**PROCEDURE FOR EVALUATION
OF
FLUVIO-GLACIAL TERRACES
FROM AIRPHOTOS**

**JULY, 1956
No. 28**

**Joint
Highway
Research
Project**

by
R. D. Leighty

**PURDUE UNIVERSITY
LAFAYETTE INDIANA**

PROCEDURE FOR EVALUATION OF FLUVIO-GLACIAL
TERRACES FROM AIRPHOTOS

To: K.B. Woods, Director
From: Harold L. Michael, Assistant Director

June 26, 1956
File: 6-6-26
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Attached is a report entitled "Procedure for Evaluation of Fluvio-Glacial Terraces From Airphotos" by Mr. R.D. Leighty. This report was prepared under the general supervision of Profr. R.D. Miles and R.E. Frost and was also used by Mr. Leighty as a thesis in partial fulfillment for the Degree of Master of Science in Civil Engineering.

This report contains an airphoto analysis of several selected terraces between Lafayette and Williamsport, Indiana. A guide to assist others in the evaluation of terraces from airphotos is presented.

Respectfully submitted,

Harold L. Michael

Harold L. Michael, Assistant
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Attachment

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OF
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FROM AIRPHOTOS

by

Robert Devine Leighty-Graduate Assistant

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Joint Highway Research Project

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Purdue University
Lafayette, Indiana

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* Now at Snow, Ice and Permafrost Research Establishment, Corps of Engineers, Wilmette, Illinois.

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ABSTRACT

Leighty, Robert D. M.S.C.E., Purdue University, June 1956. Procedure for Evaluation of Fluvio-Glacial Terraces from Airphotos. Major Professors: Robert D. Miles and Robert D. Frost.*

The purpose of this study was to develop a procedure for evaluation of fluvio-glacial terraces from airphotos. This evaluation could save time, money, and effort, when compared to existing field methods, by studying the elements of the airphoto pattern in detail.

The first portion of the thesis is introductory material. Methods of exploration for granular materials, both preliminary and detailed, are discussed and the formation of fluvio-glacial terraces are generalized. The characteristics of granular deposits to be determined from this study are then considered.

A general study of the airphoto pattern elements and their reflection of granular deposits was made and a guide for the evaluation of granular terraces was developed. Selected fluvio-glacial terraces were then evaluated according to the guide.

The findings of this work indicate that airphotos have a practical and economical application to the evaluation of fluvio-glacial terraces. In the application of airphotos, however, the photo interpreter must follow a logical, comprehensive procedure in order to obtain the maximum amount of information.

* Now at Snow, Ice and Permafrost Research Establishment, Corps of Engineers, Wilmette, Illinois.

CHAPTER I

INTRODUCTION

Section 1: General

The source and supply of natural aggregate is a subject of increasing importance to engineers in this modern area of highway construction. Years ago the location of almost any natural aggregate deposit within reasonable distance from the working site solved the aggregate problem economically. Today the cost of construction of a highway is much greater than in the past and the aggregate specifications have tightened so that economic considerations and physical characteristics now govern the use of granular materials.

Field location and sampling of granular deposits often can be difficult, costly, and require considerable time. Research at the Joint Highway Research Project, Purdue University, in the past has established that aerial photographs offer a rapid and economical method of determining the location and areal extent of granular deposits (1 through 8).^{*} Very little has been done concerning the determination of the physical characteristics of a deposit.

Section 2: Purpose

The purpose of this thesis is to develop a procedure for evaluation of fluvio-glacial terraces from airphotos by detailed investigation

^{*} Numbers in parentheses refer to Bibliography.

of the airphoto pattern elements and supplemented by the utilization of other information, such as topographic maps, geologic maps, agricultural soils maps and other literature. It is intended that this will facilitate the analysis of granular deposits from airphotos in greater detail than has been possible before. It is not intended that the detailed airphoto study replace field investigation, but rather that a savings of time and effort will result from obtaining information of greater detail from airphotos and thus minimize the field investigation.

Section 3: Scope and Limitations

The study involves only fluvio-glacial terraces along the Wabash River between Lafayette and Williamsport, Indiana. This type of deposit was chosen because it is one of the most important sources of natural aggregate in Indiana; although, it is anticipated that the procedure can be applied to other fluvio-glacial deposits with a minimum of revision. The location for study was chosen because of the varied conditions which exist in the area.

It is assumed that the person using this procedure has at least a moderate background in engineering materials and is familiar with the basic concepts of aerial photography and photogrammetry. It will also be to the reader's advantage if he is familiar with the principles of sedimentation.

The airphoto study was accomplished with Department of Agriculture photography dated from 1938 to 1941. Photography of this date range and age was ideal for this study in the respect that the granular terraces that have been worked since the photography date gave a true picture of the sub-surface of the airphoto pattern when a borrow de-

posit was visited in the field. The scale of the photography was 1:20,000. This scale is not considered to be the best for the study but will be utilized for economic reasons. This will be further explained in Chapter IV. Also, all the illustrations in this thesis are copies of the original contact prints because the negatives were not available. As a result, the illustrations lack a considerable amount of the original detail. In some cases this loss is not serious; in others it presents a very definite limitation, especially since the original photographs are of medium scale.

CHAPTER II

EXPLORATION FOR GRANULAR MATERIALS

Section 1: General

The quantity of granular materials for concrete aggregate, sub-grade improvement, base course material and other miscellaneous uses such as filter and back fill material, has increased many-fold in recent years due to the modern methods of highway design and construction. This age of super highways often necessitates a re-evaluation of granular materials available for impending projects. Where adequate supplies are not economically at hand, new exploration programs are often needed to find new sources nearer the job site.

Airphotos can be used profitably by the highway engineer or materials engineer for problems concerning the location of granular materials. By locating and determining the areal extent of the materials from airphotos, time and effort can be saved in the preliminary exploration phase. This, in effect, is inventorying the granular deposits by elimination of undesirable areas for detailed exploration; thus, enabling a greater concentration of effort for determination of the quality of the deposit, which involves a detailed exploration and testing phase.

Section 2: Preliminary Exploration Phase

The preliminary exploration phase locates the deposits from airphotos to be investigated in detail in the field. This is accomplished by making a study of the area to determine the geologic processes that

were responsible for the development of the area containing the deposit. Since glaciation and alluviation are the geologic processes which produce the bulk of granular materials, an understanding of these is necessary for locating granular materials by means of airphoto interpretation. There are many types of deposits, due to the different means of transportation and deposition of the materials, but each type of deposit will have a characteristic airphoto pattern which enables recognition by identification of the characteristic airphoto pattern elements, such as land form, drainage, erosion, vegetation and photo tone.

To reiterate, preliminary exploration for granular materials from airphotos involves, first, the recognition of areas which are apt to have granular deposits and, second, recognition of the patterns within these areas to be investigated in the field.

Section 3: Detailed Exploration Phase

The detailed exploration phase consists of field and laboratory sampling and testing to determine the properties and character of the deposit. To date no attempt has been made to research the application of airphotos to this phase of exploration. It is not intended that field work would be replaced by airphoto interpretation, but rather that any information from airphotos which heretofore could only be obtained by field exploration would be valuable and may mean a great savings of time and money to the highway engineer or other interested persons. This is particularly feasible if airphotos are also used for the preliminary survey.

Field exploration is costly and time consuming and is usually accomplished by moving a power auger to the sampling site. The problems

of moving a heavy rig on rolling or wooded terrain are readily imagined, but at the present time there is no other method of obtaining the data.

The auger borings at different locations on the deposit enable computation of the volume of the deposit. Other quantitative data obtained from the auger borings are the thickness of overburden, thickness of stratas and elevation of the ground water table. Samples are removed from the borings for field and laboratory tests to determine the suitability of the materials for engineering projects. The tests determine the types of materials within the deposit, grain size distribution, percentage of deleterious materials and strength and wearability of the materials.

There are numerous types of augers and drills but all are used to obtain about the same quantitative data and other methods have been employed to expand the data obtained from a bore hole (9). One method is the seismic method which correlates shock waves with density of materials. Another is the resistivity method which correlates the resistance of a material to electric current to determine depth and type of the material. The advantages of these methods are speed and economy in determining the depths to various general material types.

The purpose of the detailed phase of the exploration problem is to determine the properties and character of the deposit. As stated, there are many types of natural granular deposits. Those due to glaciation are eskers, kames, outwash, valley fill, kame terraces, moraines, drumlins, fluvio-glacial terraces, deltas and fans. The deposits due to alluviation are terraces, deltas, fans, valley fill and coastal sediments. Thus, it is seen that to research these types of deposits

in detail from an airphoto interpretation standpoint is an insurmountable task in time and effort for this project. Therefore, one type of deposit was chosen. This was the fluvio-glacial terrace, which is a typical source of granular materials for the highway engineers in Indiana.

Section 4: Formation of Fluvio-Glacial Terraces

The accepted definition of a glacier is a body of ice consisting of recrystallized snow, lying wholly or largely on land, and showing evidence of present or former flow (10). The center portion of a glacier is pure ice and the debris only exists near the exterior. A glacier can transport a tremendous volume of material which is collected at the contact surfaces between the ice and the soil and rock materials. This debris is mainly deposited in the vicinity where it is picked up but a small proportion of the material picked up does travel long distances.

The upper limit of melting on a glacier is the neve line and it is here where the streams originate which eventually carry the material to be deposited later. The melting occurs at the top and sides of the glacier and the streams flow only in the summer daytime in the high latitudes and flow more persistently in the lower latitudes. These flow on, within or under the glacier and usually emerge at or near the base or lateral margins. The streams are free of debris until they reach the terminal zone where they pick up the sediment load. This pick-up occurs largely because the streams flowing through the marginal zone of the glacier have steep gradients or very efficient channels or both.

After leaving the terminal zone of the glacier the water flows in existing channels or in local depressions until a channel is reached. Then the streams will deposit their load according to the laws of aggradation, with the coarsest material being deposited upstream and the finer material further downstream (11). This is usually a period of erosion as well as deposition because the stream at full load is ever widening its banks to accommodate the flow.

Stream deposition results from the loss of transporting power because of decreased velocity. This could be due to a decrease in gradient of the stream because of erosion, obstructions or erratic deposition, or a decrease in flow produced by fluctuations in climate. Thus, the streams become choked with materials and subsequent surges of stream flow removes or sluices away some deposits in the channel while others remain. Then, when the glacier retreats to where there is only a minimum of melt water contributing to the stream flow, the flow of the stream becomes braided. The flow in this braided pattern produces reworking of the surface materials of the stream bed but no down cutting results until other erosional surges take place. This rejuvenation takes place in post-glacial eras because of decreased load in streams which had received large quantities of glacial outwash. This results in valley deepening which leaves the former valley floors preserved as fluvio-glacial terraces.

Fluvio-glacial terraces differ from alluvial terraces in the respect that the glacial melt waters transport and deposit materials which have been previously transported by glacial action and thus within any strata of the terrace there could be a heterogeneous mixture of materials.

Alluvial terraces are more of a local nature in that they are usually formed from materials in the locality by normal flowing streams which have been rejuvenated.

Granular stream terraces remain relatively well preserved because of the composition of resistant materials and the inherent high permeability which deters erosional forces.

Of the ninety-two counties in Indiana, only one, Orange County, has completely escaped the effect of glaciation (12). Approximately 30,100 square miles of Indiana has been subjected to glaciation, while the area of the unglaciated portion is only about 6,250 square miles (13). A number of counties in south-central Indiana were never touched by the ice sheets, but the effect of glaciation is apparent in most of them in the form of alluvial and aeolian deposits. For a thorough discussion of Indiana glaciation the reader is referred to reference (14) of this thesis.

The glaciers modified the terrain considerably. This can be visualized by picturing Brown County filled and covered with drift that is 10 feet to 50 feet thick over the hills and more than 500 feet thick over the deeper valleys (15). Picturing this will generally present the situation of what lies underneath the surface of more than three-fourths of central and northern Indiana. For this reason limestone is only quarried where the drift is thin or nonexistent in Indiana and therefore gravels are the predominant aggregate. A large proportion of these gravels are found in terraces along the major drainage ways of today which acted as sluiceways for the melt waters in glacial times.

CHAPTER III

CHARACTERISTICS OF GRANULAR DEPOSITS TO BE DETERMINED

Section 1: Principle and Approach

Classification is a process basic to all sciences. It consists of recognizing individuals having certain important characteristics in common and of grouping these individuals into certain classes or types. By noting the similarities between numerous individuals, and then by recognizing these individuals as forming a class, the many are reduced to one. Thereby simplicity and order are introduced into what at first may have been a bewildering multiplicity of individuals. Classification thereby aids in establishing general truths from numerous individual instances. (16)

This provides for part of the basic concept of airphoto interpretation and involves recognizing and categorizing the multitudinous natural and cultural features into logical groups to which general truths are applied.

This is accomplished by a two-step process. The first step, while only general, is necessary so that the point or area in question on the photos may be related to the surroundings. This gives an interpreter an insight as to the processes by which the land obtained its present form, and the natural and cultural forces which may have altered or influenced the development of the area. In this step the outstanding airphoto patterns are differentiated by tonal contrast and arrangement and are outlined on a mosaic of the overall area. These patterns generally indicate alluvial, glacial, and residual materials but without complete identification or classification of the material types in the areas.

The second step is a detailed airphoto study which refines the position of the pattern borders and involves an analytical study of the patterns by division into airphoto pattern elements such as land form, drainage, erosion, vegetation and photo tone to determine the material types of the area and to a limited extent the characteristics.

The engineering significance of the whole or portion of the pattern is attached after the pattern elements have been studied and the material type has been determined.

There has been no attempt in airphoto interpretation to differentiate between similar types of deposits or patterns; therefore, the engineering significance is stated in very general terms. If the pattern elements were studied in greater detail so as to differentiate between similar types of deposits a more detailed statement of the engineering significance could be given which would portray better the characteristics of the deposit and more reliability would be placed upon the interpretation.

To aid the photo interpreter in the differentiation between fluvio-glacial terraces, a general discussion will follow in Chapter IV which analyzes the elements of the airphoto pattern of this type deposit in detail. This chapter also will stress the points with which the interpreter should be cognizant in his analytical investigation to evaluate the character of the deposits. In Chapter IV, the deposits along a stretch of the Wabash River will be evaluated for example purposes.

First, the characteristics of a granular deposit to be determined should be outlined so that the interpreter is cognizant of information desired about any granular source.

Section 2: Characteristics to be Determined

There are four questions that a man interested in sand and gravel will ask:

First - Where are the deposits located?

Second - What kind of material is in a certain spot and for what use is it best adapted?

Third - How many cubic yards of material in the deposit?

Fourth - What is the accessibility of the deposit and how easily can it be worked?

To answer these questions one must consider the engineering characteristics of granular materials and also the characteristics of the deposit in which the granular materials are contained. The engineering characteristics are needed to determine the kinds of materials in the deposit and their intended use and the characteristics of the deposit are necessary to determine the volume, accessibility, and methods of working the deposit. For the purposes of this thesis, it is assumed that the use of airphoto interpretation principles has already determined the location of the deposits; therefore, this phase of the evaluation will not be considered again.

The characteristics of a granular deposit to be investigated are briefly discussed below. The grouping of similar characteristics under common headings is to preserve an orderly arrangement which facilitates the use of airphotos. The last group, titled "Engineering Material Properties," will be discussed very briefly because it is assumed that a highway engineer knows the favorable and unfavorable properties of granular materials.

A. Deposit Setting

"Deposit setting" is the group title for the environmental characteristics of the deposit. The geographic, physiographic, geologic and climatic relations of the surrounding area should be studied for their effect or relation to the other characteristics of the deposit and its development. The geographic relation of the surroundings includes the transportation facilities in the vicinity of the deposit, the nature and location of settlements and urban areas for prospective markets for the granular materials, and the utilization of the land of the deposit and surrounding area which has definite influence on cost of the land. If the deposit will be exploited for only one project it must be within short hauling distance from the job site. It should be centrally located if the materials are used throughout an area.

The physiographic relation of the surrounding area to the deposit deals mainly with the configuration of the topography and the identification of land forms. A physiographic study will give the interpreter an insight of other prospective areas which may be producing or available for production of granular materials. It also indicates the general terrain conditions over which the materials will have to be transported. This is important because the deposit should be readily accessible to land transportation.

The geologic relation of the area to the deposit is determined by identifying the processes which developed the area and the deposit in question. This will indicate areas of likely locations of granular deposits or aggregate sources, the general soil types of the area and the probable need for granular materials in the area, and the materials

through or over which the access transportation routes will have to be constructed.

The climate of the area is a major factor in determining the erosional forces which tend to alter the area and the deposit, and must certainly be given consideration.

B. Space Relation

"Space relations" is the group title for the characteristics of the deposit which pertain to dimensions, the position of the deposits, and the relation to erosional base level.

The dimensions of a deposit are the measurements for computations of surface area, thickness and volume. The volume, being a function of surface area and average thickness of the granular materials, is derived from the configuration of the surface of the valley wall materials. The dimensions are important for planning for the development of the deposit and often determine whether or not the deposit warrants the expense of exploration.

The position of the deposit or portions of the deposit involves its relation, vertically and horizontally, within the drainage system; the related overburden; the presence of unrelated overburden and the borrow portion of the deposit. The deposit is situated vertically and horizontally with respect to the upland, flood plain, river, and other deposits, and its position is determined by the erosional history of the river. It is necessary to generally trace the erosional history in order to correlate the deposits along a stream. The position of a terrace aids in this reconstruction and it also has a relation between the amount and type of overburden on the deposit and the relative amount of

erosional forces to which it was subjected. The material above the usable portion of the deposit which is discarded is known as the overburden and its thickness and character are of extreme importance. It may be derived from the underlying soils by the natural pedological processes or it may be foreign material which has been transported to the area by either water, ice, wind, or gravity. These processes include aeolian, alluvial and glacial singularly or in combination, and these materials on a terrace are referred to as unrelated overburden. The overburden usually contains organic vegetable matter and other deleterious materials which prohibit its inclusion in the borrow. The material beneath the overburden or the borrow, as referred to by most, is of the prime importance. The ground surveys are designed to obtain information primarily on the engineering characteristics of this material.

The relation of the deposit to the base level or erosion is important if the features of erosion are to be used in the evaluation of the deposit. The erosional features are utilized in airphoto interpretation; thus, the erosional base level is meaningful in that the relative position from this level will determine the significance of the amount of erosion on a deposit. The regional base level is the lowest portion of that region to which water can drain. The local base level of erosion has the same definition, but is applicable to a much smaller area, such as the area covered by one aerial photograph. It can readily be reasoned that a high terrace along a stream has been subjected to a longer and usually continued lowering of the regional and local base level and, therefore, will contain more erosional scars than a more recent or lower terrace of the same type of materials. Theoretically, the base level of

erosion and the water table are synonymous (17). This is discounting solutioning and the influence of the various geologic materials upon the water table, but in granular materials the water table is said to be nearly the elevation of the major stream. (This, of course, is discounting the possibility of a perched water table.) The depth of the water table is important because it may determine the depth to which a deposit can be developed by a certain method and it is also important where washing is part of the operation.

C. Stratigraphic Character

The stratigraphic character of a deposit must include the vertical sequence and the horizontal variability within the strata of the deposit as a whole. It is well known that fluvio-glacial deposits are stratified and only in the rarest instances are they homogeneous throughout their depth. In some cases it is important to know the thickness of the strata and their depth below the surface of the deposit. This is particularly true when strata contain deleterious or bouldery materials. The horizontal variability often determines the position of the deposit which will be worked first and the direction in which the excavation effort will be directed. This of course depends upon the amount of variability. In some cases it has been necessary to reject the deposit as an aggregate source because the variability was so great that processing methods would be constantly changing in order to produce an aggregate which would pass specifications.

D. Engineering Material Properties

The engineering properties of the materials within a granular deposit must be determined to relate them to the specifications for the intended use of the materials. The properties to be determined usually concern gradation, durability, and undesirable materials.

When the deposit is sampled for gradation it is usually a general sample which involves a mixture of the sizes from all strata to the sample depth. This is considered to be representative of the gradation during operation. When the gradations of strata are nearly similar a general sample will suffice, but when the gradations vary widely between strata a separate representative sample should be taken from each stratum. This aids in the evaluation of the workable depth of the deposit.

The durability characteristics of an aggregate include strength and wearability. These properties, more than any others, influence its use as an aggregate, because granular materials would not be used if they could not transmit repeated loads.

A deposit may contain a certain percentage of undesirable materials, which are organic, coated, cemented or deleterious materials, but the specifications usually require that this percentage is very low. Remedial measures may be taken to remove the undesirable portion, but this is costly and usually only performed when the deposit contains only a little more than the specified amount of undesirable materials. These measures are flotation for organic materials, brushing and/or washing for the coated materials, crushing, washing and screening for cemented materials, and various methods of determining and removing the deleterious materials.

CHAPTER IV

GUIDE FOR THE EVALUATION OF GRANULAR TERRACES

Section 1: General

The purpose of this chapter is to outline a guide for the evaluation of granular terraces. This evaluation will be conducted largely by the use of airphotos and supplemented with existing maps and literature with the primary purpose of obtaining as much information about the deposit as possible without or before field and laboratory testing.

The detailed elements of the airphoto pattern will be discussed in general so as to serve as a guide for the airphoto portion of the investigation. To aid the photo interpreter in obtaining additional information of the type not obtainable from airphotos, a short discussion of some possible types and sources of maps and literature is included.

An evaluation of selected granular terraces along the Wabash River between Lafayette and Williamsport, Indiana will follow for purposes of example of the use of the guide. As a final section of this chapter is a summary and correlation of the field investigations of the selected terraces and the conditions predicted from the airphoto and literature evaluation.

Section 2: Outline of Guide

An outline of the evaluation guide has been prepared to direct the interpreter's study along logical lines of analysis; the amount of detail

and time spent on the evaluation of each deposit will depend upon the expected use of the borrow material, the scale and quality of the photography, and the extent of the literature and maps available for that deposit.

Initial Detailed Airphoto Study

This portion of the evaluation is concerned with the detailed investigation of the airphoto pattern elements of fluvio-glacial terraces in a manner which will aid a more detailed analysis of this type of deposit without the aid of maps and literature. Having located the deposits by a preliminary airphoto study, the detailed analysis of the deposits should begin at the furthest deposit upstream and progress downstream. The information obtained from this initial detailed airphoto study should be recorded for later evaluation and revision.

Land form, drainage, erosion, photo tone, vegetation and land use are the elements of an airphoto pattern which the interpreter uses to evaluate soil conditions in a given area (5). A forester is interested in natural vegetation and therefore will have other groups of airphoto pattern elements, which when interpreted properly will reveal the maximum amount of information about the natural vegetation from airphotos. So it can be easily visualized that a different group of pattern elements can be associated with each purpose to which the airphotos are being used. It is felt that the elements of the airphoto pattern described in this chapter best portray the character of granular deposits.

A. Locality. The locality is that area in which there are features of the environment that may assist in the evaluation of the deposit from

airphotos. The purpose of an airphoto study of the locality is to obtain information concerning the deposit which may be unobtainable from a direct study of the deposit without including the surrounding area.

The locality study can be divided into two parts. The first is a study of the natural features which may assist the evaluation of the deposit and the second is a cultural study or a study of the effects of human action on the evaluation of the deposit.

1) Natural. A study of the natural features of the locality involves the upland, flood plain, river channel and other alluvial terraces which influence or reveal information about the deposit in question.

Upland is a general term for the broad tract between rivers from which the rivers gather their drainage (18). To refine this definition so as to place limits for the delineation of the terrace surface, the upland can be said to begin with the change in slope at the inner portion of the terrace surface. This is a well-defined boundary in some instances, while in others it is an arbitrary border because often the true slope break is obscured by alluvial wash from the uplands.

The nature of the soils and parent materials which make up the upland configuration is important for estimation of the volume of the deposit and the character and extent of alluvial wash on the surface of the deposit. The true volumetric shape of the deposit cannot be obtained from airphotos; however, a reasonable estimate of this shape can be made by observing other related features. The problem is simplified by the fact that it is only necessary to know the shape of the deposit to a depth below the free water surface which would be economical for dredging or dipping. As stated later in the chapter, the elevation of the ground

water table for an alluvial terrace approximates the surface of the free water in the river channel for preliminary planning purposes. Therefore, to determine the shape for the required depth it is necessary to investigate for conditions which would affect the shape of the deposit within this depth.

The bedrock geology of Indiana is comparatively simple, in the sense that the rock is entirely of a sedimentary nature with essentially a horizontally bedded attitude. This has been complicated by glaciation and depth of glacial drift is variable throughout the state, except of course for the driftless area in the south central portion.

Knowing this, it remains to determine if the river valley in the locality is wholly within glacial drift or if it is influenced by bedrock. Indications of bedrock in the river valley are rapids, waterfalls, and controlled stream alignment. Indications of bedrock near the surface in the upland are visible outcrops and controlled topography or drainage. If none of these indications are present on the airphotos it is reasonable to assume that the river valley is within drift and it is safe to say that bedrock has not influenced the shape of the deposit.

If rock is evidenced in the upland and river valley it will be difficult, if not impossible, to approximate the lower shape of the deposit. The exception to this is in the case of an easily eroded shale, but if limestone, sandstone, or resistant shale is indicated allowances should be made in the estimate for the possibility of rock projecting into the undersurface of the deposit. When rock is evidenced in the river valley but not in the upland the estimate should also make allowances for bedrock projections.

A study of the nature of the upland soils within the drainage areas of the intermittent streams and gullies which flow onto the surface of the deposit is necessary so that the character and extent of the alluvial surface wash from the upland can be estimated. This material masks the border between the upland and terrace surface and tends to obscure terrace detail near the upland.

The uplands in the vicinity of the terrace should be investigated for foreign material such as loess or wind-blown sands which could have been blown from the terrace surface or the flood plain. Conversely, evidences of aeolian material in the upland could be a warning sign to expect this material on the terrace surface as unrelated overburden. An illustration of this is shown by closely inspecting the upland northeast of the West Lafayette terrace (in the vicinity of A on Inclosure 1). Here there are indications of loessal materials on glacial till by the "phantom drainage" pattern. Therefore, when an investigation of the terrace is made the interpreter would be cautioned as to the possibility of loessal materials on the terrace surface.

^{2c} Other alluvial terraces in the locality should be noted and evaluated roughly for comparison with the deposit in question; especially terraces which could be of the same age as the terrace in question.

2) Cultural. The cultural portion of the investigation of the locality is concerned with existing efforts of man which will aid in the evaluation and exploitation of the deposit. Excavations offer the best source of information. A study of existing granular borrow pits or other pits or quarries may divulge some characteristics that can be correlated with the deposit in question. This is especially true if the

borrow pit is in a terrace that was formed at the same time as a deposit in question. The investigation of the existing borrow area should be focused on the following points: the type of operation used to exploit the deposit, the type of equipment used, depth of overburden and workable depth to free water, evidence of wastage or waste piles, and the natural angle of repose of the working face of the borrow pit. If these are determined and there is a relation between the detailed airphoto pattern elements of the deposits it may be safe to apply the characteristics of this deposit to the deposit in question. This is an indirect evaluation and care must be exercised in the transfer of characteristics from one deposit to another.

If a borrow pit is in a deposit which is being studied in detail its study would be considered under the land use element of the airphoto pattern but if it is in a deposit in the vicinity, its study would be considered under the locality element of the airphoto pattern. For convenience, the examples of borrow pit study will be discussed under this section, knowing that as the case dictates the study will fall under the correct element of the pattern.

An illustration of a large borrow pit operation is shown in Figure 1 at a scale of 1:12,000. This is the gravel pit near the Purdue University Airport on the Wabash River. This pit is also illustrated on Inclosure 1. The material is being removed by dry methods and the following procedure is used: A walking dragline removes the material and loads a hopper bin which fills railway cars of an intra-pit system; these cars unload into a centralized bin and the material is moved to the screening plant by conveyor belts and then to stockpiles or loading onto

Figure 1. West Lafayette gravel pit, scale 1:12,000.

railway cars at a siding. There are facilities available for washing, and graded stockpiles are maintained.

The pit has facilities for batching ready mixed concrete. The depth of overburden appears to be about ten feet and the workable depth of the borrow material, before free water is contacted, is about 35 feet. Figure 1 also shows that there is a great deal of wastage before the railway cars are initially loaded and none at the screening plant, with the washed fines being pumped back to the pit. This indicates that either the cobbles are removed at the initial loading bin or a crusher exists in the screening operation. Neither can be determined from these photos.

B. Land Form. A general description of an alluvial terrace land form is a natural plain of limited areal extent in an interior valley, from which the surface ascends on the upland side and descends on the channel side. In the preliminary airphoto reconnaissance the land form was the airphoto element that was most important in the selection of the deposit for detailed investigation. This chapter will discuss the land form of an alluvial terrace in greater detail to show the relation of land form to the other airphoto pattern elements and the reflection of characteristics of a granular deposit.

1) Position. The surface of an alluvial terrace marks a former valley floor level and the position of a terrace, with respect to the river channel and other terraces or the upland, is related to the erosional history of the river. When granular terraces are echeloned it is necessary to antedate those with positions further and higher removed

from the river-channel so that a proper relative allotment of erosional time can be made when studying erosional features of a terrace within the echelon.

The position of a terrace from the base level of erosion of the area, which is usually the elevation of the free water surface in the river channel, also has an influence on the amount and type of erosion to which the terrace will be subjected. High terrace surfaces will erode more deeply and faster than low terrace surfaces of similar materials nearer the stream channel.

The position of a terrace with respect to the river channel also influences the decision as to what method will be used for removing the materials from the deposit. Usually the elevation of the ground water table in a granular deposit within a valley approximates the elevation of the river surface. This assumes that no agiocludes of clay or combinations of clay and silt are stratified within the deposit to cause the formation of a perched water table or to otherwise control the flow of water. On this basis, a high terrace can generally be worked by dry methods if the depth of excavation stays within reasonable distance of the elevation of the water in the river channel. For low terraces with expected depths of excavation below the elevation of the stream channel, a dipping or dredging process is usually employed.

The position of a terrace influences the amount of modification from upland alluvial materials. This will be discussed more fully elsewhere in this chapter, but it is necessary to state here that the terrace whose surface abuts the upland is subjected to a great deal more alluvial modification of its surface than terraces lower in the echelon.

The elevation of a terrace is of aid in reconstructing the erosional history of the river. This is attained by finding terrace tops along a stream with elevations which form a gradient pattern. The gradient does not necessarily have to be the same as that of the present stream channel because previous flow may have been under different conditions. This method is usable when elevations between adjacent terrace tops are large, but the correlation is difficult when the elevation differences are small or when earth movement may have disturbed the positions. It is difficult to bridge airphotos with a lens stereoscope, therefore photogrammetric instruments or available topographic maps are necessary. Nevertheless, this is a method with which alluvial terraces of similar ages can be compared and if the qualities of one terrace are known from published information or experience a rough approximation of the qualities of the unknown deposit can be made.

2) Surface. In the general description of an alluvial terrace land form, the surface is termed as a natural plain of limited areal extent. It is limited in the sense that a plain is usually thought of as a land form of great areal extent. The measurement of this areal extent is important for the computation of expected volume of borrow material that can be removed from the deposit. The area of the surface to be measured is that portion between the face of the terrace and the transition zone between the surface and the upland. This, of course, is assuming that the entire deposit is available for exploitation. If not, only the surface area to be exploited is measured. There are two economical and reasonably accurate methods of measuring this surface area directly from the airphotos. These are with a planimeter and by grid square estimation.

A planimeter is a device which will give a direct reading of surface area when calibrated to the scale of the airphotos and traced around the perimeter of the area. The grid square estimation method is, as the name implies, an estimation of the area by counting the number of squares in the grid within the perimeter of the area. In some states the county road systems are on one-mile section lines which form a natural grid on the airphotos. The photographs will probably contain small degrees of tip and tilt which is considered negligible for the measurement of surface area from large or medium scale photography.

The configuration of the surface of a terrace is due to the character of the overburden and the borrow portion of the deposit. In the latter case, the attitude of the borrow portion and the lower portion of the overburden of the deposit represents the bottom of the stream channel at the end of the depositional period. This surface could have been modified by erosional and depositional forces during the early stages of the rejuvenation period. Reflection of this is evidenced on airphotos by scales representing former channels of braided streams, meander scars and natural levees. Braided streams indicate that the river floor was choked with materials; therefore, when the current markings on an airphoto indicate a former braided stream on a terrace, coarse granular materials should be expected with a minimum of related overburden. Meander scrolls or scars appear in silty bottomed streams of low gradient and comparatively thick silty overburdens can be expected on terraces where these are evidenced. Meander scars and current scars are occasionally found in combination on a terrace surface. When this condition is found it indicates coarse gravels under a moderate overburden of silt

which probably grades to sand as the gravels are approached. Natural levees are composed of coarse material which grades to fines away from the former channel. Evidence of these on airphotos indicates a minimum amount of related overburden on the levee tops and considerable related overburden between or to the upland side of the levee. The above generally indicates only the upper part of the borrow materials and related overburden, but does not reflect the internal character of the borrow portion of the deposit.

A rough approximation of the character of the borrow material as a whole is qualitatively deduced from the overall attitude of the deposit. Sand and gravel are usually resistant geologic materials that are well preserved and persistent in nature because of their great permeability. Thus, a terrace which is highly eroded or dissected is not expected to consist of sands and gravels.

Another indicator of the character of the borrow materials is infiltration basins. These are relatively small, shallow depressions on the surface of the terrace. Infiltration basins may be formed as a result of differential natural compaction or settling of coarse granular materials which results from the lowering of the water table and the washing of silt and clay particles through the voids in the gravels. These basins are rarely associated with flood plains or where the water table is constantly high. No written information has been found to indicate their formation, therefore the above is offered as an hypothesis.

The configuration of the surface of a terrace is also related to the character of the overburden. When the overburden is alluvial in nature the surface approximates the configuration of the deposited mate-

rials with local erosion subduing the high areas and filling in the depressions. Unrelated overburden resulting from aeolian and alluvial processes modify the original configuration. Local sand from the river bottom or other sandy areas in the vicinity of the deposit may be blown onto the deposit or if the terrace overburden is of a sandy nature it also may be reworked to form dunes or just mask the surface with a sand smear. The dunes are discernible land forms, but the sand smears subdue the topography and cannot be recognized from a land form study from airphotos. Sand blown onto the terrace from the flood plains is usually deposited near the terrace face. The area on the lee side of the dunes can be expected to have a thick sand overburden which will decrease in depth with distance from the dunes. Loess is another aeolian modifier of terrace surface configuration. Large deposits of loess form ridges but shallow deposits, like sand, subdue the topography and are not discernible from a land form investigation.

The chief modifier of terrace surfaces is alluvial wash from the upland. The deposition of alluvium upon the surface by intermittent streams and gully wash can be considerable. This depends upon the drainage area of the gully or intermittent stream, the nature of the upland materials, rainfall, and vegetation, to only mention a few. The deposition usually occurs at the change in slope between its upland path and the surface of the terrace. This deposition causes the formation of alluvial fans on the terrace surface. Where there is a sharp break between the upland and the terrace surface, a transition zone of alluvial materials may form in a fan deposit which is visible on airphotos from a land form investigation. If the slope break is small, the allu-

vial wash will probably be undetectable from a land form study. Figure 2 illustrates the transition zone between the upland and the terrace surface. This illustration was taken from the vicinity of location B on Inclosure 4. The alluvial wash from the upland has formed a continuous apron at the base of the upland by coalescing of small individual alluvial fans and only at the major gully is the land form of an alluvial fan discernible. The alluvial materials are present further from the upland than is visible from a land form study, and these materials will decrease in grain size and depth with distance from the upland.

3) Terrace Face. The face of an alluvial terrace represents part of the terrace valley wall of the stream channel during the latest erosional period. It is a cut face through the materials which would represent the natural angle of repose of the materials if it were not for the modification of vegetation, which acts as a binder. The slope of a terrace face is quite often used to generalize the qualitative character of the deposit. The generally steep slopes are termed as granular and the shallower slopes as silts and clays with some gravels.

Usually the stratification is not visibly evident on the airphoto because of the scale of the photos, sloughing of the materials, and vegetation; however, the shape of the terrace face should be inspected for changes in slope which would indicate changes in character of the deposit. A break in slope could mean a radical change in materials or a cemented strata, to only mention a few possibilities.

The height of the terrace face is used to compute the volumes of the deposit. This height can be estimated from airphotos or it can be measured accurately from airphotos with photogrammetric instruments.

Figure 2. Typical terrace surface.

C. Drainage. There is no developed drainage pattern associated with the surface of a granular alluvial terrace. A granular terrace is usually conspicuous by the absence of developed drainage lines, where developed drainage lines are incised channels (19). This lack of developed drainage pattern results from the high permeability and generally flat surface of the deposit.

Permeability probably is the most important single factor influencing drainage textures. It is commonly observed that surface drainage lines are more numerous over impermeable materials than permeable ones. Granular alluvial terraces are highly permeable because of the large natural values of porosity. A mixture of sand, gravel and some silt may have a porosity value as high as fifteen percent (17). The porosity value for gravel varies greatly because of the variation in interstitial material. A value of 25 percent is probably the maximum for a gravel although 45 percent has been reported (17).

The surface of an alluvial terrace has no relief of significance when compared to other land forms and is generally flat with irregular relief of a very low order. There may be many basins and rises due to the random nature of alluvial deposition but these have only a few feet of elevational difference. Thus, the drainage is without pattern, weakly if at all developed, and without entrenched channels.

Rain-water falling on the surface of the deposit drains to the low shallow depressions, which are usually closely spaced, if it is not absorbed upon contact with the surface. This small amount of low velocity, low gradient flow has little erosive force and infiltrates into the deposit very rapidly. Intermittent streams and gullies which discharge

water onto the terrace during and after a rainstorm have their steep gradients broken by the transition zone between the upland and terrace. This transition zone usually has the form of an alluvial fan or apron which causes the water to be dispersed and the velocity lessened to a point where deposition occurs, erosional forces are then almost nil, and the water is easily absorbed by infiltration.

A drainage map of the study area is attached as Inclosure 5. This map was compiled from airphotos used in this thesis. A comparison of the airphoto patterns with this map will illustrate the differences in relative permeability of the materials within the area. It will be noticed that there is a great difference in the frequency of drainage lines in granular materials as opposed to the other materials of the area.

There are two types of drainage of an alluvial terrace which will concern the airphoto interpreter. The first is drainage of the terrace surface and the second is the drainage of the water from the upland.

1) Terrace Surface Drainage. The terrace surface drainage as described here will apply to that water which falls on the terrace surface. The drainage of water which is transported onto or around the terrace surface by way of upland streams and gullies will be discussed later.

The primary value of the airphoto element of surface drainage of a terrace deposit is to obtain a qualitative estimate of the relative permeability which then is roughly translated into material texture. This is accomplished by mentally comparing the drainage texture of a level and rather impermeable fine textured soil with similar position,

such as elevated lake bed silts and clays, to the drainage texture of the terrace surface in question. If the patterns appear to be similar the material textures are said to be similar, but if there is a marked change in the drainage texture, to show that all or a majority of the drainage is internal, the material is said to be relatively coarse grained.

Surface drainage is also important for disclosing the depressions where ponding occurs. This ponding may be of very short duration on a granular material and of increasing duration when the granular material has a fine textured overburden. Swamps caused by a high water table have been found on terrace surfaces. This is usually caused by a depression with an impervious stratum beneath.

The short drainage lines on the surface of the deposit may reflect terrain configuration which is not discernible from the airphotos because of scale limitations. A small local pattern of these drainage lines may indicate low topographic form, such as a low ridge, which may be interpreted as a natural levee or a current ridge. If the drainage lines enter the basins from the same direction it usually indicates a sloping surface, which otherwise may be unnoticed without aid of a topographic map of small contour interval.

Overburden texture can be differentiated from that of the borrow portion of the deposit when the overburden is deep and fine textured. This is evidenced when the infiltration basins are connected by drainage lines and also by a faint development of a drainage pattern.

Although gullies are present in the faces of most terraces they have no associated pattern of arrangement. The characteristics of these gullies will be discussed under erosion.

2) Upland Drainage. The upland drainage pertains to the water transported onto or around the margin of the terrace surface by way of streams and gullies from the upland. These streams and gullies generally have intermittent flow except during a rainy period. There are perennial streams which flow on or around a deposit but these are comparatively rare in occurrence.

The intermittent streams have longer drainage lines and larger drainage areas than the gullies, and usually exist where there is a gentle upland slope or where the upland is dissected. Gullies will probably exist where the upland is steep near the terrace. These drainage lines will cease when contact is made with the surface of a permeable terrace as in Figure 2 or they will be deflected around the perimeter of the deposit forming an anomalous drainage pattern.

A slack water basin usually exists when a gully or intermittent stream seems to disappear at the surface of the deposit. The slack water basin is a natural depression at the base of the transition zone where the upland and surface water is ponded until it infiltrates into the deposit, as shown on Figure 2. The texture of the sediments in a slack water depression will depend upon the upland materials, but usually they are quite fine, such as clay and silt, because the change in slope at the transition zone causes deposition of the coarse material. The depth and extent of these sediments will be related to the soils, the drainage area and the rainfall-permeability relationship of the upland. Borrow areas in the vicinity of a slack water basin on the terrace surface can be expected to have high ground water conditions. This is due to the finer textured soils which are associated with these basins. As shown

on Figure 2, the borrow pit is on the terrace surface at the edge of a slack water basin and water was encountered not far below the basin depth. This also may be an indication that there is a less pervious strata underlying the granular materials of this area. As the deposit was building, former slack water basins could have contained enough fine material to form an aquiclude below the material which was later deposited.

When the flow from the upland exceeds the infiltration rate and the capacity of the slack water basin, the water will follow the path of least resistance to obtain an entry point into the river. This path is usually along the perimeter of the deposit at the junction of the transition zone and the terrace surface. Streams from the upland usually have a sharp departure from the original alignment when the terrace surface is contacted. This control evidences a resistant material which deflects the flow to a path of lower resistance, which is usually to the finer textured material.

Perennial upland streams rarely ever cross deposits of granular materials on the surface because of the high permeability and the resistance of the material to erosion. Only streams of appreciable size manage to cut a channel across a deposit and these would be expected to lose a large quantity of their flow to infiltration. If this is not the case the deposit should be investigated for rock, cementation of the upper stratas, or clay strata that may retain water in the form of a perched water table. A change in cross-section alignment or gradient may be a clue to this unexpected flow as well as be responsible for deposition in the channel.

A temporary deposit is usually formed where the upland stream joins the river. This deposit will reveal the materials carried by the upland

stream. It is temporary in nature because the increased velocity of flood flow will sluice it away and therefore they should not be expected at every junction of the river and upland streams.

D. Erosion. Erosion is the wearing away and removal of materials of the earth's crust by natural means (18). In a humid climate, such as present in Indiana, the erosion is caused essentially by alluvial action, while a minor portion is due to aeolian action. The study of alluvial erosional features overlaps with the drainage study because the gullies are part of the drainage system. Drainage is more regional for purposes of determining a general drainage plan, whereas erosion is the minute part of a plan and is related to the physical characteristics. The study of erosion, however, is concerned with the effects of the erosive agent on the terrain, whether it be wind, water or ice, while a drainage study is only concerned with the character of water flow.

The study of erosional features is very important for determining general material types by means of airphoto interpretation. These erosional studies are primarily concerned with the attitude which the material assumes during erosion. The basic premise of these studies being that different materials have different character and therefore assume different attitudes when eroded, and also that similar materials will assume similar attitudes. It must be recognized that the classification of all material types under but a few erosive attitudes will lead to great generalization. When the attitude of the erosional feature is not clearly that of the stereotype the interpreter may be confused or even tend to neglect this feature in the evaluation of the materials in the area or deposit. Thus, the interpreter should strive to obtain

greater detail of the erosional feature which may reveal more of the character of the deposit.

A knowledge of the base level of erosion is important for evaluation of the erosion features. As discussed in previous chapters, this is the local or regional level to which the terrain tends to erode. For the area on one photograph, the base level of erosion is the lowest point where the water can drain. For a point within a drainage basin of a stream the base level of erosion is the elevation of the free water in the stream. Sea level is the base level of erosion for all land masses. The relative amount of erosion between two points in similar materials with the same base level depends upon the relative differences between the points and base level. The effect of base level of erosion can mentally be pictured by comparison of lake bed clays or silts with a stream flowing near the surface of the land and with the surface of the land elevated with respect to the stream. The terrain which is elevated with respect to the stream will be severely dissected, while the terrain which is near the surface of the stream will be relatively undissected.

The erosional study of an alluvial terrace can be divided into erosion of the terrace face and surface. These are discussed below for their aid in determining the character of an alluvial terrace from airphotos.

The scale of the airphotos being investigated will influence the results obtainable. To obtain the maximum information from erosional features large scale photography is necessary, for the small and medium scales mask the minute detail necessary for proper interpretation.

1) Terrace Face. The main erosive feature of a granular terrace is the not-too-frequent gullies in the terrace face. These gullies have in general a V shape cross-section with short, steep gradient. As gullies cut through the profile, they often provide detail on depth and textural differences within the deposit. The gullies will contain reworked alluvial material but the salient features will be more resistant to erosion and cause unconformities in the general gully shape. These unconformities may mean changes in cross-section and gradient which reflect such things as thick resistant strata of coarse material, cemented strata, and differential erosion of the different materials in the different strata.

Figure 3 illustrates short V-shaped gullies of uniformly steep gradient in granular materials. Close inspection of this stereopair will show the alluvial fans on the surface of the flood plain at the base of some gullies. These fans indicate coarse materials by their pronounced attitude. It will be noticed that the longer gullies have the longer fans and that the lower portion of these gullies are more rounded in shape because the steep gradient has been broken by the alluvial fan. A detailed investigation of these gullies at this airphoto scale does not indicate any change in gradient which would reflect variations within the deposit.

There seems to be little reason for the location of gullies along a terrace face other than for the drainage of surface run-off. The larger gullies are located where the greatest amount of surface drainage contributes to the flow. The exact drainage area of a gully will probably be indeterminate from airphotos when low relief exists on the

Figure 3. Erosional gullies in granular materials.

nearly level terrace surface; however, the center thread or drainage line usually may be visible. The study of a gully should start with the end of this drainage line and all changes of cross-section and gradient noted. The gully erosion begins in the overburden materials and its shape will depend on the character of this portion while there will be a definite change when the more granular portion of the deposit is reached.

2) Terrace Surface. Erosion of the surface of a granular terrace is predominantly caused by alluvial sheet wash with little or no development of an erosional gully system. The nearly level surface and high permeability character of the deposit deter active erosion. The drainage lines follow the lows of the topography and the low gradient, low volume flow does not have sufficient velocity to erode gullies. The significance of this type of erosion is subduing of the topography and the accumulation of fines in the low areas.

The streams which cross and follow the perimeter of the deposit have gullies which dissect the overburden and borrow portion of the deposit. These gullies should be studied in the same manner as those in the terrace face for clues as to the character of the deposit.

Superficial deposits of aeolian silt and sand can sometimes be distinguished from the overburden by the differential erosion of the deposit and the terrace surface.

Erosion of the transition zone materials is illustrated in Figure 2. This type of erosion occurs when uniformly steep upland abutts a terrace. Here the erosion indicates a transition zone of silty sands.

E. Vegetation. Vegetation is an airphoto pattern element which is very difficult to analyze in detail from an engineering viewpoint. This is especially true in humid areas for interpreters with little or no background or education in forestry and plant ecology. In arid areas vegetation is usually an indication of moisture or soil-moisture, while in humid areas the problem is infinitely more complicated by such factors as aspect, slope, position, surface porosity, sub-soil density and depth of soil. Also, in an arid climate only the most hardy of the vegetational species survive, whereas in Indiana alone there exist over 100 types of trees (15). These species generally are not restricted to a certain factor and the variations produced by each are not detectable by the novice. Even the experienced airphoto interpreter with an adequate background has difficulty identifying vegetational species when the scale of the airphotos is smaller than 1:5,000. Thus, the average photo interpreter should only be concerned with delineating contrasts in vegetation and as Frost (6) states, "it is up to the interpreter to decide whether or not these conditions are natural or artificial and whether or not they are associated with soil texture, soil moisture or topography."

Vegetation in general obscures the detail of a granular terrace on an airphoto. This is particularly true in the study of the erosion and drainage pattern elements because of the associated moisture conditions and land use relationship. Therefore, even though a study of vegetation will reveal little of the character of a granular alluvial terrace it usually influences the amount of detail obtainable from airphotos. For this reason the late fall, winter or early spring seasons are best for obtaining aerial photography for the study because the detrimental effect of vegetational foliage is at a minimum.

The value of a vegetational study of a granular terrace and the detrimental effects of vegetation on such a study will be discussed under the divisions of terrace face and terrace surface. They are discussed so that the interpreter will be cognizant of these effects or limitations.

1) Terrace Face. The face of an alluvial terrace is usually covered with natural vegetation. The vegetation is usually uniformly distributed in density on the face and gullies. The location where tall or dense stands exist should be investigated for other indications of high ground water conditions. The height of the trees usually depend upon the moisture conditions on a terrace face and it is generally seen that the crown heights of the trees are usually level from the top of the terrace face to the flood plain. This results from lower moisture conditions on the terrace surface and increasing moisture on the terrace face toward the flood plain, due to natural drainage conditions. Therefore, if a band of tree crowns noticeably appeared above the planes of the other crowns it could indicate a water bearing strata or aquifer.

The masking of the features of the terrace face by natural vegetation between the ground and the aerial camera is not the only detrimental feature, for unfortunately some detail is lost because of tree shadows. In areas where the natural vegetation is dense it may be necessary to have the photography taken when the rays of the sun cast the least shadow.

2) Terrace Surface. In Indiana by far the majority of terrace surfaces are under cultivation, which is termed as cultural vegetation. This type of vegetation does not lend itself to evaluation because of the various agricultural processes which can be used to neutralize detrimental soil conditions.

Natural vegetation is usually left in swampy areas such as slack water basins or deep infiltration basins. Natural vegetation may also be an indicator of a stoney surface which is too poor for cultivation. The gullies and streams of the terrace surface generally have abundant natural vegetation which obscures detail.

F. Photo Tone. An aerial photograph is a pictorial record of the light rays reflected from the photographed objects to a light sensitive emulsion on a strip of film. Under normal conditions, a change in the photo tone appearing on the airphoto will indicate a change in the type and condition of reflecting surface from which the light is received.

On panchromatic photography the objects are recorded as various shades of gray. These shades of gray generally enable recognition of certain large natural and cultural features without the aid of stereovision solely because of the arrangement of photo tones into a recognizable pattern. The photo tones are associated with the third dimension for greater detail when studied with a stereoscope. This enables the interpreter to obtain most of his information from combinations of relief and photo tones. It is thus seen that an understanding of photo tones is necessary for airphoto interpretation.

For the purposes of this study, variations in photo tones are caused or influenced by the photographic processes, by soil conditions, and by vegetational conditions. These factors will be discussed in general so that the interpreter can account for their presence when recognized. Also, emphasis will be placed on those factors which greatly affect the evaluation of an alluvial terrace.

The effects of the photographic processes on photo tones includes camera effect, photographic effect, and processing and printing effect. The camera which photographs the feature can influence photo tones if the camera lens are such that light is not admitted to the film uniformly. That is, more light is admitted through the center of the lens than around the margins, which causes lighter tones in the center of the photograph (20). Also, filters, when used on an aerial camera, will accentuate certain tones and reduce others. The film speed and lens opening of the camera will determine the amount of light which will reach the lens. The relationship of the camera to the angle of reflection of the sun's rays greatly affect photo tones. Smith states,

the amount of light reflected from a unit area of surface obviously depends on the amount received, and thus varies with the angle which it makes with the sun's rays. For slopes tending north and south the tone varies through a wide range with the time of day. Slopes tending east and west show a more gradual variation in tone with both daily and seasonal variations in lighting. (21)

Variations in processing, which includes developing and printing the photographs, can also affect the relative photo tones between flight strips, whereas the type of paper upon which the photograph is printed can affect the relative tones on the photographs.

Variations in photo tones are also caused by soil conditions such as soil moisture, soil color, and organic material. Soil moisture is dependent upon the topographic position, climatic conditions, and relative permeability of the materials. The configuration of the topography controls the flow of surface water, the climatic conditions control the amount of water which falls from the sky and the relative permeability of the material regulates the flow of excess soil moisture. Thus, immediately after a rain all areas will have comparatively uniform photo

tones, whereas a maximum contrast may exist a few days later, with the lower areas reflecting high moisture conditions or dark tones for longer periods of time than the higher areas. Soil color has an obvious effect on photo tones, as illustrated by Frost's examples:

Dry sand in the form of a dune on a dry sand plain will photograph light in tone, probably the same tone as the sand plain. Dry sand in the form of a dune on a moist sand plain will photograph light in tone against a dark grey background. In humid areas clay soils photograph dark, and silt and sand photograph light. (2).

The presence of organic material will be reflected in easily recognizable dark photo tones, whether in temporary or permanent swampy areas or in the lows of drainage lines.

A granular alluvial terrace usually has a level surface with irregular low relief and relatively high permeability qualities. Therefore, if the overburden is thin and relatively free of organic material, the photo tones will be uniformly light regardless of when the last rain fell with respect to the date of photography. The contrast in photo tones increases as the depth of overburden increases. The organic materials which accumulate from sheet wash into the drainage lines and infiltration basins, or from swampy areas, are discernible under most photographic conditions. Unrelated overburden, such as wind blown sand or silt, is sometimes discernible from photo tone alone.

Natural vegetation is usually immediately identified by the characteristic dark tones. However, Spurr (10) states that natural vegetation can register a wide variety of tones, depending upon the location of the sun with respect to the camera and the topography. Trees growing on a hillside sloping away from the sun will photograph darker in tone than similar trees growing on a hillside toward the sun. There are also

the dark photo tones associated with ever-present shadows cast by natural vegetation.

Cultural vegetation does not influence the photo tones as much as the patterns of photo tones formed by the agricultural practices. As an example, freshly disked moist soil will produce very light tones when the angles of the sun and soil reflect into the camera. This, along with the effect of cultural vegetation, tends to lighten the general photo tones; although, the crops grown in Indiana are of low density so that the soil color tones will be visible but subdued.

G. Land Use. Many of the economic considerations in terrace evaluation for future borrow areas concern land use. In Indiana the climate and the rich soils of a terrace surface are conducive to farming; thus, most terrace surfaces are devoted to agricultural uses. Many cities are located on large terrace surfaces because of the advantages which are ideal for urban and industrial developments. Some of these advantages are: good foundation conditions for structures and transportation systems, good natural drainage, level topography, adequate water supply, disposal of treated sewage in nearby streams, and the terrace surfaces are usually above flood level. The portions of terraces occupied by urban or industrial development are usually exempt from consideration as borrow area because of high property costs and zoning laws; therefore the attention should be focused on the rural areas. Photography of the latest date should be used when the proposed location of the borrow area is near an urban or industrial area because of new construction which may have utilized the terrace surface for location.

Economically, the cheapest land to purchase for materials excavation is that which is virgin or under natural cover. There are very few terrace locations in Indiana which have natural vegetal cover because of the agricultural advantages of this land form. Some of these advantages are the rich well drained soils which are usually flood free and the level surface with a minimum of erosive dissection. However, terrace farm land which has little improvements, such as houses, barns and other farm buildings will probably be cheapest to purchase.

The agricultural practices have effects on the airphoto pattern elements. The reworking of the terrace soils tend to level or subdue the irregularities in the surface and the relatively small amount of erosion that does develop in the surface soils is usually reworked and covered by plowing. The farmer may also plant trees in developed gullies to prevent further loss of land by erosion. These practices reduce the amount of detail available for interpretation from airphotos.

When a borrow pit is present in the deposit under investigation it should be studied in a manner similar to that outlined for borrow pits in the study of the locality. If the borrow pit is in a relatively small terrace the information gained from its study can probably be applied to the remainder of the terrace with safety, but if the borrow pit is in a large terrace the interpreter should be cautious in transferring the information gained.

Transportational facilities near the proposed borrow area can be of great economic importance for shipment of the materials to markets or job locations. These same facilities, however, may pose as a great disadvantage which should not be overlooked in the evaluation of the deposit.

Federal and state highways, county roads, railways and airports frequently occupy terrace locations which impede the proposed excavation direction of a granular borrow pit. These transportation facilities can seldom be relocated or purchased at prices which are commensurate with the value of the materials under or on the opposite side of the facility. If it is not economically possible to relocate or purchase the facility and the material is at a premium, another borrow area is usually opened on the opposite side of the facility. If there is an abundant supply of materials on the borrow pit side of the deposit, the transportation facilities are usually avoided by changing the direction of excavation.

Map and Literature Survey

The map and literature survey of an area employs any printed matter which aids the interpreter in the evaluation of the deposit. This information may be obtained from a single volume or many volumes; from one map or many maps. It will depend upon the interpreter's discretion as to the material which he thinks is pertinent to the study, for often a maze of material will have to be read and digested to obtain usable information. Notes should be taken while reading is in progress. The geographic location of each note should be recorded wherever possible.

This literature is not introduced prior to this phase of the study for the following reasons:

1. The best way for an interpreter to become acquainted with the conditions as they actually exist is to perform this step solely with airphotos. This instills confidence for the photo interpreter in his evaluation, especially when it is later authenticated by literature or field investigations;

2. The literature or maps used may be of inferior quality and give erroneous results which only can be checked when the photo interpreter has drawn advanced conclusions which differ with the texts;

3. Conflicting statements made in the literature can often be righted by a previous knowledge of the situation; and

4. Finally, the most important reason, the entire deposit can be studied from airphotos at one time, whereas literature will tend to be spotty and concerned with point or general observances which are better understood when related to a visible feature.

A short description of the type and source of literature and maps available to aid the photo interpreter in his evaluation of a granular terrace will follow. It is not intended that this be a complete listing or description of the references, but it is hoped that it will serve as a guide for future use until the interpreter compiles his own reference list.

A. Maps.

1) Topographic. A topographic map is a representation that is designed to portray certain selected features of a section of the earth's surface plotted on some form of projection and to a certain scale (18). The topographic maps primarily depict surface configuration by contour lines, intermittent and perennial drainage, culture in the form of transportation systems and structures, vegetation, and proper names. The value of a topographic map for engineering purposes depends upon the scale and contour interval. Large scale maps (1:25,000 and greater) are excellent for work with aerial photography of similar scales. Smaller scale maps are used for orientation and control for large areas. Large

scale maps can be used for computation of borrow material and measurement of surface area. Horizontal and vertical locations of individual features can be obtained with the proper names for drainage, topographic forms and culture. Topographic maps are particularly suited for correlating ages of terraces (22), (23).

Some sources of topographic maps are as follows:

1. State and National Geological Surveys (24), (25), (30), (31)
2. Depositories at most University libraries
3. Local libraries

2) Bedrock Geology. A bedrock geology map is a representation of the distribution of geologic formations, shown by means of symbols, patterns or colors, which are usually overprinted on a topographic map. On recent maps the amount of detail shown depends upon the scale of the map. There are large areas of the United States which have not been surveyed and this is a major limitation. Another limitation being in areas such as the drift covered portions of Indiana where the bedrock is obscured by the glacial drift. With a proper background in historical geology and a concept of physiography, a bedrock geology map will reveal much about sub-surface materials. A geology map study should always be accompanied by a literature investigation.

The sources of the bedrock geology maps are the same as the topographic maps.

3) Agricultural Soil. An agricultural soil map is a representation of the distribution of agricultural soil types of an area by symbols and colors. The areas are usually of county size. There are many methods of arranging or grouping agricultural soils into classifications, such

as by parent material, drainage characteristics, land form, or productivity. Recent maps are fairly well standardized but early maps followed a random pattern of soil classification. The reader is referred to a bulletin prepared by the Highway Research Board (26) for detailed assistance concerning the use of agricultural soil-survey maps.

When properly used the soil map and accompanying report will disclose valuable information concerning the overburden of terrace deposits.

Some sources of agricultural soil maps are as follows:

1. Agricultural experiment stations of state universities
2. Agricultural Research Administration, Division of Soil Survey, U.S.D.A.
3. Local libraries

4) Drainage. A drainage map shows surface drainage lines of an area. When compiled at a small scale only major drainage features can be shown, but when compiled at large scales all surface drainage features are shown, whether perennial, intermittent or stagnant. A drainage map should be used in conjunction with airphotos during the study of an area. Since a study of drainage is necessary for airphoto interpretation of an area, these maps can be valuable time savers. When used in a study of terraces, the interpreter should observe the alignment and frequency of drainage patterns in the vicinity of the deposits.

Some of the sources of drainage maps are:

1. County surveyors
2. In Indiana, Joint Highway Research Project, Purdue University

B. Literature.

1) Geologic. To avert unnecessary reading of geologic literature of a general nature, the interpreter should concern himself with publications which are restricted to definite areas. The United States Geological Survey publishes an index map (27) for each state, which outlines the areas covered by detailed studies. Publications of state and federal geological surveys, *Journal of Geology*, *American Journal of Science*, *Journal of Geomorphology*, *Geological Society of America* and *Water-Supply Papers* are found listed on this index. Another invaluable geological publication which any interpreter should have if he works with geology maps is the *Lexicon of Geologic Terms* (28), which will give a geological description of the symbols that appear on the geologic maps. Well logs offer another valuable source of sub-surface information. These are usually obtained from the state geological survey departments. The geological survey departments of some states publish bulletins concerning the sand and gravel deposits of the state. These are very valuable when available and usually contain analyses of a sample, if the deposit contains a borrow pit, along with other information. An example of this is a geological bulletin published by the Louisiana Geology Survey (29), which has a location map for each borrow pit and the location where the samples were obtained, sieve analysis and other properties of each sample, and logs of the sampled location with descriptions. All surveys are not as detailed as this, but any available information of this nature is valuable.

2) Soil. Soil literature of which the engineer is interested in for evaluation of a borrow pit will concern the overburden and the under-

lying or borrow material. The nature of the overburden is very well described in agricultural terms for areas covered by recent agricultural soils maps in the texts which accompany the maps. The reader is referred to a bulletin prepared by the Highway Research Board (26) for detailed assistance concerning the use of agricultural soil-survey reports and maps for engineering purposes. Purdue University has developed a key (30) for correlation of parent material, topographic arrangement and agricultural soil series names for engineering purposes of the soils of Indiana. Other states have also developed similar translations of agricultural soils data into engineering terms, but in some areas the interpreter must do his own translation. To assist in this effort, a publication by the U.S.D.A. (31) is recommended and although this book is somewhat out of date it contains the best composite description of the agricultural soils of the United States.

Evaluation

After the literature search has been made the interpreter should begin at one end of the portion of the river under investigation and work to the other, preferably downstream. Here the literature notes are compared to the notes made during the initial detailed airphoto study and a final airphoto study is made before the deposit is evaluated. This final airphoto study bridges over the sometimes spotty and general information in the literature and is supplemented with that information from the literature which cannot be obtained from airphotos. Upon evaluation of the deposits potential, the interpreter should recommend where field testing would give representative results and what should be accomplished to validate the airphoto evaluation of the deposit.

Section 3. Evaluation of Selected Terraces
Between Lafayette and Williamsport, Indiana

Two terrace deposits will be evaluated. These are terraces at Independence in Warren County and the terrace southwest of Attica in Fountain County. These deposits are considered representative for illustrational purposes.

Inclosures 1 through 4 of this thesis are reduced mosaics of the area under consideration. Inclosure 5 is a drainage map of the study area made from portions of the individual drainage maps of Fountain, Tippecanoe, and Warren Counties. These individual drainage maps were compiled from the airphotos used for this thesis.

Independence Terrace

Initial Detailed Airphoto Study

A. Locality. The deposit in question is located in a glaciated area along the Wabash River below a constriction in the valley walls. The deposit could have resulted from this constriction. The effect of the bedrock on the river channel and terrace development is seen by observing the vicinity of C on Inclosures 2 and 3. Here the channel topography is controlled by the resistant bedrock and the valley walls converge on both sides of the Wabash River about five miles above Independence. The bedrock is evidenced by the straight sided valley walls which are eroded in such a manner that till is not indicated as being present on the upland. Also, the upland streams are controlled and have steep side slopes as the river is approached. Above this convergence the valley walls are wide and only glacial till is indicated. Then about a mile upstream from Independence the valley again widens.

Below this convergence it is logical to assume that gravel deposits could be expected because the valley widening would cause a decrease in velocity which would result in deposition of the coarser material. It is seen on Inclosure 3 that Independence exists on a flat granular terrace which extends downstream to Kickapoo Creek.

There are many indications of rock underlying the glacial till in the upland to the rear of the deposit, as evidenced by stream control and deeply eroded, straight sided stream channels. Also, there are indications of bedrock at a shallow depth in the flood plains near the convergence by the dark photo tones. Across the river from the deposit there is a long narrow terrace of shallow gravel and till on rock. This is indicated by the number and controlled alignment of the stream and gullies which dissect this terrace; by the change in gradient of the gullies; by the straight sided stream walls; and by the large alluvial fans which have been deposited at the base of even the small gullies.

The volume of the deposit cannot be estimated by extending the upland slopes because of the rock in the vicinity of the deposit and the possibility of rock extending into the undersurface of the deposit. A careful study of the remaining elements of the airphoto pattern of this deposit should investigate further for the possibility of bedrock in the deposit.

The upland soil in the vicinity of the deposit is water worked glacial till of Wisconsin Age. This soil is very sandy near the surface as seen by the erosion on the steeper slopes. The gullies are deep and narrow and have sharply pointed white fringes which indicate shallow sands on the surface. These sands are not deep because this type of

erosion appears to cease when the gullies erode too deeply.

B. Land Form. The average height of the deposit above the river surface appears to be about 60 feet. It is a one-level terrace which adjoins the river and abuts the upland.

The surface varies from rolling on the northeastern portion to nearly level on the southwestern portion. The surface along the river is very level except where dissected by occasional gullies. The configuration of the northeastern portion of the deposit is due to a former braided stream condition. This is evidenced by the current markings and the directional trend of the current knolls and ridges. These elevated areas should contain coarse granular materials. The height of these knolls and ridges vary from about five to 20 feet above their adjoining low swales. Figure 4 is a stereopair of the northeastern portion of the Independence terrace. From this illustration it is seen that the areal distribution of this rolling topography on this portion of the deposit is bounded by the upland, a stream which crosses the extreme northeastern end of the deposit, and by a level area along the face of the deposit which extends through Independence.

The southwestern portion of the deposit shows little evidence of water activity and the surface is nearly level. The infiltration basins are very shallow in this section, while the ones in the northeastern surface are relatively deep.

The extent of alluvial wash is not apparent from a land form study of this deposit because of the shallow slope of the upland where it abuts the terrace surface. It is thus assumed that the transition zone is

Figure 4. Northeastern portion of Independence terrace.

shallow at the base of the upland. No transition zone exists on the western boundary of the deposit because Kickapoo Creek separates the terrace surface from the upland.

The slope of the face of the deposit varies on the northeastern portion and does not appear to be that which is generalized as a granular slope. Beginning at the stream which crosses the extreme northeastern end of the deposit the slope is steep. Then about a third of the distance to Independence the slope becomes irregular and shallow. At two-thirds of this distance the slope again changes to become very steep and at the river crossing at Independence the slope of the face is near vertical. Just downstream from the river crossing, in a gully, the slope flattens and becomes steeper as the river is approached. Below Independence, about one mile, the face of the deposit is generally obscured by natural vegetation, but where visible this face assumes the granular slope.

C. Drainage. The most significant point concerning surface drainage of this deposit is the standing water in the ponds. This indicates impermeable surface strata. The largest of these ponds is located about two miles northwest of Independence and is shown near D on Inclosure 3. This pond appears to be a kettle hole because of its steep sides and irregular outlines. This may also be true of the adjoining smaller ponds. All of these ponds appear to be perennial water holes. These ponds occur at the rear of the terrace and it is conceivable that large ice blocks may have been beached in this location after passing through the rock constriction just upstream.

There is a small ponded area in a borrow pit near the upland one mile north of Independence, as shown at E on Inclosure 3. Here the water level is about 10 feet below the ground surface. This can be expected near the transition zone or upland because fine grained sediments could have once been deposited in a slack water basin or transition zone before the later materials caused their burial. This type of pond is usually only temporary unless a very impervious strata is beneath or the ground water table is contacted.

There are a few very shallow depressions on the southwestern portion of the deposit which are temporary ponds. These could indicate an impermeable strata under the gravels.

There is only one perennial stream which affects the deposit. This stream, Kickapoo Creek, is incised to a point where its flow does not flow on the surface of the deposit. However, there is definite evidence of control as it flows along the upland boundary of the southwestern portion of the deposit.

An upland intermittent stream flows across the deposit and through Independence. It flows entirely within till in the upland, although at a location near the terrace surface there is a standing pond in its stream channel. This could indicate that the upper surface of the rock is being approached. Upon contact with the deposit, the stream flows in a controlled alignment. There are indications of rock where the down-cutting begins on the deposit. This is evidenced by the controlled alignment and the random slopes of its channel sides. These slopes vary from vertical to very shallow. Also the width of the channel is far larger than a stream from a comparable sized drainage area flowing over granular materials.

A second intermittent stream is located at the extreme northeastern end of the deposit. It flows from a deeply eroded portion of the upland. It flows on the terrace surface for a distance before it experiences a radical change in gradient and control. This evidence of former distributary flow in the wide flood plain of this terrace stream indicates that the stream has not always had its present channel and that after erosion or down-cutting it has contacted a resistant material.

Two large gullies, which are located north of Independence, discharge into a slack water basin on the surface of the deposit. There is no evidence of surface ponding present in this basin and it is assumed that infiltration has occurred at a rapid rate.

D. Erosion. At Independence there are two gullies which reflect different materials by erosional features. These are the gullies indicated by A and B on Figure 4. Gully A has most of its headward end obscured by vegetation but there are indications that this portion is generally V-shaped. This gully changes gradient and cross-section before underpassing the highway. Then the gradient is very shallow and the cross-section variable until it underpasses the bridge approach, where it becomes steep again. The island-like projection between the gully and the river, and upon which the north abutment of the bridge over the Wabash River is located, appears to be rock. This is indicated by the lack of erosion on the riverward side and its generally steep attitude. The lack of control of gully A before and after this projection is reached indicates an impervious but not a consolidated material, which could be till. Gully B is almost completely obscured by vegetation but a gradient change and control is visible.

The erosion of the terrace face on the southwestern portion of the deposit appears to be more V-shaped; however, it is mostly obscured by natural vegetation. There is no deep gully erosion on the shallow northeastern face of the deposit. There is shallow "hair line" erosion (long, straight and not deeply incised) which is not indicative of granular materials.

There is no evident erosion of the surface on the western portion of the deposit except near the large depressions and ponds. This erosion is mostly sheet wash. On the eastern portion of the deposit there is evidence of light erosion between the rolling topography. This erosion is discontinuous and underdeveloped. It appears to be only in the upper surface of the overburden or silty wash from the higher slopes.

Where the two upland gullies meet the deposit north of Independence there are two threads of shallow erosional gullies. These are discontinued upon contact with the deposit and indicate a silty sand which was washed from the upland.

E. Vegetation. The terrace face has natural vegetation along its steeper portions, but above Independence, where the slope is shallower, the timber has been removed for pasture. The date of the photography is June 4, 1939 and the natural vegetation is in full foliage. This obscures most of the detail in the gullies in the terrace face. There is no pattern formed by the natural vegetation on the terrace face which will indicate material conditions.

The natural vegetation of the terrace surface is confined to the areas in the vicinity of the streams and ponds. There are a few small isolated wooded stands which have no significance.

F. Photo Tone. The photo tones of this deposit differ from the eastern to the western portion of the deposit. The tones of the western part are more uniform and dark gray. Here tone variation is due to the accumulation of sheet wash material in the low areas. These low areas are small shallow infiltration basins. The uniform dark gray photo tones indicate a permeable material over an impermeable material. There is one area directly west of Independence which indicates a sandy overburden by the white streaks in the photo tone. Upon inspection of this area, it was found that in this small vicinity there was more relief than recognized by previous study. It is concluded that this is a small area of local ridges and scales of a sandy nature. The white photo tones are the result of sand washing into the low areas.

The eastern portion of the deposit has photo tones which reflect high and low areas. Because there is more relief in this portion of the deposit, there is a greater variation in photo tones than in the western part of the deposit. The lows thus accumulate more sheet wash material. The lighter tones of the higher areas reflect their good drainage conditions and indicate a granular material.

Along the river on the eastern part of the deposit there is a strip of uniformly dark photo tones. This strip is entirely pasture land and therefore most of the tonal color is due to the vegetation. Because of the lack of any variation in tone, this area is not indicative of granular materials.

The stream at the extreme eastern end has very light photo tones in its former flood plain which indicated sand. This sand may have been reworked overburden material from the terrace surface or washed down from the upland.

G. Land Use. The majority of the terrace surface is devoted to agricultural practices. The town of Independence, with an estimated population of 400 people, occupies an area of only about one-eighth of a square mile on the eastern portion of the deposit.

There are several small borrow pits on the terrace. These occur in current ridges on the northeastern portion of the terrace. Airphoto study of these pits reveals that the overburden is about two feet deep and the water table is at about 20 feet below the terrace surface. Because of the size and number of these pits it is surmised that the materials are used mostly for local road metal and private borrow areas. There are no indications of the general grain size or quality of the materials or the stratigraphic arrangement of the deposit.

The existing transportation network consists of an adequate highway system, except along Kickapoo Creek, where no roads exist. The highways are located in such a manner that not more than a mile of new road would have to be constructed in order to reach an existing road. There is one non-operating railroad in the vicinity. This is located on the opposite side of Kickapoo Creek. Additional highway facilities could be added anywhere on the deposit with a minimum of effort concerning soils and topography.

Map and Literature Survey

The terraces about east of Independence are underlain with Knobstone shale. The soil is light-gray, heavy silt loam to a depth of 8 to 12 inches, underlain by a mottled gray, compact silty clay loam sub-soil, which gives way to a shaly substratum. Large boulders occur on the surface. The soil is poor and largely used for pasture.

The deposit near Independence is mapped for agricultural purposes (32) as a Fox Silty Loam with the following description: "Brown or grey-brown, friable, silt loam to 12 to 24 inches, brown gravelly loam, coarse sandy loam or gravel, reddish brown coarse gravels to an undeterminable depth."

A geological report (33) has the following to say about the area:

Independence is situated on the summit of a ridge or knoll of Chester rocks. The rapid dip of underlying strata which drains the porous soil resting upon these rocks causes an outflow of many springs. These rocks were once capped with regular beds of conglomerate, which were eroded away by glacial waters. The resulting debris formed the terrace plain which surround the village for a space to the west and southwest of one to two miles. Beyond this plain on Kickapoo and Pine Creek, the sandstone develops massive blocks and cliffs of goodstone. On the hillsides north of Independence there are intercalating beds of sandstone and clay. Conglomerate sandstone is well developed on both sides of Kickapoo Creek and here the samples contain much gravel.

A river survey map (34) shows Independence and the edge of the deposit to be 550 feet above mean sea level and the edge of the Wabash River about 500 feet above mean sea level.

There is no literature available concerning the granular materials.

Evaluation

The airphoto and literature study agree on the presence of rock in the Independence area. The conglomerate indicated along Kickapoo Creek is assumed to extend beneath a thin overburden of granular materials in the western portion of the deposit. The standing water and dark photo tones on a level surface indicate that rock or till occurs at a shallow depth in the area near the ponds. This depth is approximated at 15 feet.

Immediately behind Independence, in the eastern portion of the deposit, exists the best source of granular materials. These materials

are in current ridges in a shallow rock pocket. The depth to rock should not be greater than 25 feet below the lows of this area. The overburden on the high areas should not be greater than about 18 inches. A sample from any high area or open pit in this portion of the deposit should be fairly representative of the high areas. Pits opened in the high areas near the uplands will encounter ground water at shallower depths than near the center of the area. The quality and sizes of this material are unknown; therefore it is recommended that, quality samples and depth to bedrock probings be accomplished from two high areas in this portion of the deposit.

Attica Terrace

Initial Detailed Airphoto Study

A. Locality. The deposit in question is located just southwest of Attica on the Wabash River in Fountain County (see location F on Inclosure 4). The deposit is situated just upstream from a rock constriction in the channel. The constriction is in the vicinity of G on Inclosure 4. This indicates that the deposit may have been formed as a result of damming action in the river bed during the glacial epoch. This damming could have caused a decrease in the velocity of the water which resulted in deposition. The rock in the river valley is evidenced by controlled alignment of the streams which flow from the upland, by rough uncultivated topography with random slopes just southwest of Williamsport, and by the random nature of the erosion which does not indicate granular or till materials.

The upland to the southeast of the deposit is an outwash plain over till and rock. Southeast of the deposit there are long sinuous current

markings and infiltration basins, as shown in the vicinity of H on Inclosure 4, which reflect the outwash plain. The glacial till is evidenced to the rear of the deposit in the vicinity of I on Inclosure 4. This granular material of the outwash plain and the underlying glacial till is shallow on rock. Their combined thickness is seen where the rock outcrops in the valley behind the deposit and is estimated to be about fifty feet. This is shown in Figure 5, which is an airphoto stereopair of the Attica terrace with the upland to the rear. Two borders have been drawn on this stereopair. The upland border is the edge of the valley wall. This border is easily determined by the slope break and erosion at the slope break. The second border separates the first and second terraces; where the granular terrace is the first terrace and the till and rock combined form a second pseudo-terrace in the river valley.

The rock outcrop area behind the deposit was identified by the random nature of its topography when compared to the surrounding terrain, by the standing water in two large ponds on its top surface, and by the irregular field patterns adjoining its uncultivated surface. The till was identified by its unconsolidated, non-granular nature; that is, it is deeply eroded and poorly drained with dark gray photo tones.

It is supposed that the glacial waters, when overflowing the rock constriction, eroded a portion of the outwash plain away and exposed the underlying till and rock. This is further justified by considering the shallow granular deposit behind and above the rock constriction just southwest of Williamsport (see location J on Inclosure 4). These materials are presumed to be deposited by the overflow water as a result of a gradient change.

Figure 5. Airphoto stereopair of Attica terrace.

The surface of the deposit should not be affected by alluvial wash from the upland in the areas adjacent to the rock outcrop because the drainage has been deflected away from the deposit by the rock. Upstream from the rock outcrop the alluvial wash will be eroded from the shallow till which is of an unconsolidated nature. This wash material will be deposited as alluvial fans at the base of gullies and as an alluvial apron in the transition zone.

B. Land Form. The surface of the deposit is uniformly level to very gently rolling. The surface relief is due to the shallow infiltration basins which are evenly distributed. There should not be an elevational difference on the surface greater than about seven feet between the highs and their adjacent lows. There are no current scars or ridges which suggest deposition by swift moving waters.

There is a shallow trough at the rear of the terrace that extends along the base of the rock outcrop. Its outline is easily delineated by a slope change which is generally toward the outcrop area. There is a large depression that abuts the outcrop in the trough. This depression appears to have the lowest elevation on the terrace surface. It is estimated that the bottom of this depression is about 15 feet below the average elevation of the terrace surface.

There are evidences of sand dunes along the edge of the terrace. The low irregular shaped dunes are probably formed by sand blown from the flood plain. They do not appear to extend far onto the surface of the deposit.

The terrace face has good gravel slopes along its river edge but where an upland stream cuts it on the downstream end, there are slopes

which are not granular in nature. Here the slopes are more rounded and shallower and indicate a non-granular material. This is especially true as the outcrop area is approached.

The height of the terrace face is about sixty feet above the water level in the river. This appears to be about the same along the length of the deposit.

C. Drainage. The terrace surface appears well drained except in the trough near the outcrop area, where there is evidence of ponding during the wet seasons. The slope of this trough is evidenced from the short drainage lines which lead to the depression.

All streams which affect this deposit are intermittent. The largest of these occurs at the downstream portion of the deposit and forms a boundary for that part of the deposit. This stream has its source in the outwash plain east of Attica. It attains control near the outcrop before flowing out of the outwash plain. It is surmised that rock is contacted at the point where the down-cutting stream is controlled. This means that the rock outcrop is not localized but extends below the outwash plains for some unknown distance. After the outcrop area is passed by this stream, its valley widens and deepens. This appears improper for such a small intermittent stream.

Another intermittent stream flows into the trough at the upstream end of the outcrop. This stream has its drainage area entirely within the area of the second terrace. It flows through an incised portion of the second terrace and is deflected by the outcrop before the terrace surface is reached. Upon contact with the terrace surface there is only a slightly depressed narrow channel which leads to the depression in the

trough. The portion of the stream which flows on the surface of the terrace or in the trough shows no evidence of control. The fact that water does pond in the trough depression probably indicates that the rock does project under this portion of the terrace; however, because infiltration does occur, it appears likely that this is the edge of the rock protrusion.

D. Erosion. Because of the length of the terrace face which has been borrowed, there is little erosional evidence to be observed. Where gullies do exist, there is evidence of uniform granular materials by their short steep gradient. The base of one gully has an alluvial fan with a sharp attitude which indicates granular materials. This gully appears at the upstream end of the large borrow pit.

Erosion of the old borrow pits in the face of the terrace indicates that there is a less resistant strata at the surface with a depth of about ten feet. This is seen where the erosion terminates at a common depth in all pits. A gully in one pit has a freshly deposited alluvial fan at the bottom. This material was washed from the upper ten feet of the deposit and indicates sand.

There is only one area on the terrace surface which is eroding and this is in or near the trough. This erosion is not deep and gives no indication of material types. A point of interest concerns two gullies in the trough. The longer gully appears to connect the depression with the large intermittent stream on the downstream end of the deposit. The smaller gully is superimposed on the larger one and flows into the depression. This reversed flow is indicated by small evidences of distributory flow at the edge of the depression where there probably is a small

alluvial fan. From these gullies it is surmised that the water from the upland is ponded to a certain point in the depression and the excess water flows through the large gully while the remaining water infiltrates into the deposit.

E. Vegetation. The natural and cultural vegetation has no significance in the airphoto pattern of this deposit. Almost the entire surface is devoted to cultural vegetation and the natural vegetation occurs only on the terrace face, along property lines, and in the borrow pits. The date of the photography is June 25, 1939 and the trees are in full foliage. This obscures erosional detail of the few gullies in the terrace face.

F. Photo Tones. The photo tones of the surface of the deposit are generally light and indicative of good drainage conditions. This is not true, however, in the depression area of the trough. Here the dark gray photo tones indicate poorly drained conditions.

The small superimposed gully which flows into the basin in the trough has white photo tones, which indicates a sandy upper stratum of overburden in this area.

The dark photo tones also indicate where the sheet wash has accumulated fines and organic matter in the low areas. This is seen in the infiltration basins on the terrace surface. The tails on the infiltration basins are detectable by photo tone whereas this was missed in the drainage and land form study. These tails indicate that the surface has a more random nature than presupposed before a study of the photo tones.

The sand dune area near the terrace face is discernible by the white photo tones. Also the sand in the alluvial fan at the base of a new gully in the old borrow pit is identified by the white photo tones.

The very light photo tones of the borrow pits and waste pile indicate a very clean, well-drained material.

G. Land Use. The surface of the deposit is used mainly for agricultural purposes; however, no farm houses or barns are seen. The only structure for living purposes is a small house near the terrace face. There is a race track with a grandstand structure on the extreme downstream portion of the deposit.

The majority of the terrace face is being used for borrow pits. The airphoto analysis of the larger pit, which is now in operation, is as follows: The type of operation being used in this deposit is cut and cover (that is, a dragline removes the overburden from the surface of the deposit and places it in the pit in rows where the granular materials have been removed). A shovel loads the granular material into railway cars at the base of the working face. These cars are removed to a screening and washing plant by steam locomotive and then into railway cars on a siding. There is no storage of granular materials in the area. A large waste pile on the flood plain is the accumulation of the washed fines which appear to be sand. The size of this pile with relation to the amount of material removed from the borrow pit indicates that the deposit contains a large percentage of fines smaller than gravel. This pit could be operated by a railroad for ballast material and thus account for the wastage of sizes smaller than medium gravel. The depth of over-

burden appears to be about five feet at the stripping crane. The height of the working face approaches 40 feet and there is no evidence of ground water, because the bottom of the pit is about 10 feet above the elevation of the water in the river.

An analysis of the other pits along the face of this deposit would add little to the investigation other than that there is no evidence of any type of wastage from these pits.

The existing transportation network on the deposit should suffice. A haul road to the working area not longer than a quarter of a mile would have to be constructed to contact the existing roads anywhere on the deposit. There are two railroads. One runs along the terrace face on the flood plain and the other is on the transition zone between the upland and the terrace.

Map and Literature Survey

There is no agricultural soil map for Fountain County.

One mile northeast of Attica there is a shale pit for refractory purposes. The shale is removed by shovel and blasting and has the following section (35):

Soil overburden - - - - -	1.5'
Mansfield (Pa.) Sandstone, iron-stained, thin-bedded - - - - -	10.0'
Borden (Miss.) Shale - -	25 to 30'

The bedrock formations in the county consist of limestones, sandstones, and shales of Mississippian and Pennsylvanian Ages (36).

Near the railroad station at Williamsport the rock dips west-southwest at about 70 feet and to the south at the rate of 40 feet per

mile. Here the section is as follows (37):

Soil - - - - - 1-4'
 Gravel, loose sandstone or drift - - - - - 5-23'
 Gray shale - - - - - 2'
 Sandstone, flaggy - - - - - 16'
 Bit. shale or coal - - - - - 4"

The Wabash Railway has opened a sand and gravel pit along the terrace in sections 12 and 13 (21N., 8W.). There are about 80 feet of gravel exposed in this pit. The material from the pit is good for road making, for cement work and for plastering (38). (This is the large borrow pit in the deposit.)

The river survey topographic map (34) of the area shows the Wabash River in the vicinity of the deposit to have a mean water level of 500 feet above mean sea level. The flood plain at the base of the deposit has about the same elevation. The top of the terrace face has an elevation of 560 feet above mean sea level and is generally level throughout the surface. The map does not show the upland behind the deposit. A temporary bench mark was established on the Wabash Railroad at the base of the gravel pit and it has an elevation of 515 feet.

Evaluation

The evaluation of this deposit should not be too concerned with the suitability of the materials because the extent of the developed borrow pits indicates an aggregate of high quality. Also, the granular materials are indicated to have a large percentage smaller than medium

sized gravel. Thus, the evaluation should be concerned with the extent of the remaining aggregate and the utilization of an existing pit for a work area.

It appears that the outwash plain, to the rear of the deposit, existed prior to the valley widening which sluiced the materials off of the rock that outcrops in the valley behind the deposit. High rock outcrops on both sides of the river just downstream from the deposit indicate that the deposit could have been initially formed as the result of damming action of the river in glacial times. This would mean the deposits should contain a high percentage of sand. The waste pile at the bottom of the large borrow pit indicates that this is true. Also erosion of the upper ten feet in all pits indicates a uniform sand stratum at the surface.

The large borrow pit has been worked almost to the rear edge of the deposit and no rock has been encountered. Downstream from this pit there are smaller pits in the terrace face. These smaller pits reveal no evidence for the reason why the borrowing operation was discontinued. The airphoto pattern indicates that good granular materials, the type encountered in the large pit, exist from the face to the trough near the rock outcrop area. This trough indicates an impervious stratum below but the fact that it does drain indicates that granular materials are adjacent.

There are some controlled slopes in the stream, Naves Branch, at the downstream portion of the deposit. These are indicated to be rock. It is therefore concluded that the best borrow pit to work would be the one on the terrace face between the large borrow pit and the race track.

This pit may be worked to the county road, then either the road should be relocated or the operation continued on the opposite side. This operation can continue until the bedrock is reached. The rock is estimated to be in the immediate vicinity of the trough at a depth of less than ten feet.

The estimated amount of borrow material available is 365,000,000 cubic yards. The material may be moved by road or rail facilities.

It is recommended that three soundings be made from the surface of the deposit in the vicinity of the trough to determine the depth of bedrock. Also, two soundings should be made along the expected downstream boundary of the deposit. This would be on a line extending the grandstand portion of the race track. Quality samples from the pit should suffice for the deposit for general planning purposes.

Section 4: Results

The following is a summary and correlation of the field investigations of the Independence and Attica terraces and the conditions predicted from the airphoto and literature evaluation. The field information was obtained by visual inspection because equipment for sub-surface exploration was not available. Therefore, particular attention was given to the gullies and borrow pits to determine the sub-surface conditions of the deposits and their localities.

Independence Terrace

Bedrock was first encountered downstream from Lafayette at about the Warren County-Tippecanoe County line along a road on the north side of the Wabash River. Here there was a low rock defended terrace with about five feet of granular overburden on horizontal sandstone bedrock.

One mile beyond the above point, the road was located on a rock defended upland. This point is indicated by point K on Inclosure 3. Here most of the till has been washed off of the rock and fields contain numerous large boulders.

At point L on Inclosure 3 rock was seen in the canyon of Little Pine Creek. This rock was predominantly sandstone and had a section which was about 85 to 100 feet above the water level in the Wabash River.

At point M on Inclosure 3, rock has deflected Little Pine Creek at the flood plain. This rock consisted of thick sandstones with thin interbedded shales. The same type of rock was seen to outcrop near the road junction at point N on Inclosure 3.

The above rock outcrops above Independence on the Wabash River are in the vicinity of C on Inclosure 3 where it was predicted that rock causes the constriction of the river valley walls. The type of rock was not predicted from airphotos.

The airphotos indicated rock in the intermittent stream at the extreme eastern end of the deposit. This was substantiated by observing thin platy sandstone in the stream channel at point O on Inclosure 3. Also where the airphotos indicated rock near the surface of the deposit which controlled this stream channel, a massive bed of sandstone was evidenced.

The gullies described in Figure 4 were found to be as predicted. Gully A was in gravel at the upper end and then transitioned into till which is perched by rock. Here the till was estimated to be about ten feet deep over the rock and at a depth of 15 feet below the surface of the deposit.

The rock island-like projection at the bridge over the Wabash River was found to be as predicted. The steep river slope on the north side of the river was interbedded sandstone and shales. Behind this projection till was found. The airphotos indicated a non-granular unconsolidated material.

The intermittent stream which flows through Independence was found as predicted from the airphotos. There was platy sandstone in the channel and sandstone and shale in the stream banks near the controlled portions.

Borrow pits in the current ridges of the northeastern portion of the deposit had a sandy silt overburden of about two feet in depth. The stratas were cross-bedded, which indicated deposition by currents from varying directions. The materials ranged in size from three-inch cobbles to sand with a predominance of coarse gravels.

The water level of the large pond to the rear of the deposit was about ten feet below the surface of the surrounding area. The depth of this pond was not determined in the field.

At point P on Inclosure 3 a borrow pit was found with ten feet of gravel overlying conglomerate. The conglomerate extended for an undetermined depth. It was cemented with calcium carbonate, which was probably leached from the gravels and then precipitated out of the ground water. Conglomerate was also found to outcrop in a few small places on the deposit side of Kickapoo Creek. These were not seen from airphotos because of the small airphoto scale and the dense vegetation.

At the area near Q on Inclosure 3 a high massive sandstone bluff was encountered. This bluff had a height of about 90 feet.

Attica Terrace

As indicated by the airphotos, rock was found to be the cause of the constriction in the Wabash River channel below the deposit. In the vicinity of R on Inclosure 4, numerous outcrops of sandstone and shale were encountered. At point S on Inclosure 4, a very thick bed of thin plated sandstone was found with little or no shale and only about two feet of granular overburden. Also near point S there occurred a waterfall in a gully on this same thick sandstone rock. The height of the top of the falls was about 35 feet from the flood plain. At point T, two feet of gravel was found on a thick strata of thin, platy, dark shale.

The field investigation checked the prediction of sand dunes on the edge of the terrace. These dunes were only about eight feet high. The extent of the wind blown sand could not be determined because of the general sandy nature of the overburden of this deposit.

Investigation of the borrow pits showed about one foot of silty sand over about eight feet of sandy gravel. This in turn was over approximately 50 feet of clean granular material which ranged in size from three inch cobbles to sand. The deposit consisted predominantly of gravels and sands of which the sizes ranged from 1 1/2 inches of coarse sands. The three inch cobbles occurred in one strata at a depth of about 25 feet below the surface. The waste pile at the gravel pit contained all sizes smaller than 1/2 inch gravels. The pit was being worked by a railroad company for ballast material. Although the range of grain sizes could not be determined from airphotos, the conclusion that the waste pile consisted of material smaller than medium gravel size was a valid prediction.

As predicted, no ground water was found in any of the borrow pits. There were no indications of why excavation had ceased in the other borrow pits.

At point U, on Inclosure 4, a small rock quarry was found in a gully with twenty feet of granular overburden on sandstone. It was surmised that the quarry was used for obtaining building stone for the local area. The airphotos indicated rounded slopes across the stream from the gully and a prediction of rock was made for this area.

Point V on Inclosure 4 indicates the location of a high massive sandstone wall. This is in the outcrop area which was pointed out from the airphotos. The high wall was not visible from the airphotos because of the dense vegetation, but there were indications of rock which was predicted.

CHAPTER V

CONCLUSIONS, AND RECOMMENDATION

Conclusions

The results obtained and the conclusions which may be made from this study are as follows:

1. After locating fluvio-glacial terraces from airphotos for possible borrow areas, it is economical and practical to make a detailed airphoto evaluation of the deposits.
2. The detailed airphoto study of a granular terrace should follow a logical procedure, such as the guide presented in this thesis.
3. The airphoto study should be supplemented by existing detailed literature.
4. Information which cannot be determined from airphotos are grain size, presence of deleterious materials, wearability of the materials, and depth to stratas within the deposit.
5. Ground investigation is necessary before the borrow operation begins to supplement, check, and add to details obtained from the airphotos and literature.
6. The amount of detail obtainable from airphotos is dependent upon the scale and season of the photography.

Recommendation

It is recommended that the procedure prescribed in this thesis be applied to the Engineering Soil Mapping Project, conducted by the Air-photo Laboratory of the Joint Highway Research Project.

BIBLIOGRAPHY

BIBLIOGRAPHY

1. Frost, R. E. and Mollard, J. D., New Glacial Features Identified by Airphotos, Bulletin 29, Joint Highway Research Project, Purdue University, 1940.
2. Frost, Robert E., Factors Limiting the Use of Aerial Photographs for Analysis of Soil and Terrain, Photogrammetric Engineering, June 1943.
3. Frost, Robert E., Identification of Granular Deposits by Aerial Photography, Proceedings, Highway Research Board, Volume 25, 1945.
4. Frost, Robert E., Airphoto Patterns of Southern Indiana Soils, A Thesis Submitted to the Faculty of Purdue University in Partial Fulfillment of the Requirements for Civil Engineer degree, Purdue University, 1946.
5. Frost, Robert E., The Use of Aerial Maps in Soil Studies and Location of Borrow Pits, Proceedings of the Kansas Highway Engineering Conference, Kansas Engineering Experiment Station, Bulletin 51, 1946.
6. Frost, Robert E., Evaluation of Soils and Permafrost Conditions in the Territory of Alaska by Means of Aerial Photography, St. Paul District, Corps of Engineers, Department of the Army, 1950.
7. Hittle, Jean E., An Inventory of Granular Materials in Indiana, Proceedings, 31st Annual Purdue Road School, March 1944.
8. Miles, Robert D., Preparation of Engineering Soils and Drainage Surveys from Aerial Photographs, Proceedings, 36th Annual Purdue Road School, April 1950.
9. Moore, R. W., Geophysical Methods of Subsurface Exploration Applied to the Location of Sand and Gravel, Circular 37, National Sand and Gravel Association, 1950.
10. Flint, Richard F., Glacial Geology and the Pleistocene Epoch, John Wiley and Sons, Inc., 1947.
11. Twenhofel, William H., Treatise on Sedimentation, Williams and Wilkins Company, 1932.

12. Patton, John B., Gradation and Composition of Indiana Gravels, Rock Products, May 1953.
13. ———, Handbook of Indiana Geology, Department of Conservation, Division of Geology, 1922.
14. Leverett, F. and Taylor, F. B., The Pleistocene of Indiana and Michigan, Monographs, Volume 53, United States Geological Survey, 1915.
15. ———, Indiana, A Guide to the Hoosier State, American Guide Series, Department of Public Relations, Indiana State Teachers College, Oxford, University Press, 1941.
16. Trewartha, Glenn T., An Introduction to Climate, McGraw-Hill Book Company, 1954.
17. Tolman, C. F., Ground Water, McGraw-Hill Book Company, 1937.
18. Stokes, W. L. and Varnes, D. J., Glossary of Selected Geologic Terms, Colorado Scientific Society Proceedings, Volume 16, 1955.
19. Parvis, Merle, Regional Drainage Patterns of Indiana, in Partial Fulfillment of Requirements for Civil Engineer Degree, Purdue University, June 1947.
20. Spurr, Stephen H., Aerial Photographs in Forestry, Ronald Press Company, New York, 1948.
21. Smith, H. T. U., Aerial Photographs and Their Applications, D. Appleton Century Company, New York, 1943.
22. Cotton, C. A., Classification and Correlation of River Terraces, Journal of Geomorphology, 3, 1940.
23. Johnson, D. W., Problems of Terrace Correlation, Geological Society of America, Bulletin 55, 1944.
24. ———, Index to Topographic Mapping in Indiana, Map Information Office, United States Geological Survey, December 1954.
25. ———, Index to River Surveys Made by the U.S.G.S. and Other Agencies, Geological Survey, Water-Supply Paper 995, United States Department of Interior, 1948.
26. ———, Engineering Use of Agricultural Soil Maps, Bulletin 22, Highway Research Board, 1949.
27. ———, Geologic Map Index of Indiana, Scale: 1:750,000, United States Geological Survey, 1950.

28. Wilmarth, M. G., Lexicon on Geologic Names of the United States (including Alaska), Bulletin 896, two parts, United States Geological Survey, 1938.
29. Woodward, T. P. and Gueno, A. J., The Sand and Gravel Deposits of Louisiana, Geological Bulletin 19, Louisiana Geological Survey, 1941.
30. Belcher, D. J., Gregg, L. E., and Woods, K. B., The Formation, Distribution and Engineering Characteristics of Soils, Engineering Bulletin, Purdue University Research Series 87, Highway Research Bulletin 10, 1943.
31. ———, Soils and Men, Yearbook of Agriculture, United States Department of Agriculture, 1938.
32. Grimes, E. J., Soil Survey of Warren County, Field Operations of the Bureau of Soils, 16th Report, United States Department of Agriculture, 1914.
33. Collett, John, Geology of Warren County, 57th Annual Report of the Geology Survey of Indiana, 1874.
34. ———, Wabash River and Valley, Charts Nos. 26 through 30, River Survey, United States Corps of Engineers, Louisville, Kentucky, 1929.
35. Whitlatch, G. I., The Clay Resources of Indiana, Publication 123, Indiana Department of Conservation, Division of Geology, 1933.
36. Yang, Shihte, Airphoto Interpretation and Soils of Fountain County, Indiana, A Thesis Submitted to Purdue University in Partial Fulfillment of the Requirements for Master of Science in Civil Engineering Degree, 1947.
37. Stockdale, Parvis B., The Borden (Knobstone) Rocks of Southern Indiana, Publication 98, Indiana Department of Conservation, Division of Geology, 1931.
38. Scovell, J. T., The Roads and Road Materials of a Portion of Western Indiana, 30th Annual Report, Indiana Department of Geology and Natural Resources, 1905.

- COUNTY BOUNDARY LINES
- SECTION LINES
- (500) ELEVATION ABOVE M.S.L. (500')
- STATE ROUTES
- U.S. ROUTES

DRAINAGE MAP OF PORTIONS OF FOUNTAIN, TIPPECANOE, AND WARRICK COUNTIES, INDIANA

PORTIONS OF FOUNTAIN, TIPPECANOE, AND WARREN COUNTIES

DRAINAGE MAP COMPILED FROM INDIVIDUAL
DRAINAGE MAPS OF FOUNTAIN, TIPPECANOE
AND WARREN COUNTIES PREPARED BY
J. H. R. P. PURDUE UNIVERSITY FROM AIRPHOTOS

INCL. I

INCL.3

WARREN CO.

US 41

BIG PINE CREEK

SR 56

WILLIAMSPORT

ATTICA

SR 28

SR 28

WEST LEBANON

FOUNTAIN CO.

US 41

SHAWNEE CREEK

INCL.4