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Study on the Snow Cover Stratigraphy in the Uono Basin by Rammsonde

By

Yutaka Yamada* **and Takashi Ikarashi***

Institute of Snow and Ice Studies, National Research Center for Disaster Prevention, Nagaoka, Niigata-ken 940, Japan

Abstract

Rammsonde measurements and snow pit observations were made in the plain and mountain areas in the Uono and Kiyotsu basins. The capability of stratigraphical identification by ram profile was proved in the melt-freeze metamorphism zone. From the observation results, the Uono and Kiyotsu basins were classified into four domains of snow cover environmental system by their main structural snow type.

1. Introduction

Snow cover phenomena in the districts along the Japan Sea vary in very different manners according to their geographical features and climatic conditions. Regional characteristics of snow cover conditions can be represented by the composite of snow depth, water equivalent of snow cover, stratigraphy (namely, layer structure and snow type) and physical properties such as density, free water content and hardness. Outbreak of snow damages, starting of avalanches in particular, is affected by snow cover conditions. Up to now, the regional characteristics of snow depth and water equivalent have been studied and made fairly clear. But those of layer structure and snow type have not yet fully elucidated. Therefore, it is considered very important for a fundamental study of the prevention of snow damages, prediction of avalanches in particular, to seize regional characteristics of stratigraphy in detail.

Watanabe, Ikarashi and Yamada (1976, 1978) conducted snow cover surveys in and around Niigata Prefecture in the winter seasons of 1975/76 and 1976/77, and obtained the general idea of regional characteristics in this area.

In these surveys, observations were made mainly by the snow pit method. By means of this method stratigraphy and physical properties of snow cover can be minutely obtained, however, it takes both much labor and time to observe at even one station, and there is a limitation to conduct a moving observation in a wide area. Particularly, in such areas as the Uono basin where melt-freeze metamorphism excels even in middle-winter and rate of metemorphism is large compared to that of the equi-temperature and temperature gradient metamorphism, it is almost impossible

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* First Laboratory

to observe synchronously whole area by the snow pit method only. Rammsonde is one of the instruments that can fulfil the need for simple and short-time observation to determine relative strength without resorting to digging of pits. For this reason, we employed the rammsonde together with the snow pit method this time.

Haefeli (Bader *et al.*, 1939), who developed the rammsonde, pointed out the following three items as the application of rammsonde :

(i) The general and comparative evaluation of the properties of a snow cover,
(ii) The evaluation of the avalanche danger, and
(iii) The identification of the layers.

For the purpose of evaluation of regional characteristics in snow cover by the rammsonde, it is the least conditions to identify a specific layer throughout the observation area and to evaluate snow type in that specific layer. In other words, the former is the role as the layer tracer and the latter is the role as the snow type index.

In this study, the authors show by means of simultaneous measurement with snow pit method and rammsonde that these roles of the layer tracer and the snow type index are possible by the decoding work of the ram hardness profile. And using these results, regional characteristics of snow cover in the Uono and Kiyotsu basins are to be discussed.

2. Location and Method of Study

2-1 Method of Study

A sketch of the Swiss rammsonde used to this observation appears in Fig. 1. This instrument consists of three parts: the sonde shaft with the probe (1), the hammer guide (2) and the hammer (3). If the depth of snow is larger than about 1 m, the extension shaft can be lengthened in 1 m steps. The probe is a cone having a 60° apex angle and a cross sectional area of 12.6 cm^2. Ram hardness values, henceforth designated as R values, were computed using the original formula (Haefeli, in Bader *et al.*, 1939):

$$R = Whn/X + (W + qQ) \qquad (1)$$

where

$R = R$ value in kgf
q = the number of meter shafts
Q = the weight of 1 shaft (a constant equal to 1 kg)
W = weight of hammer (1, 2 or 3 kg)
h = height from which hammer is dropped (5-50 cm)

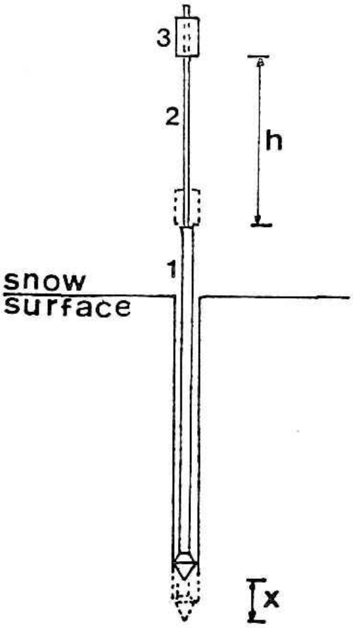

Fig. 1 Rammsonde. 1: shaft with probe, 2: hammer guide and 3: hammer. h: fall height and x: penetration depth.

n = number of times the hammer is dropped per depth interval, ΔX

X = penetration of the shaft assemblage in centimeters

And the mean R value $\bar{R}$ (kgf) and cumulative R value ΣR (kgf・cm) were defined as follows after Benson (1962):

$$\Sigma R = \Sigma R_i \Delta X_i \qquad (2)$$

$$R = \Sigma R_i \Delta X_i / \Sigma \Delta X_i = \Sigma R / HS \qquad (3)$$

where, R values R_i correspond to their associated depth interval, ΔX, and cumulative summations of depth intervals, $\Sigma \Delta X_i$ are snow depth, HS.

Stratigraphy, grain size, density, hardness by Canadian gauge and snow temperature were measured in each of the pits, each about 1.5m in width. Stratigraphic observations were made, using Japanese standard classification of snow cover (Japanese Society of Snow and Ice, 1970). Grain sizes were measured by direct numerical value in mm. Densities were measured by 100 cc snow density box and temperatures were determined with liquid mercury thermometers with a reading accuracy of ± 0.2°C.

2-2 Location of Observed Area

The area studied lies in the Uono and Kiyotsu basins as shown in Fig. 2, and moving observations were made in the plain and mountains in these basins once each.

Traverse line in the plain was along the Highway 17 that leads to Tokyo *via*

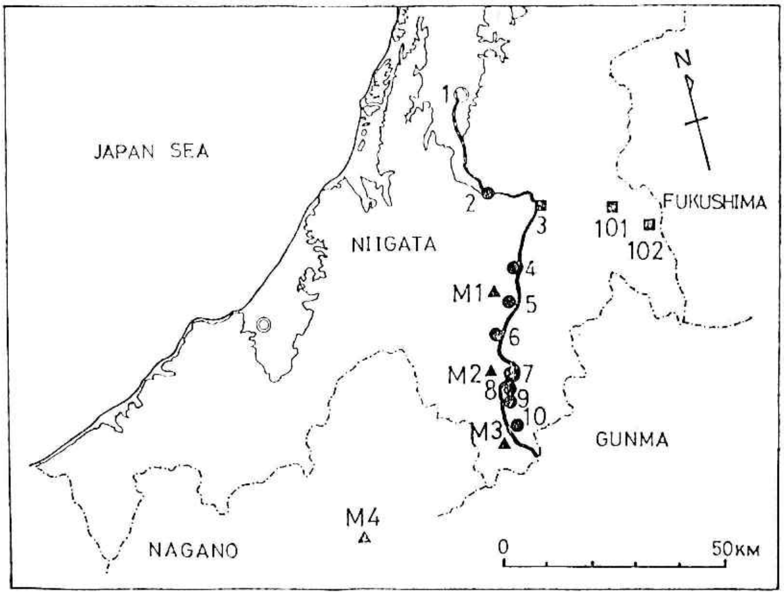

Fig. 2 Sketch map of study area showing locations along the Highway 17 (1: Nagaoka, 2: Kawaguchi, 3: Koide, 4: Muikamachi, 5: Shiozawa, 6: Sekiyama, Yuzawa, 7: Kandachi, Yuzawa, 8: Mitsumata, Yuzawa, 9: Kayatsuri, Yuzawa and 10: Motohashi, Yuzawa), locations of mountain area: M1-M4 and locations along the Koide-Okutadami line; 101: 8-9T and 102: Hassaki.

Gunma Prefecture, with Nagaoka as the starting point and Motohashi as the terminal point. From February 22 to 24, 1978, ram hardness was determined at 13 stations, and snow pits were excavated at 5 stations; Nagaoka (1), Koide (3), Sekiyama (6), Mitsumata (8) and Motohashi (10). Stations 11 (950 m), 12 (1,230 m) and 13 (1,620 m) were located Mt. Takenoko (M3) that is 3 km apart from Motohashi. Transfers between these stations were all made by jeep, because of rapid mobility.

Observed mountain areas, designated by the symbols M1–M4 in the Fig. 2, were Mt. Masugata (elevation: 680 m), Mt. Oomine (elevation: 940 m), Mt. Takenoko (elevation: 1,760 m) and Mt. Yokote at Shiga Heights in Nagano Prefecture (elevation: 2,300m). From March 20 to 24, 1976, ram hardness was determined 16 stations, and snow pits were excavated at 9 stations by employing ropeways and ski (Watanabe, Ikarashi and Yamada, 1976).

Further, the data that is employed to discuss the time-variation of ram hardness were measured at the following 3 stations along the main local road, Koide-Okutadami line (No. 850) by the Koide Power Station, Electric Power Developing Co.

1) Koide (station code 3, elevation 120 m)
2) 8–9T (station code 101, elevation 400 m)
3) Hassaki (station code 102 in the Okutadami Power Station yard, elevation 783 m)

Observation period was in the winter season of 1975/76, the same as the above-mentioned period of the mountain areas.

3. Observation Results and Discussion

3–1 Snow Cover Stratigraphy in the Uono and Kiyotsu Basins

In order to obtain the correspondence with *R* value and stratigraphy, snow pit observations taken parallel to the ram hardness measurements were made at the above-stated five representative stations, henceforce designated as key stations, along the traverse line. The whole snow cover observed at the key stations was divided into several layers; then, distinctive patterns of *R* value corresponding to their associated layer and relation between *R* value and snow type in each layer were analyzed by comparison. The purpose of rammsonde measured in this study is to speculate the stratigraphy at each specific station from its ram profile comparing to the standard ram profile of an adjacent key station.

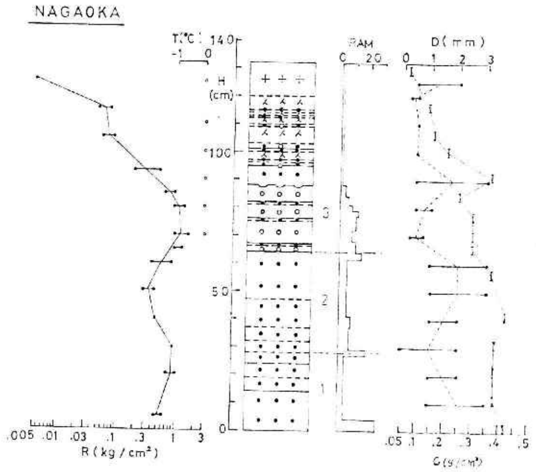

Fig. 3 (1) Stratigraphic columns including physical properties and ram hardness at 5 key stations.

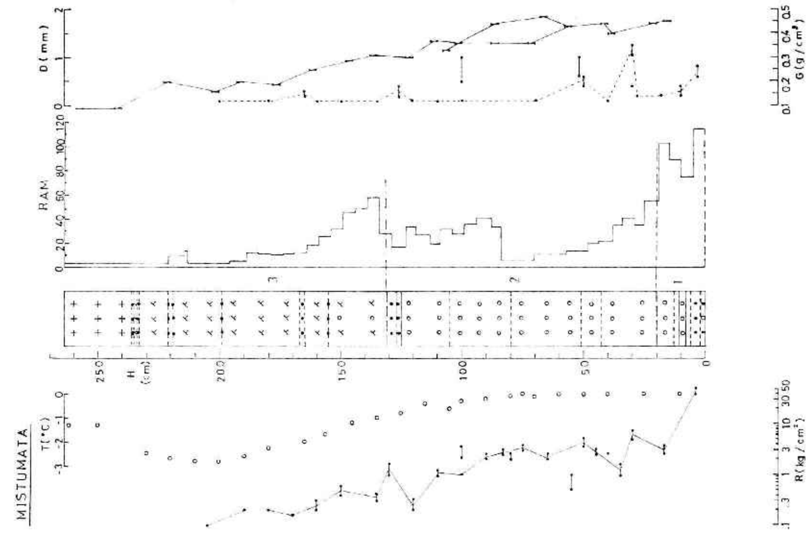

Fig. 3 (4)

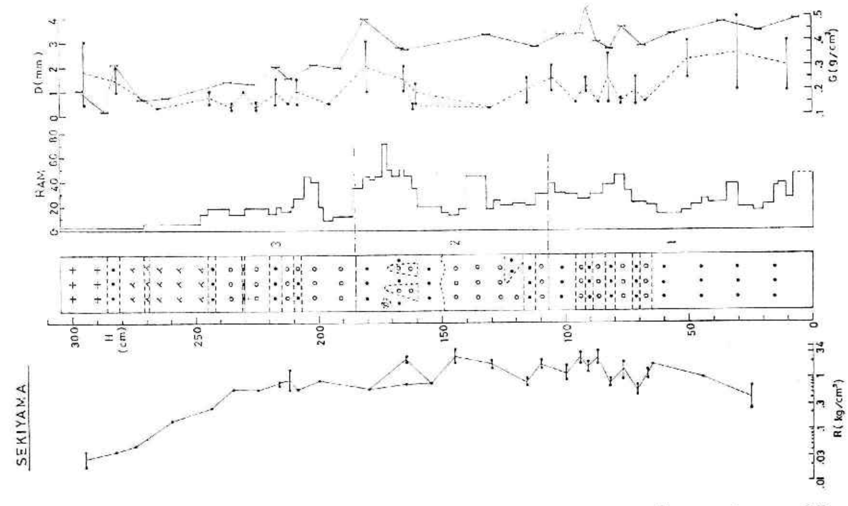

Fig. 3 (3)

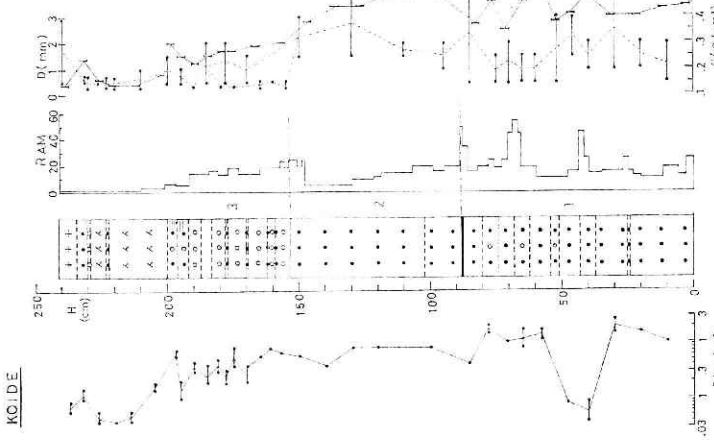

Fig. 3 (2)

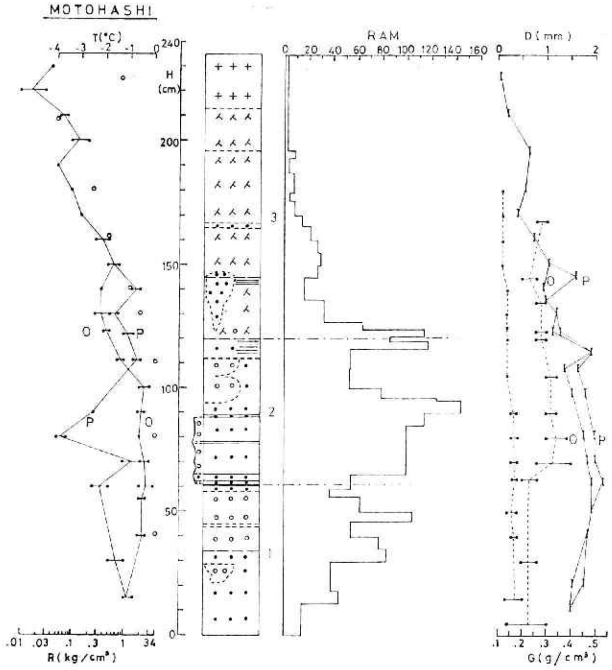

Fig. 3 (5)

Standard profiles at the five key stations are shown in Fig. 3. From the layer structure and the progress of winter weather, the whole snow cover can be divided into the following three layers. Namely, layer 1 (layers formed by the precipitation before January, 29), layer 2 (layers formed from January 30 to Februarv 3; so-called Heavy Snowfall of February 1978) and layer 3(layers formed after February 4).

Ram profiles at all stations are shown in Fig. 4. In the Figure, the ordinate is the depth from the snow surface to the ground, and the abscissa is ram hardness. Snow depth becomes larger toward upcountry. But after it reaches at No. 9 station, snow depth becomes inversely smaller toward upcountry. Two layer boundaries in Fig. 4, which were drawn with the aid of standard profiles, correspond to the boundaries of the

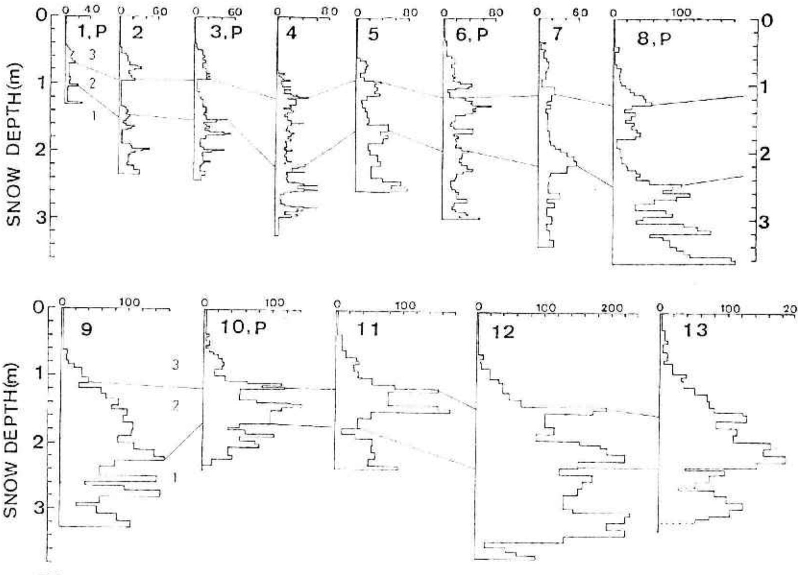

Fig. 4 Ram profile in the Uono and Kiyotsu basins. P shows the locations of snow pit observation.

above-mentioned three layers. From this result, it would be understood that the boundaries can be identified throughout the area by ram profile. Next, if one follows ram profile from the starting point Nagaoka, towards upcountry, paying attention to patterns in a divided layer (for instance in layer 2), one could recognize that initial pattern breaks off at a certain station and another pattern newly breaks out and continues for some stations and another pattern breaks out again. In the blocks where this continuity of pattern exists, it is possible to subdivide a layer into thinner layers.

According to Watanabe, Ikarashi and Yamada (1968), wet metamorphism proceeds from the coast to the upcountry in the Uono and Kiyotsu basins. Here follows the relation between ram profile and the snow type in layer 2, to examine the above-mentioned pattern uncontinuity in the whole observation area:

(1) From station 1 to 4, the *R* value profiles were scarce of irregularity and flat, and mean *R* value was 6 kgf at station 1 and 12–14 kgf at 3 other stations. Snow type in this block was all wet granular snow except for layer 3 as shown in the standard profile (Fig. 3).

(2) At stations 5, 6 and 7, ram profile in the upper half part of layer 2 was flat and snow type was wet granular snow (Zarame Yuki), the same as foregoing block. But that of the lower half part showed a step pattern, which corresponded to wet settled snow (Shimari Yuki). Mean *R* value at these 3 stations was in the range of 19–22 kgf.

(3) At station 8, both the upper and lower half parts of layer 2 showed step patterns; however, snow type of the upper half layer was dry settled snow and that of the lower half layer was wet settled snow. Mean *R* value at this station was 43 kgf.

(4) To the South of station 9 and in the mountain area, mean *R* value abruptly increases. According to the snow pit observation at the key station, Motohashi (10), layer 2 was a mixed layer of wet settled snow and granular snow, or, in other words, typical percolation facies (Benson, 1962). Percolation facies was partly seen at key stations 6 and 8. The facts that the initial stage of wet settled snow and wet granular snow in mountain area have large *R* values are to be stated in the following section. Further, at stations higher than 1,230 m in Mt. Takenoko it is speculated that the rate of dry settled snow

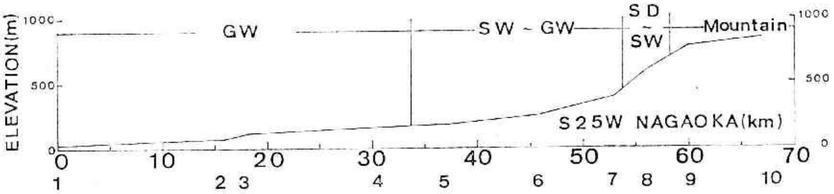

Fig. 5 Regional characteristic of snow cover in the Uono and Kiyotsu basins. GW: wet granular snow, SW: wet settled snow, SD: dry settled snow and Mountain: hard snow.

increased.

From the observation result of snow pit and analysis of ram hardness profile, it is considered that the Uono and Kiyotsu basins form a snow cover environmental system that consists of four domains as shown in Fig. 5. In Fig. 5, the degree of upcountry, with Nagaoka as the starting point and in the direction S25W, is taken as the geographical index. And elevations projected to this direction are shown for the purpose of indicating topography. This classification of domain is determined by only one moving observation in late February, and the name of domain was taken from the main structural snow type of layer 2.

3-2 Snow Cover Stratigraphy in the Mountain Area

Observation results in the mountain area are shwon in Fig. 6. The abscissa is elevation, and ram profiles are arranged in four rows of the mountain series, respectively. Besides, arrangement of each mountain from the bottom in the figure is in order by the degree of upcountry in the basins. Two layer boundaries, that are also drawn by the aid of snow profile (Watanabe, Ikarashi and Yamada, 1976), correspond to the following three layers: Layer 2, so-called Heavy Snowfall of January 1976, was formed by the precipitation from January 18 to January 27; Layers 1 and 3 were formed by the precipitation before and after layer 2, respectively.

Snow depth of the mountains in the basins is proportional to elevation at one mountain, and if the elevation is equal, the snow depth of upcountry is larger than that in coastal areas. Here follows the relation between ram profile and snow type:

(1) At the stations below 700 m in Mt. Masugata and Mt. Oomine, snow type was all wet

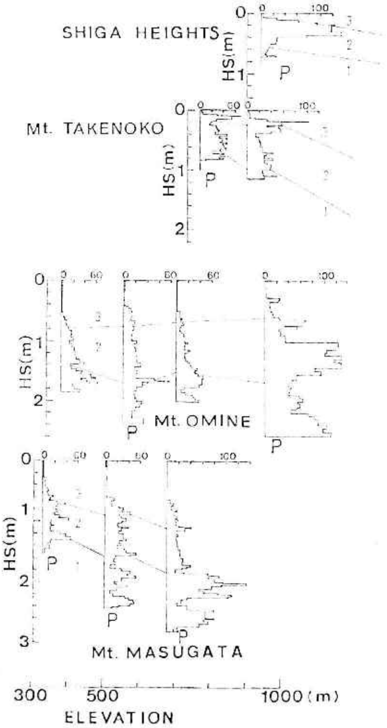

Fig. 6 (1) Ram profile in the mountain areas. P shows the location of snow pit observation.

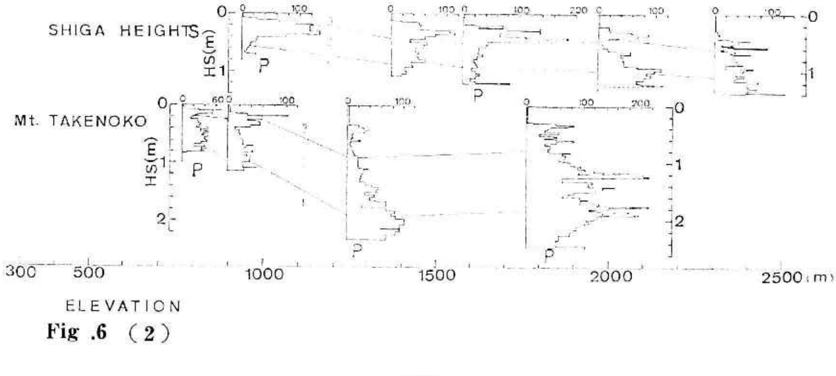

Fig .6 (2)

granular snow, except for the surface layer which consists of new snow (Shinsetsu) and partially settled snow (Koshimari Yuki). Ram profile was flat and mean *R* value of the layers was in the range from 12 to 22 kgf. Provided that at the summit of Mt. Masugata (elevation: 680 m), mean *R* value of wet granular snow in layer 1 was about 70 kgf and that of whole layer was 30 kgf. At the summit of Mt. Oomine (elevation: 940 m), layer 2 consisted mainly of wet settled snow and partly contained wet granular snow at upper part of the layer. Mean *R* value of layer 2 was about 100 kgf at the layer of settled snow and 30 kgf at the layer of granular snow. Layer 1 consisted of wet granular snow having a large mean *R* value of about 60 kgf and the mean *R* value of whole layer was 59 kgf. *R* value of mountain wet granular snow was always larger than that of plain wet granular snow. The reason is that *R* value of wet granular snow may be affected by the initial density when it gets wet.

(2) At the stations below 1,240 m in Mt. Takenoko, wet settled snow was the main structural snow type. Especially at 1,240 m station, layer 2 consisted of only wet settled snow, and dry granular snow, which was not seen in Mt. Masugata and Mt. Oomine, appeared at the surface layar 3. As the *R* value of dry granular snow is very large in comparison with other snow types at the surface layer, it is easy to identify dry granular snow from ram profile. Mean *R* value at these three stations were 29–37 kgf.

(3) At the summit of Mt. Takenoko (elevation: 1,760 m), all layers were dry; layer 2 was dry settled snow and layers 1, 3 were dry granular snow. Mean *R* value of 77 kgf at this station was the largest value among the whole mountain observations. Characteristic pattern at this summit was spike pattern having a locally large *R* value. Spike pattern mostly corresponeded to thick ice layer, but in some cases it is considered that it corresponds to microstructure which is not observable in snow pit.

Ram profiles of dry settled snow at the summit and wet settled snow at the 1,240 m station showed a typical step pattern that exists only in the uniform thick settled snow layer. And an inverse step pattern was seen in the layer 1 at the summit. The reason for this is not clear; however, it may have been caused by the snow temperature effect of the freezed layer.

(4) In the Shiga Heights, dry granular snow in the surface layer was remarkable, and its *R* value exceeds 100 kgf. Snow type of layer 2 was dry granular snow at 940 m station and mixed layer of dry and wet settled snow at 1,570 m station. At the two stations higher than 1,570 m, snow type is speculated as dry settled snow from ram profile. Mean *R* value was 32 kgf at the summit and was in the range from 43 to 52 kgf at the other 4 stations. At the summit of Mt. Yokote (2,300 m), spike patterns developed like the summit of Mt. Takenoko. And inverse patterns were seen at the whole stations except for the summit.

Putting all observation results in the mountain area together, it is concluded from ram profile that (a) wet metamorphism is delayed according to its elevation in each mountain, (b) if the elevation is equal, wet metamorphism is delayed according to its degree of upcountry, but (c) in the Shiga Heights, the elevation at which wet metamorphism progresses was higher than in other mountain areas, and surface layer was dry granular snow. These results means that the difference of cold and warm air temperatures is large in the Shiga Heights.

4. Time-Variation of R Value

4-1 Time-Variation of Mean and Cumulative *R* Value

As shown in Fig. 7, mean R value $\bar{R}$ and cumulative R value ΣR became larger in order of Koide, 8-9T and Hassaki or in the order of their elevations. Since this relation did not considerably change throughout the winter and the variation tendency of these two values were almost the same, $\bar{R}$ will be cited in the following.

At Hassaki and 8-9T, snow cover was dry until the middle of February and $\bar{R}$ gradually increased. Towards February 20, wet metamorphism started and $\bar{R}$ showed its maximum directly after or several days after the snow cover was wet. Then, it rapidly decreased with the progress of metamorphism. This reduction of $\bar{R}$ ceased in

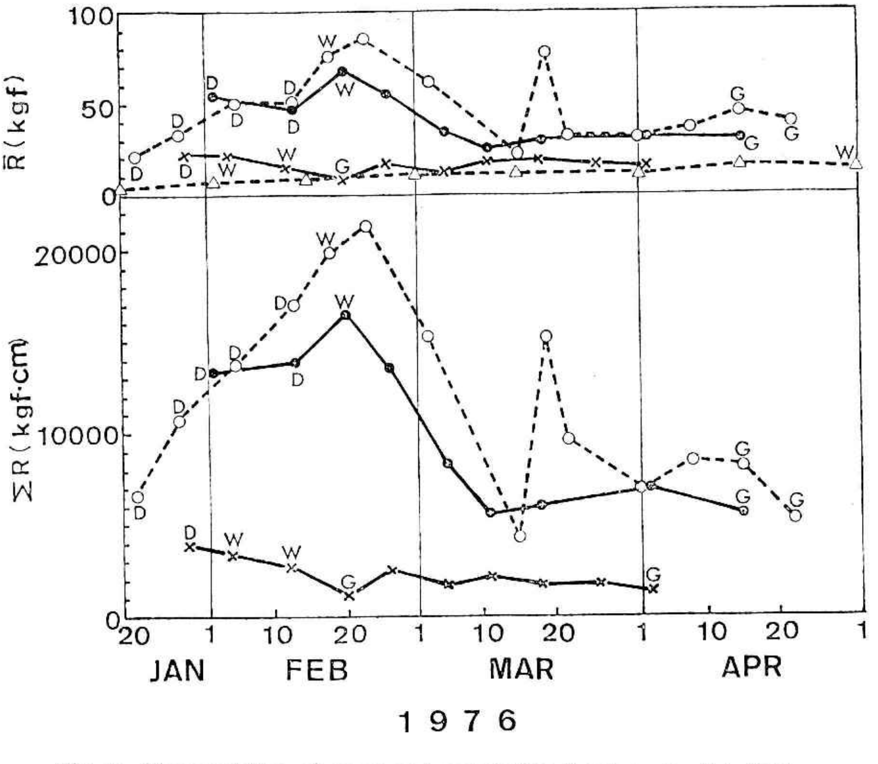

Fig. 7 Time-variation of mean and cumulative R value. ×—×: Koide, ○—○: 8-9 T, ○···○: Hassaki and △···△: Weissfluhjoch.

the middle of March and after that it was almost constant. On April 15, the whole layer became granular snow, and $\bar{R}$ of granular snow at this stage was twice or thrice as large as that of Koide on and after February 20.

At Koide, wet metamorphism started in the beginning of February. At that time $\bar{R}$ reached at its maximum value. And then it decreased rapidly. Towards February 20 when snow cover became granular snow, $\bar{R}$ showed its minimum value. It is noted that with advance of granular snow $\bar{R}$ a little increased.

In Fig. 7, $\bar{R}$ measured at Weissfluhjoch (elevation: 2,540 m) in Switzerland, the birthplace of Rammsonde, are plotted (de Quervain, 1977). Mean R value at Weissfluhjoch is always smaller than that of Koide, and starting time of wet metamorphism, in late April, is later than Hassaki in this winter season. Wissfluhjoch is in a typical temperature gradient metamorphism zone and excels in weak depth hoar. On the other hand, Koide is in a typical melt-freeze metamorphism zone along the Japan Sea and excels in weak granular snow. And Hassaki and 8–9 T is in a equi-temperature zone and excels in hard settled snow.

4–2 Time-Variation of Ram Profile Pattern

Time-variation in Koide-Okutadami area is shown in Fig. 8. Method of layer division and resultant layers are the same as the mountain area. Snow pit observation was always accompanied with rammsonde measurement.

Ram profile pattern at each station shows characteristic common throughout the winter. Particularly, if one follows the time-variation of ram profile paying attention to the two layer boundaries, one can recognize that its pattern has distinguishing marks. This fact means that main layers can be inversely identified by the decoding work of ram profile.

Mean R values of the whole layers were investigated at the preceeding section. However, the features of metamorphism process in one layer may be shaded off by

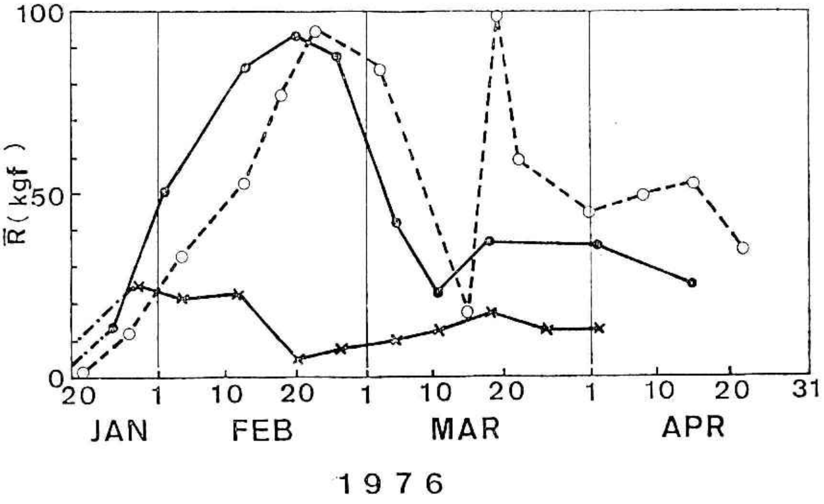

Fig. 9 Time-variation of mean R value of layer 2. ×—×: Koide, ○—○ :8–9 T and ○···○: Hassaki.

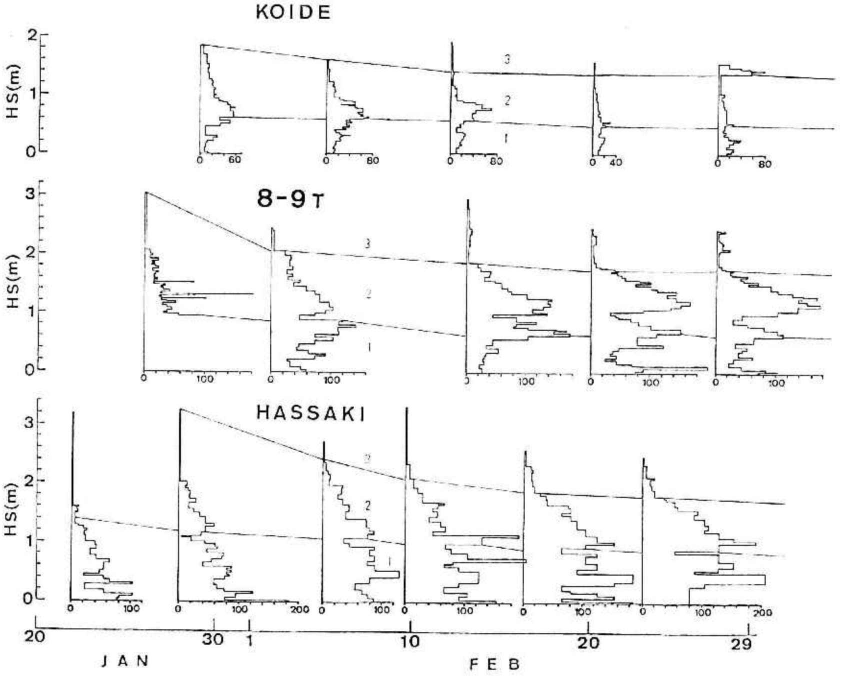

Fig. 8 Time-variation of ram profile in Koide-Okutadami area in the winter season of 1975/1976.

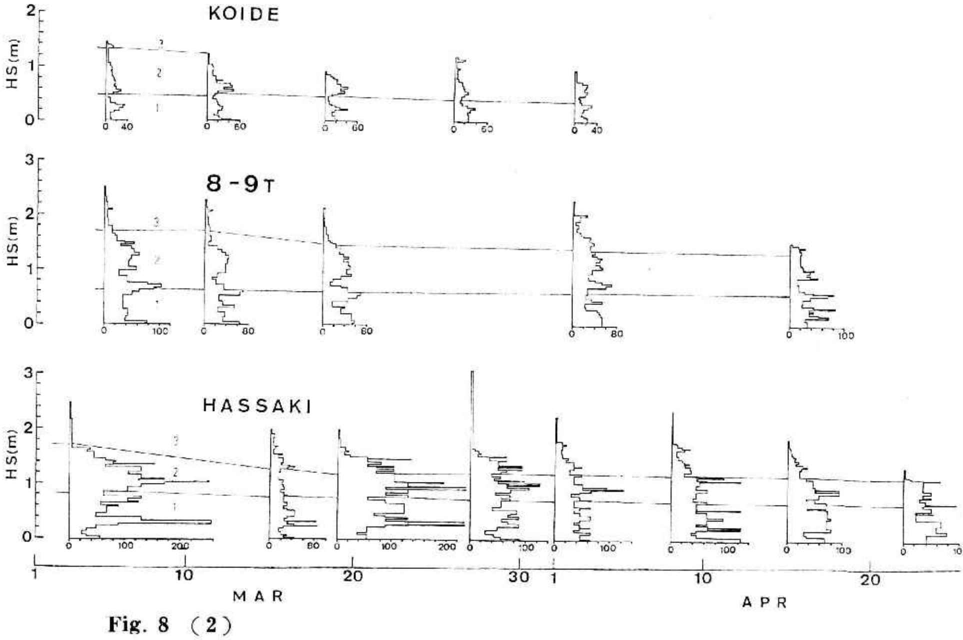

Fig. 8 （2）

the depth of new snow and other layers. So, the mean R value of layer 2 was calculated as in Fig. 9. It may look similar at a glance to that of the whole layers, but it actually has the following tendencies. Namely, the occurrence time of maximum and minimum values of $\bar{R}$ delays in the order of Koide, 8–9 T and Hassaki. Therefore, there is a case that the maximum value in layer 2 at Koide is larger than at Hassaki.

Here follows the relation between the ram profile pattern and snow type only in layer 2 at station 8–9 T. The time-variation at two other stations can be derived from the above-mentioned time delay.

At station 8–9 T, layer 2 was dry until the observation time of February 13. On February 26 when wet metamorphism had progressed, remarkable soaked layer appeared in layer 2 and ice layer was seen in layer 1. On March 5, layer 3 had some ice layers. Thereafter, on March 18 granular snow and ice layer were formed in layer 2, and at last on April 15 the whole of the layer 2 became granular snow.

There exists a step pattern in the ram profile of layer 2, during the period from dry facies to wet facies. In the dry facies period, $\bar{R}$ increases and the gradient of step (reciprocal of $\bar{R}$ value difference per unit depth) becomes smaller. Directly after the wet metamorphism, R shows the maximum value, but the gradient of step continues to decrease. In the wet facies period after the maximum value, $\bar{R}$ inversely decreases and the gradient of step becomes inversely larger. And then, from the lower part of layer 2, step pattern begins to be flat. When the layers 1 and 3 contain ice layers, $\bar{R}$ takes its minimum value and ram profile becomes completely flat. With the further progress of granular snow, $\bar{R}$ slightly increases. And at last, when the whole of the layer 2 becomes granular snow, $\bar{R}$ shows the smallest value. It is very clear that ram profile patterns correspond sensitively to the associated snow type and process of metamorphism. The above-mentioned time-variation pattern is typically and diagrammatically shown in Fig. 10. This correspondence is effective at the stations at Koide and Hassaki, too.

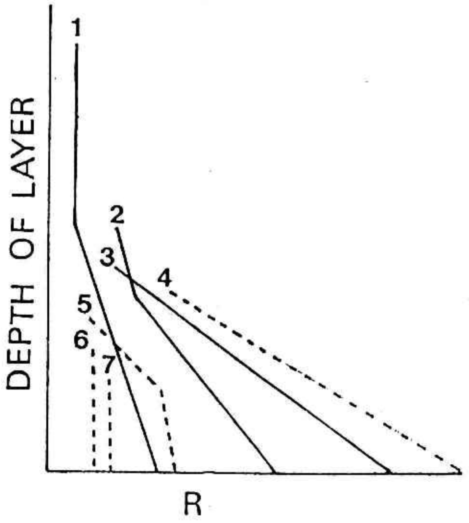

Fig. 10 Time-variation of step pattern (diagrammatically)

Now back to the Fig. 4 and follow again the pattern of layer 2 in the Uono and Kiyotsu basins from the upcountry to the coast, and one can recognize that the gradient of the step pattern becomes gradually larger and then flat at station 4. Mean R value becomes smaller. This regional variation is exactly the same as the time-variation of ram profile in wet facies period. These results support that in a wide area snow type can be divided to some extent only from the ram profile pattern and $\bar{R}$.

4-3 Relation between Mean Density and Mean *R* Value

The result is shown in Fig. 11. The subjective layer is the layer 2 at Koide-Okutadami area. Mean R value increases with increasing density. But when density increases exceeding the certain limit of density, $\bar{R}$ abruptly decreases. This boundary density is expected to correspond with the changing period of dry snow to wet snow from the Fig. 11. The reason is considered that in dry facies density increases by the sintering and densitification and in wet facies density increases by the percolation of melting water.

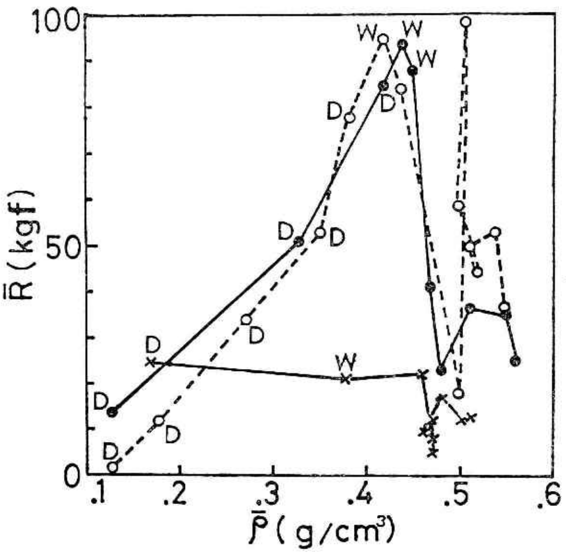

Fig. 11 Relation between mean density and mean R value of layer 2. ×—×: Koide, ○—○: 8-9 T and ○···○: Hassaki.

5. Concluding Remarks

In this study, the authors showed that Rammsonde is effective to identify the layers and to analyze snow type in a melt-freeze metamorphism zone.

Step pattern corresponds to settled snow, flat weak pattern to granular snow and spike pattern to ice layers. It is noted that R value has two equal values which appeared in the dry facies and the wet facies. Problems of wet snow ram hardness are the theme of further study.

The Uono and Kiyotsu basins form a snow cover environmental system that consists of four domains in the late February. And it remains to observe the time-variation profile through these basins.

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ラムゾンデによる魚野川流域の積雪層構造に関する研究

山田　穣・五十嵐高志
国立防災科学技術センター雪害実験研究所

魚野川・清津川流域の平野部および山岳部において，ラムゾンデ測定と積雪断面観測を行った．ラムゾンデの層構造トレーサー，雪質判別インデックスとしての有効性を温暖変態地域で実証した．これらの結果を用いて，魚野川・清津川流域を四つの領域からなる積雪環境系に分類した．