Permafrost — and its Affects on Human Activities in Arctic and Subarctic Regions *

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Abstract: In polar areas, normal techniques must often be modified at additional costs in construction and maintenance of railroads, buildings, water and sewer lines, oil and gas pipelines, dams, roads, bridges, and airfields because of permafrost. But despite problems unique to the cold regions, development of the permafrost areas will continue at an ever-increasing rate. Humans have already learned to cope with many of the problems, and future improvements in scientific and engineering approaches, plus careful geological site selection and further study of the permafrost problem, will allow successful expansion into polar areas.

Introduction

The long, cold winters and short, cool summers in the polar regions result in the formation of a layer of frozen ground that does not completely thaw during the year. This perennially frozen ground, or permafrost, affects many human activities in the Arctic as well as the Subarctic and causes problems which are not experienced elsewhere. One of the major problems concerns the construction of oil and gas pipelines in Alaska, Canada, and the Soviet Union.

Permafrost is natural-occurring material that has a temperature below 0°C continuously for 2 or more years. This layer of frozen ground is designated exclusively on the basis of temperature. Part or all of its moisture may be unfrozen, depending upon the chemical composition of the water or depression of the freezing point by capillary forces. For example, permafrost with saline soil moisture, such as occurs under the ocean immediately off the Arctic shores, may be colder than 0°C for several years but would contain no ice and thus would not be firmly cemented. Most permafrost is consolidated by ice; permafrost with no water, and thus no ice, is termed dry permafrost. The upper surface of permafrost is called the permafrost table. In permafrost areas the surficial layer of ground that freezes in the winter (seasonally frozen ground) and thaws in summer is called the active layer. The thickness of the active layer under most circumstances depends mainly on the moisture content; it varies from 10 to 20 cm in thickness in wet organic sediments, to 2 or 3 m in well-drained gravels. Permafrost is a widespread phenomenon in the northern part of the Northern Hemisphere; it is estimated to underlie 20% of the land surface of the world (Fig 1).

For the last 100 years scientist and engineers in the Soviet Union have been actively studying permafrost and applying results to development of the northern country. Similarly, prospectors and explorers have been aware of permafrost in the northern part of North America for many years, but it was not until World War II and thereafter that systematic studies of perennially frozen ground were undertaken by scientists and engineers in the United States and Canada.

Permafrost profoundly affects human activities in the Arctic and Subarctic, and requires that conventional engineering techniques be modified at additional costs. Agriculture, mining, water supply, sewage disposal, and construction are seriously affected by subsidence of the
Fig 1 Permafrost in the northern hemisphere (compiled by Troy L. Péwé, 1978)

Fig 2 Hypothetical thermal profile showing temperature and thickness of permafrost in central Alaska. (From T.L. Péwé, Geomorphic processes in polar deserts. In: Smiley and Zumberge, eds.: Polar Deserts and Modern Man, University of Arizona Press 1974.)

Sources: Alaska, land area (Péwé, unpubl. data 1978), subsea, (Hopkins, et. al., 1977); Canada, land area (R.J.E. Brown, 1978), subsea (Hunter, et. al., 1976); Greenland (Weidick, 1968; O. Olesen, personal commun., 1976); Iceland (Thorleifur Einarsen, personal commun., 1966; Piresnitz and Schunke, 1978); Norway (B.J. Andersen, personal commun., 1966); H. Svensson (personal commun., 1966); Sweden (Rapp and Annersten, 1969); Svalbard (Liestol, 1977); Mongolia (Gravis, et. al., 1978); USSR, land area (Karpov and Puzanov, 1970); subsea, (M. Vlgdorchik, personal commun, 1978); China (Institute of Glaciology, Cryopedology and Desert Research, Academy of Sciences, Lan-Chou, 1977).

Origin and Thermal Regime

In areas where the mean annual air temperature drops below 0°C, some of the ground frozen in the winter will not be completely thawed in the summer; therefore, a layer of permafrost will form and continue to grow downward in small increments from the seasonally frozen ground. The permafrost layer will become thicker each winter, and the thickness is controlled by the thermal balance achieved between the heat flowing upward from the Earth’s interior and that flowing outward into the atmosphere—a balance which depends upon the mean annual air temperature and the geothermal gradient. The average geothermal gradient is about 1°C increase in the temperature of the Earth for every 30-60 m of depth. Eventually the thickening permafrost layer reaches an equilibrium depth at which over several years the same amount of geothermal heat reaching the permafrost is lost into the atmosphere. A state of equilibrium takes thousands of years to be reached where permafrost is hundreds of meters thick.

An example of the change of temperature of frozen ground with depth and the upper and lower limit of permafrost is illustrated in Fig 2. The annual fluctuation of air temperature from winter to summer is reflected in a subdued manner in the upper few meters of the ground. This fluctuation diminishes rapidly with depth; it is only a few degrees at 8 m and is barely detectable at 15 m. The level at which the fluctuations are hardly detectable (10–15 m) is termed the level of zero amplitude. If the permafrost is in thermal equilibrium, the temperature at the level of zero amplitude is generally regarded as the minimum temperature of the permafrost. Below this depth the temperature increases steadily under the influence of heat from the Earth’s interior. The temperature of permafrost