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Highway-Materials Surveys

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Foreword

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THE problem of obtaining suitable aggregates and granular materials for highway-construction purposes under present economic and construction conditions is a major issue at the present time in many states and fast becoming the same in others. It is only a matter of time under modern demands until present acceptable sources of highway materials will become completely exhausted; therefore, new sources within economic hauling distances must be discovered to replace them. With these facts inevitable, the Committee on Material Surveys was established in 1947 by the Highway Research Board, in the Department of Materials and Construction, to study this problem.

The immediate assignment of the committee was to bring the art of material surveys up to date with the inclusion of geophysical exploration and aerial photography in conjunction with methods now in use. This would entail a study of literature and work of various research and engineering agencies and also the preparation of a bibliography.

The scope of the committee's work was understood to include all aggregate materials emanating from natural gravel deposits or rock formations which are necessary in the construction of different types of highway surfaces and granular subbases. The committee has confined its activities primarily to three specific objectives: (1) to conduct a world-wide survey to determine material-survey methods employed by the states and foreign countries; (2) to prepare a bibliography on the subject; and (3) to assemble and publish the most useful information consummated under the committee's work program.

The work has revealed that the needs of the states in locating materials are various, as one might expect in a country as vast as the United States. In certain states in glacial areas with thin topsoils, most gravel resources can be checked by surface inspection; whereas in other states, there is apparently a limitless supply of granular materials, but the deposits usually cannot be located except by subsurface exploration. Furthermore, some states are using their material resources faster than they can discover new ones, while others have such an abundance that they are not concerned with the likelihood of ever depleting their resources.

Furthermore, it is clearly indicated that the states have been slow in attacking the problem of material depletion. Although all states report using the old standby methods of test pits, sampling outcrops and exposed surfaces, only 15 states have accepted power augers; of these only three have facilities for deep-boring operations. Only four states have actually done work using well-known geophysical methods for material surveys and only two states have experience in airphoto methods. However, all of the states evidenced an interest in the more modern methods and a desire to learn more about them.

It is the intent of this symposium to bring before the reader the latest information and developments in the field of materials surveys and in such a manner as to be readily usable by those in immediate need of such information. Bibliographical data assembled by the committee will be found at the end of the four subject papers.

The papers cover only the more modern aspects of the problem of material surveys. The work of the committee revealed that the techniques employed in current soil-survey practices and exploration procedures by hand test holes and mechanical boring methods, as related to material surveys, were so well-known to highway engineers that it was believed unnecessary to repeat such information in this symposium.

The order of presentation is that representative of an attack on a materials problem. At the start, proper attention must be given to geological considerations. A thorough knowledge of the local geology is an essential prerequisite for any material survey. In connection with geological considerations, aerial photographs have now become a very valuable adjunct to agricultural and geological maps in material prospecting as a timesaver as well as an economic measure. With the establishment of possible material deposits through the foregoing methods, geophysical explorations can now be employed to locate and outline material deposits supplemented, as necessary, with borings or manually dug test pits. Finally, the recording and disposition of information relative to existing sources of suitable materials, as well as the recording of possible new sources for future use, should be a regular function of all state highway organizations.

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How to Use Airphotos and Maps for Material Surveys

OLIN W. MINTZER and ROBERT E. FROST, Purdue University

SYNOPSIS

IN areas where either geologic maps or soil-survey maps are available, materials prospecting is relatively simple if the engineer or soil surveyor understands and interprets the terminology and mapping units used by the agriculturalist and the geologist. The use of airphotos and simple field checks reduces the cost considerably.

This paper presents information on how to classify engineering materials in an area using aerial photographs, agricultural soil maps, topographic maps, geological maps, and combinations of these. Its scope is limited to a demonstration of procedure and a comparison of methods based on surveys of four areas in southwestern Indiana. Several types of materials are mapped and the materials and the methods used to identify them are discussed in detail. For purposes of comparison the discussion about each method of survey has been divided into: (1) principles, (2) techniques, (3) keys, (4) limitation, and (5) examples. The techniques used are based on evaluation of natural and physical environmental features as recorded in the airphotos.

A suggested procedure for conducting a material survey using airphotos is proposed. For the purpose of this paper the analysis of materials in an area is based on the use of the "pattern elements" as the primary interpretation key. Each situation is analyzed from the standpoint of what the various natural elements suggest about the probable characteristics such as drainage, soil profile development, relative textural range, and workability.

The limitations of the airphoto method fall into three general categories: natural, photographic, and human. The natural limitations are caused by variations in climate, erosional features, and vegetation. Photographic limitations include the type of photography, the scale of photographs, and the completeness of stereo coverage of the area under study. The human limitation is obvious and affects every phase of the process of interpreting airphotos.

The interpretation and application of agricultural soil maps, topographic maps, and geological maps for materials survey are discussed in a similar manner. The four areas used to illustrate each method in this paper provide a practical means of comparing the relative virtues of each method. The combined use of maps and airphotos is shown to be exceedingly practical.

● ONE of the most important phases of highway and airfield engineering is the survey for the location of suitable engineering materials for use in improving the subgrade. As far as road location and airfield-site selection are concerned, the best sites are those containing well-drained, granular soils which offer good support even in their natural state. However, there are many factors which influence site selection or route location and it is not always possible to pick the best site from the standpoint of engineering soils. Some of these factors might include high cost of right-of-way, inability to obtain land, location difficulties, and inadequate data about the soils of the region. In such instances, material location becomes extremely important. Available sources of suitable material must be found in order that good performance can be assured throughout the life of the project.

There are many methods of conducting material surveys for use in highway or airfield engineering, some of which include: study and analysis of geologic and pedologic literature; study of well-log data; personal contacts with land owners, contractors, and materials interests; field reconnaissance of an area either on foot, on horse, by car, or from the air; detailed soil boring operations; the use of geophysical methods; and the use of aerial photographs. Some of these methods are

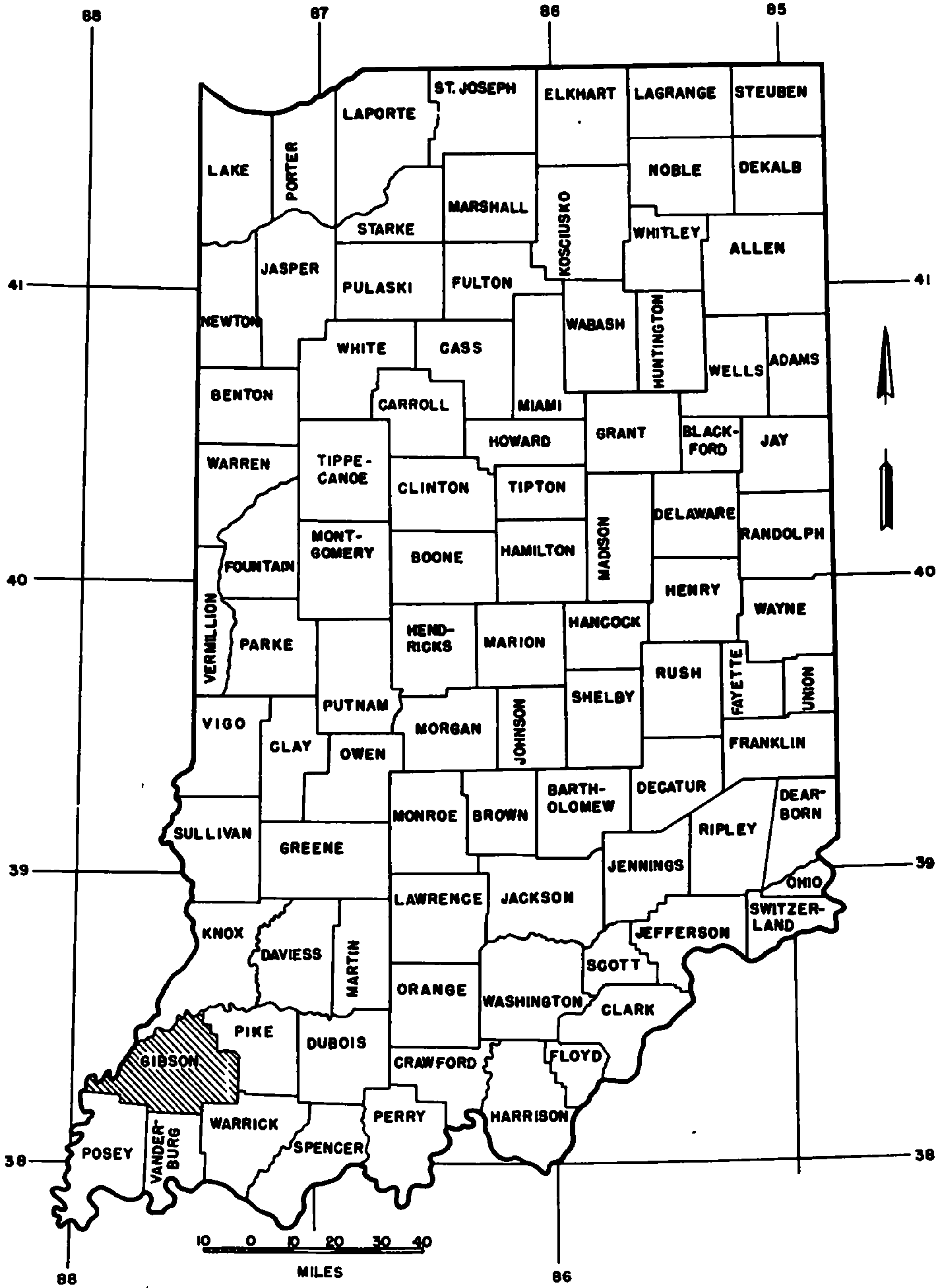

Figure 1. Map of Indiana showing location of example areas. The four site areas studied are within the blocked-in area of Gibson County.

rather detailed and will result in accurate findings. Many of them merely serve as guides for the materials prospector, showing him where to look or where to sample.

In connection with using well-log data for materials prospecting, such data are often impossible to locate since many well drillers do not file their data with state agencies. In some areas it may not be possible to gain access to an area for survey because of difficult topography, dense timber cover, lack of convenient transportation facilities, or lack of permission on the part of the land owner. From the military standpoint, an area may be inaccessible because of enemy activity. Conversations with land owners about materials are apt to be misleading because of the wide differences of opinion on what constitutes good sand and gravel. Many potential deposits may have been overlooked simply because of lack of information about their expected occurrence in an area.

Surveys of a reconnaissance nature made on foot or by horse, car, or aircraft are costly and time consuming but can be made quite reliable if the prospector grasps the areal perspective of deposits or topographic situations, viewing such as entire units. On the ground it is difficult to recognize the features associated with certain types of materials simply because of the inability to see great distances or because of natural or man-made obstructions. Occasionally a rapid reconnaissance survey for materials may be made from the air using a small, slow plane flying at low altitudes. This permits the observer to cover a considerable area in a short time. It may be difficult to identify all features associated with granular deposition or certain rock types by an aerial reconnaissance. Many outstanding deposits may be located in this manner if the vegetative cover, the human perspective, the influence of crop cover, and field patterns are used to assist gathering details. Some of these methods are much more useful and more quickly accomplished if done in conjunction with airphotos, agricultural soil survey maps, geology maps, or topographic maps, when such information is available.

Need for Information to Assist Material Surveys

The materials prospector has available four reliable methods of locating materials for use in engineering construction. They are not easy to use, but once the principles of their application have been learned and tested, it will be found that considerable time and expense can be saved through their use. These methods, or tools, require the materials prospector to learn a new language—to reorient his concepts of

Figure 2. Topography typical of the top of Mumford Hills.

materials occurrence and location. The methods referred to are: (1) the use of aerial photographs; (2) the use of agricultural soil survey maps; (3) the use of geological maps; and (4) the use of topographic maps.

These tools cannot be used without previous study directed toward developing an understanding of the principles and techniques. Basically there are two approaches to the use of any or all of these four methods: (1) the use of prepared keys and (2) the application of the principles of the method itself. Research personnel can prepare keys for use by others. These keys must be translations of the data into engineering terminology. Proficiency of the key method depends on the completeness and clarity of the key, as well as upon the user being able to grasp its significance. Considerable background study coupled with detailed field sampling is needed in the approach based on development by application of the principles of the method used. Ultimately, a key is not necessary as proficiency is gained. However, time and cost does not permit the use of the latter on a widespread basis for materials survey. Hence, the basic need is for the preparation of guide keys to permit efficient utilization of these four methods.

In areas where geologic, physiographic, soil-survey, and in some instances, topographic maps are available, prospecting for materials is relatively simple if the engineer or soils surveyor can translate the terminology and mapping units into engineering test data from similar situations obtained elsewhere. In some instances, the mapping units representing potential material are all inclusive and refer to a soil type belonging to a particular agricultural catena or to water-deposited materials of a certain geologic age. A true surface-material picture is not comprehended because of unfamiliarity with literature and maps of this type. Confusion exists in the minds of those unable to translate the literature used by the soil scientist, agronomist, geologist, or others talented in the fields of natural earth sciences. It is difficult to ascribe the proper engineering significance.

Those who conduct detailed study of agricultural, geological, and topographic maps and accompanying literature and who can translate the data to engineering materials and their related problems will be able to accomplish a good job of materials prospecting. This can only be accomplished if literature about an area is available and if the engineer or surveyor has had experience with the maps in the field. There is considerable literature concerning the use of various types of nonengineering maps for soil and material surveys. Most of the literature, however, is in the nature of progress reports or reports of an investigational nature and are not the manual type or the how-to-do-it type. Because of the confusion due to the many names of soils and rocks keys have not been representative and the user must conduct his own research to correlate the soils, as named, or rocks, as named, with engineering soils. In addition, reports discussing the principles of the various mapping methods have not been prepared which would assist the materials prospector in comprehending the system before he attempts to ascribe an engineering significance to the data.

Literature Study for Material Surveys

No matter which tool is used to prepare material-survey data there is a certain amount of study required on the literature of the area to be surveyed. The literature which will be significant in assisting the survey is that written concerning pedology, physiography, geomorphology, geography, agriculture, and climate. The purpose of reviewing such literature is to gain a perspective concerning the area. This perspective includes knowledge of the landforms expected with general information as to the surface and subsurface conditions related to each landform. In general, this perspective formulates in the mind of the surveyor a picture of what to expect in an area.

It is anticipated that the perspective will enable the surveyor to obtain more significant data from each of the tools he may wish to use (airphotos, agricultural soils maps, geological surveys, and topographic surveys). On the basis of the arrangement of landform units and topographic position within each landform unit, the materials are determined from details available in connection with the specific tool used. Map symbols are prepared to represent landforms, and in turn, landform units are subdivided with appropriate map symbols, based on topographic position. The symbols concerning topographic position are based upon the general class of materials, such as silt, sand, or gravel, to be found in a particular topographic position.

Purpose of This Report

The purpose of this report is to set forth a few principles of the methods of analyses, mapping, and presentation of

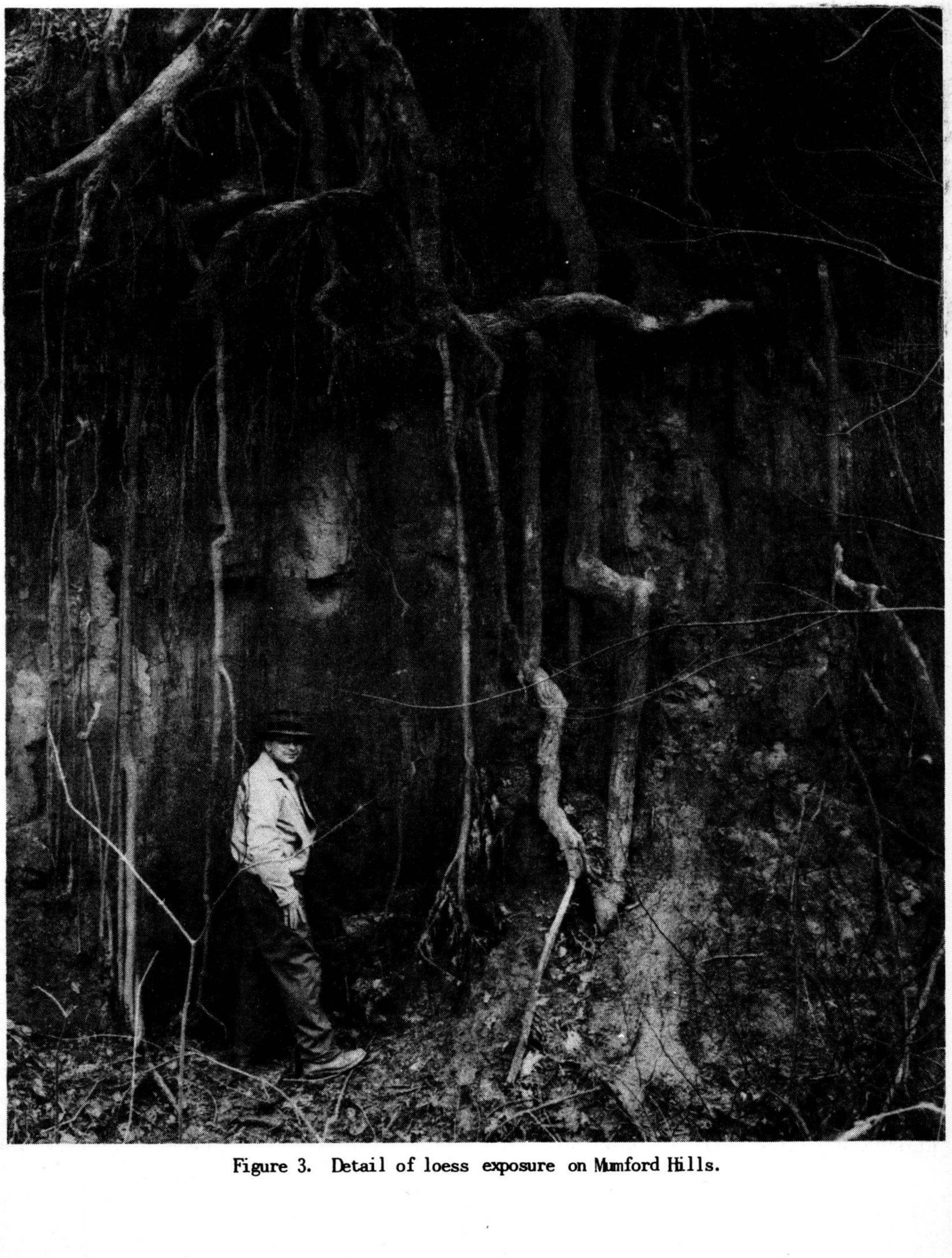

Figure 3. Detail of loess exposure on Mumford Hills.

soil and materials data from aerial photographs, agricultural maps (soil survey), geologic maps, and topographic maps and to illustrate by example how to use aerial photographs, agricultural soils maps, geological maps, topographic maps, and combinations of these for conducting engineering-material surveys.

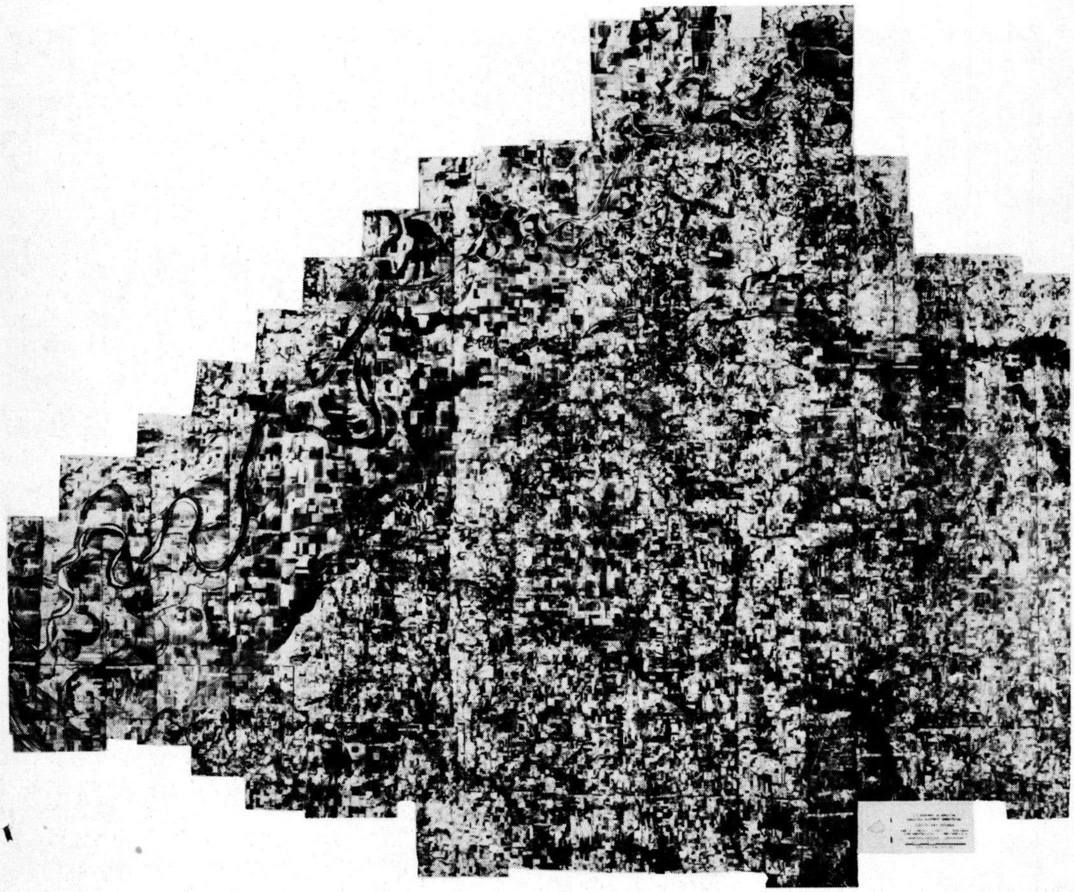

Figure 4. Airphoto mosaic of Gibson County.

Scope of This Report

This report presents qualitative information on the use of aerial photographs, agricultural soil maps, topographic maps, geological maps, and combinations of these media for making engineering-material surveys. The scope is limited to a short discussion of principles, techniques, keys, limitations, and examples for each of four major tools. Four areas in southern Indiana were selected for use in this study (see Fig. 1). Each area was surveyed with each of the four methods, and material maps were prepared. In order to illustrate the methods involved, the discussion of each tool is applied to a different area of the four selected. The last part of the report shows how all methods can be combined to obtain material information. The discussion on principles in the section of airphotos is limited to airphoto-interpretation principles in general. The discussion of principles for the other three methods has been limited to the manner in which technical data are presented in the various surveys and the engineering significance of each tool is given as it is applied to a particular area. The discussion on techniques in each section is concerned with how to do it, or standard procedures to be followed in using the method. The section on keys presents a discussion on various keys in existence or those being developed currently. The limitations of applications of each method are discussed also. The scope is further limited to discussion of granular materials.

Visual Aids Used in This Report

This report is illustrated with aerial photographs, ground photographs, charts, tables, diagrams, and photographic copies of maps for the convenience of presentation of the data and methods of conducting material surveys. The high cost of color printing precludes the use of colored symbols on the geology and agricultural soil maps. Original map colors are named and the symbols are drafted reproductions.

MASTER KEY DEVELOPMENT FOR EXAMPLE AREAS

The first major section of the report is given to the development of a master key which would be used in a material survey in any location whether being conducted by these methods or not. The key is then made to fit the location of the example by adding local details in discussions of each area.

Key

Regardless of the method of survey used, the materials prospector must group deposits in some fashion. The landform (topographic position arrangement) has proven a useful means of grouping materials. There are three major topographic situations in which granular materials may occur in this particular area. The three divisions are referenced to the base level of erosion. These are lowlands, terraces, and uplands. Each of these may vary from a few hundred yards to several miles in extent. Within any one of the three groups there are many minor or local topographic situations. Lowlands can be divided into low lowlands and high lowlands, which divisions might correspond to first and second bottoms of a flood plain. Within these two major positions can occur depressions, rises, and intermediate level areas. In the same manner, terraces can be divided into low terraces and high terraces with each further subdivided into depressions, rises, and intermediate areas. Uplands, for the sake of simplicity, are divided into depressions, rises, steep slopes, and intermediate areas.

A diagrammatic sketch showing this arrangement has been prepared (see Fig. 23). The letter L indicates lowlands, T indicates terraces, and U indicates uplands. The relative position for subdivisions appear as H (high) and L (low) before the letter of major landform position. Local topographic situations are indicated numerically following the letter of major position as 0 (depression), 1 (intermediate), 2 (rise), and 3 (steep slope). Thus, the symbol HL0 is a depression on an elevated lowland.

The concept of this arrangement is important: it has considerable engineering significance. The formation of soil profiles is influenced strongly by topographic position. The occurrence of certain types of granular-material deposits can be understood more easily by comprehension of the landform-topographic-position arrangement. Such items as occurrence of ground water and surface water depend to a large extent on the topographic position with respect to the base level of erosion. Usually the thickest overburden of undesirable materials occurs in depressed topographic situations in either lowland, terrace, or upland deposits.

Figure 23 becomes a master key because it contains descriptive data which can be used to correlate the various mapping units with the above landform-topographic arrangement. Provision has been made for short description of supplementary data on the diagram pertaining to airphotos, agricultural soil series, geological name, physiographic type, topography, and engineering materials. The key now becomes applicable only to the locale of the examples because the mapping units would be different in other areas.

In the discussion under each method this key will be referred to since all mapping has been reduced to the key units and subdivisions. It is to be used in connection with the particular key developed for a particular method.

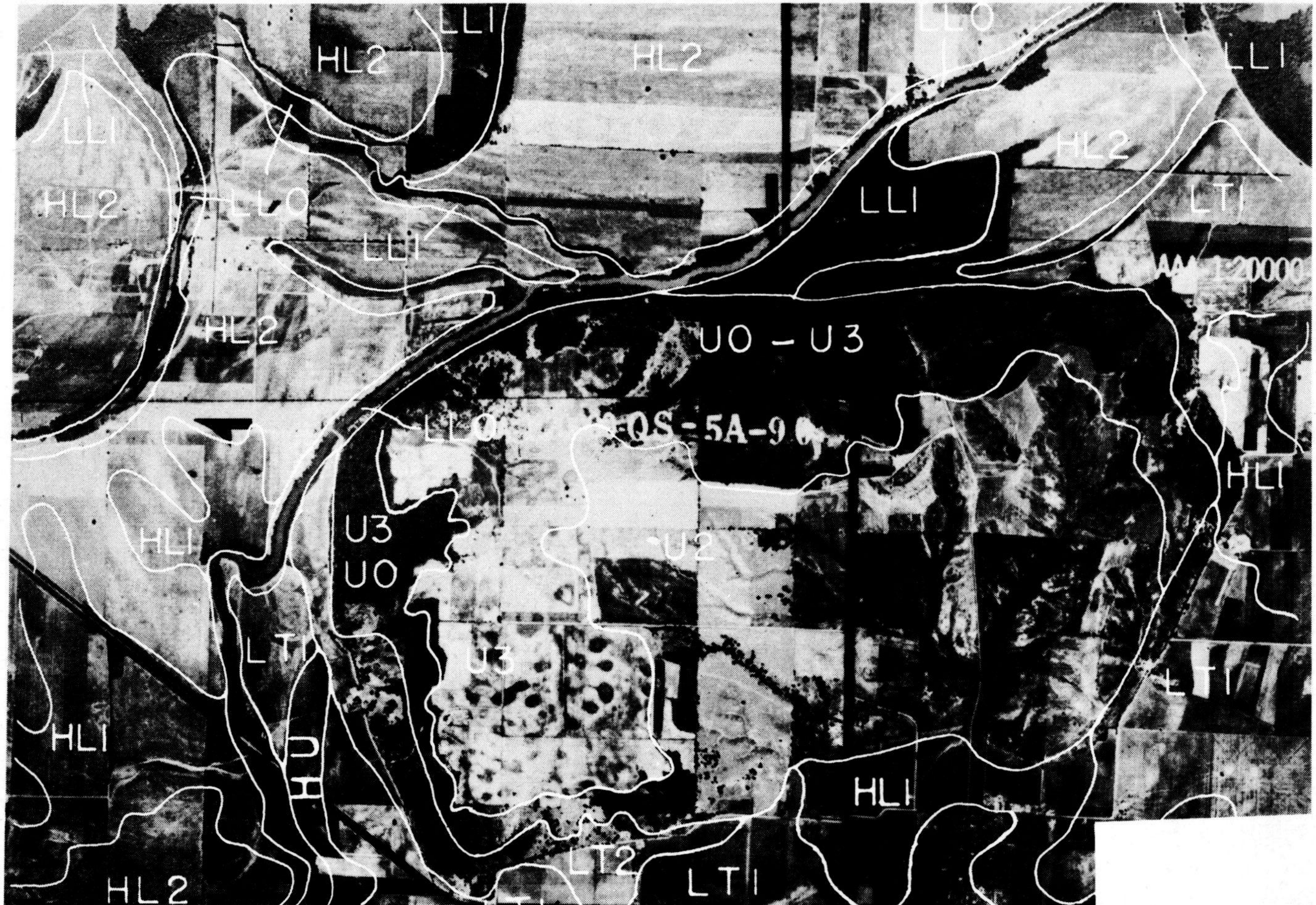

Figure 5. Airphoto of the Mumford Hills area.

AIRPHOTO METHOD OF MATERIAL SURVEY

An aerial photograph is a pictorial representation of both the natural and man-made features of the earth's surface. It pictures the sum and total of natural and physical environment. It pictures a pattern which is created by the forces of nature and modified by the forces of man. In cultivated regions one gains the impression that the pattern consists of a checkerboard field pattern and other man-made features. In a heavily forested area one gains the impression that the region is carpeted with vegetation, perhaps dense enough to obliterate surface detail. In an arid or desert region one is likely to gain the impression of a complete absence of any recognizable feature other than "oceans of sand." However, regardless of climate, vegetation, location, or man's influence, to the trained observer who gives the airphotos careful study there is another pattern distinct from the superficial vegetative pattern: the natural pattern. Through detailed study and proper evaluation of this natural-pattern mapping of soil and bedrock is accomplished.

Much has been written on this subject and only a brief review will be presented for the purpose of this paper. The reader is referred to reference material in the bibliography.

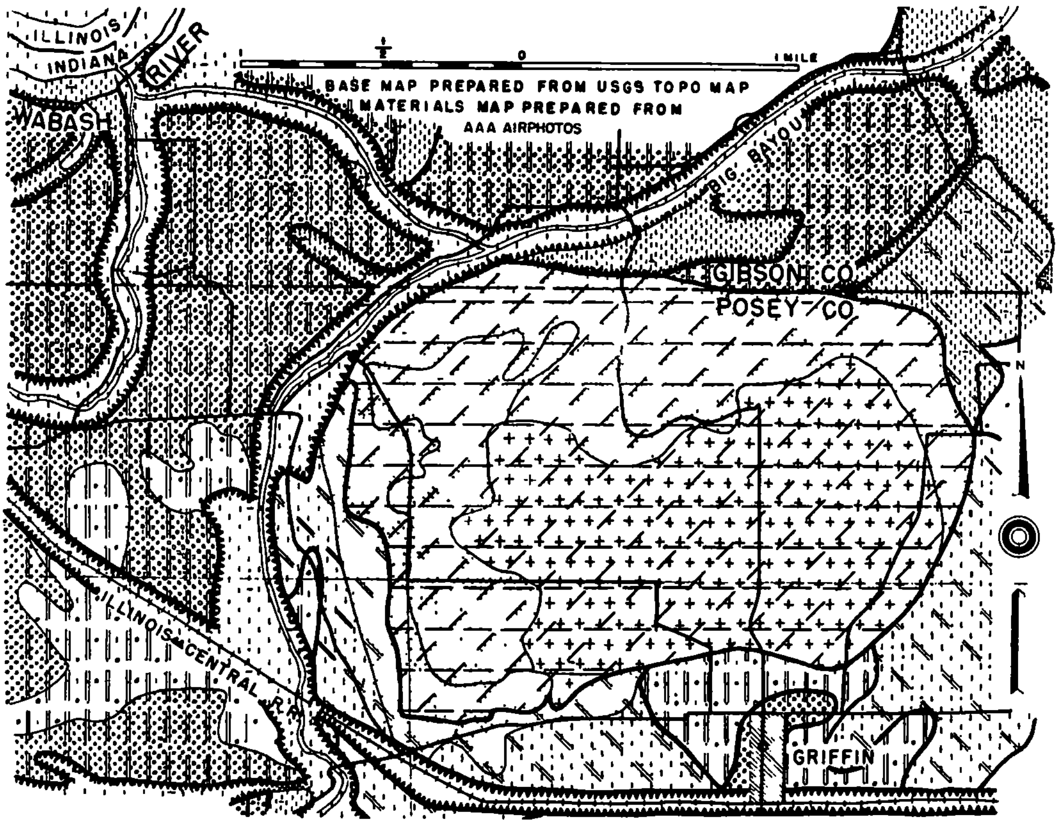

Figure 6. Engineering-materials map of Area F, Mumford Hills, Gibson County, Indiana.

Principles of Soil Evaluation from Airphotos

The analysis of an aerial photograph is based on determining the origin of a deposit and tracing the erosional history which was responsible for its present-day landscape. The pattern of a deposit, or of an area, is an accumulation of surface features which reflect the subsurface.

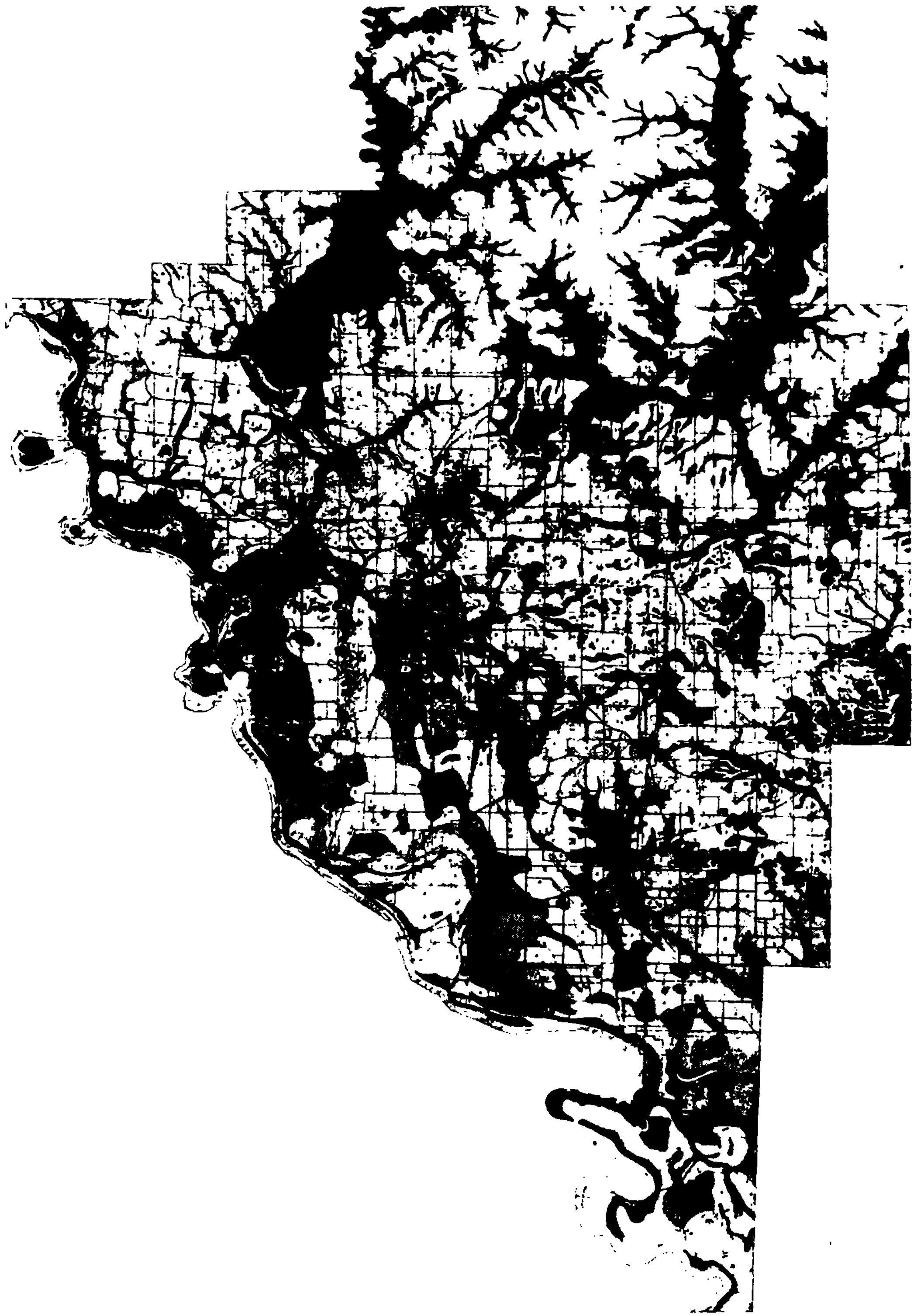

Figure 7. Gibson County Agricultural Soils Map.

Soil deposits, soil-parent materials, or soil-rock groups are areal in extent and are closely associated with the major geologic and physiographic divisions or regions; hence, the earth materials create a variety of patterns all of which are recognizable in aerial photographs because of certain contrasts between them.

A soil pattern is composed of certain physical features which can be grouped into elements of a pattern, all of which are recognizable on airphotos. Without a specific key it is necessary that the interpreter group the physical features into some classification system which lends itself readily to use and to easy analysis. The natural elements of the pattern are landform, areal-drainage pattern, gully systems, soil color tones, vegetation, special elements and man-made features.

Landform reflects geology and physiography, since it is closely associated with origin and subsequent erosional history. Landform refers to the landscape, the arrangement of the physical features.

The areal-drainage pattern also reflects geology and physiography. In addition, it reflects the general porosity of a soil-parent-material area. Six major types of patterns include dendritic, trellis, annular, radial, parallel, and rectangular.

Gully systems and gully characteristics reflect soil textural properties, and profile development. Changes in gully characteristics reflect changes in soil properties. In general, granular soils exhibit short, stubby, V-shaped gullies; plastic, nongranular soils exhibit broad, softly rounded gullies with a long shallow gradient; loessial silts and sand clays reflect box-section U-shaped gullies which erode at the headward end.

Color tones (photo-gray-scale values) reflect the product of soil moisture, topographic position, vegetative cover, and actual soil color. When evaluated in light of climate and processing (film sensitivity, exposure, development, and printing) then color contrasts become quite significant in soil study from airphotos.

The element vegetation reflects the environmental conditions for plant growth. At times, vegetation can be used to indicate certain features about soils (type, texture, and moisture) but only if vegetation is evaluated in light of regional and local environment.

Special elements are those which are characteristic of a particular soil, rock, or soil-rock mixture. Among the more outstanding ones are "silt pinnacles" and "cat steps" which are common to wind-blown silts, sinkholes and solution valleys of limestone regions, columnar structure of basalt, polygons in the Arctic and sub-arctic, and "blow outs" on sand dunes.

Techniques of Soil Evaluation from Airphotos

The analysis of soil conditions from airphotos is made possible through application of the processes of logic and deductive reason to the detailed study and evaluation of the natural and man-made surface features. Interpretation is broad in scope; it includes recognition of natural and physical features which create a pattern; it includes gathering data and analysis of the data; and finally it includes interpreting the data in light of the end point — ascribing an engineering significance to the area. Interpretation includes analysis in light of its regional and local environment. The interpreter must be able to trace the natural sequence of events in an area from the time of original deposition to the present as presented on the photos by the arrangement of the physical features. Usually all of the information is contained in the photos of an area, and it remains for the trained interpreter to apply the principles and techniques to obtain the information which he is seeking.

When all information must be obtained from photos it is important that the interpreter has considerable areal coverage. Analysis made from a few photos is exceedingly risky and cannot be done with any assurance of accuracy. This is particularly true when an interpretation must be made of an unknown or an inaccessible area. In such instances coverage should be sufficient to enable the interpreter to establish the major features such as basic climate, physiography, and geology on a regional basis, since these can only be obtained from study of a large area. The amount of photographic coverage, of course, depends on the

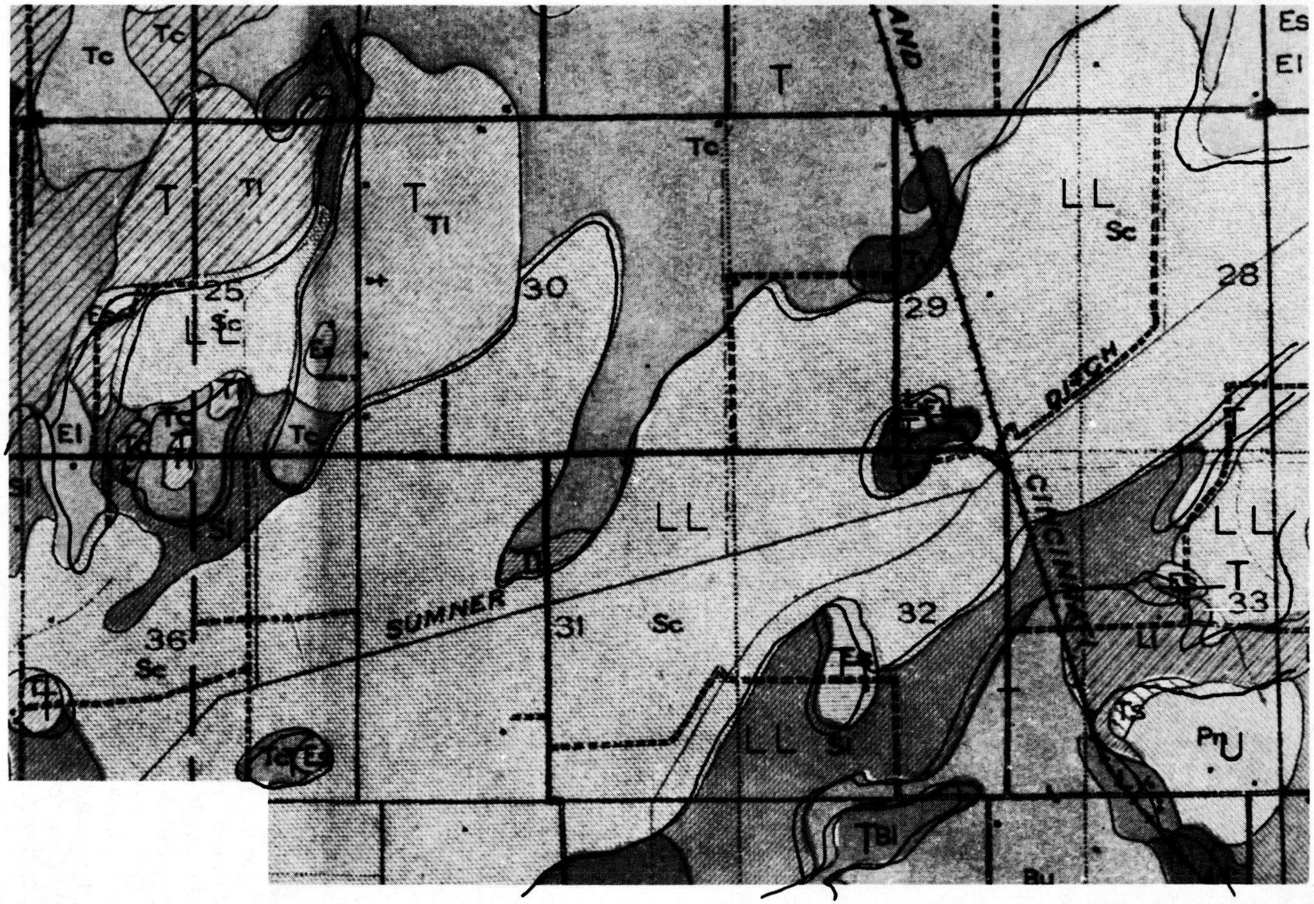

Figure 8. Agricultural-soils map of Sumner Ditch area.

relative size of the land units being studied as well as the physical setting. Once the basic features of the region have been established, the interpreter is able to identify and evaluate the local details. This is accomplished by detailed study of stereo-photographs.

In most cases advance information concerning the regional environment of an area is either known or, at least, available. There are very few areas in which such items as climate, physiography, and geology can not be located in the literature. With this material available the photo-interpreter's job is simplified. Smaller areal coverage will thus be needed and the interpreter can confine his efforts to observing, analyzing, and evaluating the local details from the airphotos.

In conducting a photographic analysis of an area the analyst should standardize the procedures he follows. His skill and proficiency is governed by constant use of airphotos not only in the office and in the field but also by constant correlation of predictions with literature, with actual field sample data, and with engineering performance data. The following suggested procedure is based on the assumption that the interpreter has an index sheet and complete vertical stereo-coverage of an area and that he is trained in the application of them.

Using the photo-index sheet as a guide, alternate prints are assembled into a mosaic form and stapled on to Celotex boards. The observer should study the entire area either as a unit or as a series of units if a definite grouping of features occurs. There will be certain items or markings or groupings which, by virtue of shape, magnitude, color, or configuration or markings, will form a group — a pattern which will stand out.

All borders and major features are studied in detail using a stereoscope and guided by a photographic guide sheet (see Fig. 24). Tentative predictions of soil type, depths, and profile development should be made from study of each element separately. If the predictions made do

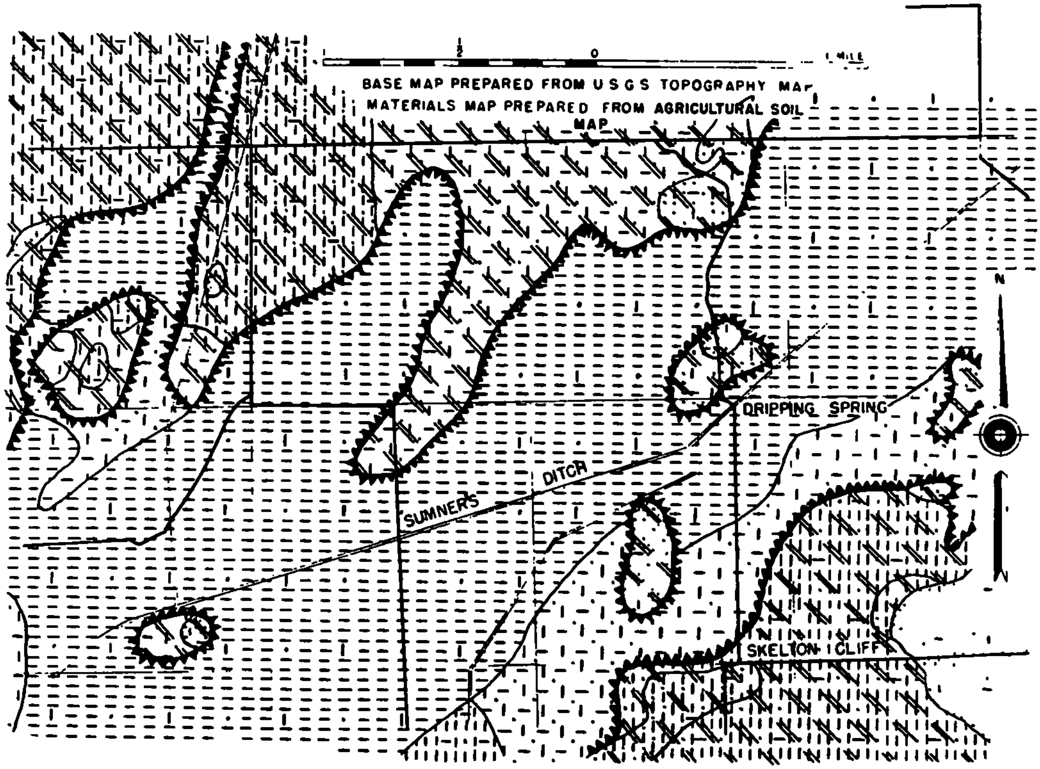

Figure 9. Engineering-materials map of Area C, Sumner Ditch, Gibson County, Indiana.

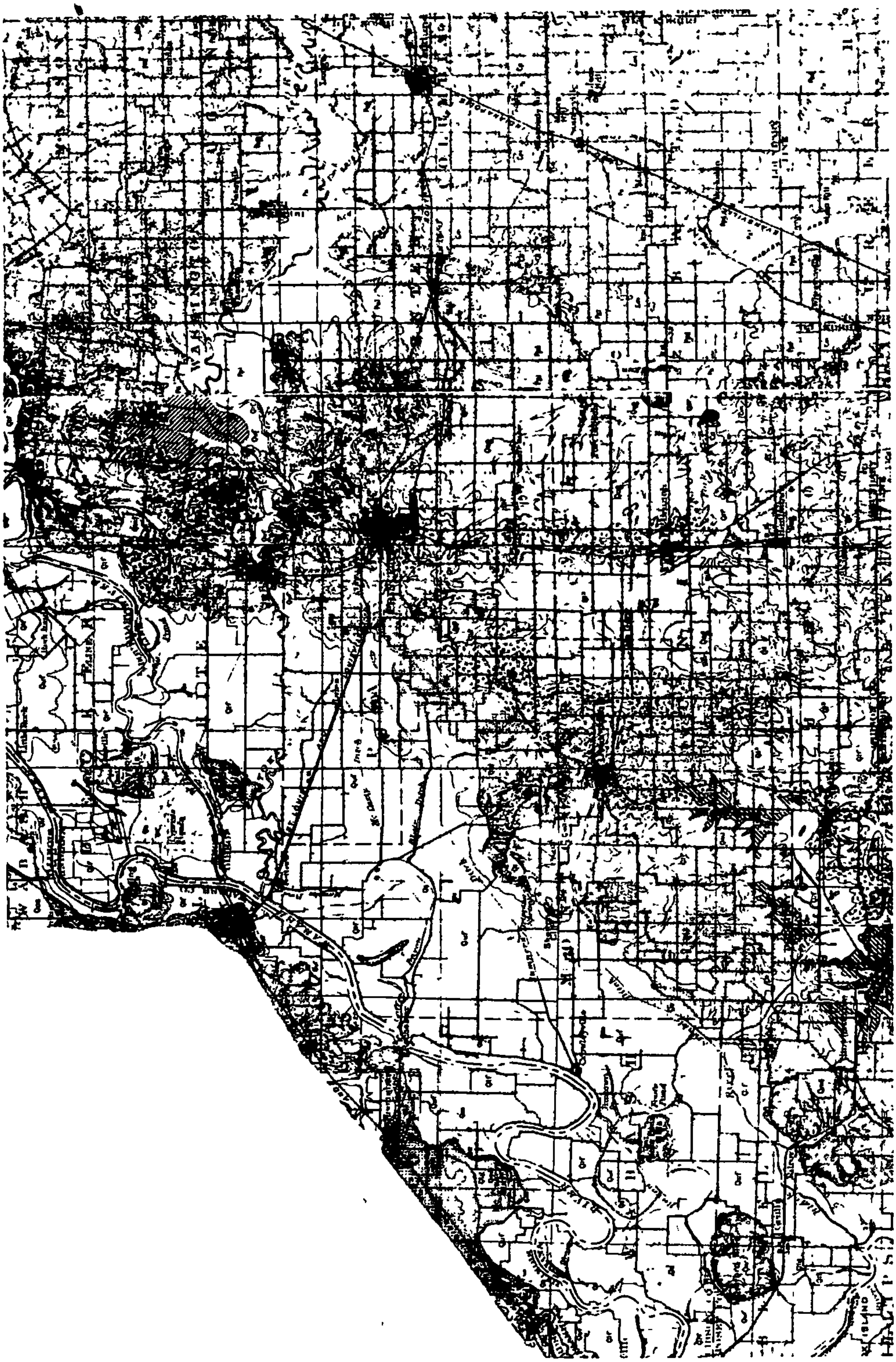

Figure 10. Geology map of Gibson County.

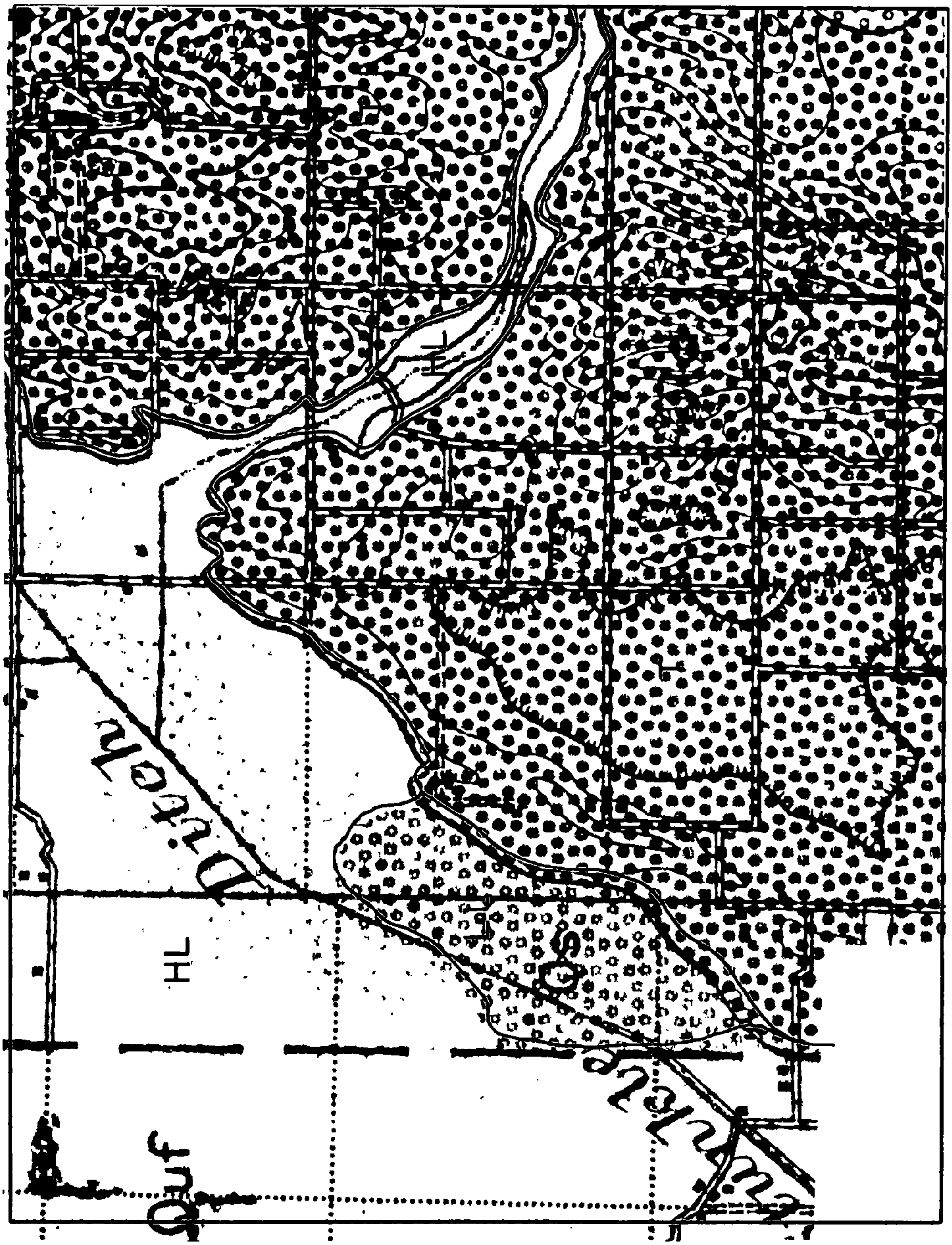

Figure 11. Geology map of Stunkle Ditch area.

not agree, then the interpreter should retrace his steps to locate any errors in judgment. During the preliminary study the observer should mark or locate areas for field checking. By making predictions in advance of any field checking the analyst will develop a high degree of reliability. It is to be remembered that the airphoto method can be used to identify and bound parent materials with a high degree of accuracy. However, estimates of profile depth, grain size, moisture contents and density are inferred from the photo analysis and should be field checked for positive assurance. After the interpreter has made his preliminary predictions based on airphotos, he should conduct a literature survey which should include the fields of pedology, geology, physiography, and agronomy available for the area in question.

Following the airphoto study and the literature study, the interpreter conducts a field study which should consist of a thorough ground check of previously made predictions in areas determined during photo analysis. Field checking should be accomplished with photos in hand and by on-the-spot stereo inspection. The engineering significance of soils and soil patterns may be gained if the interpreter observes and correlates the performance of highway pavements with soil types. Particular attention should be directed toward observing performance characteristics in areas requiring numerous cut and fill sections. The interpreter should obtain ground and aerial oblique photos which will characterize certain pattern features and which may illustrate pavement performance correlated with soil patterns. These photos will be of great help in evaluation of similar soil situations which may be extended to other areas. Of particular importance is keeping a catalog of photos illustrating the many materials sources. As a final analysis the interpreter should reanalyze all data and revise earlier predictions to suit actual field conditions. In this way the interpreter can concentrate on points where errors of judgment have been made and thus produce a more reliable materials survey.

Keys for Soil Evaluation from Airphotos

There are many types of keys which the interpreter may use in proceeding to identify, analyze, and interpret soils and materials of an area. The purpose of any key or series of keys is to point out or call attention to objects or features of a pattern which will serve as guide in a soils determination. Keys are used to identify, not interpret. The keys become the photograph's legends.

Basically, there are two types of keys: positive keys and inference keys. Positive keys permit direct identification of objects by pointing out or comparing easily recognized objects, chiefly those with which the analyst is already familiar and which lend themselves well to picturing, illustration, and description. Keys based on inference are those requiring the use of logic, deductive reason, and detailed analysis of regional and local environment. Such keys describe situations, either natural or man made, occurring in one area assumed to be typical and suggest, often by association, that analogous situations exist where natural and physical environmental conditions are similar. The development and the use of such inference keys are based on interpretive procedures.

Both positive and inference keys point to identification of objects or situations. Analysis follows identification and the success of the analysis lies entirely within the province of the analyst. The analysis is dependent upon background or major field of interest of the analyst. The data gained by recognition, inference, or deductive reason, are arranged in such a manner as to convey the picture of what is contained in the area. Interpretation of the data is the final step and must follow both identification and analysis. Interpretation must be based on the end point, desired result or field in which the information is to be used. Quite necessarily it follows that interpretation of results will be done in some major field of use. Hence, the airphoto becomes a tool by which, in this instance, the engineer gathers information concerning the soils – whether he uses a direct key, an inference key, or follows interpretive procedures without the use of a key. He will analyze the soils data in light of his background and interest. His interpretation of what to do with those soils will be based on the job requirements and on his judgment.

Some keys are built around a series of diagrams, sketches, ground photographs or airphotos of easily recognizable physical features representing the component parts of a pattern. They are

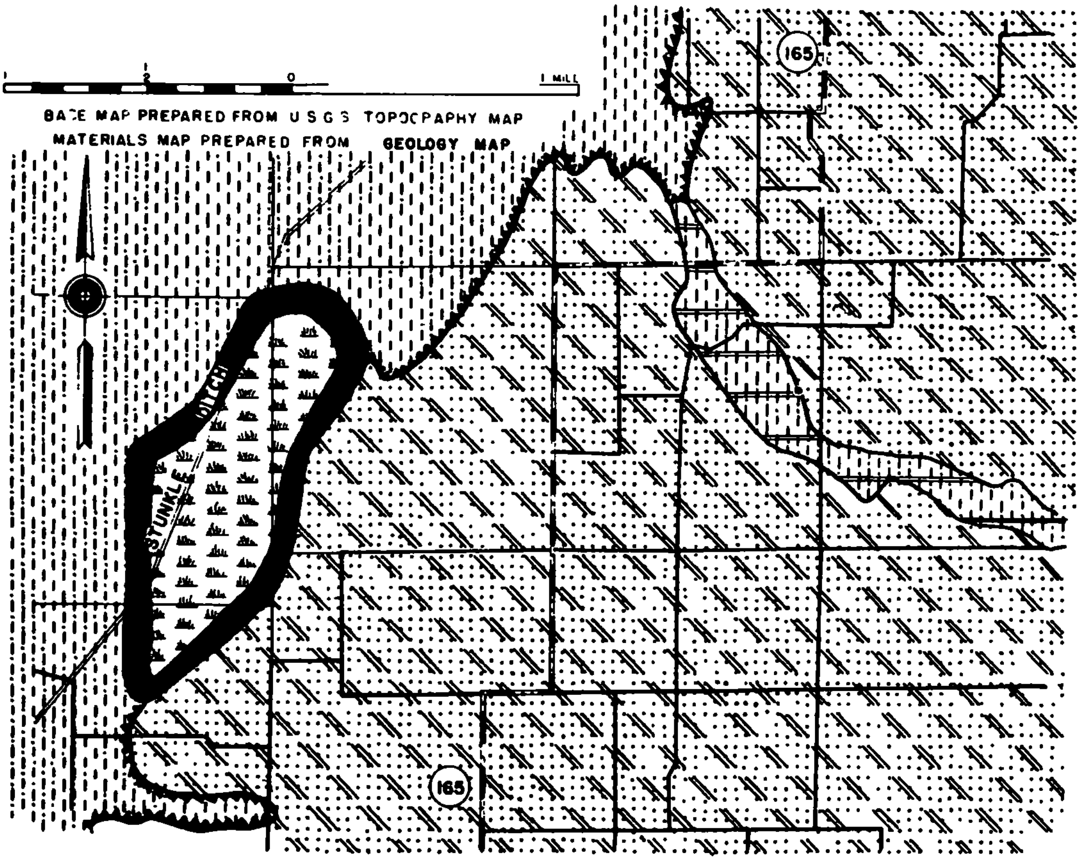

Figure 12. Engineering-materials map of Area D, Stunkle Ditch, Gibson County, Indiana.

usually ideal representations and must be outstanding in both their simplicity and their representation. In some situations a series of charts may suffice. The analyst, from a detailed stereographic study of photos of his area, proceeds to study the physical features and to look for objects which may be similar to those represented in the keys.

Another type of key may be built in the form of a catalog or encyclopedia. Many possibilities exist in this type. Many choices for first division exist; they should, however, be based on the final use. As an example they may be catalogued into natural features and man-made features at the level of the first major division. First subdivisions for man-made features may be industry, agriculture, or some other major field of endeavor. This may be further subdivided into types of industry such as manufacturing, processing, etc. Further subdivisions can occur based on the detail required in the collection. In a similar manner the natural objects can be subdivided into major earth-science fields such as physiographic forms, geologic forms, ecologic forms, geographic forms, etc. Subdivisions can occur such as construction and destructional forms under physiographic forms. Again, they may be further subdivided into agents of construction or destruction such as wind, water, ice, etc. It can be seen that the ramifications are many and such a key or catalogue can reach tremendous proportions if many off-shoots are pursued.

One type of key which may be devised and applied to photographic analysis is the question-and-answer type in which various questions are asked each having several possible answers but only one correct answer. Each answer, in turn, suggests certain questions, each of which has several possible answers but only one correct answer. This process continues until the analyst has arrived at the final and most-probably correct answer. In this type of key the various possibilities are referenced and are discussed elsewhere in the general collection of keys. The analyst continues from question and answer along a chain of connected events until he either has the answer or is forced to pursue another path. The first series of questions may refer to such major

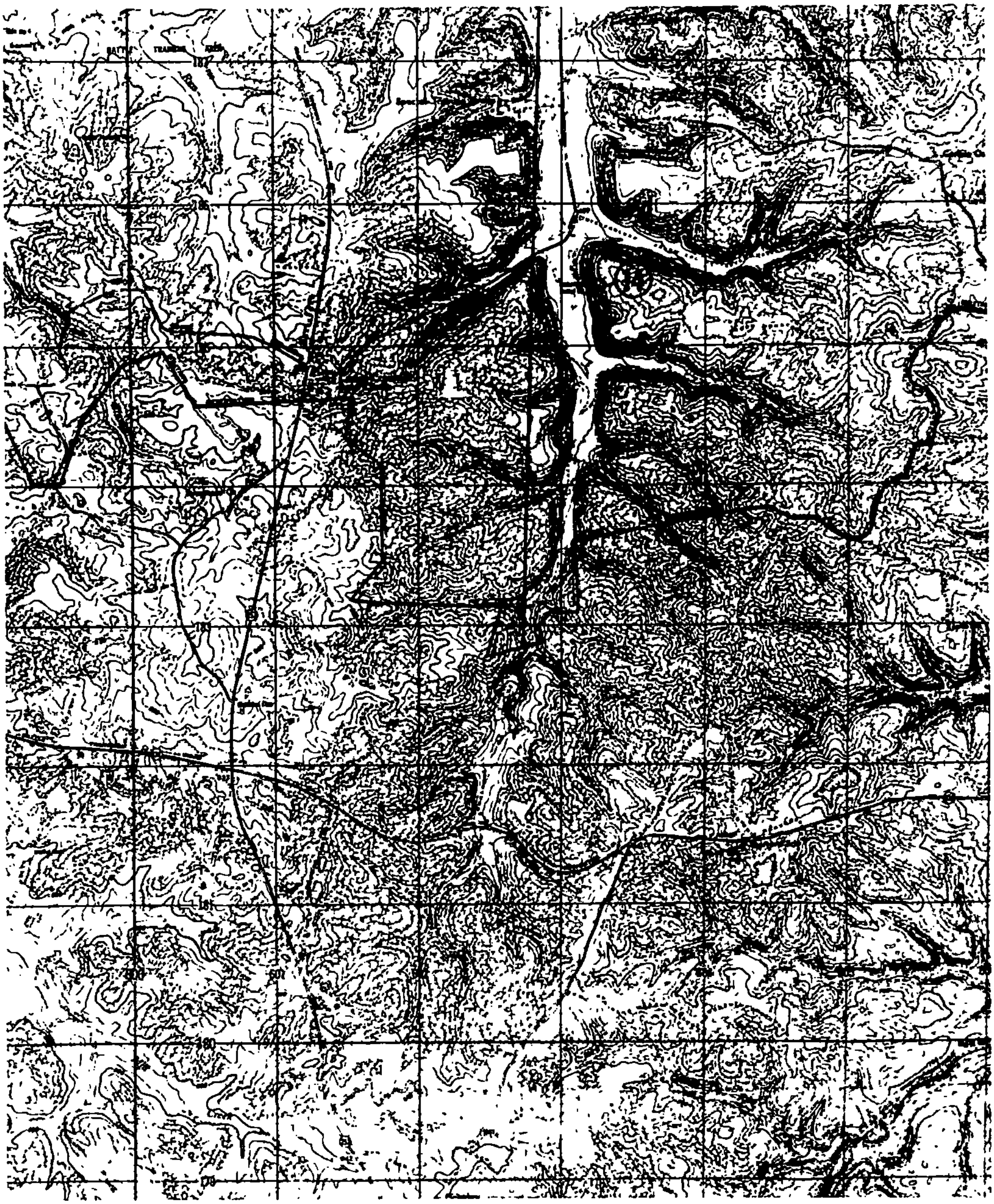

Figure 13. Topography Map of Cedar Creek, Kentucky, part of U.S.G.S. Topo Sheet, Colesburg, Kentucky, 1946.

items as climate, geology, physiography. Under climate there may be six possibilities as indicated in the vegetation-erosion features. Under geology there may be several leading questions intended to point out methods of origin, subsequent erosion, and deposition. The choice of answers and subsequent references will depend on the observation powers of the analyst — his impression of the features of the photo pattern. He must make the answers fit the case in question. Likewise, physiography may be called to the observer's attention setting forth the possibilities in question form. A second series or group of questions and possible answers are aimed at pointing out local details of the physiographic pattern. Questions and answers concerning such features as landform, erosion, drainage, color, vegetation, and others will carry the analyst to the final goal: soil identification. The above question-and-answer key must, through necessity, be all inclusive: all possibilities and all steps must be shown. A key of this type may also approach encyclopedia proportions.

Another key is that built up around the use of pattern elements as major key divisions of the landscape. At present, this is one of the more popular approaches to gathering data about the natural and man-made features which form a pattern. These were discussed previously (see Fig. 24). Analysis of the areas in Southern Indiana in connection with this report was performed following the guide sheet in Figure 24. The data in the first part under regional environment were known. Only the second portion, local environment, applies in the example areas.

Limitations of the Airphoto Method

It is of extreme importance that the interpreter be fully cognizant of the limitations imposed on the airphoto method of survey in order that he will learn to recognize conditions beyond which he cannot successfully evaluate. These limitations fall into three general categories, natural, photographic, and human.

The natural limitations are those which existed or which were reflected in the surface patterns at the time of photography. Usually they can be identified and interpreted entirely from the photographs by observing irregularities or deviations in the natural pattern. Natural limitations arise largely from the influence of environmental conditions, chiefly climate.

The climatic influence is suggested from the photographs by distribution and type of vegetation and by the presence or absence of vegetation. The vegetation limitation is of extreme importance in northern latitudes, where such items as elevation, exposure to sunlight, and protection from severe climatic conditions often govern the presence or absence of vegetation. Changes or contrasts in vegetation may reflect significant changes in soils if environment has been evaluated properly.

Another important natural influence which often imposes a serious limitation is the erosion pattern of an area. In general, gully cross section and gradient are indicators of soil texture; however, the interpreter must evaluate the climatic condition under which the gullies were formed. He must decide whether erosion has been of a geologic nature and has taken a long time to develop or whether erosion has been of a recent nature and has formed in a relatively short period of time. As an example, clay shales or clay soils normally occupy softly rounded slopes in the erosional features in humid regions; however, the flash-flood characteristics of arid and semiarid regions will carve clay shales or clay soils into fantastic shapes with unnatural vertical slopes. By knowing the general climatic conditions of an area the interpreter can establish the degree of reliability which can be assumed when studying gully characteristics.

The photographic limitations are largely a matter of recognizing the limitations associated with the various types of photography and scales. In general, there are three major types of photography which consist of trimetrogon, vertical coverage, and continuous strip. Trimetrogon photography is used chiefly in reconnaissance mapping of large areas and for this work it is usually obtained from high altitudes with the resulting scale quite small. As far as engineering soil survey is concerned, trimetrogon photography should be limited to reconnaissance use where

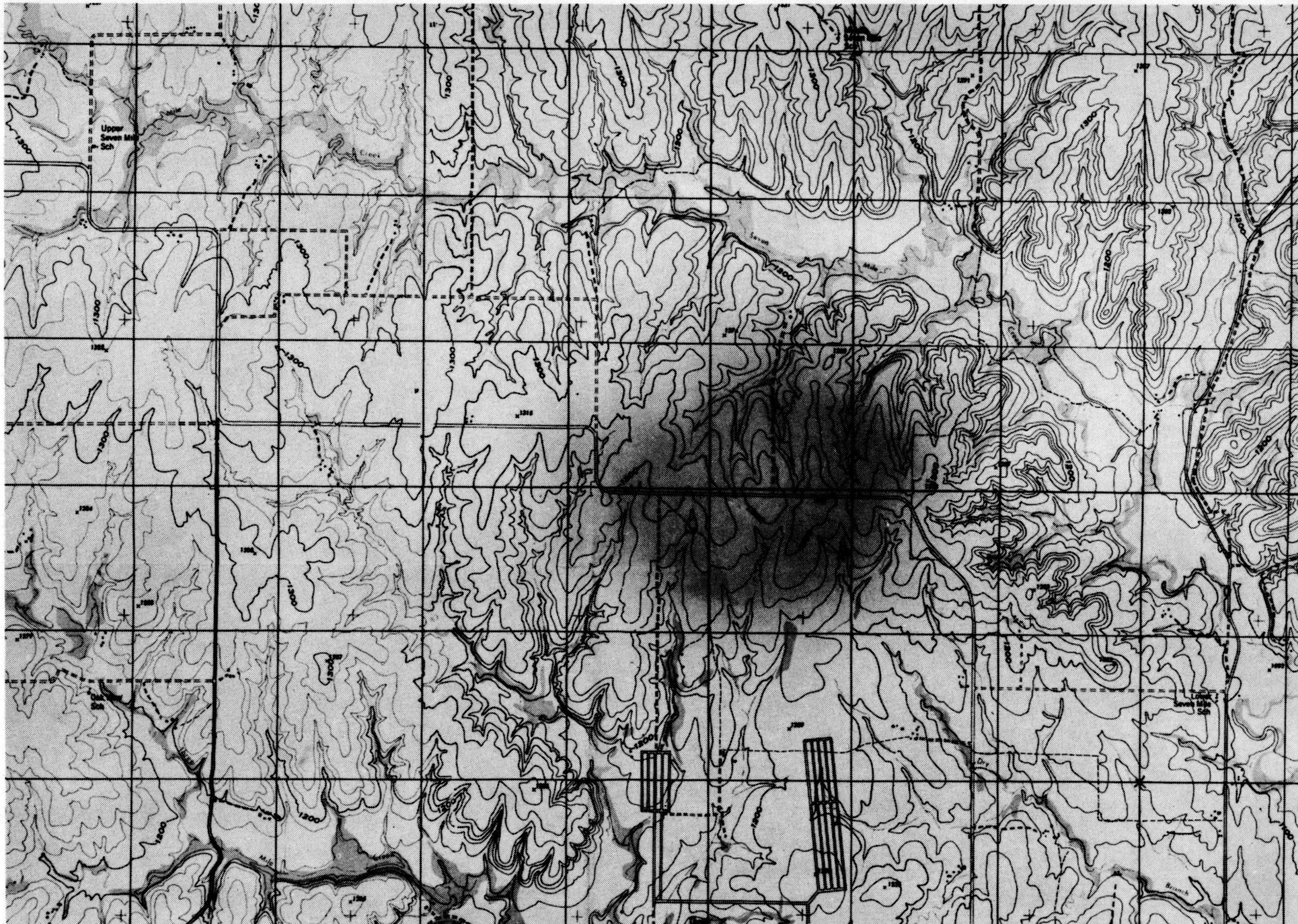

Figure 14. Topography map of Seven Mile Creek area, Kansas; from a tactical map of Fort Riley and vicinity, Corps of Engineers, 1946.

the interpreter can use it to establish the major soil-parent-material boundaries. Vertical coverage of mapping-type photography is the most common and is the most practical type for engineering surveys dealing with earth materials. Detailed preliminary soil surveys and engineering soil maps should be made from vertical-mapping-type photos. Continuous-strip photography for engineering use is best suited for making performance surveys of such structures as runways, railroads, or highways. This is important, because it is possible to correlate engineering performance with soil type, traffic, or any other variable which will show its influence. When such photos are taken periodically they provide a permanent record of progressive failure or of the condition of a particular installation.

As far as general engineering-soil survey is concerned a scale ranging between 1:15,000 and 1:22,000 is satisfactory. General soil-parent materials can be bounded with ease. Scales on the order of 1:5,000 provide an excellent scale for obtaining minute surface detail, but the photos do not include sufficient area per print to provide a practical means of mapping large areas. It is difficult to interpret such items as relief with the use of common instruments from large-scale stereophotos. When photos are taken with scales ranging from 1:30,000 to 1:40,000 the resulting images are too small to evaluate properly the engineering-soil conditions.

For engineering-soil survey, photos should be obtained in stereopairs or the area should be covered with sufficient overlap on individual photos that stereovision is possible in all parts. This usually results in two complete sets of airphotos of an area (composed of the alternate prints of the flight lines). It is important to stress that even though every other print in a flight line will provide complete physical coverage for a mosaic, it will not be possible to study the area stereoscopically; hence, it is important to obtain the total number of prints in any given flight strip. As far as soil survey and related studies are concerned, photographs should be obtained of as large an area as possible and they should be obtained in stereopairs. Photography of this type is readily available for most areas of the country and can be purchased from various government agencies at a relatively low cost per print.

The third major limitation lies within the province of the interpreter and is based on such items as his background or major interest, keen vision, and a good imagination. The interpreter must have a keen appreciation of the relationship between natural soil or soil-rock conditions and engineering problems. It is not necessary that the interpreter be especially trained to the extent that he becomes a specialist in the natural sciences dealing with the surface features of the earth. The interpreter should be aware of the sources of literature in any of the related fields, since this is of paramount importance in obtaining background material about any particular area.

Example of Airphoto Method of Material Surveys—Mumford Hills

In conducting the material survey of the Mumford Hills area from airphotos, several major steps were followed, which include: (1) assembly of airphoto mosaic; (2) study of the county index or mosaic; (3) study of the Mumford Hills portion of the mosaic; (4) detail stereostudy of the Mumford Hills area; and (5) grouping landform types and designating textures. The steps are discussed as follows:

Assembly of Mosaic. The aerial photography for Gibson County was flown in 1940. It bears the county symbol QS. Alternate prints were assembled into a mosaic form for a preliminary area study. Figure 4 is a copy of the Department of Agriculture Index Sheet covering the photography of Gibson County. This index sheet served as a guide for mosaic assembly.

Study of County Mosaic. From the preliminary study of the mosaic, Gibson County can be divided into two major features: a broad, gently rolling, dissected upland which contains several inland basins and a lowland which contains the channel and floodplains of a major river.

The basins in the upland provide the outstanding feature of the upland pattern in as much as they are dark in color

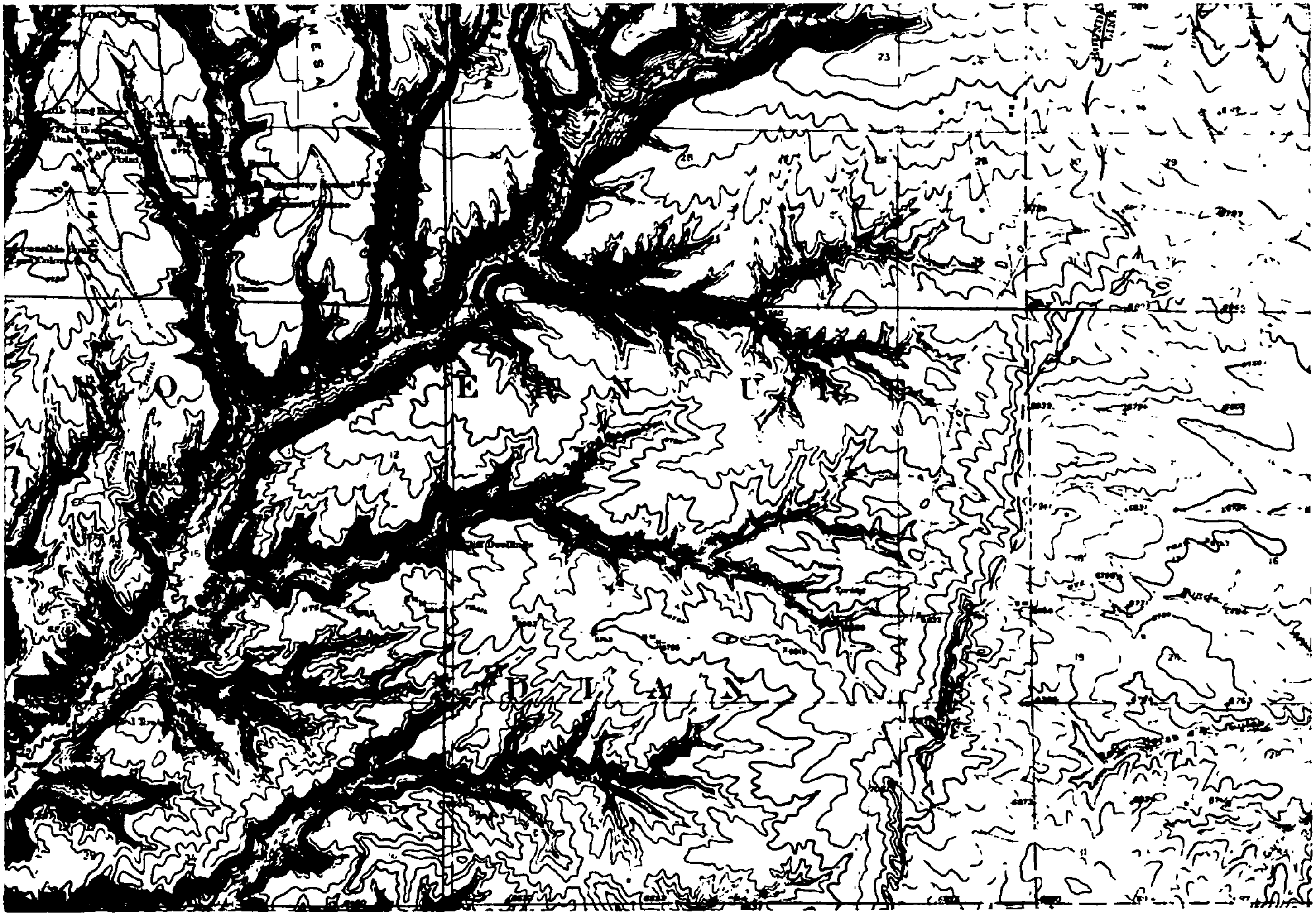

Figure 15. Topography map of Mancos Canyon area, Colorado, from part of the U.S.G.S. Topo Relief Map, Soda Canyon, Colorado, 1943.

(sharp contrast to the surroundings), they are quite broad, and they do not appear to contain a definite stream channel. The impression given is that each represents filling by sedimentation in the quiet waters of an inland lake. Inland from the major river valley the pattern is one of considerable dissection by long, broad, dark-centered gullies which extend back considerably into the upland. In the far eastern part of the county these gullies have light-colored fringes, which suggest that the parent materials might be Illinoian Drift. In the central portion of the county, fringes are absent and a sharp contrast exists between the dark center of the gully and the light tones of the adjacent uplands. This suggests that there may have been a modification of the surface by material of aeolian origin. Adjacent to the major flood plain there are considerable areas of light tones where gullying is not well-developed, suggesting that the soils might be well-drained internally. These may be sand dunes. In other areas of the upland adjacent to the major stream valley, the impression of moderately great relief is created by intense dissection. This consists of tree-filled gullies which do not extend great distances into the upland but instead are confined to small areas. Some of these gullies, which are outlined by timber cover, resemble those of windblown silts found elsewhere. Hence, it is believed that loessial silts may be deep in places along the valley wall. It is believed that the area is underlain by bedrocks, flat-lying or slightly tilted, because of the numerous sharp bends in many of the upland gullies and major upland basins. The mosaic can not be used, in this instance, to identify the rock type other than to suggest that it is possibly sedimentary and not limestone.

The major lowland, which contains the river valley, forms the western border of the county. The river appears to be in a mature stage of its development as indicated by the numerous meanders of the present stream and by the presence of abandoned meanders in the lowland, many of which are no longer connected in any way with the stream. Almost all parts of the lowland contain markings indicating current activity, all of which suggest that the soils of the lowland are chiefly alluvial in origin. There is some evidence that the stream is controlled to some extent by underlying bedrock because of the variation in the shape of some of the stream meanders. In the extreme southwest, part of the meanders form broad, free-swinging loops, while in the west-central part the stream follows a straight course for several miles to the point where it is joined by another major river. The straight portions of the stream occur downstream from a series of prominent islands, or monadnocks, which occur in the lowland and which may be responsible in some part for deflecting the stream. These islands are easily seen on the county index sheet or the mosaic by the sharp contrast in pattern of the islands with the surrounding lowlands. The islands contain dense timber on the steep slopes, which is inferred from the interrupted crescentic arrangement of the timber pattern. The timber pattern encloses a field pattern vastly different from that of the adjacent lowlands. In addition, well-developed gully systems are found on the larger of the islands. The Mumford Hills area is one of these islands, and it is believed that since it has remained in the flood plain of this mature river, it is rock and is a remnant of the strata which may underlie the remainder of the county.

From study of the index sheet it is believed that the texture of the materials in the flood plain varies considerably, as reflected by sharp contrasts in color tones from nearly black to almost white. The darkest tones appear to occupy abandoned stream meanders and in one major depression. This major depression, which occurs at the junction between the upland and the lowland, is perhaps a backwater area which may have been isolated by alluvial levee building in the central portion of the valley. Scattered throughout the lowlands are some isolated areas which are very light in color. Since they show some indication of having been swept by fast-moving water, it is believed that they are granular in nature. From this it would appear that the lowlands consist of a flood plain with at least two major stages or bottoms.

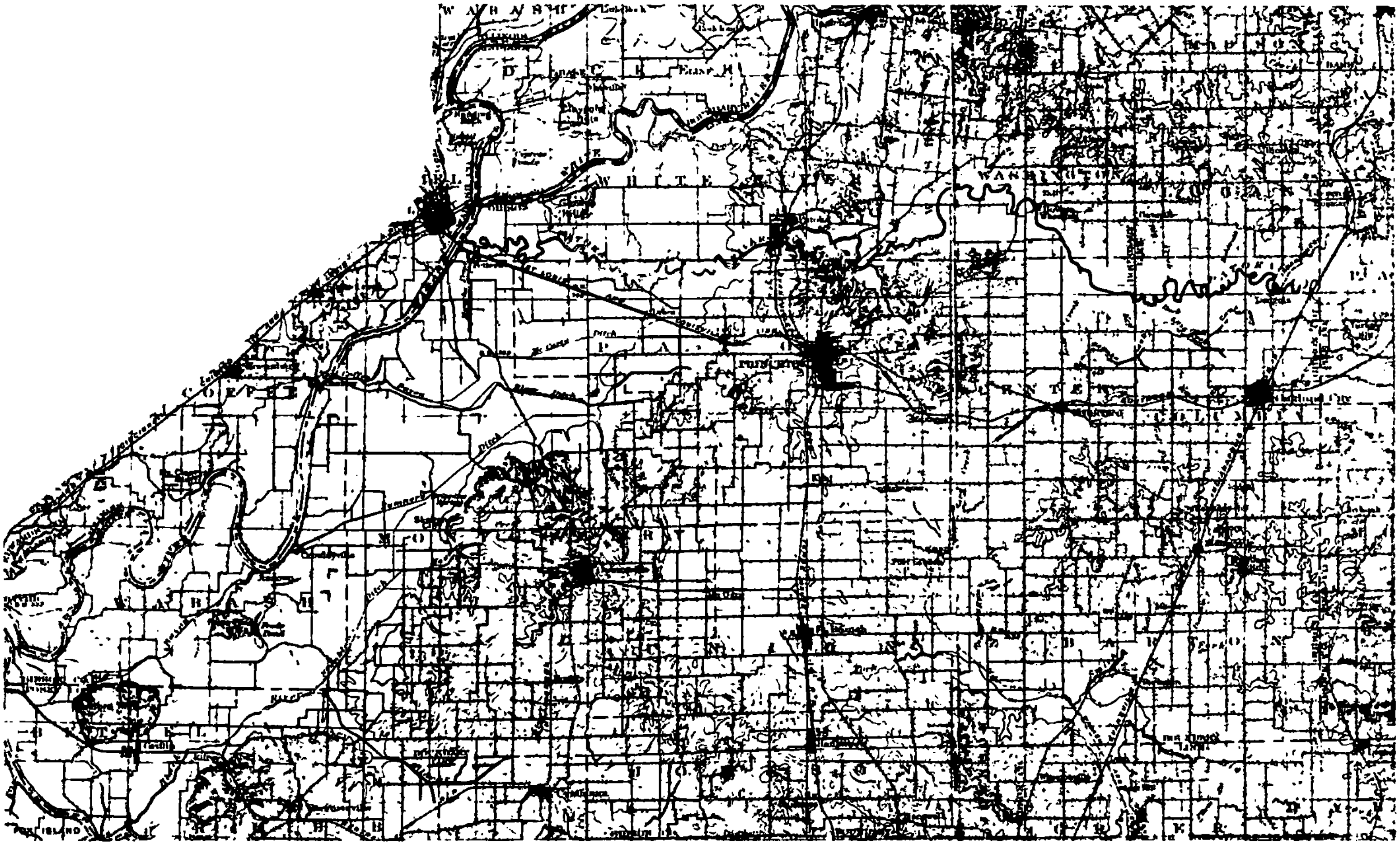

Figure 16. Topography map of Gibson County; from part of U.S.G.S. Topo Sheet (13).

Study of the mosaic can be summarized in the following manner: Gibson County contains two major physiographic situations, a dissected upland and a lowland occupied by a major river and its associated flood plains. The upland may consist of flat-lying sedimentary rocks covered to varying depths with glacial drift believed to be Illinoian in age. The drift appears to be mantled in places with aeolian deposits, sand, and silt. The lowland is composed of perhaps two stages or bottoms of the flood plains. A series of rock monadnocks appear as islands in the lowlands.

Detailed Stereostudy of Location of Survey. The next operation consists of conducting a detailed stereoscopic study of the photographs covering the Mumford Hills area. Figure 5 is a copy of photos of this area. In general, the observations made by study of the mosaic concerning the presence of monadnocks were verified. The Mumford Hills area is quite a pronounced knob lying in the lowlands surrounded entirely by alluvial deposits. There is considerable contrast in all pattern features between the lowland flood plain and the island. The most outstanding of these, in addition to the high topographic position of the knob, is a difference in drainage patterns between the two areas. The Mumford Hills area contains a well-developed drainage pattern on the south and east portion, no surface drainage on the far western part, and a well-developed system of gullies on the northern part. The surrounding lowlands do not contain any natural drainage pattern other than that associated with the series of meander scars.

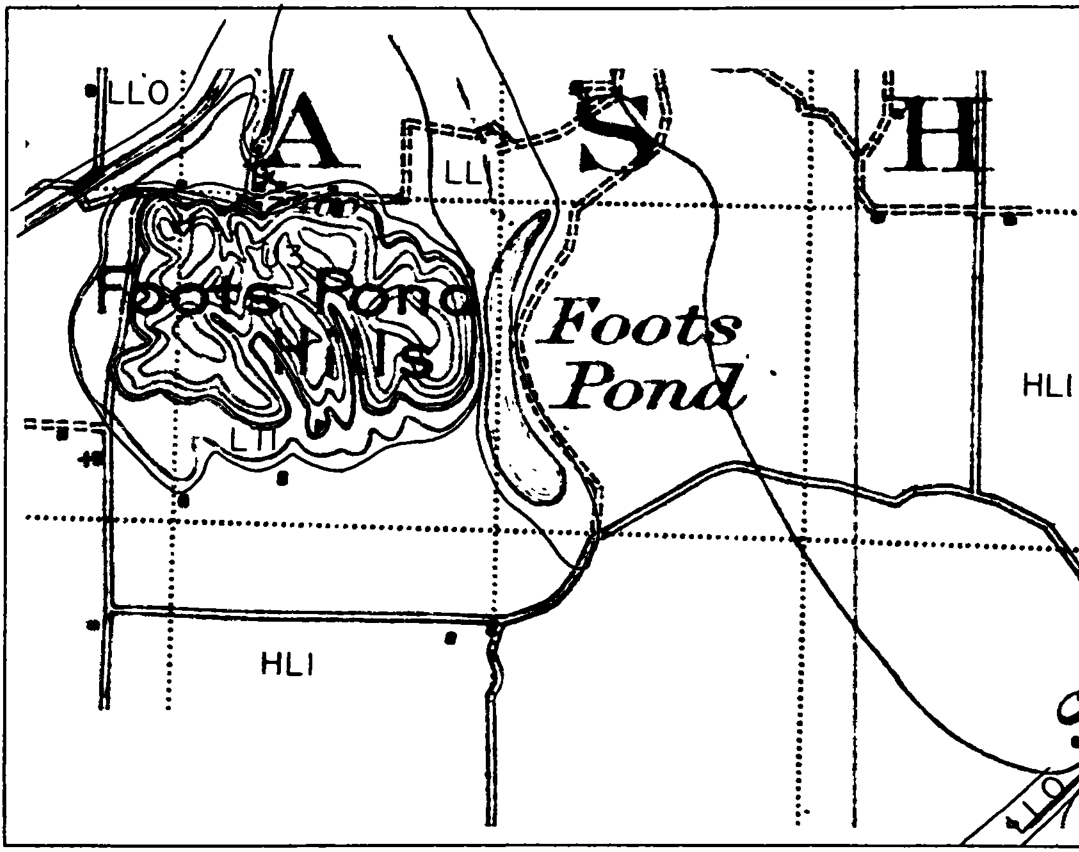

Figure 17. Topography map of Foots Pond Hills area, from U.S.G.S. Topo Sheet.

From detailed study of the elements of the pattern of the Mumford Hills area it is believed that the island is composed largely of rock. Even though it may have been originally formed by the cutting action of the river, it is not streamlined in shape. It is irregular in plan and is asymmetric in cross-section along the north-south axis. Steep, timber-covered bluffs occur along the north and far west slopes. A long backslope characterizes the southern portion. The eastern and southeastern part is believed to contain a mantle of windblown silt of varying depths as indicated by pinnate gullies (loessial silt). The western part contains numerous basins which are, to a large extent, surrounded by sharply rounded hills, some of which are crescent shaped. This, together with the light color tones and absence of surface drainage, suggests the presence of shallow sand on silt.

Detailed stereoscopic study of the lowland reveals a series of level surfaces or stages which are at different topographic locations. These are terraces and first and second bottoms of the flood plains. The parent materials in the flood plain are derived entirely from water-deposited materials. In some of the abandoned stream meanders there are indications that organic accumulations exist.

Grouping Landform Types and Designating Textures. Following a detailed study of all the pattern elements, the area was divided on a basis to topographic position. Figure 25 has been arranged to show as nearly as possible the correlation existing between the air-photo pattern, the map symbols, the landform division, and the materials expected.

The upland is divided into intermediate level areas marked U1 which contain some basins marked U0 (the combination is shown as U0-U1); rolling and mod-

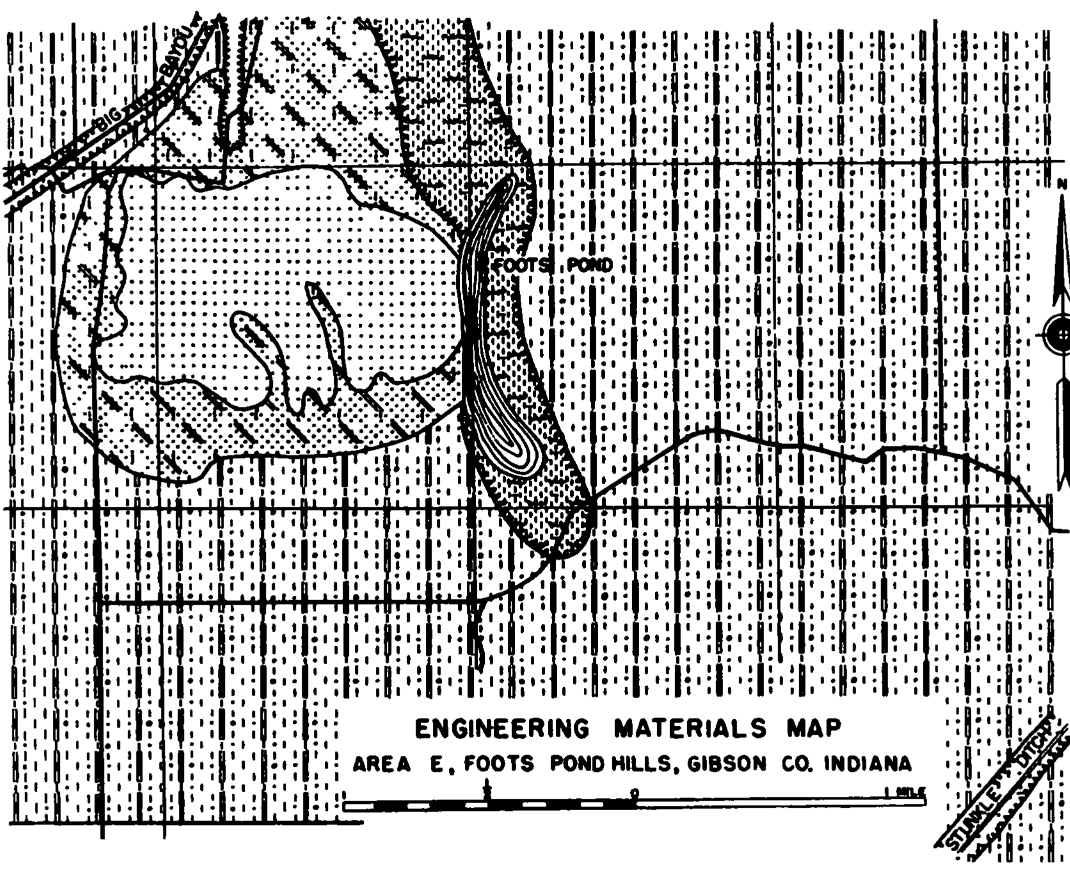

Figure 18. Engineering materials map of Area E, Foots Pond Hills, Gibson County, Indiana.

erately dissected areas marked U2, which cover the major portion of the area; and sharply rolling topography of the dunes marked U3; and steep slopes of the outward face of the knob marked U3. The uplands carry the basic parent material symbols for sandstone, symbol 10; shale, symbol 12; loessial silt, symbol 41; and windblown sand, symbol 39. These basic parent materials are obtained from the chart in Figure 31.

The lowland consists primarily of two major divisions, high bottoms marked HL and low bottoms marked LL. The appropriate parent material symbols 30 and 34 are indicated. In the low lowlands the lowest topographic situations appear as basins, usually of the abandoned stream-meander type, and these have been designated as LL0. The level areas of the first bottom are designated LL1. The basis for designation of this area, in addition to its flat topography, is the complete uniformity of color tones – an absence of scours or ridges associated with current activity. Rolling areas of the lowland are designated LL2, since they are marked with ridges which provide some local topographic differences. The second bottoms (HL) contain only two divisions – HL1 and HL2. The areas marked HL1 are level and unmarked with the usual indicators of current activity. The areas marked HL2 are marked with slight ridges left by fast-moving water which have added some local relief. The only terraces in the area are a series of dissected benches which adjoin the island proper. These are low terraces and, for the most part, fall into the LT1 class, since they are level and unmarked by current activity. Two minor terraces with rolling topography (LT2) occur on the southwestern and western portion of the island.

The appropriate soil-texture symbols are superimposed on the parent materials symbols. The symbols are obtained from the Purdue Soil Texture Chart (Fig. 31).

The results of the material survey has been incorporated into a materials map (Fig. 6). This, together with the air-photo of the Mumford Hills area and its landform overlay, presents the data on patterns, parent material, landform, topographic situation, and approximate texture ranges.

AGRICULTURAL SOIL MAP METHOD

The soils-mapping program of the U. S. Department of Agriculture in cooperation with agricultural experiment stations of the state universities provides the engineer with a very important source of information about the surface materials.

This soil-survey program provides basic data for various land-use programs of the counties. The soil-survey reports contain information pertaining to soils, crops, and general agriculture of areas being surveyed. As stated in one of the recent reports, St. Joseph County, Indiana, June 1950 (21), the soil surveys and maps present data designed to meet the needs of three groups of users: (1) farmers and others interested in specific parts of the area; (2) those interested in the area as a whole; and (3) students and teachers of soil science and related agricultural subjects. For those users in the first group valuable information is available concerning the soils and their estimated yields, productivity rating, and management. For the second group of users the soil-survey bulletin contains considerable information of a general nature which is applicable to many fields, since it discusses such factors as geography, physiography, relief, drainage, climate, water supply, vegetation, population, industry, transportation, markets, and cultural development and improvement. For those interested primarily in soil sciences and allied subjects information is available on morphology and genesis of soils.

Many years ago the engineer realized the importance of agricultural soils information for assisting in making soils and materials surveys. Michigan was the first highway department to use agricultural soil information for design purposes. A field manual containing engineering information about Michigan soils as mapped on the county agricultural maps was prepared and published in 1946 (17). Since that time many states have been developing information which should help translate the agricultural and pedologic terminology into engineering terminology. In general, the approach has been one of arranging or grouping agricultural soils into some logical classification based on one of the following:

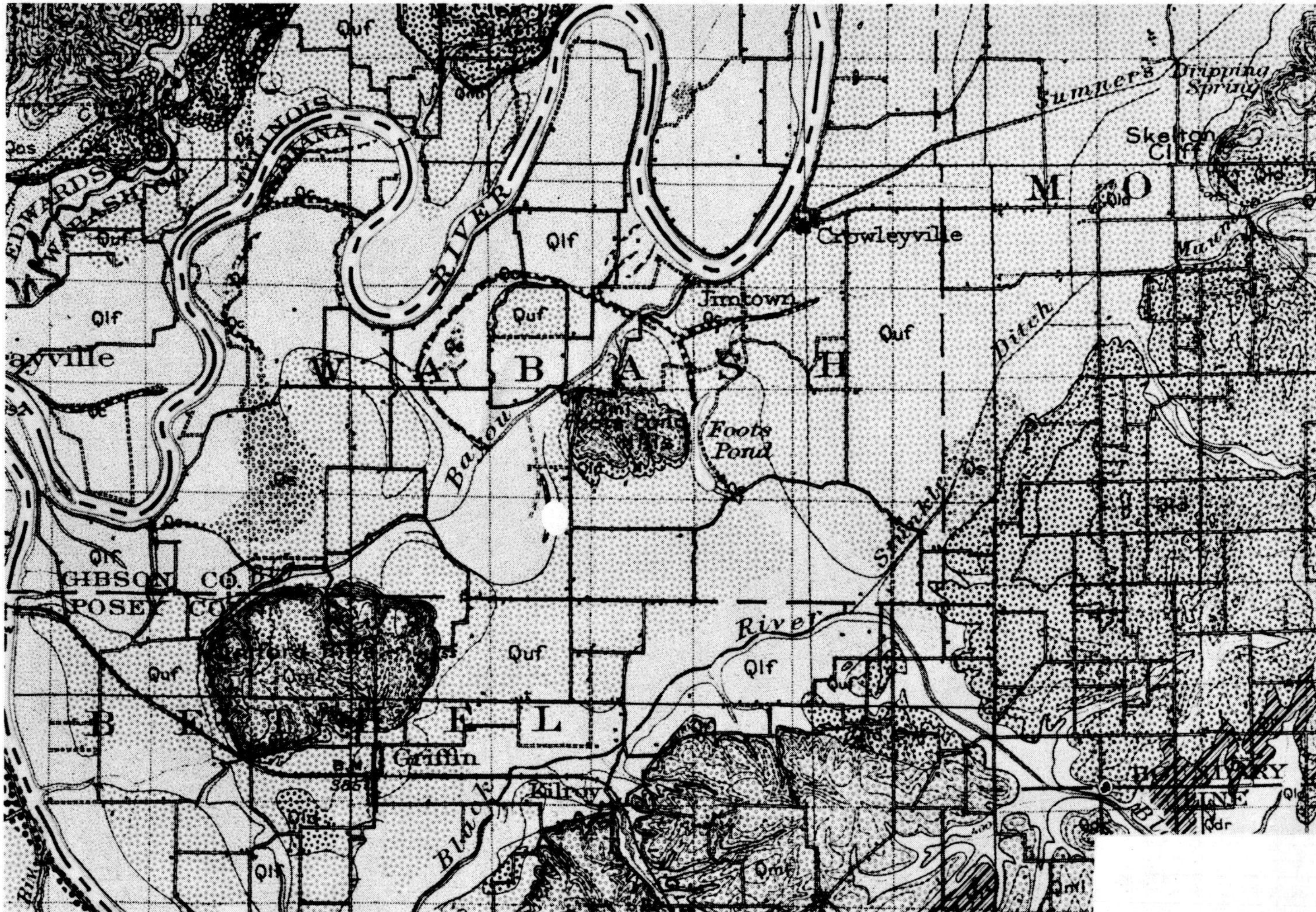

Figure 19. Geology map of example area.

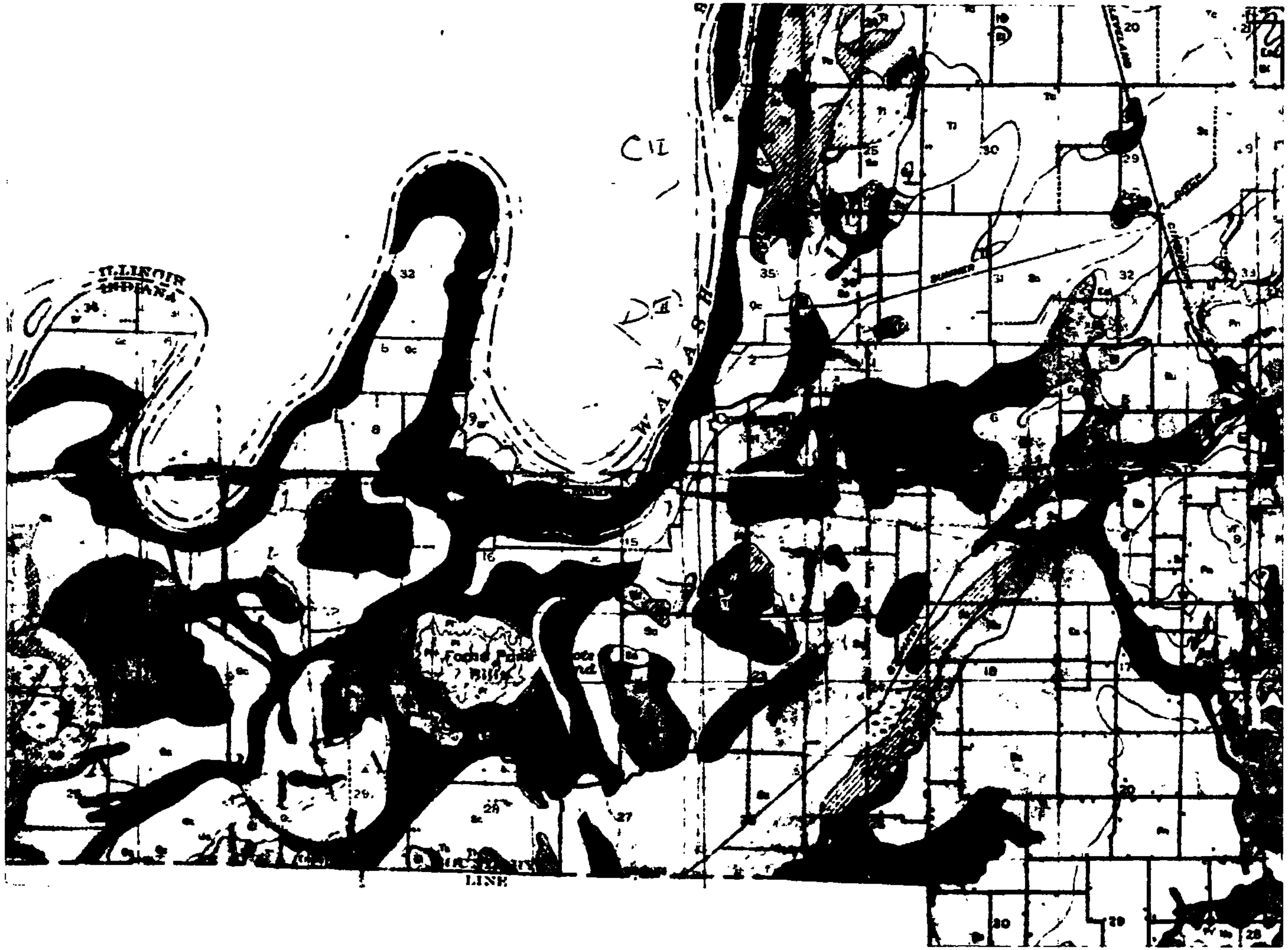

Figure 20. Agricultural-soils map of example areas.

parent material, drainage characteristics, landforms, or suitability for engineering use. The Committee on Surveying and Classifying Soils in Place for Engineering Purposes, under the direction of Frank Olmstead, chairman, prepared a bulletin for the Highway Research Board (8) which presented information concerning the status of agricultural soil surveys in each of the states. The reader is referred to this bulletin for detailed assistance concerning the use of agricultural soil-survey maps.

Principles of Materials Survey from Agricultural Maps

An understanding of the county agricultural soil map and text is necessary before the most efficient use can be achieved by the engineer for material surveys. In general, all bulletins are accompanied by a soil-survey map which is a graphic representation of the location and areal extent of surface soils—those responsible for the support of plant life. The amount of detail shown on the maps varies considerably. This variation in detail can perhaps be attributed largely to age of the report. The most recent surveys are quite detailed, since mapping procedures are not performed more efficiently today than in earlier times. In addition, more soils are recognized now than during the earlier part of the mapping program. In a similar manner, the amount of detail presented in the text varies both with the area and with the locale of the report. Use of the agricultural soil-survey literature and accompanying maps is contingent on an understanding of how the various soils are named and on an understanding of how the data are presented in the various reports.

Agricultural Soils Names. Agricultural soils are named after localities where they were first recognized. Soils are commonly thought of as occurring in families, or catenas. A catena is a group of soils derived from the same parent material and having common characteristics. It is composed of series, type, and phase. In this arrangement a series is a group having the same genetic horizons which are similar in their important characteristics and profile arrangement and having the same parent material. The series carry the catena-soil names such as Miami. Within a series there may be several types which are defined on the basis of texture. To the series name is added a textural term such as silty-clay Miami. This refers only to the upper part of the soil profile in agricultural mapping. Variations within a type are referred to as phase. The phase usually refers to unusual or outstanding features usually about slope, texture, erosion, or some topographic situation. An example might be silty-clay Miami, rolling phase.

To illustrate the above, an important Wisconsin Drift catena is Miami-Crosby-Brookston. These three are derived from Wisconsin till upland soils. They differ in profile characteristics and in topographic position. In general, Miami soils occur on steep slopes, are light in color, and have shallow profile development consisting of silty clay in the B horizon; Crosby soils occur on lesser slopes, are light in color, have a moderate profile development consisting of silty clay with some sand in the B horizon; and Brookston soils occur in the depressions, are dark in color, have an organic top soil, and a relatively thick B horizon of a plastic silty clay and clay.

Presentation of Soils Data. An understanding of the manner of presentation of agricultural-soils data in the various bulletins is important since methods change and the user must follow constantly the changes in order to obtain most efficient use of this method. A brief discussion of some of the methods of grouping soils in county soil-survey reports as presented by the Department of Agriculture follows.

In the soil-survey report on Bartholomew County, Indiana, of 1947, soils are grouped according to the major agricultural pursuit. The first major division is in two groups: (1) soils of the grain and livestock areas and (2) soils of the general farming areas. These are subdivided into soils of: (a) corn, wheat, and livestock, (b) special crops, (c) cash grain crops, (d) general farming, (e) hill farming, and (f) forestry. Under each of these latter subdivisions appear the actual soil names grouped according to whether they are well-drained, imperfectly drained, or poorly drained. This general approach is irrespective of parent material, texture, or topography.

Another type of soils grouping is that based on drainage as discussed in the Washington County, Indiana, soil bulletin of 1939. (23) In this instance, the soils are divided into "well-drained agricultural soils, imperfectly drained agricultural soils, and poorly drained agricultural soils" as primary groups. The individual soil names appear directly beneath these three headings. By such an arrangement it is possible for each group to contain soils of uplands, terraces, and flood plains. It is also possible to find one parent material contributing to each of the three groups.

The Vanderburg County, Indiana, soil-survey report of 1944 (22) groups soils on a landform-parent-material basis as the primary grouping. In this report major soil groups are: (1) deep silty soils developed over sandstones, siltstone, and shale; (2) shallow soils over sandstone, siltstone and shale; (3) deep silty soils of the upland; (4) soils developed from silts of the lakes plains; (5) soils developed from slackwater clays; (6) soils of the Ohio River Terraces; and (7) alluvial soils. These major groups are subdivided into soil catenas in which the series, types, and phases are shown. In this report a table presents additional information, such as parent material, topographic position, drainage, slope, and profile description.

The soils grouping of the Morgan County, Indiana, survey report of 1950 (19) is based on parent materials as the primary arrangement. The parent-material groups include soils developed from: (1) calcareous late Wisconsin drift; (2) calcareous early Wisconsin drift; (3) calcareous Illinoian drift; (4) sandstone, siltstone, and shale; (5) limestone; (6) deposits of windblown sand and silt of Wisconsin glacial age; (7) calcareous glaciofluvial deposits of Wisconsin age; (8) calcareous limestone silt and clay of Wisconsin age; (9) noncalcareous clay, silt and sand of stream terraces; (10) noncalcareous outwash, sand, silt, and gravel of Illinoian glacial age; and (11) calcareous slackwater silt and clay. As can be seen in Group 9, the parent material is modified by the expression "stream terraces."

An additional primary grouping is also shown for alluvial soils which is based on alkalinity or acidity. The three groups shown are (1) neutral to slightly alkaline alluvial soils from the region of Wisconsin drift, (2) slightly to medium acid alluvial soils from the Borden formation, Illinoian glacial drift, and limestone, and (3) strongly acid soils from the Borden formation and Illinoian glacial drift. Both major groups are divided further into catenas. Details of the profile and other characteristics are discussed in the text (19).

Another of the most-recent survey bulletins, St. Joseph County, Indiana, published in 1950 (21) recognizes five major divisions which are based on a landform grouping as follows: (1) soils of the uplands, (2) soils of the glaciofluvial outwash plains and terraces, (3) soils of the glacial outwash and lake deposits, (4) mineral soils of the flood plains, and (5) organic soils. Group 5 is a departure from the landform arrangement. The soil series within the landform groups are shown in tabular form in such an arrangement as to show major drainage, parent material, and position with respect to the great soil groups of the world (which in this instance are gray-brown podzolic and prairie soils, semiplanosols, Wiesenboden and half-bog soils, and bog soils). This is a convenient arrangement and easily used in development of an engineering key.

In some of the earlier reports a general soils description prefaced the detailed descriptions of the soil series. There was no attempt to grouping such as in the Porter County, Indiana, report of 1918. In this report (20) it is stated that: "The soils of the county have been identified as members of 23 series differing from each other in source of material and character and composition of the soil and subsoil." Such items as parent material, geology, and topography, are covered very generally in connection with individual series descriptions.

The text of all soil-survey manuals, particularly those published in the last 20 years, contains a good description on the various soils as to color, texture, drainage condition, and profile development. However, since the agricultural surveys are concerned primarily with that portion of the soil supporting plant growth, detailed

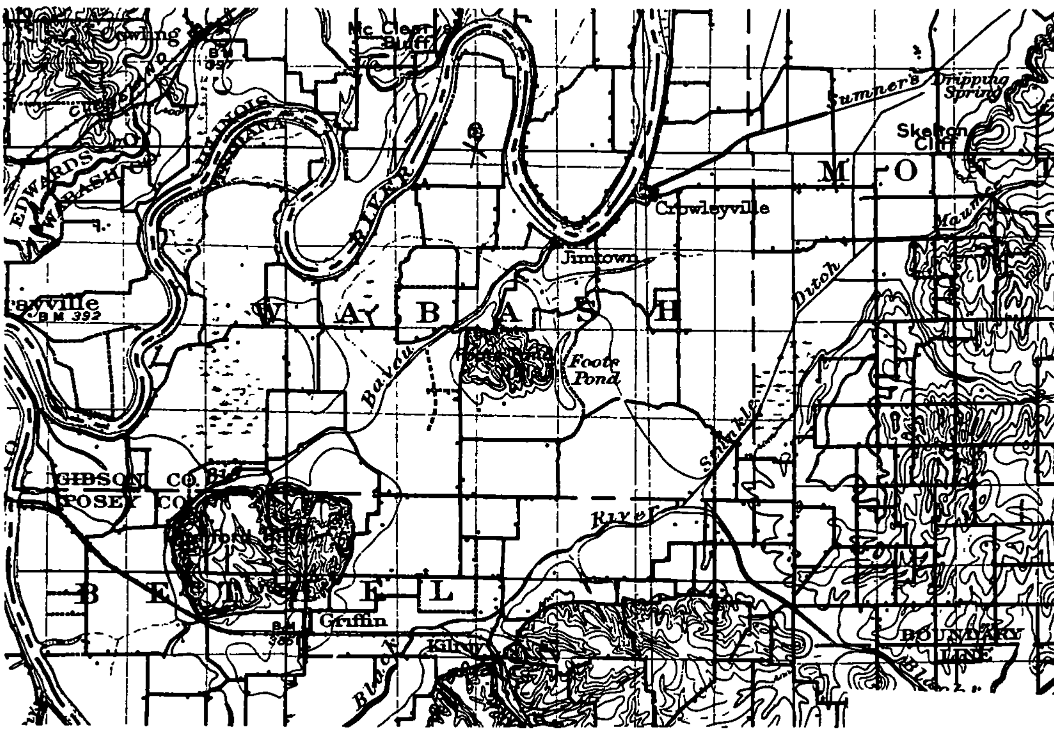

Figure 21. Topography map of example areas.

information is presented for the upper 3 to 4 ft., which is usually the portion encountered in the A and B horizons. Some description is given, in most instances, of the parent material. Some reports present mechanical analysis of samples.

Summary. In summary, the principles of materials evaluation from agricultural soil-survey maps are based on four major points which are basic and five minor points which are general and of an applied nature. The four basic points which the engineer must possess for optimum use are: (1) a working knowledge of the various agricultural systems of grouping soils for presentation both in text and map form; (2) an understanding of the pedologic concept of soil formation; (3) the ability to translate agricultural terminology into engineering terminology; and (4) an understanding of the engineering significance of the areal soils which is based on the catena arrangement.

The minor points which are of an applied nature include: (1) continuous field-sampling program for correlation of test data with agricultural-soil series; (2) correlation of pavement-preformance data with agricultural-soil series; (3) constant review of literature concerning agricultural soils; (4) constant use of the agricultural-soil maps in the field; and (5) recognition of the series names which are known to contain materials.

Techniques of Material Survey from Literature and Maps

The techniques to be followed in conducting a materials survey from agricultural literature and maps are based on the availability and amount of detail of engineering data about agricultural soils and on the background of the user. Access to a comprehensive key, which correlates agricultural soils names with engineering test data and other important features, is very useful. In such cases locating materials becomes a matter of recognizing the names of the agricultural soils which are known material sources and outlining them on an agricultural-soils map of the area under consideration. These areas should be field sampled, either by an examination of the soils in existing road cuts or by obtaining profile samples using a soil auger. Representative samples should be taken in several areas covered by the same soil symbol. It should be remembered, however, that there may be more variations in a soil series shown in an agricultural map due to slope, erosion, or textural differences than will be practical to recognize in connection with the engineering survey. If the key does not contain test data covering these variations or does not point out the engineering significance, then it will be necessary for the user to study the variations as described in the soil-survey bulletin before attempting a field sampling program.

Areas Already Mapped. In areas where agricultural-soils maps are available the procedure is shortened considerably. Material survey may be accomplished by grouping the soils types and phases of a series known to be predominantly granular. The areal extent is easily determined following such a grouping. Locations for field sampling can be accomplished in advance of field operations by studying the soil areas as indicated by such a grouping on the agricultural-soils map. In most soil surveys, the maps are of sufficient accuracy to eliminate most of the field work. Final delineation of soil boundaries may be located in many instances directly on the agricultural-soils map. Field data, when analyzed in the laboratory, will provide engineering characteristics and suitability for use in connection with highway or airports. The data from the laboratory can then be plotted and an engineering-materials map drawn.

Areas Unmapped. In areas where agricultural surveys are unavailable, information can be extrapolated from areas of known conditions where known conditions are similar, providing the user has cognizance of the pedologic concept of soils. It is necessary that the user make a field reconnaissance to establish parent materials and the topographic arrangement and to determine the landforms represented. In a rapid reconnaissance an examination of road cuts and landforms will provide information necessary to establish parent materials. This type survey will provide information for the preparation of preliminary material maps. Borders can be established on the landform basis for preliminary work. Following the preliminary map preparation a detailed sampling program should be initiated to provide qualitative and quantitative data about the material boundaries. Revision of borders can be accomplished by detailed sampling along the transition between landforms. Sampling in such an instance should be of the profile type in which samples for testing are taken of the various soil horizons and of the underlying parent material.

Keys for Use with Material Surveys Using Agricultural Soils Maps

There are several possible methods of developing keys for using agricultural-soil-survey information in connection with materials survey for engineering use. Basically, all keys are of a guide nature and are designed to assist in obtaining information. They may be elaborate and contain extreme detail, or they may be simple and merely serve as reference material.

Perhaps the easiest key and that easiest used by those not familiar with the pedologic concept is one which lists agricultural-soils names alphabetically. Accompanying each soils name is a technical description of the soil which includes physical test data of the horizons comprising the profile, drainage characteristics, and structure, as well as information concerning the parent material, topography, slope, cover, and any miscellaneous features which may be significant. Such a key becomes a legend or glossary for an agricultural soils map. The arrangement of the soils alphabetically is of no major concern, since the soil names are obtained from the map and the descriptions are obtained from the legend-glossary. The system developed by Michigan (17) is of this type. The series are listed alphabetically and accompanying information is tabulated. The table gives general information about characteristics, treatment, and resources. These groups are subdivided to permit presentation of information of greater detail. The key or soils table is accompanied by a series of detailed profile descriptions. In this series the profile of each soil is shown graphically and described in an accompanying text. Another important key, but somewhat more complicated, is that developed by North Carolina and illustrated in Bulletin 22 of the Highway Research Board (8). This key is so designed that it can be used in areas which are unmapped by extending information to analogous areas. This requires a knowledge of the pedologic concept and some knowledge of the basic geology of the area. The key is most effectively used in conjunction with a geologic map in areas not mapped by soil survey. The key is a diagrammatic presentation which correlates physiography, parent materials, drainage, profile development, and agricultural-soil-series names.

The key developed at Purdue is a diagrammatic presentation of the correlation between parent material, topographic arrangement and the agricultural soil series names. The key is supplemented by a detailed description of soils profiles listed alphabetically. This key is discussed in Purdue University Bulletin 87 (6). A copy of this correlation chart is included as Figure 26. A brief description of this key follows.

Soils derived from the same parent material form the major groups. Subdivisions are on the basis of landform and slope. Agricultural soil names appear in the proper slope position in the diagram. The catenas, consisting of the various series, extend horizontally across the table. There are four slope arrangements which are 16 to 55 percent, 4 to 16 percent, 4 to 0 percent and depressions. The fifth column is for alluvial and special types.

Limitations of the Use of Agricultural Soil Survey Data

This survey method is an excellent one for obtaining preliminary information in areas where detailed agricultural soils information is available. It is limited to those areas possessing good maps. As pointed out previously, many of the early soil surveys were not accomplished in sufficient detail to warrant use in detailed engineering surveys. This limitation results because earlier soil names included many variations which, even though not recognized at that time, are important today. Another limiting factor is the ever-increasing number of soil names which are being added as the agricultural program recognizes and maps to greater detail than in the past. This requires more work on the part of the engineer in conducting a sampling and testing program and in translating the agricultural information into engineering terminology. However, this added detail is to the benefit of the program if properly correlated. The method may be limited by the extent of the engineering testing program which has been conducted to provide test data for the various agricultural-series types and phases.

Survey procedures learned in one state or one area can be followed and adapted to other areas; however, a change in parent material and climate is accompanied by a change in the agricultural name. This necessitates the development of new keys. This becomes a limiting factor for surveys which cross state lines.

Example of Material Survey from Agricultural Soil Survey

The soil survey of Gibson County was published in 1926 (18). Figure 7 shows the county soil map. In the report the soils of Gibson County are arranged in several different methods. One grouping is on the basis of profile development, one grouping is on the basis of physiographic arrangement, and another is on the basis of parent materials. These various major arrangements assisted materially in the preparation of the Agricultural Soils Map Key (Fig. 27). From all soil-survey reports studied, detailed descriptions were obtained of each type, phase, and series and are presented here as a key. These proved very helpful in designating the proper topographic position and the proper materials symbols to be used on the materials map (Fig. 9). A landform-soils-series guide as used in the Purdue studies (6) was also helpful in developing the key (Fig. 26).

Soil Groups in the Agricultural Text. The soils arranged on the basis of profile

Figure 22. Aerial photographs of example areas.

development are subdivided into three groups (18). Group 1 includes soils with normal soil-profile development and which are well-drained, such as Bainbridge, Buckner, Elk, Princeton, Ownesville, Haubstadt, Gibson, Tilsit. Group 1 also includes soils situated on flat areas but having abnormal profiles and still retaining good drainage characteristics. These are Vigo, Lickdale, McGary, Robertsville, Robertson, and Calhoun. Group 2 soils are those poorly drained soils having a poorly developed profile. Included in this group are Tyler, Montgomery, and Lyles. Group 3 soils contain the recent alluvial deposits and include Lintonia, Genessee, Huntington, Holly, Waverly, and Sharkey.

The soils of the county are also arranged according to their proper physiographic headings of upland, terrace, and bottom. This grouping is as follows: Upland — Princeton, Owensville, Gibson, Vigo, and Lickdale. Terrace — Buckner, Elk, Bainbridge, Lintonia, Robertsville, Haubstadt, Robinson, McGary, Calhoun, Tyler, Montgomery, and Lyles. Bottoms — Genessee, Huntington, Holly, Waverly, and Sharkey.

The parent material grouping of soils is described on page 1173 of the soil survey. This arrangement is as follows: Residual — Tilsit and Lickdale; Glacial — Gibson and Vigo; Loessial — Princeton and Owensville; and Waterlaid — Bainbridge, Buckner, Elk, McGary, Robertsville, Haubstadt, Calhoun, Tyler, Montgomery, Lyle, Lintonia, Huntington, Genessee, Holly, Waverly, and Sharkey.

Soils Grouped for Materials Use. The key which has been prepared for use in this portion of the survey is Figure 27. It is an arrangement of soils into upland, terrace, and flood plain. The flood plain has been subdivided into high lowland (HL) and low lowland (LL). It is to be noted that the names Miami and Yazoo appear on the key. These names were taken from the soil survey of Posey County, since part of the area under study falls within that county. Since these names are not shown on the Gibson County map they are not discussed here.

In addition to showing the soil-series names in their proper arrangement physiographically the map shows appropriate parent material. Map symbols for the engineering-soil-texture-landform-parent-material arrangement are taken from Figure 31.

The results of the engineering evaluation of Sumner Ditch area are shown in Figure 9. This, together with the agricultural soils map (Fig. 8) of the Sumner Ditch area contain all of the data obtained for survey of the materials accumulated.

GEOLOGY-MAP METHOD

The mapping program undertaken by the U.S. Department of Interior through its Geological Survey and the mapping programs undertaken by the various state geological surveys provide the engineer with a valuable source of information which can be utilized in material surveys. The purpose of these surveys is to make available to the public information about the lands so that the natural resources that should be profitably exploited could be guided by a body of facts assembled by a competent and impartial agency (16).

In addition to literature prepared by state and federal mapping agencies, the engineer can often obtain detailed geologic data published in technical journals which are reports of research or exploration. Among these are Journal of Geology, American Journal of Science (14), Journal of Geomorphology, Geographical Review, and bulletins of the Geological Society of America (15).

Principles of Soil Evaluation from Geology Maps

The interpretation of geology maps to establish general areal soils data is dependent upon two factors: first, the knowledge and experience of the interpreter, and second, the quantitative and qualitative detail of the original map. Within certain limitations the engineering interpreter with a good knowledge of historical geology and a concept of physiography can make an excellent and reliable survey with a given set of areal geology maps. Furthermore, with a given set of geological maps of both stratigraphic and surface geology the interpreter can make a materials map which will be as accurate as the literature and map data employed.

Preliminary Survey. There are two principal steps to be taken in order to make a materials survey from a geological map and geological literature. The first of these is to assemble and study the literature and maps available concerning the area to be surveyed. These data enable the engineering interpreter to formulate a perspective as to the physiography and general materials to be expected in the vicinity. The types of literature that should be studied include geological atlas, geologic folios, quadrangles, bulletins, papers, survey reports, and professional papers. Usually a topographic map is available of every area that has a surficial geology map. This type map is also helpful as a supplement to the geology map. Water-supply papers and ground-water data published by the U. S. Geological Survey furnish excellent sources of data to use in preparing the material survey. The Lexicon of Geologic Terms and a hard-rock-and-surface-geology dictionary of some type should be handy when studying these data.

It is important that the user of such data understand the manner in which the data are presented in the various types of publications. Some discussion of this topic is covered more thoroughly elsewhere (12). A geology map is one which represents, by means of symbols and an appropriate legend, the distribution of soil and rock masses of the surface of the land and the stratigraphy underlying the surface of the land. On recent maps the amount of detail shown on a map depends upon the map scale. The surface geology map shows the surface forms. The forms that are included in the make up of the earth's surface are the valleys, uplands, terraces, beaches, and mountains. The areal geology map records these features along with the general materials that constitute the forms. The legend that accompanies an areal geology map usually represents both the landform and the materials contained therein. There are other types of geology maps which may be of use in any material survey. Among these are the economic geology map and the structure-section sheet. The former represents the distribution of minerals and rocks, showing their relation to the topographic features and to geologic formations. The structure-section map shows the arrangement of rocks in the earth's structure. The stratigraphy is represented in the form of groups of rocks according to the geologic time table. The distribution of the rocks according to the age in which the sediments were correlated are indicated. The legend on these types of maps represents the age and type of material found below the earth's surface conformably or unconformably resting layer upon layer. Each group of rocks is described briefly in the legend usually found in an appendix accompanying the map or folio.

Techniques of Material Surveys from Geology Maps

Literature and Map Survey. All of the data which can be located concerning an area should be assembled and studied before use of maps is made. The more detailed this survey is made the more reliable the resulting materials survey will be. There is a wealth of geological data available in the folios for some areas in the United States. Gibson County, Indiana, has been surveyed by various geological survey parties. The best source of geological data has been found in the geological atlas or folio. The Patoka (13) and Ditney folios (7), each cover portions of Gibson County. The western section of the county has been surveyed and the areal geology reported in the Patoka Folio. The Indiana Handbook of Geology provides good information also (11).

In order to obtain the required data from the geology maps available a perspective should be formulated. The perspective consists of a concept of the general physiography and the surface materials to be expected. This study determines if the location can be classed as mountains, plateaus, upland, or lowland. Once the physiography is known local landforms can then be determined. This includes determining whether the locality is terrace, flood plain, upland, or lakebed. The next step is to determine how these forms occurred. One should determine that the area either has been glaciated, modified by aeolian or alluvial deposits, vial, or surface deposits are derived from sedimentary, metamorphic, or igneous residual materials. When the physiography, landform, origin, and parent material are known, then the perspective of the area is enhanced and the survey is simplified to a large extent. The next step is to study available details of the various landforms.

Geology-Map Interpretation. The best map to use in the materials survey is an up-to-date, areal-geology map of a scale of 1:125,000 or larger. This map shows the distribution of the older subaqueous deposits as well as the younger more recent deposits. The map legend usually indicates the forms and layering system of all deposits within the area. The older forms will be on the bottom of the legend column and the most recent deposits appear at the top. In general, four major material-landform patterns exist, namely: residual, aeolian, glacial, and alluvial. To determine from the map the landform of a locality with a distribution of residual materials is difficult. This study is always supplemented with a study of the literature.

Some landforms, such as a few of the aeolian, glacial, and alluvial forms, usually are indicated in the legend. Primarily these latter types are of more recent origin and, in many cases, cover residual types. In such cases the residual type is usually modified. Details of modification may not be apparent from the legend; hence, further study of the literature may be necessary.

Once the landform origin has been determined, the materials listed within these types should be classified. This classification is best defined on a landform basis. The various landforms that may be local within a river valley area are flood plain, lake plain, terrace, or upland. Within a glaciated region there may be outwash plains, flood plains, lacustrine plains, terraces, eskers, kames, till plains, uplands, and others. Within an aeolian region there may be any of the above but covered over by wind-blown deposits. Within residual landform types there may be all of the above listed types and mountains or plateaus may even be underlying the types indicated. The materials within each landform class are then listed. These are interpreted directly from the legend.

Preliminary Materials Map. A preliminary materials map can be made based on the landform-materials classification system outlined in the previous paragraph. With the new legend a base map of the given area is prepared. Each landform is delineated according to types designated, then these boundaries are subdivided on a general material basis.

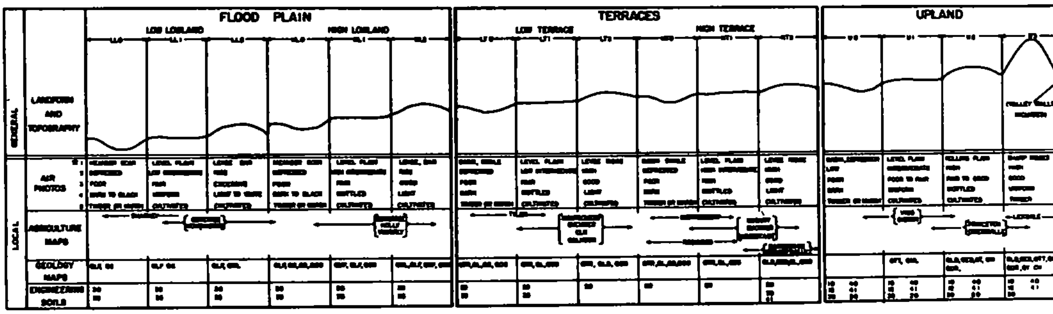

Figure 23. Master key for material survey.

The preliminary map is taken to the field for checking. Each landform type is inspected. Highway cuts and cut-banks along rivers are observed to simplify field work. Holes are augered and samples procured for laboratory analysis. The depth to which samples should be taken is determined by the use to which the materials are to be put and by the thickness of profile development.

The preliminary map eliminates a considerable amount of field work. The field investigation may then be confined to confirming the existence of the predetermined gravel or rock deposits. Once the field check and the soil laboratory analysis has been made a final materials map may be prepared. This map will show the correct delineation of materials boundaries that may be encountered in any given area within each landform.

Keys for Use with Material Surveys

In general, the key that should be employed with geological literature is one which tends to classify and determine the boundary conditions of given data. The key for use in this paper is one based upon the landform, topographic expression, or relief within the given landform, and the general materials that accompany the landform. This key (Fig. 28) is made up from the data acquired from the literature and map survey. The key is a supplement to the map legend in Figure 31. Quite often map space for scale used is insufficient. Also, too much detail on a given map tends to destroy its usefulness. Therefore, the key is a necessary adjunct to the understanding of the materials map. In general, the key is a qualitative-analysis chart. An application of the use of this key is given in the example.

Limitations of the Method

Availability of and Amount of Detail on Maps. The availability of geologic maps is a limitation to the use of this method. For example, there are areas in the United States which have not been surveyed. Obviously one could not use the method without maps or data for a given area. Some maps are very general, particularly earlier ones, and do not show sufficient detail to establish the surface materials of an area. For example, the map of the structural geology of Indiana shows only the hard-rock stratigraphy. Much of Indiana is overlain by glacial deposits which have changed the original surface features. Here is a limitation to the use of stratigraphic or structural geology maps. Likewise, many geological maps are of reconnaissance nature and very general. The detail required for survey of specific areas can be accomplished only with supplementary data to the reconnaissance.

Accuracy of Qualitative Information. The qualitative data that can be obtained from geologic maps and geologic literature is usually excellent. It is necessarily of a descriptive nature and must be supplemented by field data. However, the areal extent of surface deposits can be determined and evaluated from these data. Many spot checks can be made in the field to evaluate the depths of the deposits of representative areas. These data then can be extended to geologically similar areas.

Example of Geology-Map Method

Study of Data for an Overall Perspective. The example given in this section is known as Area D, Stunkle Ditch. Physiographically, it is located in Gibson County, Indiana, in a river valley which is within the Wabash lowland of the Till Plains Section of the Central Lowland Province of the Interior Plains Physiographic Division of the United States (9, 10). Figure 10 is a copy of the geology map of Gibson County (13). The area is in a glaciated region and within the specific area surveyed the flood plain is that associated with a mature stream valley which is believed to have been the result of glacial meltwaters occurring during the Wisconsin Age. The valley-fill material is reported to consist of sand and gravel overlain by sand or silt. Some features of the Illinoian Drift Age appear in this valley and in some cases dominate the surface pattern. In locations where the Illinoian Drift is deep and is encountered as the surface material (in the southwestern section of Gibson County) the surface imparted by the ice is flat and the major stream channels are dendritic in pattern form.

There are loessial features to be encountered in this area; they are reported overlying many parts of the valley. The present flood plain is the result of seasonal floods and lateral erosion with abandoned channels filled to the present established level. There are also some terrace remnants reported to have been formed by the old Maumee River. These border the uplands on the eastern border of the flood plain. Underlying the features of the flood plain, loess, and terrace remnants are glacial drift deposits of Illinoian Age and bedrock features related to sandstone, shale, and limestone of the upper Pennsylvanian Age. Outcrops have been correlated in various parts of the Wabash Lowland. These bedrock features do not outcrop except in the Mumford Hills (see Area F of this survey).

It is seen then that the perspective gives the picture of a landscape associated with a wide river valley consisting of upland islands of bedrock, overlain by loessial deposits; an alluvial floodplain marked by silt-filled, abandoned-stream channels, and oxbows, and bordered by old terrace remnants also overlain by loessial deposits. Hence, in general, the materials that can be expected in this part of Gibson County are silt, sand, and gravel. The section that follows is written in order that the reader may obtain a procedure for determining details of how to find materials using an areal geology map.

Geology - Map - Interpretation Procedures. The geological map (see Figs. 10 and 11) was studied and analyzed with the landform perspective in mind. It was found that the Stunkel Ditch Area on the geology map consisted of three general landform classes, namely: upland, terrace, and flood plain. The flood plain was subdivided into high lowland and low lowland, principally on basis of seasonal flood conditions. It is believed the high lowland is less subject to seasonal flooding than the low lowland. The materials as classified on the geology map are on basis of origin and formation. Some of the data listed on the map is self-explanatory. However, the description of the Wabash Formation had to be supplemented with data obtained in the Lexicon of Geologic Names of the United States (29). With the three landform classes in mind, all the materials of the area were classified in their respective landform position. A topographic map was overprinted on the geology map. This step assisted in organizing the arrangement of classes of materials into their landform positions. The landform classes were in turn subdivided into topographic (relative relief) position. The description in the legend also assisted the classification of the available materials.

The following grouping of geologic classes of symbols forms a simple arrangement of the materials available for engineering construction. Grouping by landform and topographic position simplifies the field work of an engineer and enables him to determine what materials he has available and within what topographic position these materials occur. The upland-landform arrangement of materials has several types of materials. The Stunkle Ditch Area used to illustrate the method does not have an upland form. However, there are two landforms, namely: terrace and flood plain. The flood plain has both high and low lowland situations. The terrace landform has been mapped as coarse sands over all the area. The later dune sand is applied to material of aeolian origin in part but consisting of particle sizes larger than that which can be transported by wind. The high-lowland landform has been mapped on the basis of the upper flood plain class of materials and the swamp deposit class. This upper flood plain refers to materials deposited during the Quaternary Age. It consists of silts and sands in a stratified system. In places, silt overburden is thick. The swamp deposits term applies to materials found in depressed situations. It usually consists of muck and peat and on geologic maps is referred to as vegetable mold. The low lowland of the flood plain has only one topographic situation. According to the geologic map the lower flood-plain sediments refer to materials of Quaternary origin. These sediments are found in flat areas subject to seasonal floods and are silts and sands.

In the upland the topographic situations U-1 and U-2 are shown as Qtt and Qt respectively. According to the lexicon, Illinoian Drift is applied to the third drift of Labrado and Patrician parts of Laurentian ice sheet. It consists of thick and thin deposits of till consisting of a heterogeneous mixture of silt, sand, and gravel with clay. If the Illinoian drift is surface material, silt is the dominant grain size in the upper layers, whereas silty clay predominates in the subsoil, and a mixture of sand, gravel, silt, and clay in the lower layers (29). The topographic position U-3 is designated as marl-loess by the geology map (13). According to the lexicon the marl-loess term is applied to material of aeolian origin, calcareous in character and uniform in grain size. It is the formation that overlies much of the Wabash Lowland in dune or ridge forms. The grain size is most generally silt. However, it ranges from clay-like to fine-sand materials. The Wabash Formation, where it occurred, was designated as U0 on the geologic map; thick Illinoian drift was delineated as U-2; thin Illinoian drift was delineated as U2; and loess where it was encountered was delineated as U-3. The latter was usually the highest in topographic position and the former the lower member of the formation since outcrops of it were found in gullies and lower slopes only. The symbol U0 is shown as Wabash formation, and designated as CW by the geologist (13). It consists of thick sandstones within thin shales, limestones (Pennsylvanian Age), and coal beds in the lower half with the upper half containing alternating sandstones and shales to a thickness of 180 feet (29). According to the lexicon, the formation is overlain by Tertiary Age alluvial deposits.

In the terrace three separate and distinct topographic positions were found. These were delineated as depressions, flat areas, and ridge areas. The depression form is delineated as LT0; the flat-topographic situation as LT1; and the ridge class of materials as LT2. The topographic position LT0 is designated as swamp deposits by the geologist (13). According to the Lexicon swamp deposits are depressed situations, poorly drained and having muck and peat or vegetable organic materials (29). The topographic position LT1 is designated as marl-loess by the geologist. It consists of stratified silts and fine sands in a flat topographic situation. The topographic position LT2 is designated as later dune sands by the geologist. The materials are delineated in this topographic situation as coarse sands (see Figs. 11 and 28).

The flood plain is divided into high lowland and low lowland areas. The high lowland of the flood plain consists of several geological divisions of materials. The upper-flood-plain deposits shown as Quf are mapped as HL2. These sediments consist of silts and sands in a high topographic position. The area is rarely overflowed by seasonal flooding. The abandoned channel deposits (Qc), are

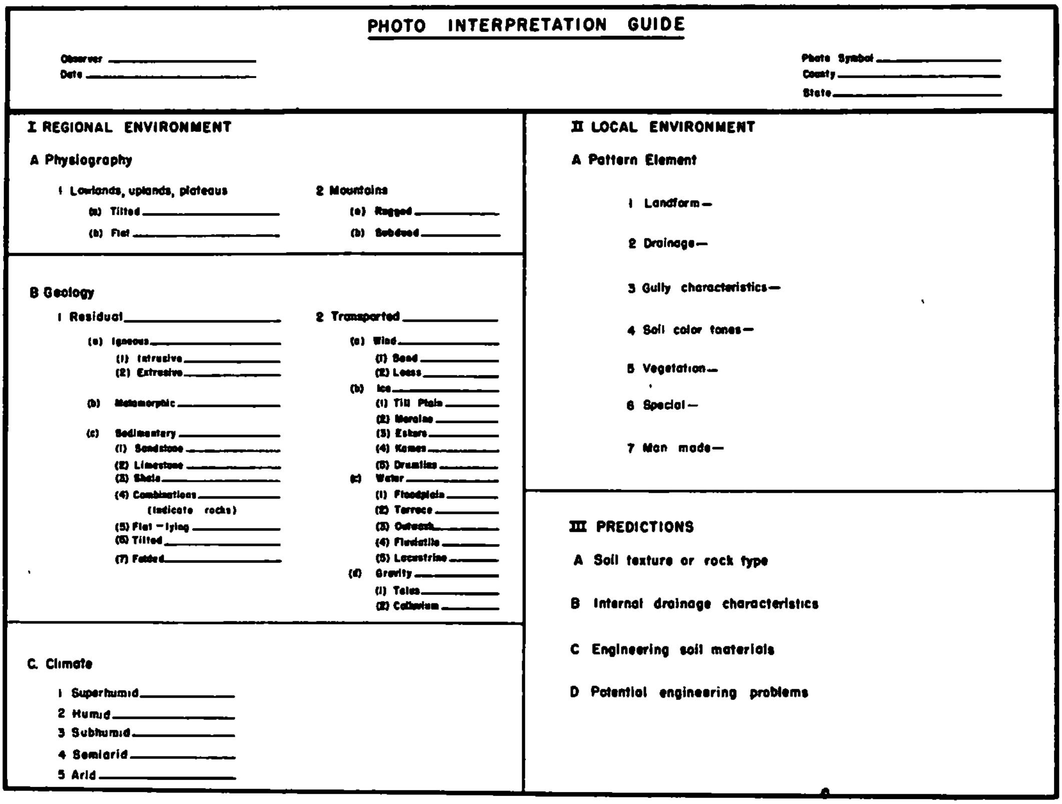
PHOTO INTERPRETATION GUIDE

Observer ____
Date ____
Photo Symbol ____
County ____
State ____

I REGIONAL ENVIRONMENT

A Physiography
1 Lowlands, uplands, plateaus
(a) Tilted ____
(b) Flat ____
2 Mountains
(a) Rugged ____
(b) Subdued ____

B Geology
1 Residual ____
(a) Igneous ____
(1) Intrusive ____
(2) Extrusive ____
(b) Metamorphic ____
(c) Sedimentary ____
(1) Sandstone ____
(2) Limestone ____
(3) Shale ____
(4) Combinations ____ (indicate rocks)
(5) Flat-lying ____
(6) Tilted ____
(7) Folded ____
2 Transported ____
(a) Wind ____
(1) Sand ____
(2) Loess ____
(b) Ice ____
(1) Till Plain ____
(2) Moraine ____
(3) Eskers ____
(4) Kames ____
(5) Drumlins ____
(c) Water ____
(1) Floodplain ____
(2) Terrace ____
(3) Outwash ____
(4) Fluviatile ____
(5) Lacustrine ____
(d) Gravity ____
(1) Talus ____
(2) Colluvium ____

C. Climate
1 Superhumid ____
2 Humid ____
3 Subhumid ____
4 Semiarid ____
5 Arid ____

II LOCAL ENVIRONMENT

A Pattern Element
1 Landform—
2 Drainage—
3 Gully characteristics—
4 Soil color tones—
5 Vegetation—
6 Special—
7 Man made—

III PREDICTIONS

A Soil texture or rock type
B Internal drainage characteristics
C Engineering soil materials
D Potential engineering problems

Figure 24. Airphoto-interpretation guide.

mapped as HL1. The materials found in this flat topographic position are mapped as fine silts and clay with organic matter by the geologist (13). The low-land position of the flood plain has similar materials to those found in the high lowland according to the geology map. These are mapped as lower flood plain, Qef, and abandoned channel, Qc. Some places swamp deposits have been indicated; these have been described already (13). The geologist indicates lower-flood-plain sediments as materials having been deposited during Quaternary Age. They consist of silts and sands in flat and depressed areas. Where found in a depression the silt overburden is thick and highly organic.

Abandoned channels are sediments of filled-in old oxbows, cut-offs, or depressions formed by the river current at former water stages. The materials found in these situations are usually fine silts and clays. Where the topographic position is low, they may be highly organic. Under high lowland of the flood plain are found such geologic classes as upper flood plain, abandoned channel, and swamp deposits. These are designated as HL2, HL1, and HL0 respectively according to where the symbol occurs topographically. The low lowland classes of the flood plain include the geology symbols for lower flood plain, abandoned channel, and swamp deposits. Each of these in turn is designated as LL2, LL1, and LL0 according to its topographic position.

Summary of Materials Based on Landform. In the Stunkel Ditch Area, a study of the areal geology map and the lexicon of geological terms revealed that the landforms and their origin are flood plain and dune or terrace deposits of silt and sands, and coarse sands respectively. Some swamp deposits were noted but were classed as insignificant sources of useful materials. The engineering-materials map has been prepared on basis of landform and topographic position as well as materials within these topographic or relief situations. Each class of surface materials was delineated within U, T, and L map units based on grain-size distribution as indicated in Figure 31.

TOPOGRAPHIC-MAP METHOD

Topographic maps are among the oldest of engineering maps. They are prepared in a variety of ways: Topography can be obtained by merely sketching, by detailed field survey procedures with instruments, or by the use of photogrammetric methods from airphotos. They can be extremely accurate and rigidly controlled or they can be poorly done with little or no control. A topography map may convey differences of elevation and nothing else. An excellent topographic map conveys more than topography. It pictures the "expression of the surface" by the arrangement of contours representative of the earth's surface. An accurately prepared topographic map reflects patterns which have elements. The patterns can be broken into elements which can be recognized easily. These collective features can be analyzed and the pattern interpreted for the purpose of preparing a material survey.

The primary sources of topographic

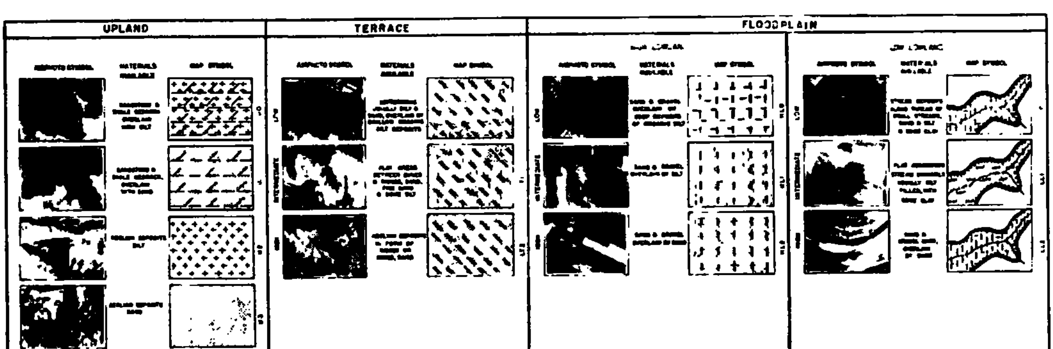

Figure 25. Airphoto-interpretation key.

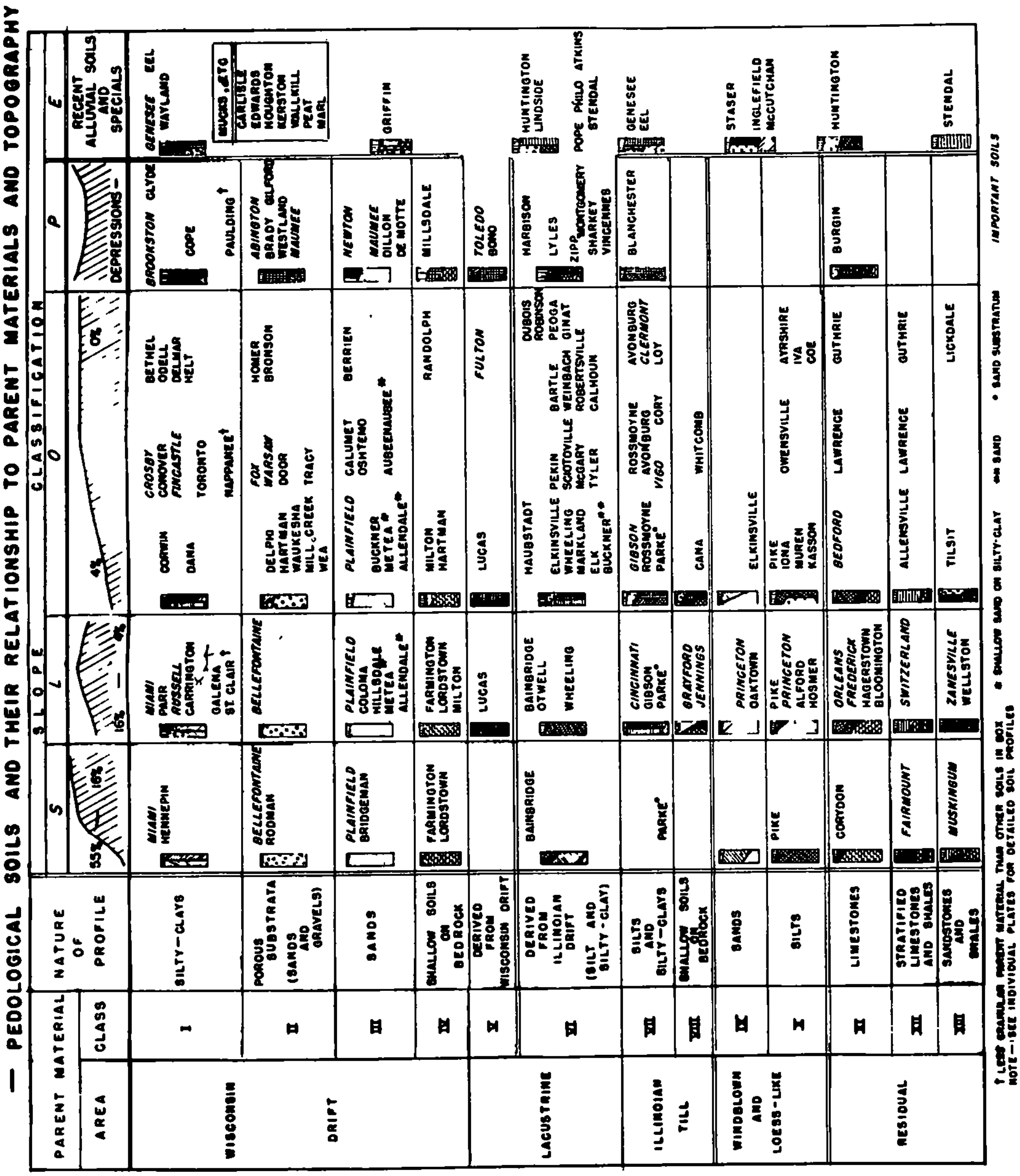

Figure 26. Landform-soil series guide.

maps are the reports of the U. S. Geological Survey, the various state geological surveys and mapping agencies, and the Corps of Engineers. Several of these agencies prepared maps which were used in this survey (7, 13).

Principles of Material Surveys from Topographic Maps

There are three principles, namely: (1) the topography map records man's impression of the surface configurations of the earth, since these surface features are the results of natural processes in the development of surface materials; (2) the earth's surface materials can be grouped together to form a pattern which is composed of recognizable features; (3) the surface- and subsurface - material patterns and their representative topographic contour patterns are repetitive in nature.

An evaluation of the earth's surface materials from a topography map is based upon the principles that the topography, as recorded on the map, is representative of the natural and physical environment influenced by certain geomorphic processes. Such processes as orogeny, diastrophism, and earthquakes have distorted the surface to form the major features and wind, water and ice have moved, transported, or deposited materials on the earth's surface to alter these major features. The distortions and deposits are recorded by man in a topography map which features a certain arrangement of contours. Once an engineer recognizes patterns as significant of a particular landform, he analyzes step by step the contour picture of the characteristics of the particular landform studied. From these maps he may be able to determine the surface materials to be expected within reasonable limits.

In order to recognize that patterns are repetitive in nature, an examination of three materials (sandstone, limestone, shale) combined in a pattern in three physiographic regions of the United States will prove helpful (see Fig. 13, 14, and 15).

At Fort Knox, Kentucky, the pattern is located in the interior low plateau of the central lowland (see Fig. 13). The area covered is one of a tributary stream known as Cedar Creek. It is located near the eastern boundary of the military reservation. The gorge created by Cedar Creek is a solution valley in a limestone plain. Cliffs rise sharply east and west of this straight, north flowing stream. Smaller streams flow into the creek from short gullies each having an entrant angle almost perpendicular to the Cedar Creek. The floor of the valley is flat and rather wide, as indicated by a wide spacing of the contour lines. The contour lines along the valley wall are regularly spaced but close together. There are no terraces. On top of the plain there is the impression of a flat plateau-like rock pediment. Thus a pattern is formed by the drawing of contour lines which represent these surface configurations.

The second topography pattern is located near Fort Riley, Kansas, in the Osage Plains of the central lowland and is shown in Figure 14. The pattern is one very similar to that described above. There is a different cover type due to the fact that the rainfall is less than in the previously described area. Again, the long, straight tributaries exist, with short stubby gullies entering almost at right angles. The valleys are flat and wide. The geological structure of the underlying rock is similar to that in the Fort Knox area. The ages of the two rocks are not too different. Hence, it can be expected that these examples and the pattern elements are comparative to a great extent.

The third topographic pattern is in the vicinity of Soda Canyon, Colorado, and is shown in Figure 15. The region is located in the southwest part of the state in the Canyon Section of the Colorado Plateaus Physiographic Division of the United States (10). It is also a pattern of limestones and sandstones with shale. From an analysis of this region it can be determined that the stream valleys are flat with short, steep gradient forming canyon-like gullies. The valley walls rise sharply from the floor of the valley. It can be seen that these patterns are related to each other. The type of materials represented in all of these examples is a cherty limestone.

From the above discussion it can be seen that the arrangement of contours form a pattern, and that the pattern represents surface and subsurface (structural) features of a region. The above, when coupled with information and other data gathered from literature, may be used to predict the type of engineering problems to expect from a typical contour pattern. The literature survey mentioned previously will be helpful in ascribing significance to topographic expression represented by the contours. The literature survey, including geology and physiography, will be helpful to determine expected relationships between earth forms and earth materials as described and pictured on a topography map.

Techniques of Material Surveys from Topographic Maps

In order to use contour maps for material surveys there are a few steps that need be followed. Having a given geographical region in which to locate materials, a set of contour maps of the given region are spread out for inspection. These contour maps should be to the scale of 1: 125,000, or smaller, in order to establish the pattern. Next, the observer should record the impressions gained from this examination in an orderly fashion. In this regard he should determine the landform, drainage pattern, gully characteristics, ratio of number of contour lines to a unit distance, erosional features, vegetation, and land use, if indicated on the map. These features are known as elements and will establish the pattern which can be analyzed. Once they have been listed, the next step is to determine pin-pcint locations for field checking. Field checks are usually made on basis of landform divisions and topographic changes within landforms. Uniform slopes, flats, breaks in slopes, valleys, depressions, ridges, and other changes can be noted in the detailed analysis and set aside as representative of changes in materials. These landform changes and significant topographic positions within landforms are drafted on a tentative material overlay map. With the tentative material map prepared then pertinent locations in the field, representative of typical areas, are sampled. The performance of engineering structures is observed. Generally highway pavements will reflect the type of performance that the underlying materials support. Upon completion of this field check and performance survey, the material map is revised, if necessary, and prepared in final form. It is obvious that the material survey from a topographic map will be of the order of a reconnaissance survey. However, this procedure if followed will enable the prospector to determine the maximum amount of data from the existing maps in a minimum of time and field work. Quite often field work is conducted first; then maps are studied. However, in the steps noted above, the field work is not nearly so extensive, nor expensive, if the procedure enumerated

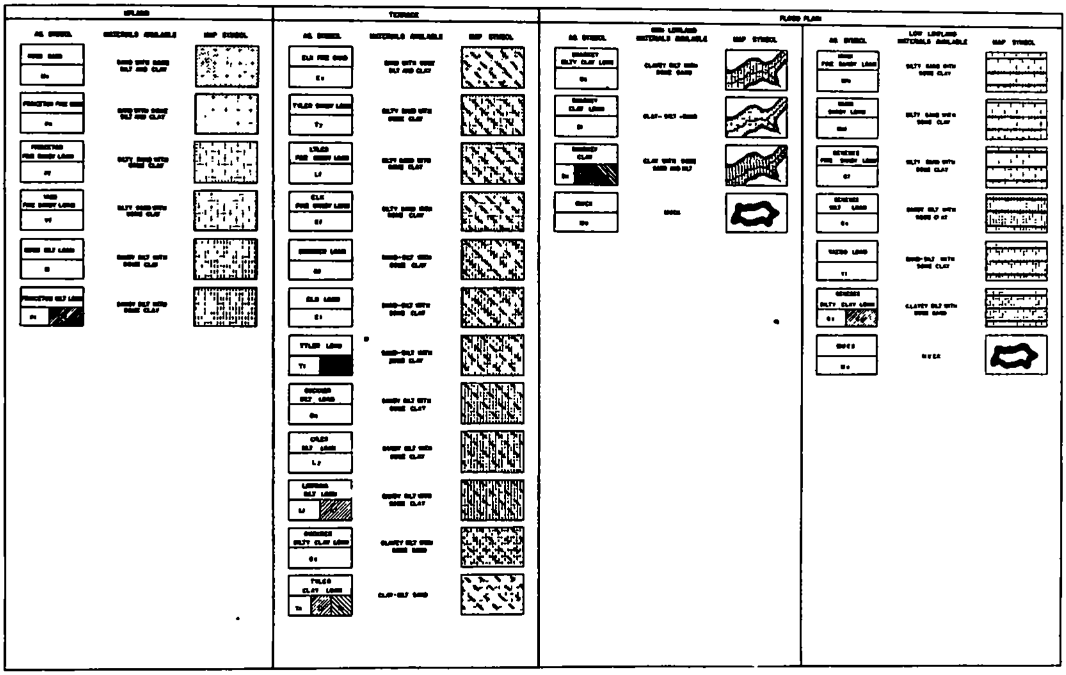

Figure 27. Agricultural-soils map key.

is followed prior to the field survey.

Keys for Use With Topographic-Map Data

Keys for studying material types are quite helpful. They should consist of an overall pattern with illustrations of all aspects of the pattern. Each element of a pattern, as listed above, should be indicated by both description and illustration, either by diagram or ground photo. Once the overall pattern is understood and the elements have given the prospector a concept of the make-up of what the pattern represents, then it is a simple analysis to delineate the materials represented by the key.

A key is based upon landform as the primary class. Each different landform is represented by its particular set of contour lines arranged in natural order. Flat plains, whether upland, terraces, or flood plains, are represented by contours spaced far apart per unit of distance. The junction or transition zone between a flood plain and an upland plain is represented by contour lines spaced close together per unit or horizontal distance. Depressions are represented by particular hachure-type of contour lines. It is to be noted that a series of contour lines to be representative of a pattern must be considered first on an overall basis. The pattern is then a significant indication of ground conditions. Each break in spacing of contour lines denotes a change in slope, which may be accompanied by a change in materials. A change in spacing per unit of linear distance is significant when there is change of slope on the ground.

Limitations of Topographic-Map Method

The contour map is limited. The map does not always cover an area sufficiently to be representative. If the scale is too large it may misrepresent the landforms. Likewise if the contour interval is too great the true arrangement, particularly slopes, may be misrepresented.

In areas where contours are spaced far apart per unit of horizontal distance (extremely flat areas), the contour map is unsatisfactory for material-survey use. In such areas, landform perspective may be lost. In areas where the slopes are so steep that contour lines will be spaced too close for accurate visual study of maps, the use is extremely limited. The techniques followed by the original draftsman in his interpretation and contour-representation of field data may become a limiting factor. As an example, it is important to know whether the brow of a hill or rise is softly rounded, sharply rounded, or angular, since such features reflect the texture of materials. If the original draftsman shows all alike in his interpretation and representation of field data, this limits the detail obtainable. Usually the technique of the draftsman, his artistic sense of proportion, and the reliability of data can be determined by detailed inspection of the minute features as described above.

In summary, the contour map, alone at best, should be confined to reconnaissance use only, since it merely groups areas into their probable landform arrangements and rarely provides detailed information about many of the surface features needed for materials study. However, when coupled with other information, the efficiency of use for material surveys is increased considerably.

Example of the Topographic-Map Method

The example selected is in Southwest Indiana in Gibson County. The general topography of the Area E, Foots Pond Hills, is flat with an upland island, or isolated hill of Pennsylvanian rocks and the alluviated flood plain of sand and gravel of the lower Wabash Valley surrounding the island. Foots Pond appears to be an abandoned cut off channel of a former position of the Wabash River. Figure 16 shows the Gibson County topography Map. Figure 17 is a copy of the Foots Pond Hills area as seen in original topography map (13).

Topography Map Interpretation Procedure. The interpretation guide (Fig. 30) is utilized to determine the materials available. There are three landform features to be analyzed: flood plain (HL and LL), low terrace (Lt), and the upland (U). Each is considered and discussed as follows.

In the flood plain there are certain

topographic features that stand out. Generally, flood plains are quite flat. Their topographic positions are difficult to outline, particularly with contour of large vertical interval. However, an examination of the overall picture (Fig. 16) gives flood-plain data concerning the site area. It can be seen from this perspective that the site area should be divided into low lowland (LL) and high lowland (HL), principally because of the position of site area intermediate between the upland to the east and the Wabash River to the west. The low-lowland (LL0) portion of flood plain was designated as such because of the two channels which cross the northwest and southeast corners of area (Fig. 16). These two channels are not significant for location of materials; their significance lies in their location in the area — that of occupying the lowest position. The low-lowland area is subject to flooding and filling in with silt during periods of high water. The high-lowland area is designated as the part intermediate between the low lowland and the low terrace. In this particular area this part of the flood plain may contain the most significant materials. According to Fidlar, the flood plain is one formed by the filled-in materials during some glacial age. These filled-in materials may be sands and gravels. The ponds located in the flood plain have the appearance of abandoned channels.

The low terrace has the smallest areal extent LT1. It is that portion between the high lowland and the upland. It does not have very steep slopes nor is it flat. The area considered as low terrace is confined to a rim of materials deposited near the base of the upland island and overlying the flood plain adjacent to the rim of the upland. The contour line between the steep slope and the flat plain is irregular and spaced far enough from the more regularly spaced lines of higher elevation that it appears to define a bench-like form. The materials available within this area defined as LT1 are most likely to be similar to the materials in the upland. Generally, colluvial slopes develop from the materials sloughing down the slope and being deposited along the lower rim of an upland by water. In this area the lower terrace materials may be sand and silt, heterogeneously mixed, with perhaps rock fragments in the gullies. The gullies are indicated by the irregularity of the top contour lines. Sharp angles, bends, and turns in the top contour line indicate evidence of erosion along the colluvial slopes. Erosional features such as these indicate less-consolidated materials.

The area confined to the upland has a more rugged appearance (U3). The contour lines are spaced closer together indicating steep easily eroded slopes. The area higher than 400 ft. has been designated as upland (U3) and there are several types of contour lines represented. These types are closely spaced and are closed. The close spacing indicate an area which may be the underlying rock exposures; the closure indicates tops of small hills. The latter are similar to those found along the uplands which are used to indicate windblown sand ridges. According to the physiographic literature survey there are sand ridges in the area, hence, these may be the ones expected.

In the floodplain of the flat area, not confined to abandoned channels or oxbows, it is anticipated that sand and gravel with a silt overburden will be found in the low terrace. There may be colluvial materials of silt and sand. Finally it is expected that the upland may have uniform sand ridges underlain by rock. The materials as represented by a map are shown in Figure 18.

COMBINED USE OF LITERATURE, GEOLOGY MAPS, AGRICULTURAL-SOILS MAPS, TOPOGRAPHIC MAPS, AND AIRPHOTOS

This section of the report is concerned with the combined use of literature, various nonengineering maps, and airphotos for evaluating earth surface materials making material survey. It seems only logical for those interested in conducting a materials survey to attempt to gain as much information in advance of field inspection as possible. In most areas this is not a difficult task, since both published and unpublished information is usually available. Reports covering the findings of the agricultural-soil survey are on file in libraries of many colleges and universities, in county agents' offices, and

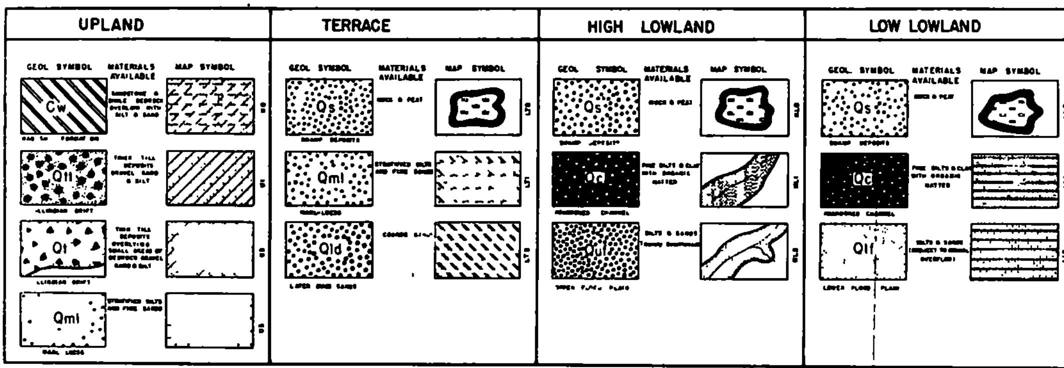

Figure 28. Geology map key.

in some public libraries. A listing of libraries is presented in Bulletin 22 of the Highway Research Board (8). Geological reports are available in libraries of many colleges and universities, as well as in the files of state geological surveys and of the U.S. Geological Survey. Many reports are available for purchase from the Superintendent of Documents, U. S. Government Printing Office, in Washington. For unmapped areas the materials prospector will find the state geological surveys, the U. S. Geological Survey, and the state agricultural experiment stations very helpful in obtaining materials data within certain areas.

Aerial photographs can be purchased from any government sources for a large portion of the United States. Maps are published by the Geological Survey showing status of photography by the various agencies. The largest source of aerial photographs is that of the Department of Agriculture. Status maps showing availability of photography and year flown are available for each state. Files of some aerial photographs are kept at some universities. in county agents' offices, in various geological survey offices, both federal and state, and in many highway departments.

Significance of the Combined Method

There are many advantages of studying literature available in several fields, such as the studies made available by the soil engineer, physiographer, the geologist, the soil scientist, the topographer, and the photoanalyst. The chief advantage lies in the fact that the materials prospector can screen the data and determine the high points of each source of information — those points which are the most significant to an understanding of the area under study.

From study of physiographic literature the type of land surface is determined such as, plain, plateau, mountain, or basin. The relationship of the area with respect to the surrounding physiographic provinces is determined. The agents responsible for the development of the landscape will be set forth.

The study of geologic literature reveals the history of an area — its origin and the development processes contributing to its present form. Such items as relative age and type of materials in the major land units are determined. From the geology map and accompanying literature, the major parent materials, whether in place or transported by wind, water, ice, or gravity, will be determined and can be located accurately. In one sense, geology is the basis for all material surveys.

From the topography map the magnitude of the landscape is determined. The various landforms are represented together with their respective positions relative to the base level of erosion. The magnitude of the landforms is represented clearly. The topography map provides a record of the earth sculpturing which has taken place.

For a grouping of surface soils into parent materials the maps and the literature provided by the soil scientists are used. Since the pedologic concept is followed in reports of this type, advance information concerning expected soil-profile types and characteristics may be obtained. The literature of this source presents information concerning not only the soil catenas of family groups but information concerning the variations, such as types and phases. Detailed description is concentrated on the development profile — that which supports plant life.

The aerial photograph records the sum and total of all surface features. It is a pictorial representation of the area recording the major as well as the minor details. In addition to picturing the distribution and density of the natural cover and cultural features such items as macro-relief are clearly shown. These minute details are often grouped in an all-inclusive symbol on other maps since expense precludes their being included in the representation of the area. The areal photograph provides a basis of comparison — it is an impartial representation — not prepared through the eyes of another. Its successful use is limited to the trained interpreter alone. The airphoto can supplement where macro-detail is needed; it can supplant where no information is available.

Combined Method Applied to the Example Areas

The following discussion has been prepared irrespective of the preceeding discussion. This discussion is divided into source data for survey, physiography, geology agricultural soil survey, and aerial photographs.

Physiography. This area is located in the Wabash River Valley which is a river valley of a glaciated region of the Till Plains Section of the Central Lowland Province of the Interior Plains Physiographic Division of the United States (9, 11). The valley consists of flood plains of a mature stream valley filled in with materials which are believed to have been deposited as the result of the flow of glacial melt waters occurring during the Wisconsin Age. The locale used in this study is located in the flood plain of this filled-in valley. The local landscape consists of flood plains, terraces, and uplands. There are generally two levels in the flood plains, one at or near the water level and one 10 to 30 ft. higher. The valley, or flood plain contains a series of island hills isolated as monadnocks.

Geology. This area is underlain with rocks of Pennsylvanian Age — Coal Measures (13). The rocks of the Central Lowland dip gently along the Cincinnati Anticline which underlies this area. Rock knobs, also Pennsylvania, protrude through the flood plain surface. The area has been glaciated as deposits of drift of Illinoian Age dominate the landscape in many places in the uplands. The results of the later Wisconsin Glacial Age are found in the vast alluvial filling of the Wabash Valley.

The present landscape reflects the glacial activity and considerable modification through the recent agents wind and

Age			Formation Names and Symbols	
Recent Epoch			Natural levees	Qn^1
Recent Epoch			Abandoned channel deposits	Qc
Recent Epoch			Swamp deposits	Qs
Recent Epoch			Lower flood-plain deposits	Qlf
Recent Epoch	Trans		Later dune sands	Qld
Pleistocene Epoch	Trans		Upper flood-plain deposits	Quf
Pleistocene Epoch	Wisc Stage		Earlier dune sands	Qed
Pleistocene Epoch	Wisc Stage		Terrace deposits	Qtr
Pleistocene Epoch	Iowan Stage		Older stream silts	Qos
Pleistocene Epoch	Iowan Stage		Loess	
Pleistocene Epoch	Iowan Stage		Marl-loess	Qml
Pleistocene Epoch	Illinoian Stage	Retreat	Lake deposits of third halt	Ql^4
Pleistocene Epoch	Illinoian Stage	Retreat	Lake deposits of second halt	Ql^3
Pleistocene Epoch	Illinoian Stage	Retreat	Lake deposits of first halt	Ql^3
Pleistocene Epoch	Illinoian Stage	Retreat	Lake deposits of maximum advance	Ql^1
Pleistocene Epoch	Illinoian Stage	Occupation	Outwash gravel plains	Qog
Pleistocene Epoch	Illinoian Stage	Occupation	Drift ridges	Qdr
Pleistocene Epoch	Illinoian Stage	Occupation	Thick till and drift plains	Qtt
Pleistocene Epoch	Illinoian Stage	Occupation	Thin till sheet	Qt
System			**Names and Symbols**	
Tertiary			River deposits (Eocene ?)	Tr
Carboniferous (Pennsylvanian)			Wabash formation	Cw
Carboniferous (Pennsylvanian)			Inglefield formation	Ci
Carboniferous (Pennsylvanian)			Ditney formation	Cd
Carboniferous (Pennsylvanian)			Somerville formation	Cs
Carboniferous (Pennsylvanian)			Millersburg formation	Cm

Figure 29.

water. According to Fidlar, the present flood plain is the result of seasonal flood and lateral erosion with abandoned channels filled into the present established level. The old Maumee River (pre-Wisconsin) formed what is now called terrace remnants. These are evident near the bordering uplands. The low gradient of the flood plain in this area causes wide meanders of the stream channel. Frequent flooding has resulted which has been responsible for forming bayous, oxbow lakes, bars, and abandoned channels. The Wabash Channel has cut through a projecting upland spur in places. Many marsh areas occur in the flood plains in the swales. Other features of the flood plain which are a direct result of alluvial activity are natural levees consisting of long ridges of a sand and gravel overwash. Both levels of the flood plain contain oxbows, meander cut-offs, swales, bars, levees, and channel scars.

The upland areas are covered with loess in various spots throughout the lower region of the Wabash Valley. There are deposits up to 50 ft. thick in places. Thornbury (24), in 1940, reported that this loess belongs to the Peorian Loess (Wisconsin Age) of Illinois. The slopes are unusually steep for unconsolidated deposits. Steep slopes are features typical of loess. Erosion of the soft, calcareous loess has produced smooth slopes along vertical-walled gullies. According to Fidlar, the loess also covers the island hills in this region — those in the flood plain of the valley. Other aeolian deposits, such as sand dunes, are scattered throughout the area. Some deposits are resting on the Maumee and Shelbyville terrace remnants and on the isolated residual remnants which protrude above the base level of the flood plain. It is said that upland dunes may have originated any time after the maximum Illinoian ice invasion. Typical dune topography marks the crest of such areas as Foots Pond Hills and Mumford Hills.

Agricultural-Soil Survey. The agricultural-soil survey provides detailed information about distribution of parent materials and the soil profiles of the various series, types, and phases. The soils are grouped into three groupings based on profile development, topography, and parent material. All three are important to a material survey.

The grouping under parent materials lists the soil series associated with residual, glacial, loessial, and alluvial. Such information provides a starting point for the development of correlations between the soil-series name and the geological designation, which is obtained from geological maps and literature. By studying the grouping of soils on a topographic basis, it is learned which of the soil series occur on uplands, terraces, or lowlands. This is irrespective of parent materials. The grouping provides a correlation between soil series, topography, and local physiography. It clarifies the concept of magnitude of various landforms comprising the landscape by pointing out areal extent of the soil series on a given landform from the

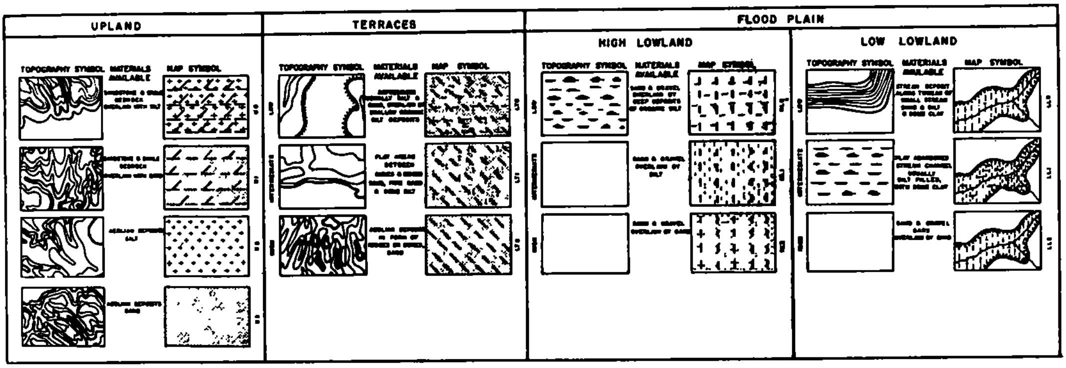

Figure 30. Topography-map key.

agricultural-soil map and relative elevation position from the topographic map. The picture now assumes three dimensions. From the description given on soil groups accorded certain profile types, information concerning drainage and profile development is obtained. It is learned which soils are old in their development and which are young. This fact is important since porosity and profile development are closely related. Detailed information of series and phase is obtained from the pedological discussion of the profiles.

As an illustration of this, information concerning the Gibson Series is given here. The Gibson soils are developed from Illinoian till, and occur as an upland soil as stated in the survey report (18):

"The Gibson series is characterized by a light brown or yellowish-brown surface soil and a heavier yellow subsoil, underlain by a noncalcareous Illinoian till, mottled with yellow and gray. This till extends to a depth of about 10 ft."

The Gibson series occur in the Group I profile soils since it has a normally developed profile. They have been developed under forest conditions. Three distinct A, B, C, horizons exist in the profile. The description given in the survey report for soils of Group I is:

"A top layer (A) which, under virgin conditions, has a surface veneer of organic matter, contains some organic matter in the upper part and less in the lower part, and is thoroughly oxidized and leached; (2) a middle-layer (B) which is well oxidized and heavier in texture than the surface layer; and (3) a bottom layer (C) consisting of the parent material."

Details of the type and phase are obtained from the profile discussion and are not repeated here. In a manner similar to that discussed above information concerning the various soils pertinent to the example areas can be obtained for use in the materials survey and maps representative of the ground condition may be prepared.

Aerial Photographs. In the particular area chosen for the examples the literature was considered to be ample to furnish material necessary for conducting a materials survey. Little can be added from a study of the airphotos regarding the location, distribution, and type of materials when used in conjunction with the other methods of this particular area. The soil series as mapped and as described have provided the necessary data. It is, however, to be pointed out that in the case of the alluvial soils the airphoto more clearly separates the well-drained and more-granular ridges (levees) left by current activity from the intermediate and basin areas which are not as granular. On some types of maps these have not been separated. From a soils standpoint the airphoto provides the only method, where it may be desirable to obtain information pertaining to relative amounts of ridge - intermediate - basin areas.

Of importance in the survey is the use of the airphoto for determining the density and distribution of timber cover for purposes of consideration in land evaluation and clearing cost. This, of course, is not contained in detail on other maps. The up-to-date cultural pattern as well as access routes is more easily determined from study of airphotos.

Perspective. The foregoing discussion gives a perspective with which a study of the materials of an area can be accomplished in a more objective manner. From general literature, it is known what to expect in the various major landform units. From detailed literature, the perspective is enhanced, since actual information concerning the soils is obtained. The information from the airphotos completes a detailed concept of any terrain for locating materials surveys. One additional feature is worth nothing: Quarries may have been opened for source of granular materials and the supply of materials exhausted during same operation. These and other conditions pertinent to an area study are easily learned from a study of up-to-date photos whereas these data may not be abailable on older maps.

Four Example Areas Compared

The results of the entire study, in which four areas in southern Indiana were surveyed with four methods each, have been tabulated and appear as Figure 32. In-

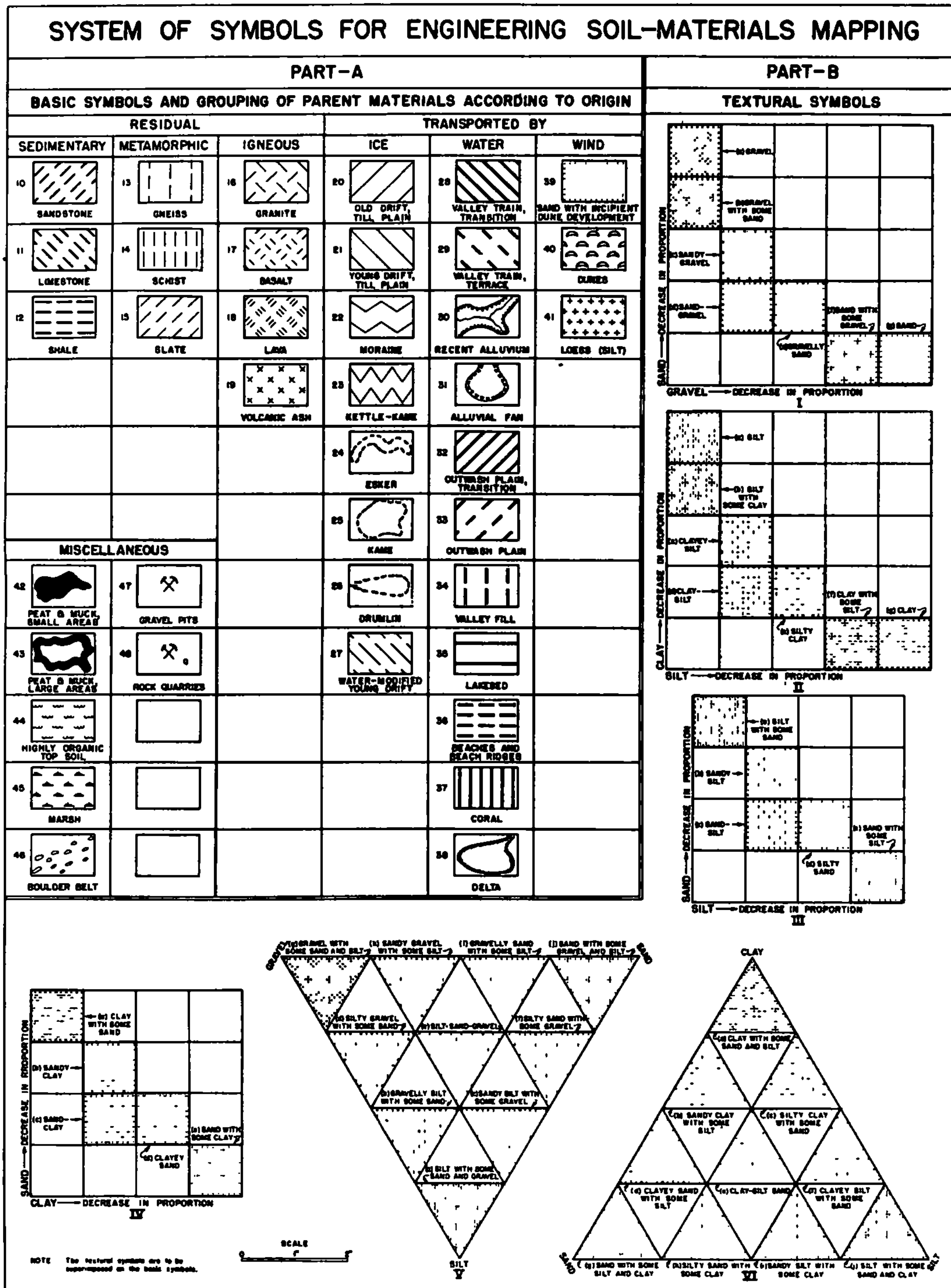

Figure 31. System of symbols for engineering soil-materials mapping.

dividual maps, airphotos, and copies of original maps have not been reproduced or discussed in this presentation. A portion of the Gibson airphoto-index sheet, agricultural soil map, geology map, and topography map which contains all four example areas, has been reproduced and is contained in Figures 19 to 22.

PURDUE ENGINEERING-SOILS-MAPPING SYMBOLS*

The accompanying chart represents the system of graphical symbols developed at Purdue University in connection with the Engineering Soils Mapping Project of the State of Indiana from airphotos. Although this system was designed primarily with the Indiana soils in mind, it possesses enough flexibility to enable its use in other areas, since all possible origins of soil materials are included and since the system admits expansion in accordance with specific needs.

The soil physical properties of foremost importance are: type of parent material, texture, and internal-drainage characteristics. An attempt has been made in this system to portray such soil properties as truly as possible.

Briefly, the following are the outstanding features of the system:

1. As shown in Part A of the chart, the soil parent materials have been arranged according to origin in two major groups: residual, and transported. In the residual group, sedimentary, metamorphic, and igneous materials are included. The transported group is further subdivided according to the agent of transportation into ice-deposited, water-deposited, and wind-deposited. Under these subheadings the corresponding types of soil formations have been listed. Part A also contains a column for miscellaneous formations, which cannot be included in either of preceding groups.

2. The symbols in Part A have been designed as uncomplicated as possible, so that they may admit superimposition of one symbol on another without confusion. This is necessary to show thin drift on rock, for instance, or wind-blown sediments on some other materials and also to combine the textural symbols (Part B) with such basic symbols. The basic symbols, by themselves, indicate the origin of the parent material, as well as the type of formation; e. g., glacial moraine.

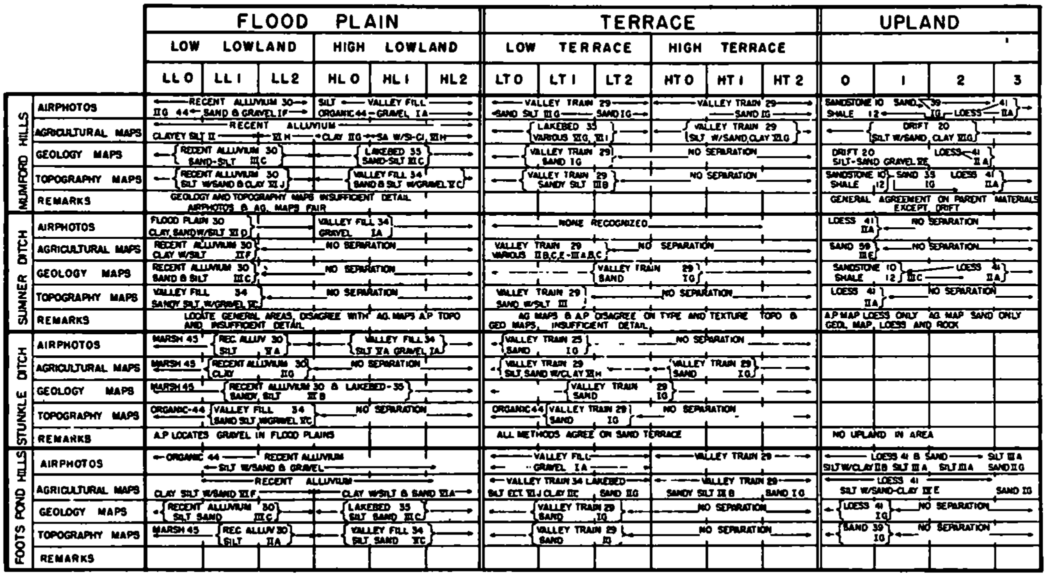

Figure 32. Correlation chart for example areas.

*Prepared by P. Montano

3. Four are the generally accepted grain size components in soils: clay, silt, sand, and gravel. A soil may be composed of one or a combination of two or more of these grain sizes. Some combinations occur in nature more frequently than others; and some almost never occur, such is the case of clay and gravel, and even silt and gravel. Discarding these unlikely combinations of two grain sizes, the first four groups of symbols shown in Part B were designed. Next, the most likely combinations of three grain sizes were chosen, as shown in the last two groups of symbols of Part B. For the sake of simplicity, and since only relative soil textures are intended to be portrayed by the textural symbols and not numerically accurate proportions of grain size components, combinations of all four generally recognized grain sizes were not included in this system. An example of relative soil texture for our purpose would be silty-sand, where the sand predominates and where the silt holds a secondary place in proportion. This however does not mean that such a combination may not contain a small proportion of gravel, for instance; however, this proportion would be so small as to be insignificant as far as the engineering properties are concerned.

All six groups of grain-size combinations shown in Part B contain some blank spaces. If symblos were to be devised for all the spaces of each group, either the proportions would be repeated or the relative textures would be so much alike that confusion would result. Symbols were devised, then, only for the most significant grain-size combinations. For our purpose, these symbols are called textural symbols.

4. Dashed horizontal lines and dashed vertical lines were chosen for the textural symbols for clay and silt, respectively; and the conventional dots and circles were adopted for sand and gravel, respectively. The horizontal arrangement was chosen for clay to denote its slow-draining properites. By similar reasoning the vertical dashed lines that represent silt, indicate better draining characteristics. The dots and circles carry the universal inference of good drainage. By noting the relative density or proportion of these conventional grain-size symbols on any combination, it is possible to acquire a reasonably good impression of the drainage characteristics of the soil represented by such a combination of symblos.

5. The textural symbols are superimposed on the basic symbols, to indicate texture and drainage characteristics of: (a) the parent materials in unconsolidated formations and (b) the derived soils in bedrock areas.

This system is especially suitable for engineering-soils mapping from aerial photographs, since by means of airphotos it is possible to tell the origin of the soil materials and the types of formations, as well as to predict the relative soil textures and drainage characteristics. The symbols should be used in full scale for best results.

It is hoped that the proposed system will constitute a common language for engineers engaged in soils mapping and will be regarded as a convenient method of grouping and graphical representation of engineering soil materials.

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Geologic Considerations in Relation to a Materials Survey

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SYNOPSIS

IN materials surveying, geology should be of maximum benefit, not as a complete informant but as a foundation for reconnaissance, assembly, and cataloging of materials. Geology in essence is a materials survey on a grand scale. Use of this science for engineering purposes involves some primary knowledge of geologic nomenclature, the basic historic approach of geologists, and the use of resources and data published by state, federal, and private agencies over a period of 75 years.

Recognition of the need for information on surface conditions as an aid to engineering and allied sciences is emphasized; and in response to this need, a new system of mapping is cited and illustrated in which a special map of surficial geology is prepared in conjunction with the traditional "bedrock" geologic maps.

The importance and the difficulty of converting geologic data to engineering uses are considered, and in lieu of a universally satisfactory means for accomplishing this, a few specific conversions are discussed and illustrated. Each is considered separately from the standpoint of possible materials requirements and the application of geologic methods to the location of usable materials.

● GEOLOGY has some application in practically every phase of a materials survey. It might be considered a starting point for every study of naturally-occurring materials. Certainly geology paves the way for such specialized techniques as airphoto interpretation and geophysical prospecting. Beyond that, the geologic approach within itself is a practical way of examining a locality and estimating the character and extent of its deposits. At the very least, a geologic system for classifying materials puts information on a universal basis, provides continuity from source to source, and serves as a means for correlation from state to state or region to region.

Many services and vast stores of information applicable to materials surveys have been developed through geologic interests and geologic endeavors. In addition to the many universities with geology departments and state geologic surveys, the federal government has several agencies dealing with geology - the principle one, of course, being the United States Geological Survey. The literature which has accumulated through the efforts of these and other organizations is tremendous, and by a conservative estimate as much as 80 percent of the reasonably populated area of continental United States has been interpreted geologically with some degree of intensity and accuracy. Usually the literature is accompanied by one or more maps, and most of these usable by persons having an elementary knowledge of geology.

BASIC PRINCIPLES UTILIZED

The basic unit of the geologist is a time unit. Practically all the maps and a large percentage of the written materials are concerned with this unit. When a name is assigned to a formation, the intent is to establish the age of that formation in relation to other formations, or simply the time this unit was deposited in geologic history. Within any given area, this time unit or formation will be continuous either beneath the surface or as an outcrop; or, if much of it has been removed at the surface, the formation will probably be recurring.

If the area considered is small enough and the depositional features attendant to the formation were constant enough, the

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material will have the same characteristics wherever it is encountered. However, where the depositional features were not constant, and particularly where the distances between points of identification are great, there may be vast differences in the characteristics of materials of a given age or time unit. Hence, deposits of sandstone in Kansas may have a geologic counterpart in deposits of limestone in Kentucky. They will without doubt carry different identifying names, but they were deposited at exactly the same time, as evidenced by the fossils embedded in the two stones.

A complete system of these time units has been worked out, and the science of stratigraphy attempts to correlate and simplify the massive groupings into a single integrated system. Every map has its own stratigraphic section, and usually the system within one state corresponds with that in an adjacent state, although quite often there are minor differences essentially unimportant.

The areal geologic map, one example of which is shown in Figure 1, is traditionally the favored mode of geologic expression, and it is by far the type map most frequently encountered. Often placed on a base with topo, this type map outlines the formations on or nearest the earth's surface. In effect, then, it outlines the materials which would be exposed if all the soil cover and vegetation were removed. In a great number of cases, the topmost deposits identified and classified geologically are unconsolidated, and in those instances there is but a fine line of differentiation between the soil actually exposed at the surface and the underlying formation which would be exposed if the soil were removed.

On the areal geologic map, the time units or formations are represented by colors or symbols. Along with the legend describing the significance of these colors and thicknesses of formations, there are written explanations or appropriate symbols describing the composition or characteristics of the different units, and also nomenclature identifying relative geologic ages. Sometimes cross sections are included to show structure which can be inferred by detailed examination of the map and the relative ages of surface formations appearing there. If all this type information, exclusive of the legend, does not appear directly on the map, it is generally included in some form within the report which is accompanied by the map.

INTERPRETING THE AREAL GEOLOGIC MAP

At a glance it is obvious to the person interested in surveying for usable materials that the areal geologic map does not tell him all he wants to know. His first impulse may be to disregard the map entirely because its primary basis of differentiating rock materials is age and not by composition, or chronologic and not petrographic. He would prefer to know, with relation to the area in Figure 1, that the most prevalent bedrock material is a "light-colored, moderately coarse-grained rock with a granular appearance," and that it is typically "composed of 25 to 50 percent of quartz, 35 to 65 percent of feldspar, and 3 to 13 percent of biotite," rather than to find that the symbol on the map represents "Monson gneiss" of the late Devonian period.

However, the petrographic description just quoted, and other references to the range of variations in Monson gneiss, are contained in the report (1) pertaining to this map. For one having no more than a rudimentary knowledge of geology, an areal geologic map and related information can be useful in many ways. First, if the problem is location of a specific rock type, such as limestone, granite, or gneiss, the map shows whether or where a material of this description is present within the area of interest. Thicknesses and possible locations for favorable investigation are indicated. If there are no outcrops, is it within reasonable depth for excavation or is mining the only feasible means for recovery? Perhaps a fault or break in the earth's crust has moved it from far underground up to a near-surface position.

Identification of formations in the field using this information is possible. Appearance or lithologic descriptions are always available, and there are references to fossils, which may be useful in establishing the continuity of a formation. For the most part, however, use of fossil evidence is reliable only when a geologist, palentologist, or someone trained in the

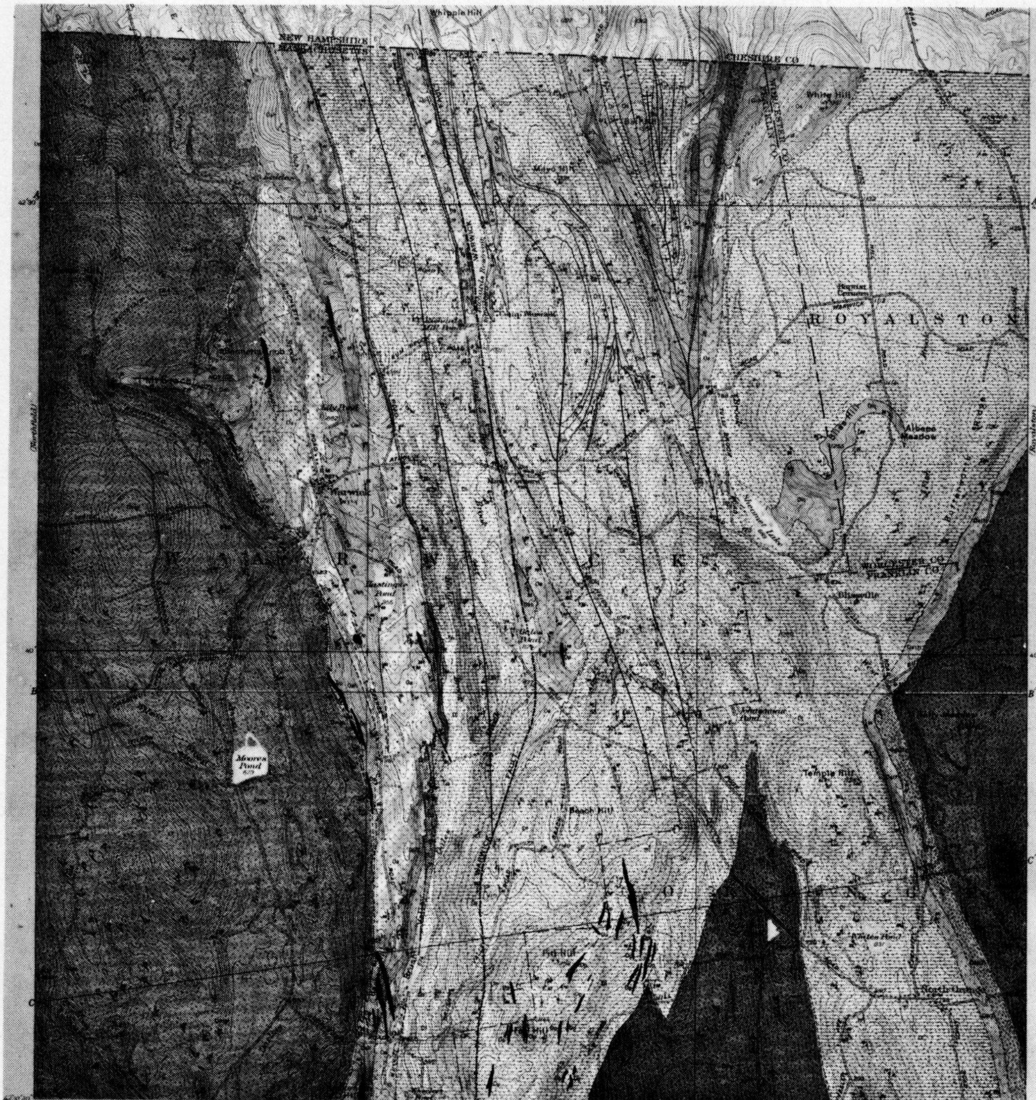

Figure 1. Map showing bedrock geologic features in the Mount Grace Quadrangle, Massachusetts.

identification and classification of fossils is engaged in the work. The geologic layman can, in many cases, record the position of a rock unit with reference to some very characteristic neighboring rock unit and, in that way, carry his survey from spot to spot with sufficient accuracy.

All this applies where consolidated rock formations are the principle sources of materials, and particularly in the regions where transported materials do not overlie bedrock. It is applicable in many regions (such as the Atlantic and Gulf Coastal Plain) where the formations to great depths are unconsolidated or poorly consolidated at best. These are identified and mapped areally in just the same way as the bedrock formations. However, for a considerable portion of the country, and particularly in the glaciated regions, the traditional geologic survey in most cases did not interpret the deposits of greatest concern as highway materials--the deposits near the surface.

Figure 2. Map showing surficial geologic features of the area illustrated in Figure 1.

SURFICIAL DEPOSITS INCLUDED

This was recognized more and more as time went on, and recently the policy of making a survey and map of surficial deposits has been instituted. Figure 2 illustrates the surficial geology of the same area represented by the map in Figure 1. Note that rock outcrops are just recognized as such, while emphasis is placed on materials of primary importance for highway use. Extensive kames and kame terraces, eskers, and late outwash sand and gravel predominate in the deep valleys, and till (which in itself is sandy) covers all the uplands.

Explanatory material with the legend, and more so the brief report (2) of this work, generalize on the character of the various deposits in order to cover the entire range. For example, the kames and kame terraces are described in the map legend as "deposits of sand and pebble gravel, cobble gravel, or boulder gravel," but in the report effort is made to reduce the generalities as much as possible. Ac-

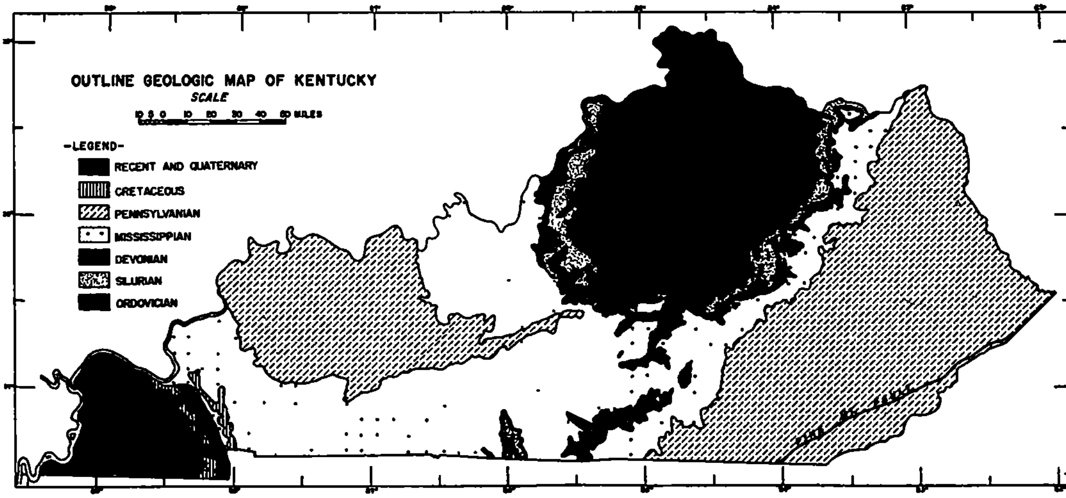

Figure 3. Outline geologic map of Kentucky showing the major divisions by geologic periods.

tually, an analysis of depositional processes might logically lead to the conclusion that the coarser materials (cobbles and boulders) lay near the middle of the valley or the logical main stream channel, and the materials would gradually become finer and finer as the valley walls were approached.

This is based on the assumption that the separation and deposition was accomplished by large volumes of melt waters flowing from the receding ice sheets in broad channels. In many cases, however, flow of water within, along the edges of, or beneath stagnant ice in the valleys caused peculiar variations, and so-called ice-hole deposits locally produced more uniform materials of graded sands and gravels. Numerous existing sand and gravel pits are indicated within the limits of these valleys, evidence that the deposits have been and undoubtedly still are utilized, for road construction. Of the 43-sq.-mi. area covered by the map and report, more than 10 percent is occupied by the granular formations of glacial deposition. Another 5 percent consists of recent alluvium which is dominated by rewashed granular materials.

The depths or the extent of deposits are not estimated. This would be added information of value if it were not for the fact that the proposed use determines the desired composition. It goes without saying that in any materials survey the suitability

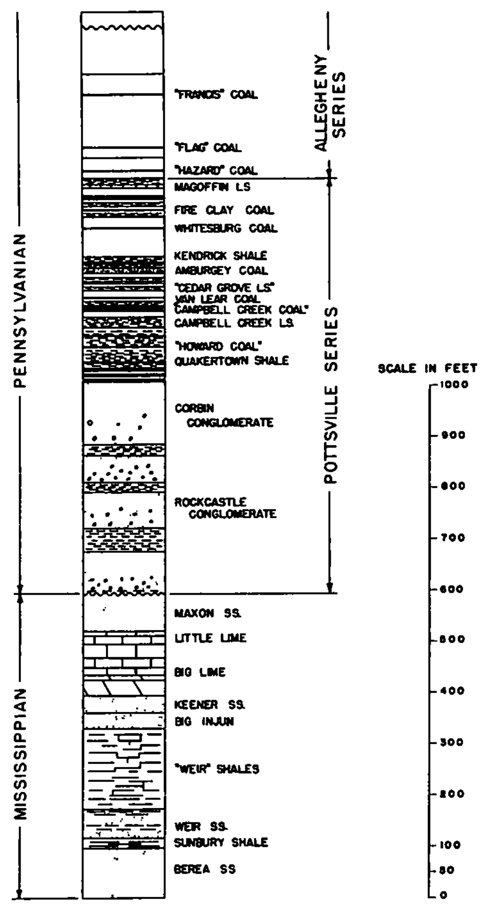

Figure 4. General stratigraphic section in the Paint Creek area of eastern Kentucky.

of a deposit for a certain use must be determined by tests; however, projection of test data from location to location can be done with approximations that satisfy the objectives of a preliminary survey at least.

STATE WIDE GEOLOGIC MAPS

Generally the survey for materials, as it applies to a project or projects within a certain locality, does not extend beyond

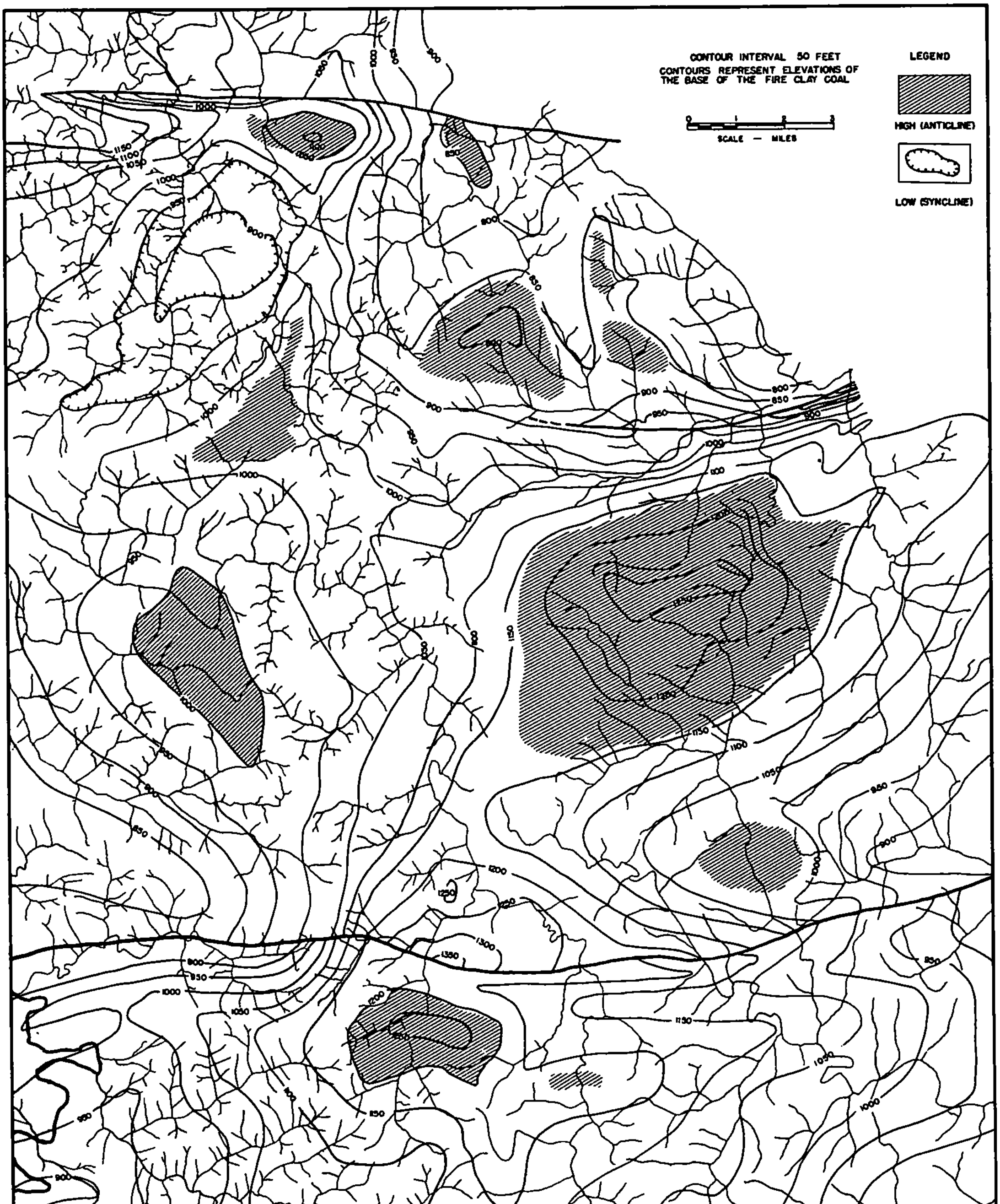

Figure 5. Simplified structural geologic map of the Paint Creek area in eastern Kentucky.

the limits of three or four adjacent quadrangles or an area three or four times as great as the maps which have been illustrated. However, transposing information from location to location or from source to source requires a use of the broader geologic classifications. This is where the time system of reference and the geologic nomenclature become more important.

In most if not all the states, the data from individual geologic studies and surveys have been gathered together and summarized in the generalized geologic map of the state. The outline map for Kentucky shown in Figure 3, represents a summary version of a much more specific map (10) of this description. Bedrock geology predominates, for unconsolidated materials on a broad scale are important only in the far western part of the state where the legend depicts Recent and Quaternary formations. This section, despite its distance from the present Gulf of Mexico, is a part of the Atlantic and Gulf Coastal Plain. It contains deposits that are related in age and have characteristics similar to those prevailing in Tidewater Virginia or the entire eastern quarter of Texas.

This fact alone justifies the use of state-wide geologic data as a basis for materials surveys, and certainly establishes the geologic approach as a foundation for materials reconnaissance. By the use of a map covering such a large area, one soon becomes accustomed to thinking of materials distribution on a time-area basis, and his concept of the relationships is thus broadened.

Throughout the eastern portion of Kentucky, in an area almost one fifth the size of the entire state, sandstones and shales of the Pennsylvanian period are practically the only formations to depths of several hundred feet. Only where faults have developed or uplifts occurred has a limestone deposit been placed in a workable position. Because of the variations in sandstone, and the limited use made of it as a construction material, other aggregates have been shipped into the region under circumstances where the shipping cost alone far exceeded the total cost of the same aggregates at other points throughout the state.

This fact stimulated the investigation and use of local deposits of sandstone, and also emphasized the importance of surveys for usable deposits of limestone. According to the generalized stratigraphic section shown in Figure 4, the so-called Little Lime and Big Lime formations of the Upper Mississippian period could be buried as much as 1000 ft. beneath the topmost Pennsylvanian formation existing in the east-central part of the area under consideration. However, there were obviously variations where uplifts had occurred and where different amounts of the overlying sandstones and shales had been removed.

These two limestones in combination represented a possible face of 90 to 120 ft. of high quality material, and the problem became one of finding where they might be within reasonable depths for profitable recovery. Near-surface conditions for quarry operations were hardly possible, but inasmuch as a mining operation for limestone at a depth of 250 ft. had been economically successful in central Kentucky under a similar set of circumstances the survey was based on locations of the limestone within 250 ft. of the ground surface.

The simplified structural geologic map (Fig. 5) shows the results of the survey. A key bed (the Fire Clay Coal) which has been logged extensively throughout the region was selected as a datum, and elevations were determined from drilling records. In many places these beds have been folded and faulted, so the upfolds or anticlines offered the best possibilities for near-surface locations of the limestone formations. These anticlines are shown as shaded areas in Figure 5, and it is within these that the specific investigations are being carried out.

Surveys with respect to the sandstone have been profitable, also. Here, however, the problem was different because sandstone as such is abundant. Yet, because of its variations, with dipping strata and beds that vary in thickness or "pinch out," there is no assurance of high quality sandstone for any great distance either horizontally or vertically at a promising quarry location. As an experimental proposition related to the surveys for these materials, the Kentucky Department of Highways developed a test road to determine what constitutes quality in sandstone as a bituminous paving aggregate.

Figure 6. Quarrying Pennsylvanian sandstone for construction of a bituminous test pavement on Kentucky Route 30. Unusual variations in the form and quality of sandstone deposits constitute problems in materials surveying.

One of the quarries from which sandstone for these tests was taken is shown in Figure 6. This quarry opening, which averaged about 35 ft. in depth, exposed three distinct and greatly different sandstones. As the quarry operations progressed laterally, the ledge composed of the intermediate-grade material pinched out within less than 100 ft. Conditions of this sort are the rule and not the exception among the Pennsylvanian sandstones, so practical use of sandstones was dependent upon broad specification limits encompassing a variety of material grades.

After 2 years of investigation and the placement of 25 mi. of hot-mix pavement sections of all types, it has been shown (7) that very soft sandstones (with Los Angeles Abrasion losses as high as 40 percent in 100 revolutions and 90 percent in 500 revolutions) can be used satisfactorily. This is so, provided the type of mix is conducive to the gradation which naturally results from the processing of such friable materials in a hot-mix plant and also from the action of 10-ton rollers on the paving mix. At any rate, sandstones having widely varying properties are usable; and from a materials-survey standpoint, the problem now is one of locating, cataloging, and making inventories of potential sources.

UNCONSOLIDATED DEPOSITS MAPPED STATE WIDE

While the state geologic maps as a rule show primarily bedrock geologic data, there have been a few surveys which have produced excellent state-wide maps of surficial deposits. As an example, one section of a map prepared as a part of a USGS professional paper (4) is shown in Figure 7. The area covered is in southeastern Minnesota, but the map in total extends over the entire state and somewhat beyond those boundaries.

This map is a generalized landform,

soils, and materials map in one, with the added advantage of detailed descriptions telling not only the basic composition of the materials but also the manner and sequence of their deposition. These descriptions, as in the case of the quadrangle discussed before, are contained in the report of the work. Materials from three stages of glaciation and some loess deposits, important only from the standpoint of soil problems, are outlined in relatively minute detail, but the greatest distinctions are made in the variety of materials left during the fourth and latest stage of glaciation.

The glacial tills designated as terminal and ground moraines dominate in area, and the separation of these is mainly on the basis of ice sheets with which they were associated rather than on the basis of differences in character. On the other hand, outwash sands and gravels associated with all the different ice sheets are scattered throughout the bulk of the state.

Unfortunately neither the map legend nor the report gives even a good indication of the properties of these granular deposits. They are hardly more specific in describing the terraces associated with major drainage ways, the numerous kames which are specifically marked, and the very prominent eskers, some of which are shown in the upper part of Figure 7. If the use of this information for materials reconnaissance had been visualized at the time the work was done, undoubtedly there would have been greater emphasis on the analysis and description of these

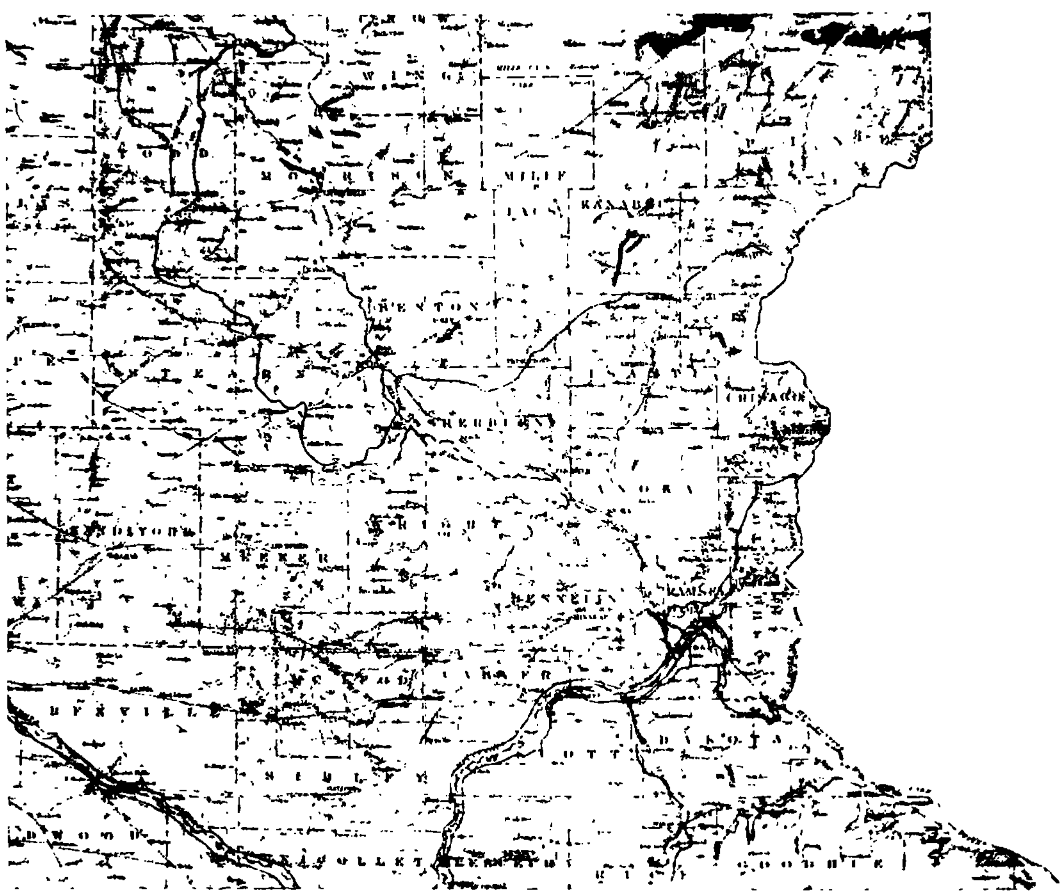

Figure 7. Excerpt from map showing surficial geologic features developed by glaciation in southeastern Minnesota.

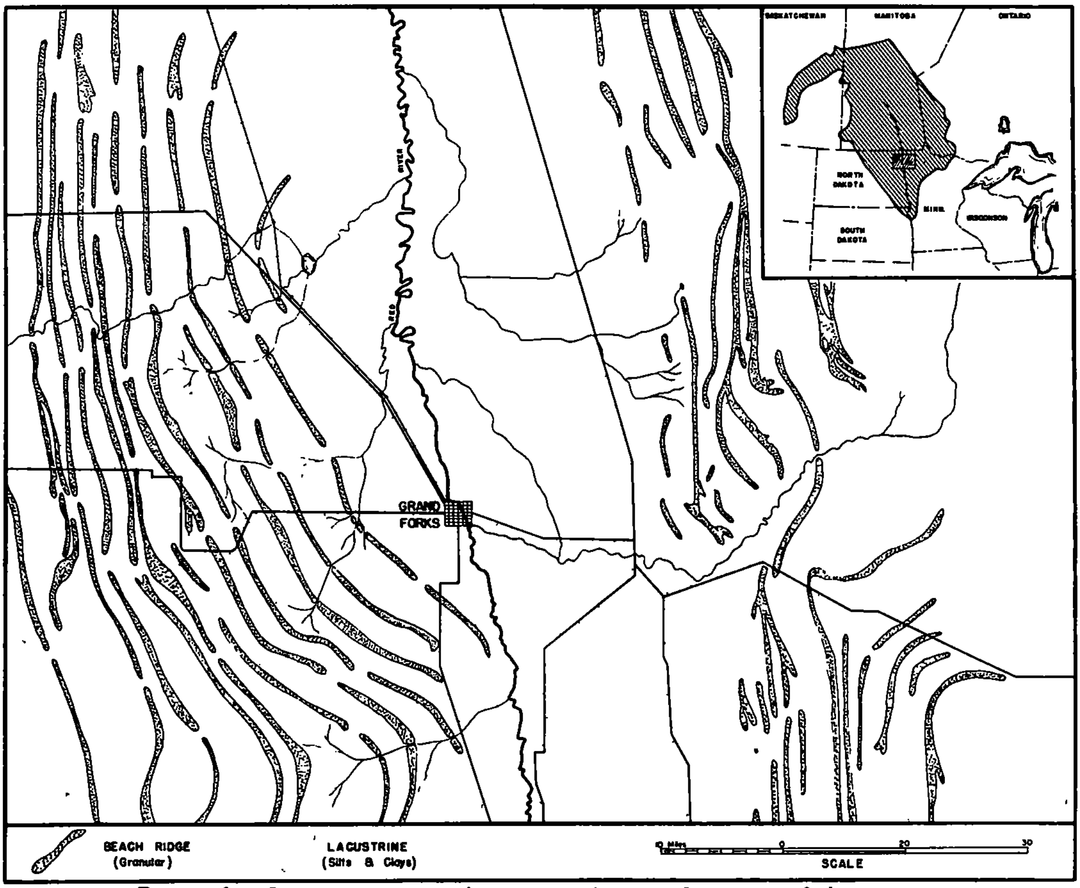

Figure 8. Location map and section showing features of deposits in the abandoned bed of glacial Lake Agassig.

deposits.

Probably because conditions were naturally more uniform over broader areas in the extinct glacial lake beds, descriptions of the lacustrine clays and sands were more specific. Beach ridges of sands and gravels were defined even better. By far the most extensive and best known of these lakes is the extinct Lake Agassiz which existed for a long period of time as the glaciers receded but normal drainage channels were blocked. The extent of this lake bed is shown by the shaded portion of a small diagram in the upper right of Figure 8. A small section of the lake bed is enlarged in the main part of the figure.

Clays and silts predominate in the central part of the abandoned lake, and topographically the land is flat. Drainage is slow, and ground water tables are high. Subgrade bearing for railroads, highways, and airports is obviously critical. It is told, by civil engineers who worked on the building of railroads in this territory near the turn of the century, that suitable material for raising grades was considered so important, lengthy searches on horseback were made in a haphazard manner. With but a hint of the origin of these deposits, these men would have reached the obvious conclusion that sorting of materials at the edges of such large bodies of water would have produced granular beaches in an orderly way.

The pattern of beaches is illustrated in Figure 8. Each set of beaches represents a different stage in the lake during its existence. Undoubtedly some of the sands of the beaches are too uniform or too fine for many requirements which must be met by granular materials, but the mere outline of such physical land features simplifies the reconnaissance and reduces the number of locations where detailed investigations must be made.

GEOLOGY THE BASIS FOR ALL SURVEYS

Certainly any detailed survey, whether carried out through extensive sampling alone, through use of airphotos, through geophysical methods, or some other means, should begin with geologic reconnaissance if there are such data available. Maybe the information is sketchy, and seldom will it provide more than just a guide. But to disregard it entirely is to disregard nature and natural processes of materials formation.

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Geophysical Methods of Subsurface Exploration Applied to Materials Surveys

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● GEOPHYSICAL methods of exploring the subsurface have proved their worth for preliminary surveys in connection with many of the problems encountered in civil engineering. These rapid and relatively inexpensive methods have been used to explore foundation conditions at proposed sites for buildings, bridges, and large dams, to classify excavation materials in highway grading operations, to determine the depth of swampy materials, to investigate proposed tunnel sites, to study potential and existing slide conditions, and to locate and outline supplies of construction materials such as sand, gravel, solid rock, and other special geologic formations of engineering importance.

Although each of the above-named fields of application may be of primary importance in cases where a particular construction problem is concerned, the last-named application is unique in that the search for construction materials is likely to be of importance in almost every type of engineering construction. The vast expansion in construction work, with its demand for greatly increased quantities of materials, already threatens to exhaust known sources of supply in some areas. Exploration for additional supply sources is necessary and every means available, including the geophysical tests, should be employed in this important task.

Of the several geophysical test methods used in the fields of mining and oil exploration, only two have been found to be well adapted to the shallow explorations usually associated with civil-engineering works. These are the refraction-seismic and the earth-resistivity methods of test.

The use of magnetic methods has been reported by several investigators in connection with the location of basalt plugs and other geologic formations possessing measurable magnetic properties. Although the magnetic method may be used to advantage in such instances, its use and the interpretation of the data obtained are somewhat involved, requiring specially trained personnel. It is the writer's opinion that magnetic methods have a limited value for use in a search for construction materials. Because of this limitation no further discussion will be made of the magnetic method.

The Bureau of Public Roads has done considerable research since 1933 in establishing the value of earth-resistivity and seismic methods in connection with highway construction. Field studies and demonstration tests have been made in 26 states and in the District of Columbia, and at the present time 13 states have used or are now using one or the other of these methods in their subsurface exploration work in connection with highway construction (5, 9, 10, 15, 39). Four other state highway departments are completing plans for use of the resistivity test in the immediate future. In addition, both seismic and resistivity methods are being used by other federal agencies, notably the Geological Survey, Bureau of Reclamation, and the Department of the Army, in ever-expanding fields of application having to do with water-supply problems, engineering geology, and investigations of dam sites for irrigation and flood-control purposes. Some of this work has been described in published papers (20, 22, 23, 24, 25, 27, 31, 42, 43). The reader is also referred to certain works for detailed discussions dealing with the theoretical aspects of the seismic and resistivity methods of test (4, 6, 7, 12, 14, 16, 19, 26, 28, 30). However, a limited description of the principles involved in these two methods of test will be presented in subsequent paragraphs in order that the reader may better understand graphs to be

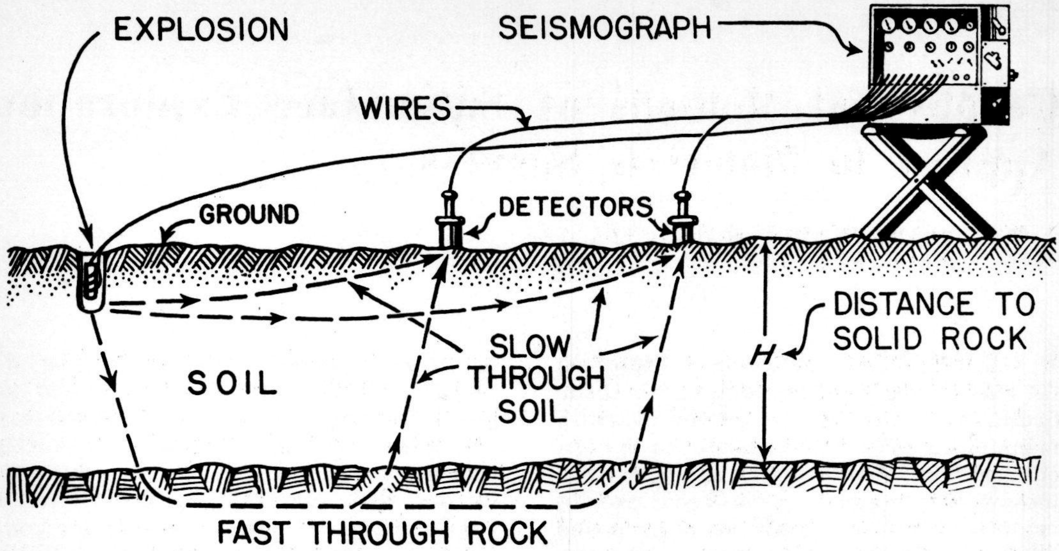

Figure 1. Sketch illustrating refraction seismic test.

presented containing data obtained in field tests with both seismic and resistivity apparatus.

REFRACTION SEISMIC TEST

In this test the velocity of propagation of sound or vibration waves is used as a means for determining the character of and the depth to a given geologic formation lying below the earth's surface. Loose unconsolidated soils can have a wave transmission velocity as low as 600 ft. per sec. whereas wave velocity in solid, hard rock may approach 20,000 ft. per sec. Various intermediate velocities have been recorded for materials of varying densities such as shale; cemented gravel; heavy dense clay or hardpan; weathered, badly seamed, or shattered rock; and for water-logged, silty soils found in some river deposits. Little trouble is experienced in locating solid rock beneath loose soils or beneath an ordinary moist clay formation. Some care must be exercised, however, in attempting to predict the type of material to be found in areas where the intermediate velocities (4,000 to 9,000 ft. per sec.) are obtained. It is good practice to make several calibration tests with the seismograph over exposures of formations believed to be typical for a given area, using the results obtained as a guide in properly identifying the various materials

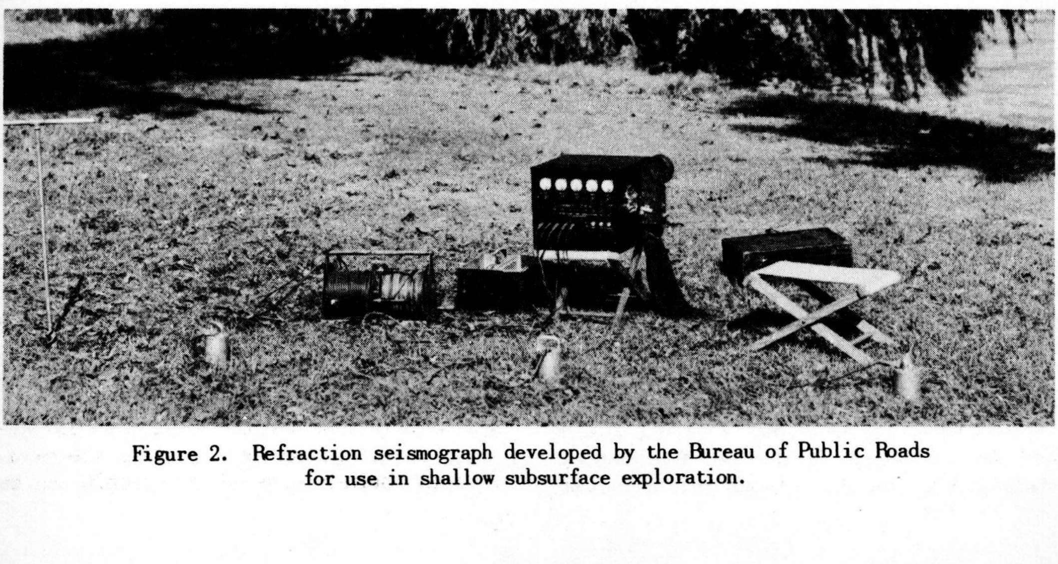

Figure 2. Refraction seismograph developed by the Bureau of Public Roads for use in shallow subsurface exploration.

as they are encountered elsewhere in the immediate locality.

The simplified sketch shown in Figure 1 illustrates the principle of the refraction seismic test. The two detectors shown are for illustrative purposes only, since in practice the number of detector units may vary from 3 to 12 or more, depending upon the type of apparatus being

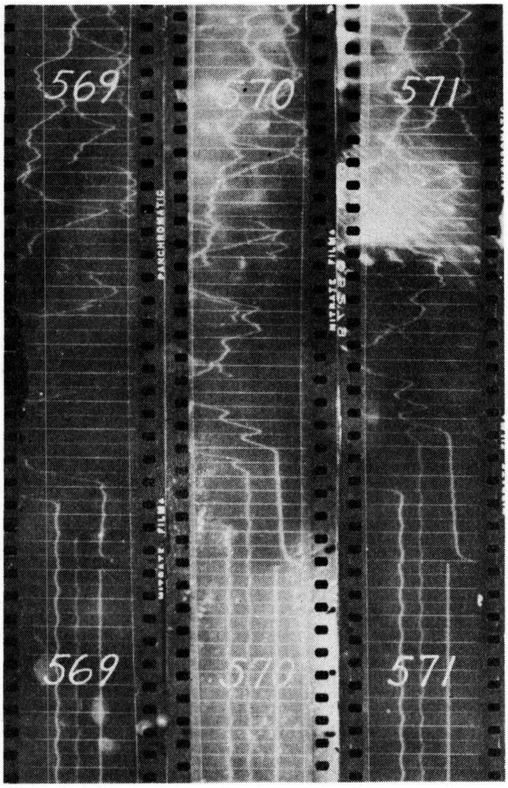

Figure 3. Typical film records obtained in seismic tests; note the kick displacement on the right-hand trace.

used. In the seismic work done by the Bureau of Public Roads three detectors are used in conjunction with a rather simple oscillograph requiring no electronic amplication of seismic impulses. This apparatus has proved very satisfactory for use in the shallow explorations usual in civil engineering work. Figure 2 shows the apparatus with the three detectors shown in the foreground.

When making a test in the field the three sensitive detectors are placed in a

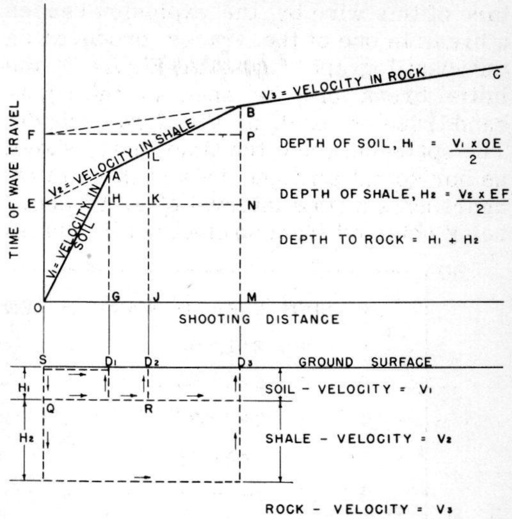

Figure 4. Theoretical time-and-distance curve.

line on the ground surface, spaced 25 to 50 ft. apart, and are connected by suitable two-conductor cables to the oscillograph which comprises the principal unit of the system. Small charges of dynamite, ranging from about 1/8 lb. to 1 or 2 lb., buried 3 or 4 ft. beneath the surface, are then fired at various distances from the group of detectors, on the detector line extended, and the time of wave travel from the shot point to each detector is recorded. Usually this line of shots must extend to a distance from the detectors, equal to approximately three to four times the depth to the particular formation under study. If rock is expected at, say, 50 ft., several shots will be required within the range 150 to 250 ft. from the detector group.

A record of the instant of firing the shot normally is obtained by a special circuit, one part of which is a length of small copper wire wrapped around the explosive. Through this wire a few milli-

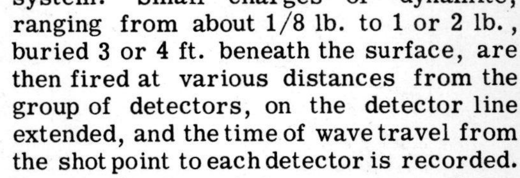

Figure 5. Seismic-wave path of least time.

amperes of current is passed. The rupture of this wire by the explosion causes a break in one of the traces produced on the oscillograph film. In Figure 3 the initial break may be seen in the right-hand trace on each of the film records. The space between the time lines, shown as horizontal straight lines in this figure, represents a time interval of 0.005 sec., being obtained from an electrically driven used by most investigators and has been used in the work of BPR at times where long shot distances were required and, where it was inconvenient to extend the four-conductor cable ordinarily used for the shot circuit.

Measured time and distance data are plotted in the form of a time-distance curve, such as the assumed or theoretical curve shown in the upper part of Figure 4.

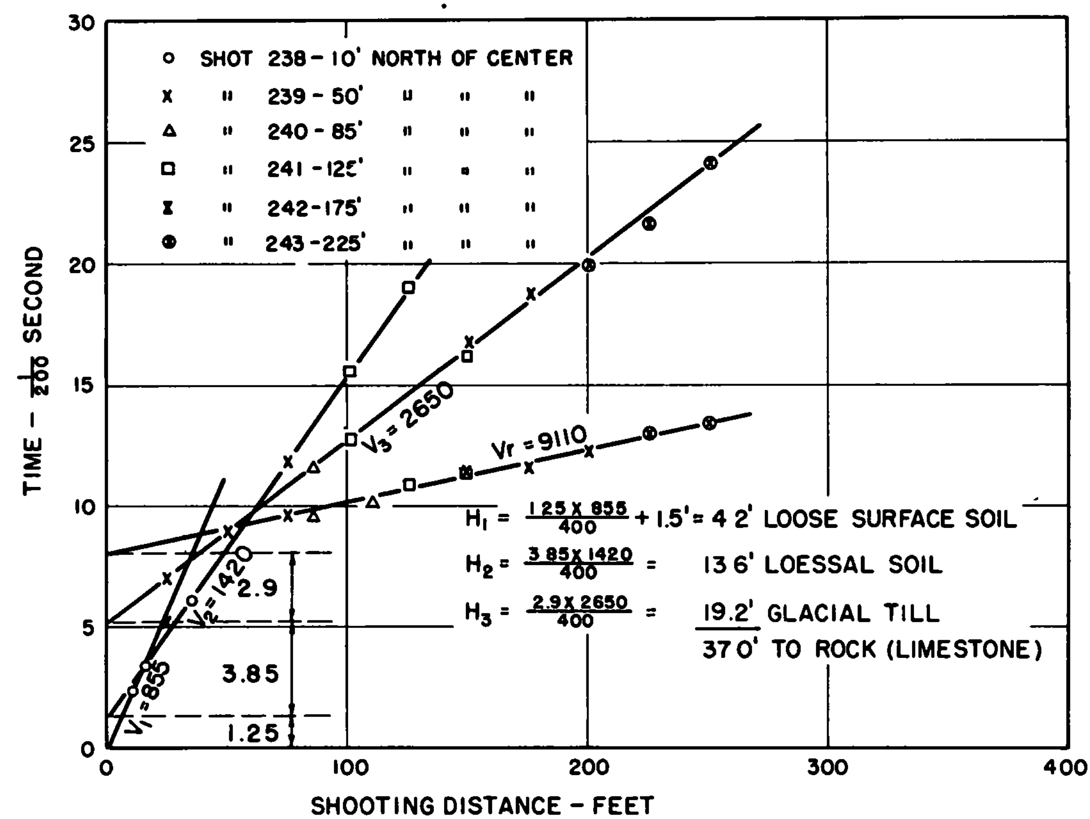

Figure 6. Time-distance graph for seismic test made near Council Bluffs, Iowa, in search for quarry material.

tuning fork operating at 100 cycles per second and so equipped as to permit 200 flashes of light from a suitably placed light source to reach the film each second.

A second method for recording the time at which the shot is fired makes use of the rupture of the bridge wire in the electric detonator to indicate the event on the oscillograph record. An auxiliary circuit is provided for this purpose.

This second method, while probably not as precise as the first method, is that The reciprocal of the slope of the line OA represents the wave velocity, V_1, in the first layer of surface soil. As the shots are fired at increasingly greater distances from the detector locations a critical distance is reached, such as OG (or SD_1), for which the wave traveling through the surface soil reaches the nearest detector at the same instant as a wave which passes down through the surface soil to the second layer, is refracted along the interface to a point beneath the detector and thence travels upward to the detector (see Fig. 1 and the lower part of Fig. 4). Beyond this critical distance a new slope, AB, will obtain, the reciprocal of which represents the velocity, V_2, in the second layer. For a path $SQRD_2$ the time JK or OE is that required for the wave to travel through the surface soil from S to Q and from R to D_2. KL represents the time of wave travel from Q to R in the second layer which will vary with the density of the second layer and the distance from the show point S. For the purpose of illustration, the distance SD_2 was arbitrarily chosen. Letting H_1 represent the thickness of the surface layer, we may set up the relation

$$H_1 = \frac{V_1 \times OE}{2} \qquad (1)$$

In like manner, for a third layer, such as rock, having a greater density than the overlying formations, there will be a second critical distance, OM, and a second break in the graph at B to a new slope, BC, the reciprocal of which will give the velocity, V_3, in the rock. The time intercept, EF, in this instance, represents the time required for the wave to travel down through the second layer and back again. Letting H_2 represent the thickness of the second layer we have

$$H_2 = \frac{V_2 \times EF}{2} \qquad (2)$$

For the equations given above it was assumed that the waves traveled vertically downward to the interface and vertically upward to the detector. This is not strictly true. However, the accuracy obtained when using Equations 1 and 2 is adequate for most shallow explorations ordinarily met with in highway work. When the ratio of V_1 to V_2 or V_2 to V_3 is of the order of one half or greater, a correction to take into account the inclination of the wave path may be required for use in the deeper tests such as may be involved in explorations of large dam sites and deep-lying geologic formations in order to attain the desired degree of accuracy.

Since the laws of optics apply to the path taken by the fastest wave, the ratio of the sine of the angle of incidence to the sine of the angle of refraction may be equated to the ratio of the velocities for the two layers involved. Figure 5 shows this relation for a two-layer system. From this

$$\frac{V_1}{V_2} = \frac{\sin \theta}{\sin \alpha}$$

Since $\alpha = 90^0$, $\sin \alpha = 1$ and $\frac{V_1}{V_2} = \sin \theta$

Thus the ratio of the velocities in the two layers determines the angle of incidence at the interface. As stated previously, where the value of this ratio is of the order of one half or greater, a correction may be required, particularly for deeper work. This correction is necessary because the distance traveled and consequently the time of travel of the wave in a given layer increases as the angle of incidence increases, the increased distance being $\frac{H}{\cos \theta}$. When this change is taken into account in Equation 1 for example, the expression for depth becomes

$$H_1 = \frac{V_1 \times OE}{2 \cos \theta} \qquad (3)$$

There are other, and perhaps more exact, formulas for obtaining corrected values for the computed depths which are described in some detail in the published literature (12, 19, 25, 31, 40). The reader is referred to these publications for more detailed discussions of the analysis of seismic data.

TYPICAL APPLICATIONS OF THE REFRACTION SEISMIC TEST

Figure 6 contains a time-distance graph for seismic data obtained in southwest Iowa while searching for quarry material in an area where surface geology indications were lacking. As shown in the figure, rock (limestone) was found at a depth of 37 ft. below the surface. The depth obtained from a seismic test is an average of the depth at the shot point and at the detector location. For this reason a correction of 1.5 ft., equal to half the shot depth, has been added as a second term in the equation for the depth of the first layer, as shown in Figure 6 and in subsequent figures dealing with seismic tests.

As stated previously, the geophysical tests may be applied to the solution of a number of the problems common to highway construction. Figure 7 shows data from a seismic test made in western North Carolina while investigating a section of the Blue Ridge Parkway in the Great Smoky Mountains National Park. This test, made at the location of a portal of one of five tunnels proposed for the 5-mi.-long project, indicated that there was little likelihood of encountering rock within 43 ft. of the surface at this particular location. The relatively low wave velocity of 7,920 ft. per sec. suggests further that the formation immediately below this depth is either

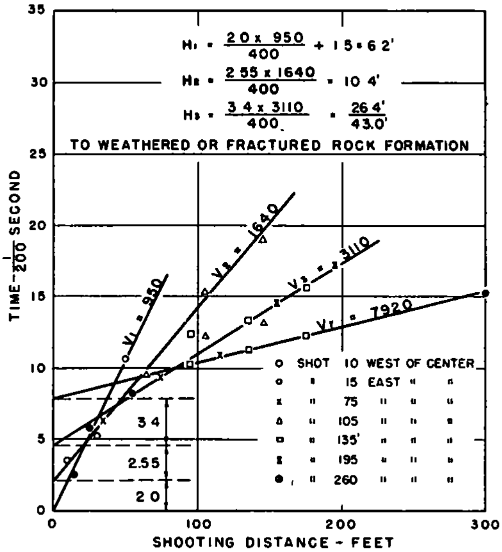

Figure 7. Seismic data obtained at proposed location of Tunnel 3, Project 2Z2, Blue Ridge Parkway, in western North Carolina.

a weathered rock or a badly shattered or jointed rock, neither of which would be well suited for successful tunnel work without lining throughout and perhaps other special construction procedures.

Being portable, the seismic apparatus may be taken into areas virtually inaccessible to other means of exploring the subsurface. Figure 8 shows the apparatus being carried into rough mountain terrain to reach the several tunnel sites referred to above.

Figure 9 shows seismic data obtained in northeast California at the proposed site for a bridge to carry the Shasta-Lassen Highway across Lake Britton. The relatively soft, chalky material found near the surface is shown to extend down

Figure 8. Seismic equipment being transported over rough mountain slopes.

to a depth of about 54 ft. to firmer, better foundation materials.

Although other data could be presented and instances cited in which seismic tests have been successfully employed, it is believed that this test has a limited value for general use in prospecting for materials of construction, other than solid rock. For this reason discussion of the use of this method for this particular application will not be extended.

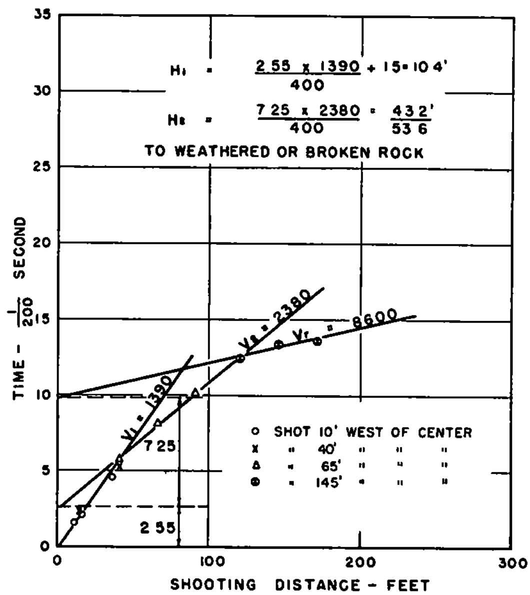

Figure 9. Refraction seismic test at north abutment location for bridge across Lake Britton, California, on Shasta-Lassen Highway.

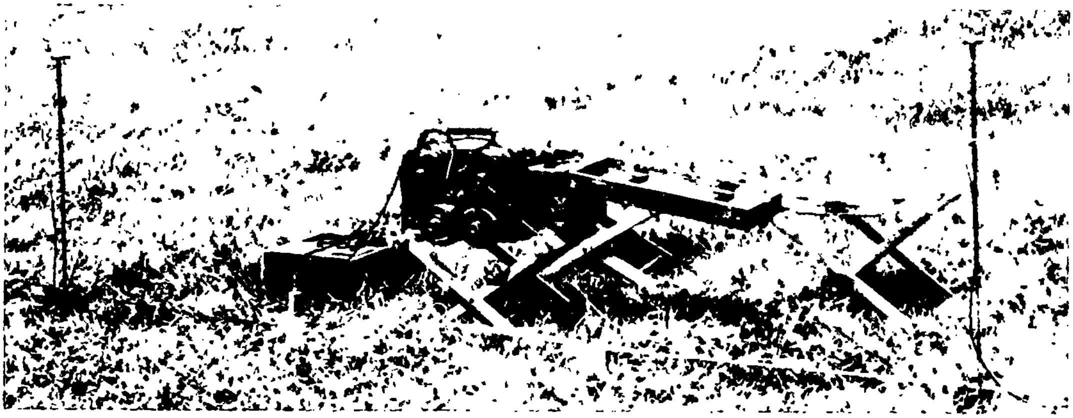

Figure 10. View of the resistivity apparatus used by the Bureau of Public Roads.

EARTH-RESISTIVITY TESTS

The earth-resistivity test consists of passing a direct current of electricity through the ground and measuring the resistance to current flow through the earth's materials. This current flow is electrolytic in nature and is dependent upon the moisture and dissolved salts within the soil and rock formations to provide a suitable path. Consequently, any materials having reasonably high moisture content, such as moist clays, silts, and organic muck soils, with an increased capacity for dissolved impurities, will usually conduct a direct current readily and will have a low resistivity. Conversely, materials such as dry, loose soil; sand and gravel; hardpan; and solid rock, having a limited amount of moisture and the all-important dissolved salts, will usually possess relatively high resistance to current flow. Because of this variation in resistivity it is quite often possible, by means of rather simple field tests, with electrodes placed on the surface or driven a few inches into the surface soil, to obtain useful information regarding the subsurface formations by utilizing measured values of resistivity at a particular location. However, materials quite different from an engineering viewpoint, that is, easy to excavate or quite difficult to

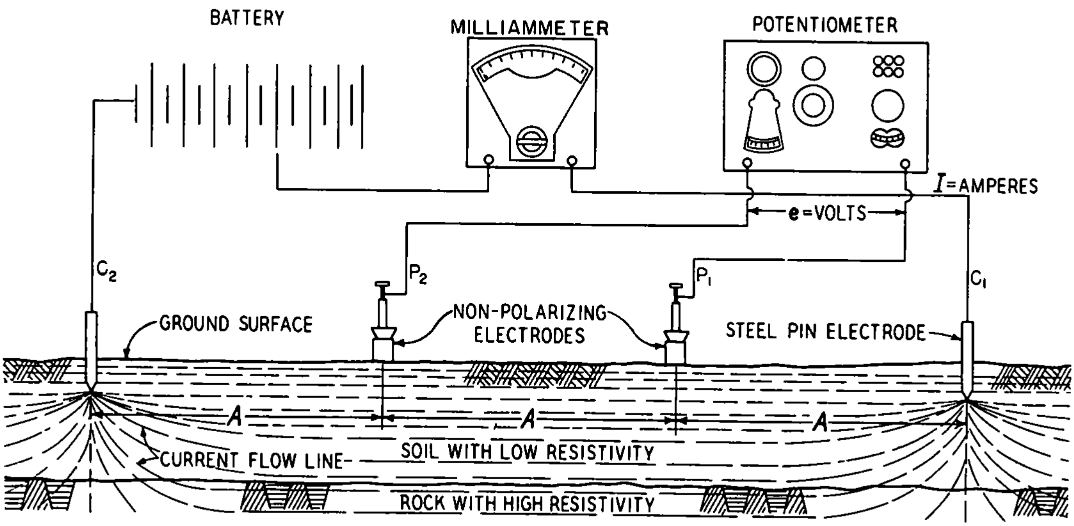

Figure 11. Electrical-resistivity instrument and the four-electrode configuration commonly used.

remove, may possess similar resistivities, particularly when found in different geographical regions, and it is essential that trial or calibration tests be made in each general area where resistivity surveys are to be made. These trial tests, made over known geologic formations exposed to view in existing road cuts or identified by drill holes, test pits, etc., provide characteristic resistivity curves for each type of soil, weathered material or solid rock typical of the area. These type curves may then be compared with each field curve obtained in testing over unknown conditions in the course of the resistivity survey. Close similarity between a field curve and a particular calibration curve is indicative of similar geologic conditions in the subsurface.

The instruments used are portable and can be taken into areas virtually inaccessible to other, less portable, apparatus. Figure 10 shows a view of the simple milliammeter-potentiometer type of resistivity apparatus used by the Bureau of Public Roads.

Although the resistivity test has been used to advantage on numerous projects having to do with classification of earthwork and for slope design, as well as the exploration of bridge foundations, tunnel sites, swampy areas, etc., its most unique application, perhaps, is in the field of materials surveys. Rapid tests, extended across relatively large areas, make it possible to locate isolated deposits of sand and gravel or solid rock where no surface indications exist. Furthermore, having located a hidden deposit of granular material, much useful information may be obtained regarding the lateral extent and thickness of the useful material. Other material such as chert, soft sandstone, caliche, solid rock, and special soil types may be located in a similar manner if the material has resistivity characteristics differing from those of the surrounding or overlying material.

THEORY AND PROCEDURE IN MAKING EARTH-RESISTIVITY TESTS

The Resistivity-Depth Test

In Figure 11 a schematic diagram shows the Wenner (1) four-electrode configuration ordinarily used in making resistivity measurements and the several component parts of the apparatus used by the Bureau of Public Roads. When conducting a test a direct current of electricity, I, supplied by a group of radio B or C batteries, is sent through the ground between electrodes C_1 and C_2 and a potential drop, E, is measured between electrodes P_1 and P_2 which are equally spaced between the two current electrodes. The measured values of E and I are inserted in a simple formula $\rho = 2\pi AE/I$, in which ρ is the resistivity in ohm-centimeters, A is the electrode spacing in centimeters, E is the potential drop in volts and I is the current, in amperes, flowing through the soil. In practice it has been found that an empirical relation exists between the electrode spacing and the effective depth of the test such that the electrode spacing is equal to the depth involved. Using an electrode spacing of 6 ft., for example, it may be assumed that the measured resistivity applies to the soil lying within 6 ft. of the surface. By progressively increasing the electrode spacing the test is carried deeper and deeper into the subsurface and the measured values of resistivity are plotted in a curve showing the relation of resistivity to electrode spacing or depth. This type of test is commonly referred to as the resistivity-depth test. For the two-layer formation shown in Figure 11 the relatively low resistivity of the soil overburden will control the measured values of resistivity until the test has been carried deep enough to involve increasingly larger volumes of the underlying high resistivity layer of rock. As this occurs an upward trend develops in the resistivity-depth curve indicating the presence of the high resistance layer and its approximate depth below the surface. Gish and Rooney (2) found that the inflection point in the curve could be taken as an indication of the thickness of the surface layer. Although this rather simple empirical method of analyzing earth resistivity data has had considerable use in the past, it is possible to obtain smoothly rounded curves which show no clearly defined inflection point, and are, therefore, difficult to analyze directly.

Another equally simple empirical method, developed by the Bureau of Public Roads, makes use of the Gish-Rooney curve together with a graphical integration of the curve for analyzing the data obtained in the depth test. This method of analysis, the cumulative-curve method, can be applied to all types of curves, whether smoothly rounded or showing sharp inflection points, with surprisingly good results.

Figure 12 contains curves illustrating the cumulative method of analysis, the upper curve, labeled A, being the Gish-Rooney curve plotted from data obtained over a two-layer formation and the lower curve, labeled B, being the cumulative curve. Table 1 contains the field data used in plotting the curves shown in the figure.

TABLE 1

RESISTIVITY-DEPTH TEST DATA USED IN FIGURE 12

Electrode spacing	Apparent resistivity	Cumulative resistivity	Remarks
ft	Ohm-centimeters	Ohm-centimeters	
3	6885	6885	Drill hole record showed clay to 13 2 feet underlain by hard rock
6	5990	12875	
9	6325	19200	
12	7735	26935	
15	9260	36195	
18	10925	47120	
21	12730	59850	
1 5	7955		Not used in cumulative curve.
7.5	6045		do

The cumulative-curve method of analysis has been described in earlier publications (34, 36, 37, 46, 48) and it has been used by the Bureau of Public Roads with satisfactory results. Briefly, the Gish-Rooney curve (Curve A, Figure 12) is used to determine the probable number of subsurface strata while the inflection points on this curve are used to give significance to the straight-line intersection points obtained from the cumulative curve (Curve B, Figure 12). The trend in Curve A at an electrode spacing of 7.5 to 9 ft. suggests the presence of the rock found at 13.0 ft. in Curve B. Had Curve A been extended on to a depth of 30 to 40 ft. an additional intersection might have been obtained in Curve B, but no significance could be given this second intersection if there was no corresponding trend in Curve

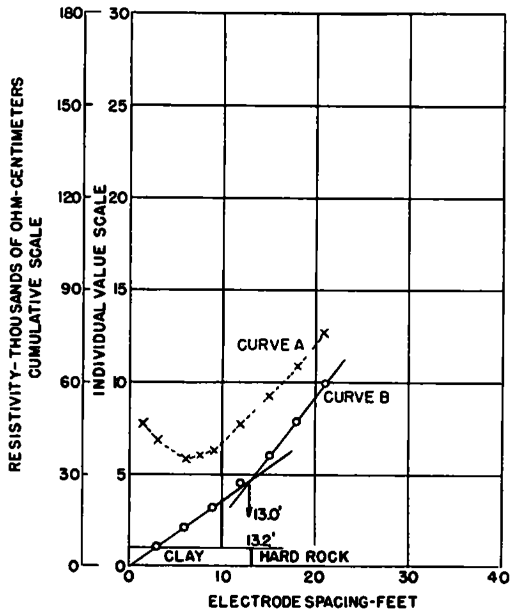

Figure 12. Empirical method of analysis applied to resistivity curve for a clay stratum underlain by rock in the vicinity of Washington, D.C.

A. Very slight trends in Curve A, often obtained where thick layers of soil overburden rest upon bedrock or sand and gravel, are used in this manner to give credence to the intersections obtained in the B curve.

Theoretical methods of analysis, based upon assumed ideal conditions seldom found in the field, have been used by many investigators in analyzing earth-resistivity data. The writer has found them of little use in the shallow explorations ordinarily involved in highway-engineering explorations. For the most part, the theoretical methods consist of using groups of curves, obtained for data computed for various assumed formation layers, resistivities, and layer thicknesses, to which the field curves are fitted to ascertain which of the assumed conditions most nearly approaches those existing where the field tests were made. Use of such methods appears to be more practical for the deeper explorations in areas where the geologic formations are likely to be of considerable thickness and more uniform in character, and where simple calibration tests over known conditions may be impractical.

These methods have been described in some detail and no attempt will be made to discuss them further. The reader should review references given in the appended bibliography for a thorough treatment of the subject (4, 6, 7, 14, 26, 28, 30). It should be emphasized, however, that in the interest of a widespread increase in the use of earth-resistivity tests by both engineer and contractor, the simple, on-the-spot evaluation of resistivity data, such as that possible when using the empirical methods heretofore referred to, is more practical for those having no previous experience with resistivity testing.

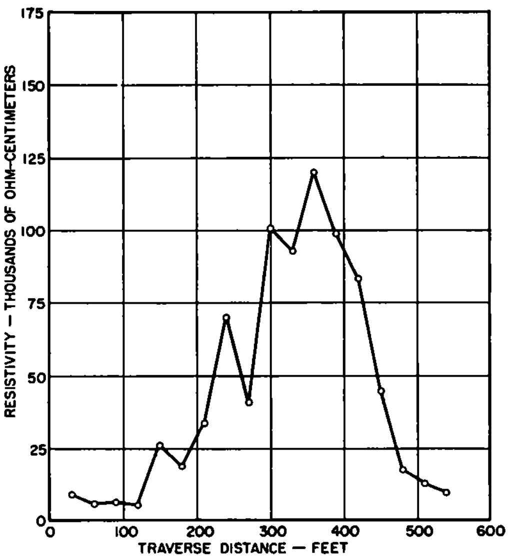

Figure 13. Constant-depth resistivity traverse over formation of Dakota Sandstone, Washington County, Kansas. Electrode spacing 30-ft.

Constant-Depth Resistivity Traverse

The resistivity-test method most useful in searching for small isolated deposits of sand and gravel or other materials useful in construction work is the resistivity traverse. In this method the four electrodes are held at a fixed spacing and a series of tests is made at a series of locations along a random line over the area where the presence of construction materials is suspected. With an electrode spacing of 25 ft., for example, resistivity values are obtained at 25-ft. intervals along the chosen traverse line. The effect of any change in subsurface conditions within 25 ft. of the surface will be shown by resistivity changes. Figure 13 contains data from such a constant-depth resistivity traverse made over a formation of Dakota sandstone located in Kansas during a search for a source of material for use in road construction. Having found a formation in this manner additional tests are made along a series of parallel lines spaced a suitable distance apart, together with other traverses at right angles to these lines. From the data a resistivity-contour map may be constructed covering the whole area and outlining those areas most likely to contain a preponderance of the materials sought. Figure 14 shows such a resistivity-contour map of a sand and gravel deposit in Maryland just north of Washington, D. C. It is often possible to test as much as 4,000-5,000 ft. of traverse per 8-hr. day. Obviously such data furnish valuable information regarding the presence of useful materials and their lateral extent at relatively low cost. Several judiciously placed resistivity-depth tests or auger borings, in conjunction with the traverse data, make possible a reasonably accurate determination of the quantities of material available. Identification of the materials depends upon calibration data as mentioned previously.

TYPICAL APPLICATIONS OF THE RESISTIVITY TEST IN THE LOCATION OF MATERIALS OF CONSTRUCTION

Several of the graphs presented together with the accompanying discussion found in subsequent paragraphs may appear to digress from the purpose commonly attributed to a materials survey. The data are included in this report, however, to further illustrate how the resistivity test may be used to obtain information concerning the materials existing at bridge sites, tunnel locations, and in highway cut sections, which may affect the final design of the structure or roadway.

Classification of Earthwork for Slope-Design Purposes

With adequate data from calibration tests over exposed formations in an area where a new roadway is planned, it is possible to interpret with some assurance

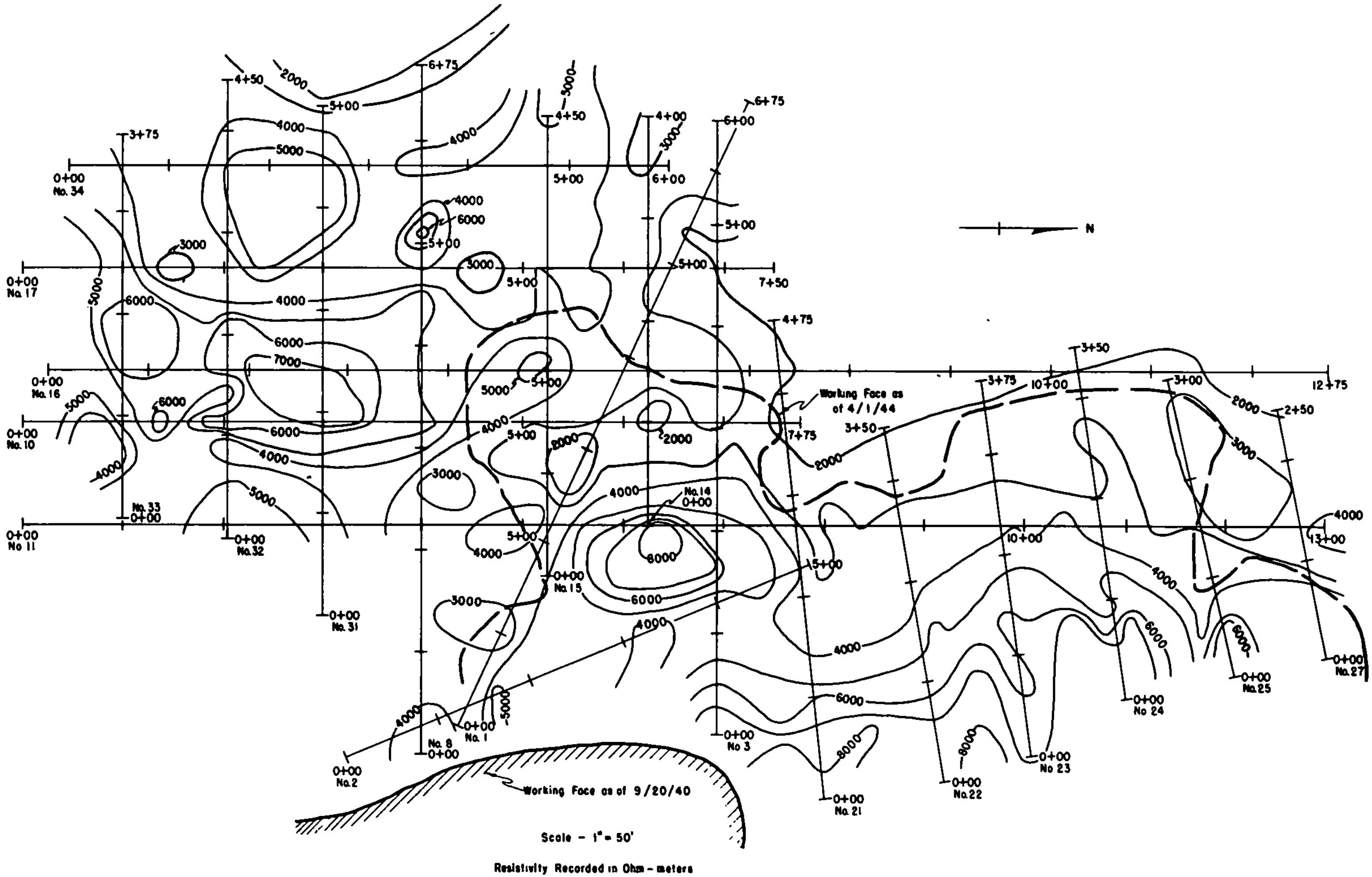

Figure 14. Resistivity-contour map of area adjacent to gravel pit near Muirkirk, Maryland.

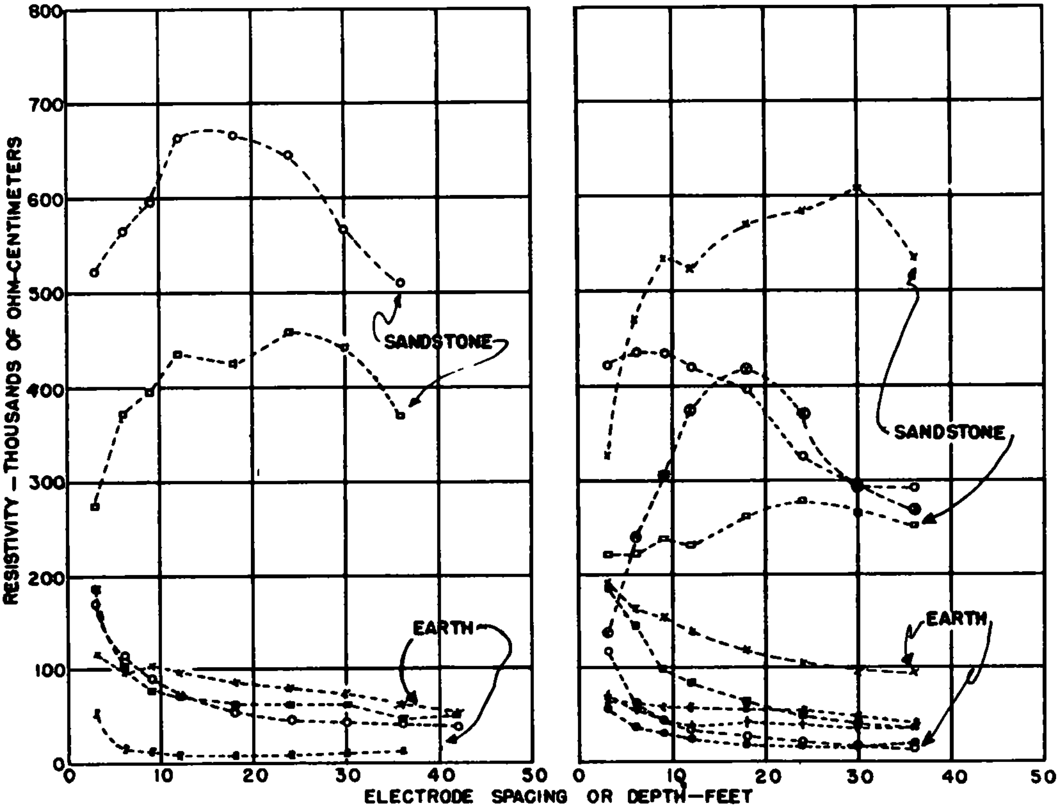

Figure 15. Resistivity-calibration curves (left) and typical field curves obtained in the Ozark National Forest near Russellville, Arkansas.

the resistivity data obtained elsewhere in the area and to obtain sufficient information regarding the subsurface formations to make possible a proper slope design without analyzing the individual curves for a specific depth to formation changes at each test location. Figure 15 shows curves for resistivity data obtained in northwest Arkansas over exposed sandstone, clay, and shale formations (left-hand graph) typical of the area, and over representative cut sections from about 22 mi. of proposed roadway (right-hand graph). This investigation, carried out in rugged country in the Ozark Mountains, required only 12 working days and the tests were made by inexperienced men with only minor supervision by the writer. Yet, even an inexperienced man could readily see the striking resemblance between many of the field curves obtained and the calibration curves obtained over "earth" easily excavated by large self-loading scraper units. Slopes designed for earth, as interpreted from the resistivity data, were found to meet actual field conditions in practically every instance for the cut sections on the two grading projects thus far completed. Wherever rock was present it was found at depths closely approximating those predicted from the results of the resistivity tests. Other investigations, made in Tennessee and Virginia, have also been quite helpful in slop design.

Foundations for Bridges

Although the mere knowledge that bedrock does or does not exist within practical depths at a particular structure location is often sufficient for preliminary design purposes, rather accurate depth determinations are possible in instances where the geologic conditions approach those assumed in a theoretical treatment of the resistivity test. Figure 16 shows data obtained in Virginia near the west abutment of the Memorial Bridge spanning the Potomac River at Washington, D. C., showing rock at a depth closely approximating the depth found by the drill at the abutment located about 150 ft. away. Other tests for structure foundations made in New Hampshire, Georgia, and Kansas have been even more accurate when compared with results obtained by drilling.

Investigations for Tunnel Sites

By calibrating over materials considered good for tunneling purposes and over materials considered unsatisfactory, control curves are obtained which make it possible to obtain valuable preliminary

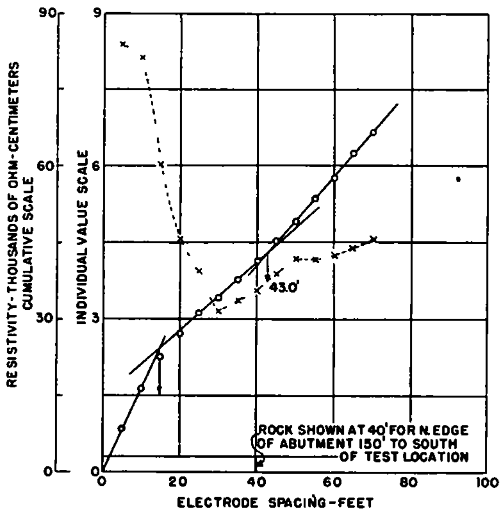

Figure 16. Resistivity test near west abutment of Arlington Memorial Bridge, Washington, D.C.

information regarding the materials present at a tunnel site with a few rapidly made resistivity tests. While studying the subsurface conditions on a section of the Blue Ridge Parkway in western North Carolina, five tunnel sites and several miles of grading were investigated in about four days' time and information obtained regarding the probable character of the materials to be found in 21 cut sections and at the several tunnel locations. Figure 17 contains resistivity curves for data obtained at two of the tunnel locations (Curves 5 and 6) and over one large cut (Curve 4), together with data from three calibration tests made over known geologic formations exposed to view on a partially completed construction project adjoining the project under investigation. Curves 1 and 2 of the calibration tests (solid-line curves) were obtained over a weathered rock formation at a location where a projected tunnel had collapsed during the early construction stages due to the unsatisfactory character of the formation involved. These two curves completely bracket the three curves obtained over unknown formations. From these data one would expect that the conditions at the two proposed tunnel sites and at the location of the large cut could be little different from that found at the location where the tunnel failure had occurred. Accordingly, as a result of these tests, and others made throughout the length of the project, earth and weathered rock formations were predicted for all five tunnel sites and in most of the 21 cut sections investigated. The sharply rising trend in Curve 3 of Figure 17, obtained from a test made over a solid rock formation exposed in a cut on the nearby project, by its contrast, adds support to the prediciton that weathered rock would probably be found at the locations of tunnels 4 and 5.

Several refraction seismic tests were made at locations where resistivity curves had been obtained that were thought to be typical of those obtained throughout the project. The rather low wave velocities obtained for the materials above grade also were characteristic of weathered material. Thus the seismic test served as a convenient and rapid check upon the more detailed resistivity survey.

Many other instances could be cited and data presented further emphasizing the practical use of the resistivity test in field surveys to study subsurface conditions in swampy areas, slide areas and soil-boulder or glacial till formations, the two latter formations being very troublesome to the drill operator. As stated previously, however, the resistivity method of test has special promise when applied in a search for materials of construction, and this important application will be discussed in subsequent paragraphs.

Location of Materials of Construction

Certain sections of the country are fortunate in having almost unlimited sup-

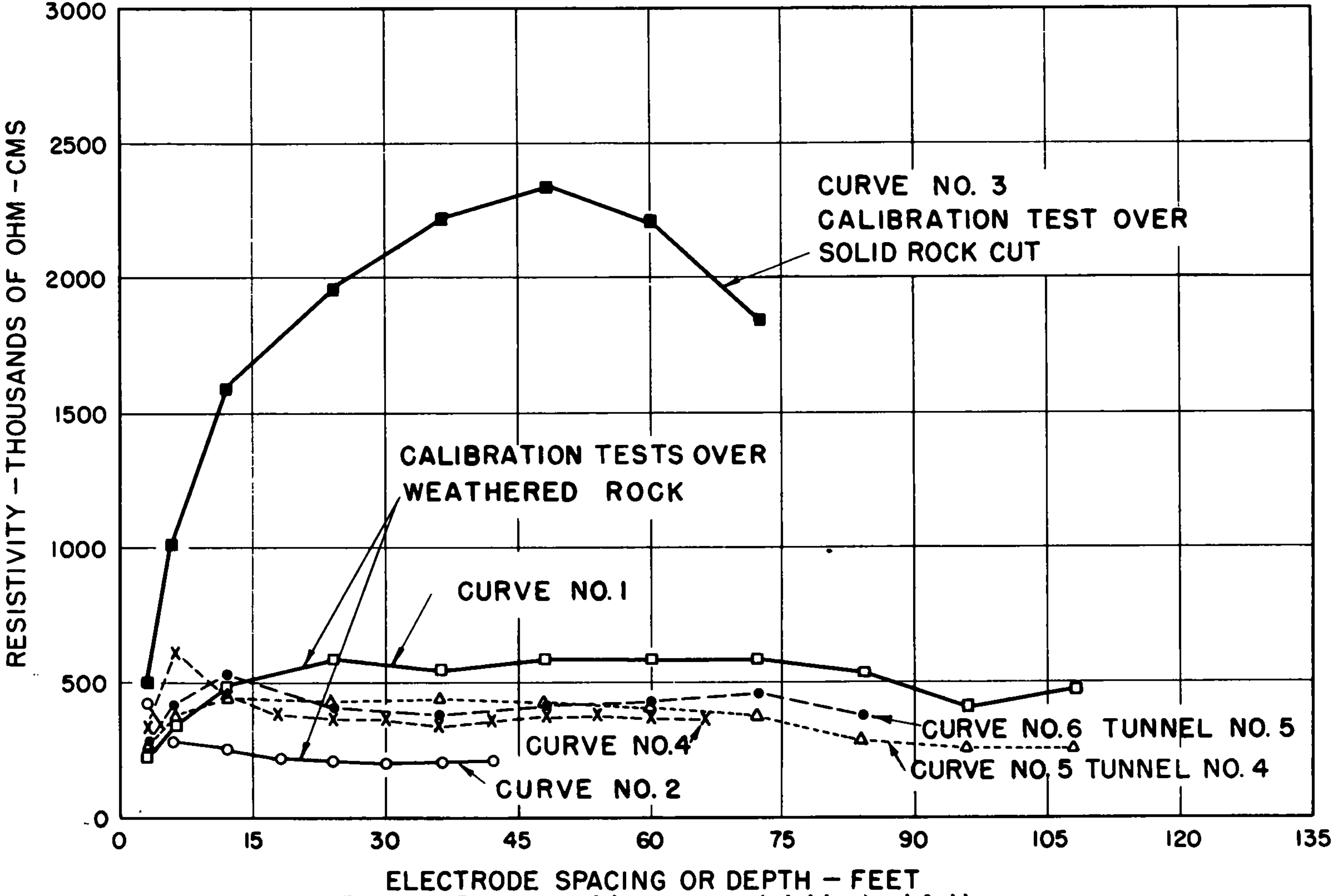

Figure 17. Resistivity-calibration curves (solid line) and field curves (dotted lines) obtained during investigation of several proposed tunnel sites on Project 2Z2, Blue Ridge Parkway, in western North Carolina.

plies of sand, gravel, and other materials useful in construction work. Other areas are less fortunate and those concerned with maintaining adequate supplies of such materials must hunt far and wide for usable deposits. Even in areas plentifully supplied there have been instances where materials have been transported for some distance for use in construction work while adequate supplies lay hidden immediately adjacent to the project. The ultimate goal for the materials survey is not only to locate the quantities of material needed, but to locate the materials as near to the project on which they are to be used as is possible.

The Baltimore-Washington Parkway, now under construction, passes through a section of Maryland underlain, for the most part, by clay soils that make it desirable to use a layer of granular materials under the pavement to provide greater stability than would obtain if the pavement were laid directly upon the clay. A recent resistivity survey was made on a 3-mi. section of the parkway, now under construction, in an effort to locate some 85,000 to 90,000 cu. yd. of granular materials needed for use over soils of the type described. Considerable trouble and expense would be avoided if the material could be located within the right-of-way boundaries at locations within the limits of the project, eliminating the necessity for purchase of the materials and hauling them in from more distant locations.

In planning a survey of this type, the usual procedure is to make full use of all existing geologic information, such as that to be obtained from geologic maps, aerial photographs, and in records of drill holes or borings made within the area. This general procedure was followed in the example being described. Reference was made to recorded data obtained from drill holes and borings that had been made in several of the larger cuts and also to an existing geologic map that showed scattered remnants of plateau gravels, laid down by ancient river action, within the general area traversed by the parkway. The projected roadway apparently passed through one of these small areas in a cut section some 30 to 40 ft. deep at a location near the north end of the project. This area was selected as the most likely for finding substantial quantities of granular materials. Aerial photographs indicated well-drained soils at this location also.

A trial test was made consisting of a constant-depth resistivity traverse to a 30-ft. depth, run along the ditchline of an existing roadway which crossed the line of the parkway at an angle with the centerline. Other tests were made along the centerline of each roadway of the parkway and a fourth test was run across a prominent "high" resistivity area that appeared in each of these two latter traverses. Figure 18 shows the plotted data from each of these tests. The high resistivity zones shown on traverses 2, 3, and 4 are characteristic of sand and gravel found in this part of Maryland.

Figure 19 shows a resistivity contour map drawn up from the data contained in Figure 18. The circled crosses marked D. T. indicate locations where resistivity depth tests were made. This map indicates a reasonably large area underlain by sand and gravel of the type desired. Figure 20 shows the results of eight depth tests made in the area to determine the depth of the materials causing the high resistivity zone shown on the map of Figure 19. Graphs B, C, and H indicate that the depth of the sand and gravel throughout the area enclosed by the 400,000 ohm-cm. contour will be in excess of the actual cut to grade, as shown on the profile sheets for the northbound and southbound roadways. In fact, within the area enclosed by the 200,000 ohm-cm. contour, the proposed cut probably contains materials equally as suitable as that shown by the log of boring No. 50, made at a point 35 ft. to the right of station 2+85, traverse No. 3, on the northbound roadway. This is indicated by the relatively low value of resistivity, 130,000 to 140,000 ohm-cms., obtained at a depth of 30 ft. in a depth test made in the vicinity of the bore hole (see Graph A of Figure 20). A rough estimate of the volume of the material available is 85,000 cu. yd. A more conservative figure for a quantity of sand and gravel comparatively free of clay might be obtained by restricting the area to that within the 300,000 ohm-cm. contour. Within this area a quantity of about 60,000 yd. of material of good quality is indicated.

Another area located in a similar man-

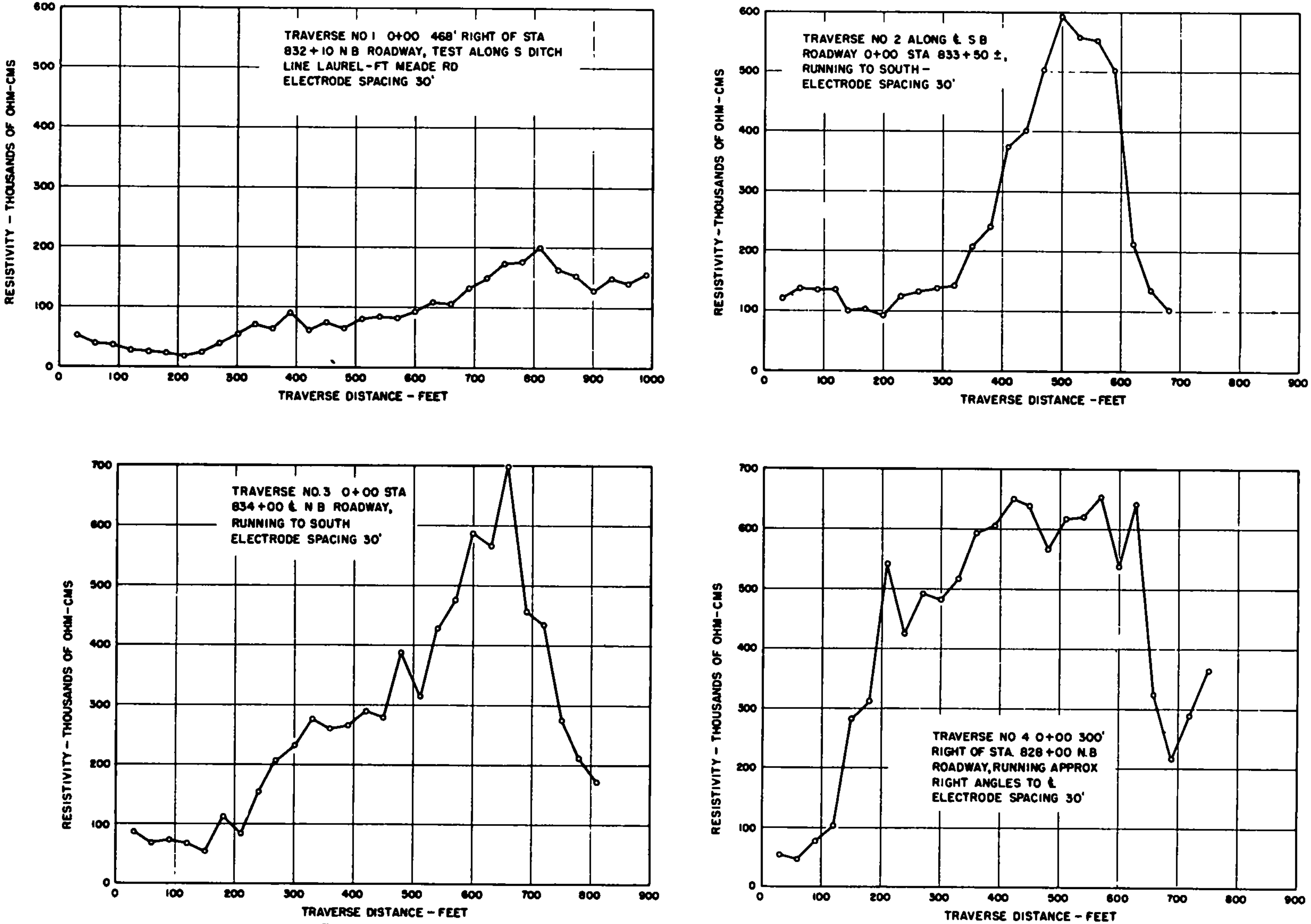

Figure 18. Curves showing effect of localized areas of high-resistivity sand and gravel upon constant-depth resistivity traverse, electrode spacing 30 ft.

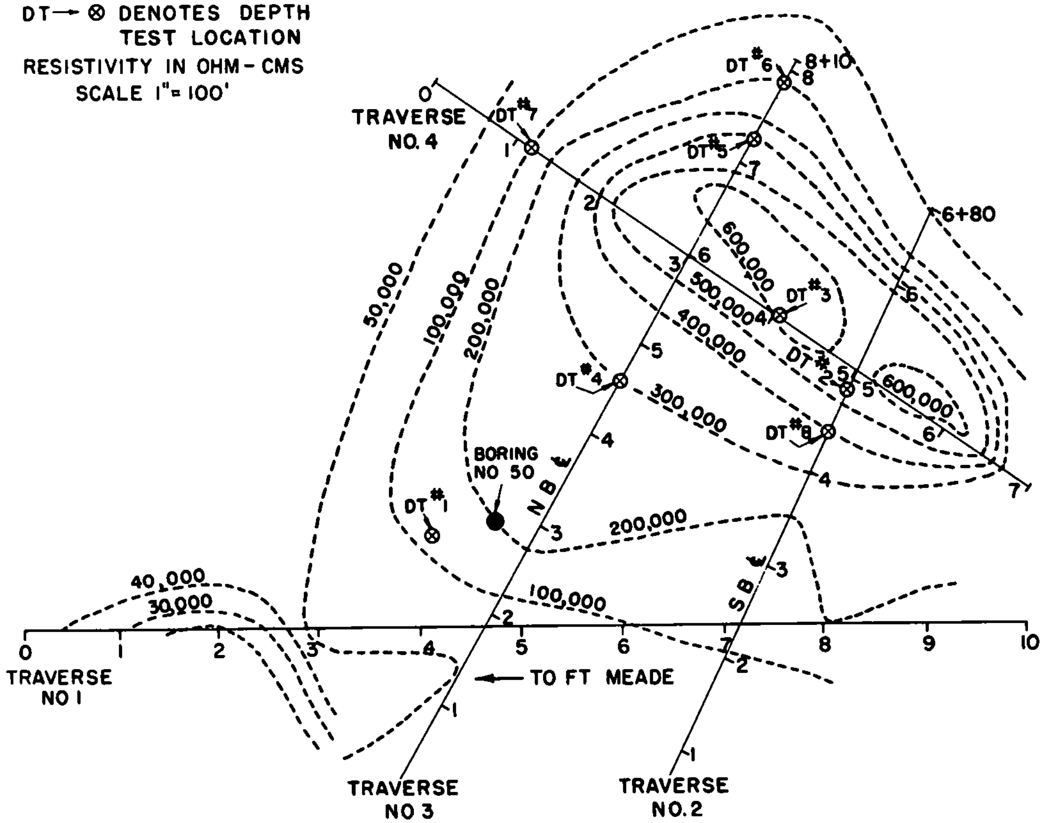

Figure 19. Resistivity-contour map outlines lateral extent of sand and gravel deposit, Baltimore-Washington Parkway.

ner within the right-of-way limits near the south end of the construction project appeared to contain a considerable amount of suitable granular material.

This somewhat-detailed discussion of the application of earth-resistivity tests to a search for granular materials has been included to emphasize the usefulness of such tests in the preliminary planning stages for a construction project. A survey such as that described in the preceding paragraphs will be of greatest value if made prior to any program of direct investigation involving borings or test pits. These slower and more expensive methods would then be restricted to areas where the resistivity tests showed promising resistivity zones, high for granular soils and low for the clayey, impervious soils. For a particular location more complete information would be obtained with a minimum of bore holes by this procedure.

For example, the granular materials found at this location by the resistivity tests had not been disclosed in a satisfactory manner by the single boring made prior to the resistivity survey. The best material was situated at some distance from the arbitrarily chosen bore-hole site. More useful information would have been obtained if the location for the boring had been selected on the basis of the resistivity survey data, that is, in the center of the high resistivity zone shown in Figure 19. Use of the resistivity test in this manner as a guide for more direct exploration work and to expand the information already available from such direct means of exploration is one of its more valuable applications.

LIMITATIONS AND RELATIVE MERITS OF SEISMIC AND RESISTIVITY TESTS

All methods of exploring the subsurface

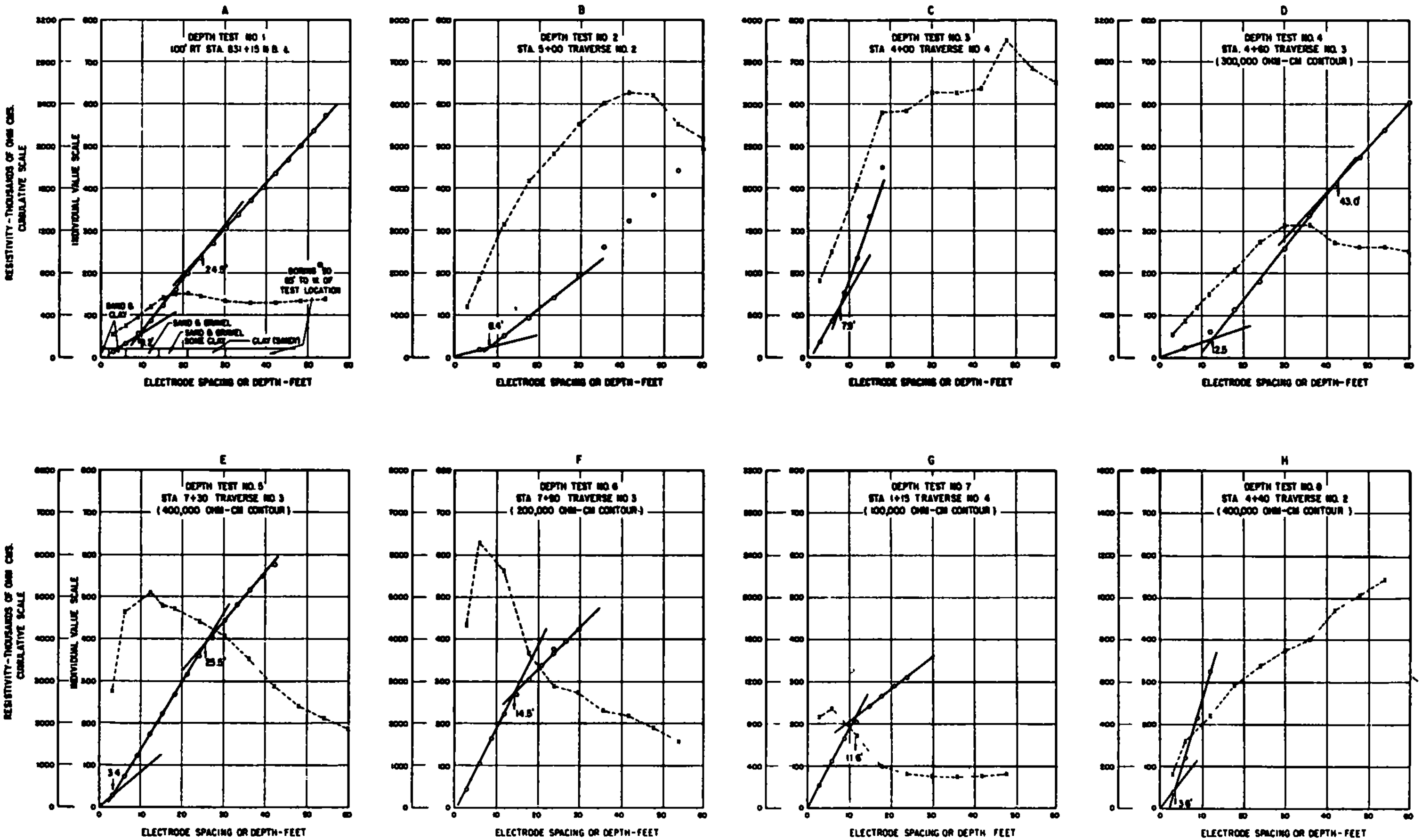

Figure 20. Resistivity-depth tests showing thickness of surface layer of clean sand and gravel underlain by clay.

have their limitations and geophysical tests are no exception to the rule. Seismic tests are efficient in locating rock formations, particularly in a restricted area such as that for a bridge location, tunnel, or dam site. This method of test, however, is not well adapted to rapid surveys over large areas. It appears to have little value in systematic surveys for sand and gravel deposits and other materials having little of the rigidity inherent in solid rock. Its use on highway-grading projects for obtaining information to control slope design has met with success in the work of the Bureau of Public Roads and in the subsurface exploration work of New York and Massachusetts (39). In certain areas where the geologic formations are made up of alternating beds of shale and limestone or sandstone, the seismic test has not proved applicable. Although the dense rock can be located without difficulty, the less-dense shale underlying the higher velocity rock layers will be difficult, if not impossible, to locate. On the other hand, this test can locate solid rock beneath the talus and boulder formations that are so troublesome in drilling operations. While the seismic method can be used in mucky soils and swampy areas its use is costly compared with the conventional methods employed for probing through such materials.

Usually from two to eight locations per day can be explored with the seismic method, the depth to be explored being the controlling factor. Although many times faster and much less expensive than any of the direct methods commonly used, the seismic test is much slower than the resistivity test in the shallow explorations (15 to 50 ft.) commonly required for highway work and cannot compete, except in areas where the conditions are such as to preclude the use of the resistivity method.

In areas where the subsurface formations are reasonably uniform and not badly upheaved or unevenly weathered, the seismic data obtained are not difficult to analyze, the novice obtaining substantially the same depth determination as the experienced operator. However, the field operation and maintenance of the seismic apparatus will require more extensive training than that required for the resistivity apparatus, and the transportation, use, and storage of explosives can be a troublesome factor at times.

Earth-resistivity tests, except under unfavorable geologic conditions, will produce results as dependable as those obtained for seismic tests in the shallow explorations required in highway work. Although interpretation of the resistivity data can become complicated for the deeper tests, it has been the writer's experience that the simple empirical methods of analysis described, together with adequate calibration of the test over known formations, can be relied upon to produce data useful for a study of foundation conditions and of problems of slope design. The talus and soil-boulder formations can be successfully explored by resistivity tests also, since the rock fragments and boulders when mixed with soil usually possess resistivities differing from that of a solid mass of rock or shale. Sand and gravel can possess a resistivity more than 100 times as high as that of some rocks and shales. However, even a superficial knowledge of local geology, coupled with the all-important calibration tests over typical local formations, will enable one to properly eveluate the results of resistivity tests in most instances.

Extremely dry, loose sand may have resistivities closely approximating that of solid rock upon which it rests and may prevent a proper identification of the boundary between the two materials by this method. In such a case seismic tests will locate the rock without difficulty.

The resistivity test can be useful in a study of formations that consist of alternate beds of hard rock and less dense materials such as shale. Figure 21 shows data, obtained in a study of slide conditions in West Virginia, that indicate the method may have possibilities for locating a shale formation beneath dense sandstone. Seismic tests at this location would have been futile.

An important advantage of the resistivity method over the seismic method is that it may be used in a constant-depth traverse procedure to locate the lateral limits of subsurface formations and abrupt irregularities in an underlying rock formation. Such a traverse, made at a rate of 4,000 to 5,000 ft. per day, can be of great value in a rapid reconnaissance survey for con-

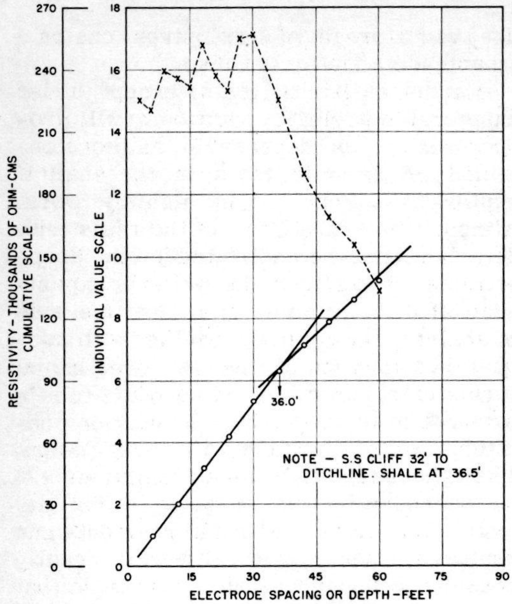

Figure 21. Resistivity test locates shale formation beneath 36 ft. of massive sandstone at large slide area on US 60, near Huntington, West Virginia.

struction materials and in a detailed study for mapping the contours of a subsurface rock formation.

The operation and maintenance of the resistivity apparatus requires only limited training— one or two days of instruction at most. Reasonably satisfactory interpretation of the data, using the simple empirical methods, can be learned almost as quickly, the interpretations becoming increasingly dependable with growing field experience. In cases where the geologic conditions are complex in nature, departing radically from the uniform homogeneous conditions assumed in theory, interpretation of the resistivity data can become well-nigh impossible. Dependance must be placed on adequate calibration tests under such circumstances.

Stray currents, emenating from ore bodies; cross-country pipe lines; or other sources can affect resistivity measurements adversely. Specially designed apparatus may be obtained for use in localized rural areas subject to such disturbances or in cities where ground currents from electrified street railways, power lines, etc., may be encountered. Figure 22 shows such apparatus which makes use of a hand- or motor-operated commutator to cause a reversal of the current some 30 to 40 times per second. This procedure usually cares for any natural currents in the ground and permits the test to be carried out without interference from such currents. When such stray currents are unidirectional, or undergo reversals at not too frequent intervals, the simple apparatus without the commutator (Figs. 10 and 11) will be entirely satisfactory. Under such conditions the operator makes two sets of observations for current and potential, with the direction of flow reversed in one instance, and averages the results obtained before computing a value for the resistivity. Actually, in the writer's experience with tests made in many parts of the country, and in urban areas as well, very little trouble has been experienced with stray currents when the simpler apparatus was used.

COST OF GEOPHYSICAL EQUIPMENT

Seismic equipment of the type shown in Figure 2 has been available in the past at a cost of $4,000 to $5,000. More recently, other seismic refraction apparatus has been placed on the market, similarly priced, which makes use of 12 detectors instead of 3, and uses electronic amplification in the detector circuits. This equipment is portable and the multiple detector circuits have some advantages in that fewer shots are required for a given

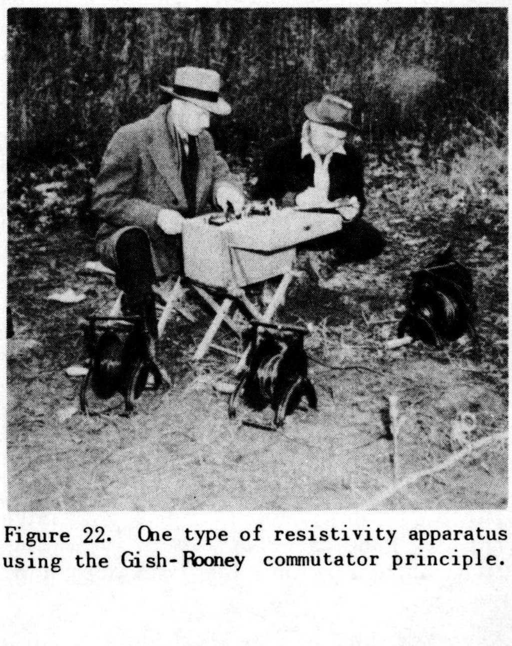

Figure 22. One type of resistivity apparatus using the Gish-Rooney commutator principle.

depth determination. Amplifying the recorded seismic impulses permits smaller charges of explosives to be used, a distinct advantage when making tests in urban areas. Some difficulty may be experienced in attempting to use the 12 detectors in rough mountain terrain due to differences in surface elevations, relative thickness of surface soil at each detector, etc. Extra weight, such as that resulting from the nine extra detector units, will be objectionable if the apparatus must be transported by hand into areas far removed from roads and trails. The emergency repair of such equipment will require some training in electronics for those attempting it. Repairs to the apparatus used by the BPR are comparatively simple.

Earth-resistivity apparatus of the type shown in Figure 10 can be purchased for about $800 and can be built for less in instances where the prospective buyer wishes to construct his own apparatus. The commutator-equipped apparatus usually has sold for about twice as much as the simpler apparatus.

TIME REQUIRED FOR TESTS

Resistivity-depth tests can be made at a rate of three per hour in rough mountain areas to depths of about 60 ft. In open fields, with successive tests made at closely spaced intervals (100 to 200 ft.), more rapid progress is possible. The nature of the problem under study, however, will determine the need for large or small increments of depth and thus will control the number of resistivity determinations required at a particular test location and the time required for completing the test. The resistivity traverse can be made at a rate of 4,000 to 5,000 ft. per 8-hr. day. Seismic tests can be made at a rate approximately one third of that possible when making resistivity tests for the shallower depths (40 to 50 ft. or less).

CONCLUSION

In conclusion, it can be stated that both seismic and resistivity tests are capable of providing dependable information when used in subsurface exploration studies for many of the problems associated with highway and other civil engineering construction. The earth-resistivity test is probably the better of the two methods in that it is faster and has wide application to all of the problems involving the shallow tests; while the seismic refraction test is of greatest use for the deeper tests to locate a rigid, dense medium, such as solid rock. In the light of the foregoing discussion, it is evident that both methods may be used jointly to explore a given subsurface condition, one to corroborate the results obtained with the other. This procedure is followed in the work done by BPR, the seismic test being used to obtain a rapid check on the accuracy of the indications from the more-rapidly made resistivity survey. The resistivity test is particularly adapted to prospecting for construction materials while the seismic test has only a limited value for such work. Use of these geophysical tests in conjunction with presently employed methods of direct exploration should result in a considerable saving of time and expense in future explorations of the subsurface and make possible a better, more-economical design of engineering structures.

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Material Inventories

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SYNOPSIS

THIS paper supplements those dealing with recent developments in exploring for and locating granular deposits. One of the most important parts of any survey involves recording and presenting data in a manner that can be most readily used. The paper has been prepared partially from a review of literature but mostly from data secured from 44 state highway departments. It contains information on published data as well as the present status of highway-material inventories. The methods employed in establishing an inventory record are discussed together with current practices in making such information available to prospective bidders.

● PREVIOUS papers in this symposium deal with recent developments in exploring for and locating granular materials. The use of aerial photographs for reconnaissance in locating materials is becoming increasingly important as techniques of interpretation are developed. Hand methods of exploration are being supplemented and, in some cases, replaced by geophysical methods. Regardless of the method employed in locating granular materials, one of the most important parts of any survey involves the recording and presenting the data in a manner that it can be most-readily used by all interested parties. The data contained in this paper has been secured partially from a survey of literature, but for the most part it has been obtained from a questionnaire circulated to each state highway department to learn if an inventory record of local material or aggregate sources had been completed, was planned, or was in progress, as well as to ascertain the methods of recording. In addition, some information was secured concerning the need for and uses made of these inventories by highway departments.

NEED FOR INVENTORY RECORD

It is recognized that the aggregate resources available to state highway departments vary considerably, even within counties of any state. In some instances abundant supplies of quality materials are readily available, while in other cases good road-building materials are nonexistent or are rapidly being depleted. Some highway departments rely mostly on commercial sources. Others use local roadside deposits almost entirely. Between these two extremes a wide variety or practices exist.

For those departments relying mainly upon commercial aggregate sources, the problem of making and keeping an up-to-date materials inventory may not be so critical. Replies from a few such states indicated that no material surveys were contemplated and that emphasis had been placed on the securing of quality materials.

On the other hand, one state which has depended largely on commercial sources indicated that due to a proposed increase in highway construction, shortages of certain size aggregates in some areas may be encountered and that eventually they may have to resort to a materials inventory for an appraisal of the situation. The engineer of materials stated that in some areas of the state there are available large quantities of aggregate of substandard quality and eventually pavements may have to be designed utilizing these substandard materials. Within most states major deposits occur in certain areas and as minor deposits are worked out in other areas, it will be necessary to move aggregates over longer distances.

Another state replied that due to retiring or shifting personnel and lack of records it had been increasingly evident that a materials inventory would constitute much toward reducing costs of preliminary surveys and subsequent construction. Because of the fact that preliminary investigations made of terrace deposits 15 or 20 years ago are lacking in information concerning depth, it is necessary to reinvestigate and record this data.

In circulating the questionnaire to the 48 state highway departments, the first question asked was: "Is there a need for an inventory record of aggregate material sources in your state?" Replies were received from 44 departments. Of these, 34 answered in the affirmative and only 7 indicated that in their opinion there was no need for such a reocrd in their state. Some mentioned that while the need for such an inventory was not apparent at the moment, however, if one were available it might prove very useful.

For the departments depending upon local materials an inventory record can be of considerable value. One materials engineer stated that his current practice was to use local materials to the fullest extent commensurate with the economics of construction and maintenance costs and that designs are varied to fit available materials wherever possible:

> After we have information as to the kinds of materials available in the immediate vicinity of a project, the actual design of that project is "tailored" to fit the available materials. In this design, consideration is, of course, given to the proximity of standard aggregates. In the location of material deposits that may be considered in the design, pedological soil maps, geological maps and previous test data are studied. The actual prospecting of the material deposits is done by boring sample holes and sometimes by digging sample pits. Through the years, we have, of course, built up a record of pits in various areas, and these are recorded by counties for convenience in referring to the data at some later time.

A recent article in "Roads and Streets" describes experiments by the North Dakota Highway Department in using a scoria aggregate bituminous wearing surface (8). Because the supply and quality of local road building materials is becoming critical in some areas, this often necessitates the use of borderline materials in some cases and taxes the ingenuity of the highway engineer to obtain satisfactory designs that utilize local materials to the greatest advantage.

Some states replied that material inventories had not only been beneficial to the design engineer in planning new projects but that such information being available to contractors had resulted in lower bid prices on contract work. One testing engineer stated, "There is no other item that expedites designs and promotes more economy than a complete inventory of material sources." Having thus established the need for material inventory records where local materials are utilized, let us now review the status of such inventories as indicated from the survey.

STATUS OF INVENTORY RECORDS

Results of the survey revealed that some type of inventory record of granular materials had been made, was in progress, or was planned by all but a few highway departments. In some instances such records contain data on commercial sources only, while others list information on local materials. In some cases inventories have consisted in keeping up-to-date information on sources as they are located and used on new projects. A few of the inventories represent cooperative endeavors between state geological and highway departments. Some of the inventories were started several years ago; others are of more recent origin. While it is not possible in this paper to give complete information on the status of all inventories reported, a few will be described briefly.

Maine

In 1930, field work was begun on the glacial road materials in Maine. The results of this survey were published in 1934 in two volumes (3). Volume I gives information as to the location, extent and quality of sands and gravel deposits in various parts of the state. Test data are given on 1,721 samples of gravel, 1,267 samples of sand, and 43 samples of rock. Part II contains supplementary maps.

Michigan

The Testing and Research Division of the Michigan State Highway Department has published both gravel pit and binder soil inventories for the purpose of furnishing the contractor, the department and those interested with data on all known pits. It was believed that this information would result in lower construction costs and thereby reflect a savings to the department. All information was assembled in the laboratory. This was then sent to the district materials engineers with instructions for checking and adding additional data.

The first gravel inventory was printed in January, 1930, by the Division of Testing and Research and contained information on about 1,000 pits. The second inventory was published in 1947 and included data on approximately 2,000 pits scattered throughout the state. It is the intent of the department to bring this information up-to-date every 3 to 5 years.

The first binder soil inventory was published in 1943 and contained data on about 1,000 pits.

These inventories contain information on the materials (gravel and clay) as follows: (1) name of pit, (2) location of pit (legal description) and direction data, and (3) test data, which in the case of gravel includes abrasion, percentage of crushed material, amount of soft, nondurable particles and percentage passing the 200-mesh sieve. Gravel pits with test data are shown on road type maps. Information in the binder soil inventory includes such test data as percentage of sand, silt, and clay as well as plasticity index.

These inventories are reported to be of great value to the department and are used extensively by design, construction, and maintenance engineers. Specifications can now be set up taking into consideration what can be produced from the pit. They are used extensively in setting up shoulder borrow for bituminous capping projects over old concrete pavements. The Maintenance Division also uses the inventories for locating suitable bank run gravel for grade lifts and base courses.

Illinois

About 20 years ago the Illinois State Geological Survey, in cooperation with the Department of Public Works and Buildings, Division of Highways, made a survey of the aggregate resources and developed maps for 72 of the 102 counties in the state, showing some of the material possibilities in these counties. In 1941 a bulletin was published listing permanently established commercial plants producing aggregate (2). The plants are listed under two classifications: sand and gravel, crushed stone. Each plant has been given a number which identifies it in the various tables and reference numbers are given to locate it on a state map. Tables in the bulletin give pertinent information such as: (1) size of material produced, (2) plant capacities, and (3) transportation facilities. It is emphasized that although a material plant is listed in the bulletin this does not guarantee that the quality of the material produced is acceptable for all types of construction covered by the standard specifications. The bulletin lists more than 170 plants.

South Dakota

In 1946, the South Dakota Highway Department initiated and adopted a method of maintaining a materials inventory. A tabulation of known sources was started, which includes compilation of pertinent data on a 4- by 8-in. file card. This data includes legal description, owner of land, location, data on quantity of material, amount of stripping, and test results. This information is eventually broken down on a county basis. Each source is assigned a code number which includes a prefix number designating the county followed by a second number representing the pit. Each location in turn is plotted on county maps bound in a series of five books representing the five highway districts. The location of pits in each county is shown by symbol and pit number. Various colors represent the different types of deposits; namely, red is used for coarse aggregates, blue for sand, yellow for clay, and green for filler. These color designations are used on both the maps and on the cards in the file. As new sources are found each is treated in like manner.

Field Procedures. As soon as a project is programmed for construction and the material requirements have been determined, a review of file data is made to ascertain what sources are present in the vicinity of the proposed project. If satisfactory established sources are available, the matter is easily and quickly settled. In many instances, however, it is necessary to make a materials survey of the area in question. A reconnaissance is made by the geologist, who locates prospective sources. The areas so outlined are thereafter tested in detail by power-driven drilling equipment under the direction of the resident engineer to determine the quantity and quality of the materials in the deposits. Logs are kept of each hole as drilled. When completely tested the area is surveyed and samples collected for analysis at the central testing laboratory. The resident engineer prepares the forms (M46R) and submits representative samples of the aggregates. Information relative to each sample is reported on a data sheet attached to each sample bag.

Information on individual pits or quarries is recorded on a pit data sheet (Form M46R). These plats are submitted as soon as possible after the deposits have been tested. Prints are made of the originals, and copies distributed to district and resident engineers. Two copies are retained by the materials section. One is filed in the materials file and the other is filed in the folder covering the basic information on the project for which the material is recommended. The original copy is sent to the plans department where it is used as document to substantiate the use of that particular source of material on the project.

The deposits designated for use on the project are optioned by the highway department. The results of these tests and the plats are available to all bidders. The successful bidder can and usually does use the sources designated on the plans, but if he so elects he may use other deposits than those set up, providing, of course, the material meets standard specifications.

Kentucky

A report of quarries has been prepared by the Kentucky Department of Highways which also reports that one is in progress on other materials, such as gravel, slag, and sand. The report or inventory gives specific information on each quarry in Kentucky as well as a few quarries in the bordering states of Missouri, Illinois, Indiana, Ohio, Tennessee, and Virginia. The reports are arranged alphabetically by counties and include the following information:

1. County.
2. Property owner (when known).
3. Operator (If operative, or last operator, if not).
4. Location (Approximate mileage from nearest town).
5. Date (Last sampled or rechecked).
6. Type of Quarry.
   (a) Open face or mine.
   (b) Commercial, local or not operative.
       (Note: Year around operation is basis for commercial rating and not tonnage.)
   (c) Whether located on railroad or not by words on R. R. or No R. R.
7. Physical Test Results.
   (a) Stripping - Dirt, etc.
   (b) Specific Gravity.
   (c) Soundness - (All uses, 15% or less).
   (d) Wear (1) Passed for all uses - 35% or less* .
       (2) Passed for Base Course and Concrete 40% or less* .
8. Ledge Number and Thickness.
9. Chemical Analysis.
   (a) $CaCO_3$ - Calcium Carbonate.
   (b) $MgCO_3$ - Magnesium Carbonate.
   (c) Insoluble - Silica, etc.
   (d) R_2O_3 - Metal Content.

Note: In reading the log sheet of each quarry look at the sheet as though you were looking at the face of quarry or mine. Start at top and read down.

*Present Specifications.

Virginia

A statewide aggregate survey was begun in February of 1947. The first phase consisted of locating and describing all active state-operated and commercial quarries producing stone, sand, and gravel in the state. Samples were taken from these quarries which were tested for abrasion, gravity, freezing and thawing, and absorption. In addition to this a mineralogical description of the chief minerals were given for the igneous and metamorphic rocks.

In 1948, a complete working plan for the location, sampling, and testing of all potential geologic materials was formulated and the work begun by the district materials engineer. This working plan is as follows:

All potential sites are located by distances from road intersections on the county map and by degrees of latitude and longitude to the nearest minute. The property owner, if available, is also given. The rock is identified and its geological age and formational name is included in the report. In sedimentary rocks the strike and dip is also given. These samples are tested for abrasion, gravity, freezing and thawing, and absorption. Liquid and plastic limits are run on that portion of dust passing the No. 40 sieve. In addition to these tests, petrographic examination of thin sections of each quarry are made to attempt to detect any objectionable minerals which may be present. Photographs of the site are taken and the quantities available are estimated. The overburden is given and any access roads which have to be built are enumerated, whether or not operating space for crusher and storage is available. Mention is also made of the proximity of water which might be used for hydraulic stripping.

This information is made in duplicate on special sheets, one copy of which is retained by the district materials engineer and one of which is sent to the geological section of the testing department.

The location of the site is plotted on a master map kept by the geological section and is also entered on a duplicate map which is retained by the district materials engineer. The county geologic maps are made for each county in the state. Sample designations are numbered using S for stone, G for gravel, and SG for sand and gravel.

The work of the survey has been greatly expedited by the use of part-time employees during the summer months. These employees are third and fourth year geological students who are selected from the various universities and colleges. These men are given a brief training course in Richmond and are sent out to work under the supervision of the district materials engineer. To date approximately 95 percent of the state has been covered by preliminary surveying and an excess of 1,000 samples of stone, sand and gravel, and sand have been tested for general construction use. It is realized that on such a survey no complete record will be possible as new sites will be located from time to time as more are discovered.

It is felt that the compilation of this knowledge will reflect in serving both the contractor and the state in its construction program.

It was originally planned to write a county by county report on the geologic construction materials within a completed county. However, it was found that after writing three such reports a great deal of the geologic description regarding the rock formations was being duplicated. Hence, this plan has been abandoned in favor of writing a report on the district as a whole. The three counties on which reports have been made are Alleghany, Albemarle, and Highland. The preparation of the first district report is now underway.

Wyoming

A material survey was initiated by the Wyoming Highway Department in the spring of 1951. A statewide inventory of known material deposits is being compiled on 30-min. quadrangle tracings at a scale of ½ in. equals 1 mi. These maps are approximately 17 by 20 in., with a binding edge at the left so that prints can be assembled into folios. Included with each map are one or more supplemental sheets of the same size for the tabulation of representative tests from each deposit. The legend shows the following information: (1) evidence of construction materials; (2) pit or quarry which has been investigated and found to be unsatisfactory (due usually to limited vertical depth); (3) prospective pit or quarry; (4) operated pit or quarry; (5) exhausted pit or quarry. A letter-numeral designation is shown at each pit or quarry. The letter indicates if the deposit is sand, gravel, gravel and boulders, conglomerate, sandstone, etc. The numeral is cross-referenced to the sample number on the representative test analysis of overburden, and granular materials are tabulated. The maps are being compiled on a county basis. Available data is first compiled from office records, the maps are then compiled and sent to the field for the project and construction engineers to review, add any other information that they may have, and submit samples where necessary. All new pit locations are being submitted on a standard form routed through the laboratory to insure its including all the required data and its being entered on the materials map.

This past summer the chief materials engineer reported that only four quadrangles including Niobrana County had been submitted for field checking and that work is being done on the 35 quadrangles included in the two largest counties, Frenant and Sweetwater.

CONCLUSION

The survey revealed that many state highway departments have prepared or are in the process of making inventory records of aggregate material sources. It is indicated that such records have been extremely useful to design and construction engineers and that they are an aid in planning construction operations and that their use has reflected lower construction costs. If local materials are to be utilized to the greatest advantage, then their extent and characteristics must first be determined. As suitable road-building materials become more scarce, the preparation of inventory records becomes an increasingly important item to the highway engineer. It is hoped that this brief summary of typical examples will be helpful to those who are contemplating the compilation of such a record. It is suggested that available geological and soil survey data and reports be reviewed carefully by those compiling information on location of aggregate sources.

In conclusion, the writer wishes to acknowledge and to express his sincere appreciation to the individuals from the various highway departments who gave of their time in supplying information on the status of material inventories in their states.

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