UNITED STATED DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

A Description of Colored Isostatic Gravity Maps and a Topographic Map of the Conterminous United States Available as 35 mm Slides

by

Robert W. Simpson[1]
Richard W. Saltus[2]
Robert C. Jachens[1]
Richard H. Godson[2]

Open-File Report 83-884

1. U.S. Geological Survey, 345 Middlefield Road, Menlo Park, CA 94025
2. U.S. Geological Survey, Box 25046, Federal Center, Denver, CO 80225

1983

Table of Contents

I. INTRODUCTION

Isostatic residual and isostatic regional gravity maps have been prepared for the conterminous United States using the Airy-Heiskanen model of compensation, and have been plotted using an Applicon Color Plotter. Standard 2" x 2" color slides of these maps and other maps described in this report are available from the U.S. Geological Survey Photo Library (Mail Stop 914, Box 25046, Denver Federal Center, Denver, Colorado 80225, telephone 303-234-4004).

The maps were constructed using the new Bouguer gravity data set assembled to produce the Gravity Anomaly Map of the United States published by the Society of Exploration Geophysicists (SEG) in 1982. This data set contains at least one station per 5 x 5-minute cell for most of the United States - a major improvement over earlier data sets. A gridded version available on magnetic tape (Godson and Scheibe, 1982a) was used as the starting point.

II. VALUE OF ISOSTATIC MAPS

Over most of the earth's surface the longer wavelengths of the Bouguer gravity field correlate inversely with the longer wavelengths of topography. This inverse correlation is quite evident on wavelength-filtered maps of Bouguer gravity and topography for which wavelengths less than 250 km have been suppressed (Simpson and others, 1982).

The principle of isostasy offers an explanation for this inverse correlation: namely, loads on the earth's surface caused by topographic features are supported (compensated) at depth by deficiencies in mass as if the earth's crust were floating on a denser substratum (Dutton, 1925; Daly, 1940; Heiskanen and Moritz, 1967; Woollard, 1966). This deficiency of mass at depth produces the observed Bouguer gravity lows over mountainous areas. (The Bouguer gravity reduction has already removed for the most part the gravitational attraction of the topographic masses down to sea level.)

The advantages of isostatic residual maps for the interpretation of gravity anomalies in mountainous areas have recently been emphasized by Jachens and Griscom (1982). Briefly stated, (1) an isostatic residual map reveals anomalies in the crust caused by bodies of geologic interest which are otherwise obscured by the large topography-related anomalies produced by compensating masses (roots) beneath topographic features. (2) An isostatic regional field (the gravitational attraction of the root system), although it must be constructed on the basis of a specified model, is still far less arbitrary than regional fields constructed by empirical smoothing, polynomial fitting, or wavelength filtering and can be adjusted to fit available geophysical data for a given study area. (3) By removing the total effect of topography and its compensation, comparisons of gravity signatures of basement terranes can be made in areas of different elevation.

A variety of different isostatic models and parameters are available, and no single model is likely to be the best one for an entire continental area. Yet, for the enhancement and interpretation of anomalies caused by shallow geologic features, the application of some isostatic correction is more important than the exact details of the correction used. The gravity fields calculated from reasonable isostatic models tend to differ by small percentages in a smooth, long-wavelength fashion. (For examples of differences, see Saltus, 1983.) Because the isostatic model is a physical earth model, it can be adjusted in the preparation of quantitative gravity models to best fit the compensating mass geometry for a given area as determined by other geophysical methods.

The application of an isostatic reduction is also compatible with the general philosophy underlying gravity reductions: the gravitational attractions of known mass distributions are subtracted to leave a map of anomalies which are caused by bodies not yet known (or by departures from assumed reduction models and parameters). The interpreter's task is to explain these anomalies.

III. CAUTION ON THE SIGNIFICANCE OF ISOSTATIC ANOMALIES

There is a common tendency (once shared by some of the authors) to ascribe anomalies on an isostatic anomaly map to "isostatic imbalances", that is, to loads which are not properly supported in an isostatic sense. We wish to emphasize that most of the anomalies (up to about 200 km across) appearing on an isostatic residual gravity map can be equally well explained by density inhomogeneities in the crust which are completely compensated. This point is best made by reference to a simple example. In Figure 1, a mountain range superimposed on a uniform crust is supported by a local Airy root. On an isostatic residual map there would be no anomaly because both the effect of the mountain range and of its root are removed. In Figure 2, a dense mass in the upper crust is also supported by a local Airy root. In this case, because there is no topography, neither the effect of the mass nor that of its root have been subtracted. The root, because it lies considerably deeper than the mass which it supports, will have an anomaly which is broader and of lower amplitude than that produced by the mass. For the example in Figure 2, the net result is a substantial anomaly even though the mass is "perfectly" compensated.

The point is that isostatic residual gravity maps by themselves do not prove the existence or non-existence of isostatic equilibrium in a given area. We maintain, however, that they do reveal quite a lot about the mass distributions in the crust and upper mantle which bear directly on the geologic history of that area.

IV. DATA SETS USED

1. Gravity data

The Bouguer gravity data used is the gridded data set described by Godson and Scheibe (1982a), which was used in the preparation of the Gravity Anomaly Map of the United States (Society of Exploration Geophysicists, 1982). Onshore, this grid was constructed from Bouguer gravity values calculated using a reduction density of 2.67 g/cm^3 and terrain corrected by computer for topography from 0.895 km (Hammer zone F) to 166.7 km (Hayford zone O) from a given station. Offshore, free-air gravity values were used. The grid has a 4 x 4 km grid interval and is projected using an Albers equal-area projection with central meridian at 96°W and standard parallels at 29.5°N and 45.5°N. In the gridding process, data within a search radius of 40 km of a grid point were used to aid interpolation in areas of sparser data coverage (Godson and Scheibe, 1982). Thus, a margin of extrapolated grid values exists around the irregular boundaries of the data area. These extrapolated values should not be used.

The distribution of stations used to construct the grid is shown as an inset map on the Gravity Anomaly Map of the United States (Society of Exploration Geophysicists, 1982). For onshore areas, 95 percent of all 5 x 5-minute cells have at least one gravity data station available.

2. Topographic data

The bathymetric and topographic data sets used to calculate the isostatic regional field were obtained from the National Oceanic and Atmospheric Administration (NOAA) Data Center. (Address: National Geophysical and Solar - Terrestrial Data Center, NOAA, Boulder, CO 80303.) Offshore, the 5 x 5-minute Synthetic Bathymetric Profiling System (SYNBAPS) data were used (NOAA announcement 81-MGG-14). Onshore, the 5 x 5-minute North American data set was used (NOAA announcement 1980 (SE-V)).

These data sets are out of register by 2.5 minutes, so they cannot be combined without some interpolation. Because a projected grid of topographic elevations was needed, grid locations were defined (at an 8 x 8-km interval) in an Albers projected coordinate system identical to that used for the gravity data. By an inverse projection, the grid point coordinates were found in degrees, and an elevation or depth was assigned to each location by two-dimensional linear interpolation in either the unprojected onshore grid or the unprojected offshore grid. Although the onshore North America 5 x 5-minute data set also contained data values offshore in many areas, the SYNBAPS data were used offshore. The SYNBAPS data were found to be more accurate in the offshore areas except in a few shallow offshore areas (for example, off the coast of Louisiana) where the SYNBAPS file contained no data. All onshore values came from the North American 5 x 5-minute data set. Note that in the North American land data set, lake bottom elevations are used rather than lake surface elevations, so that to properly calculate a surface load, the weight of the water in the lakes must be added to the bedrock load. This has not been done for the isostatic residual map described here, so that the field over the deepest parts of the Great Lakes may be in error by up to 10 mGal.

V. PROCEDURE FOR CALCULATING ISOSTATIC RESIDUAL GRAVITY

The only data required for calculating an Airy isostatic regional gravity field are a topographic data set and a choice of three parameters. The parameters required are a density for the topographic load, a sea-level depth of compensation, and a density contrast at depth. The topography defines a root geometry, and the gravitational attraction of this root geometry is the isostatic regional field. Finally, an isostatic residual gravity map is obtained by subtracting the isostatic regional field from a Bouguer gravity map. Because the Bouguer reduction steps have removed most of the effects of topography down to sea level, and because subtracting the isostatic regional field removes the effects of the roots beneath topographic loads (at least as they are defined by one specific model), the resulting isostatic residual gravity map is substantially free of topography-related anomalies -- at least insofar as compensation follows the assumed model.

In the preparation of the isostatic residual gravity maps presented here, the 5 x 5-minute topographic data sets described in the previous section were used. Calculation of the attraction of the root defined by this data set on a flat earth out to a distance of 166.7 km was performed using a program called AIRYROOT (Simpson and others, 1983) which uses a fast Fourier transform algorithm developed by Parker (1972). This result was combined with a published result for the attraction of the topography and the root system in the region beyond 166.7 km (Karki and others, 1961). Although there exists a mismatch between the model parameters for the published result and those of our model (sea level compensation depth = 30 km vs. our 25 km, and density contrast = 0.6 g/cm^3 vs. our 0.4 g/cm^3), tests suggest that this mismatch causes long-wavelength errors of no more than 3 mGal for the conterminous U.S. Tests described by Simpson and others (1983) suggest that the 5 x 5-minute topographic data are adequate for regional maps of the scale shown here, although 3 minute data would be better for larger scale maps. For a large rectangular area covering much of northern California and Nevada, when the AIRYROOT regional was compared with a regional obtained from 3 minute topographic data using program ISOCOMP (Jachens and Roberts, 1981), the average discrepancy was 0.8 mGal with a standard deviation of 0.9 mGal. The discrepancies ranged from -5.2 to +7.6 mGal as extremes.

One omission in the initial topographic data set is that it does not account for the load of the water in the Great Lakes. This omission may produce errors on the order of 10 mGal in the isostatic regional field over the deepest spots in the lakes. This omission will be corrected in the preparation of larger scale isostatic residual gravity maps.

The isostatic regional field obtained by the procedure described above is the gravitational attraction of the root system calculated at sea level. Because most gravity stations are collected at elevations above sea level, the proper isostatic correction for a given station is an upward continuation of the sea level result. This adjustment is usually not very large given the depth of the root and the consequent smoothness of the isostatic regional -- even in areas of extreme topographic relief such as the Sierra Nevada of California, the adjustment seldom exceeds 5 mGal. This correction was made by upward continuation of the sea level regional grid to two levels - 2 km and 4 km - and then interpolating between these grids and the sea level grid to derive a value corresponding to the proper station elevation. For a grid of Bouguer gravity values, the best elevation to use in adjusting a grid value is not well defined. Each Bouguer gravity grid value has been obtained by interpolating between gravity observations made at different elevations. We used the average elevation from the topographic grid to make the adjustment.

The final step in the preparation of the isostatic residual gravity map is the subtraction of the isostatic regional field from a Bouguer gravity map. The grid of Godson and Scheibe (1982a) contains free-air gravity values offshore. A Bouguer correction to this grid was made using the 5 x 5-minute offshore bathymetric data set, but because the Godson and Scheibe grid was made using a 40 km search radius, the mismatch between free-air value and Bouguer correction is potentially quite large. We estimate that in areas of extreme bottom relief, this mismatch could result in errors as large as 40 mGal, though for most ocean areas the error is probably less than 10 mGal or one color interval. We think that the patterns in the offshore data are of sufficient interest to warrant keeping these areas on the maps - provided the user is aware of the potential errors.

For land areas, isostatic residual gravity values are subject to errors caused by uncertainty in the station elevation and in the gravity measurement (probably less than 2 mGal for most stations), errors caused by ignoring the terrain correction from a radius of 0.895 km into the station (probably less than 1 mGal for most stations but tens of mGal for a few stations), and errors in the isostatic regional field caused by the use of gridded values and the resultant ambiguity as to the proper upward continuation height (probably less than 1 mGal usually but on occasion up to 5 mGal). As a result, most (probably 99 percent) of the isostatic residual values on land are accurate to better than 5 mGal or one-half of a color interval. Areas of extreme topographic relief are most likely to have the larger errors.

An ANSI standard labelled tape containing the grids for maps 1, 2, and 3 may be borrowed from the authors for copying.

VI. DESCRIPTIONS OF THE MAPS

1. Topographic map from 5 minute data

The topographic data set is Albers projected with an 8 x 8-km grid interval. It was constructed from two 5 x 5-minute data files - one onshore and one offshore - as described in Section IV. Because of the limitations of the color plotting software, this grid and the grids for maps 3 and 6 were regridded to 6 x 6 km before color plotting. The color scale interval used is not linear (color scales are given in Appendix A) because a linear scale tends to produce a single color for most of the eastern United States. In order to properly calculate a root system for the entire area of the gravity data set, the topographic data extend at least 300 km beyond the edges of the gravity data grid (166.7 km plus a margin to help reduce edge effects). Note that lake bottom elevations are shown rather than lake surface elevations.

2. Isostatic regional gravity map

The gravitational attraction of a root in the Airy-Heiskanen system of compensation is shown on this map. This isostatic regional was calculated using the topographic data shown on map 1 and the programs described in Section V. Model parameters were: density of topography = 2.67 g/cm^3, density contrast at depth of compensation = 0.4 g/cm^3, depth of root for sea level elevations = 25 km.

The original 8 x 8-km regional grid was regridded to 16 x 16 km for color plotting. As expected, the regional is a smoothed, inverted image of the topography. To first order, it is just the topography upward continued 25 km as if it were a potential field with an appropriate constant multiplier applied to convert meters to mGal.

3. Isostatic residual gravity map

This map was prepared by subtracting the regional field shown on map 2 from the gravity data set shown on map 4. Because the offshore gravity values used were free-air rather than Bouguer, we first made an approximate Bouguer correction to the gridded data using the topographic data set. This correction will be satisfactory in areas where the seafloor does not have much relief. (See discussion in Section V).

Considerable caution must be exercised in interpreting short wavelength isostatic anomalies as signs of isostatic imbalance (see Section III above). In most cases, the bodies producing such anomalies could be in perfect isostatic balance, and the question cannot be resolved without additional geophysical data. Many of the shorter wavelength anomalies can be profitably interpreted by assuming that isostatic balance holds everywhere. If this is correct, then short-wavelength highs imply the presence of massive bodies in the crust, short-wavelength lows imply the presence of sedimentary sections or light felsic bodies, and as such the isostatic residual map is not far removed from a crustal density map.

Longer wavelength anomalies such as the broad high over Montana or the broad low over the Atlantic Ocean southwest of North Carolina present a more difficult interpretational problem. These broad features also are present on free-air gravity maps (map 5) and on satellite gravity maps (Lerch and others, 1979), so we feel confident that they are not artifacts of our data processing. The breadth of these mass excesses and deficiencies is sufficiently great that they may be caused by mass anomalies within the mantle -- such mass anomalies would not be removed by normal isostatic corrections. For model studies of these longer wavelength anomalies an additional correction needs to be applied to the gravity data: namely, the data need to be reduced to the reference ellipsoid rather than to the geoid. This correction for the so-called indirect effect is explained by Chapman and Bodine (1979).

Tentative correlations of these broad gravity features with geologic surface features can be made. For example, the broad high over Montana and surrounding states falls over an area of Laramide thrusting and also merges with a high in Idaho which coincides with extensive rift-like volcanism associated with the Snake River Plain and Yellowstone Caldera. A portion of this high extends eastward to about the midcontinent gravity anomaly which runs through Minnesota, Iowa, and Kansas (King and Zietz, 1971; Chase and Gilmer, 1973; Ocola and Meyer, 1973). A broad low area lies to the east of the midcontinent anomaly. This abrupt change in base level from one side to the other of the midcontinent gravity high does not seem to be compatible with a thin (30-50 km) crust floating in isostatic equilibrium, and may provide a strong argument in support of Jordan's (1975) contention that lateral heterogeneity exists to depths of hundreds of km beneath the continents.

Another broad anomaly is the high which coincides with the Mississippi Embayment. This embayment has been a site of rifting and long-term subsidence and sediment deposition, and also a focus of major historic intraplate seismicity (McKeown and Pakiser, 1982).

4. Bouguer gravity map (free-air offshore)

This map was colored from the grid described by Godson and Scheibe (1982a), which was used in the preparation of the gravity map published by the Society of Exploration Geophysicists (1982). The values are complete Bouguer gravity onshore and free-air gravity offshore. We include it here for comparison with the isostatic regional and residual gravity maps. This map was gridded at 16 x 16 km for color plotting.

5. Free-air gravity map

The free-air grid was also prepared by Godson and Scheibe (1982b) from the same data set used for the Bouguer gravity map. This grid is still in a preliminary form and requires additional editing. We include this map for comparison with the alternate coloring of the isostatic residual gravity map (map 8), because the free-air map can be thought of as an isostatic residual gravity map with the depth of compensation at sea level. The presence of the same long-wavelength highs and lows on the free-air map as on the isostatic residual map confirms that they are not artifacts of the isostatic correction process used here. The color scale for the free-air map is identical to that used for the isostatic residual map (map 8). This map was gridded at 16 x 16 km for color plotting.

6. Map of first vertical derivative of the isostatic residual

Taking a first vertical derivative tends to enhance shorter wavelengths and suppress longer wavelengths. Thus, it can be thought of as a wavelength filtering process which will enhance sharp anomalies caused by near-surface sources at the expense of anomalies caused by deeper broader sources. The map has also been upward continued 10 km to suppress some of the high frequency noise produced by a few erroneous gravity values, because this short-wavelength noise is also greatly enhanced by taking the first vertical derivative. This map was gridded at 6 x 6 km for color plotting.

Mathematically, taking the first vertical derivative is equivalent to a pseudo-magnetic transform: the resulting map is the magnetic map which would be obtained if dense material were replaced by magnetic material in exact proportion, and if the magnetic vectors and the local field vector were oriented normal to the earth's surface. Because of this property, this map can be usefully compared with aeromagnetic maps. Several important rock groups can be distinguished by the coincidence of aeromagnetic and gravity anomalies.

7. Isostatic regional gravity map

This is an alternate coloring of map 2. See Appendix A. This map was gridded at 16 x 16 km.

8. Isostatic residual gravity map

This is an alternate coloring of map 3. See Appendix A. This map was gridded at 16 x 16 km.

VII. References cited

Chapman, M. E., and Bodine, J. H., 1979, Considerations of the indirect effect in marine gravity modeling: Journal of Geophysical Research, v. 84, p. 3889-3896.

Chase, C. G., and Gilmer, T. H., 1973, Precambrian plate tectonics: the mid-continent gravity high: Earth and Planetary Science Letters, v. 21, p. 70-78.

Daly, R.A., 1940, Strength and structure of the earth: New York, Prentice-Hall, 434 p.

Dutton, C. E., 1925, On some of the greater problems of physical geology: Journal of the Washington Academy of Sciences, v. 15, p. 359-369.

Godson, R.H., and Scheibe, D.M., 1982a, Description of magnetic tape containing conterminous U.S. gravity data in a gridded format: U.S. Dept. of Commerce, National Technical Information Service, PB82-254798 (magnetic tape with description), 5 p.

__________, 1982b, Description of magnetic tape containing conterminous U.S. free-air gravity anomaly data in gridded format: U.S. Dept. of Commerce National Technical Information Service, PB82-253378 (magnetic tape with description), 5 p.

Heiskanen, W.A., and Moritz, Helmut, 1967, Physical Geodesy: San Francisco, W.H. Freeman, 364 p.

Jachens, R.C., and Griscom, Andrew, 1982, An isostatic residual map of California: a residual map for interpretation of anomalies from intra-crustal sources: Society of Exploration Geophysicists, Technical Program Abstracts and Biographies, Fifty-Second Annual International Meeting and Exposition, Dallas, Texas, October 17-21, 1982, p. 299-301.

Jachens, R.C., and Roberts, C.W., 1981, Documentation of a FORTRAN program, 'isocomp', for computing isostatic residual gravity: U.S. Geological Survey Open-File Report 81-574, 26 p.

Jordan, T. M., 1975, The continental tectosphere: Reviews of Geophysics and Space Physics, v. 13, n. 3, p. 1-12.

Karki, Penti, Kivioja, Lassi, and Heiskanen, W.A., 1961, Topographic - isostatic reduction maps for the world for the Hayford zones 18-1, Airy-Heiskanen system, T=30 km: Publications of the Isostatic Institute of the International Association of Geodesy, Helsinki, no. 35, 23 p.

King, E. R., and Zietz, Isidore, 1971, Aeromagnetic study of the midcontinent gravity high of the central United States: Geological Society of America Bulletin, v. 82, p. 2187-2208.

Lerch, F.J., Klosko, S.M., Laubscher, R.E., Wagner, C.A., 1979, Gravity model improvement using Geos 3 (GEM 9 and 10): Journal of Geophysical Research, v. 84, p. 3897-3920.

McKeown, F. A., and Pakiser, L. C., (eds.), 1982, Investigations of the New Madrid, Missouri earthquake region: U.S. Geological Survey Professional Paper P-1236, 201 p.

Ocola, L. C., and Meyer, R. P., 1973, Central North American rift system: 1. structure of the axial zone from seismic and gravimetric data: Journal of Geophysical Research, v. 78, p. 5173-5194.

Parker, R.L., 1972, The rapid calculation of potential anomalies: Geophysical Journal of the Royal Astronomical Society, v. 31, p. 447-455.

Saltus, R.W., 1983, A description of colored gravity and terrain maps of the southwestern cordillera: U.S. Geological Survey Open-File Report, (in preparation).
Society of Exploration Geophysicists, 1982, Gravity Anomaly Map of the United States (exclusive of Alaska and Hawaii), Society of Exploration Geophysicists, scale 1:2,500,000.
Simpson, R.W., Hildenbrand, T.H., Godson, R.H., and Kane, M.F., 1982, A description of colored gravity and terrain maps for the conterminous United States, shown on 35-mm slides: U.S. Geological Survey Open-File Report 82-477, 7 p.
Simpson, R.W., Jachens, R.C., and Blakely, R.J., 1983, AIRYROOT: A Fortran program for calculating the gravitational attraction of an Airy isostatic root out to 166.7 km: U.S. Geological Survey Open-File Report 83-883, 66 p.
Woollard, G.P., 1966, Regional isostatic relations in the United States, in Steinhart, J.S., and Smith, T.J., eds., The earth beneath the continents: American Geophysical Union, Geophys. Monograph 10, p. 557-594.

FIGURE CAPTIONS

Figure 1. A zero mGal isostatic residual anomaly occurs over a mountain range which is perfectly compensated in the local Airy model. The Bouguer correction removes the attraction of the mountain range above sea level, and the isostatic correction removes the attraction of the root, the existence of which is inferred from the topography.

Figure 2. A large, non-zero isostatic residual anomaly occurs over the center of a dense shallow rectangular mass even though it is perfectly compensated by a local Airy root. In this case, there is no Bouguer correction because there is no topography above sea level, and there is no isostatic correction for a root, even though one may exist, because the Airy model only considers the roots compensating topographic loads. The amount of excess mass in the dense, shallow body is compensated for by an equal deficiency of mass in the root. However, the greater depth of the root greatly smooths the gravity low which accompanies its mass deficiency. Thus when the gravity low from the root is subtracted from the high produced by the dense body, the high remains quite evident in the residual, even though both the low and high anomaly graphs which are subtracted must have equal but opposite volumes under the curves.

Isostatic correction removes effects of roots to topographic features:

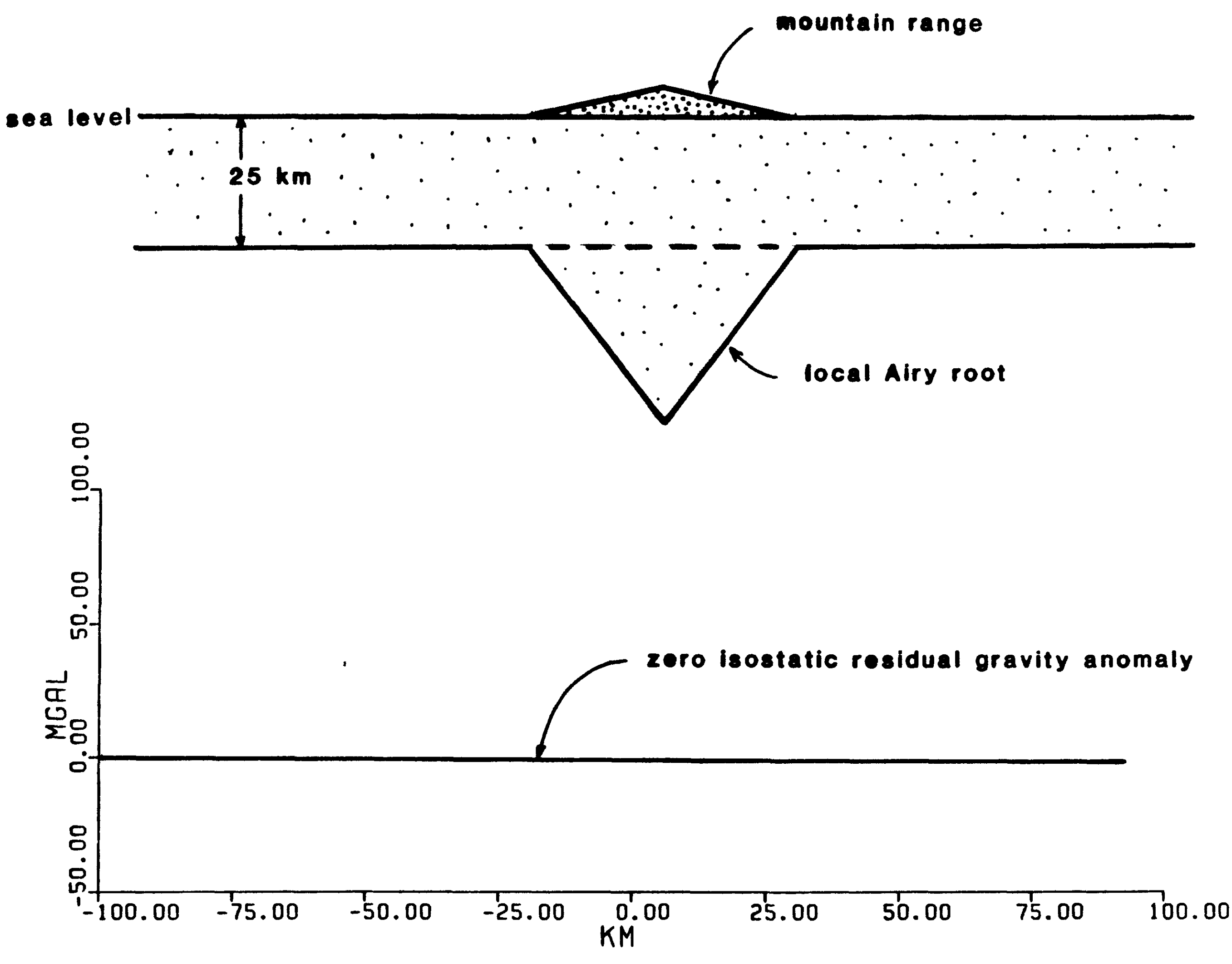

Figure 1.

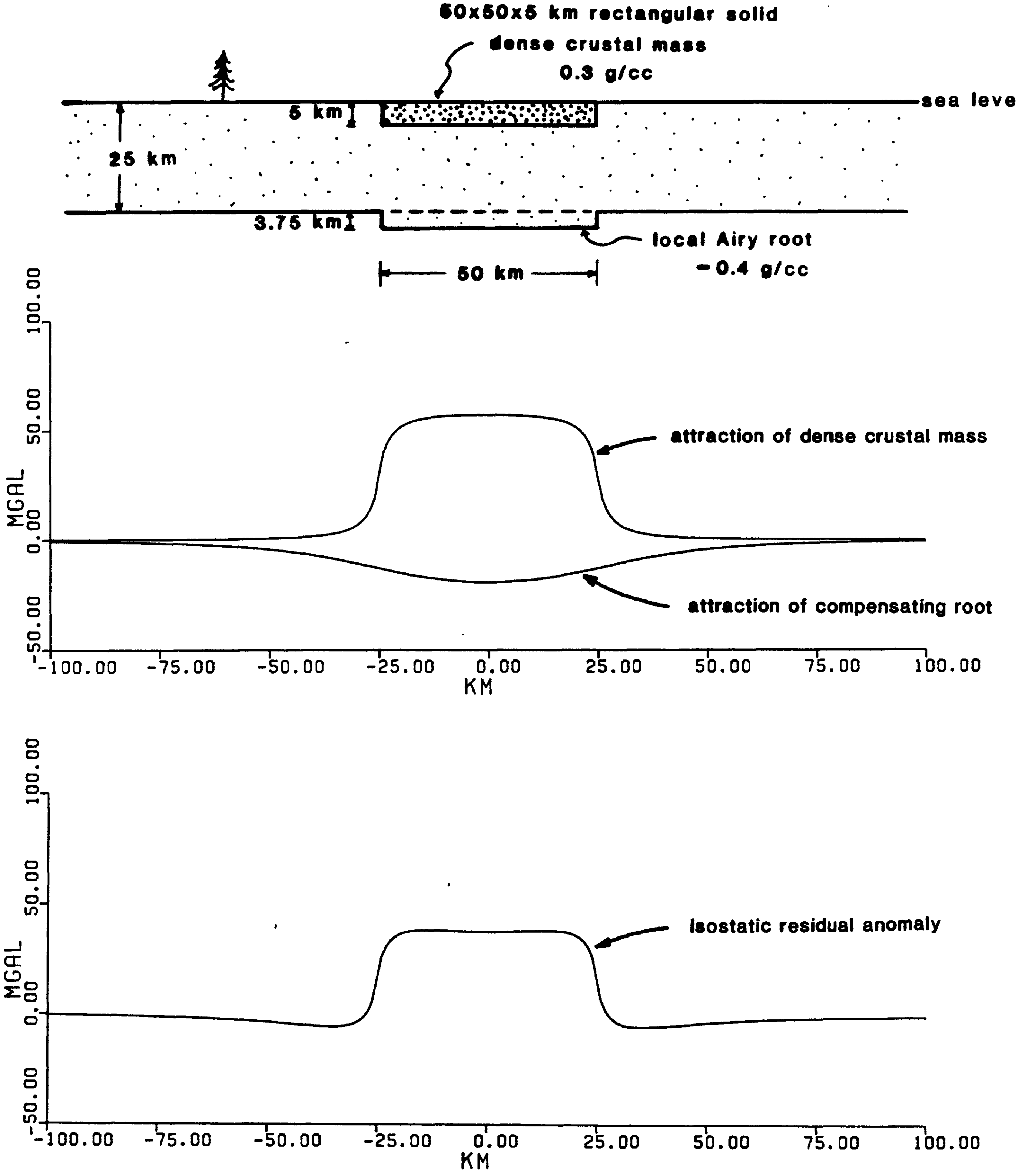

Figure 2. Isostatic residual contains effects of crustal masses and their roots.

APPENDIX A

Color Scales of the 35mm Slides

1. Topographic map. Contours are in meters with a non-linear scale as follows: -5000, -4000, -3000, -2000, -1500, -1000, -750, -500, -400, -300, -200, -100, 0, 100, 200, 300, 400, 500, 600, 700, 800, 900, 1000, 1250, 1500, 1750, 2000, 2500, 3000, 3500. Zero falls at the blue-green break.

2. Isostatic regional gravity map. Contours are in mGal with a linear scale from -280 to +80 in steps of 20 mGal. The white area in Colorado contains values off the color scale (less than -280 mGal).

3. Isostatic residual gravity map. Contours are in mGal with a linear scale from -75 to +65 in steps of 10 mGal. Yellow runs from -5 to +5 mGal.

4. Bouguer gravity map. Contours are in mGal with a linear scale from -260 to +40 in steps of 10 mGal.

5. Free-air gravity map. Contours are in mGal with a linear scale from -80 to +70 in steps of 10 mGal. Yellow falls in the interval from -10 to 0 mGal.

6. Pseudo-magnetic map. The first vertical derivative of the isostatic residual map. First break between blues is at -500 units. Rest of scale runs from -195 to +195 in steps of 30, so that yellow spans the interval from -15 to +15. Units are in mGal/km multiplied by a scale factor of 149.9. This gives a scale in pseudo-gammas where material of density contrast 0.1 g/cm^3 is replaced by magnetic material of magnetization 0.001 emu/cm^3.

7. Isostatic regional gravity map (alternate colors). This map shows the same data as does map 2. The color intervals were chosen to enhance the details which do not show up well in map 2. The scale is non-linear. Zero falls at the blue-green break.

8. Isostatic residual gravity map (alternate colors). Contours are in mGal from -80 to +60 in steps of 10 mGal. Yellow runs from -10 to 0 mGal.