Discovery of Quaternary glacial evidence of Snow Mountain in Taiwan, China

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Abstract There are glacial remains of three different periods on the main peak of Snow Mountain in Taiwan province, including cirque lake, crosswall, polished surface, striation, moraine etc. These three different periods were called, respectively, Shanzhuang ((44.25 ± 3.72) kaBP), Shuiyuan ((18.26 ± 1.52) kaBP), and Xueshan glacial stages (the late period of last glaciation). It is characterized by the earlier glacier broad in scale.

Keywords: Snow Mountain peak, last glaciation, three glacier remains, evidence.

The problem whether there are glacial remains of last glaciation on the high mountains of Taiwan province or not, has come into existence in academic field since a long time ago. Except that the Japanese geologists were certain that there existed the glacial remains of last glaciation on the high mountains of Taiwan[1–6], the geologists of Taiwan wrote two reports to challenge the theory of the Japanese geologists in the 1950s. But they also emphasized that the cause of the valleys existing from top to bottom of Nanhudashan Mountain needs to be further researched[7, 8].

Based on their field studies, Japanese geologists, such as Shikano, believed that the glacial remains must exist on the high mountain zones more than 3 300 m in altitude. They estimated that there are about 80 cirques on the high mountains of Taiwan. Among them, there are 35 cirques in Snow Mountain district, their altitude is above 3 500 m[9]. There are 12 cirques in Nanhudashan Mountain, their altitude is usually above 3 300 m. The altitude of these cirques are related with the place of snow line, therefore, based on the altitude of cirques, Shikano believed that the snow line of Snow Mountain and Nanhudashan Mountain was, respectively, situated on the altitude of 3 500 and 3 400 m (fig. 1).

The geologists of the mainland, basing on the Japanese material, also support the concept of existing glaciation of Quaternary on the high mountains of Taiwan, although they are not quite sure about it[10]. Y. Ono also had the same concept[11].

1 Evidence of glacier existence

Based on the field work in summer of 1998, there are three aspects about the evidence of Quaternary glaciation on the peak district of Snow Mountain: depression of ice erosion and crosswall in the source of No. 2 U-shaped valley; polished surface broad in scale and striation in the middle of No.1

U-shaped valley; moraine sediment in the upper, down of No.1 U-shaped valley (fig. 1).

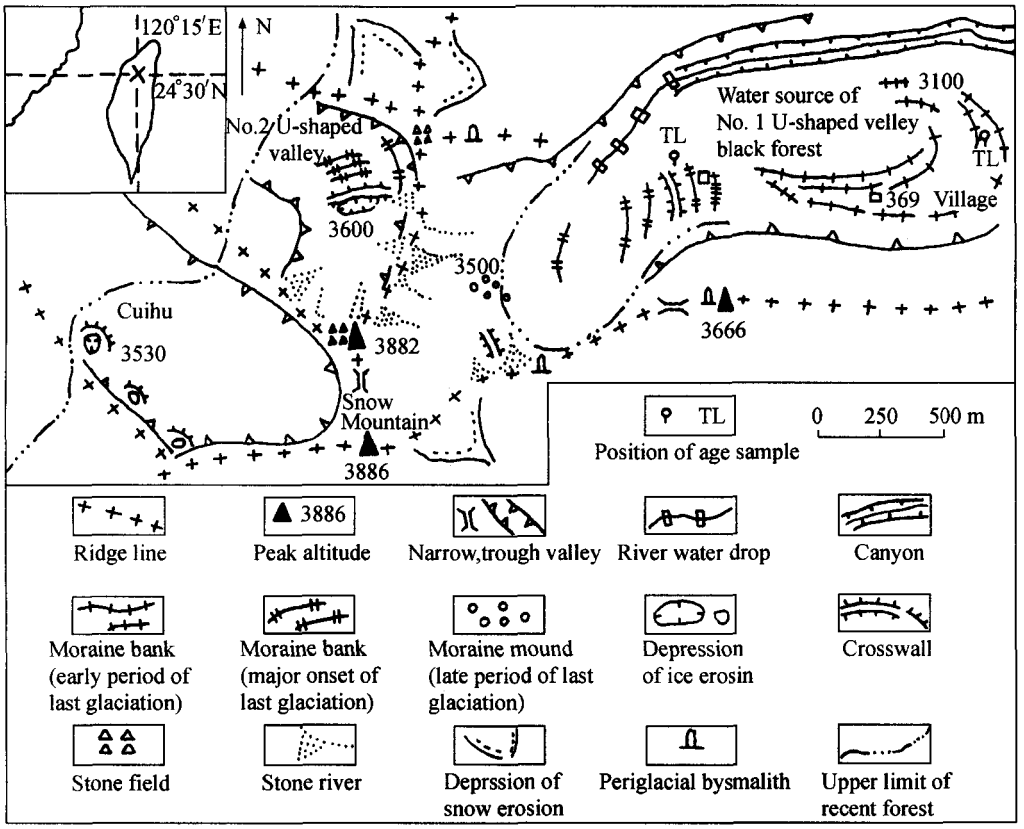

Fig. 1. The distribution of glacial remains of the main peak district of Snow Mountain of Taiwan of last glaciation.

(i) Depression of ice erosion and crosswall. The broad valley, which was located in the northwest of Snow Mountain, was called No. 2 U-shaped valley by the authors. There existed the typical combination of cirques and crosswalls in its source (fig. 2). Cirque was the depression of rock

Fig. 2. No. 2 cirque of Snow Mountain (photographed by Yang Jianfu).

caused by the excavating and transporting of shearing face in the down part of glacier, while crosswall was convex rock below the cirque. The landform and its combination can not be explained by other dynamic processes and are the special character of glacial landform. The depression of ice erosion of No. 2 U-shaped valley was 7 m lower than the top of crosswall, but the original lake sediment of depression has been covered by the gravel of taluvium, so the height difference from the top of crosswall to the bottom of depression is more than 10 m (fig. 3). We should drill in the sediment of cirque lake in order to get the series paleoclimate records since the last glaciation (e. g. Holocene). It is error that some geologists believed that the crosswall discovered in the valley of Nanhudashan Mountain and No. 2 U-shaped valley of the main peak of Snow Mountain was landslide accumulation. Based on the field work, the crosswall made up of sand stone, which was identical with the sand stone of the both sides of crosswall, in that their strike direction and inclination were the same, respectively, NW60° and NE25° . So it is no question that this protrude rock is a crosswall. The sand stone is ironbound and tough and was determined as feldspar-quartz sand stone of middle-fine granule. Its mineral composition is quartrz, 40%—50%, feldspar, 15%—20%, and rock detritus, 10%. But the rock detritus has been made into didrimit and clorite. The original rock can be formed by the low temperature deterioration of volcanite. Especially, its cement was silica and second crystallizing material of chemical liquid. So it has strong ability to challenge the weathering. The similar crosswalls are distributed around the main peak district of Snow Mountain.

Fig. 3. Ice erosion basin and crosswall (3 600 m) (photographed by Cui Zhijiu).

(ii) Polished surface broad in scale and striation. A polished surface broad in scale was discovered in the southern side of the middle of No. 1 U-shaped valley, which is located in the black forest 200 m higher than the directory board of the water resource and 3 400 m in altitude (fig. 4). Actually, it is also the place of the crosswall broad in scale. The areas of the bare polished surface just on the climbing path are about 5—6 square meters, it is only a small part of the whole crosswall. This crosswall extend 70 m on the southern slope nearby this path. There are many middle-big type of striation and bigger type of groove on the polished surface. The well marked groove on the polished surface will be seen if you remove the covered sod on the northern side of the path. In addition, there are glacial moraine rocks with striations on the climbing path. It is estimated that this crosswall could be cirque mouth of Shanzhuang glacial stage (e.g. snow line).

(iii) Glacial moraine. There are a few glacial moraine banks corresponding to the above-mentioned depression of ice erosion and the crosswall outside of the crosswall of No. 2 U-shaped valley and a lateral moraine bank on the eastern side of this valley. There are moraine materials of three different periods corresponding to the landform of ice erosion on No. 1 U-shaped valley.

The highland of glacial moraine nearby the "369" village. These moraine zones extend from the

Fig. 4. Polished surface and striations of No. 1 U-shaped valley of Snow Mountain (3 400 m) (photographed by Cui Zhijiu).

place 1 km lower than "369" village to "refuge place", its length was more than 2 km and from 3 000 m to 3 400 m in altitude. All the glacial moraine usually concentrated on the southern side of No. 1 U-shaped valley. In addition, the northern side of "369" village is a canyon if you see from "369" village. It is estimated that there existed a stream on the side of the glacier and it became an efferent duct of the melting water of this glacier because its strike direction was northeastern-southwestern and eastern-western, the southern slope had been received more sunshine to make the glacier melt fast when the glacier was forming. This glacier was eroded to form the canyon with the crust uplifted after the period of last glaciation. The highland nearby the "369" village assumed banding along the valley. Its lithologic composition was complex, including sand stone, slate, quartzose sandstone and quartz vein etc. It had deep weathering and assumed red-yellow color. The shape of the highland surface was subdued and there existed no drift boulder. It is very interesting that there existed field lawn but the forest did not develop very well. Based on the distribution of different kinds of glacial moraine and their form characters, and further by the contrast with the high mountains of the mainland, this kind of glacial moraine was believed earlier than that of the last glaciation. Its age is (44.25 + 3.72) kaBP (TL). There existed an obviously chill period in the earlier period of last glaciation (60—50 kaBP). So it should belong to the earlier period of last glaciation[13—15] and it was tentatively called Shanzhuang glacial stage. At that time, the length of glacier was about 4 km and the snow line was 3 400 m in altitude.

A few glacial moraine banks nearby the water resource in black forest. The lower bound of their distribution was about 3 300 m in altitude. There are a series of small waterfall below them which further reach canyon. There are 4—5 glacial moraine banks to reach the tree line about 3 500 m in altitude, including the above-mentioned crosswall and polished surface about 3 400 m in altitude. The ending moraine banks was about 15 m in height, 100—150 m in length. They are all concentrated on the southern side of valley, which is formed by two causes. One is that the U-shaped valley is a homoclinal valley, its northern slope is precipitous and the southern slope is subdued, the river bed and canyon concentrated on the northern side, therefore, the glacial moraine banks of the southern side is easy to be reserved. The other is that the glacier of the southern slope melted faster to make the glacier attenuate faster and to reserve fewer glacial moraine for the stronger sunshine, because No. 1 U-shaped valley extended along the northeastern direction, the different entrance angle and different slope formed the different melting. But the situation of the northern slope is reverse, so the glacial moraine banks are broad in scale and easy to be reserved. This kind of glacial moraine bank has not only a well marked

shape but also drift rocks on the surface. In addition, three terminal moraine banks (fig. 3) outside of the combination of the depression of ice erosion and crosswall of No. 2 U-shaped valley and the corresponding lateral moraine banks belonged to the same period. According to the above-mentioned altitude and the form character and the contrast with nearby districts, this combination of ice erosion and glacial moraine should belong to the major onset of last glaciation. The age of the lower and upper parts of the sediment in black forest is, respectively, (18.26 + 1.52) kaBP and (14.28 + 1.13) kaBP, average age is (16.27 + 1.19) kaBP. It is tentatively called Shuiyuan glacial stages by the authors. At that time, glacier was about 3 km in length, its ancient snow line was about 3 500 m in altitude, which has the same altitude with the upper limit of the forest of the present period.

(iii) The small lateral moraine bank and the moraine highland from the tree line (3 500 m) on No.1 U-shaped valley to the 3 700 m line on the northern steep slope of the main peak of Snow Mountain. There are two lateral moraine banks made up of huge boulders from the 3 700 m line of the northern side to the center of the valley (3 500 m). They are 250 m in length, 3 m in height. There is also a short lateral moraine bank on the southern side to reach the moraine highland (3 500 m). Especially, the bottom of valley where they are distributed is bellow the crosswall of Shuiyuan glacial stages, so they must be formed later than Shuiyuan glacial stages. Based on the form and distribution, we believed that they belonged to the late period of last glaciation and intent to call them Xueshan glacial stages. At that time, glacier was about 1.5 km in length, snow line was about 3 700 m in altitude (table 1).

Table 1 Series chart of last glaciation of Snow Mountain of Taiwan

Ice age	Glacial stage	Snowline elevation/m	Glacial tongue/m	Galcial type	Glacial length/km	AAR value	Age (TL) /kaBP	Contrast and source of references[12,13]
Last glaciation	Xueshan	3 700	3 500	cirque	1.5	0.55	14.28+1.13 10.68+0.84	late period of last glaciation, Karasawa ice stage (Japan)
	Shuiyuan	3 500	3 300	cirque-valley	3	0.5	18.26+1.52	major onset of last glaciation, late Zhiliangka ice stage (Russia)
	Shanzhuang	3 400	3 100	valley	4.5	0.45	44.25+3.72	early period of last glaciation, Yokoo ice stage (Japan), early Zhiliangka ice stage (Russia)

2 Contrast, environmental reconstruction and some viewpoints

According to the contrast (table 1), the main character of high mountains of Taiwan was the existence of early and late glacial stages in the last glaciation, which was similar to the series of last glaciation of Alps Mountain in Japan[11,12] but not similar to the situation of Chinese mainland. This difference made the authors understand that there were different types of regional glacier because they were affected by the season and the difference of geographic location caused the distinctness of the conditions of water and heat, e.g. one type is that there was a lot of precipitation in winter along the Pacific shore, the other type is that there were a lot of precipitation in summer in the interior of the mainland. But the former type was instrumental to the accumulation of glacier, which made the early and late period of last glaciation obvious in the high mountain of Taiwan and Japan. They were relatively sensitive to the climate changes. The glacial scale of the early period of last glaciation was the biggest. It is estimated that the precipitation of the early period was one third more than the major onset. The value of AAR was, respectively, 0.5 and 1.0 lower than the major onset and the late period. It indicates that the firn basin of cirque had the ample supply and a lot of ice.

Based on the researches of the glacial development of last glaciation, we found that the precipitation of the western shore of Pacific of that time was 15%—30% lower than that of the present time. But it did not have profound influence on the high mountain of Taiwan because its precipitation was up to 3 000 — 4 000 mm in a year, its glacial development was of the type of ocean climate and

now the temperature was 5° lower than that of the last glaciation. It would be in conformity to the conditions of the glacial development, if the average temperature of a year of snow line was kept from −1° to −3°.

Many references have substantiated that there were a few chill periods since Quaternary, especially the last glaciation, which took place from 70 to 10 kaBP. The Quaternary, especially the environmental vicissitude of last glaciation have become the most active program since 1970.

The snow line of northern slope of the main peak district of Xueshan Mountain was about 3 600 m in altitude, if we considered the altitude of the bottom of the cirque as that of snow line (we did not consider the uplift of mountain and the declination of sea surface). The snow line of the northeastern slope was about 3 500 m in altitude, which was a little lower than that of the northern slope. It indicated that the northeastern direction was toward the source of water steam and was instrumental to the snow accumulation. This was consistent with the estimated altitude.

There existed the glacial environment of the high mountain, which was substantiated by the pollen analysis and the fish researches. Liu Pingmei, Wang Xin, Tukuda took a point that there was a chill and dry period in the early period of last glaciation[13−15]. The gelsemium tortoise had lived in the ice age and, so far, has been reserved, which was the important evidence of glacier existing of Snow Mountain. They lived in the Qijiawan brook of Xueshan at the present time and have adapted themselves to the life of the high mountain environment. Taiwan was the most southern boundary of the distribution of this kind of fish. So the existence of glaciation of the main peak of Snow Mountain of last glaciation could explain the cause of the existence of this kind of fish.

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