Ödsmål Kville sn, Bohuslän

Hällristning
Fiskare från
bronsåldern

Rock carving
Bronze age
fishermen

**MEDDELANDE från**
**HAVSFISKELABORATORIET • LYSEKIL**

nr 90

Hydrografiska avdelningen, Göteborg

# On the Water Renewals in the Eastern Gotland Basin after World War II.

by

Stig H. Fonselius and Chalanya Rattanasen

(Contribution to ICES C.M. 1970/C:8 Copenhagen)
August 1970

C.M. 1970/C:8
Hydrography Committee



# On the Water Renewals in the Eastern Gotland Basin after World War II.

by

Stig H. Fonselius 1) and Chalanya Rattanasen 2)

1) Fishery Board of Sweden, Hydrographical Department, Göteborg, Sweden and
2) The Thai-Danish Marine Biological Center, Charlottenlund, Denmark

## Abstract.

The mechanism of the water renewals in the deep water of the Gotland Basin is described. The salinity changes in the Gotland Basin from 1898 to 1970 are discussed and it is shown that two long periods with continuously decreasing salinity values have occured. Both periods have lead to hydrogen sulfide formation in the bottom water. The reasons for the high salinity in the beginning of the 1920:s are briefly discussed.

A diagramme showing the changes in the oxygen and hydrogen sulfide conditions in the Gotland Basin after World War II is discussed. It is shown that 13 different inflows of oxygen rich water have occured. Some of them have, however, been very small. Three figures showing density, salinity and temperature changes during the same period are discussed and maxima in density and salinity corresponding to the oxygen maxima are indicated. It is also shown that the inflowing new water may have large temperature differences depending on the temperature conditions in the Belt area during the time the water passed through the Belts.

Finally the present conditions in the Gotland Basin are discussed. A fast decreasing of the oxygen values and a new hydrogen sulfide formation in the near future is predicted.

# On the Water Renewals in the Eastern Gotland Basin after World War II

by

Stig H. Fonselius and Chalanya Rattanasen

The deep water of the Eastern Gotland Basin is occasionally renewed through inflows of Kattegat water with a high density and oxygen content. This water streams in to the Baltic over the sill between Darsser Ort and Gedser and moves slowly along the bottom following the deepest connections between the different deep basins (Fonselius 1969).

The old stagnant water in the Gotland Basin has generally a relatively high density. Through diffusion and turbulence through the boundary layer (the secondary halocline) the density of the bottom water slowly decreases so much that new water may penetrate below it and force it out from the basin. Therefore salt water inflows over the sill at Darss only can renew the bottom water of the Gotland Basin if they are large enough to bring water of sufficient density down there and if the old water has been diluted enough to be forced out by the new water (Fonselius 1969).

Hydrographic measurements have been carried out in the Gotland Basin during a period of almost 80 years. The Gotland Deep has been visited almost every year since the beginning of the century. There exist also some few measurements from the 1890:s. The work has only been interrupted during the two World Wars. Before W.W.II only one expedition was normally carried out every year, mainly by the Institute of Marine Research in Helsinki. After W.W.II the amount of observations has increased enormously and normally about 4 expeditions have been performed per year, but there are years with 10-12 expeditions made by different laboratories.

Fig. 1 shows a treatise to present the salinity changes in the Gotland Deep at 200 m as annual mean values. The values before 1951 have been taken from Soskin (1963). Soskin gives mean values of salinity for every year from 1902 to 1960 at different depths in the Gotland Deep. It is, however, obvious that most of these mean values are only single measurements (Fonselius 1969). The values before 1902 are unpublished results by O. Pettersson. From the figure it can be seen that there are two extremely long periods with continuously decreasing salinity values, 1922-1933 and 1952-1960. Both periods seem to have been caused by an unusually high increase of the salinity. The second salinity increase, caused by an inflow of more than 200 $km^3$ of salt water in to the Baltic during a few weeks in November-December 1951 (Wyrtki 1954) has been described by one of the authors (Fonselius 1962). The first inflow which may have happened during 1921 or earlier, has not been described in the literature. It has not been possible to establish from light vessel data that a large and fast inflow corresponding to the 1951 inflow, has occured in the beginning of the 20:s.

Neumann (1940) has investigated the secular variations of the salinity at light vessels in Kattegat and the Belts. Unfortunately no deep measurements of salinity were carried out at the "Gedser Rev" light ship and the surface values for the period 1915-1920 are missing due to the war. Neumann, however, found indications of unusually high salinities at the "Gedser Rev" during W.W.I. In Januray 1921 the mean value of the surface salinities was extremely high, above 16 ‰ and the annual mean salinity was the highest ever recorded, 11.9 ‰. There may thus have occured an inflow of high saline water in to the Baltic just before the observations began after W.W.I.

It is, however, a fact that the salinity of the bottom water in the Gotland Basin was unusually high in 1922 when the first observation after W.W.I was made and that the salinity continuously decreased until 1933. During this long stagnation period the oxygen concentration also decreased to zero and hydrogen sulfide was reported in 1931 (Granqvist 1932). In 1933 the deep water of the Gotland Basin was renewed (Kalle 1943).

It has to be pointed out that there was a general decrease of the salinity in the whole Baltic between the two World Wars (Fonselius 1969). In 1939 a new large inflow into the Gotland Basin began but because of lack of inforamtion during W.W.II it is difficult to draw conclusions about the development between 1941 and 1947 (Hela 1966).

In the present paper the authors have tried to make a detailed study of the whole development of the oxygen conditions from 1952 to May 1970. Fig. 2 shows the changes in the oxygen conditions at 225-240 m depth during that period. In some few cases when only values for 200 m have been available during the 50:s, these values have been used. The oxygen values are expressed in ml/l as positive values in the figure. Hydrogen sulfide is given as negative oxygen values in ml/l. Because one atom of hydrogen sulfide sulfor formed, is equivalent to four atoms of oxygen utilized, the hydrogen sulfide values in ml/l have been multiplied by two (Fonselius 1969). From the figure it is possible to distinguish 13 differnt greater or smaller oxygen maxima (marked with arrows and numbers in the figure).

There are also four different occasions with hydrogen sulfide formation. Unfortunately oxygen was not analyzed during expeditions carried out before 1953. Therefore it is not possible to see the effect of the 1951 inflow which reached the Gotland Basin in 1952 (Fonselius 1962). The first oxygen value available is from 1953 and it shows that the oxygen concentration was rather high during 1952. The 1952 inflow has therefore been marked with arrow no. 1. The oxygen values decreased obviously fast, but a small inflow in 1954 raised them slightly (arrow no. 2). A fast decrease began but at the end of 1954 a remarcable increase occured. The oxygen value increased from 0.2 ml/l to 2.2 ml/l (arrow no. 3). After that a continuous decrease began and the oxygen values reached the zero point in 1957. Hydrogen sulfide was observed in the bottom water in 1957 (S. Engström pers. comm.). No renewal of the water occured during the following 7 years. Hydrogen sulfide analyses were carried out in 1960 and 1961 (Fonselius 1962). The water was finally renewed in the middle of 1961 (arrow no. 4). The hydrogen sulfide disappeared from the deep water and the oxygen value increased from 0 to 2 ml/l. The oxygen was, however, fast used up and in 1963 hydrogen sulfide was again found in the Gotland Basin. The 5th renewal began at the end of 1963 and reached its maximum in February 1964 (arrow no. 5). Two smaller inflows improved the oxygen conditions in 1964 and 1965 before hydrogen sulfide conditions were established (arrows no. 6 and 7). Then a fast oxygen decrease began but a small inflow of new water again occured in 1966 before the oxygen values reached zero (arrow no. 8). After that a hydrogen sulfide period began. At the end of 1966 a sharp decrease of the hydrogen sulfide value was observed (arrow no. 9) in October followed by an increase in November. During 1967 a small inflow occured, which raised the oxygen value to 2 ml/l (arrow no. 10) but without forcing the hydrogen sulfide containing water out from the basin. Hydrogen sulfide was during the whole year present in a layer above 200 m (Fonselius 1970a).There are indications of a very small inflow at the end of 1967 (arrow no. 11). The inflow is hardly detectable in the oxygen diagramme but it will be shown later that an increase of the salinity occured at that occasion.

At the end of 1967 hydrogen sulfide began to form in the Gotland Basin and during 1968 the sulfide poisoning spread over the whole deep water area of the Baltic proper. The water was again renewed in 1969 (Fonselius 1970b) (arrow no. 12). In January 1970 a small oxygen peak may be observed (arrow no. 13) but the values in May 1970 show that the oxygen conditions are again fast impairing and that therefore hydrogen sulfide may soon appear in the bottom water.

Fig. 3 shows the changes in density of the water during the same period. After every inflow the density decreases fast due to diffusion and turbulence. The peaks corresponding to the oxygen peaks are easily detectable and have been marked with numbered arrows. It is remarcable that the density seems to have decreased unusually much during the last stagnation period. The inflows no. 12 and 13, however, brought the density up to values about normal for the last part of the decade. The inflow no. 11 which was only faintly indicated in the oxygen diagramme is clearly visible as an increase of the density. It has, however, to be pointed out that large irregularities in the density curve exist, especially before 1961. These may be indications of inflows. The lack of oxygen or hydrogen sulfide values makes it difficult to draw conclusions. It has also to be remembered that the values used in the diagramme are from different countries and that before 1965 no interçalibration of the methods had been performed.

The density is a function of salinity and temperature. Of these factors the salinity has the greatest influence on the density. Fig. 4 shows the salinity variations in the Gotland Deep during the same period as in the previous figures. The diagramme is almost indentical with the density diagramme. To every maximum in density a corresponding maximum in salinity may be found. These maxima are marked in the figure with numbered arrows. There are no clear signs that the salinity of the deep water is decreasing. The 1951 inflow raised the salinity to abnormally high values, but after the 1961 inflow the salinity seems to remain on a relatively unchanged level. The present salinities after the inflows no. 12 and 13 are not below the values before 1951. They are almost 1 ‰ higher than the values in the beginning of the century. Apparently the salinity has now levelled out after the 1951 cathastrophe and has reached values normal for the present decade.

Fig. 5 shows a similar diagramme for the water temperature. The inflows have been marked with numbered arrows on the places derived from the previous diagrammes. Here it may be seen that some inflows consist of warm salt water and some of cold salt water. An inflow does therefore not necessarily cause an increase of the temperature of the bottom water. The inflowing water consists originally of surface water from the Kattegat and therefore its temperature is depending of the time of the year when it streamed through the Belts. During its way from Kattegat to the bottom of the Gotland Deep the water is mixed with surface water in the Belts and with deep water in the Bornholm Basin and the southern part of the Central Basin of the Baltic. In the Gotland Basin this water has only approximately 1/3 of its original salinity and has thus mixed with 2/3 of water of other origin. The temperature of the original Kattegat water will therefore probably have a very little influence on the temperature of the water in the Gotland Deep.

The temperature of the renewed bottom water will influence the oxidation rate of organic matter in accordance with Vant'Hoffs principle (Kullenberg 1970). Therefore warm inflows should utilize the oxygen faster than cold inflows. From the figure it can be seen that the inflow no. 12 increased the temperature unusually much. The result should accoringly be a fast decrease of the oxygen values. From fig. 2 it can be seen that the oxygen values actually are decreasing fast and that the oxygen soon will be completely used up. Hydrogen sulfide formation will again begin in the sediment interface when the oxygen values have reached zero.

If no new strong inflow will occur in a near future, there is not much hope for a recovery of the Baltic deep water. The alternating oxygen and hydrogen sulfide periods will continue and the conditions may grow worse than during 1968 (Fonselius 1969).

References

Fonselius, S.H., 1962: Hydrography of the Baltic Deep Basins. Fishery Board of Sweden, Series Hydrography, Report No. 13, 41 pp (1962).

---------------,1969a: Hydrography of the Baltic Deep Basins III. Ibid. No. 23 97 pp (1969).

---------------,1969b: On the Stagnant Conditions in the Baltic. Abstracts of Gothenburg Dissertations in Science 14, Acta Universitatis Gothoburgensis, 17 pp (1969).

---------------,1970a: Observations at Swedish Lightships and in the Central Baltic. Ann. Biolog. XXVI (1969) 1970 (in press).

---------------,1970b: On the Stagnation and Recent Turnover of the Water in the Baltic. Tellus 22 (1970) (in press).

Granquist, G., 1932: Croisière thalassologique et observations en bateaux routiers en 1931. Havsforskningsinstitutets Skrift N:o 81 (1932).

Hela, I., 1966: Secular Changes in the Salinity of the Upper Waters of the Northern Baltic Sea. Comm. Phys. Mathem. Soc. Sci. Fennica Vol. 31:14 (1966).

Kalle, K., 1943: Die grosse Wasserumschichtung im Gotlandtief vom Jahre 1933-34. Ann. Hydrogr. 60, H. 1 (1943).

Kullenberg, G., 1970: On the Oxygen Deficit in the Baltic Deep Water. Tellus 22:3 p 357 (1970).

Neumann, G., 1940: Mittelwerte längerer und kürzerer Beobachtungsreihen des Salzgehaltes bei den Feuerschiffen im Kattegat und in der Beltsee. Ann. Hydrogr. 68:11 (1940) pp 373-86.

Soskin, I.M., 1963: Continuous Changes in the Hydrological Characteristics of the the Baltic Sea. Hydrometeorological Press, Leningrad (1963) (in russian).

Wyrtki, K., 1954: Der grosse Salzeinbruch in die Ostsee im November und Dezember 1951. Kieler Meeresforsch. X:1, p 19 (1954).

ICES, Bull. Hydrographique. 1902-1956.

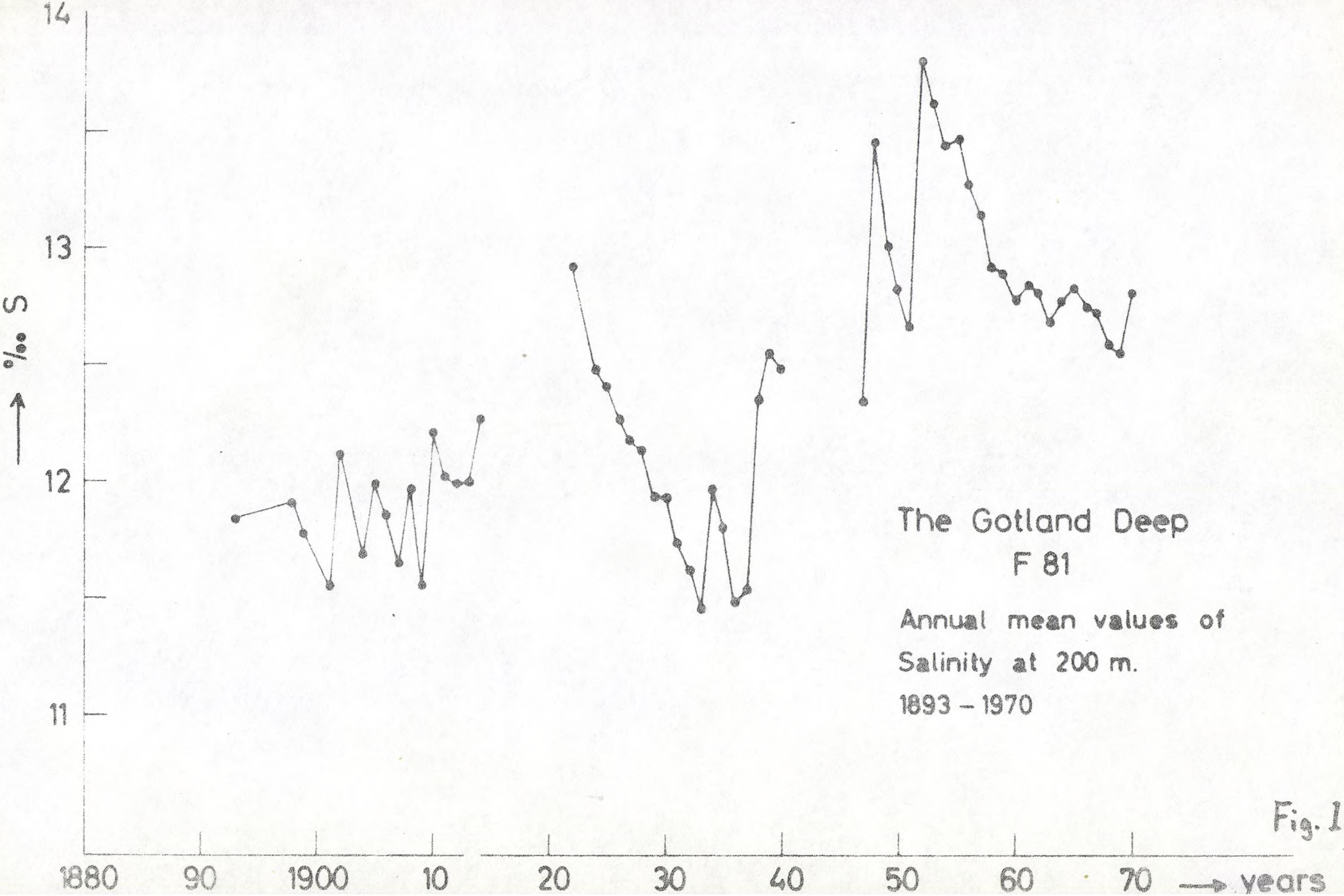
ICES, Data lists. 1957-1962.

Medd. Havsfiskelab. Lysekil.

Data soon to be published by the Fishery Board of Sweden in Medd. Havsfiskelab. Lysekil.

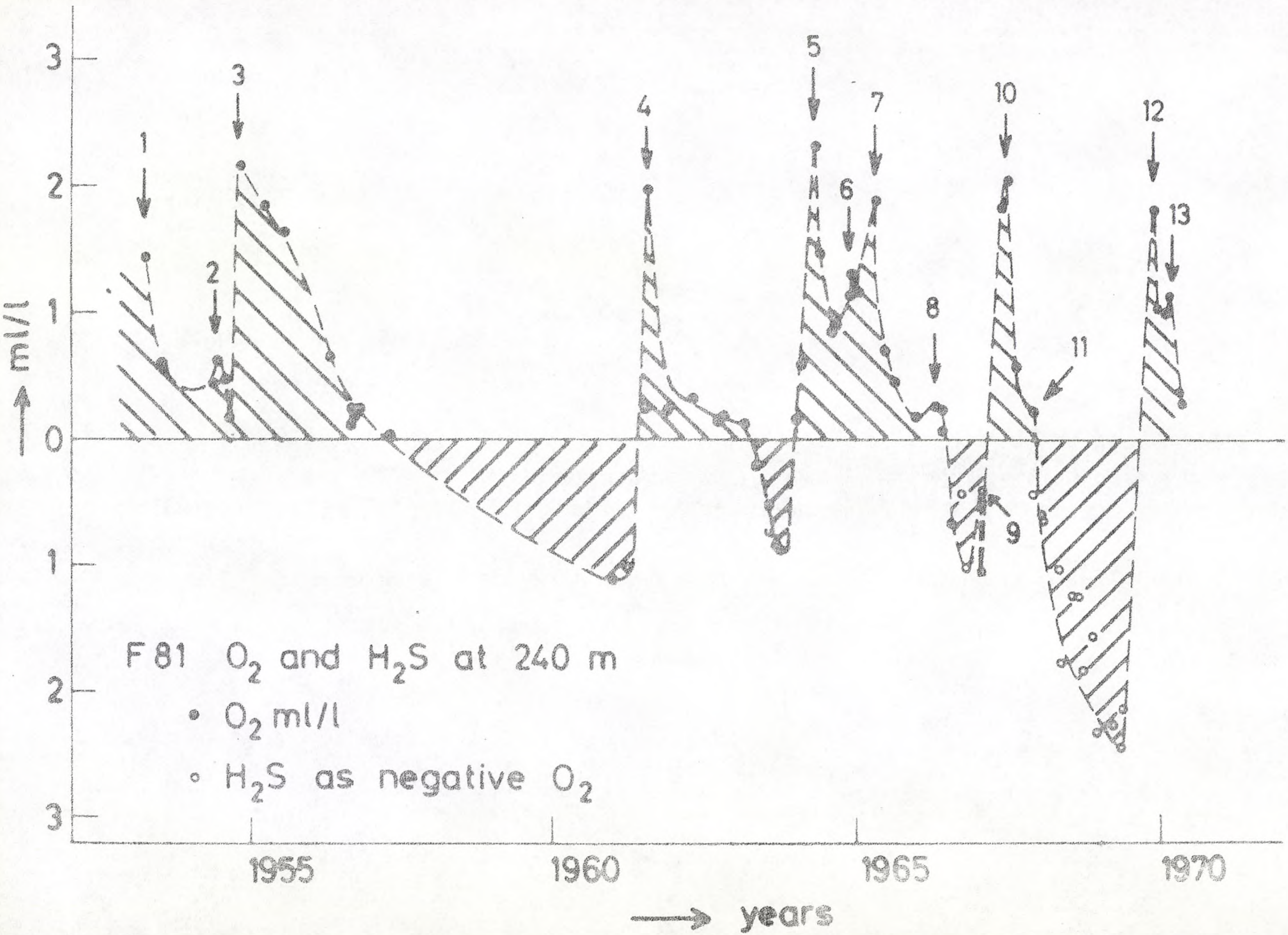
Unpublished data by O. Pettersson (old journals on Bornö Station).

Unpublished data by the Hydrographic Office of the Swedish Navy.



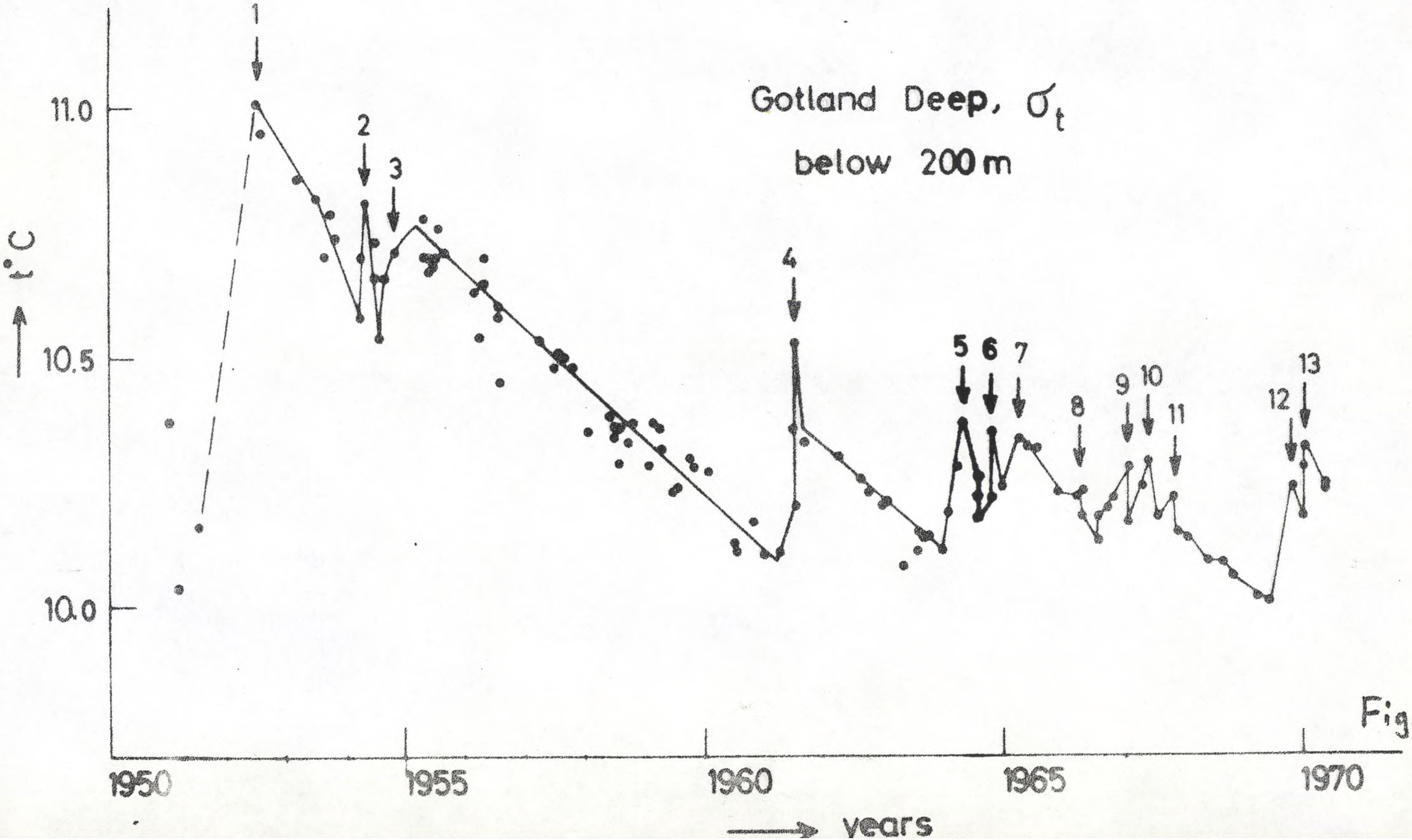
14
13
12
11
S ‰
1880
90
1900
10
20
30
40
50
60
70
years
The Gotland Deep
F 81
Annual mean values of
Salinity at 200 m.
1893 – 1970


Fig. 1.



3
2
1
0
1
2
3
ml/l
1
2
3
4
5
6
7
8
9
10
11
12
13
F 81 O2 and H2S at 240 m
O2 ml/l
H2S as negative O2
1955
1960
1965
1970
years


Fig. 2



Gotland Deep, $\sigma_t$
below 200 m
t°C
11.0
10.5
10.0
1950
1955
1960
1965
1970
years
1
2
3
4
5
6
7
8
9
10
11
12
13

Fig. 3

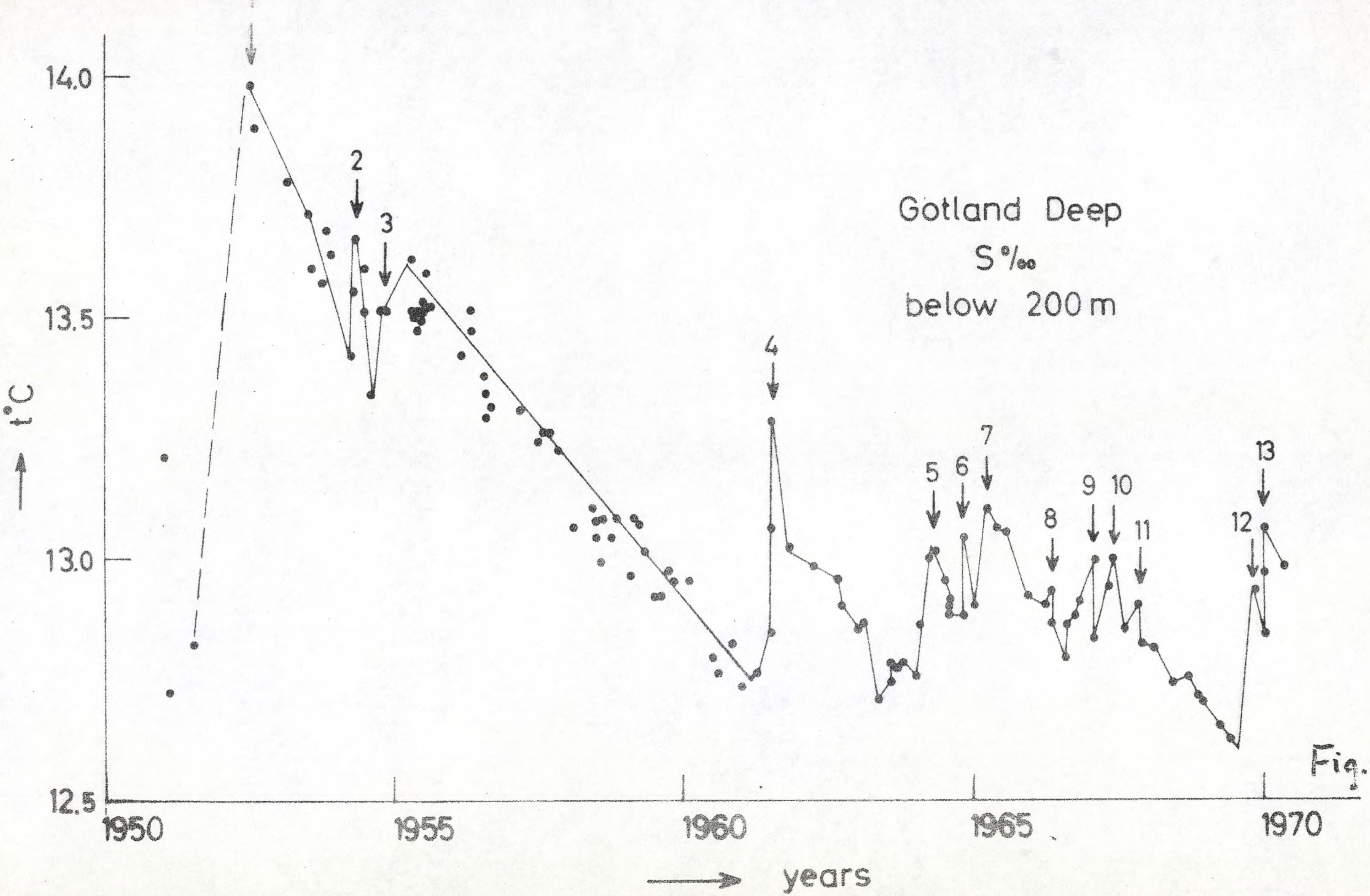

Gotland Deep
S ‰
below 200 m
t°C
14.0
13.5
13.0
12.5
1950
1955
1960
1965
1970
years
1
2
3
4
5
6
7
8
9
10
11
12
13

Fig. 4

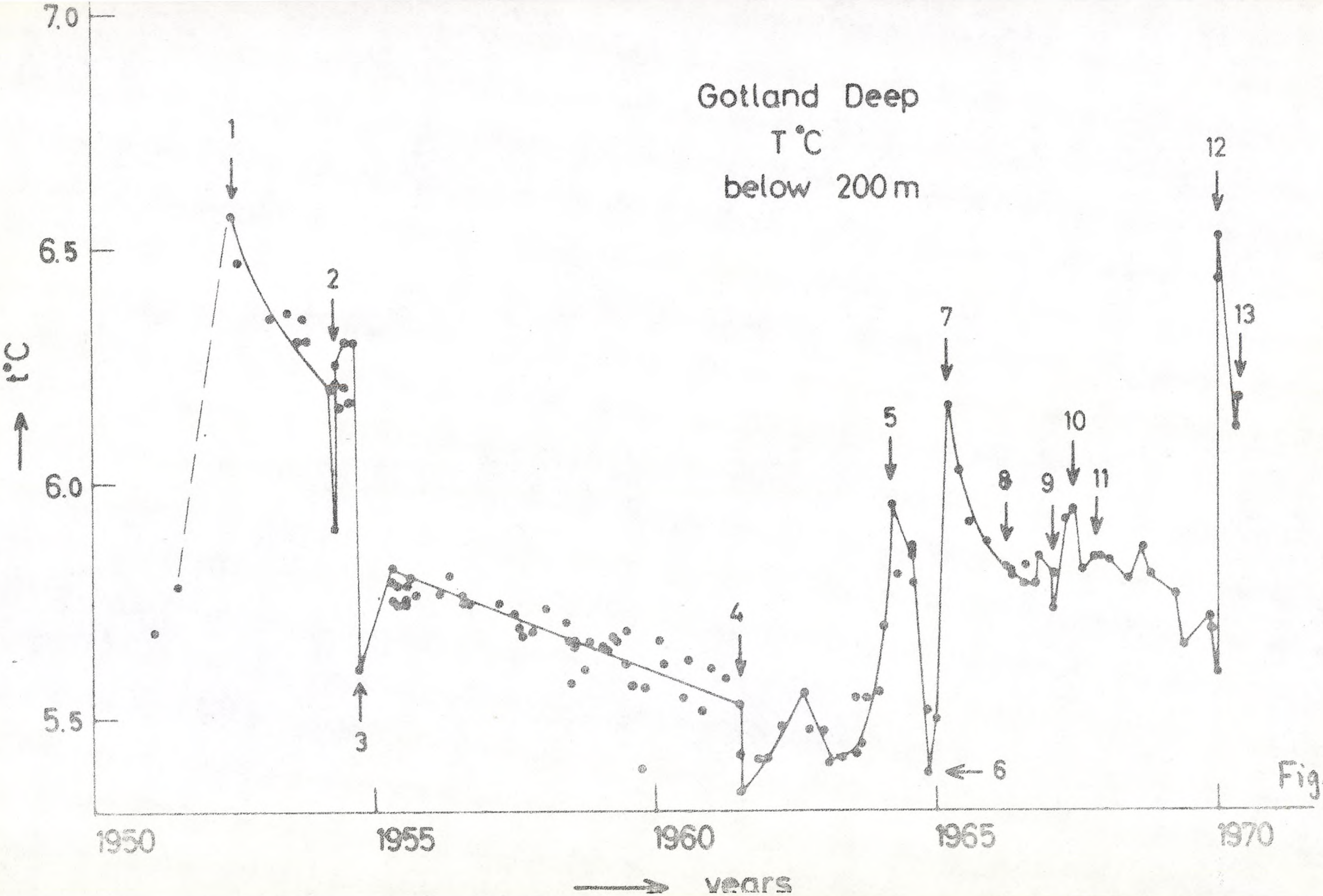

Gotland Deep
T °C
below 200 m
t°C
7.0
6.5
6.0
5.5
1950
1955
1960
1965
1970
years
1
2
3
4
5
6
7
8
9
10
11
12
13

Fig. 5