DRAINAGE PATTERN SIGNIFICANCE IN AIRPHOTO IDENTIFICATION OF SOILS AND BEDROCKS*

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ABSTRACT

This paper reports the analyses of drainage patterns for their use in the identification of regional soils and bedrocks, by means of airphotos. The study is one of several concerning the interpretation of aerial photographs by the Joint Highway Research Project at Purdue University. The relative ease with which stream systems can be observed on aerial photographs facilitates the recognition of drainage patterns.

In the natural sciences, it has been accepted for a long time that certain basic drainage patterns such as the dendritic, trellis, radial, parallel, annular, and rectangular are associated with specific land surface materials. Airphoto interpretation has revealed several modifications of the basic drainage patterns. For example, some of these modified types are the reticular, phantom, and lacunate.

Drainage patterns, traced directly from representative airphotos of various physiographic regions throughout the United States, are presented as illustrations of patterns which develop in the soils and bedrocks typical of the regions. These examples have been selected to show noticeable differences in drainage patterns. For instance, drainage patterns in regions where the rocks are bare or are covered only with shallow soils, are decidedly different from those in regions of deep glacial drift. Likewise, drainage patterns develop differently in horizontal rocks than in tilted rocks.

It is concluded that surface drainage patterns can be relied upon in the airphoto identification of soils and bedrocks on a regional basis.

INTRODUCTION

DRAINAGE patterns have intrigued scientists over a long period of years. As a result of their findings, many patterns have been classified and incorporated into the literature of the natural sciences of geology, physiography, and geomorphology. Recently—probably within the last decade—engineers have been studying drainage patterns by means of airphotos. In the laboratories of the Joint Highway Research Project at Purdue University, highway research engineers have been using airphotos to construct detailed drainage maps of Indiana on a county basis. During the progressive stages in the compilation of these maps, recurring drainage patterns were observed. This led to the investigation of drainage patterns on aerial photographs of areas of land surface materials, with known characteristics, which occur elsewhere in the United States.

The study of an area for the purpose of identifying its soils and bedrocks by means of airphotos is best effected by stereoscopic examination of the vertical aerial photographs of that area. By this means, such "elements" of the terrain as landform, drainage pattern, erosion features, vegetative cover, and land usage are revealed on the airphotos in a most realistic manner. Photo tonality is another "element" vital to airphoto interpretation. Tonality can be observed without the aid of a stereoscope. Colors found in soil, rock, vegetation, or water are recorded on the airphotos in black, white, or tones of gray which vary according to the values of the respective colors and the reflection of incident light. While all the elements are correlative and are considered equally important in airphoto interpretation, only the drainage pattern element is herein set forth. In doing this, it is not to be assumed that the drainage pattern element can be relied upon alone in the identification of soils and bedrocks by the use of airphotos. It must be used in conjunction with the other elements.

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It is known that the drainage of a region is affected by such factors as bedrock structure, soil textures, topography, artificial waterways, rainfall, vegetation, and evaporation. Since the drainage ways and landforms of a region are interdependent, they exist together as interrelated features of the region. Therefore, soils and bedrocks influence the evolution and character of the patterns of a region's many rivers and tributary streams. These facts lead to the premise that drainage patterns can be used to identify soils and bedrocks on a regional basis.

The airphotos employed in the preparation of this paper were taken during 1937–1943 in connection with the United States Department of Agriculture map program. The prints were obtained from the Agriculture Adjustment Administration (now Production and Marketing Administration). They are standard 7″×9″ and 9″×9″ contact prints having an approximate scale of 1:20,000 or 3 inches per mile.

DRAINAGE PATTERN CLASSIFICATION

A pattern has been defined by Webster as "an arrangement or composition that suggests or reveals a design." The term "drainage pattern" is used in this paper to apply to the manner, or "design," in which a given set of tributary streams arrange themselves within a given drainage basin. (See Figure 1.)

Drainage patterns are classified on the basis of form and texture. The form of the pattern is its shape which may be described by comparing the pattern

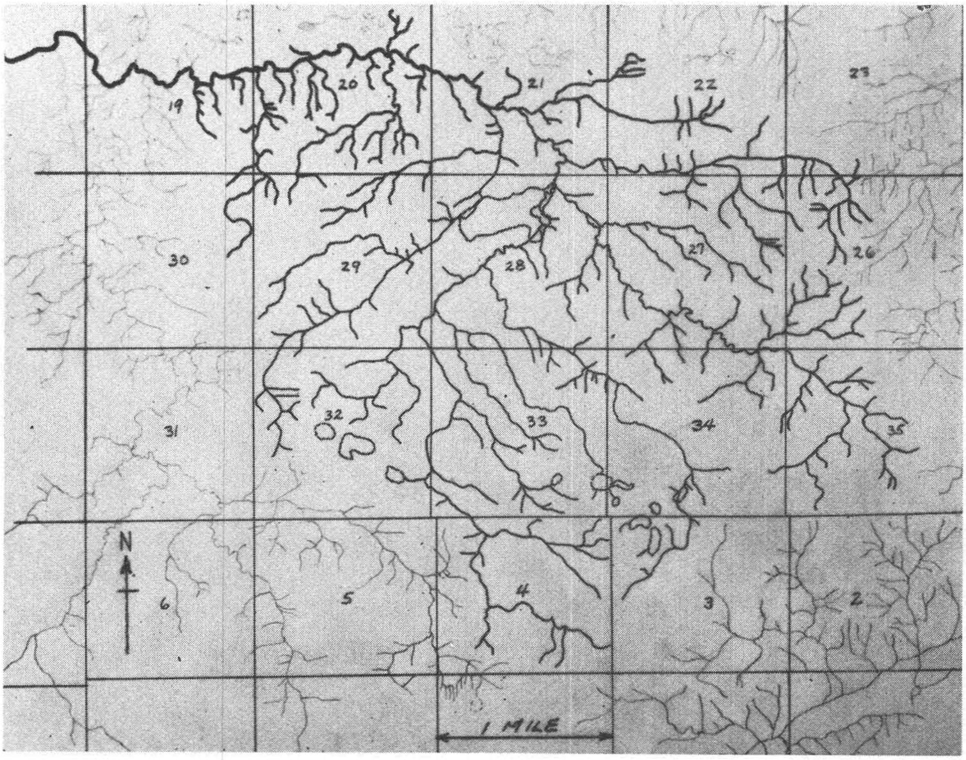

FIG. 1. Drainage pattern of the headwaters of a stream system developed in Wisconsin glacial drift. Flint Creek, Tippecanoe County, Indiana. The areas bounded by dotted lines are infiltration basins. Numbers indicate Congressional land sections. (This pattern was traced directly from aerial photographs of the area. Original scale, 1:20,000.)

with a familiar object such as the branches of a tree. The texture (or density) of the pattern refers to the spacing of the tributaries in the stream systems. If the tributaries are closely spaced, the texture is "fine," and if they are widely spaced, it is "coarse."

Certain drainage patterns are considered as the basic patterns. Variations of the basic types are known as modifications of the basic patterns.

Basic Drainage Patterns. Of the many stream patterns which have been formed by natural forces acting upon the earth's land surface materials, six have been classified as the basic drainage patterns. Analyses of the more or less characteristic arrangement and repetition of the lines of these patterns have revealed significant relationships between the patterns and the soils and bedrocks of the regions in which they are found.

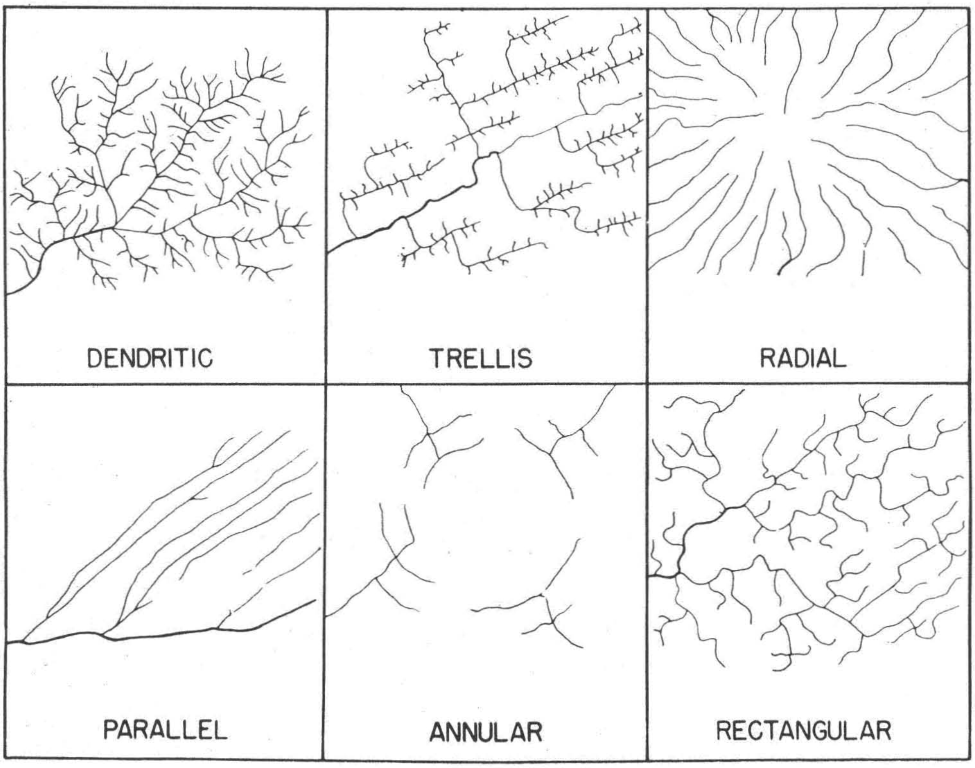

FIG. 2. Sketches illustrating basic drainage patterns (20, 21).

Figure 2 illustrates the six basic drainage patterns. They can be described briefly as follows:

1. A dendritic drainage pattern is tree-like in form; the main stream corresponds to the trunk of the tree and its tributaries resemble the irregularly subdivided branches, limbs, and twigs of the tree (22:127).* Another term for this type pattern is "arborescent" (11:300). It is the most common type drainage pattern. It is formed where the "rock structure does not interfere with the free development" of streams (15:340).
2. A trellis type of drainage pattern may be compared to a vine on a garden trellis;

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* Numbers in parentheses refer to bibliography.

the primary tributaries are long and straight and often parallel to each other and to the main stream. Numerous short, stubby secondary tributaries join the primary tributaries approximately at right angles (22:127). This drainage pattern may be thought of as one "adjusted" to structure (2:122). "Gravevine" is another name for this type pattern (26:503).

3. A radial drainage pattern may be likened to the spokes of a wheel. The pattern may be either centrifugal or centripetal; that is, the streams may flow radially either outward from a peak, or inward toward a basin (17:175) (22:127). Also, this term can refer to a group of drainage patterns originating at a common point (13:350). Stream systems on isolated hills often take this form.
4. In a parallel drainage pattern, the streams or their tributaries are parallel or nearly parallel to each other (22:127). The way in which the streams are arranged might aptly lead to the naming of the pattern cauda equina—horse's tail.
5. In an annular drainage pattern "ring-like" tributaries flow into the radial streams (22:127). This type pattern has been compared to the annual growth rings in a tree (17:175).
6. A rectangular drainage pattern shows the influence of the angularity of rock joints; it is characterized by many "abrupt bends" in both the main streams and their tributaries (22:129). This pattern is a "right-angle system of streams" (7:130). The pattern is affected locally by horizontal rock strata of different composition.

Rock structure is a major factor in the development of these six patterns. Dendritic drainage patterns are normally formed by streams flowing in horizontal homogeneous rocks. Trellis patterns develop in folded or dipping rocks where there is a series of parallel faults. These also result from adjustment, and

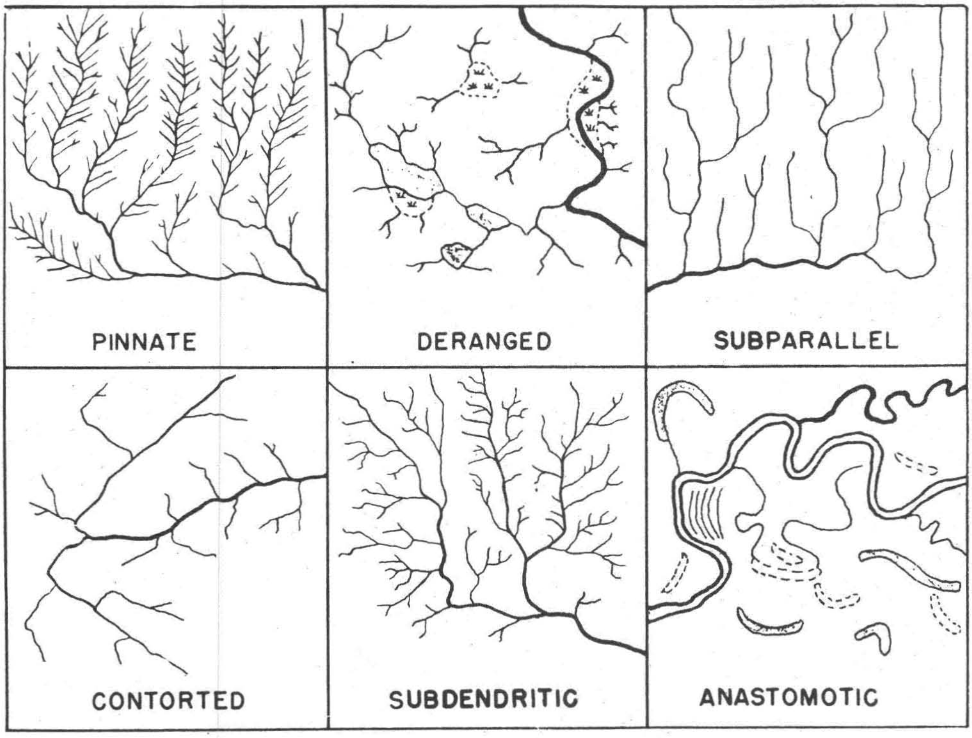

FIG. 3. Sketches of modified basic drainage patterns (20). Shaded areas are water-filled basins—lakes, ponds, sloughs, bayous. Areas bounded by dotted lines are infiltration basins.

are stream systems "aligned on a strike of the rock formations," the streams occasionally making "right-angled turns to cross strike ridges" (4:86). Streams draining volcanic peaks assume the radial type of pattern. Drainage patterns in tilted rocks having parallel faults and in valley-fill materials often show striking parallelism. A parallel drainage pattern implies a "pronounced regional slope" (26:510). Streams around a dome follow circular, or annular, courses. Streams following the faults and cracks in jointed rocks produce rectangular drainage patterns (17:175). Fractures in the rocks of the earth's surface have "influenced the activities of running water." Sometimes a river's course is in "rectangular zigzags"—"its walls are formed of joint planes" (12:224). All these drainage patterns reflect details of relief that are characteristic of the materials from which the stream valleys have been carved.

Modifications of the Basic Drainage Patterns. There are several modifications of the basic drainage patterns. Figures 3, 4, 5, and 6 illustrate some of the modified types. A number of these patterns have been described in scientific literature. The author has identified others by means of aerial photographs.

Descriptions of the patterns in Figure 3 are as follows:

1. The pinnate drainage pattern is a modification of the dendritic type. The second order tributaries are arranged in a more or less parallel manner (parallelism indicates a nearly uniform slope). The rather evenly-spaced first order tributaries join the second order tributaries at acute angles (near right angles) much in the manner of a feather—hence the name "pinnate" (26:512).
2. The deranged or disordered type of drainage pattern has been applied to the drainage of drift-covered regions. It has been so termed because of the great irregularities of its pattern and the confused intermingling of lakes, marshes, and wide-open valleys (7:503). Runoff water collects in the lakes, swamps, and marshes; and streams wander aimlessly about the landscape (8:295). The numerous lakes and swamps depict the undeveloped character of the drainage. The terms "erratic" and "haphazard" may also be applied to this pattern (12:300). Patterns of individual drainage systems within the area are usually dendritic.
3. The subparallel drainage pattern resembles the spire-like Lombardy poplar tree in its type of branching. The first order tributaries are usually nearly parallel to the second order tributaries. Again, in this type, parallelism denotes uniformity of slope (26:513). This pattern is a modified type of parallel drainage, but "lacks the regularity of the parallel pattern" (26:518).
4. The contorted drainage pattern type is a "response to rock structure" (7:215). Streams flowing in one direction may be completely reversed in direction when they encounter resistant rock of granular barriers.
5. The subdendritic drainage pattern is a modification of the dendritic type. This type shows minor slope control of the second and third order streams (first order tributaries are the field gullies); other than that, it closely resembles the dendritic type pattern (26:513). It is a result of streams flowing from a non-resistant material area through another of slight structural control.
6. The anastomotic drainage pattern is characteristic of flood-plain drainage. The meandering of the main stream has produced sloughs, bayous, oxbow lakes, and "interlocking channels." A network of anabranches may even be present. This type pattern is considered to be "a phase in the development of dendritic drainage" in restricted areas (26:514).

Patterns illustrated in Figure 4 are described as follows:

1. The colinear drainage pattern is a modification of the parallel type. Parallel streams are alternately surface and subsurface. This is a recognized type of drainage pattern found in certain foreign countries (26:519). It is a system of intermittent streams flowing in very straight lines through porous materials.
2. The centripetal drainage pattern is a modification of radial drainage. If the

headwater divide of a drainage basin is "roughly an arc of a circle," and the inside surface is steep and evenly sloping, then tributaries from opposite sides of the basin will enter the main stream at nearly the same point (13:350). This term can refer to a group of drainage patterns converging to a common point (13:350) (26:517). This pattern occurs frequently.

3. The branching pattern of the distributaries of a stream is the dichotomic pattern of alluvial fans (8). The end branches are called anabranches—branches which lose themselves in the valley fill. Also, this pattern may be applied to the arrangement of the streams in the birdfoot type of river delta.
4. In nearly level areas man has dredged ditches to drain swamps and low-lying soils. These ditches are fairly straight; they follow topographical depression channels or the section, half-section, and quarter-section lines. Often they do not "accord with the pattern of the soil and vegetation" of the area (6:73). They have been graded so that low rises are traversed which would otherwise block the natural drainage. This pattern is identified as "rectilinear" in type (22). It is a form of artificial drainage. It is not to be confused with the pattern of irrigation ditches which is a distributary pattern (6:73).
5. Drainage in horizontal limestone areas is both surface and subsurface. Where sinkholes predominate, small streams are "swallowed in holes" to continue under ground as subterranean streams. Sinkholes plugged with debris become ponds. This swallow hole pattern is common to regions of massive strata of limestone. The pattern of a youthful karst region might appropriately be called the "dot" pattern. In mature and old age limestone regions, sinkholes, fensters, and solution valleys form "unsystematic" drainage patterns in that surface drainage is interrupted by the disappearance of the streams under ground (18:116).

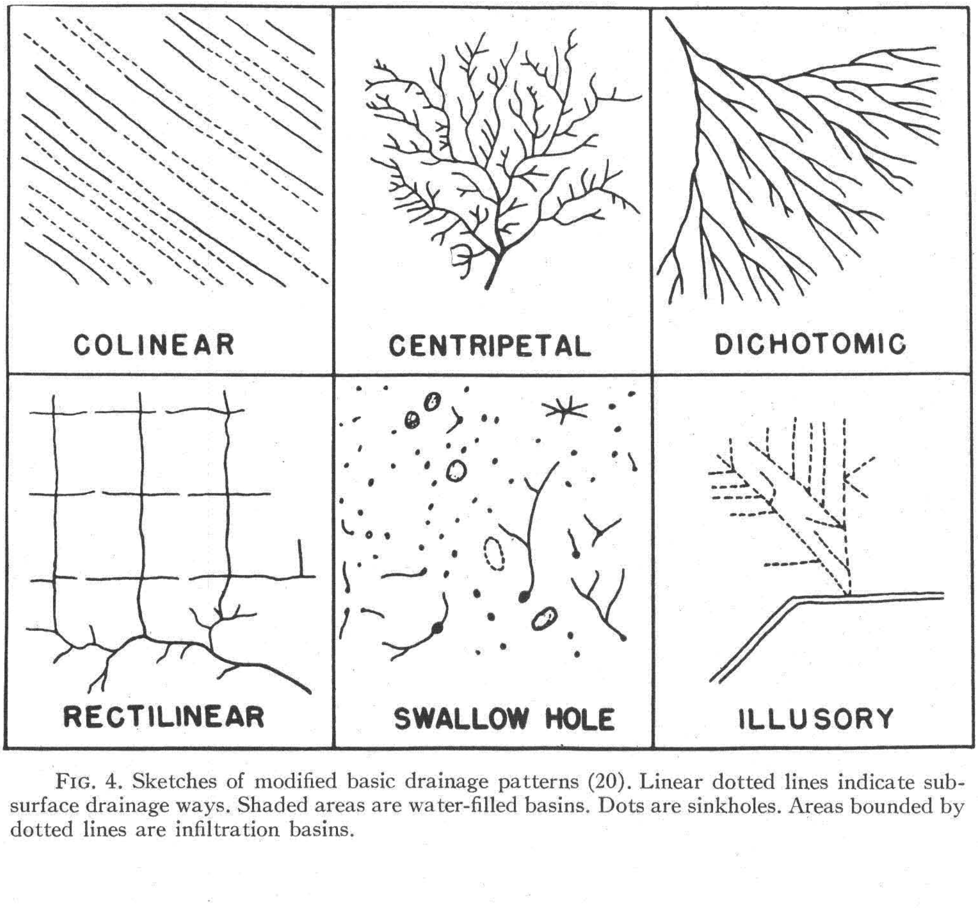

FIG. 4. Sketches of modified basic drainage patterns (20). Linear dotted lines indicate subsurface drainage ways. Shaded areas are water-filled basins. Dots are sinkholes. Areas bounded by dotted lines are infiltration basins.

6. The illusory type drainage pattern is occasionally observed on airphotos of porous low-lying soils which are tiled for drainage. While this is subsurface drainage, the network of tile drains is often "visible" on the airphotos because the soil above the tile has dried and there appears on the photos a sort of "X-ray" near-white system of lines—formed by the trunk tiles and their parallel laterals (14:30). This is a form of artificial drainage. The lines appear somewhat spectral on the airphotos—they may be likened to the spreading of the ink in a line drawn on blotting paper. This pattern is depicted graphically by dashed lines—the accepted symbol for hidden lines. The pattern is an evanescent one; as the soil dries the pattern becomes imperceptible. Also it is a deceptive pattern; a buried pipe line, a buried telephone cable, or an abandoned railway grade might easily be mistaken for a large tile.

The patterns shown in Figure 5 have the following descriptions:

1. The angulate pattern is a modified type of trellis drainage pattern. Parallelism in it is similar to the rectangular type but the tributaries join the principal streams at acute or obtuse angles (26:517). Like the rectangular pattern it reflects the influence of rock joints.
2. An "asymmetrical" drainage pattern has more tributaries on the upslope side of a trunk stream than on the downslope side. This type is commonly found in mountainous territories (13:352). It is often "pectinate"—shaped like a comb.
3. The barbed drainage pattern is a type of drainage pattern which results from stream piracy. Branching tributaries form obtuse angles with the trunk streams (11:180). The pattern is "calcarate"—spurred. It is a form of "back-hand drainage."

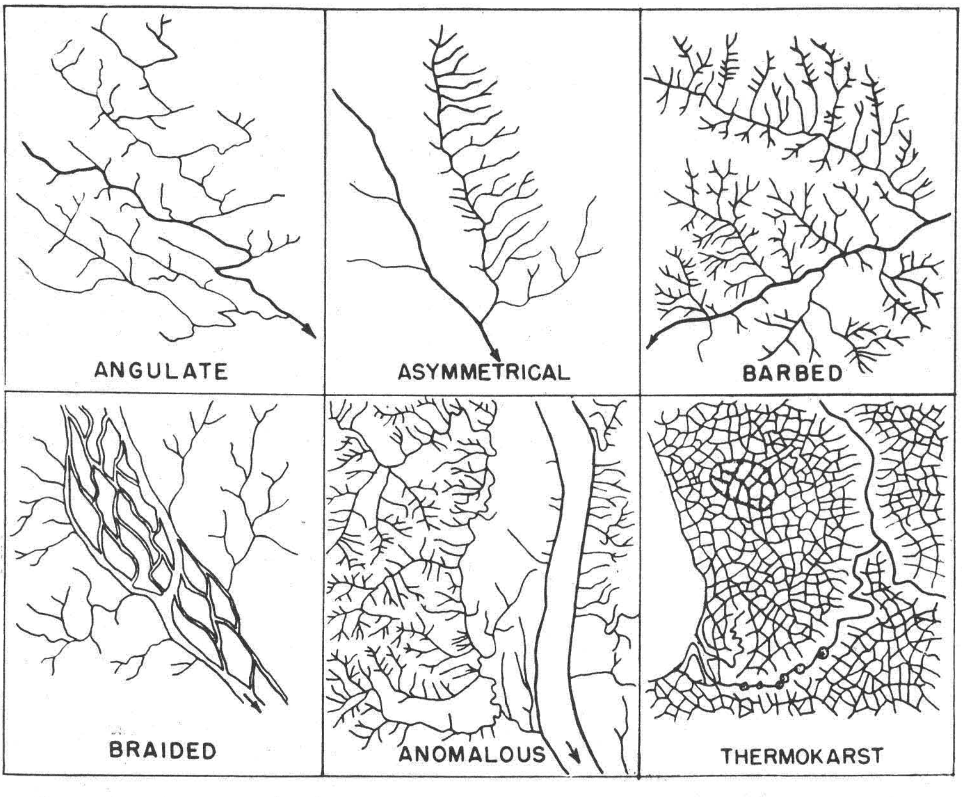

FIG. 5. Sketches of modified basic drainage patterns. Shaded areas are water-filled channels and basins—rivers, lakes, sloughs.

4. The braided drainage pattern is that of a graded stream. An intricate network of shallow channels forms "a complex pattern on the valley floor" (18:69). Usually the materials deposited by a braided stream are granular, especially in the upper reaches of the stream.
5. An anomalous drainage pattern is the general irregular pattern of an area formed by the combination of dissimilar patterns in adjoining but different types of topography. This complex pattern indicates the existence of unlike materials in an area. The component patterns of the complex pattern can be studied individually.
6. The thermokarst drainage pattern is that produced by the surface thawing of permafrost (25:2). It is formed by cave-in lakes which eventually become joined together by streams. The concatenate pattern of the "button" lakes is a singular feature. Usually the thermokarst pattern is found in areas of fine-grained alluvial sediments (9:17).

Figure 6 presents other patterns which can be described as follows:

1. The lacunate type drainage pattern is formed by small "lakes" spaced at random over an area. Individual tributary systems may be dendritic. It is found where there is an impervious substratum. This pattern occurs in areas where the erosion cycle is very young (2). It is a closed-basin type which is found in parts of the southern Great Plains region of the United States.
2. The Yazoo type drainage pattern pertains to larger stream systems than those which are usually considered. It is due to the inability of tributary streams to

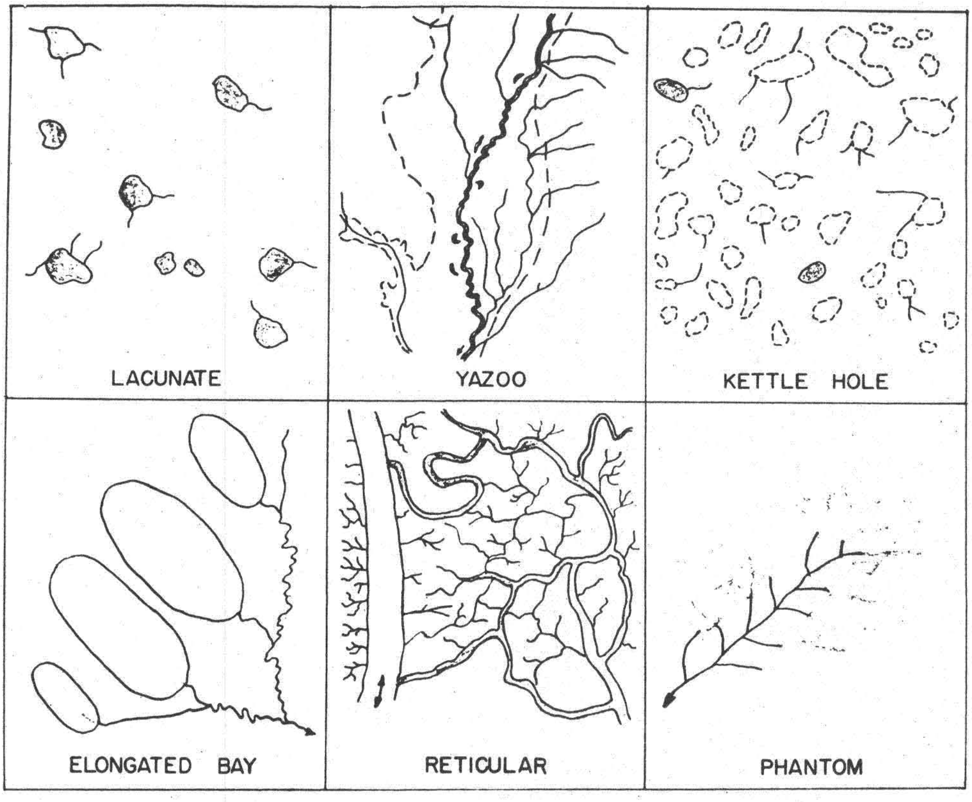

FIG. 6. Sketches of modified basic drainage patterns. Shaded outlined areas are water-filled channels or basins—rivers, ponds, lakes. Shaded lines indicate high water table areas or seepage ways. Dotted lines bound infiltration basins.

break through the natural levees of major streams. It is the pattern found on confluence plains—plains on which the tributaries unite before entering the main streams. This pattern develops in alluvial bottom lands.

3. The kettle hole type of drainage pattern is one of random-spaced depressions, with an occasional water-filled basin. Like the lacunate pattern, it is a closed basin type, but it occurs where there is a porous substratum. It is the pattern found in granular moraines and outwash plains. Individual tributary systems may be dendritic.
4. The elongated bay type drainage pattern is one peculiar to coastal plain or delta areas. (The author believes the bays in the Carolinas and Texas to be cave-in lakes formed in permafrost during glacial times.) Rows of the bays follow the lows (troughs) in old beaches. This indicates that they have been formed in fine-grained sediments.
5. The reticular type drainage pattern is a network of stream channels. It is "canaliculated"—having many channels. It is a variation of the anastomotic pattern but is different in that it is found in tidal marshes and in youthful coastal plains (26:514). At flood tide the water flows inward through the channels; at ebb tide, outward. It is a pattern of anabranches—the diverging branches of a large coastal plain stream which reenter that same stream.
6. The phantom drainage pattern is one of seepage ways. It is a network, also. The pattern is caliginous and arachnoid—dim, and cobweblike. It is found in "loose" (unconsolidated) fine-grained but well-drained soils on impervious subsoils.

Analysis of Regional Drainage Patterns. The following illustrations which show airphotos paired with drainage maps are presented as examples of representative typical regional drainage patterns. The examples show noticeable differences in drainage patterns of materials common to various physiographic regions.

The patterns are classified according to the basic or modified types of drainage patterns. The forms and textures of the patterns are studied for the influences exerted on them by the soils and bedrocks in which they exist. The effects of peculiarities of topography and extraneous materials on the patterns are noted also.

From a logical standpoint, the examples of drainage patterns found in residual materials are considered first; then, those in transported materials. The examples from different regions of residual materials are drainage patterns found in both horizontal and tilted rocks; and the examples from regions of transported materials are drainage patterns found in glacial drift, and water-laid and wind-blown soils.

Limestone-Shale. The intricately dendritic drainage pattern shown in Figure 7 compares closely to the basic dendritic pattern shown in Figure 2. It has some of the characteristics of the subdendritic pattern shown in Figure 3, but hardly enough for it to be classified as subdendritic. However, the presence of two materials, nearly horizontal thinly-bedded strata of limestone and shale of different textures, does lend the pattern an irregularity which indicates slight structural control. The primary tributaries flowing in shale are deflected, sometimes sharply when they contact the more resistant limestone. Sinkholes are found on the ridges where a limestone layer is sufficiently thick to permit their development. These sinkholes affect the drainage pattern only to the extent of occasional surface depressions, for most of the runoff water flowing through them finds its way immediately into adjacent streams. The density of the pattern is great (or fine) because of the presence of impervious shale, as well as because of a great difference in elevation between the ridges and the valleys.

This region was once covered with Illinoian glacial drift, but the drift has been removed by erosion until now only traces of it are found on the highest

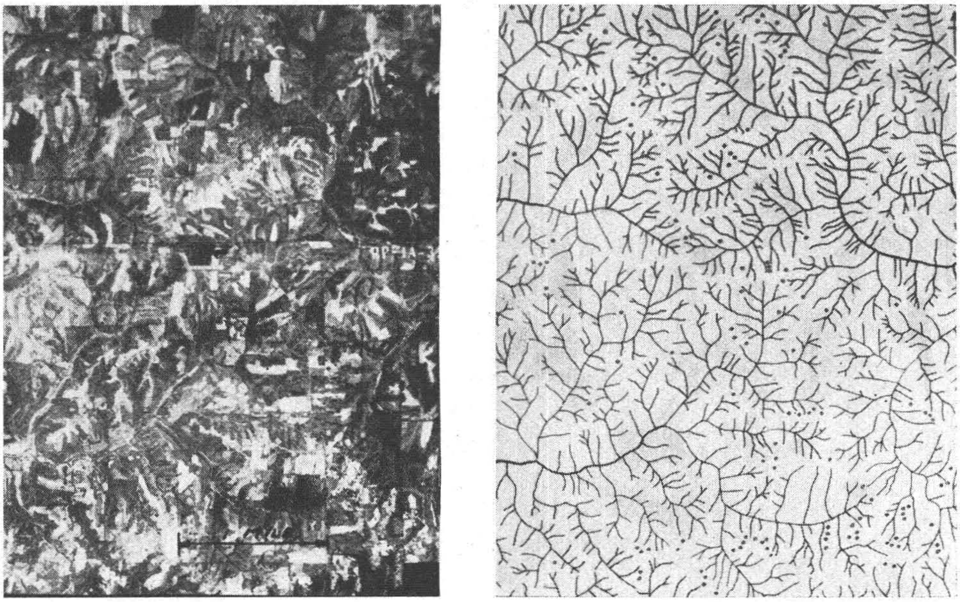

FIG. 7. Drainage pattern of limestone-shale (Ordovician) (20, 21). Left—Airphoto of area in southwestern Switzerland County, Indiana. Right—Drainage map of same area. Small circles are sinkholes.

ridges. The presence of the Illinoian drift apparently does not affect the drainage pattern. The pattern has resumed its primitive, or pre-glacial, development.

Colluvial slopes found throughout the region cause many landslides in highway construction.

Sandstone-Shale. Figure 8 illustrates the slightly modified dendritic drainage pattern—somewhat subdendritic—developed in an area of laminated sandstone and shale. The area is especially known for the "perfection and symmetry of its drainage lines" (11: 90–94). The sandstone-shale has eroded to produce a "rangy" dendritic drainage pattern of which the branching of the smaller tributaries is confined mostly to their "tip ends." The sandstones are more or less pure, are usually rather soft, and are intercalated with sandy shales. Soils weathered from them are plastic clays which erode in V-shaped gullies because of steep slopes. Forests cover most of the hills as shown by the botryoidal texture of the airphoto in Figure 8.

The influence of the shale is seen in the additional subdivisions of the smaller tributaries. Angularity in the pattern occurs because the sandstones are resistant to erosion. The density of the pattern indicates that immediate runoff is less than for limestone-shale regions (Figure 7). The medium density is due to the somewhat pervious nature of sandstone and to the considerable difference in the elevation between the ridges and the valleys. The pattern is influenced very little by the general slope of the region.

The region is mature and the interfluves have been reduced to knife-like ridges. The ridges are clearly defined by the spaces between the tip ends of the first order tributaries (field gullies).

Weathering sandstone breaks down into small flat fragments; stream deposits of this material are known as "brown gravel." Although this gravel is used locally for road building material it is not very durable. It is detrimental as an aggregate for concrete.

Massive Limestone. Figure 9 illustrates the "swallow hole" drainage pattern of a youthful karst plain. Such plains are distinctive because their surface features are the "result of the solvent work of underground water" instead of surface streams (8: 321). In the area represented by this illustration there are no small streams, although small streams are occasionally present in similar areas. The surface of a young karst plain is undulating, often rolling, and sometimes rough; it is known as sinkhole topography. The sinkholes are identified on the airphoto portion of Figure 9 by dark-centered circular light gray spots.

In the formation of young karst plains, water first flows through a fissure in the underlying limestone and begins dissolving the rock. When the surface depression has become approximately five feet in diameter, it is known as a "ponor"; it has steep vertical slopes as a result of initial erosion, but is "assymmetrical in both plan and profile." After the depression is deepened and widened, it is then called a "doline"; its slopes are regular and its outline is symmetrical—it is circular if the fissure is short, and oval if the opening is long. A "basin" is a filled doline; if the bottom outlet has become plugged with clay and other debris, swamps, temporary ponds, and even permanent lakes form (5: 713).

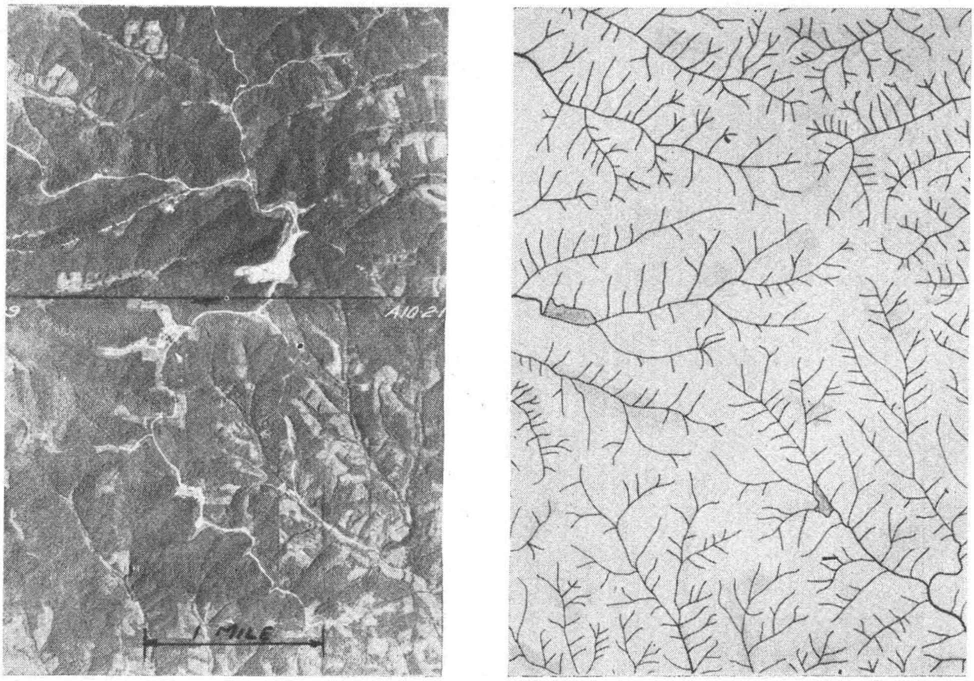

FIG. 8. Drainage pattern of sandstone-shale (Mississippian) (20, 21). Left—Airphoto of Weed Patch Hill area in Brown County, Indiana. Right—Drainage map of same area. Artificial lakes are indicated by shaded spots.

The clays that develop from the weathering limestone have a nuciform, or "nutty," structure. They are well-drained "in situ," but they are very impervious and plastic when reworked by highway construction machinery.

Clay Shale. A most minutely (very fine) dendritic drainage pattern, shown in Figure 10, is that produced by eroding clay shale. Because the shale is completely impervious, the runoff is almost equal to the total rainfall. Surface drainage is developed fully. Streams flowing in shale usually do not reflect lineal

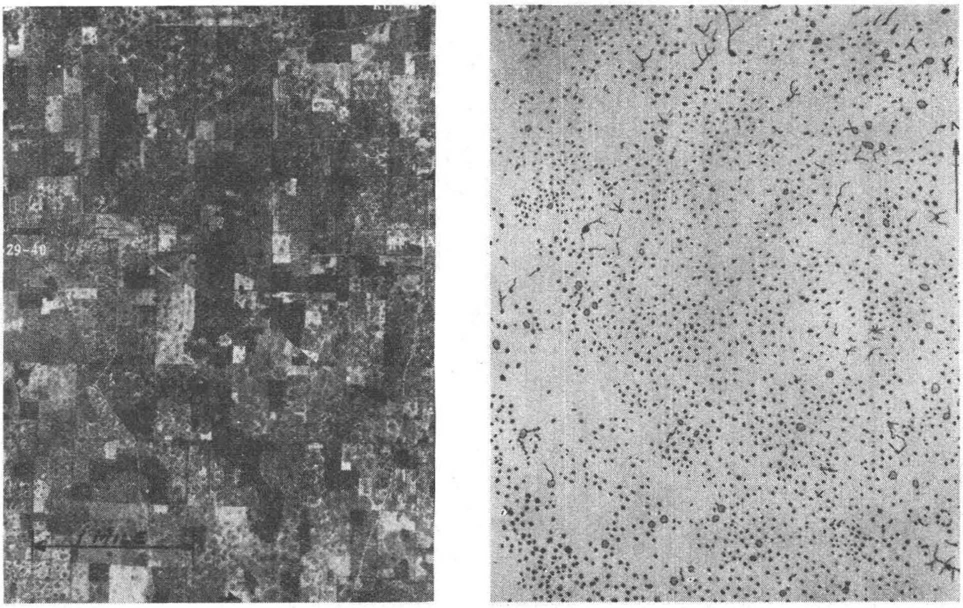

FIG. 9. Drainage pattern of young Karst topography (Mississippian limestone) (20). Left—Airphoto of sinkhole area in Washington County, Indiana. Right—Drainage map of same area. Dots indicate sinkholes, some of which have small dendritic drainage systems.

control. An intricate stream system is formed which resembles the venation of a broad leaf of a deciduous tree. This pattern approaches the true dendritic pattern illustrated in Figure 2. Where the general level of the upland is nearly flat—1 to 2 miles from the river—the gullies have "rounded" slopes; this is especially noticeable in the lower center of the airphoto in Figure 10. This is a characteristic of clay shale topography. The "smooth" areas outlined in white in the airphoto—left center and lower left—are remnants of the Great Plains mantle which is granular in texture; they do not contribute to the drainage pattern. Gravel is a material resistant to erosion; therefore, it "holds up" the hills. Near the river the drainage pattern is influenced by slope control of the streams. Some of the smaller tributaries are straight and the angles of their junctions with the larger tributaries are very acute. Another cause for this slight change in the pattern is the presence of thin layers of weak sandstones. These can be detected in the airphoto by the "bands" around some of the knolls, and by the presence

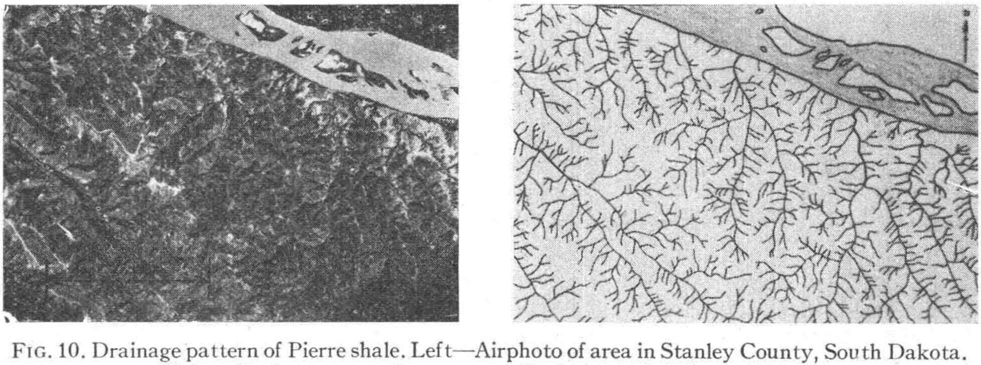

FIG. 10. Drainage pattern of Pierre shale. Left—Airphoto of area in Stanley County, South Dakota. Right—Drainage map of same area. Shaded area is Missouri River.

on these bands of vegetation—shrubs and bushes. Steep slopes cause V-shaped gullies; therefore, the cyma-curve cross sections of the upland gullies are extremely modified or lacking in the gullies near the river. The main tributaries have almost reached base level, in the vicinity of the river; here their courses have many full-curved meanderings. Parallelism may even be detected in the larger tributaries.

Clay shales weather to fine-grained, plastic, poorly-drained clay soils. Flexible pavements suffer considerable distress when placed directly upon plastic clay subgrades.

Tilted Sandstone and Shale. Figure 11 is the drainage pattern of an area of folded and tilted sandstones and shales. The drainage pattern, where the shales predominate, is dendritic. (See the upper left half of the airphoto in Figure 11.) Resistant strata—probably sandstones—in the shale area give lineal control to some of the streams in that area. Streams are absent along the crest of the sandstone ridge. (See lower right half of the drainage map in Figure 11). Small "parallel" streams are spaced at "regular" intervals along the steep slopes of the sandstone ridge and form a subparallel drainage pattern on the left side of the ridge. The stream collecting the run-off waters from both the shale and the sandstone areas is flowing in shale. This stream is a part of a regional trellis drainage pattern which can not be shown by a single airphoto. The weakly developed subparallel drainage pattern on the right of the sandstone ridge has formed partly in shale since the river is flowing in shale, also.

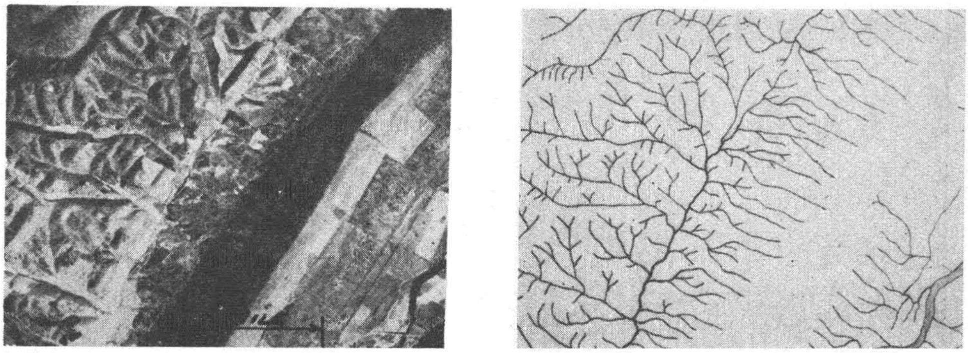

FIG. 11. Drainage pattern of tilted sandstone and sandstone-shale. Left—Airphoto of area in Hampshire County, West Virginia. Right—Drainage map of same area. Shaded area is a river.

In regions of sedimentary rocks, slope control plays an important part in the development of the drainage pattern—the more resistant the material, the steeper the slopes. Consequently, the lines of the pattern are more nearly straight on steep slopes, for fast-moving water tends to flow in straight lines. Sandstone is more resistant to erosion than shale. The drainage pattern in shale has a "roundness" contrasted to the "angularity" of the stream patterns in sandstone areas.

Granite Dome. Figure 12 illustrates the radial and annular drainage patterns of a granite dome. The streams of the plain have been forced to go around the bulging mass of granite, some of them making right-angle turns in the process. Radial streams course down the dome. These streams unite at lower elevations with sharp entrant angles. Near the base of the dome, the runoff waters are collected in annular streams inside the rim of upturned sedimentary rocks.

Illinoian Glacial Drift. Figure 13 is a typical drainage pattern of the Illinoian

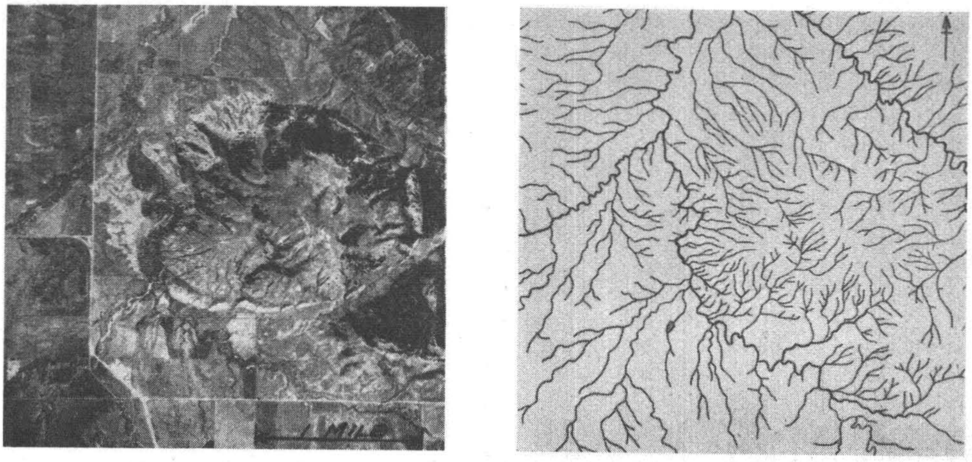

FIG. 12. Drainage pattern of granite dome. Left—Airphoto of area in Lawrence County, South Dakota. Highways are straight white lines. Right—Drainage map of same area. Shaded area is an artificial pond.

drift region in southeastern Indiana. The drainage pattern is "subdendritic," a modification of the dendritic type with long, nearly parallel tributary systems. The pattern has a pronounced "lacy" appearance. Illinoian drift is the oldest surface drift in Indiana. Its topographical features are subdued. It is free from swells and ridges. It shows the effects of age and weathering, for the soil has a developed profile of approximately ten feet (3: 187). The "A" horizon consists of about two feet of silt and the "B" horizon usually consists of eight to ten feet of "expansive silty-clay" (3: 187). Much of the surface is so nearly level that it is imperfectly drained. The subsoil is impervious and is very poorly drained in-

FIG. 13. Drainage pattern of Illinoian glacial drift (20) (21). Left—Airphoto of area in Ripley County, Indiana. Right—Drainage map of same area.

ternally. Surface drainage furnishes a particularly significant airphoto identification element which is the "white-fringed" gully. The broad flat bottom of this type of gully is formed by erosion removing the top soil (silt) from the impervious clay subsoil. Long shallow tributaries indicate low velocity of the runoff water. Where the gradient becomes steep and the runoff water cuts into the clay, the gullies become V-shaped. Secondary tributaries show minor slope control. Wide expanses show no developed drainage pattern; here the terrain is nearly flat and headward erosion has not cut into the silty "A" horizon.

Wisconsin Glacial Drift. Figure 14 is representative of a typical drainage pattern of the Tipton Till Plain which is an irregular, undulating sheet of till. Although the main streams in the illustration are "roughly parallel, with few and only short tributaries," the general drainage pattern of the till plain is broadly dendritic—very coarse textured (15: 390). It has the appearance of the forked ends of chain lightning. (Also see Figure 1.) The topography of the Tipton Till Plain is featureless—differences in elevation being from 2 to 20 feet. It has been referred to as a region of "little relief and meager modification by dissecting streams" (24: 17). The drift is recent in age—it is unconsolidated and, therefore, pervious. This reduces the amount of small gullies, for part of the runoff becomes subsurface drainage. Besides the drainage pattern, an outstanding identifying airphoto element is the "marbleized" or "black-and-white mottled" pattern often referred to as the Brookston-Crosby pattern (23: 39). (See Figure 15.) The drainage of the till plain is connected through the darker, lower-lying depressions. These dark areas indicate the presence of moisture, silty clays, clay, and organic matter in the soil (14: 27). Gentle gradients of these depressions prevent any but sheet erosion over extensive areas. The divides are flat and the streams sluggish. Wherever the gradient becomes steep enough for gullies to

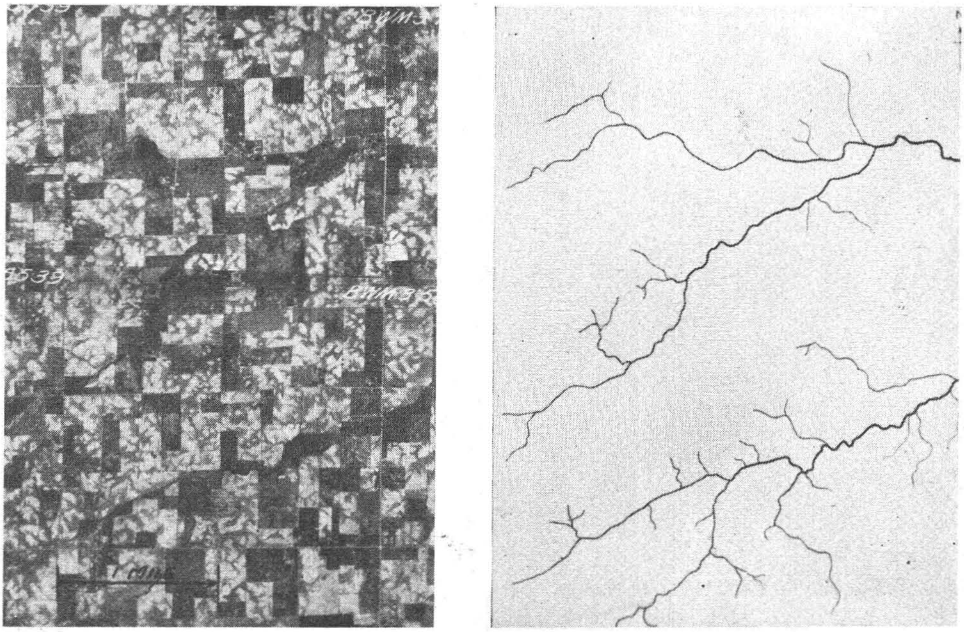

FIG. 14. Drainage pattern of Wisconsin glacial drift (20) (21) Tipton County, Indiana. Left—Airphoto of Tipton Till Plane. White lines are roads which follow land section boundaries. Right—Drainage map of same area.

form, these gullies are like "grooves" in the plain, and they empty into creeks which flow in shallow, wide "valleys." The drainage of a glaciated region has been described as "glacially disturbed," for drift deposits have obscured preglacial stream systems and new drainage systems have developed (26).

Granular Terrace. Figure 16 is the weakly developed dendritic drainage pattern characteristic of granular terraces found in the Wabash River valley in western Indiana. The almost total absence of surface drainage in the right half of the map in the illustration is a significant feature of the pattern. Internal drainage through infiltration basins provides an escape for nearly all runoff water. A few drainage ways follow depressions which are abandoned channels of the post-glacial braided stream that deposited the gravel. Occasional short, steep, V-shaped gullies are found along the terrace face next to the river. Gravel because of its porosity and permeability to water resists erosion. A most striking feature is the inability of the upland streams to cut across the terrace. The stream collecting the drainage of these upland streams flows in a slack water trough to a point where it can enter the river. The complete lack of relationship of the upland subdendritic drainage pattern of medium density to that of the terrace gives the entire area an "irregular" drainage pattern (26). (See sketch of anomalous drainage pattern in Figure 5.)

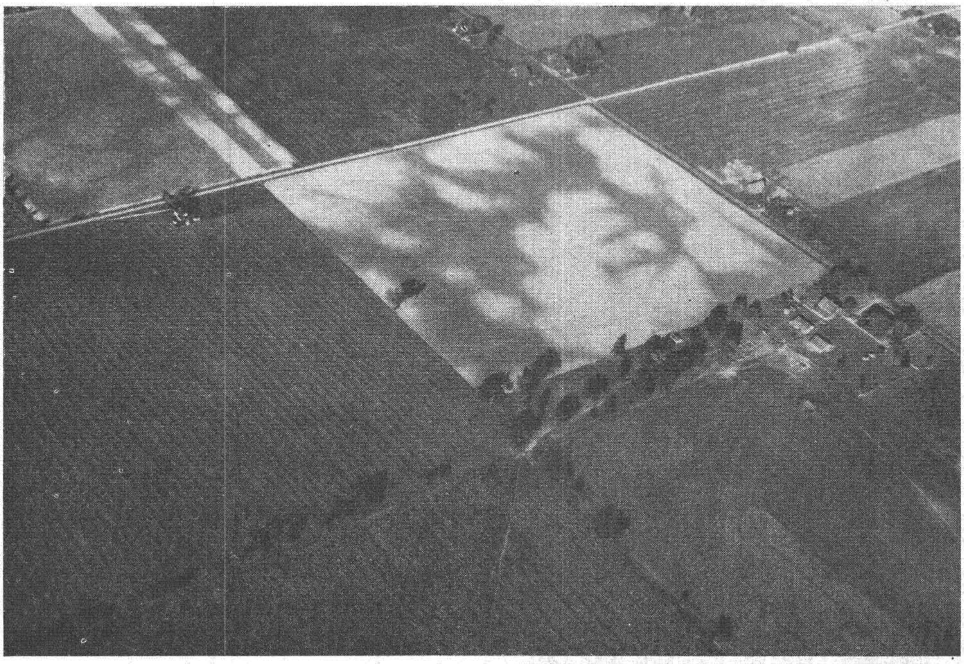

FIG. 15. Low altitude oblique airphoto of a Wisconsin glacial drift area, Tipton County, Indiana. The Brookston-Crosby soil pattern is easily identified even though the field has a cover crop. Faint near-white lines in some of the dark areas show a tendency toward gully development.

Terraces such as the one illustrated are composed of granular materials transported by glacial melt waters draining Wisconsin drift areas and are important sources of gravel and sand throughout Indiana. Excellent highway performance generally occurs on a similar granular terrace.

Glacial Lakebed. Figure 17 illustrates the anomalous drainage pattern of an area in a glacial lakebed region. The gullies in the walls of the valley of the river

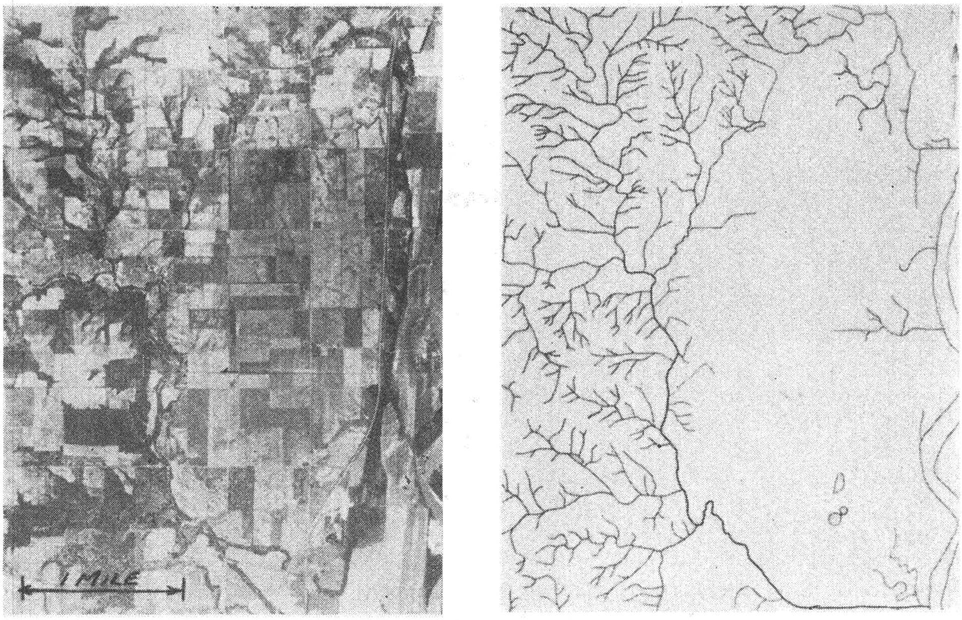

FIG. 16. Drainage pattern of granular terrace (20). Left—Airphoto of area in Vermillion County, Indiana. Right—Drainage map of same area. Shaded spots are water-filled gravel pits.

are typical lakebed gullies. The pattern of the shorter gullies is subdendritic and that of the longer stream systems is pinnate. The pinnate drainage pattern is found in eroding silty soils. The upland areas—the even floor of the lakebed itself—contain small basins. These give the overall pattern its irregularity. The lakebed sediments are "comprised largely of sand, silt, and clay" (1:59).

These lakebed sediments cover the uneven glacial drift of the inner border of a granular moraine which is a short distance southwest of the area illustrated. Lakebed silty clays are stratified and impervious to water. They are generally plastic and poorly drained internally.

Kettle Kame Moraine. Figure 18 illustrates the "kettle hole" drainage pattern of a granular moraine. Granular knolls of various sizes and shapes are scattered over the area without orderly arrangement; these consist of unconsolidated gravels, sands, and boulders "with minor amounts of finer sediments" (1:58).

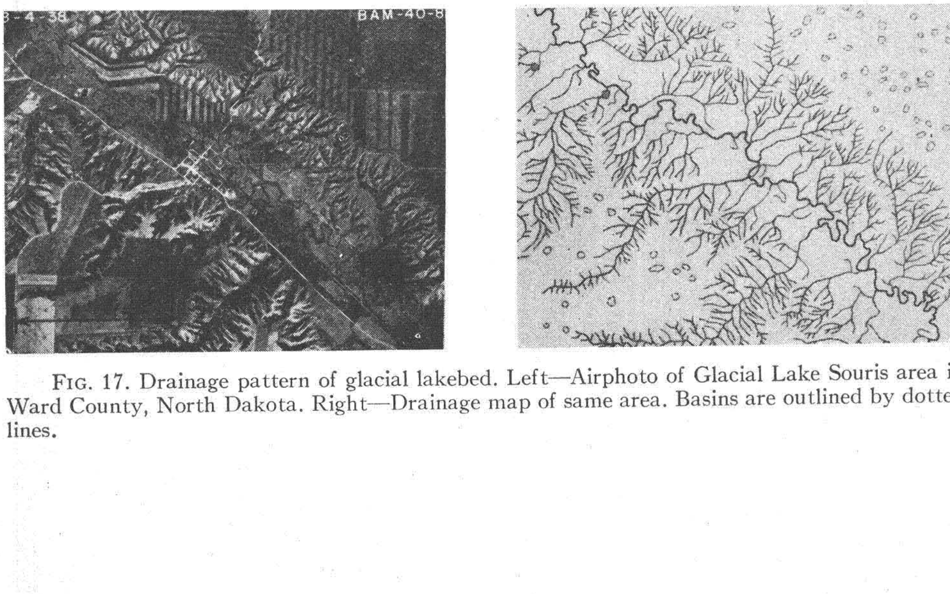

FIG. 17. Drainage pattern of glacial lakebed. Left—Airphoto of Glacial Lake Souris area in Ward County, North Dakota. Right—Drainage map of same area. Basins are outlined by dotted lines.

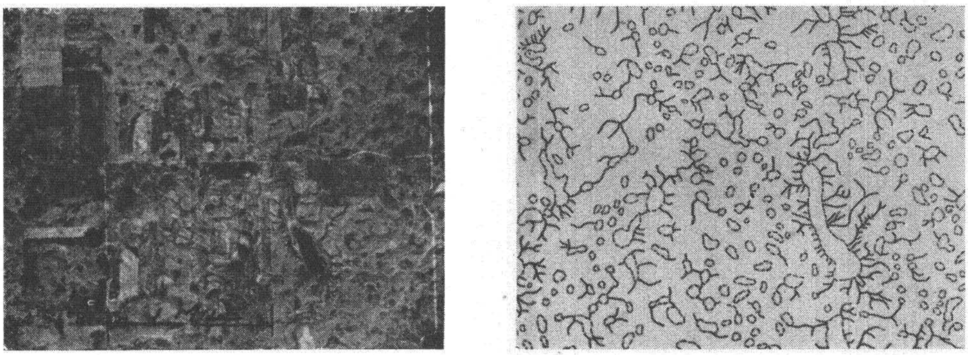

FIG. 18. Drainage pattern of kettle-kame moraine. Left—Airphoto of a portion of the Altamont Moraine in Ward County, North Dakota. Right—Drainage map of same area. Infiltration basins are bounded by dotted lines.

Numerous depressions called kettle holes are found among the knolls throughout the area. It is difficult to say whether the knolls or the depressions predominate. There is no developed surface drainage in the area. Short, V-shaped gullies having steep gradients can be seen on some of the knolls; this is an identifying characteristic of a granular deposit. Drainage from the kettle holes is through the underlying gravels. Many of the depressions have very small dendritic tributary systems. Some of the depressions are partly filled with organic accumulations while others have more or less ephemeral lakes. The smaller depressions are nearly circular while the larger ones are elongated. The depressions are closed basins from a few yards to a mile or more in extent. The floors of some of the larger basins are level and are cultivated since the soils hold moisture for a period of time.

Valley Fill Material. Figure 19 illustrates the parallel drainage pattern of valley fill materials. This area is the gently sloping apron of erosional debris accumulated from the nearby mountains. The texture of the material is predominately coarse, although dark bands in the airphoto portion of Figure 19 indicate beach lines where finer sediments (clays) have collected. These "bands" support vegetation for they retain moisture. Straight streams having box-like cross sections are formed by flash floods.

Great Plains Mantle (Ogallala). Figure 20 illustrates the lacunate drainage pattern of an Ogallala area in the southern Great Plains region. The relief of the

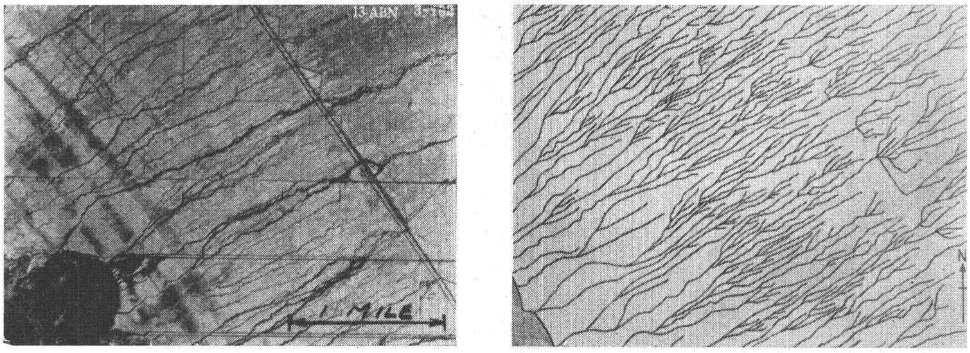

FIG. 19. Drainage pattern of valley fill material. Left—Airphoto of area in Imperial County, California. Dark bands in lower left corner of airphoto are beach lines—have fine-grained sediments. Right—Drainage map of same area. Shaded area is water filled basin (lake).

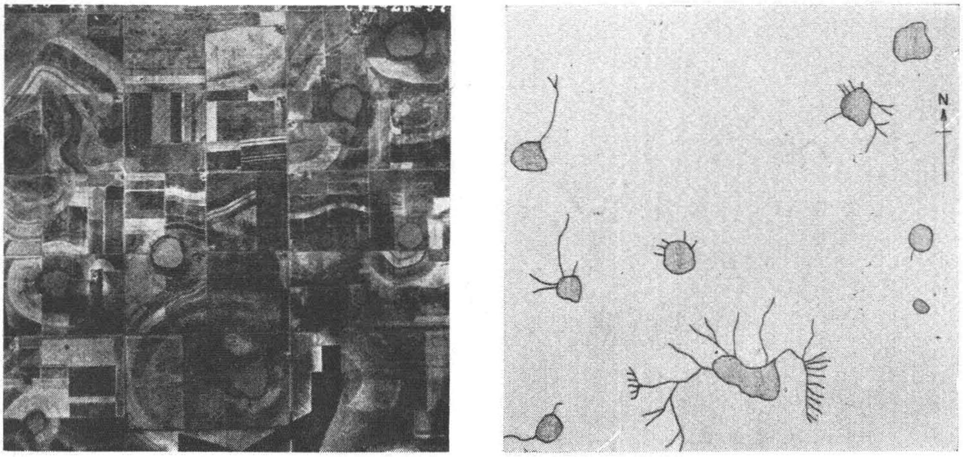

FIG. 20. Drainage pattern of Great Plane Mantle (Ogallala). Left—Airphoto of area in Lamb County, Texas. Right—Drainage map of same area. Water-filled basins are shaded.

area is gently undulating. There are no streams other than the small dendritic systems of individual basins. Many of the depressions contain water for days and even weeks after a period of wet weather. The term "poly basin" might aptly be applied to this area because of the depressions. The subsoil is impervious; it is probably a "marl." Erosion is controlled by contour farming. (See the airphoto portion of Figure 20.) In the inter-depression ridges the soils are silty and in places contain a large percentage of sand. The clay content of the soils increases toward the centers of the depressions. Locally these depressions are called "buffalo wallows."

Loess. The drainage pattern in deep loess deposits, illustrated by Figure 21, is a modified dendritic pattern referred to as pinnate because of the feather or frond-like appearance of individual tributary systems. The lateral gullies are short and spaced at "regular" intervals along both sides of the principal tributaries which they enter at nearly right angles. The gully cross sections are hyoid shaped—like a "U"; and their gradients are compound—very steep at the headward end. Figure 21 is a striking example of eroding wind-blown silt found in parts of the Great Plains Region. The density of the pattern indicates large scale erosion in this area. Great Plains loess areas are generally nearly level tracts with very long, parallel, low, and fairly broad ridges which are not easily detected on single airphotos. Loess has a peculiar structure in that internal drain-

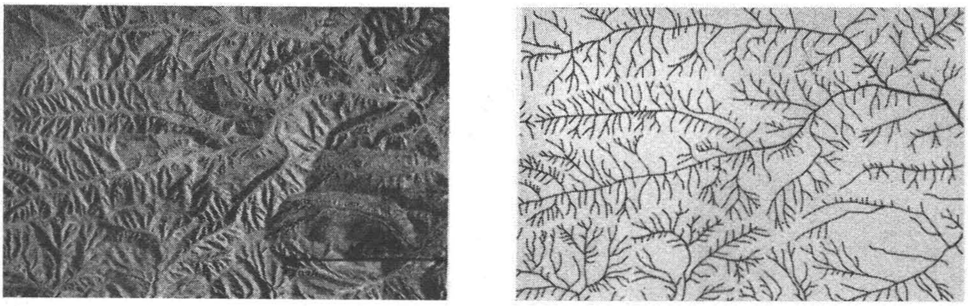

FIG. 21. Drainage pattern of loess. Left—Airphoto of area in Lincoln County, Nebraska. Right—Drainage map of same area.

age is vertical. Where slopes are steep enough for erosion to start, and where there is sufficient rainfall, the region soon becomes badly dissected. The ridges and valleys of deep loess deposits fix the direction of the trunk streams (16:98). The principal tributaries are long and often nearly parallel to each other.

The ridges of river valley loess are more pronounced than those in the Great Plains.

THE APPLICATION OF DRAINAGE PATTERNS IN THE IDENTIFICATION OF REGIONAL SOILS AND BEDROCKS

Drainage patterns can be used as aids in the identification of soils and bedrocks of an area. This statement is verified by the compilation from airphotos of a detailed surface drainage map of Switzerland County, Indiana (19). Three drainage patterns may be recognized readily in the drainage map of this county. (See Figure 22).

It is easily seen that the dendritic drainage pattern at "A" is repeated in a band 5 to 10 miles wide along the right bank of the Ohio River. It is possible, then, to state with reasonable accuracy that bedrock materials (Ordovician limestones and shales) similar to those found at "A" will be found throughout this band.

It is observed, also, that the subdendritic drainage pattern at "B" is repeated in an area, centering about "B," of 35 to 40 square miles in extent. It is possible to state, with assurance, that one material (Illinoian glacial drift) is the surface soil throughout this entire area.

The weakly developed dendritic drainage pattern at "C" identifies a granular terrace. Similar patterns are detected about 5 miles to the right of "C," and about 5 miles to the left of "C." Knowing that a granular terrace exists at "C," it is within reason to predict that granular terraces are to be found in the other two areas.

SUMMARY AND CONCLUSIONS

The recognition, on aerial photographs, of the patterns of stream systems of an area is essentially the application of keen observation on the part of the airphoto interpreter. The correlation of the salient characteristics of drainage patterns with known types of land surface materials is dependent upon his ability to understand the significances of the form and texture of the developed drainage patterns. This understanding makes possible the drawing of tentative conclusions regarding the identity of regional soils and bedrocks.

Drainage patterns are formed of straight and curved lines. Where there is no structural control stream channels are curved. In regions of residual materials the drainage network depends upon the distribution of bedrock, and its surfaces of weakness. If the plan of a drainage system conforms with the structure of the bedrock, the same repeating pattern of uniformly-spaced fractures in that rock may be expected to appear in the lines of the drainage pattern. If the bedrock fractures are straight the streams will be straight between angular bends. Streams with steep gradients tend to be straight also.

Since most streams have their beginnings in soils or thinly mantled bedrocks, the patterns of streams of lower order (first, second, third, etc.) furnish clues by which those soils or bedrocks can be identified. It is the streams of higher order that show the influence of the structural control of the bedrocks.

Drainage patterns are coarse-textured in regions where the bedrock or soil mantle is resistant to erosion; e.g., sandstones, granular deposits, unconsolidated glacial drift. Fine-textured drainage patterns are associated with materials

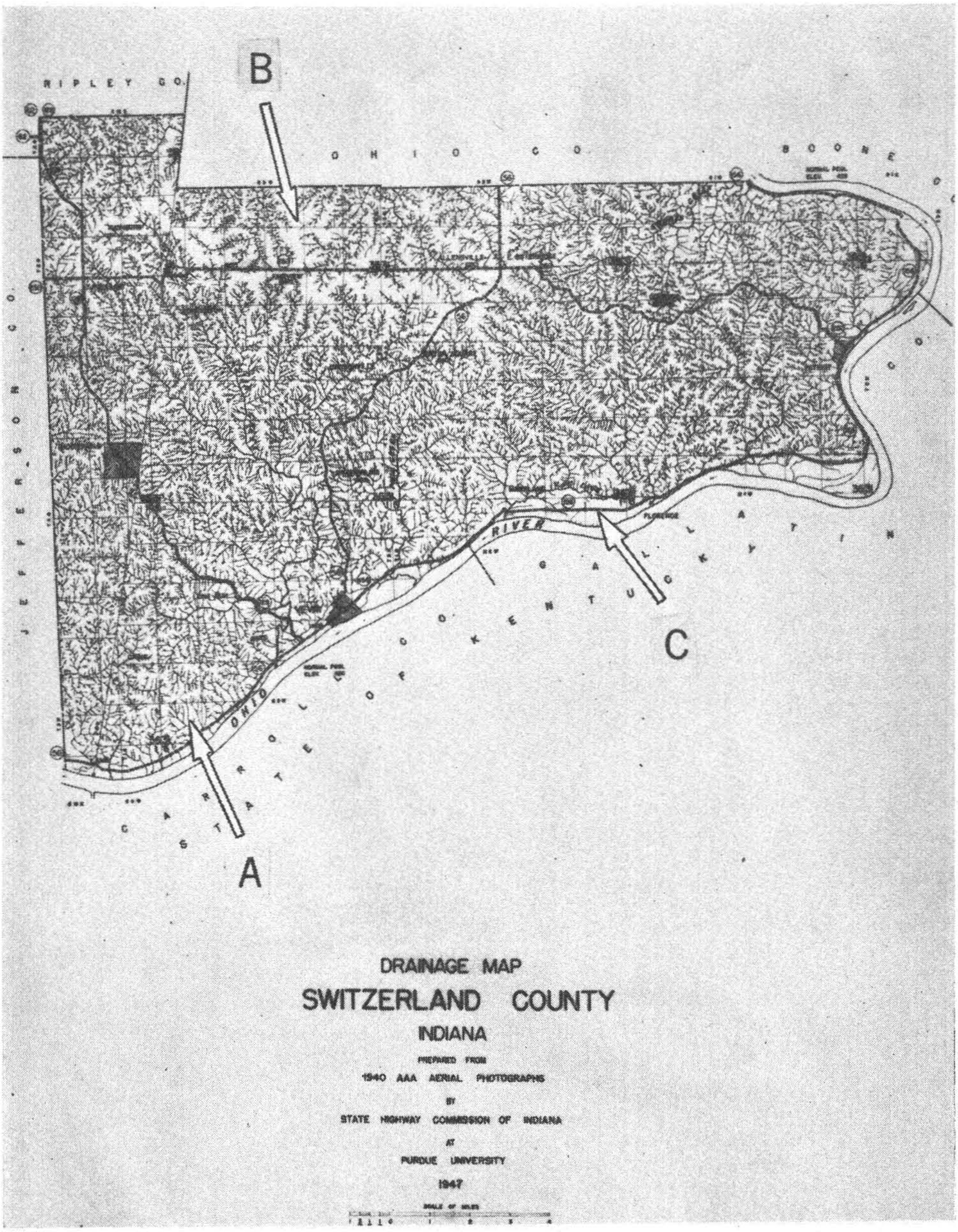

FIG. 22. The drainage map of Switzerland County, Indiana, exhibits the following drainage patterns: "A"—Dendritic drainage pattern of Ordovician limestone-shale regions. (See Figures 2 & 7.) "B"—Subdendritic drainage pattern of Illinoian glacial drift regions. (See Figures 3 & 13.) "C"—Weakly developed dendritic drainage pattern of river valley granular terraces. (See Figure 16.) (This map was compiled from aerial photographs in the laboratories of the Joint Highway Research Project at Purdue University, Lafayette, Indiana. Scale: Typical square of grid system equals one square mile.)

non-resistant to erosion; e.g., clay shales, silts, sand clays. In other words, the drainage pattern reflects the porosity of the soil or bedrock in which it is found. Likewise, the relative depth of the soil mantle and the dip of the bedrock may be inferred.

Drainage patterns are classified for convenience of describing and comparing them. However, regardless of the name assigned to a regional drainage pattern, once it is established for a particular type of soil or bedrock, similar drainage patterns recognized within the region indicate the presence of materials similar to those associated with the established pattern.

By studying first the particularly conspicuous features of the overall drainage lines of a region, it is possible to make deductions concerning bedrock structural control of the streams of the area. Moving, then, from the general to the specific, the details of the patterns formed by the headwater tributaries are the means by which repetitive drainage patterns within the region are classified. Accidental localized variations in those recurring patterns are disregarded. Recurring patterns are similar but rarely identical.

On the basis of observations made during the analyses of recurring drainage patterns in various physiographic regions throughout the United States, the following conclusions have been reached:

1. Drainage patterns may be classified according to the basic types or modifications of them.
2. There is a high degree of correlation between the drainage patterns and the soils and bedrocks of regions.
3. Drainage patterns recognized in the aerial photographs of a region can be relied upon to aid in the airphoto identification of the soils and bedrocks of that region.

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All airphotos used in connection with the preparation of this report automatically carry the following credit line: "Photographed for Field Service Branch—PMA—U.S.D.A." Other photographs taken by Joint Highway Research Project staff photographers.

SCALES OF OBLIQUE PHOTOGRAPHS

Benjamin B. Lane, Jr., Aeronautical Chart Service, Washington, D. C.

IT IS not generally realized that the scale at a point on an oblique photograph is not the same in all directions; that is, that the x-scale (scale of lines perpendicular to the principal plane), and the y-scale (scale of lines parallel to the principal plane), and the z-scale (scale of vertical lines) are not the same. This paper will show the derivations of the formulae for these scales in the hope that they will lead to a clearer understanding of the nature of oblique photographs. It is also believed that the formulae may be useful to photograph interpreters in estimating the sizes of buildings and similar small objects from simple measurements on the oblique photograph.

X-SCALE

Figure 1 shows a view of the principal plane of an oblique photograph mn. L is the exposure station, n the photograph nadir point, o the principal point, i the isocenter, Lm the trace of the horizon plane, $Lo=f$ is the principal distance, θ is the depression angle of the camera axis. Because the X-scale is measured along a photograph parallel, it is constant throughout the length of the parallel. If a