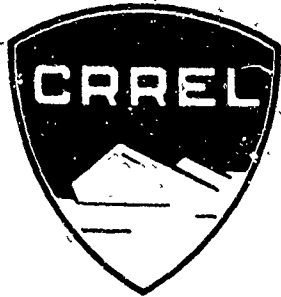


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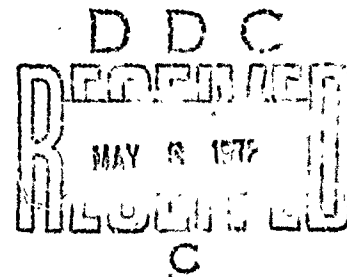
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THE MECHANICAL EFFECTS OF LAKE ICE

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On the Mechanical Effects of Water-ice

Whereas the significance of snow-ice as an automatically effective agent is well known; almost no attention has been paid so far to the automatic actions of water-ice. They are far less important but nevertheless of some geological significance. In the following I will give the fragmentary results of only occasional observations stretched out over a period of five years. Other assignments have thus far prevented me from pursuing this problem, which has interested me for a long time, with scientific exactness. As this will also be so in the near future I would like to submit the following to the scrutiny of more qualified persons.

1. Folding of the Ice

Everyone is familiar with cracks, the so-called "Hartborsten", which, in a length of up to some hundred meters, run through the ice of our lakes in all directions every winter.

In addition to these cracks other peculiar transformations occur in the ice of the Havel Lakes near Potsdam during the winter. Because of the danger they hold they are feared by skaters and fishermen, the latter who call them "Bubbeln" (bubbles). After having reached a certain thickness the ice rises in the form of a long fold along the shore or across the lakes, spasmodically shaking the whole surface in the process. The fold sometimes reaches a length of 500 meters, the profile of which closely resembles that of a mountain fold. This all happens in a time span of a few days or even just hours. It is not rare to see folds of more than one meter height. Due to

a certain plasticity, the ice often does not break apart during the process of vaulting and only radial cracks run parallel to the fold which are again reinforced through regelation. In other cases the ridge of the fold collapses during its formation and only the ruins of its wings remain. In still other cases the fold lies on its side. Its breaking up causes an overthrust in which the lying wing often makes way for the upward-pushing, hanging wing by moving downward to beneath the water surface. The upward-pushing wing is almost always part of the larger of the two ice sheets which have been separated by the folding process. It is from this sheet that the thrust power comes. During the formation of ice folds, accompanied by spasmodic vibrations, water invariably is pushed through the open spaces in spurts and with some force. This water finally again freezes and thus increases the stability of the new formation above. When the force effects, causing such phenomenon, remain active for a longer period of time, more folds, successively close to one another, may be formed in the same area. Near the Sakrower Church by Potsdam I observed such a case repeatedly for several years. This was the beginning of a scale structure.

The described phenomena are not only limited to the Havel Lakes near Potsdam; I have recently been told that they may also frequently be observed on the large lakes of Mecklenburg. Struve in his "Notiz über die Untersuchungen des Eises als festen Körpers" mentions cracks and shifting between the mouth of the Newa and Kronstadt.¹ Just recently I have also found an article by Deike, "Über Eisbildung und Entstehung

der Schründe und Spalten in den Eisdecken der Süßwasserseen? 2 in Poggendorf's "Annalen" which has not yet been taken into consideration. Deike observed the same phenomena on Lake Constance in the winter of 1860/61; he called them "crevices". His not-very-clear descriptions correspond, on the whole, to my observations, but the "crevices" of Lake Constance are of larger dimensions; their length was 20 - 30,000' (?), their width up to 14', their height up to 5'. Deike also mentions the spurting up of water at repeated intervals during the formation of the crevices; at Lake Constance this is called "bleeding of ice". Ice folding seems to be a common phenomenon on all larger, still-water areas.

Ice folding is caused by the release of stress differences within the ice. But how does this happen and where do these differences in stress come from? Deike attempted to explain this. According to him such stresses may be caused by:

- 1) temperature differences in the atmosphere, causing contraction of the ice, 2) rapid swelling of the water and wave effects beneath the ice and 3) the accumulation of compressed air beneath the ice seeking an escape. The first and the third factors are seen as especially important by Deike, but in particular the third.

The question is, from where does the air beneath the ice come? Deike explains this as well: nitrogen and carbonic acid are set free through the breathing of fish and other water animals and are not again absorbed by the water. "The ice sheet prevents an escape of the constantly renewed, non-breathable gas. This accumulates underneath the ice and can cause vibration, humming and swishing of the ice." These phenomena, as

well as the folding of the ice and the expulsion of water, "are hardly to be explained by a mere change in temperature. But when the pressure of non-breathable gas under the ice is also considered, as well as the motion of waves, these phenomena may find a possible, non-forced explanation." The first factor is not explained well enough for us to understand what the author really meant. Had he mentioned that the freezing may cause a surface expansion in the numberless crevices, a plausible explanation may have been developed after further analysis. The second factor is not based on any observations at all. What could cause such rhapsodic water swelling in the middle of winter? Besides, if such swellings were really effective, ice folding would occur especially during the time of spring floods. This, however, is not the case. Finally, each observation shows that the ice folding is caused by expansion of the ice sheet and the forces resisting this. The upward or downward vaulting ice is not pushed together, but pulled and torn during rising as well as falling levels of water. The author's third and main factor is almost ridiculous: what water animals ever produce free gases in such quantities? Where have such colossal accumulations of gas under water ever been observed and how do they produce such great effects of force? If we reconsider the foregoing facts once more, the only remaining possibility is that ice folding is caused by local pressing together of the ice. But how does this come about?

In solving the problem, place and time of the ice folding must be taken into consideration.

According to my observations on the Potsdam Lakes, ice

folding occurs every year in almost the same places, namely near the land. There is, for example, a whole series of ice folds along the northwest shore of the Templiner Lake, running from the Schmaedigschen Brick Works to the Esphan Headland, whose position has remained virtually unchanged throughout various years, and the last of which often reaches out far beyond the headland where the sea reaches its last swellings. Likewise the northern shore of the Jungfern Lake is marked by ice folds from the Sakrower Church to the Titzhorn. These show up best near the Sakrower Church where they run in an east-west direction. I am also familiar with nice formations of ice folding running along the shore from the SE bank of the lake-like enlarged Havel River across from Peacock Island to the big Tiefhorn, where the river runs into the Wann Lake. Deike also makes a few inexact but, as it seems, corresponding remarks. At the Zeller Lake, for example, between Radolfzell and Itznang, at a spot where the lake was 8000' wide, he observed two or three crevices existing at the same time which ran parallel to the shore at a distance of about 800 to 1000'.

Ice folding can also be found at mouths of small inlets of lakes, the broad sides of which border on the larger lakes and whose tops are surrounded by land. The smaller Petzin in the southwest and the Kappe in the northeast are attached as such inlets to the Templiner Lake. In the winter of 1889/90 at the mouth of the Petzin, a large ice fold ran in a northerly direction from shore to shore; behind this lay the mirror-smooth ice sheet of the Petzin. In some years the bay of the

Kappe is cut off from the larger Templiner Lake area through a similar fold. The Jungfern Lake at its western end forms a narrow water way, the so-called "Lange Zug", which curves and is, therefore, also surrounded by land at its upper end. Here too there is usually a smaller ice fold which runs from the northern neck of land, the Titzhorn, far into the mouth of the "Lange Zug". Across from this on the south side near the "Hermitage" the beginning of an ice fold can also be seen. Both flank the mouth of the "Lange Zug".

I could have given more examples if time and means had permitted more detailed research. But I think that those mentioned show that ice folding always occurs where thrust force meets resistance, either through the near shore or through a small rigid ice sheet which cannot give way because it is surrounded by land at its back.

I think that this is the key for the solution of the problem. The cracks are primary; ice folding is secondary.

How do the cracks now come into being? Obviously they are also caused by stress differences. But how do these come about? We can find an answer to this question when we consider the time of formation of the cracks. Whoever has observed these phenomena is familiar with the cannon-like thundering, the wild howling, the whistling and crackling which can continuously be heard coming from the large ice sheets of our lakes in the clear, cold nights and the sunny mid-days of January and February. It is a frightening music, but which when taken as the voice of nature, ever active in silence, is also moving and awe inspiring. These are the

"Hartborsten", which run through the ice by the hundreds. They also appear at other times, though not as frequently. The time of their appearance clearly points to differences in temperature as the cause for the stresses. During the nights the top layers of ice are considerably cooled down as a consequence of the coldness of the air and irradiation, whereas the lowest layers retain their higher temperatures because of contact with the water which has a temperature of approximately 0°Celsius. On the other hand, the top layers warm up to 0°C. during periods of strong insolation; the lowest layers at that time remain almost the same temperatures as at night; in thicker ice the middle layers approximately preserve the same temperatures they had assumed at night. Let us now consider the different coefficients of expansion of the ice at various temperatures. According to Andrews³⁾ for 1 F°(linear):

between + 16°	and + 32°F.	= 0 000 040 876
0° "	+ 16°F.	= 0 000 028 042
- 21° "	0°F.	= 0 000 020 484
- 30° "	- 20°F.	= 0 000 019 744

These are considerable differences. As soon as different ice layers vary so greatly in temperature, tensions must necessarily develop, the release of which in all probability will result in the appearance of "Hartborsten", in the same way that explosive carbon causes cracks in a glass pane.

This brings us closer to the formation of ice folds. Each crack represents a narrow crevice in the ice, ranging from several mm in width to 1 cm. The water seeps into these, sometimes also swells over and then freezes. A skater can

easily detect thousands of these lamella, formed in the cracks which run vertically through the ice and are often of a different color than the walls of the cracks. The freezing of these lamella causes, of course, an expansion of mass and, thus, a pressing apart of the walls which surround them. Individually these have only a minimal effect. Considering, however, the enormous number of cracks which run through a larger lake surface, these effects necessarily constitute a considerable power. This power, which is produced when water that has penetrated the "Hartborsten" freezes, is, in my opinion, the cause for the ice folding.

It is now also possible to explain why ice folds are often formed along shores or in front of bays surrounded by land. The expansion of ice as a consequence of the refreezing of the "Hartborsten" will, of course, continue throughout the whole surface until land or an ice floe, rigid because of the surrounding land, provides an unconquerable barrier. The pressures which accumulate in front of it are released by a lifting up of the ice. This also explains why during over-lapping the edge of the larger ice sheet is always pushed against the one of the smaller rigid sheet. The reason for this is that the pushing force is always effective in this direction.

Because of insufficient observations, the above attempted explanation still needs some improvement. For instance it has not yet been clarified why ice folds are always formed at certain spots on the lake surface and not everywhere where temperature and current would allow the formation of a thick ice sheet. Why, for instance, do they not occur along the

whole east and southeast shore of the Templiner Lake where there are no currents but where there is always a thick ice sheet? In connection with this would be the question whether the seemingly irregular direction of the cracks in the ice is subject to some law. But although this problem needs further analysis, two things may already be pointed out. First, the formation of ice folds has in all probability nothing to do with currents, excepting the fact that at our winter temperatures a thick ice sheet cannot at all develop, and thus no cracks and folds either, in places with a strong current. The mentioned examples already show clearly enough the independence from current conditions. The ice foldings in front of the Kappe and Petzin and also along the north shore of the Jungfern Lake are formed in quiet waters; the pressing which causes the folds along the west shore of the Templiner Lake, near the Titzhorn and near the "Hermitage" and also the foldings from Peacock Island to the Tießhorn cross the relatively weak currents of the Havel. Even springs can only exercise local influence. It seems impossible to attach greater significance to them as far as such widespread phenomena are concerned.

Secondly, the effects of the prevailing winds cannot be responsible for our phenomena either. It may be possible that through strong and lasting winds the expansion and pressing of the ice can be steered in a particular direction, causing a so-to-speak rolling-out of the ice. But the fact that in severe winters when ice folding is widespread, such formations occur concurrently on different sides of the lake and show thrust forces effective in completely different directions, speaks against a general consideration of this factor.

2. Shore Ridges

The lakes of Potsdam are surrounded by a great number of shoreline formations which have remained completely unknown thus far. Low ridges run for kilometers along the shores which consist of uncultivated land, namely forests. These ridges are made up of sand and humus on the inside and are grown over with grass and weeds on the outside. They reach a height of 2/3 m maximum and lie at the approximate level of the winter water line, i.e. in summer they are about 3 m from the water, depending on the inclination of the ground. Sometimes there is only one of these ridges present, at other times there are two, three or more of them. Similar formations, but only a few centimeters high, occur at places where the ice has thawed and where waves hit strongly, depositing an accumulation of sand and plant remains. But these have nothing to do with shore ridges. Whereas these show a regular low stratification, the shore ridges show the structure of a mountain profile in cross section: the layers of humus and sand are folded and over-lapped, sometimes fresh grass patches are folded together, folded in and are over-lapped by older material, similar to the Jurassic wedges in the Jungfern Mountains. Where do these minute tectonic phenomena come from? They are obviously caused by a thrust force effective from the water to the land. Furthermore, it is the same thrust force that causes the ice folding to occur.

The location of the shore ridges already supports this theory: they are found in the same areas where in winter

ice folds run along the shore, i.e. along the west shore of the Templiner Lake, from the brick works to the Esphan, along the north shore of the Jungfern Lake, from the Sakrower Church to the Tiefehorn, on the east shore above Peacock Island to the Great Tiefehorn, etc. However, nothing is known, for example, about significant ice shiftings or shore ridges on the Tiefen Lake near Babelsberg, on the "Lange Zug", on the east and west shores of the Jungfern Lake and on the southeast and south shores of the Templiner Lake.

Direct observation shows the relationship between ice shifting and the shore ridge. I found a characteristic example in February, 1890. The large ice fold which then ran, as I have already mentioned, across the mouth of the Petzin River, touched the land diagonally in the south near the northern point of the Great Wentorf. It consisted here of more than six ridges, arranged column-like one after the other and it had been pushed upwards towards the flat meadow land and had smashed it in a peculiar way. Sand and ice patches had been lifted up by the ice folds, kneaded together with pieces of ice, folded in and turned over. In the midst of this foot-deep and inch-wide cracks ran diagonally through the hard frozen ground, along which the clods of earth had been shifted in a horizontal direction against one another like a "Suess leaf". As here, ice folds are often pushed up on the shore for long stretches, namely when they run parallel to it. I have often observed the same phenomena at many spots, though not in as clear formations as here, for example, left of the Sakrower Church where folds can regu-

larly be found near the shore, lined up closely one behind the other. In addition to the formation of shore ridges because of the lifting and pushing together of ice, trees may also be up-rooted.

There is no doubt that shore ridges are formed by the pressure of the forward pushing ice. It is possible that this fact may be of relevance for a problem which has not yet been sufficiently explained. By this I mean the formation of shorelines common to higher latitudes. In the past these have been considered partly as the result of the effects of the surf. But the surf cannot be effective in sheltered and narrow fjords. On rocky precipitous cliffs frost may in part effect the formation of shorelines as the water, in the narrow bays, spurts into the crevices and freezes. During longer and severe winters even the discussed ice shiftings may play a part in moulding the shorelines by accumulating loose material as well as by breaking apart solid rock which has loosened and fallen because of weathering and frost.

Literature:

¹Struve. "Notiz über die Untersuchungen des Eises als festen Körpers", (Pogg. Ann. Bd. 66, 1845, S. 298)

²Deike. "Über Eisbildung und Entstehung der Schründe und Spalten in den Eisdecken der Süßwasserseen." in Poggen-dorff. Annalen, Bd. 121, 1864. S. 165.

³ Andrews. (Proc. Royal Soc. 1886, Vol. XL, S. 544)