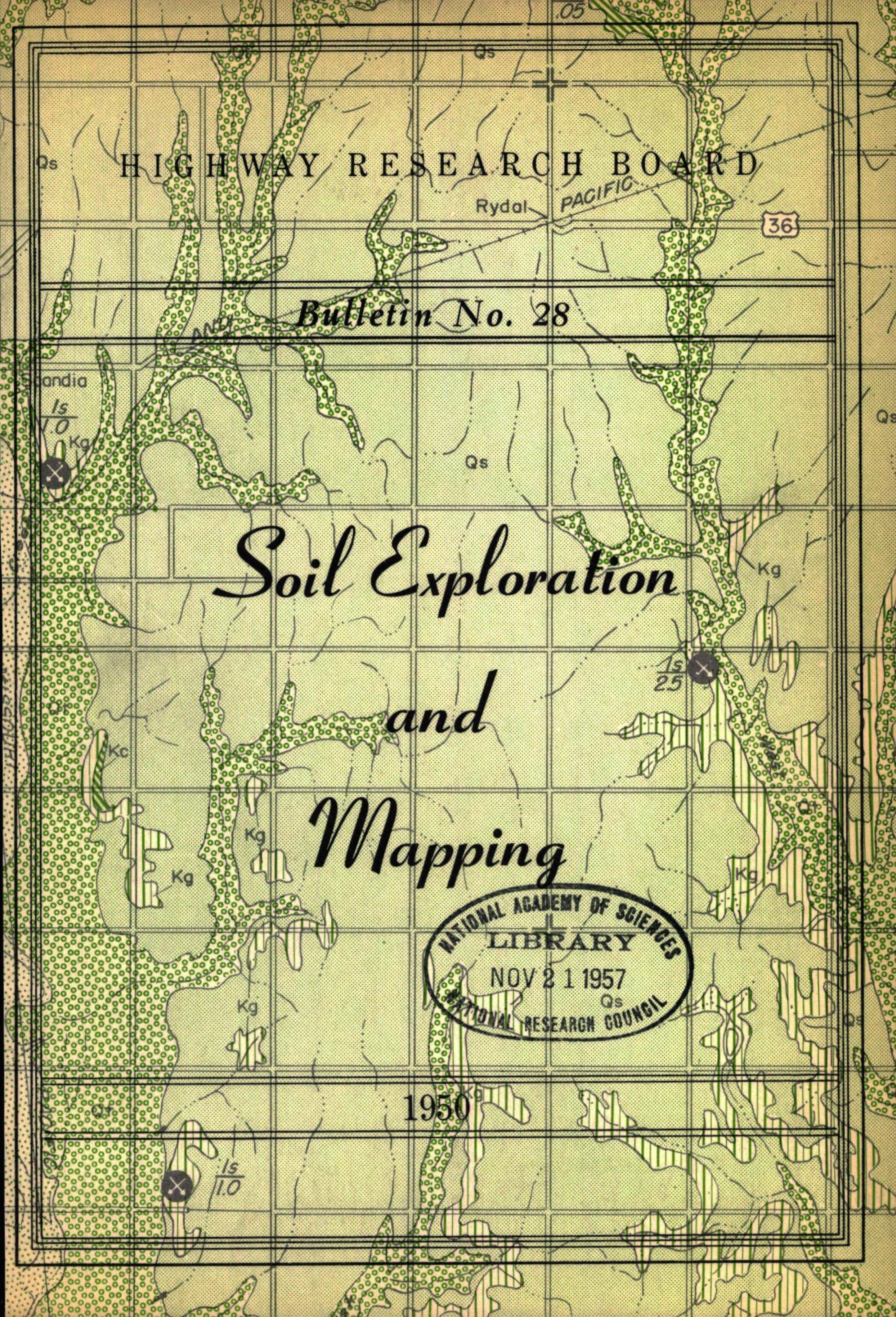

HIGHWAY RESEARCH BOARD

Bulletin No. 28

Soil Exploration and Mapping

1950

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1950

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HIGHWAY RESEARCH BOARD

Bulletin No. 28

SOIL EXPLORATION AND MAPPING

PRESENTED AT THE TWENTY-NINTH ANNUAL MEETING
1949

HIGHWAY RESEARCH BOARD
DIVISION OF ENGINEERING AND INDUSTRIAL RESEARCH
NATIONAL RESEARCH COUNCIL

Washington 25, D. C. November 1950

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CONTENTS

INTRODUCTION

Frank R. Olmstead, Chairman
Soils Engineer
Bureau of Public Roads

The information presented in this Bulletin is closely related to the engineering survey data reported in the two previous Bulletins - No. 13, "The Appraisal of Terrain Conditions for Highway Engineering Purposes", and No. 22, "Engineering Use of Agricultural Soil Maps" sponsored by the Committee.

The importance of agricultural soil maps was emphasized in Bulletin No. 22, and since it was well received by the highway engineer, it was decided that other types of useful mapping should be made available to the engineer.

This Bulletin contains information regarding the status of both geological and agricultural soil mapping in the United States. In addition, a number of geologists and soil scientists who may be able to furnish detailed information in respective parts of the United States are included to make this map information more complete.

The status of topographic mapping and airphoto coverage was presented in Bulletin No. 13 and when additional information becomes available, it is planned to issue supplemental circulars to indicate the status of new mapping.

The Committee wishes to again call the engineer's attention to the need for making use of available terrain information for planning purposes. Considerable progress can be made in engineering planning if soil information - soil test data, design recommendations, construction and maintenance experience, and pavement behavior - is correlated with one or more of the in-place systems of terrain classification developed by the geologist and soil scientist.

It is anticipated that greater emphasis will be placed upon engineering correlations because the engineer can no longer be confined to the consideration of local engineering soil problems. In the space of a few years he may be involved in construction work in widely scattered parts of the world, particularly if technical experience and know-how in road-building is accelerated in the undeveloped countries.

The engineer working in these areas must make terrain appraisals for road-building purposes, and it would appear that this could be more easily done if the pertinent engineering data found in this country were correlated with significant terrain characteristics.

Engineers in widely scattered parts of this country have found that the physical properties of soil alone will not suffice for the correlation of engineering problems. However, when both physical and environmental factors related to terrain conditions were considered, they have developed reasonable correlations.

Such a program of correlation of engineering information with terrain conditions must be readily understood by the engineer. It would be desirable if such a system interrelated the more significant factors considered in the systems of terrain classification used by the geologist and the pedologist in their mapping programs because it would make these sources of knowledge more useful to the engineer.

The airphoto system of map-unit classification reported in this Bulletin with perhaps some refinement or modification may be the logical approach to the development of a terrain classification that can be understood by the engineer. It is based on a grouping of parent material, drainage, and significant soil profile variations by means of symbols and the grouping of soil characteristics using numbers corresponding to the Highway Research Board soil group classification of the predominate soils occurring within the map-units.

The papers presented in this Bulletin indicate how the engineer can obtain some of this engineering information by the use of airphotos, material inventories, and geophysical methods of subsurface exploration.

Attention is called to the method for the preparation of State-wide drainage maps from airphotos. This method should serve as a practical means of evaluating the importance of drainage in highway location or bridge design. The relation observed between detailed drainage patterns and soil or bedrock types appears significant. If this relationship is characteristic for other types of terrain, it would appear that significant detailed drainage patterns may be made a useful criterian for the appraisal of soil conditions from topographic maps.

The paper on material inventories reported in this Bulletin should be of interest to engineers who may be considering a State-wide study of local road-building materials. Several States have completed such inventories and have found them useful for planning purposes. The rapid depletion of known aggregate sources in some States has accelerated interest in methods of finding and recording the location of new sources of construction materials. For this reason more emphasis has been placed on the engineering use of airphotos, county soil maps and geological maps. The use of these sources of information with supplemental detailed field reconnaissance has been found necessary for covering large areas such as a State. In connection with the field reconnaissance the use of geophysical methods similar to those described in this Bulletin is an effective means of accelerating site exploration because the number of test pits can be substantially reduced without sacrificing the accuracy of the field study.

Airphoto interpretation for determining the character and distribution of soils has been used rather extensively by engineers in recent years. The early work was confined to the study of glacial terrain; later it was expanded to the study of residual areas in various parts of this country. In recent years, considerable work has been done in Alaska. The paper on permafrost reported in this Bulletin points out the importance of considering topographic position in areas subject to permanently frozen soils occurring in their native environment.

The location of permafrost areas is a major consideration in highway and airport construction because the subsequent thawing of those soils after the environmental conditions have been altered by construction results in excessive maintenance or reconstruction expenditures. It is reasonable, therefore, to expect that greater use will be made for location purposes of airphoto interpretation in regions subject to permanently frozen soils.

The Committee is interested in receiving suggestions from the practicing engineer regarding new developments in soil surveying and mapping. It is only through this medium that new ideas and factual information can be obtained which will be of interest to other engineers.

THE STATUS OF GEOLOGIC MAPPING IN THE UNITED STATES

The engineer responsible for the design and construction of large structures such as dams, tunnels, bridges and buildings usually requires a detailed geologic study of the proposed construction site before starting the preparation of plans.

On the other hand, the role of the geologist in highway engineering usually has been confined to the study of major landslides, the location of sand and gravel or rock deposits and the investigation of highway locations which are likely to require deep cuts extending through the surficial mantel of soil into the bedrock.

There is considerable useful engineering information obtainable from the interpretation of geologic maps. Soils are related to the type of parent material from which they are derived. When the influence of climate and relief are considered the engineer can make reasonable predictions on the type of soils that will be associated with the different parent materials indicated by geologic maps.

In areas where the terrain is not economically suitable for agricultural use we have only limited information on soils. These areas usually are associated with regions of arid to semi-arid climate and the residual soils are apt to be thin in the areas where extensive cuts and fills are required to maintain suitable highway alignments. Under those design conditions the engineer will find that the interpretative information obtained from geologic maps will be useful for highway location and for planning the necessary engineering survey work.

In most instances, due to map scale limitations, all types of maps must be generalized to some degree. The engineer must recognize the limitations of maps. It is suggested that he consult the geologist to determine the accuracy of the particular types of maps available for the area in which he plans to do road work.

In many instances geologic maps used in conjunction with airphotos will enable the engineer to determine details omitted during the preparation of the geologic maps. Consequently, it is often possible by proper interpretation to minimize the amount of ground reconnaissance required for making engineering estimates of terrain conditions from available maps.

The following information presented on the status of geological mapping in the United States was furnished by the US Geological Survey at the request of the Committee. The Committee felt that this information should be made available to the engineer so that it could be used in highway planning work.

GEOLOGICAL INDEX MAP OF THE UNITED STATES

The index map of the United States, (Fig. 1) prepared in the US Geological Survey, shows in a general way the areas in the continental United States that have been covered by geologic maps on different scales. The areas that have the largest scale maps are shown in black. The geologic maps for much of the area shown in light gray are State geologic maps approximately 8 mi. to the in. Some of these maps were published by the US Geological Survey and others by State Geological Surveys or societies. The areas shown in white had no published geologic maps on a scale as large as 8 mi. to the in. at the time the illustration was prepared (May 1948). A geologic map of the entire country, scale about 40 mi. to the in., was published by the US Geological Survey in 1933 and may be obtained from that organization for $2. 50.

More detailed information about published geologic maps for individual States is given in a series of geologic map indexes obtainable from the US Geological Survey. Each published geologic map is outlined on a State base map; an explanatory key gives the source and date of publication, author, and scale. Publication of these geologic map indexes began in July 1947 and 23 are now available. The scale of most of the indexes is 1: 750,000, or about 12 mi. to the in. A few were published on a scale of 1: 1,000,000, or about 16 mi. to the in. Outline patterns that show the areas covered by geologic maps are printed in 4 colors to indicate approximate scales of the maps. The geologic map indexes that are now available may be obtained as indicated below.

Obtainable from Director, US Geological Survey, Washington 25, D. C., for the prices indicated:

Maine	$. 25	West Virginia	. 25
Ohio	. 25	Mississippi	. 25
Georgia	. 35	North Carolina	. 50
Tennessee	. 40	South Carolina	. 25

Obtainable from Map Distribution Office, US Geological Survey, Denver Federal Center, Denver, Colorado, for the prices indicated:

Colorado	$. 70	North Dakota	. 40
Idaho	. 25	Oregon	. 25
Iowa	. 35	South Dakota	. 30
Kansas	. 30	Utah	. 25
Missouri	. 30	Washington	. 35
Montana	. 35	Wyoming	. 50
Nebraska	. 35	New Mexico	. 70
Nevada	. 30		

Information as to geologic-map coverage of specific areas can be obtained by writing to the Director, US Geological Survey, Washington 25, D. C. Most of the States have geological surveys or similar State agencies that can supply information on availability of geologic maps and work in progress within their States. The locations of their offices are listed in Table 1. Massachusetts does not have a State survey but information on the geology of that State can be furnished by the US Geological Survey Office, room 513, at 100 Nashua Street, Boston 14, Massachusetts.

FIGURE 1. AREAS OF PUBLISHED GEOLOGIC MAPS ON DIFFERENT SCALES
REDUCED FROM ORIGINAL MAP BY LEONA BOARDMAN MAY 1948
DEPARTMENT OF INTERIOR, US GEOLOGICAL SURVEY

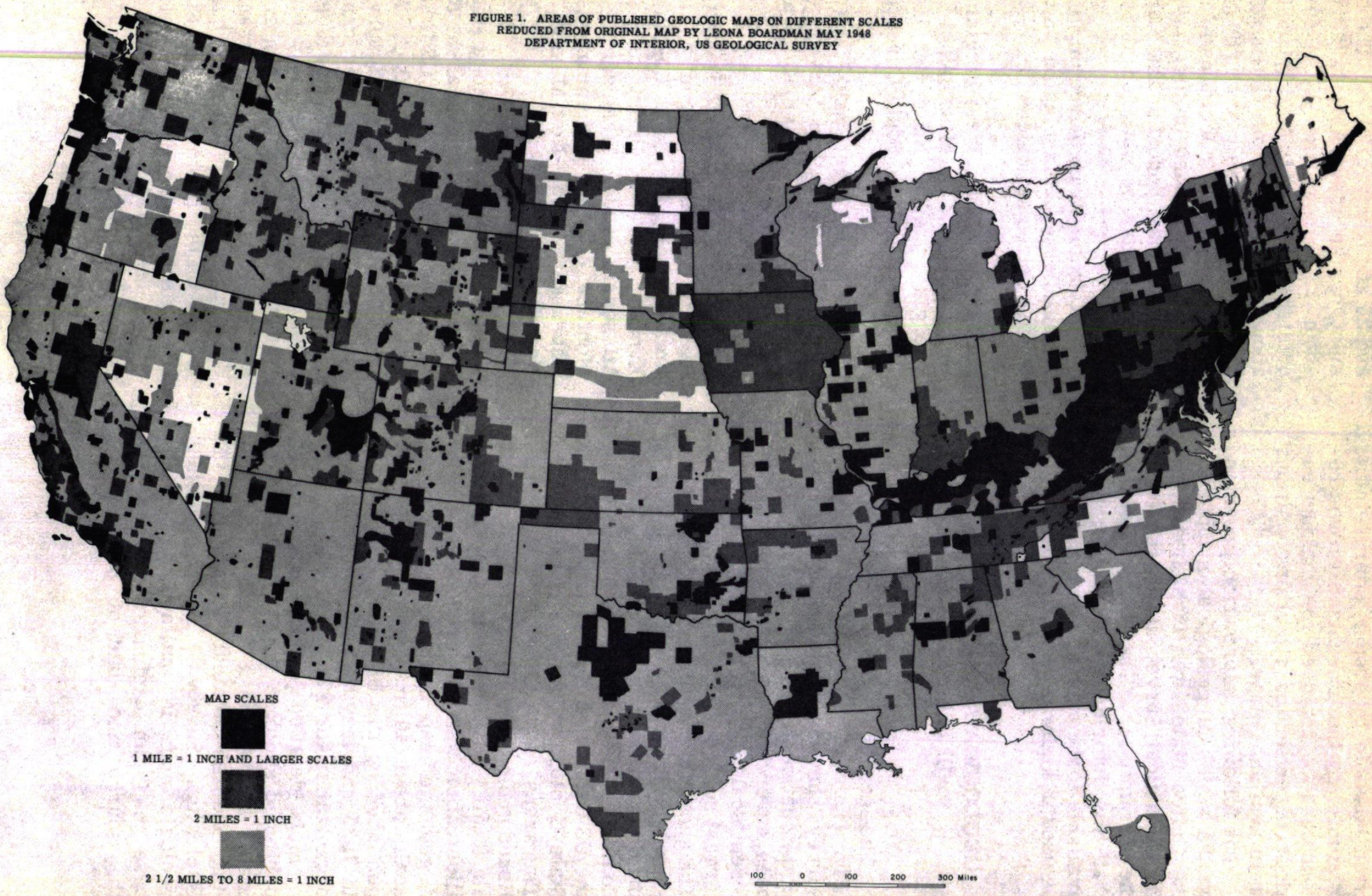

TABLE 1

TABULATION OF STATE GEOLOGISTS BY STATES

State	State Geologist and Address
Alabama	Dr. Walter B. Jones, State Geologist, Geological Survey of Alabama, University
Arizona	Dr. T. G. Chapman, Director, Arizona Bureau of Mines, University of Arizona, Tucson
Arkansas	Mr. Harold B. Foxhall, Director, Division of Geology, Arkansas Resources and Development Commission, State Capitol, Little Rock
California	Dr. Olaf P. Jenkins, Chief, Division of Mines, Department of Natural Resources, Ferry Building, San Francisco 11
Colorado	Mr. Fred Jones, Vice Chairman, Colorado Geological Survey, State Museum Building, Denver
Connecticut	Dr. Edward L. Troxell, Director, Connecticut Geological and Natural History Survey, Trinity College, Hartford 6
Florida	Dr. Herman Gunter, Director, Florida Geological Survey, P.O. Drawer 631, Tallahassee
Georgia	Capt. Garland Peyton, Director, Department of Mines, Mining and Geology, State Division of Conservation, 425 State Capitol, Atlanta
Idaho	Mr. A. W. Fahrenwald, Director, Idaho Bureau of Mines and Geology University of Idaho, Moscow
Illinois	Dr. M. M. Leighton, Chief, State Geological Survey Division, 100 Natural Resources Building, University of Illinois Campus, Urbana
Indiana	Dr. Charles F. Deiss, Chairman and State Geologist, Division of Geology, Indiana Department of Conservation, Indiana University Bloomington
Iowa	Dr. H. Garland Hershey, Director and State Geologist, Iowa Geological Survey, Iowa City
Kansas	Dr. John C. Frye, Executive Director, State Geological Survey, The University of Kansas, Lawrence
	Dr. Raymond C. Moore, State Geologist and Director of Research, State Geological Survey, The University of Kansas, Lawrence
Kentucky	Mr. Daniel J. Jones, State Geologist, Department of Geology, Kentucky Geological Survey, University of Kentucky, Lexington
Louisiana	Mr. Leo W. Hough, State Geologist, Louisiana Geological Survey, Department of Conservation, Geology Building, University Station, Baton Rouge 3
Maine	Dr. Joseph M. Trefethen, State Geologist, Maine Geological Survey, University of Maine, Orono
Maryland	Dr. Joseph T. Singewald, Jr., Director, Department of Geology, Mines and Water Resources, Board of Natural Resources, Baltimore 18

TABLE 1 (continued)

TABULATION OF STATE GEOLOGISTS BY STATES

State	State Geologist and Address
Michigan	Mr. G. E. Eddy, State Geologist, Geological Survey Division, Department of Conservation, Lansing 13
Minnesota	Dr. G. M. Schwartz, Director, Minnesota Geological Survey, University of Minnesota, Minneapolis 14
Mississippi	Dr. W. C. Morse, Director, Mississippi Geological Survey, University
Missouri	Dr. Edward L. Clark, State Geologist, Division of Geological Survey and Water Resources, Department of Business and Administration, Buehler Building, Rolla
Nebraska	Dr. G. E. Condra, State Geologist, Conservation and Survey Division, The University of Nebraska, Lincoln 8
Montana	Dr. Francis A. Thomson, Director, State Bureau of Mines and Geology, Butte
Nevada	Mr. Jay A. Carpenter, Director, Bureau of Mines, Box C, University Station, Mackay School of Mines, Reno
New Hampshire	Mr. T. R. Meyers, Geologist, New Hampshire State Planning and Development Commission, Conant Hall, University of New Hampshire, Durham
New Jersey	Mr. Meredith E. Johnson, State Geologist, Geologic and Topographic Survey, Department of Conservation and Economic Development, Room 415 State House Annex, Trenton 7
New Mexico	Dr. Eugene Callaghan, Director, New Mexico Bureau of Mines and Mineral Resources, Socorro
New York	Dr. John G. Broughton, State Geologist, State Geological and Natural History Surveys, State Education Building, University of the State of New York, Albany 1
North Carolina	Dr. Jasper L. Stuckey, State Geologist, Division of Mineral Resources, Department of Conservation and Development, Raleigh
North Dakota	Dr. Wilson M. Laird, State Geologist, North Dakota Geological Survey, University of North Dakota, Grand Forks
Ohio	Mr. John H. Melvin, State Geologist, Geological Survey of Ohio, Orton Hall, Ohio State University, Columbus 10
Oklahoma	Mr. Robert H. Dott, Director, Oklahoma Geological Survey, Norman
Oregon	Mr. F. W. Libbey, Director, State Department of Geology and Mineral Industries, 702 Woodlark Building, Portland 5
Pennsylvania	Mr. S. H. Cathcart, Director, Bureau of Topographic and Geologic Survey, Department of Internal Affairs, Harrisburg
Rhode Island	Dr. Alonzo W. Quinn, Chairman, Mineral Resources Committee, Rhode Island Port and Industrial Development Commission, Providence 3
South Carolina	Dr. Laurence L. Smith, State Geologist, Department of Geology, Mineralogy and Geography, University of South Carolina, Columbia

TABLE 1 (continued)

TABULATION OF STATE GEOLOGISTS BY STATES

State	State Geologist and Address
South Dakota	Dr. E. P. Rothrock, State Geologist, State Geological Survey, State University, Lock Drawer 351, Vermilion
Tennessee	Mr. H. B. Burwell, State Geologist, Division of Geology, Department of Conservation, G-5 State Office Building, Nashville 3
Texas	Dr. John T. Lonsdale, Director, Bureau of Economic Geology, The University of Texas, University Station, Box B, Austin 12
Utah	Mr. Arthur L. Crawford, Director, Utah Geological and Mineralogical Survey, College of Mines and Mineral Industries, University of Utah, Salt Lake City 2
Vermont	Mr. Charles G. Doll, State Geologist, State of Vermont Development Commission, East Hall, University of Vermont, Burlington
Virginia	Mr. William M. McGill, State Geologist, Virginia Geological Survey, Box 1428, University Station, Charlottesville
Washington	Mr. Sheldon L. Glover, Supervisor, Division of Mines and Geology, Department of Conservation and Development, Room 404, Transportation Building, Olympia
West Virginia	Dr. Paul H. Price, State Geologist, West Virginia Geological and Economic Survey, P.O. Box 879, Morgantown
Wisconsin	Mr. E. F. Bean, State Geologist, Geological and Natural History Survey, Science Hall, The University of Wisconsin, Madison
Wyoming	Dr. H. D. Thomas, State Geologist, The Geological Survey of Wyoming, University of Wyoming, Laramie

DIVISION OF SOIL SURVEY - BUREAU OF PLANT INDUSTRY USDA

The status of agricultural soil mapping in the United States was presented in Highway Research Bulletin No. 22, "Engineering Use of Agricultural Soil Maps". Since this survey was completed additional areas have been mapped and field work has been initiated in other areas. The following tabulations were prepared by the Committee from information furnished by the Division of Soil Survey, Bureau of Plant Industry, USDA.

The counties or soil areas in which soil surveys are in progress or have been completed are tabulated in Table No. 2. These areas are listed by States and where field work is in progress the party chief and soil correlator has been included for ready reference purposes.

The address of the soil correlator is given in Table No. 3 and it is suggested that these men should be consulted regarding specific details of mapping in these areas. In many cases they may be able to furnish the engineers with ozalid copies of their field work that has been completed in the areas. They also are likely to have useful information regarding the soil profile descriptions of the map-units used to delineate the soils in the area mapped. They can point out the soil map-units which are most likely to contain sources of granular material for road building purposes and at the same time assist the engineer in obtaining a better understanding of their system of soil classification.

Since Highway Research Board Bulletin No. 22 was published, a number of county soil maps listed as in progress have been published. The new publications are listed in Table No. 4. It is recommended that this information, together with the information in Table No. 1, be used to revise your copy of Highway Research Board Bulletin No. 22.

The Committee will issue supplemental information circulars at intervals to call the engineer's attention to new soil maps completed or to areas in which soil mapping is in progress.

TABLE 2

SOIL SURVEYS IN PROGRESS OR COMPLETED IN PRESENT FISCAL YEAR
DIVISION OF SOIL SURVEY, BUREAU OF PLANT INDUSTRY, USDA

State	County or Soil Area	Party Chief	Soil Correlator[a]
Alabama	De Kalb County[1]	G. A. Swenson[b]	M. J. Edwards
	Lawrence County[2]	- -	- -
California	Madera County	L. K. Stromberg[S]	R. A. Gardner
	Merced County	- -	- -
Colorado	Delta-Montrose Area[1]	E. W. Knobel	W. G. Harper
Connecticut	Hartford County[1]	A. E. Shearin	W. B. Lyford[b]
Florida	Escambia County[1]	J. H. Walker[S]	Hasty or Martin
	Hillsborough Co.[2]	- -	- -
	Sarasota County[1]	R. G. Leighty[b]	I. L. Martin
Georgia	Fulton County[2]	- -	- -
Idaho	Canyon County[1]	M. S. Fosberg[S]	W. J. Leighty
Illinois	Lawrence County[1]	J. B. Fehrenbacher[S]	W. D. Shrader
	Menard County[2]	- -	- -
	Will County[1]	P. T. Veale[S]	W. D. Shrader
Indiana	Fayette County[1]	S. D. Alfred[S]	O. C. Rogers
	Parke County[2]	- -	- -
Iowa	Monona County[1]	J. E. McClelland[b]	W. D. Shrader
	Shelby County[1]	J. E. McClelland[b]	W. D. Shrader
Kansas	Saline County[2]	- -	- -
	Webster Unit (Part Osborne Co.)[1]	C. H. Atkinson[b]	W. H. Johnson
	Republic Co. (All Scandia Unit)[1]	C. H. Atkinson[b]	W. H. Johnson
Louisiana	St. Mary Parish[1]	S. A. Lytle[b]	Hasty or Martin
Michigan	Keweenaw County[1]	W. H. Colburn[S]	I. J. Nygard
	Mackinac County[1]	W. H. Colburn[S]	I. J. Nygard
	Montcalm County[2]	- -	- -
	Ontonogan County[3]	- -	- -
	Sanilac County[1]	I. F. Schneider[S]	O. C. Rogers
Minnesota	Brown County[3]	- -	- -
	Fillmore County[2]	- -	- -
	Mower County[1]	H. F. Arneman[S]	I. J. Nygard
Mississippi	Bolivar County[1]	C. C. Morgan[S]	Hasty or Martin
	Coahoma County[2]	- -	- -
	DeSota County[1]	C. C. Morgan[S]	I. L. Martin
	Sunflower County[1]	C. C. Morgan[S]	Hasty or Martin
Missouri	Boone County[1]	C. L. Scrivner[S]	W. D. Shrader
	Moniteau County[1]	J. A. Frieze[S]	I. L. Martin
Montana	Bitterroot Valley Area[1]	W. C. Bourne[b]	H. H. Williams
	Roosevelt Co. (Part Mo-Souris Proj.[1])	A. J. Cline	H. H. Williams
Nebraska	Buffalo Co. (Part Wood River Proj.[1])	J. A. Elder[b]	H. H. Williams
	Hall Co. (Part Wood River Proj.[1])	D. A. Yost	H. H. Williams
	Saunders County[1]	T. E. Beesley	H. H. Williams

TABLE 2 (continued)

SOIL SURVEYS IN PROGRESS OR COMPLETED IN PRESENT FISCAL YEAR
DIVISION OF SOIL SURVEY, BUREAU OF PLANT INDUSTRY, USDA

State	County or Soil Area	Party Chief	Soil Correlator[a]
New Hampshire	Rockingham County[1]	Roeslion Feuer[S]	Lyford[b]
New York	Franklin County[1]	M. E. Austin[b]	Cline or Lyford[b]
	Lewis County[1]	C. S. Pearson[S]	M. C. Cline[b]
North Carolina	Duplin County[1]	E. F. Goldston[S]	Hasty or Lee
	Pasquotank County[2]	- -	- -
North Dakota	Renville Co. (Part Mo-Souris Proj.[1])	B. L. Matzek[b]	C. A. Mogen
Ohio	Clark County[2]	- -	- -
	Fairfield County[1]	J. E. Petro[b]	O. C. Rogers
Oklahoma	Creek County[2]	- -	- -
	Pawnee County[1]	H. M. Galloway[b]	Harvev Oakes
Oregon	Douglas County[1]	A. C. Anderson	R. C. Roberts
Pennsylvania	Potter County[1]	K. V. Goodman	W. R. Lyford[b]
South Dakota	Brooking County[1]	F. C. Weston[S]	C. A. Mogen
	Hand Co. (Part Mo-Oahe Proj.[1])	A. J. Klingelhoots[b]	C. A. Mogen
	Spink Co. (Part Mo-Oahe Proj.[1])	F. C. Weston[S]	C. A. Mogen
Tennessee	Blount County[1]	Joe Elder[S]	L. R. Odem
	Bradley County[1]	R. L. Flowers[S]	L. R. Odem
	Franklin County[2]	- -	- -
	Houston County[2]	- -	- -
	Lawrence County[1]	J. R. Overton[S]	L. R. Odem
	Marion County[2]	- -	- -
	Maury County[1]	A. B. Harmon[S]	L. R. Odem
Texas	Brazos County[1]	I. C. Mowery[b]	H. H. Templin[b]
Utah	Weber Area[1] (contains potential irrigable lands in Weber, Davis, Morgan, Summit Cos., and S.E. Cor. Boxelder Co.)	V. K. Hugie	W. G. Harper
	Beryl-Enterprise Area[1]	G. H. Schafer	W. G. Harper
Virginia	Louden County[1]	H. C. Porter[S]	Ligon or Obenshain[b]
	Norfolk County[1]	E. F. Henery[S]	Edwards or Obenshain[b]
	Nottoway County[2]	- -	- -
	Prince Edward County[2]	- -	- -
Washington	Island County[2]	- -	- -
	Mason County[1]	R. H. Fowler[S]	R. C. Roberts
	Skagit County[1]	A. O. Ness	R. C. Roberts
Wisconsin	Grant County[1]	C. H. Robinson	I. J. Nygard
	Richland County[2]	- -	- -
Wyoming	Goshen County[1]	C. J. Fox	Thorp or Johnson

[a]See Table 3 for address of soil correlator.

[b]State and Bureau

[S]State

[1]Soil Survey assignments for summer of 1950

[2]Soil survey in progress of publication

[3]Reconnaissance map in progress of publication

TABLE 3

SOIL CORRELATORS - DIVISION OF SOIL SURVEY

J. Kenneth Ableiter, *Chief Soil Correlator*, Bureau of Plant Industry USDA
Beltsville, Maryland

Northern States - Connecticut, Illinois, Indiana, Iowa, Maine, Maryland, Massachusetts, Michigan, Minnesota, Missouri (north of Missouri River), Mississippi, New Hampshire, New Jersey, New York, Ohio, Pennsylvania, Rhode Island, Vermont, West Virginia and Wisconsin

Guy D. Smith, Principal Soil Correlator, Northern States, USDA Bureau of Plant Industry, Beltsville, Maryland

O. C. Rogers, Senior Soil Correlator, East Midwestern States, USDA Bureau of Plant Industry, Beltsville, Maryland

Iver J. Nygard, Senior Soil Correlator, Northern Lake States, Div. of Soils, Agricultural Experiment Station, University Farm, St. Paul 1, Minnesota

W. D. Schrader, Soil Correlator, West-Midwestern States, Department of Soils, University of Missouri, Columbia, Missouri

M. C. Cline, Agent (correlation) New York, Department of Agronomy, Cornell University, Ithaca, New York

W. H. Lyford, Agent (correlation), Northeastern States, Department of Agronomy, College of Agriculture, Durham, New Hampshire

Southern States - Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Missouri (south of Missouri River), Mississippi, North Carolina, South Carolina, Tennessee and Virginia

W. S. Ligon, Principal Soil Correlator, Southern States, 508 New Sprankle Building, c/o TVA Knoxville, Tennessee

I. L. Martin, Senior Soil Correlator, (same address as listed above)

M. J. Edwards, Senior Soil Correlator, (same address as listed above)

L. R. Odem, Soil Correlator, Southern States, (same address as listed above)

A. H. Hasty, Soil Correlator, (same address as listed above)

S. S. Obenshain, Agent (correlation), Virginia Department of Agronomy, Virginia Agricultural Experiment Station, Blacksburg, Virginia

Great Plains States - Colorado (east of Continental Divide), Kansas, Montana, Nebraska, North Dakota, Oklahoma, South Dakota, Texas and Wyoming

James Thorp, Principal Soil Correlator, Great Plains States, 204 Nebraska Hall, University of Nebraska, Lincoln 8, Nebraska

B. H. Williams, Senior Soil Correlator, Northern Great Plain States, (same address as listed above)

C. A. Mogen, Soil Correlator, Northern Great Plains States, (same address as listed above)

W. M. Johnson, Soil Correlator, Northern Great Plains States, (same address as listed above)

R. H. Templin, Senior Soil Correlator, Southern Great Plains States, Texas Agricultural Experiment Station, College Station, Texas

Harvey Oakes, Soil Correlator, Southern Great Plains States, (same address as listed above)

Far Western States - Arizona, California, Colorado (west of Continental Divide), Idaho, Nevada, New Mexico, Oregon, Utah and Washington

R. C. Roberts, Principal Soil Correlator, Far Western States, 322 Woolsey Building, 2168 Shattuck Avenue, Berkeley 4, California

R. A. Gardner, Senior Soil Correlator, Central Far Western States, (same address as listed above)

TABLE 3 (continued)

SOIL CORRELATORS - DIVISION OF SOIL SURVEY

W. J. Leighty, Soil Correlator, Northern Far Western States, 322 Woolsey Building, 2168 Shattuck Avenue, Berkeley 4, California

G. M. Schaefer, Soil Correlator, Northern Far Western States, (same address as listed above)

W. G. Harper, Senior Soil Correlator, Southern Far Western States, US Salinity Laboratory, P. O. Box 672, Riverside, California

TABLE 4

AGRICULTURAL SOIL BULLETINS AND MAPS PUBLISHED SINCE HIGHWAY RESEARCH BOARD BULLETIN NO. 22 WAS ISSUED IN 1949

State	County or Area	USDA Rating	State	County or Area	USDA Rating
Georgia	Chandler County	(1)	New Hampshire	Chesire County	(1)
	Union County	(1)		Sullivan County	(1)
Indiana	St. Joseph County	(1)	North Carolina	Jackson County	(1)
Iowa	Tama County	(1)		Transylvania County	(1)
Michigan	Midland County	(1)	Oregon	Astoria County	(1)
Minnesota	Rock County	(1)	Tennessee	Cumberland County	(1)

SOIL CONSERVATION SERVICE - USDA

The Committee on Surveying and Classifying Soils In-Place for Engineering Purposes prepared the following information from material obtained from the Soil Conservation Service of the USDA. It is the opinion of the Committee that since a large number of the States are using the county agricultural soil maps, it would be desirable to call to the attention of the engineer another source of soil information which is similar in many respects to that found in the county soil bulletins.

In areas not covered by county soil maps there are likely to be detailed soil maps prepared by the Soil Conservation Service for individual farms. The same system of soil classification as used for county soil maps is used in making these detailed soil maps for farms. Therefore, this information can be used in a similar manner in airphoto soil interpretation. This practice will minimize the field checks usually required for estimating the engineering significance of airphoto soil patterns occurring in the area.

In many areas large parts of counties listed as not having a county soil map (see Highway Research Board Bulletin No. 22 for status of county soil mapping in the United States) may be mapped on a farm basis. These individual farm soil maps, together with the description of soil series and the soil key developed for correlating the soils found in the area will furnish the engineer with a useful source of terrain information for estimating soil conditions in the inter-farm areas from airphoto soil patterns.

The type of farm soil maps used for land classification by the Soil Conservation Service is indicated in Figure 2. The soil scientist usually can furnish the engineer with other detailed information useful for making his engineering

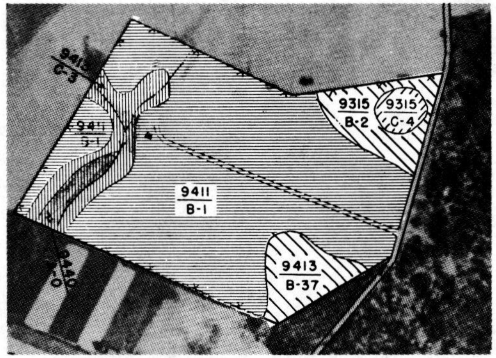

Figure A
LAND USE CAPABILITY MAP
of
a 50 acre section of a Monmouth County vegetable farm.

Land Use Capability Classes

Class II land. Deep soil, Sassafras loam (9411); gentle slope, 2-5 percent, little erosion. Can be cultivated with easily applied practices to controll runoff and erosion.

Class III land. Deep soil, Sassafras sandy loam (9413); slope 2-5 percent (B) or 5-10 percent (C); severe erosion; can be cultivated with intensive treatment to control runoff and erosion. Also deep sandy soil, Evesboro loamy sand (9315); slope 2-5 percent; moderate erosion; can be cultivated with intensive treatment to build up fertility and save moisture.

Class IV land. Deep sandy soil, Evesboro loamy sand (9315); slope 5-10 percent; severe erosion. Too droughty and erodible for regular use as cropland. Can be used for hay or pasture.

Class VI land. Level, wet land, Pocomoke silt loam (9440). Suitable for pasture or woodland.

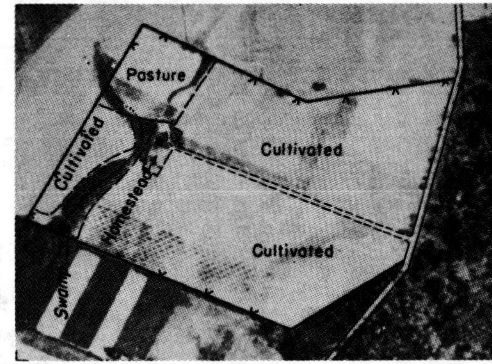

Figure B:- Same farm showing field arrangement and use at time of planning.

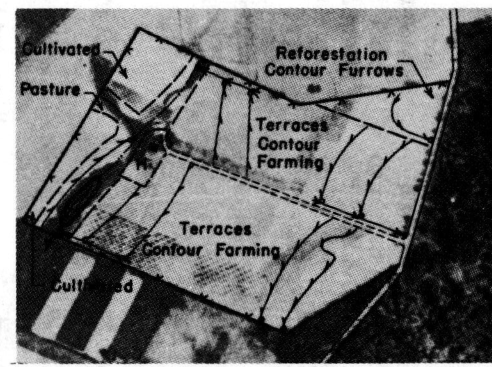

Figure C:- Same farm re-planned for erosion control, water conservation, and better land use.

LEGEND

Public road
Private road
Crop boundary
Stream
Present fence and farm boundary
Diversion terraces
Diversion outlet
House
Pond

Figure 2. Example of Farm Soil Maps Made by Soil Conservation Service

survey of the area. Information on nomenclature, soil profile characteristics of the map-units, the type of parent material from which each soil series is derived, and the internal drainage of the soil in place usually can be obtained from the soil scientist working in the area.

The extent of farm mapping in the United States is shown by the map contained in the pocket located on the back page of this Bulletin. In the areas shown in red the regional or State soil scientists listed in Tables 5 and 6 should be helpful. It is suggested that the engineer consult his regional or State soil scientists because they can often refer him to one of the district soil scientists who is working in the area where additional soil information is needed.

Another use of this farm soil map information is in counties or areas which have been mapped by reconnaissance soil survey methods or in which the nomenclature or specification of the map-units have been revised since they were published. The soil scientist usually can furnish the correlation between the older and the new map-units developed for mapping such areas.

TABLE 5

TABULATION OF REGIONAL SOIL SCIENTISTS BY STATES AND REGIONS

Region	States within Region
1. Northeastern Region H. R. Adams 6816 Market Street Upper Darby, Pennsylvania	Maine, New Hampshire, Vermont, Massachusetts, Connecticut, Rhode Island, New York, Pennsylvania, New Jersey, Maryland, Delaware, West Virginia
2. Southeastern Region G. L. Fuller Montgomery Building 199 North Church Street Spartanburg, South Carolina	Virginia, North Carolina, South Carolina, Georgia, Florida, Alabama, Mississippi, Tennessee, Kentucky, Puerto Rico
3. Upper Mississippi Region A. H. Paschall 434 N. Plankinton Avenue Milwaukee 3, Wisconsin	Ohio, Indiana, Illinois, Missouri, Iowa, Minnesota, Wisconsin, Michigan
4. Western Gulf Region R. M. Marshall (P. O. Box 1898) 3500 Cleburne Road Fort Worth 1, Texas	Texas Oklahoma Arkansas Louisiana
5. Northern Great Plains Region R. O. Lewis (P. O. Box 713) Post Office Building Lincoln 1, Nebraska	Montana, Wyoming, North Dakota, South Dakota, Nebraska, Kansas
6. Southwestern Region M. R. Isaacson (P. O. Box 1348) 222 East Central Avenue Albuquerque, New Mexico	Arizona New Mexico Colorado Utah
7. Pacific Region S. W. Cosby Swan Island Portland 18, Oregon	Washington, Oregon, Idaho, Nevada, California, Alaska, Hawaii

TABLE 6

TABULATION OF SOIL SCIENTISTS BY STATES

Alabama - Miles E. Stephens, Land Use Building, Alabama Polytechnic Institute, Auburn

Arizona - Roger D. Headley, Agricultural Experiment Station, University of Arizona, Tucson

Arkansas - Marvin Lawson, Agricultural Experiment Station, University of Arkansas, Fayetteville

California - Leonard R. Wohletz, 15 Shattuck Square, Addison Building, Berkeley

Colorado - E. Milton Payne, 202 Agronomy Building, Colorado Agricultural Experiment Station, Fort Collins

Connecticut - G. A. Quakenbush, New Jersey Agricultural Experiment Station, New Brunswick, New Jersey (Mr. Quakenbush is State Soil Scientist in both Connecticut and New Jersey.)

Delaware - M. F. Hershberger, Maryland Agricultural Experiment Station, College Park, Maryland (Mr. Hershberger is State Soil Scientist in both Delaware and Maryland.)

Florida - O. C. Lewis, Smith Building, 129 South Pleasant Street, Gainesville

Georgia - Richard R. Covell, Old Post Office Building, Athens

Idaho - C. F. Parrott, 106 Morrill Hall, University of Idaho, Moscow

Illinois - A. A. Klingebiel, Agricultural Experiment Station, University of Illinois, Urbana

Indiana - T. C. Bass, Lafayette Loan and Trust Building, Main Street, Lafayette

Iowa - Byron A. Barnes, Room 2, Landscape Architecture Building, Iowa State College, Ames

Kansas - Claude L. Fly, Agricultural Experiment Station, Manhattan

Kentucky - W. W. Carpenter, Dudley School Building, Lexington

Louisiana - D. L. Fontenot, Postal Annex, Alexandria

Maine - J. Stewart Hardesty, The Maples Building, University of Maine, Orono (Mr. Hardesty is State Soil Scientist in both Maine and New Hampshire.)

Maryland - M. F. Hershberger, Maryland Agricultural Experiment Station, College Park

Massachusetts - Montague Howard Jr., Agricultural Experiment Station, University of Vermont, Burlington (Mr. Howard is State Soil Scientist in Massachusetts, Rhode Island, and Vermont.)

Michigan - C. A. Engberg, Michigan State College of Agriculture, East Lansing

Minnesota - Alex S. Robertson, Agricultural Experiment Station, University Farm, St. Paul 8

Mississippi - D. T. Webb, Mississippi Agricultural Experiment Station, State College

Missouri - Harold E. Grogger, Post Office Building, 6th and Cherry Streets, Columbia

Montana - Dave R. Cawlfield, Montana Agricultural Experiment Station, Bozeman

Nebraska - Lloyd E. Mitchell, Conservation and Survey Section, University of Nebraska, Lincoln

Nevada - - - - -

New Hampshire - J. Stewart Hardesty, The Maples Building, University of Maine, Orono, Maine (Mr. Hardesty is State Soil Scientist in both Maine and New Hampshire.)

New Jersey - G. A. Quakenbush, New Jersey Agricultural Experiment Station, New Brunswick

New Mexico - H. J. Maker, New Mexico Agricultural Experiment Station, State College

New York - Arnold J. Baur, New York State College of Agriculture, Cornell University, Ithaca

North Carolina - W. W. Stevens, 1911 Dormitory, State College, Raleigh

North Dakota - Lloyd Shoesmith, North Dakota Agricultural Experiment Station, Fargo

Ohio - H. H. Morse, 316 Rowlands Building, 12 North Third Street, Columbus 15

Oklahoma - Louis E. Derr, Agronomy Department, Oklahoma A and M College, Stillwater

Oregon - William W. Hill, Agricultural Experiment Station, Oregon State College, Corvallis

Pennsylvania - F. G. Loughry, Agriculture Building, Pennsylvania State College, State College

Rhode Island - Montague Howard Jr., Agricultural Experiment Station, University of Vermont, Burlington, Vermont (Mr. Howard is State Soil Scientist in Massachusetts, Rhode Island, and Vermont.)

TABLE 6 (continued)

TABULATION OF SOIL SCIENTISTS BY STATES

South Carolina - P. H. Montgomery, Federal Land Bank Building, 1401 Hampton Street, Columbia

South Dakota - - - - -

Tennessee - Nathan I. Brown, 1123 Church Street, Nashville

Texas - James D. Simpson, Texas Agricultural Experiment Station, College Station

Utah - D. F. Trussell, Utah Agricultural Experiment Station, Logan

Vermont - Montague Howard, Jr., Agricultural Experiment Station, University of Vermont, Burlington

Virginia - R. E. Devereux, Eheart Building, Jackson and Main Streets, Blacksburg

Washington - Warren A. Starr, Box 508, Agricultural Experiment Station, Pullman

West Virginia - Boyd J. Patton, Agricultural Experiment Station, West Virginia University, Morgantown

Wisconsin - William DeYoung, State Farm Insurance Building, 2702 Monroe Street, Madison

Wyoming - Harold Bindschadler, 207 Grand Avenue, Laramie

A SYSTEM FOR DESIGNATING MAP-UNITS ON ENGINEERING SOIL-MAPS

Donald R. Lueder, Research Engineer [a]

INTRODUCTION

In recent years, soil surveys have gained wide acceptance as a useful, and often necessary, phase of highway engineering. Considerable attention is now being concentrated on the problem which these large scale surveys have created, namely that of providing means by which the results of a survey can be effectively disseminated for intelligent, practical use.

The soil-map has proved to be a particularly suitable means for such dissemination. The simplest soil-maps merely delineate soil areas. The most effective soil-maps, however, also tend to describe conditions within the soil areas. This self-descriptive quality necessitates a logical conversion of soil information into map-units or designations. Such an operation is always difficult, sometimes critically so. The inclusion in a map-unit of all the varied soil information which is ordinarily available yields only a hodge-podge of data. Yet, map-units which contain only single groups of facts, such as geology or laboratory test results, do not give a sufficiently complete picture of the soil and its environment. The feasible methods lie between these two extremes.

One such method, which this paper describes, is based upon an initial selection for emphasis, of certain important items of soil information which are then converted into map designations according to a logical system which satisfies a number of practical criteria. The system has been developed for use in the preparation of an engineering soil map of New Jersey, a project which is under the joint sponsorship of the United States Bureau of Public Roads, the New Jersey State Highway Department and Rutgers University, the State University of New Jersey. The Joint Highway Research Committee, which has approved the report, feels that the system offers definite advantages. However, it realizes that changes may be desirable. Therefore, it believes that this report should be considered as a proposal, presented for the study, comment and revision of other organizations which are confronted with the soil-mapping problem.

[a] Joint Highway Research Project, New Jersey State Highway Department and Rutgers University, The State University of New Jersey, in cooperation with The United States Bureau of Public Roads.

SUMMARY OF PEDOLOGICAL CONCEPTS

During the last ten years, certain pedological concepts concerning soils and soil-development have been accepted and utilized by the highway engineering profession. According to a fundamental concept, soil is a natural, unconsolidated body of variable depth, differentiated into horizons which are composed of mineral and organic constituents, and which differ from the parent material in certain important respects. [1] Other important concepts assert that the development of this natural body is a result of physical and chemical weathering processes; that these processes are a function of certain coexistent, inde-

[1] This definition is derived from a more exact and inclusive definition by Joffe. *(1)* *Italicized numbers in parenthesis refer to bibliography at the end of this paper.*

pendent variables; and that the resulting development in depth, i.e. the soil profile, reflects both chemically and physically, the combined influence of such variables. The variables may be listed as: [2]

1. Climatic factors under which weathering has progressed (mainly precipitation and temperature).
2. Parent formation from which soil is derived.
3. Time that parent formation has been subjected to weathering.
4. Topographic position at which weathering has occurred.
5. Biotic factors under which weathering has progressed.

Any detailed discussion concerning the interplay of these primary variables and their effect upon soil-development is beyond the scope of this paper.[3] It is necessary only to review the characteristics of a soil-profile which reflect such an interplay. The proposed system of map-units has been developed in connection with a single type of such a profile. This profile is typical of those developed under forest or meadow vegetative cover, upon any type of parent material, under ranges of precipitation and temperatures which are characteristic of humid-temperate to humid-cool climates. It almost invariably consists of three general horizons[4] (Fig. 1):

1. A-horizon - often called the top-soil. This horizon includes surficial, organic accumulations, together with a depth of soil which has been subjected to weathering for the longest time. Many of the fine materials produced in this horizon by the processes of weathering have been subjected to a downward leaching action, leaving a generally silty residue.
2. B-horizon - a zone beneath the A-horizon which is composed of those weathered materials produced in the horizon itself, supplemented by an accumulation of residue leached from the A-horizon. Due to the lodging of these transported fines, the B-horizon is relatively (within the profile) compact, plastic, and colloidal.
3. C-horizon [5] - a relatively unaltered horizon which is often characterized by a high percentage of rock fragments, and which passes

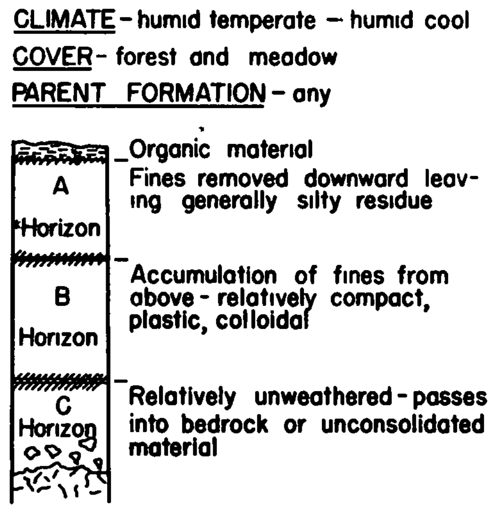

Figure 1. Diagrammatic Weathered Profile

[2] Indicative of references which discuss the primary variables in detail, are Joffe (1) and Jenny (2).

[3] For such a detailed discussion, see Jenny (2). Insofar as they are pertinent, brief considerations of climate, parent material, position and time are included in a discussion of the proposed system which forms the latter part of the presentation.

[4] For an excellent discussion of pedology and the history of pedology, see Joffe (1).

[5] This horizon is usually called the parent material. However, there seems to be some disagreement over the meaning of parent material. This is especially true for residual soils. Some opinion considers the bedrock as the true parent material, while other opinions characterize the rotten layer just above bedrock as the parent material. Jenny (2) defines the parent material as "the initial state of a soil system". This appears to be a wise definition. In this paper, the parent material refers to the material from which the significantly altered horizons develop, i.e. rock plus rotten rock in the case of residual soils.

into unweathered bedrock or transported formations.

SOIL CLASSIFICATION AND SOIL SURVEY

The highway engineer has been interested for some time in the formulation of a practical system for soil appraisal which will incorporate the factors that bear directly upon his problem. The initial efforts to formulate such a system have centered around the development of laboratory classification systems. Most of these systems have differentiated soils on the basis of their physical laboratory indices. Soils having similar indices have then been grouped together. The points of similarity have, of course, depended upon the purpose and comprehensiveness of the system. In all cases, however, the correlation of indices with field soil-behavior has enabled the systems to be used with considerable success.

In the majority of these systems, the classification tests are performed on the soil in a highly disturbed, or at least removed, state. Because of this, a most important factor which might be termed the "factor of environment", is disregarded. Many engineers can testify that soils with almost identical test constants and classifications may react quite differently in the field, even if subjected to equal traffic volumes and loads acting upon similar structures. The essential reason for these differences in performance is that the soils are characterized by different natural environments. The effect of such factors as parent material, topographic position, profile development, etc. have caused internal modifications which are significant insofar as the engineering characteristics of the soils are concerned. Realizing this, many engineers are convinced that soils must be considered in relation to their environment, and that areal studies of in-place conditions are particularly valuable.

To this end, many State highway departments have instituted soil surveys which are designed to classify soils, not only by means of their physical indices, but also according to their position in the terrain. A recent survey has indicated that some 28 States require detailed soil-surveys prior to the construction of high-type roads.[6] These surveys are based upon the reasonable assumption that "soils having similar profiles (and environments) require similar engineering treatment . . . and occur in similar types of landscape".[7] Many variations in the method of soil-survey are now in use (see reference below), and improvements in technique are constantly being reported. It is reasonable to assume that these improvements, together with time-saving methods such as airphoto interpretation,[8] will tend to increase the accuracy, scope, and comprehensiveness of such procedures.

ATTRIBUTES OF MAP-UNIT SYSTEMS FOR SOILS

Although the methods of accomplishing the soil-survey are many in number, the systems used to present the acquired information in the form of usable soil-maps are even more variable. If soil surveys are to increase in number and extent, and if the highway engineering profession is to derive maximum benefit from the assembled information, it appears highly desirable, if not imperative, that some standardized system of map-units be devised. Much of science's progress has occurred because qualified specialists have been able to discuss their problems and techniques with reference to well-established, widely accepted bases of classification. Thus, the pedologists have the Glinka soil classification, the climatoligists have the Koppen notation, the geomorphologists have the Davis nomenclature,

[6] See reference (*4*). Discussions of some representative methods can be found in references (5), (6), (7), (*8*), (*9*) and (*10*).

[7] Brackets are the writer's.

[8] Excellent discussions relating to the airphoto method can be found in references (*11*), (*12*), (*13*) and (*14*).

etc. It is believed that the effective interchange of ideas, and the progress of discussion, comparison, and research in the highway field, will be facilitated to a significant degree by the adoption of a standardized system of map-units. It is almost certain that such a system will facilitate the exchange and dissemination of constructional experiences and techniques.

Before discussing any particular type of map-unit system, it appears desirable to investigate those characteristics of a system which will make it effective in the preparation and use of engineering soil-maps. The following attributes are suggested as being a minimum:

1. Simplicity - The system should be relatively easy to learn, remember, apply and interpret. This should not imply that the learning be accomplished without effort, but rather that the effort should be justified by the benefit derived.
2. Conciseness - The system must provide concise identifications to satisfy the requirements of simplicity, and allow small areas to be properly labelled.
3. Talkability - The map-units must be of such nature that they can be used in conversation, research and publication. It is comparatively easy to devise a complicated code which will allow for every variable within a given soil-occurrence, but such a system defeats its purpose because it cannot be thought of and used as an entity.
4. Uniformity - Identical map-units should be provided for soils which are identical within the limits of the system.
5. Informativeness - The map-units should convey enough information concerning a soil area to allow an immediate rough evaluation of the soil's environment, major properties and field characteristics.
6. Reproducibility - The system should be adaptable to easy, rapid, economical reproduction on common highway base-maps. Colors and complicated patterns, while an aid, should not become a necessity.

Each of the above attributes imposes severe restrictions upon any attempts to devise a satisfactory system of map-units. Probably the most troublesome requirements are those which relate to conciseness and informativeness. It is difficult to conceive of a system which provides brief symbols that, nevertheless, convey a considerable amount of information. For instance, if one were asked to list those soil-characteristics which are desirable in a map-unit system, the following enumeration might result:

1. Climatic influences and corresponding profile type
2. Origin of parent formation
3. Type of parent formation
4. Physical characteristics of parent formation if consolidated:
   a. Hardness (and other engineering properties)
   b. Orientation
   c. Structure
   d. Depth below surface
5. Land form
6. Existence and characteristics of a significant underlying formation
7. General characteristics of the developed soil profile:
   a. Number of horizons
   b. Depth of horizons
   c. Predominant physical characteristics of each horizon
   d. Predominant mineralogical characteristics of each horizon (especially with regard to clay minerals)
   e. Predominant chemical characteristics of each horizon
8. Predominant existing drainage conditions
9. Associated engineering soil-problems

The inclusion of the above information in a mapping system which could also be characterized by the properties of simplicity and conciseness, presents difficulties which are obvious. Therefore, it is necessary to eliminate some of the listed factors. To preserve simplicity, conciseness, etc. and for various other reasons, most of which are indicated in the latter portion of the paper, all but the following factors have been eliminated in the proposed system:

1. Origin of parent formation
2. Type of parent formation
3. Land form (for transported materials only)
4. Existence of profile contrast
5. Texture of important horizons
6. General drainage conditions
7. Underlying materials (where important with regard to construction)
8. General engineering problems (by interpretation)

The mapping system hereafter described attempts to convert the above soil-information into a logical system of map-units. The system has been developed during the last two years for use in the preparation of an engineering soil-map of New Jersey. Using air-photo interpretation, supplemented by field, laboratory and reference work, the system has been experimentally applied to date over an area of some 1900 square miles. The parent formations included within this area are of sedimentary, igneous, metamorphic, glacial, marine and alluvial origin. The residual soils have been derived from shale, limestone, conglomerate, sedimentary complexes, basalt, diabase and gneiss. The non-residual soils have been derived from glacial ground moraines, terminal moraines, outwash, kames, eskers, terraces, and lacustrine areas, as well as from old drift (pre-Wisconsin); from old and recent alluvium; and from marine deposits of sand, silts, and clays. The basis for the inclusion of laboratory classifications is a file of test results on some 450 sample profiles.

The system will be described briefly, and without elaboration, in the next few pages. It will then be discussed in more detail. It is hoped that the description and discussion will be read with the following points in mind:

1. The method described has been used with, and is particularly adaptable to, the techniques of air-photo interpretation.
2. The method described is based upon humid-temperate to humid-cool climatic conditions. This does not invalidate the general technique for other climatic regions. It merely indicates that certain changes must be made within the framework of the whole.
3. The method described is of particular benefit when the soil-map is supplemented by a companion descriptive bulletin which, for each area, will include information not presented by the map-unit, as well as an amplification of the map-unit.

PROPOSED SYSTEM OF MAP-UNITS FOR SOILS

Climate - A consideration of climate is included in the discussion.

Origin of Parent Formation - The soils of any area which are to be identified by map units are first classified as:

1. Residual soils - derived from consolidated parent formations
2. Non-residual (transported) soils - derived from unconsolidated, or very weakly consolidated, materials

Residual soils are then differentiated, according to the origin of their parent formations, into the three geologic classes, each class being identified by an appropriate captial letter:

1. Sedimentary - S
2. Igneous - I
3. Metamorphic - MM

In a parallel fashion, the non-residual soils are differentiated according to the origin of their parent formations into the four geologic classes[9]:

1. Glacial - G
2. Alluvial - A
3. Windblown - W
4. Marine - M

Type of Parent Formation - Residual soils are differentiated according to the lithological character of the parent formation, i. e. shale, limestone, granite, gneiss, etc. Each of these lithological types is identified by a characteristic lower-case letter such as limestone (l), sandstone (s), shale

[9] It may be desirable to include the colluvial category (C) in some areas.

(h), granite (g) and gneiss (g). When these letters are combined with the proper letters of origin, characteristic symbols result - Sl (limestone), Ss (sandstone), Sh (shale), Ig (granite) and MMg (gneiss).

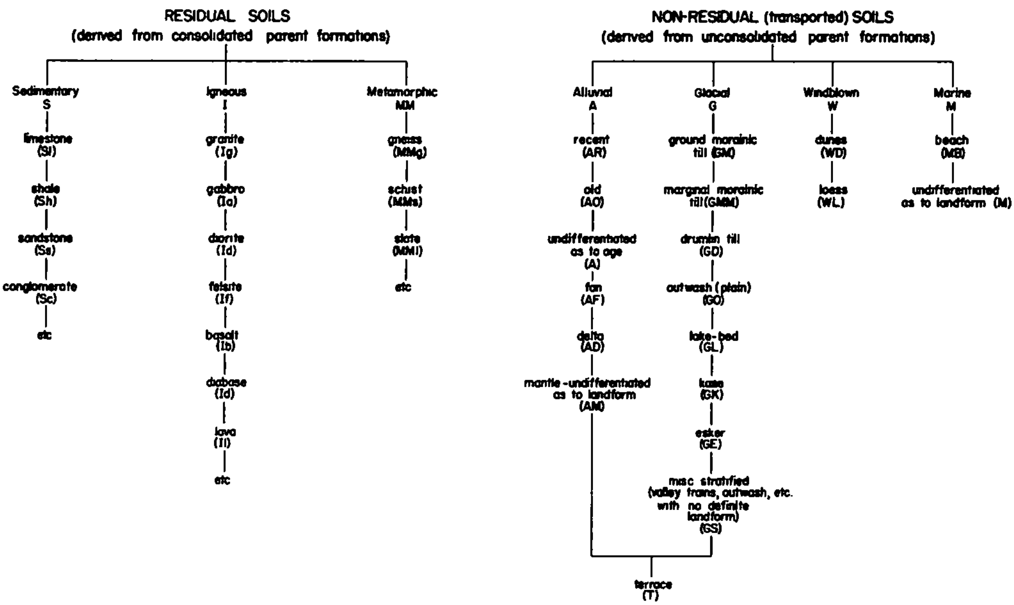

Figure 2. Origin and Type of Parent Formation

Non-residual soils are differentiated according to their types of landform. Each of these landform types is identified by a characteristic letter or letters, such as ground moraine (M), marginal moraine (MM), outwash plain (O), dunes (D), and fan (F). When these letters are combined with the proper letters of origin, characteristic symbols again result - GM (glacial ground moraine), GMM (glacial marginal moraine), GO (glacial outwash plain), WD (windblown dunes), AF (alluvial fan). A master diagram, showing the general nature of these divisions together with the appropriate symbols, is shown in Figure 2.

Land form - A consideration of land form is included in the discussion of the proposed system.

Degree of Contrast Within the Profile - As will be explained in the discussion, the degree of contrast within a soil profile is a relative term insofar as engineering is concerned. It is indicated by significant differences in the engineering properties and/or problems associated with different horizons within the same profile. It is indicated in the following manner:

1. Soil profiles with significant contrast (with regard to highway construction problems - The capital letter "C" is placed behind the proper origin-type combination. Thus, in Figure 3, GMC and IgC both indicate soils whose profiles exhibit sufficient difference between their B and C-horizons to create different engineering problems for each horizon.

2. Soil profiles with little contrast - The capital letter "C" is merely omitted. In Figure 3, GM and Ig both indicate soils whose profiles exhibit little or no effective engineering differences between B and C-horizons.

Textural Nature of Profile - Estimation of Laboratory Indices - The general textural nature of the profile, and an indication of the associated laboratory test-constants, are indicated by one or two numbers. Each number represents a textural and physical class, as established by the Highway Research

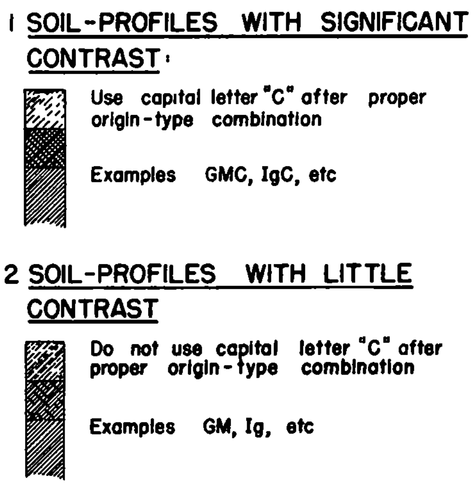

Figure 3. Existence of Profile Contrast

Board.[10] These group classifications, together with the analogous classifications incorporated in the proposed system, are shown in Table 1.

It is seen that the group-subdivisions for A-1, A-2 and A-7 have been replaced by a single number in the proposed system. This has not been done in an attempt to better reflect the characteristics of the soil, but rather to meet the requirements of simplicity and conciseness. A further consideration of this matter will be found in the discussion. The numbers indicate the nature of the profile according to the following method:

1. Soils exhibiting a significant contrast - The one or two numbers in the map-unit refer to the texture of the B-horizon (of the material in predominant topographic position or positions).
2. Soils exhibiting an insignificant contrast - The one or two numbers in the map-unit refer to the effective texture of the profile (usually the C-horizon in unconsolidated materials).

As shown in Figure 4, soils qualified

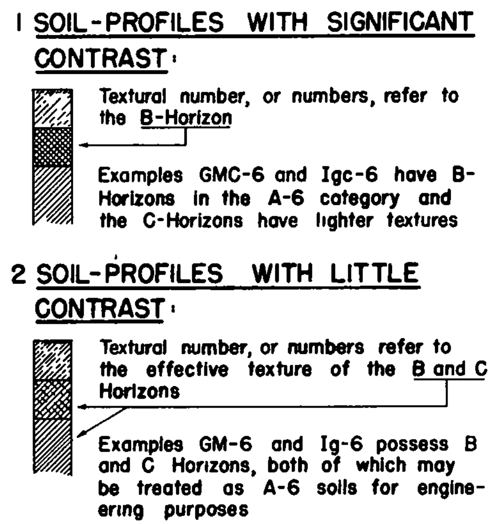

Figure 4. Indication of Profile-Texture

with a "C", indicating significant contrast, possess numbers which refer to the texture of the B-horizon where conditions are likely to be at their worst.

TABLE 1

INDICATION OF TEXTURE IN PROPOSED SYSTEM

HRB Group	HRB Group Subdivision	General Nature of Material	Analogous Number in Proposed System
A-1	A-1-a A-1-b	Stone fragments, gravel and sand	1
A-2	A-2-4 A-2-5 A-2-6 A-2-7	Silty to clayey gravel and sand	2
A-3	- -	Fine sand	3
A-4	- -	Silty	4
A-5	- -	Silty (elastic)	5
A-6	- -	Clayey	6
A-7	A-7-5 A-7-6	Clayey (elastic with high volume changes)	7

[10] See reference (15). It is to be noted that any simple, numerical system may be used in the proposed method.

In these cases, the C-horizon can usually be safely considered as being lighter in texture. Map-units lacking the qualifying "C" possess numbers that refer to the effective texture of the B and C-horizons; these horizons being essentially similar for engineering purposes.

Drainage Condition - By interpreting the complete map-unit, the internal drainage potential, the capillary potential and the height of the ground water-table can be individually or compositely evaluated in a general way. The internal drainage characteristics can usually be estimated from the textural category and the degree of profile-development. Information concerning the capillary potential is supplied by the textural category, together with the following code for ground-water positions. The height of the ground water-table over the major portion of the area (neglecting surface intersections and their accompanying effects) is indicated by the letters shown in Table 2. Variations in the position

TABLE 2

INDICATION OF WATER-TABLE CONDITIONS

Letter	Type of ground-water condition	Position of water-table [a]
e	excellent	> 10 ft
g	good	6 to 10 ft
i	imperfect	3 to 6 ft
p	poor	1 to 3 ft
v	very poor	0 to 1 ft

[a] Below major portion of surface

of the water-table can be indicated by combining two letters such as "ip" showing a water-table position varying between 1 to 6 ft. from the major portion of the surface, depending upon position.

The only other factor of major importance in an estimation of drainage condition is the surface drainage potential. This is considered in the discussion.

Special Symbols - A few letters are used to convey special meanings in situations which depart from the normal. These letters are:

1. X - Exceptional - usually used when the parent formation, textural classes or drainage conditions are not correctly implied by the regular system.
2. R - Variable - usually used when individual factors vary in such a manner that mapping, according to the rules of the system, is not feasible.
3. d - Depression - usually used to indicate a depressed position when such information will facilitate the correct interpretation of a map-unit.
4. a, b, c, etc. - usually used at the end of identical map-units which, nevertheless, refer to areas that are different in some important respect. These letters should be used very sparingly.

Typical Map-units - In order to form each map-unit, the various letters and numbers are properly combined. The combination of the various factors is indicated in Table 3. The map-units shown refer to actual soil-areas in New Jersey. Some of these map-units are interpreted at the end of the paper.

Uniformly Intermingled Soils - Existence and Type of an Underlying Significant Strata - In some areas, two significant phases of a soil may be uniformly intermingled on an areal basis. For instance, in some very gently rolling glacial ground morainic areas, slight differences of position may create differences in soils. If both positions are equally wide-spread and also intermingled, a problem in labelling is created. The proposed system uses the diagonal bar in such cases. The above area might be mapped as GM-4i/GM-6p.

In many areas, it is extremely important to indicate the existence and type of an underlying strata which is significant with respect to engineering construction. In the system as proposed, this may be done using a fractional symbol. Thus, the symbol $\frac{GM\text{-}4i}{1b}$ denotes silty ground moraine with an immature, imperfectly drained profile overlying, at a significant depth, igneous basaltic bedrock.

best-developed soils of the humid tropics [12] are noted for their great

TABLE 3

COMBINATION OF FACTORS TO FORM COMPLETE MAP-UNIT

Geologic Origin	+	Land form or Type	+	Profile Contrast	+	Textural Category	+	G.W.T	+	Addit. Info.	=	Final Map-Unit
G		O		-		2		g		-		GO-2g
G		M		-		4		i		-		GM-4i
G		O		-		2		v		-		GO-2v
G		MM		-		24		i		-		GMM-24i
G		M		C		6		ip		-		GMC-6ip
MM		g		C		6		ig		-		MMgC-6ig
S		h		-		4		i		-		Sh-4i
I		b		C		67		i		-		IbC-67i
G		M		-		4		i		—/1b		GM-4i/1b

DISCUSSION OF PROPOSED SYSTEM

Climate - It can safely be stated that climate has a significant effect upon the type of soil-profile which is developed in many regions, and that a majority of the soil-profiles included within such regions will display general characteristics which are both similar and typical.

The specific profile which has been considered in the presentation of this paper is one which is believed to be typical of humid-temperate to humid-cool climates. [11] Such climates exist in the New England, Mid-Atlantic, Central and North-Central States. An important characteristic of the profiles which develop in this region is a tendency toward relatively sharp differentiations between A, B and C-horizons. This differentiation is often particularly noticeable in the relative imperviousness of the B-horizon.

Profiles developed in other climates display other characteristics. The depth, essential uniformity of profile and the subordination of the effects of texture and parent material. Soils developed under the feebly-arid to sub-humid climates [13] of the Dakotas, Nebraska and Kansas are usually distinguished by appreciable surficial accumulations of organic matter, pronounced limey zones at relatively shallow depths (regardless of parent material) and relatively low degrees of B-horizon development.

These general similarities within climatic regions are of value in the development and use of systems such as that which has been presented. By making use of the general similarities which exist in humid-temperate to humid-cool climates, one or two numbers can serve as a key to the texture of the entire profile. In other climatic regions it may be necessary to change the significance of the textural numbers

[11] Generally termed gray-brown podsolic soils and podsols by the Russian pedologists.

[12] Generally termed laterites by the Russian pedologists.

[13] Generally termed chernozems by the Russian pedologists.

as well as that of other factors. In such cases, however, it is believed that the changes can be made within the framework of the system. If the changes are standard in character, a relatively sketchy acquaintance with the characteristics of various regional soils will enable engineers from one region to correctly interpret the map units of another region.

Although a knowledge of climate affords such interpretative advantages, it has not been included as an integral part of the proposed system. In most States, the soil-maps will cover areas which lie within the boundaries of a single climatic region. In cases of this sort, the climate becomes superfluous once the effect on the local region has been ascertained. It is true that in certain areas such as the Midwest soil-maps may transcend the boundaries of more than one climatic region. Even in these areas, however, the problem is still one of evaluating local effect. In other areas such as the Far West, the climatic effect is of such a nature that it becomes subordinate to the effect of parent material. In all areas, it is possible that the relation between climate and natural water-conditions is more important than the relation between climate and general profile-characteristics. Therefore, although the overall climatic effects are not to be disregarded, the proposed system neglects them in favor of specific factors which seem to be of more value to the user.

Origin and Type of Parent Formation - Land Form - The importance of these factors to the soils and construction engineer has been described in many professional papers of the past decade.[14] The following discussion will consider them only with regard to their use and interpretation in the proposed mapping system.

The initial letters of origin, combined with the secondary letters of type, immediately describe the fundamental characteristics of the parent

[14] See references (*5*), (*6*), (*11*), (*12*), (*13*) and (*14*).

formation in a manner which conforms to widely accepted geologic nomenclature. In addition, however, these symbols help to form in the user's mind a mental picture of important environmental conditions which exist in the mapped area. For example, the combination GMM mapped over an area indicates that the soil is unconsolidated, glacial in origin and deposited as a marginal moraine with an irregularly hummocky surface, a hetergenous composition and a probable great depth to bedrock. In general, most of the combinations shown in Figure 2 under the non-residual heading perform a similar function. Such units as GK (glacial kame), WD (windblown dune), AR (recent alluvium) and GO (glacial outwash) each give information concerning the land form, origin and general character of the material.

The same amount of information is not supplied by all of the non-residual combinations shown. Such categories as GS (miscellaneous stratified drift), AM (undifferentiated alluvial mantles) and WL (windblown loess) do not usually give information concerning both the land form environment and the general nature of the material. This calls attention to an important point concerning the non-residual land form categories listed in Figure 1. Most of these combinations are included because they:

1. Possess a land form which is usually easily identifiable both in the field and on the airphotos, and/or
2. Possess characteristics which are of importance to highway engineering.

Classifications such as GS, AM, etc. are not usually characterized by easily distinguishable land forms. They are instead, miscellaneous or general categories. They are included so that the maker and user of the map need learn only a relatively few important land forms and can place doubtful areas in a category without spending the time which might be necessary in order to formulate new combinations or precisely classify the doubtful area. The unit GS is a good example since it covers those deposits of stratified glacial drift which are often not characterized by any particular type of land form.

The combinations shown in Figure 2 under the residual heading do not supply the same information as the non-residual classification. For instance, the combination Sh indicates that the area in question has a residual soil-mantle, derived from bedded shale at a probable shallow depth. This information is extremely important to the engineer. However, other questions concerning the orientation and thickness of the beds and hardness of the rock are not answered. At least, however, these factors are indicated as being primary considerations in any discussions which may follow.

An important point about Figure 2 concerns the ease with which the various combinations can be remembered, or reconstructed, by virtue of their association with the first or second letter of the applicable word. Another advantage of the chart is its wide coverage, an estimated 90 percent of the bedrocks and unconsolidated types which would normally be encountered in ordinary engineering construction.

The labelling of residual soil areas which are developed upon interstratified formations constitutes a slightly different problem. Experience in New Jersey has indicated that interstratification may be considered normal for deposits of sedimentary origin, but that one material usually displays a definite predominance. In these cases, the developed soil-profiles have reflected this predominance to such an extent that the areas have been mapped and considered as being composed of a single material. One example is found in the large areas of interstratified silty shale and fine sandstone which cover west-central New Jersey. In these areas, the effect of the minor sandstone outcrops is negligible, the soils are essentially silty and the areas can be mapped under the combination Sh-4i. If the area to be mapped has interstratification to a significant degree, and the level of generalization is such that individual strata cannot be mapped separately, a combined symbol can be utilized. Thus, significantly interstratified beds of sandstone and shale may be mapped under the combination Ssh.

There are additional special problems encountered in the mapping of residual areas. These are discussed in connection with the special symbols.

Degree of Contrast Within the Profile - To an engineer, the contrast possessed by a soil-profile depends upon differences in the engineering properties of horizons within the profile. If the various horizons are sufficiently different to create separate engineering problems in the field, the profile can be considered as one having significant contrast. In the proposed system, the presence of significant contrast is indicated by a "C" after the proper origin-type combination. If contrast is unimportant, the "C" is omitted. It will be noted that the exact nature and probable effect of the contrast is relegated to the important descriptive bulletin which should accompany the soil-map.

The decision regarding the presence or absence of a significant contrast is left to the engineer or engineers who are responsible for mapping. In those instances when agricultural and pedological information are utilized as mapping or interpretative aids, it should be thoroughly understood that the engineering concept of profile-contrast may not necessarily have the same meaning as the pedological concept of profile-m a t u r i t y. A pedologically mature profile is one which has progressed to a state closely resembling that which might ultimately be expected to develop under the existing climatic conditions.

From the viewpoint of the highway engineer, a pedologically mature profile need not show significant contrast. An excellent example of the distinction exists in the coastal plain of New Jersey. Here the Lakewood series has developed pedologically mature profiles upon a parent material composed of quartz sand with very few fines. To the engineer, the Lakewood profiles do not show important contrast, since the engineering properties and the resulting field behavior of the various horizons are practically identical. Thus, the Lakewood series, in a practical sense, is one horizon throughout. Certain members of the Sassafras series, however, are developed upon parent material composed of quartz sand containing considerable silt and some clay. These Sassafras soils are pedologically immature, since their horizons have not progressed sufficiently far toward their ultimate development. To the engineer, however, these members show contrast, since enough silt and clay have accumulated in the B-horizon to create different properties with respect to construction operations.

Textural Nature of the Profile - As stated previously, the general textural nature of the profile is indicated by one or two numbers, each number representing a general textural category as defined by the Highway Research Board Classification of 1946. Tow numbers are allowed, because extensive sampling in New Jersey has indicated that many soils can best be defined by a range of textures rather than by a single texture. To illustrate this point, Table 4 shows the classification for

TABLE 4

CLASSIFICATION OF SOME MORAINE SOILS

Geologic Origin - glacial

Geologic Designation - marginal moraines

Geologic Description a belt of irregularly hummocky accumulations of clay, silt, sand, gravel, and boulders in a confused mixture

Counties - Union and Middlesex, New Jersey

Map-Unit - GMM-24i

Sample No.	B-Horizon HRB Class	B-Horizon Group Index	C-Horizon HRB Class	C-Horizon Group Index
306	A-1-b	0	A-2-4	0
2013	A-2-4	0	A-2-4	0
2014	A-4	3	A-4	4
2027	A-4	5	A-4	1
2028	A-4	4	A-4	1
2030	A-4	3	A-2-4	0
2034 [a]	A-6	5	A-4	5
1805	A-4	5	A-4	5
1806	A-4	2	not taken	-
1807	A-4	7	not taken	-
1812	A-4	5	A-4	6
1824	A-4	4	A-4	3
1828	A-4	2	A-4	0
1834	A-4	5	A-1-a	0
1844	A-2-4	0	A-2-4	0
1847	A-4	5	A-2-4	0
1849	A-4	5	A-4	0
1831 [a]	A-7-6	7	A-6	7

[a] Blind depressions

gently undulating to undulating surface. Since the described system, as presented, refers only to specific climatic conditions, the profile may be expected to consist of three horizons. However, since the symbol is not qualified by the letter "C", the profile can be considered, for engineering purposes, to consist of essentially a single horizon. In this case, the textural number refers to both B and C-horizons and indicates that these horizons belong in the HRB 2-group. The 2-group of soils are silty to clayey sands and have a wide range of associated test constants. This group may be expected to provide a fair to good subgrade support, and a probable good source of borrow. The absence of a fractional symbol indicates that bedrock, or any other significant strata, need not be considered during ordinary highway construction. Because the land form has a gently undulating to undulating surface, cuts and fills can probably be kept to a minimum. The letter "g" implies a ground water-table which is usually 6 to 10 ft. below the ground surface. The texture, lack of contrast, etc. eliminate internal drainage and capillarity as important considerations, leaving only surface drainage structures as possible major requirements.

The map-unit GO-2v, not shown in Figure 5, indicates similar material with, however, a very poorly drained condition at times during the year. Since the textural nature of the B and C-horizons is silty to clayey sands, it is probable that the poor drainage is not the result of either poor internal percolation or excessive capillary moisture. The letter "v" indicates that the ground water-table is high, probably because the area is a depression. If so, surface drainage conditions are adverse.[15] Depressions may be expected to accumulate organic material on the surface. Highway alignments should avoid such areas. If highway construction must be undertaken, the organic mat will probably require removal, compacted fills will be necessary, cross-drainage will be required and special techniques used throughout construction.

The map-unit GM-4i indicates that the soil is derived from unassorted ground till. The formational history of such deposits usually dictates that the area will be more or less rolling. Since there is no fractional symbol, it is probable that the till is fairly thick, tending to mask the original relief, and indicating that an underlying formation need not be considered in the construction of highways. Since the qualifying "C" is absent, the profile lacks contrast and may be considered as a single horizon throughout. The textural number, 4, indicates that the horizon is generally silty throughout. This textural group provides questionable subgrade support. The land form indicates that shallow cuts and fills may be expected with some frequency. Alignment will probably not be difficult. The letter "i", indicating a ground water-table existing at depths of 3 to 6 ft., together with the textural category, calls attention to the probability of adverse internal, capillary and ground-water conditions. The possibility of frost action may also be a factor. In general, the area may be considered as one to be avoided if possible. If construction must be undertaken, particular attention should be accorded to drainage and subgrade conditions.

The map-unit GMC-6ip, not shown in Figure 5, mapped over large areas, indicates that the soil is derived from old glacial morainic till. Since the area is large and no fractional symbols are indicated, it is probable that the drift is deep, and an underlying formation need not be considered. The land form will probably be gently rolling, with advanced erosion in some areas. Since the profile shows significant contrast, it is probable that different construction problems will be encountered on different horizons. The B-horizon has a clayey texture, probably moderately heavy, and the C-horizon is somewhat lighter, say an A-4 to an A-6, with a low index. Drainage facilities will require careful attention,

[15] The area could be mapped with a "d", i. e. GO-2vd, directly indicating a depressed position.

since the ground water-table varies between - 1 to 6 ft. from the surface (probably dependent upon position), contrast is high, and texture is not conducive to good internal drainage or low capillarity. Raised grade lines may be necessary in the lower areas. Borrow will probably have to be imported. Deep cuts need not be frequent.

The map-unit MMgC-26ig, not shown in Figure 5, indicates a residual soil derived from gneissic bedrock. The land form may be expected to be quite rough. The soil shows significant contrast, indicating that different problems may be expected when different horizons are encountered. The B-horizon shows an apparent wide variation in texture, ranging from a clayey sand to a clay. The C-horizon will probably be lighter, composed largely of clayey sand, with numerous rock fragments as bedrock is approached. The position of the ground water-table, combined with reasonably frequent sandy textures and probable steep slopes, all indicate fair surface drainage and internal drainage with probable low capillarity in many areas. The high contrast tends to discount these factors. Therefore, drainage should be carefully investigated. Cuts into bedrock and fills may be expected to occur with some frequency. Alignments may be difficult. The soil may be expected to provide a fair to good support in the C-horizon.

The above interpretations are typical and indicate that the proposed system, if properly used, provides a useful aid to the engineer who must consider soils on an areal basis. In summary, it is desired to enumerate a few less obvious attributes of the proposed system which are of special significance in highway engineering:

1. Because of a simple yet informative character, the system is of value to the higher levels of planning and supervision who do not always have the opportunity to evaluate soil conditions, either from field observations or from personal study.

2. Because of a uniform character, similar soils are identified by similar map-units. Thus, engineers from different areas can rapidly and accurately evaluate the general characteristics of soils beyond their own domains. This is of great value in disseminating constructional techniques. In addition, it serves as a point of departure for investigating unequal performances on similar soils.

3. Because of a general character, it is believed that the system can be applied to other climatic regions with different type profiles. Even though the meaning of numbers and letters will be changed, the change may occur within the framework of the system.

4. Lastly, it is couched in engineering terms and designed for practical use. While retaining most of the elements upon which agricultural identifications are based, it tends to decrease the importance of learning, and remembering, innumerable agronomic names, their associated properties, and their engineering significance.

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DRAINAGE PATTERN SIGNIFICANCE IN AIRPHOTO IDENTIFICATION OF SOILS AND BEDROCKS

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SYNOPSIS

This paper reports the analyses of drainage patterns for their use in the identification of regional soils and bedrocks by means of airphotos. The study is one of several concerning the interpretation of aerial photographs by the Joint Highway Research Project at Purdue University. The relative ease with which stream systems can be observed on aerial photographs facilitates the recognition of drainage patterns.

In the natural sciences, it has been accepted for a long time that certain basic drainage patterns such as the dendritic, trellis, radial, parallel, annular, and rectangular are associated with specific land surface materials. Airphoto interpretation has revealed several modifications of the basic drainage patterns. For example, some of these modified types are the reticular, phantom, and lacunate.

Drainage patterns, traced directly from representative airphotos of various physiographic regions throughout the United States, are presented as illustrations of patterns which develop in the soils and bedrocks typical of the regions. These examples have been selected to show noticeable differences in drainage patterns. For instance, drainage patterns in regions where the rocks are bare or are covered only with shallow soils, are decidedly different than those in regions of deep glacial drift. Likewise, drainage patterns develop differently in horizontal rocks than in tilted rocks.

It is concluded that surface drainage patterns can be relied upon in the airphoto identification of soils and bedrocks on a regional basis.

Drainage patterns have intrigued scientists over a long period of years. As a result of their findings, many patterns have been classified and incorporated into the literature of the natural sciences of geology, physiography, and geomorphology. Recently - probably within the last decade - engineers have been studying drainage patterns by means of airphotos. In the laboratories of the Joint Highway Research Project at Purdue University, highway research engineers have been using airphotos to construct detailed drainage maps of Indiana on a county basis. During the progressive stages in the compilation of these maps recurring drainage patterns were observed. This led to the investigation of drainage patterns on aerial photographs of areas of land surface materials, with known characteristics, which occur elsewhere in the United States.

The study of an area for the purpose of identifying its soils and bedrocks by means of airphotos is best effected by stereoscopic examination of the vertical aerial photographs of that area. By this means such "elements" of the terrain as landform, drainage pattern, erosion features, vegetative cover, and land usage are revealed on the airphotos in a most realistic manner. Photo tonality is another "element" vital to airphoto interpretation. Tonality can be observed without the aid of a stereoscope. Colors found in soil, rock, vegetation, or water are recorded on the airphotos in black, white, or tones of gray which vary according to the values of the respective colors and the reflection of incident light. While all the elements are correlative and are considered equally important in airphoto interpretation, only the drainage pattern element is herein set forth. In doing this, it is not to be assumed that the drainage pattern element can be relied upon alone in the identification of soils and bedrocks by the use of airphotos. It must be used in conjunction with the other elements.

It is known that the drainage of a region is affected by such factors as bedrock structure, soil textures, topography, artificial waterways, rainfall, vegetation, and evaporation. Since the drainage ways and landforms of a region are interdependent, they exist together as interrelated features of the region. Therefore, soils and bedrocks influence the evolution and character of the patterns of a region's many rivers and tributary streams. These facts lead to the premise that drainage patterns can be used to identify soils and bedrocks on a regional basis.

The airphotos employed in the preparation of this paper were taken during 1937-1943 in connection with the United States Department of Agriculture mapping program. The prints were obtained from the Agriculture Adjustment Administration (now Production and Marketing Administration). They are standard 7-by 9-in. and 9-by 9-in. contact prints having an approximate scale of 1: 20,000 or 3 in. per mi.

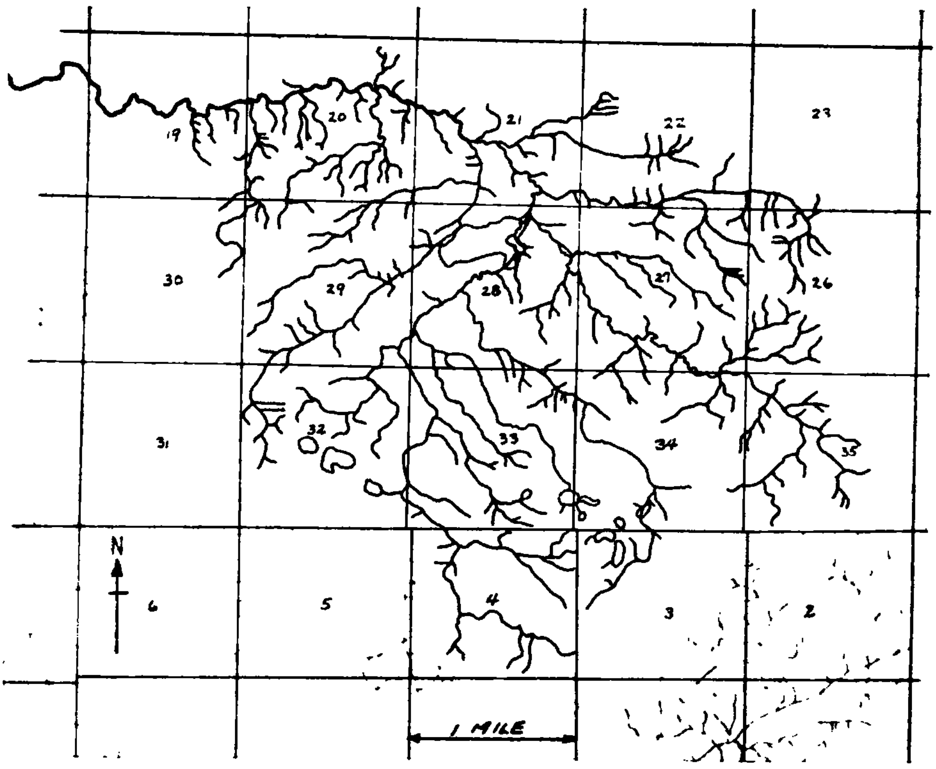

Figure 1. Drainage Pattern of the Headwaters of a Stream System Developed in Wisconsin Glacial Drift - Flint Creek, Tippecanoe County, Indiana - The areas bounded by dotted lines are infiltration basins. Numbers indicate Congressional land sections. (This pattern was traced directly from aerial photographs of the area. Original Scale : 1:20,000)

DRAINAGE PATTERN CLASSIFICATION

A pattern has been defined by Webster as "an arrangement or composition that suggests or reveals a design". The term "drainage pattern" is used in this paper to apply to the manner, or "design", in which a given set of tributary streams arrange themselves within a given drainage basin (See Fig. 1).

Drainage patterns are classified on the basis of form and texture. The form of the pattern is its shape which may be described by comparing the pattern with a familiar object such as the branches of a tree. The texture (or density) of the pattern refers to the spacing of the tributaries in the stream systems. If the tributaries are closely spaced the texture is "fine", and if they are widely spaced it is "coarse".

Certain drainage patterns are considered as the basic patterns. Variations of the basic types are known as modifications of the basic patterns.

Basic Drainage Patterns - Of the many stream patterns which have been formed by natural forces acting upon the earth's land surface materials, six have been classified as the basic drainage patterns. Analyses of the more or less characteristic arrangement and repetition of the lines of these patterns have revealed significant relationships between the patterns and the soils and bedrocks of the regions in which they are found.

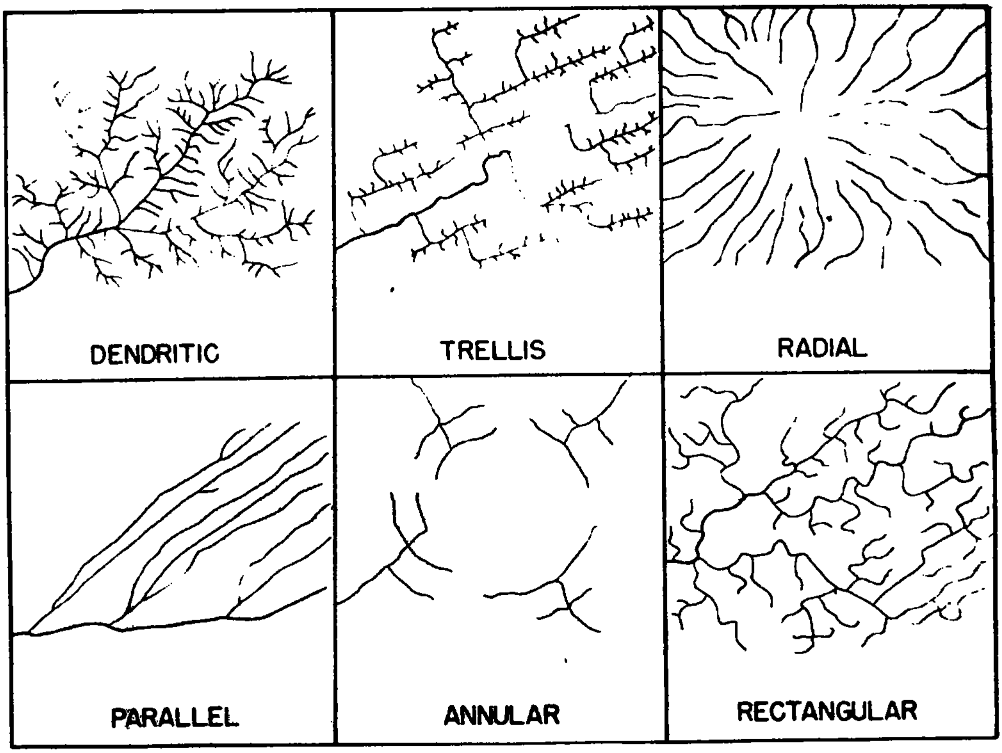

Figure 2. Sketches Illustrating Basic Drainage Patterns (20) (21)

Figure 2 illustrates the six basic drainage patterns. They can be described as follows:

1. A dendritic drainage pattern is tree-like in form; the main stream corresponds to the trunk of the tree and its tributaries resemble the irregularly subdivided branches, limbs, and twigs

of the tree (22: 127)[1]. Another term for this type pattern is "arborescent" (11: 300). It is the most common type drainage pattern. It is formed where the "rock structure does not interfere with the free development" of streams (15: 340).

2. A trellis type of drainage pattern may be compared to a vine on a garden trellis; the primary tributaries are long and straight and often parallel to each other and to the main stream. Numerous short, stubby secondary tributaries join the primary tributaries approximately at right angles (22: 127). This drainage pattern may be thought of as one "adjusted" to structure (2: 122). "Grapevine" is another name for this type pattern (26: 503).

3. A radial drainage pattern may be likened to the spokes of a wheel. The pattern may be either centrifugal or centripetal; that is, the streams may flow radially either outward from a peak or inward toward a basin (17: 175) (22: 127). Also, this term can refer to a group of drainage patterns originating at a common point (13: 350). Stream systems on isolated hills often take this form.

4. In a parallel drainage pattern the streams or their tributaries are parallel or nearly parallel to each other (22: 127). The way in which the streams are arranged might aptly lead to the naming of the pattern cauda equina - horse's tail.

5. In an annular drainage pattern "ring-like" tributaries flow into the radial streams (22: 127). This type pattern has been compared to the annual growth rings in a tree (17: 175).

6. A rectangular drainage pattern shows the influence of the angularity of rock joints; it is characterized by many "abrupt bends" in both the main streams and their tributaries (22: 129). This pattern is a "right-angle system of streams" (7: 130). The pattern is affected locally by horizontal rock strata of different composition.

Rock structure is a major factor in the development of these six patterns.

[1]Numbers in parentheses refer to references at the end of the paper.

Dendritic drainage patterns are normally formed by streams flowing in horizontal homogeneous rocks. Trellis patterns develop in folded or dipping rocks where there is a series of parallel faults. These also result from adjustment and are stream systems "aligned on a strike of the rock formations", the streams occasionally making "right-angled turns to cross strike ridges" (4: 86). Streams draining volcanic peaks assume the radial type of pattern. Drainage patterns in tilted rocks having parallel faults and in valley-fill materials often show striking parallelism. A parallel drainage pattern implies a "pronounced regional slope" (26: 510). Streams around a dome follow circular, or annular, courses. Streams following the faults and cracks in jointed rocks produce rectangular drainage patterns (17: 175). Fractures in the rocks of the earth's surface have "influenced the activities of running water". Sometimes a river's course is in "rectangular zigzags" - its walls are formed of joint planes" (12: 224). All these drainage patterns reflect details of relief that are characteristic of the materials from which the stream valleys have been carved.

Modifications of the Basic Drainage Patterns -There are several modifications of the basic drainage patterns. Figures 3, 4, 5, and 6 illustrate some of the modified types. A number of these patterns have been described in scientific literature. The author has identified others by means of aerial photographs.

Descriptions of the patterns in Figure 3 are as follows:

1. The pinnate drainage pattern is a modification of the dendritic type. The second order tributaries are arranged in a more or less parallel manner (parallelism indicates a nearly uniform slope). The rather evenly-spaced first order tributaries join the second order tributaries at acute angles (near right angles) much in the manner of a feather - hence the name "pinnate" (26: 512).

2. The deranged or disordered type of drainage pattern has been applied to

of drainage pattern has been applied to the drainage of drift-covered regions. It has been so termed because of the great irregularities of its pattern and the confused intermingling of lakes, marshes, and wide-open valleys (7: 503). Runoff water collects in the lakes, swamps, and marshes; and streams wander aimlessly about the landscape (8: 295). The numerous

(26: 513). This pattern is a modified type of parallel drainage, but "lacks the regularity of the parallel pattern" (26: 518).

4. The contorted drainage pattern type is a "response to rock structure" (7: 215). Streams flowing in one direction may be completely reversed in direction when they encounter resistant rock or granular barriers.

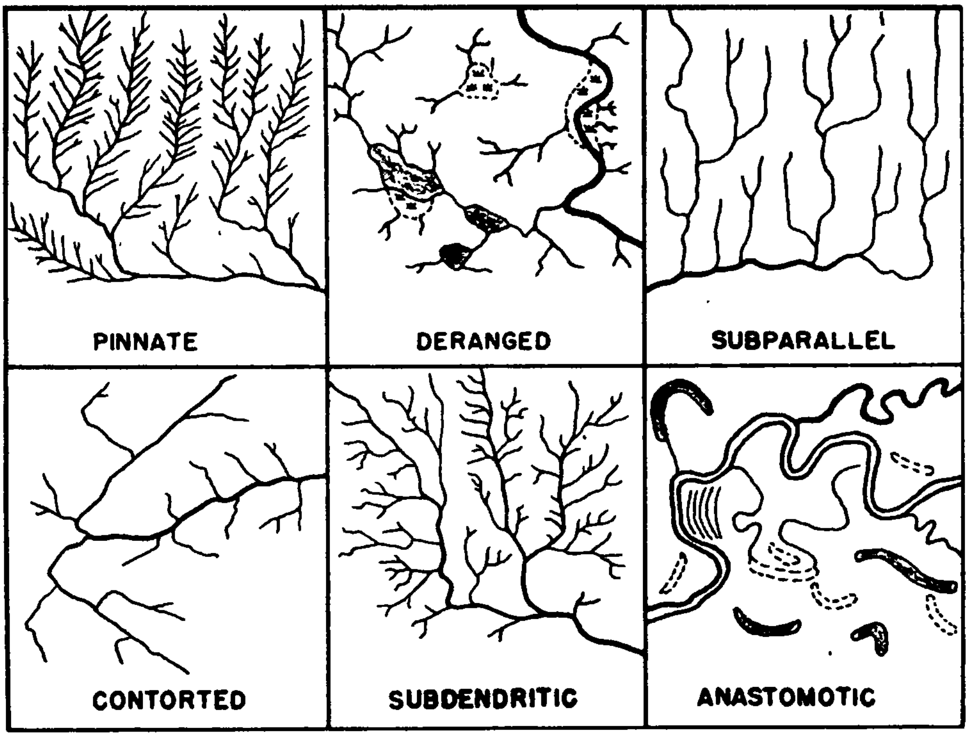

Figure 3. Sketches of Modified Basic Drainage Patterns (20) - Shaded areas are water filled basins - lakes, ponds, slough, bayous. Areas bounded by dotted lines are infiltration basins.

lakes and swamps depict the undeveloped character of the drainage. The terms "erratic" and "haphazard" may also be applied to this pattern (12: 300). Patterns of individual drainage systems within the area are usually dendritic.

3. The subparallel drainage pattern resembles the spire-like Lombardy poplar tree in its type of branching. The first order tributaries are usually nearly parallel to the second order tributaries. Again, in this type, parallelism denotes uniformity of slope

5. The subdendritic drainage pattern is a modification of the dendritic type. This type shows minor slope control of the second and third order streams (first order tributaries are the field gullies); other than that it closely resembles the dendritic type pattern (26: 513). It is a result of streams flowing from a non-resistant material area through another of slight structural control.

6. The anastomotic drainage pattern is characteristic of flood-plain drainage.

The meanderings of the main stream has produced sloughs, bayous, exbow lakes, and "interlocking channels". A network of anabranches may even be present. This type pattern is considered to be "a phase in the development of dendritic drainage" in restricted areas (26: 514).

Patterns illustrated in Figure 4 are described as follows:

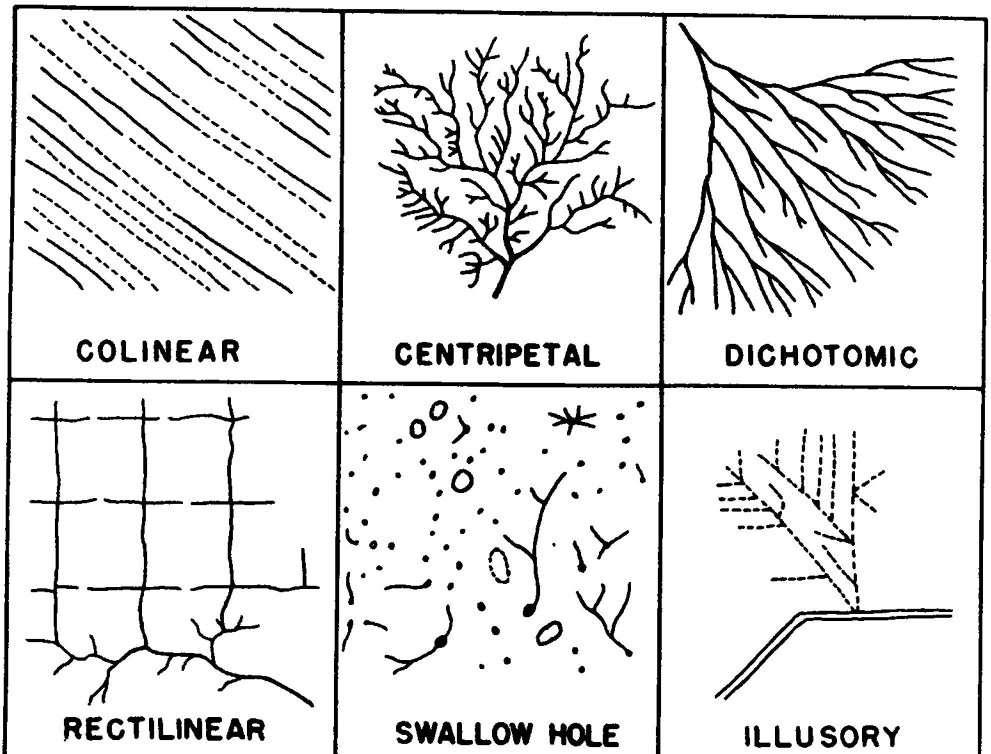

Figure 4. Sketches of Modified Basic Drainage Patterns (20) - Linear dotted lines indicate subsurface drainage ways. Shaded areas are water-filled basins. Dots are sinkholes. Areas bounded by dotted lines are infiltration basins.

1. The colinear drainage pattern is a modification of the parallel type. Parallel streams are alternately surface and subsurface. This is a recognized type of drainage pattern found in certain foreign countries (26: 519). It is a system of intermittent streams flowing in very straight lines through porous materials.

2. The centripetal drainage pattern is a modification of radial drainage. If the headwater divide of a drainage basin is "roughly an arc of a circle", and the inside surface is steep and evenly sloping, then tributaries from opposite sides of the basin will enter the main stream at nearly the same point (13: 350). This term can refer to a group of drainage patterns converging to a common point (13: 350) (26: 517). This pattern occurs frequently.

3. The branching pattern of the distributaries of a stream is the dichotomic pattern of alluvial fans (8). The end branches are called anabranches - branches which lose themselves in the valley fill. Also, this pattern may be applied to the arrangement of the streams in the birdfoot type of river delta.

4. In nearly level areas man has dredged ditches to drain swamps and low-lying soils. These ditches are fairly straight; they follow topograph-

ical depression channels or the section, half-section, and quarter-section lines. Often they do not "accord with the pattern of the soil and vegetation" of the area (6: 73). They have been graded so that low rises are traversed which would otherwise block the natural drainage. This pattern is identified as "rectilinear" in type (22). It is a form of artificial drainage. It is not to be confused with the pattern of irrigation ditches which is a distributary pattern (6: 73).

5. Drainage in horizontal limestone areas is both surface and subsurface. Where sinkholes predominate, small streams are "swallowed in holes" to continue under ground as subterranean streams. Sinkholes plugged with debris become ponds. This swallow hole pattern is common to regions of massive strata of limestone. The pattern of a youthful karst region might appropriately be called the "dot" pattern. In mature and old age limestone regions sinkholes, fensters, and solution valleys form "unsystematic" drainage patterns in that surface drainage is interrupted by the disappearance of the streams under ground (18: 116).

6. The illusory type drainage pattern is occasionally observed on airphotos of porous low-lying soils which are tiled for drainage. While this is subsurface drainage the network of tile drains is often "visible" on the airphotos because the soil above the tile has dried and there appears on the photos a sort of "X-ray near-white system of lines - formed by the trunk tiles and

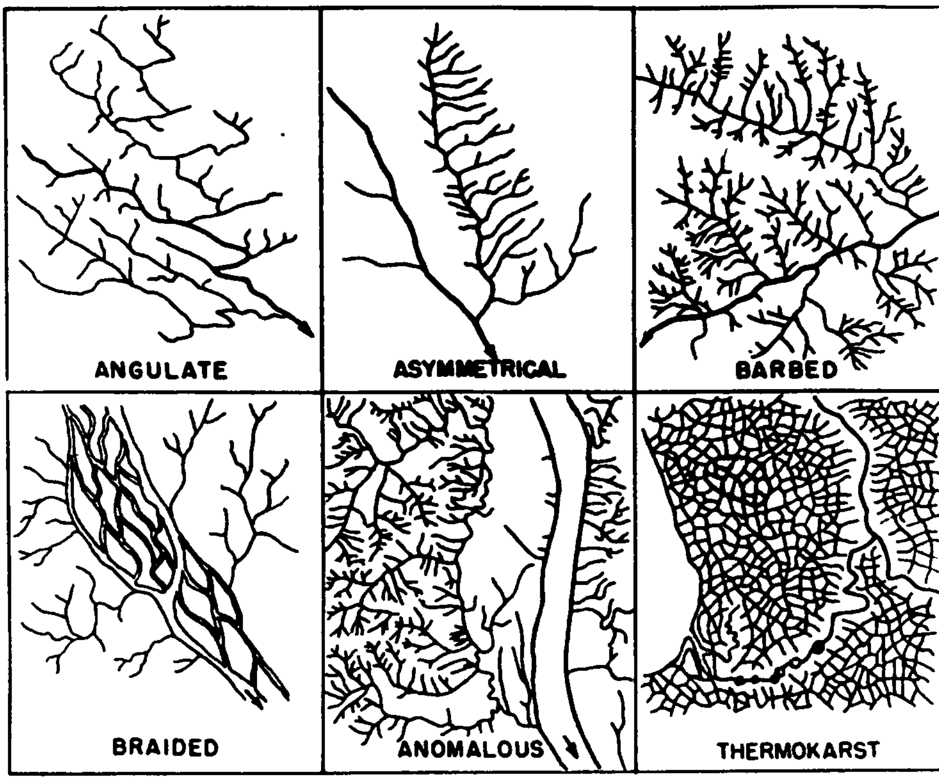

Figure 5. Sketches of Modified Basic Drainage Patterns - Shaded areas are water-filled channels and basins - rivers, lakes, sloughs.

their parallel laterals (14: 30). This is a form of artificial drainage. The lines appear somewhat spectral on the air-photos - they may be likened to the spreading of the ink in a line drawn on blotting paper. This pattern is depicted graphically by dashed lines - the accepted symbol for hidden lines. The pattern is an ovanescent one; as the soil dries the pattern becomes imperceptible. Also it is a deceptive pattern; a buried pipe line, a buried telephone cable, or an abandoned railway grade might easily be mistaken for a large tile.

The patterns shown in Figure 5 have the following descriptions:

1. The angulate pattern is a modified type of trellis drainage pattern. Parallelism in it is similar to the rectangular type but the tributaries join the principal streams at acute or obtuse angles (26: 517). Like the rectangular pattern it reflects the influence of rock joints.

2. An "asymmetrical" drainage pattern has more tributaries on the upslope side of a trunk stream than on the down slope side. This type is commonly found in mountainous territories (13: 352). It is often "pectinate" - shaped like a comb.

3. The barbed drainage pattern is a type of drainage pattern which results from stream piracy. Branching tributaries form obtuse angles with the trunk streams (11: 180). The pattern is "calcarate" - spurred. It is a form of "backhand drainage".

4. The braided drainage pattern is that of a graded stream. An intricate network of shallow channels forms "a complex pattern on the valley floor" (18: 69). Usually the materials deposited by a braided stream are granular, especially in the upper reaches of the stream.

5. An anomalous drainage pattern is the general irregular pattern of an area formed by the combination of dissimilar patterns in adjoining but different types of topography. This complex pattern indicates the existence of unlike materials in an area. The component pattern of the complex pattern can be studied individually.

6. The thermokarst drainage pattern is that produced by the surface thawing of permafrost (25: 2). It is formed by cave-in lakes which eventually become joined together by streams. The concatenate pattern of the "button" lakes is a singular feature. Usually the thermokarst pattern is found in areas of fine-grained alluvial sediments (9: 17).

Figure 6 presents other patterns which can be described as follows:

1. The lacunate type drainage pattern is formed by small "lakes" spaced at random over an area. Individual tributary systems may be dendritic. It is found where there is impervious substratum. This pattern occurs in areas where the erosion cycle is very young (2). It is a closed-basin type which is found in parts of the southern Great Plains region of the United States.

2. The Yazoo type drainage pattern pertains to larger stream systems than those which are usually considered. It is due to the inability of tributary streams to break through the natural levees of major streams. It is the pattern found on confluence plains - plains on which the tributaries unite before entering the main streams. This pattern develops in alluvial bottom lands.

3. The kettle hole type of drainage pattern is one of random-spaced depressions, with an occasional water-filled basin. Like the lacunate pattern it is a closed basin type, but it occurs where there is a porous substratum. It is the pattern found in granular moraines and outwash plains. Individual tributary systems may be dendritic.

4. The elongated bay type drainage pattern is one peculiar to coastal plain or delta areas. (The author believes the bays in the Carolinas and Texas to be cave-in lakes formed in permafrost during glacial times.) Rows of the bays follow the lows (troughs) in old beaches. This indicates that they have been formed in fine-grained sediments.

5. The reticular type drainage pattern is a network of stream chan-

nels. It is "canaliculated" - having many channels. It is a variation of the anastomotic pattern but is different in that it is found in tidal marshes and in youthful coastal plains (26: 514). At flood tide the water flows inward through the channels; at ebb tide, outward. It is a pattern of anabranches - the diverging branches of a large coastal plain stream which reenter that same stream.

6. The phantom drainage pattern is one of seepage ways. It is a network, also. The pattern is caliginous and arachnoid - dim, and cobweblike. It is found in "loose" (unconsolidated) fine-grained but well-drained soils on impervious subsoils.

ANALYSES OF REGIONAL DRAINAGE PATTERNS

The following illustrations which show airphotos paired with drainage maps are presented as examples of representative typical regional drainage patterns. The examples show noticeable differences in drainage patterns of materials common to various physiographic regions.

The patterns are classified according to the basic or modified types of drainage patterns. The forms and textures of the patterns are studied for the influences exerted on them by the soils and bedrocks in which they exist. The effects of peculiarities of topography and extraneous materials

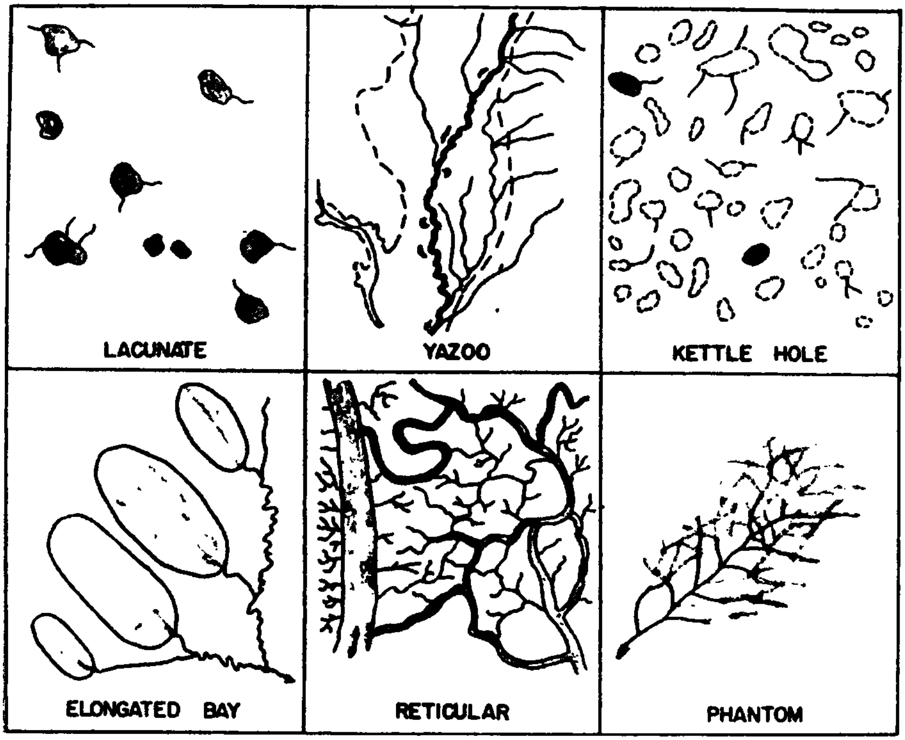

Figure 6. Sketches of Modified Basic Drainage Patterns - Shaded outlined areas are water-filled channels or basins - rivers, ponds, lakes. Shaded lines indicate high water table areas or seepage ways. Dotted lines bound infiltration basins.

on the patterns are noted also.

From a logical standpoint, the examples of drainage patterns found in residual materials are considered first; then, those in transported materials. The examples from different regions of residual materials are drainage patterns found in both horizontal and tilted rocks; and the examples from regions of transported materials are drainage patterns found in glacial drift, and water-laid and windblown soils.

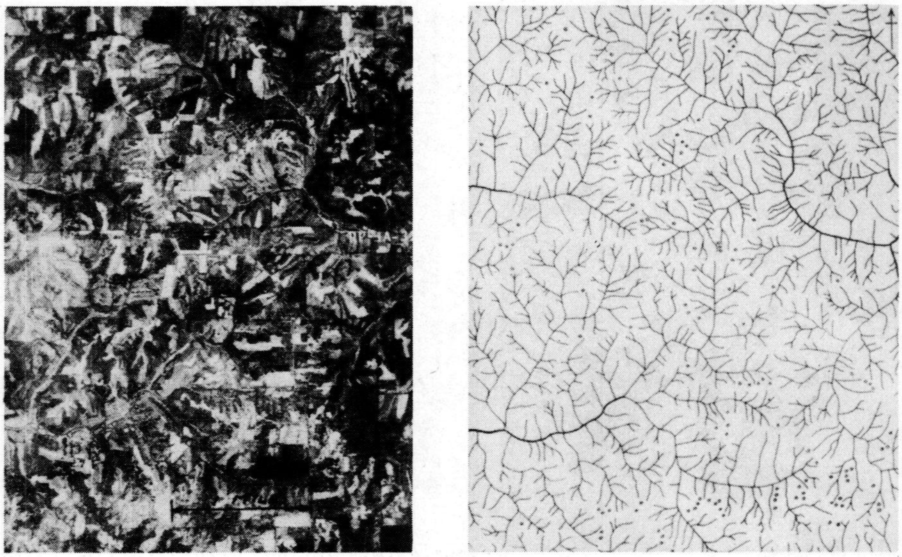

Figure 7. Drainage Pattern of Limestone-Shale (Ordovician) (20) (21) - Left - Airphoto of Area in Southwestern Switzerland County, Indiana - Right - Drainage Map of Same Area - Small circles are sinkholes.

Figure 8. Sloughing of Colluvial Hillside - Eastern Ohio County, Indiana (10) - Rock and soil break away from the hill to produce landslides.

Limestone-Shale - The intricately dendritic drainage pattern shown in Figure 7 compares closely to the basic dendritic pattern shown in Figure 2. It has some of the characteristics of the subdendritic pattern shown in Figure 3 but hardly enough for it to be classified as subdendritic. However, the presence of two materials, nearly horizontal thinly-bedded strata of limestone and shale of different textures, does lend the pattern an irregularity which indicates slight structural control. The primary tributaries flowing in shale are deflected, sometimes sharply, when they contact the more resistant limestone. Sinkholes are found on the ridges where a limestone layer is sufficiently thick to permit their development. These sinkholes affect the drainage pattern only to the extent of occasional surface depressions, for most of the runoff water flowing through them finds its way immediately into adjacent streams. The density of the pattern is great (or

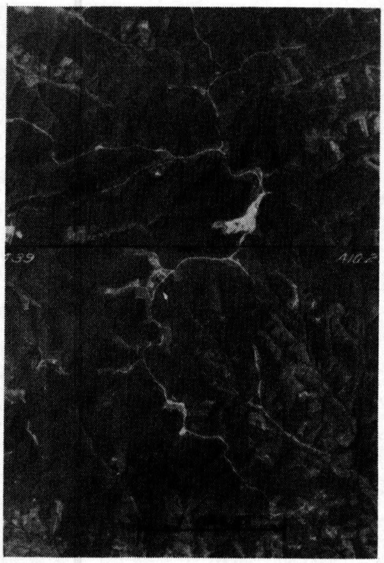

Figure 9. Drainage Pattern of Sandstone-Shale (Mississippi) (20) (21) - Left - Airphoto of Weed Patch Hill Area in Brown County, Indiana - Right - Drainage Map of Same Area - Artificial lakes are indicated by shaded spots.

Figure 10. Gully in Residual Soils Formed from Sandstone-Shale (Mississippian), East-Central Brown County, Indiana (10) - In the foreground, fragments of sandstone may be seen in the bottom of the gully.

fine) because of the presence of imperviousshale as well as because of a great difference in elevation between the ridges and the valleys.

This region was once covered with Illinoian glacial drift but the drift has been removed by erosion until now only traces of it are found on the highest ridges. The presence of the Illinoian drift apparently does not affect the drainage pattern. The pattern has resumed its primitive, or pre-glacial development.

Colluvial slopes found throughout the region cause many landslides in highway construction (See Fig. 8).

Sandstone-Shale - Figure 9 illustrates the slightly modified dendritic drainage pattern - somewhat subdendritic - developed in an area of laminated sandstone and shale. The area is especially known for the "perfection and symmetry of its drainage lines" (11: 90-94). The sandstone-shale has eroded to produce a "rangy" dendritic drainage pattern of which the branching of the smaller tributaries is confined mostly to their "tip ends". The sandstones are more or less pure, are usually rather soft, and are intercalated with sandy shales. Soils weathered from them are plastic clays which erode in V-shaped gullies because of steep slopes (See Fig. 10). Forests cover most of the hills as shown by the botryoidal texture of the airphoto in Figure 9.

The region is mature and the interfluves have been reduced to knife-like ridges. The ridges are clearly defined by the spaces between the tip ends of the first order tributaries (field gullies).

Weathering sandstone breaks down into small flat fragments; stream deposits of this material are known as "brown gravel". Although this gravel is used locally for road building material it is not very durable. It is detrimental as an aggregate for concrete.

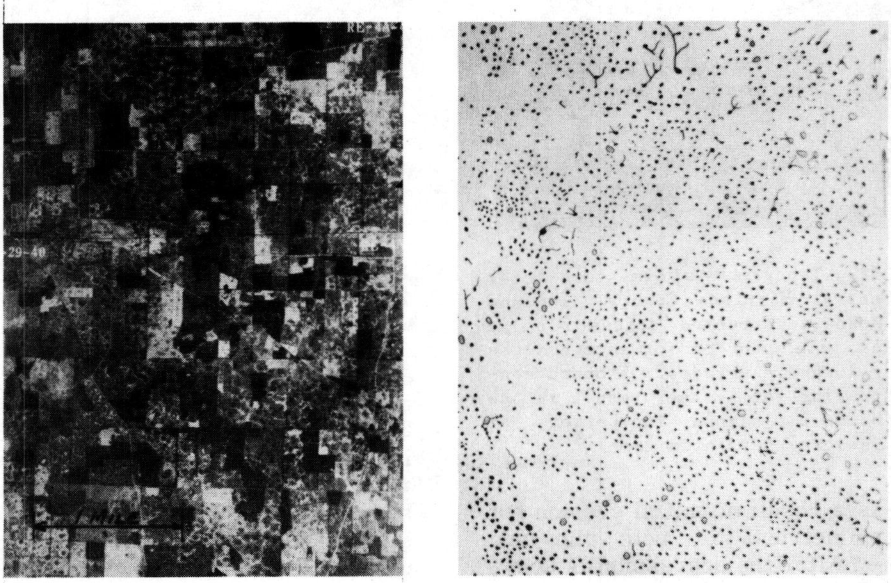

Figure 11. Drainage Pattern of Young Karst Topography (Mississippian Limestone) (20) - Left - Airphoto of Sinkhole Area in Washington County, Indiana - Right - Drainage Map of Same Area - Dots indicate sinkholes, some of which have small dendritic drainage systems. Shaded areas are water-filled basins - plugged sinkholes.

The influence of the shale is seen in the additional subdivisions of the smaller tributaries. Angularity in the pattern occurs because the sandstones are resistant to erosion. The density of the pattern indicates that immediate runoff is less than for limestone-shale regions (Fig. 7). The medium density is due to the somewhat pervious nature of sandstone and to the considerable difference in the elevation between the ridges and the valleys. The pattern is influenced very little by the general slope of the region.

Massive Limestone - Figure 11 illustrates the "swallow hole" drainage pattern of a youthful karst plain. Such plains are distinctive because their surface features are the "result of the solvent work of underground water" instead of surface streams (8: 321). In the area represented by this illustration there are no small streams although small streams are occasionally present in similar areas. The surface of a young karst plain is undulating, often rolling, and sometimes rough; it is known as sinkhole topography. The sinkholes are identified on the airphoto portion of Figure 11 by dark-centered circular light gray spots.

In the formation of young karst plains, water first flows through a fissure in the underlying limestone and begins dissolving the rock. When the surface depression has become approximately five feet in diameter it is known as a "ponor"; it has steep vertical

Figure 12. Topography of Limestone Area, North-Central Harrison County, Indiana (10) - Roads constructed across plugged sinkholes give poor performance because of water-logged subgrades. Flooded conditions during wet weather result in the roads being impassable for periods of several days at a time.

slopes as a result of initial erosion but is "asymmetrical in both plan and profile". After the depression is deepened and widened it is then called a "doline"; its slopes are regular and its outline is symmetrical - it is circular if the fissure is short and oval if the opening is long. A "basin" is a filled doline; if the bottom outlet has become plugged with clay and other debris, swamps, temporary ponds, and even permanent lakes form (5: 713) (See Fig. 12).

The clays that develop from the weathering limestone have a peculiar "nutty" structure. They are well-drained "in situ", but they are very impervious and plastic when reworked by highway construction machinery (See Fig. 13).

Clay Shale -A most minutely (very fine) dendritic drainage pattern, shown in Figure 14, is that produced by eroding clay shale. Because the shale is completely impervious, the runoff is almost equal to the total rainfall. Surface drainage is developed fully. Streams flowing in shale usually do not reflect lineal control. An intricate stream system is formed which resembles the venation of a broad leaf of a deciduous tree. This pattern approaches the true

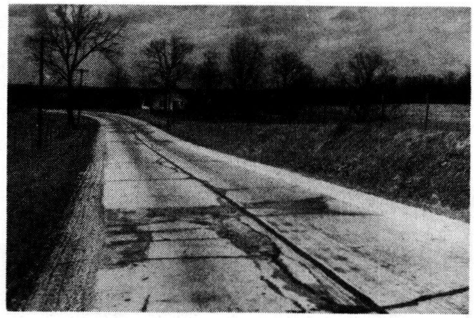

Figure 13. Concrete Pavement in Central Lawrence County, Indiana - Pavements often break up in shallow road cuts in the clays of limestone regions.

dendritic pattern illustrated in Figure 2. Where the general level of the upland is nearly flat - one to two mi. from the river - the gullies have "rounded" slopes; this is especially noticeable in the lower center of the airphoto in Figure 14. This is a characteristic of clay shale topography. The "smooth" areas outlined in white in the airphoto - left center and lower left - are remnants of the Great Plains mantle which is granular in texture; they do not contribute to the drainage pattern. Gravel is a material resistant to erosion; therefore, it "holds up" the hills. Near the river the drainage pattern is influenced by slope control of the streams. Some of the smaller tributaries are straight and the angles of their junctions with the larger tributaries are very acute. Another cause for this slight change in the pattern is the presence of thin layers of weak sandstones. These can be detected in the airphoto by the "bands" around some of the knolls, and by the presence on these bands of vegetation - shrubs and bushes. Steep slopes cause

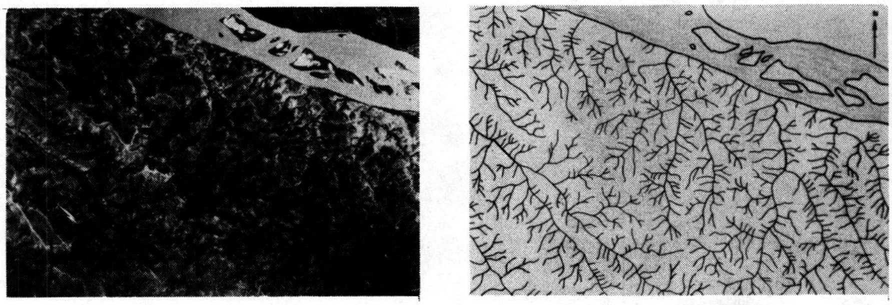

Figure 14. Drainage Pattern of Pierre Shale - Left - Airphoto of Area in Stanley County, South Dakota - Right - Drainage Map of Same Area - Shaded Area is Missouri River.

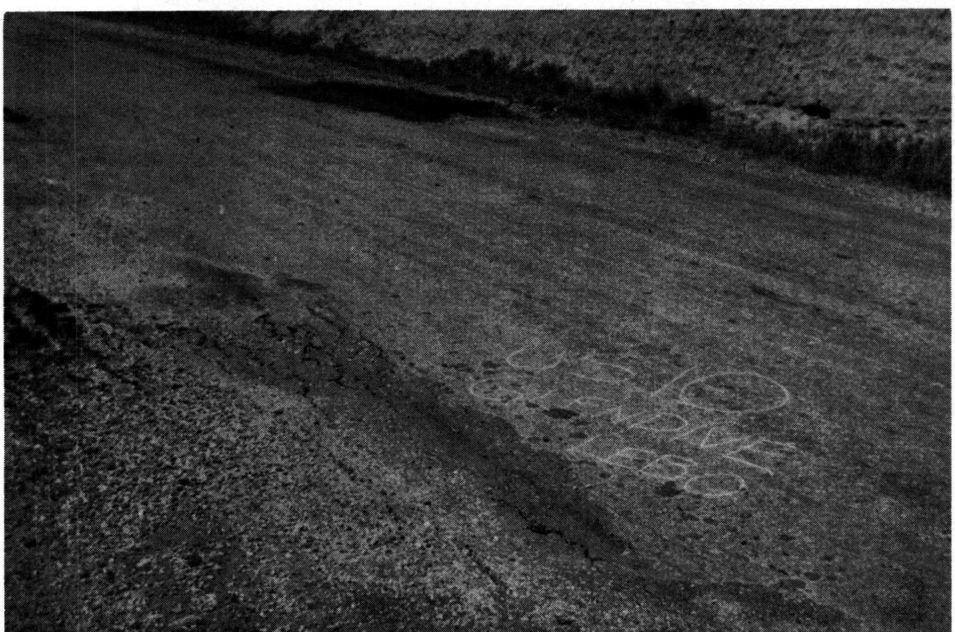

Figure 15. Poor Performance of Flexible Pavement Constructed on Clay Shales of the Northern Great Plains, Near Glendive, Montana - Lebo shales are similar to those illustrated in Figure 14.

V-shaped gullies; therefore, the cyma-curve cross sections of the upland gullies are extremely modified or lacking in the gullies near the river. The Flexible pavements, like the one shown in Figure 15, suffer considerable distress when placed directly upon plastic clay subgrades.

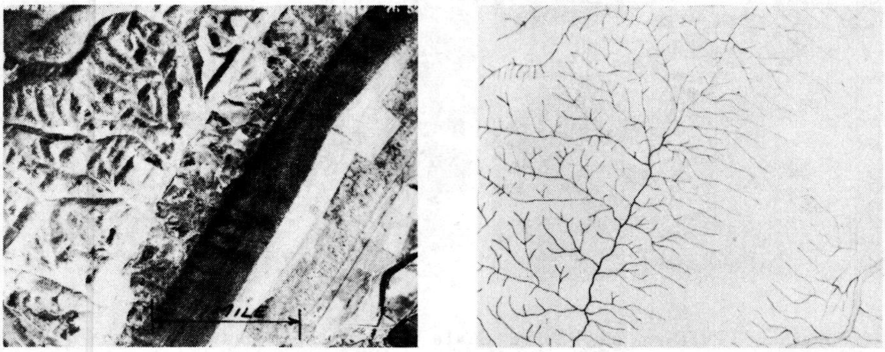

Figure 16. Drainage Pattern of Tilted Sandstone and Sandstone-Shale - Left - Airphoto of Area in Hampshire County, West Virginia - Right - Drainage Map of Same Area - Shaded area is a river.

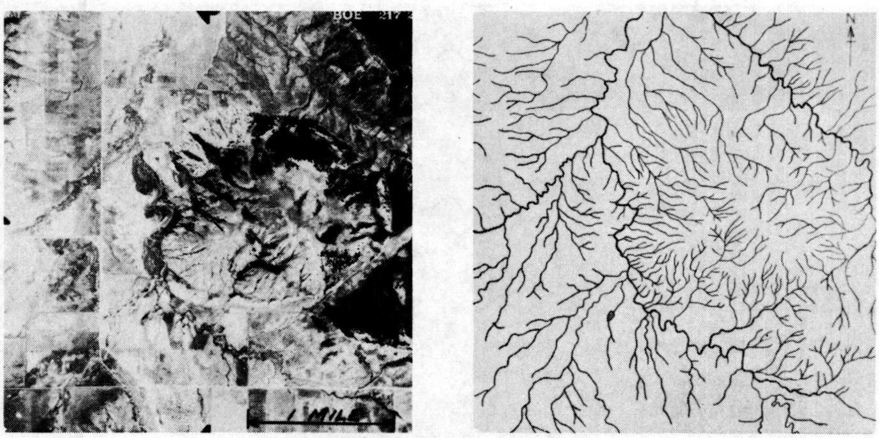

Figure 17. Drainage Pattern of Granite Dome - Left - Airphoto of Area in Lawrence County, South Dakota - Highways are straight white lines - Right - Drainage Map of Same Area - Shaded area is an artificial pond.

main tributaries have almost reached base level, in the vicinity of the river; here their courses have many full-curved meanderings. Parallelism may even be detected in the larger tributaries.

Clay shales weather to fine-grained, plastic, poorly-drained clay soils.

Tilted Sandstone and Shale - Figure 16 is the drainage pattern of an area of folded and tilted sandstones and shales. The drainage pattern, where the shales predominate, is dendritic (See the upper left half of the airphoto in Fig. 16). Resistant strata - probably sandstones - in the shale area give lineal control to some of the streams in that area. Streams are absent along the crest of the sandstone ridge (See lower right half of the drainage map in Fig. 16). Small "parallel" streams are spaced at "regular" intervals along the steep slopes of the sandstone ridge and form a subparallel drainage pattern on the left side of the ridge. The stream collecting the run-off waters from both the shale and the sandstone areas is flowing in shale.

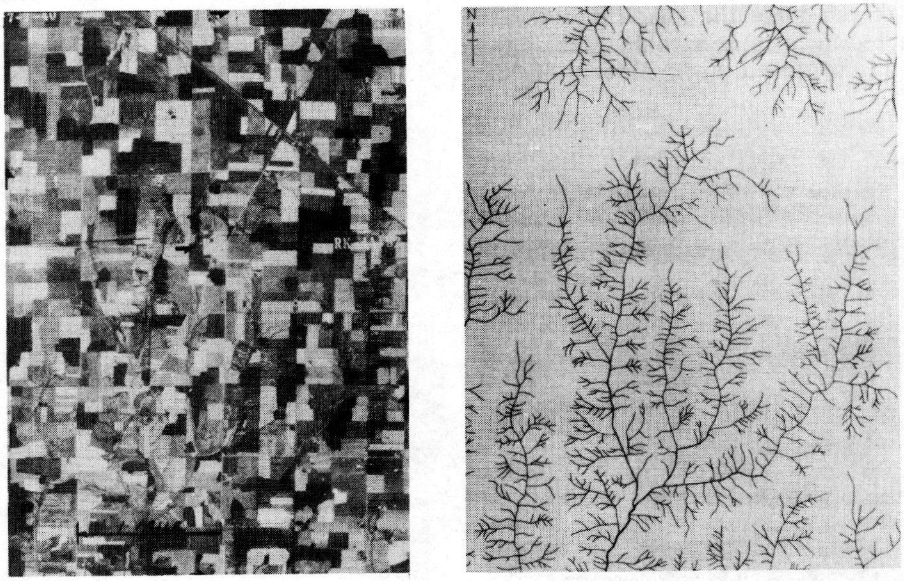

Figure 18. Drainage Pattern of Illinoian Glacial Drift (20) (21) - Left - Airphoto of Area in Ripley County, Indiana - Right - Drainage Map of Same Area

Figure 19. Erosion Control in Illinoian Glacial Drift Region, Jennings County, Indiana - At the extreme right-center, the very light tones of gray mark the silty edges of a lateral gully.

This stream is a part of a regional trellis drainage pattern which can not be shown by a single airphoto. The weakly developed subparallel drainage pattern on the right of the sandstone ridge has formed partly in shale since the river is flowing in shale, also.

In regions of sedimentary rocks slope control plays an important part in the development of the drainage pattern - the more resistant the material, the steeper the slopes. Consequently, the lines of the pattern are more nearly straight on steep slopes for fast-moving water tends to flow in straight lines. Sandstone is more resistant to erosion than shale. The drainage pattern in shale has a "roundness" contrasted to the "angularity" of the stream patterns in sandstone areas.

Granite Dome -Figure 17 illustrates the radial and annular drainage patterns of a granite dome. The streams of the plain have been forced to go around the bulging mass of granite, some of them making right-angle turns in the process. Radial streams course down the dome. These streams unite at lower elevations with sharp entrant angles. Near the base of the dome the runoff waters are collected in annular streams inside the rim of upturned sedimentary rocks.

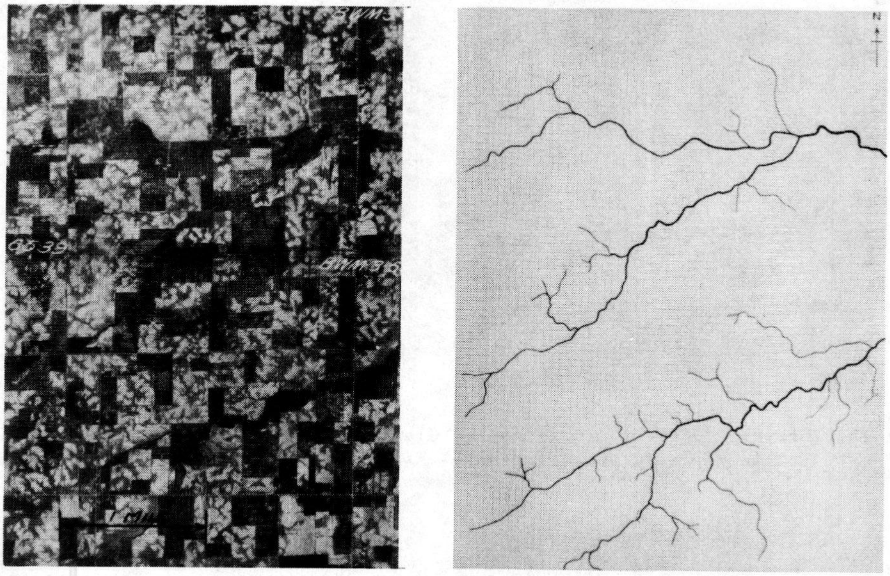

Figure 20. Drainage Pattern of Wisconsin Glacial Drift (20) (21), Tipton County, Indiana - Left - Airphoto of Tipton Till Plain - White lines are roads which follow land section boundaries - Right - Drainage Map of Same Area

Illinoian Glacial Drift - Figure 18 is a typical drainage pattern of the Illinoian drift region in southeastern Indiana. The drainage pattern is "subdendritic", a modification of the dendritic type with long, nearly parallel tributary systems. The pattern has a pronounced "lacy" appearance. Illinoian drift is the oldest surface drift in Indiana. Its topographical features are subdued. It is free from swells and ridges. It shows the effects of age and weathering, for the soil has a developed profile of approximately 10 ft. (3: 187). The "A" horizon consists of about two ft. of silt and the "B" horizon usually consists of 8 to 10 ft. of "expansive silty-clay" (3: 187). Much of the surface is so nearly level that it is imperfectly drained. The subsoil is impervious and is very poorly drained internally. Surface drainage furnishes a particularly significant airphoto identification element which is the "white-fringed" gully. The broad flat bottom of this type of gully is formed by erosion removing the top soil (silt) from the impervious clay subsoil (See Fig. 19). Long shallow tributaries indicate low velocity of the runoff water. Where the gradient becomes steep and the runoff water cuts into the clay, the gullies become V-shaped. Secondary tributaries show minor slope control. Wide expanses show no developed drainage pattern; here the terrain is nearly flat and headward erosion has not cut into the silty "A" horizon.

Wisconsin Glacial Drift -Figure 20 is representative of a typical drainage pattern of the Tipton Till Plain which is an irregular, undulating sheet of till.

Although the main streams in the illustration are "roughly parallel, with few

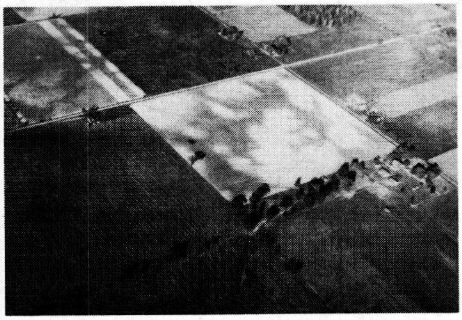

Figure 21. Low Altitude Oblique Airphoto of a Wisconsin Glacial Drift Area, Tipton County, Indiana - The Brookston-Crosby soil pattern is easily identified even though the field has a cover crop. Faint near-white lines in some of the dark areas show a tendency toward gully development.

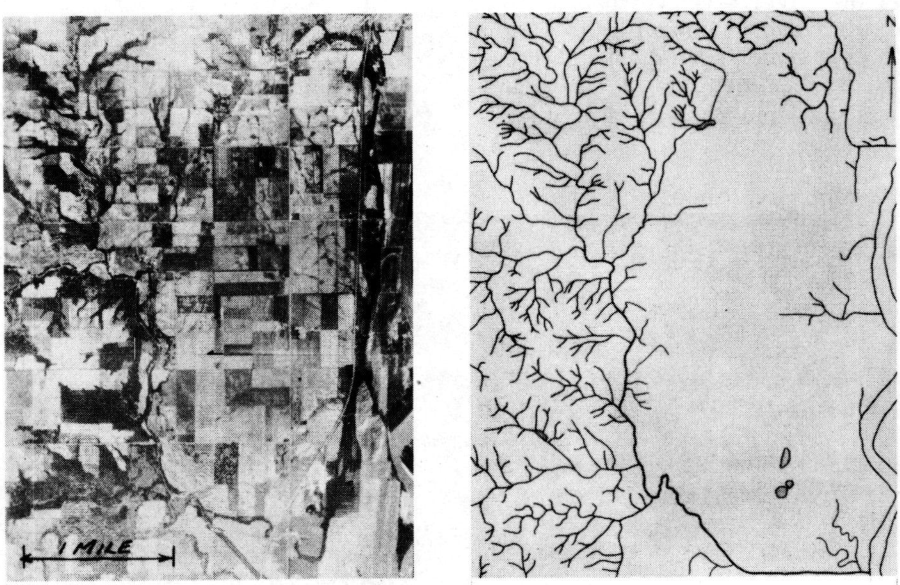

Figure 22. Drainage Pattern of Granular Terrace (20) - Left - Airphoto of Area in Vermillion County, Indiana - Right - Drainage Map of Same Area - Shaded spots are water-filled gravel pits.

and only short tributaries" the general drainage pattern of the till plain is broadly dendritic - very coarse textured (15: 390). It has the appearance of the forked ends of chain lightning (Also see Fig. 1). The topography of the Tipton Till Plain is featureless - differences in elevation being from 2 to 20 ft. It has been referred to as a region of "little relief and meager modification by dissecting streams" (24: 17). The drift is recent in age - it is unconsoildated and, therefore, pervious. This reduces the amount of small gullies, for part of the runoff becomes subsurface drainage. Besides the drainage pattern, an outstanding identifying airphoto element is the "marbleized" or "black-and-white mottled" pattern often referred to as the Brookston-Crosby pattern (23: 39) (See Fig. 21). The drainage of the till plain is connected through the darker, lower-lying depressions. These dark areas indicate the presence of moisture, silty clays, clay, and organic matter in the soil (14: 27). Gentle gradients of these depressions prevent any but sheet erosion over extensive areas. The divides are flat and the streams sluggish. Wherever the gradient becomes steep enough for gullies to form these gullies are like "grooves" in the plain and they empty into creeks which flow in shallow, wide "valleys". The drainage of a glaciated region has been described as "glacially disturbed" for drift deposits have obscured pre-glacial stream systems and new drainage systems have developed (26).

Granular Terrace - Figure 22 is the weakly developed dendritic drainage pattern characteristic of granular terraces found in the Wabash River valley in western Indiana. The almost total absence of surface drainage in the right half of the map in the illustration is a significant feature of the pattern. Internal drainage through infiltration basins provides an escape for nearly all runoff water. A few drainage ways follow depressions which are abandoned channels of the post-glacial braided stream that deposited the gravel. Occasional short, steep, V-shaped gullies are found along the terrace face next to the river. Gravel because of its porosity and permeability to water resists erosion. A most striking feature is the inability of the upland streams to cut across the terrace. The stream collecting the drainage of these upland streams flows in a slack water trough to a point where it can enter the river. The complete lack of relationship of the upland subdendritic drainage pattern of medium density to that of the terrace gives the entire area an "irregular" drainage pattern (26) (See sketch of anomalous drainage pattern in Fig. 5).

Figure 23. Flexible Pavement Constructed on an Ohio River Granular Terrace, Switzerland County, Indiana (20) - Only very shallow side ditches are required because of good internal drainage of the terrace materials. Highways on granular terraces usually give excellent performance.

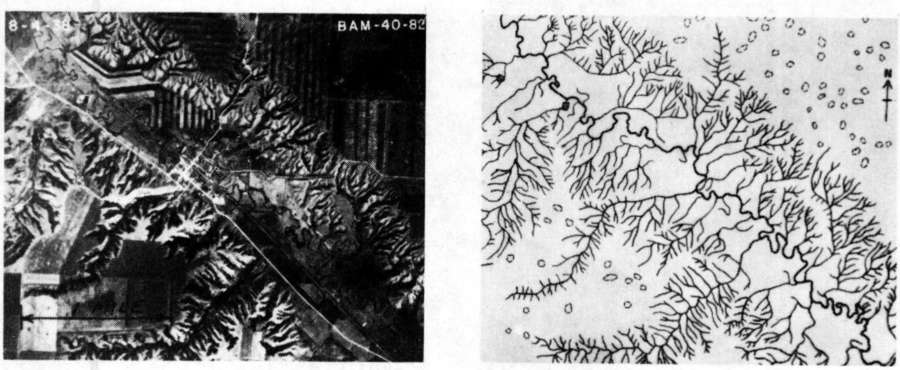

Figure 24. Drainage Pattern of Glacial Lakebed - Left - Airphoto of Glacial Lake Souris Area in Ward County, North Dakota - Right - Drainage Map of Same Area - Basins are outlined by dotted lines.

Terraces such as the one illustrated are composed of granular materials transported by glacial melt waters draining Wisconsin drift areas and are important sources of gravel and sand throughout Indiana. Figure 23 shows excellent highway performance on a similar granular terrace.

Glacial Lakebed - Figure 24 illustrates the anomalous drainage pattern of an area in a glacial lakebed region. The gullies in the walls of the valley of the river are typical lakebed gullies. The pattern of the shorter gullies is sub-dendritic and that of the longer stream systems is pinnate. The pinnate drainage pattern is found in eroding silty soils. The upland areas - the even floor of the lakebed itself - contain small basins. These give the overall pattern its irregularity. The lakebed sediments are "comprised largely of sand, silt, and clay" (1: 59).

These lakebed sediments cover the uneven glacial drift of the inner border of a granular moraine which is a short distance southwest of the area illustrated. Lakebed silty clays are stratified and impervious to water. They are generally plastic and poorly drained internally (See Fig. 25).

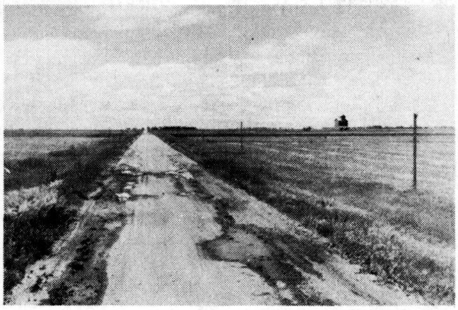

Figure 25. Poor Highway Performance on Glacial Lakebed Soils of Ward County, North Dakota

Figure 27. Topography of Altamont Moraine in Ward County, North Dakota - Left - Organic Soils of Infiltration Basin

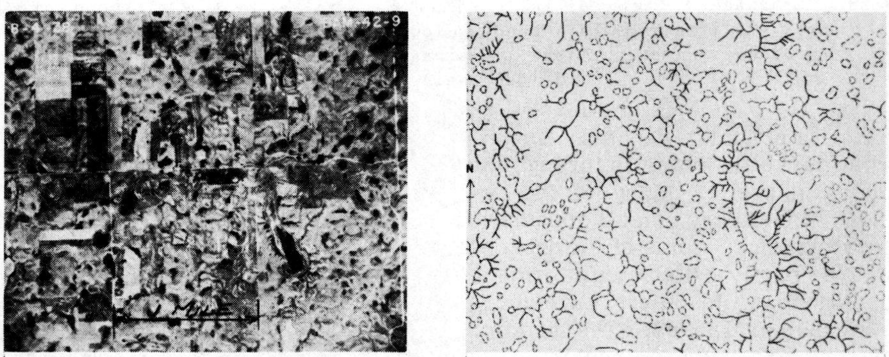

Figure 26. Drainage Pattern of Kettle-Kame Moraine - Left - Airphoto of a Portion of the Altamont Moraine in Ward County, North Dakota - Right - Drainage Map of Same Area - Infiltration basins are bounded by dotted lines.

Kettle Kame Moraine - Figure 26 illustrates the "kettle hole" drainage pattern of a granular moraine. Granular knolls of various sizes and shapes are scattered over the area without orderly arrangement; these consist of unconsolidated gravels, sands, and boulders "with minor amounts of finer sediments"

(1: 58). Numerous depressions called kettle holes are found among the knolls throughout the area. It is difficult to say whether the knolls or the depressions predominate. There is no developed surface drainage in the area. Short, V-shaped gullies having steep gradients can be seen on some of the knolls; this is an identifying charac-

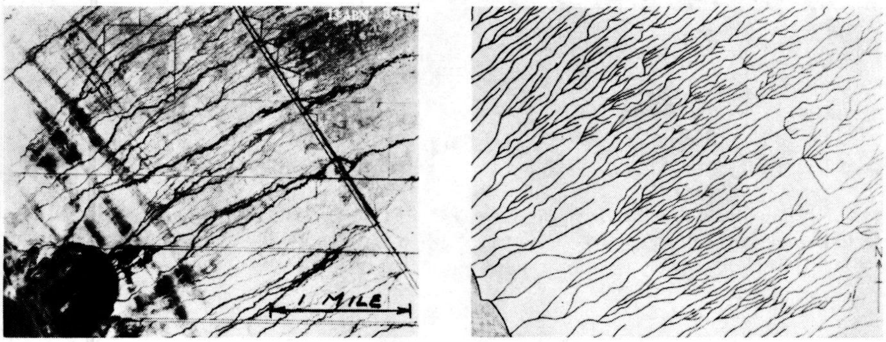

Figure 28. Drainage Pattern of Valley Fill Material - Left - Airphoto of Area in Imperial County, California - Dark bands in lower left corner of airphoto are beach lines - have fine-grained sediments - Right - Drainage Map of Same Area - Shaded area is water-filled basin (lake).

teristic of a granular deposit. Drainage from the kettle holes is through the underlying gravels. Many of the depressions have very small dendritic tributary systems. Some of the depressions are partly filled with organic accumulations while others have more or less ephemeral lakes. The smaller depressions are nearly circular while the larger ones are elongated. The depressions are closed basins from a few yards to a mile or more in extent. The floors of some of the larger basins are level and are cultivated since the soils hold moisture for a period of time (See Fig. 27).

Valley Fill Material -Figure 28 illustrates the parallel drainage pattern of valley fill materials. This area is the gently sloping apron of erosional debris accumulated from the nearby mountains. The texture of the material is predominately coarse, although dark bands in the airphoto portion of Figure 28 indicate beach lines where finer sediments (clays) have collected. These "bands" support vegetation for they retain moisture (See Fig. 29). Straight streams having box-like cross sections are formed by flash floods.

Great Plains Mantle (Ogallala) - Figure 30 illustrates the lacunate drainage

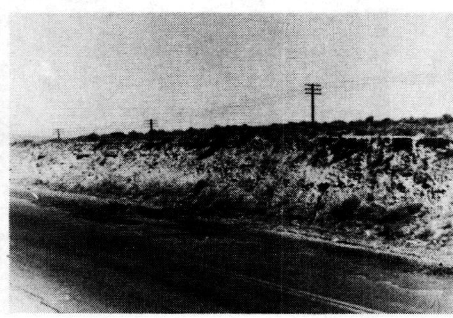

Figure 29. Poor Highway Performance in Valley Fill Materials - Northeastern Nevada - Construction operations removed granular materials - highway rests on fine-textured sediments.

pattern of an Ogallala area in the southern Great Plains region. The relief of the area is gently undulating. There are no streams other than the small dendritic systems of individual basins. Many of the depressions contain water for days and even weeks after a period of wet weather. The term "poly basin" might aptly be applied to this area because of the depressions. The subsoil is impervious; it is probably a "marl". Erosion is controlled by contour farming (See the airphoto portion of Fig. 30).

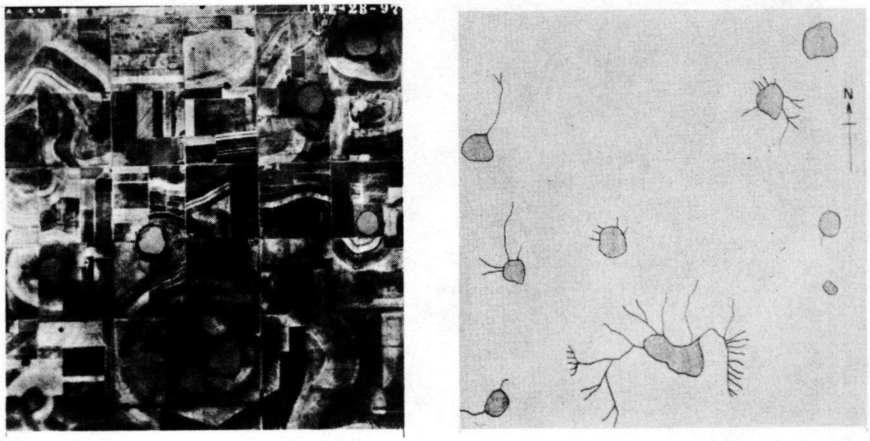

Figure 30. Drainage Pattern of Great Plains Mantle (Ogallala) - Left - Airphoto of Area in Lamb County, Texas - Right - Drainage Map of Same Area - Water-filled basins are shaded.

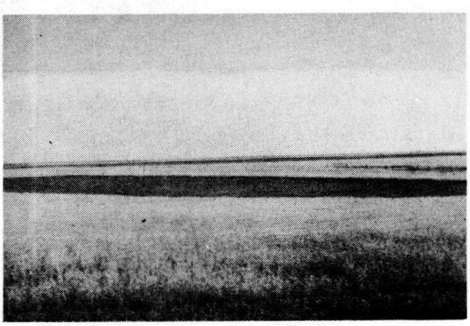

Figure 31. ''Buffalo Wallow'' in Eastern Colorado Near Kansas State Line - These slight depressions are closed basins.

In the inter-depression ridges the soils are silty and in places contain a large percentage of sand. The clay content of the soils increases toward the centers of the depressions. Locally these depressions are called "buffalo wallows" (See Fig. 31).

Loess - The drainage pattern in deep loess deposits, illustrated by Figure 32, is a modified dendritic pattern referred to as pinnate because of the feather or frond-like appearance of individual tributary systems. The lateral gullies are short and spaced at "regular" intervals along both sides of the principal tributaries which they enter at nearly right angles (See Fig. 33). The gully cross sections are hyoid shaped - like a "U"; and their gradients are compound - very steep at the headward end. Figure 32 is a striking example of eroding wind-blown silt found in parts of the Great Plains Region. The density of the pattern indicates large scale erosion in this area. Great Plains loess areas are generally nearly level tracts with very long, parallel, low, and fairly broad ridges which are not easily detected on single airphotos. Loess has a peculiar structure in that internal drainage is vertical. Where slopes are steep enough for erosion to start and where there is sufficient rainfall, the region soon becomes badly dissected. The ridges and valleys of deep loess deposits fix the direction of the trunk streams

(16: 98). The principal tributaries are long and often nearly parallel to each other.

The ridges of river valley loess are more pronounced than those in the Great Plains (See Fig. 34).

the drainage map of the county (See Fig. 35).

It is easily seen that the dendritic drainage pattern at "A" is repeated in a band 5 to 10 mi. wide along the right bank of the Ohio River. It is possible,

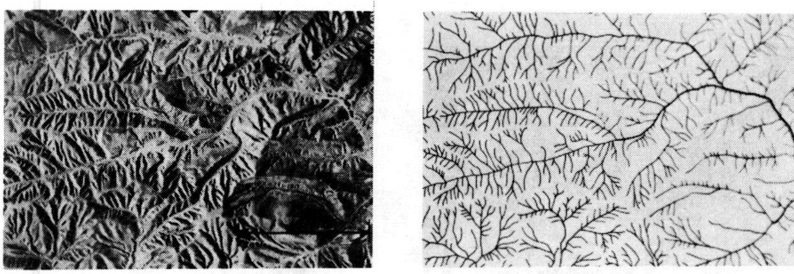

Figure 32. Drainage Pattern of Loess - Left - Airphoto of Area in Lincoln County, Nebraska - Right - Drainage Map of Same Area

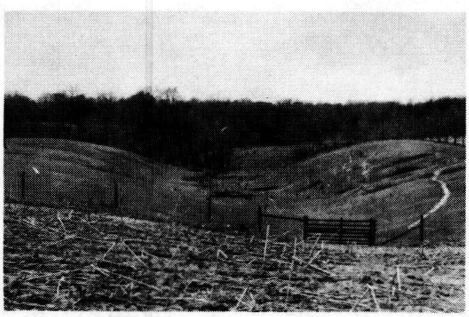

Figure 33. Gully System in Loess-Covered Area, Posey County, Indiana - Lateral gullies to the right and left of the main gully form the pinnate drainage pattern by which loess-covered regions can be identified.

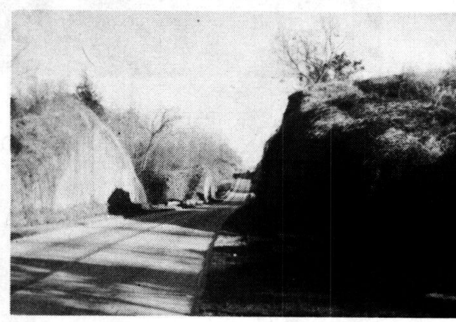

Figure 34. Highway Constructed Through Ridges of Loess, North of Vicksburg, Mississippi - Road cuts are vertical.

THE APPLICATION OF DRAINAGE PATTERNS IN THE IDENTIFICATION OF REGIONAL SOILS AND BEDROCKS

Drainage patterns can be used in the identification of soils and bedrocks of an area. This statement is verified by the compilation from airphotos of a detailed surface drainage map of Switzerland County, Indiana (19). Three drainage patterns may be recognized readily in

then, to state with reasonable accuracy that bedrock materials (Ordovician limestones and shales) similar to those found at "A" will be found throughout this band.

It is observed, also, that the subdendritic drainage pattern at "B" is repeated in an area, centering about "B", of 35 to 40 sq. mi. in extent. It is possible to state, with assurance, that one material (Illinoian glacial drift) is the surface soil throughout this entire area.

The weakly developed dendritic

drainage pattern at "C" identifies a granular terrace. Similar patterns are detected about five mi. to the right of "C", and about five mi. to the left of "C". Knowing that a granular terrace exists at "C", it is within reason to predict that granular terraces are to be found in the other two areas.

application of keen observation on the part of the airphoto interpreter. The correlation of the salient characteristics of drainage patterns with known types of land surface materials is dependent upon his ability to understand the significance of the form and texture of the developed drainage patterns. This

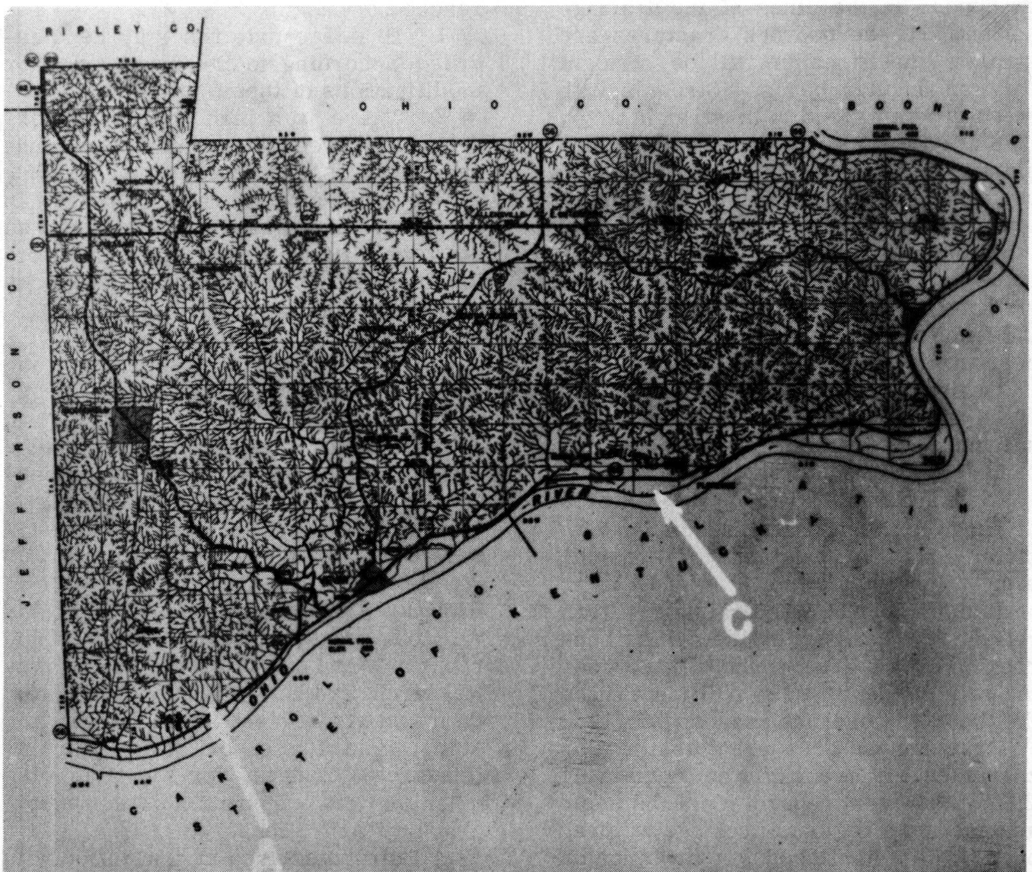

Figure 35. The drainage map of Switzerland County, Indiana, exhibits the following drainage patterns: ''A'' - Dendritic drainage pattern of Ordovician limestone-shale regions (See Fig. 2 and 7). ''B'' - Subdendritic drainage pattern of Illinoian glacial drift regions (See Fig. 3 and 18). ''C'' - Weakly developed dendritic drainage pattern of river valley granular terraces (See Fig. 22). (This map was compiled from aerial photographs in the laboratories of the Joint Highway Research Project at Purdue University, Lafayette, Indiana. Scale: Typical square of grid system equals one sq. mi.)

SUMMARY AND CONCLUSIONS

The recognition, on aerial photographs, of the patterns of stream systems of an area is essentially the understanding makes possible the drawing of tentative conclusions regarding the identity of regional soils and bedrocks.

Drainage patterns are formed of

straight and curved lines. Where there is no structural control stream channels are curved. In regions of residual materials the drainage network depends upon the distribution of bedrock, and its surfaces of weakness. If the plan of a drainage system conforms with the structure of the bedrock, the same repeating pattern of uniformly-spaced fractures in that rock may be expected to appear in the lines of the drainage pattern. If the bedrock fractures are straight the streams will be straight between angular bends. Streams with steep gradients tend to be straight also.

Since most streams have their beginnings in soils or thinly mantled bedrocks, the patterns of streams of lower order (first, second, third, etc.) furnish clues by which those soils or bedrocks can be identified. It is the streams of higher order that show the influence of the structural control of the bedrocks.

Drainage patterns are coarse-textured in regions where the bedrock or soil mantle is resistant to erosion; e.g., sandstones, granular deposits, unconsolidated glacial drift. Fine-textured drainage patterns are associated with materials non-resistant to erosion; e.g., clay shales, silts, sand clays.

In other words, the drainage pattern reflects the porosity of the soil or bedrock in which it is found. Likewise, the relative depth of the soil mantle and the dip of the bedrock may be inferred.

Drainage patterns are classified for convenience of describing and comparing them. However, regardless of the name assigned to a regional drainage pattern, once it is established for a particular type of soil or bedrock, similar drainage patterns recognized within the region indicate the presence of materials similar to those associated with the established pattern.

By studying first the particularly conspicuous features of the overall drainage lines of a region it is possible to make deductions concerning bedrock structural control of the streams of the area. Moving, then, from the general to the specific, the details of the patterns formed by the headwater tributaries are the means by which repetitive drainage patterns within the region are classified. Accidental localized variations in those recurring patterns are disregarded. Recurring patterns are similar but rarely identical.

On the basis of observations made during the analyses of recurring drainage patterns in various physiographic regions throughout the United States, the following conclusions have been reached:

1. Drainage patterns may be classified according to the basic types or modifications of them.

2. There is a high degree of correlation between the drainage patterns and the soils and bedrocks of regions.

3. Drainage patterns recognized in the aerial photographs of a region can be relied upon to aid in the airphoto identification of the soils and bedrocks of that region.

ACKNOWLEDGMENTS

The author wishes to acknowledge the assistance given by all those persons who have helped in the preparation of this report. Special acknowledgments are due: Professor K. B. Woods, Associate Director of the Joint Highway Research Project for his valuable suggestions and review of the report; Members of the Joint Highway Research Project Advisory Board, for their active interest in furthering this study; and Professor R. E. Frost, Research Engineer, for his aid in the selection and preparation of the photographic illustrations.

All airphotos used in connection with the preparation of this report automatically carry the following credit line: "Photographed for Field Service Branch - PMA - USDA". Other photographs taken by Joint Highway Research Project staff photographers.

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MAPS FOR CONSTRUCTION MATERIALS[1]

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SYNOPSIS

The basic materials that the engineer needs for construction are the rocks and sediments of the earth's crust. The geologist, because of his experience in mapping these same rocks and sediments, is well qualified to prepare the maps the engineer needs in his search for construction materials. The completion of short- and long-range construction programs requires great quantities of these basic materials. The use of the geologist in preparing materials maps will result in considerable reduction in the cost of engineering construction.

The three principal kinds of construction-material maps are discussed: material-site, mateerial-distribution, and surface-geology.

Material-Site Maps - The material-site map is the least expensive of the three kinds to prepare. It is an excellent inventory of materials that have already been found and tested, but it includes only those known to the compiler by reason of the basic data with which he has been supplied. It does not show other construction materials that may be present in the same area but have not previously been needed and tested. It is a poor basis for the search for additional materials.

Material-Distribution Maps - The map is based on the geologic maps available for a region. Each outcropping formation shown on a geologic map is classified as to the kind of construction material that can be produced from it. The area of outcrop of that geologic formation, then, is the area of distribution of that material.

The cost of a material-distribution map is only moderate. The map is an excellent inventory of all kinds of material available in a region, and it shows the potential production areas for each material.

Surface-Geology Maps - The surface-geology map combines many of the useful features of the other two kinds. It is constructed to a relatively large scale; it shows the outcrop areas of all geologic formations and the locations of existing pits and quarries in the area.

A field party maps the geologic formations, both consolidated rocks and unconsolidated sediments, usually on aerial photographs. The party plots the locations of all existing pits and quarries, locates additional materials, and collects samples for laboratory testing.

The surface-geology map is the most expensive of the three to prepare. The expense, however, is a self-liquidating one and the money expended is returned many times over. The map itself serves indefinitely as a completely adequate base for the efficient search for materials, and is also a valuable source of information for the planning engineer, for the design engineer, and for the engineer estimating the cost of construction.

Basis of this Evaluation - This paper is based upon experiences as a geologist assigned to the mapping of engineering construction materials in Kansas and the preparation of maps to be used in the search for materials in the western part of the United States. The work in Kansas is a cooperative project of the Geological and Materials Departments of the State Highway Commission of Kansas and the Engineering Geology Branch of the United States Geological Survey. It is a continuing project that was started in 1946. The work in western United States is in cooperation with the Military Geology Branch of the Geological Survey.

Definition of Engineering Construction Materials - As the term is used in this paper, engineering construction materials are defined as the naturally occurring materials of the earth's crust that require no more than inexpensive processing before use in construction. Sand, gravel, silt, limestone, and granite are some of the materials included in this restricted definition. Products derived from the rocks of the earth's crust that must be given expensive processing or

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manufacture before they can be used in construction are excluded.

Need for Construction Materials - The basic materials for engineering construction, such as sand-gravel, limestone, and granite, are needed in greater quantities than ever before. They are needed under short-range programs to repair the damages resulting from the shortages in manpower and materials prevailing during the war years. They are needed under long-range programs in ever greater quantities to complete the construction already far along in the planning stage.

These basic materials are a major item of cost in every construction project, whether it be a highway, an airport, or a dam. Through the preparation of adequate maps and by the effective use of those maps in the field exploration for materials, the nearest source of acceptable materials to the project can be located. Haulage costs, therefore, can be reduced to the minimum. In many cases this saving alone will repay the expense of map preparation many times over.

Kinds of Materials Maps - There are three principal kinds of materials maps: (1) material-site, (2) material distribution, and (3) surface-geology. The material-site map is a familiar one; maps of this kind have been prepared for many regions of the United States. The other two, the material-distribution and surface-geology maps, have been adapted for use in material exploration as the result of the work now being carried on in western United States and Kansas.

MATERIAL-SITE MAPS

Description - The material-site map shows the location of pits and quarries that are now being operated or that have been operated in the past. (See Fig. 1, Example of a Material-Site Map.) The map is usually prepared to a relatively small scale, 1 in. equals 10 or 15 mi., but may be constructed to a much larger scale if it is to be used as a part of the construction program of a single project. Although generally constructed in the office from available pit and quarry data sheets, and not field checked, this kind of map can be checked very thoroughly in the field and amplified by that field work.

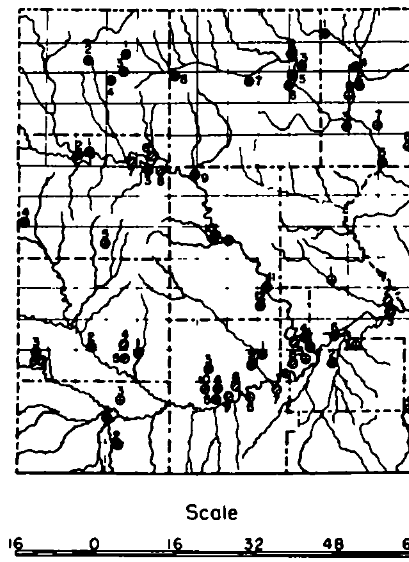


Figure 1. Example of a Material-Site Map

Most material-site maps show the kind of material available at any one place by the use of identifying symbols, which may be black and white or may be colored. In addition, each one of the pit and quarry locations shown is keyed through an index number to a source of basic data on the test properties of that material.

Advantages of Material-Site Maps - Among the advantages inherent in a material-site map is that of the relatively low cost of preparation. The basic data needed by the compiler are already available in the files of the materials department. Probably the cost of such a map for Kansas would range from $10,000 to $15,000, and would include the expenses of compilation, drafting, and publication. It would not, however, provide for collecting and testing additional samples of materials.

A material-site map is of great value in a short-range construction program. It serves as the record of materials known to be immediately available in every part of a wide area, and also indicates the existing pits and quarries from which these materials can be produced. The statistical data correlated with the map will show the quantity and quality of the material available at each site as of the date of compilation of the map. It is a useful inventory of construction materials.

In some circumstances, the material-site map is the only kind that can be prepared for a region. During World War II, for example, material-site maps were prepared by the US Geological Survey to show the available sources of construction materials in enemy-held territory. Even though the maps were prepared from no more than library data, they were found to be very useful to Army engineers after invasion had been accomplished.

Disadvantages of Material-Site Maps - Several disadvantages are inherent in a material-site map. It includes only those material-site locations known to the compiler by reason of the basic data with which he has been supplied. It is entirely possible that some agency unknown to him has opened pits and quarries in the region. Data on such sites are not available for his use and, therefore, his inventory of construction materials cannot be complete.

Nor does a material-site map show all of the kinds of construction materials available in a region; it shows only the sources of materials used in past construction. In one year, for example, a field party may explore an area for sand-gravel. This party, seeking only sources of acceptable sand-gravel, probably would take little note of other construction materials in the area. But five years later a new construction project in the same area might require limestone for use as riprap. A second materials party would then have to go over much of the area covered earlier by the first party. And with each new material requirement there would be the accompanying expense of re-exploring the area. A material-site map is not a complete record of the past exploration for materials.

MATERIAL-DISTRIBUTION MAPS

Description - The material-distribution map can be used as the basis for materials exploration in regions in which little exploration has yet been done or for which data are inadequate or are not available. The map is usually prepared to a small scale, one in. equals 10 or 15 mi. However, it is entirely possible to prepare such a map to a larger scale, one in. equals one or two mi., if there is an adequate source of information.

The map is generally prepared in the office, but a field check may be undertaken if the circumstances indicate its advisability. Maps of this kind are now being prepared for a number of states in the western part of the United States.

The material-distribution map is constructed on the basis of whatever geologic maps are available for the region. Each outcropping formation shown on the geologic map is classified as to the kind of material that can be produced from it. The area of outcrop of a geologic formation, therefore, is the area of outcrop of that construction material. Instead of depicting the outcrop areas of geologic formations, the map shows the outcrop areas of sand-gravel, limestone, granite, and other basic materials needed for engineering construction.

In one part of western Montana (see Fig. 2, Geologic Map of a Part of Western Montana), the geologic map shows the areas of outcrop of deposits laid down by present-day streams (Qa),

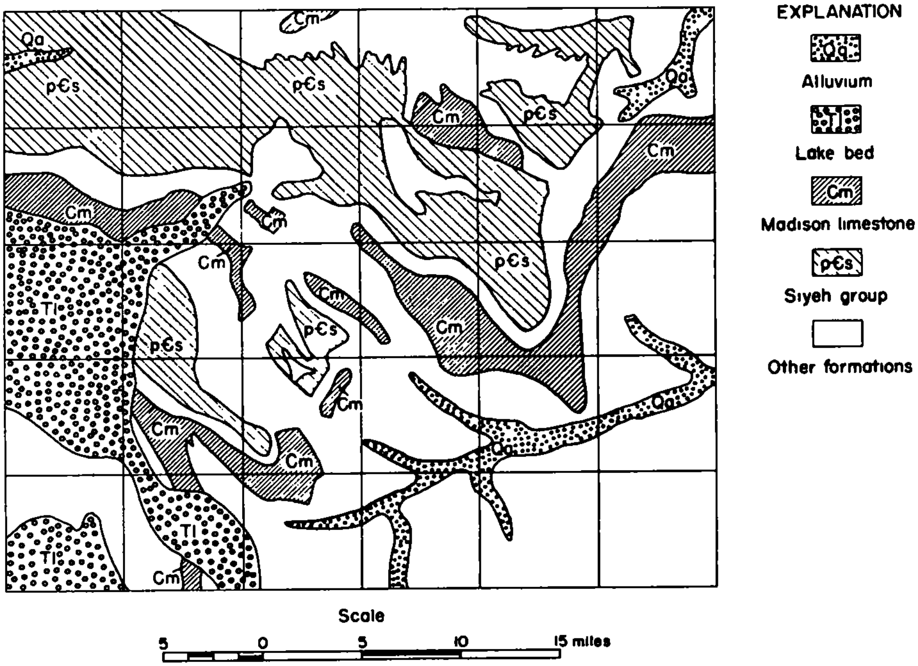


Figure 2. Geologic Map of a Part of Western Montana

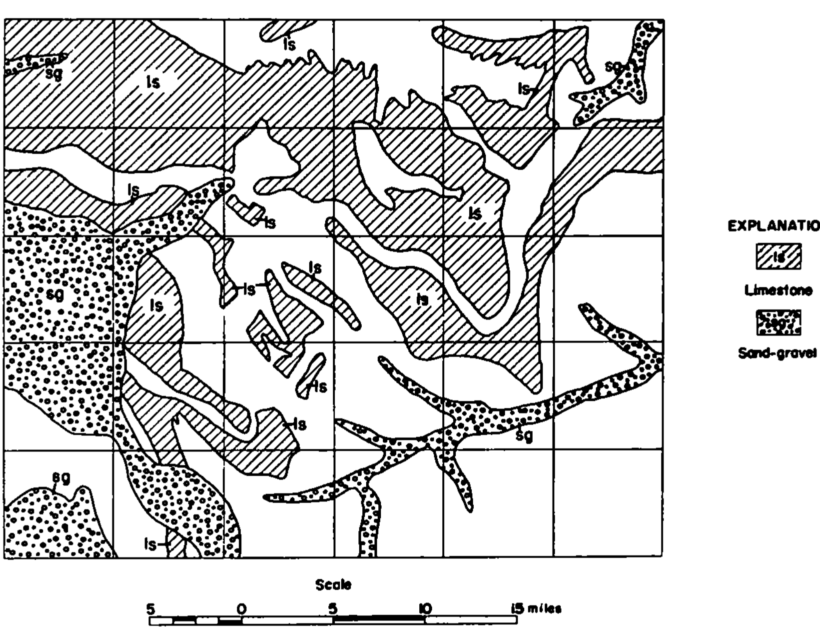


Figure 3. Material-Distribution Map of a Part of Western Montana

somewhat older deposits laid down on the floors of ancient lakes (Tl), the Madison limestone (Cm), the Siyeh group (p€s), and the outcrop areas of still other geologic formations not designated by symbols on the map. The stream and lake deposits are known to be composed predominantly of sand and gravel, and would be classified as a single materials unit, sand-gravel. The areas in which the stream- and lake-deposited sediments are shown on the geologic map would be the source areas for sand-gravel shown on a material-distribution map. (See Fig. 3, Material-Distribution Map of a Part of Western Montana.)

The Madison limestone shown on the geologic map would be classified as limestone and so, too, would the Siyeh group of formations, although the latter includes some thin beds of shale. (See Fig. 2.) The outcrop areas of the two formations, when transferred to a material-distribution map, would then show the potential production areas of limestone in this part of the State. (See Fig. 3.)

Advantages of Material-Distribution Maps - The example described above demonstrates the principal advantages of a material-distribution map. It shows the areas from which all kinds of construction materials in the region might be produced. Further, the map shows also the areas in which any one material cannot occur. A materials party, using this map as the basis for its field exploration, knows exactly the areas to search for a specified material, areas of outcrop of other materials can be eliminated from the exploration program even before the party goes into the field. Time and money are saved.

As another point in its favor, the material-distribution map serves as an adequate inventory of all the construction materials in the region it depicts, in which respect it is an improvement over the material-site map. The material-distribution map shows the areas of outcrop of all available materials, not just the places from which materials have been produced for past construction.

Although the preparation of a material-distribution map is more expensive than that of a material-site map, its final cost is still moderate. Unless a field check is undertaken, the only expenses are the salaries of a geologist to make the materials conversion and a draftsman, and the cost of publication. Using Kansas as the basis for the estimate, the total cost of the project probably would be about $20,000, including publication of the map.

Disadvantages of Material-Distribution Maps - The principal disadvantage inherent in a material-distribution map is the possible inadequacy of the geologic maps available for a region. If the geologic map is not adequate, the material-distribution map cannot be adequate. And, unfortunately, adequate geologic maps are available for only a small part of the United States, although various State and Federal agencies hope to remedy this deficiency by completing a series of long-range mapping programs.

The map does not have in it the basis for correlating test and performance data with the materials it shows. Some limestones are sound and wear-resistant; they are acceptable sources of riprap. Other limestones are unsound, or wear or slake rapidly. The acceptable limestones are not distinguished from the unacceptable on a material-distribution map. Whatever their test properties, all limestones are shown by the same map symbol and pattern.

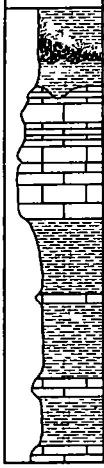
SURFACE-GEOLOGY MATERIALS MAPS

Description - A surface-geology materials map combines many of the useful features of the other two kinds. However, it is by far the most expensive of the three to prepare. The map is usually constructed to a relatively large scale, one in. equals one mi. or two in. equal one mi. It shows the areas of outcrop of all geologic formations, both the consolidated rocks and the unconsolidated sediments. And its scale is large enough that all pits and quarries can be clearly and accurately shown and indexed.

About 20 counties in Kansas have been mapped with the materials objective as the primary one. Surface-geology maps have already been published for an even greater number of counties by the cooperating Ground-Water Divisions of the Kansas and United States Geological Surveys; each of them can be readily adapted so as to show the areal distribution of sources of construction materials.

visit all pits and quarries reported in the files of the State Highway Department's testing laboratory. The location of each one is plotted on a map, and the geologic formation from which the material was obtained is noted for future correlation. They also collect samples from new prospective material sites and send them to the testing laboratory.

The materials inventory for each county consists of a combined surface-geology and material-source map, a tabulation of materials tests, and a



Legend	Description	Geologic formation	Construction materials
	Clayey silt and gravelly sand	Terrace deposit	Mineral filler Aggregate
	Clayey silt	Sanborn formation	Mineral filler
	Thin to massive beds of hard, dense limestone	Fort Riley limestone	Riprap Dimension stone
	Hard, very flinty limestone	Florence flint	
	Clay shale and a very thin limestone	Matfield shale	
	Two very flinty limestones separated by a clay shale	Wreford limestone	

Figure 4. Geologic Formations of Northeastern Kansas

Materials mapping in Kansas is done in this way: A two-man field party is sent to a county in which there is a known shortage of materials for construction already in sight. One man is employed by the Geological Department of the Kansas Highway Commission, and the other is a member of the Engineering Geology Branch of the US Geological Survey. The party generally uses large-scale aerial photographs as the map base. Experience has demonstrated that the photos serve as a means of reducing field time without sacrificing map accuracy. The outcrop areas of all geologic formations in the county are drawn directly on the photographs.

As the field men map the distribution of the geologic formations, they also

written text. The text describes the geology of the county and the construction materials available in the county. The correlation of the test characteristics of the various materials with the geologic formations from which they can be produced is also a part of the text.

Disadvantage of a Surface-Geology Materials Map - One dubious disadvantage is inherent in a surface-geology map: it is expensive to prepare. This kind of a materials inventory costs about $5,300 for the average county in Kansas. But this sum is close to the minimum; the total cost might be several times greater for many regions in the United States in which more complicated geology is

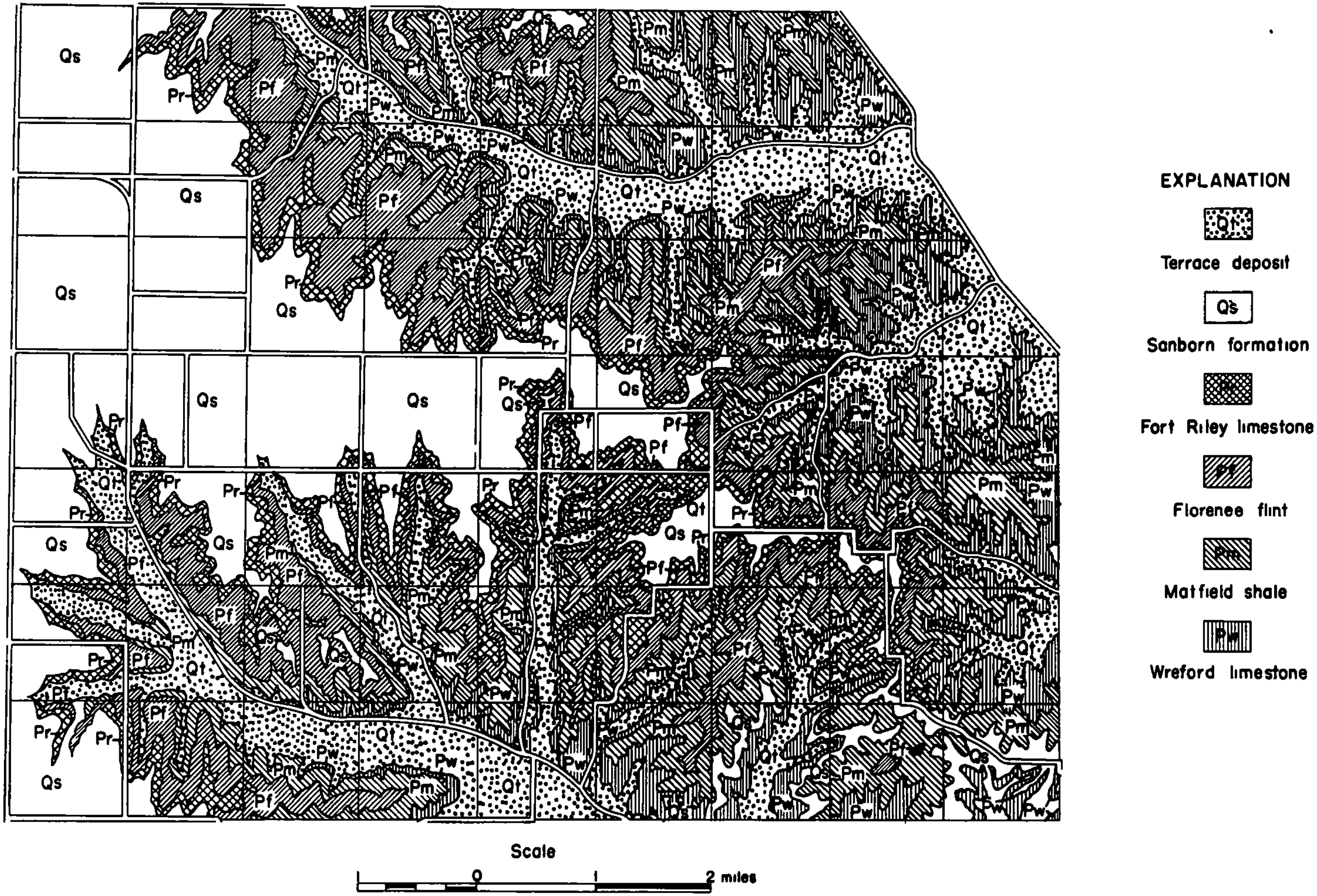


Figure 5. Surface-Geology Map of a Part of Northeastern Kansas

encountered. In preparing a cost estimate for the average Kansas county, $2,500 is allotted for the salaries and subsistence of the field men; $900 for transportation and other field expenses, $200 for laboratory tests of additional samples collected in the course of field work; $900 for the expense of drafting illustrations and writing the report; and $800 to defray the cost of publication.

possible sources of riprap. No one of them contains a material useful as riprap, as is shown in the descriptions of these formations.

However, the two limestones and the flint formation are potentially productive of acceptable riprap. The Florence flint and the Wreford limestone are flinty limestones and test data already at hand show that they are unsound and therefore fail to meet specifications.

Legend	Description	Geologic formation		Construction materials
	Clayey silt	Sanborn formation		Mineral filler
	Interbedded lenses of sand, sandy gravel, mortar bed, and quartzite	Ogallala formation		Aggregate Riprap Dimension stone
	Interbedded layers of chalky shale and chalky limestone	Niobrara formation	Smoky Hill chalk member	Calcareous binder
	Massive beds of chalky limestone		Fort Hays limestone member	Dimension stone Calcareous binder
	Soft clay shale	Carlile shale		None

Figure 6. Geologic Formations of Northcentral Kansas

Advantages of a Surface-Geology Materials Map - Two examples illustrate the usefulness of a surface-geology map in the exploration for construction materials. In one part of northeastern Kansas, outcrops of the following geologic formations occur: alluvium and terrace deposits in the valleys of streams, the Sanborn formation on the tops of the interstream areas, and the Fort Riley limestone, the Florence flint, the Matfield shale, and the Wreford limestone. (See Fig. 4, Geologic Formations of Northeastern Kansas.)

If it is assumed that stone for riprap is needed in construction planned for this area, the alluvium, terrace deposits, Sanborn formation, and the Matfield shale can be eliminated immediately as

But tests of the Fort Riley limestone indicate that it is sound, develops little abrasion loss, and has a specific gravity of 2.6; obviously it is the best local source of stone for riprap.

Using the surface-geology map of the area as its guide, the materials men locate the quarry site in an outcrop of the Fort Riley limestone at the most accessible point nearest the construction project. (See Pr on Fig. 5, Surface-Geology Map of a Part of Northeastern Kansas.) The absolute minimum of field time and expense is required, and the engineer can be confident that riprap produced from the Fort Riley limestone will give good service in the construction.

Another example selected from an

entirely different geologic setting demonstrates the same usefulness of a surface-geology map. The Sanborn and Ogallala formations, the Smoky Hill chalk member and the Fort Hays limestone member of the Niobrara formation, and the Carlile shale outcrop in a part of north-central Kansas. (See Fig. 6, Geologic Formations of North-Central Kansas.) Sand-gravel for use as mixed aggregate is needed for nearby construction. The descriptions of four of the geologic formations show that they are not potential sources of sand-gravel. The Sanborn formation is composed of clayey silt, and if not too clayey, might be a source of mineral filler; the Smoky the Sanborn formation, Smoky Hill chalk, Fort Hays limestone, and Carlile shale from the field program. (See Fig. 7, Surface-Geology Map of a Part of North-Central Kansas.) The areas nonproductive of sand-gravel are avoided, and the search is confined to the outcrop areas of the Ogallala formation as shown on the surface-geology map. The most economic source of sand-gravel is then located with the least expenditure of field time and money.

It is possible also to estimate the quantity of material available at any one place and the overburden to be expected there from information contained in the surface-geology map and the report that

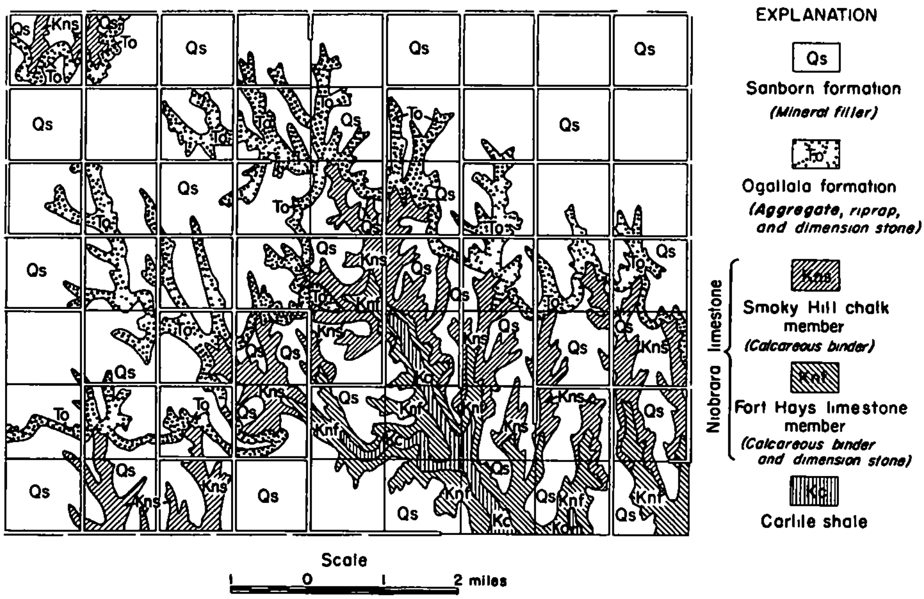


Figure 7. Surface-Ceology Map of a Part of Northcentral Kansas

Hill is a chalking shale and is a source of calcareous binder; the Fort Hays is chalky limestone and is a source of binder and dimension stone; and the Carlile is a clay shale. But the Ogallala formation contains numerous beds of gravelly sand, and the test characteristics of the Ogallala material indicate that it probably will be acceptable for use as mixed aggregate.

Basing its exploration on the surface-geology map of the area, the materials party eliminates the outcrop areas of accompanies it. The physical characteristics, including thickness, of a geologic formation composed of consolidated rock are fairly consistent over a moderately extensive area; unconsolidated sediments vary more rapidly. If a layer of limestone is known to be 10 ft. thick, the approximate quantity of it available at any one place can be estimated by determining the areal extent of its outcrop, as shown on a surface-geology map, at that place.

The character and thickness of overburden also can be interpreted from a surface-geology map. A geologic formation composed of consolidated rock that overlies a potentially material-productive formation probably will prove more difficult and expensive to remove than an overburden formation composed of unconsolidated sediment.

The surface-geology map is not only useful as the basis for materials exploration, but it can be employed also to advantage in engineering planning and design. A flinty limestone, for example, often discharges significant amounts of water. Knowing that, the engineer may want the alignment to avoid as many of the outcrops of that limestone as possible, or will specify that appropriate drains be designed for those places where avoidance is not possible. Then, too, the engineer can determine the kind of excavation to be expected at all places along an alignment from the information presented to him by the surface-geology map. Some geologic formations require rock excavation, others require common excavation, and the kind can be interpreted from the geologic map. Such a map, therefore, serves a multiple purpose in civil engineering.

SUMMARY

A material-site map serves as a useful inventory of construction materials immediately available in a region. A material-distribution map provides an excellent base for the exploration for construction materials, and is a complete inventory of all materials available in a region.

A surface-geology map, although expensive to prepare, is the most satisfactory of the three kinds of materials maps because in itself it is a complete inventory of all available construction materials and provides the best possible basis for the search for a material to meet certain specifications. It is useful also for estimating available quantities of material, the character and thickness of overburden, the existence of possible causes of failure of construction, and the kind of excavation to be expected at any one place.

DEVELOPMENT OF GEOPHYSICAL METHODS OF SUBSURFACE EXPLORATION IN THE FIELD OF HIGHWAY CONSTRUCTION

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Since 1933 the Bureau of Public Roads, through its Physical Research Branch, has had in progress a study of geophysical methods of exploring the substrata as applied to highway engineering problems, including the development of instruments and of methods of interpretation of the data obtained. Early developments were reported in papers published in 1935 (15)[1] and in 1936 (17). Both earth resistivity and refraction seismic apparatus were adapted or developed for use in the shallow subsurface explorations usually associated with highway construction. Special attention was given to the necessity for portable units capable of being transported by hand into areas where reconnaissance surveys might be required. Figures 1 and 2 show respectively the seismic equipment and earth resistivity apparatus now in use.

A large amount of data has been obtained by the Bureau of Public Roads with this equipment applied to such problems as slope design, classification of excavation materials on grading projects, foundation studies for bridges, buildings and other structures, investigation of tunnel sites, location of sand, gravel, solid rock and special soils for use in construction, determination of depth of peat and muck in swampy areas, and studies of existing and potential slide areas.

These field studies have been carried out in the following States: Washington, Oregon, California, Montana, Idaho, Colorado, Arkansas, Missouri, Iowa, Michigan, New York, Connecticut, New Hampshire, New Jersey, Pennsylvania, Maryland, Virginia, North Carolina, Tennessee, Georgia, Florida, and in the District of Columbia.

In general, the data obtained have shown that both the seismic and the resistivity methods of test have merit, particularly as rapid and relatively inexpensive methods of exploration for use in preliminary surveys. As a result of demonstration work done in the States of New York, Connecticut and New Hampshire, the Corps of Engineers, US Army, adopted the seismic test as a more or less standard procedure in preliminary subsurface explorations in connection with investigations of possible dam sites for flood control. Hundreds of dam sites have been investigated by this method since the latter part of 1938 (19, 21, 23).

World War II caused curtailment of the use of the geophysical methods of exploration with the general decrease in civilian construction, but an increased interest is being manifested at the present time. The New York Department of Public Works has purchased equipment of both types and has assigned personnel to a continuing program of geophysical test as apart of a regularly instituted program of subsurface exploration. The geophysical work has been in progress since the early part of 1948, and it is hoped that reports of the successful application of both seismic and resistivity tests to the solution of construction problems within the State of New York will be made available in the near future. The Pennsylvania Turnpike Commission has kept two earth resistivity parties in the field since July 1948 in a systematic resistivity survey of well over 100 mi. of right-of-way for extensions to the present Turnpike system. The Michigan State Highway

[1]Numbers in parentheses refer to a list of references at the end of this paper.

Department has purchased resistivity apparatus for use in locating construction materials and on other construction and maintenance problems of that State. The Massachusetts Department of Public Works has had in progress since 1944 a program involving the use of refraction seismic tests in studies of highway grading projects and structure sites in Massachusetts. A report on this work was made at the 27th Annual Meeting of the Highway Research Board (29). The States of Wisconsin, Minnesota, Missouri, California, Texas and Illinois have each had some experience in the application of earth resistivity tests to highway construction problems (5, 9, 10, 14). The State highway departments of Georgia and Arkansas have expressed an active interest in an early application of earth resistivity tests to construction problems peculiar to their respective States.

With this brief summary of the present status of geophysics as an integral part of our highway construction program, it may be of interest to review briefly the theoretical aspects of the two methods of test and to consider in more detail their application in the field.

BRIEF DISCUSSION OF THE THEORY INVOLVED IN THE GEOPHYSICAL TESTS

Refraction Seismic Test[2] - The seismic method of subsurface exploration consists of creating sound or vibration waves within the earth, usually by exploding small charges of dynamite buried three or four ft beneath the surface, and measuring the time of

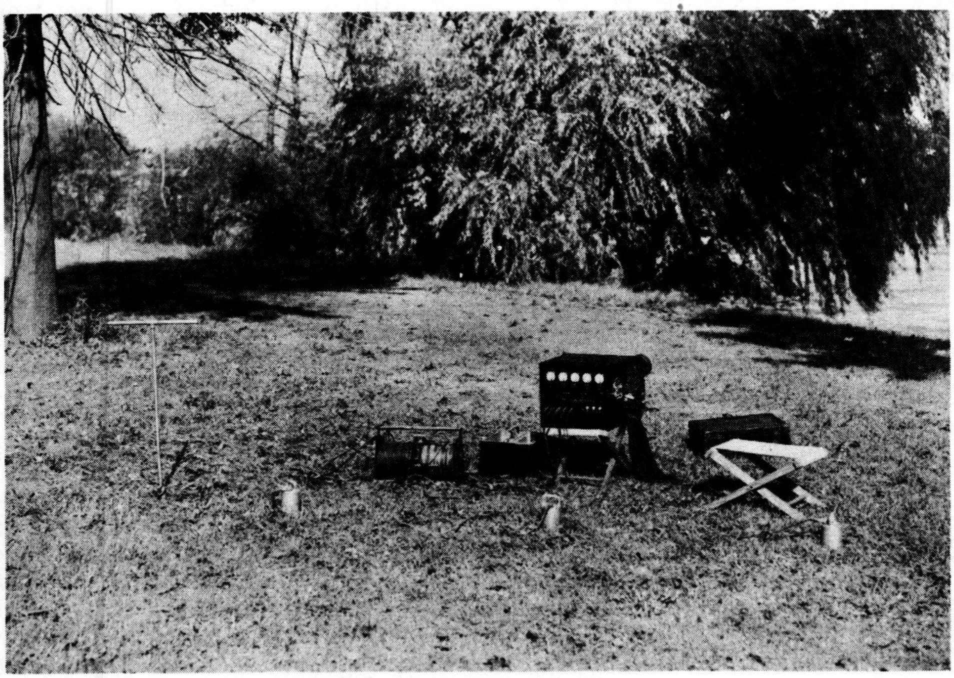


Figure 1. Refraction Seismograph Developed by the Bureau of Public Roads for Use in Shallow Subsurface Explorations

[2]For a more detailed description of the apparatus see reference 15, and for additional discussion of the interpretation of refraction seismic data, together with their application to various field problems see references 19, 21 and 23.

travel of these waves from their point of origin to each of several detectors placed at known distances from the source. The variation in mechanical energy transmitted to the detectors, or "seismic pick-ups" are converted into variations in electrical energy which, in turn, are used to deflect light rays reflected from small mirrors that are a part of sensitive galvanometers and these deflections are recorded

Figure 2. Apparatus Used by the Bureau of Public Roads in Shallow Earth-Resistivity Operations

photographically on rapidly moving film. Electrical circuits are so arranged as to obtain one impulse at the instant of firing the shot and another as the first wave reaches each detector. Figure 3 shows typical seismic records, the small break in the righthand trace on each film indicating the start of the wave and the three separate breaks in the three traces on each of the films shown indicating the arrival of the wave front at each detector. The space between the transverse lines on the film corresponds to a time interval of 0.005 sec. It is usually possible to estimate to one-tenth part of this time interval.

The time lines are placed on the film by means of a suitably placed light source and a tuning fork operating at 100 cycles per sec and equipped with thin phosphor-bronze plates on each tine having narrow slots which cause 200 flashes of light to reach the film during each sec of time.

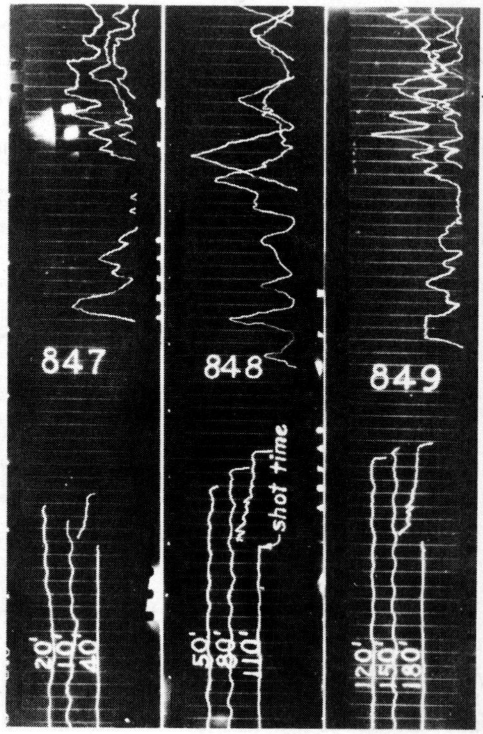


Figure 3. Typical Seismic Records - Note: For clarity in illustration the light traces were inked in before this print was made.

The time data obtained from film records and the measured distances along the ground surface, between the shot point and the detectors, are plotted in the form of time-distance graphs from which the depth and probable character of the various subsurface formations are determined. Wave velocities range from approximately 600 ft per sec in light, loose soils to about 18,000 to 20,000 ft per sec in dense solid rock. This wide range in wave velocities makes possible determination of the general character of the materials encountered and by use of simple formulas the average depth to the various substrata can be calculated. A knowledge of the local geology helps materially in a more accurate identification of the formations encountered.

Figure 4 to better illustrate the wave travel for short distances involving the low velocity soil and the longer distances in the rock stratum, only three detectors are required for the three-channel seismograph used by the Bureau of Public Roads. The usual procedure when using this type of equipment is to place the three detectors on the ground in a line and at intervals of 25 to 50 ft

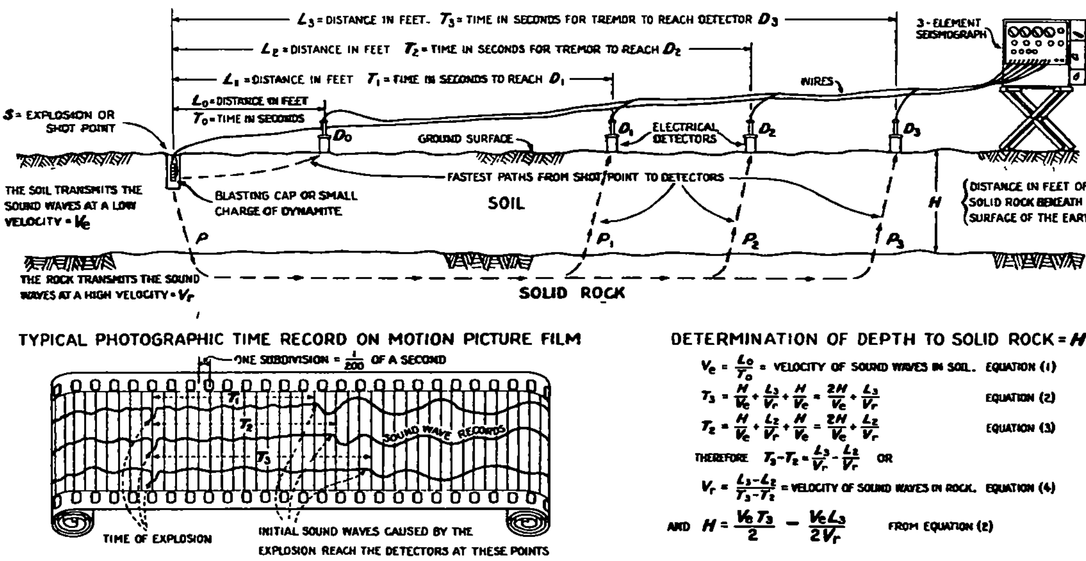


Figure 4. Sketch Showing Fundamental Principles of Seismograph Method

The theory of refraction shooting and the derivation of approximate working formulas for depth determinations are shown in Figure 4. These equations, as will be seen, are developed on the assumption that the path of the seismic wave is vertical from the shot point to the rock or other dense stratum, thence along the rock to a point directly beneath the detector and thence vertical to the detector. Although this assumption gives satisfactory values for the shallow depths involved in most highway problems, it is preferable to use a more exact formula for tests to greater depths such as are encountered in exploring locations for dams and certain other structures. The derivation and application of these formulas may be found in published papers (18, 19) and will not be discussed further.

Although four detectors are shown in apart. Shots are then fired successively at increasing distances along the detector line extended, beginning with a point 10 or 15 ft from the center detector and extending the shooting distances by increments to some greater value as, for example, 50, 85, 125, 165, 225 and 300 ft from the center detector. There is an approximate relation between shot distance and the effective depth of the test such that this depth is about equal to one-third the shot distance. The relation depends somewhat on the relative wave velocities in the materials involved. If the depth to rock were more than about 80 ft, additional shot distances greater than the 300 ft mentioned above would be required to adequately show a rock formation. A duplicate line of shots is usually placed in the opposite direction from the center detector to expand the data to allow depth determinations to be made when the interface between the overburden and the rock is not parallel to the surface but on a slope.

A theoretical time-distance curve is shown in Figure 5. As shown, a straight line through the origin will result so long as a uniform homogeneous material comprises the surface layer. The velocity of wave propagation is constant in such a medium and time of wave travel is proportional to travel distance. The reciprocal of the slope of the line, OC, passing through the origin, represents the velocity in the medium, since velocity is equal to distance divided by time.

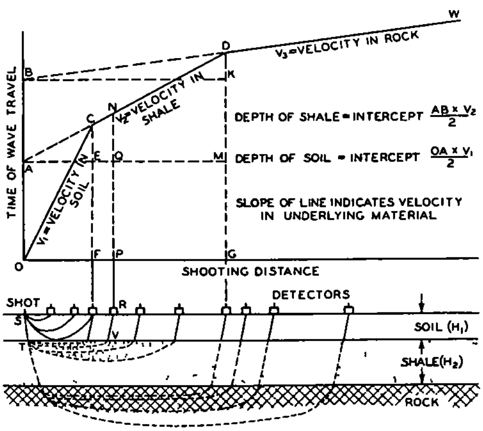


Figure 5. Time-Distance Curves from which Soil Profile Determinations are Made

If, at some greater depth, a second layer of homogeneous material of greater density is present, such as that designated as shale, there will be a point, F, at which there is a simultaneous arrival of a slower wave through the less dense surface soil and one traveling over the longer but faster route along the top of the shale stratum. Beyond this "critical distance", OF, a new slope, CD, exists, the reciprocal of which represents the faster wave travel in the shale, and for a path, STVR, the time, PQ or OA, is that required for the wave to travel through the surface soil from S to T and again from V to R. QN represents the time of travel from T to V in the shale. If H_1 is the thickness of the surface soil , we have the relation:

$$H_1 = V_1 \times \frac{OA}{2}$$

Similarly, for a third layer having an even greater density, such as that designated as rock, there will be a second "critical distance". OG, and a second break in the curve to a new slope, DW, the reciprocal of which will give the velocity in the rock. The time intercept MK or AB in this instance represents the time required for the wave to travel down through the shale

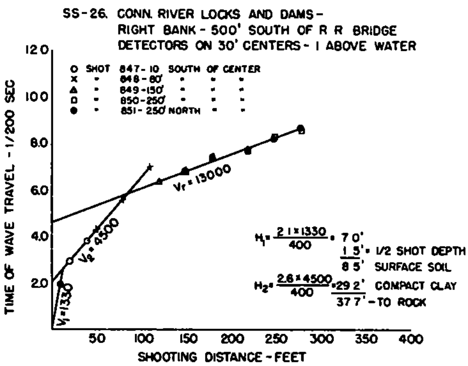


Figure 6. Time-Distance Graph for Seismic Records Shown in Figure 3

and back again. If H_2 is the thickness of the shale then:

$$H_2 = \frac{V_2}{} \times \frac{AB}{2}$$

Usually in plotting the time-distance data, the time units of 1/200 sec, as taken directly from the film records, are used and the denominator in the foregoing equations becomes 400 instead of 2.

When the geologic conditions existing at a particular test location actually approach those assumed in a theoretical analysis of the data obtained from refraction seismic tests, there is a remarkable similarity between the field curves obtained and the theoretical curve as it appears in Figure 5. This is illustrated by the time-distance curve shown in Figure 6 which was prepared from the field data shown in Figure 3, supplemented by two additional shots of electrolytic nature in which the moisture in the soils and rocks together with the dissolved impurities give to the several materials characteristic re-

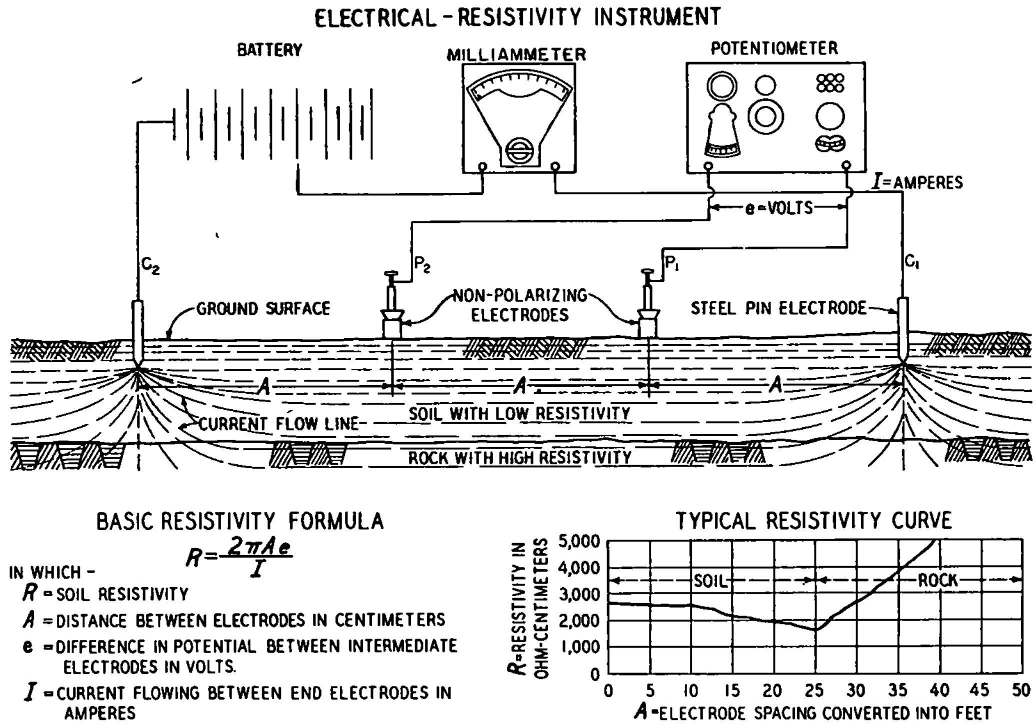


Figure 7.

placed at greater distances from the detectors. The data for this graph were obtained in New England where a relatively thin layer of loose soil was underlain by glacial till which rested upon solid rock.

Earth Resistivity Method [3] - Experience has demonstrated that many of the materials making up the earth's crust can be identified, in some degree at least, by their reaction to the flow of a direct current of electricity. This is an action

[3]For a detailed description of the apparatus and a more comprehensive discussion of the earth resistivity method of test see references 1, 3, 7, 15, 25 and 26.

sistances to a current flow. These characteristic resistances or resistivities may be used for locating and, to some degree, identifying subsurface formations. Figure 7 illustrates diagramatically the earth resistivity test and the Wenner electrode configuration (1) used by most investigators. In this test a prediction of the character of the subsurface materials is attempted by measurements indicating the magnitude of the resistance to direct current flow. Ordinary moist soils containing moderate amounts of clay or silt with some electrolytic agent more or less active, have a comparatively low resistance. In contrast, sand, gravel, extremely dry, loose soils and solid rock usually have relatively high resistivity values. However, these classifications are too general to be useful and it is very necessary to calibrate the instrument with tests made on local materials which can be identified by exposed faces, test pits, drill logs or other means. Curves obtained later for unknown conditions may then be compared with those for known conditions and a prediction can be made as to the materials lying below the surface.

Referring to Figure 7, an electric current is passed through the ground from a direct current supply, usually one or more radio "C" batteries, using the two outside electrodes. Measurement is then made of the potential drop between two intermediate points symmetrically spaced at the third points between the current electrodes as shown. The current flow is determined with the milliammeter and the voltage or potential drop with the potentiometer, from which the resistivity of the material is computed by use of the formula:

$$\rho = 2 \pi A \frac{E}{I}$$

in which A is the electrode spacing in centimeters, E is the potential drop in volts, and I is the current, in amperes, flowing in the circuit.

There is an empirical relation such that the "effective" current flows within a depth below the surface equal to A. That is to say, if A = 10 ft, the resistivity obtained with the formula represents an average of all material existing with 10 ft of the surface. Thus, as the electrode spacings of the system are expanded the current flow lines encounter the deeper portions of the underlying formations as, for example, a rock formation, as shown. This material, having an appreciably higher resistivity than the overlying soil, affects the average resistivity values, the effect of the lower bed increasing progressively as the tèst is carried to greater depths.

When using the empirical method of interpretation proposed by Gish and Rooney (2) the apparent resistivity, ρa, obtained by inserting the measured values of A, E, and I, from the field tests in the formula for resistivity as given above, is plotted as the ordinate against the electrode spacing, A, as the abscissa. The inflections in the resulting curve are interpreted as indicating changes in the materials underlying the surface. Where clay overlays rock a curve similar to that shown in the lower right-hand portion of Figure 7 is usually obtained. The depth of the surface soil is taken as the value of A (electrode spacing) at which the upward inflection of the resistivity curve occurs. This empirical solution has been used in analyzing data from many tests in the past. Cases were found, however, where the plotted curve was smoothly rounded with no inflection point, affording no criterion for predicting the depth of the surface material. Another empirical method of analysis has been proposed (25) for interpreting such curves, a brief summary of which follows.

In Figure 8 the smooth rounded Gish-Rooney curve is shown as a dash-line curve determined by the plotted crosses. The same field data are shown below this curve in the form of a cumulative resistivity curve determined by the plotted circles. When the values of apparent resistivity are plotted as a cumulative curve, a straight line or a curved line of gentle curvature is usually obtained so long as the "effective" current flow remains within the surface layer. When the electrode spacing is expanded to include increasing amounts of the deeper lying rock formation the cumulative curve shows an increased curvature upward, reflecting the influence of the higher resistivity of the rock formation. It has been found that straight lines drawn through as many points as practicable on the cumulative curve and intersecting in the region of increased curvature will give a good approximation of the thickness of the surface material if the point of intersection of the straight lines is projected to the horizontal or dimensional axis. This is a purely empirical relation with no theoretical basis whatsoever. It has given rather close approximations of the depth of the surface layer in simple two-layer formations, however.

Referring to Figure 8, it will be seen that the relatively shallow depth of 14.0 ft to rock, as determined by the test pit, affects strongly the measured values of apparent resistivity beyond an electrode spacing of about 10 ft. For this reason the plotted values of cumulative resistivity continue to show a rather marked degree of curvature well beyond what might be termed the "critical point" in the curve. The trend of the Gish-Rooney curve is used to

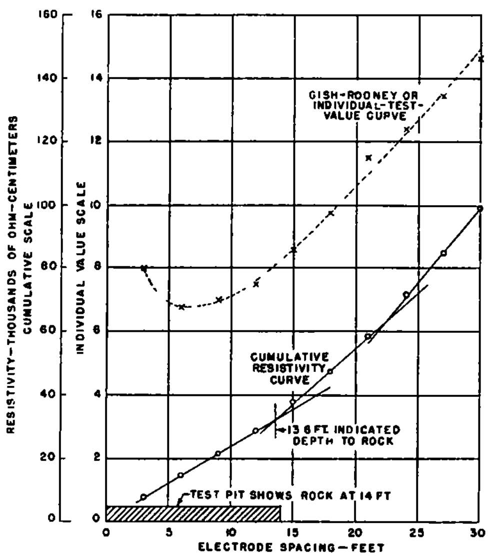


Figure 8. Typical Resistivity Data and Method of Analysis Using the Cumulative Resistivity Curve

determine the approximate "critical point" which in this curve appears to be at an electrode spacing of 10 to 12 ft. Guided by the indications of the Gish-Rooney curve and such other correlating data as may be available from test pits or borings in the general area, the additional tangent intersections beyond the "critical point" may or may not be disregarded.

Other methods of analysis of earth resistivity data based upon theoretical studies have been presented by Tagg (7), Hummel (4), Roman (6, 22), Wetzel, and McMurry (20), and others. Sets of theoretical curves for various assumed resistivities and thicknesses of materials involved have been prepared for use by the operator as control for interpreting the field curves obtained. In some instances the field data are plotted to the same scale as that used in the theoretical curves and on identical sheets and are superimposed upon the theoretical curves and where a "fit" is obtained the depths of the layers involved as well as the resistivities of each layer are obtained. Attempts to use these methods in analyzing the data obtained in the rel-

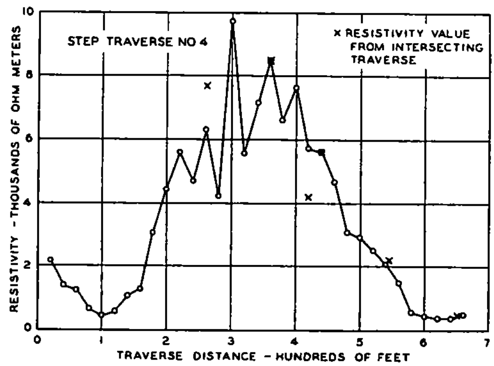


Figure 9. Step Traverse Over Deposit of Sandy Gravel - Electrode Spacing 20 Ft

atively shallow work done by the Bureau of Public Roads have been discouraging due to the time required for such studies and the frequency with which the field conditions failed to conform to those assumed in developing the theoretical curves. The empirical solutions heretofore described have been found to be more practical from the standpoint of time and cost in connection with a given exploration. This might be, in some cases, a deciding consideration between the geophysical tests and the direct methods of exploration ordinarily used.

When making surveys of areas a somewhat different test procedure, one which might be termed the "resistivity traverse" or "constant depth traverse", is often used. In this, a succession of tests using a fixed electrode spacing is made along the selected traverse line, the interval between test sites being equal to the electrode spacing. The measured resistivity values are then plotted as ordinates against traverse distance as abscissas and the resulting graph shows the variation in resistivity along the traverse line for a depth equal to the electrode spacing chosen. A typical example of such data is shown in Figure 9, the rise in resistivity between the 100-ft and 500-ft points on the traverse distance scale indicating the presence of higher resistance material within the depth explored. Traverse lines of this type carried out systematically over an area permit the preparation of a resistivity contour map, such as that shown in Figure 10. Such a map may be of considerable aid in rapidly locating and delineating critical areas that require more detailed study or that contain valuable isolated deposits of granular materials or rock in areas where such materials are scarce.

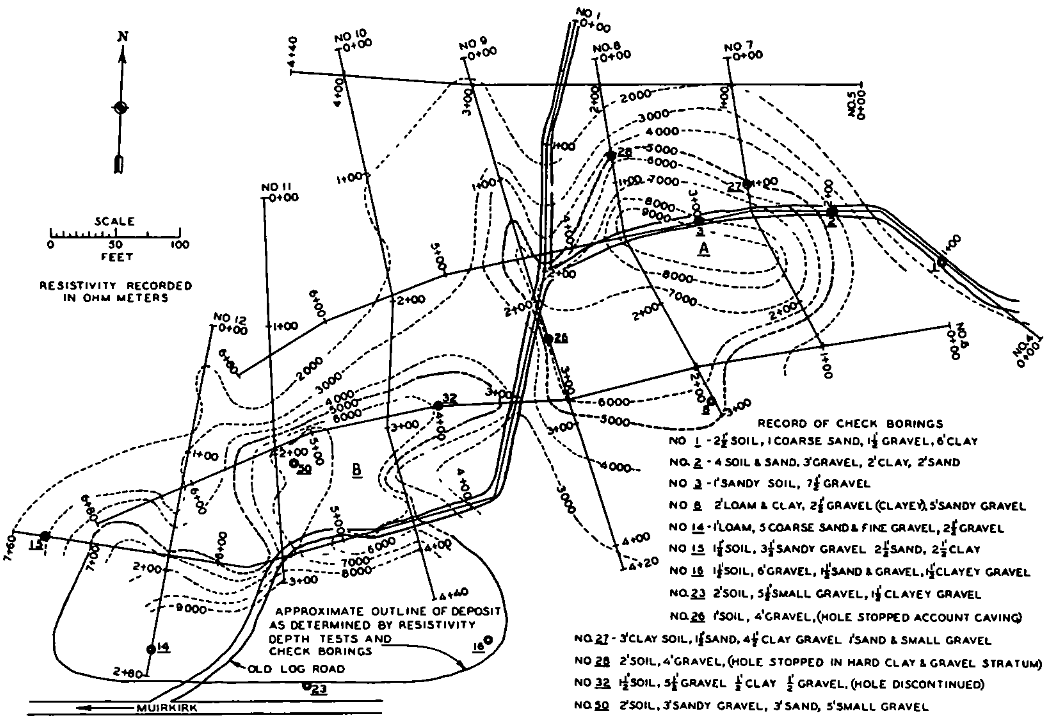


Figure 10. Resistivity Contour Map of a Deposit of Sandy Gravel

INCREASING NEED FOR RAPID AND INEXPENSIVE METHODS OF EXPLORING THE SUBSURFACE

Development during recent years of earth-moving equipment of ever increasing capacity has made possible the removal of huge quantities of excavation materials quickly and economically. However, operating costs of such equipment are high and a reasonably certain knowledge that the equipment selected will be able to handle all or a major portion of the materials on a given grading project, without costly delays from unforeseen adverse conditions, can be extremely helpful to contractors in establishing reasonable unit prices in bidding for the job. A thorough investigation of the subsurface formation prior to design of slopes in cut sections when preparing plans for a proposed roadway will help to avoid the confusion that results when solid rock cuts as shown on the plans actually are found to be soil or other easily removable materials. Such errors in the classification of materials may lead to increased costs and to the necessity for changes in design.

Stoney soil, talus materials and thin but continuous stringers of quartz or other hard materials extending throughout a cut may present insurmountable difficulties when attempting to explore subsurface conditions with hand or power operated auger equipment. Such troublesome conditions, although they may result in misleading data when the auger is used, will not affect the data obtained with geophysical tests to any appreciable extent. For this reason, preliminary surveys by geophysical methods can be used to considerable advantage in determining the overall character of the materials to be excavated and thus avoid errors of the type just mentioned. Complete and dependable information will make unnecessary hurried changes of alinement and grades to care for increased or decreased quantities of excavation materials, with possible delays of construction operations.

APPLICATION OF GEOPHYSICAL TESTS TO HIGHWAY CONSTRUCTION PROBLEMS DESCRIBED

It has been found that both seismic and resistivity methods of test are practical for use in the study of many highway construction problems. The earth resistivity apparatus, by reason of its simplicity of operation and the rapidity with which the shallow tests can be made is believed to have a more universal application than does the seismograph. Accordingly, when making a detailed geophysical survey of a grading project it has been the practice of the Bureau of Public Roads to make a resistivity survey first and, if necessary, to follow with a limited number of check tests with the seismograph in areas where the resistivity data have failed to adequately identify the subsurface formation. This procedure has been applied to 10 highway construction projects ranging from 1-1/2 to 12 mi. in length and located in the States of Virginia, North Carolina, Tennessee, Georgia, Arkansas, Missouri and in the District of Columbia. Reports have been received on four of these which have since been constructed and the conditions found during construction were substantially as predicted from results of the geophysical tests.

The following discussion will deal with the field data obtained with both types of apparatus. The discussion of the seismic method is rather brief in view of its somewhat limited use by the Bureau of Public Roads.

Results of Seismic Tests Described - In general, the velocity of the transmitted sound waves increases with an increase in the density of the transmission medium (soil, rock, etc.). Loose unconsolidated soil layers have wave velocities ranging from 600 to 1,500 ft per sec. More compact subsurface layers range from 2,000 to 9,000 ft per sec with the lower ranges 2,000 to 3,500 usually associated with clay materials and the higher ranges 4,000 to 9,000 with compact gravels, badly broken or weathered rock, and soil-boulder mixtures. Solid rock usually has wave transmission velocities between 10,000 and 20,000 ft per sec, depending upon the type of rock and its degree of weathering or fracture. In predicting the character of material that may be found, particularly in the intermediate velocity group (4,000 to 9,000 ft per sec), considerable judgment, as well as some knowledge of local geologic conditions, is required. Calibration tests over known subsurface formations are essential for a successful interpretation of the data obtained.

Actual identification of the materials involved is not always necessary, however. For example, broken rock or badly seamed rock, a highly compacted shale or a cemented gravel, having similar velocity characteristics, may also be expected to offer similar difficulties in excavation operations, possibly requiring some blasting and special handling and distribution. These same materials will probably show similar load carrying capacities when considered for foundation purposes, particularly where surrounded by materials which have been left in an undisturbed state. As an example, seismic tests made at Lincoln, New Hampshire, at a proposed bridge crossing of the Pemigewasset River, showed a comparatively high wave velocity for material lying only a few ft below the surface and apparently continuing to a depth of at least 40 ft. This material, with a wave velocity of 9,400 to 9,600 ft per sec, was predicted to be a tightly cemented boulder formation with excellent load carrying capacity. Figure 11 shows a view of subsequent excavation being made for one of the piers at this location. The material was so tightly cemented together that only a simple sandbag cofferdam was required. Soundings and drill holes through material of this type would be impossible or made only with great difficulty and at considerable cost.

Figure 11. View Showing Tightly Cemented Boulder Formation Predicted from Seismic Tests at Pemigewasset River Crossing Near Lincoln, New Hampshire

Another bridge location, near Crater Lake, Oregon, was investigated by the seismic method in about 3 hr's time and the data obtained showed the subsurface formation to be a very dense material providing a wave velocity of 8,400 to 8,600 ft per sec. Here, again, there could be no doubt regarding the existence of adequate foundation materials. Figure 12 shows the seismic data for two of the three tests made at this location.

Experience is needed to determine the particular slope design that is adequate where certain materials within a local area are involved. With proper calibration data, the seismic method often can be relied upon to establish definitely the presence of the materials. As an example the data in Figure 13 show the presence and depth to the predominant material, shale.

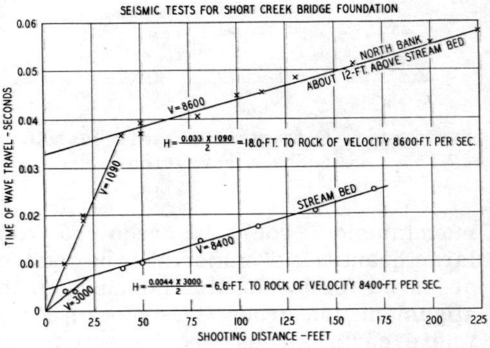


Figure 12. Time-Distance Graph Showing Results of Two Seismic Tests Made in Vicinity of Crater Lake, Oregon, While Investigating a Bridge Site on Short Creek

As mentioned previously, portability of equipment is of primary importance to the successful application of geophysical methods of test in preliminary surveys for a highway location. Figure 14 shows a view that is more or less typical of much of the terrain that is sometimes encountered in the construction of National Park and National Forest roads in various parts of the country. In designing for a modern highway through such country any information regarding the materials likely to be encountered in excavating cut sections is important. A close balance of quantities must be maintained in the interest of economy and of preserving the natural scenic beauty of the area. Unsightly borrow or waste areas are to be avoided. Therefore, a design prepared for solid rock with its 1/4 or 1/2 to 1 slopes in a cut section, such as the one shown in Figure 14, could lead to embarrassing difficulties should a comparatively loose earth or talus material be encountered. Should that happen a 1-1/4 or 1-1/2 to 1 slope reaching high up the mountainside would be required with large quantities of material to be wasted or cared for by substantial changes in alignment and grade. Conversely, where earth slopes are expected and rock is found a source of borrow would be required for adjacent large fills unless major grade changes were made.

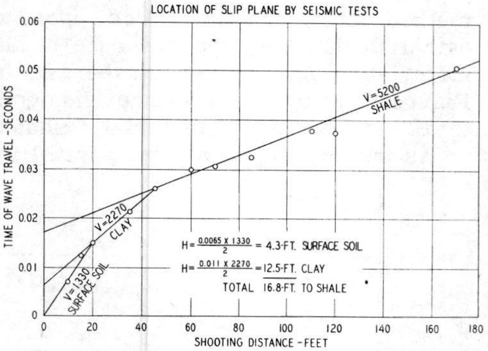


Figure 13. Refraction Seismic Test Over a Shale Formation

The ridge from which the photograph shown in Figure 14 was taken had been originally assumed to contain solid rock. A tunnel several hundred ft in length was proposed to carry the roadway through the ridge, some 100 ft below the top. Test pits dug to obtain design data for portal construction failed to encounter rock above grade. Several weeks were required for this exploration work which cost hundreds of dollars, and finally a redesign for an open cut was found necessary. Seismic tests requiring no more than two or three hr's time were sufficient to adequately establish the fact that no solid rock existed in the hill. The excavation during construction was made with the usual heavy earth-moving equipment. Studies made with seismic equipment at other sites have been of value in portal design and in indicating the probable need for lining in the tunnel.

Another problem to which refraction seismic equipment has been applied occurs in regions where slide conditions are prevalent. In some cases the loose talus material frequently involved in a slide rests upon a sloping shale formation which constitutes the sliding surface. This talus material has velocity characteristics differing from those of the more compact shales, making possible the location of the plane of separation.

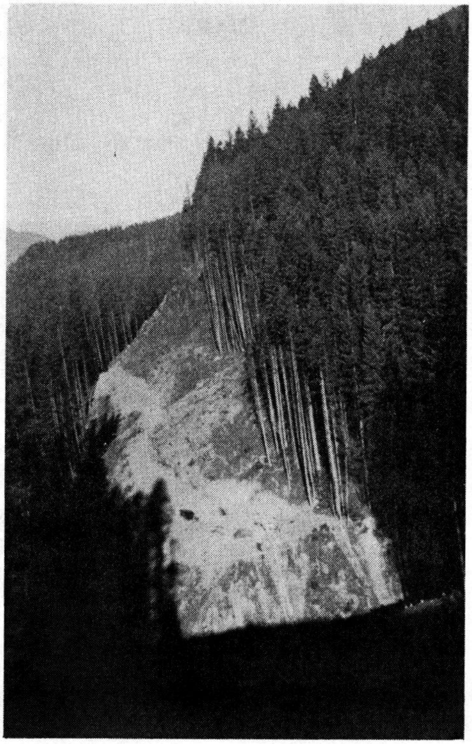


Figure 14. Rugged Construction Conditions for Highway Through National Forest Area in Oregon

Although the refraction seismic test has proved of value in preliminary surveys in various phases of highway construction, as has been pointed out, it has not been used to the same extent as the earth resistivity test in recent years because of the greater time required for a seismic test. Six or 8 seismic tests per 8-hr day is about the max number to be expected and under some field conditions even this number is not possible. Fifteen to 20 resistivity tests are usually possible under similar field conditions. Seismic tests can be utilized as a completely independent check of the indications of the more rapid resistivity tests, however, and are used for this important purpose in the routine work done by the Bureau of Public Roads.

in the Ozarks National Forest, in the course of a resistivity survey of about 22 mi. of proposed roadway. The calibration curves on the left were obtained for heavy sandstone ledges interbedded with shales and for the soils and decomposed shales typical of the

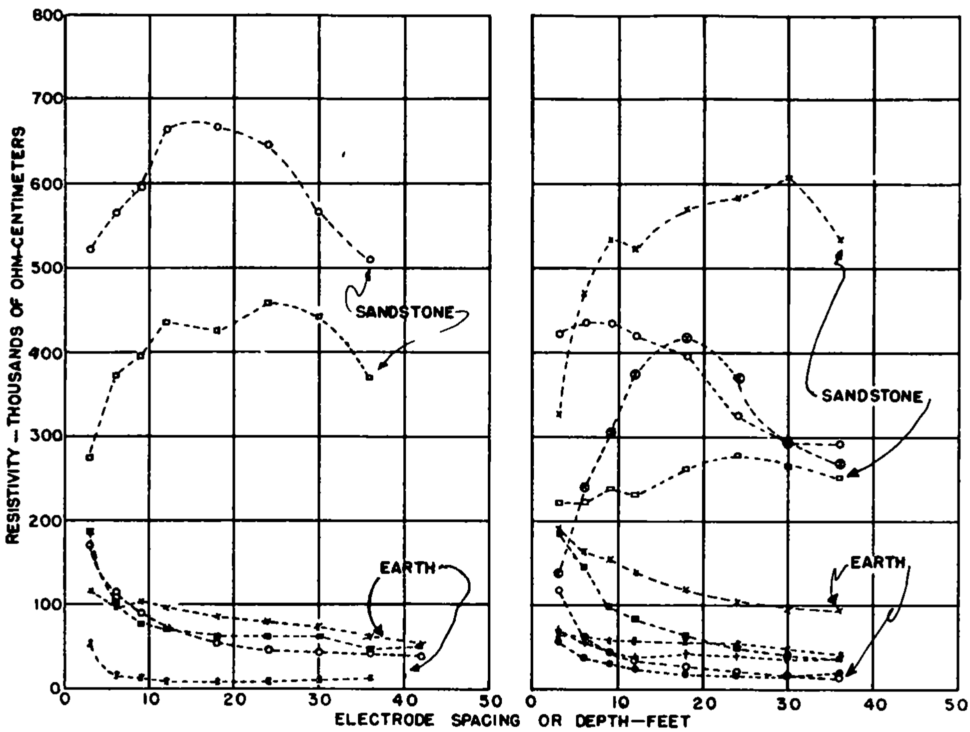


Figure 15. Resistivity Calibration Curves (Left) and Typical Field Curves Obtained in the Ozark National Forest Near Russellville, Arkansas

Earth Resistivity Tests Applied to Highway Grading Projects - In a subsurface survey in the field it is an established procedure to make calibration tests with the resistivity apparatus over exposures of formations believed to be typical of those in the area of immediate interest. Resistivity curves for the known conditions are then used for comparison with curves obtained over unknown conditions elsewhere in the area. From these comparisons reasonably accurate predictions can be made regarding the materials to be encountered below the surface and their location. Figure 15 shows typical resistivity curves obtained in Arkansas,

region. These latter are materials that could be handled with the heavy self-loading carryall scraper. Those curves of the right-hand graph are examples of the field curves obtained in the survey along the right-of-way of the proposed roadway. Little difficulty would be experienced in predicting the type of materials involved for the several curves shown. Figure 16 shows views of the two general types of material over which calibration tests were made.

Based upon the usual methods of direct exploration, the original slope design called for rock slopes over a considerable portion of the right-of-way. Actually, earth conditions, as predicted from the results of the resistivity survey, were found in a majority of the cuts during the construction of about 14 mi of roadway thus far completed.

The entire 22 mi was investigated in about 12 working days, one 8-mi project being covered in 3-1/2 days.

In northwest Georgia, resistivity calibration tests over solid rock and over earth formations produced curves as shown in the left and in the lower right-hand graphs, respectively, of Figure 17. Here again, although the shapes obtained are quite different from those obtained for materials of the same general classification in Arkansas, the two materials, rock and earth, can very easily be distinguished one from the other. On the basis of these calibration data, the typical field curves shown in the upper right-hand corner were all interpreted as "earth" curves representing materials easily removed by self-loading "pans". Figure 18 shows the two types of material over which calibrations were made.

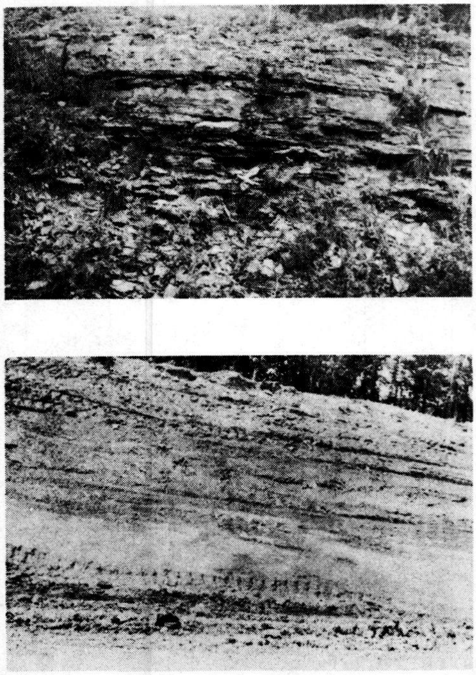


Figure 16. Views of Locations Where Resistivity Calibration Tests Were Made Over Rock (Upper) and Earth in Arkansas

In the Great Smoky Mountains National Park in western North Carolina, the dense granite rock formations typical of that area weather into a highly micaceous decomposed rock material that can be removed with self-loading "pans". As shown by the calibration curves presented in Figure 19 (solid line curves), this material has an extremely high resistivity, 1,500,000 ohm-cms, which is 10 times as great as resistivities found in some solid rock in other parts of the country. Due to the fact that the parent rock in a solid unweathered state has even higher resistivities (4,000,000 to 5,000,000 ohm-cms), it is again possible to differentiate between "earth" and rock excavation. The appearance of the materials over which the calibrations were obtained is shown in Figure 20. That section of the Blue Ridge Parkway on which the resistivity survey was made has not yet been built and no confirming correlations are available at the present time.

In southeast Missouri, the porphyry rock found in the vicinity of Farmington has a resistivity as indicated by the upper curve of Figure 21, while a calibration test over the soil common in the same area produced the lower curve of the figure, indicating almost no resistance to direct current flow. No difficulty was encountered in determining the type of material present in all but one cut of all those investigated on a 4-mi project.

Other resistivity surveys on construction projects in Tennessee, Virginia, Maryland, and in the District of Columbia have developed information regarding the subsurface formations that has been found to agree closely with conditions as actually found during construction.

Resistivity Tests Applied to Foundation Problems - Earth resistivity tests can be of assistance also in a subsurface study of the foundation conditions existing at proposed building sites, bridge locations, and in other areas where solid rock foundations are required or desirable.

In 1942, at the request of the Navy Department, a resistivity survey was made of a 150-acre tract at Carderock, Maryland, where a model testing basin is situated. The site is underlain with rock and information was desired as to the depth to rock throughout the reservation. Altogether, over 500 depth tests and upwards of 10-1/2 mi of constant-depth resistivity traverse were made in carrying out the survey. From the information obtained a rock contour map, shown in Figure 22, was drawn up showing rock elevations on 2-ft contours over the entire area. An accuracy of ± 2 ft at any point in the area mapped was predicted. In 1944 an existing building with a width of 120 ft was extended for 1,800 ft in the area that had been mapped. Cross sections of the rock surface as found, obtained at intervals of 10 ft, along the building axis, showed a difference in total amount of stripping of less than 6 percent from that computed from the rock contour map prepared in 1942. About 100,000 cu yd of stripping were involved.

Figure 23 shows typical traverse data obtained in this study and it illustrates how the resistivity test can be used in a preliminary survey to obtain information that may be used to guide a detailed survey by borings and eliminate many unnecessary soundings or borings. The flat-lying portion of the curve suggests a uniform condition for much of the distance traversed. The peaks in resistivity indicate those areas where direct borings should be concentrated to delineate in detail the obvious anomaly. These buried ridges of rock can be traced across wide areas, indicating regions where excavation will be difficult or where foundation conditions will be excellent at shallow

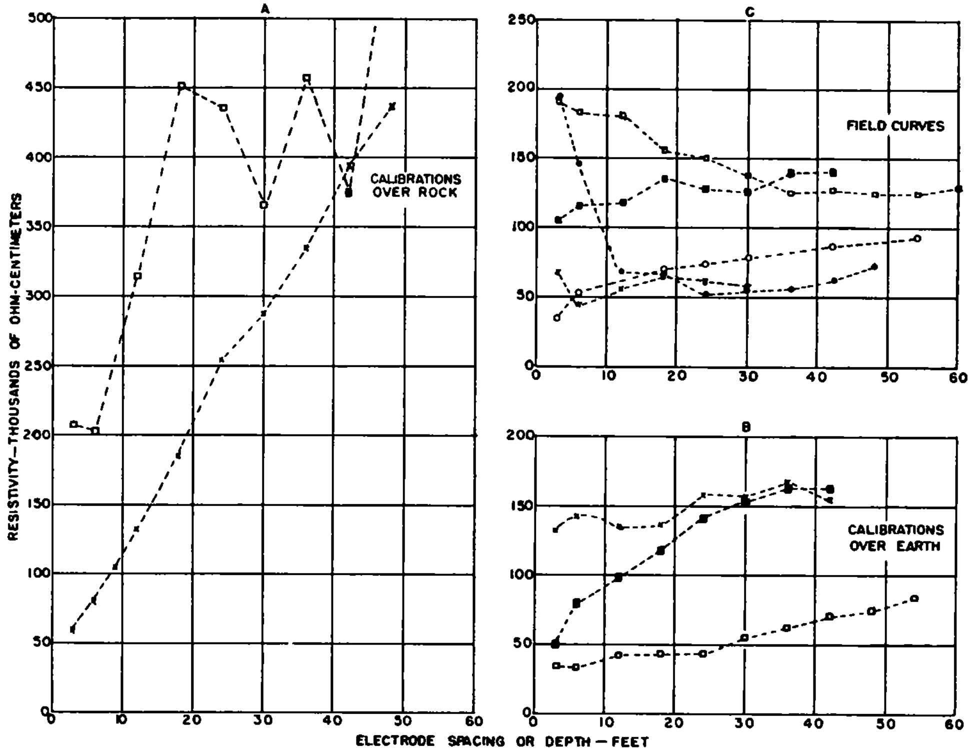


Figure 17. Resistivity Calibration Curves Obtained Over Earth and Rock Formations in Northwest Georgia and Typical Field Curves Obtained on Proposed Road Project North of Marietta

depth. The figures shown underlined are depths to solid rock obtained by resistivity depth tests made at 100-ft intervals along the line of the traverse. The two depth curves shown in the inset are a striking indication of radical changes in the subsurface at stations 2+00 and 13+00 of the traverse.

In bridge foundation studies there have been numerous instances when the routine subsurface survey using the usual methods of probing, wash boring, etc., has failed to disclose unusual conditions later found during construction. Piers designed originally for solid rock foundations have had to be carried to considerably greater depths than those shown on the original plans, or supported upon piling extending to rock at a lower elevation. Figure 24 shows several resistivity depth curves obtained in a post-construction survey of a bridge crossing of the Flint River in southwest Georgia. The individual graphs show the plan data for depth of rock, the depth to rock as found during construction, and the depth to rock as predicted from the resistivity data. The general agreement between the results of the resistivity tests and the actual conditions existing is apparent.

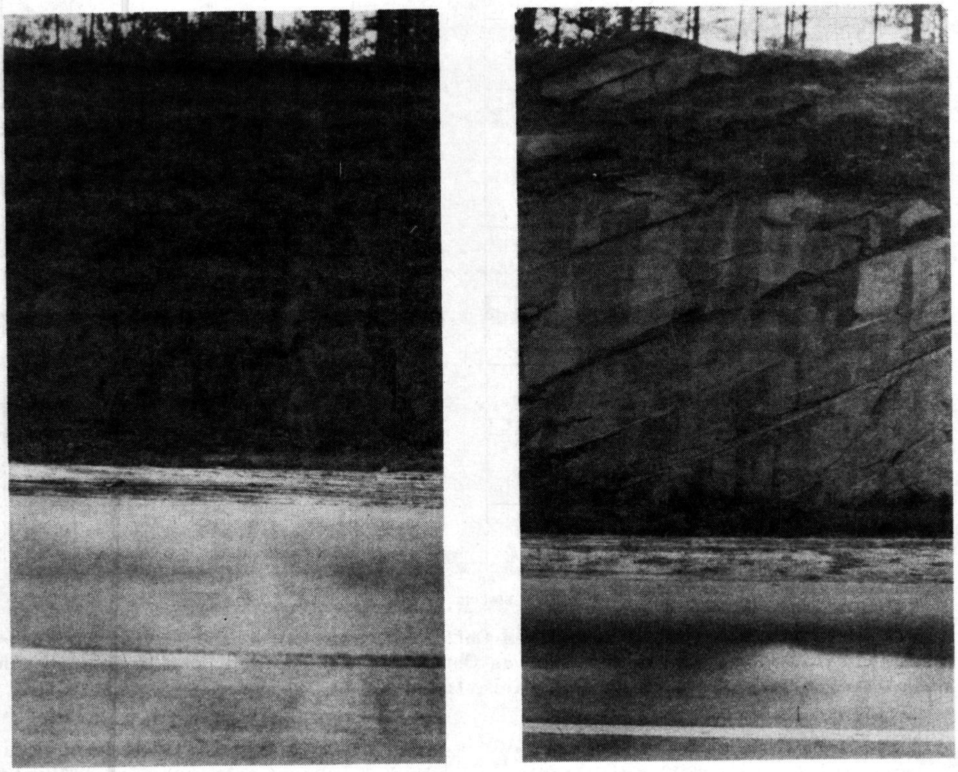


Figure 18. Locations of Resistivity Calibration Tests Made Over Earth and Solid Rock Formations in Georgia

Although it is not possible to make an unqualified statement regarding the effectiveness of the resistivity test generally in all localities and under all possible combinations of geologic formations, the fact remains that one or two hr's work at a particular location will usually determine the extent of its usefulness in solving the particular problem at hand. The data from the tests made in Georgia are similar to those that have been obtained elsewhere

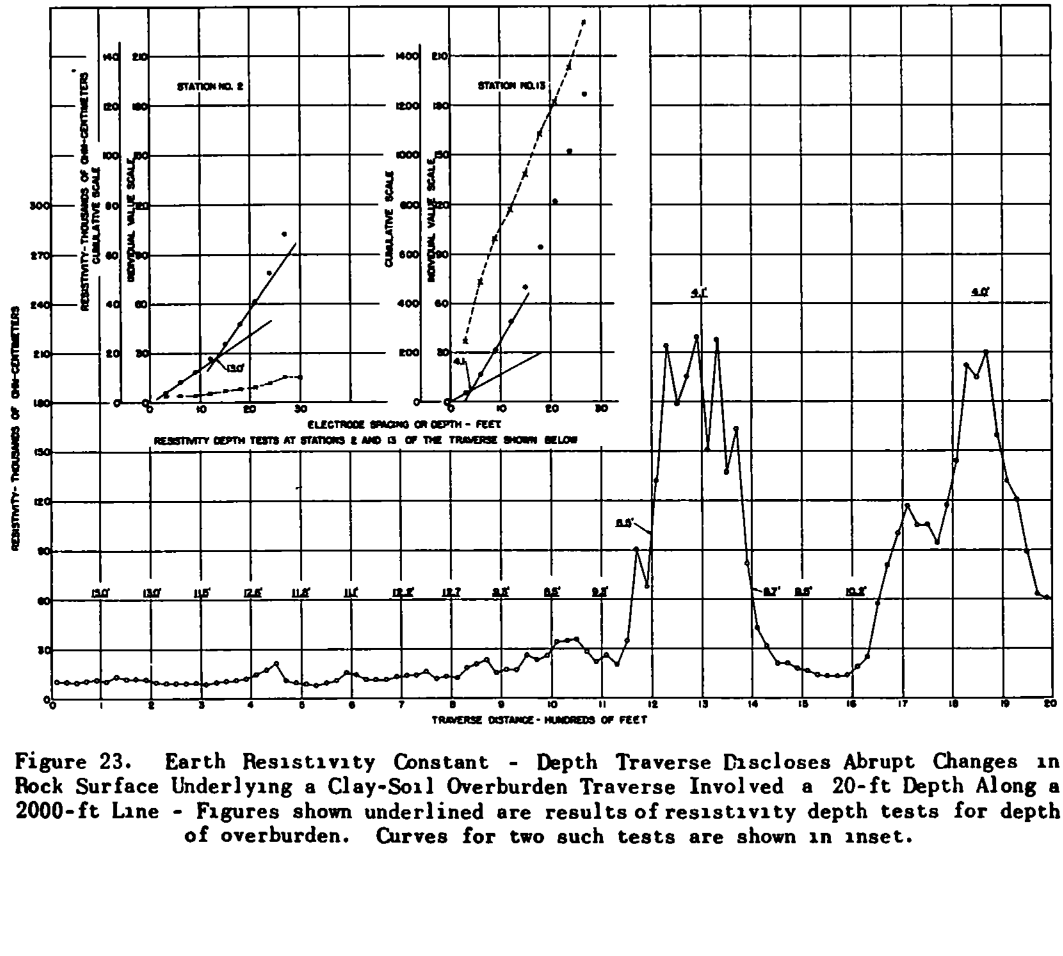


Figure 23. Earth Resistivity Constant - Depth Traverse Discloses Abrupt Changes in Rock Surface Underlying a Clay-Soil Overburden Traverse Involved a 20-ft Depth Along a 2000-ft Line - Figures shown underlined are results of resistivity depth tests for depth of overburden. Curves for two such tests are shown in inset.

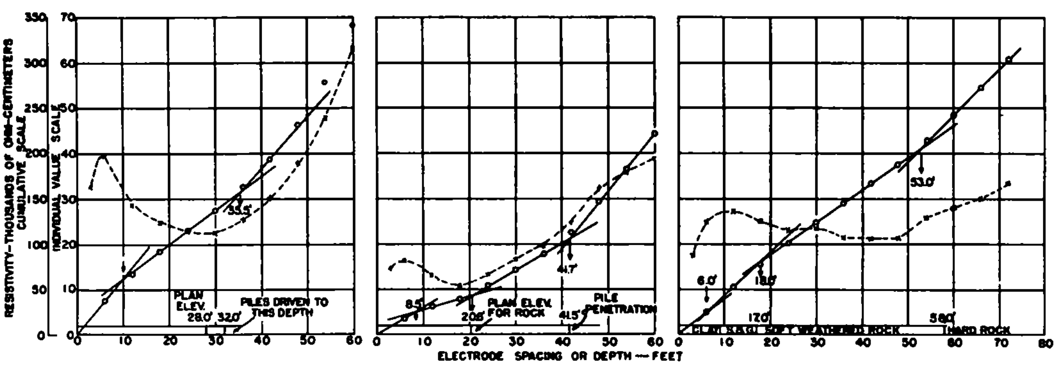


Figure 24. Earth resistivity tests at Flint River Crossing on US 19 south of Thomaston, Georgia, locate subsurface rock for bridge foundation more accurately than drill.

to the determination of conditions at a single designated spot or limited area such as a dam site, bridge location, etc. Even in the limited areas, if sharp irregularities of the rock surface present unfavorable conditions for consistent interpretation of the seismic data (24). To the writer's knowledge,

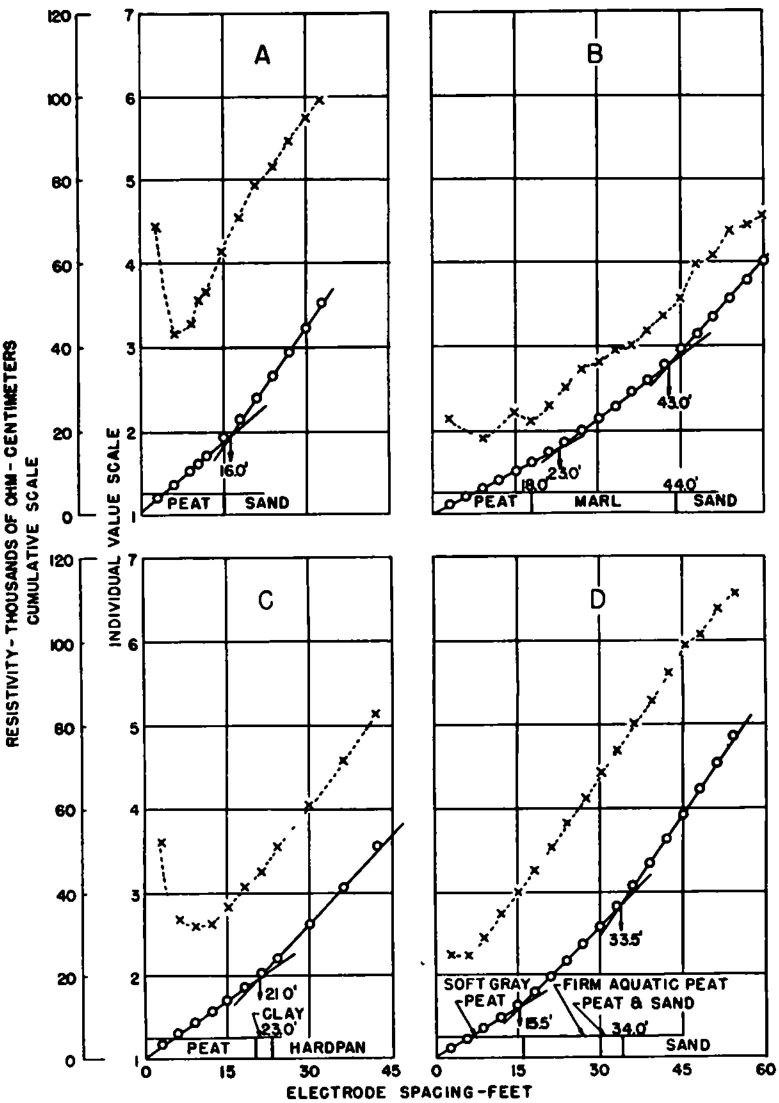


Figure 25. Resistivity Depth Tests Over Peat Bog Formations

differential weathering has been in progress, leaving pinnacles and deep valleys in otherwise hard rock, a condition sometimes encountered in limestone formations, the resistivity test may possibly prove the more valuable of the two methods. In such cases the however, there has been no report on results of resistivity tests carried out in such areas.

The use of explosives as required in the seismic method is not desirable in thickly populated areas. Compliance with local regulations regarding possession and transportation of explosives, sometimes rather strictly enforced, can be troublesome and inconvenient, placing a further handicap upon seismic exploration.

As mentioned previously, the time required for conducting a seismic test can vary from one to two or three hr, depending upon local conditions, while resistivity tests can be made at a rate of three per hr to depths of 60 ft in rugged mountainous terrain. A seismic party may require one or more men than are necessary for the efficient operation of the resistivity apparatus, particularly in isolated areas where supplies of explosives and film developing equipment must be carried in by hand. However, stray currents leaving cross-county pipe lines or emanating from electric railway systems in urban areas, and buried utilities such as water and gas pipes can, at time, be troublesome when making a resistivity survey. These will not affect the efficient use of the seismograph.

CONCLUSION

In conclusion it can be stated that, despite limitations that have been enumerated and others which may arise in future exploration work, the geophysical methods of test under consideration have definitely established their value in connection with highway work, particularly for use in preliminary surveys. Their use by the Bureau of Public Roads and other Federal agencies has emphasized the usefulness of these relatively inexpensive methods of test in shallow subsurface exploration in obtaining information to be used as control for design purposes or as control for more detailed subsurface surveys by core drilling and other commonly used direct methods. The fundamental principles of the two methods differ so widely that where both methods give concordant data they may be accepted with considerable assurance. As a result, when they are used jointly on a given project, a limited amount of confirming data from the seismic test can serve as a valuable check on a considerable number of the more inexpensive resistivity tests, at times obviating the need for test pits or auger holes for locating and identifying subsurface formations. This does not imply that test pits or auger holes may not be

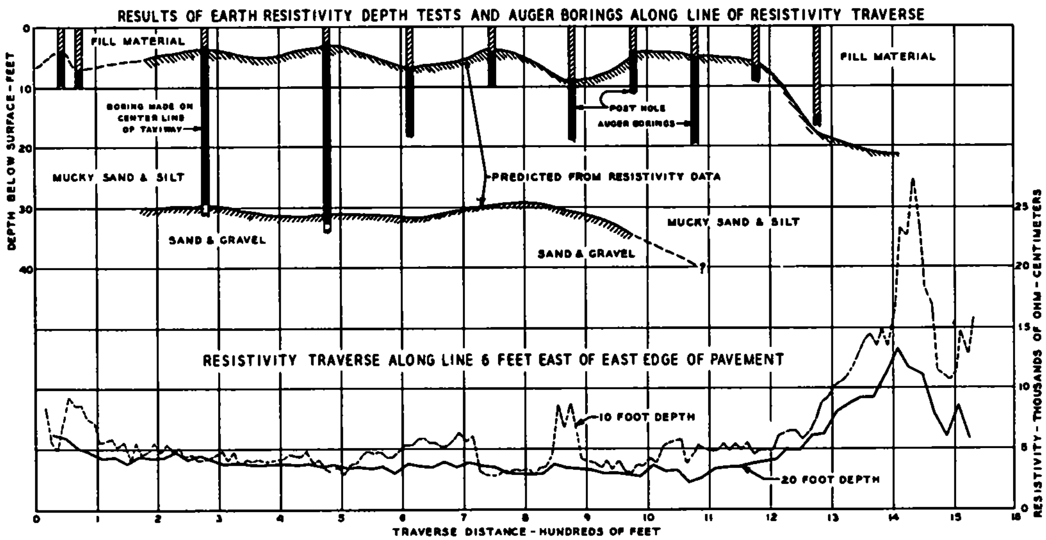
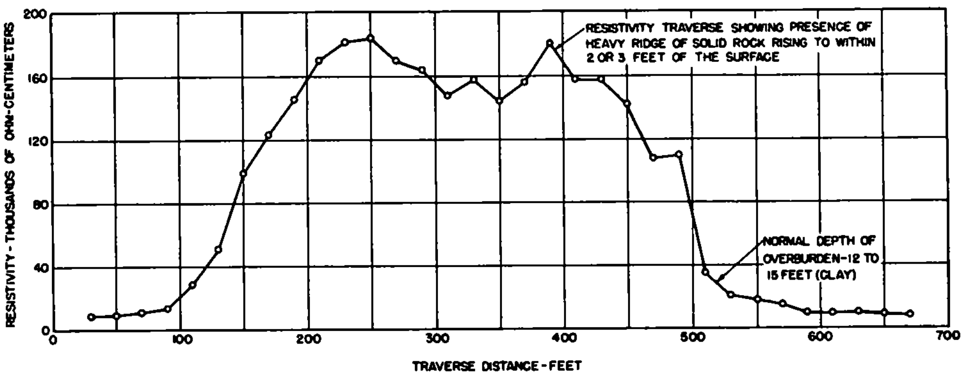
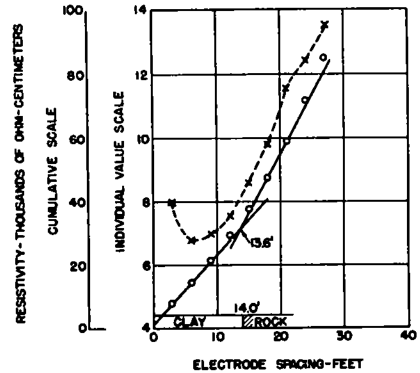


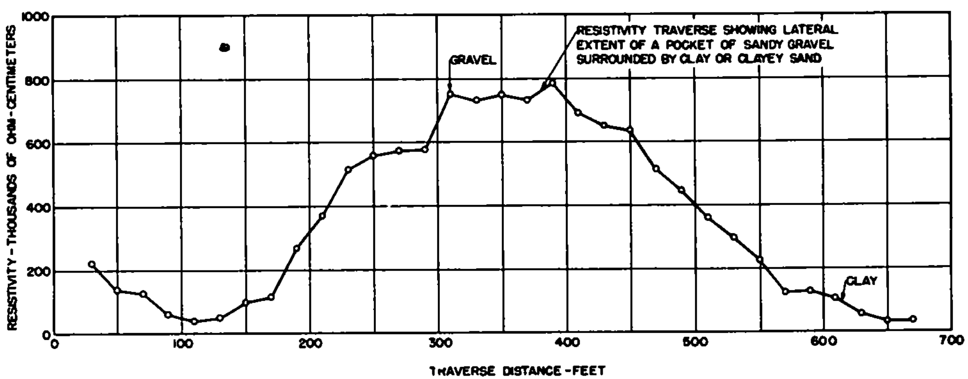
Figure 26. Results of Earth Resistivity Tests Along East Edge of Taxiway No. 4, National Airport, Washington, D. C. Traverse Station 0+00 = Station 11+17 Taxiway No. 4



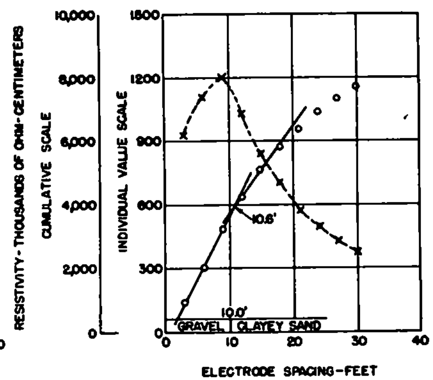
RESISTIVITY TRAVERSE OVER A BURIED GRANITE RIDGE USING A CONSTANT DEPTH OF 20 FEET



DEPTH TEST INVOLVING CLAY UNDERLAIN BY SOLID ROCK



RESISTIVITY TRAVERSE OVER A SAND AND GRAVEL DEPOSIT USING A CONSTANT DEPTH OF 20 FEET



DEPTH TEST INVOLVING SANDY GRAVEL UNDERLAIN BY CLAY OR CLAYEY SAND

Figure 27.

necessary for obtaining samples of soil and other materials for determination of their physical and other properties.

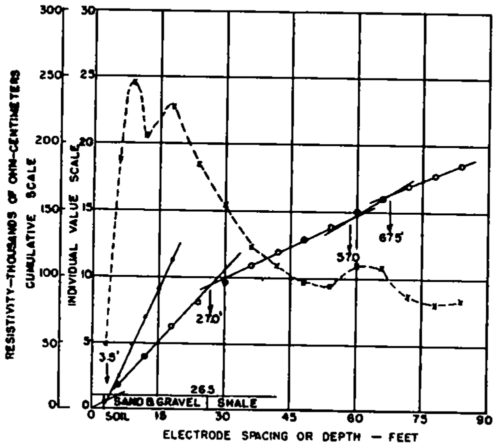


Figure 28. Resistivity Depth Test at Location of DH No. 2 19 in Right of Station 52 + 19, Susquehana River Crossing of the Pennsylvania Turnpike at Harrisburg

Even though there might exist some uncertainty that the geophysical methods of test would prove applicable to a particular subsurface condition, the simplicity, low cost and rapidity with which the tests can be made recommend their trial before resorting to the more costly and tedious methods of direct exploration ofttimes employed.

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GENERAL

1. Geophysical Abstracts, a bulletin published quarterly by the US Geological Survey, contains abstracts of currently published literature relative to subsurface exploration.

DISCUSSION

E. R. Shepard, Office of the Chief of Engineers - This paper is of particular interest to me, as we in the Corps of Engineers have been doing very similar work now for some 10 yr. The author has described very clearly the relative merits of the two methods of exploration and the particular types of problems to which each is most applicable.

Because of the relatively shallow depths with which highway construction is concerned, Mr. Moore has found the resistivity method generally preferable to the seismic method. Our explorations for the most part have been on dam sites and proposed canals, where the purpose of the test is to determine the depth to firm rock and here the seismic method has proved to be admirably suited. Best results are obtained in glaciated regions and in river flood plains where hard rock exists under alluvial or glacial deposits. Where the rock is shallow and the top deeply weathered or seamed and fractured, velocities are often no greater than those prevailing in some types of soil. Under these circumstances there is often a question as to the character of the material. Moisture is a major factor influencing velocity. In relatively dry overburden, velocities of about 1000 ft per sec or less are observed. With increasing moisture the velocity increases and in saturated sand and other coarse grained material attains a critical speed of 5000 ft per sec, or approximately that in water. In clays and other fine grained soils the critical velocity of 5000 ft per sec does not necessarily occur even though they may be fully saturated.

The fractured and seamed top zone of rock, particularly when dry and carrying only a thin overburden often exhibits a remarkably low velocity and for this reason may be mistaken for saturated sand or other unconsolidated material. A correct interpretation under such conditions may be highly important where excavation costs are concerned. Where the top of rock is at or near the water table, it is often difficult to determine whether the intermediate zone between low velocity top soil and hard, high velocity rock, is saturated sand or fractured rock. Where the top of rock is relatively deep, say 30 ft or more, the presence of moisture and the heavy load which closes up seams and fractures, tend to increase the velocity in the rock, leaving little question as to its presence and character. For these reasons better results are obtained by the seismic method at moderate and great depths than at shallow depths.

The cumulative method of interpreting resistivity data developed and used extensively by Mr. Moore appears to have been of great value in his exploration for highway construction and other shallow determinations. Seldom in nature do we find soils in layered formations to which theoretical formulae and curves are applicable. The man in the field is usually frustrated and discouraged in attempting to apply these principles to his data and is usually forced to fall back on some simple and rapid emperical method of analysis. The cumulative method, although not infallible, appears to give satisfactory results on the type of work described by the author and should receive the attention of other investigations engaged on similar projects.

INFLUENCE OF TOPOGRAPHIC POSITION IN AIRPHOTO IDENTIFICATION OF PERMAFROST

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Joint Highway Research Project
Purdue University

SYNOPSIS

This paper reports the development of the use of aerial photographs in the determination of the presence or absence of detrimental permafrost. The technique used in airphoto identification of permafrost is a direct result of past and present research done at Purdue University and conducted by the Joint Highway Research Project of the Engineering Experiment Station under contract with the St. Paul District Engineer Office of the Corps of Engineers, Department of the Army. The project is under the general direction of the Office of the Chief of Engineers, Department of the Army. The paper reports the influence of topographic position in the identification of rock and the interpretation of soil and permafrost conditions from aerial photographs.

Permafrost is defined, and the factors that affect the existence or non-existence of permafrost are given in relation to the climatic influence and the topographic position. Several basic topographic situations are discussed to illustrate this relationship. The topographic types discussed include uplands, transition zones and valley fill, terraces, and flood plains. Each of these several landforms are described; the engineering problems associated therewith are set forth; and the essential airphoto-identification elements are delineated.

It has been pointed out that airphoto-pattern elements of arctic and subarctic regions have been determined for practically all drainage features, soil-color tones, vegetative types as well as for topographic position. All of these elements are important in the determination of the extent of detrimental permafrost but it is concluded that the influence of topographic position is by far the most important factor in identification of permafrost in subarctic regions.

The purpose of this paper is to discuss the importance of topographic position in the interpretation of permafrost from aerial photographs. In accomplishing this purpose certain relationships are illustrated by discussing some of the general physiographic situations from the standpoint of description of physical features, engineering problems, and photo interpretation. Permafrost is defined and the factors which influence the occurrence of permafrost are set forth. Research has shown that topographic position, as an influencing factor, is of main importance.

The study of permanently frozen soil has been limited, until recently, to the activities of a few persons including miners, explorers, some natural scientists, and a limited number of engineers. Roads were built and many failed; buildings and other structures were built and some settled severely. Airstrips were constructed on frozen soils only to develop severe settlement because of serious thawing beneath the pavement - thus, creating cracks and rough surfaces (7)[1]. See Figures 1 to 5.

The strategic situation of Alaska with respect to future routes of travel, potential statehood, the anticipated urban and rural expansion, and tourist influx has given added impetis to the quest for knowledge about permanently frozen soils, both from the standpoint of pure and applied science. The installations which were constructed during and following the war have served as a vast proving ground where important observations have been made and where invaluable data have been collected

[1]Figures in parentheses refer to references at the end of the paper.

and made available for analysis (2).

The Corps of Engineers has and still is conducting research to determine the best procedures for combating permafrost and its serious effects on structures. These researches include determining the best method for constructing roads, airports and airport structures, buildings of all types, and utilities in permafrost areas (4, 7). The work is being conducted by the St. Paul District Office under the general direction of the Office, Chief of Engineers, Department of the Army. See Figure 6.

The Engineering Experiment Station of Purdue University is under contract with the Corps of Engineers to conduct an airphoto study of permafrost. The efforts of the Joint Highway Research Project have been directed toward the engineering evaluation of permafrost and soils of arctic and subarctic regions by use of airphotos, particularly those of Alaska (2). Sufficient field and laboratory study has been completed to permit the development of airphoto interpretative procedures for use in the selection of good construction sites and

Figure 1. This is a picture of a highway which was constructed on frozen silt which contains pockets of ice in wedge form. The ice has thawed and considerable settlement has resulted as indicated by the deep water puddle.

Figure 2. This shows a severe settlement in an airfield runway surface which resulted from thawing subgrade soils.

Figure 3. Note the general warping of this building situated on frozen silt which has thawed considerably. The support indicates the severity of the situation.

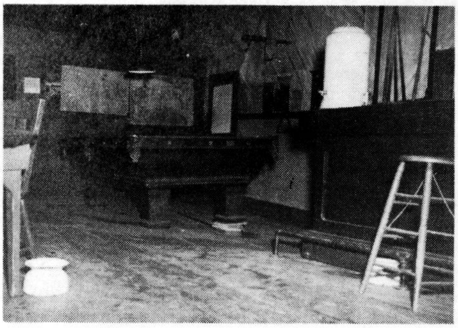

Figure 4. The interior of the building in Figure 3 shows clearly the severe effects of thaw. In the summer the soils thaw and the building settles; in the winter the soils refreeze and the building raises. A differential movement of 16 in. in the floor occurs.

for use in predicting definite permafrost conditions; namely, type, location, and relative depth to permafrost (8).

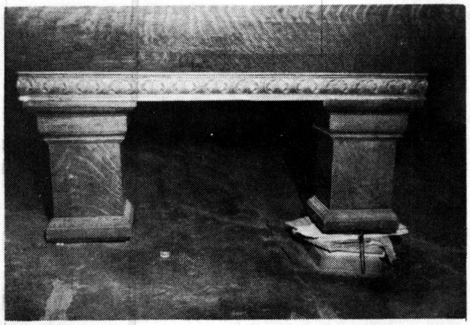

Figure 5. Note the shims under the pool table legs. In order to maintain a level table surface throughout the year it is necessary to change the shims constantly.

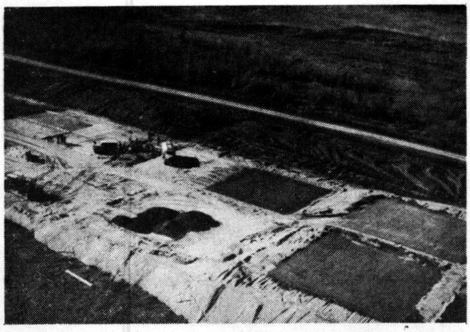

Figure 6. An Aerial View of Part of the Corps of Engineers Permafrost Experimental Area Near Fairbanks, Alaska

PERMAFROST AND INFLUENCING FACTORS

Definition - Permafrost may be defined as permanently frozen earth materials which includes bedrocks having a temperature below freezing and other materials which have become solid-like by low temperatures and have remained in such a state continuously for a long period of time. Permafrost occurs in areas where the mean annual temperature is below freezing (5), with the exception of a thin surface layer which thaws seasonally. The ground in permafrost regions is perennially frozen to depths ranging up to several hundred feet. Permafrost affects nearly

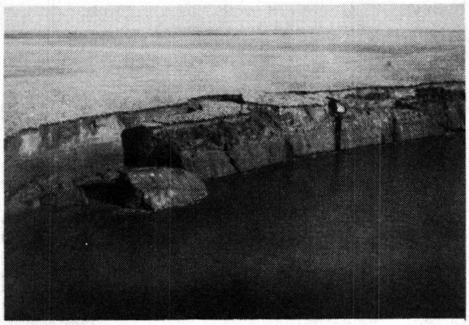

Figure 7. This figure shows massive ground ice - one form of detrimental permafrost.

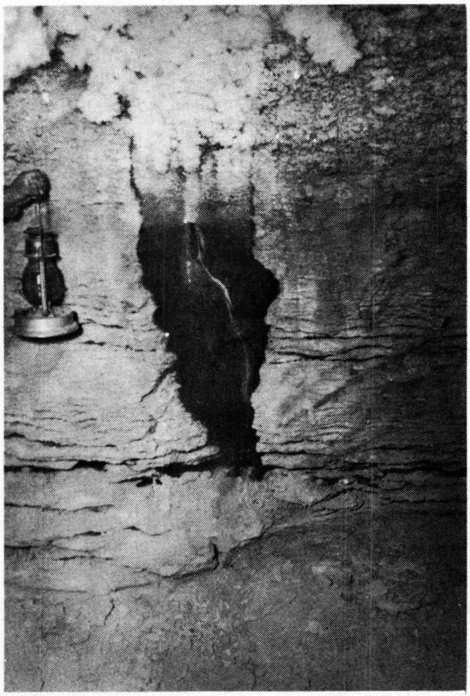

Figure 8. Another Form of Detrimental Permafrost - Here, ice in wedge form is exposed in a cold storage cellar.

all of the Arctic and a great portion of the Subarctic. It has been estimated that nearly one-fifth of all of the land area of the earth's surface is underlain by permafrost (5).

the soil mass consists of ice. Since detrimental permafrost offers the

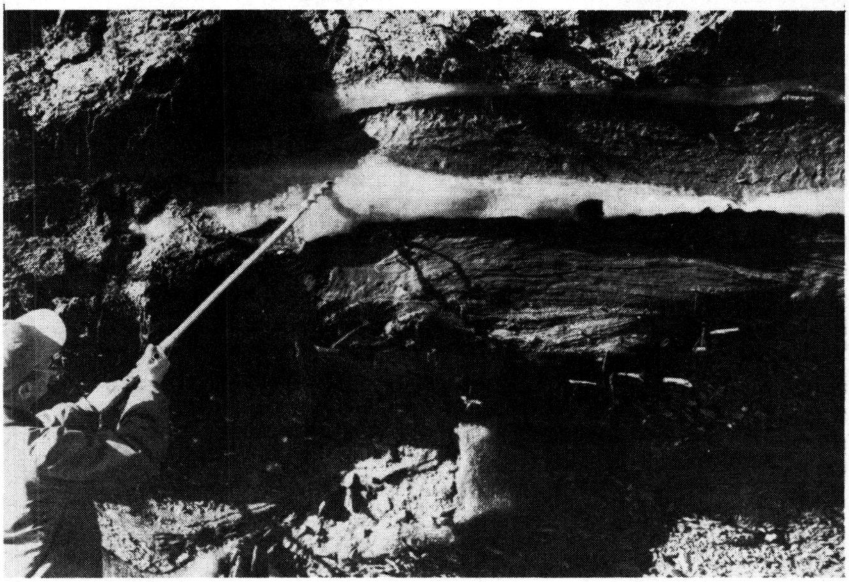

Figure 9. Detrimental Permafrost in the Form of Ice Sills and Ice Ledges

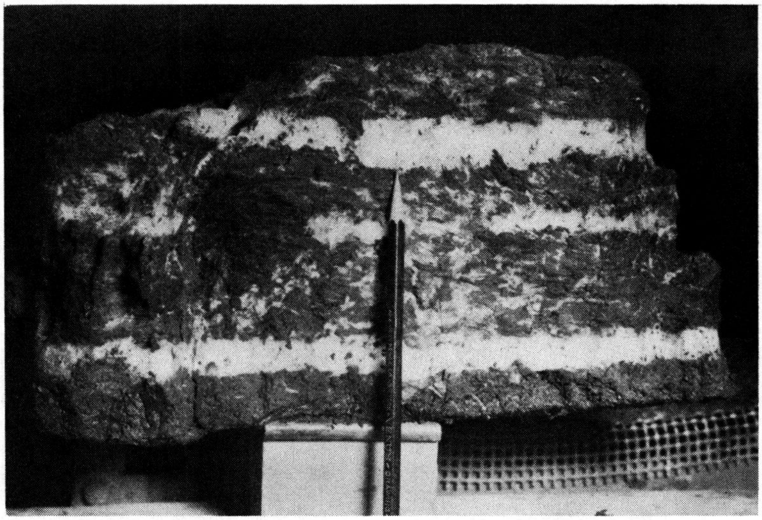

Figure 10. Layers of Ice in Frozen Silt

Forms of Permafrost - Permafrost, or frozen ground, exists in the following forms: (a) "dry frozen" in which the soil mass contains no ice but is rendered solid because the temperature is below freezing; and (b) "detrimentally frozen" in which a large percentage of

serious engineering problems, more concern is given to the variety of forms in which it exists (1). Above the permanently frozen surface is the active layer which goes through annual cycles of freezing and thawing.

The variety of forms in which detrimental permafrost exists include: (a) fine-textured soils which contain a large percentage of ice in their mass in the

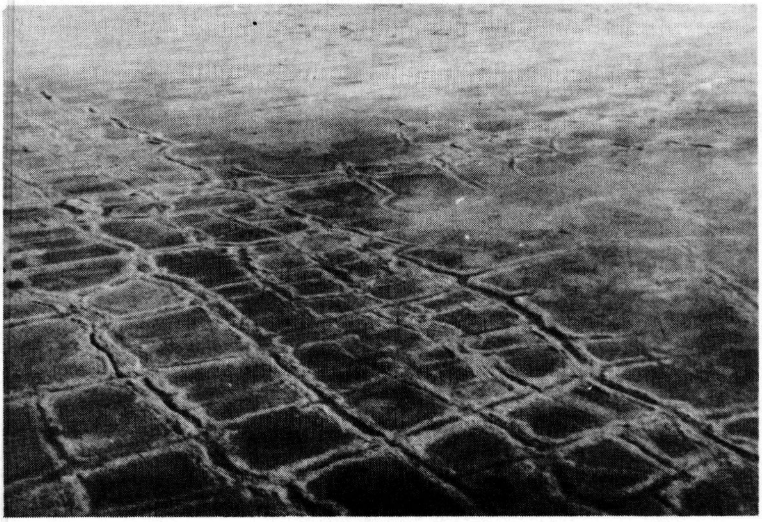

Figure 11. Depressed Center-Type Polygons - These are about 200 ft across.

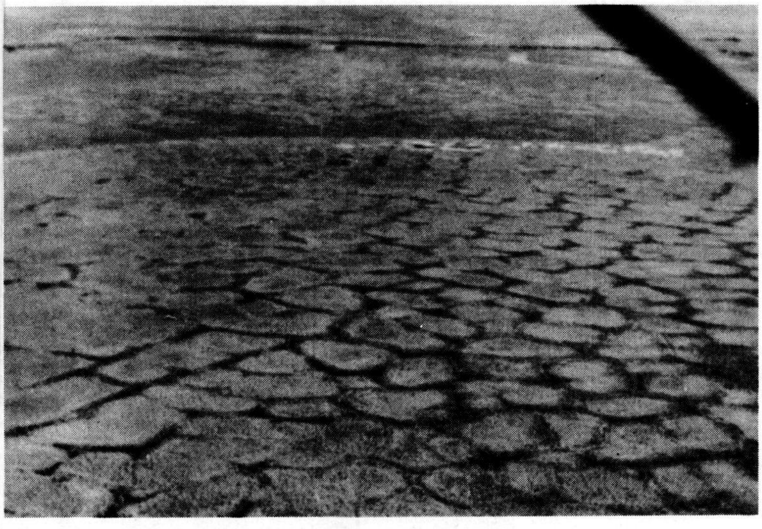

Figure 12. Another type of polygon is the raised-center type. These are about 75 ft across.

form of crystals, small lenses, or small wedges; (b) soil masses which have been so arranged by segregation of ice and soil particles that they form polygonal blocks of varying sizes and types; (c) materials situated in low topographic position in which large masses of ground ice form an integral part of the mass; and (d) large masses of buried ground ice. Figures 7, 8, 9, and 10 illustrate forms of ice-soil mixtures.

One of the most significant features

of permafrost regions in which detrimentally frozen soils abound, is the presence of soil polygons. The term "soil polygon", as generally accepted, refers to the geometric configuration of surface markings in regions of permanently frozen soils. Many types exist and are recognized in the literature. The two most important types are:

Figure 13. This is an airphoto of an upland area which is covered with an unrelated mantle. The surface is marked with numerous polygons indicating ice wedges in the soils. The bar scale is 1000 ft.

(1) those with depressed centers or pans which have a perimeter consisting of raised dykes; (2) and those with raised centers and depressed perimeters. Figures 11 and 12 illustrate two types of polygons (2).

Influencing Factors - There are many factors which influence the presence or absence of permafrost and its type or degree. Among the factors are general climatic conditions and certain local physical conditions. The local conditions, which influence the presence or absence of permafrost, include such variables as topographic position, soil texture, soil moisture, vegetation, surface drainage, slope, and exposure to light and heat. Of all local conditions it is believed that the influence of topographic position is the greatest in determining degree and type of permafrost, either from a field survey or from interpretation of aerial photographs.

In the Arctic Regions where the duration of cold temperature in number of days below freezing is great the element topographic position is not as critical as an influencing factor of permafrost as it is in warmer areas. As far as Alaska is concerned the Arctic Regions include, for the most part, the area north of the Brooks Range. In the Subarctic Regions, the permafrost-topographic situation relationship is more critical than in the Arctic Region because of such items as a shorter duration of cold temperatures, a generally higher soil temperature, and a greater depth of seasonal thaw.

TOPOGRAPHIC POSITION

It is necessary for the interpreter to determine the physiographic arrangement of an area under consideration in order to evaluate the permafrost conditions. As far as airphoto interpretation is concerned it is necessary to determine whether an area is mountainous, an upland plateau, transition zones or valley fill, terrace, flood plain, or presentation is to describe some of the physical features, discuss some of the

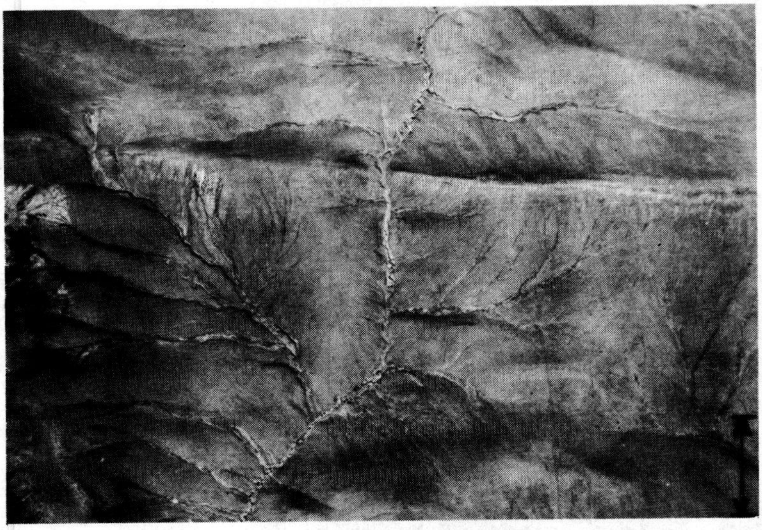

Figure 14. This is an airphoto pattern of strongly-tilted beds of sandstone and shale in Northern Alaska. The bar scale is 1000 ft.

Figure 15. This illustrates the ''button type'' gully system which frequently occurs in upland depressed areas.

some combination of the above in order to evaluate permafrost conditions.

In discussing the effect of topographic position on permafrost in these physiographic classes the scheme of this engineering problems, and demonstrate how the patterns may be identified on the aerial photograph. The mountainous areas offer insignificant permafrost problems and will not be discussed.

Uplands - Uplands may cover a range of several types of relief. The relief of an upland most generally depends upon the underlying parent material: it may reflect the influence of flat lying or tilted bedrock; it may result from bedrock types which are covered with glacial deposits; or it may result from igneous formations which have been intruded or extruded locally (3).

In upland areas permafrost is not a problem when rock-in-place is the parent material. Uplands create serious permafrost situations when a sufficient mantle of normally loose and unconsolidated material exists. The mantle of soil may represent an altogether unrelated material which has been left by either ice, wind, or water. It may be accumulations of local materials as sediments in depressions or on the side slopes of hills or in gullies.

In the areas which have a disconformant surface mantle, well-developed polygons occur widespread thus indicating the presence of detrimental permafrost (Fig. 13). The polygons are of the raised-center type. Such areas offer serious difficulties to engineering structures - particularly highways and airfields. Many of the upland gullies are broad in cross-section, they appear to be filled with local sediments, contain deep accumulations of frozen peat, and occasionally are marked with well-developed polygons. In upland depressions the thick accumulation of peat and the products of rock weathering promote severe permafrost conditions - many of which should be avoided. In such instances large masses of ground ice can be expected beneath the vegetal accumulations.

Figure 16. This figure illustrates thaw of polygons.

Construction in the upland would involve rock excavation. For highways or runways this situation would create a varying subgrade condition which would range from some of the best materials (rocks) to some of the poorest (ice and/or frozen silt).

Identification of upland situations from airphotos is fairly simple and straightforward. The rock patterns are similar to those found elsewhere. As an example, the sandstone and shale pattern occurring in the Interior Uplands (Fig. 14) bear more than striking resemblence to the sandstone and shale pattern of parts of an area of similar work materials in midwestern United

States. The major airphoto-pattern elements in each situation are similar.

they appear to be connected to a series of "thaw sinks" which appear as circular

Figure 17. This figure illustrates a small valley fill situation.

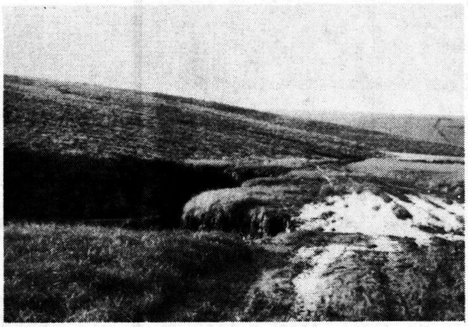

Figure 18. An Illustration of a Severe Thaw in a Local Valley Fill Situation Resulting from Excessive Flow of Water in a Gully Near the Edge of the Road

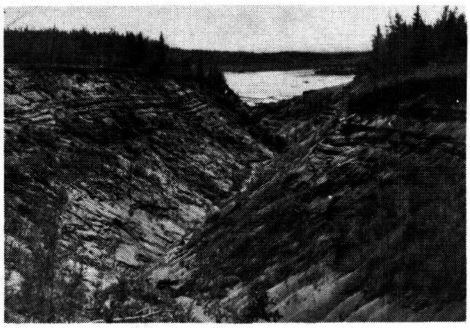

Figure 19. This illustrates the result of an upset in the thermal balance.

In the upland areas the low topographic situations which are associated with detrimental permafrost can be determined in many ways. For instance, in the Arctic Regions upland gullies often exist as "button" type gullies (Fig. 15). Spacing of the "buttons" is often quite regular (2). On the airphoto

pools or pans in colluvial fill materials occupying depressed situations. Flow in such gullies is slow, the water being retarded by the vegetation. These circular areas are locally thawed and are filled with water. They are often ten or more feet in diameter and in broad, valley-fill-type gullies the thaw sinks often form around polygon-channel intersections (Fig. 16). Upon identification on the airphoto it is significant that they indicate potential permafrost difficulties. In areas where the local topography is rugged and angular the button-type gullies do not occur. In rock areas major drainage as well as gullies show control exerted by the rocks by angularity in the system.

representative of transition zones and valley filling. Such physical features are readily recognizable as a zone between adjacent areas of difference in elevation. In general, in the high areas the streams are young and are actively degrading while in the low areas the streams are older and are aggrading

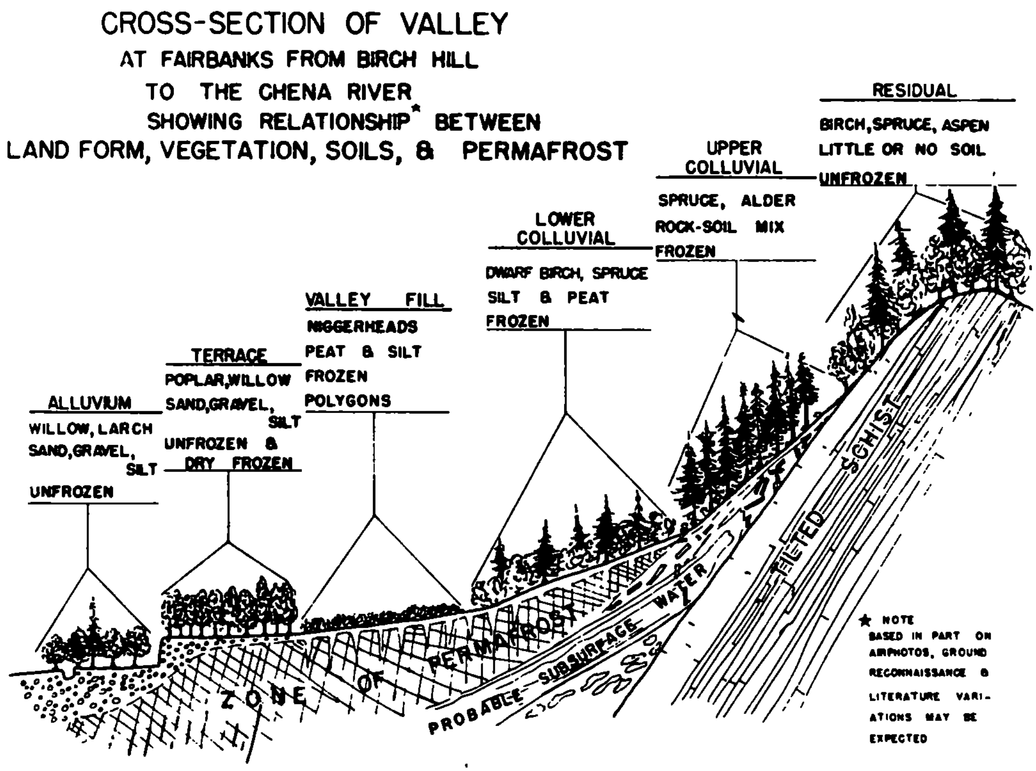

Figure 20. This schematic diagram shows some of the key permafrost influencing factors. The relationship between permafrost and topographic position is indicated. Vegetation found on the various soil-slope phases is also indicated.

Transition Zones and Valley Fill - Perhaps one of the most severe topographic situations occurring in subarctic regions from a highway standpoint which affect permafrost are those connected with transition zones and valley filling. Transition zones and valley fill are discussed together because of the general similarity in their formation and in their physical features. Material eroding from the uplands and collecting along the slope of the valley wall is (3).

The description of transition zones and valley fill is divided in two parts. The first part to be discussed concerns small valley fill situations where the contributing factors are local. The second to be discussed involves large valley fill situations which in some instances involve major physiographic changes.

An example of a small valley-fill situation would be a local valley or rather large upland gully with a not too great drainage area. When the slope or gradient of such a gully is not great the valley is usually filled with colluvial material which is normally fine textured. The local valley bottom is fairly broad and forms a slight but perceptible concave surface. In many instances the gullies do not act as normal gullies but rather follow a series of connected polygon channels. See Figures 16 and 17. Drainage through these channels is often rather slow because of the thick accumulation of swamp grasses. However, when the ground slope or the gully gradient becomes steep or if for some reason a sudden rainfall should occur which would activate the gully, then considerable thaw would occur (Fig. 16). The force of the running water together with its warming effect often results in deepening of the polygon channels without appreciable lateral erosion. When such a condition occurs, the ice in the polygon channel thaws, thus exposing vertical walls of frozen soils (Fig. 18). Such areas are of serious concern in highway location where it may be necessary to cross a small valley-fill situation. In such instances the concentration of runoff associated with highway ditching would discharge large quantities over the frozen soils thus accelerating the thaw. If left unchecked, a considerable amount of soil would be removed resulting from an upset in the thermal balance (Fig. 19) (1).

In the larger valley-fill situations the topography is more subdued and the topographic features occur on a much larger scale than in the smaller valley-fill areas. On transition slopes permafrost varies with the depth of rock-soil mantle and with the topographic position both with respect to the elevation of the hillside above the flood plain (2).

In the upper slopes where the colluvium usually is relatively free from fine-textured soils, permafrost is not as serious as it is on lower topographic positions. In the winter the difficulty of icing from water crossing the road and freezing is much more severe than the permafrost problem. In normal hillside situations the mid-portion of the hills usually contains deep colluvial materials which consist of accumulations of fine-textured soils. In such situations the soil mantle is frozen; it often contains accumulations of ground ice, ice wedges, ice lenses, and considerable ice crystal growth. Any disturbing of the mantle of vegetation, particularly in making a side-hill cut for a highway, will cause severe thawing to occur.

On the lower portion of hills, in zones where the colluvial material begins to build up and form alluvial fans, permafrost problems are severe. Such zones contain some rock fragments and the major portion of the material consists of the fine soil brought down the slopes. Frequently the slopes are not steep and considerable peat has accumulated in lower positions. In such situations ice wedges are common and occasionally masses of ground ice will occur and when the soils are chiefly silt, ice crystals occur. When silt soils are encountered frost heaving is severe. Cuts for highways will pass through the active zone into the zone of continuous permafrost which will result in a severe upset in the permafrost-vegetation-thermal balance. Unless attention is given to proper construction and drainage procedures, severe highway difficulties will result.

In airphoto interpretation topographic position plays the chief role in permafrost identification and evaluation. Whether the transition zone or valley-fill situation is large or small it is necessary to determine the topographic position where materials change from "in situ" to colluvial (Fig. 20). It is also important to detect soil-texture changes in colluvial zones which are reflected in slope, drainage and vegetation - all of which are easily recognized on good quality airphotos. See Figures 21 and 22. Some transition zones are characterized by radial markings of bare rock patches; others by soil-rock flows which are often broad in plan and which occur on the upper and middle slopes and appear to scallop the hillsides. Such features are easily seen in airphotos and form an outstanding and significant feature in their identification on the airphotos. They suggest unstable soil conditions

Figure 21. This vertical airphoto contains some of the major topographic features contained in the diagrammetric sketch of Figure 20. It covers the upper portion of valley fill to the outward part of the valley fill. The arrows point out the following features associated with the lower topographic portions where permafrost conditions vary:

1. a ridge of colluvial silt
2. a gully between two silt ridges
3. a grass-covered embayed area on the border between the flats and the lower hill slopes - Permafrost (PF) at 36 in
4. dense willow thicket very wet surface (PF at 24 in)
5. polygon area (PF at 18 in)
6. spruce thicket on an extension of one of the sloping silt ridges (PF at 36 in)
7. small gully
8. probable terrace remnant sandy soils (PF at 54)
9. flat area grass covered (PF at 27 in)
10. swampy area - floating muskeg

and many are related directly to permafrost (Fig. 23).

Terraces - Terraces generally exist as flat-topped benches, usually sloping gently toward the stream with which they are associated. In broad valleys, usually thought of as being old, terraces occur on a grand scale. In contrast, the terraces in younger valleys consist of a series of narrow bench-like prominences on the valley sides (3).

Terraces of great areal extent, such as those which are found in the major valleys, are very important for the location of major engineering structures which require considerable surface area such as airfields or urban developments. Even though the general topographic situation of such terraces is good with respect to the surroundings, there are often local features on the terrace surface which give rise to severe engineering difficulties. Most of the large terraces may be thought of having three divisions insofar as engineering problems are concerned (Fig. 24).

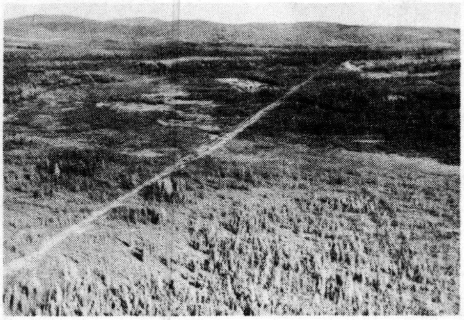

Figure 22. This is an oblique airphoto of a valley fill area near Fairbanks. It contains the area in Figure 21.

Figure 23. This shows ''hummocks'' occurring on colluvial slopes in the Subarctic Region. Such features are clearly discernable on airphotos. They indicate unstable soils.

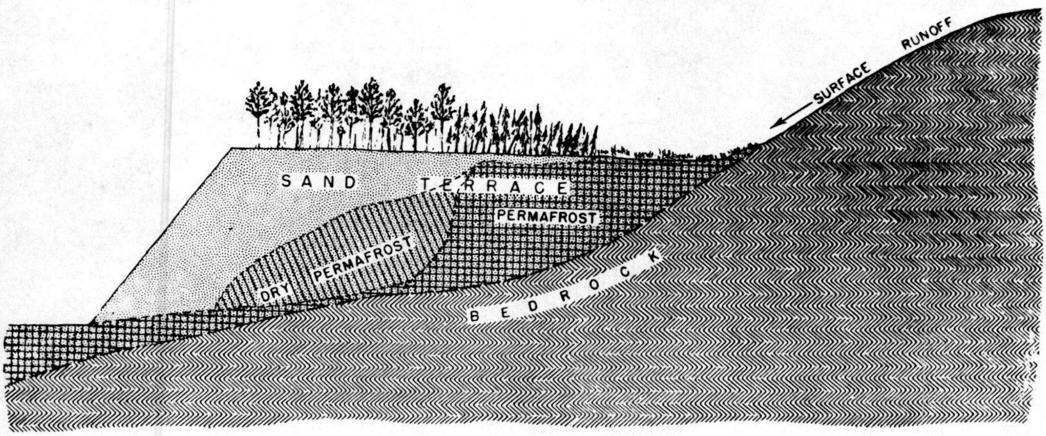

Figure 24. This is a sketch showing some of the typical permafrost conditions with respect to position on terraces.

In considering the use of a terrace for the location of an engineering structure, the design of such a structure must take into account which portion of the terrace is used. For convenience, these three zones or divisions are: inner zone, middle zone, and outer zone. The first is situated topographically nearest the valley wall, the second is located centrally, and the latter may be found nearest the adjacent flood plain. Serious engineering difficulties may be encountered on the inner portion of a terrace. Permafrost detrimental permafrost is the rule rather than the exception. Design practice for engineering structures should not be too different than on ordinary terraces in warmer areas (Fig. 27).

Identification of soils and permafrost is based on the evaluation of the airphoto pattern elements. Interpretation

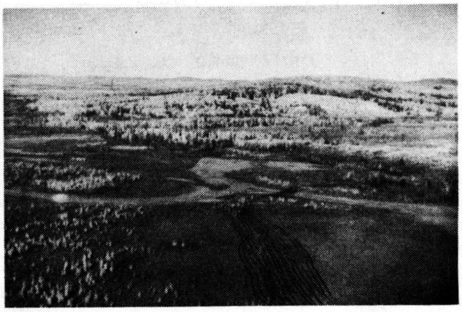

Figure 25. This is a low altitude oblique photo of the inner part of a terrace. Note the vehicle tracks in the ''floating muskeg area''.

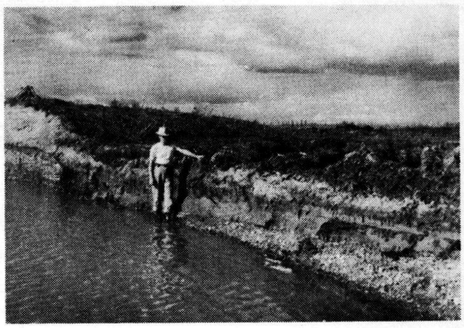

Figure 26. This is a cut made in the center part of a terrace area; it illustrates the problem of varying subgrade conditions.

conditions are usually severe in this inner zone since excessive surface water, poor drainage, and a deep overburden of fine-textured soils prevail. On the inner portion of the larger terraces, particularly in the transition zones between terrace and upland or terrace and valley wall, topographic position becomes exceedingly important because of the influence of the adjacent uplands. In such areas, a deep mantle of fine-textured soil occurs; this mantle is frozen and often contains polygons. In many instances such areas consist of extensive muskeg (Fig. 25). Pockets of ground ice occur frequently. In the central portion of terraces, surface features and permafrost conditions are variable and the problem of varying soils occurs. When designing engineering structures, constant attention is necessary to meet the requirements of changing soil and permafrost conditions (Fig. 26). In the outer portion of terraces, soils and drainage are more favorable for engineering use than in either of the other zones. The lack of of the poorest engineering situations in terraces where soils are fine-textured and detrimentally frozen is based on relatively few photo pattern elements - the local topographic situation being the most important. Under the stereoscope the land form of any terrace appears as a bench or shelf whose topographic position is between that of the flood plain on one side and the upland on the other side. When surface is nearly flat and the terrace scarp is steep, granular soils are suggested. Surface features on frozen terrace vary considerably.

The presence or absence of permafrost on terraces depends on many factors, most of which can be seen directly on airphotos. In the timbered regions, broad flat areas mantled with aspen usually indicate dry and frost-free materials (Fig. 28), while stunted spruce, tamarack or tundra-type vegetation (niggerheads and dwarf birch), usually indicate frozen soil (6). Contrasts in vegetative cover usually indicate contrasts in soil conditions (Fig.

29). As an example, the outward portion of a terrace may be mantled with aspen and may be unfrozen, the middle portion of the terrace may support stunted spruce and tamarack and may be dry frozen, and the inner part of the terrace adjacent to the valley wall (usually consisting of the lower and outward part of a transition zone) may be rather swampy, marked with polygons, and support dwarf birch and niggerheads, thus indicating detrimentally-frozen materials. Low terraces, mantled with spruce-birch forests or spruce-tamarack forests which are otherwise frozen, may be crossed with a series of unfrozen natural levees which are mantled with aspen. The presence of polygons on terraces indicates detrimentally-frozen materials (Fig. 30).

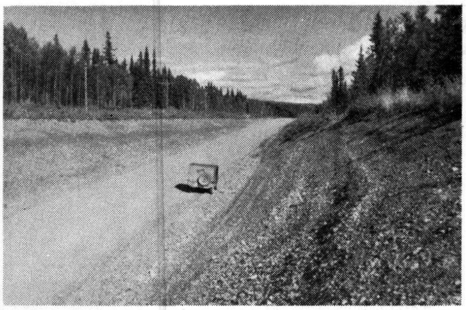

Figure 27. This shows a highway cut made in the outward part of a terrace. The gravels here are unfrozen for considerable depth.

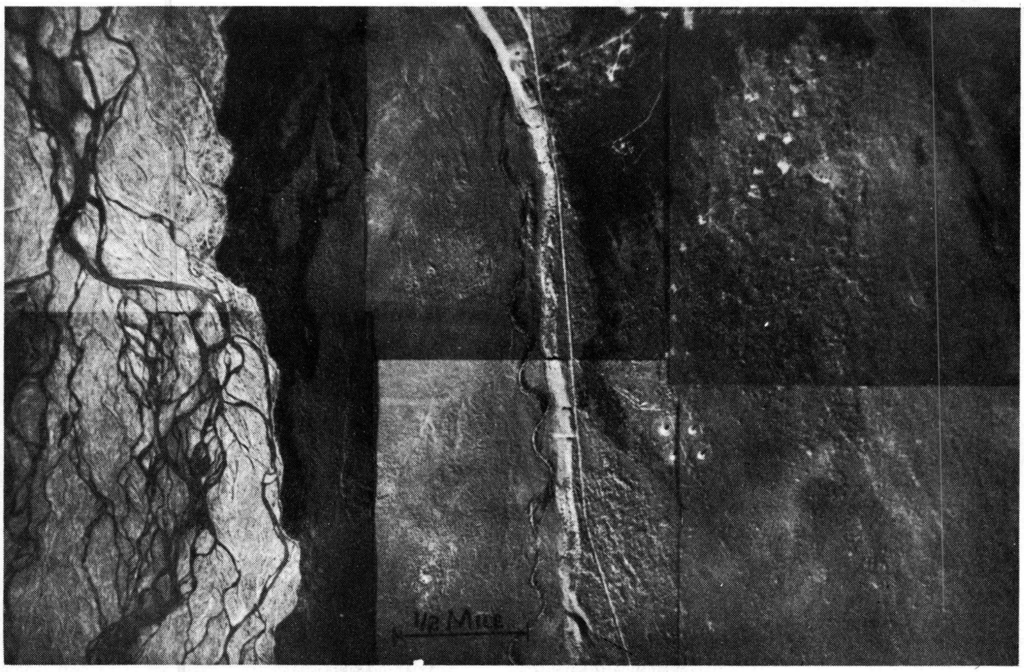

Figure 28. This airphoto contains many of the identifying elements of a good engineering location - that of frost-free granular materials.

Gullies on frozen terraces rarely exist unless they accompany a thaw and if polygons are present, the gullies will outline the geometric plan of polygon channels which are clearly evident on the airphotos. The local area around such a gully will show extensive thaw with considerable sloughing of soils. Generally speaking, gully shape, gradient, and cross section are reliable soil-texture indicators only in unfrozen

Figure 29. This low terrace has been marked to indicate various permafrost-position relationships. The following areas are described:

A grass and low brush, locally depressed, frozen silt at 19 in
B grass and willow, low channel scar, unfrozen sandy silt for 54 in
C - willow covered, slightly higher ridge left by current activity, sand, unfrozen 54 in (auger length)
D - grass-filled abandoned meander, flowing water, sand and unfrozen for 54 in
E - dense willow thicket, moss and peat, frozen silt below 24 in
F - depressed muskeg area, polygons, frozen below 24 in
G - large, sand-filled stream meander scar, dry, unfrozen for at least 54 in
H - poplar grove on gravel, dry, unfrozen
I - polygon area, frozen silt below 18 in
J - current markings - gravel, unfrozen

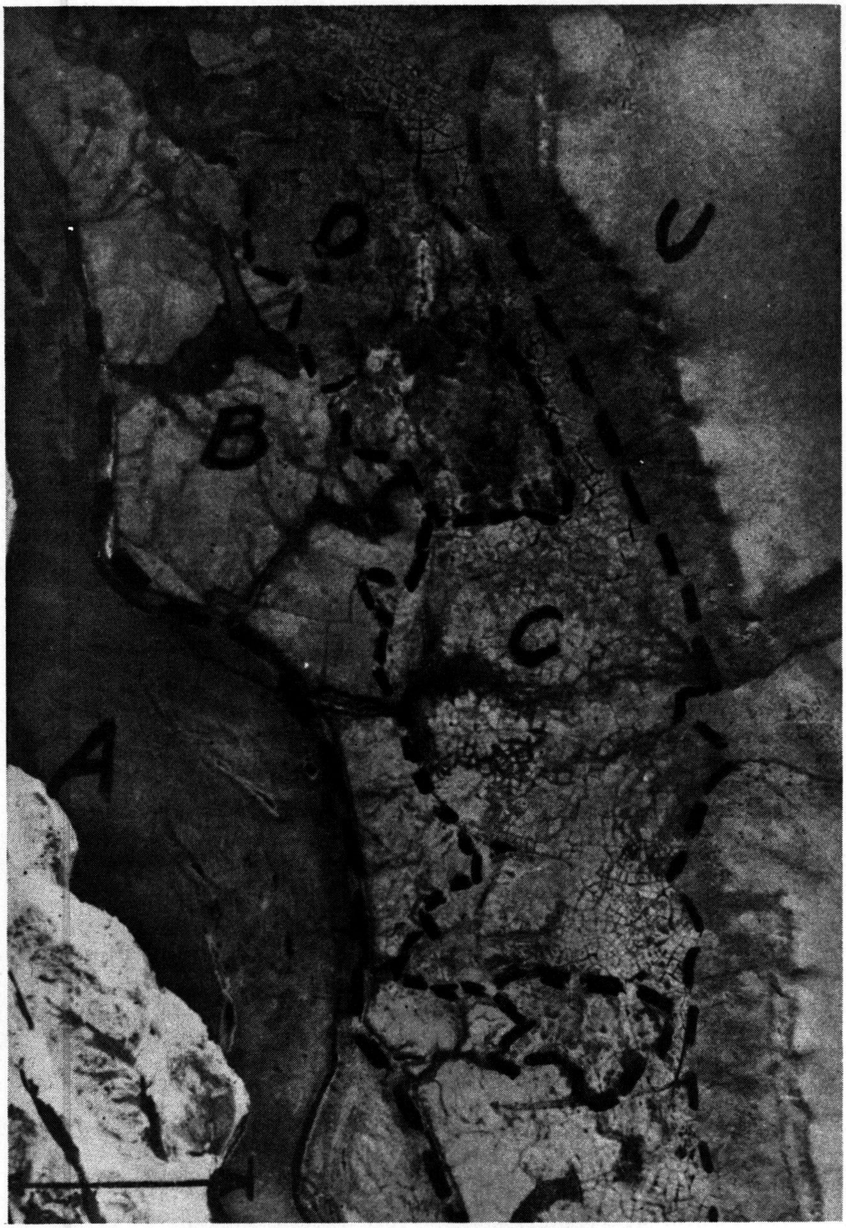

Figure 30. This airphoto shows how some of the permafrost-topographic situations appear in arctic valleys. This area contains:

U - rocky upland, chiefly shale, frozen
A - gravelly flood plain, unfrozen near the stream proper
B, D, C - form a gravel terrace
B - the outward portion, gravel, unfrozen 3 to 5 ft
C - the inner portion, silt covered, frozen below 18 in, polygons of raised-center type, ice wedges
D - depressed area, silt and ice mantle, depressed-center polygons ground ice areas

soil areas. This means that, as far as Alaska is concerned, the gullies occurring in unfrozen gravel terraces are indicative of the terrace materials regardless of where the terrace occurs.

meet this requirement.

It is in alluvial soils that the widest variations occur both in soil textures and permafrost conditions. Texturally, alluvial soils range from gravels to

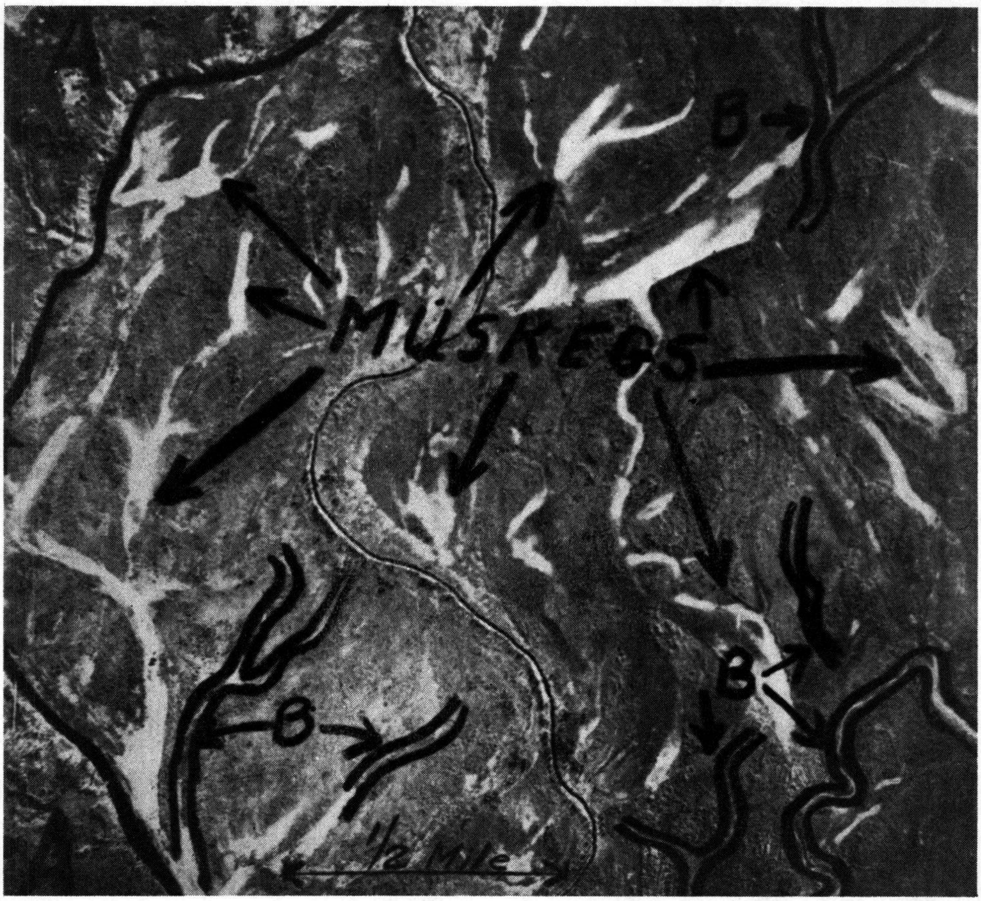

Figure 31. This is an illustration of the backwater area adjacent to the next higher major land form. Muskegs, ground ice, polygons and frozen silts usually occur.

Flood Plains - The flood plains of valleys, more commonly called recent alluvium, contain streams whose course is shifting constantly because of the heavy load of alluvial sediment and because of the relative freedom from obstructions in the flood plain. Both soil textures and permafrost conditions vary widely in alluvial soils. Modern engineering structures often require vast unobstructed areas. Flood plains offer the best topographic situations to

silt (clays are in the minority in the Arctic and Subarctic). As far as engineering conditions are concerned the best sites are the unfrozen well-drained gravels. Perhaps next in order of preference are the frozen gravels, frozen sands, and the frozen silts. Wherever possible all engineering construction should be confined to the more granular soils which in many instances are unfrozen.

In flood plain areas where the topographic position is low and often within a few ft of the local base level of erosion, permafrost is generally sporadic. In areas adjacent to the stream the soils are usually unfrozen because of the warming effect of the circulating water. Inland from the stream proper permafrost varies considerably. It exists in the long and broad channels left by current activity which are filled with silt and peat and contain muskeg-type vegetation. The most detrimental permafrost situations occur in the ponded backwater areas usually situated behind the natural levees or near upland borders (Fig. 31). Such areas occupy the lowest topographic situations in a flood plain or valley.

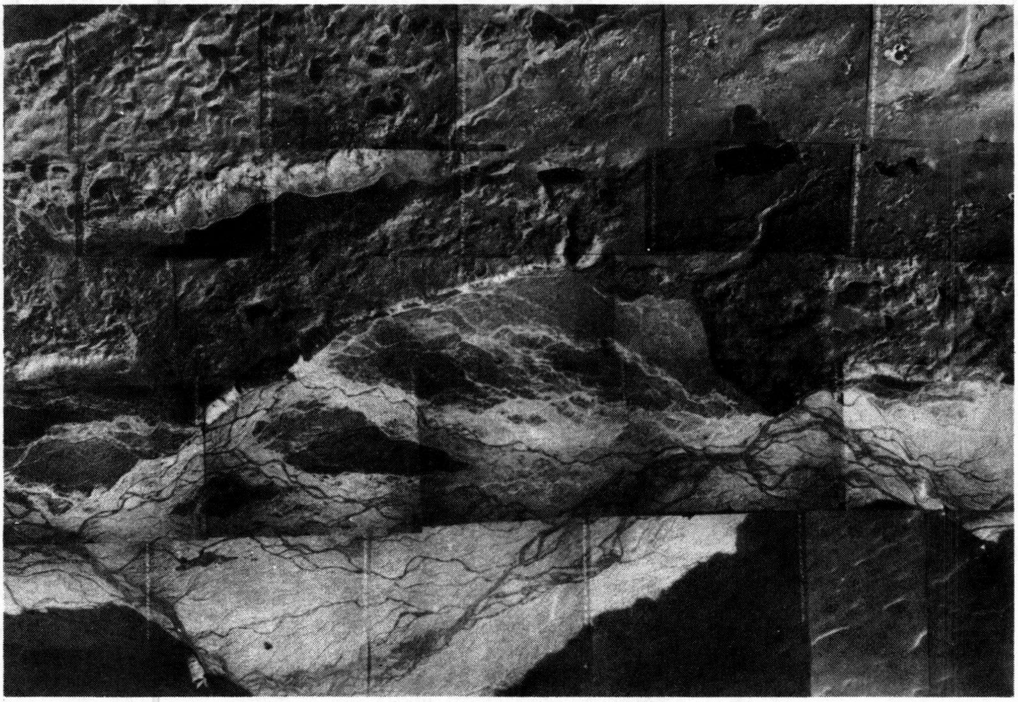

Figure 32. This shows a typical braided stream pattern.

Figure 33. This is a low altitude oblique of the Yukon Valley, known in this area as the ''Yukon Flats'', partly because of its vast size and relatively flat topography.

As far as airphoto interpretation is concerned flood plain deposits are characterized by current markings (Fig. 32) in the form of abandoned stream meanders, natural levees, bars, and ox bows. In the broad stream valley situations, the meanders form great sweeping arcs and cover a considerable portion of the valley floor (Fig. 33).

Stereoscopic study of airphotos will reveal the flood plain to be an interior basin which is low topographically. Topographically, flood plains are flat with the only relief occurring between a stream meander and an adjacent ridge or a natural levee left by current activity. In the narrow and rather confined flood plains, local relief is sometimes greater because of the increased current activity which results in deep scour in some places and deposition in others.

Photo interpretation will usually result in finding no established drainage pattern in recent alluvial or flood-plain areas. The major stream and its tributaries usually provide the only surface drainage. The natural levees are often well drained internally and do not show results of surface drainage. Inland, the flat topograpny and lack of sufficient fall together with some retarding of drainage afforded by natural levees, results in a widespread swampy condition. Polygons will occur on intermediate topographic positions where flooding rarely occurs. These features are clearly discernable on airphotos.

CONCLUSIONS

As a result of nearly five years of study including field work in the airphoto interpretation of soils and permafrost as applied to the Arctic and Subarctic Regions, a number of conclusions may be stated as representative of the progress, significance, and expected use of airphoto interpretative analysis. With regard to the factor of topographic position as it pertains to permafrost and its importance on highway location and construction, the following is offered:

1. In Subarctic Regions topographic position is one of the most important factors in the occurrence of permafrost and, therefore, in its identification both from airphoto interpretation and field practices.

2. In Subarctic Regions, topographic position can be evaluated on the airphotos, thus enabling the interpreter to determine the presence or absence of detrimental permafrost both in regional as well as in local situations.

3. By utilizing airphoto interpretative procedures in Arctic and Subarctic Regions, engineering problems can be anticipated, feasible site locations can be ascertained, and design practice can be determined with a minimum amount of field work, time, delay, and expense.

4. In general, the best location for construction of highways, airfields, and towns and cities in permafrost regions consist of the well-drained granular terraces which can be readily identified and evaluated from contact airphotos.

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