General Classification of Snow Crystals and their Frequency of Occurrence.*

By

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(Pl. I–VI)

1. Introduction.

In the foregoing papers[1] the results of the investigations on snow crystals which were carried out at Sapporo and at Mt. Tokati during the last three winters were described in full detail. The types of snow crystals observed in the course of this investigation were so abundant in variety that the former classification proposed in report No. 2, which is more or less similar to the old classification first put forward by HELLMANN,[2] NORDENSKIÖLD[3] and others, had to be revised completely.

In this paper the authors propose a general classification of snow crystals that includes all types of snow observable in Hokkaido, and the results of observations, which were carried out on almost every snowfall in the winter of 1934–35, on the frequency of occurrence of every type of crystal, will be described. The relations between the frequency of occurrence of a certain type of snow with the meteorological conditions observed on the earth surface at the time were examined for almost all of

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* Investigations on Snow, No. 8.

1) The foregoing papers of this series of investigations which were published in this Journal are as follows.

No. 1. NAKAYA & IIZIMA, Snow crystals obesrved in 1933 at Sapporo and some relations with meteorological conditions.

No. 2. NAKAYA & HASIKURA, Classification and explanation of snow crystals observed in the winter of 1933–34 at Mt. Tokati and at Sapporo.

No. 3. NAKAYA & TERADA Jr., On the electrical nature of snow particles.

No. 4. NAKAYA & TERADA Jr., Simultaneous observations of the mass, falling velocity and form of individual snow crystals.

No. 5. NAKAYA, On the correspondence of snow and rime crystals.

No. 6. NAKAYA & SATÔ, On the artificial production of frost crystals, with reference to the mechanism of formation of snow crystals.

No. 7. NAKAYA, SEKIDO & TADA, Notes on irregular snow crystals and snow pellets.

2) G. HELLMANN, Schneekrystalle, Berlin, 1893.

3) NORDENSKIÖLD, Nature, **48** (1893) 592.

the typical snowfalls of the last three winters, and these results will also be described in this paper.

2. The general classification.

Classification of snow crystals is not uniquely defined, as the physical nature of some of the crystals has not yet been clarified. The former classifications of NORDENSKIÖLD, HELLMANN and PERNTER are more or less similar to each other, classifying the crystals into plates, columns and their combinations. The recent classification of Humphreys[1] adds triangular plates and twelve-sided plates. These classifications are inclined to attach importance to the regular crystals or the simpler form. The feature of the present classification is that we regard the all sorts of crystals with equall importance, such as the irregular crystals and those consisting of a spatial assemblage of plane branches, which are as a matter of fact no less frequently observed among the natural snow crystals.

The atlas of the general classification is shown in Plates I–IV, about which brief explanations will be given in the following pages.

THE GENERAL CLASSIFICATION OF SNOW CRYSTALS

I. Needle crystal.
  1) Simple needle.
  2) Combination of needles.
II. Columnar crystal.
  1) Simple column.
    a) Pyramid.
    b) Bullet type.
    c) Hexagonal column.
  2) Combination of columns.
    a) Combination of bullet crystals.
    b) Assemblage of short columns.
III. Plane crystal.
  1) Regular crystals developed in one plane.
    a) Stellar form.
    b) Plane dendritic form.
    c) Crystal of areal extensions.
    d) Plate.
    e) Plate with extensions at corners.
    f) Stellar crystal with plates at the ends of branches.
  2) Crystal developed from two nuclei.
  3) Malformed crystal.

1) BENTLEY and HUMPHREYS, Snow Crystals, New York, 1931, p. 5.

4) Spatial assemblage of plane branches, with a stellar base.
5) Spatial assemblage of plane branches, radiating type.

IV. Combination of column and plane crystals.
1) Column with plane crystals.
2) Twelve-sided crystal.
3) Combination of bullets with plane crystals.

V. Columnar crystal with extended side planes.

VI. Crystal with cloud particles and Graupel.
1) Crystal with droplets.
2) Thick plate.
3) Graupel-like snow.
4) Graupel.

VII. Amorphous snow particle.

I. Needle Crystal.

Considering the results of the experiments on the artificial production of needle crystals of frost (in report No. 6), the needle crystal of snow had better be taken as a kind distinct from the elongated column.

1) Simple needle.

Usually this type of crystal shows a structure like a bundle of several thin pillars growing parallel to each other; illustrated in the Atlas.

2) Combination of needles.

A combination of two needles giving as X-shaped appearance is usually observed; illustrated in the Atlas.

II. Columnar crystal.

1) Simple column.

Crystals growing in the direction of the principal axis of crystallisation are grouped in this type.

a) Pyramid. This is the least frequently observed in our climate; illustrated in the Atlas.

b) Bullet type. A hexagonal column with one end pyramidal shows an appearance like a bullet; illustrated in the Atlas.

c) Hexagonal column. This is a hexagonal cylinder with both ends plane, and is considered to be a twin crystal composed of two bullet crystals; illustrated in the Atlas.

2) Combination of columns.

a) Combination of bullet crystals. The pyramidal terminations of the bullet crystals have a tendency to unite with each other at their heads. Examples of two, three, four, five or six of these crystals uniting at their pyramidal ends were observed; one example in the Atlas, see Photos. 17–19, report No. 1 and Photos. 30 & 31, No. 2.

b) Assemblage of short columns. This type is considered to form the stone of a spatial dendritic crystal of radiating type; illustrated in the Atlas, cf. report No. 7, § 5.

III. Plane crystal.

Crystals developed in the basal plane of the hexagonal system of crystallisation are grouped in this section.

1) Regular crystals developed in one plane.

This is the most common type. Microphotographs of this kind of crystal were collected by many observers in such numbers that this type is now generally considered to be the most representative of snow crystals. This is again classified into six sorts as enumerated in the following paragraph, but there are many crystals of these sorts in intermediate stages.

a) Stellar form. Six straight branches radiate from a centre; illustrated in the Atlas.

b) Dendritic form. Six branches with twigs radiate from the centre, presenting a fern- or plume-like appearance; illustrated in the Atlas.

c) Crystal of areal extensions. Not illustrated in the Atlas; Photos. 15 & 16 of report No. 2 represent examples, the branches of which show the form of tabular sectors.

d) Plate. This sort was observed by Bentley in great numbers, but is observed relatively seldom in our climate; illustrated in the Atlas.

e) Plate with extensions at corners. Extensions at corners may be simple or very elaborate; one example is in the Atlas, see also Photo. 22, report No. 2.

f) Stellar crystal with plates at the ends of branches. Not illustrated in the Atlas.

2) Crystal developed from two nuclei.

Crystals looking as if developed from two nuclei were observed in large numbers, and have an appearance like a twin crystal. In some cases this twin crystal is separated into its component parts, sometimes into two parts, each of two three-branched crystals, sometimes into two parts, four- and two-branched crystals: the origin of these crystals has been discussed by many observers without any conclusion being reached. The details of this double nuclei theory are described in report No. 7. Two examples of this type of crystal are shown in the Atlas.

3) Malformed crystal.

Malformed crystals of various forms and structures are observed only slightly less rarely than regular hexagonal ones. A detailed description is put forward in report No. 7, in which these crystals are provisionally classified into five sorts. Two examples are reproduced in the Atlas.

4) Spatial assemblage of plane branches, with a stellar base.

Most of the crystals of this sort belong to the type which is made of a base crystal of dendritic form with many dendritic branches attached at various points of the base crystal and extending upwards. The side view of this crystal, reproduced in Photo. 39 of report No. 2, will show the structure nicely. Sometimes the plate crystal with extensions at the corners is observed with spatial branches attached. Two examples representing these two cases are shown in the Atlas.

5) Spatial assemblage of plane branches, radiating type.

This sort of crystal has dendritic branches radiating in space from the centre, where a stone is usually observed, as shown in the Atlas. This stone is found to be made up of several short columns gathered together. The structure of this type of crystal together with that described in the foregoing (section 4) is discussed in report No. 7. It is rarely observed that many plates are gathered together to form a spatial assemblage of plates; one example is shown in the Atlas.

IV. Combination of column and plane crystals.

It is usually understood that this type means a hexagonal column with two plane crystals attached, usually one at each end. Many other crystals, however, have been observed which ought to be included in this type.

1) Column with plane crystals.

The typical form of this sort of crystal is a hexagonal column with two plane crystals attached to either end. The plane crystals may be of dendritic form or plates. One example is shown in the Atlas. A hexagonal column is also observed with end plates and also one or more intermediate plates attached normally to the column. Sometimes a crystal is observed which is composed of many columns standing one above another and several sheets of well-developed dendritic crystals. One example is reproduced in the Atlas. Detailed explanation is given in report No. 2.

2) Twelve-sided crystal.

As described in report No. 2, this sort of crystal is made up by the simple overlapping of two component crystals, each a combined form of short column and plane crystal. Two examples are illustrated in the Atlas. When three component crystals overlap, an eighteen-sided crystal is obtained, one example of which is given in report No. 2.

3) Combination of bullets with plane crystals.

The plane components may be of dendritic form or simple plates. Two examples are illustrated in the Atlas.

V. Columnar crystal with extended side planes.

A sort of crystal is sometimes observed that seems to be made up of an assemblage of columnar crystals with extended side planes. The structure has not yet been completely clarified, but laboratory experiments on the artificial production of frost crystals lead the authors to take the plane parts observable in the structure as extensions of the side planes of the columns which form the skeleton of this crystal. Two examples are shown in the Atlas. Detailed explanation is given in report No. 7.

VI. Crystal with cloud particles attached and graupel.

Snow crystals with numerous water droplets attached are very frequently observed in our climate. As described in report No. 4, these droplets are found to be cloud particles. Crystal with cloud particles and graupel are brought together in this section. It is difficult to distinguish these two types, because any sort of snow crystal is observable, the amount of cloud particles attached to which is varied continuously from snow to graupel. A detailed description is given in report No. 7.

1) Crystal with droplets.

Almost all sorts of crystals are observed with numerous droplets attached. Two examples are illustrated in the Atlas, the one being a needle with droplets and the other a stellar plane crystal.

2) Thick plate.

When many water droplets become attached to a plane crystal, it turns into a thick plate sometimes half a millimetre in thickness. Under the microscope this plate looks like a piece of moss when observed by reflected light and appears opaque by transmitted light. The microphotograph of the section of this crystal, Photo. 84 of report No. 2, shows that the droplets are deposited mostly on one side of the crystal. Two examples are shown in the Atlas.

3) Graupel-like snow.

Snow crystals which appear to be in the intermediate stages between snow and graupel are described as graupel-like snow. They are produced by the attachment of numerous cloud particles to the spatial dendritic crystals of ordinary snow. The spatial dendritic ones may be of a radiating type or that with a stellar base, two examples of the former being illustrated in the Atlas and one example of the latter in Photo. 43 of report No. 7.

4) Graupel.

As described in report No. 7, the authors consider that graupel is an advanced state of graupel-like snow. There are three types of the form of graupel; the lump graupel, the cone-like one and that which bears a slight resemblance to a six-petalled flower. The last mentioned one is shown in Photo. 44 of report No. 7, in which the mechanism of the development of this form of graupel is discussed. The examples of the lump graupel and the cone-like one are illustrated in the Atlas.

VII. Amorphous snow particle.

Snow particles are sometimes observed which do not show any regular crystalline structure. They are collected under this section and are provisionally called amorphous snow particles. Two examples are shown in the Atlas; one looks like an assemblage of pieces of ice and the other has a great many water droplets attached.

3. The frequency of occurrence.

It must be one of the standard undertakings in the study of snow to investigate the frequency of occurrence of each of the various types of snow crystals as classified in the foregoing section. In report No. 7 it was described how the ideal crystals of hexagonal symmetry as shown in a text-book occupy only a small part of the total number of snow particles that visit our country. Former investigators in this line of research seem to have been inclined to collect mostly microphotographs of beautiful snow crystals which developed in a symmetrical manner to their full extent. For example, the famous collection by Bentley contains more than two thousand photographs of regular dendritic crystals and plates, while only two hundred photographs of the other types are added to them. In spite of their full scientific value, these previous investigations suggest that almost all crystals of snow are of a regular plane type, with rare exceptions of a malformed or columnar sort. The observations, however, of the last three seasons showed that crystals other than the plane dendritic ones are not less frequent. Then the authors decided to carry out the investigation of the frequency of occurrence of various types of crystal for every snowfall in the winter of 1934–35. It is rather a hard task to continue the examination of the crystal forms of snow without suspension during several hours of a snowfall, the temperature being sometimes below $-10°C$. The observations were chiefly carried out by one of the authors (Y.S.). Sometimes the observations were done with a magnifying glass, which is noted as "rough" in the following Table. The "precise" observations were done with a microscope, in which case twenty and thirty crystals of snow were placed on a plane glass and the type of each crystal as well as its dimensions were examined. This was counted as one observation, and was repeated at about five or ten minute intervals during the period of the snowfall. Sometimes more than fifty observations were made in one snowfall, and this was found desirable in order to follow the unexpectedly rapid changes in the occurrence of certain types of crystal. The observations were carried out at Sapporo which is situated nearly at sea-level, and at a spot half way up Mt. Tokati, 1060 m. above sea level.

The number of days on which observations were made numbered 36 at Sapporo and 18 at Mt. Tokati, and the total number of observations reached 396 at the former place and 578 at the latter. These data are given in Table I.

Table I.

Place	Interval of observation	No. of days in which snow was observed	"precise" observation		"rough" observation	Total no. of observations
			no. of observations	total hours	no. of observations	
Sapporo	1934 XII 1—XII 22	12 days	7	1 h 40 m	36	43
	1935 I 5— II 9	13	282	22 40	49	331
	„ II 19— III 1	4	—	——	10	10
	„ III 10— III 13	2	—	——	6	6
	„ III 20— III 28	5	—	——	6	6
	Total	36	289	24 20	107	396
Tokati	1934 XII 23— 1935 I 1	10	272	27 30	28	300
	1935 II 11— II 18	8	255	44 00	23	278
	Total	18	527	71 30	51	578
Total		54 days	816	95 h 50 m	158	974

The authors learned, from the results of the continuous observations of snow crystals which were carried out in the manner above described, that a snowfall usually consisted of several types of snow and sometimes almost all types of crystal were found during the period of a snowfall. Occasionally only the dendritic plane crystals were observed at a given moment; it would continue thus for a short interval and then another type would begin to mix with them; after some time a third type would take its place, and so on. Thus a snowfall is found to consist of several

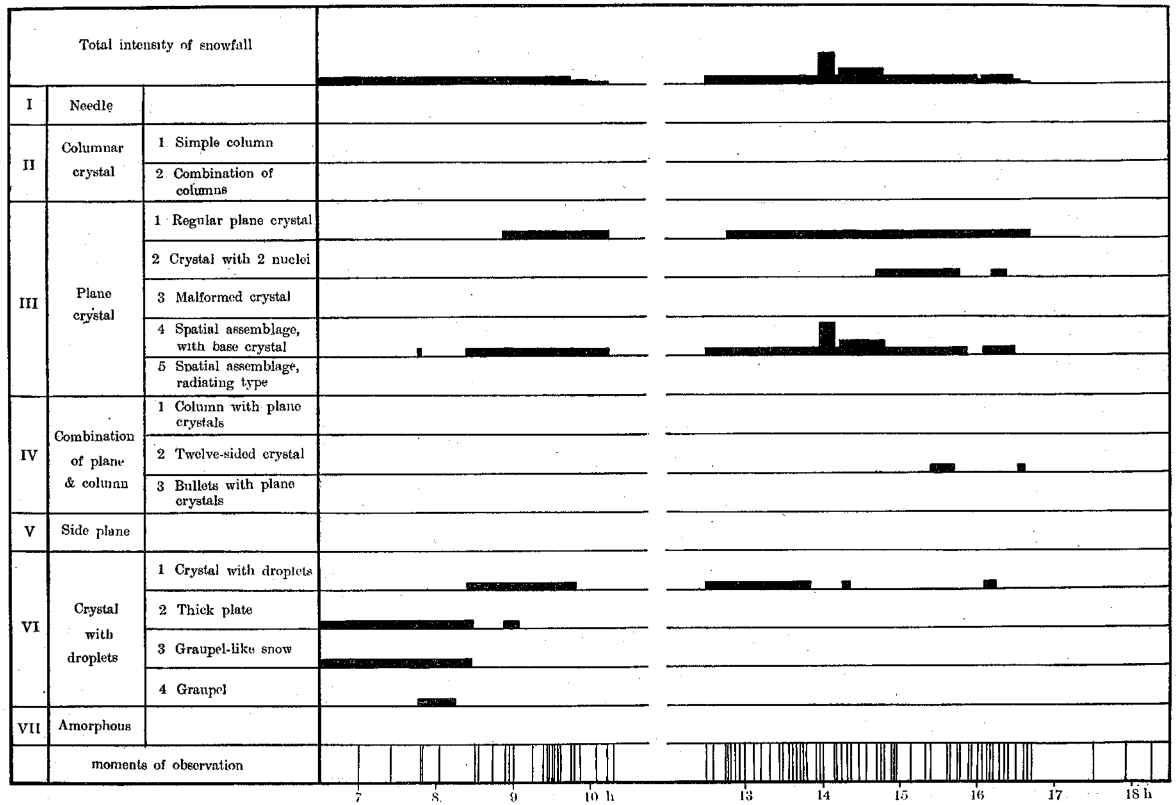


Fig. 1*a* Dec. 28, 1934

Fig. 1*b* Dec. 29, 1934

Fig. 1 a–b.

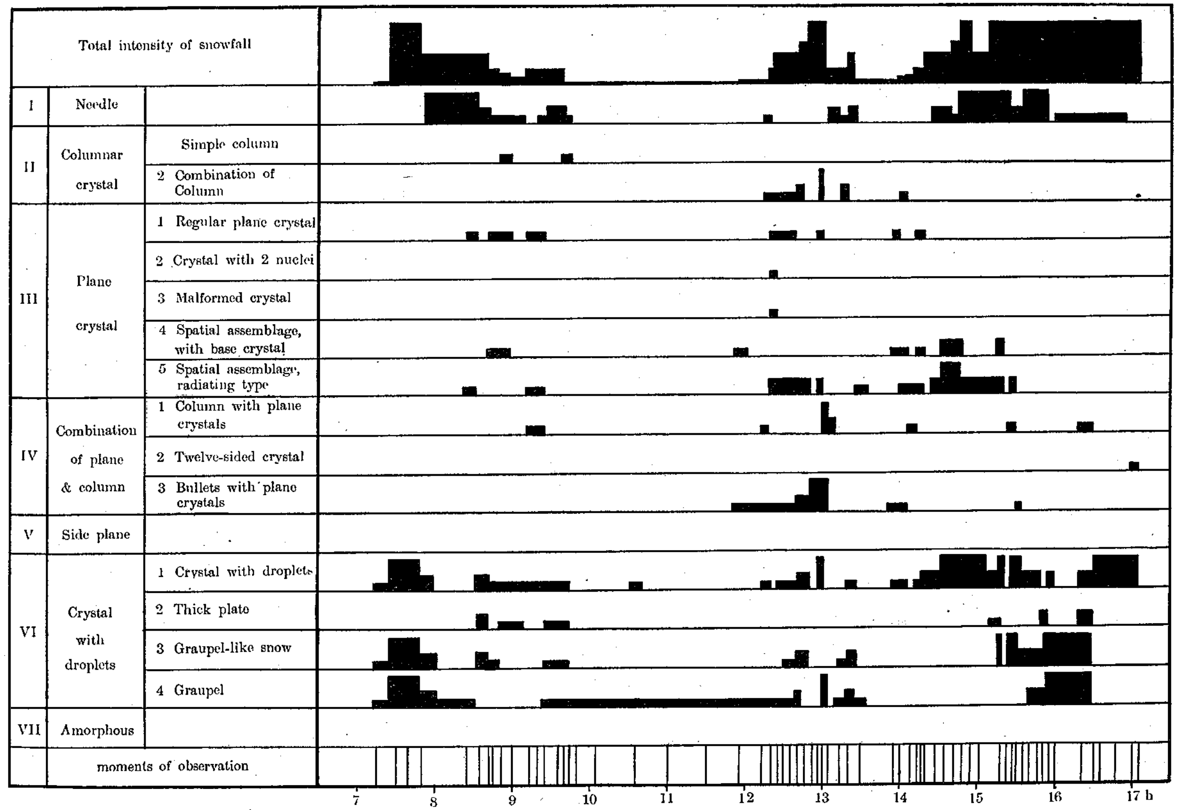


Fig. 2 Feb. 15. 1935

Fig. 2.

types of snow, when we summerize the results of the continuous observations extending over a sufficiently long period, notwithstanding that occasional observations may give an impression that only a certain type of crystal was to be observed during a snowfall. For example, the snowfall on the 28th Dec. 1934 observed at Mt. Tokati was one of the most "homogeneous" snowfalls, but even in this case plane dendritic crystals, spatial dendritic crystals with a base crystal, and crystals with cloud particles attached, were found mixing with each other.

Two examples are given in Fig. 1 *a* & *b*, in which no columnar crystal was observed. In the Figure, the curve in the uppermost row shows the intensity of total snowfall at every moment. The total intensity was qualitatively divided into five degrees by simple estimation. The abundance of a certain type of crystal compared with other types is very difficult to determine, especially when several types of crystals are falling at the same time. It was decided by an impression and no weight can be attached to it. The intensity of a certain type of crystal at every moment, however, is easier to determine than the relative abundance of various types of crystals. It was divided into three degrees and represented by the height of the blackened figure in each row of Fig. 1. The time scale is given in the x-axis, and the series of short vertical lines in the lowest row shows the moments when the observations were made.

Another example of a snowfall which was considered to be most "heterogeneous" is represented in Fig. 2. This was a snowfall observed at Mt. Tokati on the 15th of February 1935, and was characterized by an abundance of needle crystals. In this case "precise" observation with a microscope was continued for ten hours from 7 o'clock a.m. to 5 o'clock p.m. and 65 observations were carried out during that time. As shown in the Figure, this snowfall consisted of almost all types of crystals, except columns with side planes and amorphous snow. It is rather astonishing that so many types, that is fifteen kinds of snow, should be observed in one snowfall. It would be desirable to know whether the simultaneous occurrence of such a copious variety of crystals in one snowfall is characteristic of our climate or universal everywhere. It must be remembered that our climate is considerably enriched with diversified weather conditions.

The results of the observations carried out in the manner above described are summarized in Table II. The figure in the Table shows the number of days in which the crystals in question were observed. (S) means the data obtained at Sapporo and (T) those at Mt. Tokati; so that, for example, in the case of needle crystals $\frac{(S)3(T)2}{5}$ means that the needles were observed at Sapporo for three days and at Tokati for two days, being five days all together. The column which is denoted as I at the top comprises the total number of days in which the crystals at issue were observed, if any. Column II shows the number of days in which a moderate number of the crystals were observed and in column III the occasions when the crystals in question were observed as a heavy snowfall. Thus we can see the relative frequency of occurrence by comparing the figures in column I, while the relative abundance of the crystal will be inferred by comparing the figures in column III. As for the total number of crystals which fell to the ground, one snowfall in column III may cope with hundreds of snowfalls in column I. It is impossibly difficult to estimate quantitatively the relative abundance of a certain type of crystal for the light, moderate and heavy snowfalls classified in columns I, II and III, because each of the snowfalls is composed of so many types of crystals as shown in Figs. 1 and 2. We must, therefore, be satisfied by inferring the frequency of occurrence from the figures in column I and the abundance of the total number from those in columns II or III. When the figures in these three columns are all comparatively large, the occurrence of the crystal is considered to be "frequent" and in the contrary case "rare", the intermediate case being denoted as "medium". The results are summarized in the last column of Table II, in which we can see clearly that the regular plane crystals occupy only a small portion of the total number of snow particles which actually come down to the ground. Of course the results described above are deduced from the limited data observed in our district and some seasonal and local variations must be expected. Any definite conclusion will be postponed till some similar observations at another place have been conducted.

Table

	I The crystal is observed if any.	II Moderate number of the crystal is observed.	III The crystal is observed as a heavy snowfall.	
I. Needle	(S)3 (T)2 5	(S)2 (T)1 3	(S)0 (T)1 1	Simple needle
				Combination of needles
II. Columnar crystal	(S)3 (T)5 8	(S)3 (T)3 6	(S)2 (T)2 4	Simple column
				Combination of column
III. Plane crystal	(S)19 (T)17 36	(S)17 (T)16 33	(S)7 (T)12 19	Plane hexagonal
				Spatial assemblage, with a base crystal
				Spatial assemblage, radiating type
				Crystal with two nuclei
				Malformed crystal
IV. Combination of column & plane crystals	(S)5 (T)10 15	(S)4 (T)5 9	(S)2 (T)4 6	Column with plane crystals
				Twelve-sided crystal
				Combination of bullets with plane crystals
V. Column with extended side planes	(S)1 (T)1 2	(S)1 (T)0 1	(S)0 (T)0 0	
VI. Crystal with droplets and graupel	(S)20 (T)10 30	(S)18 (T)8 26	(S)12 (T)8 20	Crystal with droplets
				Thick plates
				Graupel-like snow
				Graupel
VII. Amorphous snow particle	(S)15 (T)0 15	(S)13 (T)0 13	(S)4 (T)0 4	

II.

I	II	III		I	II	III	
(S)3 (T)2 5	(S)2 (T)1 3	(S)0 (T)1 1					rare
(S)1 (T)1 2	(S)0 (T)1 1	(S)0 (T)1 1					
(S)3 (T)4 7	(S)3 (T)3 6	(S)1 (T)1 2	cylinder	(S)3 (T)4 7	(S)3 (T)3 6	(S)1 (T)1 2	rare
			bullet	(S)0 (T)1 1	(S)0 (T)0 0	(S)0 (T)0 0	
			pyramid	(S)0 (T)1 1	(S)0 (T)0 0	(S)0 (T)0 0	
(S)3 (T)3 6	(S)1 (T)2 3	(S)1 (T)2 3	cylinder	(S)3 (T)2 5	(S)0 (T)1 1	(S)0 (T)1 1	rare
			bullet	(S)1 (T)2 3	(S)1 (T)2 3	(S)1 (T)1 2	
(S)18 (T)17 35	(S)13 (T)15 28	(S)5 (T)10 15	dendritic	(S)18 (T)17 35	(S)12 (T)14 26	(S)5 (T)10 15	frequent
			areal extension	(S)3 (T)11 14	(S)2 (T)6 8	(S)1 (T)0 1	
(S)7 (T)13 20	(S)6 (T)13 19	(S)3 (T)7 10	dendritic	(S)6 (T)13 19	(S)5 (T)12 17	(S)3 (T)6 9	frequent
			areal extension	(S)1 (T)4 5	(S)1 (T)3 4	(S)0 (T)2 2	
(S)8 (T)12 20	(S)6 (T)11 17	(S)2 (T)9 11	dendritic	(S)7 (T)12 19	(S)4 (T)11 15	(S)2 (T)9 11	frequent
			areal extension	(S)3 (T)7 10	(S)3 (T)6 9	(S)0 (T)1 1	
(S)2 (T)7 9	(S)1 (T)7 8	(S)0 (T)0 0	dendritic	(S)2 (T)7 9	(S)1 (T)7 8	(S)0 (T)1 1	medium
			areal extension	(S)0 (T)1 1	(S)0 (T)1 1	(S)0 (T)0 0	
(S)1 (T)3 4	(S)1 (T)3 4	(S)0 (T)2 2	dendritic	(S)0 (T)2 2	(S)0 (T)2 2	(S)0 (T)0 0	medium
			areal extension	(S)1 (T)3 4	(S)0 (T)3 3	(S)0 (T)2 2	
(S)4 (T)9 13	(S)3 (T)5 8	(S)2 (T)3 5	dendritic	(S)4 (T)9 13	(S)3 (T)5 8	(S)2 (T)2 4	medium
			areal extension	(S)3 (T)4 7	(S)1 (T)3 4	(S)0 (T)2 2	
(S)0 (T)4 4	(S)0 (T)0 0	(S)0 (T)0 0					rare
(S)1 (T)5 6	(S)1 (T)2 3	(S)1 (T)2 3					rare
							very rare
(S)1 (T)7 8	(S)1 (T)7 8	(S)1 (T)6 7					frequent
(S)8 (T)8 16	(S)4 (T)4 8	(S)0 (T)2 2					medium
(S)9 (T)8 17	(S)8 (T)5 13	(S)6 (T)4 10					frequent
(S)19 (T)6 25	(S)17 (T)5 22	(S)10 (T)4 14					frequent
							medium

4. The size of snow crystals.

The problem of the size of snow crystals seems to have called less attention from the students of snow, compared with the comprehensive study of the form and structure of crystal. First impressions showed no definite rule on the size of crystals, but observations during the last four winters revealed that the size of the crystals observable most frequently in our climate had a definite value characteristic to their types. The microphotographs in the foregoing papers are reproduced with a varying magnification, and they are not adequate to give a clear indication of the relative dimensions of the crystals of various types.

In the course of the continuous observations of crystals which were carried out in order to study the frequency of occurrence described in the foregoing article 3, the size of the crystals was noted down at the same time. Arranging the data, an attempt was made to construct a frequency curve of the size of the crystal for each of the various types of snow crystal. Most of these frequency curves were found to represent the form of a probability curve, showing that there is a probable size for each of the various types of crystal suitable to a certain climatic condition. In order to see whether there is any difference in the probable size between the crystals observed at Sapporo, nearly on the sea level, and similar ones observed at Mt. Tokati, 1060 m. above sea level, the frequency curves are compared for the crystals of the same kind observed at these two places. As an example, the results obtained for the fern-like plane crystal are shown in Fig. 3, in which S shows the frequency curve for the crystals observed at Sapporo and TI those at Mt. Tokati in January and TII those at the same place in February. It will be seen that these three curves all reach a similar peak at 4 mm. Similar results were obtained for most of the other types of crystal and the authors concluded that there is no essensial difference in

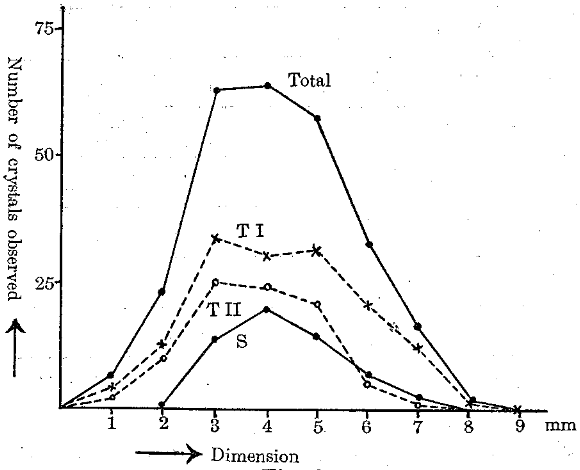


Fig. 3.

the probable size between the crystals of the same kind observable at these two places.

For the study of the probable size the previous classification described in article 2 is not adequate. In this case the growing velocity of crystal seems to play the most important rôle, and consequently attention must be paid to the habits of the branches of crystals. For example, a plane dendritic crystal of a fern-like appearance belongs to the sort "regular plane crystal" in the former classification, and a spatial dendritic one with a stellar base crystal belongs to another sort "spatial assemblage of plane branches". These two sorts were found to show the same value in regard to their probable size, as shown in Fig. 4 by the curves *a* and *b*. In the case of the spatial dendritic crystal of radiating type the probable size is about 2.5 mm., Fig. 4 curve *c*, and is decidedly smaller than the type with a stellar base. In report No. 7 it was inferred from the standpoint of the crystal form that the condition of the upper layer of the atmosphere for producing one kind of spatial dendritic crystal will be quite different from that producing the other type. The present results as regards the probable size also agree with this conclusion.

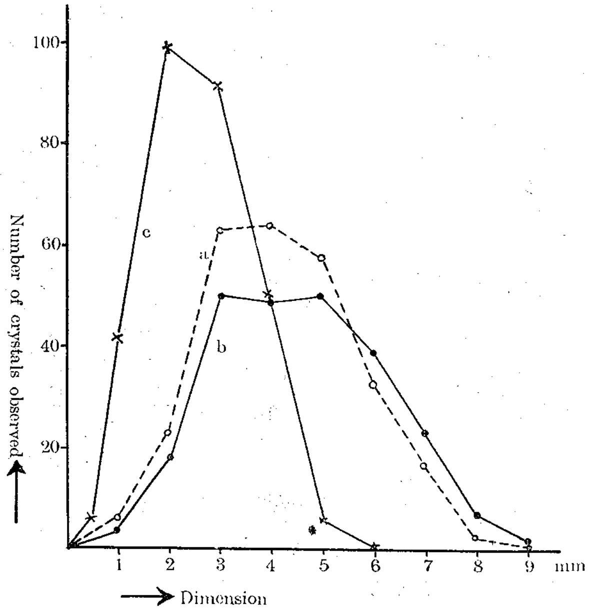


Fig. 4.

a, Plane dendritic crystal.
b, Spatial dendritic, with a base crystal.
c, Spatial dendritic, radiating type.

As the habit of the branches of crystal is an important factor in this case, the simple plane crystal must be classified further in detail for the present purpose. As a first attempt it is classified into eight kinds, the nomenclature and the schematical sketches of which are given in Fig. 5. Frequency curves have been constructed for each of these eight kinds

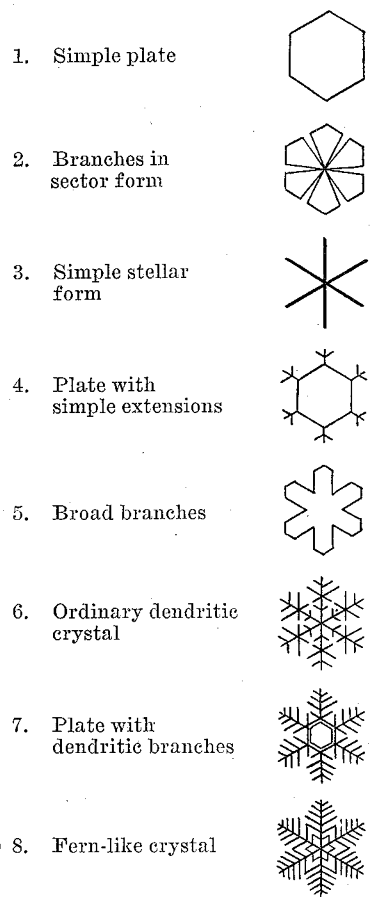


Fig. 5.

and are shown in Fig. 6. Curves 2, 5, 6, 7, 8 show more or less regularly the form of a probability curve, and the most probable size for the occurrence will be determined respectively from these curves. The other curves show some deviations from the regular form. One of the causes of this deviation will be of a statistical nature; that is, the subclassification is not circumstantial enough for the present purpose. From these curves it is very clearly seen that the fern-like crystal is largest and the plate is smallest among the plane crystals observed in our climate. Bentley observed at Jericho a quite large number of relatively large plate crystals, but in our climate the plate is usually minute, measuring only 0.25 mm and at most 1.5 mm in diameter. This difference must be due to the difference in the climatic conditions. The most probable size of the plane crystals observable in our district is, according to Fig. 6, as follows:

1,	simple plate	0.25 mm & 0.75 mm,
2,	branches in sector form	1.0 mm,
3,	simple stellar form	1.0 mm & 2.5 mm,
4,	plate with simple extensions	1.5 mm,
5,	broad branches	2.0 mm,
6,	ordinary dendritic crystal	2.5 mm,
7,	plate with dendritic extensions	3.0 mm,
8,	fern-like crystal	4.0 mm.

In order to give a clear indication of the relative dimensions of the crystals described above, typical photographs of these eight kinds are reproduced in Pl. V with the dimensions proportional to their probable sizes.

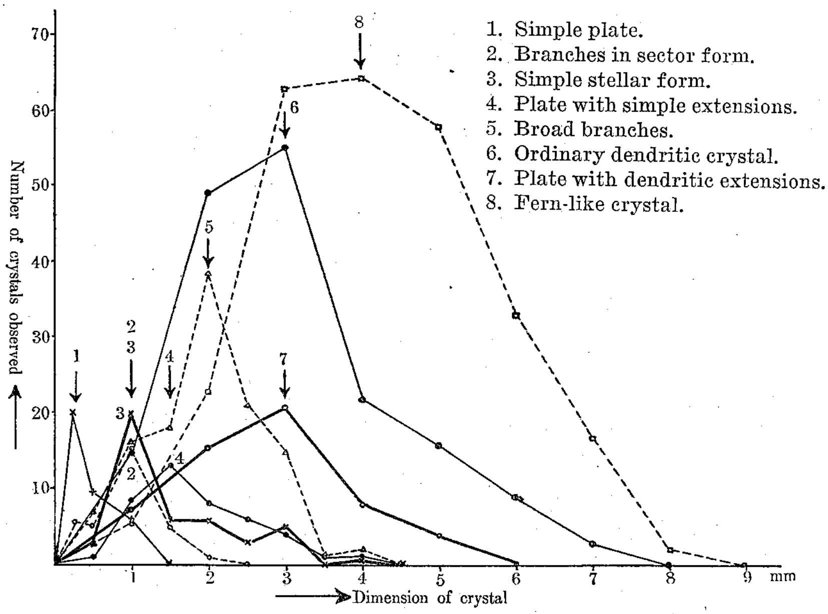


Fig. 6. The dimensions of the various types of plane crystals.

All crystals in Pl. V are shown with the magnification twenty times that of their probable size. Most of the hexagonal plates were observed at Mt. Tokati, 1060 m. high up, and the minuteness of the crystal suggests that it is an early stage in the development of almost all kinds of plane crystals.

The large plate crystals without any dendritic extensions at the corners that are rather frequently observed by Bentley and others, are very seldom observed in our climate. The difference consists chiefly in the excessive humidity of our country, which is a favourite condition for the extension of crystals in a dendritic form.

The frequency curves of the dimensions for needles, columns and combinations of bullets are shown in Fig. 7, and those for five kinds of crystals which are composed of columns and planes are given in Fig. 8. The most probable sizes for each of these crystals are as follows:

9,	needle and combination of needles	1.75 mm,
10,	columnar crystal	0.5 mm,
11,	combination of bullets	0.75 mm,
12,	column with dendritic planes at both ends	1 mm & 2.5 mm,
13,	column with plates at both ends,	0.75 mm,

14,	spatial assemblage of plates	0.75 mm,
15,	combination of bullets with planes	1 mm,
16,	combination of columns with or without planes	1 mm.

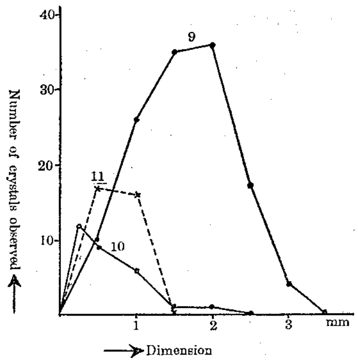


Fig. 7.

9. Needle and its combinations.
10. Columnar crystal.
11. Combination of bullets.

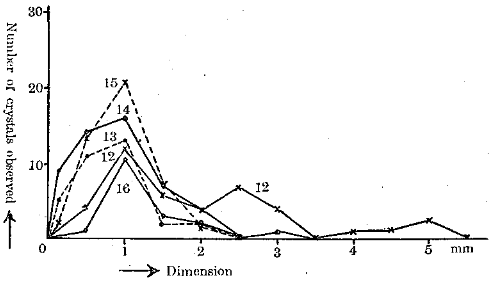


Fig. 8.

12. Column with dendritic planes at both ends.
13. Column with plates at both ends.
14. Spatial assemblage of plates.
15. Combination of bullets with planes.
16. Combination of columns with or without planes.

The microphotographs of the typical crystals above mentioned are reproduced in Pl. VI, in which the relative dimensions of all crystals are shown as before with the magnification twenty times the probable size. The Pl. V and VI will show the probable size of all sorts of crystals at a glance. One will see clearly that in any case the dendritic branches are very easily elongated and the plate forms are slowly developed, the intermediate forms as sectors or broad branches going between the two extremities.

5. Relations with meteorological conditions.

As described in report No. 1, any simple relation is hardly expected in our climate between the forms of snow crystal and the meteorological elements observed on the earth surface. Moreover, the results of the present investigation into the frequency of occurrence of the crystals summarized in article 3 showed that sometimes so many kinds of crystals are observed in one snowfall, being intermixed with each other, that it is difficult to pick up a type of crystal as representative of a certain snowfall. Results similar to those obtained by previous authors,[1] which tell of some simple relationship between the temperature or the storm section with the

1) See the report No. 1, p. 154.

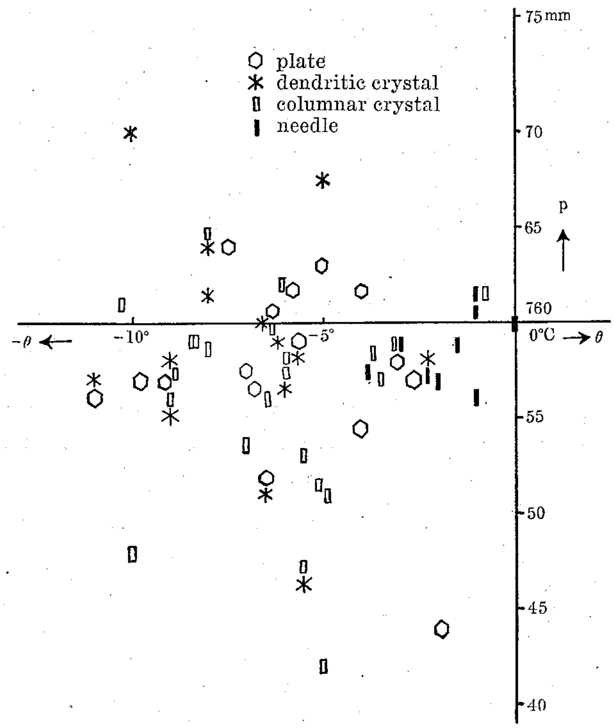


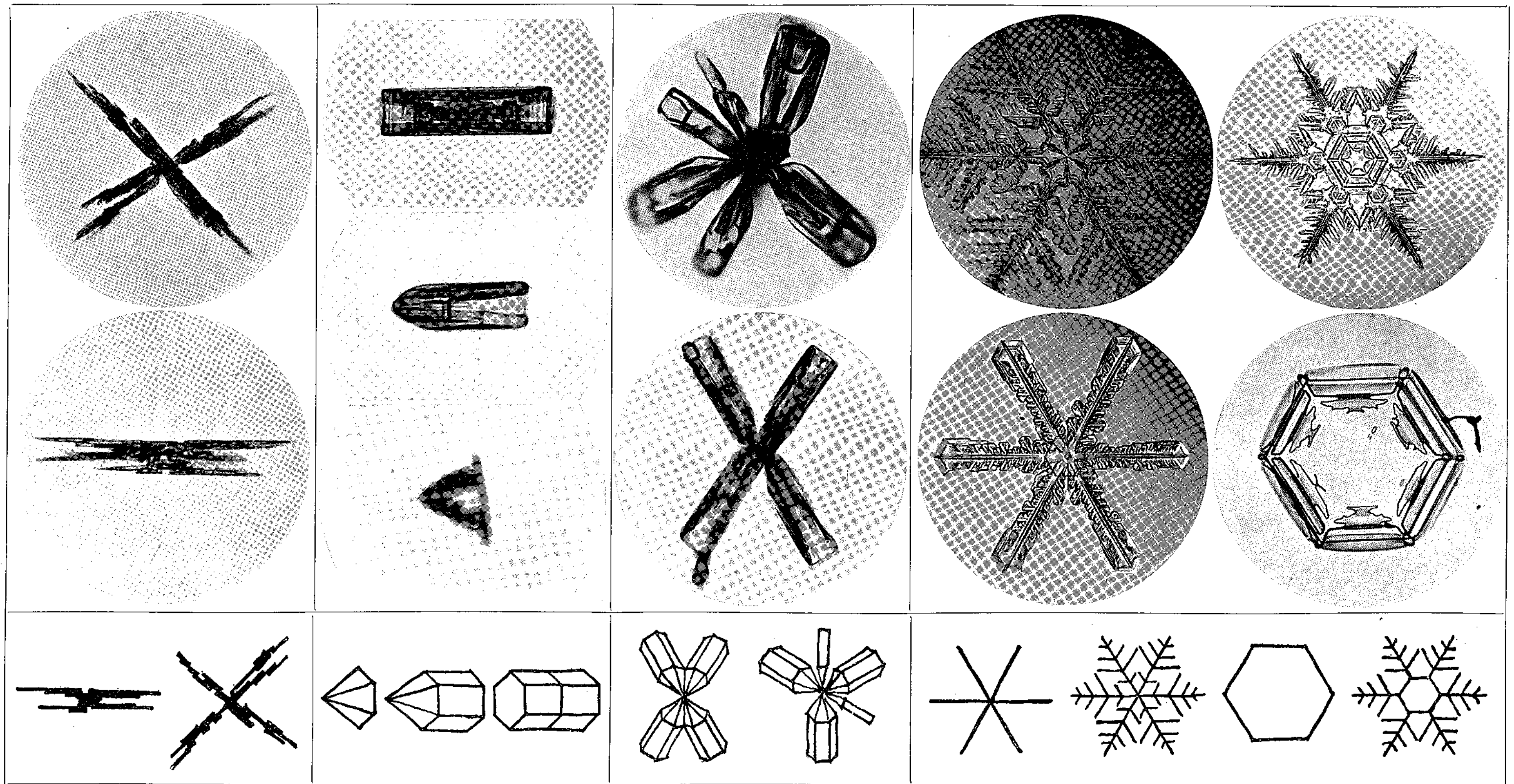
Fig. 9.

form of the crystal, could not be obtained in our climate. One rule, however, was noticed during the observations of the last four winters; the needle crystal was always observed when the temperature was higher. This fact leads us, together with the results observed in the experiment on the artificial production of frost crystals described in report No. 6, to take the needle crystal as a different kind from the simple elongated column. It is sometimes believed that when the air temperature is lower the columnar crystal is often observed and as the temperature rises higher the crystal becomes of plane type. No such relation was observed in our observations at Sapporo and Mt. Tokati. These circumstances are shown in Fig. 9, in which the distribution of various types of crystals in a pressure-temperature diagram is represented. The temperature and the pressure are each the mean of the data of 6 h and 18 h of the day in which the crystals in question were observed. For the needle and the columnar crystal, all snowfalls in which these crystals were observed, if any, were taken into account. In the case of the plate and dendritic crystals, only those snowfalls were chosen which were composed mostly of these particular crystals. Strictly speaking, these crystals, especially the dendritic ones, are always more or less observable in any snowfall. One sees in Fig. 9 that the needle crystals are seen near the normal pressure line and in the region of a higher temperature, while the other types of crystals are scattered all over the region in the diagram. No simple relationship is observed in the distributions of columnar, dendritic and plate crystals.

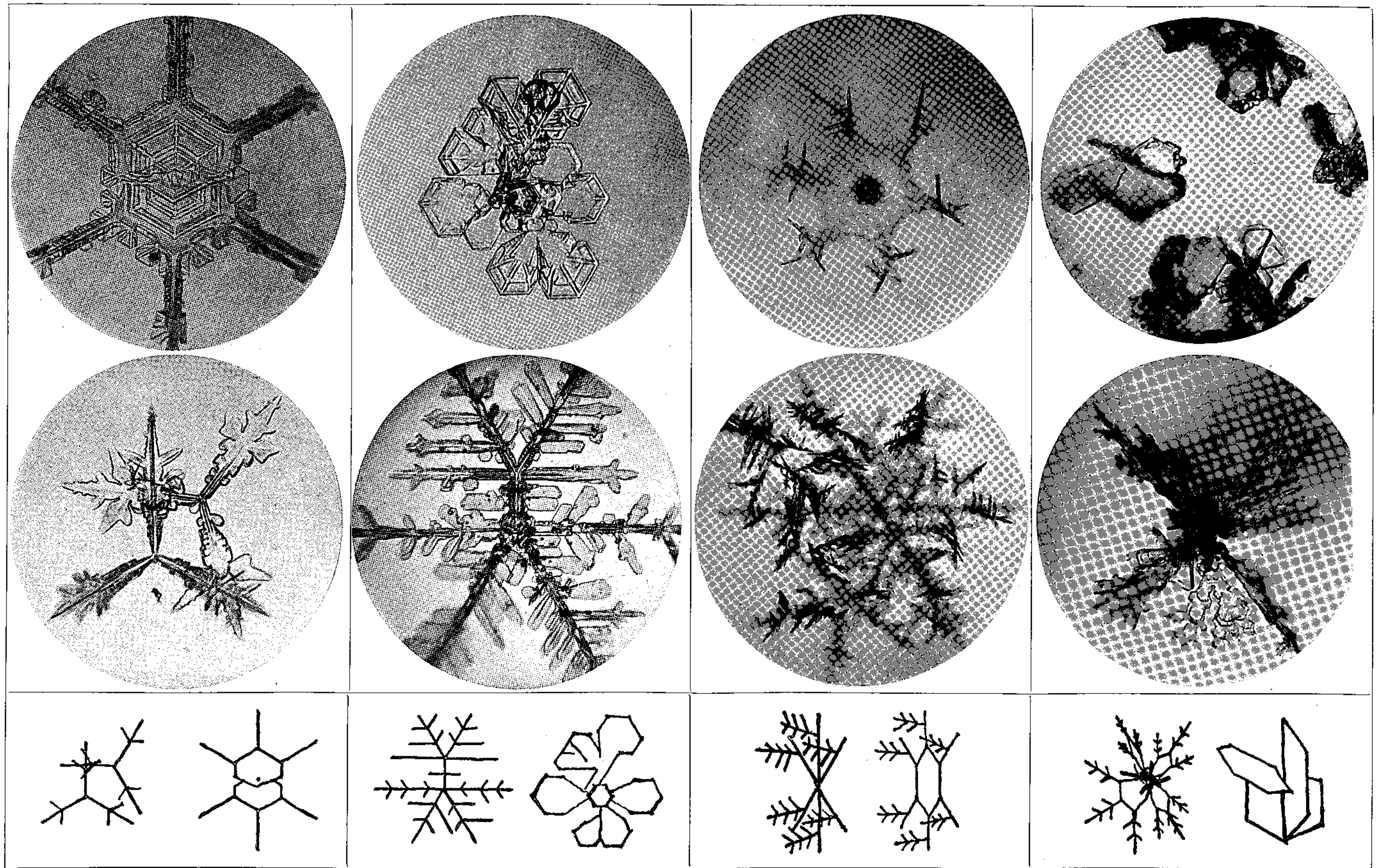
Summary.

A general classification of snow crystals is proposed which includes all types of snow observable in our climate. Some rare crystals that are not known in the literature have been observed and included in the list of this general classification. The results of observations on the frequency of occurrence of every type of crystal are described. It was seldom found that a snowfall consisted of only one or two types of crystal, and usually many types of crystal, sometimes almost all types were found in one snowfall, being intermixed with each other. The probable size of each of the types of crystal was measured and it was found that the crystals with dendritic branches were always largest, the columnar and plate forms were smallest, the intermediate forms going between the two extremities. Relations between the form of crystal and the meteorological elements were studied. No simple relation was found, except a rule that needle crystals were associated with the warmer weather.

In conclusion, the authors wish to express their best thanks to Nippon Gakuzyutu-sinkôkai for their financial assistance in this research.

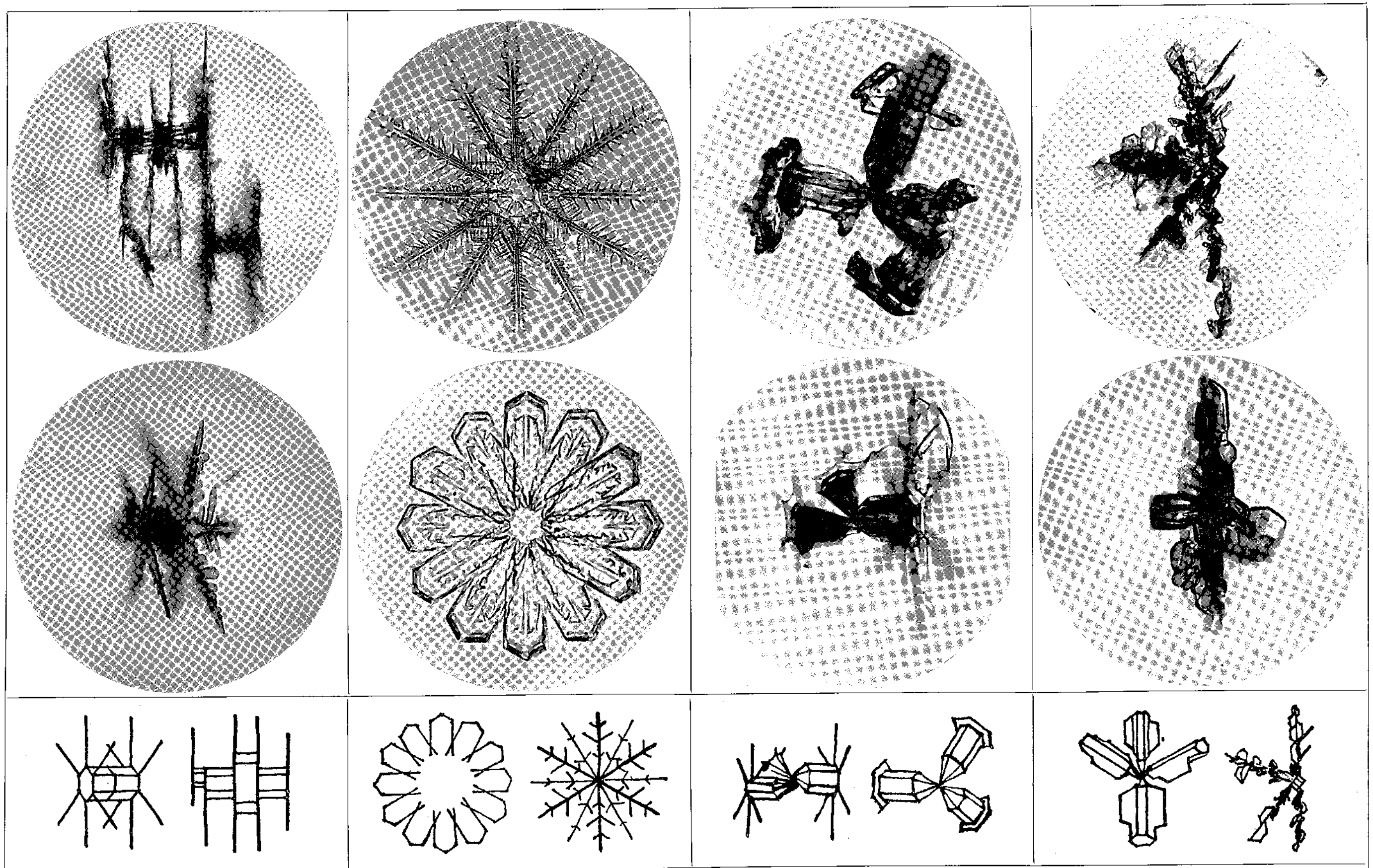


I. Needle	II. Columnar crystal		III. Plane crystal
1. Simple needle 2. Combination	1. Pyramid, Column & Bullet type	2. Combination of columns	1. Regular crystal developed in one plane



2. Crystal developed from two nuclei	3. Malformed crystal	4. Spatial assemblage, with a steliar base	5. Spatial assemblage, radiating type

III. Plane crystal, continued



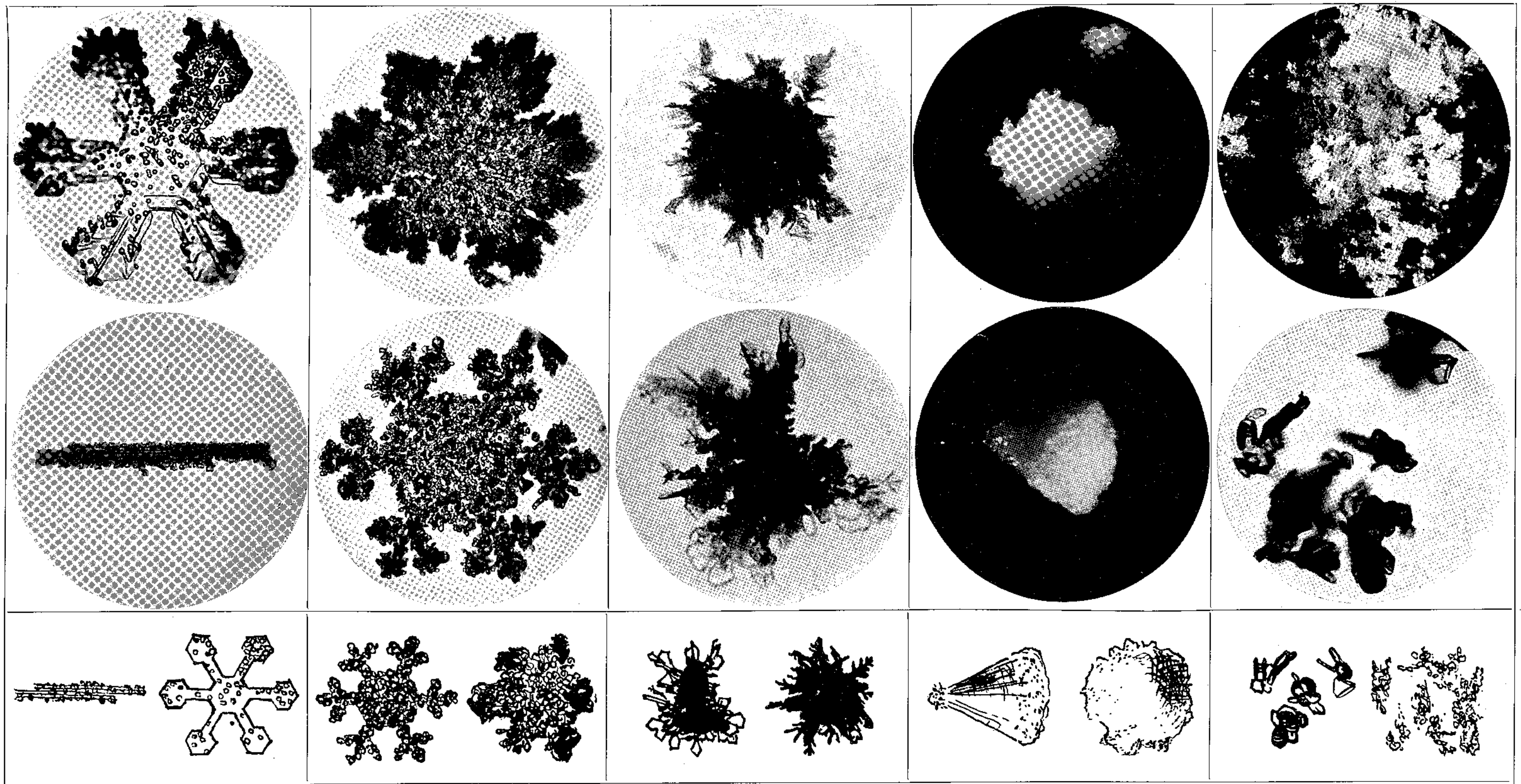
1. Column with plane crystals

2. Twelve-sided crystal

3. Combination of bullets with plane crystals

IV. Combination of Column and plane crystals

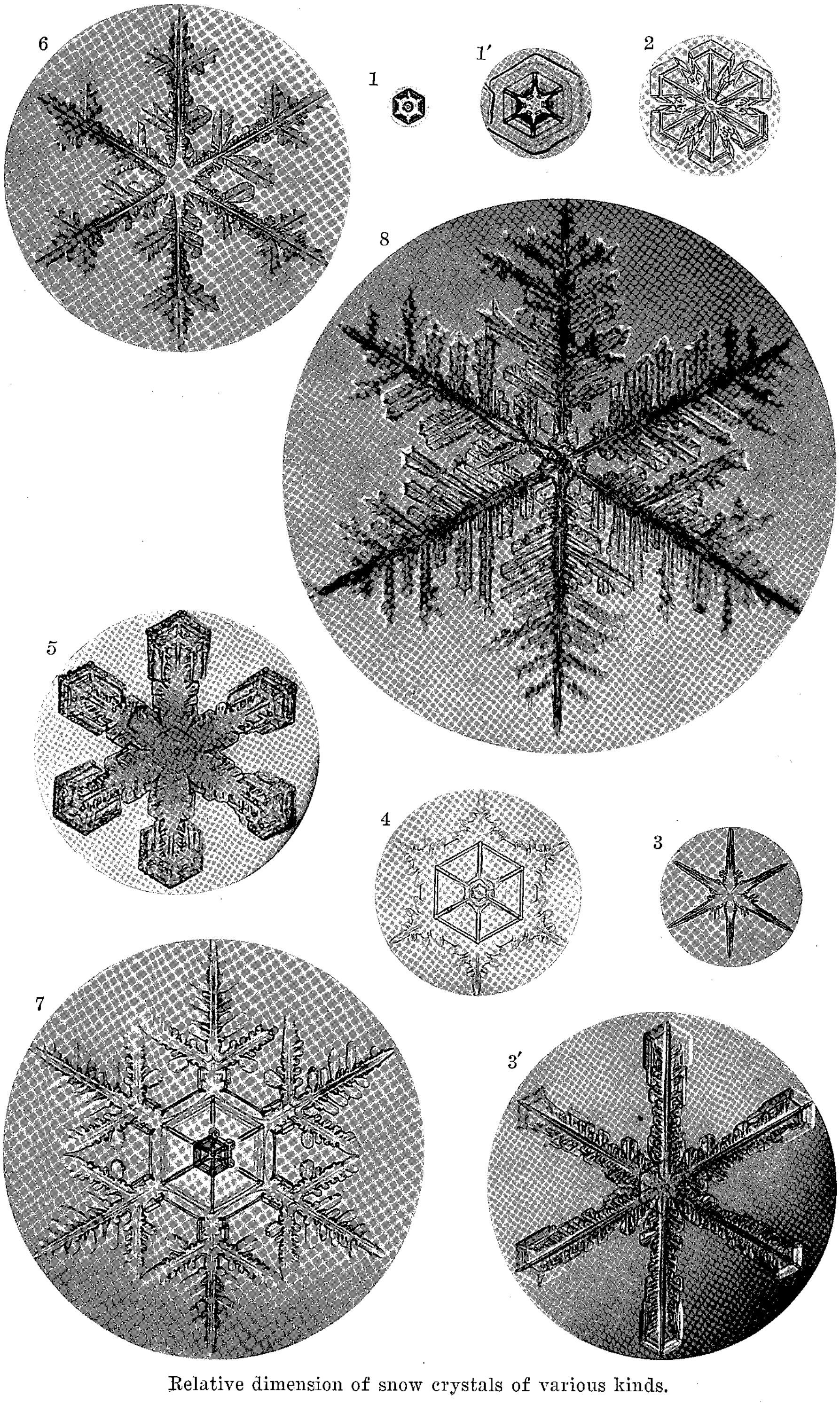
V. Columnar crystal with extended side plane



1. Crystal with droplets | 2. Thick plate | 3. Graupel-like snow | 4. Graupel

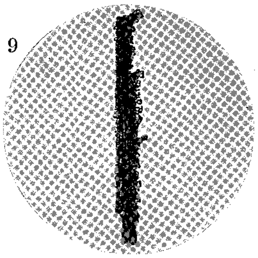
VI. Crystal with cloud particles attached and Graupel

VII. Amorphous snow particle



Relative dimension of snow crystals of various kinds.

9



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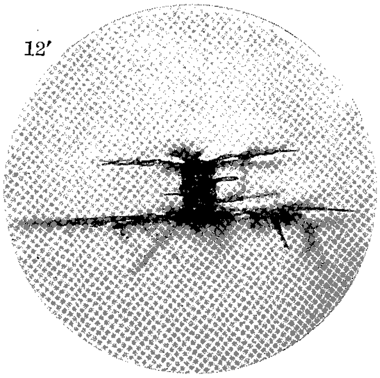
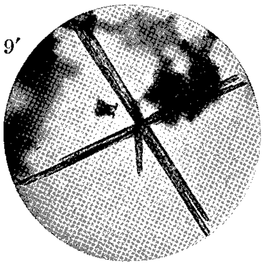


9′



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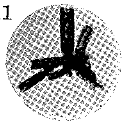

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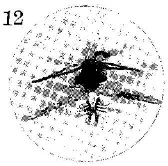

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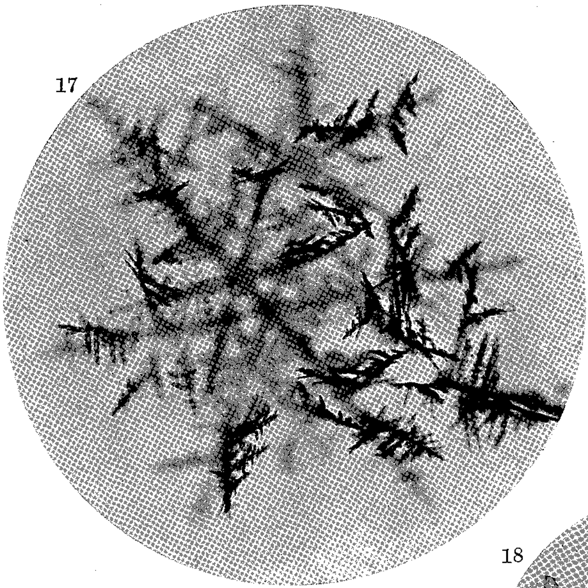

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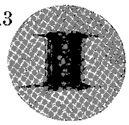

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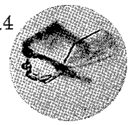

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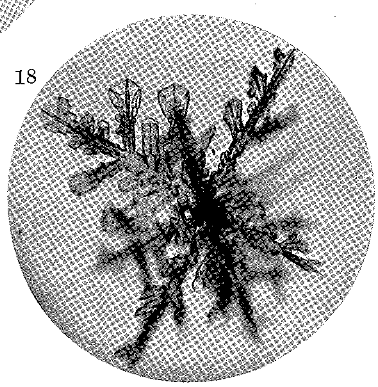

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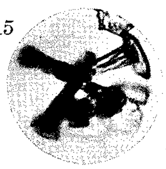

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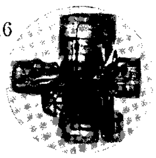

Each of the all crystals is magnified by twenty times of its most probable size.