Bulletin of Glacier Research 7 (1989) 45 – 48.

Movement of Chongce Ice Cap and recent variations of some glaciers on the south side of West Kunlun Mountains.

CHEN Jianming[1], Masayoshi NAKAWO[2], Yutaka AGETA[3], Okitsugu WATANABE[4] and LIU Lansheng[1]

1 Lanzhou Institute of Glaciology and Geocryology, Academia Sinica Lanzhou, China
2 Nagaoka Institute of Snow and Ice Studies, Suyoshi, Nagaoka, 940 Japan.
3 Water Research Institute, Nagoya University, Nagoya, 464–01 Japan.
4 National Institute of Polar Research, Kaga 1–9–10, Itabashi, Tokyo, 173 Japan.

(Received December 9, 1988; Revised manuscript received January 20, 1989)

Abstract

Surface velocity and strain rate of the Chongce Ice Cap were determinated by the methods of intersection and rhomboid network over a period of two years (1985–1987) or one year (1987–1988). The surface velocities and strain rates were of the order of 3m/a, and 10^{-3}/a respectively. Positional variation of glacier termini were obtained, by comparing maps on a scale of 1:50,000 and field observations, during a period from 1970 and 1987. It was found that the termini of the Chongce Ice Cap and the Guozha Glacier have not changed much in their position. The Chongce Glacier, however, has retreated by about 420 m in the period.

1. Introduction

Measurement of glacier movement is an important basis not only for studying glacier dynamics but also for obtaining relationships between glacier development and climate, and for predicting the trend of glacier variations in the near future. No data, however, are available on the movement of glaciers in the West Kunlun Mountains. The surface velocities and strain rates of the Chongce Ice Cap were measured using the traditional technique. The variations of glacier size, including glacier area, glacial advances and retreats as well as the changes of glacier thickness reflect climatic changes in the past. The evolution of the Quaternary glacier and environmental changes in the West Kunlun Mountains is reported by Zheng *et al.* (1990). In this report, therefore, only the basic characteristics of the Chongce Ice Cap and recent variations of glacier termini near the ice cap are described.

2. Movement of the Chongce Ice Cap

The movement of the ice cap was obtained by measuring the displacements of marker stakes, installed on the ice cap, in a certain period. The positions of the stakes at each time were observed by a triangulation survey method using a "Wild T–2" theodolite. Surface strain rate was observed by measuring changes in relative distance of stakes, installed as a rhombus network, with a Sokkisha "Redo–1A" electronic distance meter, or with a steel tape.

The rhombus network consisted of five stakes, one of which was at the center of the rhombus, and one of the diagonals was in the direction of flow. The stakes of the strain network were placed so that the length of each side was roughly equal to ice thickness at the site, which was reported by Zhu (1989).

The positions of marker stakes were surveyed by Chen *et al.* (1989), and are given in Fig. 1. Five stakes A1 to A5, were placed in July, 1985, and resurveyed in August, 1987. Fourteen stakes, B1 to B12 and C1 to C2, were installed in July, 1987. Their displacements were measured about one year later, in August, 1988. Two strain grids were prepared at B4 and B12. The measurement period for the B4 grid was the same as for the stakes (1 year), but that for the B12 grid was only one month, July to August, 1987.

The results of the surveys are given in Tables 1 to 4, in which flow directions are given in degrees clockwise from North. It can be seen in Table 1 and Table 2 that the flow speeds are roughly 3 m/a, which is rather small on the ice cap. The maximum annual speed in 1985−1988 was found, at A4 and B9, to be about 3.9 m/a, which is much less than the velocity of valley glaciers with similar size (LIGG, 1986).

Based on actual observed data, an empirical formula of annual surface velocity (U_s) for the Chongce Ice Cap was found as follows:

$$U_s = 2.90 \times 10^{-3} \alpha H^2$$

where U_s is given in m/a, α is the surface slope in radians, and H represents the ice thickness in m. This expression shows that the surface velocity is directly proportional to the surface slope and the square of the thickness. The form of the expression is slightly different from those commonly used (Paterson, 1981), but our equation gave a good fit to the data as mentioned below. The equation was compared with the actual surface velocities at points A2 to A4 and B1 to B12. The maximum difference between the calculated and measured values was 0.34 m/a and did not exceed the limit of surveying error (see Table 2).

Table 1. Surface flow vectors along A line. Reliable ice thickness data were not obtained at A1 and A5.

No.	Height	Displacement	V(m/a)	Flow direction	$U_s = K\alpha H^2$	$\partial u/\partial x$ 10^{-3}1/a
		1985.7.29−1987.8.24			(m/a)	
A5	6188	6.92±0.48	3.34	177	*	+0.69
A4	6059	8.17±0.30	3.94	182	3.38	−0.33
A3	5977	7.64±0.19	3.69	186	3.44	−2.28
A2	5930	6.36±0.13	3.07	188	3.02	−2.87
A1	5887	4.86±0.10	2.35	189	*	

Table 2. Surface flow vectors along B and C lines.

No.	Height	Displacement (m)	V(m/a)	Flow direction	$U_s = K\alpha H^2$ (/a)	$\partial u/\partial x$ 10^{-3}1/a
		1987.7.28−1988.8.12				
B12	6327	1.34±0.44	1.28	188	1.31	+3.17
B11	6270	2.50±0.42	2.39	150	2.29	+1.93
B10	6213	3.88±0.41	3.71	165	3.92	+0.11
B 9	6165	4.13±0.40	3.94	170	3.89	+1.90
B 8	6118	3.66±0.38	3.50	169	3.71	+0.44
B 7	6073	4.01±0.36	3.83	178	4.16	0
B 6	6025				3.75	?
B 5	5997	3.75±0.32	3.58	190	3.61	−2.25
B 4	5974	3.75±0.31	3.58	191	3.51	−1.42
B 3	5936	3.60±0.28	3.40	183	3.25	−3.19
B 2	5902	2.80±0.02	2.63	183	2.83	−1.31
B 1	5854	2.30±0.01	2.17	190	2.25	
C 2	5840	1.79±0.01	1.69	192	1.35	
C 1	5801	0.50±0.01	0.47	194	0.28	

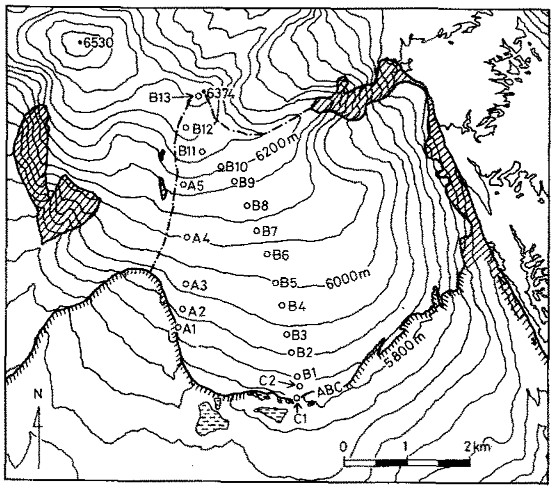

Fig. 1. Positions of marker stakes on the Chongce Ice Cap (after Chen *et al.*, 1989). ABC: Advance Base Camp.

Possible reasons for the slow ice cap movement are as follows: 1)the source of glacier mass is smaller, mean annual accumulation on the ice cap being 0.3 to 0.5 m/a (Ageta *et al.*, 1989; Kang, 1989); 2) the ice cap is a continental−type glacier, and it is conjectured from temperatures observed in bore−holes that the bottom temperature of the ice cap is −5.7°C to −13°C and the ice mass is frozen completely on the bed rock (Zhou Tao, private communication); 3) radio echo sounding showed clearly several ridges and relief forms on the ice bed (Zhu, 1989), and the ice tongue terminus is obstructed by a terminal moraine 20−30 m high.

The velocity distribution along longitudinal profiles of the Chongce Ice Cap is similar to that of valley glaciers, that is, the velocities increase to the equilibrium line from the top or source, and decrease gradually toward the terminus. The velocity distribution is parabolic, as shown in Fig. 2a and 2b.

The surface strain rate at B4 was calculated using data from July 18, 1987 to August 12, 1988, and from July 22, 1987 to August 25, 1987 for B12. The results are shown in Tables 3 and 4. From the observed

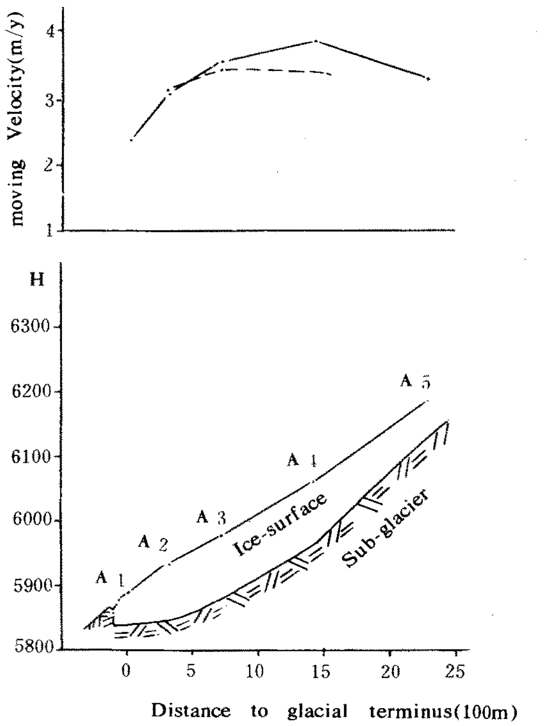

Fig. 2a. Longtudinal profile A of the moving velocity of the Chongce Ice Cap.

longitudinal strain rate $\partial u/\partial x$, and transversal strain rate $\partial w/\partial z$, the vertical strain rate $\partial v/\partial h$ perpendicular to the glacier surface and the shear strain rate $(\partial u/\partial z+\partial w/\partial x)/2$ were calculated by the least square method, as shown in Tables 3 and 4. Each stake line A or B is approximately parallel to a flow line, and hence, longitudinal strain rate can be calculated from gradients of velocity data. Strain rates thus obtained are shown in Tables 1 and 2.

These tables show the distribution of surface strain rates on the southern part of the Chongce Ice Cap: the longitudinal strain rates are +0.003/a to −0.003/a from the upper part to the terminus of the ice cap; the longitudinal strain rate is positive at B12 while the strain rates are negative at B4. The transverse strain rates are all positive, +0.0042/a at B12 and +0.0024/a at B4.

As the ice mass moves, it deforms plastically under gravity, and characterized by the extension flow in the upper part and compression flow toward the terminus, and diffusion flow vertically downward. It is considered that the extension area is above 6000 m a.s.l. and the compression area below 6000 m a.s.l.. However, both parts were characterized by lateral expansion. The transverse strain rate in the upper part is twice that in the lower part. The strain rate distribution seems to explain the fan−shape of the Chongce Ice Cap.

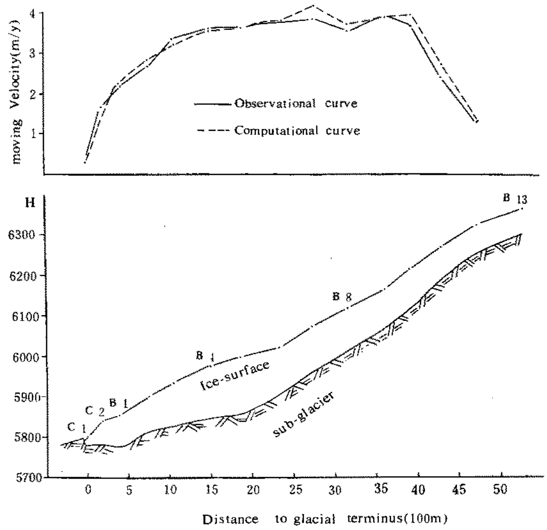

Fig. 2b. Longitudinal profile B of the moving velocity of the Chongce Ice Cap.

Table 3. Surface strain rate at B12.

$\partial u/\partial x$ (1/a)	$\partial w/\partial z$ (1/a)	$(\partial u/\partial z+\partial w/\partial x)/2$ (1/a)	$\partial v/\partial h$ (1/a)
$+2.60*10^{-3}$	$+4.18*10^{-3}$	$+3.38*10^{-3}$	$-6.77*10^{-3}$

Table 4. Surface strain rate at B4.

$\partial u/\partial x$ (1/a)	$\partial w/\partial z$ (1/a)	$(\partial u/\partial z+\partial w/\partial x)/2$ (1/a)	$\partial v/\partial h$ (1/a)
$-1.43*10^{-3}$	$+2.35*10^{-3}$	$-2.28*10^{-3}$	$-0.92*10^{-3}$

3. Recent variations of glacier terminus

The recent variation of the southern margin of the Chongce Ice Cap was obtained by a repeated survey. It was found that the glacial terminus retreated about 1−2 m during 29th of July 1987 to 13th of August, 1988. For obtaining the change for a rather long period, the positions observed on the ground in 1987 were compared with stereo air photographs taken in 1970. Because the margin of the Chongce Ice Cap contacts the ground surface smoothly, obvious

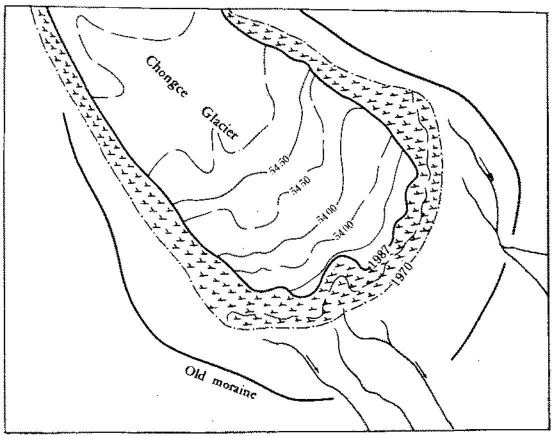

Fig. 3. Terminal variation of the Chongce Glacier.

topographic points were very hard to find. In addition, the average scale of air photographs was 1:50,000 *i.e.*, there is a significant amount of error (about 15 m) involved in the interpretation. Thus, it was very difficult to interpret small variations of the glacier terminus correctly. The variations of the terminus of the Chongce Ice Cap, however, are considered very small in the past 17 years. This is compatible with the position of the terminal moraine, which also indicated that the glacier did not advance or retreat much. The Gozha Glacier and an another glacier adjacent to it were also stable in the past 17 years; this was deduced with reference to an obvious bedrock lump (like a roches moutonnées) near the terminus clearly identified in an aerophotograph. Although Zhang and Jiao (1987) suggested that it is advancing, the ice tongue of the Chongce Glacier was found to have retreated by about 420 m ($\pm$14m) during the past 17 years, with the annual rate of 24.7 m. The recent retreat is consistent with the such distribution features grass growth on the ground surface, dry or wet boundary on the ground surface, exposure of sub-ice and no single serac in front of the glacier tongue (there are isolated seracs on both sides of the glacier tongue). The surface height of the Chongce Glacier has fallen by about 20 m during the last 17 years.

As mentioned above, three glaciers adjacent to the Chongce Ice Cap are considered very close to the stationary state. Only the Chongce Glacier and Zhongfeng Glacier (Zhang and Jiao, 1987) have retreated much. Advancing and retreating glaciers exist in close proximity in other areas, for example, the Batura Glacier in the Karakorum, Pakistan, is advancing, but the Pasu Glacier near it is retreating (Shi, 1980). The factors which cause advancing and retreating in the same area are complicated.

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