PORT AND OCEAN ENGINEERING UNDER ARCTIC CONDITIONS
TECHNICAL UNIVERSITY OF NORWAY

# INVESTIGATIONS RELATING TO PHYSICAL CONDITIONS OF SOME ENCLOSED FJORDS OF NORWAY DURING THE WINTER.

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During the last 15 years some hydrographical investigations have been carried out on a number of our fjords. The investigations were done in connection with regulation of the inflowing rivers which consequently are discharging high winter runoffs into the fjords, causing ice difficulties of various kinds.

In the following paper a short description will be given of the investigations in two selected fjords. The first is Rombaksbotn, the inner part of Rombaksfjord. This is a fjord with a comparatively small inflow of fresh water. The second is Sørfjord, a branch of the Ranafjord, which has a large inflow of fresh water from the Røssåga power plant.

The fjords which have been investigated are shown in Fig. 1.

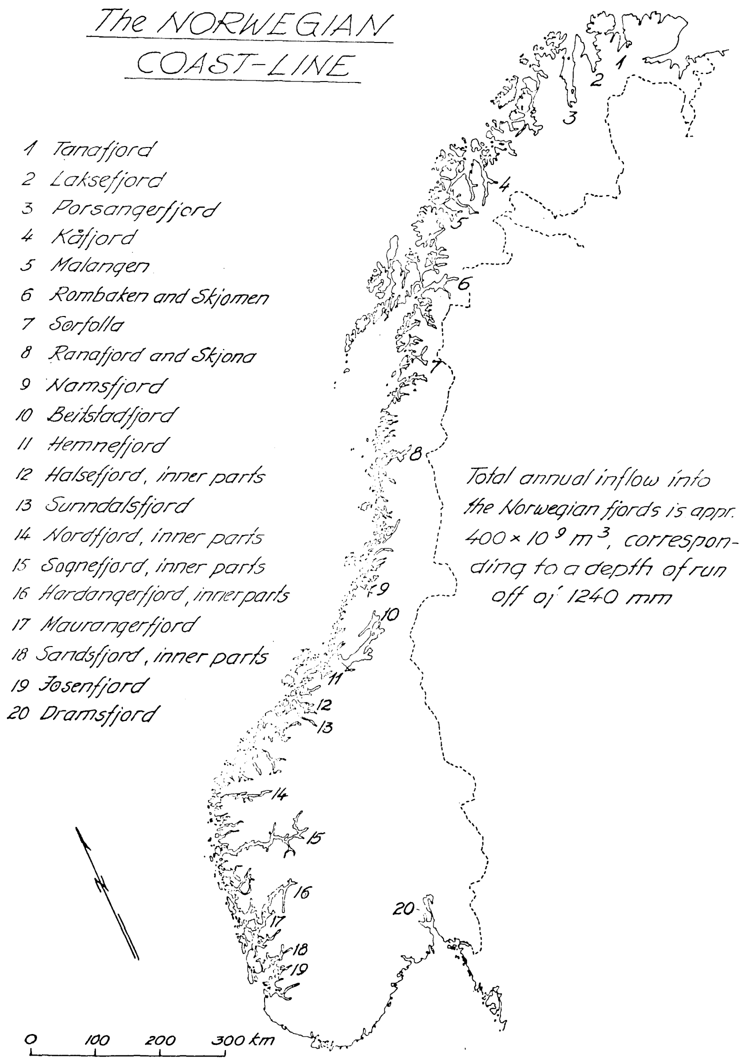



Fig. 1

Temperature and salinity measurements are used in order to distinguish between the various water masses. The following observations are taken:

a) Temperature and salinity, recorded at regular intervals in the upper layers (down to 5 m) at a number of permanent stations. Special measurements carried out as far down as 120 m at more irregular intervals in selected stations over the whole fjord. A measuring bridge is used for this purpose.

b) The tide, recorded by an automatic recorder.

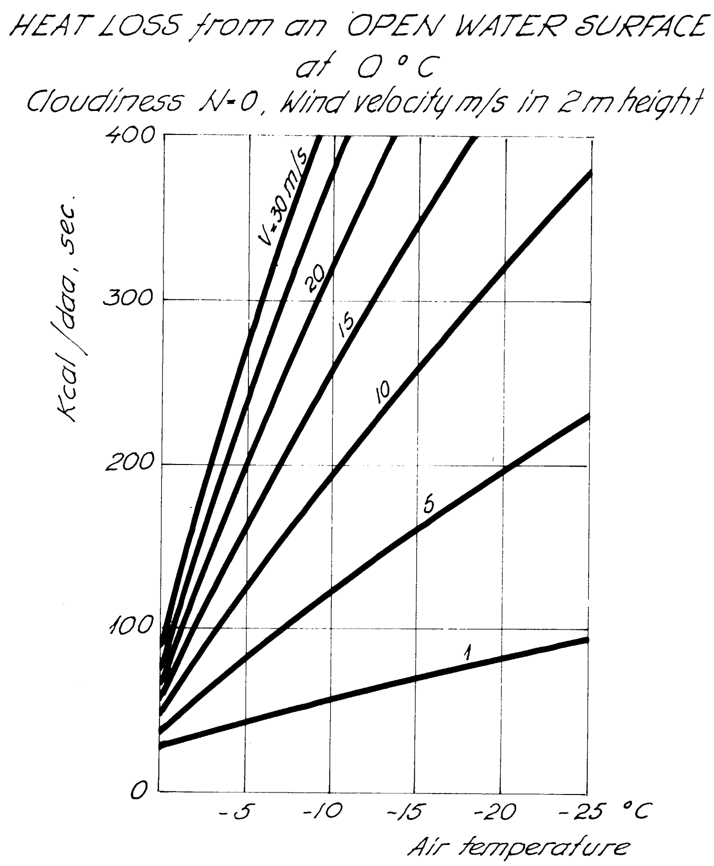
c) The currents in sounds and estuaries, measured by means of an ordinary current meter.

In addition to this the observers are mapping the extension of the ice cover and describing the ice conditions. Meteorological data are usually supplied from near-by stations. If these are not available, instruments are installed for the more important components such as temperature, precipitation and wind.

All these data are interpreted and evaluated at the Ice office of the Hydrological Division, Norwegian Water Resources and Electricity Board.

## 1. SHORT DESCRIPTION OF ICE PRODUCTION

Heat losses are caused by long wave radiation from the water surface, by evaporation and by heat exchange with the air. Calculations of the various components in an enclosed fjord show that the loss in the month of January is approx.40-60 % by radiation, 20 % by evaporation and 30 % by convexity. The graph Fig. 2 gives the heat loss from a water surface at 0 °C (after DEVIK).




Correction table

| N | 0,1 | 0,2 | 0,3 | 0,4 | 0,5 | 0,6 | 0,7 | 0,8 | 0,9 | 1,0 |
|---|---|---|---|---|---|---|---|---|---|---|
| Corr | 0 | -1 | -2 | -3 | -5 | -7 | -9 | -12 | -15 | -18 |

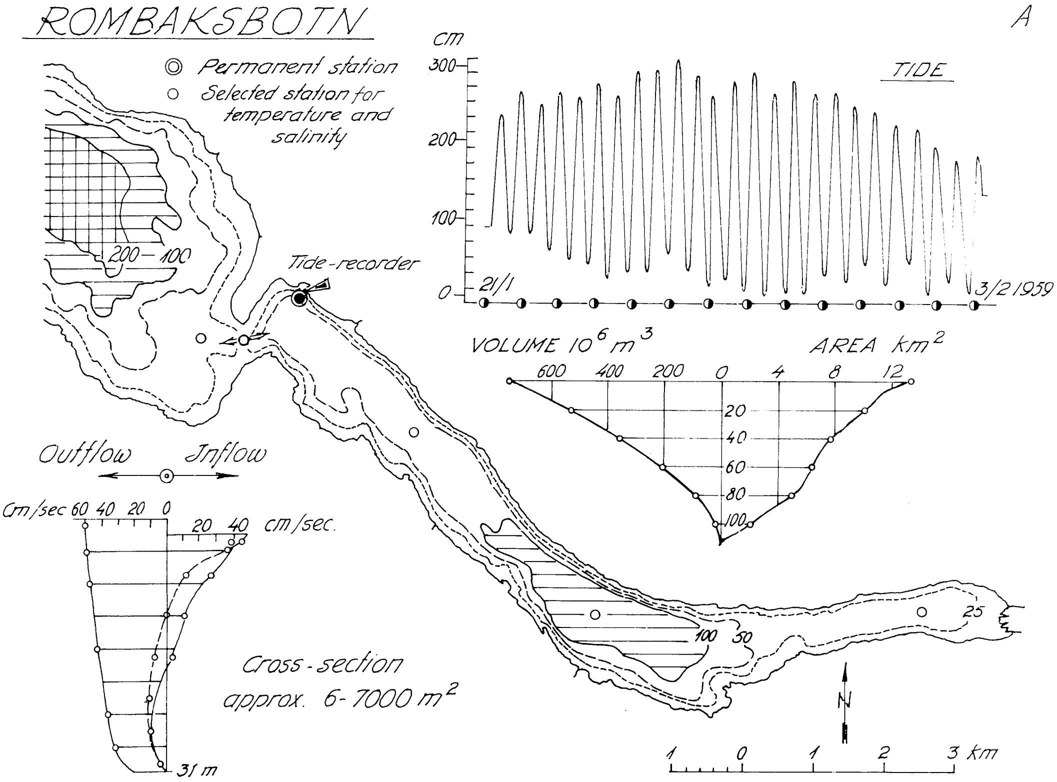
Humidity = 75 % Global radiation = 0

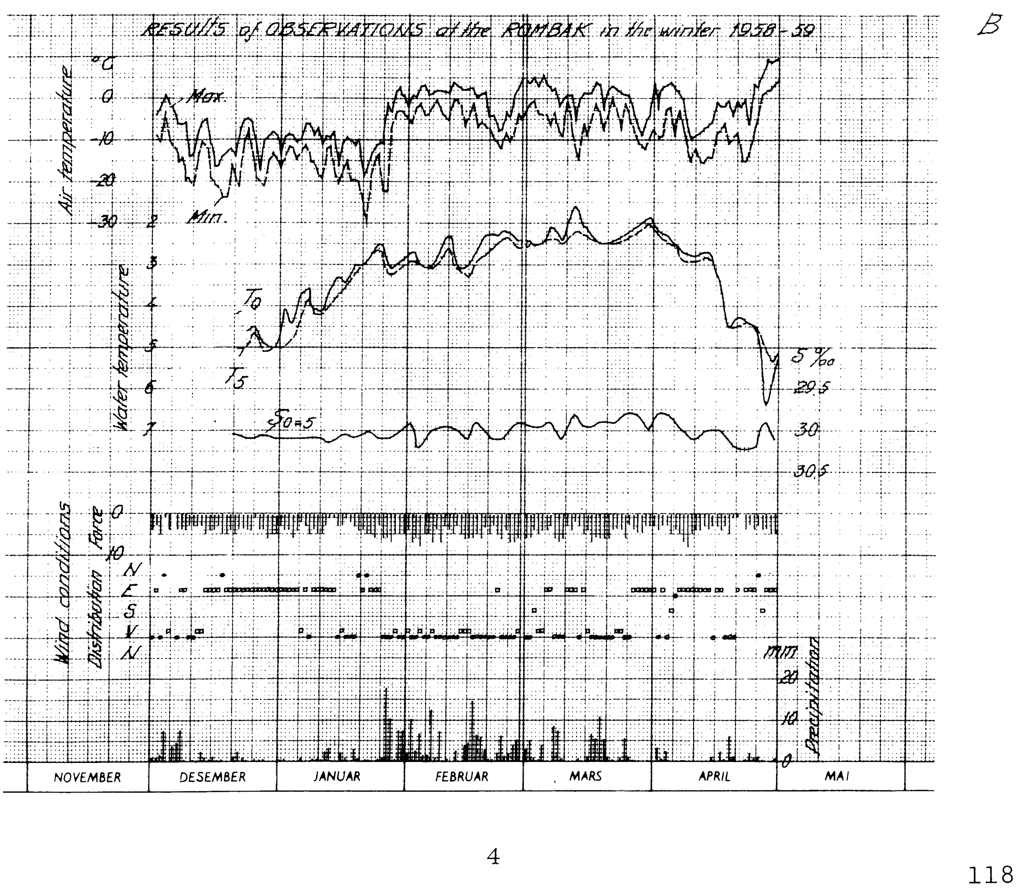
Fig. 2

## 2. SOME RESULTS FROM INVESTIGATIONS IN ROMBAKSBOTN.

Fig. 3 shows: A. Depth chart of the fjord, and an example of tidal variation and the local currents. B. Results of observations at the permanent station in the winter 1958-59.

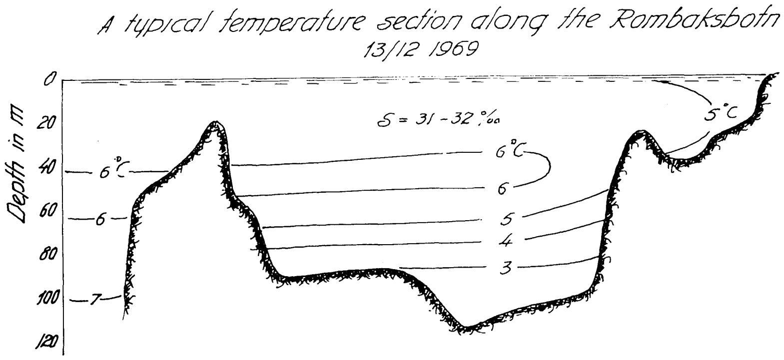
Fig. 3.


ROMBAKSBOTN
A
Permanent station
Selected station for temperature and salinity
Tide-recorder
TIDE
cm
300
200
100
0
21/1
3/2 1959
VOLUME 10⁶ m³
AREA km²
Outflow
Inflow
Cm/sec 60 40 20 0
20 40 cm/sec.
31 m
Cross-section approx. 6-7000 m²
200-100
100
50
25
N
1 0 1 2 3 km


B
RESULTS of OBSERVATIONS at the ROMBAK in the winter 1958-59
Air temperature
°C
Max.
Min.
Water temperature
T0
T5
S0=5
5 ‰
29.5
30
30.5
Wind conditions
Force
Distribution
N
E
S
V
N
mm
Precipitation
NOVEMBER
DESEMBER
JANUAR
FEBRUAR
MARS
APRIL
MAI

Observations show that the daily change in temperature can penetrate down to a depth of approx 10 metres. The annual variations can reach down to approx 100 metres. This is shown on graph Fig. 4 and a typical distribution of temper. ture in the Rombaksbotn.

Calculations show that roughly $20.10^6$ $m^3$ of sea-water is carried in and out of the fjord in one tidal-period.



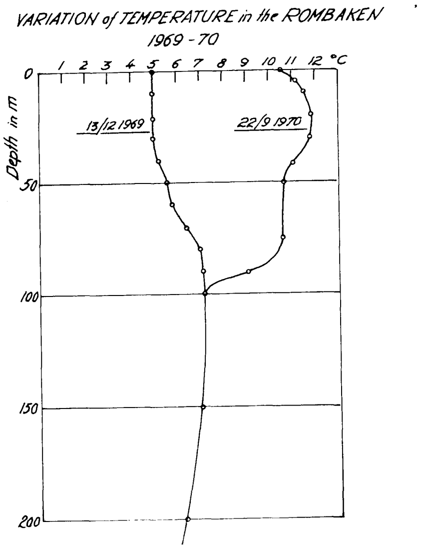




Fig. 4

The results of the winter cooling vary very much. After a wet and warm summ and autumn the stability under the surface layer is good and, therefore, the win ter cooling does not penetrate far down. After a dry summer and autumn, however, it reaches quite far down.

Observations show that if snow falls on comparatively warm seawater of high salinity the melting of the snow will start a circulation in the water-layers belov In brackish water, however, falling snow under calm conditions will cause a strong cooling without noticeable changes in the stability of the water masses.

Ice very seldom or never appears on the Rombaken.

## 3. SOME RESULTS FROM INVESTIGATIONS IN THE SØRFJORD

Fig. 5 explains the conditions at the Sørfjord. A. Bottom contourmap of the fjord and location of the measuring stations. B. Some results of the observations at the Hemnes station in the winter 1958-59.

The Sørfjord and the Elsfjord form a natural basin cut off from the Ranafjord at the Hemnes bv the shallow Sundfjord and the narrow Skarpsund, max depth 25 m.

The Røssåga catchment area is 2125 $km^2$, and the whole drainage area of Sørfjord and Elsfjord is approx 3000 $km^2$. The Røssåga power plant discharges about 120 $m^3$/sec of water with a temperature of, say 0,5 $^oC$ at a considerable velocity into the fjord.

The Sørfjord and Elsfjord are ice-covered every winter. A stirring and mixing of fresh water with warmer sea water causes an open area of a considerable size. The fresh water is transferred to more and more brackish water moving correspondingly more slowly. The slow moving water masses are in equilibrium with the surrounding sea water and result in a slow flow under the ice. The outflow from the Sørfjord is a streamline flow and causes a small open area only at the southern part of the Skarpsund.

A typical temperature section along the Sørfjord shown on graph Fig. 6.

Through the Skarpsund and Sundfjord an intense mixing of the water masses takes place. Conditions important for this mixing are: wind, tide, seiche, water density, traffic on the fjord, etc.

## CONCLUSION

In a fjord, the formation of ice is strongly dependent on stability of the water masses. This may be formed by a fresh-water layer at the surface.

External disturbances that can prevent ice formation are all forms of processes which break down the gradients of the surface layer, primarily caused by current and wind. Experience shows that during calm, high-pressure periods in the winter, cold offshore wind will often be sufficient to transport the fresh surface-layer out of the fjords. The out-going surface-current will cause an upgoing flow of warmer sea-water in the inner part of the fjord.

Further experience shows that the tidal currents are most effective in narrow and shallow sounds, while they are less important in deep and open fjords.

A snow-fall increases the risk of ice-formation for two reasons. Firstly, the snow-cover calms smaller waves and prevents a mixing of the surface layer. Secondly, and this is the most important point, the melting of the snow needs large quantities of heat, which are primarily taken from the layers below. Even where a fresh-water layer is not distinct, a snow-cover will give slush and existence-conditions to formation of slush ice.

Observations show that an enclosed fjord can be covered with ice relatively easily on the inside, where the fresh-water is supplied.

A number of different interesting problems are connected with the investigations of the physical conditions of the fjords. We need to study these in the future.

Fig. 5.

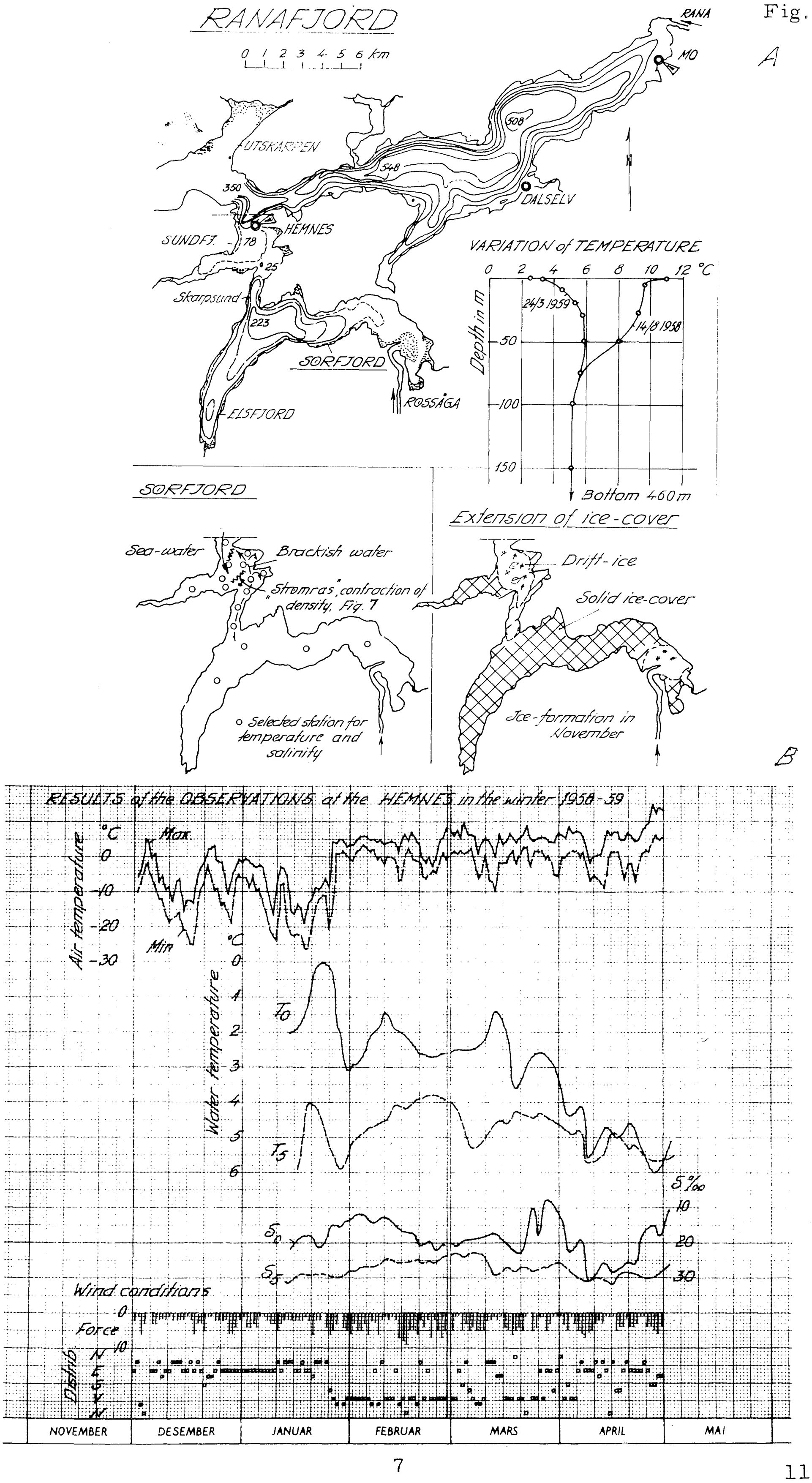

A
RANAFJORD
0 1 2 3 4 5 6 km
RANA
MO
UTSKARPEN
DALSELV
HEMNES
SUNDFJ.
Skarpsund
SØRFJORD
RØSSÅGA
ELSFJORD
VARIATION of TEMPERATURE
0 2 4 6 8 10 12 °C
Depth in m
24/3 1959
14/8 1958
50
100
150
Bottom 460 m
SØRFJORD
Sea-water
Brackish water
"Strømras", contraction of density, Fig. 7
Selected station for temperature and salinity
Extension of ice-cover
Drift-ice
Solid ice-cover
Ice-formation in November
B
RESULTS of the OBSERVATIONS at the HEMNES in the winter 1958-59
Air temperature
°C
Max.
Min
0
-10
-20
-30
Water temperature
°C
T0
Ts
S ‰
S0
Ss
10
20
30
Wind conditions
Force
Distrib.
N
E
S
V
N
NOVEMBER
DESEMBER
JANUAR
FEBRUAR
MARS
APRIL
MAI

Fig. 6.

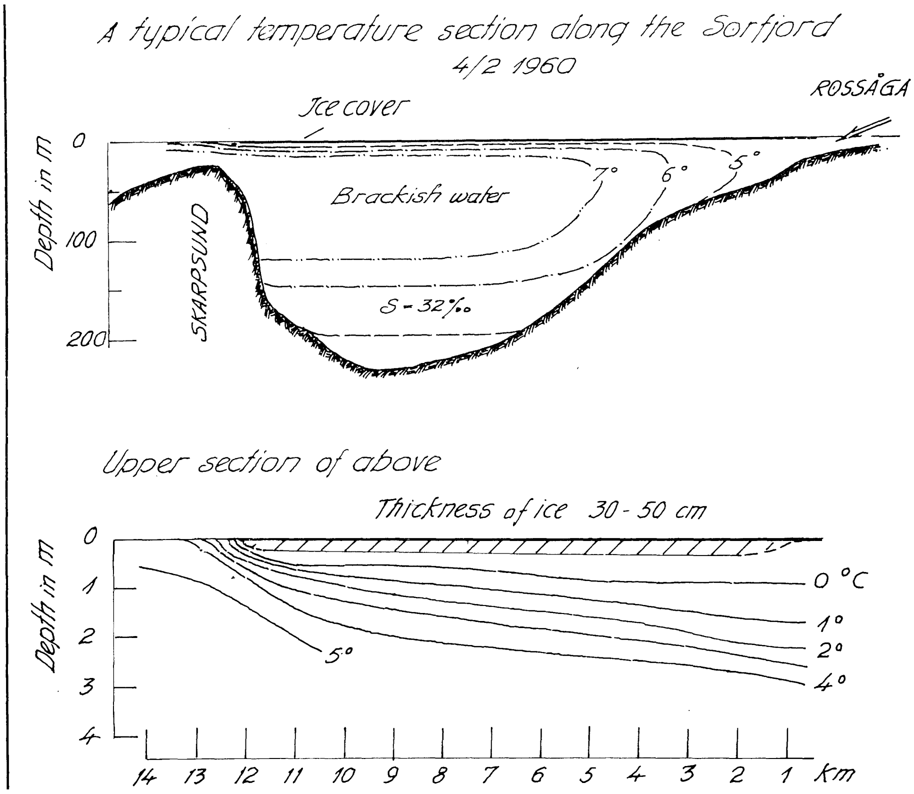
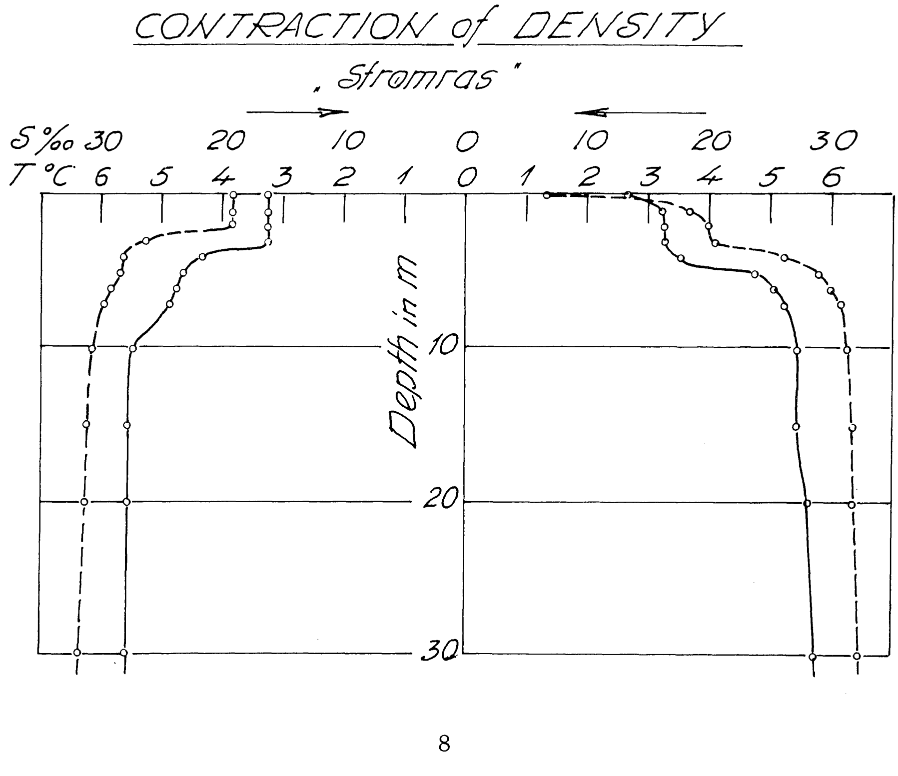

A typical temperature section along the Sorfjord
4/2 1960
ROSSÅGA
Ice cover
Depth in m
0
100
200
7°
6°
5°
Brackish water
SKARPSUND
S - 32‰
Upper section of above
Thickness of ice 30 - 50 cm
0
1
2
3
4
0 °C
1°
2°
4°
5°
14 13 12 11 10 9 8 7 6 5 4 3 2 1 km

Fig. 7.


CONTRACTION of DENSITY
„ Stromras "
S ‰ 30 20 10 0 10 20 30
T °C 6 5 4 3 2 1 0 0 1 2 3 4 5 6
Depth in m
10
20
30