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**AIRPHOTO STUDY
AND
MAPPING OF SOUTHCENTRAL INDIANA
SANDSTONE-SHALE-LIMESTONE
SOIL MATERIALS**

**Joint
Highway
Research
Project**

PURDUE UNIVERSITY
LAFAYETTE INDIANA

by

Leonidas
Constantinos
Stylianopoulos

AIRPHOTO STUDY AND MAPPING OF SOUTHCENTRAL INDIANA
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TO: K. B. Woods, Director
Joint Highway Research Project

FROM: H. L. Michael, Assistant Director

December 13, 1955
File: 6-6-24
C-36-51F

Attached is a report entitled "Airphoto Study and Mapping of Southcentral Indiana Sandstone-Shale-Limestone-Soil Materials." This report has been prepared by Mr. L. C. Stylianopoulos under the direction of Professor R. E. Frost. Mr. Stylianopoulos also used this material as his thesis in partial fulfillment for the Master of Science degree in Civil Engineering.

This study is another in the soil mapping series of Indiana. It, together with the others that have been completed, will be utilized in the preparation of county soil maps.

Respectfully submitted,

H. L. Michael

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Purdue University
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The aerial photographs that are used in this report carry the credit line: "Photographed for Field Service Branch - PMA - U.S.D.A."

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ABSTRACT

This study is a part of the statewide program for mapping the engineering soils of the State of Indiana from aerial photographs. The project consists of the following component parts:

- (a) The development of the pattern elements of the airphoto patterns found in the area under study.
- (b) The analysis of the existing airphoto patterns.
- (c) The location of the engineering soil borders of the area, and
- (d) Deduction as to the engineering significance of the soil areas in existence.

The study of the airphoto pattern elements and their incorporation into airphoto patterns was made through the correlation of airphoto studies with pertinent literature on the area under investigation and field observations of the ground conditions of the area.

The location of the soil borders was established through the airphoto study of the various soils in conjunction with the findings of previous studies on locations composed of similar parent materials.

The area under investigation was found to be an exceedingly rugged upland composed of flatlying sandstones, limestones, and shales. The soils present in this area are almost exclusively sandstone soils, except of insignificant amounts of limestone and shale soil mantle that occur in spots.

The problems associated with this area are those of high relief, as far as surface morphology is concerned, and those of silty clay

sandstone soils, from the soils' standpoint. Although limestones and shales do not constitute important soil parent materials in this area, their presence introduces special problems that have to be seriously considered by the highway engineer, when such materials are encountered.

The scale of the aerial photographs used in this thesis is 1/20,000, which is adequate for the purpose of this study. A larger scale, however, would be desirable for the study of minute features such as gully characteristics.

INTRODUCTION

The use of aerial photographs in the analysis of soil conditions for engineering purposes has been conceived and developed over the past decade by staff members of Purdue University. This approach in the matter of soil exploration is an original application of the laws of stereoscopic photography to what is already known about the origin and the development of soils from the sciences of geology, physiography, and pedology. Supplementary information derived from other allied fields such as agronomy, and soil mechanics has furnished valuable data concerning predictions about the physical properties of soils.

The airphoto interpretation of soils is realized through the following basic principles:

- (a) Like objects under similar conditions will produce similar photographic effects.
- (b) These effects fall into a pattern or patterns and those patterns are repetitive.
- (c) Like patterns imply like materials, and unlike patterns imply unlike materials.

It may be concluded, from the above general statements, that the same parent materials developed under like environmental conditions will produce similar photographic effects. This is true regardless of the location of these parent materials. Thus, the windblown silts of the Palouse section in the United States and the windblown silts of the Ukrainian Plains will produce similar airphoto patterns, which can be considered typical of the parent materials.

For purposes of analysis, the airphoto pattern is divided into smaller identifying features, that have been called the elements of the airphoto pattern. The basic elements used in airphoto soils' studies as the most important identifying features of an airphoto pattern are landform, drainage, erosional features, vegetation, and special features. The elements of landform, drainage, and erosional features were developed through long and continuous environmental influences and do not change appreciably from the one season to the other. The elements of vegetation, phototones, and some special features may very well be temporary and have seasonal changes largely depending on temperature and precipitation. For a more concise analysis of the method of airphoto interpretation of soils for engineering purposes, the reader is referred to item 5 of the bibliography.

The successful use of the method of airphoto interpretation depends to a large degree on the understanding of its limitations. Such limitations are classified as photographic, human, natural, method, time, and supplementary information.

An interpreter should never seek to arrive at conclusions beyond the limitations established by the type photography available, one's human capabilities, the natural conditions, the time available and the information available about the area to be studied (16)¹.

The purpose of this study is to develop the airphoto pattern features and variations of airphoto pattern features of materials derived from sandstones, limestones and shales in the southcentral part of the State of Indiana. This study is also concerned with the

¹ The numbers in parenthesis refer to items in the bibliography.

techniques used for the identification and interpretation of the above materials, as well as correlations that may exist between airphoto patterns, ground conditions, laboratory data, and engineering problems. As a result of such a study the borders of the engineering soils of the area will be mapped and their lines of separation from adjoining materials will be established.

The scope of this thesis is two fold: Engineering and airphoto interpretation. The engineering aim of this report is the contribution of the state-wide engineering soils mapping of the State of Indiana. As far as airphoto interpretation is concerned, this study aims to develop the airphoto soils patterns of the soil materials within the area under investigation.

The parent materials adjacent to the area under investigation have already been mapped as sandstone-shale combinations to the west (24) and as massive limestones to the east (33). The northern border of the area under study is formed by Illinoian Drift soils that have not been mapped.

The area covered in this thesis constitutes a strip of land, aligned along a northwesterly to southeasterly direction. The northernmost point of the area under study is located in western Greene County in Central Indiana and the southernmost point is found along the Ohio River in Perry County. The area covers major portions of Perry, Crawford, Martin, Orange, Greene, and Dubois counties and limited portions in Harrison and Lawrence counties.

The results of this study are presented in two principal units: First, the development of the airphoto pattern elements of the various airphoto patterns present. Second, the analysis of the engineering soil conditions of the area under investigation.

The development of the airphoto pattern elements and their variations are incorporated on a pattern basis into individual chapter units, which include itemized analyses of the corresponding element features. The analysis of the engineering soils of the area is a survey of the results of airphoto and field studies including soil conditions, delineation of soil boundaries, and engineering problems associated with the soil conditions of the area. The results of the soil study are reported in a text description of soils and their engineering problems, graphical and tabular presentation of the engineering properties of the soils, and engineering soils maps of their horizontal extent.

This study is sponsored by the State Highway Department of Indiana in co-operation with the School of Civil Engineering at Purdue University. The project has been authorized by the Advisory Board (March 10, 1953) of the Joint Highway Research Project of Purdue University and is Project C-36-51F.

CHAPTER 1

THE AREA UNDER INVESTIGATION

Geography

The area under investigation is located in the South central portion of the State of Indiana and occupies approximately 1350 square miles of rugged and precipitous terrain. It constitutes a strip of land extending from the northern banks of the Ohio River to approximately one hundred miles north (see Figure 1). That strip of land includes Crawford County, major portions of Perry, Crawford, Orange, Dubois, Martin, and Greene Counties, and small areas of Harrison and Lawrence Counties. Its eastern and western borders are very irregular and assume a general northwesterly to southeasterly direction. Its southern border is formed by the Ohio River and its northern border is in the center of Greene County, a relatively short connecting line between the border, east and west.

The area under study is the most thinly populated in the state. Its centers of population include a few larger cities, with population² between 1000-2500, and several small villages, the population of which seldom exceeds 200. The most developed cities in the area consist of a centrally located business section surrounded by residential and, in a few cases, industrial and recreational developments. Such cities are Shoals (pop. 1039) and Loogootee (pop. 2424) in Martin County, Cannelton (pop. 2027) and Tell City (pop. 5735) in Perry County, and English (pop. 839) in Crawford County. The small

² 1950 Census Reports.

FIG. 1 AREA UNDER INVESTIGATION.

villages of the area are more numerous and mostly undeveloped. Their primary function is the trade in commodities for the supply of the various farm areas. They consist of a relatively small commercial center and a limited number of residential units. Besides the urban and rural centers of population, there is also a large number of isolated rural dwellings located mostly along state and county routes.

The transportation development of the area under investigation includes three major types: Highway, Railroads, and Waterways.

The highway system of the area under study, consists of a few major U.S. and State routes and numerous state and county roads. The major highways of the area are mostly through highways connecting points of industrial and commercial importance located in areas adjacent to the section under investigation. Such highways are State Route 62 (U.S. 460), between New Albany and Evansville, U.S. Route 150, between Vincennes and New Albany, U.S. Route 50, between Vincennes and Bedford, and State Route 37, connecting Tell City with points to the north. Most of these major routes have relatively recent bituminous surfaces with limited portions surfaced with concrete. The minor routes of the area service the local centers of population and consist of an intricate network of gravel and oil treated surfaces.

Most of the railroad lines traversing the area under study are portions of main railway routes that connect cities outside the limits of area. The cities of Huntingburg to the west and Bedford to the east are important railway junctions outside the borders of

the area under investigation. Two railroad lines of the Southern Railroad System and one of the Baltimore and Ohio Railroad System traverse the area along a general east-west direction.

The only presently active waterway route in the south-central portion of the State of Indiana is the course of the Ohio River. The route is serviced by commercial barges carrying bulky materials such as coal, stone, and timber from the area in question and adjacent areas to delivery centers along the Ohio. The most important river cities in the areas under investigation are Cannelton and Tell City along the southwestern border of Perry County.

The economic life of the area under study includes agricultural production, the quarrying of limestone, and the operation of state and private recreational areas. The agricultural activity in this area is of two general types. The cultivation of grain, especially corn, located in the low areas such as river valleys and flood plains (54, p. 14) and general agriculture. A major portion of the latter is devoted to animal grazing. The limestone is quarried primarily in the eastern portion of the area under study. The limestone deposits of that area, despite their massive nature, include many fissures and minor cracks that are not suitable for the production of building stone. As a result, most of the reclaimed limestone is subsequently crushed and used for road material or as riprap for highway fill or retaining structures. The area under study has an inherent natural beauty and has been used extensively by various state and private organizations for the development of parks and

recreational areas. Locations such as the Bluffs of Beaver Bend, the McBrides Bluffs, the Jug Rock (see frontispiece), the Hindostan Falls, the Martin County State Forest, and the Ferdinand State Forest and Fish Hatchery are well known areas of scenic value visited by state and transient tourists.

The area under investigation is an old "hardwood" area. The hardwood reclamation has been recently very limited for reasons of erosion control. The old factories, however, are presently operating with imported timber on a relatively limited basis. Well known is the industrial development in English, Crawford County, engaged in the manufacturing of cabinets and parts for radio and television sets. In the western portion of the area there are areas where oil reclamation is practical. The operations are of limited nature.

The area under study abuts on lands of high economic importance due to their valuable subsurface deposits. The neighboring lands in the east are famous for their limestone deposits, that are reclaimed in the production of building stone, commercially known as Bedford limestone. Recent discoveries of gypsum deposits on the northern part of the limestone areas are anticipated to further expand the industrial life of these areas. The neighboring lands to the west possess abundant coal deposits associated with oil producing veins of considerable economic value. Both items are reclaimed for use as fuel in local industries as well as marketed to areas in northern Indiana, Ohio, Kentucky, and Illinois.

The area studied by this thesis is primarily agricultural. Despite the high relief and the steep slopes, the agricultural popula-

tion of the area has managed to develop the flatter portion of the land and produce a variety of grain products. The industrial development of this area has been limited. However, there has been a recent promotion of industrial activity, which promises an expansion of the existing industries as well as the development of new ones in the very near future.

Physiography

General: Physiography, in its accepted usage in technical terminology, is the study of landforms of the earth's surface. Fenneman (70, p. V) considered the geologic and geographic factors to be of major importance in physiographic studies. According to Fenneman, physiography "treats the landforms as effects, not as causes. But before doing so, or while doing so, it is necessary to devote..." a large portion of the study "...to the description of the landforms as they are...".

Physiography, as used in this thesis, will pertain to the study of the surface morphology of the area under investigation. It will include a study of the landforms and their association to the geological and geographical causes and effects associated with these landforms.

The interests of the engineer in physiography stem from the necessity of locating the engineering structures in the best possible position from the standpoint of functional and economic efficiency. Items such as relief, slopes and variations of slopes, sizes and shapes of landforms, are very important data, that furnish the engineer

with a general understanding of the space available, as well as the type of surface, on which a certain engineering project will have to be arranged.

In studying the development of surface forms, from a physiographic standpoint, the surface of the earth is divided into regional physiographic areas of like physiographic characteristics, called Provinces. Many provinces constitute a major physiographic division. A province is divided into sections, which are further divided on a local basis to individual physiographic units. Such a physiographic classification enables the student of surface forms to assign to these physiographic subdivisions certain typical characteristics, which one may use in more localized studies, so as to obtain a better understanding of the individual forms.

Regional Surface Morphology: According to the physiographic classification systems proposed by Fenneman (70) and Lobeck (84), the area under investigation lies in the Highland Rim Plateau of the Low Plateaus Province (labeled Figure 2). The Highland Rim Plateau is an elevated area containing portions of southern Indiana and Illinois, Western Kentucky, and Central Tennessee. This section reaches its highest point at the Cumberland Plateau Escarpment at an elevation 1200, where it assumes a westward regional slope that reaches elevations as low as 700 feet above sea level.

The Highland Rim section in Indiana covers the southern one-fifth of the state with highly dissected materials of sedimentary origin and is locally divided into the following physiographic units: The Norman

Fig. 2. The physiographic situation of Indiana (Handbook of Indiana Geology, Indiana State Department of Conservation, Division of Geology).

Upland, the Mitchel Plain, the Crawford Upland, and the Wabash Lowland (Figure 3). The area under investigation is located within the Crawford Upland, which constitutes the most dissected and most complex area of the Indiana portion of the Highland Rim section. It is an area of high relief and great diversity of topographic forms. The maximum elevation of the area is 875 feet above mean sea level south of Rock Springs in Crawford County and the lowest elevation is 337 feet above mean sea level at Tell City, Perry County. The greatest local relief is found near the southern border of Perry and Harrison Counties and exceeds 525 feet. A 200 foot relief is very common in the area under study. The overall surficial appearance of the area displays an intricate cluster of high and low areas (Figure 4) of varying shapes and forms. The high areas are surrounded by streams that are deeply entrenched, creating great bluffs, often hundreds of feet high, such as the precipitous cliffs found near the city of Shoals in Martin County.

The local topography is often blocky, with well defined slope breaks, resulting from the interbedding of hard and soft materials.

The Crawford Upland is a narrow physiographic unit extending over 2900 square miles of surface area (47, p. 98) restricted from the north by overlying deposits of Illinoian glacial origin, and from the east and the west by residual parent materials exposed at markedly lower elevations. It is a highly dissected area derived from the erosional destruction of an uplifted peneplain (48). The erosional activity within this area subsequent to the uplift progressed to the extent of erasing nearly all the surface features of the old peneplain.

Fig. 3. Physiographic Map of Indiana (Handbook of Indiana Geology, Indiana State Department of Conservation, Division of Geology).

Fig. 4. Stereopair of an upland area of high relief in Eastern Crawford County. The tops of three consecutive high areas are distinguished on a day of poor visibility.

The physiography of the Crawford Upland is not exclusively controlled by the type of parent materials present. Although the various types of parent materials are generally found in longitudinal belts, aligned from a southeasterly to a northwesterly direction, the changes of surface configuration do not observe a corresponding pattern. Largely responsible for such a divergence is the presence of the Ohio River on the southern border of the State. The Ohio River directly controls the base level of erosional activity of a major portion of the area, while exerting a corresponding but indirect influence on the drainageways to the west that are not directly connected to it. It is conceivable that the streams closer to the Ohio cut deeper into the underlying strata than the streams farther away from it. As a result, the materials exposed within this portion of the state will tend to vary with their distance from the banks of the Ohio River; generally from southeast to northwest.

Another factor to be considered in analyzing the physiography of Crawford Upland is the manner in which the parent materials were distributed upon deposition. This specifically applies to the variations in thickness of the various rock strata as well as the presence or absence of certain formations in the area, due to erosion or to the manner in which the materials were originally deposited.

The materials contributing to the surface configuration of the area under study are sedimentary rocks of varying strength and consistency. In most areas sandstones and limestones and their combinations are the predominant landform materials. Shales, whenever present, are instrumental in modifying the sandstone-limestone topography and seldom form individual landforms.

The topography associated with sandstone materials is characterized by steep slopes, relatively narrow V-shaped gullies, and an overall angularity in their erosional features. The sandstones in the western portion of the area under investigation cover the higher spots with rugged and precipitous forms. Sandstones are more resistant to erosion than limestones and shales. Thus, when they occupy hilltop areas underlain by rocks which are less resistant to erosion, they produce areas of much higher elevations than their immediate surroundings. Such an arrangement is predominant in the area under investigation. The sandstones of the Crawford Upland also occur in combinations more frequently with limestones and shales, and less frequently with limey shales and shaly limestones, both separately and in combinations. Such sandstone combinations produce step-like valley walls, rock benches, and compound gully features (Figure 5).

The contribution of limestone to the physiography of the Crawford Upland is strictly of secondary nature. Combined with sandstones and, sometimes, shales, limestone gives the topography a more rounded appearance, smoother slopes, and almost flat bottomed valleys. Topographic features of this type are dominant in the southeastern part of Crawford Upland.

In the western portions of Perry and Orange Counties the presence of shale adds to the smoothness of the topography and accentuates the effects of erosion.

The prominence of the Crawford Upland as a physiographic feature over the Mitchel Plain in the east and the Wabash Lowland in the west

FIG. 5

BLOCK DIAGRAM OF LANDFORM CONDITIONS IN THE EASTERN CRAWFORD

UPLANDS NOTE: Dimensions not to scale.

could be attributed to the abundance of erosion-resistant sandstone formations which act as a powerful skeleton in bracing the weaker strata against the destructive forces of erosion.

Local Surface Morphology: "The term landform," (96), "is applied by physiographers to each of the multitudinous features that taken together make up the surface of the earth. It includes all broad features such as plain, plateau, and mountain, and also all the minor features, such as hill, valley, slope, canyon, arroyo, and alluvial fan. Most of these features are the products of erosion, but the term includes also all forms due to sedimentation and to movements within the crust of the earth."

The area under investigation is composed of a series of landforms whose position and arrangement depends on the extent to which the forces of erosion have carved the original surface. The thickness of the component rock strata, as well as their presence or absence, is an important variable in the study of landforms of the entire Crawford Upland.

Reference is made to Figures 5 and 6 in which the landforms of the area under study are present in block diagram and profile forms, respectively. As shown in those diagrams, the landforms of the area under study form a series of high and low areas that are composed primarily of sandstones and limestones, with intercalations of shales. The shale factor was eliminated from Figure 6 for the sake of clarity. It should also be mentioned, that the landforms shown in that figure do not always occur in the same sequence as they are presented. The arrangement of landforms in a series sequence was made for purposes of comparison.

NOTE 1:

The above diagram includes the principal members of the geologic formations. To complete the picture intercalations of shale should be inserted between beds of the Kaskaskia formations. Such intercalations are not universally present in the area. The omission was made for the sake of clarity.

NOTE 2:

This diagram is not drawn to scale.

FIG. 6 LANDFORM SERIES IN EASTERN CRAWFORD UPLAND
INFORMATION DERIVED FROM HANDBOOK OF INDIANA GEOLOGY

The landforms of the area under investigation are related to each other, from the standpoint of geological materials, but differ decidedly, as far as the derivation of those materials is concerned.

The high areas designated by the letters A and B in Figure 6 produce surface forms of similar surficial characteristics. In both cases the areas are capped by sandstone materials and flanked by alternate strata of limestones and sandstones. Due to the difference in erosional resistance of these materials the side slopes of the landforms display changes in slopes, where the formation material change from a limestone to sandstone and vice versa. When the sandstone caps consist of massive sandstone, their surface morphology is angular and blocky on the surface, with sharp V-shaped gullies advancing in short spur-like fashion into the sandstone cap. Where the sandstone caps are thin, the edges of the caps are rounded-off and their outline becomes relatively regular. In the north, the sandstone-capped areas are broad and wide. The tops of those areas are from gently rolling to flat, with sharp edges that lead to steep side slopes. In the south, the sandstone-capped areas are frequently small, forming narrow snake-like ridges, or small isolated hills. As a result, the tops of those hills are sharp and their crest very irregular. The side slopes of the narrow ridges are similar to the broad sandstone-capped upland of the area under investigation, in many cases developing into step-like surfaces.

The landforms designated as C and D (Figure 6) are incidental and are very scarcely found in the area under investigation. The latter is in most cases partially or fully buried under the alluvial deposits of the area.

The landforms designated as a, b and c are valley forms found between rises in the area under investigation. They vary from deeply entrenched streamcourses to broad alluvial valleys. The side slopes of the valley forms are depending upon the types of materials composing the surface of the valley walls. Mild slope breaks are found where the beds are not very massive. Blocky step-like valley walls are indicative of massive alternations of sandstones and limestones.

Geographical Summary: The area under investigation is a prominent upland towering over the Mitchel Plain in the east and the Wabash lowland in the west. The rugged surface morphology of the area has discouraged the growth of large centers of population as well as the development of industry and communications. The lack of relatively extensive flat areas and the excessive erosion has limited agricultural pursuits to the flood plains and the flat-topped hills. However, the natural beauty of the area under investigation has encouraged the development of points of scenic value, that attract the attention of both local and transient tourist trade.

Geology

Geology classifies materials as to type and age. The classification of geologic materials as to type is based on the aggregate and mineralogical composition of the materials, as well as the geological processes that influenced their construction. The age classification of geologic materials deals with the geologic times during which the

materials were formed. Due to the wide variation in environmental conditions that transpired through the development of the earth's crust, materials of the same type, which were formed under different geological eras, may display different physical and chemical characteristics.

The use of geological information in engineering pertains to the analysis of construction sites and the development of materials of construction. In both instances the engineer must be familiar with the physical and chemical properties of geologic materials, and their behavior when subjected to certain construction conditions. Although most of the engineering structures are built on weathered rock (soils), the engineer frequently has to deal with the rock itself. This makes it necessary to consider its properties and uses, before reaching conclusions about the location, the materials of construction, and the methods to be used in order that the proper engineering results are attained.

Historical Geology: The unglaciated portion of southern Indiana belongs to an extensive geological structure called the "Cincinnati Arch." The "Cincinnati Arch" is a rather low anticline with a vertex near Cincinnati, Ohio, from which it received its name. The tensile stresses induced within the upper strata of the structure, at the time of the uplift, caused those strata to crack, and, through the process of erosion, to expose a sequence of formations of various geologic ages. The portion of the "Cincinnati Arch" in Indiana exposes materials as old as the Ordovician and as young as the Pennsylvanian.

The area under investigation includes sedimentary rock formations of Pennsylvanian and Mississippian origin (Figure 7). The Pennsylvanian formations are represented by a massive sandstone bed, which is basal to the sandstone and shale formations to the west and is called Mansfield sandstone. The Mississippian formations include limestones, sandstones, and some shales. The nomenclature of the Mississippian beds possesses a multitude of terms proposed by geologists in the past. Terms like, Chester, Kaskaskia, St. Genevieve, and many others have been in previous geological reports as the geologic names for the Mississippian formations found in the area under investigation. For the sake of consistence, however, the names to be used in this report will be that of Chester, a series name inclusive of the upper Mississippian formations established by Worthen of Illinois, and that of Kaskaskia, a series term representing the geological materials between the Mansfield formation and the Mitchel Plain limestones to the east reported by Clyde A. Malott of Indiana (48).

The presence of Tertiary deposits within the area under investigation has been a disputable question among geologists in the past. The materials proposed to be of Tertiary origin include gravel materials found in northern Martin County. These materials are mostly located on high areas and consist of pure quartz gravels. They seem to be similar to the quartz grains usually associated with sedimentary rocks except that they lack the cementing binder material. The position of the gravel particles reveals that these gravels were derived

Fig. 7. Geologic Map of Indiana (Handbook of Indiana Geology, Indiana State Department of Conservation, Division of Geology).

from sedimentary deposits, whose binder material was washed away before it had a chance to cement itself, thus, leaving the aggregate matter in a loose state.

Structural Geology: The structural arrangement of the area under investigation on a regional basis consists of nearly flat lying sedimentary rocks, with a slight westward dip. The regional dip of beds is intrinsic with the development of the "Cincinnati Arch" and is steeper towards the east, at a slope of one to thirty, tapering off to a flatter slope of one to fifty in the west. The smoothness of the regional dip of the strata is locally interrupted by broken strata which resulted from the horizontal compressive thrusts and subsequent strata displacements convergent upon the stress conditions developed during the formation of the "Cincinnati Arch."

Figure 8 shows actual geologic cross-sections of the area under study taken on an east-west direction. The Mississippian representation in Indiana, composed of twenty alternating sandstone and limestone formations (total depth: 600 feet), constitutes one of the most remarkable cyclic geologic series in existence. According to Malott, the sandstones were derived from "terrigenous materials deposited mechanically in turbid, shallow seas during rhythmic periods of disturbance and upheaval, while limestones were deposited in situ under marine conditions between periods of land disturbance" (43). The above perfect cyclic sequence is locally interrupted by intercalations of shale. These shales usually exist as contact layers between the sandstone and limestone formations except in a few limited areas

FIG 8 GEOLOGIC CROSS SECTIONS IN THE CRAWFORD UPLAND
(AFTER ASHLEY)

where sandstone members of the Chester series are in sequence with shale strata (Figure 9).

The Mansfield sandstone is massive, reaching a maximum thickness of two hundred feet near Loogootee, Martin County, with an average thickness of about a hundred feet. Although massive, the Mansfield formation is not very dense and is locally used in glass manufacture (42).

The wide variation in thickness of the Mansfield rocks stems from the high relief conditions developed on the surface of the Mississippian deposits before the Mansfield sands were deposited (Figure 10) (42). At the high points of this contact surface the Mansfield sandstone rests directly upon basal Mississippian rocks, whereas at the low points extensive deposits of kaoline form thin layers of separation (Figure 11).

The sandstones of the Chester series of the Mississippian group vary widely in thickness and consistency. They vary from thin bedded to massive and from loosely-cemented to dense. The Mississippian limestones display similar variations. In most limestones the presence of fossils is visibly evident. There are cases, however, in which the rocks were derived from the calcium carbonates deposited by organisms instead of the organisms themselves. In such cases, the rocks contain considerable amounts of clay and assume some of the physical characteristics typical of shale rocks.

Fig. 9. Sandstone and shale on limestone. The above photograph was taken in a recent limestone quarry near Derby, Perry County and shows the dividing lines of a sandstone-shale-limestone sequence.

FIG. 10 CONTOUR LINES OF CONTACT BETWEEN MANSFIELD AND KASKASKIA FORMATIONS. (STRUCTURE CONTOUR MAP) IMMEDIATELY EAST OF MARTIN COUNTY (HANDBOOK OF INDIANA GEOLOGY)

SCALE 1" = 1.25 MILES

Fig. 11. Kaoline deposits between the Mansfield and Kaskaskia formations (Handbook of Indiana Geology, Indiana State Department of Conservation, Division of Geology).

Climate

The amount and nature of precipitation, and the temperature and its variations of an area are the most important climatic factors, as far as engineering considerations are concerned. The changes in volume affected by the variations in temperature and moisture on the engineering materials are frequently considerable. Such conditions are critical in predicting the behavior of soil and rock materials subject to engineering use. Many failures of engineering structures were traced back to an insufficient consideration of the climatic factor in the construction areas.

The climate of the state of Indiana as a whole is classified as humid. The average annual precipitation for the whole state is in the vicinity of 40 inches, with an average temperature of about 32°F for the winter and 77°F for the summer, and an average duration of "killing frost" periods from 150 to 190 days (65). "Killing frost" is a term used by agriculturists to indicate exposure to temperature below 10°F for at least one day (65, p. 298).

Due to the multitude of climatic influences exerted upon the state of Indiana, as well as its own physiographic diversity, the adoption of average annual conditions as criteria in depicting the climatic condition of one part of the state is completely impossible. This is illustrated by the variations in average precipitation, which on an annual basis increases from south to north, whereas during the growing period, between May and September, the opposite is true.

The state of Indiana is exposed to the cold waves originating in the northwest during the winter and to the heat that extends from

the great central valleys. Except for the northern portion of the state there are no large water bodies in Indiana. As a result, its climate is virtually continental.

In the northern part of the state the climatic conditions are much more uniformly distributed than in the south. The surface irregularities of the unglaciated portion of Indiana are responsible for considerable local variations in temperature and precipitation. Under normal atmospheric conditions, the temperature difference between the valley bottoms and the hilltops is considerable. The valley bottoms usually experience much lower temperatures than on the hilltops. During the spring and fall months, the valley bottoms experience severe conditions of frost, whereas, the hilltop areas are exposed to a little less than the freezing point.

From reports made by the 78 weather stations of the United States Weather Bureau in Indiana, covering more than a 20 year period (65, p. 852), the climatic data are recorded in tabular form for the area under investigation in Table 1.

In the area under investigation the action of winds is not important as it is disrupted by the relief of the area. The frost depth in southcentral Indiana does not exceed 20 inches.

Table 1

County	Temperature (of)				Days of "Killing Frost"	Precipitation (inches)		
	Jan. Ave.	July Ave.	Max.	Min.		Max.	Min. Monthly	Annual
Crawford	32.3	75.9	110	-30	162	4.82	3.09	46.56
Dubois	35.5	77.9	108	-20	177	4.65	2.64	47.61
Greene	31.1	76.9	112	-24	173	4.77	1.89	41.73
Martin	32.1	75.8	114	-22	176	4.39	2.08	42.60
Orange	32.8	76.6	111	-28	174	4.39	2.47	43.22
Perry	36.2	78.7	110	-19	186	5.14	3.06	46.87

Pedology

Pedology is the science of soil formation. It deals with the processes, through which the originally dense materials develop into a loose weathered soil mantle. The knowledge of these processes assists the airphoto interpreter in predicting the type of soils derived from the various parent materials.

The principal factors responsible for the formation of soils are climate, micro-organisms, topography, parent materials and time (76, p. 18). The climate that has affected the soil formation of the area under study is that of the high arctic. The work of the micro-organisms is limited to the organic layer of the soil mantle which, in this case, varies from a few inches to one foot.

The factor of topography as a variable in soil formation is very important in the area under investigation. The higher relief of the area and the wide range of slopes are responsible for the variety of the pedological soil materials found in the area under investigation. The depth of the soil mantle varies with the slope on which it has been developed. The steeper slopes support shallower soils.

The most important contribution of pedology to soils engineering is information concerning the changes in the nature of surface soils with depth; i.e., the soil profile. There is a difference in the use of terms referring to the soil profile between pedology and engineering. The soil profile, as reported in this study, includes three horizons: the A horizon, the B horizon, and the C horizon. The A horizon represents the soil layer whose finer fractions have been carried (leached) to a lower position by downward percolating waters. The B horizon represents the soil layer where the finer fractions of the A horizon have accumulated. The C horizon represents the soil that has not been altered appreciably by the activity of internal drainage.

There are as many types of profiles as there are combinations of the factors that contribute to their formation. To facilitate the study of the soil profiles of an area, several profiles are grouped into systems that are homologous in characteristics related to all soil formation factors except drainage. Such systems are called catenas. According to Bushnell (63) a catena represents "a group of

soils defined in terms of profiles comprised of horizons characterized as to number, thickness, arrangement, color, texture, composition, etc."

In a catena the factors of climate, and parent materials are kept the same, while the other soil formation factors are reflected by the topographic position of the soil. Thus, the profile of a certain catena is representative of a certain topographic position expressed sometimes in terms of slope range, which in turn denotes the nature of the soil profile.

Despite the fact that both sandstones and limestones are found in the area under study, the soils developed in the area are almost exclusively sandstone soils. In the opinion of the author, this is due to the fact that the limestone soils being susceptible to erosion, have been washed away.

Sandstone soils: The profiles of the area under study are members of the Muskingum-Zanesville-Wellston-Johnsburg-Lickdale catena. They are Muskingum, Zanesville, Wellston, and Tilsit (Figure 12).

The Muskingum soil profile (54) is the most extensive one in the area under investigation. It exists both by itself, known as stony silt loam or stony land, and in combination with the Wellston profile, classified as the Wellston-Muskingum complex. The Muskingum profile itself is found on steep slopes (25 to 40 percent) and heavily timbered areas (more than 80 percent). The profile consists of a 3-inch topsoil, which is highly organic, chemically neutral, and dark brownish grey in color. The subsurface soil is silty with small quan-

Fig. 12. The residual soil profiles of the area under investigation: (a) Muskingum, (b) Zanesville, (c) Wellston, and (d) Tilsit (The Formation, Distribution, and Engineering Characteristics of Soils by D. J. Belcher, L. E. Gregg, and K. B. Woods.)

tities of fine sand. It is pale yellow in color and reaches from 15 to 20 inches in depth. This subsurface soil is almost invariably underlain by resistant sandstone rock. Hard stone fragments, 4 to 10 inches in diameter, are commonly found embedded in the subsoil.

The Muskingum soil is derived from the Mansfield sandstone and some sandstone members of the Chester series.

The Zanesville profile (54), classed as silt loam, is usually located on the rounded ridge tops throughout the sandstone upland. Although its more extensive areas are on the broader sandstone ridges, the Zanesville profile is more frequently associated with long, narrow, many-lobed ridge tops. It consists of a silty A horizon of brownish grey soil, which turns yellow when wet. This layer is from 8 to 12 inches deep and frequently carries a 3-inch layer of topsoil, dark brown and full of organic matter. The B horizon of the Zanesville profile is silty and friable, crumbling readily into subangular particles less than half an inch in diameter. The deeper portions of that horizon are coarser and more angular, becoming mottled with grey and yellow at a depth of 25 to 32 inches, due to the presence of hard claypan. The presence of quartz in this horizon is derived from the Mansfield sandstone.

The areas of the Zanesville soils are steep and wooded possessing a local relief that sometimes exceeds 200 feet.

The Wellston profile is very similar to the Zanesville profile described above. The main difference lies in the fact that Wellston profiles are mostly located on very narrow ridge tops and have much shallower horizons. The A horizon is from 8 to 10 inches thick and

consists of light brown to grayish-brown silty soil. The B horizon is a yellowish-brown friable silty clay, occasionally mottled at their contact with the parent material. There is no claypan layer in the Wellston soils. Decomposed rock fragments are usually found at the bottom of B horizon.

The Tilsit soil profile is found on broad sandstone ridge tops. It has an 8 to 12-inch A horizon, consisting of brownish-grey silty soil and underlain by yellow, and friable silty clay B horizon. At a depth of 20 inches the B horizon is mottled grey and yellow. Below 42 inches the B horizon becomes more friable and less mottled, grading to sandstone fragments from 4 to 7 feet.

Summary on Pedology: The sandstone soils of the area under investigation are basically silty clays and clayey silts classified according to the Joint Highway Research Project Soil Classification system as number 9, 10, and 11 (Figure 13).

The pedological information appearing in this portion of the thesis was derived from an actual soil survey of only a small portion of the area under investigation (53, 54, 55). The extrapolation of that information to include the whole area was made through airphoto and field studies, supplemented by a conference with Professor H. P. Ulrich of the Department of Agronomy of Purdue University pertaining to a recent survey made by the above department in the area covered by this study.

Fig. 13. The Soil Classification System of the Joint Highway Research Project, Purdue University (The Formation, Distribution, and Engineering Characteristics of Soils by D. J. Belcher, L. E. Gregg, and K. B. Woods).

CHAPTER II

REGIONAL AIRPHOTO STUDY OF THE AREA UNDER INVESTIGATION

Pattern Elements

Landforms: The six stereopairs appearing on Figures 14 and 15 were selected from various locations over the area under investigation and they represent a composite picture of the regional landform features of the Crawford area. The stereopairs of Figure 14 were taken from locations away from the alluvial areas, whereas the stereopairs of Figure 15 were taken from locations near those alluvial areas.

The general characteristic of the area is the high dissection and relief that typifies the landform features of the terrain. Most of the shapes are blocky and the slopes are discontinuous and broken into abrupt "slope-breaks." These slope-breaks constitute the valley walls of flat-bottomed valleys (Figure 14) and the sideslopes of deep V-shaped gullies (Figure 15).

Figure 14a presents the lower order streams of the upland under investigation. The streams cover a relatively small portion of the picture with gently rolling to flat areas between the individual streams. The gullies are V-shaped and are steeper towards the top of the valley and almost flat towards the bottom.

Figure 14b shows more erosional activity. In this location the terrain dissection inflicted by the streams has reduced the originally flat uplands into sharp ridges and broad valleys. It is particularly interesting to note the configuration of the valley appearing on the lower portion of the picture. The point designated with the letter A

Fig. 14. Stereopairs of typical airphoto patterns of the area under study.

Fig. 15. Stereopairs of typical airphoto patterns of the area under study.

is a rock bench lower in elevation than the ridge at the center of the picture and higher than the immediately surrounding area. Near that location, as well as a similar location immediately below, the development of saucer-like depressions, known as sinkholes, is evident.

Figure 14c shows an elongated ridge between two flat-bottomed valleys. The ridge, although relatively large in areal extent, is heavily dissected with a hump-like surface, sloping away from the center. The sideslope of the ridge is rugged and blocky on one side (at the lower part of the picture) and smooth and rounded-off to a scallop-like pattern on the other. The flat portions on top of the ridge in question are limited and show evidence of deforestation, probably in an attempt to clear the area for agricultural purposes. The valleys that flank the ridge on both sides are virtually flat-bottomed with distinct slope-breaks on their valley walls.

Figure 15a is an area of irregularly shaped high areas separated from each other by deep V-shaped gullies. The area is located close to a major stream, appearing at the lower portion of the photography. In this locality, like in the preceding pictures examined above, the sideslopes of gullies, as well as valleys display distinct slope-breaks.

In picture 15b large parallel streams flow into the flat area that constitutes the bed and bank of a major stream. The location depicted by this stereopair shows complete eradication of the higher areas through erosion and the revelation of their underlying materials. The difference between the pictures in question and the pictures previously examined is the position of the base-level of erosion with respect to the highest point of the terrain, which in the case of

Figure 15b is much deeper. It should also be noted that in the latter case the streambed is much wider, and, as shown in Figure 15b, the stream is of a higher order.

The location of Figure 15c is adjacent to the Ohio River, which is the base level of erosion of the whole area under investigation. A large portion of the terrain is covered by gently rolling to flat areas developed at the banks of the tributaries to the Ohio. Evidences of the once rugged terrain are the steep slopes and the slope breaks. In this case and in the one previously examined the excessive erosion results in a much smoother and less blocky topography than that of Figure 15a.

The examination of the above stereopairs demonstrates the following about the area under investigation: The degree of erosion is a very important factor in the development of the terrain features on a local basis. It has been observed that the closer a certain area is to a major stream, the more dissected and eroded that area will be.

Summarizing the observations made on the photographic evidence presented in Figures 14 and 15, the area under investigation is a dissected upland of high relief (Figure 4) and great diversity of topographic shapes. The slope changes created by the sequence of high and low areas is blended into series of slope-breaks that develop in most all the area in a contour-like fashion. These slopebreaks vary in sharpness and form, from gentle slope changes (Figure 14b) to distinct and sharp stairsteps (Figure 15c). The valleys of the area are flat-bottomed and vary in width and shape.

Drainage: Reference is made to Figures 14 and 15 and to Figure 16. The latter is a drainage map of Perry County, prepared by the Staff of the Joint Highway Project of Purdue University. As it appears on the above references, the drainage pattern of the area under investigation is a modified dendritic. The higher order streams are winding within the valley walls of broad alluvial valleys, whereas the lower order streams show rock control in the bending of streams in conforming with the rock construction of the various locations. Some pure dendritic patterns exist only locally.

The overall drainage pattern displays many geometrical variations of the shapes and lengths of the drainage pattern of various sections of the area under investigation. These variations were investigated by the author as a possible means in detecting the parent materials present in the area under investigation.

In an attempt to associate the angles of stream of concurrence with the surface slopes of a terrain, a straight-line model of a trough-like simile of a valley was graphically analyzed. In Figures 17 and 18 the top and front views of such a valley simile are used to find the actual size of the plane representing the sideslope of the valley. Then, the dip of that plane is found and transferred back to the top view. The above graphical solution showed that milder-sloped terrains will tend to produce smaller angles of concurrence of the streams. This was found to be true for locations on the area under investigation. Figures 19 and 20 were taken from a sharp rolling and a gently rolling area, respectively. In comparing the overlays pre-

Fig. 16. Drainage Map of Perry County, Indiana (Joint Highway Research Project, Purdue University).

FIG. 17 GRAPHICAL SOLUTION FOR HORIZONTAL ANGLE BETWEEN VALLEY BOTTOM AND VALLEY-WALL DIP.

VALLEY SIDE SLOPE $2:2\frac{1}{2}$

ANGLE $50^\circ 30'$

FIG. 18 GRAPHICAL SOLUTION FOR HORIZONTAL ANGLE
BETWEEN VALLEY BOTTOM AND VALLEY-WALL DIP.

VALLEY SIDE SLOPE 2:1

ANGLE: 68° 30'

Fig. 19. Airphoto stereopair illustrating the relationship between drainage pattern angles and relief in a sharp rolling area.

Fig. 20. Airphoto stereopair illustrating the relationship between drainage pattern angles and relief in a gently rolling area.

pared for those two areas it can be seen that the angles of concurrence between streams of higher order are smaller for the sharply rolling areas than are for the gently rolling ones.

Another interesting variation of the drainage pattern features within the area under investigation is the relation between the lengths of tributaries and the spacing of those tributaries along the higher order stream. Let the latter be called a stem for the sake of simplicity. The ratio of the lengths of the tributary and the stem along a stream vary from place to place along the area under investigation. This is shown very effectively by comparing the drainage systems of Figure 21. They are taken from two different locations within the area under investigation and show a distinct difference in tributary-to-stem ratios. The reason for that difference is not easy to show by using only photographs taken from the area under investigation. For purposes of illustration the photographs from other areas within the United States were selected. The materials in the areas selected for that illustration are consisting of uniform materials of sedimentary origin. Figure 22 is a sandstone area and Figure 23 is shale area. Comparing these Figures it can be found that the average tributary-to-stem ratio in the former are smaller than one, whereas in the latter it is larger than one. Although, it may reasonably be deduced that a difference in parent materials will influence the value of the tributary-to-stem ratio, an exact value for the tributary-to-stem ratios for a certain type of parent materials is not possible, because of the so many variations and combinations of parent materials

Fig. 21. Comparison of drainage pattern features in the area under study. Tributary-to-stem ratios of gently (upper cut) and sharply rolling areas.

Fig. 22. Drainage pattern study of a sandstone area.

Fig. 23. Drainage pattern study of a shale area, in the state of California.

that may make the tributary-to-stem ratios vary from one to two. For areas, however, that some facts are known, the values of the tributary-to-stem ratios may be used to differentiate between materials that differ as far as their resistance to erosion is concerned.

An important question to answer about the application of the tributary-to-stem ratios in airphoto interpretation is whether their value changes with the degree of erosion. This may be illustrated not to be the case by comparing Figure 23 with the drainage pattern of the "badlands" of South Dakota, shown on Figure 24. Both pictures include shale materials, and in both cases the scale is the same (1/20,000).

Surface Erosion: The factors that determine the form and extent of surface erosion of a soil may be classed as dynamic and static. The dynamic factors are intrinsic to the climatic conditions of the area, and the static factors are related to the soil per se. The climate of the area is presently classified as humid and varies to some extent within the area under investigation. The most important climatic variations include the temperature gradients existing between high and low areas, the difference in rainfall patterns and intensity between areas of high relief and gently rolling areas, and the variation in duration of "killing frost" between high and low points. The high areas consume more precipitation, but also are subject to more and faster evaporation. These two factors compensate for each other, and neutralize most of the effect of difference of climatic conditions on soil erosion.

Fig. 24. Drainage pattern of an area from the "badlands" of South Dakota.

The static factors that influence surface erosion are many but they are closely inter-related. The most important ones are the surface slope, the soil thickness, the profile depth, the type of parent materials and surface cover.

As shown in Figures 14 and 15, there is a large number of slopes in the area under investigation. Most of the valley slopes of the area are steep at the top and shallow at the bottom of the valley (Figure 15). The valley bottoms are either flat bottomed (Figure 15) or V-shaped (Figure 14).

The gully erosion in the area under investigation is mostly noticeable on the airphotos in areas where the tree growth has been removed for agricultural purposes. These areas are mostly tops of high terrain similar to the one shown on Figure 25. A ground view of the point labeled on the airphoto as B shows the degree which such gully erosion may reach. Another evidence of excessive gully erosion in the area under investigation was located at the sideslopes of high areas also in locations that have been deforested (Figure 26).

The stream erosion of the area under study is excessive. Long drainage systems develop towards flat-topped uplands or uplands already reduced to sharp crested ridges (Figures 27 and 28). These stream developments consist of large gullies with V-shaped cross-sections. Besides the organized systems of streams, the area under investigation includes large numbers of small independent streams that develop along the course of larger streams. These streams are highly irregular as far as arrangement and direction. Their presence, how-

Fig. 25. Correlation of airphoto and ground photographic illustrations of a highly eroded high area. The ground photo was taken towards a westward direction from point B on the airphoto.

Fig. 26. Erosional activity on a sideslope, vegetation-free area.

Fig. 27. Stream erosion developing towards the flat-topped upland.

Fig. 28. Stream erosion in a sharply rolling upland. The headward erosion has reduced the originally flat-topped upland to a sharp-crested ridge.

ever, indicates a local increase in erosional activity. Especially in areas where such small independent streams mushroom between larger drainage systems, it is reasonable to infer that weaker soils are overlain by weather resistant soils. Referring to the tributary-to-stem ratio concept, which was advanced in the section, Drainage, of this chapter, it is evident that such tributaries will tend to increase the tributary-to-stem ratio locally, thus, indicating the presence of weaker soils.

Vegetation: The presence of vegetation in the area under investigation almost invariably is indicative of slopes too steep for the cultivation of crops (Figure 29). The arrangement of farm and forest areas in the area under investigation displays a unique farm vegetation pattern which possesses the quality of a general slope map of the area. In that respect the forest covered areas will represent the steeper-sloped areas, whereas the farm areas will represent the flatter portion of the terrain.

In addition, the dense tree-covered areas, there are other locations where tree growth is found in a rather sparse form. They are the banks of the main courses of streams on the alluvial valleys in the area under study (Figure 30).

Phototones: A photograph is a pictorial record of the light rays reflected from the object of photography. Therefore, under standard photographic conditions, a change in tone appearing on the photographic print will necessarily indicate a change in the type of

Fig. 29. Typical vegetation pattern of the upland areas in the area under study.

Fig. 30. Typical vegetal growth of the alluvial valleys. The tree growth is limited along the banks of the main streams.

reflecting surface from which the light was received. In black and white photography the objects are reflected on the photographic print as various shades of grey.

In landscape photography, such as the aerial photography used in this study, the major photographic objects are soils and vegetation. The phototones produced by soil largely depend upon the field moisture conditions, whereas the phototones produced by vegetation depend upon the type and color of vegetal cover.

In the area under investigation the major forms of vegetation, such as trees and bush growth reflect dark grey phototones. The crops of the farm areas produce light grey to white phototones.

A very interesting feature of the regular light grey soil phototones is the white tassel-like designs appearing in many portions of the area under investigation not covered with soil (Figure 25). The locations where these designs are found possess a fair slope. In gentle sloped areas the tassel-like designs appear as white fringe similar to those found in areas covered by old Drift soils (Figure 31).

Special Features: The only special feature of the area under investigation is associated with the quarrying of rock. The presence of quarries is evidence of the presence of useful rock deposits within the area under investigation.

Airphoto Interpretation

Parent Materials: Reference is made to the section on geology of Chapter 1. The area under study consists of a flat-lying massive

Fig. 31. Comparison between the white fringes developed on Illinoian Drift soils and those developed on the soils of the area under study.

sandstone bed, the Mansfield sandstone, and a cyclic sandstone-limestone series, the Kaskaskia formation (also flat-lying). The analysis of the airphotos reveals the variations in rock type. The slope-breaks and the contour-like arrangement of these slope-breaks betray the presence of flat-lying materials of varying resistance to erosion (Figure 15). The blocky edges and steep bluff-like sideslopes dominant in the area under investigation are typical of sandstone. The rounded off edges usually form scallop-like designs indicative of limestone. A few sinkholes are also found within the area, but are very few and most of them belong to the limestone deposits adjoining the area under study to the East. The geological evidence received from the airphoto study of the pattern elements shows a distinct predominance of sandstone throughout the area.

The western portion of the area under study includes blocky sandstone-capped high area, underlain by alternating sandstones and limestones (Figure 14). The blocky sandstone cap marked SS on the photograph belongs to the Mansfield formation whereas the underlain materials are members of the Kaskaskia Formation. The arrow pointing south indicates the sandstone member of the formation. The arrow pointing east indicates the limestone member of the formation.

The upland area shown on Figure 32 is typical of the landforms that cover the western portion of the area under study. The western edge of these upland areas disappear under the sandstone-limestone deposits to the west (Figure 33) and have been completely eroded away towards the east.

Fig. 32. Stereopair of typical landforms in the western border of the area under study.

Fig. 33. Stereopair of typical landforms in the eastern border of the area under study.

The eastern portion of the area under investigation includes sandstone and limestone combinations. Figures 34 and 35 represent typical upland areas of that portion. The tops of the areas are covered by sandstone caps underlain by alternations of sandstones (arrow pointing north) and limestones (arrow pointing east - note quarry on limestone).

Comparing Figures 36 and 37 a noticeable difference in the erosional shapes can be detected. The shapes of Figure 36 are more rounded and smooth. Furthermore, using the tributary-to-stem ratio idea advanced in the Drainage section of this chapter, it is possible to notice a much higher value for that ratio in Figure 36. In both cases it is indicated that the location of Figure 36 includes a softer formation that is not present in the location of Figure 35. The presence of shale was later verified from field studies of that location.

Engineering Soils: The area under investigation, as evidenced from the airphoto study of the geological materials, is likely to include residual soils derived, either from sandstones or limestones, and water-transported soils near the major streams.

As it was shown previously in this study, most all of the tops of the upland under study is covered with sandstone materials. The limestones are mostly found on sideslopes and, especially, at the bottom of the valleys. The absence of limestones from nearly flat-lying areas may indicate the absence of limestone soils from the area under study.

Fig. 34. Stereopair illustrating the allocation of the parent materials in a gently rolling upland.

Fig. 35. Stereopair illustrating the allocation of the parent materials in a sharp rolling upland.

Fig. 36. Stereopair illustrating the erosional forms of an area chiefly composed of sandstone.

Fig. 37. Stereopair illustrating the erosional forms of an area chiefly composed of sandstone and limestone.

The residual soils found on sandstone areas erode into small V-shaped gullies. These gullies show either white over dark grey background or dark-bottomed with white fringes, also over dark grey background. The whiteness of the erosion gullies indicate the presence of a well-drained layer of soil on the surface of the areas. The white fringes are typical of areas where the erosion has cut deeper than the well-drained layer into a less well-drained layer, which constitutes the bottoms of the gullies.

The water-transported soils of the area under investigation cover flat-bottoms of valleys. The dark grey-bottom of the few streams that traverse these alluvial areas, as well as those of the smooth saucer-shaped depressions (Figure 15c), reveal bad drainage conditions and fine-grained soils.

The previous airphoto analysis for the engineering soils of the area under investigation is later correlated with field data in Chapter VI of this study. The airphoto analysis was in all respects corroborated by the field checks.

CHAPTER III

AIRPHOTO PATTERN STUDY OF GENTLY ROLLING UPLANDS

Regional Aspects

Location: The gently rolling uplands occupy areas where erosion has been moderate in the extents occupied by the Kaskaskia formations and in areas of severe erosion that contain extensive remnants of the Mansfield sandstone formation. The former are located mostly in Crawford County and in limited areas of Perry and Orange Counties. The latter are almost exclusively contained in northern Perry County.

In Crawford County the areas under consideration comprise most of the upland areas found in the western part of the county, and taper off into the areas occupied by smaller relatively sharply rolling uplands in the eastern part of the county. In Perry County the gently rolling uplands exist in a random form and alternate in places with rugged, sharply rolling serpentine ridges. Orange County includes a few gently rolling areas in the southern part of the county, surrounded by areas of extensive dissection and high relief.

The gently rolling uplands vary from about a mile across to more than three miles. Their height over surrounding areas is from fifty to a little more than a hundred feet, depending upon the relief of the area in which they are located.

Referring to the landform study of Chapter II, the areas in question may be either landform A or B. (Figure 6)

Pattern Elements

Landform: The gently rolling upland areas in question represent high areas rising over the surrounding lands in a platform-like fashion. These areas are irregular in shape and possess little or no relief. Figure 38 is a typical airphoto stereopair of a gently rolling upland. Except for the gullies and surface streams that develop inward from the edges of the area, there are no surface irregularities of any major form. The surface area displays a slight curvature sloping away from two hump-like rises (points A and B). These rises are small and isolated, obviously remnants of an overlying formation.

The sideslopes of the areas vary in shape and size. The sideslope to the north is gradual and forms distinct slope breaks. It is interesting to note the step-like curvature (arrow pointing north) on the top of the northern edge. Downslope from that location the areas marked C, D, and E are found at lower elevation. They are also step-like in form but more rugged and blocky in shape. The sideslopes east and south of the upland in question are smoother than the previously examined one.

Drainage: The drainage of the gently sloping uplands is limited to several dendritic systems (Figure 38) that develop through headward erosion within the borders of the elevated areas. Most of the main streams are less than a mile long and are usually fairly straight.

Besides the well developed dendritic systems, there are also short individual streams (Figure 39) that extend inward on the gently

Fig. 38. Typical airphoto stereopair of a gently rolling upland.

Fig. 39. Drainage gullies of gently rolling uplands.

rolling uplands. These streams are usually spaced irregularly between the dendritic drainage systems of the uplands and are seldom more than a thousand feet in length.

Erosion: The erosion of the areas in question is limited to gully forms. The slight outward slope existing over the areas may be attributed to limited amounts of sheet erosion, stimulated by the slight hydraulic gradient developed on the high points of the uplands (Figure 38).

The erosional forms of the gently rolling uplands are V-shaped gullies varying from shallow towards the headwaters to a depth equal to the full height of the uplands toward the edges of the areas.

Vegetation and Agriculture: Due to the flatness of these high areas, most all of their surficial extent is used by agriculture, and, as a result is devoid of major forms of native vegetation. The farm patterns are regular toward the center and irregular towards the ends.

The vegetation of these uplands is mostly limited to the steep sideslopes and the gullies of the upland. The vegetation is dense and consists mostly of tree and bush growth. Despite the density of the vegetal cover it is possible in this case to distinguish the individual members. Areal vegetation surveys such as tree count and tree size estimates may be performed in this area under the photographic conditions at hand. In this and similar areas identification of tree types may also be performed on a general basis in thinly forested sections.

Phototones: The phototones of the gently sloping uplands are largely controlled by the type and stage of growth of the crops cultivated in the respective farm areas. The edges of the areas include limited non-cultivated soil portions in which the phototones reflect the soil conditions.

The phototones of the farm areas vary from white to light grey, without any tone variations within the same farm area. A diversion from that rule are the short dark streaks produced by gully developments that have advanced within the farm areas of the uplands and are used by the farmers for the drainage of the fields (Figure 38).

The phototones of the limited soil areas present interesting phototone variations. The phototones representative of uncultivated areas are grey with white streaks (Figure 38, pt. F).

The major forms of vegetation invariably display dark grey phototones. In most all cases, lighted shades of grey separate the individual vegetal members to the extent of making it possible to distinguish individual trees. This is clearly illustrated on the sideslopes of the upland shown in Figure 38.

Airphoto Interpretation

Parent Materials: The flatness of the gently rolling uplands and the arrangement of the slope-breaks indicate the presence of flatlying materials of varying resistance to erosion. The steep slopes of the edge of the upland indicates the presence of a resistant cap that covers the area. The V-shaped gullies that develop in the upland and

the blocky appearance of the cap are typical of sandstone. The round shaped forms appearing on the northern edge of the edge of the upland reveals the presence of limestone immediately under the sandstone cap. The bottom of the northern slope is blocky, indicative of sandstone.

Summarizing the features of the upland in question mentioned above, the materials are sandstones and limestones. An extensive sandstone formation caps the area and is underlain by one limestone and one sandstone formation.

Soils: The soils of the landforms under study are sandstone soils developed on the sandstone cap. Whenever the sideslopes of the upland possesses sandstone areas similar to those shown on Figure 38 (pts. C, D, E), sandstone soils may develop on the sideslope.

The white fringes of the upland streams and the white channel marks on the sideslope area indicate a well-drained first horizon overlying a less well-drained second horizon.

CHAPTER IV
AIRPHOTO PATTERN STUDY OF SHARPLY ROLLING TO
RUGGED UPLANDS

Regional Aspects

Location: The sharply rolling uplands of the area under study constitute its most common physiographic feature. Such upland areas may be found in eastern Perry County, southwestern Crawford County, southwestern Orange County, eastcentral Dubois County, northern and eastern Martin County, and eastern Green County.

On the western portion of the area under investigation the sharply rolling uplands consist of the sandstones and shales of the neighboring section to the west. On several occasions such areas penetrate well into the adjacent territories to the west and disappear under the mantle of the southwestern Indiana lakebeds.

On the eastern portion of the area under study the surface rocks of the sharply rolling uplands overly the limestones to the west and on many occasions constitute the caps of isolated limestone ridges.

In the landform study of Chapter II the uplands in question are landforms A and B. (Figure 6)

Pattern Elements

Landform: The sharply rolling uplands of the areas under investigation consist of sharp crested ridges of various sizes and shapes,

scattered throughout the area surveyed by this thesis. In Perry County they form long serpentine ridges and other compound forms of high relief and irregular and abrupt sideslopes (Figure 40). In Crawford and Orange Counties the blocky appearance of the side slopes assumes a step-like, or, otherwise called, "stair-step" form (Figure 41). In Martin and Dubois Counties the side-slopes are bluff-like, with fewer slopebreaks (Figure 42).

The airphotos chosen for the study of the sharply rolling uplands of the area under study were taken from Martin County. They display a highly dissected area, with irregularly shaped ridges separated by steep V-shaped gullies. The sideslopes of the gullies have slope-breaks, shown by arrows on Figure 42.

The flat-bottomed valley in the center of the picture is narrow with numerous short gullies branching away from it into the upland.

Drainage: The drainage pattern of the sharply rolling uplands is dendritic. Signs of rock control are found along the course of the major streams in Figure 42. The drainage of the sharply rolling uplands consists of short gully developments along the sideslopes spaced at irregular intervals. These streams seldom form branches and may not be considered as drainage systems. They are tributaries to the drainage systems that drain the valley forms adjacent to the rugged uplands of area under investigation.

Erosion: The erosional forms of the sharply rolling uplands consist of the main drainage gullies and of sideslope gullies, moderately

Fig. 40. Typical airphoto stereopair of sharply rolling uplands in Perry County.

Fig. 41. Typical airphoto stereopair of sharply rolling uplands in Crawford County.

Fig. 42. Typical airphoto stereopair of sharply rolling uplands in Martin County.

penetrating towards the crest of the uplands. The drainage gullies are steep and V-shaped. The sideslope gullies are generally arranged parallel to each other.

Another form of erosional activity associated with the upland area under investigation are small local systems of surface erosion gullies found on the higher points of the areas (pt. A, Figure 42). Those gullies are located within hilltop farm areas. The individual streams combine into tassel-like bunches and, subsequently, drain into single channels that discharge into the sideslope gullies.

Vegetation and Agriculture: As shown on Figures 42 and 43 the rugged upland areas are mostly covered by a blanket of dense forest growth. This vegetal cover is continuous throughout the sideslopes and the sharp crests of the areas, except for a few open sections located at the tops of the uplands. These sections were cleared of their tree growth in order to be developed into small farm areas. Such areas are mostly located on the more extensive ridge tops of the sharply rolling uplands, with irregular shapes in general geometrical similarity to the shapes and the areas they occupy.

Other open areas may be found on the more gently sloping portions of sideslopes. In such cases the steeper slopes support forest cover along the full length of the sideslope surface.

Phototones: Due to the scarcity of the vegetation-free areas in the areas under study the phototones are primarily those reflected by the forest covered sections. The phototones of such areas are dark

Fig. 43. Airphoto stereopair of a thickly forested area in the sharply rolling uplands.

grey, and those of the farm areas are from light grey to white. Some of the farmed areas on the rugged uplands are exposed to erosion and in several cases have been abandoned (Figure 42). Such areas display extensive surface erosion in the form of white, tassel-like designs (Figure 43).

Special Features: The only special feature of the airphoto pattern of the rugged uplands is the presence of limestone quarries occurring at the bottoms of the sideslopes. They appear as crescent-shaped holes carved in the sideslope materials (Figure 44). Most quarries show chalk-white phototones with little or no vegetation growth. Such are the active quarries of the area. The inactive quarries display light grey surfaces and patches of vegetal growth. The occurrence of water in quarries varies with the conditions of drainage of the areas in which the quarries are situated. Quarries constructed within the water table usually contain variable amounts of water.

Airphoto Interpretation

Parent Materials: The sharply rolling uplands of the area under study present the same general features as the gently rolling uplands. As far as parent materials are concerned, these areas also consist of a blocky sandstone cap underlain by a limestone and sandstone formation.

Engineering Soils: The soils of the uplands under study develop on the tops of the areas and on the flatter portions of the sideslopes.

Fig. 44. Limestone quarries in the sharply rolling uplands.

The white fringed gullies and the tassel-like designs of the area are also indicative of a well-drained A horizon and a less well-drained B horizon.

CHAPTER V

AIRPHOTO STUDY OF THE BROAD ALLUVIAL VALLEYS

Regional Aspects

Location: The broad alluvial valleys of the area under study are directly connected with either the Ohio River or the West Fork of the White River. They constitute the channels of the major streams of the area under investigation. Such broad alluvial valleys are found in Southern Crawford County, Eastern Perry County, and Central Martin County.

Several broad alluvial valleys were also located in Central and Southwestern Crawford County, and in Northwestern Dubois County. These alluvial valleys, however, will not be included in the area under study, because the materials, on which they are developed belong to the limestone section to the east of the area under investigation.

Pattern Elements

Landform: The broad alluvial valleys are associated with the solution topography prevalent in many sections of the area under investigation. Except for a limited number of water marks and saucer-shaped gullies, these areas are virtually flat.

Figures 45 and 46 are stairsteps of the two typical broad alluvial valleys found in the area under investigation. Figure 45 is a

Fig. 45. Typical airphoto pattern of a broad alluvial valley.

Fig. 46. Typical airphoto pattern of a broad alluvial valley.

portion of the West Fork of the White River in Martin County. Figure 46 is a broad alluvial valley in northwestern Perry County.

The alluvial valley of the West Fork of the White River is a typical valley of a major stream that has reached the stage of deposition. The water course is winding from the one side to the other across the flood plain. The outsides of the river bends sweep near the sideslope of the valley, whereas the insides are separated from the opposite sideslope by a relatively flat plain. This plain possesses a number of ripples nearly parallel to each other. An interesting feature of the broad alluvial valley in Figure 45 is the dividing of the stream by high points along the bed of the stream.

The broad alluvial valley of Figure 46, although much smaller than the alluvial valley of Figure 45, possesses many of the qualities of the latter in a limited degree. The stream of the valley is winding between the valley walls. The ripples on the flood plain of the valley are noticeable (arrow, Figure 46).

The width of the alluvial valleys is variable and in many cases disappear completely, only to reappear again a few hundreds of feet upstream. The widest of these valleys in the area under investigation was measured at a little over one third of a mile in width.

The presence of terraces in the area is random and is almost exclusively associated with the widening of streams.

The streams of the alluvial valleys are almost invariably winding and occupy a small portion of the full width of the flood plain.

Drainage: The major drainage ways of the alluvial valleys under study are the main streams of the valleys and their tributaries. The tributaries of these main streams are of two types; those that cut deep into the uplands past the limited areas included within the valley walls and those that are limited by the bounds of the valley walls and drain only the adjoining areas. The latter are unevenly spaced and follow the flood plain ripples. Their lengths vary from a third to the full length of the valley wall, and carry most of the drainage of the broad alluvial valleys.

Erosion: The erosional activity within the broad alluvial valleys is very limited. It consists of few valley wall tributaries and their saucer-shaped portions on the flood plain.

Vegetation and Agriculture: The vegetal cover of the valley walls reflects the upland conditions that are mentioned in Chapters II and III. The vegetation of the flood plain is restricted to the banks of streams. The type of vegetation typical of floodplain growth is limited to bushes and small trees.

The floodplains of the valleys in question are invariably used by agriculture. The farm patterns are irregular and proportioned according to the flood plain areas available (pt. A, Figure 45). The prevalent type of crops raised in flood plain areas of this region are corn and tobacco.

Phototones: The phototones of the flood plain areas are generally darker than those found on the uplands. This is primarily due to

the higher moisture contents encountered in the former. The farm areas display light shades of grey in corn areas (pt. B, Figure 45) and deeper shades of grey in areas of tobacco cultivation (pt. C, Figure 45).

Airphoto Interpretation

The study of the airphoto pattern elements of the broad alluvial valleys of the area under investigation indicates a stage of deposition. The chief reason for that tendency lies in the extensive erosional activity in the area. Ground pictures taken along the streambeds of the alluvial valleys in question during dry season (Figures 47 and 48) show an excessive accumulation of sideslope and hilltop debris along the bottoms of the streams.

The dark mottlings and water marks shown on the flood plains of the areas indicate bad drainage conditions. The saucer shaped channels of the drainage-ways are typical of fine-grained soils.

Fig. 47. Streambed conditions in the broad alluvial valleys. The pictures were taken in dry season.

Fig. 48. Streambed conditions in the broad alluvial valleys. The pictures were taken in dry season.

CHAPTER VI
ENGINEERING SOILS AND SIGNIFICANCE

Soils

Residual Soils: According to the interpretation of the airphoto patterns of the area under investigation, the engineering soils formed within the area under study are derived from sandstone. This was actually verified through extensive field investigations, which revealed that, although the limestones are present and responsible for the shapes and forms of many of the physiographic features of the area, only negligible amounts of residual limestone soils may be found in the area under investigation. The same was found to be true with the few shale intercalations within the area. The reason for the absence of soils derived from limestone and shale is the fact that the limestones and shales of this area are extremely susceptible to erosion, and, whenever they outcrop, the limestones quickly go into solution and the shales disintegrate and get carried away by the drainage streams of the area. Most of the load found deposited at the bottoms of streams included large quantities of limestone and shale fragments. The residual limestone and shale soils found within the area under study occur on outliers of the areas adjacent to it, already mapped as limestone (33) and sandstone-shale (24) areas, respectively. Limestone and shale fragments were also found on the milder sideslopes of the area under investigation, as colluvial soils.

The Sandstone Soil Profile: The sandstone soil profile varies from a very shallow two-foot depth to more than five feet to bedrock, depending upon its location. The shallowest profiles were found on the steep-sloped sandstone ridges (Chapter IV) and the deepest profiles were located on the flat-topped sandstone uplands (Chapter III). The depth of the horizons included in this analysis are found only in areas where the surface erosion has removed only negligible amounts of soil. Very often, however, especially in the case of the A horizon, part or all of the soil has been removed by surface erosion.

The shallow profiles consist of a half a foot A horizon and a one foot B horizon. Below the B horizon the shallow profiles are sandy with ample amount of sandstone fragments of varied size and shape. The deep profiles possess an A horizon from one to two feet thick (sometimes it reaches thicknesses as great as three feet). The B horizon of the deep profiles is slightly thicker than the A horizon and rests on a sandy C horizon that in some cases includes sandstone fragments. See Figure 49.

The typical A horizon of the sandstone soils is basically silty with small amounts of clay. Their dry density varies from 80 to 100 pounds per cubic foot. The Atterberg Limits of these materials vary as follows:

		Average
LL	20% to 35%	30%
PL	15% to 25%	22%
PI	5% to 10%	8%

Fig. 49. Typical sandstone soil profile on a high area in Perry County.

The above results, as well as the characteristic gradation curves shown on Figure 50, were derived from tests run on actual samples taken from the field.

The B horizon contains large amounts of clay and is plastic. Samples taken from the field gave the following variations in Atterberg Limits:

		Average
LL	30% to 40%	37%
FL	20% to 25%	23%
PI	10% to 20%	16%

Typical gradation curves are shown on Figure 51.

Considering the thickness of the A horizon, in most types of construction, it will be removed and construction will rest invariably on the B horizon. Consequently, the A horizon is not important as far as engineering is concerned.

Both A and B horizons of the sandstone soils are classified as No. 9 soils according to the Joint Highway Research Project (Purdue University) Classification, and as A-5 soils according to the Bureau of Public Roads Classification. Such soils are reported to be expansive clays and silts of high compressibility and poor drainage and compaction characteristics. They display poor subgrade support when subject to frost action and are of little value as foundation or road material.

Limestone and Shale Soils: The limited traces of limestone and shale soils are not important from an overall standpoint in the area under

Fig. 50. Typical gradation curves of the A Horizon of the sandstone soils in the area under study.

Fig. 58. Typical gradation curves of the B Horizon of the sandstone soils in the area under study.

investigation. Traces of limestone soils were located near Shoals, Martin County and southwest of Derby, Perry County. Traces of shale soils were located in the southeastern section of Perry County and in southcentral Orange County.

Generally, both limestone and shale soils are primarily clays in the upper two horizons, with stone fragments in the C horizon.

Colluvial Soils: In addition to the soil fragments found in the bottoms of the streams, limited quantities of sandstone, limestone, and shale fragments occur on the milder sideslopes of the area under investigation as colluvial soils. Although the general appearance of these soils show an excessive amount of fragments larger than a half inch in size, a major portion of them includes sandy and fine-grained material.

The colluvial soils of the area under study may not be accurately detected from airphotos, due to the ample tree growth that exists on most all sideslopes.

Soils Mapping: The soils maps appearing in Appendix A of this thesis delineate the borders of the areas in which soils derived from sandstone in an area of sandstone-shale-limestone parent materials are situated. The mapping illustrates the engineering soils areas on a parent materials basis.

Engineering Significance

The engineering problems investigated for the area studied by this report list as follows: (a) frost action, (b) weak subgrade

support, (c) pumping of rigid pavements, (d) rock cuts, (e) highway fills, (f) slides, soil slipping, and subsidence, and (g) surface erosion.

The surfaced highways available in the area under study to evaluate the performance of the soils with respect to highway construction are limited. Most of the surfaces are bituminous. The primary routes, such as U.S. 50, 150, 460 and State Route 37 have relatively new surfaces that do not display any serious failures as yet. The secondary routes are old and well under way to complete destruction (Figure 52). A contributing factor in this respect is the lack of continuous maintenance, due to their limited use.

The frost section in soils containing high percentages of silt is severe. Such soils are those of the A horizon of the sandstone soils, but the frost index in these areas is too low, not exceeding 500, to create frost action.

The soils of the flat-topped sandstone uplands display a marked weakness in supporting the loads carried by the bituminous surfaces located on them. In most cases the base of such flexible pavements lie on a silty clayey B horizon.

The lengths of rigid pavements in the area under study are relatively short and newly constructed, therefore limited studies could be made on the problem of pumping of the rigid pavements. Some old concrete sections, that have subsequently been covered by bituminous surfacings show clearly traces of pumping at the joints in the concrete. The major highways of the area under study do not

Fig. 52. Road conditions on a sandstone upland. The road is a secondary route between state highway routes.

carry frequent heavy loads. According to research performed at Purdue University (see Reprint No. 18) regarding the pumping of rigid pavements, the A and B horizons of the sandstone soils of the area under study answer the description of soils that will not produce serious pumping problems.

In areas such as Martin County, Crawford County, and eastern Perry County any extensive highway construction will have to battle the problem of high topographic relief by the use of rock cuts and highway fills. The reader is referred to the cuts and fills employed in the construction of U. S. routes 50, 150, and 460. On many occasions the problem of cuts and fills has been effectively countered by locating the highway routes along the valleys in the southern portion of the area under study and on the flat-topped ridges in the northern areas. This may be adequate for the traffic of the past decades. Due to the increase in traffic and the adoption of more rigid specifications concerning minimum grades of primary routes, as well as demands for longer sight distances on vertical and horizontal curves, the above practice will have to be modified by the use of deep cuts and fills. The engineer soon will be faced with the problem of designing fairly direct routes through sections where the local relief often exceeds two hundred feet.

Although not universally present, the problem arising from the presence of shale in the construction site must be discussed due to the seriousness of its effects. The key to the problem lies in the nature of the soils derived from shale. The shale soils are largely

composed of highly expansive clays. A small change in the field moisture of the soils create considerable volume changes that result into planes of weakness within the soil mass. These planes of weakness consequently become overstressed and fail causing slides, soil sloughing on the sideslopes, and even subsidence. Such failures were located in southeastern and central Perry County. To avoid such failures special care should be taken in locating the structures away from slopes that may contain even small amounts of shale soils. Special care should be exercised where cuts are made through rock combinations containing shale as a contact layer. A careful examination of the stability of the rock structure should be made before a cut is made, especially in locations where the dip of the rock strata is directed toward the cut.

Erosion is a very important problem in many upland areas, and especially the sharply rolling upland of the area under study. The presence of shale is in this case a contributory factor in erosion and certainly not an originator. The surface erosion is primarily due to the lack of adequate forest cover to check the rapid advance of the winter rain storm waters and the meltwaters from sudden melting of snow often experienced in these areas. Most of the upland timber has been removed in the past for development of agricultural areas, as well as using that timber for the manufacture of wooden articles. Presently the Department of Conservation of the State of Indiana has prohibited such practices for the sake of soil conservation.

CHAPTER VII

RESULTS AND CONCLUSIONS

Results

The results of this thesis are:

- (a) The contribution to the general soil mapping program of the Joint Highway Research Program by constructing an engineering soils map for an area of 1350 square miles, covering seven counties.
- (b) The study and development of airphoto patterns and techniques, contributing to the overall knowledge of airphoto analysis, which may be used in teaching, research, and development, and may be extended to areas analogous to the area under study.

Conclusions

The area under study: From the airphoto study of the area outlined in Figure I of this thesis the following are concluded:

- (a) In areas where erosion has cut through more than one type of massive rocks, as in the area under study, it is impossible to make a satisfactory airphoto analysis of the area by developing pattern elements for the whole area. In such areas the degree of erosion is a very important factor in the

development of the terrain features. For that reason, the areas under study should be divided into sections of comparable degrees of erosion and studied separately.

- (b) The airphoto pattern element of Landform is the most important factor in developing the airphoto patterns of the area under study. Due to the fact that the materials are flat-lying and differ, as far as resistance to erosion is concerned, the range and order of slopes are very important in determining the arrangement and location of the parent materials.
- (c) The major forms of vegetation in the area under study occupy the steeper slopes of the terrain and the banks of major streams. With the exception of a few rectangular tree patches, the tree cover of the area under interpretation may be used as a means of location of steep slopes and major streams without the aid of stereo-vision.
- (d) The study of the drainage pattern of the area under study revealed an interesting variation of its geometrical features, consistent with the variation in parent materials within the area under investigation. The study of this variation revealed that ratios of lengths within the same drainage pattern may be used as a means of differentiating between areas of different parent materials. Further study in this matter is warranted.

APPENDIX A
MAPS OF
THE SANDSTONE-SHALE-LIMESTONE AREAS

SANDSTONE
SOILS

APPENDIX B

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