STATE OF SOUTH DAKOTA
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STATE GEOLOGICAL SURVEY
Duncan J. McGregor, State Geologist

Report of Investigations
No. 95

EVALUATION OF EXPLORATION METHODS FOR COARSE AGGREGATE IN EASTERN SOUTH DAKOTA

by
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South Dakota State Geological Survey
South Dakota State Department of Highways

Prepared in cooperation with
United States Department of Commerce
Bureau of Public Roads

Science Center
University of South Dakota
Vermillion, South Dakota
1964

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ABSTRACT

The coarse aggregate research project was initiated to assist the South Dakota Department of Highways in the organization of an aggregate inventory.

Aggregate in the glaciated portion of South Dakota is found in recognizable landforms. These landforms may be in the form of outwash, lake beds, kames, kame terraces, eskers, and collapse features. Minor sources of aggregate may be found in some local bedrock sources.

Potential aggregate sources may be outlined on geologic, pedologic and topographic maps and a materials location map may be compiled from these maps. Air photos can then be used to make detailed studies of potential areas shown on this materials location map. When the potential sources have been detailed, geophysical methods are used to determine the areal extent and depth of the deposit.

A well integrated background in the geological sciences and physics is a prerequisite for any materials investigation.

This study showed that by use of these exploration "tools" up to 90 percent of the field work associated with materials investigations can be eliminated. The use of the resistivity method can eliminate a great majority of the drill holes usually needed to prove an aggregate deposit.

INTRODUCTION

The coarse aggregate research project was initiated in February of 1962 to evaluate exploration methods for sand and gravel, and other coarse aggregate in eastern South Dakota. This project was financed with a portion of the research funds made available from the Federal Interstate Highway program through the United States Department of Commerce, Bureau of Public Roads.

The South Dakota State Highway Commission and the South Dakota State Geological Survey entered into an agreement on February 15, 1962, under which they agreed to make available to the project all the information in their files and to give full cooperation in the study and in the preparation of a comprehensive report on its findings. The Geological Survey furnished technical assistance to the project and the Highway Commission supplied field expenses and wages to the personnel.

The field work and preparation of this study were performed under the direction of C. P. Jorgensen, State Manager, Research and Planning Division, State Highway Commission, and A. F. Agnew, State Geologist, State Geological Survey, at the initiation of this project, and D. J. McGregor, State Geologist, at its conclusion. Field work was carried out during the period June 1 through August 31, 1962, and from June 1 through August 31, 1963. Field assistance in 1962 was given by George Shurr, George Ferley, and Leander Stroschein, and in 1963 by George Ferley, James Harvey, and Ronald Little. The earth-resistivity portion of the project was directed and prepared by B. E. Lundberg of the Electrical Engineering Department of South Dakota State College.

Numerous other states have undertaken studies similar to this one. This study has been slanted entirely towards the glaciated portion of South Dakota, and the results should be applicable to similar areas of other states.

In this study much of the geologic information available in eastern South Dakota, both published and unpublished, was studied and field checked. Soil maps and reports were studied for a majority of the counties and topographic maps of all scales and sizes were evaluated. Approximately 250 resistivity stations were set up and over 40 auger drill holes were drilled to evaluate the resistivity measurements. Existing drill hole data were used and numerous 5 and 10 foot hand auger holes were dug.

Figure 1 is an index map showing the areas in eastern South Dakota in which detailed as well as reconnaissance surveys were made during 1962 and 1963.

Appendix A is a glossary of geological, pedological and engineering terms which have been defined for laymen and professionals who desire the meaning of these terms as used in this report.

I wish to thank the residents of the areas in which we worked for their cooperation, the staffs of the two cooperating agencies and the Soils and Materials section of the Highway Department for their helpful criticism. Special thanks are due the United States Bureau of Public Roads for making this study possible and for their practical suggestions.

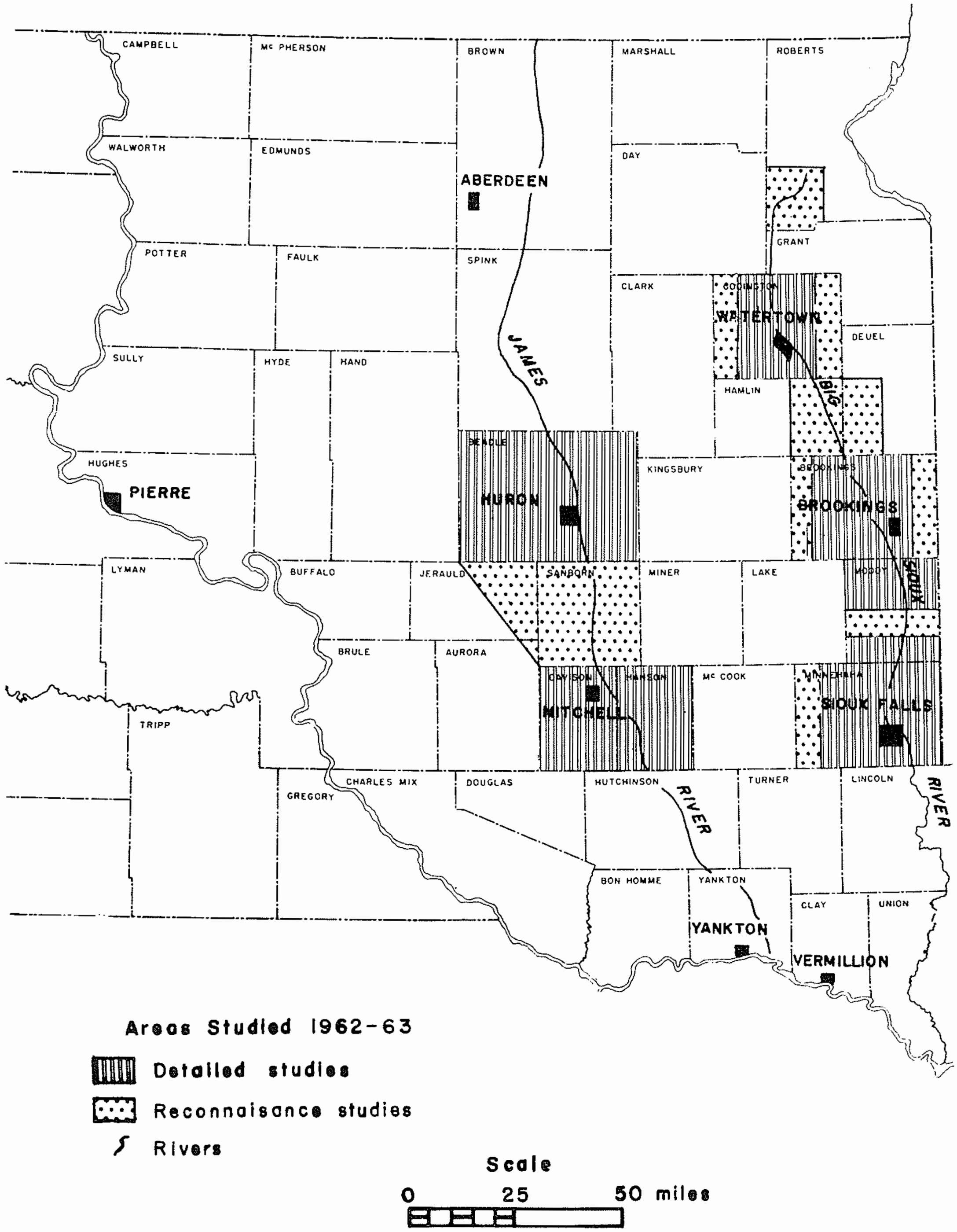


Figure 1. Index Map of Eastern South Dakota Showing Areas Studied

Economics of Aggregate

In the mineral industry of the State of South Dakota, aggregate ranks second only to gold in value. Sand and gravel makes up the majority of the aggregate produced.

In the period 1932 to 1962, 215 million short tons of sand and gravel have been produced at a value exceeding 110 million dollars (U. S. Bureau of Mines Minerals Yearbooks, 1932-1962). Ninety percent of all aggregate produced was used in construction, and a great percentage of this was used in building highways.

Figure 2 shows the amount of sand and gravel produced in South Dakota and its total value during the period 1932-1962. Since 1954 two to three times the amount of sand and gravel has been produced than previously; this is due largely to the Interstate Highway Program. If the demand for this commodity continues to rise, known reserves of our top grade aggregate will soon become depleted. This means that those top grade pits now in existence will be mined out and either a lower quality material will have to be used, or the less obvious good quality sources will have to be located.

In keeping with this need, the South Dakota State Highway Department has begun to organize a state-wide aggregate survey. The primary purpose of the present study is to assist the Highway Department in this aggregate survey.

SOURCES OF COARSE AGGREGATE IN EASTERN SOUTH DAKOTA

Generally, eastern South Dakota is defined as that portion of South Dakota which has been subjected to glaciation and is essentially that portion which lies east of the Missouri River. The area lies partly in the Central Lowland physiographic province and partly in the Great Plains province (fig. 3).

Two features distinguish the Central Lowland province. The Coteau des Prairies is a hilly, lake-dotted highland 60-70 miles wide extending north-south along the eastern border of the State. The James Basin (fig. 3) is a flat to slightly rolling lowland and is as wide as and parallels the Coteau for the entire length of the State (Rothrock, 1943, p. 12).

The Great Plains province is represented by the Coteau du Missouri in eastern South Dakota. This Coteau is hilly, 25-30 miles wide, and lies between the Missouri River and the James Basin (Rothrock, 1943, p. 34).

The glaciated portion of South Dakota has a total area of 34,000 square miles (Flint, 1955, p. 1) which is covered with 0-750 feet of glacial drift.

The glacial drift is underlain by flat-lying sandstones and shales of Cretaceous age, and locally by Tertiary and Precambrian rocks. The floodplains of the larger streams have varying thicknesses of alluvial cover.

The primary source for coarse aggregate in eastern South Dakota is glacial drift, but secondary sources of bedrock exist. Fine aggregate may be found in deposits of windblown material and in recent stream deposits.

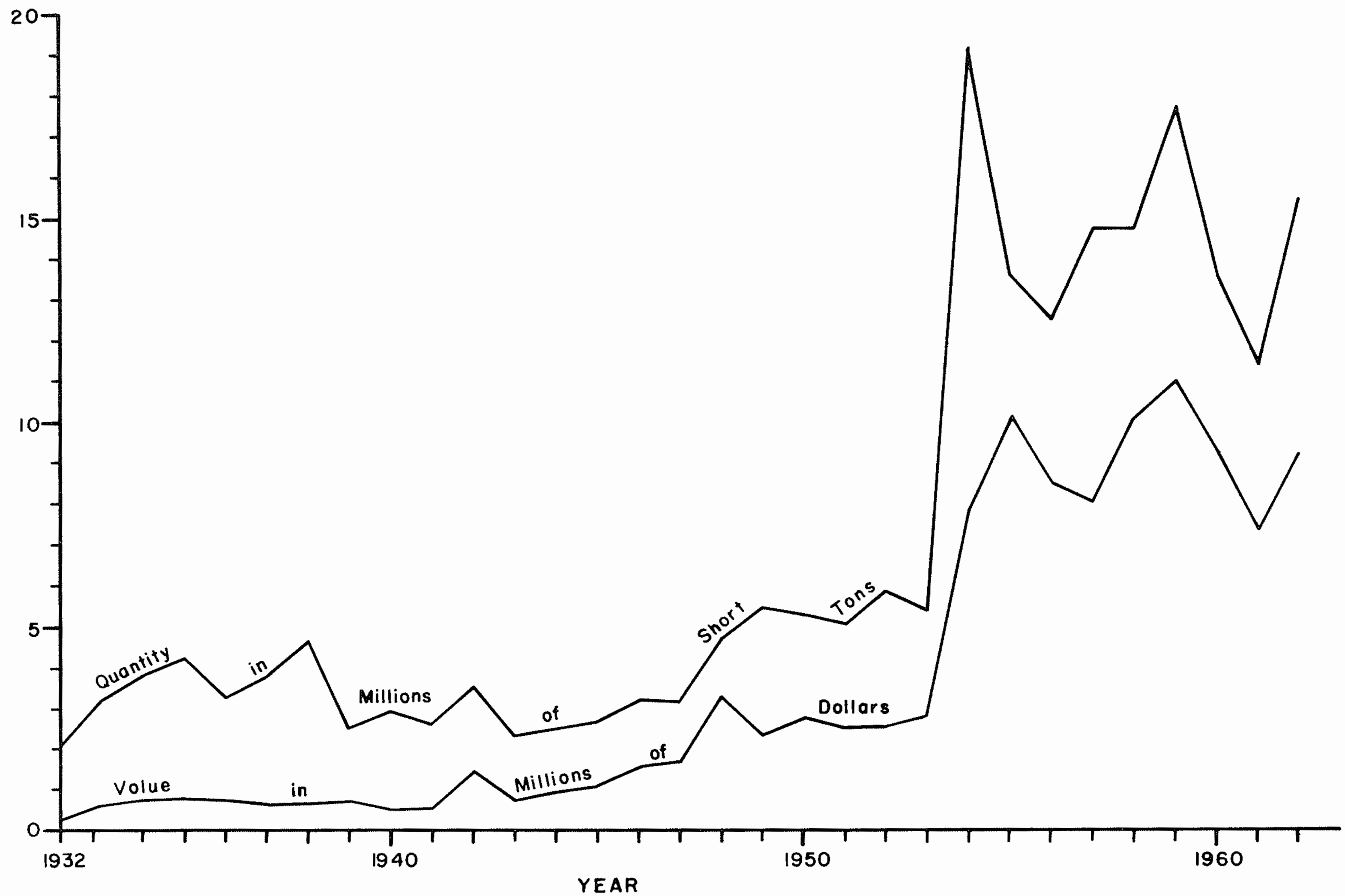


Figure 2. Sand and Gravel Production and Value in South Dakota, 1932-1962. (U.S. Bureau of Mines Minerals Yearbooks 1932-1962.)

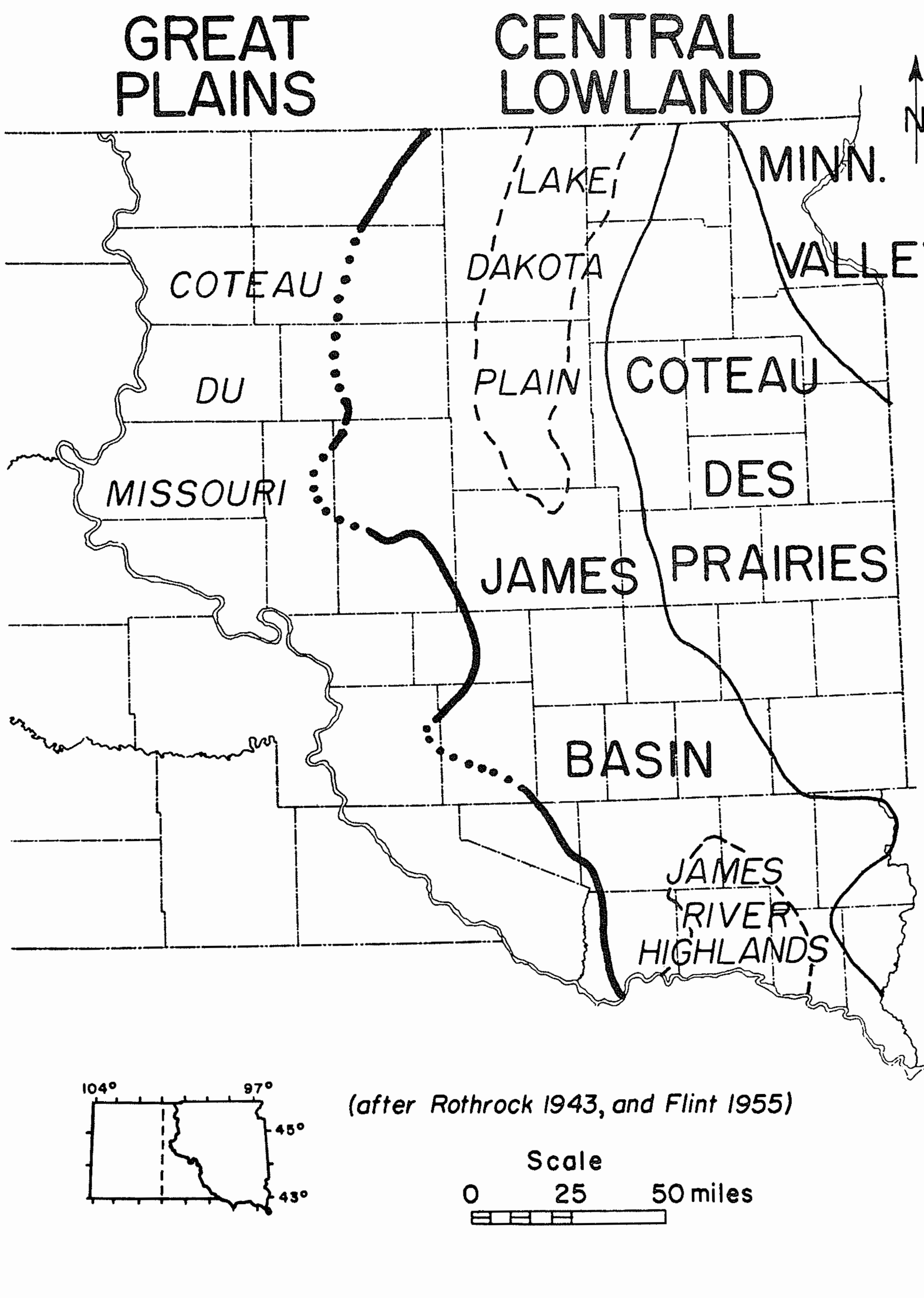


Figure 3. Major Physiographic Divisions of Eastern South Dakota

Glacial Drift

Glacial drift can be classified in two ways--in terms of sediments and in terms of landforms. Both classifications must be used despite the fact that they are only partly related (Flint, 1957, p. 108). Coarse aggregate in eastern South Dakota is usually found in recognizable landforms and the problem, therefore, resolves itself into a search for these landforms.

Drift as a Sediment

Glacial drift as a sediment is defined as any rock material transported by a glacier and deposited by the ice, or by water derived from the melting of the ice. In eastern South Dakota this includes till, proglacial stratified drift, and ice contact stratified drift.

Till is composed of clay- and silt-size particles mixed randomly with sand, pebbles, and boulders, and was deposited by the glacial ice itself. Although till is the most prevalent type of drift in South Dakota, it is not usually suitable for coarse aggregate due to its high clay content and highly variable nature.

Proglacial stratified drift was deposited beyond the limits of a glacier by the action of meltwater. It is composed generally of layered sands and gravels and is more highly sorted than till. For this reason, it is a very valuable source of aggregate in eastern South Dakota.

Ice contact stratified drift is characterized by extreme ranges and abrupt changes in grain sizes, by bodies of till which are included in the deposit, and by contortion and deformation of the bedding in the deposits (Flint, 1957, p. 146). This internal character shows that it accumulated in contact with glacial ice.

Drift as a Landform

The landforms found in eastern South Dakota composed of glacial drift are: moraines, outwash, lake beds, kames, kame terraces, eskers, and collapse features.

(Moraines)

Moraines are generally composed of till, but may have stratified drift deposits associated with them. Moraines are accumulations of drift (mainly till) having a constructional topography which is independent of the surface beneath it and which is built by the direct action of the glacial ice (Flint, 1957, p. 130). Two types of moraines occur--ground moraine and end moraine, each of which has a distinct landform. Their subdivision is made on mode of occurrence.

Ground moraine is a landform having low relief devoid of transverse linear elements. In eastern South Dakota ground moraines are generally typified by rolling topography that has little relief. The areas of ground moraine usually are cultivated except for the lower wet areas.

An end moraine has a discontinuous linear ridgelike form. It is marked by topography that is rougher than that found in areas of ground moraine. This is due to the way it was formed and to the way associated streams have dissected it.

(Outwash)

Proglacial stratified drift which is washed out beyond the glacier by streams and deposited in the form of broad flat fan-shaped deposits or as fill in glacial valleys is called outwash.

Outwash is indicated by many surface forms, the most important being broad flat plains areas, and broad flat-bottomed river valleys. Most outwash has well developed internal drainage and little or no relief. In some instances where it has been cut through and eroded by rivers, outwash occurs as benches or terraces along valley walls.

Outwash is the most productive source for aggregate in eastern South Dakota. It is found at the surface as outwash plains and as valley train deposits in many of the major river valleys, and in the subsurface as buried outwash. Local outwashes may be found as isolated pockets within moraines and as such are difficult to recognize.

(Glacial Lake Beds)

Glacial lake beds are a minor proglacial aggregate source. The sediments in the center of these deposits are usually fine sands and silts, but coarse aggregate may be present around the margins, where streams entered the lakes and where waves built up beaches. Some of the larger glacial lakes still contain water while others appear as broad, flat, relatively steep-sided dry basins. Lake basins are not farmed because of their swampy nature.

(Kames)

Kames are ice contact features which appear as moundlike hills or short ridges on drift plains. The mounds are true kames, while the short ridgelike features may be crevass fillings. Kame deposits are built in or on the glacier. Basins in the ice are filled with coarse material; as the ice melts, this material is let down on the surface and kames result. They appear in eastern South Dakota as irregular mounds and discontinuous ridges. They are not usually farmed due to their highly porous structure and to their coarse-grained texture.

(Kame Terraces)

Kame terraces form by meltwater deposition of coarse material between the edge of the glacier and a valley wall; when the ice is removed, the material remains plastered high on the valley wall. They differ from outwash terraces in that they are not former flood plains but were formed in their present location. They appear as knobby high-level remnants on valley walls. They may occur in pairs on opposite sides of the valley, or singly on only one side.

(Eskers)

Eskers are long narrow sinuous ridges usually composed of coarse material. They may be formed by streams in, on, or under the glacier. Some extend for miles whereas others are but local features. They appear as irregular lines in the topography. They may be associated with all types of glacial deposits and are sometimes difficult to recognize because of their discontinuous nature.

(Collapse Features)

Collapse features appear as basins and depressions in outwash and sometimes in moraines. These are caused by ice blocks which have been incorporated in these deposits. Upon melting, the space that the ice occupied no longer was able to support the weight of overlying material and it collapsed forming a depression. Often these depressions are filled with water or are filled with outwash material from succeeding glaciers.

Windblown Deposits

Windblown deposits of sand and silt are relatively unimportant sources of aggregate. In eastern South Dakota these deposits are--sand in the form of dunes and loess.

Sand dunes may be recognized by their scanty cover of vegetation and by their long, low, curving profile. Dunes are possible sources for sand.

Loess is an accumulation of silt-size particles deposited by the wind. It is recognized by its sorted nature and its tendency to stand in nearly vertical cliffs.

Bedrock

The Sioux Quartzite in Minnehaha, Davison, and Hanson counties and the Milbank Granite in Grant County are mined as bedrock aggregate. The difficulty in quarrying these hard and durable materials has pre-empted any large scale use, but as glacial material becomes more scarce and of lower quality this source may become more economical to use.

Other exposures of bedrock are limited to local outcrops along stream valleys.

Stream Deposits

Since the last glaciation some 10,000 years ago, streams have been depositing material or eroding that which has been deposited. In all but the very large streams, this deposition has resulted in alluvium composed predominantly of clays and silts. The Missouri River is the only major stream which has deposited coarse material of any extent. The surface alluvium along this river is fine to medium sand, and is of commercial quality and quantity locally.

GEOLOGIC MAPS AND REPORTS

Geology is defined "*** as that branch of natural science devoted to the study of the physical features of the earth, the composition and structure of the rocks composing it, the forces at work in altering it, and the record of the animals and plants that have lived on its lands and inhabited its seas" (Legget, 1962, p. ix). The science of geology is valuable to a materials investigation only as it may be applied to the location and description of sources of material. Other workers (Highway Research Board, 1952) have discovered, however, that a geologic investigation should be the starting point in every study of naturally occurring material, and that the science of geology can be applied to practically every phase of materials work.

The application of geology to materials investigations in eastern South Dakota requires a background in geology and a working knowledge of a few of the specialized branches of the science: geomorphology, glacial and subsurface geology, petrography and geophysics.

Geomorphology is the description, classification and correlation of landforms. In terrain of glacial origin, as is found in eastern South Dakota, landforms are very significant. The recognition of the various landforms and a knowledge of what material may be expected in each is a prerequisite for any materials study. An outline of the various landforms and how they may be recognized is included in a later section of this report.

Because all the landforms encountered in eastern South Dakota are of glacial origin or have been modified by glacial processes, a knowledge of the features resulting from glacial erosion and deposition is mandatory. With such an understanding of the glacial processes, one soon becomes trained in the search for landforms that may be possible sources of aggregate.

Subsurface geology is used here to mean all material either consolidated (bedrock) or unconsolidated (glacial, alluvial) found beneath the surface of the earth. As the hunt for aggregate progresses, the more accessible areas will be depleted and deeper sources with greater overburden will have to be exploited. A thorough knowledge of subsurface geology is a prerequisite to this type of exploration.

The phase of geology which discusses the physical description of rocks is known as petrography. By a petrographic study of aggregate sources, the various deleterious constituents can be isolated.

Geophysics is the application of physics to geology and geological processes. The resistivity and seismic geophysical methods will be discussed in a following section.

Sources of Geologic Literature

Geologic literature is available through various sources, but the major information of interest in materials investigations in South Dakota can be obtained from publications of the South Dakota State Geological Survey and the United States Geological Survey.

South Dakota State Geological Survey

The South Dakota Geological Survey is publishing in the near future a series of index maps showing the geological maps and reports which are available for South Dakota. This index is divided into 10 parts which are listed below.

1. Geological Quadrangles Mapped.
2. Published Geologic Reports on South Dakota Economic Geology.
3. Published Geologic Reports on South Dakota Water, Sand, Gravel, and Engineering Geology.
4. Published Geologic Reports on South Dakota Reconnaissance Geology.
5. Published Geologic Reports on South Dakota Stratigraphic, Paleontologic, and Glacial Geology.
6. Published Geologic Reports on South Dakota Mineral Resources and Geophysical Studies.
7. Published Geologic Reports on South Dakota Structural and Igneous Geology.
8. Published Geologic Reports on South Dakota Pegmatite and Associated Minerals.
9. Published Geologic Reports on South Dakota Gold and Radioactive Materials.
10. Published Geologic Reports on South Dakota Oil and Gas.

In materials investigations of eastern South Dakota the first six of these index maps are of most interest.

The index maps will show the areas in South Dakota which are covered by the various geologic reports or maps. Each area on the index map is keyed to a number in the text. The text describes what type of publication it is and from which agency it may be obtained. Because most geologic reports cover more than one of these general headings, any one report may appear on more than one index map.

When this publication becomes available, all personnel interested in any phase of materials work should have a copy.

The South Dakota Geological Survey publishes geologic material in various forms. A list of publications can be obtained free by writing the Publication Section, South Dakota State Geological Survey, Science Center, Vermillion, South Dakota.

The main types of publications available through the South Dakota Geological Survey are:

Reports of Investigations: These reports include studies of economic, structural, engineering, and stratigraphic geology as well as studies of particular local areas.

Bulletins: Bulletins cover studies of a larger scale. They may cover the State or large parts of it. They also include very detailed geologic studies of selected areas.

Circulars: Circulars give information of general interest in the State.

Special and Miscellaneous Reports: These reports are published for limited distribution and cover small areas in various amounts of detail. They are of interest mainly to those persons living in the various areas.

Maps: Maps are published as detailed geologic studies covering $7\frac{1}{2}$ to 15 minutes of latitude and longitude, or as general studies covering the whole State or large portions of it. Detailed mapping in eastern South Dakota includes areas in the Big Sioux River basin and the James River basin. In addition, county geologic maps of Beadle, Sanborn and Clay Counties are being compiled.

Each map is accompanied by a text which explains the geology, in detail, and usually points out the area where aggregate may be found.

United States Geological Survey

The United States Geological Survey has printed an index to geological information published in South Dakota prior to 1958. It can be obtained through the U. S. Government Printing Office in Washington, D. C. This should be in all materials reference libraries.

The United States Geological Survey publishes information in format very similar to that of the State Survey. These include Bulletins, Professional Papers, Circulars, Maps, etc.

One publication worthy of special mention is the Geologic Folio. This type of publication includes geologic and topographic maps of large areas and was published as part of the Geologic Atlas of the United States. Although no folios have been published since 1945, and some of the earlier ones are out of print, all can be found in many libraries in South Dakota.

Other Sources

Other sources of geologic literature include:

Bibliography of North American Geology: This reference is published as a series of bulletins by the United States Geological Survey and gives a complete listing of formal geologic literature in North America from 1785 to the present.

Theses: Geologic Masters' and Doctors' theses are available in eastern South Dakota. They may be found listed in the "Bibliography of Theses in Geology" (Chronic and Chronic, 1958). This volume lists theses through 1957.

Areal Geologic Maps

Areal geologic maps are the basic geologic tool available to the materials investigator. In order to utilize these maps to their fullest extent in materials investigations, a firm grasp of the geologic terminology is essential. Appendix A gives a short glossary of geologic and associated terms a materials engineer should master before he attempts to use geologic literature. He should have available also the "Glossary of Geology and Related Sciences", published by the American Geologic Institute (American Geologic Institute, 1960).

As has been pointed out previously, the majority of aggregate found in eastern South Dakota is present in recognizable landforms. Areal geologic maps indicate the presence of these landforms and illustrate the geology of the land surface as if all soil cover were removed. These maps, therefore, illustrate areas where sand and gravel is present as well as areas where no aggregate exists. Areal geologic maps show:

1. The distribution and lithology of the geologic units.
2. The geologic ages of the mapped units.
3. An indication of structure and geologic history of the area.

These maps are usually accompanied by a report dealing with the area mapped. The report includes a written explanation of the map, and geologic and related information on the area.

Scales of a geologic map differ with the type of study. Some maps which cover the entire State or large portions of it, are issued at a scale of 1:500,000 or 1:250,000. Generally because of the detail required in a highway materials survey, scales of 1 inch = 1 mile (1:63,360) or larger are the chief maps used in the search for aggregate.

Use of Geologic Maps and Reports

A portion of a typical geologic map in eastern South Dakota has been selected as an example of the type of information presented and its use. The map selected is "Geology of the Alexandria Quadrangle, South Dakota", by H. D. Wong, published by the South Dakota State Geological Survey in 1960 (fig. 4).

The map was published at a scale of 1:62,500 and covered an area of 217 square miles in Davison and Hanson Counties, South Dakota. A text accompanies this map. Figure 4 shows nine square miles of the Alexandria Quadrangle at approximately twice the scale of the published map for

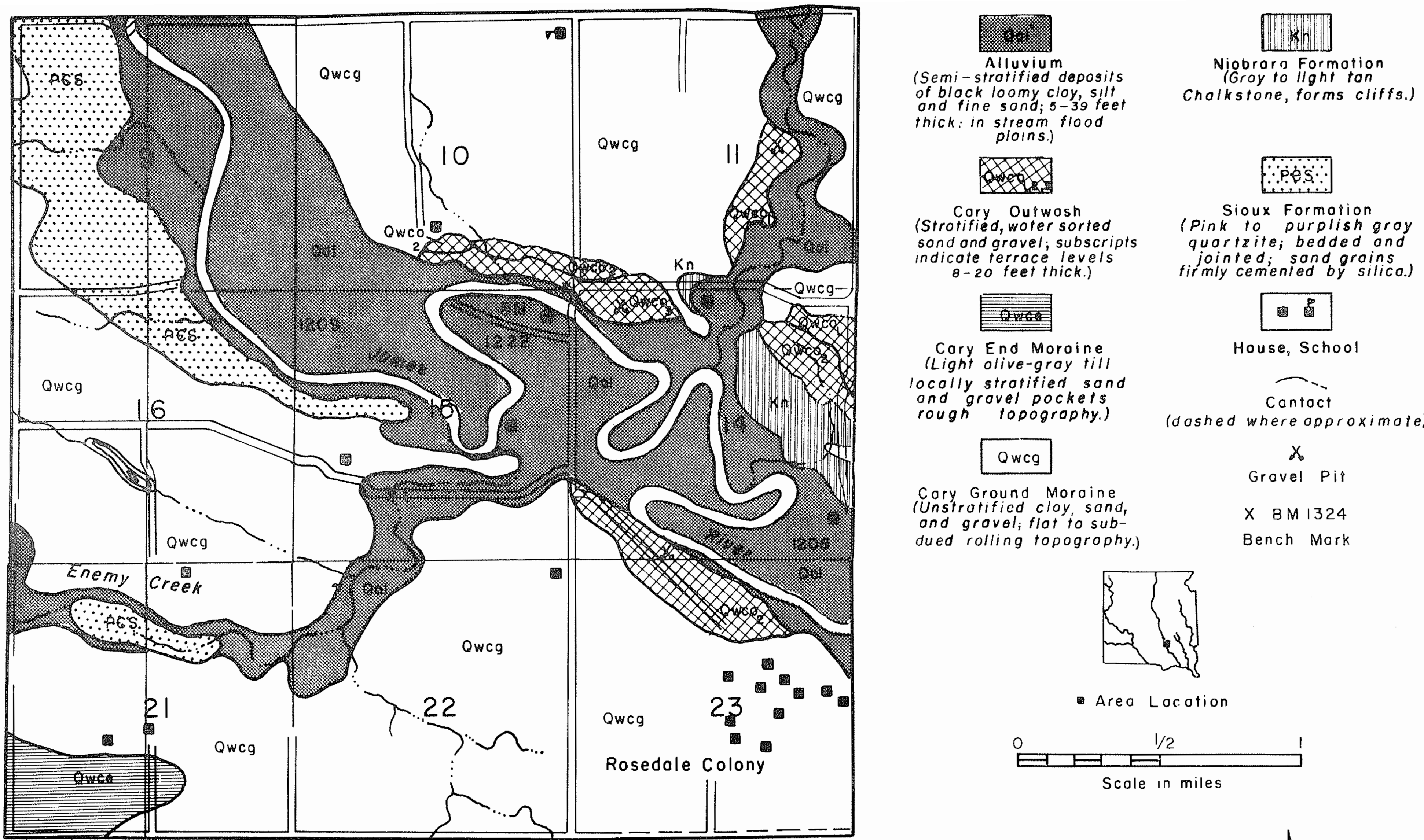


Figure 4. Geologic Map of Portion of Alexandria Quadrangle, South Dakota
(Adapted from Wong, 1960)

illustrative purposes. The area shown illustrates typical deposits as they are mapped in eastern South Dakota.

Letter symbols on the map (Qal, Qwco, Qwce, Qwcg, Kn, P€s) are a code which tells the investigator what type of material may be expected and the age of the deposit at a glance. For example, Qwco means Quaternary Wisconsin, Cary Outwash. From this we gather that the deposit is of the Quaternary System, the Wisconsin Stage of the Pleistocene Series, and the Cary Substage (table 1), and that it is an outwash. We may expect, therefore, to find coarse aggregate in this area. Similarly

Qal - Quaternary alluvium;
Qwce - Quaternary, Wisconsin, Cary end moraine;
Qwcg - Quaternary, Wisconsin, Cary ground moraine;
Kn - Cretaceous Niobrara Formation;
P€s - Precambrian Sioux Quartzite.

A detailed description of each of these units is given in the legend on the map. Qwco is a stratified sand and gravel averaging 8 to 20 feet in thickness. These areas would be the first place to check for aggregate because the description of all other units on the map indicates they would be unsuitable for coarse aggregate.

A second choice would be in the area of Sioux Quartzite (P€s), but the description indicates that it is firmly cemented and would need heavy crushing equipment before it could be used.

The text which accompanies the map states under the subheading of "Sand and gravel":

> "Sand and gravel deposits in the Alexandria Quadrangle occupy an estimated area of 5,120 acres within the outwash and terraces along the stream valleys. Reserves are approximately 165,000,000 cubic yards. The gravels are used as road metal."

An indication of reserves and total amount of aggregate expected as well as suggested use is indicated in most geologic reports, under the main heading "Economic Geology".

In using all this information, it is possible to draw a materials map as determined from geologic information (fig. 5).

Qal, Qwcg, Qwce, and Kn are considered unsuitable for coarse aggregate sources. The alluvium is fine-grained; the ground moraine has a mixture of clay, sand, and gravel and would be unsuitable; the end moraine may have some isolated spots of gravel and if all other sources of aggregate fall short of expectations the end moraine area may be given closer examination. The Niobrara is a chalkrock which implies it is soft and unsuitable for aggregate.

By changing geologic maps to geologic materials maps, the area for future investigation is cut to one-third its original size. Thus the time in the field by use of this method alone is cut by two-thirds.

Table I. Time-Rock Units Exposed in Eastern South Dakota

SYSTEM	SERIES	STAGE	SUB-STAGE
QUATERNARY	Recent		
	Pleistocene	Wisconsin	Mankato
			Cory
			Tazewell
			Iowan
		Illinoian	
		Kansan	
		Nebraskan	
TERTIARY			
CRETACEOUS	Upper	Pierre Fm.	
		Niobrara Fm.	
		Carlile Fm.	
		Greenhorn Fm.	
PRECAMBRIAN		Sioux Quartzite	
		Milbank Granite	

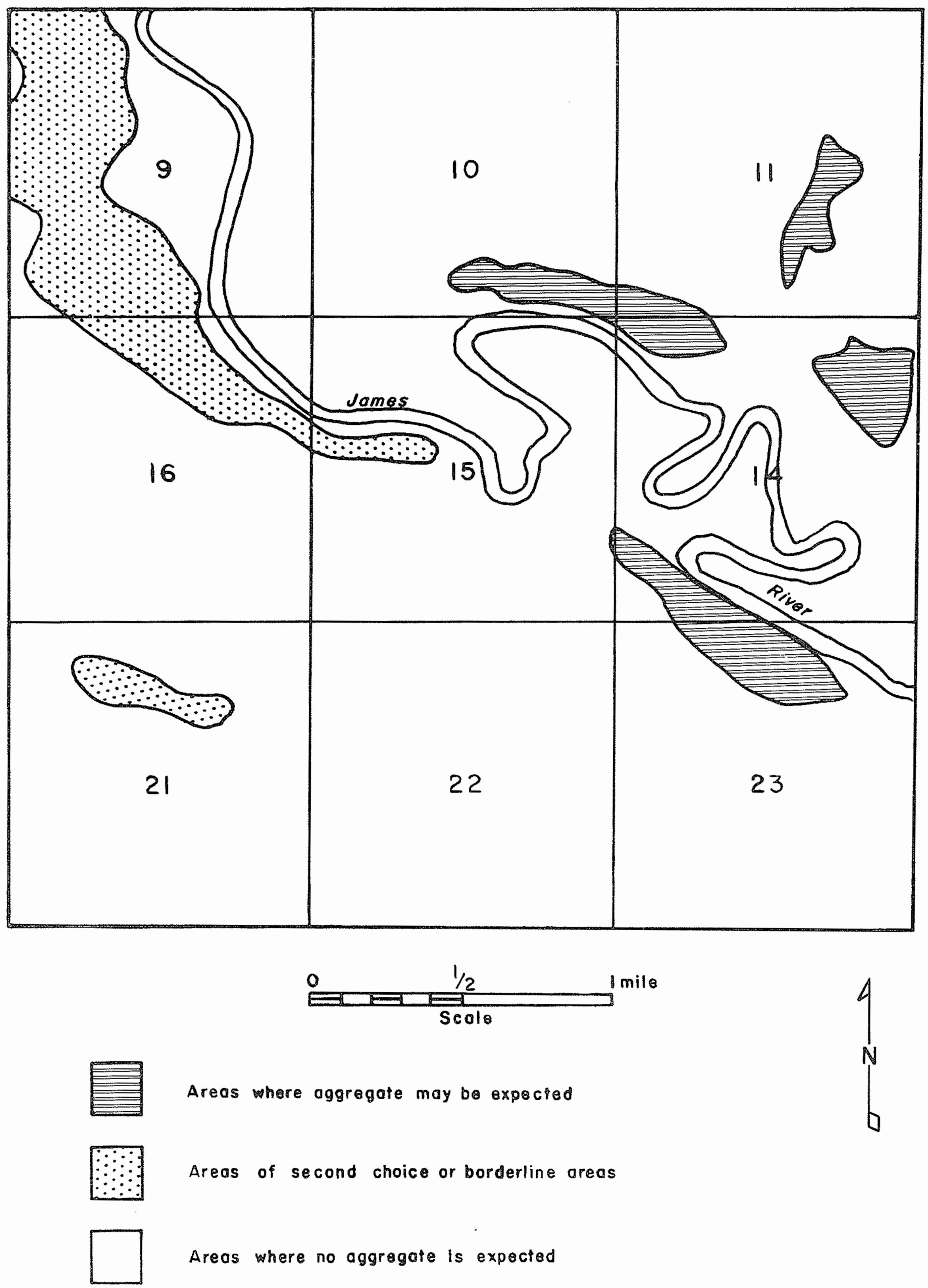


Figure 5. Materials Map as Interpreted from Geologic Map (Figure 4)

Evaluation

Geologic maps and reports are valuable in materials investigations for they give clues to the kind of material present and in what form it occurs. With a working knowledge of geology, the investigator can outline areas for further study.

Geologic maps and reports have limitations, however, because the normal mapping carried out for geologic reports is not detailed enough and can be used only as a reconnaissance tool. The scale is often too small to be of much assistance, and the geologic terminology may be difficult to understand and interpret.

It is recommended therefore that geologic maps be used as a reconnaissance tool to delineate areas favorable for more detailed investigation.

AGRICULTURAL SOILS MAPS AND REPORTS

Agricultural soils survey reports are one of the most underrated tools available to the highway materials investigator. With a basic knowledge of pedological terminology and soil-forming processes, a great abundance of materials information can be gleaned from these reports.

For the purpose of this report soils are defined as in Thornbury (1957, p. 74), " *** a natural part of the earth's surface, being characterized by layers parallel to the surface resulting from modification of parent materials by physical, chemical, and biological processes operating under varying conditions during varying periods of time." These layers differ chemically and physically from each other but are genetically related. A vertical section through these layers, or horizons, into the parent material is called the soil profile (fig. 6). The pedologic system of soil classification is based on the soil profile.

Figure 6 shows a generalized soil profile of a typical soil in eastern South Dakota. The A horizon is characterized by maximum biological activity and removal of dissolved or suspended material, or eluviation. The B horizon is the zone of illuviation or accumulation of the material removed from the A. The C horizon is the parent material and may be characterized by weathering of the upper portion and layers of calcium carbonate or calcium sulphate. These horizons may be divided on the basis of minor variations and designated the A_0, A_1, A_2, etc.

Soils and soil development are the result of the action of five major factors. These are climate, vegetation, topography, parent material, and time.

The climate in eastern South Dakota varies from humid to subhumid with extreme temperature fluctuations through the seasons (Flint, 1955, p. 18). The annual precipitation varies from 16 inches in the northwestern counties of Campbell, Walworth, and Potter to 24 inches in the southeastern counties of Clay and Union.

Climate and vegetation are called the active factors of soil formation and the distribution of native vegetation is controlled by the climate. The principal native vegetation in eastern South Dakota is the tall and medium grasses (Westin and Buntley, 1962).

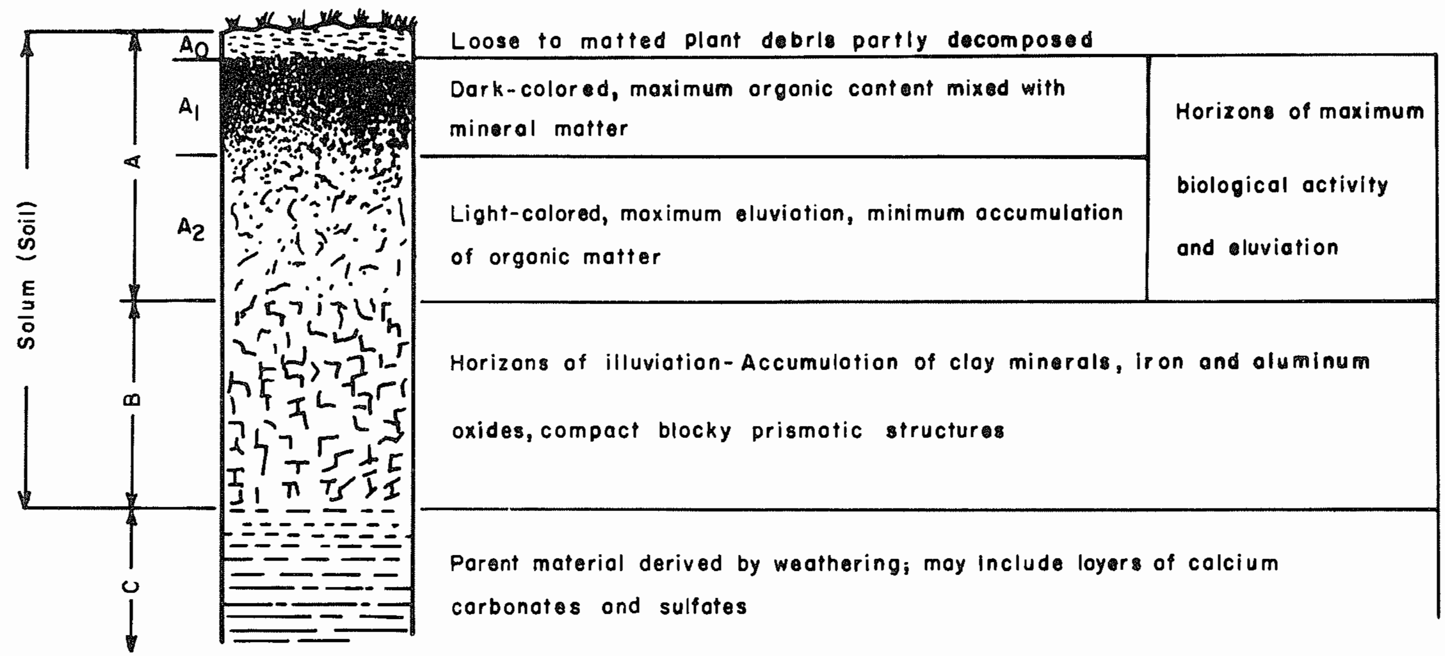


Figure 6. Generalized Soil Profile of a Typical Soil in Eastern South Dakota

The remaining three factors of the soil forming process, which are most important to a materials investigation, are geologic in nature. Topography is an indication of the type of landform present and therefore of the type of materials expected. Parent material indicates the type of geologic deposit on which the soil has developed, and time governs the depth to which weathering can progress, which in turn is related to the depth of overburden on an aggregate source.

Availability of Soils Maps and Reports

Soil surveys have been published in 16 of the 44 counties in eastern South Dakota (fig. 7). In addition, surveys have been started in 25 of the remaining 28 counties. Some of these surveys are of the conservation or planning type while others have been standardized by the government in their symbols and terminology and are called standard surveys.

Figure 7 shows the progress of soil surveys in eastern South Dakota. The completed reports are published by the Soil Conservation Service of the U. S. Department of Agriculture; and the South Dakota Agricultural Experiment Station, Brookings, South Dakota. These reports can be purchased through the county agent in each county. In counties where published reports are not available, valuable information on those portions of the counties that have been surveyed can be obtained from the Soil Conservation Service offices in the county seats.

In addition to the county soil surveys the Department of Agriculture and the Experiment Station have various miscellaneous publications of a general nature which should be included in the investigator's library. Some of these general publications are included in the reference section of this report.

Description of Soil Survey Reports

County soil surveys of eastern South Dakota are discussed in three main groups. These groups are based on the year of their publication; (a) 1920 to 1930, (b) 1950 to 1958, and (c) later than 1958. No surveys were published for eastern South Dakota for the period 1930 to 1950.

The Highway Research Board through the Committee on "Surveying and Classifying Soils In-place for Engineering Purposes" has set up a rating system for agricultural soil surveys (Highway Research Board, 1949, p. 3-4).

Soil surveys are divided into the following classes:

Class 1. These surveys show the distribution of soils accurately and areas as small as 2 acres may be mapped. The maps are prepared using air photos as base maps or using plane table traverses at scales of 2 to 4 inches per mile. Nomenclature is usually in accordance with recent correlation.

Class 2. Soil type names used are not usually in accord with modern nomenclature. Maps were made using plane table traverses

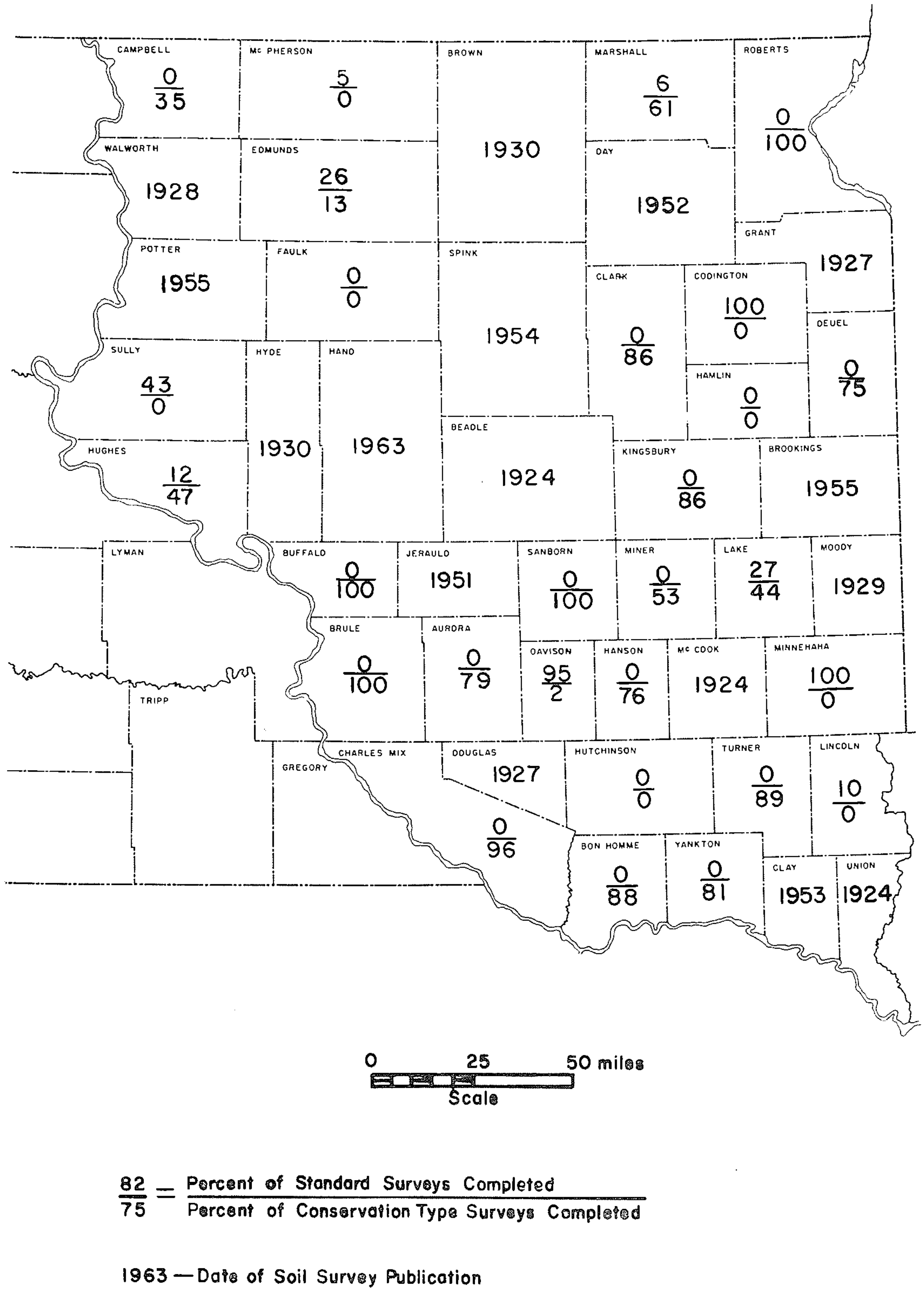


Figure 7. Progress of Agricultural Soil Surveys in Eastern South Dakota

or topographic maps as a base without the use of air photos. Those soils most favorable for the growth of crops are more accurately delineated, while those of relatively low growing potential are less accurately differentiated.

Class 3. These reports are highly generalized and are often inaccurate.

Class 4. These reports are of the reconnaissance type and are of very little use in civil engineering.

Surveys published in 1920-1930 have a U. S. Department of Agriculture rating of 2 (Highway Research Board, 1949, p. 4). These surveys consist of a colored map of the county at a scale of 1 inch = 1 mile, on which various soil series, types, and phases are delineated. The text which accompanies the map consists of a series of chapters discussing: (1) the physical setting of the county, its location, topography, and culture; (2) the climate of the county; (3) the agricultural products produced and those capable of being produced; and (4) the soils developed in the county. This last section includes a brief description of the soil profile, the extent of the soil in the county, and to some extent what crops may be grown on each soil.

These reports were written primarily for those persons who are directly associated with the soil, such as the farmer and rancher. In materials location work this type of report is of interest only as a preliminary investigation tool.

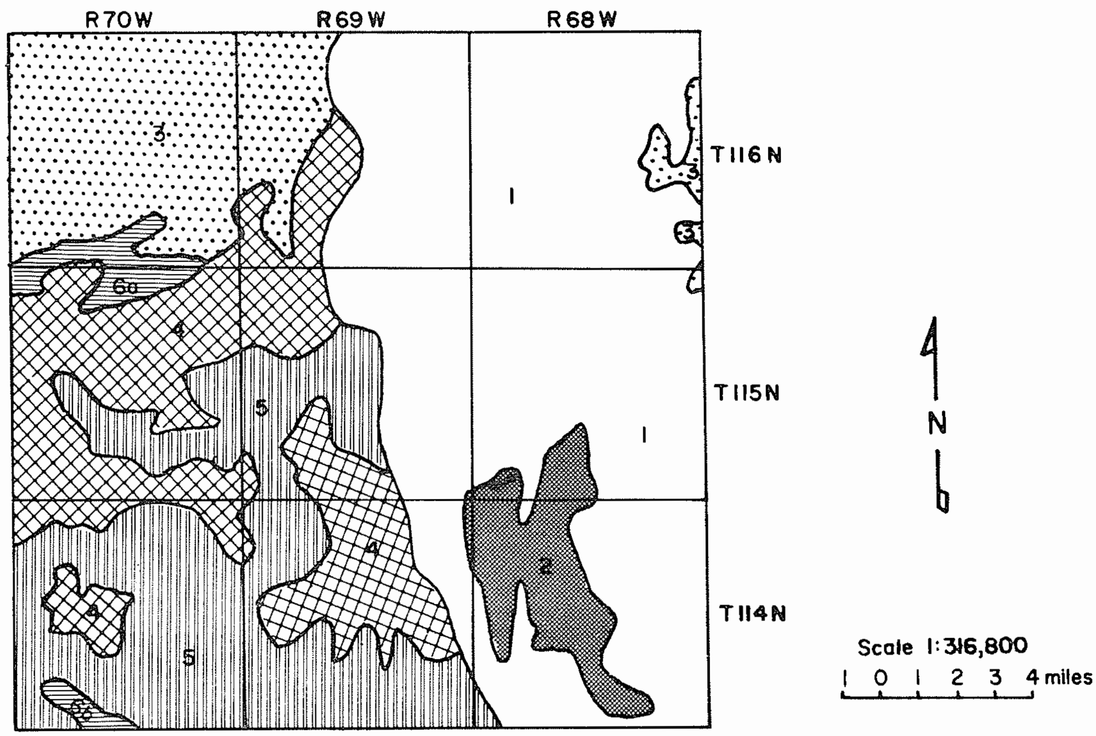
County soil surveys published during the 1950's represent an advancement in soils mapping techniques in South Dakota. Because of the utilization of air photos, these later reports have a U. S. Department of Agriculture rating of 1.

The report contains all the information included in earlier publications plus more detailed descriptions of the various soils and additional geologic and physiographic sections. These reports can be utilized in the search for granular material.

Surveys published since 1958 are in a standardized form and are written for groups of varying interests. These groups include (1) farmers, ranchers, and others who work directly with the soils; (2) engineers, land appraisers, scientists, students and teachers; and (3) persons wishing general information about the county (White et al, 1963).

Two reports have been published since 1958--the Brookings and Hand County reports. The Hand County report (White et al, 1963) is the most recent of this series.

The general soil maps and the engineering sections of these reports deserve special emphasis. General soil maps show the main patterns of soils in different areas in the county. The general soil areas on these maps are called soil associations. Each association contains several types of different soils which show a particular pattern. Figure 8 shows a portion of the general soil map of Hand County (White et al, 1963). General soil maps can be used to outline large areas of soils which may



SOIL ASSOCIATIONS

1 — Houndek-Bonilla association: Nearly level to gently undulating loamy soils from glacial till.

2 — Houndek-Cavour-Miranda association: Nearly level to gently sloping loamy soils from glacial till; some soils contain claypan.

3 — Zahl association: Rolling to hilly soils from mixed materials.

4 — Williams-Bonilla association: Nearly level to gently undulating soils from loam or coarse clay loam till.

5 — Williams-Cavour-Miranda association: Nearly level to gently undulating loamy soils from clayey till; some soils contain claypan.

6a — Sioux-Oahe association: Gravelly, hilly soils in water-deposited material.

6b — McKenzie-Harriet-LaDelle association: Nearly level loamy soils that have silty clay loam or silty clay subsoil; some soils contain claypan.

Figure 8. Portion of the General Soils Map of Hand County, South Dakota. (Adapted from White and others, 1963.)

be developed on aggregate. Such an area is shown on figure 8 as soil association 6a.

The engineering section of the Hand County report is of great interest to the highway engineer. It includes a table which gives the physical properties of the soils. Headings in this table are slope, soil description, high water table, engineering classifications (both unified and AASHO), hydrologic soil groups, depth of each horizon, salt content, permeability, water holding capacity, and shrink and swell potential.

Another table gives interpretations of the engineering properties of the various soils. This table rates each soil as poor, fair, or good in use as subgrade, fill, or as a base for seeding and sodding. The next column gives its suitability as sources of sand, gravel, and clay, This section is of particular interest in materials location surveys. The remaining portion of the table is devoted to the susceptibility of the soil to frost action and slides, its suitability as a reservoir area or embankment, and what features in the soil affect irrigation, terracing, and waterways.

Soils maps for the latest reports are prepared and published on aerial-photo mosaics. Figure 9 shows a portion of one of these maps from the Brookings County Soils Survey (Westin and others, 1959). The basic soil units delineated on these maps are soil types and phases with some scattered areas where a complex intermingling of soil types are mapped as soil complexes. This type of map has many advantages over the earlier type because (1) the air photos show the details of the surface of the ground, (2) the changes between the soils can be seen, and (3) when used in the field the exact location of the soils can be found.

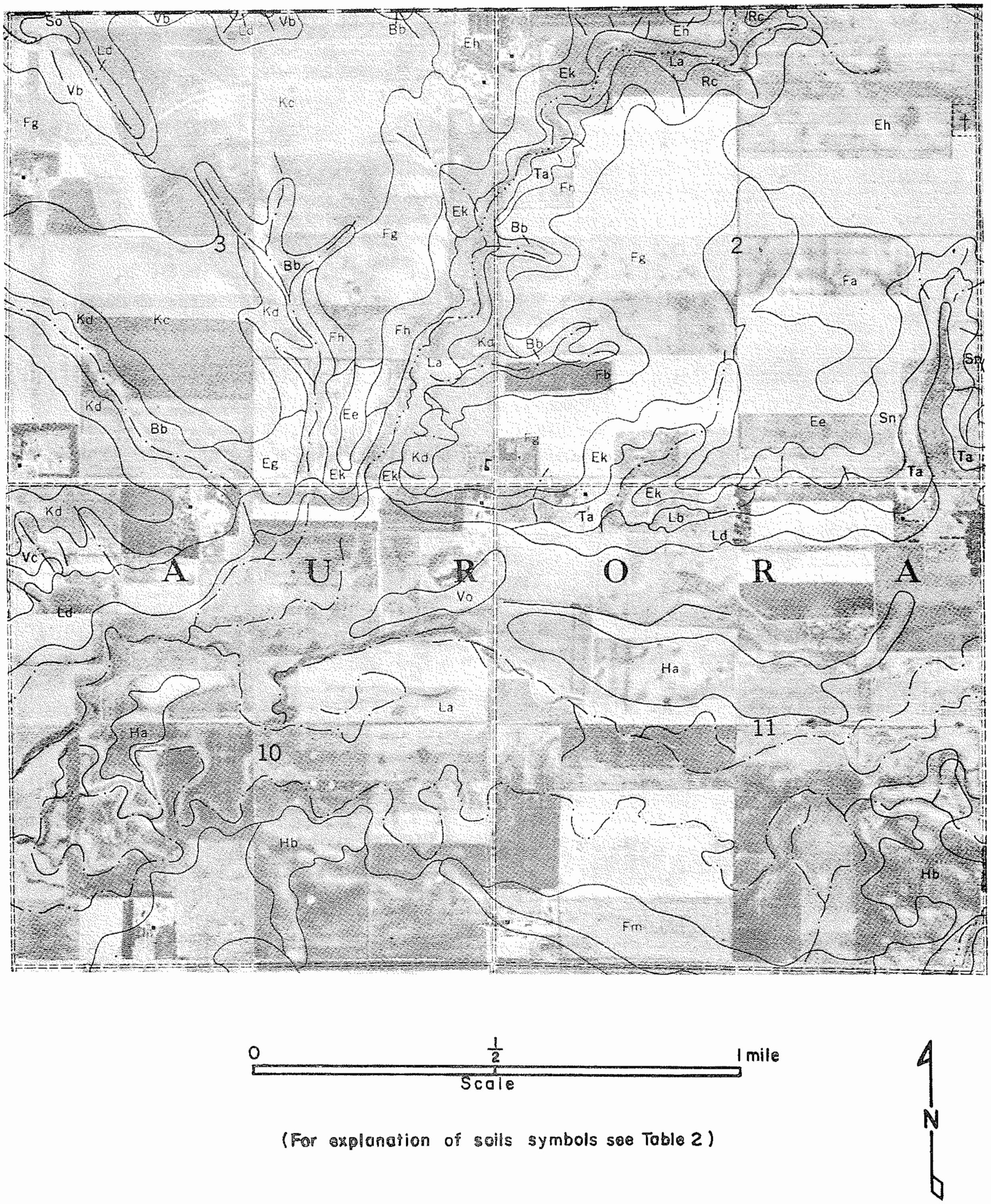
Uses of Soil Survey Reports

The techniques of using soil survey information are the same regardless of the year of publication, but the information contained in the most recent reports is in more detail than that in the early reports.

The first step in the use of soil survey reports is to become familiar with soil mapping methods and with soil terminology. Secondly, the investigator must become completely familiar with the reports and maps available in the area. This can best be accomplished by reading the material, and paying special attention to descriptions of soils which may be developed on sand and gravel. An example of two soils described in the Hand County Soil Survey Report follows:

Bonilla Series

"The surface layer of these soils is dark, friable loam, 6 to 10 inches thick. It has granular structure. In nearly level areas of the uplands, the material is loam glacial till. In sags and drainageways, it is loamy alluvium that washed from adjacent slopes ***" (White et al, 1963, p. 17).



(For explanation of soils symbols see Table 2)

Figure 9. Portion of a Soils Map of Brookings County, South Dakota. (Westin and others, 1959)

Sioux Series

"The Sioux series consists of dark-colored, friable, shallow soils with a gravelly subsoil ***

The Sioux soils are well drained and have formed from material deposited by glacial meltwater *** The loam or clay loam subsoil has prismatic structure. It is underlain by a gravelly and sandy substratum that generally begins at a depth of 12 to 60 inches." (White et al, 1963, p. 31.)

It is obvious that in areas mapped as the Bonilla series of soils, the underlying material will be till and therefore these areas could be disregarded as potential aggregate sources. In areas mapped as Sioux, however, gravel should be encountered very near to the surface. These areas would be closely field checked.

Some soils are borderline cases in so much as they may develop on material which may or may not be acceptable as aggregate sources. In areas where these soils occur, close observation in the field is necessary.

It is suggested that a three-fold engineering materials classification of agricultural soils be established similar to the classification set up for the geologic materials maps (fig. 5).

Class I. Soils developed on coarse aggregate sources of gravel, sand and intermediate grades. Class I_s. A subclass indicating soils developed on fine sand.

Class II. Soils which may or may not be developed on granular material. They may on further investigation prove to be granular but of fair to poor quality. This class would also apply to soils developed on some material which might overlie sand and gravel. Class II_s. A subclass of soils which may lie on fine sand.

Class III. Soils which are definitely not developed on sources of aggregate.

The actual resolution of a soil survey into a form for use in materials investigations is illustrated by transforming a soils map (fig. 9) into a materials map (fig. 10).

The first two columns of table 2 show the part of the soil legend from the Brookings County Soil Survey that applies to the area shown in figure 10. It is suggested that a table similar to this be set up in all investigations, listing the various soil mapping units and their parent material and materials class. In order to set up this table, reference to the detailed descriptions of each soil in the report will give the parent material and from this the various classes may be assigned.

With this phase completed the next step is to outline the various classes on the soils map. This information may then be transferred to a map showing clearly the areas favorable for detailed field study.

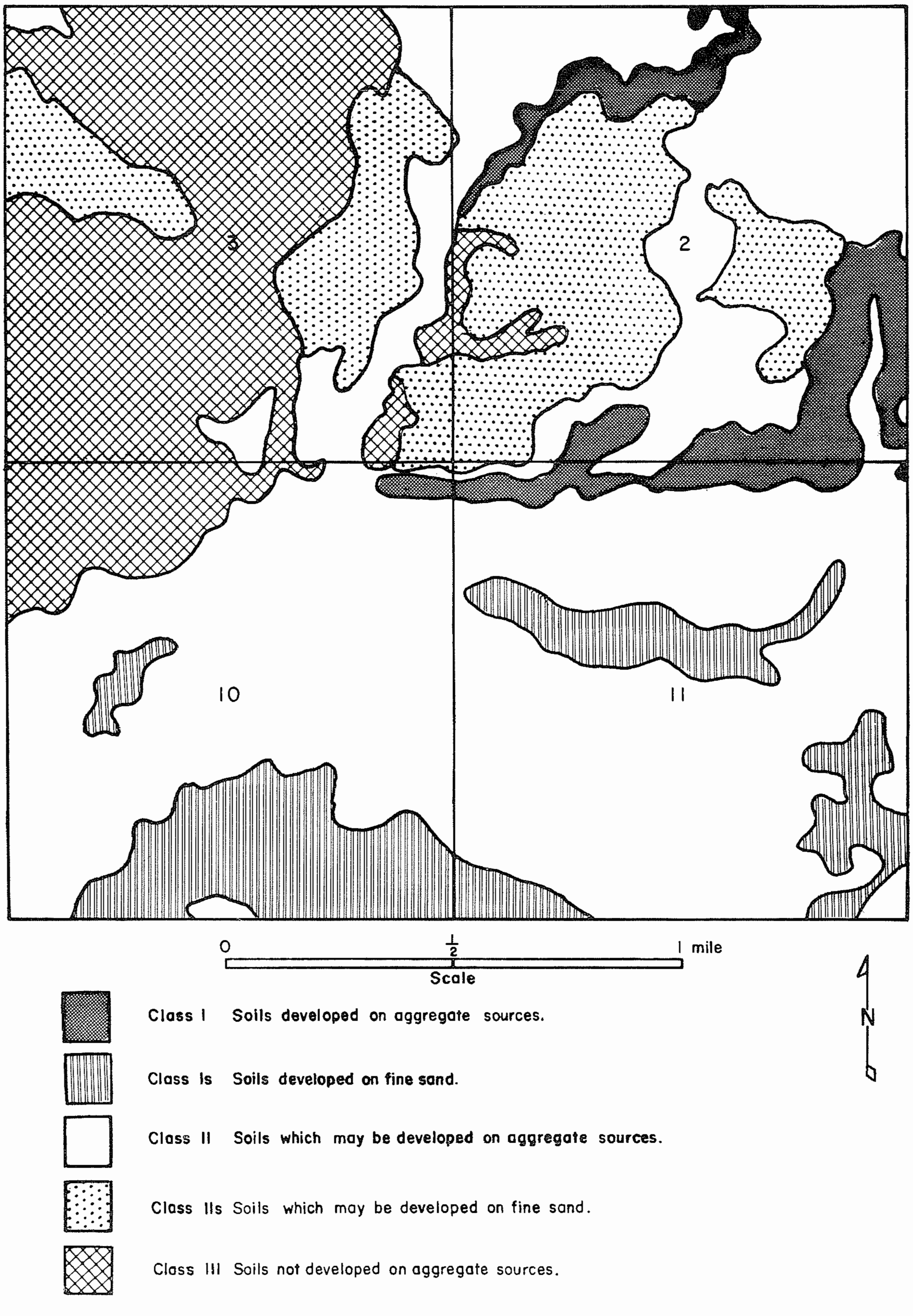


Figure 10. Materials Map as Interpreted from the Soils Map of Figure 9.

Table 2.--Engineering Materials Classification of Various Soil Units in Eastern South Dakota

Symbol	Name of Soil Unit	Parent Material	Class*
Bb	Brookings silty clay loam	Till	III
Bd	Buse complexes	Till or stratified material	II
Ee Eg Eh Ek	Estelline silt loam	Loess over sand and gravel	II
Fa	Flandreau loam	Loess over sand	IIs
Fg Fh	Flandreau silt loam	Loess over sand	IIs
Fm	Fordville loam	Alluvium over sand or gravel	II
Ha	Hecla loam	Windblown sand	Is
Hb	Hecla sandy loam	Windblown sand	Is
Kc Kd	Kranzburg silt loam	Loess over till	III
La Lb Ld	Lamoure silty clay loam	Alluvium over sand and gravel	II
Rc	Renshaw sandy loam	Sand and gravel	I
Sn	Sioux gravelly loam	Sand and gravel	I
So	Solomon clay	Alluvium over sand and gravel	II
Ta	Terrace escarpments	Sand and gravel	I
Vb Vc	Vienna loam	Till	III
Vo	Volga loam	Alluvium over sand and gravel	II

* Engineering materials classification (see p. 26).

In figure 10, the first areas to be investigated are those of Class I; when these are depleted or prove to be of poor quality, the areas of Class II can be examined.

This procedure can be followed in the use of all types of soil survey publications. It is especially good in those reports which have expanded engineering sections, for this procedure can be used in conjunction with these sections.

Not all counties in eastern South Dakota have published soil surveys, but most have some type of mapping program underway (fig. 7). This information is available in the Soils Conservation Service office in each county.

The information may be presented in various ways. Usually it is drawn on aerial photos and the soils are keyed as to growing potential, parent material, geologic formation, etc. Keys accompany each map and may be organized as outlined above. Soils information in this form, although not as easy to work with as published material, is just as accurate and valuable in the search for aggregate.

Evaluation

Soil survey reports and maps of the glacial portion of South Dakota have proved to be an important exploration tool for the location of aggregate.

This information should be used in conjunction with all other available information. The reports can be as useful as the interpreter's knowledge and experience in the soils field.

These reports have limitations, however, for they are mapped on the basis of the first 6 or 8 feet of material below the surface of the ground and do not consider that material below this depth; thus, some valuable deposits may be overlooked. Because these reports are written primarily for use in agriculture, they should be used with discretion when applied to aggregate investigations, and should be accompanied with field examination.

TOPOGRAPHIC MAPS

Topographic maps show the configuration of the land surface--that is, the size and shape of the physical features and their relationships to each other (Emmons, et al, 1955, p. 612). Most maps present the topography by lines drawn through points of equal elevation, called contour lines. The spacing of these lines in feet is called the contour interval. Other methods of presentation include color, shading, hachures, or a combination of these methods.

Sources and Scales of Topographic Maps

Topographic map coverage in eastern South Dakota is limited to approximately one-half the area. The maps available are published by the United States Geological Survey and the U. S. Army Corps of Engineers. Figure 11 is an index to areas covered by topographic sheets in eastern South Dakota.

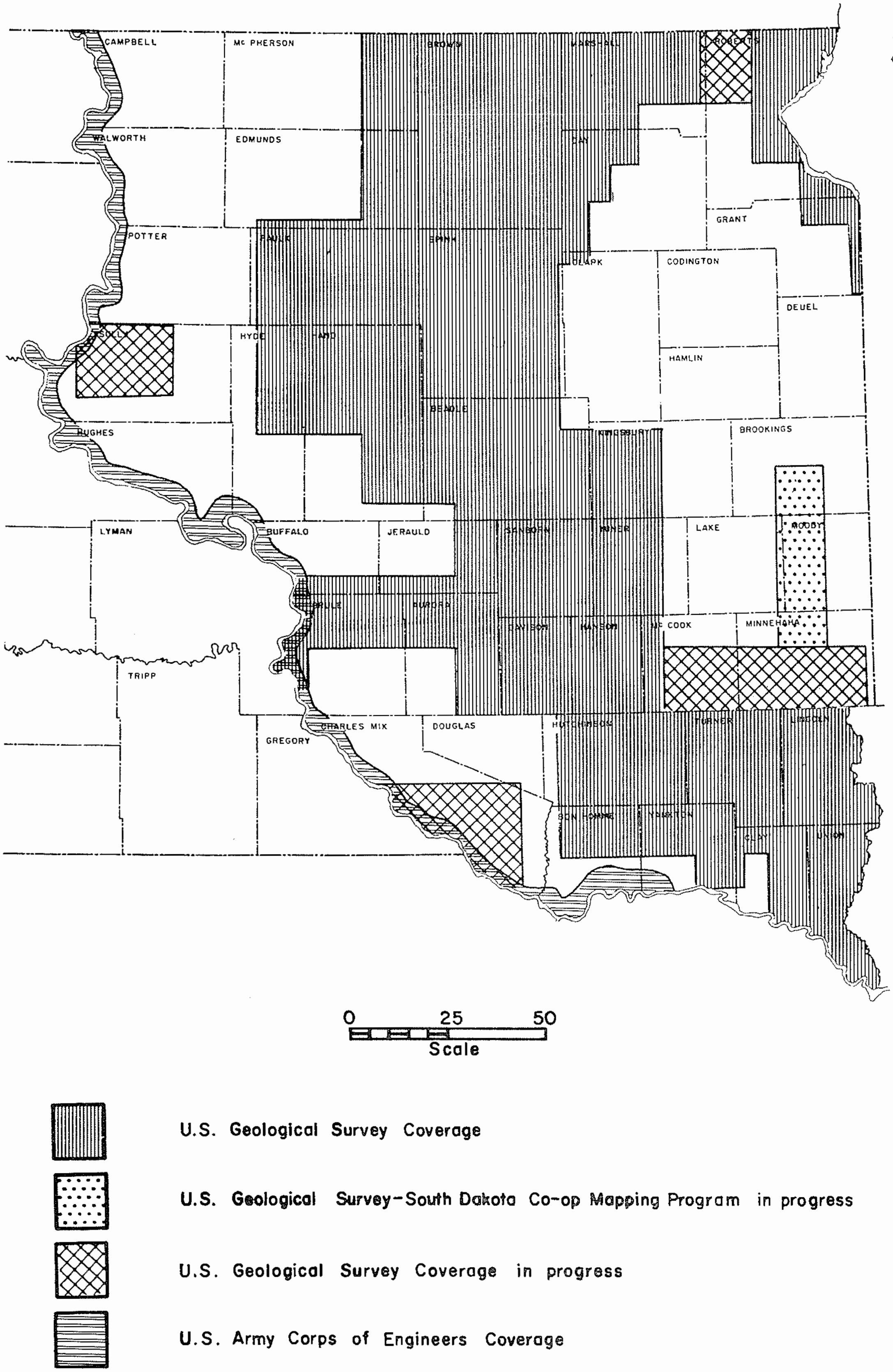


Figure 11. Index to Areas Covered by Topographic Maps in Eastern South Dakota.

United States Geological Survey Topographic Maps

The majority of the maps available are published by the United States Geological Survey. An index to topographic mapping in South Dakota can be obtained from the Map Information Office, United States Geological Survey, Washington 25, D. C. This index gives all information regarding the selection and purchase of topographic maps.

These maps range in date of publication from 1893 to the present. The earlier maps are not as accurate or as comprehensive as the more recent maps because of the difference in the mapping techniques employed.

In addition to these maps, the United States Geological Survey and the State of South Dakota are cooperating in a topographic mapping program. The State Highway Commission and the State of South Dakota through the State Geologist are each contributing equal amounts to this program, and the Federal Government is matching these funds. The maps are to be published as $7\frac{1}{2}$ minute quadrangles in areas where coverage is most needed. This need is decided by a commission composed of the 11 State agencies most likely to use such maps. The first 10 quadrangles to be done under this program are located in the Big Sioux River basin (fig. 11), and are in various stages of completion.

Topographic maps are published in three scales with usually not more than one scale available for any given area. Maps covering $7\frac{1}{2}$ minutes of latitude and longitude are published at the scale of 1:24,000 (1 inch = 2,000 feet). Maps covering 15 minutes of latitude and longitude are published at the scale of 1:62,500 (1 inch = approximately 1 mile), and maps covering 30 minutes of latitude and longitude are published at the scale of 1:125,000 (1 inch = approximately 2 miles). In addition, total coverage of the State is available on maps covering 2 degrees of latitude and longitude at the scale of 1:250,000 (1 inch = approximately 4 miles).

The contour interval for the smaller scale maps may be 25, 50, 100, or even 200 feet. The larger scale maps ($7\frac{1}{2}$ minute) have a contour interval of 5 or 10 feet. Because the landforms associated with some materials sources in eastern South Dakota have local relief in some instances of 10 feet or less, it is suggested that contour intervals not exceeding 10 feet be used.

United States Army Corps of Engineers Topographic Maps

The United States Army Corps of Engineers has published topographic maps along the Missouri River (fig. 11). These are at scales of 1 inch = 1,000 feet and 1 inch = 2,000 feet. The contour interval is 10 feet. Any highway materials study which is conducted along the Missouri River should refer to these maps.

Description and Use of Topographic Maps

Figure 12 shows a topographic map of the 9 square miles illustrated on the geologic map of figure 4. This topographic map has been made by joining the Riverside, Alexandria, Rockport Colony, and Ethan, United States Geological Survey (1957a, b, c, d) $7\frac{1}{2}$ minute topographic quadrangles.

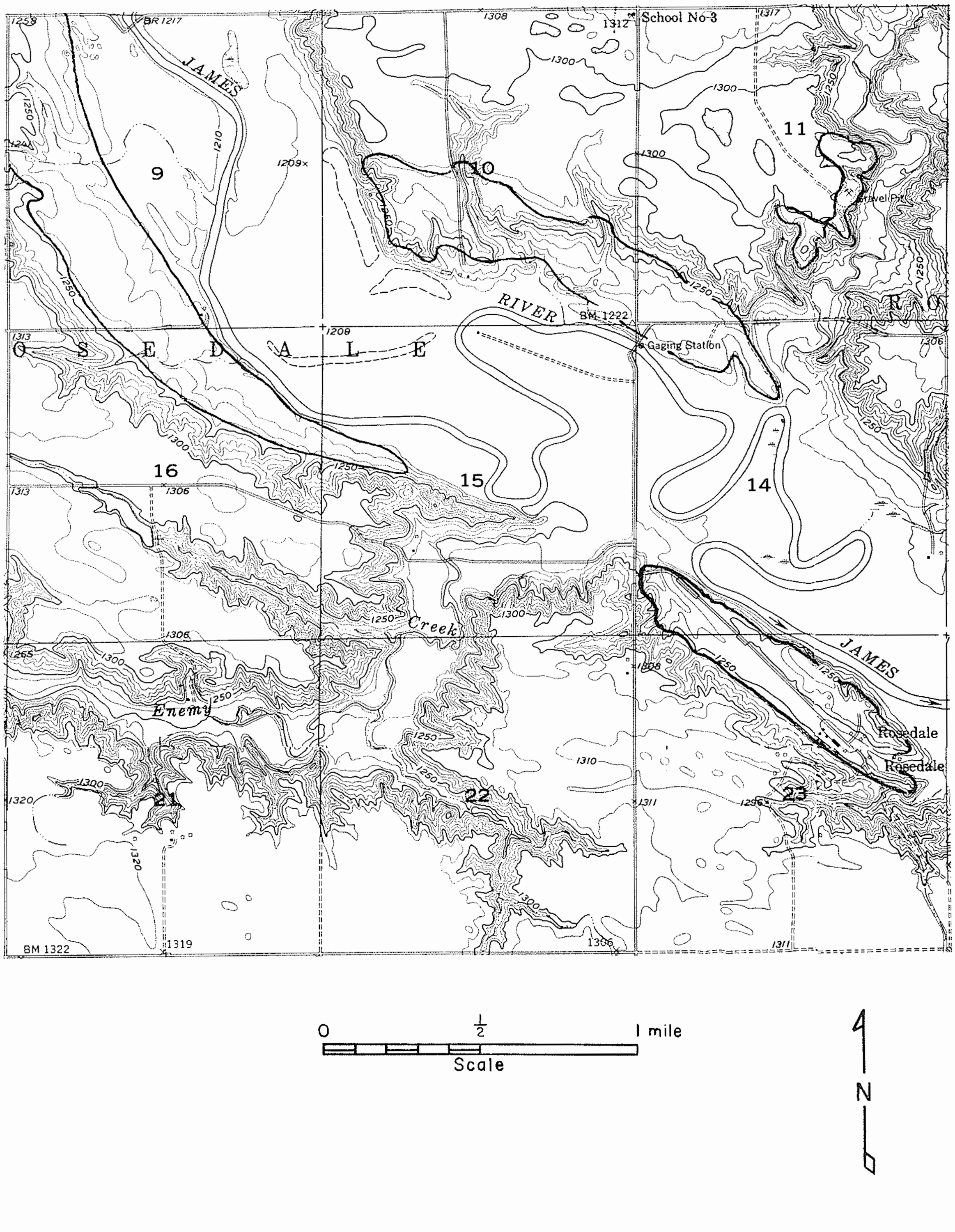


Figure 12. Topographic Map of Portion of Alexandria Geologic Quadrangle as Shown in Figure 4. (U.S.G.S. 1957a, b, c, d)

The various landforms and general topography can easily be seen on this map by an experienced observer. The steep valley walls are illustrated by closely spaced contours; the relatively flat uplands by more widely spaced contours. The wide flat valley containing the meandering James River can be contrasted to the narrow V-shaped valleys of the two small tributaries.

The three terraces on figure 4 ($Qwco_{1,2,3}$) can be easily traced by their topographic expression on figure 12.

One terrace extends from Section 14 through Section 11 into Section 10. This terrace is shown topographically on the map by a steep slope from the upland onto the flat terrace area which in turn drops off into the James River floodplain. The Rosedale Colony is built on the second terrace and it exhibits the same type of topography. The third terrace, in Section 11, is not as evident but can be recognized by the presence of a gravel pit. The two bedrock areas cause a change in the shape of the valley walls and indicate the river has come in contact with a different type of deposit. It is impossible to use the topographic map to determine what is causing these changes, but it does point out their existence.

In general, topographic maps can be used to delineate landforms which are possible sources of aggregate. Drainage characteristics can be established also from these maps.

Evaluation

Topographic maps can be a useful tool in locating aggregate when used with a good background in landform recognition. Topography is presented in great detail on the more recent maps compiled with photogrammetric methods. The earlier maps, however, are less accurate and have contour intervals too great to be of much use.

Topographic maps show the landforms as they appear now and usually erosion and mass wasting will destroy the primary form and present a picture which does not resemble the original form. It is essential, therefore, that the personnel using topographic maps become familiar with the various geologic processes acting on the surface of the earth and the effects of these processes on the existing topography.

Topographic maps can be used to their greatest potential if: (1) they have a large scale and small contour interval such as the more recent type mapped with photogrammetric methods; (2) they are used by personnel trained in landform recognition; and (3) they are used in conjunction with all other available methods.

AIR PHOTO INTERPRETATION

Air photos are the most valuable tool available to the highway materials investigator. They show the surface of the earth exactly as it is, with but minor exaggerations. With skill acquired through experience and observation, the investigator can outline aggregate sources very accurately in less time than if he were in the field. Depending on the proficiency of the interpreter, the use of air photos can eliminate as much as 90 percent of the field work associated with materials exploration.

Many scales of air photos are available. It is suggested that photos at scales of 1:20,000 (approximately 3 inches = 1 mile) or larger be used for materials investigations. It is sometimes advantageous to have two scales available--a smaller scale to delineate general trends and a larger scale to outline details.

Sources of Air Photos

A map titled "The Status of Aerial Photography" is available upon request from the United States Geological Survey, Federal Center, Denver, Colorado. This map shows all areas in the United States where photo coverage exists and the governmental agencies from which these photos may be purchased.

In eastern South Dakota air photos may be purchased from the U. S. Soil Conservation Service, U. S. Department of Agriculture, Washington 25, D. C., and the United States Geological Survey, U. S. Department of the Interior, Washington 25, D. C. In addition, the photos used in the topographic mapping program may be consulted in the office of the State Geological Survey in Vermillion. It is also possible to hire commercial firms to fly coverage. The firms which do this work are listed on the "Status" map. It is possible that the State may wish to fly coverage in areas of primary importance.

Types of Air Photos

Air photos are classified according to the orientation of the optic axis of the camera. The optic axis is the line which would extend through the center of the film, the center of the lens, and straight out in front of the camera (Miller and Miller, 1961, p. 6).

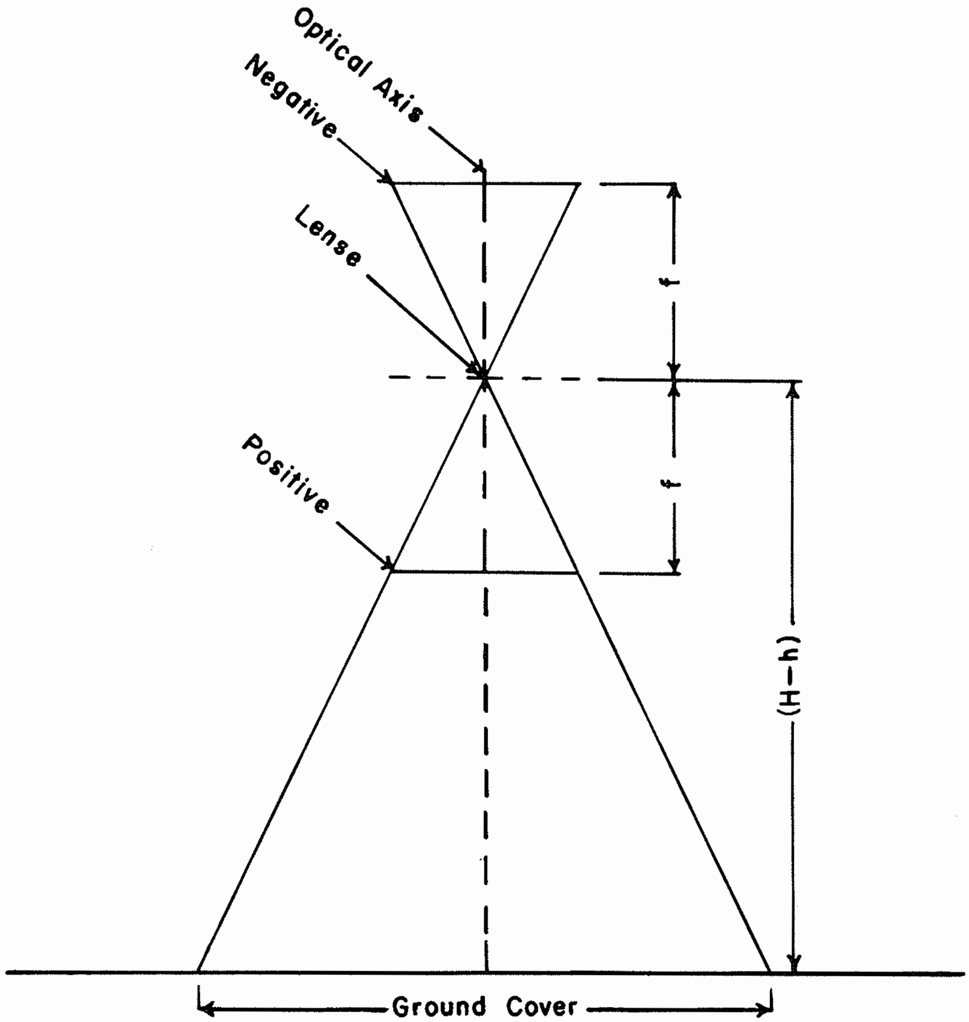
Vertical

Vertical photographs are taken with a single lens camera with the optic axis of the lens no more than 3 degrees from the normal. Figure 13 diagrammatically illustrates the simple geometric relations involved in vertical aerial photography. This type of photo is used for topographic mapping (photogrammetry) and for all types of interpretation. Contact prints can be easily made from vertical photos and they are therefore the least expensive of all types. They do have one disadvantage in that each individual photo has a limited ground cover.

Oblique

The camera lens and therefore the optic axis is inclined at some angle from the normal in an oblique air photo. When the inclination is great enough to include the horizon, the photos are called high obliques; those with less inclination are called low angle oblique photos.

These photos are used in the reconnaissance of very large areas because a larger area is shown on each photo. Obliques are difficult to



f = focal length of camera lense
H = elevation of lense above sea level
h = elevation of ground
(H-h) = altitude of lense

Figure 13. Geometric Relations of Vertical Aerial Photography
(Adapted from Miller and Miller, 1961, p. 6)

use, however, because the scale on each photo is changing due to the angle of tilt of the optic axis.

Convergent

Convergent photos are similar to obliques except that two cameras are used, one pointing forward and one backward at a fixed angle. This produces stereoscopic pairs.

Composite

Combination of oblique and vertical photos results in composite air photos. Multilens cameras are used in this technique and the result is photo coverage of very large areas. The principal disadvantage to this type is that a great deal of effort goes into rectifying the resulting photos to a form which can be utilized.

Continuous Strip

Continuous strip coverage is obtained by moving the film past a slit opening in the camera similar to that used in taking motion pictures. Two lenses are used, one pointing forward and one backward at fixed angles, thus giving stereoscopic coverage. The resulting film gives continuous coverage. Special stereoscope equipment is needed with this type of coverage.

Scale of Air Photos

The scale of an air photo is neither uniform nor does it change regularly; therefore, only an approximate scale can be determined (Miller and Miller, 1961, p. 8). Figure 13 shows the relationships between the elements used to determine the scale of an air photo.

The approximate scale is given by the formula

$$\text{Scale} = \frac{\text{focal length}}{\text{camera height } (H-h)}$$

or

$$S = \frac{f}{(H-h)}$$

It can be seen that as the focal length of the lens increases the scale also increases; as the height increases the scale decreases. The normal focal length used is 6 inches, although smaller and larger lengths are not uncommon. According to Ray (1960, p. 4), "It should be noted that if a photo is enlarged or reduced, the effective focal length for that photo is also changed in direct proportion to the amount of enlargement or reduction."

There are two major factors causing variations in the scale of air photographs. These are the relief of the area photographed and the angle of inclination of the optic axis. It is because of these two factors that objects on the ground do not photograph in the correct horizontal positions (Miller and Miller, 1961, p. 8).

Because the camera focal length is constant, a change in the height of the camera above the ground will produce a change in scale. If, for example, a tall building is photographed from directly overhead, the top of the building will be closer to the camera than the base; therefore, the scale of the photo at the top of the building will not be the same as that at the base. In other words, the scale is larger at the building top than at the base.

If the optic axis is tilted from the normal, a scale change from one side of the photo to the other is introduced. The scale varies with the angle of inclination.

Displacement due to relief is another factor which affects vertical photography. Tall structures appear to have their tops displaced outward from their bases. This is caused by the physical relations of the light rays as they pass through the camera lens. It is obvious that only one point on a photo will be directly under the optic axis of the lens. This is called the principal point. At this point there will be no displacement. The principal point can be located on photos by connecting the fiducial marks on the edges of the photograph.

Stereoscopy

The viewing of photos in three dimensions or stereoscopically greatly adds to their value. Interpretive elements can be determined more rapidly and precisely when viewed in this manner.

Prerequisites for stereoscopically viewing photos are few. They include complete coverage of photos (60 percent overlap), and a means by which the interpreter can focus one eye on one photograph and the other eye on another photograph.

With training and practice, one may become proficient in stereoscopic examination of air photos without the aid of a stereoscope. However, the work is made easier with the aid of a stereoscope.

Two types of stereoscopes are most commonly used--lens and mirror. The lens stereoscope is most useful in field examination or for rapid scanning of great numbers ofphotographs. It is smaller and usually can be slipped into a pocket or field pack. The mirror stereoscope is larger and more bulky and is used for more detailed studies. It is recommended that personnel working with air photos be equipped with one of each of these types of steroescopes. It is also recommended that the instruments be of good optical quality as inexpensive instruments create eye fatigue after prolonged usage.

Interpretation of Air Photos

The basis upon which all air photo interpretation is built is that soils are a product of pedological and geological processes and that the surface features developed by these processes reflect a pattern on photos which will be repeated in any area in which the conditions of formation are similar. Six pattern elements which are of primary importance in interpretation of the glacial portion of South Dakota are: topography, drainage, erosion, tone, vegetation, and culture. A brief discussion of these basic patterns follows; for a detailed discussion, the reader is referred to the works listed in the Selected Bibliography.

Topography

This pattern element consists primarily of three factors: position, the relationship of each landform to the other topographic features; the shape of the landform; and relief of the landform (Colorado Department of Highways, 1962, p. 23). In addition, the origin of the topography is important to its classification.

Drainage

The development of surface drainage is a function of soil permeability, climate and slope of the ground. It can give a clue to the porosity of the deposit upon which it develops and any structure that may be developed such as joints, fractures, etc. Figure 14 illustrates the most typical drainage patterns found in eastern South Dakota.

Dendritic drainage is characterized by branching tributaries meeting the major streams at acute angles. The pattern resembles the branching of a tree. It may develop on weak shales, till, or any homogeneous deposit which lacks structural control.

Pinnate or "fishbone" drainage develops in thick loess. It is a modification of the dendritic pattern. Short steep tributaries are developed due to the high permeability of the loess.

Deranged drainage pattern consists of numerous closed depressions and swampy areas with drainage channels which bear little relationship to each other. It is common in till in the form of end moraines.

Phantom drainage develops in thin porous material overlying a non-porous, nonpermeable material. It may develop in a thin sand or loess over till in ground moraines.

The texture of drainage patterns is an indication of the texture of the material on which the drainage is developed.

Coarse drainage develops in hard or durable material as Sioux Quartzite, or a permeable coarse material as sand and gravel.

Fine drainage develops on impervious material as till, shale, etc.

Erosion

The shape and size of gullies is a good indication of the type of material in which they have developed. Fine material as found in till landforms has a tendency to erode in broad gentle sags with flattened cross-sections and long low profiles. Granular material, such as sands and gravels, erodes as deep V-shaped gullies with sharp slopes and has a tendency to stand in nearly vertical cliffs.

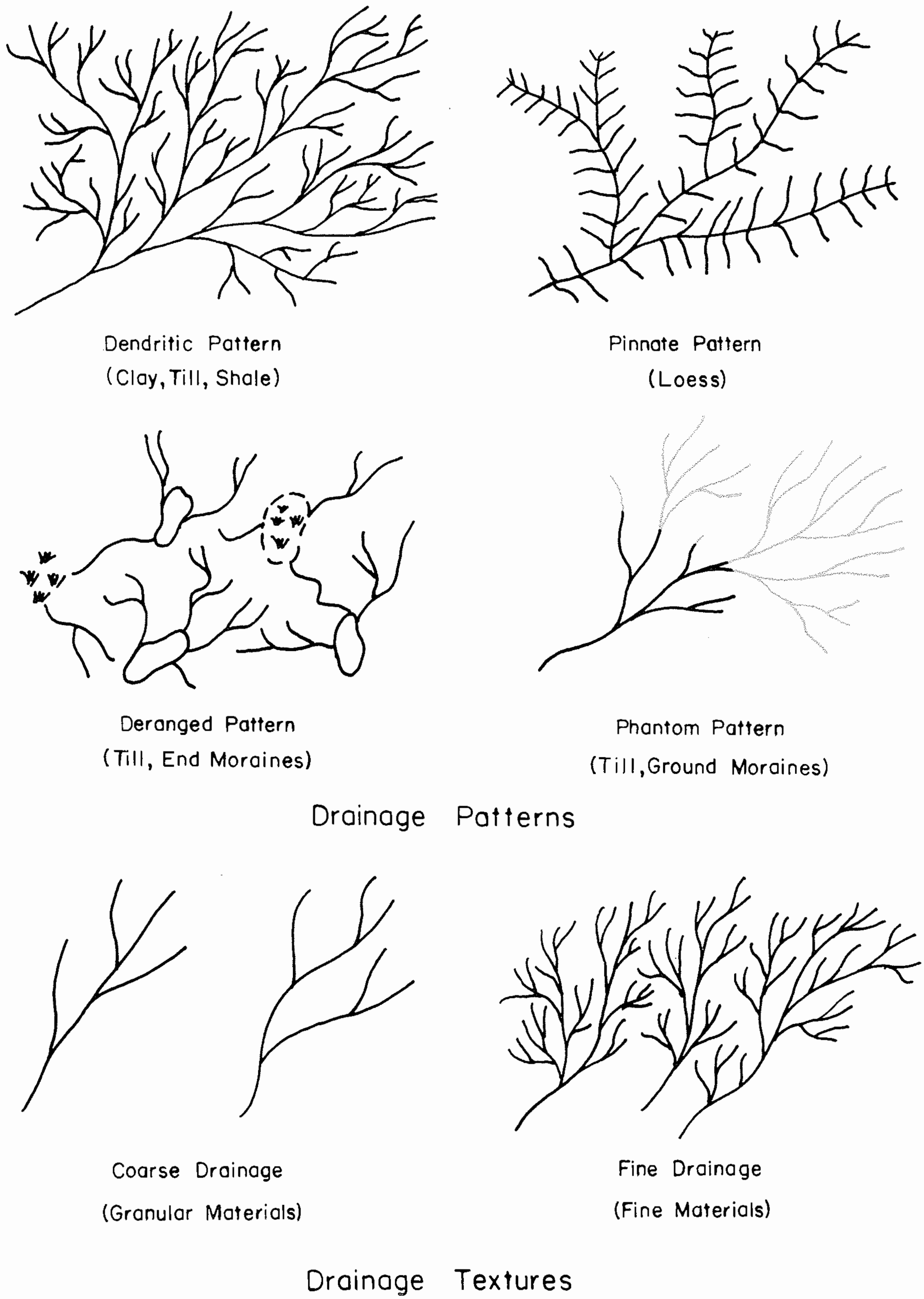


Figure 14. Typical Drainage Patterns and Textures Found in Eastern South Dakota

An important feature in gully formation is that of compound gullies. One example is a wide gentle gully which turns into a sharp V-shaped notch. This may illustrate fine clays overlying coarse sand and gravel.

Tone

Tone is a pattern element which when used with care can be very useful. Although climate, topography, and photograph quality can influence this element, a broad generalization can be made: the lighter the tone, the coarser the material.

Vegetation

Vegetation is an indication of the type of material present, as certain types of vegetation develop only on certain types of deposits. An example is the growth of cottonwood trees in areas of high moisture content.

Culture

What man does with the land is a good indication of its landform and composition. Orchards may be planted on granular soils, while straight fields of grain with evidence of tiled rows may indicate areas of poor drainage as in silty lake beds or floodplains.

Landforms

Since certain landforms are known to be composed of granular material, recognition of these forms on aerial photos is of primary importance. Each landform develops certain characteristics of the six interpretation patterns just mentioned.

The most important glacial landforms are included in the following outline listing their characteristic patterns and pointing out those elements which are most diagnostic to each. Most of these data was taken from personal experience, but some was taken from Leuder (1959), and the American Society of Photogrammetry (1960).

(Youthful Ground Moraine)

Topography: broad, gently undulating plain with low relief devoid of linear ridges; may have other features such as kames superimposed on surface.

Drainage: coarse dendritic pattern, phantom drainage, closed depressions, intermittent lakes.

Erosion: sheet erosion, gullies have broad gentle slopes except next to major drainages where they may become V-shaped.

Tone: coarse mottled tones of grays and whites due to drainage characteristics, composition, and topography.

Vegetation and Culture: vegetation consists of grasses, trees appear along major drainages and near settlements; square intersections, straight roads; heavily farmed.

Diagnostic Features: low relief, lack of linearity, phantom drainage, closed depressions, mottled tone.

Rating* and Composition: Class III, generally clayey till.

(End Moraine)

Topography: constructional, rough, hilly areas having linear extent, variable slopes, rises abruptly from surrounding areas, many knobs and depressions.

Drainage: deranged pattern, nonconnected drainage ways, lakes in closed depressions at various elevations.

Erosion: steep slopes marked by deep gullies; sometimes absent.

Tone: variable, well drained areas have light tones while undrained areas have dark tones.

Vegetation and Culture: scrub grasses, very little cultivation due to rough topography, winding and discontinuous roads.

Diagnostic Features: topography, deranged drainage, variable tones, lack of culture.

Rating and Composition: Class III but may have local deposits of coarse aggregate of Class II; generally heterogeneous till.

(Drumlins)

Topography: elongated hills, sometimes shaped like inverted teaspoons but may be long and very straight, usually occur in belts orientated parallel to ice movement. Uncommon in eastern South Dakota.

Drainage: small features with little drainage developed.

* See page 26

Erosion: may have short steep gullies along margins.

Tone: variable, usually light toned.

Vegetation and Culture: grasses common, little cultivation or culture.

Diagnostic Features: shape and linearity.

Rating and Composition: Class III, usually thin veneer of till over a bedrock core.

(Terraces)

Topography: discontinuous, steplike, flat-surfaced features along valley side which are remnants of old floodplains or valley outwashes; characteristic sharp break between upland and flat-topped terrace, another break between terrace and valley; may be found singly or in pairs in the valley.

Drainage: internal due to granular material; may exhibit infiltration basins, backwater areas may develop along valley walls; may have current and scour marks on surface if of large extent; drainage from upland seems to disappear when crossing terrace.

Erosion: usually slight, marked V-shaped gullies on edges.

Tone: "worm-eaten" texture common, usually light tone when composed of sand and gravel, may be darker along contact with upland due to colluvial deposits.

Vegetation and Culture: brush, grass, usually highly cultivated, gravel pits common.

Diagnostic Features: steplike topography, lack of drainage, V-shaped gullies, "worm-eaten" pattern, gravel pit development.

Rating and Composition: usually Class I; granular material predominates but in rare instances may be composed completely of fine material.

(Outwash)

Topography: flat, low, featureless area of very little relief found in broad plains or in valleys (valley trains); may have "pitted" surface; may have current scars.

Drainage: absent, internal, infiltration basins, may have remnants of abandoned channels.

Erosion: generally absent.

Tone: usually light, may have "worm-eaten" pattern, may have abrupt tone change from light areas of granular material to dark areas of fine material.

Vegetation and Culture: native grasses and brush, cottonwood trees, farming common, orchards, fields may be tiled, roads straight.

Diagnostic Features: featureless, lack of drainage, current scars, "worm-eaten" pattern, light tone, culture.

Rating and Composition: Class I or II, composition variable, usually coarse granular material.

(Lake Beds)

Topography: unusually flat smooth plains, may have beach ridges around margins.

Drainage: absent to rare.

Erosion: absent to rare.

Tone: usually uniform dark tone except where beach ridges are evident; these are light in contrast.

Vegetation and Culture: highly farmed, native grasses and trees, roads straight.

Diagnostic Features: flat topography, beach ridges, uniform tone.

Rating and Composition: Lake bed Class III, usually clayey material; beach ridges Class II or II_s, usually granular material.

(Kames)

Topography: rounded knobs, usually found in groups, uncommon in eastern South Dakota.

Drainage: internal, very little developed due to small size.

Erosion: uncommon, some V-shaped gullies around edges.

Tone: light.

Vegetation and Culture: grass, cottonwood trees on larger features, usually bypassed by construction; gravel pits common.

Diagnostic Features: topography, tone.

Rating and Composition: excellent material sources; Class I, usually good aggregate.

(Eskers)

Topography: low sinuous ridges, long, narrow steep sides, rounded crests, rare in eastern South Dakota.

Drainage: absent.

Erosion: absent.

Tone: light.

Vegetation and Culture: rarely farmed, native grasses, usually contain gravel pits.

Diagnostic Features: topography.

Rating and Composition: Class I, gravel.

(Sand Dunes)

Topography: may be crescent, long and narrow, or irregular in shape; usually have a steep side leeward and a gentle back slope.

Drainage: internal, almost always absent.

Erosion: absent.

Tones: light, usually much lighter than surrounding areas.

Vegetation and Culture: some farming, vegetation patchy to absent.

Diagnostic Features: shape, tone, lack of vegetation.

Rating and Composition: Class IIs, usually fine sand.

(Loess Plains)

Topography: flat to undulating topography, may have parallelism of minor ridges; uniform to vertical slopes, catsteps common.

Drainage and Erosion: pinnate drainage, steep-sided or U-shaped gullies with flat bottoms, low profile gradients, pinnacles common.

Tone: uniform, light to medium.

Vegetation and Culture: highly farmed, straight roads, vertical cuts.

Diagnostic Features: catsteps, drainage, ability to stand on vertical slopes.

Rating and Composition: Class III, silt.

Techniques

Purchasing photo coverage is the first step in any materials invesigation. Since it takes over one month for delivery of photos from existing sources and much longer to have coverage flown, it is important to order photography very early in the investigation. Aerial photo index maps for all of eastern South Dakota should be purchased first. These can be bought from the Soil Conservation Service and the United States Geological Survey. The photos can then be selected and purchased. Three main factors should be kept in mind when ordering coverage.

1. Photos should be purchased for the total area to be investigated plus coverage of some of the surrounding area. This is important, since regional trends should be studied to determine what type of deposits may be present.

2. Total overlap (60 percent) should be purchased so the photos can be viewed stereoscopically.

3. Photos having scales equal to or larger than 1:20,000 should be purchased. Harold Rib of the United States Bureau of Public Roads reports that recent material surveys by the Bureau and various highway departments indicate that a scale of approximately 1:8,000 is the optimum scale to be used in materials surveys (Rib, personal communication). If economics are not a factor, two scales should be purchased, one small scale on which to delineate regional trends, and one large scale to delineate aggregate sources.

When the photos are received they should be cataloged in some systematic way. It is suggested that the photos be organized as to county, then township and range in each county. It is practical to make an index map on a county highway map showing the coverage of each photo in relation to cities and roads.

The next step is a study of the photo index, on which the broad regional trends can be sketched. A rapid scanning of air photos follows and those photos showing potential areas are set aside and studied in detail; those which show no potential sources are disregarded.

The potential areas are outlined on the photos with light colored pencils and some notes are made directly on the photo. These may include type of landform, type of aggregate expected, etc. It is important that these notes and lines be light, since they will be removed later.

When all photos of importance have been studied, the next phase is to visit the areas in the field. At this time the photos can be marked and later detailed in the office. After the deposit has been examined and the limits have been proven, the deposit can be outlined with a thin line of india ink. A pin hole in the center of the deposit will mark it on the reverse side of the photo. Notes can then be made on this side of the photo for permanent reference.

Figure 15 shows an aerial photo of the area shown in figures 4 and 12. The three terrace areas are clearly shown, as are the Sioux Quartzite outcrops.

Drainage and topography are the most diagnostic patterns of these terraces. Notice the steplike features of the terraces and the disappearance of the drainage upon entering the terrace, illustrating the internal drainage of granular material.

This photo is an uncontrolled mosaic made from four Soil Conservation Service photos. It can be seen that the roads and fields in places do not match. Uncontrolled mosaics may be made by selecting every other photo in a flight strip and fastening them to a board or table. This enables the interpreter to see the total area at a large scale and still enables him to use stereo-methods of evaluation.

Controlled mosaics may be purchased or may be made. In this type of mosaic, the photos are corrected for distortion and represent a map which is accurate with all features in their proper perspective. There is little need for this type of mosaic in aggregate exploration, as it is expensive and not of great value unless an accurate photo-base map is needed.

Evaluation

Aerial photos are by far the most important exploration tool available to the trained materials investigator. With the accumulation of knowledge of landforms, their formation and description, and experience in photo interpretation, it has been estimated that up to 90 percent of the field time can be eliminated. It should be stressed again that no method of exploration can completely eliminate field work.

Figure 15 Aerial Photo of Portion of Alexandria Geologic Quadrangle as Shown in Figure 4.

The main disadvantage of this method is that a certain amount of background, training, and experience is necessary before the interpreter can fully appreciate the use of aerial photos.

It is recommended that complete photo coverage of eastern South Dakota be purchased and a long-range program of evaluation of all areas in this glaciated portion of South Dakota be set up.

EARTH RESISTIVITY MEASUREMENTS

General Statement

Earth resistivity methods were evaluated in this study to determine to what extent resistivity measurements can be applied as an exploration method for coarse aggregate in eastern South Dakota. In the search for an answer, the following specific problems evolved.

1. What electrode configuration is most effective?
2. What factors influence resistivity measurements?
3. What ranges of resistivities can be expected for various deposits?
4. What methods of interpretation are most useful?

In answer to these problems approximately 250 resistivity stations were established, and over 40 auger drill holes were drilled in the Big Sioux and James River basins to an average depth of 44 feet.

The Bays, Model ER-7 earth resistivity instrument manufactured by Urbana Engineering Products Corporation, of Urbana, Illinois, was used for all resistivity measurements. Figure 16 shows the instrument set up in the field. This instrument is calibrated to show apparent resistivity directly in ohm-centimeters (ohm-cm), which is an advantage over other instruments in which apparent resistivity must be calculated. The instrument operates from a 12-volt battery power source and utilizes a vibrator to provide low frequency, 24-cycle-per-second field current.

When used with adequate control in the form of logged drill holes and/or geologic exposures and in conjunction with all other available exploration methods, the resistivity method can reduce the number of drill holes needed to prove a deposit by a substantial amount.

It is mandatory that experienced personnel with a well-rounded background in geology and physics operate the instrument. This should include the various geologic subjects previously outlined and knowledge of physics, of the earth and electronics.

Evaluation of Electrode Configurations

Four different electrode configurations were evaluated in this study.

1. The Wenner configuration.
2. Lee's partitioning method applied to the Wenner configuration.
3. The asymmetrical Wenner configuration.
4. Petsch's method (a modification of the Wenner configuration).

Figure 16. Photograph of Resistivity Instrument

The diagrams of these configurations are shown in figure 17. The Wenner and Lee configurations proved to be the most useful in prospecting for gravel deposits.

When using the Bays apparatus, the Wenner configuration (fig. 17) utilizes two steel current electrodes (C_1 and C_2) and two copper potential electrodes (P_1 and P_2) located in line and spaced equally. The resistivity instrument is located at the center of the configuration and is connected electrically to the four electrodes with cable reels and jumper wires (as shown in figure 16). For depth-probing, the distance (a), in figure 17, is increased in appropriate steps (from 1 foot to 150 feet in this study) and the apparent resistivity is recorded for each electrode separation.

Lee's partitioning method (fig. 17) is similar to the Wenner configuration except that a fifth electrode (copper) is located midway between the potential electrodes. This electrode is connected to the resistivity instrument by a jumper wire, making it possible to take independent resistivity readings for the right and left half of the configuration, as well as the over-all resistivity. These right and left readings aid in location of the deepest, or the most highly resistive, deposit of gravel. If the right reading is higher than the left (at a depth where gravel readings are obtained) the best gravel deposit is to the right of the set-up, as indicated by the higher reading.

The asymmetrical Wenner method (fig. 17) is a modification of the Wenner configuration in that one of the current electrodes is located at infinity. In practice this electrode is located at a distance several times the maximum electrode separation. The values of resistivity, using this method, are about half that of the Wenner configuration for a given electrode separation.

The asymmetrical Wenner configuration has the disadvantage of not being directly interpretable by use of the Mooney-Wetzel master curves (see p. 68), and also tends to give inaccurate readings when the distance to the (assumed) infinitely spaced electrode is less than about ten times the electrode spacing. For the equipment used in this survey, the infinitely spaced electrode was located 450 feet from the center of the configuration (450 feet being the full length of the longest cable reel). This gave inaccurate readings for the larger electrode spacings. While this could be remedied by use of a longer cable reel, the extra expense and set-up time do not seem justified because this method has no evident advantages.

Petsch's method (fig. 17) utilizes the Wenner configuration in all respects except for the manner in which the electrode separation is increased. In this method the resistivity instrument is set up at one fixed current electrode, and the other current electrode and the potential electrodes are moved outward as the electrode separation is increased.

Petsch's method was used on the premise that it would reduce the effect of changes in overburden over short distances. The opposite was generally found to be true. In this method the resistivity of a different volume of earth is measured at each consecutive electrode spacing, because the center of the configuration moves progressively outward from the fixed current electrode. On a few occasions the field curve became irregular

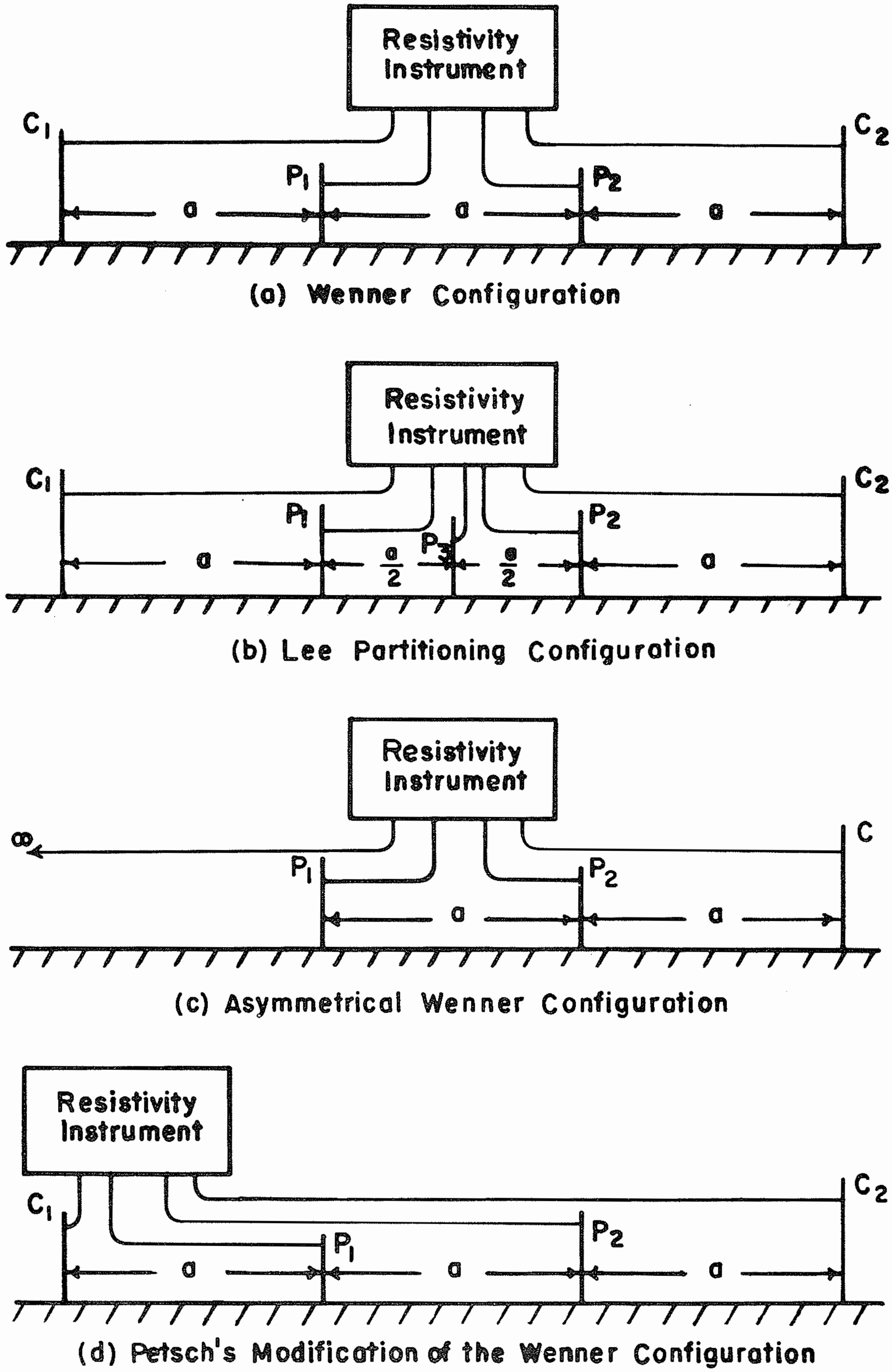


Figure 17. Diagrams of Electrode Configurations Used

and jagged for electrode separations greater than 50 feet. This was probably due to variation in overburden. This method has the one advantage of requiring only three cable reels, instead of four, which reduces the number of changes in electrode location.

Field Factors Influencing Resistivity Measurements

Electrode Spacing

While evaluating the various electrode configurations, the effects of incorrect electrode spacing were studied. The method used to locate the electrodes could introduce errors in readings. The cable on the outer reels (fig. 16) is marked with aluminum markers which are taped in place at pre-determined intervals. These markings are used as guides for placing the electrodes at a given spacing. A consistent tension is applied to these cables when locating the electrodes, in an effort to keep errors in electrode separation to a minimum.

Since this method could introduce errors if the electrodes were improperly spaced, several resistivity readings were taken with the electrodes purposely located incorrectly. It was found that any electrode could be out of line by almost 10 percent of the electrode separation before the reading had an appreciable error. But a 10 percent error in the distance between electrodes caused an error of more than 30 percent in the reading. Therefore, electrodes should be spaced as accurately as possible with special emphasis on the proper distance between electrodes.

Effects of Water

Resistivity measurements can be used in the exploration for coarse aggregate because each lithologic deposit has its own characteristic resistivity due to differences in electrical properties of the various deposits.

The resistivity of a deposit is proportional to the amount of ionized water contained in the voids of the deposit, and determines the amount of current which will flow through the material. Current flow in the earth is generally electrolytic in nature; that is, the electric charge is carried by ions of the dissolved salts in the earth. Pure water is a poor conductor of electricity, but water which contains a sufficient number of ions is a good conductor.

Porosity is a ratio of the volume of the voids in a material to the total volume of the material. Rocks may have porosities ranging from less than one percent up to 29 percent, while sand and gravel porosities generally range from 25 to 40 percent and clays from 40 to 80 percent (Perret, 1949, p. 3). Some rocks have high resistivities because of their low porosities. Sand and gravel usually has a higher porosity than most rock and may have a lower resistivity as a result. However, the permeability of sand and gravel is high allowing movement of the water to dilute the electrolyte(reduce the number of ions present in the solution), thereby increasing the resistivity. Clays have a high porosity and a low permeability which combine to give a low resistivity.

In an effort to determine the effects of water-saturated surface soil on resistivity measurements, several stations were set up before and after a rain. The added moisture due to the precipitation generally caused a decrease in resistivity readings. However, the general shape of the resistivity field curves was not affected. It was also found that variation of ground water conditions had little effect on the shape of the resistivity curves. Therefore, variation in surface water conditions or of ground water conditions should have little influence on resistivity interpretations. One notable exception was found. Resistivity interpretations were influenced by a cover of a dense fine-grained saturated material such as alluvium.

Readings taken under such conditions were often--but not always--erratic. In these cases it was possible to obtain readings only by using the filter on the instrument. In a few instances the readings were erratic even when using the filter. When this occurred, interpretations were not possible.

One explanation of the erratic readings is that field current leakage might occur between the wet earth and the cables connecting the instrument to the electrodes. This seems a logical explanation since Perret (1949, p. 33) states that fouled insulation on the commutator of the instrument he used caused erratic field current which would in turn result in erratic readings. This means that erratic readings should be expected in areas of wet topsoil and not in areas of dry topsoil. However, some of the erratic readings occurred for relatively dry alluvium, while readings taken in wet topsoil--other than alluvium--were not erratic.

When the erratic readings occurred in dry alluvium, it was speculated that poor contact between the electrodes and the earth might be the cause. Pouring water around the base of the electrodes to provide a better contact improved, but did not always correct, this condition. This seems to point to conditions which are peculiar to the alluvium as the cause of the erratic readings. It is also possible that the instrument used, since it utilizes alternating field current obtained from a vibrator, may be subject to these erratic readings.

Effects of Fences, Power Lines, and Buried Pipe

When a resistivity station is set up with the electrodes parallel to fences with steel posts, power lines, and buried pipe, the measured resistivity may be influenced. Since these are all good conductors, the field current may find a low resistance path through the conductor, allowing only a small amount of current to flow through the earth between the current electrodes. This reduced current causes a smaller potential difference to exist between the potential electrodes, and the instrument reads a reduced value of resistivity.

Readings taken near and parallel to a fence with steel posts were found to be lower than readings taken some distance from the fence. This effect is reported by Johnson (1959, p. 85) who states: "The presence of such a conductor (pipe lines or fences with metal posts) is indicated by abnormally low readings which do not change appreciably with an increase in depth or spacing."

However, this problem may not be as great as it first appears. Metal exposed to the damp earth will corrode. This corrosion tends to insulate a pipeline or a metal post from the earth. The wires on a fence, after long exposure to the elements, will also corrode, resulting in a poor electrical contact between the wire and the metal post. Thus, the condition of a fence or a buried pipeline may be such that readings are not greatly affected.

If a station must be set up near and parallel to a conductor, the data obtained may be reliable, but it should be used with discretion. To obtain the best readings, the station should be set up with the electrodes perpendicular to the conductor so the field current will flow in a direction perpendicular to the conductor, and not through it. If it must be set up parallel, the station should be no nearer the conductor than the maximum electrode separation.

Control Stations

Before resistivity measurements can be interpreted a control station must be set up to provide a reference for interpretations in the local area. This control station may be either near an exposure of the deposits (such as a road cut or an eroded river bank) or at a location for which a drill log is available. (Core drill holes, if economically feasible, are the most accurate control station.) Both types of control stations (or more than one of a given type) should be used, since common agreement will establish the control station accuracy.

Methods of Interpretation

Four methods were found to be the most useful in the interpretation of resistivity measurements.

1. Observation of field curve shape.
2. Direct linear interpretation.
3. Moore's cumulative method.
4. Mooney-Wetzel master curves.

While many other methods exist, several of which were used with poor results, they will not be discussed since they are adequately described in the literature. (See Selected Bibliography.)

Observation of Field Curve Shape

The following table shows the range of resistivities found for various deposits in eastern South Dakota.

Resistivities observed for various deposits

Lithologic Deposit	Range of Resistivities (ohm-cm)
Till	1,000 - 4,000
Sand and gravel with thick alluvium or loess cover	2,000 - 20,000
Sand and gravel with thin cover	10,000 - 70,000
Kame and Kame Terrace sediments	10,000 - 50,000
Sioux Quartzite with shallow overburden	6,000 - 200,000
Niobrara Formation with shallow overburden	1,000 - 4,000

The resistivity ranges shown in this table overlap in many cases; however, the field curve of each deposit usually has a distinct shape, and the type of deposit can generally be determined from the field curve.

Sand and gravel with a thick cover of alluvium or loess may lie in the same range of resistivity as till (2,000 to 4,000 ohm-cm), but it is usually easy to distinguish between the two from the field curves. The resistivity of till may vary considerably over short distances because of its composition. In general, till is covered with a shallow layer of topsoil that is relatively homogeneous. This topsoil usually has a higher resistivity than till, depending on the moisture content.

Due to the topsoil, the typical till resistivity curve starts as a smooth curve with resistivity decreasing with depth. When electrode separation approximately equals the depth to till, the curve is in the 1,000 to 4,000 ohm-cm range, and for increasing depth fluctuates in a random manner due to the heterogeneous nature of till. A typical till curve is shown in figure 18.

Sand and gravel will usually be covered with a layer of topsoil having a much lower resistivity than the sand and gravel beneath. Therefore, the field curve for sand and gravel will begin at a low resistivity of a few thousand ohm-cm for very close electrode spacing. At greater separations, the sand and gravel will cause a continuing increase in resistivity until the effects of the layer below the sand and gravel influence the readings. If the lower layer is till the readings will decrease when it is encountered.

When sand and gravel is covered with a thick layer of alluvium or loess the magnitude of the resistivity readings is greatly reduced, but the curve still has the shape typical of sand and gravel over till. This type of curve is shown in figure 18.

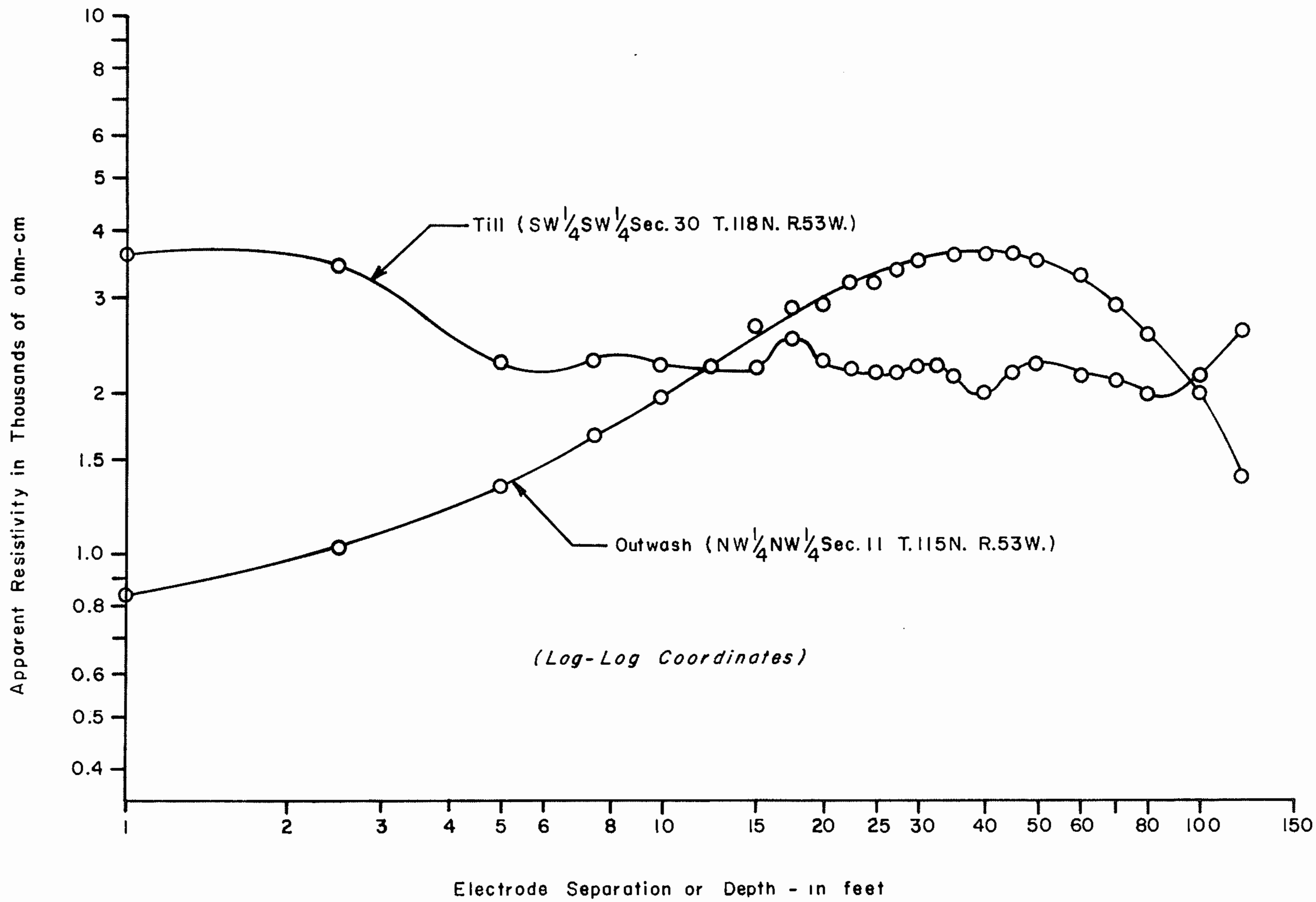


Figure 18. Comparison of outwash sediment and till resistivity curves.

Although the curves of figure 18 are in the same resistivity range, the curve shape distinguishes sand and gravel from till. However, it is not always easy to make this distinction. If the outwash sediment consists of very silty sand, or layers of sand and silt, the curve will closely resemble a till curve. An example of this is shown in figure 19. A deposit exhibiting such low resistivity readings, however, would not usually be considered as a potential aggregate source, so the curve shape is still a good indicator of deposits having commercial value.

Also shown in figure 19 is an outwash sediment over a till resistivity curve which has the same general shape as the one shown in figure 18. This curve has a maximum resistivity of about 45,000 ohm-cm as compared to a maximum of 3,600 ohm-cm in figure 18. The greater thickness of the gravel deposit is probably the main reason for the high reading. The type and thickness of overburden and the thickness and nature of the outwash deposit all have an effect on the magnitude of the outwash readings.

Resistivity field curves for kames and kame terrace deposits are similar to those of outwash sand and gravel. This is to be expected because kames and kame terraces are also stratified sand and gravel deposits.

Figure 20 compares a resistivity curve for the Niobrara Formation with shallow overburden to the till curve shown in figure 18. The Niobrara curve begins at a higher resistivity due to a dry topsoil having a high resistivity. However, the general curve shape is so similar that it is impossible to distinguish between the two from the field curves. Thus, it should not be surprising that outwash over Niobrara (also shown in figure 20) is similar in shape to an outwash over till curve.

The resistivities of outwash and of Sioux Quartzite with shallow overburden are also of the same order of magnitude, but again the two can generally be distinguished from the field curves provided the measurements are taken to sufficient depths. Depth measurements for sand and gravel over till show a decreased resistivity when the till is encountered, whereas the resistivity of Sioux Quartzite with shallow overburden continues to increase in an almost linear manner up to the maximum electrode separation. This is illustrated by the continuing increase in resistivity between 80 and 150 feet in figure 21. The continuing increase is due to the greater thickness of the quartzite and because the quartzite has a very high resistivity when compared with glacial sediment.

Under some conditions it is difficult to distinguish between the two deposits. For example, outwash overlying quartzite could easily be misinterpreted as quartzite since the actual resistivity of the two may be of the same order of magnitude, and the contact between them might not be detected. Such a curve is shown in figure 21. The drill log for this resistivity station shows outwash between 11 feet and 40 feet with quartzite at 40 feet. A thick layer of alluvium (11 feet) above the outwash reduces the normally high resistivity readings of sand and gravel or of quartzite.

Direct Linear Interpretation

During the study of "The Resistivity Method Applied to Ground Water Studies of Glacial Outwash Deposits in Eastern South Dakota" by Lum (1961),

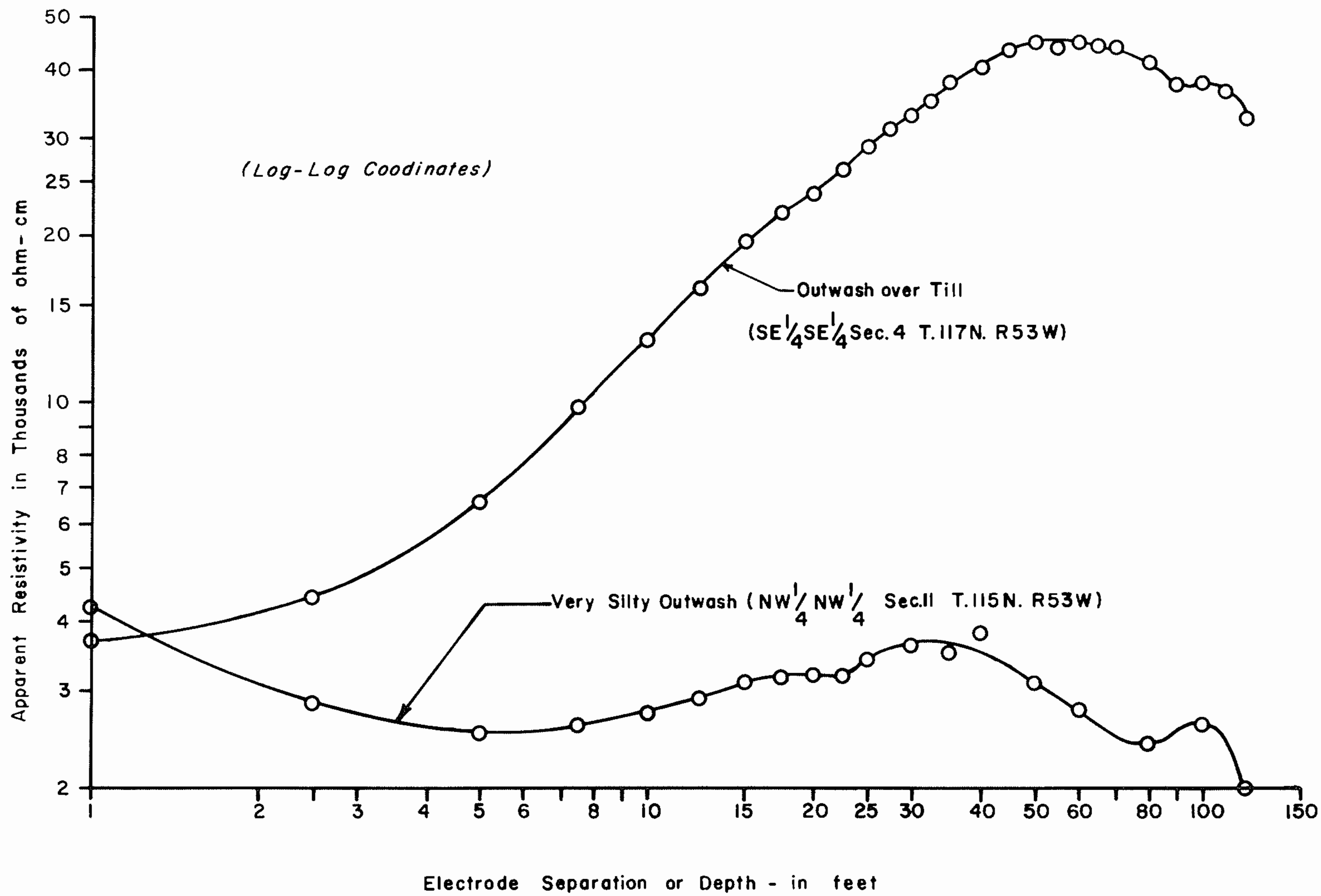


Figure 19. Sand and gravel over till resistivity curves.

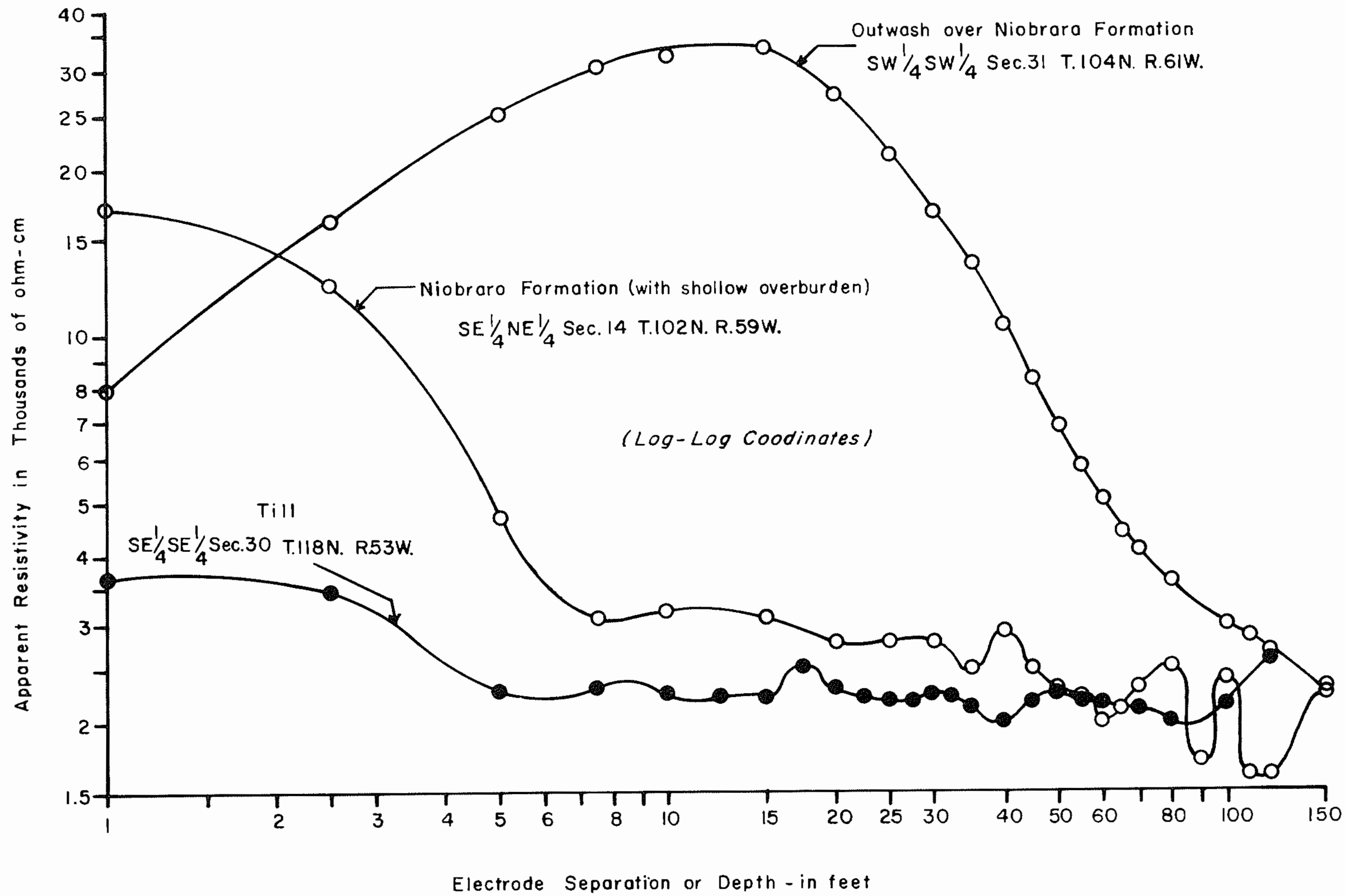


Figure 20. Comparison of Niobrara Formation and Till Resistivity Curves

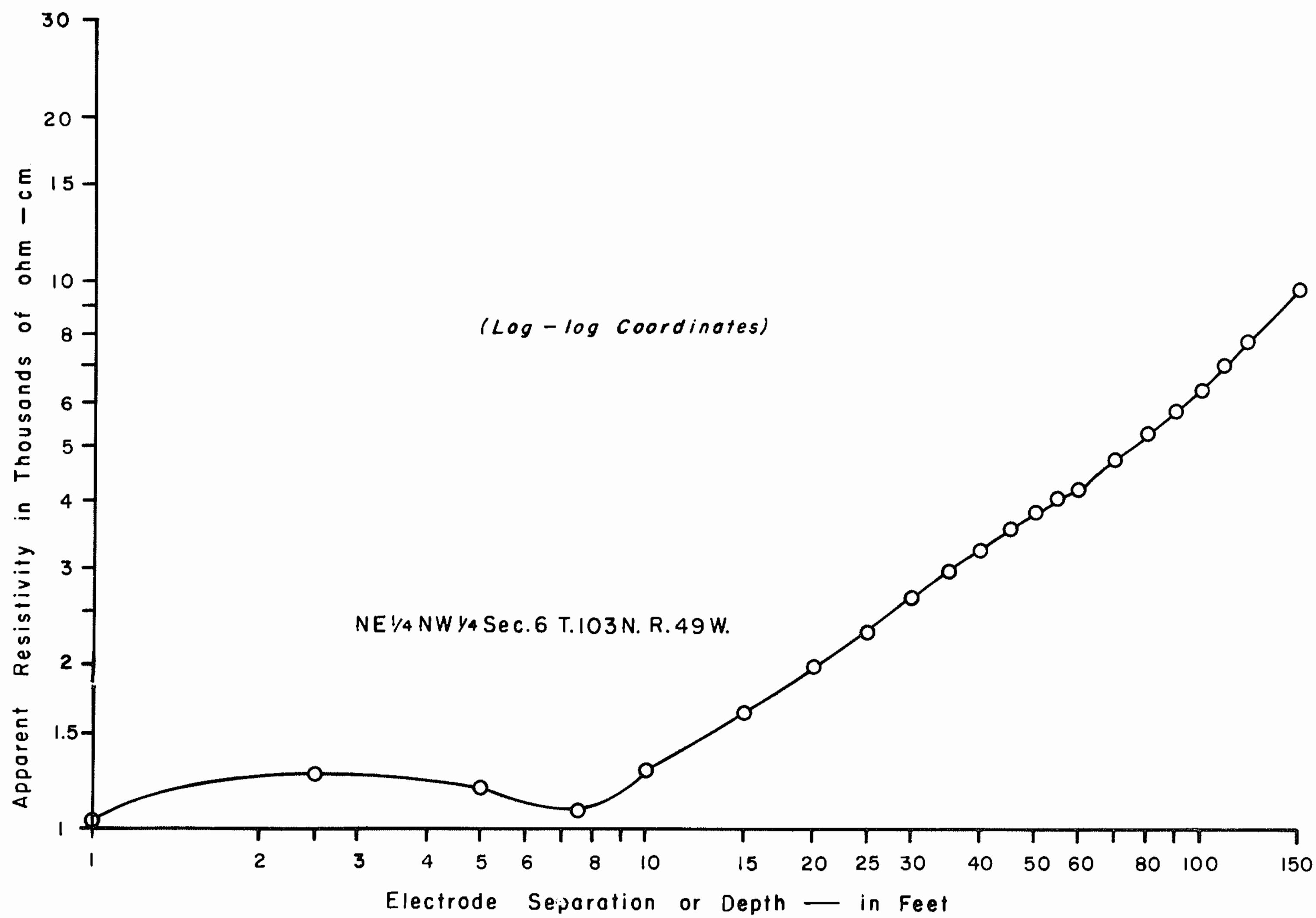


Figure 21. Outwash Sediment over Sioux Quartzite Resistivity Curve.

it was noted that contacts could frequently be predicted from the field curve. When plotted on log-log paper the field curve generally consists of several connecting curve segments. If each segment is considered to represent one sub-surface layer, the contacts occur approximately at a depth corresponding to the midpoints of the segments. In practice it is difficult to determine the inflection points on the log-log curve; however, if the field curve is plotted on linear graph paper many of the segments are transformed into straight lines whose midpoints can readily be determined.

In using this method of interpretation, the field data are plotted as points on linear graph paper. Straight lines are then drawn through the points in a manner that best represents the curve as a series of straight lines. The intersections of the lines are noted, and a point midway between two intersections is taken as the approximate location of a contact.

Figure 22 shows a field curve interpreted by this method. The nature of the various beds can be determined to a large degree from the slopes of the straight lines, along with the information obtained from base stations. The steep positive slopes indicate beds with a high resistivity; the degree of steepness corresponds to the magnitude of the resistivity. In like manner, negative slopes indicate a layer of low resistivity material. The lines with a near-zero slope may indicate a bed of changing resistivity.

A study of three- and four-layer theoretical resistivity curves shows the curve to asymptotically approach the true value of resistivity of the lower layer. Thus, if any layer is thick enough, resistivity measurements approach a constant value, and show up on the field curve as a straight line with a near-zero slope.

When adjacent beds have greatly different resistivities, the upper bed initially has a dominating influence on the readings. But as the electrode spacing is increased the lower bed has an increasing influence on the readings, and at some point becomes dominant. When this occurs, the readings begin to rapidly change from the resistivity of the upper bed toward that of the lower bed. If the lower bed is relatively thin, only the part of the curve for which the readings are rapidly changing is present on the field curve. If the lower bed is thick, the readings will rapidly change toward the resistivity of the lower bed and then become asymptotic to this value.

In explaining the interpretation of figure 22, it should be noted that the line segments A-B, B-C, C-D, and D-E each represent a layer of high resistivity. However, because each segment has a different slope, the beds represented by each have different values of resistivity. Segment B-C, which has the steepest slope, corresponds to the bed with highest resistivity. Although sand and gravel is predicted for segments B-C and C-D as shown on the resistivity interpretation log, the resistivity of the two segments is not the same and a contact is shown between them.

The assumption is made that a bed will begin influencing readings before the electrode separation equals the depth to the contact. Thus, the midpoint of a line segment represents the upper contact of the bed corresponding to the line segment. For example, in figure 22 contact "b"

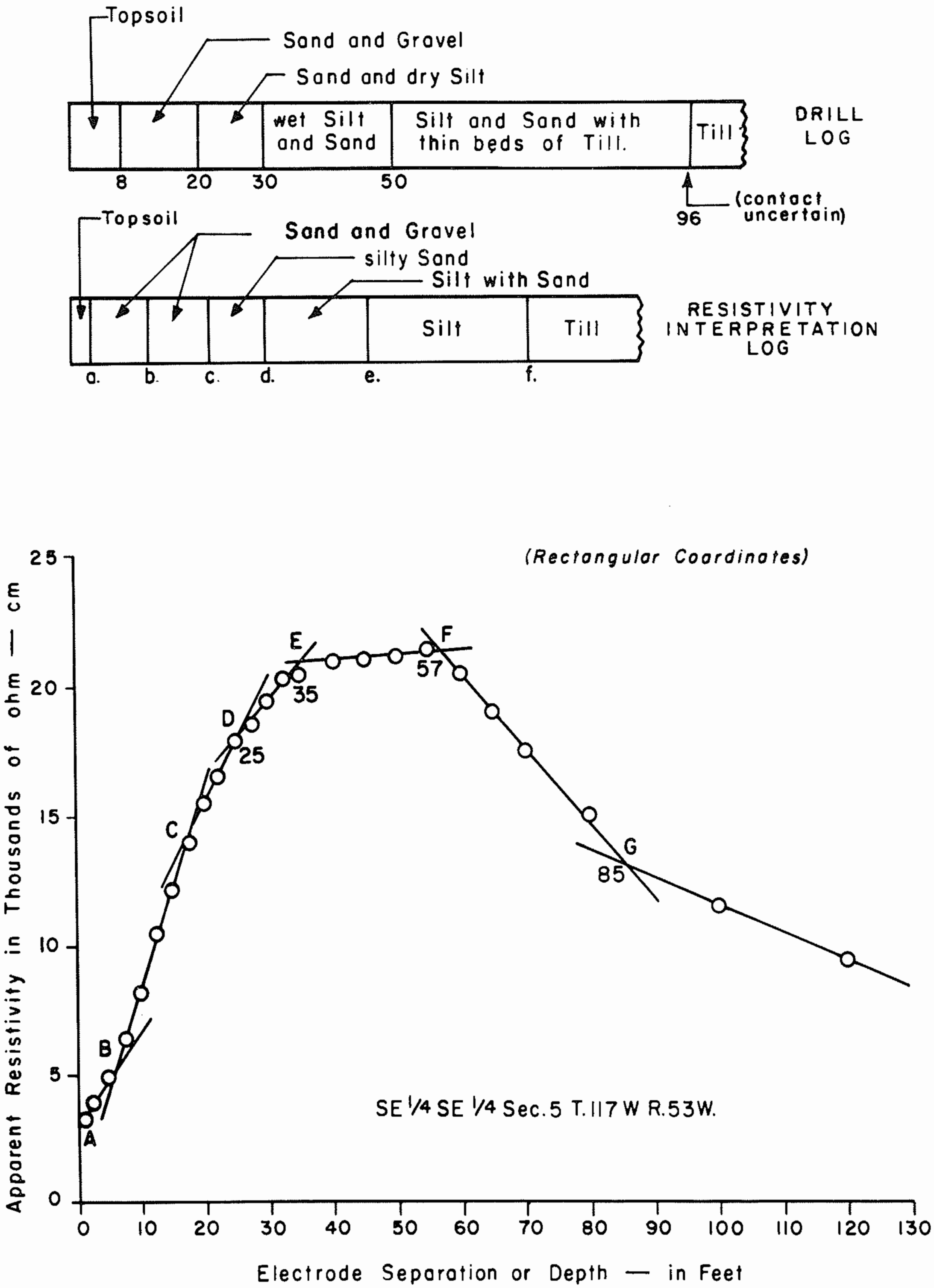


Figure 22. Linear interpretation of outwash resistivity curve.

(resistivity interpretation log) is the upper contact of the sand and gravel layer indicated by line segment B-C of the resistivity curve, and contact "a" is the upper contact of the sand and gravel layer indicated by segment A-B.

The portion of the curve between D and F can be interpreted in two different ways. In addition to the interpretation shown, we could assume that this entire curve segment is caused by one layer, and that the readings are merely becoming asymptotic to the true resistivity of the layer. In this case a single contact would replace contacts "d" and "e".

Since it is frequently possible to interpret the linear plot in more than one way, the experience and judgment of the interpreter must be used in arriving at the best interpretation.

This method of interpretation cannot be used when the linear plot is a smooth curve, since any number of lines might be drawn to represent the curve and a number of different interpretations would result.

The Direct Linear Interpretation method was used to interpret all outwash resistivity curves and was found to generally give good results. Although the contact location often disagreed with the drill log by several feet, the order of occurrence of the various beds was usually correct. A comparison of the interpretations to the drill logs showed the lower contact of the sand and gravel to generally disagree in a systematic manner. For shallow deposits (less than 20 feet to the base of the sand and gravel) the interpretation predicted the deposit to be deeper than shown on the drill log. For deep deposits (more than 40 feet to the base of the sand and gravel) the deposit was predicted to be shallower than shown on the drill log. This indicates that a correction factor should be used when determining the depth of sand and gravel from the linear plot. This correction factor is used to decrease the predicted depth to the base of shallow sand and gravel deposits and to increase the predicted depth to the base of deep deposits.

Since the composition of outwash sediments may vary from one location to another, the magnitude of the correction factor can only be determined approximately, and the location of contacts will also be approximate. The magnitude must be determined from experience in interpreting field curves in a local area.

Figure 23 shows the Direct Linear Interpretation of outwash over Niobrara Formation curve shown in figure 20. In figure 23 the contacts have been located at the mid-points of the intersections of the lines. The base of the sand and gravel is predicted at 21 feet, somewhat deeper than the 17 feet shown on the drill log (fig. 23). Had the interpretation been modified by the correction factor of 15 to 20 percent (determined from experience in the area), the agreement with the drill log would be very good.

Moore's Cumulative Plot

An empirical method of interpretation was developed by Moore (1944) in which the cumulative sum of the resistivities is plotted against electrode separation. "The initial value of apparent resistivity is plotted

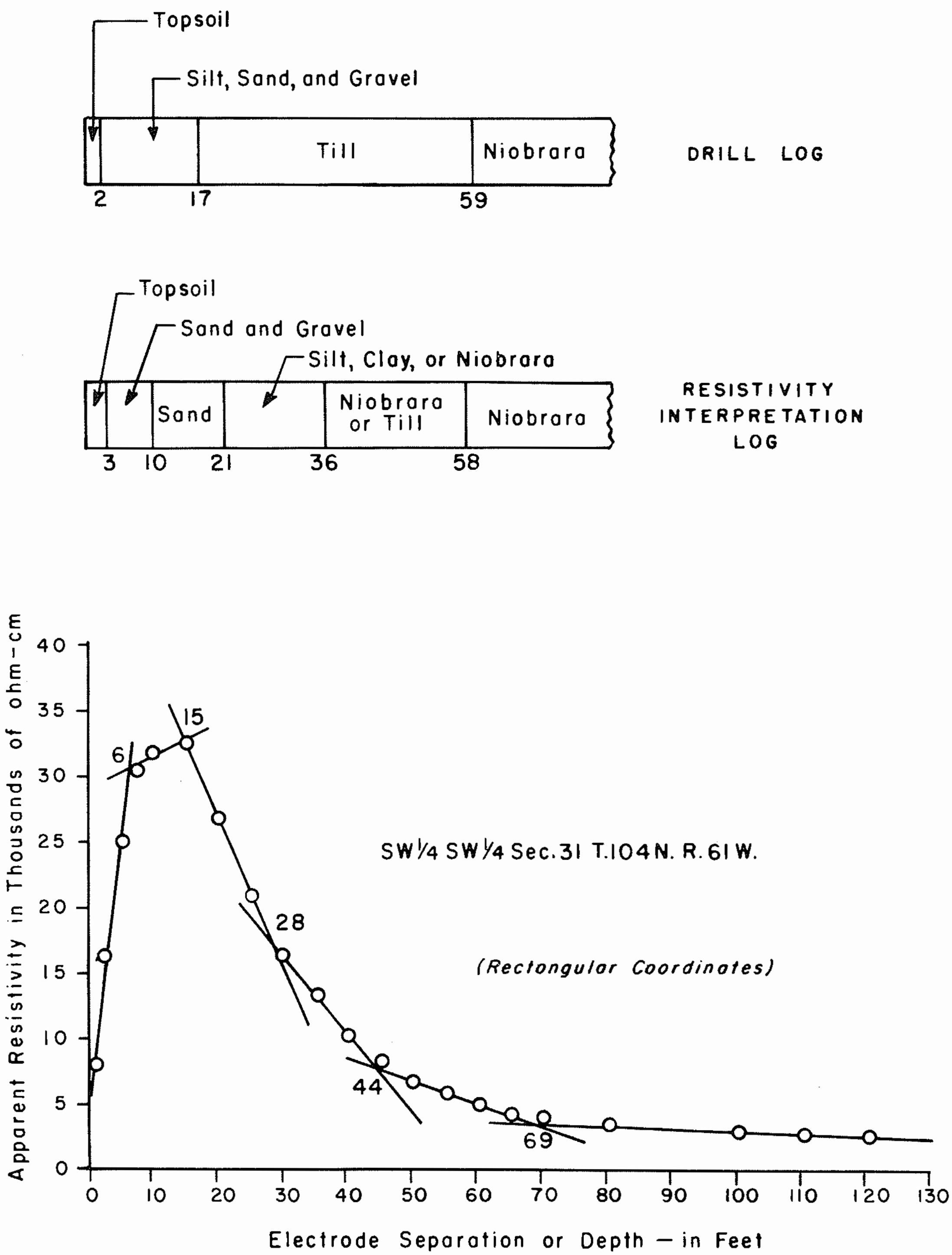


Figure 23. Linear interpretation of outwash over Niobrara Formation Resistivity Curve.

as the initial ordinate of the cumulative curve. Each subsequent value of apparent resistivity is added to the sum of all preceding resistivity values and each total thus obtained is plotted as the ordinate of another point on the cumulative curve." (Moore, 1944, p. 201.) The electrode separation at which the lines (drawn tangent to the cumulative plot) intersect is taken as the approximate depth to the contact, providing the field curve undergoes a change in resistivity at a depth corresponding (approximately) to the intersection. Thus the field curve (usually a linear plot) is used in conjunction with the cumulative plot. According to Moore, the cumulative plot minimizes the effect of variation in the resistivity data due to local irregularities in the surface and subsurface layers, and due to the inaccuracies of taking the measurements. This is because a greatly reduced scale is required to plot the cumulative sum of the resistivities.

Cumulative curves were plotted for all the field data using Moore's method. In many cases the predicted location of contacts agreed favorably with the contacts shown on the drill log. Figure 24 shows the cumulative plot for the outwash over Niobrara Formation curve of figure 20. The plotted points between 0 and 15 feet, and between 55 and 70 feet form a straight line; but the points between 20 and 50 feet form a relatively smooth curve. This curved section of the plot has been represented by two straight lines for the interpretation shown, but the intersection of the two lines is considered an unreliable contact for two reasons: (1) a number of straight lines could be drawn to represent this section of the cumulative plot, and (2) the field curve (fig. 23) undergoes only a gradual, smooth change between 20 and 50 feet. This section of the cumulative plot should probably be represented as a constant smooth curve. This would result in an interpretation predicting contacts at about 20 and 50 feet (which agrees quite well with the drill log).

The previous discussion should point out that an interpreter cannot blindly apply this method and expect to get good interpretations.

Moore's cumulative plot appears to work best for interpreting shallow outwash deposits, such as that of figure 24. For deeper deposits the interpretation is not always this good. The smooth curve of figure 25 is typical of many of the cumulative plots for deep outwash deposits. The process of dividing this type of curve into a series of straight lines is very inexact as many combinations of lines might be drawn to represent the curve. When a smooth cumulative curve is obtained, some method other than Moore's should be used.

The nature of the various beds can be determined to some extent from the angle of the slopes of the cumulative plot. The steep slopes correspond to the high resistivity beds. In figure 24 the line from 0 to 20 feet indicates sand and gravel which has a high resistivity. However, a plot of the field curve should be used, along with drill hole and geologic information, in predicting the nature of the beds. This means an interpreter must be familiar with the various shapes of field curves for many combinations of beds.

Theoretically, abrupt changes of slope in the cumulative curve are caused by errors in measurements rather than by a contact between beds

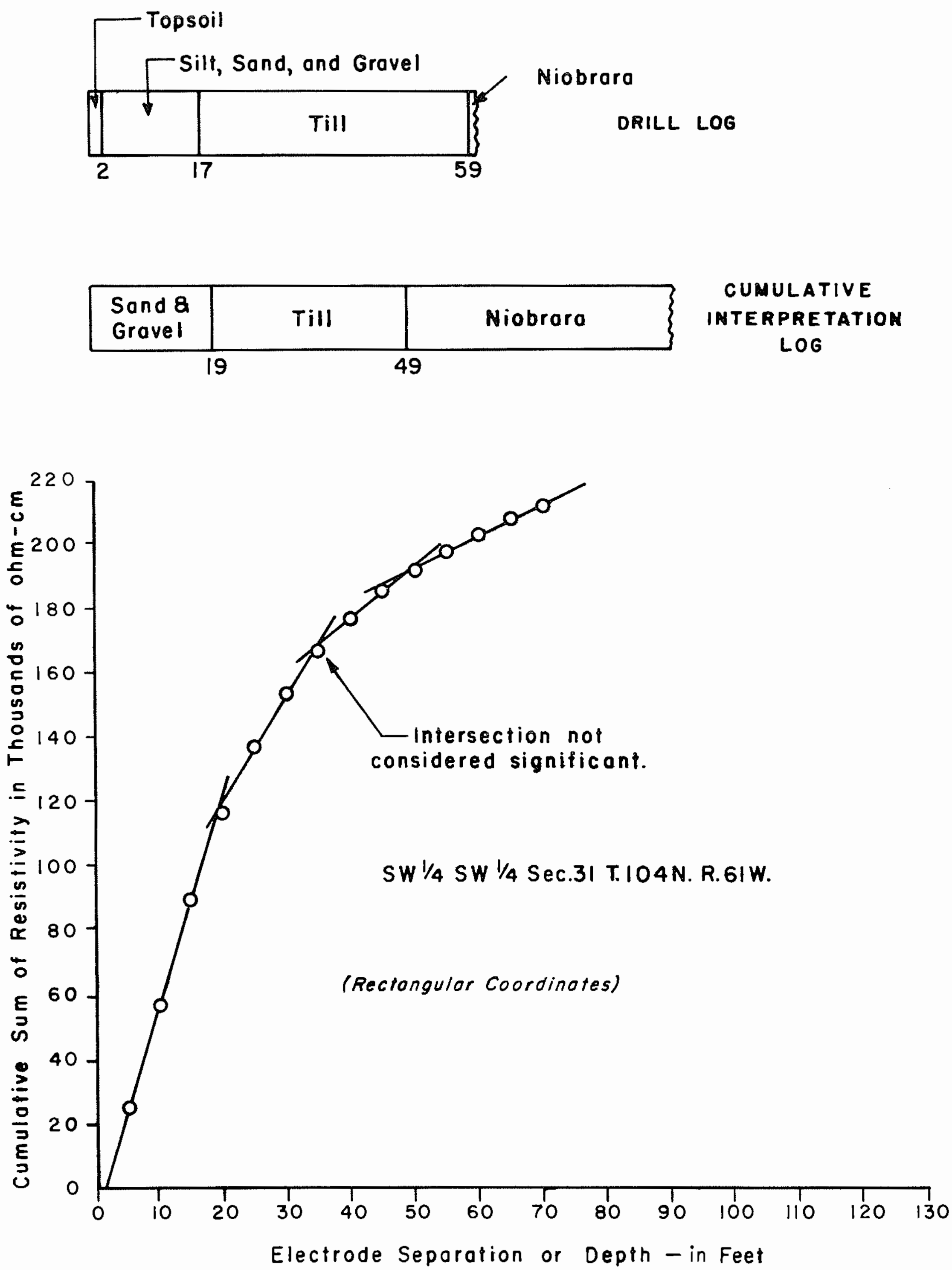


Figure 24. Cumulative plot for outwash curve of Figure 20.

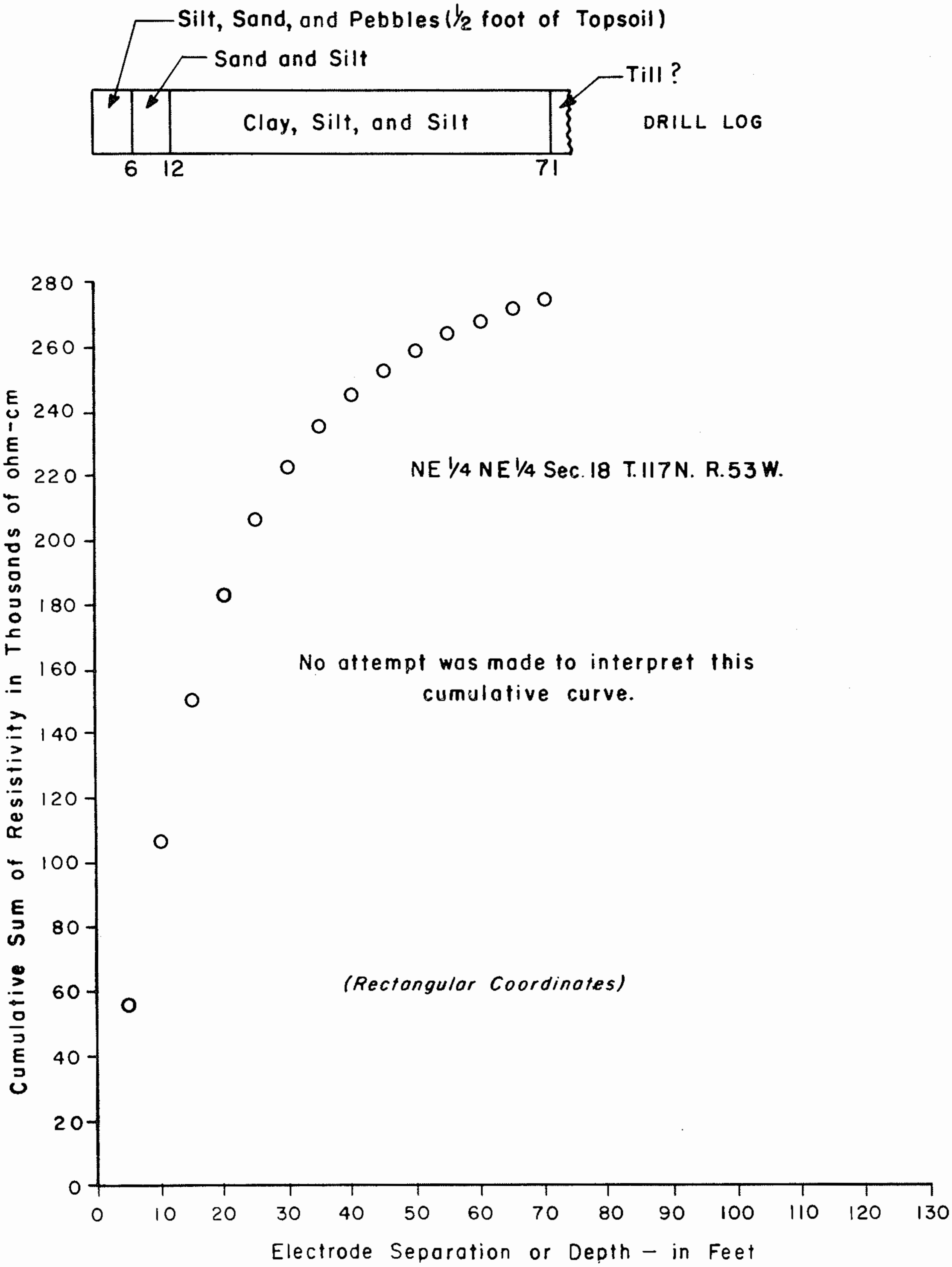


Figure 25. Smooth cumulative curve as sometimes obtained for outwash deposits.

of different resistivity, but in practice these changes in slope very often do correspond to the contact between layers. From a practical standpoint, the intersections of the straight lines drawn through the points of the cumulative plot usually represent contacts between beds (providing the field curve also indicates a contact).

Mooney-Wetzel Master Curves

Mooney and Wetzel (1956) have published a large number of theoretical earth-resistivity curves (called master curves) which can be used for interpreting field curves. In computing the curves, the assumptions are made that each layer is electrically homogeneous and that the contacts between layers, as well as the earth surface, are horizontal plane surfaces. Each curve represents a set of assumed values of resistivity for each layer and for depth to the various contacts between layers. The curves are plotted on log-log paper with relative depth as abscissa and relative resistivity as ordinate and as such are independent of units of depth and resistivity.

Field curves are plotted as log-log curves to the same logarithmic scale as the master curves. When a master curve can be found that matches the field curve, the interpretation is simply a matter of reading the value of resistivity of the top layer and the depth to the bottom contact from reference lines on the master curve. The assumed relationships between the various contact depths and between the layer resistivities (of the master curve) can then be used to determine the remaining values of resistivity and depth to contacts.

Master curves representing approximately 2,400 different resistivity and depth ratios were used in an attempt to match the field curves to a master curve. In using the master curves, it is essential that the interpreter becomes familiar with the general shape of the master curves which represent a particular resistivity ratio and depth ratio, so that only a small number of the master curves need to compared to the field curve. The resistivity ratio is the ratio of the various layer resistivities to the resistivity of the first layer. The resistivity ratio 1:3:10:1/3 indicates a second layer with three times the resistivity of the first, a third layer with 10 times the resistivity of the first layer, etc. The depth ratio is defined in like manner.

An experienced interpreter can predict a curve match between the outwash curve of figure 18 and a master curve of resistivity ratio 1:3:10:1/3 or 1:10:1. He would not attempt to match the figure 18 outwash curve with master curves having resistivity ratios of 1:100:10, 1:1/3:10 or 1:1/10:1 because these curves have shapes far different from the field curve.

Figure 26 compares the outwash curve of figure 18 to the master curve of resistivity ratio 1:3:10:1/3 and depth ratio 1:2:6. This is the best curve match found for this outwash curve and is a reasonably good match between 5 and 60 feet. The reference lines of the master curve coincide with 1,070 ohm-cm and 28 feet of the outwash curve and predict the resistivity of the first layer (R_1) to be 1,070 ohm-cm and

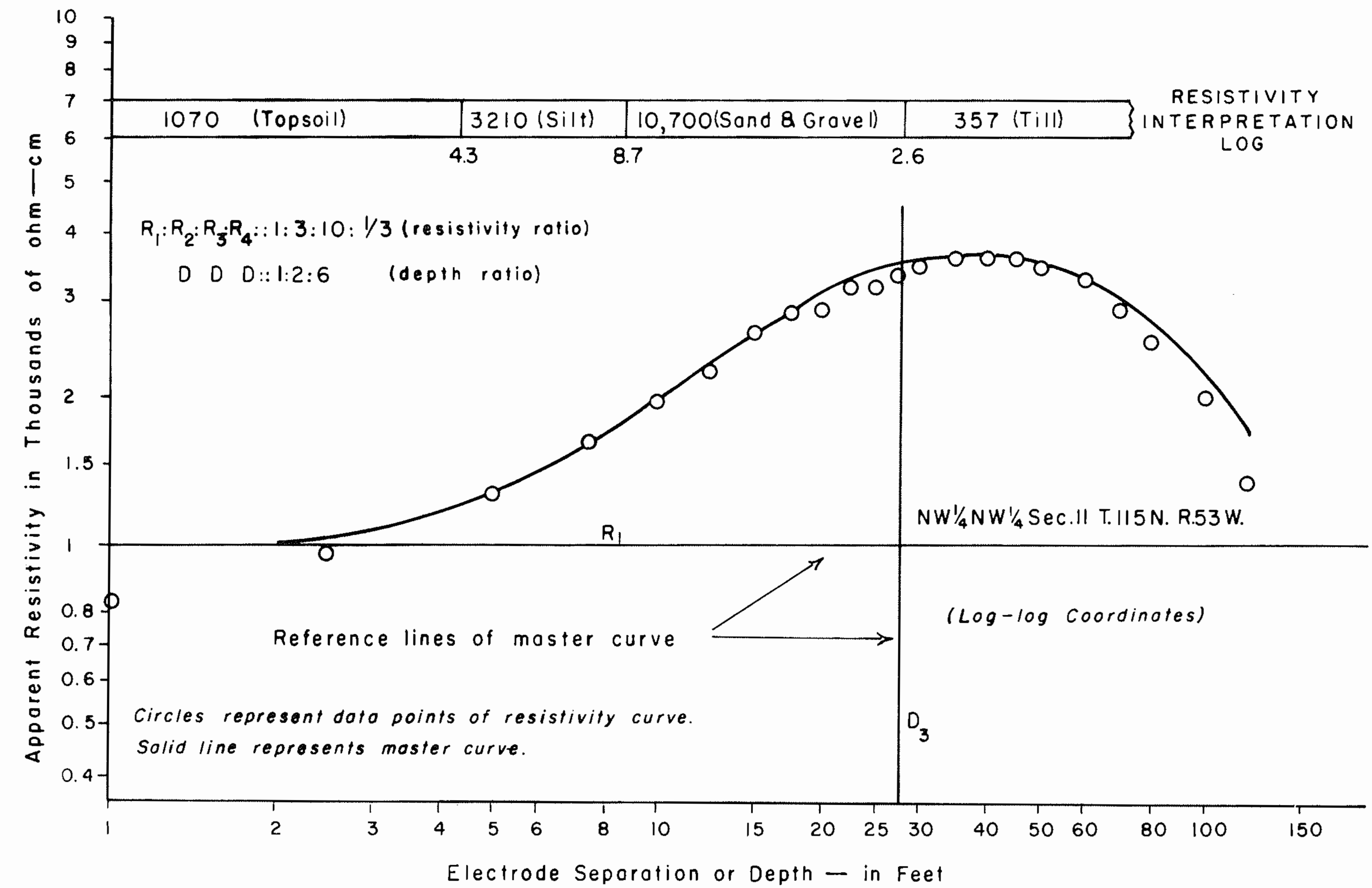


Figure 26. Mooney — Wetzel master curve matched to outwash curve of Figure 18.

the depth to the third contact (D_3) to be 28 feet. Using the resistivity ratios, the resistivity of the second layer is 3,210 ohm-cm, of the third layer 10,700 ohm-cm, and of the fourth layer 357 ohm-cm. From the depth ratio, the first contact is at 4.3 feet and the second contact at 8.7 feet.

This interpretation indicates a sand and gravel layer (10,700 ohm-cm) between 8.7 feet and 28 feet while the drill log for this station shows sand and gravel between 10 feet and 60 feet. It should be noted that the curve match is not good for the small and the large electrode separations (the data points do not coincide with the master curve), thus, we should not be surprised that this interpretation is very poor in predicting the base of the outwash.

In figure 27 the outwash over Niobrara curve of figure 20 is interpreted using a master curve with a 1:10:1/10:1/3 resistivity ratio and a 1:5:6 depth ratio. This is a very good curve match except at the 1 and the 10 foot readings. This interpretation indicates sand and gravel (88,000 ohm-cm) between 1.7 and 8.3 feet. The drill log shows sand and gravel between 2 and 17 feet. Although the curve match is good the interpretation does not agree very well with the drill log. The discrepancy could be due to an inaccurate drill log, but it could also be due to an incorrect interpretation.

Figures 28 and 29 show that the master curve interpretations can be incorrect even when the curve match is very good.

Figure 28 shows a hypothetical outwash over till curve matched to master curve 1:10:1 with depth ratio 1:6. The interpretation indicates a bed of sand and gravel (37,500 ohm-cm) between 5 and 30 feet.

A second interpretation of this same hypothetical outwash curve using another master curve is shown in figure 29. The master curve has a 1:100:1 resistivity ratio and a 3:4 depth ratio. This curve match predicts sand and gravel (410,000 ohm-cm) between 6.5 and 8.6 feet.

The master curve matches the hypothetical curve very well in both figures; (at no place does a point on the hypothetical curve deviate from the master curve by more than a few percent of the resistivity reading at the point), yet the interpretations given by the two master curves are in wide disagreement. This shows that in some cases, the master curves can give a very inaccurate interpretation, and so they should not be unquestionably accepted as giving correct interpretations for a good curve match.

Another disadvantage of the master curves is that very often one cannot be found that matches the field curve. Even with the numerous master curves available, the author found less than 10 percent of the field curves could be matched to a master curve reasonably well. Only in one case was a good curve match found (fig. 27). At present theoretical master curves are only available for two, three and four layers of earth, and for a limited number of layer conditions. In practice, five or more layers are frequently encountered and an infinite number of layer conditions can exist. Therefore, a field curve can rarely be made to match completely a calculated curve (Mooney, 1954). Another reason why the field curve may not match the theoretical curve is that the assumed conditions of homogeneous layers and plane contacts between layers are often not satisfied in the field.

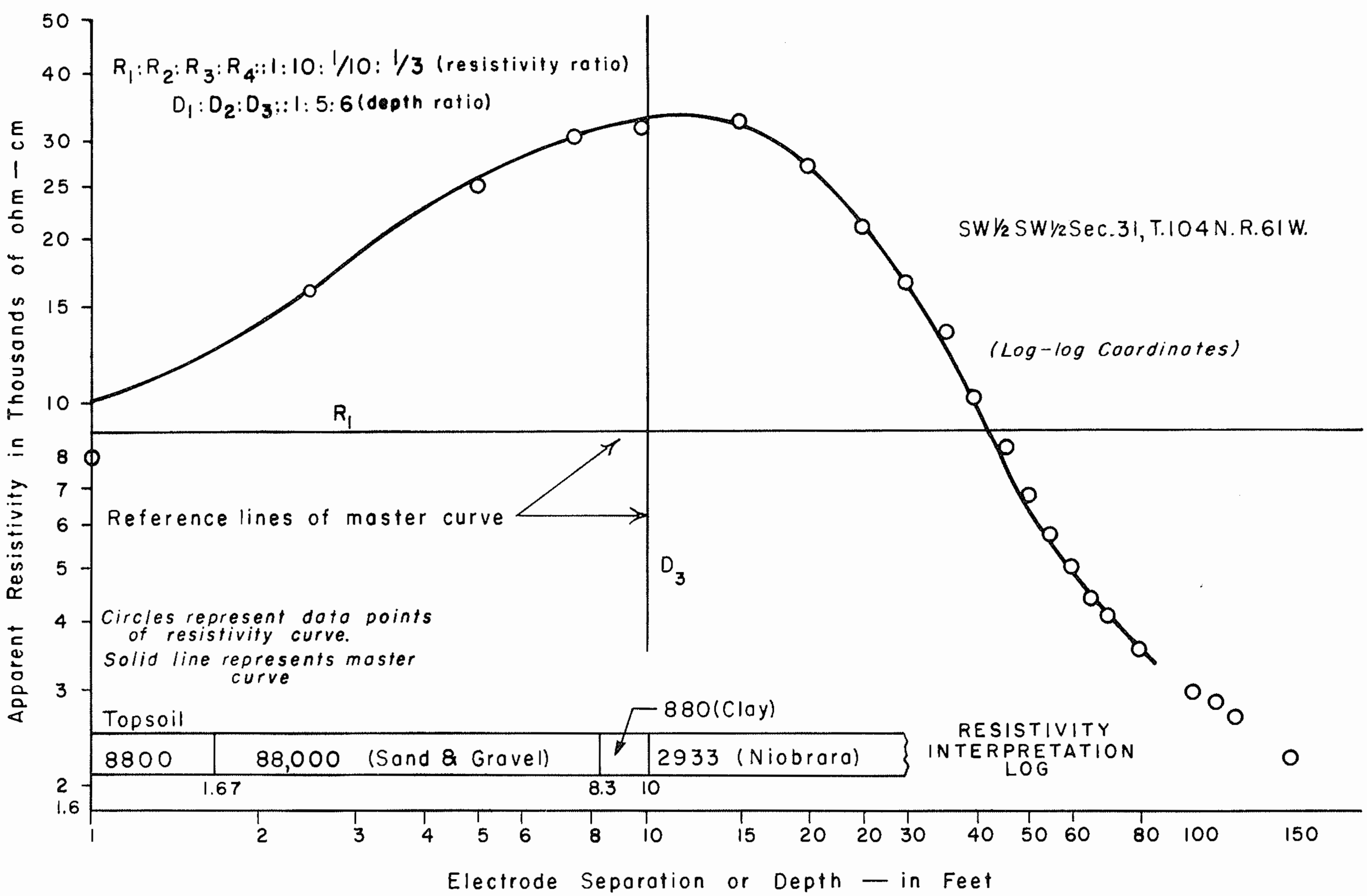


Figure 27. Mooney — Wetzel master curve matched to outwash curve of Figure 20.

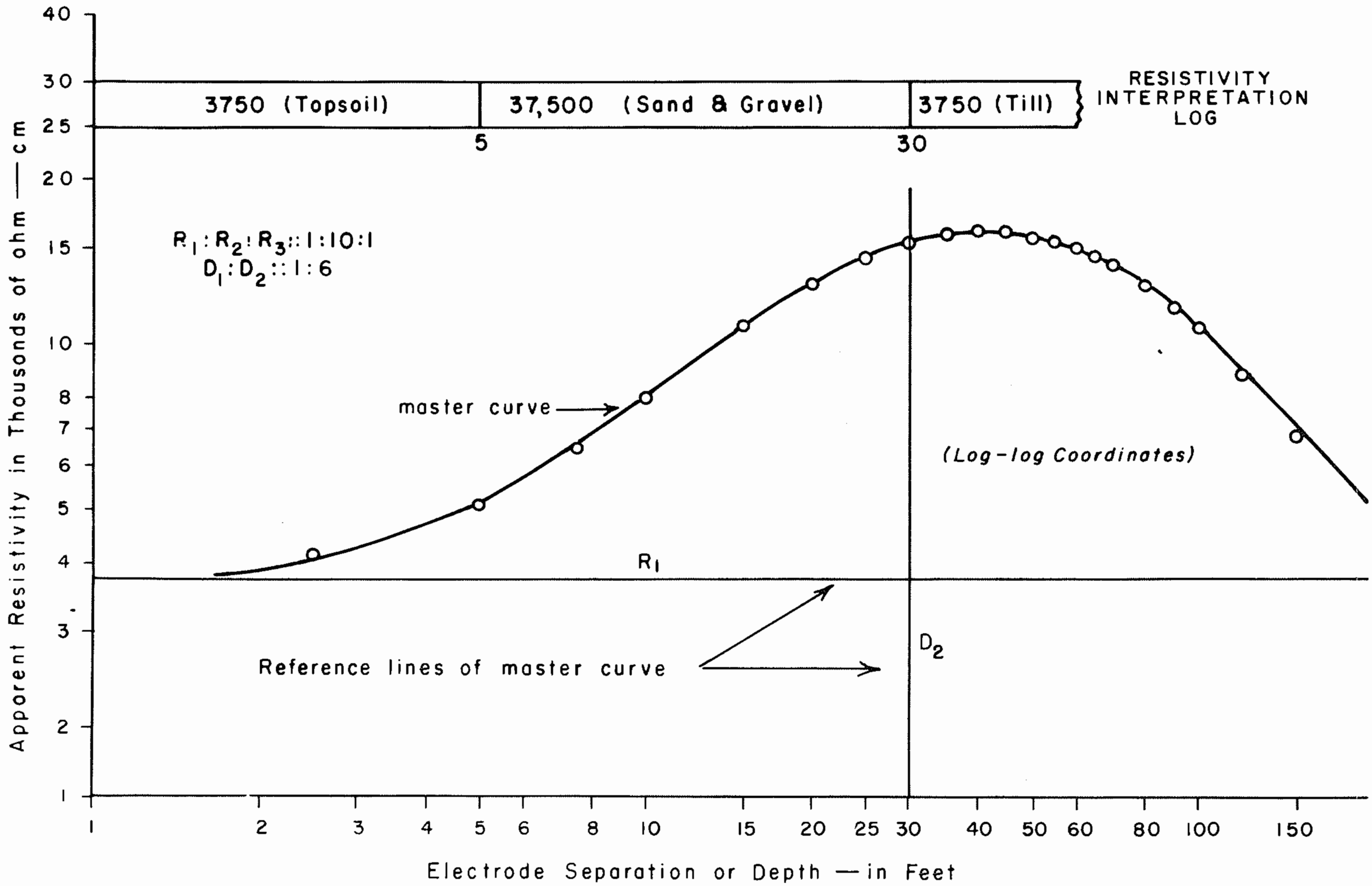


Figure 28. Mooney—Wetzel master curve matched to hypothetical outwash curve.

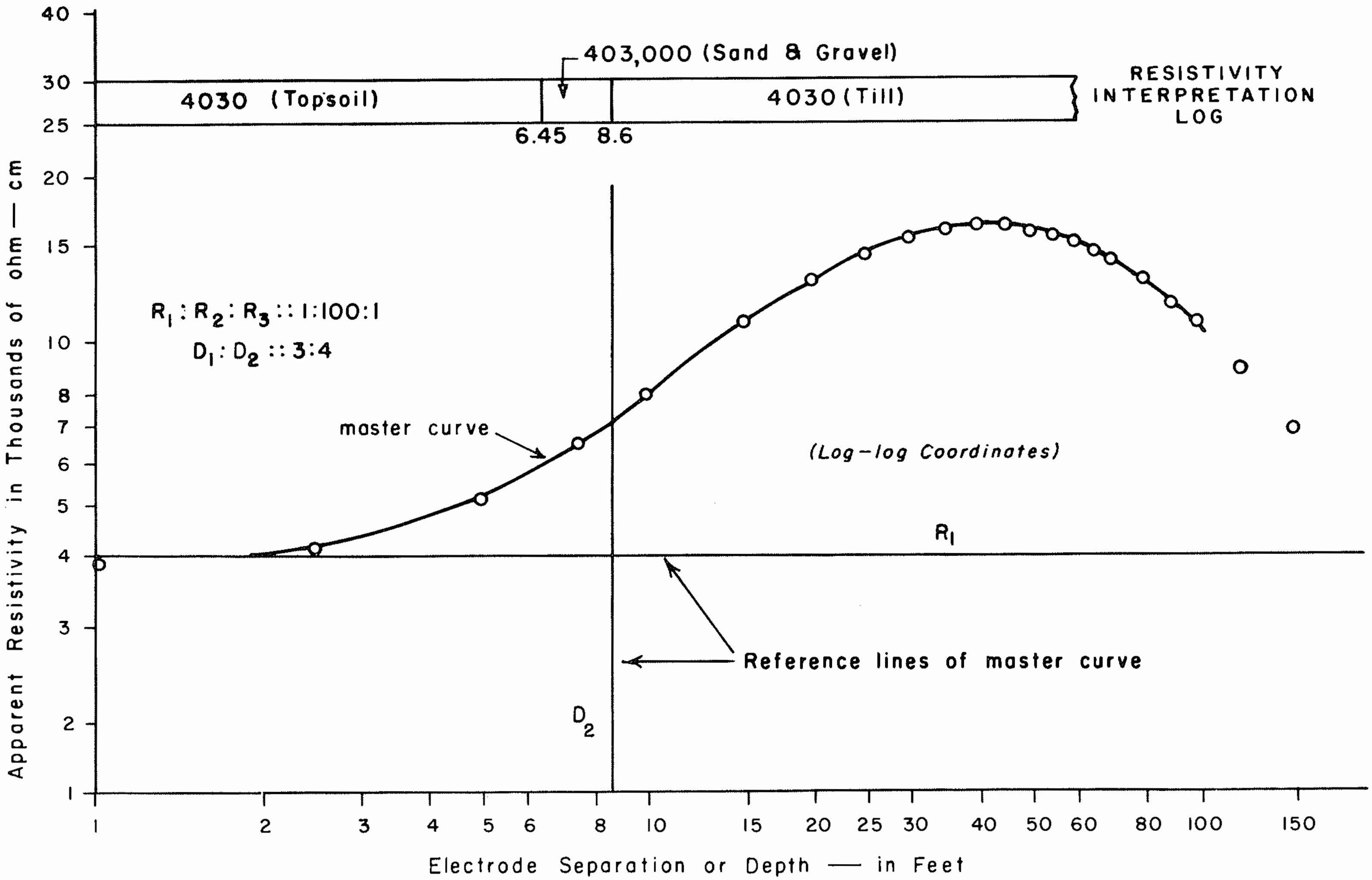


Figure 29. Mooney — Wetzel master curve matched to hypothetical outwash curve.

However, it should not be concluded that the master curve interpretations are of little value. Although an interpreter may find that the master curves can be used for interpretations only on occasion, the experience gained from using them gives him a feel for the behavior of the resistivity curves under various conditions. This is an invaluable knowledge that can be used in any method of interpretation.

Recommendations and Conclusions

Upon completion of a preliminary materials map using all available techniques, and after a thorough field check of this map, the resistivity method can be applied to outline the best area for development and to estimate reserves with a minimum of exploratory drilling.

Because glacial material is highly variable over short distances, it is necessary to establish control stations before the start of a survey. These stations will yield a standard set of resistivities which may be expected in the area. These stations can also be used to check the calibration of the instrument in the field.

The Werner electrode configuration should be used in conjunction with the Lee Partition method, since they have proven to be the most versatile of those evaluated. Measurements should not be taken unless necessary near buried pipelines, fences with steel posts and other conductors since these conductors may adversely affect the readings.

Of the numerous methods of field curve interpretation, four were found to give the best results. These are: (1) observation of field curve shape, (2) direct linear interpretation, (3) Moore's cumulative method, and (4) Mooney-Wetzel master curves. It has been pointed out that all methods do not yield contacts or solutions under some field conditions.

The resistivity operator must have a good background in the physical sciences with emphasis on physics and geology to fully utilize this method of exploration.

EVALUATION OF THE SEISMIC METHOD

Refraction seismic surveys are based on the theory that sound (shock) waves travel with greater velocity in dense material and with less velocity in less dense material. When shock waves travel from a less dense material into a more dense material they are refracted and this refraction can be picked up by sensitive sound detectors (geophones) at the earth's surface. By simple calculations considering the time of wave travel, the velocities of each material can be obtained and then the thickness and depth of each layer.

Observation of seismic devices in the field and literature research showed that the information recorded by these devices is valuable when less dense (gravel) materials overlie dense material (till). If the converse is true, however, this method has little value since the shock waves will be diffused downward into the less dense material.

If a very dense overburden of some thickness overlies an aggregate source, the aggregate is not likely to be recorded on the seismic instrument.

New shallow seismic devices have been developed that use a hammer blow on a steel plate instead of a powder charge to propagate the shock waves. There is no doubt that these instruments are effective in areas of shallow bedrock. They are, however, not of great use in glacial areas where many layers of varying velocities are encountered.

It was found that resistivity measurements were more accurate, easier to accumulate, and easier to calculate. It is believed that seismic instruments would be of great use in western South Dakota where aggregate if it exists would rest directly on bedrock.

SUMMARY AND CONCLUSIONS

The primary purpose of this study is to evaluate methods to be used in the location of potential aggregate sources in eastern South Dakota and to recommend a procedure to follow in the exploration for these sources. Geophysical and drilling techniques were evaluated in an attempt to devise a rapid field check of potential sources.

This study has shown that proper use of the various methods of exploration can eliminate a great percentage of the time usually spent in the field, thus releasing personnel to other projects. Field work, however, is a necessary and important part of all aggregate investigations, and these methods, if used properly, can only reduce field work to a minimum.

A complete set of all geologic, pedologic and topographic literature and maps available for eastern South Dakota should be on permanent file in the Highway Department and should be available for instant reference.

Complete air photo coverage of South Dakota should be purchased before any long range aggregate investigation is attempted. Air photos should be ordered as soon as possible, for delivery of these items is usually slow. Two scales of photos are ideal for aggregate exploration, one small scale to determine trends and areas for detailed study, and one large scale to delineate detailed areas. When this material is available a full-scale investigation can be started.

The first step in any investigation is an exhaustive review of the literature. This includes a review of all geological and pedological maps and reports, topographic maps, and existing geophysical and drill hole data. Special attention should be paid to the areas of sand and gravel mentioned in the reports and shown on the maps.

In this preliminary phase of the investigation air photo indexes should be studied for regional trends. The air photos of the particular area under study should be "pulled" from the files.

The second phase of the investigation consists of a detailed study of all geologic, soils, and topographic maps. A preliminary materials map as interpreted from geologic and soils maps should now be constructed. Landforms which can be recognized should be outlined on the topographic maps.

Combining all of these maps yields a materials location map.

The air photos of the area are now rapidly scanned and areas which show potential aggregate sources are noted. When all photos have been examined those on which probable sources are located are studied in detail, paying special interest to the six basic pattern elements. The areas shown on the "Materials Location Map" are carefully checked and noted on the photographs. The location of all existing pits in the area is plotted on the photos.

The investigator now plans a field trip, selecting particular areas he wishes to visit. Detailed field mapping of the potential areas follows with measurements of depth and extent of the deposits being taken with the resistivity instrument.

After the deposits are mapped in detail on the air photos and preliminary samples have been taken, the investigator can return to the office to write a report and to mark the areas permanently on the photos or some predetermined base map.

An outline of this procedure follows:

I. Purchasing of Equipment

A. Maps and reports: geologic, pedologic, topographic

B. Air photo indexes

C. Air photos: two scales

II. Review of Literature

A. Geologic reports and maps

B. Soils reports and maps

C. Topographic maps

D. Geophysical and drill hole data

E. Air photo indexes

III. Detailed Study

A. Prepare a materials map as interpreted from available geologic maps

B. Delineate landforms on topographic maps

C. Prepare a materials map as interpreted from available soils maps

IV. Prepare detailed materials map using all information

V. Preliminary and detailed study of air photos

VI. Field Study

A. Detailed study of selected areas

B. Preliminary samples taken

C. Deposit outlined with resistivity

VII. Detailed outlining of photos, preparation of report, and preparation of finished map

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APPENDIX A

Glossary of Geologic, Pedologic and Engineering Terms

Abscissa: The horizontal or "x" axis.

Aggregate: Material such as sand, gravel, and broken stone with which cement or bituminous material is mixed to form a mortar or concrete.

Alluvium: Gravel, sand, silt, or clay deposited on land by streams.

Apparent Resistivity: The measured resistivity of a deposit, where the beds above the deposit contribute to the resistivity reading and mask the true resistivity of the deposit.

Bedrock: Any solid rock in place, exposed at the surface of the earth or overlain by unconsolidated material.

Boulder: Rounded fragments of rock which will be retained on a 3-inch sieve.

Catsteps: Narrow, backward-tilting terraces on steep hillsides, produced by slumping.

Clay (minus No. 200 material): Material smaller than 0.005 mm.

Coarse Aggregate: Aggregate which will not pass a $\frac{1}{4}$-inch screen.

Commutator: A rotating electrical device which is used to change a direct current (one with a constant magnitude in one direction) to an alternating current (one that periodically reverses in direction).

Conductance: A measure of the ability of a material to pass electrical current.

Depth-probing: A procedure for taking resistivity measurements where the data obtained indicate the composition and depth below the surface of the various subsurface layers of earth.

Dip: The angle at which a rock layer is inclined from the horizontal.

Electrode: A steel or copper stake used in resistivity surveys to make electrical contact with the earth.

Field Curve: A plot of apparent resistivity versus electrode separation from the resistivity readings taken in the field. The plot may be made on either rectangular or on log-log coordinate paper.

Filter: An arrangement of electrical components that allows current of certain frequencies to pass, but will not pass currents of other frequencies.

Fine Aggregate: Aggregate which will pass the $\frac{1}{4}$-inch screen.

Granite: A coarse-grained igneous rock consisting chiefly of the minerals quartz and feldspar.

Gravel: Rounded particles of rock which will pass a 3-inch sieve and be retained on a No. 10 sieve.

Ground Water: Used in this report to mean that part of subsurface water found beneath the water table.

Inflection Point: A point on a curve where two curve segments (each having a different radius of curvature) meet or cross.

Ion: In any solution an atom or group of atoms with an electric charge.

Landform: The topographic expression of the land, as indicated by surface features such as relief, slope, shape, and arrangement.

Lithology: The composition and texture of a rock.

Negative Slope: The slope of a curve in the first quadrant of a graph from upper left to lower right.

Ohm-centimeters: The units of resistivity.

Ordinate: The vertical or "y" axis.

Overburden: Consolidated or unconsolidated rock that overlies a useful deposit.

Permeability: Ability of a rock to transmit a fluid under pressure.

Photogrammetry: The science of obtaining reliable measurements from photographs.

Physiography: The study of the surface of the earth.

Porosity: The ratio of the sum of the volumes of interstices in a rock or soil to its total volume.

Positive Slope: The slope of a curve in the first quadrant of a graph from upper right to lower left.

Potential: The voltage measured relative to an arbitrary zero reference.

Quartzite (Sedimentary): A sandstone consisting of over 95 percent quartz and cemented by silica.

Resistance: The ability of a rock to resist the flow of an electrical current.

Sand: Granular material resulting from the disintegration, grinding or crushing of rock, and which will pass the No. 10 sieve and be retained on the No. 200 sieve.

Sediment: Solid material that has been moved from its origin by air, water, or ice and has come to rest on the earth's surface.

Short Ton: A unit of weight: 2,000 lbs.

Silt (minus No. 200 material): Material passing the No. 200 sieve and larger than 0.005 mm.

Soil Complex: An association of soils that are mapped as a single unit.

Soil Genesis: Mode or origin of the soil.

Soil Morphology: The physical constitution of the soil.

Soil Phase: That part of a soil type having minor variations in characteristics from the normal for the type.

Soil Series: A group of soils developed from the same parent material and having similar soil horizons.

Soil Type: A subdivision of soil series based on texture of the surface soil.

Stereoscopy: The science of viewing in three dimensions, usually with the aid of a stereoscope.

Stratified: Formed or lying in beds, layers, or strata.

Terrace: Relatively flat surfaces bounded by a steep ascending slope on one side and by a steeper descending slope on the opposite side, found in valleys. Formerly a flood plain.

Time Rock Unit: Term applied to rock units with boundaries based on geologic time.

Topography: The relief and shape of the land surface.

Traversing: A procedure for taking resistivity measurements where the data obtained are used to determine approximate surface boundaries between deposits having contrasting resistivities.

True Resistivity: The value of resistivity that would be obtained if a sample of a deposit could be isolated and its resistivity measured.

Vibrator: An electromechanical device used to change a direct current to an alternating current.

Worm-eaten: A drainage characteristic which, when viewed on air photos, appears as a mottling of blacks and white. Indicates granular soils.