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A GLACIAL OUTWASH STUDY IN SOUTH DAKOTA

by

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University of South Dakota
Vermillion, South Dakota
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A THESIS

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INTRODUCTION

This report summarizes the detailed investigation of a glacial outwash in Douglas County near the town of Delmont, South Dakota. The purpose of the investigation was primarily to determine the potential resources of shallow ground water in this area in South Dakota. A detailed study of the amount and economic value of the sands and gravels is also important as possible industrial aggregate and for geological interpretation. This project was done in conjunction with the South Dakota State Geological Survey in the search for possible new water resources and greater conservation of other known resources. A detailed study was made of the sedimentation characteristics, and an attempt was made to correlate the outwash stratigraphically with other Pleistocene deposits within the state of South Dakota. Since the Carl A. Bays Resistivity Instrument and its uses are virtually unknown to many geologists as a means of exploration and development of geologic resources, a full description of the function of the instrument and the methods of its use are included in this report.

The field work for this investigation was completed during the summer of 1954 while the author was employed by the South Dakota State Geological Survey. Since then, four field trips have been made to the outwash and adjacent areas in order to complete the study of the glacial outwash and to further the study of the regional geology. The drafting of the maps and several of the plates was nearly finished during the summer of 1955. Laboratory and office work was completed during the autumn months of 1955.

An attempt has been made by the author to review all the published information on the Pleistocene geology of eastern South Dakota. Of special interest is the United States Geological Survey Professional Paper number 262, Pleistocene Geology of Eastern South Dakota by Richard Foster Flint. Also, many of the South Dakota State Geological Survey Bulletins dealing with water resources and sand and gravel surveys have been referred to. Unfortunately, no thorough study has been made heretofore of the outwash. The Delmont Glacial Outwash was included in a soils map of Douglas County, South Dakota, published by the Department of Agriculture in 1923. An interesting parallelism can be noted between this map and the map included in this report.

Underground water tables have been reported as lowering over most of the United States, alarmingly so in many areas. The average drop from Texas to California in recent years has been forty feet. Wells in Atlantic City, New Jersey, used to flow at twenty to twenty-five feet above sea level. Now the ground water level has dropped to eighty-five feet below sea level. In parts of Arizona, it is dropping at a rate of five feet a year. Most of the artesian wells in South Dakota are drilled into either the Dakota or Lakota sands. Most of these wells formerly flowed. For example, Redfield, South Dakota, got its electricity from generators propelled by artesian pressure. Today these wells have to be pumped. Artesian water is not quickly replaced. It has been estimated that four hundred years are required for a drop of water to reach Pierre, near the center of South Dakota, from the Black Hills hogbacks, the source area for most of the artesian water in South Dakota, (Berg, 1924). If the present rate of consumption continues, many areas within the United States will be without water. Many communities are desperate now. With such conditions prevailing, any investigation dealing with ground water is important.

ACKNOWLEDGEMENTS

The author is indebted to the South Dakota State Geological Survey staff for helpful support in the investigation of the area and for aid rendered in compiling this report. Dr. E. P. Rothrock, State Geologist of South Dakota, created the opportunity both for the investigation and the completion of this report. His personal advice and support were invaluable in completing this report.

The author wishes to express his gratitude to Mr. Akeley Miller, professor of physics at the University of South Dakota, who was employed by the South Dakota State Geological Survey as operator of the Resistivity Instrument. His help with the explanation of the instrument and its function were of great value in the compilation of this report.

The author is indebted to the geology staff at the University of Nebraska, especially Dr. A. L. Lugn, whose guidance has been invaluable in completing this project.

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GEOGRAPHY AND PHYSIOGRAPHY

The Delmont Glacial Outwash is located almost entirely within Douglas County, South Dakota, three miles west of the small town of Delmont. The southernmost extremity extends into Charles Mix County. U. S. Highway number 18 extends across the middle of it from east to west. The St. Paul and Pacific Railroad diagonals across the northern half. Several good county and township roads facilitate accessibility for automobile travel over most of the area.

Choteau Creek and its tributaries drain the outwash and surrounding uplands. Drainage is in a southerly direction. The area lies on a divide between the Missouri and the James rivers.

Low gently rolling hills rise from the south and west sides of the outwash. The north and east boundaries are flanked by gently rolling but higher hills. A comparatively large flood plain of one of the Choteau Creek tributaries trends generally eastward from the southeast corner of the outwash nearly to Tripp, South Dakota, thirteen miles east and south of Delmont.

The mean elevation of the outwash is approximately 1430 feet above sea level, while some of the higher hills in the area rise to 1500 feet and above.

The climate of Douglas County is very similar to that of the rest of the eastern part of the state. Summers are generally short and winters are long. The mean annual temperature is 46, (Fahrenheit), degrees above zero, with a recorded maximum of 109 degrees above zero and a recorded minimum of 45 degrees below zero. The mean annual precipitation is 24 inches, the summer months usually being wetter and the winter months the drier.

The larger part of this region is farmed; corn is the major crop, although several kinds of small grain are raised. Trees are quite abundant along the drainages and also are important as windbreaks and shelter-belts on many of the farms.

REGIONAL GEOLOGY

Most of the geologic formations of Eastern South Dakota exposed at the surface are of Pleistocene age. However, exposures of pre-Pleistocene rocks are available in the trenches cut by the Missouri River and the lesser rivers and streams. Therefore, most of the information regarding these older rocks is available mainly from well logs. A brief description of these rocks is essential to understand the composition of the glacial till because, obviously, much of the glacial drift probably has its origin in the older rocks that were once in place over the area traversed by the great ice sheets.

Most of the upper Cretaceous formations outcrop along the Missouri River from Sioux City, Iowa, to the North Dakota line above Mobridge, South Dakota. Lakota sandstone, Fuson shale, Dakota sandstone, Graneros shale and probably part of the Carlile shale outcrop in the Sioux City Brick and Tile Company's quarry at the southwest side of Sioux City, Iowa. A more complete exposure of the Carlile shale outcrops in a stream cut in Union County State Park a few miles south of Beresford, South Dakota. The Niobrara chalk is exposed in the Missouri trench from close above Sioux City, Iowa, to Ft. Thompson, South Dakota. Less extensive outcrops can be found in various stream cuts in eastern South Dakota. The Pierre shale is exposed in the Missouri River trench from Yankton, South Dakota, where lowermost members are exposed to the North Dakota line (Crandell, 1950). Many of the hills along the east side of the Missouri are of Pierre shale. The Fox Hills sandstone is exposed only in the upper few miles of the Missouri River trench. The Hell Creek formation, the only remaining Cretaceous formation, is not exposed in eastern South Dakota or along the Missouri River.

Pre-Cambrian granites outcrop in the extreme northeast corner of the state. However, only a few feet of glacial drift cover the granite in the northeast and in isolated areas of northern South Dakota. The Sioux formation, mostly quartzite, is exposed in the Sioux Falls and Mitchell areas (Baldwin, 1949).

A few outcrops of tertiary marls and sands are found in isolated areas between the Missouri and the James rivers (Rothrock, 1943). The larger of these exposures is found in the Ree Hills southwest of Miller, in the Wessington Hills near Wessington Springs and the Bijou Hills south of Chamberlain (S. D. Geological Map).

The rocks of eastern South Dakota are essentially flat lying. In broad terms, the regional dip is toward the northwest and constitutes the east limb of what has been called the Lemmon Syncline (Flint, 1955, p. 76).

Pleistocene Geology

One of the greatest changes wrought by the glaciers in eastern South Dakota was the rearrangement of the drainage. Prior to the ice advance, probably in one of the pre-Wisconsin glacial ages, the major rivers and streams flowed generally eastward. Evidence of ancient river channels, probably extensions of the rivers west of the Missouri River, can be traced eastwardly across most of eastern South Dakota. The present drainage is generally southward, oblique to the regional topographic dip, which is toward the east. A dam of ice could conceivably have caused this change in drainage direction.

There are exposed in eastern South Dakota pre-Wisconsin glacial tills. At certain localities there are tills exposed which are believed to be Kansan or Nebraskan in age. Much of the pre-Wisconsin till exposed in eastern South Dakota may be Illinoian in age, but evidence is too meagre or indirect to prove that Illinoian till is present.

The Wisconsin stage of the Pleistocene has been divided into four substages by Leighton in 1933 (Flint, 1955, p. 76).

Mankato substage
Cary substage
Tazewell substage
Iowan substage

Four substages of the Wisconsin stage are recognized in South Dakota and are no doubt correlative to the standard divisions of the Wisconsin stage. Although correlation of drift sheets by continuous tracing is not yet possible in all cases, it seems reasonable to infer their correlativeness by their identical sequence with type areas. In most cases the substages are recognized by the presence of separating loess deposits (Lugn, 1935). Some differentiation of the substages is also recognized by the differences in topographic expression between each substage.

Although the break between the Iowan and Tazewell substages can be recognized in Iowa, it is not easily recognized in South Dakota. The Tazewell drift, is recognized in South Dakota only because of continuous tracing from southwestern Minnesota by Ruhe (Flint, 1955, p. 90). Satisfactory discrimination between the Iowan and Tazewell substages west of the James River is extremely difficult due to the thinness of drift sheets and the dissection of the surface.

The interval between the Cary and Tazewell substages is much more conspicuous than the break between the Iowan and Tazewell. The Tazewell surface is well-drained while the Cary surface, away from major streams, is poorly drained. Dark humified soils between the two drifts suggest a conspicuous Tazewell-Cary break. The Cary substage has not been traced continuously from the type Cary in Illinois, but has been identified as Cary because it is the third of four substages, as it is in Illinois.

The evidence of a time interval between the Cary and Mankato substages is less conspicuous than it is between the Cary and Tazewell. However, a thin, poorly developed, sometimes calcareous soil profile can sometimes be found on the Cary drift between the Cary and Mankato substages. The Mankato substage is closely related to the Cary substage in time, but can often be separated topographically. The Mankato drift border is characterized by the high massive end moraine recognized by Chamberlin (Chamberlin, 1883, p. 388). Much of the Mankato drift border is fringed by outwash.

STRATIGRAPHY

Stratigraphic correlation of the Delmont Glacial Outwash was unusually difficult. No paleontological data are available. No ancient soil profiles are available within the immediate area. Morphologic evidence suggests that the Delmont Glacial Outwash is of Mankato age. As has been pointed out, high end moraines indicate Mankato drift. Conversely, low, less massive end moraines, less topographic relief, and areas which are poorly drained suggest Cary drift. The area north and east of the Delmont Glacial Outwash is of comparatively high massive end moraines. Most of the region is well drained. Conversely, south and west of the Delmont Glacial Outwash, the area is of low gently rolling moraines. Topographic relief is only approximately half of that of the area to the north and east. Much of the area is rather poorly drained. Large portions of the Mankato drift are fringed by outwash.

Richard Foster Flint placed the southern boundary of the Mankato drift in Douglas County about four miles north of the southern county line, which cuts off the lower seven miles of the Delmont Outwash (Flint, 1955).

In the writer's opinion, the Mankato boundary line should be drawn several miles farther north, along the northernmost boundary of the Delmont Glacial Outwash.

The outwash sands and gravels appear to be of Mankato origin, since they appear to have been washed out of the Mankato drift area by glacial-melt waters and deposited as outwash on top of the older Cary drift. A thin soil mantle, from zero to a few feet thick, covers the gravels. The Cary drift had been eroded off parts of the area, and the sands and gravels have been deposited on top of Niobrara chalk and Pierre shale.

Unfortunately, exposures of outwash sands and gravels are few and limited. Most of the exposures available are located in Section 36, Township 98 North, Range 63 West. A few gravel pits have incomplete exposures in the area adjacent to Section 36. The entire thickness of sand and gravel is not available at any place. However, several outcrops were measured where exposures were encountered. The more significant outcrops measured are described in the sections below. See Plate I for localities.

Locality	Thickness in feet
I. NE $\frac{1}{4}$, NE $\frac{1}{4}$, NE $\frac{1}{4}$, Sec. 36, T. 98 N., R. 63 W.	

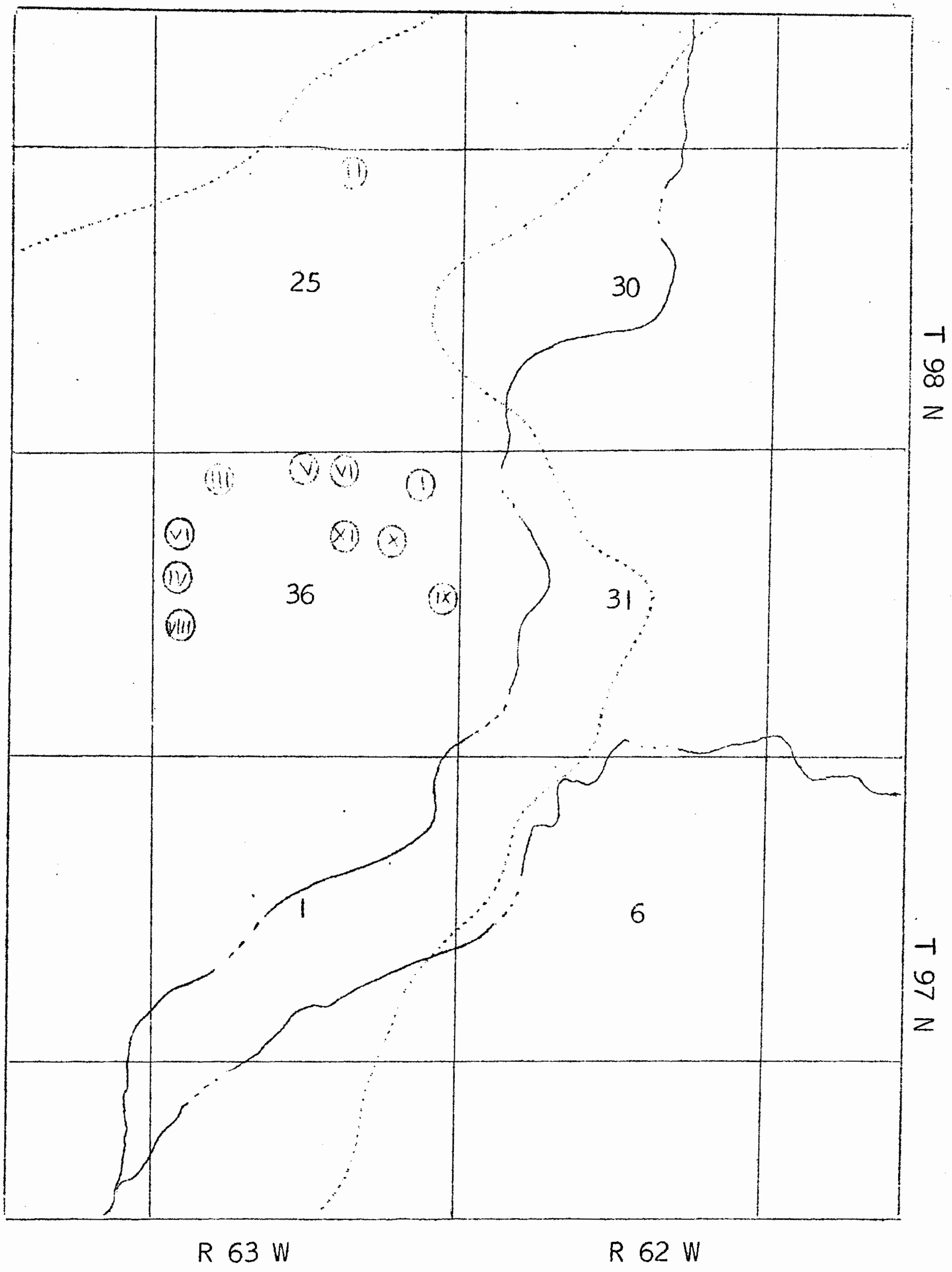
Locality	Thickness in feet
Sandy soil mantle with numerous pebbles	2.5
Poorly sorted gravel ranging from sand size to pebble size with a few cobbles	7.0 exposed
II. NW ¼, NE ¼, NE ¼, Sec. 25, T. 98 N., R. 63 W.	
Sandy soil mantle with a few small pebbles	0.3
Sand yellow clay with numerous pebbles	0.5
Poorly sorted medium to coarse grained sand with numerous pebbles and scattered cobbles (Cobbles are very angular)	2.6 exposed
III. NW ¼, NE ¼, NW ¼, Sec. 36 T. 98 N., R. 63 W.	
Sandy soil mantle	0.3
Poorly sorted sandy gravel dominantly of coarse sand with many rounded pebbles	8.1
Water table	
Sandy gravel, dominantly of pebble size with sparse cobbles, well rounded	3.0
Blue fissile shale, somewhat iron stained, believed to be Pierre shale . . .	unknown
IV. SW ¼, SW ¼, NW ¼, Sec. 36 T. 98 N., R. 63 W.	
Sandy black loamy soil mantle	0.8
Sandy gravel dominantly of pebble size. Pebbles predominantly of limestone and dolomites	9.6
Water table	
Poorly sorted sandy gravel dominantly of pebble size with sparse cobble of limestone and granite	unknown
V. NE ¼, NE ¼, NW ¼, Sec. 36, T. 98 N., R. 63 W.	

Locality	Thickness in feet
Sandy black soil mantle with a few pebbles	0.9
Poorly sorted sandy gravel dominantly of pebble size Pebbles are about half calcareous with numerous granite pebbles	9.8
Water table	
Poorly sorted sandy, cobbly gravel	unknown
VI. NE ¼, NE ¼, NE ¼, Sec. 36, T. 98 N., R. 63 W.	
Sandy black soil mantle with numerous pebbles	0.3
Poorly sorted sandy gravel with numerous pebbles and sparse cobbles of limestone	9.9
Water table	
Poorly sorted sandy cobbly gravel	unknown
VII. NW ¼, SW ¼, NW ¼, Sec. 36, T. 98 N., R. 63 W.	
Sandy soil mantle with numerous limestone pebbles and a few cobbles	0.1
Poorly sorted gravel, mostly limestone	10.2
Water table	
Poorly sorted sandy gravel dominantly of pebble size with numerous cobbles. Pebbles and cobbles of well-rounded limestone	unknown
VIII. NW ¼, NW ¼, SW ¼, Sec. 36, T. 98 N., R. 63 W.	
No soil mantle	
Poorly sorted sandy gravel predominantly of pebbles Pebbles are well-rounded limestone with sparce granite pebbles and very sparse cobbles	8.7
Water table	
Poorly sorted sandy gravel dominantly limestone	unknown
IX. SE ¼, SE ¼, NE ¼, Sec. 36, T. 98 N., R. 63 W.	

Locality	Thickness in feet
Black soil mantle	2.0
Poorly sorted medium to coarse-grained sand	7.1
Water table	
Sands of unknown thickness	
X. SW $\frac{1}{4}$, NE $\frac{1}{4}$, NE $\frac{1}{4}$, Sec. 36, T. 98 N., R. 63 W.	
Sandy soil mantle with numerous pebbles and occasional cobbles	1.3
Sandy pebble gravel with decreasing pebbles lower in the section	7.1
Buff colored sandy silty clay becoming more sandy 3 feet farther down the section	4.5
Poorly sorted sandy gravel of pebble size	1.6
Water table	
Sands and gravels of unknown thickness	
XI. SW $\frac{1}{4}$, NW $\frac{1}{4}$, NE $\frac{1}{4}$, Sec. 36, T. 98 N., R. 63 W.	
Sandy soil mantle with numerous pebbles	1.0
Poorly sorted sandy gravel of pebble size, predominantly of medium to coarse grained sand	11.1
Water table	
Sands and gravels of unknown thickness	
XII. NW $\frac{1}{4}$, NE $\frac{1}{4}$, NE $\frac{1}{4}$, Sec. 17, T. 98 N., R. 63 W.	
Sandy pebble soil mantle	1.5
Rather well sorted, somewhat lenticular sands and gravels dominantly of coarse sand size ranging from fine grained to cobble size	9.1
Water table	
Sands and gravels of unknown thickness	

The best grade of sands and gravels for use as aggregate for roads and concrete is available in the north half of Section 36, Township 98 North, Range 63 West. Farther south, the sands become finer and finer until washing is necessary in order to provide suitable aggregate of any value for concrete. Farther west in Section 36, limestone makes up a large part of the gravels. According to the South Dakota Highway Commission, the gravels along the north half of Section 36 are good for road aggregate. At the present time, gravel from the north half is being sieved and washed to render it usable for concrete aggregate.

PLATE I--LOCALITY MAP



PORTION OF DELMONT GLACIAL OUTWASH LOCATING SAND AND GRAVEL EXPOSURES.

FIELD PROCEDURE

The first problem the writer faced in attempting to complete a map of the Delmont Glacial Outwash was to determine the areal extent of the outwash. A general areal geology map was drawn after a few days of reconnaissance mapping (Plate I).

This reconnaissance mapping was initiated by a thorough inspection of terrain. Along the north and east sides of the outwash, comparatively high gently rolling hills make up the moraine (Mankato). A reasonably accurate boundary could be drawn between this moraine and the flat outwash plain. Bordering the south and west sides of the outwash, the moraine hills were very gently rolling and of much less relief (Cary). Drawing an accurate boundary between the outwash and the adjacent terrain was more difficult in this area, and especially, along the southeastern edge where a wide flat alluvial valley trends eastward.

Outwash plains are formed by water, much of it glacial melt water flowing out of the glacier and off the moraines. Sands and gravels were deposited. Most of the finer silts and clays were carried beyond the outwash plain. The larger boulders remained in the moraines. By observing the presence or absence of boulders, a fairly accurate boundary can be drawn.

The sands and gravels usually contain an abundance of water. Water was sparse in the boulder clays of the moraines. The farmers and well drillers in the area were consulted. If their wells were deep, it could be inferred that they were off the outwash. Conversely, should their wells be shallow, it was reasonable to infer that they were drilled on the outwash.

In 1923 the Department of Agriculture published a soils map of Douglas County, South Dakota. Since most of the sands and gravels of the outwash were close to the surface, the soil was sandy and many pebbles were present in the soil. An interesting comparison between the areal extent of this particular soil type and the areal extent of the outwash was noted. The area of sandy soil is nearly coterminous with the outwash.

With average rainfall sufficient moisture is generally retained in boulder clays to supply the water nedded for plant growth. However, the rain that falls over the outwash plain is immediately absorbed by the sands and gravels near the surface to provide for very abundant plant growth. During early summer, when this outwash was first mapped, the native grasses and domestic crops were noticeably greener on the moraines adjacent to the outwash than on the outwash itself. Conversely, the abundant water at shallow depths below the surface provides for larger trees. These trees, mostly cottonwoods and elms, were noticeably taller on the outwash than on the adjacent moraines, but were more subject to uprooting by strong winds because of shallow root systems.

By observing all of these aforementioned conditions, a surprisingly accurate outwash boundary was drawn. For reconnaissance purposes this boundary was drawn on blank township sheets to be later transferred to a larger, more complete map. Distances were measured for this map with the speedometer on the jeep used for field work.

After the reconnaissance map was completed, traverse lines covering the entire outwash were surveyed. A plane table and telescopic alidade were used to establish the points of elevation to be later used for horizontal and vertical control. These temporary bench marks were placed on every section corner and several other pertinent and convenient points. These points were used later to establish elevations for all the resistivity sounding stations.

Wherever exposures of the sands and gravels were available, samples were collected and sections measured. These samples were later analyzed to determine texture, composition, and sorting of the sands and gravels.

Should the resistivity soundings indicate sands and gravels within four feet of the surface, that is, within accessibility of the auger, holes were augered to the top of the sands and gravels as a check on the accuracy of the resistivity instrument.

Seven field pebble counts were made in order to determine the type of rock composing the pebbles and cobbles. This was accomplished by picking 500 pebbles at random, identifying them and calculating the percentages of rock type. The results are as follows (Table I). See Plate I for localities.

The water table was above the bottom of the pit in several of the gravel pits on the outwash. Depths to the water table were always measured as another check on the accuracy of the resistivity instrument.

After the samples were collected and all necessary field notes were completed, office and laboratory work was necessary to analyse the samples, compile the field notes, and draft the maps.

Five maps were drafted: a locality map, a topographic map, an isopach map, a contour map of the top of the gravels, and a contour map of the bottom of the gravels. The contour map drawn on the bottom of the gravels represents the pre-Mankato or the old Cary erosional surface (Plate V).

TABLE I

FIELD PEBBLE COUNT

	Locality						
Type Rock	I	II	III	IV	V	VI	VII
Granite	16%	29%	15%	26%	25%	25%	24%
Basalt	15	10	5	9	7	6	6
Gabbro	2	2	2	8	1	6	7
Rhyolite	1	10	5	9	2	1	5
Feldspar	2	1	2	1	6	2	3
Mica Schist	3	2	1	3	1	21	4
Quartzite	5	2	32	30	33	14	12
Limestone	2	20	16	10	5	6	7
Dolomite	6	18	5	1	6	3	10
Shale	20	1	17	-	-	8	8
Sandstone	13	-	-	2	-	3	4
Iron Concretions	15	5	-	1	14	5	10

LABORATORY PROCEDURE

Several samples were analyzed in order to determine the possible uses of the sands and gravels. Six different samples were analyzed to determine the grain size. Large pebbles, the particles between 16 and 64 millimeters in diameter, make up the largest percentage of each sample by weight. However, the total percentages of the several smaller sizes make up the larger part of each sample. The finest, below 1/256 millimeters in diameter, make up a comparatively small percentage. If size were the only factor, the dominant size is ideal for both road and concrete aggregate.

Six samples were analyzed to determine the mineral and rock content of the gravels. A field pebble count was made to determine the percentages of different rocks and the larger mineral particles. Granite was by far the most common rock. However, limestone was abundant, especially along the west side of the outwash, and limestone is very poor for concrete aggregate and only fair for road aggregate.

In the laboratory, representative small samples were distributed evenly over a sheet of coordinate paper and examined with a binocular microscope. The coordinate paper served as a grid on which to make the estimation of percentages less difficult. With this type of procedure, a reasonably accurate mineral percentage was obtained. Percentages were calculated considering only the number of grains and not the size. The smaller grains were generally more rounded than the larger grains. Quartz was well rounded. The feldspar grains were nearly all cleaved. Other than the feldspars, the harder grains were comparatively well rounded and the softer rock and mineral grains were more angular.

The results of the microscopic examination of sand samples are illustrated in Table II. See Plate I for localities.

A simple porosity test was carried out with satisfactory results. This was accomplished by filling a 500 cc. graduated cylinder with a sample of sand and pouring in a measured amount of water, and then calculating the percent of pore space. Six different samples were tested and an average porosity of 30.8 percent was determined (Table III).

Because the sands and gravels of the outwash are unconsolidated and the range in grain sizes is predominantly from medium to coarse, the resistance to the flow of fluids through the deposits is low. For this reason, an accurate determination for the permeability was not deemed necessary.

Several limestone pebbles were collected from the west side of the outwash. An attempt was made to determine the origin of the gravels by identifying the fossils. These limestone pebbles were disintegrated and the residue examined for microfauna. No fossils were obtained from most of the pebbles. However, several chalk pebbles, resembling Niobrara chalk lithologically, yielded several specimens of two different species, *Globigerina globulosa* and *Globigerina cretacea*. These two species are common in the Smoky Hill member of the Niobrara formation (Bolin, 1952, p. 6). One shaly concretionary pebble was found containing several specimens of the pelecypod, *Nucula planimarginata*, a fossil common to the Fox Hills sandstone. Other than these three allogenetic fossils, no significant paleontological materials were found in the outwash sands and gravels.

Explanation of Histograms

Certain size analyses were necessary to determine the grain size of the sands and gravels of the outwash. Five-hundred-gram portions of each sample collected were first sieved to determine the percentage of the coarser fraction. The pipette method was used to determine the percentage of the finer fraction below 1/16 mm. in diameter (Krumbein and Pettijohn, 1938, p. 162). Such an extremely small percentage of the fines was recovered, less than 0.05 per cent, that the writer considers it of no significance. Each 500-gram portion was picked at random from a larger sample in an attempt to pick a representative sample. After the analyses were finished, the percentages were plotted on histograms with the percentages along the vertical axis and the size of the grains along the horizontal axis (Table IV and Histograms I-VI).

TABLE II

MICROSCOPIC ANALYSIS

	Locality					
Type Grain	I	II	III	IV	V	VI
Quartz	30%	33%	32%	34%	29%	28%
Feldspars	12	14	15	16	16	12
Chert	2	5	2	3	1	7
Chalcedony	1	0.5	--	2	--	6
Olivine	1	0.5	0.8	0.4	0.9	1.5
Serpentine	0.3	0.3	--	0.3	--	1
Jasper	1	1	--	7	--	1
Garnet	--	1.7	1	0.7	0.9	1
Amphibole	4	3	4	2	5	4
Pyroxene	4	13	4	1.0	5	4
Biotite	2	3	1.5	2	1.5	2
Hematite	0.5	5.4	0.2	0.7	2	1
Limonite	4	2.6	3	2	4	2
Pyrite	0.6	0.9	0.5	0.8	1	1
Glauconite	1	--	--	1	1	0.6
Calcite	1	0.3	1	1	0.5	1.4
Araganite	4	1	3	1	1	4
Dolomite	2	4	1	1	1	1.5
Limestone	8	1	6	6	8	4
Shell fragment	0.6	--	--	0.6	--	--
Basalt	--	1	--	1	2.3	1
Sandstone	4	1	0.3	0.5	3	1
Shale	5	--	14	9	8	6
Slate	1	2.8	0.7	3	1	2
Quartzite	6	1	3	1	1.5	3
Granite	4	2	7	3	4.4	4

TABLE III

POROSITY

Locality	Sample	Amount of Sand by Volume	Volume of Water	Percentage
I	I	500 cc	160 cc	32
II	II	500	150	30
III	III	500	140	28
IV	IV	500	155	31
V	V	500	155	31
VI	VI	500	165	33

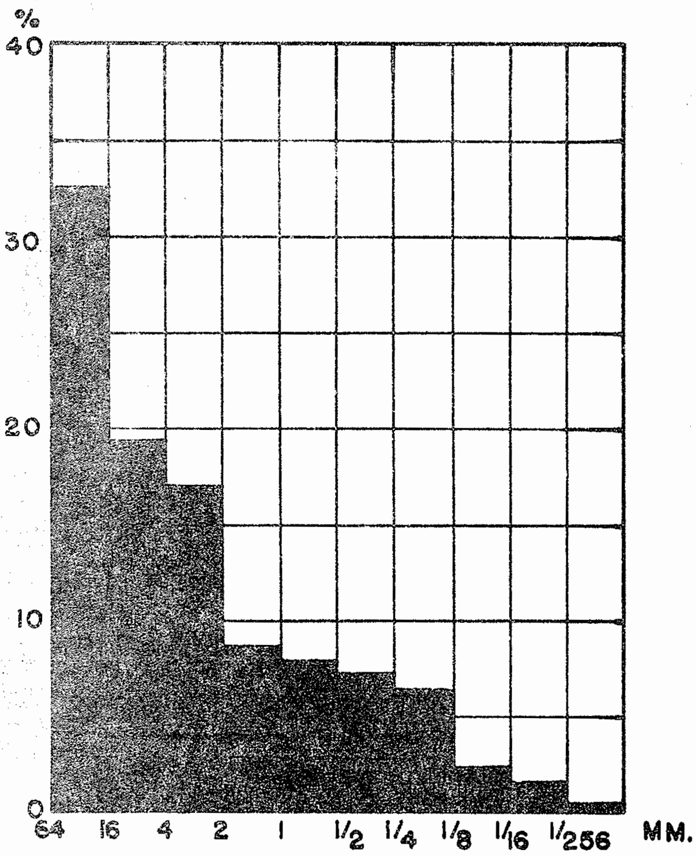
TABLE IV

SIZE ANALYSIS

		Sample					
Name of Particle	Dimensions, Mm.	I	II	III	IV	V	VI
	64						
Large Pebble		35.4	21.3	-	-	32.5	23.7
	16						
Small Pebble		18.6	19.2	33.0	23.5	18.9	17.1
	4						
Granule		11.1	19.1	4.9	27.5	16.6	14.1
	2						
Very Coarse Sand		8.3	12.2	11.2	30.6	8.9	12.8
	1						
Coarse Sand		7.4	10.1	26.6	6.9	7.5	11.3
	1/2						
Medium Sand		6.6	9.0	15.9	4.8	6.7	8.6
	1/4						
Fine Sand		6.4	6.4	5.0	3.6	5.2	6.2
	1/8						
Very Fine Sand		3.4	1.5	2.2	2.2	2.3	3.2
	1/16						
Silt		2.6	1.0	1.0	0.6	1.3	1.2
	1/256						
Clay		0.2	1.2	0.2	0.3	0.1	1.9
	1/512						

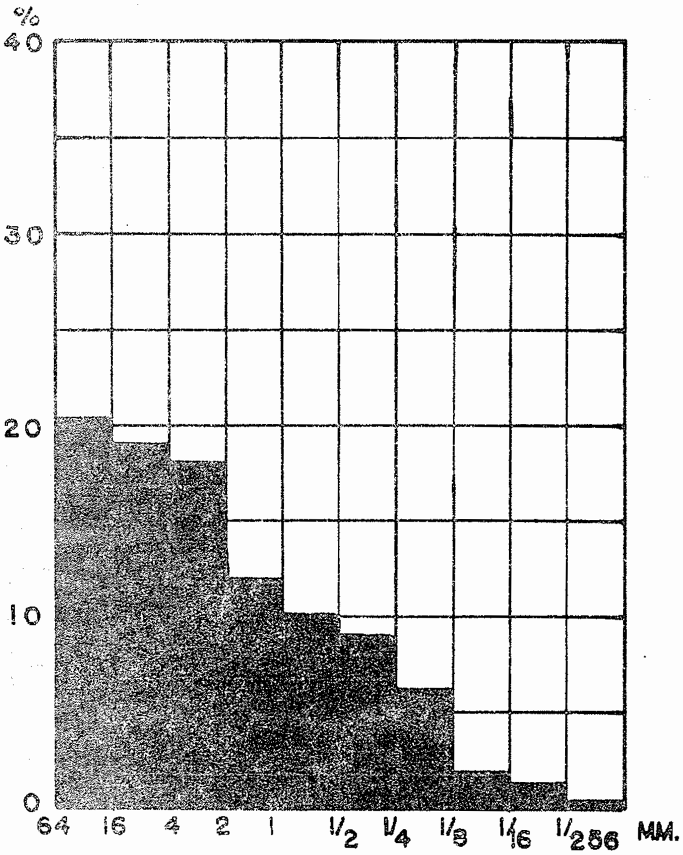
Histogram I

Locality NE $\frac{1}{4}$ NE $\frac{1}{4}$ NE $\frac{1}{4}$
Section 36,
T 98 N, R 63 W



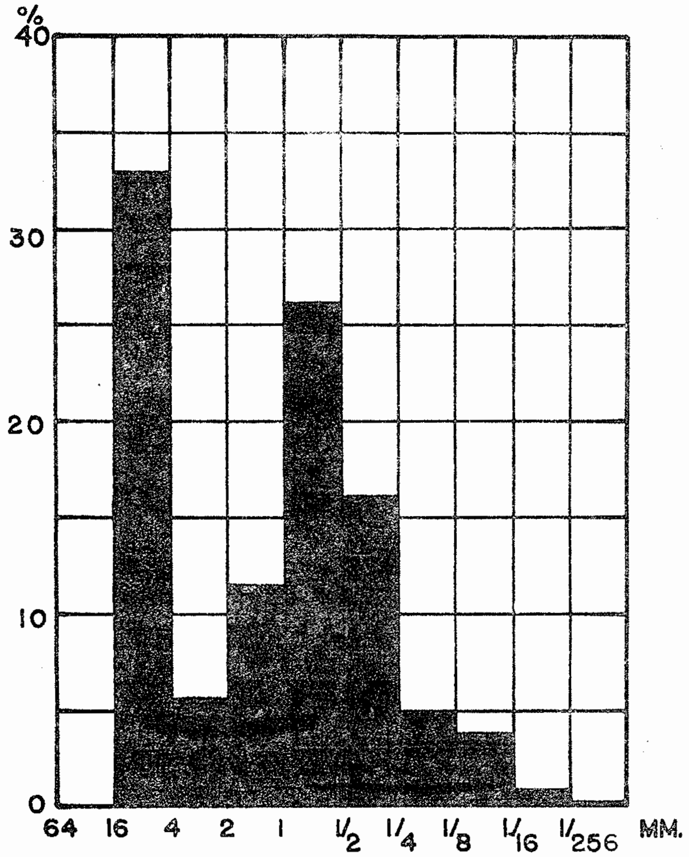
Histogram II

Locality NW $\frac{1}{4}$ NE $\frac{1}{4}$ NE $\frac{1}{4}$
Section 25,
T 98 N, R 63 W



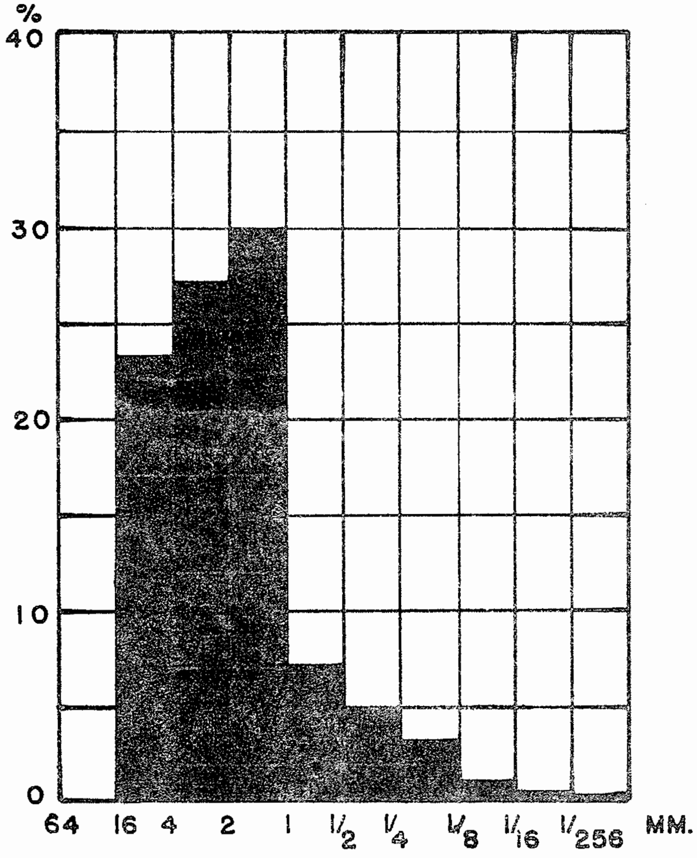
Histogram III

Locality NW $\frac{1}{4}$ NE $\frac{1}{4}$ NE $\frac{1}{4}$
Section 36,
T 98 N, R 63 W



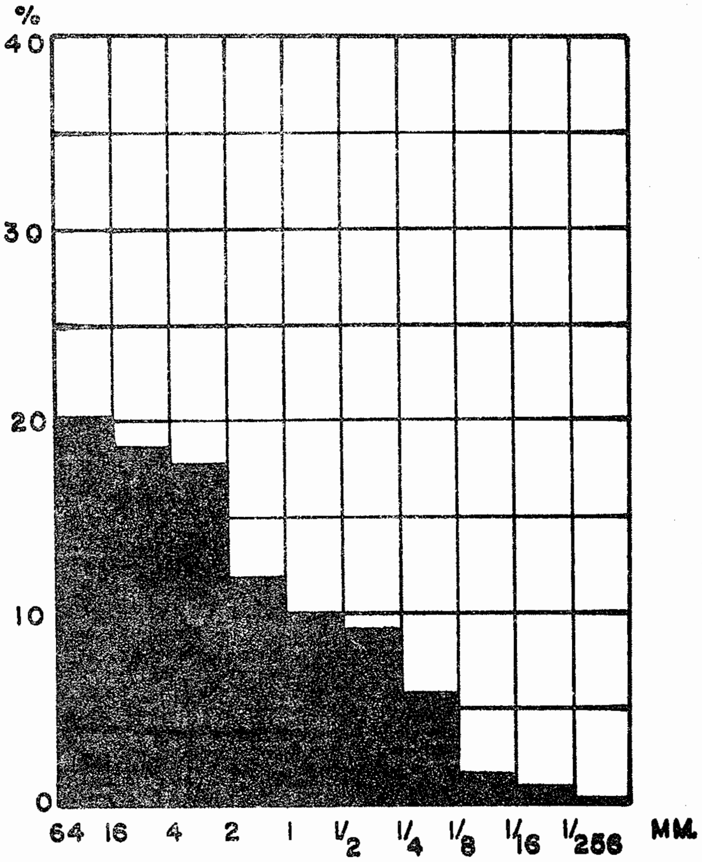
Histogram IV

Locality SW $\frac{1}{4}$ SW $\frac{1}{4}$ NW $\frac{1}{4}$
Section 36,
T 98 N, R 63 W



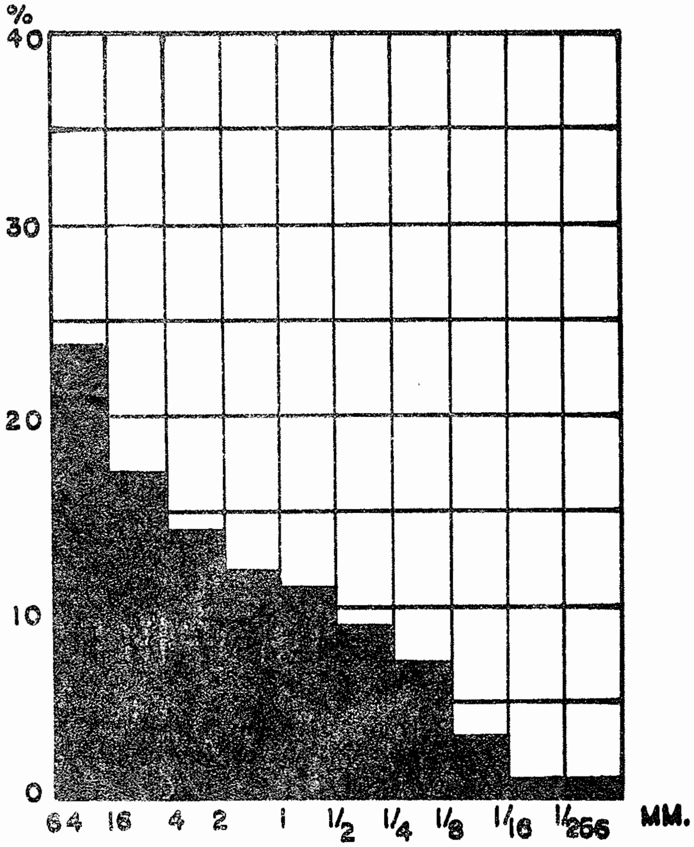
Histogram V

Locality NE ¼ NE ¼ NW ¼
Section 36,
T 98 N, R 63 W



Histogram VI

Locality NW ¼ NE ¼ NE ¼
Section 36,
T 98 N, R 63 W



RESISTIVITY PROCEDURE

The Carl A. Bays Resistivity Instrument is primarily a development apparatus rather than an exploratory instrument (Nettleton, 1940). The measurement of the varying resistivities of the heterogeneous earth's crust is of little importance as far as geological information is concerned. However, if limited geological knowledge is supplemented by additional electrical data, the interpretive value of the geological data is greatly increased.

For resistivity data to be of value to the geologist, resistivity soundings must be taken in an area where portions of geologic features can be observed in order to correlate resistivity data with geologic data. Many exposures of outwash sands and gravels are available in Section 36, Township 98 North, Range 63 West. Several soundings were taken in this section so as to be able to accurately correlate the resistivity data with the observed geological facts. Care was taken in setting up each station sufficiently distant from fences, telephone lines, and electric power lines so that electrical information would not be affected by these obstacles.

A complete description of the instrument and its operation seems desirable at this point. The instrument is not a "doodlebug," but a proven and tested scientific machine, accurate to less than ten per cent of error.

All the various artificial current methods apply an electrical current or radiation of some kind to the ground (Nettleton, 1940). The electrical impulse may be applied directly, by means of electrodes inserted into the ground, or the current may flow in the ground by electromagnetic induction from alternating currents in lines or loops or coils at or above the surface of the ground. The first method is called the inductive method. Measurements are made either of the difference in potential or of the electromagnetic field set up by the ground currents. The Carl A. Bays Resistivity Instrument is of the conductive type, so only conductive methods will be considered here.

In the conductive methods, the electric current is applied to the ground through two electrodes which make electrical contact with the ground. The potential difference is usually measured between two other electrodes. The quantity that is thus determined is essentially the conductivity of the ground. Copper stakes were used for electrodes. Ordinarily sufficient electrical contact was obtained by driving these stakes approximately six to eight inches into the ground. If the ground is very dry, poor electrical contact results. As a remedy, each electrode was wet down. Pure water is a poor conductor of electricity while ionized water is a good conductor. Usually water alone would suffice to gain good electrical contact in dry ground, but in extreme conditions salt was added to the water in order to obtain good electrical contact.

A few definitions are necessary in order to clarify this report on resistivity methods (Sears and Zemasky, 1953; Handbook of Chemistry and Physics, 1953-1954; Heiland, 1940).

Electrical current can be defined as the motion constituting the forces between charges, the final steady-rate distribution of charge brought about by these forces, and the motion of charged particles in empty space.

Direct current: If the direction of motion is consistently in one direction even though fluctuating in magnitude, the current is called direct current.

Alternating current: If the flow of particles changes direction periodically, the current is called an alternating current.

Conductor is a material within which there are free charges which will move when a force is exerted on them by an electric field.

Circuit is the property of a conductor which determines the current produced by a given difference in potential.

Conductivity is measured by the quantity of electricity transferred across unit area, per unit potential gradient per unit time.

Resistivity is the reciprocal of conductivity, and is in fact, a measurement of the conducting properties of a substance.

The earth is a conducting body which completes the circuit, which is the path followed by the electrical current generated from the Carl A. Bays apparatus (Lahee). Since the earth is not a homogeneous substance, the many different materials of which the earth is composed have widely varying degrees of resistance to the flow of an electric charge through them. Actually, true resistivities are observed in homogeneous substances only. Therefore, the presence of vertical and horizontal boundaries within the earth's crust and within the range of the instrument determine what is called apparent resistivity. A complete description of the instrument seems necessary before the operation of the instrument is described.

The value of resistivity is related to a volume of ground that depends on the electrode spacing. As the spacing is increased, the current penetrates more deeply into the ground. For a homogeneous earth, it can be shown that at a vertical plane midway between the two electrodes, just half the current flows at a depth greater than half the electrode spacing, and half flows at shallower depths. (Figure I, p. 52) (Nettleton, 1940, p. 368).

As the electrode spacing is increased, part of the current spreads out to greater and greater depths and thus apparent resistivities from deeper and deeper beds can be measured.

Several methods of measuring electrical resistivities are possible. The method used on this particular survey is the Gish Rooney (Heiland, 1940, p. 28) method and therefore the only one with which this paper is concerned.

The Carl A. Bays Resistivity Instrument is a portable apparatus (Miller, 1954). It consists of the instrument case and its component parts, a twelve volt wet cell battery, various electrical leads, and the electrodes themselves. Only those parts which are housed within the instrument case will be considered in this description.

The parts included within the instrument case include various electric meters, switches, rheostats, the vibrator and its transformer, the flashlight cell used in the potentiometer circuit and several resistors and condensers.

The Carl A. Bays Instrument consists of two essentially different circuits, the power circuit and the potentiometer circuit. By inserting two electrodes into the ground, each connected to the power circuit, the earth becomes part of the power circuit. Similarly, by the insertion into the ground of two electrodes connected to the potentiometer circuit, the earth becomes part of the potentiometer circuit. Other than the earth, the two circuits have no electrical elements in common outside of the instrument case.

The Vibrator

The vibrator is an important mechanical element within the case, common to both circuits. The vibrator is a form of switch, which is always mechanical. An electromagnet drives the vibrator. The electromagnet is turned on during the half-cycle when the vibrator is bent away from the electromagnet. It is turned off during the half-cycle when the vibrator is bent toward the electromagnet (Miller, 1955).

During the "on" half-cycle the vibrator makes connections so that the direct current from the twelve volt battery is a flow in one direction through one-half of the primary coil of the transformer. During the "off" half-cycle the connections are such that this direct current is a flow in the opposite direction through the other half of the primary coil. Thus an alternating current is formed within the primary coil.

The secondary coil of the transformer has many more turns than the primary coil so that from it a voltage of more than 500 may be obtained. This is the apparent source of electromotance for the power circuit. When applied to the earth through the power electrodes, an alternating current is caused within the earth. This current in turn causes an alternating potential drop between the two potential electrodes. This alternating potential drop is converted to direct current by the vibrator and registered on the potentiometer. Thus the vibrator converts a direct current to an alternating current for the power circuit and converts an alternating current to a direct current for the potentiometer circuit.

Selector Switch

A six-pole quadruple throw switch, called selector switch, is the only other switching element which causes any major change in the circuit connections. The four selector switch positions are denoted: Calibrate, P-L & R, P-L & C, and P-C & R. These denotations are those listed in the instrument panel and are used with the Wenner electrode configuration for the Gish Rooney method. With the switch in Calibration position, the instrument is adjusted for calibration. P-L & R designates switch position when the left and right electrodes are in connection with the potentiometer circuit. P-L & C position denotes left and center electrodes in connection with the potentiometer circuit and P-C & R denotes right and center electrodes are in connection with potentiometer circuit. Only the P-L & R and Calibrate positions are used with the Wenner configuration of electrodes, so only those two will be discussed in this paper.

Resistivity Scale and Scale Factor Selective Switch for Potentiometer

The helical slide wire potentiometer is calibrated in one-to-one correspondence with the position of the contact to the slide wire. The scale so calibrated, and labelled Resistivity, is a uniformly graduated circular scale consisting of two rotating plastic disks. The outside disk completes one revolution for every ten revolutions of the inside disk. For simplicity, these scales are depicted as linear scales rather than circular scales in the diagram.

The calibration of the scale is in ohm-centimeters. By estimation to the number of tenths on the small scale, the figure can be read to four significant decimal places. The position of the Scale Factor Selector Switch determines whether the figure taken directly from the Resistivity scale should be multiplied by ten or one hundred to obtain the proper order of magnitude for the

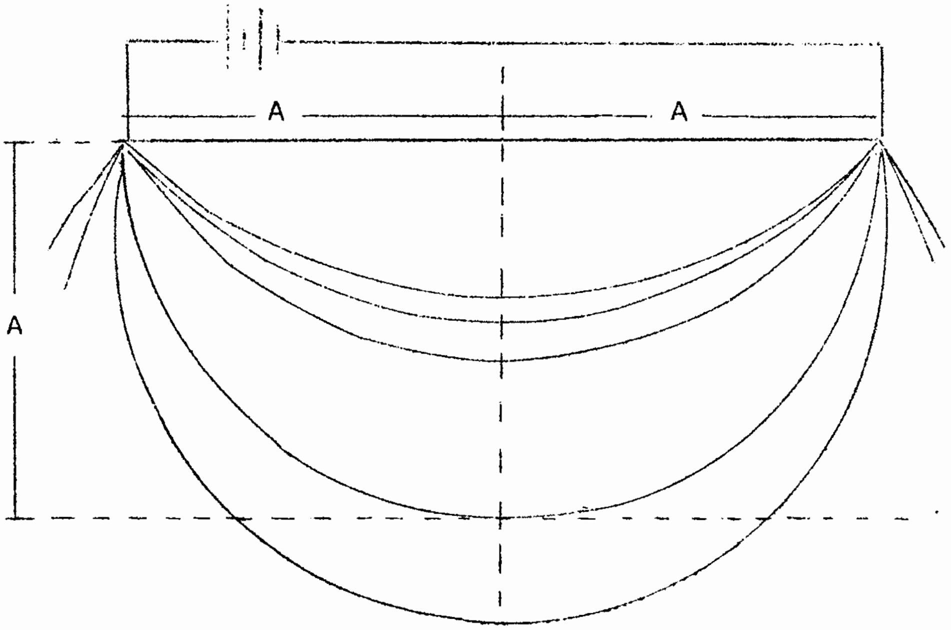


FIGURE 1: CURRENT DISTRIBUTION BETWEEN ELECTRODES IN A HOMOGENEOUS EARTH.

resistivity in ohm-centimeters. This resistivity is apparent resistivity.

In order to have significance for interpretation for the Gish Rooney method, the following conditions must be met: (1) the Wenner configuration of electrodes is used, (2) the number of feet of separation between electrodes is set equal to the number of milliamperes of current in the power circuit and (3) the reading corresponds to a true zero reading on the galvanometer (Heiland, 1940).

If the algebraic symbol "a" is set equal to the number of feet of separation between electrodes, the algebraic symbol "I" is equal to the number of milliamperes of current in the power circuit, the algebraic symbol "P" is equal to resistivity in ohm-centimeters, and the algebraic symbol "V" is equal to the number of volts potential drop between the potential electrodes, the following working equation could be set up:

$$P=2\pi Ka\frac{V}{I}$$

where K equals 30,480, a constant of proportionality (Jakosky, 1940). Since one requisition is that the number of feet of separation of electrodes must equal the number of milliamperes of current in the power circuit, "a" would equal "I" and the equation could be rewritten as:

$$P=2\pi KV$$

Explanation of Diagrams

Introduction

Quite often simple explanatory diagrams are less difficult to interpret than several paragraphs of written explanations. Standard symbols as used by physicists have been used in these diagrams. The information used in compiling these diagrams comes from the instrument itself, several geophysics books, and largely from Mr. Akeley Miller who was physics professor at the University of South Dakota at the time the field work for this paper was being done.

Diagram I

The first diagram is a simple diagrametric view of the ammeter in the calibration circuit and the elements which compose the ammeter.

Diagram II

The second diagram depicts a detailed circuit for all relevant circuit elements in the calibration circuit.

The galvanometer and the five ohm shunt together make up the ammeter in this circuit.

The scale factor selector switch, although it does not affect this calibration circuit, is here diagrammed in detail. For either position of the switch, the potentiometer and associated resistors amount to a little less than 515 ohms in series with the rest of the circuit.

The rheostat labelled CALIB in this diagram is one of two resistors in parallel. Adjustment of this rheostat varies the resistance of this parallel combination from zero to somewhat more than 500 ohms. This is the rheostat controlled by the small knurled knob labeled CALIB on the instrument panel.

The GALV switch, so denoted in the diagram and on the instrument panel, is a hold-to-read switch. When not depressed it shunts the galvanometer so that no current passes through the galvanometer. When it is depressed the current must pass through the galvanometer.

Diagram III

This diagram is a simplified version of the calibration circuit.

Diagram I

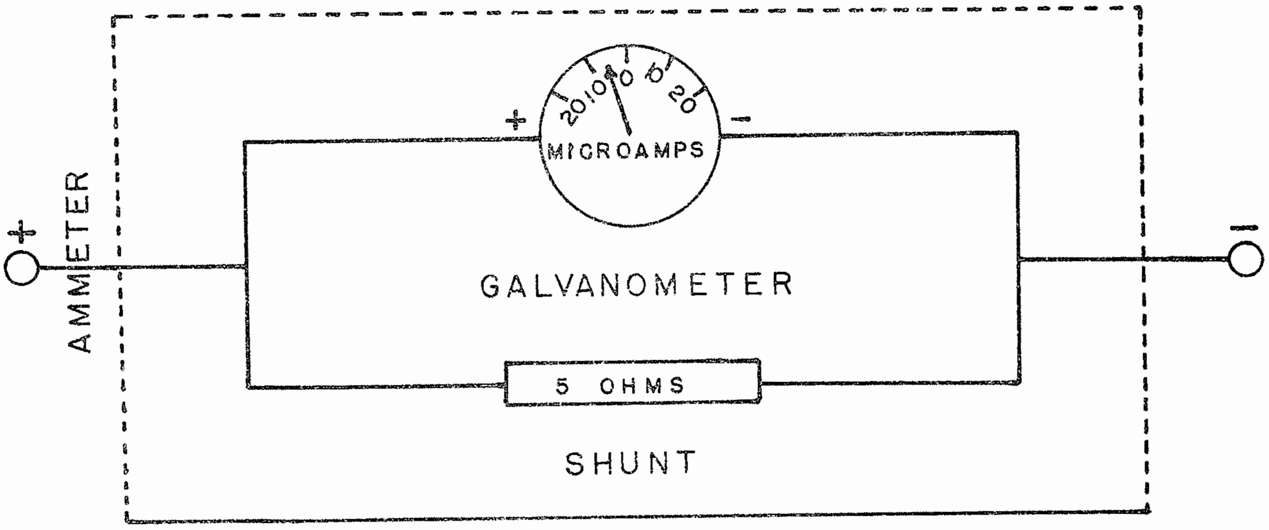


Diagram II

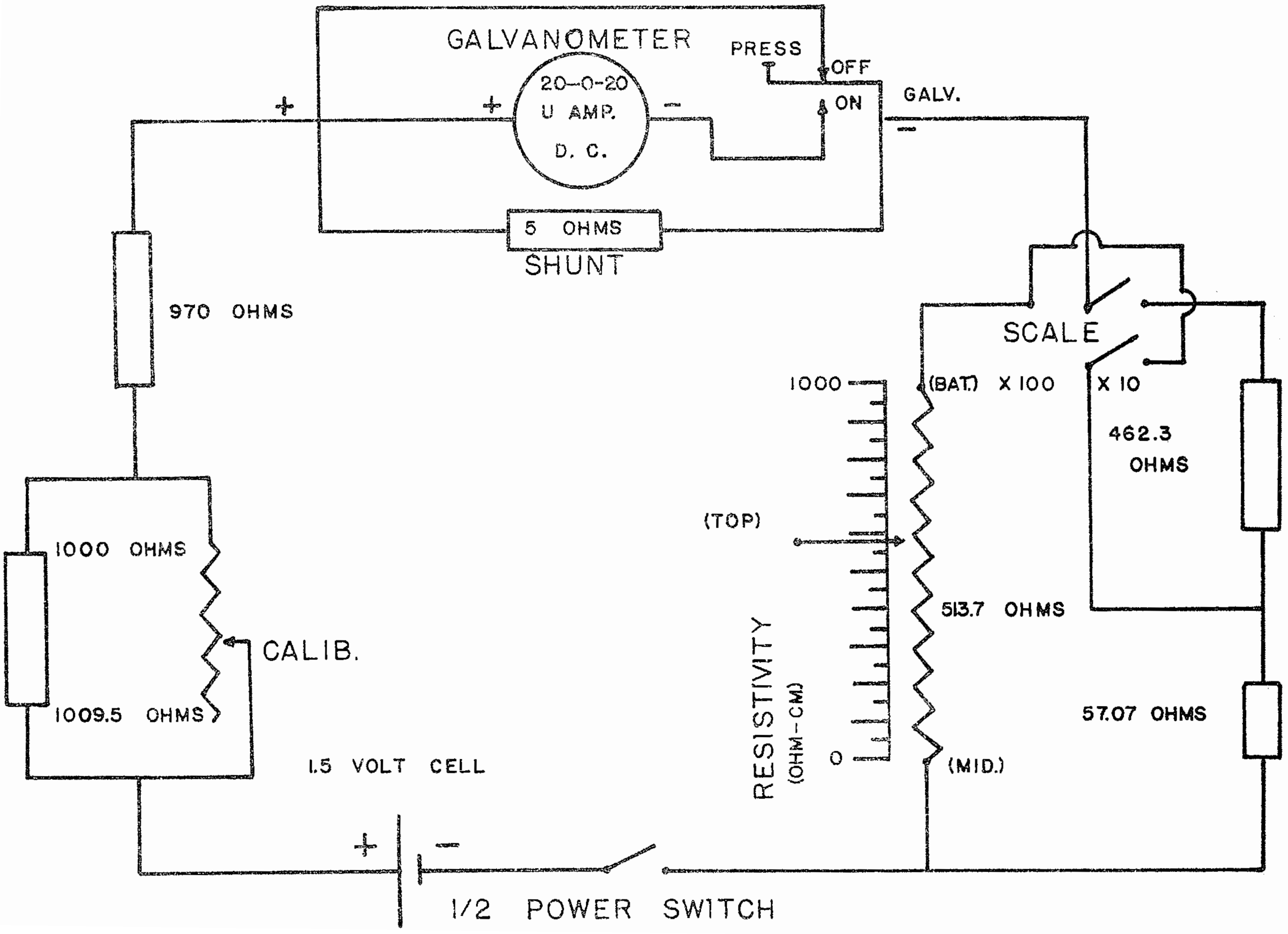


Diagram III

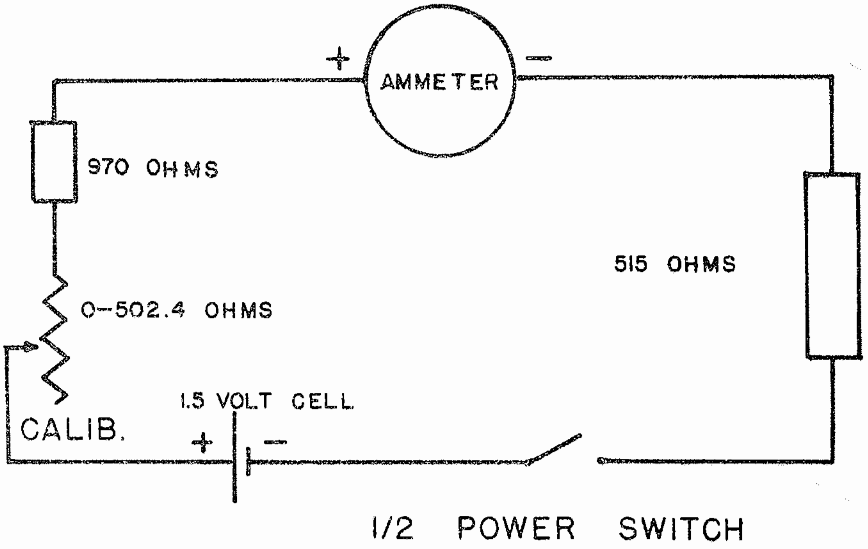
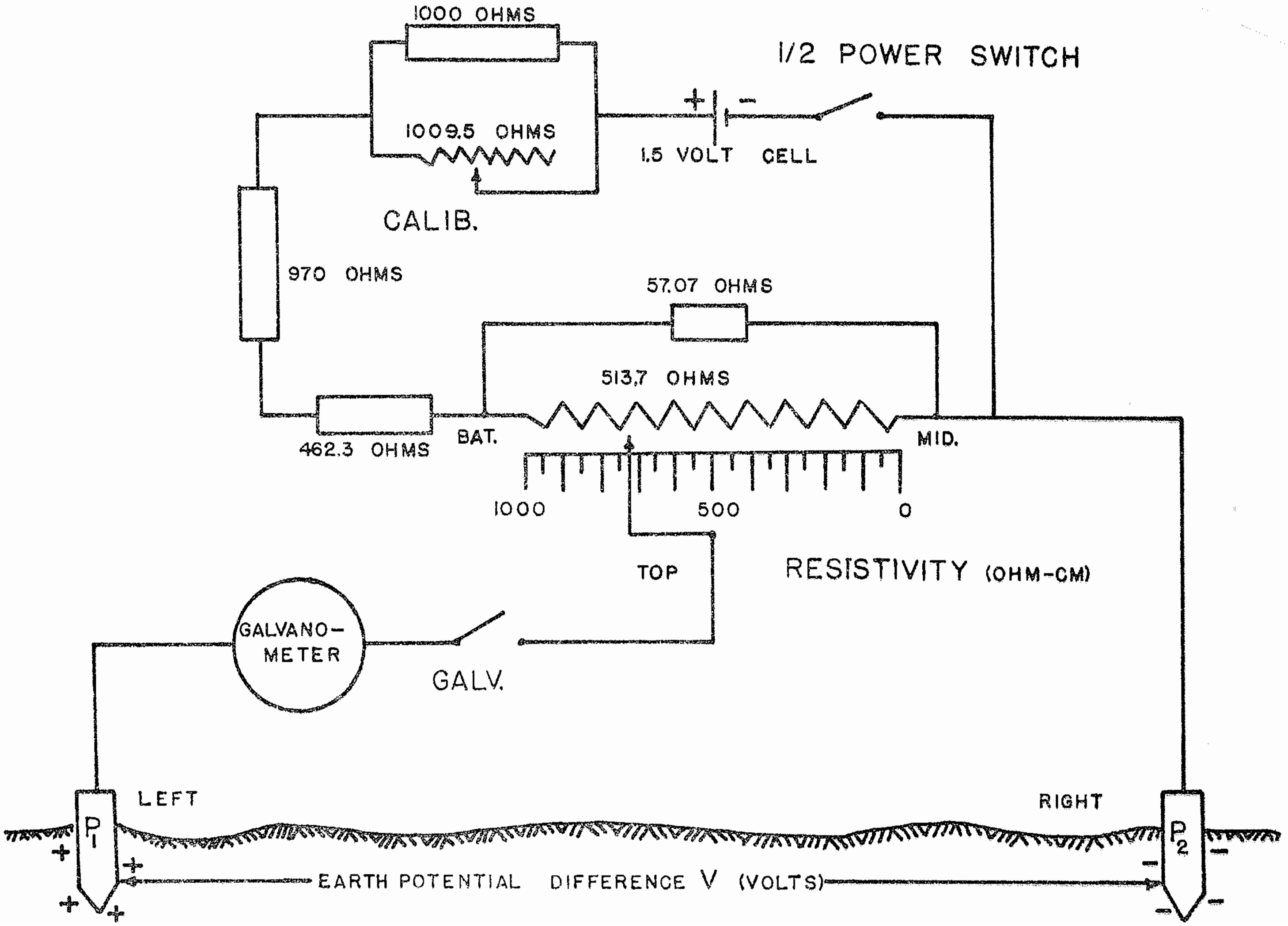


Diagram IV



In the potentiometer of this instrument a 1.5 volt dry-cell flashlight battery is the source of direct current electromotance which causes current to flow through the slide wire of the potentiometer. This causes a potential drop across the entire slide sire.

By moving the slide wire contact the drop across the amount of the slide wire between "Top" and "Mid" may be selected so that it equals V, the earth potential drop being measured. This equality is established when the galvanometer has a zero deflection. This is accomplished when the GALV switch is depressed.

Calibration is accomplished in this calibration circuit by adjustment of the CALIBRATION rheostat so that the ammeter has a certain determined deflection of its needle to a point marked on its scale. This adjustment assures, then, that the potential drop across the potentiometer slide-wire will be the same, despite the variations in electromotance of the dry cell during use and its replacement.

Diagram IV

Diagram IV shows the Selector Switch in P-L & R position which is the only position pertinent to this paper. This diagram contains only the circuit fragment showing the potentiometer circuit when the vibrator is in that half of its cycle during which it is bent toward the electromagnet, that is, when the electromagnet is off.

The circuit shown is that for which the SCALE switch is in the position so that the resistivity taken from the scale must be multiplied by ten. The SCALE switch is not shown in this diagram.

The positive and negative signs at the electrodes indicate the momentary polarity of the earth due to the current in the power circuit. This assumes, for purposes of brevity, that this potential drop across the potential electrodes changes polarity at the same time that the current in the power circuit changes. Actually this would only be true if the ground in which the electrodes are inserted is highly inductive. However, the time factor is exceedingly small so the above assumption is very nearly accurate except in conditions where a layer of extremely high resistance is sandwiched between two layers of extremely low resistance.

"V" is the earth potential difference in volts, but is measured in ohm-centimeters on the RESISTIVITY scale after multiplication by the SCALE factor which is ten in this diagrametric circuit.

Because the RESISTIVITY scale is actually circular, the first and last graduations of the linear scale representing this scale schematically, are actually the same point on the circular scale.

Galvanometer polarity could be either way depending on the position of the contact to the slide wire. As shown, the polarity corresponds to a counter-clockwise deflection of the galvanometer, and to a position of contact to the slide wire.

The setting of the CALIB rheostat is not disturbed for this P-L & R position of the Selector switch. Whatever its setting, it is a constant resistance so far as this circuit is concerned.

Diagram V

This diagram is the remaining portion of the circuit for the Selector switch in P-L & R position.

This circuit fragment shows the power circuit when the vibrator is bent toward the electromagnet when the electromagnet is off.

The ten ohms in the circuit serve to limit the alternating components of transient current in the electromagnet's circuit.

The 0.5 microfarad condenser, being in series with the electromagnet prevents any direct current through the electromagnet, hence the electromagnet is off. Also, the capacitative reactance of this condenser to any alternating components of transient current tends to balance the inductive reactance of the electromagnet to any such alternating components.

The alternating current meter labelled A. C. MILLIAMMETER could be either of the two milliammeters. A, B, and C are the labels given to the two terminals and the centertap of the primary coil of the transformer.

Diagrams VI & VII

Diagrams VI and VII depict the two remaining circuit fragments for the selector switch in the P-L & R position.

In Diagram VI the fragment of the potentiometer circuit is shown when the vibrator is bent away from the electromagnet when the electromagnet is on.

A fragment of the power circuit is shown in Diagram VII when the vibrator is bent toward the electromagnet. Here the ten ohm resistor and 0.5 microfarad condenser are shorted out so that the battery is connected directly across the electromagnet, there is a direct current in the electromagnet, and hence the electromagnet is on.

Diagram

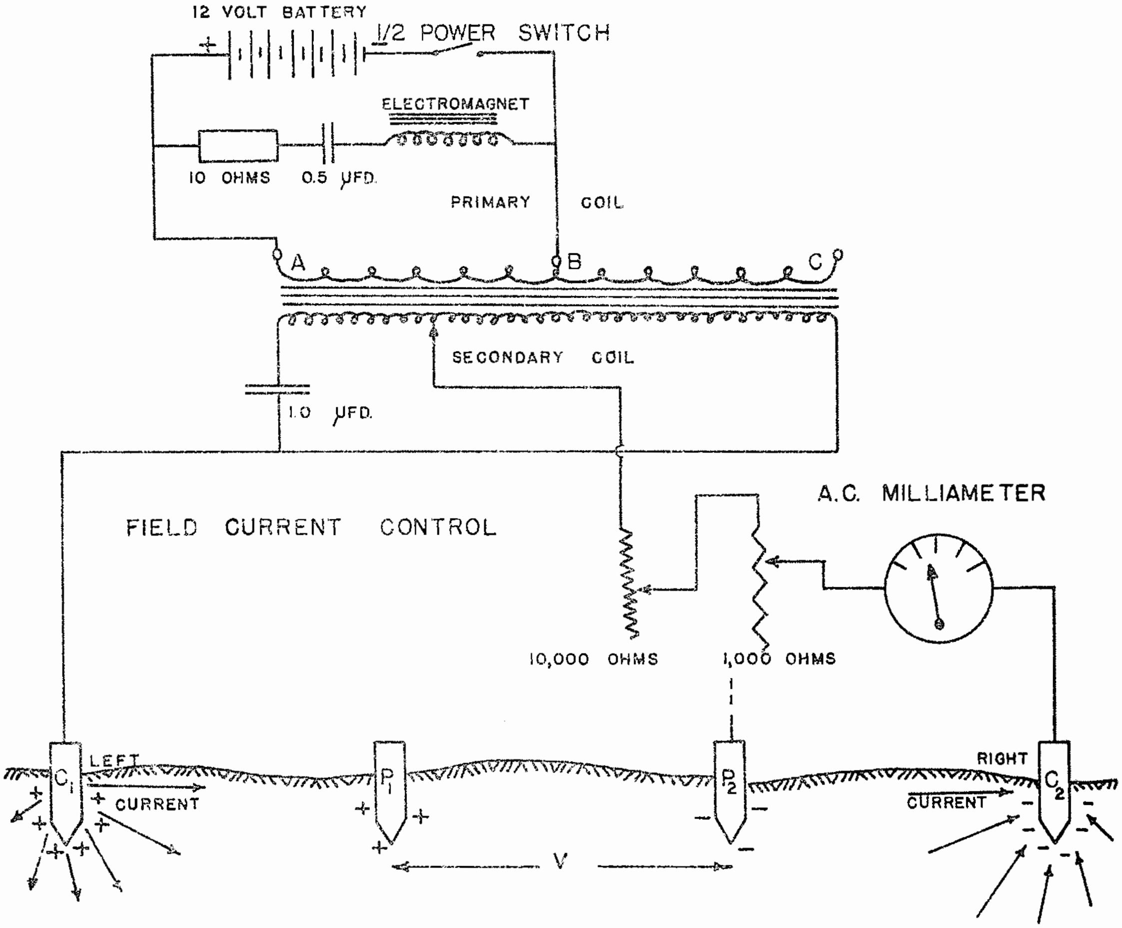


Diagram VI

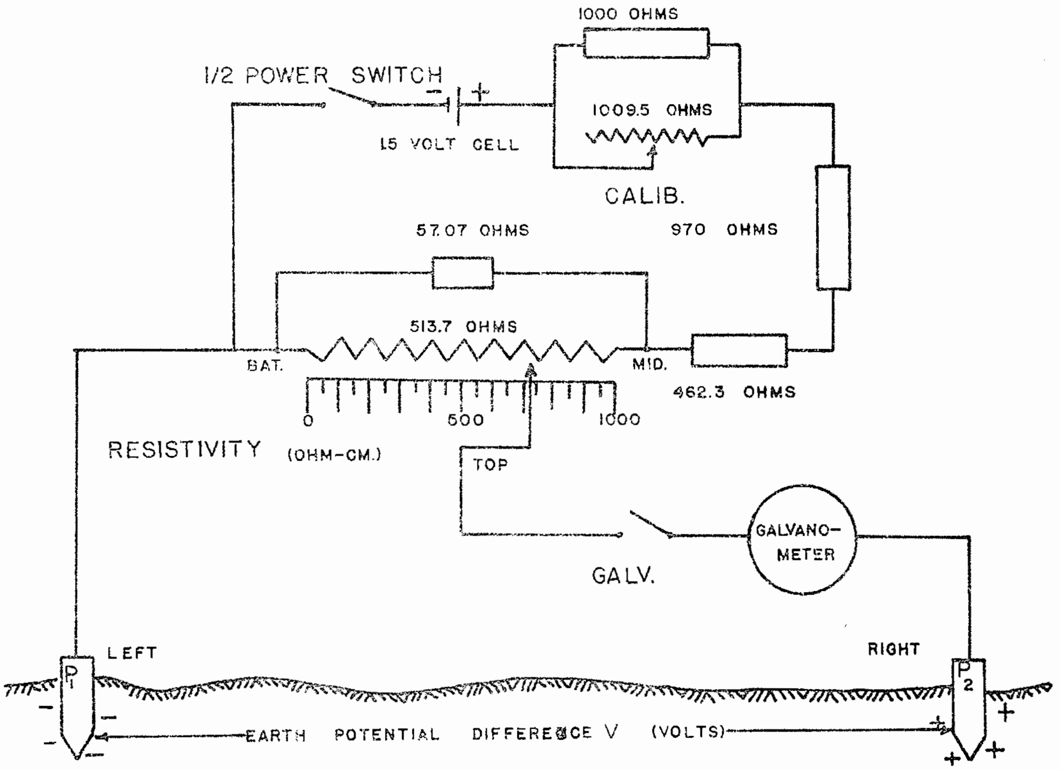


Diagram VII

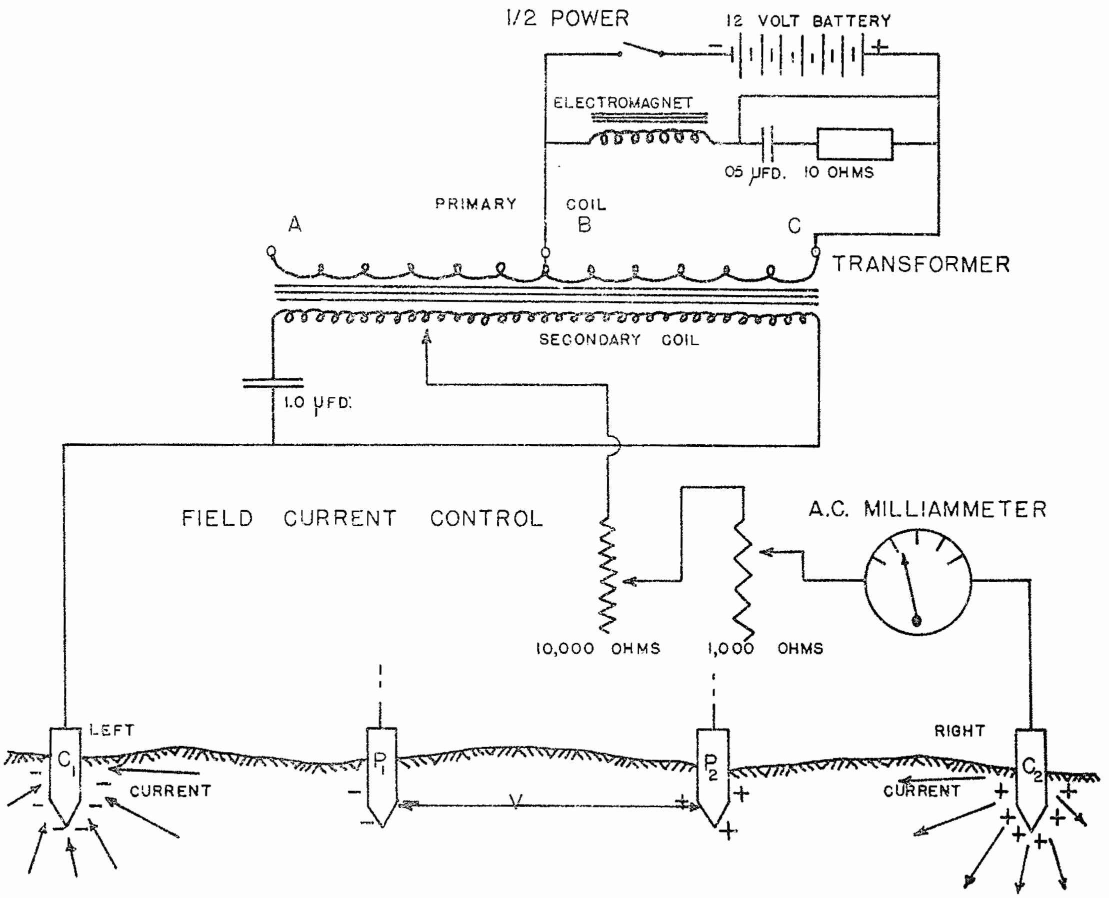


Diagram VIII

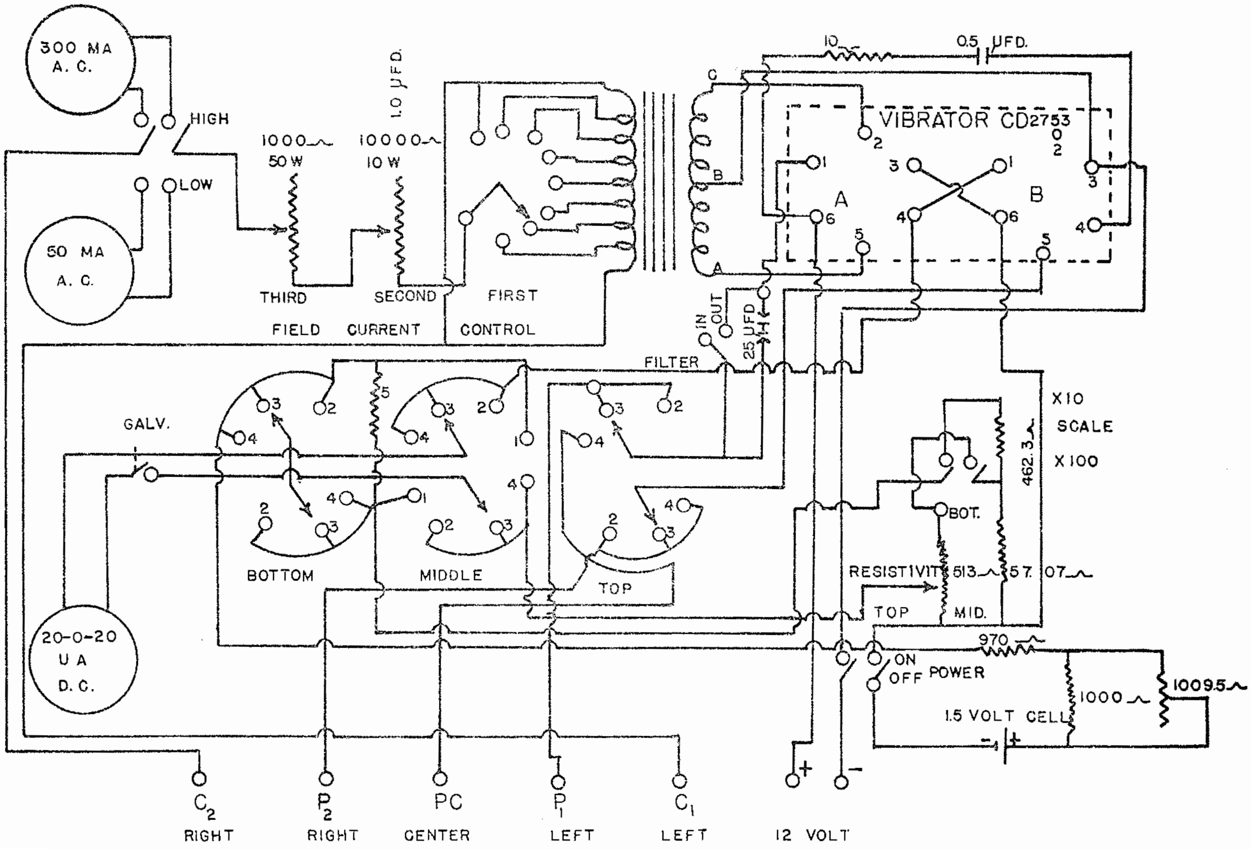


Diagram VIII

The circuit diagram furnished with the instrument is shown in this diagram.

The vibrator connections are shown from the bottom of the vibrator sockets. There are two six pronged sockets.

The three stages, two poles or moving contacts for each stage, of the selector switch are shown staggered or separated in the diagram. The stages are labelled "Bottom," "Middle," and "Top" as one views them from the underside of the panel where the circuit is in view.

The four positions of this selector switch are shown by numbers with the significance denoted in the section on the selector switch described earlier in this paper.

A reference system by labels, "Bot.," "Mid.," and "Top," applies to the terminals of the potentiometer. These terminals protrude from the vertical plastic cylinder housing the helical slide wire, and this labelling system, like that above has reference to this part of the circuit when viewed from the underside of the panel.

The labels for the three potential electrodes have the following significance: P_1 denotes the terminal to which the electric lead to the potential electrode to one's left, in actual use of the instrument, is connected; P_2 denotes the terminal to which the electrical lead to the potential electrode to one's right is connected; PC denotes the terminal to which the potential electrode at the center is connected by a short lead. This terminal, and the center potential electrode corresponding to it, are not used in the Gish Rooney usage of the instrument.

The "Right" and "Left" designations for the terminals, to which the leads for the various electrodes are connected, apply to the order in which one views these terminals when using the instrument and reading its meters and scales. Since all of the references in this diagram are to the circuit as one views it when the panel is removed, and turned upside down to expose the circuit leads and elements, these position-order references appear in reverse to the order in which one refers oneself to the diagram in viewing it.

At the vibrator frequency of 24 vibrations per second, the 1.0 microfarad capacitor offers approximately 7,000 ohms of capacitative reactance to alternating current of this frequency, the 0.5 microfarad capacitor offers approximately 14,000 ohms of capacitative reactance to current of this frequency, and the 2.5 microfarad capacitor offers approximately 2,800 ohms of capacitative reactance to current of this frequency (Miller).

The POWER switch is a double pole, single throw switch, one-half of which closes the circuit common to the flashlight cell and the potentiometer slidewire in the potentiometer circuit. The other half of this switch closes the circuit connecting the battery with the vibrator and its electromagnet, and, hence, to the primary of the transformer through connections established by the vibrator while the instrument is in operation.

The switch labelled FILTER takes out of the circuit or puts into the circuit the 2.5 microfarad capacitor. This places this capacitor out of, or in, that part of the potentiometer circuit common to the ground between potential electrodes and to the slide wire. Its purpose there is to balance with its capacitive reactance any large inductive reactance the ground may introduce so that the potential difference across the slide wire due to the earth potential difference "V" will be in phase with the vibrator so as to be properly rectified.

In the three stages of the FIELD CURRENT CONTROL the first stage is the coarse adjustment by which one selects the amount of secondary coil to be used as the source of electromotance for the power circuit. The other two stages make possible successively finer adjustments to obtain the value of field current desired. If, in ground of high resistivity, one cannot obtain the magnitude of current desired, a number of milliamperes equal to the number of feet of electrode separation in the Wenner configuration of electrodes, then one can take the resistivity reading obtained for a lower value of field current and multiply it by the ratio of the desired value of current to the actual value of current to obtain the proper resistivity reading. This method should be used sparingly and with due caution.

The Gish Rooney method with the Wenner electrode configuration of electrodes was used exclusively on this survey. At each station two power electrodes and two potentiometer electrodes were inserted into the ground. Relatively flat surfaces were chosen so as to obtain accurate readings with a minimum of disfiguration of curves due to irregularities on the surface. After each reading of apparent resistivity was taken, the electrodes were moved toward the center, always keeping a corresponding distance in feet between electrodes with the number of milliamperes of current. Such resetting of electrodes corresponds to depths below the surface.

With the center of the power circuit on a predetermined elevation, the depth, elevation, and thickness of the subsurface strata could be calculated.

By observing noticeable "breaks" in an otherwise regular curve of apparent resistivity readings, a rough interpretation of the strata was possible.

This procedure of making observations was used along the outwash boundary. By observing breaks and amount of resistivity, it was not difficult to determine whether the instrument was set within or without the outwash boundary, as the water filled sands and gravels offered very little resistance, while the clays of the adjacent moraines offered considerably more resistance. Should the instrument be set outside the outwash, it was not necessary to complete the soundings. If the instrument was set inside the boundary, soundings were taken to a depth of 100 feet and more, to determine the depth, thickness, and elevations of the sands and gravels and water table, and also in order to locate the bottom of the sands and gravels which is, in most cases, the erosional surface of the rocks not affected by the glacier.

By "zig-zagging" along the outwash boundary as predetermined by reconnaissance mapping, it was possible to draw an accurate outwash boundary.

Fifty-four resistivity soundings were taken on the outwash in order to obtain sufficient data for geologic interpretation and for accurate estimation of possible sand and gravel resources.

For such soundings, rough interpretation of the resistivity curves was not sufficient. Instead, the apparent resistivity readings were plotted on double logarithmic graphs of apparent resistivity versus electrode separation. Plotted in this way, the shape and size of the field curve is independent of the units used for resistivity and electrode separation. The problem is to find out what characteristic manifestations in these curves mean in terms of depth. Theoretical master curves plotted on double logarithmic curves by Wetzel and McMurry of electrically homogeneous substances were compared with the curves plotted from field apparent resistivity readings. Thus by a curve fitting procedure, accurate depths of various strata could be determined. By using a sequence of master curves, depths could be obtained indefinitely within the range of the instrument. With such a procedure, net results obtained from any one master curve affect essentially only one strata of the immediate field. Each strata must be assumed to be very nearly homogeneous. By assigning depths in feet to these different strata as determined by the curve comparison method, the exact depth can be obtained from the apparent resistivities read from the instrument, because the electrode spacing in feet corresponds to the milliamperes of resistivity. Electrode spacing in turn corresponds to depth of penetration of the recorded electrical current.

As stated before, the Carl A. Bays Earth Resistivity Instrument, when properly used is accurate to 10 per cent of error and less (Miller, 1954, p. 203). Its uses are limited. Without the presence of some knowledge concerning the area in question, interpretation of the resistivity data would be extremely difficult. The instrument, even though limited as an exploratory tool, is valuable as an accurate development tool (LeRoy, 1950).

Fifty-four resistivity soundings were taken in order to provide for adequate coverage of the outwash for the determination of elevations and the calculations of thicknesses (Table V).

The elevations of these stations were determined by a plane table survey. The gravel top elevations and the gravel bottom elevations were calculated after the mantle thicknesses and gravel thicknesses were interpreted from the resistivity curves (Table VII).

TABLE V

LOCATIONS OF RESISTIVITY SOUNDING STATIONS

Resistivity Sounding Station	Location
1	SE 1/4, NW 1/4, NE 1/4, Sec. 36, T. 98 N., R. 63 W.
2	SW 1/4, SW 1/4, NE 1/4, Sec. 36, T. 98 N., R. 63 W.
3	SE 1/4, SE 1/4, NE 1/4, Sec. 36, T. 98 N., R. 63 W.
4	SE 1/4, SW 1/4, NW 1/4, Sec. 36, T. 98 N., R. 63 W.
5	NE 1/4, NW 1/4, SW 1/4, Sec. 36, T. 98 N., R. 63 W.
6	NE 1/4, NE 1/4, SW 1/4, Sec. 36, T. 98 N., R. 63 W.
7	SW 1/4, NE 1/4, SW 1/4, Sec. 36, T. 98 N., R. 63 W.
8	SW 1/4, SW 1/4, SW 1/4, Sec. 36, T. 98 N., R. 63 W.
9	NE 1/4, SW 1/4, NW 1/4, Sec. 36, T. 98 N., R. 63 W.
10	NE 1/4, SE 1/4, SE 1/4, Sec. 25, T. 98 N., R. 63 W.
11	SE 1/4, SW 1/4, SW 1/4, Sec. 25, T. 98 N., R. 63 W.
12	SE 1/4, NE 1/4, NE 1/4, Sec. 1, T. 97 N., R. 63 W.
13	NW 1/4, NE 1/4, NE 1/4, Sec. 1, T. 97 N., R. 63 W.
14	NW 1/4, NW 1/4, SW 1/4, Sec. 31, T. 98 N., R. 62 W.
15	SW 1/4, NW 1/4, NE 1/4, Sec. 2, T. 97 N., R. 63 W.
16	NE 1/4, NE 1/4, NE 1/4, Sec. 2, T. 97 N., R. 63 W.
17	NW 1/4, NW 1/4, SE 1/4, Sec. 36, T. 98 N., R. 63 W.
18	SE 1/4, SE 1/4, SE 1/4, Sec. 34, T. 98 N., R. 63 W.
19	NE 1/4, NW 1/4, NW 1/4, Sec. 3, T. 97 N., R. 63 W.
20	NE 1/4, SE 1/4, SE 1/4, Sec. 2, T. 97 N., R. 63 W.
21	SW 1/4, SW 1/4, SW 1/4, Sec. 2, T. 97 N., R. 63 W.
22	NW 1/4, NW 1/4, NW 1/4, Sec. 34, T. 98 N., R. 63 W.

TABLE V (Continued)

Resistivity Sounding Station	Location
23	SE 1/4, SE 1/4, SE 1/4, Sec. 27, T. 98 N., R. 63 W.
24	SE 1/4, NW 1/4, NW 1/4, Sec. 27, T. 98 N., R. 63 W.
25	SE 1/4, SW 1/4, SW 1/4, Sec. 22, T. 98 N., R. 63 W.
26	SE 1/4, NW 1/4, SE 1/4, Sec. 26, T. 98 N., R. 63 W.
27	NE 1/4, NE 1/4, SW 1/4, Sec. 26, T. 98 N., R. 63 W.
28	NW 1/4, SE 1/4, SW 1/4, Sec. 27, T. 98 N., R. 63 W.
29	SE 1/4, NW 1/4, SE 1/4, Sec. 28, T. 98 N., R. 63 W.
30	SE 1/4, NE 1/4, NW 1/4, Sec. 22, T. 98 N., R. 63 W.
31	NE 1/4, NE 1/4, NE 1/4, Sec. 22, T. 98 N., R. 63 W.
32	SE 1/4, SW 1/4, SW 1/4, Sec. 15, T. 98 N., R. 63 W.
33	NE 1/4, SW 1/4, SW 1/4, Sec. 11, T. 98 N., R. 63 W.
34	SE 1/4, SE 1/4, NE 1/4, Sec. 10, T. 98 N., R. 63 W.
35	NE 1/4, NE 1/4, SW 1/4, Sec. 3, T. 98 N., R. 63 W.
36	SE 1/4, SE 1/4, SW 1/4, Sec. 24, T. 98 N., R. 63 W.
37	SE 1/4, NE 1/4, NE 1/4, Sec. 25, T. 98 N., R. 63 W.
38	SE 1/4, SE 1/4, SE 1/4, Sec. 24, T. 98 N., R. 63 W.
39	SE 1/4, SW 1/4, SW 1/4, Sec. 19, T. 98 N., R. 63 W.
40	NW 1/4, NW 1/4, SE 1/4, Sec. 19, T. 98 N., R. 62 W.
41	NE 1/4, NE 1/4, NW 1/4, Sec. 19, T. 98 N., R. 62 W.
42	SE 1/4, NE 1/4, SW 1/4, Sec. 18, T. 98 N., R. 62 W.
43	NW 1/4, NE 1/4, SE 1/4, Sec. 18, T. 98 N., R. 62 W.
44	SE 1/4, SE 1/4, NW 1/4, Sec. 17, T. 98 N., R. 62 W.
45	SW 1/4, SW 1/4, SE 1/4, Sec. 8, T. 98 N., R. 62 W.

TABLE V (Continued)

Resistivity Sounding Station	Location
46	SW ¼, SE ¼, NE ¼, Sec. 8, T. 98 N., R. 62 W.
47	SW ¼, NW ¼, NE ¼, Sec. 15, T. 98 N., R. 63 W.
48	SE ¼, SE ¼, NW ¼, Sec. 35, T. 98 N., R. 63 W.
49	NE ¼, NE ¼, SE ¼, Sec. 35, T. 98 N., R. 63 W.
50	SE ¼, SE ¼, NW ¼, Sec. 1, T. 97 N., R. 63 W.
51	SW ¼, NW ¼, NW ¼, Sec. 14, T. 97 N., R. 63 W.
52	SE ¼, SE ¼, NE ¼, Sec. 10, T. 97 N., R. 63 W.
53	SE ¼, SE ¼, SW ¼, Sec. 15, T. 97 N., R. 63 W.
54	NE ¼, NW ¼, SW ¼, Sec. 11, T. 97 N., R. 63 W.

TABLE VI

RESISTIVITY SOUNDINGS STATION DATA

Station	Surface Elevation	Gravel Top Elevation	Gravel Bottom Elevation	Mantle Thickness	Gravel Thickness
1	1438.7	1436.5	1413.9	2.3	23
2	1438.2	1436.5	1415.6	1.6	21
3	1440.4	1438.2	1415.8	1.6	23
4	1432.6	1431.3	1406	1.2	25
5	1430.7	1428.9	1415	1.3	24
6	1431.7	1430.6	1407	1.1	24
7	1428.8	1426.7	1402	2.1	25
8	1427.4	1426	1412	1.5	15
9	1434.3	1434	1409	0.3	25
10	1445.9	1438	1424	7.9	14
11	1436.5	1433	1407	2.9	26
12	1430.2	1424	1418	6.2	6
13	1430.7	1423	1417	7.7	6
14	1434.9	1428	1423	6.9	5
15	1427.3	1421	1414	6.3	7
16	1427.9	1422	1398	5.9	24
17	1435.3	1430	1405	5.3	25
18	1426.0	1424	1408	2.0	16
19	1419.4	1412	1400	7.4	12
20	1425.7	1420	1396	5.3	24
21	1421.0	1414	1399	7.0	15
22	1422.9	1417	1404	5.9	13

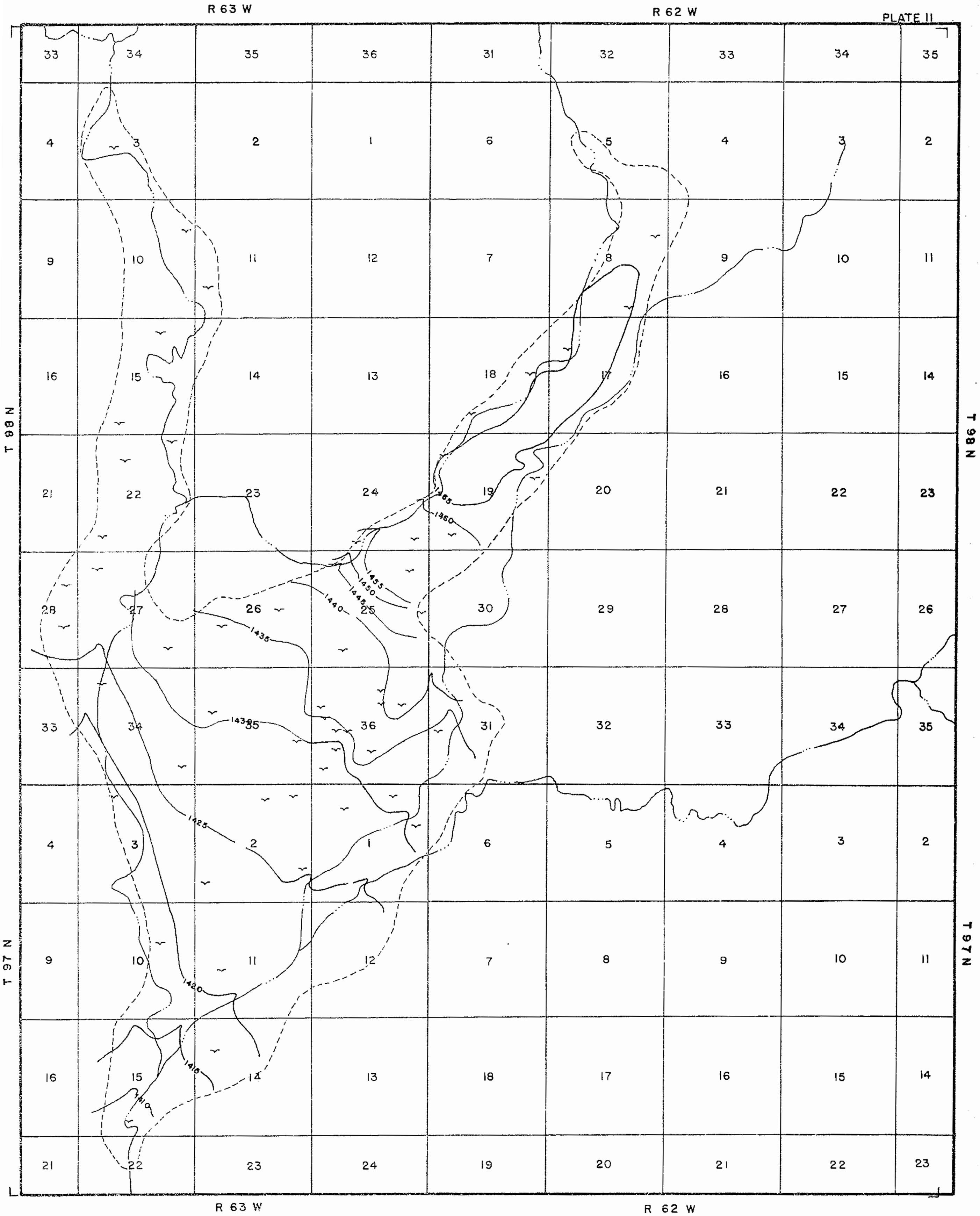
TABLE VI (Continued)

Station	Surface Elevation	Gravel Top Elevation	Gravel Bottom Elevation	Mantle Thickness	Gravel Thickness
23	1426.7	1401	1397	25.7	14
24	1425.6	1421	1414	4.6	7
25	1429.2	1426	1411	3.2	15
26	1436.8	1433	1417	3.6	16
27	1432.2	1429	1412	3.2	7
28	1432.8	1425	1418	7.8	7
29	1426.5	1418	1411	8.5	7
30	1425.3	1424	1412	1.3	12
31	1424.9	1419	1405	5.9	14
32	1426.1	1418	1405	8.1	13
33				7.9	4
34				10.0	10
35	1426.4	1415	1405	9.4	10
36	1452.7	1445	1442	7.7	3
37	1458.7	1457	1432	1.7	25
38	1458.5	1451	1446	7.5	5
39	1458.8	1455	1448	3.8	7
40	1464.1	1457	1437	7.1	20
41	1469.2	1464	1444	5.2	20
42	1452.5	1443	1423	9.5	20
43	1460.0	1456	1448	4.0	8
44	1466.7	1463	1456	3.7	7
45	1465.9	1466	1450	0.0	15.9

TABLE VI (Continued)

Station	Surface Elevation	Gravel Top Elevation	Gravel Bottom Elevation	Mantle Thickness	Gravel Thickness
46	1460.9	1461	1449	0.0	11.9
47				8.2	10
48	1430.2	1430	1410	0.2	20.2
49	1429.9	1430	1414	0.0	15.9
50	1427.4	1422	1409	5.4	11
51	1416.1	1412	1381	4.1	31
52	1419.2	1413	1392	6.2	21
53	1409.4	1403	1369	6.4	34
54	1422.2	1414	1387	8.2	27

PLATE II



DELMONT GLACIAL OUTWASH
SOUTH DAKOTA

RESISTIVITY SOUNDING STATION

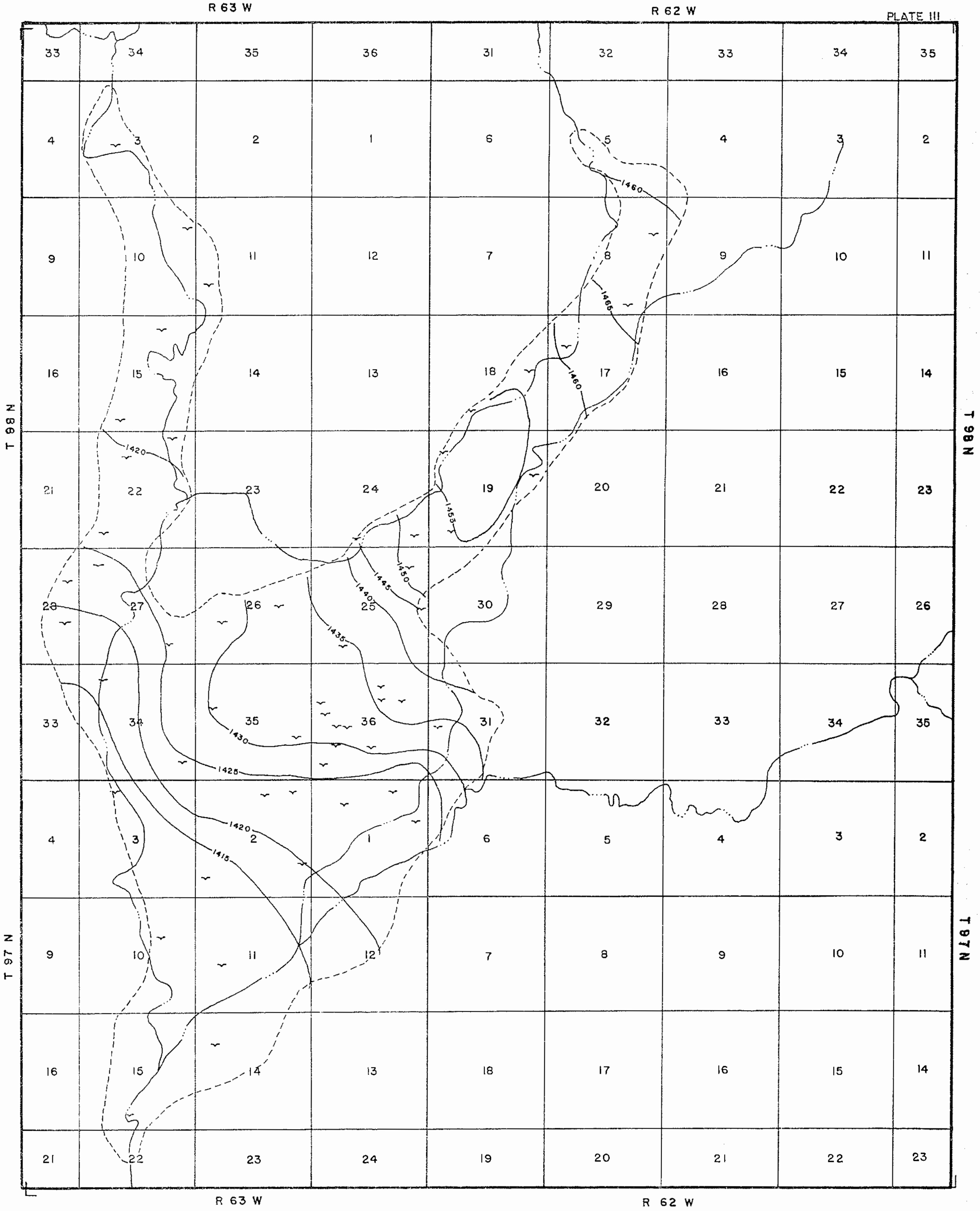
TOPOGRAPHIC MAP

SCALE

0

2 MILES

PLATE III



DELMONT GLACIAL OUTWASH
SOUTH DAKOTA

GRAVEL TOP CONTOURS

⏝ RESISTIVITY SOUNDING STATION

SCALE

0 2 MILES

ECONOMIC GEOLOGY

From time to time gravel has been dug in Sections 36 and 25, Township 98 North, Range 63 West. Most of the pits in Section 25 have been abandoned. Many of the pits in Section 36 have been abandoned, but several are still being operated. The South Dakota Highway Commission drilled several test holes on this section to determine the quality of the gravel and the feasibility of economic utilization. Analysis of the samples indicated that gravel is of fair quality for road aggregate. The percentage of the softer rocks is too high for good quality gravel.

In the north half of Sections 35 and 36, and in the south half of Sections 25 and 26, Township 98 North, Range 63 West, the gravel is sufficiently close to the surface to facilitate easy excavation. Approximately ten feet of gravel can be utilized before the water table is reached. Perhaps floating dredges might be used for excavation below the water table.

Most of the sand and gravel is too poor in quality for concrete aggregate. However, a washing and sieving plant is now in operation, which delivers sand of a quality suitable for concrete aggregate.

The most valuable resource of the glacial outwash is water. Subsurface drainage is adequate for irrigation over the entire outwash and much of the alluvial valleys.

An inspection of the three contour maps indicates that the general dip of all three is southward. It can be inferred that the glacial melt water, as well as the modern stream water, drained southward.

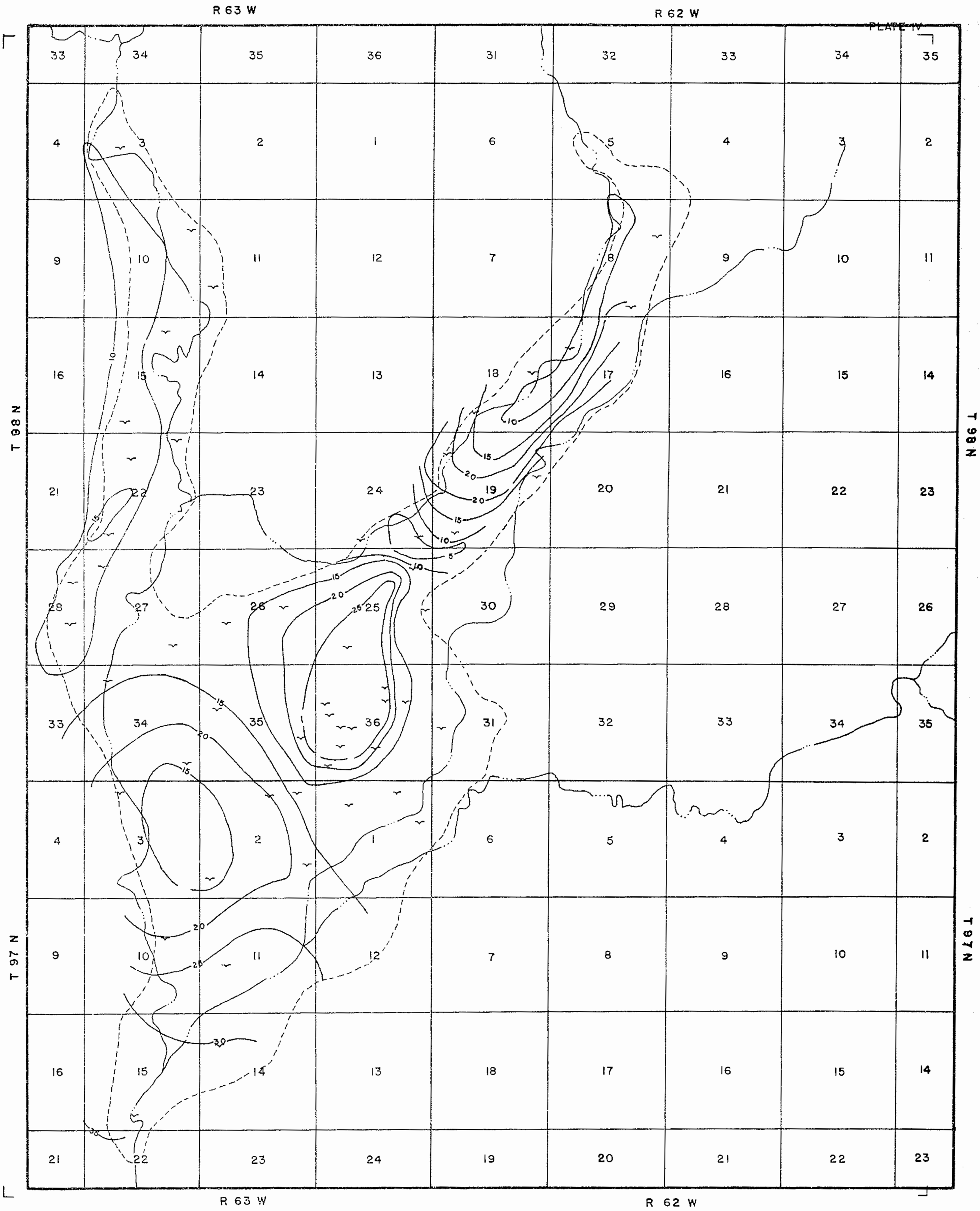
Approximately thirty square miles of flat surface suitable for irrigation with a minimum of leveling are available. This includes the thirteen square miles of outwash and the alluvial valley floors within short distances of the outwash.

The total volume of gravel, 200,000,000 cubic yards, is obtained by multiplying the average thickness of gravel by the total area. The average depth to the water table is 14 feet. The average depth to the bottom of the gravel is 21 feet. By subtracting the average depth to the water table from the average depth to the bottom of the gravels, an approximate thickness of water filled sands and gravels is obtained, seven feet. The approximate volume of water saturated sands and gravels, 93,800,000 cubic yards, is obtained by multiplying this thickness by the total area. The porosity, as determined in the laboratory, is 30.8 percent. By multiplying the percent of porosity by the volume of water filled sands and gravels, an approximate volume of water is obtained of 31,200,000 cubic yards. This volume converted to cubic feet, 842,400,000, and divided by 43,560 square feet, the number of square feet in one acre, expresses the volume of water in acre-feet. It is 19,350 acre-feet. An acre-foot of water is the volume of water required to cover one acre with one foot of water.

The water table in the outwash is very nearly stable. According to personal communication with farmers and well drillers in the vicinity, the water table fluctuates very little even in exceptionally wet or dry years.

This available ground water, when supplemented by the mean annual precipitation of 24 inches, would make irrigation of the available irrigable land feasible as long as reasonable conservation of ground water is practised.

PLATE IV



DELMONT GLACIAL OUTWASH
SOUTH DAKOTA

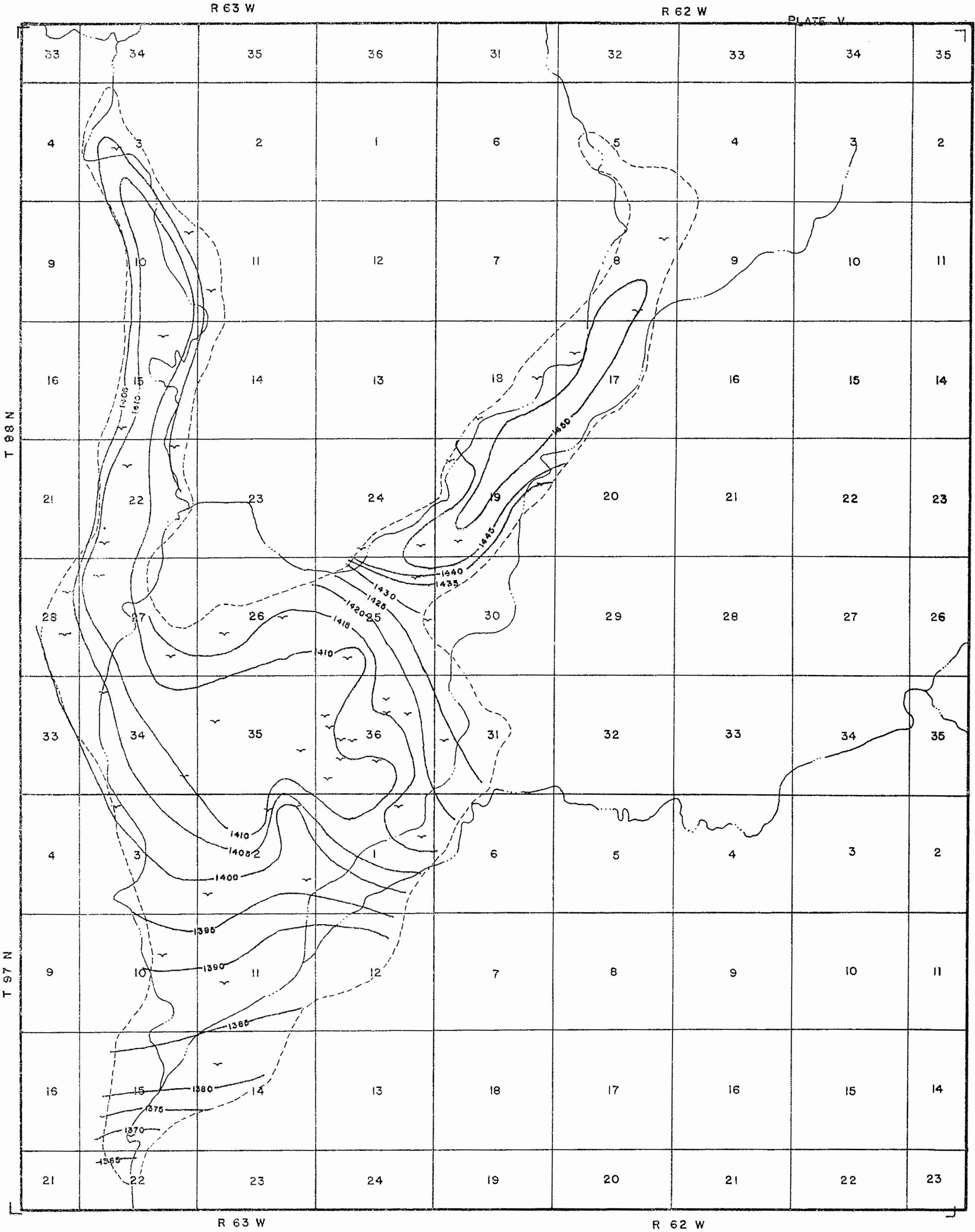
RESISTIVITY SOUNDING STATION

ISOPACH MAP

SCALE

1 0 1 2 MILES

PLATE V



DELMONT GLACIAL OUTWASH
SOUTH DAKOTA

GRAVEL BOTTOM CONTOURS

SUMMARY AND CONCLUSIONS

The approximate total area of the Delmont Glacial Outwash is thirteen square miles. The entire area is almost flat and very nearly level with a gentle southward dip. In most cases, the outwash terminates abruptly against higher, more rolling moraine hills. Along the extreme northeast side there appears to be an esker. Evidence for this esker is an irregular, comparatively high meandering hill, the body of which consists of poorly sorted subangular gravels ranging in size from silts to rather large boulders. A relatively wide flat flood plain trends eastward from the southeast side of the outwash. A topographic map of the outwash is included in this report (Plate II).

A thin veneer of soil and alluvial sediments mantle the outwash. The minimum thickness of the mantle is very nearly zero feet. Most of the north half of Section 36, Township 98 North, Range 63 West, is covered by an extremely thin soil mantle from zero to two feet in thickness. The maximum thickness, 25.7 feet, is found in the southwest quarter of Section 18, Township 98 North, Range 62 West. The average thickness of soil mantle, or the silt covering of the sands and gravels of the outwash is 5.5 feet. In general, the minimum depths to the sands and gravels, corresponding to the thickness of the mantle, are near the center of the outwash, and the maximum depths are in the southern portion and in the modern stream valleys of the northwest and northeast portions. A contour map on the top of the gravels is included in this report (Plate III).

Generally speaking, the thickest occurrence of sands and gravels is found in the center of the outwash in Section 36, Township 98 North, Range 63 West. The maximum thickness is 34 feet. Thicknesses averaging nearly 25 feet are found in several places in Section 36, Township 98 North, Range 63 West. The average thickness is 15.5 feet. An isopach map depicting the thickness of the sands and gravels of the outwash is included in this report (Plate IV).

In order to illustrate the erosional surface of the bed rock, contours were drawn on the bottom of the gravels (Plate V). This is the post-Cary erosional surface. The outwash sands and gravels of Mankato glaciation have been deposited on this erosional surface. The general dip of this surface is southward.

Stratigraphic correlation of the Delmont Glacial Outwash was nearly impossible. No Pleistocene fossils were found, and geomorphologic correlation largely failed. However, after careful study was made of the surrounding area, it can be inferred that the Delmont Glacial Outwash sands and gravels are of Mankato age. The sands and gravels were washed out of the Mankato ice and moraines and deposited on the post-Cary erosional surface. The high moraines north and east of the outwash are Mankato and the low moraines south and west are Cary (Flint, 1955, p. 103, Fig. 29). The general direction of the flow of the water was west of south as indicated by the presence of coarser particles in the northern portion of the outwash. All three contour maps, bottom of gravel, top of gravel, and topographic, indicate gentle dip to the south.

The sands and gravels are of good enough quality and sufficient in quantity, and are close enough to the surface in the central portion of the outwash to make economical exploitation feasible. The sands are of poor quality for concrete aggregate unless sieved and washed, but with a minimum of crushing or sieving, most of the gravel is suitable for road aggregate.

With seven feet of water-filled sands and gravels of an average porosity of 30.8 per cent, an ample water supply of 19,340 acre-feet is available for the irrigation of approximately 20,000 acres when used as a supplement to the mean annual precipitation of 24 inches. This would amount to approximately 11 inches of water over the 20,000 acres of irrigable land. Very little of this ground water would be needed most of the time, but it is available when precipitation is below normal. The reservoir storage can be rapidly and easily replenished by normal precipitation and from the flow of the three streams which traverse the outwash.

Most of the soil on and near the glacial outwash is of irrigable quality, especially if a sprinkling irrigation system is used. The sandy soils covering the outwash and alluvial valley floors facilitate the infiltration of water to storage. All of the glacial outwash and much of the alluvial valleys are underlain by sands, silts and gravels, which provide sufficient subsurface drainage, also desirable in irrigation (Eric, 1952).

The Carl A. Bays Resistivity instrument is a precision instrument, being about 90 per cent accurate. Its most valuable use is for the exploration of known geologic resources rather than the exploration of new areas. The instrument is economical to operate. Large areas can be covered in a short time.

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