A STUDY OF THE FREEZING CYCLE IN AN ALASKAN STREAM

by

Carl S. Benson

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A Completion Report

by

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INTRODUCTION

The summer history of arctic and subarctic streams has received considerable attention. This is especially true for glacier streams. But these streams also have an interesting winter history which has been largely ignored.

Their freeze-up takes several weeks with repeated formation and melting of underwater ice, *i.e.*, "frazil ice" and "anchor ice", which affects the turbidity and the flow characteristics of the stream. The streams frequently freeze to the bottom over most of the channel width. Continued discharge through channels constricted by freezing builds up pressure in the water which is relieved when the water breaks out of its confining channel. This water freezes and forms "aufeis" deposits. The total ice thickness may be greater than the normal water depth by a factor of 5 or more; it often fills and may exceed the bounds of stream banks. In spring, when snow melt water drains into these stream channels, which are choked with ice, the potential for flooding is high.

All liquids, including water, become supercooled before crystallization begins. In non-flowing bodies of water, such as laboratory samples, cloud droplets, and lakes, the supercooling lasts for a short time and terminates when the ice phase is nucleated.

The maximum extent of supercooling is about 40 C but this extreme is reached only in small cloud droplets. Dorsey (1948) performed many freezing experiments on bulk water from various sources. He protected the samples from the atmosphere, which can introduce freezing nuclei, by sealing them in glass bulbs (volume about 8 cm^3). The samples were placed in a temperature controlled alcohol bath and repeatedly frozen and thawed. The spontaneous freezing points varied from -5 to -22 C. In no case was a spontaneous freezing point of 0 C observed.

The freezing of rapidly flowing turbulent water presents quite a different problem from the freezing of quiet waters or slowly flowing streams. The main complications associated with freezing in turbulent water are caused by the formation of underwater ice. The terms frazil ice and anchor ice have been applied and widely used for many years in the discussion of underwater formations of ice (Timonoff, 1936).

Frazil ice forms in supercooled running water; the degree of supercooling may be very slight. The structure of frazil ice was first described by Barnes (1906) as small disclike plates, and this observation has been confirmed by Altberg (1936) and others. Excellent photos of these discs and other modifications of early ice crystal forms have been taken (Altberg, 1938; Altberg and Lavrow, 1939; Schaefer, 1950). The frazil ice crystals are distributed throughout a flowing turbulent stream. They sometimes cluster together to form curtain-like spongy masses which move along underwater with the current.

Anchor ice forms on the bottoms of rivers and on objects under water. It is firmly attached to the bottom and grows outward. Barnes (1906) attempted to explain that anchor ice is formed by radiation from river beds at night which permits cooling of the river bed to the point where ice forms and grows continuously from the bottom outward. Altberg (1936), however, produced anchor ice under laboratory conditions which completely eliminated any possibility of radiation from the bottom. It has been conclusively proved that the formation of underwater ice is entirely independent of radiation from stream beds (Altberg, 1936; Nybrant, 1943; Gerdel, 1952). Indeed, it is physically impossible to form anchor ice by radiation through the water from the stream bottom because water is opaque to long range radiation. The case was well stated by Gerdel (1952) p. 127:

> Computations based upon data for the monochromatic absorptivity of water presented by Dorsey (1940) will show that all of the long-wave radiation (greater than 1.5μ) which can be lost from the bed of a stream at 0 C would be absorbed in less than one centimeter of water. Since anchor ice is produced at depths of several feet, radiational losses of heat must be ruled out. That Barnes himself realized the error in his hypothesis is shown by Altberg's (1936, p. 377) statement that Koblenz finally succeeded in persuading Barnes that his point of view had to be revised.

Altberg did not distinguish between frazil and anchor ice but classed them together as underwater ice which forms when the water temperature falls below 0 C. He found that the water temperature remained fairly constant throughout the river from top to bottom, because of turbulence. The more turbulent the water, the closer the temperature at any point to the mean temperature (Altberg, 1923). Measurements showed that the supercooling exists in these streams for long periods - hours, sometimes days - even in the presence of ice. Altberg (1936) proposed that flowing supercooled water provides a vehicle for removing latent heat and this allows the formation of underwater ice. Furthermore, irregularities on the bottom are accentuated because heat is removed from sharp points or edges faster than from flat or rounded shapes.

In general, problems associated with freezing and thawing of water are of major importance in the Alaskan environment. The problems are fascinating from a purely scientific point of view and of immediate economic importance from an engineering point of view. In particular, the problems associated with freezing in streams may be separated into two groups:

1. Problems of supercooling, nucleation, and underwater ice formation ("anchor ice" on the bottom and "frazil ice" within the stream) before the water surface is completely frozen over, *i.e.*, before "freeze-up", and
2. Problems of overflow icing, *i.e.*, water flowing over the ice surface after "freeze-up". The water in these overflows freezes and forms sheets of overflow ice (aufeis) which in aggregate are thick and widespread.

These problems have attracted attention because of questions concerning the mechanisms by which underwater ice nucleates and grows. The amount of supercooling in running water is very small compared with other water systems but it occurs repeatedly and lasts for long periods of time. Also, freezing in rivers brings problems which have direct and significant effects on the activities of man. Underwater ice formation may plug underwater intakes for hydroelectric plants and water supply lines. As an excellent example, Altberg's (1936) classic work began as an investigation of ice formation on water intake pipes in 1914, when the whole bottom of the River Neva was found to be covered with a thick (1-meter) crust of porous anchor ice. This left the city of Leningrad without water. It also initiated 20 years of research on underwater ice formation in the laboratory and in the rivers of eastern and north-central Russia (including the Neva, Amgara, Amur, and Yenisei rivers).

Overflow icings cause serious problems when they cover roads and bridges. A dramatic Alaskan example occurred in December, 1965, when aufeis, combined with extensive overflow of the Klutina River, deposited ice more than a meter thick in all the buildings of Copper Center. As a result, it was necessary to evacuate the community until the summer.

One must also understand the nature of ice formation on streams when one plans to use ice covers for transportation aids such as landing fields, ice bridges, and roads, or when one desires to obtain water from streams which freeze from top to bottom and allow flow only through complex channels in and under the ice.

PREVIOUS INVESTIGATIONS AT THE UNIVERSITY OF ALASKA

1963-1964

Research on stream freezing began at the University of Alaska during autumn, 1963, as part of the laboratory and field aspects of a seminar course in glaciology. It was part of a general study on ice formation in various geological environments including the atmosphere (Benson, 1965, 1970). Observations were made on several streams in interior Alaska and a site for detailed study was selected on Goldstream Creek at a point only 5.5 km north of the campus. Five surveys of the ice overflow volume were made throughout the winter and the periods of freeze-up and break-up were observed. Reports on this work were presented at the Alaska Science Conference, August, 1964, and in the 1963-64 Annual Report of the Geophysical Institute, University of Alaska.

Graduate students involved in the work were: Gary Anderson, Donald Grybeck, and James Stout.

1964-1965

During the 1964-65 winter season, field work was limited to the research site on Goldstream Creek. Efforts were concentrated on rate of aufeis accumulation, topography of the aufeis surface, and an attempt to correlate overflows with variations in air temperature. A cross-section was excavated through the ice to the bottom of the stream in a place which was frozen from top to bottom. Photographic records were made of the entire section in place as well as of 40 thin sections of the ice cut with vertical and horizontal orientations. These thin sections were stored for petrofabric studies with the Rigsby 4-axis universal stage. Unfortunately, the samples were lost as the result of a power failure which turned off the refrigerated storage unit. However, analysis was completed to the extent that the major types of ice structure were identified: (1) the fine-grained, randomly oriented ice formed as underwater ice during freeze-up and during winter overflows; (2) ice similar to (1) but finer grained, formed as winter overflow water soaked into snow covering the ice; and (3) large crystals, elongated vertically but with c-axes horizontally oriented in two clearly defined aufeis layers as well as in the ice which formed at the base of the ice sequence by freezing the water of the original stream. This work was reported in the 1964-65 Annual Report of the Geophysical Institute, University of Alaska.

Graduate students involved in the work were: George Wharton, Jürgen Kienle, and Douglas Bingham.

OBJECTIVES OF THE PRESENT STUDY

The goal of this study as listed in the original proposal and its extension was basically to "...shed more light on the mechanics of streams under cold weather conditions." More specifically, the objectives were as follows:

1. To measure the water temperature in an attempt to determine the extent of supercooling in the stream prior to and during the formation of underwater ice.
2. To observe the shape, size and abundance of frazil ice crystals and the effects of underwater ice formation on the physical characteristics of the stream.
3. To locate how and where the water flows via channels in and under the ice and to relate the occurrence of overflows to the sealing of such channels. It was planned to do this by making temperature measurements through a cross-section of the stream.
4. To carry out a petrofabric analysis of the 1965-66 and the 1966-67 stream ice from top to bottom.
5. "It is important to keep in mind that there is no standard approach to the problems involved. Part of the research effort involves identification of the problems and methods to deal with them. Finally, the entire program is to be coordinated with educational needs. Both undergraduate and graduate students are encouraged to participate in the research problems. The course work mentioned above served as the starting point for studies on snow cover and streams in the Fairbanks area and it is hoped that this research support will further augment the course work." (Original proposal, page 4.)

RESULTS AND DISCUSSION

Research Site

Goldstream Creek, at the research site, is about 8 m wide and, prior to freeze-up in October, it varies from 20 to 40 cm deep across the main test section. The deepest holes near cut banks in the stream are barely over 1 m deep. A meteorological instrument shelter, with a recording thermograph, was placed on the west bank of the stream. During the fall of 1966, a building approximately 2.5 m square with a wood-burning stove and gasoline lantern was also placed on the west bank to provide heated shelter with light during mid-winter.

Every September, from 1964 to 1970, a horizontal datum plane was established on marked pipes driven into the banks of the stream. Profiles of the stream bottom were leveled across four selected cross-sections prior to freeze-up, and the ice topography was measured weekly on these cross-sections until after break-up in May. A plane-table map of the ice topography was made prior to break-up each year.

Freeze-up

During the last three weeks prior to formation of a complete surface ice cover on Goldstream Creek, the water temperature varies within a range of about 0.2 C. Early in the nightly cooling cycle it drops to -0.01 to -0.05 C for periods of several minutes up to several hours. Discs of frazil ice, 1 to 6 mm in diameter and 0.025 to 0.1 mm thick, form in the supercooled water and gradually raise its temperature to near 0 C. At this stage, dendritic forms begin to grow on the discs. These adhere to the stream bottom and crystals continue to grow as turbulent flow of slightly supercooled water transports the heat of fusion to the stream's surface, where it is lost as long-wave radiation or by advection or evaporation. This process produces underwater ice.

Anchor ice frequently appears spongy and grey because it contains bottom sediments. Rock fragments, including pebbles 3 to 5 cm diameter, are lifted 20 to 30 cm off the stream bed by a rolling action of the current on the growing anchor ice. During the following day, short wave solar radiation penetrates to the stream bed where it begins to melt the debris-laden anchor ice. Large masses break loose and rise to the surface. By afternoon, the stream is free of ice and its temperature is 0.05 C or higher. This process is repeated daily for several weeks. During the last 10 days before freeze-up in 1967, the day-time stream temperature rarely reached 0.1 C. During the last three days, it did not exceed 0.05 C. When the surface ice cover finally forms and the original stream is frozen, it frequently contains rocks incorporated by the anchor ice.

The formation of underwater ice increases the electrical conductance of the remaining water because the ice rejects impurities as it grows. During the first night of strong supercooling and underwater ice growth on 7 October 1967, conductance increased from 180 to 200 μmho-cm^{-1}. Subsequent melting of the ice caused a return to the previous value. If one assumes that all impurities are rejected by the growing ice, then it is possible to use the electrical conductance measurements to calculate the amount of ice formed. This would be a useful result since the irregular shape and distribution of anchor ice makes it very difficult to estimate the quantity of underwater ice. A first approximation to this problem is to assume that the total quantity of salts, S, remains constant in the water during the formation of underwater ice. Then we may proceed as follows:

Let us assume that the concentration of salts per unit volume may be written as

$$C = \alpha k,$$

where α is a constant over the temperature range ±0.5 C from +0.5 C to −0.1 C, and
where k is the electrical conductance.
Then the total salt quantity before freezing is

$$S_1 = \alpha k_1 V, \text{ before formation of underwater ice,}$$
$$\text{and } S_2 = \alpha k_2 (V-\Delta V), \text{ after formation of underwater ice.}$$

Here, V is the water volume before freezing and ΔV is the reduction of water volume caused by freezing.

We have assumed that

$$S_1 = S_2,$$

so that

$$\frac{k_1}{k_2} = 1 - \frac{\Delta V}{V}.$$

If we assign a value of 180 μmho·cm^{-1} for k, and 200 μmho·cm^{-1} for k_2, values measured on 7 October 1967, we obtain

$$\frac{\Delta V}{V} = 0.10.$$

In other words, 10% of the water was converted to underwater ice during the night of 7 October, and most of this ice melted during the daytime on 8 October.

The concentration of frazil discs is on the order of one in 1 to 10 cm^3 of water. Crystals also grow and/or accumulate on obstructions such as rocks, buried logs, or thermocouple wires. The specific surface area of the suspended and fastened discs is on the order of 200 to 900 cm^{2}gm^{-1}.

For example: a crystal disc 4 mm diameter and 0.1 mm thick has a mass of 1.15 mg and a specific surface of 229 cm^{2}g^{-1}; a crystal disc 0.01 mm diameter and 0.025 mm thick has a mass of 0.018 mg and a specific surface of 915 cm^{2}g^{-1}.

The suspended and anchored ice increases the resistance to stream flow and reduces its velocity by about 40%. When the ice melts during the day, the velocity returns to its former value. Since the discharge remains virtually constant, except for the 5 to 10% reduction due to underwater ice formation discussed above, the variation in velocity changes the cross-sectional area of the stream. This has been recorded by daily variations of 10 to 15 cm in the water level measured on reference posts during the weeks before freeze-up.

The rates of cooling in the water of Goldstream Creek were on the order of 0.0017 C min^{-1}. This is two orders of magnitude slower than the cooling rates observed in Michel's (1968) experimental flume. Cooling rates observed by Altberg (1936, p. 386) were 0.062 C min^{-1}. The durations of supercooling in both Michel's and Altberg's experiments were on the order of 5 to 10 minutes. In our outdoor work on Goldstream Creek, supercooling lasts for several hours. Thus, we are dealing with the phenomenon on a larger scale with slower rates; yet the extent of supercooling, *i.e.*, several hundredths of a degree is essentially the same in all cases. We plan to investigate the ratio of heat transfer and relate them to the amount of latent heat release during the ice growth phase.

Temperature of the Ice

A string of thermocouples was installed across the stream bottom prior to freeze-up. After freeze-up, a second string of thermocouples was frozen onto the ice surface directly over the one on the bottom. When the original ice surface was buried by an overflow, a third string of thermocouples was frozen onto the new ice surface. Five strings of thermocouples were emplaced in this way during each of two successive years. Temperature measurements were made with them every week to obtain vertical thermal cross-sections of the stream ice. Places where water was flowing along the bottom and within the ice were identified by zones of maximum temperatures. The thermal cross-sections varied throughout the year and were notably different during successive years. Temperature measurements were also made in the air and in the adjacent soil and snow pack.

The sequences of overflow layers measured in 1966-67 and in 1967-68 are shown in Fig. 1. The layers are numbered and explained in Tables 1 and 2. Thermal cross-sections measured in midwinter, *i.e.*, 20 January 1967 and 20 January 1968 are presented in Fig. 2. The locations of running water, as detected by these temperature measurements are indicated. During the 1966-67 winter, there was significantly more overflow from the side with the highest bottom temperatures.

Petrofabric Structure of the Ice

Since 1964, ice cores have been taken from selected places and a cross-section of the frozen stream was exposed by quarrying the ice to the stream bed in March or April each year. The north (shaded) walls of the section were cleaned and polished to expose stratigraphic detail *in situ*. These sections were photographed and oriented samples were cut from them. The ice varied from clear, transparent layers formed by massive overflows on an ice surface which had negligible snow cover, to opaque layers formed when overflow water percolated into an overlying snow cover. Vertical and horizontal thin sections from these years, 1965-66, 1966-67, and 1967-68, were examined and photographed under ordinary and polarized light. The c-axis of individual crystals was oriented with a Rigsby four-axis stage and plotted on Schmidt equal-area nets. Examination of photographs and stereograms revealed five basic types of ice: (1) clear, massive, original stream ice composed of elongate, tapered crystals in which the c-axes are primarily horizontal and

TABLE 1. SURFACE PROFILES ACROSS GOLDSTREAM DURING THE 1966-67 WINTER

Surface	Comments
1	Stream bed, the first string of thermocouples placed on October 2, 1966.
2	Water level, October 7, 1966.
3	Ice surface of November 4, 1966. The second string of thermocouples placed on this surface on November 4, 1966.
4	Ice surface of November 11, 1966.
5	Ice surface of November 18, 1966. The third string of thermocouples was placed on this surface on November 18, 1966.
6	Ice surface of November 25 to December 23, 1966. The fourth string of thermocouples was placed on this surface on December 3, 1966.
7	Ice surface of January 6, 1967.
8	Ice surface of January 13, 1967. The fifth (last) string of thermocouples was placed on this surface on January 13, 1967.
9	Ice surface of February 19 to March 31, 1967.
10	Ice surface of April 7 to overflow of spring flood waters on top of ice beginning on May 3, 1967.

TABLE 2. SURFACE PROFILES ACROSS GOLDSTREAM DURING THE 1967-68 WINTER

Surface	Comments
1	Stream bed, the first string of thermocouples placed on September 30, 1967.
2	Water level, September 23, 1967.
3	Ice surface of October 28, 1967. The second string of thermocouples placed on this surface on same day. Surface then dropped down to position of November 1, 1967.
4	Ice surface of November 1, 1967.
5	Ice surface of November 18, 1967. The third string of thermocouples was placed on this surface on November 22, 1967.
6	Ice surface of November 29, 1967. The fourth string of thermocouples was placed on this surface on November 29, 1967.
7	Ice surface of December 22, 1967. The fifth string of thermocouples was placed on this surface on December 22, 1967.
8	Ice surface of January 6, 1968 to January 31, 1968.
9	Ice surface of January 31 to overflow of spring flood waters on top of ice beginning on April 17, 1968.

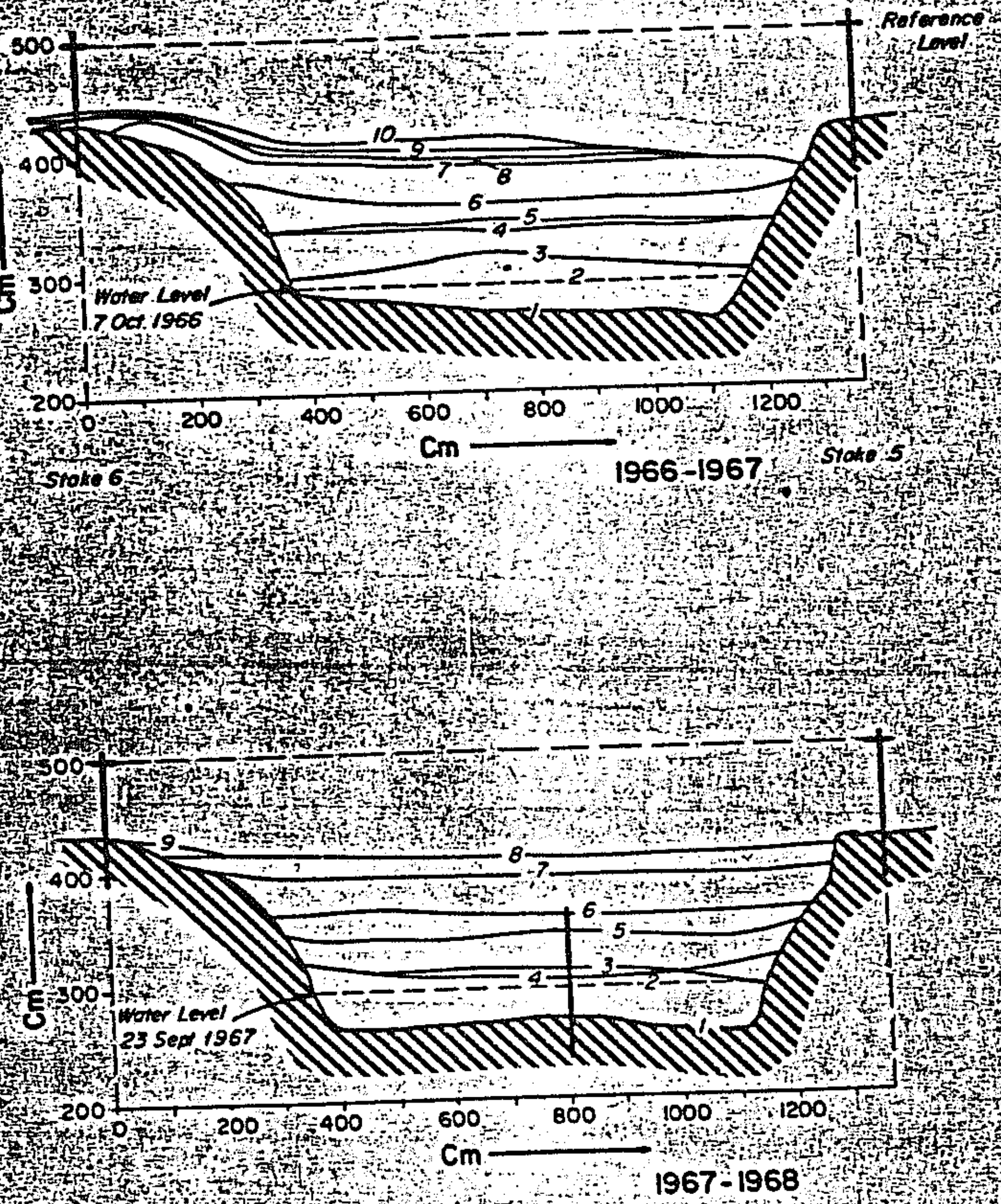

Fig. 1. Ice surfaces in a cross-section of Goldstream Creek. The cross-section is in the center of the research area. The 500 cm level is an arbitrary reference level used every year.

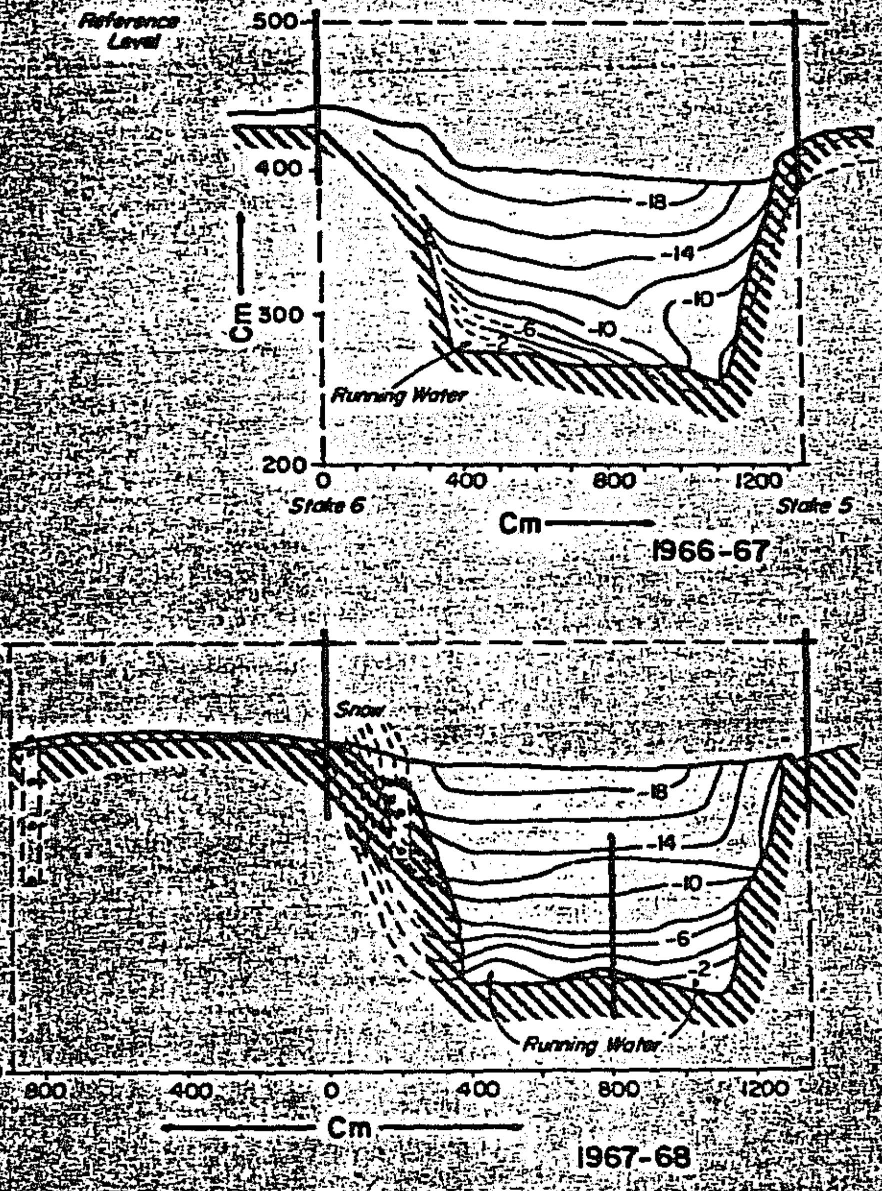

Fig. [illegible]. Thermal cross-sections (degrees Centigrade) of the stream section shown in Fig. 1. The sections were measured on [illegible] January 1967 and 1968, respectively. The isotherms show a 10°C difference in the bottom temperatures in 1967 with the possibility of water moving only on one side. In 1968 the isotherms were nearly parallel to the stream bed and moving water may have been present in two separate bottom channels.

randomly oriented; (2) bubbly overflow ice layers with horizontal c-axes which are sometimes aligned parallel to the stream flow; (3) thin skim-ice layers formed on free water surfaces with vertical to horizontal c-axes; (4) fine-grained equigranular snow ice; and (5) anchor ice with slightly coherent, randomly oriented, rounded plates with c-axes normal to the plates. Some boundaries between individual layers contain layers of air bubbles encased in ice, while in some places 2 to 3 cm voids occur with hoarfrost crystals growing in them.

Other Characteristics of the Overflow Ice Layers

Biological. During the 1967-68 winter, a thick ((28 cm) ice layer formed by flooding in late December, contained significant organic matter. Samples of this material were examed by Dr. Vernon Harms of the Biology Department at the University of Alaska and by Dr. Ted Roeder of the Alaska Water Laboratory, U. S. Department of the Interior. Cell structure was not identifiable and no viable material could be found. The organic matter appeared to be decayed vegetation which had been scoured from the bottom of swampy areas before the water flooded onto the surface.

This observation is important from the point of view of water pollution, in that it introduces the possibility of transport of polluted waters by winter flooding. Goldstream Valley and similar areas are experiencing a rapid development of homesites. The potential for transporting polluted water by winter transport of bottom sediments to the surface of streams by winter flooding merits investigation.

Electrical Conductance. The electrical conductance of the water derived from ten separate layers in the 1967-68 ice was measured and the values ranged from 15 to 110 μmho$\cdot$cm^{-1}. The conductance of the water from the clear overflow layers ranged from 15 to 110 μmho$\cdot$cm^{-1}, but that in the water from the bubbly snow-ice layers ranged from 80 to greater than 100 μmho$\cdot$cm^{-1}. It seems that the clear ice layers are formed by the freezing of thick (10-20 cm) layers of overflow water, impurities being excluded from the growing crystals and concentrated in the running water. On the other hand, if the stream ice is covered with snow, the overflow water will disperse within the snow grains and freeze in the interstices so that the impurities become trapped along crystal boundaries. Thus, there are more impurities in snow-ice layers than in those frozen from clear water even though the snow itself is very clean (conductance = less than 10 μmho$\cdot$cm^{-1}) and the original stream water has higher conductance values (in excess of 150 μmho$\cdot$cm^{-1}) than any of the values measured in the ice layers.

Break-up

During break-up, the stream bed was always full of ice and the overflowing floodwaters peeled off the ice layers. The layer boundaries frequently represent planes of weakness, but where cracks exist from top to bottom, two or three layers may be removed together in a patch manner. The layer-by-layer ice erosion takes several weeks, during which time swift water flowing on smooth ice makes it impossible to wade across the stream. The strings of thermocouples, frozen into the ice as it formed, were undamaged by the erosion of the ice layers. As each string was exposed, it merely washed to the side of the stream where it could easily be removed.

The original stream's ice, which was frozen to the bottom over most of the stream bed, was resistant. It came off slowly and irregularly, and was honeycombed with vertically oriented holes. These holes form by the action of turbulent water on the pebbles imbedded in the bottom ice layer.

SUMMARY

An 8 mm color motion picture has been made which illustrates most features of the ice cycle described in this paper.

The observations and measurements on freeze-up, detailed petrofabric structure of the overflow aufeis layers, and mechanism of break-up, are summarized in the M.S. thesis by J. D. Kreitner. The temperature distribution in the ice and surrounding soil as a function of time is presented in the M.S. thesis by S. W. Corbin.

Students who have participated in this work include: G. Anderson, D. Bingham, S. Corkin, G. Furst, D. Grybeck, J. Kienle, J. D. Kreitner, J. C. H. Mungall, J. Stout, D. Trabant, and G. Wharton.

There are many facets of stream freezing problems which need further study. Our knowledge of nucleation in supercooled water in turbulent streams, the subsequent growth of frazil and anchor ice, the formation and structure of overflow layers and how they are eroded and melted during spring break-up is not very complete. Indeed, we now know much more about sea ice and lake ice than we do about river ice and ice in small glacier streams. In particular, the source of the water which continues to flow all winter should be sought. The extent of sediment transport by anchor ice during the brief fall season needs to be investigated. The extent of supercooling and the mechanisms of nucleation in turbulent water need more detailed study. Also, the thermal regimen in, below, and around arctic and subarctic streams should be investigated. A start on the thermal aspects of the problem is underway as an M.S. thesis. Some of the other points mentioned are being pursued in a study funded by the National Science Foundation.

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REPORTS AND PAPERS RESULTING FROM THIS RESEARCH

Reports on the research at Goldstream Creek have been published in:

A. The Annual Reports of the Geophysical Institute, University of Alaska:

Annual Report of 1963-64, page 55
Annual Report of 1964-65, pages 59-60
Annual Report of 1965-66, pages 59-60
Annual Report of 1966-67, pages 70-71
Annual Report of 1967-68, pages 62-63

B. The Annual Reports of the Institute of Water Resources of the University of Alaska:

Annual Report of 1966, pages 100-117
Annual Report of 1967, pages 19-22A
Annual Report of 1968, pages 13-21

C. Papers have been presented at the Alaskan Science Conference, Alaska Division, Am. Assoc. Adv. Sci.:

Anderson, G., C. Benson, D. Grybeck, and J. Stout. A preliminary study of freezing in turbulent streams of Interior Alaska. Proceedings of the Fifteenth Alaskan Science Conference, August 31 to September 4, 1964. Pub. by Alaska Division, AAAS, p. 95. March 1965.

Kreitner, J. and C. Benson. The freezing cycle in a small turbulent stream. Proceedings of the 20th Alaskan Science Conference, August 24 to 27, 1969. Pub. by Alaska Division, AAAS, p. 332-333. July 1970.

Corbin, S. and C. Benson. The Winter Thermal Regimen of Goldstream Creek, Alaska. Proceedings of the 22nd Alaskan Science Conference, 1971. (in Press).

D. Master of Science Theses:

Kreitner, J. D. (1969). The petrofabrics of aufeis in a turbulent Alaskan stream. M.S. thesis, Department of Geology, University of Alaska, Fairbanks. (Abstract and Table of Contents attached.)

Corbin, S. W. The thermal regime in and near the aufeis of a stream in central Alaska. *In preparation.*

APPENDIX

THE PETROFABRICS OF AUFEIS IN A TURBULENT ALASKAN STREAM

A

THESIS

Presented to the Faculty of the
University of Alaska in Partial Fulfilment
of the Requirements
for the Degree of
MASTER OF SCIENCE

By
Jerry D. Kreitner, B.S.
College, Alaska
May 1969

APPENDIX

THE PETROFABRICS OF AUFEIS IN A TURBULENT ALASKAN STREAM

Jerry D. Kreitner, B.S.

ABSTRACT

The growth, form, and decay of ice in turbulent Goldstream Creek, Alaska, has been observed each year since 1964. Overflows which occur throughout the early part of the winter deposit layers of ice (aufeis) upon the pre-existing ice surface.

Vertical and horizontal thin sections of the stream ice from the years 1965-66, 1966-67, and 1967-68 were examined and photographed under ordinary and polarized light. The c-axes of the crystals were oriented with a Rigsby four-axis stage and plotted on Schmidt equal-area nets. Examination of photographs and stereograms revealed five basic types of ice in Goldstream Creek: (1) clear, massive, original stream ice composed of elongate, tapered crystals in which the c-axes are primarily horizontal and randomly oriented; (2) bubbly overflow ice layers (aufeis) with horizontal c-axes which are sometimes aligned parallel to the stream flow; (3) skim ice layers with vertical and horizontal c-axes crystals; (4) fine-grained equigranular snow ice; and (5) underwater ice masses of slightly coherent, rounded plates with the c-axes normal to the plates and randomly oriented.

During breakup, the melt-water flows on top of the stream ice and slowly erodes the ice layers in the stream by a combination of melting and mechanical fragmentation. The layers are eroded away in descending order from the top to the bottom of the stream.

APPENDIX

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