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Soil and Materials Surveys by Use of Aerial Photographs

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The Engineering Soil Survey and Its Relation to Engineering Problems

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This article describes the engineering soil survey and the research techniques and methods which were applied in the preparation of the engineering soil maps. Each of the 21 New Jersey county reports presents detailed information concerning the various soil areas which are delineated on the engineering soil map. The symbols shown on these maps are explained; engineering test values are given for the major soil types, and comments are presented relative to each type of material.

This article also illustrates some of the applications to various engineering problems.

The soil survey work was greatly facilitated by the use and interpretation of aerial photographs. The photographs were of particular value in mapping soil types in mountainous areas, as well as in the coastal plain province.

NEED FOR AN ENGINEERING SOIL SURVEY IN NEW JERSEY

● AS IN ANY other enterprise, so in highway engineering research is essential for progress in highway safety, technology and economy.

In the middle '40's, the New Jersey State Highway Department became increasingly aware of the damage to highways caused primarily by climate and traffic. Climatologically and geologically, soil was the prime factor with which highway engineers became concerned. For example, frost action in certain types of soils causes heaves of roads, because the increase in soil moisture content affects adversely the strength of the soil. Particularly detrimental is spring break-up of pavements when frost leaves the ground. In respect to traffic, it is safe to say that New Jersey, being a corridor state between two great ports, carries the greatest amount of traffic not only in this country but in the world. Traffic, therefore, does its share in wearing and damaging its highways.

Repairs to roads damaged by climate and traffic cost large sums of money. To cope with this damage, the factors causing it should be studied and understood, and the highway design and construction techniques adjusted accordingly. It was evident that particular attention had to be focused on those factors causing damage to roads by frost. The frost problem, therefore, established the need for highway research in New Jersey. Three questions arose: Which of the soils present in the state are more likely to cause frost damage to highway pavements? Where are these soils located? What are their engineering properties? These questions had to be answered in order to reduce highway maintenance costs.

THE JOINT HIGHWAY RESEARCH PROJECT

To pursue highway research, Rutgers, The State University, and the New Jersey State Highway Department, entered into a cooperative effort known as the Joint Highway Research Project. On September 12, 1946, The Joint Highway Research Committee, administrator of the Project, held its initial meeting.

One of the main objectives of the Project was to study the performance of New Jersey highways under freezing and thawing conditions. Upon closer consideration of this problem, however, it became obvious that before such studies could be undertaken successfully, it was necessary first to investigate the soil materials involved—their origin, distribution, extent and engineering characteristics.

Thus an engineering soil survey of New Jersey was considered of basic importance, and the project entitled "Engineering Soil Survey of New Jersey" was established.

An engineering soil survey is one means of (a) taking inventory of soil materials; and (b) providing applicable data on the engineering characteristics of soils, particularly for preliminary design and construction of highways and other earthworks.

The engineering soil survey was planned for the entire State of New Jersey, consisting of 21 counties and comprehending an area of approximately 7,836 sq mi.

THE ENGINEERING SOIL SURVEY OF NEW JERSEY

Contents of Survey

The engineering soil survey required that (a) the soils be identified and classified, and (b) the boundaries of each soil type be delineated on an engineering soil map.

The soils of the entire state were mapped from an engineering standpoint in the belief that a knowledge of the various soil types and their properties is the real basis of good highway design. The engineering soil survey was completed in October 1955, when New Jersey became the first state in the country to have a complete statewide engineering soil survey with engineering soil maps and soil descriptions published in the form of bulletins. These engineering soil survey bulletins provide an excellent reference source of information about the general engineering characteristics of the soils of any area in the state.

Procedures Used in the Soil Survey

To undertake a statewide survey, it became apparent that the methods and procedures of such an effort must be made uniform. A rigid system must be adopted so that all maps and reports can be equally understood and there should be a minimum of repetition from one county report to another. It was decided, therefore, to publish first a statewide report to present both the broad aspects of soil and soil environment for the entire state and descriptions of all research techniques employed by the Project. Report No. 1, Soil Environment and Methods of Research, presents information on climate, geology, soils, soil mapping techniques, airphoto mapping methods, soil testing procedures, soil identification and reprints of AASHO standard test methods. The first edition of Report No. 1 was published in 1950, and in 1955 a revised edition was issued.

In producing the county maps and reports, a thorough investigation was made of the literature pertaining to natural materials reported to be present in each county. This literature embraced the Geologic Map of New Jersey, U. S. Geological Survey Folios, past geologic reports, bulletins and special papers. Attention was directed to the significance of agricultural soil series, types and phases as shown on agricultural soil maps and land-use maps and as described in agricultural bulletins. Parallel with this investigation of the literature was a very careful study of the aerial photographs of each county in the office as well as in the field, with the dual purpose of gaining familiarity with the area and of correlating the geology and agricultural soils with the in-place engineering materials. It was found that this careful preliminary study greatly facilitated ease and accuracy in the later airphoto interpretation.

The next step was actual soil delineation directly on the airphotos, with constant checking against the literature and reference maps in order to correlate the geology with the engineering map units. Airphoto interpretation was the major technical tool employed in making the survey, and therefore about 50 percent of the time spent on a given county was devoted to this part of the work.

In order to insure the accuracy of map unit boundaries on the airphotos, extensive field trips were taken to many localities, and soil samples brought back to the Project laboratory at Rutgers for analysis as to some of their engineering properties—particle size distribution, consistency limits and the Proctor density curve. The results of those analyses are given in Appendix A of each county report.

Where soil conditions were difficult to interpret on the airphotos, particular care was taken in field checking. It was sometimes found desirable for the sake of clarity to modify the mapping symbols used to indicate complicated areas, or even to use substitute symbols. All such cases are fully described in the appropriate reports.

Figure 1 is a diagram illustrating the procedures used in the soil survey.

Standard Symbolic Notations Used

The symbols used to designate the delineated soil areas on the engineering soil maps consist basically of three parts. For example, in the symbol AM-24ge the first part, AM, indicates the geologic formation or the parent material from which the soil in question is derived. The second part, 24, is the soil textural symbol based on the Highway Research Board's soil classification system. The third part, ge, is the so-called drainage symbol. It indicates an estimated depth from the ground surface to the ground-water table. In this example the symbol ge shows that the drainage conditions in the area concerned are from good to excellent, meaning that, according to established soil-mapping criteria, the position of the ground-water table is over 6 ft below the ground surface.

The geologic part of the mapping symbol, AM for example, implies also the approximate topographic position relative to the occurrence of the soil and likewise specifies the character of the underlying material. Thus the letter A of the AM symbol indicates the agent which deposited the parent geologic formation (A = alluvial), which is mostly unconsol-

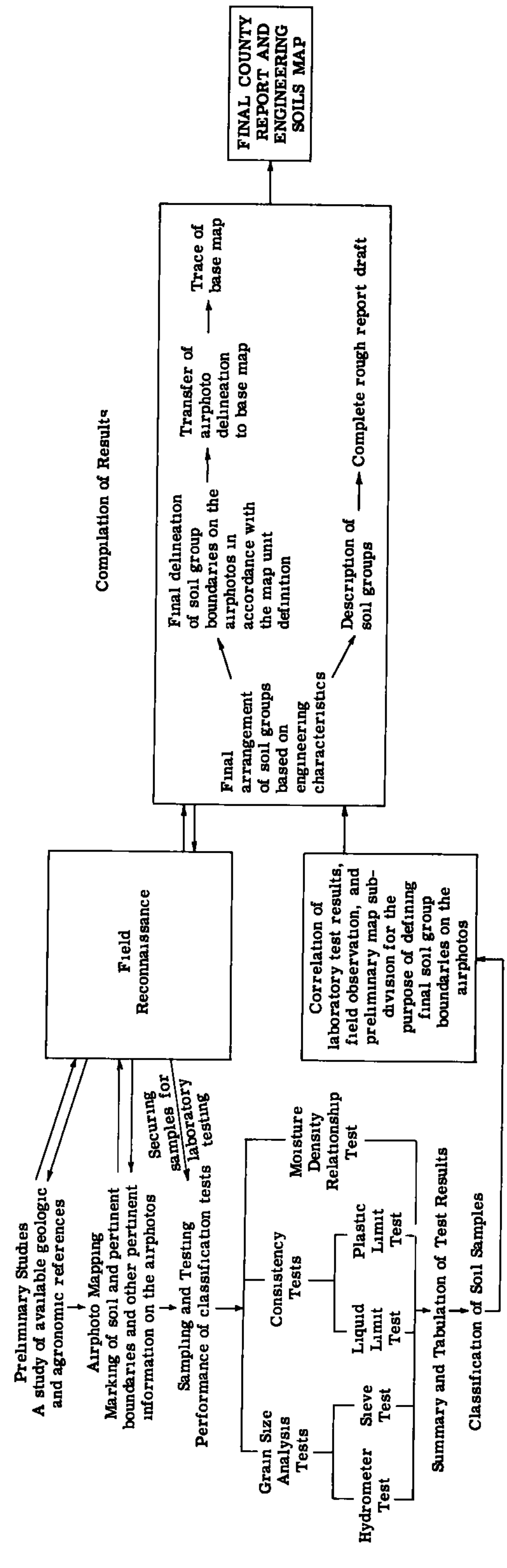

Figure 1. Procedures of the Engineering Soil Survey of New Jersey.

idated. In another symbol, Sh-4ge, the letter S means that the soil is the weathering product of hard sedimentary bedrock. Hence the first letter in the symbol can mean not only the process of the rock formation but also the rock type itself from which the soil is derived. The various parts of the soil mapping symbols imply also soil texture, consistency, soil density, surface drainage, internal drainage, depth to the ground-water table, and possible engineering aspects relative to construction operations in these soils.

The second letter, M, in the symbol AM may have one of two possible meanings. When capitalized, it indicates the land form associated with the soil area. In this case AM means a broad plain or mantle of alluvial material. On the other hand a lower case letter such as h in the symbol Sh indicates bedrock from which the parent material of the soil is derived. For example, the symbol Sh means that the hard sedimentary rock is shale. The numeral 4 indicates a silty texture of the soil, and ge shows good to excellent drainage conditions.

Often two soil types may be encountered on the engineering soil maps which are designated by the same textural symbols, for example AM-24 and M-24. The difference between these two is that the AM-24 soils are generally composed of relatively coarse materials, whereas the M-24 soils contain a high percentage of silt. These textural differences are clearly brought out in the proper county bulletins by the engineering soil test values (averages of all laboratory test results made from areas of a certain soil mapping unit).

In general there are four

drainage symbols used. They indicate, by convention, the following range in depth to the ground-water table:

vp—very poor to poor, 0 to 1 ft
pi—poor to imperfect, 1 to 3 ft
ig—imperfect to good, 3 to 6 ft
ge—good to excellent, over 6 ft

The relationship between the geologic formations and the letter symbols of the various soil mapping units is shown in Figure 2.

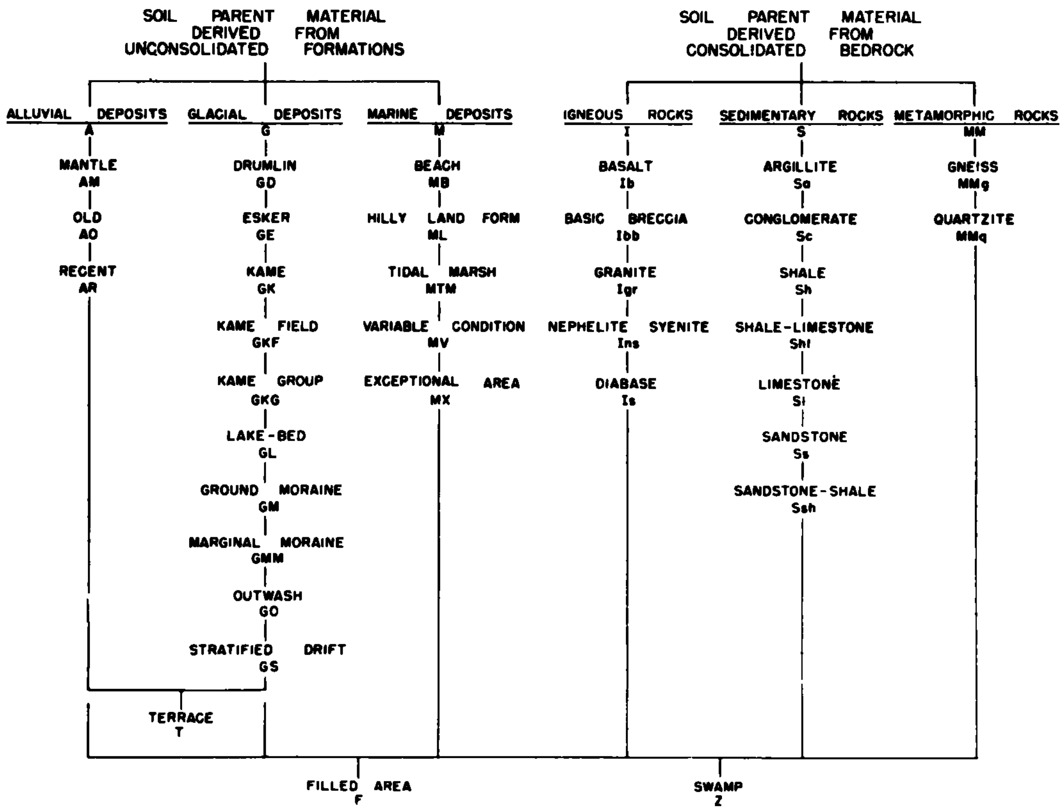

Figure 2. Correlation of geology and letter symbols.

Use and application of the soil mapping units as here reported is very easy and convenient.

Comparative Usefulness of Engineering Soil Maps

The engineering soil maps were designed with the needs of the civil engineer specifically in mind. Containing the most recent scientific data available on the engineering materials of New Jersey, presented in standard form, using modern techniques of investigation, they focus in one place much information drawn from related sciences and correlated from an engineering point of view.

Drawn to a scale (2 in. to the mile) eight times larger than the geology map of the state, it was possible to show on the engineering maps a much greater amount of detail. The use of aerial photographs as a technological tool for interpretation in conjunction with the geology map enabled the staff of engineers and geologists of the Joint Highway Research Project to cover all areas of the state, however inaccessible to field parties.

An understanding of land form and soil texture is essential for the engineer, and this information is provided by several land form designations, such as esker, kame and outwash, which occur in the mapping code, while the HRB classification numerals included in the symbols indicate the texture. Compound of fractional symbols convey yet more specific information to the engineer, since they show that the material designated by the numerator of the fraction is underlain at variable and often shallow depths by the material indicated in the denominator.

The greater scale of the engineering soil maps permits showing specific areas of a frequently occurring material. For instance, a gneissic formation, indicated on the geology map by the letter symbol Ign, crops out in The Highlands Province of New Jersey. The type of coding used on the engineering soil map not only discloses the location of each outcrop but also allows the engineer to draw inferences as to the soil development and its thickness, the location of glacial deposits on the gneiss, the land form, drainage conditions and other factors influencing good construction. In the case of ground moraine, for instance, the geology map does not use a mapping symbol, but refers to its presence by a general footnote. The exact location of deposits of ground moraine, as shown on the engineering soil map, is a matter of some importance to the civil engineer, and the more exact the information he can get the better. Equally in the case of the textural characteristics of deposits of the Cape May formation, a footnote is used on the geology map, whereas the HRB classification numerals included in the engineering mapping code give precise information in specific areas.

Figure 3 shows the comparable geologic and engineering soil maps for the same area in Sussex County, New Jersey. On the soil maps cultural detail and political subdivisions have been subdued to emphasize soil boundaries.

Topographic maps are useful to a civil engineer in preliminary planning and reconnaissance of highway alignments. They show only contour, however, and give no indication of the nature of the in-place materials which will be met in construction. It is very important to know what may be found beneath the surface—whether the drainage will be good, for instance, or whether there will be suitable borrow material available nearby. Consideration of factors like these is essential in reducing the costs of construction and maintenance.

It is quite possible to apply an agricultural soil map as an engineering soil map. However, the agricultural maps are prepared with a view to the surface or near-surface soil (the top three feet), and are not concerned with the greater depths which may often be of equal importance to the civil engineer. It is possible to translate the agricultural maps profitably if the civil engineer has some knowledge of the related sciences of pedology, geomorphology, geology, etc., but not all civil engineers possess this extra knowledge. The engineering soil maps offer information from these additional sources already translated into engineer-

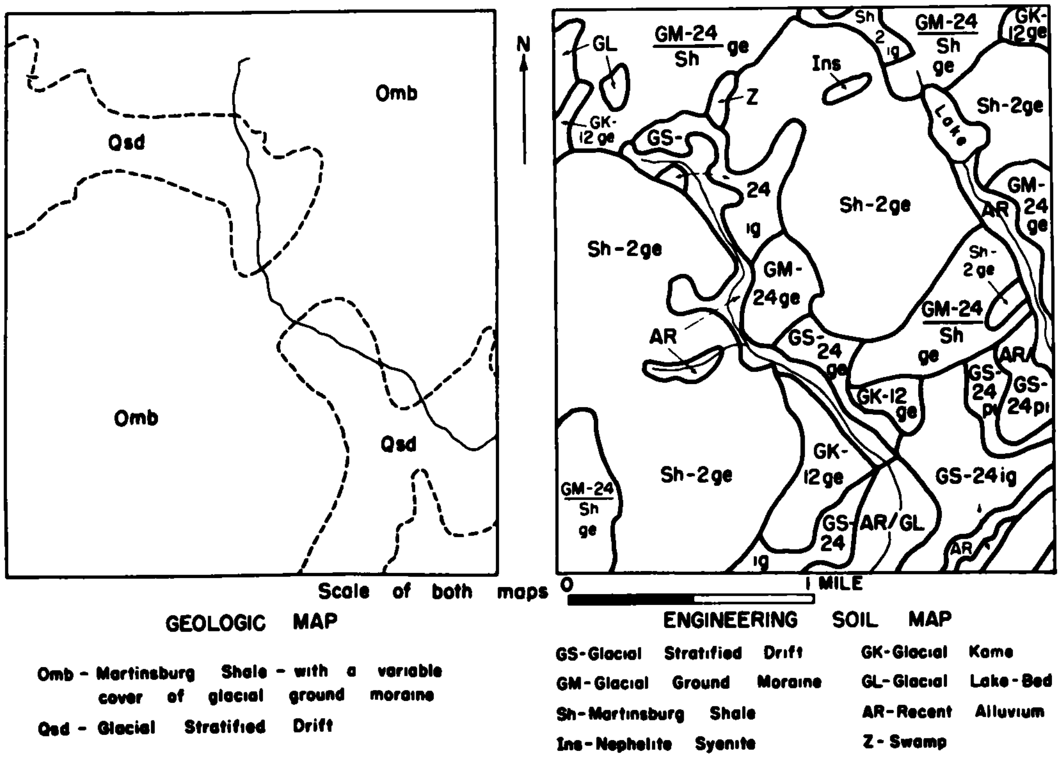

Figure 3. Geologic map and engineering soil map of an area in Sussex County.

ing terms, prepared on the fuller and more accurate basis of aerial photo interpretations.

Contents of County Engineering Soil Bulletins

Each of the twenty county reports presents detailed information concerning the various soil areas which are delineated on the engineering soil map of that particular county. Each of the major soil groups and soil areas is treated in a separate chapter, and each chapter includes comments on Parent Material, Land Form, Soils, Drainage Conditions, and Engineering Aspects. Also, engineering test values are tabulated for the various soil types. One such set of test values is shown in Figure 4, AM-24 Test Values.

The written description of the soil area is an excellent guide and reference source for the engineer; he will understand the background of the area and will know what to expect prior to seeing the area in the field. The test values are a necessity in pavement design—to evaluate the need for drainage structures, to determine the need for, and the depth of, subbase material, and to determine the possible use of the soil type as borrow material.

In Appendix A of each county report there is a summary of soil test data. This summary comprises test results of all samples taken in that county. Each sample is identified as to its boring and all of the borings are plotted on the soil maps which accompany each report.

SUMMARY OF SOIL TEST DATA

Sample No.	Agronomic Name (as mapped 1917-27)	Airphoto No	Lat. Deg. Min. Sec.	Long Deg. Min. Sec.	Slope at Sample Hole deg.	Horizon	Depth to Bottom inches	Test Results: Sieve Analysis, Cumulative Percent Passing 3/4	4	10	40	200	Hyd. Anal. Silt Sizes %	Hyd. Anal. Clay Sizes %	Physical Minus #40 L.L. %	Physical Minus #40 P.I. %	Proctor Max. Dens. p.c.f.	Proctor Opt. m c. %	HRB Designation Sub-grade Group	HRB Designation Group Index	Remarks
												AM-24 continued									
15	Sassafras	21-127	40 25 03	74 29 17	3-4	A B C	8 27 40H	100 100 97	93 94 72	88 89 61	66 65 39	21 20 12	• • •	• • •	NL NL 17	NP NP 3	• 127 127	• 10 10	A-2-4 A-2-4 A-1-b	0 0 0	Sample taken on top of knoll
16	Sassafras	21-127	40 25 05	74 29 18	0-3	A B C	7 18 36H	100 100 100	94 99 100	88 97 97	53 72 82	12 35 46	• • •	• • •	NL 19 26	NP 3 5	• 123 118	• 11 14	A-2-4 A-2-4 A-4	0 0 2	
17	Sassafras	21-175	40 26 26	74 27 08	1-2	A -	9 43H	100 100	100 100	97 99	96 87	16 64	• •	• •	NL NL	NP NP	• 121	• 10	A-2-4 A-4	0 6	
18	Portsmouth	21-129	40 23 43	74 29 14	0-1	A B C -	10 18 35 48H	96 97 99 100	85 86 91 95	77 79 90 91	63 64 68 68	28 31 19 11	• • • •	• • • •	25 16 NL NL	5 1 NP NP	• 115 118 116	• 12 12 11	A-2-4 A-2-4 A-2-4 A-2-4	0 0 0 0	Sample taken in low area.
19	Sassafras	21-193	40 19 10	74 33 34	1-2	A -	14 36H	99 95	92 56	91 44	72 27	11 4	• •	• •	NL NL	NP NP	• •	• •	A-2-4 A-1-a	0 0	
20	Sassafras	21-173	40 24 15	74 28 15	2-3	A B C -	18 30 44 48H	100 100 100 100	98 96 99 99	96 94 94 97	79 64 56 71	46 33 24 55	• • • 25	• • • 28	28 20 21 30	5 4 2 10	• 127 124 118	• 10 11 14	A-4 A-2-4 A-2-4 A-4	2 0 0 4	
21	Collington	21-163	40 16 11	74 28 18	1-2	A -	7 36H	100 100	100 100	99 100	85 85	18 22	• •	• •	NL NL	NP NP	• 122	• 12	A-2-4 A-2-4	0 0	Marine deposit (MV-47) at shallow depth.
22	Collington	21-163	40 15 42	74 28 02	2-3	A B C	11 24 36H	100 100 100	100 100 100	99 99 100	93 94 94	14 15 23	• • •	• • •	NL NL NL	NP NP NP	• • •	• • •	A-2-4 A-2-4 A-2-4	0 0 0	

Figure 4. AM-24 test values.

PRACTICAL APPLICATIONS OF ENGINEERING SOIL MAPS AND BULLETINS

General Applications

The principal uses of the engineering soil maps are as follows:

1. In the initial planning and reconnaissance for the location and relocation of road alignments.
2. In locating sources of soil material suitable for making fills.
3. In planning soil surveys for a specific project.
4. In subsurface investigations for foundation.
5. In highway design.
6. For preliminary planning airports.
7. As a materials inventory map and record.
8. For community planning.
9. As an ideal base map for pavement performance studies and other research dealing with natural in-place materials.

An inquiry made of the various users of the Engineering Soil Survey maps and reports disclosed that in addition to the principal uses described above, the engineering soil maps and their bulletins are employed by many consulting engineers and other engineering agencies for the following types of studies:

1. Estimating subsoil conditions for specific geologic reports.
2. Preparation of foundation investigation reports. The soil map and bulletins indicate a range of anticipated soil conditions. They help to determine rapidly the depth and nature of the bedrock, the general geology of the area concerned, and the type of fill material available. They also help to determine, in general, the scope of the soil exploration pro-

gram necessary for a certain site and structure. The depth of borings and type of soil samples to be taken can also be predetermined for many areas.

3. Interpretation of boring data.

4. Identification and classification of the soil types encountered in shallow borings.

The following are some of the projects which have found the soil survey maps and reports valuable:

1. Study of the approaches to the George Washington Bridge.
2. Study of New Jersey's water resources.
3. Planning field work on potential clay deposits and location of possible raw materials for production of lightweight aggregates.
4. Studying and calculating the potential increase in population and future density patterns of development in some of the communities of the state.
5. Preliminary planning of sites for industry.
6. Pavement evaluation and design for the Garden State Parkway.
7. Location of the New Jersey Turnpike in the northern part of the state.

The logistics of any subsurface exploration program becomes more efficient as a result of the proper application of the soil maps. For example, because the manual accompanying the map provides an estimate of the depth to bedrock, a description of the rock and detailed properties of overburden, drilling crews can be supplied with the proper equipment, tools and accessories for a particular job. For another example, in preparing contracts for geophysical exploration or for foundation drilling, bidders, not particularly familiar with the area, appreciate the inclusion of general underground conditions as determined from the Engineering Soil Survey of New Jersey. Bidders can quote more intelligent prices on contracts because, within the established scope of the maps, the reliability and authenticity has been verified. Likewise the estimates of the work to be performed on these contracts are more realistic and are no longer guesses, as a result of using the maps to prepare the contracts.

The soil maps are also useful in preparing and executing time schedules for earthworks requiring the use of heavy equipment; a glance at the map, with its indication of soft or firm ground, will enable the contractor to know at once where to shift heavy equipment in rainy seasons to prevent its being bogged down in mud.

Some of the difficulties which might be encountered during the execution of technical projects are indicated by the soil maps. Thus the compound mapping units with a horizontal bar, for example $\frac{\text{AM-24}}{\text{MV-47}}$, imply a contact between the permeable top layer and the clayey layer of soil underneath it. Undercutting such a contact may mean seepage into the cut. Therefore such a compound mapping unit indicates the necessity for planning and installing proper drainage structures to cope with the water.

In a general way the soil maps can indicate or imply, by use, where ground water and its movement can cause difficulties in highway construction. They can provide the longitudinal extent of subgrade treatment, general subbase and base design for pavement; give an indication as to slope requirements in both cut and fill, internal soil drainage characteristics, and provide data relative to the phenomenon of frost action. Such general information is of immense benefit when estimates are being prepared in conjunction with proposed alternate route locations.

The Engineering Soil Survey of New Jersey, in the hands of contractors recognizing its practical applications, has been responsible for exploding the myth that certain soil materials are in scarce supply, even though urban development has placed many restrictions on borrow pits. By applying the most fundamental principles of geology, and knowing the details of the soil classification system employed on the maps, engineers have been able to indicate potential areas where the type of material required for a specific purpose can be explored. Since the soil map defines areal extent and the manual gives a range of test values for the "A", "B" and "C" horizons, it is essential to plan further exploration to verify depth, exact quality and areal extent prior to negotiation for purchase or specifying use in contracts.

The soil maps are also useful in planning a pavement performance or evaluation study. Once the locations of a particular design have been established, the soil maps enable the evaluator to pick locations for further study, based on the maximum number of soil types, and drainage conditions which exist for a particular design. A certain amount of field work is necessary in connection with such research, because the soil classification of embankment material cannot always be associated with the nearest cut. In preparing the final analysis and interpretation of results, the maps provide considerable assistance.

CONCLUSIONS

In these days of scarcity of top talent, the engineering soil map has done much to extend the potential scope of service of a soil engineer. Within the recognized limits of application, the maps and manuals are a valuable supplement to a highway engineer who believes in economy from conception to completion. The many possible applications of the maps of the Engineering Soil Survey of New Jersey indicate that they are a valuable and very practical contribution to soil engineering and highway technology.

ACKNOWLEDGMENT

Successful completion of the Engineering Soil Survey of New Jersey was due in great part to the continued interest and support of E. C. Easton, Dean of the College of Engineering of Rutgers University, and J. J. Slade, Jr., Research Director of its Bureau of Engineering Research, as well as to the helpful guidance and advice on the part of the Joint Highway Research Committee, of which A. C. Ely, representing the New Jersey State Highway Department, was Chairman. Acknowledgment also is made of the effective efforts of a competent and cooperative staff, many members of which worked on the project for a large part of its duration. The authors wish to express their appreciation to Mrs. Ruth Ahrens for technical editorial assistance in connection with Engineering Soil Survey publications and preparation of the typescript of this article.

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An Engineering Soil Survey of Fayette County, Kentucky

R. C. DEEN, Research Engineer, Kentucky Department of Highways

Agricultural soil scientists have developed a system of soil classification and mapping that has been and is continuing to be of great value to the soils engineer in reconnaissance and mapping. This report covers a statistical method of correlation used in a pilot study conducted in order to make engineering soils data available from a pedological map of Fayette County, Ky.

Assuming that the reliability of pedological classifications holds true for engineering properties, the engineering test constants for a given horizon of a given soil should fall within a narrow range; and the limits of this range should be reasonably determinable from the results of tests on a small number of random samples. In the present study a range with a confidence coefficient of 0.90 was determined by the statistical method used.

● THE NEED for soils data in the site selection, design, construction and maintenance of any major structure is generally appreciated by the engineer. The "rule of thumb" methods often used in developing smaller structures can prove unsatisfactory, or even disastrous, when applied to larger projects.

Probably the most pressing need is for use in preliminary surveying—maps and/or surveys giving the areal distribution of local soils and their engineering characteristics. Were such information available, together with the topographic maps now obtainable for many areas, much preliminary work for structures could be accomplished without the engineer's ever having to leave his office.

Agricultural scientists have developed a soil classification and mapping system that could be of great use to engineers. Belcher, et al. (2), appreciating this possibility, in 1943 published a report giving engineering significance to the pedological classification of Indiana soils. Since that time much work has been done toward translating and developing the data made available by the sciences of geology, physiography and pedology, and airphoto interpretations into terms familiar to the engineer. Many states are now preparing soil surveys and maps, using the principles of pedology and airphoto interpretation, for use by their engineers.

METHODS

As a first step in obtaining a soil map of Kentucky, an engineering soil survey of Fayette County was made. Since there was available a sufficiently reliable pedological soil survey and map of the county, no actual mapping or delineation of soil areas was required for this study. The problem became, therefore, one of determining the engineering test constants and giving engineering significance to the pedological soil classifications. The work consisted of field sampling, laboratory testing, analysis and correlation of data, and finally, preparing the material in a form suitable for use by the engineer.

The first step in the solution of the problem was to answer the question, "How many samples of each horizon of each soil series would be required to give significant results?" To obtain an answer, the question was approached from a statistical viewpoint.

If the thesis that the pedological properties of a given soil are similar wherever the soil is mapped is correct and can be applied to engineering properties also, then the engineering test constants for a given horizon of a given soil should fall within a more or less narrow range, determinable from considering test results from a few samples taken at random. This range of values for a given engineering property could be assigned to the particular soil horizon in question, and no matter how many times this horizon is sampled in the many different locations it may be mapped, it could be confidently assumed that the soil is sufficiently uniform for the test value to fall within the range established. The number of samples required to give such a significant range varies, of course, with the accuracy desired and with the variability of the parricular engineering test constant under consideration.

The limits first established for this project were such that the test results on a given sample out of a hundred might deviate from the mean by not more than 10 percent. The selection of these particular limits is not to be considered the establishment of a satisfactory range; it merely served as a starting point in determining the number of samples required. Assuming that the engineering test constants fall into a normal distribution about their respective means, this statement of accuracy desired can be represented by the general equation

$$z\,\sigma' = E\bar{X}' \qquad (1)$$

where $z = \dfrac{X - \bar{X}'}{\sigma'}$

σ' = standard deviation of the universe,
E = allowable error expressed as a decimal,
$\bar{X}'$ = mean of the universe, and
X = any value of the universe.

The above equation can also be stated in the following terms:

$$z\,\frac{\sigma}{\sqrt{N}} = E\bar{X} \qquad (2)$$

where σ = standard deviation of a group of samples,
N = number of items in the group of samples,
$\bar{X}$ = mean of a group of samples,
$\sigma' = \sigma/\sqrt{N}$, and
$\bar{X}' \approx \bar{X}$.

In arriving at Equation 2, two assumptions were made. The first was that the engineering test constants for a given soil series assume or are closely approximated by a normal or Gaussian distribution. This is not an unreasonable assumption to make. For example, if the liquid limit were determined for a very large number of samples of the C horizon of the Maury series, as many results would be expected to fall above the mean as would fall below, and these results would be concentrated about the mean. The second of the assumptions was that the mean of the universe was approximated by the mean of a group of samples. This assumption was based on the method of maximum likelihood; that is, the sample statistic is the maximum likelihood estimate of the corresponding universe parameter. This is usually the case and this method is favored by many statisticians (4).

In Equation 2, letting $z = 2.57$ satisfies the requirement that 99 of 100 sample results be within the desired range about the mean. Letting $E = 0.10$ establishes this range as ± 10 percent of the mean. Using the values σ and X obtained from a group of samples, the number of samples, N, required can then be calculated.

By making a preliminary field sampling and laboratory testing of one soil series, it was estimated that three samples from each horizon of each soil series would be needed to meet the requirements established in all cases except that of the plastic limit and plasticity index. The number of samples required for these test values was as high as 30, seemingly an unreasonably large figure. Calculations indicated that test results from three samples, however, would show only a 20 percent deviation from the mean of the universe for these two test constants. On the basis of this preliminary study, it was decided to attempt to obtain samples of each horizon of each of the soil series from three different locations in the county.

The sample sites were located by reference to the pedological soil map and were selected in such a way as to distribute the sites in each soil series over the county. An attempt was made to place the sites near the centers of the large areas of a soil series in order to obtain typical samples and not fall in the transition zones between the series.

No unusual methods of sampling were used. Most of the samples were obtained by a 4-in., Iwan post hole auger; and this proved to be a quite satisfactory method except in the very wettest horizons. In these cases, sampling was delayed until the dry season. Samples were obtained to depths of 15 ft with the auger, and others were obtained from test pits. In all instances depth, color, texture, moisture conditions, and any other features that might be of interest or use in identification or classification were noted and recorded. A 20- to 30-lb disturbed sample was taken from each of the major horizons at every location and sent to the laboratory for testing.

Once in the laboratory the samples were prepared for the determination of engineering soils constants by the following methods:

Soil Preparation	ASTM Designation: D 421-39
Mechanical Analysis	ASTM Designation: D 422-39
Liquid Limit	ASTM Designation: D 423-39
Plastic Limit & Plasticity Index	ASTM Designation: D 424-39
Specific Gravity	ASTM Designation: D 854-45T
Moisture-Density Relations	ASTM Designation: D 698-42T
Laboratory CBR	Kentucky Modified Procedure

A small portion of the material smaller than one micron was recovered by sedimentation and decantation from 17 selected soil samples. These fractions, representing the near-colloid portion of the soil and consisting predominantly of clay-type minerals, were leached with acid or otherwise treated to remove X-ray scattering and masking impurities and subsequently conditioned with ethylene glycol preparatory to analysis or identification by X-ray diffraction.

The diffractometer was a Hayes instrument using Cu radiation, 14 cm diameter twin cameras, and wedge-type powder mounts. Patterns were recorded on film and the lines measured on a plain vernier scale.

In order to be of value to the engineer, data obtained from an investigation such as this must be presented in a form that is quickly and easily read and understood. In an attempt to satisfy this requirement it was decided to give first a pictorial representation of each soil with a brief, general written description of each of the major horizons.

This was followed by a table of typical engineering test constants. Rather than give the mean of the test constants as obtained by laboratory testing, it was felt that some significant range should be reported. With this in mind, the 90 percent confidence limits for each test constant were calculated and the values recorded in the table. Since the number of samples was small in each case, it was decided to base these confidence limits upon a "t" of "Student's" distribution rather than the normal distribution as was done earlier. With small sample sizes, the "t" distribution will give better estimates of the universe parameter. The confidence limits were calculated by the procedure given by Duncan (4) from the limited data obtained during this investigation. These data are so determined, however, that regardless of the number of times the particular soil is sampled in the future the engineering test constants will fall within these limits 90 percent of the time. These ranges, then, do have some significance, since a given horizon of soil may be represented by a more or less narrow range of values for a certain property.

The three classifications (textural, HRB, the group index) given in the table are not subject to the previously mentioned analysis, but are the actual designations given each sample. The table is followed by a general discussion of some features and properties of the soil that might affect the engineering treatment of that soil.

This description of each soil—a pictorial view of the profile with description, a range of values with statistical significance for certain engineering test constants, and a general discussion of other items of interest—could be used with the agricultural soil survey of the county and with the topographic maps of the area and be of great value to the engineer in planning and carrying to completion the soils portion of his engineering work.

SOILS OF FAYETTE COUNTY

The pedological soil map of Fayette County published in 1931 is one of the five highest rated county maps of Kentucky. Its soil boundaries are accurately delineated, and modern nomenclature is used except in a few instances.

There are 17 soil series and 28 soil types recognized and used in Fayette County. All but three of these series, accounting for 99 7/10 percent of the total area of the county, were sampled during the present investigation. One hundred twenty-six samples from 47 locations were obtained from the remaining 14 soil series. No attempt was made to obtain a sample from each soil type; however, 18 of the 28 types are represented.

Most of the soils of the county are residual, developing for the most part from limestones or calcareous shales. These soils are relatively plastic, as shown by laboratory tests; but nonetheless they are very well drained, there being practically no poorly drained areas in the county. This well drained condition is possible because the joints, cracks and solution channels of the bedrock allow the water to escape quite rapidly and because the soils develop a fragmentary structure which results in a relatively permeable unit. When this natural structure is destroyed in engineering construction, the soils become plastic and react in much the same manner as other clay-like materials.

Soils formed in alluvium cover less than six percent of the area of the county. The alluvium has been derived from limestone uplands.

The topography is so gentle over the county that in most cases rock excavation is of no concern in highway construction. However, because of the solution channels, bedrock properties do become a point of concern in connection with foundations for large buildings.

The data for selected soil series were collected during the sampling and testing of the Fayette County soils. These data have been reviewed and reorganized and are presented in Figures 1, 2, 3, and 4 in a form suitable for field use. The field data are summarized in Table 1, the laboratory data in Table 2. A geological map of Fayette County is given in Figure 5, and a comparative pedological map in Figure 6.

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2. Belcher, D. G., Gregg, L. E., and Woods, K.B., "The Formation, Distribution and Engineering Characteristics of Soils." Highway Research Bull. No. 10, Eng. Exper. Sta., Purdue Univ. (Jan. 1943).
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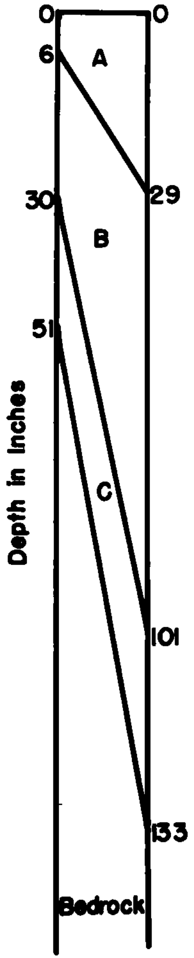
4. Duncan, A. J., "Quality Control and Industrial Statistics." Richard D. Irwin, Inc., Homewood, Ill. (1955).
5. Higbee, H. W., and Venable, K. S., "Soil Survey of Fayette County, Kentucky." U. S. Dept. Agric., Washington, D. C., Series 1931, No. 25 (1931).

HAGERSTOWN

PROFILE



DESCRIPTION

Horizon A - Grayish-brown or dark brown silty clay or clay silt - friable.

Horizon B - Light brown to reddish-brown silty clay or clay silt - friable when dry, plastic and sticky when wet - common black concretions.

Horizon C - Light reddish-brown to yellowish-brown clay or silty clay - firm and slightly compact, brittle when damp.

Bedrock - Massive, hard limestone.

HAGERSTOWN

Engineering Test Constants	Horizon A	Horizon B	Horizon C
% Sand - 2 0 0 05mm	5-20	13-20	9-34
% Silt - 0.05 0.005mm	50-59	31-67	30-33
% Clay - -0.005mm	26-40	19-50	34-60
% Colloids - -0.001mm	7-19	6-24	17-35
Liquid Limit, %	32-39	36-45	40-56
Plasticity Index, %	10-14	16-20	14-28
Max. Dry Density, PCF	100-102	97-104	87-104
Opt. Moisture Content, %	20-24	20-26	22-30
Laboratory CBR, %	3-12	5-12	2-3
Textural Classification (Miss. River Comm)	Silty Clay or Clay Silt	Silty Clay or Clay Silt	Clay or Silty Clay
HRB Classification	A-6	A-7-6;A-6	A-7-6;A-6
Group Index	8-9	11-12	8-18
Clay Minerals	--	--	Illite

<u>Topography:</u> Level to gently rolling terrain.

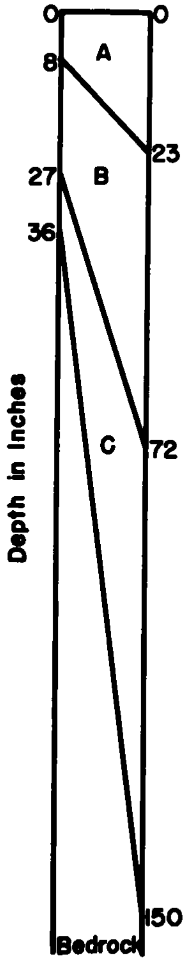
<u>Drainage:</u> Well drained. Surface and internal drainage good.

<u>Distribution:</u> Limestone areas in Pennsylvania, Maryland, West Virginia, Virginia, Kentucky, and Indiana.

Figure 1.

LORADALE

PROFILE



DESCRIPTION

Horizon A - Dark grayish-brown to dark reddish-brown clay silt or, occasionally, silty clay - friable.

Horizon B - Dark brown to reddish-brown silty clay or clay silt - sticky and plastic when wet, firm when moist, hard when dry a few small round dark concretions near top of horizon increasing to many small and medium round concretions, giving way to abundant splotches of soft irregularly shaped concretionary material mottled yellowish-brown to brownish-gray in lower portion of horizon.

Horizon C - Light olive brown to yellowish-brown clay - very sticky and very plastic when wet, very firm when moist, very hard when dry - a few small round dark concretions and some soft, black, irregularly shaped concretionary material - mottles of brownish-gray or light olive gray common.

Bedrock - Interbedded high-grade, medium phosphatic limestones and calcareous shales.

LORADALE

Engineering Test Constants	Horizon A	Horizon B	Horizon C
% Sand - 2.0-0.05mm	9-15	17-34	14-24
% Silt - 0.05-0.005mm	56-63	30-48	26-29
% Clay --0.005mm	25-32	31-41	49-58
% Colloids --0.001mm	7-11	12-19	31-35
Liquid Limit, %	33-39	33-41	51-59
Plasticity Index, %	11-15	12-21	18-32
Max. Dry Density, PCF	97-104	96-106	84-91
Opt. Moisture Content, %	20-22	21-25	28-33
Laboratory CBR, %	5-10	2-18	4-8
Textural Classification (Miss. River Comm)	Clay Silt or Silty Clay	Silty Clay or Clay Silt	Clay
HRB Classification	A-6;A-7-6	A-6; A-7-6 A-7-5	A-7-5 A-7-6
Group Index	8-10	8-14	14-20
Clay Minerals	--	--	Illite

Topography: Moderately rolling topography exhibiting in some areas a slight Karst configuration. Soil develops on gently sloping ridge tops and hillsides with slopes of 3 to 15 percent, occurring most commonly on the gentler slopes.

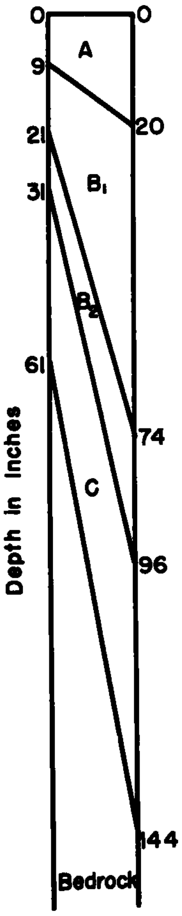
Drainage: Well drained; runoff medium to rapid; internal drainage medium.

Distribution: Extensive in the Inner Blue Grass Region of Kentucky and the Central Basin Area of Tennessee. Closely associated with Mercer soils.

Figure 2.

MAURY

PROFILE



DESCRIPTION

Horizon A - Dark brown or dark reddish-brown silty clay or clay silt -- very friable -- a few very small, almost black, round concretions.

Horizon B_1 - Dark reddish-brown to reddish-brown silty clay or clay silt -- friable in top portion becoming sticky and slightly plastic when wet in lower portion, firm when moist, hard when dry -- small, black concretions that increase in number with depth.

Horison B_2 - Yellowish-red, slightly variegated with brown, silty clay or clay -- sticky and plastic when wet, firm when moist, hard when dry -- many small, round, black concretions -- some soft, irregularly shaped concretionary splotches -- a few weathered fragments of chert and limestone in the power portion.

Horizon C - Yellowish-red to brown silty clay or clay, mottled with dark brown and yellowish-brown -- sticky and plastic when wet, firm when moist, very hard when dry -- few to common small, black concretions and soft, irregularly shaped concretionary splotches -- many weathered fragments of chert and limestone that increase in number with depth.

Bedrock - Highgrade phosphatic limestone.

MAURY

Engineering Test Constants	Horizon			
	A	B_1	B_2	C
% Sand - 2.0-0.05mm	5-14	12-20	10-24	12-25
% Silt - 0.05-0.005mm	55-59	44-53	22-45	25-47
% Clay - -0.005mm	29-38	28-40	35-64	26-65
% Colloids - -0.001mm	9-14	10-18	18-45	8-43
Liquid Limit, %	35-38	38-41	47-54	45-61
Plasticity Index, %	11-13	15-19	19-23	18-32
Max. Dry Density, PCF	93-104	98-103	92-98	90-99
Opt. Moisture Content, %	20-25	21-23	24-29	24-33
Laboratory CBR, %	3-17	7-11	1-13	3*
Textural Classification (Miss. River Comm)	Silty Clay Clay Silt	Silty Clay Clay Silt	Silty Clay Clay	Silty Clay Clay
HRB Classification	A-6 A-7-6	A-6 A-7-6	A-7-6 A-7-5	A-7-6 A-7-5
Group Index	8-10	8-11	12-16	12-20
Clay Minerals	--	--	--	Illite

* Insufficient data to establish a meaningful range.

Topography: Gently to steeply sloping terrain with gradients generally 2 to 12 percent and some as great as 20 percent. Many areas have Karst topography.

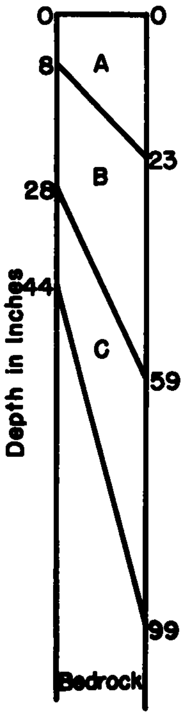
Drainage: Well drained. Runoff and internal drainage are medium.

Distribution: The most extensive of the highly phosphatic soils in the Inner Blue Grass Region of Kentucky and the Outer Basin Area of Tennessee. Found in close geopraphic association with soils of the McAfee, Braxton, Salvisa, Hagerstown, Loradale, Hampshire, Culleoka, Inman, and Hicks series.

Figure 3.

MERCER

PROFILE



DESCRIPTION

Horizon A - Dark grayish-brown to dark yellowish-brown clay silt, or, occasionally, silty clay - friable.

Horizon B - Yellowish-brown silty clay - friable when moist increasing in firmness until becoming brittle with depth. Sticky when wet - a few small round black concretions increasing in number and then gradually giving way to very abundant soft black, irregularly shaped concretionary splotches with greater depth - strong brown to light-brownish-gray distinct mottling near bottom of horizon.

Horizon C - Strong brown to light olive-gray clay or silty clay - mottled with yellowish-brown - firm when moist, sticky and very plastic when wet, very hard when dry - a few small round black concretions.

Bedrock - High-grade, medium phosphatic limestones with strata of calcareous shales.

MERCER

Engineering Test Constants	Horizon A	Horizon B	Horizon C
% Sand - 2.0-0.05mm	8-23	14-22	18-37
% Silt - 0.05-0.005mm	52-63	37-55	32-36
% Clay --0.005mm	21-32	31-42	23-61
% Colloids - -0.001mm	5-9	12-18	11-36
Liquid Limit, %	36-42	36-41	28-56
Plasticity Index, %	8-13	14-19	3-35
Max. Dry Density, PCF	88-108	99-108	93-109
Opt. Moisture Content, %	16-28	18-23	20-26
Laboratory CBR, %	2-11	3-18	9*
Textural Classification (Miss. River Comm)	Clay Silt or Silty Clay	Silty Clay	Clay or Silty Clay
HRB Classification	A-4;A-6 A-7-6	A-6 A-7-6	A-6 A-7-6
Group Index	8-10	9-11	11-18
Clay Minerals	--	--	Illite, Kaolinite & Montmorillonite(Nontronite)

* Insufficient data to establish a meaningful range

Topography: Nearly level to slightly sloping ridge tops with gradient usually from about 1 to 7 percent, sometimes as high as 10 percent.

Drainage: Moderately well drained. Runoff is slow to medium, internal drainage is slow. Fragipans often encountered at depths of 15 to 30 inches and range in thickness of about 10 to 20 inches.

Distribution: Fairly extensive soils of the Inner Blue Grass Region of Kentucky and the Outer Basin of Tennessee. Found in close geographic association with the Hampshire, Inman, Loradale, Hagerstown, Maury and Eden series.

Figure 4.

TABLE 1

SUMMARY OF FIELD DATA

Site No.	Location Description	Date Sampled	Slope Class	Water Table Depth	Solid Rock Depth	Pedological Soil Type	Sample No.	Field Description	Color	Horizon Depth
					Hagerstown Series					
34-20	30 ft W of centerline, 0.4 mi N of RR crossing in W. Fork of Ware Rd.	28 Apr 56	0-4%	-	10 ft-1 in.+	Hagerstown silt loam	20A	Friable silt loam.	Brown	0-29 in.
							20B	Sticky and plastic clay loam, many small black concretions (some ½-in. dia)	Bright reddish brown	29-101 in.
							20C	Friable clay loams, many large black concretions (½ in. dia)	Yellowish-brown	101-121 in.+
34-24	30 ft W of Russell Cave Rd, 0.2 mi N of Loradale.	5 May 56	0-4%	6 ft-8 in.	7 ft-0 in.	Hagerstown silt loam	24A	Friable silt loam	Brown	0-13 in.
							24B	Friable silt clay loam, small black concretions which increase in size and number at 35 in.	Reddish-brown	13-55 in.
							24C	Firm and sticky clay loam, many concretions.	Yellowish-brown	55-84 in.
34-26	135 ft E of Nicholasville Rd, 500 ft N of Wilson Rd.	12 May 56	0-4%	-	9 ft-1 in.+	Hagerstown silt loam	26A	Friable silt loam	Brown	0-20 in.
							26B	Friable silt clay loam, slightly firm, small black concretions.	Reddish-brown	20-44 in.
							$26C_1$	Firm but friable silty clay loam, few small black concretions, grayish streaks increase with depth.	Yellowish-brown	44-80 in.
							$26C_2$	Firm, friable silty clay loam, much black and gray mottling.	Yellowish-brown	80-109 in.+
					Loradale Series					
34-2	110 ft N of Lexington-Winchester Rd, 0.8 mi W of intersection of US 60 & Ky. 859.	14 Mar 56	0-4%	3 ft-10 in.	6 ft-0 in.+	Loradale silt loam	2A	Friable silt loam	Brown	0-22 in.
							2B	Firm silty clay, few black concretions.	Reddish-brown	22-46 in.
							2C	Plastic, sticky clay	Brownish-yellow to yellow.	46-72 in.+
34-10	900 ft S of Stone Rd, E of Southern RR	22 Feb 55	-	-	-	Loradale silt loam	10A	-	-	0-12 in.
34-18	30 ft E of Combs Ferry Rd, 0.4 mi N of Pine Grove.	28 Apr 56	0-4%	None	6 ft-8 in.	Loradale silt loam	18A	Friable silt loam	Brown	0-22 in.
							18B	Friable silty clay loam, many black concretions, gray mottling increasing rapidly at 43 in.	Reddish-brown slight yellowish tinge.	22-71 in.
							18C	Friable clay, black mottling, rock fragments encountered at 71-80 in.	Dark reddish-brown, yellowish tinge.	71-80 in.

TABLE 1 (Continued)

Site No.	Location Description	Date Sampled	Slope Class	Water Table Depth	Solid Rock Depth	Pedological Soil Type	Sample No.	Field Description	Color	Horizon Depth
					Loradale Series (Continued)					
34-21	40 ft W of Cleveland Rd, 1.3 mi N of US 60.	28 Apr 56	0-4%	None	6 ft-3 in.	Loradale silt loam	21A	Friable silt loam, small black concretions.	Grayish-brown; top 6 in.-chocolate brown	0-18 in.
							21B	Moderately friable silty clay, many small black concretions.	Reddish-brown	18-52 in.
							21C	Friable silty clay, few black concretions, clods have glossy appearance.	Yellowish-brown	52-75 in.
34-25	35 ft N of Ironworks Rd, 600 ft W of Newtown Pike.	5 May 56	0-4%	4 ft-2 in.	7 ft-4 in.	Loradale silt loam	25A	Friable silt loam	Grayish-brown	0-23 in.
							25B	Sticky clay loam, small black concretions, concretionary splotches.	Reddish-brown, slight yellowish tinge.	23-60 in.
							25C	Sticky clay, black concretions.	Yellowish-brown	60-88 in.
34-34	40 ft E of Crawley Lane, 700 ft S of Jacks Creek Rd.	14 May 56	0-4%	-	4 ft-8 in.+	Loradale silt loam	34A	Friable silt loam	Brown	0-32 in.
							34B	Friable gritty clay loam, many moderate sized black concretions.	Reddish-brown slight yellowish tinge in lower portion.	32-56 in.+
					Maury Series					
34-4	0.4 mi NW of Hospital entrance, on Lexington-Frankfort Rd, US 421 E of Rd, SE of RR.	Sept 54	-	-	-	Maury silt loam Slope phase	4A	-	-	-
							$4B_1$	-	-	-
							$4B_2$	-	-	-
							4C	-	-	-
34-5	100 ft N of Ironworks Rd, 600 ft E of intersection of Russel Cave Rd.	Sept 54	-	-	-	Maury silt loam	5A	-	-	-
34-6	1.2 mi W of Boone Creek on 1st Rd to the E south of Nihizertown.	Oct 54	-	-	-	Maury silt loam	6A	-	-	-
							$6B_1$	-	-	-
							$6B_2$	-	-	-
							6C	-	-	-
34-7	0.6 mi SW of Cave Hill Rd on Lexington-Harrodsburg Rd, US 68, 75 ft SE of Road. Samples from face of cut.	Sept 54	-	-	-	Maury silt loam	7A	-	-	-
							$7B_1$	-	-	-
							$7B_2$	-	-	-
							7C	-	-	-
34-11	100 ft E of Russell Cave Rd, 600 ft N of intersection with Ironworks Rd.	Sept 54	-	-	-	Maury silt loam	11A	-	-	-
							$11B_1$	-	-	-
							$11B_2$	-	-	-
							11C	-	-	-
34-12	75 ft E of Clays Mill Rd, 200 ft N of Holly Hill Drive.	26 Mar 56	0-4%	5 ft-10 in.	9 ft-0 in.+	Maury silt loam grayish-brown phase.	12A	Friable silt loam	Grayish-brown	0-16 in.
							$12B_1$	Sticky clay, small black concretions.	Reddish-brown	16-48 in.
							$12B_2$	Increasingly friable, black concretions increase in number.	Yellowish-brown, grayish mottling near bottom.	48-70 in.
							12C	Heavy clay, many black con-	Yellowish-	70-108 in.+

34-13	200 ft N of Holly Hill Drive, 800 ft E of Clays Mill Rd.	30 Mar 56	4-16%	-	10 ft-5 in.+	Maury silt loam Slope phase	13A	Friable silt loam	Brown	0-10 in.
							$13B_1$	Slightly plastic clay becoming friable in lower portion, black concretions increase in number with depth.	Reddish-brown, changes to reddish black near bottom.	10-75 in.
							$13B_2$	Friable silt loam, black concretions,gray sticky mottling encountered at 125 in.	Yellowish-brown, yellow inc. w/depth	75-125 in.+
34-14	25 ft N of Military Rd, 1.5 mi E of Little Texas.	11 Apr 56	0-4%	-	9 ft-9 in.+	Maury silt loam	14A	Friable silt loam, numerous roots.	Brown	0-48 in.
							$14B_1$	Sticky heavy clay loam, black concretions.	Reddish-brown	48-102 in.
							$14B_2$	Firm, friable clay, rock fragments 90-117 in. stopped sampling at 117 in. No sample.	Yellowish-brown	102-117 in.+
34-16	25 ft NW of Bowman Rd., 0.6 mi S of Parkers Mill Rd.	23 Apr 56	4-16%	None	4 ft-5 in.	Maury silty clay loam, slope phase	16B	Friable silty clay loam, rock fragments at 3 ft-6 in.	Grayish-brown	0-42 in.
							16C	Stiff clay loam, few black concretionary splotches.	Reddish-brown, slight yellowish mottling.	42-53 in.
34-17	25 ft S of Athens-Boonesboro Rd, 1.1 mi E of Athens. Samples from face of cut.	28 Apr 56	0-4%	None	6 ft-0 in.	Maury silty clay loam, slope phase	17A	Friable silt loam	Dark brown	0-18 in.
							17B	Friable clay loam, small black concretions.	Reddish-brown	18-68 in.
							17C	Plastic clay loam, with sticky light gray mottling. No sample.	Dark reddish-brown	68-72 in.
						Mercer Series				
34-1	120 ft N of Lexington-Winchester Rd, US 60, 0.5 mi W of Clark Co. line.	14 Mar 56	0-4%	6 ft-6 in.	6 ft-6 in.+	Mercer silt loam	1A	Friable silt loam	Blackish-gray	0-22 in.
							1B	Silty clay, clay content increases with depth, black concretions	Brownish-yellow	22-48 in.
							1C	Firm silty clay, black concretions, brown mottling.	Brownish-yellow	48-80 in.+
34-15	800 ft W of RR and Rd Intersection at Walnut Hill Station, samples from 6 ft cut face S of RR.	18 Apr 56	0-4%	None	8 ft-3 in.	Mercer silt loam	15A	Friable silt loam	Brownish-gray	0-18 in.
							15B	Friable silt clay, many black concretions.	Reddish-brown	18-65 in.
							15C	Friable clay loam, black concretions give way to grit and gravel in large amounts.	Bright brownish-yellow	65-99 in.
34-19	40 ft S of Ware Rd, 0.4 mi N of L&N RR crossing.	28 Apr 56	0-4%	None	3 ft-2 in.	Mercer silty clay loam, eroded phase	19A	Friable silt loam	Brown	0-23 in.
							19B	Silty clay loam, black concretions and mottling.	Reddish-brown, yellow tinge	23-38 in.
34-23	30 ft W of the Hume-Bedford Rd, 500 ft S of the Greenwich Rd Intersection.	5 May 56	0-4%	3 ft-7 in.	6 ft-8 in.+	Mercer silty clay loam, eroded phase	23A	Friable silt loam	Brown	0-4 in.
							23B	Plastic clay, gray mottling, red streaks, few black concretions.	Yellowish-brown	4-32 in.
							23C	Plastic clay with reddish streaks (planes of weakness), small, black concretions.	Gray, reddish coloring increases with depth.	32-80 in.+

TABLE 2

SUMMARY OF LABORATORY DATA

Sample No.	Liquid Limit	Plasticity Index	Specific Gravity	Grain Size Distribution: 2.0-0.05 mm % Sand	Grain Size Distribution: 0.05-0.005 mm % Silt	Grain Size Distribution: 0.005 mm % Clay	Grain Size Distribution: 0.001 mm % Colloids	Std. Proctor: Maximum Density	Std. Proctor: Opt. M.C.	Lab. CBR	Classification: U. S. Bureau of Soils	Classification: Miss. River Commission	HRB	Clay Minerals
Hagerstown Series														
34-20A	33.0	11.6	2.68	8.0	58.0	34.0	10.0	101.2	21.4	8.0	Silty clay	Silty clay	A-6(9)	--
34-24A	36.1	10.7	2.63	17.0	54.0	29.0	12.0	--	--	--	Silty clay loam	Clay silt	A-6(8)	--
34-26A	37.1	13.1	2.72	12.0	51.0	37.0	17.0	101.0	22.0	6.7	Clay	Silty clay	A-6(9)	--
34-20B	37.9	16.9	2.74	14.0	54.0	32.0	14.5	102.7	20.9	9.6	Clay	Silty clay	A-6(11)	--
34-24B	40.8	19.5	2.74	17.0	56.0	27.0	10.0	100.4	23.4	5.9	Silty clay loam	Clay silt	A-7-6(12)	--
34-26B	42.7	17.3	2.77	18.0	37.0	45.0	20.5	98.6	24.1	9.7	Clay	Silty clay	A-7-6(12)	--
34-20C	37.4	12.8	2.87	36.0	32.0	32.0	17.0	105.2	22.4	--	Clay	Sandy clay	A-6(8)	--
34-24C	53.4	27.9	2.89	23.5	32.0	44.5	23.0	89.2	30.0	2.7	Clay	Silty clay	A-7-6(18)	Illite
34-26C_1	51.7	21.0	2.80	16.0	29.0	55.0	34.0	91.0	27.4	2.9	Clay	Clay	A-7-6(16)	--
34-26C_2	47.7	22.0	2.81	11.5	32.5	56.0	31.0	96.9	25.2	2.4	Clay	Clay	A-7-6(14)	--
Loradale Series														
34-2A	36.9	11.3	2.64	8.0	56.0	36.0	11.5	98.3	20.0	3.0	Silty clay	Silty clay	A-6(9)	--
34-10A	36.8	16.3	2.71	18.1	53.2	28.7	11.7	107.3	20.1	--	Silty clay loam	Clay silt	A-6(10)	--
34-18A	33.9	10.7	2.71	13.0	64.0	23.0	8.0	101.0	20.9	9.3	Silty clay loam	Clay silt	A-6(8)	--
34-21A	31.9	10.5	2.70	13.0	61.0	26.0	8.0	104.0	19.6	7.5	Silty clay loam	Clay silt	A-6(8)	--
34-25A	41.8	13.9	2.66	11.5	61.0	27.5	6.5	96.6	23.6	6.2	Silty clay loam	Clay silt	A-7-6(10)	--
34-34A	33.4	13.3	2.67	9.5	61.5	29.0	6.5	97.6	22.2	10.0	Silty clay loam	Clay silt	A-6(9)	--
34-2B	42.1	23.2	2.75	17.0	40.0	43.0	19.0	104.4	21.7	4.5	Clay	Silty clay	A-7-6(14)	--
34-18B	37.4	15.7	2.91	39.5	22.5	38.0	19.0	92.9	26.2	--	Clay	Sand clay	A-7-5(9)	--
34-21B	38.3	17.1	2.76	20.0	44.0	36.0	14.5	100.3	24.8	5.4	Clay	Silty clay	A-6(11)	--
34-25B	37.5	15.6	2.75	26.0	45.0	29.0	11.5	102.5	21.9	9.8	Clay loam	Clay silt	A-6(10)	--
34-34B	30.0	9.5	2.73	24.0	44.0	32.0	12.5	104.8	20.0	20.0	Clay	Silty clay	A-4(8)	--
34-2C	58.7	29.1	2.82	13.0	28.5	58.5	34.0	83.6	29.6	5.7	Clay	Clay	A-7-6(20)	--
34-18C	51.6	21.2	2.82	22.0	26.5	51.5	35.0	85.6	33.2	--	Clay	Clay	A-7-5(15)	--
34-21C	53.6	18.6	2.75	21.0	28.0	51.0	32.0	90.2	29.8	6.3	Clay	Clay	A-7-5(14)	Illite
34-25C	56.6	30.0	2.88	21.0	26.5	52.5	31.0	89.5	28.6	--	Clay	Clay	A-7-6(19)	--
Maury Series														
34-4A	38.2	9.2	2.68	6.0	59.5	34.5	12.0	--	--	--	Silty clay	Silty clay	A-4(8)	--
34-5A	40.3	15.3	--	--	--	--	--	--	--	--	--	--	A-7-6(--)	--
34-6A	35.8	14.5	2.69	6.2	57.4	36.4	12.5	--	--	--	Silty clay	Silty clay	A-6(10)	--
34-7A	31.6	8.9	--	--	--	--	--	--	--	--	--	--	A-4(--)	--

34-17A	38.5	12.9	2.70	18.0	55.0	27.0	9.5	97.0	23.0	10.7	Silty clay loam	Clay silt	A-6(9)	--
34-4B_1	41.9	16.5	2.76	10.0	47.0	43.0	21.5	100.1	22.4	--	Clay	Silty clay	A-7-6(11)	--
34-6B_1	43.6	22.8	2.76	--	--	--	--	103.1	21.1	--	--	--	A-7-6(--)	--
34-7B_1	44.4	18.6	--	--	--	--	--	102.6	20.6	--	--	--	A-7-6(--)	--
34-11B_1	38.0	16.3	2.74	--	--	--	--	99.4	23.2	--	--	--	A-6(--)	--
34-12B_1	35.9	15.1	2.74	15.5	49.5	35.0	12.0	102.8	20.7	11.2	Clay	Silty clay	A-6(10)	--
34-13B_1	40.7	17.1	2.73	15.0	48.5	36.5	18.0	103.8	20.8	10.7	Clay	Silty clay	A-7-6(11)	--
34-14B_1	39.3	19.2	2.74	12.0	49.0	39.0	15.0	103.0	21.5	10.8	Clay	Silty clay	A-6(11)	--
34-16B	37.2	10.6	2.67	20.0	57.0	23.0	7.0	93.2	24.1	5.3	Silty clay loam	Clay silt	A-6(8)	--
34-17B	38.1	14.8	2.80	21.5	40.0	28.5	11.5	97.8	25.0	7.4	Clay loam	Clay silt	A-6(9)	--
34-4B_2	50.6	20.8	2.84	12.5	36.5	51.0	31.0	94.8	27.0	--	Clay	Silty clay	A-7-6(14)	--
34-6B_2	49.2	26.1	--	--	--	--	--	97.8	23.7	--	--	--	A-7-6(--)	--
34-7B_2	51.6	20.1	--	--	--	--	--	98.0	25.4	--	--	--	A-7-5(--)	--
34-11B_2	47.0	20.2	--	--	--	--	--	91.2	29.4	--	--	--	A-7-6(--)	--
34-12B_2	45.8	17.3	2.79	21.0	38.5	40.5	23.0	97.0	24.3	8.1	Clay	Silty clay	A-7-6(12)	--
34-13B_2	58.5	20.8	2.84	17.0	25.5	57.5	40.0	89.4	31.6	6.2	Clay	Clay	A-7-5(16)	--
34-4C	47.4	19.7	2.80	19.0	39.0	42.0	21.0	--	--	--	Clay	Silty clay	A-7-6(13)	--
34-6C	67.4	38.4	--	--	--	--	--	102.4	35.6	--	--	--	A-7-6(--)	--
34-7C	52.0	18.3	--	--	--	--	--	89.6	30.0	--	--	--	A-7-5(--)	--
34-11C	46.5	20.2	2.76	--	--	--	--	93.9	25.0	--	--	--	A-7-6(--)	---
34-12C	62.7	31.7	2.82	13.5	28.5	58.0	37.0	92.2	24.6	3.3	Clay	Clay	A-7-5(20)	Illite
34-16C	41.7	18.5	2.77	24.0	40.0	36.0	18.5	95.4	25.7	--	Clay	Silty clay	A-7-6(12)	--
Mercer Series														
34-1A	35.2	8.8	2.68	13.0	58.0	29.0	8.0	103.1	18.8	4.0	Silty clay loam	Clay silt	A-4(8)	--
34-15A	38.9	9.1	2.54	19.0	60.0	21.0	7.0	87.6	23.2	9.0	Silty clay loam	Clay silt	A-4(8)	--
34-19A	40.0	11.4	2.68	23.0	51.0	26.0	5.0	99.1	23.5	6.7	Silty clay loam	Clay silt	A-6(9)	--
34-23A	41.5	13.7	2.62	8.5	61.0	30.5	9.0	--	--	--	Silty clay	Silty clay	A-7-6(10)	--
34-1B	35.3	16.9	2.75	20.5	43.0	36.5	12.0	109.1	18.2	14.2	Clay	Silty clay	A-6(11)	--
34-15B	38.2	13.4	2.75	17.0	49.0	34.0	14.0	104.0	20.5	11.8	Clay	Silty clay	A-6(9)	--
34-19B	41.0	17.3	2.79	20.0	37.5	42.5	19.0	100.6	23.2	5.5	Clay	Silty clay	A-7-6(11)	--
34-23B	39.0	18.0	2.77	13.0	55.0	32.0	14.5	101.6	20.2	--	Clay	Silty clay	A-6(11)	--
34-1C	40.0	17.5	2.70	26.0	35.0	39.0	18.0	102.5	22.5	8.2	Clay	Silty clay	A-6(11)	Kaolinite & Montmorillonite (Nontronite)
34-15C	34.9	10.3	2.87	34.0	34.0	32.0	20.0	104.3	21.4	15.5	Clay	Sandy clay	A-6(8)	Kaolinite & Montmorillonite (Nontronite)
34-23C	50.7	29.1	2.80	23.0	33.0	54.0	32.0	95.2	25.0	2.2	Clay	Clay	A-7-6(18)	Illite

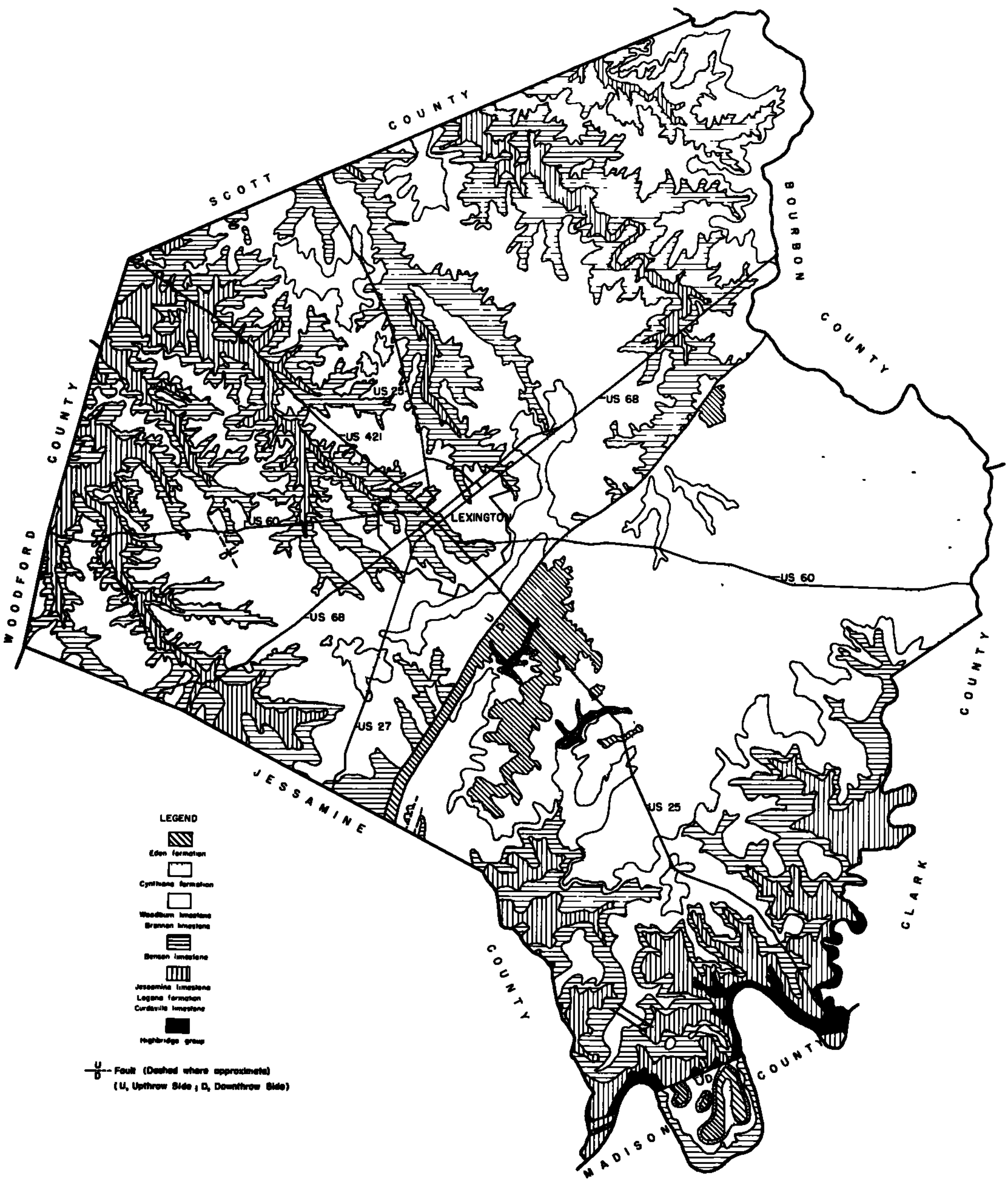


Figure 5. Geological map of Fayette County, Kentucky.

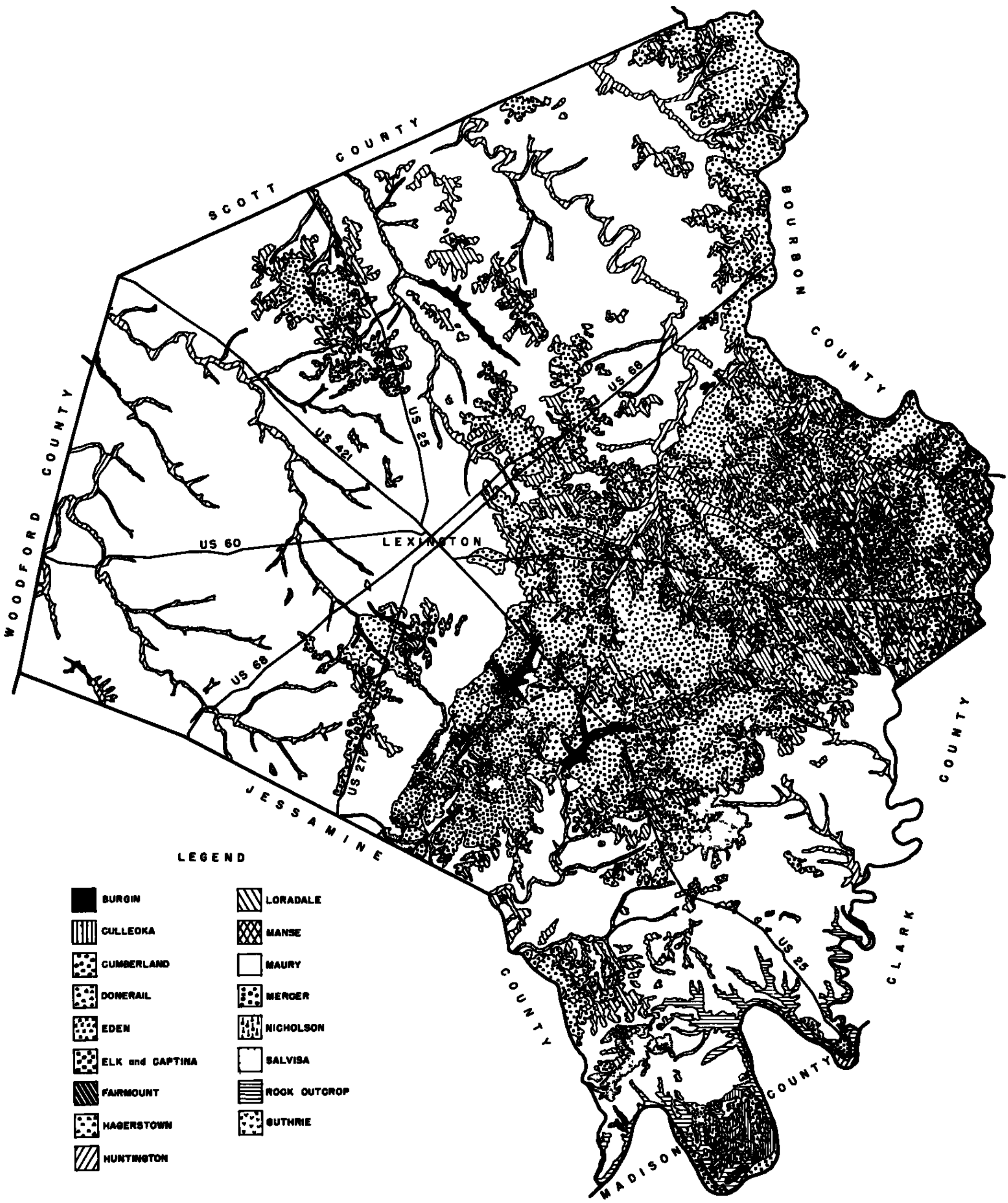


Figure 6. Pedological map of Fayette County, Kentucky.

Discussion

JAMES H. McLERRAN, Assistant Chief, Photographic Interpretation Research Branch, U. S. Army Snow Ice and Permafrost Research Establishment—The author has applied a commendable approach to the problem of obtaining the range of values for a given engineering property to be assigned to a particular soil horizon of a certain soil series. The range of values as shown with his soil descriptions are sometimes rather wide. Note the values of percent clay in the C horizon and the plasticity index for the Mercer soil. This wide range could be narrowed if the soil type was chosen to describe rather than the soil series.

A description of the soil series is fine for a generalized report on a statewide basis, but when you have a county map available this information should not be generalized by defining only the soil series. There are differences within a soil series that are significant to the engineer and are defined by the soil type.

Since the surface texture is strongly influenced by what lies below it, there will be differences throughout the profile for different soil types within a series. This is particularly true in residual soils but also is true of other soils.

Airphoto Analysis of Terrain for Highway Location Studies in Maine

E. G. STOECKELER, Airphoto Interpretation Specialist,
University of Maine; and
W. R. GORRILL, Soils Engineer, Maine State Highway Commission

Aerial photographs have been used in Maine in the following types of highway location studies: (a) preliminary cost estimates for portions of the Interstate System, (b) detailed study of proposed route locations, and (c) relocation studies for secondary roads. The Interstate route studies included soils, rock excavation, gravel sources and haul distance, and drainage conditions; changes in P-line were made to avoid peat or muck. The detailed study of a proposed route included the preparation of large scale engineering-soil strip-maps. The relocation studies for secondary roads included information regarding soils, gravel sources and drainage.

● THE AIRPHOTO Interpretation Project at the University of Maine is financed jointly by the Maine State Highway Commission and the U. S. Bureau of Public Roads. The function of this project is to provide information on soils, drainage and other natural and cultural features which might be useful in all phases of highway engineering from preliminary planning to construction operations.

Engineering soils, drainage and materials maps have been prepared for an area of approximately 3,500 sq mi. These maps were made by quadrangles, an area of approximately 200 sq mi, at a scale of 2 in. = 1 mi. Precedence was given to the areas where most construction was anticipated. These maps are especially useful in the preliminary planning phases of location studies and the preparation of cost estimates.

In addition to these maps, a number of strip studies, using photo interpretation techniques, were accomplished. The main subject of this paper is a discussion of various types of photo strip studies and their applications in highway engineering.

TYPES OF STRIP STUDIES

Approximately 300 linear miles of new location and relocation strip studies were completed during the past year. Areas covered by these projects are shown in Figure 1. Individual projects varied in length from 3 mi to over 100 mi. In practically all cases, aerial photography was flown specifically for the State Highway Commission. Photo scales ranged from 1:5,400 to 1:20,000 depending on the type of study desired. Most of the photography was taken in the spring after snow had disappeared and before new foliage was developed. Photos taken in fall after deciduous foliage has been shed are also acceptable. The seasonal aspect is of special significance in Maine because at least 90 percent of the areas studied to date were in densely wooded wilderness sites where terrain interpretation from summer photography is difficult because surficial fea-

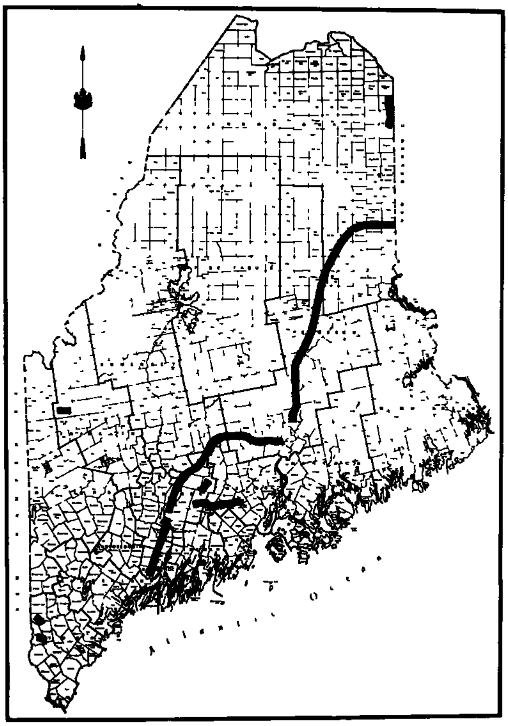


Figure 1. Airphoto strip studies completed in 1957.

tures are often masked by the forest canopy.

These studies covered proposed routes of the Interstate Highway System as well as a number of highway relocations. The type of data and methods of presentation of the information varied somewhat for individual projects. The four major types of strip studies which were made include (a) engineering soils, (b) drainage, (c) gravel haul, and (d) highway relocation and reconstruction.

ENGINEERING SOILS STRIP

The Main Reconnaissance Engineering Soils Classification System was devised by the authors specifically for engineers. While this system is based on a geological approach, the nomenclature is given in engineering terminology. This system reduces the number of soil units to a minimum, yet provides the information required by local highway engineers. The eight map units listed below are tailored for Maine terrain and climatic conditions and are adaptable to airphoto interpretation techniques which require a minimum amount of field checking. Figures 10-18 are stereograms that illustrate these soil units:

R—Rock, ledge within 5 ft of the surface.
BG—Boulder Granular, glacial till having a sandy or gravelly matrix.
B—Boulder, glacial till having a silty or clayey matrix.
G—Granular, sand or gravel.
F—Fines, silt or clay.
S—Swamp, surficial peat less than 3 ft thick.
P—Peat, surficial peat more than 3 ft thick.
W—Water, generally more than 2 ft deep.

For preliminary planning soils studies, 1:20,000 scale photography was used. In most cases a single 3-mi wide strip centered on a preliminary line was provided for delineating soils areas. Occasionally two or three parallel strips were flown where more widely separated alternate routes were to be studied. The minimum size area delineated was approximately 5 acres in extent except for such elongated forms as esker ridges and narrow valley swamps.

In addition to soils delineation, annotations were made on the photos emphasizing significant terrain features such as deep bogs, extensive rock outcrops, steep slopes and other obstacles which should be avoided. Annotations depicting favorable terrain conditions were also indicated.

Figure 2 is an uncontrolled mosaic showing a 5-mi segment of the proposed 110-mi section of the Interstate Highway System between Orono and Houlton, Maine. The soils information was transferred directly from the airphotos to a profile which had been prepared by photogrammetric methods. The P-line and Stationing were placed on the photos used for soils interpretation to facilitate the procedure of transferring soils data to the profile sheet as shown in Figure 3. With the engineer and the interpreter working together, the grade line was often adjusted to take advantage of terrain characteristics. For example, other conditions permitting, cuts were frequently increased at locations where ledge probably would not be encountered, especially where good granular excavation was anticipated. In areas where rock outcrops were numerous, the grade line was adjusted to minimize the amount of rock excavation. In addition to adjusting the grade line, the preliminary horizontal alignment was modified to avoid difficult terrain and also to take advantage of favorable construction areas. This information was used for the preparation of a preliminary estimate of cost of the Interstate Highway System.

Another more detailed engineering soils strip study was made of a 30-mi portion of the Interstate Highway System in a more advanced planning stage. Airphotos for this study were taken in spring at a scale of 1:5,400. A private photogrammetric concern was engaged to prepare topographic maps of a 3,200-ft wide strip at a scale 1 in. = 200 ft and a contour interval of 5 ft. For this project the soils information was transferred from the photos to the topographic sheet, thus en-

Figure 2. Uncontrolled mosaic showing engineering soils areas. Stations were placed at 1,000-ft intervals on the originals.

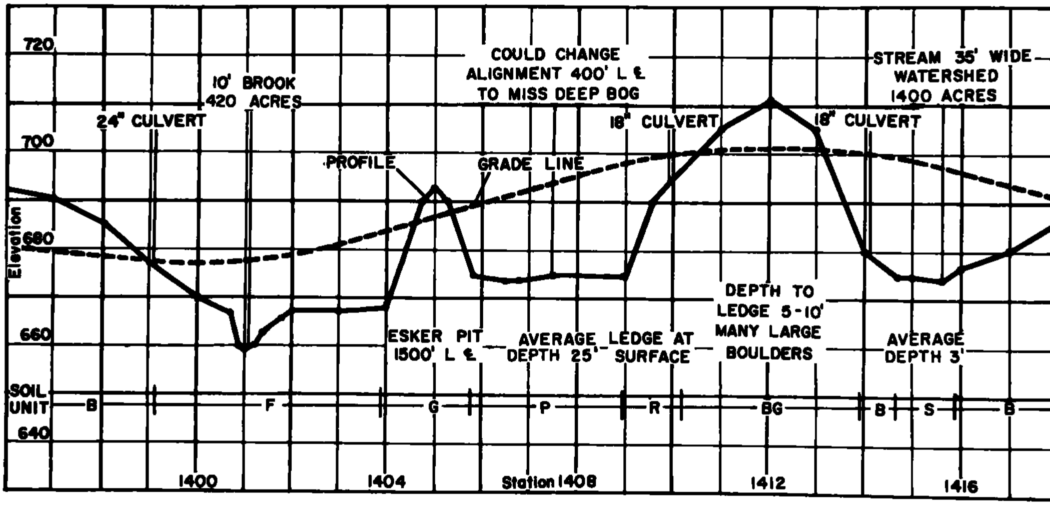


Figure 3. Profile with engineering soils and drainage annotations.

abling the location engineer to evaluate the engineering and economic aspects of a number of possible road lines within the 3,200-ft wide strip. After detailed analyses of a number of possible lines were made, a centerline was selected and photogrammetric methods were used to determine cross-sections.

With large scale photography of this type the interpreter can delineate small problem areas such as rock outcrops and swamps less than one-tenth acre in extent. In boulder-strewn glacial deposits, even in wooded areas, it is often possible to measure individual boulders for the purpose of estimating the amount of ledge-sized boulders (larger than 1 cu yd) contained in the deposit. Areas where seepage, settlement and frost action might occur were also annotated on the photos.

The detailed engineering soils map and annotated photos were then provided to field geologists for detailed soils investigation. Suggested probe and drill hole locations were pinpointed on the photos to assist the geologist in determining actual soil type boundaries. Additional explorations were made at the discretion of the geologist in order to obtain an adequate soils profile. After an evaluation was made of the field investigation and laboratory analysis of the samples, the soils map was modified and extended to include detailed information on critical areas. Frequently the field work was expedited by trails and access roads indicated on the photos. By following this procedure, a maximum amount of soils and terrain data was obtained with the minimum expenditure of manpower, time and money.

DRAINAGE STRIP STUDIES

In Maine, as elsewhere, the design of drainage structures in relocation projects is often based on observations of the past performance of existing structures not far distant from the proposed new location. If the existing structure proved adequate over a long period of years a comparable design for the nearby location is used. However, for most of the proposed Interstate Highway System and many major highway relocations, this method of design cannot be employed because often no existing nearby structures are available for evaluation. U. S. Geological Survey topographic sheets having a scale of 1 in. = 1 mi and a contour interval of 20 ft are often inadequate for determining watershed areas, especially small watersheds less than 1,000 acres in extent. In addition, many quadrangle sheets in Maine were compiled over 20 years ago and some are of pre-World War I vintage. Because of these inadequacies, highway engineers have recently exhibited considerable interest in photohydrological studies.

The suitability of photography for drainage interpretation studies is dependent principally on scale and season of photography. In densely wooded areas the seasonal aspect is probably of prime importance. In summer photography many drainageways and minor relief breaks are hidden by the forest canopy. In these cases the interpretation of vegetation provides the only clue to the existence of a drainageway. Due to climatic conditions in Maine, photography taken during the spring break-up period just after the snow has disappeared is excellent for drainage interpretation purposes. During this period every little drainageway and depression is filled with water and the photo patterns are very easy to interpret. Even in dense forests containing 75 percent coniferous trees there are enough canopy breaks formed by the leafless deciduous trees to permit the interpreter to see a sufficient amount of the earth's surface so that even small drainageways can be traced.

For preliminary reconnaissance drainage surveys, photography having a scale of 1:20,000 is adequate. Figure 4 is an un-

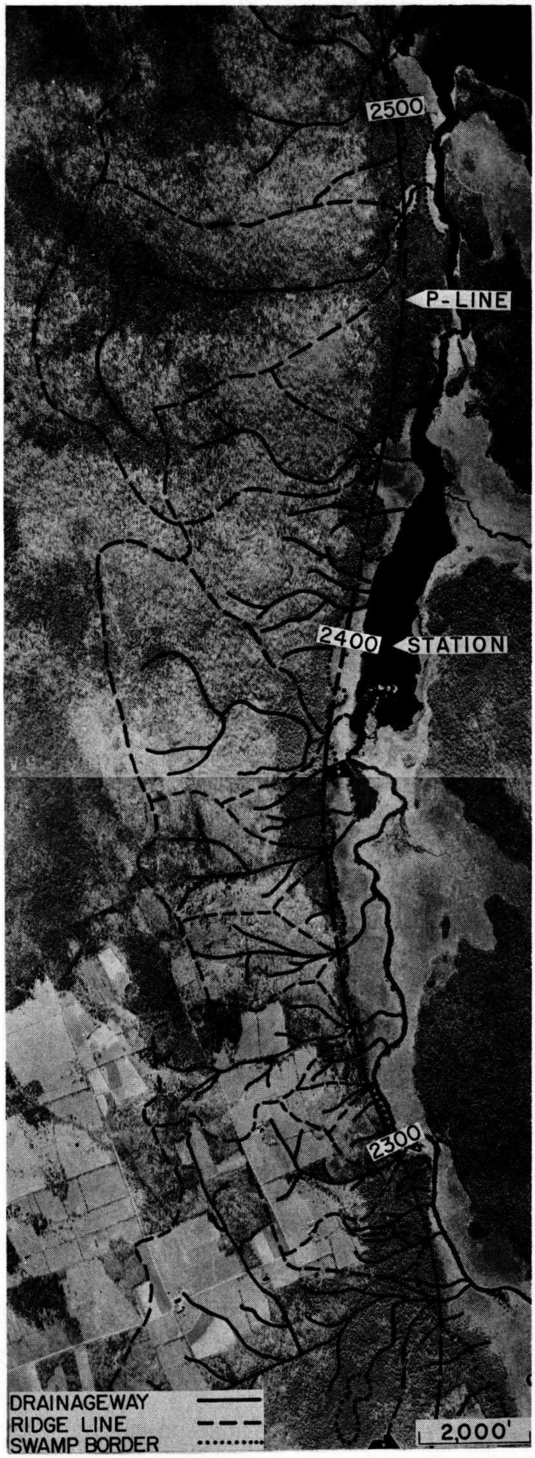


Figure 4. Uncontrolled mosaic of drainage delineations. Watershed areas were obtained directly from the photos.

controlled mosaic of a drainage study made along a portion of the proposed Interstate Highway System. Many smaller drainageways and minor ridge lines delineated on the original 1:20,000 photos were omitted in this illustration for reproduction purposes. Drainage strip studies of this type were made of approximately 240 linear miles of the Interstate Highway System in Maine.

Area, slope and cover type information for each individual watershed was provided to the highway engineer who calculated the preliminary drainage structure sizes. This information was then transferred to the profile using the same procedure described previously (see Fig. 3). In addition, information on nearby drainage structures, the existence of water storage areas in individual watersheds, possible seepage areas and similar hydrological data were noted on the profile sheet. This information was used for the preparation of preliminary cost estimates.

For more detailed drainage studies, photography having a scale of 1:5,000 to 1:10,000 is preferred. In densely wooded areas, especially on relatively flat terrain, small drainageways are difficult to identify on 1:20,000 photography. Ridge lines can also be plotted more accurately on large scale photography.

GRAVEL HAUL STRIP

Another type of airphoto strip study made in connection with the Interstate Highway System was an analysis of the availability and accessibility of granular materials along a 110-mi section. Much of the proposed route was located in a wilderness area several miles from existing roads. The purpose of the study was to provide a basis for estimating the amount of overhaul which could be anticipated at various portions of this large project. In Maine, the maximum free haul distance is 2 mi.

An engineering soils strip study of this area was completed previously. Granular deposits delineated on these photos were rapidly restudied to obtain the "big picture" over the entire length of the 110-mi section. The section was then subdivided into 8 projects to facilitate study of shorter sections for analysis purposes. Arbitrary separation points between projects were based on an evaluation of a number of factors including (a) major stream crossings; (b) number, spacing and location of potential gravel deposits in the particular area; (c) location of towns and major highway crossings where entrance lanes would probably be required; and (d) general characteristics of the terrain.

Figure 5 is an uncontrolled mosaic of a 5-mi section showing the preliminary line, stationing and possible access routes from the delineated deposit to the project. Figure 6, a stereogram detail of a portion of Figure 5, illustrates the type of information which is presented in the gravel haul report.

As seen in Table 1, the haul distance was indicated by the road types described, as follows:

1. Two-lane - paved or all-weather gravel roads permitting two-way traffic, no improvements required.
2. One-lane - narrow, gravel-surfaced roads such as country lanes and main haul logging roads which may have turnouts at irregular intervals, probably very soft and inoperable during the spring break-up period, improvements to varying degrees should be expected.

3. Unimproved - single lane roads, either dirt or with a thin gravel surfacing, considerable improvements even for one-way traffic are definitely required.

4. Road Required - access road from deposit to project nonexistent or the need for a more direct route is indicated. For construction through wooded areas the letter "W" is appended to the distance, and "C" is added if the area is cleared or brush covered. Where streams must be crossed, the letter "B" plus the width of the stream in feet is tabulated.

Volume estimates (as shown in the table) are for areas designated on the original photography. Where long continuous eskers were found near the preliminary line, select 2,000- to 3,000-ft portions of the deposit were outlined and the volume was appended with a "+" sign, meaning that additional materials could be obtained by extending the indicated boundaries. In cases where the distance between deposits was rather long a number of access roads to the project were plotted, especially if a large amount of material was available. In plotting proposed access routes, downhill hauls were chosen and unfavorable terrain was avoided where possible. Existing roads were utilized where feasible. In Figures 5 and 6, note that suggested routes cross the narrowest portions of the extensive swampy area found between the deposits and the preliminary line.

A brief description of each project was also included in the gravel haul report. The type of information presented is illustrated by the following quote from the actual report pertaining to the area shown in Figure 5.

"Project 4. Canadian Pacific R.R.-Medway (Station 2047 to

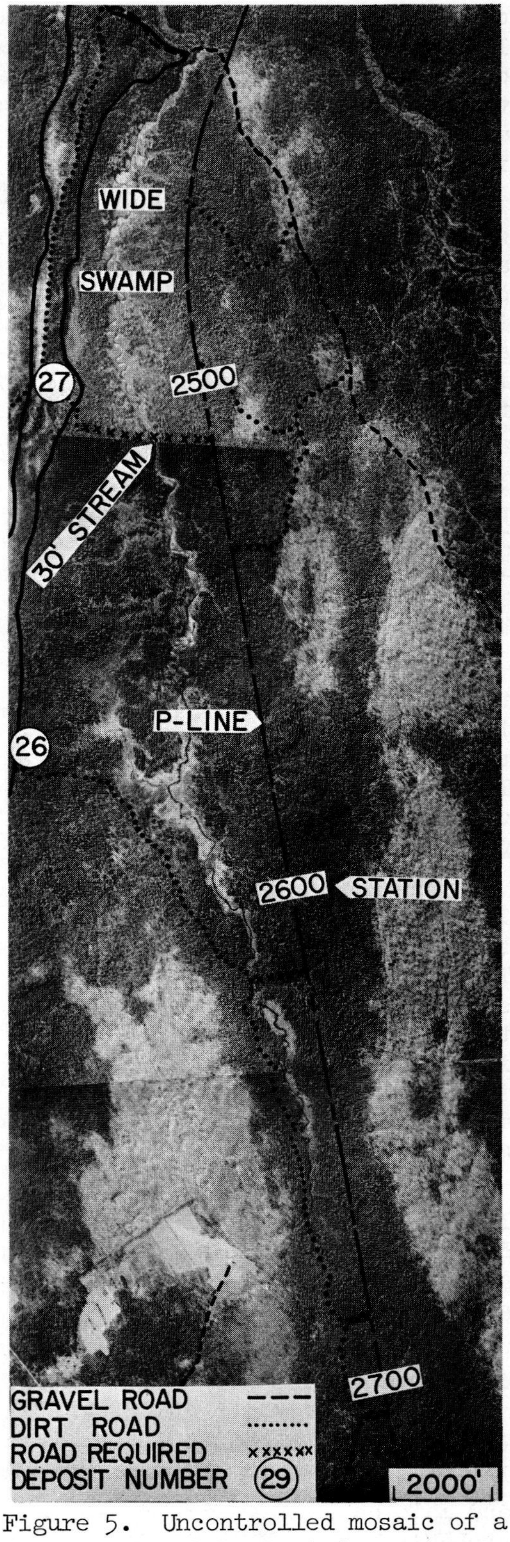


Figure 5. Uncontrolled mosaic of a gravel haul study.

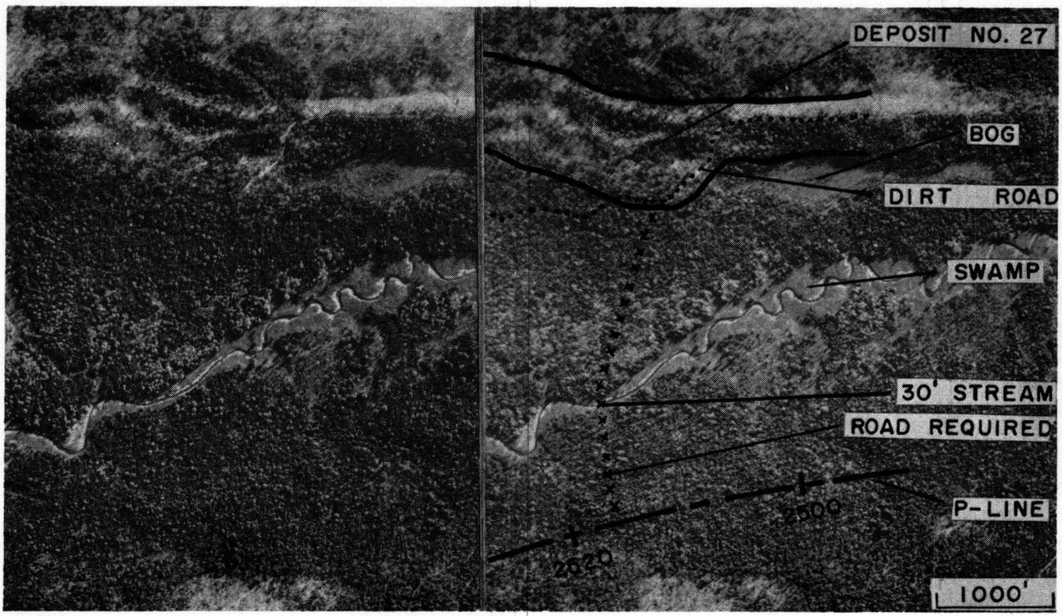


Figure 6. Stereogram of a portion of the area shown in Figure 5.

TABLE 1

GRAVEL HAUL DATA SHEET

Deposit Number	Volume Cubic Yards	Access at Station	Haul Distance (Miles): Improved 2-Lane	Improved 1-Lane	Dirt	New* Road	Total
26	300,000+	2435	--	0.5	--	--	0.5
26A	"	2466	--	1.2	0.6	--	1.8
26B	"	2495	--	1.9	0.8	--	2.7
26C	"	2539	--	1.9	0.9	0.1W	2.9
27	200,000+	2516	--	--	--	0.7W B 30'	0.7
28	200,000+	2618	--	--	1.9	0.2W B 30'	2.1
28A	"	2635	--	--	2.2	0.1W B 30'	2.3
28B	"	2682	--	--	3.3	0.1W	3.4
28C	"	2702	--	--	3.7	0.1W	3.8

*"W" indicates wooded land. "B" is length of bridge required.

2813). There are no public roads of any type in this 14.5-mi section except in the immediate vicinity of Medway. A 1-Lane main haul logging road which is operable about 11 months per year crosses the preliminary line at several points. In the area immediately north of the railroad there are numerous secondary logging roads and sled trails which are generally too winding to be of much value as access roads. A logging camp, located at Station 2103, 2800 ft left of centerline, is the only building within a mile of the preliminary line in the 25-mi section between Howland and Medway. The most promising development possibility appears to be Deposit 26 located at the midpoint of the project. Because of the probable dearth of granular materials between Stations 2400 and 2800, a number of access roads are indicated from Deposits 26 and 28 to various points on the project. In several instances it would be necessary to span the East Branch of Medunkeunk Stream which is about 30 ft wide. Most feasible crossings are at Stations 2516, 2618, and 2635. At other points it would be necessary to traverse swampy terrain varying in width from 250 to 1,000 ft. Deposit 29 is.."

Approximately 90 deposits located in the vicinity of the centerline of this 110-mi section of the Interstate Highway System were described in the gravel haul report. An analysis of this information indicated that less than 20 percent of the total mileage would probably incur overhaul charges. This information was incorporated in preliminary cost estimates.

In addition to the gravel haul analysis a number of gravel prospect spot studies were completed during the past year. These studies, not shown in Figure 1, usually covered an area of approximately 100 sq mi centered on a construction project located in a quadrangle where materials maps have not been prepared to date. Any available photography, having scales ranging from 1:3,600 to 1:70,000 was used for interpretation. Considerable photo coverage of Maine is already in the possession of the State Highway Commission and the University of Maine Photo Interpretation Project. Figures 7 and 8 are reductions of photos having original scales of 1:70,000 and 1:40,000 respectively, showing extensive gravel deposits on single photos covering vast areas. Very small scale photos of this type are useful for reconnaissance studies of extensive areas. Multiple coverage at scales of 1:20,000 and 1:5,000 are ideal for interpretation purposes.

Potential granular deposits were delineated on the photos and suggested spots for field checks were pinpointed. Access to potential depos-

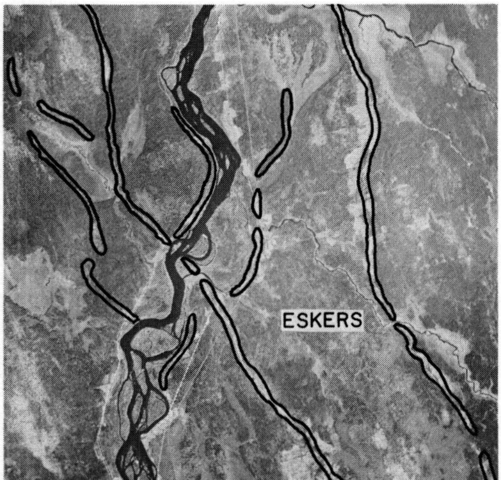


Figure 7. Esker system in the Penobscot Valley, Maine. It is estimated that over 30,000,000 cu yd of granular materials appear in this vertical photo which covers approximately 80 sq mi.

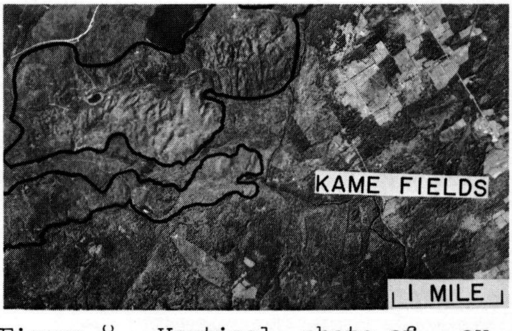


Figure 8. Vertical photo of extensive kame fields in Western Maine.

its was plotted on the photos. In areas devoid of easily recognizable cultural features, conspicuous natural features such as rock outcrops, local forest clearings, and creeks were annotated on the photos. Distances and compass bearings were also indicated for the convenience of the field checkers. Identification numbers were assigned to each potential deposit on both the photography and a U.S.G.S. topographic sheet.

The annotated photos and maps were furnished to the field geologists who determined actual field conditions. Volume estimates were prepared and samples taken for laboratory tests. This information was made available to bidders.

RELOCATION AND RECONSTRUCTION STRIPS

Terrain analyses were made of six proposed relocation projects scheduled by the State Highway Secondary Division. These strip studies varied in length from 3 to 25 mi. Several of the longer strips were flown for the Highway Commission at a scale of 1:12,000. For the shorter studies the best available photography was used.

These studies required close cooperation between the secondary highway engineer and the interpreter. Because of his many years experience in observing the behavior of a particular stretch of road, the engineer was intimately acquainted with practically every bad curve, dip, frost boil and excessive grade for the entire length of the proposed construction project. He was also well informed on future planning which might influence relocation, traffic counts, local needs and similar important information which cannot be gleaned from the photos by the interpreter. Consequently, the first stage of relocation studies consisted of the engineer's "going over" the entire length of the project with the interpreter. The engineer indicated general segments of the road where relocation or improvements of one type or another was anticipated. These locations were noted on the photos by the interpreter. Pertinent information directly or indirectly affecting the location of the new road was noted directly on the photo. For example, "Feeder road will be relocated in five years so that PC cannot be north of this point," or "Centerline should not be more than 1,000 ft east of this intersection."

After the interpreter was thoroughly briefed by the engineer, soils areas were delineated in a band of varying width which would amply cover any possible relocation line. Conspicuous natural features such as swamps and rock outcrops were annotated. Significant cultural features such as houses, stores, cemeteries, schools, churches, gas stations, feeder roads and trails were traced directly from the photograph, using the central portion of the photo to minimize distortion. Strip tracings were made in 4- to 6-mi long sections, or 20 to 30 in. per drawing at a scale of 1:12,000. After the tracing of features for the entire strip was completed, the project was subdivided into shorter sections to facilitate analysis. Depending on terrain and road characteristics, the subsections varied in length from 2,000 to 15,000 ft.

The photos were then restudied in detail to analyze natural and cultural features and an evaluation of each subsection was made. Instead of plotting a suggested preliminary line and perhaps one or two alternates, a "recommended band for detailed study" was outlined on the tracing. The intent of this approach was to bound a strip which offered the least construction difficulties by avoiding, where possible, unfavorable terrain.

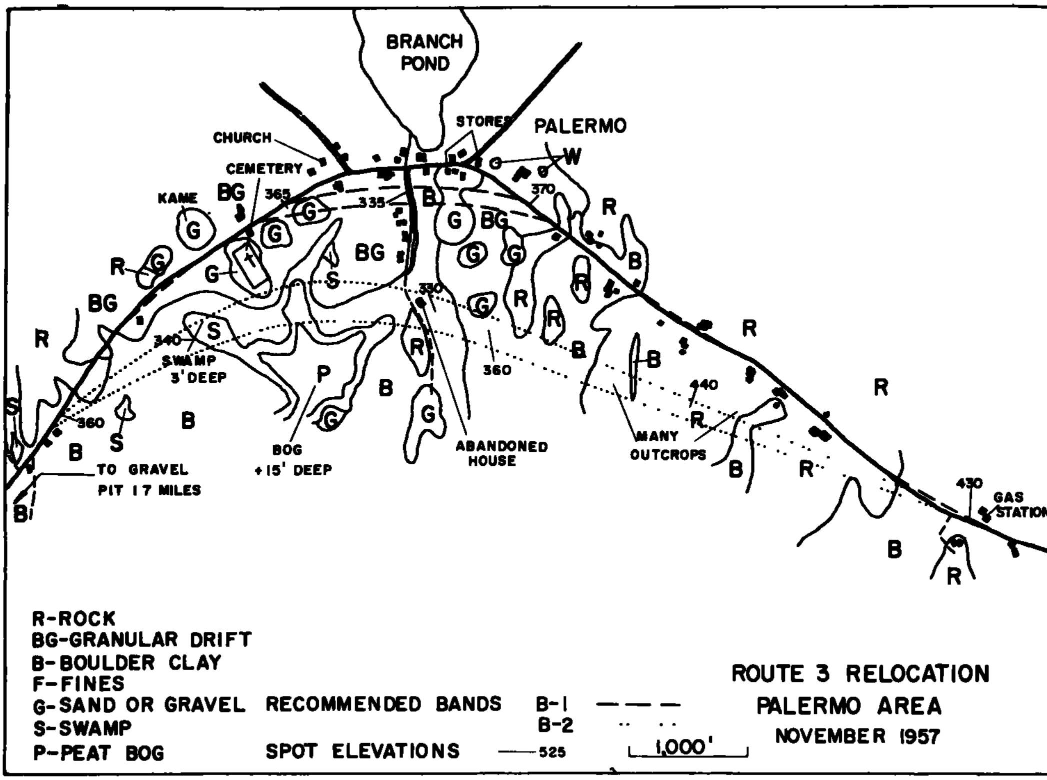
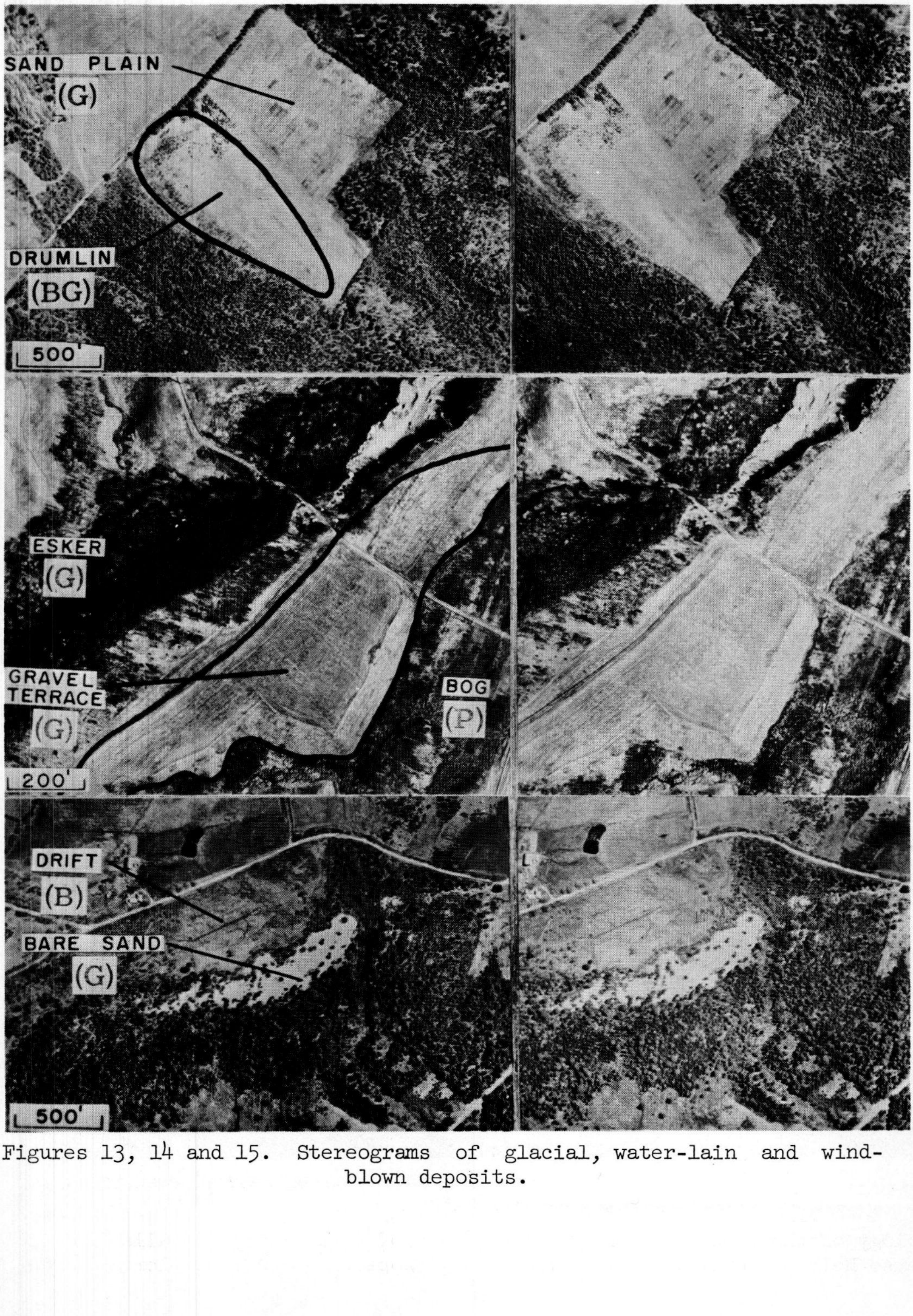


Figure 9. Secondary highway relocation study showing recommended bands for detail study.

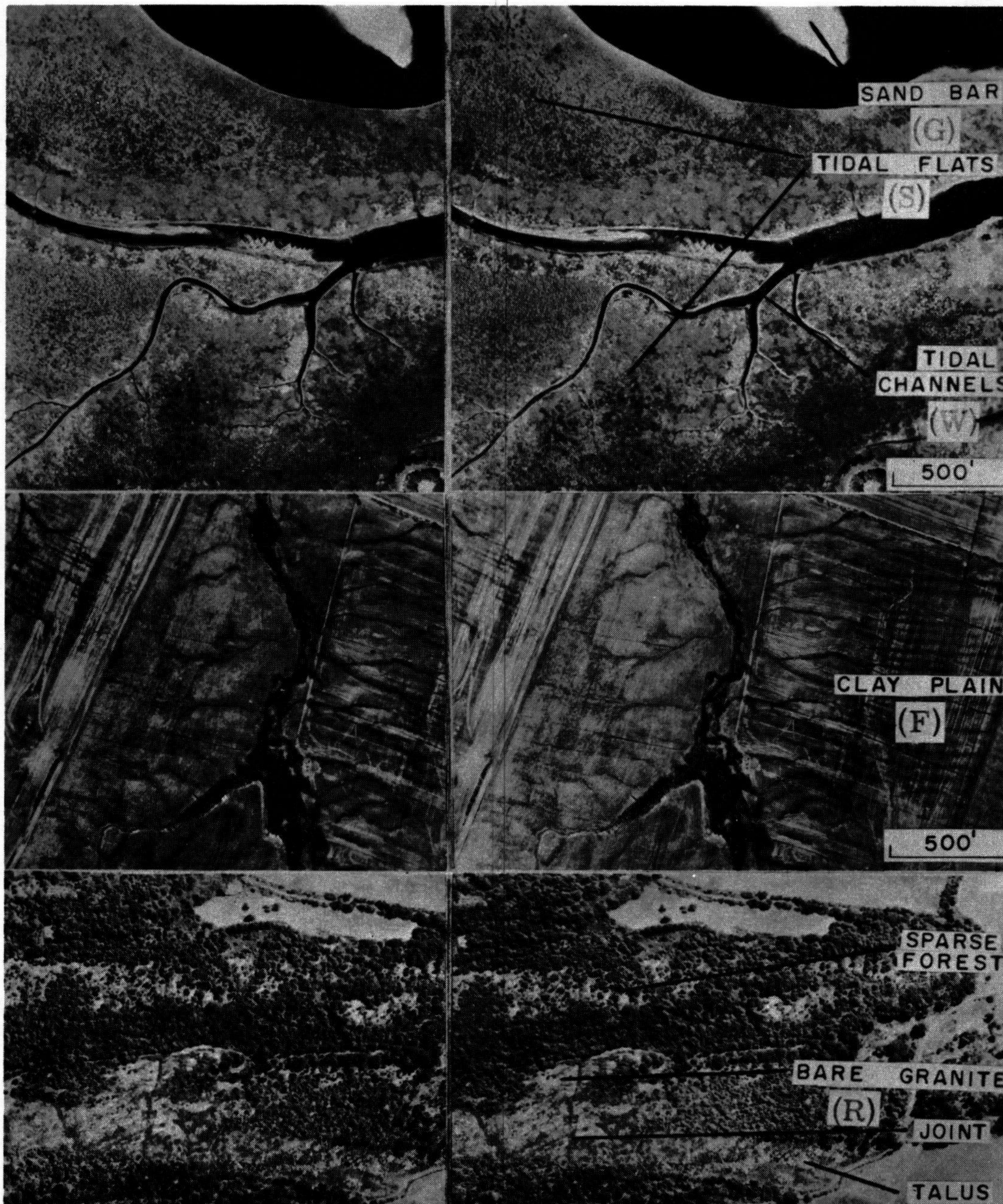
The width of the recommended band ranged from 50 to over 500 ft, depending principally on the length of the cut-off, terrain conditions and the location of cultural features. This allowed the location engineer considerable leeway in plotting various grade-alignment design combinations to meet the road requirements, still keeping within the recommended band. Alternate bands were given if feasible. In instances where the improvement amounted to a simple road widening, a single line was indicated in lieu of a band. Spot elevations at major topographic breaks within the recommended band were pinpointed on the tracing. Locations of existing gravel pits and also potential deposits were annotated. The engineer was provided with ozalid prints, transparent overlays and overlapping airphotos.

A brief verbal description of each subsection was included in relocation study reports. To illustrate, the following is quoted from a report describing the subsection shown in Figure 9. "Two recommended bands for detail study are indicated at the Palermo cut-off. The first, labeled B-1, consists of a series of three widenings and one 2,500-ft cut-off located 300 ft south of the main village. This band traverses two granular soils areas which may yield suitable borrow. Band B-2, a wide sweeping curve located 1,000 ft south of the village, would require 8,000 ft of new construction, of which 400 ft is through a shallow swamp and about 3,000 ft is over ledge terrain. The southern edge of the band skirts a very deep bog and the northern boundary is limited by a cemetery. Based

Figures 10, 11 and 12. Stereograms of several glacial landforms.



Figures 13, 14 and 15. Stereograms of glacial, water-lain and wind-blown deposits.



Figures 16, 17 and 18. Stereograms of fine-grained marine and lacustrine deposits and ledge terrain.

on terrain considerations only, the northern portion of Band B-2 is preferred. A wash plain containing an operable pit is located less than 2 mi from the west end of the project (Photos SHC-2, 115610 # 38, 39, and 40)."

CONCLUSION

Airphoto interpretation techniques are especially useful for highway engineering terrain studies in wilderness areas where little or no detailed information on geology or soils is available. In Maine, time-consuming and expensive field reconnaissance surveys were reduced to a minimum by the intelligent use of aerial photography. Detailed field investigation and laboratory testing is still required to obtain information for final design purposes, especially in critical areas. The Maine State Highway Commission has successfully employed airphoto interpretation techniques for obtaining a variety of information valuable in various phases of highway engineering. The four types of strip studies described in this paper are only a few of many possible applications of this field. It is highly probable that more intensive and specialized photo interpretation studies will be made in the near future in Maine as well as throughout the nation.

ACKNOWLEDGMENT

Airphoto credits are as follows:

1. Maine State Highway Commission—Figures 2, 3, 5, 6, 10, 11, 12, 14, and 17.
2. Sewall Company, Old Town, Maine—Figures 13 and 15.
3. Maine Department of Inland Fisheries and Game—Figures 16 and 18.
4. Army Map Service—Figure 7.
5. U. S. Geological Survey—Figure 8.

Gravel Prospecting by Use of Aerial Photographic Interpretation

R. J. KASPER, Geologist, North Dakota State Highway Department

●DUE TO A rapidly diminishing aggregate supply as compared with a greatly increased highway construction program, the North Dakota State Highway Department has found it imperative to expedite the rate of prospecting through the utilization of available scientific methods. Presently, the sciences of geology, aerial photographic interpretation, and geophysics are being combined as a research unit for the reconnaissance and exploration of sand and gravel deposits situated in an economically important location to the interstate highway system.

PHYSIOGRAPHIC SETTING

North Dakota can be divided into three various provinces on the basis of the physically characteristic land forms contained by each (Figure 1).

The easternmost province in the state, known as the Red River Valley, takes its physiographic name from the Red River, which incidentally forms the eastern boundary of North Dakota. However, the implied river valley, given to understand by the name, is not actually a river valley but more properly the remnant lacustrine plain of ancient Glacial Lake Agassiz. The portion of the plain lying within North Dakota is 30 to 40 miles wide thinning at its southern end to approximately 10 miles. Along the west-

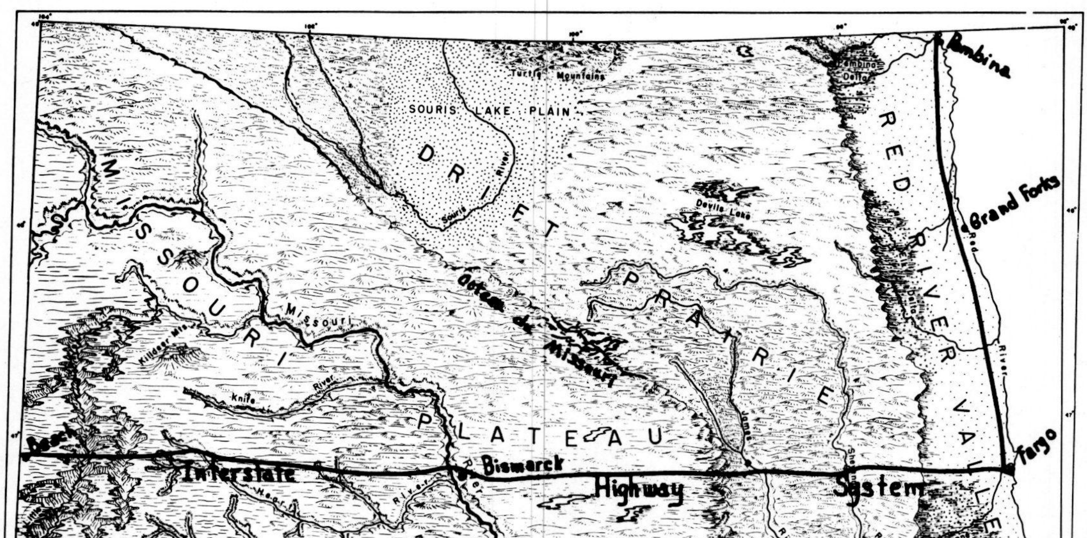


Figure 1.

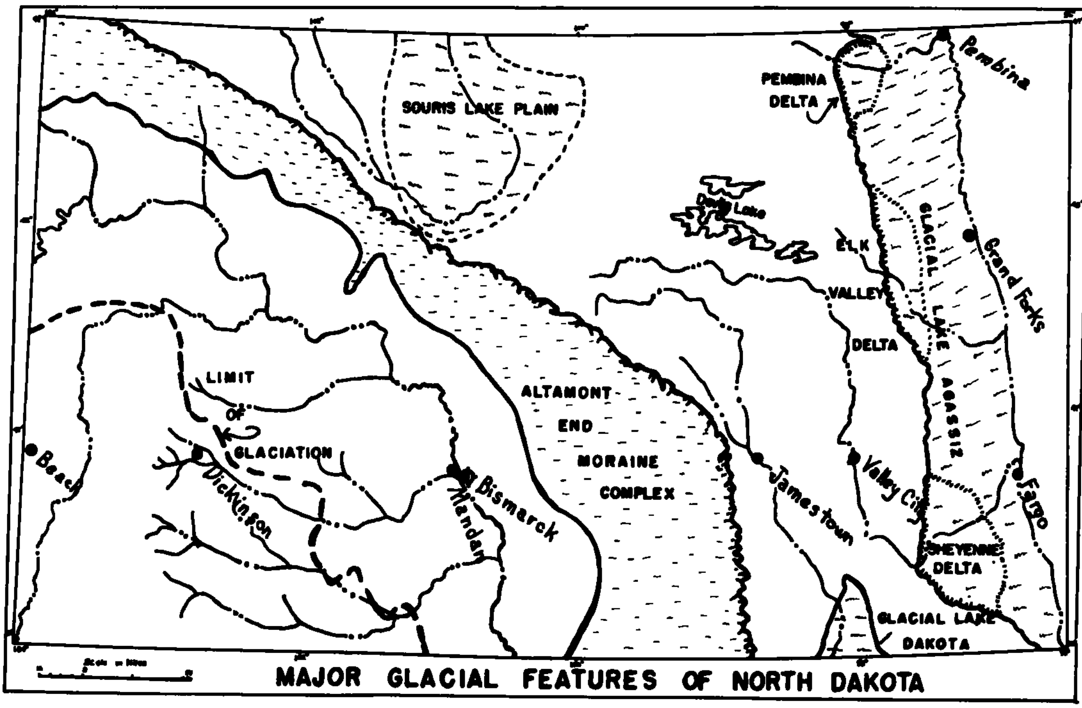
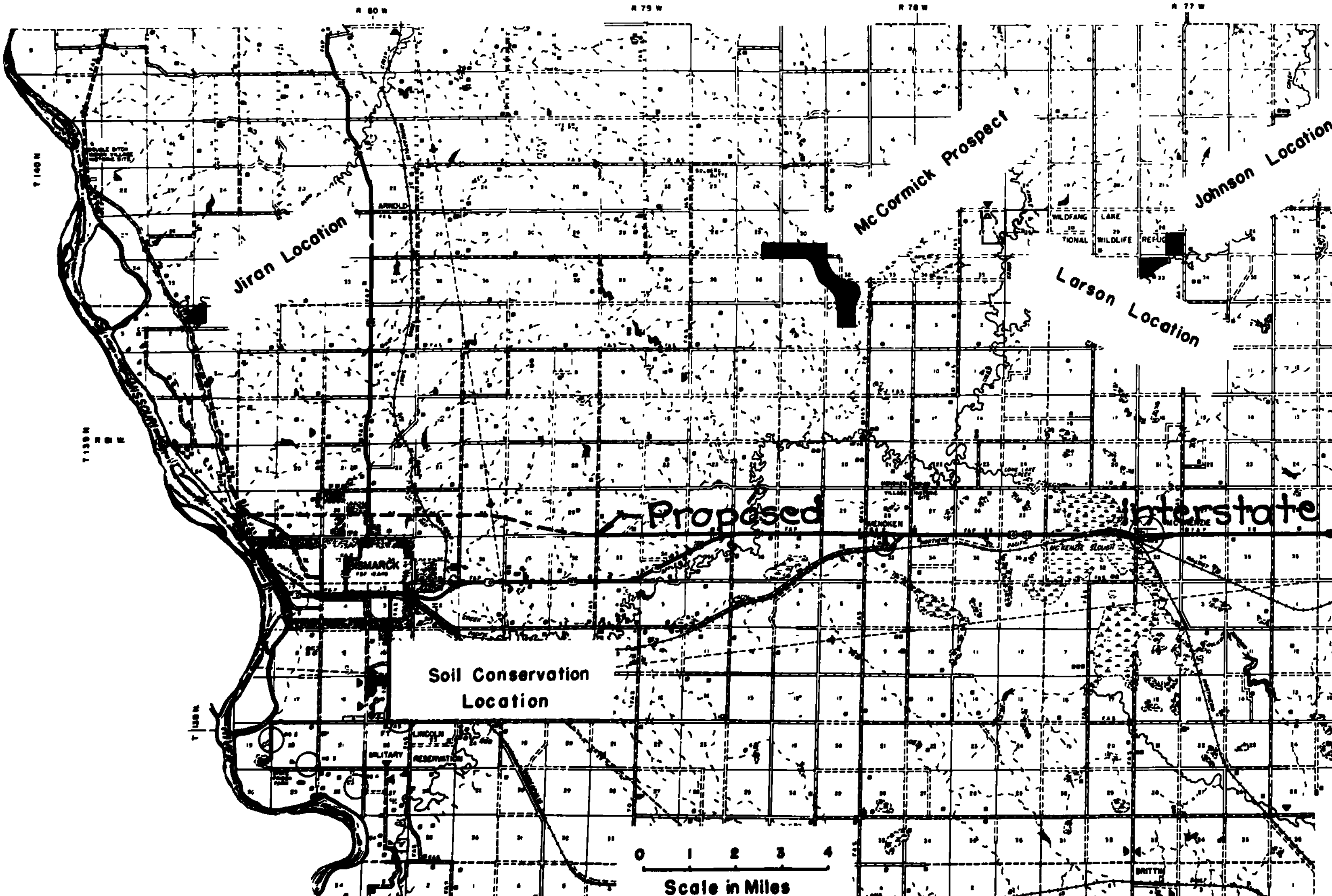


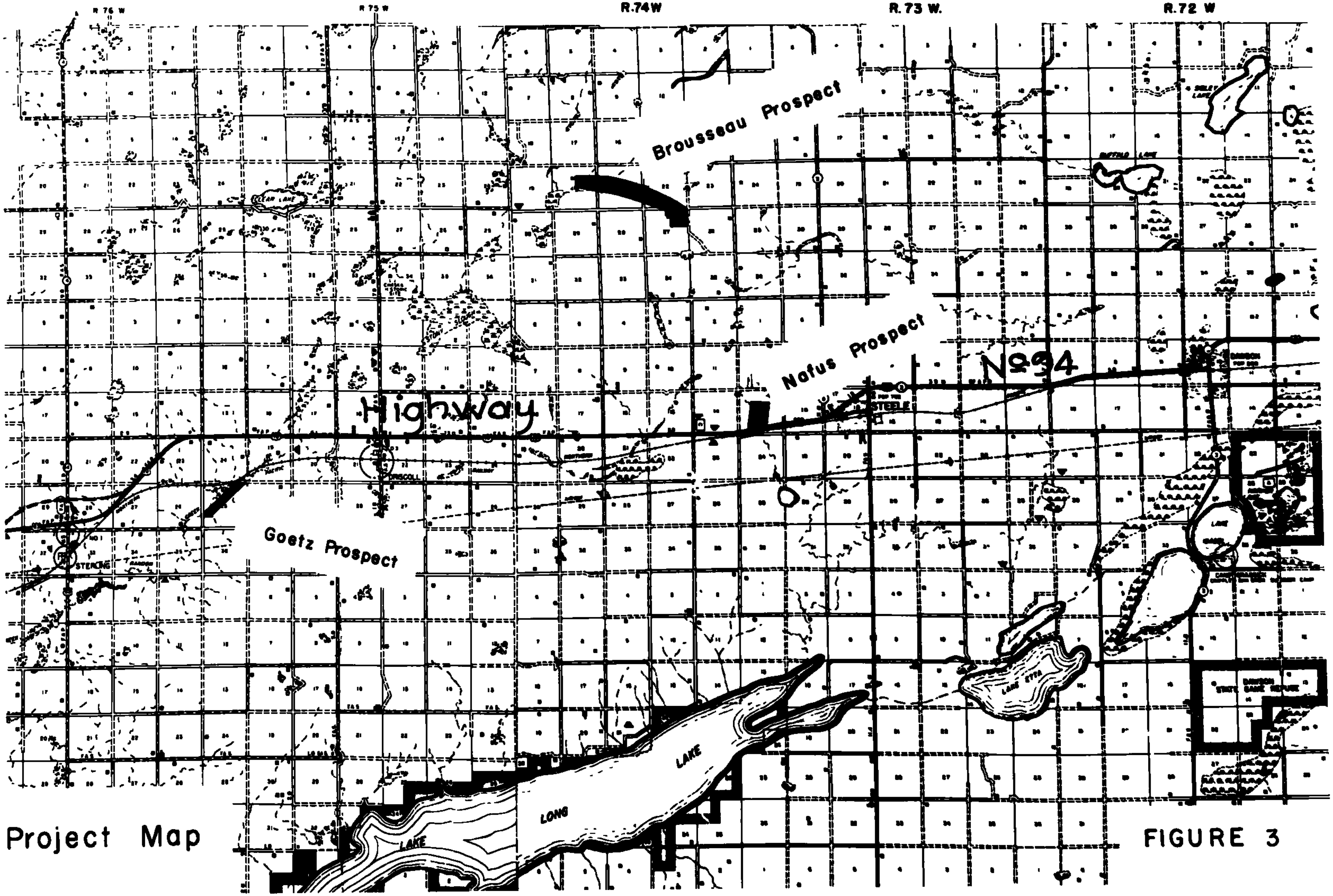
Figure 2.

ern edge of this extremely flat lying physiographic plain, an escarpment rises quite abruptly to heights of 200 to 500 ft above the valley floor. This escarpment is physiographically significant, in that it forms both the western edge of the Red River Valley and the eastern edge of the Drift Prairie, which is the next physiographic province to the west.

Contained within the boundaries of the Drift Prairie is a gently undulating through rolling to hilly topography consisting of both stratified and unstratified glacial drift deposits. Much of the past history of continental glacial advancements is revealed throughout the Drift Prairie by numerous irregular moraines, undrained kettle lakes, and broad outwash plains. Similar to the western edge of the Red River Valley, the western edge of the Drift Prairie is also distinguishable by an escarpment referred to geologically as the Coteau du Missouri or the "Hills of the Missouri." The Coteau du Missouri is in reality a series of terminal moraines lying on the eastern edge of the Missouri Plateau. This series of moraines is called the Altamont End Moraine Complex (Figure 2).

The Missouri Plateau province embraces nearly half of North Dakota; its eastern extremity is marked by the Coteau du Missouri, while the western extent within the state is drawn by the state's western boundary line. The plateau is divided by the Missouri River into two very distinct topographic features. West of the river, the plateau forms a wide plain distinguished by thinly vegetated, broad to very steeply eroded slopes, while the eastern plateau's portion is much more gradual, due to a more or less resistant cover of glacial drift and dense vegetation.


R 80 W
R 79 W
R 78 W
R 77 W
McCormick Prospect
Johnson Location
Jiran Location
Larson Location
Proposed Interstate
Soil Conservation
Location
BISMARCK
0 1 2 3 4
Scale in Miles



Project Map

FIGURE 3

GEOLOGIC SITUATION

The superficial geology within North Dakota cannot assert itself to be the parent body from which aggregate deposits in the state have been derived. North Dakota can best be thought of as transitional zone where sand and gravel were transported by different agents from varying directions. Those agents of erosion most involved in the conveyance of material from its source to its present depositional locality are glacial flow and stream flow.

During the Pleistocene epoch of geologic time, the Kansan and the Wisconsin glaciers uprooted rock material and debris largely from the Canadian Shield region and transported it both interglacially and subglacially to its various depositional localities. The unstratified drift material of the earlier Kansan glacier was dispersed over all but the southwestern portion of North Dakota, while the Wisconsin drift did not reach beyond the Altamont End Moraine Complex. Upon the ablation and final recession of each glacier, stratified drift deposits of sand and gravel were developed by the melt water re-working the unstratified drift material. Some of the more notable stratified drift deposits encountered and processed for highway sand and gravel needs within the state are kames, outwash terraces, eskers, crevasse filling, kame terraces, and deltaic deposits formed at the intersection of smaller glacio-fluvial streams with larger major streams.

Glacial topography is recognizable over most all of the state, except in western and southwestern regions where it is largely in absentia. Within this non-glaciated region, aggregate material possibly owes its origin to streams flowing from source rock areas and depositing sand and gravel in flood plains, which were later dissected so as to leave terrace remnants.

PROCEDURE FOR GRAVEL SEARCH IN A LIMITED CRITICAL AREA

The area extending approximately 50 miles eastward from Bismarck and 10 miles on each side of and paralleling present US 10 (Figure 3) was the first area designated for aerial photographic research.under the new gravel search program in connection with the interstate highway system. This area lies within the eastern portion of the Missouri Plateau and is partially covered by the Altamont End Moraine Complex.

Initiation of the program began with the compilation of all data relative to the subject of sand and gravel. All of the available published geologic literature was gathered. A complete volume of the U. S. Geological Survey ground water studies pertaining to North Dakota was acquired from the U. S. Geological Survey. The Bureau of Reclamation furnished drilling reports of subsurface geology in areas sited for future governmental projects. Drilling records were obtained from private companies for areas that they had explored. Most of the relatively few soil survey studies and topographic maps for areas in North Dakota were obtained from Government agencies. Although little of the foregoing subject matter gathered pertained directly to the immediate area undergoing research, it aided most beneficially in establishing a basic operating concept. Direct assistance was received from the Division of Physical Research of the Bureau of Public Roads in formulating a narrowed more experienced approach.

A complete coverage set of aerial photos of North Dakota had been previously obtained by the North Dakota State Highway Department and was made available for the research program. The total given project under observation east of Bismarck was divided into its respective townships and then each undertaken as an individual study. In the course of actual study and interpretation of these individual areas, both the over-all terrain and drainage patterns were given special emphasis. Within a few short weeks of full time aerial photographic study and ground operations, an exceptionally interesting geologic depositional area was discovered. The selected area lying within four miles of the proposed interstate highway site just north of Bismarck would, if aggregate material were found, be of definite economic importance to the project. The prospect was selected on the basis of a comparatively narrower stream valley at its point of intersection with the Missouri River Valley than the width of the valley farther up-stream. The narrower, more youthful mouth, suggested a possible channel change or re-routing due to some blocking agent such as

Figure 4. Aerial photograph of the Jiran Location displaying a glacio-fluvial deltaic deposit of sand and gravel.

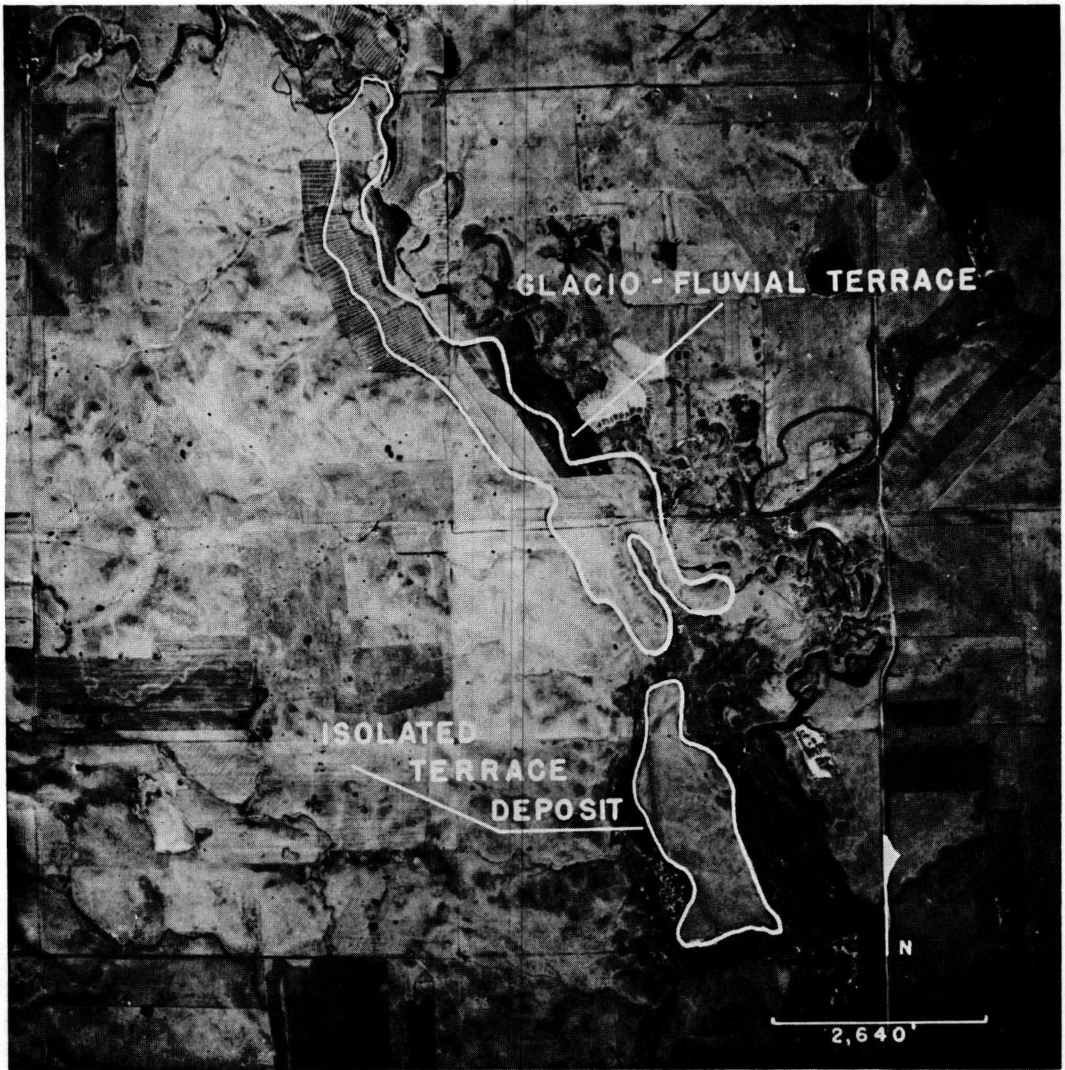


Figure 5. Aerial photograph of the McCormick Prospect displaying glacio-fluvial terrace deposits of sand and gravel.

glacial ice or sediment. Upon exploration and testing both north and south of the present mouth of Burnt Creek, a glacio-fluvial deltaic deposit of sand and gravel was located as shown in Figure 4. The Jiran Location, as this deposit is now referred to, contains 1,500,000 cu yd of sand and gravel. South of Bismarck at a distance of two miles a situation similar to the Jiran Location exists. Lying between the present channel of Apple Creek, which has a much larger watershed than Burnt Creek and the Missouri River channel, is a vast, deserted, glacio-fluvial deltaic deposit of sand and gravel. This deposit has for a number of years been under commercial and highway department production. Exploration and testing of a segment of the total depositional area on property belonging to the North Dakota Soil Conservation Service revealed an additional total of 2,600,000 cu yd of sand and gravel.

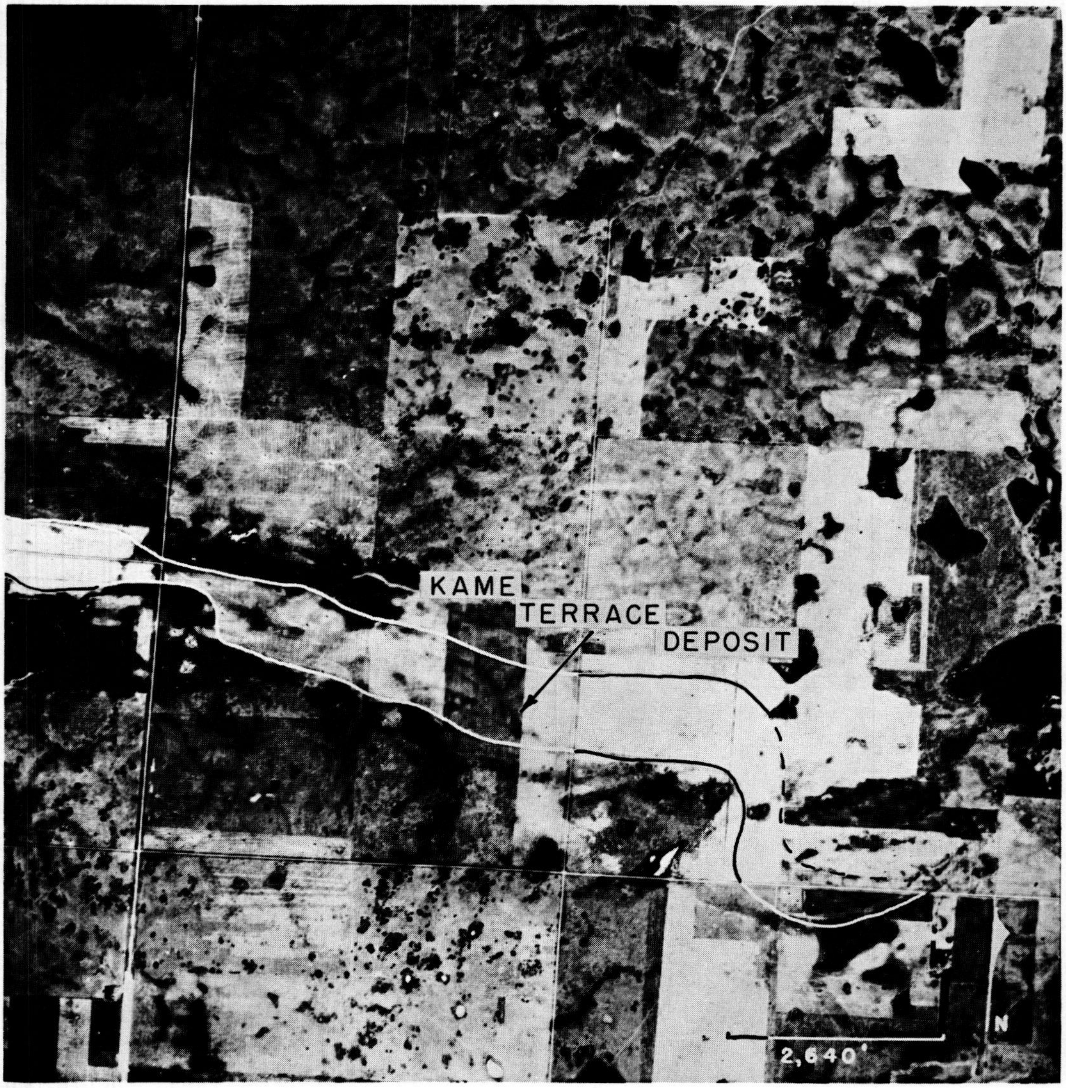


Figure 6. Aerial photograph of the Brousseau Prospect displaying a kame terrace deposit of sand and gravel.

While progressing eastward from Bismarck, special attention was given to present drainage patterns as well as to ancient glacial outwash channel markings. The areial photographs were of a most significant value in this typr of study in that sedimentational deposition points could be outlined much more clearly on the aerial photographs than could be done with months of tedious ground operations. Six glacio-fluvial terrace deposits were outlined by this procedure over the remaining extent of the project. For additional data on these aggregate locations refer to Table 1 and Figures 5 and 6.

FIELD OPERATIONS

Aerial photographs have played a key role in working out the solution to many problems in the field. Often times, reference must be made again

TABLE 1

PIT LOCATION DATA

Name	Location	Type Deposit	Estimated Quantity[1] (cu yd)	Remarks
Jiran Location	NE¼ Sec. 2 & NW¼ Sec. 1 T-139N, R-81 W	Glacio-fluvial deltaic	1,500,000	Drilled and resistivity test
Soil Conservation Location	NW¼ Sec. 15, T-138 N, R-80 W	Glacio-fluvial deltaic	2,600,000	Drilled and resistivity test
McCormicak Prospect	Sec. 25, T-140 N, R-79 W Sec's. 30, 31 & 32, T-140N, R-78W Sec. 5, T-139 N, R-78 W	Glacio-fluvial terrace	500,000	Preliminary test
Larson Location	NW¼ Sec. 33, T-140N, R-77W	Glacio-fluvial terrace	500,000	Drilled
Johnson Location	SE¼ Sec. 28, T-140N, R-77W	Glacio-fluvial terrace	700,000	Drilled
Goetz Prospect	N½ Sec. 25, T-139N, R-76 W	Glacio-fluvial terrace	350,000	Preliminary test
Brousseau Prospect	Sec's 20, 21, 22 & 27, T-140 N, R-74 W	Glacio-fluvial terrace	1,000,000	Preliminary test
Nafus Prospect	S½ Sec. 13, T-139 N, R-73 W	Glacio-fluvial terrace	100,000	Preliminary test

[1] Total quantity, 7,250,000 cu yd.

and again to the particular photos embodying prospective appearing areas in an effort to produce an exact geologic interpretation of sedimentation. The field party uses a compact assembly of aerial photographs, field chair and table, stereoscope, rule and masking tape in each site investigation.

After arriving at the field location designated on the aerial photograph, a small mobile drilling unit is positioned and a test boring made. Other probes are made to establish the location and the approximate average thickness of the deposit over the area.

At present, it is the policy of the department to test and determine the quality and quantity of a sand and gravel source by the use of a large power driven hydraulic auger but plans are for the future usage of earth resistivity equipment to assist in the field exploration. In July of 1957, the Division of Physical Research of the Bureau of Public Roads sent, at the request of the North Dakota State Highway Department, R. Woodward Moore, Head, Geophysical Explorations Section, to instruct departmental personnel in the use of such equipment. Both the Jiran Location and the Soil Conservation Location were traversed during the course of instruction. The resistivity survey was made before either of these locations had been drilled. It is interesting to note that similar quantities of sand and gravel were recorded by both procedures and that the earth resistivity method took very much less time and expense to arrive at approximately the same quantity of material as the drilling method. However, the analysis of material for quality will have to remain as a laboratory procedure.

ACKNOWLEDGMENT

This report is based on information developed in a study sponsored cooperatively by the North Dakota State Highway Department and the U. S. Bureau of Public Roads.

THE NATIONAL ACADEMY OF SCIENCES—NATIONAL RESEARCH COUNCIL is a private, nonprofit organization of scientists, dedicated to the furtherance of science and to its use for the general welfare. The ACADEMY itself was established in 1863 under a congressional charter signed by President Lincoln. Empowered to provide for all activities appropriate to academies of science, it was also required by its charter to act as an adviser to the federal government in scientific matters. This provision accounts for the close ties that have always existed between the ACADEMY and the government, although the ACADEMY is not a governmental agency.

The NATIONAL RESEARCH COUNCIL was established by the ACADEMY in 1916, at the request of President Wilson, to enable scientists generally to associate their efforts with those of the limited membership of the ACADEMY in service to the nation, to society, and to science at home and abroad. Members of the NATIONAL RESEARCH COUNCIL receive their appointments from the president of the ACADEMY. They include representatives nominated by the major scientific and technical societies, representatives of the federal government, and a number of members at large. In addition, several thousand scientists and engineers take part in the activities of the research council through membership on its various boards and committees.

Receiving funds from both public and private sources, by contribution, grant, or contract, the ACADEMY and its RESEARCH COUNCIL thus work to stimulate research and its applications, to survey the broad possibilities of science, to promote effective utilization of the scientific and technical resources of the country, to serve the government, and to further the general interests of science.

The HIGHWAY RESEARCH BOARD was organized November 11, 1920, as an agency of the Division of Engineering and Industrial Research, one of the eight functional divisions of the NATIONAL RESEARCH COUNCIL. The BOARD is a cooperative organization of the highway technologists of America operating under the auspices of the ACADEMY-COUNCIL and with the support of the several highway departments, the Bureau of Public Roads, and many other organizations interested in the development of highway transportation. The purposes of the BOARD are to encourage research and to provide a national clearinghouse and correlation service for research activities and information on highway administration and technology.