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Thin Sections of Deposited Snow Made by the Use of Aniline.

by

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1. Introduction

All the physical properties of deposited snow depend wholly upon how the small pieces of ice composing it are joined together. They make a three dimensional ice network of complicated texture. BADER¹⁾ was the first who succeeded in cutting snow into a thin section to see that texture under a microscope. Snow must be made rigid to be cut because it is fragile. BADER filled the air spaces in the snow with liquid tetrabromomethane and made it freeze as it was in the spaces. FUCHS²⁾, SHIMIZU³⁾, STEPHENSON and LISTER⁴⁾ successfully followed BADER using different liquids. But those liquids, including BADER's, were difficult for the present authors to get or to make. They wanted to have a cheap liquid with which they could reinforce the snow in order to cut it. They tried many kinds of liquid and finally found liquid aniline as the best. By the use of aniline they succeeded in cutting snow with a carpenter's plane into sections as thin as one- or two-hundredths of a millimeter in a short time.

2. Aniline as a filling liquid.

BADER¹⁾ pointed out the conditions which the liquid to be used must satisfy. The following are BADER's conditions which the present authors have somewhat modified.

- (1) The freezing point of the liquid should not lie too much below 0°C.
- (2) The liquid should not dissolve ice.
- (3) It wets thoroughly the surface of ice. Otherwise it cannot get into the snow.
- (4) The coefficient of viscosity is small. The liquid should be fluidal so as to permeate snow quickly.
- (5) The volume change on freezing is small.
- (6) The rigidity in the solid state does not differ too much from that of ice.
- (7) The density is near that of ice.
- (8) The liquid should easily be distinguished from ice under a microscope.

In connection with those conditions aniline has the following properties:

- (1) It freezes at -6.2°C when pure. When saturated with water it freezes at -11.7°C .
- (2) Pure aniline dissolves ice to a small extent (3%). But when saturated with water beforehand, it does not any more dissolve ice.
- (3) Aniline wets well the surface of ice.
- (4) The coefficient of viscosity is 0.102 poise at 0°C . This value is only six times as large as that of water which is known as one of the most fluidal liquids.
- (5) According to the International Critical Tables pure aniline contracts 8.5% of its own volume on freezing. But that value of contraction cannot be taken up here because the aniline used in the present experiments was not pure one. The authors made measurements on the contraction of the aniline saturated with water by cooling a test tube containing it. The tube was cooled from below and the contraction was determined from the lowering of the surface of aniline at the freezing. When the cooling was made slowly the contraction amounted to about 5% while at rapid cooling it was found to be as small as 2%. The water-saturated aniline filling the spaces in snow freezes rapidly. Therefore the contraction occurring to that aniline at its solidification would not exceed 2% without exerting any appreciable deformation upon the ice network of snow. It should be noted that the aniline solidifies into an aggregate of very small solid grains. This makes the solidified aniline opaque.
- (6) The solid aniline is moderately rigid, accordingly it may easily be cut with a carpenter's plane or saw.
- (7) The density is 1.02 gr/cm^3 .
- (8) Aniline in solid as well as in liquid state can easily be distinguished from ice under a microscope; in the solid state it is opaque while in the liquid state it has a refractive index 1.586 which is very different from that of ice. The refractive index of ice is 1.3106 for ordinary rays and 1.3120 for extraordinary rays at 0°C .

In this way the aniline satisfies almost completely each of the requirements.

3. Method of making a thin section.

The series of figures (a), (b), (c), (d), (e), (f) in Fig. 1 illustrate the steps to be followed in making a thin section of snow. It should be remarked beforehand that steps (a) and (f) are at temperatures $-5^{\circ}\sim-10^{\circ}\text{C}$ while (b), (c), (d) and (e) below -20°C .

(a) A plate of snow ($3\text{ cm}\times 3\text{ cm}\times 5\sim 10\text{ mm}$) is cut with a knife from one of the snow layers composing a snow cover. When the plate should be cut out vertically, it is better to make the plate in an asymmetrical form such as trapezoid.

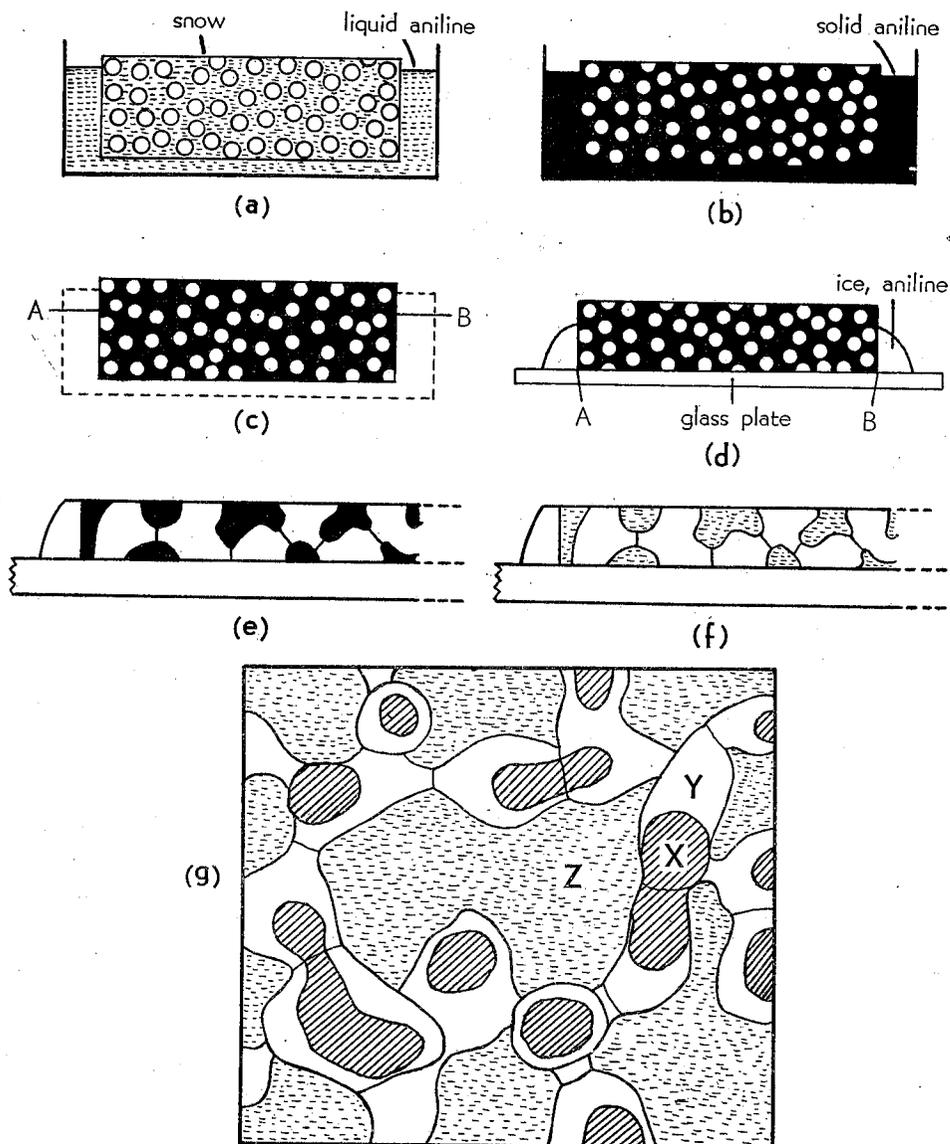


Fig. 1. How to make a thin section of snow by the use of aniline.

(a) A plate of snow is immersed in liquid aniline at $-5^{\circ}\sim-10^{\circ}\text{C}$. Circles represent the ice network of snow. (b) The temperature is lowered to below -20°C ; aniline solidifies to become opaque. Circles—ice network, black part—solidified aniline. (c) The plate of snow is pulled out of the dish. A flat surface AB is made on it by planing. (d) Surface AB is stuck to a glass plate. (e) The plate of snow is thinned by being shaved off with a plane on the side opposite to that stuck to the glass plate. Thin section is made. (f) The thin section is warmed up to $-5^{\circ}\sim-10^{\circ}\text{C}$. The solid aniline is melted to turn transparent. The whole texture of the ice network is seen under a microscope. (g) Schematic figure of the thin section under a microscope. X and Y are the ice network. X: cut ends of the network. Y: those parts of the network dipped in liquid aniline. Z: liquid aniline.

It helps one afterwards in judging which side of the plate stood at the top in the snow cover originally.

At $-5^{\circ}\sim-10^{\circ}\text{C}$ several pieces of ice are put into liquid aniline; it becomes saturated with water. The liquid aniline thus saturated is poured into a shallow dish 4 cm in diameter and 1 cm deep.

The plate of snow is placed in the dish. The liquid penetrates quickly into the snow, drives out the air, and fills the spaces in the ice network.

(b) The temperature is lowered to below -20°C . The liquid solidifies as it is in the ice network. The plate of snow becomes rigid. It looks white and opaque.

(c) The shallow dish is warmed from outside by placing the palm of the hand on its bottom. A thin layer of solid aniline in contact with the bottom and the wall of the dish is melted. The rigid plate of snow is drawn out of the dish. The sides of the plate are shaved off with a carpenter's saw or plane. Then one of the surfaces of the plate is cut carefully with the plane to make a flat surface AB. When viewed under a microscope, this surface looks like the photograph shown in Photo. 1, Pl. I. The dark shapes are cut ends of the ice network imbedded in the solidified aniline. The cut ends appear dark in this photograph because it was taken by the use of reflected light.

(d) The snow plate is placed on a glass plate with the surface AB in contact with it. Along the border line of the contact between the solidified snow plate and the glass plate is put a small amount of liquid aniline with a writing brush. It freezes immediately to fix the snow plate to the glass one. Then the glass plate is slightly warmed to melt plane AB of the snow plate. In this case only the solidified aniline on plane AB should be melted but not the ice. The warming must be done carefully. The melted plane soon solidifies again to stick firmly to the glass plate. The plate of snow is made more strongly adherent to the glass plate by putting along the border line between them some small amount of water which immediately freezes.

(e) The plate of snow is shaved off with the plane on the side opposite to that stuck to the glass plate. By the use of a well-sharpened plane, the plate of snow can be thinned down to a thickness of 0.05 mm or less. It is not difficult to thin the plate down to 0.01 mm by careful planing or by polishing with fine grain sandpaper.

The spaces in the ice network of the thin section made in this way are filled with solidified aniline which is opaque. Photo. 2, Pl. I shows a portion of the section in this state of opaque aniline. In making this photograph the light source was placed behind the thin section in place of on this side as in the case of Photo. 1. Therefore in this case the cut ends of the ice network look light instead of dark. What can be seen is still the cut ends of the ice network, its main part being concealed by the opaque aniline.

(f) The thin section is warmed up to $-10^{\circ}\sim-5^{\circ}\text{C}$, so that the solidified aniline

is melted and becomes transparent. The whole texture of the ice network makes its appearance as illustrated in Photo. 3, Pl. I. This is the same portion as that in Photo. 2.

When laid uncovered, the thin section will gradually thin away by the sublimation of the ice and the evaporation of the liquid aniline. For preservation a cover glass should be put on the thin section after an addition of a small quantity of liquid aniline to it.

Fig. 1(g) shows the thin section of snow diagrammatically. The hatched portions X's are the cut ends of the ice network. As stated before, when the aniline is solid and opaque, only the cut ends X's can be seen out of the whole body of the network. Usually the cut ends are so apart from one another that no one can imagine how they are connected actually. The whole texture Y of the network comes clearly to be seen when the aniline is made transparent by melting. In this figure the dashed areas Z's show the spaces filled with liquid aniline. It should be noted that portions indicated Y are dipped in aniline.

4. Necessary appliances.

The articles needed for making thin sections of snow are simple and small in number. They are:

- (1) A small quantity of aniline in a bottle.
- (2) A small quantity of water in a bottle.
- (3) A knife and a saw to cut snow.
- (4) Shallow glass dishes.
- (5) Two carpenter's planes. One of the two should be well sharpened.
- (6) Glass plates—slide glass and cover glass for microscopy.
- (7) A writing brush to smear liquid aniline or water with.
- (8) A thick wooden board, not necessarily very large, upon which the sample of snow is planed.

The pieces cut off with the plane or saw from the reinforced sample of snow are gathered together in a glass bottle. The solid aniline contained in the pieces is melted by warming the bottle to $-5^{\circ}\sim-10^{\circ}\text{C}$. The contents are poured out through a sheet of absorbent cotton into another bottle. In that the liquid aniline saturated with water is kept for subsequent use.

A cold as low as -20°C is needed for the application of the above method. The present authors mostly used the cold room attached to their Institute. Sometimes the natural cold at midnight was low enough to make possible work in the field.

5. Some remarks.

(1) The solubility of ice in aniline.

As stated in Section 3 the authors used liquid aniline after having made it saturated with water. Then the aniline was expected to have been deprived of power to dissolve ice. But the saturation depends upon the temperature. The

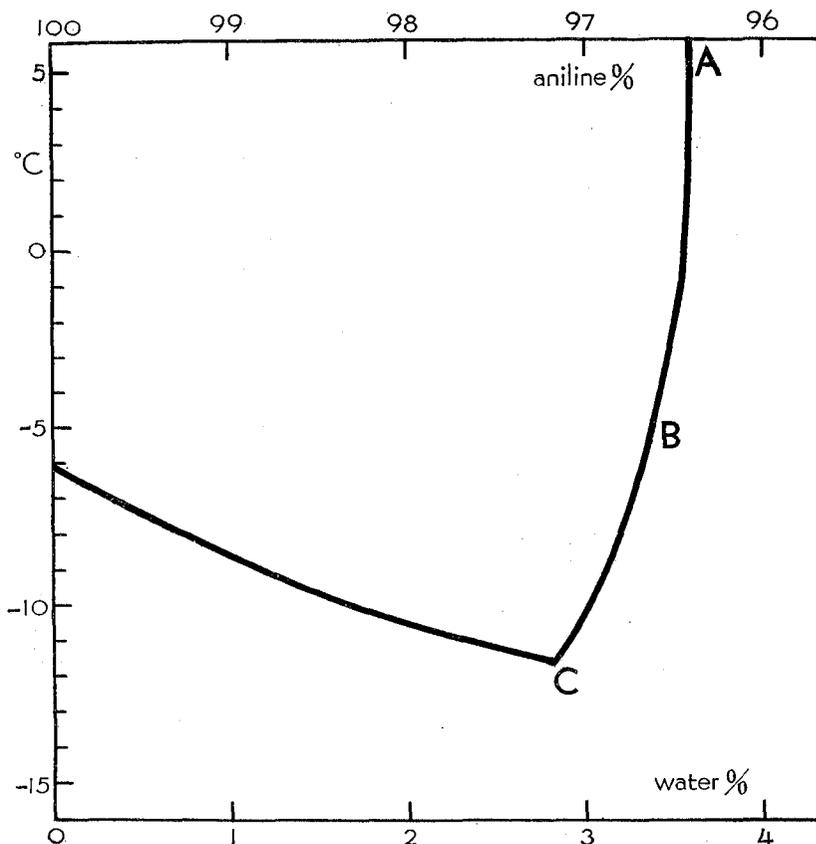


Fig. 2. Solubility curve ABC of water in aniline.

saturated concentration of ice or water in aniline varies with temperature as shown by the solubility curve ABC in Fig. 2.

According to this figure the liquid aniline saturated with ice at -5°C (point B) contains 3.4% of water. The sample of snow is put in the liquid aniline of this concentration. As the temperature is lowered to solidify the liquid aniline, the concentration of water in it decreases along the solubility curve to point C where the solubility is 2.8%, a value 0.6% lower than that at point B. Point C is the eutectic point for solidification of liquid aniline saturated with water. That decrease in solubility caused by the lowering temperature will cause some water to precipitate from the liquid aniline upon the surface of the ice network. Conversely, when the thin section of snow is warmed to melt the solidified aniline, the surface of the ice network will be dissolved into the melted aniline. Both the precipitation and dissolution will make the form of the ice network change. But actually the amount of ice precipitated or dissolved is not as large as will be given by the solubility curve of Fig. 2. The above noted change in the concentration of water amounting

to 0.6% can occur only in the case of very slow cooling or warming, because the solubility curve in Fig. 2 is concerned with the equilibrium state. The actual cooling or warming are made so rapidly that only a very small amount of ice, if any, is precipitated or dissolved. This can be shown by the following experiment. A hoar crystal with a fine texture as shown in Photo. 4, Pl. II was put in the liquid aniline. The aniline was solidified and melted several times. But the fine hoar texture remained unchanged as illustrated by Photo. 5, Pl. II which shows the crystal after completion of the experiment.

(2) The suitable thickness of a section.

As mentioned in the preceding section it is not difficult to thin the section of snow down to 0.01 mm. But in order to see the texture of the ice network, a different thickness should suitably be chosen for different kinds of snow. If the section is made too thin, the network disintegrates into separate pieces as shown in Photo. 6, Pl. II; they move about in the melted aniline. The most suitable thickness is 0.05~0.2 mm for soft snow, 0.1~0.2 mm for compact snow, 0.2~0.3 mm for granular snow and 0.4~0.6 mm for firn snow or ice crust whose grains are large.

The ice network is composed of many crystalline ice grains connected to one another. Sometimes it is desired to determine by a polarizing microscope the crystal orientation on each grain. For that purpose the section should be made very thin because the ice grains must be bounded with parallel planes on their upper and lower sides. In such a case the section is observed below -20°C without melting the solidified aniline.

(3) Poison of aniline.

Aniline is slightly poisonous to the human body. One should take care not to touch aniline and not to breathe aniline vapour needlessly.

6. Examples of thin section.

Liquid aniline has a small viscosity and permeates easily into the air spaces in the ice network however narrow they may be. Any kind of snow, including the softest new snow as well as a layer of depth hoars, can be made into sections of any thickness down to 0.01 mm.

(1) Thin sections made in the cold room.

Photos. 7~12 shown in Pl. III are thin sections cut out of a snow cover deposited at Sapporo. They were made in the cold room attached to the authors' Institute. Photo. 7 shows a horizontal section of new snow (density of snow $\rho=0.05$ gr/cc; thickness of thin section $d=0.1$ mm) at several hours after its deposition. The original forms of snow crystals—needles, columns, capped columns—are clearly seen. But the crystals are already melted together at their points of contact.

Photo. 8 shows a horizontal section ($d=0.15$ mm) of soft snow in which the

dendritic form of the original snow crystals is still discernible. This section was made one day and a half after the deposition of the snow when its density ρ was 0.08. That same snow changed in the following forty days into compact snow of density $\rho=0.3$ having an ice network as shown in Photo. 9.

Photos. 10 and 11 show sections from a block of snow kept for several months in the cold room. The ice particles composing that block had become large due to sublimation. The authors determined the crystallographic orientation on those ice particles by means of a polarizing microscope provided with a universal stage. The six-angled particle near the bottom of Photo. 10 had its optical axis perpendicular to the plane of the paper. The authors found a regularly shaped rectangular crystal as shown in the right lower corner of Photo. 11. Although it had a rectangular form, it could not be regarded to belong to the regular system of crystallography; it had an optical axis directed vertically in the plane of paper.

Photo. 12 is a thin section of ice crust imbedded within the natural snow cover. An ice crust is hard. But it is not so rigid as to stand the carpenter's plane by itself. Reinforcement with aniline is needed for cutting. As seen from Photo. 12, ice crust still has much air space.

(2) Thin sections made in the field.

The thin sections on Pl. IV were made on a Hokkaido mountain under conditions of natural cold. Photos. 13, 14, 15, 16, 17 show in that order the microscopic texture of snow layers lying from top to bottom in the snow cover. The density of that snow cover and the depths at which the thin sections were made are indicated in Diagram 18. Compared as those made in the cold room (Photos. on Pl. III), the thin sections here are somewhat bad in appearance. Such cannot be helped because of many difficulties inherent in the field work.

(3) Firn snow and lake ice brought to the cold room.

It is not difficult to carry samples of snow or ice a long distance under protection with heat insulating material and solid carbon-dioxide. Therefore it is a good idea to bring the samples to the cold room where they can be most conveniently cut into thin sections. Professor NAKAYA brought a block of firn snow from the Greenland ice-cap to the authors' cold room. Photo. 19, Pl. V shows a section of that firn snow. It was of density 0.54 gr/cc.

Photos. 20, 21, 22 in Pl. V show sections of lake ice brought from a distant lake of Hokkaido to the authors. It was fragile. Snow had fallen into the water of the lake and had frozen together to make such an ice. Photo. 21 is an enlarged portion of Photo. 20. When looked at under a polarizing microscope that portion appeared as Photo. 22. It should be noticed that the grain boundaries are quite straight.

(4) Snow which has undergone a forced deformation.

A rectangular bar of snow was bent statically by applying a load at its end as

shown in Photo. 25, Pl. VI. The long photograph (Photo. 26) is of the thin section made at the most bent portion ABCD of the bar from top to bottom. Its actual length is 2.3 cm. The ice network is spread out near the top due to tension while it is dense near the bottom because of compression.

A snow pillar was plastically compressed to about half its original height at a constant speed 1 mm/min.⁵⁾ Photos. 27, 28, Pl. VI and the coloured photograph marked Photo. 30 in Pl. VII show portions from some of the sections cut out vertically from that compressed snow pillar. The ice grain at the center of Photo. 27 looks like a staircase. It must have slipped at three slip planes marked 1, 2, 3. The authors found here and there in the sections long thin ice bridges connecting ice grains. An example is seen in Photo. 28 indicated by mark 1. It reminds the authors of the single crystal which GLEN and PERUTZ⁶⁾ extended considerably. That single crystal in the form of thick rod changed into a long thin tape as it was stretched. The portion marked 2 in Photo. 28 seems to be at the beginning stage of stretching.

Colour Photo. 30, Pl. VII shows a portion of a thin section cut from the compressed pillar of snow when looked at under a polarizing microscope with crossed polaroids. Use was made of a sensitive colour plate. Therefore the back ground of the photograph is coloured purple instead of being dark. The ice network in the photograph appears as if it had been pressed together from above and below. Indeed that was the case. Colour Photo. 29 in the same Pl. shows a thin section of compact snow in the natural state, that is, not deformed by any external force.

In both Photos. 29 and 30, individual ice grains composing the ice network are divided into regions of different colour. This means that one ice grain does not make a single crystal as a whole but is composed of a small number of single crystals. But a difference is found in the shape of the regions in Photos. 29 and 30. In the case of Photo. 29 the boundaries between the two adjoining regions are straight like in the case of Photo. 22, which is an indication that all the single ice crystals are in the state of equilibrium. On the other hand, the boundaries are irregularly curved in Photo. 30. Such a change in the form of boundaries must have been caused by the compression of the ice network. There are found some boundaries across which no change in colour is seen. Such boundaries would perhaps have been made anew in the process of compression.

(5) Snow which is undergoing a forced deformation.

In the preceding paragraph (4) mention was made of thin sections of snow which had undergone a forced deformation. In those cases the initial form of the deformed ice network was unknown. Therefore no information could be got on how much or in what way the ice network had changed. The authors succeeded in pressing together from both sides a thin section of snow, keeping it in the plane form without bending upwards or downwards. In this way they could see under a microscope how the ice network was changed from its initial form by the force applied. The

thin section used was 0.5 mm thick and of area 2 cm × 2 cm.

Photo 23, Pl. V shows a portion of the thin section before the application of the force. Photo. 24, Pl. V is the same portion after the thin section had contracted by 10% in three hours under a force of magnitude 1 kg/cm². The lines marked A and B in Photo. 23 are boundaries between single crystals of ice. As the thin section of snow was pressed together those single crystals slipped at their boundaries to take such an appearance as that shown in Photo. 24. One will notice that the ice grain positioned to the right of boundary A has shifted towards the left obliquely while the portion between the two boundaries marked B has protruded downwards. But those slips at the boundaries were not the only phenomena which accompanied the deformation of the ice network. The ice grains composing the network themselves changed their forms, which one could see by careful comparison of the two Photos. 23 and 24. Sometimes there appeared groups of many parallel straight lines on the ice grains. They must have resulted from the internal slips of the grains taking place along their crystallographic basal planes. Irregular patterns of lines as shown in Colour Photo. 30 were also found. Further experiments on this subject are now in progress. The details of the experimental results will be reported elsewhere in the near future.

7. Summary.

Aniline is a common and cheap liquid. By the use of that liquid the authors were enabled to make thin sections of snow to be looked at under a microscope. Aniline saturated with water was allowed to permeate a sample of snow at $-5^{\circ}\sim -10^{\circ}\text{C}$ and then was solidified by lowering the temperature to -20°C . The sample of snow now reinforced by the solidified aniline was cut into a thin section with a carpenter's plane. All sorts of snow, soft and hard, could be thinned down to 0.01 mm. Many examples of thin sections are shown by black-white and coloured photographs.

Acknowledgment. The authors wish to express their hearty thanks to Prof. Z. YOSIDA for having given many kind advices and valuable comments.

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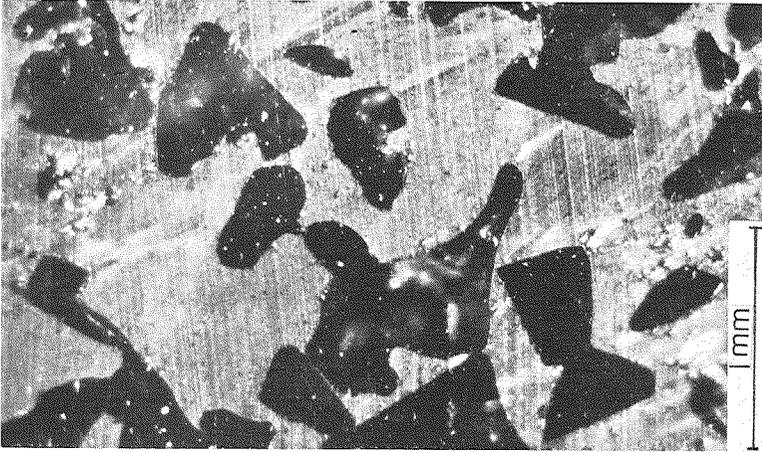
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PLATE I

- Photo. 1. A planed surface of the plate of snow reinforced by solidified aniline. Illuminated by reflected light. Dark portions indicate the cut ends of the ice network while the white ones solid aniline. Compact snow with density $\rho=0.4$.
- Photo. 2. Thin section at -20°C with solid aniline illuminated from behind. White portions are the cut ends of the ice network. Thickness of the section $d=0.1$ mm. Soft compact snow, $\rho=0.22$.
- Photo. 3. The same section as Photo. 2 with the aniline melted at -6°C . The whole texture of the ice network is seen.

1



2



3

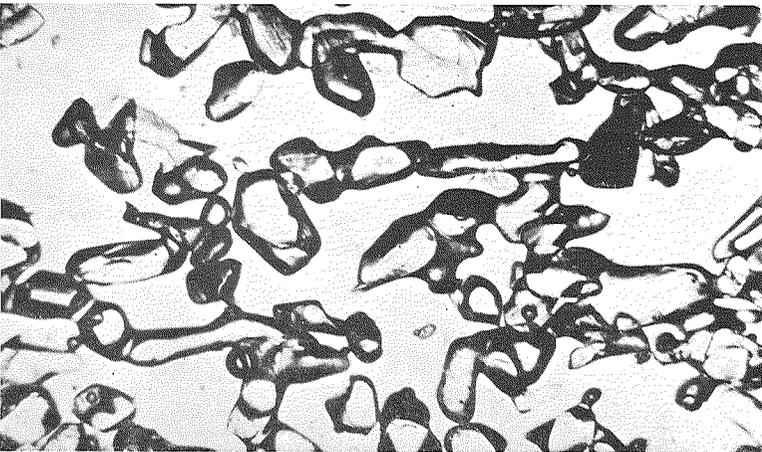
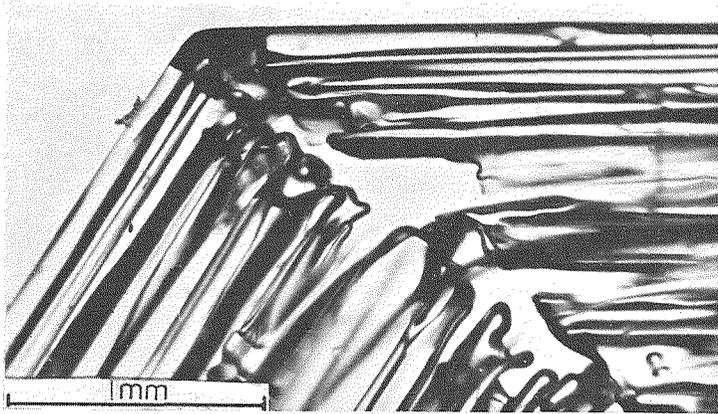


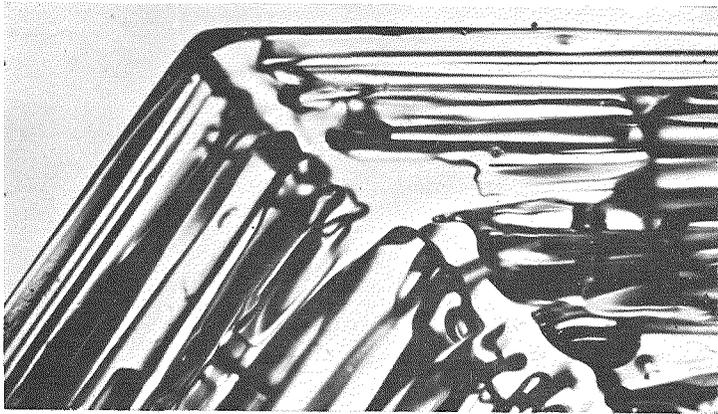
PLATE II

- Photo. 4. A hoar crystal dipped in aniline at -5°C .
- Photo. 5. The same crystal after the aniline had been solidified and melted several times within six hours.
No appreciable change is discerned in the form of the crystal.
- Photo. 6. A very thin section with $d=0.01$ mm. Compact snow with $\rho=0.3$. The ice network is separated into separate pieces.

4



5



6

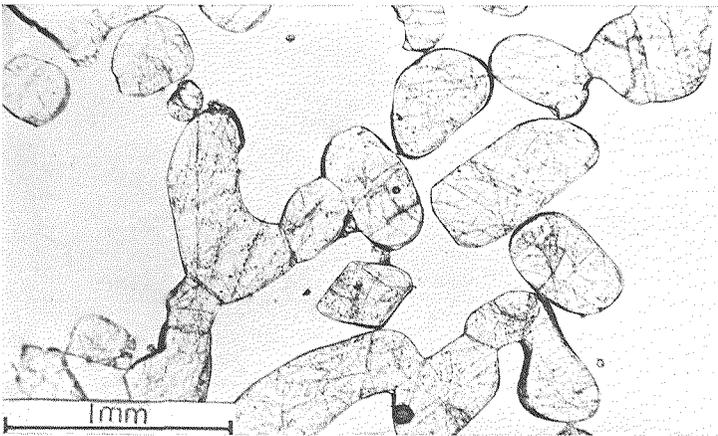


PLATE III

Thin sections made in the cold room.

- Photo. 7. New snow at several hours after its deposition. $\rho=0.05$,
 $d=0.1$ mm.
- Photo. 8. Soft snow one day and a half old. $\rho=0.08$, $d=0.15$ mm.
- Photo. 9. The same snow as Photo. 8 after forty days. $\rho=0.32$,
 $d=0.1$ mm.
- Photo. 10. and 11. Snow subjected to heavy sublimation in the the cold
room. $\rho=0.35$, $d=0.06$ mm.
- Photo. 12. Ice crust found in snow cover. $\rho=0.3$, $d=0.15$ mm. (The
magnification is the same respectively on Photos. 7, 8, 9 and
Photos. 10, 11, 12.)

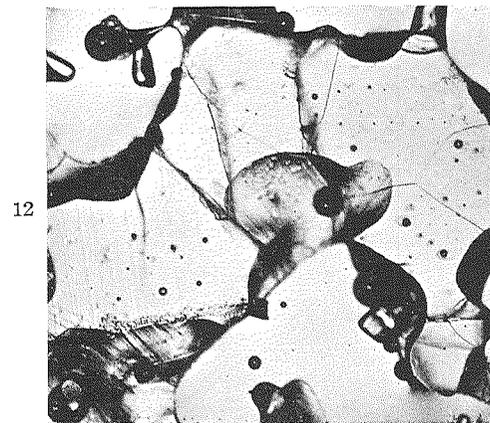
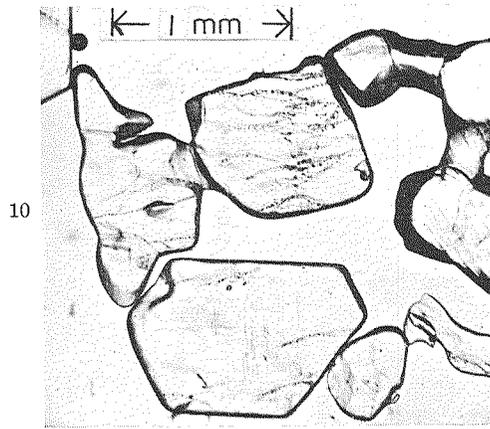
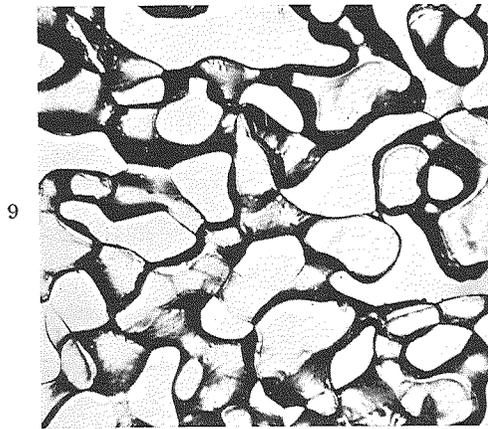
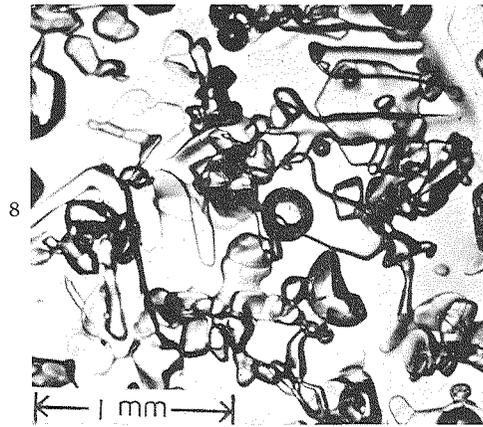
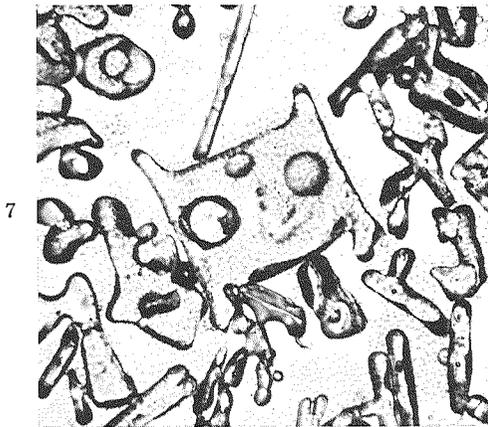


PLATE IV

Thin sections made in the field. They were cut out vertically from different parts of the same snow cover. They stood upright in the snow cover as shown in Photos.

Photo. 13. Soft compact snow 25 cm below the surface of the snow cover. $\rho=0.18$, $d=0.2$ mm.

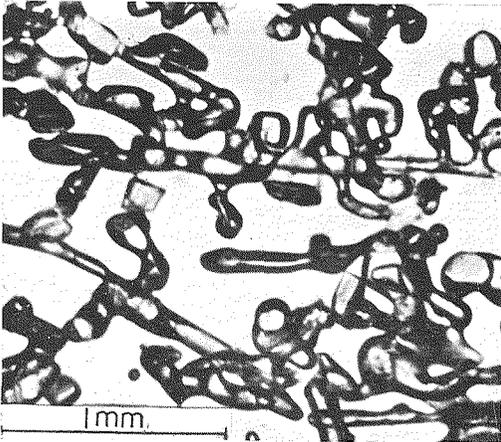
Photo. 14. Compact snow, 50 cm below. $\rho=0.28$, $d=0.15$ mm.

Photo. 15. Compact snow, 80 cm below. $\rho=0.37$, $d=0.15$ mm.

Photo. 16. Compact snow, 110 cm below. $\rho=0.45$, $d=0.15$ mm.

Photo. 17. Granular snow, 140 cm below (20 cm above the surface of the ground). $\rho=0.36$, $d=0.3$ mm.

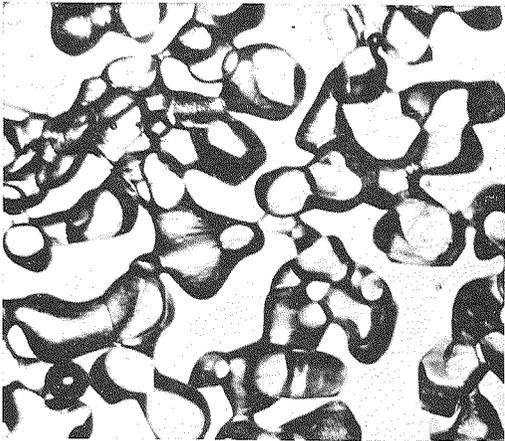
Diagram 18. Vertical distribution of snow density in the snow cover. The positions where the above thin sections were cut out are indicated by arrows.



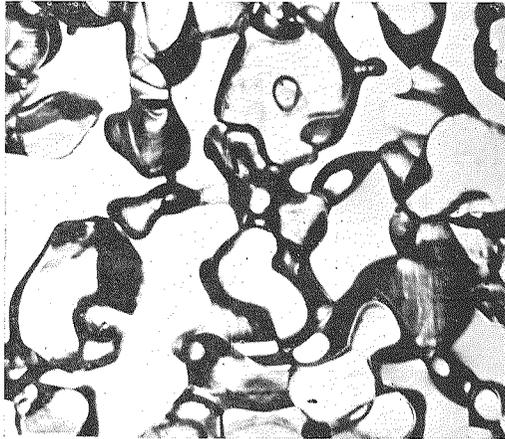
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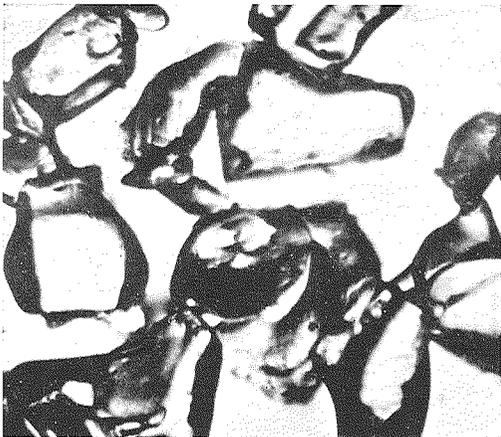
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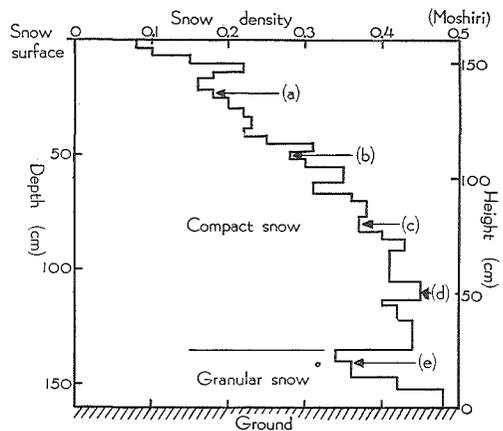
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16



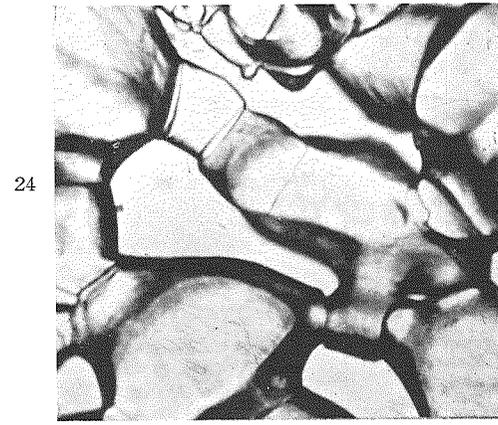
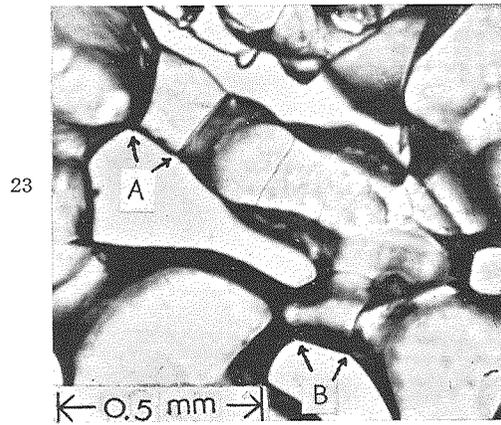
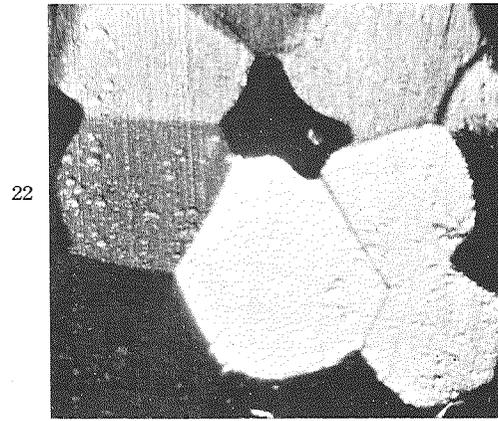
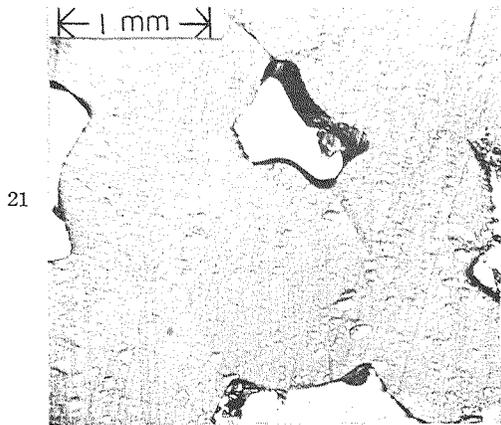
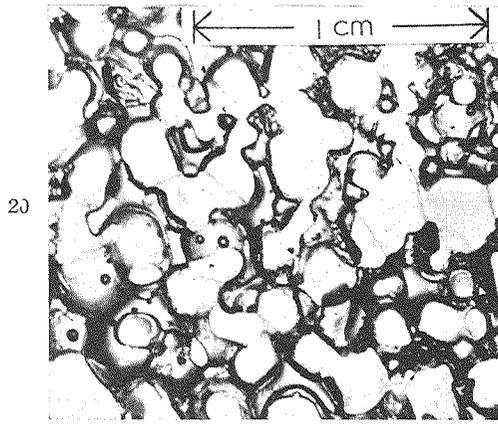
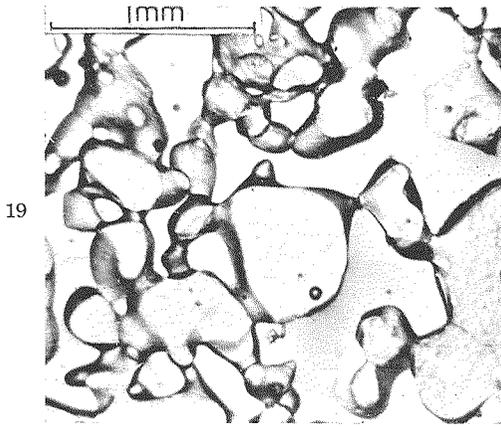
17



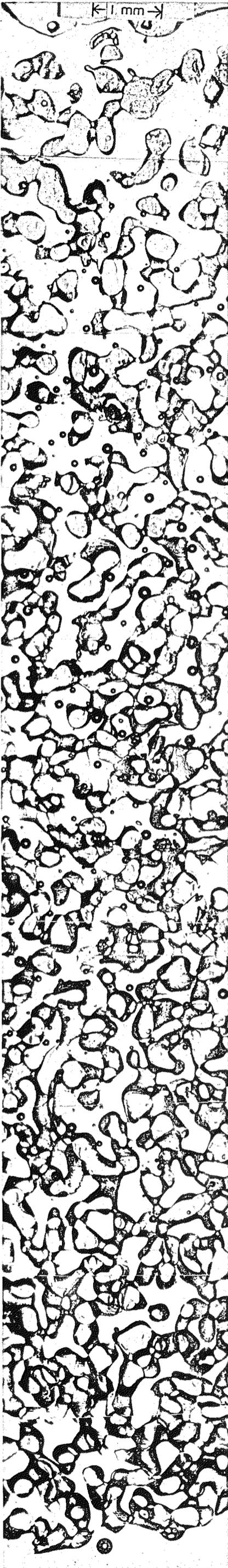
18

PLATE V

- Photo. 19. Firn snow brought from the Greenland ice-cap. $\rho=0.54$,
 $d=0.2$ mm.
- Photo. 20. Lake ice—snow frozen together with the lake water. $\rho=0.65$,
 $d=0.6$ mm.
- Photo. 21. An enlarged portion of Photo. 20 under an ordinary micro-
scope.
- Photo. 22. The same portion under a polarizing microscope. The grain
boundaries are distinctly seen to be straight.
- Photo. 23. A portion of a thin section which is to be compressed
sideways. $\rho=0.5$, $d=0.5$ mm.
- Photo. 24. The same portion subjected to a compression of 10%. Slips
have occurred at boundaries A and B.



26



25

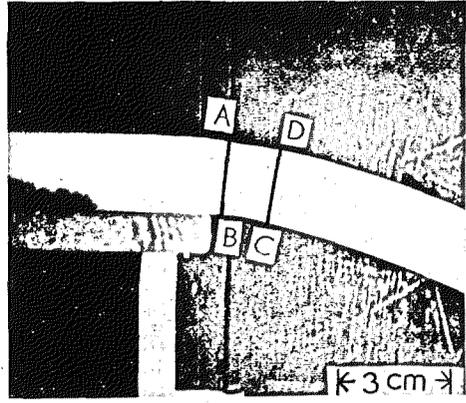


Photo. 25. A rectangular bar of snow bent statically by applying a load at the right end. A thin section is made at the most bent portion ABCD.

Photo. 26. Thin section covering the whole thickness of portion ABCD. (This long photograph was made by Dr. KUROIWA. The authors thank him for permission to reproduce it here).

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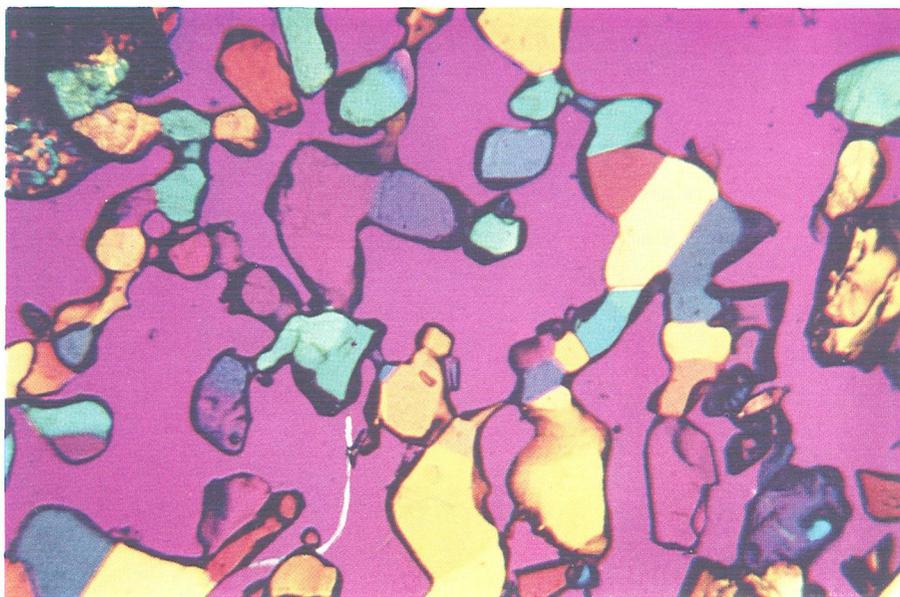
Photo. 27. Thin section from a heavily compressed snow pillar. Large slips have occurred to the ice grain at the centre across the planes marked 1, 2, 3. Initial snow density $\rho=0.38$.

Photo. 28. The same as Photo. 27. An ice grain has been pulled apart into a thin ice string as indicated by 1. Initial snow density $\rho=0.25$.

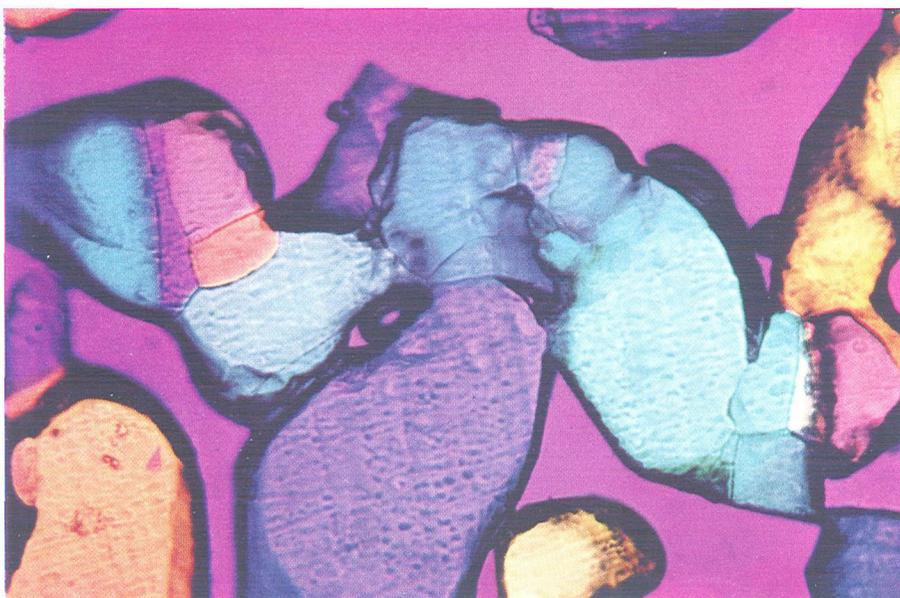
PLATE VII

Coloured thin sections as seen under a polarizing microscope.

- Photo. 29. Compact snow in the natural state. The grain boundaries are straight. $\rho=0.38$, $d=0.1$ mm. ~~$\times 56$~~ $\times 26$.
- Photo. 30. Snow pillar plastically compressed to 40% of its original height. The grain boundaries are not simple in form and in arrangement as in Photo. 29. Initial snow density $\rho=0.38$, $d=0.1$ mm. ~~$\times 26$~~ $\times 56$.



29



30