Permafrost*

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Before the advent of the past war and the extensive military construction program in arctic and subarctic regions, the study of permanently frozen soil was limited to a very few persons which included miners, explorers, some natural scientists, and a limited number of engineers. Undoubtedly, those who knew the most about the effects of permanently frozen soils were those who were either mining or were attempting to build some structure on frozen soils—only to discover that they were dealing with a difficult situation. Explorers, geologists, or others engaged in conducting field surveys in gathering information about the northern lands were aware of the existence of this phenomenon; some developed theories as to its origin.

During the last world war new problems were brought to light in arctic and subarctic lands as a result of the application of construction and procedures normally followed in the temperate climates. Time did not permit conducting academic and applied research to establish procedures for combating such a natural phenomenon prior to construction of needed installations. Roads were built and many failed; buildings and other structures were built and some settled severely. Airstrips were constructed and as a result of serious thawing beneath the pavement, great cracks and an otherwise rough surface resulted.

The strategic situation of Alaska with respect to the polar mediterranean and future routes of air travel has given added impetus to the quest for knowledge about the 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 and invaluable data have been made available for analysis.

The term permafrost refers to permanently frozen earth materials which include bedrocks having a temperature below freezing and other materials which have been rendered consolidated by low temperatures and have remained in such a state continuously for a long period of

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FIGURE 1. Soil Polygons. This low altitude oblique photo shows a network of the raised-center type polygons. These polygons are 75 to 100 feet across. Soils are fine-textured and permanently frozen.

FIGURE 2. Cross-Section of an Ice Wedge. Ice wedges occur beneath the outlining perimeter of polygons (channels). They extend many feet below the surface. This wedge is about four feet across at the top. Exposures such as this occur in placer mines, along river banks and coast lines.

time. Permafrost occurs in areas where the mean annual temperature is below freezing; it extends downward many hundreds of feet and only the thin surface layer is subjected to seasonal refreezing and thawing (1, p. 1436). This condition affects nearly all of the arctic and a great portion of the subarctic regions. Permafrost occurs in most of Alaska, in northern Canada, and in about half of the territory of the U.S.S.R. About one-fifth of all the land area of the world is underlain by permafrost (2, p. 1).

Three types of frozen soils exist in the arctic and subarctic: the upper soils, the active layers, which represent materials which go through annual cycles of freezing and thawing; the subsoils, dry frozen, in which the soil mass contains no ice but is rendered consolidated merely because the temperature is below freezing; and the subsoils, detrimentally frozen, in which the material contains a large percentage of ice in the forms of lenses, wedges, veins, or large masses of ground ice.

The active layer is of varying thickness; in the north, or arctic regions, it is relatively thin and is a matter of 12 to 20 inches while in the southern part of permafrost regions this layer is thicker and often more than 36 inches thick. In any region, however, either in arctic or subarctic, the active layer (depth of seasonal thaw) depends on such factors as soil texture, topographic situation, vegetative cover (which provides natural insulation from heat), and exposure to heat. Detrimentally frozen materials exist in a variety of forms which include: fine textured soils which contain a large percentage of ice in their mass in the form of crystals, small lenses, or small wedges; soil masses which have been so arranged by segregation of ice and soils that they form polygonal blocks of varying sizes and types; materials situated low topographically in which large masses of ground ice form an integral part of the mass; and large masses of buried ground ice.

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 configurations on the surface of the earth in permanently frozen regions. Presumably the polygon pattern is the result of the stress adjustment within the upper few feet of the mass of frozen earth material resulting from seasonal expansion and contraction which are caused by the raising and lowering of the temperatures (3, pp. 205-212).

The frozen surface breaks into a polygon pattern and during the summer the open cracks are filled with meltwater which freezes and fills the crack with ice. Hence the polygons are outlined by a continuous ice wedge which extends downward many feet. Some of the wedges are four to five feet across at the top. Soil polygons are a variety of sizes and shapes and situations but the most important two types are as follows: (a) those with depressed centers or pans which are inclosed by raised perimeters or dykes; and (b) those with raised centers and depressed perimeters, or channels. Polygons of both types vary from 20 to 200 feet across the polygon and the number of sides varies considerably with five-and-six-sided shapes more prevalent. Soil polygons are confined largely to unconsolidated materials (largely water deposited) which have been rendered solid by freezing. They do not occur as an integral part of bedrock areas.

A delicate balance exists between permafrost, soil, and the protective insulation. Once the protective insulation has been destroyed or even slightly disturbed the sun's heat penetrates and a thaw results. To illustrate the delicacy of this balance the constant use of a game trail by rabbits is sufficient to produce a thaw. One field investigation of such a trail showed that the soils in the trail had thawed to 36 inches while three feet on either side of the trail (in the undisturbed area) the normal thaw was 18 inches. The root systems of the trees cannot penetrate the frozen soils and the difference in depth of thaw had affected the root system and the trees were pulled inward toward the thaw area.

All soils are not frozen detrimentally; those which are frozen, vary in the degree and type of permafrost. Those soils which are well-drained internally and are elevated topographically are rarely frozen. Gravels, sands, and some sand and gravel mixtures may be dry frozen. Fine-textured soils such as silts and silty clays are detrimentally frozen. In freezing, these soils permit the accumulation of ice crystals. This is accompanied by a large volume change. It is the latter soils which create the problems in permafrost areas. When such soils thaw because of the removal of the insulating moss, or the heat of a building, or the construction of a runway, the soil-ice mixture decreases in volume and the supporting power is lost.

Construction in permanently frozen soils is difficult and costly. Ordinary construction procedures as followed elsewhere cannot be followed in arctic regions because of the serious thaw which results once the insulation provided by the vegetation has been destroyed (4). Buildings and runways constructed on fine-textured soils which are frozen cause severe thaws to develop resulting in severe settlement. Large cracks develop in runways and highways. Concrete floors in heated garages have been known to settle as much as three feet. Consider, for a moment, the damage which can result to a large hanger constructed on frozen soils.

FIGURE 3. Ice Wedge in a Cold Storage Cave. This wedge extends downward at least 20 feet below the surface. Note the horizontal sills of ice. The frost accumulation on the upper part of the walls and on the ceiling is frozen vapor from the workmen's breath.

The Corps of Engineers through the St. Paul district office is conducting considerable research in the Territory (5). A large research area has been established near Fairbanks for the purpose of solving the problems of arctic construction to insure successful performance of engineering structures. Here, various construction procedures are being tried. New and varied insulation materials are used under model buildings and under runway test sections. Thermocouples have been installed in the subsoils making it possible to obtain data pertinent to soil temperature and rate of thaw during the various seasons.

The Corps of Engineers has contracted with the Engineering Experiment Station of Purdue University to develop a method of interpreting engineering soils and permafrost conditions from aerial photographs (6). The object of the study is to develop a method of interpreting soils and permafrost conditions in arctic and subarctic regions for engineering use from aerial photographs; to set forth the techniques and procedures involved in manual form for use by those engaged in planning and development in arctic and subarctic regions; and to develop an engineering soils map of the Territory which will serve as a guide in airphoto-soil studies related to planning and development.

The permafrost study which is being conducted by the Joint Highway Research Project has been in progress nearly six years (7). During the past five summers the university has sent members of its staff to Alaska to study the soil patterns and engineering problems in the field. Aerial photographs for the project were flown by the 46th (now 72nd) Reconnaissance Squadron. Both single lens mapping type photography (1:10,000) and the tri-metragon (1:20,000) photography were obtained.

Field studies have been directed toward obtaining information in each of the major soil areas in the Territory. Such data as vegetation, topography, geology, drainage, depth to permafrost, soil texture, and physiography are obtained by field inspection. Field conditions are compared to conditions indicated on aerial photographs. Transportation to and from areas was either by military aircraft or by "bush" facilities. Field parties usually spent from two to ten days in a particular soil area. Most of the areas were covered by walking and sampling was performed with hand tools. When sampling was accomplished in the vicinity of military bases a weasel or a tractor provided transportation. When facilities were available dynamite was used to obtain soil samples and to permit study of subsurface conditions. In areas where placer mining operations were in progress, the washed exposures made it possible to study ice and frozen soil conditions. A considerable por-

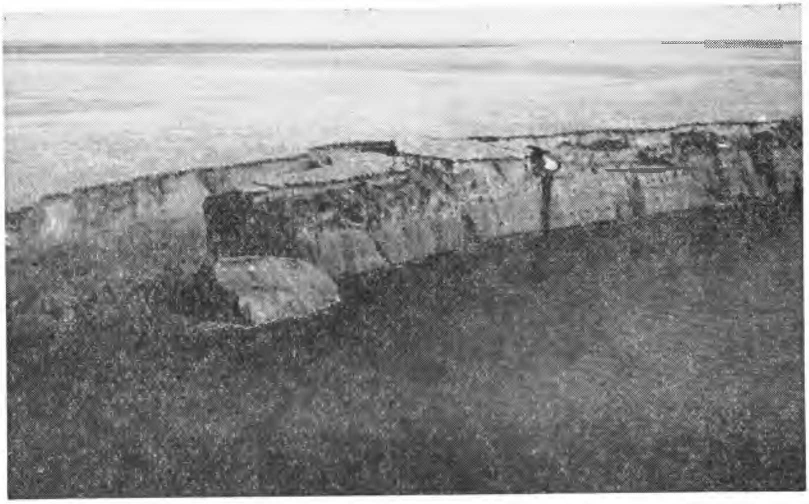

FIGURE 4. Massive Ground Ice. Many of the south flowing streams have cut deeply into the Arctic Coastal Plain exposing thick beds of ice. In this instance the ice is 15 to 20 feet thick. Note the thin mat of vegetation on the surface (one foot of moss and grass). Under-cutting by the river causes large pieces to break off.

FIGURE 5. Damage to an Arctic Airstrip. This runway was constructed by blading off the moss and other protecture insulation which resulted in severe thaw. The polygon blocks are 25 to 40 feet across; the channels are 5 to 8 feet wide and 3 to 4 feet deep.

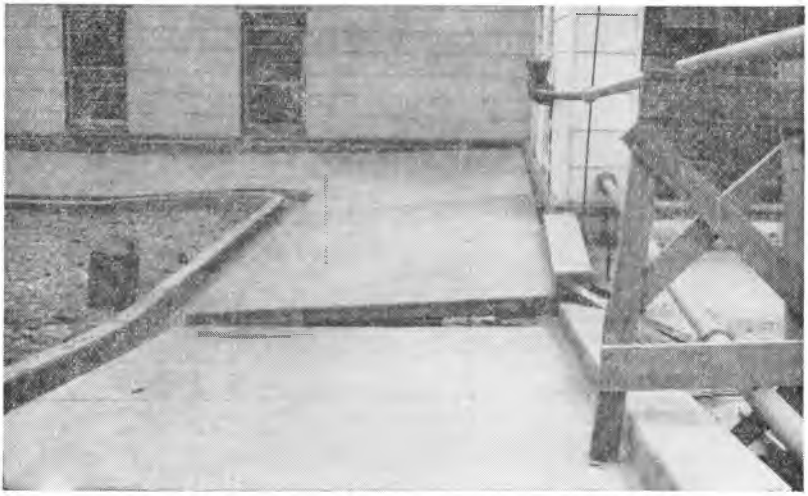

FIGURE 6. Permafrost Damage. This shows severe damage to a sidewalk due in part to differential settlement of the building caused by thawing subsoils.

FIGURE 7. Severe settlement of a house resulting from thawing subsoils.

tion of the Territory was studied by reconnaissance flights performed both by the military and the bush facilities. By selecting typical topographic positions for making the soil borings it was possible to correlate the soil and permafrost conditions with the respective airphoto patterns in a short period of time.

In a relatively undeveloped region, such as the Territory of Alaska aerial photographs can be used to a great advantage for military or civilian use in locating airports, highways, or other installations. When it is known that some engineering structure is to be built in a particular region, a general engineering soils map can be produced in a relatively short time which will show the good, poor, and intermediate soil areas evaluated on the basis of anticipated performance of engineering structures. Thus, the poor soil areas can be eliminated and the field investigation can be concentrated on those areas best suited to construction.

Although the complete details of permafrost patterns have not been worked out, sufficient data are available at present to indicate that the extremely poor and the very good areas can be identified by means of aerial photographs. Extensive field work with airphotos in hand is showing that areas of detrimental and nondetrimental permafrost can be identified from the aerial photographs and that soil textures can be predicted.

With the completion of the project it is believed that most of the major soil patterns of Alaska will have been worked out in detail. With this phase of the program successfully completed, it will be possible to develop engineering information on soil textures and permafrost from aerial photographs alone, not only for the Territory of Alaska but in other regions throughout the world where arctic and subarctic conditions prevail.

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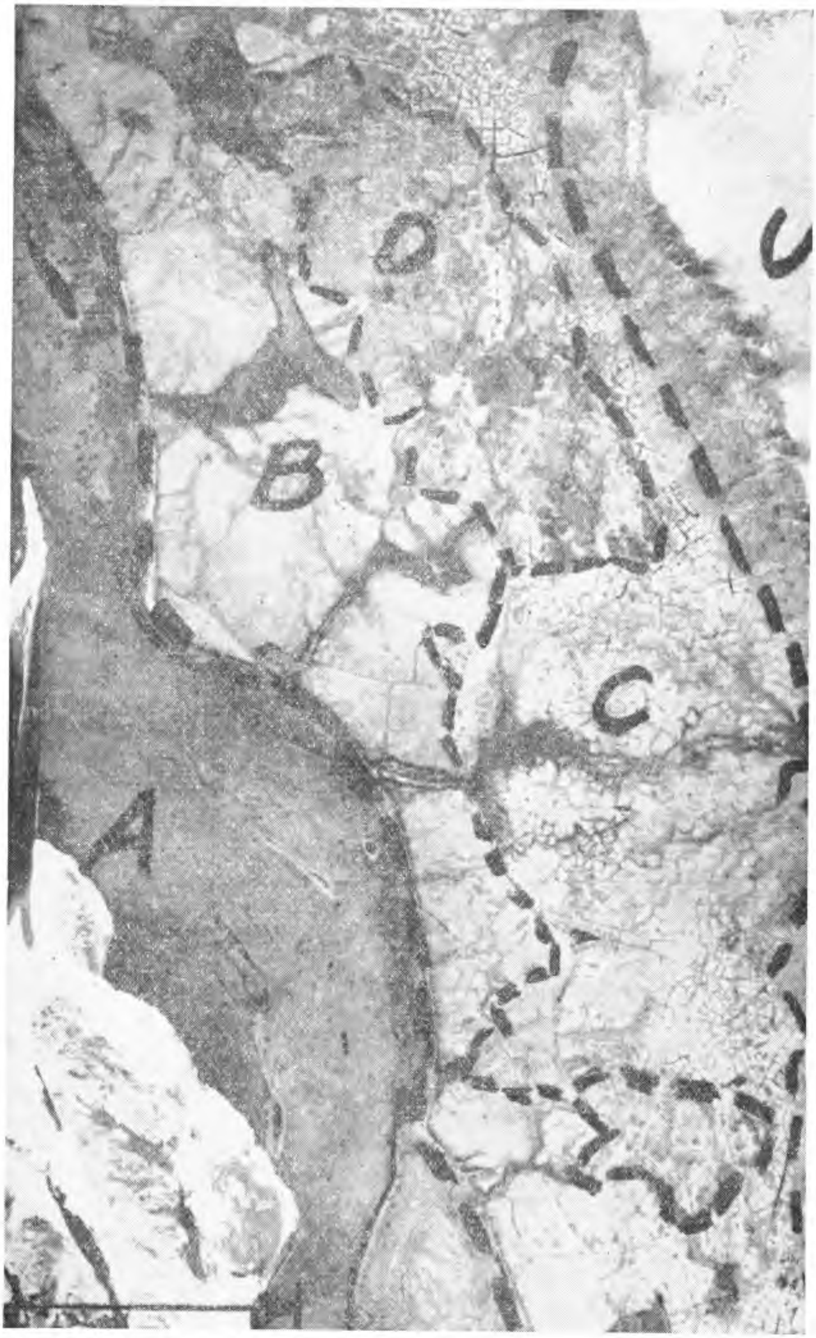

FIGURE 8. Soil-Permafrost Determination from Aerial Photographs. Area U is the rocky shale upland. Temperature in the rock is below freezing. Area A is the gravelly flood plain of the stream. Areas B, C, and D are parts of a low terrace between the flood plain and the upland. Area B is frozen gravel, area C is frozen gravel with a deep peat and silt overburden (note the polygons), and area D is a large depression which is very swampy and which contains considerable ground ice.

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