

ESTIMATING THE AGE OF ROCK GLACIERS FROM WEATHERING RIND THICKNESS IN THE YARI-HOTAKA MOUNTAIN RANGE, NORTHERN JAPANESE ALPS

Masafumi AOYAMA

Abstract Formative periods of rock glaciers distributed in the Yari-Hotaka Mountain Range, northern Japanese Alps, were estimated from weathering rind thickness. The results suggest that the age of rock glaciers in the Minamisawa-Kita cirque and the most headward of the Tenguppara cirque is between the age of Early Yarisawa Stage II moraines and the Late Yarisawa Stage II moraines, and the age of rock glaciers in the northern part of the Tenguppara cirque and Ohkiretto cirque is same or younger than the age of the Late Yarisawa Stage II moraines. The ages of the Early Yarisawa Stage II and the Late Yarisawa Stage II are estimated to 15 ka and 10 ka. Therefore, rock glaciers in the Minamisawa-Kita cirque and the most headward of the Tenguppara cirque were considered to be formed during the Late Glacial Stage (15 ka-10 ka), and rock glaciers in the northern part of the Tenguppara cirque and Ohkiretto cirque were considered to be formed about 10 ka or the early Holocene.

Key words: rock glaciers, weathering rind thickness, relative dating, the Late Glacial Stage, Yari-Hotaka Mountain Range

1. Introduction

The ages of rock glaciers provide significant palaeoenvironmental information at certain periods because rock glaciers are indicators of mountain permafrost (Barsch 1996). In Japan, however, few studies (Shiki 1975) have been made so far at rock glaciers, and no studies have ever tried to investigate the age of rock glaciers in detail.

It is difficult to find organic materials at the rock glaciers because there are no interstitial fines between the clasts at the surface. Therefore, relative dating techniques such as weathering rind thickness and lichenometry are used (Barsch 1996). In the North American Mountains and the Southern Alps, there are several studies, which estimate the age of rock glaciers from weathering rind thickness (e.g., Birkeland 1973, 1982; Anderson and Anderson 1981; Kirkbride and Brazier 1995). Birkeland (1973) has shown that weathering rinds provide the best weathering index for relative age assignment. Birkeland (1982) identified five groups of Holocene glacial and rock glacier deposits in the Ben Ohau Range, by use of weathering rind.

In the Yari-Hotaka Mountain Range, northern Japanese Alps, there are many rock

glaciers and moraines (e.g., Imamura 1940; Kobayashi 1958; Shiki 1969; Shiki 1975; Iozawa 1979; Ito and Vorndran 1983; Aoyama 2000). The ages of glacial landforms were revealed with tephrochronology (Ito and Masaki 1989) and differences in the dissection of glacial landforms (Ito and Vorndran 1983). Therefore, the age of rock glaciers should be able to be revealed by comparing it with the age of moraines.

The purpose of this paper is to estimate the age of rock glaciers by using weathering rind thickness. Moreover, measurements of the Schmidt hammer rebound value were carried out at the several measuring sites of the weathering rind thickness.

2. Study Area

The Yari-Hotaka Mountain Range is located in the southern part of the northern Japanese Alps. There are many peaks in this mountain range that are higher than 3,000 m a.s.l. Investigated rock glaciers in this study are located in the upstream area of Yarisawa. Minamisawa-Kita cirque, Tengguppara cirque, and Ohkiretto cirque (Fig. 1). In the Yari-Hotaka Mountain Range, four glacial advance stages have been recognized (Ito and Vorndran 1983). In the study area, one of these four stage, called the Yarisawa Stage II moraines are distributed. The Yarisawa Stage II moraines are considered to have been formed between about 15 ka and 10 ka (Ito and Vorndran 1983). This age was estimated from differences in the dissection of glacial landforms (Ito and Vorndran 1983). The moraines of the Yarisawa Stage II are subdivided into two sub-stages such as the Early Yarisawa Stage II and the Late Yarisawa Stage II, based on the difference of distance from the cirque headwall. Most of the bedrock consists of the Maehotaka Welded Tuff and the Minamidake Tuff Breccia (Harayama 1990).

3. Measurement of Weathering Rind Thickness

Method

In this study, measurements of weathering rind thickness were carried out to follow previous studies (e.g., Watanabe 1990; Aoki 1994; Kariya 1995; Shimizu 1998). The method is as follows: (1) The measuring clast was restricted to that of the Maehotaka Welded Tuff. (2) 30 clasts were measured at each measuring site. (3) The weathering rind thickness is affected by the presence of late-lying snow (Thorn 1975; Ballantyne *et al.* 1989; Kariya 1995). Therefore, measurements of weathering rind thickness were carried out at the ridge crest on the surface of the rock glacier in order to minimize the possible influence of late-lying snow on the weathering rates. (4) The measuring clasts were selected from 5 × 5 m quadrats. The selected clasts were not covered with vegetation, and the long axes were over 20 cm. (5) The clasts were split with a hammer. The rinds on the upper surface, except for the corners and near joints, were divided into three parts, and the maximum weathering rind thickness for each part was measured to the nearest 0.5 mm with a ruler. Three measured values were averaged to calculate the weathering rind thickness of each clast.

The measurements of Schmidt hammer rebound values (R-values) were also carried out

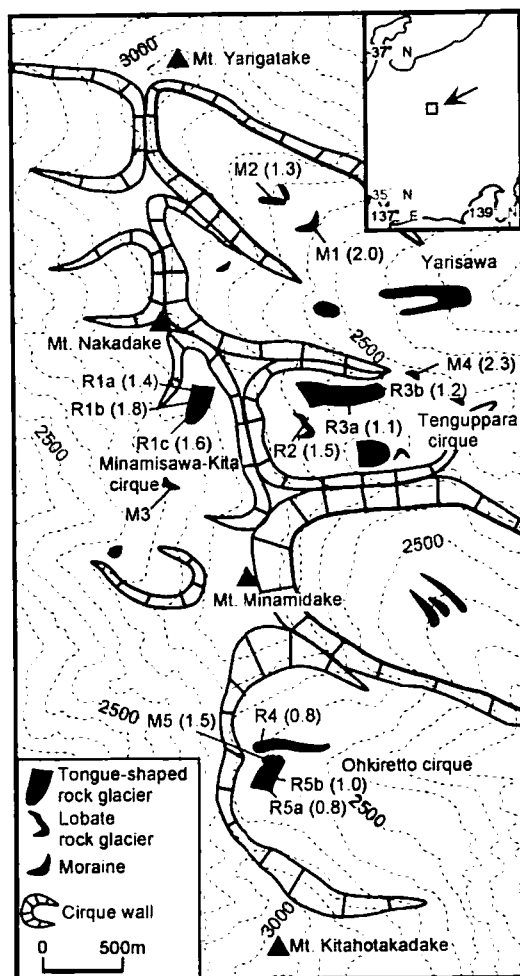


Fig. 1 Location of the measuring sites and average values of weathering rind thickness (mm).

at the part of the measuring site of the weathering rind thickness. Measurements of R-values were carried out to follow previous studies (e.g., Matthews and Shakesby 1984; Shiraiwa and Watanabe 1991). The method is as follows: (1) The measuring clasts were restricted to those of the Maehotaka Welded Tuff. (2) 30 clasts were measured at each measuring site. The impacts of the strikes of the Schmidt hammer are large, therefore boulder size clasts were selected to avoid the clasts shifts their position (Watanabe 1990). (3) Measurements of R-values were carried out on the upper surface of the clasts. (4) On each of these clasts, five measurements were made at different positions, providing 150 recorded measurements from each site. The maximum and minimum measured R-values were excluded from each clast, and the three remaining values were averaged to calculate the R-value for each clast.

Measuring site

1) Yarisawa upstream area

The measuring sites are shown in Fig. 1. The Ohyari moraine is located at 2,620 m a.s.l., and this moraine is a shaped arcuate ridge. This moraine is almost covered with vegetation (e.g., *Pinus pumila*). However, clasts are exposed sporadically. The measuring site (M1) is located around the central part of this moraine, where clasts are exposed. Many clasts are subangular and subrounded, and the long axes are from 40 to 60 cm. There are interstitial fines between the clasts. This moraine is assigned to the Early Yarisawa Stage II.

On the higher upstream side of the Ohyari moraine, Bouzuiwa moraine is situated at 2,690 m a.s.l. The measuring site (M2) is located on the ridge crest. At this moraine, many clasts are subangular, and the long axes are from 40 to 60 cm. There are no interstitial fines between the clasts. This moraine is assigned to the Late Yarisawa Stage II.

2) Minamisawa-Kita cirque

In the Minamisawa-Kita cirque, there is a tongue-shaped rock glacier that developed ridge and furrow relief on the upper surface (Aoyama 2000). Measuring site R1a is located on the upper part of this rock glacier, measuring site R1b is located on the middle of the rock glacier, and measuring site R1c is located on the lower part of the rock glacier. These measuring sites are located on the ridge crests of the rock glacier. Many clasts are angular and subangular, and the long axes are around 50 cm. There are no interstitial fines between the clasts at the surface. Vegetation does not cover most of the rock glacier, but *Pinus pumila* shrub is distributed sporadically.

An arcuate-shaped moraine M3 is located at the lower end of the cirque. Shimizu (1998) measured weathering rind thickness at this moraine. Many clasts at this moraine are subrounded, and the long axes are 30 to 60 cm. There are no interstitial fines between the clasts at the surface. There is little vegetation covering the moraine. This moraine is assigned to the Early Yarisawa Stage II.

3) Tenguppara cirque

Many rock glaciers and moraines are distributed in the Tenguppara cirque (e.g., Iozawa 1979; Koaze 1985; Aoyama 2000). A pronounced M-shaped ridge is located at the foot of the talus in the most headward part of the cirque. This landform is interpreted as a fossil rock glacier (Aoyama 2000). The M-shaped ridge had been recognized moraine (Iozawa 1979). However, the ridge is located at the foot of talus and cirque wall, and the distance from foot of talus is too short for the M-shaped ridge to be of the glacial origin. Since a ridge is formed as a result of the melting of interstitial ice of a rock glacier, the M-shaped ridge is interpreted as a fossil rock glacier. The ridge crest is rounded. The measuring site (R2) is located around the middle part of the M-shaped ridge crest. There are no interstitial fines between the clasts at the surface. Many clasts are angular and subangular, and the long axes are around 50 cm at this rock glacier. The rock glacier has little vegetation.

In the northern part of the Tenguppara cirque, a tongue-shaped rock glacier is located. Several arcuate ridges are situated on the rock glacier. Measurements of weathering rind thickness were carried out on the ridge in the middle part (R3a) and at the lower part (R3b) of the rock glacier. At the surface of the rock glacier, interstitial fines are absent and many clasts are angular and subangular. The long axes of these clasts are over 50 cm. The rock glacier has little vegetation.

A moraine assigned to the Early Yarisawa Stage II is located at the lower end of the Tenguppara cirque. This moraine is about 2 m high, and is almost covered with vegetation. However, clasts are exposed sporadically, and at the measuring site (M4), the clasts are exposed. Many clasts are subangular and subrounded, and the long axes are more than 50 cm.

4) Ohkiretto cirque

In the Ohkiretto cirque, a tongue-shaped rock glacier is located at the foot of the talus just under Mt. Kita-Hotakadake, and a lobate rock glacier is located at the foot of the talus just under Mt. Minamidake.

Transverse ridges are developed in the upper zone of the tongue-shaped rock glacier. In contrast, longitudinal ridges extend parallel to the downslope direction in the lower zone of the rock glacier. The measurements were carried out at the upper (R5a) and middle parts (R5b) of the rock glacier. There are no interstitial fines between the clasts at the surface. At this rock glacier, many clasts are angular and subangular, and the long axes are 30 to 50 cm. The rock glacier has little vegetation.

At the lobate rock glacier, many clasts are angular and subangular, and the long axes are over 40 cm. The measuring site (R4) is situated at the frontal crest of the rock glacier.

The arcuate-shaped moraine is situated adjacent of the frontal part of the tongue-shaped rock glacier. The moraine is almost covered with vegetation, and many clasts are subangular and subrounded. The long axes of these clasts are 40 to 60 cm. The measuring site (M5) is located on the crest of the moraine where the clasts are exposed. This moraine is assigned to the Late Yarisawa Stage II.

Results

The frequency distribution of weathering rind thickness for each measuring site is presented in Fig. 2, and the average values of the weathering rind thickness for each measuring site are presented in Fig. 1. At all of the measuring sites, the frequency distribution of weathering rind thickness has a single mode.

The average rind thickness values at M1 and M2 sites of the Early Yarisawa Stage II moraines are 2.0 mm and 2.3 mm, respectively. The rind thickness mode at M1 site is from 1.6 to 2.0 mm, and at M4 site is from 2.1 mm to 2.5 mm. The frequency distribution of the weathering rind thickness at the M4 shows relatively scattering. At M3 site of the Early Yarisawa Stage II, according to Shimizu (1998), the rind thickness mode is 2 mm, and the frequency distribution of the weathering rind thickness has a single mode.

The average rind thickness values at M2 and M5 sites of the Late Yarisawa Stage II moraines are smaller than that of the Early Yarisawa Stage II moraines, and those of both sites are 1.3 mm and 1.5 mm, respectively. The rind thickness modes are from 0.6 to 1.0 mm (M2) and 1.6 to 2.0 mm (M5).

The average rind thickness values of rock glaciers located in the Minamisawa-Kita cirque and the most headward of the Tenguppara cirque range between those of the Early Yarisawa Stage II moraine and the Late Yarisawa Stage II moraine. At the rock glacier located in the Minamisawa-Kita cirque, the average values of rind thicknesses are 1.4 mm (R1a), 1.8 mm (R1b), and 1.6 mm (R1c). The rind thickness mode is from 1.1 to 1.5 mm for these three sites. At the middle part of the rock glacier (R1b) there are large values of rind

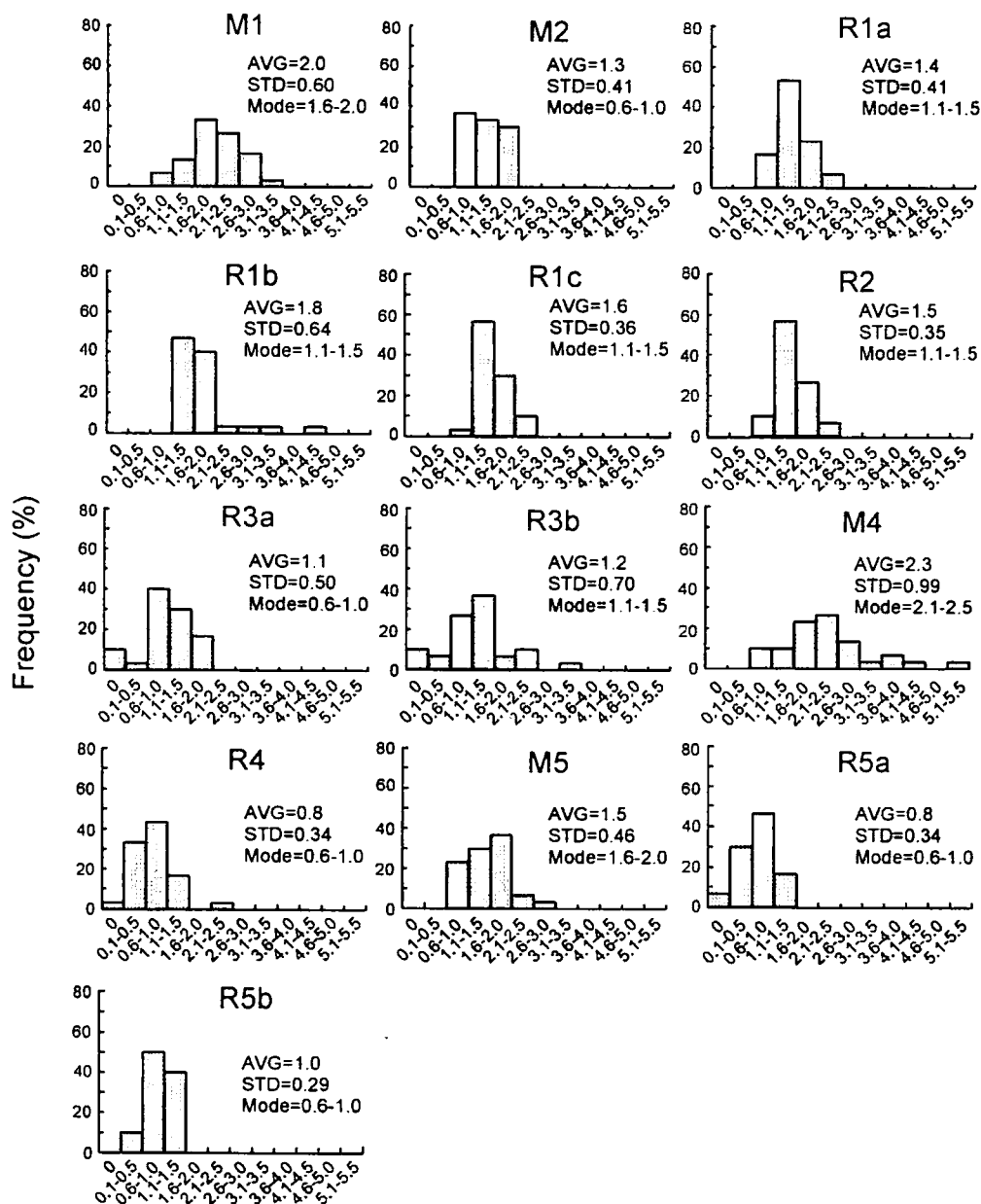


Fig. 2 Histograms for weathering rind thickness from the measuring site.
Measuring sites are shown in Fig. 1.
AVG: average value (mm), STD: standard deviation.

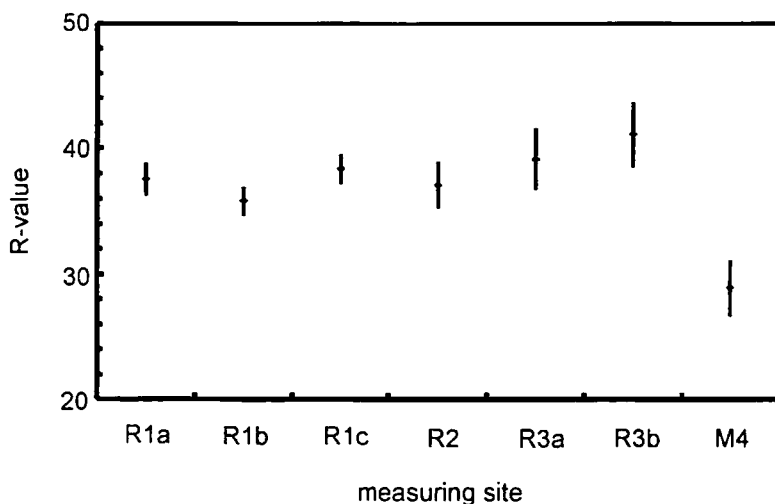


Fig. 3 Results by using a Schmidt hammer type 'N' at measuring site. Horizontal bars represent mean R-values. Vertical bars are 95% confidence intervals.

thickness. The average rind thickness value of M-shaped rock glacier (R2) located at the most headward of the Tenguppara cirque is 1.5 mm. The rind thickness mode of R2 is from 1.1 to 1.5 mm.

The average rind thickness values of rock glaciers located at the northern part of the Tenguppara cirque and the Ohkiretto cirque show smaller values rather than those of the Late Yarisawa Stage II moraines. At the tongue-shaped rock glacier located at the northern part of the Tenguppara cirque, the average values of rind thickness are 1.1 mm (R3a) and 1.2 mm (R3b). The rind thickness modes are from 0.6 to 1.0 mm (R3a) and 1.1 to 1.5 mm (R3b). At the rock glaciers located in the Ohkiretto cirque, the average values of rind thicknesses are 0.8 mm (R4, R5a) and 1.0 mm (R5b). The rind thickness modes are from 0.6 to 1.0 mm at these three measuring sites.

The results of the Schmidt hammer rebound value (R-value) are shown in Fig. 3. R-value indicates surface hardness or strength of the clast and relatively high R-value shows a younger age, while low R-value shows an older age (Matthews and Shakesby 1984). R-values at the rock glacier located in the Minamisawa-Kita cirque (R1a, R1b, R1c) and the Tenguppara cirque (R2, R3a, R3b) are higher than those of the moraine located at the lower end of the Tenguppara cirque (M4) that is correlated to the Early Yarisawa Stage II. At the rock glacier located in the Minamisawa-Kita cirque, the average R-values are 38 (R1a), 36 (R1b), and 38 (R1c). In the Tenguppara cirque, the average R-value of the M-shaped rock glacier (R2) is 37. At the tongue-shaped rock glacier located at the northern part of the Tenguppara cirque, the average R-values are 39 (R3a) and 41 (R3b). At the moraine located at the end of the Tenguppara cirque (M4), the average R-value is 29. The average values of weathering rind thickness at the rock glaciers located in the Minamisawa-Kita cirque and Tenguppara cirque show smaller values to the moraine located at the lower end of the

Tenguppara cirque. The results of R-value measurements and weathering rind thickness measurements indicate that these rock glaciers are younger than the moraine located at the lower end of the Tenguppara cirque. Therefore, the results of the R-value measurements are in accord with the results of the weathering rind thickness measurements.

4. The Age of Rock Glaciers

The studied moraines and rock glaciers are classified into two groups each based on average rind thickness value (Table 1). The average rind thickness values of the first group of moraines (M1 and M4) are 2.0 mm and 2.3 mm, which are assigned to the Early Yarisawa Stage II, and those of the second group of moraines (M2 and M5) are 1.3 mm and 1.5 mm, which are assigned to the Late Yarisawa Stage II. The relative age of the moraines shown by this classification corresponds to that indicated by the geographic positions of the moraines and previous studies. Thus, the average rind thickness values are valid to estimate the age of rock glaciers. Rock glaciers are classified into two groups as follows that based on the average rind thickness value of the Early Yarisawa Stage II moraines and the Late Yarisawa Stage II moraines. (1) Rock glaciers in the Minamisawa-Kita cirque (R1a, R1b, R1c) and the most headward of the Tenguppara cirque (R2) show the average weathering rind thickness values of 1.4 to 1.8 mm. These values range between those of the Early Yarisawa Stage II moraines and the Late Yarisawa Stage II moraines. Therefore, these rock glaciers were formed between the Early Yarisawa Stage II and the Late Yarisawa Stage II. (2) Rock glaciers in the northern part of the Tenguppara cirque (R3a, R3b) and the Ohkiretto cirque (R4, R5a, R5b) show the average weathering rind thickness values of 0.8 mm to 1.2 mm.

Table 1 Average value of weathering rind thickness of rock glaciers and moraines

Landform	Location	Measuring site	Average value of weathering rind thickness (mm)	The age of moraines
Moraine	Tenguppara cirque	M4	2.3	Early Yarisawa stage II
Moraine	Yarisawa upstream area	M1	2.0	Early Yarisawa stage II
Tongue-shaped rock glacier	Minamisawa-Kita cirque	R1b	1.8	
Tongue-shaped rock glacier	Minamisawa-Kita cirque	R1c	1.6	
Tongue-shaped rock glacier	Minamisawa-Kita cirque	R1a	1.4	
M-shaped (Lobate) rock glacier	Tenguppara cirque	R2	1.5	
Moraine	Ohkiretto cirque	M5	1.5	Late Yarisawa stage II
Moraine	Yarisawa upstream area	M2	1.3	Late Yarisawa stage II
Tongue-shaped rock glacier	Tenguppara cirque	R3b	1.2	
Tongue-shaped rock glacier	Tenguppara cirque	R3a	1.1	
Tongue-shaped rock glacier	Ohkiretto cirque	R5b	1.0	
Tongue-shaped rock glacier	Ohkiretto cirque	R5a	0.8	
Lobate rock glacier	Ohkiretto cirque	R4	0.8	

Measuring sites and average values are shown in Fig. 1

These values show almost same or smaller values rather than those of the Late Yarisawa moraines. Therefore, the age of these rock glaciers is same or younger as compared with the Late Yarisawa moraines.

The Early Yarisawa Stage II moraines are considered to be formed about 15 ka. and the Late Yarisawa Stage II moraines are considered to be formed about 10 ka. Rock glaciers located in the Minamisawa-Kita cirque and the most headward of the Tenguppara cirque were formed between the Early Yarisawa Stage II and the Late Yarisawa Stage II. Thus, these rock glaciers are estimated to be formed between 15 ka and 10 ka. Rock glaciers located in the northern part of the Tenguppara cirque and the Ohkiretto cirque were formed after the Late Yarisawa Stage II. Therefore, these rock glaciers are estimated to be formed about 10 ka or the early Holocene.

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