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Glaciological importance of microorganisms in the surface mud-like materials and dirt layer particles of the Chongce Ice Cap and Gozha Glacier, West Kunlun Mountains, China

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Abstract

Samples of surface mud-like material (cryoconite) and dirt layer particles from the Chongce Ice Cap and Gozha Glacier in the West Kunlun Mountains were analyzed for the mineral- and microbiota -content.

Mud-like material (cryoconite) covering the surface of the ablation area of the Gozha Glacier was mainly composed of granular aggregations of filamentous blue-green algae (mainly *Ocillatoria* 2 spp.), bacteria and mineral grains. It contained 10.6 μg/g chlorophyll a and 4.8 to 14.4 percent of organic matter, most of which was found to be microorganisms, in dry weight. This suggested that the production of these microorganisms formed a great part of the mud-like material in wet mass on this glacier, and accelerated surface melting of the ablation area by absorbing the solar radiation more effectively than snow, ice and airborne mineral grains. But, the percentage of the microbial production in the mud-like material of this glacier was smaller than those of Himalayan and Greenland glaciers.

Dirt layer particles in the ice core samples bored in the accumulation area of the Chongce Ice Cap (6,130m a.s.l.), contained many granular colonies of bacteria with occasional blue-green algae, besides very fine mineral grains, possibly loess. The presence of these organisms strongly suggested that those layers experienced melting or melt-water percolation which is essential for their growth. After further works, the microbial contents could be a new information source in ice core analysis for the studies on past environmental change of this area.

1. Introduction

Mud-like material covering glacier surfaces and small particles forming visible dirt layers in glacial strata are often observed in many types of glacier. But, since the glacier has long been believed to be an almost non-biological environment, most glaciologists appear to have unanimously believed them to be airborne accumulations (Grove, 1960; Orheim, 1975) and called them "mud" or "dust". However, as for the surface mud-like material, several biologists already reported in early studies on the Greenland Ice Cap that the material, deposited at the bottoms of characteristic cylindrical holes in the surface ice of the ice cap, contained a large amount of microorganisms such as blue-green algae, and applied the name "cryoconite" to the material (Steinböck, 1936; Gerdel & Drouet, 1960). And, Kol and Peterson (1976) studied the algae in the mud-like material of the New Guinean glaciers, and discussed the effect of their growth on the glacier ablation process.

Recently, the present author showed on a Himalayan glacier (the Yala Glacier, Langtang region, Nepal) that not only the mud-like material but the dirt layer particles, collected by a full depth boring of 60 m at the accumulation area, were also mainly composed of granular aggregations of blue-green algae and bacteria, both were feeding newly found cold-tolerant animals (insects and copepods) living in the glacier (Kohshima, 1984a and b, 1987, 1988), and suggested that the growth of these micro-plants formed a dirt layer annually and accelerated ablation rate by covering the glacier surface (Kohshima 1984b, 1987).

These studies indicated the glaciological importance of these microorganisms, especially in mass-balance study and ice core analysis.

From this view point, this study aimed to clarify the contents of the surface mud-like material (cryoconite) and the dirt layer particles of glaciers in the West Kunlun mountains, and discuss their origin and glaciological implications by comparing with those of other glaciers.

This study was a part of the research by the Sino-Japanese Joint Glaciological Expedition in the West Kunlun Mountains in 1987.

2. Field description

The research was carried out on the Chongce Ice Cap (35°14'N, 81°07'E) and Gozha Glacier located on the southern slope of the West Kunlun Mountains lying in the northern part of Xizang (Tibet) plateau of China (Fig. 1).

The Chongce Ice Cap (6,530-5,800 m a.s.l.) is the second largest ice cap in this area with two noticeable peaks (6,530 m and 6,374 m a.s.l.) and a gentle slope, extending over an area of 16.4km^2 (Zhang & Jiao, 1987). The ice samples which enclose the dirt layer particles were collected in the accumlation area of the ice cap (6,130 m a.s.l.) by mechanical drilling (Nakawo *et al.*, 1989).

The Gozha Glacier is partly fed by the western part of the Chongce Ice Cap at the point about 5,900 m a.s.l. and the terminus locates at 5,400m in a.s.l. This glacier, especially its western half, had a very rough surface with many crevasses and ice seracs. The surface mud-like materials were observed and collected on the eastern half of the glacier, which was fed by the Chongce Ice Cap.

The glaciers of this area are of "continental type" with arid climate and low ice temperature (Zhang *et al.*, 1989) and "summer-accumulation type" in which both the main accumulation and ablation occur during summer (Ageta & Higuchi, 1984, Ageta *et al.*, 1989). The field research period was July 15 to August 28, 1987. In this period, the area above about 5,900 m a.s.l. of these two glaciers were always covered with new

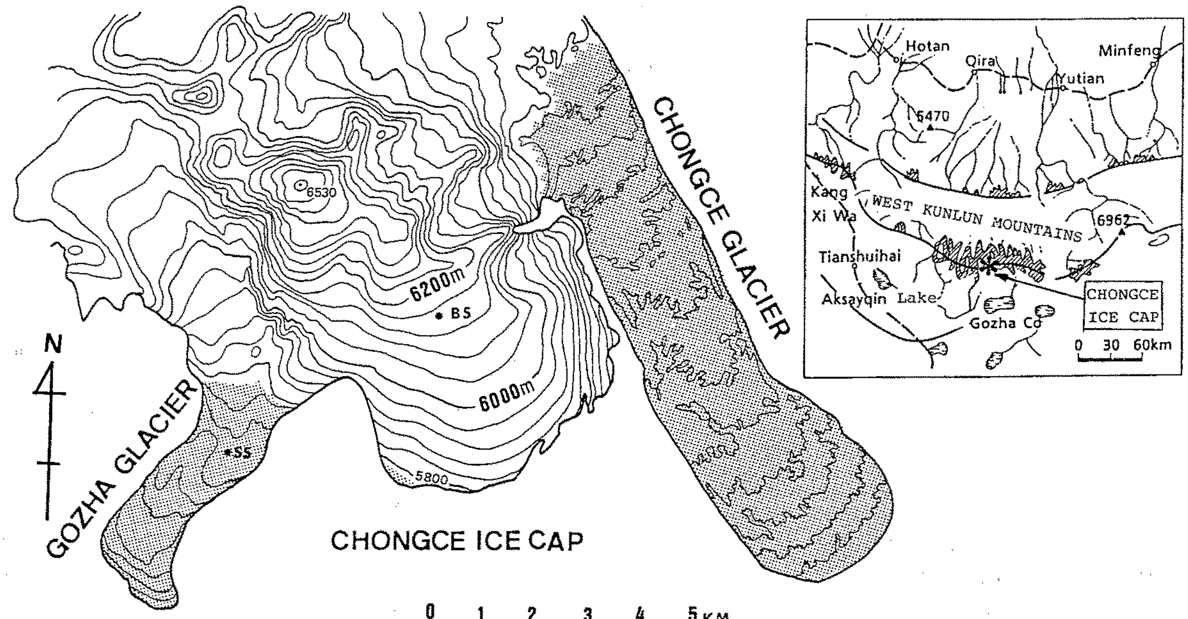

Figure 1: Map of the Chongce Ice Cap and Gozha Glacier, showing the sampling site and distribution of surface mud-like material (dark colored area). BS: boring site. SS: sampling site of surface mud-like material.

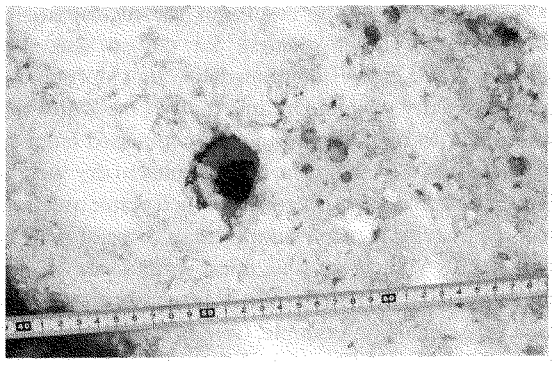

Figure 2: Cryoconite holes (cylindrical hole) with mud-like material (cryoconite) at the bottom, observed under the new snow cover on the Gozha Glacier.

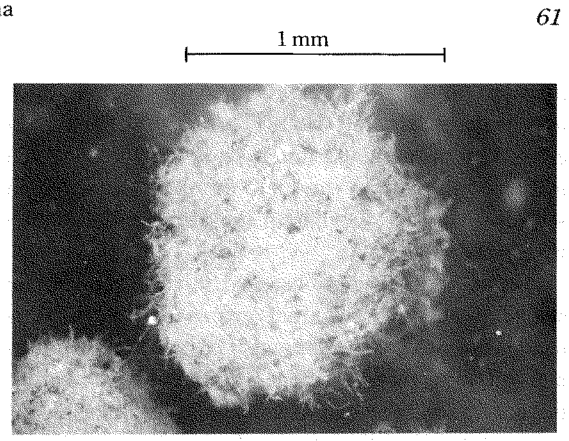

Figure 3: Mud-like granule (cryoconite) with much filamentous blue-green algae.

snow by frequent snow fall.

3. Surface mud-like materials

3.1. Distribution of mud-like materials and cryoconite holes

During the study period, almost all of the surface of the Chongce Ice Cap was covered with new snow and only the area near the terminus (5,800 m a.s.l. occasionally showed clean and smooth bare ice without debris. However, on the surface ice of the area lower than about 5,750 m a.s.l. where a part of the ice cap branches as the eastern half of the Gozha Glacier (Fig. 1), dark colored mud-like material was observed under the new snow cover (Fig. 2). It mainly consisted of small brown granules ranging from 0.1 mm to 2.0 mm in diameter and deposited on the flat bottoms of vertical cylindrical holes (cryoconite holes) with some water. The holes ranged from a few millimeter to about 30 cm in diameter and in depth. Each minute hole of a few millimeter in diameter contained a single mud-like granule at the bottom, and the larger holes contained many granules forming a single layer on the flat bottom beneath the water. The size of these holes increased as altitude or inclination of the surface decreased. In a slightly lower area about 5,700 m a.s.l. many large cryoconite holes were observed. In this area many melt-water drainage channels, pools and water-filled crevasses were also observed among seracs and crevasses. The bottoms of these structures beneath the water, were characterized with closely spaced, many large cryoconite holes. And, the slanting surface of the seracs were slightly tinted brown due to the mud-like granules in minute cryoconite holes covering the surface. It seemed that the holes tended to be larger at the place with much stable water.

Samples of these mud-like materials, collected and preserved in 3% formalin or 70% ethanol solution, were analyzed.

3.2. Structure and contents of mud-like material

All samples of the mud-like material from various structures of ice, showed a similar microscopic structure and contents. They mainly consisted of brown colored spherical granules ranging from 0.1 mm to 2.0 mm in diameter. The granules were spherical aggregations of filamentous blue-green algae and bacteria, with some fine mineral grains tightly bound by the long algae filaments (Fig. 3). The most abundant algae were the following four species of filamentous blue-green algae (Cyanophyceae); *Ocillatoria* 2 spp., *Schizothrix* sp. and *Sphanocatsa* sp., and the following unicellular green algae species (Chlorophyceae), free floating in the water or mixed with mud-like granules, were also found; *Protococcus* sp., *Cyrindrocystis* sp. and *Trochschia* sp.

The amount and long filaments of the algae clearly indicated their active growth on the glacier, and the tight aggregation of the algae and bacteria seemed to suggest that the granules were symbiotic colonies of these microorganisms in which the algae probably depending on the bacteria for nitrogen and carbon dioxide, and bacteria depending on algae for their nutrients.

The structure and size of the material were very similar to those of the mud-like material on a Himalayan glacier (Kohshima 1984), but the flora of dominant filamentous blue-green algae was quite different.

In addition to these micro-plants, one species of brown colored water-bear (Tardigrada), a kind of microscopic animal (0.4 mm in body length) was found in the samples from the melt-water streams, but insects which were populer in the Himalayan glaciers were not found.

Mineral materials observed in the samples consisted of clear, transparent grains of quartz, some orange stained grains, yellowish brown stained grains, a few bluish green stained grains and black grains, possibly mica. The grains ranged from less than 0.05 mm to 1.2 mm in diameter, and many large grains (0.5 – 1.2 mm in diameter) with sharp edges and little evidence of weathering or surface erosion, were contained besides very fine grains, possibly loess. Such large grains were never seen in the dirt layer particles in the ice of the accumulation area. They might have been wind-transported over a short distance from the adjacent moraines and permafrost areas, and it is very probable that the "seed" algae are also transported from these environments and "re-seed" the lower part of the glacier.

To know the contribution of the micro-plant production in formation of the mud-like material, the amounts of chlorophyll a and organic matter of the mud-like material were measured. The amount of Chlorophyll a was measured by absorption spectrophotometry, and the organic matter was measured by a following simple gravimetric analysis. After oven-drying (70℃, 6 hours), a few drops of nitric acid were added and the ashing completed over a Bunsen burner. The percentage of weight reduction by this manupilation was measured.

Table 1 shows the results of the measurements with those of other glaciers for comparison. The sample of this glacier contained 10.6 μg chlorophyll a per 1.0 g in dry weight. Organic matter, most of which was found to be microorganisms, comprised from 4.8 to 14.4 percent of the oven-dry samples in dry weight. Since algae and bacteria contain much water and their specific gravity is much smaller than those of mineral grains, the volume of the micro-organisms in wet granules is accordingly much larger than that of mineral grains. For example, Gerder and Drouet (1960) analyzed the mud-like material of the Greenland Ice Cap and reported that the organic matter, which was found to be largely blue-green algae and comprised 13.9 - 20 percent of the oven-dry samples (Table 1), occupied about 95 percent of the wet mass. Thus, the results suggests that a great part of the mud-like material on the Gozha Glacier is also formed by growth of the microorganisms. But, Table 1 indicates that the percentage of the microbial production in the mud-like material on this glacier is smaller than those of Himalayan and Greenland glaciers.

3.3. The effects of the microbial production on glacer ablation

The microorganisms in the mud-like material of this glacier seem to accelerate surface melting of the ablation area by producing dark-colored materials which absorb the solar radiation more effectively than snow, ice and pale-colored airborne mineral grains. On a Himalayan glacier, Kohshima (1987) observed that a plot of the glacier surface covered with the mud-like material was ablated faster than a plot experi-

Table 1. Amount of organic matter and chlorophyll a in cryoconite (mud-like material) of the glaciers.

Name of Glacier and its location	Sample site	Altitude of sample site (a. s. l.)	Organic matter % in dry weight (mean value)	Chlorophyll a μ g/g in dry weight
Gozha Glacier West Kunlun Mountains	surface of ice seracs	5,700 m	14.4 %	—
	Bottoms of melt-waters	5,700 m	4.8 – 11.0 % (8.6 %)	10.6
Yala Glacer Nepal Himalaya	Bottoms of melt-waters	5,100 m	6.3 – 22.0 % (14.4 %)	21.6
Greenland Ice Cap Thule Area (from R. Gerder and F. Drouet, 1960)	Bottoms of cryoconite holes	1,700 m	15.7 %	—
		1,900 m	19.2 %	—
		2,000 m	20.1 %	—

mentally cleared of the material, by about 6 cm per day in September.

In particular, blue-green algae, the most dominant algae in the mud-like material, seem to have an important role in this effect, because the algae use the radiation wave length primarily in the blue region between 0.40 and 0.65 m, where snow and ice have the greatest transmissivity (Gerder and Drouet, 1960). Kol and Peterson (1976) studied the mud-like material on the New Guinean glaciers and reported that the material, which was found to contain much blue-green algae, selectively absorbed most strongly in the blue-green region, and an increase in temperature of the material over the surrounding ice and water, under uninterrruped sunlight, was from 1.2°C to 7.5°C.

Since, even in the mid-summer, the surface of the ablation area of this glacier was usually covered with a new snow layer, through which only the diffused sunlight with short wave length could reach the ice surface, absorption by the blue-green algae in the mud-like material is thought to have an important role in surface melting in the ablation area of this glacier. Many cylindrical holes with the mud-like material at the bottom, observed in the ice surface under the new snow cover, seem to support this assumption.

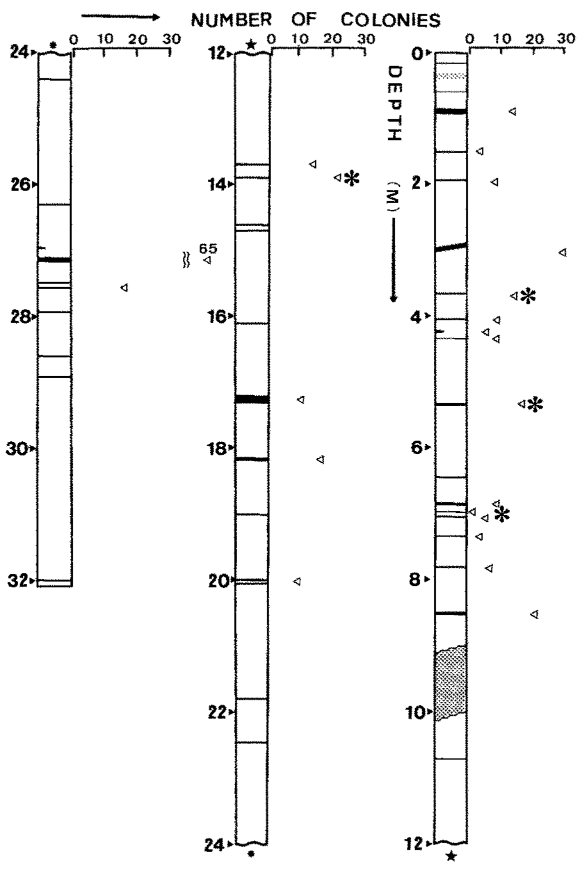

Figure 4: Dirt layers in the ice core from Chongce Ice Cap. (modified from Han *et al.*, 1989) Sediments of each samples were well stirred in 20 ml water and the number of bacterial colonies in a view field of x100 microscope were counted. black lines in columns: dirt layers.
*: dirt layers with algae

4. Dirt layers and the dirt layer particles

4.1. Dirt layers in the ice core

Dirt layers observed in the strata of this glacier were not so conspicuous as those reported from Yala Glacier, a Himalayan glacier (Kohshima, 1987). In many cases , they were only vague snow or ice layers dimly tinted yellowish brown without clear boundaries, but some were more conspicuous layers with darker color and clear boundaries.

The samples of the dirt layer particles were collected from the 32 m-long ice core bored in the accumlation area of the Chongce Ice Cap (6,130 m a.s.l.) by mechanical drilling in August, 1987 (Nakawo *et al.*, 1989). Thirty seven visible dirt layers were observed in this ice core (Han *et al.*, 1989) and 22 of them were sampled for this study (Fig. 4).

The parts of the ice core containing dirt layers were melted in clean polyethylene bags and preserved as 3 % formalin solution in clean polyethylene bottles. These operations were completed on the gracier site, and the samples were analyzed in the laboratory of Kyoto University, Kyoto Japan.

4.2. Contents of the dirt layer particles

All samples analyzed were composed of many fine mineral grains, some granular bacterial colonies (Fig. 5) and small organic debris (mainly minute fragments of plant tissue).

The mineral grains included many clear, transparent grains of quartz, some yellowish brown stained grains and a few black grains, possibly mica. The grains were very small. Most of the mineral grains were less than 0.2 mm in diameter; very fine quartz grains less than 0.05 mm in diameter were predominant. Those mineral grains seemed to be loess deposition (Watanabe & Zheng, 1987). A loess fall associated with northeasterly wind was observed to slightly tint the surface snow yellow on August 13, 1987 on the Chongce Ice Cap.

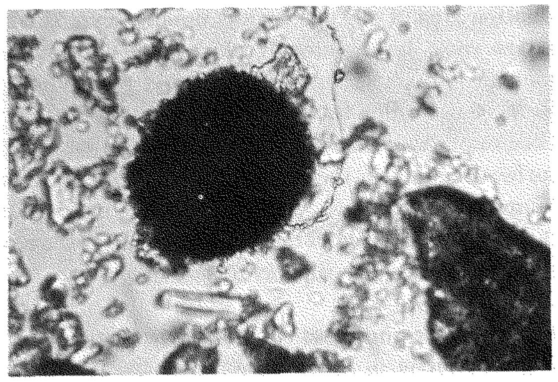

Figure 5: A bacterial colony with a short fragment of blue-green algae, observed in a sample of the dirt layer particles.

4.3. Bacterial growth in the dirt layers.

The bacterial colonies (unidentified) in the samples took a spherical form and blackish color (Fig. 5). The size of the colonies ranged from 0.02 mm to 0.2 mm in diameter. The large colonies occasionally associated with a small amount of filamentous blue-green algae, possibly *Schizothrix* sp. or unicellular algae, possibly some species of snow algae.

The spherical form of the granular aggregations of bacteria indicates that they are never accidental aggregations of air-borne bacteria fallen on the glacier, rather, that they are the colonies formed by proliferation of the airborne "seed bacteria" deposited in the glacier.

4.4. Glaciological implication of the bacterial growth

Since liquid water and organic matter are essential for bacterial growth, the presence of bacterial colonies in dirt layers indicates that these layers experienced melting or percolation of melt-water from the upper strata, and contained some organic matter.

The number of colonies significantly varied among layers (Fig. 4). Because, even in mid-summer, melting and percolation can occur only in a layer very near the surface (within a few tens of cm in depth) at the boring site (6,130 m a.s.l., Ageta *et al.*, 1989), the variety in bacterial growth among the layers is thought to correspond with that of the extent and duration of surface melting during some period after the particle deposition, and/or amount of airborne organic matter deposited in those layers. And, since the sun lay is essential for algal growth, occasional association of algae with bacterial colonies strongly suggests that the layers with such particles experienced melting or melt-water percolation at the depth so near the surface that enough amount of sunlight for algal growth could reach them.

In a Himalayan glacier (the Yala Glacier) which also belongs to the "summer accumulation type", but is an "marine type" glacier with wetter and warmer climate and high ice temperature, the dirt layers contained far more amount of filamentous blue-green algae (*Phormidium* spp.) associated with granulous bacterial colonies, which was almost the same structure and contents as the surface mud-like granule on the ablation area (Kohshima 1984, 1987). The difference in the algal growth between these two glaciers seems to come from the differences in some condition for the algal growth in the glacial strata of the accumulation area; for example, amount of melt-water, the sunlight and/or inorganic nutrients the algae can use.

After further works, the microbiota-contents such as bacteria and algae could be a new source of information in ice core analysis for the studies on past environmental change of this area. For example, the amount of bacterial growth seemed to be a possible index of "warmness" of past climate of this region.

5. Concluding remarks

This report pointed out the glaciological importance of the microorganisms in the glaciers of the Kunlun Mountains, in particular, the effect of the microbial production on the surface melting in the ablation area and the meaning of the bacterial growth in the glacial strata of the accumulation area. However, to clarify the "biological effect" on glacier mass-balance and to obtain more information in ice core analysis from the microbial contents, further works on the growth condition and productivity of these organism are needed. More basic studies on the biology of these organisms and comparative studies on flora and fauna of various types of glaciers, will also expand our understanding of the glacier.

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