Gravity Maps of

NORTH CENTRAL NORTH DAKOTA

by

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INTRODUCTION

The gravity maps presented here are a part of the continuing program of the North Dakota Geological Survey to investigate the geology of the state. These maps are expected to be of considerable interest to those studying the geologic structure of this area.

Field data was obtained during the 1960 and 1961 field seasons using elevations taken from the United States Geological Survey topographic maps. The location of the topographic maps may be found by reference to the "Index to Maps of North Dakota" published by the U. S. Geological Survey. In instances of road construction after publication of the maps new elevations were estimated by determining the change in elevation from the old road to the new road or from bench marks to the new surface. Detailed work would necessitate considerably more accurate elevations, but for a regional map, as presented here, such elevations were deemed sufficiently accurate.

The writer is indebted to Miller Hansen, Assistant State Geologist, for his advice and instructions and for the initial field work accomplished in the mapped area.

INSTRUMENT DATA

A Carter Type "Y" gravity meter was used for all observations in this report. The meter is a null-type instrument so constructed as to be unaffected by variations in barometric pressure. The combination of a vacuum filler for insulation and a self-contained thermoregulator, permits the use of this meter through a wide range of temperature variations. Adaptation for use in North Dakota required only a latitude adjustment.

Each dial division is equal to 0.71 gravity units. Rider readings taken occasionally indicated that during the course of the survey no appreciable change in instrumental sensitivity occurred.

FIELD PROCEDURE and COMPUTATIONS

The gravity meter was transported in a specially adapted vehicle for field operation, thus providing protection for the meter and decreasing the time required for observations.

Lines of observations were restricted to no more than three miles apart, where possible, with stations normally established at each section corner. Lines were generally established in an east-west direction to facilitate observation of the more rapid gravity changes. Whenever necessary, due to extreme variation in readings, the lines were run at one mile intervals. Experience indicated that in much of the region covered observation lines at two mile intervals were sufficient especially when supplemented with occasional readings one mile apart.

Instrumental drift was normally quite low, being on the order of tenths of a gravity unit. The drift was determined by making a second observation at the base station at the close of each run. Runs were limited to three hours or less, and corrections were made by distributing the difference linearly with time among all stations read between the two base station readings. On occasion, extreme variations on the order of 5 gravity units or more were observed between the two base station readings. These extremes were attributable to excessive rises in the daily temperature causing the gravity meter to overheat. On such occasions these stations were re-run during cooler weather to insure accuracy.

Values determined for this map are directly dependent upon the first base stations established by Hansen (1960) in Section 32, T. 163 N., R. 94 W. Subsequently, Hansen completed an unpublished gravity profile from the Columbus area to the Antler region via State Highway 5. The present map is a continuation of Hansen's work. The initial base station was arbitrarily assigned the value of 500 gravity units, with all other stations dependent upon this value as the gravimetric survey was expanded eastwardly from the western part of North Dakota. No station was considered to be a base station unless it was tied in from at least two directions with successive readings closely related. Tie-ins of this nature varied commonly by no more than one gravity unit, with extremes being less than two gravity units.

Computations were conducted in accordance with the method of Nettleton (1940). Free-air and Bouguer corrections were combined into a single correction. Latitude corrections for the area mapped amount to 12.9 gravity units per mile.

Terrain correction were unnecessary throughout most of the area mapped due to the low topographic relief. Terrain corrections were computed for stations in the Turtle Mountains region in the northeastern portion of the mapped area, but were not included in the final values for several reasons. The primary reason was that complete topographic map coverage was not available for all stations in and around the Turtle Mountains to allow complete terrain corrections for all zones in the method outlined by Hammer (1939). Attempted corrections indicate an average increase of 0.37 gravity units for those stations located more than four miles from the Turtle Mountains, 1.83 gravity units for stations located in a belt of one to four miles width along the perimeter of the mountains, and 0.63 gravity units for those in the Turtle Mountains. In view of the fact that these stations are all located on a rapidly increasing gravity high, and that the corrections are relatively minor in comparison to the size of the anomaly it seems unnecessary to consider the terrain corrections in order to keep within the accuracy of this map.

RESIDUAL GRAVITY

Because observed gravity values are a superposition of local gravity fields upon regional gravity fields it was deemed advisable for better definition of local anomalies to produce a residual gravity map. Since there is no one accepted method, the residual gravity map is a reflection of the writer's conception of the proper procedure for the north-central North Dakota area and for a regional map of this type. Griffin (1949) indicates that a residual map is dependent upon the selection of the size and shape of the geometric form used to calculate the residual value. Thus it may be that the reader will prefer a variation on the writer's system or perhaps even a new system.

In the absence of observed values at various section corners, estimated values were obtained for these positions by assigning the average value of the surrounding stations to that location.

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

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

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

The value $\bar{g}(r)$ was determined by using an octagon with its points lying on a circle with a radius of 3 miles (Fig. 1). In order to achieve maximum accuracy residual gravity values were determined for only those points so located that all points of the octagon possessed either observed or estimated values. Therefore, residual gravity values were determined for all stations exclusive of a peripheral belt three miles wide along the fringes of the mapped area. Also, due to the sparseness of stations in the Turtle Mountains region no attempt was made to evaluate the remaining unobserved positions, and to remain within the established procedures no residual values were determined for this region.

Positive residual values indicate that the value of g(o) is greater than the average value of the surrounding points while negative residual values at point g(o) indicate that this point has a lower gravitational attraction than the surrounding average value.

DISCUSSION OF THE OBSERVED GRAVITY MAPS

Corrected values in gravity units were plotted on the map and gravity contours were drawn at intervals of 10 gravity units or 1 milligal. The map indicates a gravity high north and east of Dunseith, T. 162 N., R. 73 W., with a relatively gentle gradient to the east and south. West of this anomaly the gradient is uniform and extremely steep until reaching a north-south line running appproximately through Souris, T. 163 N., R. 77 W., and east of Kramer and Upham, T. 160 N., R. 78 W., and T. 159 N., R. 78 W. respectively.

West of this north-south line the overall character of the observed gravity map changes considerably. A series of parallel gravity highs and lows occur to the western edge of the map. The first series of anomalous highs consists of one northwest of Kramer and a second northwest of Upham. Gravity lows occur southwest of Souris and at Kramer.

A second row of anomalous gravity highs is composed of one located northeast of Westhope, T. 163 N., R. 80 W., a second west and southwest of Newburg, T. 160 N., R. 79 W., and a third due south of the Pratt oil field.

A major gravity low extending from a position southwest of Westhope almost due south to an area southeast of Glenburn, T. 158 N., R. 82 W., separates the previous series of gravity highs from a third row of highs positioned along the western border of the map. Here an anomalous high lying west of the Minot Air Force Base extends northward with a gradual decrease in size. South of Antler, T. 163 N., R. 82 W., this gravity high reverses its character and increases in degree as the International Boundary is approached.

Dr. H. D. B. Wilson reports (personal communication to Dr. W. M. Laird, State Geologist) that teams from the University of Manitoba in making gravity observations have traced a large Precambrian mountain range from the Hudson Bay area to the Manitoba, Saskatchewan, North Dakota boundaries. The southern extension of the gravity high referred to by Dr. Wilson is shown in the Antler vicinity on the observed gravity map.

In general the overall situation in regard to the observed gravity map is one of decreasing gravity values from east to west. This conforms with the configuration of the basement complex which becomes deeper toward the western part of North Dakota.

Indicated on the observed gravity map are all wells drilled outside of the oil field boundaries. Within the limits of the fields only the discovery well is shown. The well numbers used are North Dakota Geological Survey well file numbers.

DISCUSSION OF THE RESIDUAL GRAVITY MAP

Residual gravity values were plotted for each location possessing a complete complement of surrounding observed or estimated values. Gravity contours were drawn at intervals of 5 gravity units or 0.5 milligals.

The area south of Dunseith has two major trends apparent. The first is manifested by a north-south residual gravity high south of Dunseith. This is delimited on the west and east by residual lows. The second trend is found midway between Dunseith and Rugby, T. 157 N., R. 72 W., where the anomalies assume an approximate east-west lineation. In this area a residual east-west high is again bordered by negative residual values. Northwest of Rugby another east-west trending high occurs.

Between Willow City, T. 159 N., R. 75 W., and the Souris-Kramer-Upham line the apparent trend of anomalies is northwesterly. These anomalies lack the degree of development found in other areas. In contrast to these less well defined anomalies there occurs, on the southern edge of the map just east of the Souris-Kramer-Upham line, the most pronounced residual high within the entire mapped area. For several reasons this residual high is of interest. First, it is the most westerly expression of any of the features oriented in an approximate east-west manner. Second, it is exceedingly well developed in an area which seems to lack significant residual gravity strength. Third, a comparison of this residual anomalous area with the comparable area on the observed gravity map shows that it is masked by the regional gravity field when viewed on the observed gravity map. In the case of the latter only a slight nose is indicative of its presence.

West of the Souris-Kramer-Upham line the approximate trend of residual gravity features has become reoriented to an apparent north-south lineation. This orientation persists to the western edge of the mapped area. Its first manifestation is a series of residual lows lying immediately west of the Souris-Kramer-Upham line and extending from the south edge of the map through Upham, Kramer, and to a northeasterly trending gravity low at Souris. It should be further noted that west of the Souris-Kramer-Upham line observed gravity and residual gravity anomalies are closely related in respect to position and outline.

A residual gravity high is present northwest of Upham and a second lies northwest of Kramer. These residual anomalies were orginally indicated on the observed gravity map. The southern half of the Kramer anomaly is covered by the Starbuck group of oil fields.

On the west these residual highs are separated from a second set of north-south highs by a series of lows. The latter residual highs extend from the southern border of the map to the area west and northwest of Newburg with only a minor interruption near the Pratt oil field. The northern extension of this residual high is covered by the Newburg and South Westhope oil fields.

A pronounced north-south residual low extends throughout nearly all the mapped area from a position southeast of Glenburn to the southwest corner of the Westhope oil field. West of this low the residual gravity is almost plateau-like in character with only minor fluctuations above and below the zero value.

Oil fields in the north-central North Dakota region are located in various modes with respect to the residual gravity. As previously noted the Starbuck group and the South Westhope and Newburg fields occur on prominent residual highs. The Haas group of fields is located on an area of increasing residual values starting in a residual low. The Wiley field and the Glenburn field are similary positioned. The Wayne and Landa fields on the other hand, lie within residual highs, while the Westhope field is almost entirely within a residual low.

DISCUSSION OF ANOMALOUS FEATURES

The gravity survey covers approximately 3200 square miles, portions of which have been mapped for other investigations conducted by the North Dakota Geological Survey.

The gravity high west of Newburg occupies the same general locations as the anomaly shown on a magnetic map prepared by Hansen (Folsom, et al, 1958).

A comparison of the gravity maps with the Madison subcrop map (Anderson and Carlson. 1958) shows several similarities of features. First, a prominent nose which extends southward from the Canadian border in T. 160 N. through T. 164 N., R. 81 W., R. 82 W., and R. 83 W., is similarly located with respect to the observed gravity high and the residual gravity plateau found in the western portion of the gravity maps. Further comparison in this area shows that in T. 162 N., R. 83 W., a trough is suggested in the Madison subcrop map where gravity lows occur in both the observed and residual maps.

The Madison subcrop map referred to above shows an apparent trough with a north-south orientation in T. 159 N. through T.. 163 N., R. 80 W. and R. 81 W., as well as a thickening of the Spearfish Formation in the same general area. This trough occupies the approximate location of the gravity low occurring on both gravity maps east of Glenburn and extending toward the Westhope oil field. Another expression of this trough-like feature is illustrated on the structure map of the Frobisher-Alida marker (Eastwood, 1961) where a pronounced structural low occurs southeast of the Glenburn field and extends northward. Since the publication of Eastwood's report, Cardinal Petroleum's No. 1 Henderson (Section 17, T. 160 N., R. 81 W.) has reported the Frobisher-Alida marker at 2561 feet below the datum, which would tend to extend the trough even further northward (Eastwood, personal communication).

One further illustration of similarity is the prominent nose developed in T. 159 N. and T. 160 N., R. 78 W. and R. 79 W., as seen on the Madison subcrop map. The same feature is also well developed on the Frobisher-Alida structure map. Both gravity maps show, in this area, a north-south anomalous high with a slight nose toward the southwest.

Sedimentation in certain areas of the Williston Basin has been influenced by salt tectonism. Anderson (1958) mentioned this phenomenon in conjunction with his study of California Oil Company's No. 1 Thompson (Section 31, T. 160 N., R. 81 W.). McCabe (1959) discussing Mississippian stratigraphy in Manitoba, disclosed that similar tectonism may be regional in certain areas. On the observed gravity map the No. 1 Thompson well lies within the gravity low that extends from a position southwest of Westhope to an area southeast of Glenburn, and it lies within the increasing gradient going west from a similarly located low on the residual gravity map.

CONCLUSIONS

The cause of gravity anomalies on the observed gravity map is the result of the superposition of regional gravity fields upon local gravity fields. Through this, anomalous areas may have their actual character masked or altered. A residual gravity map more thoroughly portrays the actual local gravitational conditions.

However, residual gravity anomalies are still a composite of many factors. Basically they are manifested by changes in density of the material being observed. In the area under consideration anomalies may be created by lithologic changes in the sedimentary rocks, or by subsurface structures. Whatever the cause of residual anomalies there is no surface expression appearing in this portion of the Williston Basin to account for any of these anomalies. Deeper drilling is needed since most drilling in the area is carried no deeper than the upper part of the Mississippian leaving 2500 to 3000 feet of sediment above the Precambrian virtually untested.

The development of the increased regional gravity field east of the Souris-Kramer-Upham line is prompted by the basement complex becoming shallower towards the eastern portions of the mapped area.

There are certain similarities of features on several maps when compared with the observed and residual gravity maps. The distinct possibility exists that structures shown on subcrop maps or structure maps are also reflected by the gravity maps. Also structures which are known in Mississippian sediments may also be present in deeper formations.

Not all the gravity anomalies have apparent known similarities. However, this should not exclude them from exploratory consideration for they may be reflections of pre-Mississippian features.

References:

Anderson, S. B. 1958, Mississippian Possibilities, World Oil, Dec., 1958, North Dakota Geological Survey, Report of Investigation No. 31.

.... , and Carlson, C. G., 1958, Madison Subcrop-Spearfish Isopach Map-Bottineau Area, North Dakota Geological Survey, Report of Investigation No. 30.

Eastwood, W. P., 1961, Maps of the Frobisher-Alida Interval, North Dakota, North Dakota Geological Survey, Report of Investigation No. 37.

Folsom, C. B., Jr., Hansen, M., and Anderson, S. B., 1958, Preliminary Report on the Newburg-Spearfish-Charles and South Westhope-Spearfish-Charles Pools, North Dakota Geological Survey, Report of Investigation No. 29, p. 11.

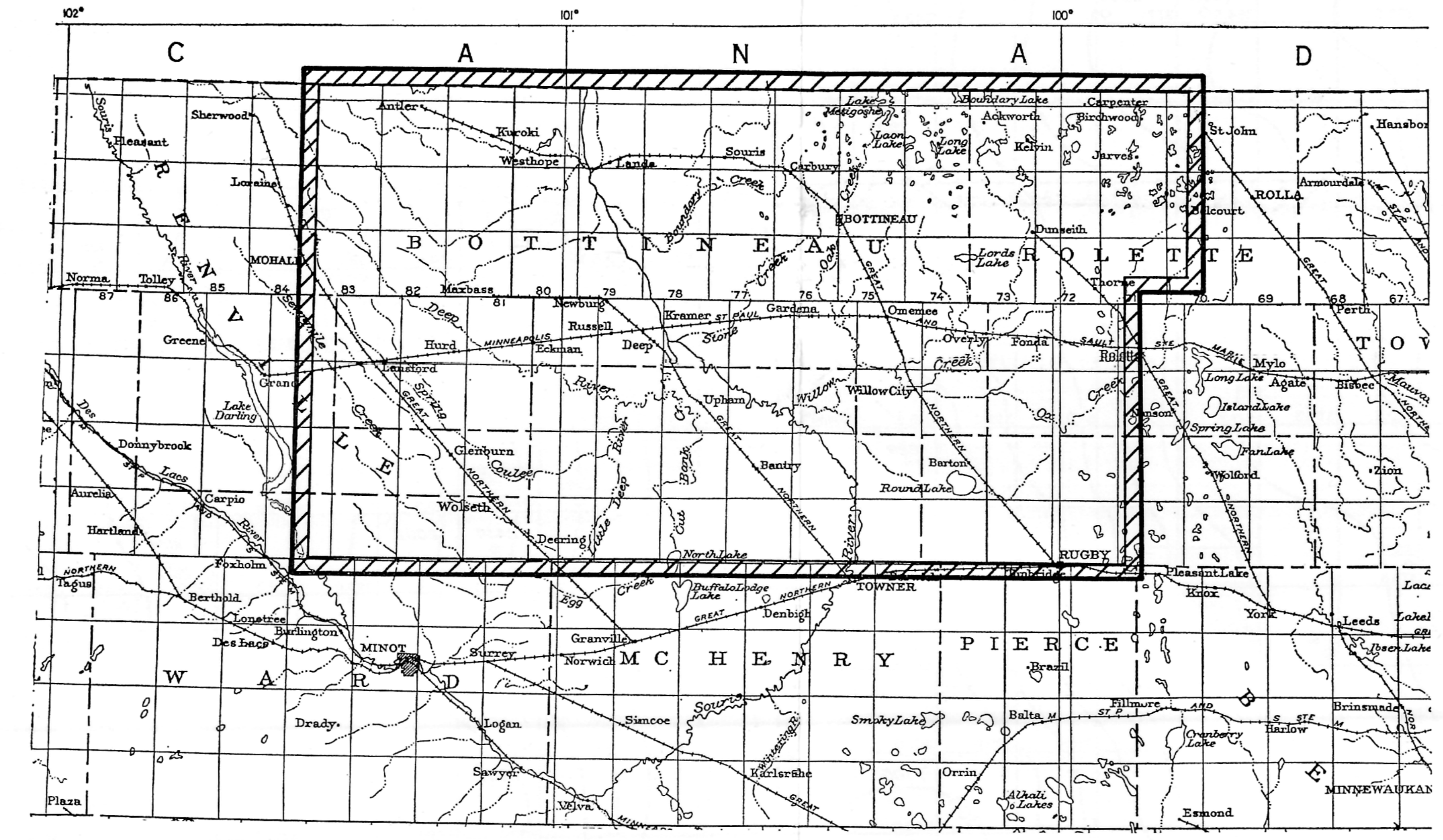
Griffin, W. R., 1949, Residual Gravity in Theory and Practice, Geophysics, Vol. 14, N. 1, p. 38-56.

Hammer, S., 1939, Terrain Corrections for Gravimeter Stations, Geophysics, Vol. 4, No. 3, p. 184-194.

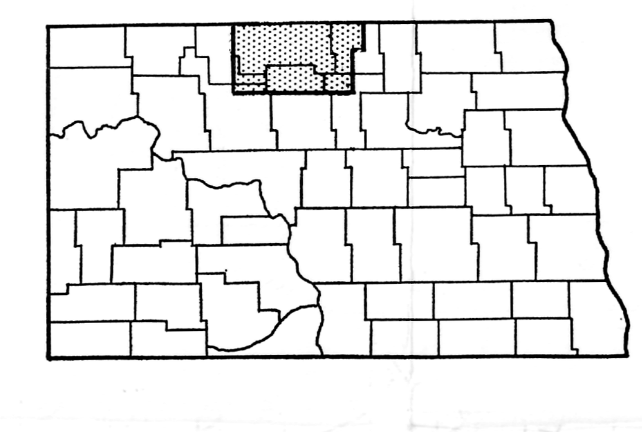
Hansen, M., 1960, Regional Gravity Map of Northwestern North Dakota, North Dakota Geological Survey, Report of Investigation No. 35.

McCabe, H. R., 1959, Mississippian Stratigraphy of Manitoba, Manitoba Department of Mines and Natural Resources Publication 58-1, p. 51-52.

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



LOCATION MAP



INDEX MAP

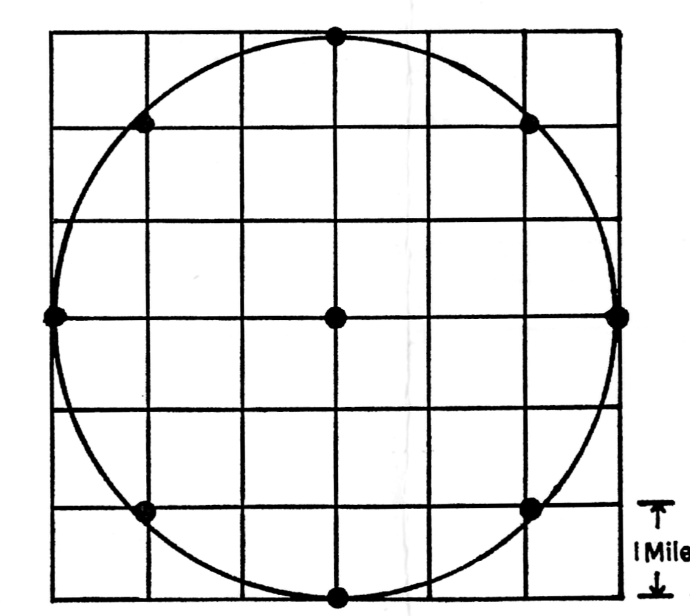


Fig. I. Rectangular grid for residual calculation

NORTH DAKOTA GEOLOGICAL SURVEY

WILSON M. LAIRD, State Geologist

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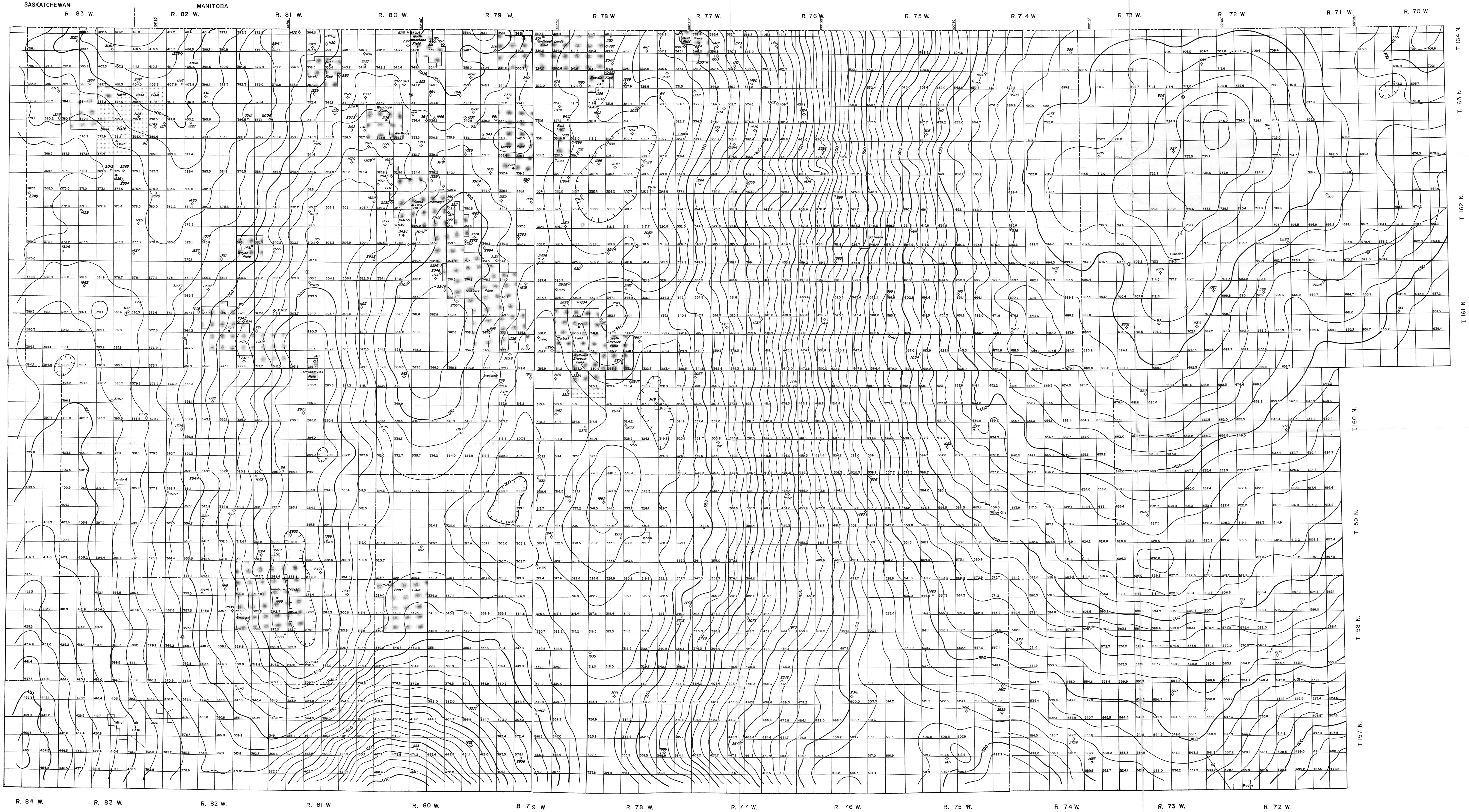


OBSERVED GRAVITY NORTH-CENTRAL NORTH DAKOTA

CONTOUR INTERVAL 10 GRAVITY UNITS OR 1 MILLIGAL

N

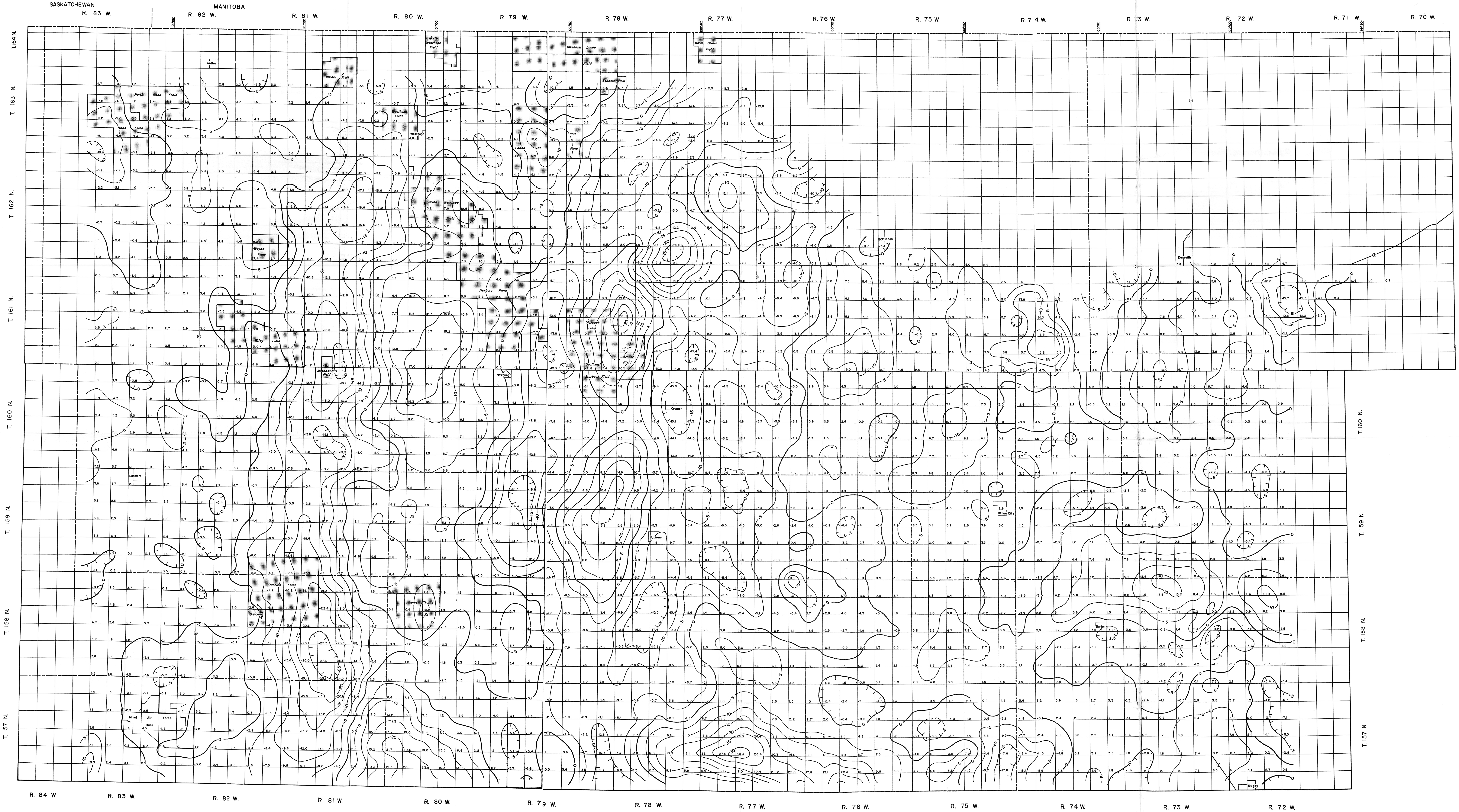
1 0 1 2 3 MILES

HIGHWAYS

OIL FIELDS

(Over)

PLATE I



RESIDUAL GRAVITY NORTH-CENTRAL NORTH DAKOTA

CONTOUR INTERVAL 5 GRAVITY UNITS OR .5 MILLIGAL

N

1 0 1 2 3 MILES

HIGHWAYS

OIL FIELDS

PLATE II