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Permafrost and ground water on the southern slope of West Kunlun Mountains

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Abstract

Condition of permafrost and ground water was investigated in the southern slope of West Kunlun Mountains, north of Gozha Co. There was difference in altitudinal distribution of thawing depth above and below 5600 m a.s.l.. The ground condition at two observation site BC on the grass land and ABC just below the glacier terminus was quite different, although height difference was only 600 m. Soil moisture was high and depth of permafrost table was shallow at ABC. The volumetric water content of permafrost at BC was only 18%. This difference is thought to arise from the difference in air temperature, soil texture and relative distance from the large water source, that is , glacier. An interesting phenomena was found on the non–uniform water discharge system in the sorted ground area near ABC.

1. Introduction

The West Kunlun Mountaihins are located in a dry climate, but many glaciers and lakes exist. One big problem is how the water balance and water circulation are maintained in this region. To consider this problem, soil moisture and subsurface water movement are very important. Because not only these give the quantity of subsurface water itself, but these affect the water balance, energy balance and water circulation through evaporation and runoff. As permafrost is widespread in this region, it may affect the water circulation by regulating subsurface water movement. So soil moisture and subsurface water movement must be known, but no observation had been done from this point of view. This report describes the foundamental soil water condition in the active layer on the south slope of the West Kunlun Mountains in summer 1987.

2. Site description

Field investigations were conducted on the slope between BC (35°10'N, 81°10'E, 5260 m a.s.l.) and ABC (5805 m a.s.l.) shown in Fig. 1. Inclination of the slope was about 6 degrees on an average, and it was clearly divided by the surface state. Below 5400 m, it was covered with sparse grass of Kobresia species, and very large sorted stripes were widespread with rare vegetation above 5550 m. BC was a typical site in the grassland area, and ABC in the large sorted stripes area. It is widely considered that permafrost underlies the whole slope except near Gozha Co (Li, 1987).

3. Observation methods

Observations were carried out from middle of July to the end of August, 1987. Thawing depth was determined by measurement of the penetrating depth of a steel rod, and was confirmed by the 0°C temperature measured by thermister thermometer stick. At some sites this depth was obtained by extrapolating the ground temperature at two different depths at which daily temperature fluctuation can be neglected. Surface flow and suprapermafrost water table were investigated together. Soil moisture tension was measured by mercury manometer tensiometer with accuracy of 1 mmHg (1.5H20cm) at three depths (10, 40

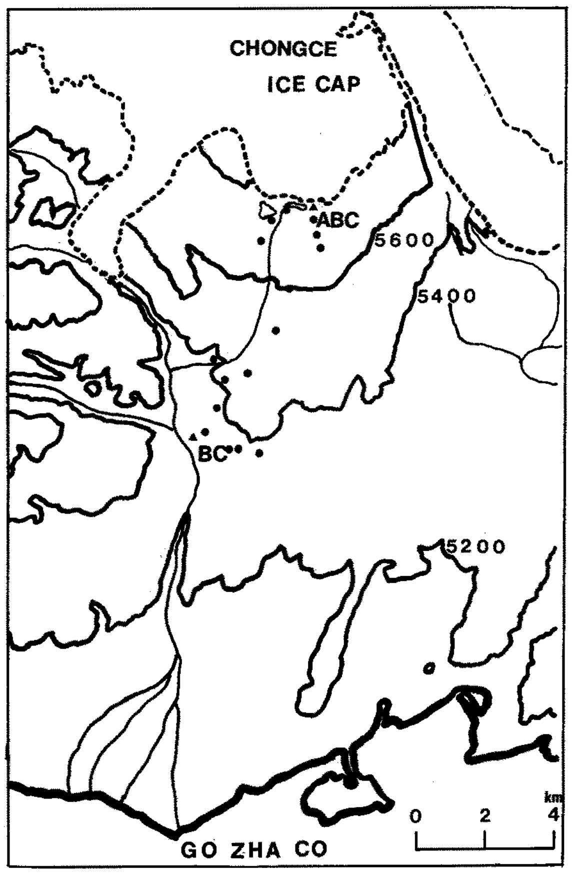

Fig. 1. Map of the observation area.
▲; Main observation sites BC and ABC,
●; Minor observation sites.

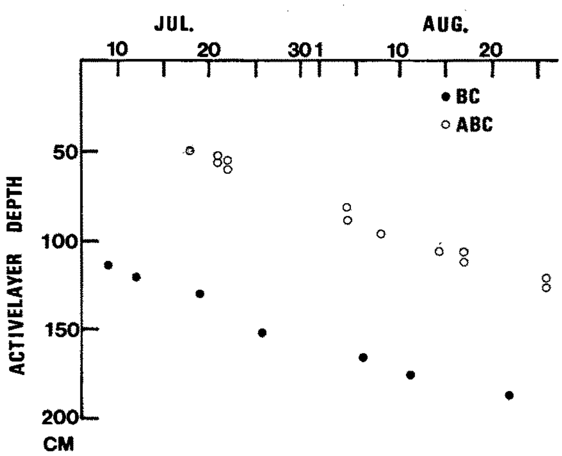

Fig. 2. Change of thawing depth of permafrost layer at BC and ABC for the observation period.

and 80 cm below surface) at BC. This measurement was made 5 times, that is, 8:00, 11:00, 14:00, 17:00 and 20:00 in the daytime. Moisture content was determined by taking core samples and measuring by oven—drying gravimetric method at BC and ABC. A pit was dug to the depth of the permafrost table at BC, and samples were also obtained from it. Particle size distribution and hydraulic conductivity were determined in the laboratory. Soil temperature were continuously monitored, using thermister and platinum resistor probes at the depth of 0, 5, 10, 20 and 40 cm at BC and ABC. Surface temperature was measured by probes covered with a very thin layer soil. The time used in the present report is Beijing Standard Time (GMT+8hours).

4. Result and discussion

4.1 Thawing depth

Figure 2 shows the change of thawing depth at BC and ABC. At the end of August it reached about 2m at BC and 1.3m at ABC. In spite of the low air temperature, especially at ABC where the daily mean air temperature dropped below zero almost every day (Ohata *et al.,* 1989), this value is not small. Due to strong insolation the warming and melting of ground directly by radiation is more intense in this region than in Arctic tundra. This effect is also seen in soil temperature data, and is important in hydrology and geomorphology. Thawing depth can be expressed by the following equation.

$$Z = a\sqrt{\Omega_T} \tag{1}$$

Z: thawing depth (cm)
a: coefficient
Ω_T: accumulated daily mean surface temperature (degree days)

Coefficient a depends on surface condition and soil type. As surface temperature was not observed before July 14, Ω_T was transformed to $\Omega_T + b$, and a and b was obtained from regression analysis between Z and Ω_T after July 14. The values of a and b for BC were 6.8 and 343, and for ABC they were 7.3 and 18, and is shown in Fig. 3. From this equation, the beginning of thawing (the day on which $Z=0$) is calculated. Assuming that the surface temperature before observation was the same as in July 17—25 (snow fell every day), the starting date of thawing was early June at BC and early July at ABC. The actual date, however, should be earlier at BC, because surface temperature should be lower in June. Altitudinal variation of thawing depth at the four dates is shown in Fig. 4. This suggests that thawing depth depend on altitude below 5600 m, but does not depend on altitude above 5600 m in the area of large sorted stripes.

4.2 Soil texture and soil moisture

Particle size distribution and saturated hydraulic conductivity for BC and ABC soils are shown in Fig. 5. Textural multilayering was not evident at ABC. The texture of <2.0 mm fraction affects water holding capacity, flow rate and frost heaving force. The difference between BC and ABC is apparent principally in the layer near the surface. Soils at ABC have significant components of silt. This may cause such large sorted stripes with the capacity of silt for frost heaving. Soil at BC is much coarser. An organic layer was not seen at either site.

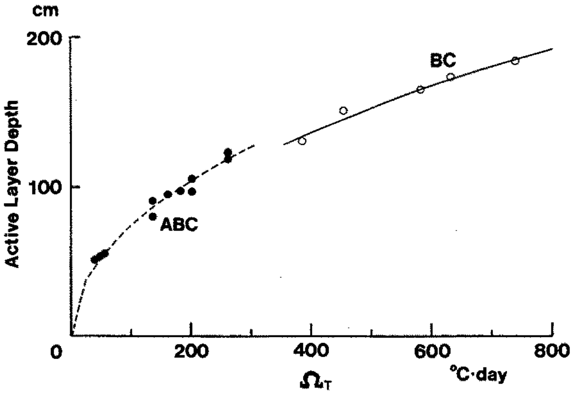

Fig. 3. Relation between thawing depth (Z) and accumulated daily mean surface temperature (Ω_T) at BC and ABC.

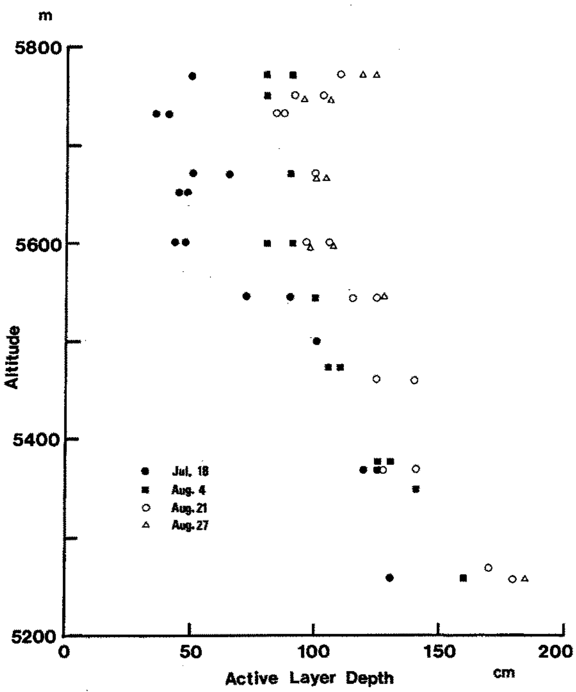

Fig. 4. Altitudinal variation of thawing depth for four dates.

Observed variation of soil moisture tension is graphed for BC site in Fig. 6 with precipitation data. At 10 cm depth, moisture increased under rather heavy rain (July 24–26) and after that rapidly decreased due to evaporation. On August 1, soil moisture content of the core sample reached 0.3% at 0–5 cm and 5% at 5–15 cm (volumetric water content), the minimum value during the observation period. In August, soil moisture tension changed little; its value, however, was maintained in a range between 110 mmHg and 120 mmHg (6 – 8% volumetric water content). At 40 cm depth, percolation of precipitation (July 24–26) was clear with some time lag. And in August, data show that moisture was gradually lost. At 80 cm depth, in July moisture change was not evident and in August moisture gradually decreased.

Figure 7 shows changes of soil moisture for 0 – 45 cm depth at BC during a rather dry period by volumetric water content θ_w. Loss of moisture reached to about 40 cm due to evaporation. Until August 7, moisture mainly decreased in the upper 15 cm layer; after that the main moisture loss occurred at 15 – 35 cm depth, and at the end of August, the soil was drier near the surface. These moisture changes agree with soil moisture tension data.

Soil moisture near the surface affects actual evaporation. Figure 8 shows the relation between daily evaporation (Takahashi *et al.*, 1989) and soil moisture at 0 – 5 cm depth at BC. This shows that actual evaporation depends strongly on surface soil moisture. In this region potential evaporation is high, so actual evaporation is mainly determined by the quantity of water which is available for evaporation.

Soil moisture in the BC pit and at ABC is shown in Figs. 9 and 10. The notation P.T. stands for permafrost table. On July 28, sample of the freezing layer at 130 cm depth was obtained from the BC pit. Moisture content was 18% (volumetric water content), about half the value of saturated water content, and ice-rich condition was not observed. At ABC, loss of

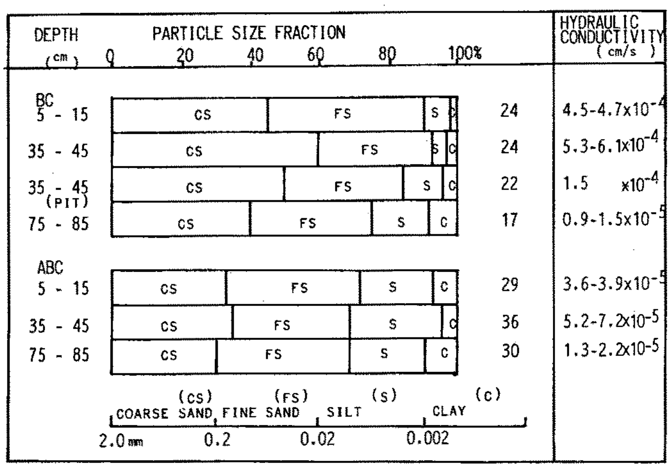

Fig. 5. Particle size distribution and saturated hydraulic conductivity for BC and ABC.

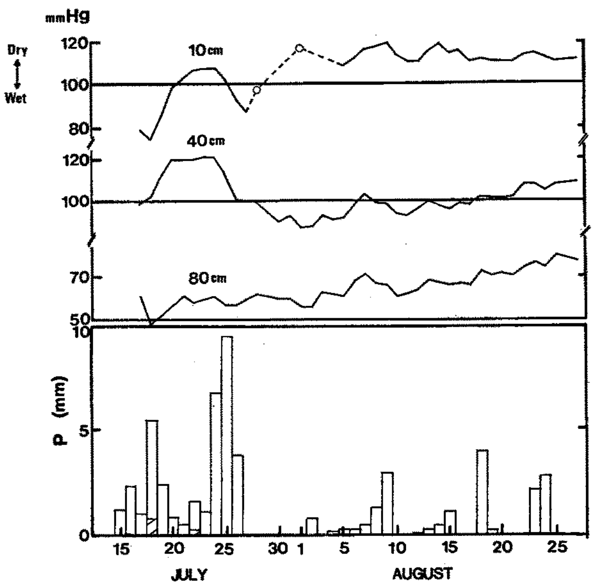

Fig. 6. Variation of soil moisture tension and precipitation (P) at BC.

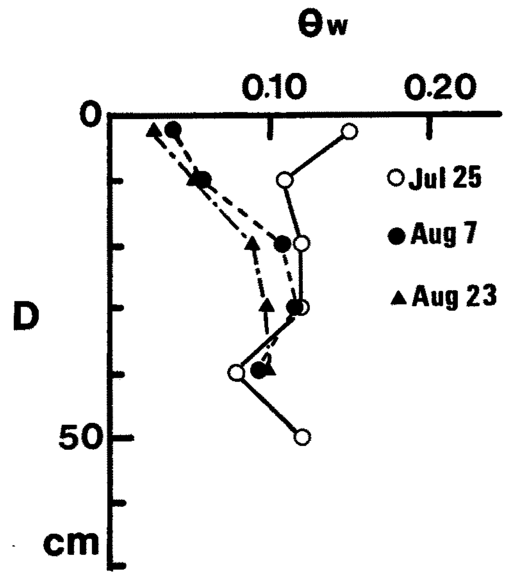

Fig. 7. Soi moisture in volume content (θ_w) for 0 – 45cm depth (D) at BC.

moisture was apparent at almost all depths including disappearence of the water table. In fact, as the ground surface had been very wet until the middle of July in the area of large sorted stripes, our autotruck to ABC was often stuck.

In the area of large sorted stripes, the ground surface where soil consisted of fine materials was moist on every morning without nighttime precipitation. And in the daytime this moist condition disappeared due to evaporation. It is thought that the moisture moves from subsurface to the surface with freezing of the surface at night. This type of moisture concentration occurs most easily in silty soils like that at ABC. Including this effect, actual evaporation from soil of fine materials at ABC was higher than at BC (Takahashi *et al.*, 1989). But determining actual evaporation is difficult in the area of large sorted stripes, because evaporation of a coarse material surface is difficult.

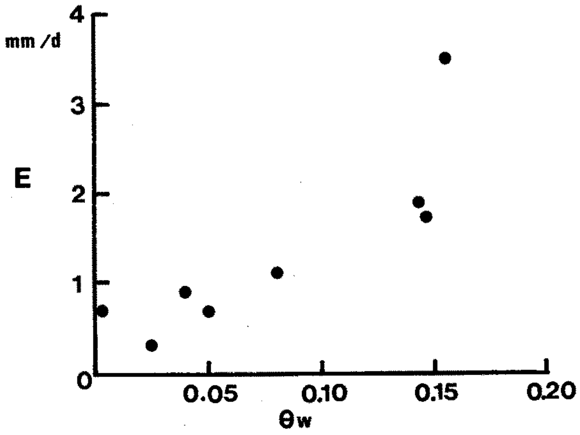

Fig. 8. Relation between daily evaporation (E) and soil moisture (θ_w) at 0 – 5cm depth.

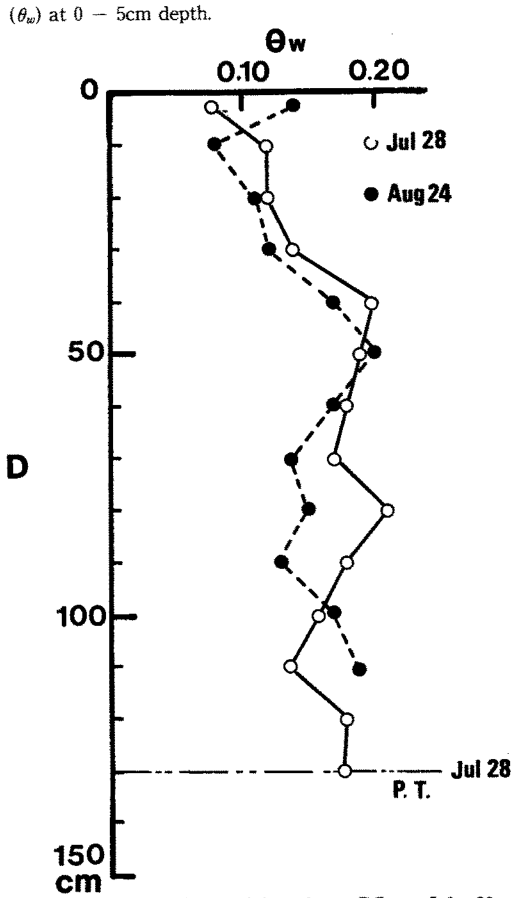

Fig. 9. Soil moisture observed by pit at BC on July 28 and August 24. P.T. stands for permafrost table.

4.3 *Suprapermafrost water table and surface flow*

Suprapermafrost water table and surface flow could not be observed in BC and the area of grass land of Kobresia sp. except in large rivers. There was only one site where spring water existed until early August, at the upper limit of grass land (5380 m). It is assumed that water movement on and through the thawing layer is not important in this area during the observation period. At ABC site, a water table was seen at depth of 10 – 20 cm above the permafrost table until July 22, and then disappeared. On August 19, however, it appeared again and increased to 20 cm above the permafrost table on August 24.

In the area of large sorted stripes, there were surface flows in all areas of stone boulders on July 13. This flow disappeared after July 20, until the end of August when melting water from snow patches and glaciers was supplied. Water table was observed in the whole area above 5550m on July 18, when the depth was 1 – 40 cm above the permafrost table. It gradually disappeared, and in August rarely existed except

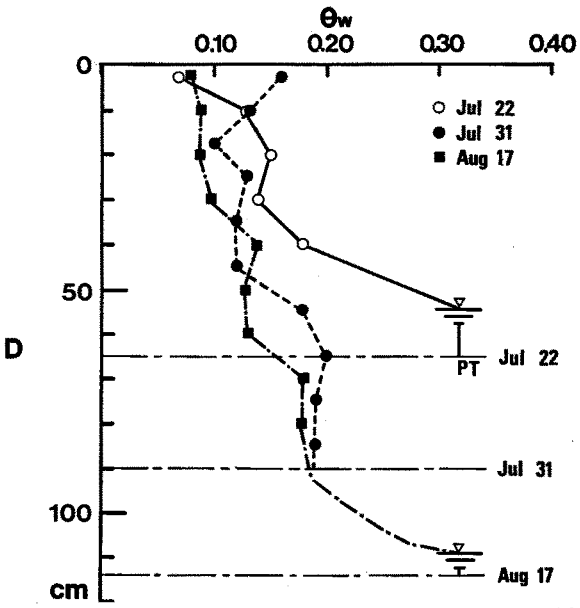

Fig. 10. Soil moisture observed by pit at ABC on July 22 and 31, and August 17. P.T. stands for permafrost table.

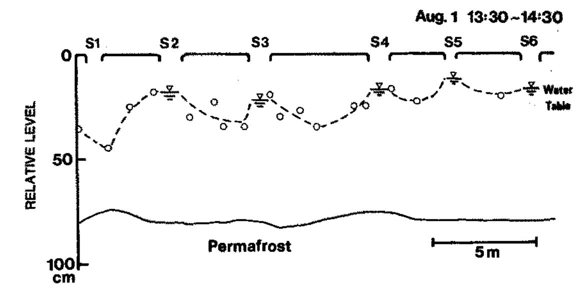

Fig. 11. Surface flow, and water table and permafrost table for the experimental cross section, near ABC on August 1, 13: 30–14:30. S1 – S6 shows sections of stone boulder.

around surface the flow mentioned before. On August 1, the runoff of surface flows in the stone boulders and water table under them was observed. An experimental cross section was established at a right−angle to the slope direction at 5760 m (Fig. 11). Surface flow flux is determined by the velocity−cross section method and direct measurment by a bucket. Total flow was $0.5-1.0\times10^3$ cm^3/s, while the total subsurface flow in the whole cross−section was 1.5 cm^3/s, which was calculated from the following Darcy's law.

$$Q=KIA. \qquad (2)$$

where K: saturated water conductivity
I : hydraulic gradient
A: area of cross−section

These parameters in the present case took the values $K=1.3\times10^{-4}$ cm/s, $I=0.1$, $A=1.3\times10^5$ cm^2, respectively. K was obtained from pumping test in the laboratory; I was assumed to be equivalent to the inclination of ground surface; and A was obtained by assuming that aquifer was 60 cm deep. The flux of surface flows in stone boulders is 2−3 orders larger than that of subsurface flow in the whole cross section. This suggests that the section of stone boulders is very efficient section in carrying melted snow and glacier water. Especially at a time of melting snow cover and when the active layer is thin, these flows have a more important role in runoff of melting water, because boulders in the area of large sorted stripes contribute to runoff. Structural characteristics of periglacial landforms are very important for considering movement of melted snow and glacier water.

4.4 Ground temperature

At BC minimum surface temperature was about 0°C until July 25 because of the effect of snowfall almost every night. In August, minimum surface temperature dropped below 0°C and the maximum became higher compared with period before July 25 because of less snow cover and less moisture. The mean value of surface temperature was 8.6°C (July 17−25) and 9.8°C (August 11−23). This is 5.2°C and 7.6°C higher than air temperature, and this difference is larger than in Arctic tundra. This effect was also mentioned in Sec. 4.1. The temperature at 5 cm depth dropped below 0°C only twice during the observation period (July 17−25, August 11−23).

5. Concluding remarks

The present observation focussed on the warmest summer season when water is most available. Characteristic processes can be understood by comparing conditions at sites BC and ABC. Although the altitude difference was less than 600 m between BC and ABC, the surface ground layers at the two sites showed quite different tendencies in soil moisture and permafrost depth. This is due to the following facts.

1) These two sites are in different stages of permafrost thawing in the annual cycle.
2) Difference in soil texture is quite prominent.
3) Different distances from the one large water source, that is, the glacier.

Ground conditions at BC may be more representative of this area, as ABC was very close to the glacier and its altitude was high.

From these observations, some interesting findings were revealed. A few of them are a) difference in altitudinal distribution of thawing depth above and below 5600 m (Fig. 4); b) non−uniform water discharge system in the sorted ground area. These phenomena were discussed more deeply in Aoki (1988), and will be analyzed further.

Acknowledgments

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References

Aoki, Y. (1988): Characteristics of water near the ground surface in the permafrost region in West Kunlun, China. MS. Thesis, Faculty of Science, Nagoya University. 115p.

Li, S. (1987): Permafrost and periglacial phenomena in the West Kunlun Mountains of China. Bulletin of Glacier Research, **5**, 103−109.

Ohata, T., Takahashi, S. and Kang, X. (1989): Meteorological conditions of the West Kunlun Mountains in the summer of 1987. Bulletin of Glacier Research, **7**, 67−76.

Takahashi, S., Ohata, T. and Xie, Y. (1989): Characteristics the of heat and water fluxes on glacier and ground surfaces in West Kunlun Mountains. Bulletin of Glacier Research, **7**, 89−98.