THE ENGINEERING SIGNIFICANCE OF SOIL PATTERNS*

By Donald J. Belcher, Research Engineer,
Joint Highway Research Project, Purdue University

SYNOPSIS

The term soil pattern is used in the comprehensive sense that includes not only the color pattern of soils but the numerous other factors recorded in an aerial photograph that are influenced by the soil. When properly evaluated they indicate the engineering properties of the soil.

This work stems, in a large measure, from an engineering evaluation of pedology—the science of soil formation—and its application to the problems of highway design, construction, and maintenance. Its subsequent use in airport site selection has permitted an analysis of the soil patterns and their significance in areas existing under a wide range of soil, parent material, and climatic conditions.

Inasmuch as pedology is an important phase of photo-interpretation a simplified form that may be termed engineering pedology is discussed from the standpoint of subgrade problems. Since this soils engineering technique applies to large areas, a number of extensive soil areas are described in detail and test data showing their uniformity are presented. These have been chosen to illustrate the similarity of soils having a common origin regardless of geographic location. Photographs of these areas are included to illustrate their respective patterns.

The individual soil areas have patterns that indicate their properties. Lacking any information other than that shown in the photograph, the observer may study each of the elements that make up the soil pattern. These elements, consisting of erosion characteristics, soil color, surface drainage, and numerous others, reflect the nature of the profile. Gullies assume various shapes and thereby reveal certain properties of the soil such as texture and claypan developments; surface drainage is a function of slope and porosity of the soil; while color patterns often reflect ground water conditions.

The elements of the soil pattern change and their significance varies in differing climatic zones. The effect of climate is to change the type of vegetative cover and the significance of soil color. However, the soil pattern emphasizes the significance of land forms and weathered slopes. Evaluation of the pedologic classification of the great soil (climatic) groups indicates that it is of little value in engineering work. This assessment is necessary since in some western states and in many foreign areas, this is the only type of soil information available. Therefore, reliance must be placed on the interpretation of the soil pattern and its engineering implications. A group of photographs show the basic soil patterns, geologic patterns, and the occurrence of granular deposits.

The geologic pattern is considered in its relation to problems of location and grading. By example and test results the properties of various strata visible in photographs are shown.

The data show that the soil pattern has engineering significance and that it indicates the conditions that affect the location and construction of highways and airports.

THE PATTERN

THE soil pattern as seen in aerial photographs[1] is the result of the influence of natural and human forces acting on the original material from which the soil was derived. The elements that make up the soil pattern are visible features that are directly or indirectly influenced by the physical properties of the soil profile. These elements form patterns of their own; among them are the land form, soil color, erosion, surface drainage, vegetative cover, slope, land use, and others such as biological evidence, micro-relief, and farm practices. Although these will be discussed in detail later, it is worthwhile to mention here that apparently insignificant features appear in the photographs in remarkable detail. As an example in photographs of arid and semi-arid areas it is not unusual to see holes dug by prairie dogs and ants. Since these animals and insects dig their holes in certain types of soil positions, we know something of the soil when there is evidence of their presence in an area.

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[1] Aerial photographs have been approved for release by the War Department and the New Zealand Defense Command where concerned.

In some areas all of these visible features are present while in other areas one or more are absent. It is helpful to realize that, independently, the natural elements may vary in their significance and that judgment based on a single element may often be in error. For this reason it is desirable that the aerial photograph contain two, three, or four elements that indicate similar properties of the particular profile. Each element, although not duplicating the exact meaning of the others, adds its portion to the interpretation of the nature of the soil profile. Before examining these elements and their significance some attention must be given to the process of soil formation and profile development.

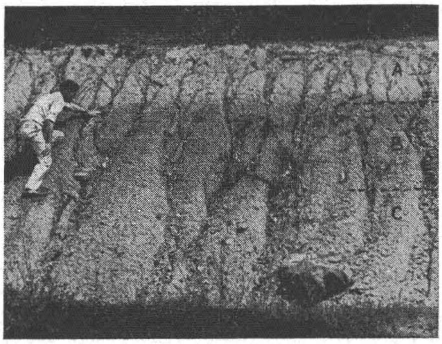

FIG. 1. A weathered profile exposed in a highway cut. The light-colored silty topsoil approximates the "A" horizon. The "B" horizon appears as a horizontal dark band below the topsoil and the "C" unaltered parent material marked by granular fragments.

Engineering Pedology

Knowledge of the weathering of the parent material and the consequent development of the soil profile into horizons (layers) of differing textures is not widely applied in engineering work. For this neglect we are castigated by the words of Ibn-Al-Awam, the Moor who, in 1250 A.D., wrote in his Kitab-Al-Felahah, "All soils are underlain by a layer that differs radically from that at the surface. Such a subsoil is found everywhere and can be said to form one of the layers of the globe. . . . He who does not possess this knowledge lacks the first principles and deserves to be regarded as ignorant." (1)[2] These radical differences are principally textural and therefore may directly influence the performance of highways and runways.

Figure 1 is an example of profile development. The light topsoil, A, is a silt, the dark, B, horizon appearing as horizontal band is a plastic silty clay, and the semi-granular parent material, C, below contains material of all sizes.

Under some conditions the subgrade may be of plastic clay when located in the B horizon whereas in deeper cuts the pavement will rest on the more stable parent material of the C horizon. In areas of gently rolling relief where profile development is strong each cut presents a similar problem in which the subgrade varies from a compacted fill through the A and B horizon to the parent material, C, in the deepest part of the cut. Drainage problems, performance, and subsequent maintenance vary in the same manner. Proof of this lies in the results of performance surveys, pumping surveys, and inventories of spring "breakups." These highway problems can be traced in part to a disregard of soil conditions. Figure 2 illustrates performance in an average highway cut.

In applying soil science to engineering problems it has been possible, and necessary, to eliminate many of the points on which soils are classified, since they have little direct bearing on present engineering use. The essence of the entire subject can be stated as follows: Regardless of geographic distribution, soils developed from similar parent materials under the same conditions of climate and relief are related and will have similar engineering properties which

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[2] Numbers in parentheses refer to Bibliography at end of paper.

in comparable positions will present common construction problems and produce like pavement performance.

Whether the parent material is a hard, resistent bedrock; a soft, easily-eroded loess; or a glacial material (till); each in its own manner develops a soil profile. Because of their individual properties, these parent materials produce a soil pattern that is related to their texture, slope, ground water conditions, and origin. This can be termed "the principle of the recurring profile" which becomes significant not only in engineering soil surveys but in standardizing highway or airport pavement design and construction methods.

When a soil profile recurs, as it does in comparable positions within a parent-material area, the soil pattern will also occur. This is the link between the soil pattern in the airphotos, the soil profile, and the related soil problems. Thus, by the proper sampling of a given soil area the results may be used to determine soil characteristics in other areas having a similar pattern in the airphoto without respect to distance.

Aerial photographs can be a major factor in making soil investigations a practical economic success for at least two reasons. First; under present procedures the average soils laboratory is handicapped by lack of funds and personnel to keep field and laboratory investigations abreast of design and construction requirements; second, the present methods of pavement design do not, except in a generay way, take into account the soil information supplied by surveys.

Aerial photographs combined with geology and pedology (soil science), if used properly, will minimize the first and improve the latter of these two weaknesses. Using the already available standard Agricultural Adjustment Administration photographs as a tool, a soils engineering organization can make a field survey with photos in hand, sample, test and report soil conditions on most projects long before the design department requires the information. The second weakness, that of lack of use of soil data, is equally acute but less easily remedied. The first solution is easily executed since everyone likes to produce more results with less work. The second concerns the field of those not primarily interested in soils but in the final performance of the pavement. If soil tests cannot be shown to effect a reduced cost or an increased pavement life then they will probably be discarded. A soils organization then should pay its own way. If scant use is made of this type of information then something is wrong and soils men are at least partially to blame for not assisting others to use their data.

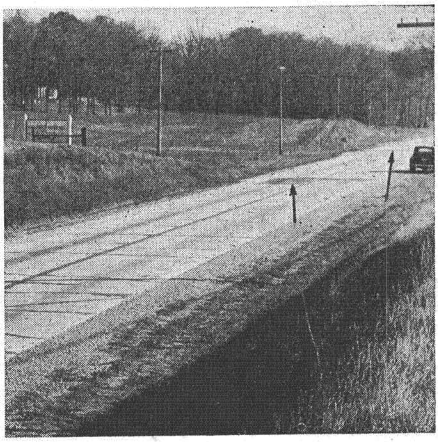

FIG. 2. A road cut into glacial drift parent material. Some method of equalizing subgrade conditions between cut and fill would eliminate the wide difference in performance existing in these adjacent positions. Note patches indicating a failure where the subgrade intersects the plastic material in the "B" horizon.

Aerial photographs can help in this process by providing the necessary factors of interest, understanding of the problem, and a view of the "soil-position." The factor of position is often as important as the physical properties of the soil. The test data plus the relative position of the material tested should equal a given design for one type of road in an area. For example, the results of tests on the extensive silt soils of the Devil's Lake and Lake Agassiz basins in North Dakota and Minnesota are the same as those from the windblown silts that form hills lining the banks of the Mississippi, Missouri, Arkansas, and Platte Rivers. However, the flat, poorly-drained soils of the lakebeds have a high water table—of depressed position—while the silt hills are comparatively dry and well-drained. By any common system of testing, soils from these two areas will appear alike, resulting in one design. Obviously the proper design for one soil-position will result in an over- or under-design for the other situation. Soil tests do not describe the entire situation that effects the subsequent service life of the pavement. The answer lies in relating tests and soil-positions to a standard design proven for each general case.

CHART I — LEGEND AND CLASSIFICATION FOR ENGINEERING SOIL IDENTIFICATION

LEGEND			B.P.R. (1) CLASS	C. AGG. % ON #10	C. SAND % #10—#60	F. SAND % #60—#200	SILT (%) 0.05—0.005M.	CLAY (%) BELOW 0.005M.	LIQUID LIMIT	PLASTICITY INDEX	MAX. DRY WT. LBS. PER CU.FT.	SOIL NO.
SOIL NO.	SYMBOL	DESCRIPTION										
1	▥	TOPSOIL	—	—	—	—	—	—	—	—	—	1
2A	▥	SAND-CLAY	A-2	—	5 - 30	30 - 60	5 - 15	10 - 35	20 - 35	5 - 15	105 - 115	2A
2B	░	SAND	A-3	0 - 25	30 - 70	30 - 70	0 - 25	0 - 10	—	—	100 - 110	2B
3	░	GRAVEL & SAND	A-2	35 - 70	20 - 40	20 - 40	0 - 15	0 - 10	—	—	115 - 130	3
4	▦	GRAVEL-SAND, SILT & CLAY	A-1	30 - 65	15 - 30	15 - 30	10 - 30	5 - 15	15 - 35	0 - 15	120 - 135	4
5	▩	SILT-CLAY, SAND & GRAVEL	A-2	10 - 35	15 - 35	15 - 30	10 - 40	5 - 20	15 - 40	10 - 30	115 - 125	5
6	⊞	SILT (EXPANSIVE)	A-4	0 - 5	0 - 5	0 - 40	35 - 90	10 - 30	20 - 35	0 - 10	95 - 110	6
7	▧	SILT WITH SAND &/OR GRAVEL	A-4	0 - 5	5 - 55	0 - 25	20 - 65	10 - 25	20 - 25	6 - 12	110 - 125	7
8	▨	SILT WITH SAND & CLAY	A-4, A-7	0 - 5	0 - 20	5 - 20	30 - 50	20 - 50	25 - 35	10 - 15	110 - 120	8
9	▩	SILT-CLAY (EXPANSIVE)	A-5	0 - 10	0 - 10	0 - 10	35 - 75	15 - 35	35 - 50	10 - 20	95 - 105	9
10	▤	CLAY WITH SILT & SAND	A-7	0 - 5	0 - 35	0 - 15	15 - 65	15 - 40	35 - 45	15 - 30	100 - 110	10
11	▓	CLAY WITH SILT (PLASTIC)	A-6, A-7	0 - 5	0 - 15	0 - 15	30 - 55	25 - 50	45 - 60	20 - 35	95 - 105	11
12A	▓	CLAY WITH SILT (COLLOIDAL)	A-6	0 - 5	0 - 10	0 - 5	40 - 60	30 - 50	+60	+30	-95	12A
12B	▓	CLAY WITH SILT (ORGANIC)	A-5	0 - 5	0 - 5	0 - 5	50 - 80	5 - 35	45 - 150	10 - 50	-85	12B
12C	▓	CLAY WITH SILT (EXPANSIVE)	A-5	—	—	—	—	—	50 - 70	15 - 25	-95	12C
13	▦	ROCK-SOIL MIXTURE	—	+50	—	—	—	—	—	—	—	13
14	■	MUCK, PEAT, OR COAL										14
15	▓	SOFT OR WEATHERED SHALE										15
16	▤	HARD SHALE										16
17	▦	SANDSTONE										17
18	▦	LIMESTONE										18
19	░	GRANITE										19
20	▨	MICA SCHIST										20
21	░	BASALT										21
22	▨	CORAL										22
23	□											23

1- BUREAU OF PUBLIC ROADS, NOW PUBLIC ROADS ADMINISTRATION

Aerial photographs functioning as a scale model permit examination of the situation without an inspection trip. Since position is determined chiefly by the relief of an area, the numbers of positions is limited to perhaps two types of cuts, shallow or deep; fills, high or low; level areas; and special or miscellaneous positions. Thus, there are approximately five standard positions. The soil factor then enters into the equation. In working with an average State the soils should be divided into as many groups as will warrant changes in design or construction methods—no more. Currently this permits, as it should, classification of soils—from the most plastic to the granular—into a few groups. Chart I, a tentative step in this direction, has 11 soils with a strong possibility of a future reduction by grouping. The theoretical number of soil-positions (five positions times the number of types of soil) and resulting designs are further reduced inasmuch as the same design may apply to sands and gravels in all positions. Further, there are large areas in which some of these soils do not occur and too there are some soils that occur in one or two positions only.

The resulting table would then combine the soil-position factor in a columnar arrangement with the soil number or class ranging from top to bottom on the left with the various positions forming vertical columns. At the intersection of each "soil" and "position" a box is formed to contain design recommendations

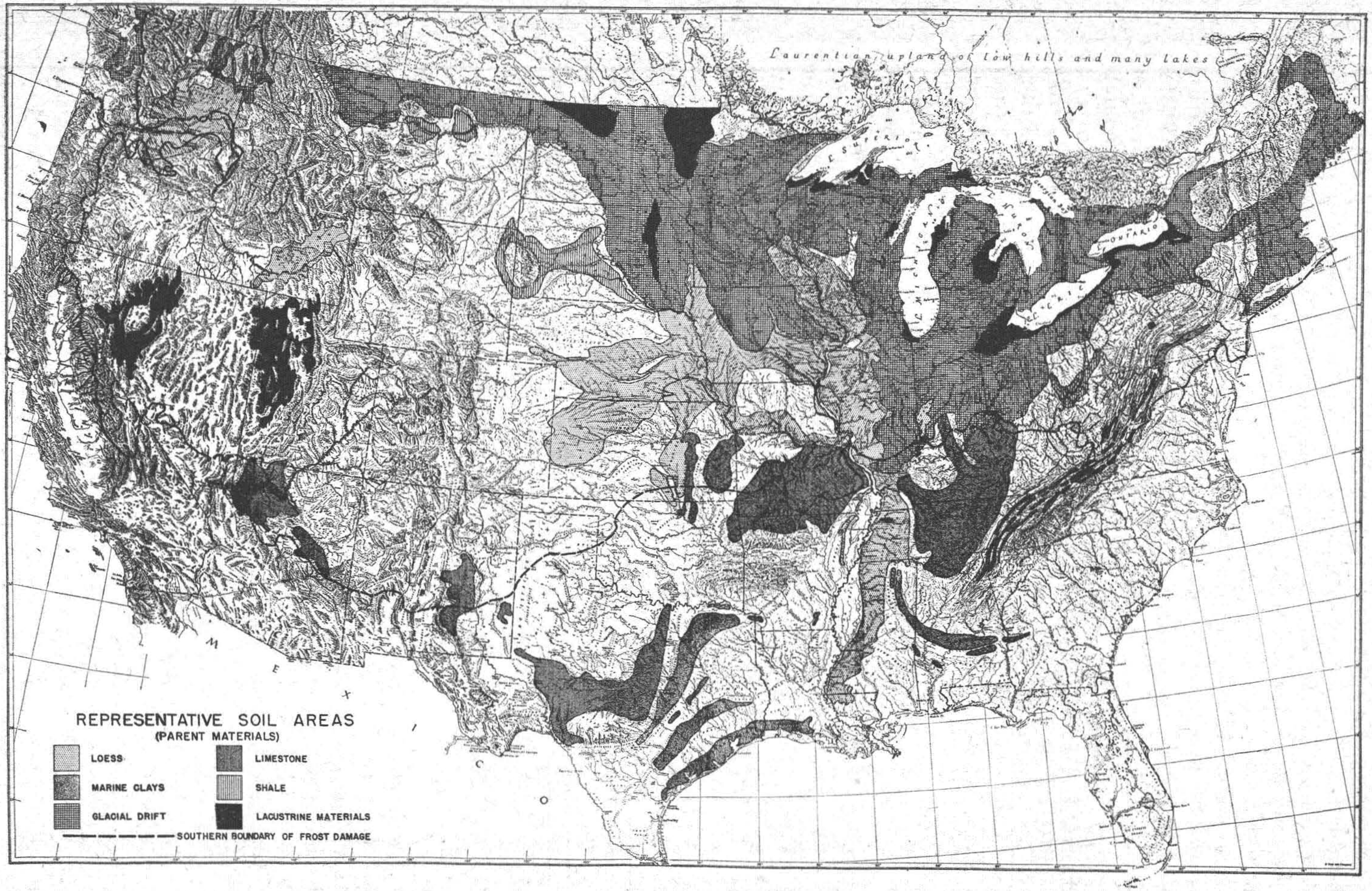

FIG. 3. Location map showing the distribution of four soil areas of United States representing different types of parent materials. The balance of the area may be proportioned as follows: Great Plains materials and Coastal plains—water deposited; residual soils from sandstone, shales, granites, volcanics, etc.; and alluvium or recent stream deposits.

wherever the particular situation is encountered. As an example of this system a skeleton table is shown in Table I in which several "soils" require the same design in one position for a given class of road. The table applies to roads carrying the heaviest commercial traffic in a hypothetical region that includes the industrial east and midwest.

It is reasonable that the regions should be established on a climatic basis to include problems produced by weather conditions. On the basis of temperature a boundary has been suggested by the Public Roads Administration (19) defining the practical southern limit of frost action occurrence. This boundary separates the country into two general areas (See Fig. 3): 1, that subject to serious ground freezing, and 2, that relatively safe from ground freezing. In the light of more recent studies other problems directly related to rainfall and pavement performance permit several eastwest sub-divisions of the temperature belts into areas based on rainfall. In attemping to establish these boundaries a modification of both the Koppen and the Thornthwaite methods of climatic classification is necessary in order to emphasize the important climatic conditions influencing pavement performance.

TABLE I

TENTATIVE FORM AND CONTENT OF SUBGRADE DESIGN TABLE FOR HIGH TYPE ROADS

REGION W$^{(1)}$

SOIL NO. (CHART I)	RELATIVE GRADE LINE POSITION			
	CUTS$^{(2)}$	FILLS	LEVEL	MISCELLANEOUS$^{(3)}$
2	A	M	A	X (SHALLOW SAND ON IMPERVIOUS TILL)
3	A	M	$A_1^{(4)}$	—
4	B	M	A	—
5	B	M	A	—
6	C	B	K	K_1 (UNDERLAIN BY CLAYPAN)
7	D	N	—	—
8	D	N	—	—
9	—$^{(5)}$	O	—	Y
10	E	F	F	Z
11	—	G	G	Z
12	—	R	R	Z

DESIGN OR CONSTRUCTION RECOMMENDATION (BRIEFED)

(A) SUBGRADE PAPER.
(C) COMPACTION — SPECIAL MOISTURE CONTROL.
(D) 6 INCH, DRAINED, GRANULAR INSULATION COURSE
(E) 8 INCH, DRAINED, GRANULAR INSULATION COURSE.

(1) INCLUDES SOILS DERIVED FROM GLACIAL DRIFT, SANDSTONE, LIMESTONE, LOESSIAL AND LACUSTRINE DEPOSITS, AND ALLUVIUM. ANNUAL RAINFALL 25 TO 45 INCHES. SUBJECT TO GROUND FREEZING IN WINTER MONTHS.

(2) INTO PARENT MATERIAL.

(3) INCLUDES LOCATIONS WHERE GENERAL SUBGRADE MATERIAL IS UNDERLAIN BY HORIZONS OR STRATA OF CONTRASTING TEXTURE.

(4) SUBSCRIPTS INDICATE DEVIATIONS FROM STANDARD PRACTICE INFLUENCED BY POSITION.

(5) DOES NOT OCCUR IN THIS POSITION.

In warm climates where frost action is not anticipated the moisture content of the subgrade is governed by the soil and the seasonal rainfall. Tentatively it is indicated that under wide variations in annual rainfall two separate subgrades composed of similar soil would at some period each year reach saturation. The distinction between 20 in. annual rainfall and 50 in. in similar soil areas would exist in the duration of the problem period or the period of highest subgrade moisture content. In desert and semi-arid areas it is becoming increasingly evident that in these areas having a low P/E[3] ratio the subgrade moisture content is cumulative over a relatively long period of time, finally resulting in pavement distress.

Table I indicates the form that a subgrade design chart may assume. For example Design C applies to silts in rolling terrain and would include the required improvements of the exposed subgrade, such as compaction, to a specified density or some other form of stabilization that had been found to give satisfactory performance with a given pavement design. This design would probably specify the permissable tolerance in moisture content for compacting these materials to the required density. Since this is a critical factor in the compacting of this particular material, that phase would be important to all positions. Furthermore, it is probable that, in this hypothetical Region W, proper compaction

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[3] Precipitation—Evaporation.

in cuts and fills will provide excellent performance with standard pavement design.

The situation with respect to the Nos. 7 and 8 soils (Table I) is sufficiently similar to warrant a single design for all cuts. Under these road conditions in cuts an early failure by pumping is common. A simple design feature incorporated during construction will prevent this failure. Similar failures occur in areas of No. 10 material and if Region W included some of the coastal plains States, Nos. 11 and 12 would also carry a similar design with some possible adjustment to compensate for the increased plasticity (and related properties) of these clays. A corresponding table applying to secondary roads would be necessary.

EXTENT OF SOIL AREAS

If we are to accept the principle of the recurring profile, the burden of proof then lies in the uniformity with which nature has deposited the parent materials of these areas. In the exploration of this question a large number of representative samples were taken. Standard tests were applied on several hundred to furnish a basis of classification (2) and comparisons were made between corresponding horizons in the profiles. Thus, parent material areas were explored and found to be consistent. Where exceptions occur the soil pattern in photographs indicates a change in physical properties as well as the nature of that change. It is important to note that the illustrations that follow are of wide geographic distribution as well as being of a contrasting origin. The intent in selecting these examples has been to show that the uniformity of soil properties and patterns is neither confined to a few selected areas nor to a particular mode of origin. Where parent materials vary they do so in a manner related to their formation. The variation, if significant, can be expected to influence the soil pattern.

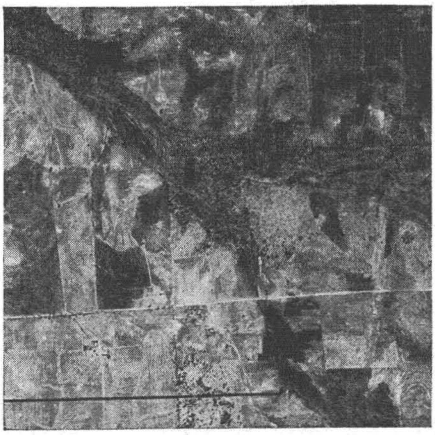

FIG. 4. The photograph shows the variation in colors in an area that, from the ground, appears black. Chalk underlies the entire area and where light tones appear the influence of the chalk has modified the silty clay to a No. 9 material. The darkest areas represent Nos. 11 or 12 material. Erosion control in the form of "terracing" is evident. Sheet erosion on these gently sloping areas indicates a condition of retarded internal drainage and implies a clay texture in the subsoil. Bar scale on aerial photographs indicates a distance of one mile.

Figure 3 is a location map showing the four parent material areas to be described. 1, Marine clays; 2, soils of the loess areas; 3, a residual soil— in this instance derived from limestone; and 4, glacial drift. These represent the major classes of parent materials from the standpoint of origin. The marine clays were deposited under water; the loessial soils, derived from windblown silts; the residual soils, developed in place from rock; and the glacial drift materials were deposited by ice during glacial periods.

The Marine Clays of the Coastal Plains

During one geologic period of the earth's history, large areas of the Gulf and East Coast states were submerged. During this period gravels, sands, silts, and clays washed from the nearby mountains were deposited under water. Subsequently, continental uplift has raised these materials above sea level. The area is now known as the coastal plains and it extends in varying widths from New York to the Rio Grande. Included in the coastal plains (See Fig. 3) is an extensive area of black plastic clay, generally known as the "Black Belt." Figure 4 is an aerial photograph that illustrates the pattern of the upper coastal plains areas' Black Belt. These soils are underlain by a layer of chalk, marl, or limestone in the substratum that sometimes introduces a silt influence that is indicated by the Class No. 9 (Chart I) soil.

TABLE II(1)

REPRESENTATIVE SAMPLES OF COASTAL PLAINS CLAYS

NO.	LOCATION	DEPTH IN INCHES	LIQUID LIMIT	PLASTICITY INDEX	LABORATORY DRY WEIGHT (PROCTOR)	CLASS(2)
1	ALABAMA, SOUTH EASTERN	40 (−)	55.3	27.4	90.8	12 A
2	TEXAS, NORTH CENTRAL	24 (0–40)	59.4	35.2	99.2	11
3	TEXAS, NORTH EASTERN	168	58.4	42.6	—	12 A
4	TEXAS, CENTRAL	60	52.4	31.3	—	11
5	ALABAMA, CENTRAL	60	63.7	36.4	—	12 A
6	ALABAMA, CENTRAL (LIGHT AREAS IN FIG. 4)	60	45.7	19.0	95.0	9
7	ARKANSAS, SOUTH CENTRAL	48	52.6	30.8	—	11
8	ALABAMA, CENTRAL	60	57.4	27.5	89.8	12 A
9	TEXAS, NORTH EASTERN	20	57.9	20.0	82.9	12 C
10	MISSISSIPPI, SOUTH	BORROW PIT	59.5	26.8	—	12 A
11	ALABAMA, EAST CENTRAL	72	59.0	20.4	93.8	12 C
12	TEXAS, SOUTH	24 +	46.2	26.4	107.0	11(3)

(1) The data presented in this and the following tables are necessarily brief because of the stipulations of the Federal contract under which the work is being conducted.

These are random samples representative of large areas and are, therefore statistically significant. However, within each area related variations occur and due weight should be given to the exceptions represented by the single examples.

Locations 1–6 represent Black belt area.

Locations 7–12 represent other Marine clays.

(2) See Chart I.

(3) Gulf Coast Clay.

Other areas of the coastal plains vary through the texture range from the famous "sand clays" in the southeast to the fine sands and sandy silts of local areas in the eastern lower plains, and the sands of the majority of the southern coastal areas, especially of Florida. Some of the other coastal plains clays (light colored, Table II—samples 7–12), developed under similar circumstances, are defined under a variety of catenary[4] names such as Susquehanna, Orangeburg, Oktibbeha, Lake Charles, Lufkin, and others. These soils, being of an impervious nature develop the same indications of clay-like properties in the soil pattern regardless of their pedologic name. Figure 5 is representative of some of these clay areas. In it are the inevitable signs of highly developed surface drainage, "clay shaped" gullies and distinctive color tones. Many highway pavements on these soils show a marked distress directly related to the subgrade conditions.

Soils of the Loess Areas

Although an unrelated type of soil deposit such as windblown silt offers a restricted parallel, it permits observation of the effect of wide climatic variations on a uniform parent material. The origin of loess is attributed to the wide flood plains of our major rivers, to glacial deposits, and to the great plains areas spreading eastward from the foot slopes of the Rocky Mountains. Violent winds generated by the proximity of the continental ice sheets swept silt size material from these broad open areas. Adjacent uplands were covered with this mantle of silt that today forms one of the outstanding examples of soil uniformity. Where the water-laid coastal plains varied in texture from clay to gravel these wind-laid materials consist of particles principally in the silt size. Clay sizes are absent initially because the cohesive property of clay resists wind erosion; the more coarse materials because of the limited carrying power of the wind, and the absence of sand in the wide alluvial areas. The clay found in some silt profiles is formed by subsequent weathering of the loess.

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[4] A catena is a family of soils derived from the same parent but occurring on different slopes.

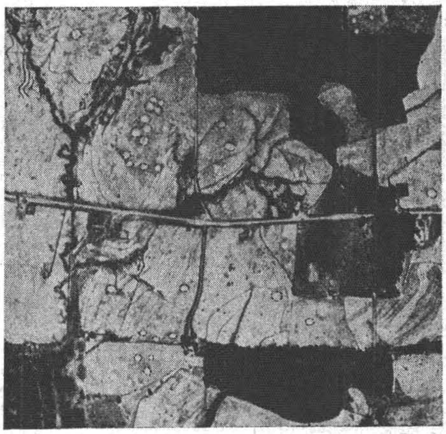


FIG. 5. Soil pattern in a light colored clay area of the coastal plains. Note the well developed surface drainage. "Gas well" sand, occurring as rough light spots (outlined) in some parts of the area, is the only granular material available in many of these localities.

Soils formed from these materials lend themselves readily to airphoto interpretation because of the many distinguishing features that are peculiar to the soils of these deposits (see Fig. 6). In this country (Fig. 3) the loess belt begins in semi-tropical Louisiana and extends northward along the east bank of the Mississippi until near the junction of the Ohio it spreads into Illinois, Iowa, Kansas, Nebraska, Missouri, Indiana, Wisconsin, and Minnesota. Loessial soils are found locally in other disconnected but related areas. In the west a large section of Washington and adjacent areas of Idaho and Oregon are covered with a similar mantle. The remarkable consistency of these materials both in texture and test results can be appreciated only partially by viewing the presented data. The results shown in Table III are divided into two parts, those data obtained on the weathered portion of the profile (A and B horizons) that is influenced by climate and slope and those of unweathered parent material.

Although only one test has been run on loess from China its properties do not vary materially from those in this country. On the basis of this continuing uniformity it is reasonable to expect the large belts of loess in Europe, South America, and Asia to conform in physical characteristics to those of the United States. In fact, the local silt area of the northwest African coast has textural indications in the form of "sunken paths" similar to the "sunken roads" of

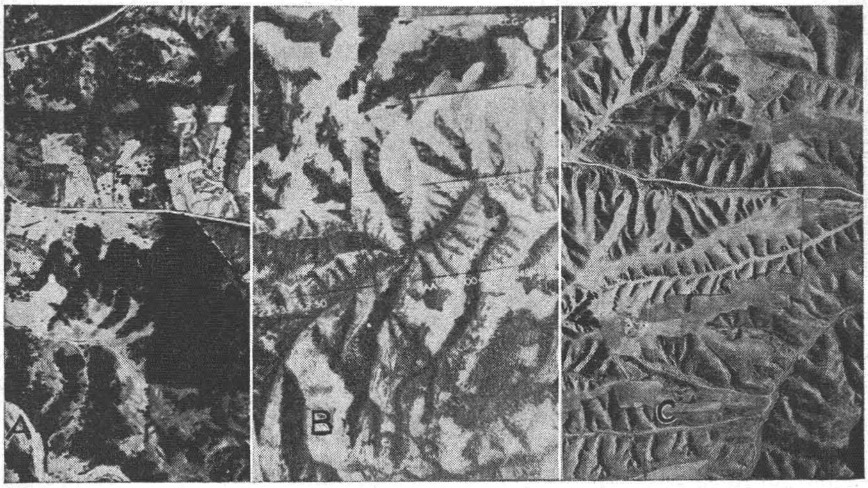


FIG. 6. The loess pattern in various climates. A, humid Mississippi; B, subhumid Washington, and C, semi-arid Nebraska. Note the similarity of the erosion pattern. The amount of vegetation is the chief variable in the soil pattern.

TABLE III

REPRESENTATIVE SAMPLES OF LOESSIAL SOILS FROM VARIOUS DEPOSITS

WEATHERED PORTION OF PROFILE (A & B HORIZONS)

LABORATORY NUMBER	APPROXIMATE LOCATION	LIQUID LIMIT	PLASTICITY INDEX	DRY WEIGHT[1]	CLASS[2]
1158-C	IOWA - EASTERN	38.8	17.0	—	9
1324-C	MISSOURI - EASTERN	33.6	16.3	—	9
1177-C	IOWA - WESTERN	43.2	17.9	—	9
1327-C	MISSOURI - WESTERN	40.5	15.9	—	9
1251-C	WASHINGTON-S.E.	34.5	12.1	—	9
1360-C	KANSAS - WESTERN	31.7	12.5	—	9
1279-C	UTAH - IDAHO LINE	36.1	7.5	—	9
340-I	INDIANA - SOUTHEASTERN	41.2	16.5	101.8	9
957-C	ILLINOIS - WESTERN	53.6	30.2	—	11[3]
903-C	MISSISSIPPI - WESTERN	45.5	16.8	—	9
838-C	TENNESSEE - WESTERN	38.4	11.8	104.2	9
PARENT MATERIAL (LOESS)					
1384-C	KANSAS - WESTERN	(TEXTURAL &	INSPECTION	CLASSIFICATION)	6
1247-C	WASHINGTON - S.E.	30.7	7.5	99.5	6
288-2	INDIANA - SOUTHEASTERN	29.2	7.3	109.0	6
838-C	TENNESSEE - WESTERN	29.0	4.9	104.5	6
901-C	MISSISSIPPI - WESTERN	31.8	3.1	104.5	6
—	CHINA - NORTHERN	—	6.1	—	6[4]
1254-C	WASHINGTON - S.E.	38.9	13.4	—	9
1324-C	MISSOURI - EASTERN	33.6	16.3	—	9

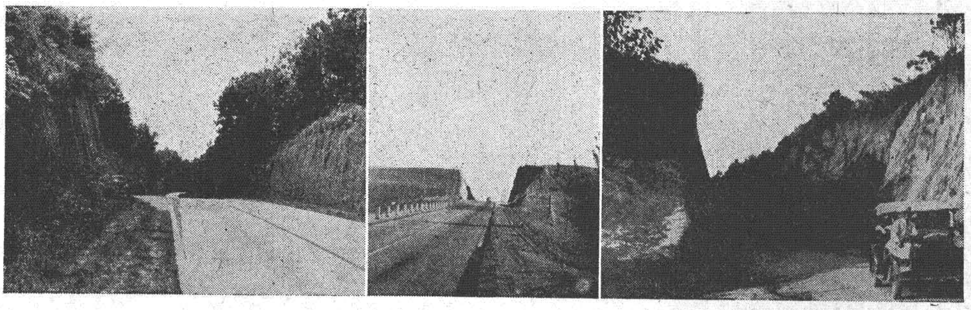
(1) LAB. MAX. AT PROCTOR'S OPTIMUM (2) JOINT HIGHWAY RESEARCH PROJECT CLASIFICATION (3) DEPRESSION
(4) CLASSIFICATION BASED ON PLASTIC LIMIT

Mississippi and to the extremely deep roads reported (3) in the northern China area. One illustration of uniform engineering treatment in similar soil areas is shown in Fig. 7, illustrating vertical cuts in Mississippi, in the Palouse area of Washington, and in north China.

Soils of the Limestone Areas

Residual soils are those developed by the weathering process that destroys the parent bedrock. They are the residue that remains when the soluble materials have been removed by leaching or when the individual grains have become loosened by physical weathering. These two processes largely determined the nature of the soil. In humid climates the leaching by percolating water predominates; in arid climates physical weathering is active and the moisture movement is retarded or reversed.

In this paper limestone has been considered as a consolidated rock high in calcium carbonate and often including appreciable quantities of magnesium (dolomite). Marls and chalk have been excluded because they have not been encountered as soil-producing materials. However, soil information and airphotos of the chalk areas of England indicate (18) that a silty, friable material is produced. These limestones are divided into two soil-producing types: the hard dolomitic limestones, and the more common, relatively pure limestones. The dolomitic limestone, confined to relatively minor areas, is highly resistant



A B C

FIG. 7. An example of the distribution of a soil material (loess) and the uniformity of engineering treatment required by the physical properties (Table III) of the soil. Nearly-vertical cut slopes are required unless immediate and complete sodding are scheduled. A, Mississippi—note the effect of climate on the tree cover (55–60)[a]; B, Washington (15–20)—lack of tree cover indicates low rainfall. Patch in settled area of fill reflects the difficulty of compacting silt without sufficient moisture; C, Vertical cuts in loess area of China (12–17) (Courtesy of Prof. Mo Chih Li, National Tsing Hua Univ.)

[a] Annual rainfall in inches.

to weathering, retains its features relatively unmodified, and produces very little soil. The majority of limestones produce a rather deep profile and have been found to be remarkably consistent in engineering characteristics in humid and sub-humid climates, regardless of geographic location.

Table IV illustrates the distribution and representative test data on several limestone soils. Since these soils occur on rolling relief, cuts into the profile are common. Therefore the test data concern the important lower portion of the soil profile exposed as subgrade in cuts.

TABLE IV

REPRESENTATIVE SAMPLES OF SOME LIMESTONE RESIDUAL SOILS IN THE UNITED STATES

LABORATORY NUMBER	APPROXIMATE LOCATION	LIQUID LIMIT	PLASTICITY INDEX	DRY WEIGHT	CLASS (1)
938-C	OKLAHOMA, CENTRAL	51.0	30.6	—	11
946-C	MISSOURI, SOUTHWESTERN	38.6	18.88	—	10*
862-C	KENTUCKY, CENTRAL	59.1	20.3	92.8	11
1007-C	OHIO, EASTERN	62.6	42.6	81.2	12 A
928-C	OKLAHOMA, NORTH CENTRAL	60.0	40.9	—	12 B
1380-C	KANSAS, SOUTHEASTERN	56.8	28.4	—	11
842-C-4	ALABAMA, EASTERN	69.3	27.6	86.0	12 A
1026-C	OHIO, SOUTHEASTERN	65.0	35.5	—	12 A
1395-C	WEST VIRGINIA, NORTHEASTERN	54.1	31.7	97.7	11
1347 C	ARIZONA, CENTRAL	57.4	33.9	—	11
1085-C	WISCONSIN, WEST CENTRAL	83.8	57.2	84.0	12 A
1309-C	UTAH-ARIZONA LINE	58.1	39.3	—	12 A
281	INDIANA, SOUTH CENTRAL	63.6	29.5	82.5	12 A

* Has a high chart—see Fig. 8 airphoto pattern.
(1) See Chart I.

In some of the limestone deposits there have been appreciable quantities of chert in the soil profile. In some instances there has been a sufficient quantity to make the material in the profile more of a rock-soil mixture. When the chert content reaches this proportion it can be distinguished by a characteristic pattern that is illustrated in Figure 8. In this view surface drainage is undeveloped indicating good internal drainage despite the fact that physical tests give an

FIG. 8. Illustrations of a soil pattern in a cherty limestone area. Sinkholes (arrows) indicate limestone. The white speckled pattern is related to the chert and indicates a particularly difficult compaction problem. Close observation of cut slopes and detailed ground inspection are necessary to distinguish this condition when on general reconnaissance survey.

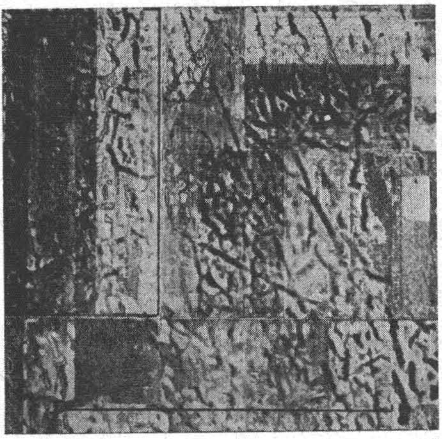


FIG. 9. Air view of glacial Lake Agassiz basin. The pattern so clearly visible from the air is indistinguishable on the ground. Ponded water, extremely flat terrain and the V-shaped drainage way are directly related to origin, soil conditions, and a definite design procedure to overcome a poor subgrade material in this soil-position.

opposite impression. This is the influence of natural structure in the soil profile that permits drainage even in clay soils.

There is ample evidence to indicate that the pattern of limestone soils and their similarity of engineering properties can also be projected to the humid tropics. Associated with these limstones there are plastic clays and silty clay soils derived directly from the limestone as well as alluvial soils washed from the hills. In addition plastic soils weathered from limestone occur in North Africa and the adjoining Mediterranean coast of Europe (4), Palestine (5), and India (6).

Among sedimentary deposits the clay shales contribute more than their proportional share to highway failures in the form of landslides, fill failures, and unstable subgrades. In general, these materials are of limited extent and occur as minor outcrops in predominantly sandstone or limestone areas; in some notable areas (Fig. 3) however, the shales appear as surface material and dominate the entire region. Where the shale is exposed to erosion it becomes highly dissected forming rounded slopes. Inasmuch as these are marine clays partially consolidated it is logical that their texture when weathered is that of a No. 10 or higher, material. Figures 13, 15, and 20 B, C illustrate the characteristic weathering that distinguishes these materials whether viewed from the ground or from the air.

Soils of the Glacial Drift Areas

The Continental ice sheets provide what is probably the largest continuous parent material area in the United States. Figure 3 indicates the area covered by glacial drift. Similar areas occur in England, Scandinavia, North Germany, and the U.S.S.R. in Europe and Asia. Smaller glacial areas are associated with most of the mountainous regions of the world. The glacial drift that mantles large sections of many of the northern states has been derived from a large variety of rocks and yet the parent material of the till plains consists almost entirely of material that can be classed as Nos. 7 or 8 (Chart I). A small percentage of the area falls into the No. 4 class material and some in the No. 10. Because of the varied origin of the drift in the United States, these parent material classes can also be expected to embrace much of the European and Asiatic till. The major remaining portion of

TABLE V
REPRESENTATIVE SAMPLES OF GLACIAL PARENT MATERIALS (TILL) IN THE UNITED STATES

LABORATORY NO.	LOCATION	LIQUID LIMIT	PLASTICITY INDEX	LABORATORY DRY WEIGHT (PROCTOR)	J.H.R.P.(1) CLASS
1171-C	SOUTH DAKOTA, CENTRAL	30.8	13.4	109.3	7
1370-C	KANSAS, SOUTH CENTRAL	—	—	111.9	7
1392-C	MICHIGAN, WESTERN	—	—	125.2	7
1096-C	MINNESOTA, NORTHERN	20.2	6.5	117.1	7
1102-C	IOWA, NORTH CENTRAL	29.8	10.7	—	8
989-C	INDIANA, NORTHEASTERN	28.4	11.5	112.4	8
965-C	MICHIGAN, WEST CENTRAL	25.5	12.5	115.9	8
1010-C	OHIO, NORTH CENTRAL	29.4	13.1	111.3	8
1032-C	OHIO, CENTRAL	16.8	1.7	—	7
1082-C	WISCONSIN, SOUTH CENTRAL	28.3	14.2	—	8
1051-C	MICHIGAN, UPPER PENINSULA	—	—	130.1	4
1076-C	ILLINOIS, NORTH CENTRAL	35.1	17.1	104.1	10

the drift is made up of stratified materials deposited by glacial streams. These take the form of outwash plains, eskers, kames and terraces or valley trains and consist chiefly of sands and gravels. Glacial lakes occupy a small proportion of the area and range in texture from silts to silty clays. Figure 9 shows an area of the glacial Lake Agassiz basin (No. Dakota-Minnesota) in which wave marks, low relief, poor drainage and "clay gullies" indicate the origin and texture of the soil.

FIG. 10. A semi-granular glacial drift area in a dry climate. Lack of vegetative cover and the type of land use indicate a semi-arid condition. Semi-granular texture is indicated by lack of surface drainage. Notice the directional trend of the pattern influenced by the ice movement.

Table V illustrates the distribution and uniformity of glacial parent materials. Although the texture of these parent materials remain substantially alike, differences in the ground slope or "position" create differences in the weathered horizons of the profile above the parent material (Fig. 1).

Figures 10, 11, and 12 illustrate a range in glacial drift patterns ranging from semiarid in Figure 10 to humid in the other figures. Although the patterns are not alike, since the textures and profiles vary, each is distinctly a glacial drift pattern.

ELEMENTS IN THE SOIL PATTERN

In making soil surveys of this type without field exploration it is always advisable to check, by photographs, the reliability of data obtained from other sources. In instances where no supplementary soil information is available detailed examination of the elements will permit, in most cases, a rather accurate description of soil conditions. If errors occur they lie within the province of the interpreter and not in whims of nature.

Since it is impossible to deal with each element the more important are presented in as much detail as is feasible.

Landform (Parent Material)

The local structure of the earth is perhaps the most general element of the soil pattern. In single or paired pictures covering an area of several square miles it is not always possible to identify positively the parent material that controls the form of the land. With additional pictures showing a greater portion of local area identification of the land form is usually practical. Figure 13 illustrates two variations in a land form pattern produced by sedimentary rock. Figure 13A is a contour-like pattern produced by dissection of horizontal beds of limestone and shale in a sub-humid area; Figure 13B shows the same materials (in beds of greater thickness) tilted and exposed to erosion in a humid area. Obviously, the greater the area available for inspection the more apparent becomes the landform pattern.

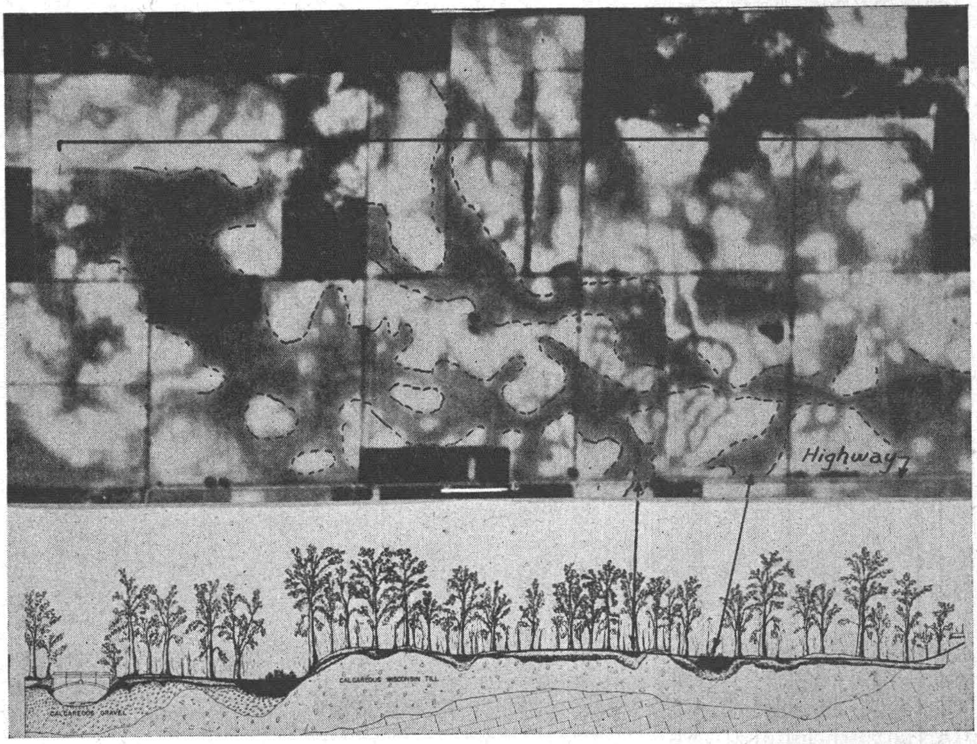


FIG. 11. A common glacial till pattern in the younger drift areas of the humid midwestern states—Ohio to Iowa. In this area the color pattern is well developed and the profile recurs in a similar pattern. These are plastic, poorly-drained soils of the till plains. The section sketch shows the relationship between the slope of the ground, profile development, soil color, and vegetation. Gravel terrace on left and rock ledge on right not included in airphoto.

By determining the landform the engineer largely determines the type of parent material with which he will deal. Reference to geologic maps will assist in this determination. Geology, like pedology, requires some translation for engineering use and therefore may be disappointing at first. Where bedrock forms the parent material, geologic literature (12) should supplement experience in visualizing the general structure. The photographs will provide most of the

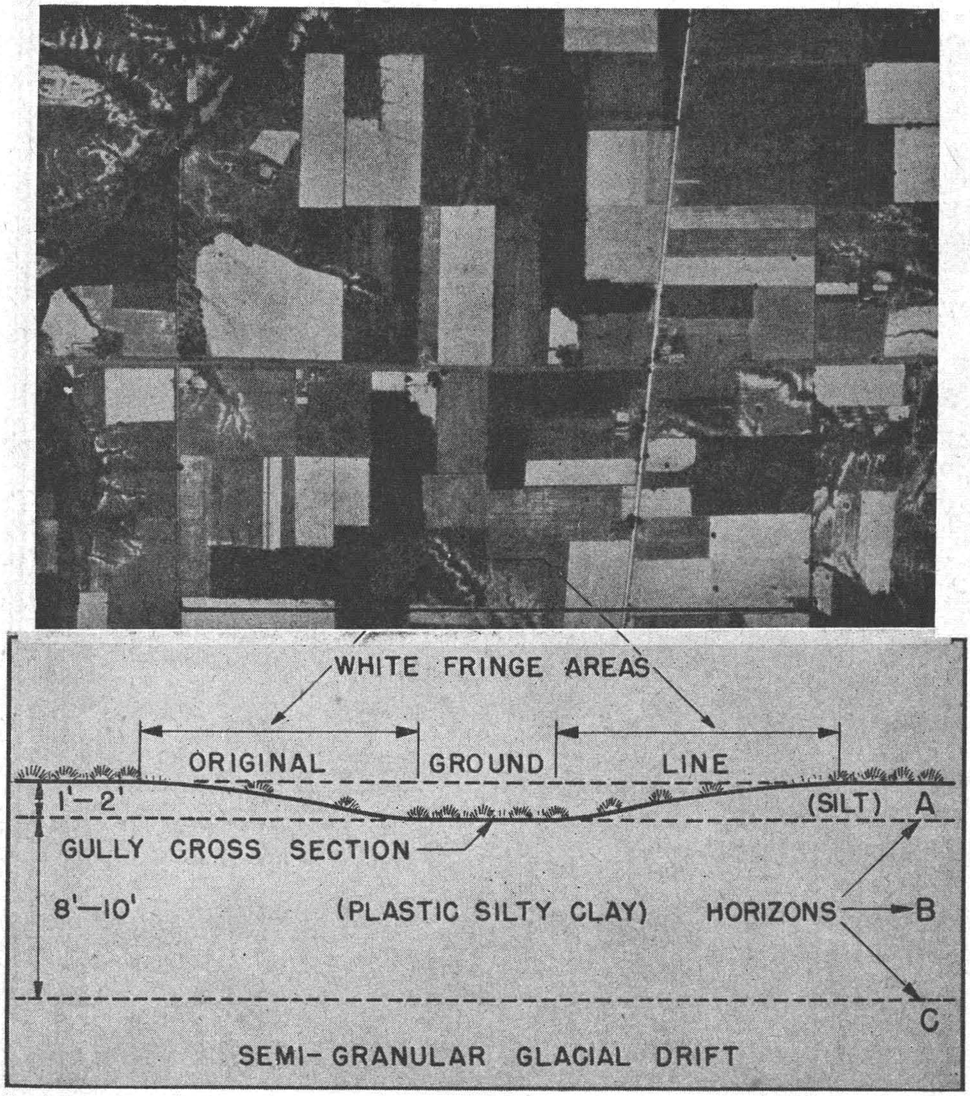


FIG. 12. A striking pattern of old drift common to Ohio, Indiana, Illinois and Missouri. These are the clay-pan areas having silty topsoils and deep plastic profiles promoting a surface drainage pattern. Sketch shows relationship between the texture of the horizons in the soil profile and the gully shape (See Figs. 1 and 27). This profile becomes waterlogged for long periods since the "A" is pervious and the "B" relatively impervious. Wet weather construction is seldom practical in these areas.

necessary details, since it is in these that we have a record of the relative weather resistance, depth of soil mantle, water conditions, and other properties and features that are directly related to construction and location problems. Where transported surface deposits cover the bedrock, geologic maps often prove misleading. As a rule, with the usual exceptions, in areas where bedrock influences the soil, indications of the type of bedrock will be apparent. Likewise,

FIG. 13. A. Aerial view of nearly horizontal beds of limestone and shale. Geologic erosion has cut through a series of these strata forming a contour-like pattern. In this relatively dry climate the limestone (white) outcrops to form comparatively steep slopes while the soft shale (dark) assumes low, gentle slopes. Sketch on section A-A′ illustrates formation. B. Down-dipping beds of shale and limestone form the pattern shown. Shallow impervious soils form on the shale while deep soils mantle the limestone. Note the abrupt change in surface drainage.

glacial-drift areas also have distinctive patterns as do aeolian deposits of sand or silt. To review these briefly: Sedimentary rocks such as limestone, sandstone, or shale or originally formed under water in nearly level beds. When these are elevated above sea level and remain in a horizontal position, erosion reduces them by dissection that produces a particular type of stream pattern and often leaves flat-topped islands of rock. In arid countries (Fig. 14) these are mesas or buttes, in humid climates they are monadnocks, having the same island-like shape but somewhat modified side slopes caused by the protecting influence of vegetation. These have retained their shape because a cap of resistant rock protects the underlying materials from erosion. Since sedimentary rocks are stratified, and the strata vary in physical properties, a difference is reflected in the weathering resistance of each stratum. Thus, in examining such formations (see Fig. 15) the existence of clay-shales is indicated by the presence of "soft" slopes occurring below the cap rock. The choice of location in these situations may be optional but slight differences in grade line elevation change the subgrade from sandstone to plastic clay-shale. Consideration of the dip of the strata should influence the location of a road since a location on one side invites landslides because of the necessity of cutting into down-dipping shales.

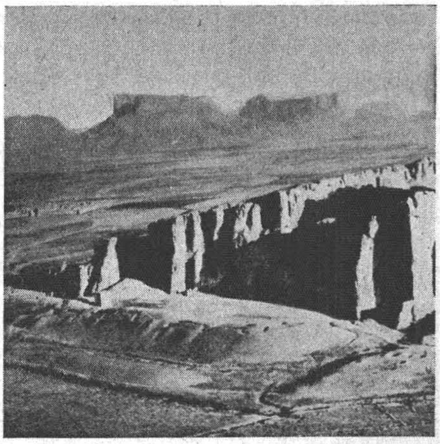


FIG. 14. The pattern of weathering in sandstones and stratified rock. This view in arid Iran shows the abrupt slope changes while in moist climates slopes are more modified. Highways and airports are located on the valley floor where soils related to the associated rock are deposited by water. Reprinted from Erich F. Schmidt, Flights Over Ancient Cities of Iran (Areal Survey Expedition, Mary-Helen Warden Foundation) 1941. By permission of the University of Chicago.

Where these stratified formations are folded, as in the Appalachian Moun-

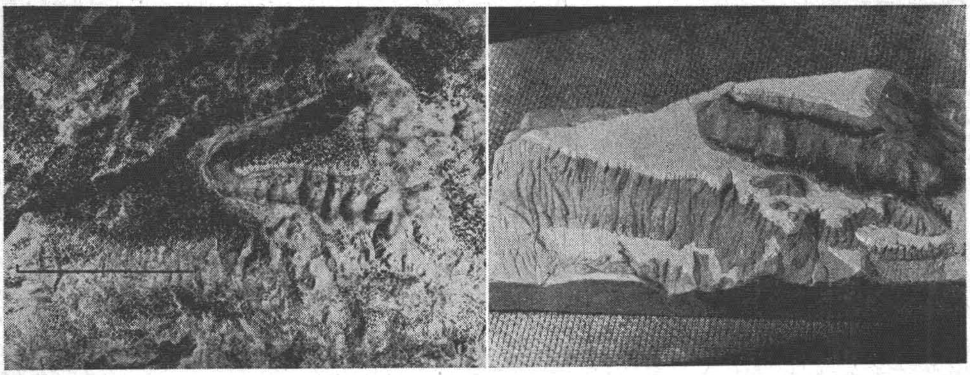


FIG. 15. An aerial view and model of a dissected sedimentary rock formation. A thin sandstone caprock protects a deep bed of clay shale that weathers to a "soft" slope typical of clays. In such areas of dipping strata, landslides can be caused or avoided depending upon the right-of-way location.

tains, they control the stream pattern to such an extent that a rectangular pattern is developed. Branches of streams follow parallel courses in the alternate beds of soft rock or shale. Instead of the ordinary bends expected in a stream the turns are often right-angled.

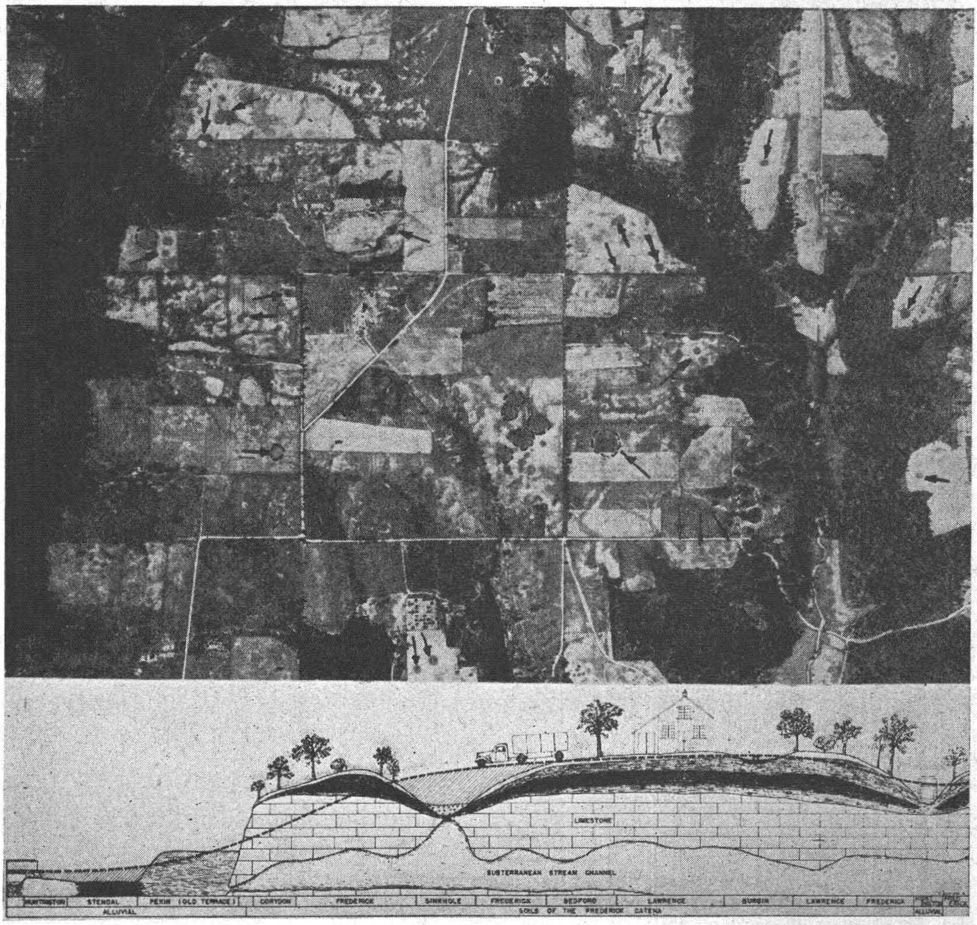


FIG. 16. Sinkholes in a limestone area as they appear from the air. On the basis of the uniformity of limestone soils in similar positions subgrade conditions in cuts and compaction requirements for fills can be anticipated from a photograph. Section sketch shows relationship of sinkholes to underground drainage channel and depth of soil mantle to ground slope.

The intensity of the general pattern is in proportion to the age or progress that weathering has made. As in the case of limestone, sinkholes are usually the first stage of weathering (Fig. 16—Indiana). As weathering progresses the roofs of subterranean caverns collapse and leave ridges and limestone that assume a cucumber shape when viewed from above. These further weather into domelike forms called haystack hills. Figure 17 shows these developments in a tropical climate. Sedimentary rocks and volcanic (basalt) rock develop plateau forms or related patterns when folded. Granites by reason of their method of occurrence as mountain cores and similar intrusions readily lend themselves to iden-

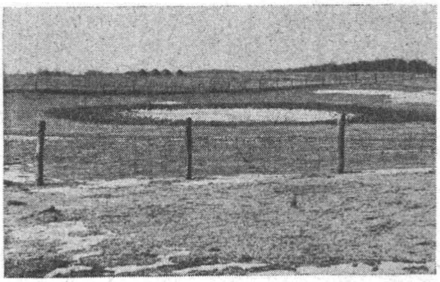


FIG. 16a. Ground view of an average size sinkhole in a limestone area.

tification. Again the significance of this particular element is general since it is an indication of the soil mantle as well as the related soils (alluvial) derived by erosion from these areas. Thus the land form is influenced by the parent material. The distinguishing features by which glacial drift, loess, sand, and other parent material areas can be identified are related either to their texture or to some physical features peculiar to their method of deposition. Perhaps the most outstanding feature common to glaciated areas, either continental or mountain, is the disproportion between present and past drainage. Vast rivers of water supplied by melting glaciers cut valleys and built gravel terraces that dwarf the streams that are in balance with our present climate and now occupy the valleys. The tremendous terraces and fans at the foot slopes of many mountains (Figs. 18 and 21) are of glacial gravel just as the kames, eskers and river terraces of our northern States and Canada are products of the continental ice sheets.

Texture, composition and origin largely determine the resistance of a material to erosion and weathering, and under similar conditions of weathering the same type of parent will respond in a similar fashion. It is reasonable to assume that, regardless of distance the same type of rock will produce similar soils under similar climatic conditions. Figures 19 and 20 show the "soft" slopes produced by the weathering of granites in the relatively dry climates. Similarly the weathering of limestones is related to the climate. These are but the more definite examples of rock types having distinctive weathering characteristics. Both the occurrence and the weather resistance combine to aid in identification. Where slopes appear to be "soft," the soil can be expected to have a relatively high clay content and the materials washed from such slopes to form terraces will have a stratified profile grading from a granular subsoil or substratum to a silty or sandy clay overburden. The more rugged slopes produce less soil and more granular material. Figure 21 shows a well developed series of terraces forming an excellent source of granular material as well as providing a very stable location for runways or highways. In contrast Figure 22 shows a highly dissected terrace in Palestine having a deep uniform profile in Lisian marl. The gullies' side slopes indicate uniformity, and the shape, a silty clay material.

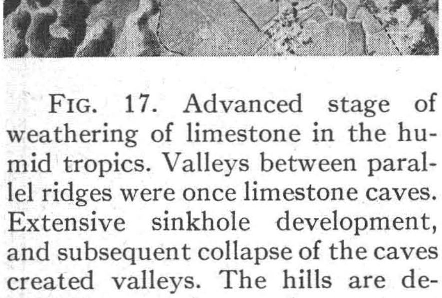


FIG. 17. Advanced stage of weathering of limestone in the humid tropics. Valleys between parallel ridges were once limestone caves. Extensive sinkhole development, and subsequent collapse of the caves created valleys. The hills are described as pepinos and mogotes—cucumbers and haystacks because of their shape. Related soils are plastic silty clays.

Slope. Prevailing ground slopes may

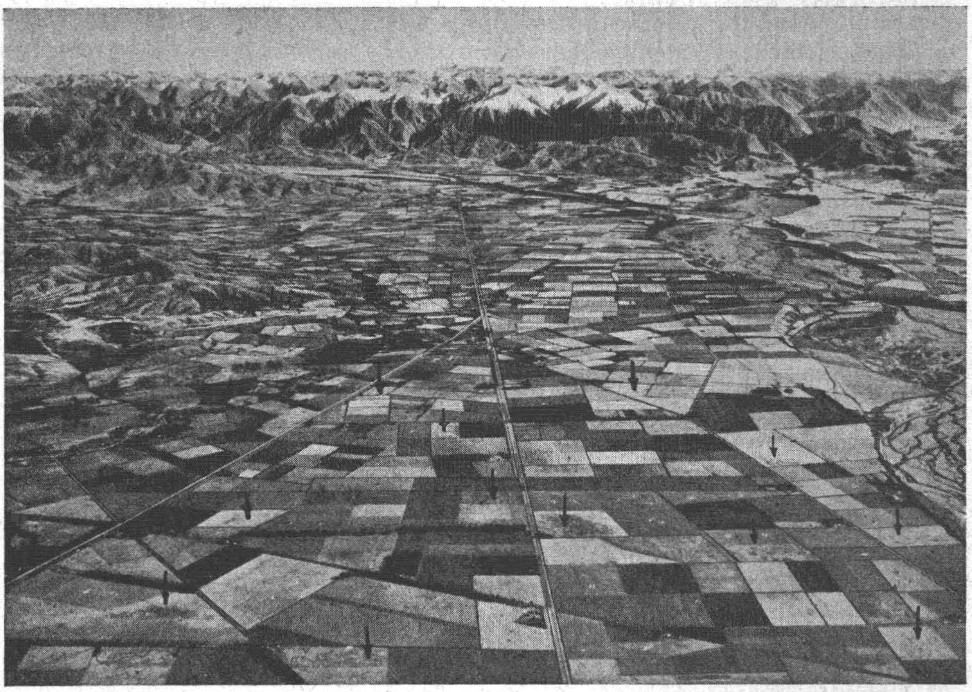


FIG. 18. An oblique view of a gravel terrace in New Zealand illustrating the wide application of the major elements of analysis. Not only is the land form apparent but the absence of surface drainage, source of the material, vertical stream banks, and color pattern (arrows) are clearly shown. The checkered field pattern is caused by a variety of crops. Reproduced by permission of New Zealand Aerial Mapping, Ltd.

also be considered an element of the soil pattern. In examining photographs the observer receives a general impression of the local slopes in an area. These are generally a function of texture with granular and semi-granular materials assuming the steepest slopes. The observer will find areas adjacent to stream the most productive in which to examine this feature. At bends where the current may be attacking the bank of the stream, fresh exposures unmodified by the accumulation of debris at the foot are available for inspection. However, slopes over which runoff passes are the more reliable indicators. Even the uninitiated can readily detect the difference between the prevailing slopes in areas of, No. 9 or higher, silty clay and the less plastic, No. 8 or lower, materials.

Surface Drainage. Surface drainage or runoff is the result of melting snow or ice or of rain falling on the ground. Whether it soaks in or runs off the ground surface determines the existence of a drainage pattern. The portion that runs off the surface determines the intensity of the pattern. In this sense surface drainage does not mean rivers and streams but the immediate and local pattern caused by runoff on an acre, a section, or a square mile of ground surface. Briefly stated it is a direct function of soil permeability and ground slope and, within rather wide limits of slope, surface drainage is a function of the permeability of the profile. Porous sands absorb the rainfall and surface drainage does not develop (Fig. 23). But plastic clays and silty clays resist the penetration of moisture, which promotes surface runoff and the development of a drainage pattern.

A drainage system may vary in complexity. Complete absence or a simple extension of surface drainage from a stream into the upland probably indicates a pervious material. A highly integrated system with branches reaching to all parts of the area indicates poor internal drainage (Fig. 24) which for engineering use means a plastic subgrade, difficult construction, a need for an adequate base course, and provisions for drainage. Obviously on the same parent material the amount of surface runoff will be greater on the steepest slopes. This relation to slope in itself creates differences in the respective soil profiles: those on the steepest slopes are shallow and weakly developed, while those on the flat slopes are deep and less pervious. In most cases, where there is sufficient year-around rainfall the surface drainage element is highly reliable.

"Functional texture" is offered as a qualifying term for soil classification regardless of the method of survey. Aerial photographs show the effective drainage of the profile regardless of texture. The limestone soils have a well-drained profile. They are often red in color and lack

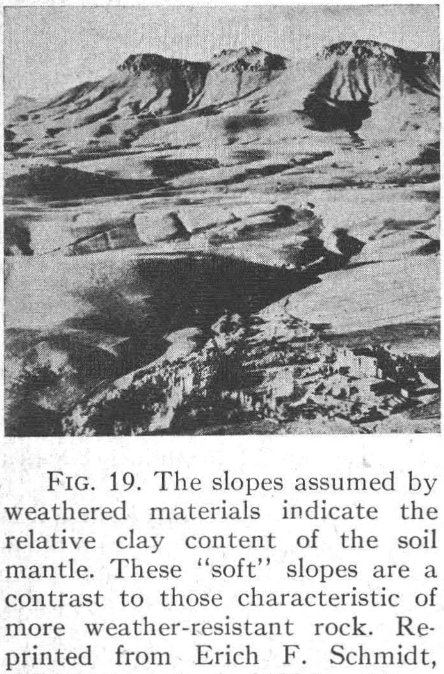


FIG. 19. The slopes assumed by weathered materials indicate the relative clay content of the soil mantle. These "soft" slopes are a contrast to those characteristic of more weather-resistant rock. Reprinted from Erich F. Schmidt, Flights Over Ancient Cities of Iran (Areal Survey Expedition, Mary-Helen Warden Foundation) 1941. By permission of the University of Chicago.

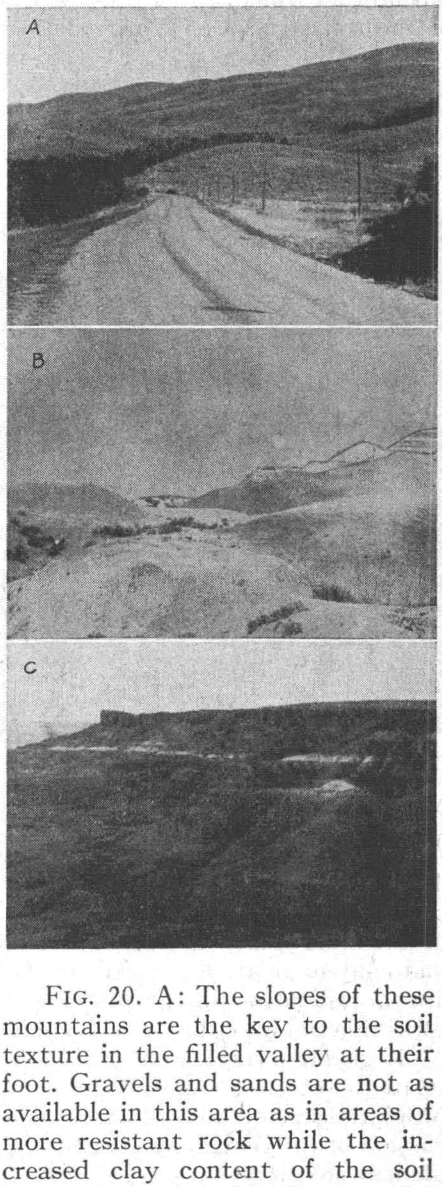


FIG. 20. A: The slopes of these mountains are the key to the soil texture in the filled valley at their foot. Gravels and sands are not as available in this area as in areas of more resistant rock while the increased clay content of the soil makes the use of granular material more desirable. B and C: Clay-shale slopes in South Dakota and in Arizona indicating a No. 10 to No. 11 material. Note resistant caprock in each.

evidence of complete surface drainage, indicating a porous profile. However, this is a condition not related to the common conception of texture since these soils are high in active clay content. The process of weathering and profile development produces an open structure in which the clay particles are segregated into lumps with ample space between for percolating water. The porous limestone parent material absorbs the water and prevents waterlogging of the profile, a condition which would otherwise result in a consequent swelling and closing of the soil structure. When compacted during construction this structure is destroyed and the immediate subgrade or fill reacts essentially as any other plastic clay. The qualifying term aptly applies to the slightly plastic, well drained, clay-size soil materials of the high rainfall tropics. Although the colloid content of these inactive clays is high (as much as 90 percent), they will appear porous in photographs (Fig. 25) and will act as such in engineering structures functioning as a semi-granular material.

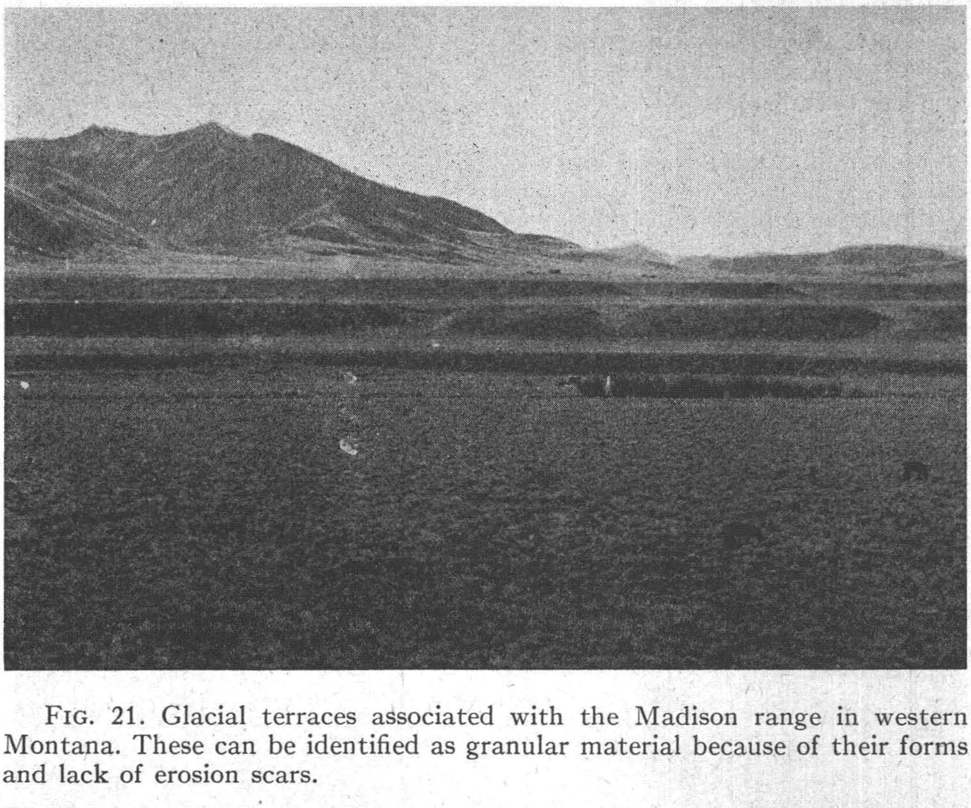


FIG. 21. Glacial terraces associated with the Madison range in western Montana. These can be identified as granular material because of their forms and lack of erosion scars.

Logically a discussion of erosion should follow surface drainage since it is a related process. Actually erosion in gully form cuts through the profile and provides some detail on textural differences within the profile. Therefore, a discussion of the remaining elements produced by the net effect of the entire profile will be completed first.

Soil Color Tones. The color of the surface soil material is often a result of conditions that have controlled the soil-profile development. In such instances the color tones evident in photographs give indirect information on the texture and drainage of the profile. Soil color (surface) is a function of the natural vegetative cover which is in turn controlled over large areas by the climate and in local situations by the immediate ground-water condition—often regardles of climate. The climatic influence will be omitted here and considered more completely under another heading. Initially the most confusing part of photo-interpretation is that pattern created by crops. These are regular in shape and are obviously a product of human effort. The soil color pattern usually shows through most crops and can be traced upon close examination or by interpolation from adjacent fields. The color pattern is always irregular.

The color element or pattern varies from one area to another, assuming, as does drainage, different shapes and varying in actual color. Fig. 11 is an example of a highly developed color pattern (Indiana—glacial drift) faithfully reflecting slight changes in elevation and ground water conditions. The black areas are deep, wet, plastic silty clays while the slightly higher light areas have a better water condition, a shallow profile and a higher silt content. A comparison pattern in red and black occurs in Tanganyika and Somaliland (8). Red, white and black are the common colors found in surface soils. In humid areas temperate or tropic, the black color is related to soils existing in low, poorly drained situations. Since this applies equally to sands it can be seen that reliance on color alone is as erroneous as dependence on any other single element. This continuity of color often carries over long distances since the "mbuga" of Tanganyika and the "vlei" of South Africa are wet, black clays. The following description of depression soils in the Uganda Protectorate applies precisely to the black soils in Fig. 11. They "consist typically of an intensely black topsoil overlying a gray or bluish-gray waterlogged clay" (9). These soils regardless of their location will have a similar soil pattern in aerial photographs and will present the same difficulties in engineering construction. The so-called black soils or chernozems are a product of climatic influences that are favorable to grass cover. When these are viewed from the air they are found not to be uniformly black but to contain a

FIG. 22. A land form in Palestine similar to that shown in Figure 21. In this instance erosion indicates an impervious texture and the gulleys show the existence of a deep uniform profile. The Orient Press Photo Co. (Tel-Aviv).

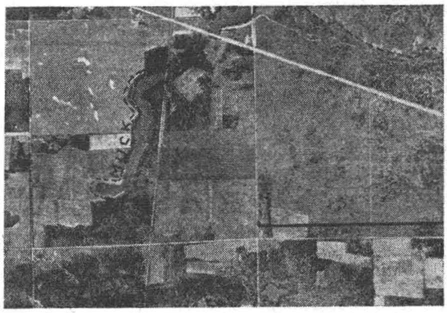


FIG. 23. A sand plain showing no surface drainage, a uniform color pattern and sparse vegetation representing an excellent subgrade material. Muck occurs in the channel (glacial) remnant outlined.

variety of shading with a distinctly black soil in depressions.

Red in soils often indicates a well-drained profile having a low water table. In ordinary photography red filters used to remove haze give the red areas a dark value in the prints. Many soils in the south have a red color and almost all limestone soils except under special rainfall conditions, are red.

Red is also a dominant color in many clay shale deposits and the outcropping of "red beds" that weather to rounded slopes (Fig. 15) are inevitably associated with landslides and fill failures. In these cases the color is not indicative of good drainage.

White or light gray colors in soils of the humid regions are usually an indication of extremes in moisture variation. They are subject to seasonal saturation and drought; saturation during long rainy periods because of retarded internal drainage and dryness because of a favorable position. Obviously sands are an exception to this and can be distinguished from a light colored silty clay by other elements of surface drainage and dune shapes (if present).

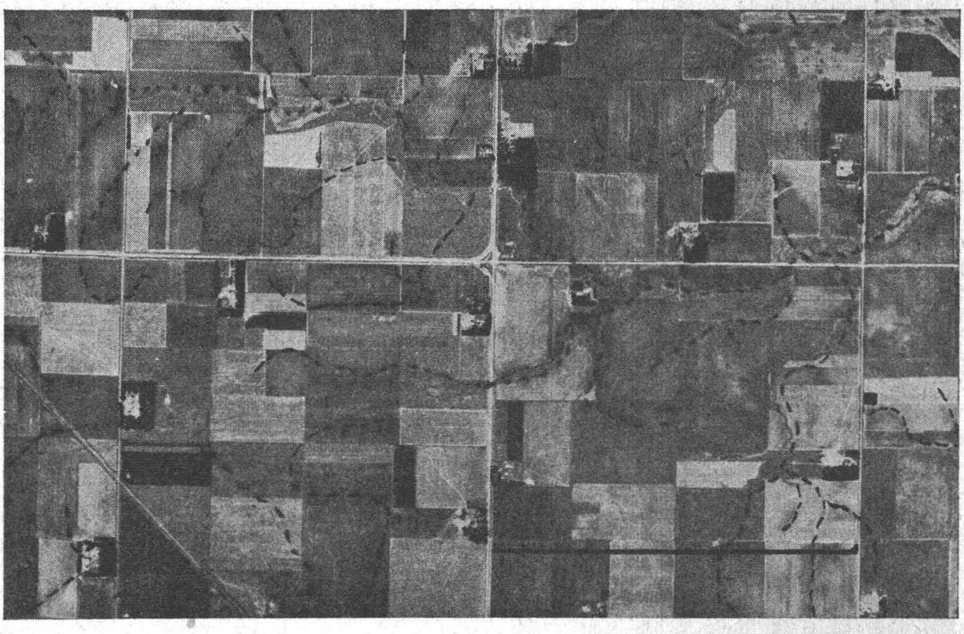


FIG. 24. An air view of a plastic silty clay soil and a tracing of the surface drainage pattern. Note the transition from drainage ways to a dark color pattern. Compare the drainage pattern on these Nos. 10 and 11 soils with the sand (No. 2) pattern in Fig. 23.

With the co-operation of the Army Air Forces, experimental photographs are being flown in five sections of the country. These aerial photographs (transparencies) in color, exposed at various altitudes give remarkable details of the vegetative cover as well as the natural colors of the various horizons in the soil profile. Where erosion is active, the colors of the major horizons can be seen by noting their sequence from the headward ends to the mouths of gullies. Likewise, the color bands of the horizons can be seen on the slopes of highway cuts.

The value of color in this work lies in the added detail that it furnishes with respect to these two elements of the soil pattern. The cost of color film, while somewhat higher, is justified in special work and particularly in remote areas because of the separations by color of many minor details.

Vegetative cover is perhaps the most difficult of the elements of the soil pattern for the engineer to interpret. Only the more obvious details required for interpretation on the basis of vegetation is to be had in high-altitude (12,000 ft.) photographs. Various types of trees are difficult to identify but drastic changes in soil conditions create vegetative contrasts that mark the boundary between soil areas. This is especially true in the vast northern swamp areas represented by Figure 26. Within a swamp area where the water table is sufficiently high to obliterate other elements of the soil pattern, vegetation alone remains. Muck and peat bogs have separate and distinguishing patterns of their own but the so-called tamarack swamps have proven difficult to decipher. In forested areas, forest fires complicate the pattern although the fires are often confined to the dry land. Lumbering operations also tend to influence the pattern. In general wet and dry positions are distinguishable by the vegetation that they support, giving the observer a general impression of cover type. Although the presence of poplar indicates dry ground, jack pine implies sand and gravel beds; tamarack, muskeg, and willow, wet ground. It is also true that many species such as white pine and aspen are tolerant of drainage and soil conditions and will grow on sandy as well as clay soils and in wet or dry positions.

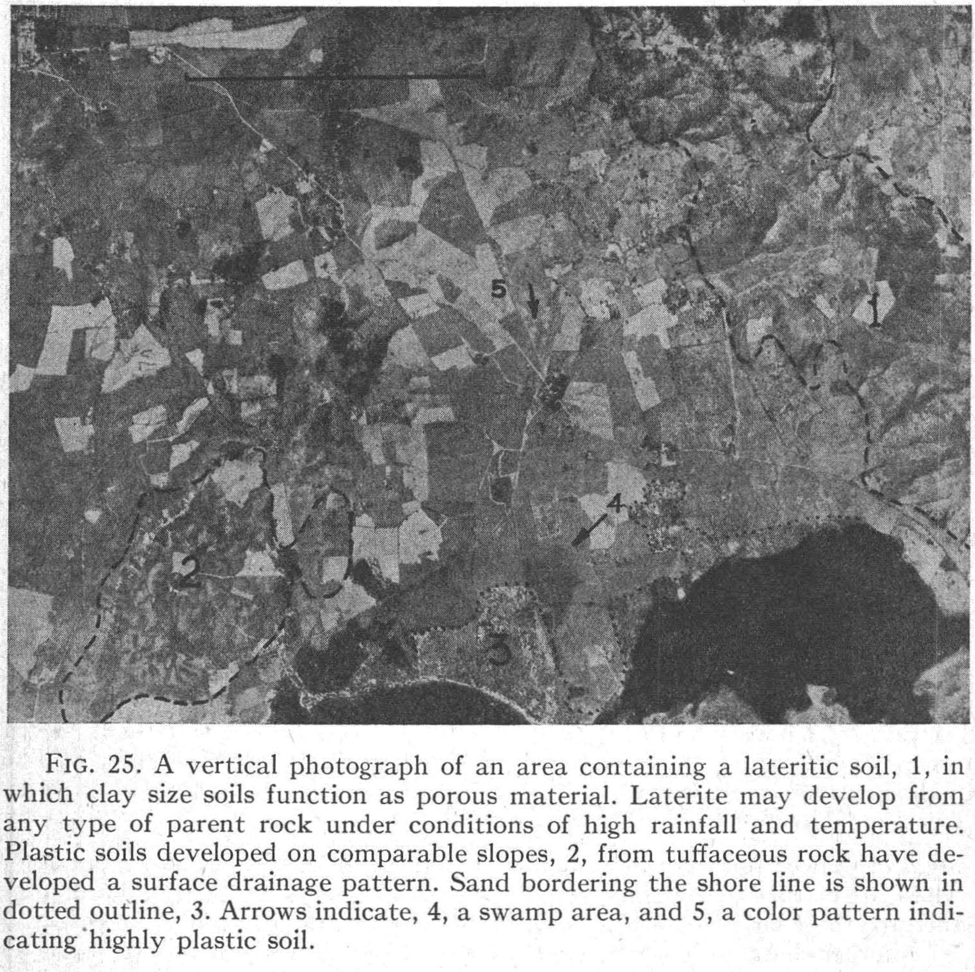


FIG. 25. A vertical photograph of an area containing a lateritic soil, 1, in which clay size soils function as porous material. Laterite may develop from any type of parent rock under conditions of high rainfall and temperature. Plastic soils developed on comparable slopes, 2, from tuffaceous rock have developed a surface drainage pattern. Sand bordering the shore line is shown in dotted outline, 3. Arrows indicate, 4, a swamp area, and 5, a color pattern indicating highly plastic soil.

Location work on the Alcan highway was based on photo interpretation of this element. Low altitude photographs and experience would improve the reliability of this type of interpretation. Since some types of vegetation grow over a wide range of soil conditions it is well to avoid placing too much emphasis on this one factor without supporting evidence from other elements.

Vegetation also acts as a partial indicator of perennially frozen ground in northern latitudes. Within the general region of frozen ground there are small areas of thawed soil that are probably caused by circulating ground water (19). These are marked by contrasts in vegetation since the unfrozen ground promotes the growth of larger plants, shrubs, and bushes, having deep root systems.

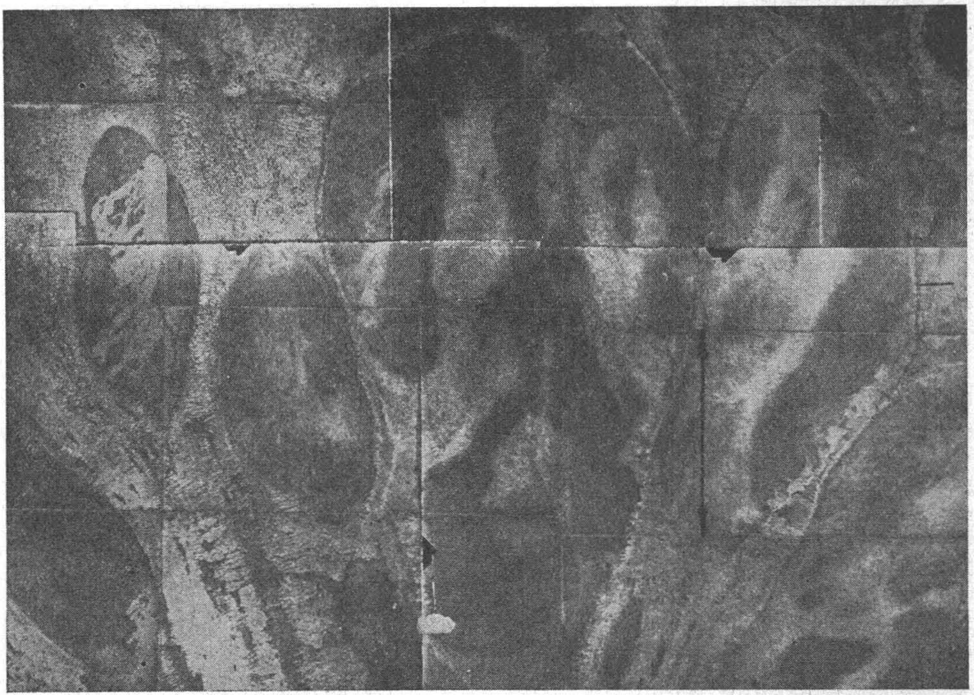


FIG. 26. A northern peat-bog area. This unusual pattern occurs in a glaciated area. Flowing water has obviously influenced the shaping of the pattern. The area is extremely difficult to explore and the variations in relief are so slight as to escape detection on the ground.

Another characteristic of these frozen areas observable in aerial photographs is the polygonal pattern probably developed best on the silt soils of the wide flood plains and terraces of the river valleys. This pattern, also found in other positions, is created by ground ice forming more or less vertical veins in the soil mass, extending in some instances to depths or 30 or more feet. Marked by vegetational changes and micro-relief these immense polygons (20 to 70 feet in diameter) fore-warn of extraordinary subgrade conditions.

Erosion is probably the most valuable index of subsurface conditions of the soil profile. Generally speaking two types of soil erosion occur, one in the form of gullies and the other as sheet erosion. Although certain chemical properties of soil influence the degree of erosion it is controlled largely by texture.

Gullies, being the most significant, merit the principle consideration. Cut by surface runoff, they often occur on sloping ground between the shallow upland drainage-ways and the flood plains of established streams. The cross-section shape of a gulley is controlled by the cohesive properties of the soil. Silts, sands, and sand-clays develop vertical sides or U-shaped gullies.[5] Examples of these are found in sandy coastal plains areas. Figure 27 shows a ground view of a gully of this type. They are characterized by a sharp drop-off, from the ground surface to the bottom of the gulley, at the headward end. They are often stubby, extending only a short distance into the upland. V-shaped gullies indicate a deep uniform profile in a semi-plastic to plastic soil; where the V-gulley becomes very broad and shallow (Fig. 27) a stilty or fine sandy material on a claypan is indicated. This same shape may indicate a shallow soil on bedrock but the presence or absence of rock outcrops in the vicinity will confirm or deny this alternate choice. These latter two types will progress for long distances into the upland. Thus we may say that the gully is a partial key in recognizing the plastic unstable silty clays or the sands, in distinguishing between well-drained and poorly-drained soils, and in anticipating dirt excavation or rock excavation. Unfortunately airphotos cannot be used satisfactorily to illustrate gulley shapes since they often appear in minute proportions requiring magnification of stereoscopic pairs. Silt gullies have the additional feature of vertical fins or columns preserved by sod or brush. Other erosion features of silt occurring in north China (12) take the form of chimneys and pinnacles. "Catsteps," another form of erosion common in some areas characterize loess on steep slopes. These contour-like shelves resulting from the slipping of the loess are clearly visible with magnification.

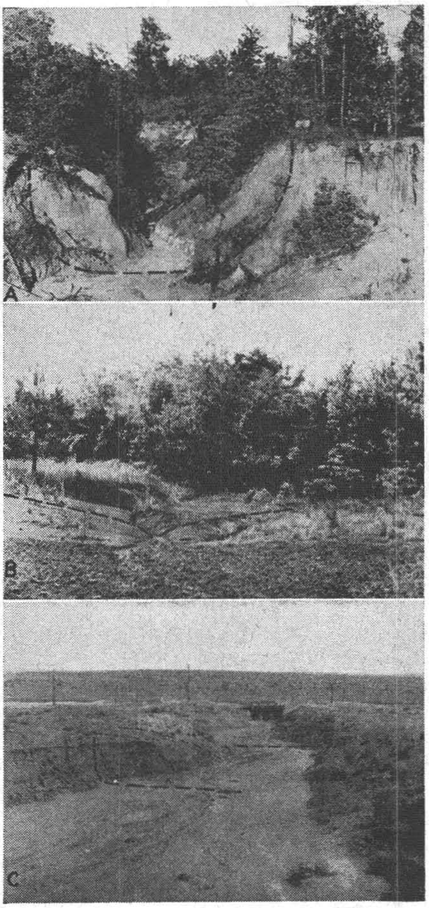


FIG. 27. An illustration A, of gullies in sandy soils and, B, in claypan soils. The U-shaped gullies are short and begin abruptly—photo taken at head of gully. V-shaped and flat angle-shaped gullies in the more plastic soils extend well into the upland on a more uniform gradient. C: A typical gully found in arid regions where "flash floods" attack dry soil banks and often create U-shaped gullies in clay soils.

Land use and other human influences are included as an element of the soil pattern. The pattern of contour plowing, terracing, and strip cropping are forms of erosion control signifying a friable soil on a less pervious subsoil. Check dams, levees, crops, crop boundaries, plow lines and many others carry some special significance depending upon the locality. "Dead furrows," the inevitable sign of plastic, poorly-drained soils, are the farmer's attempt to obtain surface drain-

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[5] This relationship does not carry over in the same degree to arid climates (See Fig. 27c).

age in an impervious profile. Orchards thrive in well-drained locations and therefore, when observed on level ground, good subdrainage is implied.

These then are the major elements of the soil patterns, the land form, surface drainage, color, vegetative cover, erosion, and land use. Created directly or indirectly by physical properties of the soil they form a basis of interpreting the engineering characteristics of the soil and of fore-seeing problems that affect the cost of construction and maintenance of pavements.

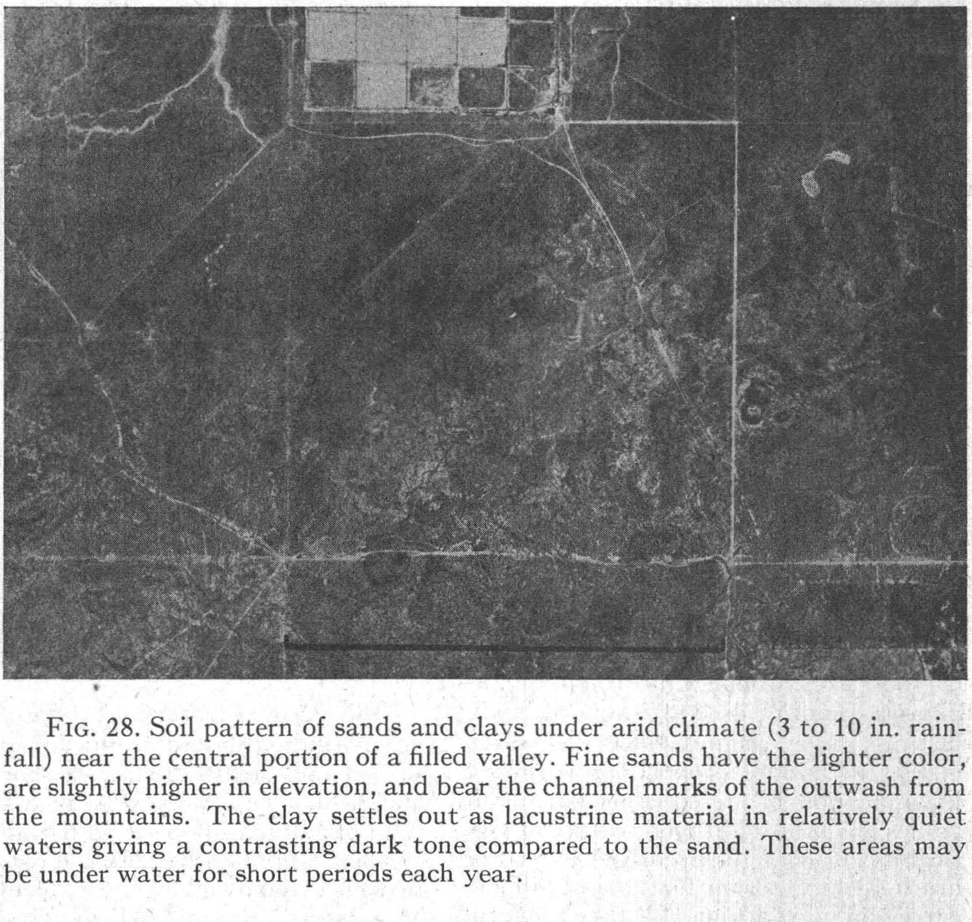

FIG. 28. Soil pattern of sands and clays under arid climate (3 to 10 in. rainfall) near the central portion of a filled valley. Fine sands have the lighter color, are slightly higher in elevation, and bear the channel marks of the outwash from the mountains. The clay settles out as lacustrine material in relatively quiet waters giving a contrasting dark tone compared to the sand. These areas may be under water for short periods each year.

Climatic Effects on Soil

It is evident that in applying photographic interpretation to soil surveys in unfamiliar areas lack of experience may require investigation of available information concerning the area. In the eastern and midwestern States a good coverage of soil information exists. The more recent reports are usually excellent and can often be used without supplementing photographs. Unfortunately, a large number of these were completed between 1900 and 1925. The methods then used, the accuracy of mapping, and the descriptive matter make them difficult to use effectively for engineering purposes. Outside of the area mentioned there are few extensive areas that are mapped in detail.

The bulk of the published information on the soils of the western States (10) Europe (5) and Africa (7) is based on the Russian system of classification or some variation of it. Where pedology contains many phases that are directly applicable to engineering the climatic classification conceived in Russia has only a few minor applications in some areas. In the event that this type of information is available it is well to realize that it is based on climatic influence, chiefly rainfall. The names given the various soils are the Russian terms for soil colors or other general distinguishing features. The chernozems are black earths or the prairie soils; black because of the restricted rainfall that promotes the growth of grass which in turn produces a deep (12–24 in.) organic development in the profile. The podzols are soils having an ash-colored layer immediately below the surface; these are developed in cool climates usually under pine forests. There are also the gray brown podzols, the red and gray desert soils, the chesnut soils and the laterite.

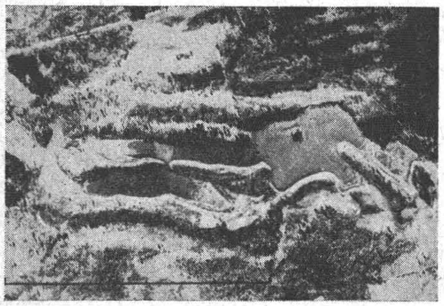

FIG. 29. A series of parallel eskers in a glacial drift area. While the eskers (ridges of gravel) themselves indicate a glacial area the associated muck deposits and general pattern are also indicative of glaciation.

FIG. 30. Drumlins, a glacial form that should not be mistaken for eskers. Examination of the elements of this pattern will indicate a material less pervious than the sands and gravels in kames and eskers.

In comparing these soil areas with the parent material areas it is impossible to escape the conclusion that they are not related. Examining the chernozem belt that roughly parallels the Mississippi River from central North Dakota to Texas leads to the conclusion that all types of soil exist in that area—clays, silts, sands, and gravels. The same variations occur in the other classifications. An example of this occurs in an area of Liberia mapped as laterite soil. Actually the area consists of "occasional swamps and stretches of clay soil that necessitate the hauling of laterite gravel for a few miles for road surfacing, but the supply of this ideal road building material is inexhaustible. It occurs in all parts of the country, often in a layer 3 or 4 ft. thick just beneath the topsoil . . . " (11). Even the term laterite is so broad as to include many forms of soil and does not always indicate gravel or brick-like material used for road metal in parts of Africa, India and the Malay States.

A soil area that would be classed as a Gray Desert soil (Sierozem) is shown in Figure 28. Here sands and clays occur as indicated by the color and drainage patterns. This is the general pattern of the central or low-gradient areas of the arid, filled, intermontane valleys variously described as "bolsons," "playas," or "chotts."

THE SIGNIFICANCE

Obviously the significance of the soil pattern lies in its relationship to engineering problems affected by the soil. Currently the soil problem resolves itself into two parts, one in which the soil in place is satisfactory as subgrade, and the second, where the soil is unsuitable. In areas of unsuitable soils some form of improvement, by stabilization or insulation, is required. Insulation involves the economic location of granular materials in the form of rock to be crushed, cinders (volcanic), or sand and gravel. The preceding discussion has dealt with each element of the soil pattern; therefore, some grouping of these elements will illustrate the common soil patterns not already described.

Inasmuch as gravel and sand or other granular deposits exist to some extent in nearly every county in the country the significance of soil patterns indicating granular materials is of considerable economic importance to engineers.

Because of differing origin, granular deposits occur in various forms in various sections. Regardless of the area, isolated deposits of gravel and sand are related to present or past drainage systems. On the basis of soil areas the glacial drift has a variety of interesting gravel and sand deposits. Each has the usual elements that indicate the presence of granular material.

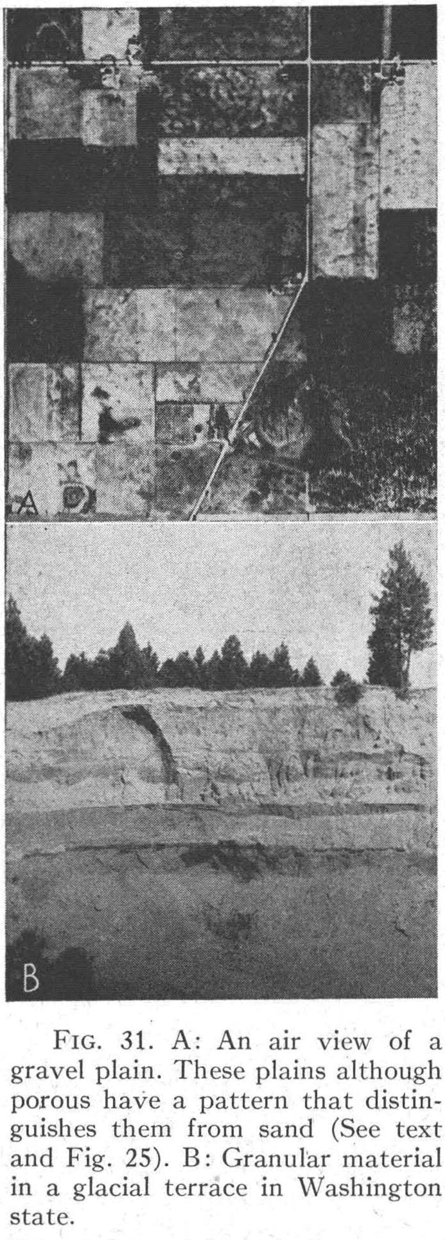

FIG. 31. A: An air view of a gravel plain. These plains although porous have a pattern that distinguishes them from sand (See text and Fig. 25). B: Granular material in a glacial terrace in Washington state.

Kames and eskers are gravel deposits dumped by the glacier onto the unassorted till or drift of the surrounding area. They bear no necessary relation to the general soil texture of the surrounding terrain and, fortunately, often occur in areas of plastic soils. Kames are round, usually symmetrical, hills of gravel that have been dumped from holes in the bottoms of rivers flowing on or in the glacier. Eskers, formed in a similar way, often resemble abandoned railway fills. Because of their shape and abrupt slopes these two forms are readily distinguished in aerial photographs. Figure 29 shows eskers occurring in a northern area. They are, as yet, undeveloped sources of excellent gravel in the particular areas shown. Figure 30 shows a characteristic drumlin pattern that should not be confused with eskers since they furnish a semi-granular material unsuitable for commercial aggregates.

Other formations in glacial areas containing sands and gravels are directly associated with stream channels. These take the form of outwash plains (sand), granular drift, and river or stream terraces. Outwash plains are also found in mountainous country, and they represent areas in which water moved with sufficient velocity to carry sand or larger size material. They are usually level plains, having a rather uniform color pattern, an absence of surface drainage, and a sparse vegetative cover (Fig. 23). Sands develop a color tone that with experience becomes unmistakable in aerial photographs. Gravelly drift plains have the same form of relief and lack of surface drainage but they can be readily distinguished from sand because of their color pattern. Figure 31 is an air view of such a plain. Close observation shows the presence of an infinite number of small irregular black spots. The general impression is that the area has a worm-eaten appearance. The difference in composition of sand and sand-gravel mixtures accounts for this. The sand, being chiefly silica, is highly resistant to weathering while the gravels, whether igneous or calcareous, weather and form a silty or sandy clay horizon at the surface. This horizon development partially retards the downward percolation of water and insignificant sinks or solution basins form where sufficient water concentrates to make a moisture condition more favorable to vegetation which in turn promotes a slight increase in organic material. This difference creates the pattern that identifies this class (No. 3) of material in gravel plains throughout the humid areas of glacial drift.

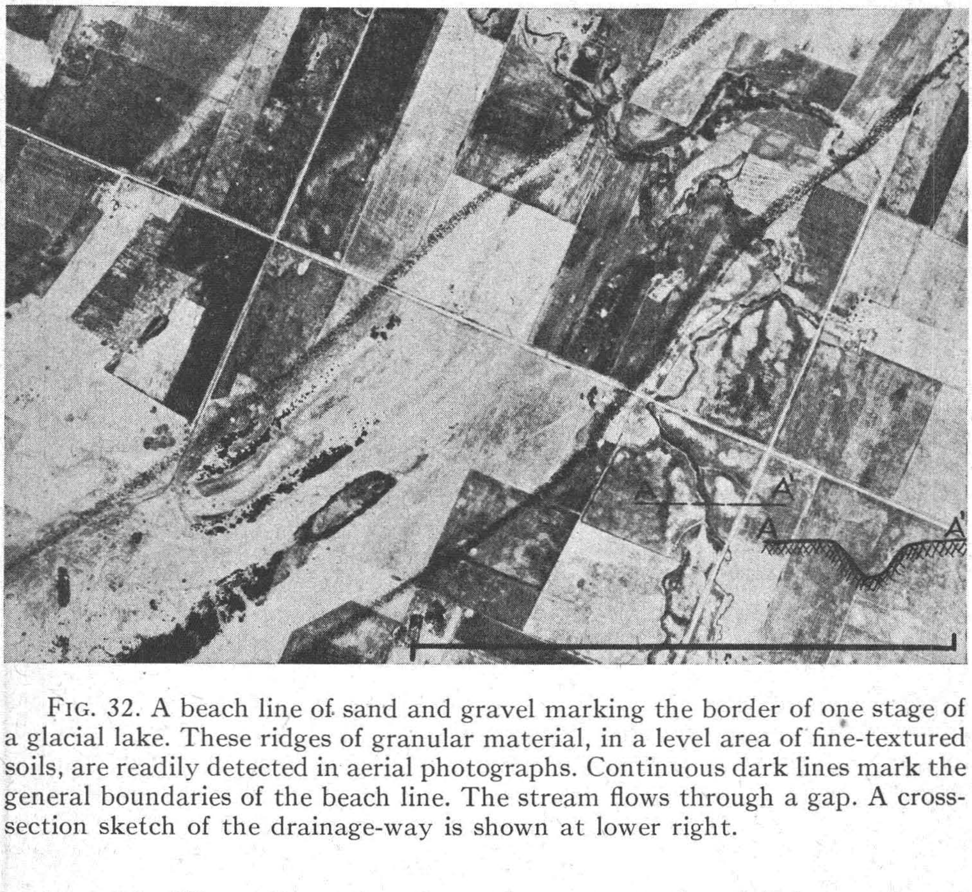

FIG. 32. A beach line of sand and gravel marking the border of one stage of a glacial lake. These ridges of granular material, in a level area of fine-textured soils, are readily detected in aerial photographs. Continuous dark lines mark the general boundaries of the beach line. The stream flows through a gap. A cross-section sketch of the drainage-way is shown at lower right.

Gravel terraces occur in these areas in association with streams both large and small. Figure 18 shows this type of land form. These granular terraces are

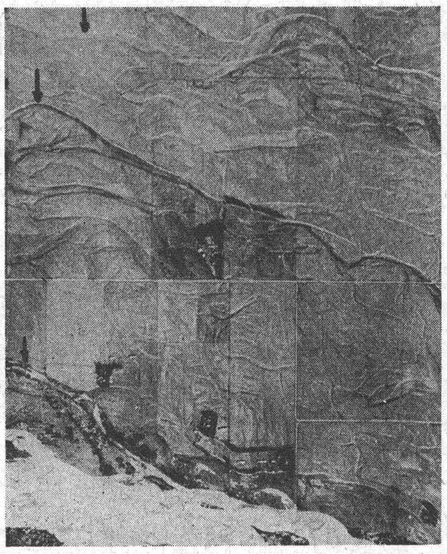

FIG. 33. Gravel terraces at the junction of two rivers in New Zealand. Braided stream channel at left. The continuous lines (arrows) mark definite stages of terrace development while the less distinct scars are channel marks. On each terrace the surface is sufficiently level for a safe landing by airplanes. Being gravel, these soils are stable in all seasons. Courtesy of New Zealand Aerial Mapping, Ltd.

usually high above the present floodstage of the stream. They are level, they vary in width, and they may or may not be continuous. The adjoining uplands are dissected with many gullies emptying water onto the terrace, while the stream border of the terrace usually drops abruptly to the flood plains. The truly granular terraces absorb the water that they receive from the upland and remain undissected.

Glacial lake beds (See Fig. 3) present one of the most unsatisfactory subgrade soil areas. Despite their plastic properties most have a series of beach lines that often serve as the only source of gravel and sand for many miles. Fortunately beach lines are clearly visible from the air since they present a striking pattern in contrast to the adjacent areas. Figure 32 shows the pattern of a small section of an ancient beach line striking across the bed of a glacial lake; its light color, vegetative cover, and form make it as a source of granular borrow material so necessary for subgrades in these areas.

Since water transports and assorts these granular materials, washing away the fine particles, it is possible to generalize and apply to most of the other areas of the country the rule that granular deposits occur where the velocity of water decreases. This is true along the fall line in the east, at the base of mountains in the west and at the junctions of streams in nearly all areas. If the watershed of a stream contains rock, sand, or gravel, then assorted deposits of these materials will occur in or near the channel. Abrupt changes in channel direction are caused by a body of resistant material that may either be rock or buried gravel and sand. Figure 33 shows a remarkable series of gravel terraces occurring in New Zealand near the junction of two rivers.

Figure 5 illustrates an unusual source of granular material peculiar to the coastal plains in Arkansas and Texas. The small white spots appearing in the picture are natural deposits of "gas-well sand". These occur in many of the clay areas of this region and form the only source of granular borrow in many localities. They often have a texture of coarse sand and fine gravel, are round in shape, 10 to 50 ft. in diameter, and vary from a few inches to several feet high.

These modes of occurrence apply also to areas where mountains rise abruptly from the sea. In Figure 34 a slightly dissected granular terrace stands above the sea level at the base of mountain slopes in a hot, arid climate. Gully erosion in arid areas is more severe, since the total annual rainfall often falls during a few violent storms. Here the terrace, the parent stream, and the steep slopes are included in a small area.

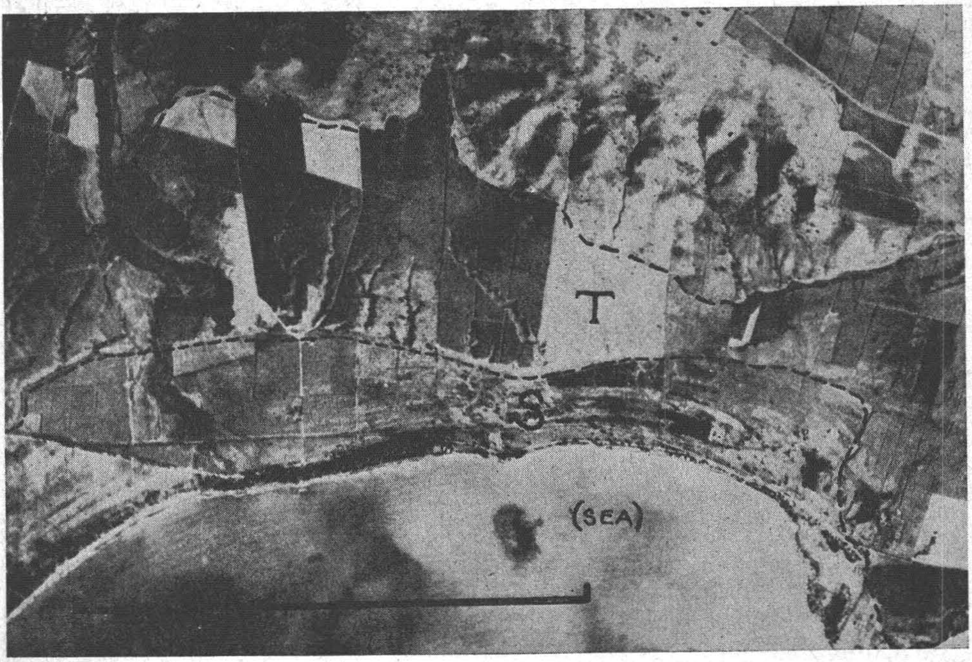

FIG. 34. A gravel terrace, T, at a shoreline transition from mountainous country to sea level. Simple gullies are beginning to dissect this terrace. A belt of loose sand, S, separates the terrace from the sea.

In areas showing signs of past volcanic activity, cinder cones furnish, in most instances, a source of granular material suitable for base construction. These are recognizable from the air as well as from the ground by their distinctive cone shape. The cinder cone in Figure 35 is typical of this type of deposit. In dry areas where vegetation does not cover the slopes their form is more obvious. From the air an observer has the added advantage of detecting lava flows that stem from the base of the cone and form a pattern having fluid outlines.

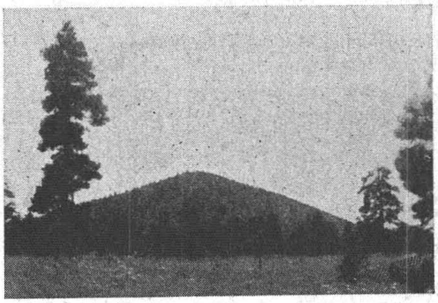

FIG. 35. A ground view of a typical cinder cone. The symmetrical peak and side slopes mark this type of granular deposit.

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