Studies on Blowing Snow I*

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Abstract

The amount of snow blown under high velocity wind conditions was estimated at Syowa Base with the aid of several simple collectors. The vertical distribution of the horizontal mass flux of the blowing snow on sea ice and at a point half way up of a small hill was obtained. On the sea ice, the horizontal mass flux increased with the decrease of height. On the hill, similar changes as observed on the sea ice were seen, but the mass flux increased in a less degree at the low level just above snow surface.

The particle shape and the size distribution of blowing snow was obtained from the microphotograph. For the preparation of a microscopic sample of flying snow, a slide glass was painted with silicone oil and was exposed to the blowing snow for a short period. Some sheets of glass were covered with a polyethylene film and then painted with oil. When the samples were warmed, each snow particle trapped in the silicone oil melted and became round, though not spherical. This was convenient for the estimation of the volume of the particle. But, the snow particles sticking to each other became one droplet in melting and it caused the error in grading.

The change of the profile of the snow surface in a strong wind was observed by marking the snow surface with sprayed coloured water.

I. Introduction

All parties in Antarctica will encounter numerous blizzards in their wintering period. However, it is considered to be difficult to make quantitative estimations of such blizzards, during sorties. The author wintered at the Syowa Station in 1961 as a member of the fifth wintering party of the Japanese Antarctic Research Expedition. From July to August during the night period no sorties were made, thus the author had ample time to observe blizzards in detail. Since this observation was not anticipated no previous preparations were made. To cover this a simple measuring apparatus was made to render the observation possible. The erosion and the sedimentation of snow on snow fields were also observed.

II. Particle Size and Shape of Blowing Snow

It is easy to expect that the shape of snow particles blown by wind retains a part of the figure of regular snow crystals, when the blizzard occurs immediately after a snow fall. In fact, numerous fragments of dendritic snow crystal were observed microscopically as shown in Fig. 1. But, on the second or third day of the blizzard,

* Contribution No. 786 from The Institute of Low Temperature Science.

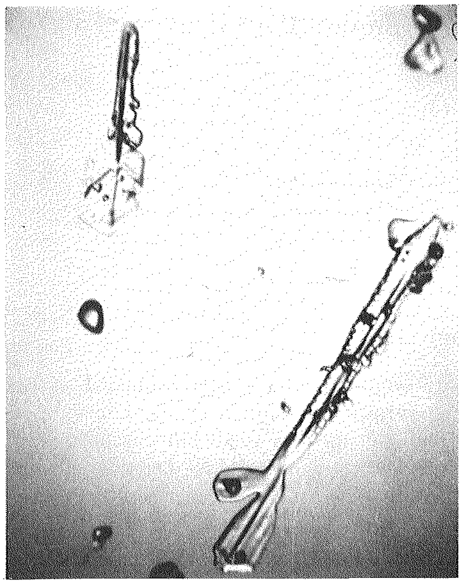

Fig. 1. Microphotograph of snow particles blown at the beginning of the blowing snow just after a slight snow fall. The photograph was taken on June 28, 1961. The longer side of the photograph corresponds to about 2 mm in the original

Fig. 2. Microphotograph of snow particles commonly seen in the blowing snow. The photograph was taken on August 3, 1961. The last snow fall was July 29. The magnitude of the photograph is equal to Fig. 1

the shape of all particles became granular as shown in Fig. 2. The grading of blown snow particles by size was determined on the microphotographs. The samples were obtained by exposing a slide glass for about five seconds to the blowing snow. The size of the slide glass was 2 cm by 7 cm. The surface was coated with silicone oil. The slide glass thus prepared was attached to the end of a slender wooden slat and covered with a hard paper sheath. For the exposure, the slide glass was pushed out into the blowing snow at right angles to the wind direction.

The projected area of these particles was measured with a planimeter on the enlarged microphotograph. The diameter of a sphere having the same projective area to a particle was used as an effective diameter of the particle and the volume of the particle was assumed to be equal to the volume of the sphere. The relation between the particle size and the cumulative *frequency* of particles finer than the size is shown in Fig. 3, and the relation between the particle size and the cumulative *volume* of particles finer than the size is shown in Fig. 4. The sample for curve A was obtained at 1800 hours on August 3, at 5 cm above the snow surface at the observation point halfway up a small hill. The mean wind speed was 11.7 m/s at 5 m in height and the air temperature was about $-13°C$. The exposure time was about five seconds. The sample for curve B was obtained at 1520 hours on August 6, at 5 cm above the snow surface in snow fields on sea ice. The mean wind speed was about 10.5 m/s. The exposure time was about five seconds. The sample for curve C was obtained at 2200 hours on August 3 at the same place as A. The mean wind speed was 16 m/s and the exposure time was not more than one second. The median of the particle size, that is to say the particle size which had 50% in cumulative frequency was 0.14, 0.14 and 0.10 mm for curves A, B and C respectively. The particle size which had 50% in cumulative volume was 0.23, 0.20 and 0.47 mm for curves A, B and C respectively. Special care must be taken to compare these curves, since the sample C was obtained

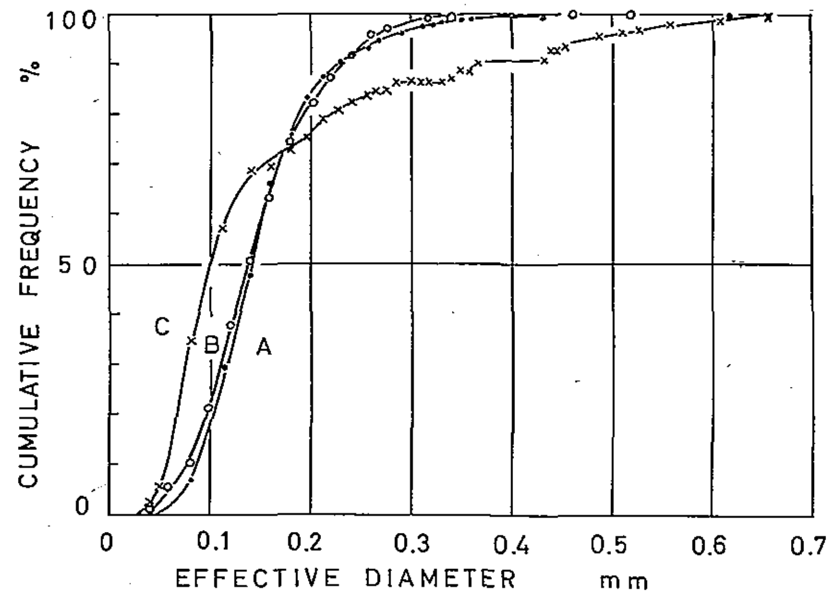

Fig. 3. The relation between the particle size and the percentage of the cumulative frequency of particles finer than the particle size

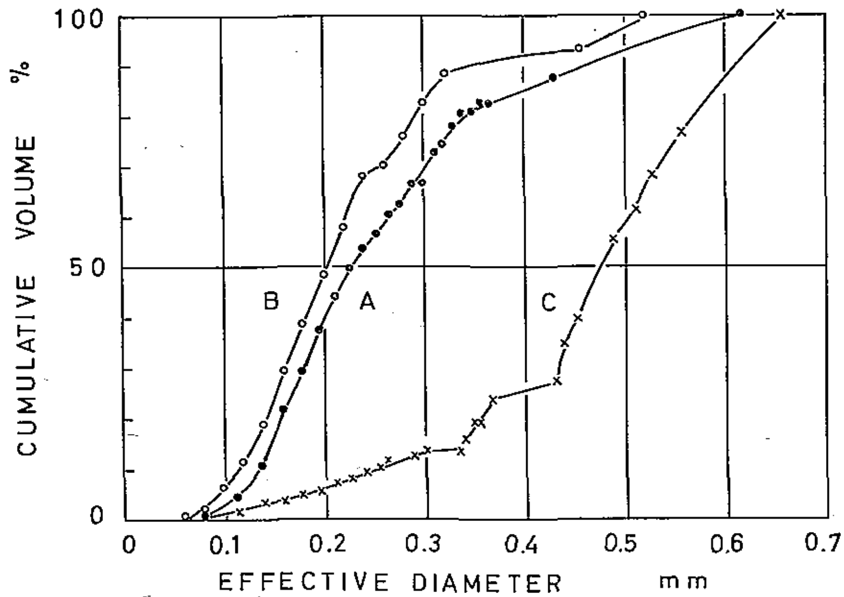

Fig. 4. The relation between the particle size and the percentage of the cumulative volume of particles finer than the particle size

by a different method. In this case the slide glass was covered with a polyethylene film and then the film was covered with silicone oil. The exposure time was very short in order to have a scattered sample on the slide glass which did not have overlapping of particles caughted in oil film layer. The sample was placed in a covered case and exposed to room temperature of +10°C. After the snow particles melted, the microphotograph was taken. The shape of the particles was circular as shown in Fig. 5 and the measurements were very easy.

But it was found that the shape of the particle was not spherical because of the surface tension of the silicone oil.* A particle which had 1 mm diameter in the projected circle, was only 0.6 mm in thickness. Then the volume of all particles with diameters of projected circles exceeding 0.6 mm was corrected being considered that they are 0.6 mm in thickness and the diameter of the particle was also represented by the diameter of the sphere having the same volume as the particle. It is noted here that these tests were carried out in Sapporo, after the author returned to Japan. Thus it is not certain whether the silicone oil had the same properties as that used at Syowa Station and then whether the correction based on this test is applicable for the microphotographs taken at Syowa Station. In photograph Fig. 5, the shape of a drop seems to be not spherical and the center seems to be depressed. But this may

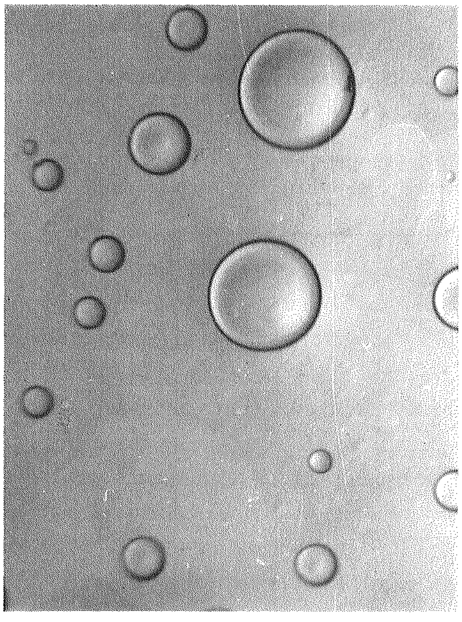

Fig. 5. Microphotograph of blown snow particles melted in the silicone oil film on the slide glass. The photograph was taken on August 3, 1961. The magnitude of the photograph is equal to Fig. 1

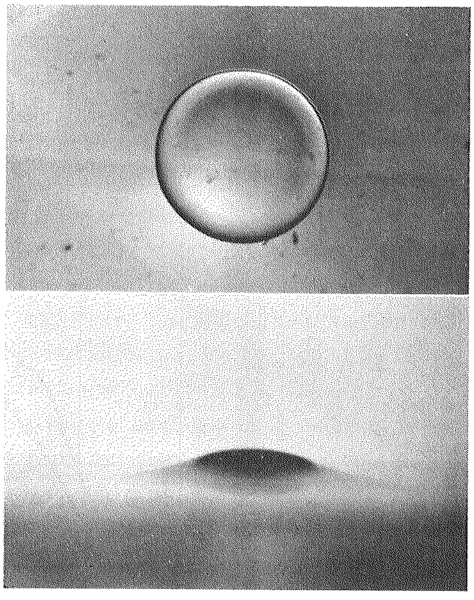

Fig. 6. Vertical and side view of a droplet being enclosed in the silicone oil film on a slide glass. The diameter of the particle is about 1 mm

* It may be readily understood that the deformation is due to the effect of surface tension of silicone oil. A water drop, transfered from a slide glass in a vessel containing silicone oil, becomes spherical at the bottom of the vessel and the diameter of the sphere becomes smaller than that of the circle which was shown on the slide glass oiled with silicone oil.

be attributed to the effect of the high index of refraction of silicone oil. This may be confirm in the horizontal view given in Fig. 6.

But, considering from the curve C in Figs. 3 and 4, it seems to be the fact that each group of neighbouring snow particles on the slide glass melted and became one large particle. Therefore, the shorter exposure of slide glass in the blowing snow is desirable to get accurate distribution curve.

III. Vertical Distribution of Horizontal Mass Flux

The snow particles blown by wind were caught by a simple collector. The opening was made of a tin tube 6.7 cm in diameter and 10 cm in length. The outlet of the tube was covered with a polyethylene film tube 9.5 cm in diameter, that is, 15 cm in width in a folded state and 30 cm in length with the end closed. The shape of opening of the collector which was placed on the surface of the snow field was bent to form a rectangle, so as to collect all snow particles rolling on the snow surface (*cf.* Fig. 7).

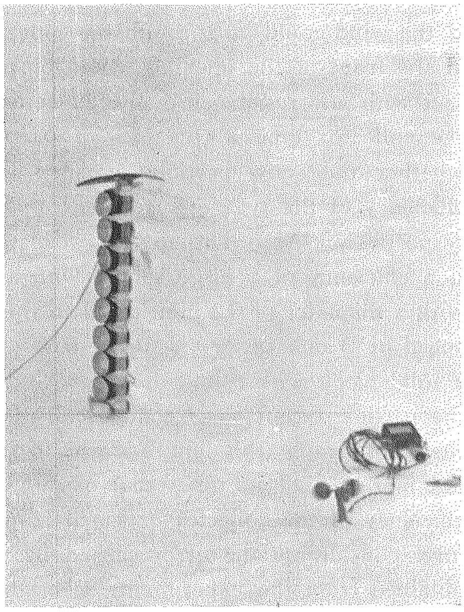

Fig. 7. The collectors set on a alpine pick

The collection efficiency of the collector was obtained by the following method. The collection efficiency is defined as the ratio of the amount of particles caught by the collector to the amount of particles passing through an imaginary frame which has the same shape as the opening of the collector. Two collectors were tied to an alpine pick opposing each other in such a way that they are on the same level when the alpine pick was stood upright on the snow surface. One of these was the collector mentioned

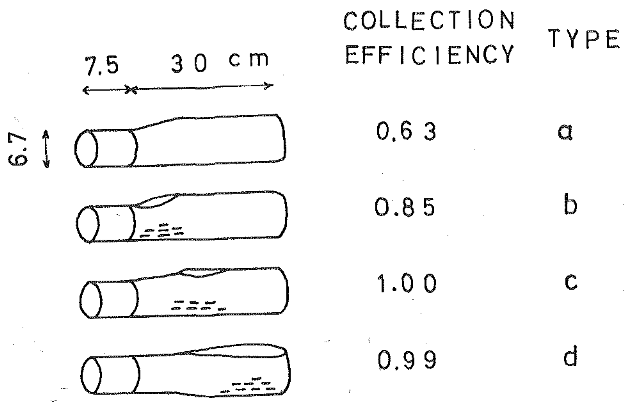

Fig. 8. *Four types of collectors and their collection efficiency*

above (type a in Fig. 8) and the other was a modified version with a higher efficiency of collecting (types b, c and d in Fig. 8). The position of the two collectors was switched at the half time of the exposure, in order to cancel errors, caused from the difference of position. After four to ten minutes exposure, the amount of snow caught by these collectors was measured and compared. The types of modification were three. The polyethylene film tubes were slit lengthwise into three types. One of them was slit 10 cm at wind ward part (type b), the second was slit 10 cm at middle part (type c), and the third was slit 20 cm at tail part (type d). The collection efficiency was compared with each other under the condition that the wind speed was about 10 m/s. Type c and d were found to be the best. The other method of estimating the collection efficiency is to observed the loci of snow particles at the front of the opening. If the wind could go through the collector with no resistance, the loci of snow particles at the front of the opening would be parallel to the wind direction, but if the wind is met with any resistance in the collector the loci of snow particles would diverge. For the collector type d, the loci of particles was hardly disturbed, but it is not clear whether the snow particles escaped from the tail outlet or not. If the collection efficiency of the type c is 1.0, then that of the types a, b and d are 0.63, 0.85 and 0.99 respectively. According to the calculation of Langmuir and Blodgett (1949), the collection efficiency of a large sphere with a diameter of 7 cm, for small droplets of water with a diameter of 0.2 mm (equal to the median in Fig. 4) under conditions of a relative speed of 3 m/s in air, is about 0.88. The blown snow particles shown in Fig. 2 is a solid block with rounded corners and no void as seen in a dendritic form. Though the particle is not exactly spherical, the length of the boundary line of the particle on the photograph (this length seems to be effective in the resistance for viscuss flow) is not more than four times that of the sphere of the same volume. Thus the collection efficiency of the collector expected from the theory is more than 0.64 (aprox.). Therefore, considering the error caused by the fluctuation of wind direction, the value 0.63 obtained from the experiments seems to be acceptable for the following calculation of correction.

The mass flux corrected by the above value of collection efficiency at various heights were shown in Fig. 9. The vertical profile of mass flux measured behind our hut situated halfway up hill is shown by the broken line in Fig. 9 and that measured in the snow field on sea ice is shown by a solid line.

On sea ice the flux at just above the surface is extremely large. But halfway up hill, the flux is not quite as large as on the sea ice and when the wind speed is large (about 19 m/s), the profile is not a monotonous curve. This may be attributed to the influence of the ground surface conditions. Although the ground condition on sea ice is simpler, there are many sastrugi on it. Therefore it was desirable to make measurements for high velocity winds on the sea ice, likewise.

From statistical calculations on microphotographs, the mass flux can be obtained under the assumption that the collection efficiency of the slide glass is 1.0. It is about 10 $g/m^2 \cdot s$ at about 5 cm above the snow surface for the same sample as that for the curve A in Fig. 4. In Fig. 9, this value is plotted by a circle with a point in it, near the line No. 9. The corresponding result of the collector at the same time and at the

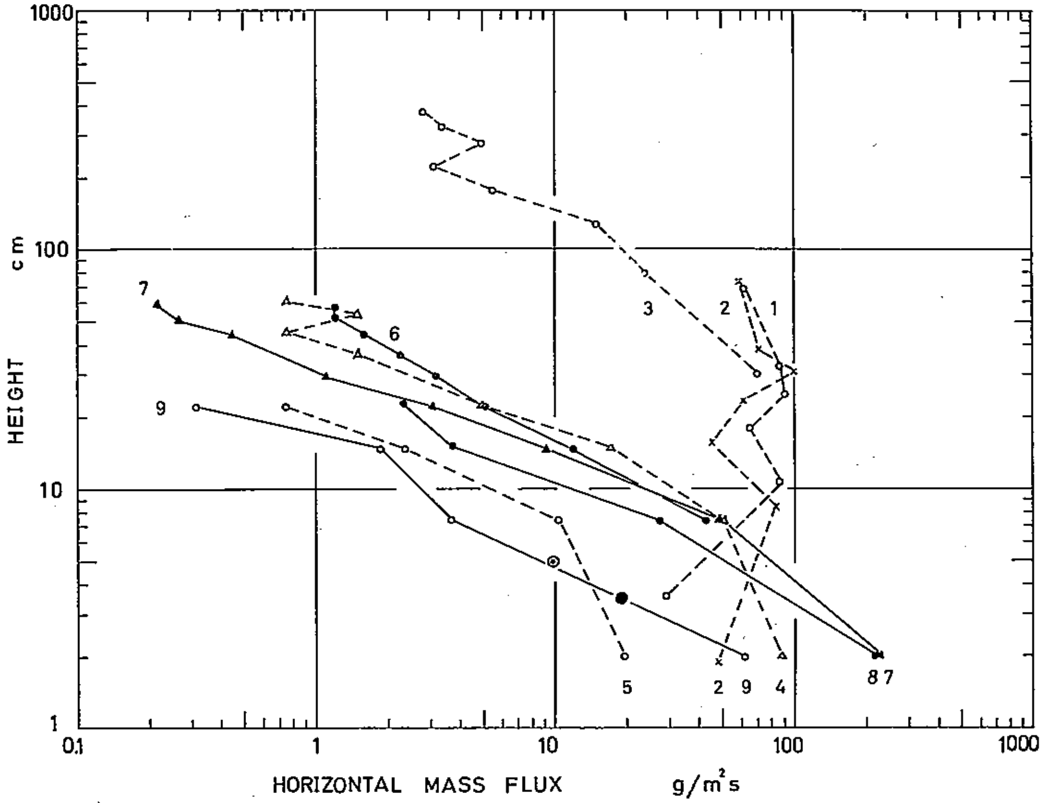

Fig. 9. Relation between horizontal mass flux and height above snow surface. Full lines represent the values obtained on sea ice, broken lines represent the ones halfway up the hill. The numbers denoted by the side of the curves correspond to the numbers of Table 1

Table 1

No.	Date time of start	Duration of observation (minutes)	Location	Standard* (m/s)	Wind speed Mean speed** [variation] (*height*) (m/s)	(m/s) (cm)
1	Aug. 4. 10:35	32	hill	18.5	12 [10–15] (*8*) 14 (*22*)	17–18 [15–22] (*70*)
2	Aug. 4. 11:58	31	″	19.0	15–18 (*25*)	18–19 [17–22] (*70*)
3	Aug. 4. 14:30	50	″	17.5	12–15 (*20*)	14–15 [11–12] (*150*)
4	Aug. 6. 10:13	10	″	10.7	7– 9 (*60*)	
5	Aug. 5. 15:09	10	″	8.3	7 [6–8] (*30*)	
6	Aug. 5. 11:25	30	sea ice	12.2	6 (*6*)	9–10 (*60*)
7	Aug. 6. 11:47	10	″	11.3		7– 8 (*60*)
8	Aug. 5. 13:54	10	″	10.2		5– 7 (*30*)
9	Aug. 5. 15:53	12	″	9.5		5– 8 (*30*)

* The value is the official one recorded by a three-cup anemometer mounted on the top of an iron pipe of 5 m height at a site 40 m northeast from the hut.

** The value obtained by a three-cup portable anemometer which indicates instantaneous wind speed.

neighbouring area is about 19 $g/m^2 \cdot s$ at 3.4 cm above snow surface. It is shown by a large solid circle on the line No. 9, in Fig. 9. Considering the effect of the difference of height above the snow surface and the fluctuation of value by time and by place, the results from the microphotograph are consistent with the result of the collector.

IV. Removal and Deposition by Wind on Snow Field

It is a well known fact that the strong wind carries a large amount of snow. The source of snow particles blown by the wind is the surface snow of vast snow fields. If the snow particles blown by wind are not deposited on the surface of the snow field, even though the amount of snow particles transported by the wind from a unit surface is slight, the particles will be concentrated during the long journey on the wind and become a heavy blowing snow. But, it may be assumed that some snow particles are deposited on the snow surface while some snow particles are transported from the surface which forms a steady state of blowing snow. Therefore, it becomes necessary to know the amount of snow transported and deposited during a blowing snow.

Tatsumi and Kikuchi (1959) reported on the process of developement of the sastrugi. Quote, in the initial stage of sastrugi, small grooves elongated parallel to the direction of the prevailing wind are marked on the surface of hard snow layers. Then the grooves lengthen and link up with each other along the direction of the prevailing wind and then the linkage take place in a direction perpendicular to the former, unquote. On a hard snow surface polished by wind, a sharp fine scratch of about 2 or 3 cm in length is seen. And it was not infrequent that two or three scratches having a different direction were seen forming a pattern resembling a footmark of a small bird. This indicated that the area of the hard snow surface was not all carried off, but only several fine scratches were made on it in a series of blowing snow and afterwards new fine scratches with different directions were made by other series of

Fig. 10. Hard snow surface with many scratches similar to the footmarks of a small bird. The length is about 3 cm. The wind direction is from the bottom to the top right of the photograph

blowing snow (*cf.* Figs. 10 and 11). In this type of observation, it was difficult to determine which scratch was newly formed. Especially, it was not easy to analyse the complicated pattern as shown righthand side of Fig. 11.

To cover this the author sprayed coloured water on the snow surface on a day of strong wind and made the following observations. On May 29, 1961, the wind speed was about 11 m/s at noon. An area with hard sastrugi and the snow surface around them was selected and sprayed with coloured water. The area was about 2 m^2. Snow particles carried by a gust of wind were deposited on the head of a sastrugi making

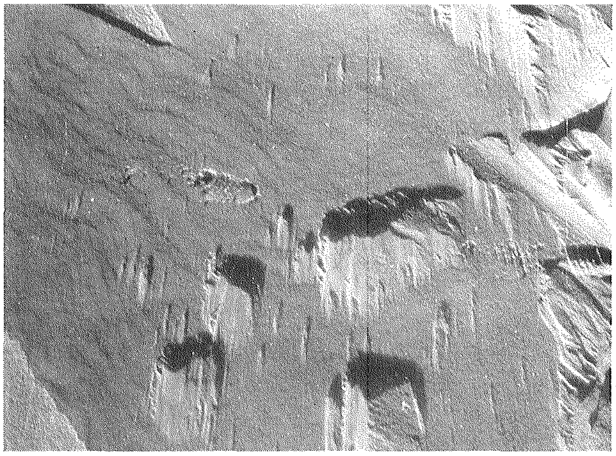

Fig. 11. Hard snow surface with scratches and shallow pits. Almost all scratches are parallel to the wind direction from the bottom to the top. The shallow pits are made of scratches which have developed perpendicular to the wind direction. The fine scratches directing from the right bottom to the left top can be seen in the shallow pits or on some scratches which direct from the bottom to the top

Fig. 12. The peeled off pattern of the coloured hard snow surface. The length of the stick is about 50 cm. The wind direction is from the bottom to the top

the head white, but were blown away with the next gust. It seemed that the snow surface itself was intact. The next day, however, it was found that many parts of the coloured surface were blown off which appeared as bald patches as shown in Fig. 12. The shape of patches was irregular and the size was in a range from about 10 cm to about 40 cm.

The patches of snow deposited on the coloured surface were small and were several centimeters in size and the number was few. In coloured areas of a rather soft and even snow surface, the surface snow was also blown off. But the area of a patch where the surface was blown off was large. The size was more than 50 cm. The coloured area was encroached from the windward boundary and was not divided

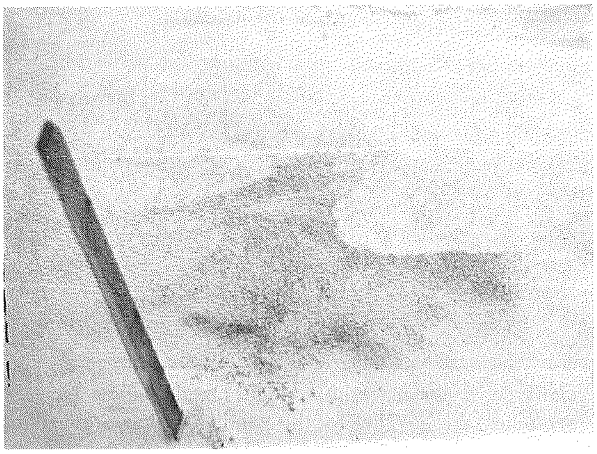

Fig. 13. The peeled off pattern of the coloured soft snow surface. The length of the stick is about 40 cm. The wind direction is from the right to the left

Fig. 14. The soft snow surface with scratches which have developed perpendicular to the wind direction. This resembles the palm of a hand. A match stick 5 cm in length is placed at the right lower side of the photograph

in small parts as seen on a hard and irregular snow surface as shown in Fig. 13. But some white traces of scratches were marked on the coloured area. The size was about 10 cm. Among them a shape resembling the palm of a hand directing the fingers windward was found. It was a laterally developed type made of many fine scraches (Fig. 14).

At about 1400 hours on May 31, another place was sprayed with coloured water. A large but flat sastrugi was present and the surface was sufficiently hard to allow an imprint of gum boots of several millimeters depth. The wind speed was about 15 m/s. Within half an hour, two snow blocks of about 2 cm in size had attached to the head of the sastrugi. At about the same time of the next day, a photograph of the vertical section of the sastrugi was taken. The wind speed at 2100 hours was 18.5 m/s, at 0600 hours on June 1 was 14 m/s and at noon it was 6.8 m/s. The direction of the wind was E or ENE. Some sastrugi showed white heads by the deposition of snow on the coloured head as shown in Fig. 15, and some others in the neighbouring area of the above mentioned sastrugi showed white heads since the coloured head was blown off as shown in Fig. 16. In Figs. 15 and 16, the wind direction is from right to left. As seen in Fig. 15, in front of the initially coloured head shown by the black line in the vertical section, a fairly large amount of snow was deposited. The upper surface of the head was blown off, as shown by a lack of a black line. In Fig. 16, no black line are seen in the vertical section. It means that the initially coloured head was blown off. The head had been moved back leeward. The black spots appearing on the upper surface of sastrugi show that the layer blown off by wind was very thin.

Fig. 15. The vertical and longitudinal section of a small sastrugi. The coloured head is covered by newly deposited snow. The wind direction is from the right to the left

Some sastrugi showed newly deposited snow on its top surface. This new snow showed fine stripes of layers on its side. This means that the snow deposited in stratiform first and then the deposited snow was shaved by the blowing snow. The deposition and the erosion of snow happened in a single day in one series of blowing snow at the same place or in the neighbouring area not more than 30 cm distance

(*cf.* Fig. 16. The deposition can be seen on the upper part of the photograph, while the result of the erosion is shown.)

The vertical and transversal section of a sastrugi is shown in Fig. 17. This section is made of many sets of layers, in other words, it has many unconformities. As each set of layers must have been made in one series of blowing snow, this sastrugi must have been formed in the process of many series of blowing snow. But this is not true in all cases. Sometimes snow dunes are made in one series of blowing snow. Figure 19 is a section of a large snow dune shown in Fig. 18 which was 60 cm in height and about 3 m in width and about 8 m in length. The section showed one set of stripes occupying almost all parts of the sectional plane upon the underlying layer,

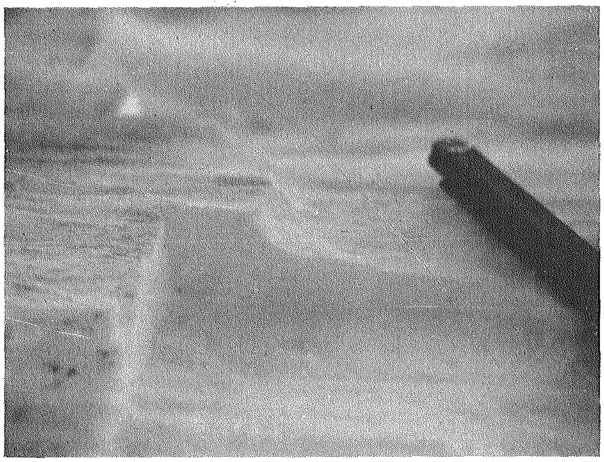

Fig. 16. The vertical and longitudinal section of a small sastrugi. The coloured head has been blown away. The wind direction is from the right to the left

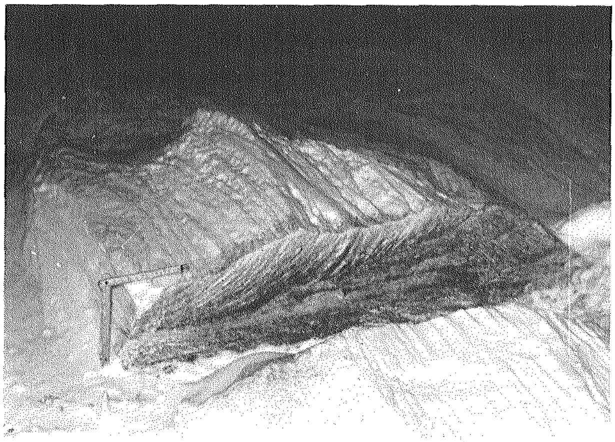

Fig. 17. The vertical and transversal section of a sastrugi about 1 m in breadth. Three or four sets of layers can be seen. Each set of layers may have been made during the respectively different series of blowing snow. The wind direction is from the left upper corner to the right downward corner

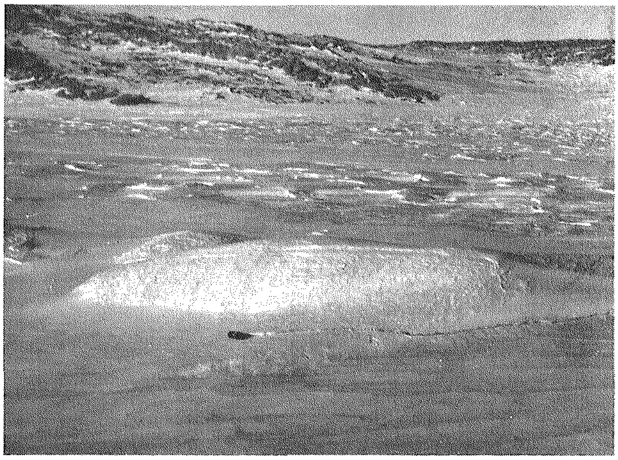

Fig. 18. A snow dune, 60 cm in height, 8 m in length and 3 m in width. The wind direction is from left to right

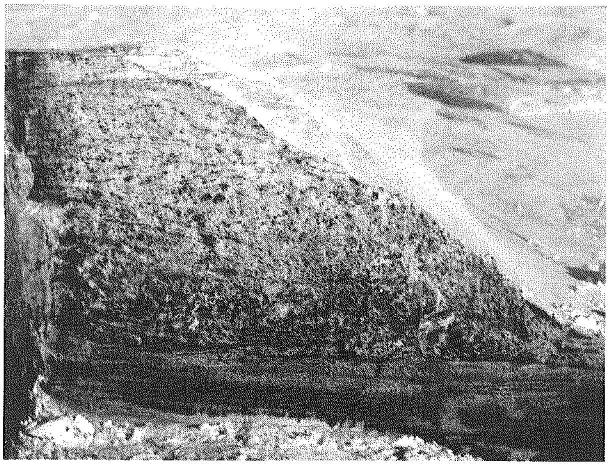

Fig. 19. The vertical and transversal section of the snow dune shown in Fig. 18. Photograph from the windward

though some parts showed the presence of turbulent flow around the snow dune at that time in the period of the blowing snow.

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