GEOLOGICAL SURVEY OF CANADA COMMISSION GÉOLOGIQUE DU CANADA

Saskatchewan Energy and Mines
Saskatchewan Geological Survey

GSC Open File 3883 - SEM Open File 2000-1

RATIONALIZED DETAILED GRAVITY DATA SOUTHERN SASKATCHEWAN

INTRODUCTION

More than 150 detailed gravity surveys acquired by the exploration industry and archived as Bouguer anomaly maps at Saskatchewan Energy and Mines (SEM) cover much of southern Saskatchewan. Most of the available maps had been digitized by SEM, however, individual gravity surveys were tied to arbitrary datums and the Bouguer anomaly corrections were calculated with many different crustal rock densities. In order to generate a gridded data set suitable for regional scale interpretation it was necessary to level the data to a single datum and regenerate Bouguer anomalies with standard densities. The levelled data are presented as a flat file of principal facts with a FORTRAN program to extract data and recalculate anomalies based on user-specified Bouguer densities and geoid models.

Variations in the force of gravity are due to variations in the mass of underlying materials. Gravity surveys acquire data that map these small variations. These data are useful for geological interpretation and have applications in oil, gas, and mineral exploration. The gravity field is also used to define the geoid, which is the ideal shape of the Earth, or mean sea level if the Earth were completely covered with water.

SASKATCHEWAN'S DIGITIZED GRAVITY ARCHIVE

The (SEM) Geodata Branch Archive contains gravity data acquired by the exploration industry, under permit from SEM. The archive consists largely of 1:63 360 or 1:50 000 scale plots of contoured and posted Bouguer gravity anomalies as well as plots of the corresponding elevations. These maps represent approximately 174,000 gravity stations. In addition, 47,745 gravity stations, also in map form, were donated to SEM by Mobil Oil Corporation. The gravity data were tied to arbitrary datums and the Bouguer anomalies were calculated with differing crustal rock densities. The data on these maps were digitized by SEM and the National Imaging and Mapping Agency (NIMA, USA) between 1992 and 1995. Figure 1 presents the digitized Bouguer anomalies before levelling, illustrating the necessity of levelling these data.

In order to produce a consistent, meaningful data set from the Bouguer anomaly maps, it was necessary to calculate the observed gravity for each station and level it to the observed gravity of the National Gravity Anomaly Data Base (NGDB). The NGDB data are tied to the International Gravity Standardization Network 1971 (IGSN71). The NGDB is maintained by the Geodetic Survey Division, Geomatics Canada. The NGDB stations are marked as black dots on Figure 2. Once the observed gravity values were levelled to a common datum the Bouguer anomalies were recalculated using a single crustal rock density.

GRAVITY

Gravity is the attraction one mass has for another. According to Newton's Law, the force of gravity increases with increasing mass. The force of the attraction between two masses also increases as the distance between their centres of mass decreases. If one geological body is denser than another, it will have a greater mass and a greater gravitational attraction. Measurements of gravity yield little direct geological information other than to represent the Earth's oblate spheroidal shape, unless corrections are made to account for variations in the Earth's shape and topography. As the Earth's diameter is approximately 20 km smaller from pole to pole than through the equator, the force of gravity increases as the poles are approached. In addition, the Earth's rotation results in a slightly smaller gravitational attraction at the equator than near the poles. In order to isolate the effect of lateral variations in density within the Earth, the bulk gravity effects of the Earth due to latitude must be removed. The theoretical gravity (g_t) is given in milligals ($10^{-5} m \cdot s^{-2}$) by the International Gravity Formula:

$$g_t = 978031.85(1.0 + 0.5278895 \sin^2(\theta) + 0.000023462 \sin^4(\theta)) \qquad (1)$$

based on the 1967 Geodetic Reference System, where θ is the latitude in degrees of any point on the Earth. The effect of latitude is removed by subtracting the theoretical value of gravity from the observed values. To correct for the effect of topography, the vertical gradient of gravity (vertical rate of change of the force of gravity, 0.3086 $mGal \cdot m^{-1}$) is multiplied by the elevation of the station and the result is subtracted from the latitude corrected value producing the free air anomaly. The gravitational attraction of the slab of material between the observation point and mean sea level must be accounted for to reduce gravity to the effect of lateral density variations. This is the Bouguer gravity anomaly (BA), which is given for static land measurements by the formula:

$$BA = g_o - g_t + (\delta g/\delta z - 2\pi G \rho_c)h \qquad (2)$$

where g_o = observed gravity (mGal), g_t = theoretical gravity (mGal), $\delta g/\delta z$ = vertical gradient of gravity (0.3086 $mGal \cdot m^{-1}$), G = gravitational constant ($6.672 \times 10^{-11}\ m^3 \cdot kg^{-1} s^{-2}$ or $6.672 \times 10^{-6}\ m^2 \cdot kg^{-1} \cdot mGal$), ρ_c = density of crustal rock ($kg \cdot m^{-3}$), and h = elevation above mean sea level (m).

In areas of high relief, a correction for the effect of nearby masses above (mountains) or mass deficiencies below (valleys) the gravity measurement point can be calculated and applied. There is no indication that terrain corrections were calculated for any of the digitized data. The final Bouguer gravity anomaly reflects lateral variations in rock density.

METHODOLOGY

As most of the gravity surveys in this study were performed before 1967, the theoretical gravity was assumed to be calculated from the Potsdam 1930 reference ellipsoid. This value is given by:

$$g_{t1930} = 978049.0(1.0 + 0.0052884 \sin^2(\theta) - 0.0000059 * \sin^2(2\theta)) \qquad (3)$$

The rock densities used to calculate the Bouguer anomalies posted on the archived maps were rarely documented. Commonly the density was included in an elevation correction factor (ecf) equivalent to the term:

$$ecf = (\delta g/\delta z - 2\pi G \rho_c) \qquad (4)$$

generally given in milligals per foot, although some were in gravity units (one tenth of a milligal) per foot.

The Geological Survey of Canada became involved in the project in November 1997 with the aim of rationalizing the digital archives in order to produce a continuous, seamless gridded data set for the purposes of regional interpretation. After inspection of the data, it was decided to level to the national datum by the following steps:

1. Convert digitized Bouguer values to observed gravity values (g_o) Substituting (4) in (2) and rearranging;

$$g_o = BA - (h * ecf) + g_{t1930} \qquad (5)$$

Note that it was assumed that the Potsdam 1930 ellipsoid was used in the original calculation of the theoretical gravity value for data of this vintage.

2. Find the difference in observed gravity between stations of an unlevelled survey and approximately coincident (+/– 400 m) previously levelled data (including NGDB data).

3. Interpolate the differences to a 1 km correction grid.

4. Add values interpolated from the correction grid to the digitized observed gravity data.

5. Recalculate Bouguer anomalies using the digitized elevations and a standard crustal rock density.

As one survey was levelled, the observed gravity values from that survey were added to the levelled database and used to level subsequent surveys.

Some of the digitized survey elevations appear to contain systematic errors when compared to geodetic benchmarks and digitized elevations that agree with the benchmarks. A levelling of the elevations of these surveys was performed in a manner similar to the levelling of the observed gravity values. Figure 3 represents the digital terrain model generated from gravity station elevations.

DIGITIZING

The Bouguer gravity anomaly maps and corresponding elevation maps were digitized by SEM and NIMA between 1992 and 1995. The elevation correction factors (ecf) were either marked on each map or noted in accompanying documents. The gravity data, elevation data and elevation correction factors were digitally archived. The data were organized into three sets; Pre-1994, 1994, and 1995 data. The names of the data sets refer to the years in which they were digitized.

The locations of the digitized points when compared with 1:50 000 topographic maps indicates the horizontal positioning is accurate to within 200 m, but usually much better. For the purposes of creating regional gridded data sets and maps, this accuracy is reasonable. However, finer scales of display may benefit from correction of the positioning of the data. Most elevations of the digitized points matched the elevation of topographic benchmarks. The elevations were largely established with transit surveys based on these benchmarks. Reasonable digital terrain models can be generated from these data. However, some elevations have been corrected to minimize systematic errors.

PROCESSING

The three sets of digitized gravity data were processed separately. The 1994 data set was processed first as it covered a large area and was largely internally consistent, allowing it to be used as a levelling base for many of the smaller surveys of the other data sets.

1994 Data: Z13_14 & 49-50

The 1994 data set was digitized at SEM from maps supplied by Mobil Oil Corporation. The locations of these gravity stations are marked in blue on Figure 2. These data were the most carefully checked for digitizing accuracy by SEM. The data were supplied in digital form in two sets, Z13_14 and 49-50. The former consists of 47,745 stations and the latter 1,447 stations. The data in set Z13_14 had two separate datums; one group of 1,358 stations with digitized Bouguer values less than 1450 mGal and a second group of 46,387 stations with values greater than 1450 mGal. The two were levelled separately. All elevations were compared with available geodetic control and, where the two were roughly coincident, found to be in agreement. There were 879 stations with no elevation and these were deleted. During processing, new, unique station numbers were generated to avoid confusion at the editing stage.

The Z13_14 digitized data's observed gravity values were subtracted from NGDB observed gravity values located within 500 m. The differences were written to a file of latitude, longitude, and difference which was then gridded to a 1000 m interval to generate a correction surface. Corrections for each digitized observed gravity value were interpolated from the correction surface. The two subsets of data were levelled to the same datum and were merged. The merged data set was found to contain duplicates which were then deleted. No elevation corrections were required. These data were given the project number 19942.

The 49-50 digitized data were processed similar to the Z13_14 data. Of the 1,447 stations, 19 had erroneous elevation correction factors and were deleted. Again, no elevation corrections were required. These data were given the project number 19941.

1995 Data: GRAVITY and INFILL

The 1995 data set consists of two parts; the GRAVITY data set and the INFILL data set. The GRAVITY data set includes 16 surveys digitized by SEM from submissions to the Geodata archives by the petroleum exploration industry. There are a total of 27,422 stations in this data set and their locations are marked in green on Figure 2. One survey, 214, was digitized with incorrect registration. This was corrected by generating a transformation grid in x and y directions from digitized and actual road intersections. The INFILL data set was part of the data provided by Mobil Oil Corporation. and consisted of 5,566 points, 3,512 of which had no elevation and were deleted. SEM records show that the digitizing has been verified. Elevation control factors were not provided with the data, but were determined by SEM from archived reports and maps.

The 1995 data were levelled using the NGDB data and the levelled 1994 observed gravity data. Methodology was the same as for the 1994 data.

Pre-1994 Data

The pre-1994 data set was digitized by NIMA from Bouguer gravity maps held by SEM's Geodata Branch. These maps represent 118 gravity surveys consisting of 139,680 observations marked in red on Figure 2. Digitizing was registered by referencing road intersections to geodetic control supplied by SaskGeomatics. NIMA converted the digitized locations from North American Datum 1927 (NAD27) to North American Datum 1983 (NAD83). For this compilation, all NAD83 were converted back to NAD27 (all data presented in this open file are referred to NAD27). Elevation correction factors supplied by SEM and digitized elevations were used by NIMA to calculate observed gravity values for each station. These values were levelled to IGSN71 by adding the difference between the calculated gravity values and coincident NGDB observed gravity values. Unfortunately, the original digitized points and their Bouguer anomaly values were not retained. After several surveys were found to have been recorded as gravity units (1 g.u. = 10^{-1} mGal) but reduced as milligals, the archived gravity plots and reports were rechecked to determine the true elevation correction factors and units of measurements. As the original digitized Bouguer values for these surveys were not available, they were recalculated from the NIMA computed observed gravity values. The recalculated Bouguer values were then used to calculate the true observed gravity values using the correct elevation correction factors.

The pre-1994 data were levelled using the NGDB data, levelled 1994 data, and levelled 1995 data. Methodology was the same as for the 1994 and 1995 data. Differences between elevations of some pre-1994 surveys and NGDB, geodetic and other gravity survey elevations required that either the Bouguer anomalies of these surveys be disregarded or that the elevations be levelled. In order to include these data in the final compilation, it was decided to level the elevations. The levelling was achieved in the same manner as the observed gravity levelling. The pre-1994 digitized data's elevation values were subtracted from geodetic points, NGDB elevations and the elevations of previously levelled digitized gravity surveys located within 500 m. The differences were written to a file of latitude, longitude, and difference which was then gridded to a 1000 m interval to generate a correction surface. Corrections for each digitized observed gravity value were interpolated from the correction surface.

GRIDDING AND PRESENTATION

The data were collected largely along roads and tend to reinforce the NGDB data along the roads but not in the great expanses between the roads. This means that, although the data may be spaced in places at 100 m along the road, the optimum gridding interval will be at least 1/4 to 1/6 the road spacing. Based on road spacings of as little as 3 km, the optimum interval for gridding the data (with a minimum curvature algorithm) is about 800 m. Other gridding algorithms may prove more effective in representing the closely spaced data.

The data were largely collected along north-south- or east-west-trending roads. As a result, there tend to be linear levelling errors in these directions as well as artifacts introduced between parallel roads by the gridding algorithm. To minimize these effects the final Bouguer grid was decorrugated in both east-west and north-south directions. Decorrugation involves the application of a directional cosine filter to isolate and remove anomalies in a given direction. The decorrugation corrections were applied to gridded data sets only, not to the original point data.

The results of the levelling, gridding, and decorrugation can be seen in Figures 4 and 5. Figure 4 is the colour shaded relief of Bouguer gravity anomalies. The crustal rock reduction density used was 2.00 g/cm^3. The colour in this image illustrates the continuous long wavelength of the data and the shading represents the higher frequency content of the data. Figure 5 is the first vertical derivative of the Bouguer anomalies with an upward continuation of 800 m. In this image, the long wavelength has been effectively removed leaving the shorter wavelength portion of the data corresponding to nearer surface sources. Clearly the digitized surveys have been reasonably well levelled to each other while maintaining the high frequency.

ORDERING INFORMATION

The GSC Open File 3883/SEM Open File 2000-1 is available as this map and/or a CD-ROM. The CD-ROM contains a data file of pertinent and principal facts, a PC-based program to retrieve data and recalculate anomalies, a format descriptor for the data file and a DBF format database file as well as grids of Bouguer gravity anomalies, first vertical derivative, second vertical derivative, and elevation in GXF, GEOSOFT, ArcInfo ASCII grid, and .TIF/.TFW formats.

The map and CD-ROM are available from both the GSC and SEM. Contact either at:

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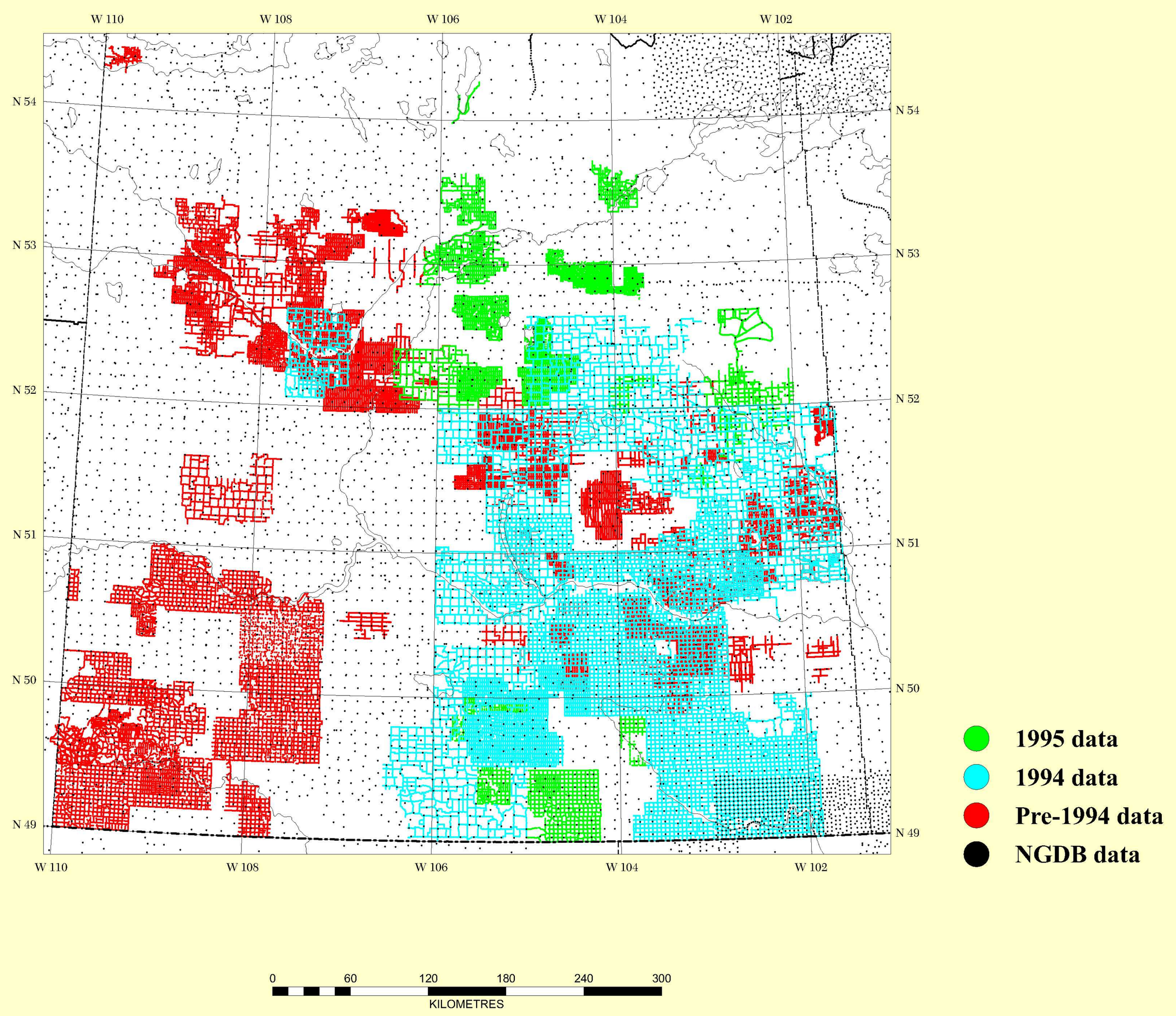


Figure 2. Gravity station locations.

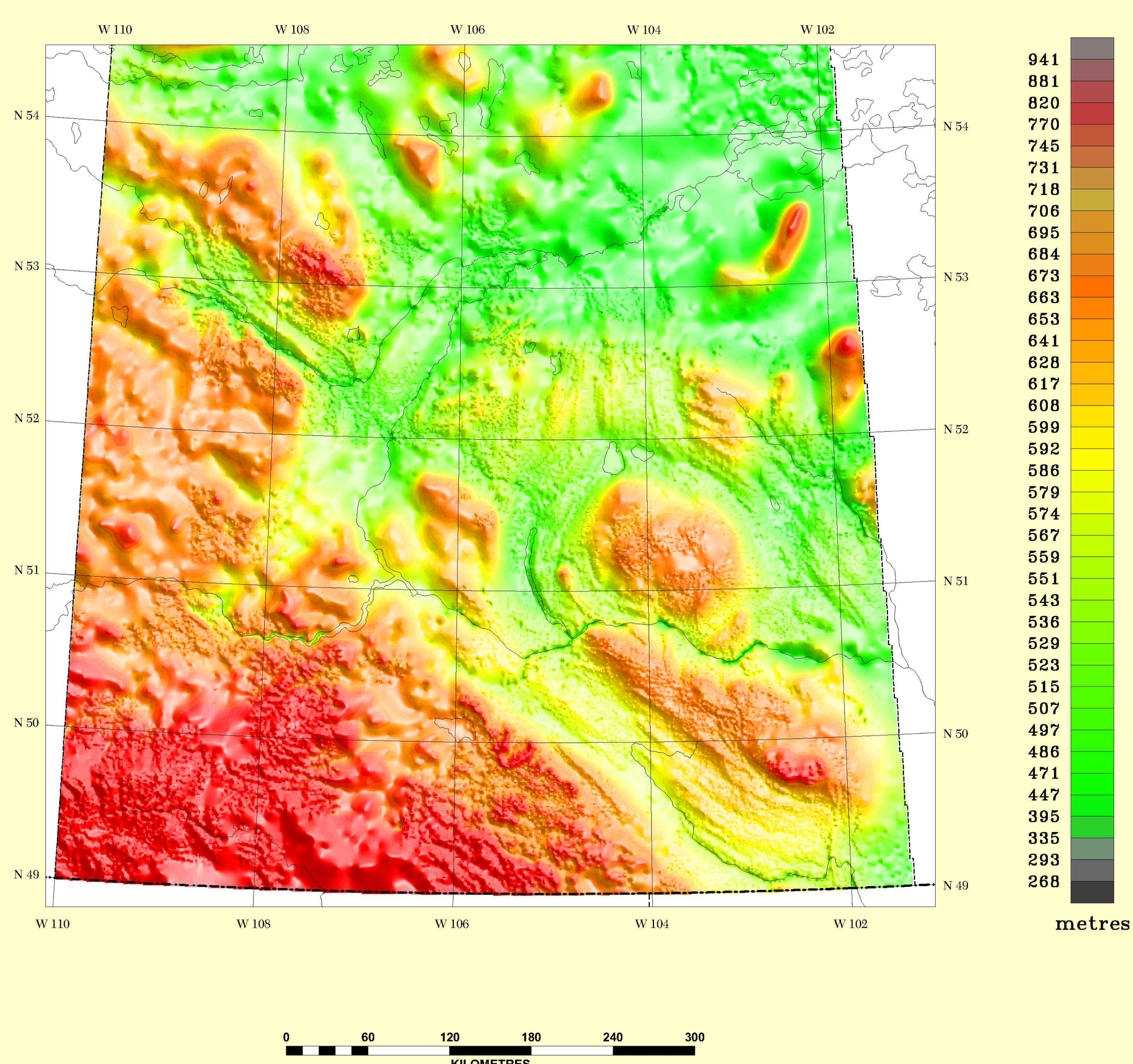


Figure 3. Digital terrain model derived from gravity station elevations.

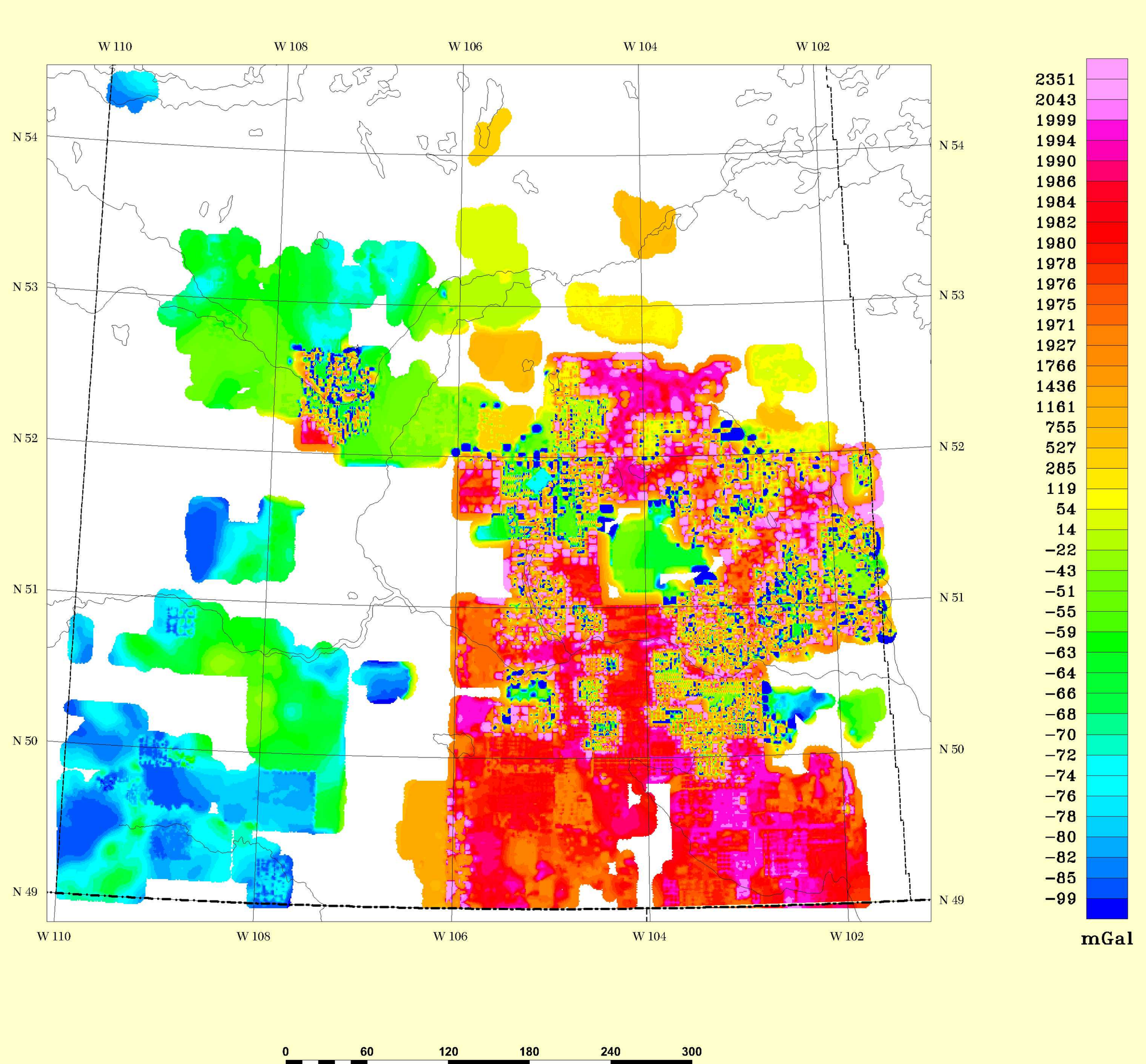


Figure 1. Bouguer gravity anomalies from unlevelled digitized data.

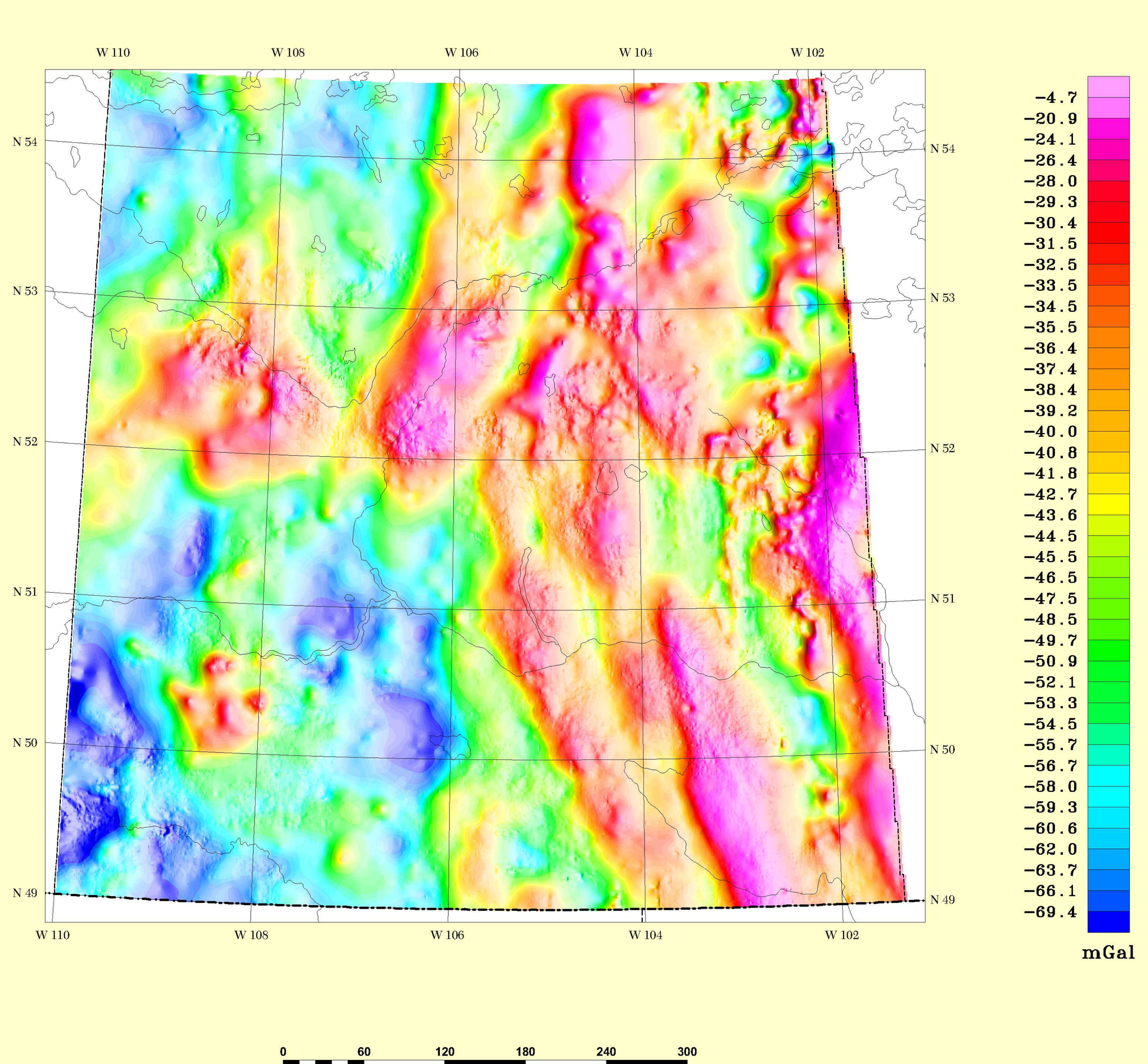


Figure 4. Levelled Bouguer gravity anomalies.

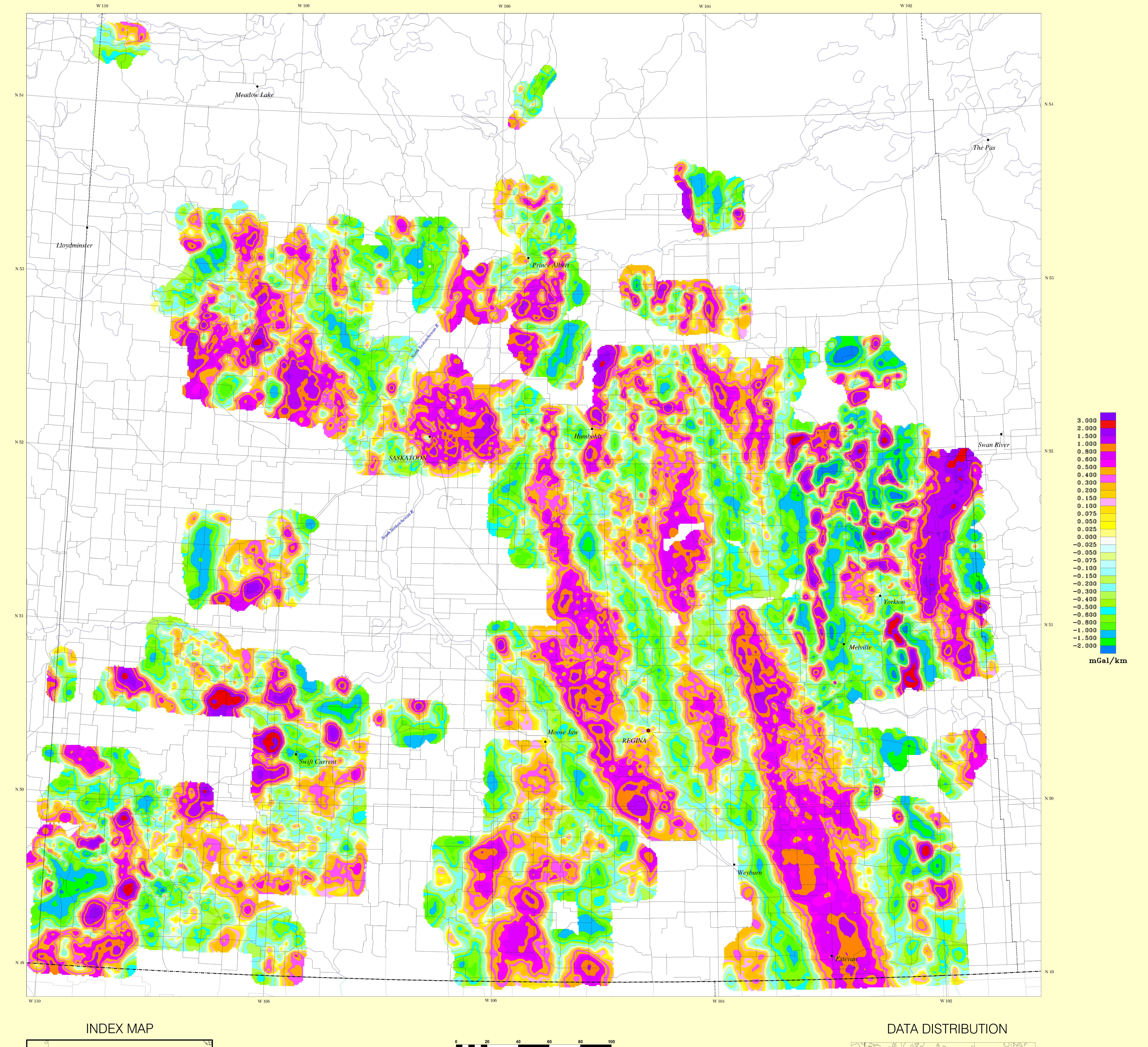
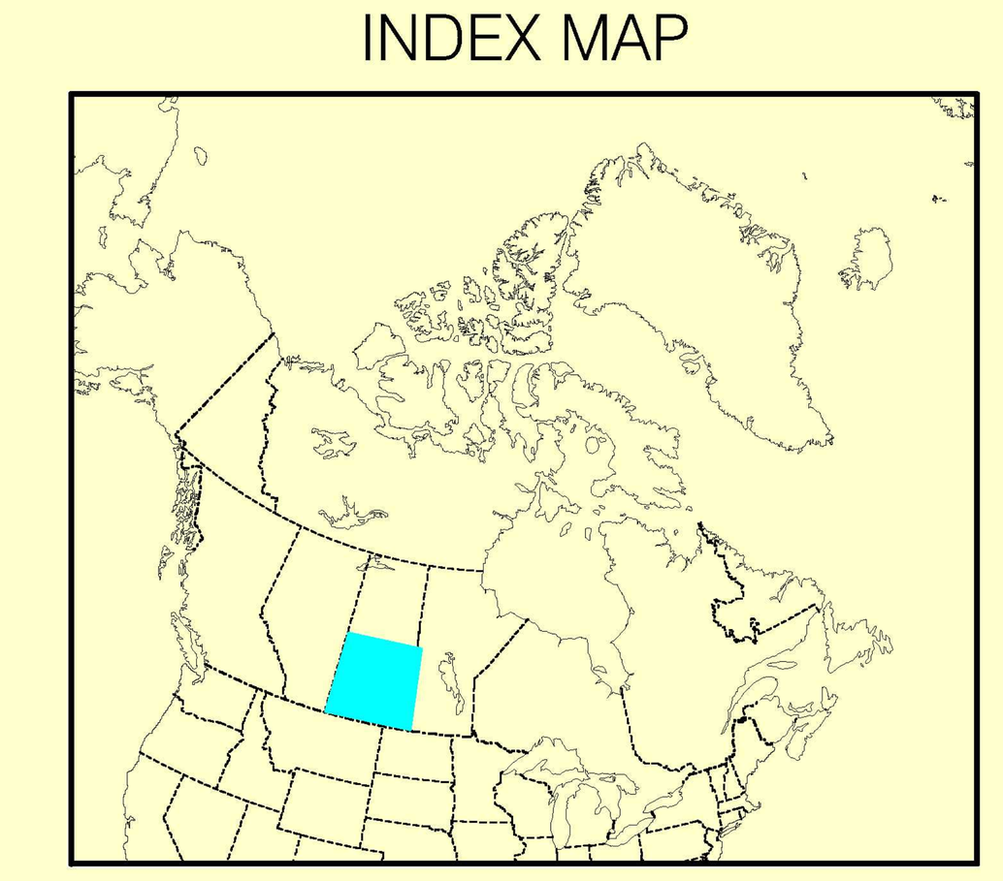


Figure 5. First vertical derivative of levelled Bouguer gravity anomalies.

INDEX MAP



DATA DISTRIBUTION