Some Experiments on the Growth of Depth Hoar*

Eiji AKITAYA
秋田谷英次
The Institute of Low Temperature Science
Hokkaido University, Sapporo, Japan

Abstract

The process of the metamorphosis of snow particles of fresh, compact and granular snow into crystals of depth hoar was studied in the cold room of the Institute of Low Temperature Science. Blocks of snow were kept at several constant temperature gradients for about 6 weeks and in the course some pieces of snow were removed from the blocks and the forms of snow particles were observed under a microscope. As a result crystals of depth hoar were found to be classifiable into two types; the skeleton type and solid type. Experiments showed that the crystal types of the depth hoar and their growth rates depend on snow temperature, temperature gradient, grain size of the original snow and its original density.

The snow particles of compact snow transformed into skeleton type crystals under a high snow temperature and a large temperature gradient. While a small temperature gradient causes transformation of the particles of compact snow into solid type crystals. Fresh snow of fine grains with a low density was transformed into the solid type crystals of fine grain under a large temperature gradient. The largest crystals of skeleton type depth hoar were obtained from granular snow of a low density exposed to high temperatures and a large temperature gradient.

I. Introduction

The fragile structure of depth hoar in the snow cover has been mentioned as one of the major causes of avalanches. The depth hoar is formed in the presence of a temperature gradient, and actually the snow temperature increases with the depth of snow cover in cold countries. As the saturated vapour pressure of water decreases with the temperature, the temperature gradient produces a vapour pressure gradient in the snow cover. And water vapour diffuses upward through the air void of the snow cover under such a condition. Yosida and his colleagues showed that the vapour was transferred from a snow particle to the next upper particle, in the same direction as that of the heat flow, and condensed on it owing to the lower saturation vapour pressure.

II. Depth Hoar from Compact Snow

A block of compact snow with a density of 0.32 g/cm^3, and a dimension of $26\times26\times26$ cm was placed in a thermally insulated box in the cold room (Fig. 1). The upper and lower sides of the snow block were kept at constant temperatures of -12 and -3.7°C respectively by the aid of electric heaters and thermal regulators. The gaps between the container and the snow block were filled with foamed polystyrene as a thermal insulator.

* Contribution No. 792 from the Institute of Low Temperature Science.

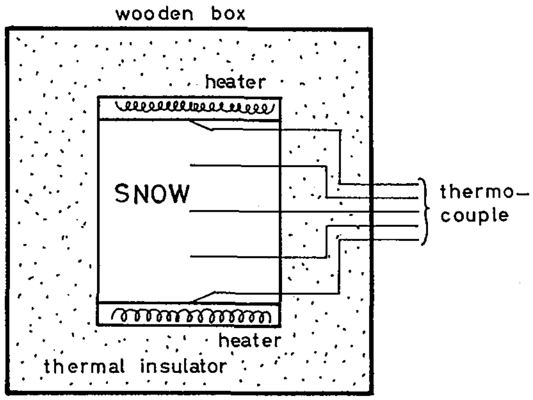


Fig. 1. Experimental device

Once a week, samples of the snow block were removed from the block, and the structure was observed in thin sections, by aniline method, under a microscope. Figure 2 shows the process of metamorphism of a snow particle, from compact snow into depth hoar with a serial number indicating the time lapse of the experiment at upper part of the frame and temperature gradient at bottom. Also, upper, middle and lower rows of the frames correspond to the exact location of the thin sections removed from the orginal snow block. The snow temperature was measured at several levels in the snow block by thermocouples. Thin section No. 7, for example, is from the sample piece taken out of the lower part of the snow block, 3

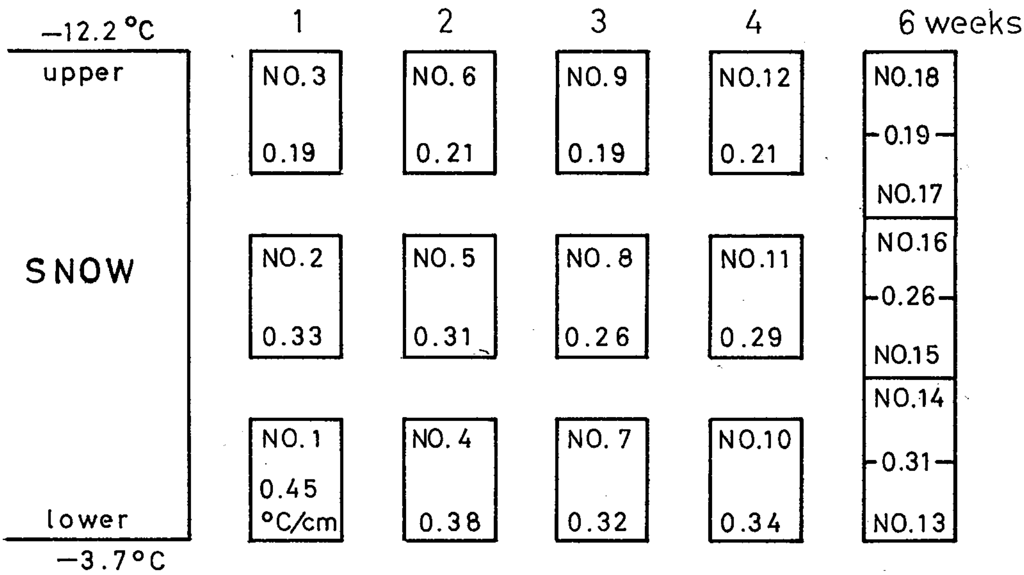


Fig. 2. Time lapes (weeks), temperature gradient and location of thin sections

weeks after initiation, under a temperature gradient of −0.32°C/cm.

Figure 3 shows the microstructure of the original snow block, and Figs. 4 to 7 show those of metamorphosed structures from the first to sixth weeks. The orientation of figures coincide with that of the snow block. It was shown that the snow particles metamorphosed from round shaped particles of compact snow into sharply edged particles of regular depth hoar with a decrease in number of particles.

Figures 8 and 9 are the depth hoar crystals taken out of the snow and they clearly show that there are two kinds of depth hoars, skeleton type and solid type. Their vertical sections are presented in Fig. 10, with (a) as the skeleton type and (b) as the

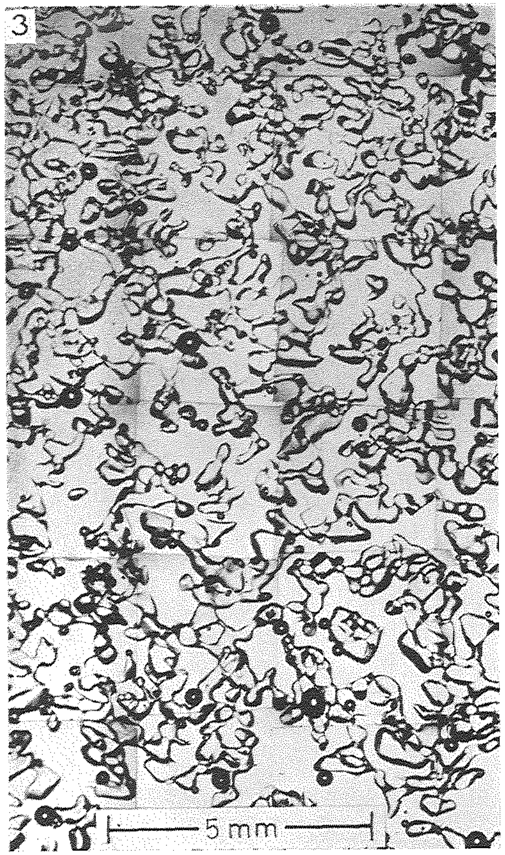


Fig. 3. Original structure of compact snow

Density : 0.32 g/cm^3

Fig. 4. Sample No. 1

Time lapse : 1 week
Mean temp. : -4.0°C
Temp. grad. : -0.45°C/cm

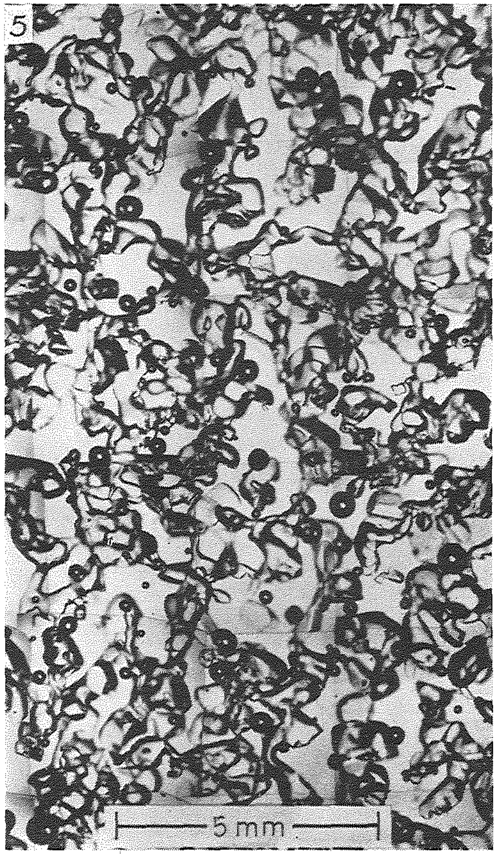


Fig. 5. Sample No. 3

Time lapse : 1 week
Mean temp. : -12.0°C
Temp. grad. : -0.19°C/cm

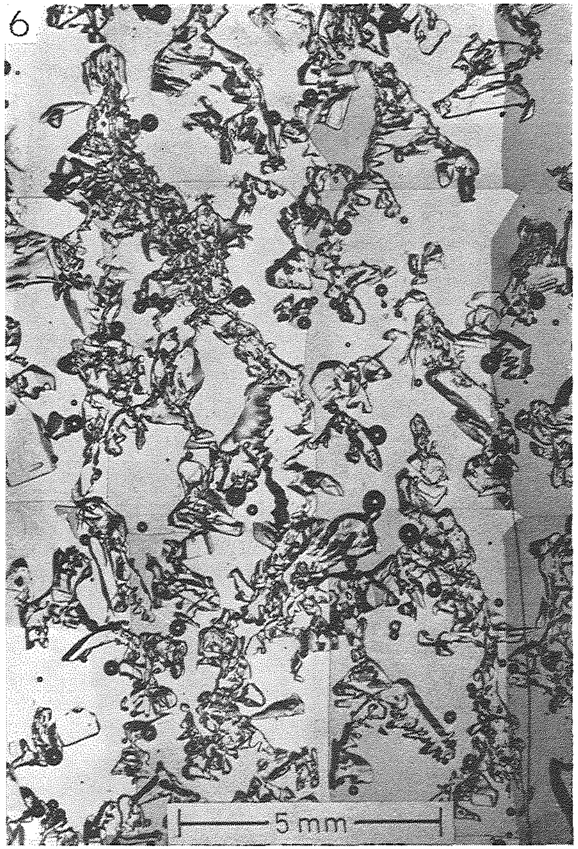


Fig. 6. Sample No. 13
Time lapse : 6 weeks
Mean temp. : $-4.0°C$
Temp. grad. : $-0.31°C/cm$

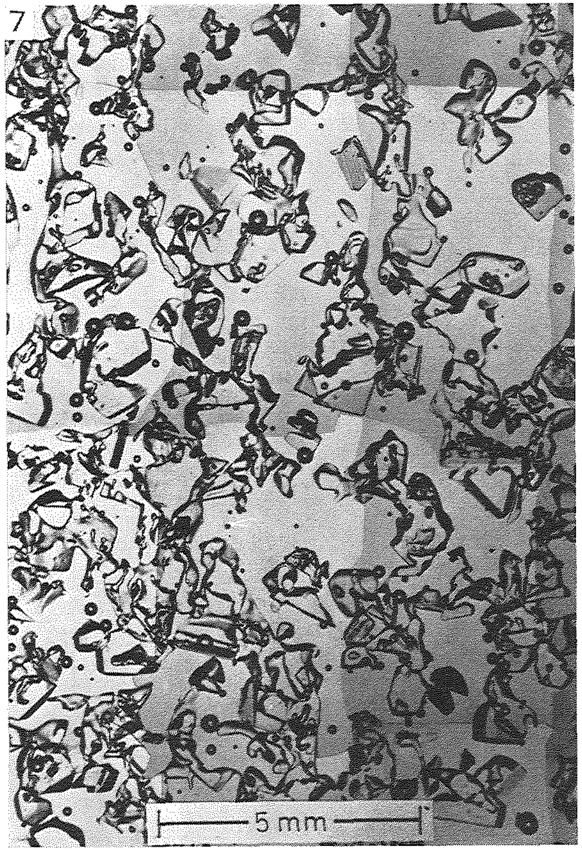
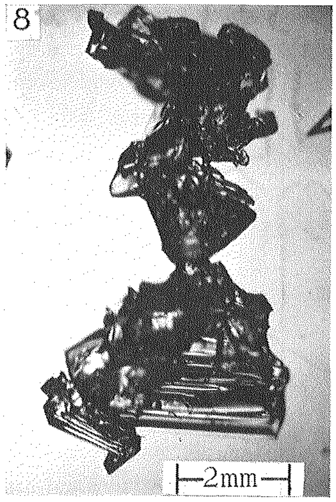
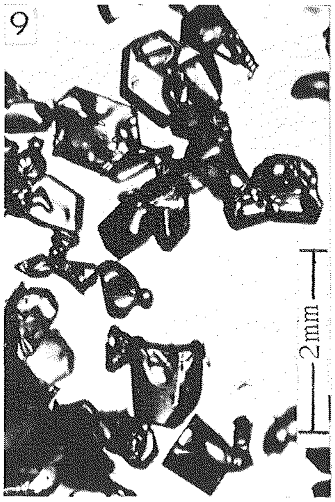
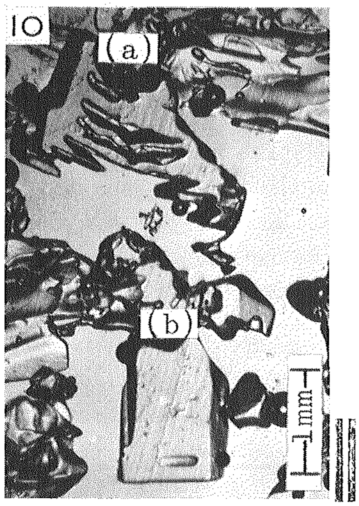
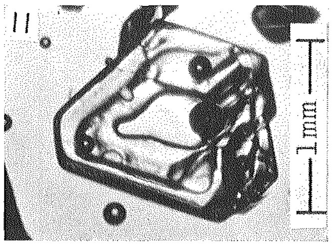


Fig. 7. Sample No. 18
Time lapse : 6 weeks
Mean temp. : $-12.0°C$
Temp. grad. : $-0.19°C/cm$









Figs. 8 and **9.** The depth hoar crystals taken out of the snow
Fig. 8: Skeleton type. Fig. 9: Solid type

Fig. 10. Vertical thin section of depth hoar
(a) skeleton type; (b) solid type

Fig. 11. Horizontal thin section of skeleton type depth hoar

solid type and Fig. 11 shows the horizontal section of the skeleton type depth hoar.

Table 1 gives the number of depth hoar crystals appearing in a thin section of snow samples (7 cm^2 in area), the average size and the ratios of the number of caystals of the skeleton type and that of solid type against the total number of depth hoar crystals, together with the time lapse from the start of the experiment. At the upper part of

Table 1. The number, type and average size of depth hoar crystals

	Upper part of the block					Lower part of the block				
Sample No.	3	6	9	12	18	1	4	7	10	13
Time lapse (weeks)	1	2	3	4	6	1	2	3	4	6
Total number of depth hoar	0	50	51	57	61	89	65	45	46	37
Solid type (%)	—	100	98	85	95	79	76	29	42	32
Size (mm)	—	0.7	0.8	1.0	1.2	0.7	0.7	1.0	1.0	1.1
Skeleton type (%)	—	0	2	15	5	21	24	71	58	68
Size (mm)	—	—	—	—	—	0.9	0.9	1.6	1.4	1.7

the snow block, 50 crystals of depth hoars of solid type appeared after 2 weeks, and later the skeleton type crystals made their appearance. Crystals have a mean diameter of 0.7 mm at 2 weeks and then grew to 1.2 mm during the next 4 weeks. The mean temperature and temperature gradient in the snow of this part were $-12°C$ and $-0.20°C/cm$ respectively.

At the lower part of the snow block, the mean temperature and the temperature gradient were $-4°C$ and $-0.31 \sim 0.45°C/cm$ respectively. Table 1 shows that 90 crystals of depth hoars developed during the first week of the experiment and later the number decreased to one half the number during the next weeks. The large hoar crystals continued to grow and the small crystals disappeared.

The ratios of the number of crystals of skeleton type and solid ones against the total number of the depth hoar crystals were 21 and 79% respectively, at the end of the first week of the experiment. Later the number of skeleton crystals increased at the expense of the solid crystal.

III. Depth Hoar Crystal from Fresh Snow

After the previous experiment some changes were made on the experimental device (Fig. 12). A wooden box was set in the cold room and the temperature inside the box was controlled by an electric heater with a fan. In the box, a kerosene reservoir was set and on top of this, a block of snow with thermal insulators on its four lateral sides was placed. The temperature of kerosene was controlled precisely. This new device was designed to give a constant temperature and a temperature gradient to the snow block in spite of the fluctuation in the temperature of the cold room.

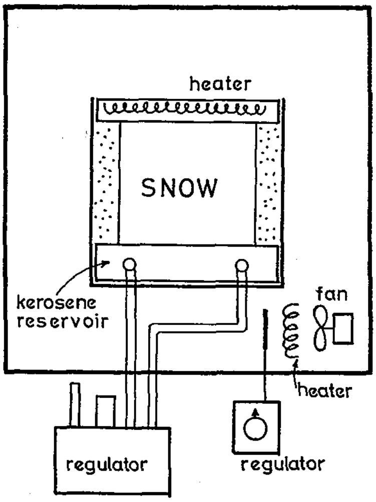


Fig. 12. New experimental device

The block of fresh snow was kept at a mean of temperature $-1.9°C$ and a temperature gradient of $-0.50°C/cm$ for 9 days. Settling of the fresh snow during the experiment lowered the height of snow to half of the original, and increased the snow density from 0.09 to 0.19 g/cm^3.

Figure 13 shows the original structure of the fresh snow which had been previously stored in the cold room at a constant temperature $-25°C$ for 2 months. Figures 14 and 15 show the microstructure of the vertical and horizontal section of the snow 9 days after the beginning of the experiment. As may be seen many tiny crystals of solid type of depth hoar are observed. In the previous experiment on compact snow, depth hoar of skeleton type grew under such a large temperature gradient.

Experiments on the growth of depth hoar from the compact snow by the newly designed device were also conducted. Figures 17 and 18 show the vertical and horizontal thin sections of the metamorphosed snow from the compact snow, the original structure of which is illustrated on Fig. 16. The solid type crystals showed in Figs. 17 and 18 were formed during the lapse of time of 10 days. The temperature and temperature gradient were $-0.7°C$ and $-0.17°C/cm$ respectively.

Experiments on the compact snow under high temperatures (-3.0, -1.3 and $-1.5°C$), and under large temperature gradients such as -0.3, -0.5 and $-0.7°C/cm$ showed that snow particles metamorphosed into the skeleton type depth hoar in 12 deys.

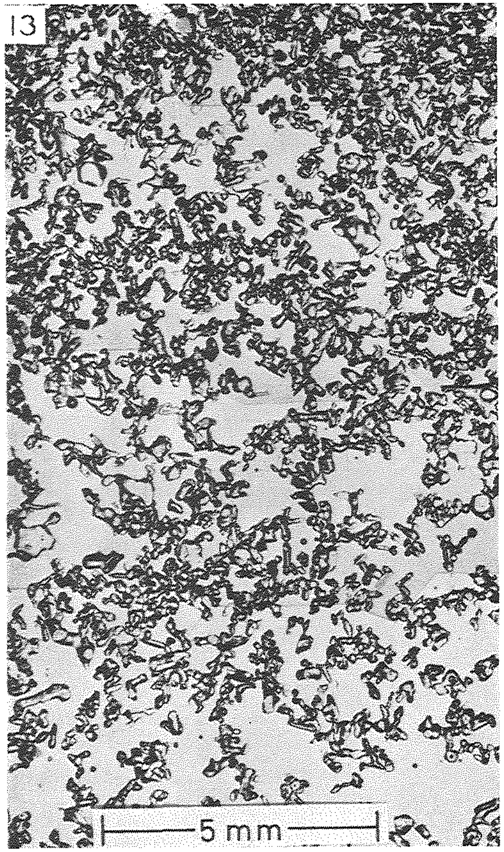
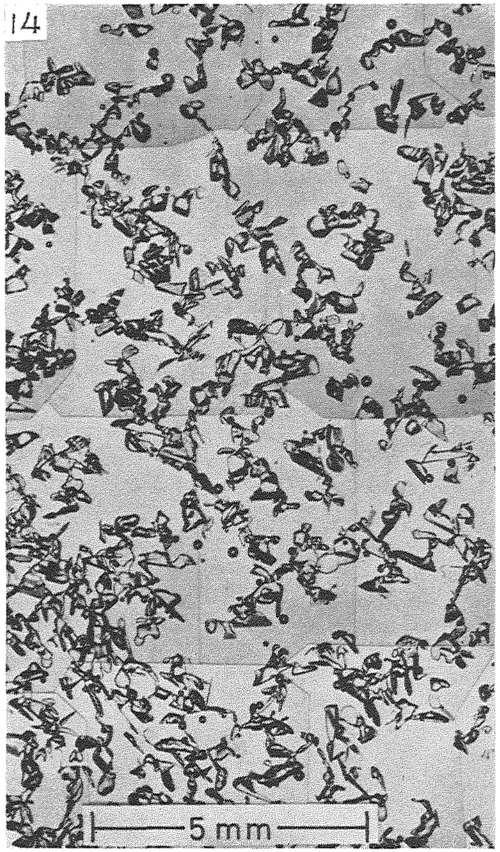
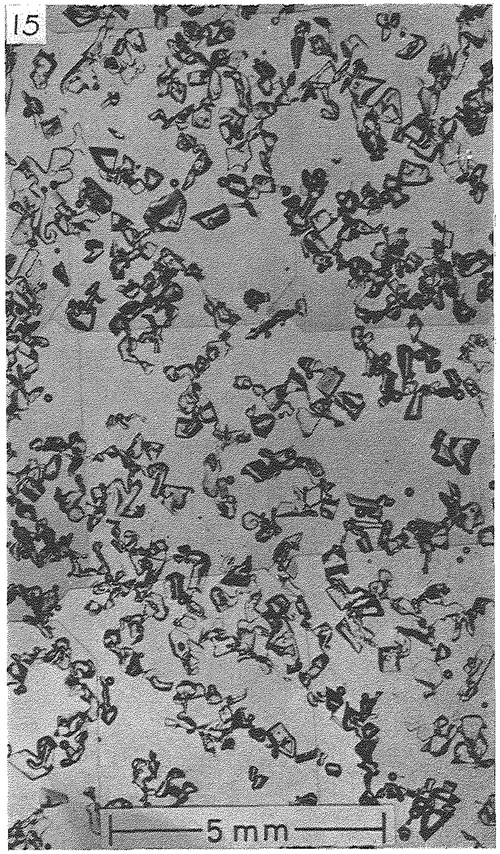


Fig. 13. Original structure of fresh snow
Density: 0.09 g/cm^3 (vertical thin section)





Figs. 14 and **15.** Time lapse, 9 days; Mean temp., -1.9°C; Temp. grad., -0.50°C/cm; Density, 0.19 g/cm^3
Fig. 14: Vertical thin section. Fig. 15: Horizontal thin section

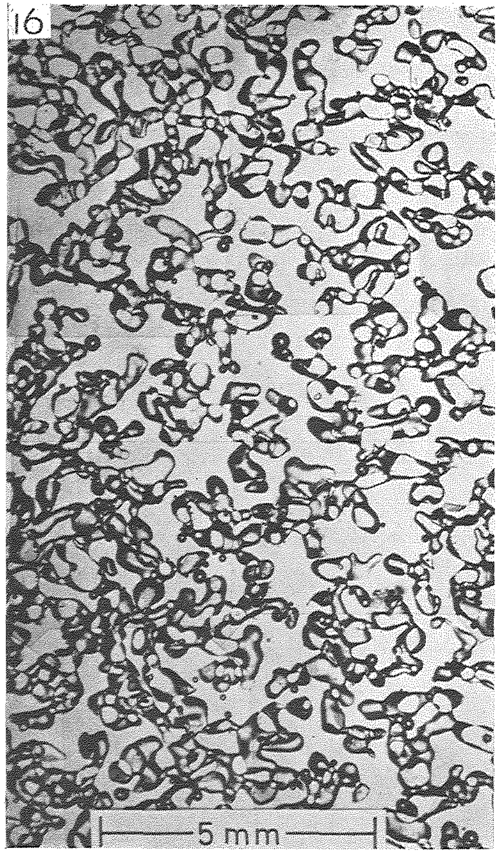


Fig. 16. Original strucure of compact snow

Density: 0.34 g/cm³ (vertical thin section)

Figs. 17 and 18. Time lapse, 10 days; Mean temp., −0.7°C; Temp. grad., −0.17°C/cm

Fig. 17: Vertical thin section. Fig. 18: Horizontal thin section

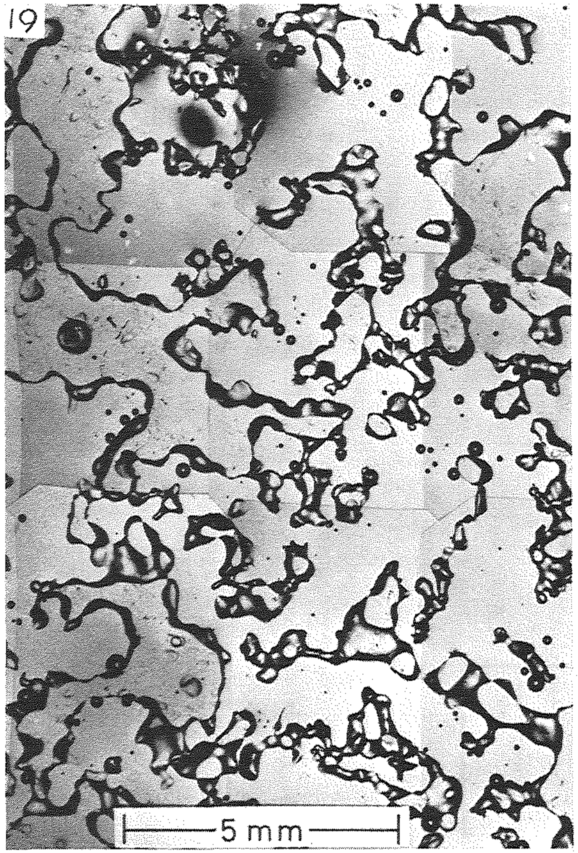


Fig. 19. Original structure of granular snow Density: 0.30 g/cm^3 (vertical thin section)

Fig. 20. Time lapse, 12 days; Mean temp., -3.4°C; Temp. grad., -0.37°C/cm. (vertical thin section)

IV. Depth Hoar from Granular Snow

Granular snow with a density of 0.30 g/cm^3, the microstructure of which is illustrated in Fig. 19, transformed into depth hoar of both types in 12 days. The temperature and the temperature gradient applied were -3.4°C and -0.37°C/cm respectively. The largest crystals of the skeleton type were found in this experiment. The structure of the granular snow seems to be the most suitable for the growth and development of skeleton type crystals of depth hoar. Figure 20 shows the thin section of the snow 12 days after the commencement of the experiment. The snow has many large skeleton type depth hoar, one of which is lossened from the snow and presented on the upper right of the figure. By the procedure of making thin section of snow, large crystals of depth hoar were reduced into fragments and only the pieces of the sharp edged facets can be seen in the figure.

V. Supply of Water Vapour from the Ground or Wet Snow

When the snow cover is deep enough to protect the ground against coldness, the bottom layer of the snow cover on the ground surface is sometimes wet. The supply of the water vapour from this wet snow or from the ground may possibly favor the development of depth hoar. Thus the following experiments were made.

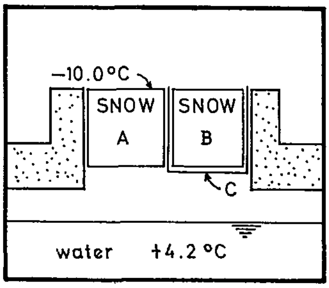


Fig. 21. Experimental device for suppling water vapour

Two blocks of compact snow A and B (0.35 g/cm^3) in Fig. 21 were set in a box with a water reservoir to supply weter vapour to the snow blocks. The temperatures of water and the upper surface of the snow were kept at +4 and -10°C respectively and the temperature gradient in the snow was set at -0.43°C/cm. All of the lateral sides and the bottom of the snow block B were covered by aluminum foil C to shield the snow block from the water vapour from the reservoir.

Four days aftar, the snow blocks were observed with respect to their densities and microstructures, but no particular difference between A and B was found. Many crystals of depth hoar were observed within the snow blocks, and the number and crystal size of the depth hoar were the same in both snow blocks. Thus it was shown that the supply of water vapour from the ground or wet snow of bottom layer has little bearing on the development of depth hoar. Hence it may be said that this kind of vapour supply from liquid water does not actively contribute to the active growth of depth hoar in a snow cover. And the major part of vapour transfer seems to be done by diffusion of vapour from one grain to its neighbouring grain, hand over hand as it were, along the temperature gradient.

References

1) AKITAYA, E. 1964 Studies of depth hoar. I. *Low Temp. Sci.*, **A 23**, 67–74 (In Japanese with English summary).

2) DE QUERVAIN, M. 1958 On metamorphism and hardening of snow under constant pressure and temperature gradient. *IUGG, Intern. Assoc. Sci. Hydrol., Publ.* **46**, 225–239.

3) YOSIDA, Z. 1955 Physical studies on deposited snow I. Thermal Properties. *Contr. Inst. Low Temp. Sci.*, **7**, 19–74.