D. S. Clarke Esqr
with Authors Compts

Ernest Marceau

HENSHAW

ON

FRAZIL ICE.

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BY

GEO. H. HENSHAW,

M. CAN. SOC. C.E.

BY PERMISSION OF THE COUNCIL.

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J. KENNEDY, *Vice-President*, in the Chair.

Paper No. 1.

FRAZIL ICE:

ON ITS NATURE, AND THE PREVENTION OF ITS ACTION IN CAUSING FLOODS.

By GEO. H. HENSHAW, M. CAN. SOC. C. E.

The subject of this paper is one destined to become of increasing interest to Engineers in Northern countries, especially to those engaged in works liable to be affected by ice, whether through direct attack or through floods caused by the arrest of its movements. The author's object is to define the true nature of frazil, and to suggest a method of dealing with it, so as to prevent its more than suspected agency in producing floods.

Whether the vast masses of comminuted ice, which in places are found to underlie the surface ice, are composed of true subaqueously formed ice, or are made up largely of drifted snow and the broken scales of surface ice carried down by the current, is yet to be positively determined; still, from the evidence which exists of enormous quantities of spongy looking ice seen rising from the bottom, it is reasonable to conclude that whatever may be the proportion of these substances, true frazil is, really, their principal constituent.

Now, for an engineer to meet a difficulty with intelligence and success, it is almost essential to understand the actual character of the enemy against which he is to contend. To speculate on this, in the present case, brings us somewhat out of the sphere of the practical engineer and into that of physical science; but we are often compelled to this course when scientific men neglect the subject, or leave us in the dark.

That so little of the nature of frazil is known among engineers is not surprising, when we find that the haziest notions, if any, regarding it, prevail among our highest scientific authorities.

At a meeting of the B.A.A.S., held in Montreal on the 1st September, 1884, in presenting a paper on the subject, the writer was confronted with a casting in type metal, made in a plaster mould, by Mr. W. B. Dawson, of frazil ice, as stated on the label, but which was really a representation of anchor ice.

As explained by the President (Sir William Thompson), frazil was supposed to be the product of currents of water passing over and disintegrating solid anchor ice, exposing, as he expressed it, its "bones," just as rock is worn into irregular forms by the removal of its softer parts. Now, it is difficult to conceive how anyone, practically familiar with the appearance of frazil, could attribute its minute, needle-like fragments to a water-worn origin, or believe that a substance so developed could be produced in large quantities. We do, indeed, in the spring, see ice disintegrated to its bones, and falling to pieces, but that is only when it is exposed to sun and air, and when the formation of frazil is already a thing of the past. This experience convinced me that science had as yet no information to give; and that up to the present, the best authorities regarded frazil merely as a curious formation of rare and limited occurrence.

The author thinks that many are hasty in assuming that all is known about the philosophy of ice formation. Tyndall, when he overthrew the theory of Rumford, did not exhaust the subject. We know that water can be brought above its boiling point without ebullition, and we know that it can be brought below its freezing point without congealing. We know that superheating requires pressure, but how much do we know of the conditions accompanying supercooling?

The author believes that ice never forms in water without an independent nucleus; that when it appears free on the surface the nucleii are supplied by minute particles of vapour, which, becoming frozen in their ascent and falling back upon the water, form, perhaps, the very stars seen in a block of ice when melted through a lens, by the sun's rays.

That frazil, like anchor ice, forms under water seems unquestionable. Mr. Frank Gilbert, engineer, contractor for deepening the channel through the Gallops Rapids, states that he has passed in a boat over great beds of it, covering the bottom in dense masses of a spongy appearance, through which his pole swept with scarcely perceptible impediment. He also observed it upon a wire rope extended beneath the water, between his vessels, looking like bunches of iron filings lifted up by a magnet. In this case he noticed the curious fact that parts of the rope were bare and others covered with the growth, which seemed to negative the idea that the cold had been conducted through the rope. Under the circumstances it is plain that the exposure of the ends of the rope had little or nothing to do with the formation of the ice.

The conclusion come to by the author is, that frazil ice is formed in currents cold enough not only to preserve its crystals but to induce their formation.

But why should it grow luxuriantly on one spot, and yet refuse, as we have seen, to grow upon a closely adjacent spot of a character precisely similar?

Well, that is a question yet to be settled; but with your indulgence an attempt will now be made to offer an explanation.

All who have observed the action of fine drifting snow, when driven by the wind over a plane surface, such as a roof or a railway platform, will have noticed that it does not sweep along in clouds, or rolling volumes, but in long rifts or streaks, with bare spaces between. With every lull of the wind these streaks rest for a moment, to be swept away by succeeding blasts into new combinations of a similar form, according to the variations, in force and direction, of the wind.

Now it is evident that these rifts are produced by the small inequalities of the surface of the plane; that the bare places are where the wind is least obstructed; and that the snowy streaks are the eddies where its force is partially obstructed. Now if this is admitted, we are brought to the important conclusion, that if the obstructions on the plane remain unaltered, and the direction, volume and force of the wind continue unchanged, the streaks of snow with the spaces between will always occupy precisely the same position upon the plane.

If we now apply these observations to the flow of a river, we shall find a close approximation to such supposed conditions. For, taking the case of a stream with a rocky bed, we have the more or less permanent obstructions on the bottom; while, unlike the air, the volume, speed, and direction of the water are but little affected by superficial influences.

The bottom of such a river presents a confused succession of irregular obstructions, around, over and between which the water rushes in every direction possible at once, and at every variety of speed. Along its main channel, greater freedom gives the river current its highest velocity, so raising its volume at the quieter reaches that backward currents or eddies are formed at its edges.

Looking at the troubled tumbled surface such a river sometimes presents, one is tempted to believe it a hopelessly involved chaos of complicated motion; but there is no chaos there. Every movement is made under as strict a law as to which governs the piston of an engine. Every bulge or swirl that we notice at some particular spot comes from the self-same sunken rock or cranny, and each would repeat itself precisely, were it not for molecular variations, which we will not here take account of further than to note that they modify, in a minor way, the results about to be referred to.

Bearing these facts in mind, let us take a horizontal or plane section of the river.

Here we have, in the currents so intersected, instead of the long streaks seen in our snow drift, an irregular network, with meshes of every size and threads of every thickness. The threads represent the currents, and the meshes the comparatively still spaces enclosed. If we wish to present the molecular effects alluded to, they may be shown as a sort of fringe of eddies along the sides of the threads.

As in the case supposed, the general plan and position of the network is permanent, and as we know that water is a bad conductor of heat, it is plain that a sudden cooling of the water up stream would cause the threads of the network to become colder than the enclosed meshes; while the reverse would be the case on the water above becoming warmer, so that objects placed, the one in the mesh and the other in the thread, would be affected differently as to temperature.

Now for the formation of frazil.

The river is cooled down nearly to congelation; there is, we known, a very small margin to go upon at freezing point. The thermometer goes down to zero or below. The river in its efforts to part with its remaining heat steams, but its current is too rapid to freeze over; and so a supercooled current is borne down through the network. It is designated a supercooled current, because the author does not wish to commit himself to the statement that the water itself is below freezing point. Such water is always charged with minute icy particles, which may in themselves be the cause of the refrigeration of the bottom; the water charged with these particles is the current referred to.

The result is obvious; objects that present suitable nuclei in the threads are covered with a growth of frazil, while similar objects in the meshes remain bare. Similarly, on a sudden change to a warmer temperature the masses of frazil are thawed from their frail anchorage, rise, and are carried down by the stream; a phenomenon noticed by many observers. This theory also explains why frazil does not form on sandy or fine gravelly bottoms; for wherever there is any shifting of the obstructions on the bottom, there will also be changes in the threads and meshes, preventing that continuous contract with the cold current which is necessary to the formation of frazil, or so mixing thread and mesh as to bring the whole above the required temperature. To this theory, even if it is not an absolute demonstration, at least belongs the merit of accounting for all known facts in connection with the nature and action of frazil.

Frazil, as we know, appears in the form of a mass of frail particles, with very little cohesive power. It is plain then that in small quantities, or with anything like a free passage, it would pass away harmlessly seaward. It could not under such circumstances become sufficiently dense to stop even its own passage, except in eddies, wedge spaces, or " culs de sac."

Unfortunately in the St. Lawrence there are too many of all these. Every shoal or batture affords such asylums, into which the frazil graduallypacks. Fragments of ice are thrust into the mass affording new crannies for accumulation, until the flow of the stream is confined to the deeper or more direct channels. In their turn these channels will be most choked at their bends, especially where shoals or low lying islands exist on the outer side of the curve of the current and receive its centrifugal impact.

Now when we consider that the volume of a river like the St. Lawrence is not greater in winter than in summer, but rather less, and that at certain points there are floods one year, and none the next, we naturally conclude that the floods are caused by more than usual obstruction below, and not by increased volume. The trouble is, therefore, local, and may be removed without injuriously affecting other parts of the river.

We revert once more to the nature of frazil, in order to clearly point out the difference between it and surface formed ice, when in motion and floating down stream.

Surface ice may be seen in process of formation on the open channel, shooting out its lances from floating nuclei, or, more frequently, projecting itself from the shore ice under the lee of salient points. It forms thin sheets through which the oars of passing boats crash like brittle glass. All along the open channel fragments are broken off by the action of wind and wave, and float down until stopped by some obstacle. In cold weather these are either cemented together on their way or quickly consolidated when they arrive at a barrier, and thus, as a rule, is formed the surface crust over the open channel. Where the water is still or the current sluggish the opening closes smoothly by the extension of the ice from either side.

A channel closed by packing is always more or less rough, and it would be quite possible, by critical examination, to determine the relative force of the current at different places, at the time of its taking, from the degree of roughness in which it was left.

There is no evidence to show that floating ice is carried beneath the fixed ice to any great extent, except in a sttrong current. Even then the tendency to rise in packing seems nearly to balance the downward movement. Huge hummocks are formed in such places, and the obstruction to the river caused by them is due chiefly to broken sheets caught vertically, or at an angle with the surface.

The character and action of frazil are totally different. Rising in masses from the bottom, its buoyancy is so little that it floats to a considerable distance below the surface; while so small is its cohesion that when the mass becomes compacted enough to elevate its upper face above the water, it falls apart and spreads over the surface. It often attaches itself to floating ice or forms a nucleus for a new sheet of ice; and should severe cold sufficiently consolidate the whole, the surface ice would be swept beneath the barrier ice, in the train of the frazil to which it was attached.

The Caughnawaga Indians, who in winter daily transport the mails to and from Lachine, state that frazil or slush ice runs only in the early part of the winter; and that when it ceases to come down, they know that the channel is closed at the upper end of the lake. If this is so, it shows either that the frazil formed below the Cascade Rapids remains fixed to the bottom as anchor ice; or, what is more likely, that being arrested by the friction of the overlying ice, it is thrust aside and jammed between the ice and the bottom, over the battures or shoals. At any rate, it goes to prove that, without an open channel, frazil is not carried down to any great extent from lake St.-Louis. As a factor in Montreal floods, therefore, we need seek it no further up than the foot of the Lachine rapids.

By keeping the channel open from these rapids down to the foot of Montreal Island, it would seem that the frazil would be carried past without serious lodgment; but as there appears as yet no means of effecting this object, our natural recourse must be to so prepare the bottom of the river so as to give as free a passage to the frazil ice as we possibly can.

As will readily be inferred, I am strongly of the opinion that the disastrous spring floods, from which the City of Montreal has suffered, are caused primarily by the choking of the river during winter, by which the area of the waterway is so reduced as to be unable to carry away the increased volume produced by the melting of the snow. Of course this is aggravated by the down flow of ice from the lakes above.

This latter difficulty it has been proposed to prevent by placing ice breakers, or rather ice-arresting piers, in Lake St. Louis, intended to keep the ice back until the barrier below has broken away.

Curiously enough, this contrivance, though one of the oldest known, has of late been received by some with so much enthusiasm, that disputes have arisen as to who had the honour of first suggesting it; not among engineers, however. It has been used in various beneficial ways, chiefly in securing an ice bridge at some dangerous spot. The latest case of the kind, known to the author, was for the purpose of making a road upon which to haul stone and other material for the repair of the Carillon dam; a part of which had been undermined and carried away the previous year. The attempt, which was entirely successful, was made under the direction of Mr. Stark, superintending engineer of the Ottawa River Canals.

No doubt such a plan applied to Lake St. Louis would ameliorate spring floods at Montreal, if we were sure that it would entail no other consequences. But there remains a serious question; whether in so doing, the ice would not pack so heavily above as to flood the upper country, and the water obtain so great a head as to carry piers and everything else before it, and bring a worse disaster upon the city.

From the foregoing considerations it seems reasonable to conclude that the direction of any effective operations for the prevention of floods should be in the following lines:—

1st. Straightening the channels; or, where this cannot be done, enlarging them at their bends, by cutting away the inner sides.

2nd. Clearing away boulders and other elevations, on the shoals outside the bends, wherever the thrust of the stream tends to carry ice and frazil into wedge places and culs de sac, and giving the bottom a downward grade of the stream to give free egress to ice entering from above.

3rd. Removing over the whole area of the part of the river affected, all boulders, ledges and other projections of the bottom. Thorough cutting all sub-channels, as to give them a free discharge at the outlet; and benching such shallow slopes along the shoals as in combination with the surface ice afford the natural traps in which the frazil is caught.

Since writing the above, a recommendation of the Government Commission on Floods has been partially put into effect, namely, an attempt to keep open the river channel between Three Rivers and Sorel, by means of vessels fitted to break up the ice.

While very doubtful of its success as a means of preventing floods at Montreal, the author nevertheless heartily endorses the experiment. In such a difficult question the experience gained in an effort of this kind must greatly help on a solution, and may lead to other discoveries of benefit to the country, which otherwise would remain unknown.

DISCUSSION ON FRAZIL ICE.

Mr. Herschel Mr. C. Herschel stated that the New England equivalent for "Frazil" is "Anchor ice." Anchor ice is formed in the New England rivers only at times when there is no covering of solid ice upon them, and, generally, only for the 12 to 24 hours just preceding the formation of such a covering of solid ice. For instance:—in the winter of 1885–6, the ice formed in, and went out of, the Connecticut River 4 times, giving 4 days of anchor ice, where there is usually but one. Its most distinguishing characteristics are: its low specific gravity, being nearly the same as that of water, and its adhesiveness to any protruding object in its path, as well as of the different particles, among hemselves. For instance:—some years ago it accumulated on the inlet pipe of the Detroit Water Works, in the Detroit River, which is laid in a considerable depth of water, until it threatened to or actually did shut off all supply to the city. He has seen it gather on the crest of the Holyoke Dam, and accumulate in bunches, aided, perhaps, by one or two flashboard pins, or other irregularities, until it would stop the flow of water over that part of the dam; this flow being at the time, in other parts, over a foot in depth. Mr. Herschel knows of no remedy for it, short of that which nature supplies, when she forms the covering of solid ice. Judging from the facts stated in the paper, the Caughnawaga Indians are entirely correct in their statement that frazil runs only in the early part of the winter, and its cessation to run is a sign that the channel is closed above. Where the situation is such that the channel cannot close, by reason of rapids, for example, frazil may continue to form all winter. In such cases, and if it did continue to form, the depth and regularity of the channel below would constitute the only available mitigation of the evils to be expected from such frazil.

Mr. Ranney Mr. Ranney has never observed the formation of frazil in still water or smooth current. It is formed in rapids where the water is broken up and intermixed with air. From the foot of Crow Bay to the commencement of the Rapids (Middle Falls on the Trent), a distance of about 1000 ft., there is a current with a smooth surface. At 0° F. prisms of ice begin to form about 200 ft. down stream from the surface ice. The anchor ice begins to form as soon as the rapid commences, but does not adhere to the bed of the river until it has travelled 500 or 600 ft. down the rapid, where it commences so to settle on the bed of the river and to adhere to everything with which it comes in contact. Mr. Ranney built a mill on the Falls about 2,000-ft. below the outlet of the Bay, and formed the head of water by means of a ring dam which was filled with anchor ice, upset and forced sideways into the stream a distanceof 100-ft. He has never observed anchor ice in any stream having abrupt falls, with a smooth current above and below, shewing that it requires a broken surface and cold air to form frazil. Frazil has sometimes formed an island on the very verge of Ranney Falls, with the current running at 10 miles an hour, and has remained there until the weather has moderated, while on the smooth floor of the Ranney slide it has made 2 ft. to 3 ft. in the throat with a decline of 1 in 20. On one occasion a chain cable was broken by a run of anchor ice which formed around the chain as thick as a barrel. Mr. Ranney has made bridges where the current was so strong as to prevent formation of surface ice, by placing obstructions to collect the frazil, and watering the surface. Anchor ice very soon dissolves where it is not covered with surface ice at about 20 ° F. He approved of Mr. Henshaw's suggestion to anchor the ice in Lake St. Louis until the river below is clear. Mill owners have to keep open channels through their ponds to the mills. He doubted whether any advantage would be derived from the straightening or smoothing of the sides or bed of the river, as anchor ice will adhere to a smooth flat-rock or slide-floor.

Dr. R. Bell considers the action described in Mr. Henshaw's paper to be secondary, and that the real origin of frazil is due to terrestrial radiation, aided by the action of the chilled water in carrying down particles of ice from the surface. Dr. T. Sterry Hunt, Prof. Carpmael, and other meteorologists concur in this latter view. He suggests the advisabilty of subjecting specimens of every variety of ground ice to careful and minute examination, so that the forms and arrangements of the component crystals may be ascertained, and thus shew whether there is such a substance as anchor ice differing essentially in origin and structure from frazil. Mr. Gilbert's observations at the Gallops Rapids strengthened the radiation theory, and the fact that the frazil formed on some parts of the rope and not on others is probably due to differences of conductivity in the bottom immediately below the rope, or to the fact that there were objects obstructing radiation above the rope. That frazil ceases to run when the channel at the upper end of Lake St. Louis is closed, as observed by the Caughnawaga Indians, is another confirmation of the radiation theory, as water must be open to the sky in order that frazil may form, and the process of formation ceases when the surface is covered with ice. The rise of frazil to the surface, and its floating down stream in large quantities, when there is a sudden change of weather, does not indicate that it has been thawed, but that the stony bottom has lost its holding power on account of the check to radiation. Dr. Bell.

Mr. Hannaford. Mr. Hannaford's experience has led him to the conclusion that frazil ice is to be found at the foot of rapid currents and in broken and shallow water, rather than in currents of greater depth. For example, frazil ice is practically unknown in the Niagara River at the International Bridge, where its width from shore to shore is 1,800-ft., its depth 46-ft., while the current runs from 5 to 8 miles per hour. At Montreal, on the other hand, the St. Lawrence is six times wider than the Niagara River at Fort Erie, its greatest summer depth at the Victoria Bridge being only 23-ft., while the flow of water at ordinary summer level is about 2,100,000 gallons per sec., as against 1,535,000 gallons in the Niagara River at Fort Erie. This great width and consequent shallowness tends to the blockage of the St. Lawrence above Montreal. The ship channel below Montreal along St. Helen's Island, where there is a width of 1,800-ft., a depth 60-ft., and a swift current, would act as a free carrier of frazil and ice, did it not back up from below by reason of the frazil and ice grounding on the flats below the city, where the river again widens. There are two periods of high water at Montreal, the first between the middle of December and the middle of January, the second in April. If the statement is true, that frazil forms an important factor in the early winter rise, then, in Mr. Hannaford's opinion, the spring rise is clearly attributable to the ice brought down from Laprairie basin and the Upper Lakes, which chokes or gorges the channels below the city, causing the water to back up. His remedy to prevent the floods at Montreal would be to raise the buildings, yards and streets in the lowest parts of the city above the highest known or recorded level of the River.

Mr. Gzowski. Mr. Gzowski considers that the jams and flooding caused by frazil ice might be remedied by giving the streams freer passage, removing obstructions, straightening and deepening the channel.

Mr. Brush. Mr. Brush dissents from the theory that frazil plays much part in obstructing the flow of the river St. Lawrence. His observations have shewn that the frazil forms in greatest quantities in the rapids during the months of January and February when the water-level is steadily *falling*. The fact that there has never been a spring flood, except when the lake ice has been prematurely broken up, and has come down in large masses while the ice bridge opposite the city has remained strong enough to resist its passage, seems a conclusive proof, 1st, that however mischievous frazil may be in choking up pipes and aqueducts or the channels of small and sluggish streams, it forms no obstacle to the flow of the St. Lawrence; and, 2nd, that it is the strong surface ice which, brought down in large quantities by a strong current, and resisted by an impassable ice barrier, is carried underneath, packs the shoals, and naturally so obstructs points of the river that there is no passage for the volume of the water. To obviate these evils, either the moving of the ice must be prevented or its passage facilitated.

Mr. Lesage stated that the water supply of the city of Montreal was brought by an open aqueduct from a point in the river St. Lawrence above the Lachine rapids, where the river in winter is always open for a distance of seven miles to Lake St. Louis, and where immense masses of anchor ice are being daily manufactured at the bottom of the river. These masses becoming detached from the bottom are carried down stream and propelled by a S. W. wind, a large portion finds its way into the aqueduct. Various means have been undertaken with more or less success to prevent blockage. A channel was made in the border ice opposite the entrance to the aqueduct by means of gunpowder, with the effect of dislodging those spongy masses of frazil which could not be moved with a pole or other implement. Next a pier about 40-ft. in length was thrown out at right angles to the river shore a little above the entrance, with the object of diverting the current and frazil, but without success. Indeed it seemed to cause an eddy, producing precisely the contrary effect to that anticipated. In the following year a similar pier was built below the entrance, but without any appreciable effect, and the subsequent extension of this pier towards the first, until a water-way only 20-ft. wide was left, made matters still worse, and the piers had to be removed. Mr. Lesage suggested that a new aqueduct should be cut with an entrance 4,000-ft. higher up the river. Subsequently the entrance to the aqueduct was moved up to a deep bay called the Inland cut. A large basin was formed by part embankment and part crib work, which allowed the surface ice to be formed over an area of about 10 acres, and from this place the water-supply is now drawn without any further trouble from anchor ice. This seems another proof that frazil cannot form under surface ice. The entrance to the basin is about 1,500-ft. wide, and the frazil forming on the edge of the ice in the river offers no appreciable obstruction. Every winter he has observed large masses of anchor ice attached to the bed of the river, to boulders and in all places where there were eddies. The anchor ice assuming a fungus shape, gradually grows upwards. A rise of a few degrees in the temperature will cause the whole mass to break away from its anchorage, often carrying with it a boulder or any substance to which it is attached. Sometimes the river is nearly covered with these floating masses, plainly showing that they had formed in the open water of the river. The formation was most marked on cold bright days, and the frazil rose to the surface on a cloudy day with a slight rise of temperature. Experiment has shewn that the temperature of the river water at the aqueduct mouth is generally 32° F., and some

Mr. Lesage.

times 31 ° F., down to a depth of 20-ft., while the temperature of the atmosphere is several degrees below zero. Every year, when ice first covers the aqueduct, frazil forms in the settling basin and is carried into the wheels, which have to be stopped a few hours until the ice has covered the settling basin.

Mr. Poole. Mr. Poole stated that at the Acadia Colliery, Nova Scotia, the boilers are supplied with water from an artificial pond, and the feed pipe passes through an embankment at a depth of 5 feet below the surface of the water. The pipe has a movable elbow in the pond, so arranged that its inlet may be turned up at any time to the surface for examination. The open end of the pipe has attached to it a barrel from which the head has been removed. In place of the head there is a partition of coarse wire netting $\frac{3}{4}$ in. mesh, filled with sponge to filter the water going to the boilers. On the morning of the 26th November last the supply of water diminished, and the end of the pipe was turned up and examined. It was found that the netting was coated over with coarse crystals of ice and the sponges solid lumps. The pond was open the day before, but the night was clear and very cold, a high wind blowing, which died away towards morning and allowed ice to form on the surface. The flow of water through the pipe was not large, occasionally only at a rate of some 30 gallons per minute; but as the crystals of ice were uniformly distributed over the netting, and had every appearance of growing in situ, the possibility that they formed on the surface of the water and were drawn down by the current is very remote; and when it is remembered that the sponges were also frozen the evidence is almost conclusive to the contrary.

Mr. Murdoch. Mr. Murdoch has always seen anchor ice in the bottoms of shallow rapid rivers with rocky beds, and never in clay bottoms. Frazil, which he considers the same as anchor ice, will float under the surface of running water. He states that he has found the water under the ice in Thunder Bay to be considerably below 32 ° F. At the mouth of the Saskatchewan, where the bottom is a limestone, and the banks for two miles below the rapids are 20-ft. high, it freezes from the bottom upwards until the ice reaches the level of the banks, and the river overflows. Mr. McAdams, from fourteen years' experience at the Carillon rapids, states that frazil does not adhere to surface ice formed previous to the accumulation of the frazil underneath.

Mr. Rheaume. Mr. Rheaume stated that in many of the bays of the St. Lawrence river frazil attained a depth of 12 to 14 feet. That the cause of the Morrisburg flood was the swinging of an ice bridge between Croil's island and the shore. He had no doubt that Mr. Henshaw's suggestion for the prevention of floods would prove effective, if carried out, but doubted its practicability on account of the magnitude of the work involved.

Mr. Wicksteed discussed the causes of the floods at Montreal, and in considering the proposals brought forward in the paper for their amelioration, feared they would involve enormous cost of maintenance. He considered that the jamming of the ice was due more to the general contraction of the water-way than to individual obstruction, and desired to point out the applicability of Captain Eads's remedies for the obstruction in the Mississippi, to the case of the St. Lawrence. **Mr. Wicksteed.**

Mr. Steckel, remarking on the origin of the word frazil, considered it to be a purely French-Canadian expression for "slush ice," and stated that frazil was also the French for forge cinders. He pointed out the propriety of adopting some term which would have but one meaning and be common to both French and English, and suggested the word "Frasis." **Mr. Steckel.**

The discussions seem to point almost entirely to frazil formed on the bottom or anchor ice, as distinguished from any other form of ice, as the chief obstruction in the river channels. Probably, however, only a minor part of the frazil blocking channels has at any time been attached to the bottom. Anchor ice is not supposed to form in deep water, hence its formation is probably restricted to shoals and to a comparatively narrow border along each shore, varying, of course, with the general depth of the river at the locality. On the other hand, ice in thin sheets is forming over a large proportion of the whole area of open water, while the thermometer is below 32° F. This thin ice, varying from the thickness of paper to perhaps an inch thick, is carried downward and broken up in rapids, or is ground against the bordage ice, and the ice under which it is drawn. This process reduces the thicker surface-formed ice to fragments, and the thin films to snow-like masses, which are probably often mistaken for frazil that has been attached to the bottom; but on close examination they will be found quite different. If it is borne in mind that according to the generally accepted theory frazil proper forms only at very low temperatures, and under comparatively restricted circumstances, while a surface film is forming daily, hourly, every minute, when the temperature is a few degrees below the freezing point, and is being carried onward constantly by a current of from one to two miles per hour, thereby allowing film after film to form in succession for weeks and months, it must seem that a very large proportion of the obstructions found in river channels must be attributed to ice formed on the surface as described. **Mr. Sproule.**

Mr. Harris stated his own experience went to confirm Mr. Henshaw's opinion as to the origin and means of accumulation of this ice. It might **Mr. Harris.**

be mentioned that the railway bridge across the Gatineau river close to Ottawa was built in 1877-78, with stone piers founded on piles driven into a blue clay river bed. During the winter of 1878 it was found that although no great reduction of the water-way had been caused by the piers, yet a very rapid shove was taking place over the bed of the river adjacent to several of the piers. It had gone to the extent of removing some 5 feet in depth of the clay before it was discovered and choked by riprap. The shove undoubtedly occurred by reason of the accumulation of frazil ice clinging to the under side of the surface ice, and causing a great reduction of avaliable water-way adjacent to the piers, thereby increasing the velocity of current. Probably the stationary surfaces offered by the piers caused this accumulation to form at the time referred to.

Mr. Keefer. Anchor ice, called by the French-Canadian "habitants" "frasil," and by our English-speaking river men "frozee," is so designated because it has been found "anchored" upon the bottom in open running water during extreme cold weather. When so found, it is a coarse, granulated ice of nearly uniform texture; but when it leaves the bottom, and is carried under the fixed ice of the river surface, to the underside of which it becomes attached by frost, it is found more or less mixed with fragments of thin plate ice, as well as with saturated snow and "slush" ice of a similar granulated texture, which it has picked up in its descent, and also with earthy material which it has torn up when rising from the bed of the river. It never forms upon the bottom or in the water when covered with surface ice. The name "anchor ice" is evidence of its being found at the bottom, while all other ice is at the surface, although it does not remain at the bottom as other ice does on the surface; but there is still much difference of opinion as to its origin, and even as to its formation at the bottom, among those who have not seen it there, yet know that all ice is lighter than water, and who also know that it is not *always found* at the bottom when there is ice at the surface. There are, however, persons who insist that ice is not under all conditions lighter than water, that it sometimes sinks, and that solid surface ice has been found under water. This last statement is true only when such ice has been frozen to the bottom, and is overflowed and held down by the current. Anchor ice will form on the bottom in shallow streams whenever there are about 15° of frost, or more; but in deep water it is not found until there are 40 or 50 degrees of frost. The depth at which it will form in the most severe weather has not been determined, on account of the difficulties and danger connected with the exploration. There is, however, little doubt that in the latitude of Montreal, this extends to at least forty feet, and the depth of water in which it is found is in direct proportion to the descent of the mercury and the duration of that descent. The depth or thickness of its formation on the bottom depends on the duration of the cold which, if sufficiently prolonged, would cause such a bottom growth as to raise the river out of its bed, and cause it to overflow its banks. In November Mr. Keefer has forded a shallow stream flowing rapidly over a stony bottom, having less than a foot of water, and on his return, three days afterwards, has found it impassable from anchor ice—a thin sheet of very cold water flowing over a mass of porous ice, filling the stream to the top of its banks. There is an abundant formation of " slush " ice on the surface in the main channel, at the setting in of winter, when the current or wind prevents the formation of sheet ice, which collects in masses by mutual attraction or cohesion of the spicules, the appearance of which is similar to that which is found as anchor ice at the bottom. If this be the raw material from which the growth of anchor ice is made at the bottom, the fact still remains that this ice is most abundant on the surface when there is no anchor ice at the bottom; on the other hand the growth of anchor ice at the bottom is most rapid, when and where there is no visible ice of any kind floating upon the surface. He has crossed the St. Lawrence in a canoe opposite Montreal when the thermometer was much below zero, and where there was no floating ice; but the water, instead of being transparent as usual, was lead colored, thick and " sandy, " with ice, invisible from the surface, flowing apparently with difficulty, as does the Missouri when loaded with sand; spicules of ice, about the size of darning needles, attached themselves to the paddle by their points, and when it was withdrawn from the water stood out at right angles to the wood—like iron filings on a magnet. In this condition of the river, the water, no doubt at the deepest point, is loaded with ice spicules to the bottom, densely and uniformly distributed throughout the whole mass, and would supply the raw material for the formation of anchor ice at the bottom whenever the latter was prepared to receive it. That it is not at all times so prepared, is evident from the fact that anchor ice is not always found when ice spicules are abundant in the water. If anchor ice is derived from ready-made ice in the water above it, the only explanation, in Mr. Keefer's opinion, is that the bottom must first become frozen before its formation can begin. Whether it be formed from the water or from ice in the water, the condition precedent is a frozen bottom. Ice will attach itself to ice or to other frozen bodies, but not to the unfrozen bed of a river. The magnetism of frost seems necessary to attract the minute particles; and when once a covering is formed a rapid congelation may take place, which will continue as long as the frozen bottom overcomes the lighter specific gravity of ice and holds the mass down. The supposition of a frozen bottom would also explain the rising of the anchor ice. When the air and the water are above the freezing point, anchor ice leaves the bottom. This generally occurs at an air temperature of about 40 ° F., when the water is near its maximum density, and when its colder surface current has resumed its position at the bottom, so far as these conditions do prevail in rapidly flowing water. If the rising of anchor ice were assisted by the increased density of the water which accompanies its departure from the bottom, its tendency to let go would be retarded by the now colder water in contact with it; but it is not probable that either of these conditions has any influence upon its rising or remaining. It is the change in temperature of the water, and not in its position or density, which releases the hold of the bottom on the ice, and this not by the contact of the now warmer water with the frozen bottom,—for the two are separated by a mass of ice—but by return of internal heat, in other words by the diminution or cessation of radiation from a warmer surface to a colder one, from earth to water. When the air temperature is much below zero, that of the running water is below freezing, and prevented from freezing only by its motion. The rapid abstraction of heat from the bottom by such a cold current, if intense and long enough continued, would freeze the bottom, and thus prepare the foundation for anchor ice; and whether this ice is derived in whole or in part from the disseminated spicules in the water, or is a new creation from the water, the radiation, which is an important factor in the formation of ice, is, in his opinion, the chief cause both in supplying the material and in anchoring it at the bottom, that is radiation as well as convection from the water to the colder air, and radiation from the earth bottom of the river to the colder water above it, if not also through it to the still colder air above both. As the water in a rapidly flowing river descends from the surface to the bottom, and rises from the bottom to the surface, the ice spicules must be carried down to the bottom when the thermometer is above zero, as well as when it is below it; but in the first case they do not remain there as anchored ice; and in the other case they must do so, unless anchored ice is formed out of the water at the bottom during very low temperatures. Whether anchored ice, therefore, is of surface origin depends on whether any kind of ice can be formed except in contact with the atmosphere. Doubtless some air is carried down with the current, and some may be disengaged in the process of freezing. Mr. Keefer has stirred anchor ice in twelve feet of water where it was two feet in thickness on the bottom, and bubbles (either of air or gas) came to the surface.

This form of ice is a great enemy to water-power taken from portions of the river uncovered by ice. Even in canals it forms before the surface is frozen over to an extent sufficient to clog gateways, but disappears as soon as the surface is covered by ice. A covering of ice, or any artificial covering, is sufficient to stop its formation, by preventing both convection and radiation. As it does not form under the arches of a bridge, while it may be found immediately above and below it, and as an overcast sky has been known to cause it to leave the bottom of a stream, the presumption is that radiation has more to do with its formation than convection. It has also proved an embarrassing obstruction to engineers in sinking crib work through the ice, whenever it has been deposited there from the open water above. It cannot be displaced by pressure, but must be entirely taken out or floated away. Intelligent and reliable mill-owners assert that this troublesome ice is never found in their millraces—no matter how cold the weather is, whenever the sun is shining, or whenever there is a cloudy sky at night.

In conclusion,—anchor ice, which in certain rivers or portions of rivers, is by far the most abundant formation of ice there, is not an unmixed evil—on the contrary, it is a great benefactor. All the sections of our rivers which are open water in winter are factories of anchor ice, the formation of which liberates enormous quantities of heat to temper the severity of our climate. After the slack water portions of our rivers and our lakes are covered with ice and snow, and all other sources of terrestrial heat either by radiation or convection are cut off, abundant stores of water are poured forth from the lakes into the rapid sections of the rivers, and by their conversion into ice liberate the heat they have retained in greater or less quantities, and always in the greater quantity when most needed. Mr. E. Lewis, jun., in his "Physics of Ice," says :

"To melt a pound of ice requires 142 units of heat, that is an amount which would raise a pound of water, 142 F. This is the equivalent of the molecular force exerted in solidifying the water, and the mechanical value of the two forces is the same. Expressed in figures it is the equivalent in mechanical force of the work done in lifting the same pound of ice 110,000 feet high. The melting of 20 lbs. of ice is equivalent in mechanical force to lifting 1,000 tons, nearly, to a height of one foot; or lifting two persons, weighing 300 lbs., 1,000 feet higher than Mount Washington."

The great rivers of Canada, the St. Lawrence and the Ottawa, with the large majority of their tributaries, are terrace-like in their profile, and studded with numerous lakes, as contrasted with the almost uniform slopes of the Mississippi, Missouri and Ohio, in the southern and greater portion of their length. At the outlets of all our lakes, great and small, there are rapids with water open to a greater or less extent in winter. The amount of latent heat given out in the formation of anchor ice at all these numberless "breathing holes" must give a powerful check to the duration of that same temperature under which this peculiar form of ice is so abundantly developed, especially when we remember that the colder the weather the greater the disengagement of heat, being in this respect similar to the steam blast in the Locomotive, "the harder she blows the faster she goes."

Sir William Dawson.

Sir Wm. Dawson, being called on by the President, remarked that he did not profess to know much of those practical questions which depended on the so-called *Frazil*, a term which as applied to ice did not seem to be always used in the same sense. The best term for the form of ice referred to is that of "Spicular ice," which has been used by geologists in discussing this question. Such ice consists of thin blades or needles of a crystalline character, which may either form in a separate or detached manner in water which is cooled below the freezing point, and which is agitated by the wind or by a rapid current so that the ice cannot become compact; or it may grow in the bottom in the manner in which crystalline needles form in some saturated saline solutions. In the first form the spicular ice constitutes what fishermen and boatman on the coast call "lolly," which floats in the water and is perfectly soft and mobile. In the second case it constitutes sheets, masses or shrub like aggregates of crystal attached to hard bodies in the bottom of the water. It is then called "ground ice" or anchor ice." This ground ice when it attains to certain dimensions, or when the temperature rises, may float up, sometimes carrying with it bodies to which it may be attached, and then, of course, it drifts in the same manner with lolly. Ground ice does not usually form under a covering of sheet ice; but, from the sections submitted by Mr. Kennedy, it would seem that in very cold weather spicular masses run down from the lower side of the ice in places, just as they do from the under side of the surface sheet of water in a dish of water when freezing, and these spicular growths may detain and accumulate the floating lolly drifting under the ice. With respect to the formation of ground ice proper, the principle is exactly the same as in the case of crystals forming around any hard body in a saturated saline solution. The water has first to be cooled to the point of crystallization, and when in this state it comes into contact with any hard substance, cooled by radiation or otherwise to the same or a lower temperature, it will crystallize on or around that substance, and shoot upward in needles, until broken off by violence, or until it becomes too buoyant to be any longer held down in the bottom.

The fact that it forms most readily in open water without any covering of ice, and in clear cold weather, indicates that radiation from the bottom has an important influence in its formation; but where the water is sufficiently cold it may crystallize on any nucleus presented to it; and more especially, it would seem, on metallic bodies and stones which are good conductors of heat. Hind states that on the coast of Newfoundland anchor ice forms in large masses in the sea, at depths of sixty and seventy feet, and it has been known to raise stones and anchors from the bottom, and to freeze around fish caught in nets. He also states that when the salt water has been cooled below the freezing point, the fresh water of streams pouring into it from the land is at once converted into lolly or floating frazil. In this last action there is something analogous to what takes place when water at about the temperature of 32° is tossed about in a rapid, and mixed with air at a still lower temperature, perhaps below zero. These are merely desultory observations from the point of view of a geologist; but they may serve to show that there are different kinds of spicular ice, and that they may be formed in various ways. It seems certain that several of these modes of formation are concerned in the production of the spicular ice so troublesome in our river, so that it is not prudent to limit ourselves merely to one theory of formation, any farther than the general principle that they all depend on the somewhat rapid crystallization of water, under circumstances in which it tends to form groups of spicular crystals rather than solid sheets.

Mr. Tate remarked that whenever the water at a temperature of 32° F., or less, was passing over the river bed at a higher temperature, a formation of ice might occur after the manner of hoar frost possessing great cohesiveness and tenacity, until disturbed by a higher temperature or other forces. A thickness of 2 or 3 ft., as observed by Mr. Peterson, might be thus formed, and might then be detached by the weight and possibly by fluctuations of temperature. **Mr. Tate.**

Mr. W. Bell Dawson remarked that there was one point of difference between the conditions in still water and running water that had not been sufficiently emphasized. As water attains its maximum density at 39° Fahr., the coldest water remains at the surface after reaching that temperature if the water is calm, and the ice naturally forms there. But in rapidly running water the current mixes the different parts together, and the whole volume may fall to 32° or even a little below, and it may then crystallize on the bottom or sides, or on any object in the stream. The crystals so forming would most of them be detached by the current and swept on with it, so adding to the amount of frazil in the water. With regard to the word itself, the term "fraisil" or "frasil" is correct French and means coal-dross or cinders. It has probably become applied to the kind of ice it denotes, much on the same principle as "poudrer" is used for the drifting of snow, a word which originally referred to dust. **Mr. Dawson.**

Mr. Guerin. Mr. T. Guerin, after remarking upon the point of maximum density of water, stated his opinion that frazil consists of particles which must have been frozen separately ; that this might be effected, the water must have been divided into separate and distinct particles at the time of freezing, which could only occur in a rapid or series of falls, where the water is violently agitated and converted into foam and spray, of which the minute watery particles are frozen, and form the frazil under discussion. He does not believe that frazil is always formed at the bottom. The lifting and displacing of anchors, and other substances, are caused by ice, which, from shoving and piling, has become so thick as to reach the bottom, and has afterwards risen with the rise of the water level, carrying the anchor, etc., with it. He does not think that the rise of frazil masses to the surface is not affected by a change of temperature. He finds it difficult to believe that the frazil was found lying at the bottom of the C.P.Ry. bridge at Lachine, especially when it has been shown that a current of 10 miles an hour, such as that in the place in question, can move loose rocks or boulders 6 feet in diameter. He has never found frazil at the bottom of lakes and rivers in any place in which it did not also reach to the surface.

Mr. Peterson. With reference to what Mr. Guerin had stated as to frazil only forming below rapids, Mr. Peterson remarked that during the winter of 1881-82, when engaged upon the survey of the river where the present St. Lawrence Bridge is located, above the Lachine rapids, and below a long reach of slack water (Lake St. Louis), he found, when taking soundings in depths of water, varying from five feet to forty feet, that the bottom of the river was frequently covered over its entire area, with frazil from two to three feet in thickness ; when the sounding rod was let down upon it, the frazil was of such a consistency as to sustain the rod, which could be forced through it by a couple of strong men without much difficulty. This frazil formed during a period of intense cold, when the thermometer was below zero, the frazil would rise from the bottom, and on a mild day it could be seen jumping up above the surface of the water all over the open portion of the river, which here extends over a distance of from four to five miles. This formation of frazil and its subsequent rise to the surface occurred during the entire winter whenever a period of intense cold was followed by mild weather.

Mr. Walbank. Mr. W. McLea Walbank was of the opinion that the Indians referred to by Mr. Henshaw did not properly understand what was meant by frazil. He spoke from experience, having crossed the river at the points in question twice daily for the past five winters, and stated that frazil formed in the Lake at both sides, and in fact almost all over the river between Lachine and Caughnawaga during the whole winter, and could be seen on the bottom on a clear day at the end of the new pier of the Lachine Canal. It always came up to the surface on cloudy days, turned upside down, and floated down stream. He also stated that it was generally known that the ice bridge had formed at Pointe Claire when the sheet ice and slush stopped coming down. Mr. Walbank did not agree with Mr. Guerin that frazil was formed from spray and foam caused by rapids, as he had often seen it form where the bottom was rough and the current strong, but no spray or foam existed.

The temperature of the river bed cannot well be less than 32° in the case of large rivers, and is very probably higher, as it would be kept up by heat from below. The fact that large stones and masses of earth become detached from the bottom, by the floating power of anchor ice, proves that the ground below the bed of any large river is not frozen solid. How then could a stone, whose upper surface is at, or almost at 32°, and whose lower surface is at a somewhat higher temperature, radiate cold into a body of water from which it is itself receiving cold? Is it not much more likely that such stones are only kept cold enough for ice to adhere to them, the cold in the atmosphere above the water being transmitted through the water, a theory borne out by the fact that when the air gets warmer the frazil begins to rise from below? Is it not probable that anchor ice and frazil both have the same origin, their formation being finally completed under different conditions? It has been stated that frazil did not form under ice, it is also well known that a body of ice thickens from below so that the water under such ice must be cooled enough to freeze; and, further, it is well known that quite a considerable quantity of air mixes with the water of a river while flowing, enough to purify the water by oxidation. Now, the air cannot mix with the water when it is covered with ice, and may not that be the reason why frazil does not form under ice, and that a greater part of the frazil is formed by particles of very cold air mixing with water? This being the case especially below rapids, where more air would be mixed with the water. Frazil formed in this way, being very cold, might well be almost as dense as the surrounding water (for ice contracts on cooling), and would, therefore, be easily carried to the bottom, and would crystallize most readily round any substance with a cold and rather rough surface. If forming in large quantities, and so partially able to protect itself, and not subject to too strong a current or too great pressure, what is known as a mass of frazil would be formed; but if forming in small quantities, and subject to great pressure or a strong current, the frazil will be consolidated into anchor ice. In the case of the suction-pipe referred to by Mr. J. Kennedy, the failure to prevent the Mr. Irwin.

formation of anchor ice may have been due to the fact that the covering did not extend over a sufficiently wide area. Particles of ice formed in the water would be carried by the suction of the pipe towards its mouth, adhering to the stones which would be kept cool by the stream of cold water, and made to consolidate by the strength of the current. Such a formation would take place slowly, but a small deposit of ice per hour would soon choke up a large pipe; how stones around such a pipe, receiving their cold from the water, could yet give up to the water enough cold to deprive it of its latent heat of liquidation, seems difficult to understand.

Mr. Francis.

Mr. J. B. Francis saw no reason to change the views expressed by him on the subject of anchor ice (or frazil) in an address before the convention of the American Society of Civil Engineers, held in Montreal in the year 1881, and published in the transactions of that Society.

Mr. Kennedy.

Mr. J. Kennedy said he held views as to the formation and accumulation of anchor ice, similar to those set forth by Mr. J. B. Francis. He supported these views at some length, and by way of illustration and proof cited numerous facts which had come under his own observation, and had been gathered from reliable sources. Plans and sections, showing large accumulations of anchor ice in the St. Lawrence at Montreal, were exhibited.

Mr. Henshaw.

In replying to the remarks made by those who have taken part in a very full discussion of my paper, it is a matter of regret that a generally recognized terminology regarding this kind of ice formation does not exist. The American and some of the Canadian critics state that what is termed frazil in the paper is known by them as anchor ice.

Now, the word frazil is, in Canada, commonly used to designate slush ice of every description, but for want of a better word, especially refers in the paper to that kind of ice, seen in a sort of efflorescence, clinging to the bottom of streams. Its origin is the same as that of anchor ice, but it detaches more readily and frequently. Anchor ice is formed when the current is too swift to allow efflorescence, and may be likened to an accumulation of roots when branches and foliage have been swept away. The objection to regelation is that it is purely a theory without a single fact to support it, except the still-water experiments of Faraday and Forbes. It seems incredible to suppose that the loosely combined masses that are seen floating can ever have been able to attach themselves to the bottom of flowing streams, even if it is assumed that the nuclei have by some means reached the necessary temperature, and still more so that particles from the surface should arrange themselves in forms suggestive of luxuriant vegetable growth.

Objections were made by some members to the description of subcurrents, apparently with the idea that it was original. It was, of course, only stated as an incontrovertible fact, in order to show the manner in which the river bottom could become refrigerated. To prove that these currents do and must exist, and that in unchanging river bottoms they must be permanent, it is only necessary to invoke the law of persistence of force, which lies at the base of all physical science. A current then highly charged with ice particles, formed under a very low temperature, must have a strongly refrigerating effect, and this has only to be demonstrated in order to account for a natural growth of ice below the surface or on the bottom.

Interchanging currents in running streams are mainly offshoots from the subcurrents and the consequent reflex action; their strongest action is from below, and their intensity is proportioned to the obstructions met by the subcurrents. When there is no subcurrent there is no formation either of frazil or anchor ice. In lakes or ponds the interchange is due to waves or ripples, and the weak action of such currents would not permit the formation of ice at any considerable depth, unless aided by artificial currents, such as those produced by the supply pipes of waterworks, where, according to Mr. Herschell, Mr. Poole, and others, the ice has formed in large quantities. The theory of radiation is attended with as great difficulty as that of regelation, for while there is no trouble in accounting for hoar frost by radiation through the air, the denser medium supplied by water would render it very doubtful in the case of frazil, even if the still more important difficulty of a surface more or less ruffled or uneven were thrown aside.

31st March, 1887.

Mr. JOHN KENNEDY, M. Can. Soc. C.E., Vice-President, in the Chair.

The discussion upon Mr. G. H. Henshaw's paper on Frazil ice occupied the evening.