HIGHWAY RESEARCH BOARD

Bulletin 180

Air Photo and Soil Mapping Methods: Appraisal and Application

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1958

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Air Photo and Soil Mapping Methods: Appraisal and Application

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Contents

Introduction

PRESTON C. SMITH, Supervisory Highway Research Engineer
Bureau of Public Roads

●THE HIGHWAY RESEARCH BOARD Committee on Surveying, Mapping and Classification of Soils described in Bulletins 28, 46, and 65 the status and usefulness of geologic maps for highway engineering purposes. Bulletin 83 listed geologic investigations involving geologic mapping in progress in 1953. Most of those investigations have been completed and new investigations are under way; therefore, a list of current geologic investigations is presented in this bulletin. The geologic mapping information in this bulletin was furnished by the U. S. Geological Survey at the request of the committee.

Bulletin 22, "Engineering Use of Agricultural Soil Maps" gave the status of soil surveys by the U. S. Department of Agriculture. A revision, Bulletin 22-R, "Agricultural Soil Maps, Status, July 1957," lists the soil surveys completed and in progress, and rates the soil surveys with respect to adequacy of the mapping for agricultural and engineering purposes. Bulletin 22-R also gives the names and addresses of Soil Survey staff personnel, State Conservationists, and State Soil Scientists of the U. S. Soil Conservation Service.

Geologic Survey Mapping in the United States

●THE U. S. GEOLOGICAL SURVEY, in more than one of its divisions, prepares geologic maps for several purposes. The Geologic Division conducts systematic surveys and research and investigations related to mineral resources and to engineering geology 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.

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

The following list of investigations includes only areal geologic mapping which may be useful to engineers engaged in construction work in the areas concerned.

Any inquires about geologists in charge of the Geologic Division projects (listed in Table 1) should be addressed to the Director, U. S. Geological Survey, Washington 25, D. C., since these men are in the field for only a part of the year, and investigations frequently involve considerable laboratory and office research not generally performed in the field area. 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.

Index to Geological Mapping in the United States

The map indexes, which are available for all 48 states, show the areas of published geologic maps in each state and give the source of publication of each map. The state index maps and the price of each are listed in the following table. Most indexes are on a scale of 1:750,000, others are 1:500,000 or 1:1,000,000. Each index shows the outline of each area mapped and the approximate scales are shown by patterns in four colors. Bibliographies are printed with the indexes giving the sources and the dates of publication and the names of the geologists responsible for the work.

Copies of these index maps may be obtained from the Chief of Distribution, U. S. Geological Survey, Washington 25, D. C., or for the convenience of persons living west of the Mississippi River, indexes for states in that part of the country may be ordered from the Distribution Section, U. S. Geological Survey, Denver Federal Center, Denver, Colorado. Copies may be consulted in many libraries.

AVAILABLE GEOLOGIC MAP INDEXES

State	Year of Publication	Price
Alabama	1951	$0.40
Arizona	1957	.60
Arkansas	1952	.65
California(2sheets)	1952	(set) 1.00
Colorado	1954	.60
Delaware & Maryland	1951	.40
Florida	1953	.60
Georgia	1950	.35
Idaho (In prep)	1957	
Illinois	1954	.60
Indiana	1950	.45
Iowa	1948	.35
Kansas	1954	.60
Kentucky	1952	.50
Louisiana	1950	.50
Maine	1949	.25
Massachusetts, Rhode Island & Connecticut	1952	.40
Michigan	1953	.60
Minnesota	1953	.60
Mississippi	1950	.25
Missouri	1949	.30
Montana	1955	.60
Nebraska	1948	.35
Nevada	1955	.60
New Hampshire & Vermont	1952	.50
New Jersey	1951	.40
New Mexico	1956	.70
New York	1952	.60
North Carolina	1950	.50
North Dakota	1954	.60
Ohio	1949	.25
Oklahoma	1953	.60
Oregon	1950	.25
Pennsylvania	1952	.60
South Carolina	1950	.25
South Dakota	1957	.30
Tennessee	1950	.40
Texas	1951	.60
Utah	1954	.60
Vermont & New Hampshire	1952	.50
Virginia	1951	.40
Washington	1950	.35
West Virginia	1949	.25
Wisconsin	1953	.60
Wyoming	1955	.60

Investigations by State Geological Surveys

Most of the states have geological surveys or similar state agencies that can furnish information on the availability of geological maps and work in progress within the state. The names of state geologists and the location of their offices are shown in Table 3.

TABLE 1

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

Project	Project Chief
ALABAMA	
Pennsylvanian of Alabama in Walker, Winston, Cullman, Blount, and Jefferson Counties	W. C. Culbertson
ARIZONA	
Fuels Potential of the Navajo Reservation, Navajo County	R. B. O'Sullivan
Jerome Copper District, Yavapai County	M. H. Krieger
Globe-Miami Copper District, Gila County	N. P. Peterson
Little Dragoons Copper District, Cochise County	J. R. Cooper
Geologic Studies in Carrizo Mountains, Apache and San Juan Counties	J. D. Strobell
San Manuel, Jr., Pinal County	S. C. Creasey
East Vermillion Cliffs Area, Coconino County	R. G. Petersen
Twin Buttes; Pima County	J. R. Cooper
Klondyke Quadrangle, Pinal County	F. Simons
Holy Joe Peak Quadrangle, Pinal County	M. H. Krieger
Eastern Mogollon Rim Area, Navajo and Apache Counties	W. R. Hansen
ARKANSAS	
Southern Arkansas Oil and Gas in Hot Spring, Clark, Pike, Nevada, Hempstead, and Howard Counties	W. Danilchik
CALIFORNIA	
Engineering Geology of the San Francisco Bay Area in San Francisco, Alameda, Contra Costa, Marin, and San Mateo Counties	J. Schlocker
Surficial Geology of the Beverly Hills and Topanga Quadrangles, Los Angeles County	J. T. McGill
Quaternary Geology of Upper Amargosa Valley, Inyo County	C. S. Denny
Northeast Santa Ana Mountains, Orange County	J. E. Schoellhamer
Quaternary Geology of Death Valley, Inyo County	C. B. Hunt
Funeral Peak Quadrangle, Inyo County	H. Drews
Barney Area, Shasta County	G. A. Macdonald
Panamint Butte Quadrangle, Inyo County	W. E. Hall
Furnace Creek Borate District, Inyo County	J. F. McAllister
Bishop Tungsten; Inyo County	P. C. Bateman
Eastern Sierra Tungsten Belt; Mono and Alpine Counties	D. Rinehart
Sierra Foothills Mineral Belt	L. D. Clark
Cave Mountain Quadrangle, San Bernardino County	A. M. Bassett
Mt. Pinchot Quadrangle, Inyo and Fresno Counties	J. G. Moore
South Klamath Mountains; Shasta and Trinity Counties	W. P. Irwin
Geology of Midland and Big Maria Mountains Quadrangle, Riverside County	W. B. Hamilton
Oakland East Quadrangle, Contra Costa and Alameda Counties	D. H. Radbruch

Table 1 (continued)

Project	Project Chief
COLORADO	
Upper South Platte (North Fork) in Park, Jefferson and Douglas Counties	G. R. Scott
City Geology of Denver in Adams, Denver, Arapahoe and Jefferson Counties, Colorado	R. Van Horn
Mountain Front Recharge Area, South Platte River	Glenn R. Scott
Trinidad Coal Field, Los Animas and Huerfano Counties	R. B. Johnson
Uintah Basin Oil Shale, White River in Uintah, Utah, Garfield and Rio Blanco Counties	W. B. Cashion
Carbondale Coal Field; Garfield and Pitkin County	J. R. Donnell
East Half of Rangely Quadrangle, Moffat and Rio Blanco Counties	A. D. Zapp
North Park in Jackson County	D. M. Kinney
Investigations of Uranium in the Maybelle-Lay Area, Moffat County	M. J. Bergin
Kokomo (Tenmile) mining District, Lake and Eagle County	A. H. Koschmann
San Juan in Dolores, Hinsdale, Ouray, San Juan, and San Miguel Counties	R. G. Luedke
Holy Cross Quadrangle in Eagle, Lake, Summit and Pitkin Counties	O. L. Tweto
Wet Mountain Thorium in Custer and Fremont Counties	Q. D. Singewald
Central City-Georgetown, Jefferson County	P. K. Sims
Creede and Summitville Districts in Mineral, Rio Grande, and Conejos Counties	T. A. Steven
Sage Plain Quadrangle, San Juan County	L. C. Huff
Lisbon Valley Area	G. W. Weir
Gunnison County (Powderhorn), Gunnison County	J. C. Olson
Ralston Buttes District, Jefferson County	D. M. Sheridan
Slick Rock District, San Miguel and Dolores Counties	D. R. Shawe
Uravan District, Montrose and Mesa Counties	R. L. Boardman
Minturn Quadrangle, Eagle and Summit Counties	T. G. Lovering
La Sal Creek Area, Grand and San Juan Counties	W. D. Carter
Ute Mountains Area, Montezuma County	E. B. Ekren
Taylor Park Quadrangle, Gunnison, Chaffee, and Pitkin Counties	M. G. Dings
CONNECTICUT	
Connecticut Cooperative	E. B. Eckel
IDAHO	
Hagerman section across Snake River Valley, Gooding County	H. A. Powers
Cross-section of the Idaho batholith, Valley County	B. F. Leonard
Blackbird Mt. quad. and NW Cobalt, Lemhi County	J. S. Vhay
Coeur d'Alene, Shoshone County	S. W. Hobbs
Soda Springs quad., Bannock, Bear Lake and Caribou Counties	F. C. Armstrong
Aspen Range-Dry Ridge, Bannock, Bear Lake, Caribou and Franklin Counties	E. R. Cressman
Pend Oreille, Bonner County	J. E. Harrison

Table 1 (continued)

Project	Project Chief
IDAHO	
Owyhee-Mountain City, Owyhee County	R. R. Coats
Snake River Valley, Elmore, Bingham, and Power Counties	H. A. Powers
INDIANA	
Quaternary geology, Owensboro quad. Spencer and Warrick Counties	L. L. Ray
IOWA	
Omaha and vicinity, Pottawattamie and Mills Cos.	R. D. Miller
KANSAS	
Kansas Pennsylvanian rocks, Wilson and Shawnee Cos.	W. D. Johnson, Jr.
KENTUCKY	
Geology and mineral resources of a part of the southern Appalachian folded belt, Bell County	J. G. Stephens
Quaternary geology, Owensboro quad.; Davies County	L. L. Ray
Eastern Kentucky underclay studies; Carter, Rowan, Lewis and Elliott Counties	S. H. Patterson
Salem quadrangle; Crittenden and Livingston Counties	R. D. Trace
Geology of the Lee formation, Rock Castle, Pulaski, Laurel, Wayne, and McCreary Counties	E. J. Lyons
MAINE	
Border Mountains, Somerset County	A. L. Albee
Bedrock geology of the Danforth quadrangle, Washington and Aroostook Counties	D. M. Larrabee
Bridgewater quadrangle, Aroostook County	L. Pavlides
Greenville quadrangle, Piscataquis and Somerset Cos.	G. H. Espenshade
MARYLAND	
Stratigraphy of Allegany County	W. de Witt, Jr.
MASSACHUSETTS	
Massachusetts cooperative	L. W. Currier
MICHIGAN	
Michigan copper, Keweenaw and Houghton Counties	W. S. White
Iron River-Crystal Falls district, Iron County	H. L. James
East Marquette, Marquette County	J. E. Gair
Eastern Iron County	K. L. Weir
Southern Dickinson County	R. W. Bayley
MONTANA	
Big Sandy Creek—South half, Chouteau and Blaine Cos.	R. M. Lindvall

Table 1 (continued)

Project	Project Chief
MONTANA	
Wolf Point project, Richland, McCone, Roosevelt, and Valley Counties	R. B. Colton
Great Falls-Sun River project, Teton, Cascae, Lewis and Clark, and Chouteau Counties	R. W. Lemke
Sun River Canyon, Teton and Lewis and Clark Counties	M. R. Mudge
Winnett-Mosby area, Petroleum and Garfield, Rosebud and Fergus Counties	W. D. Johnson, Jr.
Sumatra-Alice Dome area, Rosebud, Garfield, and Musselshell Counties	H. R. Smith
Geology of the Livingston-Trail Creek area, Gallatin and Park Counties	A. E. Roberts
Geology of the Southwest Montana phosphate field, Beaverhead County	W. B. Myers
Browning project, Glacier County	G. M. Richmond
Stratigraphy and structure of the Belt Series in the vicinity of Missoula, Missoula County	W. H. Nelson
Toston quadrangle, Gallatin and Broadwater Counties	G. D. Robinson
Three Forks quadrangle, Gallatin, Jefferson and Broadwater Counties	G. D. Robinson
Duck Creek Pass quadrangle, Broadwater County	W. H. Nelson
Gravelly Range-Madison Range cross section, Madison County	J. B. Hadley
Petrology of the Bearpaw Mountains, Blaine and Chouteau Counties	W. T. Pecora
Coeur d'Alene, Mineral County	S. W. Hobbs
Boulder batholith, Jefferson County	M. R. Klepper
NEBRASKA	
Lower Platte, Valley County	R. D. Miller
Omaha and vicinity, Douglas and Sarpy Counties	R. D. Miller
NEVADA	
Fallon project, Churchill County	R. B. Morrison
Mt. Lewis and Crescent Valley Quadrangles, Lander and Eureka Counties	J. Gilluly
Railroad district, Eureka and Elko Counties	J. F. Smith
Quaternary geology of Upper Amargosa Valley, Nye County	C. S. Denny
Cortez quadrangle, Eureka and Lander Counties	J. Gilluly
Eureka mining district, Eureka and White Pine Counties	T. B. Nolan
Antler Peak quadrangle, Lander and Humboldt Counties	R. J. Roberts
Jarbidge quadrangle, Elko County	R. R. Coats
Snake Range, White Pine County	A. B. Griggs
Humboldt Range (Lovelock), Pershing County	R. E. Wallace
Bullfrog, Nye County	H. R. Cornwall
Owyhee-Mountain City, Elko County	R. R. Coats
NEW JERSEY	
Northeast iron, Warren and Sussex Counties	A. F. Buddington

Table 1 (continued)

Project	Project Chief
NEW JERSEY	
Delaware River Basin, Hunterdon County	J. T. Stark
NEW MEXICO	
Sangre de Cristo Mountains, Santa Fe, San Miguel, Taos, Mora, and Colfax Counties	C. B. Read
Chaco River coal field; San Juan and McKinley Counties	E. C. Beaumont
S.E. New Mexico stratigraphy; Eddy and Otero Counties	P. T. Hayes
Southern Oscura and Northern San Andres Mountains; Socorro and Lincoln Counties	G. O. Bachman
Coking coal of the Raton coal field; Colfax County	A. A. Wanek
Petrology of the Valles Mountains; Sandoval and Rio Arriba Counties	C. S. Ross
Silver City mining region; Grant County	W. R. Jones
Geologic studies in Carrizo Mountains; San Juan County	J. D. Strobell, Jr.
Grants area; McKinley and Valencia Counties	R. E. Thaden
Laguna area; Valencia and Bernalillo Counties	R. H. Moench
NEW YORK	
Delaware Basin surficial geology; Steuben, Tioga, Chemung, and Tompkins Counties	C. S. Denny
Northeast iron; St. Lawrence and Clinton Counties	A. F. Buddington
Richville quadrangle; St. Lawrence County	H. M. Bannerman
NORTH CAROLINA	
Geology and mineral resources of a part of the southern Appalachian folded belt; Morrison and Haywood Counties	J. G. Stephens
Great Smoky Mountains; Swain, Haywood, and Jackson Counties	J. B. Hadley
Grandfather Mountain area; Watauga, Avery, Caldwell and Burk Counties	B. Bryant
Hamme tungsten; Granville and Vance Counties	J. M. Parker
Volcanic slate series; Davidson and Randolph Counties	A. A. Stromquist
Central Piedmont; Cabarrus, Mecklenburg, Gaston, and Lincoln Counties	W. C. Overstreet
OHIO	
Geology of Clinton (Medina); eastern counties	W. deWitt, Jr.
OKLAHOMA	
Permian sediments; Cotton and Jefferson Counties	E. J. McKay
OREGON	
Portland industrial area; Multnomah, Clackamas, and Columbia Counties	D. E. Trimble
Coast Range; Yamhill, Polk, and Marion Counties	E. M. Baldwin
Anlauf-Drain area; Lane and Douglas Counties	L. Hoover

Table 1 (continued)

Project	Project Chief
OREGON	
John Day chromite; Grant and Harney Counties	T. P. Thayer
Geology of Monument 15' quadrangle; Grant County	R. E. Wilcox
PENNSYLVANIA	
Bituminous coal resources; coal-bearing counties of western Pennsylvania	E. D. Patterson
Southern anthracite field; Dauphin, Schuylkill, Carbon, Lebanon, and Northumberland Counties	G. H. Wood, Jr.
Surficial geology of the Delaware Basin; Tioga, Bradford, Lycoming, and Sullivan Counties	C. S. Denny
Northeast iron; York and Lancaster Counties	A. F. Buddington
Mauch Chunk quadrangle; Carbon and Monroe Counties	H. Klemic
Anthracite drainage project; Schuylkill, Carbon, Northumberland, Columbia, Dauphin, Lebanon, Luzerne, Lackawanna, Susquehanna and Wayne Counties	G. H. Wood, Jr.
Delaware River Basin; Bucks County	J. T. Stark
RHODE ISLAND	
Rhode Island Cooperative	A. W. Quinn
SOUTH DAKOTA	
Fort Randall Reservoir Area	C. F. Erskine
TENNESSEE	
Knoxville and vicinity	J. M. Cattermole
Tennessee coal investigations	K. J. Englund
Geology & mineral resources of a part of the southern Appalachian folded belt	J. G. Stephens
Great Smoky Mountains, Sevier County	J. B. Hadley
Geology of the Lee Formation, Jackson County	E. J. Lyons
Mississippi-Embayment-Nashville Dome	J. T. Stark
TEXAS	
Del Rio in Val Verde, Terrell, Brewster Counties	W. R. Hansen
Pennsylvanian oil and gas investigation	A. E. Roberts
Permian Sediments	E. J. McKay
Eagle Mountains, Hudspeth County	J. F. Smith
UTAH	
Upper Green River Valley	W.R. Hansen
Strawberry Valley Quadrangle	A. A. Baker
Southern Colob Plateau Coal, Kane County	W. B. Cashion, Jr.
Uintah Basin Oil Shale, White River Area	W. B. Cashion, Jr.
Cedar City SE Quadrangle	P. Averitt
Fuels Potential of the Navajo Reservation, Navajo County	R. B. O'Sullivan

Table 1 (continued)

Project	Project Chief
UTAH	
Southern half Utah Valley, Utah County	H. J. Bissell
Tintic District, Juab County	H. T. Morris
Abajo (Blue) Mountains	I. J. Witkind
Alta Quadrangle in Salt Lake, Wasatch, and Uintah Counties	M. D. Crittenden, Jr.
Drums - Thomas Range fluorite	M. H. Staatz
Thompson District, Grand County	E. S. Santos
Deer Flat Area, White Canyon District, San Juan County	W. B. Gazdik
Inter-River Area Strip Mapping	E. N. Hinrichs
Sage Plain Quadrangle	L. C. Huff
Circle Cliffs	E. S. Davidson
Lisbon Valley Area	G. W. Weir
Capitol Reef Area, Wayne and Garfield Counties	J. F. Smith, Jr.
San Rafael Swell	C. C. Hawley
Elk Ridge Area, San Juan County	R. Q. Lewis
Orange Cliffs Area, Wayne County	F. H. McKeown
Snake Range, White Pine County	A. B. Griggs
Bingham District, Salt Lake and Toole Counties	R. J. Roberts
San Francisco; Millard and Beaver Counties	D. M. Lemmon
VIRGINIA	
Geologic mapping of Duffield, Stickleyville, Olinger, Keokee, and Pennington Gap Quadrangles in Lee, Scott, and Wise Counties	L. D. Harris
Geologic and mineral resources of a part of the southern Appalachian folded belt	J. G. Stevens
Geology of the Lee Formation	E. J. Lyons
Hamme Tungsten District	J. M. Parker, 3d
WASHINGTON	
Portland Industrial Area, Clark County	D. E. Trimble
Lower Snake River Canyon in Franklin, Walla Walla, Columbia, Whitman, and Garfield Counties	L. M. Gard
Puget Sound Basin	H. H. Waldron
Olympic Mountains, Lake Crescent Area, Clallam County	R. D. Brown, Jr.
Stevens County lead-zinc	R. G. Yates
Turtle Lake Quadrangle, Stevens County	G. E. Becraft
Metaline District, Pend Orielle and Stevens Counties	M. G. Dings
Republic Area, Ferry County	S. J. Muessig
Bald Knob; Ferry County	M. H. Staatz
WYOMING	
Whalen-Wheatland Fault System	L. W. McGrew
Southeast Gros Ventre	W. R. Keefer
Clark Fork; Park County	W. G. Pierce
Lenore Area, Wind River Basin	J. F. Murphy
Investigation of Uranium Deposits in Baggs Area	G. E. Prichard

Table 1 (continued)

Project	Project Chief
WYOMING	
Investigation of Uranium Deposits in the Crooks Gap Area	J. G. Stephens
Big Piney project	N. C. Privasky
Hiland area - investigations of uranium	E. I. Rich
Grand Teton National Park	J. D. Love
Tertiary geology of SW Wyoming, Lincoln County	J. I. Tracey
Fort Hill Quadrangle, Lincoln County	S. S. Oriel
Powder River Basin	W. N. Sharp
Carlile Quadrangle, Crook County	M. H. Bergendahl
Storm Hill Quadrangle, Crook County	R. C. Vickers
South Powder River Basin	W. N. Sharp
Hulett Creek, $7\frac{1}{2}'$ quadrangle, Crook County	C. S. Robinson
Strawberry Hill, $7\frac{1}{2}'$ quadrangle, Crook County	G. Izett

TABLE 2

CURRENT INVESTIGATIONS INVOLVING GEOLOGIC MAPPING, 1:62,500 OR LARGER SCALES, WATER RESOURCES DIVISION, GROUND WATER BRANCH

Project	Project Chief
ALABAMA	
Wilcox County	P. E. LaMoreaux
Tuscaloosa County	J. D. Miller
Montgomery County	D. B. Knowles
Birmingham iron ore district	T. A. Simpson
Marengo County	John Newton
Sylacauga Area	G. W. Swindel
Colbert County	H. B. Harris
Lauderdale County	H. B. Harris
Calhoun County	J. E. Warman
Morgan County	C. L. Dodson
ALASKA	
Matanuska Valley agricultural area	R. M. Waller
Anchorage Area	R. M. Waller
ARIZONA	
Navajo-Hopi Indian Reservations, Arizona-Utah-New Mexico	J. W. Harshbarger
Mogollon Rim region of central Arizona	D. G. Metzger
Navajo and Apache Counties	P. W. Johnson
Northwestern Pinal County	J. W. Harshbarger
Flagstaff Area	J. W. Harshbarger
Lower Bonita Creek area, Grahan County	L. A. Heindl
Northern part of Apache County	J. P. Akers
McMullen Valley, Yuma, Maricopa, and Yavapai Counties	W. Kam
Grand Canyon National Park	D. G. Metzger
Hualpai Indian Reservation	F. R. Twenter

Table 2 (continued)

Project	Project Chief
ARKANSAS	
Lincoln County	J. E. Reed
St. Francis County	R. W. Ryling
CALIFORNIA	
Selected valleys in the Mojave Desert	L. G. Dutcher
San Joaquin Valley	J. F. Poland
Edison-Maricopa Area	P. R. Wood
Ducor-Famosa Area	P. R. Wood
Point Mugu Area, Ventura County	R. W. Page
COLORADO	
Kit Carson County	G. H. Chase
South Platte Valley between Denver and Hardin	R. O. Smith
Prowers County	P. T. Voegeli
Ute Mountain Indian Reservation	J. H. Irwin
Yuma County	W. G. Weist
Denver Basin	G. H. Chase
Washington County	H. E. McGovern
CONNECTICUT	
New Haven Area	R. V. Cushman
Farmington River lowland	A. D. Randall
Southington quadrangle	A. M. LaSala
Lower Quinnipiac lowland	A. M. LaSala
Tariffville Quadrangle	A. D. Randall
Thompson Quadrangle	J. E. Upson
DELAWARE	
Clayton and Milton quadrangles	W. C. Rasmussen
D. C., AND VICINITY	
Washington, D. C. and vicinity	P. M. Johnston
Fairfax quadrangle, Virginia	P. M. Johnston
GEORGIA	
Dougherty and Calhoun Counties	R. L. Wait
Dawsonville Area	J. W. Stewart
HAWAII	
Kauai Island	D. A. Davis
IDAHO	
Western Snake River plain	E. G. Crosthwaite
Eastern Spokane River Basin	S. W. West
Mud Lake Basin	P. R. Stevens

Table 2 (continued)

Project	Project Chief
INDIANA	
Westcentral Indiana (Ten-county area)	F. A. Watkins, Jr.
Northwestern Indiana (Ten-county area)	J. S. Rosenshein
IOWA	
Linn County	W. L. Steinhilber
KANSAS	
Wilson County	C. K. Bayne
Pratt County	D. W. Berry
Gove County	Warren Hodson
Douglas County	H. G. O'Connor
Johnson County	H. G. O'Connor
Kingman County	C. W. Lane
Harper County	C. K. Bayne
Sumner County	K. L. Walters
Prairie Dog Valley area	C. R. Johnson
Republican Valley between Concordia and Clay Center	C. K. Bayne
Cowley County	C. K. Bayne
Sedgwick County	C. W. Lane
Trego County	K. Wahl
Wallace County	W. G. Hodson
Montgomery County	H. G. O'Connor
KENTUCKY	
Eastern Coal Field region	W. E. Price, Jr.
Mammoth Cave Area	R. F. Brown
Alluvial terraces of the Ohio and Mississippi River	W. E. Price Jr. & J. T. Gallaher
Jackson Purchase region	L. M. MacCary
MASSACHUSETTS	
Ipswich River Drainage Basin—downstream section	John Baker
Brockton-Pembroke Area	Richard Peterson
MICHIGAN	
Kalamazoo Area	Morris Deutsch
Alma Area	J. C. Ferris
Holland Area	Morris Deutsch
MINNESOTA	
Redwood Falls area, Redwood County	G. R. Schiner
Bedrock topography of the Eastern Mesabi Range Area, St. Louis County	
Mt. Iron-Virginia Area, St. Louis County	R. D. Cotter
Chisholm area and Balkan Township, St. Louis County	
Lyon County	H. G. Rodis
Nobles County	R. F. Norvitch

Table 2 (continued)

Project	Project Chief
MISSISSIPPI	
Greater Jackson Area	E. J. Harvey
MONTANA	
Two Medicine Irrigation Project	Q. F. Paulson
Western Bitterroot Valley, Ravalli County	R. G. McMurtrey
Northeastern Blaine County	E. A. Zimmerman
Hardin Bench unit, lower Bighorn River Valley	Q. F. Paulson
Deer Lodge Valley in Powell County	R. L. Konizeski
Fort Belknap Indian Reservation, S. E. Blaine County	E. A. Zimmerman
NEBRASKA	
Hamilton County	Charles F. Keech
North Loup River Valley	Marvin P. Carlson
NEVADA	
Truckee Meadows Area, Washoe County	O. J. Loeltz
Quinn River Valley, Humboldt County	F. N. Visher
Boulder Valley & portion of the Humboldt River Valley	C. P. Zones
NEW HAMPSHIRE	
Seacoast region of New Hampshire and adjacent areas	Edward Bradley
Lower Merrimack River Basin	James W. Weigle
NEW JERSEY	
Salem County	J. C. Rosenau
Monmouth County	L. A. Jablonski
Gloucester County	W. F. Hardt
Cape May County	H. E. Gill
Lebanon State Forest	E. C. Rhodehamel
Phillipsburg and vicinity	J. R. Randolph
Wharton Tract	E. C. Rhodehamel
NEW MEXICO	
Los Alamos area	J. E. Weir
Area between Lake McMillan and Carlsbad Springs, Eddy County	E. R. Cox
Southern Lea County	Alfred Clebsch, Jr.
Northern part of the White Sands Integrated Range, Lincoln and Socorro Counties	J. E. Weir, Jr.
Meade Valley, Lincoln County	W. A. Mourant
Gallup area, McKinley County	S. W. West
Albuquerque area	L. J. Bjorklund
McMillan delta, Eddy County	E. R. Cox
Three Rivers drainage area, Otero and Lincoln Counties	E. H. Herrick
Roswell Basin	Ward Motts

Table 2 (continued)

Project	Project Chief
NEW YORK	
Southern Nassau County	J. E. Upson, N. M. Perlmutter
Northwestern Nassau County	W. V. Swarzenski
Southold Township, Suffolk County	H. C. Crandell
Huntington-Smithtown area, Suffolk County	E. R. Lubke
Ontario County	Frederick K. Mack
Dutchess County	I. G. Grossman
Putnam County	I. G. Grossman
West Milton area, Saratoga County	Frederick E. Mack
Massena Waddington area, St. Lawrence County	Frank Trainer
NORTH DAKOTA	
Kidder County	J. W. Brookhart
Traill County	J. W. Brookhart
OHIO	
Franklin County	J. J. Schmidt
Champaign County	A. J. Feulner
Madison County	S. E. Norris
Portage County	J. D. Winslow
Licking County	G. D. Dove
Dayton area	S. E. Morris
Geauga County	J. Baker
OKLAHOMA	
Southern McCurtain County	L. V. Davis
Harmon County and parts of Greer and Jackson Counties	J. E. Barclay
Terrace deposits flanking the northeast side of the Cimarron River	M. E. Davis
Woodward County	C. E. Steele
Whitehorse group on the north flank of the Anadarko Basin	L. V. Davis
Alluvial Valleys of the Arkansas and Vordigris Rivers	
OREGON	
Grande Ronde Valley, Union County	S. G. Brown
The Dalles area	R. C. Newcomb
PENNSYLVANIA	
The Coastal Plain sediments of southeastern Pennsylvania	D. W. Greenman
The Triassic sediments of southeastern Pennsylvania	D. R. Rima
The Pottsville formation in western Pennsylvania	C. W. Poth
The Plateau sediments of western Pennsylvania	D. W. Greenman
East Providence area	W. B. Allen
The Fall River Quadrangle	
The Coventry-Oneco area	

Table 2 (continued)

Project	Project Chief
SOUTH CAROLINA	
The Northeastern section of the Coastal Plain	G. E. Siple
Parts of Aiken, Barnwell, and Allendale Counties	G. E. Siple
TENNESSEE	
The Byersburg area	R. L. Schreurs
The Dover area	M. V. Marcher
The Middleton quadrangle	S. I. Strausberg
TEXAS	
Kinney County	R. R. Bennett
Travis County	T. Arnow
Moore County	J. G. Cronin
Hays County	K. J. DeCook
Tyler County	L. A. Wood
Edwards County	A. T. Long
Bandera County	E. C. Lee
Bexar County	R. M. Petitt, Jr.
Kernes County	R. B. Anders
Uvalde County	Frank Welder
Knox County	W. Ogilbee
Haskell County	W. Ogilbee
Live Oak County	R. B. Anders
Grayson County	E. A. Moulder
UTAH	
Ogden Valley, Weber County	B. E. Lofgren
Navajo Lake and vicinity Kane County	H. E. Thomas
WASHINGTON	
Central Pierce County	
Clark County	M. J. Mundorff
Ahtanum Valley, Yakima County	B. L. Foxworthy
Central Lewis County	J. M. Weigle
Whitman County	B. L. Foxworthy
WISCONSIN	
Portage County	C. L. R. Holt, Jr.
Fond du Lac County	T. G. Newport
Waushara County	W. K. Summers
Rock County	E. F. LeRoux
Dane County	E. F. LeRoux
Waupaca County	C. F. Berkstresser
WYOMING	
Platte County	D. A. Morris

Table 2 (continued)

Project	Project Chief
ALASKA	
Nenana coal investigations, Central Alaska Range	Clyde Wahrhaftig
Yakataga petroleum investigations	D. J. Miller
Petroleum investigations, Iniskin-Tuxedni Region	R. L. Detterman
Nelchina area Mesozoic investigations	Arthur Grantz
Hecata-Tuxekan nonmetals investigations	G. D. Eberlein
Engineering and construction materials investigations	T. L. Pewé
Stratigraphic and structural studies of the lower Yukon-Koyukuk area	W. W. Patton, Jr.
Tofty placer investigations	D. M. Hopkins
Nome C-1 and D-1 quadrangles	C. L. Hummel
Big Delta-Delta River area, terrain and permafrost studies	T. L. Pewé
Windy Curry area, engineering geology	Reuben Kachadoorian
Mt. Michelson area	E. G. Sable
PUERTO RICO	
Puerto Rico cooperative mineral investigations	W. H. Monroe

TABLE 3

STATE GEOLOGISTS

Alabama	Dr. Walter B. Jones, State Geologist, Geological Survey of Alabama, University
Arizona	Dr. J. D. Forrester, Director, Arizona Bureau of Mines, University of Arizona, Tucson
Arkansas	Mr. Norman F. Williams, State Geologist, Arkansas Geological and Conservation 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 and State Commissioner of Mines, Colorado Geological Survey, State Museum Building, Denver
Connecticut	Dr. John B. Lucke, Director, Connecticut Geological and Natural History Survey, Department of Geology and Geography, University of Connecticut, Storrs
Delaware	Mr. John J. Groot, State Geologist, Delaware Geological Survey, University of Delaware, Newark
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, 19 Hunter Street, Atlanta 3

Table 3 (continued)

Idaho	Dr. Earl F. Cook, Director, Idaho Bureau of Mines and Geology, University of Idaho, Moscow
Illinois	Dr. John C. Frye, Chief, State Geological Survey Division, 121 Natural Resources Building, University of Illinois Campus, Urbana
Indiana	Dr. Charles F. Deiss, State Geologist, Indiana Geological Survey, Indiana Department of Conservation, Indiana University, Bloomington
Iowa	Dr. H. Garland Hershey, Director and State Geologist, Iowa Geological Survey, Iowa City
Kansas	Dr. Frank C. Foley, Director and State Geologist, State Geological Survey, The University of Kansas, Lawrence
Kentucky	Dr. Daniel J. Jones, State Geologist, Kentucky Geological Survey, 307 Mineral Industries Building, 120 Graham Avenue, Lexington
Louisiana	Mr. Leo W. Hough, State Geologist, Louisiana Geological Survey, Geology Bldg., P. O. Box 8847, University Station, Baton Rouge 3
Maine	Mr. John R. Rand, State Geologist, Department of Industry and Commerce, State House, Augusta
Maryland	Dr. Joseph T. Singewald, Jr., Director, Department of Geology, Mines and Water Resources, Johns Hopkins University, Baltimore 18
Michigan	Mr. William L. Daoust, State Geologist, Geological Survey Division, State Department of Conservation, Lansing 13
Minnesota	Dr. G. M. Schwartz, Director, Minnesota Geological Survey, University of Minnesota, Minneapolis 14
Mississippi	Dr. W. C. Morse, Director, Mississippi Geological Survey, University of Mississippi, University
Missouri	Dr. Thomas R. Beveridge, State Geologist, Division of Geological Survey and Water Resources, Box 250, Buehler Building, Rolla
Montana	Dr. Edwin G. Koch, Director, State Bureau of Mines and Geology, Butte
Nebraska	Mr. Eugene C. Reed, Director and State Geologist, Conservation and Survey Division, The University of Nebraska, Lincoln 8
Nevada	Mr. Vernon E. Scheid, Director, Nevada Bureau of Mines, University of Nevada, Reno
New Hampshire	Dr. T. R. Meyers, Geologist, New Hampshire State Planning and Development Commission, Conant Hall, University of New Hampshire, Durham

Table 3 (continued)

New Jersey	Mr. Meredith E. Johnson, State Geologist, Bureau of Geology and Topography, Department of Conservation and Economic Development, 520 East State Street, Trenton 7
New Mexico	Mr. Alvin J. Thompson, Director, New Mexico Bureau of Mines and Mineral Resources, Socorro
New York	Dr. John G. Groughton, 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, State Office Building, Raleigh
North Dakota	Dr. Wilson M. Laird, State Geologist, North Dakota Geological Survey, University of North Dakota, Grand Forks
Ohio	Mr. Ralph Bernhagen, Chief, Division of Geological Survey, Orton Hall, Ohio State University, Columbus 10
Oklahoma	Dr. Carl C. Branson, Director, Oklahoma Geological Survey, Norman
Oregon	Mr. Hollis Dole, Director, State Department of Geology and Mineral Industries, 1069 State Office Building, Portland 5
Pennsylvania	Mr. Carlyle Gray, State Geologist and Director, Bureau of Topographic and Geologic Survey, Department of Internal Affairs, Harrisburg
Rhode Island	Dr. Alonzo W. Quinn, Chairman, Mineral Resources Committee, Rhode Island Port and Industrial Development Commission, Providence 3
South Carolina	Dr. Laurence L. Smith, State Geologist, Department of Geology, Mineralogy and Geography, University of South Carolina, Columbia 19
South Dakota	Dr. Allen F. Agnew, State Geologist, State Geological Survey, State University, Lock Drawer 351, Vermilion
Tennessee	Mr. W. D. Hardeman, State Geologist, Division of Geology, Department of Conservation, State Office Building, Nashville 3
Texas	Dr. John T. Lonsdale, Director, Bureau of Economic Geology, The University of Texas, University Station, Box B, Austin 12
Utah	Mr. Arthur L. Crawford, Director, Utah Geological and Mineralogical Survey, College of Mines and Mineral Industries, University of Utah, Salt Lake City 2
Vermont	Dr. Charles G. Doll, State Geologist, State of Vermont Development Commission, East Hall, University of Vermont, Burlington

Table 3 (continued)

Virginia	Mr. James L. Calver, State Geologist, Division of Geology, Virginia Geological Survey, Box 3667, University Station, Charlottesville
Washington	Mr. Marshall Huntting, Supervisor, Division of Mines and Geology, Department of Conservation and Development, 335 General Administration Building, Olympia
West Virginia	Dr. Paul H. Price, State Geologist, West Virginia Geological and Economic Survey, P. O. Box 879, Morgantown
Wisconsin	Mr. George F. Hanson, State Geologist, Geological and Natural History Survey, Science Hall, The University of Wisconsin, Madison 6
Wyoming	Dr. H. D. Thomas, State Geologist, The Geological Survey of Wyoming, University of Wyoming, Laramie

Locating and Mapping Granular Construction Materials From Aerial Photographs

J. D. MOLLARD*, President, and H. E. DISHAW**, Materials Engineer
J. D. Mollard and Associates Limited, Consulting Engineers

This paper summarizes data covering ten years of mapping granular construction materials from aerial photographs. During this period the authors have mapped 2,165 granular-material prospects. Individual deposits mapped from the photos and checked on the ground range in quality from dirty gravelly sand to clean coarse gravel and in quantity from a few hundred to several hundred thousand cu yd.

Data from 75 construction projects covering 32,000 sq mi of search area indicate that airphoto interpretation techniques yield remarkably good results when the interpretation is carried out by experienced photoanalysts familiar with airphoto patterns of granular deposits in the region being searched. As a prospecting tool, the airphoto technique is fast and economical. Results from ten years airphoto mapping show that the areal extent and probably quality of deposits can be reliably predicted in a high proportion of cases. The method particularly aids follow-up subsurface investigations by pin-pointing where to explore in the field, at the same time indicating what to expect in terms of material quality and quantity.

In this paper the need to discover granular construction materials is first pointed out. Pertinent data from construction projects on which granular airphoto searches were made is then presented. This information is followed by review of prospecting problems facing the ground-investigator and a brief discussion of customary granular-search methods used in locating granular construction materials. A summary of the more common granular land forms found in the plains area of western Canada and their identifying features in aerial photographs are presented. In each project area surveyed, the land form contributing the greatest quantity of high-quality aggregate is tabulated. Tables and other statistical data illustrate the frequency of occurrence of various granular land forms in parts of western Canada. Information is presented to indicate, for different geologic environments, the percentage of photo-identified deposits that are commonly suitable as subbase, base course, and wearing-course material. In conclusion the accuracy of airphoto interpretation predications is assessed in terms of the training, experience, and judgment of the photo-interpreter.

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*Formerly Chief, Air Photo Analysis and Engineering Geology Division, PFRA.
**Formerly Special Projects Engineer, Materials Branch, Saskatchewan Department of Highways, Regina.

●IN THE QUEST for granular construction materials, airphoto analysis is employed as a prospecting rather than an exploratory tool. Indeed airphoto analysis is the initial study in a continuous series that includes prospecting, subsurface exploration, testing of materials, and plans for processing and developing a deposit. Obviously the prospecting phase of this series is the one most amenable to air-survey methods.

Airphoto analytic techniques are used to systematically search large areas in order to isolate potential sand and gravel sources to be explored in the field. The information derived from the photos aids subsurface exploration in two distinct ways: (a) it largely obviates ground search operations by pin-pointing where to explore; and (b) it facilitates field operations by informing the ground observer what to expect in terms of general quality and quantity.

Granular deposits identified in aerial photographs may be classified according to expected quantity, probable quality, possible use of the materials, or what can be discerned about past development of sources at the time of the airphoto search. In the latter case, for instance, granular deposits may be classed as (a) deposits that are developed and virtually exhausted; (b) deposits that are partly developed; (c) deposits that are undeveloped (no pits) and, therefore, probably unknown.

The airphoto shows inaccessible terrain as well as accessible terrain, and no trespassing property as well as property which the ground observer is permitted to inspect. Until a promising prospect is discovered the observer analyzing airphotos does not interfere with the operations of property owners.

THE NEED TO DISCOVER GRANULAR DEPOSITS

The need to discover partly developed and undeveloped sources of sand and gravel hardly deserves to be emphasized. As the pace of construction increases, the necessity of finding new sources increases. It should also be pointed out that the volume of sand and gravel available for future use is rapidly diminishing, for sand and gravel is a non-renewable resource. Many of the best deposits—and for the most part the more obvious and nearby ones—have already been developed. And a large proportion of these deposits are now all but exhausted.

Specifications of naturally occurring aggregate materials have become increasingly rigid with the result that many gravel deposits suitable for different uses 20 years ago are no longer satisfactory. In many parts of the Canadian prairies considerably less than one granular deposit in ten has any chance whatever of being suitable as wearing-course aggregate. This ratio might well be extended to include deposits that can be rendered suitable with an economic amount of beneficiation. One reason for this low figure is that on the prairies the bedrock underlying glacial drift is composed largely of clay shales and soft friable sandstones and siltstones —rocks that are deleterious in paving mixtures.

With the depletion of known sources, with greatly increased demand, increased rigidity of specifications and the absence of suitable quarry rock in virtually all parts of the prairies, there is manifestly a need to search carefully large areas in order to discover new commercial sources.

DATA FROM CONSTRUCTION PROJECTS ON WHICH GRANULAR SEARCHES WERE MADE

In the decade from 1947 to 1956 the authors mapped 2,165 granular-material prospects from aerial photos. Of these, 932 were mapped in a nine-month period. Virtually all prospects are located in the plains of western Canada. These photo-identified granular-material prospects are distributed over a search area of roughly 32,000 sq mi; they were mapped in connection with preliminary engineering studies on 75 individual projects. Not all prospects mapped from the airphotos were checked in the field because the more promising looking deposits were investigated first. Wherever an ample supply of satisfactory granular material was confirmed on the ground, field exploration was discontinued.

Although the area of outlined prospects varied from ½ acre to 10 sq mi by far the greatest percentage of mapped deposits ranged between 2 and 20 acres. In fact, only 206 of the 2,165 mapped deposits covered an area greater than ¼ sq mi or 160 acres. That is slightly less than 10 percent. The average area searched on each construction project was 425 sq mi; the range, however, varied between 10 and 1,500 sq mi.

In the summer of 1951, a 1,500 sq mi area representing typical Canadia Great Plains surface geologic conditions was selected to determine the accuracy of airphoto identification of granular deposits. In this region granular deposits, which are mainly glaciofluvial materials, might range anywhere from 20 percent to 80 percent gravel sizes (above ¼ in.). But in nature a high proportion of deposits yield 60 percent to 80 percent sand sizes. Few granular deposits identified in airphotos contain more than 7 percent passing the number 200 sieve.

Results of the test made in 1951 revealed that granular glaciofluvial materials were found at 305 of 340 prospective deposits identified and delineated in the aerial photographs. Alluvial and deltaic sands noted in the airphotos were not mapped because gravel as well as sand was required.

Furthermore, 227 deposits out of those 305 deposits at which sand and gravel were found in the field had no existing pits in them at the time the photographs were taken. In other words, roughly 75 percent of the deposits were correctly identified in the photos without the "give-away" clue of an existing pit.

On this search the interpreter had formal training in airphoto analysis techniques and five years airphoto mapping experience following training. However the analyst was totally unfamiliar with the location and disposition of possible granular deposits in the area being searched.

PROSPECTING PROBLEMS FACING THE GROUND INVESTIGATOR

In the past, problems facing the investigator on the ground have been many and, more often than not, very trying. The materials-location engineer must find a source of aggregate having suitable quantity and quality. To do this he often arbitrarily defined the area he planned to search. The following illustration points up some of the difficulties met in this sort of investigation when airphotos are not used.

Assuming that the area to be searched is 10 mi wide and 100 mi long (1,000 sq mi) and that there actually exist 50 unknown granular deposits, 20 known and partly developed ones which still contain appreciable untapped material, and 20 exhausted sources which have small to large pits in them, the ground investigator must first try to ferret out the locations of the known as well as the unknown deposits. Many undeveloped prospects will be unknown even to the farmer who owns and works the topsoil overlying gravel. A second task of the ground observer will be to classify accurately known deposits in two categories: those that to all intents and purposes are exhausted and those that have a significant quantity of material yet available. Once the materials-location engineer has located all prospective sources, he is then obliged to grid the more promising areas with test holes in order to (a) determine the areal extent of each deposit, and (b) locate the best portions within a deposit for future commercial development purposes.

CUSTOMARY SEARCH METHODS AS AIDS IN AIRPHOTO STUDIES

In the search for undiscovered gravel sources, customary practice has been, and often still is, to contact farmers, local municipal officials, and various provincial government agencies. However, too commonly the information obtained does not answer these questions: Where are the undeveloped sources located? What is the prospective quality of a deposit? What is the extent and depth of a deposit and, thus, quantity available? Which partly developed deposits still contain large supplies?

Recourse may be made to agricultural soils, surficial geologic, topographic and groundwater geology maps. Although they should always be consulted they often have certain shortcomings and limitations when used alone in the search or appraisal of a source of specification material. They are limited to showing only relatively few features of the cultural and natural landscape. None of these maps has the delineation and tabulation of commercial sand and gravel sources as its express objective. In practically all cases map scales at 3 to 6 miles to the inch preclude showing small deposits even though they are important sources of aggregate. In nature a good many commercial deposits are only a few acres in extent. More often the maps referred to above show favorable environments in which commercial granular deposits may be expected to occur.

Generally speaking, on the Canadian prairies those granular deposits that are extensive enough to be shown on published maps are predominately sand and have little if any commercial value. Submarginal and marginal arable lands and inaccessible areas often have the greatest sand and gravel potential; unfortunately they usually correspond to map areas that show the least landscape detail.

Many of the uncertainties of finding undiscovered deposits and much of the routine work of testing large prospective deposits in order to isolate the best portions are taken out of ground operations by the analyst with experience in mapping sand and gravel from aerial photographs.

GRANULAR LAND FORMS IDENTIFIED FROM AIRPHOTOS

There are a great number of granular land forms that may be identified in aerial photos of western Canada. In order to estimate potential quantity and quality of material, each deposit should be studied in its environment, taking into account its physiographic and geologic history. Because all land forms listed below may contain small to large quantities of poor to good quality material, each deposit seen in the photos must be studied individually.

Ice-Contact Granular Land Forms

Eskers and crevasse fillings (both single ridges and intercommunicating networks), esker deltas, individual kames, kame moraines, kame terraces kame deltas, and glacial inwash.

Proglacial Granular Land Forms

Pitted and unpitted outwash plains, meltwater-channel deposits such as granular terraces, valley trains and isolated remnants of valley outwash; glacial-spillway deposits adjoining and, in valleys, developed during rapid draining of glacial lakes. Where sediment-bearing tributary streams entered former glacial lakes or joined major spillway valleys, glacial deltas commonly formed. The water level in most of these lakes and valleys fell, leaving the sand and gravel delta deposits "hanging." Glacial-lake beach ridges are another source of sand and gravel. Although quite common around Glacial Lake Agassiz, they are relatively rare in other parts of the southern Canadian prairies.

Postglacial Granular Land Forms Located in Glaciated Terrains

A number of granular land forms showing variable mechanical composition and varying degrees of sorting have been deposited in recent times. Indeed some of them are still actively accumulating, especially in mountainous and foothill terrains. They are useful for certain types of construction purposes. Some of the more important are talus, or scree, deposits; alluvial fans, cones and deltas; and, probably most important of all, channel-lag deposits in present-day rivers, the so-called "river deposits." Because of dense vegetal cover in the mountains, many of these forms are inconspicous elements of the landscape.

The foregoing list, although not intended to be complete, illustrates the multiplicity of landscape forms that produce different volumes and different types of granular construction material. Engineering problems associated with the development of these deposits vary with each local situation. All land forms listed have been identified and mapped from aerial photos covering western Canada.

THE AIRPHOTO IDENTIFYING FEATURES OF GRANULAR DEPOSITS

The airphoto pattern is both detailed and regional. In a single view it shows various types of land use, accessibility to and from specific places, problems associated with development such as quality of haul roads, probable amount of stripping, possible property damage, high-water tables and other information about anticipated ground conditions.

The vertical aerial view presents a 3-D replica; it shows a miniature scaled model rather than a 2-D map. Minor landscape details of granular deposits are viewed in relation to near and remote identifiable geologic features. These minor details are commonly subtle bits of evidence that reflect the general type and nature of subsoil materials.

The experienced specialist examines airphotos stereoscopically and, where possible, makes use of mosaics to grasp the regional picture. Ordinarily he first maps all granular deposits regardless of quantity, depth, expected quality, or whether or not deposits are partly developed or undeveloped. Each deposit is then carefully checked against all relevant available data, usually in the form of maps and reports. Commonly these maps provide one or more helpful clues. From its appearance in the photos, each prospect can frequently be classified according to the probable origin of rock materials composing the deposit and, nearly always, according to the mode of land-form deposition. Three examples illustrate this:

1. A broad alluvial fan at the base of a mountain containing shale strata.
2. An esker in the Canadian shield.
3. A local meltwater-channel deposit situated in a deep valley carved out of glacial drift.

From decipherable airphoto details relating to mode of land-form deposition and source terrane of rock particles in each land-form, the analyst may suggest that the material in deposit 1 is likely to be dirty, poorly sorted, and high in shale content; that deposit 2 is complexly stratified but probably composed of durable rock particles; and that 3 is well sorted, fairly clean, and contains a small percentage of the very extreme particle sizes, such as boulders and clay. If, in example 3, soft clay-shale bedrock were seen to outcrop locally along the sides of the depression in which the granular deposit is located, the observer might logically infer that the deposit would contain greater or lesser amounts of shale. Geologic setting, therefore, commonly tells the experienced observer something about the lithologic composition and variability of granular deposit.

Special characteristics of granular land forms seen in aerial photos usually tell the observer something about the depth and gradation of a deposit, for example, whether shallow and sandy or deep and gravelly. Particular features of microrelief and erosion, their relation to photo tones, and a variety of special markings are the analyst's "tools of the trade." A good knowledge of special earmarks and an appreciation of the degree of reliability that should be placed on various identifying criteria in different climatic and geographic situations often spell the difference between a mediocre and a really top-notch analyst.

On one rather extensive engineering project a check was made to determine the frequency that certain airphoto characteristics were helpful in identifying the location of a granular deposit and in predicting the nature of the material contained therein. Sixty-five deposits were mapped from the photos and confirmed in the field. The results are as follows:

Identifying Feature Observed in Airphotos	Number of Instances the Feature Aided Identification
Physiographic setting	62
Details of microrelief.	40
Details of gully form	34
Soil tones and, especially, their relation to microrelief	26
"Fossil" current markings, kettleholes and other diagnostic microfeatures	7
Land use and vegetation	10

DATA ON GRANULAR LAND FORMS MAPPED FROM AIRPHOTOS

Relative Quality of Materials in Various Land Forms

The following figures were taken from the results of airphoto gravel searches on 75 projects; they indicate the number of times out of 75 that a particular granular land form contained the best material in a project in terms of quality, quantity and suitability for paving aggregate: small and isolated outwash deposits along meltwater channels, 18; outwash-plain deposits not associated with a valley, 14; large individual kames or clusters of kames, 12; glacial deltas, 9; valley trains, 7; tertiary gravels, 4; extensive glacio-fluvial terraces, 3; glacial-lake beach ridges, 3; present-day stream channel (lag) deposits, 3; and esker deltas, 2. On four projects, there were no deposits suitable for aggregate in bituminous and concrete pavement.

No small and relatively inconspicuous kames and no esker ridges contained high-quality aggregate in quantity. Although eskers seldom yield high-quality wearing course aggregate in large quantities, they often provide a source of road-surface gravel as well as subbase material in bituminous road construction.

Frequency of Occurrence of Granular Land Forms in Different Physiographic Environments

The general physiography of the search area has a marked influence on the number and distribution of various types of granular land forms. An understanding of the physiography is helpful in locating gravel deposits. For example, in a 100-sq mi area and a geologic setting extending on both sides of a former glacial-lake strandline, the following land forms were mapped and checked in the field: beach ridges, 3; glacial-lake deltaic gravelly sands, 3; outwash plains, 1; kame terraces, 2; kames, 4. As another example, in a 110-sq mi area of undulating dead-ice moraine landscape, the following deposits were mapped and checked: stream terraces, 7; outwash plains, 4; kames, 3; eskers, 1; and crevasse fillings, 1. In a third example covering 1,500 sq mi of till plain containing several wide valleys with "misfit" streams, dead-ice moraine and glacial lakebed plain, the following land forms were mapped: individual kames and kame moraine, 13; level and pitted glacial outwash plains, 13; glacial deltas, 4; and granular deposits along the sides and bottoms of meltwater and glacial-lake spillway channels, 35. The fourth illustration is from a mountain-valley region and is only a 60-sq mi area. Results from it are as follows: channel-lag deposits (i. e., shifting gravel bars in the streambed), 12; alluvial fans, 3; high-level stream terraces, 3; alluvial cones, 2; and "hanging" deltas, 2.

Actually in the prairies of western Canada eskers are scarce. But occasionally, where one esker is found there may be a great many. In the fall of 1954 a study of 29 construction projects covering a granular search area of 7,000 sq mi and including 666 granular prospects indicated that only 5 eskers had been mapped. Yet in other airphoto studies of the terrain made up to this time, where construction-materials location was not the express purpose of study, 21 eskers had been noted. These 21 eskers are located in the southern prairies and outside of the 29 granular-search map-areas referred to previously. On the other hand, in the summer of 1956, 10 eskers were mapped on a single project. These figures indicate the variation in distribution of certain land forms.

Suitability of Airphoto-Identified Deposits for Highway Subbase, Base and Wearing Course Material

Six construction projects having geologic terranes typifying better-than-average, average, and below-average granular-material prospects were statistically analyzed to indicate the type of assistance that might be expected from airphoto searches. These are given in Table 1. The following general geologic conditions apply to all areas included in this table:

1. No extensive outwash deposits occur in upland positions in any of the project areas.
2. There are no granular river terraces in any of the areas.
3. All search areas are located in glacial-drift-covered, grass-vegetated terrain.
4. One or more former meltwater and/or glacial-lake spillway channels exist in all project areas.
5. Dominant surficial deposits in the project areas are glacial till, postglacial alluvium and silty or sandy glaciolacustrine material.

TABLE 1

Relative Granular Material Potentiality of Area	Area Searched in Sq Mi	Number of Deposits Mapped	Number of Deposits Field Checked	Number of Checked Deposits Not Usable for Subbase, Base or Wearing Course	Number of Deposits Suitable for		
					Subbase Only	Base Course	Wearing Course
Example A Above Average	150	29	16	2	14	4	2
Example B Above Average	100	27	18	2	16	3	2
Example C Average	150	15	13	4	9	4	2
Example D Average	1500	102	65	8	57	14	10
Example E Below Average	350	19	10[a]	0	10	4	1
Example F Below Average	500	13	13	4	9	2	1

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[a] Selected as the best 10 prospects for field checking (based on airphoto indications).

EXAMPLES

The gravel area outlined by white dots in Figure 1 was located from aerial photographs. The material was used in the construction of a concrete spillway, whose approximate location is also indicated. Both on the ground and on aerial photographs this deposit is difficult to detect because of level topography and an unlikely geologic setting. The deposit was revealed in the photos by a very subtle tonal pattern.

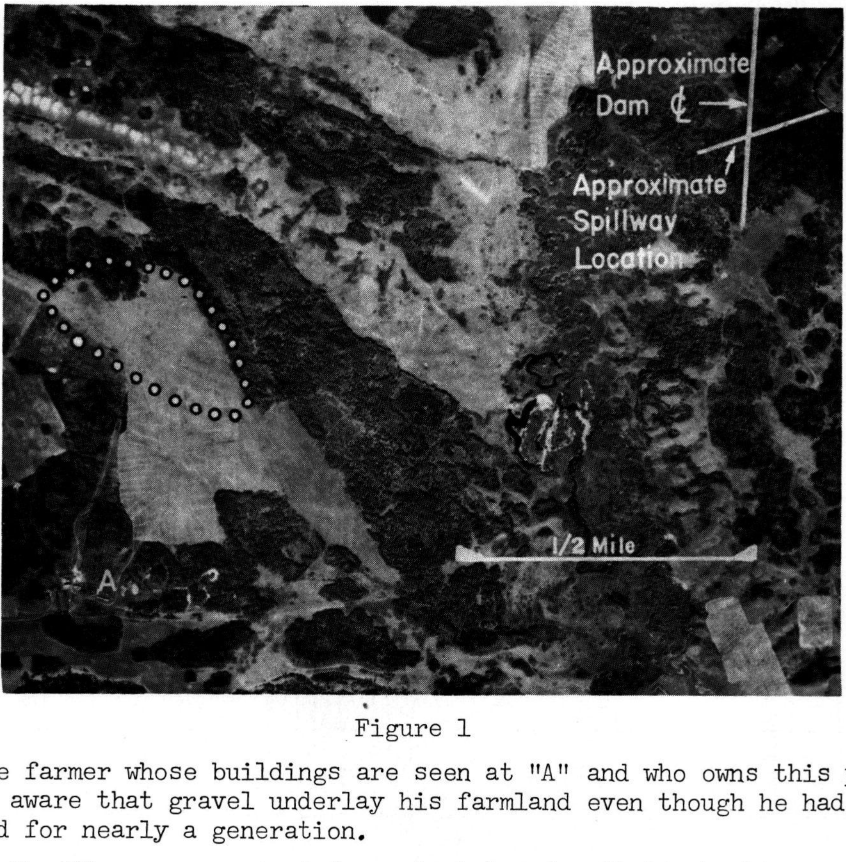

Figure 1

The farmer whose buildings are seen at "A" and who owns this property was not aware that gravel underlay his farmland even though he had worked the land for nearly a generation.

Of the 20 sources mapped from airphotos for field checking on this project, the deposit seen here happened to be the closest source to the construction site. Moreover it contained an insignificant amount of deleterious rocks while most of the others contained excessive amounts of shale. Although superior to other deposits in coarseness and over-all quality of material, this deposit nonetheless required washing and grading to render it suitable for high-grade concrete.

The gravel area outlined by white dots in Figure 2 was located by airphoto analysis in 1955. This deposit contains a good quality gravel. It is worth noting that the deposit was not discovered by ground investigators who previously searched the area, even though it is situated only 1.5 miles from a main highway and in an area where gravel is very scarce. In contrast to Figure 1, topographic position and geologic setting are helpful in identifying this deposit; photo tones on the other hand provide very little assistance.

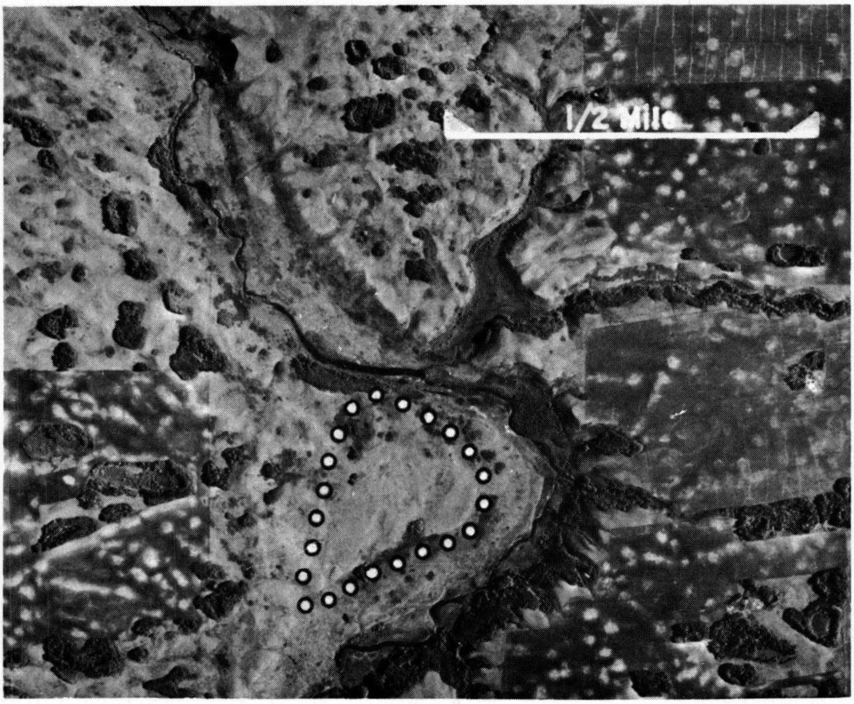

Figure 2.

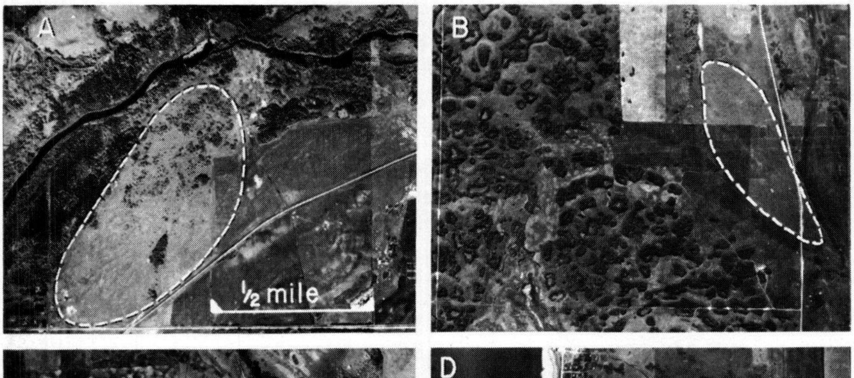

Figure 3.

The four airphoto patterns in Figure 3 were located from airphotos and marked as good coarse gravel prospects. "A" is situated on one major construction job; "B" and "C", on a second; and "D" on a third.

Specifications on all three projects called for one-half to three-quarters million yards of crushed material, graded between $\frac{1}{4}$-in. and $1\frac{1}{2}$-in. In nature each deposit shown above ranged from 65 to 75 percent retained on the $\frac{1}{4}$-in. sieve, and 35 to 45 percent retained on the 2-in. sieve. Each deposit is capable of producing the required quantity of finished material and is moreover located within 3 miles of the closest point on the principal transportation system where the material will be used. These coarse gravel gradations are extremely uncommon in the regions in which they were discovered. In these regions a very high percentage of granular deposits contain 65 to 75 percent passing a $\frac{1}{4}$-in. sieve, that is, sand sizes which on projects like these must be wasted. All coarse gravel deposits marked for future development are outlined by a dashed white line. Field work to date indicates the four deposits are the most promising of several dozen mapped from the photos.

CONCLUSION

In conclusion, it should be restated that the airphoto technique is a prospecting tool, not a subsurface exploratory tool. Basically the objectives of the two are different. The former indicates definite areas of promise to investigate in the field and in addition, and in a high proportion of instances, what to expect in terms of quality and volume of granular material. Ground methods either prove or disprove these airphoto-based expectations with the least expenditure of time and money. In a very high percentage of cases, airphoto predictions by experienced analysts familiar with the region being searched are reliable and accurate. Because i is systematic and regional, the airphoto method has many advantages not inherent in the old conventional methods, which tend to be random and localized and in many cases dependent on hearsay.

The main requirements of the photo interpreter are: (a) a precise knowledge of all granular land forms and the situations in which they most commonly occur in nature; (b) experience in airphoto analysis, which of course influences predictions as to quality and quantity; (3) field checking experiences; and (d) ability and self-discipline to qualify description of prospective deposits so that these descriptions are helpful rather than misleading to the field investigator.

Of paramount importance in locating and mapping granular deposits is familiarity with the airphoto patterns of a region. Familiarity with the variety of airphoto patterns and meaningful nuances in airphoto patterns of granular material can be gained only through analytic and systematic study of the aerial photographs of the region being searched.

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Discussion

D. R. LUEDER, Chief, Engineering Division, Hunting Technical and Exploration Services, Ltd., 1450 O'Connor Drive, Toronto 16, Canada—In addition to reviewing the general association between efficient materials survey and the aerial photographic approach, this paper presents some factual, quantitative data regarding the results that might reasonably be expected through the proper use of the aerial method.

This is something that has been wanted for some time. Everyone has heard much about aerial photographic interpretation during the past ten or fifteen years, and it has been discussed as an operational technique for many types of engineering projects. However, practically no one has bothered to do more than be expository—or at most, qualitative—regarding its efficiency. It is this latter characteristic that will decide its future importance and acceptance as an engineering method. Of particular interest, are two quantitative conclusions that can be drawn from the paper.

One of these shows that physiographic setting, i.e., land form plus relation to surrounding topography, is of importance to materials location more than 90 percent of the time, while such things as micro-relief, gully-shapes, and soil tones also are helpful approximately one-half (or more) of the time. This conclusion agrees quite well with that of the writer, and points up the exceptional importance to a materials engineer, of an adequate knowledge of geomorphology. At the same time, it corroborates the "classical" contention that airphoto interpretation is not done by landform alone, but also depends upon a coincidence of evidence as provided by other elements of the airphoto pattern.

The other conclusion shows that airphoto interpretation, by qualified people, should be successful 75 to 100 percent of the time. However, it also shows that the technique is not really a method for assessing the quality of granular deposits, but rather a technique for identifying deposits whose visible characteristics are those commonly associated with sand and gravel. In other words, while interpretation may be successful 75 to 100 percent of the time, and the located deposits will yield subbase material approximately the same percentage of the time, suitable wearing course material may be expected about 10 to 15 percent of the time. These figures, of course, disregard the specific area and objective of search. The writer's experience has been virtually identical with that indicated by these figures.

There is another application of airphoto interpretation. Recently, a consulting engineer approached the writer's firm with a difficult materials problem. In connection with earth dam construction in Quebec, he desired well-graded material for interior zone construction.

The ideal gradation specifications cited were those of a gently curved line crossing the sand gravel line at 66 percent passing; the sand/silt boundary at 33 percent passing and the clay line at 5 to 10 percent passing.

The area was filled with granular materials (sand and gravel) which comprised even the till. The firm had already spent several unsuccessful weeks in the field looking for the desired material, but the best samples were fine to medium sands with some gravel, but only 5 to 10 percent minus 200.

The area was heavily forested with coniferous-deciduous cover. The scale of the only available photography was 1:60000. Yet the desired material was located after a few days of photo examination, in an area which was considered to have the highest probability. It was a well graded till located primarily upon the basis of landform and gully shapes.

The client was surprised and pleased, although he expressed some mild disappointment that the located material possessed only 27 percent minus 200 instead of the desired 33 percent.

Although the quantitative data provided in the paper is of value, it should be used with care lest it be considered indicative of expected results over a much broader area (geographically and professionally) than that upon which it is actually based.

Use of Soils Maps in Operation and Planning of County Highway Activities

FRANK K. EVANS, Engineer-Superintendent,
Ingham County Road Commission, Mason, Michigan

● INGHAM COUNTY, located in the south central part of Michigan, is 553 sq mi in area, and is considered to be one of the southern Michigan industrial counties. However, approximately 75 percent of the area is typical farming country encountered in any of the so-called rural counties of the state. The geology of the county is typical of the glacial area of the United States. The relief as a whole is smooth or generally rolling although a few sections of the county are choppy and comparatively hilly. The secondary topographic features are typical of the old glacial drainage valleys in this area and are composed of moraines, till plains and drainage basins. The climate is fairly cold in the winter with rather mild summers. The annual precipitation is about 30 in. with a yearly snowfall of approximately 48 in. The spring break-up or thawing period normally begins about February 15 and extends until April 15 or slightly later.

The county highway system, exclusive of the state trunk lines which are maintained by the County Road Commission, is composed of 1,155 miles of roads and streets, 357 miles are classified as county primary highways, and 798 miles are made up of local roads and streets.

There are 25 well-defined soil types within the county ranging from sand gravels through loamy series to heavy clays and muck in the swampy black ground farming area. A very high percentage of these soils are not desirable for the construction of good road grades unless they are given proper corrective measures. Mineral soils comprise about 85 percent of the total land area and the ramaining 15 percent of the soils are organic in nature.

SOIL GROUPS,
PERCENT

Organic soils	15.3
Alluvial soils	2.0
Poorly drained sand	8.8
Imperfect poorly drained clays	30.1
Well drained clay	12.6
Well drained loamy and sandy soils	25.9
Well drained very sandy soil	5.3

The redeeming feature of local highway construction is the availability of numerous sand and gravel deposits in the eskers and moraines which provide excellent subbase and base materials.

A great many county road departments in the United States are in the same situation as Ingham County which cannot afford a technical staff of adequate size to give complete and proper study to numerous problems of an engineering nature. Much work must be based on rational designs, convenient rules of thumb, and horsesense; however, certain aids are available which provide guidance and help in the maintenance and construction of roads. The Michigan Agricultural Experiment Station in cooperation with the United States Department of Agriculture during the early 1930's conducted a rather detailed soil survey of this county and published the results of the survey together with a soils map adequate to provide considerable detailed information. This map and the report are used extensively as a reference in solving construction and maintenance problems. In addition to this soils map, the county has been covered by an aerial survey which provided stereo pairs of aerial photographs covering the entire county. These aerial photographs provide a great deal of topographic information. The Michigan State Highway Department's "Field Manual of Soil Engineering" has also been helpful.

The entire engineering and supervisory staff—in fact, the entire organization—is fairly familiar with the soil types to be encountered and is aware of the many advantages of better road construction that can be obtained by the proper use of local resources.

When a road is to be reconstructed, soils maps are consulted and conferences held between the engineers, the maintenance foreman, and the construction superintendent. The soil conditions are reviewed both as shown on the maps and as observed in the field. As a result of these conferences information is pooled, and adequate grades and road bases can be constructe with greater efficiency and a saving of tax dollars. From the soils maps, the type of soils and their characteristics are checked off and then the maintenance men indicate localized trouble spots and road sections which are inadequate for normal use. Because of climatic conditions (an annual thaw or break-up period of a 2- to 3- month duration) road failure due to natural soils conditions is of great importance. Road grades are checked for frost heaves and weak sections caused by poor soils. In severe cases natural soils normally are under-cut and wasted, backfilled with a free-draining sandy soil; or the grades are raised with sand or sand-gravel to provide a subbase. The extensive corrective measures that most of the state highway departments undertake in this section of the country are not feasible because of financial limitations. The work accomplished during the last 8 or 10 years has made such a vast improvement on the over-all condition of the roads that ordinary citizens are apparently satisfied with the approach to providing better roads.

A 3-mi section of road was recently up-graded or reconstructed from a local gravel road to a medium type bituminous surfaced highway. During normal springs, serious difficulties had been encountered throughout the entire area. On the south mile of this section, there were five types of soils; three of these types (Miami loam, Conover, and Brookston) are loams and clays with imperfect drainage characteristics. These soils extended over 80 percent of the south mile. A 12-in sand-gravel subbase was placed on the earth grade, and the regular 6-in. gravel base was constructed thereon. Then a 2-in. bituminous aggregate surfacing was placed on the new base

In this one 3-mi section of highway, eleven different types of soils were encountered ranging from muck and sand to imperfectly drained clays and wet loams. In the middle mile approximately 1,900 ft received an insulator course of 6-in. of sand-gravel as a subbase, and on the north mile the base depth was increased to 8 in. of gravel, thus obtaining a satisfactory standard. The new 22-ft blacktop on a 28-ft grade has gone through two spring break-up periods and no surface failures of any kind have been noted. This road is an important cross-county route, carrying light to moderate trucking and a variable vehicular traffic of 800 to 1,200 cars per day. Reasonable maintenance costs are anticipated for the 15-yr estimated life of the light bituminous aggregate surface.

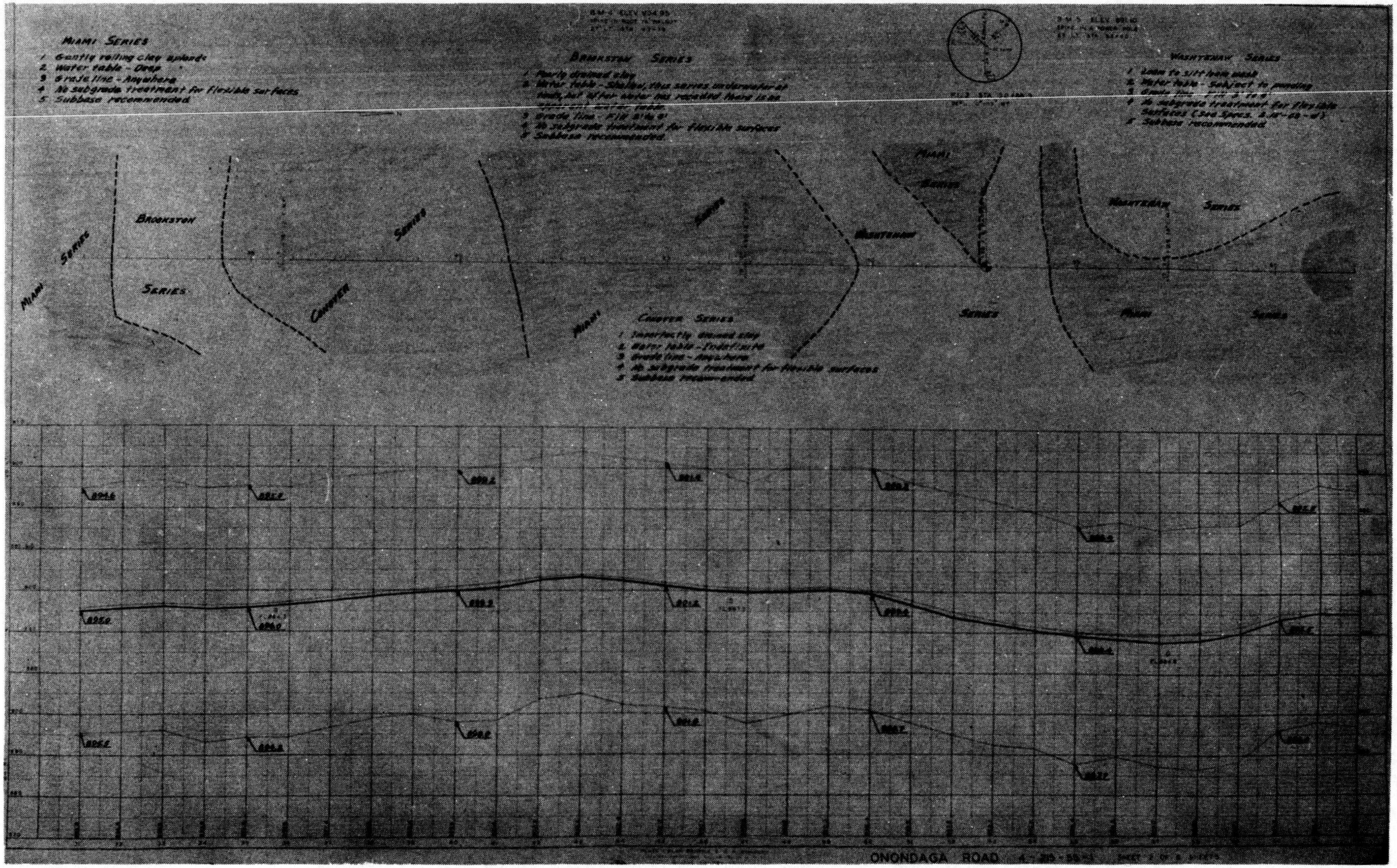

Figure 1. Use of soil map on county road plans, Ingham County, Michigan.

Figure 2. Typical muck excavation and backfill with selected material.

The county soils map and aerial photographs were used to make a survey and map on which are shown the various potential locations for sand and gravel deposits available in each of the 16 townships. Township maps were prepared to a scale of 1 in. equals 2,000 ft, and the limits of some four different mineral soils which produce sand and sand gravel for road work were outlined. The data from the county soils map was checked against the aerial photographs which clearly showed the well drained areas. The use of the aerial photographs also showed many old pits and locations which had not been worked in recent years. These complete records of the deposits are of great assistance in planning the road program and construction activities. In addition to these visual aids, the resistivity methods of soil survey are occasionally used—combined with actual borings in order to determine more accurately the amount of material available in certain deposits. The resistivity surveys are usually carried on by consultants.

As a result of using this approach during the past ten years (particularly since 1951 when the financial structure was materially improved) real progress in providing the people with better roads at a lower cost is being made. Savings in surface repair costs are providing additional highway services, such as road signing, pavement marking, roadside mowing and brush control, and more extensive winter maintenance which results in a more satisfied tax-payer group.

In Michigan, in accordance with state law, counties must report annually to the people and the legislature as to the condition and adequacy

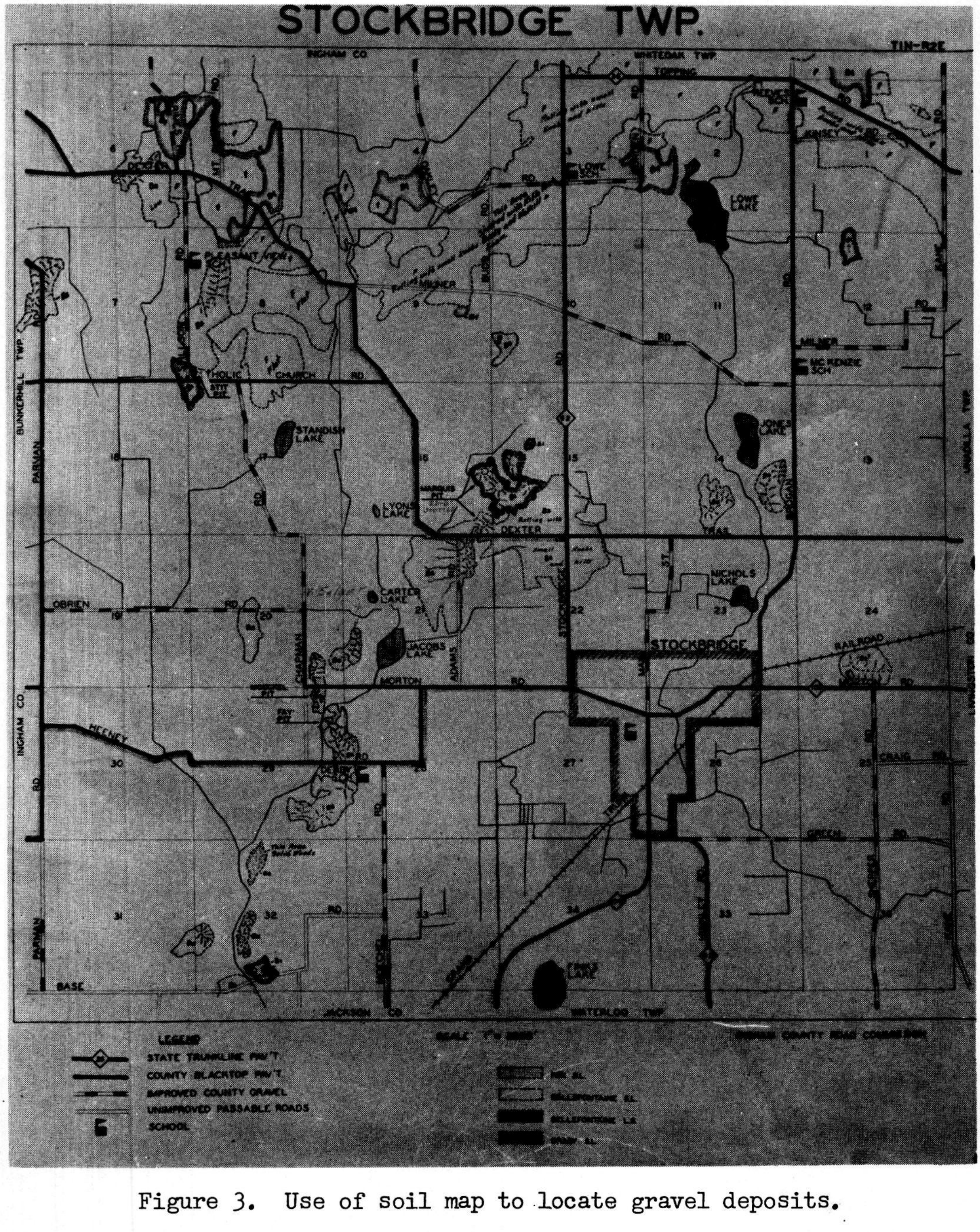

Figure 3. Use of soil map to locate gravel deposits.

of each mile of road. The Ingham County report for the year ending December 31, 1951 showed a county arterial system of 333 miles of which 30 percent was inadequate; and a county local road system of 785 miles of which 40 percent was inadequate. However, the county report of December 31, 1955 showed a county primary system of 362 miles with only 15 percent inadequate, and a county local road system of 793 miles with only 28 percent inadequate. A summary of costs for maintenance of road surfaces shows that over the 4-yr period from 1952 to 1956, during which time price indexes indicate that the cost of labor, materials and equipment has increased about 15 percent, the average per mile cost on routine surface maintenance has decreased as follows: (a) primary bituminous surfaces—1951 cost per mile $266.00, 1955 cost per mile $158.00; and (b) local road surfaces—1951 cost per mile $158.00, 1955 cost per mile $127.00.

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