Reconstruction of the depositional environment upstream of Potanin Glacier, Mongolian Altai, from pollen analysis

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Abstract
This study analyzed pollen in snow pits dug in September 2008 and September 2009 upstream of Potanin Glacier in the Mongolian Altai Mountains, which is a summer accumulation-type glacier, to investigate the environment for recent snow deposits. The snow pit observations in both years were carried out at sites 0 and 4, which are 3752 and 3890 m above sea level, respectively. Seasonal layers of the pits were identified according to the taxon of pollen scattered during different seasons. In the 2007 and 2008 layers, concentration peaks of pollen taxa scattered from spring to summer were found at the same depth. Thus, the summer melt reached the spring layer such that pollen grains in the melted layer became concentrated on the summer melt surface and caused the pollen peaks. In contrast, the concentration peaks associated with each season appeared at different depths in the 2009 layer, suggesting that the degree of melting in 2009 was less than that in 2007 and 2008. This interpretation was supported by summer temperature data (June–August) for this region. Deviations in summer air temperatures from mean monthly temperatures for the summers of 1990–2009 were negative in 2009, whereas they were positive in 2007 and 2008.

Keywords: pollen, glacier, dating, ice core, Altai

1. Introduction
Variations in mountain glaciers worldwide have recently attracted considerable attention due to their link with rising sea levels. Glaciers in the Asian highland regions that include the Himalayas and Tibet are thought to be shrinking at a remarkable pace and glaciological observations show that glacier retreat in the regions is accelerating (e.g., Fujita et al 1997, Fujita et al 2001, Naito et al 2002, Yao et al 2004, Pu et al 2008).

Many glaciers are found in the Altai Mountains located in Central Asia, which extends into Mongolia, Russia, China and Kazakhstan. However, the only study on mass balance that has been carried out in this region is in the Russian Altai, where long-term mass balances are monitored (WGMS 2007). Conversely, information on the fundamental characteristics, including the mass balance, of glaciers in the other three
countries is limited. Understanding these characteristics has
been the subject of several recent studies.

Although Kadota and Davaa (2007) reported that glaciers
in the Mongolian Altai are shrinking, and that their retreat
rates are higher than those in the Russian Altai, no practical
information has been reported with regard to volumetric
glacier shrinkage. Evaluation of volumetric shrinkage requires
knowledge of the magnitude of not only the retreating area
but also the lowering surface level. Hence, we selected
Potanin Glacier, the largest glacier in western Mongolia, for
monitoring. The aims of the present study were to investigate
the recent snow depositional environment upstream of the
glacier through snow pit observations and to provide annual
and seasonal deposition data for mass balance calculations.
Our study of the mass balance is reported in detail in another
paper (Konya et al 2012).

Studies of snow pits and an ice core in the Russian
Altai demonstrated the potential for identifying and separating
seasonal layers with high resolution by analyzing pollen
taxa in samples as small as 10 ml (Nakazawa et al 2004, 2005, 2011).
Pollen grain production and liberation follow a distinct seasonal phenology depending on the
taxon. We therefore attempted to analyze pit samples from
Potanin Glacier by pollen analysis in order to realize the
abovementioned study aims.

2. Study area and methods

Potanin Glacier (49°09'N, 87°55'E) is situated in the Tavan
Bogd region of the Mongolian Altai Mountains (figure 1). The
glacier is categorized as a summer accumulation-type glacier
that has greater accumulation in the six months constituting
summer than in the winter months. Potanin Glacier is 10.4 km
in length, and is approximately 1.5 km wide in the ablation
area and 5 km in the accumulation area. Its altitude ranges
from 4373 to 2900 m above sea level (a.s.l.). The nearest
climate station in Mongolia is Ulgii (48°97'N, 89°97'E; 1730 m a.s.l., World Meteorological Organization station
number 442140), located 155 km east of Potanin Glacier
(figure 1).

On 14–15 September 2008 and 9–10 September 2009,
snow pit observations were performed at sites 0 and 4 (3752
and 3890 m a.s.l., respectively; figure 1). The depths of the
pits were 1.55 m for site 0 and 2.71 m for site 4 in 2008, and
2.68 m for site 0 and 3.34 m for site 4 in 2009. To measure
snow density ($\text{kg m}^{-3}$), a block of snow was taken from the
pits with a specially designed sampler. We used two types
of the sampler, one was a square shaped sampler with a capacity
of 100 cm$^3$, which was inserted horizontally into the pit walls,
and another was a cylindrical sampler, which was used only
to collect the upper snow layer (0–1.20 m in depth) at site
4 in 2008 and was vertically pushed into the wall. Then, a
snow sample was taken out and was weighed. Snow was also
sampled from the pits for analyses of pollen and $\delta^{18}$O value.

$\delta^{18}$O values in the meltwater samples were measured in
the laboratory with a dual-inlet isotope mass spectrometer
(Delta Plus, Finnigan). For pollen analysis, 10 ml of meltwater
was sampled. These samples were processed by the procedure
outlined in Nakazawa and Suzuki (2008). To simplify the
process and prevent pollen loss, the samples were subjected
to neither acetolysis treatment nor centrifugation. Because the
cytoplasm in the pollen grains was not chemically removed,
Betulaceae (which appeared to include Betula and Carpinus)
could be identified at only the family level. Identification and enumeration were only performed for major pollen-types (Betulaceae, Pinus and Artemisia) since this study was focused on the seasonality of pollen deposition.

3. Results

3.1. Stratigraphy, $\delta^{18}O$ value and precipitation data

The stratigraphies for 2007 and 2008 show that melting occurred even at the pit sites located near the top of the accumulation area (figure 2). Surface melt ordinarily starts on Potanin Glacier at the beginning of June and ends at the beginning of September. Moreover, automatic weather station (AWS; figure 1) and visual observations near the glacier revealed that precipitation occurred a few days before the pit observations. Thus, the uppermost layer of compacted snow in each pit consisted of fresh snow.

$\delta^{18}O$ profiles for the pits show seasonal variation except for that of the 2008 pit at site 0 (figure 2). Continuous high values in the profiles are due to high rates of snow accumulation in the summer. In contrast, the ambiguous seasonal variation of the 2008 pit at site 0 is caused by high meltwater percolation.

3.2. Pollen record

Profiles of the pollen concentrations for 2008 and 2009 are shown in figure 2. Distinct pollen peaks are seen in each profile. Pollen analysis results for the 2008 samples from site 0 indicate two pollen peaks of the three taxa at the same depths. Artemisia pollen also has another pollen peak at a depth of 1.15–1.20 m. Similarly, pollen analysis of 2008 samples at site 4 shows that each peak of the taxa appears at the same depth. In addition, an Artemisia pollen-rich region is found at the bottom.

The 2009 profiles at sites 0 and 4 are different from those for 2008. Artemisia-rich layers are found above Pinus-rich layers, whereas Pinus-rich layers are found above Betulaceae-rich layers. At site 0, additional peaks of the three taxa appear at a depth of 2.14–2.20 m. Also, an Artemisia pollen-rich region is found at the bottom.

4. Discussion

4.1. Recent depositional environment at the pit sites

To date the snow deposits in the pits, each of the analyzed pollen taxa is used as a time marker. Potanin Glacier
Figure 2. (Continued.)

is located within a few kilometers of considerable pollen sources, and pollen grains arrive at the glacier shortly after pollen release. The glacier is located about 100 km from Belukha Glacier in the Russian Altai, where Nakazawa et al (2005, 2011) attempted to date pit depositions by pollen analysis. Therefore, the flowering and pollen seasons in the region of Potanin Glacier are anticipated to be the same as those near Belukha Glacier. The observed pollen layers are thought to have formed on the snow surface during the respective flowering seasons: predominantly May for Betulaceae, June for Pinus (Luchik 1970) and from late August to early September for Artemisia elsewhere in Asia (Satake et al 1981, Polunin and Stainton 1984, Qiao 2004). Based on the position of each pollen peak and the known flowering seasons, the seasonal layers in the pits were identified as shown in figure 2.

Substantial melting seems to have occurred in the summers of 2007 and 2008. For the 2008 profiles at both sites and the lower part in the 2009 profile at site 0, pollen peaks of the three taxa were observed at the same depth. Nakazawa and Suzuki (2008) investigated the redistribution of pollen grains by melting in snow cover. That study used pollen grains of Cryptomeria japonica, whose grain size is relatively common and ranges from 27 to 32 µm. The grains in snow cover were shown not to move toward the lower layers in the event of heavy melting, and the grains in the snowmelt remain on the snow surface. The grain size of the pollen taxa observed in this study is the same or more than that of C. japonica. Thus, these pollen grains also should remain on the snow surface during melting. For this reason, the appearance of peaks at the same depth indicates that heavy melting occurred in the summer and reached the spring layer. In other words, the depths of the peaks likely correspond to the summer melt surface of each year. The layer located immediately below the summer melt surface should be the spring layer. Although the results of Nakazawa and Suzuki (2008) suggested the possibility that pollen grains scattered during different seasons may be concentrated in a certain layer by snowmelt, the present report
provides the first observation of the phenomenon. In contrast, heavy melting appears not to have occurred in summer 2009 because the pollen-rich layers formed a regular profile with the three taxa found at different depths in the 2009 profiles of sites 0 and 4.

An additional Artemisia peak found above the depth of the summer melt surface in each profile likely indicates the annual peak of the high-pollen season. Since the high-pollen season of Artemisia should be after the summer, the Artemisia pollen peak in the layers of the summer melt surface is likely formed by concentration through melting. Hence, we regard each Artemisia peak in the lowermost layer of the 2008 pit at site 4 and the 2009 pit at site 0 as the autumn peak of 2007, because no peak of the other two taxa appeared at that depth.

The δ18O records in the pits enabled us to identify winter layers except for the 2008 profile of site 0. Low δ18O values are found in precipitation during the winter in the Altai region (Nakazawa et al. 2011). The minimal δ18O values are found between Betulaceae and Artemisia pollen-rich layers. In addition, the layer having the minimal value in each profile contains a very low pollen concentration. No pollen source peaks in the winter. Therefore, the depths of minimal δ18O values in the profiles likely indicate midwinter. However, identification of a winter layer in the 2008 profile at site 0 is difficult because the δ18O records have been distorted by melting. The depth of 0.78 m, where the Artemisia pollen concentration decreases to near zero and the Betulaceae pollen concentration starts to increase, is defined here as the midwinter layer of 2007/2008.

From the above discussion, the time period is estimated for each pit. In the 2008 observation, the pollen analysis revealed that the pit at site 0 included the deposition from spring 2007 to autumn 2008, while the pit at site 4 included the deposition between the autumn 2007 to autumn 2008. In contrast, the pollen analysis in the 2009 observation showed that the snow pit at site 0 contained the deposition between autumn 2007 to autumn 2009, while the pit at site 4 contained the deposition from winter 2008/2009 onward.

4.2. Difference in degree of summer melting

The difference between the degrees of summer melting in 2007 and 2008 and that in 2009 is expected to be the result of summer air temperatures. Figure 3 shows deviations of monthly air temperatures in summer (June–August) 2007–9 from mean monthly air temperatures in the summers of 1990 to 2009 in Ulgii. Monthly deviations in 2007 and 2008 were positive, whereas those for 2009 were negative. Due to the higher summer air temperatures, net balances between spring and summer in 2007 and 2008 should have been almost zero or minus, and annual depositions in 2007 and 2008 seem to consist of mainly autumn and winter depositions. Hence, pollen profiles for Potanin Glacier enable us to estimate the degree of melting, as well as the dating of pit depositions.

4.3. Estimation of annual deposition

Annual snow depositions were estimated from Artemisia pollen concentration peaks because these peaks coincide with the stake observations on the glacier. Depositions at site 0 were 1.18 m (0.61 m water equivalent (w.e.)) and 1.69 m (0.69 m w.e.) for autumn 2007 to autumn 2008 and autumn 2008 to autumn 2009, respectively. The respective snow depositions for the same periods at site 4 were 2.44 m (1.04 m w.e.) and greater than 3.34 m (1.38 m w.e.). The measured layer thicknesses were converted to water equivalent (w.e.) thicknesses using the corresponding densities for each depth interval (figure 2). Densities were calculated for the depths lacking data through interpolation between anteroposterior values. The main reason for the higher depositions between the autumns of 2008 and 2009 appeared to be negligible summer melting; however, precipitation on the glacier in both years is unknown.

5. Conclusion

This study analyzed pit samples obtained from Potanin Glacier in the Mongolian Altai Mountains, which is a candidate for monitoring glacier variations in order to understand the recent depositional environment of snow. Pollen analysis combined with δ18O data identified seasonal layers in the pits. Pollen analysis of 2008 samples revealed that the pit at site 0 contained depositions from spring 2007 to autumn 2008, whereas the pit at site 4 contained depositions between autumn 2007 and autumn 2008. Meanwhile, pollen analysis of 2009 samples showed that the snow pit at site 0 contained depositions between autumn 2007 and autumn 2009, while the pit of site 4 contained depositions from winter 2008/2009. In the 2007 and 2008 layers, concentration peaks of pollen taxa scattered from spring to summer were found at the same depth. Thus, the summer melt reached the spring layer such that pollen grains in the melted layer become
concentrated on the summer melt surface and caused the pollen peaks. This is the first time that this phenomenon has been observed in the snow cover of a glacier.

In contrast, the concentration peaks of pollen taxa scattered in different seasons appeared at different depths in the 2009 layer, suggesting that the degree of melting in 2009 was less than that in 2007 and 2008. This possibility was supported by data on summer air temperatures for this region.

Annual depositions were estimated from *Artemisia* pollen concentration peaks, which were used as a marker of autumn in this study. Annual snow depositions at site 0 were $1.18$ m (0.61 m w.e.) and $1.69$ m (0.69 m w.e.) for autumn 2007 to autumn 2008 and autumn 2008 to autumn 2009, respectively. The respective snow depositions for the same periods at site 4 were $2.44$ m (1.04 m w.e.) and greater than $3.34$ m (1.38 m w.e.).

Pollen grains in glaciers can provide seasonal information and appear to be less affected by meltwater percolation since they are of large size. Therefore, application of pollen analysis combined with stake observations is considered useful for studying glacier mass balance.

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References

Fujita K, Nakawo M, Fujii Y and Paudyal P 1997 Changes in glaciers in Hidden Valley, Mukut Himal, Nepal Himalayas, from 1974 to 1994 *J. Glaciol.* 43 583–88

Kadota T and Davaa G 2007 Recent glacier variations in Mongolia *Ann. Glaciol.* 46 185–88

Konya K, Kadota T, Nakazawa F, Gombo D, Khaizan P, Yabuki H and Ohata T 2012 Surface mass balance of Potanin Glacier, Mongolian Altai, for 2005, 2008 and 2009 *Arct. Antarct. Alp. Res.* submitted

Luchik Z I 1970 *Introduction of Trees and Bushes in Altay Territory* (Moscow: Kolos) (in Russian)

Naito N, Kadota T, Fujita K, Sakai A and Nakawo M 2002 Surface lowering over the ablation area of Lirung Glacier, Nepal Himalayas *Bull. Glaciol. Res.* 19 41–6

Nakazawa F, Fujita K, Takeuchi N, Fujiki T, Uetake J, Aizen V and Nakawo M 2005 Dating of seasonal snow/ firn accumulation layers using pollen analysis *J. Glaciol.* 51 483–90

Nakazawa F, Fujita K, Uetake J, Kohno M, Fujiki T, Arkhipov S M, Kameda T, Suzuki K and Fujii Y 2004 Application of pollen analysis to dating of ice cores from lower-latitude glaciers *J. Geophys. Res.* 109 F04001

Nakazawa F, Miyake T, Fujita K, Takeuchi N, Uetake J, Fujiki T, Aizen V B and Nakawo M 2011 Establishing the timing of chemical deposition events on Belukha glacier, Altai Mountains, Russia, using pollen analysis *Arctic Antarct. Alp. Res.* 43 66–72

Nakazawa F and Suzuki K 2008 The alteration in the pollen concentration peak in a melting snow cover *Bull. Glaciol. Res.* 25 1–7

Polunin O and Stainton A 1984 *Flowers of the Himalayas* (New Delhi: Oxford University Press)

Pu J C, Yao T D, Yang M X, Tian L D, Wang N L, Ageta Y and Fujita K 2008 Rapid decrease of mass balance observed in the Xiao (Lesser) Dongkemadi Glacier, in the central Tibetan Plateau *Hydrol. Process.* 22 2953–58

Qiao B 2004 *Color Atlas of Air-Borne Pollens and Plants in China* (Beijing: Peking Union Medical College Press) (in Chinese)

Satake Y, Ohwi J, Kitamura S, Watari S and Tominari T 1981 *Wild Flowers of Japan: Herbaceous Plants Including Dwarf Subshrubs* (Tokyo: Heibon-sha) (in Japanese)

WGMS 2007 Haebeler W, Hoelzle M and Zemp M (ed) *Glacier Mass Balance Bulletin. No. 9* (2004–2005) (Zurich: ICSU (FAGS)/IUGG (IACS)/UNEP/UNESCO/WMO, World Glacier Monitoring Service)

Yao T, Wang Y, Liu S, Pu J, Shen Y and Lu A 2004 Recent glacial retreat in High Asia in China and its impact on water resource in Northwest China *Sci. Chin. D* 47 1063–75