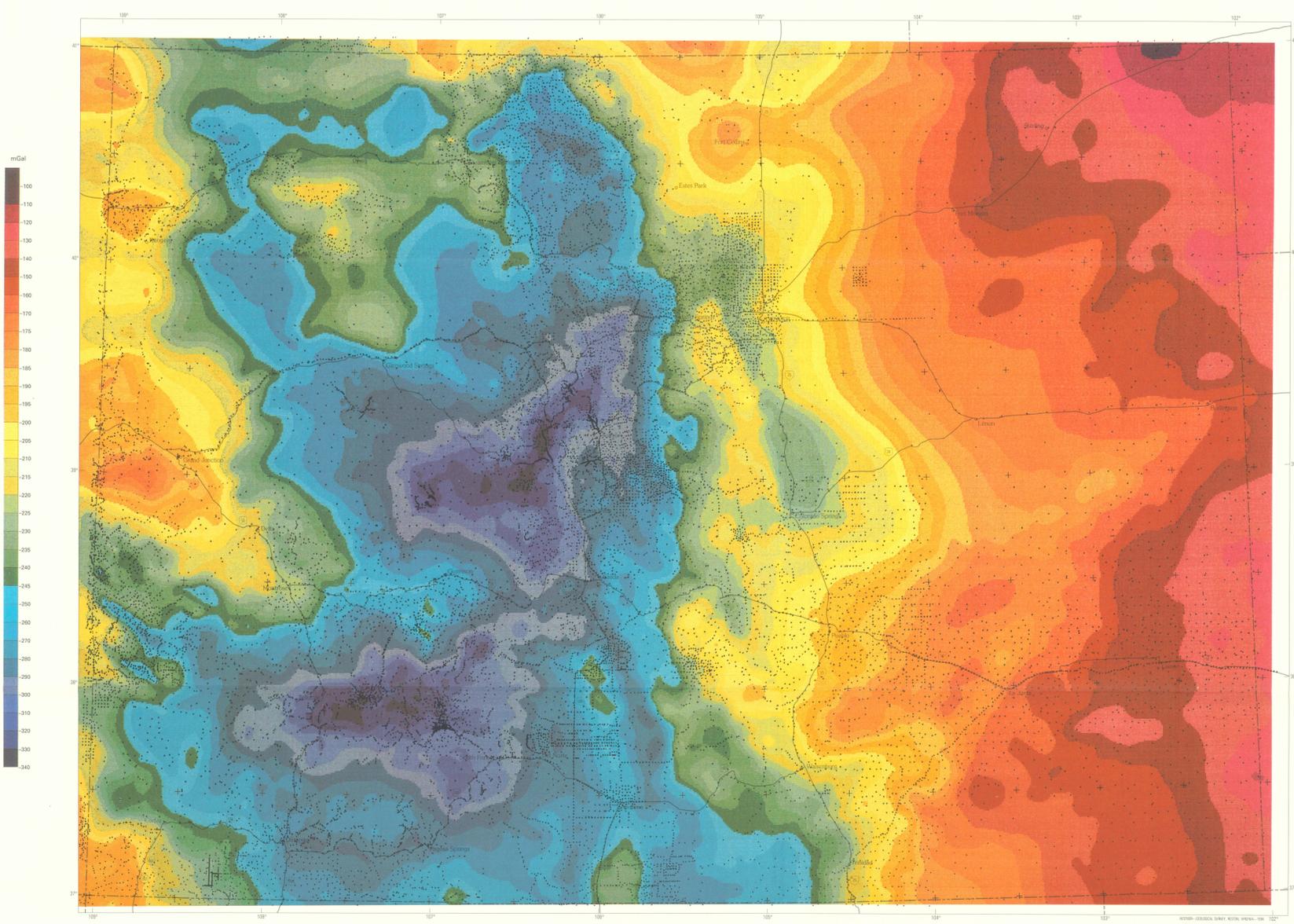


MAP A. DIGITAL TERRAIN MAP



MAP B. COMPLETE BOUGUER GRAVITY ANOMALY MAP WITH GRAVITY STATIONS (DOTS)

COMPLETE BOUGUER GRAVITY ANOMALY, ISOSTATIC-RESIDUAL GRAVITY, HORIZONTAL GRADIENT, AND TERRAIN MAPS OF COLORADO

By
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INTRODUCTION

As part of the National Mineral Resource Assessment Program (NM-RAP), gravity measurements in the state of Colorado were processed to show complete Bouguer gravity anomalies, isostatic residual gravity anomalies, and horizontal gravity gradients from the isostatic gravity data. Also, a color-shaded relief map of the 3-minute digital terrain data of Colorado was prepared for reference (map A). Color contour maps (1:1,000,000 scale) of the Bouguer gravity anomalies (map B) and isostatic-residual gravity anomalies (map C), and a color-shaded relief map of the horizontal isostatic gravity anomaly gradients (map D) were prepared to assist in geologic studies to assess the mineral resource potential and tectonic setting of the state. All of the color maps were prepared on a CalComp 5845 XP color electronic plotter using CalComp proprietary plotting software.

Behrens and Bajan (1974a, 1974b) prepared a Bouguer gravity anomaly map of Colorado using data obtained from approximately 12,000 gravity stations. Since that time, many additional gravity measurements have been made by the U.S. Geological Survey (USGS), and other institutions and universities. This latest compilation of gravity data (Abrams, 1993) was obtained from 28,735 stations. The distribution of gravity stations is shown on map B.

Measurements of the gravitational field at the Earth's surface are sensitive to the density of the crustal rocks beneath the measurement sites. Areal measurements of the gravity field provide a means of detecting lateral variations in the density of crustal rocks, which can be interpreted in terms of lithological variations and tectonic structures that isolate rocks of differing density. Before the gravity measurements can easily be used for geologic applications, however, corrections are made to account for physical differences in the measurement sites, such as elevation, mass above sea level, and irregularities in the topography. After data reduction, the reduced gravity measurements show positive anomalies (light and negative anomalies (low) that can be interpreted as indicating the distribution of high-density and low-density rocks, respectively. The patterns of these anomalies often provide clues to the location and nature of geologic structures. Long-wavelength variations in the gravity anomaly data are chiefly produced by sources at great depth, short-wavelength variations are usually produced by shallow or surficial rocks and small geologic structures. Gravity lows correspond to masses of low-density rocks or sediments, such as sedimentary basins, caldera fill, and granitic masses, and sediment-filled grabens; gravity highs are often identified with uplifts, horn blocks, and dense mafic rock masses.

TERRAIN MAP

Colorado can be divided into three physiographic zones (Thornbury, 1965, fig. 1) and map A. The eastern or high plains zone covers about 40 percent of the state and rises from an elevation of 5,300 ft (1,600 m) near the Nebraska and Kansas border to 6,500 ft (1,980 m) near the mountain front. Elevations in the Rocky Mountain zone range from 6,500 ft (1,980 m) to more than 15,000 ft (4,571 m). The plateau zone was of the Rocky Mountains consists of a series of mesa and plateaus that extend to the Utah border. The Rocky Mountain and plateau zones cover approximately equal areas of the state.

The three physiographic zones approximately correspond to three geologic tectonic zones. The high plains and plateau zones are geologically sedimentary terranes. Eopaleozoic rocks in the high plains zone are predominantly clastic, dated about 600 million years old. The Rocky Mountains, underlying Paleozoic and Mesozoic sedimentary rocks of the high plains zone dip gently westward except near the front of the Rocky Mountains, where they dip steeply eastward west of the axis of the Denver basin (fig. 1). The plateau zone is also primarily a sedimentary terrane, but it is more structurally complex and has considerably more local structure and topographic relief than the high plains zone. Although most of the plateau zone is characterized by gently dipping sedimentary rocks, strongly folded Paleozoic strata are exposed in the Frontal basin (fig. 1) at the western edge of the state and Cenozoic stocks, laccoliths, and volcanic rocks are exposed at numerous localities (Thornbury, 1965, p. 405-411). The Rocky Mountain zone is characterized by high elevation and topographic relief, and presents a strong contrast to the high plains and plateau zones. The mountains are primarily broad, north-south trending Precambrian-cored anticlinal uplifts separated by broad, high altitude intermontane basins; the San Juan Mountain part of the zone in southwestern Colorado was formed by a highly dissected mid- to late Tertiary volcanic pile eroded from numerous centers.

BOUGUER GRAVITY ANOMALY MAP

Map A is a color-shaded relief map of the state of Colorado. It was compiled using the computer program CSRELEF (M. Wehring, unpublished, 1987). The program produces a three-dimensional effect by artificially illuminating the data from any chosen direction and angle; the illumination direction (225°) and angle (45°) were chosen to enhance structures with a north-south trend, perpendicular to the axis of the Frontal basin. The data were projected on the Lambert conformal system with a central meridian of 106° W, and a base latitude of 38° N. Bouguer gravity anomalies have a strong inverse correlation with topography. In general, areas with high elevations have negative gravity anomalies and areas with low elevations have relatively positive anomalies. The terrain map was compiled from the 3-second GEO tape series (Elsal, 1983).

ISOSTATIC-RESIDUAL GRAVITY ANOMALY MAP

The complete Bouguer gravity anomaly map (map B) shows variations in the gravitational field due to horizontal variations in the density of surface and subsurface rocks. A Bouguer gravity anomaly is the difference between a corrected gravity value and the theoretical value for gravity in function of latitude. Measured values are corrected for (1) instrument drift, (2) tides, (3) the height of the station (free-air correction) above or below sea level, (4) the mass mass above sea level (Bouguer correction), and (5) irregularities in the topography (terrain correction). All Bouguer gravity anomaly values are negative in Colorado, indicating that the corrected gravity value is less than the theoretical value. The relationship between Bouguer gravity anomalies and regional topography can be explained by the principle of isostasy (Dutton, 1889), which states that loads on the Earth's surface produced by topographic features are supported at depth by deficiencies in mass (commonly called compensating masses or roots). An isostatic regional correction (Simpson and others, 1986) was removed from the Bouguer gravity anomaly data to produce the isostatic residual gravity anomaly map (map C). This correction is based on the complete Bouguer gravity anomaly values (lower, Bouguer, and terrain corrections) were calculated using the USGS program BOUGLER (Gordon and Pfaff, 1988) assuming an average crustal density of 2.67 g/cm³. The effects of terrain on local gravity fields are corrected for by the program using the method of Pfaff (1977) with a radius of 166.7 km from each gravity station. These computed terrain corrections are mean absolute digital data at a 15-second grid for corrections from 0.59 to 5.7 m, 1-minute terrain data for corrections from 5 to 21 m, and 1-minute terrain data for corrections from 21 to 166.7 m. Terrain located less than 0.59 km from a station is not corrected for by the procedure described above due to the coarseness of the digital terrain model. The terrain corrections are the most likely source of error in the data reduction process because of the coarseness of the terrain grid; they may account for an error of as much as 10-20 percent (R. Salts, 1993, personal communication), which translates to 6 mGal as a maximum possible error at the highest elevations. In general, however, data are accurate to within about 1 mGal. Observed gravity values were adjusted to conform to the International Standardization Net of 1971 (International Association of Geodesy, 1974). The theoretical gravity values were calculated using the 1967 formula of the Geodetic Reference System (International Association of Geodesy and Geophysics, 1971). Cordell and others (1982) described gravity reduction equations and approximations used by the program BOUGLER.

The complete Bouguer gravity anomaly data were projected on the Lambert conformal system with a central meridian of 106° W, and a base latitude of 38° N. The values were then gridded to an interval of 2 km using a minimum curvature algorithm (Briggs, 1974; Wehring, 1981). The actual data interval varies widely; there is a close distribution along roads and a sparse distribution in remote areas (see gravity station locations on map B). The grid spacing has an effect on the nature of the resulting map calculations made using a smaller grid spacing emphasize shorter wavelength anomalies, whereas those using a larger grid spacing emphasize broader wavelength anomalies. The actual data spacing also strongly influence the wavelength of anomalies and, hence, the size of the features that can be identified; some data do not allow resolution of smaller features. Even when great care is used in selecting the gridding interval, some of the isolated anomalies on map B may be artifacts of the data reduction procedure or inaccuracies in the field measurements and may not represent true crustal-density variations. The data were plotted on 5- or 10-mGal color contour slices with red indicating gravity highs and purple indicating gravity lows (map B). The Bouguer gravity anomaly values range from a low of -310 mGal to a high of -106 mGal. The locations of the gravity stations on map B show the actual spacing of the gravity measurements.

HORIZONTAL GRADIENT MAP OF THE ISOSTATIC GRAVITY FIELD

Map D shows the horizontal gradient (rate of change) of the isostatic gravity field calculated using techniques discussed in Growth and Cordell (1987). Maximum gradients occur at inflections in the gravity field and can be interpreted as locations of steeply dipping boundaries between rocks that have distinct density contrasts. To highlight steep gradients, gradient maxima are located and plotted as lines (Blaich and Simpson, 1986) representing density boundaries between crustal materials, such as contrasting lithological units juxtaposed by a fault.

The color shaded relief map was illuminated from the southwest, causing anomalies trending northeast and southeast to be emphasized and the southwest-northeast-trending anomalies to be subdued. This illumination angle was chosen because of the numerous structures that have north-south trends, including most salt-cored anticlines in the Frontal basin, and the major Laramide uplifts in the Rocky Mountains.

Mapping the horizontal gradient of the isostatic gravity and determining where gradient maxima occur aids the interpretation of gravity data by locating patterns and features that might not be apparent on other geologic or geophysical maps.

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PLATEAU MOUNTAINS PLAINS

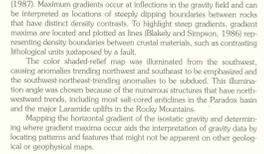


Figure 1. Location of major tectonic and geographic features.

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