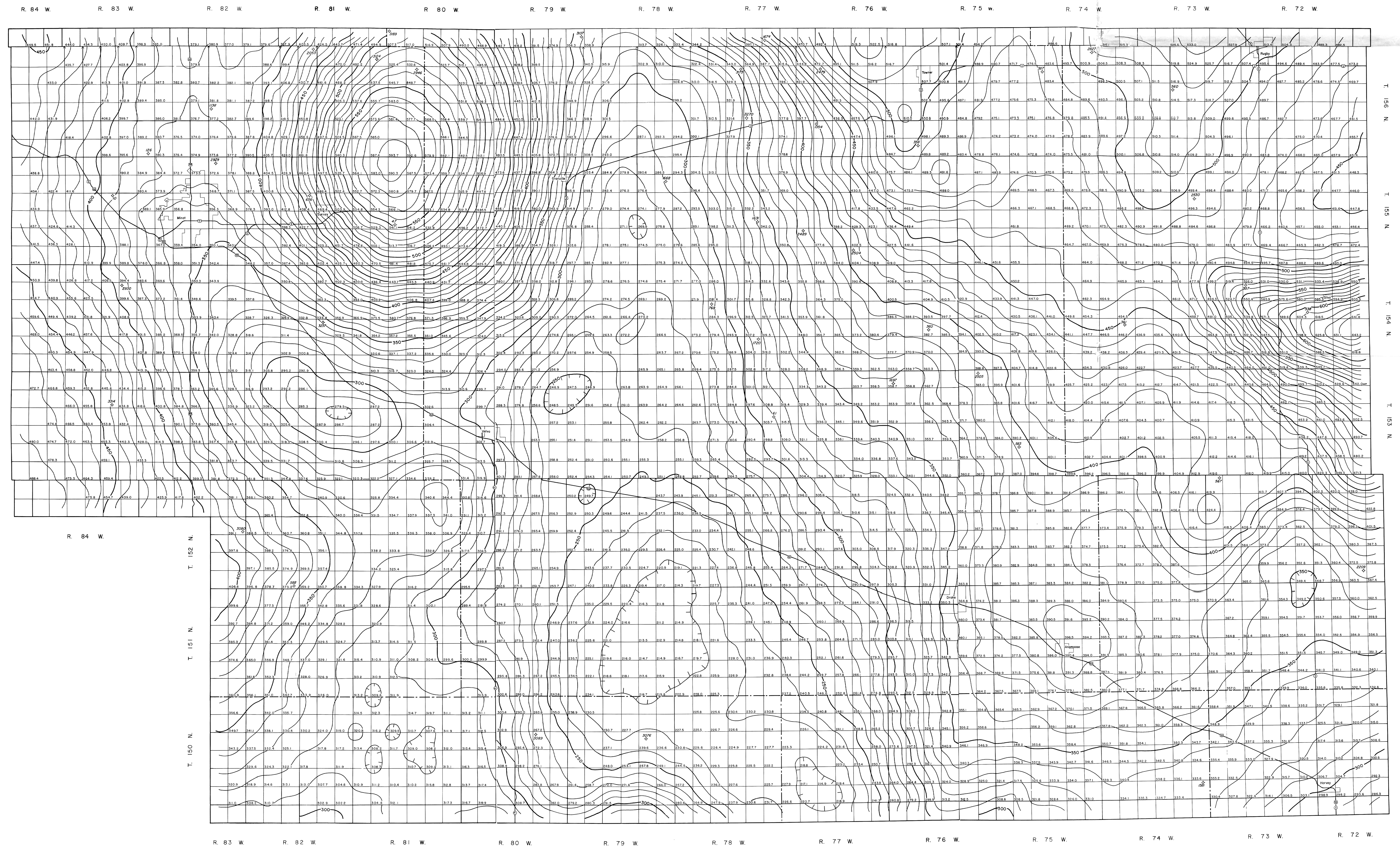
North Dakota Geological Survey

Wilson M. Laird, State Geologist

Report of Investigation 40



OBSERVED GRAVITY CENTRAL NORTH DAKOTA

CONTOUR INTERVAL 10 GRAVITY UNITS OR 1 MILLIGAL

N 1 0 1 2 3 MILES HIGHWAYS DRY EXPLORATORY WELL 3076

1

Gravity Maps

of CENTRAL NORTH DAKOTA

by

JOHN B. HUNT

Introduction

The use of gravity as an aid to mapping subsurface features is a part of the continuing efforts of the North Dakota Geological Survey to investigate the geology of the state. The gravity maps presented here are expected to be of considerable interest to those concerned with the geologic structures in the central portion of North Dakota.

The area covered by this report consists of approximately 3600 square miles in Central North Dakota. Data was actually obtained from two closely adjacent regions. The larger region is approximately defined as that area near and between the towns of Rugby, Harvey, Minot, and Garrison. The second area lies to the west of Garrison (See Location Map).

Gravity values for this report were obtained during the 1961 and 1962 field seasons. Elevations used in the computations were taken from United States Geological Survey topographic maps. Names and locations of these maps may be found by referring to "Index to Maps of North Dakota" published by the U. S. Geological Survey. Where road construction occurred subsequent to the publication of the topographic maps necessary adjustments in the elevations were made by correcting for the change from the old road surface or bench mark to the new surface.

Instrument Data

The instrument used throughout this investigation is a Carter Type "Y" gravity meter a null-type instrument. Its construction and operation were described previously both by Hansen (1960) and by Hunt (1962).

Field Procedure and Computations

A specially adapted vehicle was used to transport the gravity meter. Modifications to the vehicle permitted more rapid observations in addition to protection to the meter.

Lines of observations were generally established along east-west section lines with readings taken at each section corner in order to observe the more pronounced gravity changes. In the north-south direction observation lines were restricted to two mile intervals with frequent supplemental readings taken at one mile intervals. Spacing of this nature permitted rapid observation of a large area as well as maximum detail. It also facilitated the determination of and increased the accuracy of the average values calculated for those stations where actual observations were not made, since a complete gird is essential for the determination of the residual gravity.

Instrumental drift was determined at the close of each run. Normally it was quite low being on the order of tenths of a gravity unit. The drift was determined by returning to the base station for a second reading within a three hour period. Discrepancies between the first and second readings at the base station were then distributed linearly with time among all stations read between the two base station readings. Extreme variations of three to five gravity units between the two base station readings were rare and when such occurred they were attributable to excessive daily temperature increases. In such instances the stations were rerun under more favorable conditions.

Hansen (1960) established the first base station in Section 32, T. 163 N., R. 94 W. This station was arbitrarily assigned the value of 500 gravity units. All values determined for this report are directly dependent upon the initial station. Hansen ran an unpublished profile from the Columbus area along State Highway 5 to the Antler region. Part of his observations were incorporated into "Gravity Maps of North-Central North Dakota" (Hunt, 1962).

A station was utilized as a base station only after it had been tied-in from two previously used base stations with successive readings being closely related. Commonly the degree of variance was less than one gravity unit, and extremes were under two gravity units.

Computations were made according to the method described by Nettleton (1940). Bouguer and free-air adjustments were combined into a single correction. In the area of this report latitude corrections amount to 12.9 gravity units per mile. Terrain corrections were not necessary due to the low topographic relief of the area.

Residual Gravity

In that observed gravity values reflect the superposition of local gravity fields upon regional gravity fields a residual gravity map was produced to better define local anomalies. Though several methods have been advanced for the delineation of residual gravity none has received complete acceptance. Therefore, the residual gravity map in this report is a reflection of the writer's conception of a valid procedure. This is a continuation of the same procedure used for "Gravity Maps of North-Central North Dakota" (Hunt, 1962). It is one which is easily programmed for and computed by an IBM 1620 Digital Computer. The residual gravity values in this report were computed in such a manner.

Other methods may be preferred by the reader. Griffin (1949) demonstrated that residual gravity maps are dependent upon the size and shape of geometric form used in their calculation. However, there is no displacement of the center of the anomaly.

A complete network of observed values was not obtained for two reasons: 1) inaccessibility of the section corners, 2) desire to cover a maximum of territory in a minimum of time while maintaining adequate coverage to bring out salient features. Where observed values were absent, estimated values were assigned to these locations by adopting the average value of the surrounding stations.

Residual gravity values for each section corner were determined by the formula

$$\Delta g = g(o) - \overline{g}(r)$$

where Δg is the residual gravity value, g(o) is the observed or estimated gravity at a given point, and $\overline{g}(r)$ is the average observed gravity value at a radial distance r from point g(o).

The value $\overline{g}(r)$ was calculated from the points of an octagon lying on a circle with a radius of three miles (Fig. 1). The value $\Delta(g)$ was calculated for only those points having a complete complement of observed or estimated values on the octagon. Consequently fringe belts three miles in width bordering the eastern and western margins of the mapped area have no residual values.

Residual values of a positive nature indicate g(o) has a greater gravitational attraction than the average value of the surrounding points. Conversely a negative $\Delta(g)$ indicates that g(o) has a lower gravitational attraction than the surrounding average value $\overline{g}(r)$.

Discussion of the Observed Gravity Maps

The observed data following Bouguer, free-air, and latitude corrections were plotted on the maps and isogals were drawn at intervals of 10 gravity units or 1 milligal. In that this report lies immediately adjacent to the southern boundary of the area covered in "Gravity Maps of North-Central North Dakota" (Hunt, 1962) many of the anomalies discussed in this report are continuations of previously mentioned features.

Southwest of Rugby, T. 156 N., R. 72 W., a prominent nose is developed. This is the continuation of a similar less well developed feature found northwest of Rugby. The nose appears to have two extensions at its southern tip. The more pronounced extension is a strongly developed gravity rise in the Silva, T. 154 N., R. 72 W., region. The Silva anomaly, to the extent it is mapped, has a triangular shape with a well-defined northern border striking east-west. Its equally well-developed southern or western side has a north-west-southeast strike.

The second extension of the Rugby anomaly is a slightly developed nose extending to the southwest culminating in a minor closure at Anamoose, T. 151 N., R. 75 W. It then continues to the southern border of the map, again, as a minor nose.

Another feature of interest in this general area is the gravity high midway between the Anamoose high and the Silva high. This is separated from the Anamoose anomaly by a minor trough or gravity low.

A trough also separates the Rugby anomaly from one near Towner, T. 156 N., R. 76 W. The Towner feature is the southernmost extension of a pronounced nose originally indicated on the "Observed Gravity Map of North-Central North Dakota" by Hunt (1962). The entire anomalous feature is of interest for it disrupts the continued southern extension of the rapidly increasing gravitational field indicated by the steep gradient in the area directly to the north. Along the western edge of the nose in T. 156 N., R. 76 W., R. 77W., and R. 78 W., the rapid increase in the gradient persists but then it diminishes to the south. However, the regional gradient continues to increase from west to east.

An elongated area of low gravitational attraction occurs in R. 78 W., and R. 79 W., west of the Towner anomaly. The low has a north-south orientation throughout nearly all the area of this report as well as the region to the north. At the southern edge of the map the trough develops a southeasterly attitude moving away from the stronger gravitational field located in T. 150 N., R. 79 W.

The north-south trough is joined by a second trough in T. 153 N., R. 80 W. The latter low gravity feature is a partially arcuate trough extending from the point of junction, through Minot, T. 155 N., R. 83 W., and then north into a prominent low which has an approximate north-south orientation and which can be followed to the region of Westhope, T. 163 N., R. 80 W., (Hunt, 1962).

These two major troughs combined, isolate an extremely well-developed gravity high near Surrey, T. 155 N., R. 81 W. This nearly circular anomaly possesses an essentially equal gravity gradient on all sides. The Surrey anomaly has a high of 593.7 gravity units which is slightly less in total gravitational attraction than found on the Silva anomaly which has a high of 643.2 gravity units. However, the total amount of gravitational closure shown by the isogals is approximately 200 gravity unit, while the Silva anomaly has an apparent closure of approximately 150 gravity units.

The Surrey anomaly is a southern continuation of a north-south oriented series of gravity highs starting northeast of Westhope, and continuing through the Newburg area (Hunt, 1962). This series of higher gravitational features possibly continues further south as manifested by the nose in T. 152 N., R. 81 W., and the plateau-like feature in T. 150 N., R. 81 W.

Both of these latter features appear to emanate as noses, from an area of increasing gravitational attraction to the west. This continuous high persists along the western margin of the mapped area of this report as well as the area immediately to the north and into the Antler area, T. 163 N., R. 82 W., (Hunt, 1962). Though the greater part of this westermost gravity high has an apparent north-south orientation its southern expression has a northeast-southwest attitude. Unfortunately an area lacking topographic map coverage exists between the maps of Central North Dakota and those of Northwestern McLean County. The lack of elevations precluded gravity observations in this region. Nevertheless, the persistence of the northeast-southwest strike is readily apparent on the observed gravity map of Northwestern McLean County where the gravitational attraction increases to a high in the northwestern corner of this area.

Indicated on both the observed and the residual gravity maps are all the exploratory wells drilled within the mapped areas. None of these wells produced commercial quantities of oil. The well numbers are North Dakota Geological Survey well file numbers.

Discussion of the Residual Gravity Maps

Residual gravity values were plotted for each location that possessed a complete complement of sourrounding observed or estimated values. Isogals were drawn at intervals of 5 gravity units or 0.5 milligals.

The reason for computing residual gravity is to better define local gravity fields which are often obscured or masked by regional gravity fields. One illustration of this, on the residual gravity map, is found beginning in T. 156 N., R. 73 W., just west of Rugby, where an elongated ridge-like positive residual anomaly is present. It is nearly continuous in its extension to the southwest where it reaches a maximum in T. 150 N., R. 76 W. Residual gravity lows occur on either side of it. In contrast to this clearly defined positive feature the observed gravity indicates its presence only by a minor nosing of the isogals.

The ridge-like feature is also of interest because of its apparent northeast-southwest orientation. The overall attitude of features in the area within which the ridge-like anomaly lies appears to be northwest-southeast. The regional attitude will be dealt with more thoroughly later.

Due south of Rugby there is a minor low, followed by a slight positive area, and then a major residual low before reaching a positive residual high near Silva. This positive anomaly is extremely well defined having very steep gradients on its flanks, and the highest residual gravity value of 56.1 gravity units or 5.61 milligals of any anomaly in the mapped area.

Southwest of the Silva anomaly is another well developed positive high separated from that at Silva by a northwest-southeast striking low. The positive anomaly is flanked by residual lows on three sides.

Another positive anomaly, though not as strongly pronounced occurs near Anamoose, in an area of relatively minor residual differentiations.

Between the Rugby anomaly and Towner is an area of predominantly negative values, with a positive residual feature developing near Towner. The approximate strike of this anomaly is north-west-southeast, though various extensions at its southern end are oriented in an east-west manner. This positive anomaly continues to the north where a portion of it is also oriented in an east-west fashion (Hunt, 1962). The western flank of this anomaly is limited by a pronounced residual low.

The central portion of the mapped area lacks any distinguishing features or apparent pattern. Near Granville, T. 155 N., R. 79 W., however, there is a north-south trending residual low which is the southern extension of a major trough found to the north (Hunt, 1962). South of Granville the trough is divided into two branches by an elongated positive area. Both branches of the trough continue southward and rejoin. At the southern border of the map the trough is divided again by a positive residual area in T. 150 N., R. 79 W.

West of and parallel to this residual trough is a series of positive residual anomalies. The first and most prominent of these lies just east of Surrey, T. 155 N., R. 81 W. Its western flank has a steeper gradient than any of its other sides. This positive anomaly covers more than four townships within the area mapped for this report.

Another positive residual anomaly occurs southwest of Velva. It is separated from the Surrey anomaly by a zone of negative values. South and slightly east of the Velva feature is a third positive anomaly located in T. 150 N., T. 151 N., R. 80 W. This is an elongated form with its major axis striking approximately north-south.

These three positive residual anomalies plus the one in T. 150 N., R. 79 W., when considered together, lie on a slightly arcuate northwest-southeast trend. This trend is also apparent on the observed gravity map. It is approximately parallel to the northwest-southeast striking isogals east of the major trough located in the center of the observed gravity map.

To the west of the arcuate series of positive anomalies there are two residual lows. These are located in T. 153 N., R. 82 W., and T. 153 N., R. 81 W. Other than these two features the western portion of the map lacks any major anomalies and any definite trends other than minor negative features parallel to the arcuate positive trend. The lack of any clear definition of features is also apparent in the residual gravity map of northwestern McLean County.

Discussion of Observed and Residual Gravity Maps

In general, when studying both the observed and the residual gravity maps, there are two readily apparent major features influencing the field of gravity. The first is a northwest-southeast influence, manifested in the arcuate trend of positive anomalies near Minot and Velva and extending at least to the high in T. 150 N., R. 79W. On the observed gravity map this is also apparent in the overall appearance of the trough east of the highs as well as in the northwest-southeast strike of the isogals east of the trough. The northwest-southeast attitude of the major gravitational influence is of interest for this is the southern extension of major north-south striking influences in the area immediately north of this region.

The second region occurs along the extreme western border of the mapped area. This is readily seen on the observed gravity maps where the westward increase in the observed values creates a north-south high along the border. The anomalous high is continuous to the north (Hunt, 1962). In its southern portion the anomaly changes to a northeast-southwest orientation which is continuous into the area of Northwestern McLean County.

The area considered in this report in conjunction with that of North-Central North Dakota thus seems to encompass two major gravitational fields and their related density changes. One has essentially a north-south orientation which shifts to the southeast, while the second has a similar north-south attitude before it shifts to the southwest.

Conclusions

The observed gravity map reflects the superposition of regional gravity fields upon local gravity fields. The superposition of the two gravity fields frequently covers entirely or obscures pertinent local gravity anomalies. Therefore, a map of the residual gravity, with the regional gravity removed, is a better representation of the local gravitational conditions.

Residual gravity, nevertheless, is still a function of many factors, though basically, it is dependent upon the density of the materials being observed. Gravity anomalies reflect a change in density which may be due to lithologic changes in the sediments or in the basement rocks. The variation in density may also be due to structure in either the sediments or the basement complex, or a combination of the two.

Both the observed and the residual gravity maps, from their various anomalies, clearly indicate that some or all of these changes do occur in the portion of the Williston Basin covered by this report. Since there is no surface expression of these changes, the causes of the anomalies must be determined by interpretation from exploration wells. Unfortunately most of these wells penetrate only to Mississippian strata and only two reach the Precambrian. Consequently insufficient data is available to determine the cause of even the large anomalies near Surrey, Towner, and Silva. The fact that anomalies such as these do exist should encourage further exploration with emphasis on tests deeper than Mississippian strata.

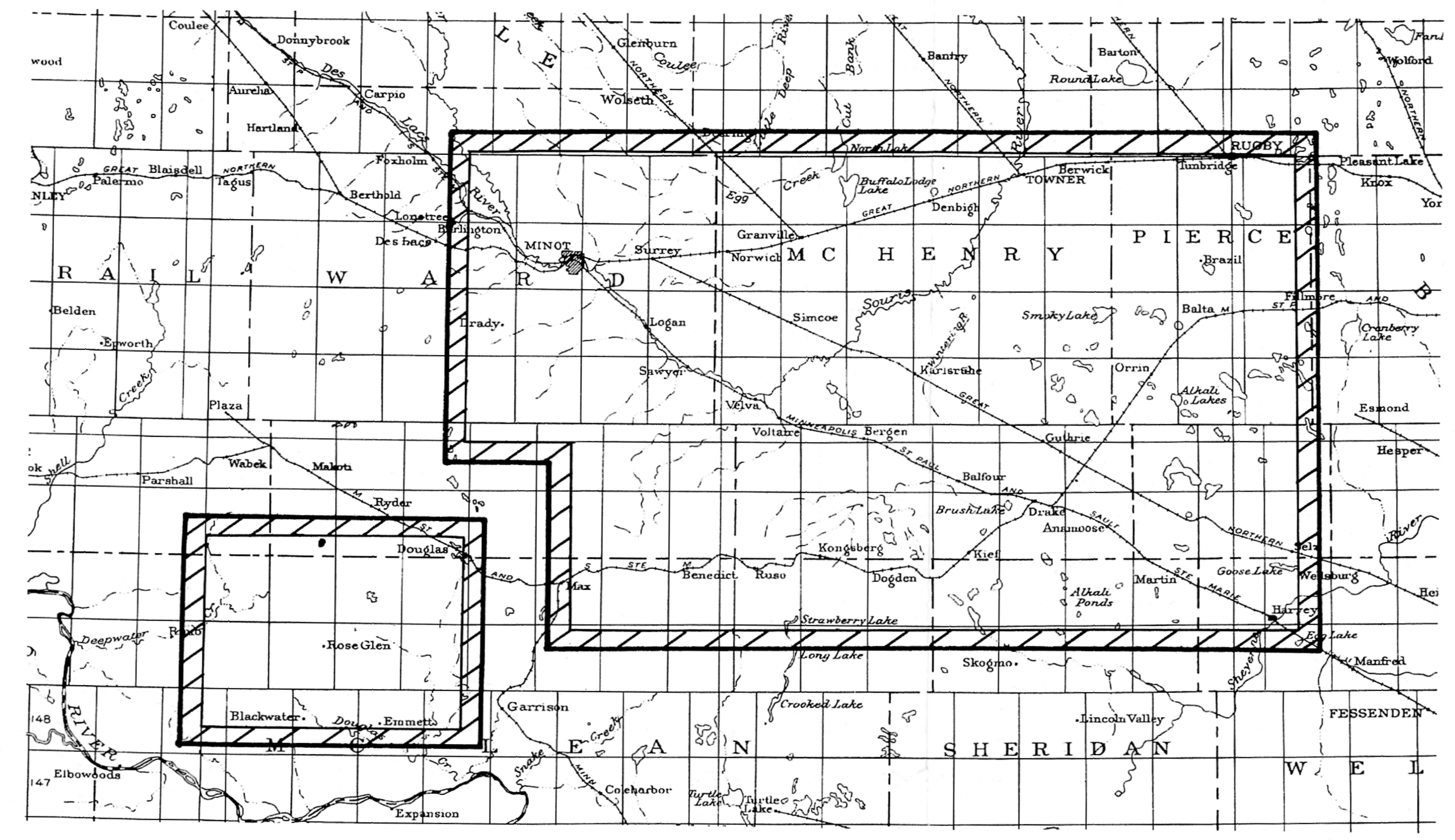
References

Griffin, W. R., 1949, Residual Gravity in Theory and Practice, Geophysics, Vol. 14, No. 1, p. 38-56.

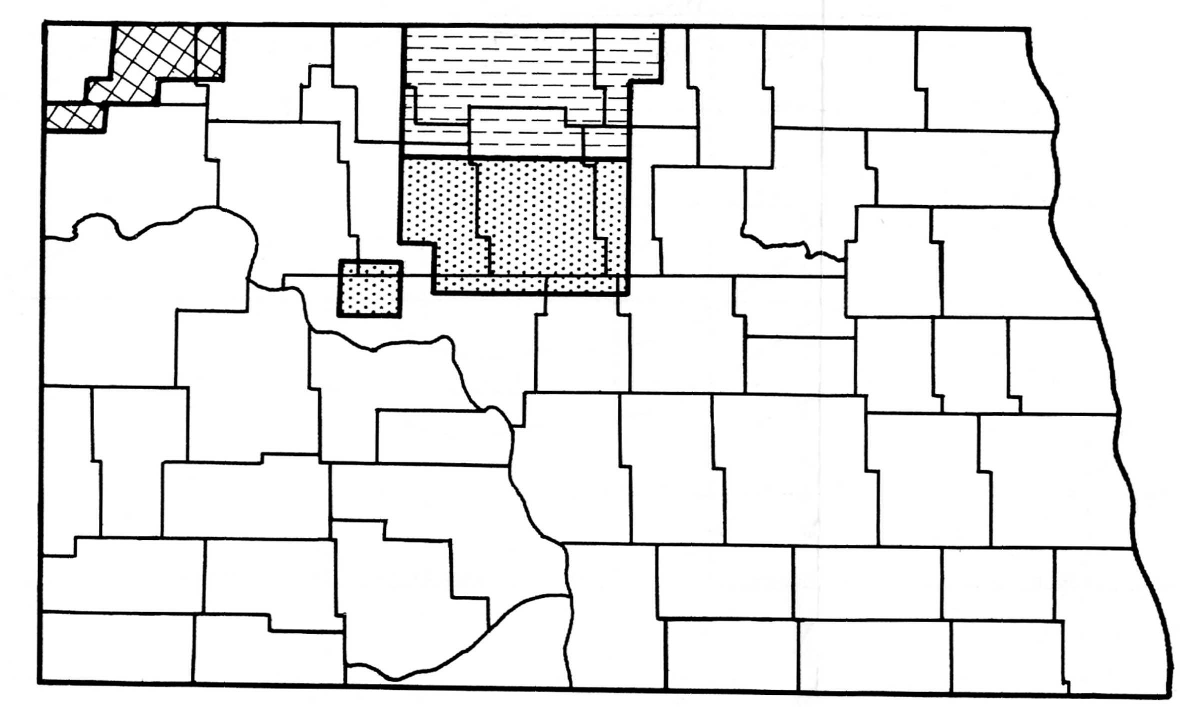
Hansen, Miller, 1960, Regional Gravity Map of Northwestern North Dakota, North Dakota Geological Survey, Report of Investigation No. 35.

Hunt, J. B., 1962, Gravity Maps of North-Central North Dakota, North Dakota Geological Survey, Report of Investigation No. 39.

Nettleton, L. L., 1940, Geophysical Prospecting for Oil, McGraw-Hill 1st. Edition, p. 51-62.



LOCATION MAP



INDEX MAP

THIS REPORT

N.D.G.S REPORT OF INVESTIGATION 39

N.D.G.S. REPORT OF INVESTIGATION 35

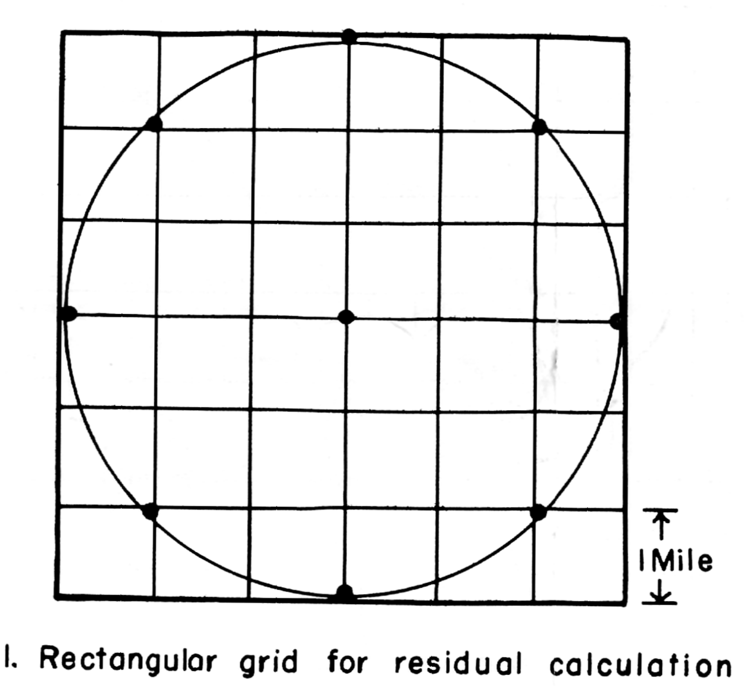
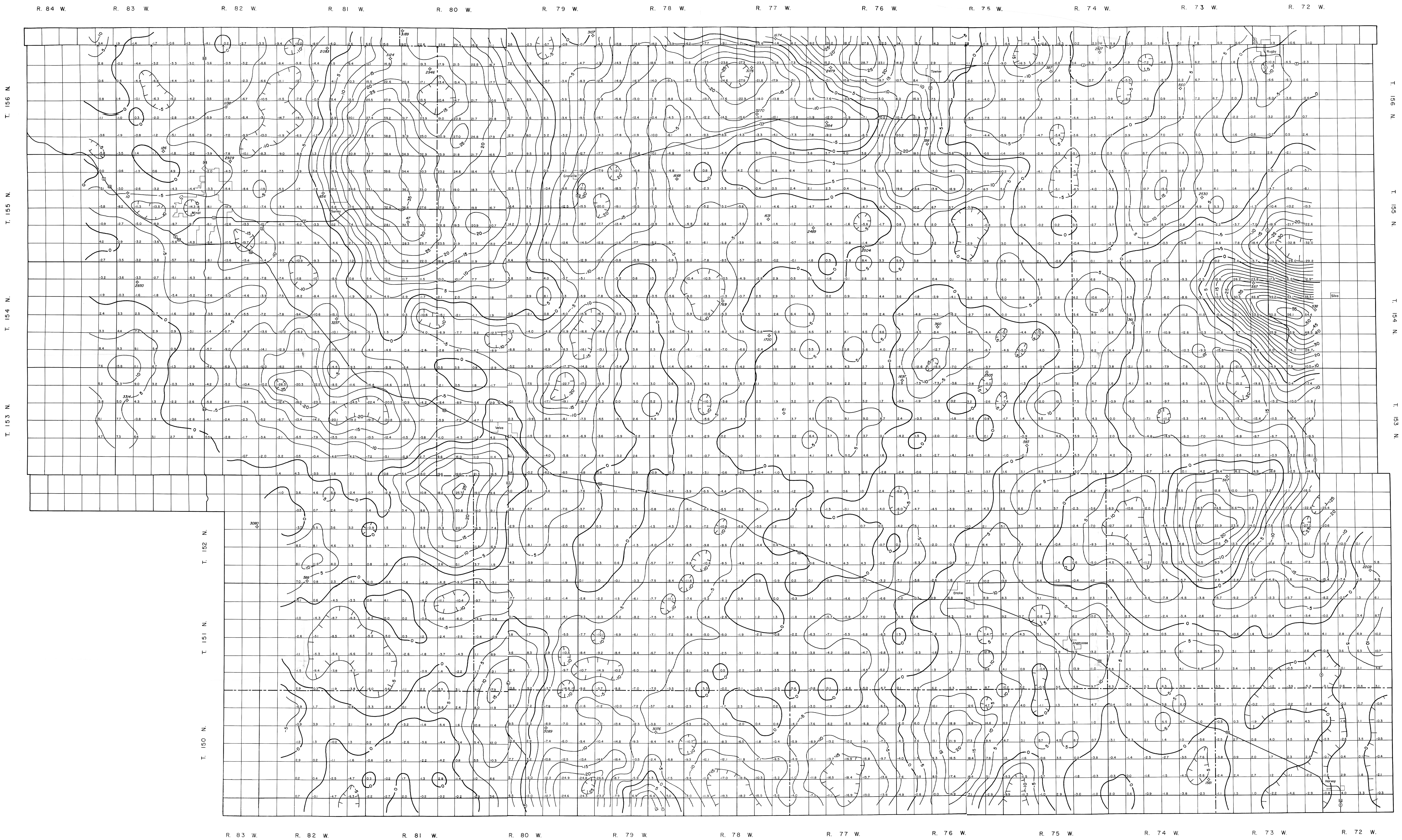


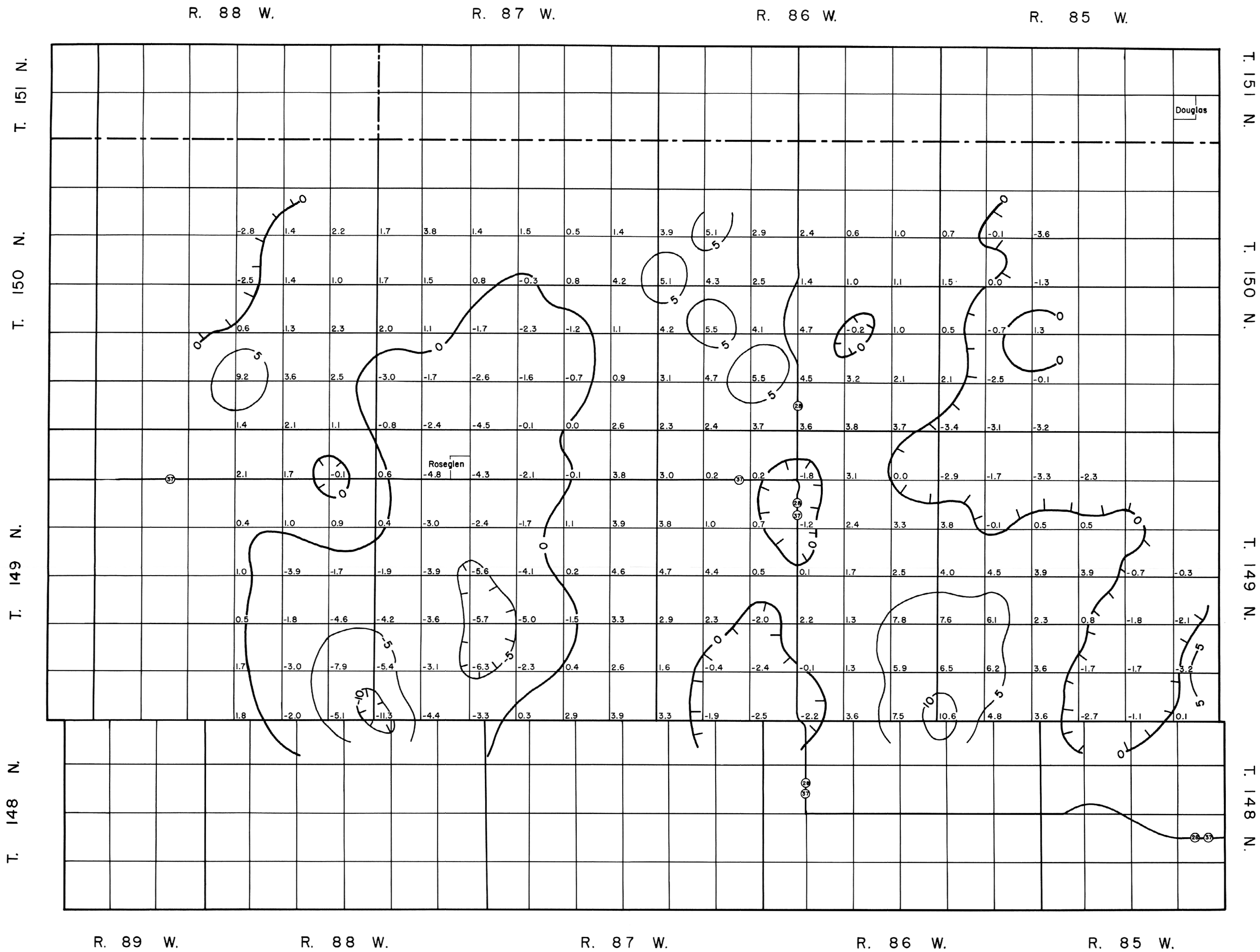
Fig. 1. Rectangular grid for residual calculation



RESIDUAL GRAVITY CENTRAL NORTH DAKOTA

CONTOUR INTERVAL 5 GRAVITY UNITS OR 0.5 MILLIGAL

N 1 0 1 2 3 MILES HIGHWAYS DRY EXPLORATORY WELL 3076



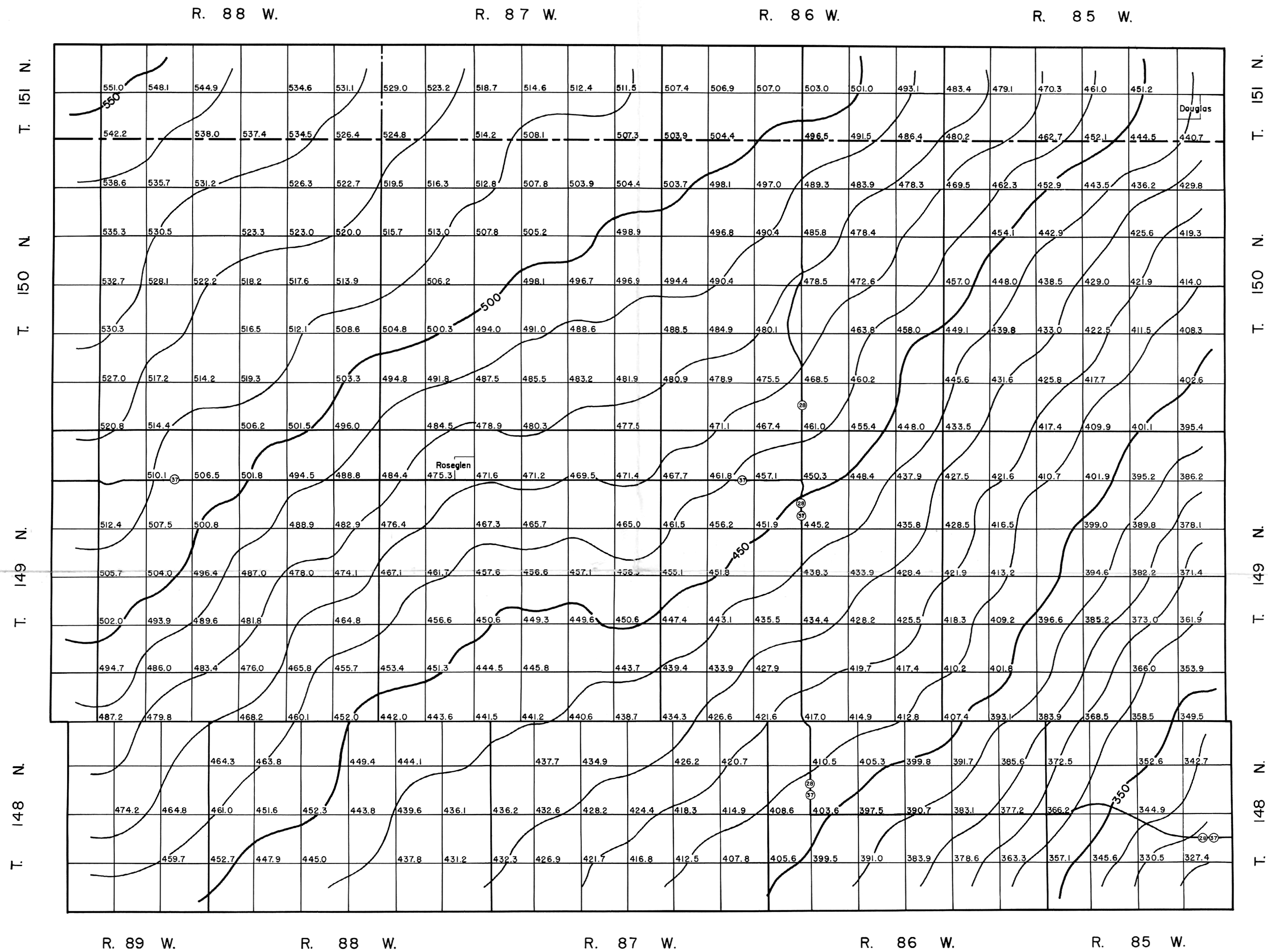
RESIDUAL GRAVITY NORTHWESTERN MCLEAN COUNTY, NORTH DAKOTA

CONTOUR INTERVAL 5 GRAVITY UNITS OR 0.5 MILLIGAL

N

1 0 1 2 3 MILES

HIGHWAYS



OBSERVED GRAVITY NORTHWESTERN MCLEAN COUNTY, NORTH DAKOTA

CONTOUR INTERVAL 10 GRAVITY UNITS OR 1 MILLIGAL

N 1 0 1 2 3 MILES

HIGHWAYS 28 37