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A HYDROGRAPHICAL SURVEY OF THE WATERS IN THE ÅLAND SEA

by

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Abstract

An effort is made to survey hydrographically the waters in a limited sea area, in the Åland Sea, being a transitional basin between the Gulf of Bothnia and the Baltic Sea proper. By means of the rather high number of practically synoptic data, the different water types could be determined. The salinity data were used to show the surface currents and also the deep currents. The pattern of surface currents proves more complicated than previously assumed. A distinction is made between the discontinuity layers of temperature and salinity. An exceptionally high degree of stability is encountered where the summer thermocline and the maximum vertical gradient of salinity come together.

Along the eastern edge of the Åland Sea warm water intrusions are observed flowing downhill along the isopycnic surfaces below the thermocline but above the minimum temperature layer. Finally, the degree of lateral mixing is estimated.

1. *The Åland Sea*

The water exchange between the Gulf of Bothnia and the Baltic proper proceeds both through the Åland Sea and through the Archipelago Sea, east of the main island of Åland. The area of the Archipelago Sea, 8,300 square kilometers, is larger than that of the Åland Sea, which

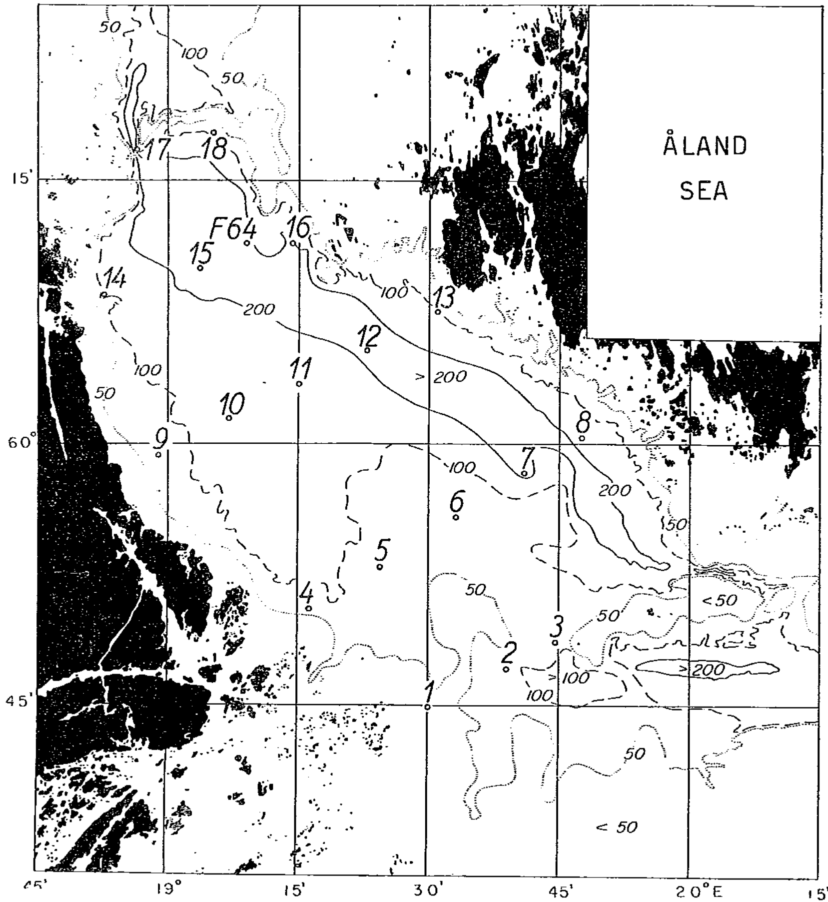

Fig. 1. The depth contours of the Åland Sea, with the location of the hydrographical stations.

is only 5,200 square kilometers. However, as indicated by the mean depth figures, 23 and 77 meters, the water exchange through the Åland Sea must be much less restricted. As can be seen in Fig. 1, the length of the Åland Sea, from the southern sill to the lighthouse of Märket (near the station 18), is approximately 90 kilometers, while the width is at its minimum only 35 kilometers.

The southern sill, approximately along the latitude 59°35′, has an approximate maximum depth of 40 meters. However, a narrow canyon with a depth of almost 200 meters, intersects this sill; the position

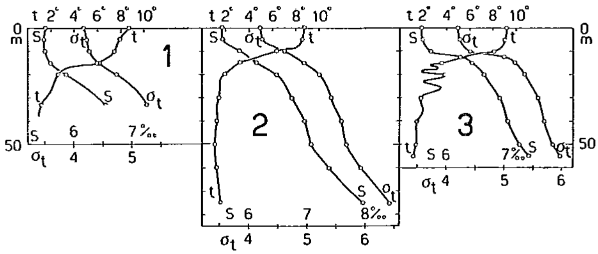

Fig. 2. Cross section 1—3, Åland Sea. 21 June 1956.
t = temperature with reversing thermometers (circles) and BT,
S = salinity of water samples drawn from Nansen bottles,
σ_t indicates the density.

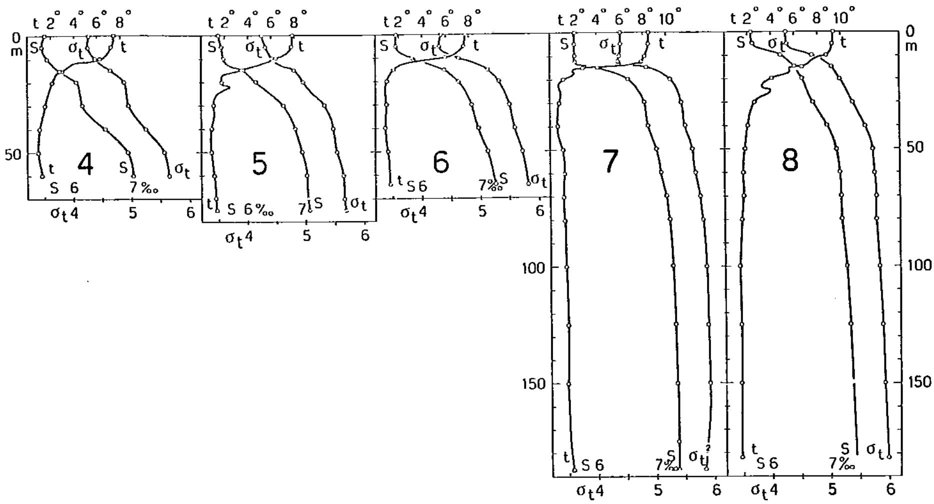

Fig. 3. Cross section 4—8, Åland Sea. 21 June 1956.
t = temperature with reversing thermometers (circles) and BT,
S = salinity of water samples drawn from Nansen bottles,
σ_t indicates the density.

of its southern opening is 59° 30′ N., 20° 38′ E., with depths of some 70 meters south of the opening. The deeper waters which are able to cross the southern sill through this canyon penetrate the deeper, separate basin at 59° 47′ N., 20° E. The sill depth west of this basin is some 80 meters. The depth of the sill northnortheast of it is approximately 65 meters. Thus the actual minimum depth of the southern sill is about 70 meters.

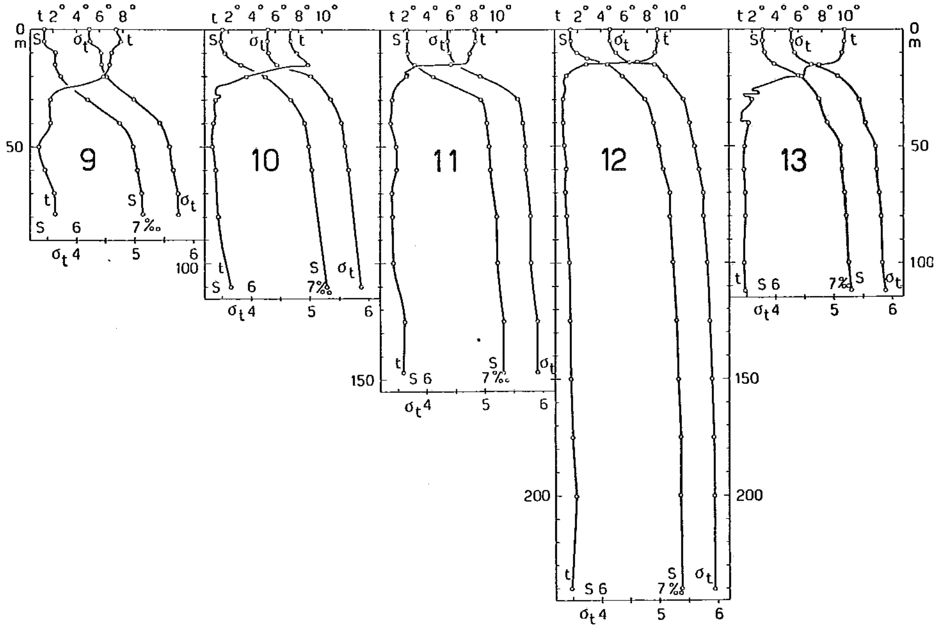

Fig. 4. Cross section 9—13, Åland Sea. 20 June 1956.
t = temperature with reversing thermometers (circles) and BT,
S = salinity of water samples drawn from Nansen bottles,
σ_t indicates the density.

The maximum depth found in the Åland Sea is 301 meters between Eckerö and Grisslehamn. In the eastern part of the Åland Sea there is an elongated deep with depths greater than 200 meters. This deep continues as a rather narrow canyon through the northern sill of the Åland Sea.

2. *The hydrographic stations*

The location of the hydrographic stations is given in Fig. 1. Beside the water samples taken by means of Nansen bottles at the standard depths of the Baltic area, protected reversing thermometers were used in pairs at the same depths. Owing to the rather calm sea and slow currents the wire angle was at every station practically zero, except for the depths greater than 125 m at St. 12. For this reason, the unprotected reversing thermometers were not used, that is, the sampling depths were taken directly from the readings of the meter wheel. As an addition

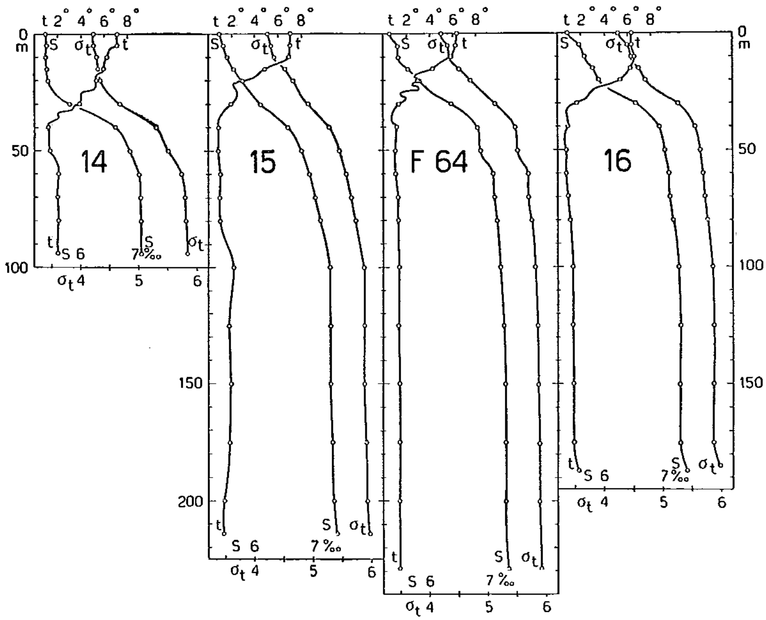

Fig. 5. Cross section 14—16, Åland Sea. 20 June 1956.
t = temperature with reversing thermometers (circles) and BT,
S = salinity of water samples drawn from Nansen bottles,
σ_t indicates the density.

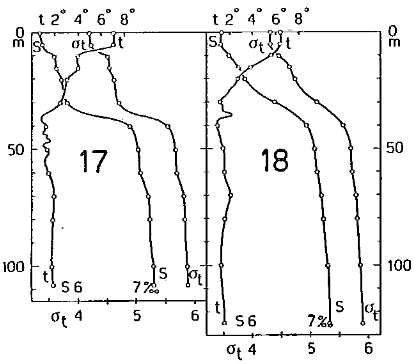

Fig. 6. Cross section 17—18, Åland Sea. 20 June 1956.
t = temperature with reversing thermometers (circles) and BT,
S = salinity of water samples drawn from Nansen bottles,
σ_t indicates the density.

a BT was used at every hydrographic station. As a reference temperature the whole set of readings of the reversing thermometers was used in order to avoid the sometimes erroneous surface readings. In order to record all the details of the thermal structure, a minimum speed was used at the winch.

The period of study, consisting of 36 hours only, during which time all the 19 stations were occupied, was short enough to allow the data to be considered synoptic. This is possible since the tidal range of the Åland Sea is of the order of magnitude of 2 centimeters and since the winds before and during the period of study were rather calm.

The data are given as temperature, salinity and σ_t curves in Figures 2—6, which correspond to the different cross sections from south to north. The curves show, in spite of the restricted size of the sea area under consideration, a quite varying character. A few remarks about the curves are necessary as an explanation to the Figures.

3. *Vertical distribution of temperature and salinity*

The vertical distribution of temperature is characterized at most stations by a relatively warm surface layer, by a discontinuity layer (summer thermocline), by a temperature minimum, and by a slightly warmer deep water. The salinity distribution is characterized by a less saline surface layer, by a discontinuity layer (»halocline») of the salinity, and by a more saline deeper water. At St. 2 also another »halocline» is seen with still more saline water underneath. As will be seen in Fig. 8, this water of a salinity of 8 parts per thousand is just penetrating the basin of the Åland Sea across the southern sill. The density distribution is predetermined mainly by salinities, since even at the surface the temperatures were rather low.

It is quite surprising to notice the remarkable differences between the bathythermograms. Schematically the BT curves can be divided into two groups:

(a) The »normal» temperature curves with an isothermal layer and with a well defined thermocline more or less immediately underneath.

(b) The deviating temperature curves which show, instead of one well defined thermocline, either a set of thermoclines with isothermal layers between them or an analogous but well smoothed curve. A whole set of thermoclines is observed very clearly at St. 14. It is, of course, difficult to gorup all the BT curves into the above two categories, nevertheless,

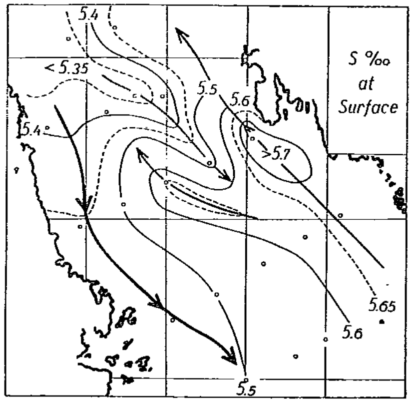

Fig. 7. Distribution of salinity at the surface of the Åland Sea, 20—21 June 1956.

at least the stations 15, F64, 17 and 18 also belong to the second one. All these stations have two more characteristics in common: they are in the tongues of less saline surface water flowing from the Bothnian Sea into the Åland Sea and, secondly, at all these stations the maximum vertical gradient of salinity (»halocline») is encountered much deeper than the maximum gradient of temperature or summer thermocline, defined for our purposes this way. Thus it is evident that the temperature distribution is predetermined to a great extent by the salinity distribution and by the processes of advection or, in other words, a »halocline», if not too deep, has the tendency to become a strong summer thermocline.

4. *Horizontal distribution of temperature and salinity*

The horizontal distribution of salinity and temperature show many interesting features. First of all, the direction of the surface currents can be seen in Fig. 7, where the surface salinities are given. Layers of 5, 10, 15 and 20 meters give a similar but still more pronounced pattern. The corresponding temperature distributions, when the less conservative character of this element is taken into account, are in good correspondence with the current arrows of Fig. 7, that is, the southerly more saline waters are also much warmer than the northerly waters. For instance, at the depth of 10 meters, the temperature was at St. 13 not less than 9.71°C, while at St. 17 the temperature was only 3.99°C.

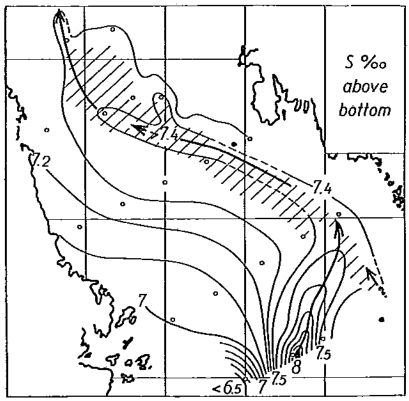

Fig. 8. Distribution of salinity above the bottom of the Åland Sea, 20—21 June 1956.

5. *Surface currents*

In the movements of surface waters the following significant details can be seen. In the easternmost region there is observed a relatively warm, rather saline surface current from southeast to northwest or, rather, in the direction between the opening between Lågskär (east of St. 3) and the Åland mainland towards Märket (just east of St. 18). In the westernmost part of the Åland Sea the traditionally known colder, less saline surface current follows the Swedish coast. Beside these two currents, another pair of current branches is observed. A current from the south follows roughly a route between the stations 7, 11 and 15, while a current from the north follows the route F64 and 12. The permanency of these more or less secondary current branches cannot be estimated by means of these few data; nevertheless, the reality of them is beyond any doubt, as indicated by other distributions at other levels. Actually, as seen in the degree of slopes of the »halocline», the westernmost, southeastbound current is the most significant one, as shown also by Palmén [4] in an analysis of the current observations of the lightships.

6. *Deep currents*

The salinity distribution just above the bottom, as shown in Fig. 8, is a very simple one. Close to St. 2, water of relatively high salinity is penetrating the Åland Sea across the sill between Söderarm and Lågskär. By means of our data it is not quite easy to estimate whether or not similar saline water penetrates the Åland Sea also along the canyons north and east of Lågskär, as indicated in the Figure by a question mark. Nevertheless, the saline deep water follows the downhill contours of the bottom topography, reaches the eastern deep of the Åland Sea, being more than 200 meters deep, not far from St. 8 and takes a path along this deep through the stations 8, 12, 15 and 17 towards the Bothnian Sea. The distribution of bottom temperature is not indicative to the water movements, since it shows a variety of the effects of the, most probably not continuous, advection of the bottom water and of the cooling during the previous winter, which is recognized as the temperature minimum.

7. *Water types*

It is evident that in the basin of the Åland Sea a continuous mixing is going on between waters of different origin. Normally in oceanography the TS diagram is an ideal tool for the study of mixing processes between different water masses. In the Baltic Sea, however, as can be seen in the paper of Granqvist [1], it has proved difficult to make use of the TS diagram since, instead of a few clearly defined water masses, all the different intermediary waters between North Sea water and river water take part in the mixing processes. The difficulties become even more pronounced, when it is remembered that in this case the North Sea water is Kattegat water with most varying salinity and that all the waters have an annual cycle of temperature. Nevertheless, it should be possible to use the TS diagram in a small section basin like the Åland Sea for the separation of the different water types. In Fig. 9 the result of our experiment is seen. It must be understood that this representation is both schematic and more or less arbitrary, since another set of stations would most probably give a somewhat different diagram.

Nevertheless, this scheme, where the TS curves are actual ones from the stations 5, 10 and 13, can be used to explain the origin of different water types. (The word »water type» is used instead of the more traditional one of »water mass» in order to emphasize their more or less varying character.) As an explanation to our TS scheme a few words are needed. The upper waters are characterized in our scheme by straight sloping lines which indicate continuous mixing between the surface and a colder and more saline water type called in our scheme »winter water». On the other hand, the upper waters having a northern origin (St. 5) must be less saline than upper waters having a southern origin (St. 13),

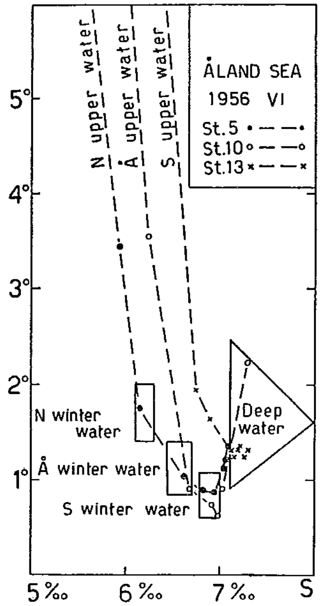

Fig. 9. TS diagram with the stations 5, 10 and 13 representing the different water types which take part in the mixing processes in the Åland Sea.

while there must be also intermediate types. These waters have been labeled Åland upper water (St. 10) in order to emphasize the effect of lateral mixing having taken place in the Åland Sea.

Both in the Åland Sea and north and south of it the surface waters are cooled off during the winter time, and as a result of this cooling a thorough mixing takes place up to a certain depth. This mixed layer is less saline in the north than in the south. Its temperature is not always the same, and its depth varies. When the upper waters are warmed again during the spring and summer, the lowermost layer of the waters cooled off during the previous winter appears as a temperature minimum, as seen in Figures 2—6 (or likewise in 10—14). It does not seem impossible to find, in our TS diagram, relatively well defined remains of the temperature minima of the Bothnian Sea (N winter water), of the northernmost part of the Baltic proper (S winter water) and of a third temperature minimum possibly produced locally in the Åland Sea (Å winter water).

It is interesting to recognize that the layer of minimum temperature, that is, the lower limit of winter convection appears in many regions of the Baltic also as an upper limit of the recent sedimentation. This

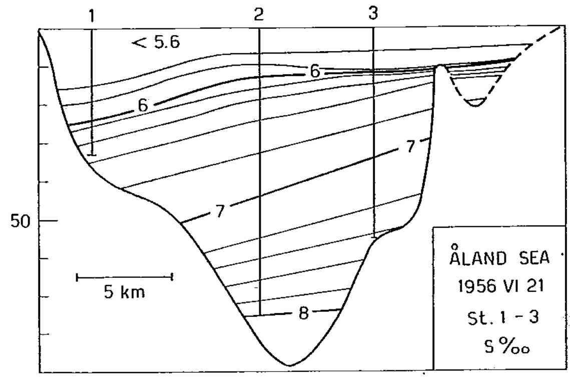

Fig. 10 a. Salinity cross section 1—3, Åland Sea.

means in practice that the winter convection is able to erode the material sedimented on the bottom during the summer, provided that the convection reaches the bottom.

An interesting feature of several of the temperature curves of Figs. 2—6 is indicated by the warm water »lenses» just above the temperature minimum. This feature, which is observed mainly at the stations along the eastern edge of the Åland Sea, will be considered in greater detail in connection with the cross sections.

In addition to the above water types, »deep water» is observed under the temperature minimum at several stations. This water, being of a rather high salinity and of higher temperature, penetrates the Åland Sea as a bottom current from the south. When not using the name »bottom water» for this water close to the bottom of the Åland Sea, an effort is made to emphasize the fact that this water is originally deep water and not bottom water of the northernmost part of the Baltic proper.

8. *S and t cross sections*

The salinity and temperature cross sections are given as Figures 10—14 where the depth exaggeration is 200. They need a few numerical figures as an explanation.

Stations 1—3. Salinity cross section (Fig. 10a). The surface salinities less than 5.6 $^0/_{00}$, the bottom ones more than 8 $^0/_{00}$. The depths of the maximum vertical gradient of salinity: St. 1, 25 meters, 6.17 $^0/_{00}$; St. 2, 15 meters, 6.13 $^0/_{00}$; St. 3, 12 meters, 6.10 $^0/_{00}$. This discontinuity layer of salinity slopes from station 3 towards the west. There were no

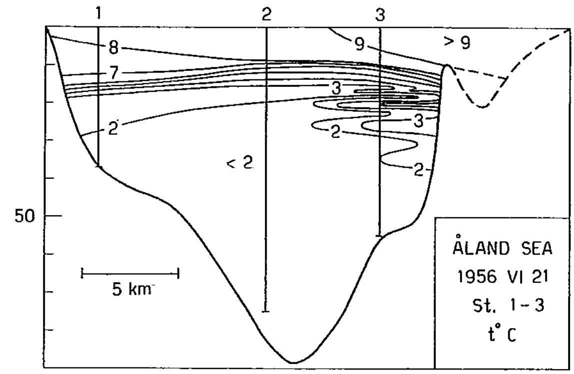

Fig. 10 b. Temperature cross section 1—3, Åland Sea.

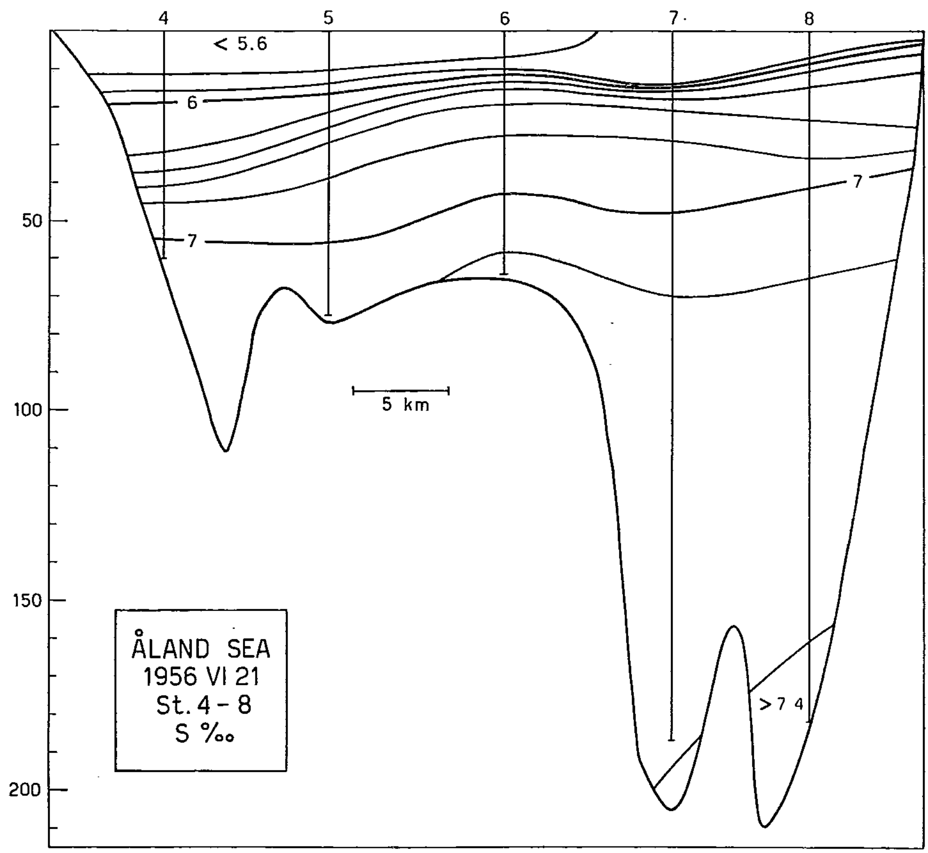

Fig. 11 a. Salinity cross section 4—8, Åland Sea.

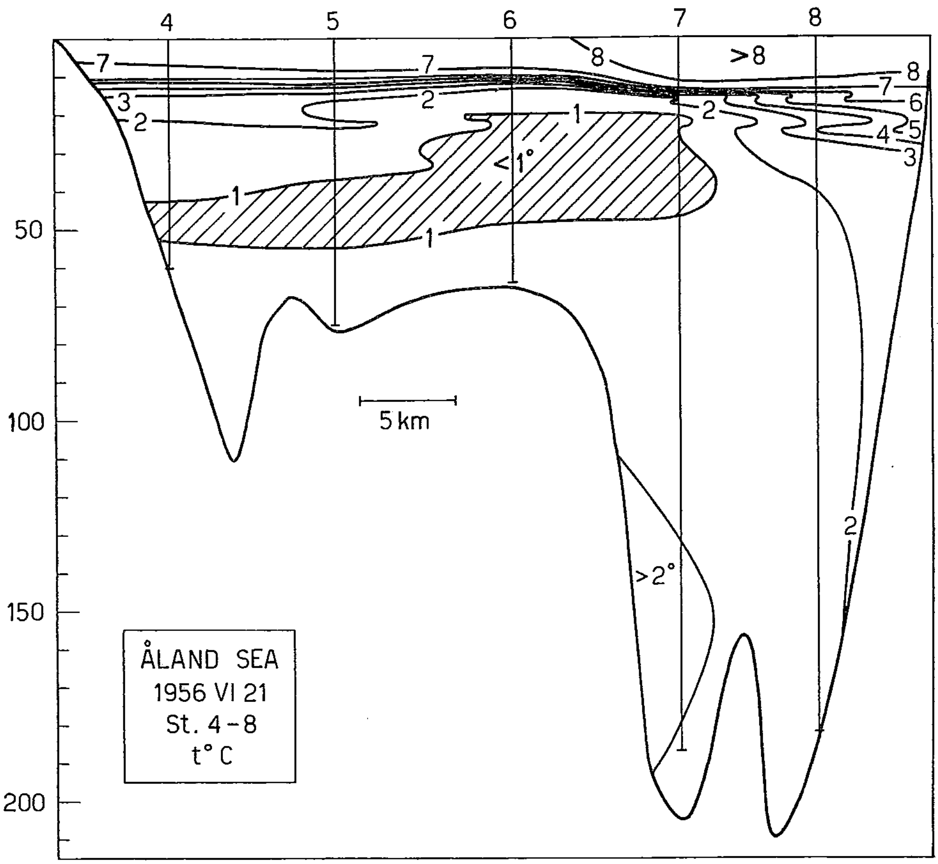

Fig. 11 b. Temperature cross section 4—8, Åland Sea.

data available east of St. 3, although the isohalines have been drawn more or less horizontal.

Stations 1—3. Temperature cross section (Fig. 10b). The surface temperature above 9°C in the east and above 8°C in the west. The temperature of the deepest part below 2°C. The maximum vertical gradient of temperature: St. 1, 16 meters; St. 2, 10 meters; St. 3, 11 meters. There are no signs of the temperature minimum brought about by the cooling of the previous winter. At St. 3 the warm water intrusions are observed.

Stations 4—8. Salinity cross section (Fig. 11a). The surface salinities less than 5.6 ‰ in the west and less than 5.8 ‰ in the east. The bottom

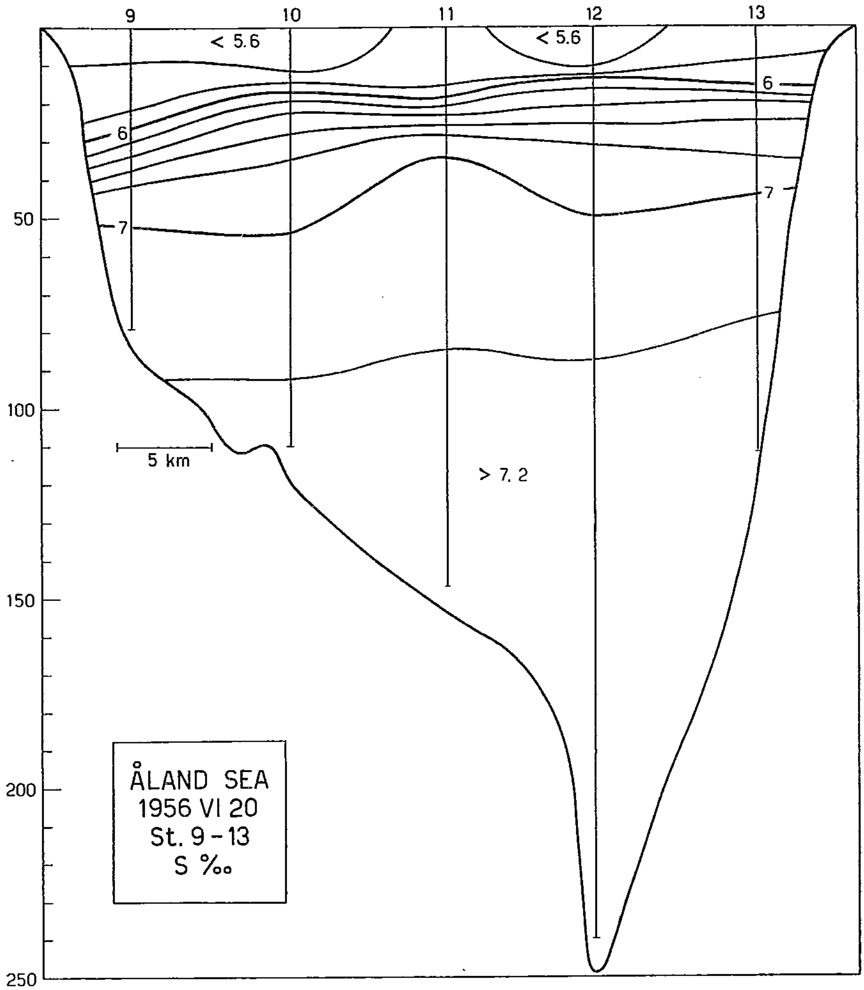

Fig. 12 a. Salinity cross section 9—13, Åland Sea.

salinities above 7.4 ‰. The depths of the maximum vertical gradient of salinity: St. 4, 18 meters, 5.92 ‰; St. 5, 14 meters, 5.84 ‰; St. 6, 13 meters, 6.17 ‰; St. 7, 15 meters, 6.00 ‰; St. 8, 9 meters, 6.10 ‰. This discontinuity layer of salinity slopes towards the west between stations 7 and 8, and west of station 6.

Stations 4—8. Temperature cross section (Fig. 11b). The surface temperature above 8°C in the east and above 7°C in the west. The temperature of the deepest part about 2°C. The maximum vertical

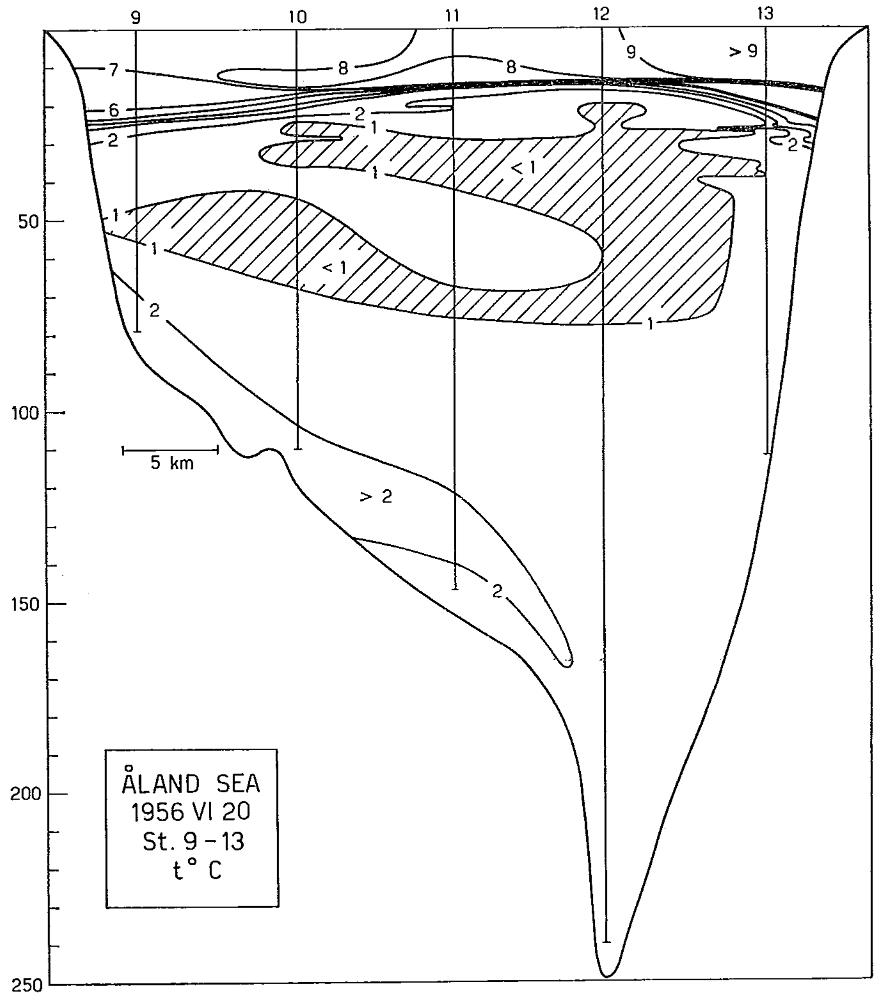

Fig. 12 b. Temperature cross section 9—13, Åland Sea.

gradient of temperature: St. 4, 5, 6 and 8, 11 meters, St. 7, 14 meters. This gradient has a value of 5°C per 2 m at St. 7. A temperature minimum with temperatures below 1°C is seen at stations 4—7 at a mean depth of 50 meters in the west and of 35 meters in the east. At St. 8 warm water intrusions are observed.

Stations 9—13. Salinity cross section (Fig. 12a). The surface salinities less than 5.6 ‰ both in the west and around St. 12, less than 5.8 ‰ in the east and around St. 11. The bottom salinities near 7.4 ‰. The depths

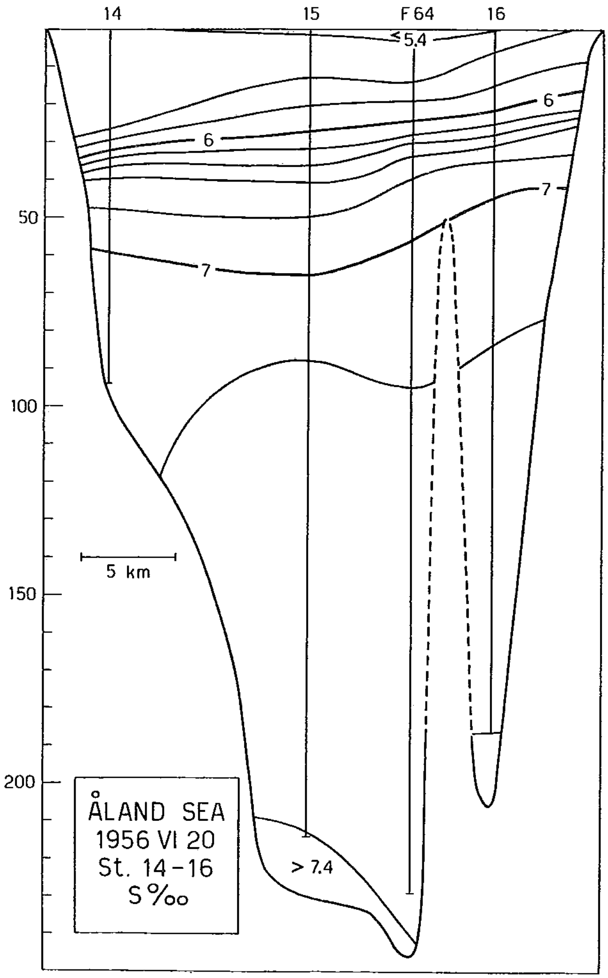

Fig. 13 a. Salinity cross section 14—16, Åland Sea.

of the maximum vertical gradient of salinity: St. 9, 29 meters, 6.15 ‰; St. 10, 17 meters, 5.95 ‰; St. 11, 20 meters, 6.10 ‰; St. 12, 14 meters, 5.98 ‰, St. 13, 18 meters, 6.22 ‰. This discontinuity layer of salinity slopes towards the west between stations 11 and 12 and west of station 10; and towards the east between stations 10 and 11 and east of station 12.

Stations 9—13. Temperature cross section (Fig. 12b). The surface temperature above 9°C in the east and above 7°C in the west. The

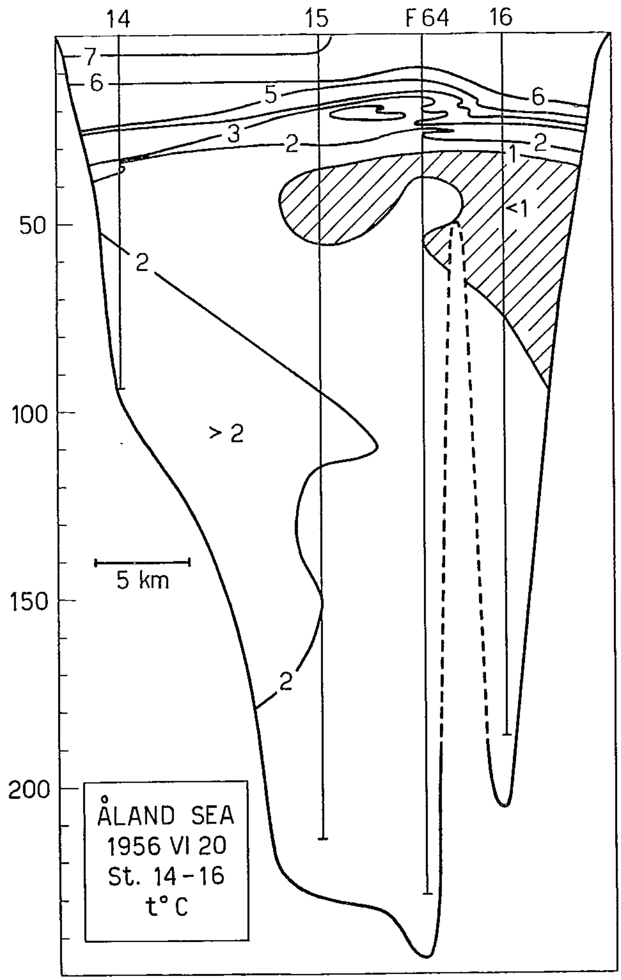

Fig. 13 b. Temperature cross section 14—16, Åland Sea.

temperature of the deepest part about 2°C. The maximum vertical gradient of temperature: St. 9, 24 meters; St. 10, 16 meters; St. 11, 15 meters; St. 12, 15 meters; St. 13, 20 meters. This gradient has a value of 4°C per 0.6 m at St. 11, and 4°C per 1.0 m at St. 12. A temperature minimum with temperatures below 1°C is seen at stations 9—12 at a mean depth of 50 meters in the west and 45 meters in the east. This minimum has to a certain extent the appearance of several sheets both towards west and east. At St. 13 warm water intrusions are observed.

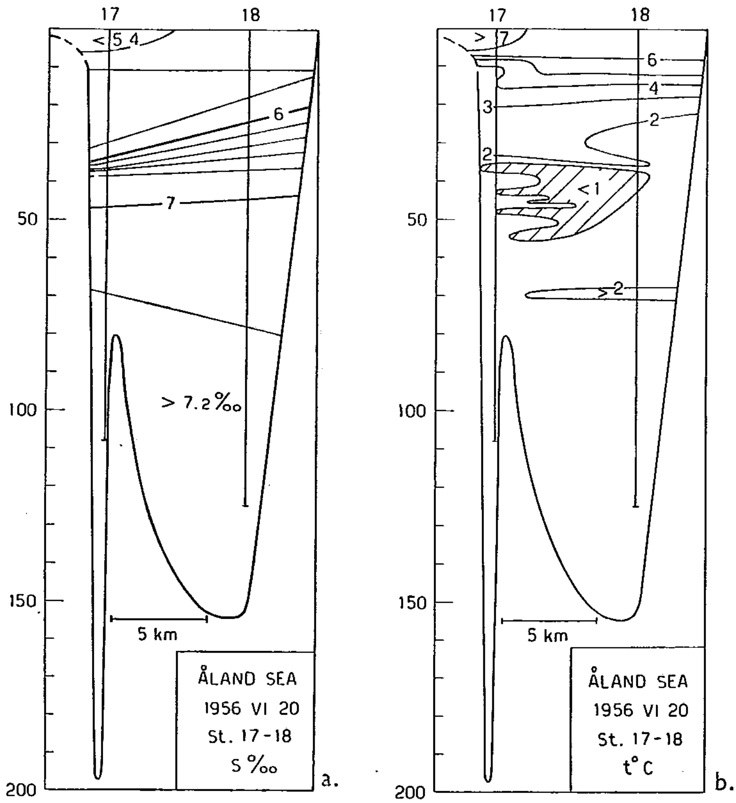

Fig. 14 a. Salinity cross section 17—18, Åland Sea. — 14 b. Temperature cross section 17—18, Åland Sea.

Stations 14—16. Salinity cross section (Fig. 13a). The surface salinities less than 5.4 ‰ in the middle, otherwise apparently less than 5.6 ‰. The bottom salinities about 7.4 ‰. The depths of the maximum vertical gradient of salinity: St. 14, 35 meters, 6.25 ‰; St. 15, —; St. F64, 29 meters, 6.30 ‰; St. 16, 27 meters, 6.32 ‰. This discontinuity layer slopes towards the west between stations F64 and 16 and west of station 15; and towards the east between stations 15 and F64 and possibly east of station 16.

Stations 14—16. Temperature cross section (Fig. 13b). The surface temperature above 7°C in the west and above 6°C in the east. The temperature of the deepest part about 2°C. The thermocline is not well defined at any station, nevertheless, the maximum gradients are observed as follows: St. 14, 24 meters; St. 15, 20 meters; St. F64, 16 meters; St. 16, 22 meters. A temperature minimum with temperatures less than 1°C is observed between stations 15 and 16 at a mean depth of 45 or 50 meters. At St. F64 warm water intrusions are observed.

Stations 17—18. Salinity cross section (Fig. 14a). The surface salinities less than 5.4 ‰ in the west and less than 5.6 ‰ in the east. The bottom salinities apparently about 7.3 ‰. The depths of the maximum vertical gradient of salinity: St. 17, 36 meters, 6.36 ‰; St. 18, 30 meters, 6.37 ‰. This discontinuity layer of salinity slopes towards the west.

Stations 17—18. Temperature cross section (Fig. 14b). The surface temperature above 7°C in the west and above 6°C in the east. The temperature of the deepest part about 2°C. The maximum vertical gradient, though not well defined, is observed at St. 17 at the depth of 8 meters and at St. 18 at the depth of 15 meters. A temperature minimum with temperatures less than 1°C is seen at 45 meters in the west and at 40 meters in the east; however, the minimum consists in the west of several sheets of cold water.

9. *Margules's equation*

First of all, the MARGULES's [3] equation

$$tan\ \gamma = \frac{2\omega \sin \varphi}{g} \frac{\varrho u - \varrho' u'}{\varrho' - \varrho}$$

can be applied to the sloping »halocline» in order to estimate the speed of the surface current. In this equation, as usual, γ is the slope of the »frontal surface», u and u' are the speeds on both sides of the surface, and ϱ and ϱ' are the corresponding densities of water.

In our case, approximately,

$$u \approx 10800 \quad tan\, \gamma \quad (\text{cm sec}^{-1}),$$

if it is assumed that $u' \sim 0$. In the representation of the surface currents in the seas around Finland PALMÉN (*loc. cit.*) has given approximate values for the southsoutheast bound current of the western Åland Sea. Those local values were based upon interpolation solely; nevertheless, their order of magnitude can be estimated from his Fig. 2 to some 6 cm sec^{-1} in the western part (and some 3 cm sec^{-1} east of the middle line) of the Åland Sea. This speed would correspond to the slope $tan\ \gamma = 5.5 \times 10^{-4}$, or in the Figs. 10—14 where the depths are exaggerated 200 times, to 1:9. This slope is actually seen in the western parts of the cross sections 4—8, 14—16 and 17—18 (Figs. 11, 13 and 14). Thus PALMÉN's estimation seems to be of the right order of magnitude, at least on the average. The southbound surface current between stations 1 and 2 seems to be some 15 cm sec^{-1}, according to this way of estimation. This value may not be impossible.

10. *Summer thermocline and »halocline»*

When studying more carefully the depths of the maximum vertical gradient of salinity (»halocline») and temperature (a true summer thermocline) it is seen that they are in general identical only in the regions of surface currents from the south. In the regions with surface currents from the north the »halocline» is always observed at a greater depth than the thermocline.

The mean salinities of the »halocline» for the cross sections are from the south to the north: 6.13, 5.99, 6.08, 6.29 and 6.36 $^0/_{00}$. These figures must be very approximate only, since, especially in the southernmost section, the three stations cannot represent the whole section properly; nevertheless, it is evident that the mean salinity of the maximum vertical salinity gradient increases from the south to the north. At the same time the »halocline» has the tendency to sink deeper in the water column: east of St. 3 and around St. 8 this depth is less than 10 meters, while at St. 17 it is more than 35 meters. Thus the slope of the »halocline» is of the order of magnitude of 5×10^{-4}. The isohaline surfaces must slope in the same direction; however, the »halocline» is not identical with one of them, which would be the case if a surface current would move above it uphill from the north to the south and a deeper current of higher salinity under it downhill from the south to the north, without any considerable mixing between them. Instead, the isohalines between the salinities 6.0 and 6.3 $^0/_{00}$ cross the »halocline» surface, each in turn. The existence of the »halocline» can be explained geometrically assuming that each isohaline bends down at the »halocline», bringing about a congestion of the isohaline surfaces, i.e., a maximum of the vertical gradient of salinity.

The thermocline is at its sharpest at the stations 12, 11 and 7. In general the thermocline is sharper in the open part of the Åland Sea than on the sills, sharper in the east than in the west, and sharper on the southern sill than on the northern sill where one cannot find any real thermocline. The main explanation to this distribution is simply based upon the existence or lack of differences in advection at the thermocline.

11. *Vertical stability*

It is interesting to check the degree of vertical stability introduced by HESSELBERG [2] in the from

$$E = \lim_{\Delta z \to 0} \frac{1}{\varrho} \frac{\Delta \varrho}{\Delta z}$$

or, roughly,

$$E \approx 10^{-3} \frac{1}{\varrho} \frac{\Delta \sigma_t}{\Delta z} .$$

E is not a perfect measure of the stability, since its computation is always based upon one layer between two sampling depths, the choice of which is arbitrary, whereby attention is not paid to the additional stability of the neighbouring layers. In the following list the vertical stability is given for two stations 4 and 6, the former of which represents the southbound current with different levels for the maximum gradients of temperature and salinity, and the latter representing the northbound current with a combined level for the two maximum gradients.

Depth	$10^8 E$ (m^{-1})	
	St. 4	St. 6
0		
5	−400	−600
10	2600	6600
15	5200 1)	10000 3)
20	4600	3800
30	800	1900
40	3000 } 2)	900
50	3200 } 2)	1300
60	800	700

1) Discontinuity layer of temperature;
2) Discontinuity layer of salinity;
3) Combined discontinuity layer of temperature and salinity.

The extreme value of the vertical stability $10^8\ E{=}42000\ m^{-1}$, was observed at the station 12 between 14 and 15 meters in a combined discontinuity layer of temperature and salinity.

12. *Layer of minimum temperature*

The layer of minimum temperature is observed, as mentioned above, at most stations but not at 1—3, 8, (13) and 14. The lack of a temperature minimum on the southern sill can be explained as an effect of the swift advection across the sill. The stronger mixing closer to the edges than in the middle of the basin explains the lack of a temperature minimum on the few other stations. It is also interesting to note that a high temperature of the minimum corresponds to a lower salinity or, as an example, if the salinity of water at the temperature minimum is 5.8 ‰, the probable temperature is 2.4°C (or 0.3°C less than the temperature of the maximum density), and if the salinity of water at the temperature minimum is 6.8 ‰, the probable temperature is 1.0°C (or 1.6°C less than the temperature of the maximum density). Without several hydrographical surveys, which would cover the whole year, this feature cannot be explained fully. Nevertheless, it must be connected with the beginning of the previous winter and with the processes of advection.

13. *Warm water intrusions*

The warm water »lenses» (cf. Figs. 2—6) appear just above the temperature minimum and in every case under the summer thermocline (in most cases even under the discontinuity layer of the salinity). WÜST [5] has shown an identical phenomenon in the Baltic proper by means of data collected between July 23 and August 11, 1956. Those of his warm water lenses, which were similarly related to the temperature minimum, were observed in the Bornholm Deep and in the Gotland Deep northeast of Gotland. He assumes that these »weak and thin temperature inversions», observed by him, are remnants from the vertical convection of the previous winter and not warm water intrusions from the west. (In addition, he has observed in Arkona Basin much stronger temperature inversions, which can be explained only as intrusions of warm and more saline water.)

The temperature inversions observed by us in the Åland Sea, the most typical of which are given in the TS diagram, Fig. 15, seem to be warm water intrusions from the south. In this case they cannot be

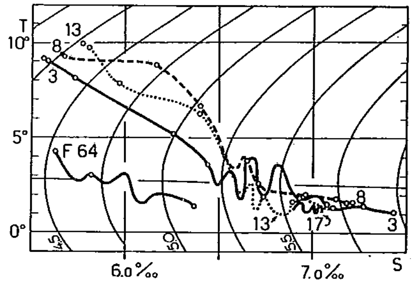

Fig. 15. TS diagram with the stations 3, 8, 13, F64 and 17, showing evidence for the warm water lenses.

connected with the vertical convection of the previous winter, since they are observed only in the eastern part of the Åland Sea, as can be seen in Figs. 10—14. The warm water intrusions (or lenses, if one prefers to emphasize the pulsatory character of them) at the stations 3, 8 and 13 seem to have been caused by more or less the same phenomenon: all of them are observed close to the temperature of maximum density and, in addition, they are in the same salinity interval. Since the range of the temperature inversions appears on both sides of the temperature of the maximum density, the effect of the temperature upon the density is very small, and therefore the necessary compensation of density through changes in salinity is minimal. Finally it can be stated that the topographies of the σ_t surfaces through the stations 3, 8 and 13 show that the warm water intrusions have to travel down isopycnic surfaces which have a slope of 1.80×10^{-4}. The warm water lenses of the stations F64 and 17 are an independent phenomenon.

14. *Lateral mixing*

The degree of lateral mixing in the surface layers can be estimated from the salinity data, supposing that the conditions would be stationary and that only the lateral mixing would be significant, which must be rather correct owing to the great vertical stability of the waters. In this case

$$u \frac{\partial S}{\partial x} = \frac{\partial}{\partial y}\left(K_y \frac{\partial S}{\partial y}\right),$$

where u is the speed of current in the direction of x-axis,
K_y the coefficient of eddy diffusion and
where x corresponds to the direction SE and
y to the direction NE.

Further, it is reasonable to assume that $\frac{\partial K_y}{\partial y} \approx 0$, in which case

$$\frac{K_y}{u} = \frac{\frac{\partial S}{\partial x}}{\frac{\partial^2 S}{\partial y^2}} .$$

The surface isohalines (Fig. 7) indicate a value of, on an average, about 1 km for this fraction, and if it assumed that the average current is 3 cm sec^{-1}, the coefficient of lateral mixing becomes 3×10^5 cm^2 sec^{-1}.

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