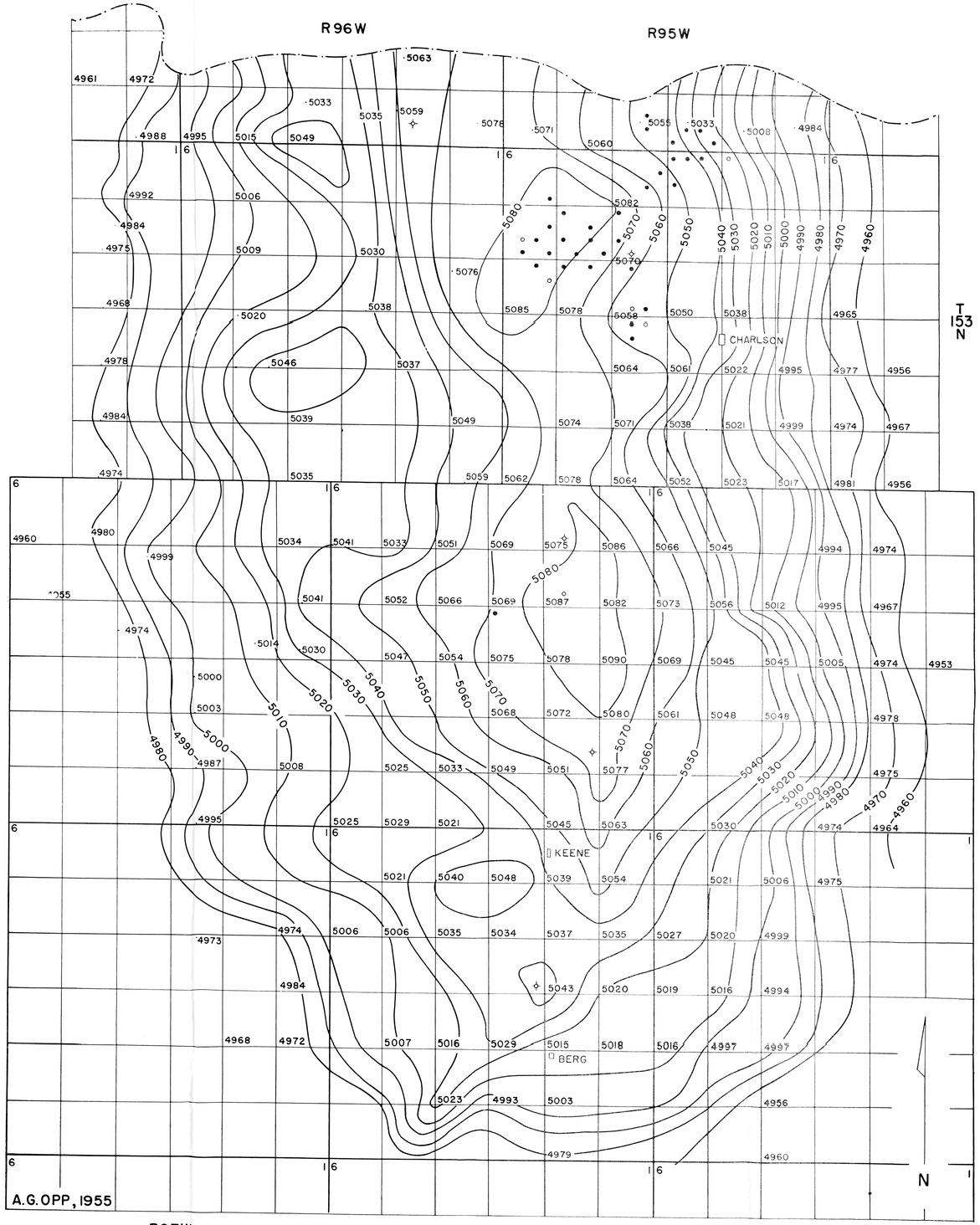

NORTH DAKOTA GEOLOGICAL SURVEY

WILSON M. LAIRD, State Geologist

A Magnetometer Survey of the Keene Dome, McKenzie County, North Dakota

by

ALBERT G. OPP

Report of Investigations No. 19

Grand Forks, North Dakota, 1955

This report is extracted from a thesis presented to the graduate school of St. Louis University by Lt. Albert G. Opp of the U S A F Institute of Technology.

ABSTRACT

This magnetometer survey of the Keene Dome was conducted during August and part of September, 1954. The data were obtained with a Ruska, Type V, vertical intensity magnetometer. Corrected station values were plotted on a base map and isogamma contours drawn.

Producing oil wells, dry holes, and holes still being drilled were plotted on the same map to show the relationship between the magnetic anomalies and the oil fields. This relationship is not always too clear since the oil fields are still in the development stage.

The magnetometer data were interpreted by Peters' method and these results integrated with the known gology. This information led to the following conclusions:

1. The Keene Dome was probably formed by a vertically faulted basement.
2. The Keene Dome and the Beaver Lodge structure are separate anomalies on the Nesson anticline.

Acknowledgments

The author wishes to express his sincere thanks to Dr. Wilson M. Laird, State Geologist for suggesting the problem and for the assistance and constructive comments given; and to Mr. Miller Hansen of the North Dakota Geological Survey for his help during the field season and for making available his magnetometer work on an adjacent area. Thanks are also due Dr. Otto W. Nuttli and the late Dr. Florence Robertsen, the author's advisors at St. Louis University.

CHAPTER I

Introduction

In April of 1951, Amerada Petroleum Corporation discovered oil on the Nesson anticline in northwestern North Dakota. A short time later, oil was also discovered to the south on the Keene dome. This added economic impetus greatly enlarged the interest in the geology of that region.

Dr. Wilson M. Laird, North Dakota State Geologist, suggested to the author that a magnetometer survey of the Keene dome coupled with similar work previously completed by the North Dakota Geological Survey on the Nesson anticline, would add materially to the existing knowledge of the area. Dr. Laird's suggestion was followed in this report which is an attempt to determine the cause of deformation of the sediments of the Keene dome by means of a magnetometer survey interpreted with respect to geologic knowledge.

The Keene dome lies in northeastern McKenzie County, North Dakota and is bounded on the north and east by the Missouri River. Immediately across the Missouri River lies the northward extension of the Nesson anticline. The Nesson anticline of which the Keene dome is a part was first described in literature by Collier (1). During the summer of 1945, Charles Nevin (2) studied the area in northeastern McKenzie County, immediately south of the Missouri River. Nevin named the structure the "Keene dome".

Nevin's work was the only report of its kind published on this area. A great deal of geological and geophysical exploration has been conducted on the Nesson anticline, but this information is still largely held as confidential by the oil companies concerned. Two other papers dealing with the Beaver Lodge and Tioga oil fields were made available to the writer. The first, by Laird, Hansen, Folsom, and Anderson (3), available to the author in manuscript form only, deals with the geologic structure, stratigraphy, and oil production of the Beaver Lodge and Tioga fields. The second was a magnetometer survey of the Beaver Lodge field by Miller Hansen (4) of the North Dakota Geological Survey, who ran a line of observations south across the Missouri so that the survey run by the writer could be tied to a common base with the North Dakota Geological Survey's map of the Beaver Lodge field. Mr. Hansen conducted some of his work during the same period as the data for this thesis were being gathered. The author compared his results with Hansen's and found a marked correlation.

Instrument Data

The instrument used in this survey was a Ruska, Type V, vertical magnetometer. The only adjustment required was that for latitude after which the instrument was calibrated by means of a Helmholtz coil. Initially the sensitivity of the instrument was set at 18.9 gammas per scale division. This was changed to 24.5 gammas per scale division in order to correspond more closely to the sensitivity of the instrument used by the North Dakota Geological Survey in magnetic mapping of the Beaver Lodge field.

Field Work

The field work for this report was done during the months of August and part of September, 1954.

It was the original intention to have a station interval of one mile where possible. Observations were made at section corners where the roads permitted, and lines of observations were tied into another observation loop at least once in order to maintain a check on accuracy.

Readings were recorded in field notebooks and corrected according to a method outlined by Jakosky (5).

Stratigraphy

There are many good descriptions of the stratigraphy of the Williston basin appearing in the literature and a detailed discussion is beyond the scope of this report. The thickness of sediments in the vicinity of the Keene Dome is estimated to be about 15,000 feet. Detailed sample studies of several wells from published circulars of the North Dakota Geological Survey indicate that none of the formations so far penetrated in northwestern North Dakota vary sufficiently in magnetic susceptibility to account for the anomalies mapped. The anomalies are therefore assumed to reflect the basement complex.

Historical Development

The Williston Basin (6), in which the Keene dome is located, is a 200,00 square mile basinal structure that has been sinking intermittently during geologic time (7). It is thought that the Williston Basin as a structural basin was non-existent during Cambrian time, however there are some axes of thinning present which would suggest movement (8). The center of the basin has migrated only slightly with time, remaining in the general area of northwestern North Dakota and adjacent portions of Saskatchewan and Montana. According to Laird, *et al.*, the most pronounced sinking took place during Devonian, Mississippian, and Cretaceous time. This is shown by the greater thickness of sediments assigned to those periods.

Topography of the Area

The general surface is a rolling upland type terrain, dissected in many places by streams. The general elevations of the area under consideration range from 2400 to 2600 feet.

The Missouri River in this area has cut and eroded a valley up to five miles wide. The dissection of the terrain by the Missouri and smaller streams made parts of the area difficult of access for ground magnetometer exploration.

The area of the Keene dome was glaciated several times during the Pleistocene period. One of these later glacial advances reached its southern limit a few miles beyond the southern boundary of this survey. Some of the topography reflects the presence of the glacier, notably glacial boulders, as well as end moraine and other glacial features.

STRUCTURE AS DERIVED FROM GEOLOGY

The two most recent papers on the structure of this area are by Laird, Hansen, Folsom, and Anderson, and by McCabe. Laird, *et al.*, (9) say the exact origin of the Nesson type structure is unknown, but recurring basement faulting appears to be the best explanation at the present time.

By comparing structure maps drawn on the top of the Mission Canyon and on the top of the Greenhorn, Laird, *et al.*, found the crest of the structure to move westward with depth. This is most noticeable at the southern end of the Beaver Lodge Oil field. The structure also appears to increase in closure with depth. In their report a cross-section was drawn parallel to the anticlinal axis which showed a southerly drop in the beds below the Triassic-Spearfish formation. This coupled with the westward shifting crest of the anticline suggests cross faulting as well as faulting parallel to the trend of the struture. It is thought that these possible cross-faults cause the local complexities which today produce oil and gas.

McCabe (10) uses a fault in the Glendive field, Montana as an example of the structures of this general area. This fault is believed to be of pre-Mississippian, late-Devonian age.

By citing various stratigraphic sequences and in some cases their repetition, McCabe has reasonably proved faulting. A Laramide age thrust fault complicates the situation, but the evidence is fairly clear that the structure was formed by a Mississippian or late Devonian normal fault.

Nevin (11) expresses doubt as to whether or not the dome is a separate structure. By consulting Nevin's map, Figure 2, it can be seen that the Keene dome may well be a southerly extension of the Nesson anticline. If it is an integral part of the Nesson anticline, and there is very little evidence to the contrary, then it is safe to assume that the examples given by Laird, *et al.*, and by McCabe probably hold for the Keene dome also.

INTERPRETATION OF MAGNETOMETER DATA

Corrected values for all stations were plotted on a base map and isogamma contours were drawn on a 10 gamma interval. Figure 1 illustrates the results of the magnetic contouring and the relationship between the magnetic anomalies and the oil fields in their present stage of development.

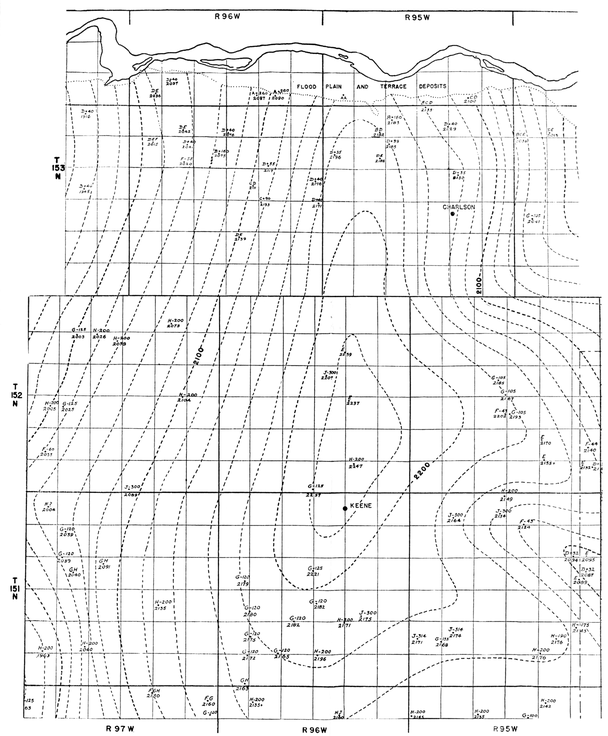

FIGURE 2, Portion of Nevin's 1946 Surface Structure map of Keene Dome covered by 1954 Magnetic Survey (see figure 1). Reprinted from Plate 1 — Bulletin 21, Part 1, "The Keene Dome, Northeast McKenzie County, North Dakota", by C. M. Nevin, North Dakota Geological Survey, 1946.

Figure 2 shows that portion of Nevin's surface structure map of the Keene dome covered by the writer's magnetic survey, and a comparison of the two shows the marked coincidence between the surface structure and the magnetic highs. The calculated structure is presented in Figure 3 with both magnetic and surface structure profiles.

Leo J. Peters (12) of the Gulf Research and Development Company has evolved a method of interpreting magnetic anomalies from a two-dimensional structure.

Evaluation of the Keene structure by Peters' method was undertaken for experimental purposes and assumptions had to be made concerning depth and magnetic susceptibility of the basement complex in addition to an assumption of leveling of the profile of vertical magnetic intensity on the flanks of the magnetic high. The results of the structure calculations should be considered with these assumptions in mind.

In Peters' method a structure must be uniform in one direction and vary predominantly in the other, in order that it may be considered as two-dimensional. By consulting Figure 1, it can be seen that the magnetic anomaly associated with the Keene dome is quite uniform in the north-south direction while rising and falling in the east-west direction. It was on the basis of this that the anomaly was treated as a two-dimensional structure.

The method of Peters was applied to the Keene dome anomaly along a profile running through Township 152 North and along the southern boundary of sections 13, 14, 15, 16, 17, and 18, Ranges 93, 94, 95, 96, 97, and 98 West.

Application of Peters' Method to Keene Dome Anomaly

In applying Peters' method of interpretation to the Keene dome, it was necessary to know the vertical magnetic intensity beyond the limits of the survey. To obtain this information, it was assumed that the magnetic profile tended to flatten to the east and west, giving a constant value for the difference in vertical intensity between the east and west profile extensions away from the magnetic high.

The most glaring weakness in the use of this method is choosing a susceptibility when so little is known of the basement complex. The nearest deep well that provides accurate basement information is the Carter Oil Company—Emma L. Semling No. 1, located in Oliver County, North Dakota. Towse and Anderson (13) describe the basement as amphibolite with masses of dark red iron minerals and a trace of pyrite. Heiland (14) gives the magnetic susceptibility of magnetic amphibolite as .009 c.g.s. units and this figure was used in the calculations.

A map by Deel and Howe (15) of the vertical magnetic intensity of the United States shows an intensity of 58,420 gammas with an annual decrease of 80 gammas per year for this particular part of the nation. Based upon this, the absolute vertical magnetic intensity was taken as 57,700 gammas. The depth to basement in this area is around 15,000 feet. For ease in calculation, the depth was chosen as three miles. The separation between points at which the change in structure was calculated was also taken as three miles.

The calculations were begun at the point of maximum intensity, and carried first west and then east. The changes in structure were obtained in fractions of the three mile depth. Converting these to feet, the change in structure between two consecutive points was determined and plotted as shown in Figure 3.

CONCLUSIONS

In arriving at the following conclusions as to the cause of deformation of the sediments, the author has made use of the results of Nevin (2) and Hansen (4) and (16), in addition to the results of the magnetic survey of the Keene Dome.

In determining the cause of deformation, the following evidence has been considered:

1. There are about 15,000 feet of sediments in this portion of the Williston basin. The author knows of no sequences in the sedimentary section that could cause a magnetic anomaly of the magnitude found in this survey.
2. The surface structural high (Figure 2) and the geomagnetic high (Figure 1) are very nearly coincident.
3. A magnetic low exists between the magnetic highs of the Beaver Lodge field and the Capa field (4). The Capa field is north of the area of Figure 1 in the southeast corner of T 155N-R 96W.

This evidence led to the following conclusions:

1. The uplift of the sediments was probably caused by a basement deformation.
2. The basement was probably uplifted by vertical or nearly vertical faulting. This interpretation is based on Figure 3 and the known geology. By considering only the evidence presented in Figures 1 and 3, it might be possible to consider the structure as being due to a Pre-Cambrian topographic high. However, in order to have a surface expression through 15,000 feet of sediments, this hypothesis would necessitate a remant of improbable magnitude.
3. The Keene dome and the Beaver Lodge structure are separate anomalies on the more extensive Nesson anticline.

REFERENCES

1. Collier, A. J., The Nesson anticline, Williams County, North Dakota: U. S. Geol. Survey, Bull. 691, pp. 211-217, 1918.
2. Nevin, C. M., The Keene Dome, Northeast McKenzie County, North Dakota: North Dakota Geol. Survey Bull. 21, pp. 1-10, 1946.
3. Laird, W. M., Hansen, Miller, Folsom, C. B., and Anderson, S. B., Beaver Lodge and Tioga fields, North Dakota: 1955 Geological Record, Rocky Mountain Section, Amer. Assoc. Petroleum Geologists, Published by Petroleum Information, pp. 37-54, 1955.
4. Hansen, Miller, Unpublished magnetometer map and additional information on magnetic survey of Beaver Lodge field in files of North Dakota Geol. Survey.
5. Jakosky, J. J., Exploration geophysics, Second Edition, Trija Publishing Co., Los Angeles, pp. 149-155, 1950.
6. McCabe, W. S., Williston Basin paleozoic unconformities: Amer. Assoc. Petroleum Geologists Bull. Vol. 38, No. 9, pp. 1997-2010, September, 1954.
7. Laird, W. M. **et al**, op. cit, 1955.
8. McCabe, W. S., **op. cit.,** 1954.
9. Laird, W. M. et al, op. cit., 1955.
10. McCabe, W. S., **op. cit.,** 1954.
11. Nevin, C. M., **op. cit.,** 1946.
12. Peters, L. J., The direct approach to magnetic interpretation and its practical applications: Geophysics, Vol. 14, No. 3, pp. 290-320, July, 1949
13. Towse, D. F., and Anderson S. B., Summary of the Carter-Emma L. Semling No. 1 Well: North Dakota Geological Survey Circ. No. 98, December, 1954.
14. Heiland, C. A., Geophysical exploration, Second Printing, Prentice-Hall, Inc. New York, pp. 293-436, 1946.
15. Deel, S. A., and Howe, H. H., United States Magnetic Table and Magnetic Chart for 1945: U. S. Coast and Geodetic Survey, Serial No. 667, Figure 4. 1948.
16. Hansen, Miller, Personal communication pertaining to item (4) above, March 4, 1955.

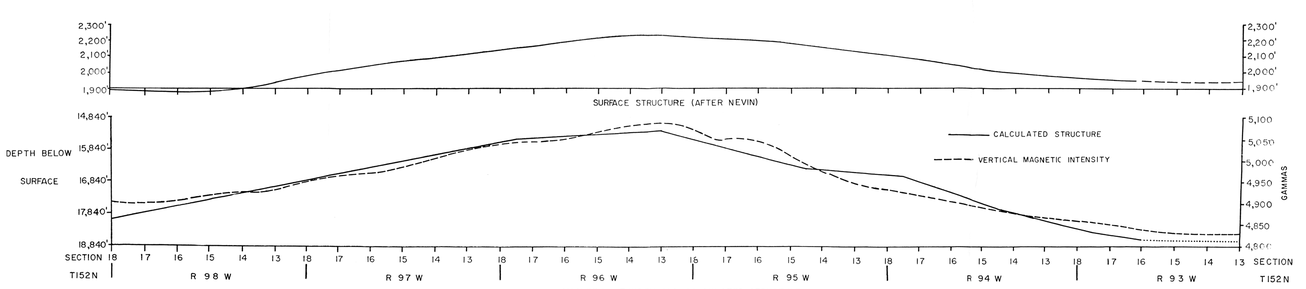

FIGURE 3, COMPARATIVE PROFILES OF VERTICAL MAGNETIC INTENSITY, CALCULATED STRUCTURE, AND SURFACE STRUCTURE