HIGHWAY RESEARCH BOARD

Bulletin No. 13

The Appraisal of Terrain Conditions for Highway Engineering Purposes

1948

PRESENTED AT THE
TWENTY-SEVENTH ANNUAL MEETING

PUBLICATION OFFICES

2101 Constitution Avenue   Washington 25, D. C.

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HIGHWAY RESEARCH BOARD
DIVISION OF ENGINEERING AND INDUSTRIAL RESEARCH
NATIONAL RESEARCH COUNCIL

Washington 25, D.C. November, 1948

DEPARTMENT OF SOILS

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"SURVEYING AND CLASSIFYING SOILS IN PLACE FOR ENGINEERING PURPOSES"

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REVIEW OF THE PROBLEM

Two basic methods of classification are used for making engineering soil surveys. One method depends upon the classification of various types of soils into groups on the basis of their physical properties, and indicates the engineering use of the soils in a disturbed state. This method is not a terrain classification since it does not consider the characteristics of soils associated with their natural environment, because soil characteristics related to the movement of soil moisture and ground water within the soil profile are not used as a part of the classification. The method of preparing the soil survey by this method emphasizes laboratory tests, and considerable sampling and testing of representative soil samples are required to prepare the detailed soil survey. The soil boundaries for the various soil groups are estimated by visual inspection of the disturbed soil during the field survey of the road location.

The other basic method has been developed on the principle that soils can be classified in place by means of soil profile characteristics; that soils having similar profiles require similar engineering treatment, and soils with similar profiles occur in similar types of landscape. This method of grouping soils has been used by Michigan and others to correlate pavement behavior, methods of handling soils during construction operations, and the general physical properties of soils. Michigan (*1*)[1], Indiana (*2*), and Missouri (*3*) have prepared soil manuals showing the range in soil profile characteristics for the various soils occurring in these states. This information has been of considerable value for the identification and classification of soils from field observations.

The mapping unit for this system of in-place soil classification is the medium whereby soil engineering information can be transferred quickly from one project to another with only a minimum of laboratory soil testing. It has been found that each mapping unit developed by this system of classification expresses a characteristic range in parent material, relief, vegetation, and climate, and that each of these mapping units reflects a characteristic set of terrain conditions which can be recognized readily by field observations.

During the past several years there have been several methods of appraising terrain conditions developed to meet the requirements of military engineers in the theater of war operations. These methods appear to be based to a large extent upon deductive reasoning in which a limited amount of soil information from laboratory tests, and the interpretation of geologic, topographic, and agronomic soil maps, and aerial photographs were used to estimate the engineering characteristics of terrain conditions.

One of these methods (*4*) utilizes significant airphoto soil patterns to establish the mapping units used to distinguish between soils requiring different engineering treatment. The airphotos are interpreted by trained technicians by using pedologic and geologic evidence and limited test data to evaluate the en-

1 Numbers in parentheses refer to references in bibliography.

gineering significance of soils developed upon the various slopes and rocks comprising the landscape. The landscape with its various landforms is revealed by stereoscopic projections of oriented paired airphotos of the area to be studied. Whenever soil design data have been obtained for the various distinctive photographic soil patterns for a particular area, a fairly accurate reconnaissance engineering soil map can be prepared.

Another method (5), very similar in many respects to the previous method, was developed by geologists in which considerably more emphasis has been placed upon the basic geology of the parent material to prepare structural maps indicating information concerning probable water supply for military operations in forward areas. In connection with this type of work, the engineering characteristics of the overburden (soil) derived from the parent rock by weathering has been estimated for construction purposes. Airphotos are interpreted to determine the boundaries of various parent materials, and estimates of engineering properties of the soils are based upon the study of geologic and topographic maps. The topographic maps probably were prepared in many cases from airphotos using photogrammetric methods to translate the relief into contour maps. It is likely that the airphoto interpretation in this method of terrain appraisal is based to some extent upon the consideration of the soil-forming processes.

The military forces prepared a considerable number of general reconnaissance maps of forward areas using this method of terrain classification, and it has been observed that a good correlation between estimated soil conditions and observed soil conditions were found when the forward areas were occupied. The Fort Knox Folio (6), prepared by the Geological Survey, is an excellent example of the type of engineering information assembled for military terrain appraisal. Attention is called to the close similarity of the geologic, the soil, and the trafficability maps for this area.

A recent survey of state soil practices indicates that 28 states require a detailed soil survey for the higher type of road construction. They have found that this type of preliminary engineering information is essential for the design and construction of these highways. Many of the states require similar soil surveys for their lower class of highways. It has been a forward step in the practical application of soil engineering to the systematic planning of highway programs.

It is reasonable to expect that when the highway engineer has a better understanding of these methods of making terrain appraisals of soil conditions on an interregional basis, a greater use will be made of these engineering soil maps by those responsible for the design and construction of large highway programs.

The engineering soil map will serve as a vital link between laboratory and field research, and a considerable part of soil research will automatically shift to the study of pavement design by observations of pavement behavior under actual traffic and climatic conditions for the various types of subgrades defined in terms of the map units used to classify the soils in place. A better understanding between the divisions of design, construction, and tests, for many of the current highway problems, can be established on the basis of information revealed by the correlation of these problems with the map units developed to classify terrain conditions. Certain states (Michigan, North Carolina, Missouri, etc.) have correlated much engineering information with the map units used for the preparation of county agricultural soil maps, and use these agricultural maps as engineering soil maps for planning and assisting in their soil survey work.

The intelligent use of engineering soil maps will reduce the time required for the preparation of detailed soil surveys. It should be possible to make available a considerable amount of soil engineering knowledge for future highway planning by preparing engineering maps on a state-wide basis. Such maps would be excellent for training the younger engineers. A field trip and an occasional soil or rock sample may be all that is required to verify the accuracy of these generalized maps for planning and instruction purposes.

The use of these types of maps would extend the field of practical application of soil engineering to secondary road planning, as it would permit the county and township engineer with limited road funds to use generalized soil engineering data for the design and construction of roads in the secondary network. This field has been neglected and its roads have perhaps the most critical type of pavements to design from the standpoint of foundation soils. Pavement thickness, by necessity, must be held to a minimum, local materials must be utilized to their best advantage, and a knowledge of the behavior of soils used for subgrades will always be essential for the planning of the secondary road.

Several states - Indiana, New Jersey, Maine, and New York - have started to prepare engineering soil and drainage maps on a state-wide basis. They plan to correlate general engineering design data and pavement behavior with the mapping units so that previous experience and design recommendations can be made available for use on future construction and maintenance road programs.

There is a need for the standardization of map units for classification of terrain conditions related to highway engineering problems before too many of these engineering soil maps are prepared by the states. The various methods of in-place classification of soils and environmental conditions discussed are subject to a wide range in map-unit specifications, depending upon the viewpoint and limitations of the mapmaker. The available funds to do the work, the time permitted for correlation of terrain conditions and engineering problems, the type of terrain and the reliability of geologic and agronomic information, the interpretive skill and experience of the engineer making the terrain appraisal, and the scale of the proposed engineering map are some of the factors that must be considered in setting up the specifications of map units.

Offsetting factors will be the ability of the map reader to estimate the effect of these factors for a more detailed appraisal of terrain conditions (lower levels of generalization) with respect to soils, rocks, and ground water or soil moisture conditions affecting the design and construction practices.

When these factors cannot be evaluated from the study of an engineering soil map, they must be determined by means of the detailed soil survey during the preliminary location survey.

One of the functions of this Committee on Soil Surveying and Classifying of Soils-in-Place is to assist in the standardization of methods for the preparation of engineering soil maps. This Committee would like to hear from any state starting research work on soil maps so that they can exchange information on the latest practices developed for this type of engineering work.

The location and depth of bedrock and evaluation of subsurface and ground water conditions, especially in areas of heavy grading operations or in connection with large highway structures, usually require a detailed site study, since this type of terrain appraisal is beyond the scope of a general engineering soil map.

Subsurface explorations by normal soil survey methods (auger borings) are usually limited to about 30 ft. in depth below the natural ground surface. In areas of disintegrated bedrock or where nests of boulders occur, other methods of exploration are more practical (*7, 8*). There is an increasing use being made of geophysical methods (seismic or resistivity) for this type of soil survey work to locate positions for exploratory test pits or deep borings by churn or rotary drills for the purpose of obtaining the maximum amount of engineering information on subsurface conditions.

The present highway road network in the United States contains about 3,000,000 mi. of roads. They have been built and maintained over a complex terrain involving all types of location and design problems. The wide range in climate and parent materials have produced many different soils and types of relief.

These roads carry a variety of traffic, and the regional study of pavement design and subgrade performance of these roads can be made to furnish practical design and construction information. It is believed that the development of engineering soil and drainage maps on a state, regional, or interregional basis is a practical method of correlating this information so that quick appraisals of terrain conditions can be made for the systematic planning of future road progress.

The following group of papers indicates some of the methods developed for making appraisals of terrain conditions and indicates how such information can be obtained quickly and at a reasonable cost.

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TOPOGRAPIC MAPPING AND THE HIGHWAY PROGRAM

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The earliest surveys made in this country, long before the US Geological Survey was organized, were conducted by special exploratory expeditions sent out by the early settlers and later by the War Department at the request of Congress to study and find transportation routes for the settlement of the territories lying beyond the borders of the developed lands along the Atlantic Coast. The first expeditions produced only very sketchy maps of the country, but they were invaluable as reconnaissance maps for the blazing of trails into the rich and undeveloped interior regions. As the population increased and the need for more agricultural lands and new territories developed, more surveys and mapping expeditions were organized. The location of transportation routes was always one of the primary purposes of these expeditions. Most of you are familiar with the expeditions of Lewis and Clark, followed by those of Wheeler, Hayden, King, and Powell, which resulted in small scale reconnaissance maps of vast areas of the then unknown regions of the United States.

The Geological Survey was organized in 1879 with the primary objective of making geologic investigations of the resources of the country. A prime necessity in such work was the preparation of topographic base maps on which to plot the result of the geologic work. The first of these topographic maps to be produced were reconnaissance type topographic maps, usually at a scale of four miles to the inch, and a contour interval of 250 feet. The scale of 1:125,000, or two miles to the inch with a 100-foot contour interval was also widely used. These maps were a great aid in the development of the West. As the region became more populated, the need for larger scale maps was apparent, and about 1900 the scale of 1:62,500 or one mile per inch was adopted as the standard scale for a topographic map of the United States. At the present time, the highly developed industrial, agricultural, and urban areas are mapped for publication at 1:24,000 or 2,000 feet per inch.

The mapping operations of the Geological Survey have proceeded since the earliest days in a systematic program of completing the coverage of the entire United States. Funds to carry on an adequate program have never been made available and our mapping needs have been consistently far in excess of our ability to produce adequate topographic maps.

Figure 1 shows the status of topographic mapping in the United States. This index shows areas covered by published topographic maps of the Geological Survey and other agencies. Some additional areas have been covered by very old reconnaissance surveys which are now considered entirely inadequate for present day use. Inquiries regarding the availability of topographic maps may be directed to the map information office of the U. S. Geologic Survey in Washington, D. C.

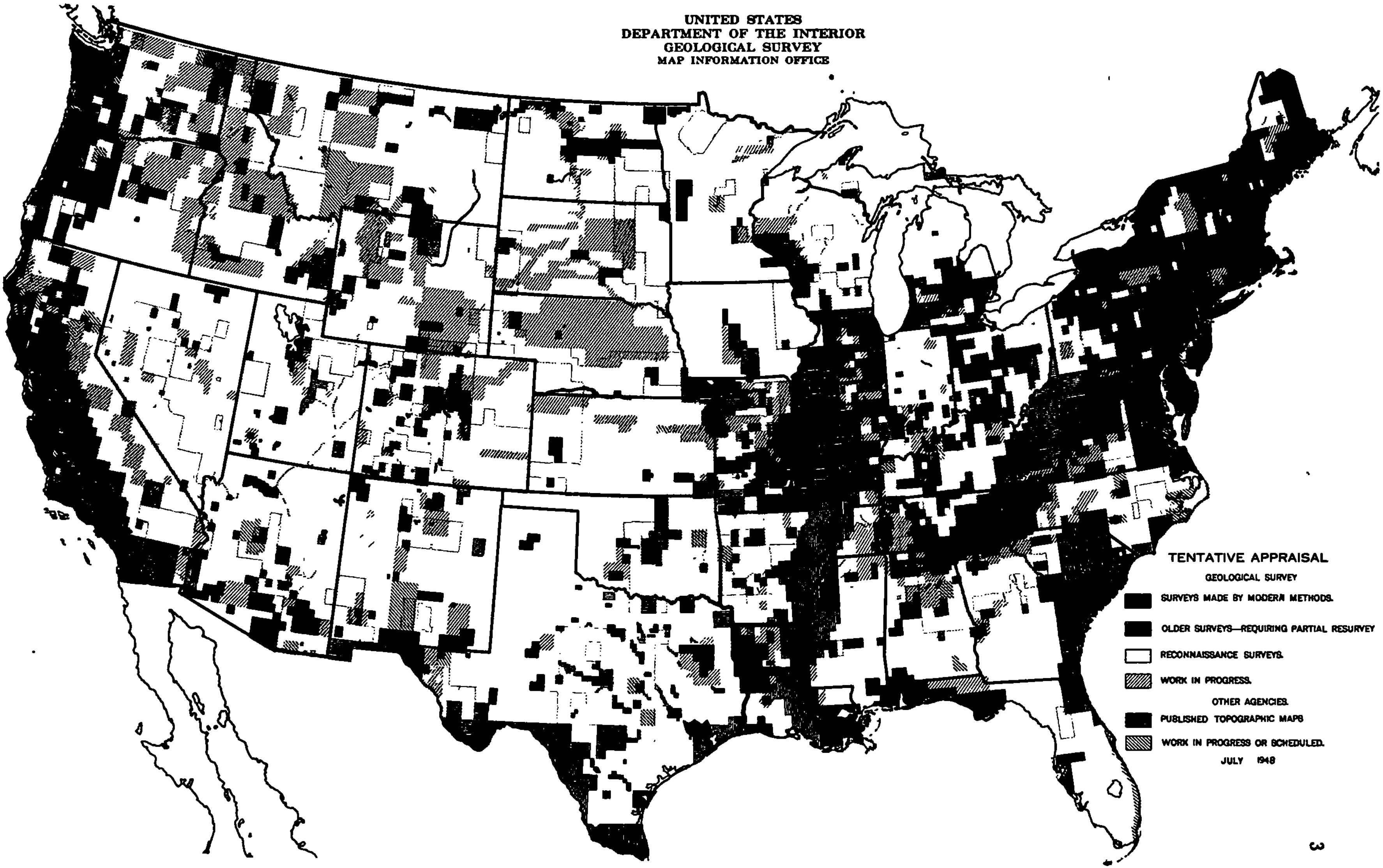
During the first World War, the need for maps aroused considerable interest, and the Temple Act was passed in 1923 authorizing the completion of the topographic mapping of the United States within a 20 year period. Funds to implement this legislation, however, were never appropriated.

During the recent World War, the national security was threatened and our military forces used all possible means to secure topographic map coverage of the strategic areas. This resulted in considerable map coverage, much of which unfortunately was substandard and faulty due to the extreme speed with which the work had to be performed and the inexperience of many of the operators.

Within the past 10 years, the use of aerial photography in topographic mapping has been perfected to a point whereby adopted standards of accuracy can be more economically maintained and at the same time maps can be produced on a mass production basis. To fit in with this development, the Topographic Branch of the Geological Survey has been reorganized so as to take full advantage of the possibilities afforded for expanding our operations in accordance with these newest improvements in map making. Until the development of the multiplex and other photogrammetric processes to their present stage of perfection, the preparation of topographic maps was performed by a very select group of highly trained topographers who were thoroughly familiar with the various operations required in the preparation of a standard topographic map. These men were assigned specific areas in which they performed all the various functions and operations required from supplementary control surveys, including triangulation and precise leveling, through the actual mapping, contouring, field checking, and final drafting stages. Under our new methods of mapping, the normal time schedule for a complete mapping operation is three years. The first year is devoted largely to the planning of the operations, securing of aerial photography, and similar preliminary steps, and the initiation of control surveys. The second year the actual compilation of the map is accomplished to the stages of final drafting; and the third year is required for final editing and publication of the manuscript.

Most of the operations performed by the Topographic Branch in the preparation of topographic maps are of such a nature that they can supply much valuable basic information to assist highway engineers in their various problems of planning transportation routes, and designing major highway systems as well as the actual location of highways. In this short paper, it is impossible to do more than mention a few of these items. I wish to call your attention, however, to some of the various classes of information and surveys which the Geological Survey has available for the benefit of those who are charged with the responsibilities of maintaining and improving highway transportation systems. A brief enumeration of some of these services includes the following:

1. In cooperation with the US Coast and Geodetic Survey which establishes the primary horizontal and vertical control nets, the Geological Survey established third and fourth order control required as a necessary base for the preparation of topographic maps. In



Status Of Topographic Mapping In The United States carrying out this work, triangulation stations are established for which the true geodetic position is determined. Level lines are run, and permanent bench marks established with correct elevations adjusted to the sea level datum. All of this information is recorded in such form that it is readily available to the highway engineers, and to federal and state agencies as well as private consulting engineers and private contractors.

2. Aerial photography is used as one of the tools in preparing the modern topographic map. Whereever possible we use existing photographic coverage. To assist the Geological Survey in determining the existence of such aerial photography, a Map Information Office is maintained, one of whose functions is to obtain up-to-date information on the existence of all aerial photography in the United States by all federal agencies as well as state agencies and private concerns, when available. Where new photography is required, this is taken to specifications best suited for the mapping operations. Similar information is also maintained on aerial mosaics which have been compiled within the United States.

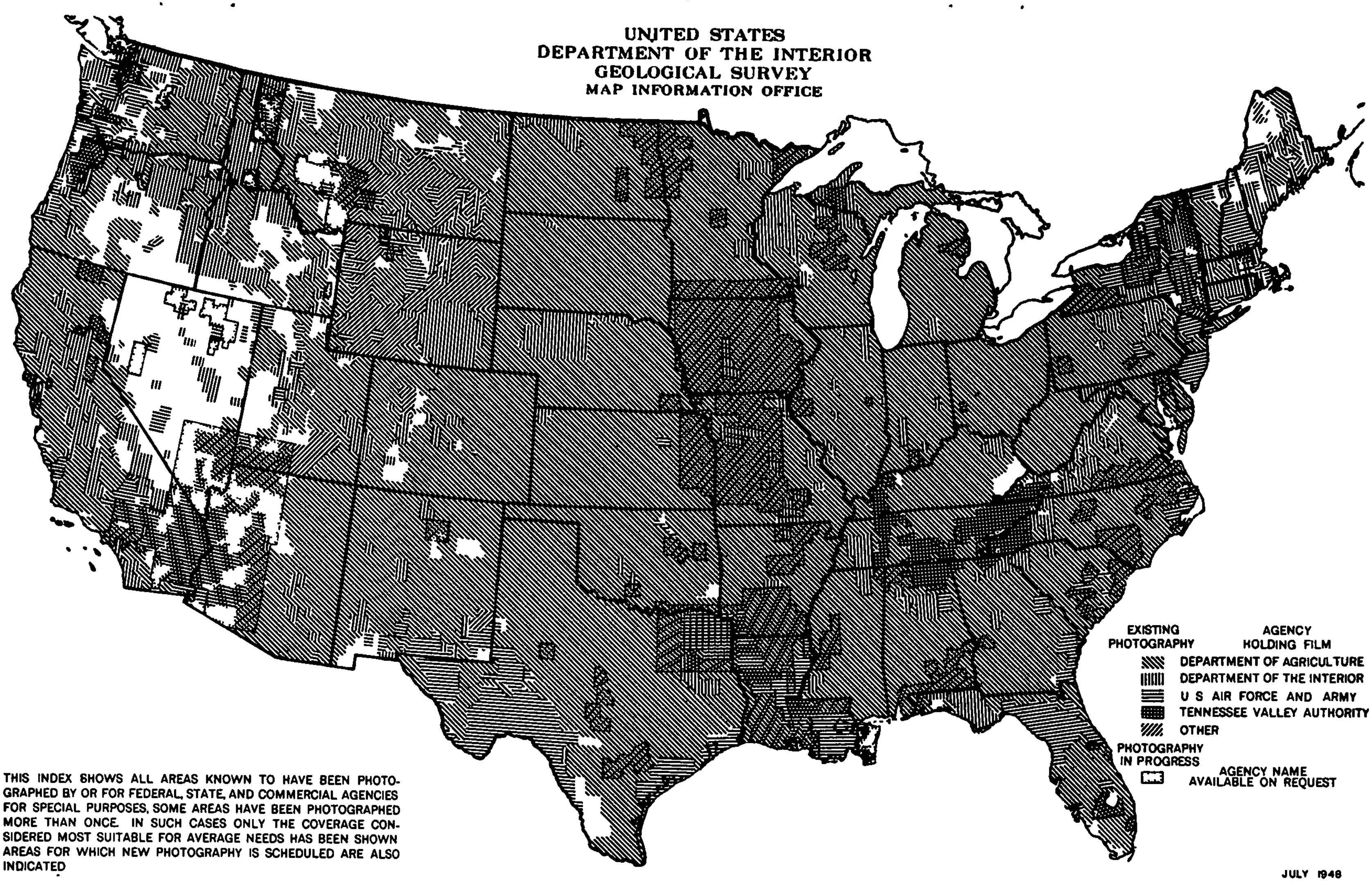
Figure 2 is a map of the United States showing the status of aerial photography.

3. In the preparation of topographic maps by modern photogrammetric methods, the compilation scale is much larger than the final publication scale. For example, Figure 3 is a small section of a print of the map manuscript near New Milford, Connecticut. The scale of Figure 3 is the same as the scale to which it was originally plotted, 1:5000. It will ultimately be published at 1:24000. In mountainous terrain the original plotting scale is generally smaller; for example, Figure 4 is a section of the map manuscript for Craigsville, Virginia, plotted at 1:15840 for publication at 1:62500. The manuscript is usually available in 12 to 18 months after the initiation of a project, and in some respects, it shows more detail than the final published map.

Some highway departments are taking advantage of this service and are using these manuscripts in making highway reconnaissance surveys of alternate routes, and in some cases, preliminary location surveys. We have recently entered into a cooperative agreement with the State of North Carolina whereby they will use copies of our map manuscript in studying problems involving the redesign of the national system of interstate highways traversing the state.

Cooperative mapping projects are under way at the present time in 21 states, and this constitutes a major source of funds for our topographic surveys. Several of these mapping agreements are directly with State highway departments. In most of the other states the state geologist is the designated cooperator with strong support from the highway department. By these cooperative agreements, our mapping operations can be coordinated and timed to meet the specific highway requirements for topographic maps.

I wish to call your particular attention to an excellent article entitles "Aerial Surveys in Highway Location," written by Mr. William T. Pryor of the Public Roads Administration, which appeared in the December, 1946 issue of *Photogrammetric Engineering*. This article is an excellent description and analysis of various methods of using aerial photographs and topographic maps to assist in the solution of highway problems. The plans for the eastern extension of the Pennslyvania Turnpike were prepared from aerial surveys made in this way.



STATUS OF AERIAL PHOTOGRAPHY IN THE UNITED STATES

Figure 2

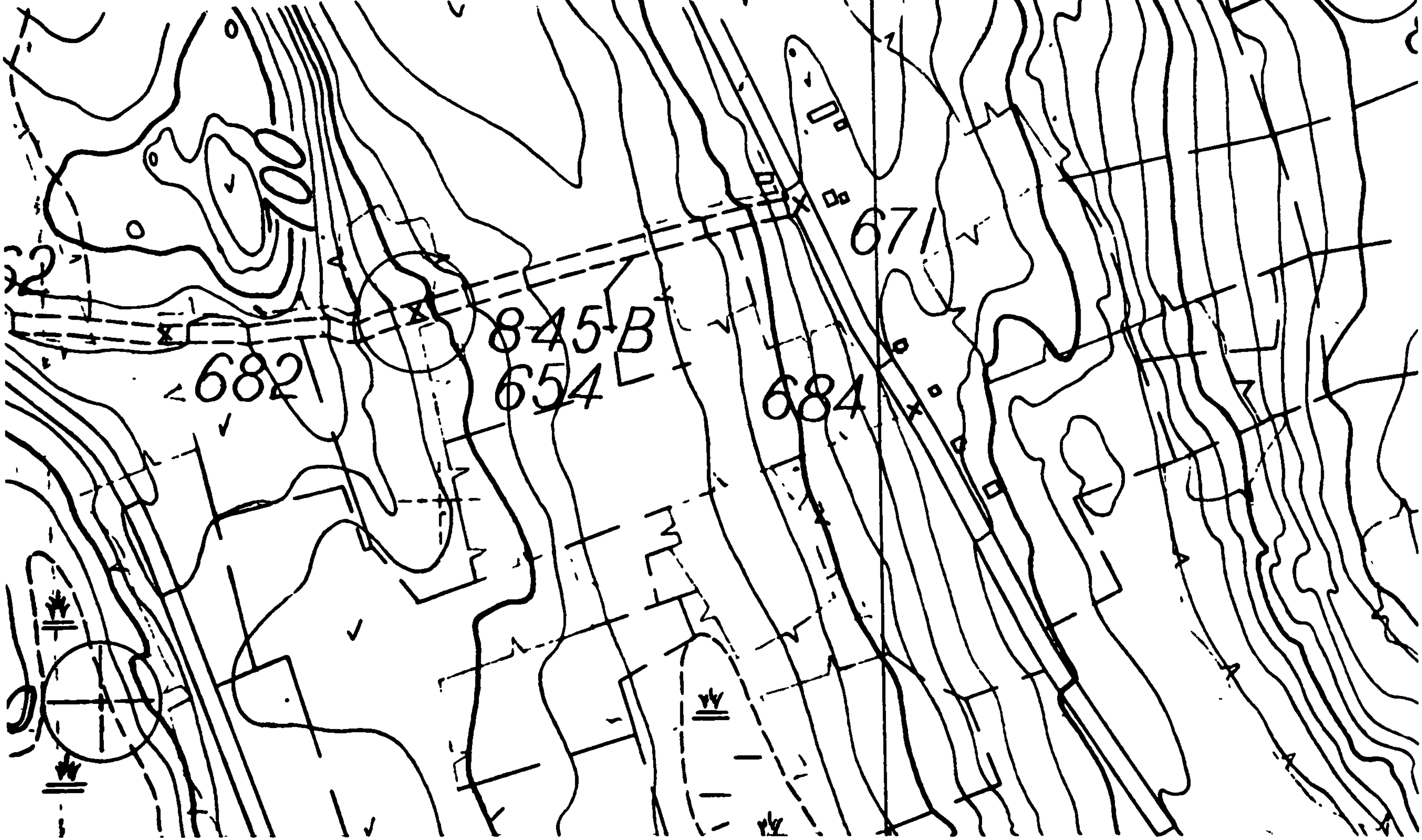


Figure 3. Full Size Section of Map Manuscript - New Milford, Conn.
Plotted Scale 1:5000 for Publication at 1:24000- Contour Interval, 10 ft.

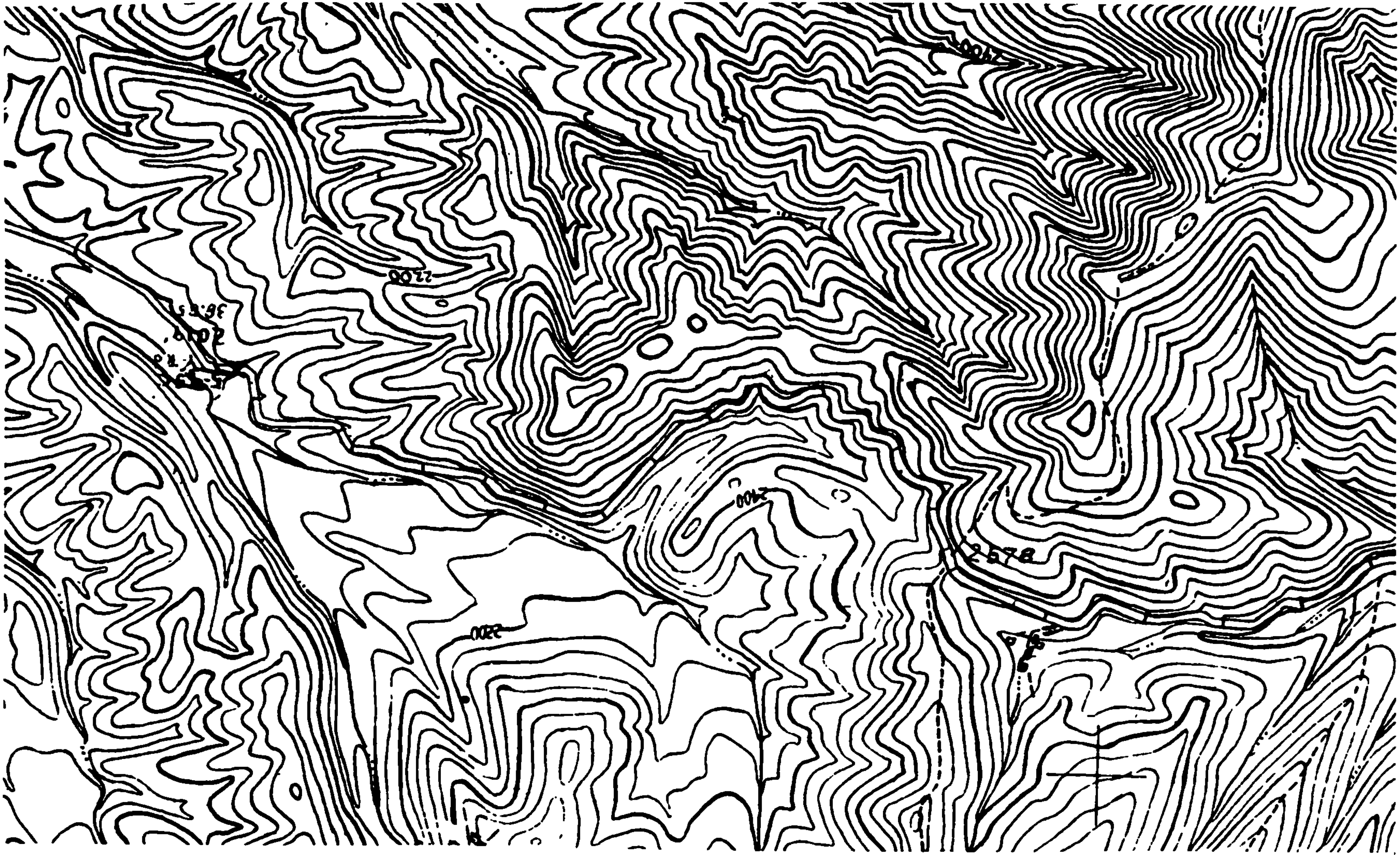


Figure 4. Full Size Section of Map Manuscript- Craigsville, Va. No. 1
Plotted Scale 1:15840 for Publication at 1:62500 - Contour Interval 40 ft.

larly anxious to conduct its operation so as to be of maximum service to the various other State and federal agencies. We have proposed a 20-yr. mapping program to complete the topographic mapping of the entire United States. The accomplishment of this goal will require the increasing of our operations to three times the present magnitude. The federal mapping program is strongly supported by many highway people, particularly in the states of California, Missouri, Illinois, Wisconsin, Michigan, and North Carolina. In many states topographic surveys are a dominant factor in highway planning, location, and design. As the location of highways becomes more difficult and costly, adequate topographic maps are more essential to aid the highway engineer in selecting the most economical and feasible route. Many state highway departments and the Public Roads Administration are familiar with our services and are making full use of this information. We heartily invite inquiries and suggestions from any of you as to how our work can be made more effective to assist you in the important problem of supplying more adequate transportation for the ever increasing demand of the Nation.

Note: The Geological Survey, will furnish upon request any of the following published maps with descriptive text describing map information of particular interest to highway engineers and map users.

1. United States Map scale 1:5,000,000, (28" x 42"), showing Status of Topography Mapping. All Status of Topographic Mapping. All mapping by the U.S. Geological Survey is shown in red and that by agencies in green with an appraisal as to the adequacy of these maps for present requirements.

2. United States Map, scale 1:5,000,000, (28" x 42"), showing the Status of Aerial Photography, which is an inventory of areas that have been photographed by the various federal agencies.

3. United States Map, scale 1:5,000,000, (28" x 42"), showing the Status of Aerial Mosaics or Photo-Maps which is an index of mosaics of areas of general interest and indicating the scale of the mosaics, the date of the photography and the agency holding the mosaic negatives. Any of these maps may be obtained by making a request to the Map Information Office of the United States Geological Survey, Washington 25, D.C.

THE ENGINEERING SIGNIFICANCE OF LANDFORMS

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SYNOPSIS

The design, construction, and maintenance of highways are influenced to a large degree by the land unit or land form with which it is locally associated. Primarily, land form means the form of the land. While this is important in identifying a land form, it is more important to know that specific solid rock and moisture conditions exist in that land form. Therefore, a given land form possesses a distinctive type of relief, the texture of the soil varies in a prescribed way from a "normal" for that land form; the ground water and soil moisture follow typical trends.

Land forms are of significance in engineering because they influence the quality and type of grading, pre-determine the drainage requirements and fix the soil or rock conditions. They have added significance because there are an infinite number of duplicates of each type. Consequently, when the best practice is established for a given land form, those procedures can be generally applied to other similar units.

Such a process permits a high degree of standardization. At the same time it confines that standardization to permissible limitations not always recognized in the blanket application of standard methods. Using this procedure, investigational work is minimized and the occurrence of "unforeseen" events is reduced.

In the training of personnel, the land form gives them a tangible physical form to visualize. Since we learn by association, this helps by taking a soil out of the abstract or detached condition and definitely relates it to topography and moisture conditions. In small organizations where testing equipment and skill cannot be financially justified, design can be a matter of relating existing road conditions to new road requirements on similar land forms.

In the discussion of various land forms, emphasis is placed on the physical characteristics of the materials that compose them, and the inter-relationship of the relief, soil, rock and ground water characteristics.

In engineering practice, it is desirable to consider small units such as individual hills, as land forms. If, then, there is a series of hills composed of the same material, they represent a repetition of the same land form - a repetition of the same conditions.

Generally, each of these forms has some prominent characteristic that requires special consideration by the engineer. Among these to be discussed are the landslide tendencies of the basalt, clay, and clay shale land forms; special considerations in loessial areas; unusual soil conditions in dry areas, and the special problems found in the Arctic.

Aerial and ground photographs have been used to illustrate individual forms as well as to identify the variations that occur within each unit area.

The object of a soil survey is to provide useful information on ground conditions so that engineering structures can be designed economically. In the category of useful information is to be found soil textural descriptions, indications of plasticity, elasticity, shrinkage, and other physical properties of the soil and its bearing capacity. In addition to the soil itself, there are considerations of soil moisture and ground water conditions and the location and type testing of these samples, and the plotting of profile information can not be justified economically. On heavily travelled roads where hundreds of thousands of dollars are expended for each mile, considerable sums can be allotted for the detailed work that may be necessary. In contrast, thousands of miles of road have and will be built without the benefit of soil information. Where these roads have failed repeatedly, a soil survey of some order would normally have antici-

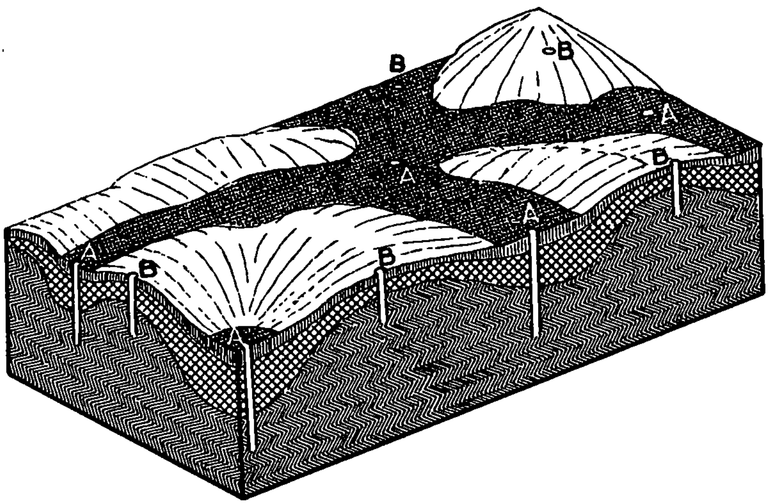


Figure 1

of bedrock when it is present. The depth to which the survey extends depends upon the type of structure involved and the depth of the excavation with reference to the ground surface.

The operation of soil surveying is an expensive one; when combined with the cost of testing the material sampled, the amount often becomes prohibitive. This cost is a function of the number of samples obtained and tested; therefore, each sample must be representative as well as significant. On the majority of highway projects, detailed station-to-station sampling, pated and corrected or compensated for the unsatisfactory condition. At the other extreme, a soil survey may have indicated an equally satisfactory and a more economical design.

The basis of making soil surveys economical lies in the judicious selection of sampling locations. The samples obtained from such locations should represent an area of soil having some considerable depth. Figure 1 illustrates the principle of soil-area surveying in which a) one sample location is the key to a soil area, and b) soil areas recur, eliminating the need for additional samples in similar soil areas. This land form subdivides, on a pedological basis, into two recurring soil areas. A representative location permits the soil to be classified in three dimensions, in area, and in depth. Sampling at all "A" locations would produce the same types of soil material at corresponding depths. Sampling at locations "B" differ from the "A" but are similar within the "B" group. Without this concept the samples from a given location have little significance beyond the hole from which they were obtained.

Where it is applicable, the principle of recurring soil areas is directly derived from soil science (pedology). That principle can be stated as: similar soils are developed on similar slopes (positions) under the action of weathering of similar materials. This is best illustrated by example: where limestones occur, the action of weathering produces a reddish silty clay soil. Where the slopes are the same, and the climate not greatly at variance, the depth and nature of the soil mantle are similar regardless of geographic location. Evidence of this has been presented elsewhere (*10*, (*2*)[1] This concept forms the basis of the "Michigan" method where a large amount of design detail has been related to specific soil occurences (*3*).

It was implied previously that the pedological methods are not always applicable to highway engineering. Such instances may occur particularly in the semi-arid areas where weathering influences are minimized and soil profiles are weakly developed. Attention is directed to the fact the principles of pedology apply, but that under those circumstances soil changes mapped on a pedological basis may often be too refined for utilization by engineers.

It is not the purpose of this paper to propose a specific method to be used in the execution of surveys. The intent is to direct attention to the land form as a unit common to all regions and climates. A land form is a unit of land having a definite form. The form of a land unit is controlled by its originating process, subsequent earth movement, and the weather resistance of the materials that compose it. For example, a volcano is a land form. It is a unit having a definite shape and that shape is caused by the repeated process of molten lava welling up through a vent, flowing out, and cooling to form a cone. In this instance, the origin is unique to this one land form and therefore there are no similar land forms having another origin.

The group of land forms that comprise the sedimentary rock group (sandstone, limestone, and shale) have the same origin, and therefore the same initial form - level surface and horizontal beds. In spite of this original similarity the resistance of these materials to weathering is so varied that they readily assume separate and distinctly individual forms. Figure 2 shows two adjacent, unlike land forms. Within the valley area the numerous low hills comprise a group of morainic (glacial) land forms. The particular road problems associated with this form are repeated in each cut. The massive hills rising above the moraine are composed of hard shale. Rock cuts and seepage are considerations in this land form. In those regions where climate has relatively little effect on soils the land form may suffice as a unit in the highest (most detailed) order of surveys. In the regions of higher rainfall and/or

[1] Figures in parentheses refer to the bibliography at the end of the paper.

greater weathering, the pedologic soil series may be an acceptable unit. Under those circumstances a land form may have two or three or more soil-areas possessing characteristics sufficiently different to warrant separate engineering consideration.

(Photo: Robinson)

Figure 2. An Example of Two Adjacent Unlike Land Forms.

Likewise, it is not an objective to advance a particular means of achieving the survey. All methods of executing the soil survey are based upon the indispensible field sampling. Depending upon the quality and detail required, the nature of the area, type of personnel available and other requisites, this basic type may be expedited by the use of county soil survey maps (USDA Bureau of Plant Industry), topographic maps, and aerial photographs. The degree to which these can supplement detailed sampling and testing depends upon circumstances; it suffices to point out that a growing number of organizations are able to produce soil-design recommendations at a reasonable cost by utilizing these supplementary methods.

At the present time the Highway Research Board Committee on The Sampling of Subgrade and Foundation Soils (F. R. Olmstead, Chairman) has secured an up-to-date compilation and evaluation of soil survey maps through the cooperation of the Soil Survey Division (USDA). The US Geological Survey has recently published index maps showing the status of topographic mapping and of aerial photographic coverage.

The soil survey listing shows that in some states mapping has been completed to an extent that their use would permit the adoption of the pedologic method as a basis of gathering and applying soil information.

The following quotation indicates the topographic mapping situation, "Barely half of the United States is topographically mapped in some manner and less than one-quarter of the country is covered by maps of sufficient detail to meet present day engineering requirements." (4). In contrast, more than eighty percent of the country has been photographed. Those arras not now covered are generally the mountainous and desert areas.

Land forms are perfectly recorded on a low contour interval map and in aerial photographs; they are indirectly shown on soil maps. The land form as a unit is the common denominator of civil engineering construction; in the pedologic type of soil mapping the land form is synonomous with a parent material area, a catena area, or a soil-association area. In geologic mapping it becomes the smallest land unit that consistently receives the attention of the geologist. It is important to engineers because it is more than a basis of soil surveying; it is also the controlling factor in drainage requirements and excavation quantities. It specifies the type of material to be excavated and otherwise includes such characteristics as susceptibility to (land) sliding.

The land forms discussed are generally subdivisions of the land forms acceptable in geomorphology. The broad and general classification of land forms is not often sufficiently specific for the detailed treatment of engineering projects; therefore, when the geologist stops with the third (lowest) order land forms (valleys, ridges, basins, etc.) an engineer must continue to subdivide these into sub-forms of a suggested fourth or fifth order. The need for this may be illustrated by visualizing two contour maps of the same area; one map having a 50-ft. contour interval may present a general picture of the area but details necessary to engineers are shown only on the map having a 5-ft. contour interval. Where sub-order land forms are considered, more than topographic form is involved, for within a given land form type the mass of soil and/or rock and ground water conditions will vary to some extent and these are reflected in variations in soil color and vegetative cover. (5).

LAND FORMS

The earth's features may be divided into land forms so that each form presents separate and distinct soil characteristics, topography, rock materials, and ground water conditions. The recurrence of a land form, regardless of location, implies a recurrence of the basic characteristics of that land form.

The bedrock land forms follow the conventional delineation with several notable exceptions: granites are ultimately subdivided into low and high quartz granites; soluble limestones are separated from the dolomites and young coraline limestones; shales into the clay and sandy types; sandstones into hard-massive and soft. Glacial drift is subdivided into moraines, till plains, outwash plains, kames, eskers, drumlins, valley trains, lake beds, and peat bogs; aeolian materials into sand dunes and loess. Water-laid materials also include flood plains, terraces, alluvial fans and costal plains as well as those already assigned to other categories.

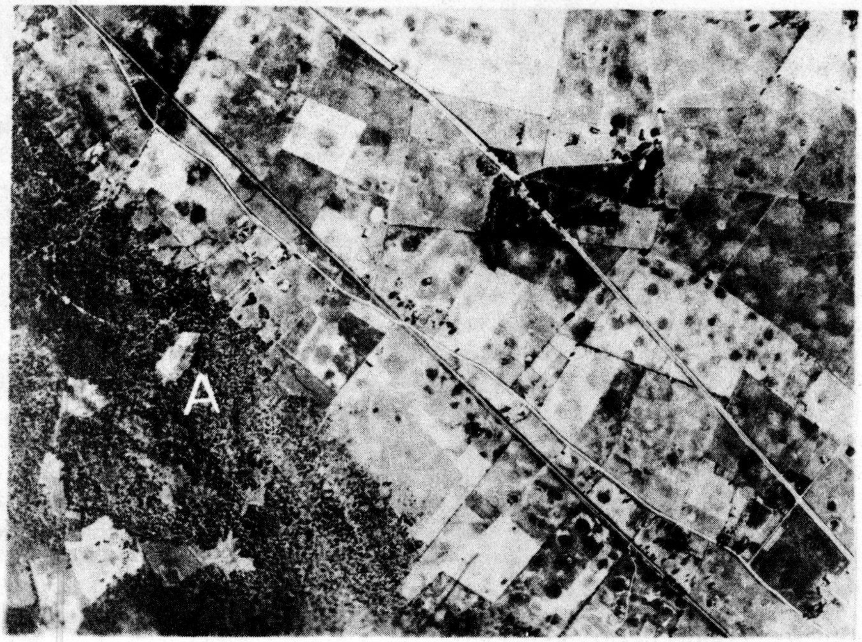
While several of the forms are usually recognized as geological units, each has been classified primarily upon its physical characteristics, especially those that are closely related to engineering.

The following examples have been selected to illustrate a variety of land forms and to point out the effect of extreme climatic conditions in the arid and arctic regions.

SOLUBLE LIMESTONES

The wide distribution of limestone on the surface of the earth, and the information existing regarding the soil material weathered from these rocks, are considerations that make this an excellent illustration of a bedrock land form.

The soluble limestones weather to forms having combined characteristics that set them apart from all other types. These features are recognizable particularly in aerial photographs by those having the most elementary training, whereas, on the ground they may be indistinguishable to all but the expert. The identifying features to be seen on topographic maps of aerial photographs are found in the cross-section and profile characteristics of the valleys supplemented by the presence of sink holes in the upland and the relatively angular outline of the land form. Figure 3



(USDA Photo)

Figure 3. (Scale: 1 in. = 1250 ft.) Surface Physical Features Identifying the Soluble Limestone Bedrock.

is a vertical photograph recording in exact detail the surface physical features and the numerous sinkholes identifying the soluble limestone bedrock. Water standing in the sinks marks those blocked with eroded soil. The majority are dry and free draining. The dark area (A) is a group of forested clay-shale hills differing in every way from the adjacent limestone. The outline is represented in a plan view by the line marking the contact between the alluvium and the upland, or between the limestone and an underlying formation. Modification of this is found in the tropics under advanced stages of weathering and also in tilted structures. The process of weathering reduces the limestone to a reddish silty-clay soil varying in thickness between one and 20 ft. Inspection identifies the land form as limestone; the general depth of the mantle can be estimated by reference to outcrops. By sampling, the general texture of these soils has been established. Table 1 is an extract of data accumulated from the samples of these soils.

Within the limestone types of land form there is a relatively narrow variation from average conditions. However, this material presents so much of a contrast to others that it is unique. Initially, the horizontal beds of limestone presented a relatively level surface. Subsequent weathering produces sink hole topography in the upland. This topography creates many small cuts and short fills in road alignment together with a special need to protect the roadway from the further caving of the sinks. Inasmuch as some sinks are free-draining into underground caverns and others are plugged, their presence creates alternate conditions of bad and excessive drainage. As in Florida on Highway No. 9 (6) these provided the only reasonable means of disposing of

TABLE 1

Geographic Correlation Of Limestone Soils Based Upon Some Atterberg Limits[a]

Geographic Location	Atterberg LL	Atterberg PI
1. US - Alabama	69.3	27.6
2. US - Arizona	57.4	33.9
3. US - Indiana	63.6	29.5
4. US - Kansas	56.8	28.4
5. US - Kentucky	59.1	20.3
6. US - Ohio	65.0	35.5
7. US - Oklahoma	60.0	40.9
8. US - West Virginia	54.1	31.7
9. W. Indies - Barbados	107.0	79.1
10. W. Indies - Puerto	61.8	26.2
11. E. Indies - Papua	68.5	37.3

Without exact data, soils at the following locations have been classified as indicated.

12. Zanzibar, Tanganyika, N. W. Africa, Spain, Greece, Turkev, Palestine Trinidad, Cuba, Haiti and Java as medium heavy clay to fat waxy clay ranging from plastic to very plastic in consistency.

[a]Source: Nos. 1-8 (*8*); 10 (*9*); 12 (*10*)

surface water.

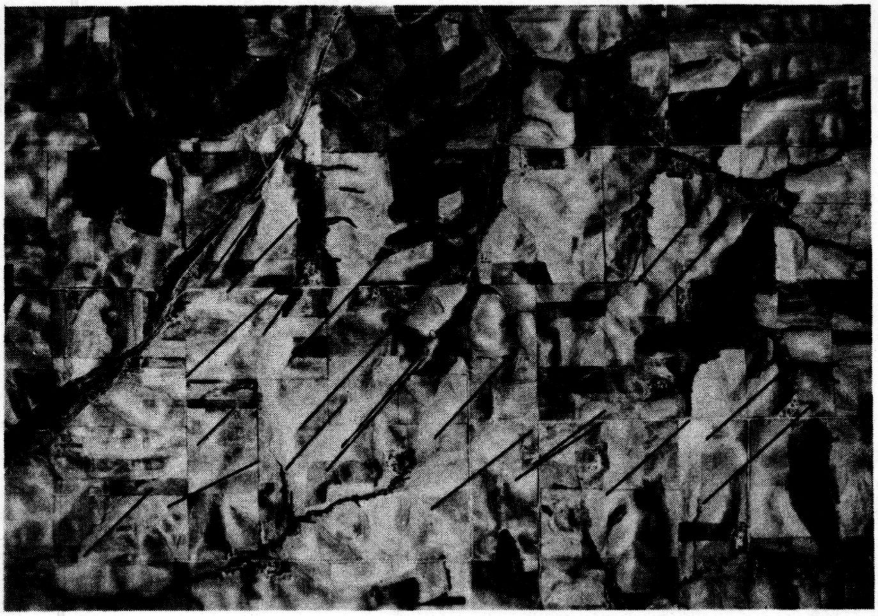
The peculiarities of weathering produce a smooth but highly irregular rock surface. In cuts the soil mantle is often found to vary as much as 10 ft. in thickness within a few feet measured horizontally, thus the soil cushion beneath the pavement may vary from one to many feet within short distances. Although a silty clay, these limestone soils, normally developed, seem to be the exception to the textural criteria for pumping beneath rigid pavements.

LAND FORMS OF WIND-TRANSPORTED MATERIALS

Windblown materials or extensive and important deposits in many parts of the world. They vary in size from the vast loess plains of North China, Central Europe, and the Central United States, to relatively insignificant isolated dune deposits occurring in almost every country. The texture and uniformity of these deposits has been shown by local investigations but only in isolated instanees have there been efforts to bring the significance of these to the attention of engineers.

The loess (silt) and sand have separate and distinct land forms. While there are some wide variations from the normal forms, it has been observed (5) that loess is usually deposited in ridges whose axes are approximately parallel. This tendency that is apparent in aerial photographs and in some topographic maps is lost to an individual on the ground. Figure 4 is a vertical photograph of deep loess near the source. The axes of the individual ridges have been indicated to emphasize the parallelism of this land form. Studies have shown the presence of very fine sand near the source (flood plains) with a replacement by silt and clay at great distances. Samples listed in Tables 2 and 3 reflect their position with respect to the source by the amount of sand present or higher indices where sand was absent.

The data shown in Tables 2 and 3 also illustrate the remarkable uniformity of texture and consistency regardless of geographical location. This is emphasized by the similar construction methods that are practiced in widely separated areas. These characteristics are so consistent from land form to land form that several highway departments have found that in the loess areas numerous elements of design and construction achieve identical results, even though widely separated. On this basis, the "shrinkage" of the material between the excavation and the embankment is relatively



(USDA Photograph)

Figure 4. (Scale: 1 in. = 3520 ft) Deep Loess Near the Source.

TABLE 2

Grain-size Date on Various Loess Deposits[a]

Geographic Location	Percentages of: Sand	Silt	Clay
1. China	6.4	67.1	26.5
2. Germany	8.0	66.0	26.0
3. Iowa	6.5	76.0	17.5
4. Nebraska	13.0	75.0	12.0
5. Illinois	19.0	73.0	8.0
6. Missouri	15.0	67.0	18.0
7. Idaho	17.5	60.5	22.0
8. Tennessee	11.5	72.5	16.0
9. Mississippi	11.0	83.0	6.0
10. Kansas	9.0	71.2	26.6
11. Washington	6.8	64.0	29.2
12. Wisconsin	1.0	68.0	31.0
13. Colorado	11.0	68.8	20.2
14. South Dakota	2.0	76.3	20.4
15. Louisiana	4.0	88.0	8.0
16. Kentucky	0.6	88.8	10.6

[a]Source (*12*) (*8*)

TABLE 3

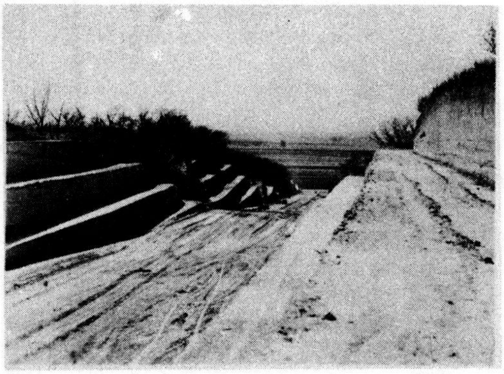
Some Physical Test Results On Loessial Materials[a]

Geographic Location	LL	PI	Max. Wt.[b]	Opt. Moist
1. China	29.	6.1	-	-
2. Tennessee	29.0	4.9	104.5	18.2
3. Mississippi	31.8	3.1	104.9	17.8
4. Illinois	26.2	3.9	106.2	15.5
5. Washington	30.7	7.5	99.5	21.4
6. Missouri	33.6	16.3	-	-
7. Nebraska	32.0	8.0	-	-
8. Indiana	29.6	7.6	-	-
9. Iowa	28.0	9.5	-	-

[a]Source: 1-9 (*5,8*)

[b]Lb. percu. Ft. (dry) Proctor

fixed since the natural density and the compacted density are nearly constant values. Likewise, limited data on the amount of portland cement required to stabilize loess indicates that over considerable areas, 10 to 12 percent by volume has been satisfactory. Figure 5 illustrates a construction characteristic to be observed in all loess areas. When a land form type exhibits this degree of uniformity in soil and related conditions, the amount of field sampling and laboratory testing becomes insignificant. The rule of vertical cut slopes introduces an element of instability in deep cuts in loess. In sub-humid climates of the northwestern U. S. and China, simple slopes in 80 to 100 ft. cuts have been satisfactory. Excessively erosion, these soil materials require special protection from running water. The source area of the loess can be seen in the background of this picture. Back of the camera the loess extends, as a gradually thinning deposit, for more than 100 mi.

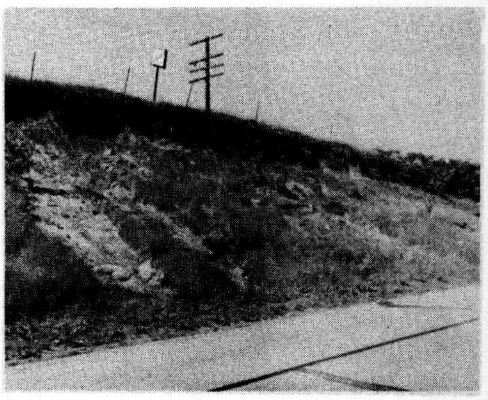


(Courtesy: The Highway Magazine)

Figure 5. Bench-type Construction in Loess

The tendency to assume a vertical slope can be seen developing at the original ground line in Figure 6. In this instance, the loessial silt was sloped and sodded in a cut section. Subsequent erosion has been so severe as to destroy the established cover.

Dune sand also presents a remarkable uniformity that has been caused by the sorting action of the wind. The recognition of the dune forms of all sizes in airphotos established the limits of the grain size within a narrow range. A specific soil series will be found to be related to old dunes when found on soil maps. Recent or active dunes are so labeled. Seldom are topographic maps suitable for this land form identification. Figure 7 shows a typical dune pattern in the sub-arctic in a vertical photograph of a heavily forested dune and swamp area. In spite of the vegetative cover the light gray of the dry sand is obvious. Similar dunes are commonplace in the tropics. Samples of dunes from the arctic coast to the southern hemisphere have furnished the statistical proof of their uniformity in topographic and textural characteristics. Protection of slopes against



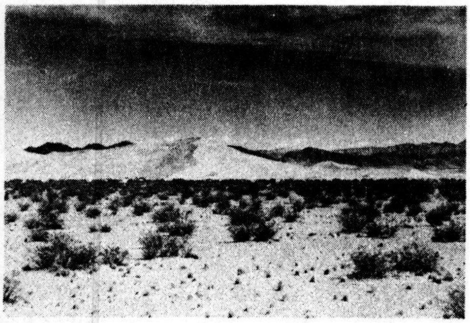
(Photo: H. E. Nelson)

Figure 6. Erosion of Loessial Silt Cut Section

wind erosion, excessive wear on equipment, high binder-soil requirements and an exceedingly porous

Figure 7 (Scale: 1 in. = 1259 ft.) Heavily Forested Dune and Swamp Area.

subgrade are features of the many dune areas whether in Maine or in Nevada, as shown in Figure 8. The white sand hills in the foreground of the picture contrast in every way to the dark rock hills in the background.



(Photo: Nevada Dept of Highways)

Figure 8. The Sand Dune as a Land Form

A brief of this data is shown in Table 4. Recognizing the characteristic form of dunes and estimating their distance from the source permits reference to the table for a close approximation of the grain size distribution. Having established the land form and the texture of these soils by one of the methods, observations and records will indicate the best practice to be followed in dealing with them as sub-grade or foundation material. Thus the concept of the land form provides a tangible basis for gathering and comparing, not only soil data but design and subsequent performance records.

LAND FORMS IN GLACIATED REGIONS

The areas of the earth that have been influenced by glaciation may contain any or all of the land forms

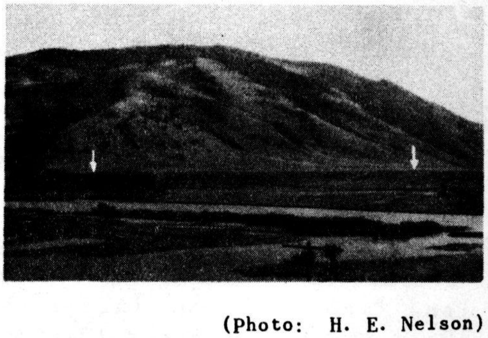
TABLE 4

Mechanical Analyses Of Dune Sands[a]

Geographic Location	Number Samples	Plus 20	Sieve Analysis (Average) Pass 20 Ret. 40	Pass 40 Ret. 60	Pass 60 Ret. 100	Minus 100
1. U. S. Nebraska	20	Trace	5.9	20.8	66.1	6.9
2. U. S. Wisconsin	3	0.4	20.8	33.4	36.6	8.6+
3. U. S. Illinois	8	-	2.1	14.0	69.9	14.0
4. U. S. N. Dakota	5	Trace	9.2	20.3	58.9	11.4
5. U. S. Kansas	3	Trace	4.7	24.3	67.3	2.6+
6. U. S. Massachusetts	2	Trace	5.5	23.4	67.6	2.3+
7. U. S. Washington	1	6.0	14.0	41.0	27.5	11.5
8. U. S. Alaska	2	-	-	21.8	58.2	20.0
9. British Columbia	1	-	6.5	31.2	43.6	17.5+
10. Peru, S. A.	1	-	Trace	0.3	87.3	12.3+
11. Laborador	1	-	3.2	26.6	59.2	11.0
12. Churchill, Manitoba	1	-	6.6	38.5	54.7	0.2
13. Pan American Hwy., C. A.	1	-	0.5	5.4	59.2	34.7

[a]Source: 1-6 *(12)*

previously enumerated. Of particular interest to engineers are the level, well-drained terraces or "valley trains." A ground view of a terrace land form is shown in Figure 9, showing the flat surface, the associated upland, and the recent alluvium in the foreground. The well defined edges, lack of surface drainage, and absence of gulleys on the terrace face indicate the presence of gravel. The low mountain in the background is a typical "granite" land form to be found in many parts of the world.



(Photo: H. E. Nelson)

Figure 9. Terrace Land Form

These gravel and sand plains offer excellent sites for airports and highways since the essential feature of this land form is its nearly level surface. While good sub-drainage is the rule in such areas, an inspection of soil maps or aerial photos will show considerable variation in soil and drainage conditions within the terrace area. Figure 10 illustrates such an area. The vertical view presents the strong contrast in soil patterns found in relatively impervious silty clay and that associated with gravels. The integrated drainage pattern and the mottled black and white soil pattern mark two-fifths of the area as a silty clay. The relatively plain appearance of the central portion is a typical gravel pattern. The small irregular dark dots in this area are very slight depressions acting as "infiltration basins" for surface water. Although the area represents several square

(AAA Photograph)

Figure 10. (Scale: 1 in. = 5000 ft.) The Strong Contrast in Soil Patterns Found in Relatively Impervious Silty Clay

miles, no surface runoff occurs. Coarse gravel occurs in the light band that parallels the boundary between the two deposits.

Figure 11 is a ground view of a flexible road surface on a terrace land form corresponding to that shown in Figures 9 and 10. This illustrates the "standard" performance expected on the level, well-drained (gravel) land forms. Ground-line profiles, insignificant ditch requirements, few culverts and a thin (4-in.) base are commonplace elements that produce satisfactory service on this road. The small dark areas within the terrace land form, mentioned in reference to Figure 10, are shown at close range in Figure 12. In such areas, two or three extra inches of base materials are needed to distribute the traffic load to the soil that is more plastic and imperfectly drained.

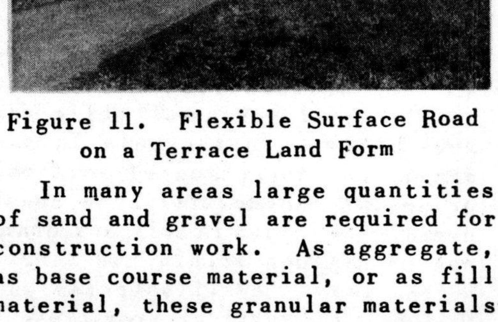


Figure 11. Flexible Surface Road on a Terrace Land Form

In many areas large quantities of sand and gravel are required for construction work. As aggregate, as base course material, or as fill material, these granular materials are often of utmost importance. An esker is a land form in which gravel and sand are found.

One of these ridges is shown in Figure 13. This gravel ridge resembling a long "fill" has an unmistakable land form. Eskers, common in most glaciated areas, sometimes reach the length of 100 mi., other a few hundred yards. In this view, lakes interspersed among bare granite hills comprise the balance of the area. This unique form consists of water-washed and assorted gravels and sands. They are excellent as a source of gravel and because of their well-drained character they are adapted to winter grading. Even in the arctic they remain unfrozen when adjoining deposits become filled with ground ice.

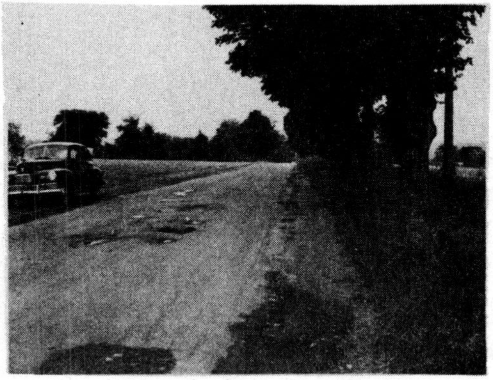
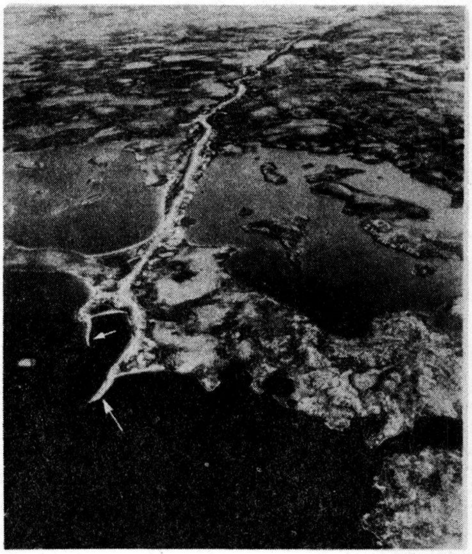


Figure 12. "Infiltration Basins" in Terrace Land Form

CLIMATIC INFLUENCES ON LAND FORMS

In areas where extremes of climate are experienced there are numerous influences which are not present under moderate climatic conditions. In such areas airphotos are particularly valuable because of the limited knowledge of terrain conditions and the lack of maps of other types. Desert areas and the arctic regions are examples of extremes of climate that exert great influence on soil and foundation conditions. In such areas where the climate influences engineering works the land forms naturally present are not greatly altered by the climatic forces. These unusual effects are found superimposed upon land forms found elsewhere; thus as a unit it remains a common denominator regardless of climate.

The particular problems of the arctic are associated with areas where the average annual temperature falls below the freezing point; under such circumstances the temperature of the ground is generally



(RCAF photo)

Figure 13. An Oblique View of an Esker.

below freezing. Perennially frozen ground, or permafrost, exists under these conditions but the problem becomes critical only when water has been supplied to the soil and that water has been concentrated into ice lenses and masses of ground ice. The construction of buildings, roads, and runways, or in fact any disturbance of the ground cover initiates melting and a resulting excessive settlement.

Two general conditions are encountered. In areas where unconsolidated materials are present, the young deposits such as flood plain (land form) materials have ice present in minor lenses and veins 1/8 to ½ in. in thickness. In older materials (coastal plain, morain, terrace land forms) the ground ice has formed into massive wedges of ice that are often several feet wide at the surface and taper downward to depths of as much as 40 ft. In plan these wedges form into the polygonal pattern shown in Figure 14. The polygon pattern is outlined by very slight depressions in which swamp grass is found. Arctic moss covers the surface on the interior of the polygon. Large masses of ground ice are coincident with the outlines. The hill in the center of the foreground is a rock land form. Figure 15 is a ground view of arctic terrain on Baffin Island showing the level surface of a terrace (marine) land form in the foreground and bare rock in the background. Ground ice has accumulated in the terrace material to form the polygon outline partially shown. The block diagram in Figure 16 shows the relationship between the surface pattern and the sub-surface conditions

Figure 14. Arctic Land Form Containing Ground Ice.

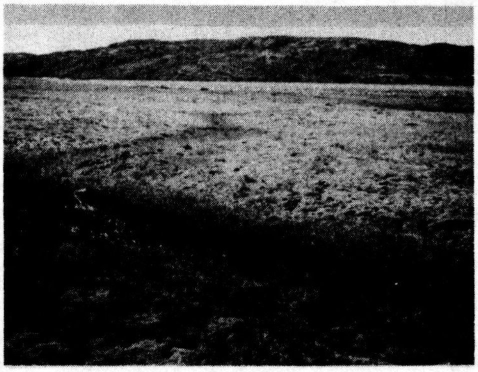


Figure 15. Ground View of Arctic Terrain Showing Polygon Outline Formed by Ground Ice.

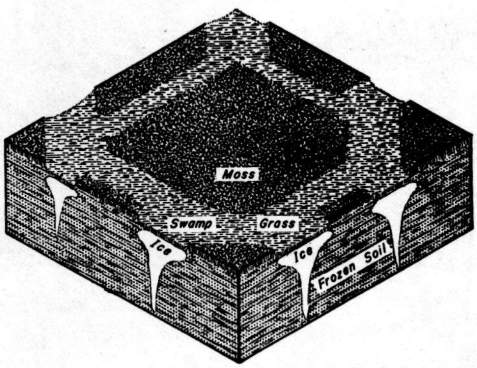


Figure 16. Section of an Old Alluvial Land Form Containing Ground Ice.

Figure 17 shows a wedge of ground ice melting after the surface insulation of moss had been removed. The distance from the ground surface to the top of the ice is about 12 in. The process of thawing, as seen in Figure 18, produces deep

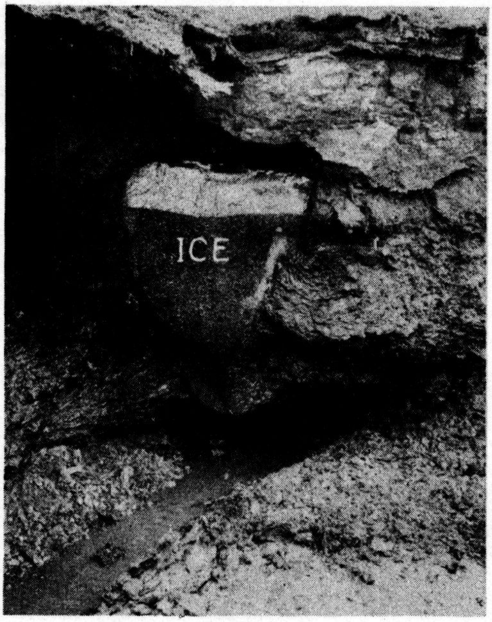


Figure 17. Wedge of Ground Ice

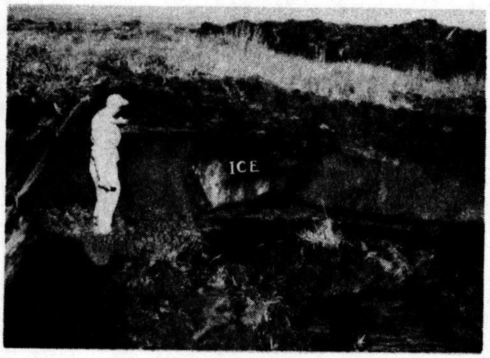


Figure 18. Process of Thawing Produces Deep "cave in" Trenches

"cave in" trenches. Here, thawing along one arm of a polygon exposes a connecting ice wedge. The stripping of the area in Figure 19 resulted in the formation of a polygon "trench" system. There has been no erosion or loss of soil. The runway in the background of the picture and sections of road were similarly "dissected." Failure of the simplest types of structures resulting from the thawing of ground ice are difficult to repair. Continued melting at a variable rate proceeds over a period of several years. Progressive failure results in the deep caving shown in Figure 20.

(Ungava Bay, NWT.)

Figure 19. Formation of a Polygon "trench" system

As a result of studies in the arctic it is possible to establish a series of land forms in which permafrost may be expected. Photoanalysis of these land forms indicates the degree of development of the ground ice in these, and the exact location of the ice in some. Ground examination of representative land forms of this grouping from western Alaska to Laborador and Baffin Island establish this similarity.

The apparent alternative to construction on these land forms is to seek bedrock land forms. Exploration in the Canadian Shield area reveals that massive and resistant rock such as granite or quartzite is susceptible to distortion by permafrost. Figure 21 shows massive blocks of rock weighing many tons

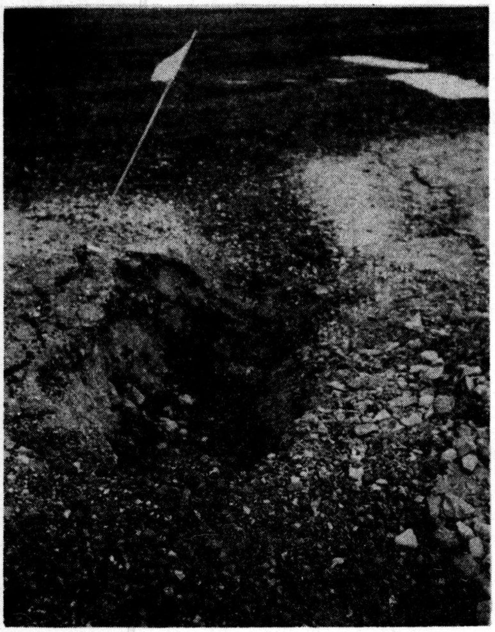


Figure 20. Progressive Failure Results in Deep Caving

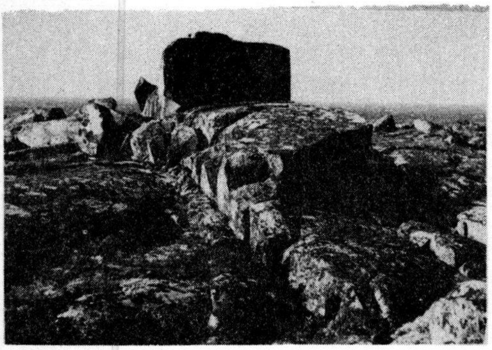


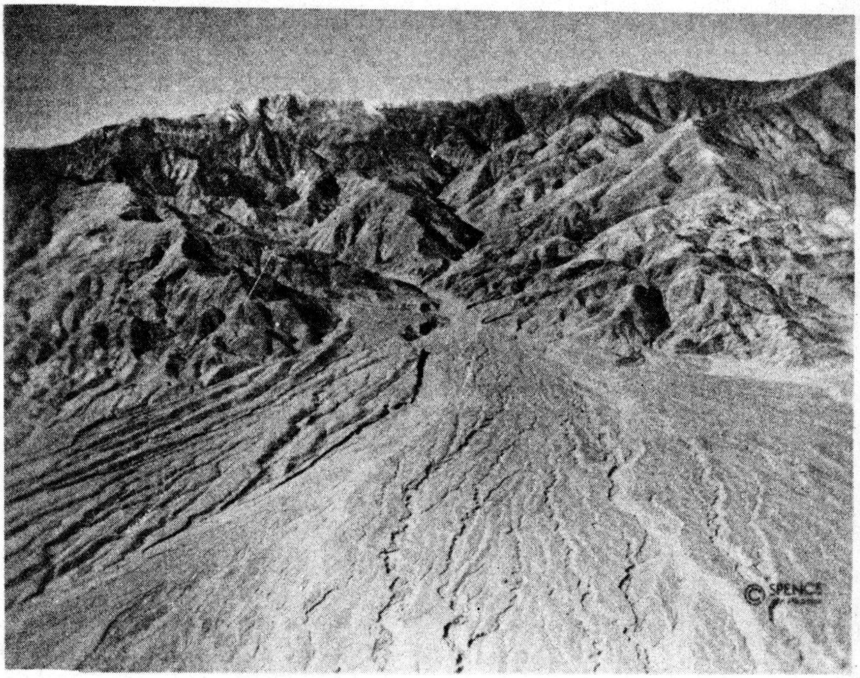
Figure 21. Rock Heaved from Original Position by Ground Ice

that have been heaved by the formation of subsurface ice. The highest projection is about 20 ft. above the original surface. As in other land forms containing ground ice, ordinary construction practice may result in disasterous settlement.

ARID REGIONS

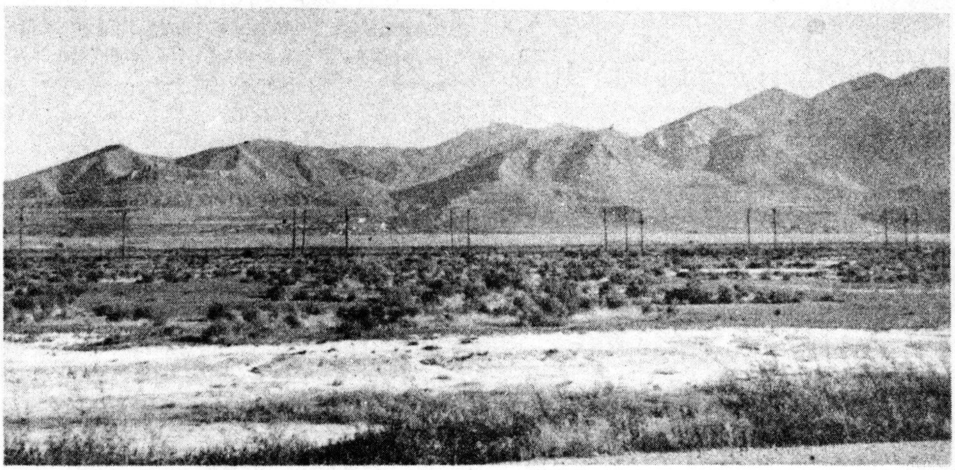
In dry areas the excessive run-off occassioned by the lack of vegetation carries great masses of soil material and rock debris from the mountain slopes out into the low valley areas typical of these regions. Because of the detail shown these areas are of great value in selecting the best available location for engineering works. Railroads and highways, because of soil and water conditions are generally located on the transition slopes between the hills and valley floor. These transition slopes generally take the form of alluvial fans or outwash material. Figure 22 is an oblique view of a land form of this type, showing the general shape of this land unit formed by the deposition of materials washed from the mountain valley. The numerous channels are an indication of the difficulty in locating roads on these land forms. In this transition area the shifting channels and accumulating debris require detailed planning for the protection of the right-of-way. Aerial photographs provide the precise record of many details that are necessary for proper original location and subsequent protection.

Pipe lines and airports, as well as the other transportation lines also must transect the "Basin" areas that lie at the outer fringe of these fans such as that shown in Figure 23. Alkali flats are found in the arid regions of all countries. In addition to identification of soil areas on the basis of texture, soil maps and aerial photographs can be used to locate alkali soils, ground water seepage zones, and active channel areas. The white area in the foreground is crusted with salts of potassium, magnesium,



(Photo: Spence)

Figure 22. Oblique View of an Alluvial Fan



(Photo: H. E. Nelson)

Figure 23. Alkali Flats

sodium, calcium and other compounds. These alkali flats (lake-bed land form) are relatively important since in these, high concentrations of salts are to be found; the same compounds used in the accelerated weathering or "soundness" tests of aggregates and concretes. Early disintegration of concrete and the rapid corrosion of pipe lines and metal culverts are associated with the alkali soils in this land form. For example, the U. S. National Bureau of Standards correlation (7) shows that 8-in. steel pipes placed in such areas can be expected to corrode and leak within five years. Similarly, muck soils (a land form common in glaciated areas) can be expected to corrode pipe within seven years.

LANDSLIDE LAND FORMS

The risk of the unexpected is often a contributing item to high construction costs. This factor also carries on into the service life of highways and other engineering structures. While landslide occurrances are but an example of a great many varieties of risk, they well illustrate the use of the land form as a basis of projecting experience. Here the land form establishes the permissible limits t which experience can be projected from one land form to another similar one.

In the consideration of landslides, two facts are outstanding:

1. There is a group of land forms (identified by rock type) such as clay shale, mixed shale, sandstone and/or limestone, and basalt that are prone to sliding along their unsupported edges. Conversely, a large number of land forms do not fail by sliding.

2. Landslides are a means by which nature adjusts slopes to a stable form. For that reason it is true that old landslides may be found in these land forms. Rarely will an engineer create an original landslide in a given land form. Therefore, a land form should be examined carefully when it is one of the susceptible types. Old slides will indicate the landslide tendencies of the land form; drainage conditions on the upland will indicate the possible locations of new slides. Photo-analysis is particularly well suited to this type of an investigation.

Figure 24, a vertical photograph, records the predisposition of the above-mentioned materials to fail by sliding. The highway (white line) is located on sloping terrain. Recent, A (indicated by arrows) and old, B slides along the unsupported face, running diagonally upper left to lower right, show that roads and structures near this face are susceptible to destruction by slides. Dense forest cover prevents adequate ground reconnaissance. The light gray area C which the road engineers attempted to circumvent is a shallow swamp; its upper border marks the approximate limit of material susceptible to sliding.

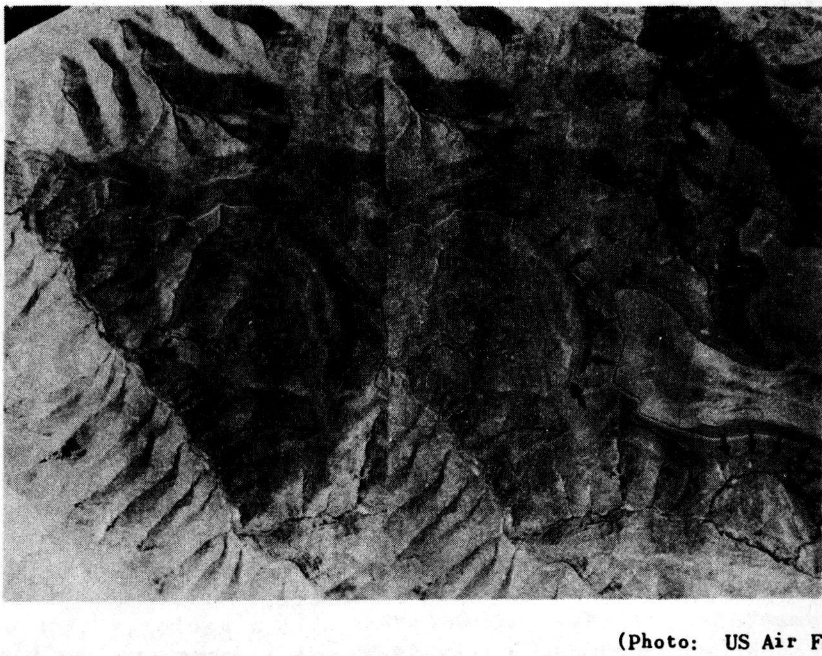
A stereo pair of vertical photographs showing numerous landslide scars in a basalt land form are shown in Figure 25. Encircling arrows indicate three major slides. The outcrops of basaltic rock appear as contour outlines at lower left center. Where surface streams parallel the border of these land forms, sliding is imminent.

SUMMARY

A study of the engineering history of a land form would include the investigation of design methods and construction procedures. Such an investigation would inevitably show that within that land form, the process of trial and error, as well as intelligent engineering planning, had evolved certain practices that are the best for those particular conditions. Those particular conditions are characteristics of the land form under study conditions of topography, soil, water, and bedrock.

Since there are a small number of land form types and a great number of each type, they assume a

Figure 24. Predisposition of Materials To Fail by Sliding Shown by Old Slides



(Photo: US Air Force)

Figure 25. Landslide Scars in a Basalt Land Form

significance to engineers, for they represent a repeating situation, a basis for scientific standardization, a means to economy in men and money.

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DISCUSSION

PROFESSOR D. P. KRYNINE, *Yale University* The last quarter of a century has been characterized by the growing interest of the engineering profession in soil mechanics and geology. Particularly, the highway engineers are influenced in all phases of their activities by soil performance and local geological features. Soil mechanics, a branch of engineering knowledge created by engineers, rapidly found common language with its users. Geology, however, is not in the same situation; and engineers are often lost in the mass of geological information available. It seems to the writer that articles and books on geology for engineers should be written with a two-fold purpose: a) to acquaint the engineer with the geological problems that he has to face and to help him understand and overcome the ordinary and routine geological difficulties that he meets in his everyday practice and b) to indicate to him the major difficulties when he may have to call a geologist for consultation and to make it possible for him in such a case to interpret and apply geological recommendations successfully. Professor Belcher's paper is a fortunate and proper step in this direction. The title of the paper rightly indicates to both the engineer and the geologist what is important in applications of geology to engineering - "the engineering significance" of geologic features. Without entering into details, the writer wishes to call attention of the highway engineers to this interesting and important paper.

AN AIRPHOTO STUDY OF THE TRIASSIC AREA IN ALBEMARLE COUNTY, VIRGINIA

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SYNOPSIS

This paper is concerned with an airphoto study of deposits of Triassic age in Virginia. The area investigated is located at the southern part of Albemarle County. The purpose of this investigation is to determine the usefulness of airphotos in correlating existing soils with highway problems.

The problems involved in connection with the occurrence of Triassic formations are manyfold. Successful highway construction has to be specially adapted to the different physiography and has to take into account unusual pedological features.

Though the Virginia Department of Highways has been using airphotos for location work, this study has brought new light on the topography and valuable data on soils. In the past, geological and agriculturo-pedological publications were the only sources of information and they were found more than once to be conflicting. The airphoto pattern furnished easily a more reliable boundary for the Triassic basin and a possibility to differentiate the soils in the basin as a function of their parent materials: sandstones and shales. They are often interbedded and intermixed so that identification on the ground is not always possible. The airphoto pattern shows clearly the main outcrops since the sandstone will weather into a soil which, even if plastic, is less fine-grained, hence somewhat better drained than the soil derived from shales. The shales and sandstones weather at about the same rate. The topography rarely contains series of parallel ridges usually formed by tilted beds of sandstone and shale, but shows the low gradients and flat slopes associated with fine-grained soils. The drainage has not usually the typical trellis pattern. The land is fertile and used intensively and extensively for farming. A remarkable agronomic landmark is the cedar tree: it usually occurs in rows of small trees and its evergreen, dense foliage is easily recognizable either on a ground or an aerial survey.

A road performance survey was made in connection with the investigation. Important differences were observed though lack of original field data was a handicap. Paved roads required more maintenance in the zone of Triassic soils: others had to be stabilized first across the Triassic zone to make then year-round passable, and wherever the traffic became heavier, it was again in the Triassic zone that they had to be reinforced first. A cost survey covering a nine-year period showed that the average maintenance cost of unpaved roads was higher in the Triassic basin than for equivalent routes in the surrounding Pre-Cambrian area.

This study confirms the importance of a thorough knowledge of the Triassic basins for highway engineering and the airphoto survey as used for this investigation has remarkable possibilities for furthering that knowledge. This improved or new knowledge and resulting techniques were rather easily obtained and

proved to be reliable. It is hoped to extend this method of study to other similar areas and to use airphoto engineering investigations of soils as one more tool for better roads.

Soil mapping and investigation have made some remarkable progress in recent years, thanks to a new tool which was developed by some distinguished engineers. Most Civil Engineers are familiar by now with the astounding possibilities of aerial photography. It is practically a pass card to the realms of topography, drainage, pedology, geology, agronomy, and ecology. (*3*)[1]

The airphoto is for the highway engineer an accurate record of the physical features of the earth's surface. It is up to him to interpret them and obtain from them the wealth of useful and practical information they contain.

Their value when applied to soil surveying is now a well established fact. Our knowledge of aerial photography for such use is being all the time enhanced by the work of civil engineers connected with various highway departments, universities, the Public Roads Administration, the Civil Aeronautics Administration (*10*), and the US Geological Survey. For a number of years the Highway Research Board *Proceedings* have featured papers on aerial photography (*6*). The study of soil patterns has received special attention at the Joint Highway Research Project of Purdue University under the leadership of Professor Donald J. Belcher (2), now of Cornell University, Robert E, Frost, and others (*7, 8, 9*).

The aim of this study is to apply the principles and known advantages of mapping soils from airphotos to a particular type area of Virginia. Triassic formations occur at different locations in the Commonwealth (see Figure *1*) and it is believed that aerial photography can facilitate the work of the highway engineer. The Triassic zones always contrast very much with their surroundings in geology, topography, pedology, drainage, agronomy, ecology, and especially as far as highway engineering is concerned.

One trip through a Triassic basin in Virginia will be enough to convince anyone, engineer or not, of the unusual nature of the problems involved. Upon crossing the boundary into a Triassic basin one has the impression he is entering a different land. It is indeed striking to witness the effect of soils on men as illustrated by that difference. For the highway engineer this will mean special designs, locations, construction and maintenance problems. The main contrasts will be derived from the nature and properties of the soils. For instance, anyone who has been through a Triassic basin at the time of the spring break-up or even only after a rain cannot help noticing the slick deep red mud. This is just one token reminder of the great importance of the engineering problems involved.

Thus, it is a remarkable opportunity to study the possibilities of aerial photography as applied to the study of the Triassic areas. The Scottsville area was selected as an example: it is one of the smallest Triassic outcrops in the State. Only the larger part of it which lies in Albemarle County was considered for this paper since this study, intended to be for the time being more intensive than extensive, can later be extended if proved successful. The remaining of the Scottsville Triassic Basin lies in Buckingham and Nelson Counties. An attempt especially was

[1] Numbers in parentheses refer to bibliography at the end of this paper.

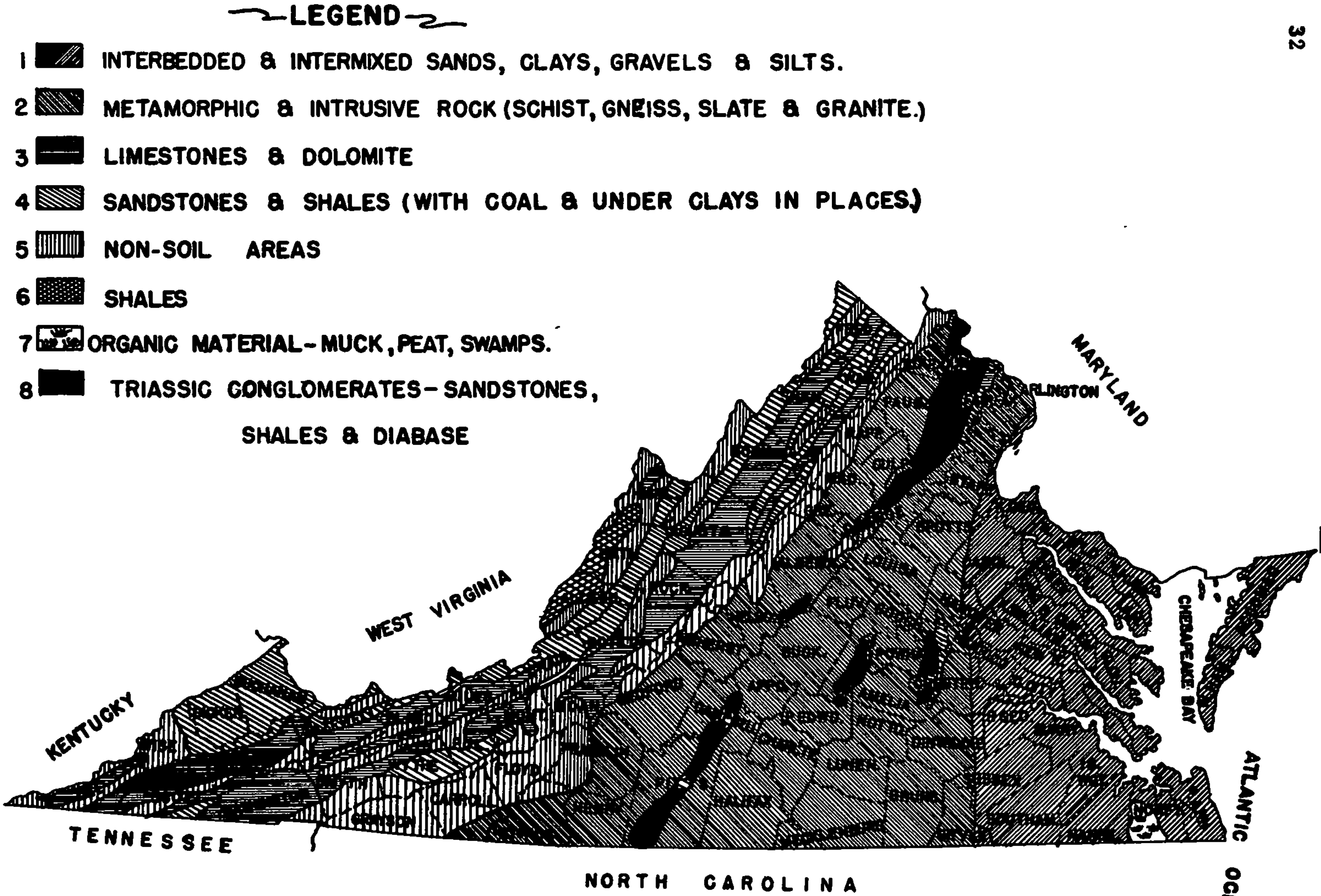

Figure 1. General Soil Areas Of Virginia As Classified By The C.A.A And Purdue University 1946

made at correlating the geology (mainly as reported by the Virginia Geological Survey), the pedology (mainly as reported by the US Department of Agriculture), the airphoto soil survey, and highway performance.

The area is about 80 mi. west of Richmond. It is part of a long belt of such formations extending from northern Massachusetts through northern South Carolina. The Scottsville area is about 20 mi. long and has a maximum width of some four mi. Its total area is about 35 sq. mi. lying in three counties. As stated previously, the project was temporarily restricted for practical purposes to Albemarle County with a square mileage of about 25. Any further reference in this paper to the Scottsville area should thus be construed as being only the part of it in Albemarle County.

It is west of the Fall line within the physiographic province commonly known as the Piedmont Plateau, close to the Blue Ridge. The elevation ranges from about 400 to 500 ft. above sea level. The drainage is fairly simple in pattern and the streams flow into the James River which bounds the area to the southeast. The topography is gentle with flat land and rolling hills as illustrated by Figures 2 and 3. (*11*)

From an agronomical point of view the area is quite important. The agriculture consists mostly of the production of corn, hay, oats, wheat, apples, dairy products, and livestock. Some large farms and beautiful stables may be found there (see Figures 4 and 5). Except for places of rougher topography or where the bedrock is at or near the surface, the area may be broadly described as one of rich farmland. The natural vegetation is comprised mostly of oaks, hickory, persimmon, poplar, some pine and the Triassic landmark: the cedar. The occurrence of cedar trees in connection with Triassic formations is always striking (see Figure 6). Only two primary highways cross the area: Route 6 from Scottsville westward and Route 20 from the same town to Charlottesville. The State Highway Department also maintains a network of secondary roads.

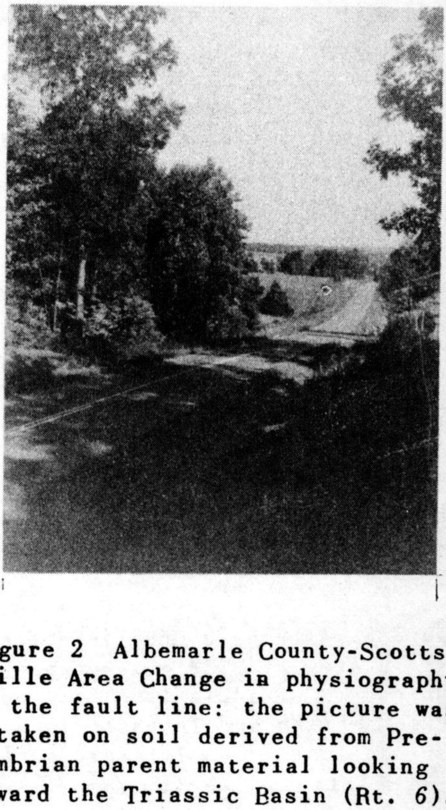

Figure 2 Albemarle County-Scottsville Area Change in physiography at the fault line: the picture was taken on soil derived from Pre-Cambrian parent material looking toward the Triassic Basin (Rt. 6).

The climate is fairly mild with a mean annual precipitation of 44.6 in. evenly distributed throughout the year. The average annual snowfall is 19.4 in. The mean temperatures at Charlottsville, the county seat, are: winter 37.5 F; spring 56.0 F; summer 74.6 F; fall 58.7 F (*5*).

GEOLOGICAL STUDY

It is to be noted that from a geological point of view the Triassic period is one of the most interesting. It is part of what is known as the Mesozoic era. Though the word Mesozoic means medieval life, it is not to be concluded that it is halfway in the past geological time. Just as it is the case for medieval times in history, there is much more elasped time before than after, but this medieval time is the turning point to what we might call "modern" times.

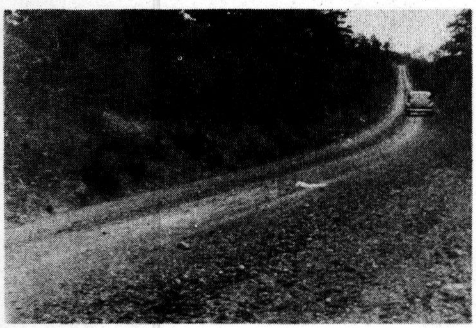

Figure 3 Albemarle County-Scottsville Area Rt. 723 White paper on road is at fault line between Pre-Cambrian and Triassic formations (car is on Triassic soil)

The Triassic period may be remembered as the time of the reptiles. It is the time when some of these huge animals were ruling our world. One has seen in many a museum the reconstructed skeleton of a dinosaur or brontosaurus. For any neophyte in geology who is more interested in stones for highway aggregates, all these bones are extremely impressive but do not mean too much. Yet to complete the picture one should recall that those reptiles sometimes weighed as much as two large size streetcars, that they dominated not only the land but also the seas and the air and it is only with the progressive disappearance of their rule in the animal world over a period of many thousands of years that the first mammals and then the first birds evolved.

The word Triassic was first used in Germany about a century ago to describe a three-fold sequence of rock. The three-fold description is not applicable to this country and the part of this geological period in which we are interested may be more properly described as represented by the Newark series in the latter half of the Triassic time. An arid or semi-arid climate seems to have been most common at that time and no indication of

Figure 4 Albemarle County-Scottsville Area Typical Pre-Cambrian Landscape with farm (Rt. 712)

glaciation has apparently been found in Triassic formations (*12*).

One of the most striking features of the Newark series is the predominantly red color of the sediments. It has been variously described as deep red, chocolate brown, red brown, or "Indian red," and the color is a limited, yet remarkable, "rule of thumb" in identifying Triassic formations. It is not an absolute rule since there are "red beds" of other ages, and as one follows the Newark basins in a southerly direction, more and more of the sediments are greenish gray instead of the typical red. This is due apparently to their mesophytic origin.

From a stratigraphic point of view the Scottsville Triassic basin is almost exclusively composed of sedimentary rocks (see Figure 7). They may be subdivided into three groups: conglomerates, sandstones, and shales. The conglomerate found in the Scottsville zone is quite probably known as a "trap" border conglomerate in view of the large number of "trap" or diabase pebbles in the rock. It has been used very widely as a road metal and the Commonwealth is commonly quarrying it in northern Virginia. It is a heavy stone and will weather very slowly, the matrix and the pebbles weathering usually at about the same rate.

The border conglomerate along the fault line forming the western boundary of the basin is the only formation that is not intermingled with others: at no place can one locate shale - or sandstone - exclusively since they are usually interbedded. But there is sufficient predominance of one or the other to permit the description of any given area as one underlain by shale or by sandstone as the case may be.

The formations which usually grade toward the center of the basin from border conglomerate to sandstone and turn into still finer sediments of the shale group are apparently reversed in the area under study since as a result of some geological phenomena, the shales lie at the western and eastern sides of the belt of sandstones.

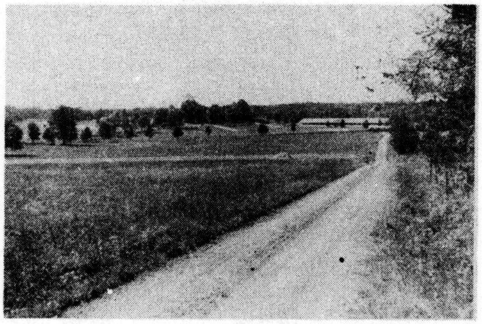

Figure 5 Albemarle County-Scottsville Area Typical Triassic landscape with secondary road leading to farm (Rt. 712)

This is especially noticeable for the main outcrops and an east-west section going through Scottsville would show after the Pre-Cambrian formations: shale for about one mi., sandstone for about one mi., shale for about two mi., border conglomerate for a few hundred feet to the fault line. As shown in Figure 8 this is also the case at other locations where the beds are smaller in extent and not as clearly differentiated.

The sandstone main outcrop is thus a narrow north-south belt of Manassas sandstone as it was identified at the time of the War Between the States. It does not usually withstand weathering too well, furnishing a fairly sandy soil as soon as the iron oxide cement has sufficiently weakened. The shale which lies to the east and west of the sandstone is commonly known as Bull Run shale (*11*).

Alongside the streams and especially in the James River Valley can be found some deposits of recent alluviums.

From a structural point of view one should note that the beds dip west and the existence of a series of faults especially along the western end of the area and of several dikes. The dikes are of diabase and only one being actually in the area under study, the igneous formations may be overlooked as far as this paper is concerned.

The surrounding formations are all of Pre-Cambrian or Cambrian age with the exception of some deposits of Ordovician limestone. The older deposits are extremely metamorphosed (schists, gneisses, phyllites, slates, and soapstones).

PEDOLOGICAL STUDY

As it may be expected from a study of the parent materials, the soils of the area will have one common visible trait: the red to brown color. Two main types are recognized by the US Department of Agriculture and identified as the Bucks and the Penn soils (see Figure 9).

The Bucks soils are derived from the purple or Indian red to brown sandstones and shales. It is a good agricultural soil with fair drainage. The Penn soils are more shallow and are usually better drained than the Bucks soils. Both will vary in properties whenever larger beds of shales occur. The Bucks soil is more favorable to cultivation and this explains why the Penn soil areas are still heavily forested.

Besides the two main soil series three minor ones have been identified. The Granville soil is fairly sandy and is usually derived from the sandstones and has good natural drainage. The Landsdale soil is heavier in texture and is derived from sandstones and shales. The small occurrences of igneous rocks, as previously noted, as diabase dikes result in soil of the Iredell series, which is quite properly nicknamed the "blackjack" soil. It has a poor drainage.

The surrounding Pre-Cambrian area contains soils derived from the older rocks. The main series are: Davidson, Congaree, Altavista, Nason, Wickham, Orange, York, and Tatum (5).

Figure 6 Albemarle County-Scottsville Area A Triassic landmark, the cedar tree (Rt. 626)

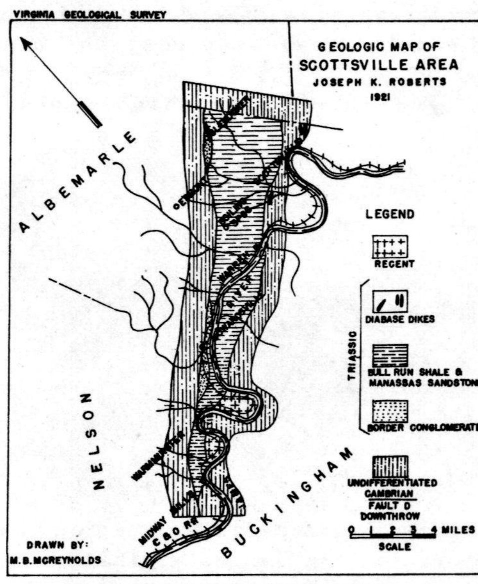

Figure 7

If one compares the geological to the pedological map it is obvious that they differ to a large extent as far as types of formation and boundaries are concerned. Of course one cannot expect them to be identical since the geologist will base his observation on rock outcrops and structural formation, while the pedologist will be more interested in what the soil is regardless of where it comes from. The geologist gives less extent to the Scottsville Triassic area and especially he places the western and still more the northern boundaries several miles inside where the US Department of Agriculture has located them. This may be explained by two facts. First is the "flow" of weathered materials, within a certain range, away from the rock parent material, and second is the fact that the northern and western boundaries are, as far as the geologist is concerned, made by a series of faults. Those faults may have been located more exactly as far as the structure, than as far as the stratigraphy of the basin is concerned. The eastern boundaries coincide quite satisfactorily.

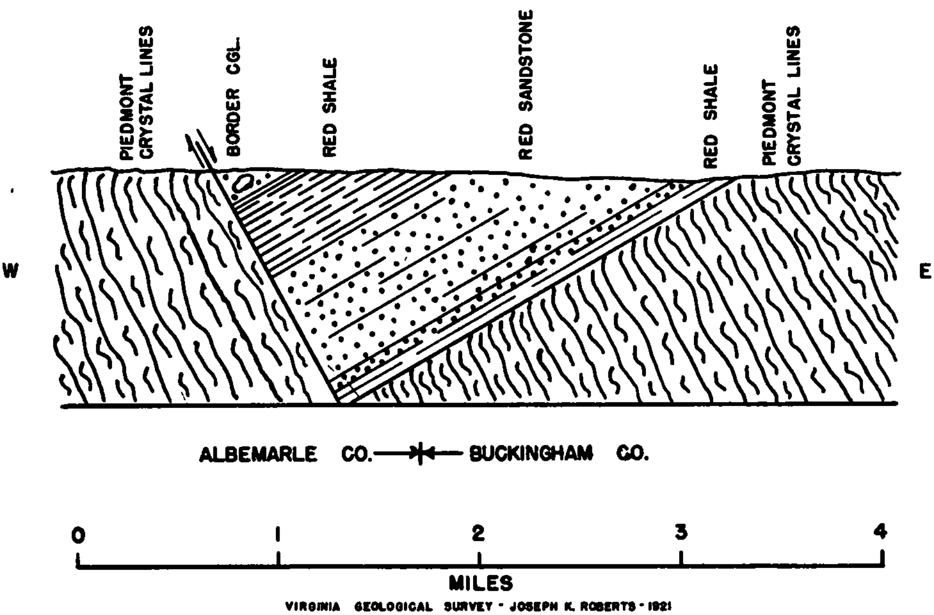

Figure 8 Cross Section Of Triassic Through Howardsville, Albemarle County

AIRPHOTO STUDY

Figure 10 shows an uncorrected airphoto mosaic of the area, and Figures 11, 12, and 13 are close-up views of the three main patterns that may be observed. The first one shows the rugged topography resulting from the Pre-Cambrian gneisses and schists. In opposition the two others show long, low uniform grades and smooth slopes. The latter patterns are quite typical of plastic fine-grained soils (*10*).

Tilted shales and sandstones usually result in fairly rugged relief. Yet since the angle of dip (west dip in this case) is small and the interbedding extremely pro-

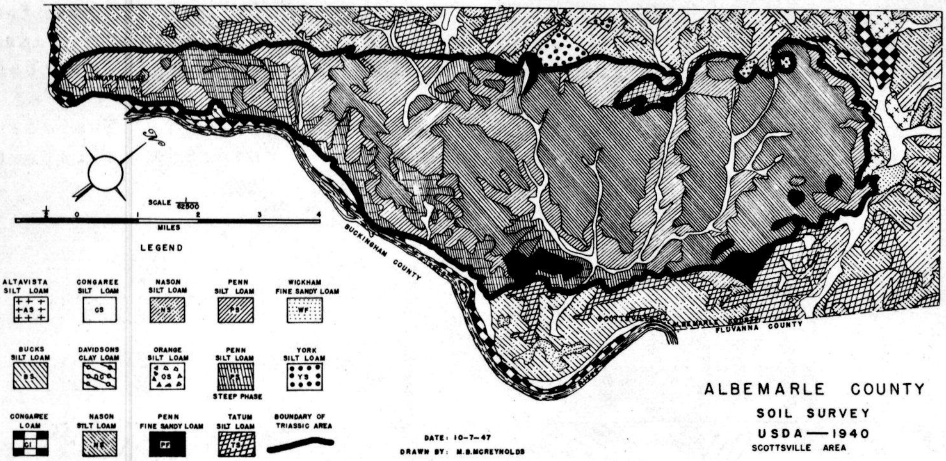

Figure 9

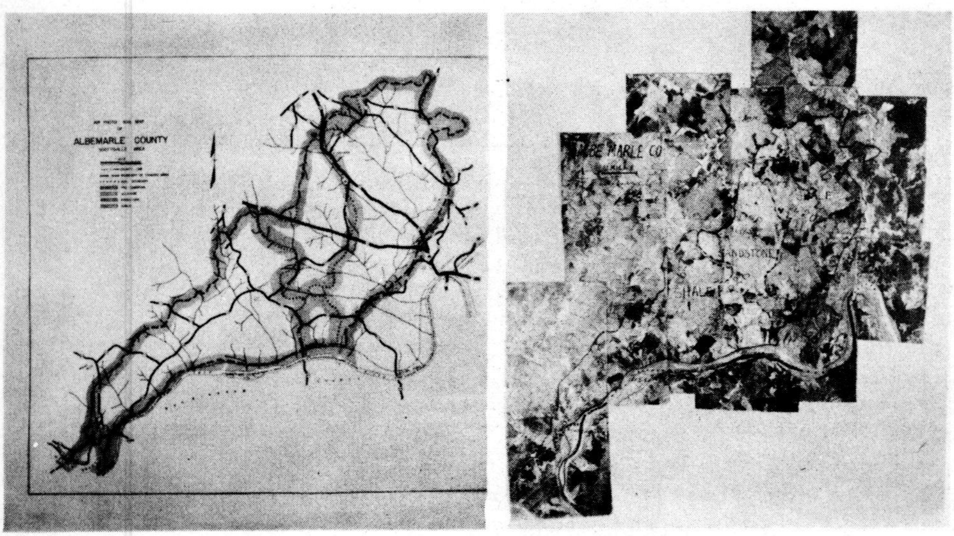

Figure 10

nounced, the landform is not strongly developed. The pattern of parallelism that one would expect from the alternance of strata is hardly existent. This is due to the fact that the sandstones and the shales have weathered at about the same rate and that (with one outstanding exception which will be studied in detail) they are usually closely interbedded and intermixed. It is only at a few places (due north of Scottsville, for instance) that a series of ridges may be observed. The strike is almost due north and the short depressions in between are filled with alluviums, often of Pre-Cambrian origin. A more definite landform due to different weathering may be attributed to the border conglomerate along the fault line. But it is so small in extent that it is not significant for highway soil engineering.

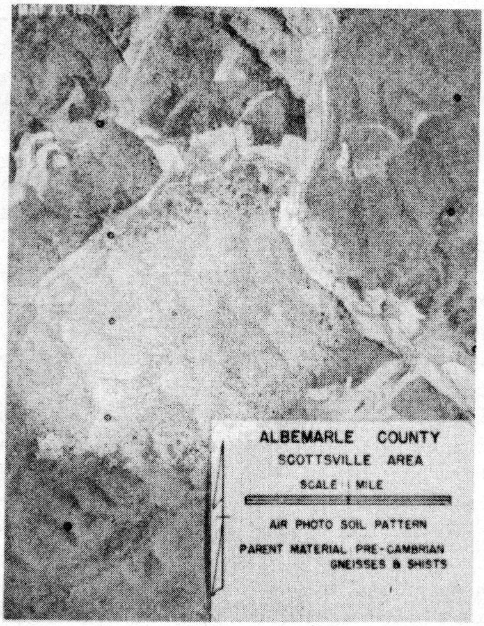

Figure 11

The drainage pattern also is not typical of an area of tilted sandstones and shales. The usual "trellis pattern" is almost non-existent except at one or two locations such as the above mentioned area due north of Scottsville. No major stream crosses the area but all the drainage is south or east, usually against the dip, toward the James River.

A soil map attached to Figure 10 was prepared from the mosaic and shows some extremely interesting features. The soil boundaries were established after a careful and close study of soil patterns, drainage and landform.

The limits of the Triassic Basin which were thus determined coincide closely with those offered in the pedological study (see PEDOLOGICAL STUDY). One should remember that the map shown on Figure 9 was made from ground surveys without quoted reference to airphotos. Thus, the airphoto soil survey

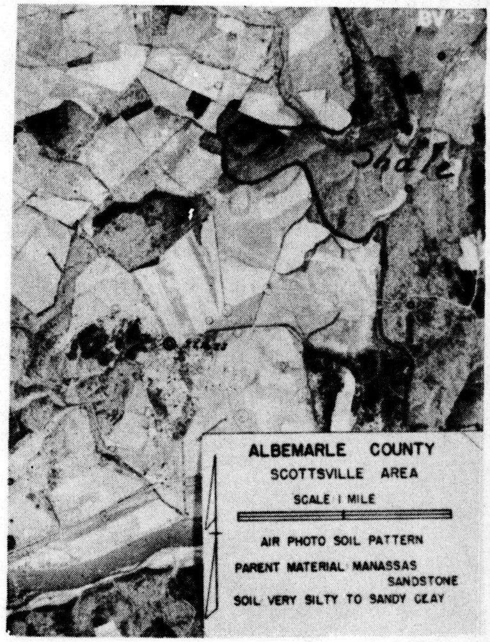

Figure 12

verifies the findings of the Agricultural Soil Survey and conflicts with some opinions of the Virginia Geological Survey.

One of the most important features brought out by the airphoto study is the location of the major sandstone deposit in relation to the beds of shale. As stated previously it is hardly possible to take them apart in geological or agriculturo-pedological study on account of interbedding, blending, close similarity in composition and rate of weathering. As a rule the sandstone in this area will furnish a sandy to silty clay at about the same rate as the shale will give a very plastic, silty clay (*4, 1*).

Yet Figure 10 clearly indicated the major area of sandstone and those of shale. This distinction can be made through the difference in drainage properties of the resulting soils. The sandstone will weather into a coarser grained, somewhat better drained soil than the shale. It has been found at some locations that the sandstone will result in a sandy clay with sufficiently good vertical drainage to give on the mosaic a light gray to whitish pattern. The color pattern for the shale is a dark uniform gray.

Figure 13

As shown in Table 1, a series of soil samples was obtained along State Highway 6. The samples were taken from the side of cuts about three to five ft. below the ground surface and represent vertically from three to 24 in. below the surface of the cut. All tests were performed according to current standard specifications.

As it will be seen, the soil samples corresponding to a shale parent material showed more plasticity than those derived from the outcrops of border conglomerate and still more than those weathered from beds of sandstone. This verifies the findings of the airphoto survey though the outcrops of border conglomerate are not of sufficient continuous extent to be significant for airphoto survey unless some low altitude pictures are used.

It can be readily observed that the area is one of rich farmland. About the only places where the ground has not been cleared of its natural vegetation are where the bedrock is too close to the surface. The fairly regular field pattern indicates that there is little variation in ground elevation. The occurrence of cedar trees, as previously noted, is noticeable on the airphotos. They often occur in straight lines and have dense evergreen foliage.

From the point of view of constructional materials, the airphoto pattern indicates that small deposits of sand and gravel (mostly fine grained alluviums) are available along the James River (*9*). Neither the shale nor the sandstones would be very suitable as a highway aggregate since they would weather fairly readily into the too common very plastic clay. The border conglomerate could be quarried at a number of places along the western fault line.

PERFORMANCE

In 1932 the State Highway Department took charge of the maintenance and construction of practically all

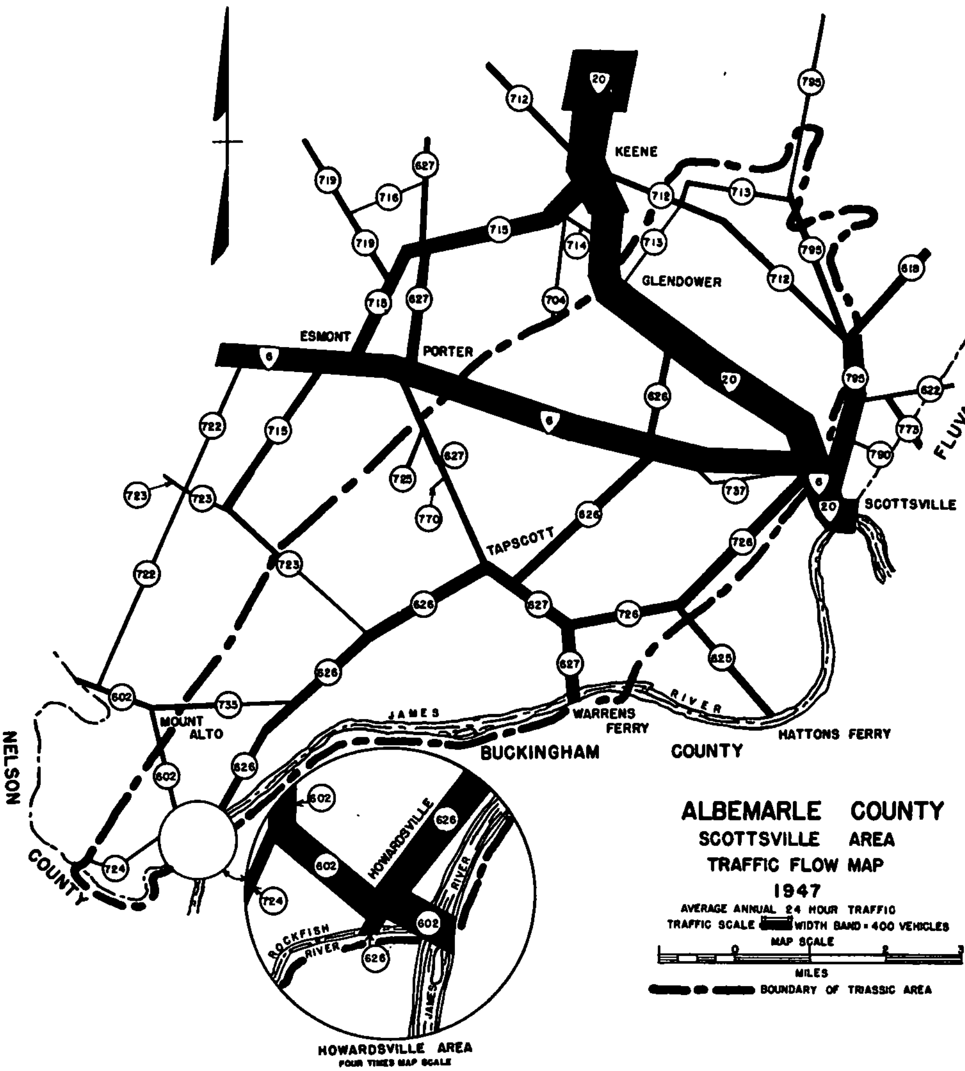

Figure 14

the county roads; some of them were added to the primary road system, others formed the secondary network. As a result, adequate records of the work done under county supervision are not available today. This was a handicap for the road performance survey which was made in connection with this study.

All the roads in the area were driven over at low speed and their condition recorded as it could be determined by careful visual inspection. In order to avoid variables due to climatic conditions, the survey was accomplished in two consecutive days of uniform weather conditions. This should be kept in

TABLE 1

RESULTS OF SOIL TESTS

Rt. 6

Sample No.	Mileage from Scottsville	Sp. Gr.	LL	PL	PI	Opt.Moist.	Max. Dens.	Parent Material
S1	2.8	2.69	64	32	32	27	95	Shale
S3	3.5	2.66	46	29	17	23	102	Sandstone
S4	4.0	2.74	54	31	23	26	97	Sandstone
S5	4.7	2.73	65	37	28	28	97	Shale
S6	5.0	2.73	53	38	15	30	93	Border Conglomerate

mind when examining the illustrations. A traffic flow map was prepared from counts taken during the summer of 1947 (see Figure 14). It shows that the traffic was quite light on the secondary roads which may be classified as belonging to the "farm-to-market" type. The two primary roads (Routes 6 and 20) have slightly heavier traffic counts and were at the time of the survey the only two paved roads (*13*)

Route 6 is an important east-west highway. It has a waterbound macadam base covered with a bituminous surface treatment. Though it is in excellent condition both on Triassic and non-Triassic soils, it is interesting to note that it was in 1938 that the section through the Triassic basin had to be modernized to the present standard while the old soil base road outside of the area under study was not rebuilt until 1942. Though other factors will enter into the picture, it is obvious that the drainage and bearing power conditions encountered in connection with Triassic soils made necessary a better and more expensive type of pavement in the Triassic basin four years before it was necessary in an adjoining Pre-Cambrian area.

The other primary highway is Route 20 linking Scottsville and Charlottesville. It is one of the oldest portland cement pavements in the state and was built by the County Road Department in 1919. Since accurate records on this pavement are not available, one should remember that any findings of the performance survey might be infirmed by the fact that different sections were built by different contractors with different materials. This fact will obviously affect the quality of the resulting concrete, but since the section boundaries are not available, it had to be overlooked in the survey. Nevertheless, it is indeed striking to note the difference in performance of the pavement in the two soil areas as shown in Figures 15 and 16. A crack count was made over two five mile stretches of road: in the Triassic basin the average number of cracks for 0.1 mile was 32 against 12 on adjoining Pre-Cambrian soil for approximately the same traffic. This means a crack interval of 44.0 against 16.5 feet. The pavement built without joints (either longitudinal or transversal) is still in excellent condition for its age in the Pre-Cambrian area but shows generalized failure in the Triassic basin. Map cracking, spalling, and scaling were observed, but from the large amount of patching it was not possible to determine the occurrence of blowups. Thus, it appears that the poor drainage and bearing power properties of soils derived from Triassic parent materials were reflected in the performance of the pavements, but it was not possible from the data available to determine different performances of primary highways between the shale and the sandstone areas.

This is also clearly shown in another way on the secondary road system. At the time of the study, all were soil roads with variable amounts of crusher run or crushed rock material for stabilization added every year to the surface as needed. Some of the rock used has also been of Triassic age but most of it has come from the surrounding Pre-Cambrian area.

Figure 15 Albemarle County-Scottsville Area Poor performance of concrete pavement on soil derived from Triassic parent material. (Rt. 20)

An inspection of Figures 17 and 18 will show clearly the difference in appearance of the roads in the two areas. Especially obvious is the difference in drainage characteristics which are emphasized at the time of the "spring break-up." As shown in Figure 19, at any season the surface water will remain for days after any rain while it disappears much faster on surrounding soils derived from Pre-Cambrian parent materials. The deep red-brown sticky mud is unfortunately too common a sight on secondary roads built on Triassic soils.

A study of expenditures on secondary roads was undertaken to determine the relative costs of construction and maintenance as a function of soil types. This undertaking was handicapped by the fact that in the Scottsville area only four secondary roads are exclusively on one soil type and all other routes cross soil boundaries. The result of the investigation is representative inasmuch as the data covers a nine-year period. As the routes were selected by a process of elimination not based on their performance, the process was thus about equivalent to lot sampling.

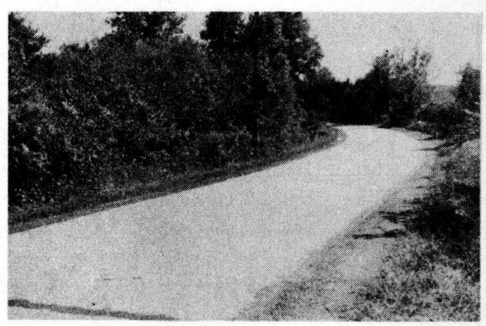

Figure 16 Albemarle County-Scottsville Area Excellent performance of concrete pavement on soil derived from Pre-Cambrian parent material. (Rt. 20)

The results are shown on Table 2. The first two lines are for routes entirely in the Triassic area while the two other ones are just on the outside. Otherwise they are the same kind of untreated soil roads, though Route 626 is subjected to a much heavier traffic than the others. It will be seen that the average cost per mile per year for maintenance on Triassic soil has a mean value of $226 against $81 for Pre-Cambrian soil. The striking difference would still be

TABLE 2
COSTS OF TYPICAL SECONDARY ROADS IN ALBEMARLE COUNTY-SCOTTSVILLE AREA
1939-1947

Rt.	Mileage	Soil Area	Avg. Daily Traffic 1947	Total Cost in Dollars (1939-1947)		Yearly Avg. Cost in Dollars		Yearly Avg. per Mile in Dollars		Yearly Avg. Cost per Mile per Car in Cents	
				Maint.	Const.	Maint.	Const.	Maint.	Const.	Maint.	Const.
626	10.4	Triassic	104	19126	5209	2125	579	204	56	.54[a]	.15
713	2.3	Triassic	25	5123	343	569	38	247	17	2.71	.18
714	1.0	Pre-Cambrian	15	569	-	63	-	63	-	1.15	-
725	0.6	Pre-Cambrian	24	535	74	59	8	99	14	1.13	.16

[a] This low value is due to the much heavier traffic to which this route is subjected.

larger if Route 626 were omitted on account of the heavier traffic on this road as compared to that on the other three routes. If the traffic is taken into account, Route 626 cannot be used for comparison, but for approximately the same total mileage, one can compare Route 713 against a combination of Routes 714 and 725. Yet for Route 713 on Triassic soil, the yearly average cost per mile per car is 2.71 cents against a mean value on Pre-Cambrian soil of 1.14 cents. Similar conclusions may be drawn from an analysis of the construction costs though they are less striking as far as performance is concerned.

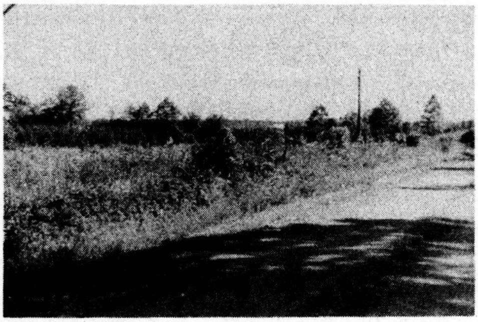

Figure 17 Albemarle County-Scottsville Area A secondary road on poorly drained soil from Triassic parent material (note typical flat landscape and vegetation of cedar trees

CONCLUSIONS

From the airphoto study of the Triassic basin of Scottsville, the following conclusions are indicated:

1. It is possible to use airphotos to investigate the soil areas connected with Triassic outcrops. It was found that whenever a formation was of sufficient extent to be of highway engineering significance it could be determined and bounded.

2. Existing geological data, though highly valuable, are conflicting with information obtained from agricultural soil surveys. Airphoto investigations agree with the latter though no evidence was found of correlation between parent materials and agricultural soil series.

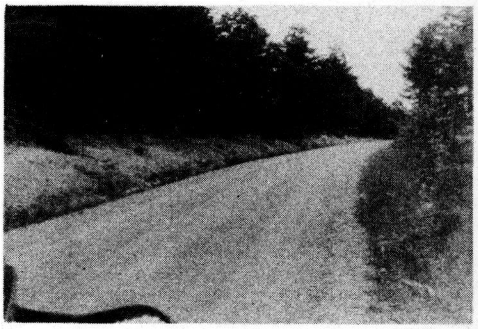

Figure 18 Albemarle County-Scottsville Area A secondary road on fairly well drained soil from Pre-Cambrian parent material (note typical vegetation of pine trees)

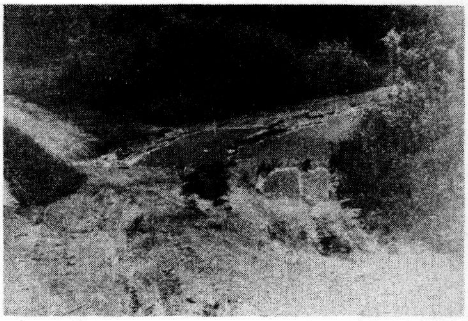

Figure 19 Albemarle County-Scottsville Area A secondary road on soil derived from Triassic parent material. Note poor drainage of plastic soil. (Rt. 735)

3. The airphoto soil pattern is typical of a fine-grained plastic soil but due to local conditions the landform and drainage do not usually conform to the "trellis" pattern expected from tilted beds

of sandstones and shales.

4. Only the airphotos permitted an easy distinction between the major outcrops of Triassic sandstone and shale, and all significant soil boundaries were found reliable.

5. The area is one of fertile farmland and as is usually the case, the rich agricultural soils correspond to poor highway soils on account of their plastic properties.

6. A performance survey indicated that for over a period of years more maintenance and a higher type of pavement were required for primary highways inside the Triassic basin. The average cost of maintenance of secondary roads was also higher when built on soils derived from Triassic parent material than for similar routes on nearby soils derived from Pre-Cambrian parent material.

7. Though it was possible to determine the major outcrops within the Triassic basin from the airphoto patterns and to evaluate a difference in performance between roads in the basin and outside, it has not yet been possible to correlate performance and the different outcrops within the Triassic basin.

8. The findings from the airphoto investigation were verified by every soil test performed to ascertain the reliability of the investigation.

9. This investigation thus is considered worthwhile, reliable and practical, and would apparently warrant a systematical extension to other similar Triassic basins in Virginia and other states.

ACKNOWLEDGEMENTS

The writer wishes to express his most sincere gratitude to Mr. T. E. Shelburne, Director of Research, Virginia Department of Highways, for his encouragements in preparing this report and his enlightening leadership. He desires to extend his thanks to other members of the staff of the Research Section who helped in preparing this report.

Mr. W. T. Parrott, Engineering Geologist of the Division of Tests, Virginia Department of Highways, and Mr. J. K. Ableiter, Chief Soil Correlator, United States Department of Agriculture at Beltsville, Maryland, furnished much valuable information. This project was conducted under the general supervision of Mr. Shreve Clark, Testing Engineer, and was approved by the Research Advisory Board of the Virginia Highway Department, Mr. C. S. Mullen, Chief Engineer being Chairman of the Board.

Finally, the writer is grateful to the division of Location and Design for putting the necessary aerial photographs at his disposal, to the Division of Traffic and Planning for the data on traffic, and to Auditing Division for information on costs of highway construction and maintenance.

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PREPARATION OF AN ENGINEERING GEOLOGIC MAP OF THE HOMESTEAD QUADRANGLE MONTANA [1]

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SYNOPSIS

The increased engineering demand for geologic data has focused attention on the engineering geologic map. Four basic requirements for this kind of map are: 1) avoidance of highly technical geologic terms; 2) emphasis on the physical differences and similarities of both rock and soil materials; 3) a three-dimensional quality to aid in subsurface interpretation; and 4) emphasis on deposits of constructional material. The engineering geologic map of the Homestead quadrangle in northeastern Montana attempts to fulfill these requirements by using several special techniques of presentation. The map is accompanied by a tabulation of engineering properties of each of the map units.

Within recent years, the increasing demand for comprehensive engineering planning has made evident serious inadequacies of essential technical information. Prominent among these is the lack of geologic information that is readily adaptable to engineering needs. Diverse engineering planning studies such as for highways, industrial and urban developments, flood control, power, and reclamation, have all shown in one way or another the need for interpretation of geologic data. In an effort to fill this need, the U.S. Geological Survey has directed a part of its current geologic program to the field of engineering geology and is experimenting with the problem of the engineering geologic map as one phase of this work.

The geologic map made specifically for civil engineers - the engineering geologic map - is not a new concept nor yet has it ever been crystallized into any conventional form. One reason for this is the extreme range of interest covered by civil engineering. Geologic maps made especially for the study of a dam are no new story, nor are those made for structures with critical foundation requirements, nor those for highway route surveys. The conventional areal geologic map has often been profitably used by engineers trained in geology. Moreover, one of the duties of the geologic staffs retained by the larger engineering offices is to interpret such maps for engineering use.

The integration of the pedologic map and the geologic map has impressed Olmstead[2] as a necessary step in preparing the highway engineering map. Jenkins, Belcher, Gregg, and Woods[3] have pursued the

[1] Published by permission of the Director, U.S. Geological Survey.

[2] Olmstead, F. R., "Systematic Planning of Low Cost Roads," *Proceedings*, Association of Asphalt Paving Technologists, Vol. 12, 1940.

[3] Belcher, D. J., Gregg, L. E., and Woods, K. B., "The Formation, Distribution, and Engineering Characteristics of Soils." Purdue University, *Engineering Bulletin*, Research Series No. 87, 1943. Cont. next pg.

"engineering pedology" map to great length. They have indicated a relatively fast and inexpensive kind of regional mapping based on the synthesis of geologic and pedologic factors. A study of the Fairfax quadrangle, Virginia, by V. P. Sokoloff and A. H. Nicol of the U.S. Geological Survey, now being prepared in cooperation with the Public Roads Administration, is another example of a type of highway engineering map that can be made. Some of the recently published county soil surveys of the U.S. Bureau of Plant Industry, Soils, and Agricultural Engineering satisfy many of the requirements of a highway engineering map. The terrain intelligence maps prepared by the Military Geology Unit of the U.S. Geological Survey are noteworthy attempts to interpret geology for the military engineer.

Despite the efforts that have been made from time to time by various groups, there still is a very real need for maps that present the wide range of geologic data that are of interest to engineers in a form that is readily comprehensible to them. To be of maximum usefulness in planning engineering structures, such maps should fulfill the needs of the small independent engineer as well as those of municipal, state, and federal agencies. On the other hand, the range of possible future construction projects in any area large enough to be considered in a regional study is probably too great to be taken care of by any one geologic map. A certain definition is therefore required as to what engineering problems can be economically answered by a single map.

Broadly speaking, the requirements of an engineering geologic map are relatively simple. First, all technical geological terms that are of no practical use to the engineer should be eliminated or subordinated. Foremost in this category are historic and genetic terminology which, although of great interest to the geologist, are often an encumbrance to the engineer. Second, emphasis should be placed on materials, and map units should be adjusted, insofar as possible, so that lithologically similar rocks and texturally similar soils are identified as such on the map. Conversely, different rocks and different soils should be sufficiently differentiated. In addition, fully as much attention should be given to overburden or soils as is given to the underlying bedrock. Third, a three-dimensional quality should be given to the map so that the engineer will be able to "look" under the surface and estimate with some degree of assurance what materials and conditions will be encountered at depth. Fourth, deposits and workings of natural construction materials should be conspicuously indicated.

The map of the Homestead quadrangle is an attempt to resolve the requirements described above by clarifying the presentation of data that are usually shown on an orthodox areal geologic map. The map itself is a geologic map in every sense of the word; the text which accompanies it is concerned only with the engineering aspects of the map data. Part of the map is shown in Figure 1.

The area covered by the map is a

Belcher, D. J., Discussion on paper, "Geology in Highway Engineering," *Proceedings*, American Society of Civil Engineers, May 1944.

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Jenkins, D. S., Belcher, D. J., Gregg, L. E., Woods, K. B., "The Origin, Distribution, and Airphoto Identification of United States Soils," *Technical Development Report No. 52*, Civil Aeronautics Administration, May 1946.

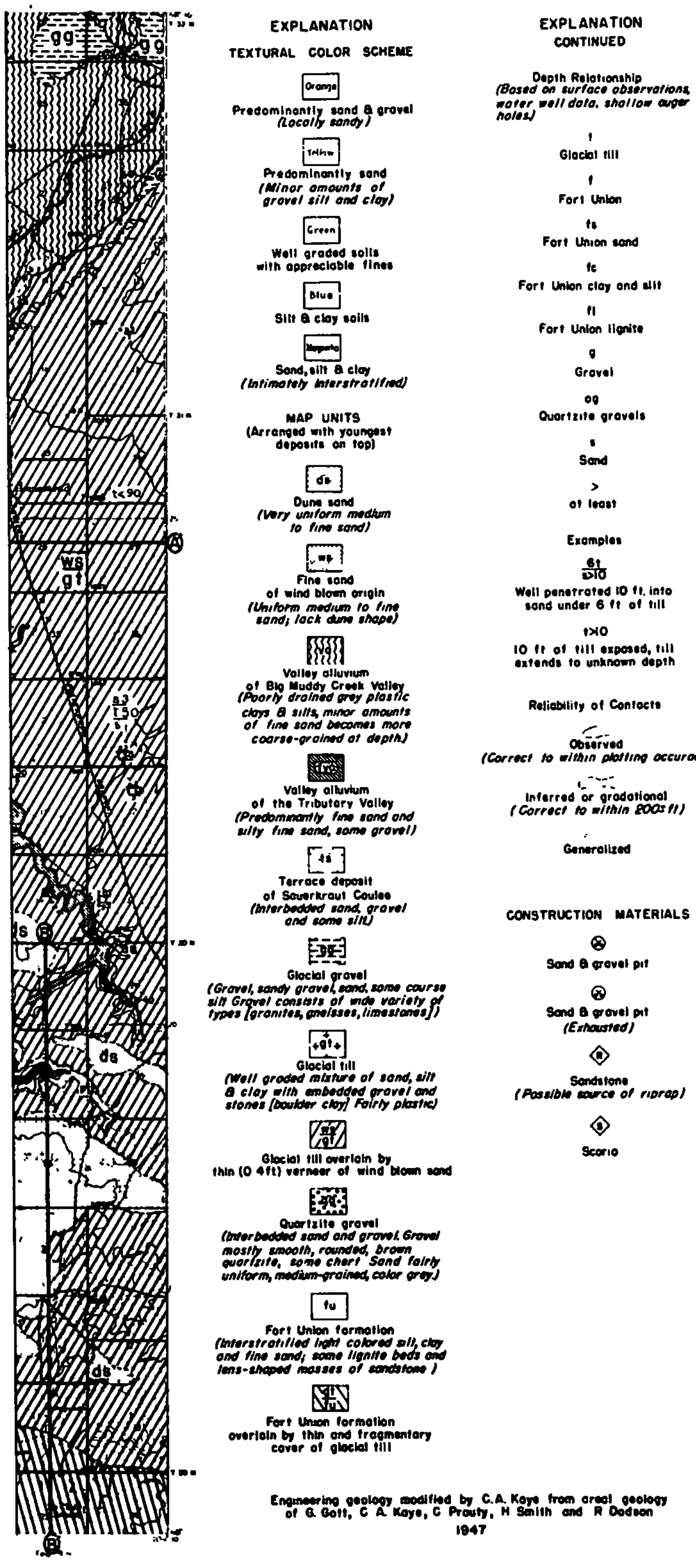

Figure 1. Engineering Geologic Map of the Homestead Guadrangle showing the Map Legend and Part of the Map-USGS

standard 15-minute quadrangle located in Roosevelt and Sheridan counties in northeastern Montana. The study was made as part of the Geological Survey's investigations in the Missouri River Basin, and the particular quadrangle was chosen because it fell within the area of the proposed Missouri-Souris unit of the Interdepartmental Missouri River Basin development plan. The region is largely given over to wheat farming and grazing, and contains few engineering structures of any importance. No hard-surfaced roads occur within the quadrangle. The selection of this area for the preparation of an engineering map was somewhat influenced by the proximity, just south of the quadrangle, of the site of a proposed large earth-fill dam. Because the area contained no hard bedrock and the relief was nowhere very great, a full range of geologic conditions was not encountered in making the engineering geologic map. The area is, however, fairly typical of the northern glaciated Great Plains and as such is of interest from a regional point of view.

The Homestead quadrangle consists chiefly of a moderately well-drained glacial till plain of low to moderate relief. The soft bedrock (silt, clay, and sand of the Fort Union formation) crops out in a number of places. The flood plain of Big Muddy Creek is a conspicuous feature of the quadrangle. It is underlain by clay and at greater depth by sand and gravel. Several large areas of sand dunes occur in the southern half of the quadrangle. A gravel, consisting predominantly of quartzite pebbles, crops out on the valley sides where it rests on the Fort Union formation and underlies the glacial till.

Field mapping consisted of the systematic examination of all outcrops and road cuts. The bedrock was examined in detail in the sides of the deeper valleys and ravines. Auger holes were put down where road cuts and outcrops were scarce Well logs were collected from farmers and drillers, and, after a certain amount of interpretation, were incorporated into the geological picture. Most of the area was accessible to automobile by a network of section-line roads. Mapping at a scale of 1:20,000 was done on aerial photographs. The geology was later transferred to the published topographic map of the quadrangle (scale 1:62,500).

As in most geological work, the aerial photographs were an invalu able aid. The broad features of the glacial geology of the area were relatively simple and in many cases could be interpreted from a study of the photographs. The slightly undulating and imperfectly drained till plain was clearly distinguishable from the flat clayey floodplain of the river and creeks. Low gravel terraces in the river valleys were indicated by a difference in pattern and the sand dune areas were clearly visible. Outcrops of sediments of the Fort Union formation were identified from the light coloration and the characteristic shape of slopes. All of the interpretations made from aerial photographs were checked and confirmed in the field.

The use of aerial photography in engineering geologic mapping has been ably described by Eardley[4] and by Jenkins, Belcher, Gregg, and

[4] Eardley, A. J., *Aerial Photographs: Their Use and Interpretation*, Harper and Bros., 1942.

Eardley, A. J., "Aerial Photographs and Distribution of Constructional Materials," *Proceedings*, Highway Research Board, Vol. 23, 1943.

Woods[5]. The writer's experience indicates, however, that accurate mapping by this method requires considerable ground checking. Characteristic land forms possessing typical material associations occur too rarely in nature to permit extensive armchair mapping. It is safe to say that the accuracy of the final map is in direct proportion to the amount of energy expended in actual field mapping.

The Homestead, Montana, topographic map, published by the U.S. Geological Survey on a scale of 1:62,500, with a 20-foot contour interval, served as a base map on which the engineering geologic data was plotted. The finished map and a text in tabular arrangement are printed on one double folio-size sheet. Distribution has been limited to official of the federal agencies concerned with Missouri River Basin development.

In order to emphasize the distribution of materials on the Homestead map, certain colors were adopted as standard for materials of different textures. This color scheme is explained separately on the side of the map sheet. Because the quadrangle is almost entirely lacking in hard rock, the textural classification is necessarily limited to unconsolidated sediments. Materials that occur in the quadrangle were subdivided into five groups: 1) predominantly sand and gravel, locally sandy; 2) predominantly sand, minor amounts of gravel, silt, and clay; 3) well-graded soils with appreciable fines; 4) silt and clay; and 5) sand, silt, and clay intimately interstratified. All map units that are predominantly sandy are given the same color on the map (yellow), and similarly all units that are clayey or gravelly are given their characteristic colors. The advantage of establishing colors for easily definable lithological or textural types lies in the fact that the textural picture is in that way made clear and obvious. As an example of its application, one can imagine that the engineer looking for gravel will be able to appraise an area rapidly by looking for the orange color. In order to satisfy the needs of a broad regional program of engineering geologic mapping a more comprehensive textural and lithologic breakdown, perhaps along the lines suggested by Belcher[6], should be adopted and standardized. The relatively simple textural legend used in the Homestead quadrangle seemed adequate, however, for that particular area.

An additional breakdown of map units is necessary in order to facilitate the interpretation of stratigraphic relationships and to distinguish essential differences between materials of the same predominant texture. Map units of the same texture, and therefore the same color, but of different origin or stratigraphic position, are distinguished by different letter symbols and by print patterns. This type of map presentation for engineers differs from the traditional geologic map only in the use of similar colors for similar textures or lithologies, instead of similar colors for similar geologic ages.

The three-dimensional quality of the map was handled by adopting directly several features long employed in German geologic mapping. A mappable area that is character-

[5] Jenkins, D. S., Belcher, D. J., Gregg, L. E., Woods, K. B., "The Origin, Distribution, and Airphoto Identification of United States Soils," *Technical Development Report No. 52*, May 1946.

[6] Belcher, D. J., "Engineering Significance of Soil Patterns," *Proceedings*, Highway Research Board, Vol. 23, 1943.

ized by one type of material mantling another is shown by a striped color pattern combining the two colors employed to symbolize the two materials. Thus, a thin sand mantle overlying glacial till is visually suggested by a striped yellow (sand) and green (till) pattern. In addition, the letter symbols of the two soil types indicate this superposition by being combined in the manner of a fraction, the symbol of the upper material over the symbol of the lower. Abbreviated well logs or sections measured in the field were also noted on the map in order to give a clearer picture of relative thicknesses and depths of materials. This was done by a small notation that again resembles a fraction. Each map unit and soil type was indicated by a letter and the sequence of materials encountered in the well are shown by the appropriate letters ranged correctly in vertical order and separated by short horizontal lines. The thickness of each material is shown to the right of the small letter symbols. These notations should prove a definite aid to the engineer in helping him form an idea of foundation materials. It would seem advisable to record this sort of data as densely as is compatible with the legibility of the map.

Sand and gravel pits are shown on the Homestead map by solid red circles rather than by the inconspicious conventional symbol of the black crossed shovels. Deposits of potential construction materials are similarly indicated by brightly colored symbols which are explained in the lengend.

The report that accompanies the map is arranged in tabular form. The map units are described under the following headings: 1) the textural and lithologic classification; 2) distribution and thickness; 3) terrain and natural slopes; 4) stability (both undisturbed and reworked) and the probable frost-heaving characteristics; 5) drainage and permeability; 6) workability; 7) use in highways, and as construction material; and 8) the pedologic soil series equivalent. Because of space limitations necessitated by the folio format, only a brief paragraph was devoted to each map unit under the above headings. The soil description and properties were mainly empirical qualitative judgments by the writer, and no soil tests were made in this study. Although it is recognized that some local variation in texture and physical properties may occur within the map units, the physical characteristics described are probably valid for the unit as a whole. The fact that the geologic map units more or less conform to pedologic soil units is of especial significance to the usefulness of the map for highway engineering. In explaining the term "engineering pedology," Belcher[7] wrote: "Regardless of geographic distribution, soils developed from similar parent materials under the same conditions of climate and relief are related, and will have similar engineering properties which in comparable positions will present common construction problems and produce like pavement performance."

It is evident that an engineering geologic study of a type suggested by the Homestead quadrangle does not eliminate the need for detailed foundation investigation. Each structure carries with it a series of foundation problems sufficiently unique to render impossible anything but a presentation of more or less generalized information on a map of this type. The

[7] Belcher, D. J., "Engineering Significance of Soil Patterns," *Proceedings*, Highway Research Board, Vol. 23, 1943.

greatest usefulness of the engineering geologic map is in planning and in preliminary site studies. Further refinements of the map are obviously indicated, although in its present state it answers a number of engineering questions. Additional mapping will lead to a wider interest in this type of work and improved forms of map presentation.

AN ENGINEERING GROUPING OF NEW YORK STATE SOILS

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SYNOPSIS

During the past year the Bureau of Soil Mechanics has prepared for the New York State Department of Public Works engineering soil maps for current projects covering a total of 3,360 square miles. This paper presents the engineering soil grouping used in New York State, the development of soil maps, and the application of the maps as aids in presenting soil information for highway design and construction.

The engineering grouping of New York State soils is based upon the following:
1. The division of the state into its physiographic provinces with analyses of the geologic history, topography, soil, rocks, and highway problems associated with each province.
2. A grouping of the soils on the basis of their deposition, parent material, soil and rock profile, land form and drainage characteristics as these factors affect highway problems.

The engineering soil maps are prepared to show the areal distribution of soils to be encountered in the particular region. The maps are assembled on the basis of existing soil and geologic information and with the aid of aerial photographs. Soil deposits, are grouped as glacial and post-glacial and are further divided into glacial ice deposits, glacial stream deposits, glacial lake deposits, glacial marine deposits, weathered bed rocks, recent stream deposits and organic deposits. The grouping at the present time consists of the following: thick till, thin till, drumlins, major moraines, outwash, kame fields, eskers, lake bottom sediments, deltas, bars and beaches, marine bottom sediments, residual, alluvial, muck and peat, meadow, and muck over marl.

The engineering soil maps form a part of both the preliminary and final soil report for each project and constitute a basis for the planning, control and review of soil work in the design and construction of highways.

For many years, Soils Engineers have relied almost exclusively upon detailed borings for the development of soil conditions and the extent of various soil profiles in connection with engineering projects. Little attention has been given to the past history of the area being investigated or to the general characteristics of the soil profile that may be common to soils in other areas. The broad viewpoint of soils as they exist because of their past history has led to the use of the area concept of soils in New York State.

This paper presents the research in soil and ledge conditions envolved in the development of engineering soil maps on an area basis in connection with the soil work for the design and construction of highways. This development has required an area grouping of soil information governed both by soil conditions and highway engineering practice. The area concept of soils in its broad aspect is a valuable aid to the Soils Engineer in the development of regional soil behavior, engineering practices and the performance of engineering structures. It has a special application to the practice of soils engineering for highways. This concept of soils depends upon the geological history of the soil deposit, the manner in which it was deposited, the material from which it was derived, and the weathering processes to which it has been subjected by erosion; drainage, mechanical disintegation and chemical reaction in the development of the soil profile and the surface topography of the deposit. The relationship of adjacent soil areas represented by a soil series from the same parent material subjected to erosion, weathering, drainage, and other climatic conditions is shown by the area concept.

The determination of whether the land forms as seen today are controlled by the deposition of the soil from the glacier or by the underlying bed rock adds to the information which is available to the engineer from a study of area soil concepts.

Area concept of soils provides a background on which to base the detailed soil studies, so that more information is available to the engineer in interpreting the subsoil investigation for the purposes of the design of the engineering structure. It is the opinion of the authors that more mutual understanding between the behavior of soils in different areas of the country will result from the use of the area soil concept as a basis for detailed soil work and the performance of engineering structures.

GEOLOGY OF NEW YORK

New York State has an area of 49,170 square miles including 1550 square miles of water. The state has been covered by multiple glacial ice advances leaving the entire State glaciated except for a small section in the southwestern plateau. The average elevation of the state is about 900 feet above sea level with a maximum of 5344 feet at Mount Marcy in Essex County in the Adirondacks.

Geologists have divided the state into well defined physiographic provinces. The authors have modified these provinces somewhat to fit the regional soil conditions of the state. Wide variation of soil and geological conditions make it necessary to divide the state into its physiographic provinces to facilitate the analysis of soil conditions and the related highway problems. In New York the provinces are roughly indicated by differences in elevation as shown in Figure 1. The following description of the provinces also refers to Figure 1.

Southwestern Plateau This is the largest clearly defined province in the state, covering about one-third of the total area. It contains unaltered sediments of Devonian rocks which are predominantly shales and contain some sandstones and conglomerates. Only minor disturbances have occurred in the form of a slight tilt to the south or southwest of 20 to 30 feet to the mile. Major relief is afforded by north-south trending valleys that, during glacial times, served both as drainage channels for the flow of melt-waters and as basins for ponded lakes. The soils in these valleys vary from assorted granular deposits that occur as kames, kame terraces, and outwash, to the la-

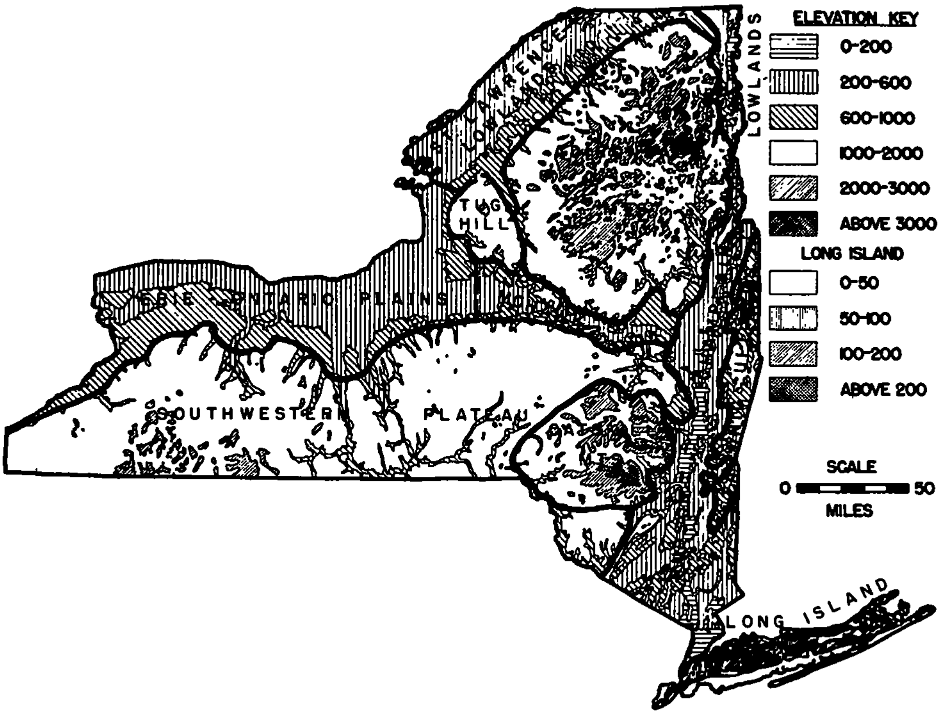

Figure 1. Elevation Map of New York State showing Physiographic Provinces

custrine fine sands and silts. While the glacial history of the valleys is very complex, the sequence of deposition can usually be determined within small areas with the accuracy required to identify the general engineering characteristics of the deposits.

The soils of the uplands are predominantly glacial till in origin and are usually underlain at shallow depth by bedrock. They are mainly silts with a varying percentage of rock fragments derived from the native bedrock. A major moraine crosses the province in an east-west direction, which, because of its soil profile characteristics and topographic expression, offers particular engineering problems.

Erie-Ontario Plains This province provides the east-west routes for all up-state New York transportation. The original Clinton's Ditch, the old Erie Canal, the present Barge Canal, the New York Central Railroad main line, and the new Thruway, now under construction, all traverse this province.

The entire province is one of low relief with a prominent escarpment marking its southern boundary and hundreds of elongated glacial hills or drumlins in the section between Rochester and Syracuse.

The area was flooded for a considerable period of time by a large glacial lake which, in its contracted form, constitutes the present-day Lakes Erie and Ontario. This lake was superimposed on an area consisting of glacial tills and glacial stream deposits. Its occurrence modified and altered the previously deposited sediments to such an extent that the present soil pattern is very complex. Difficulty is encountered in grouping the soils of this area and many borderline cases exist.

St. Lawrence Lowland This lowland area borders the present river and has in the past been visited by both glacial and marine waters. Most of the area is underlain at shallow depths by limestone of Ordovician age with some Cambrian sandstone. Deep deposits of silt and clay exist over a portion of this area.

Adirondack Mountains These mountains are the highest in the State and are composed of igneous rock injected into highly metamorphosed pre-Cambrian sediments.

The glacial till encountered is sandy, and crystalline cobbles and boulders are the rule. Deep swamps are common.

Tug Hill This area is a plateau separated from the Adirondacks by the Black River. It constitutes an outlier of the Southwestern Plateau and is composed of nearly horizontally bedded Ordovician limestone and shales and Silurian sandstones. Because of the more favorable topography around this area, it is not crossed by any main highway.

Mohawk Valley This valley provides the lowland connection between the Erie-Ontario plains and the Hudson River. It was a major drainageway in glacial times and immense granular deposits now occur along the valley walls in the form of outwash terraces. In the bordering uplands there are large areas of silt and clay that were deposited in high-level glacial lakes. The river-flats are deep valley-fill with a wide variation on soil characteristics and profile.

Catskill Mountains These mountains were formed by the deep dissection of a high plateau area. The bedrock is nearly horizontally bedded Devonian rocks, consisting chiefly of sandstones and conglomerates. Valley type of glaciation is common with numerous small moraines, deltas, and outwash fans. Localized glacial lakes resulted in deposits of silt and clay that are especially troublesome in highway construction.

Hudson-Champlain Lowlands The Hudson Valley completes the water level route from New York City to Buffalo. The province as a whole represents a number of distinct topographic features that have been considered as a unit as a matter of convenience. A prominent feature occurs in the southern portion of the province where an area of crystalline rock, known as the Hudson Highlands, interrupts the lowlands.

It is known that marine waters have existed in both the Champlain Valley and in the southern portion of the Hudson Valley, but the extent of the deposits resulting from these waters has not been defined. Another featured soil area is the extensive sand plains existing in the Schenectady-Saratoga area which was deposited by glacial waters from the Mohawk Valley. The thickness of this deposit decreases with the distance from the intersection of the Mohawk and Hudson lowland and becomes absent south of Albany where the underlying varved silts and clays are exposed. It is these clays that present the major engineering design and construction problem of the province.

Taconic Uplands The highlands along the eastern border of the state are a part of the Taconic Mountains.

The rocks are intensely folded and are comprised of metamorphosed shales, sandstones and limestones. In general, the soils are thin and prominent glacial deposits are confined to the major drainageways. The identification of the type of underlying bedrock and its structural characteristics are of importance in design and construction considerations.

Long Island This province is essentially a complex glacial terminal plain to the south. The latter slopes vary gradually down toward the ocean. The soils are predominantly sands and gravels.

ENGINEERING GROUPING OF SOILS

The division of the soils of an area into groups is extremely diffcult. If a very broad grouping is desired, borderline cases constantly occur. If it is intended that the grouping will provide detailed soil identification it will be found that the number of groups will continue to increase as additional data is obtained. It has been found desirable to group the soils of New York State on a broad basis and to subdivide this grouping only after an accumulation of data indicates that such a subdivision is absolutely necessary. The detailed identification of soils is not included in the area grouping and is made only after borings and samples have been analyzed for a project.

The soil grouping now used gives consideration to many factors of soil and bedrock history, topography, drainage, and soil profiles; however, each division within the grouping must exhibit individual engineering characteristics that distinguish it from other divisions. No compromises are made with this last provision.

The designation of each group employs geologic terminology and reflects primarily the mode of disposition of the formation. The details of the grouping are shown in Figure 2 and the characteristics peculiar to each division are discussed below:

ENGINEERING GROUPING
NEW YORK SOILS

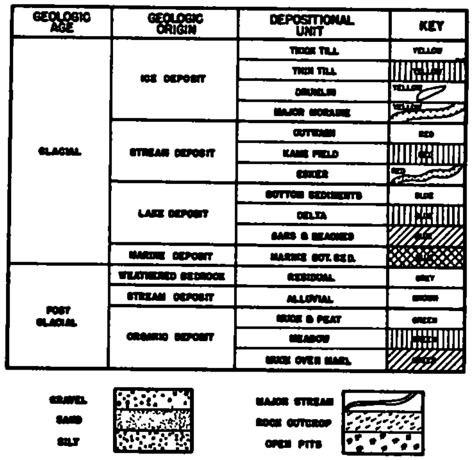

Figure 2. Engineering Grouping of New York Soils

Thick Glacial Till These soils were deposited as glacial drift and have assumed a wavy or slightly hummocky land form. Their textural composition varies widely from one area to another, but in general, consists of an unassorted mixture of soils with a predominance of silt. Cobbles and boulders are common and internal drainage is moderate. Excavations in these deposits may encounter troublesome wet silt pockets that will require underdrainage or special handling. In general, the material is suitable for embankments; however, in the Southwestern Plateau province, the material often contains a sufficient quantity of large slabby pieces of shale to make compaction operations and control difficult.

Thin Glacial Till A distinction is made in the thickness of glacial till deposits primarily because of the importance in engineering design of the depth to bedrock. The thin tills are predominantly silts with varying percentages of fragments of the underlying bedrock and little foreign gravel is encountered. The topography in these areas is controlled by the nearness of bedrock, the type of rock and the inclination of the bedding planes. The uniformity of subgrade in cuts must be checked and special attention given to the area of transsition from cut to fill. Underdrainage will be required at many sites to intercept flow along the surface and bedding planes of the rock.

Drumlins Drumlins are elongated, cigar-shaped hills, composed of compact unassorted till that has been overridden by the glacial ice. They occur as the major relief feature in a part of the Erie-Ontario Plains Province and for this reason are of engineering importance as a source of common borrow. They are given special designation within the grouping because of their topographic form.

Major Moraines The soils found in the major moraines of New York consist of assorted granular materials. The percentage of fines contained in the soils varies considerably. Some deposits consist of acceptable foundation course gravel while other have more of the characteristics of an assorted till because of the high percentage of fine material. The moraines appear as discontinuous, smooth to slightly hummocky ridges and are made a separate division in the grouping because of this special topographic form. In general, the materials are only medium compact, and in many cases pockets of wet fine sand and silt are encountered.

Outwash The identifying land form of glacial outwash is a smooth to pitted plain that gradually slopes down-valley as valley-wall terraces. The deposits consist of clean horizontally stratified sand and gravel and usually offer the best source of run-of-bank gravel. However, some sites are unacceptable because of the predominance of sand. In a few areas of the State, the percentage of shale gravel is an important consideration.

Kame Field This classification is used to encompass all glacial stream deposits other than Outwash and Esker. Such deposits are identified in the field by their characteristic knob and sag topography. They consist of roughly stratified sand and gravel with occasional pockets or strata of silt. They represent a likely source of run-of-bank gravel but must be carefully explored because of wide variations in texture.

Esker Glacial deposits formed by ice-walled streams which flowed either in canyons cut in stagment ice or sub-glacial tunnels are termed eskers. They are long, narrow, steep-sided ridges and are almost triangular in cross-section. Eskers consist generally of sand, gravel, and cobbles. They are usually a source of run-of-bank gravel and always an excellent source of select borrow.

Bottom Sediments Those soil deposits laid down in glacial lakes are referred to as Bottom Sediments. The topography is level to hummocky with frequent deep disection by modern streams. In the Hudson-Champlain valleys, the Catskill Mountains and the uplands of the Mohawk area, these deposits consist of varved silts and clays. In the Southwestern Plateau they are in general stratified fine sand and silt, and, in the Erie-Ontario Plains, they are predominantly silts. It is this group of soils that present the most troublesome engineering problems. Their shearing strength and consolidation characteristics must be determined when they are to serve as embankment foundations; as material for embankments they are rated from poor to unsuitable; cut-slopes must be given special attention to prevent severe sloughing and erosion. A high grade line is generally recommended in these areas.

Delta In some sections of the State, run-of-bank gravel occurs only in deltas formed in glacial lakes. These deposits are recognized in the field by their smooth to pitted top and by the steep sides around their border. The textural composition of these deposits varies considerably and may be predominantely silt or an acceptable quality of gravel. The materials are sorted and in general exhibit a horizontal stratification in the top beds and bottom beds with an inclined stratification in the middle portions.

Bars and Beaches Remnants of glacial bars and beaches are found in many locations. They consist of assorted sand and gravel with a predominance of sand. The bars are elongated ridge-like land forms and the beaches appear as smooth slightly sloping areas. Both land forms represent an excellent source of select borrow and are considered good subgrade material.

Marine Bottom Sediments Deposits laid down by marine waters consist primarily of silts and clays and in general do not exhibit the characteristic varve structure of the fresh water lake deposits. The materials exist at a very high natural moisture content and are greatly affected by remolding. They appear in the field as smooth, almost level plains and their thickness may be as great as 100 feet. The same general engineering recommendations hold in these areas as for the bottom sediments deposited by glacial lakes.

Residual The soils in the small unglaciated area in the southwestern plateau are termed Residual. These soils vary in texture from sand to silt and clay. Bedrock is usually encountered at a shallow depth. The topography is controlled by the type and characteristic of the underlying bedrock and the engineering characteristics of these deposits are the same as those for the thin till areas.

Alluvial Materials deposited by modern streams are termed alluvial. They are generally found in a fairly loose condition, and are silty with occasional lenses of fine sand and gravel. These deposits represent the smooth flat areas adjacent to present streams and are in some instances terraced. During field exploration work in these areas, special attention must be given to the location of old ox bows and abandoned channels. If serving as foundation material for embankments or structures, a careful check must be made of the strength characteristics of these soils. In some areas alluvial deposits have been superimposed on previous muck areas.

Muck and Peat All deposits representing an accumulation of vegetable matter are termed muck and peat and it is always recommended that such materials be excavated beneath embankments. These deposits occur as flat smooth surfaces and a high grade line is always required. If the depth of the material is excessive, special analysis is necessary to determine the most advantageous means of removal.

Meadow Those poorly drained areas occuring as minor depressions in comparatively level topography and containing some organic matter are termed meadow deposits. In general they represent a drainage condition rather than a deep accumulation of vegetable matter. Unsuitable material in such areas is always removed and the structure of the underlying material determined if it is to serve as an embankment foundation.

Muck over Marl In numerous areas of the state, there are extensive deposits of marl overlaid by vegetable muck. The marl is generally of very low stability and represents an unsuitable material for highway construction. The general recommendation in such areas is that the muck and marl be removed until a firm strata is found for the placement of embankment materials. Numerous areas will require a detailed analysis for the adequate and economic handling of the problem.

PRODUCTION OF AREA SOIL MAPS

The area concept of soils is best presented to the engineer in map form using colors and symbols for the basic grouping. The preparation of engineering soil maps includes the identification of the soil deposits as well as the determination of the areal extent of these deposits. For assistance in this latter problem, reference is first made to the pedological maps prepared by the State and Federal Agronomists for agricultural purposes. While the identification of the soils on these maps is not accepted without verification, it has been found that in general the soil boundaries have been thoroughly and accurately determined. The use of these maps as a starting point has the additional advantage that they are at a scale of approximately 1-inch to the mile which is the same scale as the USGS Topographic Maps.

The soil classification shown on the Pedological Maps is analyzed together with the description for each class given in the soil bulletin. Usually it is possible to interpret the Agronomist's description of a particular soil deposit in terms of the engineering soil grouping. A tentative grouping of the pedological classes is made and tested against other known information concerning the area.

Review is then made of all existing geological information for the area involved. The history of the section, the glacial drainage features, the bedrock characteristics and the topography are reviewed. The tentative grouping based on the pedological map must fit the geological and topographical data.

By use of the aerial photograph index sheets, the general aspects of the entire area are checked when trouble is encountered in the identification of a particular portion of the area. Detailed examination is made of aerial photograph contact prints. This procedure of analysis is excellent and is being used to a greater extent as personnel and equipment permit. After utilizing all existing information concerning the type and extent of the different deposits in the area under consideration, a field inspection is made to check the general conditions in the overall area and any questionable areas. At the conclusion of this inspection, a final conference is held by the Soils Engineers, Agronomist and Geologist on the accuracy of the soil grouping. If agreement is reached, the soil grouping is given to the draftsmen together with the Pedological Map on which any revised boundaries have been noted. It has been found that the superimposing of the soil boundaries of a large area on USGS Topographic Sheets offers the best method of presenting these data to the design and construction forces. Colors are used to indicate the geological origin of the deposit and symbols to indicate the depositional units. All map reproduction and coloring are hand work at the present time.

Some maps have been prepared to a scale of 500 feet to the inch from aerial photograph contact prints with a large sized Saltzman Projector. This projector greatly expedites the preparation of the maps by permitting photographs and maps of different scales to be superimposed on a drawing at any desired scale. Since the preliminary highway plans are prepared on a scale of 500 feet to the inch emphasis is also being placed on the development of maps at this scale.

Figure 3 is an engineering soil map for a section of the proposed State Thruway. The section lies just west of the city of Utica and is in Oneida County. The plain area in the central portion of the figure is thick glacial till and is a portion of the southwestern plateau province. The immediately bordering cross hatched areas are the thin glacial till soils. In the eastern section of the map is shown the outwash granular deposits bordering the Mohawk Valley and the alluvial sediments in the immediate vicinity of the present river. In the extreme western section of the map, the thruway will enter the Erie-Ontario Plains Province which consists of bottom sediments in this area. The northerly projection in the central portion of the map also provides information for the connection from the city of Rome to the Thruway. It will be noted that a large muck area is shown in this vicinity and that bars, beaches and delta formations are prominent features. The original map was produced with colors and symbols.

It is expected that the mapping will improve through the continued use of soil survey work in connection with current projects and that the ground work will be done for the development of a statewide engineering map.

USE OF ENGINEERING SOIL MAPS

The area concept of soils embodied in the engineering soil maps is used extensively by the Bureau of Soil Mechanics of the New York State Department of Public Works in organizing and controlling the soil work of the department. The bureau has been organized during the past four years at a time when the largest highway program of the State has been in progress. Many plans were prepared during the war years and a large volume of work is being designed at the present time.

Engineering soil maps have been made during the past year on current projects which required the mapping of a total area of 3,360 square miles. The new Thruway has required the mapping of 1,353 square miles; regular highway projects and one complete county, 1,537 square miles; and, the location of sand and gravel deposits, 470 square miles. In addition to the areas for which maps have been produced, the soil boundaries have been determined in outline form for all projects reviewed by the bureau.

It would have been impossible for the bureau to be organized, check soil conditions on projects already designed and to progress soil surveys on current designs as well as on construction projects without the aid of the area concept of soils.

The first use of an area soil map is in the study of general location problems before actual alignment surveys are started. General soil conditions, the extent of

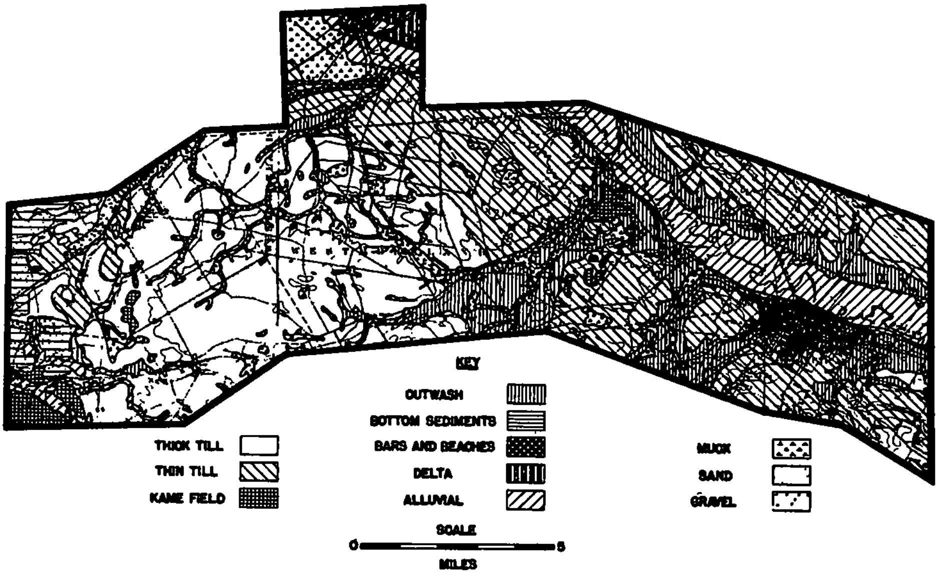

Figure 3. Engineering Soil Map of Mohawk Thruway Oneida County, New York

swamp areas and the availability of selected borrow and granular sub-base material are basic information which the engineer considers in locating the preliminary line for a highway. The maps prepared at a scale of one mile equals one inch are considered the best presentation for general location determinations. After the general location is determined, the soil map is a basis for detailed borings along the highway alignment which must be made to show detail soil conditions for every feature of the highway design. Engineering soil maps to the scale of 500 feet to one inch are best for detailed soil studies. Grade line and general soil boundaries control the spacing of borings and the extent of explorations and subsequent structural soil mechanics analyses. The detailed borings must be sufficient to answer the questions of design and construction. An important feature of the soil map is the delineation of areas in which the deposits are a possible source of selected borrow, granular base course material and local aggregate. These areas are carefully explored in connection with the detailed soil survey.

The preliminary soil report, which is based upon the engineering soil map, presents the general characteristics of the soils and their relationship to the engineering considerations of alignment and grade, earthwork, compaction, subgrade, drainage, frost action, swamps, and source of run-of-bank gravel and selected borrow. Recommendations are made on each soil problem. The engineering considerations contained in the preliminary report are based on the grouping of soils described in this paper. Reference is made to the general engineering statements contained in the description of the soil groups. It is anticipated that with continued use of this grouping, correlation with construction experience and performance of highways, the general recommendations which can be made for any particular soil group will be of more value.

The soil survey work of the bureau is progressed with the alignment survey and design of the highway so that the soil work will be practical and provide the basis for engineering decisions which will result in the design of a highway that will include the best utilization of soils in the area. It is the policy of this bureau to include definite recommendations based on soil conditions for consideration by the Designing Engineer. All general soil information is checked by detailed borings, and final recommendations are based on the detailed soil work. At the completion of the design of the project, a final soil report is made which summarizes the preliminary soil report, the detailed boring information and recommendations which are made by Soils Engineers. This report is used by the bureau in making a final check and approval for the soil work for the project and by the department in reviewing plans, specifications and estimated quantities of contract work.

It is the present policy of the department to require final approval by the Bureau of Soil Mechanics of the soil work and the adequacy of the design and contract quantities for the soil conditions. The engineering soil maps together with the soil report, have proved very valuable in making these final inspections and review of soil work, especially on those projects which have been designed for some time and for which only a check soil survey can be made. On this type of project, the check borings are requested on the basis of the soil areas and the results obtained before the projections can be placed under contract.

The final soils report is made available for the Construction Engineer during every phase of construction.

It is the opinion of the authors that the area concept of soils and the soil grouping should not be considered in competition with existing soil classification systems and neither should notations on a single engineering soil map be used to replace highway engineering experience. Engineering soil maps should be developed on a broad regional basis and the fine detail of soil information obtained by borings should be presented in the soil report for the specific project under design.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the work of the staff of the Bureau of Soil Mechanics on the development of engineering soil maps. The work has been a bureau project and every phase of soils engineering has contributed to the development. The authors wish to express their particular appreciation to Mr. Karl Kurtenacker and Mr. Paul Bird, Engineering Geologists; Mr. John B. Fleckenstein, Agronomist, and Miss Lenore J. Traver, Soils Engineer on Aerial Photographs.

APPLICATION OF GEOLOGY AND SEISMOLOGY TO HIGHWAY LOCATION AND DESIGN IN MASSACHUSETTS

INTRODUCTION

The necessity for securing all possible data pertaining to subsurface conditions in locating and designing highways has long been recognized. In Massachusetts, the usual techniques - test pits, borings, field inspections, et al - have been employed. Usual limitations, however, inherent in such techniques are recognized. The type of highway now being designed, with separated roadways, all grades separated, etc., has greatly accentuated the obligation upon the Highway Department to secure all such data and to establish the proper organization to carry on the work.

In developing the procedure to be followed, and the organization to be established, the Massachusetts Department of Public Works had available to it a cooperative project with the United States Geological Survey for determining the nature of the soils and rocks encountered, but it was recognized that for some purposes ordinary geologic field mapping, especially in locating bedrock, needed to be made more exact and flexible. The seismic method of securing data was suggested by the geologist, although at the time this method had been applied primarily to locating bedrock at relatively great depths and but little work had been done to locate bedrock at shallow depths. In order that the Department might have all possible data on subsurface conditions, arrangements were made for seismic studies to locate shallow bedrock, and for geological studies to provide the geologic interpretation from bedrock to the surface, together with data on ground water conditions.

The application of data obtained through these arrangements to the highway program of the Department was assigned to the Project Division under the supervision of George H. Delano, Project Engineer. L. W. Currier, of the U.S. Geological Survey supervises the joint project. Seismic studies obtained under

[1] Published by permission of the Director, U.S. Geological Survey, and the Commissioner, Massachusetts Department of Public Works.

this program are made by Rev. Daniel Linehan, S. J., of Weston College, Weston Massachusetts.

It is recognized that the work done under this cooperative arrangement since its inception in 1944 has been of an experimental nature and that conclusive results cannot yet be drawn from this research, but it is felt that a progress report of these activities will be of present interest. With this in mind a brief statement follows, giving in turn the approach of the geologist, the seismologist, and the highway designer to the application of geological and seismological research to highway location and design in Massachusetts.

GEOLOGIC METHODS AND INTERPRETATIONS

L. W. CURRIER
Geologist, U.S. Geological Survey

In the design and construction of modern major highways the engineer faces a diversity of problems. These are in considerable measure concerned with the topographic characteristics of the terrains, and the physical properties and structures of the underlying materials. In the days of narrower and lower-speed highways there was greater latitude in choosing a road site. Today the highway route must be as direct as possible, and the design must meet all the requirements of modern highway standards, with curves of adequate sight distances, easy grades, and well-drained foundations capable of sustaining heavy traffic loads. To fulfill these requirements, less favorable topographic features must be traversed rather than avoided in many places, so that deep and wide cuts, and long, heavy fills are frequently necessary. Costs of excavation are greatly increased because many of the cuts penetrate well into bedrock, and costs of filling rise with the greater volume of suitable material to be provided often obtainable only at a considerable distance from the fills. In places, as in boggy areas, unsuitable materials must be removed and suitable ones substituted. Shallow or perched water tables may exist and require special construction to provide good subgrade drainage. Footings of heavy bridge piers must in places be spread in soft or even plastic materials instead of on sound bedrock; in the design of such piers it can be advantageous to know if bedrock can be reached economically, or if the overlying unconsolidated material is uniform and can adequately support the loads to be imposed. Thus the engineer is faced with problems of design and construction that involve many geologic factors. We are concerned, therefore, with the techniques of the engineering geologist insofar as they can contribute valuably to the analyses and solutions of the problems, or facilitate the work of construction. The engineer is not ordinarily prepared by either training or experience to make geologic interpretations.

A land mass that has been subjected to uninterrupted weathering, erosion, and deposition through geologic time normally develops a soil mantle and topography that bear certain clear relations to each other and that reflect the local subsurface rock structures and materials. The mineralogic composition of a residual soil formed under such conditions is consistent with that of the underlying rock from which it was derived. Except where it is a residual from impure limestone, or other less common soluble formations, the soil grades from unconsolidated material at and near the surface through a transition zone into solid rock. In such places, the, the contact between the bedrock and the derived soil is not sharply defined. The thickness of the soil zone, too, varies with the lithology of the area, the depth of the ground-water table during the formation of the soil, and other geologic factors, but the variations follow a consistent pattern with respect to the topography and lithology, so that many of the local engineering problems have geologic factors that are resolvable in fair measure through accumulated experience in the terrain. Without much formal knowledge of the geology, the engineer of local experience can often interpret the features and predict what subsurface conditions he will probably find. He may be able to project his experience from place to place over a considerable area with reasonable assurance, according to his store of knowledge and the keenness of his powers of observation, even though he may not be able to describe his data in established geologic terms. When finer details of interpretation are needed, he must call upon specialists, but many of the simpler problems of the terrain he is able to solve for himself because the geologic phenomena are gradational and are integrated according to a consistent regional pattern; it is this "pattern" that he may learn to sense through experience.

In an area where former continental ice sheets have transgressed, however, as in New England, the normal integrated cycle of weathering, erosion, and deposition has been interrupted and the characteristic land forms have become disordered, so to speak. The thick ice sheet moving across the region covers both hills and valleys. Commonly its thickness is from a few hundred to several thousand feet, so that the pressure at its base is considerable. The ice sheet picks up or pushes along the loose soil mantle, scrapes the bedrock clean of its previously decomposed and disintegrated surface layers, and further abrades the bedrock itself. The materials picked up or pushed along by the ice includes particles that range from clay sizes to large boulders or blocks plucked from rugged ledges. The rock debris is so mixed up that, when later left in place by the melting ice, the components of the resulting heterogeneous soil layer may no longer accurately reflect the underlying bedrock formations. The material at a given point may have been derived in large measure from a distant area. Such unsorted glacially deposited material is known as *till*, and may have been drived from many bedrock formations, local and distant.

Glacial erosion broadens and deepens preexisting bedrock valleys and steepened their sides. It reduces and rounds hills and ridges. The meltwaters pick up abraded material incorporated in the ice or heaped beneath it, and sort and transport it so that gravel, sand, silt, and clay are deposited along the glacial stream courses. Thus outwash plains are formed over the valley floors in front of the ice sheet. Deltas and lake-bottom deposits form in temporarily ponded areas. Long sinuous ridges of gravel and sand may be left within broad valleys and mark the positions of streams that flowed between the ice walled channels. High-perched terraces may line the valley walls where they were deposited between the walls and the sides of an ice tongue. It follows, therefore, that glacial deposits characteristically rest with sharp contacts on fresh, hard bedrock, or on other glacial deposits, in contrast with the gradationally zone between soils and bedrock in a nonglaciated area, as described above. Finally, among the effects of glaciation that may be of great importance to the engineer is the disarrangement of the drainage pattern. Valleys are filled partly or are blocked, and the postglacial drainage lines frequently do not follow the courses of the preglacial channels. Entirely new channels may be cut along the paths even of major streams that have been locally displaced; these new channels are commonly cut into bedrock, with the preglacial channel lying buried somewhere in the vicinity. Thus the effect of glaciation is to obscure the orderly results of the earlier normal erosion cycle.

The engineer who is untrained in the applications and techniques of geologic science is, therefore, not only unable to project his local experience from point to point in a glaciated area with reasonable assurance, but many times he cannot interpret even the local soils and rocks with sufficient certainty; it is the third dimension that is not disclosed to him, and it is the variation in this vertical dimension of the terrain with which he is particularly concerned. The surface deposits may be misleading, the soil zone greatly variable even within shallow depths, and hidden boulders may, and often do, mislead or confuse him with regard to the position and nature of the bedrock. It is true, of course, that the geologist cannot always make accurate interpretations from surface data alone, but must rely on some other techniques; nevertheless, even where surface data are inconclusive to him, the geologist's guess is considerably better than the engineer's, and is based on laws of geologic probability as suggested by the local surface geology. He is, by virtue of training and experience in his science, in a far better position to make directive interpretations and give warning of probable or possible difficulties. He should, in general, be better equipped to work with specialists in the fields of seismology and soil mechanics, and, indeed, should be in a position to advise when such collateral services are needed or desirable; moreover, he should not be reticent or hesitant in recommending such services.

The common impression that geology is an inexact science arises largely from the fact that geological phenomena are generally gradational through all degrees and between wide limits. Appreciation of this fact is necessary if the science is to be used to its maximum benefit. For the most part, however, it is neither the geologic concepts nor the geologic techniques that are inexact; rather it is the variability of the phenomena and difficulty in obtaining enough exact measurements that make it appear as a qualitative science. But even if the engineer approaches it from the qualitative viewpoint he can find it very useful, particularly in the preliminary and planning stages. It is a serious mistake for him to disregard the concepts and teachings of a science whenever its techniques do not justify the use of the slide rule or calculation of its physical data with "engineering accuracy." It is worse than futile - it is misleading - to report data to a fraction that is measurable only within units. Much of the geologic data usually acquired is of this nature, though the techniques employed are capable of considerably greater refinement. To recognize these techniques, then, and to bring them into the formative stages of the engineering project is as much the duty of the engineer as it is the duty of the geologist to evaluate his own methods and apply them with appropriate care.

The physical features of the terrain, that is, the topography, rocks, and soils, are elements that may be analyzed by the special techniques of the geologist and the soil scientist. These technicians, therefore, are able to supplement and aid the work of the engineer by furnishing pertinent physical data are not otherwise available to him. It seems axiomatic that insofar as these special techniques can furnish such data they should be available in the preliminary stages of highway location and design. As these techniques advance through experience and research they should be under constant critical scrutiny so that their potential usefulness may be recognized. The geologist and the soil scientist should each know his own limitations as well as each other's, and should be able and ready to advise where the use of other techniques may be helpful. as in the field of seismology.

The geologist's aim is to call the attention of the engineers to the kinds of data available through geologic techniques, and to make such data as directive and quantitative as possible. It is helpful if he knows something about the technical methods of the engineer, but he should not presume to advise in purely engineering methods. Upon the engineer, on the other hand, rests the responsibility to seek and use all available data that will contribute to sound and economic design or construction of highways and bridges. This, then, is the philosophy that determines the pattern for engineering geologic work under the Massachusetts program.

The Massachusetts geologic program was started in July 1938, as a cooperative project between the Massachusetts Department of Public Works and the U.S. Geological Survey. The primary and principle purpose is to make a complete and detailed geologic study of the State, the results of which are to be embodied in two geologic maps and accompanying brief reports. The maps are to be printed in colors. One of them is to show the distribution and structures of bedrock units beneath the soil mantle, as interpreted from bedrock exposures and available subsurface data; the other is to show the distribution and nature of the unconsolidated, superficial formations, the "soils" in an engineering sense, that overlie the bedrock, and also to show the actual bedrock exposures. Among the mineral resources to be indicated on these maps are the materials used in highway construction, such as gravel, sand, rock for crushed stone, and so forth. Mapping is being done by quadrangles, on new 7½-minute topographic base maps, the scale being two inches to the mile and the contour interval 10 feet. These maps permit considerable detail and accuracy, and engineers and geologists engaged in either public or private work will thus have fundamental geologic control for their own more detailed work in small areas or on special problems. Two compiled geologic maps of the State will be prepared from the quadrangle maps, on a scale of 1:125,000, or about ½ inch to the mile.

Special geologic studies are made under the program at the specific request of the project engineer of the Department. These studies are of four types, as follows:

1. *Gravel and sand resources of particular areas.* For areas of projected highways where the resources are as yet unknown, or the known deposits are unavailable or inadequate, detailed geologic maps are made to show the distribution and

land forms of all deposits of sand and gravel. An accompanying table indicates for each potentially important deposit the approximate volume, areal extent, dimensions, accessibility, and type of material. Pertinent general observations are made regarding the quality of the material, pebble sizes, proportion of sand, freshness of the pebbles, and probable utility. No grade-sizing tests are made, as these are considered to be outside the province of the geologic program. The map is intended as a guide to point out apparently favorable deposits for further investigation by engineers of the Department.

2. *Reconnaissance geology* When a segment of a proposed highway has been located by engineers, a detailed geologic map is made along the centerline for the purpose of determining the kinds of materials, the geologic structures that may have a bearing on engineering operations, and the distribution of bedrock outcrops (see Figure 1). Usually, the reconnaissance strip so mapped is from a quarter to half a mile wide, but may be greater or less according to the complexity of the area and the need for finding additional data to aid in the interpretation of the geology along the centerline. A brief report summarizes the geology and calls particular attention to features that may prove troublesome. Where the geologic data appear to be clear and unequivocal no further studies are made. Where geologic conditions are complex or obscure, and more specific data are needed, other kinds of studies (such as ground-water investigations or seismic tests) are indicated by the geologist. Occassionally this preliminary reconnaissance study leads to a consideration of other possible locations for the highway segment. It is always desirable to have an engineer review the strip in the field with the geologist; in this way interpretations are clarified and pointed up, the geologist becoming more acute with respect to the engineer's problems, and the engineer learning how to use the geologic data with greatest profit and to judge the limitations of geologic studies.

3. *Ground-water investigations* The highway engineer is concerned with ground-water conditions along the highway site because of the effects of ground saturation and seepage upon the stability of the subgrade, especially in freezing weather, or upon the walls of cuts that have reached to or even penetrated the local water table. Perched water tables are quite commonly found in glaciated regions where lakes have once existed. Even certain types of compact till overlain by loose till or sand and gravel are so impervious as to cause seepage into the walls of a cut during the more humid seasons. The engineer wishes to foresee such conditions and to provide for adequate drainage. The conditions vary from place to place and the variations are direct functions of the geologic materials, structures, and topography. In places the possible effects on highway construction of local ground-water supplies and individual wells present problems that require study by ground-water specialists. When necessary, ground-water problems are referred to geologists of the Ground Water Division of the Geological Survey, working also under a continuing cooperative program with the Department of Public Works, for ground-water studies in the Commonwealth. Separate reports or statements are prepared by this Division upon request of the supervising geologist.

4. *Seismic studies* Where more exact knowledge of the subsurface materials, and especially the depths

to bedrock or compact, hard till is needed, seismic tests are recommended by the geologist. The details of the seismic operations and the fundamental theory of the technique are described in Part II of this paper, by Rev. Daniel Linehan. In brief, the method determines the velocities of explosion shock waves in the successive subsurface media, and from these velocities and their variations are interpreted the general characters and depths of the materials. The method provides physical constants of the media, and because the materials vary in their physical properties and the ranges of these properties overlap, their interpretation in geologic terms must be made with a knowledge of the geology of the general area. It is necessary, therefore, for the geologist and the seismologist to work in close cooperation, so that the data obtained by each may be coordinated. The preliminary geologic study of the highway strip furnishes the necessary background, inasmuch as the seismic locations are recommended as a result of the geologic study, but the geologist also accompanies the seismologist in the field when the seismic work is done so that controlling interpretations may be made on the spot, when necessary, and changes made in locations of profiles, or additional profiles recommended. A joint report is prepared by the geologist and seismologist.

The seismic method is used primarily to determine depths to the bedrock surface, and to interpret the probable profiles of this surface along the line of traverse. The depths to bedrock are determinable only for the ends of a traverse, at which points the explosive charges are set off. The variations of the wave velocities between these points will, however, indicate the slope and changes in slope of the rock surface relative to the ground surface so that the seismologist is able to interpret a complete profile of the bedrock surface between the ends of the traverse. By using a sufficient number of seismic detectors and choosing the proper spacing for them a considerable amount of detail may be obtained. The closer the spacing of detectors the more detailed will be the data, but in some places, where the bedrock surface is very irregular, the data obtained by close spacing may become very complicated and the bedrock irregularities may be interpreted with less clarity than the general slope of the surface. Using the profiles plotted by the seismologist, the geologist completes the geologic section along the traverse by interpreting the materials on the basis of his local geologic studies. In places it is possible to interpret, from coordinated seismic and geologic data, several successive layers, such as loose sand on clay on bedrock, or loose till on compact till on bedrock. Figure 2 illustrates geologic sections interpreted upon seismic profiles for a specific highway location.

It has been standard practice to make a profile first along the highway centerline, and as needed to make additional parallel or cross profiles. A few locations have required but the single centerline profile together with areal geologic data to show that the bedrock surface is well below the proposed cut and the soil material is uniform. Where shallow bedrock is indicated by the centerline profile, however, and probable variability is indicated by the surface geology, additional profiles are agreed upon by the geologist, the seismologist, and the engineer, to satisfy their individual requirements for control data. Where it is desired to plot

COMMONWEALTH OF MASSACHUSETTS
DEPARTMENT OF PUBLIC WORKS

COOPERATIVE GEOLOGIC PROJECT

U. S. DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

GEOLOGIC RECONNAISSANCE ALONG A PROPOSED HIGHWAY SEGMENT RELOCATION OF ROUTE 2; LEOMINSTER, MASSACHUSETTS.

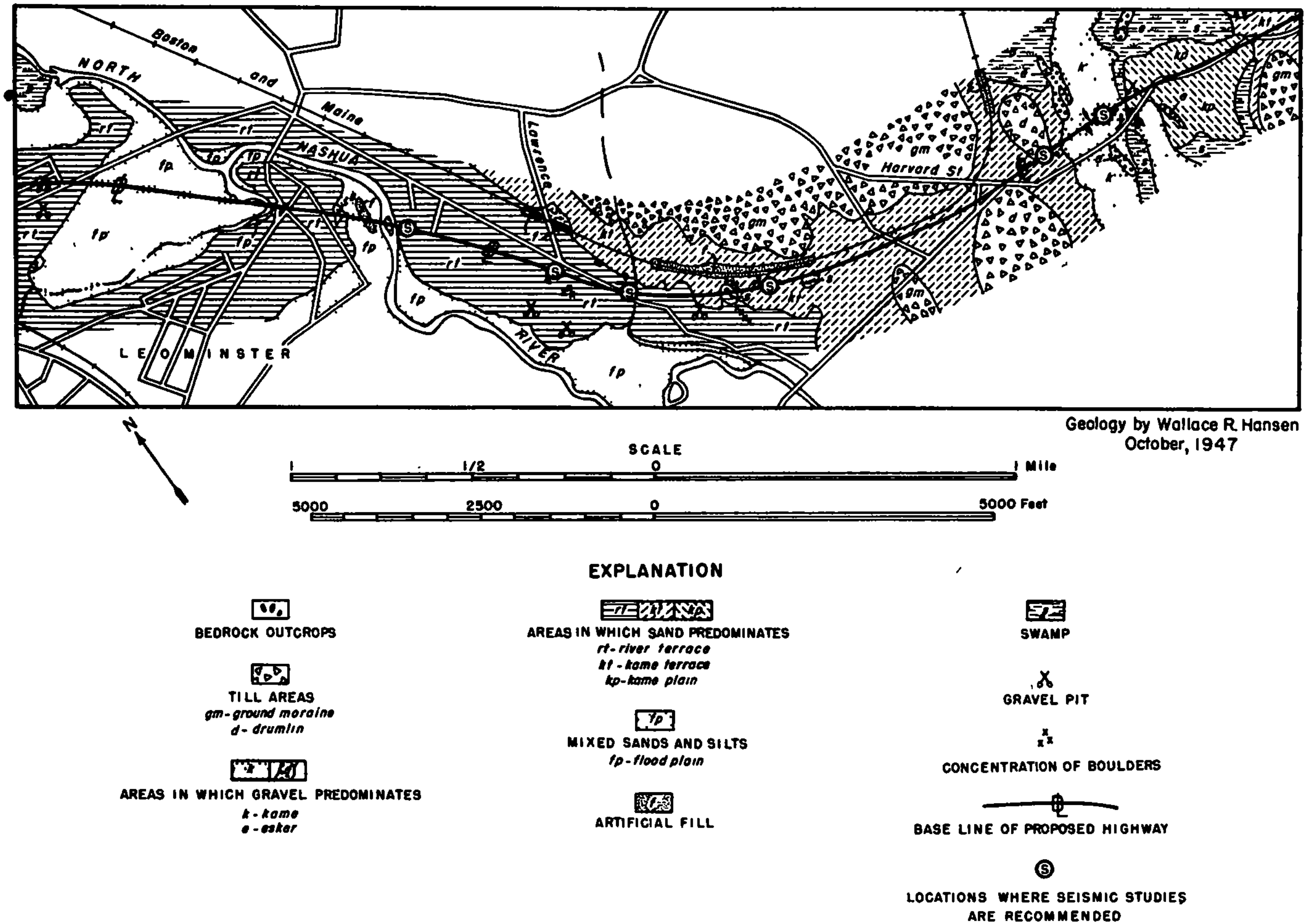

Figure 1. Geologic "strip" map showing distribution of soil materials, bedrock, and land forms along a segment of a proposed highway location.

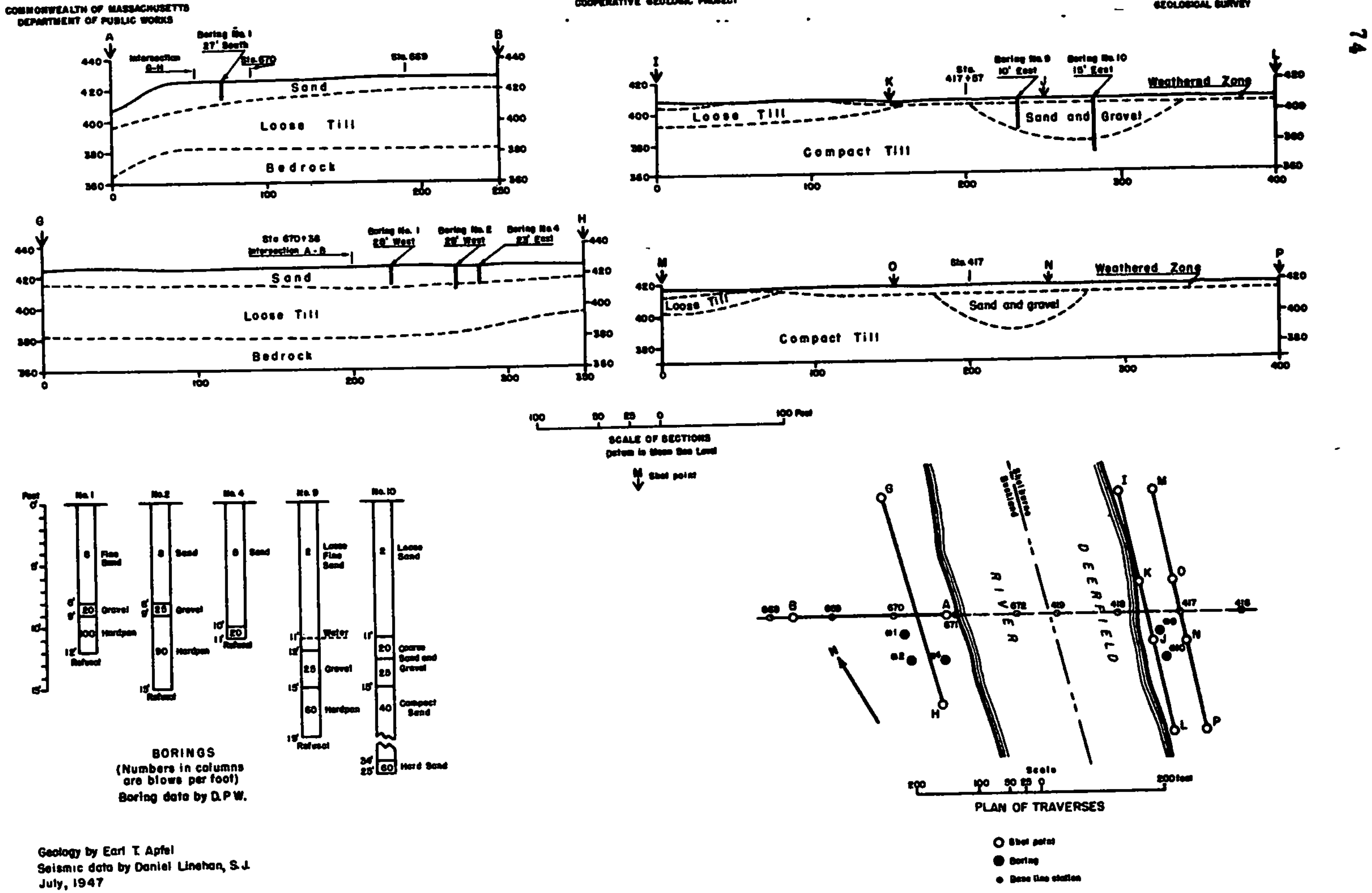

Figure 2. Interpretative Geologic Sections Along Seismic Traverses, Showing Correlation With Boring Data: Relocation Of Route 2, Deerfield River Crossing; Shelburne-Buckland, Massachusetts

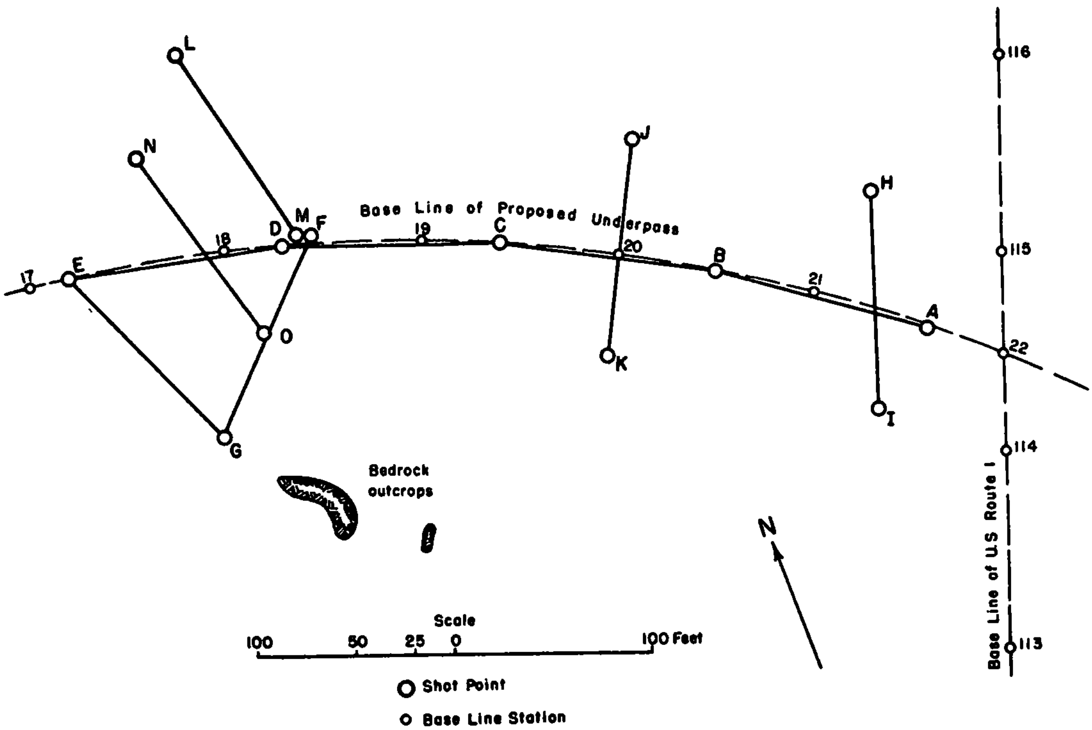

Figure 3. Plan Of Seismic Traverses At Proposed Underpass Of Route U. S. 1, Peabody, Massachusetts

contours of the bedrock surface, additional profiles are made to give an areal spread of actual depth determinations. At bridge sites traverses have been arranged in T-shape on both sides of the river; this arrangement gives several depth determinations at the pier locations, and the slopes of the bedrock surface along the centerline. Cloverleaf underpass locations may require a considerable net of traverses (see Figure 3).

Wash borings have commonly been used to determine subsurface conditions and materials; "refusals" in such boring, however, are commonly unsatisfactory, because there is no discrimination between refusal due to a boulder and one due to bedrock. Numerous borings may be required to distinguish a large glacial boulder from bedrock, but a single seismic traverse will indicate whether or not refusals along a line of borings are due to one or the other. Thus the seismic method is of considerable value for interpreting boring data and controlling or limiting the choice of bore-hole locations.

Seismic methods have been used for a long time in deep subsurface exploration, especially by the petroleum industry, but the application of the seismic refraction method to such shallow-depth studies as are involved in highway engineering is believed to be rather a pioneer approach to the problems of highway location and design. There are certain difficulties to overcome and certain others that may not be resolved, but the technique is improving and has been decidedly helpful in many places. Experimentation is being carried on to determine the optimum spacing of detectors and lengths of traverses for various purposes and terrain conditions. Further research is needed on certain particular application, as in some types of swampy ground, and areas in which the bedrock surface is very uneven. It is expected that some of the problems will be solved through the research that is being included in the Massachusetts cooperative program.

SEISMOLOGY AS A GEOLOGIC TECHNIQUE

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This paper, as one of three treating geological and seismological research and their application to highway location and design, deals especially with the seismological aspect of the study. The seismic surveys were operated by Weston Observatory, a department of Boston College, Chestnut Hill, Massachusetts.

For a more complete understanding of the seismic refraction method as used in these surveys, the reader is referred to the texts listed at the end of this paper. However, in consideration for these unfamiliar with the method and who may not have the time or opportunity to study a text, a very brief outline of the procedure is inserted.

The Method The seismic method is based primarily on the measurement of the time for the advance of a wave front generated from an explosion. This measurement is made by timing the arrival of the wave at various instruments placed in progression away from the explosion or "shot point".

The diagram, Figure 4, represents the advance of a wave front in a two layer structure consisting of about 80 ft. of gravel on bedrock. The wave travels about 5,000 ft. per sec. in the gravel, and about 20,000 ft. per sec. in the bedrock. In such a condition a wave front will be an approximate sphere of 50-ft. radius .01 sec. after it leaves the shot point as represented in the diagram. About .016 sec. after the shot, it reaches the rock surface at point A. From this point of contact a wavelet starts into the rock with a velocity of 20,000 ft. per sec. and .02 sec. after the shot the wavelet has reached the distance noted by that circle in the diagram, not only vertically below A, but radiating in all directions within the rock, so that even along the gravel-rock contact the wave front has reached the point B. However, along the contact the the wave in the rock starts a new series of wavelets that emanate into the gravel and are directed to the gravel surface. The wavelets at B and C are but two of many such wavelets present, and their envelope is the new refracted wave as shown (D- E) .025 sec. after the shot.

Figure 5 diagrams the continued advance of the wave front until .05 sec. after the shot, with the arrival times at the instruments plotted against the distance from the shot point. Clearly, the wave front through the gravel travels on to each instrument at 5,000 ft. per sec., but there is a point along the line, or profile, where the wave front refracted from the rock, owing to its higher velocity gained from the rock, will reach an instrument before the direct wave. In the diagram this is a point a little more than 200 ft. from the shot point. Thus the velocities of the materials may be determined; those of the earlier arrivals may be computed to be 5,000 ft. per sec., the velocity of the gravel in the problem, and the later arrivals fall along a line whose slope equals 20,000 ft. per sec., or the velocity of the bedrock. The distance from the shot point to the point of intersection of these two lines is controlled by the thickness of the

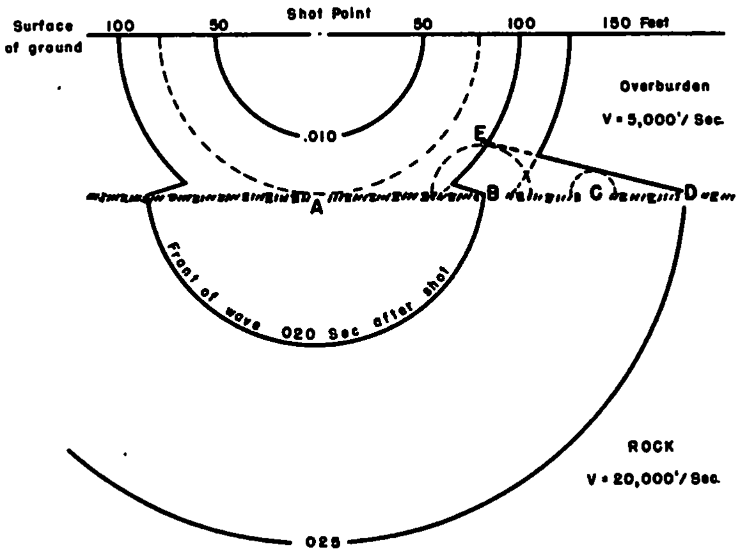

Figure 4. Diagram To Illustrate Successive Positions Of An Advancing Wave Front Generated From An Explosion, In A Two-Layer Region

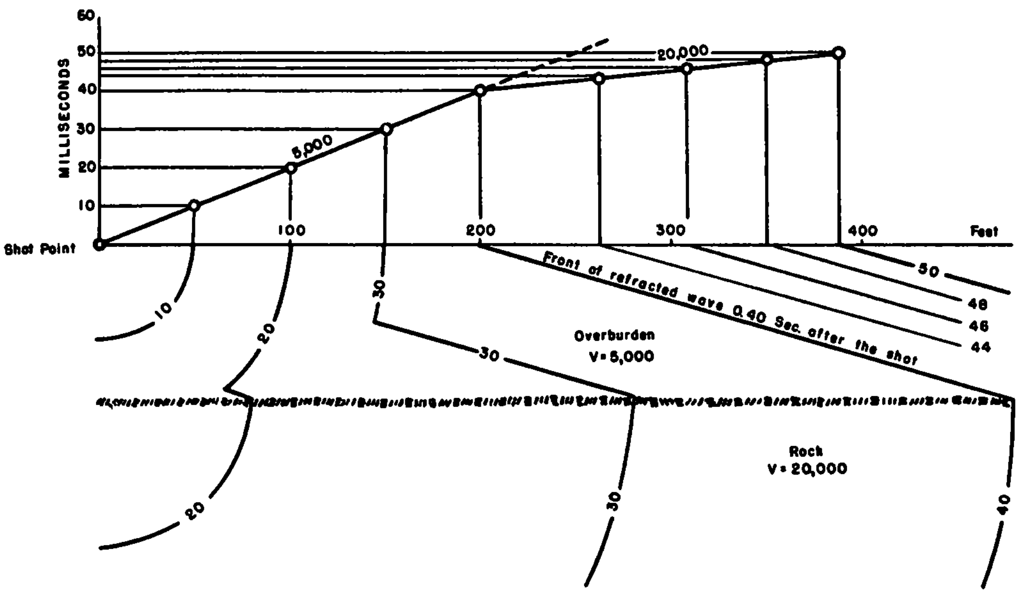

Figure 5. Diagram Of Wave Fronts, And The Related Travel-Time Graph For A 400-Foot Refraction Profile, In A Two-Layer Region

gravel, and the greater the thickness, the greater will be the distance of the intersection from the shot point. From this the seismologist is able to determine the depth to bedrock. The velocities are functions of the types of soil cover and bedrock. A few of these velocities will be listed below.

Furthermore, and as may readily be seen, if the rock surface is inclined instead of parallel to the surface of the ground, the velocities of the rock as determined will differ according to the direction in which the shot was recorded. Such velocities are known as the "apparent" velocities. If the rock surface slopes downward from the shot point, the refracted wave will have to travel farther to the surface at each successive instrument and the velocity will be slower than the "true" velocity of the rock. If the rock slopes upward from the shot point there is less distance for the wave to travel and the apparent velocity is greater than the true one. The true velocity value must be computed from the two apparent velocities; these do indicate, however, the direction and approximate amount of slope of a rock surface. Hence, each profile must be "reversed," that is, shot points are taken at both ends of the instrumental set-up or profile.

Again, if the rock surface is smooth the arrival times will fall along a straight line; if the surface is irregular the arrival times will vary according to the rise or fall of the rock surface. The positions of these points generally give a mirror reflection of the rock surface.

Field Equipment Employed The seismic equipment employed in making these surveys is owned in part by Weston Observatory, and in part is on loan to the Observatory by the Humble Oil and Refining Company, Houston, Texas. The equipment consists of 12 seismometers of the magnetic-reluctance type suitable for surface or underwater work, 12 amplifiers, recording camera, darkroom, water supply, two reels holding 750 ft. each of 12-channel cable, ground augers, etc. These are mounted in a 1½-ton panel truck fitted with four wheel drive and front end winch. Thus the equipment could be carried to almost any type of terrain.

Profile Lengths Outlets on the cable were placed every 100 ft. permitting profiles up to 1100 ft. long to be made with instrument intervals of 100 ft. When closer spacing is desired the extra wire is coiled near the instruments. The closer the spacing used the more detailed will be the bedrock velocity line, although less depth can be determined per set-up and less territory covered per day. The various profile lengths and corresponding depths that may be determined are given below:

Spacing ft.	Profile Length ft.	Depth Desired ft.
10	110	0 to 30
15	165	0 to 40
20	220	10 to 70
50	550	25 to 160
100	1100	50 to 300

Other set-ups have been tried but the above distances are those most commonly used in the types of problems described herein. Such arrangements considered in the light of the method given above will show that the seismologist, geologist, and engineer working together may determine a fairly accurate picture of subsurface conditions. A few of our type problems and results follow.

Bedrock Depth Determinations Depth to bedrock is frequently one of the more important quests of the highway engineer, and fortunately one of the easiest problems for the seismologist to solve. The latter requires but a rock with sufficiently high velocity in comparison with the overburden. In Massachusetts both crystalline and noncrystalline bedrocks transmit longitudinal waves with velocities favorably high. Rarely are the rock velocity constants less than 12,000 ft. per sec., and from what has been explained in the previous paragraphs such velocities facilitate depth determination. Moreover, irregularities in the rock surface as slopes, terraces, etc., stand out clearly with offsets in the velocity line. In some of the metamorphosed rocks of Massachusetts, local parts of the rock may raise the velocity under an instrument or two; such an effect might be misleading and usually calls for several cross profiles as well as the reversal to delineate the bedrock surface. The opinion of the geologist and his knowledge of the local geology plays a great part in the interpretation of such conditions.

Determination of Soils, Gravels, Etc. Sound velocities are frequently indicative of the type of cover, and the following table is characteristic of some of these deposits in Massachusetts.

Evidently, the overlapping of these velocities precludes any exact designation of many of the buried deposits, but the velocity range does give some measure of the engineering characteristics of the material, especially its strength, that are determined by compactness and crystallinity.

Throughout the greater part of Massachusetts it is quite impossible to determine the depth of the water table by the seismic method because most of the materials, wet or dry, have velocities in that range. On Cape Cod, where the unconsolidated surface sediments may extend to depths of several hundred feet, we believe we have located water tables in places but to date we have not been able to check our data against borings. These velocities may change during the season of the year depending upon the water content of the soils, that is, the marked rise and fall of the water table.

Velocity ft. per sec.	Material
1,000 to 2,000	Dry loam; some aeolian deposits.
1,500 to 3,000	Dry sands; loose till, etc.
3,500 to 5,500	Compact tills; gravels within the water table, etc. Some clays.
5,000	Varved clays in Connecticut River Valley.
6,000 to 8,500	"Hardpan" compact older tills, etc; some foliated bedrock across schistocity

Road Cuts Through Clays If a clay layer is thin it may not be detected unless the instrumental spacing is very short; with greater thickness its detection is possible by seismic methods, and such detection is necessary if a road cut passes into or through the clay. If such a layer appears on the face of the cut, it may drain water from the surrounding area onto the cut face and cause erosion. It is also important to know whether this layer is draining into the cut or away from it.

In Chicopee such a site was surveyed seismically with very good results. The varved clays present gave velocities of exactly 5,000 ft. per sec., and the sand cover was less than 2,000 ft. per sec. Instruments were spaced at 5-ft. intervals and the sound energy was supplied in some cases by striking the ground with a shovel. Small depressions, dips, etc., were easily seen in the surface of these clays.

Bridge Foundations Although bedrock might be desired for a bridge foundation, it is not always necessary. If it is too deep, then a compact till is satisfactory and the shape and structure of the foundation is determined by the supporting strength of the material. Borings alone may be misleading in glaciated regions owing to the presence of boulders or variations in the surface of the till.

At Shelburne Falls, a site treated more completely in another paper of this series, the seismic data demonstrated bedrock some distance below the refusal depths of the borings (see Figure 2). As is evident from the profile of this section, the borings stopped at the till surface. However, the seismic data did show an area of low velocity cutting into the till surface across two parallel profiles. This was interpreted as an early drainage channel that became filled with lower velocity material, and, for the engineer, material of less strength. Without the accompanying seismic data the results of the driller might prove confusing here.

Location of Fill Materials having good binding properties for fill in dams, retaining walls, etc., are easily discovered from their velocities. Deposits with velocities from 6,000 to 8,000 ft. per sec. appear to satisfy the engineer's requirements. Frequently these materials are buried under other deposits and unless the seismic method is employed in searching for them, the investigation may become expensive. One example of such a deposit was surveyed in Worcester. The seismic data showed a cover of about 20 ft. of low velocity material over 70 ft. of high velocity till. The entire area was surveyed seismically and the approximate number of cubic yards of material could be determined. Borings at one point brought up samples that met the engineers' demands.

Close Spacing of Instruments Close spacing of instruments, as mentioned above, affords detail on bedrock and cover conditions. At times, however, a plethora of detail may confuse the interpreter, a case of not seeing the woods because too many trees obscure the line of vision. Where the rock surface is very irregular the variations of the velocity lines are likewise so irregular that the determination of a true velocity may be almost impossible. The apparent velocities run the gamut from extremely low to very high and even "negative" velocities. Under these conditions it is better to operate several wider-spaced profiles merely to obtain the true velocity and a general idea of the bedrock slope. Afterwards the shorter profiles become understandable and cross profiling clarifies the picture.

In Peabody a pass under U.S. Route No. 1 requiring at least 20 ft. of cut demonstrates the use of this spacing. The plan of this area with ledge and apparent ledge outcrops made the proposal appear expensive. This plan as given in Figure 3 shows the locations of bedrock outcrops and of the operated profiles.

A seismic survey was run along the centerline using 110 ft. profiles, with one 220 ft. profile from A to C to determine bedrock velocities where conditions were least confusing. Cross profiles were

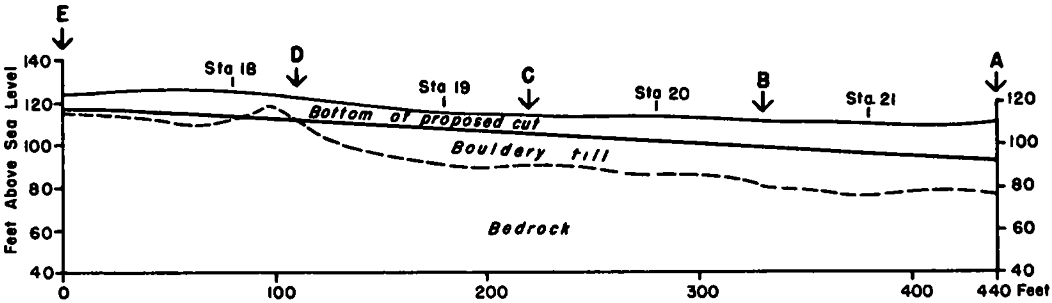

Figure 6. Geologic Interpretation of Seismic Profiles Along Centerline Underpass of Route U. S. 1, Peabody, Massachusetts (see also Figure 3).

also freely used to check the centerline profiles as well as the depth along the width of the cut. Evidence of a sharp rise between stations 17 and 18 resulted from the seismic survey, and after several cross and angular profiles in this vicinity the seismologist interpreted this rise to be in the shape of a small but prominent knob. These profiles also showed some apparent outcrops to be large boulders. Near G is a large outcrop ledge, but the seismic evidence showed that this ledge dropped abruptly, so that a few feet away from it bedrock was at least 20 ft. deep. Excavation to date has broadly substantiated the seismic interpretation. The ledge has been found to drop sharply, and certain apparent outcrops are very large boulders, one of which is at least 10 ft. in diameter. The knob of rock rises, but is approximately 20 ft. to the west of the spot indicated and a little off the centerline. The seismic profile of this traverse appears in Figure 6, a heavy line showing the exact position of the ledge as uncovered and a dotted line showing the amount of excavation to date of this paper.

Difficulties Several times during the excavation at the Peabody site, just described, the steam shovel operator was under the impression that ledge had been reached above the seismic line, but further excavation proved such to be boulders. We have found it difficult to distinguish between so-called "boulder nests" and rock surface irregularities. Usually, when such discrepancies appear, our profile line signifies velocity changes that might indicate either. Financially it will prove as expensive to excavate large boulders as it does ledge, although planning by the engineer for drainage, etc., may not be as complicated. It is unfortunate that a greater distinction in these velocity lines was not obtainable. It will be several months before the cut is completed at this site, and, no doubt, further excavation will delineate conditions different in some respect from the simple interpretation of the seismologist. We feel that the general picture will not differ too much from it and experience gained here may be applied to future and similar problems. We have found that the close spacing of short profiles can be worked with success.

Frequent difficulties arise in generating sufficient energy in certain materials. This is true where the ground has been reworked, and material such as quarried stone has been dumped as a shallow cover. The lack of binding material in the interstices of the rock pieces damps the sound wave. In some dry sands, ashes, etc., it is better, if possible to place the shot hole outside of or below these materials; they do not permit the generation of a wave, but will readily transmit it once it has been generated outside of the material.

In some swamplands we have met with little success if there is a layer of thick peat on the surface. Our results have not checked with the borings in two such places; at Lunenberg and Manchester. In both places, the record characteristics were such that the seismologist was aware even before plotting that results would not be satisfactory. We are quite certain that our error was due to improper planting of the instruments. Plans have been made to reshoot these swamplands using deeper instrument planting to get below the loose peat on top. When the instruments were placed at the edge of some road fill and out of peat at Lunenberg, the seismic results checked with those of the driller.

In densely populated areas seismic surveying may become difficult, but not impossible. Foot or vehicular traffic may cause sufficient ground unrest to render trimming of the amplifiers so low that the amount of explosive required becomes embarrassing, if not dangerous. Usually, however, it is possible to halt traffic for the few moments of actual shooting operations. Ground unrest from factory operations is another question, and we have to operate during their inactive periods. One factory owner did accomodate us by shutting down his plant while we shot.

Power lines and airports cause trouble at times. The former may be taken care of by proper filtering in the circuits, but the latter not so easily. The airwave from the propeller noise is very troublesome and the larger planes give us the more trouble as the frequency is nearer to that of the instruments.

The proximity of buried water and gas mains, oil tanks, etc., must also be determined beforehand lest an explosive charge be fired too close to them.

Areas of irregular topography may be corrected afterwards in the plotting, but we prefer to operate a profile along a contour line if possible to avoid the later corrections.

Amount and Kind of Explosive Used The amount of explosive used per shot is not great. Profiles of 110 to 220 ft. in length demand no more than ¼ to ½ lb. charge of 60 percent nitro-glycerine. If the shot hole is made with a bar and hammer to a depth of four feet, it will not blow out unless the soil is unusually soft or is wet clay over rock. For longer profiles up to 550 ft. in length, 1 to 2 lbs. of *Nitramon* is used. For these latter charges shot holes are dug with augers to a depth of about six feet. In populated areas or when near power lines, we have made it a general practice to cover all shots with a blasting mat.

Area Covered Per Diem In seismic surveying for highway design and location the amount of work accomplished should be considered in the number of profiles operated rather than the area covered. In open and accessible country, two seismologists, a geologist, an engineer, and four laborers can easily operate eight 110-220 ft. profiles and their reversals in a day. This includes driving the shot holes, tying-in the location, mapping profile elevations, and making preliminary field readings of the records. Where paths must be cut through brush and undergrowth, and the cables "snaked" through obstacles, the number of profiles is decreased. Time could be saved if the cables were standardized to a definite length profile, and the cables thus used for measuring positions as well as profile lengths, but it has proven impossible to choose any standard, as conditions may vary at each location. Whenever possible, the seismologist attempts to make a complete plot of his readings for the day's work. This permits a more judicious placing of profiles on the day following so that other profiles may cover areas of doubtful subsurface conditions. Even then, we have found that, with the seismic work apparently completed for an area, conference with the geologist and engineer has resulted in placing other profiles to clarify the picture.

ACKNOWLEDGEMENTS

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DISCUSSION

Philip Keene, *Soils and Foundations Engineer, Connecticut Highway Department* The author is to be congratulated on an interesting paper, forming part of a well-integrated group of three on the use of geological methods in solving some highway problems.

The paper brings two questions to mind regarding information from seismic surveying. These are:

First, is it not often difficult to distinguish between dense glacial till and bedrock? Many glacial tills in Connecticut are composed of exceedingly well-graded soil - boulders, cobbles, gravel, sand, and silt, with or without clay. These silty and clayey tills have densities of 135 to 145 lb. per cu. ft., dry weight, and sometimes must be blasted to be readily excavated. They are definitely soils, for they slough and become "soupy" when subject to unfavorable ground water and surface water conditions. When washed and sieved in the laboratory their component parts are immediately recognized. Their velocity constant might be as high as 10,000 ft. per sec., which is about the same as for weathered rock.

Frequently these tills lie directly on bedrock. One of our foremost seismologists, who is also a leader in the field of seismic surveying, related to me a few years ago his unfortunate experience in a northeastern state where his seismic survey data led him to label as soft bedrock a thick stratum of clayey till which overlay bedrock.

The second question is whether location of rock surface by the seismic method is more accurate in the valleys than on the hills. In Connecticut, rock surface in valleys is frequently irregular, but on the hills it is very much more so.

Closure, Rev. Linehan

The existence of high velocity tills does offer difficulty to the seismologist, but where the bedrock is moderately "hard" interpretation is usually possible and moreover accurate. We have encountered these tills with velocities varying between 6,000 and 10,000 ft. per sec. in Massachusetts, Connecticut, and New York. Subsequent borings have shown these materials to be similar to those described by Mr. Keene.

Rarely, if ever, have we found local bedrock velocities as low as these till velocities, although there might be a difference of only a few thousand feet per second. The solution lies in the arrangement of the profiles. If a system of continuous profiling is operated the till velocities are readily distinguished from those of the bedrock. If, on the other hand, isolated profiles are employed, the computer is apt to confuse the lower till velocity as an apparent low velocity of the bedrock signifying a slope-dip of the bedrock surface. With continuous profiling the computer observes "tie-ins" of till velocities from one profile to another as well as the "tie-ins" of the rock velocities.

Usually the surface of the till is uniform whereas the bedrock surface may be irregular, and this irregularity may be used as an occasional norm in distinguishing between the two materials.

The problem of distinguishing between soft rocks and high velocity tills is a more difficult one to solve. Some Berkshire limestones, for example, are so weathered that they may easily be crumbled by hand, and may offer velocities in the till range. We have operated sections in this area and are awaiting boring data to prove or disprove our interpretation. We believe the velocity of 7500 ft. per sec. encountered there to demonstrate till and not the weathered rock. Again, near Portsmouth, Rhode Island, velocities in shale are so low as to hazard differentiation between these and tills of high velocity. For the geologist, this would offer difficulty in mapping, but it does not present as great a practical difficulty to the engineer. These Portsmouth shales may be excavated as easily by power shovels as the tills, with little or no blasting required. In brief, while the seismologist may not be able to name the material, the velocities will inform him what strength, density, elasticity, and other similar properties the material possesses.

In response to the second question, the accuracy of rock location does depend upon the regularity of the rock surface. The igneous intrusives and metamorphics of New England differ little on account of their location; however, the igneous intrusives and sedimentary series of the Connecticut River Valley may differ greatly. The seismologist can usually tell from his completed graphs what accuracy may be expected.

COORDINATION OF METHODS IN HIGHWAY LOCATION AND DESIGN

GEORGE H. DELANO

As a modern highway will cost up to one half million dollars or more per mile, particularly in our urban areas, it is important that the location and design of these facilities be given most serious consideration. Although the need of a projected highway and the approximate location it should follow can be determined from traffic flow and desire lines, the exact location can generally be varied within normal limits to take advantage of economic features to be encountered along the proposed route. Many of the features that show above the ground can be determined fairly accurately by the designing engineer, but the knowledge of the geologist and seismologist is required to reveal conditions that exist below the ground surface. Because the subsoil conditions are very important economically, and because they control such details as alignment, drainage facilities, and foundations for bridges, all possible information dealing with subsoils and ground water should be derived to locate intelligently and to design our highways.

Under the cooperative program previously referred to, the Massachusetts Department of Public Works is securing valuable information relative to the nature of subsoil conditions for all of its principal projects. When the approximate location of each new facility is determined from reconnaissance survey, the project engineer prepares a reconnaissance plan showing the proposed line and this plan along with a topographic sheet on which the line is plotted, is furnished to the geologist who prepares a geologic strip map along the line shown. This geologic map informs the engineer regarding the kinds of soil materials, the location of bedrock outcrops, and the various land forms to be traversed by the highway. In preparing this map, the geologist also indicates locations where seismic explorations are needed to amplify his report (see Figure 1). These are generally at locations of cuts of ten feet or more, sites of important structures, clay formations, or swamps, These data are obtained, analyzed, coordinated with geologic data, and then furnished in report form to project engineer for use by him as a guide in determining the final location line and in preparing the design for all features of the project. A specimen report is appended to this paper. If seismic readings indicate heavy ledge cuts, the location of the highway can generally be changed to avoid this expensive type of excavation. If other controlling features preclude changing the line, an accurate estimate of the quality of ledge to be excavated can be made available from the geologic sections based on the seismic data, supplemented as may be necessary by borings; thus eliminating the possibility of seriously underestimating the quantity of ledge to be removed. On a project with heavy cuts, such an error when accompanied by a high unit of bid price for ledge could be more expensive than the cost of the present cooperative project for an entire year.

Information on ground water conditions in cuts and fills is obtained whenever necessary to insure a proper design of subgrade and subdrainage. One of the interesting problems with ground water characteristics recently studied by the Water Resources Branch of the U.S. Geological Survey dealt with possible interference with a town water supply. A proposed relocation of one of our principal main routes passes between the drilled wells from which the town gets its water supply, and a pond from which the town authorities believe the wells are supplied by underground sources. The town authorities know that when we cross the valley between the pond and the wells with our new road we will excavate existing peat and other soft materials and will backfill with stable material. Even though our back fill will be of granular material, the town officials believe that there is a grave possibility that the new fill will act as an underground dam and shut off their source of water between the pond and the wells. The geologic study recently completed through our cooperative project indicates that the proposed highway at the planned location will not affect the town's water supply.

As stated, one of the primary purposes of the geologic survey is to make a complete detailed geologic map of the state, a feature of which will be to indicate all available sources of highway construction materials : trap rock gravel, sand, etc. This information, and especially that referring to granular materials, may soon be of greater interest to us than in the past, because of the depletion of existing deposits and the continued increase in demand for these materials.

Some of the specific applications of geological interpretations and seismic explorations to the location and design of highways in Massachusetts are listed below.

In Templeton, a portion of Route 202 was relocated so as to bring it above the flood level of the Birch Hill Dam. As construction of the highway required a large amount of fill, and as there was a proposed cut on the project from which a considerable portion of the fill could be obtained, it was desirable to establish the lowest practical grade through the cut, unless an extensive amount of ledge should be encountered. Seismic studies showed that no ledge would be met in this cut to the desired depth. This proved to be the case when the cut was made.

A similar problem was presented in the preliminary studies for the reconstruction of the Newburyport Turnpike in Topsfield. Here, the present alignment passes over the crests of several high and steep hills. If the present alignment were to be followed, it would be necessary to cut the crests of the hills as much as 50 ft. in order to achieve the high standards for sight distance required on such a highway. As large quantities of fill would be required, the heavy cuts would not be objectionable unless they involved a large amount of ledge. Four days were sufficient to run seismic profiles along 5700 ft. of highway to show that ledge is well below the bottom of the proposed cut.

In Chicopee, the Department is studying a proposed relocation of Route 20, the principal east-west route of the State, to bypass Springfield, crossing the Connecticut River north of Chicopee. A large prehistoric glacial lake occupied the area at one time, in which a considerable thickness of lake clays and silts were deposited. The eastern end of the strip investigated is on a high terrace about 140 ft. above the general level of the plain to the west (see Figure 7). The surface of the terrace is

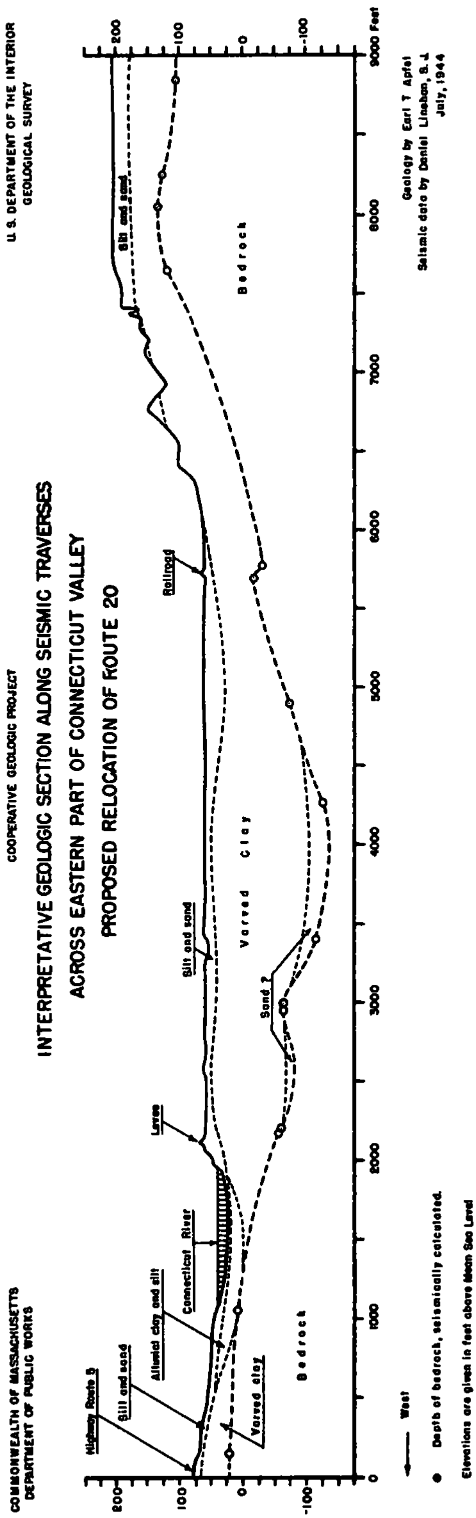

Figure 7

of fine sand over a laminated deposit of clay and silt, known as varved clay. Proceeding westerly, the line drops to the level of the plain, then westerly across the plain and the Connecticut River. As the proposed line comes off the terrace, a cut about 25 ft. deep will be required in the varved clay. Then as the proposed line crosses the low plain of the valley, several structures will be required where it crosses the railroad, the Connecticut River, and existing highways. Through surface geologic studies, and geologic interpretation of seismic surveys, the Department knows what soil and subsoil conditions will be found in the clay cut, at structure locations, and for the heavy fill required in the low area to keep the new road well above the flood level of the river.

On the Mohawk Trail, Route 2, the Department has made studies for a highway project in the towns of Shelburne and Buckland. The proposed project is to bypass Shelburne Falls by skirting the easterly side of the village and crossing the Deerfield River about three-quarters of a mile north of the present crossing, which is in the center of the town. At the point where the new line is to cross the river, the site of the proposed bridge abutments was investigated both by borings and by taking seismic profiles. All but one of the borings were driven to refusal, but seismic profiles later showed that refusal occurred practically at the surface of the till, which in this area contains a large number of boulders. Seismic data showed bedrock to be many feet below the refusals obtained through the borings (see Figure 2).

Although the depth to bedrock at the Shelburne Falls bypass location will not affect the bridge foundations, the results of the two methods indicate a point which should be mentioned. It is not now the opinion of this Department that seismic data will obviate the need of borings or field observations, nor is it expected that further check data to be secured will result in any change. It is expected, however, that seismic data will enable the engineer to spot and interpret the borings more accurately and intelligently and thus to reduce the number of borings required.

While it should again be emphasized that the work being done is experimental, and that much further study is needed to develop the technique of seismic study and the correlation of geologic interpretation with our highway problems, the results already achieved are very encouraging. We are learning to apply intelligently the data being furnished through the cooperative projects.

As the highway construction program of the Massachusetts Department of Public Works continues to expand under the impetus of postwar needs, the geologic and seismic studies will continue to play their very helpful part in providing Massachusetts with highway facilities designed to meet existing subsoil conditions.

GEOLOGIC INTERPRETATION OF SEISMIC DATA BRIDGE SITE OVER DEERFIELD RIVER ON RELOCATION OF ROUTE 2 MOHAWK TRAIL - SHELBURNE-BUCKLAND

EARL T. APFEL, *Geologist*
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This report is based upon field work performed under a cooperative geologic program of the Massachusetts Department of Public Works and the U.S. Department of the Interior, Geological Survey.

A proposed relocation of the Mohawk Trail crosses Deerfield River about 0.55 mi. north of Shelburne Falls, near station 671 (Buckland) and station 417 + 57 (Shelburne). The site of the proposed crossing was investigated geologically and seismically. A series of seismic traverses was run on each side of Deerfield River, parallel with and near the banks, and one traverse was run along the centerline of the proposed highway on the west side of the river, between station 668 + 40 and station 670 + 90 (profile A-B 250 ft. long). Profile C-F, 400 ft. long, was run as two overlapping segments, each 250 ft. long, making the overlap 100 ft., the center of the overlap being at point A, on the centerline of the proposed highway. Profile G-H is nearly parallel with profile C-F, and crosses the centerline at station 670 + 35, or 60 ft. west of C-F. Profiles A-B, C-F, and G-H are on the west side of the river.

Profiles I-L and M-P were run on the east side of the river, parallel with it, and 66 ft. apart, I-L being along the river bank. Each was run as two overlapping segments, each segment 250 ft. long, the overlap being 100 ft. The center of I-L crosses the centerline at station 417 + 66, and the center of M-P crosses the centerline at station 417.

West Side of Deerfield River, Near Station 671 The seismic profiles indicate that the bedrock surface is 35 to 40 ft. below the surface of the ground, or near altitude 365 ft., along the west bank of Deerfield River. To the west, bedrock surface rises under the terrace so that at a point 250 ft. from the river it is at a depth of 46 ft. (altitude 381 ft. above sea level).

Glacial till extends from bedrock up to river level, approximately, altitude about 405 ft.; sand overlies the till and forms a terrace 20 ft. high.

East Side of Deerfield River, Near Station 417 + 57 The two seismic profiles parallel with the bank of the river and on the east side show bedrock to be more than 75 ft. below the surface, but the full depth to bedrock was not determinable from these lines.

Most of the unconsolidated material under this site is compact and firm, and is probably glacial till; however, this till is channelled to a depth of 15 to 20 ft. and for a width of about 100 ft., the channel being filled with sand. Apparently this sand-filled channel crosses the base-line at a rather sharp angle, being entirely south of the base-line along the profile nearest the river (I-L), and under the base-line along profile M-P, 60 ft. to the east. Some gravel may be expected in this sand. The existence of this sand-filled channel was interpreted from lower velocities along the profiles; the delineation of the interpreted channel is not clear, but it would seem wise to test the area to determine if footings should be extended to the deeper and more firm underlying material.

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