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BY

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INFLUENCE OF VEGETATION ON PERMAFROST

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In permafrost regions numerous climatic and terrain features operate singly and in combination, determining the extent, thickness, and thermal regime of the perennially frozen ground. One of the terrain features is vegetation which forms a continuous or discontinuous mantle on the ground (soil) surface and exerts direct and indirect influences on the underlying permafrost.

Vegetation has a direct influence on the permafrost by its thermal properties which determine the quantity of heat that enters and leaves the underlying ground in which the permafrost exists. Components of the energy exchange regime at the ground surface and thermal contribution of each of them to permafrost are modified by surface vegetative cover. Vegetation also exerts an indirect influence on permafrost by affecting climatic and other terrain features, which in turn have a direct influence on the permafrost.

These direct and indirect influences vary with time and space. The environment in which permafrost exists is dynamic as are the individual components of this environment. Vegetation is one of these dynamic factors and varies with time. As one type of vegetation is succeeded by another, so the underlying permafrost is changed with time. As a result, permafrost existing today reflects direct and indirect influences of the past as well as the present. The effects of vegetation also vary in space, being greater, for example, in the taiga zone than in the tundra.

The sum of these influences with their variation in time and space is manifested in the variations which exist in the permafrost. The depth from ground surface to permafrost table, the temperature regime of the ground above the permafrost and of the permafrost, and the extent and thickness of permafrost are all conditioned by vegetation on the ground surface. Because vegetation is so closely interwoven with climatic and other terrain factors affecting permafrost, it is frequently difficult or impossible to single out the role of vegetation alone.

Even within the vegetation complex itself, some components have more influence than others. It is frequently difficult to delineate the boundary between living vegetation and underlying organic matter, litter, humus, peat, muck, and to separate the influence of these two layers. It is most convenient, therefore, to consider the combined living and dead material lying on the mineral soil as vegetation, although each may have a different effect.

Further complications are caused by the fact that the influences of vegetation may vary depending on conditions under which they occur. As a result, it is possible for a certain combination of vegetation and other factors to produce one set of permafrost conditions at one time or place, and a different set of conditions at another time or place.

Because vegetation is such a widespread factor of the permafrost environment, a large body of literature is devoted to this topic in North America and the USSR. Russian literature is particularly voluminous, the most prominent authors being B. A. Tikhomirov and A. P. Tyrtikov. (The latter has compiled two lengthy and comprehensive review papers on the influence of vegetation on permafrost [1, 2].) Work has also been carried out in Scandinavia on variations in near-surface ground temperatures under different types of plants and on use of plant types as snow depth indicators [3, 4]. Both have important implications in the relationship between vegetation and permafrost.

Present knowledge of the influence of vegetation on permafrost are reviewed. The complex nature of the problem makes it impossible to cover all facets. Canadian experience is cited when available with supplementary information derived mostly from Russian observations.

SURFACE ENERGY EXCHANGE

The annual heat exchange equation [5, 6] at the earth's surface can be written as

$$R + LE + P + B = 0 \quad (1)$$

where (R) is the annual radiation balance (net radiation), (LE) is heat involved in evaporation (including evapotranspiration)-condensation, (P) is heat involved in conduction-convection (turbulent heat exchange), and (B) is thermal exchange in the ground.

The contribution of each of these components to the heat transfer mechanism operating between soil and atmosphere is modified by vegetation properties at the interface of these two media which comprise the permafrost environment. Russian studies show that the heat exchange equation can be used in permafrost regions to relate the ground thermal regime to the surface energy exchange regime [7, 8].

Net Radiation and Albedo

Studies undertaken in Labrador-Ungava [9], using a Kipp and Zonen solarimeter, confirm the higher albedo—solar radiation mostly 0.3-2.0 μ—of treeless lichen-covered surfaces, being 13.55% in contrast to 11.67% for lichen-spruce woodland, 6.52% for spruce bog, 9.78% for muskeg, and 11.13% for a closed forest.

At Norman Wells, NWT, where permafrost is widespread, observations by the Division of Building Research, National Research Council, Canada, showed that lichen posessed higher reflectivity values than true mosses and *Sphagnum*. Nevertheless, these two plant types maintain the permafrost table at about the same level in a given area, and ground temperatures under both plant types are similar. Therefore, if lichen rejects a higher proportion of the net radiative flux than moss, this may be compensated by the moss rejecting a higher proportion than lichen of some other component of the energy exchange.

Another aspect of the radiation component of heat exchange is the influence of forest growth in reducing the intensity of solar radiation at the ground surface which decreases the heating of the ground. If, for example, radiation in an open area is 1.5 cal/sq cm/min it may be reduced to 0.01 cal/sq cm/min under a dense forest canopy. In winter the forest hinders the rate of radiation from the ground but the effect is not as pronounced because of reduced foliage [1, 2].

Conduction-Convection

Direct measurement of the convective component is extremely difficult. In energy exchange studies, quantitative values can be obtained by two methods: (1) All of the other components of the heat exchange equation are measured and it is assumed that the remainder equals the convective component; (2) Bowen's ratio can be used which relates this component to the evaporative flux. Since the annual heat exchange equation at the earth's surface can be written as

$$R = LE + P \quad (2)$$

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it follows that an increase in heat transfer by evaporation decreases the amount of turbulent exchange and vice versa. Investigators in the USSR stated that the ratio of (P) to (LE) at the treeline is about 1 to 6 or 1 to 7, increasing to about 1 to 3 with increased surface roughness in the south-central part of the taiga where the permafrost boundary occurs [5]. The (P) to (LE) ratio at Point Barrow, Alaska, was 1 to 0.7 [10, 11]. Bowen's ratio for saturated Sphagnum in Ottawa, Canada, at the Division of Building Research, was about 1 to 8.

Variations in turbulent heat exchange with different plant species have not been examined in permafrost regions. On a microscale, the roughness factor provided by the vegetation is greatly reduced north of the treeline. On a microscale, Sphagnum tends to produce an uneven microrelief in the form of hummocks, mounds, and peat plateaus in contrast to areas covered with true mosses and lichen which have less microrelief. This could result in ground surface air turbulence being significantly greater over a Sphagnum-covered area.

Evaporation

Evaporation (including evapotranspiration) withdraws heat from the surrounding atmosphere and from incident solar radiation [12]. Vegetation draws water from the soil by transpiration, thus depleting the soil of the heat held by that water. There appear to be variations in these mechanisms from one plant species to another in permafrost regions, but the magnitude of variations and the contribution of this component to ground thermal regime are not clear.

The mechanism of moisture transfer in moss and lichen is not clearly understood, but both are nonvascular plants and cannot transpire in the sense that vascular plants do. Sphagnum especially, and to a lesser degree true mosses, tend to absorb and raise water in the manner of a lamp wick. Mosses and lichens have a large water-holding capacity and are strongly hygroscopic [13, 14, 15]. They absorb water not only from precipitation but also from atmospheric vapor, the latter being absorbed in direct proportion to the relative humidity of the air. Yet during a dry period they tend to lose moisture rapidly. Probably at some point in the humidity scale for the atmosphere, losses exceed the gains of moisture by the lichens.

Tyrtikov [2] postulates that as vegetation absorbs moisture from the soil there is a commensurate increase in the soil thermal conductivity. This occurs at the same time as the evaporation of the water lowers the air temperature, especially near the ground surface, and so reduces the warming of the soil. Immediately after a rainfall, the sun rapidly dries the tips of the moss but this drying extends only to a depth of about 5 cm, thus protecting the lower layer of moss from excessive loss of moisture.

When dry, lichens absorb water slowly from water vapor. This process is negligible, however, compared with the absorption of liquid water because, during a rainfall, the water content of the aerial parts may rise from 50 to 250% within a few hours [14]. The loss of water vapor to the air may occur rapidly if the difference in vapor pressure between the air and the lichen is great, so that on a drying day, the surface of the lichen becomes dry rapidly. Observations by the Division of Building Research at Norman Wells, NWT, of the moisture content in a lichen cover during a dry period showed 8% moisture content in the top 1 in. of the lichen in contrast to nearly 200% at the bottom of the 2-in. lichen cover. Unlike Sphagnum and true mosses, lichen may not be acting as a wick in drawing moisture from beneath, but it appears to be protecting underlying moisture from evaporating influences of the air above. Rapid evaporation or diffusion exchange of water vapor from the wet basal layer to the atmosphere above the lichen may contribute, however, to low soil temperatures and a high permafrost table.

Despite speculation that the high permafrost table under true moss, Sphagnum, and lichen may be caused in part by high evaporation rates that prevent large quantities of heat from entering the ground, observations at Norman Wells in the summer of 1959 showed that rates of water loss from moss and lichen were about equal to each other but lower than from a grass-like sedge, species unknown, or grass [16]. Observations in the summer of 1960 showed that rates for moss, lichen, and the sedge were about equal to or lower than for grass.

Meteorological factors play a prominent role in evaporation and transpiration rates where soil moisture is not a limiting factor. Physiological characteristics and radiation and thermal properties of plants such as moss and lichen, which maintain high permafrost tables, probably contribute significantly by evaporation and transpiration to the energy exchange regime of permafrost. A discrepancy arose at Norman Wells where the sedge did not maintain a high permafrost table but displayed evapotranspiration rates comparable to rates of moss and lichen. This may have been caused by the lower insulating values of the sedge which permitted a greater depth of thaw during the summer.

Conductivity

Vegetation has a marked insulating effect on underlying permafrost. This is true of mosses, lichens, and particularly, of peat. Increase in depth of thaw in permafrost areas where vegetation has been removed has been widely observed.

Variations in the thermal conductivity of peat with moisture content contribute to conditions conducive to formation of permafrost [2]. When dry, peat has a low thermal conductivity, equivalent to that of snow (about 0.00017 g cal/sec sq cm °C cm). When wet, its thermal conductivity is greatly increased (unsaturated peat is about 0.0007 g cal/sec sq cm °C cm; saturated peat—e.g., about 0.0011 g cal/sec sq cm °C cm); when frozen, its thermal conductivity is increased many times over that of dried peat and approaches the value for ice (e.g., saturated frozen peat about 0.0056 g cal/sec sq cm °C cm). During the summer a thin surface layer of dried peat, which has a low thermal conductivity, hinders heat transfer to underlying soil. During the cold part of the year, peat is saturated from the surface, and when it freezes its thermal conductivity greatly increases. Because of this, the amount of heat transferred in winter from ground to atmosphere through the frozen ice-saturated peat is greater than the amount transmitted in the opposite direction through the surface layer of dry peat and underlying wet peat in summer. A considerable portion of heat is also required during the warm period to melt the ice and to warm and evaporate the water. The net result is favorable to a permafrost condition.

The rate of organic and peat accumulation varies with the type of vegetation and influences thermal conductivity of the surface soil layer and thermal regime of the underlying permafrost. In a given climatic zone, less organic material accumulates from meadow and steppe vegetation than from forest and bog vegetation. Organic material accumulates more quickly in a coniferous forest than in a deciduous forest. Coniferous forests with their dense tree crowns and acidic litter tend to create conditions suitable for the development of mosses, particularly where a cool climate has reduced evaporation to a point where the forest floor will be moist despite a low rain fall. The rate of accumulation in a forest is related to many factors, including the presence or absence of moss and lichen cover, its species composition, and the degree of swampiness. In a forest with a surface cover of Sphagnum, a peat horizon forms more quickly than in a forest with true moss.

CLIMATIC AND TERRAIN FEATURES

Vegetation exerts both an indirect influence on permafrost by modifying climatic and other terrain features, which themselves influence permafrost, and a direct influence by its role in the heat transfer mechanism between ground and atmosphere. The influence of vegetation on various microclimatic features, drainage and the water regime, snow cover, and the influence of one type of vegetation on another, are important aspects. These features are so closely interrelated that it is difficult to assess their individual contributions without including some aspects of other features.

Microclimate

Vegetation decreases air current velocities within its strata and therefore impedes heat radiation from the soil to the air when the latter is cooler, as at night [15], and during periods of the year when soil temperatures are warmer than the air [13].

The density and height of trees influence wind velocities near the ground surface. Wind velocities are lower in areas of tall dense tree growth than where trees are stunted and scattered, or absent. Higher velocities, resulting possibly from fewer obstructions in areas of sparse tree growth cause more heat to move away from these areas per unit time than from the areas of dense growth. In the southern fringe of the permafrost region, permafrost is more commonly associated with areas of sparse or no tree growth for a number of reasons. Other factors being equal, the possibliity of slightly lower air temperatures because of higher wind velocities in these areas may contribute to a ground temperature condition conducive to the existence of permafrost.

Air movement, such as the drainage of cold air at night from an elevated area downslope to a depression, is a microclimatic feature associated with relief, which may also be significant. Even microrelief features, such as peat plateaus, may produce sufficient differences in elevation to cause downslope air drainage at night.

Vegetation, especially tree growth, intercepts a significant portion of atmospheric precipitation, both rain and snow, by as much as 10 to 40% [2]. Any rain that reaches and penetrates the ground carries heat with it toward permafrost so that interception of rain results in a reduction of heat entering the ground. On the other hand, interception of snow by trees results in a lower accumulation on the ground and the possibility of deeper seasonal frost penetration. Increased shading caused by snow on tree branches reduces the amount of solar radiation received at the ground surface, but this is counteracted partly, at least, by the reduction of radiation from ground surface into atmosphere.

Drainage

Ground that permits the greatest degree of water penetration usually thaws to the greatest depth [13]. There is evidence that extensive root systems impede downward percolation of water and therefore restrict soil thawing [13]. On the other hand, roots, especially dead and decaying ones, may provide channels for water penetration and sometimes loci for the growth of granules and small stringers of ice [13].

Vegetation impedes surface runoff. In forests, particularly where vegetation is not disturbed, runoff amounts to less than 3% of the total rainfall, whereas in open areas and on the plains, it exceeds 60% [1]. The rate of runoff to precipitation is probably also significant to permafrost. Subsurface drainage is slow in peat because of its filtration properties.

Snow Cover

The low thermal conductivity of snow and its double role as inhibitor of frost penetration during winter and soil thawing in spring has been noted by many authors [13]. The retention of snow in the crowns of trees has already been mentioned. In spring, the snow cover remains on the ground longer in forested areas than in the open. Where strong winds prevail, more snow accumulates under a vegetation cover than in open areas. Snow protects the ground from freezing in winter but it also increases the moisture content of the soil in summer, thus contributing to lower summer ground temperatures [1].

In Labrador-Ungava a good correlation was noted by Ives [17] and Annersten [18] between the vegetation and snow accumulation and the distribution of permafrost. On exposed ridge summits, where vegetation was virtually absent, snow accumulation was kept to a minimum by the wind, and permafrost 200 ft thick existed. In sheltered gullies, vegetation was better developed, snow accumulated in the winter, and permafrost was only a few feet thick or absent.

Vegetation Properties

Within the framework of the complex interrelation existing among various terrain features that affect the ground thermal regime, such as relief, drainage, soils, snow cover, and vegetation, special characteristics of some plant types may significantly influence permafrost and also indicate the existence of permafrost.

Tikhomirov [19] mentions several characteristics that influence the ground thermal regime of true mosses and *Sphagnum*: it possesses low thermal conductivity, high moisture holding capacity, and may shield roots of vascular plants from low air temperatures; it promotes uniform thawing and protects soil from runoff, solifluction, erosion, and thermokarst. Moss reduces the temperature amplitude of underlying soil. Tikhomirov postulates that heat from moss in late winter recrystallizes snow at the moss contact, that photosynthesis is possible under a thin snow cover, and that hollows form in the snow in which the air temperature is higher than the outside air temperature, producing favorable conditions for plant growth under the snow. Porsild states that solar radiation is the more likely source of heat [20]. He also questions photosynthetic activity beneath even a thin snow cover and the provision of favorable conditions for plant growth under the snow.

Robinson noted that in fall the melting of early snow fills the moss with moisture enabling it to conduct heat at a more rapid rate; this permits greater heat loss from the ground and deep penetration of seasonal frost [21]. In summer the top few inches dry to a point where they act as an effective insulating blanket. Therefore the presence of a deep layer of moss keeps the soil at a low temperature continuously and favors development of permafrost. Moss is very water absorbent. The lower portion of a moss layer is usually moist and this maintains the ground in a damp or wet condition.

Certain plant types provide rather reliable indicators of the existence of permafrost. At Thompson, Man., Canada, the presence of *Sphagnum*, and/or stands of spruce varying from small trees in open stands to moderately large trees in nearly closed stands, was found usually to be associated with permafrost, if the drainage was fairly good [22]. In northern Alberta, all but a few of the permafrost occurrences were found in low flat depressions [23].

In these areas two associations of vegetation predominated. One was grass-like sedge with little or no tree growth and thin moss cover. These areas were almost always wet and no permafrost existed. The other consisted of *Sphagnum*, lichen patches, and scattered stunted black spruce. Some of these areas were wet and contained no permafrost. The remainder were drier, and permafrost occurred at depths ranging from about 2 to 4 ft. At the edges of these areas, the permafrost dropped off abruptly.

Three varieties of vegetation are shown in Fig. 1, taken Sept. 20, 1962 (57°47'N, 117°50'W), 3.2 miles west of Mackenzie Highway, Alberta, Canada, in the southern fringe of the discontinuous zone of the permafrost region.

Fig. 1. Variety of vegetation associations with related variations in permafrost occurrence

The light-toned vegetation in the foreground and middle ground consists of sedge (Carex sp.) and grass with a thin discontinuous cover of feather and other non-Sphagnum mosses in standing water. No permafrost was encountered.

The dark toned island in foreground (man kneeling) is a slightly elevated peat plateau with ground cover of hummocky Sphagnum and Labrador tea. Depth of moss and peat is 4 ft 2 in.; black organic silt 4 ft 2 in. to 6 ft 0 in.; dense bluish silt clay 6 ft 0 in. to below 7 ft. Permafrost table extends from from 2 ft 9 in. to 7 ft below ground surface. Permafrost occurs also in the dark almost treeless patch (same ground vegetation) at right, between sedge area in middle ground and forest in background. The forested area consists of spruce, poplar, jackpine, and birch; no permafrost was encountered here.

VEGETATION ZONES AS A PERMAFROST INDICATOR

In Canada, Alaska, and the USSR, the influence of vegetation varies from one geobotanical zone to another. In Canada and Alaska, permafrost occurs in tundra and taiga zones. In the USSR, it occurs in these two zones and also extends southward into the steppe. The variety of vegetation associations, the quantity of vegetable matter, stand height, and density, and rate of peat accumulation are all greatest in the taiga, gradually diminishing northward into the tundra and southward into the steppe. The degree and variety of the influence of the vegetation on the permafrost changes in a parallel manner [2].

In the northern part of the tundra the vegetation has little influence on permafrost because it is sparse and the vegetative period lasts less than two months. It causes local variations in depth of thaw and helps impede erosion. The destruction of the vegetation accelerates thawing only slightly.

In the southern part of the tundra, the vegetation becomes more abundant, peat mantles part of the surface and attains thicknesses of several feet in some basins. The main influence of the vegetation is on the depth of thaw. If vegetation is removed, the depth of thaw will increase; erosion will increase and thermokarst will develop if thawing proceeds at different rates over an area or if there are local differences in the ice content of the frozen ground.

In forest tundra, vegetation mass is greater than in the tundra, and the rate of accumulation of organic material is higher. Extensive peat bogs form and water basins are encroached by vegetation and permafrost forms. Woody and brush vegetation grow which accumulate snow leading to higher permafrost temperatures than in the tundra. If the vegetation is removed, the depth of thaw increases but this is counteracted to some extent by lower snow accumulation and a decrease in permafrost temperatures [1].

The maximum development of vegetation occurs in the taiga. Here vegetation has its greatest influence on permafrost even in very small localized areas causing variations in its extent, depth of thaw, and ground temperatures. Frequent forest fires cause variations in the occurrence and thickness of permafrost over short distances in the taiga.

Mass, density, height and influence of vegetation, and rate of accumulation of organic matter are less in the steppe than in the taiga, but depth to permafrost is greater.

ALTERATION OF PERMAFROST CONDITIONS

Changes take place in the permafrost as a result of the vegetation. The influences include the effect of vegetation on depth of thaw and depth to permafrost, the temperature regime in permafrost and the ground above, and extent and thickness of permafrost.

Depth of Thaw

The most easily observed and measured characteristic of permafrost is depth of thaw and variations in types of vegetation are often readily noticeable. Because this is so, more observations have been made on this aspect of the relation of vegetation to permafrost than any other. Despite the large number of observations reported in the literature, mechanisms operative in thawing of the active layer and permafrost and causes of variations from one type of vegetation to another are not clearly understood. One difficulty in comparing depth of thaw observations in various localities is caused by variations in climate, variations in other terrain factors closely associated with the vegetation, and by minute, but possibly significant, variations within a particular type of vegetation.

Removal of vegetation cover in a permafrost area causes an increase in the depth of thaw. At Inuvik, NWT, in the continuous permafrost zone, the maximum depth of thaw in an undisturbed moss-covered area was 2 ft in contrast to depths of 5 to 8 ft in areas stripped three years previously [24]. On land stripped for cultivation at Inuvik, the original maximum depth of thaw was about 2 ft prior to disturbance (1956). By 1959 the ground thawed to a depth of 70 in. [25].

The surface cover and peat appear to have much greater influence on depth of thaw than the underbrush and trees. At Inuvik, in undisturbed areas and in areas where the underbrush and trees had been removed three years previously but with the moss cover left intact, the depth of thaw was 2 ft—similar to the depth prior to any disturbance [24]. At Norman Wells, depth of thaw measurements were recorded by the Division of Building Research in different types of vegetation from 1957 to 1959. The greatest depth of thaw occurred in the grass-like sedge area with no moss cover reaching a depth of 5 ft 6 in. after about 3350 degree days of thawing. The next greatest depth of thaw was observed in a wooded area having a ground cover of 4 in. of moss overlying 3 in. of peat, reaching 4 ft 6 in. after 3350 degree days of thawing. The next greatest thaw, 3 ft 3 in., occurred in a treeless grass-like sedge and moss area with a 3-in. moss cover overlying 6 in. of peat. The shallowest depth of thaw, 2 ft, was observed in a sparsely treed area having 5 in. of moss overlying 18 in. of peat. Evidently, the depth of thaw decreased with an increase in the combined thickness of living moss and peat; the density and size of tree growth did not appear to make much difference.

Russian investigators found that of all the types of ground cover, Sphagnum appears to retard thawing most. In the Igarka region of the USSR, the depth of thaw in 1950 under this cover was 18 cm (7.1 in.) on 13 July, 22 cm (8.7 in.) on 3 August, and 26 cm (10.2 in.) on 2 September in contrast to 25, 31, and 35 cm (9.8, 12.2, 13.8 in.) on the same dates under true mosses consisting of Hypnum and other species [1, 2].

The relative influence of living ground cover and underlying peat has been investigated. It has been postulated that peat retards thawing even more than living mosses and lichens. In the arctic region of the Yenisey River in Siberia, removing the moss and lichen but leaving the peat layer resulted in an increase in the depth of thaw by 20 to 50%. After both living cover and peat were removed, depth of thaw increased by 1.5 to 2.5 times [1, 2].

Temperature Regime

Just as the vegetation exerts a marked influence on the depth of thaw and the depth to permafrost, it also modified ground temperatures both in permafrost and the ground above. An increase in depth of thaw leads to an increase in ground temperature and degradation of permafrost. A decrease in depth of thaw leads eventually to an aggradation of the permafrost.

At Norman Wells, ground temperatures were measured in the thawed layer by the Division of Building Research in 1959 and 1960 to assess the effect of different types of vegetation on underlying soil temperatures during the summer. In September 1959 the mean air temperature was 41.2°F and the mean ground temperature at the 1-ft depth for this period in various vegetation areas were: grass (no moss or peat) 40.0°F, sedge (no moss or peat) 36.5°F, grass-like sedge (3 in. true moss over 6 in. peat) 35.0°F, moss (5 in. Sphagnum over 18 in. peat) 32.5°F, lichen (2 in. lichen over 24 in. peat) 32.6°F.

There appeared to be a general decrease in temperature with increased combined moss and peat thickness. Temperatures were similar under moss and lichen although living moss was much thicker than lichen. The combined thickness of living cover and peat was, however, approximately equal. Ground temperatures taken in 1960 in the thawed layer showed that they were highest under the grass area, lower under the sedge, and lowest under the moss and lichen. Temperature amplitudes also decreased in the same order. Thermal resistance and damping effect of moss and lichen were shown by the fact that monthly mean air temperatures were about 10°F higher in 1960 than in 1959, but the difference in mean ground temperature at the 1-ft depth was less than 1°F.

Ground temperature readings were also taken at Norman Wells down to the 20-ft depth in permafrost under the sedge, moss, and lichen. Even below the 10-ft depth, the mean temperature under the sedge for August and September 1960 was about 3°F higher than under the moss and lichen, which were about equal. Above this depth the difference was even greater. Similarly, the temperature amplitudes in the top 10 ft were twice as much under the sedge.

There is no doubt that vegetation modifies the temperatures of the seasonally thawed layer and permafrost. In all cases, ground temperatures in summer will rise when the vegetation cover is removed. On the other hand, the effects of winter air temperatures will penetrate to greater depths than in undisturbed areas. The net effect on mean annual temperature will depend on other factors, such as snow cover.

It is difficult to compare the effects of different types of vegetation on permafrost because different types frequently grow in close association or in a mosaic, and the individual effect of each may not be readily apparent.

Extent and Thickness

A change in depth of thaw and a change in temperature of the active layer and the permafrost produced by a change in vegetation establishes a change in temperature gradient. This results in either aggradation or degradation of the permafrost. In the southern fringe of the permafrost, the removal of the vegetation may result in disappearance of the permafrost. The establishment of a moss cover may lead, perhaps, to the formation and accumulation of permafrost.

CONCLUSION

This paper reviews various ways in which vegetation affects permafrost. Some mechanisms add heat to the ground, others facilitate heat loss from the ground. Some add heat at one time and contribute to heat loss another time. Influences of vegetation are almost all reversible depending on the conditions under which they occur. The complexity and multifaceted effects of vegetation on permafrost often lead to a situation where under one set of conditions a plant community decreases the soil temperature and increases it under other conditions.

It is very difficult to attach absolute quantities to each facet of the vegetation influence—total them, and arrive at the resultant direction and magnitude of heat flow at a particular time, much less perform this operation for all the past influences and assess their effect on the present permafrost situation. Even if each factor could be measured quantitatively, the contribution of some is so minute that the cumulative error would be unrealistic. In addition, there are factors which are probably not even known or possible to measure.

The best solution appears to be to measure obvious effects of vegetation, such as depth of thaw, temperatures, extent and thickness of permafrost which are manifestations of the net heat gains and heat losses to the ground, and relate these to variations in environmental components. The same permafrost conditions may occur in two adjacent areas, but the combination of vegetation and other factors producing two similar sets of permafrost conditions may be quite different.

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