Ground Temperature and its Relation to Permafrost Occurrences in the Khumbu Region and Hidden Valley*

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Abstract

In order to detect the existence of permafrost and study its relation to ground temperature distribution in high altitude of the Himalayas, ground temperature measurements were carried out in the Khumbu region and Hidden Valley, Mukut Himal. The results indicate that permafrost occurs above 4900-5000 m in the Khumbu region and above 5000 m in Hidden Valley. The lapse rates of the ground temperature at a depth of 50 cm below the surface are about 0.9-1.0°C/100 m and about 0.4°C/100 m above and below the lower altitudinal limit of permafrost distribution in both regions.

1. Introduction

There are a few alpine permafrost studies, such as in the Rocky Mountains (e.g. Ives and Fahey, 1971), the Alps (e.g. Furrer and Fitze, 1971), Mt. Fuji, Japan (Fujii and Higuchi, 1972) and Mauna Kea, Hawaii (Woodcock, 1974) but little is known about permafrost occurrence in the Himalayas except by Müller (1958) and Hsieh et al. (1975).

In order to detect the existence of permafrost and to observe the thermal character of the ground in the high altitudes of the Himalayas, ground temperature measurements were carried out in the Khumbu region and Hidden Valley, Mukut Himal in 1973 and 1974 respectively.

Field observations in the Khumbu region were made mainly above the height of the Lhajung Weather Station (4420 m) established by the expedition. Tree line lies at about 4200 m, above which alpine meadows extend up to the lower limit of steep, glaciated rock wall at 5300-5400 m. On the other hand, the study area in Hidden Valley in the northern side of Himalayas, is remarkably different from that in the Khumbu region, showing a typical periglacial environment with poor vegetation.

The present report is an outline of the results of ground temperature measurements carried out as initial alpine permafrost studies in the high altitudes of the Nepal Himalayas.

2. Ground temperature conditions at the Lhajung Weather Station in the Khumbu region

Ground temperatures at the depths of 0 cm (surface), 10 cm, 20 cm, 30 cm, 50 cm and 100 cm below the surface have been measured as a part of the ordinary climatological observations at Lhajung Weather Station (4420 m) in the Khumbu region since April 1973.

Fig. 1 is a 20-month record of the ground temperature from three depths, 20 cm, 50 cm and 100 cm. The rapid decrease in ground temperature as well as air temperature (Inoue, 1976) was recorded following the monsoon season with a rate of around 0.3°C/day.

Maxima of 10-day mean ground temperatures in both 1973 and 1974 were recorded in early July, and minimum was recorded in early January, 1974.

The durations of below-zero temperature at various depths in the winter of 1973-1974 were 120 days for 20 cm depth, 95 days for 50 cm depth and 55 days for 100 cm depth, though a longer duration of 170 days was recorded for air temperature.

The monthly variations of the ground temperature profile in 1974 are shown in Fig. 2. The gradients below 20 cm depth were very small during the monsoon season. As the dashed line

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Fig. 1. Ground temperature record from April 1973 to December 1974 at the Lhajung Weather Station (4420 m) in the Khumbu region.

Fig. 2. Monthly variation of ground temperature profile in 1974 at the Lhajung Weather Station (4420 m) in the Khumbu region.

in Fig. 2 indicates the mean annual profile, the mean annual ground temperatures at 20 cm, 50 cm and 100 cm depths were 5.0°C , 5.3°C and 5.6°C respectively.

Therefore, the mean annual thermal gradient in the ground is $0.56 \times 10^{-2}^{\circ}\text{C}/\text{cm}$ to $1.00 \times 10^{-2}^{\circ}\text{C}/\text{cm}$, and if we take $0.6 \times 10^{-3} \text{ cal}/\text{cm} \cdot \text{sec} \cdot ^{\circ}\text{C}$ as the thermal conductivity of the soil for a 20% moisture ratio (Higashi, 1950), the upward heat flow is estimated to be 105 cal/yr. to 190 cal/yr..

As the mean annual air temperature at Lhajung in 1974 was 0.1°C , the ground temperature was about 5°C higher than the air temperature.

3. Field observations of ground temperature in the Khumbu region

Ground temperatures, mainly at a depth of 50

Fig. 3. The relation of the difference between the ground temperature at 50 cm depth measured at the Lhajung Weather Station and at other locations in the Khumbu region, to altitude.

cm below the surface, were measured from May to August, 1973 at more than 100 points between 3850 m and 5400 m. The diurnal variation of the ground temperature is negligibly small below 40 or 50 cm from the surface.

Fig. 3 shows the results of ground temperature measurements, indicating the relation of the difference between the ground temperature measured at Lhajung Station and at other locations to altitude. In this observation period, the difference of ground temperature at different observation times was not more than 1°C . The inclination between any two points in this figure gives the lapse rate of ground temperature at a depth of 50 cm below the surface.

Though the ground temperature generally decreases with altitude, there is a clear difference in the lapse rate in the altitude zone above and below 4900 to 5000 m. The lapse rate below this height is 0.44°C per 100 m so that this value is close to the wet adiabatic lapse rate at 500-600 mb and $5-10^{\circ}\text{C}$ in the air temperature, which are the climatic conditions during the observation period in this region. Above this height, it is 0.98°C per 100 m on the average, being larger than that of the air temperature, which ranged from 0.5 to 0.6°C per 100 m measured in this observation period from the premonsoon to the mature-monsoon stage.

This may be explained as follows; the thickness of the thawed layer in the upper part of the seasonally or perennially frozen ground decreases

with altitude. The depth of 50 cm below the surface, therefore, is getting nearer to the cold source of the frozen layer with altitude.

The ground temperature varies with the direction of the slopes. The measurements were carried out on the west-facing slope of Mt. Pokalde and on the east-facing slope of Tauche Peak, facing across the Lobuche Khola (river) from Mt. Pokalde. The ground temperature on the east-facing slope was 0.5°C to 1.0°C higher than on the west-facing slope. This is probably the result of stronger surface cooling on the windward west-facing slope brought about by the predominant upward wind along the Imja Khola than on the lee east-facing slope (Fujii, 1976 a).

4. Field observations of ground temperature in Hidden Valley, Mukut Himal

Ground temperature measurements were carried

Fig. 4. The relation of the difference between the ground temperature at 50 cm depth measured at the Station (5055 m) and at other locations in Hidden Valley, to altitude.

Fig. 5. Ground temperature profile with depth measured at 5055 m (a), 5240 m (b) and 5340 m (c) in July and August, in Hidden Valley.

out at about 70 points from June to September 1974 in Hidden Valley and on the Kali Gandaki slope of Dambush Pass, using a portable thermistor thermometer in the form of a stainless bar with a sensor (Fujii and Higuchi, 1972).

Readings were made when the indication of the thermistor-thermometer had almost been stabilized after sinking the bar to the appointed depth in the ground. It took about 5 minutes.

The results are shown in Fig. 4 in the same form as Fig. 3. The temporary Weather Station was established at the height of 5055 m in Hidden Valley.

The lapse rates are 0.89°C per 100 m and 0.35°C per 100 m above and below about 5000 m respectively.

Measurements of ground temperature gradient with depth were made in excavated pits at 5055 m, 5240 m and 5340 m at and near the Station from the end of July to early August. The thickness of the thawed layer of frozen ground, namely the depth from where the ground temperature became 0°C , were 220 cm, 190 cm and 165 cm respectively (Fig. 5). From the results shown in Fig. 4 and Fig. 5, it is clear that permafrost occurs above about 5000 m in Hidden Valley.

As the same tendency of altitudinal distribution of ground temperature at the depth of 50 cm was obtained in Khumbu region (Fig. 3), permafrost should occur above 4900 m to 5000 m in the Khumbu region, though Müller (1958) reported the non-existence of permafrost in the periglacial area of Mount Sagarmatha (Everest).

5. Permafrost distribution and environmental conditions in the Khumbu region and Hidden Valley

The results of ground temperature measurements indicate the existence of permafrost above 4900 m to 5000 m in the Khumbu region and above about 5000 m in Hidden Valley as described above. These altitudinal levels, in other words, are the lower limits of the distribution of permafrost in both regions.

The mean air temperatures of the year, the warmest month and the coldest month at the lower limit of permafrost distribution in the Khumbu region are -2.8 – -3.4°C , 3.5 – 4.5°C and -10.5 – -11.5°C extrapolated from those observed at the Lhajung Station (Appendix 2 of the issue). This mean annual air temperature for the lower limit of the permafrost distribution in the Khu-

mbu region is lower by about 1.5°C than that at the southern limit of the discontinuous permafrost zone in high latitudes (Brown, 1960).

The mean annual ground temperature at the lower altitudinal limit of permafrost, however, should be from 1.5°C to 2.8°C on the average. Furthermore, as the temperature even on west-facing slopes is about 1.0°C lower than that on the average, permafrost should be expected in such places as on north-facing slope, under wet sites, or in the shade. It is, therefore, clear that the 4900 m-5000 m level is the lower limit of the discontinuous alpine permafrost zone in the Khumbu region.

Periglacial studies (Iwata, Fujii and Higuchi, 1976) provide supporting evidence such as the existences of sorted polygons, vegetated polygons, active rock glacier and so on.

On the other hand, permafrost in Hidden Valley occurs extensively at least above 5240 m, since the existence of frozen ground at this level was confirmed even under a dry site at the end of July (Fig. 5) and active solifluction which is associated with frozen ground (e.g. Washburn, 1973) occurs widely on the slopes above this height (Fujii, 1976 b).

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