MARCH 3, 1849

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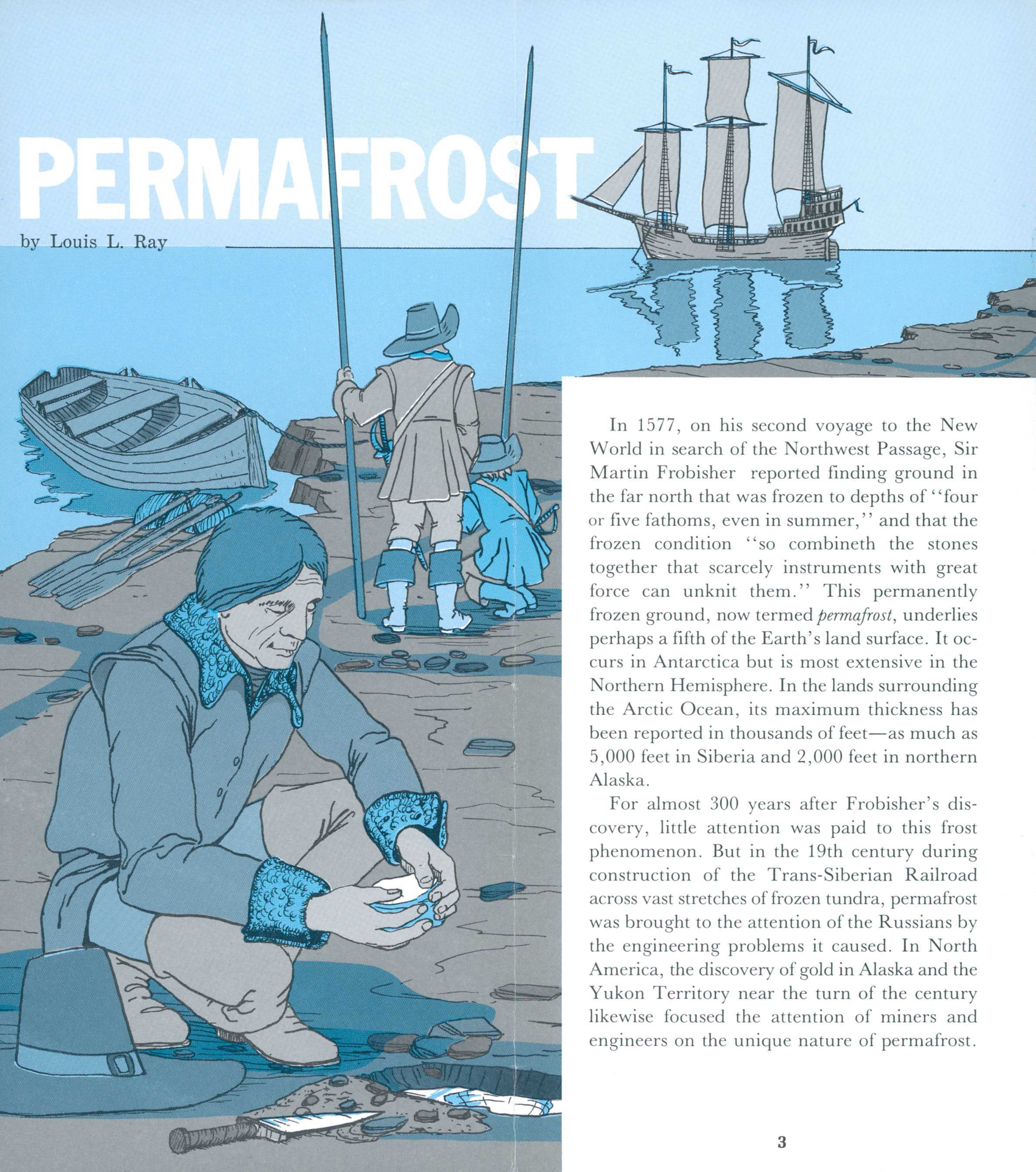
Permafrost

PERMAFROST

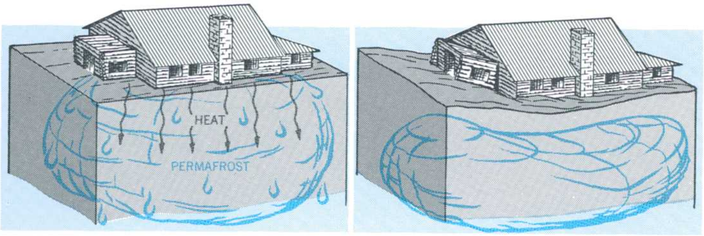
by Louis L. Ray



In 1577, on his second voyage to the New World in search of the Northwest Passage, Sir Martin Frobisher reported finding ground in the far north that was frozen to depths of ''four or five fathoms, even in summer,'' and that the frozen condition ''so combineth the stones together that scarcely instruments with great force can unknit them.'' This permanently frozen ground, now termed *permafrost*, underlies perhaps a fifth of the Earth's land surface. It occurs in Antarctica but is most extensive in the Northern Hemisphere. In the lands surrounding the Arctic Ocean, its maximum thickness has been reported in thousands of feet—as much as 5,000 feet in Siberia and 2,000 feet in northern Alaska.

For almost 300 years after Frobisher's discovery, little attention was paid to this frost phenomenon. But in the 19th century during construction of the Trans-Siberian Railroad across vast stretches of frozen tundra, permafrost was brought to the attention of the Russians by the engineering problems it caused. In North America, the discovery of gold in Alaska and the Yukon Territory near the turn of the century likewise focused the attention of miners and engineers on the unique nature of permafrost.

Building located south of Fairbanks, Alaska, is subsiding because of thawing permafrost.

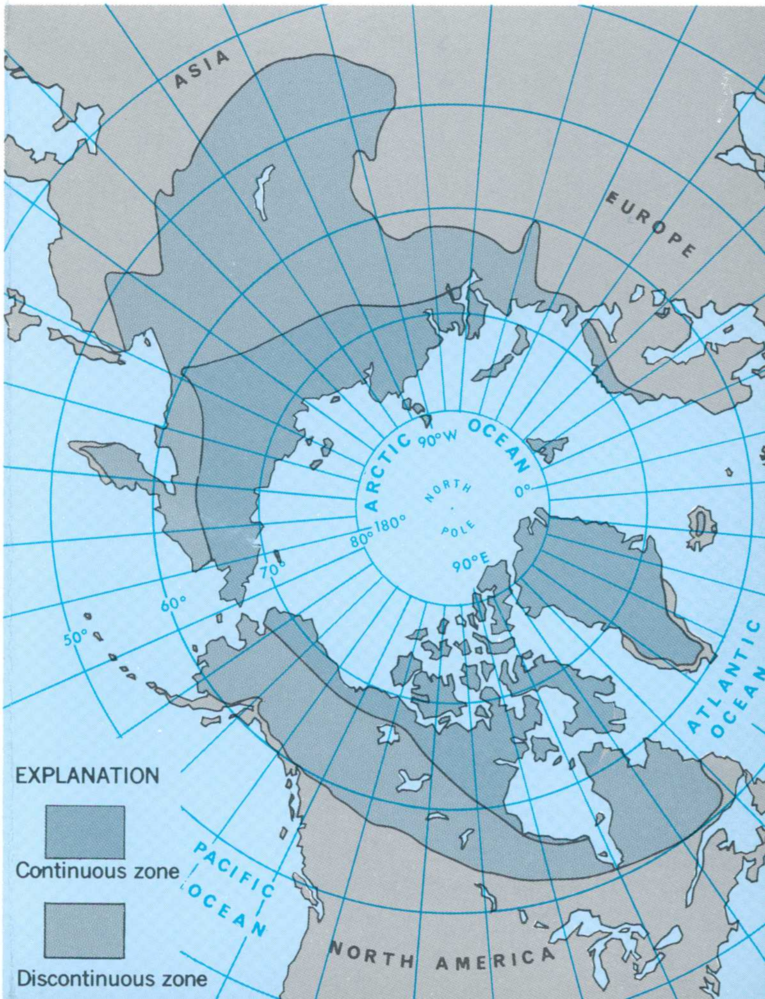


Heat used to warm the interior of a structure thaws the underlying permafrost and leads to the subsidence of the ground and the eventual collapse of the building.

Frozen ground poses few engineering problems if it is not disturbed. But changes in the surface environment—such as the clearing of vegetation, the building of roads and other construction, and the draining of lakes—lead to thawing of the permafrost. This in turn produces unstable ground susceptible to soil creep and landslides, slumping and subsidence, icings, and severe frost heaving. The many environmental problems stemming from the rapid expansion of human activities during and following World War II in areas underlain by frozen ground have demonstrated that a thorough understanding of the nature of permafrost is of prime importance for wise land-use planning. Not only is it an economic requirement that the least possible disturbance be made of the frozen ground, but it is a practical necessity if the land-use potential of the vast areas underlain by the frozen ground is to be preserved.

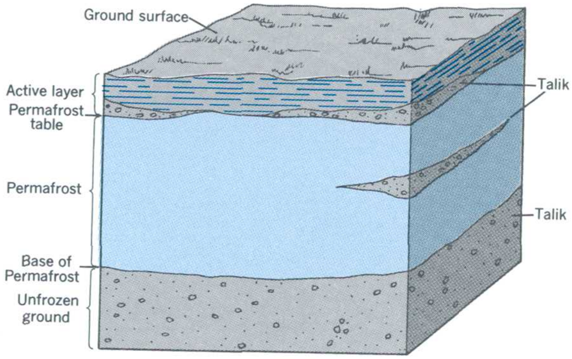
In the Northern Hemisphere, permafrost decreases in thickness progressively from north to south. Two major zones are distinguished: a northern zone in which perma-

Distribution of permafrost in the Northern Hemisphere.



frost forms a continuous layer at shallow depths below the ground surface and, to the south, a discontinuous zone in which there are scattered permafrost–free areas. Land underlain by continuous permafrost almost completely circumscribes the Arctic Ocean. A less clearly defined zone of so–called sporadic permafrost occurs along the southern margin of the discontinuous zone where widespread permafrost–free ground contains scattered small isolated masses of the frozen ground.

The term *permafrost,* a contraction of permanently frozen ground, was proposed in 1943 by Siemon W. Muller of the U.S. Geological Survey, to define a thickness of soil or other superficial deposit, or even of bedrock, beneath the surface of the Earth in which a temperature below freezing has existed continuously for 2 or more years. When the average annual air temperature is low enough to maintain a continuous average surface temperature below 0°C, the depth of winter freezing of the ground exceeds the depth of summer thawing, and a layer of frozen ground is developed. Downward penetration of the cold will continue until it is balanced by the heat flowing upward from the Earth's interior. In this manner, permafrost hundreds of feet thick can form over a period of several thousand years. Distribution and thickness of permafrost depends, however, on many factors that control surface temperatures and cold penetration. Some of these factors are geographic position and exposure, character of seasonal and annual cloudiness, precipitation, vegetation, drainage, and the properties of the earth materials that underlie the ground surface.



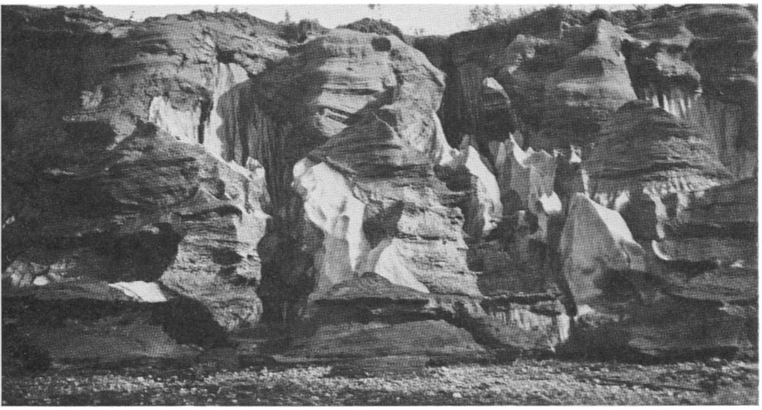
Typical section of permafrost terrain.

Although the surface and near surface layers may thaw quickly when summer thawing exceeds winter freezing, it would require long periods of time, estimated to be as high as tens of thousands of years, for thawing air temperatures to penetrate and melt the thickest known permafrost. Thus, the distribution and variations of subfreezing temperatures recorded at depth in the thicker permafrost layers reflect the ancient cold temperatures of the past that are commonly assigned to the Pleistocene Epoch, the so–called Great Ice Age, which began about 3 million years ago.

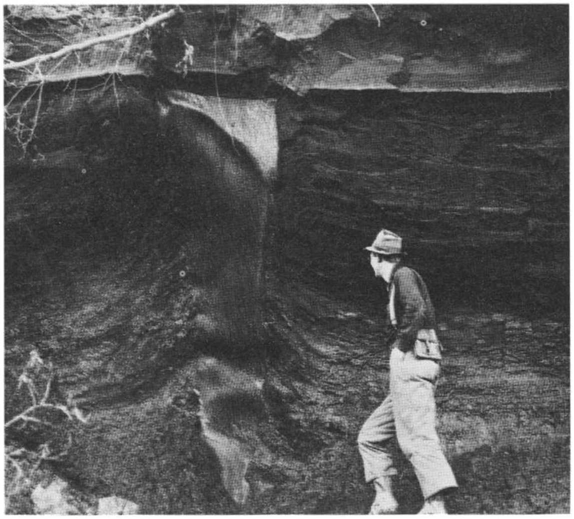
The ground above the permafrost that thaws in summer and refreezes in winter is known as the *active layer*. Its thickness, like that of the underlying permafrost, depends on the many factors that influence the flow of heat into and out from the Earth's surface.

The upper surface of the permafrost layer is known as the *permafrost table*. When winter freezing does not penetrate to the permafrost table, an unfrozen layer remains between the base of the frozen active layer and the permafrost table. This unfrozen material, as well as the rare isolated masses of unfrozen ground present within the permafrost itself, are called *talik,* a term adopted from the Russian. The talik, like the ground ice, is a major consideration in any appraisal of the permafrost environment because unfrozen ground water, commonly concentrated within the talik, may be highly mineralized and under hydrostatic pressure. Frequently the water bursts forth under pressure to the ground surface where a point of issue has been opened either by natural or artificial means. On reaching the surface the water may freeze, producing a thick and perhaps widespread ice sheet or an icemound. Such *icings* may pose serious problems in areas of concentrated human activity.

In the upper part of the permafrost layer, large masses of ground ice of various shapes and origins may be present. In places in Alaska it is estimated that more than half the volume of the upper 10 feet or so of the permafrost layer consists of ice. The ice may occur as coatings, as individual grains, as veinlets and lenses, and as ice wedges that extend downward from the permafrost table.



Ground ice in central Alaska.



Ice wedge extending below the permafrost table.

The presence of ice–rich permafrost is readily apparent whenever the insulating effect of vegetation is modified or destroyed. Such changes trigger the thawing of the underlying permafrost and ground ice so that distinct changes in the landscape are produced. Especially important from the standpoint of human activities are the ground subsidence that results from thawing of the ground ice and the *solifluction* or gravity controlled mass movement of thawed, water–saturated surficial sediments that produce a variety of land forms.

Artificial stripping of the insulating vegetation mat from the active layer or the removal or destruction of the active layer while preparing the land for agricultural use or construction projects such as roads, railroads, airfields, and buildings, disturbs

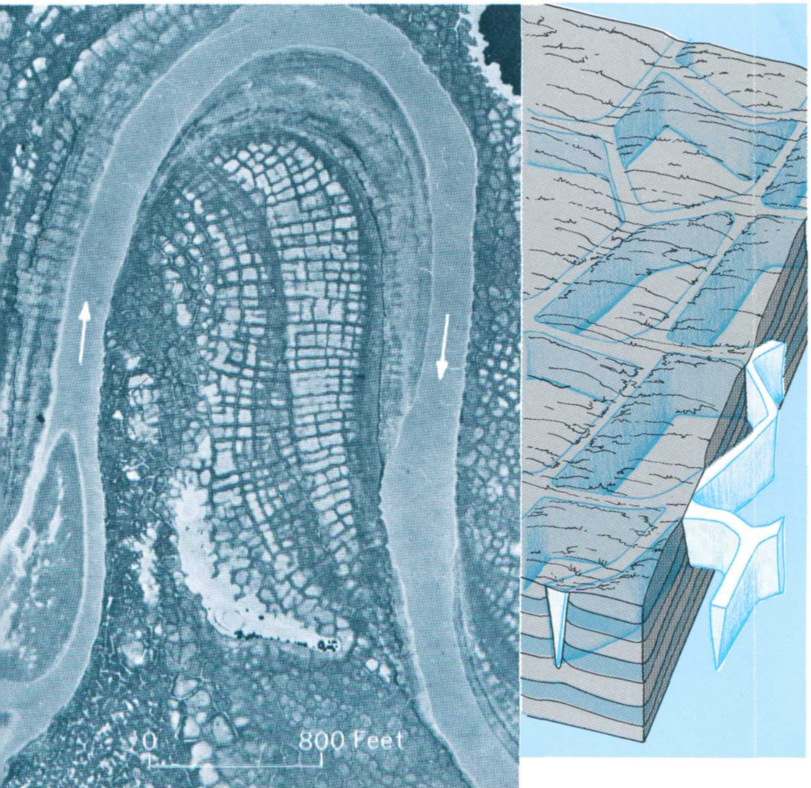
Ground subsidence along the abandoned Copper River Railroad.

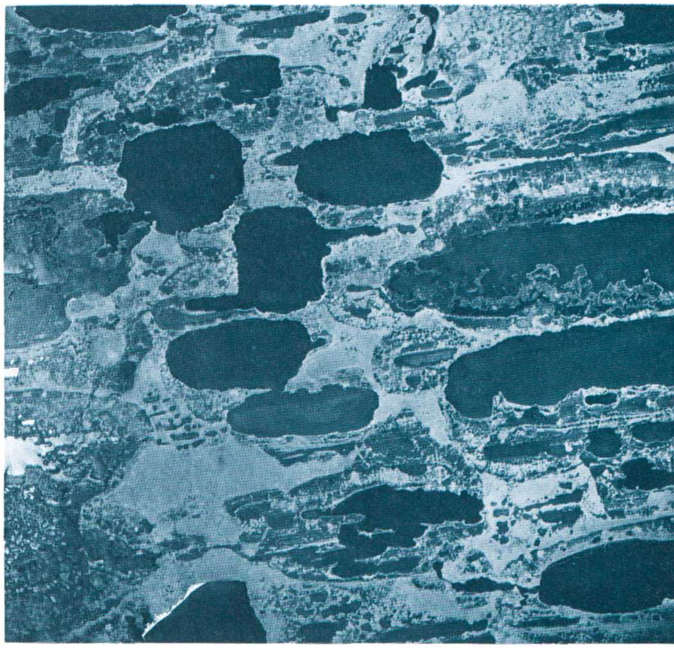
the delicate thermal balance. This may, unless preventive measures are taken, result in thawing of the ice masses in the underlying permafrost with consequent irregular subsidence of the land surface. Even the casual crossing of tundra areas on foot or a single traverse by a wheeled vehicle may so upset the thermal balance through slight changes in the insulating properties of the vegetation mat that thawing of the underlying ground may result. Once thawing starts, its control may be difficult or even impossible.

Experience has shown that ice–rich permafrost is generally present where the active layer is relatively thin, the drainage poor, and the frozen materials are fine–grained sediments. These conditions are well developed on the Arctic Slope of Alaska where ground ice is commonly present as a honeycomblike polygonal network of vertical ice wedges that extends downward from the base of the active layer. Where the thermal balance has been so modified that thawing is initiated, the normal thickness of the active layer is increased, and the surface of the permafrost table is depressed below the upper part of the ground ice. Consequent melting of the tops of the ice wedges produces subsidence in the overlying ground that is reflected on the land surface by a network of shallow to deep interconnected furrows that form a polygonal pattern.

Where conditions are such that no polygonal ground has developed, the presence of the underlying network of polygonal ice wedges may be reflected in the character of the stream courses. The concentrated heat in the water flowing across terrain underlain by the ice–wedge polygons thaws them to produce a series of subsidence pools along the stream course at ice-wedge intersections. When viewed from the air, such stream courses with their series of pools

Polygonal ground on Arctic Slope of Alaska (photo). Ground ice commonly is present as a honeycomblike network of vertical ice wedges that extend downward from the base of the thin active layer (diagram).

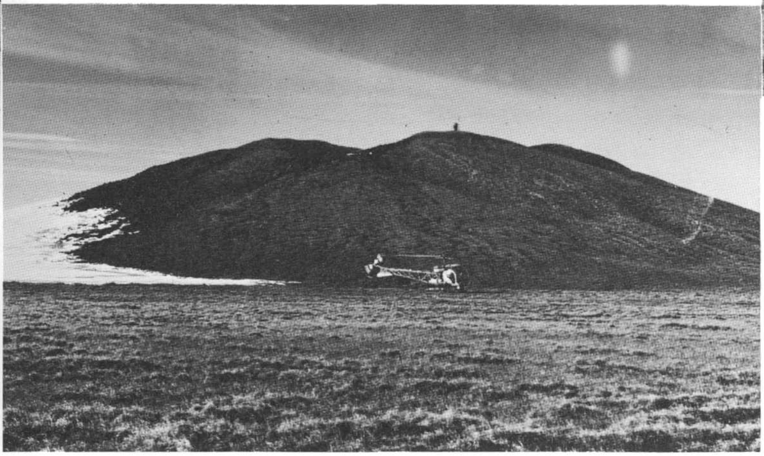




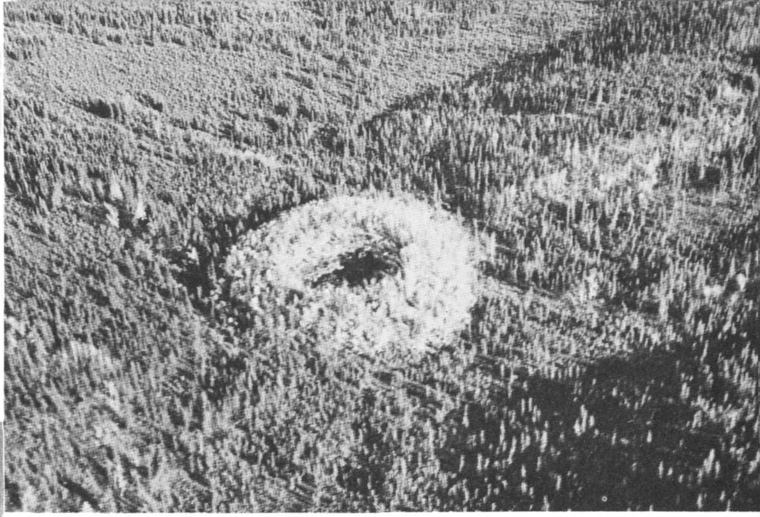
Oriented lakes on the Arctic Slope of Alaska.

give the impression of a string of beads, hence the name *beaded drainage.*

When masses of ground ice thaw, subsidence may produce isolated depressions, *thermokarst pits,* or basins occupied by *thaw lakes.* Once initiated, thawing and consequent calving along the thaw lake shores increase the lake area. If wind directions are relatively constant in the summer season, thawing may be concentrated in directions controlled by the wind and wave action along the lake shores, producing features such as the well–known "oriented lakes" of Alaska and Russia.


Pingo, with central crater, rises above valley floor on Arctic Slope of Alaska.

Curious, rounded, ice–cored hills called *pingos* are present both in areas of tundra and boreal forest. Rising above the surrounding landscape of unconsolidated fine–grained sediments to heights as much as several hundred feet, the largest pingos may be as much as several thousand feet in diameter. Pingos are relatively ephemeral features of the landscape, believed to result from concentrations in the talik of unfrozen water under hydraulic pressure that bows up the overlying sediments and freezes. The summits of pingos may contain crater–like lakes fed by springs of freshwater that may flow throughout the year.


Pingo in boreal forest of central Alaska.

On the tundra of the Arctic Slope of Alaska and Canada, pingos are generally present in old lake basins that may be partly filled with swamp deposits (muskeg). In the forested areas to the south, pingos form in areas of valley–bottom alluvium adjacent to the base of steeply sloping, south–facing valley walls. Pingos in areas of boreal forests may commonly be recognized by the vegetation that grows profusely on the well–drained soils of their steeply sloping sides.

Solifluction, the slow mass movement of surficial, unconsolidated, water–saturated sediments downslope, is another commonplace phenomenon in regions underlain by permafrost. Commonly, during the summer season of thawing, the surficial sediments become supersaturated because melt waters are unable to percolate into the impervious permafrost below. At the interface between the frozen and unfrozen materials, these melt waters provide a lubricant to the frozen surface over which the mobile unfrozen mass can readily slide by gravity. Surficial materials may move as sheets or lobes over fronts ranging from a few to several hundreds of feet wide. Where there is a well–developed vegetation mat above the fluidlike mass of supersaturated debris, a *solifluction* *sheet* may move downward as a well-defined sheet, or lobe, or as a series of partially overriding folds. At times the vegetation mat may rupture, and the slurry of water-saturated sediments may produce sudden destructive mud flows. Because solifluction can be triggered on slopes as low as 3°, and movement may be increased by disturbance of the normal ground conditions, it is a serious hazard at construction sites, especially those underlain by permafrost at shallow depth.

Frost heaving, commonplace in all environments where there is marked freezing and thawing of the ground, results from an upward or expanding force occasioned by swelling of the ground during freezing. The effects of this process are magnified in the colder climates where the land is underlain by permafrost, although in most areas there is generally little evidence of frost heaving under natural conditions. If surface conditions are disturbed, however, by construction or other activities that permit an increase in summer thawing and a consequent thickening of the active layer to which frost heaving is confined, it expectedly becomes a serious problem. It is necessary, therefore, to preserve the insulating value of the ground surface as much as possible, so that the thickness of the active layer will be retained at a minimum so that the effects of frost heaving may also be kept at a minimum. This can be accomplished by not removing the vegetation mat and by increasing the surficial insulation of the ground at the construction site, generally by the addition of a coarse gravel fill.

It is readily apparent that man's uninhibited and careless use of land underlain by permafrost can produce serious problems today and, in some cases, can cause lasting detrimental effects. Likewise, natural changes such as variations in climate, erosion by shifting streams, increased precipitation, unusually severe storms, earthquakes, landslides, forest fires, and many other natural phenomena can also modify the environment, producing similar adverse effects. Each modification, whether naturally or artificially induced, must be carefully evaluated, and if necessary controlled in order to minimize the detrimental effects if the vast regions underlain by permafrost are to remain continuously serviceable to man.

Suggested Reading

Ferrians, O. J., Jr., Kachadoorian, R., and Greene, G. W., 1969, Permafrost and related engineering problems in Alaska: U.S. Geol. Survey Prof. Paper 678, 37 p.

Lachenbruch, A. H., 1968, Permafrost, *in* Fairbridge, R. W., ed., The Encyclopedia of Geomorphology: New York, Reinhold Publishing Corp., p. 833–839.

Muller, S. W., 1943, Permafrost or permanently frozen ground and related engineering problems: U.S. Army, Office of Chief of Engineers, Mil. Intelligence Div. Strategic Eng. Study 62, 231 p.; reprinted with corrections, 1945; also, 1947, Ann Arbor, Mich., Edwards Bros.

Ray, L. L., 1956, Perennially frozen ground, an environmental factor in Alaska: 17th Internat. Geog. Cong. and 8th Gen. Assembly, Washington, D.C., 1952, Proc., p. 260–264.

★ U.S. GOVERNMENT PRINTING OFFICE: 1993-356-619