altered" porphyries have measured susceptibilities in the range $0.1\text{-}2.0 \times 10^{-3}$, and are weakly to moderately magnetic. Remanent magnetization is weak: Q values are on the order of 0.1. Reversed remanent magnetization is not a factor in the samples measured to date but, admittedly, the sampling of altered porphyries is inadequate at this time.

Local zones of magnetic lows are present over the Mount Princeton batholith, and the correlation with zones of alteration and mineralization is very conspicuous. On figure 8, heavily prospected areas shown by Dings and Robinson (1957) are indicated by the shaded pattern. It is evident that the magnetic lows are concentrated in the prospected areas.

Thus the aeromagnetic lows constitute direct evidence for alteration zones in the porphyry and indirect evidence for mineralization which commonly occurs in the alteration zones. Apparently original magnetite in the porphyry has been altered to relatively nonmagnetic pyrite or iron oxides.

Some very prominent aeromagnetic lows occur in areas where relatively little prospecting has been done. One such low occurs along the east-central edge of the Garfield quadrangle over both intrusive porphyry and andesitic volcanic rocks. This area merits further investigation by geochemical techniques to test for mineralization.

In summary, some suggestions for prospecting in the region can be made on the basis of the geophysical studies:

1. Most of the known major mining districts are within the regional gravity low along the Colorado mineral belt. Moreover, some of the most productive districts are at or near the axis of the gravity low. These relations suggest that the ore mineralization was concentrated near the apex of a batholithic mass.
2. Future prospecting is warranted along the gravity low in areas covered by alluvium, glacial deposits, and thin veneers of Mesozoic or Paleozoic sedimentary rocks.
3. Aeromagnetic lows may point to areas of rock alteration, which in turn may be areas of ore deposits.
4. Targets selected on the basis of geology, gravity, and magnetics should be further explored by other geophysical techniques and, particularly, by field geochemical surveys.

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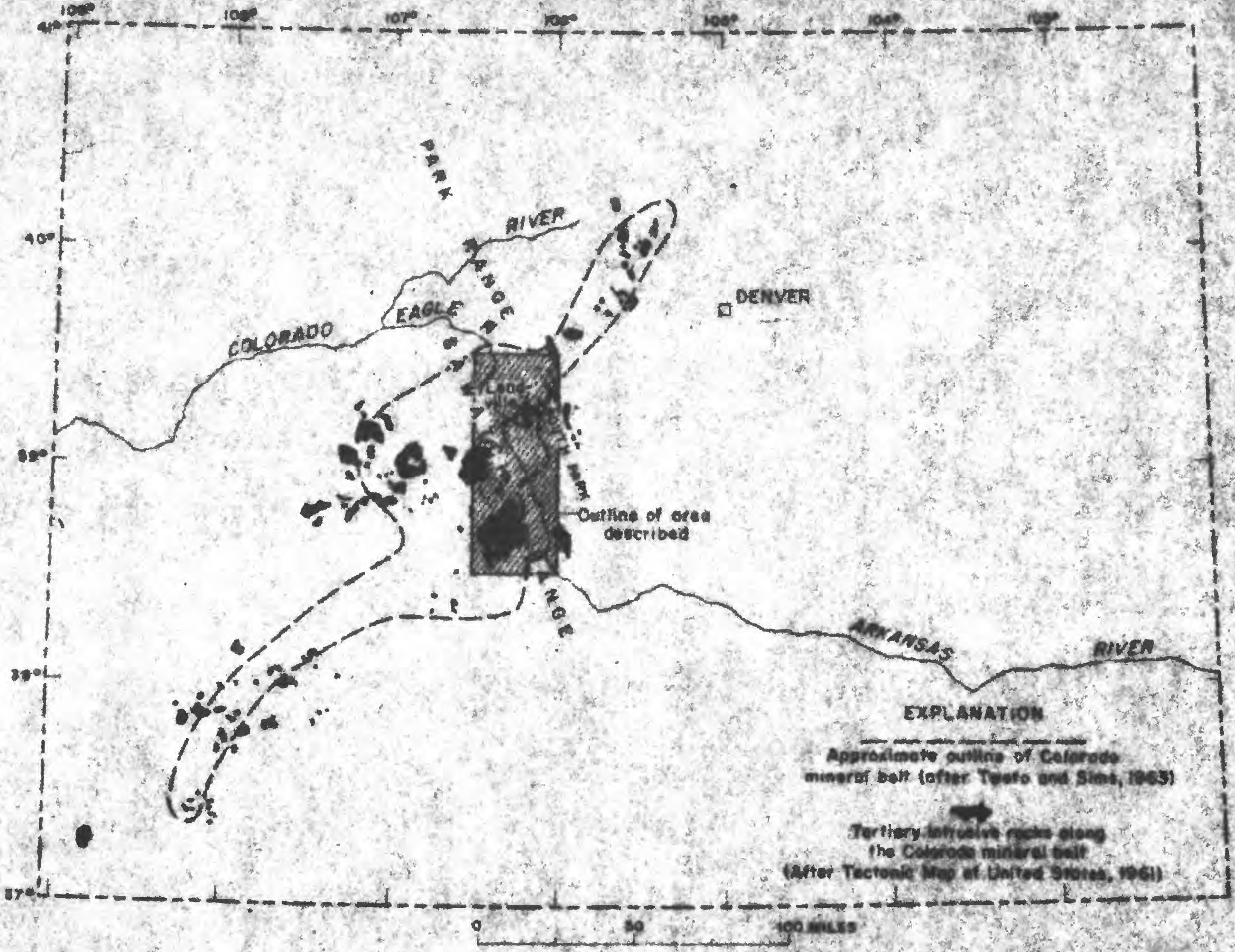

Figure 1.--Index map of Colorado showing the approximate outline of the surveyed area.

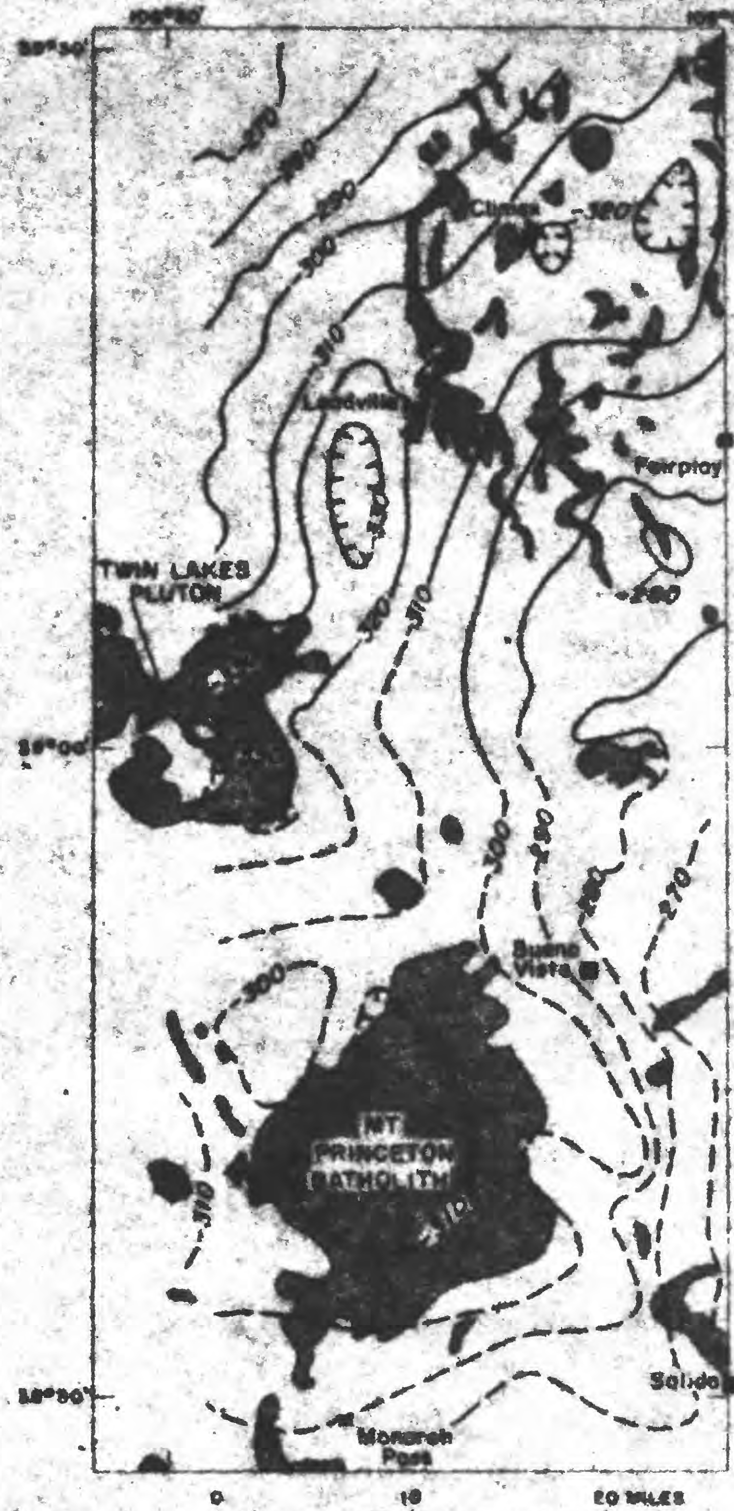

Figure 2.--Map showing generalized Bouguer anomaly contours (interval 10 milligals) and distribution of larger Tertiary igneous masses (stipple pattern). Geology generalized from geologic map of Colorado.

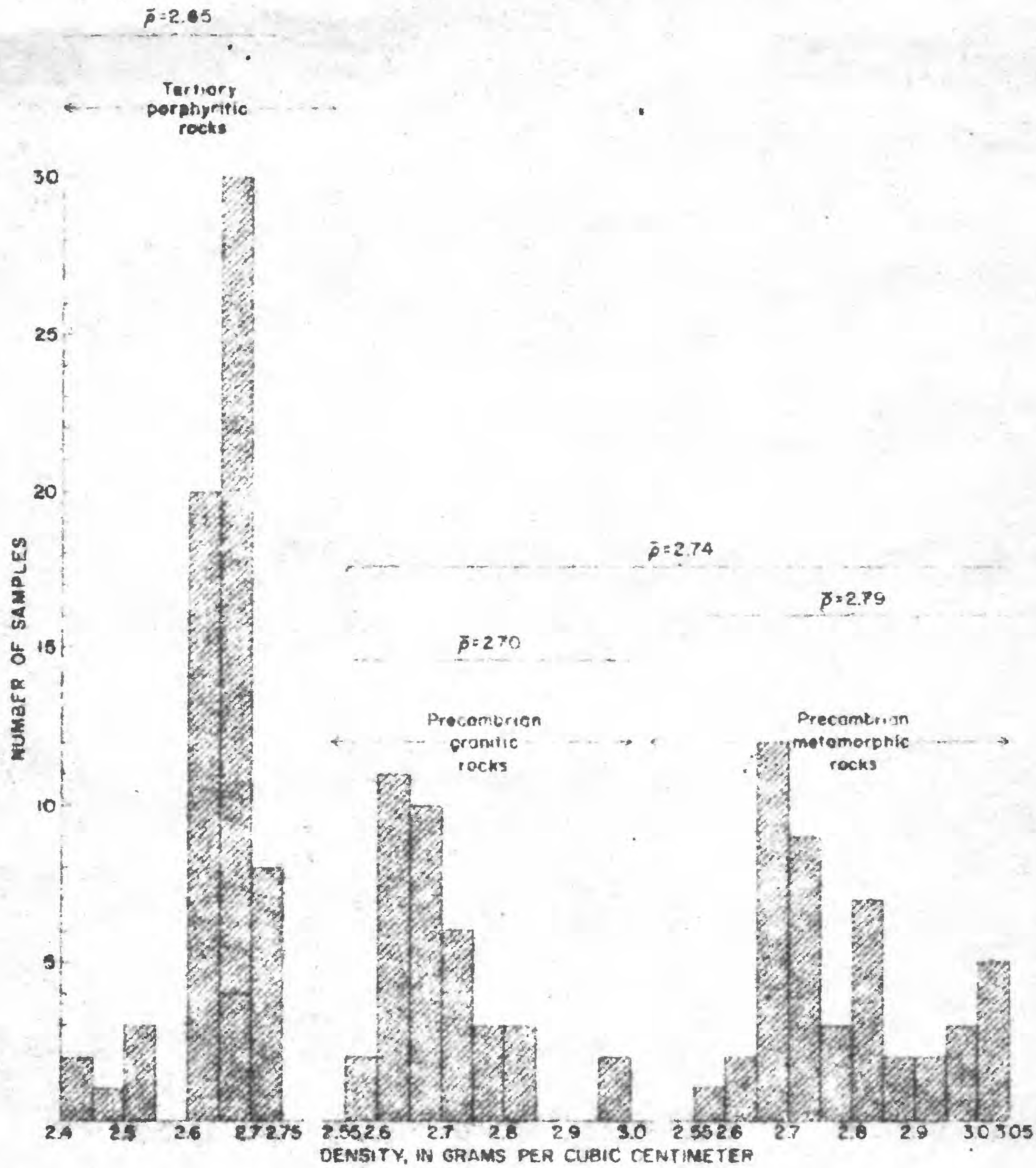

Figure 3.--Histograms showing densities of silicic Tertiary porphyritic intrusive rocks, Precambrian granitic rocks, and Precambrian metamorphic rocks. Measurements by William E. Huff, Myrl Beck, and Kenneth G. Books, U.S. Geological Survey.

Figure 4.--Bouguer anomaly map of the Leadville 30-minute quadrangle, showing distribution of the larger Tertiary intrusive masses (stipple pattern) and Tertiary and Quaternary sedimentary deposits (line pattern). Interval 5 milligals. Bouguer anomalies computed using a reduction density of 2.67 g per cm^3. Geology generalized after unpublished compilation by Ogden Tweto, U.S. Geological Survey. A-A', line of profile shown on figure 5.

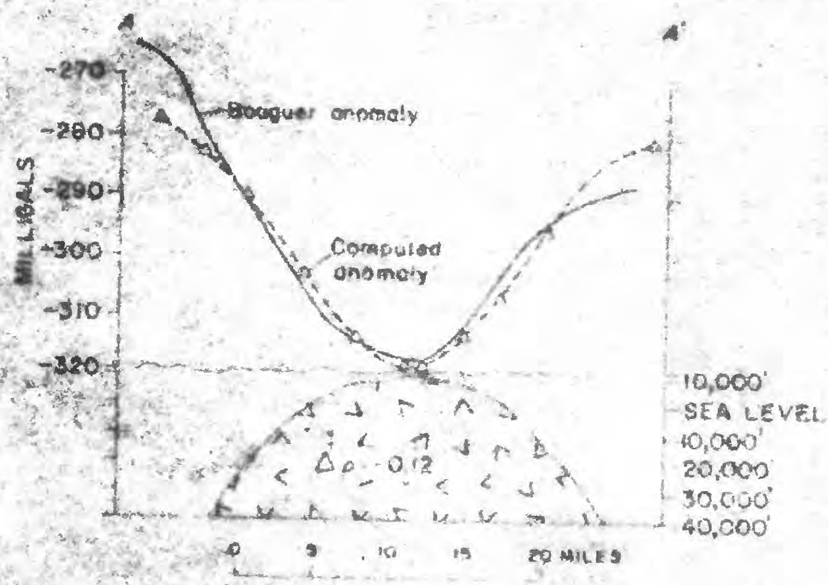

Figure 5.--Interpretation [illegible] profile A-A' (shown [illegible]).

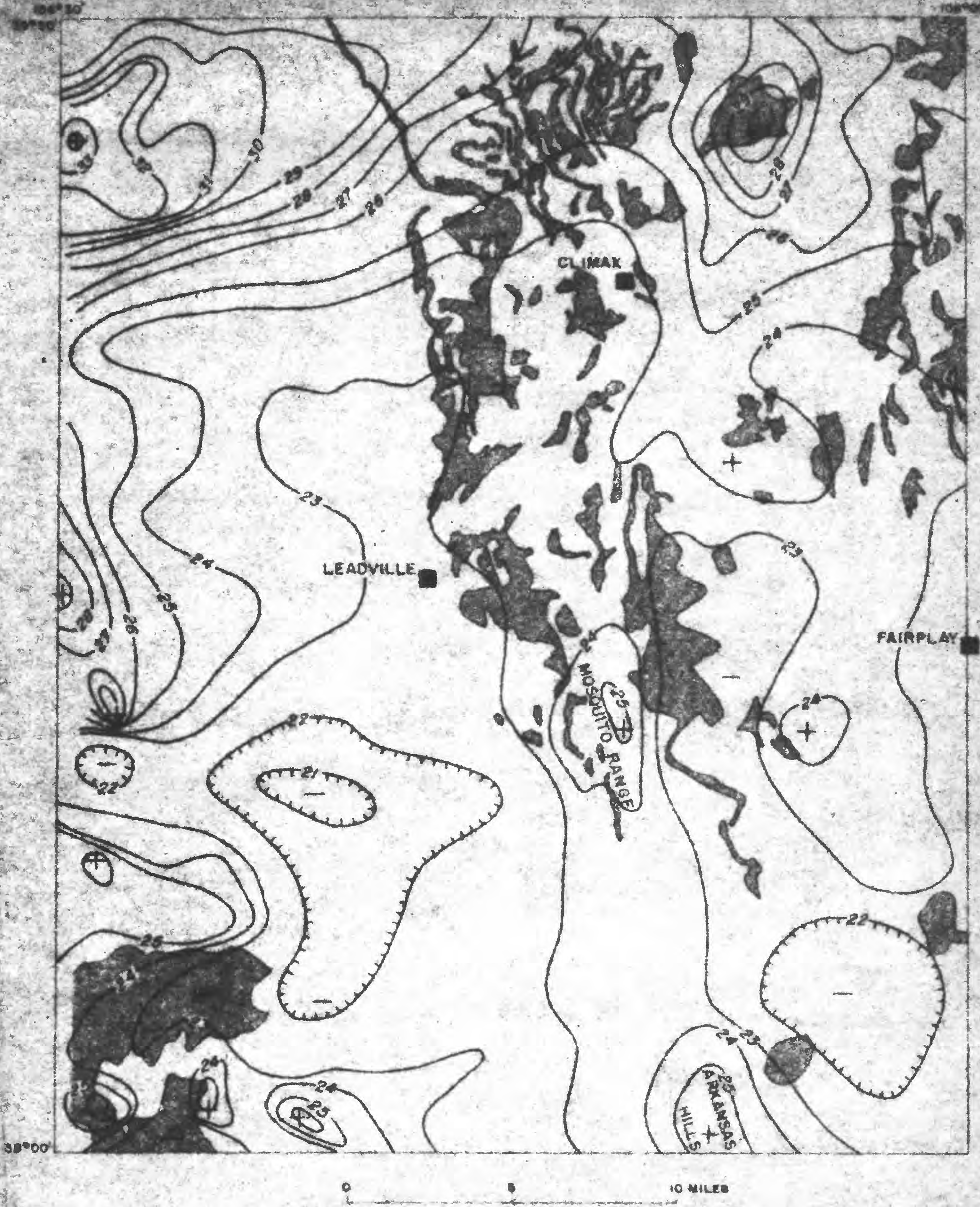

Figure 6.--Generalized aeromagnetic map of the Leadville 30-minute quadrangle showing larger Tertiary intrusive masses. Geology generalized from unpublished compilation by Ogden Tweto, U.S. Geological Survey. Interval 100 gammas.

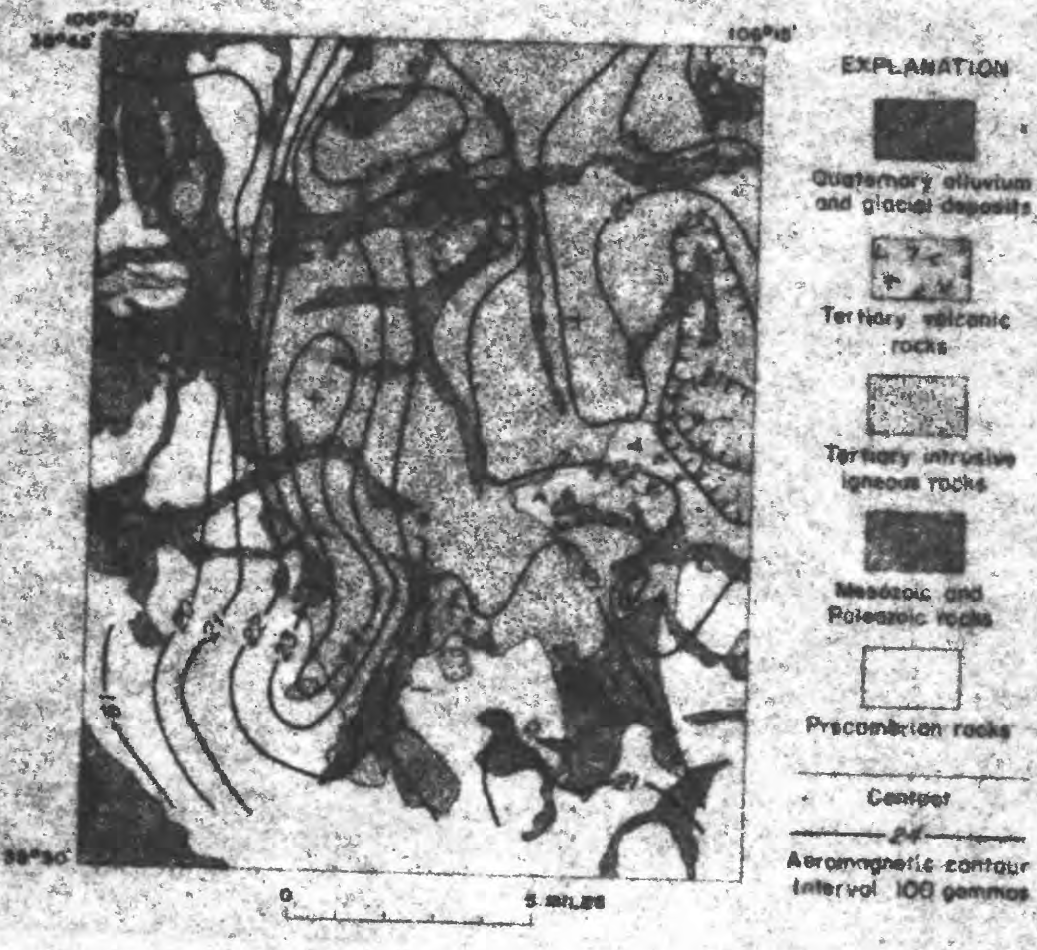

Figure 7.--Generalized geologic and aeromagnetic map of the Garfield 15-minute quadrangle. Geology simplified from Dings and Robinson (1957, pl. 1).

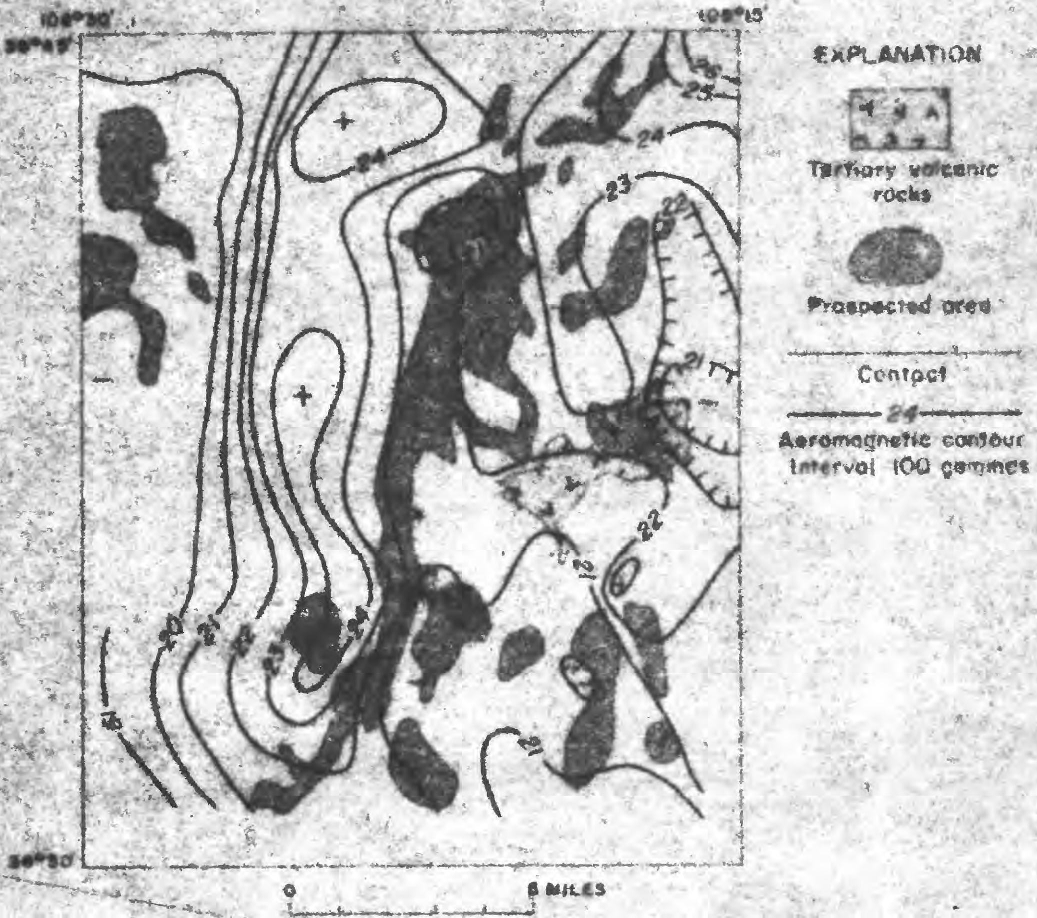

Figure 8. --Map showing distribution of heavily prospected areas the Garfield 15-minute quadrangle. Simplified from Dings and Robinson (1957; pl. 2).