INFLUENCE OF TOPOGRAPHIC POSITION IN AIRPHOTO IDENTIFICATION OF PERMAFROST

Robert E. Frost and Olin W. Mintzer
Joint Highway Research Project
Purdue University

SYNOPSIS

This paper reports the development of the use of aerial photographs in the determination of the presence or absence of detrimental permafrost. The technique used in airphoto identification of permafrost is a direct result of past and present research done at Purdue University and conducted by the Joint Highway Research Project of the Engineering Experiment Station under contract with the St. Paul District Engineer Office of the Corps of Engineers, Department of the Army. The project is under the general direction of the Office of the Chief of Engineers, Department of the Army. The paper reports the influence of topographic position in the identification of rock and the interpretation of soil and permafrost conditions from aerial photographs.

Permafrost is defined, and the factors that affect the existence or non-existence of permafrost are given in relation to the climatic influence and the topographic position. Several basic topographic situations are discussed to illustrate this relationship. The topographic types discussed include uplands, transition zones and valley fill, terraces, and flood plains. Each of these several landforms are described; the engineering problems associated therewith are set forth; and the essential airphoto-identification elements are delineated.

It has been pointed out that airphoto-pattern elements of arctic and subarctic regions have been determined for practically all drainage features, soil-color tones, vegetative types as well as for topographic position. All of these elements are important in the determination of the extent of detrimental permafrost but it is concluded that the influence of topographic position is by far the most important factor in identification of permafrost in subarctic regions.

The purpose of this paper is to discuss the importance of topographic position in the interpretation of permafrost from aerial photographs. In accomplishing this purpose certain relationships are illustrated by discussing some of the general physiographic situations from the standpoint of description of physical features, engineering problems, and photo interpretation. Permafrost is defined and the factors which influence the occurrence of permafrost are set forth. Research has shown that topographic position, as an influencing factor, is of main importance.

The study of permanently frozen soil has been limited, until recently, to the activities of a few persons including miners, explorers, some natural scientists, and a limited number of engineers. Roads were built and many failed; buildings and other structures were built and some settled severely. Airstrips were constructed on frozen soils only to develop severe settlement because of serious thawing beneath the pavement - thus, creating cracks and rough surfaces (7)[1]. See Figures 1 to 5.

The strategic situation of Alaska with respect to future routes of travel, potential statehood, the anticipated urban and rural expansion, and tourist influx has given added impetis to the quest for knowledge about permanently frozen soils, both from the standpoint of pure and applied science. The installations which were constructed during and following the war have served as a vast proving ground where important observations have been made and where invaluable data have been collected

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

and made available for analysis (2).

The Corps of Engineers has and still is conducting research to determine the best procedures for combating permafrost and its serious effects on structures. These researches include determining the best method for constructing roads, airports and airport structures, buildings of all types, and utilities in permafrost areas (4, 7). The work is being conducted by the St. Paul District Office under the general direction of the Office, Chief of Engineers, Department of the Army. See Figure 6.

The Engineering Experiment Station of Purdue University is under contract with the Corps of Engineers to conduct an airphoto study of permafrost. The efforts of the Joint Highway Research Project have been directed toward the engineering evaluation of permafrost and soils of arctic and subarctic regions by use of airphotos, particularly those of Alaska (2). Sufficient field and laboratory study has been completed to permit the development of airphoto interpretative procedures for use in the selection of good construction sites and

Figure 1. This is a picture of a highway which was constructed on frozen silt which contains pockets of ice in wedge form. The ice has thawed and considerable settlement has resulted as indicated by the deep water puddle.

Figure 2. This shows a severe settlement in an airfield runway surface which resulted from thawing subgrade soils.

Figure 3. Note the general warping of this building situated on frozen silt which has thawed considerably. The support indicates the severity of the situation.

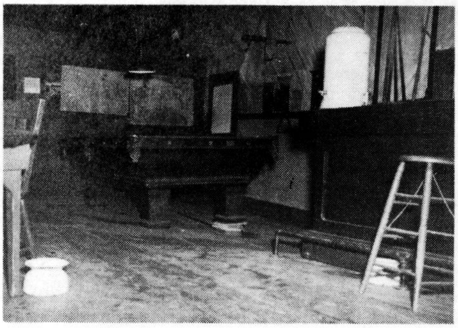

Figure 4. The interior of the building in Figure 3 shows clearly the severe effects of thaw. In the summer the soils thaw and the building settles; in the winter the soils refreeze and the building raises. A differential movement of 16 in. in the floor occurs.

for use in predicting definite permafrost conditions; namely, type, location, and relative depth to permafrost (8).

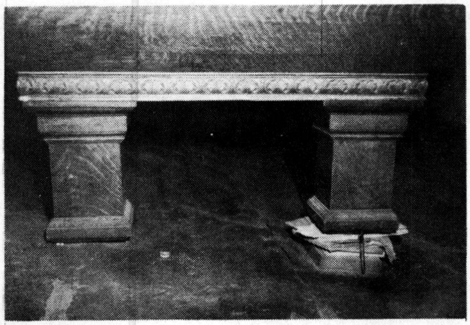

Figure 5. Note the shims under the pool table legs. In order to maintain a level table surface throughout the year it is necessary to change the shims constantly.

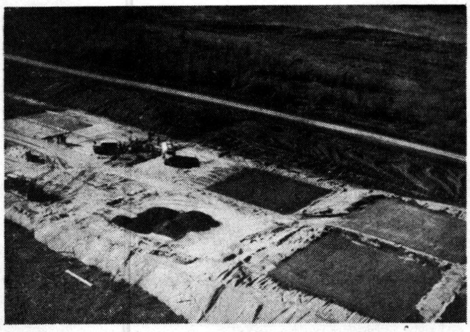

Figure 6. An Aerial View of Part of the Corps of Engineers Permafrost Experimental Area Near Fairbanks, Alaska

PERMAFROST AND INFLUENCING FACTORS

Definition - Permafrost may be defined as permanently frozen earth materials which includes bedrocks having a temperature below freezing and other materials which have become solid-like by low temperatures and have remained in such a state continuously for a long period of time. Permafrost occurs in areas where the mean annual temperature is below freezing (5), with the exception of a thin surface layer which thaws seasonally. The ground in permafrost regions is perennially frozen to depths ranging up to several hundred feet. Permafrost affects nearly

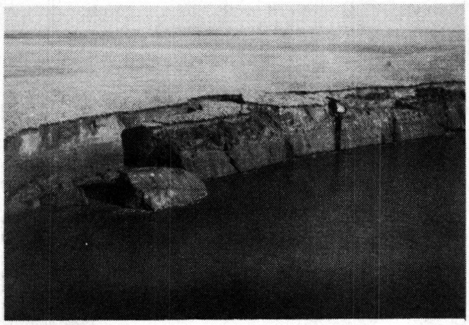

Figure 7. This figure shows massive ground ice - one form of detrimental permafrost.

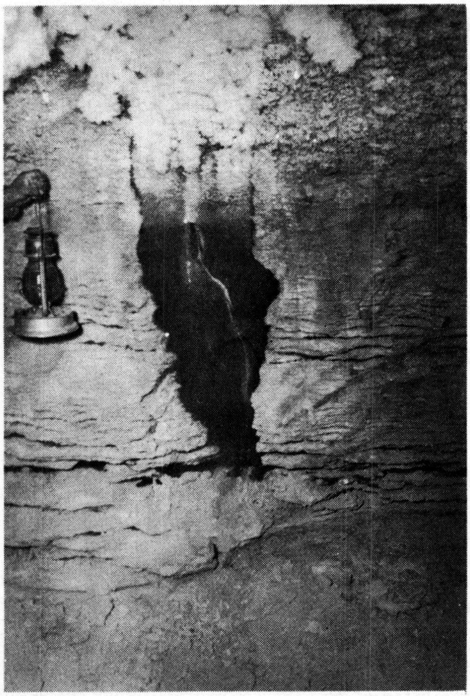

Figure 8. Another Form of Detrimental Permafrost - Here, ice in wedge form is exposed in a cold storage cellar.

all of the Arctic and a great portion of the Subarctic. It has been estimated that nearly one-fifth of all of the land area of the earth's surface is underlain by permafrost (5).

the soil mass consists of ice. Since detrimental permafrost offers the

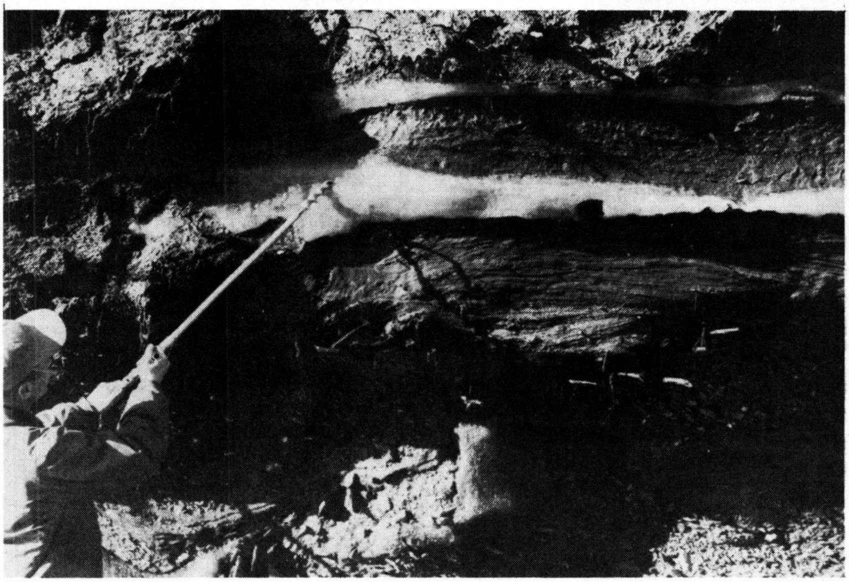

Figure 9. Detrimental Permafrost in the Form of Ice Sills and Ice Ledges

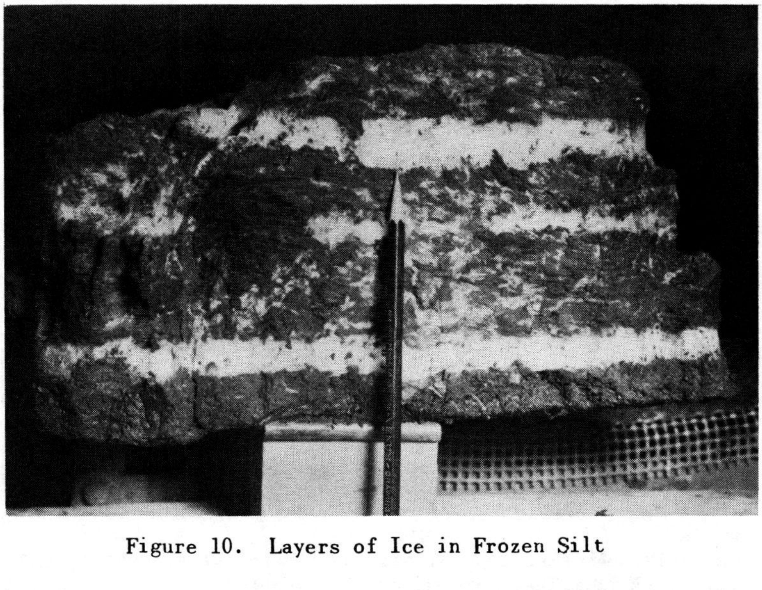

Figure 10. Layers of Ice in Frozen Silt

Forms of Permafrost - Permafrost, or frozen ground, exists in the following forms: (a) "dry frozen" in which the soil mass contains no ice but is rendered solid because the temperature is below freezing; and (b) "detrimentally frozen" in which a large percentage of

serious engineering problems, more concern is given to the variety of forms in which it exists (1). Above the permanently frozen surface is the active layer which goes through annual cycles of freezing and thawing.

The variety of forms in which detrimental permafrost exists include: (a) fine-textured soils which contain a large percentage of ice in their mass in the form of crystals, small lenses, or small wedges; (b) soil masses which have been so arranged by segregation of ice and soil particles that they form polygonal blocks of varying sizes and types; (c) materials situated in low topographic position in which large masses of ground ice form an integral part of the mass; and (d) large masses of buried ground ice. Figures 7, 8, 9, and 10 illustrate forms of ice-soil mixtures.

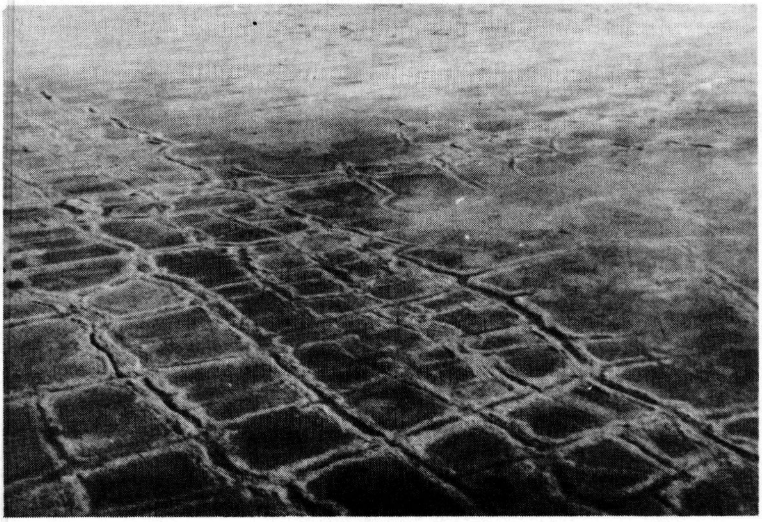

Figure 11. Depressed Center-Type Polygons - These are about 200 ft across.

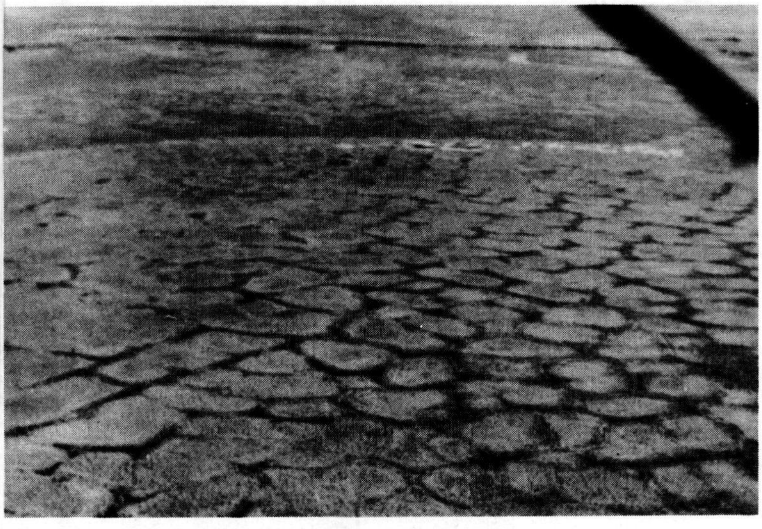

Figure 12. Another type of polygon is the raised-center type. These are about 75 ft across.

One of the most significant features

of permafrost regions in which detrimentally frozen soils abound, is the presence of soil polygons. The term "soil polygon", as generally accepted, refers to the geometric configuration of surface markings in regions of permanently frozen soils. Many types exist and are recognized in the literature. The two most important types are: (1) those with depressed centers or pans which have a perimeter consisting of raised dykes; (2) and those with raised centers and depressed perimeters. Figures 11 and 12 illustrate two types of polygons (2).

Influencing Factors - There are many factors which influence the presence or absence of permafrost and its type or degree. Among the factors are general climatic conditions and certain local physical conditions. The local conditions, which influence the presence or absence of permafrost, include such variables as topographic position, soil texture, soil moisture, vegetation, surface drainage, slope, and exposure to light and heat. Of all local conditions it is believed that the influence of topographic position is the greatest in determining degree and type of permafrost, either from a field survey or from interpretation of aerial photographs.

In the Arctic Regions where the duration of cold temperature in number of days below freezing is great the element topographic position is not as critical as an influencing factor of permafrost as it is in warmer areas. As far as Alaska is concerned the Arctic Regions include, for the most part, the area north of the Brooks Range. In the Subarctic Regions, the permafrost-topographic situation relationship is more critical than in the Arctic Region because of such items as a shorter duration of cold temperatures, a generally higher soil temperature, and a greater depth of seasonal thaw.

Figure 13. This is an airphoto of an upland area which is covered with an unrelated mantle. The surface is marked with numerous polygons indicating ice wedges in the soils. The bar scale is 1000 ft.

TOPOGRAPHIC POSITION

It is necessary for the interpreter to determine the physiographic arrangement of an area under consideration in order to evaluate the permafrost conditions. As far as airphoto interpretation is concerned it is necessary to determine whether an area is mountainous, an upland plateau, transition zones or valley fill, terrace, flood plain, or

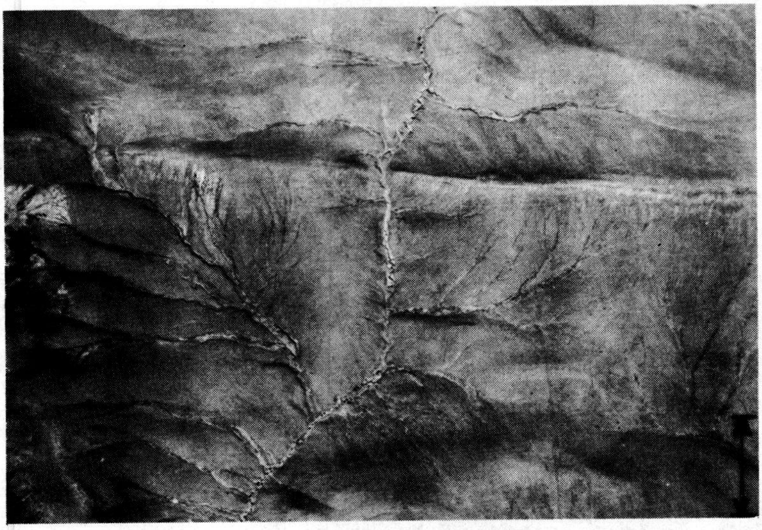

Figure 14. This is an airphoto pattern of strongly-tilted beds of sandstone and shale in Northern Alaska. The bar scale is 1000 ft.

Figure 15. This illustrates the ''button type'' gully system which frequently occurs in upland depressed areas.

some combination of the above in order to evaluate permafrost conditions.

In discussing the effect of topographic position on permafrost in these physiographic classes the scheme of this presentation is to describe some of the physical features, discuss some of the engineering problems, and demonstrate how the patterns may be identified on the aerial photograph. The mountainous areas offer insignificant permafrost problems and will not be discussed.

Uplands - Uplands may cover a range of several types of relief. The relief of an upland most generally depends upon the underlying parent material: it may reflect the influence of flat lying or tilted bedrock; it may result from bedrock types which are covered with glacial deposits; or it may result from igneous formations which have been intruded or extruded locally (3).

airfields. Many of the upland gullies are broad in cross-section, they appear to be filled with local sediments, contain deep accumulations of frozen peat, and occasionally are marked with well-developed polygons. In upland depressions the thick accumulation of peat and the products of rock weathering promote severe permafrost conditions - many of which should be avoided. In such

Figure 16. This figure illustrates thaw of polygons.

In upland areas permafrost is not a problem when rock-in-place is the parent material. Uplands create serious permafrost situations when a sufficient mantle of normally loose and unconsolidated material exists. The mantle of soil may represent an altogether unrelated material which has been left by either ice, wind, or water. It may be accumulations of local materials as sediments in depressions or on the side slopes of hills or in gullies.

In the areas which have a disconformant surface mantle, well-developed polygons occur widespread thus indicating the presence of detrimental permafrost (Fig. 13). The polygons are of the raised-center type. Such areas offer serious difficulties to engineering structures - particularly highways and

instances large masses of ground ice can be expected beneath the vegetal accumulations.

Construction in the upland would involve rock excavation. For highways or runways this situation would create a varying subgrade condition which would range from some of the best materials (rocks) to some of the poorest (ice and/or frozen silt).

Identification of upland situations from airphotos is fairly simple and straightforward. The rock patterns are similar to those found elsewhere. As an example, the sandstone and shale pattern occurring in the Interior Uplands (Fig. 14) bear more than striking resemblence to the sandstone and shale pattern of parts of an area of similar work materials in midwestern United

States. The major airphoto-pattern elements in each situation are similar.

they appear to be connected to a series of "thaw sinks" which appear as circular

Figure 17. This figure illustrates a small valley fill situation.

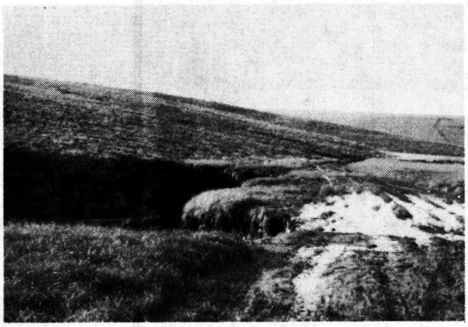

Figure 18. An Illustration of a Severe Thaw in a Local Valley Fill Situation Resulting from Excessive Flow of Water in a Gully Near the Edge of the Road

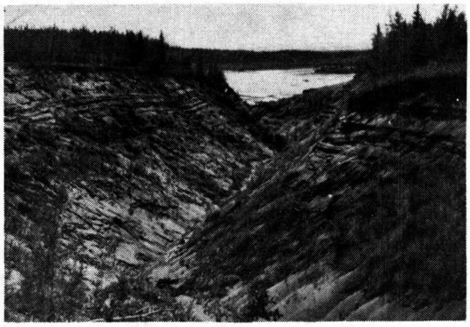

Figure 19. This illustrates the result of an upset in the thermal balance.

pools or pans in colluvial fill materials occupying depressed situations. Flow in such gullies is slow, the water being retarded by the vegetation. These circular areas are locally thawed and are filled with water. They are often ten or more feet in diameter and in broad, valley-fill-type gullies the thaw sinks often form around polygon-channel intersections (Fig. 16). Upon identifi-

In the upland areas the low topographic situations which are associated with detrimental permafrost can be determined in many ways. For instance, in the Arctic Regions upland gullies often exist as "button" type gullies (Fig. 15). Spacing of the "buttons" is often quite regular (2). On the airphoto cation on the airphoto it is significant that they indicate potential permafrost difficulties. In areas where the local topography is rugged and angular the button-type gullies do not occur. In rock areas major drainage as well as gullies show control exerted by the rocks by angularity in the system.

representative of transition zones and valley filling. Such physical features are readily recognizable as a zone between adjacent areas of difference in elevation. In general, in the high areas the streams are young and are actively degrading while in the low areas the streams are older and are aggrading

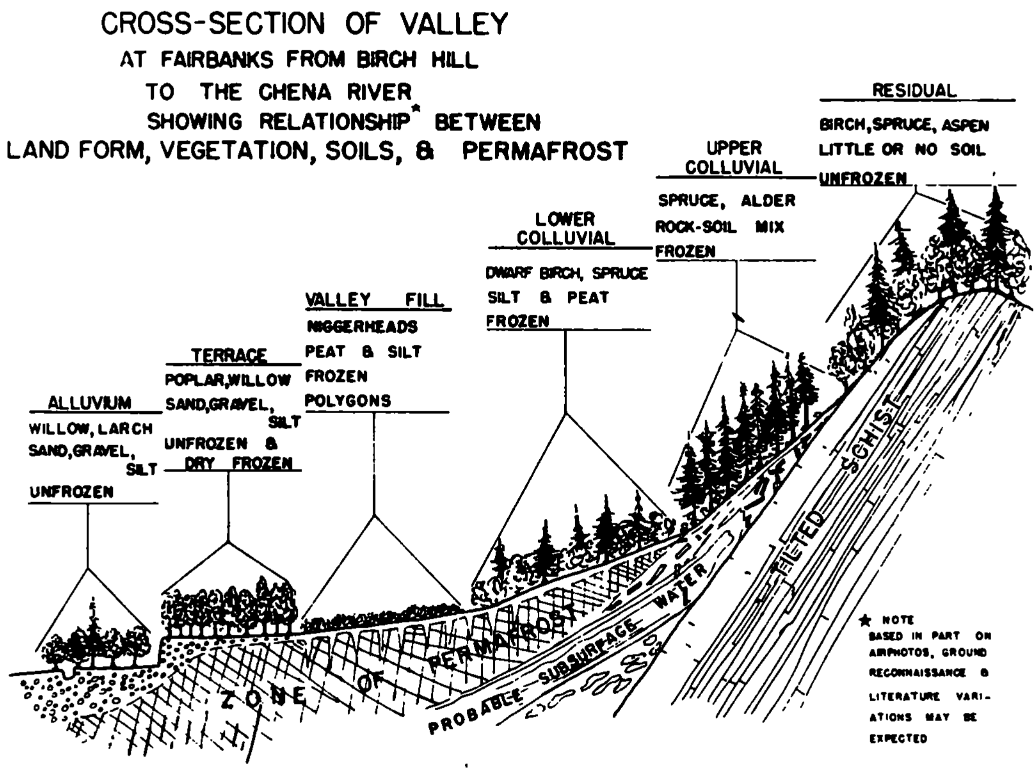

Figure 20. This schematic diagram shows some of the key permafrost influencing factors. The relationship between permafrost and topographic position is indicated. Vegetation found on the various soil-slope phases is also indicated.

Transition Zones and Valley Fill - Perhaps one of the most severe topographic situations occurring in subarctic regions from a highway standpoint which affect permafrost are those connected with transition zones and valley filling. Transition zones and valley fill are discussed together because of the general similarity in their formation and in their physical features. Material eroding from the uplands and collecting along the slope of the valley wall is

(3).

The description of transition zones and valley fill is divided in two parts. The first part to be discussed concerns small valley fill situations where the contributing factors are local. The second to be discussed involves large valley fill situations which in some instances involve major physiographic changes.

An example of a small valley-fill situation would be a local valley or rather large upland gully with a not too great drainage area. When the slope or gradient of such a gully is not great the valley is usually filled with colluvial material which is normally fine textured. The local valley bottom is fairly broad and forms a slight but perceptible concave surface. In many instances the gullies do not act as normal gullies but rather follow a series of connected polygon channels. See Figures 16 and 17. Drainage through these channels is often rather slow because of the thick accumulation of swamp grasses. However, when the ground slope or the gully gradient becomes steep or if for some reason a sudden rainfall should occur which would activate the gully, then considerable thaw would occur (Fig. 16). The force of the running water together with its warming effect often results in deepening of the polygon channels without appreciable lateral erosion. When such a condition occurs, the ice in the polygon channel thaws, thus exposing vertical walls of frozen soils (Fig. 18). Such areas are of serious concern in highway location where it may be necessary to cross a small valley-fill situation. In such instances the concentration of runoff associated with highway ditching would discharge large quantities over the frozen soils thus accelerating the thaw. If left unchecked, a considerable amount of soil would be removed resulting from an upset in the thermal balance (Fig. 19) (1).

In the larger valley-fill situations the topography is more subdued and the topographic features occur on a much larger scale than in the smaller valley-fill areas. On transition slopes permafrost varies with the depth of rock-soil mantle and with the topographic position both with respect to the elevation of the hillside above the flood plain (2).

In the upper slopes where the colluvium usually is relatively free from fine-textured soils, permafrost is not as serious as it is on lower topographic positions. In the winter the difficulty of icing from water crossing the road and freezing is much more severe than the permafrost problem. In normal hillside situations the mid-portion of the hills usually contains deep colluvial materials which consist of accumulations of fine-textured soils. In such situations the soil mantle is frozen; it often contains accumulations of ground ice, ice wedges, ice lenses, and considerable ice crystal growth. Any disturbing of the mantle of vegetation, particularly in making a side-hill cut for a highway, will cause severe thawing to occur.

On the lower portion of hills, in zones where the colluvial material begins to build up and form alluvial fans, permafrost problems are severe. Such zones contain some rock fragments and the major portion of the material consists of the fine soil brought down the slopes. Frequently the slopes are not steep and considerable peat has accumulated in lower positions. In such situations ice wedges are common and occasionally masses of ground ice will occur and when the soils are chiefly silt, ice crystals occur. When silt soils are encountered frost heaving is severe. Cuts for highways will pass through the active zone into the zone of continuous permafrost which will result in a severe upset in the permafrost-vegetation-thermal balance. Unless attention is given to proper construction and drainage procedures, severe highway difficulties will result.

In airphoto interpretation topographic position plays the chief role in permafrost identification and evaluation. Whether the transition zone or valley-fill situation is large or small it is necessary to determine the topographic position where materials change from "in situ" to colluvial (Fig. 20). It is also important to detect soil-texture changes in colluvial zones which are reflected in slope, drainage and vegetation - all of which are easily recognized on good quality airphotos. See Figures 21 and 22. Some transition zones are characterized by radial markings of bare rock patches; others by soil-rock flows which are often broad in plan and which occur on the upper and middle slopes and appear to scallop the hillsides. Such features are easily seen in airphotos and form an outstanding and significant feature in their identification on the airphotos. They suggest unstable soil conditions

Figure 21. This vertical airphoto contains some of the major topographic features contained in the diagrammetric sketch of Figure 20. It covers the upper portion of valley fill to the outward part of the valley fill. The arrows point out the following features associated with the lower topographic portions where permafrost conditions vary:

1. a ridge of colluvial silt
2. a gully between two silt ridges
3. a grass-covered embayed area on the border between the flats and the lower hill slopes - Permafrost (PF) at 36 in
4. dense willow thicket very wet surface (PF at 24 in)
5. polygon area (PF at 18 in)
6. spruce thicket on an extension of one of the sloping silt ridges (PF at 36 in)
7. small gully
8. probable terrace remnant sandy soils (PF at 54)
9. flat area grass covered (PF at 27 in)
10. swampy area - floating muskeg

and many are related directly to permafrost (Fig. 23).

Terraces - Terraces generally exist as flat-topped benches, usually sloping gently toward the stream with which they are associated. In broad valleys, usually thought of as being old, terraces occur on a grand scale. In contrast, the terraces in younger valleys consist of a series of narrow bench-like prominences on the valley sides (3).

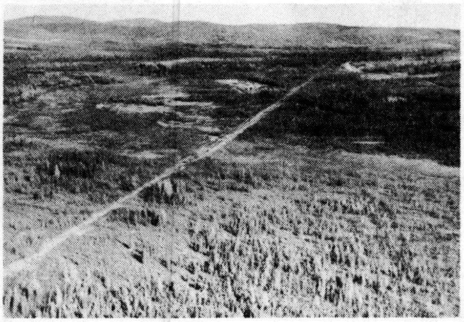

Figure 22. This is an oblique airphoto of a valley fill area near Fairbanks. It contains the area in Figure 21.

Figure 23. This shows ''hummocks'' occurring on colluvial slopes in the Subarctic Region. Such features are clearly discernable on airphotos. They indicate unstable soils.

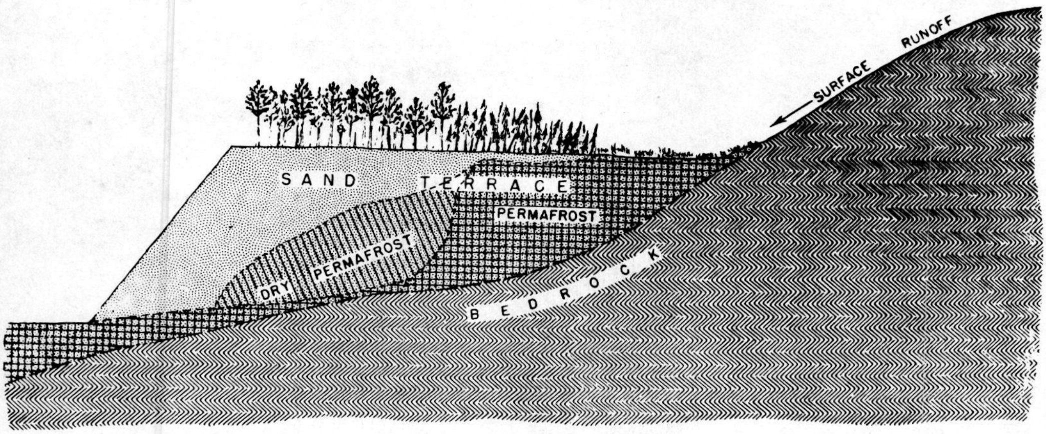

Figure 24. This is a sketch showing some of the typical permafrost conditions with respect to position on terraces.

Terraces of great areal extent, such as those which are found in the major valleys, are very important for the location of major engineering structures which require considerable surface area such as airfields or urban developments. Even though the general topographic situation of such terraces is good with respect to the surroundings, there are often local features on the terrace surface which give rise to severe engineering difficulties. Most of the large terraces may be thought of having three divisions insofar as engineering problems are concerned (Fig. 24).

In considering the use of a terrace for the location of an engineering structure, the design of such a structure must take into account which portion of the terrace is used. For convenience, these three zones or divisions are: inner zone, middle zone, and outer zone. The first is situated topographically nearest the valley wall, the second is located centrally, and the latter may be found nearest the adjacent flood plain. Serious engineering difficulties may be encountered on the inner portion of a terrace. Permafrost conditions are usually severe in this inner zone since excessive surface water, poor drainage, and a deep overburden of fine-textured soils prevail. On the inner portion of the larger terraces, particularly in the transition zones between terrace and upland or terrace and valley wall, topographic position becomes exceedingly important because of the influence of the adjacent uplands. In such areas, a deep mantle of fine-textured soil occurs; this mantle is frozen and often contains polygons. In many instances such areas consist of extensive muskeg (Fig. 25). Pockets of ground ice occur frequently. In the central portion of terraces, surface features and permafrost conditions are variable and the problem of varying soils occurs. When designing engineering structures, constant attention is necessary to meet the requirements of changing soil and permafrost conditions (Fig. 26). In the outer portion of terraces, soils and drainage are more favorable for engineering use than in either of the other zones. The lack of detrimental permafrost is the rule rather than the exception. Design practice for engineering structures should not be too different than on ordinary terraces in warmer areas (Fig. 27).

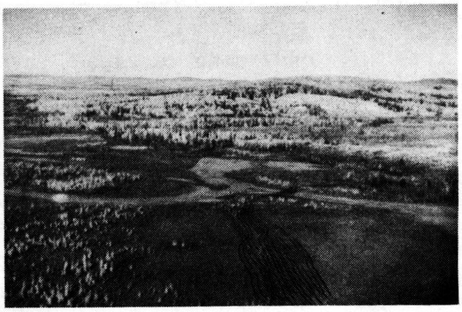

Figure 25. This is a low altitude oblique photo of the inner part of a terrace. Note the vehicle tracks in the ''floating muskeg area''.

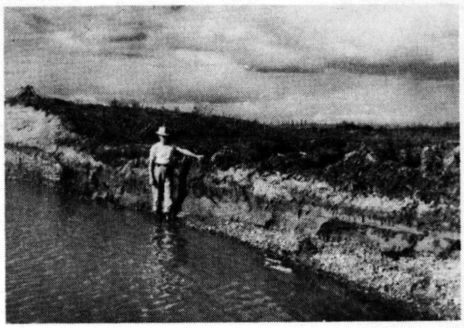

Figure 26. This is a cut made in the center part of a terrace area; it illustrates the problem of varying subgrade conditions.

Identification of soils and permafrost is based on the evaluation of the airphoto pattern elements. Interpretation of the poorest engineering situations in terraces where soils are fine-textured and detrimentally frozen is based on relatively few photo pattern elements - the local topographic situation being the most important. Under the stereoscope the land form of any terrace appears as a bench or shelf whose topographic position is between that of the flood plain on one side and the upland on the other side. When surface is nearly flat and the terrace scarp is steep, granular soils are suggested. Surface features on frozen terrace vary considerably.

The presence or absence of permafrost on terraces depends on many factors, most of which can be seen directly on airphotos. In the timbered regions, broad flat areas mantled with aspen usually indicate dry and frost-free materials (Fig. 28), while stunted spruce, tamarack or tundra-type vegetation (niggerheads and dwarf birch), usually indicate frozen soil (6). Contrasts in vegetative cover usually indicate contrasts in soil conditions (Fig.

29). As an example, the outward portion of a terrace may be mantled with aspen and may be unfrozen, the

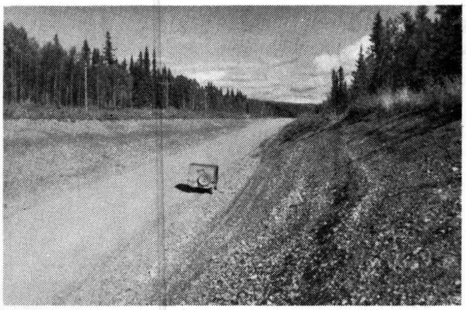

Figure 27. This shows a highway cut made in the outward part of a terrace. The gravels here are unfrozen for considerable depth.

wall (usually consisting of the lower and outward part of a transition zone) may be rather swampy, marked with polygons, and support dwarf birch and niggerheads, thus indicating detrimentally-frozen materials. Low terraces, mantled with spruce-birch forests or spruce-tamarack forests which are otherwise frozen, may be crossed with a series of unfrozen natural levees which are mantled with aspen. The presence of polygons on terraces indicates detrimentally-frozen materials (Fig. 30).

Gullies on frozen terraces rarely exist unless they accompany a thaw and if polygons are present, the gullies will outline the geometric plan of polygon channels which are clearly evident on the airphotos. The local area around such a gully will show extensive thaw

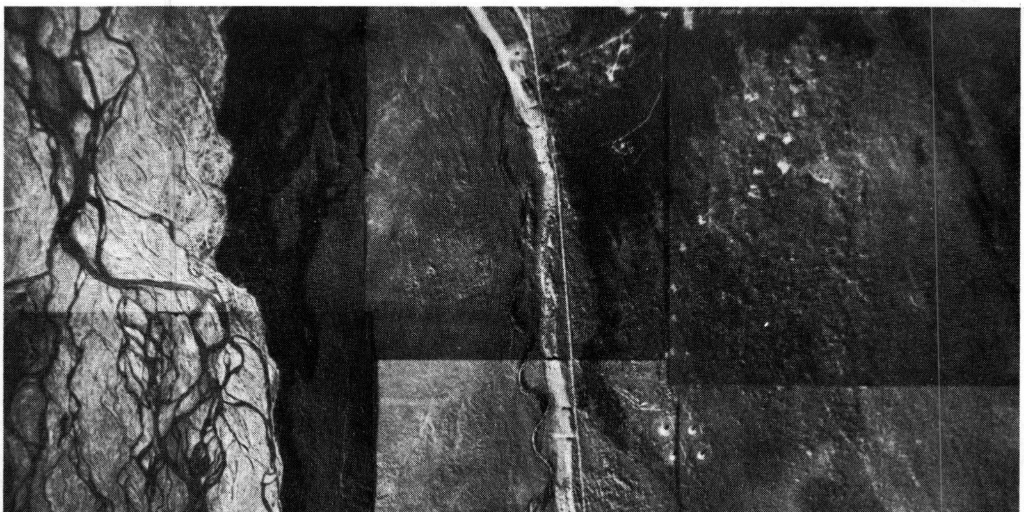

Figure 28. This airphoto contains many of the identifying elements of a good engineering location - that of frost-free granular materials.

middle portion of the terrace may support stunted spruce and tamarack and may be dry frozen, and the inner part of the terrace adjacent to the valley

with considerable sloughing of soils. Generally speaking, gully shape, gradient, and cross section are reliable soil-texture indicators only in unfrozen

Figure 29. This low terrace has been marked to indicate various permafrost-position relationships. The following areas are described:

A grass and low brush, locally depressed, frozen silt at 19 in
B grass and willow, low channel scar, unfrozen sandy silt for 54 in
C - willow covered, slightly higher ridge left by current activity, sand, unfrozen 54 in (auger length)
D - grass-filled abandoned meander, flowing water, sand and unfrozen for 54 in
E - dense willow thicket, moss and peat, frozen silt below 24 in
F - depressed muskeg area, polygons, frozen below 24 in
G - large, sand-filled stream meander scar, dry, unfrozen for at least 54 in
H - poplar grove on gravel, dry, unfrozen
I - polygon area, frozen silt below 18 in
J - current markings - gravel, unfrozen

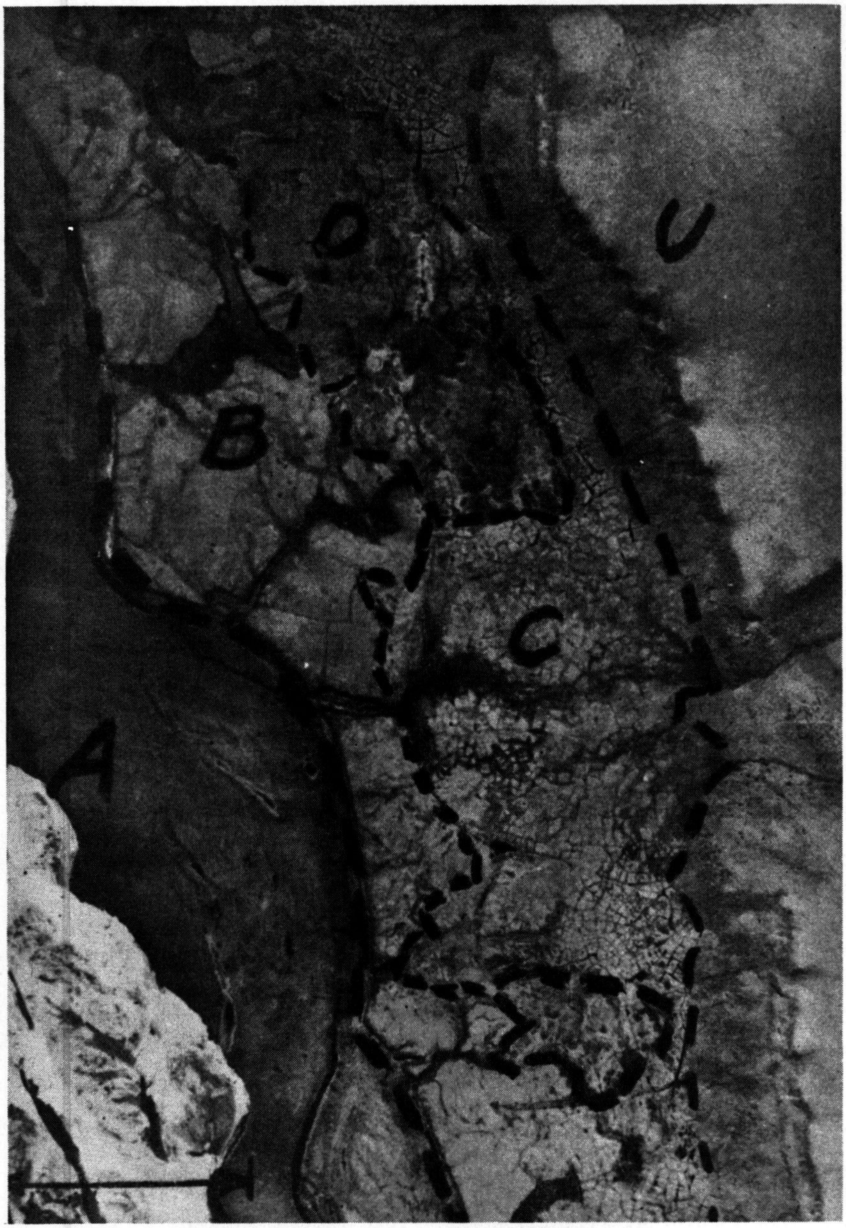

Figure 30. This airphoto shows how some of the permafrost-topographic situations appear in arctic valleys. This area contains:

U - rocky upland, chiefly shale, frozen
A - gravelly flood plain, unfrozen near the stream proper
B, D, C - form a gravel terrace
B - the outward portion, gravel, unfrozen 3 to 5 ft
C - the inner portion, silt covered, frozen below 18 in, polygons of raised-center type, ice wedges
D - depressed area, silt and ice mantle, depressed-center polygons ground ice areas

soil areas. This means that, as far as Alaska is concerned, the gullies occurring in unfrozen gravel terraces are indicative of the terrace materials regardless of where the terrace occurs.

meet this requirement.

It is in alluvial soils that the widest variations occur both in soil textures and permafrost conditions. Texturally, alluvial soils range from gravels to

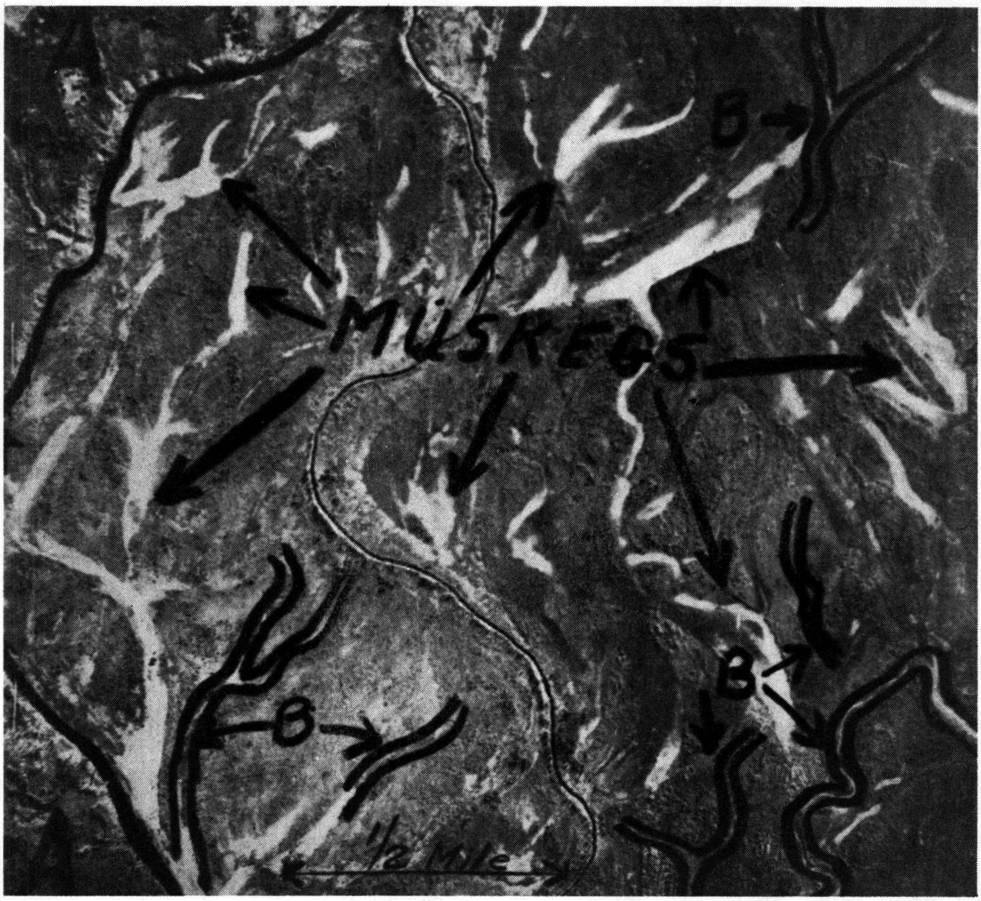

Figure 31. This is an illustration of the backwater area adjacent to the next higher major land form. Muskegs, ground ice, polygons and frozen silts usually occur.

Flood Plains - The flood plains of valleys, more commonly called recent alluvium, contain streams whose course is shifting constantly because of the heavy load of alluvial sediment and because of the relative freedom from obstructions in the flood plain. Both soil textures and permafrost conditions vary widely in alluvial soils. Modern engineering structures often require vast unobstructed areas. Flood plains offer the best topographic situations to

silt (clays are in the minority in the Arctic and Subarctic). As far as engineering conditions are concerned the best sites are the unfrozen well-drained gravels. Perhaps next in order of preference are the frozen gravels, frozen sands, and the frozen silts. Wherever possible all engineering construction should be confined to the more granular soils which in many instances are unfrozen.

In flood plain areas where the topographic position is low and often within a few ft of the local base level of erosion, permafrost is generally sporadic. In areas adjacent to the stream the soils are usually unfrozen because of the warming effect of the circulating water. Inland from the stream proper permafrost varies considerably. It exists in the long and broad channels left by current activity which are filled with silt and peat and contain muskeg-type vegetation. The most detrimental permafrost situations occur in the ponded backwater areas usually situated behind the natural levees or near upland borders (Fig. 31). Such areas occupy the lowest topographic situations in a flood plain or valley.

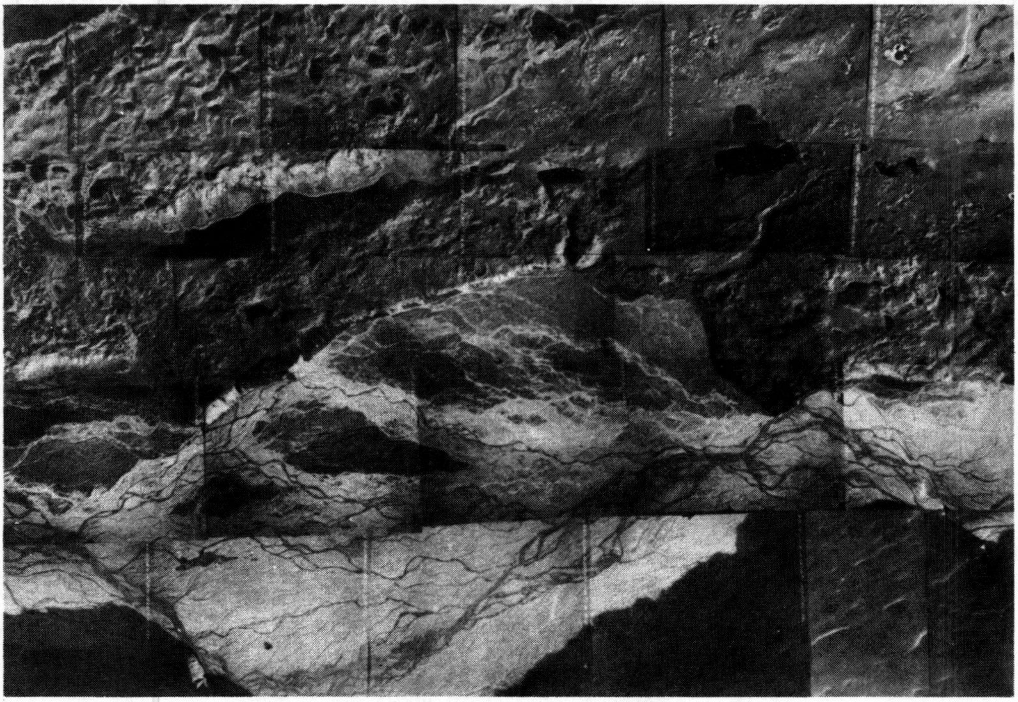

Figure 32. This shows a typical braided stream pattern.

Figure 33. This is a low altitude oblique of the Yukon Valley, known in this area as the ''Yukon Flats'', partly because of its vast size and relatively flat topography.

As far as airphoto interpretation is concerned flood plain deposits are characterized by current markings (Fig. 32) in the form of abandoned stream meanders, natural levees, bars, and ox bows. In the broad stream valley situations, the meanders form great sweeping arcs and cover a considerable portion of the valley floor (Fig. 33).

Stereoscopic study of airphotos will reveal the flood plain to be an interior basin which is low topographically. Topographically, flood plains are flat with the only relief occurring between a stream meander and an adjacent ridge or a natural levee left by current activity. In the narrow and rather confined flood plains, local relief is sometimes greater because of the increased current activity which results in deep scour in some places and deposition in others.

Photo interpretation will usually result in finding no established drainage pattern in recent alluvial or flood-plain areas. The major stream and its tributaries usually provide the only surface drainage. The natural levees are often well drained internally and do not show results of surface drainage. Inland, the flat topograpny and lack of sufficient fall together with some retarding of drainage afforded by natural levees, results in a widespread swampy condition. Polygons will occur on intermediate topographic positions where flooding rarely occurs. These features are clearly discernable on airphotos.

CONCLUSIONS

As a result of nearly five years of study including field work in the airphoto interpretation of soils and permafrost as applied to the Arctic and Subarctic Regions, a number of conclusions may be stated as representative of the progress, significance, and expected use of airphoto interpretative analysis. With regard to the factor of topographic position as it pertains to permafrost and its importance on highway location and construction, the following is offered:

1. In Subarctic Regions topographic position is one of the most important factors in the occurrence of permafrost and, therefore, in its identification both from airphoto interpretation and field practices.

2. In Subarctic Regions, topographic position can be evaluated on the airphotos, thus enabling the interpreter to determine the presence or absence of detrimental permafrost both in regional as well as in local situations.

3. By utilizing airphoto interpretative procedures in Arctic and Subarctic Regions, engineering problems can be anticipated, feasible site locations can be ascertained, and design practice can be determined with a minimum amount of field work, time, delay, and expense.

4. In general, the best location for construction of highways, airfields, and towns and cities in permafrost regions consist of the well-drained granular terraces which can be readily identified and evaluated from contact airphotos.

ACKNOWLEDGMENTS

The authors wish to acknowledge the work of the staff of the Airphoto Laboratory of the Joint Highway Research Project. The work has been an airphoto research project and every phase of soils engineering has contributed to its development. The authors wish to express their appreciation to Professor K. B. Woods, Associate Director, and R. E. Peterson, Photographer, Joint Highway Research Project. The aerial photographs used in this paper were supplied through the courtesy of the United States Air Force.

REFERENCES

1. Frost, Robert E., Hittle, Jean E., and Woods, K. B., "Summary and Statement of Technique Aerial Photographic Reconnaissance Investigation Frozen Soils in the Territory of Alaska", Appendix No. 3, of "Comprehensive Report Investigation of Airfield Construction in Arctic and Subarctic Regions", 2nd Revision, Engineering Experiment Station, Purdue University, May, 1948.
2. Frost, R. E., "Evaluation of Soils and Permafrost Conditions in the Territory of Alaska by Means of Aerial Photographs", To be published by the Engineering Experiment Station, Purdue University, Lafayette, Ind., in 1950.
3. Lobeck, A. K., "Geomorphology", First Ed., McGraw-Hill Book Co., Inc., New York, 1939.
4. Manger, H. J., "Proper Construction Procedures in Permafrost Areas", *Civil Engineering*, Vol.

17, No. 7 and 8, July and August, 1947.

5. Muller, S. W., "Permafrost or Permanently Frozen Ground and Related Engineering Problems", Edwards Bros., Ann Arbor, Mich., 1947.
6. Stoeckeler, E. G., "Identification and Evaluation of Alaskan Vegetation from Airphotos with Reference to Soil, Moisture, and Permafrost Condition", a preliminary paper prepared by the Field Operations Branch, Permafrost Division, US Corps of Engineers, June, 1948.
7. Wilson, K. K. Jr., "The Problems of Permafrost", *Military Engineer*, Vol. 40, No. 270, pp. 162-164, April, 1948.
8. Woods, K. B., Hittle, Jean E., and Frost, R. E., "Use of Aerial Photographs in the Correlation Between Permafrost and Soils", *Military Engineer*, Vol. 40, No. 277, pp. 497-499, Nov., 1948.
9. Woods, K. B., Hittle, J. E. and Frost, R. E., "Correlation Between Permafrost and Soils as Indicated by Aerial Photographs", *Proceedings*, 2nd Int. Conf. on Soils Mechanics and Fdt. Engr., Vol. 1, pp. 321-324, Rotterdam, June, 1948.

SELECTED REFERENCES FOR FURTHER READING

Beskow, G., "Soil Freezing and Frost Heaving with Special Application to Roads and Railroads", Swedish Geol. Soc., 26th Year Book No. 3 - Series C. No. 375, Tech. Inst. Northwestern Univ., Evanston, Ill., 1947.

Black, Robert F., and Barksdale, William L., "Oriented Lakes of Northern Alaska", *Journal of Geology*, Vol. 57, No. 2, pp. 105-118, March, 1949.

Bryan, K., "Study of Permanently Frozen Ground and Intensive Frost-Action", *Military Engineer*, Vol. 40, No. 273, pp. 304-308, July, 1948.

Cressey, George B., "Frozen Ground in Siberia", *Journal of Geology*, Vol. 47, pp. 472-488, 1939.

Emery, K. O., "Topography and Sediments of the Arctic Basin", *Journal of Geology*, Vol. 57, No. 5, Sept., 1949.

"Essentials of Foundation Design in Permafrost", *Public Works*, Vol. 79, No. 2, pp. 28-30, Feb., 1948; No. 3, pp. 27-30, March, 1948.

Frost, R. E., "Prospecting for Engineering Materials", Pan American Conference, March 24, 1949.

Frost, Robert E., "How Can a Highway Department Use Aerial Photographs", *Proceedings*, Mississippi Valley Highway Conference, March, 1949.

Hart, C. A., and Bradbeer, B. F. J., "Use of Aerial Photography", *Surveyor*, Vol. 107, No. 292, pp. 135-136, March 12, 1948.

"Highway Systems of Alaska", *Western Construction News*, Vol. 23, No. 1, pp. 70-71, Jan., 1948.

Hopkins, David M., "Thaw Lakes and Thaw Sinks in the Imuruk Lake Area, Seward Peninsula, Alaska", *Journal of Geology*, Vol. 57, No. 2, March, 1949.

Johnston, R. M., "Speeding-up the Alaska Highway by Aerial-Survey Methods", *Roads and Bridges*, Nov. 1942.

Krynine, D. P., "Soil Investigations in Russia", *Proceedings*, Highway Research Board, Vol. 9, pp. 66-74, 1930.

Miller, James Nevin, "Sky Mappers of Alaska Aerial Survey", *Science News Letter*, Vol. 16, No. 451, pp. 333-335, Nov. 30, 1929.

Pryor, W. T., "Aerial Surveying on the Alaskan Highway 1942", *Public Roads* Vol. 24, No. 11, Jan., Feb., Mar., 1947.

Siddall, K. H., "Planes Blaze Trail for Alaska Highway", *Flying*, Vol. 33, pp. 54-56, Sept., 1943.

Spofford, C. M., "Low Temperatures in Inaccessible Arctic Inflate Construction Costs", *Civil Engineering*, Vol. 19, No. 1, Jan., 1949.

Taber, Stephen, "Perennially Frozen

Ground in Alaska: Its Origin and History", *Bulletin*, Geological Society of America, Vol. 54, 1943.

Taber, Stephen, "Some Problems of Road Construction and Maintenance in Alaska", *Public Roads*, Vol. 23, No. 9, July-Sept., 1943.

Wahrhaftig, Clyde, "The Frost-Moved Rubbles of Jumbo Dome and their Significance in the Pleistocene Chronology of Alaska", *Journal of Geology*, Vol. 51, No. 2, March, 1949.

Williams, G. A., "Winter Maintenance Problems on the Alaska Highway", *Roads and Bridges*, p. 27, Nov., 1943.

Wilson, J. D., "Arctic Construction", *Military Engineer*, Vol. 41, No. 282, pp. 258-260, July-Aug., 1949.