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The alteration in the pollen concentration peak in a melting snow cover

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Abstract

We have investigated the changes in *Cryptomeria japonica* pollen concentrations in a melting snow cover at different time points in order to understand the alterations in their concentration peaks. Recent studies have revealed that the pollen concentration peaks in mountain snow covers in temperate regions are useful for distinguishing between annual and several seasonal layers. Moreover, a dating method was applicable to a melting ice core. However, the manner in which pollen grains and their concentration peak values get influenced by melt water needs to be clarified. The present study intends to clarify this issue. Snow samples were collected from the Norikura Highland in central Japan during two snow-melting seasons: (1) from March to April in 2005 and (2) from March to May in 2006. The analysis of the *C. japonica* pollens was carried out because the pollen release reaches a high level from March to April in Japan when the winter seasonal snow still remains at the site; further, the pollen grains are commonly found within a typical size range. The results showed that the snow depth from the ground surface decreased because of snow melting during April and May, and the pollen concentration peak was consistently observed at the surface of the snow cover during the melting process. This indicated that the pollen concentration peak was not redistributed to the lower layers because of melting and the pollen grains present in the melted snow were concentrated at the surface. However, when the snow cover was about to disappear, the peak value decreased. This might account for the horizontal relocation of the pollen grains at the surface. Additionally, the peaks persisted at the surface even in the regions of the snow cover where water channels were formed. This indicated that the pollen peaks in the snow cover did not move toward the lower layers because of significant melting, although the peak values themselves may be changed due to the horizontal relocation of pollen grains.

1. Introduction

Pollen analyses to date have been applied to numerous ice core studies especially in Arctic regions. These studies have been conducted on the origins of the pollen found in Arctic ice caps (Ritchie and Lichti-Federovich, 1967; Lichti-Federovich, 1973, 1975; Bourgeois, 1990, Bourgeois *et al*., 2000), the seasonal variations in the ice cap pollen assemblages (Short and Holdsworth, 1985; Bourgeois, 1990, 2000), and the global circulation patterns responsible for their dispersal (Bourgeois *et al*., 1985, 2001). Several studies in nonpolar ice cores have also shown that sensitive records of past vegetation changes can be obtained through the analysis of pollen (Liu *et al*., 1998, 2005). Recent pollen analyses of snow pits and an ice core in the Altai Mountains, Russia, revealed that the annual and several seasonal layers could be distinguished by using the concentration peaks of different pollen taxa of the samples (Nakazawa *et al*., 2004, 2005). In addition, Nakazawa *et al*. (2004) showed that the pollen dating method may be applicable to melting firn and ice cores. The size of a pollen grain typically ranges from 10 to 200 μm, and it appears that this size allows the pollen grain to remain stable at its original depth in the snow despite the incursion of meltwater. However, the percolation of pollen grains through the snow layers because of snow melting has received marginal attention. In particular, the alterations in the pollen concentration peak values during significant melting or the behavior of the peaks in the regions of snow cover where water channels were formed are unknown. This issue needs to be clarified for a comprehensive application of the pollen dating method in snow pit and ice core studies. The purpose of the present study is to examine the changes in the pollen concentrations in a snow cover during the snow-melting season and alterations in the pollen concentration peaks at different time points.

2. Study area and methods

We selected the Norikura Highland of central Japan as the study site (lat 36°06′N, long 137°35′E; 1590 m a.s.l.; Fig. 1) because of a relatively convenient access

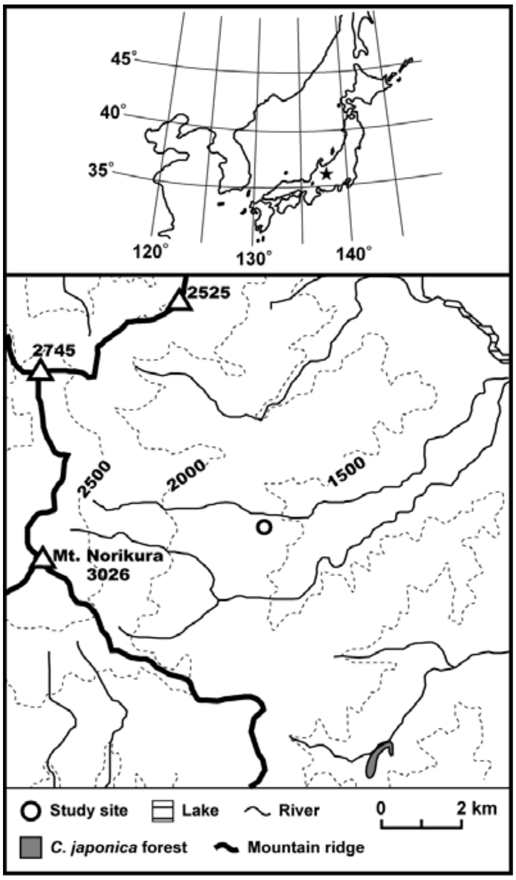

Figure 1. Location map of Norikura Highland, Japan, (top) and a detailed map of the study site (bottom).

and a late thaw. The region has an extent of 3 km in the north–south direction and 6 km in the east–west direction and a height of 1300–1800 m a.s.l. The study site, located at the center of the Norikura Highland, is an open space (length of 100 m and width of 50 m). It experiences snowfall during winter, and the snow cover attains a height of 1.5 m; this cover remains until the end of April. The major types of vegetation on the east slope of Mt. Norikura shown in Figure 1 are as follows: at a height of less than about 1800 m a.s.l., *Castanea crenata-Quercus mongolica var. grosseserrata* community (a deciduous broad-leaved forest) and *Larix kaempferi* plantation (a deciduous conifer) are found; above this height, *Abietum veitchii-mariesii* (conifer) is found (Environment Agency, 1988).

We used the pollen grains of *Cryptomeria japonica*. These pollen grains are characterized by spherical shapes with a single papilla (Fig. 2). *C. japonica* is a forest tree and is native to Japan and southern China; it is also the only species in its genus. Pollen releases from this tree are carefully examined annually by research institutions, public health centers, and so on all over Japan because many Japanese people are allergic to pollen grains. The nearest *C. japonica* forest is at a distance of 6 km from the study site (Environment Agency, 1988). Therefore, the *C. japonica* pollen grains found in the snow should be those transported over long distances. Generally, the pollen releases of all the trees and grasses cease during winter. The *C. japonica* tree releases pollen shortly after winter, and the dispersion of pollen begins from late February or March. Around the study site, the pollen release reaches a high level in late March or the beginning of April, and it persists for a few weeks (Nagano Environmental Conservation Research Institute, 2006).

Moreover, a comprehensive study on pollen movement can be conducted by using the *C. japonica* pollen since its grains are commonly found in the typical size range. The grain size ranges from 27 to 32 μm (Nakamura, 1980). As mentioned earlier, the size of a pollen grain is typically between 10 and 200 μm: the most common size ranges from 20 to 60 μm (Matsushita, 2004). The grain sizes of the *C. japonica* pollen are equal to the most common size. Therefore, *C. japonica* is considered to be an appropriate pollen species even in terms of its size.

Snow depth from the ground surface (m in snow) was measured by an automatic snow gauge (KONA System Corp., KADEC21-YUKI) and a manual snow gauge in the 2004–05 (from December 2004 to April 2005) and 2005–06 (from December 2005 to May 2006) snow seasons, respectively. For this study, the measurements of the snow depths were recorded daily at 1200 h by using the automatic snow gauge, and the manual measurements were conducted at a frequency ranging from every day to every few days.

During the snow-melting season, the snow samples were obtained from the surface to the bottom of the pit walls at 9- and 3-cm intervals on March 24, April 2, and April 13, 2005, and on March 31, April 13, April 17, April 22, and May 2, 2006. First, we analyzed the 9-cm-interval snow samples to determine a general

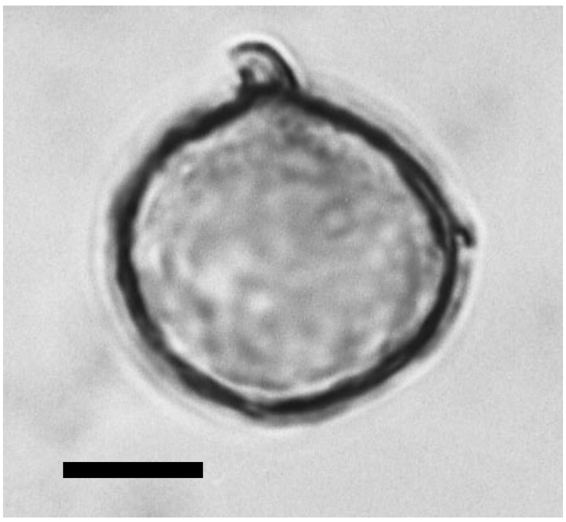

Figure 2. Light micrograph of *C. japonica* pollen found at the study site. Scale bar = 10 μm.

trend of the *C. japonica* pollen concentrations. The 3-cm-interval samples were used to obtain detailed information about the changes in the pollen concentration in the 9-cm-interval samples. For the pollen analysis, 20 ml of each water sample that was obtained following the snow melting was first filtered through a hydrophilic PTFE membrane filter with a pore size of 1 μm and a diameter of 13 mm (Millipore, Omnipore Membrane Filters, Catalogue Number: JAWP 013 00); then, the filter was placed in a centrifuge tube with 1 mL of 48% hydrofluoric acid for one day in order to decompose the soil particles. Following the hydrofluoric acid treatment, the pollen grains were stained by adding 1 mL of 95% sulfuric acid into the tube. Finally, the processed sample was refiltered through the same type of filter. The pollen grains on the filters were counted by observing them under a microscope. If the number of pollen grains on the filters appeared to exceed 500, the samples were reprocessed by reducing the volume of water from 15 mL to 1 mL in order to facilitate the counting of the grains. The total *C. japonica* pollen counts in the samples ranged from 0 to 845 grains (n = 175; median = 18).

3. Results and discussion

3.1 Snow depth and C. japonica pollen release

The changes in the snow depths and the timing of *C. japonica* pollen releases in 2005 and 2006 were similar to those observed previously. Figure 3 shows the changes in the snow depths at the study site during 2005 and 2006. The squares in the figure indicate the snow depths obtained from the pit observations conducted in 2005. Every year, the snow depths increase until March and then decrease in April. In 2006, we observed the disappearance of snow on May 6. However, at the start of May 2006, marked depressions were observed in the snow surface, partly revealing the ground surface in these regions. Probably, the surface condition immediately before the disappearance of snow in 2005 was also similar to that of 2006, although we did not observe it. Granular-type snow was observed along with ice layers at intervals, except for the new or compacted snow at the surface; the size of the snow grains ranged from 0.5–4.0 mm, although most of them were 1.0–1.5 mm in size. The snow pit stratigraphies and vertical profiles of the grain sizes showed no remarkable relationships with the pollen profiles obtained from the snow samples that we mention hereafter.

The *C. japonica* pollen deposition coincides with the onset of a decrease in the snow depth (Fig. 3). The pollen data were obtained at the Matsumoto Joint Government Building in Matsumoto city (585 m a.s.l.), which is located approximately 35 km northeast of the study site, and it was provided by the Nagano Environmental Conservation Research Institute (2006). The pollen depositions were also measured in Nagano city and Ueda city, which are located approximately 50 km northeast and 35 km north-northeast of the Matsumoto Joint Government Building, respectively. These data obtained in 2005 and 2006 showed a similar trend to those at the Matsumoto Joint Government Building; they exhibited the same peak dates with a margin of a few days. Therefore, we used the pollen deposition data at the Matsumoto Joint Government Building as the observed data from the nearest location to the study site in order to determine the daily changes in the pollen depositions. The amounts of pollen deposition differed by 10-fold during the two years. However, the pollen depositions occurred at a time when the winter seasonal snow still remained at the study site during both the years. Therefore, our samples appear to be valid for examining the movement of pollen grains during the snow-melting season.

3.2 Changes in pollen concentrations at different time points during snow melting

The pollen analyses of the pit samples revealed that snow melting increased the value of the pollen concentration peak at the surface. Figure 4 shows the

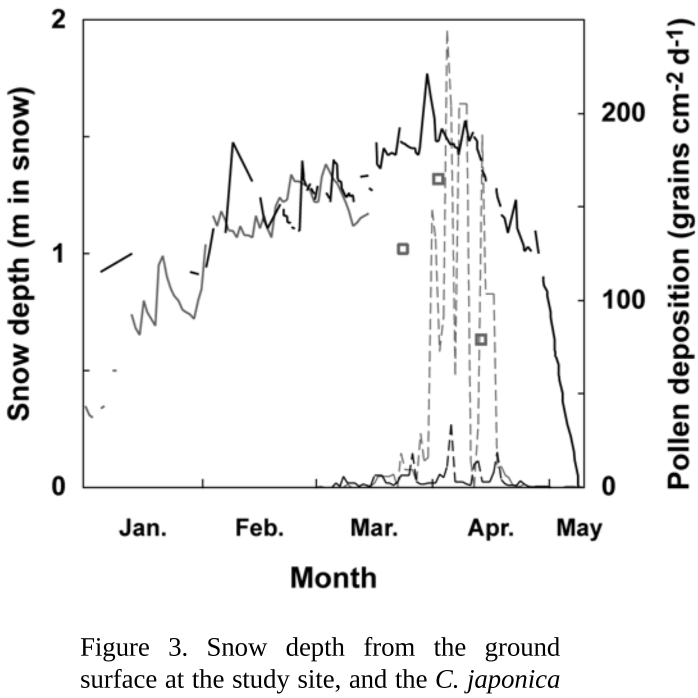

Figure 3. Snow depth from the ground surface at the study site, and the *C. japonica* pollen collected at the Matsumoto Joint Government Building. The gray and black solid lines represent the changes in the snow depths in 2005 and 2006, respectively. The gray and black broken lines represent the daily changes in the *C. japonica* pollen depositions in 2005 and 2006, respectively. Gray squares plotted in the figure indicate the snow depths from the pit observations on March 24, April 2, and April 13, 2005.

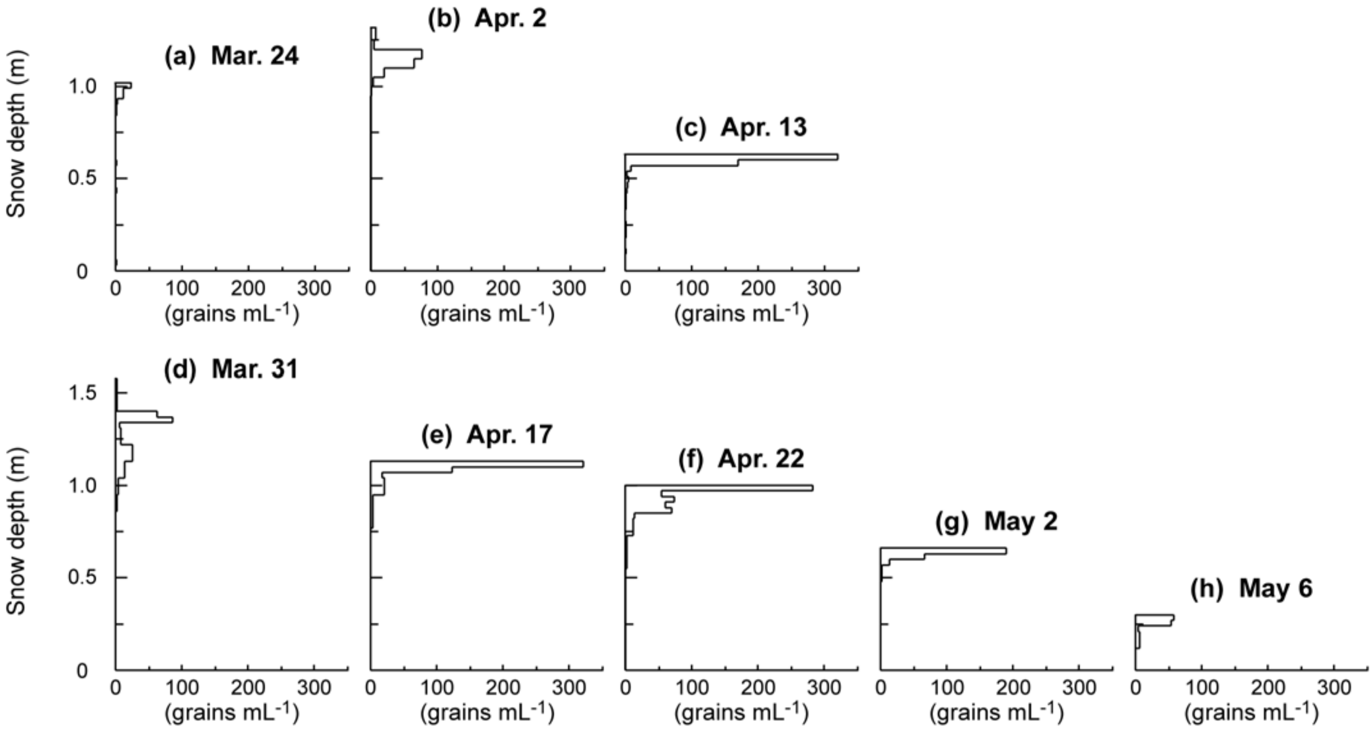

Figure 4. Vertical profiles of the *C. japonica* pollen concentrations obtained from the pit samples in Norikura Highland. The snow samples were obtained on (a) March 24, (b) April 2, and (c) April 13, 2005, and (d) March 31, (e) April 17, (f) April 22, (g) May 2, and (h) April 13, 2006. Each value on the vertical axis indicates the daily snow depth.

changes in the *C. japonica* pollen concentrations at different time points in the snow covers during 2005 and 2006. Each value on the vertical axis indicates the daily snow depth. In 2005, the snow depth increased by 0.30 m from March 24 to April 2 and then rapidly decreased by 0.69 m during the subsequent 11 days. The pollen profile on April 2 showed a concentration peak that coincided with an increase in the amount of pollen deposition at the Matsumoto Joint Government Building. Further, a peak in the pollen concentration exists on the surface of the snow cover, in spite of a rapid decrease in the snow depth and increases in size, on April 13. The total pollen depositions in the snow cover are estimated to be 305 × 10^4 and 533 × 10^4 grains/m^2 for April 2 and April 13, respectively. These results evidently indicate that pollen grains are concentrated at the surface of the snow cover during snow melting, although the subsequent pollen deposition on the snow also contributes to the enhancement of the peak value. The pollen analyses of the samples collected in 2006 can be also explained by the same process mentioned above. The appearance of a peak in the pollen concentration at the surface of the snow cover between March 31 and April 17 coincides with the enhancement of pollen deposition. Additionally, the peak persisted at the surface even though the snow depth decreased. However, the value of the pollen concentration peak gradually decreased.

In contrast to the strong pollen peak observed at the surface on April 17, there was a broad pollen distribution below the surface peak on April 22. It was assumed that these pollen grains moved with the meltwater from the upper layers or horizontally from the same layer.

However, no such observation was noted in the pollen profiles on May 2 and May 6. The decrease in the value of the pollen concentration peak without the broad pollen distribution on May 2 and May 6, 2006, can be attributed to the horizontal relocation of the pollen grains at the snow surface. Adhikary *et al.* (1997) scattered soil dust with sizes in the range of 0.15–0.35 mm over a wet snow surface to understand the behavior of dust particles on the snow surface and their effects on albedo changes and ablation. The results indicated that the particles changed their location after the melting started and showed a trend to aggregate at the melting crusts. In other words, their study suggested that the horizontal relocation of particles was observed on the snow surface. In this study, the snow sampling was conducted at a location with a convex surface under a rough surface condition. The pollen at the surface might have preferentially moved to the concave surface; hence, the decrease in the pollen concentration peak values on May 2 and May 6, 2006, can be attributed to the horizontal relocation of the pollen grains. However, in order to ascertain this assumption, we need a further examination of the spatial variations in the pollen concentrations at concavo-convex surfaces of snow covers during the melting season.

On the other hand, in this study, the decrease in the value of the pollen concentration peak without the broad pollen distribution on May 2 and May 6, 2006, appears to be marginally influenced by spatial variations in the pollen depositions on the snow surfaces. Reese and Liu (2002) and Reese *et al.* (2003) investigated the pollen concentrations in the surface snow samples (samples obtained from the top 5 cm of the snow cover) obtained from the tropical ice caps in the Andean Altiplano in order to clarify the spatial variations in the pollen depositions. The results showed that significant spatial variations were observed at a scale of several kilometers, whereas no significant differences were found within a distance of 1 m. The pollen concentration values for all the samples in Reese and Liu (2002), i.e., at a scale of several kilometers, differed by up to 3.2- and 6.4-fold in the 2000 and 2001 observations, respectively. On the other hand, the differences between the paired samples obtained within a distance of 1 m were less than 1.3- and 1.4-fold in 2000 and 2001, respectively. Similarly, the pollen concentration values in the study of Reese *et al.* (2003) changed by up to 7.0-fold at a scale of several kilometers and by less than 1.1-fold within a distance of 1 m. The 1.3-, 1.4-, and 1.1-fold values were estimated by tracing the figures in these studies. We did not collect several surface samples from the same location for a single observation in order to test the intrasite variability. However, the total pollen depositions in the snow cover are estimated to be 640×10^4 and 592×10^4 grains/m^2 for April 17 and April 22, 2006, respectively, when the daily pollen deposition at the Matsumoto Joint Government Building denotes the end of the pollen season in the year: these values are very similar. In addition, we collected the samples at a distance of approximately 5 m from the previous sampling point. Therefore, it can be considered that the spatial variations in the pollen depositions are relatively small at a scale of several meters. Incidentally, these similar values of the total pollen depositions conform to the fact that the penetration of pollen grains on April 22 was mainly due to vertical relocation because the total value remains unchanged.

3.3 Behavior of pollen grains in the snow cover with water channels

Peaks in the *C. japonica* pollen concentration persisted even in the regions with the snow cover where water channels were formed. We compared the pollen profiles of the snow covers with and without water channels on April 17 and May 2 (Fig. 5). These paired samples were collected within a distance of 1 m. The water channels were observed in the uppermost region of the snow covers, and their dimensions were as follows: a thickness of 0.55 m and a width ranging from 0.18 to 0.23 m on April 17 and a thickness of 0.26 m and a width ranging from 0.07 to 0.15 m on May 2. The pollen profiles showed that some pollen grains were found at the lower regions—less than approximately 0.15 m—of the snow column with the water channels. However, the vertical locations of the peaks in the snow columns with and without the water channels were similar, suggesting that the meltwater flowing down through the water channels did not influence the vertical locations of the peaks. In addition, we observed that on April 17, the pollen concentration peak value in the snow column with the water channels was considerably smaller than that in the snow cover without water channels. This may also be explained by means of the horizontal relocation process. The concentrated water that flows in the water channels may cause the snow surface to become more rugged (similar to snow dimples) than the surrounding snow. Alternatively, the pollen at the surface might have moved to lower regions. Since the location selected in our snow sampling had a convex surface, the pollen concentration on the surface of the snow cover appears to be lower at the sampling point.

The results of this study reveal that the pollen concentration peaks in the snow cover do not move toward the lower layers, although the peak value itself can be changed by meltwater. Therefore, the depths of the pollen concentration peaks in the pits and ice cores should indicate the time points at which the pollen was deposited on the snow surface, even though these samples underwent melting. Moreover, the pollen peaks should be reliable seasonal and annual markers even in the regions with the snow cover where water channels have formed.

4. Conclusion

In this study, we examined the changes in the *C. japonica* pollen concentrations at different time points in a melting snow cover to understand the alterations in the pollen concentration peaks. The results showed that the pollen peaks in a snow cover do not move toward the lower layers due to significant melting, although some pollen grains moved due to the meltwater incursion into the snow. Additionally, the surface melting of the snow cover increased the concentration of the pollen grains that were present in the melted snow at the surface. This concentration was observed even when a rapid reduction (0.69 m) in the snow depth was observed within a span of 11 days in 2005. However, the subsequent melting, resulting in

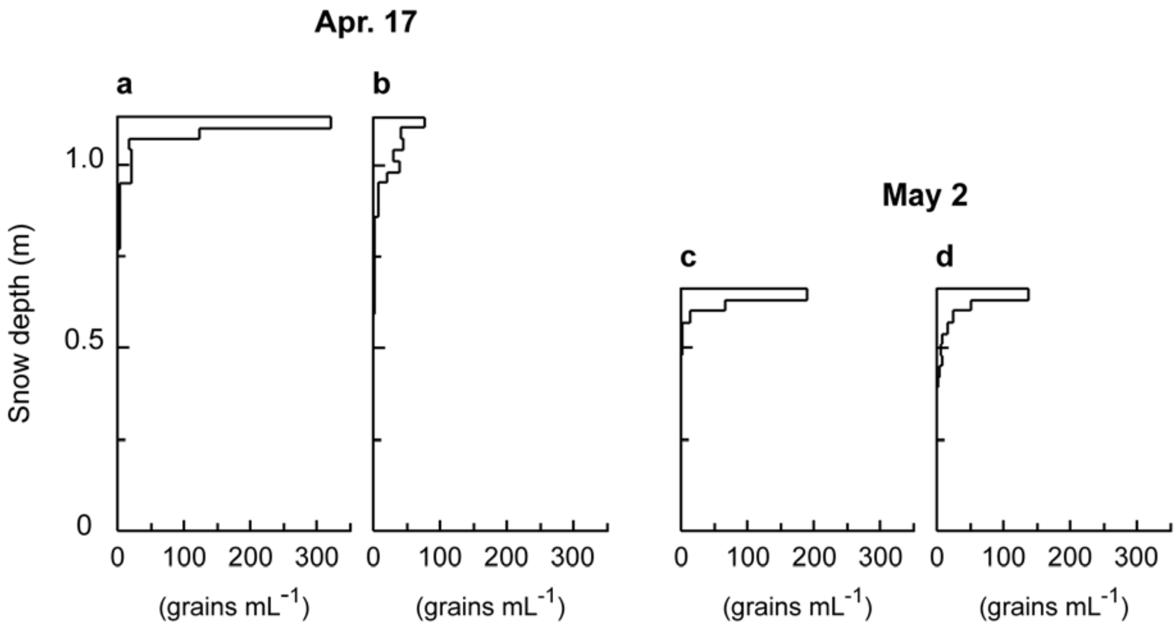

Figure 5. Comparison of the pollen profiles of *C. japonica* in the snow covers with and without water channels. (a) Pollen profile in the snow cover without water channels on April 17, 2006. (b) Pollen profile in the snow cover with water channels on April 17, 2006. (c) Pollen profile in the snow cover without water channels on May 2, 2006. (d) Pollen profile in the snow cover with water channels on May 2, 2006.

the surface to become rough, decreased the peak value. The most likely explanation for this was the horizontal relocation of pollen grains at the surface of the snow cover. In this study, the samples were collected from a snow column with a convex surface. The pollen at the surface might have preferentially moved to the concave surface, resulting in a horizontal relocation of the pollen; hence, it was likely that the value of the pollen concentration peak decreased with the advancement of melting. However, to ascertain this assumption, further investigation of the horizontal relocation of pollen grains at concavo-convex snow surfaces is required. On the other hand, the pollen grains showed a similar behavior even in the columns with water channels, although some pollen grains penetrated into them by less than approximately 0.15 m. However, the disappearance of the pollen concentration peaks or the appearance of new peaks at the lower layers of the snow cover following the penetration of pollen grains was not observed. Finally, it should be noted that the pollen concentration peak value in the snow pits and ice cores with significant melting may not provide vital information due to the horizontal relo cation of pollen grains induced by the melting process.

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