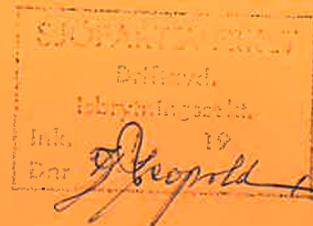


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STYRELSEN FÖR  
**VINTERSJÖFARTSFORSKNING**

WINTER NAVIGATION RESEARCH BOARD

Research Report No 22

MEASUREMENTS OF PHYSICAL CHARACTERISTICS  
OF RIDGES ON APRIL 14 AND 15, 1977  
BY ARNO KEINONEN

Sjöfartsstyrelsen  
Finland

Finnish Board of Navigation

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Sverige

Swedish Administration  
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MEASUREMENTS OF PHYSICAL CHARACTERISTICS  
OF RIDGES ON APRIL 14 AND 15, 1977

Arno Keinonen

Report No.

HELSINKI FINLAND

F O R E W O R D

The Winter Navigation Research Board presents its report No 22. This report deals with a survey of the sails of two ice ridges in the Gulf of Bothnia, which is a part of the effort to get more information about the formation and the structure presented of ice ridges. Previous studies are in reports Nos 12 and 17.

The Winter Navigation Research Board expresses its thanks to Mr Keinonen and his assistants, and to Prof. Palosuo of the University of Helsinki, who is coordinating these studies.

Helsinki and Norrköping      November 1977

Jan-Erik Jansson

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MEASUREMENTS OF PHYSICAL CHARACTERISTICS OF RIDGES ON APRIL 14 and 15, 1977

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Research Assistant  
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In this paper the measurements of two ridge sails in the northern part of the Gulf of Bothnia are reported. The measurements are limited to the upper part of the ridge because at this stage of knowledge it was believed that this is the most effective and easiest way to get additional knowledge of Baltic ridges related to ship-ridge interaction.

1.  
Choice of profiles

It was possible to measure two ridge profiles. Thus it was a matter of choosing two different types of pressure ridges of which as much knowledge as possible could be received and which at the same time could be considered representatives for the majority of Baltic ridges. The size of these ridges should be average; if they were too large, they would be too difficult to handle, if too small, the results would be statistically unsatisfactory.

The first profile was of a single pressure ridge about 200 metres east of lighthouse Kemi 1. The average ice block thickness was 0.32 metres and a sail height 1.26 metres (Fig. 1). The second ridge was found about six kilometres south of lighthouse Kemi 1. It was inside a large hummocked area. It had ice blocks of 0.14 metres and a sail height of 1.12 metres (Fig. 2).

2.  
Measurements

The following measurements were made:

- the top profile
- mapping of the ice blocks in a sail in one cross section
- snow contents
- temperatures in different parts of the sail
- densities of ice and snow in different parts of the sail
- salinity of ice in different parts of the sail
- thickness of frozen ice layer
- environmental characteristics (temperature, salinity and density of water, air temperature)
- photographing of ridge.
- depth of keel

The techniques were as follows: the profile was levelled. Then a path was sawn with motor saws through the sail (Fig. 3) so that a vertical cross section could be seen. The cross section was mapped, temperature measured in certain points and ice samples taken. Further, deeper recognizing through the frozen ice layer was made by drilling until water came through. The depth of the keel was measured by drilling as far as possible. (Only a 2-metre ice auger was available.)

### 3. Results

#### Ridge 1

The age of the ridge was less than two months. This approximation is made on the basis of the evaluation of the growth of the surrounding level ice thickness after the ridge formation.

The level ice thickness was different on the different sides of the ridge (0.45 m and 0.53 m) and it was observed that the sail of the ridge was composed of ice blocks with two thicknesses 0.27 and 0.34 metres and snow, and a small amount of crushed ice. The ice blocks were only lightly frozen to each other. This is in good accordance with Palosuo's observations /1/. The 0.27 m thick ice blocks have most probably come from the level ice field that was 0.45 m thick at the measuring moment and the 0.34 m thick blocks from the level ice field with a thickness of 0.53 m .

The ice blocks in the sail were mainly in a horizontal position. The average maximum length of the ice blocks in the sail was about 0.9 metres varying between 0.4 and 1.5 metres excluding a few small blocks. The length to the thickness ratio was thus on the average 2.95. The frozen ice layer below the ridge sail (Fig. 5) was on the average 23 cm (or 49 %) thicker than the surrounding level ice. An interesting relation is also the one between the additional thickness of the frozen ice layer and the block thickness in sail, the former being 72 % of the latter. The ice layer was probably not rafted or at least there was no other horizontal ice layer below the level ice frozen to it, which according to Palosuo (/1/ Fig. 21) can also take place. This deduction is based on drillings. The level ice to the left was considerably deflected which is typical of the majority of ridges.

In Fig. 11 a map of the cross section of the sail is shown and for comparison the levelling results are plotted which were used for a mass balance calculation. The section where the levelling was done was 0.1 to 0.4 metres aside from the one that was sawn (Fig. 4). Thus there are some differences between the levelling and the manual profile mapping block by block. A comparison between the ice masses shows these: Between metres 10 and 18.8 the cross sectional areas are as follows:

levelled cross section (without snow)	5.90 m <sup>2</sup>
mapped cross section (without snow)	6.39 m <sup>2</sup>
summed cross section of ice blocks	4.09 m <sup>2</sup>
snow cover	2.59 m <sup>2</sup>

The ice porosity value is the ice cross section divided by the mapped section giving 36 % of non-ice. The relative amount of snow compared to ice is 63 %. In Fig. 6 the cross profiles of ice and snow along the ridge are shown.

The error due to random profile choice can be evaluated comparing the slightly separate levelling and mapping lines. This difference is 8.4 %.

The original levelling results are shown in Fig. 5.

It is of great importance to note that the levelling must give an average outline of the sail leaving sharp ice edges outside. This way the porosity value comparable to keel porosity may be got.

The idea may be clearer if we think that the original ice pile would be increased. Then it is easy to imagine that the edges of the added ice blocks fall inside the original levelling line. The correct levelling line is the one where as much ice from inside falls out as from outside the line falls in. This is by no means an exact determination but it has been satisfactory in accuracy and it is quick to use.

There were ice blocks sticking out from the frozen ice layer between metres 12.55 and 16.35. This leads to the idea that one or both of the ice fields have been submerged in this area during the ridge formation, or after it for balance reasons. Dashed lines are drawn in Fig. 5 explaining this proposal. These lines are only imagined, no field measurements of this one are made.

In accordance with the method of /2/ the mass balance calculations are made and the whole profile is drawn (Fig. 8 and Table 1). Only a part of the original levelling results are used for this calculation to make the results applicable for the method (mapped line). The density values of water and ice used in this balance calculation are taken from our own measurements (Table 3). The ice density below the water level is assumed to be the same as in the sail ( $871 \text{ kg/m}^3$ ).

The density of ice in the sail (Table 2) had decreased from its original value  $914\text{--}916 \text{ kg/m}^3$ , which was the actual ice density around the ridge, to  $867\text{--}884 \text{ kg/m}^3$  after the ridge formation. The most weathered topmost ice blocks had a yet lower density,  $854 \text{ kg/m}^3$ .

The strength of ice is determined by means of salinity, temperature and density measurements (Fig. 5). According to these the brine volumes (Table 2) and then the strength of ice have been calculated. The strength was clearly decreased at the measuring moment due to warm weather and great air brine volume. The greatest value of salinity,  $1.4\text{‰}$ , was observed close to the frozen top layer and below the level where the minimum temperature was observed. The salinity of ice in the sail was decreased in the upper ice blocks and increased in the lower ones due to the drainage and migration which is quite natural.

The amount of snow in the sail was considerable. An exact value of precipitation after the ridge formation was not registered. The thickness of snow on the top of a great level ice field near the ridge was less than 0.2 metres which is likely above the right value of precipitation. According to the author's experience the nearly fresh ridges have very often more snow than the surrounding level ice fields. It is probable that even a few centimetres of new snow and some wind cause a kind of filling and covering of a ridge with snow, as was observed.

The observed average density of snow,  $371 \text{ kg/m}^3$ , was considerably above the average winter snow.

The shape of the keel may deviate from that computed, as indicated in /2/. In this respect the drillings through the ridge showed a satisfactory correlation with the computed profile (Fig. 8).

#### Ridge 2

To the left of the ridge number 2 there was an unbroken, deflected level ice field of approximately  $50 \times 100 \text{ m}$ . That field was mainly rafted and the rafting is a logical reason to prevent the unbroken field from breaking and to let a ridge form at its edge. This ridge (Fig. 9) was built up of ice blocks with only one thickness ( $0.14 \text{ m}$ ) which is characteristic of hummocked ice fields. Additionally, there was a small amount of crushed ice inside the sail, but only in a limited area. The area can be seen in Fig. 12.

As in the Ridge 1, the ice blocks stick out from the frozen layer. This happens in the positions between 25 and 30.1 metres. In this area the thickness of the frozen ice layer before the water came through when drilling, was up to 0.65 metres (Fig. 13), on the average 7 cm (or 20 %) more than the surrounding thickness. The additional thickness is 50 % of the sail block thickness. These indicate about a similar behaviour of the ice blocks as in the Ridge 1. The basic ice thickness 0.14 metres at the time of the ridge formation seems to have grown up to 0.36 metres, which is the most general thickness of level ice.

The block size in the sail was on the average 0.5 metres varying between 0.25 and 0.8 metres. The length to the thickness ratio is thus on the average 3.6.

The ice blocks were practically loose from each other. The blocks could be loosened by a light kick. In this ridge the positions of ice blocks are not predominantly horizontal as in the Ridge 1, but they cannot be regarded as totally randomly positioned either. Clear lines can be seen where ice has risen up (Fig. 10) in the middle and to the right of the middle of the sail.

To the right of the main part of the sail, metres 29---30, the ice blocks are vertical like in shear ridges (Fig. 12). The direction of ice movement has probably changed during the ridge formation causing this special formation, which is also proposed by Palosuo (/1/ Fig. 33).

The sail was not so totally filled with snow as that of the Ridge 1. The exact registration was utmost difficult to do because the great amount of "snow" born when the ice blocks were sawn with a motor saw. From observations approximately 3/4 of all the holes were snow-filled, the holes in the lowest mid parts of the sail being generally empty. In Fig. 7 the snow and ice distribution is shown, the voids are not separated from the snow-filled areas.

The composition of the sail was as follows:

levelled cross section (without snow)	4.55 m <sup>2</sup>
mapped cross section (without snow)	4.26 m <sup>2</sup>
summed cross section of ice blocks	2.44 m <sup>2</sup>
snow cover	1.86 m <sup>2</sup>

Thus the ice porosity (ice/mapped) is 43 %, the difference between the levelled and mapped profile was 6.8 %. The relative amount of snow in the area of the sail, the empty voids subtracted, is 76 % of the amount of ice. The computed profile based on the mass balance calculations is shown in Fig. 14. The original levelling data are in Table 2.

The density of snow was registered to vary between 300 and 450 kg/m<sup>3</sup>, the top layers being more dense. An average 371 kg/m<sup>2</sup> was indicated as in the Ridge 1.

In this ridge there was a layer of melt water on the frozen ice layer. The salinity in this layer was considerably higher than that of the sea water (Table 3). This water in the ridge (Fig. 13) seems to collect the salt drained and migrated from the sail.

Drillings through this ridge showed that the ridge was above two metres thick in all locations which agrees well with the computed profile (Fig. 14).

#### 4. Conclusions

The main conclusions of this study are as follows:

1. The porosity of ice blocks in the sail varied between 36 and 43 %.
2. The density of ice in a sail decreases after ridge formation approximately from 914 to 871 kg/m<sup>2</sup>.

3. The frozen ice layer is thicker inside the sail than in the level spots of the surrounding level ice field. In this study the average additional thickness was 20---49 % of the surrounding level ice thickness (0.07---0.23 metres).
4. The ice blocks in ridge sails are not randomly oriented near the frozen ice layer. The direction of the ice movement is the most probable one. (A horizontal or scew.)
5. The ice blocks in a ridge sail in the Baltic can be held practically loose from each other.
6. The salinity of the sea water was 3.50 ‰, that of the level ice 0.70 ‰ and that of the sail ice 0.35 ‰ on the average. In the lowest middle part of the sail some water was found with a salinity of 6.40 ‰ and ice with a salinity of 1.40 ‰.
7. The average length to the thickness ratio of the ice blocks in the sail was 2.95 to 3.6.

Besides the regional limitations of these conclusions, the time and changes of environmental conditions with it have an effect of their own. In this respect especially the temperature is most important. It seems that "normal" ridges were found and the results are characterizing.

At this stage the weakest point of knowledge is bound to the submerged part of ice ridges and when further studies will be made, the whole ridge is recommended to be considered.

#### Acknowledgements

I warmly thank professor Palosuo who assisted me during the whole research trip with his great experience and Matti Teinonen who assisted in measurements and analysis of the results. I also thank Wärtsilä for the economical and technical support of this study.

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KEMI 1 1977-04-14

TABLE 1

DENSITIES (KG/M<sup>3</sup>) WATER 1000.00 ICE 871.00 SNOW 371.00  
 AVERAGE RIDGE THICKNESS 3.57 M  
 MEAN DEVIATION OF RIDGE THICKNESS 3.28 M  
 CROSS SECTIONAL AREA OF THE RIDGE 90.01 M<sup>2</sup>  
 AVERAGE SNOW THICKNESS 0.24 M  
 ICE BLOCK THICKNESS 0.32 M  
 LEVEL ICE THICKNESS, LEFT 0.42 M  
 LEVEL ICE THICKNESS, RIGHT 0.53 M

RESULTS OF LEVELING AND PROFILE CALCULATIONS

NR	S/M	HA/M	HS/M	HE/M	HB1/M	HB2/M	HB3/M	RULE
1	0.00	0.02	0.11	0.07	0.71	0.42	0.00	0
2	6.30	0.13	0.12	0.19	1.91	1.33	0.00	0
3	10.00	0.04	0.15	0.10	1.10	4.05	0.00	0
4	11.20	1.26	0.47	1.01	10.62	7.12	0.00	1
5	13.40	0.97	0.38	0.75	7.90	7.87	0.00	1
6	14.90	0.68	0.11	0.48	5.09	5.56	0.00	1
7	17.00	0.55	0.05	0.37	3.94	4.05	0.00	1
8	18.80	0.15	0.48	0.30	3.17	3.19	0.00	1
9	22.00	0.05	0.43	0.23	2.46	2.49	0.00	0
10	23.50	0.15	0.19	0.18	1.87	2.03	0.00	1
11	25.20	0.09	0.20	0.18	1.85	0.53	0.00	0

TABLE 2

KEMI : 1977-04-15

DENSITIES (KG/M<sup>3</sup>) WATER 1000.00 ICE 871.00 SNOW 371.00  
 AVERAGE RIDGE THICKNESS 3.79 M  
 MEAN DEVIATION OF RIDGE THICKNESS 3.39 M  
 CROSS SECTIONAL AREA OF THE RIDGE 121.36 M<sup>2</sup>  
 AVERAGE SNOW THICKNESS 0.27 M  
 ICE BLOCK THICKNESS 0.14 M

RESULTS OF LEVELING AND PROFILE CALCULATIONS

NR	S/M	HA/M	HS/M	HE/M	HB1/M	HB2/M	HB3/M	RULE
1	0.00	0.17	0.02	0.18	2.10	2.44	0.00	0
2	6.00	0.26	0.01	0.26	3.11	2.63	0.00	0
3	11.50	0.20	0.02	0.21	2.45	2.81	0.00	0
4	17.50	0.23	0.07	0.26	3.06	2.85	0.00	0
5	21.50	0.08	0.40	0.25	2.95	2.68	0.00	0
6	24.10	-0.05	0.50	0.16	1.92	4.19	0.00	0
7	25.00	1.07	0.32	0.75	8.83	6.95	0.00	1
8	27.00	1.12	0.32	0.78	9.17	7.51	0.00	1
9	29.00	0.25	0.40	0.31	3.69	5.02	0.00	1
10	30.50	0.04	0.48	0.24	2.88	3.55	0.00	0
11	32.00	0.32	0.45	0.38	4.42	3.90	0.00	1

ICE MEASUREMENTS

TABLE 3

Ridge 1		Ridge 2	
Sample no.	Place of sample	Sample no.	Place of sample
1	top of the sail	1	topmost block
2	block 1	2	block, inside sail
3	block 1	3	block, bottom sail
4	block 2	4	sea water
5	block 2	5	ridge water <sup>x)</sup>
6	block 3		
7	block 3		
8	bottom of the sail		

Sample no.	Density (kg/m <sup>3</sup> )	Salinity (‰)	Temperature (°C)	Salt brines	Brine volume Air brines	Bending strength (10 <sup>5</sup> N/m <sup>2</sup> )
1	854	0.1	-0.05	n. 0.14	0.066	< 2
2	867	0.5	-0.10	0.14	0.051	< 2
3	869	0.6	-0.20	0.15	0.049	< 2
4	868	0.1	-0.15	0.032	0.050	2.8
5	881	0.3	-0.20	0.065	0.036	2.2
6	877	0.3	-0.40	0.030	0.033	3.5
7	884	1.4	-0.30	0.16	0.040	< 2
8	914	0.7	-0.20	0.16	0	< 2

Sample no.	Density (kg/m <sup>3</sup> )	Salinity (‰)	Temperature (°C)	Salt brines	Brine volume Air brines	Bending strength (10 <sup>5</sup> N/m <sup>2</sup> )
1	810	0.35	-0.10	0.15	0.116	< 2
2	858	0.65	-0.20	0.18	0.063	< 2
3	916	0.7	-0.80	0.04	0	4.5
4	1000	3.5	-0.15	-	-	-
5	-	6.4	-0.30	-	-	-

x) Ridge water is a melted water layer in the frozen top layer, see Fig. 11



Fig. 1. Ridge 1 before sawing

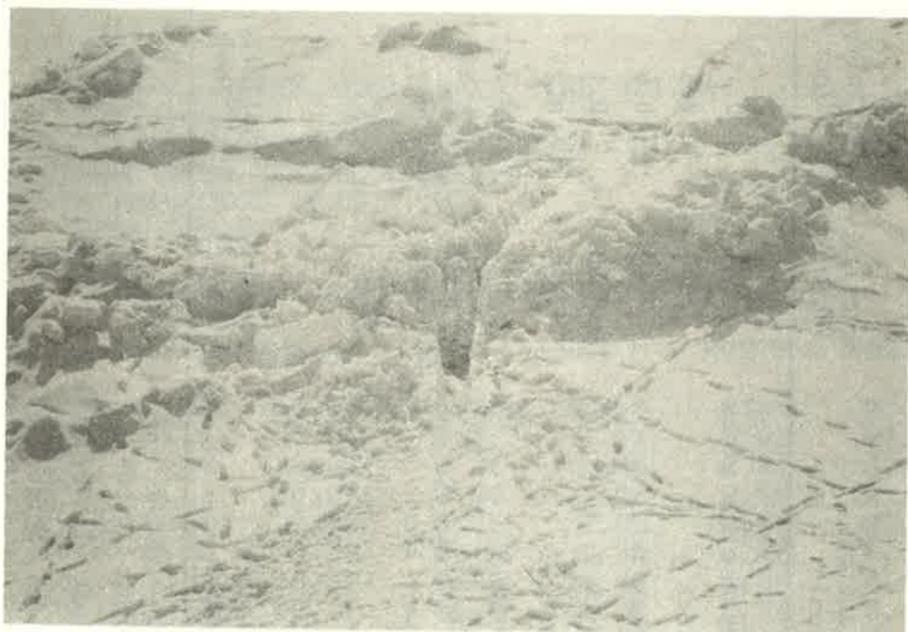


Fig. 2. Ridge 2 after measurements



Fig. 3. Sawing of the sail (Ridge 1)



Fig. 4. Ridge 1, profile mapping after sawing

FIG. 5 RIDGE No. 1 1977 - 04 - 14  
 LEVELLED AND DRILLED PROFILE, TEMPERATURE MEASUREMENTS

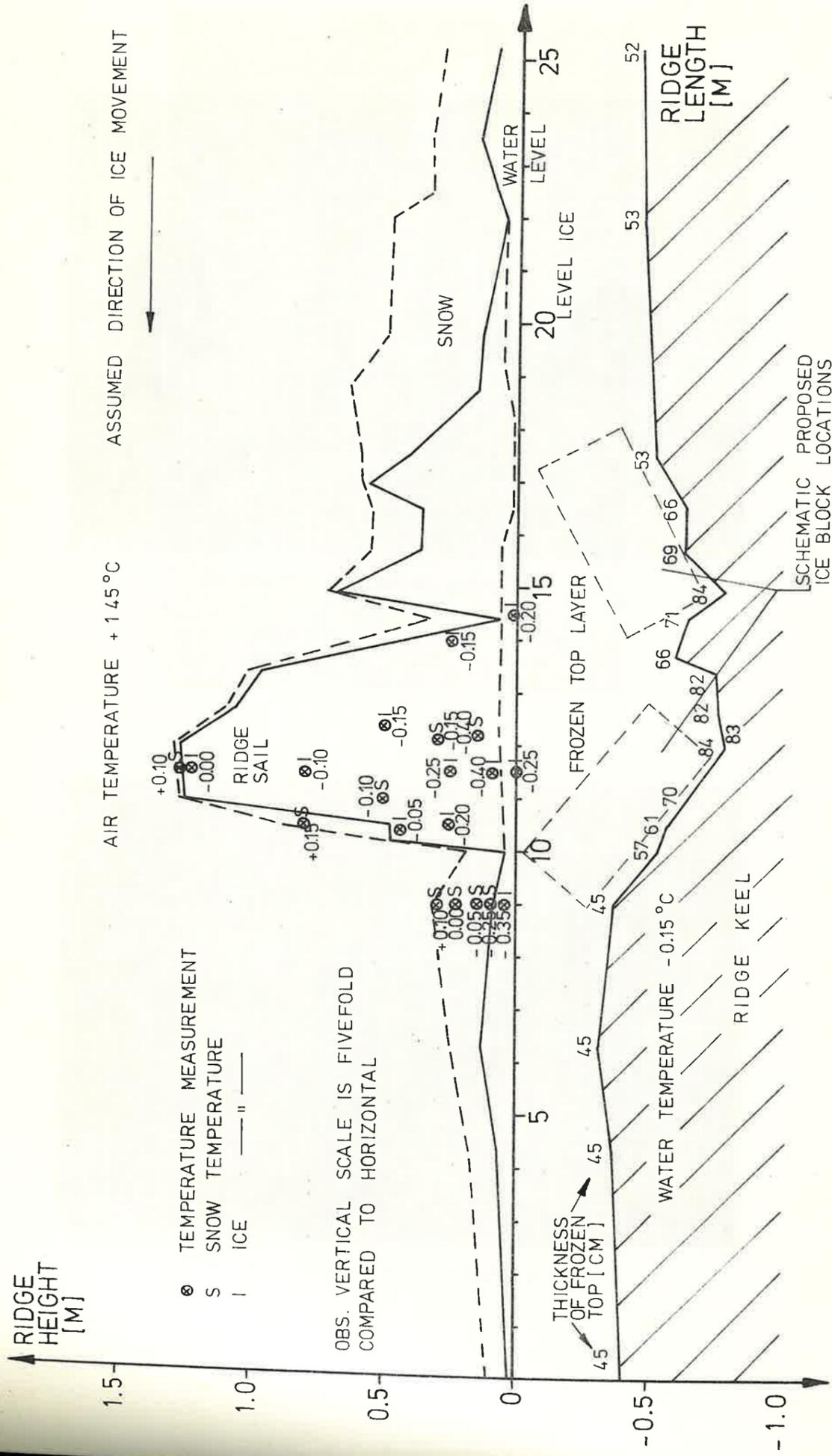


FIG. 6

RIDGE 1 DISTRIBUTION OF SNOW AND ICE

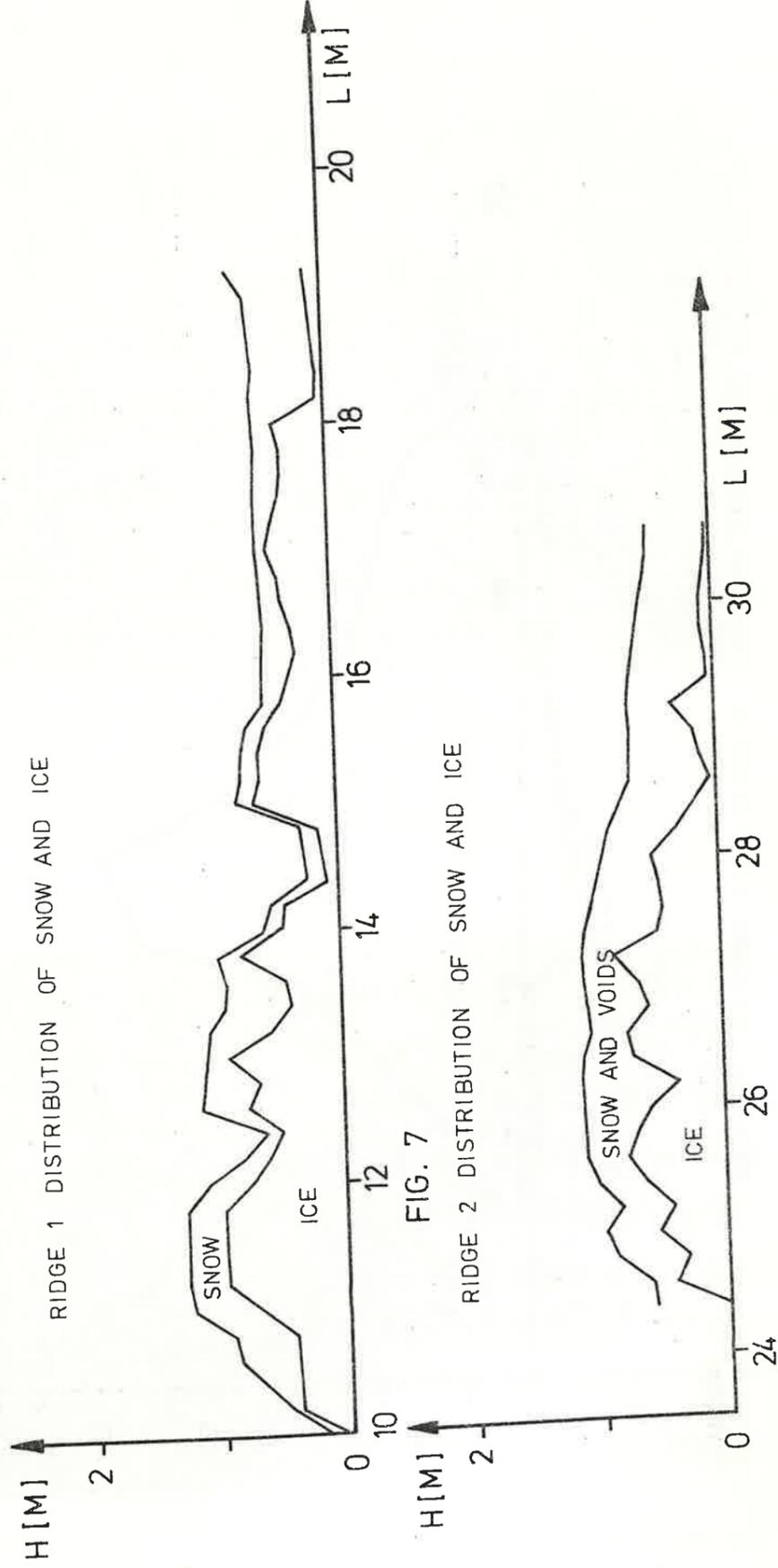


FIG. 7

RIDGE 2 DISTRIBUTION OF SNOW AND ICE

FIG. 8

KEMI 1 1977-04-14 RIDGE 1, COMPUTED PROFILE AND RESULTS OF DRILLING

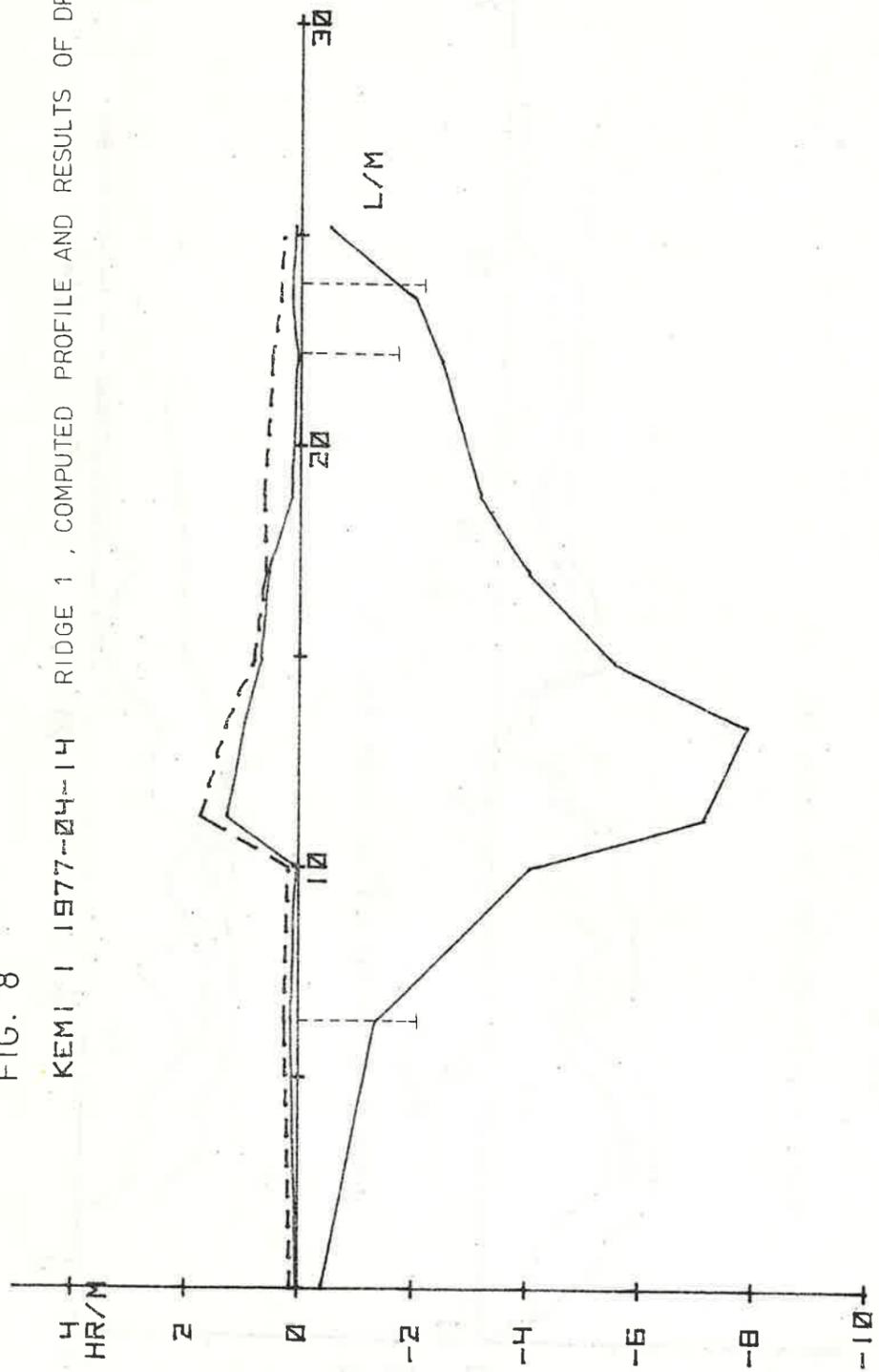


Fig. 9. Ridge 2 after sawing

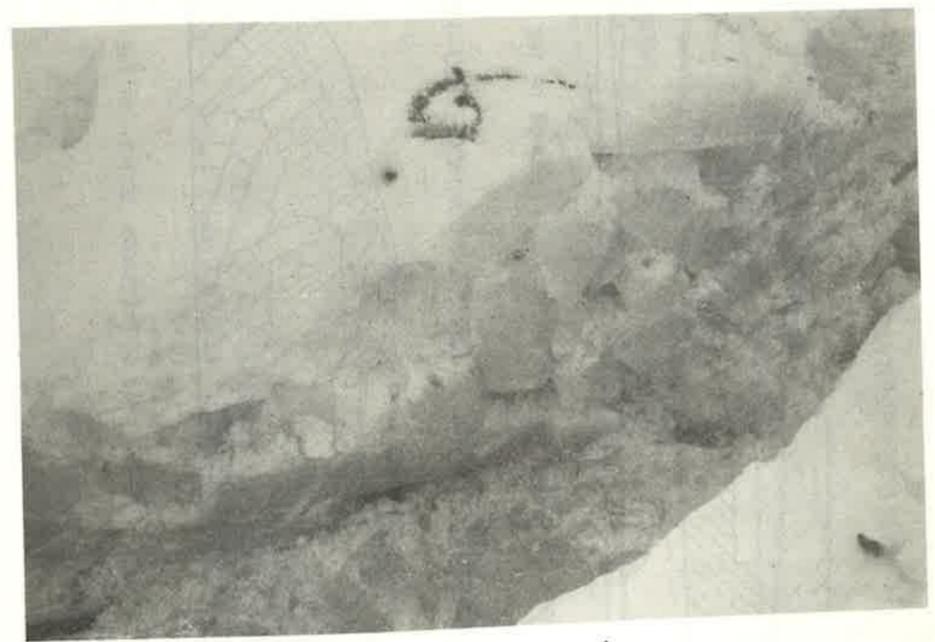
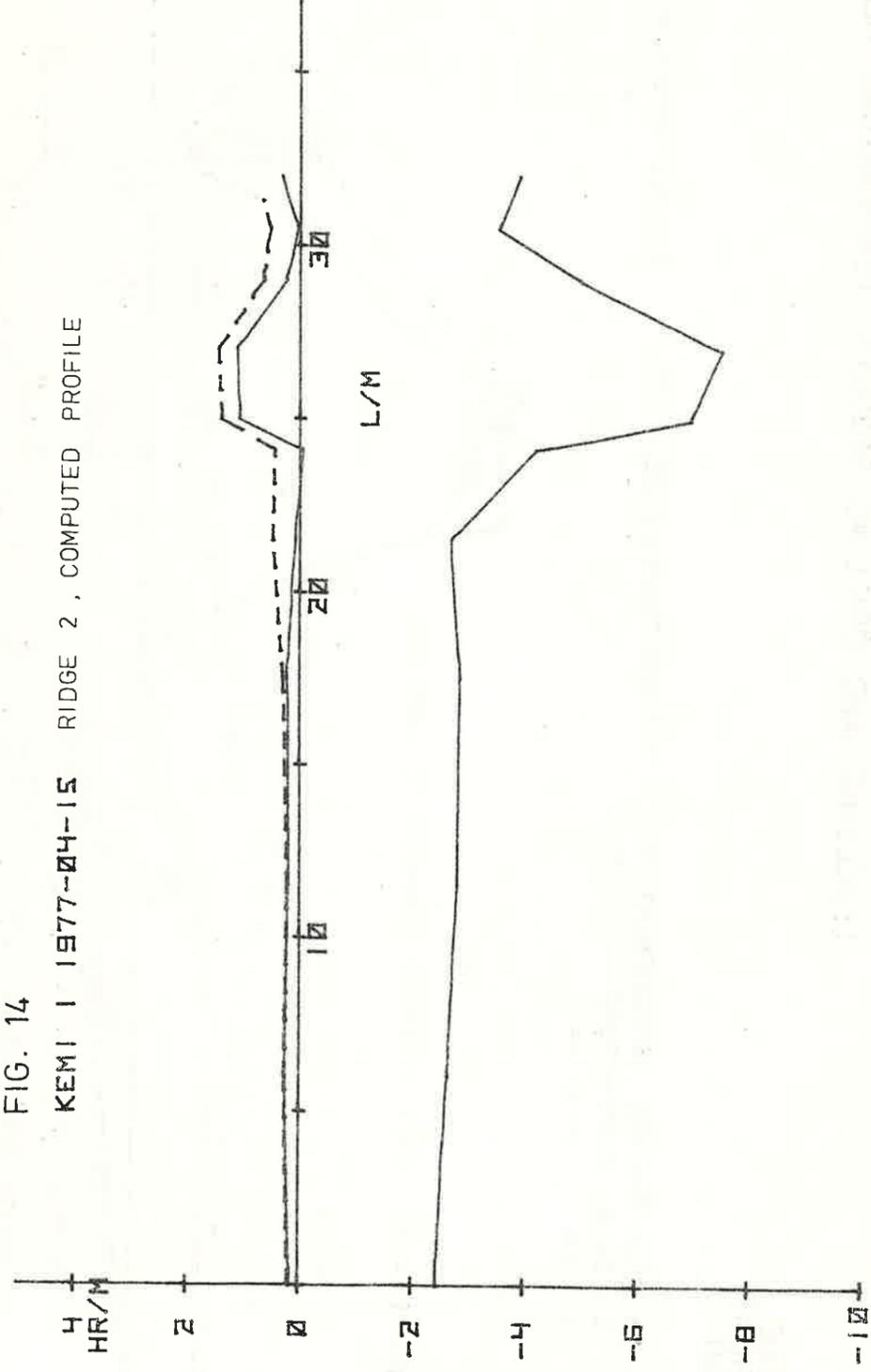


Fig. 10. Ridge 2 after sawing.  
A screw line of ice blocks to the left.



FIG. 14

KEMI I 1977-04-15 RIDGE 2, COMPUTED PROFILE



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