Locating and Mapping Granular Construction Materials From Aerial Photographs

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This paper summarizes data covering ten years of mapping granular construction materials from aerial photographs. During this period the authors have mapped 2,165 granular-material prospects. Individual deposits mapped from the photos and checked on the ground range in quality from dirty gravelly sand to clean coarse gravel and in quantity from a few hundred to several hundred thousand cu yd.

Data from 75 construction projects covering 32,000 sq mi of search area indicate that airphoto interpretation techniques yield remarkably good results when the interpretation is carried out by experienced photo-analysts familiar with airphoto patterns of granular deposits in the region being searched. As a prospecting tool, the airphoto technique is fast and economical. Results from ten years airphoto mapping show that the areal extent and probably quality of deposits can be reliably predicted in a high proportion of cases. The method particularly aids follow-up subsurface investigations by pin-pointing where to explore in the field, at the same time indicating what to expect in terms of material quality and quantity.

In this paper the need to discover granular construction materials is first pointed out. Pertinent data from construction projects on which granular air-photo searches were made is then presented. This information is followed by review of prospecting problems facing the ground-investigator and a brief discussion of customary granular-search methods used in locating granular construction materials. A summary of the more common granular land forms found in the plains area of western Canada and their identifying features in aerial photographs are presented. In each project area surveyed, the land form contributing the greatest quantity of high-quality aggregate is tabulated. Tables and other statistical data illustrate the frequency of occurrence of various granular land forms in parts of western Canada. Information is presented to indicate, for different geologic environments, the percentage of photo-identified deposits that are commonly suitable as subbase, base course, and wearing-course material. In conclusion the accuracy of airphoto interpretation predications is assessed in terms of the training, experience, and judgment of the photo-interpreter.

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●IN THE QUEST for granular construction materials, airphoto analysis is employed as a prospecting rather than an exploratory tool. Indeed airphoto analysis is the initial study in a continuous series that includes prospecting, subsurface exploration, testing of materials, and plans for processing and developing a deposit. Obviously the prospecting phase of this series is the one most amenable to air-survey methods.

Airphoto analytic techniques are used to systematically search large areas in order to isolate potential sand and gravel sources to be explored in the field. The information derived from the photos aids subsurface exploration in two distinct ways: (a) it largely obviates ground search operations by pin-pointing where to explore; and (b) it facilitates field operations by informing the ground observer what to expect in terms of general quality and quantity.

Granular deposits identified in aerial photographs may be classified according to expected quantity, probable quality, possible use of the materials, or what can be discerned about past development of sources at the time of the airphoto search. In the latter case, for instance, granular deposits may be classed as (a) deposits that are developed and virtually exhausted; (b) deposits that are partly developed; (c) deposits that are undeveloped (no pits) and, therefore, probably unknown.

The airphoto shows inaccessible terrain as well as accessible terrain, and no trespassing property as well as property which the ground observer is permitted to inspect. Until a promising prospect is discovered the observer analyzing airphotos does not interfere with the operations of property owners.

THE NEED TO DISCOVER GRANULAR DEPOSITS

The need to discover partly developed and undeveloped sources of sand and gravel hardly deserves to be emphasized. As the pace of construction increases, the necessity of finding new sources increases. It should also be pointed out that the volume of sand and gravel available for future use is rapidly diminishing, for sand and gravel is a non-renewable resource. Many of the best deposits—and for the most part the more obvious and nearby ones—have already been developed. And a large proportion of these deposits are now all but exhausted.

Specifications of naturally occurring aggregate materials have become increasingly rigid with the result that many gravel deposits suitable for different uses 20 years ago are no longer satisfactory. In many parts of the Canadian prairies considerably less than one granular deposit in ten has any chance whatever of being suitable as wearing-course aggregate. This ratio might well be extended to include deposits that can be rendered suitable with an economic amount of beneficiation. One reason for this low figure is that on the prairies the bedrock underlying glacial drift is composed largely of clay shales and soft friable sandstones and siltstones —rocks that are deleterious in paving mixtures.

With the depletion of known sources, with greatly increased demand, increased rigidity of specifications and the absence of suitable quarry rock in virtually all parts of the prairies, there is manifestly a need to search carefully large areas in order to discover new commercial sources.

DATA FROM CONSTRUCTION PROJECTS ON WHICH GRANULAR SEARCHES WERE MADE

In the decade from 1947 to 1956 the authors mapped 2,165 granular-material prospects from aerial photos. Of these, 932 were mapped in a nine-month period. Virtually all prospects are located in the plains of western Canada. These photo-identified granular-material prospects are distributed over a search area of roughly 32,000 sq mi; they were mapped in connection with preliminary engineering studies on 75 individual projects. Not all prospects mapped from the airphotos were checked in the field because the more promising looking deposits were investigated first. Wherever an ample supply of satisfactory granular material was confirmed on the ground, field exploration was discontinued.

Although the area of outlined prospects varied from $\frac{1}{2}$ acre to 10 sq mi by far the greatest percentage of mapped deposits ranged between 2 and 20 acres. In fact, only 206 of the 2,165 mapped deposits covered an area greater than $\frac{1}{4}$ sq mi or 160 acres. That is slightly less than 10 percent. The average area searched on each construction project was 425 sq mi; the range, however, varied between 10 and 1,500 sq mi.

In the summer of 1951, a 1,500 sq mi area representing typical Canadia Great Plains surface geologic conditions was selected to determine the accuracy of airphoto identification of granular deposits. In this region granular deposits, which are mainly glaciofluvial materials, might range anywhere from 20 percent to 80 percent gravel sizes (above $\frac{1}{4}$ in.). But in nature a high proportion of deposits yield 60 percent to 80 percent sand sizes. Few granular deposits identified in airphotos contain more than 7 percent passing the number 200 sieve.

Results of the test made in 1951 revealed that granular glaciofluvial materials were found at 305 of 340 prospective deposits identified and delineated in the aerial photographs. Alluvial and deltaic sands noted in the airphotos were not mapped because gravel as well as sand was required.

Furthermore, 227 deposits out of those 305 deposits at which sand and gravel were found in the field had no existing pits in them at the time the photographs were taken. In other words, roughly 75 percent of the deposits were correctly identified in the photos without the "give-away" clue of an existing pit.

On this search the interpreter had formal training in airphoto analysis techniques and five years airphoto mapping experience following training. However the analyst was totally unfamiliar with the location and disposition of possible granular deposits in the area being searched.

PROSPECTING PROBLEMS FACING THE GROUND INVESTIGATOR

In the past, problems facing the investigator on the ground have been many and, more often than not, very trying. The materials-location engineer must find a source of aggregate having suitable quantity and quality. To do this he often arbitrarily defined the area he planned to search. The following illustration points up some of the difficulties met in this sort of investigation when airphotos are not used.

Assuming that the area to be searched is 10 mi wide and 100 mi long (1,000 sq mi) and that there actually exist 50 unknown granular deposits, 20 known and partly developed ones which still contain appreciable untapped material, and 20 exhausted sources which have small to large pits in them, the ground investigator must first try to ferret out the locations of the known as well as the unknown deposits. Many undeveloped prospects will be unknown even to the farmer who owns and works the topsoil overlying gravel. A second task of the ground observer will be to classify accurately known deposits in two categories: those that to all intents and purposes are exhausted and those that have a significant quantity of material yet available. Once the materials-location engineer has located all prospective sources, he is then obliged to grid the more promising areas with test holes in order to (a) determine the areal extent of each deposit, and (b) locate the best portions within a deposit for future commercial development purposes.

CUSTOMARY SEARCH METHODS AS AIDS IN AIRPHOTO STUDIES

In the search for undiscovered gravel sources, customary practice has been, and often still is, to contact farmers, local municipal officials, and various provincial government agencies. However, too commonly the information obtained does not answer these questions: Where are the undeveloped sources located? What is the prospective quality of a deposit? What is the extent and depth of a deposit and, thus, quantity available? Which partly developed deposits still contain large supplies?

Recourse may be made to agricultural soils, surficial geologic, topographic and groundwater geology maps. Although they should always be consulted they often have certain shortcomings and limitations when used alone in the search or appraisal of a source of specification material. They are limited to showing only relatively few features of the cultural and natural landscape. None of these maps has the delineation and tabulation of commercial sand and gravel sources as its express objective. In practically all cases map scales at 3 to 6 miles to the inch preclude showing small deposits even though they are important sources of aggregate. In nature a good many commercial deposits are only a few acres in extent. More often the maps referred to above show favorable environments in which commercial granular deposits may be expected to occur.

Generally speaking, on the Canadian prairies those granular deposits that are extensive enough to be shown on published maps are predominately sand and have little if any commercial value. Submarginal and marginal arable lands and inaccessible areas often have the greatest sand and gravel potential; unfortunately they usually correspond to map areas that show the least landscape detail.

Many of the uncertainties of finding undiscovered deposits and much of the routine work of testing large prospective deposits in order to isolate the best portions are taken out of ground operations by the analyst with experience in mapping sand and gravel from aerial photographs.

GRANULAR LAND FORMS IDENTIFIED FROM AIRPHOTOS

There are a great number of granular land forms that may be identified in aerial photos of western Canada. In order to estimate potential quantity and quality of material, each deposit should be studied in its environment, taking into account its physiographic and geologic history. Because all land forms listed below may contain small to large quantities of poor to good quality material, each deposit seen in the photos must be studied individually.

Ice-Contact Granular Land Forms

Eskers and crevasse fillings (both single ridges and intercommunicating networks), esker deltas, individual kames, kame moraines, kame terraces kame deltas, and glacial inwash.

Proglacial Granular Land Forms

Pitted and unpitted outwash plains, meltwater-channel deposits such as granular terraces, valley trains and isolated remnants of valley outwash; glacial-spillway deposits adjoining and, in valleys, developed during rapid draining of glacial lakes. Where sediment-bearing tributary streams entered former glacial lakes or joined major spillway valleys, glacial deltas commonly formed. The water level in most of these lakes and valleys fell, leaving the sand and gravel delta deposits "hanging." Glacial-lake beach ridges are another source of sand and gravel. Although quite common around Glacial Lake Agassiz, they are relatively rare in other parts of the southern Canadian prairies.

Postglacial Granular Land Forms Located in Glaciated Terrains

A number of granular land forms showing variable mechanical composition and varying degrees of sorting have been deposited in recent times. Indeed some of them are still actively accumulating, especially in mountainous and foothill terrains. They are useful for certain types of construction purposes. Some of the more important are talus, or scree, deposits; alluvial fans, cones and deltas; and, probably most important of all, channel-lag deposits in present-day rivers, the so-called "river deposits." Because of dense vegetal cover in the mountains, many of these forms are inconspicous elements of the landscape.

The foregoing list, although not intended to be complete, illustrates the multiplicity of landscape forms that produce different volumes and different types of granular construction material. Engineering problems associated with the development of these deposits vary with each local situation. All land forms listed have been identified and mapped from aerial photos covering western Canada.

THE AIRPHOTO IDENTIFYING FEATURES OF GRANULAR DEPOSITS

The airphoto pattern is both detailed and regional. In a single view it shows various types of land use, accessibility to and from specific places, problems associated with development such as quality of haul roads, probable amount of stripping, possible property damage, high-water tables and other information about anticipated ground conditions.

The vertical aerial view presents a 3-D replica; it shows a miniature scaled model rather than a 2-D map. Minor landscape details of granular deposits are viewed in relation to near and remote identifiable geologic features. These minor details are commonly subtle bits of evidence that reflect the general type and nature of subsoil materials.

The experienced specialist examines airphotos stereoscopically and, where possible, makes use of mosaics to grasp the regional picture. Ordinarily he first maps all granular deposits regardless of quantity, depth, expected quality, or whether or not deposits are partly developed or undeveloped. Each deposit is then carefully checked against all relevant available data, usually in the form of maps and reports. Commonly these maps provide one or more helpful clues. From its appearance in the photos, each prospect can frequently be classified according to the probable origin of rock materials composing the deposit and, nearly always, according to the mode of land-form deposition. Three examples illustrate this:

1. A broad alluvial fan at the base of a mountain containing shale strata.
2. An esker in the Canadian shield.
3. A local meltwater-channel deposit situated in a deep valley carved out of glacial drift.

From decipherable airphoto details relating to mode of land-form deposition and source terrane of rock particles in each land-form, the analyst may suggest that the material in deposit 1 is likely to be dirty, poorly sorted, and high in shale content; that deposit 2 is complexly stratified but probably composed of durable rock particles; and that 3 is well sorted, fairly clean, and contains a small percentage of the very extreme particle sizes, such as boulders and clay. If, in example 3, soft clay-shale bedrock were seen to outcrop locally along the sides of the depression in which the granular deposit is located, the observer might logically infer that the deposit would contain greater or lesser amounts of shale. Geologic setting, therefore, commonly tells the experienced observer something about the lithologic composition and variability of granular deposit.

Special characteristics of granular land forms seen in aerial photos usually tell the observer something about the depth and gradation of a deposit, for example, whether shallow and sandy or deep and gravelly. Particular features of microrelief and erosion, their relation to photo tones, and a variety of special markings are the analyst's "tools of the trade." A good knowledge of special earmarks and an appreciation of the degree of reliability that should be placed on various identifying criteria in different climatic and geographic situations often spell the difference between a mediocre and a really top-notch analyst.

On one rather extensive engineering project a check was made to determine the frequency that certain airphoto characteristics were helpful in identifying the location of a granular deposit and in predicting the nature of the material contained therein. Sixty-five deposits were mapped from the photos and confirmed in the field. The results are as follows:

Identifying Feature Observed in Airphotos	Number of Instances the Feature Aided Identification
Physiographic setting	62
Details of microrelief	40
Details of gully form	34
Soil tones and, especially, their relation to microrelief	26
"Fossil" current markings, kettleholes and other diagnostic microfeatures	7
Land use and vegetation	10

DATA ON GRANULAR LAND FORMS MAPPED FROM AIRPHOTOS

Relative Quality of Materials in Various Land Forms

The following figures were taken from the results of airphoto gravel searches on 75 projects; they indicate the number of times out of 75 that a particular granular land form contained the best material in a project in terms of quality, quantity and suitability for paving aggregate: small and isolated outwash deposits along meltwater channels, 18; outwash-plain deposits not associated with a valley, 14; large individual kames or clusters of kames, 12; glacial deltas, 9; valley trains, 7; tertiary gravels, 4; extensive glacio-fluvial terraces, 3; glacial-lake beach ridges, 3; present-day stream channel (lag) deposits, 3; and esker deltas, 2. On four projects, there were no deposits suitable for aggregate in bituminous and concrete pavement.

No small and relatively inconspicuous kames and no esker ridges contained high-quality aggregate in quantity. Although eskers seldom yield high-quality wearing course aggregate in large quantities, they often provide a source of road-surface gravel as well as subbase material in bituminous road construction.

Frequency of Occurrence of Granular Land Forms in Different Physiographic Environments

The general physiography of the search area has a marked influence on the number and distribution of various types of granular land forms. An understanding of the physiography is helpful in locating gravel deposits. For example, in a 100-sq mi area and a geologic setting extending on both sides of a former glacial-lake strandline, the following land forms were mapped and checked in the field: beach ridges, 3; glacial-lake deltaic gravelly sands, 3; outwash plains, 1; kame terraces, 2; kames, 4. As another example, in a 110-sq mi area of undulating dead-ice moraine landscape, the following deposits were mapped and checked: stream terraces, 7; outwash plains, 4; kames, 3; eskers, 1; and crevasse fillings, 1. In a third example covering 1,500 sq mi of till plain containing several wide valleys with "misfit" streams, dead-ice moraine and glacial lakebed plain, the following land forms were mapped: individual kames and kame moraine, 13; level and pitted glacial outwash plains, 13; glacial deltas, 4; and granular deposits along the sides and bottoms of meltwater and glacial-lake spillway channels, 35. The fourth illustration is from a mountain-valley region and is only a 60-sq mi area. Results from it are as follows: channel-lag deposits (i. e., shifting gravel bars in the streambed), 12; alluvial fans, 3; high-level stream terraces, 3; alluvial cones, 2; and "hanging" deltas, 2.

Actually in the prairies of western Canada eskers are scarce. But occasionally, where one esker is found there may be a great many. In the fall of 1954 a study of 29 construction projects covering a granular search area of 7,000 sq mi and including 666 granular prospects indicated that only 5 eskers had been mapped. Yet in other airphoto studies of the terrain made up to this time, where construction-materials location was not the express purpose of study, 21 eskers had been noted. These 21 eskers are located in the southern prairies and outside of the 29 granular-search map-areas referred to previously. On the other hand, in the summer of 1956, 10 eskers were mapped on a single project. These figures indicate the variation in distribution of certain land forms.

Suitability of Airphoto-Identified Deposits for Highway Subbase, Base and Wearing Course Material

Six construction projects having geologic terranes typifying better-than-average, average, and below-average granular-material prospects were statistically analyzed to indicate the type of assistance that might be expected from airphoto searches. These are given in Table 1. The following general geologic conditions apply to all areas included in this table:

1. No extensive outwash deposits occur in upland positions in any of the project areas.
2. There are no granular river terraces in any of the areas.
3. All search areas are located in glacial-drift-covered, grass-vegetated terrain.
4. One or more former meltwater and/or glacial-lake spillway channels exist in all project areas.
5. Dominant surficial deposits in the project areas are glacial till, postglacial alluvium and silty or sandy glaciolacustrine material.

TABLE 1

Relative Granular Material Potentiality of Area	Area Searched in Sq Mi	Number of Deposits Mapped	Number of Deposits Field Checked	Number of Checked Deposits Not Usable for Subbase, Base or Wearing Course	Number of Deposits Suitable for		
					Subbase Only	Base Course	Wearing Course
Example A Above Average	150	29	16	2	14	4	2
Example B Above Average	100	27	18	2	16	3	2
Example C Average	150	15	13	4	9	4	2
Example D Average	1500	102	65	8	57	14	10
Example E Below Average	350	19	10[a]	0	10	4	1
Example F Below Average	500	13	13	4	9	2	1

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[a] Selected as the best 10 prospects for field checking (based on airphoto indications).

EXAMPLES

The gravel area outlined by white dots in Figure 1 was located from aerial photographs. The material was used in the construction of a concrete spillway, whose approximate location is also indicated. Both on the ground and on aerial photographs this deposit is difficult to detect because of level topography and an unlikely geologic setting. The deposit was revealed in the photos by a very subtle tonal pattern.

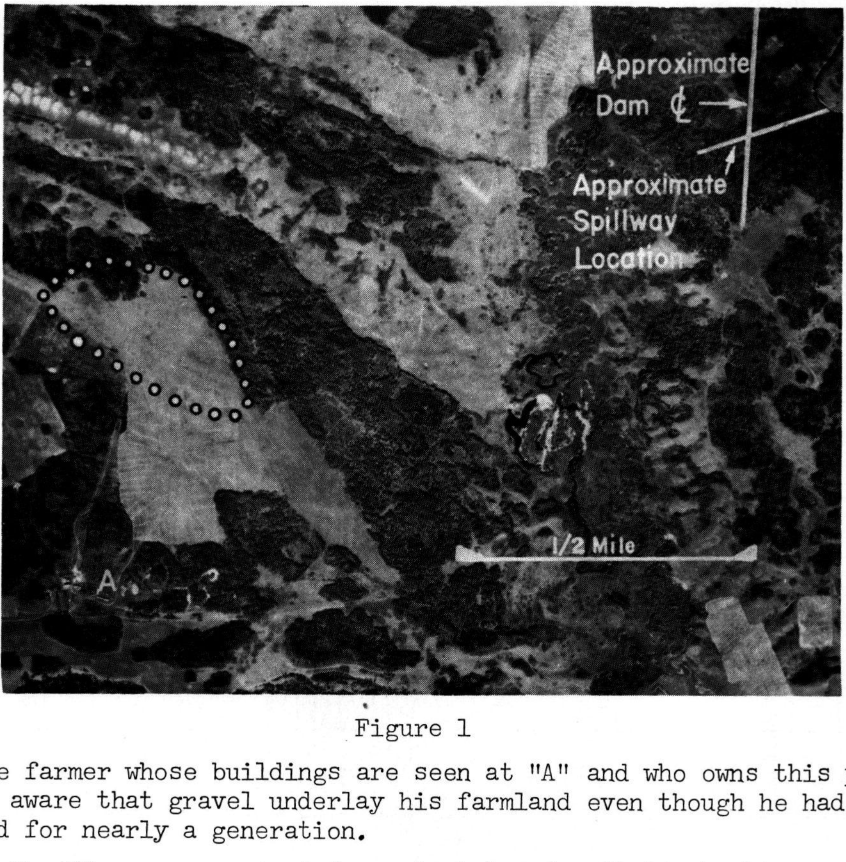

Figure 1

The farmer whose buildings are seen at "A" and who owns this property was not aware that gravel underlay his farmland even though he had worked the land for nearly a generation.

Of the 20 sources mapped from airphotos for field checking on this project, the deposit seen here happened to be the closest source to the construction site. Moreover it contained an insignificant amount of deleterious rocks while most of the others contained excessive amounts of shale. Although superior to other deposits in coarseness and over-all quality of material, this deposit nonetheless required washing and grading to render it suitable for high-grade concrete.

The gravel area outlined by white dots in Figure 2 was located by airphoto analysis in 1955. This deposit contains a good quality gravel. It is worth noting that the deposit was not discovered by ground investigators who previously searched the area, even though it is situated only 1.5 miles from a main highway and in an area where gravel is very scarce. In contrast to Figure 1, topographic position and geologic setting are helpful in identifying this deposit; photo tones on the other hand provide very little assistance.

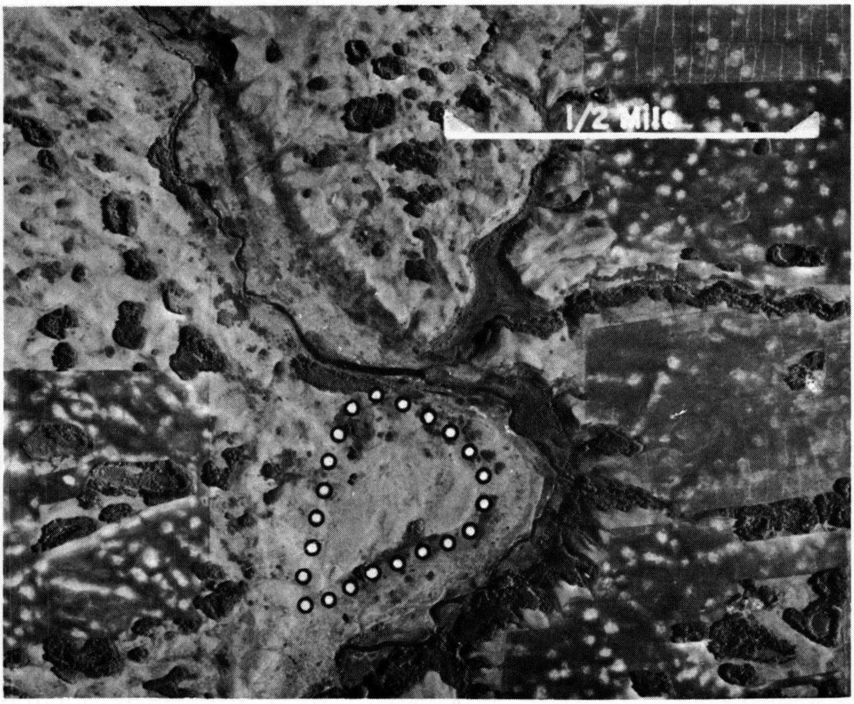

Figure 2.

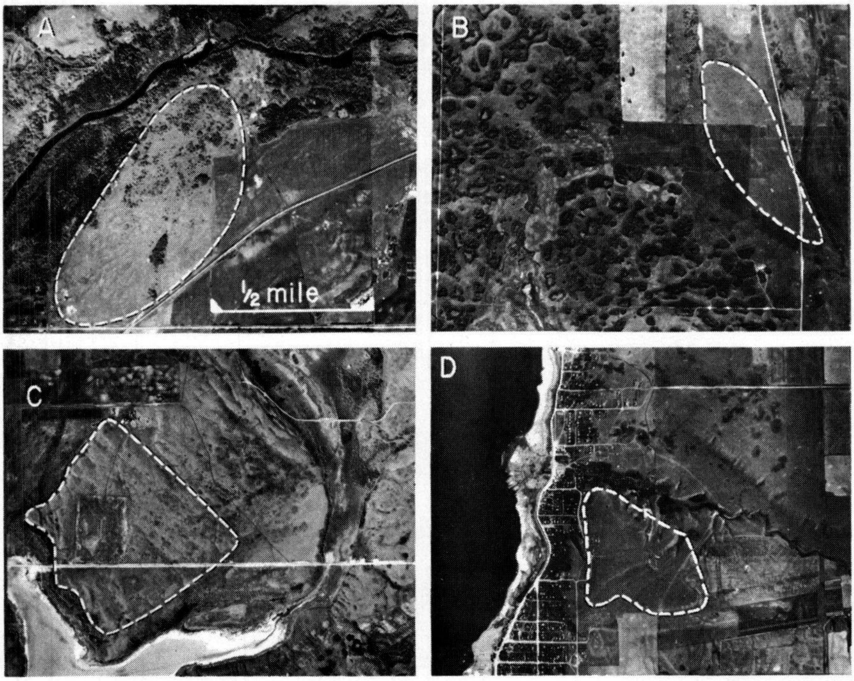

Figure 3.

The four airphoto patterns in Figure 3 were located from airphotos and marked as good coarse gravel prospects. "A" is situated on one major construction job; "B" and "C", on a second; and "D" on a third.

Specifications on all three projects called for one-half to three-quarters million yards of crushed material, graded between $\frac{1}{4}$-in. and $1\frac{1}{2}$-in. In nature each deposit shown above ranged from 65 to 75 percent retained on the $\frac{1}{4}$-in. sieve, and 35 to 45 percent retained on the 2-in. sieve. Each deposit is capable of producing the required quantity of finished material and is moreover located within 3 miles of the closest point on the principal transportation system where the material will be used. These coarse gravel gradations are extremely uncommon in the regions in which they were discovered. In these regions a very high percentage of granular deposits contain 65 to 75 percent passing a $\frac{1}{4}$-in. sieve, that is, sand sizes which on projects like these must be wasted. All coarse gravel deposits marked for future development are outlined by a dashed white line. Field work to date indicates the four deposits are the most promising of several dozen mapped from the photos.

CONCLUSION

In conclusion, it should be restated that the airphoto technique is a prospecting tool, not a subsurface exploratory tool. Basically the objectives of the two are different. The former indicates definite areas of promise to investigate in the field and in addition, and in a high proportion of instances, what to expect in terms of quality and volume of granular material. Ground methods either prove or disprove these airphoto-based expectations with the least expenditure of time and money. In a very high percentage of cases, airphoto predictions by experienced analysts familiar with the region being searched are reliable and accurate. Because i is systematic and regional, the airphoto method has many advantages not inherent in the old conventional methods, which tend to be random and localized and in many cases dependent on hearsay.

The main requirements of the photo interpreter are: (a) a precise knowledge of all granular land forms and the situations in which they most commonly occur in nature; (b) experience in airphoto analysis, which of course influences predictions as to quality and quantity; (3) field checking experiences; and (d) ability and self-discipline to qualify description of prospective deposits so that these descriptions are helpful rather than misleading to the field investigator.

Of paramount importance in locating and mapping granular deposits is familiarity with the airphoto patterns of a region. Familiarity with the variety of airphoto patterns and meaningful nuances in airphoto patterns of granular material can be gained only through analytic and systematic study of the aerial photographs of the region being searched.

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Discussion

D. R. LUEDER, Chief, Engineering Division, Hunting Technical and Exploration Services, Ltd., 1450 O'Connor Drive, Toronto 16, Canada—In addition to reviewing the general association between efficient materials survey and the aerial photographic approach, this paper presents some factual, quantitative data regarding the results that might reasonably be expected through the proper use of the aerial method.

This is something that has been wanted for some time. Everyone has heard much about aerial photographic interpretation during the past ten or fifteen years, and it has been discussed as an operational technique for many types of engineering projects. However, practically no one has bothered to do more than be expository—or at most, qualitative—regarding its efficiency. It is this latter characteristic that will decide its future importance and acceptance as an engineering method. Of particular interest, are two quantitative conclusions that can be drawn from the paper.

One of these shows that physiographic setting, i.e., land form plus relation to surrounding topography, is of importance to materials location more than 90 percent of the time, while such things as micro-relief, gully-shapes, and soil tones also are helpful approximately one-half (or more) of the time. This conclusion agrees quite well with that of the writer, and points up the exceptional importance to a materials engineer, of an adequate knowledge of geomorphology. At the same time, it corroborates the "classical" contention that airphoto interpretation is not done by landform alone, but also depends upon a coincidence of evidence as provided by other elements of the airphoto pattern.

The other conclusion shows that airphoto interpretation, by qualified people, should be successful 75 to 100 percent of the time. However, it also shows that the technique is not really a method for assessing the quality of granular deposits, but rather a technique for identifying deposits whose visible characteristics are those commonly associated with sand and gravel. In other words, while interpretation may be successful 75 to 100 percent of the time, and the located deposits will yield subbase material approximately the same percentage of the time, suitable wearing course material may be expected about 10 to 15 percent of the time. These figures, of course, disregard the specific area and objective of search. The writer's experience has been virtually identical with that indicated by these figures.

There is another application of airphoto interpretation. Recently, a consulting engineer approached the writer's firm with a difficult materials problem. In connection with earth dam construction in Quebec, he desired well-graded material for interior zone construction.

The ideal gradation specifications cited were those of a gently curved line crossing the sand gravel line at 66 percent passing; the sand/silt boundary at 33 percent passing and the clay line at 5 to 10 percent passing.

The area was filled with granular materials (sand and gravel) which comprised even the till. The firm had already spent several unsuccessful weeks in the field looking for the desired material, but the best samples were fine to medium sands with some gravel, but only 5 to 10 percent minus 200.

The area was heavily forested with coniferous-deciduous cover. The scale of the only available photography was 1:60000. Yet the desired material was located after a few days of photo examination, in an area which was considered to have the highest probability. It was a well graded till located primarily upon the basis of landform and gully shapes.

The client was surprised and pleased, although he expressed some mild disappointment that the located material possessed only 27 percent minus 200 instead of the desired 33 percent.

Although the quantitative data provided in the paper is of value, it should be used with care lest it be considered indicative of expected results over a much broader area (geographically and professionally) than that upon which it is actually based.