Three Dimensional Representations of Aeromagnetic and Isostatic Residual Gravity Surfaces with Geology in Montana

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Introduction

The U.S. Geological Survey has recently released 500 meter grids of aeromagnetic and isostatic residual gravity data covering the state of Montana (McCafferty et al., 1998). These potential field data sets can be useful for interpreting lateral changes in density or the abundance of magnetic minerals in surficial or subsurface geology.

Correlation of aeromagnetic and isostatic residual gravity patterns to maps of surficial geology is often the first step to making interpretations such as those noted above. This requires the overlay of potential field data with the mapped geology. Although Geographic Information System (GIS) technology makes this overlay simple, the resulting displays are often difficult to visualize, especially for users unfamiliar with potential field data.

This paper outlines a method for using GIS to create three-dimensional (3D) displays of potential field and geologic data. First, a 3D surface is built from the aeromagnetic or gravity data. Then, a layer representing geology can be draped over these surfaces, with geologic formations represented with colors.

Aeromagnetic Data

The U.S. Geological Survey Open-file report 98-333 (McCafferty et. al., 1998) merged existing aeromagnetic data covering the state of Montana into one grid consisting of 500 x 500 meter grid cells. This grid was constructed using information from 65 separate aeromagnetic surveys conducted over a 40-year interval (Figure 1). The 65 surveys varied in many of their specifications, including terrain clearance, sampling rates, line spacing, and reduction procedures. For example, spacing of flight lines varies from 0.167 miles to 6 miles. Specifications for all 65 original surveys are summarized in Table 1.

The U.S. Geological Survey processed this aeromagnetic data in the following manner:

1.Grids were constructed from the original aeromagnetic survey data with a cell size of between 1/3 and 1/5 of the flightline spacing of the survey, using a minimum curvature gridding algorithm when necessary due to wide flightline spacing. For digitized contour line data, the initial grid was constructed using a minimum curvature algorithm and spacing appropriate for the scale of the digitized map.

2.Data quality problems were addressed.

3.The Definitive Geomagnetic Reference Field (DGRF) was applied for the date of the original survey (in some cases this required the determination and removal of the original reference field applied).

4.The survey grids were regridded, as necessary, to the final grid cell size of 500 m using a minimum curvature algorithm.

5.The datum levels of adjacent surveys were adjusted (by addition or subtraction of a constant value) to minimize differences at the boundaries.

6.The original survey grids were upward or downward continued and converted from level to drape as necessary to produce a consistent survey specification of 1000 ft above ground. Upward continuation of the NURE surveys was by standard 2D FFT filtering techniques. Downward continuation and level-to-drape was performed (Cordell and others, 1992).

7.The datum levels of the converted grids were then adjusted to minimize differences at the boundaries.

8.These adjusted grids were combined into a single merged grid.

(McCafferty et al., 1998)

The resulting grid for Montana has a spatial resolution of 500 meters, with each grid cell assigned a measure of the local magnetic field in nanoteslas (Figure 2). These values define a continuous potential field surface, much as the elevation Digital Elevation Model (DEM) grid cells define a topographic surface. Variations in the aeromagnetic potential field are due to lateral variations in content of magnetic minerals in surfical or subsurface geology, especially variations in the mineral magnetite (Telford et. al., 1976).

Isostatic residual gravity data

McCafferty et al. (1998) also created gravity grids from more than 40,000 stations within or adjacent to Montana (Figure 3). This data was extracted from a gravity database maintained by the National Geophysical Data Center (from Department of Defense unclassified data) and augmented with data from the USGS and several university theses and dissertations. A Bouguer gravity grid was created using observed gravity relative to the IGSN-71 datum, reduced to the Bouguer anomaly using the 1967 gravity formula and a reduction density of 2.67 g/cc. Terrain corrections were calculated radially outward from each station to a distance of 167 km using a method developed by Plouff (1977). The data were converted to a grid using minimum curvature techniques.

The isostatic residual gravity grid applies further corrections to the Bouguer gravity anomaly grid to account for lateral variations at the crust/mantle interface resulting from topography (Simpson et al., 1986). The computation assumes an Airy model of isostacy, thus topographic highs have associated low density crustal roots to provide, allowing them to "float" on the mantle in a manner similar to an iceberg on water. The isostatic correction used the Bouguer gravity anomaly grid, a topographic grid, and three assumptions. It assumed a crustal thickness of 30 km., a density for the crust of 2.67 g/cc, and a density contrast between crust and mantle of 0.35 g/cc.

Given these assumptions, the resulting isostatic residual gravity grid should give the best image of lateral density variations associated with surficial or near-surface geology. The isostatic residual gravity grid cells are 500 meters, with each grid cell assigned a value of the local isostatic residual gravity field in milligals (mgal)(Figure 4). The combined grid cells define a continuous surface for the isostatic residual gravity field.

common methods of displaying potential fields with geology

Two methods are generally used to display potential field data and geology simultaneously. The first method assigns colors to the geology based on geologic formations, and overlays equipotential contours of the gravity or magnetic field. The second method assigns colors to equipotential intervals, and overlays geologic formation contacts as a layer of lines.

Figure 5 is an example of a geologic map with equipotential contours of magnetic data. This display is not easy to interpret. Equipotential lines define aeromagnetic highs and lows, but the two are often difficult to differentiate. To interpret this display, individual contours would have to be labeled, or all highs and lows would have to be annotated. Additionally, isolated spikes in the areomagnetic surface create closely spaced contours that conceal the underlying geology. Finally, even users experienced with interpreting topographic contours could have trouble interpreting aeromagnetic field highs and lows, as usual topographic rules of thumb (e.g. broad lows draining downstream) do not necessarily apply.

Figure 6 is an example of an isostatic residual gravity map with a geologic formation contact overlay. This display clearly indicates gravity highs and lows, but geologic formations are difficult to visualize. Only larger geologic polygons can be labeled at this scale. Also, it is difficult to see the continuity of formations that are comprised of a number of polygons.

Three dimensional potential field surfaces draped with geology

An alternative method for displaying geology and potential fields simultaneously is documented in an example from the Mari Lake region of east-central Saskatchewan, Canada (Harris et.al., 1999). In this example, a three dimensional surface is created from the aeromagnetic potential field. The z-value for this surface is the strength of the areromagnetic field in nanoteslas. The geology is displayed in color and draped over the 3D surface. The Mari Lake example uses high resolution magnetic data and detailed geologic mapping to create a large scale 3D map image.

This same method, however, can be applied to statewide geologic, gravity, and magnetic data. In our poster, we show 3D surfaces from isostatic residual gravity and aeromagnetic data overlain by geology is from the 1:500,000 Geologic Map of Montana (Ross et. al., 1955). The geologic data was digitized as a vector coverage, then converted to a grid. Grid values relate to the geologic formation information used to assign colors to the geology. Grid cells for this new grid match in size and location those of the isostatic residual gravity and aeromagnetic grids distributed by the USGS.

Once the geology has been converted to a grid, the geology can be displayed on a 3D potential field surface with ArcView and the 3D Analyst extension. To create such displays, open a 3D scene, add the geology grid theme, and use the legend editor to assign colors based on geologic formation information. Then, select “3D properties” under the “Theme” dropdown menu. In the “Assign base height by:” portion of the menu, select the radio button for “Surface”, then select a potential field grid. To enhance the 3D effect, select “Properties” under the “3D Scene” dropdown menu. Then, adjust the “Vertical exaggeration factor:” until the appropriate 3D effect is achieved. These numbers are not true vertical exaggerations as horizontal units are in distance and vertical units are in nanoteslas for aeromagnetic data and milligals for gravity data. In our examples below, the vertical exaggeration factors are 30x’s for the aeromagnetic data and 750x’s for the isostatic residual gravity data.

Figure 7 shows geology displayed on an aeromagnetic surface. The most obvious correlation is between isolated, volcanic intrusives and sharp spikes in the magnetic field. Examples can be seen in the southwest of the map, as well as in a single spike in the northwest. Other less magnetic intrusive volcanics, such as the Idaho batholith on the west-central Idaho border, have no associated highs.

Figure 8 shows geology displayed on an isostatic residual gravity surface. This map shows lateral changes in density of rock formations. The narrow NNW trending Cedar Creek anticline is defined by a gravity high and adjacent lows on the western edge of Montana. A broader feature, the Sweet Grass arch, is defined by an isostatic residual gravity high in northwestern Montana. The Powder River basin in southeastern Montana is defined by a gravity low correlating to Tertiary sediments surrounded by Cretaceous rocks. As with its magnetic intensity, the Idaho batholith on the western edge of Montana has no large density variations with surrounding formations.

Conclusions

The resulting images clearly display both geologic and potential field data. This facilitates the visual correlation of aeromagnetic and isostatic residual gravity anomalies with geologic features. In this manner, such displays can be used for effective communication or exploration of geophysical potential field data.

Aeromagnetic and isostatic residual gravity data for other states is also available from the U.S. Geological Survey. These data can be accessed from <http://crustal.usgs.gov/crustal/geophysics/index.html>.

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