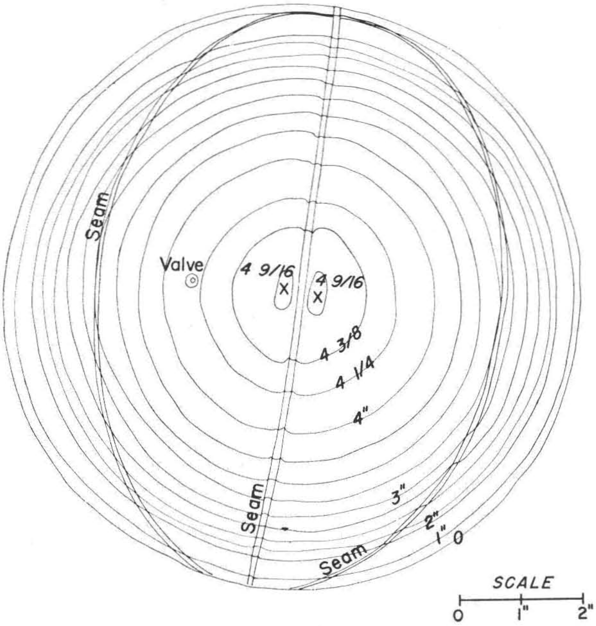

FIG. 2. Photogrammetric "map" of a basketball.

8. Young, H. E., "Supplement to 'Photogrammetric Volume Determination of Huge Pulpwood Piles'." PHOTOGRAMMETRIC ENGINEERING, Vol. 21, March, 1955.

*Airphoto Analysis of Terrain for Highway Location Studies in Maine**

E. G. STOECKELER[1] *and* W. R. GORRILL[2]

INTRODUCTION

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 square miles. These maps were prepared by quadrangles, an area of approximately 200 square miles, at a scale of 2 inches equals 1 mile. Precedence was given to the areas where the most construction was anticipated. These maps are especially useful in the preliminary planning phases of location studies and the preparation of cost estimates.

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* For the privilege of publishing this paper, thanks are extended to Mr. Fred Burggraf, Director of Highway Research Board and to H. A. Radzikowski, Chief, Div. of Development, Office of Operations, U.S. Bureau of Public Roads. *Editor.*

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 miles to over 100 miles. 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 per cent of the areas studied to date were in densely wooded wilderness sites where terrain interpretation from summer photography is difficult, because surficial features 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 (1) engineering soils, (2) drainage, (3) gravel haul and (4) highway relocation and reconstruction.

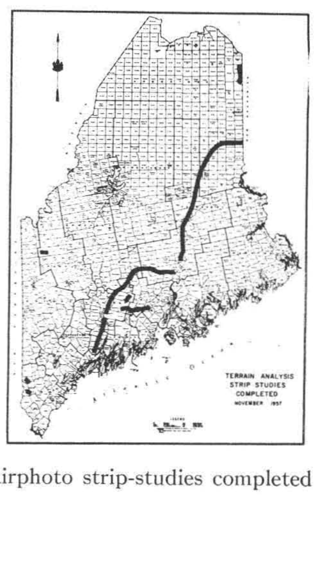

FIG. 1. Airphoto strip-studies completed in 1957.

Engineering Soils Strip

The Maine 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. The 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. Nine stereograms illustrating these soil units are found in the last pages of this paper.

R—*Rock*, ledge within five feet 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 three feet thick.

P—*Peat*, surficial peat more than three feet thick.

W—*Water*, generally more than two feet deep.

For preliminary-planning soils-studies, 1:20,000 scale photography was used. In most cases a single 3-mile 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 five acres in extent except for such elongated forms as esker ridges and narrow valley swamps.

In addition to soils delineations, 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-mile segment of the proposed 110-mile

* Photo 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 Cooperative Wildlife Research Unit, Figures 16 and 18.
(4) Army Map Service, Figure 7.
(5) U. S. Geological Survey, Figure 8.

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 4. 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

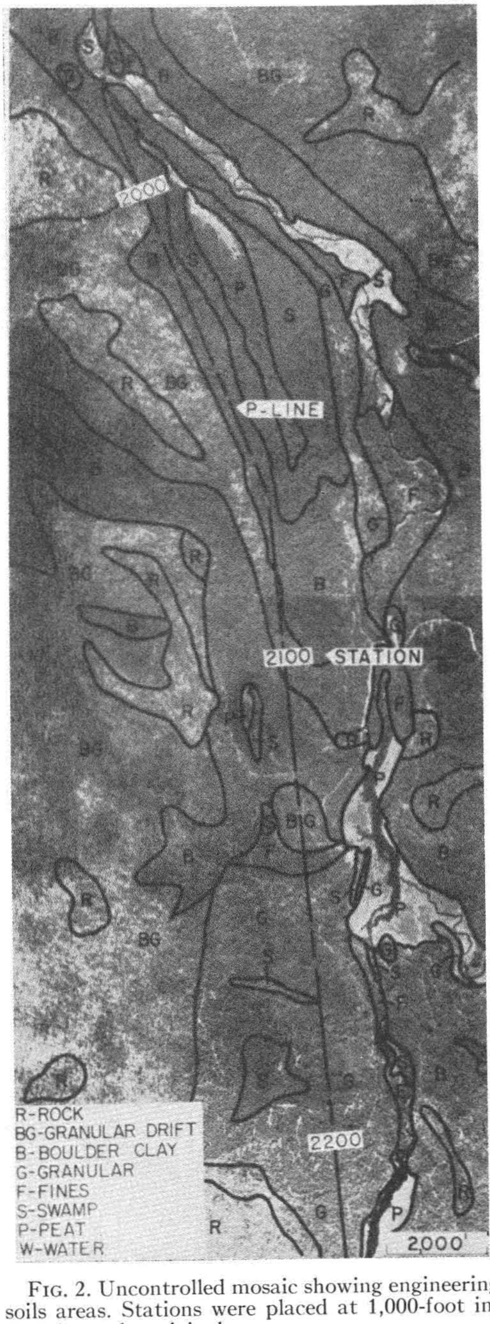

FIG. 2. Uncontrolled mosaic showing engineering soils areas. Stations were placed at 1,000-foot intervals on the originals.

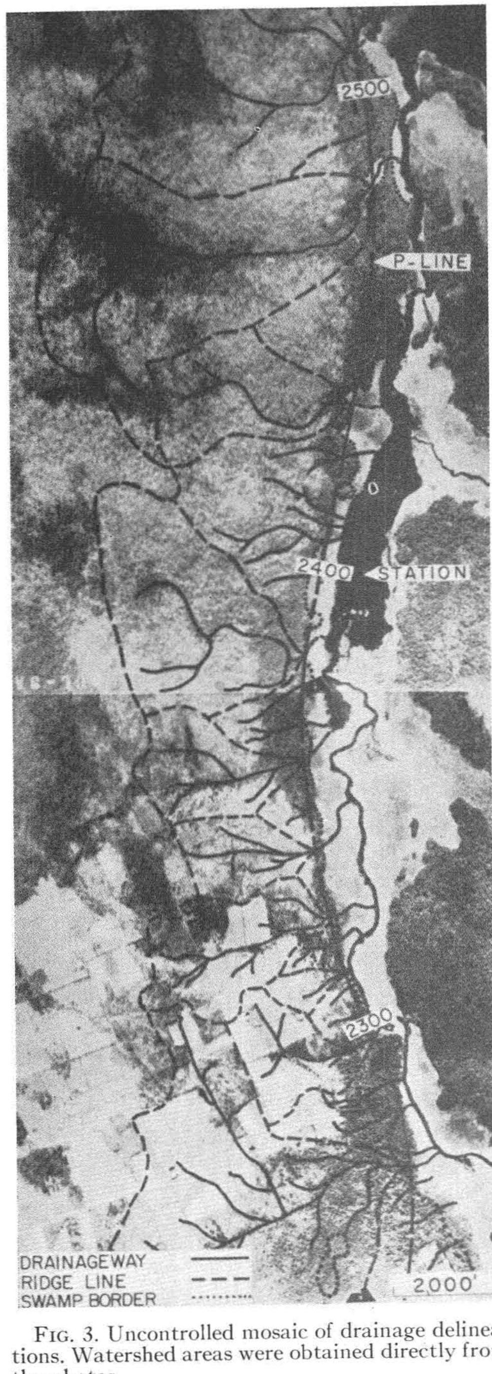

FIG. 3. Uncontrolled mosaic of drainage delineations. Watershed areas were obtained directly from the photos.

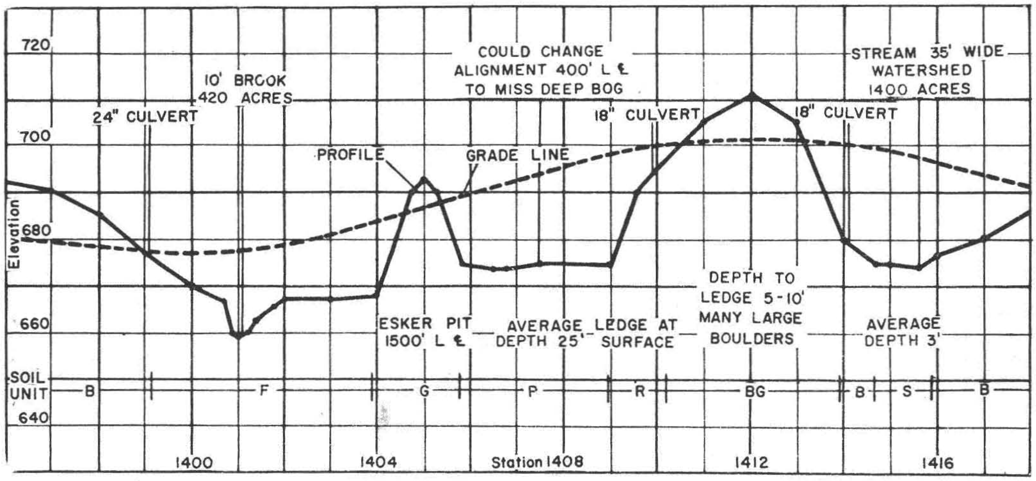

FIG. 4. Profile with engineering soils and drainage annotations.

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-mile 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-foot wide strip at a scale 1 inch equals 200 feet and a contour interval of 5 feet. For this project the soils information was transferred from the photos to the topographic sheet, thus enabling the location engineer to evaluate the engineering and economic aspects of a number of possible road lines within the 3,200-foot wide strip. After detailed analyses of a number of possible lines had been 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 of 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-size boulders (larger than one cubic yard) 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 had been 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 for 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 inch equals 1 mile and a contour interval of 20 feet are often inadequate for determining watershed areas, especially small watersheds of 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 photo-hydrological studies.

The suitability of photography for drainage interpretation studies is dependent principally on the 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 per cent of 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 to permit tracing even small drainageways.

For preliminary-reconnaissance drainage surveys, photography on a scale of 1:20,000 is adequate. Figure 3 is an uncontrolled 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 for his use in calculating the preliminary drainage structure sizes. This information was then transferred to the profile using the same procedure described previously (see Figure 4). 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 in preparing 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 which was made in connection with the Interstate Highway System was an analysis of the availability and accessibility of granular materials along a 110-mile section. Much of the proposed route was located in a wilderness area which was several miles distant from existing roads. The purpose of the study was to provide a basis for estimating the amount of overhaul which could be expected at various portions of this large project. In Maine, the maximum free-haul distance is 2 miles.

An engineering soils strip-study of this area had been completed previously. Granular deposits delineated on these photos were rapidly restudied to obtain the "big picture" over the entire length of the 110-mile 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 (1) major stream crossings, (2) number, spacing and location of potential gravel deposits in the particular area, (3) location of towns and major highway crossings where entrance lanes would probably be required and (4) general characteristics of the terrain.

Figure 5 is an uncontrolled mosaic of a 5-mile 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 below.

A. *2-Lane*—paved or all-weather gravel roads permitting two-way traffic; no improvements required.

B. *1-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.

C. *Unimproved*—single lane roads, either

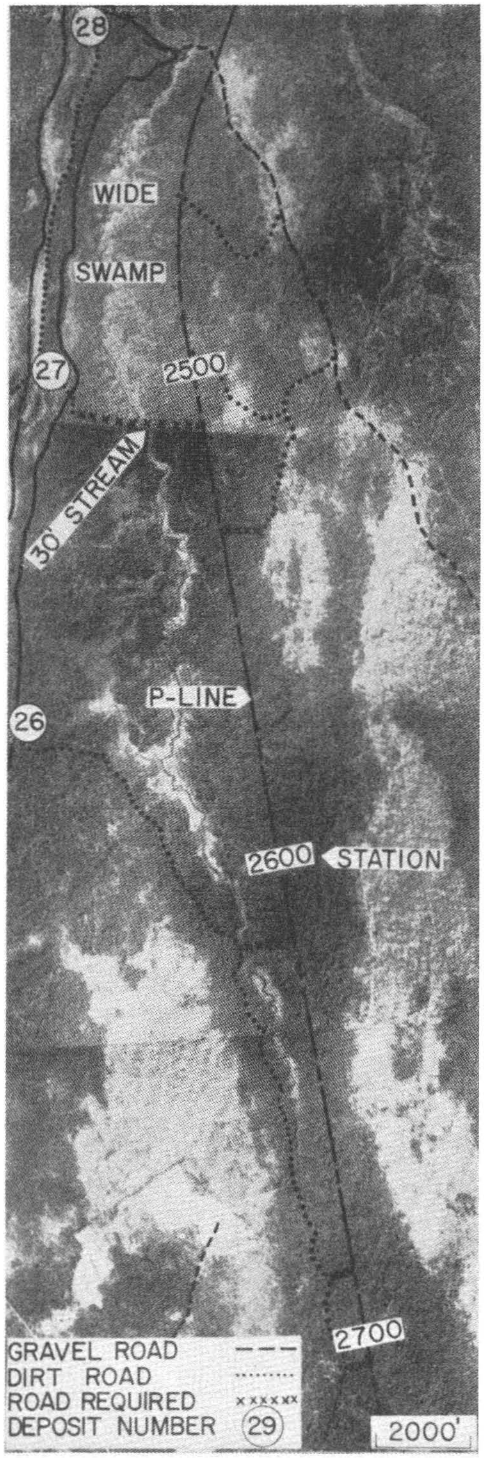

FIG. 5. Uncontrolled mosaic of a gravel haul study.

dirt or with a thin gravel surfacing, considerable improvements even for one-way traffic are definitely required.

D. *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 2,000–3,000-foot portions of the deposit were outlined and the volume was appended with a "+" sign, which meant 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 wherever possible. Existing roads were utilized when feasible. In Figures 5 and 6, it should be noted 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 2813). There are no public roads of any type in this 14.5-mile 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, 2,800 feet left of centerline, is the only building within a mile of the preliminary line in the 25-mile 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 Medunkaunk Stream which is about 30 feet 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 feet. Deposit 29 is . . . "

TABLE 1
GRAVEL HAUL DATA SHEET

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

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

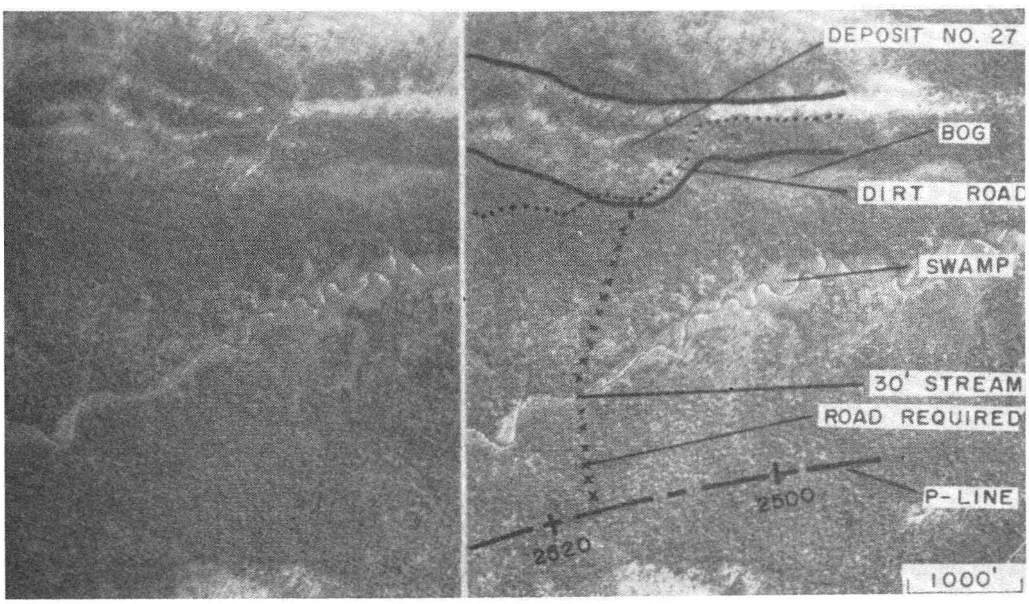

FIG. 6. Stereogram of a portion of the area shown in Figure 5.

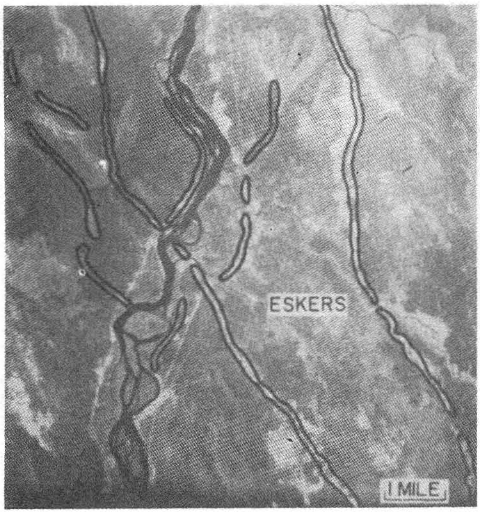

FIG. 7. Esker system in the Penobscot Valley, Maine. It is estimated that over 30,000 cubic yards of granular materials appear in this vertical photo which covers approximately 80 square miles.

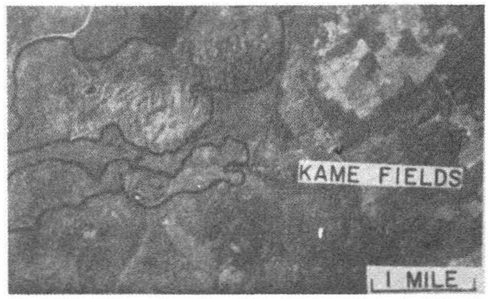

FIG. 8. Vertical photo of extensive kame fields in Western Maine.

Approximately 90 deposits located in the vicinity of the centerline of this 110-mile section of the Interstate Highway System were described in the gravel haul report. An analysis of this information indicated that less than 20 per cent 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 square miles, 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 deposits 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 miles. 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 of 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 the PC cannot be north of this point," or "Center-line should not be more than 1,000 feet 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 Sections of 4- to 6-mile length, or 20 to 30 inches 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 feet.

The photos were then restudied in detail for the purpose of analyzing natural and cultural features; 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. The width of the recommended band ranged from 50 to over 500 feet, 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.

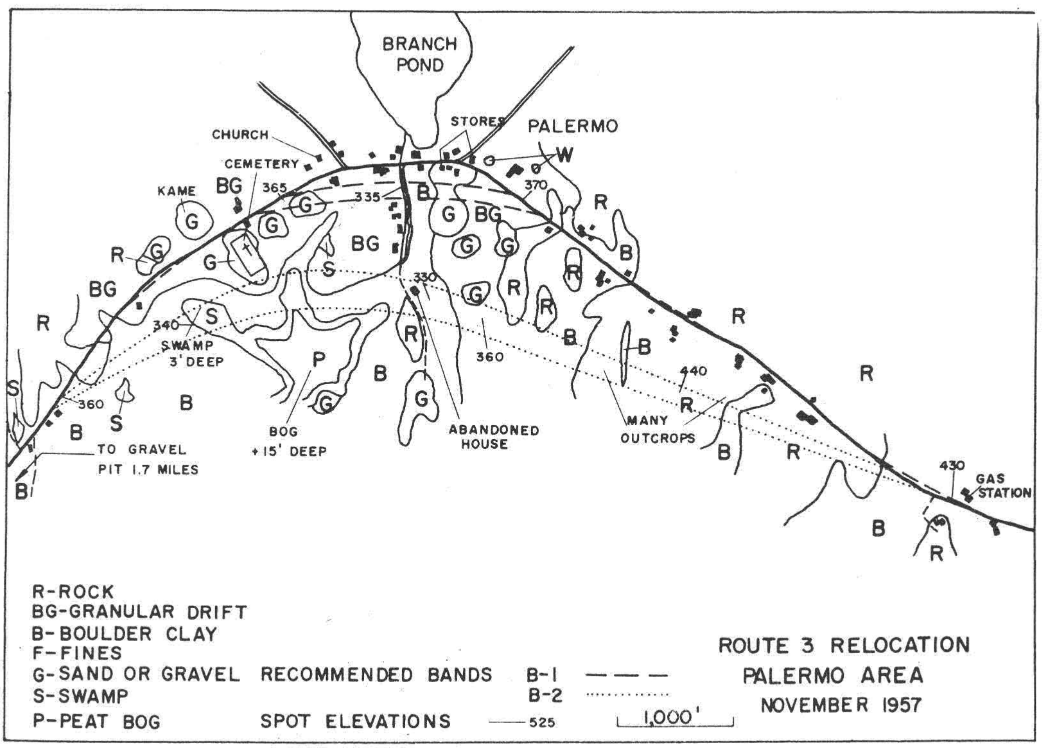

FIG. 9. Secondary highway relocation study showing recommended bands for detail study.

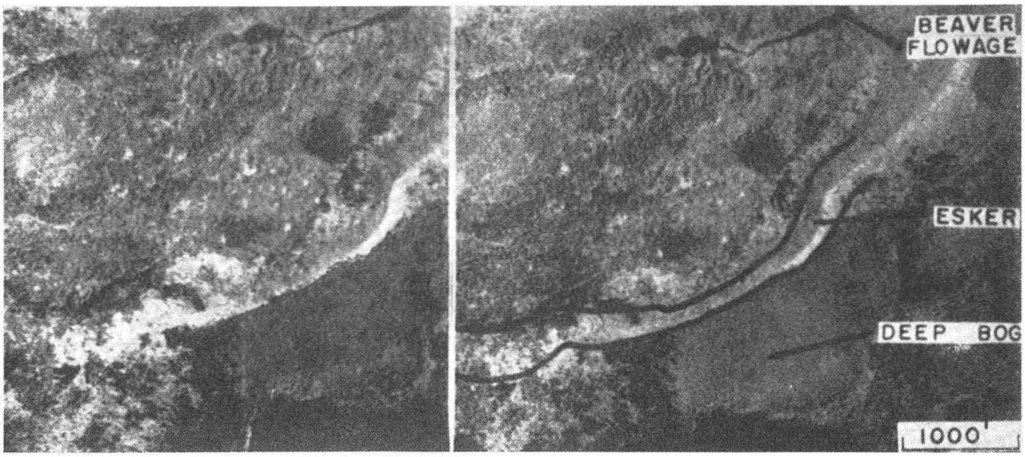

FIG. 10. Stereogram of glacial landform.

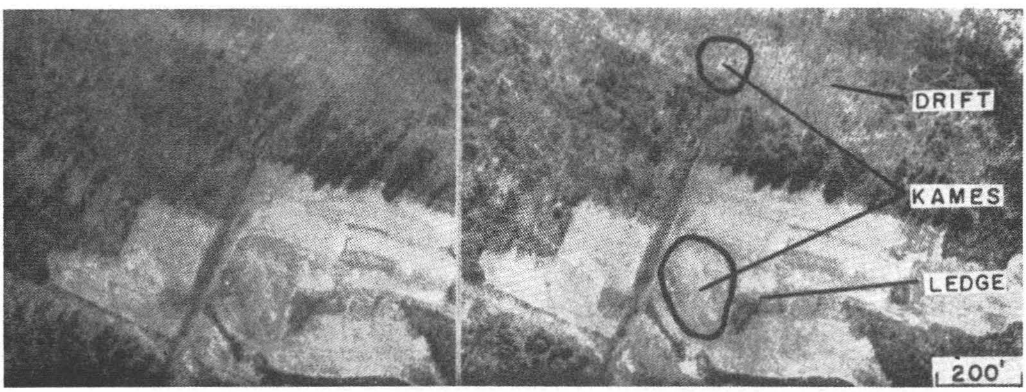

FIG. 11. Stereogram of glacial landform.

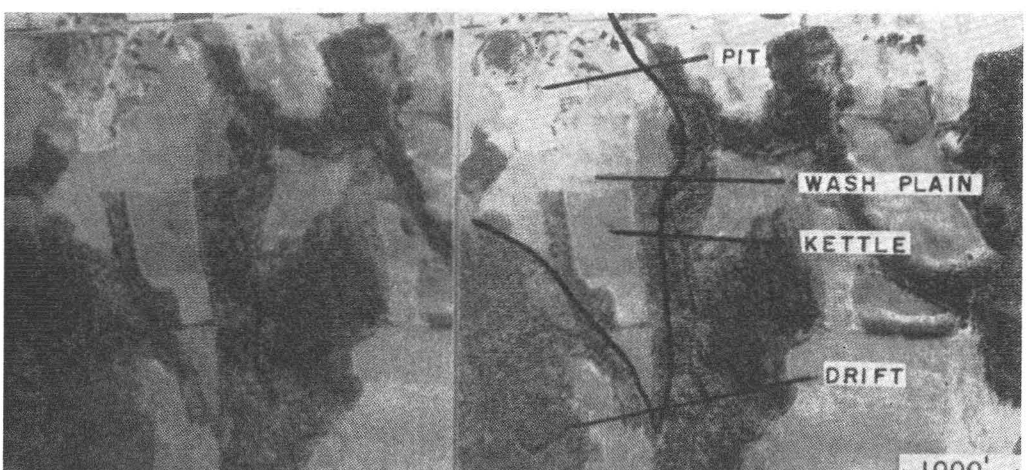

FIG. 12. Stereogram of glacial landform.

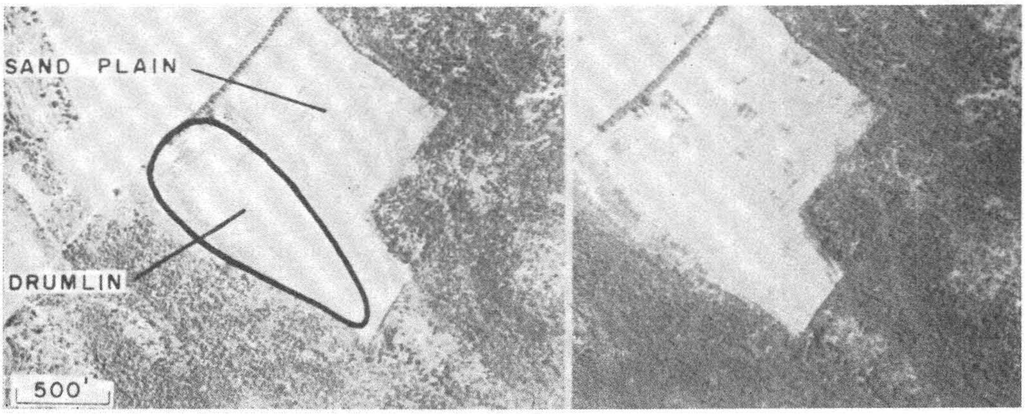

FIG. 13. Stereogram of glacial, water-lain and wind-blown deposits.

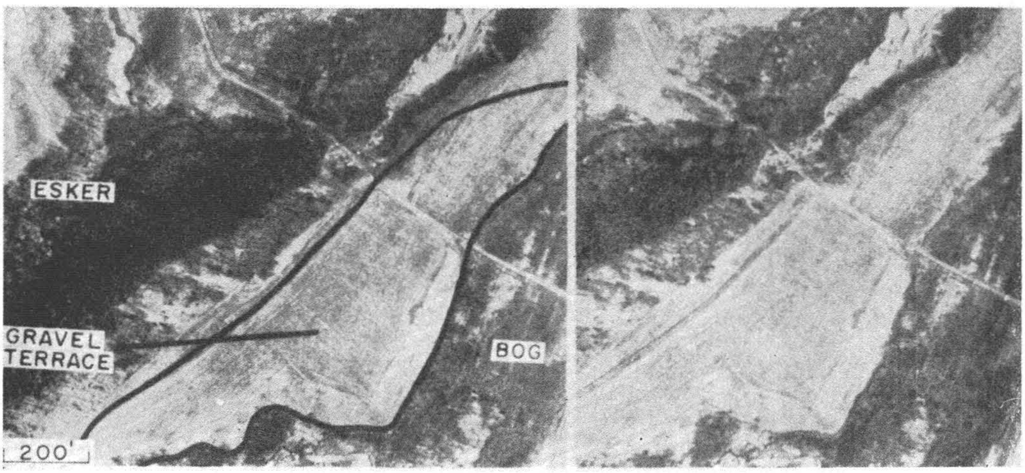

FIG. 14. Stereogram of glacial, water-lain and wind-blown deposits.

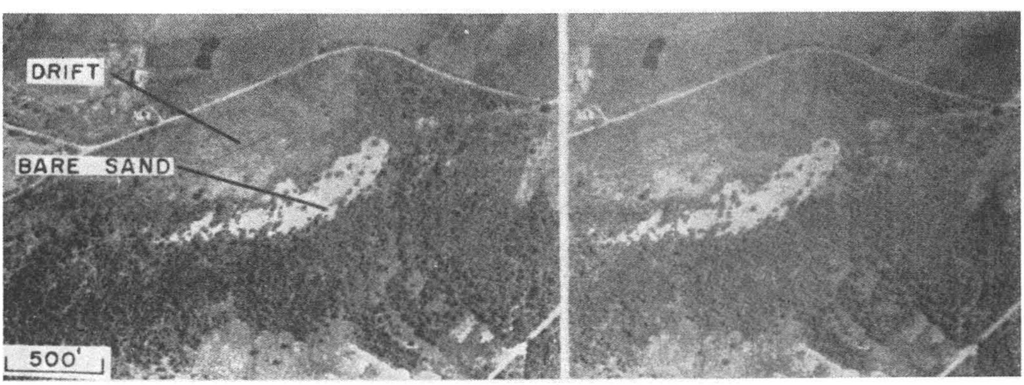

FIG. 15. Stereogram of glacial, water-lain and wind-blown deposits.

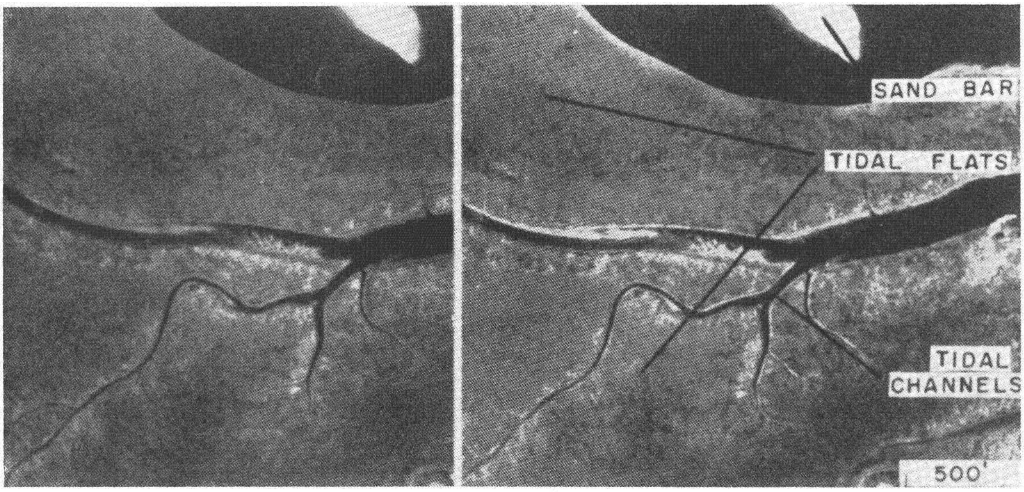

FIG. 16. Stereogram of fine-grained marine and lacustrine deposits and ledge terrain.

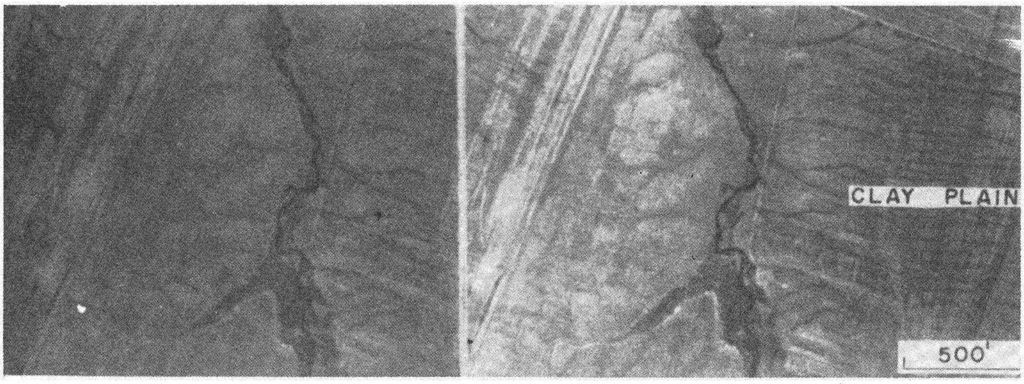

FIG. 17. Stereogram of fine-grained marine and lacustrine deposits and ledge terrain.

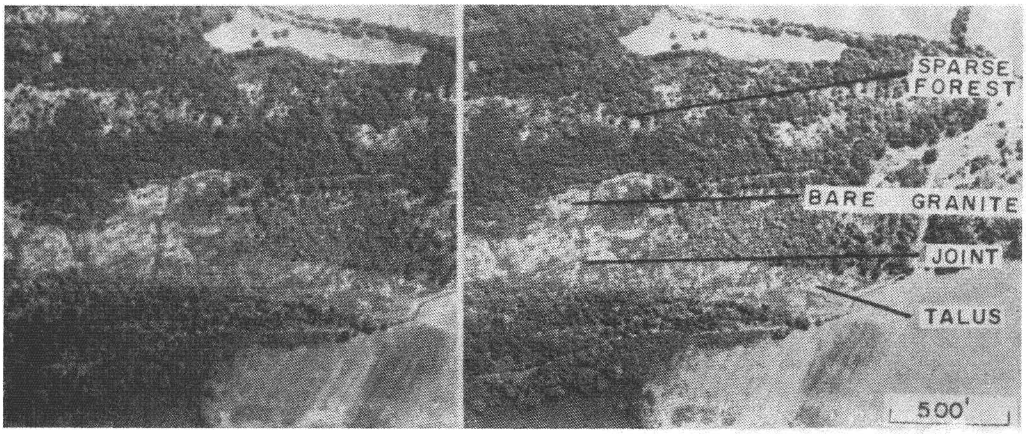

FIG. 18. Stereogram of fine-grained marine and lacustrine deposits and ledge terrain.

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-foot cut-off located 300 feet 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 feet south of the village, would require 8,000 feet of new construction, of which 400 feet is through a shallow swamp and about 3,000 feet 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 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 miles 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.

Reconsideration of the Quadruple Camera

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ABSTRACT: *The quadruple camera, least popular of all camera aggregates, is reexamined under the new light thrown by analytical aerial triangulation, and is compared to vertical or convergent systems. The conclusion is reached that this tool may possibly offer significant advantages of economy, accuracy, or easy availability. Further investigation of the matter is suggested, particularly by camera designers and executives who have available all the elements of appreciation.*

WHAT follows refers primarily to mapping with near-vertical photography and aerial triangulation.

Two convergent aerial cameras, tandem mounted in an airplane (Figure 1) and synchronized, constitute practically the equivalent of a quadruple camera. Close tolerances in the mutual relationships of the four camera cones are quite useless. If there is a common mount, as is desirable but not indispensable, then a fore-fore-aft-aft sequence of the cones should yield a very compact setup.

The total coverage of such an aggregate, for example, can be made equal to the coverage of a standard $f=6''$-$9''\times 9''$ camera. The angular field of each component is then about 62°, as against 94° for the whole system. Longitudinal and transversal tilts of the camera axes are about 15°.

It is obvious that lens designers and camera