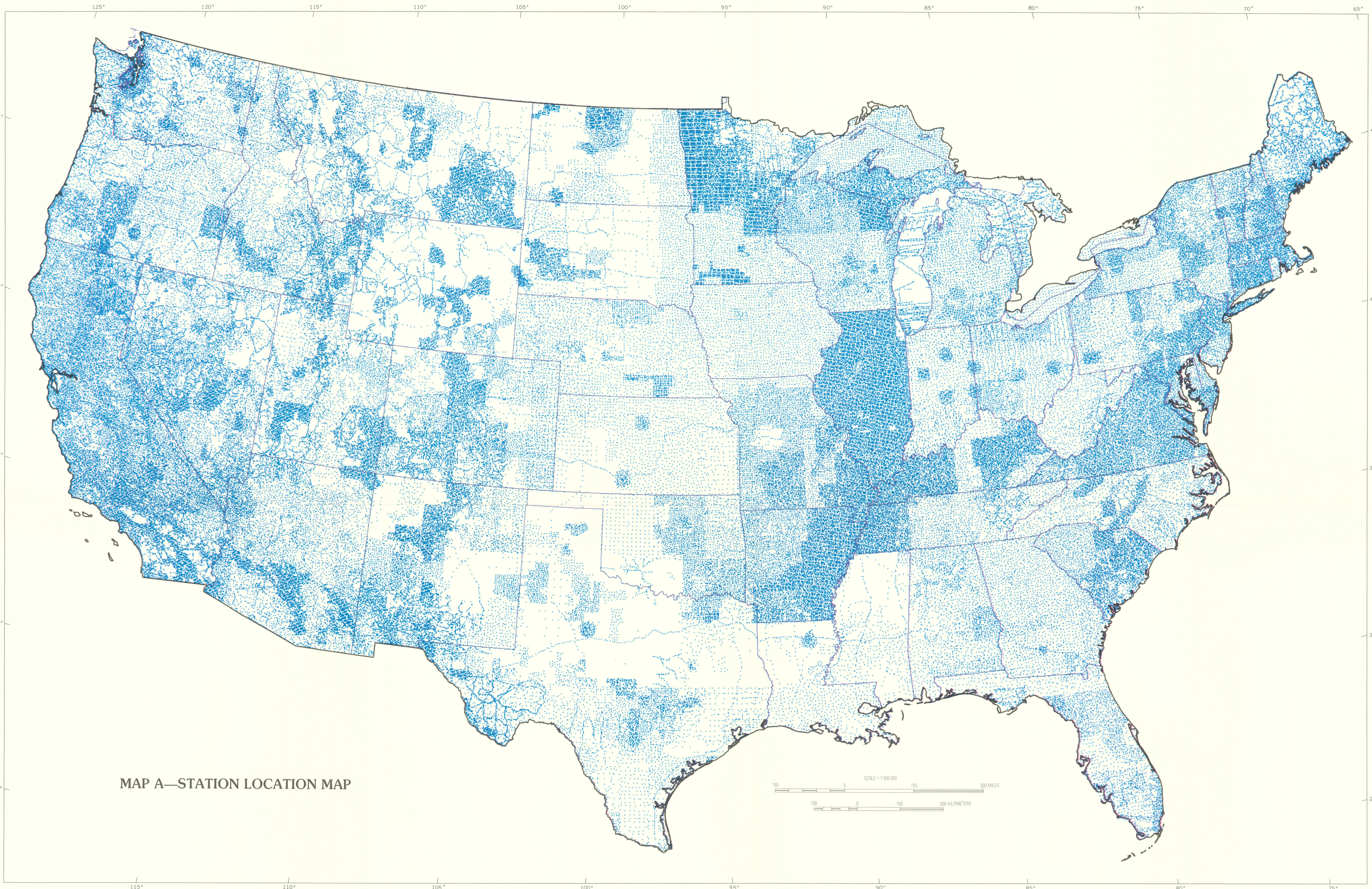
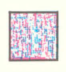
DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

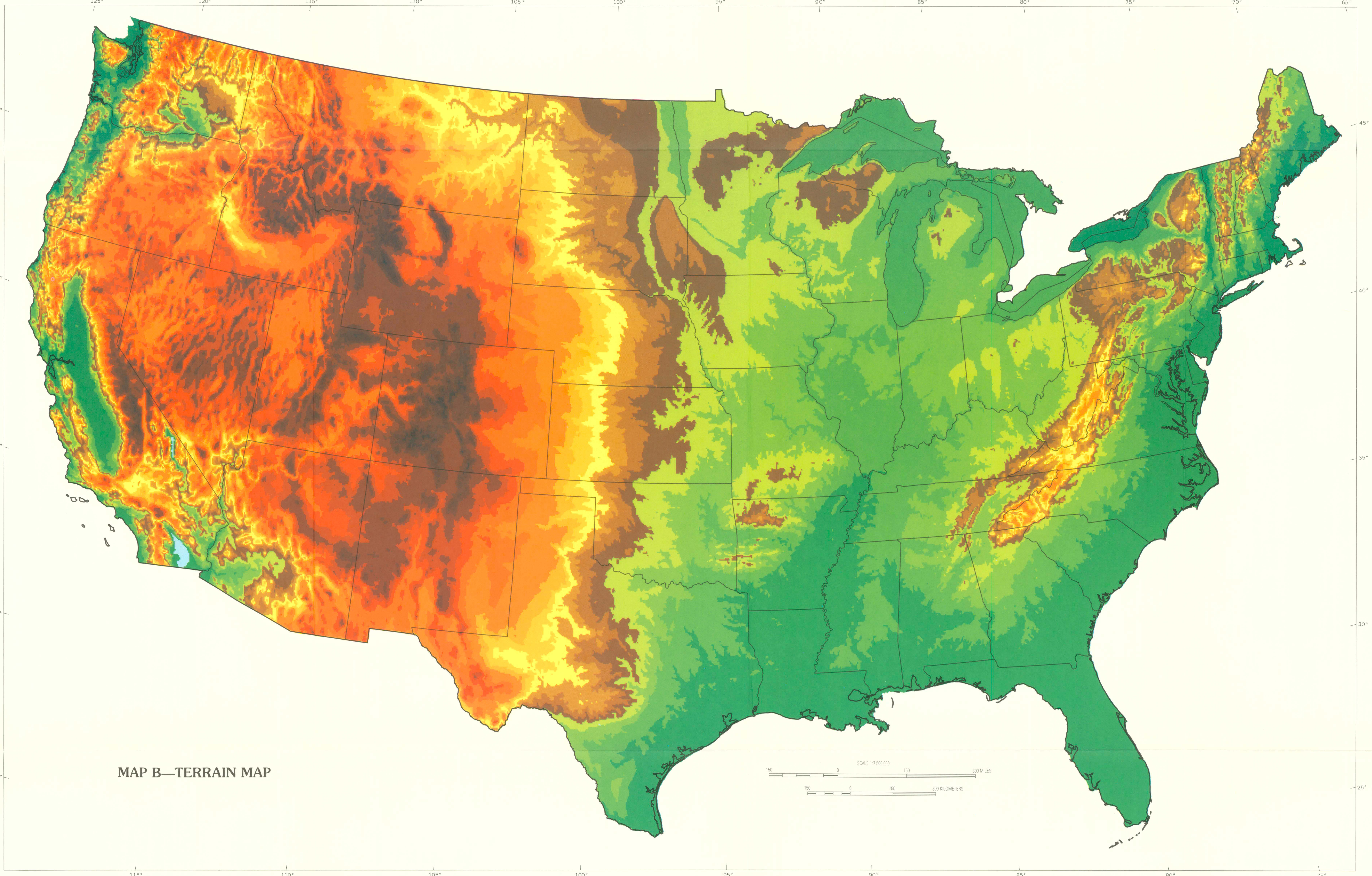


EXPLANATION



GRAVITY STATION—Dot marks location of gravity observation used to prepare Free-Air and Bouguer gravity maps. Data compiled in 1981. Sources of data described in text

Data were screened to select one observation per 4x4 km cell
Albers Conic Equal-Area projection with 29.5°N and 45.5°N as standard parallels



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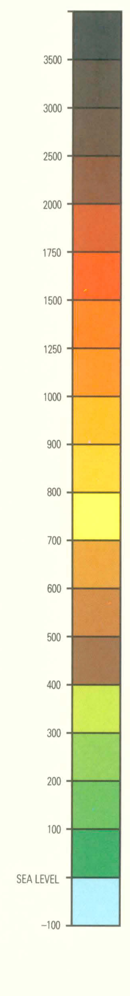

Data gridded at a spacing of 6 km. Albers Conic
Equal-Area projection with 29.5°N and 45.5° N as standard parallels

INTERIOR—GEOLOGICAL SURVEY, RESTON, VA—1987 –G85121

DATA COMPILED IN 1980

INTRODUCTION

The availability of gravity and terrain data sets in digital form and the advent of computer-driven color plotters have opened up new possibilities for studying the Earth's gravity field. Data spanning an entire continent can now be displayed in great detail with unprecedented ease. Mathematical techniques for filtering and enhancing the data promise new insights into the sources of gravity anomalies and their geologic and tectonic significance.

The first maps in this series (GP–953–A) presented wavelength-filtered versions of the Bouguer gravity field for the conterminous United States (Hildenbrand and others, 1982). Maps displayed in this report show the Bouguer gravity data (map D) used to make the wavelength-filtered maps and the locations of the observations (map A) used in the preparation of the Bouguer map. A free-air gravity map (C) and a topographic map (B) are also displayed so that the effects of the Bouguer reduction and the correlations of anomalies with topography can be seen more readily.

The gravity data set used in preparing these maps has been superseded by the more complete data set compiled for the Gravity Anomaly Map of the United States (Society of Exploration Geophysicists, 1982). The more complete data set is available in digital gridded format on magnetic tape (Godson and Scheibe, 1982a; 1982b). We have continued to use the older data set for these maps in order to document the data used in GP–953–A and because at the scale of this publication (1:7,500,000) the differences are not marked. Maps in this series are available as color slides (Simpson and others, 1982) from the U.S. Geological Survey Photo Library (Mail Stop 914, Box 25046, Denver Federal Center, Denver, CO 80225, telephone 303-234-4004).

OVERVIEW OF THE GRAVITY REDUCTION PROCESS

The philosophy behind the reduction of gravity data is to calculate and remove the gravitational attractions of known masses and the acceleration caused by the Earth's rotation, leaving a residue of anomalous attractions caused by unknown sources. The interpreter's task is then to explain these gravitational anomalies in terms of geologically reasonable source bodies and density contrasts, with the help of any additional geophysical or geologic information that might be available. The theory and practice of gravity reduction is described in detail by Dobrin (1976), Nettleton (1976), Heiskanen and Moritz (1967), and Swick (1942). The discussion that follows explains in general terms the rationale for the various reduction steps.

There are two different ways to view the reduction process. (1) In the "correction" view, each step of the process adjusts the observed gravity value at a site for the attractions of known masses before comparing that value with the theoretical gravity on the reference ellipsoid. (2) In the "prediction" view, each step refines the theoretical value by adding to it the effects of known masses. The resulting predicted value is then compared to the observed value to yield an anomaly.

Both viewpoints have corresponding conceptual Earth-density models associated with them, which are refined at each step in the reduction process. The correction model starts with the true (and unknown) density distribution in the Earth, and subtracts "known" densities at each step. The prediction model starts with the theoretical reference ellipsoid (Moritz, 1968) and adds "known" density distributions at each step; the ultimate prediction model will have a density distribution matching that within the Earth. The differences between these two approaches may seem rather subtle—a mere reordering of additions and subtractions. We have observed, however, that the prediction approach seems to avoid many of the pitfalls that arise in understanding the physical significance of the reduction steps. In the discussion that follows we use terminology to fit the predictive approach.

To prepare a free-air gravity anomaly map, an observed gravity value is compared with a predicted value that incorporates (1) the total mass of the Earth, (2) the ellipsoidal shape of the Earth, (3) the spin of the Earth, and (4) the distance of the observation above sea level. The first three terms are included in the formula for theoretical gravity on the normal ellipsoid defined by the Geodetic Reference System of 1967 (International Association of Geodesy, 1971; Chovitz, 1981). The fourth term, called the free-air term, predicts the decrease in the gravitational attraction as the observation point moves farther from the center of the Earth. The free-air adjustment amounts to approximately 0.3086 mGal/m. Note that 1 mGal = 1 milligal $= 10^{-3}$ Gal = an attraction producing an acceleration of 10^{-3} cm/s^2. The gravitational attraction at the Earth's surface is approximately 980 Gal, so that anomalies equal in amplitude to 1 mGal represent variations in the Earth's gravity field of approximately one part in a million.

The predicted gravity, after the free-air adjustment has been added to the theoretical gravity, is the attraction that would be measured at the given latitude on and elevation above the reference ellipsoid. However, a practical consideration intrudes–elevations are commonly measured above the geoid (sea level and its extrapolation on land by leveling) and the geoid has undulations relative to the surface of the reference ellipsoid. Thus, the gravity has not been predicted at the proper elevation above the reference ellipsoid if the elevation of the observation site was measured relative to sea level. This so-called indirect effect (Chapman and Bodine, 1979; Swick, 1942, p. 76) needs to be considered in modeling gravity anomalies which extend over distances that are large compared to the generally smooth undulations in the geoid. For the conterminous United States, the largest deviation of the geoid from the reference ellipsoid is approximately −35 m (Taylor and others, 1983), which amounts to a maximum indirect effect of approximately 11 mGal.

The next reduction step, called the Bouguer reduction, attempts to predict the attraction of topographic masses lying above sea level in the vicinity of the observation. Without this adjustment, the gravity anomaly recorded on the top of a hill would be greater than the anomaly recorded at the base of the hill, simply because of the extra mass contained in the hill. The effect is predictable if the shape and density of the hill are known, and needs to be removed if one is concerned with density contrasts associated with geologic features which are not related to the topography.

Usually the Bouguer reduction is calculated in two parts. (1) The simple Bouguer adjustment, by definition, adds to the predicted gravity the attraction of an infinite slab of mass with a thickness equal to the elevation of the observation above sea level. Thus, the observation point is imagined to be situated on top of a flat plateau. This assumption usually yields a good first approximation to the attraction of the topography, but in areas of rugged terrain the departures of topography from the simple plateau model need to be included. (2) The complete Bouguer adjustment is, by defintion, an estimate of the attraction of the true topography, on a curved Earth, out to a radius of 166.7 km from the observation point. The calculation is generally carried out in three steps outlined by Bullard (1936). First, the simple Bouguer infinite-slab correction is made. Second, a curvature correction is applied to convert this result to the attraction that would be expected from a spherical cap of radius 166.7 km (Lambert, 1930). Finally, a terrain correction is applied which incorporates the details of the topography out to 166.7 km (that is, the departures from a spherical cap), usually with the help of digitized topographic data and computer programs (Plouff, 1977). The chosen radius of 166.7 km is somewhat arbitrary and coincides with the outer radius of Hayford-Bowie Zone O (Hayford and Bowie, 1912). The choice works because topography at a distance of 166.7 km is usually not contributing very greatly to the vertical attraction at the observation point. Topography at larger distances once again becomes important, because the curvature of the Earth places the distant topography at more favorable angles underneath the observation point. However, for local gravity surveys the complete Bouguer reduction can successfully ignore the distant topography, because its attraction varies slowly with distance. Thus, ignoring the distant topography in the Bouguer reduction effectively results in a datum shift for most gravity studies confined to areas smaller than several hundreds of kilometers in width. For maps covering broader areas, the Bouguer reduction by itself is no longer entirely satisfactory for other reasons.

To calculate the Bouguer reduction term, a density for the topography must be assumed. For local studies, this choice can be tailored to the densities of the rock units forming the topography, but for regional studies, a density value of 2.67 g/cm^3 is frequently chosen. With this value the simple Bouguer adjustment is approximately +0.1119 mGal/m. An inappropriate choice of density may give rise to Bouguer anomalies which correlate with topography. In that case the predictive Earth model, when subtracted from the real Earth, leaves density contrasts above sea level that can often be accounted for at the modeling stage.

DATA PROCESSING

The assembled gravity data set was screened to select one observation per 4x4-km cell. If several observations were available for a given cell then their Bouguer gravity values were compared as a consistency check, although only the first station encountered was retained, provided it passed all consistency checks. This screening process served to eliminate some of the more discrepant observations, to make the data set more manageable in size given the scale of the final product, and to somewhat reduce bias caused by wide variations in data density. The final screened data set contained 221,215 stations.

Observed gravity values were adjusted to conform to the International Gravity Standardization Net of 1971 (Morelli, 1974). The gravity data were reduced using the 1967 Geodetic Reference System formula for theoretical gravity (International Association of Geodesy, 1971). Formulas used in the reduction process are listed by Cordell and others (1982).

Each on-land gravity observation has been terrain corrected for topography lying between radii of 0.895 km and 166.7 km from the observation using a computer program of Plouff (1977). The inner-zone corrections from 0 to 0.895 km which have been omitted are probably not significant for most of the stations. That is, the inner corrections are expected to be substantially less than the 2 mGal uncertainty estimated for the majority of the land observations. Some mountainous areas do have inner-zone corrections in excess of 2 mGal, but we do not expect that those corrections would change the regional anomaly patterns in any significant way at this scale (1:7,500,000).

The irregularly spaced data, after being screened and terrain corrected, were gridded using a program of Webring (1981) based on the minimum curvature algorithm of Briggs (1974). The gridding process interpolates and extrapolates in the randomly spaced data set to produce a regularly spaced grid of values. In this case, a 6x6–km grid was produced.

The data were projected using the Albers Conic Equal-Area projection with standard parallels for the United States at 29.5°N and 45.5°N, so that the maps are compatible in projection with the 1:7,500,000-scale geologic and tectonic maps in the U.S National Atlas (U.S. Geological Survey, 1970).

In spite of much editing, some isolated bad data points are still apparent. Questionable isolated anomalies with diameters on the order of 6 km should be checked against more detailed maps and original sources where possible. Anomalies in areas with sparse data coverage will necessarily exhibit less detail, and their smoother appearance should not be mistaken for a change in the fabric or character of the gravity field indicative of a difference in underlying geology.

Text continued on sheet 2 of 2

DIGITAL COLORED BOUGUER GRAVITY, FREE-AIR GRAVITY, STATION LOCATION, AND TERRAIN MAPS FOR THE CONTERMINOUS UNITED STATES

By
R.W. Simpson, T.G. Hildenbrand, R.H. Godson, and M.F. Kane

1987

For sale by U.S. Geological Survey, Map Distribution,
Box 25286, Federal Center, Denver, CO 80225