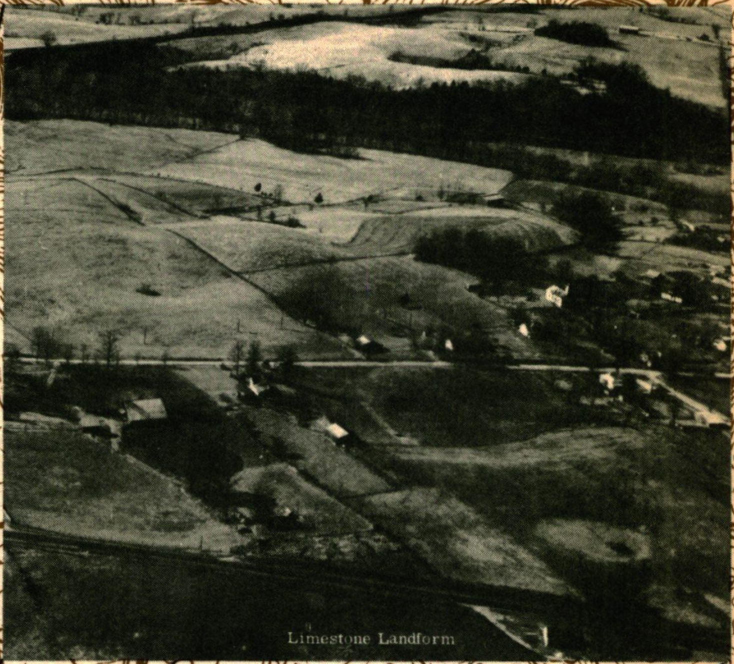
HIGHWAY RESEARCH BOARD

bulletin no. 46

1951



Limestone Landform

Engineering Soil Survey Mapping

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1951

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HIGHWAY RESEARCH BOARD

Bulletin No. 46

ENGINEERING SOIL SURVEY MAPPING

PRESENTED AT THE THIRTIETH ANNUAL MEETING

1951

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

Washington 25, D. C.

December 1951

DEPARTMENT OF SOILS INVESTIGATIONS

Harold Allen, *Chairman*
Principal Highway Engineer,
Bureau of Public Roads

COMMITTEE ON SURVEYING AND CLASSIFYING SOILS
IN PLACE FOR ENGINEERING PURPOSES

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INTRODUCTION

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

This is the fourth in the series of related publications sponsored by the Committee on Soil Surveying and Mapping. The three previous bulletins - No. 13, "The Appraisal of Terrain Conditions for Highway Engineering Purposes," No. 22, "The Engineering Use of Agricultural Soil Maps," and No. 28, "Soil Exploration and Mapping" presented information on methods and applications of terrain classification and subsurface exploration for engineering purposes. These bulletins also indicated the status of geological and agricultural soil mapping in the United States and lists of geologists and soil scientists were included for ready reference purposes.

This bulletin is a continuation of the policy of the committee to present information which should be useful to the highway engineer. It contains a group of related papers on the use of aerial photographs to obtain terrain information, such as, type of soils, parent material and drainage from the study of airphoto soil and rock patterns. The status of current geologic and agricultural soil mapping are indicated, and revised lists of geologists and soil scientists, tabulated by states, are given to amend previous published lists. This bulletin contains an information circular prepared by the U.S. Geological Survey which indicates the status of topographic mapping in the United States. The circular will be found in a pocket which follows the last page of this publication.

The committee is in general agreement with the principle of identification and classification of soils and parent material from the study of aerial photographs, but at this point it wishes to offer a word of caution to engineers who may be considering the use of aerial photographs to obtain soil and rock information. It is not a direct method of analysis and errors in making engineering estimates of soil and rock characteristics may occur as the result of improper interpretation of the airphoto patterns. The accuracy of this indirect method depends upon the ability of the airphoto analyst to obtain satisfactory correlation of the airphoto soil patterns with geologic and agronomic features of the terrain. To be able to do this requires a knowledge of both geology and pedology as it is related to highway soil problems. One way to expedite the training of engineers in this specialized field is to initiate research projects which consist of the preparation of engineering soil and drainage maps, material inventories and field studies of pavement performance on an area basis. Several states have cooperative research projects with the Bureau of Public Roads to develop engineers who can make the proper interpretation of airphoto soil patterns occurring in their state. Other states are working along similar lines to develop the necessary know how.

It is reasonable to predict that as more and more states complete the engineering soil mapping on a state-wide basis there will be a development of regional correlations of design, construction, maintenance practices, and traffic patterns on an area basis. It is likely that these areas will have similar ranges in terrain conditions which can be identified and classified on the basis of landform drainage and texture or from the soil-profile characteristics related to those elements of the landscape. The results of such coordinated research should be reflected in the better understanding of highway engineering problems as they are related to terrain and traffic conditions. The airphoto method of terrain analysis supplemented with a limited amount of ground reconnaissance to obtain reliable checks should be an economical and reasonable way to make these regional correlations.

GEOLOGIC SURVEY MAPPING IN THE UNITED STATES

The committee indicated in bulletin 28 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 28.

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 state index maps are available and may be obtained from Director, U. S. Geological Survey, Washington 25, D. C., for the prices indicated. The indexes for states west of the Mississippi River may also be obtained from the Map Distribution Office, U.S. Geological Survey, Denver Federal Center, Denver, Colorado. Each published geologic map is outlined on a state base map; an explanatory key gives the source and date of publication, author and scale. The scale of most state index maps is 1:750,000, a few were published on a scale of 1:1,000,000. Outline patterns that show the areas covered by geologic maps are printed in four colors to indicate approximate scale of maps.

Alabama	$ 40	New Jersey	$.-
Arizona	35	New Mexico	.70
Colorado	.70	North Carolina	.50
Georgia	.25	North Dakota	40
Idaho	.25	Ohio	.25
Indiana	.45	Oregon	.25
Iowa	.35	South Carolina	.25
Kansas	.30	South Dakota	.30
Louisiana	.50	Tennessee	.40
Maine	.25	Texas	.60
Maryland-Delaware	.40	Utah	.25
Mississippi	.25	Virginia	.40
Missouri	.30	Washington	.35
Montana	.35	West Virginia	.25
Nebraska	.35	Wyoming	.50
Nevada	.30	California - in progress	

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.

TABLE 1

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

STATE	PROJECT	PROJECT CHIEF
Alabama	Survey of the belt of Cretaceous rocks in Central Alabama	L C Conant
Arizona	Geologic Mapping of areas long the Colorado River, Mojave County	C R Longwell
	Ft McDowell Quad , Maricopa County	R C Townsend
	Jerome Copper District, Yavapai County	C A Anderson
	Globe-Miami Copper District, Gila County	N P. Peterson
	San Manuel Copper District, Pinal County	G M Schwartz
	Little Dragoons Copper District, Cochise County	J R Cooper
	Central Cochise County	J Gilluly
	Carrizo Mountains, Northeastern Arizona	J D. Strobell, Jr.
Arkansas	North Arkansas Oil and Gas, Geologic Mapping and studies of resources, Newton-Searcy Counties	J C Maher
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 Co	D M Kinney
	Study of Miocene and Pliocene deposits of the Santa Clara Valley, Ventura and Los Angeles Counties	E L Winterer
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
	Crystal Mountain, Pegmatite District, Larimer County	W. R Thurston
	Quartz Creek Pegmatite District, Gunnison County	M H Staatz
	Garfield Quadrangle, Chaffee and Gunnison County	M G. Dings
	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
Connecticut	Pegmatite districts in Hartford and Middlesex Counties	F Stugard, Jr
Idaho	Seven Devils Copper District, Adams County	R S Cannon
	Blackbird-Noble #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
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
Maine	Poland Quadrangle, Androscoggin, Cumberland, and Oxford Counties	J B Hanley
Maryland	Brandywine area, Prince Georges and Charles Counties	J T Hack
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

TABLE 1 (continued)

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

STATE	PROJECT	PROJECT CHIEF
Montana	Great Falls-Sun River Area	R W Lemke
	Bentonite Deposits of the Yellowtail District, Bighorn County	M M Knechtel
	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
	Powder River Coal Fields, Powder River, Rosebud, and Bighorn Counties	R P Bryson
	Lewistown, Forest Grove-Button Butte Area, Fergus County	L S Gardner
	Stanford-Hobson area, Judith Basin County	J D Vine
	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
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
	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
	Ione Quadrangle, Nye County	Siemon W Muller
New Jersey	Study of Magnetite Deposits, New Jersey Highlands	A F Buddington
	Dover Iron Mining District, Morris County	P K Sims
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
	Socorro County	C B Read
	Colfax County	G H Wood, Jr.
	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
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
	Deep River Coal Field, Chatham, Lee and Moore Counties	J A Reinemund
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
Oklahoma	Tri-State Lead-Zinc District, Ottawa County	E T McKnight
Oregon	Portland Industrial Area	D E Trimble
	John Day Chromite District, Grant County	T P. Thayer
	Galice Quadrangle, Josephine County	F G Wells
	Region west of Willamette River, Northwestern Oregon	H E Vokes and E M Baldwin
Pennsylvania	Potter County	C S Denny
	Magnetite Deposits, York and Lancaster Counties	A F Buddington
	Selected coal mining areas in Pennsylvania Anthracite Region	Boyd Haley

TABLE 1 (continued)

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

STATE	PROJECT	PROJECT CHIEF
Rhode Island	Northeastern Rhode Island	A W Quinn
South Dakota	Pleistocene Geology, Eastern half of S D	R F Flint
	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
Texas	Areas in Hudspeth County	J F Smith
	Oil and Gas Investigations, North central Texas	D H Eargle
	Scurry Oil Field	H E Rothrock
Utah	Blue Mountains, San Juan County	J D Sears
	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
Vermont	Vermont Talc	W M Cady
Virginia	Hamme Tungsten District	J M Parker, 3d
	Fairfax Quadrangle, Fairfax and Loudoun Counties	C Milton
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 County	P D Snavely, Jr
	Toledo-Castle Rock Coal District, Cowlitz County	A E Roberts
Wisconsin	Lead-Zinc Deposits in Grant, Lafayette, and Iowa Counties	Allen Agnew
Wyoming	Cokeville Area, Lincoln and Sublette County	W. W. Rubey
	Bentonite Deposits of the Yellowtail District, Sheridan County	M. M Knechtel
	Iron deposits in Laramie Range, Albany County	W. H. Newhouse
	Bear River Phosphate Deposits, Lincoln and Uinta Counties	R W. Swanson
	Jackson Hole Area, Teton County	J D. Love
	Spotted Horse Coal Field, Sheridan and Campbell Counties	W. W. Olive
	Wind River Basin	R M Thompson
	Badwater Area, Fremont, Natrona, and Hot Springs Counties	H. A. Tourtelot
	Clark Fork Area, Park County	W G Pierce
	Lake De Smet Area, Johnson County	W. J. Mapel, Jr
	Bull Creek Area, Johnson County	R K. Hose

TABLE 2

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

STATE	PROJECT	PROJECT CHIEF
Alabama	Baldwin, Madison, Mobile, Monroe, Wilcox Counties	P E LaMoreaux
	Mapping Scale 1 31680	
	Publishing Scale 1·125,000	
Arizona	Alamo Crossing Area - Yuma County	S F Turner
	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 Irrigation District	
	Doney and Black Bill Parks Area, Coconino County	
	Mapping Scale 1:30,000	
	Publishing Scale 1·62,500	
	Navajo Country - Coconut-Navajo-Apache Counties	
	Mapping Scale 1.31680	
	Publishing Scale 1:125,000	
Arkansas	Reconnaissance of Little River County and parts of Sevier, Howard, Pike, Clark, Hot Springs, Ouachito Nevada, Hempstead and Miller Counties	Roger C Baker
	Scale 1 inch = 3 miles	
California	Antelope Valley - Kern and Los Angeles Counties	Arthur A Garrett
	Camp Pendleton - San Diego County	
	Scale 1 24000	
	San Bernadino and Chino Basins, San Bernadino County	
	Scale 1·31680	
	Napa Valley - Napa County	Joseph E Upson
	Sonoma Valley - Sonoma County	
	Santa Rosa and Petaluma Valleys	
	Mapping Scale 1 31680	
	Publishing Scale 1 62,500	
	Foothill and valley-flow area of Solano and southern Yolo Counties	
	Mapping Scale 1 24000	
Colorado	Eastern Huerfano County	S W Lohman
	Mapping Scale 3 inches = 1 mile	
	Publishing Scale 1 inch = 1 mile	
	South Platte Basin- Republican R Basin- no scale	
Connecticut	Hartford, Holland and Middlesex Counties	R V Cushman
Florida	Highlands and Indian River Counties Everglades and Southeastern Coast areas Some parts of Collier, Glades, and Hendry Counties	M D Hoy
	Manatee County	H. H Cooper
	Part of Hillsborough County	
Georgia	Coastal Plain area (Subsurface)	S M Herrick
	1 inch = 10 miles	
	Summer, Dooly, Pulaski, Lee, Crisp, and Wilcox Counties	- Chase
	½ inch = 1 mile	
Hawaii	Island of Kauai	Dan A Davis
	Scale 1 62500	
Idaho	Parts of Jefferson, Booneville, Bingham, Butte Counties (Lost and Little Lost River area)	R L Nace
	Scale 1 12000	
Indiana	Tippecanoe, Vermillion, Parke, Montgomery, Putman, Vigo, Clay, Owen, Sullivan, Green, Adams, Wayne, Fayette, Union, Franklin, Ripley, Ohio, Jefferson, Switzerland, Dearborn Counties	Gordon E Davis
	Scale ?	
Iowa	Marshall County - (subsurface) Webster and Cerro Gordo Counties (Surface and subsurface) Revision of bedrock contour map for the entire State	H Garland - Hershey
Kansas	Rawlins, Decatur, Marshall, Pratt and Kingman Counties, Parts of Wallace, Logan, Gove, Saline and McPherson Counties	V C. Fishel
	Mapping Scale 1 inch = 1 mile	
	Publishing Scale ½ inch = 1 mile	
	Osage County	
	Mapping Scale 2½ inches = 1 mile	

TABLE 2 (continued)

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

STATE	PROJECT	PROJECT CHIEF
	Publishing Scale ½ inch = 1 mile	
Kentucky	Kenton and Campbell Counties	M I Rorabaugh
	Mapping Scale 1 16000	
	1·12000	
	Johnson, Floyd, Allen, Christian and Henderson Counties	
	Mapping Scale 1 16000	
	Ballard, McCracken, Carlisle, Hickman, Graves, Fulton, Marshall and Callaway Counties	
	Published map 1 inch = 2 miles	
Maryland	Charles, St Marys', Calvert, Prince Georges, Anne Arundel, parts of Howard, Baltimore and Harford (all coastal plains)	R R Bennett
Michigan	Small areas in Gogebic, Houghton, Iron and Marquette Counties	W T Stuart
	Scale 1¼ inches = 1 mile	
	Bay, Midland, Gratiot, Saginaw, Genessee and Oakland Counties, Parts of Shiawassee and Tuscola Counties	John G Ferris
	Scale 1 inch = 6 miles	
Minnesota	Pennington County	R Schneider
	No scale given	
Montana	Lower Marios Valley, Montana	F. A. Swenson
	Pumping area (Missouri R)	
	Scale 4 inches = 1 mile	
	Helena, Townsend, and Gallatin Valleys	
	Scale 1 inch = 4000 feet	
	Dillon Valley, Crow Agency area, Yellowstone Valley (Miles City to Sidney)	
	Scale 1 inch = 1 mile	
	Buffalo Rapids (Yellowstone R)	
	Scale 1 inch = 400 feet	
Nebraska	Valentine Lakes Refuge and Ainsworth unit, Niobrara R basin	H A Waite
	Prairie Creek unit, lower Platte R basin	
	Loup-Platte divide area, lower Platte R. basin	
	North Platte Irrigation Project (Morrill Co.)	
New Jersey	Newark area - no scale	H C Barksdale
	Subsurface of Coastal Plains	
	Scale 1 inch = 8 miles	
	Bedrock contours - Greater Philadelphia and parts of Burlington, Camden, and Gloucester Cos	
	2 inches = 1 mile	
	Salem Co , Subsurface 1 inch = 1 mile	
New Mexico	Santa Fe County	C S Conover
	Scale 1.63360	
	Los Alamos area	
	Scale 1 63,360	
	Pueblo Laguna Indian Res (Velencia County)	
	Scale 1·126780	
	Part of Torrance County	
	Scale 1 63360	
	Roswell Basin	
	Scale 1 126780	
Nevada	Buena Vista Valley, Crescent Valley, Spring Valley, Dixie Valley, Antelope Valley, Smith Valley, Warm Springs Valley, Truckee Meadows areas	T W Robinson
	No scale indicated	
New York	Dutchess-Putman-Bronx, Westchester-Nassau Counties	M L Brashears
	Mapping Scale 1 62500	
	Publishing Scale 1 125000	
North Carolina	Catawba, Dredell, Davie, Rowan, Davidson Counties	H. E LeGrande
	Scale 1 inch = 2 miles (to be completed by June 1951)	
North Dakota	Mylo and Gronna Quadrangles	P. D Akin
	Mappings Scale 3 inches = 1 mile	
	Devils Lake Irrigation Project	
	Fairmont area - Streeter area	

TABLE 2 (continued)

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

STATE	PROJECT	PROJECT CHIEF
North Dakota	Scales 3 in = 1 mile, 1 in = 1 mile	
	Fort Berthold Indian Reservation, Wells and Foster Counties	G A LaRocque
	Sargent County	
	Scale 1 inch = 1 mile	
Ohio	Champaign, Madison, Franklin, Pickaway, Cuyahoga, Portage, Ross, Columbiana Cos	E J Schaefer
Oklahoma	Caddo, Choctaw, Beaver, Beckham Counties	Stuart L Schoff
	Mapping Scale 3.2 in = 1 mile	
	Publishing Scale 1 in = 1 mile	
	McCurtain County	
	Mapping Scales from 2 6 inches per mile to 3 2 inches per mile	
	Lake County and Walla Walla area	R C Newcomb
	Scale 1 125,000	
	Yonna - Swan Lake Valleys, Rouge River Valley, Tualatin Valley	
	Scale 1 62500	
South Carolina	Aiken and Barnwell Counties	George E Siple
	Mapping Scale 1 inch = 1 mile	
	Marlboro and Chesterfield Counties	
	Mapping Scale 1 inch = 1 mile	
	½ inch = 1 mile	
South Dakota	Oahe unit - James R Valley, James River Basin - Brown and Marshall Counties	G A LaRocque
Tennessee	Mississippi Basin Tertiary and Cretaceous outcrop areas, also Sumner, Macon, Jackson, Smith, Wilson, Davidson, Williamson, Rutherford, DeKolb, Cannon, Maury, Marshall, Bedford, Giles, Lincoln, Anderson and Bradley Counties	E M Cushing
	Mapping Scales - contour maps when available $\frac{1}{2400}$ & $\frac{1}{62500}$	
	Otherwise - aerial photographs $\frac{1}{2000}$	
Texas	Fort Bend, Galveston, Harris, Waller, Bandera, Bexar, Medina, Atascosa, parts of Uvalde, Frio and Zavala Counties	W L Broadhurst
	Tom Green County	
	Scale 1 inch = 1 mile	
	Also some parts of Galveston and Harris Counties on	
	Scale 1 inch = 1000	
	Part of Harris County 2 inch = 1 mile	
Utah	Southern Juab Valley	P F Fix
	(Problematic) - Milford District, Escalante Valley	
	Scale 1 inch = 1 mile	
Virginia	Coastal Plain Counties north of James River	A Sinnott
Washington	Part of King County east of Lake Washington	M J Mundorff
	Ahtanum Valley (Yakima County)	
	Scale 1 20000	
	Kitsap and Clark Counties	
	Tocoma area (Pierce County)	
	Spokane Valley (Spokane County)	
	Scale 1 62500	
	Yelm and (Thurston and Pierce Counties)	
	Scale 1 34600	
Wisconsin	Brown County	A H Harder
	Scale 1 inch = 2 miles	
	Langlade and Portage Counties	
	Scale 1 inch = 1 mile	
Wyoming	Goshen County - Wind River Basin	H M Babcock
	Fremont County	D A Morris
	Heart Mountain, Paintrock, Owl Creek, Kaycee, Riverton, Crowheart and Fremont areas	F A Swenson
	Scale 1 inch = 1 mile	

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 in 1950 were listed in Bulletin 28. Since the publication of this bulletin, additional county, or area, agricultural maps have been published; also new soil surveys have been started or are in process of completion. Table 4 lists the counties or areas in which soil surveys are in progress. Those areas are listed by states and where field work is in progress the the party chief and soil correlator has been included for ready reference purposes. The addresses of the soil correlators are given in Table 5 and it is suggested that these men should be consulted regarding additional details about the mapping in these areas.

County soil maps published since Bulletin 28 have been listed in Table 6 so that Bulletin 22, showing the status of mapping in 1948, can be brought up to date. Table 7 lists a number of soil areas which were not recorded in Bulletins 22 and 28. The field work for these areas has been completed but the preparation of the map and report for publication is in some stage of progress.

The committee suggests that engineers who may not be familiar with the classification system used in the preparation of these maps consult with the soil correlator designated in Table 5 for the area in question. In many instances he can indicate which soil map units 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 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 who are making engineering appraisals of terrain conditions from the study of aerial photographs. Often in areas which are not covered with published county agricultural soil maps a major part of the area has been mapped on an individual farm basis. Since these farm maps indicate the soil type and soil series they can be made an invaluable aid for furnishing factual ground information on soils thereby minimizing 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 type of parent material associated with the various soil series mapped in the area under study. The regional soil scientists for the various regions are listed in Table 8. The state soil scientists are listed in Table 9. It is suggested that these men be consulted for detailed information useful in making engineering appraisals of specific areas for highway purposes.

TABLE 3

TABULATION OF STATE GEOLOGISTS BY STATES

STATE	State Geologist and Address
Alabama	Dr Walter B Jones, State Geologist, Geological Survey of Alabama, University
Arizona	Dr T G Chapman, Director, Arizona Bureau of Mines, University of Arizona, Tucson
Arkansas	Mr 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, 100 Natural Resources Building, University of Illinois Campus, Urbana
Indiana	Dr. Charles F Deiss, Chairman and State Geologist, Division of Geology, Indiana Department of Conservation, Indiana University, Bloomington
Iowa	Dr H Garland Hershey, Director and State Geologist, Iowa Geological Survey, Iowa City
Kansas	Dr John C Frye, Executive Director, State Geological Survey, The University of Kansas, Lawrence
	Dr Raymond C Moore, State Geologist and Director of Research, State Geological Survey, The University of Kansas, Lawrence
Kentucky	Mr Daniel J Jones, State Geologist, Department of Geology, Kentucky Geological Survey, University of Kentucky, Lexington
Louisiana	Mr Leo W Hough, State Geologist, Louisiana Geological Survey, Department of Conservation, Geology Building, University Station, Baton Rouge 3
Maine	Dr Joseph M Trefethen, State Geologist, Maine Geological Survey, University of Maine, Orono
Maryland	Dr Joseph T Singewald, Jr , Director, Department of Geology, Mines and Water Resources, Board of Natural Resources, Baltimore 18
Michigan	Mr F G Pardee, State Geologist, Geological Survey Division, Department of Natural Resources, Lansing 13
Minnesota	Dr G M Schwartz, Director, Minnesota Geological Survey, University of Minnesota, Minneapolis 14
Mississippi	Dr W C Morse, Director, Mississippi Geological Survey, University
Missouri	Dr Edward L Clark, State Geologist, Division of Geological Survey and Water Resources, Department of Business and Administration, Buehler Building, Rolla
Nebraska	Dr G E Condra, State Geologist, Conservation and Survey Division, The University of Nebraska, Lincoln 8
Montana	Mr A E Adami, Acting Director, State Bureau of Mines and Geology, Butte
Nevada	Mr. Vernon E Scheid, Director, Bureau of Mines, Reno
New Hampshire	Mr T R Meyers, Geologist, New Hampshire State Planning and Development Commission, Conant Hall, University of New Hampshire, Durham
New Jersey	Mr Meredith E Johnson, State Geologist, Geologic and Topographic Survey, Department of Conservation and Economic Development, Room 415 State House Annex, Trenton 7
New Mexico	Dr Eugene Callaghan, Director, New Mexico Bureau of Mines and Mineral Resources, Socorro
New York	Dr John G Broughton, State Geologist, State Geological and Natural History Surveys, State Education Building, University of the State of New York, Albany 1
North Carolina	Dr Jasper L Stuckey, State Geologist, Division of Mineral Resources, Department of Conservation and Development, Raleigh
North Dakota	Dr Wilson M Laird, State Geologist, North Dakota Geological Survey, University of North Dakota, Grand Forks
Ohio	Mr John H Melvin, State Geologist, Geological Survey of Ohio, Orton Hall, Ohio State University, Columbus 10
Oklahoma	Mr Robert H Dott, Director, Oklahoma Geological Survey, Norman
Oregon	Mr. F W. Libbey, Director, State Department of Geology and Mineral Industries, 702 Woodlark Building, Portland 5
Pennsylvania	Mr S H. Cathcart, Director, Bureau of Topographic and Geologic Survey, Department of Internal Affairs, Harrisburg
Rhode Island	Dr Alonzo W Quinn, Chairman, Mineral Resources Committee, Rhode Island Port and Industrial Development Commission, Providence 3
South Carolina	Dr Lawrence L Smith, State Geologist, Department of Geology, Mineralogy and Geography, University of South Carolina, Columbia

TABLE 3 (continued)

TABULATION OF STATE GEOLOGISTS BY STATES

STATE	State Geologist and Address
South Dakota	Dr E P Rothrock, State Geologist, State Geological Survey, State University, Lock Drawer 351, Vermilion
Tennessee	Mr H W Ferguson, 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 SURVEYS IN PROGRESS IN PRESENT FISCAL YEAR (1951) OR FIELD WORK COMPLETED SINCE BULLETIN 28 WAS ISSUED

State	County or Soil Area	Party Chief	Soil Correlator
Alabama	DeKalb County[1]	G A Swenson	M J Edwards
	Marshall County[1]	G A Swenson	M J Edwards
California	Eastern Fresno[1]	G L Huntington[S]	R A Gardner
	Eastern Stanislaus[1]	R J. Arkley[S]	R A Gardner
	Glenn County[1]	E L. Begg[S]	R A Gardner
	Madera County[2]		
	Merced County[2]		
Colorado	Delta-Montrose Area[2]		
Connecticut	Hartford County[1]	A. E. Shearin	W H Lyford[b]
Florida	Escambia County[1]	J H Walker[S]	I L Martin
			A H Hasty
	Central and Southern Flood Control District (Kissimmee and Upper St Johns Valleys, all of Osceola and Indian River Counties and parts of Highland, Okeechobee, St Lucie, Polk Brevard, Orange, Volusia and Seminole Counties)[1,3]	R G. Leighty[b]	I L Martin
	Sarasota County	R W Wildermuth	I L Martin
			A H Hasty
Idaho	Canyon County[1]	M S Fosberg[S]	W J Leighty
Illinois	Lawrence County[1]	J. B Fehrenbacher[S]	W D Shrader
	Will County[1]	P T Veale[S]	W D Shrader
Indiana	Fayette County[1]	S D. Alfred[b]	O C. Rogers
Iowa	Jefferson County[1]	Geo M Schafer	W. D. Shrader
	Monona County[1]	Everett White[S]	W D Shrader
	Polk County[1]	J E McClelland[b]	W D Shrader
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[1] (All of Scandia Unit)	C H Atkinson[b]	W. M. Johnson
Louisiana	St Mary Parish[1]	S A Lytle[b]	I. L Martin
			A H Hasty
Michigan	Arenac County[1,3]	Wm H Colburn[S]	I J Nygard
	Gogebic County[2,3]		
	Keweenan County[1,3]	Wm H Colburn[S]	I J Nygard
	Mackinac County[2,3]		
	Sanilac County[1]	I F Schneider[S]	O C Rogers
Minnesota	Isanti County[1]	R S. Farnham[b]	I J Nygard
	Mower County[2]		
Mississippi	Bolivar County[1]	G E Rogers[S]	I L Martin
			A H Hasty
	SeSoto County[1]	E J McNutt[S]	I L Martin
	Sunflower County[1]	J C Powell[S]	I L Martin
			A H Hasty
Missouri	Boone County[2]		
	Moniteau County[1]	J A Frieze[S]	I L Martin
Montana	Bitterroot Valley Area[1]	W C. Bourne[b]	B H Williams
	Roosevelt County (Part of Missouri-Souris Irrigation Project)[1]	A J Cline	B H Williams
	Yellowstone County[1]	W C Bourne[b]	B H Williams
Nebraska	Buffalo County (part of) (part of Wood River Irrigation Project)[1]	John A Elder[b]	B H Williams
	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[1]	T E Beesley	B H Williams
New Hampshire	Rockingham County[4]		W H Lyford[b]
New York	Franklin County[1]	F J Carlisle[b]	W H Lyford
			M G Cline
	Lewis County[1]	C S Pearson[S]	M. G Cline[b]

TABLE 4 (continued)

SOIL SURVEYS IN PROGRESS IN PRESENT FISCAL YEAR (1951) OR FIELD WORK COMPLETED SINCE BULLETIN 28 WAS ISSUED

State	County or Soil Area	Party Chief	Soil Correlator
North Carolina	Duplin County[1]	E F Goldston[S]	A H Hasty
North Dakota	Lake Souris area (McHenry and Bottineau Counties)[1]	B L Matzek	C A. Mogen
	Renville County (Part of Missouri-Souris project)[4]		C A Mogen
Ohio	Fairfield County[1]	J. H. Petro[b]	O C Rogers
Oklahoma	Pawnee County[1]	H M. Galloway[b]	H Oakes
Oregon	Douglas County[2]		
	Prineville Area[1]	Geo K Smith	W J Leighty
Pennsylvania	Potter County[1]	K. V Goodman	W H Lyford
South Dakota	Brookings County[1]	A. H 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
	Bradley County[2]		
	Franklin County[2]		
	Lawrence County[1]	J. R Overton[S]	M J Edwards
	Maury County[1]	A B Harmon[S]	M J Edwards
Texas	Brazos County[2]		
	Lynn County[1]	I. C Mowery	E H. Templin
Utah	Beryl - Enterprise area[1] (Part of Iron County)	R Ulrich	W G Harper
	Weber area (parts of Weber, Davis, Morgan, Summit, and Boxelder Counties)[1]	V K Hugie	W G Harper
Virginia	Loudoun County[2]		
	Norfolk County[1]	E H. Henry[S]	W S Ligon M J Edwards
	Nottoway County[1]	C S Coleman	W S Ligon M J Edwards
Washington	Mason County[2]		
	Skagit County[2]		
	Walla Walla County[1]	A O Ness	W J Leighty
Wisconsin	Dodge County[1]	G. B Lee[b]	I J Nygard
	Grant County[2]		
Wyoming	Goshen County[1]	C J Fox	W M Johnson J Thorp

1 Soil survey assignments for summer of 1951
2 Soil survey areas with field work completed since Bulletin 28 was issued
3 These are reconnaissance or reconnaisance-detailed surveys
4 No personnel assigned to area in summer 1951
* See Table 3 for address of soil correlator
b State and bureau
S State

TABLE 5

SOIL CORRELATORS - DIVISION OF SOIL SURVEY

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

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

Guy D Smith, Principal Soil Correlator, Northern States, USDA Bureau of Plant Industry, Beltsville, Maryland
O C Rogers, Senior Soil Correlator, East Midwestern States, USDA Bureau of Plant Industry, Beltsville, Maryland
Iver J Nygard, Senior Soil Correlator, Northern Lake States, Div of Soils, Agricultural Experiment Station, University Farm, St Paul 1, Minnesota
W. D Schrader, Soil Correlator, West-Midwestern States, Department of Soils, University of Missouri, Columbia, Missouri
M G Cline, Agent (correlation) New York, Department of Agronomy, Cornell University, Ithaca, New York
W. H. Lyford, Agent (correlation), Northeastern States, Department of Agronomy, College of Agriculture, Durham, New Hampshire

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

W S Ligon, Principal Soil Correlator, Southern States, 508 New Sprankle Building, c/o TVA Knoxville, Tennessee
I. L. Martin, Senior Soil Correlator, (same address as listed above)
M J Edwards, Senior Soil Correlator, (same address as listed above)
A. H Hasty, Soil Correlator, (same address as listed above)
S S Obenshain, Agent (correlation), Virginia Department of Agronomy, Virginia Agricultural Experiment Station, Blacksburg, Virginia

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

James Thorp, Principal Soil Correlator, Great Plains States, 204 Nebraska Hall, University of Nebraska, Lincoln 8, Nebraska
B H Williams, Senior Soil Correlator, Northern Great Plain States, (same address as listed above)
C A. Mogen, Soil Correlator, Northern Great Plains States, (same address as listed above)
W. M Johnson, Soil Correlator, Northern Great Plains States, (same address as listed above)
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 6

SOIL SURVEYS PUBLISHED SINCE HIGHWAY RESEARCH BOARD BULLETIN 28 WAS ISSUED IN 1950

Arizona	Duncan Area	Michigan	Newaygo County
California	Stockton Atea	Nebraska	Otoe County
Idaho	Idaho Falls Area	New Mexico (See Arizona)	Duncan Area
Indiana	Franklin County	Oklahoma	Woods County
	Morgan County		
Kentucky	Marshall County	Washington	Clallam County

TABLE 7

SOIL SURVEYS NOT RECORDED IN EITHER BULLETIN 22 OR BULLETIN 28

Except where indicated otherwise, these are unpublished detailed surveys with rating of 1 Field work is completed, but the map and report are in some stage of progress, preparatory for publication

Arizona	Yavapai Area
California	Coalinga Area
	Colusa County
	Imperial East Mesa
Colorado	Akron Area - published
Florida	Collier County
	Manatee County
Idaho	Emmett Valley Area
Indiana	Carroll County
	Tippecanoe County
Iowa	Allamakee County
Minnesota	Faribault County
	LeSueur County
	McLeod County
	Nicollett County
Missouri	Daviess County
	Jasper County
	Livingston County
	St Charles County
Montana	Upper Flathead Area
North Carolina	Avery County
	Graham County
	Swain County - published.
	Watauga County
Ohio	Huron County
Oklahoma	Logan County
Oregon	Umatilla Area - published.
Pennsylvania	Clinton County - Reconnaissance - To be published by State
	Columbia County - Reconnaissance - To be published by State
	Fayette County (Rating of 2)
	Fulton County - Reconnaissance - Published by State
	Juniata County - Reconnaissance - To be published by State
	Lebanon County - Reconnaissance - To be published by State
	Northumberland and Montour Counties
	Mifflin County - Reconnaissance - Published by State
	Perry County - Reconnaissance - To be published by State
	Snyder County - Reconnaissance - To be published by State
South Dakota	Angostura Project
Tennessee	Cocke County
	Greene County
	Johnson County
	McMinn County
	Sevier County
	Washington County
Texas	Cherokee County
	McLennon County
Utah	East Millard Area
	Provo-Goshen Area
	Richfield Area
	Roosevelt-Duchesne Area
Virginia	Fluvanna County
	Mecklenburg County
Washington	Skamania County
	Thurston County
Wisconsin	Barron County
	Bayfield County - Semi-detailed
Wyoming	Campbell County

TABLE 8

TABULATION OF REGIONAL SOIL SCIENTISTS BY STATES AND REGIONS

REGION	STATES WITHIN REGION
1. Northeastern Region H. R. Adams 6816 Market Street Upper Darby, Pennsylvania	Maine, New Hampshire, Vermont, Massachusetts, Connecticut, Rhode Island, New York, Pennsy-lvania, New Jersey, Maryland, Delaware, West Virginia
2. Southeastern Region G. L. Fuller P. O. Box 612, Lee and Church Streets Spartanburg, South Carolina	Virginia, North Carolina, South Carolina, Georgia, Florida, Alabama, Mississippi, Tennessee, Kentucky, Puerto Rico
3. Upper Mississippi Region A. H. Paschall 434 N. Plankinton Avenue Milwaukee 3, Wisconsin	Ohio, Indiana, Illinois, Missouri, Iowa, Minnesota, Wisconsin, Michigan
4. Western Gulf Region R. M. Marshall (P. O. Box 1898) 3600 McCart Street Fort Worth 1, Texas	Texas, Oklahoma, Arkansas, Louisiana
5. Northern Great Plains Region R. O. Lewis (P. O. Box 713) Post Office Building Lincoln 1, Nebraska	Montana, Wyoming, North Dakota, South Dakota, Nebraska, Kansas
6. Southwestern Region M. R. Isaacson (P. O. Box 1348), 222 East Central Avenue Albuquerque, New Mexico	Arizona, New Mexico, Colorado, Utah
7. Pacific Region S. W. Cosby 209 S.W. Fifth Street Portland 4, Oregon	Washington, Oregon, Idaho, Nevada, California, Alaska, Hawaii

TABLE 9
TABULATION OF SOIL CONSERVATIONIST AND SOIL SCIENTIST BY STATES

State	State Conservationist	SCS State Office	State Soil Scientist	Headquarters
Alabama	Olin C Medlock	New Ext Service Annex, Ala Polytechnic Inst., Auburn	Miles E. Stephens	Land Use Bldg , Ala Polytechnic Inst , Auburn, Ala
Arizona	Allen F. Kinnison	Goodrich Bldg , 14 North Central Ave , Phoenix, Ariz	Roger D Headley	101 Agriculture Bldg , Univ. of Arizona, Tucson, Ariz
Arkansas	Hollis R Williams	Old P O. Bldg , 2nd and Center Sts., Little Rock	Marvin Lawson	Agr Exp. Sta , Univ of Arkansas, Fayetteville, Ark
California	John S Barnes	Post Office Building Berkeley, Calif	Leonard R Wohletz	15 Shattuck Square, Addison Bldg , Berkeley, Calif
Colorado	Kenneth W. Chalmere	223 S College Ave. Fort Collins, Colo.	E Milton Payne	202 Agronomy Bldg , Colo Agr. Exp Sta , Fort Collins, Colo
Connecticut	N Paul Tedrow	Agric Engineering Bldg , Univ of Conn , Storrs	G A Quakenbush	N J Agr Exp Sta., New Brunswick, N. J
Delaware	Richard S Snyder	66 E Main St Newark, Delaware	M. F Hershberger	Md Agr Exp Sta , College Park, Md
Florida	Colin D. Gunn	Smith Bldg., 129 South Pleasant St., Gainesville	O C Lewis	Smith Bldg , 129 South Pleasant St , Gainesville
Georgia	J G Liddell	Old Post Office Bldg , Athens, Georgia	Frank T. Ritchie, Jr	Old Post Office Bldg , Athens, Georgia
Idaho	Robert N Irving	Yates Bldg , 9th and Main Sts , Boise, Idaho	C. F Parrott	106 Morrill Hall, Univ of Idaho, Moscow, Idaho
Illinois	Bruce B. Clark	Nogle Bldg , 605 S Neil St., Champaign, Illinois	A A Klingebiel	206 Davenport Hall, Univ of Illinois, Urbana, Illinois
Indiana	Kenneth Welton	Lafayette Loan & Trust Bldg , 4th & Main Sts., Lafayette	T C Bass	Lafayette Loan & Trust Bldg , 4th & Main Sts., Lafayette
Iowa	Frank H Mendell	208-212 Fifth Street Ames, Iowa	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, Kansas	Claude L Fly	Agricultural Exp Station Manhattan, Kansas
Kentucky	Hubbard K. Gayle	Dudley School Bldg., Lexington, Kentucky	W W. Carpenter	Dudley School Bldg , Lexington, Kentucky
Louisiana	Harold B Martin	Postal Annex Alexandria, Louisiana	D. L. Fontenot	Postal Annex Alexandria, Louisiana
Maine	William B. Oliver	Maples Hall, Univ of Maine, Orono, Maine	J Stewart Hardesty	Maples Hall, Univ of Maine, Orono, Maine
Maryland	Edward M Davis	Agric Bldg , Univ of Md , College Park, Md.	M F Hershberger	Md Agric Exp Station, College Park, Md
Massachusetts	Arthur B. Beaumont	Stockbridge Hall, Mass. State College, Amherst, Mass.	Montague Howard, Jr.	Agr Exp Station, Univ of Vermont, Burlington, Vermont
Michigan	Everett C. Sackrider	Agricultural Bldg , Mich State College, East Lansing	C. A Engberg	Michigan State College of Agriculture, East Lansing
Minnesota	Herbert A. Flueck	Federal Courts Bldg , 6th & Market Sts , St. Paul	Alex S Robertson	Agric. Exp Sta , University Farm, St Paul 8, Minn
Mississippi	Charles B Anders	Masonic Temple Bldg , 1130 W Capitol St , Jackson	D T Webb	Masonic Temple Bldg , 1130 W Capitol St., Jackson
Missouri	Kenyon G. Harman	Post Office Bldg., 6th & Cherry Sts , Columbia	Harold E Grogger	Post Office Bldg , 6th & Cherry Sts., Columbia
Montana	Truman C. Anderson	Gallatin Block Building Bozeman, Montana	Dave R Cawlfield	Montana Agric Exp Station Bozeman, Montana
Nebraska	Emrys G Jones	Rudge & Guenzel Bldg , 13th & N Sts , Lincoln	Lloyd E. Mitchell	Conser & Survey Section, Univ of Nebr , Lincoln, Nebr
Nevada	George Hardman	Morrill Hall, Univ of Nevada, Reno, Nevada	E A Naphan	Morrill Hall, Univ of Nevada, Reno, Nevada

TABLE 9 (continued)

TABULATION OF SOIL CONSERVATIONIST AND SOIL SCIENTIST BY STATES

State	State Conservationist	SCS State Office	State Soil Scientist	Headquarters
New Hampshire	Allen J Collins	29 Main Street Durham, New Hampshire	J Stewart Hardesty	The Maples Bldg , Univ of Maine, Orono, Maine
New Jersey	Linwood L Lee	Post Office Bldg , 86 Bayard St , New Brunswick, N J	G A Quakenbush	New Jersey Agric Exp Sta , New Brunswick, N J
New Mexico	Robert A Young	Metropolitan Bldg , 103-½ W Central Ave , Albuquerque	H J Maker	New Mexico Agr Exp Sta , State College, New Mexico
New York	Irving B Stafford	Sprague Block Bldg , 147-151 E State St , Ithaca	Arnold J Baur	Caldwell Hall, Cornell Univ , Ithaca, N Y
North Carolina	Earl B Garrett	1911 Dormitory, State College, Raleigh, N C	W W Stevens	1911 Dormitory, State College, Raleigh, N C
North Dakota	Lyness G Lloyd	P O Bldg , Broadway & 3rd Sts , Bismarck, N Dak	Lloyd Shoesmith	N Dak Agric Exp Station, Fargo, North Dakota
Ohio	Thomas C Kennard	81 N 3rd Street Columbus, Ohio	H H Morse	81 N 3rd Street Columbus, Ohio
Oklahoma	Harry M Chambers	2800 S Eastern Ave Oklahoma City, Okla	Louis E Derr	Agronomy Dept , Okla A & M College, Stillwater, Okla
Oregon	Samuel L Sloan	Benton Hotel Bldg , Corvallis, Oregon	William W Hill	Agr Exp Sta , Oregon State College, Corvallis, Oregon
Pennsylvania	Ivan McKeever	Dauphin Bldg , 203 Market St , Harrisburg, Pa	F G Loughry	Agriculture Bldg , Penna State College, State College, Pa
Rhode Island	L Russell Albright	Washburn Hall, R I State College, Kingston, R I	Montague Howard, Jr	Agr Exp Sta , Univ of Vt , Burlington, Vermont
South Carolina	Ernest Carnes	Fed Land Bank Bldg , 1401 Hampton St , Columbia, S C	P H Montgomery	Fed Land Bank Bldg , 1401 Hampton St , Columbia, S C
Tennessee	William M Hardy	1123 Church Street Nashville, Tennessee	Nathan I Brown	1123 Church Street Nashville, Tennessee
South Dakota	Ross D Davies	P O Bldg , 410 Dakota St , Huron, South Dakota	Glenn A Avery	Agronomy Dept , College Sta , Brookings, S Dak
Texas	Paul H Walser	114-118 S 3rd Street Temple, Texas	James D Simpson	Texas Agr Exp Station, College Station, Texas
Utah	Josiah A Libby	Atlas Bldg , 36-½ West Second South, Salt Lake City	D F Trussell	Utah Agr Exp Station, Logan, Utah
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Virginia	Sam W Bondurant	Eheart Bldg , Main Street Blacksburg, Virginia	R E Devereux	Eheart Bldg , Main Street Blacksburg, Virginia
Washington	Paul C McGrew	College Station Pullman, Washington	Ray W Chapin	Box 508, Agr Exp Sta , Pullman, Washington
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HOW TO CALCULATE A CALCULATED RISK

An Engineering Appraisal of Limestone Landforms

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Construction jobs are not often considered in terms of areas and the particular problems related to them. When a construction project, such as a highway or airport or a dam and reservoir, extends for some distance, an area concept is particularly valuable as a money and time-saving factor. Beyond the consideration of turning in a good job, the understanding of what a landform is, what it means, and how it affects a job goes a long way in saving unnecessary expense.

How does it do this? Simply by directing your efforts in an intelligent way. If you know the characteristics of a landform, then you know when to be careful and when the risks are small. In other words, it is easier to judge the type and degree of risk, or even better, how to calculate a calculated risk. This is especially true in subsurface exploration and in job estimations for excavation.

Landforms are land units in which the geology, soils, and topography are generally the same. Some are simple, others are complex; some are large and some small. In many places, a highway will cross one or more landforms in the course of a mile. Landforms are not only topographic units, but they are units containing definite soil associations (several soils that are distinctly associated and somewhat similar in some respects). This does not say that the topography within a land form is identical, nor is the soil exactly the same at each point within these unit areas. See "The Engineering Significance of Landforms," Highway Research Board Bulletin No. 13, 1948. With these oft-repeated conditions within the landform of topography, soil material, and drainage come the repetition of conditions that affect design, construction, and maintenance of structures and pavements. Much of this influence is felt in surface and near-surface construction and deals mainly with soil problems. But in rock problems, the landforms are equally useful as units in which problems will be repeated or uncertainties acknowledged. In this respect, it is as important to know what you do not know as to be sure of your knowledge.

The limestone landform is a potent illustration of one of these rock landforms. Because it is so full of uncertainties, many expensive errors have been made and a review is in order.

Because topography is an important factor in the description of landforms, they are classified into two divisions, Level Terrain and Hilly Terrain.

Limestone is a common rock. It is formed in deep and extensive deposits, and as a result, large areas are scattered throughout the United States and elsewhere. Limestones are also formed in thin layers along with shales and sandstone, but under these circumstances the effect of the limestone is diluted by the presence of strata of other rocks.

The most important distinguishing characteristic of this rock is that of solubility. The fact that it dissolves quite readily in rainwater is the predominant force in creating both the topography of the limestone landform and the engineering problems.

Terrain - The surface of the limestone landform differs from all others. Usually, it is gently rolling and dotted with sinkholes or depressions as illustrated in Figure 1. The topography is seldom cut up by streams, since most of the water falling on the surface drains downward through the rock. This unusual factor makes each depression more or less independent of others nearby, so there is little gullying or

LEVEL TERRAIN

Landform	What	Where
1. Alluvium	Flood plains of streams and rivers rivers (Sands, silts and clays)	Everywhere.
2. Terraces	Elevated benches above floor stage (coarse texture)	Near mountains and all northern states.
a. River		
b. Lake or Ocean		
3. Filled Valley (Coarse alluvium)	Waterlaid by perennial streams and sheet flow	Western states.
4. Coastal Plain	Marine sediments near coast. (Sands and clays)	Especially Atlantic and Gulf Coast areas.
5. Continental Alluvium	Outwash from remote mountain areas.	Colorado to Texas.
6. Glacial Outwash	Gravelly plains in glaciated regions.	North of the Ohio and Missouri Rivers.
7. Tidal Flats	Clays to sands in pockets along the coast, exposed by tidal changes.	All coastal areas.
8. Beach Lines	Very low sand ridges along some coastlines.	Intermittently along coastlines.
9. Alluvial Fans	Fan-shaped deposits of coarse material.	Transition between steep and flat slopes
10. Deltas	Level lowlands	River mouths.
11. Lakebeds	Fine soils deposited in lake bottoms.	In glaciated areas and in mountain basins.
12. Till Plains	Undulating clay mantle over drift	Midwestern states.
13. Marsh and Swamp	Lowlands at or near ground water table.	Everywhere
14. Basalt	Lava	Colorado, Washington and Oregon.
15. Sandstone	Flat-lying beds.	Eastcentral and southwestern states.

HILLY TERRAIN

Landform	What	Where
1. Dunes	Sand (wind-blown)	Widely distributed.
2. Loess	Silt (wind-blown)	Central states; Idaho and Washington.
3. Eskers	Glacial gravels and sands in ridges.	Northern states.
4. Kames	Glacial gravels and sands in ridges.	Northern states.
5. Drumlins	Glacial drift; cigar-shaped ridges.	Northern States.
6. Moraines	Glacial drift, jumbled hills.	Northern states.
7. Lava	Porous lava with flow marks.	Western states.
8. Basalt	Viscous lava, forms tableland and mesas.	Western states.
9. Dikes	Dense lava ridges.	Western states.
10. Cones	Largely cinders and lava.	Western states.
11. Tuff	Volcanic ash.	
12. Limestone	Pitted terrain.	Kentucky, Missouri, Pennsylvania
a. Horizontal	Stratified sedimentary rock	
b. Tilted	Ridges	
13. Sandstone	Massive hills	Pennsylvania and western states.

HILLY TERRAIN (continued)

Landform	What	Where
14. Shale	Low rounded hills.	Pennsylvania and western states.
15. Mixed Sedimentaries		
a. Horizontal	Contour outlines as hillsides	
b. Tilted	Ridges.	
16. Gneiss	Metamorphic hills.	Southeastern and western states.
17. Schist	Metamorphic hills.	Southeastern and western states.
18. Slate	Metamorphic hills.	Southeastern and western states
19. Serpentine	Small areas of soft rock.	Southeastern and western states.

stream action as in other rock landforms.

The variation in limestone landforms are related to topographic position, (thickness sequence of the various rock strata), to type of climate, and to stage of development in the erosion cycle. The effect of these factors must be considered in the study of airphoto soil patterns for the identification of limestone landforms.

When limestone and associated rocks occur in relatively horizontal bedding and occur at or near the surface, a limestone plain with little or no surface drainage is likely to develop. The stage of sinkhole development will depend upon the climate, thickness of rock strata, and length of exposure of the limestone to weathering. Figure 1 illustrates a limestone plain in a humid-temperate climate. Figure 2 illustrates the effect of a shale strata overlying the limestone bed on the development of the landform. Where the erosion has removed the protecting shale layer, the sinkhole and associated underground drainage has developed; where the shale layer has not been removed, the underground drainage has not developed; and the airphoto soil pattern reflects the characteristics of the shale. Figure 3 shows the contrast in topography of the limestone and shale landforms.

Sinkholes are an outstanding feature of limestone landforms. They may vary in size, depth, spacing, and elevation, as shown in Figure 4. When sinkholes are widely spaced the sinkholes are deep and the limestone thick. Figure 1 illustrates the pock-marked appearance of limestone terrain as seen from the air. The sinkholes will vary from a few feet up to several hundred yards in diameter. A study of them in any limestone region will show a few to contain water. Those holes containing water are the result of the washing of reddish clay soil into the sinkholes and the occasional plugging of local subterranian channels. In the airphoto, those containing water can be distinguished from the dry ones by the distinct regular line developed where the water makes a contour in the depression. Depending upon the angle of the sun, and its reflection into the aerial camera, some may appear as dark spots and others as light areas.

When the limestone occurs in a tilted position the development of the surface and underground drainage usually will reflect the geologic structure. The typical sinkhole pattern of the limestone plain usually will be modified to the extent that elongated sinks and solution valleys occur over the limestone outcrop, as illustrated in Figure 5. The development of surface drainage will be associated with the noncalcareous rocks.

The type of climate past and present, the time the geologic and soil forming processes have acted, and the age of the parent material are important factors to be considered in the identification and comparison of limestone landforms on a regional basis. In semi-arid climate the solution action is not as great as is found in the humid-temperate climate for the same degree

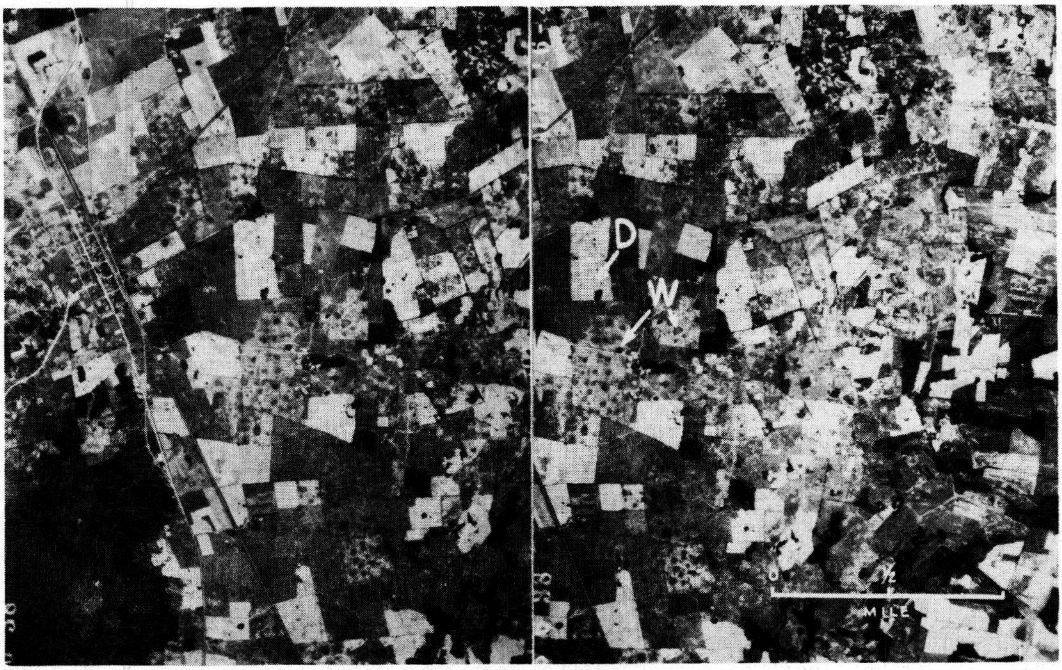

Figure 1. This limestone plain is dotted with many sinkholes. The terrain is gently rolling to rough, depending on the number and depth of the sinks. The sinkhole (D) is dry and is connected to the subterranean channels below. Those marked (W) are filled with water to form temporary ponds.

of exposure to the climatic factor. Figure 6 illustrates the airphoto soil pattern developed on tilted limestone in semi-arid climate. Figure 7 illustrates the rugged topography developed under tropical climate where more intense weathering has resulted in a rather complete collapse of the subterranian caverns in an advanced stage of the limestone-erosion cycle. Thus, in making appraisals of limestone areas it is important to consider the influence of many factors; however, the development and type of drainage is one of the most important factors for the identification of limestone landforms.

Drainage - Drainage is primarily underground. The absence of any surface drainage, except large streams or rivers, is another unusual feature common in the limestone landform. For this reason, highways and railroads are committed to tunnels and deep cuts rather than "climbing" by following stream valleys. When the underground-drainage system is inadequate, surface flow occurs during brief periods. This inverted drainage may come as a flushing of sinkholes, as at Belleville, Ohio, or as in some sections, "lost rivers" again flow until the subsurface capacity is again adequate.

The few valleys that do exist are like trenches in cross-section (Fig. 8). The shear rock walls that form the valley sides are typical of portions of the Mississippi, Tennessee, and Kentucky rivers where they flow through limestone landforms. These vertical-sided valleys are explained as being remnants of underground rivers exposed by the collapse of the cavern roof. Since this is the process that produces the sinkholes, it is reasonable to assume it to be accurate. In this way the entire limestone landform decays or is dissolved.

Because of this unusual type of drainage, culverts, as such, and bridges are less important items than in most other landforms. However, the special treatment of sinkholes, whenever they are crossed, counteracts the saving in surface-water

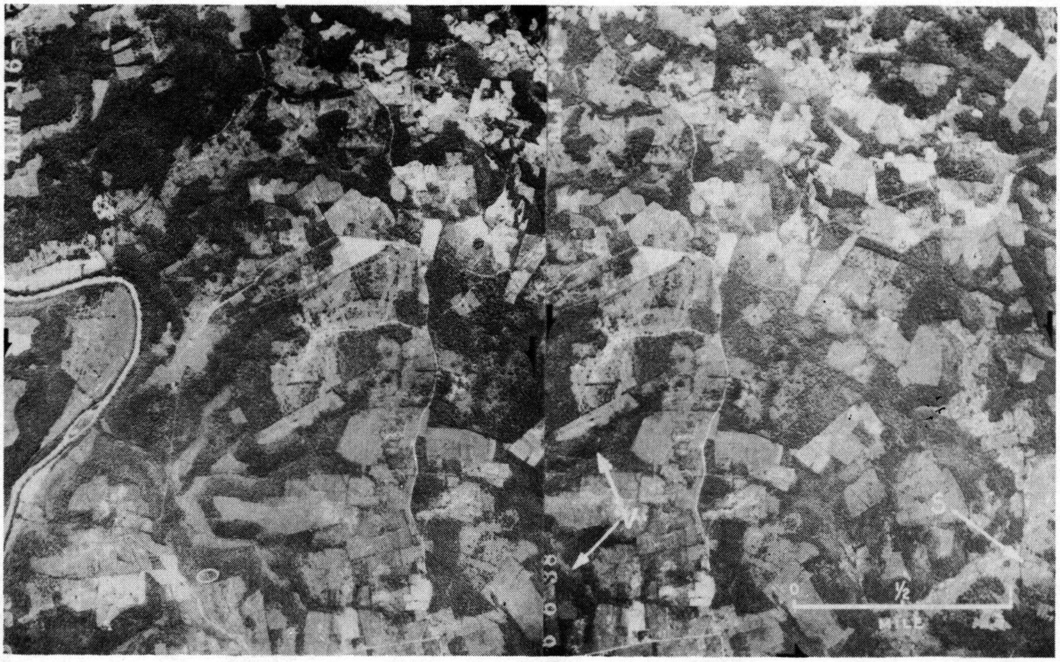

Figure 2. This view shows many features of a typical limestone area. In the upper portion a valley (without stream) has been formed by the complete collapse of a cavern system. It is worth spending extra time on this complex example to follow the process of analysis. The lower portion of the photo shows no sinks and a considerable amount of surface drainage. This indicates an impervious material (shale) rather than limestone at the surface. Since there is no sign of tilting of the rock, the deeply pitted valley at the top implies that the same limestone underlies the entire area. This is confirmed by: 1) steepsided "limestone" valleys (V) cut through the shale and take on the features of the underlying rock; 2) sinks (beyond stereo-coverage) in fields at far right (S) and included in the bend of the river at left. The shale cap will eventually erode away and expose the limestone.

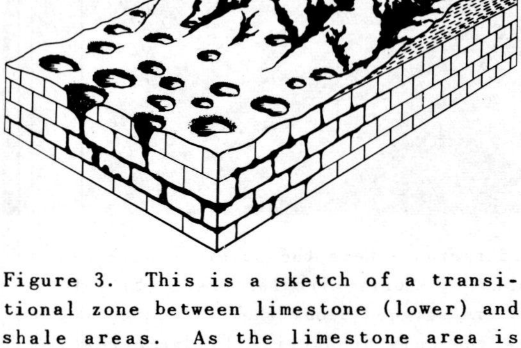

Figure 3. This is a sketch of a transitional zone between limestone (lower) and shale areas. As the limestone area is approached, there are more sinkholes and fewer streams and gullies.

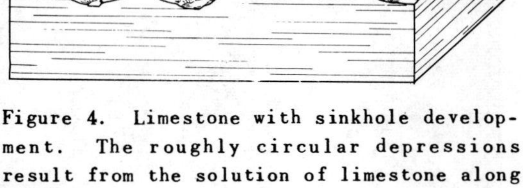

Figure 4. Limestone with sinkhole development. The roughly circular depressions result from the solution of limestone along cracks and fissures which are enlarged by percolating groundwater. They are often drained by subterranean streams but these are sometimes plugged and temporary ponds result. In tilted limestones, these depressions are interconnected and form long, shallow valleys along bedding planes.

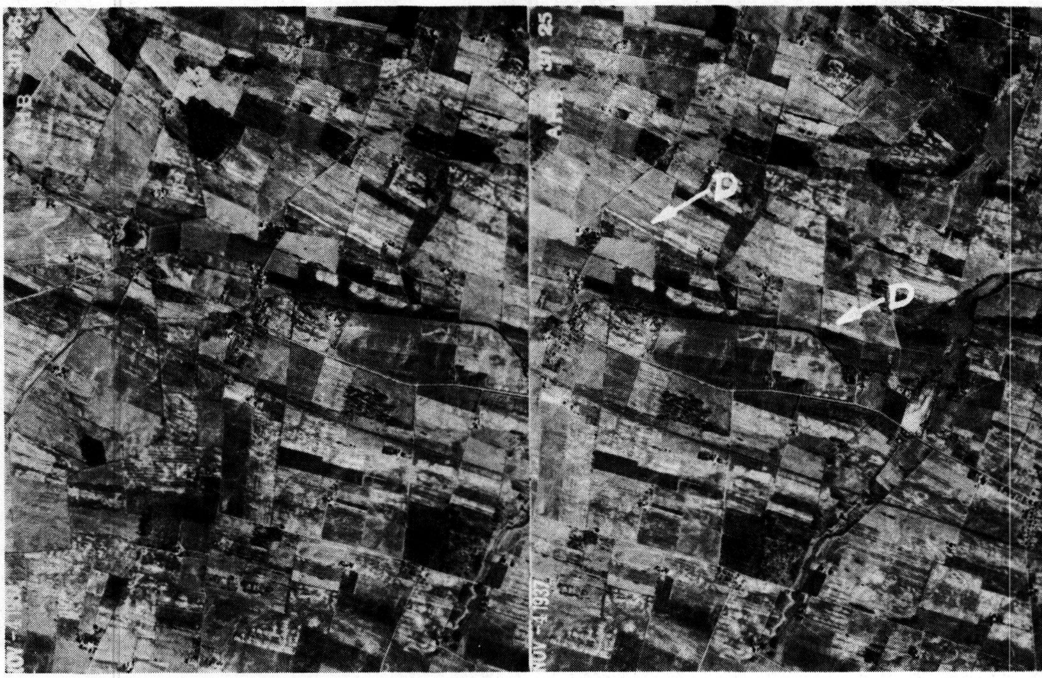

Figure 5. This is an area of tilted limestone. The streaks across the photos (D) are the result of solution along the bedding planes of the tilted limestones. There are no sinkholes here but, instead, these elongated solution valleys and a marked absence of surface drainage indicate a limestone bedrock.

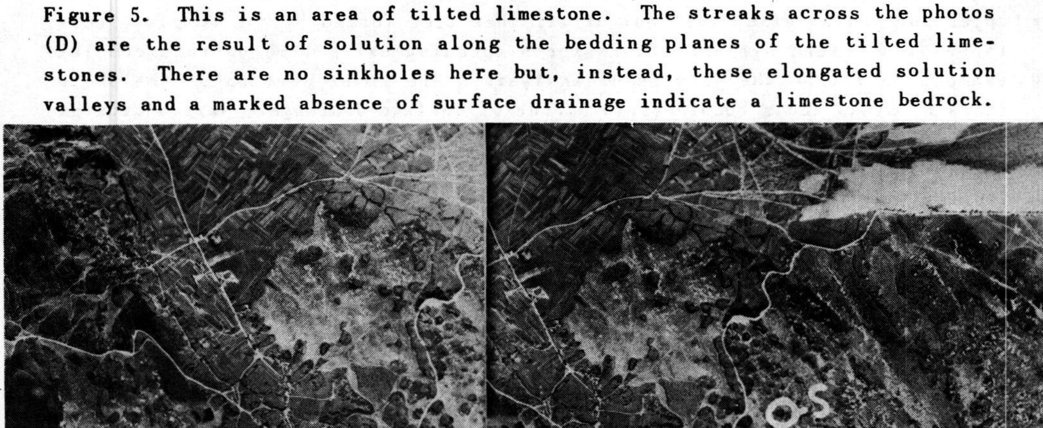

Figure 6. Tilted limestone in a semi-arid region. Here the solution work had not progressed enough to connect the sinkholes - dark circular areas (S) - to form elongated channels. The depressions are aligned along the tilted bedding planes. In this area, the sinkholes are the only productive land, whereas, in humid climates they are usually the only non-productive lands. Cultivation is possible in these sinks because soil and water have accumulated in them.

Figure 7. This area in Puerto Rico is typical of tropical limestone. These photos show the steep-sided hills, the flat-bottomed, vertical-walled valleys, and in particular, several levels of erosion which indicate the variable resistance of limestone beds. The uniform tone throughout the area is the result of vegetative cover. A dense growth of sugar cane covers the level land.

culverts. The small number of bridges required is also offset by the fact that the few bridges needed are large and expensive. For this reason, some sections of Kentucky have remained virtually cut off from modern motor traffic.

The underground, and therefore unseen, drainage system is the basis of most of the engineering problems in these limestone regions. Leakage around and under dams follows these subterranean-stream courses and solution crevices (Fig. 8). The intricacy of these channels and crevices introduces one of the greatest uncertainties in subsurface work. Also, they promote the quick reaction of ground-water flow to rainfall and eliminate the valuable filtering capacity associated with most landforms. Thus, ground-water in these areas is often polluted and the source of pollutionis difficult to detect.

ENGINEERING PROBLEMS IN LIMESTONE LANDFORMS

The Soil - Limestone soils range from silty clays to fat clays and vary in color from yellow to deep red. In a few places they are known to be black, but this is rare in the United States. Although fine textures, the soil is well drained because the porous limestone beneath permits the water to filter through the soil without "backing up" and saturating the clay. For the same reason, the soil is unusually pervious. It is not tight, as most clays are. It absorbs the water quickly with little runoff because of the highly developed soil structure. This structure can be seen by examining cut faces and breaking out the ¼ to ½ in. soil aggregates that form as cubes. The cubes fit loosely together so that between them there is ample space for water to percolate through the soil column. The red color of the soil profile shows that air circulates freely and oxidation has been thoroughly carried out. When engineering projects are carried out using this soil, the working and compacting destroys these natural drainage channels and the reworked soil is converted to a typical impervious plastic clay.

Beneath the soil mantle, which ranges from 2 to 30 ft. in depth, lies the bedrock surface. Ordinarily, there is some correlation between surface and bedrock conformation. But in limestone, as in some

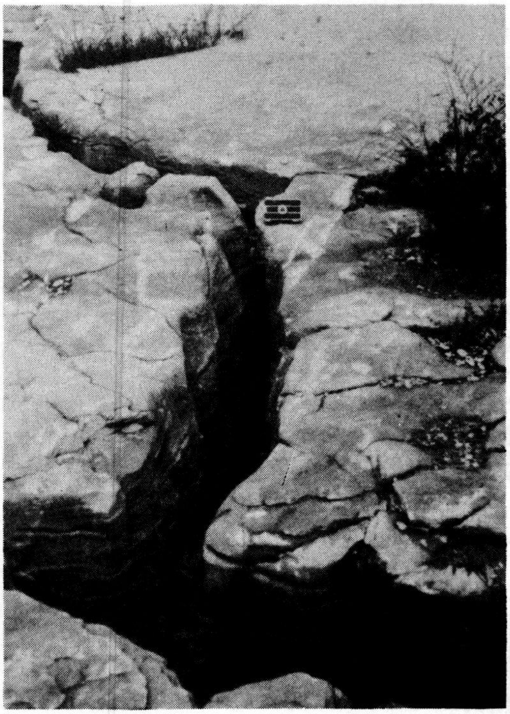

Figure 8. The crevice shown above is typical of the enlargement of joints in limestone. Solution work is active along these joints; they are enlarged and become, in time, the basis for the angular drainage system found in limestone areas. In miniature, the features shown are those of many valleys in limestone.

granites, the depth to rock is extremely variable. Unlike other residual soils, the transition from the clay soil to rock is abrupt. The most important characteristic of all is the highly irregular rock surface (Figs. 9, 10, 11) which in a few feet horizontally, will vary as much as 25 ft. below the surface. These irregularities make the results of borings highly unreliable and estimates of earth-rock quantities undependable. These are the relatively minor irregularities and do not include the deep fissures and caves that represent another class of problems for engineers.

The Bedrock - Below the irregular surface the bedrock is interlaced with various solution features. These caves, cavities, fissures, and underground channels are constantly enlarged by the action of groundwater. These form along the horizontal bedding planes in the rock and in the vertical cracks that were initially shrinkage and settlement cracks resulting from the drying of the limestone. Figure 8 shows the enlargement of one of these and illustrates the development of small streams on the surface of this landform. As the underground streams enlarge, the roof continues to erode, and when weakened to a point of collapse, sinkholes form on the surface (Fig. 12), giving evidence of underground caves and streams. This erratic perviousness of the rock mass (not individual rock fragment) has an important effect on domestic water-supply problems, sewage disposal, and dam and highway construction. Engineers and contractors building highways, runways, and industrial buildings must use a special set of precautions, because of existing sinks and fissures and impending collapse.

The grouting methods used to seal dam foundations are extensive and costly but necessary to insure against the loss of water. Likewise, the capping of sinkholes with concrete is practiced under roadways to minimize settlement or eventual loss of a section of road. Many contractors, taking a chance on the results of a few test

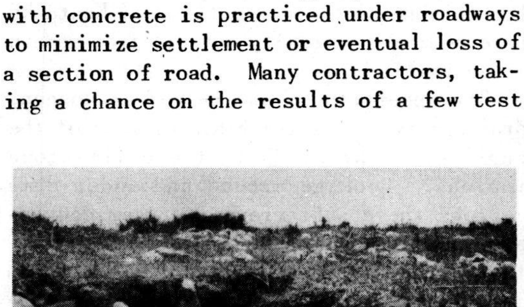

Figure 9. A ground view of weathered limestone in French Morocco shows the surface character of the rock exposed by erosion of the soil mantle. The white forms in the background are bare outcrops of the rock. In the foreground, the variations in depth of the soil can be seen. The doubtful value of random soil borings and test pits can be visualized.

holes, have found it disasterously expensive but necessary to bring in air hammers to knock off rock pinnacles during the grading operation.

With these hazards associated with limestone in all areas, it is a matter of professional protection to make sure of the landform on which a project is to be constructed. The same features in an advanced

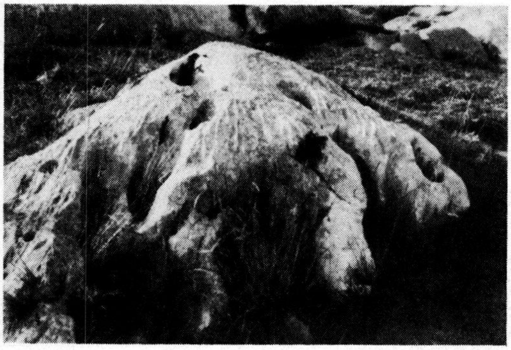

Figure 10. A closeup view of a limestone outcrop in eastern France shows in minute detail the erratic occurrence of solution pits and rivulets on the rock surface. The more or less circular holes are relatively deep. These same features, when expanded several hundred times, are the features that make engineering in limestone land form an interesting experience.

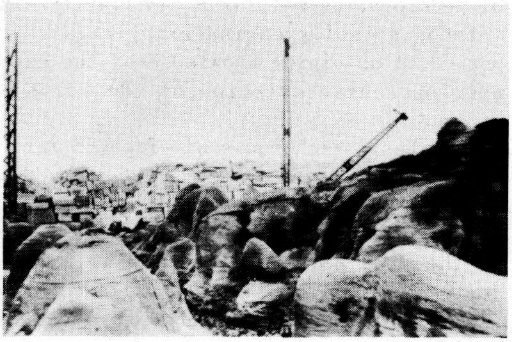

Figure 11. This view of a midwestern limestone quarry shows the same irregular rock surface found elsewhere. These dome-shaped mounds are miniatures of the weathered limestone hills found in tropical countries. At this site the soil depth varied from six to thirty-five feet within short distances. Photo by Professor Fred Serviss

Figure 12. This view of a sinkhole in Kentucky shows that they can be large and deep. Others may appear as small "punctures" in the ground or as shallow depressions containing temporary ponds. The topography is usually pleasantly undulating.

Figure 13. This road cut in the limestone landform (tropical) in Puerto Rico shows by cross section the honeycombed nature of this rock. Opposite the figure a cave entrance can be seen.

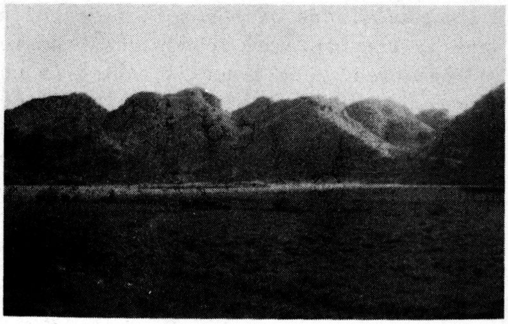

Figure 14. This is a ground view of the rugged limestone hills in tropical Puerto Rico (Plate V). The hills are formed by collapse of the caverns. The low areas between are not actually valleys because they are poorly connected and seldom have the same elevations as adjacent areas.

state occur in most tropical countries. Figures 13 and 14 illustrate these in Puerto Rico. Each landform has its strength and weaknesses, and by identifying the landform and knowing its traits, a better job of engineering can be done. In this way, the risk can be calculated with some reasonable assurance of safety.

On the good side of the record, it is certain that most limestones furnish one of the best and most extensively used aggregates. With the exception of the very cherty limestones, it forms a dependable and high quality material.

ENGINEERING SIGNIFICANCE OF SAND AREAS INTERPRETED FROM AIRPHOTOS

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Wayne University

The investigation summarized here was established as a doctoral thesis in the interpretation of soils by the use of aerial photographs, the interpretation to include both engineering mapping and analysis of highway problems associated with the types of soils classified. It was attempted to interpret the complex patterns of the airphotos of northwest Indiana--patterns which have been made complex by the large variety of glacial and post-glacial deposits which have provided the parent material for the developments of the soils of the region. All or portions of twelve counties were mapped, using airphotos, in the belief that a good knowledge of the soil types of an area is the basis of good highway design in that area. Consequently, the area was studied both from the standpoint of developing techniques of mapping engineering soils from aerial photographs and from the standpoint of determining applications of the knowledge of the mapped soils to problems of highway design and construction. Studies of pavement performance were made during the spring breakup and during the summer season to correlate soil types with the performance of both rigid and flexible pavements.

Before the variable of soil texture can be applied to the performance of a highway, it is necessary to know what the soils involved are--their origin, profile development, drainage characteristics, texture, plasticity, and topography. In the interests of economy it is necessary to develop rapid means of identification of soil types and of characteristics. Until the recent advent of the techniques of airphoto soils interpretation, no rapid method of soils mapping had been developed. To the skilled interpreter, the aerial photograph, combined with a knowledge of the general development of the area being studied and of some of the basic concepts of pedology, as well as a familiarity with methods of soils engineering, is a rapid method of obtaining knowledge of the engineering characteristics of the soils of an area.

The basic techniques of airphoto interpretation of soils have been described in the past (1,2). They include acquaintance with geological developments and processes in the area being studied and with pedological information as to profile development, erosion, and vegetative cover. Study of broad areas is combined with stereoscopic examination of matching prints to determine the details of the surface features. The elements of the airphoto pattern (color tones, drainage, erosion, vegetation, topography, and land use) are used to bound soil areas on the basis of origin, development, texture, topographic position, climate, drainage and plasticity. An important factor used in airphoto mapping is the concept that any given pattern will be changed if other deposits are accumulated on top of the soil of that pattern. The amount of modification depends upon the amount and nature of the overburden. The complex patterns of northwest Indiana proved to be modifications of the more standard patterns and could be worked out by a process of reasoning following careful observation of the elements of the patterns.

Many states have realized that in their highway system they have an extensive field research laboratory, and large-scale performance surveys have been undertaken in many areas. Many of these have been reported in part and some have established strong correlation between soil types and pavement performance (3,4,5). There are many factors which may affect the performance of a particular section of concrete pavement; coarse aggregate, fine aggregate, mix design, construction procedures, joint design, subgrade, base, drainage, and others. A similar list of factors can be developed in regard to flexible pavements. Consequently, isolating one of these factors and successfully correlating it with pavement performance is not a simple task, but it has been handled with apparent success in at least some areas.

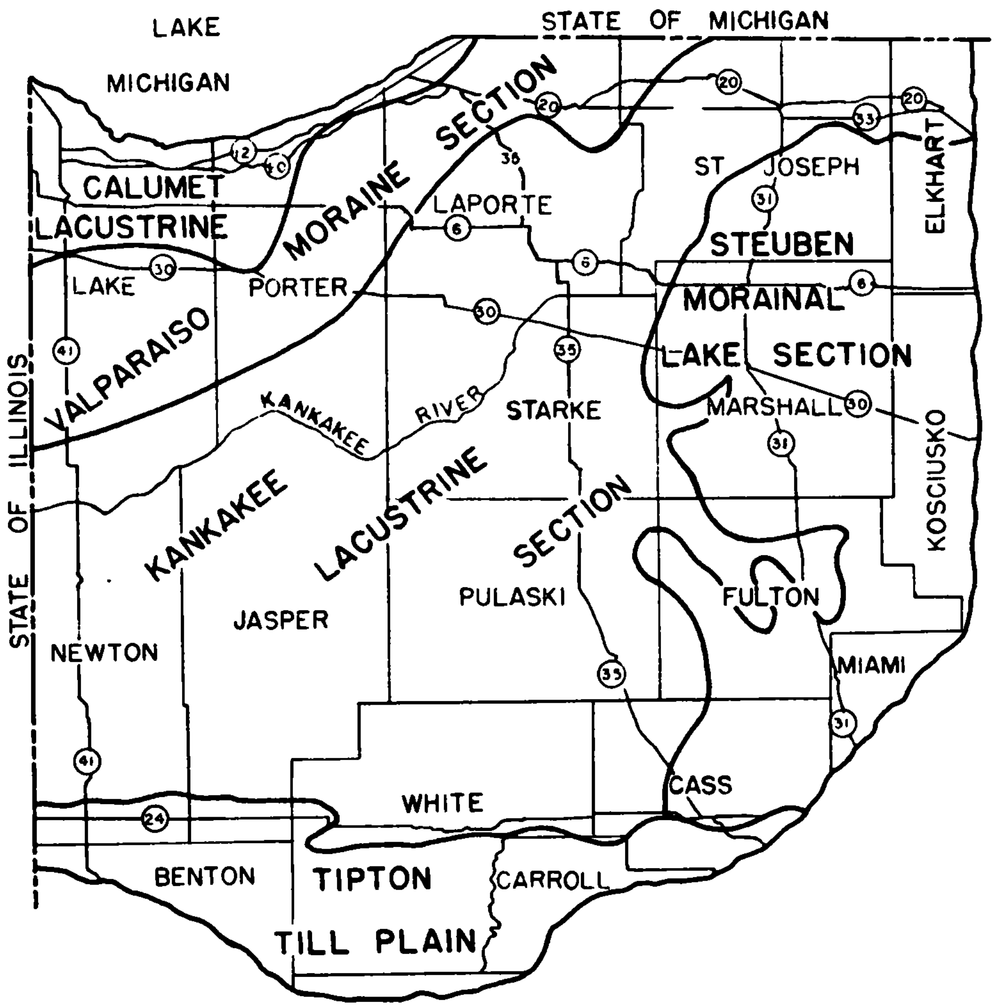

Figure 1. Physiographic Divisions and Federal Highways in Northwest Indiana

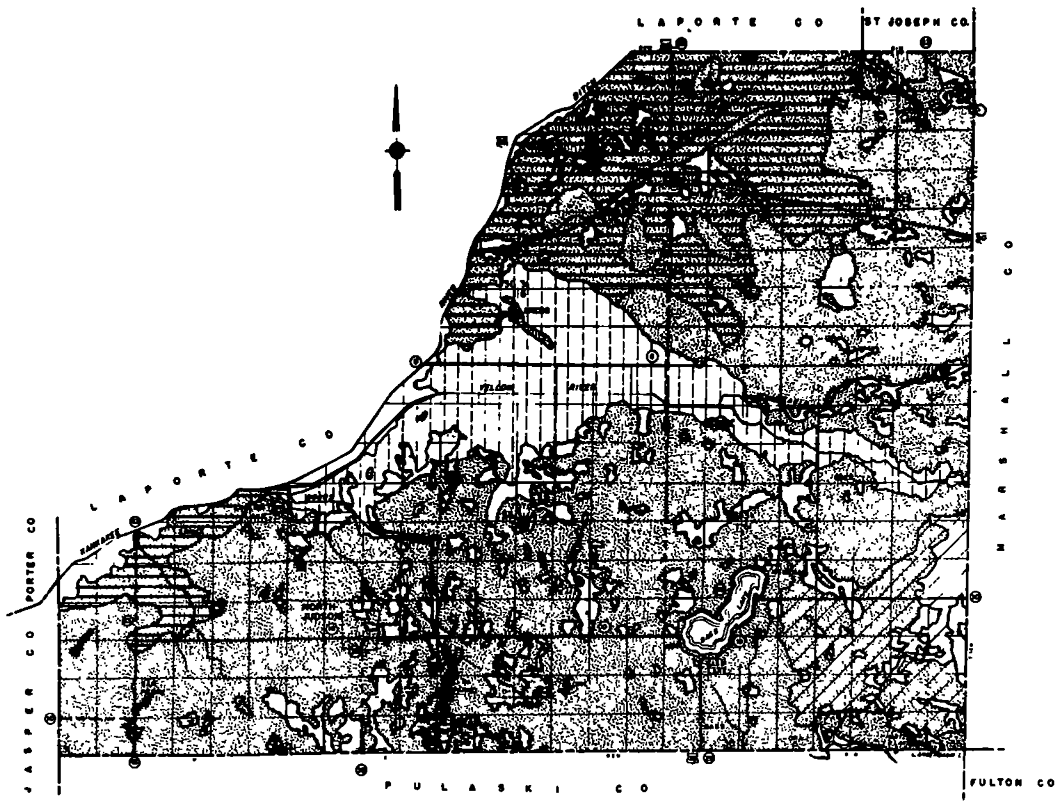

Figure 2. Typical County Engineering Soils Map. This soils map is of Starke County in Indiana in the Kankakee basin. It is typical of the several counties which have the Kankakee River for their northern boundary. The soils are largely of lakebed development except for a small area of outwash gravels in the northeast corner and an area of semi-plastic drift in the southeast portion of the county. Eight soils were mapped in this county and the detail is representative of that which can be obtained from airphotos.

AREA AND METHODS

Seventeen counties in northwest Indiana were surveyed in order to map the sand areas described in this report. They fall within the region known physiographically as the Northern Moraine and Lake Section, a region bounded on the south by the Tipton Till Plain. Three of the divisions of the section are involved in the area studied, illustrated in Figure 1. These are the Calumet Lacustrine section, the Valparaiso Moraine section, and the Kankakee Lacustrine section. The Steuben Morainal Lake section borders the area studied on the east. The major portion of Indiana has been covered once or more by the glaciers and their heterogeneous deposits of drift. The northern part of the state lies within the bounds of the last great advance of the glaciers--Late Wisconsin--so that the soils and topography of that part of the state are almost wholly controlled by the glacial deposits and some subsequent development. In the Valparaiso Moraine section and the Steuben Morainal Lake section the surface deposits are those of the glaciers--the Valparaiso Moraine being the most prominent terminal moraine of the Michigan lobe of the glacier and the deposits in the Steuben area being those of the Erie and Saginaw lobes. The rolling hills of the terminal moraine are the predominant features of the topography in these areas. Actual till plains are rather rare in this section of Indiana. In the Lacustrine sections, the deposits are those which were laid down by running or impounded waters during and following the time of the glaciers.

The entire region is so comparatively young that with the possible exception of sand dune formation there have been no great natural changes in topography since the respective deposits were laid down. Drainage developments and erosion have been relatively scant. Other surface changes have been wrought by the efforts of man in the past hundred years. These are vegetation, construction of highways and railroads, and artificial drainage of many of the swampy areas. The Calumet Lacustrine section is the former lakebed of glacial Lake Chicago--an extension of Lake Michigan --and is marked by several prominent beach ridges, plastic and sandy lacustrine deposits, swamps, and the more recently developed prominent dunes bordering Lake Michigan. The Kankakee Lacustrine section embraces a large area lying south of the Valparaiso Moraine. It centers about the Kankakee River which at one time carried vast quantities of glacial waters and when dammed up to the west in Illinois, impounded water over a large area, giving rise to the deep sand deposits which cover much of the basin. Extensive areas of outwash materials occur about the borders of the basin and to the north and east. Artificial drainage has lowered the water table in most of the sandy basin reclaiming a vast swamp for productive pursuits and drying the surface sands to the extent that many active dunes have been and are being formed.

Many prominent federal highways from the Chicago area fall within the area studied and other important east-west and north-south highways were available for performance studies as well as many state highways and surfaced roads of lesser importance. The US highways crossing the area are also shown in Figure 1 and include US 6, 12, 20, 24, 30, 31, 33, 35, and 41. These heavily traveled roads, traversing many different soil areas, made this area

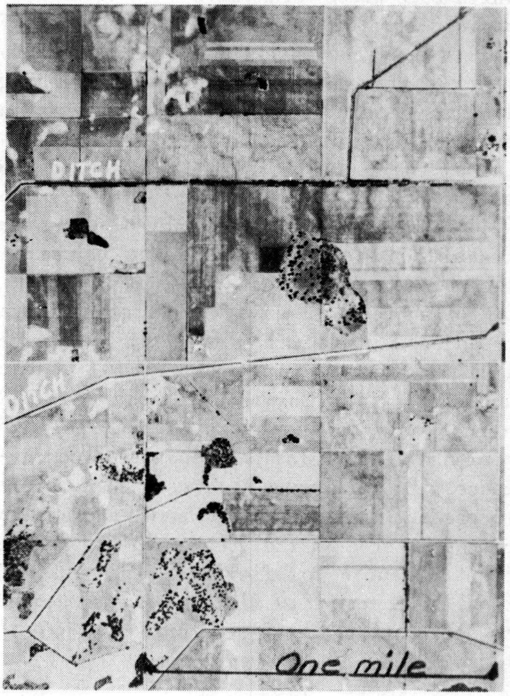

Figure 3. Airphoto of Large Flat Areas of Sands. This pattern of flat-lying sands in Jasper County, Indiana, has been modified by wind-swept sands, both active and stabilized. The white spots are currently shifting sands whereas the patches of trees mark dunes which have become stable. The main area shows the very flat topography and uniform light-gray color tones of the flat sand areas. There is almost complete lack of natural surface drainage but the area has been ditched to lower the water table.

a particularly fruitful one for performance studies.

Mapping was conveniently done in units of counties. A mosaic of the prints of the county was assembled on a board and studied. After a preliminary understanding of the area and its soils had been developed and after preliminary approximate boundaries had been lightly marked on the prints where it seemed possible to make an early prediction, the prints were examined stereoscopically in considerable detail. When it had been ascertained what boundaries could be marked with strong assurance and which boundaries were somewhat questionable, a field trip was planned. Field checks of soil types were made and samples taken to check textural composition and Atterburg limits. After the additional information of the field work was available, the marking of the boundaries was completed on the airphotos and the markings transferred to a base map of the county by means of a transfer table. Figure 2 is an illustration of a typical county soils map.

Soils areas as marked were combined into broad groupings, such as are described later in this report, on the basis of features and characteristics identifiable from the airphotos. On the basis of previous experience in correlation of pavement performance with soil types, it was then possible to predict the type of highway problems to be encountered in the areas mapped. Spring breakup studies of flexible pavements and condition surveys of rigid pavements served to substantiate these predictions.

SOIL AREAS AND THEIR INTERPRETATION

Large Flat Areas of Sand - These were laid down as lakebed deposits at the time when the Kankakee River was dammed and perhaps have been reworked during lower stages of of the lake. Topographically, they are monotonously flat. During the time of Kankakee Lake, numerous beaches and islands were formed and modified so that many long-standing mounds and ridges are scattered throughout the area. Later wind action has further modified these hills so that they have the appearance of and are commonly referred to as dunes. These may occur at random in the flat sand areas or in close groupings over large areas, in which latter case they were mapped separately on the strength of topography, position, and drainage. The surface deposits in the flat areas are fairly uniform in size and tend toward one-size sands, although silt may occur in the topsoil. In many cases they

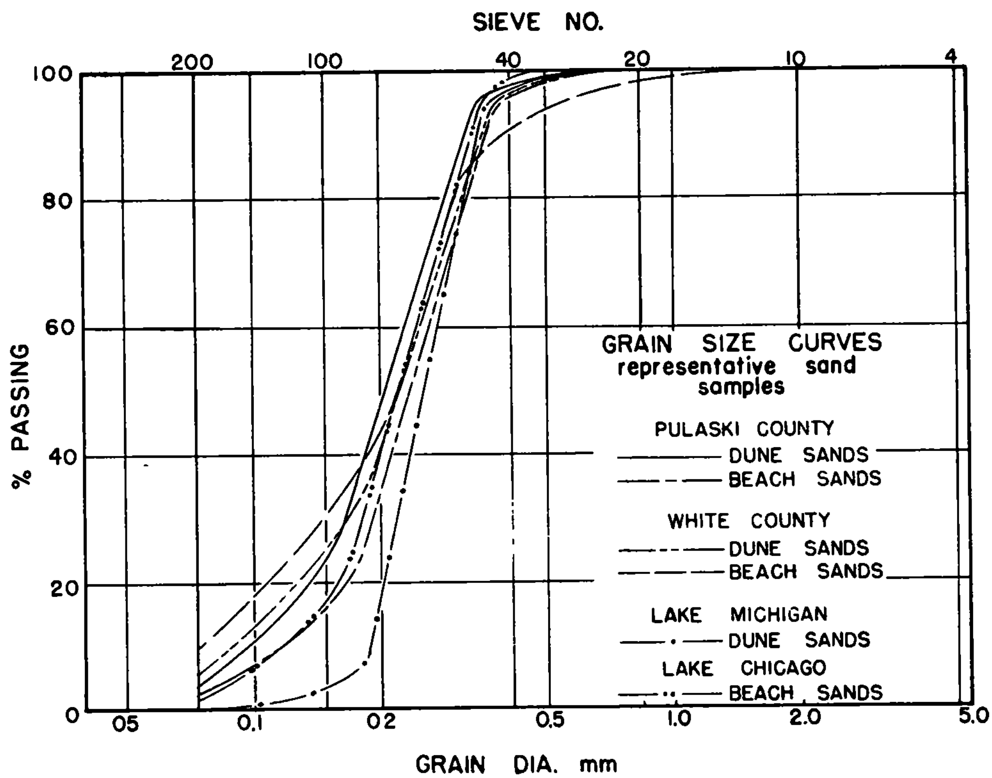

Figure 4. Grain Size Curves of Dune and Beach Sands

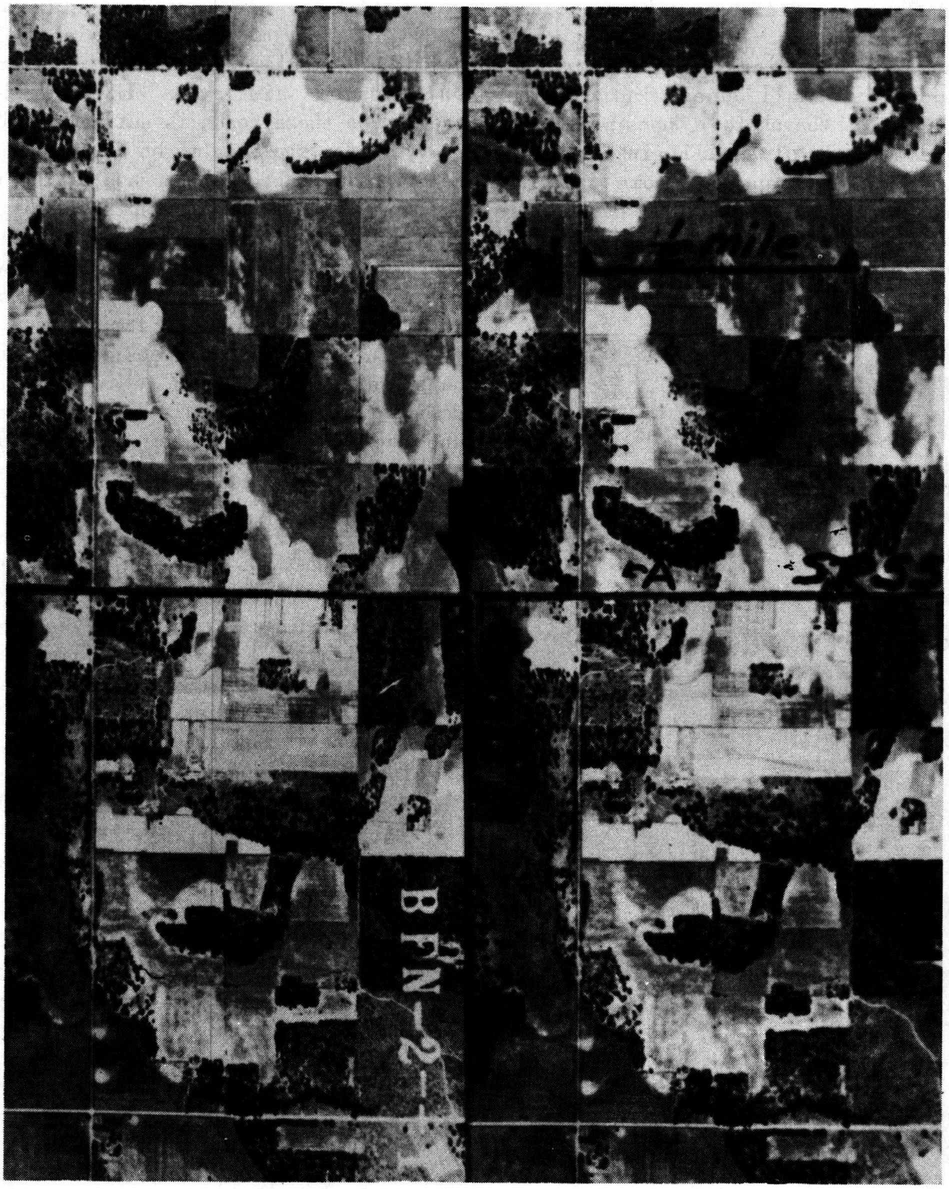

Figure 5. Airphoto of Sand Dune and Ridge Area. This stereogram is very representative of the sand dune areas in the Kankakee basin. It covers a portion of a band of dunes two or three miles wide extending across the flats. In the lower left corner of the picture may be seen the change to the flat areas of sands.

are underlain by coarser sands and gravels. They drain well when the water table is low enough and artificial drainage has accomplished this in most of the area.

These areas are marked by rather uniform light-gray color tones (Fig. 3). The topography is very flat and the field pattern is rectangular. Wind whipping across the surface has picked up sand and deposited it in small dunes, indicated by white spots on the photo. Dunes which have reached a state of equilibrium and have retained their shape for some time are marked by native trees, usually oaks. There is an almost complete absence of natural surface drainage and at least one ditch may be found in every square mile of the area.

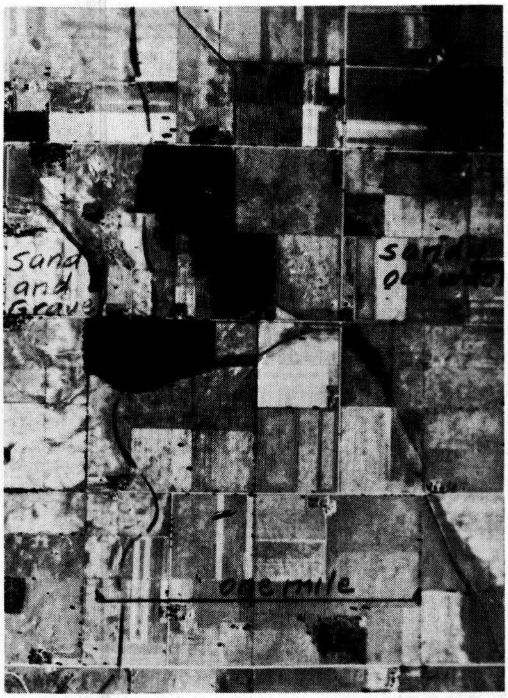

Figure 6. Airphoto of Sandy Outwash. The major portion of this photo is of the sandy outwash area in northwestern St. Joseph County in Indiana. It shows gently rolling to flat topography and light-gray color tones. Infiltration basins are faint and there are no gullies. The left portion of the picture bounded by the dashed line, shows the contrast of the more granular pattern. Figure 7 is illustrative of the topographic change at this boundary.

There are some faint indications of slow-flowing water to be seen in the area but these are probably due to a former condition at the time of draining.

In regions where artificial drainage has lowered the water table, these soils generally provide excellent subgrades. There are many miles of excellently performing flexible and some rigid pavements on sands of this type. In general the traffic on these roads is not heavy. Under heavy loads, faulting might be appreciable. Location is no problem because of the flatness of the area and no cuts, with their changes in profile, need be considered. The area contains many small regions where the top soil is very highly organic and this soil presents a problem in location. If these small regions, easily identified on the airphotos, cannot be avoided, it is desirable to excavate the organic material and back-fill with clean sand. No other granular materials are likely to be available in the immediate vicinity.

Sand Dunes and Ridges - There are extensive areas of this soil type lying south of the Kankakee River and another broad belt of dunes surrounding the south and west shores of Lake Michigan. Their most characteristic feature is the topographic expression of sands in the dunes and ridges. The dunes appear in modifications of the crescent shape, as long ridges, and occasionally as mounds. An effort was made to determine whether the ridges might not be of water-laid origin rather than wind-blown. Many comparative samples were taken from wind-blown tops of ridges and from deeper down where it was expected the sands may have been water-laid. The plot of the grain-size distribution curves (Fig. 4) showed no significant difference in the grain sizes at the two locations. To determine whether a difference in grain size of wind-blown and water-laid sands might be expected, similar samples were taken from the large dunes along Lake Michigan and from deep in the beach ridges of Lake Chicago. The data were compared and it was concluded that the beach sands and the dune sands were of essentially the same size. This conclusion is reasonable because all the sands are from the same source,

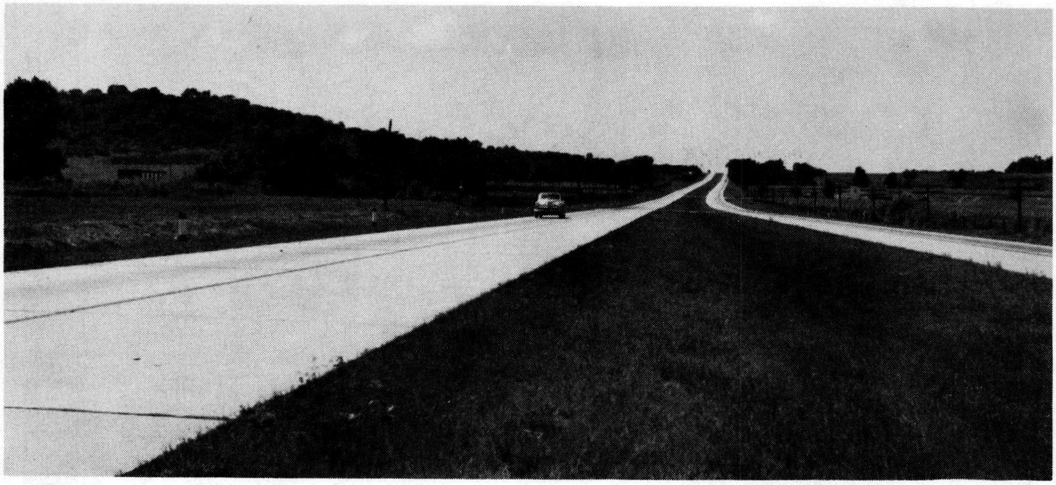

Figure 7. Ground Photo of transition From Sandy Outwash to Gravel Outwash. This photo, taken along SR No. 2 in Eastern St. Joseph County, shows the sharp change in topography at the border between the sandy outwash area and the gravelly outwash marked in Figure 6. The hill to the left rises over 100 ft. above the level of the adjacent plain--an extreme local change in elevation for these types of materials.

although it might be expected that water action could wash up larger particles and that wind deposition would be more selective. It was also noted that there was a striking uniformity in size between the sands surrounding Lake Michigan and those in the Kankakee basin.

This soil type is one of the easiest to recognize on the airphotos as the shape and topography of the dunes, the light color tones, the blowouts, the absence of gullying and surface run-off, and the patches of trees can hardly be mistaken (Fig. 5). Another strong feature of the area marked in the airphoto pattern is the large number of muck pockets found in some portions of the area. The field pattern is likely to be irregular and ditches are frequently used to lower the water table in the muck-filled depressions.

Location of highways in this area is largely a problem of avoiding the muck pockets. Cuts are required through the dunes and ridges but the sands are deep and no change in texture is involved. A definite problem with these sands is the matter of stabilization. The sands are subject to wind erosion in the natural state, which will also cause some modification of cut and fill slopes. This process is slow, however, and the slopes are usually left bare on secondary roads. Rounding the slopes, bringing in top soil, and developing a sod cover or planting special grasses are practiced on some primary roads. The sands are stable when confined but are likely to rut in a natural surface because of lack of binder. The same is true of these sands under very thin surface treatments. To be entirely satisfactory, the subgrade should be stabilized or the pavement should have some structural strength. It has been shown that bituminous materials and other additives may aid in such stabilization. Sands also present a problem in compaction because of their uniform size. They are subject to vibratory compaction and consequently are prone to compact under the action of traffic and cause settling and faulting of the pavement. It is this type of action that has led to faulting on many rigid pavements placed on a 4 or 6-in. insulating blanket of sand. In some instances the sands may be mechanically stabilized by bringing in fine material. The excellent drainage characteristics of

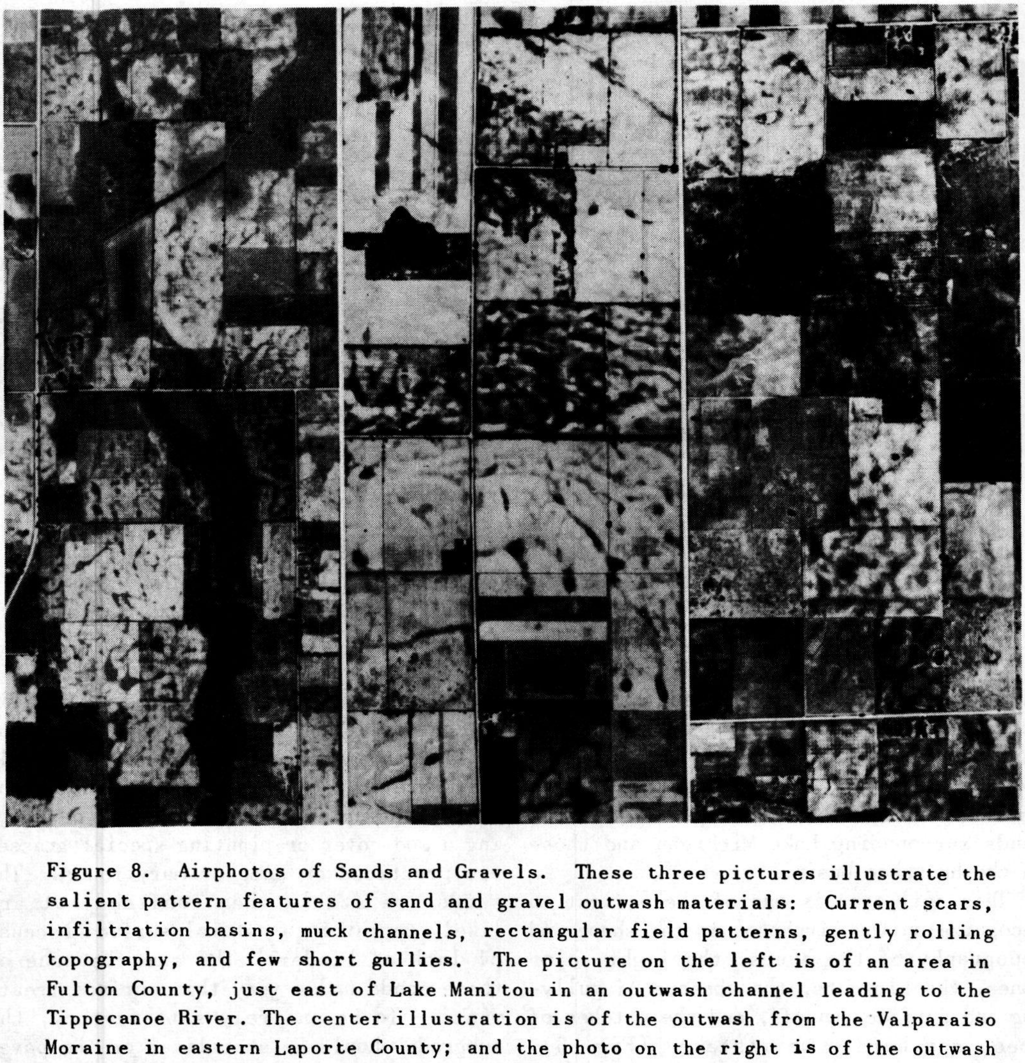

Figure 8. Airphotos of Sands and Gravels. These three pictures illustrate the salient pattern features of sand and gravel outwash materials: Current scars, infiltration basins, muck channels, rectangular field patterns, gently rolling topography, and few short gullies. The picture on the left is of an area in Fulton County, just east of Lake Manitou in an outwash channel leading to the Tippecanoe River. The center illustration is of the outwash from the Valparaiso Moraine in eastern Laporte County; and the photo on the right is of the outwash pattern in northern St. Joseph County. All three photos are to the same scale.

the sand may require that water-proof paper be laid on the subgrade before concrete is poured to halt the draining of the water from the mix into the subgrade.

Sandy Outwash - Northern Indiana has many areas of sandy outwash formed during the time of the Late Wisconsin glacier by break-throughs or over-flows of the moraines by waters impounded by rapid melting of the glacial front. The surface and topography is quite similar to the area mapped as large flat areas of deep sands except that sand dunes are much less in evidence. The texture of the surface sands does not fall within such narrow bands as that of the sands previously described and the under-lying material, frequently gravel, may occur at shallow or considerable depths. The topography may be gently rolling and there is little surface drainage. The granular nature of the soil and the under-lying gravel is such as to give excellent internal drainage, but artificial drainage has been practiced to lower the usually high water table.

There is often marked contrast in the airphoto pattern between soils of this group and the adjacent sand and gravel areas, as seen in Figure 6. The topographic contrast is also well-marked (Fig. 7). The color tones of the airphoto of sandy outwash are quite uniform gray. There are no gullies in evidence although faint infiltration basins and current scars may be seen. The field pattern is rectangular. The highway problem of major consequence in this area is that of drainage, for unless the area has been ditched the freewater surface may be too near the surface to allow stable subgrade conditions. Faulting also may occur.

Sands and Gravels - Large areas in northern Indiana were mapped as sands and gravels consisting largely of outwash deposits along glacial streams and from water impounded behind moraines. Soil profiles in this area usually show 6 to 18 in. of sand, including some topsoil, over a foot or two of gravel containing varying amounts of sand, silt, and clay. Since the materials were water-laid they are stratified, and layers of sands and gravels may be encountered to an appreciable depth. The topography varies from undulating to strongly rolling. Surface drainage is not strongly developed as the drainage is largely internal. Muck channels may be fairly numerous.

The feature of the airphoto pattern is the mottled and pitted appearance typical of coarse, granular materials. Although the surface drainage is slight there are short V-shaped gullies and many current scars and infiltration basins. Color tones are predominantly light to light gray but many dark muck pockets and channels are likely to develop. The field pattern is usually rectangular, and orchards are frequently visible on the photos. The similarities among the patterns from widely scattered locations may be observed in the photos in Figure 8.

These materials are among the best of the subgrade soils. They are well drained and stable. In some areas the topography is sufficiently rugged to cause fairly steep grades and rather deep cuts. Excellent performance may be expected in general in these soils although some faulting may occur at slab joints under heavy traffic. Muck pockets should be avoided but an abundance of granular materials is available for fills and other construction. Slight evidences of pumping have been observed in cuts in this area, but samples of the subgrade soil from the locations involved showed no measurable plastic or liquid limits and had but 3 to 15 percent of the total sample finer than the No. 200 sieve.

Plastic and Semiplastic Drift - Although the terminal and ground moraines of the Wisconsin drift sheet are not included in

Figure 9. Airphoto of Plastic Drift. This airphoto, covering an area just south of US 24 in southern Jasper County, Indiana, is representative of the pattern of large areas of Wisconsin drift till plains. It shows absence of intense erosion, abundance of phantom drainage as indicated by the arrows, gently blended light and dark color tones, and rectangufield which are features usually found in airphotos of this soil type.

the "sands" discussed here, it is necessary to describe them in order for them to be used as background for the airphoto interpretation of shallow sands on drift as well as for description of the engineering characteristics of the shallow sands. Mapped as plastic drift are the ground moraines, occurring in the area, many of the terminal and marginal moraines, and areas of waterworked drift. The B horizon of these soils may be a combination of plastic clays and silts with sands while the parent material is a somewhat heterogeneous mass of clays, silts, and pebbles. The soil is relatively impermeable and has flat to gently rolling topography except in the morainic areas where it is somewhat rougher. The semiplastic moraines exhibit topography somewhat less regular than the plastic till. Its profile development is similar to that of the plastic drift although the B and C horizons are somewhat more granular. The parent material contains sufficient sand and gravel to provide some permeability.

The airphoto pattern of plastic drift as seen in Figure 9 exhibits an absence of intense erosion, and in the non-morainic areas ditching has been necessary to provide some drainage. The patchy light and dark areas, gently merging, are a development of the drainage conditions, the dark areas being the depressions and the lighter areas the relative rises. There is an abundance of phantom drainage because of the impervious nature of the subsoil. Rec-

Figure 10. Airphoto of Semiplastic Drift. This photo is of an area in southern Fulton County mapped as semiplastic drift. By contrast with the pattern of plastic drift, illustrated in Figure 9, it shows more irregular slopes, some eroded slopes, a more definite transition from light to dark color tones, and a somewhat more developed drainage but with some infiltration basins as indicated by the arrows.

Figure 11. Airphoto of Granular Drift. Representative of the granular drift of the Maxinkuckee Moraine in northern Fulton County, this photo is of an area along US 31. It exhibits the typical features of the pattern of this type of area: Abundance of steep slopes and freshly eroded slopes with V-shaped striated gullies (a) There are muck pockets and an abundance of infiltration basins (b) and light color tones predominate.

tangular field patterns are characteristic of a plastic soil. The pattern of the semigranular areas (Fig. 10) is intermediate between the plastic drift as described and granular drift. The slopes are more irregular than in plastic drift; there are some evidences of phantom drainage and also some fresh gullies; the color transition from light to dark is more pronounced; and there may be some infiltration basins.

The major problem in the plastic drift area is that of cuts into the plastic B horizon and parent material. Due to the gently rolling nature of the topography, there is a tendancy in design to cut in the rises and fill in the depressions. The fill in the depressions is advantageous for it provides an elevated grade line in an area where drainage is poor. However, further elevation of the grade line is desirable to avoid cuts. Performance of pavements in cuts, particularly where the grade crosses changes in profile, is generally rather poor. The impervious nature of the soil makes drainage a problem in these areas. Rigid pavements will frequently develop pumping in these cuts. Frost heaves are also frequent occurrences in cut sections and spring breakups of flexible pavements are prevalent in the cut sections during the season. If the grade line cannot be sufficiently elevated and cuts prove to be necessary, a blanket layer of granular material is recommended. Problems in the semiplastic areas are not unlike those just described; although the texture of the soils is less plastic, it is still sufficiently poor to cause poor pavement performance in cuts. The rougher nature of the topography makes elimination of cuts unlikely so that the blanket course in cuts is desired in construction. Drainage measures need also be taken.

Granular Drift - These deposits are more likely to have been left as terminal or edge moraines than as ground moraines. They exhibit a rougher topography than the more plastic forms of drift. The parent material is granular and contains large percentages of sand and gravel, as well as some silt and clay. It is often characterized as "dirty gravel." The comparative steepness of the slopes has retarded the development of the B horizon so that this horizon is more shallow than in the more plastic drift soils and it tends to be predominantly silty.

The steepness of the slopes is accompanied by relatively greater depressions and the development of muck areas is more prevalent in this type of drift. Except in the muck areas, light color tones predominate, but they are interspersed with many infiltration basins, indicating the granular nature of the parent material. The slopes are more freshly eroded and gullies are more numerous than in plastic or semiplastic drifts. The gullies frequently have a striated appearance and have

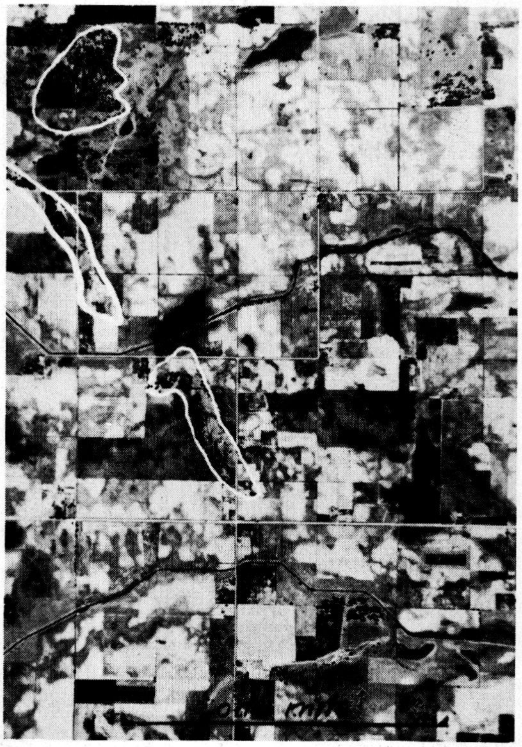

Figure 12. Airphoto of Sand (3 to 5 feet deep) Area. This area in central Jasper County occurs on the northern slopes of the Marseilles Moraine where the sands of the Kankakee basin have been carried up over the drift. It is marked by smooth slopes with some dunes which are usually covered by native trees. Three of these dunes are outlined on the photo. There is little evidence of surface runoff and the light and gray color tones take the pattern of the underlying drift.

fairly steep sides. Many of these features will be noted in Figure 11. Ditching is not necessary to secure drainage for these soils.

The major problem of this area is probably that of location. The topography is relatively rough and the slopes are sufficiently steep to introduce the need for moderately deep cuts and correspondingly high fills. Another factor in the location problem is the occurrence of muck pockets in the area. However, the problem of cuts and fills is not a difficult one because of the granular nature of the soils. They provide excellent embankment material and drain well, even in cuts. Gutters of moderate depth in deep cuts should keep the subgrade reasonably well drained. The materials are sufficiently graded to provide excellent borrow material and can be used as surfacing for county roads. Poor performance is not to be expected except under adverse conditions of traffic and climate. The problem of surface erosion is one which should be considered, and protection is needed for cut and embankment slopes to retard eroding.

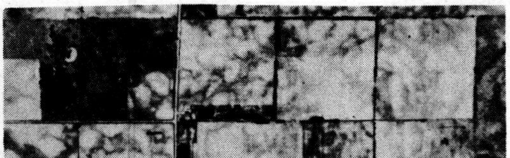

Figure 13. Airphoto of Shallow Sands on Plastic Drift. This area occurs in central Newton County in Indiana on the northern slopes of the Marseilles Moraine, but unlike the similar location in Jasper County (Fig. 12) these sands average less than 3 ft. in depth. This photo exhibits most of the features of the airphoto pattern of plastic drift, including phantom drainage. Color tones are very light on the elevated areas and gray in the depressions.

Sands on Drift - These sands were included as an intermediate group between the shallow sands, which were mapped as 3 ft. or less in depth, and the deep sands, which included those 5 ft. deep and more. In sands of this intermediate depth the character of the underlying drift has some influence on the airphoto pattern as well as on the highway problems involved, but it did not appear feasible to attempt to diffentiate between the different types of underlying drift on the basis of the airphoto pattern. Field sampling showed sands of this depth lying on plastic, semiplastic and granular drift. The superficial features of this area are those of the deep sands as discussed earlier. The sands are either water-laid or wind-blown and generally are one-sized in texture although the water-deposited sands may include larger grains.

Figure 12 shows that the color tones of this soil pattern are light and gray, occurring in a pattern similar to that of the underlying drift. However, the characteristic mottling shows through in a modified form and the surface is further modified by sand dunes and ridges. The slopes are generally smooth and there is a certain amount of phantom drainage. Surface runoff is generally lacking. As is characteristic of sand dunes, they may be covered with oak trees when they are sufficiently rough and have so little topsoil development that they are not tillable. Depth of sand in the dunes may, of course, be over 5 ft. but on a small scale map it was not reasonable to map such isolated spots.

The highway problems of this soil area are not dissimilar to those of the areas of more shallow sands, except that the problems can be expected to occur with less frequency. The sands are of sufficient depth that they provide a good subgrade in spite of the character of the underlying drift, unless cuts penetrate too deeply. Consequently, only in the deeper cuts need we be concerned with poor subgrade conditions. The topography will be affected by that of the underlying drift. If the drift is granular there is the problem of location to avoid deep cuts and fills and to avoid muck pockets. In the more shallow areas of sand and where the cuts are deeper, the problems involved are those of the underlying material. In deep cuts into plastic drift it is particularly necessary to provide intercepting drainage for ground-water flow from the sand-drift boundary. The grain size of these sands makes them subject to wind erosion, as well as erosion by running water. The lack of binder material leads to problems in embankment construction as discussed earlier.

Shallow Sands on Plastic Drift - This classification includes sands of depths to about 3 ft. This type may occur in areas where deep, water-laid sand deposits are bordered by pre-existing areas of drift and also includes areas of shallow windblown sand which may or may not be isolated from their source of supply. The surface is well-drained but the drift below necessarily has the characteristics of sands-on-drift as described above. The topography will take the form of the underlying drift with some modifying by the sands, particularly where scattered dunes have formed.

Salient features of this soil pattern may be seen in Figure 13. Slopes are generally rather smoothly rounded except at the random dunes. There is little erosion, and phantom drainage may be seen in many places. The field pattern is regular and some ditching is evident. The smoothly blended light and dark areas of the plastic drift pattern are in evidence through the overlying sand but the overall pattern has been lightened in color so that the higher portions of the terrain show up very light in color tone and the depressed areas are not black but gray.

The undulating nature of the topography in this soil area indicates that cuts through the shallow sand and into the underlying drift may be expected frequently. The zone of intersection of the sand and drift boundary is likely to show evidences of poor performance. The combination of sharp change in soil texture combined with the plastic and impervious nature of the drift makes this soil area one of the worst mapped from the standpoint of highway problems. The usual problems of silty clays will be encountered in the regions of cut where the pavement is laid on the drift. Where pavements are laid on 1 to 2 ft. of sand, a good subgrade condition may prevail although faulting at joints is possible under heavy axle loads. Drainage is a

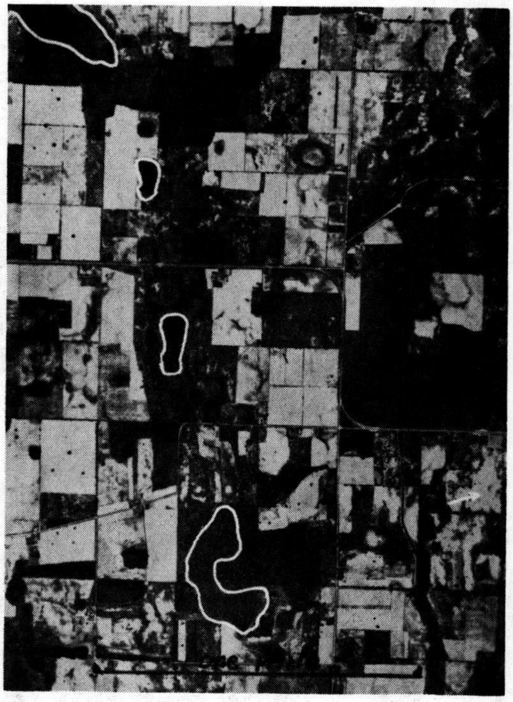

Figure 14. Airphoto of Shallow Sands on Granular Drift. This airphoto exhibits a combination of the features of sands superimposed on those of granular drift. Infiltration basins are evident and many muck pockets are seen, some of which are outlined on the photo. An area of deeper sands and dunes may be observed in the lower right side of the print as indicated by the arrow. This photo is of an area along Indiana SR No. 17 in western Marshall County.

problem in the moderate and deep cuts and it will be necessary to intercept the ground-water flow. Frost heaves may be encountered, not only in the cuts but possibly in other areas where the sand is shallow. The solution for the problems is essentially that of maintaining a high grade line or of providing a blanket layer in the deep cuts and maintaining proper drainage.

Shallow Sands on Granular Drift - Again, as was the case with granular drift, the topography of this soil area tends to be irregular and is influenced almost entirely by that of the underlying drift. The sands tend to modulate the slopes, but there are occasional dunes providing accents to the topography. The surface is well drained, largely internally, except in the depressions where muck pockets have formed. The depth of the sands varies from ½ to 3 ft.

Figure 15. Airphoto of Scattered Areas of Sands on Plastic Drift. This pattern is predominantly that of plastic drift, but superimposed on it are light sand patches as outlined. It represents an area in southeast Newton County.

and they are underlain by a partially developed granular drift B-type horizon with the gravelly parent material below.

Comparison of Figure 14 with Figure 11 will show how the surface layer of sand has modified the airphoto pattern of the granular drift. There is still an abundance of steep slopes, slightly modified by the sand. The gullies are fairly sharp and inflitration basins are noted. The greatest difference in the patterns is perhaps the contrast in color tones. On the shallow-sand print, the higher areas are much whiter than on the granular drift but there are much blacker tones on the shallow-sand prints for muck pockets are more prone to develop. Scattered areas of wind-blown action may be seen, some of it still active, and native trees cover most of the dunes.

The problems of this soil area, other than that of location because of the rough topography and muck pockets, are not expected to be great. The change in texture is less sharp than for shallow sands on plastic drift with the result that performance, even in deep cuts, will not ordinarily be bad. The soil provides good subgrade support, except possibly in regions of high ground water where there may be appreciable softening of flexible pavements. Sufficient granular material is available for fill as needed. Problems of compaction and erosion, as discussed for sand dunes and ridges, have some application in the shallow sand areas too.

Scattered Areas of Sands on Drift - These soil areas were separated and mapped not because of their importance but because of the danger of including them as sand areas if they were not pointed out. The characteristics vary from those of the underlying drift, whether it is plastic or granular, to those of deep sands. The drift predominates, but it may be covered with sand in scattered areas. These sands will vary from thin smears of wind-blown sand only a few inches deep to wind-blown deposits in dune form, the latter sometimes being many feet deep. There may also be areas of water-laid sands which were deposited along shores of small former lakes. As with most sand surfaces, the topsoil development is limited, particularly on the slopes. The topography is basically that of the drift, undulating for plastic drift and comparatively rough for granular drift, with occasional modifications where the sand has caused rounding of the slopes or where wind-formed dunes have punctuated the high points of the topography.

Airphoto patterns of this type are illustrated by Figures 15 and 16. In the plastic drift areas, the features of the plastic drift pattern predominate. The slopes are smoothly rounded, sometimes accentuated by dune formation. The patchy light and dark color tones are occasionally punctuated by a lighter area indicating a sand deposit. Phantom drainage and ditching are prominent. Color tones of the pattern in the granular drift area will not be greatly changed by the scattered areas of sand since the drift pattern was fairly light due to the well drained nature of the soil. However, the scattered areas of sand may introduce occasional lighter spots. The amount of modification of the pattern is an indication of the depth of the overlying sand; if the pattern is but little modified, there is very little cover; if the pattern is greatly modified, the influence of the sand is evidently stronger. Slopes will be steep and freshly eroded with V-shaped gullies with occasionally a wind-swept appearance to the modifications.

Soils in these regions should receive essentially the same consideration as those in the surrounding drift areas. It is important that they not be treated generally as sand areas, particularly in the plastic drift region for the soil type is little better than that of the underlying drift and has the further disadvantage of an additional change in texture.

Associated Muck, Peat, and Flood Plains - Alluvial areas have been subjected to flooding during comparatively recent times and may currently be liable to flood. They are made up of a series of waterlaid deposits which may vary appreciably in texture. They form an area of possible shifting stream channel as evidenced by oxbows, old current marking, meanders, and other like markings (Fig. 17). The soils are predominantly granular but may be found with plastic layers. The characteristic markings make airphoto identification easy. Color tones are usually dark gray, even when not covered by heavy vegetation, because of the depth of the organic matter in the upper horizons. There will frequently be a sharp drop from the upland to the alluvium, and short gullies may occasionally be found cutting down through the wall.

Muck and peat deposits are particularly numerous in the areas of sand dunes and ridges and in the other predominantly granular soil areas and consequently it is appropriate to discuss them in connection with the sand with which they so often occur in conjunction. The deposits may vary from shallow to great depths and may be underlain by sands, gravels, marl, silts, clays, or combinations. The nature of oc-

Figure 16. Airphoto of Scattered Areas of Sands on Granular Drift. This photo is representative of a large portion of western Fulton County. It has many of the characteristics of the granular drift pattern but is modified with many smoothly rounded slopes of windswept appearance. Color tones are light and gray except for the muck pockets.

Figure 17. Airphoto of Alluvial Soil Area. This photo shows the alluvial area along the Tippecanoe River in northwest Fulton County. Current scars may be seen as slight variations in the color tone.

curence of the areas is such that their drainage will be very poor unless they have been thoroughly ditched. The heavy black areas are so evident on the airphoto as hardly to require pointing out, the interpretation may rather be one of degree of development. Figures 18 and 19 are illustrative of these areas.

The highway problem is usually one of carrying the highway across the area because it cannot be avoided. Alluvial areas are generally found parallel to streams, so it is as necessary to cross them as it is to cross streams. A high, level grade is usually indicated in both cases; across alluvium because of projecting the grade line from the level in the upland to the level of the bridge crossing (and to stay above flood level) and in muck and peat areas because fill is usually required for foundation support. The matter of foundation support is not likely to be serious in alluvial areas because of their frequently granular texture. The totally inadequate supporting power of muck and peat soils acting as a subgrade under a pavement is so well known as not to require any consideration. Rather, in construction across these beds it is a problem of designing and constructing a fill which will carry the pavement without settlement. The problem resolves into either removing the questionable material and backfilling with a granular material or speeding the consolidation of the muck and peat so that detrimental settlement will not occur after the pavement has been laid. The failure to accomplish this end is attested to by obvious settlements across muck and peat areas. These problems are currently being studied by a committee of the Highway Research Board.

SUMMARY AND CONCLUSIONS

The basic techniques of interpretation of aerial photographs for engineering soil characteristics have been applied to an extensive and glacially complex areaof northwest Indiana. Working from techniques of interpretation of airphoto patterns previously established, using field trips to aid in classifying areas in which the airphoto pattern was complex, and applying

TABLE I

SUMMARY OF AIRPHOTO AND HIGHWAY ENGINEERING CHARACTERISTICS OF SOIL AREAS

SOIL AREA	CHARACTERISTICS	AIRPHOTO PATTERNS	HIGHWAY PROBLEMS	CORRECTION
Large Flat Areas of Sands	Very Flat over large areas Occasional dunes Granular Textures Artificial drainage Uniform grain size in surface sands	Very flat Uniform light gray color tones No natural surface drainage Ditching Oak trees on dunes	Faulting Depressions	Fill across depressions Elevated grade Ditching
Sand dunes and Ridges	Topographically irregular Dunes and ridges Uniform grain size Muck Pockets	Dunes and ridges Blowouts No surface run-off Ditching Irregular field pattern	Muck Pockets Slope erosion Faulting	Grass or sod for slope protection Fill across muck
Sandy Outwash	Flat to rolling Little surface drainage Sandy materials	Gently rolling to flat More uniform light gray color tones No gullies Some ditches Faint infiltration basins	High water table Faulting	Ditching Elevated grade
Sands and Gravels	Sand topsoil Layers of gravels and sands Rolling topography Well-drained internally Muck channels	Rolling Few gullies Pitted appearance Current scars Infiltration basins Muck channels Short gullies	Muck channels Faulting	Good construction practices
Plastic Drift	Flat to gently rolling Impermeable Plastic to semi-plastic	Smoothly-rounded slopes Intense erosion absent Patchy light and dark merging areas Phantom drainage Rectangular field pattern	Very poor subgrade in cuts Drainage Pumping Frost heaves	Blanket layers Elevated grade Granular bases Deep gutters or subdrainage in cuts
Semi-Plastic Drift	Less regular topography More granular soil	More irregular slopes Some eroded slopes Sharper color tone changes Phantom drainage More infiltration basins	Poor subgrade in cuts Drainage Frost action	Elevated grade Blanket layers Deep gutters or subdrainage in cuts
Granular Drift	Often morainic Granular parent soil Steep slopes Muck areas	Steep slopes Freshly-eroded slopes V-shaped gullies Light color tones Muck pockets	Location Erosion of cut and embankment slopes Fill across muck areas	Slope protection Gutters in cuts Good muck construction
Sands (3 to 5 feet deep) on Drift	Variety of underlying material Sands are one-sized Some features of underlying material Dunes	Smooth slopes Some dunes, covered with trees Light and gray color tones in drift-like pattern Phantom drainage	Poor subgrade in deepest cuts Drainage at soil boundaries Faulting	Blanket layers Intercepting drainage
Shallow Sands on Plastic Drifts	Drained surface Impervious below Occasional dunes	Plastic drift pattern underlying Light color on rises Gray color in depressions Phantom drainage	Poor subgrade in cuts Drainage Frost heaves	Blanket layers Elevated grade Intercepting drainage
Shallow Sands on Granular Drift	Irregular topography Muck pockets Occasional dunes Well-drained	Sand pattern over granular drift pattern Infiltration basins Muck pockets	Location for cut and fill and to avoid muck pockets Fill across muck Slope erosion	Slope protection Good embankment procedures Special muck construction
Scattered Areas of Sand on Plastic Drift	Like plastic drift with some dunes and thin smears of sand	Plastic drift patterns with light-colored patches	Same as plastic drift	Same as plastic drift
Scattered Areas of Sand on Granular Drift	Like granular drift with scattered dunes and thin surface smears of sand	Granular drift patterns with light-colored patches	Same as granular drift	Same as granular drift
Muck and Peat	Heterogeneous subsurface materials Low lying Low density	Unconformities Sharp boundaries Black to dark gray color tones	Support Drainage Settlement	Elevated grade Special methods of construction
Recent Flood Plains	Water-laid deposits Meanders Marsh	Low areas Adjacent to stream Dark gray color tones Much vegetation Current scars, Oxbows	Flooding Settlement	Elevated grade Improved embankment design and compaction methods

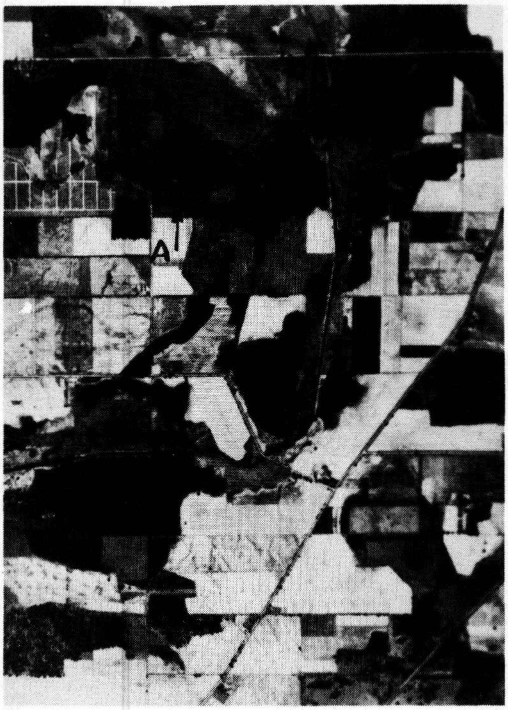

Figure 18. Airphoto Showing Stages of Muck Development. This picture was taken near the outwash-sand border in southeast Laporte County. The black spot in the upper left corner of the picture is a portion of a lake which at one time spread over a much larger area. The black spot at "A" is a marsh which has developed in the bed of the former lake. The area surrounding the marsh is enough higher that mucky soils are developing there.

Figure 19. Airphoto of Muck Channel Along Kankakee River. This is the narrowest constriction of the Kankakee basin and the walls, particularly on the right, are quite distinct. The outwash to the right furnishes some of the best gravel in Indiana. That to the left of the channel is more sandy. Muck and peat deposits here are many feet deep, causing the uniform flat gray color tone.

knowledge of soils engineering and of geological and pedological developments in the area, all or portions of 12 counties were mapped.

It was found that the comparatively complex airphoto patterns of soils in glaciated regions can be interpreted, with confidence, to predict the salient characteristics of the soils photographed. The method is essentially one of adding to knowledge already gained about some patterns and, by a reasoning process, determining how those patterns would be changed if the ground they represented were covered by some other soil material. For instance, the pattern of shallow sands on plastic drift shows evidences of the airphoto patterns of both materials, but the combination is a new one.

Results from extensive pavement performance surveys make it possible, after the soils of a given area have been identified from the airphotos, to predict the type of highway performance to be expected in that area or to outline the general features to be considered in the design of new construction. Table 1 is submitted as a summary of the characteristics of the various soil areas discussed in this report.

It may be concluded from the study that:

(1) Mapping of glacial deposits and reworked glacial materials of Wisconsin glacial origin can be done in considerable detail where accompanying field investigations can be made.

(2) Complex patterns, or patterns of combinations of surface soil conditions can usually be identified as combinations of the components of the constituent prints. This lends support to the belief that similar methods can be applied to many other types of areas.

(3) From a knowledge of highway problems in different types of soil areas and from the ability to identify these soil areas on the airphotos, it is possible to predict the type of highway problems to be encountered in a given area by studying the aerial photographs.

(4) On the basis of observations made, plastic drift, shallow sands on plastic drift, and scattered areas of sand on plastic drift along with muck and peat may be grouped as the soils studied on which the poorest performance is to be expected. Grouped as soils contributing most to good pavement performance are sands and gravels, sandy outwash, large flat areas of sands (if well drained), and areas of sand dunes and ridges (excluding muck pockets).

ACKNOWLEDGEMENTS

The author is indebted to Professors K. B. Woods and R. E. Frost, Associate Director and Research Engineer respectively of the Joint Highway Research Project at Purdue University, for interested help and suggestions throughout the research project summarized here. To Pacifico Montano of the same staff is due particular appreciation for his unrelenting zeal and skilled assistance, which was a large factor in the carrying of this project to its scheduled completion.

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PIEDMONT SOILS IDENTIFIED BY AERIAL PHOTOGRAPHS

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SYNOPSIS

To supplement published information several states have begun to use aerial photographs for developing soils and materials maps. A number of published reports describe the methods and applications of airphoto mapping, particularly concerning glacial deposits and bedrock of igneous and sedimentary origin; little applying to deeply weathered soils derived from igneous and metamorphic rocks has been written. These soils prevail throughout the Piedmont.

Piedmont formations, shown on the General Geology Map of Virginia, have been delineated insufficiently to be helpful in local problems. In addition, few counties in Virginia have existing recent agricultural soil maps. Therefore, aerial photographs are the only economical means of obtaining detailed areal soil information.

Correlations of airphoto patterns to the various major parent materials, were established for the Piedmont Province and associated Triassic areas in Virginia. Once the major areas are identified, local soil changes can be differentiated readily. Certain soils and parent materials were observed to have a marked effect upon pavement performance. Recognition of the relationship between soils and pavement performance should serve as a guide for new construction in those areas. Even more significant, similar soils and associated engineering problems reoccur at all locations where similar parent materials are found, regardless of the location within the state.

Under the pressure of modern living we are often swept with the tide, having little opportunity to determine our course. Unfortunately this is true in highway engineering, for increased work demand and shortage of suitable personnel may preclude full organization and utilization of valuable information. Each year a maze of soil-test data is accumulated by the Virginia Department of Highways from numerous construction projects. To tabulate and correlate this data with respect to soil areas would be desirable, for in this way a more adequate concept of the areal soil problems could be established and testing could be minified. Several states make extensive use of existing agricultural soil survey maps in their soils engineering. This method is particularly adaptable if a state is blessed by extensive map coverage. To date in Virginia, relatively few counties have been mapped by the Department of Agriculture. Of these only nine are recent, detailed, ClassI maps (1). In trying to correlate soils and their physical properties on an areal basis some means of mapping the soils had to be developed since few adequate maps were available. Within the Department of Highways there was available state-wide airphoto coverage; but before these photos could be used for interpretating soil conditions, airphoto patterns of various soil types had to be established (2). Soils vary from one physiographic province to another; therefore, the State of Virginia, which is situated within five major provinces, has an extensive variety of soil types. This paper describes the findings of some initial investigations within the Piedmont province. Forty-one percent of the state's area, 19,188 miles of its roads, and all or portions of 49 counties are in this region (3). In spite of its size, only two of the agricultural maps mentioned above cover areas in this province.

In recent years much has been written pertaining to the interpretation of the soils derived from sedimentary and igneous rocks, glacial debris, aeolian deposits and coastal plain material; this information has contributed much to the realm of soils engineering. To date little has been published pertaining to airphoto interpretation of deep residual soils derived from old crystalline rocks resembling those found in the Piedmont.

Soils of the Piedmont are unique for they have developed from very deep weathering of old, complex rock having many facies changes (often the depth of weathering may exceed one hundred feet). Erosion has been quite active; thus over large areas weathered, decomposed rock may be exposed at the surface. Soils developed in this region are as complex as the parent rock itself. While the parent rock may undergo many facies changes, any one particular parent may create several soil types; again one soil type may evolve from other than one parent formation.

PHYSIOGRAPHY AND GEOLOGY

The Piedmont is an old land mass bounded on the west by the Blue Ridge and to the east by the Coastal Plain. Older than any other area within the United States, it has been submaturely dissected by active streams. Many of the rocks, altered by metamorphism, have become laminated, resulting in a northeast-southwest strike. Local differences in elevation of the province may be as great as several hundred feet but normally do not exceed 75 ft. (4).

This province embodies a complex system of crystalline Precambrian rock. These formations include: rocks of igneous origin (both extrusive and intrusive, and metamorphic rock) of both sedimentary and igneous origin. This complex system entails many facies changes, thus causing continually varying rock textures. These parent rocks and their geologic history influence the resulting residual soils.

INTERPRETATION OF AERIAL PHOTOGRAPHS

Several projects in the Virginia Piedmont applying airphoto interpretation have been undertaken by the council. One is a cooperative study with the United States Bureau of Public Roads known as the "Charlotte County Low Cost Road Study"; another is a strip map of engineering materials along Route 7, Loudoun County, Virginia; and one recently completed is an engineering soils map for a proposed relocation of US 58 in Patrick and Henry Counties. Performance surveys of existing roads and soil-test data (excepting the latter project) have established the true significance of airphoto patterns in these areas. In Table I are some test results typical of soils found in this province in Virginia.

Schists and gneisses - Schists and gneisses are the most common parent materials of the Virginia Piedmont, comprising about 40 percent of the province. Metamorphosed in varying degrees, all of these rocks display definite cleavage or lamination. A subparallel regional drainage pattern is created by this structure. However, local drainage patterns ordinarily are subdendritic. Small gullies have compound gradients, steepest at the headward ends. In addition to the drainage pattern and gully section, another feature common to the airphoto patterns of these rocks is a heavy timber cover. This timber exists since the soils are relatively unproductive and are subject to severe erosion. Here the similarities cease! Chemically and physically these rocks have extraordinary differences that necessitate differentiation.

Granitized formations include those which have been altered by intrusion of granitic masses (5). Most of these rocks have become soft from intensive weathering. As one might envision, low, smoothly rounded ridges and broad, rounded drainage cross-sections create distinctive topographic features. Profiles of the residual soils normally have sandy silt topsoil, a silty-clay B-horizon, and friable disintegrated parent material in the C-horizon. These soil textures are conducive to erosion, which can be observed on the photograph. The most common pedologic soil type

TABLE I

SUMMARY OF SOIL TESTS

Parent Material	Pedologic Soil Type	Soil Profile Horizon	Depth Represented inches	Liquid Limit	Plasticity Index	Max Dry Density pcf	Optimum Moisture percent	H R B Classification	Modified C B R [a]	County
Granitized	Cecil	B	8-50	63	25	88	31	A-7-5(18)	9 2	Louisa
schists	"	C	50+	50	10	92	28	A-5(10)	7 7	"
and	"	A	0-12	25	4	113	15	A-4(3)	-	"
Gneisses	"	B	12-60	55	19	97	26	A-7-5(11)	-	"
	"	C	60+	48	5	95	28	A-5(5)	-	"
	"	B	12-60	33	6	100	23	A-6(6)	-	"
	"	B	12-60	79	16	86	33	A-7-5(9)	-	Charlotte
	"	B	12-60	53	10			A-7-5(10)	-	"
	"	C	60+	40	NP	92	21	A-4(1)	-	"
Mica	Madison	A	0-10	12	NP	120	12	A-2-4(0)	-	"
and	"	B	10-34	61	13	85	26	A-7-5(12)	-	"
Kyanite	"	C	34+	49	NP			A-5(0)	-	"
Schists	Talledega	C	36+	37	NP	101	17	A-2-5(0)	-	Grayson
	Louisa	C	24+	47	4	90	26	A-5(6)	-	Charlotte
	"	B	6-30					A-4(3)		"
	"	A	0-8					A-4(2)		Patrick
	"	B	8-24					A-7-5(11)		"
	"	C	24+					A-2-4(0)		"
Granites	Appling	A	0-10	13	NP			A-4(3)		Charlotte
and	"	A	0-10	26	5	118	12	A-4(3)		"
Granite	"	B	10-50	64	25	95	26	A-7-5(16)		"
Gneiss	"	B	10-48	47	4			A-5(6)		"
	"	B	10-48	47	15	103	22	A-7-5(8)		"
	"	B	10-48	63	14	88	24	A-7-5(14)		"
	"	B	6-40	61	17	96	24	A-7-5(15)		"
	"	B	8-45	62	15	94	25	A-7-5(14)		"
	"	C	48+	45	NP	104	18	A-5(3)	53 0	"
	"	C	48+	30	NP	121	12	A-1-b(0)		"
	"	C	45+	33	5	123	10	A-2-4(0)		"
	"	C	40+	27	NP	126	13	A-1-b(0)		Albemarle
	"	C	36+	33	NP	114	17	A-2-4(0)		"
	Wilkes	-	0-240+	39	NP	103	17	A-2-4(0)		Charlotte
	"	-	"	34	NP	114	16	A-2-5(0)		Henry
	"	-	"	47	NP	95	23	A-2-5(0)		"
Slates	Herndon	A	0-8							Charlotte
	"	B	8-24	52	17	93		A-7-5(13)		"
	"	B	8-30	66	23	88		A-7-5(17)		"
	"	B	8-24	56	24	101		A-7-5(16)		"
	"	B	8-24	61	13	-		A-7-5(14)		Halifax
Slate &	Georgeville	A	0-10	56	17	99	23	A-7-5(12)		Charlotte
Green-	"	B	10-30	58	17	99	25	A-7-5(14)		"
stone	"	B	10-28	76	35	-	-	A-7-5(20)	3 3	"
Associated	"	C	28+	46	19	99		A-7-6(11)		"
	"	C	28+	41	NP	84		A-5(8)		"
Aporhyo-	Davidson	B	8+	79	34	83	35	A-7-5(20)	6 8	Charlotte
lite	"	B	8+	40	7	196	22	A-4(7)		"
	"	B	8+	48	14	99	22	A-7-5(11)		"
	"	B	10+	48	19	-	-	A-7-6(14)		"
Green-	"	A	0-7	39	9	102	19	A-4(8)		Orange
stone	"	B	8-50	70	23	-		A-7-5(12)		"
	"	C	50+	weathered rock						"
Horn-	Iredell	C	30+	29	3	109	19	A-4(8)		Charlotte
blende	"	B	12+	63	15	93	27	A-7-5(12)	3.0	"
Gabbro,	"	A	0-10	14	NP	122	9	A-2-4(0)		"
Diorite	"	B	10-32	31	14	-	-	A-6(2)		"
Diabase	"	C	32+	25	9	121	15	A-4(1)		"
&	"	A	0-14	-	NP	-	-	A-4(2)		"
Amphibo-	"	C	50+	55	19	-	-	A-7-5(9)		"
lite	"	A	0-10	54	5	91	27	A-5(4)	5 3	Louisa
	"	B	10-30	31	11	114	16	A-6(9)	7 3	"
	"	B	10-30	73	34	85	26	A-7-5(20)	1 2	"
	"	B	10-30	57	26	93	26	A-7-5(17)	1 2	"
	"	A	0-8	30	10	106	19	A-4(PRA)	3 7	Loudoun
	"	B	8-30	47	23	101	22	A-6(PRA)	1 8	"
	"	B	8-30	60	34	93	30	A-6(PRA)	1 5	"
	"	C (weathered)	30+	31	9	109	17	A-4(PRA)	6 7	"
	"	C (weathered)	30+	33	8	108	19	A-4(PRA)	6 3	"
	"	C	30+	30	NP	124	14	A-2(PRA)	10 0	"
	"	C	30+	28	NP	124	14	A-2(PRA)	17 0	"
Sandstone	Bucks	B	10-30	29	3	115	-	A-4(1)		Charlotte
and	"	B	10-30	20	3	100	-	A-4(4)		"
Shales	"	B	10-30	28	16	110	-	A-6(8)		"
(Triassic)	"	B	10-30	41	12	-		A-7-6(5)		"
	"	C	30+	35	1	106		A-4(3)		"
	"	C	30+	40	20	113		A-6(6)		"

[a]The Virginia Department of Highways, Division of Tests, specifies that field compaction shall be 95 percent standard Proctor Therefore, California Bearing Ratios are determined on samples compacted accordingly - otherwise the C B R test and design procedure are standard

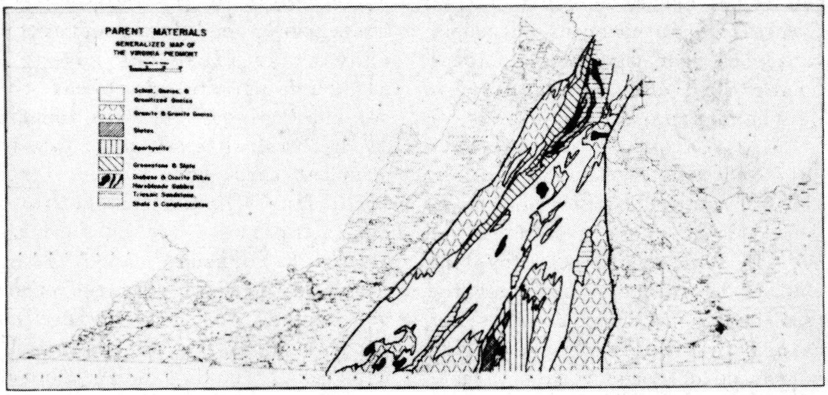

Figure 1. Geographic location of the Piedmont Physiographic Province in Virginia and associate parent material areas.

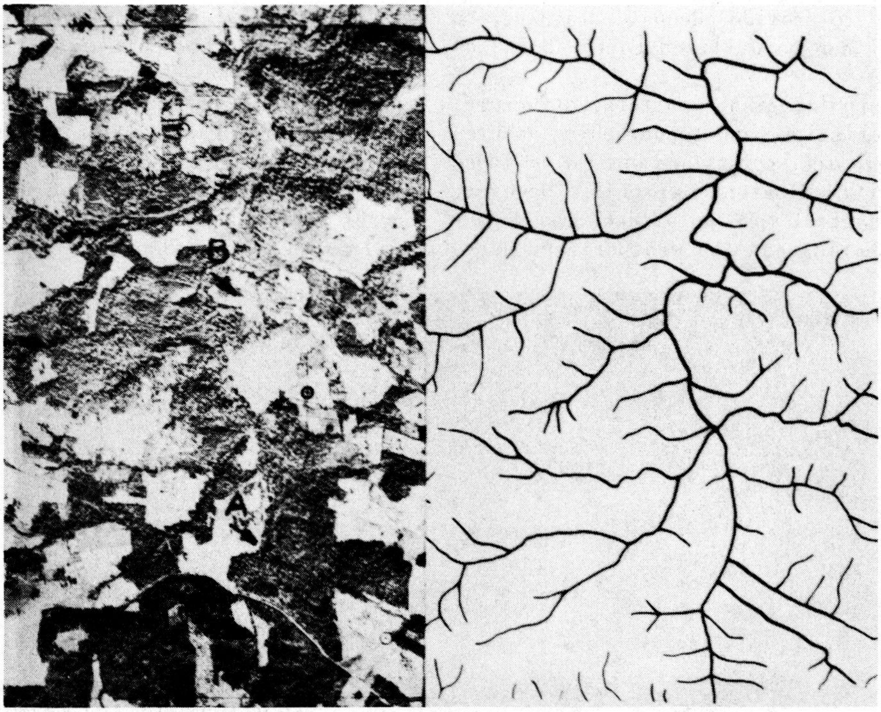

Figure 2. Left - Airphoto of granitized schist. Right - drainage map of same area. Narrow outcrops of garnitiferous talcose mica schist control drainage locations A and B.

is the Cecil series (6). Light gray soil color tones indicate that this soil is well drained. In place the B-horizon of this soil has a coarse, blocky structure that accelerates internal drainage. This structure is important in cut sections. Once the soil has been remolded, however, good drainage no longer exists. For engineering purposes the Cecil soils are fairly stable. If adequate drainage is provided, pavements constructed in these areas should perform well.

Hornblende gneisses and schists, although closely akin to the granitized rocks have several distinguishing features. These dark-colored rocks are more resistant to weathering, resulting in numerous outcrops. With resistant rock near the surface, local relief is increased and angularity, or control, of the drainage pattern is intensified. Soils, although shallow, are more clay-like and less erosive than those of the Cecil. The most common pedologic soil developed from these rocks is the Lloyd series. In addition to its clay-like properties, Lloyd has slabs of disintegrated rock in its C-horizon. This soil is not so well drained internally as the Cecil, thus darker gray color-tones result on aerial photographs. Excepting the effects of moisture, soils of the Lloyd series are fairly stable. Therefore the engineer is behooved to provide adequate drainage, so the soil can be utilized to the best advantage.

The areal drainage pattern, structural characteristics, and topographic features of quartz mica schists are similar to those of granitized parent material. However, their chemical make-up affects the degree of weathering and the weathered product, soil. Soils of the Madison series are the most common pedologic category developed upon these micaceous parent materials. Although almost identical to the Cecil series, Madison soils are identified readily by visual examination, for mica is abundant throughout the soil profile. This mica, finely divided in both A and B-horizons, imparts a greasy feel to the soil. In the C-horizon, large mica flakes and weathered or disintegrated parent material are found. Finely divided mica in the profile imparts elasticity and expansiveness to the soil. These properties apparently cause the Madison to be highly erosive, at least it is much more erosive than the Cecil series. Extreme erosion and medium-gray soil tones, as seen on aerial photographs, differentiate soils of the Madison from those of the Cecil. Additionally, Madison soils give the appearance on photographs of being "soft and fluffy," like freshly sifted flour. (Wind blown silt has this same peculiarity.) Darker color tones indicate these soils to be less pervious than Cecil soils. An

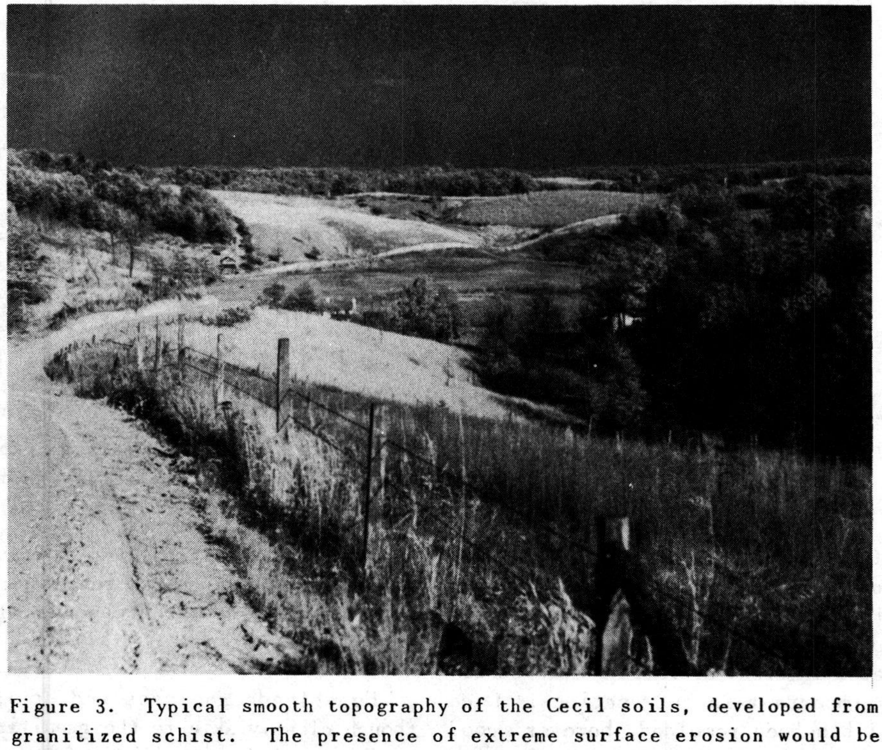

Figure 3. Typical smooth topography of the Cecil soils, developed from granitized schist. The presence of extreme surface erosion would be indicative of Madison soils.

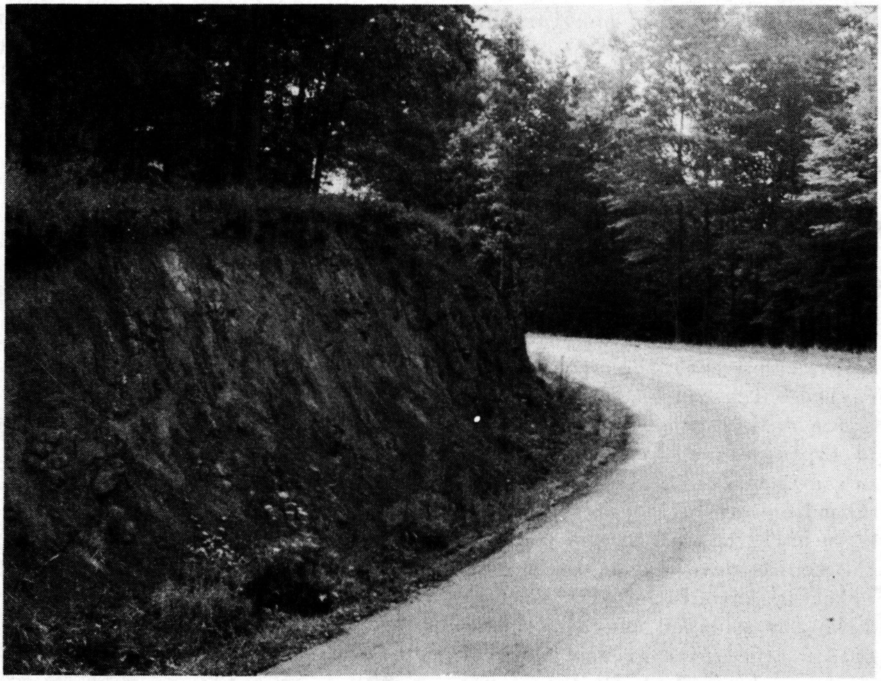

Figure 4. Soft weathered rock exposed in the profile of the Lloyd Soil Series. Poor surface drainage and clay-like soils caused the edge failure in the curve.

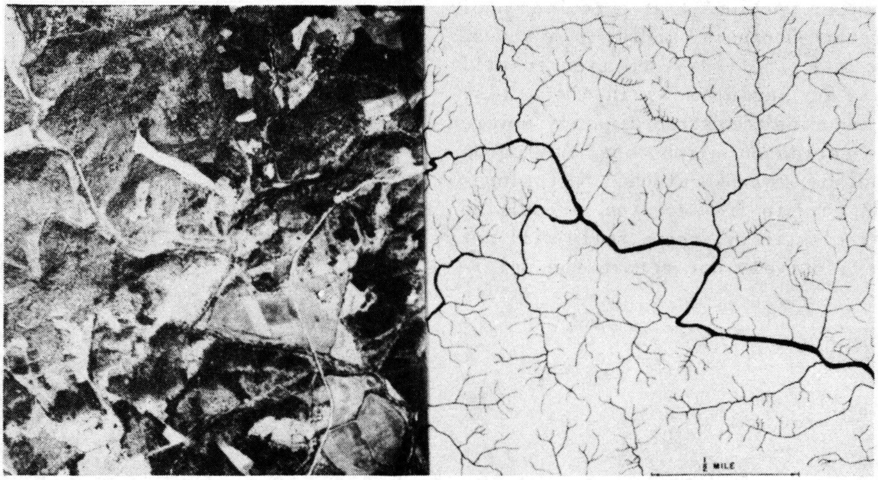

Figure 5. Left - Airphoto covering an area of talcose-mica schist. Rock structure causes the stream to divert sharply at A, while severe erosion creates surface scars at B. Right - drainage map of the area.

affinity to retain moisture and expansive properties make these soils undesirable for engineering purposes. Likewise, intense erosion causes caving-in of exposed embankments and back-slopes.

Chlorite-mica, talcose-mica, and kyanite schists are interspersed with other rock masses of the Piedmont (7). In most of their occurrences these rocks form ridges that rise as much as 150 ft. above surrounding terrain. Always these areas have numerous rock out-crops and angular surface features, e.g., spur ridges, sharp knobs, stream impediments. Likewise, larger streams express marked angularity and control. Both of these features denote a platy and fractured composition of parent formations. Small gullies egress from craggy ridges via short, steep ravines, thence plunge into rocky channels of principal watercourses. Peculiar to these rocks, gullies have an unusual cross-section which perhaps should be described as a broad V. However, the slopes have some concavity which causes rotundness of the V-section. Included among the pedologic soil types derived from these rocks is the Louisa-Chandler-Talladega Catena. Both the Chandler and Talladega series develop only in hilly to mountainous terrain, whereas the Louisa develops at lower elevations, closely associated with Madison soils. Like the Madison, each of these soils displays a definite greasy property throughout the soil. They are distinguished from Madison by an absence of distince profile horizons, grading from one texture to another. Soils are sufficiently clay-like in their upper portions that percolation of water is retarded causing medium-gray tones. Both talc and finely divided mica instill elasticity or springyness in the soils, probably inducing the extraordinarily severe erosion observed on airphotos. Analogous to the Madison, embankments and back slopes frequently cave in from erosion. Resulting from their elasticity, these soils will not compact effectively nor retain the original degree of compaction. Proper control of moisture during compaction and provision for surface drainage will improve the subsequent performance of pavements. However, location of highways outside these areas is recommended wherever possible.

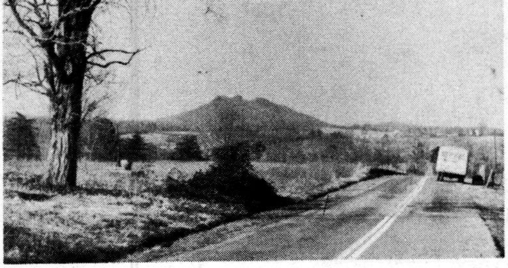

Figure 6. Topography of a Kyanite-schist ridge towering above normal Piedmont landscape.

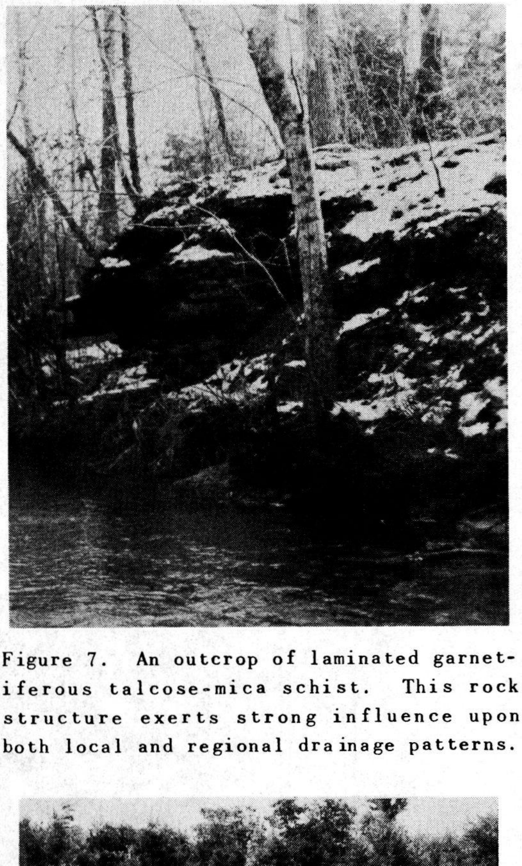

Figure 7. An outcrop of laminated garnetiferous talcose-mica schist. This rock structure exerts strong influence upon both local and regional drainage patterns.

Figure 8. Erosion of a highway cut in an area of Louisa Soil. A comparable display can be found in areas of the Madison, Talladega and Chandler Series. All are highly elastic and greasy, talc-like soils.

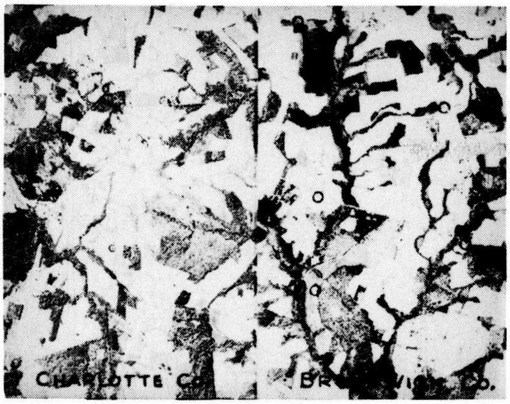

Figure 9. Airphotos of two distinctly different granites. Left - High quartz rock. Right - An aplitic or basic rock with broad dark areas indicative of poor internal drainage. Gullys are lined by trees in both locations.

Granites and Granite Gneisses - The next major parent material type of the Piedmont includes granites and granite gneisses which comprise about 25 percent of the province (8). These gneisses are introduced here rather than in the above section for they retain many features of the unaltered granite and they develop identical soils. Like the parent materials themselves, the associated airphoto patterns have a definite similitude. Terrain features and soils are dependent upon the chemical composition of the parent materials. Basic and aplitic rocks produce low undulating topography and soils with an abundance of expansive silty clay, particularly in the B-horizon. High quartz and binary rocks create hilly and sometimes mountainous topography and sandy soils. Gullies have broad, V-shaped cross-sections but rounded bottoms. Also, inter-

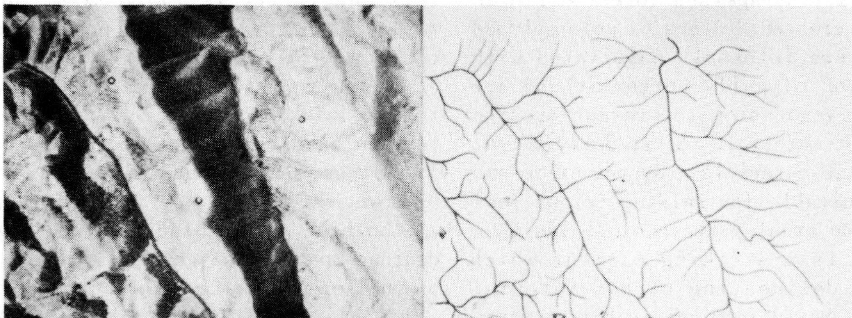

Figure 10. Left - Airphoto of granite area and quartzite (under sharply crested ridge to right of area). Right - Drainage map. Pattern elements for granite at B and for quartzite at C.

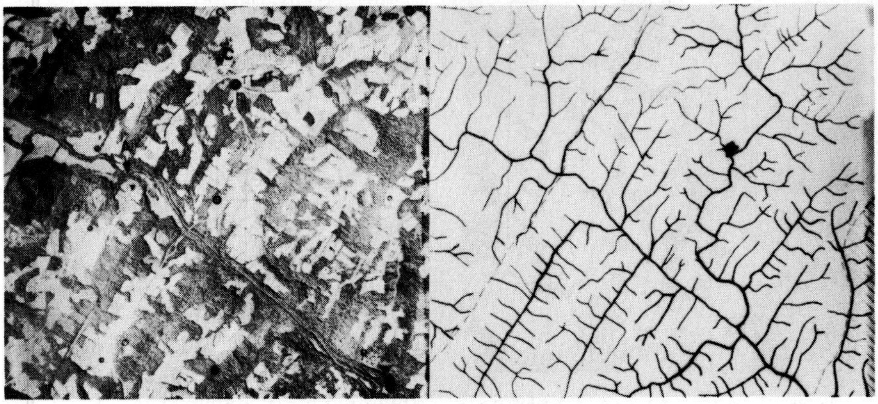

Figure 11. Left - Airphoto of granite gneiss and a schist. Streams deviate abruptly at boundaries of gneiss - locations A and B. Contour plowing and terracing at C. Right - Drainage map. Shaded area indicates schist.

stream divides have narrow but rounded crests. These terrain features become more rotund on the softer rocks. In more mountainous situations, gullies are decidedly V-shaped and interspersed forested ridges are sharply crested. Areas of more subdued topography are intensely cultivated with the exception of gully bottoms-these are shrouded by vegetation to prevent erosion of the parent material. Soils derived from these granitic materials are productive and often are suitable for raising bright-leaf tobacco. The areal pattern of fields thus cultivated is a striking element which assists in delineating parent-material boundaries. Soils from acidic (high quartz and binary) granites are quite porous, thus causing light-gray or white soil color tones. Basic and aplitic parent materials develop expansive silty clay soils that are only moderately pervious, thus resulting in darker soil color tones. Principal differences in the airphoto patterns of a granite and a granite gneiss are land forms and regional-drainage patterns. Both of these differences stem from a laminated structure in the gneiss, but locally even these features are similar. Granites have a combination radial and dendritic regional drainage pattern. Since the parent materials occur as intrusive dome-shaped masses streams radiate from the central portions. However, uniformity of the parent material causes local watersheds to be dendritic, hence the compound system. Near the border of a granite intrusion streams are affected by contrasting rock types, thus, frequently annular drainage patterns are established. This annularity is indicative that some marked structural feature prevails at the contact. Since landforms are developed, at least in part, by erosion, they must be interrelated to the stream system. Thus terrain features of granite accentuate the lithologic significance of the drainage pattern.

Contrasting the landforms and regional-drainage pattern of granite gneiss to those of unaltered granite, one notices a decided parallelism. A stream system associated with these metamorphic rocks will vary from a subparallel to trellis pattern. Consistent with this drainage system, the topographic features are parallel elongated ridges between watercourses. One peculiar feature of the drainage systems is identical for both granite and granite gneiss-small field gullies merge as tangential arcs, thus producing a distinctive curvilinear appearance.

Granitic rocks develop several soil types, depending upon chemical composition and topographic situation. Pedologically, residual soils include the Durham, Appling, Porters, and Ashe series from high-quartz and binary rock and occasionally some of the Helena series from basic and aplitic rock. (9) Durham and Appling soils, in that order, are about the most pervious soils in the Piedmont. Topographically they are situated on rolling to hilly terrain and their profiles are composed of sandy silt topsoil, a sandy silt-clay B-horizon, and disintegrated granite (containing much quartz sand) in the C-horizon. Good internal permeability and gradation of particle sizes make these soils desirable for subgrade and for select borrow, in some locations. As testimony for their quality, during the 1948 spring breakup survey the performance of 42 percent of the pavements in these soil areas was good. That survey did not subdivide granitic soils but the Appling Series predominated. Perhaps the most detrimental feature of these two soils is that of erosion. Their sandy texture and topographic position stimulate active gullying, therefore erosion of banks and slopes can be anticipated in advance. Entirely different from the above mentioned soils, the Helena series are impervious, dark-colored soils. In their profile Helena soils have a dense-clay B-horizon about 2 ft. thick, which restricts percolation and holds absorbed moisture. This wetness causes the dark soil color tones mentioned in the first paragraph of this section. These soils occupy low, flat to gently undulating topography. Pavements placed upon these soils have performed poorly, particularly in shallow cuts or where the B-horizon is intersected. Porters and Ashes series are found only in mountainous localities and

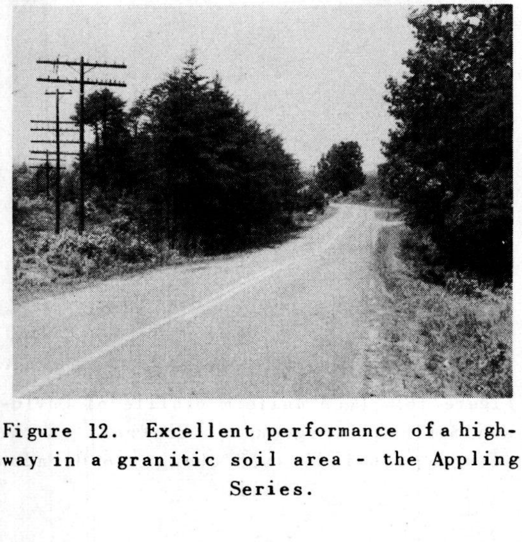

Figure 12. Excellent performance of a highway in a granitic soil area - the Appling Series.

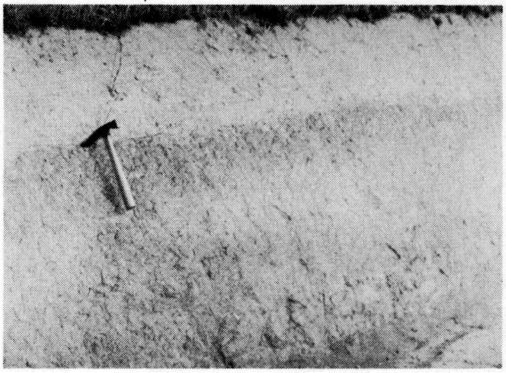

Figure 13. Soil profile of the Appling Series. Pick is driven at the top of the B-horizon. Small shrinkage cracks are evident near handle. Soil structure expedites percolation.

are well drained topographically and internally. Pavements in these areas appeared to perform well during the 1948 survey. Our airphoto work has not involved these soils as yet; therefore, further study is necessary before airphoto patterns can be correlated with the soil characteristics.

Some areas of binary granite or granite gneiss produce a soil classed as Wilkes. The Wilkes represents a phase rather than a soil series. In these areas a friable, elastic micaceous material extends from the ground surface to solid rock. This material usually has a dark-gray color. Erosion of this soil is atrocious and this characteristic, easily noted on aerial photographs, is the identifying clue to the soil type. As one would surmise, this soil is very poor for engineering purposes.

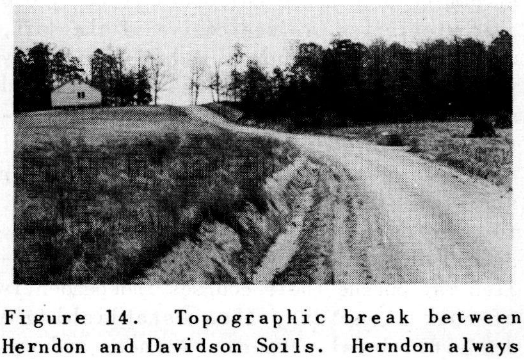

Figure 14. Topographic break between Herndon and Davidson Soils. Herndon always are situated lowest.

Figure 15. Erosion of typical Herndon soil profile. Dark color and shrinkage cracks indicate clay-like properties of B-horizon above the point indicated - C-horizon is below.

Slates - Slates are developed from metamorphosed, ancient, finely grained sediments - some being classed as siltstone or argillite (10). In Virginia are two major occurrences of slate, both south-centrally located. One is in the Virgilina State Belt, which comprises a system of slates, aporhyolite and greenstone. Another narrow belt, located in Buckingham County about 40 mi. north of the first group, includes some hard massive formations. The principal difference between these two formations is the degree of hardness, which affects their airphoto patterns. Slightly higher and more rolling topography is noticed in the northern section. Other elements of the airphoto patterns are alike for both areas.

Terrain features and stream cross-sections are broad and smoothly rounded; stream gradients are uniformly flat. These characteristics are indicative of the soft, uniform parent materials and residual clay soils. Structure of these metamorphosed sediments, which usually are laminated vertically, has decided influence upon areal drainage patterns. Streams, following strike features of the underlying slate, form subparallel to subtrellis patterns, dependent upon regional slope. Small gullies may pursue their courses independently of rock structure, thus establishing a dendritic local pattern. Wetness and unproductiveness of the soils have induced property owners to leave the land forested. However, where cleared fields are observed one can predict the impervious and wet soil condition on the strength of uniform dark color tones. In cultivated fields ditching is required to expedite surface runoff; these trenches are evident on the photographs.

The pedologic soils developed upon slate parent materials are the Georgeville, Alamance and Herndon Series, grading from the most porous to the least porous. Small areas underlain by black graphitic slates should be mapped as Helena series; these areas always are low and swampy. Georgeville soils are the highest of the group topographically. In addition, they are more silty and are uniform throughout to a depth of about five feet; here slabs of soft weathered slate are encountered. A fine cubical structure induces greater permeability than routine engineering-classification tests indicate. Both the Herndon and Alamance series are located in low topographic situations. Their soil profiles are shallow, for slate is found within 3 ft. of the surface. In this profile the B-horizon is quite plastic. Even more plastic and less pervious soils are included in the Helena series. This soil series, like the Herndon and Alamance, has a distinct but shallow profile.

Pavements constructed in slate areas have not given good performance. Low subgrade support is prevalent for the subgrade

Figure 16. Deep uniform profile of Davidson Soil in foreground. Contrast at the second post indicates change to Herndon Soil.

soils are susceptible to water. This quality is expressed by wavy centerlines, rough pavements, alligator cracking and subgrade failures. These soil areas require special considerations compared to such soils as the Durham, Appling, and Cecil series.

Aporhyolite - Found in the Virgilina Slate Belt is a material that has been classified as aporhyolite. As the name implies, this substance was developed by the alteration of rhyolitic lavas. The parent materials, either having no significant structure or losing it during weathering, are leached deeply and uniformly. This uniformity of parent material and soil permits a drainage system to select its own course without structural control. Thus, the areal drainage pattern can be described as a dendritic system. Maturely dissected soils from the aporhyolites have a somewhat higher topographic position than the adjoining slates, with hills creating local differences in elevation of about 30 ft. Deep, uniform, clay-like soils are reflected by the terrain characteristics. Interstream divides are wide and smoothly rounded. Gullies are long with uniform flat gradients and shallow, rotund cross-sections. Most of this locale is densely forested, but where fields are cleared soil color tones range from medium to light gray, indicating good internal drainage of the residual soils, which are the Davidson series. Locally, surface erosion of these soils appears as a white scar on the photographs; this feature is particularly noticeable along the boundary between aporhyolite and an adjacent material which has an impervious residual soil, such as Iredell or Herndon. Davidson soils are characteristically uniform beneath the A-horizon to great depths. They are elastic silty clays that become tempermental at certain moisture contents. When moist they may display a "rubbery" quality under compaction equipment. This quality can reduce the effective degree of compaction considerably, thus creating excess void space to be saturated later. Surface drainage is imperative in these soil areas.

Greenstone - Associated with slate and aporhyolite in the Virginilina Slate Belt is another parent material, commonly called greenstone. This is a green-colored product of altered volcanic rocks. Greenstone is not confined to the slate belt for other occurrences are even more signifi-

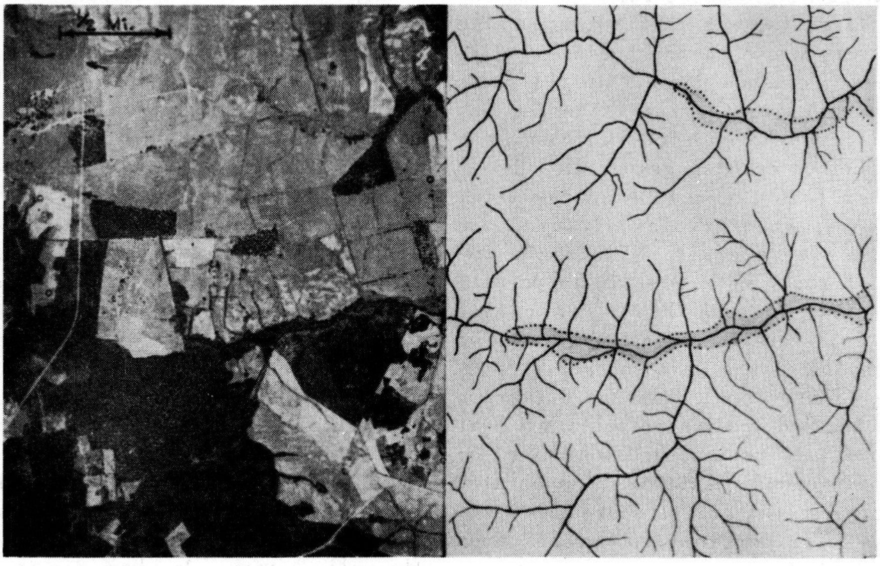

Figure 17. Left - Airphoto of schist and hornblende-gabbro. (Gabbro area is cleared.) Right - Drainage map of same area. Swampy stream bottoms are shaded.

Figure 18. Airphotos of hornblende gabbro in three widely scattered counties to show general similarities.

cant (11). This rock is the backbone of the northern Blue Ridge and is responsible for a number of prominent ridges in north-central Virginia. On the ridges durable rock is very close to the surface and is suitable for crushed stone. In the slate belt, however, weathering is deeper and only soft, weathered rock is found near the surface. Here topography is subdued but higher than the nearby aporhyolite.

Where resistant ridges dictate, the landscape watercourses reflect the influence of rock, but local drainage patterns appear uncontrolled, dendritic. Residual soils are identical with those of the aporhyolite, the Davidson series prevailing. Thus, local drainage patterns, gully shapes and gradients, soils and soil color tones, and agricultural practices of man are analogous. Likewise, associated engineering characteristics are the same. In fact, soils derived from greenstones are singularly uniform.

Dark-Colored Igneous Intrusive Rocks - Scattered throughout the Virginia Piedmont are small areas of basic igneous intrusive rocks, such as diorite, diabase, hornblende-gabbro, soapstone, chlorite schist and associated rocks. Within any one of these parent material areas uniform, clay-like soils are instrumental in developing a surface expression normally consisting of smooth, low, undulating watersheds and broad, shallow stream channels. Physiographically these soil areas may have the situation of a lowland with respect to surrounding parent materials. In each instance the areal drainage pattern is dendritic with gullies curving to merge at narrow angles, similar to those of granite. Individual watercourses, separated by broad, flat interstream divides that provide an open, or sparce, drainage pattern, have broad, shallow cross-sections and flat gradients. Occasionally a channel will widen, and an elongated swamp will occupy the gully bottom. In these parent material areas residual soils are too impervious for most agricultural pursuits; however, they are adapted to dairy farming. Thus, open, cleared pasture-land typify these parent materials, and the extensive clearing presents a striking contrast to adjacent forested areas associated with schist and other Piedmont formations. These open fields have overall dark soil color tones which reflect the impervious nature of underlying soils; actually the B-horizon is highly impervious, thus causing the ground to be wet almost continually. Soils derived from these basic rocks include Iredell, Helena, and Mecklenburg series.

All of these soils are poorly drained externally as well as internally; but the Mecklenburg soils are situated somewhat higher topographically, thus runoff is slightly accelerated. This higher situation has been conducive to deeper oxidation of the Mecklenburg, resulting in a deeper and siltier soil profile. Also this higher topographic situation, which may be only several feet in magnitude, differentiates this soil from its associates. Usually the Helena series is derived from a chlorite schist, soapstone, or graphitic slate, and these parent materials have a structure that is conducive to a subparallel stream pattern. If so, this feature will delineate the Helena from the Iredell. Members of this soil catena have a sandy A-horizon, an impervious B-horizon and a C-horizon of weathered disintegrated parent material. With one exception the C-horizon materials are friable and sandy, the Helena have an elastic, moderately friable silty clay material. Moisture permeates the clay-pan slowly where it then is retained for long periods. Upon drying, the clay-pan develops large shrinkage cracks which indicate high volume change. Pavements placed upon this clay suffer almost continuous failures, singularly severe during summer months when most roads are at their best. However, in the Iredell and Mecklenburg soils sandy parent material is encountered under the clay-pan. Pavements placed upon this sandy soil perform excellently. Significant performance is observed in cut-sections, failures always

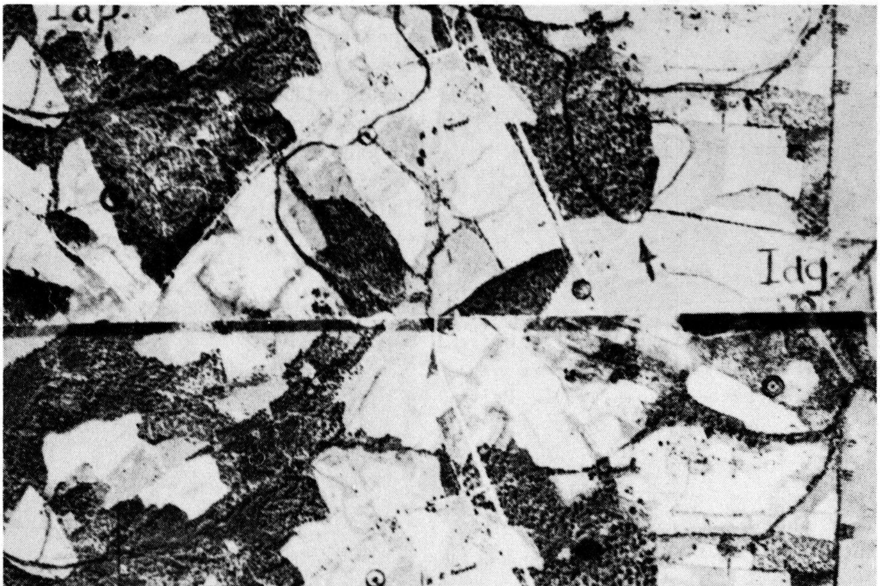

Figure 19. Stereoscopic aerial photograph showing contact of aporhyolite (Iap) and hornblende gabbro (Idg).

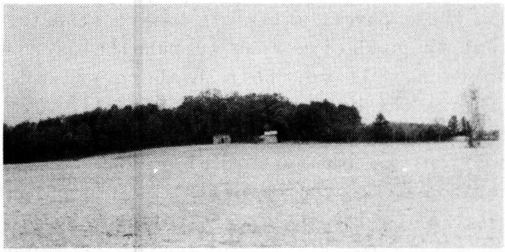

Figure 20. Relative topographic situation of Davidson and Iredell Soils, seen at the arrow in Figure 18. Davidson Soils comprise the forested rise.

Figure 21. Profile of Iredell Soil. Large shrinkage cracks indicate expansive clay in the B-horizon (between pointers). Below is the sandy C-horizon.

occur at the intersection of the B-horizon but not in the sandy C-horizon. Logically, traffic and pavement designs may modify this picture slightly.

Triassic Lowlands - At one period during geologic time, the Triassic period, sections of the Piedmont were down-faulted and inundated causing shallow inland bodies of water (12,13). These basins subsequently were filled by sediments washed in from the adjacent Piedmont upland. Occasionally the basal member will be a conglomerate, cemented by calcium carbonate, and lying above this will be many beds of shale and sandstone. Locally intercallated with the sedimentary formations, may be found beds which represent volcanic flows. Then at some more recent time these formations were intruded by dykes and stocks of basic magma which did not reach the surface, hence the name "trap rock." Subsequent uplifting, tilting and eroding have had marked influence upon the development of surface features and stream systems. Soft sedimentary strata have eroded readily, creating flat to gently undulating topography. These soft rocks were reduced more rapidly than the intrusive igneous bodies; this trap rock creates low, broad hills or ridges. This diabase material is similar in every way, except in age and topographic situation relative to surrounding materials, to other basic intrusive bodies scattered throughout the Piedmont Province; residual soils are identical. The areal drainage pattern in Triassic Lowlands is affected by type and inclination of parent formations. Tilted strata cause a general trellised appearance of stream systems. To be correct, this stream pattern might be described as subtrellis to subparallel, except where streams encounter sandstone and trap rock; the harder material causes abrupt deviation of stream channels.

Gullies developed in shale meander noticeably along their courses, but princi-

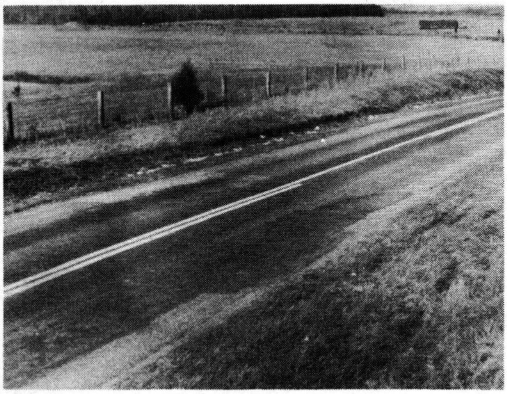

Figure 22. Performance of pavement in an area of Iredell. Failures always occur on B-horizon; none on C-horizon.

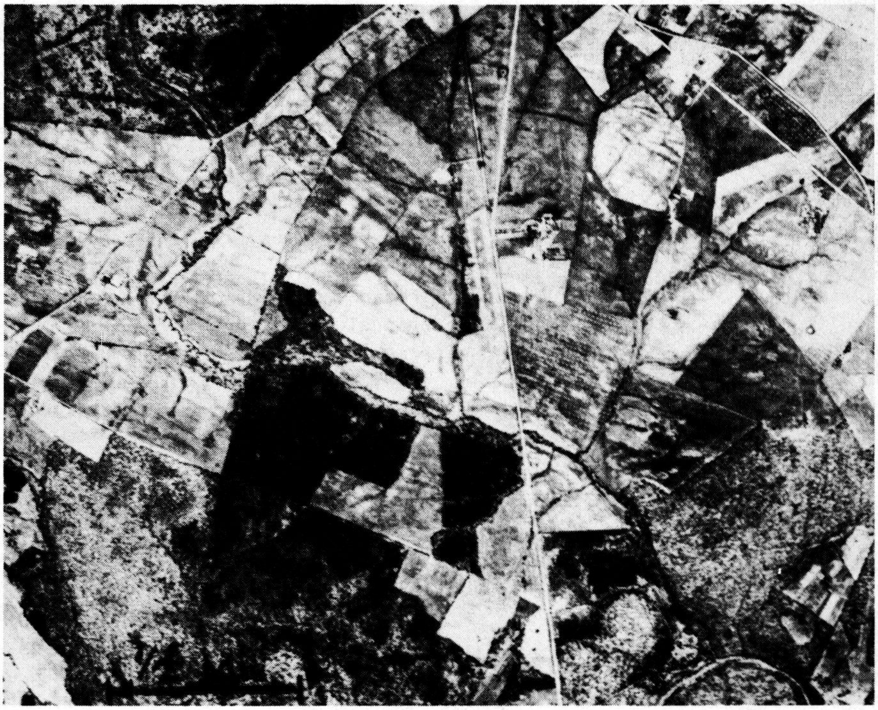

Figure 23. Airphoto of Triassic Lowlands. Shales predominate. Beds dip westward with about thirty degree inclination. Thus stream systems display parallelism.

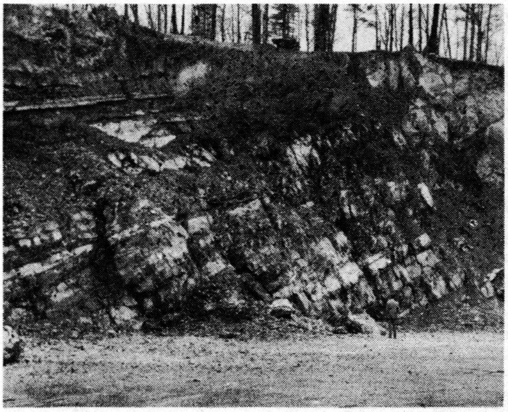

Figure 24. Exposure of tilted Triassic strata - volcania rock intercallated with sediments.

Figure 25. Topography of Triassic Lowland viewed from the Piedmont upland. The first break in slope observed along the road indicates the beginning of Granville Soils. Foreground soils are Cecil Series.

pal watercourses follow bedding planes. Gullies have broad, shallow cross-sections and flat, uniform gradients; interstream divides have low, rotund profiles. Both of these features are indicative of soft parent material and clay soils. In addition, dark soil color tones indicate low permeability of the soils.

The presence of sandstone gives rise to low, elongated ridges, to V-shaped gully

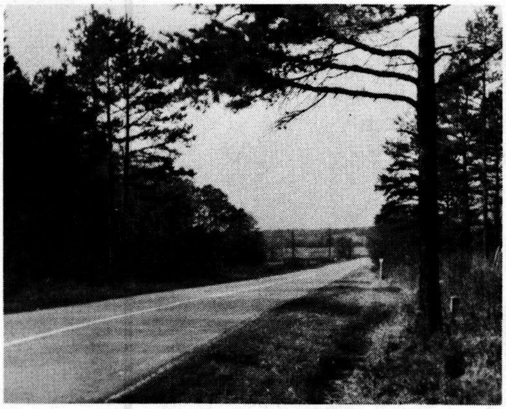

Figure 26. Flat terrain of Wadesboro soils. Wet subgrade has caused the rutting which is evidenced by a wavy centerline.

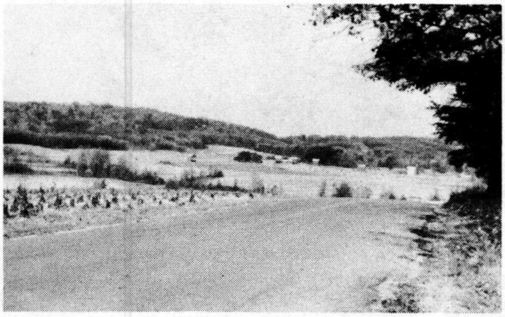

Figure 27. Landscape of Granville and Wadesboro Soils. Wadesboro are found on the prominent ridge, Granville in the foreground.

cross-sections and to sharp deviations in the courses of streams. If the rock is quite hard, the ridges probably will be timber-covered. Frequently, soft sandstones are encountered, and they are delineated only on the basis of soil color tones and, with luck, a slight rise in the ground surface. Residual soils from sandstone are much more porous than those of shale. Thus if a white streak is observed on an airphoto, by correct evaluation of all elements one can determine whether or not it represents sandstone.

The description of pedologic soils developed in Triassic Lowlands usually include several parent materials, probably a result of interbedded strata. Common soils are Penn, Lansdale, Bucks, Granville, Whitestore, and Wadesboro series. Our work has not necessitated delineation of all these soils, but several of them are easily decernible. Granville soils occupy low, flat terrain that is underlain, at shallow depths, by argillaceous shale. Found in rolling situations, the Bucks series develops smooth rolling topography; this smoothness reflects clay-like soils and parent shales. The Whitestore is situated higher topographically than the Bucks, and is developed from soft sandstone and some arenaceous shales. Closely associated with Whitestore soils, and at even higher topographic situations, is the Wadesboro series. The Wadesboro develop upon ridges composed of sandstone, arenaceous shale, conglomerate, and igneous rock (which probably represents an intercalated volcanic flow).

Internally, these various soils have low permeability; they have good surface drainage only if their topographic situation is suitable. Thus, prevailing clay-like soils and little surface drainage create undesirable subgrade conditions. Pumping of rigid pavements and base or subgrade failures of flexible pavements are some of the common ailments of highways located in the Triassic Lowlands.

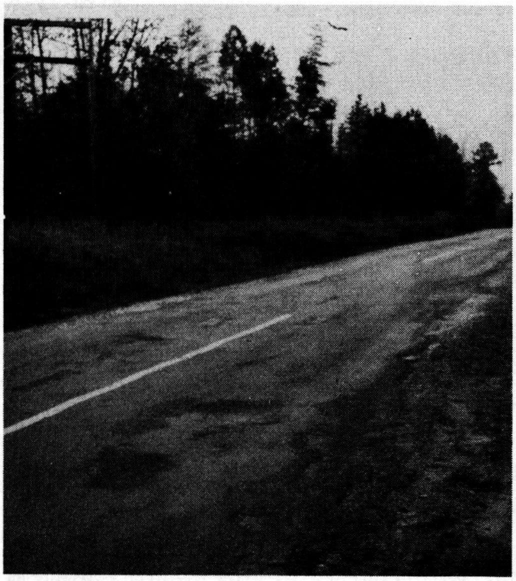

Figure 28. Poor performance of a pavement placed upon clay-like soils of the Bucks Series. Clay shales and moisture have this detrimental effect unless a high level profile is employed.

SUMMARY

Identification of soils by airphoto interpretation is based upon the premise that any given parent material in one climatic belt and in similar topographic situations will weather to produce the same soil and that the properties of a given soil influence the development of its surface features, natural or man-made. In mapping differences observed upon an aerial photograph one should be delineating different soil types. In the Piedmont soils are very complex, just as are the parent materials. A close interrelationship exists which must be considered if the soils are to be differentiated adequately. Our work has progressed for only a short time, but these applications have indicated a definite correlation exists between reoccurring soils and their airphoto patterns, even though the areas are widely separated. Much work must be done in actual correlating and checking a number of soil types and their airphoto patterns before this method can be extended; however, to date certain features are obvious.

CONCLUSIONS

1. Piedmont parent materials can be identified and mapped by the interpretation of aerial photographs even though their occurrence be complex and intermixed.
2. Soil types, as well as parent materials, have definite features which are obvious on aerial photographs and which are significant in their segregation.
3. The soils are related to their parent materials, but a given soil type may be found in several different parent material areas.
4. More than one soil type might be found in a single parent-material area.
5. Parent materials alone do not provide a complete picture of the extent of soil types. One must delineate soil types within major parent materials areas before the engineering characteristics associated with a soil province can be utilized.
6. The performance of pavements is related to the soil types, and therefore, the soils must be mapped to accomodate significant differences other than parent material borders.
7. Although mapping done from aerial photographs does not include the detail one finds on a Class-I agricultural soil survey map, it does group the soils into significant major areas, from an engineering materials standpoint.
8. Work completed so far demonstrates feasibility of this mapping technique, and with additional work a greater number of the soil types found in the Piedmont can be mapped. Once airphoto patterns are established and correlated, assistants could be trained and engineering soil maps could be developed on an areal basis.
9. Maps could be prepared by graduate students as thesis projects and would be combined to provide coverage for the Virginia Piedmont.
10. Further work in other areas would make possible the publication of an engineering soil manual of the entire state.

ACKNOWLEDGEMENTS

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MAPPING OF GEOLOGIC FORMATIONS BY THE APPLICATION OF AERIAL PHOTOGRAPHY

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SYNOPSIS

Previously generalized parent-material areas have been mapped successfully by the application of aerial photographs. This project is unique in that geologic formations have been mapped by this method.

This paper describes the geologic mapping of an area in the Ridge and Valley Province of central Augusta County, Virginia The rocks are of sedimentary origin with a few igneous intrusives, shale, limestone, and sandstone being the predominant rock types. The formations are of late Cambrian and Ordovician age. Some of the limestone formations have a high calcium content, with little impurities; others contain much chert and argilaceous material. For this reason separation of these formations was desirable.

Key formations with known physical characteristics and chemical composition produced distinctive airphoto patterns, the repetitive nature of which made possible the delineation of each formation. As an example, one formation contained much chert; upon weathering knolls and rounded hills resulted. These features stood out from surrounding topography making the formation easy to trace. Another formation high in calcium was found to occupy low topography. This too was delineated. By knowing the relative position of these key formations in stratigraphic sequence other formations thus fell into place.

Representative samples of soils and aggregates were obtained and routine tests were performed. Results of these tests were tabulated so that the extent of formations containing both suitable and unsuitable materials would be known.

This paper describes the procedure, methods, and results of the application of aerial photography to geologic mapping. The successful application of this technique has been proven. Its extension to other areas is indicated.

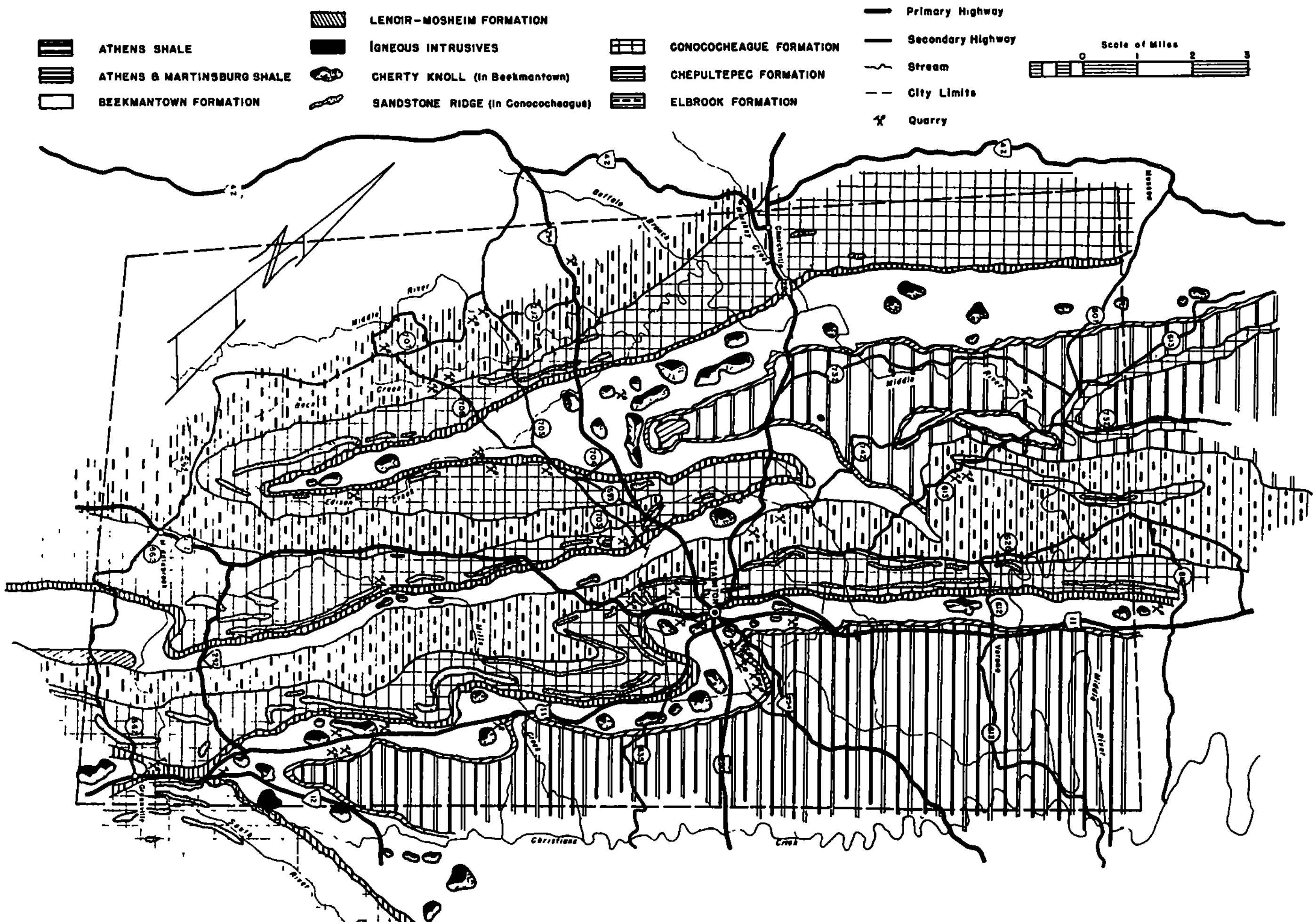
Since the year 1858 when the first aerial photograph was taken (22), aerial photopography has contributed much to the advancement of science and industry. Airphotos were used by the U.S. Coast and Geodetic Survey as early as 1920. Soon after this the United States Geological Survey began using them in making topographic maps and in 1933 airphotos were applied in soils conservation work (23). Military forces have used airphotos quite extensively and the greater portion of all military and naval intelligence is based on their interpretation (10).

Today aerial photographs have many uses. Some of the most notable are in forestry and in many phases of engineering work. Some of the engineering uses are in highway, airport, and railway locations and in highway performance studies, traffic studies, location of dams and reservior sites, drainage and watershed problems, irrigational projects, city and regional planning.

Aerial photographs have been used to some extent in geology for determining structural features (16); but principly they have been used as a base map for field work. As far as can be determined to date, airphoto interpretation has not been utilized for preparing stratigraphy maps, i.e., maps showing the extent of and naming geologic formations in the correct age sequence.

It is the purpose of this paper to demonstrate the application of airphoto interpretation to geological mapping of sedimentary strata. The project was initiated as a research problem for the Virginia Department of Highways and also as a thesis

Geologic Map of a Portion of Augusta County, Virginia



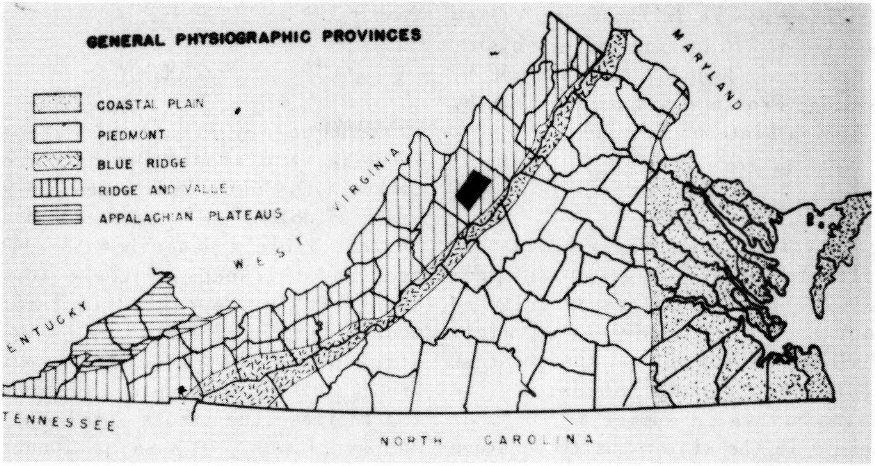


Figure 1. Map of Virginia showing relationship of area investigated to physiographic provinces.

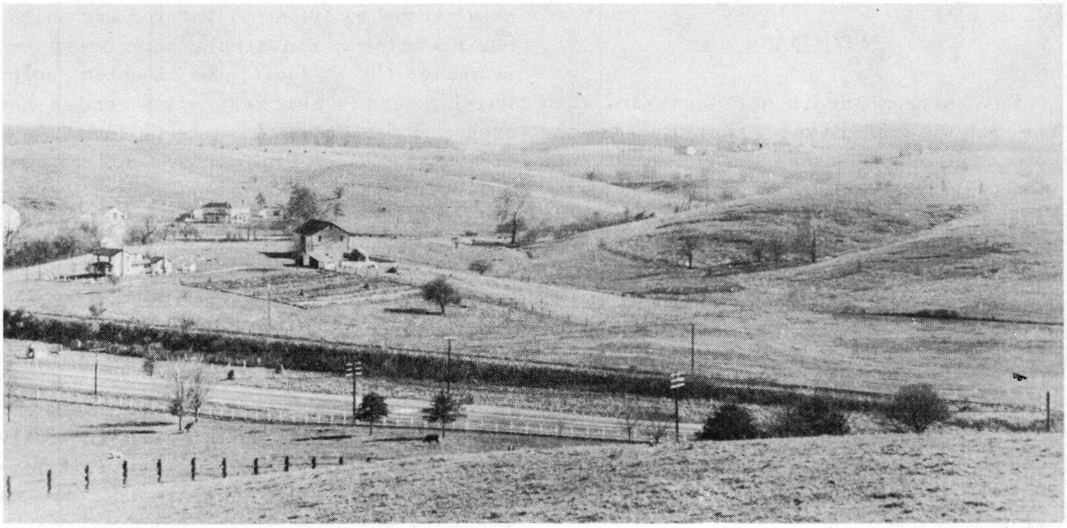


Figure 2. Typical shale topography. Notice rounded broad hills and gully system.

in partial fulfillment for a master's degree in geology at the University of Virginia.

Before beginning this study a survey of all existing literature pertaining to the investigation was made, included was geology, pedology, and airphoto techniques.

After completing this initial literature survey the airphotos were assembled as a moziac and studied to provide an overall areal picture. On this mozaic were traced generalized boundaries of areas which were strikingly different and features that were obvious. Refinement of these general borders was accomplished by stereoscopic study of individual photo pairs. Subsequent field work provided correlation of the geologic formation with airphoto patterns.

LOCATION

The area discussed in this paper is in the central portion of Augusta County and comprises approximately 200 sq. mi. (See Fig. 1.) This area is in the Great Valley of the Appalachian Ridge and Valley Physiographic Province, bounded on the east by the Blue Ridge Province and on the west by the Appalachian Plateaus Province.

CLIMATE

The county is situated in a humid-temperate climate. An average annual precipitation of about 38 in. is distributrd throughout the year. Heaviest rainfall occurs from May to August and the greatest snowfall in January and February. The average temperature in summer is 70 F. or more, whereas in the winter the temperature averages approximately 37 F. The prevailing wind direction throughout the year is southwestward, in line with the strike of the strata and of the ridges.

DRAINAGE

Most streams drain northeastward into the Shenandoah River, thence into the Potomac River; however, the southwest portion of this area is drained by tributaries of the James River. Streams of the area have a trellis regional drainage pattern, principal water courses being of subsequent origin. Perenial gullys, of resequent origin, locally form dendritic drainage patterns.

In limestone areas drainage is internal through sinkholes and caverns formed by percolating waters through bedding planes, shaly partings, points, fractures and other structural openings.

TOPOGRAPHIC FEATURES

The general relief of Augusta County is that of a broad relatively smooth valley flanked both on the east and west by high mountains. Within this so-called valley certain erosional features are distinctive. Over broad areas the terrain features are those of a sinkhole-studded plain; but locally other surface expressions included are: elongated knolls; discontinuous low ridges, rounded conical hillocks; and smoothly undulating landscape. The elevation above sea level in this area ranges from 1,200 to 2,200 ft.

GEOLOGY

Sedimentary strata of Paleozoic age underlie the area. Ranging from Upper Cambrain to Middle Ordovician the rock consists of dolomite, limestone, sandstone and shale. Table 1 describes the lithology, age, and thickness of these formations. These strata, deposited in large inland seas millions of years ago, were greatly stressed at the close of the Paleozoic Era by crustal movements. Resultant folding inclined the strata forming anticlines and synclines. The major structure developed was the Massanutten Syncline which plunges under north of Greenville, Virginia. The western limb of this syncline is exposed in the area investigated, its' axial trough is filled by Martinsburg shale. During deformation strata were disrupted by a major thrust fault, the Staunton Fault, which extends northeastward across the area. Older strata have been thrust upon strata of younger age. Subsequent erosion, following this folding and faulting, exposed resistant strata.

PREVIOUS INVESTIGATIONS

Geological work done previously in Augusta County, has been of a general nature only. One of the workers was William Barton Rogers, who with his brother H. D. Rogers, was the first to interpret correctly structural geology of the Valley of Virginia (18). In 1911 a geological map of Virginia was published by Dr. Thomas L. Watson, then director of the Virginia Geological Survey. In 1928 the current geologic map was published under the direction of G. W. Stose.

One publication of Dr. Charles Butts, on the Appalachian Valley of Virginia (2), contains a concise summary of the character of each of the formations together with a geologic map. Another of his publications on this same area consists of a descriptive text, in two parts, including illustrations of stratigraphy, geologic structure, geologic history, and index fossils (3).

A later publication by Dr. Raymond S.

Edmundson gives accurate information on the location, thickness and chemical composition of important industrial limestones and dolomites of the Appalachian Valley of Virginia (7).

DISCUSSION OF RESULTS

In studying aerial photographs stereoscopically, minute differences are observed. These differences constitute airphoto patterns of several so-called pattern elements, including: landform, regional drainage pattern, gully cross-section and gradiants, soil color tones, vegetation, man made features, and breaks in stream coarses. Much has been done in correlating airphoto pattern elements with differing material types; but for this study these pattern elements have been correlated with individual geologic formations.

The several formations of the area investigated have distinguishing features that are evident on aerial photographs. A detailed discussion of these formations with their characteristic airphoto patterns is given as follows:

1. Athens and Martinsburg formations, of middle Ordovician age, are predominantly shale and calcareous shale, the Athens containing interbedded limestone. Figure 6 shows an outcropping of this limestone.

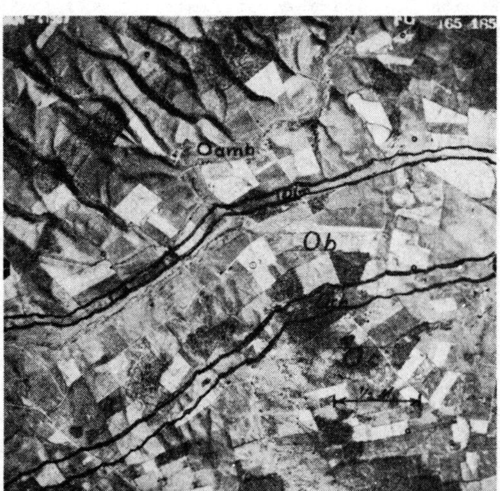


Figure 3. Airphoto showing contact of Athens and Martinsburg shale (Oamb) and Lenoir - Mosheim Limestone (Olm).

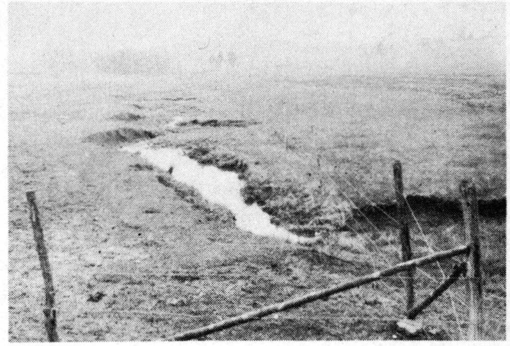


Figure 4. Photo showing meandering stream course typical of uniform soft shale.

Both of these formations were found to be characterized by low subdued topography. Streams develop a meandering course and have a smooth round cross-section, indicative of a uniform soft material. (See Fig. 4.) Interstream divides are broad, rounded and very smooth. Gradients are flat and uniform. In Figure 2 may be noted this typical shale topography. Figure 3 shows this same topography as seen on an aerial photograph. Here it may be seen that the shale differs greatly from the limestone. As compared to the limestone area shale is much more dissected, the shale being a uniform softer material weathering only by surface water action and the limestone weathering mostly by solution. Figures 5 and 7 show the differences in drainage of these differing rock types. Also, in Figure 5 a break in the stream course passing from limestone to shale may be noticed. The color tones of the shale are darker than those of the adjacent areas, indicating the imperviousness of the shales (Fig. 3). These shales are bounded below by older limestone strata and may be distinguished from the other formations by the evidences mentioned above.

2. The Mosheim and Lenoir formations occur conformably below the Athens shale. The Lenoir, which over lies the Mosheim is a thick-bedded, medium grained, dark-gray limestone containing thinly bedded chert. The Mosheim is a glassy-textured chemically-pure limestone.

Due to bedded chert, the Lenoir upon

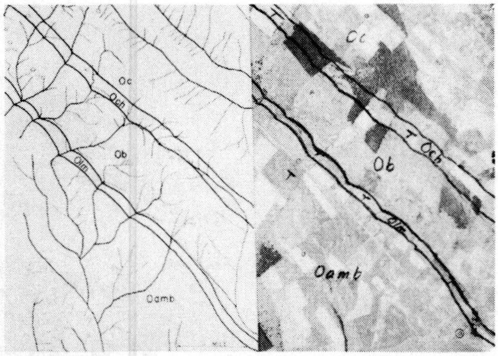


Figure 5. Drainage crossing limestone into younger shale strata. Notice stream pattern and change of stream course entering shale.

weathering resulted in low elongated knolls, as may be seen in Figure 12. These knolls have a rounded top and steep slopes. Solution is not in great evidence, however, a few scattered sink holes were noticed on top of these knolls. These probably were at the contact of the Mosheim and Lenoir, since there is a great difference in lithology. Numerous water gaps are found cutting across the strata. Streams parallel both edges of this formation and cut across the gaps. Comparing these knolls to sandstone ridges developed in a nearby formation it was noticed that the Lenoir-Mosheim knolls were more rounded and less covered by forest growth.

The Mosheim, being a high-calcium limestone, is quarried extensively for industrial lime, and it may be noticed in Figure 9 that quarries follow the strike of this strata. Due to the excessive chert content the Lenoir-Mosheim formation had color tones which were lighter than the adjacent formations as seen in Figure 10. Figure 11 shows one of the structures in this area. The strata is seen on the airphoto to bend around and change in its dip, indicating a syncline. Of interest also in the pocket of Lenoir-Mosheim within the axis of the syncline. This is due to minor local folding of the Lenoir-Mosheim formations. The break in stream course and topographic relations are the main criteria used in determining the boundaries of this formation.

Figure 6. Outcropping of Athens limestone. Note slablike structure.

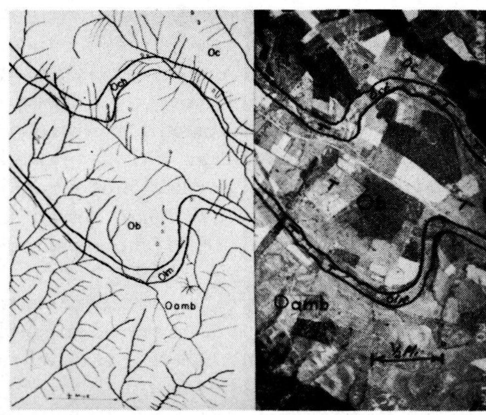


Figure 7. Drainage of limestone and shale. Notice break in stream course on entering the shale strata and the relation of the streams on the geologic formations.

3. The Beekmantown formation occurs below the Mosheim formation. This is a dark-blue compact limestone interbedded with dolomite. Great pockets of spongy chert contained in the formation results in large conical hills that stand out pronouncely above the terrain. These hills slope steeply and are covered by forest growth (Fig. 13). Streams that traverse this area develop a trellis pattern, major streams paralleling the strike with tributaries cutting in at right angles (see Fig. 14). Only a few scattered sinkholes occur in the Beekmantown, for on the whole this limestone is resistant to solution. Indicative of this are rocky streams beds. Streams that cross this formation break at

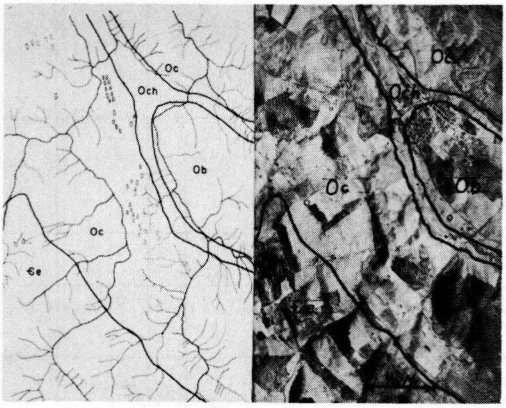


Figure 8. Drainage of limestone strata. Notice the alignment of the stream with the strike of the strata.

its boundary. Generally the color tones are medium to light in intensity.

4. The Chepultepec formation occuring below the Beekmantown, contains pure limestone and some dolomite both of which produce lower topography than adjacent strata (see Fig. 15). Streams crossing this formation break in their course at the boundaries. Major streams follow the strike of the strata either at a contact with adjacent formations or through the center of the Chepultepec. Figure 8 shows drainage crossing and paralleling the Chepultepec. Although streams usually flow in filled channels scattered outcrops of bedrock occur. An absence of solution is quite noticeable.

5. Conococheague, an upper Cambrian formation which underlies the Chepultepec, is a thick-bedded, predominantly blue limestone. Most diagnostic features, megascopically, of this formation are beds of coarse-grained sandstone and laminae of siliceous and clayey material, as seen in Figure 19. Beds of sandstone, occuring as irregularly distributed lenses, may be evident in some localities but absent in others.

Where these sandstone beds are steeply inclined, weathering makes low but long sharply crested ridges (Fig. 20). Figure 21 illustrates the steepness of some of these sandstone ridges. These ridges conform with the strike and where there is flexure within a formation the ridges also bend (Fig. 17). These ridges are thickly covered with forest growth, for they are too rocky and steep to farm (Fig. 16). Streams flow in rocky channels along the strike of the strata and occasionally across the strata thus developing a regional trellis drainage pattern. Sinkholes are numerous in certain parts of the formation. These sinkholes are in line with each other and tend to be a bit elongated (Fig. 18). Due to the internal drainage the Conococheague locally gives a mottled color.

6. The Elbrook formation occurs below the Conococheague formation. The Elbrook

Figure 9. Lenoir-Mosheim formation (Olm). Notice the flexure in the strata and the quarries following along the border of the formation.

TABLE 1

GEOLOGIC FORMATIONS IN AREA INVESTIGATED

AGE	FORMATION	THICKNESS	LITHOLOGY
Middle Ordovician	Martinsburg Shale	1,500-3,000	Dark colored calcareous shale with interbedded limestone.
Lower Ordovician	Athens Shale	600-5,000 ±	Black fissile shale with black thin-bedded compact conchoidal limestone and argillaceous bluish limestone.
	Lenoir Limestone	50-200	Fine to medium grained dark gray limestone with thin beds of chert.
	Mosheim Limestone	50-100	Glassy (vaugnitic) textured limestone very pure limestone (chemically).
	Beekmantown Limestone	800-3,200	Interbedded dolomite and limestone - the limestone dominates the dolomite in quantity - contained in the limestone are immense pockets of spongy chert.
	Chepultepec Limestone	400-500	Chemically a rather pure limestone with intercalated beds of more or less magnesium limestone and dolomite. The limestone is commonly thick bedded, blue and finely crystalline with a few siliceous partings.
Upper Cambrain	Conococheague Limestone	1,200-2,000	Thick bedded blue limestone which forms about 75% of the formation most of the remainder being dolomite. The most diagnostic features are beds of coarse grained sandstone and laminae of siliceous and clayey material.
	Elbrook Dolomite	2,700-3,400	Interbedded clayey limestone and impure dolomite.

TABLE 2
SOIL TEST RESULTS

GEOLOGIC FORMATIONS	LIQUID LIMIT	PLASTICITY INDEX	H. R. B. SOIL CLASSIFICATION	OPTIMUM MOISTURE	OPTIMUM DENSITY	MODIFIED C B.R.*	HORIZON	DEPTH INCHES
	36	10	A-4 (8)	21.8	102.3	3.5	A	0-10
	30	N-P	A-4 (4)	20.5	102	23.3	A	0-10
	36	7	A-4 (8)	23.5	95	10	A	0-10
	33	3	A-4 (4)	20.8	102	17	A	0-10
	35	6	A-4 (8)			0	A	0-10
	36	8 0	A-4 (8)	20.3	98.2	5	A	0-10
	55.20	16.28	A-7-5 (14)				B	10-50
Elbrook Dolomite	58	26	A-7-5 (18)	31.3	88.8	9	B	10-50
	67	18	A-7-5 (16)	30.2	88 9	10	B	10-50
	46	9	A-5 (10)	22.8	99.5	13.2	B	10-50
	51.1	18.2	A-7-5 (14)				B	8-30
	55	13.1	A-7-5 (11)				B	8-30
	32	12	A-2-6 (1)	13.2	121	23.3	C	50-
	38	11	A-6 (3)	17.7	108.8	7.5	C	50-
	35	8	A-4 (8)	20.8	100	6 7	C	50-
	52.4	4.1	A-5 (11)	25	93	16	C	30-
	43.5	14.46	A-7-6 (10)				C	36-
	48.80	23.48	A-7-6 (15)				C	36-
	24.60	9.72	A-4 (8)				A	0-10
	28.8	4.2					A	0-10
	28.4	11.8					A	0-10
Conococheague Formation	42.23	16.68	A-7-6 (11)				B	10-50
	45.40	24.65	A-7-6 (15)				B	10-50
	47.8	13.8					B	10-50
	60.20	28.62	A-7-5 (19)				C	50-
	46.30	23.76	A-7-6 (14)				C	50-
Chepultepec Formation	34.30	12.06	A-6 (9)				A	0-12
	58.84	26.81					B	12-48
Beekmantown Formation	26.0	5.39	A-4 (8)				A	0-12
	25.5	5 05	A-4 (6)				A	0-12
	34.5	14.5	A-6 (10)				B	12-36
	38	14	A-6 (9)	21.7	99.2	11.3	C	36-60
	31	9	A-4 (8)	17.1	110.2	15.8	C	36-60
Lenoir-Mosheim Formation	30.00	10.16	A-6 (8)				A	0-8
	26.4	7.65	A-4 (8)				A	0-8
	32.70	10	A-4 (8)				A	0-8
	67	38.08	A-7-6 (12)				B	8-42
	51	18	A-7-6 (12)				C	42-
	51.40	27.83	A-7-6 (17)				C	42-
	56.60	29.33	A-7-6 (19)				C	42-
Athens Formation	30.20	6.17	A-4 (8)				A	0-8
	50.70	29.37	A-7-6 (18)				B	8-40
	48.80	24.73	A-7-6 (16)				C	40-

* Modified C.B.R. is based on 95 percent standard Proctor Compaction, the rest of the test is standard.

TABLE 3

AGGREGATE TEST RESULTS

GEOLOGIC FORMATIONS	SPECIFIC GRAVITY	ABSORPTION	SOUNDLESS LOSS	LOS ANGELES GRADING	LOS ANGELES LOSS (500 REV.)	QUALITY GRADE
Conococh-eague	2.72	.33	O.K.	A	24.6	A
	2.81	.05	O.K.	A	22.1	A
Beekmantown	2.70	.26	O.K.	A	30.3	A
	2.81	.67	O.K.	A	22.9	A
Lenoir-Mosheim	2.73	.29	O.K.	A	28.7	A
	2.74	.19	O.K.	A	26.0	A
	2.78	-	-	B	20.0	A
	2.76	-	-	B	27.0	A
Chepultepec	2.83	-	-	B	24.0	A
Elbrook	2.81	-	-	A	14.2	A

TABLE 4

RESULTS OF ADHESION TESTS

Courtesy of Division of Tests, Virginia Department of Highways

Sample No.	Elbrook Percent Adhesion By (1) Weight	Elbrook Percent Adhesion By (2) Estimate	Conococheague Percent Adhesion By Weight	Conococheague Percent Adhesion By Estimate	Beekmantown Percent Adhesion By Weight	Beekmantown Percent Adhesion By Estimate	Lenoir-Mosheim Percent Adhesion By Weight	Lenoir-Mosheim Percent Adhesion By Estimate
1	76	95	63	80	79	85	51	90
2	71	95	98	99	60	85	96	98
3	27	85	33	80	69	95	83	98
4	22	85	49	88	91	95	93	99
5	43	88	82	95	67	95	71	95
6	36	80	48	88	48	90	35	75
7	36	85	61	85	76	90		
8	16	70	50	85	76	90		
9			47	90	91	98		

(1) Tested by Type I method, see Appendix, page 34.

(2) Tested by Type II method, see Appendix, page 36

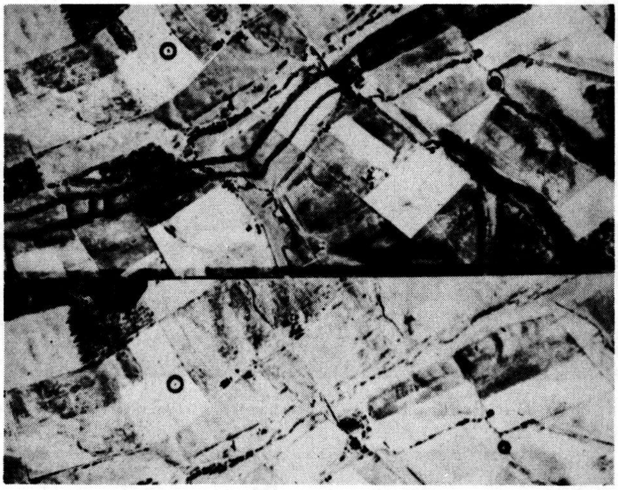


Figure 10. Stereo pair showing Lenoir-Mosheim formations. Note soil color tone is lighter than adjacent strata.

Figure 11. Synclinal structure showing the Lenoir-Mosheim formations (Olm) plunging under the Beekmantown formation (Ob). Note the pocket of (Olm) within the axis of the syncline. This is due to local folding of the Lenoir-Mosheim formations.

is predominantly a dolomite, however locally it contains considerable amount of thinly bedded argillaceous limestone or dolomite.

Due to low solubility, the Elbrook also results in ridges; however, these are not as sharply crested or as extensive as the sandstone ridges of the Conococheague. Streams have a trellis pattern and also a rocky bed. Because of the argillaceous material striations of parallel bands were noted on the airphotos.

It may be seen from this brief discussion that all of these formations have characteristic features distinguishing them from one another. Figure 23 shows characteristic topography of each formation.

The Staunton Fault extends northeastward across the area. Criteria aiding in the tracing of the fault were many. A large brecciated zone is in the fault area. Because of this zone selective erosion dominated and therefore the fault occurred in valleys and other low places. Along this fault Elbrook strata of Upper Cambrian age have been shoved up on Beekmantown

Figure 12. Lenoir-Mosheim knoll striking across a road.

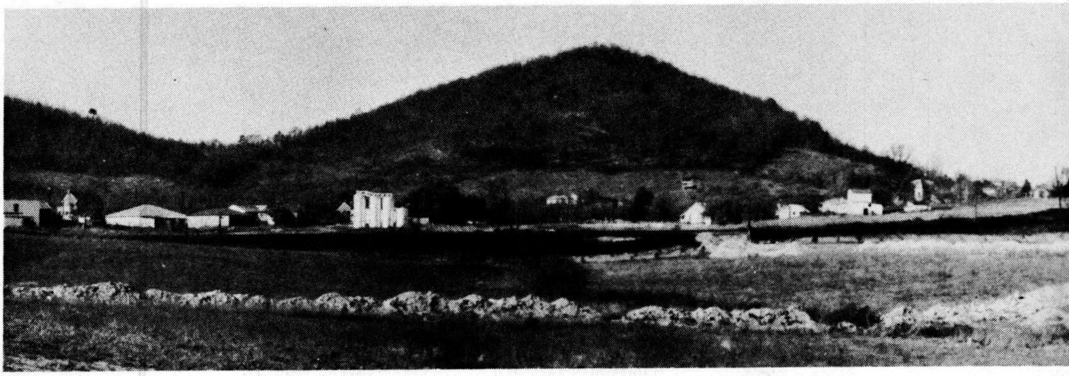


Figure 13. Knoll within the Beekmantown formation. Notice forest growth on the slopes.

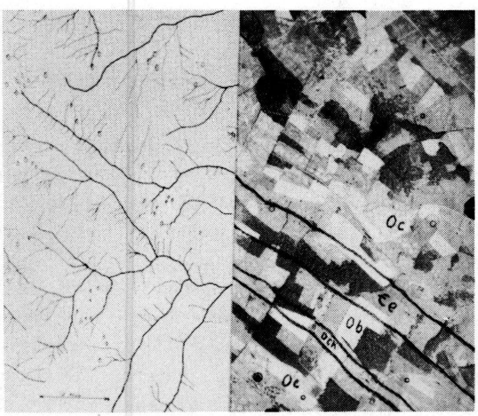


Figure 14. Drainage and airphoto showing extent of formations. Notice stream following strike of the strata.

Figure 15. Photo showing break in topography between the Chepultepec limestone (Och) and Conococheague limestone (Oc) on the left and the Beekmantown limestone on the right.

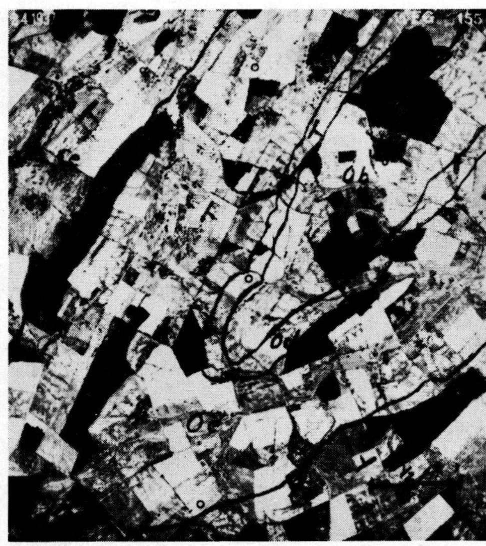


Figure 16. Airphoto showing syncline plunging southwestward. Notice convergance of sandstone ridges (wooded areas) within the Conococheague limestone. (Oc).

strata of Lower Ordovician age - although the Elbrook occurs normally below the Conococheague. Airphoto patterns of these formations, as mentioned previously, aided in pointing out the horizontal trace of this fault. Figure 24 shows a structure section indicating the attitude of the fault and formations.

SOILS AND AGGREGATES

Since the geologic formations in the area investigated differ in their chemical and physical make-up, they produce distinctive and different soils upon weathering. The soils being mature in age are well developed and show distinct horizons. The following, in table form gives the geologic formations with their corresponding soils and horizons·

This classification is based solely on the Los Angles Abrasion Test, as used by the Virginia Department of Highways, Division of Tests, Grade A being less than 40 percent loss on abrasion after 500 revolutions.

Table 4 shows results of adhesion tests made on aggregates taken from the various formations. This test, which is reiterated in the Appendix, was developed and adopted for use by the Virginia Department of Highways, Division of Tests.

1. Martinsburg shale - Berks soils

   A horizon - silt from - 0 in. to 7 in.
   B horizon - brittle silty clay - 7 in. to 18 in.
   C horizon - silty clay - 18 + in.

2. Athens shale - Westmoreland soil

   A horizon - clayey silt - 0 in. to 10 in.
   B horizon - plastic silt-clay - 10 in. to 48 in.
   C horizon - silty clay - 48 + in.

3. Lenoir-Mosheim formation - Clarksville soils

   A horizon - silt - 0 in. to 10 in.
   B horizon - stiff brittle silty clay - 10 in. to 34 in.
   C horizon - silty clay containing chert fragments - 34 + in.

4. Beekmantown formation - Clarksville soils (mentioned previously) and Frederick soils

   A horizon - silt and clay-silt - 0 in. to 14 in.
   B horizon - elastic silty clay - 14 in. to 50 in.
   C horizon - crumbly elastic silty clay containing chert - 50 + in.

5. Chepultepec formation - Hagerstown soil

   A horizon - silt and clay-silt - 0 in. to 14 in.
   B horizon - elastic silty clay - 14 in. to 50 in.
   C horizon - crumbly elastic silty clay - 50 + in.

6. Conococheague formation - Clarksville and Frederick soils (mentioned previously).
7. Elbrook dolomite - Frederick, Clarksville, and Hagerstown soils (mentioned previously).

Results of tests made upon soils from the various formations is shown in Table 2. Table 3 includes results of tests made on aggregate samples from the various formations. Some of the samples selected contained chert which may be detrimental to highway constructional work. It has been established that chert is a deleterious constituent in coarse aggregate for concrete. Also aggregate containing chert is conducive to stripping in bituminous material. These samples tested as Grade A.

SUMMARY AND CONCLUSIONS

Geologic mapping may be accomplished by the application of aerial photography. In studying airphoto pairs stereoscopically, the interpretor sees the land surface as if flying over in an airplane. Features that are distinctly different were observed and marked on the airphoto. As the work progressed it was found that these features had a direct relationship to the geologic formation and upon their repetitive nature

Figure 17. Airphoto showing features used in differentiating geologic formations in the area investigated. Notice cherty knolls (encircled areas) in Beekmantown formation (Ob) and the sandstone ridges (also encircled) in the Conococheague formation.

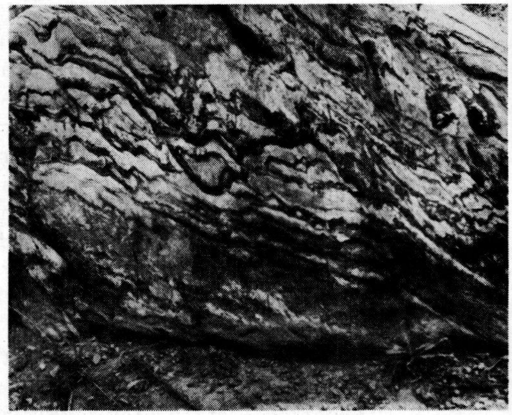


Figure 19. Thin laminae of argillaceous material within the Conococheague limestone.

made possible the delineation of each geologic formation.

A summation of the conclusions reached from this study is given as follows: (1)

Figure 18. Sinkholes within the Conococheague limestone. Notice the elongation and alignment of the sinkholes. This is typical of tilted limestone strata.

Figure 20. Sandstone ridges within the Conococheague limestone.

Figure 21. Photo showing steep slope of sandstone ridge.

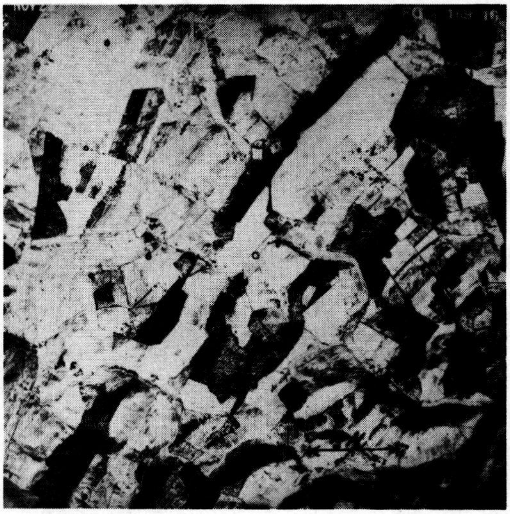


Figure 22. Element of vegetal cover. Note wooded areas trending in a relatively straight line. These wooded areas are along the steep slopes of the sandstone strata within the Conococheague formation.

Differing material types present distinctive unlike airphoto patterns; (2) There is a definite relationship of airphoto patterns to geologic formations, reoccurrence of a pattern is indicative that it's associated formation likewise repeats; (3) A much wider coverage of an area may be witnessed on an aerial photograph than can be seen on the ground, thus considerable time is saved by applying this method; (4) Local details such as folds and faults are evident on aerial photographs; (5) Aerial photographs are excellent as a base map for they contain all land features and map culture, in essence aerial photographs are minitures of the actual land surface; (6) Field checks are necessary for correlation of airphoto patterns to geologic formations; (7) If undertaken correctly this method proves as accurate as field methods when mapping out the areal extent of formations, interpretor should be well versed in airphoto techniques and in geology; and (8) Application of this method can only be made where adjacent formations differ in their physical and chemical make-up.

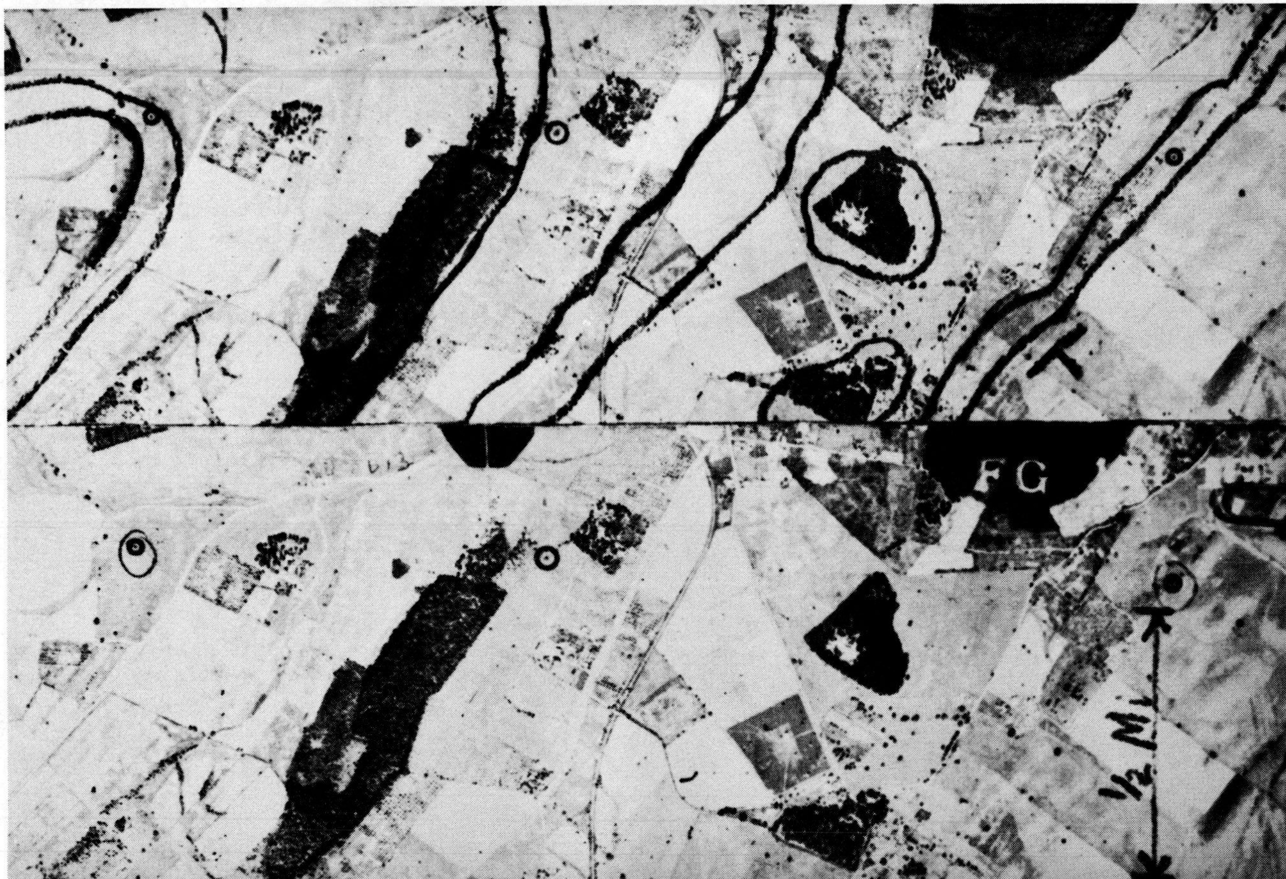


Figure 23. Stereo pair showing cherty hills in the Beekmantown formation (Ob), cherty elongated knolls in the Lenoir-Mosheim formation (Olm) and sandstone ridges in the Conococheague formation.

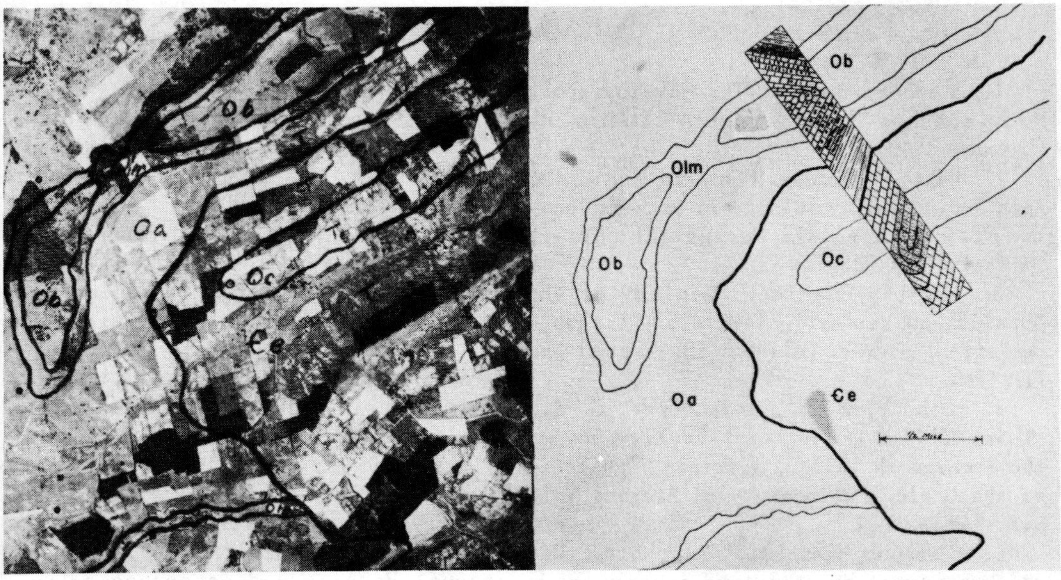


Figure 24. Airphoto showing Athens, Lenoir-Mosheim, Beekmantown, Conococheague and Elbrook formations and the Staunton Fault. Also structure section showing the attitude of these formations. Note Staunton Fault (dark line), anticlinal structure, and overturned Syncline.

Figure 25. Airphoto showing the end of the Massanutten syncline.

ACKNOWLEDGEMENTS

Special acknowledgements are extended to Tilton E. Shelburne, director of research of the Virginia Council of Highway Investigation and Research, for his many helpful suggestions and for extending the facilities of the Research Council to the writer. To Dr. Raymond S. Edmundson, professor of geology at the University of Virginia, the writer is deeply grateful for his helpful criticism and for his aid in the more complex geology of this area. To John C. Stevens, associate research engineer of the Virginia Council of Highway Investigation and Research, the writer is deeply grateful for his initiating the interest in this project, for his tutoring in aerial photograph techniques, and for his helpful suggestions on the interpretation of airphotos of this area. Also to Mr. Lovell, district materials engineer of the Staunton District, and to members of the testing laboratories the writer is deeply grateful. Acknowledgements are extended to the members of the Virginia Council of Highway Investigation and Research for their assistance in the preparation of many phases of this report.

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APPENDIX

ADHESION TEST ON AGGREGATES

Procedure, Type I

The following is a general procedure for the Adhesion Test for Bituminous Materials, Type I. For specific information relating to mixing procedure, curing period, etc., see the notes regarding each specific type of bituminous material.

(1) Fifty grams of Shady Dolomite Aggregate,[1] washed in a distilled water[2] having a minimum pH of 6.3, air-dried for a minimum of 24 hours, and graded to a size that 100 percent passes a 3/8-in. sieve and is retained on a 1/4-in. sieve, shall be weighed into an 8-oz. seamless tin box. The aggregate shall be thoroughly mixed and completely coated with two grams of the bituminous material being tested. To insure that every particle is completely coated, the thoroughness of the mixing process shall be observed under an adequate light. At times it may be helpful to place the tin box on a hot plate for a few seconds, while mixing.

(2) The mixture shall then be transferred to a 600-cc. beaker containing 400 cc. of distilled water at a temperature of 25 C.±1.5 deg. C. (77 F.±3F.) having a minimum pH of 6.3 and allowed to remain immersed for a period of from 15 to 18 hours.

(3) The mixture shall then be removed from the beaker and placed on absorbent paper for air-drying. When dry the particles shall be immediately examined for uncoated areas. The particles containing uncoated areas shall be separated from those particles that are completely coated. Both shall then be weighed and the percentage of completely coated particles computed on the basis of total weight.

(4) Any bituminous material which under the conditions of the test fails to coat completely at least 90 percent by weight of the total shall be rejected.

[1] Samples of the Shady Dolomite Aggregate for testing purposes may be secured from the Division of Tests, Virginia Department of Highways, Richmond, Virginia.

NOTES ON PROCEDURE - STEP (1) WITH SPECIFIC BITUMINOUS MATERIALS -

(A) Cut-back Asphalts, RC-2a and RC-3a; and Emulsified Asphalts, (Immiscible Types) AEM-1, AEM-2, and AEM-3 - With these materials the aggregate shall be mixed at room temperature with two grams of the bituminous material which has been heated to 60 C. (140 F.) until a uniform coating results. The sample shall then be placed in a constant temperature oven at 60 C. (140 F.) and cured for a period of one hour. On removing from the oven, the sample shall be remixed for about two minutes before being placed in the distilled water.

(B) Asphalt Emulsions, AE-1, AE-2, AE-3, and AE-4 - Prior to coating, the aggregate shall be heated in a constant temperature oven for one-half hour at 130 C. (266 F.). Two grams of asphalt emulsion at room temperature shall be weighed into another tin box. The aggregate shall then be dropped into this box and mixed. After complete coating, the mixture shall be cured in a constant temperature oven at 60 C. (140 F.) for one hour. After this curing period, the sample shall be remixed for about two minutes before being placed into the beaker of distilled water.

(C) Hot Bituminous Materials, AP-O, AP-OO, and OH-1 - Approximately 10 grams of the asphaltic material shall be placed in another tin box. The two boxes shall then be placed in a constant temperature oven at 130 C. (266 F.) for a one-half-hour period. Exactly 2 grams of the asphalt shall then be poured onto the aggregate in the first tin box and the materials thoroughly mixed. About two minutes should be allowed for the asphalt to set mixed. About 2 minutes should be allowed for the asphalt to set up, stirring constantly during this time. No curing period is necessary before placing the sample into the distilled water.

[2] Distilled water of the proper pH shall be obtained by boiling and/or redistillation, and not by the use of an electrolyte.

Procedure, Type II

Adhesion Test for Bituminous Materials, Type II, is designed to procure a bituminous material that will satisfactorily coat and adhere to wet and cold aggregates being used under severe and adverse weather conditions. The test procedure is applicable to Rapid Curing Cut-back Asphalts RC-2a and RC-3a; and Emulsified Asphalts, (Immiscible Types) AEM-1, AEM-2, and AEM-3, and Tar RT-5.

(1) Fifty grams of the standard reference gravel[3], washed in a distilled water[4] having a minimum pH of 6.3, air-dried for a minimum of 24 hr., and graded to a size that 100 percent passes a 3.8-in. sieve and is retained on a 1/4-in. sieve, shall be weighed into an eight-ounce seamless tin box and thoroughly wetted with one gram of distilled water. The wet aggregate shall be thoroughly mixed and completely coated with three grams of the bituminous material which has been heated to 60 C. (140 F.) The mixing process shall be performed in adequate light and the bituminous material shall satisfactorily coat 95 percent of the surface area of the aggregate as determined by the visual estimation method. At times it may be helpful to place the tin box on a hot plate for a few seconds while mixing. The mixture shall then be placed in a constant temperature oven at 60 C. (140 F.) and cured for a period of one hour. On removal from the oven, the sample shall be remixed for about two minutes to insure a uniform coating of the aggregate.

(2) The sample shall then be transferred to a 600-cc. beaker containing 400 cc. of distilled water at a temperature of 37.8 C. ± 2.5 C. (100 F. ± 5 F.) having a minimum pH of 6.3 and allowed to remain immersed for a period of from 15 to 18 hr.

(3) At the end of the immersion period the sample shall be observed under water and the percentage of surface area of the aggregate remaining coated shall be evaluated by visual estimation.

(4) Any bituminous material which under the conditions of the test fails to coat 95 percent of the surface area of the aggregate originally or to retain 95 percent coating of the surface area of the aggregate by visual estimation shall be rejected.

Note: For a test on selective aggregate samples a standardized given bituminous material is used. The asphalt used was RC-2 from the Mexican Petroleum Corporation.

[3] Samples of the standard reference gravel (Commonwealth Sand and Gravel Company) for testing purposes may be secured from the Division of Tests, Virginia Department of Highways, Richmond, Virginia.

[4] Distilled water of the minimum pH shall be obtained by boiling and/or redistillation, and not by the use of an electrolyte.

THE PREPARATION OF SOIL-ENGINEERING MAPS FROM AGRICULTURAL REPORTS

Thomas H. Thornburn, *Research Assistant Professor in Civil Engineering, University of Illinois*, J. R. Bissett, *Associate Professor of Civil Engineering, University of Arkansas*

In most states possessing land of agricultural value, there is generally available a large amount of information about surface soils contained in county agricultural reports prepared by the State agricultural experiment stations and published jointly by the stations and the U.S. Department of Agriculture. A contribution to the field of soil engineering presenting the usefulness of these reports has been published by the Highway Research Board as Bulletin 22, "Engineering Use of Agricultural Soil Maps."

In spite of the availability of county agricultural reports, the state highway departments have, in general, neglected to utilize them. The reasons for this are readily apparent to any civil engineer who has ever consulted one.

Although the method of soil classification used in the reports is scientific, being the realm of pedology, the reports themselves are full of agricultural terms and interpret the soil conditions in the light of agricultural usage. Few highway engineers have the time to read through the extraneous information contained in these reports in order to find soil information which can be utilized for engineering purposes.

Nevertheless, the information is there and can be used to advantage, as is evidenced by such valuable publications as the "Field Manual of Soil Engineering," of the Michigan State Highway Department; "The Formation, Distribution and Engineering Characteristics of Soils" by Belcher, Gregg, and Woods; and the "Soils Manual" of the Missouri State Highway Commission. In a state where a large number of up-to-date agricultural reports are available these publications have their greatest usefulness. However, their overall value to highway engineers decreases with a decrease in the quality or quantity of county agricultural reports.

Up-to-date county reports usually contain maps showing much more detailed variations in soil type than is necessary for engineering purposes. Although this is no great disadvantage, the number of soil types mapped usually increases each year as new county reports are prepared. Furthermore, in states where mapping has been in progress for a period of 30 years or more there is a considerable difference between the nomenclature and mapping techniques used in the early reports as compared to those published in the last 10 to 15 years. This variation in quality of agricultural soil maps in a very real impediment to the use of pedologic information by the highway engineer.

All of the county agricultural reports for Illinois have been prepared and published by the University of Illinois Agricultural Experiment Station. Reports prepared during the period 1911 to 1929, of which there are about 45, use an old type of descriptive nomenclature for the soil profile which does not lend itself to interpretation for engineering purposes without considerable study. The 10 reports published in the period from 1930 to 1933 might be termed transitional reports, since the method of description and classification of the soil profile is better than the one used in the early reports but does not involve the use of soil-series names. The remainder of the reports published since 1933 use the most modern techniques of pedologic survey. These reports, about 20 in number, utilize soil-series names which could be directly correlated with engineering properties.

In order to utilize county agricultural reports for relating engineering properties to soil-series or type names, at least two

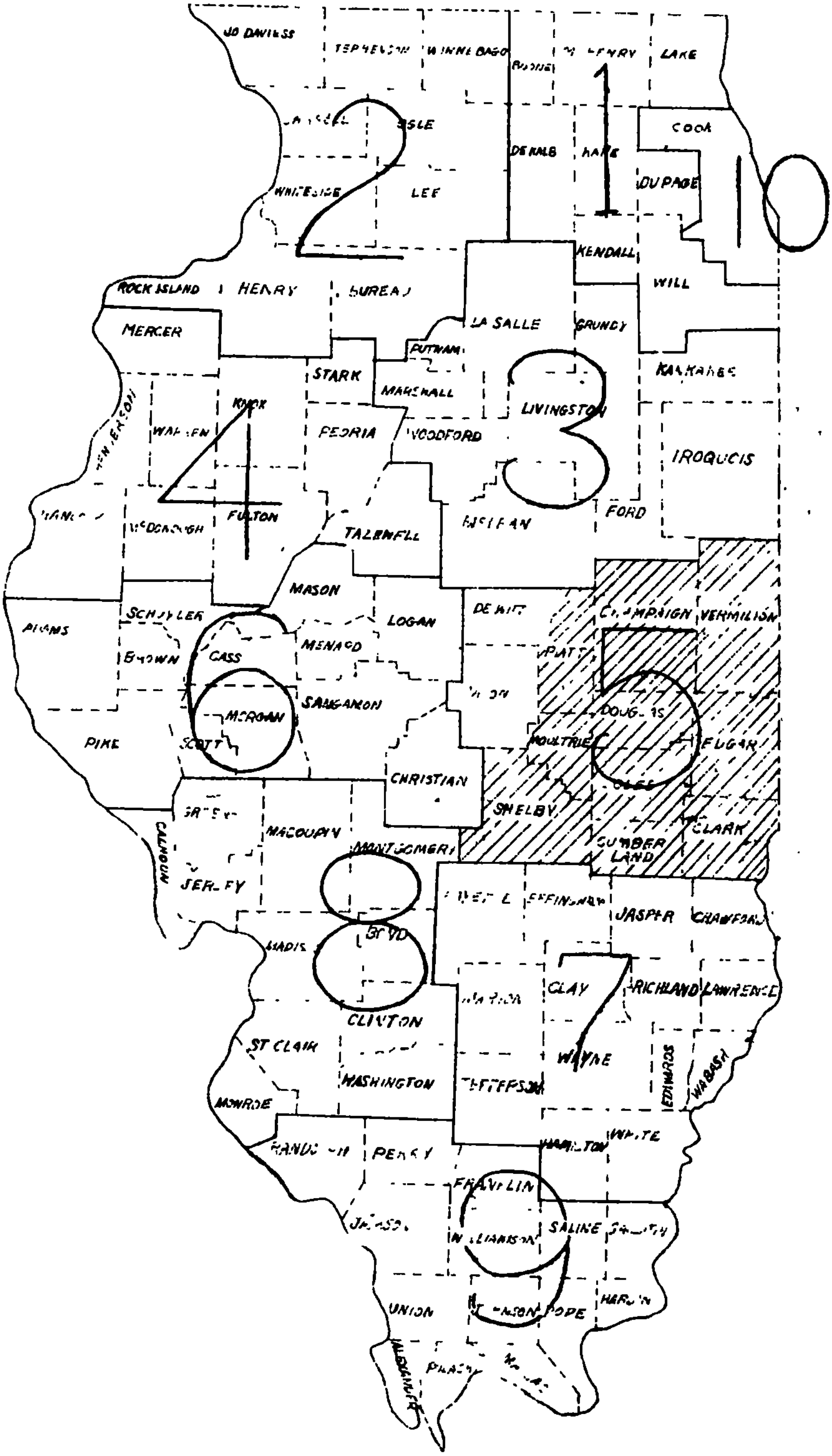


Figure 1. Highway Districts and Counties in Illinois

and possibly three different systems of correlation would have to be devised. On the other hand, if a soils manual of the type utilized so successfully by the Michigan State Highway Department were prepared, it could be used directly in only 20 of the 102 counties in Illinois. It would also require constant additions as new counties were mapped. In order to apply the available data to counties having no up-to-date reports it would be necessary to train the soils engineers of the Illinois Division of Highways in the techniques of pedologic survey. This would be a time-consuming operation, however desirable it might be.

In the spring of 1949 it was decided to inaugurate a project on the preparation of a soil manual for District 5, Illinois Division of Highways, as a part of the Cooperative Research Program on General Highway Problems. This program is directed by a joint committee representing the Illinois Division of Highways and the Department of Civil Engineering of the University of Illinois, Engineering Experiment Station. The program is sponsored by the Illinois Division of Highways and the work carried on by members of the university staff in the field and in laboratories.

District 5 comprises the 12 counties in east-central Illinois, indicated on Fig. 1. In this district up-to-date county reports were available for 4 counties, transitional reports for 1 county, and old-type reports for 6 counties. There was no published report for Clark County, but an old unpublished map was available.

It did not seem possible to reconcile the nomenclature used in the three different classes of reports in one soils manual. Consequently the decision was made to prepare new engineering soils maps for the district. Obviously, it would not be possible to remap on a strict pedologic basis each county for which only old-type reports existed without a tremendous amount of field work. Since time is an important factor in the preparation of the manual, this approach was ruled out. Furthermore, almost 300 different soil-type names have already been used in the preparation of the up-to-date county agricultural reports.

TABLE 1

ENGINEERING CLASSIFICATION OF THE PEDOLOGIC PROFILE

SYMBOL	SUBSURFACE PLASTICITY	SUBSOIL PLASTICITY
A	None to very slight	None to very slight
B	Slight to moderate	None to very slight
C	None to very slight	Slight to moderate
D	Slight to moderate	Slight to moderate
E	High	None to very slight
J	High	Slight to moderate
W	None to very slight	High
X	Slight to moderate	High
Z	High	High
O	Highly organic materials	

PARENT MATERIAL SYMBOLS

H	Highly Permeable materials (Granular terrace, alluvial or windblown sands and granular outwash)
M	Moderately Permeable Materials (Leached or permeable till, leached or sandy loess, alluvial silt, and local wash.)
S	Slowly permeable materials (Plastic till, modified loess or lacustrine clay)
R	Bedrock
O	Peat and Muck

TABLE 2

ILLINOIS SOIL TYPE DESCRIPTION SHEET

1. Number and Name - *146 Elliot Silt Loam*
2. Descriptive Name - *Brown silt loam on compact, medium plastic till*
3. Location in State - *East-central, north-central Illinois*
4. Rating: General Crops - 4 Pasture - Timber -
5. Topography - *Gently rolling to rolling - slopes 1 to 5 percent*
6. Drainage: Surface - *moderate* Under - *slow* Outlets - *good*
7. Native Vegetation - *Grass*
8. Parent Material - *Thin loess on compact, med. plastic Wisconsin till*

SOIL CHARACTERISTICS

SURFACE

1. Texture - *Silt loam* Structure - *Fine granular to crumb*
2. Color - *Brown to dark brown* Organic Content - *medium*
3. Thickness - *7 to 8 inches*
4. Reaction - *Medium acid* Available Phos. - *low* Nitrogen - *Medium to low* Available Potash - *medium*
5. Workability - *Fair but becoming poorer as organic matter decreases*

SUBSURFACE

1. Texture - *Heavy silt loam or silty clay loam* Structure - *Weakly coarse-granular*
2. Color - *Yellowish brown to dark grayish yellow*
3. Thickness - *6 to 12 inches*
4. Reaction - *Slight to medium acid* Available Phos - *low*

SUBSOIL

1. Texture - *Clay loam* Structure - *Subangular to angular aggregates*
2. Color - *Pale brownish yellow to dark grayish yellow with rusty brown spots*
3. Consistency - *Compact and plastic*
4. Thickness - *8 to 12 inches*
5. Reaction - *Slightly acid to neutral* Available Phos. - *Substrate* Nature and composition - *slowly pervious Wisconsin till, highly calcareous at 30 to 35 inches, igneous pebbles, not abundant*

For engineering purposes many of these soil types can be grouped together, since they have similar engineering characteristics. In order to utilize all of the pedologic information available and yet present it in a usable manner, the classification system shown in Table 1 was developed.

On the basis of this classification, each pedologic soil type mapped in a given area was assigned a two-letter group symbol. The first letter represents the plasticity of the subsurface and the subsoil; that is, the lower part of the A- and the B-horizon respectively of the pedologic profile. The classification was arranged so that letters at the beginning of the alphabet represents granular or slightly plastic materials, whereas those at the end of the alphabet represent highly plastic soil materials.

The second letter of the symbol designates the character of the parent material; for example, H represents highly permeable granular materials; M, moderately permeable, predominantly silty materials; S, slowly permeable clayey materials, and R, with a suitable subscript, represents bedrock, the subscript denoting whether it is shale, limestone, or sandstone.

The authors have no illusions that this system represents the acme of soil-classification systems but do feel it utilizes, to the best advantage, soils information already available. Furthermore, it provides a basic system with which engineering properties of soils in any part of the state may be directly correlated. Its form depends more upon the type of information available rather than upon the desirable ideal.

Table 2 is an illustration of a typical soil-type information sheet used by the Department of Agronomy of the University of Illinois in pedologic mapping. It can be seen that definite information in regard to the plasticity of the various horizons is not always given. In many instances it was necessary to deduce the plasticity characteristics from the information on tecture and permeability. The chart shown in Table 3 was used for this purpose.

In the mapping of District 5, 99 different pedologic soil types have been encountered. All of these have been classified into 13 engineering groups. The number of types in each group is indicated in Table 4 along with a brief description of the group. With the classification as presently devised it would be possible to have as many as 37 different groups, however it is expected that the actual number required to map the whole state will not exceed 20.

TABLE 3

CLASSIFICATION OF PLASTICITY
FROM TEXTURAL CLASS

None to very slight plasticity
sand
clayey sand
silty sand
loamy sand
sandy loam
silt

Slight to moderate plasticity
loam
silt loam
sandy clay loam }
silty clay loam } - { moderate permeability, slight to moderate plasticity
clay loam }

High plasticity
clay loam }
silty clay loam } - { slow permeability, high plasticity
sandy clay loam }
silty clay
sandy clay
clay

TABLE 4

GROUPING OF PEDOLOGIC SOIL TYPES IN DISTRICT 5
ACCORDING TO ENGINEERING CLASSIFICATION

NUMBER OF PEDOLOGIC TYPES	GROUP SYMBOL	SUBSURFACE PLASTICITY	SUBSOIL PLASTICITY
7	AH	None to very slight	none to very slight
11	CH	none to very slight	slight to moderate
8	DH	slight to moderate	slight to moderate
4	XH	slight to moderate	high
1	CM	none to very slight	slight to moderate
26	DM	slight to moderate	slight to moderate
6	XM	slight to moderate	high
4	ZM	high	high
2	CS	none to very slight	slight to moderate
15	XS	slight to moderate	high
13	ZS	high	high
1	DR	slight to moderate	slight to moderate
1	OO	muck and peat	
99	13	total	

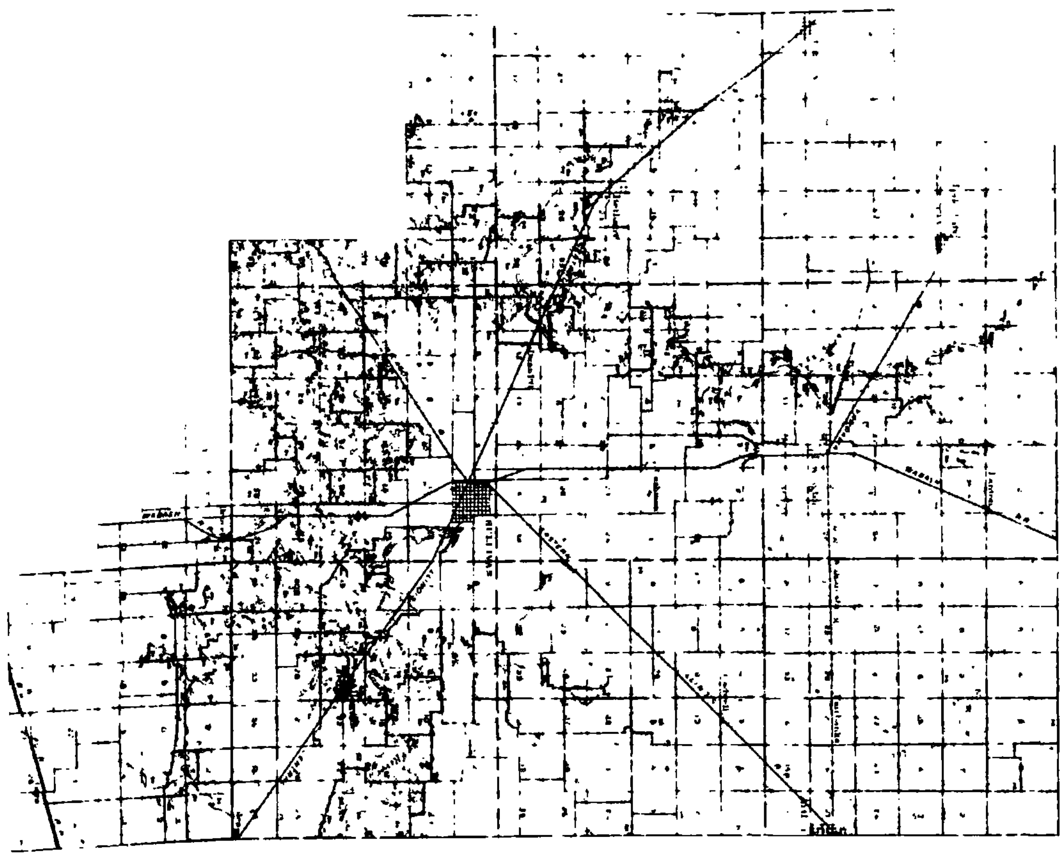


Figure 2. Agricultural map of Moultrie County

Once the new classification system had been worked out, the process of preparing an engineering soils map for counties having up-to-date agricultural reports was relatively simple and direct. It consisted of the following steps: (1) classification of each pedologic soil type mapped in the county according to the engineering symbols (Table 1) using the information contained in the soil information sheet (Table 2) and the plasticity-texture correlation (Table 3); (2) designation by a distinctive color of each engineering soil area on a photographic reproduction (scale: 1 in. equals 1 mi.) of the county agricultural map; (3) tracing of the boundries of each engineering soil area on a vandyke positive of the county highway planning map; (4) preparation of a vandyke negative of the completed soils map; and (5) reproduction of the engineering soils map.

In the counties where up-to-date agricultural reports were not available, the first step was preceded by a reclassification of the descriptive type names in terms of type names for which soil description sheets were available. This was frequently a time-consuming procedure and involved consultation with members of the agronomy department of the university; considerations of the correlation between topographic position, geology of the parent material and pedologic classification, and the use of aerial photographs to check soil boundries.

The relationship between the agricultural maps and the resulting engineering maps is illustrated in Figures 2 to 5.

In conjunction with the preparation of the basic maps, the soils engineer of District 5, assembled all reliable sampling and test data in the form shown in Figure 6. The location map was prepared on tracing

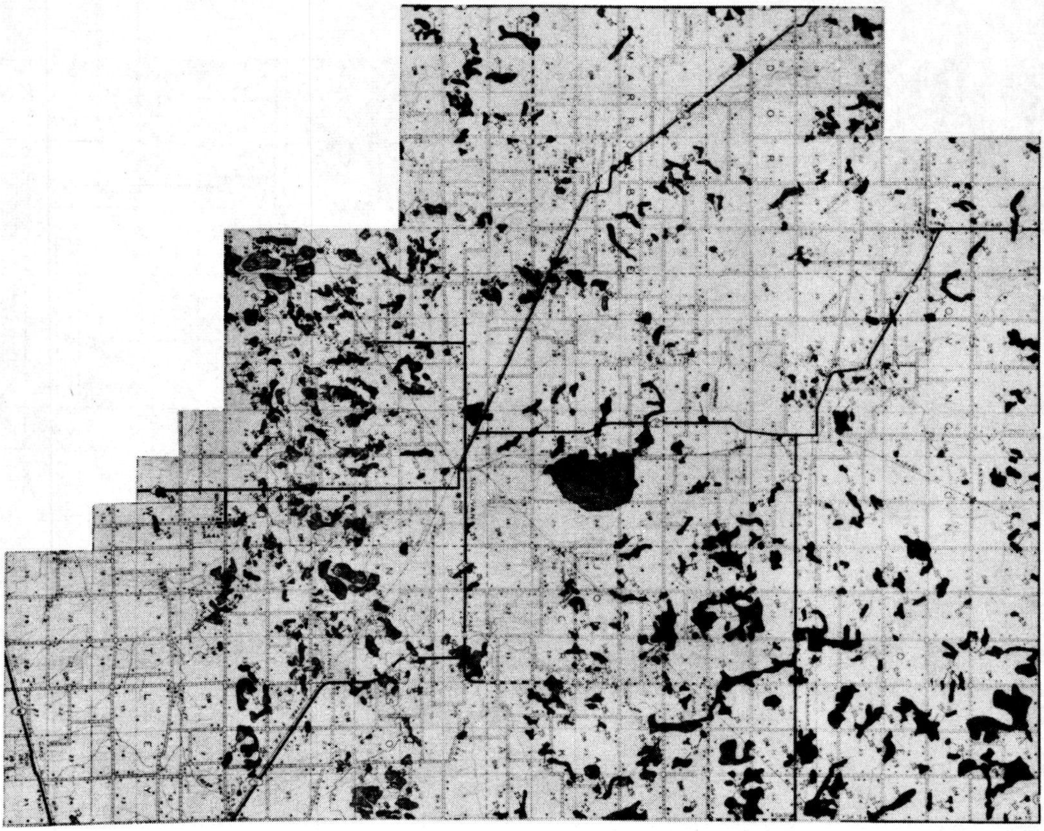


Figure 3. Engineering Soils Map of Moultrie County

cloth to the scale of 1 in. equals 1 mi., and the position of each exploratory boring was plotted as accurately as possible. The location could then be spotted readily on the preliminary soils map, and the test data used as a further check on the engineering classification. Unfortunately, the amount of reliable test data which could be correlated with a specific location and depth was found to be small. The data which are available will be, however, of further value in estimating the physical properties of each engineering soil group when a soils manual is prepared for the district.

At the present time basic engineering maps have been prepared for all 12 counties which comprise District 5, but only 4 have been reproduced in final form. This represents the effort of one staff member half-time during one academic year and full-time for three months. In addition, two undergraduate students have been employed about half-time for two months in preparing maps for reproduction. Now that the system has been formulated, it is felt that the average highway district comprising 10 to 12 counties could be mapped in a period of from 6 to 8 months using the same staff which has been available in the past.

The preparation of the engineering soil maps represents only the first phase of the project on the preparation of the soils manual. However, in order to make the maps of immediate use, each one will be accompanied by a brief summary of the geology, major soil types, and associated engineering problems of each type. In addition, a map showing the important geologic features of the district will be prepared for inclusion in the manual.

The authors wish to acknowledge the assistance received from the engineers of the Illinois Division of Highways, espec-

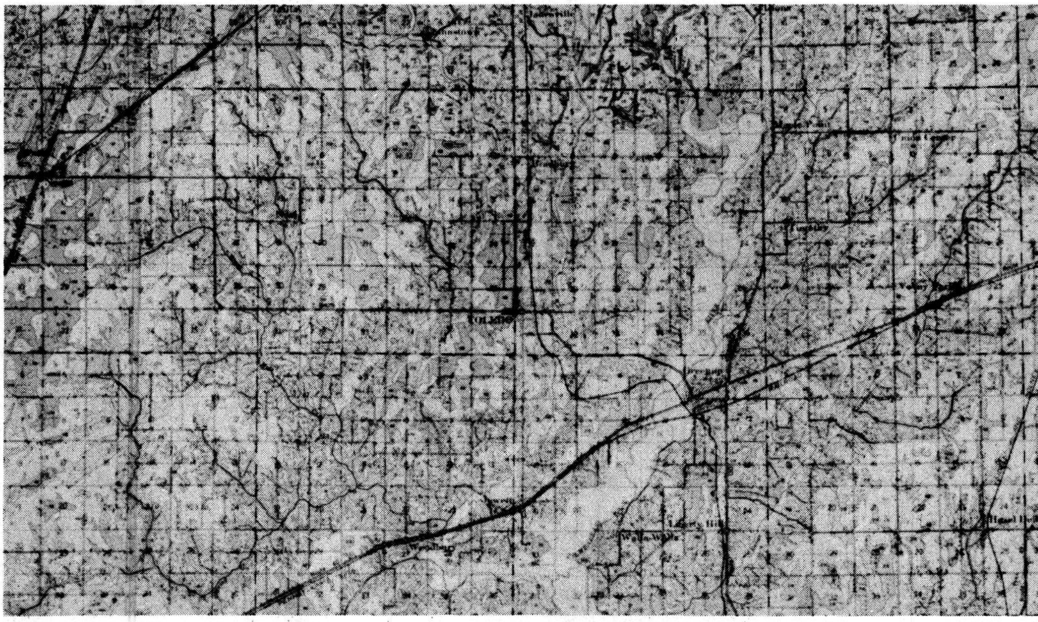


Figure 4. Agricultural map of Cumberland County

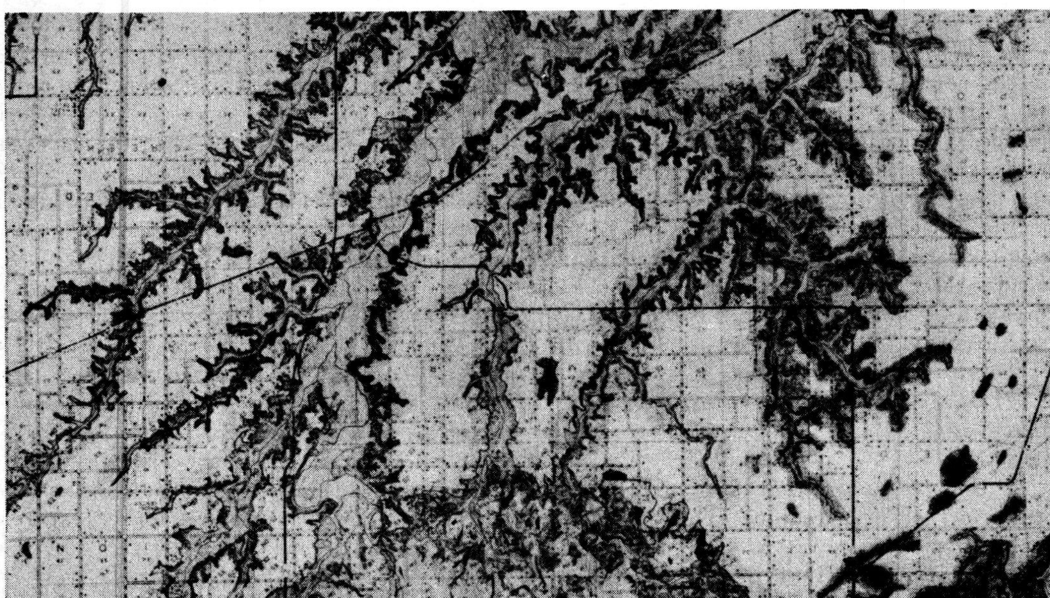
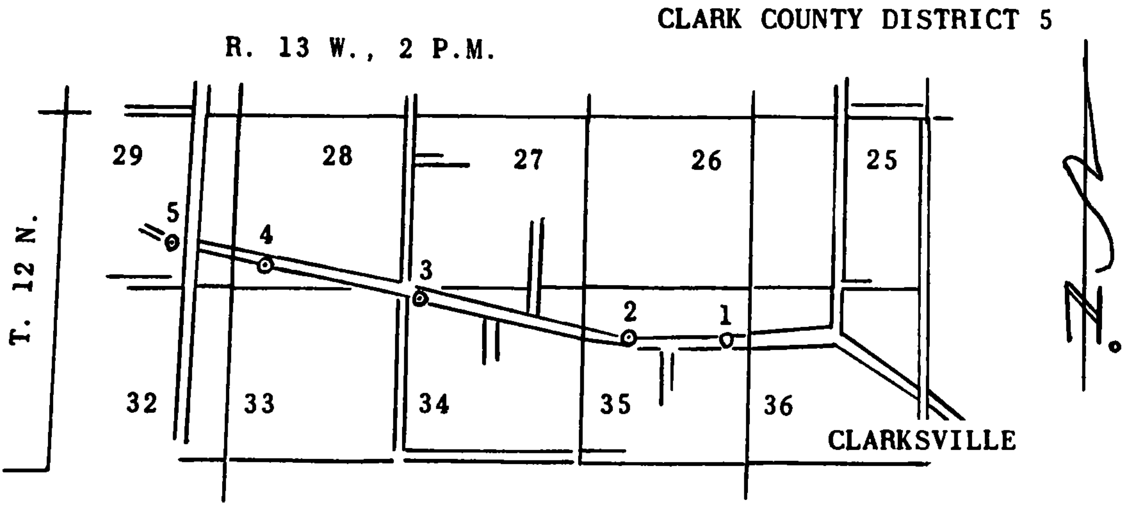


Figure 5. Engineering Soils Map of Cumberland County

ially from H. W. Russell, engineer of materials, who supervises the Cooperative Research Program on General Highway Problems for the sponsors; F. N. Barker, engineer of highway research, who furnished reproduction negatives of the highway planning maps; and Martin Zogg, engineer of materials, and Walter Lyon, soils engineer of District 5, who supplied much useful data and many helpful suggestions. The assistance provided by R. T. Odell, associate professor of soil physics, University of Illinois, in furnishing original county soil maps and in the interpretation of old county soil reports has been invaluable. Special acknowledgement is due to W. S. Pollard, Jr., instructor in civil engineering, University of Illinois, for his part in the preparation of the engineering maps and in the interpretation of aerial photographs.



NO.	DEPTH FEET	COLOR	SAND	SILT	CLAY	LL.	PL.
1	0-½	Gray	9	60	31	27	11
	½-3	Yellow	4	51	45	30	14
	3-5	Yellow	8	57	35	30	17
	5-10	Yellow	24	44	32	29	21
2	0-1½	Brown	8	59	33	34	15
	1½-3	Yellow	8	57	35	43	24
	3-4	Yellow	6	52	42	55	42
	4-5	Yellow	7	58	35	41	25
	5-5½	Yellow	4	54	42	52	38
3	0-1	Yw.-Bn.	10	55	35	32	12
	1-2½	Yellow	6	52	42	61	45
	2½-5	Yellow	16	49	35	43	31
	5-8	Yellow	25	43	12	35	22
4	0-1½	Gray	12	56	32	32	12
	1½-3½	Yellow	6	45	49	42	31
	3½-6	Yellow	13	49	38	32	18
5	0-½	Gray	32	48	20	26	8
	1/2-1½	Yellow	10	53	37	45	26
	1½-3½	Yellow	11	50	39	53	36
	3½-4½	Gray	10	50	40	46	30

Figure 6.

TOPOGRAPHIC MAP SYMBOLS

VARIATIONS WILL BE FOUND ON OLDER MAPS

ROADS

Hard surface, heavy duty, four or more lanes wide

Hard surface, heavy duty, two or three lanes wide

Hard surface, medium duty, four or more lanes wide

Hard surface, medium duty, two or three lanes wide

Loose surface, graded, and drained or hard surface less than 16 feet in width

Improved dirt

Unimproved dirt

Trail

Dual highway with dividing strip 25 feet or less in width

Dual highway with width of dividing strip exceeding 25 feet

Under construction—if classification is known appropriate width and red fill are shown

Private roads are sometimes labeled for clarity — PRIVATE

Traffic circle—Clover leaf

RAILROADS

U. S. Standard Gage

Single track

Multiple main line track If more than 2 tracks, number is shown by labeling

Abandoned track

Track under construction

Juxtaposition

Yards—Siding

Narrow Gage

Single track

Multiple track

Abandoned track

Miscellaneous

Carline

Railroad in street

Dismantled railroad or carline

Turntable and roundhouse

BRIDGES—TUNNELS—CROSSINGS

Bridge, road

Drawbridge, road

Footbridge

Tunnel, road

Bridge, railroad

Drawbridge, railroad

Tunnel, railroad

Overpass, underpass

Ford, road — Ford, Fd

Ferry — Fy, Ferry

DAMS—PIERS—BREAKWATERS

Important small masonry or earth dam

Large masonry dams

Dam with lock

Dam carrying road

Breakwater, jetty, pier, wharf

Covered pier or wharf

Seawall

Canal with lock

MISCELLANEOUS CULTURE SYMBOLS

Buildings (dwelling, place of employment, etc.)

School—Church—Cemetery — Cem

Buildings (barn, warehouse, etc.)

Cliff dwelling

Sewage disposal or filtration plant

Power transmission line

Telephone, telegraph, tramway, pipe line, etc. (labeled as to type)

Wells other than water (labeled as to type) — Oil, Gas

Tanks, oil, water, etc. (labeled as to type) — Water

Located or landmark object

Windmill—Gaging station — Windmill, Gaging Sta

BOUNDARIES

National

State

County, parish, municipio

Civil township, precinct, town, barrio

Incorporated city, village, town, hamlet

Reservation, national or state

Land grant

Small park, cemetery, airport, etc.

U. S. land survey township or range line

Township or range line, location doubtful

U. S. land survey section line

Section line location doubtful

Township line (not U. S. land survey)

Section line (not U. S. land survey)

Found section corner—Land grant monument

Boundary monument—U.S. mineral monument

MINE SYMBOLS

Open pit or quarry

Shaft—Tunnel entrance

Prospect

CONTROL DATA

Triangulation or transit traverse station

monumented with spirit level elev. — BM△1062

with vertical angle elevation — VABM△2240

with other checked elevation — △5675

Monumented bench mark with spirit level elev. — BM×958

with vertical angle elevation — VABM×1254

Less permanently marked bench mark

with spirit level elevation — ×624

Checked spot elevation — ×5924

Unchecked spot elevation—Water elevation — ×5655 870

HYPSOGRAPHIC FEATURES

Index contour

Intermediate contour

Supplementary contour

Depression contours

Cut

Fill

Levee

Levee with road

Large earth dam or levee

Wash

Tailings

Tailings pond

Strip mine, waste area

Mine dump

Gravel beach

Distorted surface area

Sand area, sand dunes

FORESHORE—OFFSHORE FEATURES

Foreshore flat

Rock or coral reef

Piling, dolphin, stump, snag

Rock bare or awash at low tide

Rock bare or awash at low tide dangerous to navigation

Exposed wreck

Sunken wreck with masts exposed

Depth curve

HYDROGRAPHIC FEATURES

Perennial streams

Intermittent streams

Stream disappearing at definite point

Intermittent lake or pond

Dry lake or pond

Canal, flume, or aqueduct

Aqueduct tunnel

Elevated conduit

Water well—Spring

Large rapids

Small rapids

Large falls

Small falls

Channel in water area

Glacier or permanent snowfield

Marsh or swamp

Wooded marsh or swamp

Submerged marsh or swamp

Land subject to inundation

Mangrove

OVERPRINTED AREAS

Area in which only landmark buildings are shown

Woods—brushwood

Orchard

Vineyard

Scrub

LETTERING STYLES

Place, feature, boundary line, and area names

Richview, Union Sch, MADISON CO, C E D A R

Public works—Descriptive notes

ST LOUIS, ROAD, BELLE STREET, Tunnel - Golf Course, Radio Tower

Control data—Elevation figures—Contour numbers

Florey Knob, BM 1333, VABM 1217-*5806*-*5500*

Hypsographic names

Man Island, Burton Point, HEAD MOUNTAIN

Hydrographic names

Head Harbor, Wood River, NIAGARA RIVER

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

TOPOGRAPHIC MAPS

The United States Geological Survey was created by an Act of Congress in 1879, for the purpose of making a systematic study of the geology and natural resources of the United States, and the classification of the public lands From the very beginning of this work it was evident that no adequate classification of lands or conclusive geologic determinations could be made without suitable base maps This led to the organization of the Topographic Division, which, since 1882, has been engaged in making a series of standard topographic maps to cover the United States, Alaska, Hawaii, and Puerto Rico

MAP SCALE

Under the general plan adopted each published map covers a quadrangle of area, bounded by parallels of latitude and meridians of longitude, and hence the maps are sometimes referred to as quadrangles, or quadrangle maps The map boundaries of parallels and meridians are based on the international system of latitude and longitude by which the location of any point on the surface of the earth is readily fixed The quadrangle maps are published on different scales, the map scale selected for each section of the country being, for economic reasons, the smallest scale adequate for general use in the development of each part of the country On the lower margin of each map are printed graphic scales showing distances in feet, miles, and kilometers In addition, the scale of the map is shown by a fraction expressing a fixed ratio between linear measurements on the map and corresponding distances on the ground For example, the scale of 1 62,500 means that one unit (such as 1 inch, 1 foot, or 1 meter) on the map represents 62,500 of the same units on the earth's surface The scale of "1 inch equals 1 mile" means that 1 inch on the published map corresponds exactly to 1 mile on the ground

Each quadrangle map is usually designated by the name of a city, town, or prominent natural feature within it, and on the margins of the map are printed the names of adjoining maps that have been published The adjoining maps are published at the same scale, unless otherwise noted.

FEATURES OF A TOPOGRAPHIC MAP

Topography is the configuration or shape of the land surface A topographic map is a graphic representation of the configuration or shape of a part of the earth's surface, and it is this distinctive feature that differentiates it from other maps Topography may be shown by several methods The most striking and realistic method is probably the familiar relief model formerly made of plaster or clay, now sometimes made of rubber or plastic. The ordinary topographic map is printed on a flat sheet of paper, and hence a symbol must be used to depict the topography There are several such symbols in use, including hachures, shading, and contours The contour method is used almost entirely by the Geological Survey, although a few maps have been published with relief shading overprinted on the contours Contours are superior to other topographic symbols for engineering needs, because they generally afford more precise information Contours make it practical to represent the form of the land surface with high precision The height of each hill, the depth of each valley, and, in fact, the elevation and slope of the ground at any point can be determined from a good contour map

A contour may be defined as an imaginary line on the ground, every part of which is at the same altitude, or elevation, above sea level. The shore line of any relatively stable body of water, as the sea or a lake, is, in effect, a contour If the level of the water rises or falls by any amount, the water's edge conforms to the shape of the land at the new level and traces out a new contour. Contour lines could be drawn at any elevation, but in practice only the contours at certain regular intervals of elevation are shown The contour interval, or the vertical distance between one contour and the next, is selected according to the steepness of the terrain in the area being mapped. In flat country it will usually be 5 feet, occasionally less In a mountainous region it may be as great as 50 feet, sometimes more. To make the contours easier to read and follow, every fifth one (usually) is made heavier than the others (accentuated), and is accompanied by figures showing the altitude of the contours above sea level The contour interval used on each map sheet is explained in a note printed in the bottom margin of the map

In addition to the contour lines and elevation numbers, the heights of many identifiable points, such as road intersections, summits, and surfaces of lakes, are shown on the map in printed figures giving altitudes to the nearest foot, except on the Puerto Rican maps, where contour intervals in meters are used, and individual heights are given to the nearest meter or tenth of meter These individual elevations are commonly called spot heights, or spot elevations.

The information shown on topographic maps may be divided into three general classes The first class includes all water features such as the ocean, lakes, rivers, glaciers, canals, swamps, and other bodies of water These are known as the hydrographic features, and are printed on the map in blue The second class of features includes all the works of man, such as roads, trails, dams, transmission lines, buildings, airports, railroads, bench marks, civil boundaries, and lettering. These are sometimes called the culture, or cultural features, and are shown on the map in black The third classification comprises the configuration and elevation of the terrain, including the mountains, hills, plateaus, valleys, and all other natural features that form the land surface These features, comprising the topography, are sometimes called the hypsographic features, signifying heights, and are printed on the map in brown

In addition to these general classifications, certain maps carry other information, printed in other colors Large bodies of water are usually shown with a light blue tint, or with the conventional blue water lining Several varieties of stipples, which are patterns of closely spaced dots, or hachure lines, printed in red, and simulating different shades of pink tint, are sometimes utilized in narrow strips for emphasis alongside such features as State, county, city, and Federal-reservation boundaries A light red or gray tint is sometimes overprinted on the closely built-up areas of cities, and indicates that only the landmark or other important buildings are shown within the tinted areas A solid red color has been used on recent maps for clarity and emphasis of certain cultural features, including the classification of the surfacings of higher-type roads, and the subdivision lines of the townships, ranges, square-mile sections, and land grants in the States subdivided by the public land surveys On the more recent maps, a green tint is used to show wooded areas, scrub, orchards, and vineyards The green overprinting is made only on a limited number of the published maps, because it is not required by all map users. In ordering maps "woodland" copies should be requested if they are desired, as they are furnished only upon specific request

Accompanying this text is a set of the symbols, printed in appropriate colors, most commonly used on modern topographic maps There is also shown a small sketch and map of a typical area, illustrating the use of contours in a variety of topographic forms.

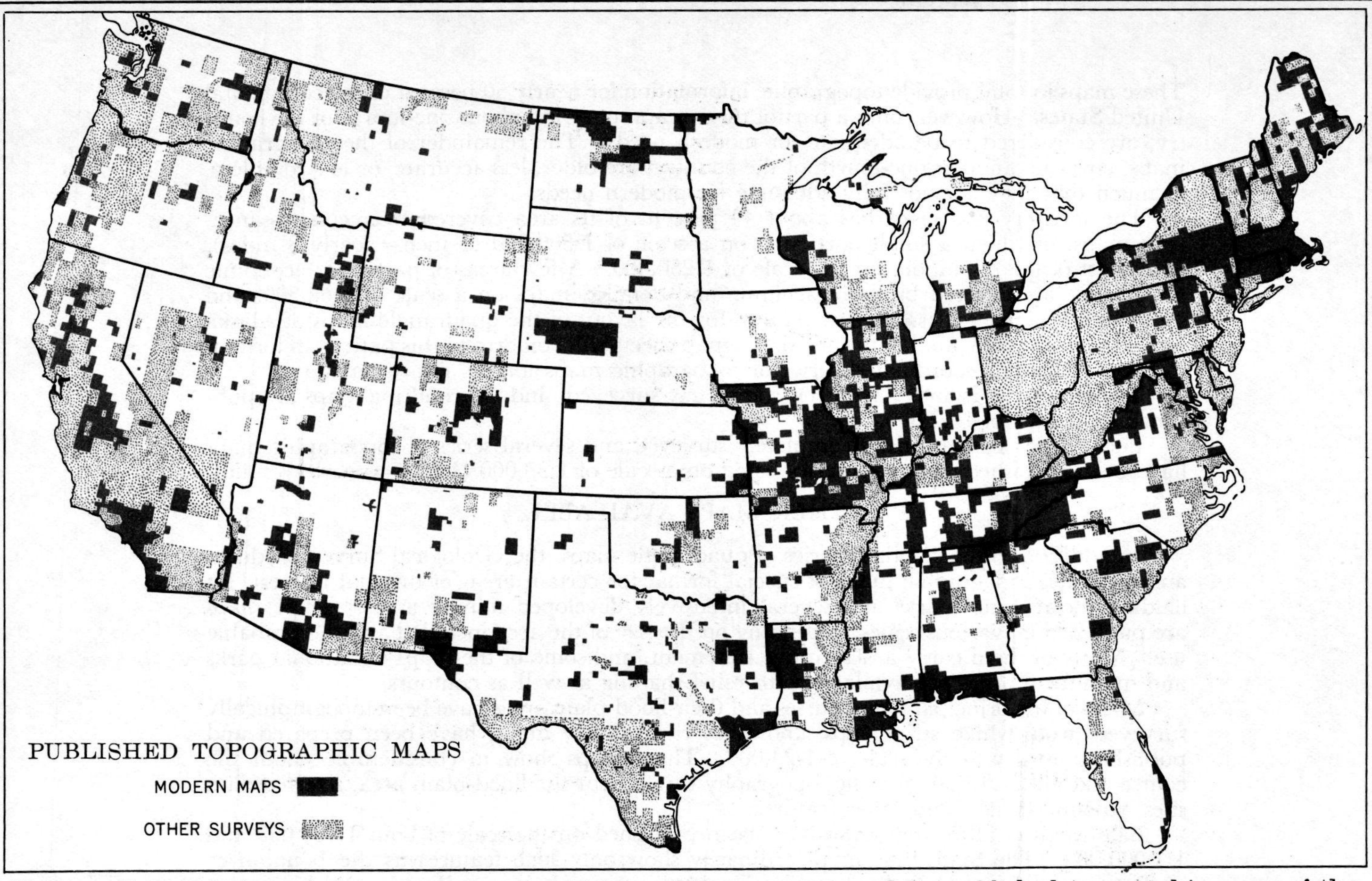
NATIONAL TOPOGRAPHIC MAP SERIES

Although some areas are surveyed and some maps are compiled and published on different scales for special purposes, the standard topographic surveys and the resulting maps of the continental United States have for many years been of three general types, differentiated as follows:

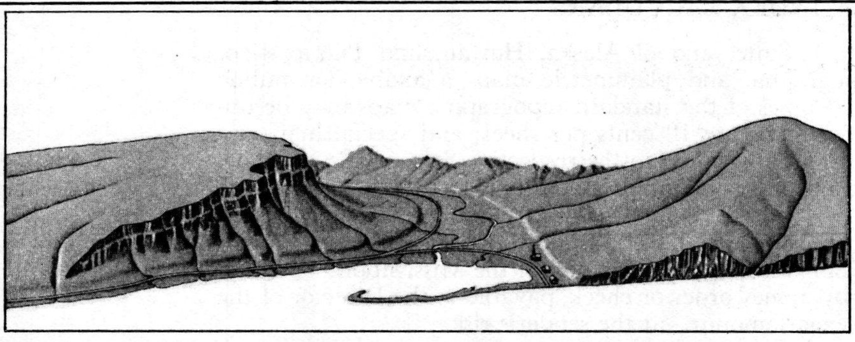
1. Surveys of areas in which there are problems of great public importance—relating, for example, to metropolitan and industrial areas, mineral development, dam and reservoir projects, irrigation, or reclamation of swamp areas—are made with sufficient detail to be used in the publication of maps on a scale of either 1·24,000 (1 inch = 2,000 feet) or 1:31,680 (1 inch = ½ mile), with a contour interval of 1 foot to 50 feet, the contour interval varying from area to area according to the steepness of the terrain. Quadrangle maps published on these scales measure 7½ minutes in both latitude (north-south) and longitude (east-west), and cover an area ranging from 49 square miles in the northern latitudes along the Canadian border, to 68 square miles in the southernmost latitudes of Texas and Florida The usual and preferred publication scale for the 7½-minute quadrangle maps is 1 24,000. The 1:31,680 scale will be continued temporarily only in a few localities where status of previously published maps or other local circumstances make the use of the 1:24,000 scale inadvisable for the time being

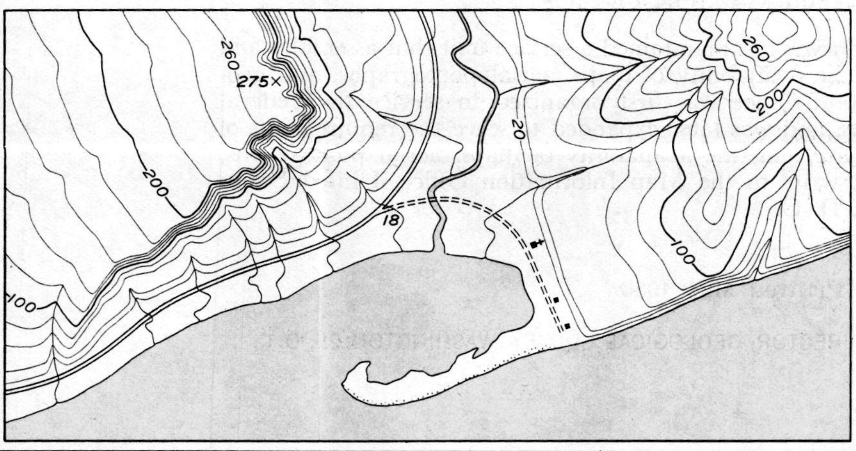
2 Surveys of areas in which there are problems of average public importance, as in much of the agricultural land of the Mississippi Basin, are made with sufficient detail to be used in the publication of maps on a scale of 1 62,500 (1 inch = nearly 1 mile), with a contour interval of 5 to 100 feet. Quadrangle maps published on this scale measure 15 minutes in both latitude and longitude, and each map covers an area of 195 to 271 square miles, the area depending on the latitude. One of the objectives of the Geological Survey is ultimately to supply a complete atlas of 15-minute topographic quadrangle maps, at the scale of 1 62,500, of the entire area of the continental United States

3 Surveys of areas in which the development problems are regarded as of less magnitude or urgency, such as certain of the desert regions of the West, were formerly made with only generalized detail, and the resulting maps were published on a scale of either 1.125,000 (1 inch = nearly 2 miles) or 1:250,000 (1 inch = nearly 4 miles), with a contour interval of 20 to 250 feet Quadrangle maps published on the scale of 1 125,000 measure 30 minutes in both latitude and longitude and each map covers an area of 790 to 1,084 square miles. Maps published on the scale of 1 250,000 measure 1 degree in each direction, and each map covers an area of 3,120 to 4,336 square miles.



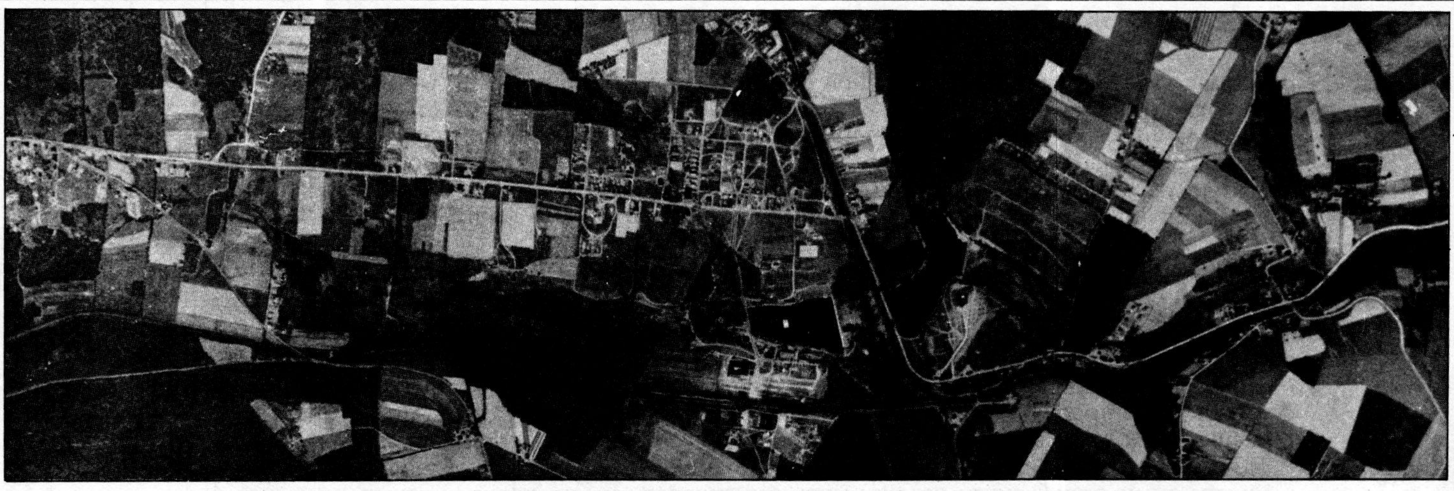
This small map is intended to give a general picture of the areas covered by published topographic maps of the U. S. Geological Survey and other government agencies. Some additional areas have been covered by old reconnaissance surveys which are now considered inadequate. Larger size status maps of the United States covering topographic mapping, aerial photography, aerial mosaics, vertical control, and horizontal control may be obtained on application to the U. S. Geological Survey, Washington 25, D. C. State index circulars showing the details of map coverage and the names of map sheets printed for distribution, are also available without charge.



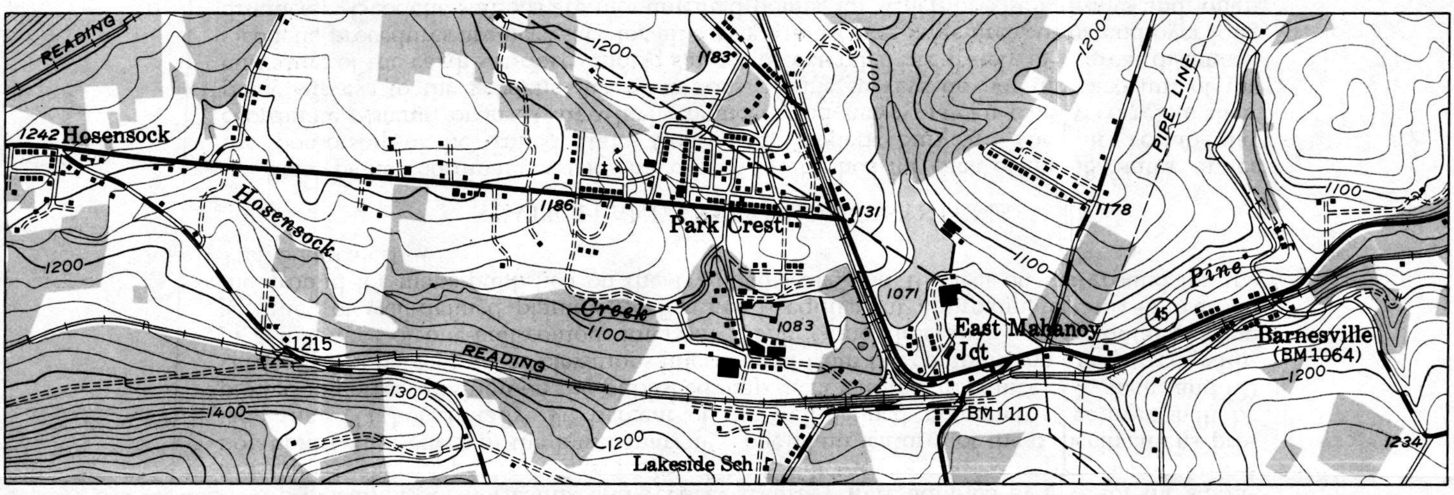


LAND FORMS AS SHOWN ON A TOPOGRAPHIC MAP

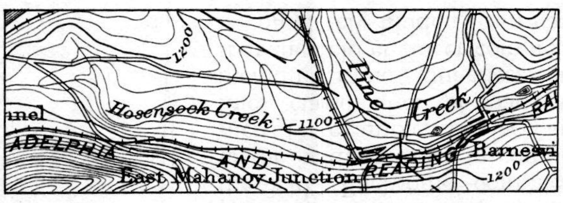
This illustration shows the manner in which relief, hydrographic, and cultural features are shown on a topographic map. The upper part of the illustration is a perspective view of a river valley that lies between two hills. In the foreground is the sea with a bay partly enclosed by a hooked sandbar. On each side of the valley are terraces through which streams have cut gullies. The hill on the right has a gradual slope with rounded forms while that on the left rises abruptly and ends in a sharp precipice from which it slopes gradually away forming an inclined tableland that is traversed by a few shallow gullies. The lower part of the illustration shows the same ground forms represented by contour lines. The contour interval used here is 20 feet, which means that the vertical distance between one contour and the next is 20 feet.



AERIAL PHOTOGRAPH USED IN THE PREPARATION OF MAP SHOWN BELOW.



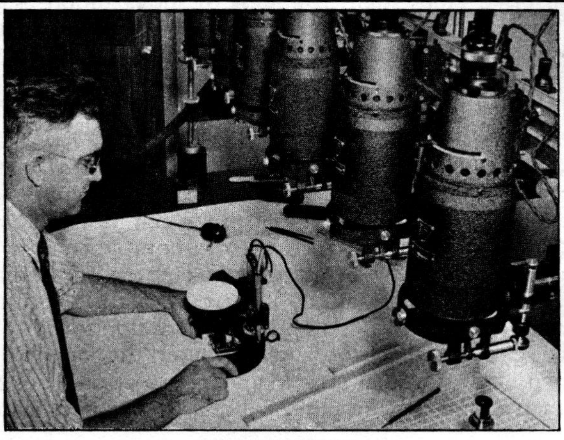
Portion of U. S. Geological Survey's Delano, Pa. 7.5′ quadrangle. Scale 1:24,000 (1″=2000′). Contour interval 20 feet. Topography from aerial photographs by multiplex methods. Surveyed in 1946.



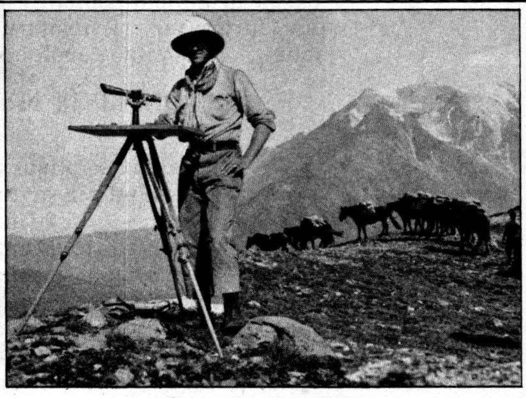
Portion of U. S. Geological Survey's Mahanoy, Pa.15′ quadrangle. Scale 1:62,500 (1″=approximately 1 mile). Contour interval 20 feet. Surveyed in 1889.

The maps shown above cover the same ground area. A comparison of the two will show the extensive changes that have been made since the mapping of the Mahanoy quadrangle in 1889. They also illustrate the value of large scale mapping where culture is dense or where greater detail is needed. Older maps, such as the small one shown above, will be replaced with modern maps as funds become available.

BENCH MARK TABLET



MULTIPLEX



PLANE TABLE

Survey marker and some of the instruments used in the preparation of a topographic map

A new series of generalized topographic maps, planned to cover the entire area of the United States, on a scale of 1:250,000, with contour intervals ranging from 100 feet in the plains areas to 500 feet in the mountains, with relief emphasized by shading, is now in process of preparation and publication This series, which will require several years to complete, is intended primarily to meet military requirements, and original compilation is being done mainly by the Department of the Army An edition for civilian use is planned to follow the military edition of each of these maps, as such maps will be found useful for geographic information and for general planning on a regional basis.

All of the standard quadrangle maps of the United States areas are published on sheets about 16½ by 20 inches in size, except for the 1 24,000 scale maps, which are 22 by 27 inches.

AERIAL PHOTOGRAPHS USED IN MODERN MAPPING

The technical procedures of topographic mapping have undergone considerable change in recent years Aerial photographs, and precise plotting instruments for measuring and converting these photographs to standard maps, now perform a major function in nearly all topographic mapping operations The use of aerial photographs makes it economically practical to prepare the entire series of standard topographic map sheets in conformance with modern engineering standards of accuracy. Although in using aerial photographs each original map sheet is "compiled" in the office, extensive field surveys are still required—first for determining the latitude, longitude, and elevation of a number of control-survey points within each map-sheet area, and second, for checking and completing the map in the field Each office-compiled map sheet, if it is to be of standard quality, must be taken to the field, in order to complete all those features which the photographs do not show—such, for example, as place and feature names, political boundaries and land-subdivision lines, classification of roads and buildings, and numerous small but important features including mines, quarries, cemeteries, large springs, and oil wells It is also necessary that the field engineer complete the map by conventional surveys whenever the land surface is completely hidden from camera view by dense forest growth.

MAP ACCURACY SPECIFICATIONS

Specifications for horizontal and vertical accuracy were adopted in 1942 for the standard topographic maps, and those maps which fulfill these accuracy requirements carry a notation to that effect in the lower margin The main features of these specifications provide that (1) horizontally, 90 percent of the well-defined planimetric features shall be plotted in correct position on the published map sheet within a tolerance of 1/50 inch, and (2) vertically, 90 percent of the elevations interpolated from the contours shall be correct within a tolerance of one-half contour interval (The 1/50 inch tolerance for horizontal position accuracy of well-defined planimetric features is equivalent approximately to 40 feet on the ground for maps published on the 1 24,000 scale, and 100 feet on the ground for the 1:62,500 scale)

STATE PLANE COORDINATE SYSTEMS

State plane coordinate systems have been established for each of the 48 States, under the sponsorship of the United States Coast and Geodetic Survey These are rectangular coordinate systems, or grids, by which engineers and surveyors can readily correlate their plane surveys to the geodetic survey stations Plane surveys do not take account of the curvature of the earth's surface, and so cannot be extended accurately over great distances. Geodetic procedures are necessary for all surveys that cover large areas or extend over long distances. Geodetic stations are monumented points, for which precise latitudes and longitudes have been determined These geodetic positions, referred to the sphere of the earth, can be readily converted into plane, rectangular coordinates of any State system, and vice versa On all recent topographic maps certain of the grid lines of the State rectangular coordinate system may be drawn, by joining with straight lines the corresponding grid ticks, or short sections of lines, which extend at regular intervals just outside the map border, and which are labeled with appropriate north and east coordinate values in feet. In cases where State grid zones overlap, two or more systems will be shown on the map, in which case one zone will have its grid ticks indicated by dotted lines

EXTENT OF AREAS MAPPED

For the United States proper, nearly 10,000 topographic maps, and several hundred planimetric maps (maps that do not depict relief), have been published and are available to the public Some of these maps were originally prepared by other agencies, including the Tennessee Valley Authority, the Department of the Army, the United States Forest Service, and the Coast and Geodetic Survey. All of these maps are now distributed by the Geological Survey, and most of them have been edited and published by the Survey.

These maps in total provide topographic information for nearly 50 percent of the continental United States However, only a part of these maps, covering about one-fourth of the country, are considered to be adequate for modern needs. The remainder of the topographic maps, covering another one-fourth of the country, are older, less accurate, or less complete, so much that they are not fully adequate for modern needs.

The territory of Alaska has about 44 percent of its area covered by reconnaissance-type maps, of which a small portion is on a scale of 1.500,000 (1 inch = nearly 8 miles), with most of the remainder on the scale of 1.250,000 A few areas of particular economic importance are covered by more accurate and detailed maps on a scale of 1.62,500, and some are on larger scales. A new pattern for the layout of the quadrangle maps of Alaska was adopted in 1948, and all future Alaska map sheets will conform to this pattern in format, so as to provide a coordinated series of topographic maps for the entire territory

The Hawaiian Islands have been completely surveyed, and the resulting maps are published on a scale of 1:62,500

Puerto Rico has also been completely surveyed and several series of topographic maps have been published, the main series being on a scale of 1:30,000 (1 inch = nearly ½ mile).

OTHER MAPS AVAILABLE

In addition to the standard series of quadrangle maps, the Geological Survey produces and publishes topographic maps of special format for certain areas of unusual interest, including the national parks and several intensively developed mining areas These maps are published on various scales, depending on the size of the area included and the probable use. Many of them carry a descriptive statement, and some of the maps of national parks and monument areas are available with relief shading as well as contours

Many of the principal river courses and their flood-plain areas have been topographically surveyed, from which strip maps, known as river survey maps, have been prepared and published, usually at the scale of 1.24,000 These maps show in considerable detail the course and fall of the stream, the topography throughout the flood-plain area, selected dam sites, stream profiles, and other features.

Base maps of all of the States have been published on the scale of both 1:500,000 and 1:1,000,000. The State base maps ordinarily show only such features as the boundaries of States, counties, and Federal reservations; the principal cities, railroads, and highways; and the larger rivers and lakes In some States revisions are being prepared which will provide special editions with contours and relief shading. For Alaska, base maps at four different scales are available, the most popular of these being Alaska map E, on the scale of 1:2,500,000.

For the United States as a whole, there are available several series of base maps, contour maps, and relief maps, on different scales, and with varying amounts of information.

STATE INDEX CIRCULARS

Index maps and circulars of each State, and of Alaska, Hawaii, and Puerto Rico, showing the areas covered by topographic and planimetric maps available for public distribution, may be obtained free. Copies of the standard topographic maps may be obtained for 20 cents each; river survey maps are 10 cents per sheet; and special maps are available at different prices which are usually stated in the respective State index circulars. A discount of 20 percent is allowed on orders for maps amounting to $10 or more at the retail price.

Orders for maps should be addressed to the United States Geological Survey, Washington 25, D. C. (or to Denver 15, Colo., for maps of areas west of the Mississippi) Prepayment is required and may be made by money order or check, payable to the Director of the Geological Survey, or in cash—the exact amount—at the sender's risk.

MAP INFORMATION OFFICE

For some years the Geological Survey has maintained a service unit that assembles and distributes information concerning the availability of maps, aerial photographs, and geodetic control. The Map Information Office was first organized to service the Federal surveying and map-making agencies, and was later expanded to serve the requirements of all map users. For information concerning the availability of maps, aerial photographs, geodetic control, and related data, write to the Map Information Office, United States Geological Survey, Washington 25, D C.

Printed May 1950

FREE ON APPLICATION TO THE DIRECTOR, GEOLOGICAL SURVEY, WASHINGTON 25, D. C.

NATIONAL RESEARCH COUNCIL

The National Academy of Sciences is a private organization of eminent American Scientists, chartered under a special act of Congress in 1863 to "investigate, examine, experiment, and report on any subject of science or art." The Academy maintains the National Research Council as its operating agency.

The Council, organized with the cooperation of the scientific and technical societies of America, enjoys the voluntary services of more than 2600 scientists making up over 400 standing committees, boards, and panels in all fields of the natural sciences; its membership includes representatives of business and industry. The Council provides advisory and administrative services for research, and attempts to stimulate and coordinate research effort.

DIVISION OF ENGINEERING AND INDUSTRIAL RESEARCH

The National Research Council operates through eight divisions covering fundamental and applied natural sciences, as well as matters of international relations in scientific research. The Division of Engineering and Industrial Research is concerned with the stimulation and correlation of research in a wide variety of fields in engineering and the applied sciences.

EXECUTIVE COMMITTEE - C. RICHARD SODERBERG, Chairman; WM. R. HAINSWORTH, Vice Chairman; FREDERICK M. FEIKER, T. H. MacDONALD, PAUL D. FOOTE.

EXECUTIVE SECRETARY - LOUIS JORDAN.

HIGHWAY RESEARCH BOARD

The Highway Research Board is organized under the auspices of the Division of Engineering and Industrial Research of the National Research Council. Its purpose is to provide a national clearing house for highway research activities and information. The membership consists of 42 technical, educational, industrial, and governmental organizations of national scope. Associates of the Board are firms, corporations, and individuals who are interested in highway research and who desire to further its work.

The purposes of the Board are: "To encourage research and to provide a national clearing house and correlation service for research activities and information on highway administration and technology, by means of: (1) a forum for presentation and discussion of research papers and reports; (2) committees to suggest and plan research work and to correlate and evaluate results; (3) dissemination of useful information and (4) liaison and cooperative services."