Effect of Native Materials on Roadbuilding in Ohio

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

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

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

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

In the construction and maintenance of a highway, the roadbuilder must reckon continually with the natural earth materials which will make up its foundations or through which it may be cut. Pavements, roadways and bridges must all be built on or cut through the native soils and rocks. Further, the material of construction for earthwork, for pavement or for structures must be obtained from sources within

reasonable hauling distance for economical construction. Therefore, the native soils, rocks, gravels, etc., exercise a considerable influence over the character and cost of our highways.

NATIVE MATERIALS OF OHIO

Geologic History

The native materials which make up the surface soils and the exposed bedrock of Ohio have been developed through a variety of geologic processes over the long eons of geologic time. For a clear

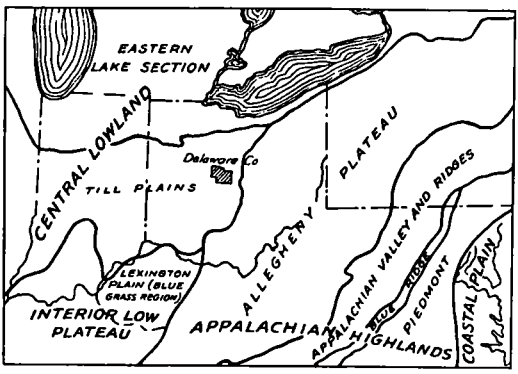

Figure 1. Physiographic divisions of Ohio and adjacent territory.

understanding of these materials, a general knowledge of the salient features of the State's geology is very helpful.

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

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

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

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

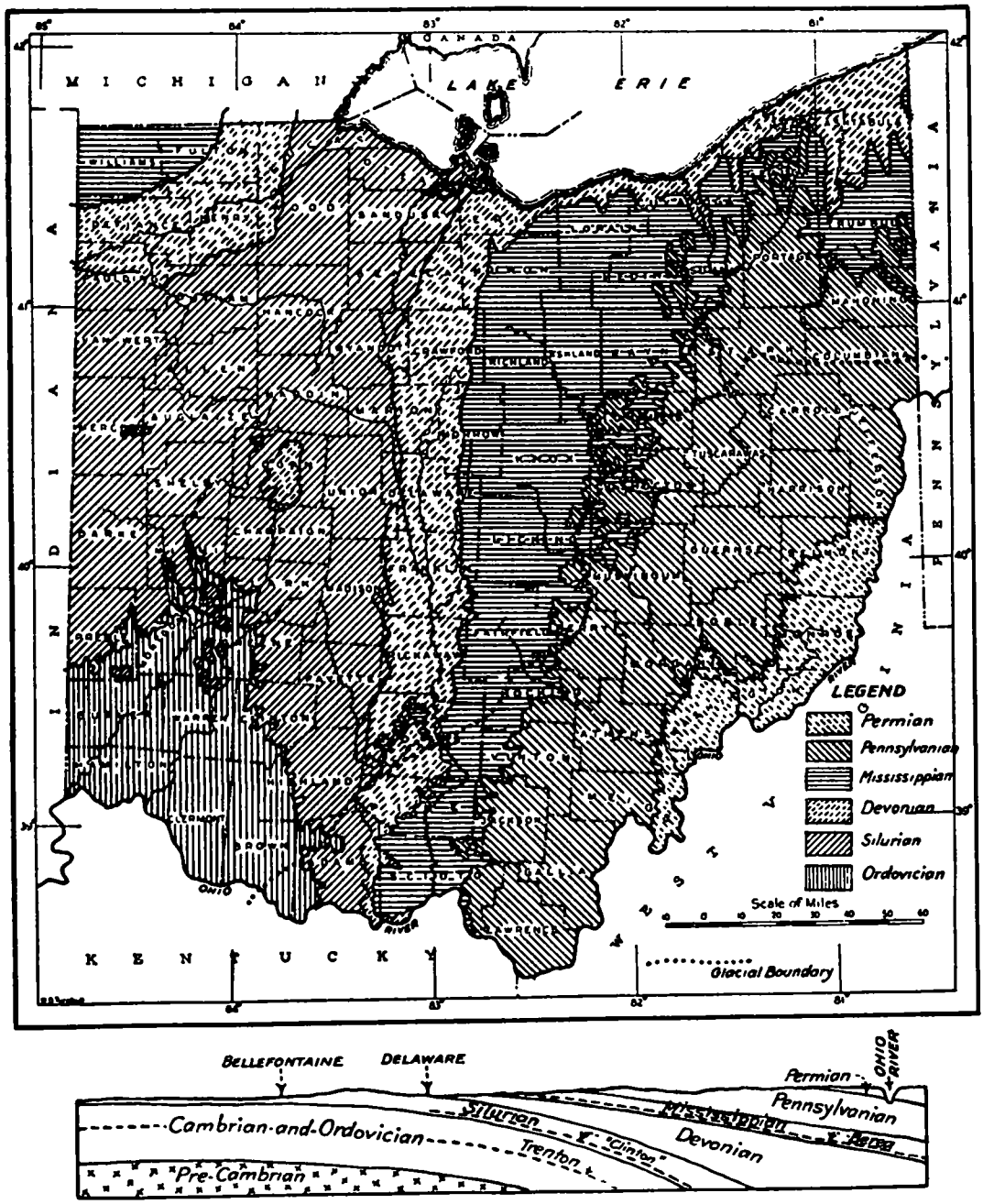

Figure 2. Geologic map of Ohio from Ohio Geological Survey. Below is a cross section from Bellefontaine, Logan County, through Delaware to the Ohio River.

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

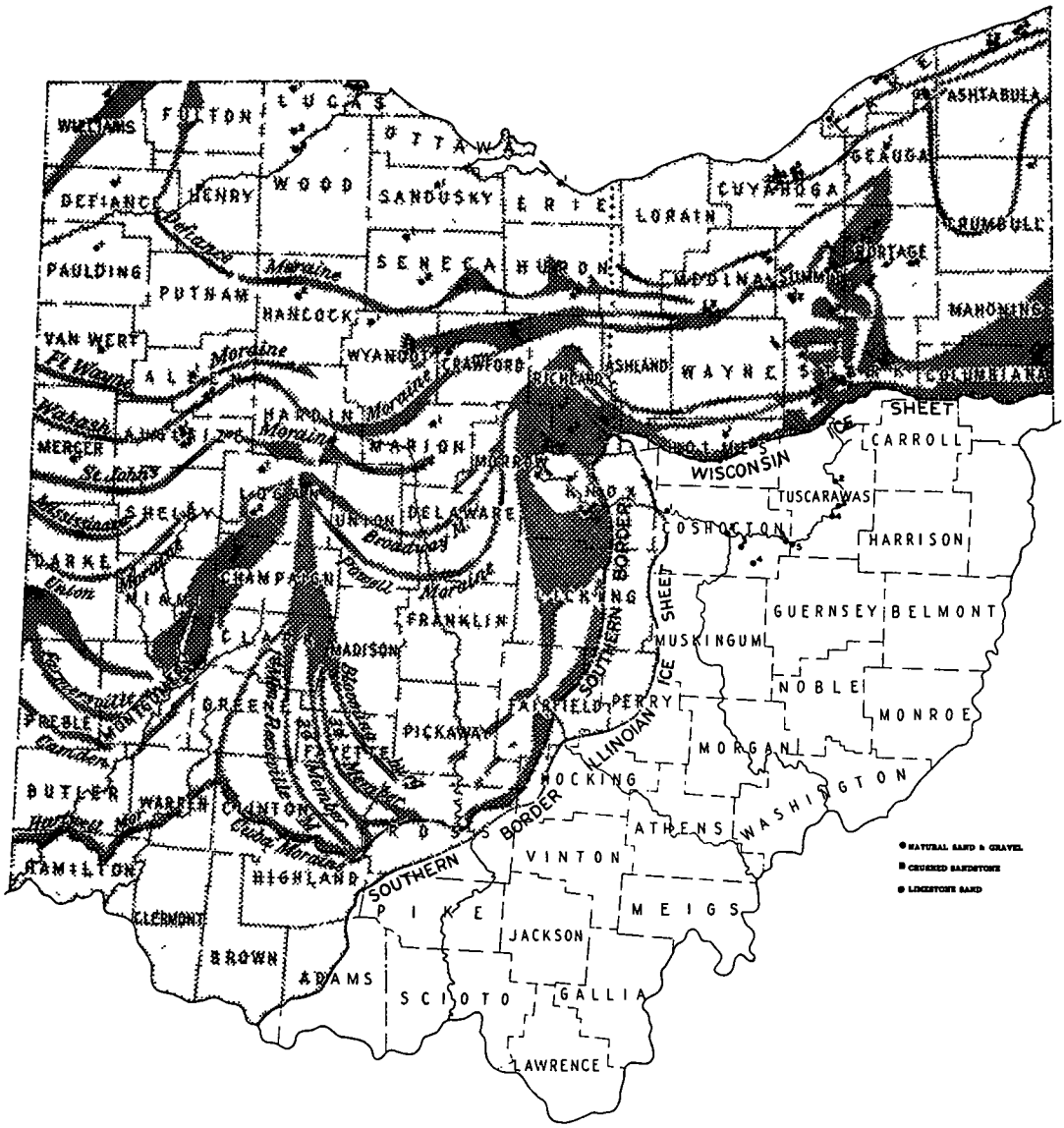

Figure 3. Glacial map of Ohio from Ohio Geological Survey.

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

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

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

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

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

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

Surface Soils

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

The principal soils of the State are as follows:

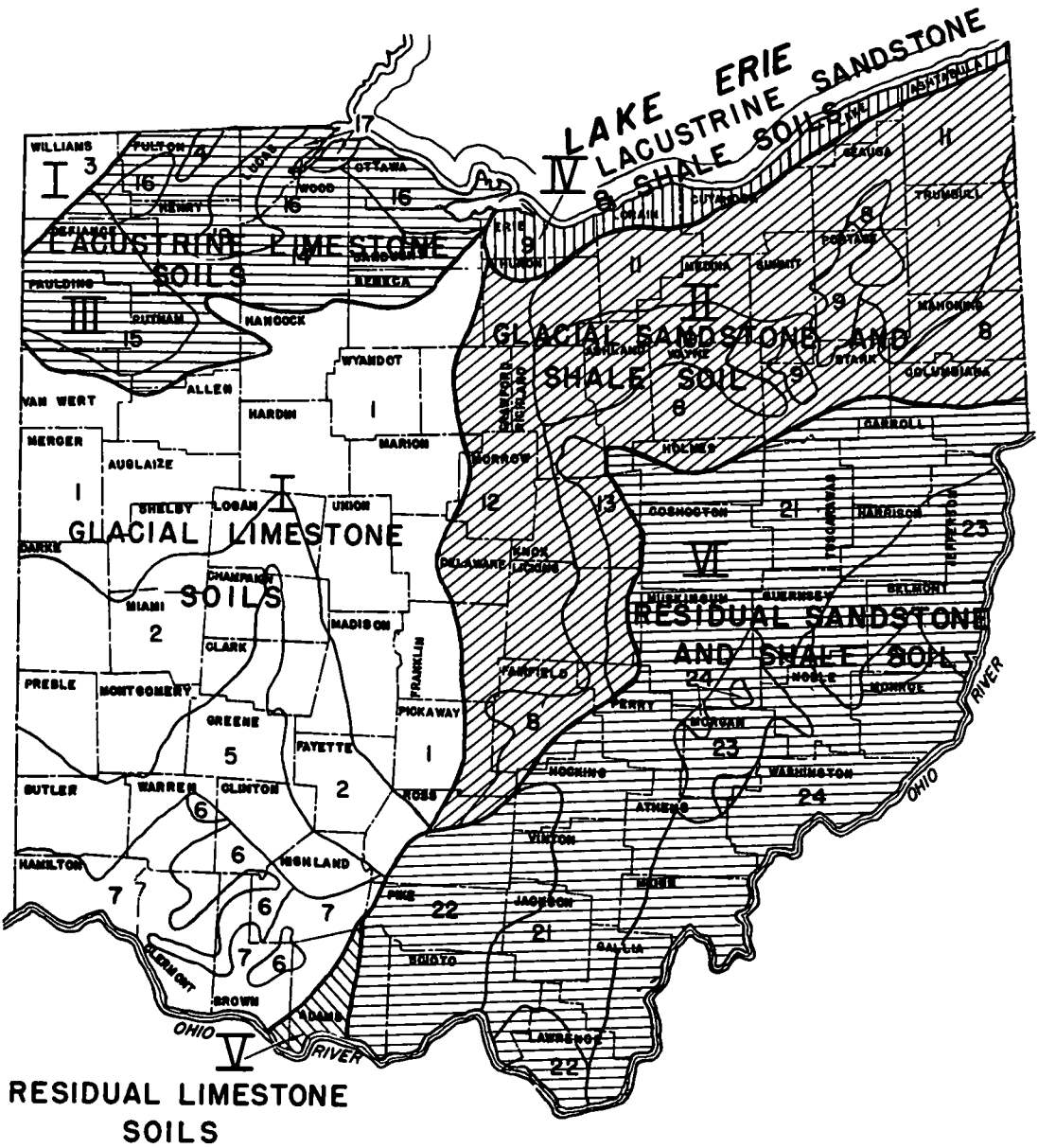

Figure 4. Generalized soil map of Ohio from the Ohio Agricultural Experiment Station, Wooster.

TABLE 1

LEGEND FOR GENERALIZED SOIL MAP OF OHIO (Figure 4)

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

I. Glacial limestone soils.

a. Late Wisconsin Drift soils.
   1. Miami, Crosby, Brookston, and Clyde silty clay loam.
   2. Bellefontaine, Miami and Crosby silt loam; Brookston and Clyde silty clay loam.
   3. Miami and Crosby loam and silt loam; Brookston clay loam and silty clay loam.
   4. Mixed sands and find sandy loams - Coloma, Miami, Nappanee, Wauseon, etc.

b. Early Wisconsin Drift soils.
   5. Russell and Fincastle silt loam with Brookston silt loam.

c. Illinoian Drift soils.
   6. Clermont, Avonburg, Rossmoyne, and Blanchester silt loam.
   7. Cincinnati and Rossmoyne silt loam; Fairmount silty clay loam.

II. Glacial sandstone and shale soils.

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

b. Illinoian Drift soils.
   13. Hanover and Fallsbury silt loam.

III. Lacustrine limestone soils.

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

IV. Lacustrine sandstone and shale soils.

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

V. Residual limestone and shale soils.

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

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

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

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

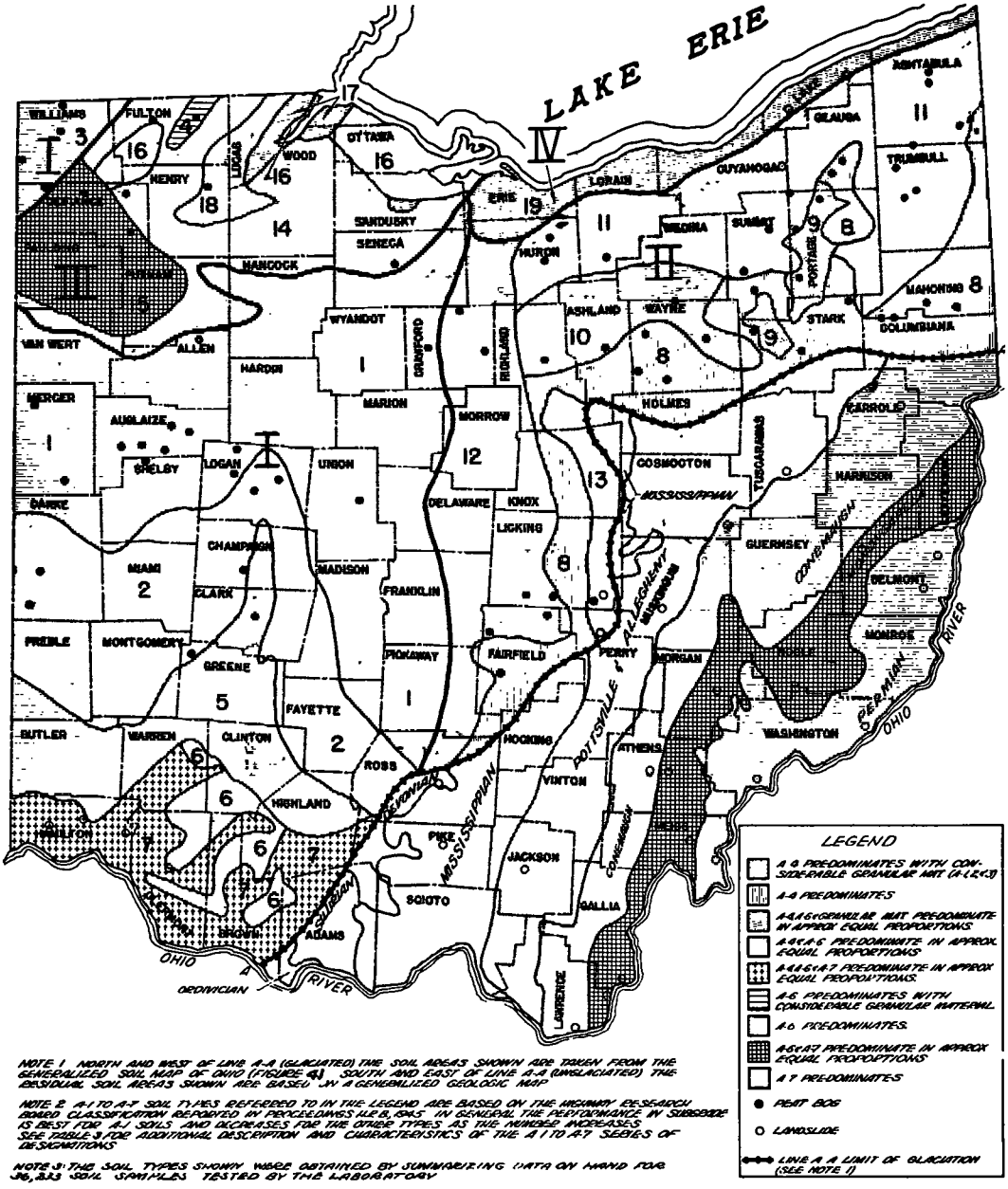

Figure 5. Generalized engineering-soil map of Ohio prepared by Ohio State Highway Testing and Research Laboratory.

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

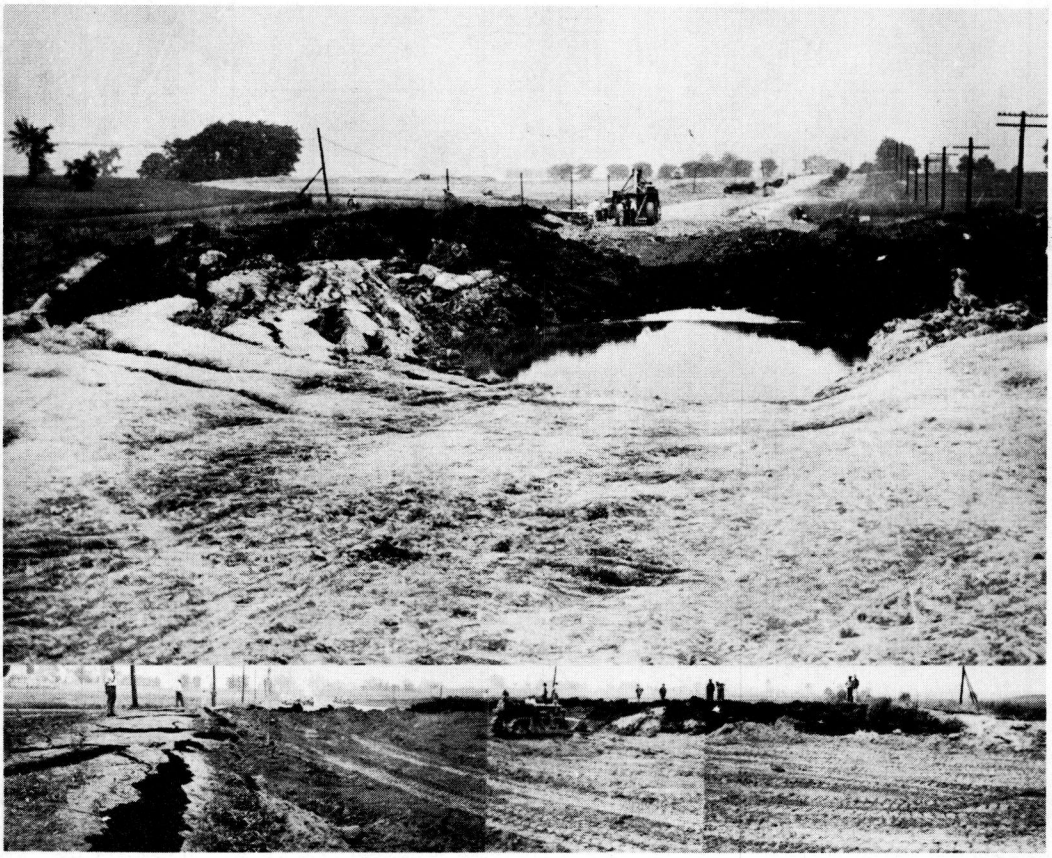

Figure 6. Peat bog, Wisconsin Glacial Drift. S.R. 18, Lorain County, Ohio. The peat is being displaced by loading. Note upheaved peat at left and right of the lower photograph.

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

Glacial Lake Plains. On the broad, even, low areas in northwestern Ohio which represent bottoms of pre-existing extensions of Lake Erie are found the most uniform soils in the State. These soils are fairly heavy clays. Crossing these plains at various points are pronounced ridges which represent old shore lines of the lake. Many of these ridges are followed by highways. Granular material, principally sand, predominate both in these ridges and in a few localized areas on the Lake flats in the form of sand dunes.

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

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

TABLE 2

LEGEND AND CLASSIFICATION FOR SOIL TYPE IDENTIFICATION ON SOIL PROFILES

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

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

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

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

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

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

SOIL CLASSIFICATION CHART

PLAN PREPARATION MANUAL

APPROVED: ACTING CHIEF ENGINEER

BUREAU OF TESTS
OHIO DEPARTMENT OF HIGHWAYS

DATE 4-20-44

№ 1

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

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

Effect of Ohio Geology on Road Construction

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

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

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

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

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

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

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

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

in various parts of the State which form stable fill only when placement and compaction are very carefully controlled.

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

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

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

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

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

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

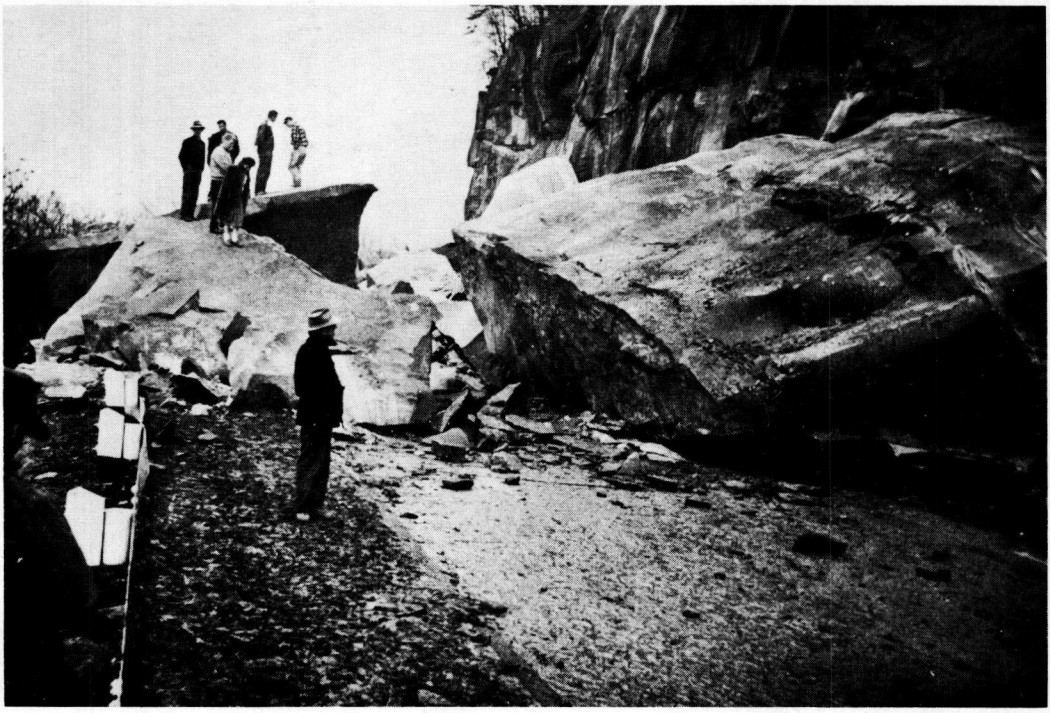

Figure 8. Rock Fall, Permian sandstone, Route 7, Washington County, Ohio. Joints and mud seams in the sandstone and weathering of a soft shale under the stone resulted in this rockfall.

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

5. Shift line to avoid the area.

B. Side Hill Fills.

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

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

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

TABLE 3

DESCRIPTION AND CHARACTERISTICS OF SOIL TYPES

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

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

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

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

Good surface and sub-surface drainage are essential for good pavement performance. Many of the soils which make up subgrade are too dense to be much improved by sub-surface drainage. However, sub-surface drainage is very effective in stabilizing sandy silt soils of low plasticity. These soils are often found in the hilly, moranic areas. They have fairly high stability at moisture content below optimum but become elastic

and subject to excessive deformation and rebound at high moisture contents. Subsurface drainage is also of considerable value in intercepting lateral seepage and in lowering high ground water table wherever these conditions occur.

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

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

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

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

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

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

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

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

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

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

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

Safety Factors and Highway Construction Costs

As was pointed out, highway embankment, pavements and structures depend directly on the natural soil or rock foundations for their support. The engineering properties of soil such as their compressibility, cohesion and resistance to shear which taken together provide its strength are at best difficult to measure. Further, soils are far from uniform in composition, gradation, and moisture content even through relatively short distances. It would, therefore, be desirable to design structures which depend upon soils for their support with a fairly high factor of safety to compensate for the uncertainties of presently available testing procedures and the known variability of the material. However, economic considerations have often made the use of high safety factors impossible. D. W. Taylor, in a paper presented at the Highway Research Board in 1939, entitled, "Limit Design of Foundations and Embankments," states that, "experience has shown that for practical and economic reasons, factors of safety with respect to strength in embankment analyses must frequently be limited to values on the other of 1.1 to 1.5." Likewise, in the design of embankment over questionable foundation soils or of pavement structures, it has long been the practice to provide only a narrow margin of safety. In addition to the considerable economies which are effected in initial construction by the use of these low safety factors, such low safety factors have been acceptable because failure does not usually result in complete loss of a substantial part of the investment in the structure, and almost never would be physically hazardous to the user. For example, if a flexible pavement deforms under the application of loads greater than those for which it was designed, the material which went into its construction is still there and can be used to form a base for a new pavement. Many miles of concrete pavements which had become badly cracked and rough under the steadily increasing weight and volume of traffic have been salvaged by the use of relatively thin resurfacings and have then given excellent service under much heavier traffic than ever was anticipated when the original concrete was placed.

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

The importance of different subgrade materials on pavement construction is readily seen when a comparison is made between relative costs of pavements built on soils which require no subgrade treatment and those built on the usual fine grained soils. On the good granular subgrades such as the beach ridge sands of the Erie Basin or the gravel terraces in some of the river valleys, a pavement thickness of about 8 inches is adequate for very heavy commercial traffic. Such

a pavement 24 ft. wide would cost approximately $50,000 per mile at present day prices. On the low supporting strength clay soils which prevail in much of the State, cost of the 8-in. pavement plus about 14 inches of sub-base and necessary sub-surface drainage would be about $76,000 per mi. If it was considered advisable to utilize a higher safety factor of say 2.5 instead of the currently accepted low safety factors, cost of the high type pavement of 10-in. thickness plus 18 in. of subbase and subsurface drainage would probably be on the order of $93,000 per mile for a 24 foot width pavement.

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

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