HIGHWAY RESEARCH BOARD

Bulletin 65

Mapping and Subsurface Exploration for Engineering Purposes

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DEPARTMENT OF SOILS INVESTIGATIONS

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Bureau of Public Roads,
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Contents

Introduction

FRANK R. OLMSTEAD, Chairman,
Highway Research Engineer, Bureau of Public Roads

● THIS is the fifth in a related series of bulletins sponsored by the Committee on Soil Surveying and Classifying Soils In-Place for Engineering Purposes. The four previous bulletins, 13, 22, 28, and 46, contain useful information on the interpretation of aerial photographs, agricultural and geological maps for planning and organizing engineering soil surveys and mapping on an area basis, on the use and application of geophysical methods of subsurface exploration, on the location of granular materials for road-building purposes, and on the status of topographic, agricultural, and geologic mapping by the U. S. Geological Survey and the U. S. Department of Agriculture. Lists of geologists and soil scientists, who may be able to assist the highway engineer in obtaining more precise information for mapping and map interpretation for any particular part of the United States, have been included for ready reference.

This bulletin is a continuation of the policy of the committee to present information useful to the engineers responsible for planning and building our highways.

The rapid rise in construction costs, the increased road damage by the greater volume and type of traffic in recent years have made the highway administrator aware of the urgent need for locating, evaluating, and selecting local soils with high-bearing power for subbase and base courses of roads. This trend of thought has been accelerated by the recent findings of road tests by the Highway Research Board and States and even more emphasis will be placed on the use of the better types of local soils and geologic materials when the factual evidence of other road tests is more widely known.

The committee considers that the methods of terrain appraisal and subsurface exploration described in previous H. R. B. bulletins 13, 22, 28, and 46 can be used to locate and evaluate local materials on a State or Nation-wide basis.

At the present time 10 States are making State-wide appraisals of soils and engineering soil maps. Four of these, New Jersey, Maine, Virginia and Rhode Island, have cooperative research projects with the Bureau of Public Roads and there are indications that other States are interested in similar projects.

Local deposits of suitable road gravel are rapidly being exhausted in many parts of the country. Consequently, materials must be imported from more distant points. In some areas, the situation is quite acute and any method which can be utilized to relieve this shortage of local materials should be fully examined before making the final decision to write off these critical areas from further exploration.

The two papers presented in this bulletin should be of particular interest to those faced with the problem of shortages in local materials. Often usable deposits can be found in areas where surface indications do not reflect the economical occurrence of such deposits.

The first paper by Mr. Barnes on a new method of interpretation of resistivity data shows considerable promise in the area in which it has been developed. It is suggested that engineers in other areas consider this method of layer-value interpretations in their use of resistivity for subsurface exploration so that further improvements can be made in this method of exploration.

The second paper by Mr. Marshall on the effect of native materials on road-building in Ohio should be of special significance to the highway administrator because it points out how the complex information obtained from geological and pedological systems of terrain classification can be correlated with considerable laboratory test data and simplified so that it can readily be understood by the average highway engineer and applied to the improvement of their roads and streets.

It is important to call attention to the fact that this correlation work in soils and geology and engineering test data was a part of the Ohio Department of Highway's intensive study of the State's roads and streets to obtain a comprehensive picture of their highway needs. It should also be noted that this work was undertaken by experienced soil engineers and technical research personnel who are thoroughly acquainted with the design, construction, and maintenance problems in the state.

The decision to use experienced personnel to compile this type of terrain information and the subsequent reduction of this information into usable form is significant because it would be difficult and perhaps impossible to carry out this work without a complete understanding of the relations between geology, climate, soils, traffic, design, and construction practices.

PURPOSE AND SCOPE OF COMMITTEE

Purpose

To assist in the development of a program of engineering papers and publications to emphasize the need for soil survey information in highway planning and construction, and to point out practical applications of the use of soil surveys in highway engineering work.

To assist in the development of new methods for making soil surveys or for the identification and classification of soils from laboratory or field data.

To review and recommend for approval any technical papers on soils under the jurisdiction of this committee which may be submitted for presentation and publication by the Highway Research Board. Also to furnish the Highway Research Board with recommendations on engineering soil problems that may be assigned for review and comment.

Scope

In general all phases of the soil survey work such as, interpretation of airphotos, geologic maps or agronomic soil maps for soils information, the preparation of engineering soil maps, or the preparation of material inventories on an area basis, the methods of subsurface exploration - seismic or resistivity, the evaluation of soil survey data for the design, construction or maintenance of highways and the methods of correlation of soil data with pavement performance are considered within the scope of this project committee activity.

Geologic Survey Mapping in the United States

● THE committee indicated in Bulletin 46 the status and usefulness of geologic maps for highway-engineering purposes. The following information furnished by the U. S. Geological Survey at the request of the committee has been included to supplement the information contained in Bulletin 46.

The usefulness of geologic maps for highway engineering purposes was brought out in Bulletin 28, 1950. This bulletin included a map showing the status of geologic mapping in the United States furnished by the U. S. Geological Survey and information about available indexes to geologic mapping obtainable by States from that organization. A new map which brings the information about published geologic maps up to 1952 has just been released by the Geological Survey and is reproduced in Figure 1. Extra copies of this map may be obtained on application to the Geological Survey, Washington 25, D. C.

Current Investigations of the U.S.G.S. Involving Geologic Mapping

The Geological Survey prepares geologic maps for several purposes in more than one of its divisions. The Geologic Division conducts systematic surveys and research and investigations related to mineral resources and to engineering geologic problems. Many of the geologic maps prepared by this division are highly detailed and restricted to mineralized areas. The Water Resources Division, through its Ground Water Branch, makes systematic and special geologic investigations in connection with the occurrence of ground water. Many of the studies have special application to highway construction and planning. Geologic maps, cross-sections, and texts are published.

The following list of investigations include only a real geologic mapping which it is felt may be useful to engineers engaged in construction work in the areas concerned.

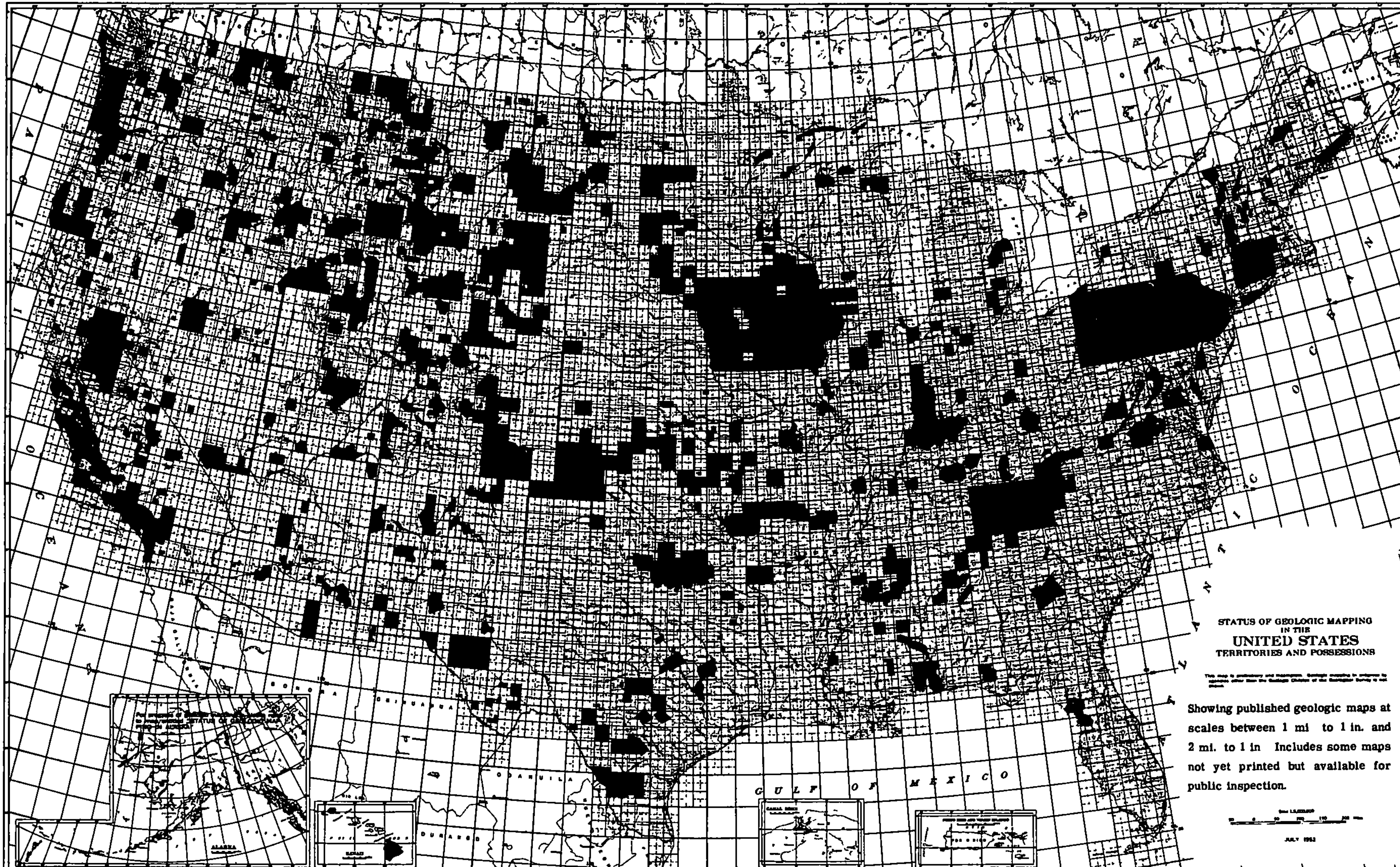
As geologists in charge of the Geologic Division projects, Table 1, are in the field for only a part of the year, and as the investigations frequently involve considerable laboratory and office research generally not performed in the field area, it is suggested that any inquiry about them should be addressed to Director, U. S. Geological Survey, Washington 25, D. C. Water Resources Division projects, Table 2, are directed from permanent offices in the states where both original and published records are available. Inquiry may be made through the field offices or through the Director, as indicated above.

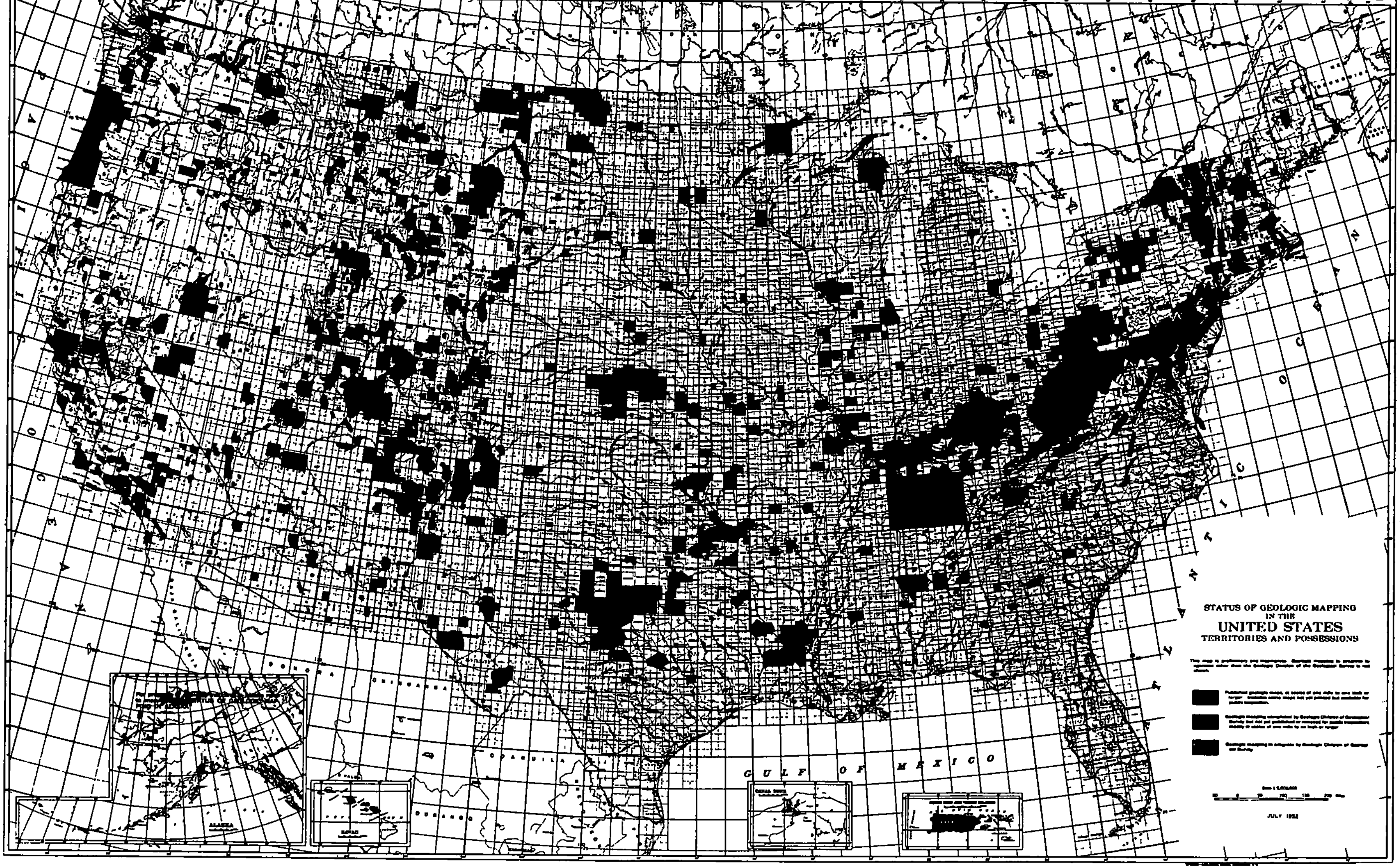
STATE GEOLOGICAL INDEX MAP

The following map indexes, which are now available for most of the States, show the areas of published geologic maps in each State and give the source of publication of each map. Following is a list of the available geologic map indexes with price of each. Most of these indexes are on a scale of 1:750,000, others are 1:500,000 or 1:1,000,000. They may be obtained from the Chief of Distribution, Geological Survey, Washington, D. C., or for the convenience of persons living west of the Mississippi River, indexes for States in that part of the country may be ordered from the Distribution Section, Geological Survey, Denver Federal Center, Denver, Colorado.

Alabama	$0 40	Nevada	$0 30
Arizona	35	New Hampshire-Vt	50
Arkansas	65	New Jersey	.40
California	1.00	New Mexico	70
Colorado	70	New York	60
Georgia	.35	North Carolina	50
Idaho	25	North Dakota	.40
Indiana	45	Ohio	25
Iowa	35	Oregon	.25
Kansas	30	Pennsylvania	.60
Kentucky	50	South Carolina	.25
Louisiana	50	South Dakota	30
Maine	25	Tennessee	40
Maryland-Delaware	40	Texas	60
Mass -R I -Conn	40	Utah	.25
Mississippi	25	Virginia	40
Missouri	.30	Washington	35
Montana	35	West Virginia	25
Nebraska	35	Wyoming	50

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 names of the state geologists and the location of their offices have been listed in Table 3 for ready reference.


PACIFIC OCEAN
ATLANTIC OCEAN
GULF OF MEXICO
SONORA
CHIHUAHUA
COAHUILA
DURANGO
STATUS OF GEOLOGIC MAPPING
IN THE
UNITED STATES
TERRITORIES AND POSSESSIONS
Showing published geologic maps at scales between 1 mi to 1 in. and 2 mi. to 1 in Includes some maps not yet printed but available for public inspection.



STATUS OF GEOLOGIC MAPPING
IN THE
UNITED STATES
TERRITORIES AND POSSESSIONS
JULY 1952
GULF OF MEXICO

U.S.D.A - Division of Soil Survey

The status of soil mapping in the United States was presented in Highway Research Board Bulletin 22, "Engineering Use of Agricultural Soil Maps". Additional areas mapped for 50 and 51 were shown in Bulletins 28 and 46. Since the publication of the last bulletin additional county, or area, agricultural maps have been published; also new soil surveys have been started or are in the process of completion. Table 5 lists the soil mapping completed since the publication of Bulletin 46 and Table 6 lists the counties or areas in which soil surveys are in progress. This mapping is listed by states and where field work is in progress the party chief and the soil correlator has been included for reference purposes. The address of the soil correlators are given in Table 4 and it is suggested that these men should be consulted regarding additional details about the mapping in these areas.

The committee suggests that engineers who may not be familiar with the classification system used in the preparation of agricultural soil maps consult with the soil correlator designated in Table 4 for the area in question. In many instances he can indicate which soil map units (soil type) are likely to contain sources of road-building materials and also assist the engineer to better understand the county soil maps.

Soil Conservation Service - U.S.D.A.

The status of soil mapping by the Soil Conservation Service has been indicated in Highway Research Board Bulletin 28 "Soil Exploration and Mapping" and a map was included to show the extent of this type of coverage in the United States.

This information should be useful to engineers making engineering soil surveys or preparing generalized soil maps from the study of aerial photographs for engineering purposes in areas which do not have published agricultural soil maps. Often areas which are not covered by published county or area agricultural soil maps have been mapped rather extensively by individual farm maps. Since these maps indicate the soil type and series they can be made an invaluable aid for furnishing factual ground information and minimize the number of field checks required for estimating the engineering significance of terrain in the interfarm areas from the study of aerial photographs.

The regional soil scientist usually can furnish the engineer with soil profile descriptions, soil keys, nomenclature and the type of parent material associated with the various soil series mapped in his region. The regional soil scientists for the various regions are listed in Table 7 and the State Soil Scientists are shown in Table 8. It is suggested that these men be consulted for detailed information useful for making engineering appraisals for highway purposes.

TABLE 1

CURRENT INVESTIGATIONS INVOLVING GEOLOGIC MAPPING, GEOLOGIC DIVISION, 1·62,500 OR LARGER SCALES

Project	Project Chief
ALABAMA	
Survey of the belt of Cretaceous rocks in Central Alabama	L. C Conant
ARIZONA	
Jerome Copper District, Yavapai County	C. A Anderson
Globe-Miami Copper District, Gila County	N. P. Peterson
Little Dragoons Copper District, Cochise County	J. R Cooper
Carrizo Mountains, Northeastern Arizona	J D. Strobell, Jr.
Investigations of uranium in pre-Morrison formations	J. F. Smith, Jr.
Upper Gila River Basin	R. B. Morrison
ARKANSAS	
North Arkansas Oil and Gas, Geologic Mapping and Studies of Resources, Newton-Searcy Counties	J. C. Maher
Waldron quadrangle	J. A. Reinemund
CALIFORNIA	
San Andreas Rift Zone, Los Angeles and San Bernardino Counties	Levi F. Noble
Areas in Mojave Desert Region, San Bernardino and Kern Counties	D. F. Hewett
San Francisco Area	Julius Schlocker
Bishop Tungsten District, Inyo County	P. C Bateman
Motherload Gold District, Tuolumne and Calavaras Counties	A A. Stromquist
Shasta Copper District, Shasta County	A. R. Kinkel
Cerro Gordo Quadrangle, Inyo County	W. C. Smith
Pala Pegmatite district, San Diego and Riverside Counties	R. H. Jahns
Ubehebe Peak Quadrangle, Inyo County	J. F McAlister
Darwin Area, Inyo County	J. F. McAlister
Study of deep drill cores of Los Angeles Basin	A O. Woodford
Northwest Santa Ana Mountains, Orange County	D M. Kinney
Study of Miocene and Pliocene deposits of the Santa Clara Valley, Ventura and Los Angeles Counties	E L. Winterer
Los Angeles and vicinity	R. C. Townsend
Eastern Sierra tungsten belt, Mono and Alpine Counties	P C. Bateman
Sierra Foothills mineral belt	L D. Clark
COLORADO	
Surficial Geology—Denver Area	C. B. Hunt
Detailed Geologic mapping along Upper South Platte (North fork), Park, Jefferson and Douglas Counties	Glen R. Scott
Kokomo (Tenmile) Mining District, Summit, Lake, and Eagle Counties	A H. Koschmann
Central San Juan Mountains	W S. Burbank
Holy Cross Quadrangle, Eagle, Lake, Summit, and Pitkin Counties	O. L. Tweto
Trinidad Coal Field, Southeastern Colorado	G. H. Wood, Jr.
Oil Shale areas in Garfield County	J. R. Donnell
Glenwood Springs Quadrangle, Garfield County	N. W. Bass
Animas River Coal Field, LaPlate, Archuleta and Montezuma Counties	H. Barnes
Uinta Basin Oil Shale-White River Area, Garfield and Rio Blanco Counties	W. B. Cashion
City geology, Denver	M. R. Mudge
Northwest extension, Animas River area	A A. Wanek
Northern coal field of the Denver Basin	F. D Spencer
Clay deposits in the foothills of the Front Range	K. Waage
Areas in the Colorado Plateau, uranium inves.	R. P. Fischer
Hardscrabble mining district	Q. D. Singewald
Central City-Georgetown area	P. K. Sims
Carbondale coal field	J. R Donnell
IDAHO	
Blackbird-Noble No. 3 Quadrangle, Lemhi County	J S. Vhay
Phosphate districts in Bear Lake, Caribou, Bannock, and Brigham Counties	R W. Swanson
Coeur d'Alene mining district, Shoshone County	S. W Hobbs
Orofino Area, Clearwater County	A. Hietanen-Makela

CURRENT INVESTIGATIONS INVOLVING GEOLOGIC MAPPING, GEOLOGIC DIVISION, 1:62,500 OR LARGER SCALES (Continued)

Project	Project Chief
INDIANA	
Owensboro quadrangle	L. L Ray
IOWA	
City geology, Omaha and vicinity	R D. Miller
Lead-zinc investigations	A. F. Agnew
KANSAS	
County by county survey of construction materials in northern and central Kansas	F E Byrne
Geologic mapping of Pennsylvanian rocks in Kansas beginning in Wilson County	H. C. Wagner
KENTUCKY	
Geology of the coal-bearing region in eastern Kentucky	J. W. Huddle
Owensboro quadrangle	L. L. Ray
MAINE	
Poland Quadrangle, Androscoggin, Cumberland, and Oxford Counties	J. B. Hanley
MASSACHUSETTS	
Mapping of Quadrangles in Massachusetts in cooperation with Massachusetts Department of Public Works	L. W. Currier
MICHIGAN	
Michigan Copper District, Houghton, Keweenaw, and Ontonagon Counties	W S. White
Iron Deposits, Iron and Dickinson Counties	H. L. James
MINNESOTA	
Cuyuna Range, Crow Wing County	R G. Schmidt
MONTANA	
Medicine Lake Area, Sheridan, Roosevelt, and Daniel Counties	I. J. Witkind
Stratigraphy of Belt Series in and near western Montana	C. P. Ross
Plentywood, Sheridan and Roosevelt Counties	R B. Colton
Fort Peck Dam Project, McCone and Valley Counties	F. S. Jensen
Big Sandy Creek, South half Chouteau and Blaine Counties	R. M. Lindvall
Cat Creek region	W. D. Johnson, Jr.
Winifred area	W. W. Olive
Jordan coal field	G. E. Prichard
Three Forks quadrangle	G D. Robinson
Great Falls-Sun River Area	R. W. Lemke
Stillwater Chromite Deposits, Stillwater and Sweetgrass Counties	J. W. Peoples
Phosphate deposits of Southwest Montana, Beaverhead and Madison Counties	R W Swanson
Judith Mountains, Fergus County	E. N. Goddard
Boulder Batholith, Broadwater and Jefferson Counties	M. R. Klepper
Lewistown, Forest Grove-Button Butte Area, Fergus County	L S. Gardner
Mission Canyon Project, Park County	P. W. Richards
Girard Coal Field, Richland County	G. E. Prichard
Bearpaw Mountains, Hill, Choteau, and Blaine Counties	W. T. Pecora
NEBRASKA	
Yankton Area, Cedar and Knox Counties	H. E. Simpson
Geology and Construction Materials of Quadrangles in the Republican River Valley	E. Dobrovolny
Quadrangles along the Lower Platte River, Valley and Howard Counties	E. Dobrovolny
City geology, Omaha and vicinity	R. D. Miller
NEVADA	
Carson Sink Basin, Churchill County	R. B. Morrison
Mojave Desert Region, Clark County, (Scale 1:120,000)	D. F. Hewett
Geology along Colorado River, Clarke County	C. R. Longwell
Hilltop and Crescent Valley Quadrangles, Lander County	James Gilluly

CURRENT INVESTIGATIONS INVOLVING GEOLOGIC MAPPING, GEOLOGIC DIVISION, 1:62,500 OR LARGER SCALES (Continued)

Project	Project Chief
NEVADA	
Gabbs Magnesite District, Nye County	C. J. Vitaliano
Antler Peak Quadrangle, Lander and Humboldt Counties	R. J. Roberts
Sonoma Range Quadrangle, Pershing, Humboldt, and Lander Counties	H. G. Ferguson
Steamboat Springs District, Washoe County	D. E. White
Eureka Mining District, Eureka County	T. B. Nolan
Pioche Mining District, Lincoln County	C. F. Park, Jr.
Osgood Mountains quadrangle	P. E. Hotz
NEW JERSEY	
Study of Magnetite Deposits, New Jersey Highlands	A. F. Buddington
NEW MEXICO	
Potash resources in Eddy and Lea Counties	C. L. Jones
Burro Mountains Fluorspar District, Grant County	E. Gillerman
Silver City Mining Region Grant County	R. E. Hernon
Sangre de Cristo Mountain area, Santa Fe, San Miguel, Taos, Mora, and Colfax Co.	C. B. Read
Chaco River Coal Field, San Juan County	E. C. Beaumont
Carrizo Mountains, Northwestern New Mexico	J. D. Strobell, Jr.
Tohatchi Area, McKinley County	J. D Sears
Animas River Coal Field, San Juan County	H. Barnes
Valles Mountains Region, Sandoval County	C. S. Ross
Investigations of uranium in pre-Morrison formations	J. F. Smith, Jr.
Upper Gila River Basin	R. B. Morrison
NEW YORK	
Gouverneur Talc district, St. Lawrence County	A. E. J. Engel
Magnetite Deposits, St. Lawrence and Clinton Counties	A. F Buddington
NORTH CAROLINA	
Great Smoky Mountains National Park, Swain, Haywood and Jackson Counties	P. B. King
Shelby Quadrangle	R. G. Yates
Spruce Pine Pegmatite District, Avery, Mitchell, and Yancey Counties	J. L. Kulp
Hamme Tungsten District	J. M. Parker, 3d
NORTH DAKOTA	
Pleistocene Geology, Western North Dakota	A. D. Howard
Medicine Lake Area, Divide and Williams Counties	I. J. Witkind
Missouri-Souris Project, Northwest N. D.	R. W. Lemke
Square Butte Coal Field, Oliver County	W. D. Johnson, Jr.
Knife River Area, Mercer County	W. E. Benson
OHIO	
Geology and coal resources of Belmont County	H. L. Berryhill, Jr.
OREGON	
Portland Industrial Area	D. E. Trimble
John Day Chromite District, Grant County	T. P. Thayer
Galice Quadrangle, Josephine County	F. G. Wells
Coast Range	E. M. Baldwin
PENNSYLVANIA	
Magnetite Deposits, York and Lancaster Counties	A. F. Buddington
Selected coal mining areas in Pennsylvania Anthracite Region	H. H. Arndt
RHODE ISLAND	
Northeastern Rhode Island	A. W. Quinn
SOUTH DAKOTA	
Pleistocene Geology, Eastern half of S. D.	R. F. Flint

CURRENT INVESTIGATIONS INVOLVING GEOLOGIC MAPPING, GEOLOGIC DIVISION, 1:62,500 OR LARGER SCALES (Continued)

Project	Project Chief
SOUTH DAKOTA	
Pierre Area, Stanley and Hughes Counties	D. R. Crandell
Chamberlain Area, Brule, Lyman, and Buffalo Counties	C. R. Warren
Yankton Area, Yankton and Bonhomme Counties	H. E. Simpson
Custer-Keystone Pegmatite District, Custer and Pennington Counties	J. J. Norton
TENNESSEE	
Great Smoky Mountains National Park, Sevier and Cocke Counties	P B. King
Detailed mapping of Zinc deposits in East Tennessee	A. L. Brokaw
Knoxville and vicinity	J M. Cattermole
TEXAS	
Areas in Hudspeth County	J. F. Smith
Oil and Gas Investigations, North central Texas	D. H. Eargle
UTAH	
Blue Mountains, San Juan County	G. O Robinson
LaSal Mountains, San Juan County	C. B. Hunt
Northern Bonneville Basin, Cache, Box Elder, and Weber Counties	J Stewart Williams
Southern half Utah Valley, Utah County	H. J Bissell
Marysvale Alunite District	E. Callaghan
East Tintic Mining District, Juab County	T. S. Lovering
Iron Springs District, Iron County	J H Mackin
Bear River Phosphate District, Rich County	R. W. Swanson
Alta Quadrangle, Salt Lake, Wasatch, and Uintah County	M. D. Crittenden
Strawberry Quadrangle	A. A. Baker
Woodside Quadrangle, Carbon and Emery Counties	V. H. Johnson
Uinta Basin Oil Shale Region, White River Area, Uintah County	W. B. Cashion
Cedar City SE quadrangle	P. Averitt
Areas in the Colorado Plateau, uranium invest	R. P. Fischer
Investigations of uranium in pre-Morrison formations	J. F. Smith, Jr.
Drum Mountains, Utah	M. H. Staatz
Upper Green River Valley	W. R. Hansen
VERMONT	
Vermont Talc	W. M Cady
VIRGINIA	
Hamme Tungsten District	J. M. Parker, 3d
Fairfax Quadrangle, Fairfax and Loudoun Counties	C. Milton
Richmond coal basin	E. I. Rich
Potomac Basin erosion studies	J. T Hack
WASHINGTON	
Portland Industrial Area, Clark County	D E. Trimble
Landslide Studies, Franklin D Roosevelt Lake	F. O Jones
Lower Snake River Canyon, Franklin, Walla Walla, Columbia, Whitman, and Garfield Counties	H. H. Waldron
Chewelah Magnesite District, Stevens County	Ian Campbell
Northport District, Stevens County	C. D. Campbell
Centralia-Chehalis coal district, Lewis and Thurston Counties	P. D. Snavely, Jr.
Pysht, Lake Crescent, Port Crescent and Port Angeles Quadrangle, Clallam Co.	P. D Snavely, Jr
Toledo-Castle Rock Coal District, Cowlitz County	A. E Roberts
Holden-Glacier Peak quadrangle	F. Cater
Puget Sound Basin	H H. Waldron
WEST VIRGINIA	
Potomac Basin erosion studies	J. T. Hack
WISCONSIN	
Lead-Zinc Deposits in Grant, Lafayette, and Iowa Counties	Allen Agnew

CURRENT INVESTIGATIONS INVOLVING GEOLOGIC MAPPING,
GEOLOGIC DIVISION, 1:62,500 OR LARGER SCALES (Continued)

Project	Project Chief
WYOMING	
Cokeville Area, Lincoln and Sublette County	W. W. Rubey
Iron Deposits in Laramie Range, Albany County	W. H. Newhouse
Bear River Phosphate Deposits, Lincoln and Uinta Counties	R. W. Swanson
Spotted Horse Coal Field, Sheridan and Campbell Counties	W. W Olive
Clark Fork Area, Park County	W. G. Pierce
Lake De Smet Area, Johnson County	W. J. Mapel, Jr
Crazy Women Creek Area, Johnson County	R. K. Hose
Beaver Divide area, Fremont County	F. B. Van Houten
Lenore area, Wind River Basin	J. L Murphy
DuNoir area, Wind River Basin	W. R. Keefer

TABLE 2

CURRENT INVESTIGATIONS INVOLVING GEOLOGIC MAPPING,
WATER RESOURCES DIVISION, GROUND WATER BRANCH

Project	Project Chief
ALABAMA	
Baldwin, Choctaw, Madison, Montgomery, Monroe, Randolph, Tuscoloosa, Wilcox Counties Mapping Scale 1:31680, Pub. Scale 1:125,000	P. E. LaMoreaux
ALASKA	
Anchorage area, Knik and Anchorage Quadrangles Mapping Scale 1:48,000	D. J. Cederstrom
Matanuska Valley (Agricultural area) Mapping Scale 1:50,000	F. W. Trainer
Parts of Sutton, Matanuska, Eklutna, Houston Quadrangles and Knik County Mapping Scale 1:50,000	
ARIZONA	
Douglas Basin, Cochise County Mapping Scale 1:3168, Pub. Scale 1:125,000	
Papago Indian Reservation, Pinal County	
Papago Indian Reservation, Pima County	
Lower San Pedro Valley, Pinal County and parts of Pima, Cochise and Graham Cos.	
San Carlos Indian Reservation, Graham County	
Navajo County Irregation District Mapping Scale 1:30,000, Pub. Scale 1:62,500	
Mogollon Rim area, Coconino, Navajo and Apache Counties	L. C Halpenny
Navajo Reservation - Coconino - Navajo - Apache Cos., Includes areas in San Juan County Utah, and McKinley and San Juan Cos., New Mexico Mapping Scale 1:31680, Pub Scale 1:125,000	J. W Harshbarger
ARKANSAS	
Reconnaissance of Little River County and parts of Sevier, Howard, Pike, Clark, Hot Springs, Quachito Nevada, Hempstead and Miller Counties Scale 1-inch = 3-miles	Roger C. Baker
CALIFORNIA	
Eureka - Fortuna Area Mapping Scale 1:62,500	
Napa Valley - Napa County No Scale indicated	
Sacramento Valley Mapping Scale 1:62,500	
Coastal Area, Torrance - Santa Monica Mapping Scale 1:24,000	
Coastal Area, Orange County Mapping Scale 1:31,680	

CURRENT INVESTIGATIONS INVOLVING GEOLOGIC MAPPING, WATER RESOURCES DIVISION, GROUND WATER BRANCH (Continued)

Project	Project Chief
CALIFORNIA	
San Rosa and Petalumn Valley Mapping Scale 1:31,600 Pub. Scale 1:62,500	J. F. Poland
Inyokern, Edwards and Twenty-Nine Palms Mapping Scale 1:50,000	G. F. Worts, Jr.
Camp Pendelton - San Diego County Scale 1:24,000	
San Bernadino Basin, San Bernadino County Scale 1:31,680	A. A. Garrett
Foothill and Valley - flow area of Solano and Southern Yolo Counties Mapping Scale 1:24,000	H. G. Thomasson
COLORADO	
Baca County, eastern Huerfano County, South Platte Valley, Grand Junction Area Mapping Scale - All over 2-inch = 1-mile, Pub. Scale 1-inch = 1-mile	T. G McLaughlin
CONNECTICUT	
Hartford, Holland and Middlesex Counties	R. V. Cushman
FLORIDA	
Parts of Highlands, Lee, Gladea and Hendry Cos.	N D. Hoy
GEORGIA	
Coastal Plain Area (Subsurface) Scale 1-inch = 10-miles	S. M. Herrick
Sumner, Dooly, Pulaski, Lee, Crisp and Wilcox Counties Scale 1-inch = 2-miles	G. H. Chase
HAWAII	
Island of Kavai Scale 1:62,500	Dan A. Davis
IDAHO	
Parts of Jefferson, Booneville, Bingham, Butte Counties (Lost and Little Lost River Area) Scale 1:12,000	R. L. Nace
INDIANA	
Tippecanoe, Vermillion, Parke, Montgomery, Putman, Vigo, Clay, Owen, Sullivan, Greene, Adams, Wayne, Fayette, Union, Franklin, Ripley, Ohio Jefferson, Switzerland, Dearborn Counties No Scale indicated	Claude M Roberts
IOWA	
Appanoose, Dallas, Guthrie, Lucas, Madison, Marion, Monroe, Polk, Story and Warren Counties. Pub. Scale 1:125,000	
Subsurface geologic mapping on a state-wide basis, current work in several different areas	H. Hershey
KANSAS	
Gove, Jewell, Pratt, Rawlins, Reno Counties Mapping Scale 1-inch = 1-mile. Pub. Scale 1-inch = 2-miles	
Douglas, Elk, Osage Counties Mapping Scale 2½ -inch = 1-mile. Pub. Scale 1-inch = 1-mile	V. C Fishel
KENTUCKY	
Parts of Allen, Campbell, Floyd, Grove, Johnston, Kenton and McCracken Cos. Mapping Scale 1:16,000 Pub. Scale 1:24,000	
Part of Henderson County Mapping Scale 1:16,000 Pub Scale 1-inch = 1-mile	M. I Rorabaugh

CURRENT INVESTIGATIONS INVOLVING GEOLOGIC MAPPING, WATER RESOURCES DIVISION, GROUND WATER BRANCH (Continued)

Project	Project Chief
LOUISIANA	
Areas bordering the Calcasieu and Vermilion Rivers, and Boyou Cocodrie Mapping Scale 1 or 2-inches = 1-mile	R. R. Myers
MARYLAND	
Charles, Calvert, Montgomery, Anne Arundel, parts of Howard, Baltimore and Hartford (all coastal plains)	R. R. Bennett
Caroline, Dorchester, Kent, Somerset, Talbot, Wicomico and Worchester Cos. Mapping Scale 1·62,500 and 1·31,680	W. C. Rasmussen
MICHIGAN	
Small areas in Houghton and Marquette Counties Scale 5-inches = 4-miles	W. T. Stuart
Bay, Midland, Gratiot, Saginaw, Genesse, and Oakland Counties, Parts of Shiawassee and Tuscola Counties Scale 1-inch = 6-miles	John G. Ferris
MINNESOTA	
Small area in Redwood County Mapping Scale 1 20,000	R. Schneider
MONTANA	
Lower Marias Valley, Liberty, Hill, Chouteau Cos. Airphoto Scale 4-inches = 1-mile Lewis and Clark, Jefferson Counties Airphotos 1-inch = 4000 ft. Pub. Scale 2-inches = 1-mile Helena, Townsend, and Gallatin Valleys Scale 1-inch = 4,000 ft. Dillon Valley, Crow Agency area, (Yellowstone R) Scale 1-inch = 1-mile Buffalo Rapids (Yellowstone R) Scale 1-inch = 400 ft Lower Yellowstone (Glendive - Sidney) Airphoto 2-inches = 1-mile	E. A. Swenson
NEBRASKA	
Dutch Flats area Mapping Scale 1-inch = 2-miles Lodgeporte Creek Mapping Scale 1-inch = 1-mile Pumpkin Creek area Mapping Scale 1-inch = 1-mile	H. M. Babcock
NEVADA	
Buena Vista Valley, Cresent Valley, Spring Valley, Dixie Valley, Antelope Valley, Warm Springs Valley, Truckee Meadows areas Scale not indicated	O. J. Loeltz
NEW JERSEY	
Newark Area Scale not indicated Subsurface of Coastal Plains Scale 1-inch = 8-miles Bedrock contours - Greater Philadelphia and parts of Burlington, Camden and Gloucester Counties Scale 2-inches = 1-mile Salem County (Subsurface) Scale 1-inch = 1-mile	H. C. Barksdale
NEW MEXICO	
Sante Fe County Scale 1:63360	

CURRENT INVESTIGATIONS INVOLVING GEOLOGIC MAPPING,
WATER RESOURCES DIVISION, GROUND WATER BRANCH (Continued)

Project	Project Chief
NEW MEXICO	
Los Alamos area Scale 1·63,360	
Pueblo Laguna Indian Res. (Velencia Co.) Scale 1·126,780	
Part of Torrance County Scale 1:63,360	
Boswell Basin Scale - - - - - - -	
El Paso area - parts of El Pasco Co. Texas, and Dona Ana and Otero Counties Scale not indicated	C. S Conover
NEW YORK	
Dutchess - Putman - Bronx, Westchester - Nassau Counties Mapping Scale 1:62,500 Pub. Scale 1 125,000	
Rockland, Delaware Counties Scale not indicated	J. E. Upson
NORTH CAROLINA	
Alexander, Catawa, Davie, Iredell, Rowan, Davidson Counties Scale 1-inch = 2-miles	H. E. LeGrand
NORTH DAKOTA	
Oakes, Buxton, Aneta, Wimbledon, Zeeland Streeter, Minnewaukan, Michigan, Lakota, Devils Lake, Rolla - St. John - Mylo, Stanley Mapping Scale 1:20,000	P D. Akin
Sargent County Scale 1-inch = 1-mile	G. A. LaRocque
OHIO	
Lucas, Licking, Fairfield, Trumbull, Portage, Ross, Columbiana Counties	E S. Schaefer
OKLAHOMA	
Beaver, Beckham, Cleveland, Grady, McCurtain Counties Mapping Scale 3.2 inches = 1-mile Pub. Scale 1-inch = 1-mile	
Parts of Alfalfa, Major, Garfield and Kingfisher Counties Mapping Scale 1-inch = 1-mile	Stuart L. Schoff
OREGON	
Lake County and Walla Walla area Scale 1 125,000	
Yonna - Swan Lake Valleys, Rogue River Valley, Tualatin Valley Scale 1 62,500	R C. Newcomb
PENNSYLVANIA	
Lawrence County Scale 1:62,500	Paul H Jones
SOUTH CAROLINA	
Aiken, and Edgefield Counties Mapping Scale 1-inch = 1-mile	
Marlboro and Chesterfield Counties Mapping Scale 1-inch = 1-mile Pub. Scale ½-inch = 1-mile	George E. Siple
SOUTH DAKOTA	
Oahe unit - James R. Valley, James R. Basin, Brown and Marshall Counties Scale not indicated	G. A. LaRocque
TENNESSEE	
Mississippi Basin Tertiary and Cretaceous outcrop areas, also Summer, Macon,	

CURRENT INVESTIGATIONS INVOLVING GEOLOGIC MAPPING, WATER RESOURCES DIVISION, GROUND WATER BRANCH (Continued)

Project	Project Chief
TENNESSEE	
Jackson, Smith, Wilson, Davidson, Williamson, Rutherford, DeKalb, Cannon, Maury, Marshall, Bedford, Giles, Lincoln, Anderson, and Bradley Counties. Mapping Scales - contour maps when available 1:2400 and 1:62,500, otherwise aerial photographs 1:2000	E. M. Cushing
TEXAS	
Galveston, Harris, Bandera, Bexar, Medina, and Zavala counties, Wilbarger, Comal Counties. Mapping Scale 1-inch = 1-mile	
High Plains of Texas - Cross sections extending through Sherman, Randall, Moore, Potter, Swisher, Hale, Lubbock, Lynn and North Dawson counties. No Scale indicated	
Geologic cross-sections showing subsurface geology in Ector, Dimit, Lamb, Lynn, western Maverick counties. Mapping Scale 1-inch = 1-mile	
Kinney County - surface geology No Scale indicated.	
El Paso area - Parts of El Paso County Texas, and Donna Ana and Otero County New Mexico No Scale indicated	W. L. Broadhurst
UTAH	
Southern Juab Valley, Milford District and Ogden Valley Scale 2-inches = 1-mile See Navajo Reservation Project, Arizona	H. A. Waite
VIRGINIA	
Coastal Plain Counties North of James River	A. Sinnott
WASHINGTON	
Part of King County east of Lake Washington, Part of Lewis County	
Ahtanum Valley (Yakima County) Scale 1 20,000	
Kitsap and Clark Counties	
Tacoma area (Pierce County)	
Spokane Valley (Spokane County) Scale 1:62,500	
Yelm area (Thurston and Pierce Counties) Scale 1:34,600	M. S. Mundorff
WISCONSIN	
Portage County Scale 1-inch = 1-mile	A H Harder
WYOMING	
Cheyenne area - Scale 1-inch = 2-miles	
Egbert Pine Bluffs - Carpenter area Mapping Scale 1-inch = 1-mile	
Gillette, Glendo - Wendover, Horse Creek, La Prele, Laramic Plains, Pass Creek Flats, Wheatland Flat, New Castle areas Mapping Scale All over 1-inch = 1-mile	
Goshen, Platte counties Mapping Scale 1-inch = 1-mile	
Kaycce and Ranchester areas Highway Planning map base	
Barthel area (Soil Moisture demonstration study) Mapping Scale 1-inch = 400 ft.	
North Platte irrigation project - Goshen county Mapping Scale 1-inch = 1-mile	H. M. Babcock
Paintrock Project, Bighorn county Mapping Scale 1-inch = 1-mile	
Heart Mountain Unit, Park Co. Mapping Scale 2-inches = 1-mile	
Riverton Project, Freemont county. Mapping Scale 2-inches = 1-mile	F. A. Swenson

TABLE 3

TABULATION OF STATE GEOLOGISTS BY STATES

	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. Norman F Williams, 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 Walter E. Scott, Jr., Vice Chairman, Geological Survey Board, 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, 121 Natural Resources Building, University of Illinois Campus, Urbana
Indiana	Dr. Charles F. Deiss, State Geologist, State Indiana Department of Conservation, Indiana Geological Survey, 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 Geo-Logical 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, P.O. Box 8847, University Station, Baton Rouge 3
Maine	Dr. Joesph 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, Johns Hopkins University, Baltimore 18
Michigan	Mr. William L. Daoust, Acting State Geologist, Geological Survey Division, State 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, Director and State Geologist, Division of Geological Survey and Water Resources, Buehler Building, Rolla
Nebraska	Dr. G E. Condra, Director and State Geologist, Conservation and Survey Division, The University of Nebraska, Lincoln 8
Montana	Dr. J. R. Van Pelt, Director, State Bureau of Mines and Geology, Butte
Nevada	Mr. Vernon E. Scheid, Director, Nevada Bureau of Mines, University of Nevada, Reno
New Hampshire	Mr. T. R. Meyers, Geologist, New Hampshire State Planning and Development Commission, Mineral Resources Committee, 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

TABULATION OF STATE GEOLOGISTS BY STATES (Continued)

	State Geologist and Address
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, P.O. Box 2719, 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. W. E. Ham, Acting Director, Oklahoma Geological Survey, Norman
Oregon	Mr. F. W. Libbey, Director, State Department of Geology and Mineral Industries, 1069 State Office 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. Lawrence L. Smith, State Geologist, Department of Geology, Mineralogy and Geography, University of South Carolina, Columbia
South Dakota	Dr. E. P. Rothrock, State Geologist, Director, State Geological Survey, State University, Lock Drawer 351, Vermilion
Tennessee	Mr. W. D. Hardeman, State Geologist, Division of Geology, Department of Conservation, 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

TABLE 4

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
A. J. Cline, Soil Correlator, West-Midwestern States, Room 117 Agronomy Department, Iowa State College, Ames, Iowa
M. G. Cline, Agent (correlation) New York, Department of Agronomy, Cornell University, Ithaca, New York
W. H. Lyford, Senior Soil Correlator, 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)
A. H. Hasty, Soil Correlator, (same address as listed above)

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

W. M. Johnson, 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)
E. 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 5

SOIL SURVEYS PUBLISHED SINCE HIGHWAY RESEARCH BOARD BULLETIN 46 WAS ISSUED IN 1951

California	Los Banos Area
Maine	York County
North Carolina	Cherokee County Mitchell County Yancey County
North Dakota	Morton County
Oklahoma	Okfuskee County
Virginia	Scott County

TABLE 6

SOIL SURVEYS IN PROGRESS IN PRESENT FISCAL YEAR (1953) OR FIELD WORK COMPLETED SINCE BULLETIN 46 WAS ISSUED

State	County or Soil Area	Party Chief	Soil Correlator*
Alabama	DeKalb County[2]		
	Marshall County[4]		M. J. Edwards
Arizona	Yuma area[6]		W. G. Harper
California	Eastern Fresno County[1]	G. L. Huntington[S]	R. A. Gardner
	Eastern Stanislaus County[1]	R. J. Arkley[S]	R. A. Gardner
	Glenn County[1]	E. L. Begg[S]	R. A. Gardner
	Tehama County[1]	K. D. Gowans[S]	R. A. Gardner
Connecticut	Hartford County[1]	A. E. Shearin	W. H. Lyford[b]
Florida	Escambia County[1]	J. H. Walker[S]	I. L. Martin
	Central and Southern Flood Control District (Kissimmee and Upper St. Johns Valleys, all of Oscola and Indian River Counties and parts of Highland, Okeechobee, St Lucie, Polk, Brevard, Orange, Volusia, Martin, Palm Beach, and Seminole Counties)[2], [3] Orange County[1]	R. G. Leighty[b]	I. L. Martin A H. Hasty
	Sarasota County[1]	R. Wildermuth	I. L. Martin A. H. Hasty
Idaho	Canyon County[1]	M. A. Fosberg[S]	W J. Leighty
Illinois	Lawrence County[2]		
	McHenry County[1]	B W. Ray[S]	A. J. Cline
	Will County[2]		
	Williamson County[1]	J. B. Fehrenbacher[S]	A. J. Cline
Iowa	Jefferson County[1]	Geo. M. Schafer	A. J. Cline
	Monona County[2]		
	Polk County[1]	J. W. McCracken[b]	A. J. Cline
	Shelby County[1]	Everett White[S]	A. J Cline
Kansas	Brown County[1]	O. W Bidwell[S]	W. M. Johnson
	Kaw Division, Kansas River Valley[1]	C. H. Atkinson[b]	W. M. Johnson
	Republic County[4] (All of Scandia Unit)		
Louisiana	Bossier Parish[1]	S. A. Lytle[b]	I. L. Martin
	St. Mary Parish[2]		A. H. Hasty
	Terrebonne Parish[1]	S. A. Lytle[b]	I. L. Martin A. H. Hasty
Michigan	Arenac County[1]	Wm. H. Colburn[S]	I. J. Nygard
	Ionia County[1]	S. D. Alfred	O. C. Rogers
	Keweenaw County[2]		
	Sanilac County[1]	I. F. Schneider[S]	O. C. Rogers
Minnesota	Crow Wing County[1]	H. F. Arneman[S]	I. J. Nygard
	Isanti County[1]	R. H. Farnham[b]	I. J. Nygard
Mississippi	Bolivar County[2]		
	DeSoto County[1]	E. J. McNutt[S]	I. L. Martin A. H. Hasty
	Humphreys County[1]	J C. Powell[S]	I. L. Martin A. H. Hasty
	Leflore County[1]	W. E. Keenan[S]	I. L. Martin A H. Hasty
	Newton County[1]	L. C. Murphree	I. L. Martin A. H. Hasty
	Sunflower County[2]		
	Washington County[1]	G. E Rogers[S]	I L. Martin A. H. Hasty
Missouri	Moniteau County[2]	J. A. Frieze	I. L. Martin
Montana	Bitterroot Valley area[2] Roosevelt County (Part of Missouri-Souris Irrigation Project)[4]		B. H. Williams

SOIL SURVEYS IN PROGRESS IN PRESENT FISCAL YEAR (1953) OR FIELD WORK COMPLETED SINCE BULLETIN 46 WAS ISSUED (Continued)

State	County or Soil Area	Party Chief	Soil Correlator
Montana (cont.)	Yellowstone County[1]	W. C. Bourne[b]	B H. Williams
Nebraska	Buffalo County (Part of Wood River Irrigation Project)[2]		
	Gage County[1]	T. E. Beesley	B. H. Williams
	Hall County (Part of Wood River Irrigation Project)[1]	D A. Yost	B. H. Williams
	Saunders County[2]		
New Hampshire	Rockingham County[4]		W. H. Lyford[b]
New York	Franklin County[1]	F. J. Carlisle[b]	W. H. Lyford[b]
	Lewis County[1]	C. S Pearson[s]	M. G Cline[b]
North Carolina	Duplin County[1]	E F. Goldston[s]	G H. Robinson
North Dakota	Lake Souris area (McHenry and Bottineau Counties)[4]		C. A Mogen
	New Rockford area[1]	J. E. McClelland[b]	C. A. Mogen
	Oakes Area[2]		
	Renville County (Part of Missouri-Souris Project)[4]		C. A. Mogen
Ohio	Fairfield County[2]		
	Ross County[1]	J. H. Petro[b]	O. C Rogers
Oklahoma	Pawnee County[2]		
	Wagoner County[5]	H. M. Galloway[b]	E H. Templin
Oregon	Prineville area[1]	Geo. K. Smith	W. J Leighty
Pennsylvania	Potter County[1]	K. V. Goodman	W H. Lyford[b]
South Dakota	Brookings County[1]	A. J Klingelhoets[b]	C. A Mogen
	Hand County (Part of Missouri-Oahe Project)[1]	A. J. Klingelhoets[b]	C A. Mogen
	Spink County (Part of Missouri-Oahe Project)[1]	F C. Westin[s]	C. A. Mogen
Tennessee	Blount County[1]	Joe A Elder[s]	M. J. Edwards G H. Robinson
	Coffee County[1]	I. B. Epley[s]	M. J. Edwards G. H Robinson
	Henderson County[1]	R. L. Flowers[s]	M. J Edwards G. H. Robinson
	Lawrence County[2]		
	Maury County[2]		
Texas	Fort Bend County[1]	Gordon McKee[s]	E. H. Templin
	Lynn County[1]	I. C. Mowery[b]	E. H. Templin
Utah	Beryl-Enterprise area (Part of Iron County)[2]		
	Davis County[1]	Vern K. Hugie	W. G. Harper
	Weber area (Parts of Weber, Davis, Morgan, Summit, and Boxelder Counties)[2]		
Virginia	Norfolk County[1]	E. F. Henry[s]	W S. Ligon G. H Robinson
	Nottoway County[1]	C. S. Coleman	G. H Robinson
Washington	Walla Walla County[1]	A. O. Ness	W. J Leighty
Wisconsin	Dodge County[1]	G B. Lee[b]	I. J. Nygard
Wyoming	Goshen County[1]	C J Fox	E. M. Johnson

[1] Soil Survey assignments for summer of 1952
[2] Soil Survey areas with field work completed since Bulletin 46 was issued
[3] Reconnaissance or Reconnaissance-detailed survey
[4] Temporarily suspended, no personnel assigned
[5] Personnel to be assigned October 1
[6] Discontinued for summer 1952
* See table for address of Soil Correlator
b State and Bureau
s State

TABLE 7

TABULATION OF REGIONAL SOIL SCIENTISTS BY STATES AND REGIONS[1]

Region	States Within Region
1. Northeastern Region H R. Adams 6816 Market Street Upper Darby, Pa.	Maine, New Hampshire, Vermont, Massachusetts, Connecticut, Rhode Island New York, Pennsylvania, New Jersey, Maryland, Delaware, West Virginia
2. Southeastern Region G. L. Fuller P. O. Box 612 Spartanburg, S. C.	Virginia, North Carolina, South Carolina, Georgia, Florida, Alabama, Mississippi, Tennessee, Kentucky, Puerto Rico
3. Upper Mississippi Region A. H Paschall 434 N. Plankinton Ave. Milwaukee 3, Wisconsin	Ohio, Indiana, Illinois, Missouri Iowa, Minnesota Wisconsin, Michigan
4. Western Gulf Region R. M. Marshall P. O. Box 1898 Fort Worth 1, Texas	Texas Oklahoma Arkansas Louisiana
5. Northern Great Plains Region R. O. Lewis P. O. Box 713 Lincoln 1, Nebraska	Montana, Wyoming, North Dakota, South Dakota, Nebraska, Kansas
6. Southwestern Region M. R. Isaacson P. O. Box 1348 Albuquerque, N. Mex	Arizona New Mexico Colorado Utah
7. Pacific Region S. W. Cosby 209 S. W. Fifth Street Portland 4, Oregon	Washington, Oregon, Idaho, Nevada, California, Alaska, Hawaii

[1] As of March 1952.

TABLE 8

TABULATION OF SOIL CONSERVATIONIST AND SOIL SCIENTIST BY STATES[1]

State Conservationist	SCS State Office	State Soil Scientist	Headquarters
		ALABAMA	
Olin C Medlock	New Ext. Service Annex, Ala Polytechnic Inst., Auburn	Miles E. Stephens	P.O. Box 311, Auburn
		ARIZONA	
Julian J. Turner	Goodrich Bldg., 14 North Central Ave., Phoenix	Roger D. Headley	202 Agriculture Bldg., Univ. of Arizona, Tucson
		ARKANSAS	
Hollis R. Williams	New P.O. Bldg., and Fed Court House Building Little Rock	Marvin Lawson	P. O. Box 521 Fayetteville
		CALIFORNIA	
John S Barnes	Post Office Building Berkeley	Leonard R Wohletz	P.O. Box 369, Berkeley
		COLORADO	
Kenneth W. Chalmere	950 Broadway, Agri. Bldg., Denver	E. Milton Payne	202 Agronomy Bldg., Colo Agr. Exp. Sta., Fort Collins
		CONNECTICUT	
N Paul Tedrow	500 Capitol Ave. Hartford	G. A. Quakenbush	126 Lipman Hall, College of Agri., New Brunswick
		DELAWARE	
Richard S. Snyder	501 Academy St. Newark	M. F. Hershberger	Md. Agr. Exp. Sta., College Park
		FLORIDA	
Colin D Gunn	Gilbert Hotel Bldg. 35 N Main St. Gainesville	O C. Lewis	P.O. Box 162, Gainesville
		GEORGIA	
J. G. Liddell	Old Post Office Bldg., Athens	Frank T. Ritchie, Jr.	P.O. Box 832, Athens
		IDAHO	
Robert N. Irving	Yates Bldg , 9th and Main Sts , Boise	C. F. Parrott	445 Yates Building, Boise
		ILLINOIS	
Bruce B. Clark	Nogle Bldg , 605 S. Neil St., Champaign	Lindo J. Bartelli	206 Davenport Hall, Univ. of Illinois, Urbana
		INDIANA	
Kenneth Welton	Lafayette Loan & Trust Bldg. 4th & Main Sts., Lafayette	T. C. Bass	133 N. Fourth Street, Lafayette
		IOWA	
Frank H. Mendell	Iowa Bldg., 505 6th. Ave. De Moines	Byron A. Barnes	Rm. 2, Landscape Architecture Bldg., Iowa State Coll., Ames
		KANSAS	
Fred J. Sykes	Public Utility Bldg., 116-½ W. Iron St., Salina	Claude L. Fly	Agronomy Dept. Kansas State College, Manhattan

TABULATION OF SOIL CONSERVATIONIST AND SOIL SCIENTIST BY STATES (Continued)

State Conservationist	SCS State Office	State Soil Scientist	Headquarters
		KENTUCKY	
Hubbard K. Gayle	231 W. Maxwell St. Lexington	W. W. Carpenter	231 W. Maxwell St., Lexington
		LOUISIANA	
Harold B. Martin	Svebeck Bldg., 6th & Winn Sts., Alexandria	D. L. Fontenot	P.O. Box 1630, Alexandria
		MAINE	
William B. Oliver	Maples Hall, Univ. of Maine, Orono	J. Stewart Hardesty	Maples Hall, Univ. of Maine, Orono
		MARYLAND	
Edward M. Davis	Agric. Bldg., Univ. of Md., College Park	M. F. Hershberger	Agronomy Dept. U. of Md. College Park
		MASSACHUSETTS	
Arthur B. Beaumont	Stockbridge Hall, State College, Amherst	Montague Howard, Jr.	Agr. Science Bldg., Univ. of Vermont, Burlington
		MICHIGAN	
Everett C Sackrider	Agricultural Bldg., State College, East Lansing	C. A. Engberg	Room 410 Agriculture Bldg., East Lansing
		MINNESOTA	
Herbert A. Flueck	Federal Courts Bldg., 6th & Market Sts., St. Paul	Alex S. Robertson	517 Fed. Court Building St. Paul 4
		MISSISSIPPI	
Charles B. Anders	Masonic Temple Bldg., 1130 W. Capitol St., Jackson	D T. Webb	P.O. Box 610, Jackson 5
		MISSOURI	
Kenyon G. Harman	Post Office Bldg., 6th & Cherry Sts., Columbia	Harold E. Grogger	Federal Building, Columbia
		MONTANA	
Truman C. Anderson	Gallatin Block Building Bozeman	Dave R. Cawlfield	Montana State College, Bozeman
		NEBRASKA	
Emrys G. Jones	Rudge & Guenzel Bldg , 13th & N Sts., Lincoln	Lloyd E. Mitchell	Nebraska Hall, Univ. of Nebr , Lincoln 1
		NEVADA	
George Hardman	Rm 210 Western Bldg., 818 S. Va. St., Reno	E. A. Naphan	Morrill Hall, Univ. of Nevada, Reno
		NEW HAMPSHIRE	
Allan J. Collins	29 Main Street, Durham	J. Stewart Hardesty	The Maples Bldg , Univ. of Maine, Orono, Maine
		NEW JERSEY	
Linwood L. Lee	Post Office Bldg., 86 Bayard St., New Brunswick	G. A. Quakenbush	126 Lipman Hall, College of Agri., New Brunswick

TABULATION OF SOIL CONSERVATIONIST AND SOIL SCIENTIST BY STATES (Continued)

State Conservationist	SCS State Office	State Soil Scientist	Headquarters
		NEW MEXICO	
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		NORTH CAROLINA	
Earl B. Garrett	State Office Bldg., N. C. College, Agri., & Engr., Raleigh	W. W. Stevens	P.O. Box 5126, Raleigh
		NORTH DAKOTA	
Lyness G. Lloyd	P.O. Bldg., Broadway & 3rd Sts., Bismarck	Lloyd Shoesmith	State College, Fargo
		OHIO	
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		OKLAHOMA	
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		OREGON	
Samuel L. Sloan	515 S.W. 10th Ave. Portland	William W. Hill	515 S.W. 10th, Portland
		PENNSYLVANIA	
Ivan McKeever	Dauphin Bldg., 203 Market St., Harrisburg	F. G. Loughry	Agriculture Bldg., Penna. State College, State College
		RHODE ISLAND	
N Paul Tedro	Rhode Island combined with Connecticut	Montague Howard, Jr.	Hills Agricultural Science Bldg. Univ. of Vt., Burlington
		SOUTH CAROLINA	
Ernest Carnes	Fed. Land Bank Bldg., 1401 Hampton St., Columbia	P. H. Montgomery	P.O. Box 417, Fed. Land Bank Bldg., Columbia 29
		SOUTH DAKOTA	
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		TENNESSEE	
William M. Hardy	U. S. Court House Nashville	Nathan I. Brown	806 Broadway, Nashville 3
		TEXAS	
Paul H. Walser	114-118 S. 3rd Street Temple	James D. Simpson	Texas Agr. Exp. Station, College Station
		UTAH	
Josiah A. Libby	Atlas Bldg., 36-½ West Second South, Salt Lake City	John W. Metcalf	College Hill, Box 151, Utah Agr. Exp. Station, Logan

TABULATION OF SOIL CONSERVATIONIST AND SOIL SCIENTIST BY STATES (Continued)

State Conservationist	SCS State Office	State Soil Scientist	Headquarters
		VERMONT	
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		VIRGINIA	
Sam W. Bondurant	605-609 Main Street Richmond	R. E. Devereux	P O Box 497, Blacksburg
		WASHINGTON	
Paul C. McGrew	Hutton Bldg., 950 Wash. St., Pullman	Ray W. Chapin	Box 448 College Station. Pullman
		WEST VIRGINIA	
Longfellow L. Lough	Bank of Morgantown Bldg., 265 High St., Morgantown	Boyd J. Patton	Agr Exp. Sta., West Va. Univ., Morgantown
		WISCONSIN	
Marvin F. Schweers	State Farm Ins Bldg., 2702 Monroe St., Madison	William DeYoung	State Farm Ins. Bldg., 2702 Monroe St., Madison 5
		WYOMING	
Edgar A. Reeves	Tip Top Bldg., 355 E. 2nd. St. Casper	Harold Bindschadler	P.O. Box 966, Roach Bldg., Laramie
		A LASKA	
		Thomas H. Day*	P.O. Box F Palmer, Alaska
		HAWAII	
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[1] As of September 1952

* Territorial Soil Scientist

Soil Investigation Employing A New Method of Layer-Value Determination for Earth Resistivity Interpretation

H. E. BARNES, Soils Engineer,
Michigan State Highway Department

● IN an effort to improve methods of making soil investigations of proposed borrow sites and highway construction the Michigan State Highway Department is now employing the "earth resistivity" method as a means of obtaining information. The objective in adopting this method is to eliminate, or at least reduce, the chances of costly errors in estimates of earth quantities and quality of earth borrow due to the lack of adequate information. Until this resistivity instrument was acquired nearly all investigations were made by hand augering with the occasional assistance of jet borings when the importance of the information warranted its cost of operation. These methods are laborious and in most cases, give inadequate data. It is impossible to auger into a granular material which lies below water table without the use of power drilling and some form of casing. Although a soils engineer can determine the source of good granular borrow, for example, from a few hand borings and trained observations, it is very difficult to estimate the size and location of the deposit or to detect a hidden clay stratum even if its presence is suspected. With the purchase of the resistivity instrument it was the intent of the Department to develop a procedure that would give more detailed and accurate information of soil conditions.

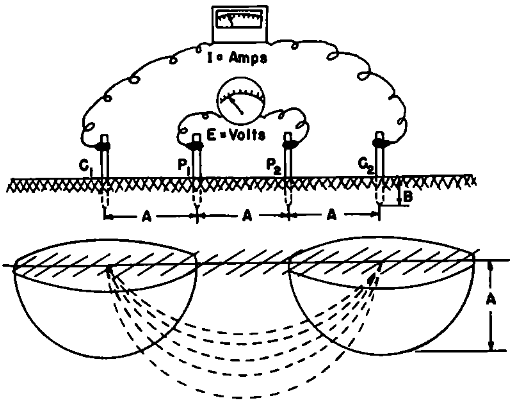
It has now been about two years since the instrument was purchased during which time considerable experimentation has been carried on with the result that detailed information on types, quantities, and locations of certain soil materials can now be determined with an accuracy which is considered to be within practical limits.

BACKGROUND AND METHODS OF USE

Instruments for measuring earth resistivity have been used for many years by geologists and geophysicists in their attempts to prospect and explore the earth's crust in search of oil, minerals, etc. In the course of years much research has been done to improve the techniques, instruments, and interpretation of results to obtain better detail and accuracy. It is not the writer's intention to go into an explanation of the numerous methods used by various groups of geophysicists and engineers other than to give a partial list of the more common ones as follows: Porous Pot, direct method; Gish-Rooney[1] method; "Megger" method; Single Probe method.

After considerable study and experimentation to determine the advantages and disadvantages of various methods with respect to the type of information desired from soil investigations, the Gish-Rooney method was selected. One of the main advantages of this method is the elimination of the effects of ground and stray currents by the use of an alternating, or more correctly, commutated circuit. Voltages and currents are read separately from which the apparent average resistivity of the soil is computed. The arrangement of four electrodes in a straight line spaced an equal distance from each other is used almost exclusively. This arrangement

[1]Gish, O H, "Improved Equipment for Measuring Earth-Current Potentials and Earth Resistivity". National Research Council, Bulletin, Nov 1926, Vol II, Pt 2, No 56.



*Wenner's equation for the average resistivity of soil

$$\rho = \frac{4\pi AR}{1 + \frac{2A}{(A^2 + 4B^2)^{\frac{1}{2}}} - \frac{A}{(A^2 + B^2)^{\frac{1}{2}}}}$$

When B is small compared to A, the equation simplifies to:

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

*Wenner, U.S. Bureau of Standards Scientific Paper No. 258

Figure 1. Wenner's configuration in the spacing of electrodes used in the Gish-Rooney method for measuring earth resistivity, illustrating the equipotential-bowl theory.

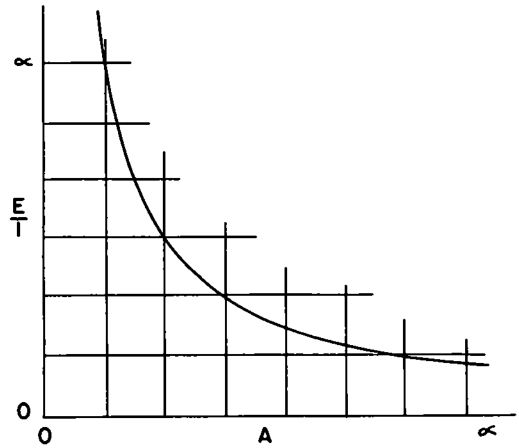


Figure 2.

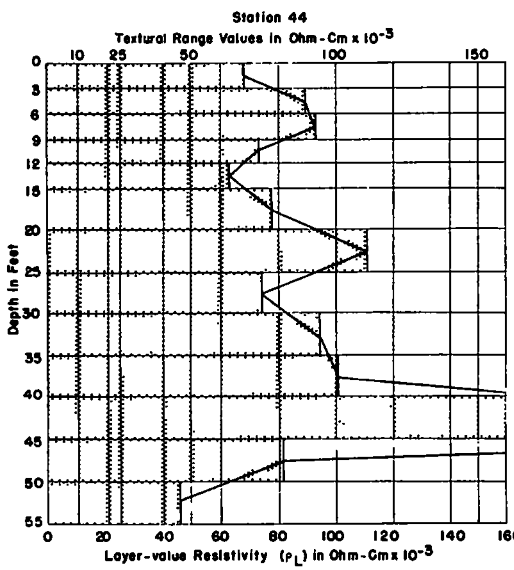


Figure 3.

is generally known as Wenner's[2] configuration. By using this arrangement the spacing between electrodes is equal to the depth of soil investigated as shown in Figure 1. As with any tool being applied to a new field, there is a stage of development during which different approaches and practices are studied, tried, revised, discarded or improved, and finally a definite procedure embracing the limitations of the tool is adopted as standard practice. The procedure adopted by the Department as standard practice, at least for the present time, consists of making depth-profile measurements at selected stations along one or more lines of traverse. The distance between stations and the number of traverse lines selected depend upon the size and depth of the soil body for which information is desired and the time allowed to make the investigation. Naturally there are exceptions made to the standard practice for those cases requiring specific and particular information. In general, traverse lines are made not more than 100 feet apart and the distance between stations is held to not more than 100 feet. In measuring depth profiles, it is considered good practice to use 3-foot intervals of layer thickness for depths up to 15 or 21 feet and 5-foot intervals for depths of investigation greater than this 15 or 21 feet. The advantages obtained by measuring several shallow layers in preference to fewer layers of greater thickness will be appreciated when the interpretation of field results as developed and used by the Department is understood.

[2]Wenner, Frank, "Method of Measuring Earth Resistivity". U S Bureau of Standards, Scientific Paper No. 258, Bulletin, Vol 12-No 3, 1915-16

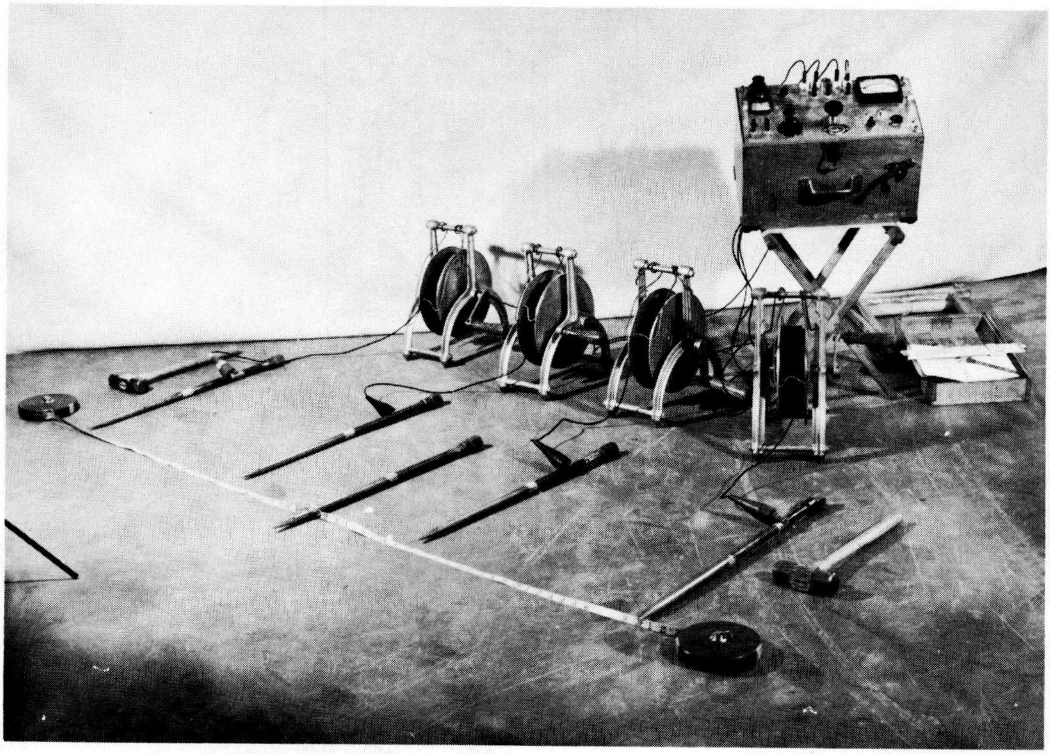


Figure 4. Assembly of equipment for earth-resistance survey.

INTERPRETATIONS OF FIELD MEASUREMENTS

The interpretation of field measurements from which reliable deductions can be made presented a most difficult problem. A study was made of the several different methods of interpretations as presented in various published bulletins and papers, some of which are based on theoretical and mathematical considerations and at least one of which is based upon purely empirical considerations.

In general, theoretical and mathematical methods require such a great volume of computations that the amount of time required to obtain the desired information would defeat the purpose of using the resistivity instrument inasmuch as time and costs of obtaining accurate information are prime considerations. On the other hand, after many attempts to apply empirical methods, it was found that even the more recent methods of empirical interpretation were somewhat inadequate and not sufficiently reliable.

Therefore, it was felt that a method of interpretation might be developed which would give the particular type of detailed and reliable information such as required by the Department if only on a comparative basis. As a result of much field work and calculation of electrical measurements a method of interpreting field data has been developed on the premise that Wenner's formula is a truly fundamental expression for determining the average apparent resistivity of any thickness of an earth mass.

EQUATION FOR DETERMINING LAYER VALUE

Wenner's formula[3] for the 4-electrode, equal spacing configuration is given as:

$$\rho = 2\pi A \frac{E}{I} \qquad (1)$$

where ρ = average specific resistivity of depth A in ohm-cms

A = spacing of electrodes and depth investigated in cms

[3]op cit.

E = potential differential across the inner two electrodes through "A" depth of earth in volts
I = current carried through the mass as introduced through the outer electrodes in amperes

See Figure 1 for Wenner's formula and a sketch illustrating the equi-potential bowl theory.

Inasmuch as A is a variable, then in order that ρ remain constant for different thicknesses of a homogeneous soil, the ratio of E/I must vary inversely with A. The curve in Figure 2 shows the relationship of E/I to A.

The equation for determining layer values which is being presented at this time is based on the hypothesis that layers of earth are analogous in behavior to parallel electrical resistances.

On the basis of this hypothesis, each layer of a two or more layer system will have its particular value of resistance as illustrated in the following sketch for a three-layer system:

A'	R_1	Layer 1	Three layers of non-homogeneous soil.
A'	R_2	Layer 2	
A'	R_3	Layer 3	

A' = thickness of layer interval
R = average resistance of layer

For the above condition the average

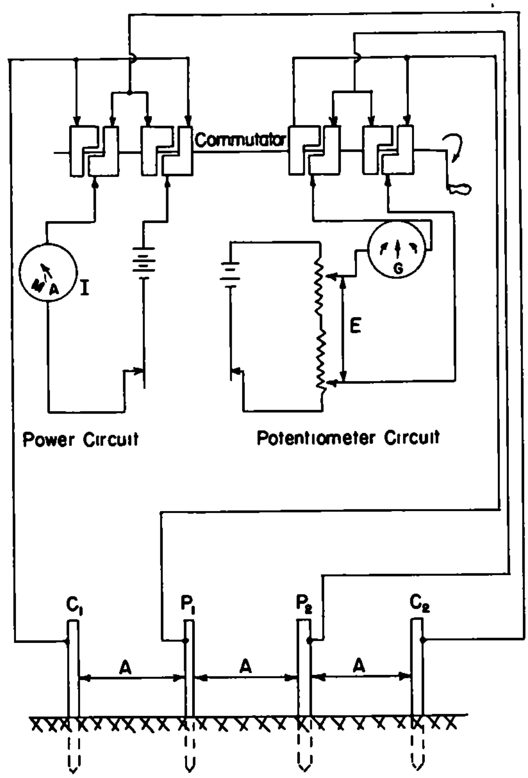


Figure 5. Schematic circuit diagram of earth-resistivity equipment.

resistivity values obtained by the earth resistivity equipment would be ρ_1 for depth A', ρ_2 for depth 2A', and ρ_3 for depth 3A', etc. It is recognized that the

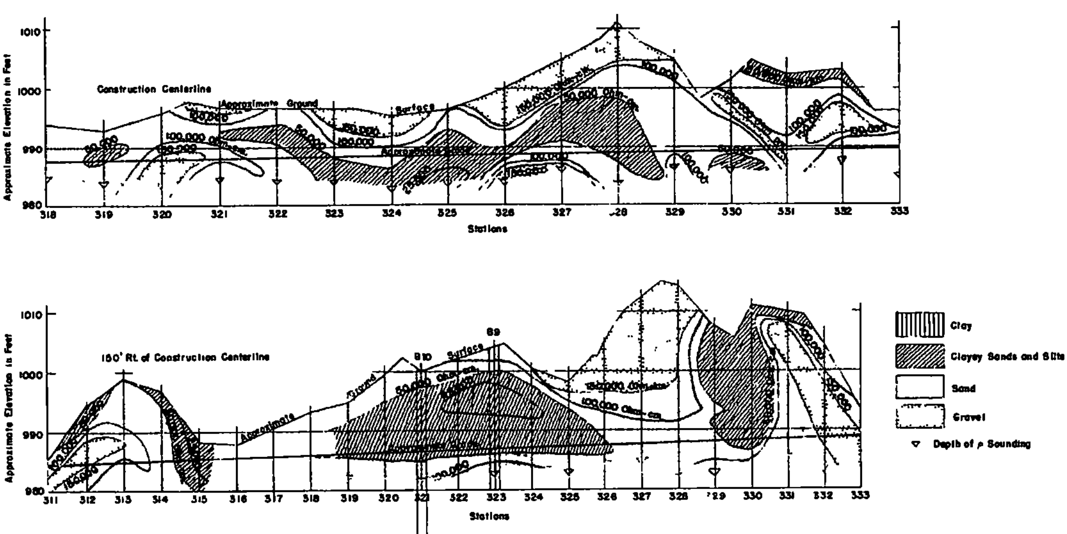


Figure 6. Profile contours, Stations 311 to 333.

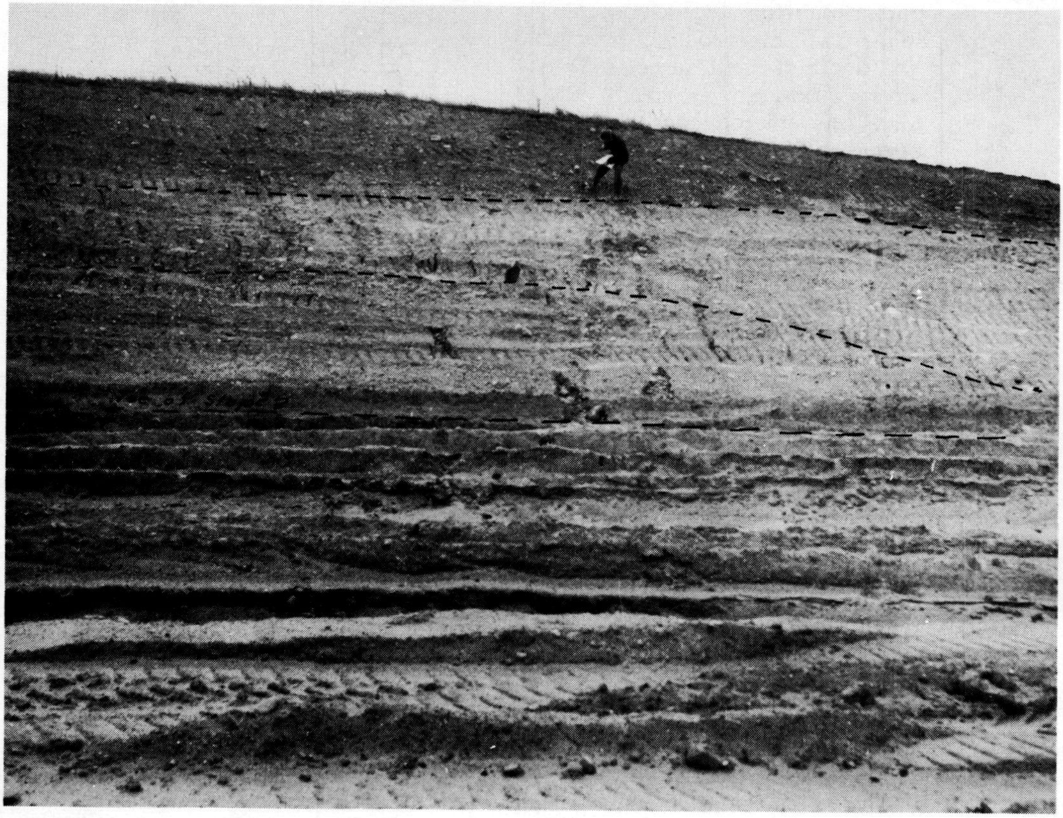


Figure 7. Slope stake in center at top of cut is 60 ft. right of Station 332 (see Fig. 6).

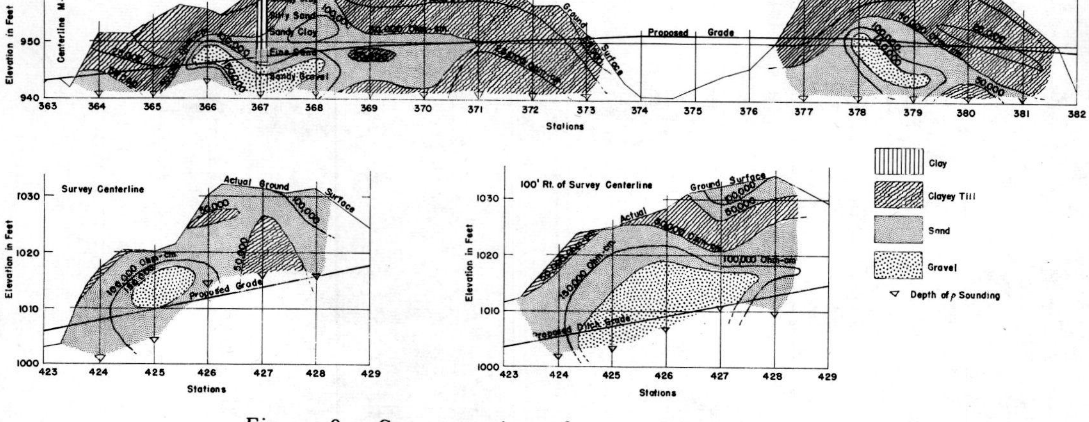


Figure 8. Cross sections from profile contours.

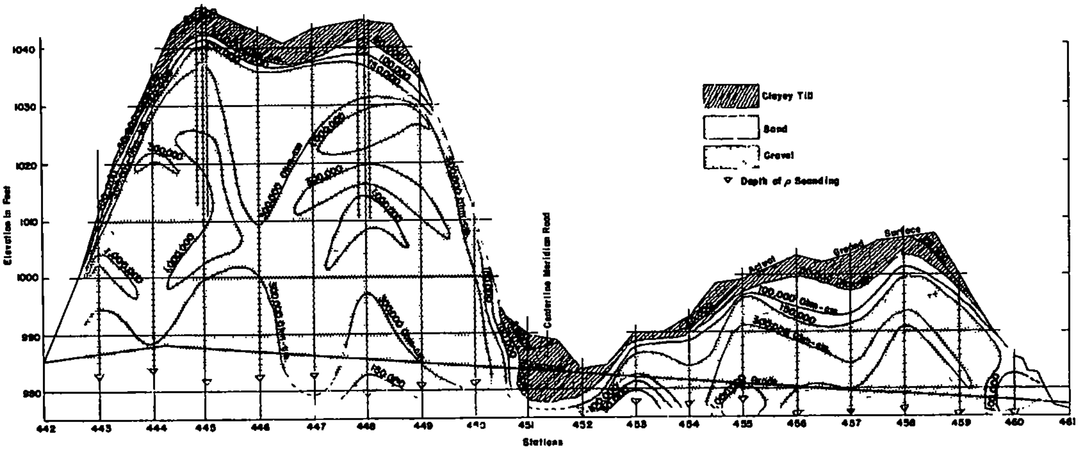
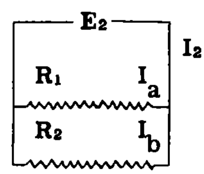


Figure 9. Cross section from profile contour.

value of $\frac{E}{I}$ in Wenner's formula (Eq. 1) may give only an approximate value of resistance for the soil because the equipotential bowl theory does not take into consideration the warping effect caused by the varied paths taken by the current through heterogeneous materials. Nevertheless, it serves as a comparative value with which different types of soil may be differentiated from each other. Considering now the value of resistance for the first layer, in the sketch above, it may be assumed that A' represents a layer of homogeneous soil and, therefore, the value of resistance is equal to the quotient obtained by dividing the potential differential by the current carried as read from the resistivity instrument.

Thus: $R_1 = \frac{E_1}{I_1}$, or the average specific resistance for Layer 1. If E_2 and I_2 are the values read when investigating the depth 2A' and the assumption is made that Layers 1 and 2 act as parallel resistance of different values through which the current is pushed, then this condition may be illustrated by the following analogy:



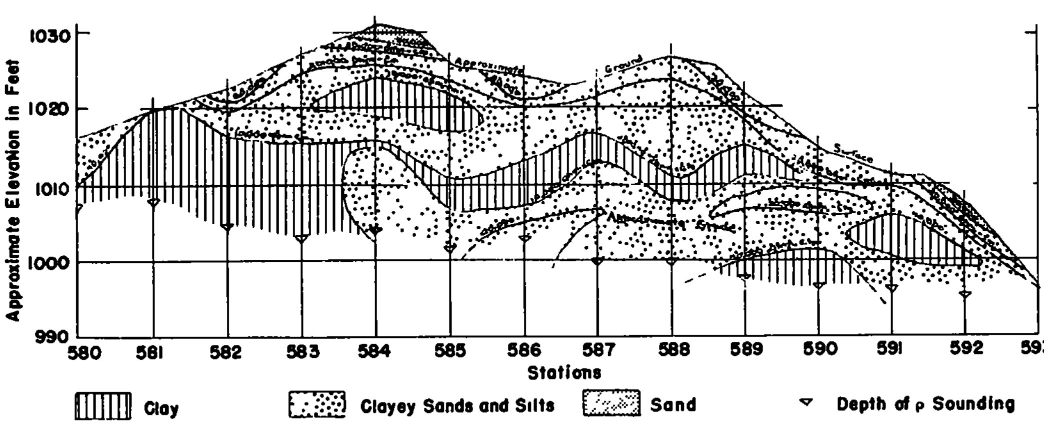


Figure 10. Profile contours taken on construction centerline.

Figure 11. Slope stake at top of cut is 50 ft. left of Station 586+50 (see Fig. 10).

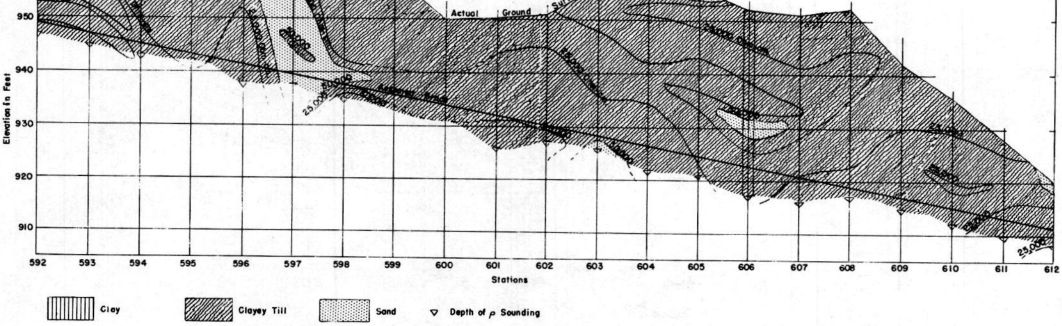


Figure 12. Cross sections from profile contours.

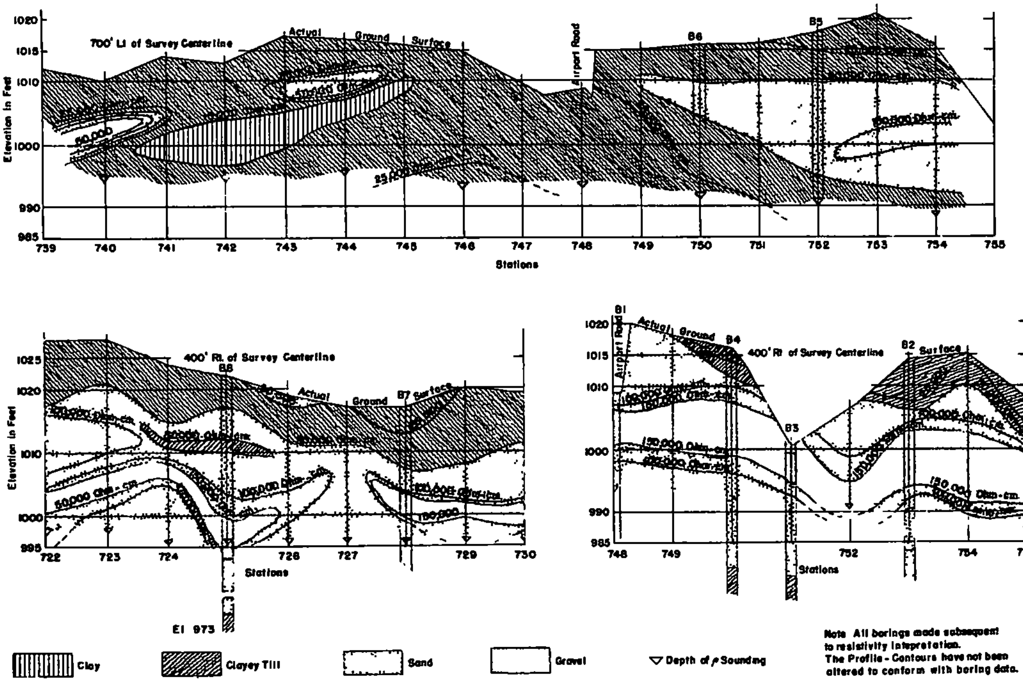


Figure 13. Cross sections from profile contours.

The unknown value of R_2 in the above analogy is determined as follows:

Step 1) $R_1 = \frac{E_1}{I_1}$ (known)

2) $I_a = \frac{E_2}{R_1}$ (known)

3) $I_b = \frac{E_2}{R_2}$

4) $I_2 = I_a + I_b$

5) $I_2 = \frac{E_2}{R_1} + \frac{E_2}{R_2}$

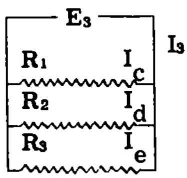
6) $\frac{E_2}{R_2} = I_2 - \frac{E_2}{R_1}$

7) $R_2 = \dfrac{E_2}{I_2 - \frac{E_2}{R_1}}$

Substituting R_2 for $\frac{E}{I}$ in Wenner's equation, the value of resistivity, ρ_{L2}, for Layer No. 2 will be

$$\rho_{L2} = 2\pi A R_2 \qquad (2)$$

Using the same analogy and principles as used above for R_2 the value of R_3 for the third layer may be found as follows where E_3 and I_3 are the respective potential differential and current values given by the resistivity instrument for the 3A' depth.



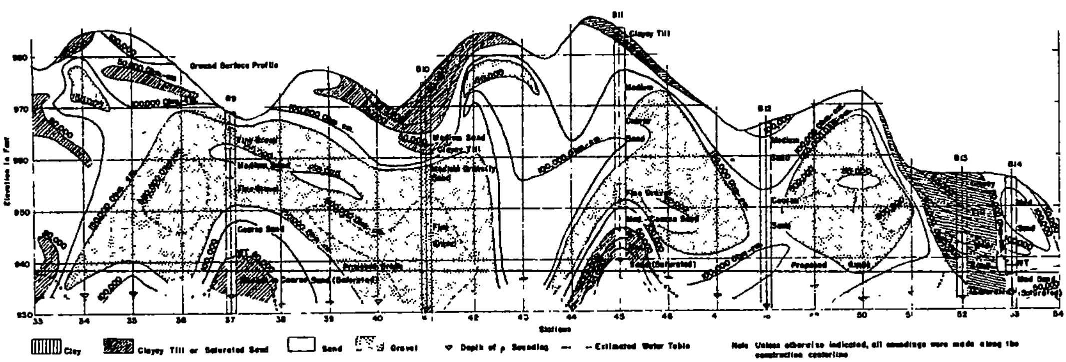


Figure 14. Cross sections from profile contours.

Figure 15. Cut partially excavated, 60 ft. left of Station 41+50.

8) $I_c = \frac{E_3}{R_1}$ (known) 11) $I_3 = I_c + I_d + I_e$

9) $I_d = \frac{E_3}{R_2}$ (known) 12) $I_3 = \frac{E_3}{R_1} + \frac{E_3}{R_2} + \frac{E_3}{R_3}$

10) $I_e = \frac{E_3}{R_3}$ 13) $\frac{E_3}{R_3} = I_3 - \left(\frac{E_3}{R_1} + \frac{E_3}{R_2}\right)$

$$14)\ R_3 = \frac{E_3}{I_3 - \left(\frac{E_3}{R_1} + \frac{E_3}{R_2}\right)}$$

All of the values in Step 14) are known except R_3 which, therefore, can be determined. This equation may, of course, be used for any number of layers and will take the general form for any number of layers n as:

$$R_n = \frac{E_n}{I_n - \left(\frac{E_n}{R_1} + \frac{E_n}{R_2} + \ldots\ldots \frac{E_n}{R_{n-1}}\right)} \quad (3)$$

The use of Equation 3 becomes rather laborious when it is desired to determine the value of resistivity for a layer located several depth-intervals below the surface. However, it can be proven that the term $\left(\frac{E_n}{R_1} + \frac{E_n}{R_2} + \ldots\ldots \frac{E_n}{R_{n-1}}\right)$ equals the term $\frac{E_n}{\bar{R}_{n-1}}$. The substitution of the latter term in Equation 3 then renders ths solution of the layer values of resistivity much more expedient.

Proof of the identity of the above terms is given as follows with reference being made to the three-layer case: Let R designate the average value of resistance for an individual layer of material, and let $\bar{R}$ designate the average value of resistance for any depth of soil measured from the surface as given by the ratio of $\frac{E}{I}$. It is evident that for the first layer $R_1 = \bar{R}_1 = \frac{E_1}{I_1}$, but for subsequent layers the equality does not hold. Therefore, $\bar{R}_{(n-1)}$ will represent the average resistance value for the depth of n number of layers minus one, or

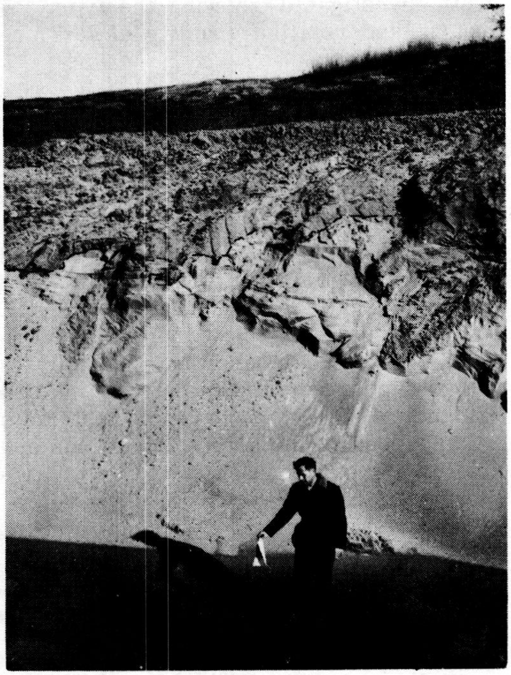


Figure 16. Station 45 ℄.

$$\bar{R}_{n-1} = \frac{E_{n-1}}{I_{n-1}}$$

$$R_3 = \frac{E_3}{I_3 - \frac{E_3}{\bar{R}_2}} = \frac{E_3}{I_3 - \left(\frac{E_3}{R_1} + \frac{E_3}{R_2}\right)} \text{ (from Step 14)}$$

where $\bar{R}_2 = \bar{R}_{n-1} = \frac{E_2}{I_2}$

$$R_2 = \frac{E_2}{I_2 - \frac{E_2}{R_1}} = \frac{E_2}{I_2 - \frac{E_2 I_1}{E_1}} = \frac{E_2 E_1}{E_1 I_2 - E_2 I_1} \text{ (from Step 7)}$$

If,

15) $\frac{E_3}{\bar{R}_2} = \frac{E_3}{R_1} + \frac{E_3}{R_2}$

Then substituting $\frac{E}{I}$ for respective $\bar{R}$s and Rs,

16) $\frac{E_3 I_2}{E_2} = \frac{E_3 I_1}{E_1} + \frac{E_3 E_1 I_2 - E_3 E_2 I_1}{E_2 E_1}$

17) $\frac{E_3 I_2}{E_2} = \frac{E_3 I_1}{E_I} + \frac{E_3 E_1 I_2}{E_2 E_1} - \frac{E_3 E_2 I_1}{E_2 E_1}$

18) $\frac{E_3 I_2}{E_2} = \frac{E_3 I_1}{E_1} + \frac{E_3 I_2}{E_2} - \frac{E_3 I_1}{E_1}$

19) $\frac{E_3 I_2}{E_2} = \frac{E_3 I_2}{E_2}$

Equation 3 can now be expressed as,

$$R_n = \frac{E_n}{I_n - \frac{E_n}{\bar{R}_{n-1}}} \qquad (4)$$

If in the three layer case all of the soil is considered to be homogeneous, then $R_1 = R_2 = R_3$. Now, referring to Figure 2, the question arises as to whether the layer Equations 3 and 4 take into consideration the fact that for a homogeneous material the ratio of $\frac{E}{I}$ or $\bar{R}$, varies inversely with the depth.

If the layer equations do take into consideration this variation, then it can be proved, when $R_1 = R_2 = R_3$, that $\bar{R}_3 = \frac{\bar{R}_1}{3}$, or that $\bar{R}_n = \frac{\bar{R}_1}{n}$

14) $R_3 = \frac{E_3}{I_3 - \frac{E_3}{R_1} + \frac{E_3}{R_2}}$ or $\frac{E_3}{I_3 - \frac{E_3}{\bar{R}_2}}$

Since $R_2 = R_1$

20) $\frac{E_3}{R_3} = I_3 - \frac{2E_3}{R_1}$

Also $R_3 = R_1$

21) $I_3 = \frac{3E_3}{R_1}$

22) $R_1 = \frac{3E_3}{I_3} = 3\bar{R}_3$

23) $\bar{R}_3 = \frac{R_1}{3}$, or

$$\bar{R}_n = \frac{R_1}{n} \qquad (5)$$

THE USE OF THE LAYER EQUATION PRACTICE

In order to classify the types of soils encountered, a system of recognition is provided based upon ranges of layer-value resistivities determined from experience.

For the types of soils existing in the lower Peninsular of Michigan the following table has been developed:

ρL	Soil Types
0 - 10,000	Clay and Saturated Silt
10,000 - 25,000	Sandy Clay and Wet Silty Sand
25,000 - 50,000	Clayey Sand and Saturated Sand
50,000 - 150,000	Sand
150,000 - 500,000	Gravel

When the value of the layer resistivity is greater than 500,000 ohm-cm the interpretation of soil must be augmented with boring information. The reason for this is that a number of conditions can exist which will show high resistivity values, and these conditions range from dry loose sand and gravel to weathered rock and bedrock.

Inasmuch as the thickness of the layer is an arbitrary selection, the layer-value of resistivity must represent the average resistivity of all the soil types lying within the boundaries of any particular layer.

After all of the layer-values have been calculated they are plotted in bar-graph fashion against their respective intervals of depth as shown on Figure 3. The values for the layers are then connected to each other by lines drawn from the middle of each layer. The intersection of the various range values with the resistivity connecting lines will determine the elevation limits for the soil types. These intersection points can then be connected from station to station to from contour boundaries which, in effect, gives a cross-sectional view of the soil profile to any depth investigated showing the type, location, and relative quantity of soil materials.

CONCLUSION

It is the writer's opinion that investigations of borrow and proposed cut-sections of considerable size can be made faster and provide greater accuracy and detail by the resistivity method than by such methods as hand augering and soil borings. For example, there have been a number of occasions when the analysis of soil deposits by the resistivity method has indicated the presence of materials not apparent from surface conditions and shallow borings usually employed. Although this method is still in the development stage, subsequent borings and pit excavations proved the analyses to be correct. Thus the method of interpreting the field data by the layer-value determination equation has been successful to date.

It is felt that the layer-value determination as outlined here is not seriously affected, if at all, by the warping of the equipotential bowl which necessarily must take place to conform to the various resistances of the heterogeneous layers of material. Therefore, it is the writer's opinion that as more experience is obtained and with further laboratory study, the method will prove to be sufficiently accurate and reliable to satisfactorily predict the soil characteristics and conditions as required by the Department.

Effect of Native Materials on Roadbuilding in Ohio

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Bureau of Location and Design, Ohio Department of Highways

THE native soils and rocks have a profound effect on highway construction in Ohio. The boundary between the Appalachian Plateaus to the east and the central lowlands to the west passes north and south through the central part of the State. The bedrock consists entirely of sedimentary strata including mostly limestones and dolomites in the western part of the State and of sandstone and shales in the eastern part. The northwestern three-fourths of the state has been subject to continental glaciation. Road building aggregates are obtained principally from the limestone and dolomites of the central and western part of the State and from sands and gravels deposited either directly from the ice or as glacial outwash in the principal river valleys.

The soils are of major importance in highway construction in Ohio. Due to the several geologic processes which have been at work in the State a wide variety of soil types are found. To aid in interpreting soil conditions and their effect on highway construction an engineering soils map has been prepared by combining data presented on a generalized pedological soil map of the state, the geological map of the state and the considerable data on the engineering properties of Ohio soils which has been compiled by the Ohio State Highway Testing and Research Laboratory during the past 15 years.

Granular soils which provide good support to pavement structures are confined principally to a few old glacial lake beaches in the northern part of the State and to some of the principal river valleys elsewhere. The predominating subgrade soils through most of the state are fine grained silty clay and clay soils of intermediate to low supporting strength. Pavement design for these materials must take into account the stability of the various soils as well as the volume and weight of the traffic which must be supported. For economical construction careful consideration must be given to the various available potential construction materials. In view of the high cost of pavement construction for modern day heavy commercial traffic on low stability soils a thorough knowledge of the State's soils and of available aggregates of suitable quality and reasonable cost for pavement surfaces, bases and subbases is of utmost importance.

● IN 1950 and 1951, the Ohio Department of Highways, in conjunction with the Automotive Safety Foundation, made an intensive study of the State's roads and streets in order to get a comprehensive picture of their use and to determine the needs for expansion and improvement. As a part of this study, a subcommittee was assigned the task of reviewing the natural earth materials of the state in relationship to their effect on the construction and maintenance of highways. This paper presents a brief résumé of the data assembled for this report.

In the construction and maintenance of a highway, the roadbuilder must reckon continually with the natural earth materials which will make up its foundations or through which it may be cut. Pavements, roadways and bridges must all be built on or cut through the native soils and rocks. Further, the material of construction for earthwork, for pavement or for structures must be obtained from sources within reasonable hauling distance for economical construction. Therefore, the native soils, rocks, gravels, etc., exercise a considerable influence over the character and cost of our highways.

NATIVE MATERIALS OF OHIO

Geologic History

The native materials which make up the surface soils and the exposed bedrock of Ohio have been developed through a variety of geologic processes over the long eons of geologic time. For a clear understanding of these materials, a general knowledge of the salient features of the State's geology is very helpful.

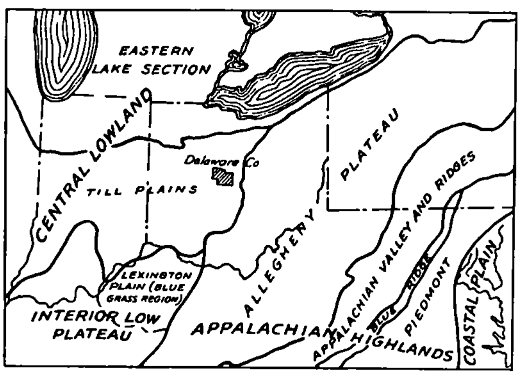

Figure 1. Physiographic divisions of Ohio and adjacent territory.

Physiographically, Ohio is divided into two major provinces, namely, the Central Lowlands in the western half and the Appalachian Plateaus in the eastern half. The line dividing these provinces is across most of the State, a rather clear-cut escarpment. This escarpment parallels the south shore of Lake Erie westwardly from the Pennsylvania-Ohio line to Cleveland, where it turns southwesterly and passes just west of Mansfield, thence through the central part of the State, along the east edge of the Scioto basin which it crosses at Chillicothe, turning westward to the eastern border of Highland County and thence south to the Ohio River east of Manchester in Adams County. Level to gently rolling plains make up the major portion of the State west of this escarpment, while the Appalachian Plateaus section is quite hilly with local relief varying from something over 100 ft. to approximately 600 ft. along the extreme eastern edge of the State.

Bedrock. The bedrock of the state from which a considerable part of soils are derived and which also is the source of much of its economic wealth includes practically all types of sedimentary strata ranging from conglomeratic sandstones to massive beds of limestone and dolomite.

The principal structural feature affecting the bedrock of Ohio is the broad Cincinnati Anticline whose axis extends across the western part of the State from the vicinity of Cincinnati to Toledo. On either side of this broad arch, the rocks dip away at an average rate of about 20 ft. to the mile. This dip is so slight that in any one exposure of the rock, the strata appear to lie approximately horizontal. Erosion has removed the higher and younger strata from the peak of this arch and, consequently, the oldest strata now outcrops along the axis of the anticline and successively younger rocks appear going away toward the east or west. The total thickness of the rock strata measured on the outcrop in the State is about 5,000 ft. All of the rock strata were deposited on the bottom of shallow seas or swamps during the Paleozoic era, a time through which most of the east central portion of North America was a shallow sea.

The exposed strata range from those of the Ordovician system consisting of alternating thin layers of limestone and calcarious clay shale which outcrop in a circular area around Cincinnati to the coal bearing rocks of the Pennsylvanian and Permian Systems. The older rocks, i. e., those of the Ordovician, Silurian and Devonian systems outcropping in the western half of the State are predominantly calcarious, consisting of limestone and dolomite with small amounts of calcarious shales, while the younger rock outcropping in the eastern and more rugged portion of the State are clastic in character consisting of sandstones and shales. In the western part of the State, the limestones and dolomites are extensively developed as sources of commercial aggregate, agricultural lime, flux stone, building stone, cement, etc.

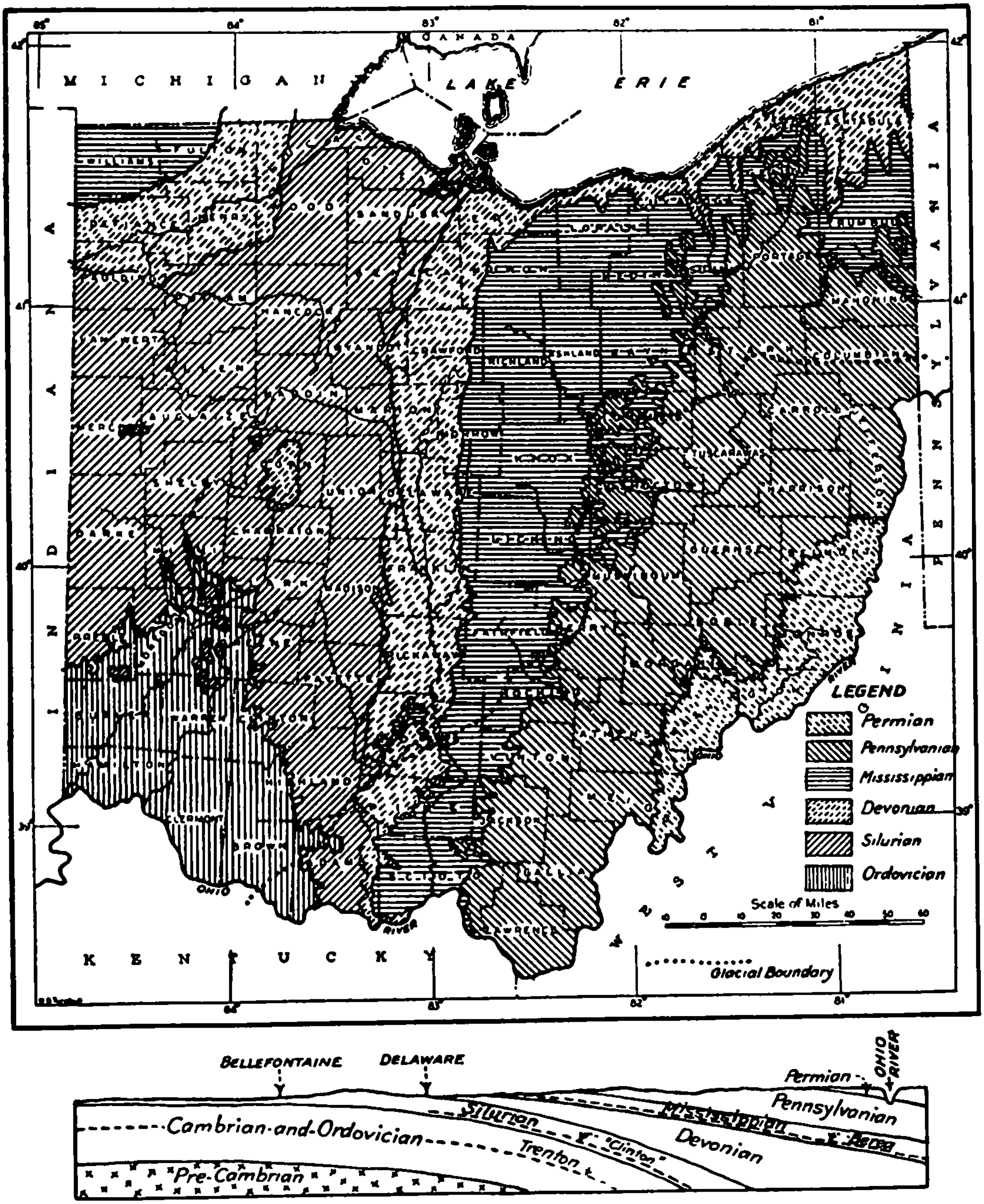

Figure 2. Geologic map of Ohio from Ohio Geological Survey. Below is a cross section from Bellefontaine, Logan County, through Delaware to the Ohio River.

The sandstone members of the central and eastern part of the State, notably the Berea formation of the Mississippian System, constitute an important regional source of building stone, sandstone curbing, grindstones, etc. The Pennsylvanian rocks contribute much to the economic wealth of the State, both as a source of coal and of clays and shales which form the basis for a large ceramic industry.

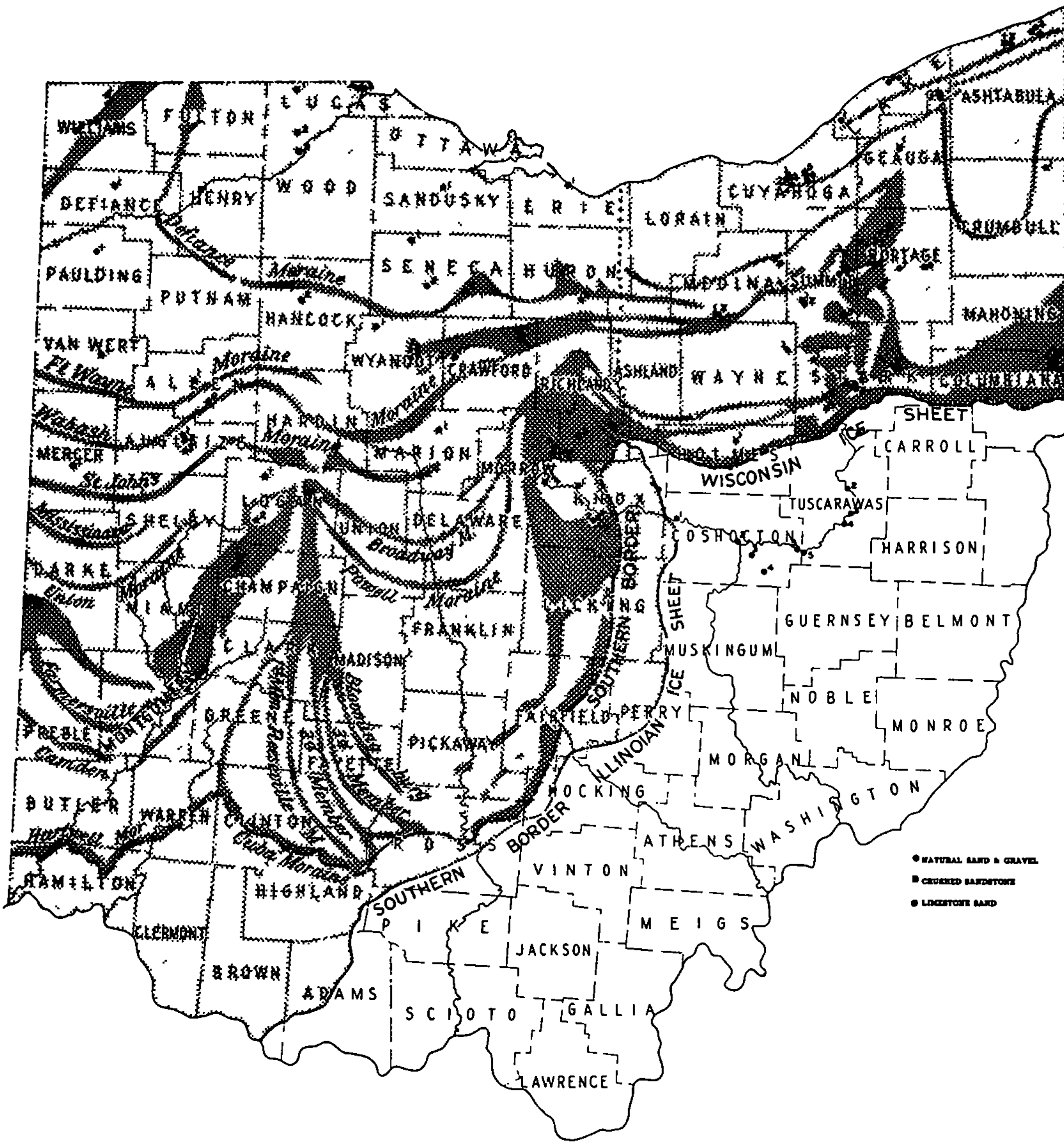

Figure 3. Glacial map of Ohio from Ohio Geological Survey.

Generally, however, the bedrock of the eastern half of the State contains but little rock suitable for producing highway construction aggregates.

Glacial Deposits. Of particular importance for the highway builder are the glacial deposits which cover most of the western and northern two thirds of the State. At least three separate advances of continental glaciers into Ohio are recognizable from their deposits while an older advance appears to have been instrumental in shifting of the preglacial river pattern and the development of the present surface drainage system.

The oldest widespread glacial deposits are those occurring in the southwestern portion of Ohio and are of Illinoian Age. These deposits except in the larger valleys are thin, generally less than 15 feet in thickness. The surface materials, therefore, show considerably more the influence of the underlying bedrock than do those in the remainder of the glaciated area.

The major portion of the surface deposits of the glacier were left by the most recent, Late Wisconsin Ice Sheet. The deep mantle of glacial drift left by this advance of the ice greatly modified the pre-existing topography by filling the old valleys with considerable thicknesses of drift and covering the hilltops and uplands with only a thin veneer of material. Further, at the edges of the glacial advance and at numerous points where the ice front halted for a time in its retreat, greater accumulations of drift in the form of moraines were left in irregular low hills and ridges which can be traced for many miles.

One of the major works of the glaciers was the development of the Great Lakes. For example Lake Erie has not always been exactly as it now is, but has, during various times during the glacial period, extended far out into the Maumee River basin in northwestern Ohio and south of its present shore for several miles at the foot of the Portage escarpment in the area east of Cleveland. The basins of these various older extensions of the Lake are marked by sandy and gravelly ridges in the positions of their shores and by uniform heavy clays on the lake bottoms.

The glaciers had a profound effect on the surface drainage system, both within the area covered by ice and far out beyond its boundaries. Many old valleys in the unglaciated section of the State are partially filled with thick layers of silt and clay which were deposited from the quiet waters formed by blocking of old northward drainage outlets by ice and the consequent damming up of the streams. Of greater economic importance to the roadbuilder are the considerable deposits of outwash gravel which were deposited from the sediment chocked rivers which flowed away from the ice front. Abundant quantities of gravel and sand were thus deposited in such valleys as the Tuscarawas, Muskingum, Scioto, Miami and Ohio.

Surface Soils

The surface soils developed from the weathering of the parent rock or drift are of utmost importance in the construction and maintenance of our highways. From the above description of the State's geology, considerable variation can be expected in the soils which have developed in different parts of the State. The principal soils areas of the State recognized by the Agronomists of the Department of Agriculture are indicated in Figure 4. The close relationship of these areas to the geology of the State is apparent. In studying soils for highway work in Ohio, an engineering soil classification system similar to the Highway Research Board system is used. An engineering soils map of the state has been prepared combining the H. R. B. classification with the soil areas mapped by the agronomists, Figure 5. The test data used in preparation of this map have been obtained from our experience in testing approximately 80,000 soil samples from highway projects during the past 15 years. In addition, during the last 13 years, we have been making detailed studies of the soils and rocks which will be encountered in cuts, subgrade and foundations for all major highway work. To the first of January 1951, such soil studies referred to in Ohio as soil profiles have been made for 2,082 mi. of road.

The principal soils of the State are as follows:

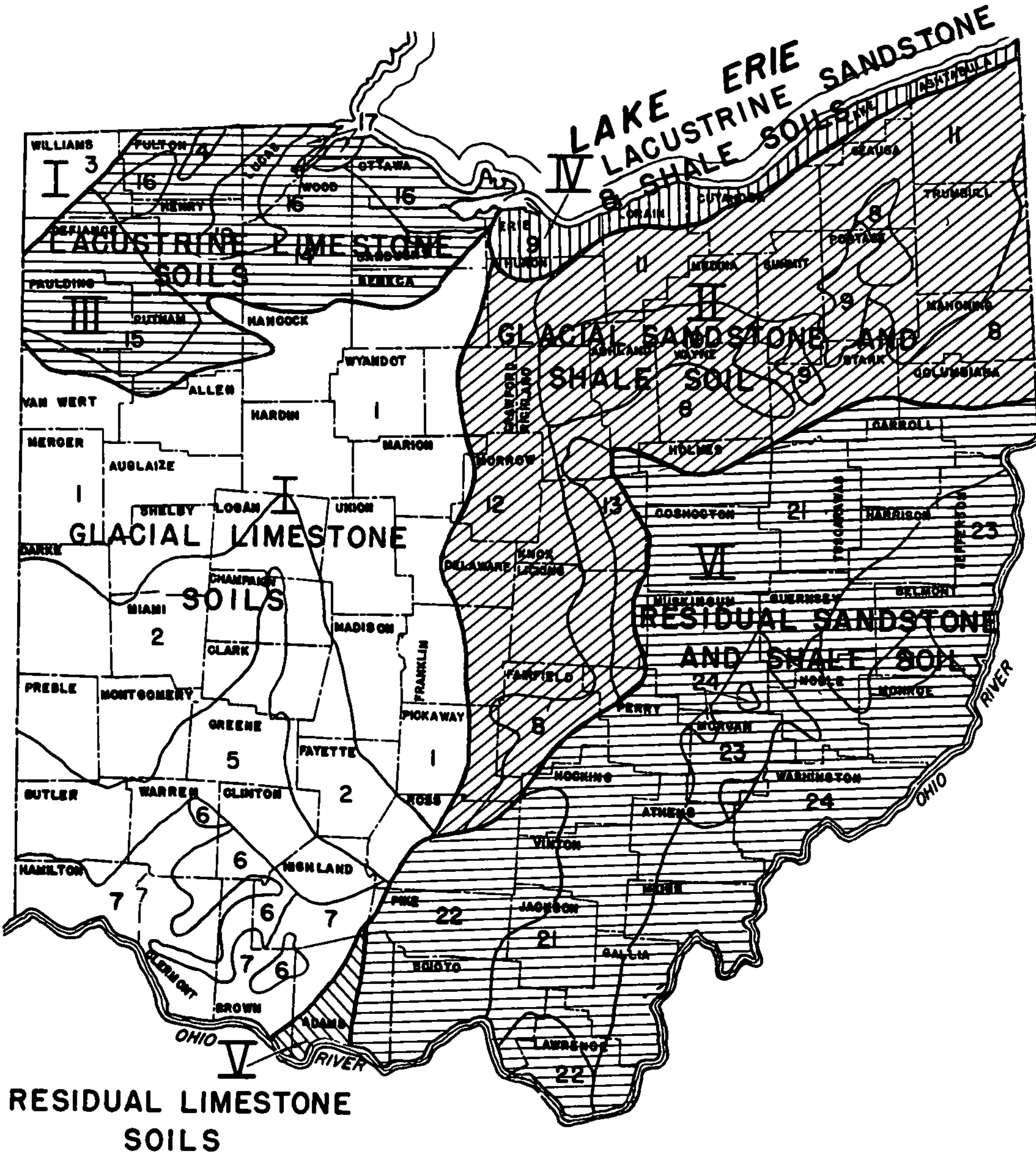

Figure 4. Generalized soil map of Ohio from the Ohio Agricultural Experiment Station, Wooster.

TABLE 1

LEGEND FOR GENERALIZED SOIL MAP OF OHIO (Figure 4)

From Special Circular No. 44 (Revised, 1937) published
by the Ohio Agricultural Experiment Station, Wooster, Ohio

I. Glacial limestone soils.

- a. Late Wisconsin Drift soils.
  1. Miami, Crosby, Brookston, and Clyde silty clay loam.
  2. Bellefontaine, Miami and Crosby silt loam; Brookston and Clyde silty clay loam.
  3. Miami and Crosby loam and silt loam; Brookston clay loam and silty clay loam.
  4. Mixed sands and find sandy loams - Coloma, Miami, Nappanee, Wauseon, etc.
- b. Early Wisconsin Drift soils.
  5. Russell and Fincastle silt loam with Brookston silt loam.
- c. Illinoian Drift soils.
  6. Clermont, Avonburg, Rossmoyne, and Blanchester silt loam.
  7. Cincinnati and Rossmoyne silt loam; Fairmount silty clay loam.

II. Glacial sandstone and shale soils.

- a. Late Wisconsin Drift soils.
  8. Wooster, Canfield, Ravenna, and Trumbull silt loam.
  9. Wooster and Canfield loam and sandy loam.
  10. Rittman, Wadsworth, and Trumbull silt loam.
  11. Ellsworth, Mahoning, and Trumbull silty clay loam and silt loam.
  12. Alexandria, Cardington, and Bennington silt loam; Marengo silty clay loam.
- b. Illinoian Drift soils.
  13. Hanover and Fallsbury silt loam.

III. Lacustrine limestone soils.

14. Brookston clay, with Nappanee clay loam, Wauseon fine sandy loam, etc.
15. Paulding clay, with Nappanee clay.
16. Toledo silty clay with Fulton and Lucas silty clay loam.
17. Toledo very fine sandy loam, loam, silt loam, and clay loam.
18. Plainfield, Berrien, and Newton fine sand.

IV. Lacustrine sandstone and shale soils.

19. Painseville, Caneadea, and Lorain loam to silty clay loam; Plainfield and Berrien fine sand.

V. Residual limestone and shale soils.

20. Hagerstown, Bratton, Maddox, and Ellsberry silt loam; Heitt, Eden and Fairmount silty clay loam.

VI. Residual sandstone and shale soils.

21. Muskingum silt loam, with Muskingum loam.
22. Muskingum silt loam (largely steep phase).
23. Westmoreland and Belmont silty clay loam, with Muskingum silt loam.
24. Meigs silty clay loam and Upshur clay, with Muskingum silt loam.

Illinoian Glacial Drift. In southwestern Ohio, the principal area of Illinoian Drift, the soil mantle outside of the valleys is usually thin. The character of the soil is strongly influenced by the limestone and shale bedrock and for these reasons the soils are largely clays. However, on certain upland areas there are deposits of windblown silts. Thickness of the glacial deposits in the valleys is much greater and includes both boulder clay or till and glaciofluvial sands and gravels.

Wisconsin Moraines. The low hills and ridges which mark the limits of advance of the Wisconsin glaciers or areas in which the icefront during its recession

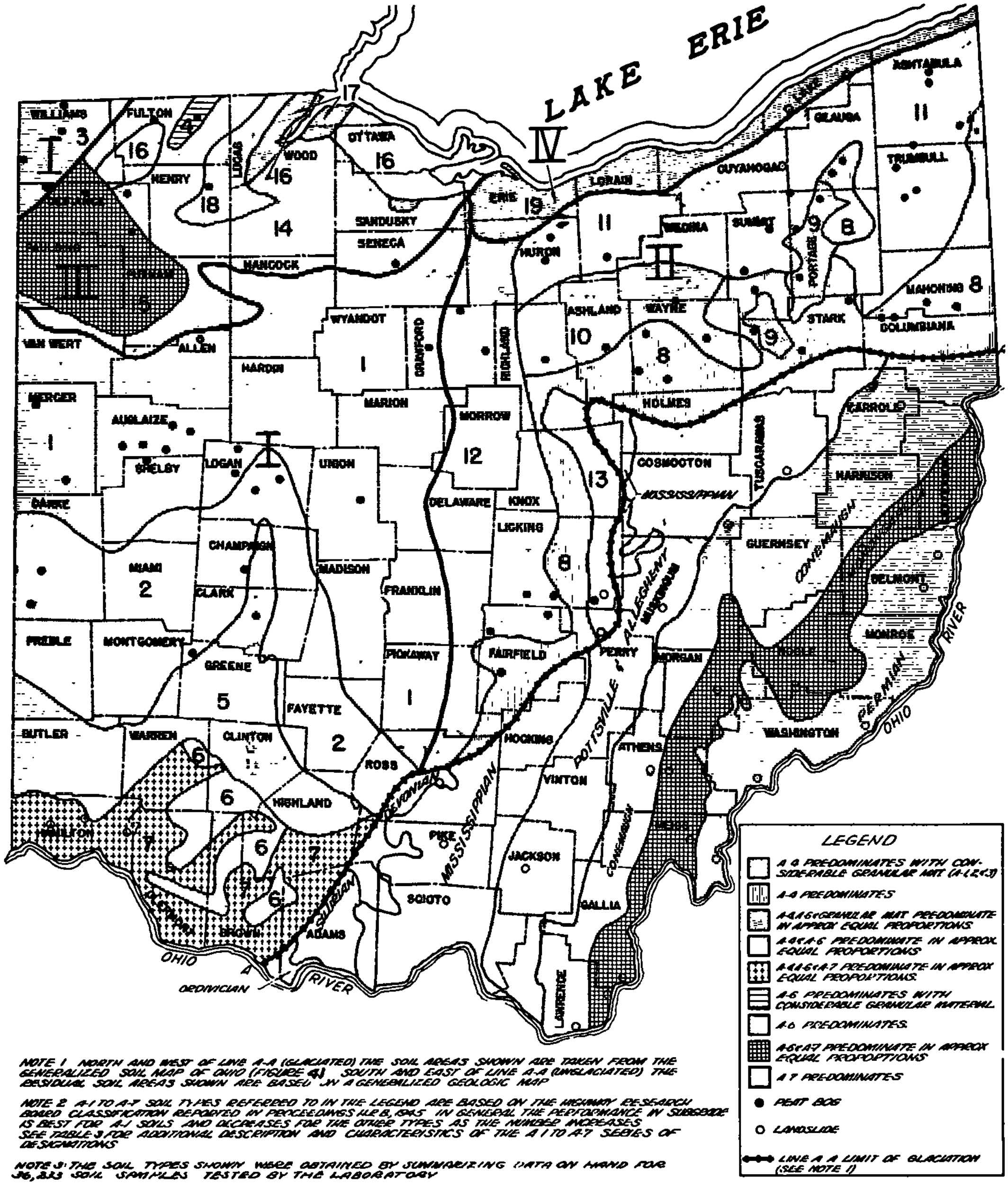

Figure 5. Generalized engineering-soil map of Ohio prepared by Ohio State Highway Testing and Research Laboratory.

remained approximately stationary over a considerable time, contain the most widely variable soils in the State. Deposits of boulders, gravel and sand are irregularly distributed through these areas together with sandy silt and silty clay soils. Also, numerous pockets of peat are found in many of the undrained depressions both in the moraine areas and on the till plains.

which represent bottoms of pre-existing extensions of Lake Erie are found the most uniform soils in the State. These soils are fairly heavy clays. Crossing these plains at various points are pronounced ridges which represent old shore lines of the lake. Many of these ridges are followed by highways. Granular material, principally sand, predominate

Figure 6. Peat bog, Wisconsin Glacial Drift. S.R. 18, Lorain County, Ohio. The peat is being displaced by loading. Note upheaved peat at left and right of the lower photograph.

both in these ridges and in a few localized areas on the Lake flats in the form of sand dunes.

<u>Wisconsin Till Plains.</u> The largest single soil area of the State is the area of Wisconsin Till. This area consists of gently rolling to almost completely flat plains covered with a considerable thickness of unsorted drift. The soils in the area consist almost entirely of fairly heavy silty clays and clays.

<u>Glacial Lake Plains.</u> On the broad, even, low areas in northwestern Ohio

In northern Cuyahoga and Lake counties, in the valleys of the major streams, are found considerable deposits of uniform textured silt soils apparently of lacustrine origin.

<u>Alluvial Terraces.</u> Both in the areas covered by the ice sheets and far out be-

TABLE 2

LEGEND AND CLASSIFICATION FOR SOIL TYPE IDENTIFICATION ON SOIL PROFILES

SMT'L CLASS NUMBER	SYMBOL	DESCRIPTION	PUBLIC ROADS ADMINISTRATION GROUPS	COARSE AGGREGATE RETAINED ON #10 SIEVE	COARSE SAND #10 TO #60	FINE SAND #60 – #200	SILT #200-.005 mm	CLAY BELOW .005 mm	LIQUID LIMIT	PLASTICITY INDEX	FIELD MOISTURE EQUIVALENT	SHRINKAGE LIMIT	MAXIMUM DRY WEIGHT
1		GRAVEL	A-3	50-100	0-40	0-30	0 —	— 10		N.P-10			
2		GRAVEL, SAND & SILT	A-2	30-60	15-30	15-20	15 —	— 40	13-35	NP-15	10-30	10-25	120-135
3		GRAVEL & SAND	A-1 A-2	30-70	15-40	15-30	0 —	— 20	13-35	NP-10	10-30	10-25	120-130
4		SAND	A-3	0-30	50 —	— 100	0 —	— 35		NP-5			100-115
5		SANDY SILT WITH COARSE MATERIAL	A-4 WITH C M	20-30	15-35	5-20	20 —	— 50	15-35	NP-15			
6		CLAY WITH COARSE MATERIAL	A-7 WITH C M	20-30	15-35	5-20	20 —	— 50	35-50	15-30			
7		BERM MATERIAL		CLASSIFIED BY VISUAL INSPECTION									
8		SILT	A-4	0-5	0-10	0-30	50-85	5-35	15-30	NP-12			105-115
9		SANDY SILT	A-4	0-30	10-40	10-40	20-50	5-30	15-30	NP-10	10-25		110-120
10		TOP SOIL	A-4	LOAMY MATERIAL CONTAINING DECAYED VEGETABLE MATTER AND HUMUS CLASSIFIED BY VISUAL INSPECTION									
11		SANDY SILT & CLAY	A-4	0-10	0 —	— 35	30-65	15-35	20-35	10-15	10-30		105-115
12		ELASTIC SILT & CLAY WITH ORGANIC MATERIAL	A-5						35+	P I LESS THAN $\frac{LL-14.0}{1.6}$			
13		ELASTIC SILT & CLAY WITH MICA	A-5						35+	P I LESS THAN $\frac{LL-14.0}{1.6}$			
14													
15		CLAY & SILT	A-7	0-10	0-25	0-15	50 —	— 100	35-40	15-25	25-35		100-110
16		CLAY	A-7	0-10	0-25	0-15	50 —	— 100	40+	20+	35+		90-105
17		CLAY	A-6						35+	P I GREATER THAN $\frac{LL-14.0}{1.2}$			
18		CINDERS		CLASSIFIED BY VISUAL INSPECTION									
19		ROCK-SOIL MIXTURE		30-90 % LARGE ROCK — CLASSIFIED BY VISUAL INSPECTION									
20		ORGANIC MATERIAL, PEAT, COAL OR COAL BLOSSOM	A-8	0 —	—	— 30			60+				
21		SOFT SHALE		CLASSIFIED BY VISUAL INSPECTION									
22		LIMESTONE		CLASSIFIED BY VISUAL INSPECTION									
23		SANDSTONE		CLASSIFIED BY VISUAL INSPECTION									
24		SHALE		CLASSIFIED BY VISUAL INSPECTION									

LIQUID LIMIT:— The moisture content, expressed as a percentage by weight of the oven-dried soil, at which the soil will just begin to flow when jarred slightly.

PLASTIC LIMIT — The lowest moisture content, expressed as a percentage by weight of the oven-dried soil, at which the soil can be rolled into threads 1/8 inch in diameter without breaking into pieces.

PLASTICITY INDEX — The difference between the liquid limit and the plastic limit.

FIELD MOISTURE EQUIVALENT — The minimum moisture content, expressed as a percentage by weight of the oven-dried soil at which a drop of water placed on the smooth surface of the soil will not be immediately absorbed but will spread out over the surface and give it a shiny appearance.

SHRINKAGE LIMIT — The moisture content, expressed as a percentage by weight of the oven-dried soil at which a reduction in moisture content will not cause a decrease in volume of the soil mass but at which an increase in moisture content will cause an increase in the volume of the soil mass.

BUREAU OF TESTS
OHIO DEPARTMENT OF HIGHWAYS

SOIL CLASSIFICATION CHART

PLAN PREPARATION MANUAL

APPROVED [signature] ACTING CHIEF ENGR.

DATE 4-20-44

No 1

yond the glacial boundaries there are terraces and valley fills formed by deposition from the glacial melt waters in the major river valleys. The terraces particularly and also often a considerable part of the valley fill are made up of fairly clean washed gravels and sand.

Residual Soils. In the southeastern part of the State beyond the area covered by glaciation, the soils have been developed by direct weathering of the parent rock. They are, therefore, quite variable on a local basis depending on the character of the bedrock. Taking the area as a whole, the predominating materials are shales and clays and the resulting soils, therefore, consist principally of clays.

Effect of Ohio Geology on Road Construction

The relative importance of the various problems involved in constructing roads in Ohio varies considerably from one region to another. For example, proper design of side slopes in cuts is a major consideration in the hilly terrain of the eastern half of the State but of little importance in the flat lands of the glacial lake plains. The effect of Ohio Geologic and Soil Conditions on various phases of highway work will be discussed under the headings of Foundation, Earthwork, Subgrades and Pavement.

Foundation. Foundations for structures and embankment in the glaciated portion of the State are usually quite adequate for the necessary loadings. However, there do exist many deposits of peat ranging in size from those covering a small fraction of an acre to large bogs covering several hundred acres (see Fig. 6). Depths of these deposits range from as little as one or two feet to over 50 feet. There is some variation in the composition and character of the peat which effects its commercial value, however, as foundation for embankment the material is uniformly poor. The instability of this soil is indicated by the fact that water almost always makes up between 2 to 5 times as much of the total weight of the deposit as do the solid particles. These deposits may be treated in one of the several ways outlined below:

(a) Change of alignment: Where practicable, particularly in all new construction work, this is by far the most satisfactory treatment.

(b) Removal and Replacement with suitable Material: This is perhaps the most positive method of providing lasting stability at the outset. It is also usually the most costly.

(c) Displacement by loading: This may be done either with or without the assistance of blasting. It also is usually an expensive process and final settlement of the new fill may take several years with the resultant necessity for continued maintenance.

(d) Floatation: In some cases, it may be possible by the use of flat fill slopes and slow application of load to construct across a bog area without lateral displacement of the underlying peat. Slow settlement of the finished roadway is likely to occur for a considerable time, when construction is done by this procedure. However, the initial savings in construction cost by this method will often be considerably greater than the cost of maintenance of the section over a great many years.

In the unglaciated part of the State, foundations are usually good. In the valleys of the smaller streams, bedrock often occurs within a few feet of the surface affording excellent support both for structures and embankment. In some of the larger valleys of the unglaciated areas, there are thick deposits of fine textured silts or silty clay soils. For high fills and structures, some of these materials have questionable supporting stregnth and require special treatment.

Earthwork. All highway construction involves some grading to provide suitable cross section and to obtain the desired smoothness of profile and adequate sight distance. Grading becomes particularly important in the hilly Appalachian Plateaus region of the eastern part of the State. Here deep cuts and high fills are often necessary. The soils and rocks of the State are practically all suitable for embankment construction when properly handled. However, there are some materials such as the red clays found in the upper portion of the coal measures, rocks, and the silts which occur as valley filling in various parts of the State which form stable fill only when placement and compaction are very carefully controlled.

Due to the wide variety of sedimentary rocks which occur in the eastern part of the State, cut slopes present a problem which must be worked out from area to area and oftentimes different slopes must be used in the several materials which may occur in different cuts on the same project or at different levels in the same cuts.

excavation in the thick mantle of soil overburden on the lower slopes of the hills, or when embankment must be constructed on sloping rock or soil foundation, landslides are of common occurrence (see Figures 7 and 8).

Many of the situations conducive to landslide are readily recognizable from general observation and from routine field soil studies. Where landslides appear definitely probably, preventitive measures as follows may be used:

Figure 7. Landslide, Conemaugh Formation Pennsylvania Series S.R. 7, Lawrence County, Ohio. This slide developed after construction of a side-hill fill on sloping talus. Correction consisted of loading the toe of the slide and adding fill at the top together with improvement of the surface drainage.

Landslides are a problem particularly in the clay soils and associated bedrock of the upper Pennsylvanian and Permian formations. Landslides are also common in the clay soils derived from the weathering of the limestone and shale formations of the Ordovician system in southwestern Ohio particularly in the vicinity of Cincinnati. Due to the hilly topography in these areas, considerable grading is necessary. When this grading involves

A. Side Hill Cuts.
   1. Flatten slopes.
   2. Provide benches at level of the new roadway or higher in the slope as specific conditions indicate.
   3. Use interceptor ditches above cut slope.
   4. In slides which have already developed, excavate the slip material and reconstruct, usually

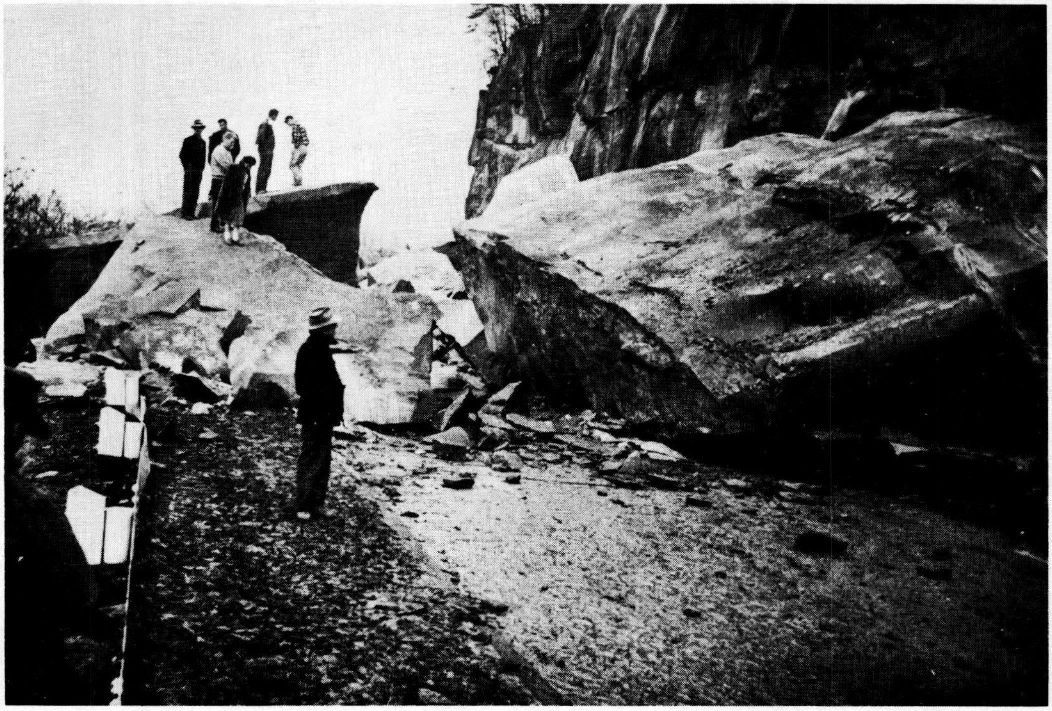

Figure 8. Rock Fall, Permian sandstone, Route 7, Washington County, Ohio. Joints and mud seams in the sandstone and weathering of a soft shale under the stone resulted in this rockfall.

providing a cut off drain at the back of the excavated area.

5. Shift line to avoid the area.

B. Side Hill Fills.

1. Cut benches into original ground to solid foundations material and construct fills out of selected high quality material such as rock.
2. Drain natural seepage planes.
3. Hold roadway with piling, rock, concrete or bin type walls founded on solid material.
4. Counter-balance forces tending to produce slippage by flattening slopes or providing a buttress of heavy rock or soil fill at the toe of the slope.
5. Shift line to avoid the area.

Most of the above preventive or corrective procedures are very costly. For this reason, it is often more economical to use preventive measures only where slides appear to be inevitable, than to use them in all cases where slides seem to be a possibility. If, in new construction all possible sections where slips might occur were treated to guarantee stability, construction costs in the hilly terrain of the State would soar high above present costs for both new construction and the remedial measures necessary in areas where landslides have occurred.

Pavements and Subgrades. The widely varying character of different Ohio soils makes pavement design adequate for these soils and for the traffic demands on roads ranging from those which carry 100 vehicles per day to those which carry several thousand vehicles a complex problem. It might at first be assumed that all roads in the state should be built to handle maximum legal loadings. However, it is a well established fact that many of our secondary roads, which constitute the greater part of the total mileage of the state system, seldom carry heavy vehicles. It is also known that the frequency of repetition of load has a great deal to do with the rate at which a pavement wears out. A pavement subject to

TABLE 3

DESCRIPTION AND CHARACTERISTICS OF SOIL TYPES

Classification H. R. B.	Classification S. H. T. L	Description	Percent Passing No. 200 Sieve	Liquid Limit	Plasticity Index	AASHO Moisture-Density: Maximum Dry Weight (lb /cu. ft.)	AASHO Moisture-Density: Optimum Moisture %	Modified C. B. R. Results (Avg.)	H. R. B. Group Index	Performance in Subgrade
A-1	1, 3	Well graded mixture of stone fragments or gravel and sand, either with or without a well graded soil binder.	25 Max	-	6 Max.	115-142	7-15	51	0	Highly stable under wheel loads, irrespective of moisture conditions.
A-3	4	Principally fine sand with no soil fines or with a very small amount of non-plastic silt	10 Max.	-	Nonplastic	100-115	9-15	32	0	Unaffected by moisture conditions. Not susceptible to frost damage or shrinkage or expansion. Furnishes excellent support when confined.
A-2	1, 2, 3, 4	Includes a wide variety of granular materials with grading or plasticity or both in excess of limitation for A-1 or A-3.	35 Max	-	-	110-135	9-18	26	0 to 4	Stable when fairly dry.
A-4	8, 9	Silt or sandy silt soil, nonplastic or with low plasticity.	36 Min.	40 Max.	10 Max.	95-130	10-20	11	8 Max.	Tendency to absorb water readily. Low stability when wet. Susceptible to frost damage. Generally requires drainage or granular insulation material.
A-5	12	Silt soil similar to A-4 group except that it usually includes organic material or mica.	36 Min.	41 Min.	10 Max.	85-100	20-35	No tests	12 Max.	May be highly elastic. Usually requires special subgrade treatment.
A-6	11, 15	Silt clay soil of moderate plasticity.	36 Min.	40 Max.	11 Min.	93-125	10-30	7	16 Max.	Subject to considerable volume change. Medium to low supporting strength.
A-7	16, 17	Clay soil of high plasticity.	36 Min.	41 Min.	11 Min.	90-115	15-30	5	20 Max.	Subject to high volume change. May be elastic. Low supporting strength.

only occasional repetition of a load greater than that for which it was designed will give many years of service while one which is repeatedly used by loads greater than the design load may fail within a relatively short time. To illustrate, fatigue curves published by the Portland Cement Association show that a concrete pavement designed for an unlimited number of repetitions of 18,000-lb. axle loads will carry 22,000 lb. axle loads at the rate of two per day for over 30 years without producing failure. However, if repetitions of 22,000-lb. axle loading are increased to 10 per day, life of the pavement is reduced to about 7 years. For economic reasons, it is essential that pavements be designed, not for some arbitrary load such as the maximum legal load, but for the actual magnitude and number of load applications to which it will be subjected.

Silt soils susceptible to frost heave are frequently encountered in the glacial soils of the State. To prevent damage to the pavement either by heaving during subfreezing weather or through loss of support during periods of thaw, these soils must be either drained or replaced. The most commonly occurring potentially frost heaving soil in Ohio is a silt which will not drain rapidly enough to assure complete protection against frost heave. This material is usually replaced to depths of 12 or 18 inches below the pavement with non-frost susceptible granular material. Drainage is used in conjunction with this replacement to insure stability both in the replaced material and in the underlying undisturbed soil.

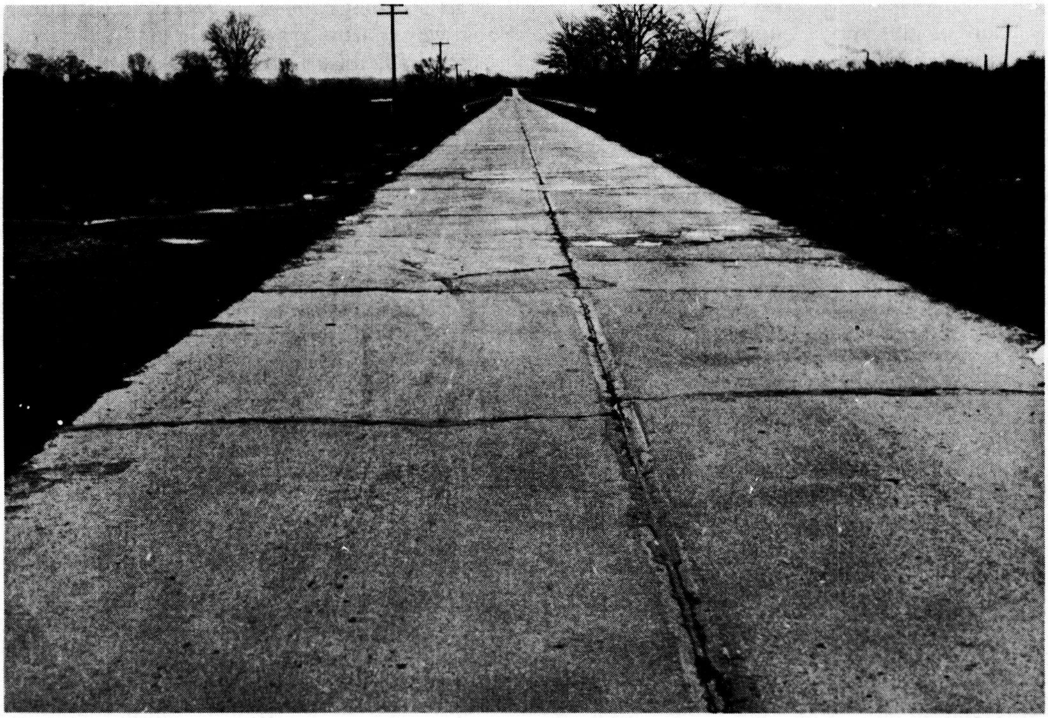

Figure 9. Pumping and broken concrete pavement on Route 30N, Crawford County, Ohio. A 9-7-7-9 concrete pavement on till plain clay of late Wisconsin Age; no subbase.

Good surface and sub-surface drainage are essential for good pavement performance. Many of the soils which make up subgrade are too dense to be much improved by sub-surface drainage. However, sub-surface drainage is very effective in stabilizing sandy silt soils of low plasticity. These soils are often found in the hilly, moranic areas. They have fairly high stability at moisture content below optimum but become elastic and subject to excessive deformation and rebound at high moisture contents. Subsurface drainage is also of considerable value in intercepting lateral seepage and in lowering high ground water table whereever these conditions occur.

Most Ohio subgrades are made up of fine textured soils of intermediate to moderately high plasticity. Supporting strength of these silty clay soils is usually low. As measured by the California Bearing Test, the bearing value of these soils is almost always less than 10 and for the majority of cases is less than 5.

One of the most serious of the problems which these low bearing value soils present under rigid types of pavement is that of pumping (Fig. 9). Pumping is the extrusion of water and soil from joints and cracks in concrete pavements under the action of moving heavy loads. It results in erosion of the soil below the slab and consequent loss of support. The effects of pumping on the slab are progressive, leading to the development of secondary cracks which in turn become pumpers and the final destruction of the pavement. Extensive studies of this phenomenon in Ohio and in other states have established the following four conditions as essential to produce pumping.

1. Presence of free water.
2. Presence of fine grained soil subgrade.
3. Repeated application of heavy loads which produce slab deflection.
4. Joints or cracks in the pavement.

From study of concrete pavements in Ohio and in adjacent states, it has been found that pumping is confined principally to soils which have less than 55% total sand and gravel (material retained on a No. 200 sieve). This limit includes most natural soil subgrades in Ohio. With respect to the effect of load, the studies show:

(1) Little pumping occurred on the majority of projects carrying 50 and less 14,000 pound axles, and 20 and less 18,000 pound axles, per 8 hours even under unfavorable conditions of subgrade soil and design. It appears that careful consideration should be given to the possible omission of granular sub-bases for the prevention of pumping where expected volume of axle loadings is within these limits.

(2) Where the number of 14,000 pound axles per 8 hours is expected to be within 51 and 250, it may be well to consider the use of a granular sub-base even though it is not a first class, low plasticity material. Traffic data indicates that this load group would include 20 to 80 axles of 18,000 lb. and greater.

(3) The study shows that granular subbase material having a plasticity index of 6 or less should be used over fine grained subgrade soils to prevent pumping where the traffic is expected to have over 250 axles of 14,000 pounds per 8 hours. Traffic counts indicate that this volume of trucks would include more than 80 axles of 18,000 lb. or greater.

Soil and traffic conditions are such on most of the primary roads in the State that some pumping preventive measures are necessary. The most uniformly effective treatment is the use of a subbase of nonpumping granular material. Data are not yet available to determine the exact minimum depth required. In the early years of use of sub-base in Ohio, 12- and 15-in. depths were widely used. In more recent years, 4- and 6-in. depths have been commonly used since experience gained with granular sub-bases both in this and other states indicated that the greater thicknesses previously used were not essential. Additional studies both as to depth and type of nonpumping sub-base material needed are to be investigated in the near future, in an experimental project.

The low supporting strength afforded by the fine textured subgrade soils in Ohio necessitates the use of thick flexible pavements and sub-bases so that heavy wheel loads will be transmitted to a large enough area of the soil that its strength will not be exceeded. For the traffic on primary roads on the heavy clay soils of the State, flexible pavements with a total thickness of 19 to 27 in. are required. The thicknesses of flexible pavements required for the different supporting strength of various subgrade soils varies through a wider range than do slab and sub-base thickness of rigid pavements on similarly varying subgrade soils.

In flexible pavement design, it is also recognized that stresses are most severe in the upper portion of the structure and that, therefore, the highest stability materials need be used only in this part of the structure. The usual practice is to use high grade bases such as macadam or bituminous concrete in the upper 7 to 10 inches of the structure and to make use of locally available lower cost granular materials in the lower part of the structure.

The materials used in the lower part of flexible pavements and as pumping preventives under concrete are described as sub-bases. Specifications for this material have been written and revised from time to time to make the best possible use of local materials. Further, detailed field and laboratory tests are often made to ascertain what local materials are available which might be used for sub-base and design and specification requirements modified to utilize materials from these sources.

Safety Factors and Highway Construction Costs

As was pointed out, highway embankment, pavements and structures depend directly on the natural soil or rock foundations for their support. The engineering properties of soil such as their compressibility, cohesion and resistance to shear which taken together provide its strength are at best difficult to measure. Further, soils are far from uniform in composition, gradation, and moisture content even through relatively short distances. It would, therefore, be desirable to design structures which depend upon soils for their support with a fairly high factor of safety to compensate for the uncertainties of presently available testing procedures and the known variability of the material. However, economic considerations have often made the use of high safety factors impossible. D. W. Taylor, in a paper presented at the Highway Research Board in 1939, entitled, "Limit Design of Foundations and Embankments," states that, "experience has shown that for practical and economic reasons, factors of safety with respect to strength in embankment analyses must frequently be limited to values on the other of 1. 1 to 1. 5." Likewise, in the design of embankment over questionable foundation soils or of pavement structures, it has long been the practice to provide only a narrow margin of safety. In addition to the considerable economies which are effected in initial construction by the use of these low safety factors, such low safety factors have been acceptable because failure does not usually result in complete loss of a substantial part of the investment in the structure, and almost never would be physically hazardous to the user. For example, if a flexible pavement deforms under the application of loads greater than those for which it was designed, the material which went into its construction is still there and can be used to form a base for a new pavement. Many miles of concrete pavements which had become badly cracked and rough under the steadily increasing weight and volume of traffic have been salvaged by the use of relatively thin resurfacings and have then given excellent service under much heavier traffic than ever was anticipated when the original concrete was placed.

The tremendous increase in number of heavy commercial vehicles in the past 20 years and the increase both in weight and frequency of heavy axle loadings make even more desirable the use of higher safety factors. This is particularly true if legal limitations on loads are to be continuously pushed upward or disregarded as larger and more powerful commercial units are developed. Further, if the designer of today must build pavements to last a century or more, he will have to drastically increase his safety factors with a consequent sharp increase in initial construction costs.

The importance of different subgrade materials on pavement construction is readily seen when a comparison is made between relative costs of pavements built on soils which require no subgrade treatment and those built on the usual fine grained soils. On the good granular subgrades such as the beach ridge sands of the Erie Basin or the gravel terraces in some of the river valleys, a pavement thickness of about 8 inches is adequate for very heavy commercial traffic. Such a pavement 24 ft. wide would cost approximately $50,000 per mile at present day prices. On the low supporting strength clay soils which prevail in much of the State, cost of the 8-in. pavement plus about 14 inches of sub-base and necessary sub-surface drainage would be about $76,000 per mi. If it was considered advisable to utilize a higher safety factor of say 2.5 instead of the currently accepted low safety factors, cost of the high type pavement of 10-in. thickness plus 18 in. of subbase and subsurface drainage would probably be on the order of $93,000 per mile for a 24 foot width pavement.

From the above, it is evident that the low supporting strength of most Ohio soils increases the cost of pavement construction by about 50% over that which would prevail on good subgrades.

If the public demand is for pavements which will carry continually increasing loads and, at the same time require no substantial improvement or repair for as much as 50 or 100 years, it will be necessary to adopt the higher safety factors common in other engineering practice. Cost of initial pavement construction above that required on good subgrades would then be increased by about 90 percent.

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