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Mass balance studies on Chongce Ice Cap in the West Kunlun Mountains

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Abstract

Mass balance observations on an inland ice cap of summer–accumulation type were carried out in summer, 1987. Vertical profiles of oxygen isotopic composition in surface snow layers of the ice cap were obtained for dating each seasonal snow layer. One year cycle of the isotopic variation of precipitation was clearly seen in the profile where a dirty winter layer had the minimal value of heavy isotope content. Altitudinal profiles of accumulation, ablation and balance during August were obtained from precipitation, amount of refreezing of infiltrated water and balance at the surface. The pattern of altitudinal profile of the surface balance in August, 1987 was similar to that of the amount of snow deposit after the previous winter. The mass balance during the 2 years from the end of July 1985 to July 1987 tended to decrease at a higher rate with lowering of altitude on the lower part of the ice cap, in comparison with that in August 1987. For mass balance of glaciers in the West Kunlun Mountains under a continental climate, evaporation–sublimation is considered to be important for ablation, and refreezing of infiltrated water contributes to preservation of ice mass, owing to coldness of the glacier.

1. Introduction

The West Kunlun Mountains lie in the northwestern part of Xizang (Tibet) Plateau. Although this area adjoins the arid Taklimakan Desert, there are many glaciers in these mountains. According to Zhang *et al*. (1989), there are 317 glaciers with a total area of 1,495km^2 on the southern slope of the West Kunlun Mountains; large portion of the glacier area is occupied by valley glaciers (73%) and ice caps (flat–top glaciers, 13%) (Zhang and Jiao, 1987). The glaciers in this area are typical 'continental–type glaciers'.

As one of the studies for clarifying the process of preservation of many glaciers in the arid inland area of Asia, observations were carried out on an ice cap to study the characteristics of glacier mass balance in this area, as part of the research work by the Sino–Japanese Joint Glaciological Expedition in the West Kunlun Mountains in 1987. Preliminary results of analyses of mass balance including composition of the oxygen isotopes in surface layers of the ice cap will be described in this report.

2. Outline of the observations

The Chongce Ice Cap (35°14'N, 81°07'E) on the southern slope of the West Kunlun Mountains was observed from the end of June to the end of August. This ice cap has an area of 16.4km^2, which makes it the second largest ice cap in this area (Zhang and Jiao, 1987), and has highest and lowest altitudes of 6374m and 5750m, respectively, as shown in Fig. 1.

The annual precipitation at Kangxiwar in the West Kunlun area (3986m a.s.l., 240km west–northwest from the observed ice cap) is 37.7mm on an average (1963–1984); and 71% of that occurs from May to August (Zhang and Jiao, 1987). At Hotan

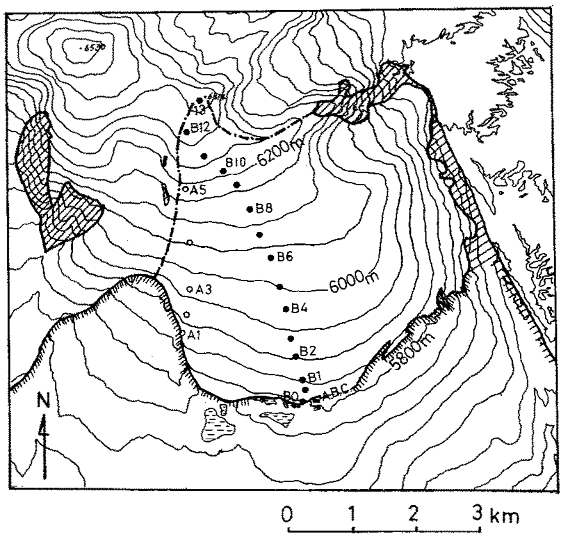

Fig. 1. The Chongce Ice Cap, and positions of stake stations and Advance Base Camp (A.B.C.). (after Chen *et al.*, 1989)

(1375m a.s.l.), 230km northwest of the ice cap, 63% of the annual precipitation of 33.4mm (in average of 1954–1980) is also concentrated during the above 4 months. Accordingly, the glaciers in the West Kunlun Mountains belong to the 'summer–accumulation type' (Ageta and Higuchi, 1984). On such glaciers, much of the annual accumulation and ablation occur simultaneously in summer.

Positions of stakes along 2 observation lines on the Chongce Ice Cap are shown in Fig. 1. Since 5 stations along the western line on the ice cap (A1–A5) were set at the end of July 1985 by a reconnaissance party of our expedition, the changes of surface levels for 2 years could be measured along this line. Results obtained at 15 stations along the central line on the ice cap (B0–B13) are mainly described in this report.

Stratigraphic observations of snow pits were carried out on the ice cap mainly in August. Continuous snow/ice samples at 5cm–depth intervals were taken at 7 stations to obtain vertical profiles of oxygen isotopic composition.

3. Snow stratigraphy and isotopic profile of surface layers

Results of stratigraphic observations on surface snow layers and oxygen isotope composition of those layers are shown in Fig. 2. Oxygen isotopic composition is expressed by the relative deviation, δ, of the heavy isotope content ($^{18}O/^{16}O$) of a sample from that of the Standard Mean Ocean Water.

The profile of the oxygen isotope composition of the surface layers shows the distinct minimal value around the shallowest dirt layer at each station, though the profile of the lower part tends to have less variation. Since the dirt is concentrated in snow during the dry season, the dirt layer is considered to be

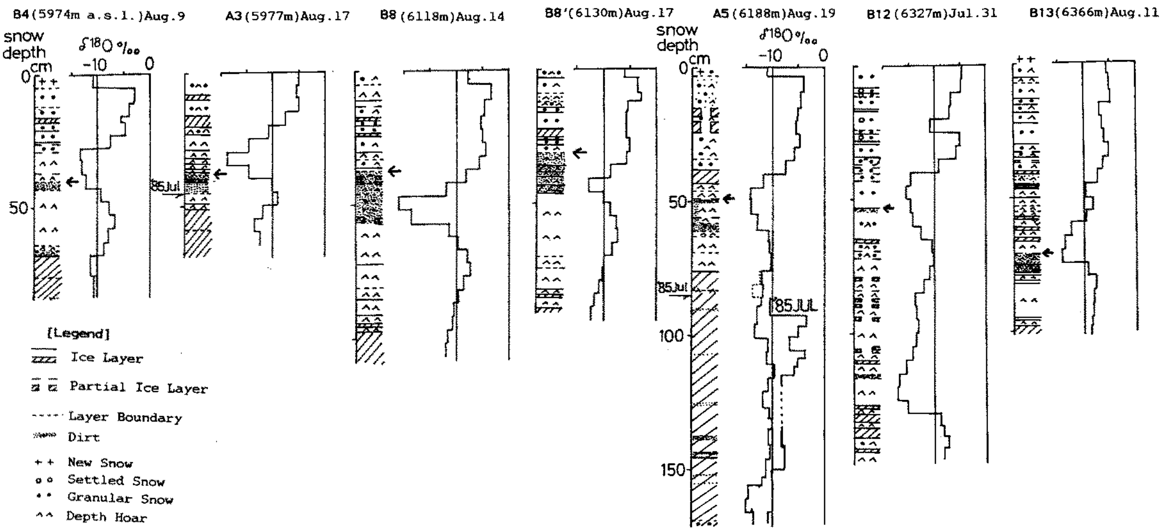

Fig. 2. Stratigraphic columnar sections and profiles of oxygen isotopic composition at stations on the Chongce Ice Cap in 1987.

formed in winter. It can be seen in Fig. 2 that the heavy isotope increases in the following summer layer near the surface, which is thicker than the winter layer due to more precipitation.

Although there are no isotopic measurements of winter precipitation in the West Kunlun area, it can be confirmed that the heavy isotopic content of summer precipitation is higher than that of winter precipitation, because summer precipitation has higher values than run−off water from glaciers which roughly represents the annual mean composition. Consequently, it can be said that the isotopic profile in the surface layers keeps an annual cycle of the isotopic variation of precipitation, though melt water has the effect of redistribution of the isotopic composition.

In the ice layers at Stations A3 and A5, the surface levels on July 27, 1985 can be detected from stake measurements, as shown in Fig. 2. In the upper part above this level at each station, only one isotopic minimum in winter can be seen in the isotopic profile. Since air temperature in July and August was higher and summer precipitation from June to September less at Kangxiwar in 1985 than those in average of 1963−1984, and snow cover thickness above the continuous ice layer was only around 5cm and 20cm at A3 and A5, respectively at the end of that month in 1985 (Watanabe and Zheng, 1987), there is a possibility that the 1985 layer was absent to the upper part of the ice cap.

The oxygen isotope profile on the lower part is smoothed and shows lower content of the heavy isotope in comparison with that on the upper part at Station A5 in Fig. 2. On the contrary, the isotopic profile in temperafe glaciers usually shifts toward higher content. A typical example is seen in a result in Iceland (A'rnason, 1981), where melt water with lower content of the heavy isotope due to the isotope fractionation percolates out through snowpack. In the case of the Chongce Ice Cap, which belongs to the sub−polar type, melt water from the upper layer infiltrates into the lower part and is considered to be refrozen there due to low snow/ice temperature. As seen also in the result at Station A5 in Fig. 2, the isotopic profile of the surface layers in 1985 (Watanabe and Zheng, 1987) shifted to lower content of the heavy isotope during 2 years. Quantitative examination is necessary on the changes of isotopic composition in ice−water systems on an ice cap of sub−polar type.

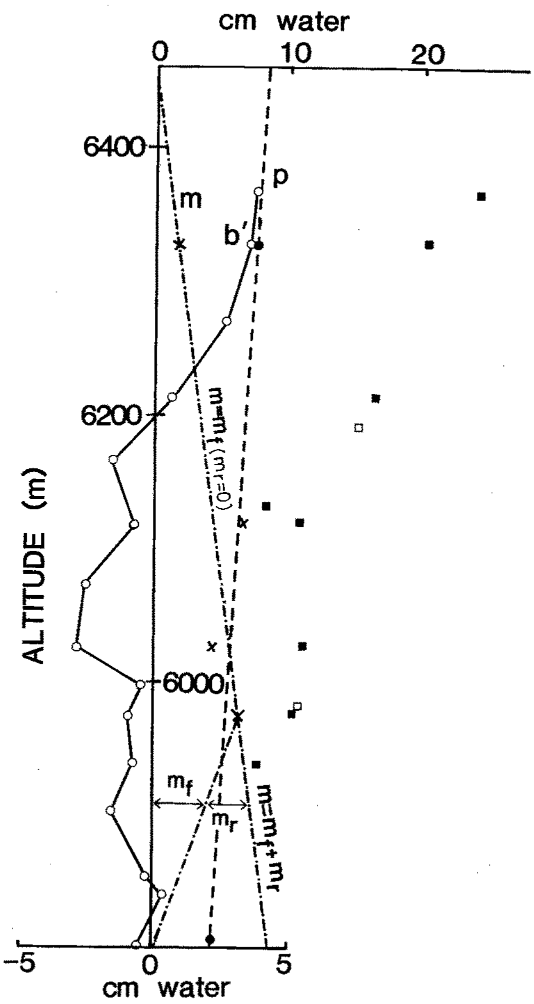

Fig. 3. Altitudinal profiles of precipitation (p), surface balance (b') and amounts of melt water ($m=m_f+m_r$) along the central line of the Chongce Ice Cap in August (1st−26th), 1987 with the lower horizontal scale. Amounts of snow deposit on August 26 after the previous dry season (above the levels indicated with arrows in Fig. 2) are also shown by squares with the upper horizontal scale (open squares show results along the western line).
m_f: refreezing water, m_r: run−off water
[measured value]
p: solid circle, b': open circle, m: cross

4. Preliminary results of mass balance elements

Since most accumulation and ablation occur in the same season on summer−accumulation type glaciers, it is difficult to observe accumulation and ablation separately. In addition, direct observation of the balance is also difficult, because infiltrated melt water refreezes and causes growth of ice layers in the snowpack, showing a complicated distribution as seen in Fig. 2. Therefore, mass balance elements need to be estimated from relevant observational data on the basis of some assumptions.

In this report, mass balance at each station is described dividing them into surface balance (balance at the glacier surface) and balance (balance including refreezing water as internal accumulation). Relations between elements of the mass balance are as follows.

accumulation: $c=p+m_f$
ablation: $a=-(m+e)$
balance: $b=c+a=(p+m_f)-(m+e)$
surface balance: $b'=p+a=p-(m+e)$

Here, p and e are the amounts of precipitation and sublimation(evaporation)−condensation, respectively. All precipitation on the ice cap was solid, even in the warmest season. The amount of melt water, m, is divided into refreezing water (m_f) and run−off water ($m_r=m-m_f$). Other factors, for example drifting snow, are neglected.

Figure 3 shows the altitudinal profiles of the observational results concerning mass balance along the central line of the ice cap in August (1st−26th), 1987 when intensive observations were carried out. Surface balance (b') in Fig. 3 was calculated from the stake measurement and snow density data at every station. The altitudinal profile of precipitation (p) is given as linear from data at 2 stations near the top (B12) and at the terminus (Advance Base Camp) of the ice cap. The amounts of melt water (m) were observed at 6 stations by collecting percolated melt water with a plastic bottle (8cm in diameter and 11cm in depth). This bottle, being filled with snow, was buried in snowpack at around 10cm below the surface at the upper edge of the bottle, and the increased weight of the bottle was measured. A linear profile of the amount of melt water against altitude was obtained, excluding unreliable data at 2 stations. The proportion of refreezing water in melt water was roughly estimated from data on growth of superimposed ice and snow temperature at each station to be 100% above 5970m in altitude and 0% at the terminus as shown in Fig. 3.

The amount of snow deposited above the first dirt layer represents the surface balance (partly including m_f) after the previous dry season (winter) at each main station. Those amounts on August 26 above the levels indicated with arrows in Fig. 2 are plotted also in Fig. 3. A pattern of the altitudinal profile of them is similar to that of the surface balance in August, as seen in this figure.

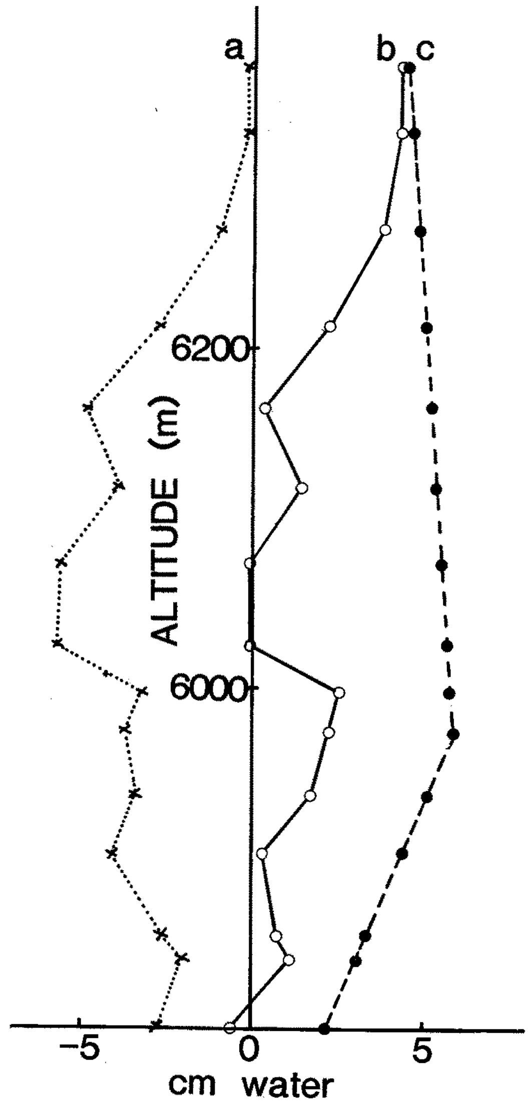

Fig. 4. Altitudinal profile of accumulation (c), ablation (a) and balance (b) along the central line of the Chongce Ice Cap in August (1st−26th), 1987, calculated from the results shown in Fig. 3.
($c=p+m_f$, $a=b'-p$, $b=b'+m_f$)

On the basis of the results shown in Fig. 3, accumulation ($c=p+m_f$), ablation ($a=b'-p$) and balance ($b=b'+m_f$) in August (1st−26th) at every station along the central line were estimated and shown in Fig. 4. It can be seen in this figure that the profile of balance below about 6,200m was irregular, and the balance in August, 1987 was positive as a whole.

Mass balance during the 2 years from the end of July 1985 to the end of July 1987 could be obtained along the western line of the ice cap from observations of changes of snow surface level and ice surface level, and an altitudinal profile is shown in Fig. 5. It can be seen in this figure that the equilibrium line altitude during this period was 5930m. The mass balance tends to decrease at a higher rate with lowering of altitude on the lower part of the ice cap. Such a pattern is distinctly different from that in August, 1987 as shown in Fig. 4. This difference is thought to be related to critical glacio–meteorological conditions. For example, when snow cover disappears for a long time on the lower part of the ice cap, ablation is accelerated by radiation due to the low albedo of bare ice. In this case, the altitudinal profile of mass balance can assume a pattern like that in Fig. 5.

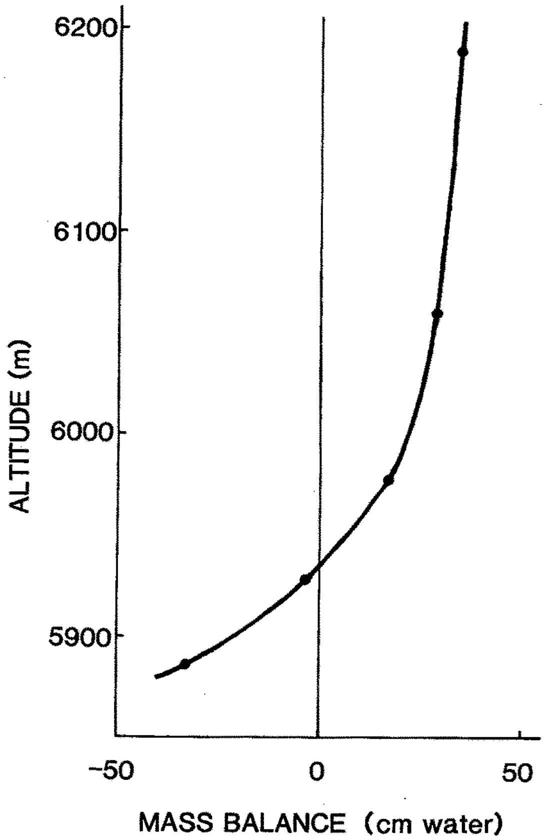

Fig. 5. Mass balance during 2 years from July 27, 1985 to July 29, 1987 along the western line of the Chongce Ice Cap.

5. Characteristics of mass balance of continental–type glaciers in the West Kunlun Mountains

Some characteristics of the glacier mass balance in the West Kunlun Mountains attributable to the continental climate were found from observational results on Chongce Ice Cap. One of them is the importance of evaporation–sublimation for ablation of the glaciers, as also reported by Takahashi *et al.* (1989) on the basis of glacio–meteorological observations on this ice cap.

Since precipitation from July 29 to August 4 was negligible, the surface balance during this period which was obtained by the stake method corresponds to ablation. The relation between ablation and mean air temperature during the period at every station along the central line and the western line on the ice cap is shown in Fig. 6. Air temperature at each station was calculated by use of the temperature lapse rate during this period which was obtained from data near the top (at Station B12) and near the terminus (near Station B1) of the ice cap, as 0.59°C/100m.

An example of a small glacier (Glacier AX010) during summer in the Nepal Himalaya (Ageta *et al.*, 1980) is also shown in Fig. 6. As seen in this figure, similar amounts of ablation occur in the West Kunlun at air temperature around 4°C lower than that in

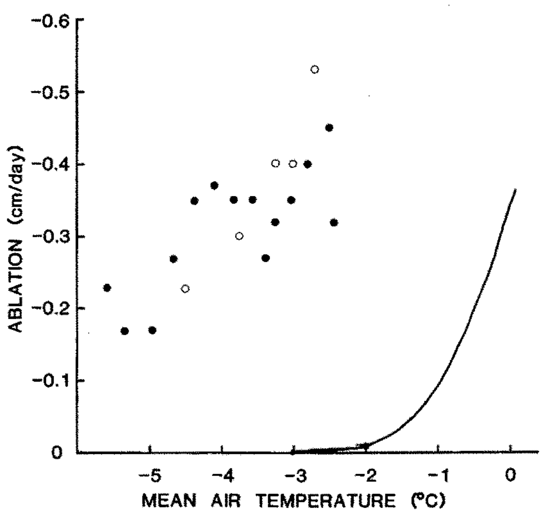

Fig. 6. Relations between ablation and mean air temperature during the period from July 29 to August 4 at every station along the central line (solid circle) and the western line (open circle) of the Chongce Ice Cap. A curve shows the relation during summer in the Nepal Himalaya (Glacier AX010: after Ageta *et al.*, 1980).

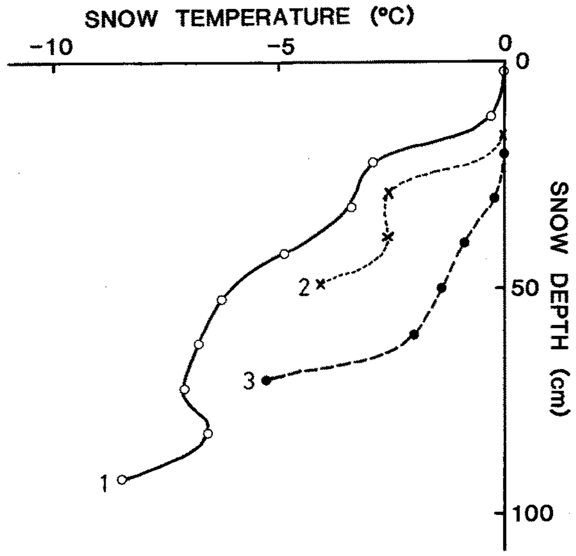

Fig. 7. Snow temperature of the surface layers of the Chongce Ice Cap in the middle of August, 1987.
1: St. B8 (6118m a.s.l.), 14th/15h LT
2: St. A3 (5977m a.s.l.), 17th/16h LT
3: St. A5 (6188m a.s.l.), 19th/13h LT

Nepal, namely, under air temperature range below about −2°C in this case. This suggests a large contribution of evaporation−sublimation to ablation due to the dry continental climate in the West Kunlun.

As described in the previous section, most of the infiltrated melt water in the ice cap refreezes in the snowpack due to its low temperature. This means little contribution of melting to mass loss of the ice cap; the coldness contributes greatly to preservation of the ice mass in the area of poor precipitation.

This cold characteristic is seen in the snow temperature of the ice cap surface layers as shown in Fig. 7. The observations were made roughly at the warmest hour in the warmest season. The thickness of the 0°C layer was only a few tens of cm in the ice cap, but in the case of a small glacier in the Nepal Himalaya (Gl. AX010: 5000m−5300m a.s.l.), which is also the sub−polar type, snow/ice temperature was nearly 0°C from the surface to around 1m in depth at the same season, the middle of August (Tanaka *et al.*, 1980). In the accumulation area of the ice cap, snow/ice temperature decreases from −8∼−9°C at 1m depth to −14∼−16°C at a depth between 5m and 20m (Zhou, T., personal communication).

Shi and Xie (1964) pointed out the coldness of glaciers in northwestern China compared with other areas. This cold characteristic of the glaciers is attributed to the severe decrease of air temperature in winter due to the inland effect, in addition to the high location of the glaciers.

6. Concluding remarks

Preliminary results of analyses of mass balance of the Chongce Ice Cap are described in this report. However, field observations by our expedition were limited to only a few months during summer. The mass balance throughout a year should be studied, coupling the field data of glaciology and glacio−meteorology with climatological data around this area. For the above study of this glacier area, the morphological difference between ice caps and valley glaciers which occupy the largest portion of the glacier area must be taken into account. The former has an ablation area of belt−shape along the terminus with a small altitudinal span; the latter has one of tongue−shape with a much lower terminus than the former. This difference porbably causes the difference of the glacier regime between them.

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