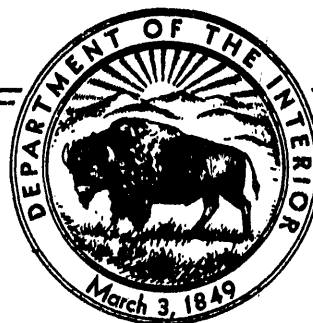


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GEOLOGICAL SURVEY CIRCULAR 97



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February 1951

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**A PRELIMINARY REPORT ON THE  
ELECTRICAL RESISTIVITY SURVEY AT  
MEDICINE LAKE, MONTANA**

By  
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# A PRELIMINARY REPORT ON THE ELECTRICAL RESISTIVITY SURVEY AT MEDICINE LAKE, MONTANA

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## ABSTRACT

In the vicinity of Medicine Lake, Montana, known information from well logs and tests on outcrops were correlated to electrical resistivity depth profiles to determine the electrical characteristics of the Fort Union formation. From the interpretations of the apparent resistivity curves of the depth profiles, the altitudes of the Fort Union formation were mapped and presented both as a contour map and as horizontal profiles. The contour map shows a bedrock channel under Medicine Lake trending to the northeast.



## INTRODUCTION

A geophysical investigation was undertaken by the Geophysics Branch, upon request of the Ground Water Branch office of the U. S. Geological Survey at Bismarck, N. Dak., to determine the depths to the Fort Union formation over a large area and also to determine the existence of a buried channel. The area investigated is in the northeast corner of Montana, in Sheridan and Roosevelt Counties, in the vicinity of Medicine Lake. (See fig. 1.) The field measurements were made during the period June 7 to July 24, 1948. The report was prepared subsequent to the interpretations of the apparent resistivity curves. The writer is grateful to Mr. Robert Vorhis, of the Bismarck Ground Water office, for assistance and cooperation in obtaining the field measurements. The geophysical work was done under the supervision of H. Cecil Spicer.

## GEOLOGY OF THE AREA<sup>1</sup>

During the Wisconsin glaciation a vast sheet of ice covered northern and eastern Montana. Upon the retreat of the ice a cover of glacial drift was deposited upon the eroded surface of the Paleocene Fort Union formation. The Fort Union consists of sandstone, shale, and lignite. The Fort Union forms the escarpment on both sides of the Big Muddy valley as far west as Redstone, Mont.

Northeast of Medicine Lake lies a broad depression bordered by terminal moraines, low ridges, and irregularly placed hills. The depression, filled with glacial drift, may be followed from Poplar on the west to Westby in the east by a chain of alkaline and fresh water lakes. Geologists state that the pre-glacial Missouri River flowed northward through this depression into the Hudson Bay.

In the vicinity of Medicine Lake, east of profile B-B' and south of profile C-C' (see figs. 5 and 6), areas covered with migrating sand dunes limited the lengths of these profiles. The origin of these dunes is traced back to the retreat of the glaciers.

<sup>1</sup>Gieserker, L. F., Soils of Sheridan County, preliminary report, Univ. of Montana, Agr. Experimental Sta. Bull. 158, April 1923.

## FIELD MEASUREMENTS

Shallow-depth profiles were run on an outcrop of the Fort Union formation to determine its electrical characteristics. The outcrop tested was in a high bluff on the south shore of Medicine Lake, about 1 mile east of State Highway 16. The Fort Union was found, on these tests, to range from 800 ohm cm. in a lignite seam to 5,430 ohm cm. in a sandy clay and gravel below the lignite. Additional correlation was obtained along profile A-A' (fig. 4) by taking depth profiles near the drill hole sites of the Ground Water Branch, the Bureau of Reclamation and the village of Froid. Two conditions typical of the survey as a whole were found as results of these correlations. The first consisted of a high-resistivity sand and gravel overlying the low-resistivity Fort Union, and second a low-resistivity till overlying the slightly higher resistivity Fort Union.

The field measurements of apparent resistivity were made with an Earth Resistivity Apparatus, a Gish-Rooney type of instrument as modified and constructed by the former Gico Company of Arlington, Va. The electrodes are copper-clad steel rods, with steel driving heads, which were driven into the earth to make the contacts for the potential and current connections. To reduce the contact resistance at the electrodes, the earth was wetted and tamped tightly against the electrodes. As the primary purpose of this investigation was to determine the depths to the Fort Union formation, depth profiling was used throughout.

To obtain the apparent resistivity curves of the depth profiles a modification of the Lee variation of the Wenner electrode configuration was used. The electrode intervals were expanded outward from the central station and three apparent resistivity observations were made on each expanded interval - one in each direction from center and one over the full interval. These observations are termed P-1, P-2, and Full curves. The apparent resistivity was computed from equation  $\rho_a = 2\pi a^2 E$  instead of the formula proposed by Lee as this spreads the curves on the graph. Bearings for the depth profiles are given for the P-1 direction. The altitudes of the depth-profile centers were made with a Taylor altimeter.

The power to operate the motor driven commutator of the instrument was supplied by the truck battery and the current to pass through the earth was provided by a bank of super "B" batteries. The fundamental technique for operating the Gish-Rooney type instrument is described<sup>2</sup> by the maker of the instrument, by Heiland,<sup>2</sup> and others.

## METHOD OF INTERPRETATION

The resistivity curves were interpreted by means of theoretical two- and three-layer curves as described in the following publications.

Roman, Irwin, How to compute tables for determining electrical resistivity of underlying beds and their application to geophysical problems; U. S. Dept. Commerce, Bur. Mines, Tech. Paper 502, 1931.

Roman, Irwin, Some interpretation of earth resistivity data; Am. Inst. Min. Met. Eng. Trans., vol. 110, p.183-200, 1934.

Roman, Irwin, Superposition in the interpretation of two-layer earth resistivity curves: U. S. Geol. Survey Bull. 927-A, 18 pp, 1941.

Watson, R. J. and Johnson, J. F., On the extension of two-layer method of interpretation of earth resistivity data to three or more layers: Geophysics, vol. 3., no. 1, pp. 7-21. Jan. 1938.

Wetzel, W. W., and McMurry, H. V., A set of curves to assist in the interpretation of the three-layer resistivity problem: Geophysics, vol. 2, no. 2, pp. 314-329, Oct. 1934.

## SUMMARY OF RESULTS

To show the altitude changes of the Fort Union formation over the entire area, a contour map of the Fort Union was prepared based on the interpreted depths from the apparent resistivity curves, (see fig. 3). The

<sup>2</sup>Heiland, C. A., Geophysical exploration, Prentice-Hall, 1940.

depth profile locations correspond to those on the map of the area, (fig. 1), and the surface contour map of the area, (fig. 2). Figures 4 through 8 are the horizontal profiles prepared from the interpretations of the apparent resistivity curves. The altitude is plotted as the abscissa and distance as the ordinate. The surface altitudes are connected by a solid line and the altitudes of the Fort Union by a dashed line.

Inspection of figure 3 shows a channel in the Fort Union which extends eastward under Medicine Lake and then turns and continues on to the northeast. The channel filling from the Big Muddy Creek to the narrow western entrance to Medicine Lake is composed of sand, gravel, and clay. (See fig. 4, profile A-A' and fig. 5, profile B-B'). Between these two profiles the downward gradient of the buried stream bed is from B-3 on profile B-B' to A-4 on profile A-A'.

Although there is an escarpment on the southern border of the channel, to the north is a gentle slope. The greatest width of the channel appears on the eastern edge of Medicine Lake where the interpretations show a broad depression with a minimum altitude on the Fort Union formation at depth profile C-6. (See fig. 6, profile C-C'). Toward the northeast the channel narrows reaching a minimum altitude on the Fort Union formations at locations 1-D-2 (see fig. 7 profile D-D' and at E-6 (see profile E-E' fig. 8). The channel filling on profiles C-C', D-D', and E-E' is mainly till. If the locations 1-D-2 and E-6 are not in the bottom of the channel, then the downward gradient of the buried streambed appears to be to the northeast. From the interpretations the lowest altitudes on the Fort Union formation, from the Big Muddy to east of the village of Dagmar, are as follows: profile B-B' 1,793 feet; profile A-A' 1,788 feet; profile C-C' 1,788 feet; profile D-D' 1,795 feet; and profile E-E' 1,789 feet.

A closer spacing of the resistivity line centers on all the profiles might have revealed lower altitudes on the Fort Union formation. However, the number of depth profiles made were not adequate to depict the definite course, width, and downward gradient of the buried channel or to show conclusively that the

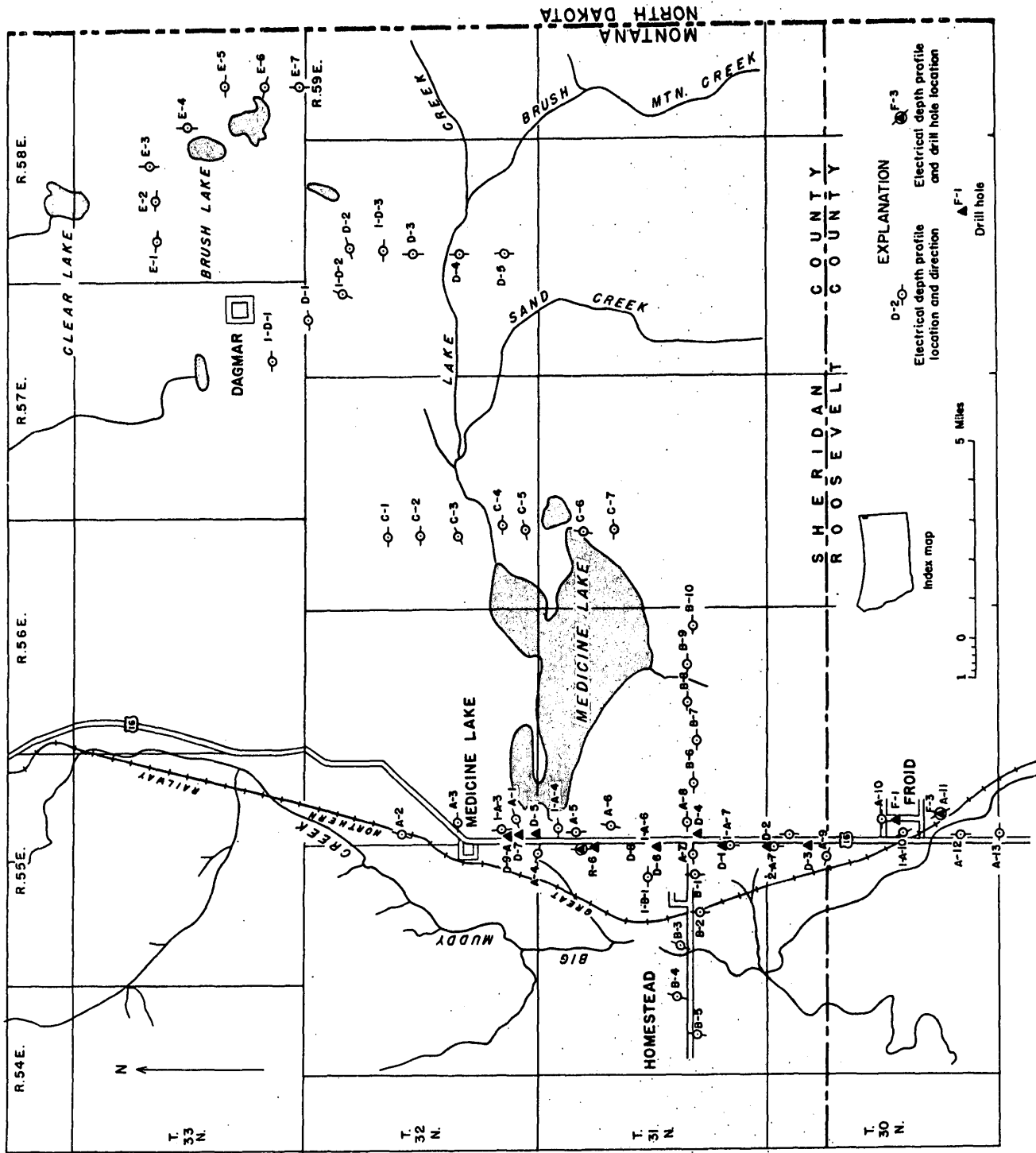


Figure 1.--Map of the Medicine Lake, Montana Area

channel in the Big Muddy is part of the one running under Medicine Lake.

Figure 9 is the graphic presentation of the well logs along profile A-A' that were used for correlation with geophysical work. The depths to the Fort Union formation in the well logs were taken from a personal communication from Mr. I. J. Witkin, U. S. Geological Survey geologist, working in this area. Despite the eroded features of the Fort Union formation and its heterogeneous composition, its trend from drill holes D-9-A to D-6 is similar to the interpreted geophysical trend from depth profiles 1-A-3 to 1-A-6. But between drill holes D-6 and D-3 the trend deviates from the resistivity interpretations in that the interpreted geophysical trend of the Fort Union is shallower than that shown by the well logs. This may be

due to the larger interval between drill holes and depth profiles at the southern end of profile A-A' or to the heterogeneous bed rock.

## CONCLUSION

From the electrical characteristics of the Fort Union formation which were interpreted in this survey, it was possible to map the changes in its altitude as well as that of the overlying materials by electrical-resistivity depth profiling in the Medicine Lake area. A much closer spacing of stations would have given a more complete picture of the bed rock surface, but the interpretations from the apparent resistivity curves show the general location of a buried channel and its probable downward gradient.



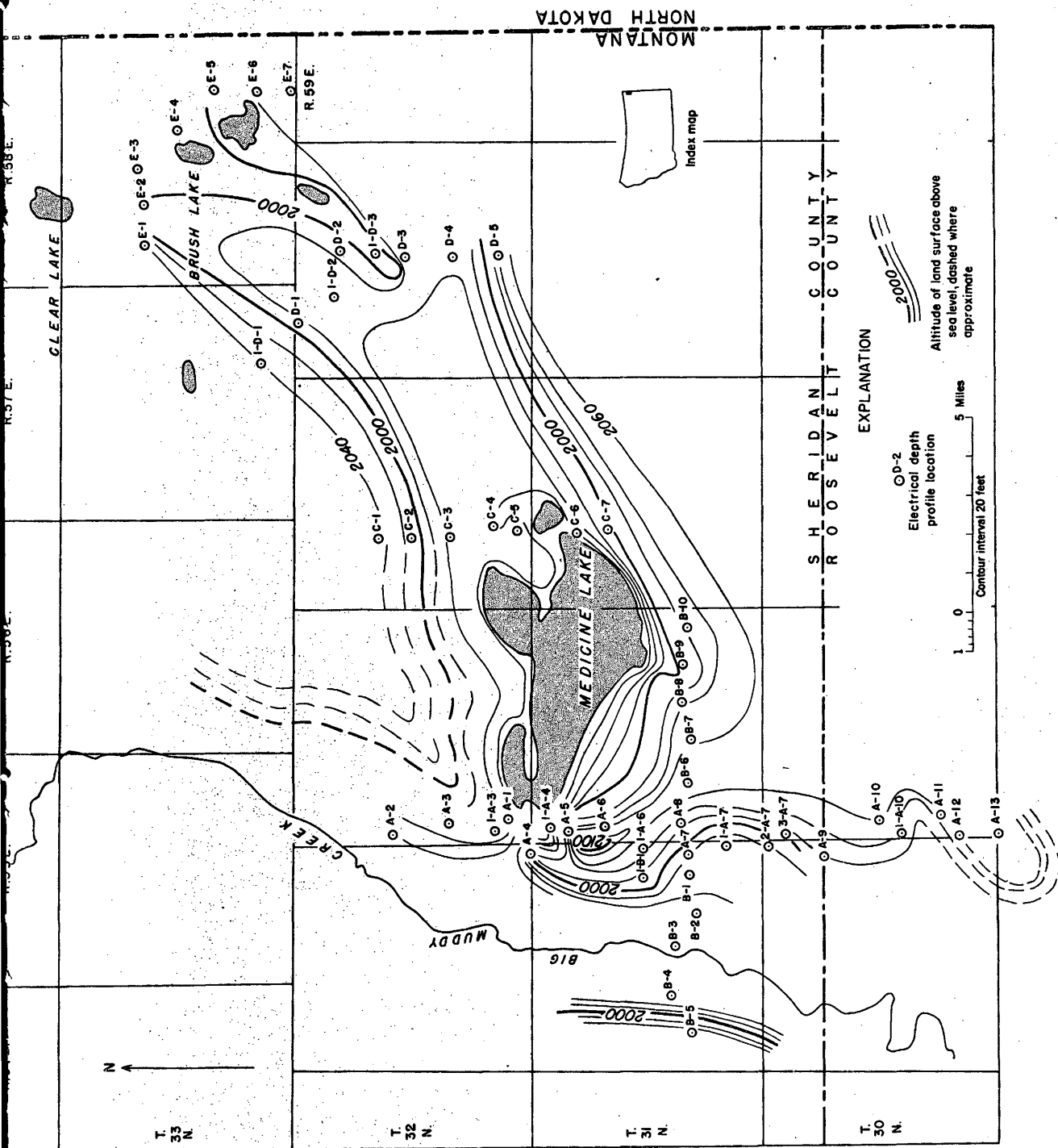


Figure 2.--Topographic Contour Map of the Medicine Lake, Montana Area  
Contour Interval 20 Feet

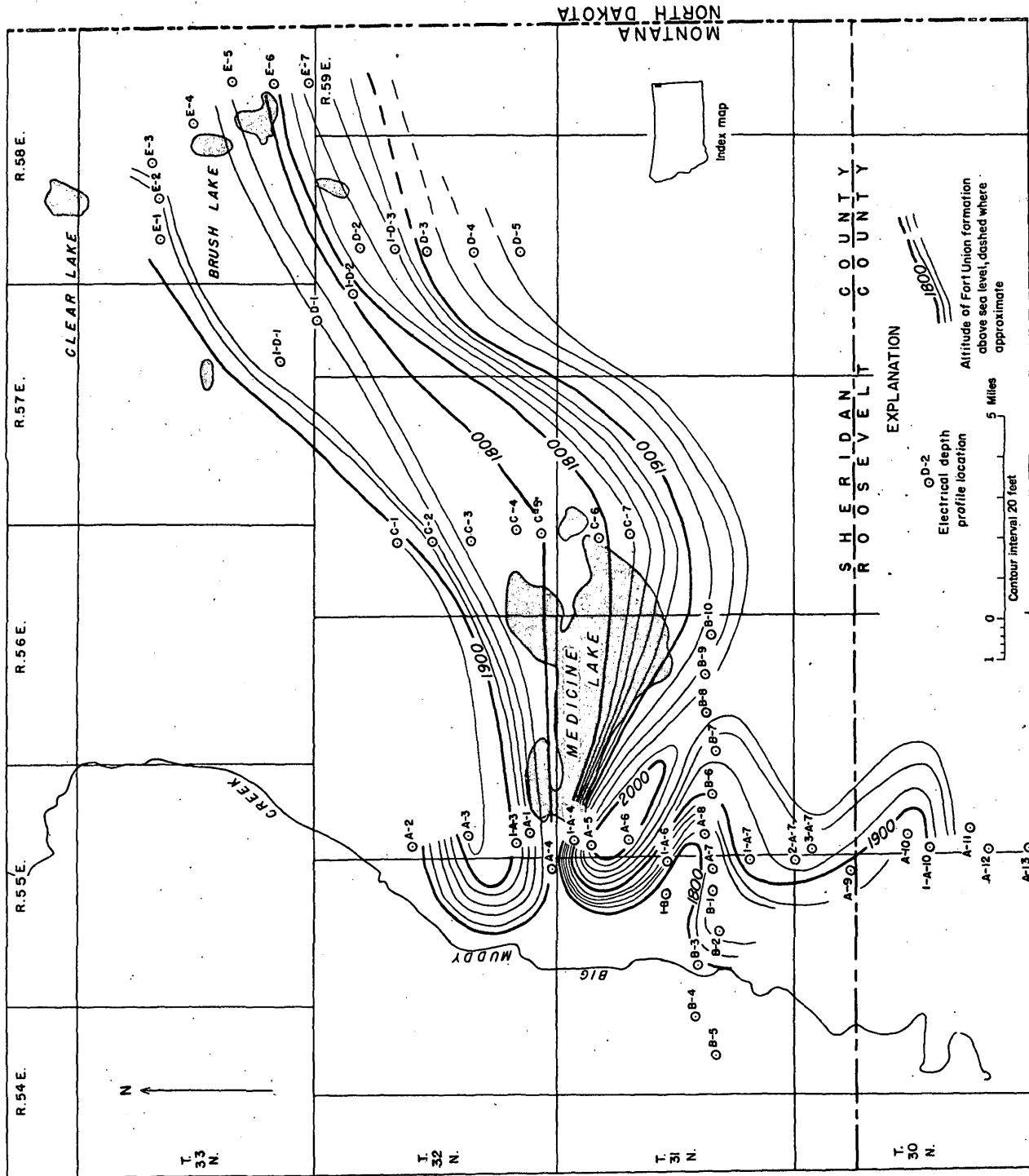


Figure 3.--Contours of the Fort Union Formation from Resistivity Results  
Medicine Lake, Montana. Contour Interval 20 feet

## APPENDIX

### *Interpretations of Apparent Resistivity Curves*

**Line A-1 6/9/48.** 0.5 mile east of State Highway 16. NE  $\frac{1}{4}$  SW  $\frac{1}{4}$  sec. 31, R. 56 E., T. 32 N., P-1, N. 72° E. Altitude 1,958 feet.

<i>Electrical depth profile.</i>	Depth (feet)
Sandy till	0-6
Sand and gravel	6-55
Sand, gravel, coal, and clay	55-135
Fort Union formation	135

**Line A-2 6/10-11/48.** East of county road and west of Great Northern Railway, along east side of ditch, NE  $\frac{1}{4}$  NW  $\frac{1}{4}$  SW  $\frac{1}{4}$  sec. 18, T. 32 N., R. 56 E. at  $\frac{1}{4}$  sec. post. P-1, S. 17° W. Altitude 1,940 feet.

<i>Electrical depth profile.</i>	
Sandy clay	0-7
Clay	7-33
Sand, gravel, and clay	33-160
Fort Union formation	160

**Line A-3 6/11/48.** 0.5 mile east of State Highway 16 along north side of road. SW  $\frac{1}{4}$  SE  $\frac{1}{4}$  sec. 19, T. 32 N., R. 56 E., P-1, S. 85° E. Altitude 1,975 feet.

<i>Electrical depth profile.</i>	
Sandy soil	0-10
Till	10-47
Fort Union formation	47

**Line 1-A-3 6/21/48.** 332.5 feet east of State Highway 16. NW  $\frac{1}{4}$  NW  $\frac{1}{4}$  sec. 31, T. 32 N., R. 56 E., 162.5 feet east of drill hole D-9, P-1, N. 2° E. Altitude 1,965 feet.

<i>Electrical depth profile.</i>	
Sandy soil	0-2
Sand	2-8
Coal, clay, sand, and gravel	8-75
Fort Union formation	75

**Line A-4 6/14/48.** 0.3 mile west of State Highway 16 along south side of trail. NE  $\frac{1}{4}$  NW  $\frac{1}{4}$  sec. 1, T. 31 N., R. 56 E., 0.8 mile west of drill hole 0.5, P-1, S. 85° E. Altitude 1,943 feet.

<i>Electrical depth profile</i>	Depth (feet)
Till	0-10
Sand, gravel, and clay	10-155
Fort Union formation	155

**Line 1-A-46/25/48.** South of Medicine Lake and 0.26 mile east of State Highway 16 SW  $\frac{1}{4}$  NE  $\frac{1}{4}$  sec. 6, T. 31 N., R. 56 E., 1/8 mile south of drill hole number 5 (not the same as drill hole 5), P-1, N. 90° E. Altitude 2,028 feet.

<i>Electrical depth profile</i>	
Sand and gravel	0-2
Till	2-35
Fort Union formation	35

**Line A-5 6/14/48.** 235 feet east of State Highway 16 on sec. line near northwest corner of sec. 7., T. 31 N., R. 56 E., P-1, N. 2° W. Altitude 2,083 feet.

<i>Electrical depth profile</i>	
Sandy soil	0-3
Till	3-11
Sand and gravel	11-43
Fort Union formation	43

**Line A-6 6/15/48.** 0.3 mile east of State Highway 16, on north side of road southwest corner of sec. 7, T. 31 R. 56 E., P-1, S. 88° E. Altitude 2,072 feet.

<i>Electrical depth profile</i>	
Sandy soil	0-3
Till	3-13
Sand and gravel	13-53
Fort Union formation	53

*Line 1-A-6 6/15/48.* 220 feet west of State Highway 16 and 56 feet east of drill hole D-8, SE  $\frac{1}{4}$  SE  $\frac{1}{4}$  sec. 13, T. 31 N., R. 55 E., P-1, N. 2° E. Altitude 2,040 feet.

<i>Electrical depth profile</i>	Depth (feet)
Sandy soil	0-4
Till	4-16
Gravel, sand, coal, and clay	16-240
Fort Union formation	240

*Line A-7.* C-1 was set wrong most all the way. Could not find the error so the station abandoned.

*Line 1-A-7 6/22/48.* 40 feet west of State Highway 16 and 1 mile south of Homestead road. 26 feet east-southeast of drill hole D-1. Southeast corner of SE  $\frac{1}{4}$  SE  $\frac{1}{4}$  sec. 36, T. 31 N., R. 55 E., P-1, N. 4° E. Altitude 1,970 feet.

*Electrical depth profile*

Silty clay	0-14
Till	14-85
Fort Union formation	85

*Line 2-A-7 6/22/48.* 200 feet south of Sheridan County line and 30 feet east of State Highway 16. Northeast corner of NE  $\frac{1}{4}$  NE  $\frac{1}{4}$  sec. 1, T. 30 N., R. 55 E., P-1, N. 0° E. Altitude 1,983 feet. 194 feet southeast of drill hole D-2.

*Electrical depth profile*

Silty clay with gravel	0-5
Clay, sand, and gravel	5-18
Till	18-55
Fort Union formation	55

*Line 3-A-7 6/25/48.* 0.5 mile south of Sheridan County line and 30 feet east of State Highway 16. Southwest corner of SW  $\frac{1}{4}$  NW  $\frac{1}{4}$  sec.

6, T. 30 N., R. 56 E., P-1, N. 0° E. Altitude 2,000 feet. 0.4 mile south of drill hole D-3.

*Electrical depth profile*

<i>Electrical depth profile</i>	Depth (feet)
Sandy clay	0-7
Till	7-15
Gravel and clay	15-70
Fort Union formation	70

*Line A-8 6/16/48.* 0.5 mile east of State Highway 16 on north side of road near  $\frac{1}{2}$  sec. line 19, T. 31 N., R. 55 E., P-1, S. 88° E. Altitude 2,028 feet. 0.4 mile northeast of drill hole D-4.

*Electrical depth profile*

Sandy clay	0-5
Till	5-19
Gravel, sand, coal, and clay	19-220
Fort Union formation	220

*Line A-9 6/16/49.* 0.4 mile west of State Highway 16 on north side of road. SW  $\frac{1}{4}$  SE  $\frac{1}{4}$  sec. 12, T. 30 N., R. 55 E., P-1, S. 85° E. Altitude 2,020 feet.

*Electrical depth profile*

Sandy clay	0-4
Till	4-66
Sand and gravel	66-130
Fort Union formation	130

*Line A-10 6/17/48.* North of Froid, Mont., and 0.5 mile east of State Highway 16 on north side of road, SE  $\frac{1}{4}$  SW  $\frac{1}{4}$  sec. 18, T. 30 N., R. 56 E., P-1, S. 88° E. Altitude 2,065 feet.

*Electrical depth profile*

Sandy soil with gravel	0-4
Till	4-185
Fort Union formation	185

*Line 1-A-10 6/24/48.* 0.3 mile east of State Highway 16, 703 feet south-southeast and 15 feet east of Great Northern Railway. NW  $\frac{1}{4}$  SW  $\frac{1}{4}$  sec. 19, T. 30 N., R. 56 E., P-1, N. 30° W. Altitude 2,025 feet.

<i>Electrical depth profile</i>	Depth (feet)
Sandy soil	0-6
Till	6-12
Gravel and clay	12-25
Till	25-110
Fort Union formation	110

*Line A-11 6/17/48.* SW  $\frac{1}{4}$  NE  $\frac{1}{4}$  sec. 30, T. 30 N., R. 56 E., P-1, N. 26° W. Altitude 2,040 feet. 56 feet southwest of Froid drill hole F-3.

<i>Electrical depth profile</i>	
Sandy soil	0-3
Till	3-15
Gravel and clay	15-130
Fort Union formation	130

*Line A-12 6/18/48.* 200 feet east of State Highway 16 on sec. line SW  $\frac{1}{4}$  SW  $\frac{1}{4}$  sec. 30, T. 30 N., R. 55 E., P-1, N. 2° E., Altitude 2,075 feet.

<i>Electrical depth profile</i>	
Sandy soil	0-4
Till	4-75
Fort Union formation	75

*Line A-13 6/18/49.* 0.3 mile east of State Highway 16 on north side of road. SW  $\frac{1}{4}$  SW  $\frac{1}{4}$  sec. 31, T. 30 N., R. 56 E., P-1, S. 88° E. Altitude 2,065 feet.

<i>Electrical depth profile</i>	
Sand	0-4
Till	4-90
Fort Union formation	90

*Line 1-B-1 6/21/48.* 1 mile west of State Highway 16 and 1.4 miles northeast of Homestead. SW  $\frac{1}{4}$  SW  $\frac{1}{4}$  SW  $\frac{1}{4}$  sec. 13, T. 31 N., R. 55 E., P-1, S. 88° E. Altitude 2,017 feet.

<i>Electrical depth profile</i>	Depth (feet)
Silty clay	0-6
Till	6-12
Gravel and clay	12-165
Fort Union formation	165

*Line B-1 6/25/48.* 1 mile west of State Highway 16 and 0.2 mile south of Homestead road. NW  $\frac{1}{4}$  NW  $\frac{1}{4}$  sec. 25, T. 31 N., R. 55 E., P-1, N. 0° E. Altitude 1,972 feet.

<i>Electrical depth profile</i>	
Silty clay	0-4
Till	4-6
Gravel and clay	6-24
Till	24-120
Fort Union formation	120

*Line B-2 6/26/48.* 2 miles west of State Highway 16 and 0.24 mile south of Homestead on east side of road. SW  $\frac{1}{4}$  NW  $\frac{1}{4}$  NW  $\frac{1}{4}$  sec. 26, T. 31 N., R. 55 E., P-1, N. 0° E. Altitude 1,947 feet.

<i>Electrical depth profile</i>	
Sandy clay and silt	0-4
Till	4-6
Gravel and clay	6-30
Till	30-95
Fort Union formation	95

*Line B-3 6/28/48.* 2.7 miles west of State Highway 16 and 700 feet north of Homestead road. SE  $\frac{1}{4}$  SW  $\frac{1}{4}$  sec. 22, T. 31 N., R. 55 E., P-1, N. 12° E. Altitude 1,948 feet.

<i>Electrical depth profile</i>	
Clay and gravel	0-3
Till	3-10
Gravel and clay	10-155
Fort Union formation	155

*Line B-4 6/28/48.* 4.1 miles west of State Highway 16 and 1,520 feet north of Homestead road. At the foot of west valley wall of Big Muddy Creek, NE  $\frac{1}{4}$  SE  $\frac{1}{4}$  SE  $\frac{1}{4}$  sec. 20, T. 31 N., R. 55 E., P-1, N.  $10^{\circ}$  E. Altitude 1,947 feet.

<i>Electrical depth profile</i>	Depth (feet)
Alluvial soil	0-7
Gravel and clay	7-29
Till	29-90
Fort Union formation	90

*Line B-5 6/28/48.* 5 miles west of State Highway 16 and 0.15 mile south of Homestead road. NW  $\frac{1}{4}$  NW  $\frac{1}{4}$  sec. 20, T. 31 N., R. 55 E., P-1, N.  $5^{\circ}$  E. Altitude 2,057 feet.

<i>Electrical depth profile</i>	
Sandy soil	0-1
Clay and gravel	1-8
Till	8-50
Gravel	50-200
Fort Union formation	200

*Line B-6 7/8/48.* 1.5 miles east of State Highway 16 on south side of road. NW  $\frac{1}{4}$  NE  $\frac{1}{4}$  sec. 29, T. 31 N., R. 56 E., P-1, N.  $90^{\circ}$  E. Altitude 2,075 feet.

<i>Electrical depth profile</i>	
Sandy soil	0-5
Till	5-15
Sand	15-170
Fort Union formation	170

*Line B-7 7/8/48.* 2.5 miles east of State Highway 16 and 0.1 mile south of sec. line road. NW  $\frac{1}{4}$  NE  $\frac{1}{4}$  sec. 28, T. 31 N., R. 56 E., P-1, N.  $88^{\circ}$  E. Altitude 2,045 feet.

<i>Electrical depth profile</i>	
Sandy soil	0-4
Till	4-19
Sand	19-40
Till	40-54
Sand and gravel	54-150
Fort Union formation	150

*Line B-8 7/9/48.* 3.5 miles east of State Highway 16, SW  $\frac{1}{4}$  SE  $\frac{1}{4}$  sec. 22, T. 31 N., R. 56 E., P-1, N.  $90^{\circ}$  E. Altitude 2,025 feet.

<i>Electrical depth profile</i>	Depth (feet)
Sandy soil	0-3
Till	3-7
Gravel and clay	7-17
Till	17-48
Fort Union formation	48

*Line B-9 7/12/48.* 4.5 miles east of State Highway 16, NE  $\frac{1}{4}$  NW  $\frac{1}{4}$  sec. 23, T. 31 N., R. 56 E., P-1, N.  $90^{\circ}$  E. Altitude 2,005 feet.

<i>Electrical depth profile</i>	
Sandy soil	0-12
Till	12-63
Fort Union formation	63

*Line B-10 7/13/48.* 5.5 miles east of State Highway 16, NW  $\frac{1}{4}$  NE  $\frac{1}{4}$  sec. 25, T. 31 N., R. 56 E., P-1, N.  $90^{\circ}$  E. Altitude 2,025 feet.

<i>Electrical depth profile</i>	
Sandy soil	0-4
Till	4-7
Gravel and clay	7-90
Fort Union formation	90

*Line C-1 6/29/48.* 6 miles east of State Highway 16, 30 feet southeast of corner NE  $\frac{1}{4}$  NE  $\frac{1}{4}$  sec. 17, T. 32 N., R. 57 E., P-1, S.  $88^{\circ}$  E. Altitude 2,048 feet.

<i>Electrical depth profile</i>	
Sandy soil	0-4
Till	4-12
Gravel and clay	12-125
Fort Union formation	125

*Line C-2 6/29/48.* SE  $\frac{1}{4}$  SE  $\frac{1}{4}$  sec. 17, T. 32 N., R. 57 E., P-1, S.  $85^{\circ}$  E. Altitude 2,008 feet.

<i>Electrical depth profile</i>	Depth (feet)
Gravel and clay	0-6
Till	6-25
Gravel and clay	25-155
Fort Union formation	155

*Line C-3 6/30/48.* 0.1 mile north of SE  $\frac{1}{4}$  SE  $\frac{1}{4}$  sec. 20, T. 32 N., R. 57 E., P-1, N. 70° E. Altitude 1,958 feet.

*Electrical depth profile*

Sandy soil	0-11
Sand	11-42
Till	42-147
Fort Union formation	147

*Line C-4 7/1/48 and 7/13/48.* 0.15 mile east of sec. line road, NW  $\frac{1}{4}$  NW  $\frac{1}{4}$  sec. 33, T. 32 N., R. 57 E., P-1, N. 88° E. Altitude 1,948 feet.

*Electrical depth profile*

Sandy soil	0-5
Till	5-150
Fort Union formation	150

*Line C-5 7/2/48.* 0.6 mile south of C-4. NW  $\frac{1}{4}$  SW  $\frac{1}{4}$  sec. 33, T. 32 N., R. 57 E., P-1, N. 78° E. Altitude 1,948 feet.

*Electrical depth profile*

Clay or alluvium	0-24
Sand, gravel, and clay	24-145
Fort Union formation	145

*Line C-6 7/1/48.* On the east shore of Medicine Lake. 1,000 feet south of sec. corner NW  $\frac{1}{4}$  NW  $\frac{1}{4}$  sec. 9, T. 31 N., R. 57 E., P-1, N. 8° E. Altitude 1,938 feet.

*Electrical depth profile*

Sand and gravel	0-3
Clay and gravel	3-38
Till	38-150
Fort Union formation	150

*Line 7 7/2/48.* 510 feet east of sec. line SW  $\frac{1}{4}$  SW  $\frac{1}{4}$  sec. 9, T. 31 N., R. 57 E., P-1, N. 90° E. Altitude 1,998 feet.

*Electrical depth profile*

Sandy clay	0-6
Till	6-27
Gravel and clay	27-180
Fort Union formation	180

*Line D-1 7/6/48.* 40 feet east of sec. marker NE  $\frac{1}{4}$  NW  $\frac{1}{4}$  sec. 5, T. 32 N., R. 58 E., P-1, N. 86° E. Altitude 1,995 feet.

*Electrical depth profile*

Sandy soil	0-5
Sand and clay	5-10
Till	10-155
Fort Union formation	155

*Line 1-D-1 7/13/48.* NW  $\frac{1}{4}$  NW  $\frac{1}{4}$  sec. 35, T. 33 N., R. 58 E., P-1, N. 90° E. Altitude 2,035 feet.

*Electrical depth profile*

Sandy soil	0-7
Till	7-37
Gravel and clay	37-187
Fort Union formation	187

*Line D-2 7/19/48.* NW  $\frac{1}{4}$  NW  $\frac{1}{4}$  sec. 10, T. 32 N., R. 58 E., P-1, N. 67° E. Altitude 1,985 feet.

*Electrical depth profile*

Sand	0-17
Till	17-140
Fort Union formation	140

*Line 1-D-2 7/15/48.* 650 feet east of road SW  $\frac{1}{4}$  SW  $\frac{1}{4}$  sec. 4, T. 32 N., R. 58 E., P-1, N. 16° E. Altitude 1,965 feet.

*Electrical depth profile*

Gravel and some clay	0-6
Gravel	6-35
Clay	35-170
Fort Union formation	170

*Line D-3 7/19/48. SW ¼ SW ¼ sec. 15, T. 32 N., R. 58 E., P-1, N. 0° E. Altitude 1,970 feet.*

	Depth (feet)
<i>Electrical depth profile</i>	
Sand	0-11
Till	11-57
Fort Union formation	57

*Line 1-D-3 7/15/48. 0.1 mile east sec. corner SW ¼ SW ¼ sec. 10, T. 32 N., R. 58 E., P-1, N. 90° E. Altitude 2,010 feet.*

<i>Electrical depth profile</i>	
Sand	0-6
Till	6-50
Gravel and clay	50-175
Fort Union formation	175

*Line D-4 7/16/48. 0.15 mile north of sec. corner on east side of road, SW ¼ SW ¼ sec. 22, T. 32 N., R. 58 E., P-1, N. 0° E. Altitude 1,977 feet.*

<i>Electrical depth profile</i>	
Sand	0-2
Till	2-40
Fort Union formation	40

*Line D-5 7/15/48. 0.15 mile south of sec. corner NW ¼ NW ¼ sec. 34, T. 32 N., R. 58 E., P-1, N. 0° E. Altitude 2,047 feet.*

<i>Electrical depth profile</i>	
Sand, clay	0-2
Till	2-13
Gravel	13-50
Fort Union formation	50

*Line E-1 7/19-20-21/48. 50 feet west of sec. corner NE ¼ NE ¼ sec. 18, T. 33 N., R. 58 E., P-1, N. 90° E. Altitude 2,056 feet.*

#### *Electrical depth profile*

	Depth (feet)
Sandy clay	0-4
Till	4-9
Gravel and clay	9-45
Gravel	45-165
Fort Union formation	165

*Line E-2 7/21/48. NW ¼ NW ¼ sec. 16, T. 33 N., R. 58 E., P-1, N. 90° E. Altitude 1,990 feet.*

<i>Electrical depth profile</i>	
Clay and possibly some gravel	0-15
Gravel	15-110
Fort Union formation	110

*Line E-3 7/21-22/48. 0.15 mile north of sec. corner SE ¼ SE ¼ sec. 9, T. 33 N., R. 58 E., P-1, 0° E. Altitude 2,010 feet.*

<i>Electrical depth profile</i>	
Sandy clay	0-10
Till	10-75
Gravel and clay	75-160
Fort Union formation	160

*Line E-4 7/22/45. SE ¼ SE ¼ sec. 15, T. 33 N., R. 58 E., northeast of Brush Lake, P-1, N. 0° E. Altitude 2,026 feet.*

<i>Electrical depth profile</i>	
Sandy clay	0-6
Sand	6-23
Till	23-160
Fort Union formation	160

*Line E-5 7/22/48. 500 feet east of north-south road. SE ¼ SE ¼ sec. 23, T. 33 N., R. 58 E., P-1, N. 90° E. Altitude 1,996 feet.*

<i>Electrical depth profile</i>	
Sandy clay	0-7
Sand	7-17
Till	17-180
Fort Union formation	180



		Depth (feet)
<i>Line E-6 7/23/48. In sag between two kettle lakes. NE ¼ NE ¼ sec. 35, T. 33 N., R. 58 E., P-1, S. 85° E. Altitude 1,976 feet.</i>		
	Depth (feet)	
Sand	0-4	Gray sandy clay with some coal and gravel fragments 211-226
Till	4-19	Brown clay 226-228
Gravel and clay	19-187	Gray sandy clay 228-252
Fort Union formation	187	Coal 252-256
		Gray clay and coal fragments 256-264
		Gray clay 264-270
		Gray clay with some hard coal strips 270-281
		Coal with some clay 281-294
		Gray clay 294-295

*Line E-7 7/23/48. 0.12 mile north of sec. corner SE ¼ SE ¼ sec. 35, T. 33 N., R. 58 E., P-1, N. 0° E. Altitude 1,966 feet.*

#### *Electrical depth profile*

Clay	0-7
Gravel and clay	7-14
Till	14-45
Gravel and clay	45-110
Fort Union formation	110

#### *Well Logs*

*D-1 Ground Water Branch Drill Hole (D-1) on map. SE ¼ SE ¼ sec. 25, T. 31 N., R. 55 E. Altitude 1,970.29 feet.*

Tight soil	0-1.5
Yellow clay and rocks	1.5-8
Brown clay, some pebbles in layers	8-16
Yellow clay with some pebbles	16-37
Gray clay	37-67
Gray clay with some very fine particles of sand	67-84
Gray clay with some coal and fine sand particles	84-130
Gray clay	130-167
Gravel with coal fragments	167-176
Very sandy gray clay	176-188
Gravel	188-190
Sandy gray clay	190-192
Gravel	192-211

*D-2 Ground Water Branch Drill Hole (D-2) on map. SE ¼ SE ¼ sec. 36, T. 31 N., R. 55 E. Altitude 1,990.70 feet.*

Surface	0-1.5
Gypsum	1.5-4
Fine sand with some clay and rock	4-9
Sandy clay with gravel mixed in	9-44
Blue clay with strips of brown clay, some rock	44-67
Blue clay with strip of brown clay, and some gravel	67-110
Strips of blue clay, fine sand, and some gravel	110-140
Strips of blue clay, fine sand, gravel, and coal	140-150
Strips of coal, blue clay, and some gravel	150-155
Strips of coal, gravel, and blue clay	155-160
Strips of blue and brown clay and gravel	160-167
Strips of blue and brown clay mixed with some gravel and coal	167-186
Coal with strips of clay	186-197
Brown and gray clay with some coal	197-200
Gray clay mixed with brown clay, bentonite, coal, and gravel	200-209
Gray clay with brown sandy clay, rocks, and coal	209-214
Hardstone	214-215

*D-3 Ground Water Branch Drill Hole (D-3) on map.*  
SE ¼ SE ¼ sec. 1, T. 30 N., R. 55 E. Altitude 1,988.07 feet.

	Depth (feet)
Surface	0-2
Brown sandy clay mixed with gravel and rock	2-31
Gray sandy clay mixed with gravel	31-46
Gray clay mixed with some gravel	46-100
Gray sandy clay mixed with gravel and coal	100-120
Gray clay mixed with coal and some gravel	120-164
Gravel and boulders, (loose)	164-170
Coal	170-173
Boulders and gravel	173-175
Gray clay with coal mixed in	175-181
Brown-gray shale mixed with coal	181-185
Light-gray sandy shale	185-190

*D-4 Ground Water Branch Drill Hole (D-4) on map.*  
NW ¼ NW ¼ sec. 30, T. 31 N., R. 56 E. Altitude 2,007.06 feet.

Soil	0-2
Sandy yellow clay with a few large rock and pebbles	2-15
Sandy yellow clay with a few pebbles	15-35
Gray-blue clay with few pebbles	35-76
Gravel and coal	76-83
Gray clay	83-97
Gray clay with strips of coal	97-101
Gray clay	101-124
Gray sandy clay with pebbles in it	124-142
Coal with some clay in it	142-147
Light-gray clay	147-156
Soft light-gray clay with pebbles in it	156-170
Light-gray clay	170-181
Coal with some clay	181-185
Gray-brown clay	185-191
Coal	191-194
Shale	194-195
Gray clayey sand, cross-bedded	195-203

*D-5 Ground Water Branch Drill Hole (D-5) on map.*  
SW ¼ SW ¼ sec. 31, T. 32 N., R. 56 E. Altitude 1,937.54 feet.

	Depth (feet)
Surface	0-4
Yellow clay	4-10
Yellow sandy clay, mixed with gravel	10-24
Fine sand	24-30
Fine sand with strips of coal and some clay	30-54
Sandy clay and brown clay mixed with coal and gravel	54-66
Gray clay mixed with some gravel	66-72
Gray clay with strips of sand	72-80
Gray clay mixed with gravel	80-94
Fine sand	94-100
Fine sand with strips of fine sandy clay	100-115
Gray sandy clay with some fine sand strips	115-120
Gray clay mixed with gravel	120-127
Gray sandy clay mixed with gravel and coal, and strips of fine sand	127-138
Gray sandy clay mixed with gravel and coal	138-151
Gravel and boulders	151-153
Gray sandy clay	153-156
Gray sandy clay with strips of gravel	156-161
Gravel and boulders with strips of gray sandy clay and coal	161-170
Boulders and gravel	170-184
Hard gray limestone	184-186
Small strips of hard gray limestone and gray clay	186-190
Gray clay with strips of gray limestone	190-194
Coal	194-198
Strips of coal and gray sandy clay	198-210

*D-6 Ground Water Branch Drill Hole (D-6) on map.*  
NE ¼ NE ¼ sec. 24, T. 31 N., R. 55 E. Altitude 2,037.68 feet.

	Depth (feet)
Surface	0-2
Sandy yellow clay	2-6
Yellow sandy clay with pebble and rock in it	6-19
Very coarse gravel	19-37
Medium gravel and fine sand	37-45
Clay	45-51
Gravel and fine sand	51-86
Yellow sandy clay	86-94
Gravel, coarse	94-95

*D-7 Ground Water Branch Drill Hole (D-7) on map.*  
SW ¼ SW ¼ sec. 31, T. 32 N., R. 56 E. Altitude 1,936.96 feet.

Surface	0-1
Brown clay with some rock in it	1-14
Blue clay	14-33
Blue clay with strips of sand and gravel	33-37
Fine gravel with strips of clay	37-40
Gravel	40-55
Gravel and sand	55-65
Fine sand with gravel and coal	65-70
Fine sand and coal	70-75
Fine sand with gravel and coal	75-90
Coal with sand and some gravel	90-100
Coarse round gravel with mixed coal	100-120
Coal with sand and gravel and small strips of clay	120-140
Coarse gravel mixed with coal	140-156
Gray clay with strips of gravel and coal	156-170
Gravel and coal	170-180
Coarse gravel with some coal and boulder	180-189.5
Brown shale	189.5-192
Gray and light-gray clay	192-205
Coal with some strips of gray clay	205-214
Gray clay with coal strips	214-220
Strips of soft and hard coal, with strips of brown sandy clay	220-229
Brown sandy clay	229-230

*D-8 Ground Water Branch Drill Holes (D-8) on map.*  
SE ¼ SE ¼ sec. 13, T. 31 N., R. 55 E. Altitude 2,039.38 feet.

	Depth (feet)
Soil	0-2
Sandy yellow clay with pebbles in it	2-22
Coarse gravel	22-36
Sandy yellow clay	36-47
Gravel	47-54
Fine sand and clay	54-65
Gravel	65-71
Gravel with some clay	71-74
Gravel	74-83
Gravel with strips of yellow clay	83-113
Blue clay	113-116
Sandy blue clay	116-139
Blue clay and coal	139-145
Coal	145-150
Gray clay	150-170
Gray clay some gravel and sand	170-182
Gray clay	182-190
Brown shale	190-195

*D-9-A Ground Water Branch Drill Hole (D-9) on map.*  
NW ¼ NW ¼ sec. 31, T. 32 N., R. 56 E. Altitude 1,969.34 feet.

Soil	0-2
Fine sand	2-17
Yellow clay with some gravel	17-27
Fine silty sand, some coal	27-33
Very fine sand with some coal	33-44
Fine sand	44-68
Gray sandy clay	68-75
Gray clay and fine sand with some coal fragments	75-93
Gray clay with some gravel	93-104
Gray clay with coal fragments	104-134
Gravel	134-165
Fine gravel and coal fragments	165-198
Gravel with much coal	198-207
Coal	207-215
Gray clay	215-218
Coal	218-225

*R-6 Bureau of Reclamation Drill Hole (R-6) on map.*  
SE ¼ NE ¼ sec. 12, T. 31 N., R. 55 E. Altitude 2,101 feet.

Fill	0-25
Sand and gravel	26-91
Fort Union formation	92

*F-3 Froid Drill Hole (F-3) on map.*  
SW  $\frac{1}{4}$  NE  $\frac{1}{4}$  sec. 30, T. 30 N., R. 56 E. Altitude 2,025 feet.

	Depth (feet)
Brown silty dry sand	0-2
Sand, fine to coarse derived from drift	2-12
Gravelly clayey gray till	12-41
Yellow sand	41-42
Gravelly clayey gray till	42-78

*F-1 Froid Drill Hole (F-1) on map.*  
NE  $\frac{1}{4}$  SE  $\frac{1}{4}$  NW  $\frac{1}{4}$  sec. 19, T. 30 N., R. 56 E. Altitude 2,040 feet.

Sand	0-20
Clay and rocks	20-70
Sand and clay	70-80
Clay	80-115
Clay and sand	115-120
Clay	120-180
Clay, sand, and rocks	180-192
Clay and gravel	192-197

Clay, sand, and rocks	197-220
Coal and clay	220-225
Clay	225-272
Clay, coal, and rocks	272-276
Clay	276-284
Rock	284-289
Clay and rocks	289-333
Rock	333-334
Clay, rocks, and some coal	334-355
Clay and coal	355-375
Clay and rocks	375-427
Sandstone and clay	427-495
Sand, clay, rocks, and some coal	495-560
Clay	560-570
Sandstone	570-580
Clay and coal	580-618
Coal and some clay	618-670
Clay and coal	670-690
Clay and coal	690-695
Coal	695-715
Rock	715-720
Clay hard	720-740
Clay, sand, and coal	740-800