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General trends in the development of the oxygen regime in the deep water of the Baltic

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The oxygen content of the deep water is one of the most important environmental parameters affecting the maintenance and reproduction of commercial fish stocks in the Baltic. Fluctuations in the oxygen content over periods ranging from a few years up to a century are of fundamental value for studies on the tendencies of the oxygen regime in the deep water. Of such fluctuations, those of a long term nature have come to occupy the interest in the past few years (ANTONOV, 1967; FONSELIUS, 1962, 1969; FRANCKE, NEHRING, ROHDE, 1977; MATTHÄUS, 1973a).

Our investigations present mean changes in the oxygen content over various periods during the present century at 10 stations in the most important basins and deeps in the central Baltic (Fig. 1). The frequently observed occurrence of hydrogen sulphide concentrations in the deep water, which have been quantitatively determined from the end of 1960 on, have been considered in our work as "negative oxygen" according to FONSELIUS (1969). An uncertain trend is denoted by an asterisk (*) in the table and figures.

1. The development of the oxygen regime since the beginning of this century

The diagram in Fig. 2 showing the trend in the oxygen content of the bottommost layer investigated over the whole period was

elaborated on the basis of a compilation of all available oxygen observations at the 10 stations involved. The most important results of this analysis are summarised in table 1 for the period 1900 – 1975, the symbols $\bar{O}_2$ and $\overline{\Delta O}_2$ signifying the mean value and the mean variation respectively in the oxygen content over the period involved.

Table 1: Mean values and mean variations of oxygen content of the deep water of the Baltic within 1900 – 1975

Station	Intern. symbol	Depth (m)	$\bar{O}_2$ (ml/l)	$\overline{\Delta O}_2$ (ml/l)
Arkona Deep (AT)	BY 2 A	45	0,30 1)	-0,76 *
Bornholm Deep (BT)	BY 5 A	80	2,91	-2,33
Gdańsk Deep (DT)	P_1	100	2,64	-2,02
Southern Gotland Basin (SGB)	BY 9 A	100	2,86	-2,43
Gotland Deep (GT)	BY 15 A	200	1,16	-2,69
Fårö Deep (FT)	BY 20 A	150	1,17	-2,54
Northern Gotland Basin (NGB)	BY 28 B	150	1,42	-2,99
Landsort Deep (LT)	BY 31 A	400	1,40	-2,87
Norrköping Deep (NT)	BY 32 B	150	1,84	-4,37
Karlsö Deep (KT)	BY 38 A	100	1,71	-3,66

1) Mean value of the deviation between measured values and mean annual course

Since the beginning of the present century, the bottommost layer at all stations investigated has exhibited a considerable mean decrease in oxygen content, which differs in magnitude according to region. This drop can also be observed in other layers of the deep water as shown here in extract form only (Figs. 3, 4 and 6) (see MATTHÄUS, 1978).

Regional differences in the long-term trend may be caused by the different distances of the various deep basins from the inlets to the Baltic, since the effects of salt water inflows and intrusions differ according to the sites of the basins relative to the inlets. In this connection, the configuration of the basin will probably also play some role. The secular changes expected in the oxygen content of the deep water of the Arkona Basin, for example, must be lower than those expected in the bottommost layers of other basins in the Baltic as a result of its location in the main mixing region between North Sea and Baltic water and due to the orographical and exchange situation. The effects of vertical exchange processes which depend upon the stability of the stratification are also important.

The mean values $\bar{O}_2$ of oxygen content in the deep water shown according to station and depth in Fig. 5 decrease with increasing depth. However, due to the mode of calculation, the mean values also consider the hydrogen sulphide concentration in the form of "negative oxygen". In general, the mean values at a depth of 100 m become lower as the distance from the entrances to the Baltic increases, reaching values of 1.7 - 1.8 ml/l between the Northern Gotland Basin and the Karlsö Deep stations. The lowest mean value at a depth of 150 m was 1.2 ml/l measured in the Fårö Deep and the lowest 200 m value was 1.2 ml/l in the Gotland Deep. These are simultaneously the lowest mean values of all calculated values. Both of these deeps belong to those in the Baltic which are most strongly affected by stagnation.

If the mean long-term variations of the oxygen content $\overline{\Delta O_2}$ over the period 1900 - 1975 at the different stations are plotted against the depth, we obtain the diagram shown in Fig. 6. The oxygen content has decreased considerably on average at all depth in the course of the present century. Furthermore, the mean drop in the oxygen concentration seems to depend on the distances of the stations from the entrance to the Baltic. At a depth of 100 m in the Gdańsk Deep, the mean decrease during the period 1900 - 1975 was about 2 ml/l and rose to 3.3 - 3.5 ml/l in the Gotland and Fårö Deeps. Whereas the mean drop in the Landsort Deep once again reached a value of about 3.1 ml/l, the highest mean drops of 3.7 - 4.1 ml/l were calculated at a depth of 100 m for the Norrköping and Karlsö Deeps. However, the high values in the western part of the Gotland Basin may be due to the absence of measured values prior to the middle of the twenties (see Fig. 2).

Consideration of the long-term changes at the bottommost investigated levels shown as mean annual variations in Fig. 7 has the advantage

that all basins can be taken into account independent of their depths and that the measuring levels (stated under the station designation) are relatively uniform between a few metres (AT, BT, DT) and a maximum of about 60 m above the bottom (FT, NGB, LT, NT). Fig. 7 shows, the larger the distance of the station from the entrance to the Baltic the greater the decrease in oxygen content. Even if it is assumed that the values for the western part of the Gotland Basin are too high due to the absence of measured data prior to 1924, it is still apparant that the long term-variations depend on the region involved.

2. The development of the oxygen conditions since 1952

2.1. Mean variations within the period 1952 - 1974

For several reasons interest has centred upon the development of the oxygen conditions since the middle of this century. On the one hand, intensive observation activities did not begin until the fifties, so that 60 - 90 % of all measured values have been obtaine during the period following 1950 (see Fig. 2). On the other hand, the largest salt water inflow into the Baltic so far observed at the end of 1951 resulted in the highest salinities and, in some cases, temperatures in numerous basins. This was associated with an increase in stability of the stratification and a decrease in vertical exchange. Finally, during the sixties increased attention was paid to the pollution and its possible effects on the marine environment of the Baltic, particular attention being paid to the oxygen conditions in the deep water.

Since 1952 the salinity in the eastern and northern parts of the Gotland Basin between the Gotland and the Landsort Deeps has decreased on average (MATTHÄUS, 1978). At least as far as the deep water of the Gotland Deep is concerned, the stability of the stratification has also decreased since the mid-fifties (VOIPIO, MÄLKKI 1972; MATTHÄUS, 1973b). The consequent more intense possible vertical exchange between the surface and the deep water does not, however, lead to any improvement in the oxygen conditions in the deep water. The averages for all stations over the period 1952 - 1974 reveal a further decrease in the oxygen content, the drop at most stations even being more pronounced than for the period

1900 - 1975 (see also Figs. 3 and 4). The mean values of oxygen content are all 0.7 - 1.1 ml/l below the values for the period 1900 - 1975.

2.2. Mean fluctuations within different stagnation periods

Against the background of the average variations processes initiated by the inflow or intrusion of salt water take place in the different deep basins. In general, only major salt water inflows lead to effective turnover in the deep basins. These water renewals are followed by periods of stagnation in which the salinity always and the temperature usually drop. With regard to the oxygen content, biological consumption, biochemical demand and mixing processes lead to drops in relatively short periods and may even lead to the complete disappearence of oxygen and the formation of considerable hydrogen sulphide concentrations extending up even to immediately below the halocline.

During the analysis, water renewals with only small effects have generally been subordinated to the major inflows. The beginning of stagnation was determined from the time at which the highest oxygen concentration was observed. The end of stagnation was taken to be that of the occurrence of the lowest concentration after which, generally in a relatively short time, a considerable increase in the oxygen content could be observed.

Figs. 8 and 9 show the fluctuations and mean annual variations in the oxygen content during different stagnation periods. The numbers shown in Fig. 8 correspond to the figures used by FONSELIUS and RATTANASEN (1970) and of ENGSTRÖM and FONSELIUS (1974) to identify inflows of saline oxygen-rich water near the bottom during investigations of water renewals; identical figures denoting the same inflow into the different basins. The durations used for the calculations for the different periods are plotted above the time scale in Fig. 9.

Despite the difficulties in coordinating the stagnation periods in the basins to the different salt-water inflows into the Baltic, the analysis of the oxygen distributions in all three basins indicate a number of these characterised deep water renewals. The

effect of the distance from the entrance to the central Baltic is indicated by both the decreasing scattering of the measured values with increasing distance (Fig. 8) and the mean annual variations in the oxygen content during the analysed periods. At the 80 m level in the Bornholm Basin the mean annual variations are about one order of magnitude higher than the fluctuations at the 200 m level in the Gotland Deep or at the 400 m level in the Landsort Deep. The trends shown by the mean annual variations in the oxygen content in all three basins which achieved their highest mean annual decreases towards the end of the sixties is remarkable (see Fig. 9). These results support the idea that the oxygen in the deep water is being consumed with increasing rapidity and that hydrogen sulphide is occurring increasingly frequently.

3. Conclusions

(1) The oxygen content of the deep water in the central Baltic has dropped by about 2 - 4 ml/l since the beginning of this century and the mean rate of this decrease has become higher since 1952. The periods of unfavourable living conditions in the deep water have become longer, the oxygen is being consumed more rapidly and anoxic conditions are becoming increasingly frequent.

(2) At present it is not to decide with any degree of certainty whether the present deterioration in the deep water oxygen conditions is primarily the result of a natural process or a consequence of the increasing discharge of sewage into the Baltic. It is possible that the increased input of nutrients and organic substances has promoted the formation of hydrogen sulphide, thus accelerating the deterioration in the oxygen regime. Correlations between the discharge of sewage, eutrophication and oxygen conditions have already been found in shallower regions of the Baltic.

(3) Inflows of high saline water leading to the renewal of the deep water in the Baltic can be expected every three or four years. If the organic stressing and pollution of the salt-rich water entering the Baltic continue to increase, the trend towards the increasingly rapid consumption of the oxygen in the deep water during stagnation periods will become more pronounced and the hydrogen sulphide concentration will gradually be able to assume higher values.

(4) The eutrophication of the Baltic and its coastal waters leads to a greater biomass and thus to an increase in the amount of dead organic matter which finally contributes to the deterioration of the oxygen conditions in the deep basins and to the spreading of the unfavourable living conditions.

(5) Taking into consideration the development of the various factors affecting the oxygen regime in the deep water the trends derived from the available data reveal no change in the overall negative tendency at present.

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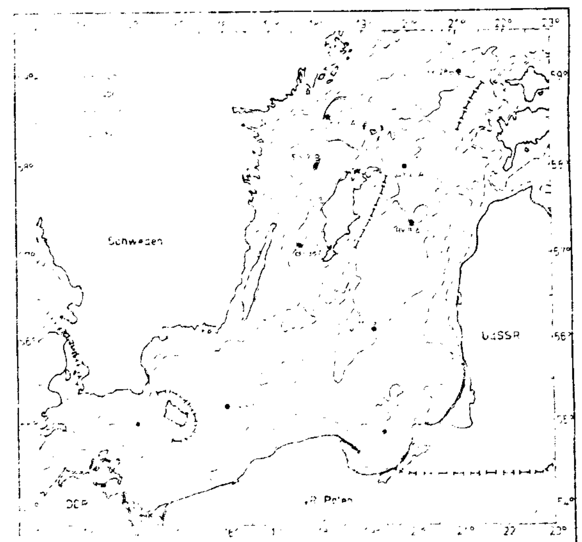

Fig. 1. Depth lines of the central Baltic and positions of the observation stations

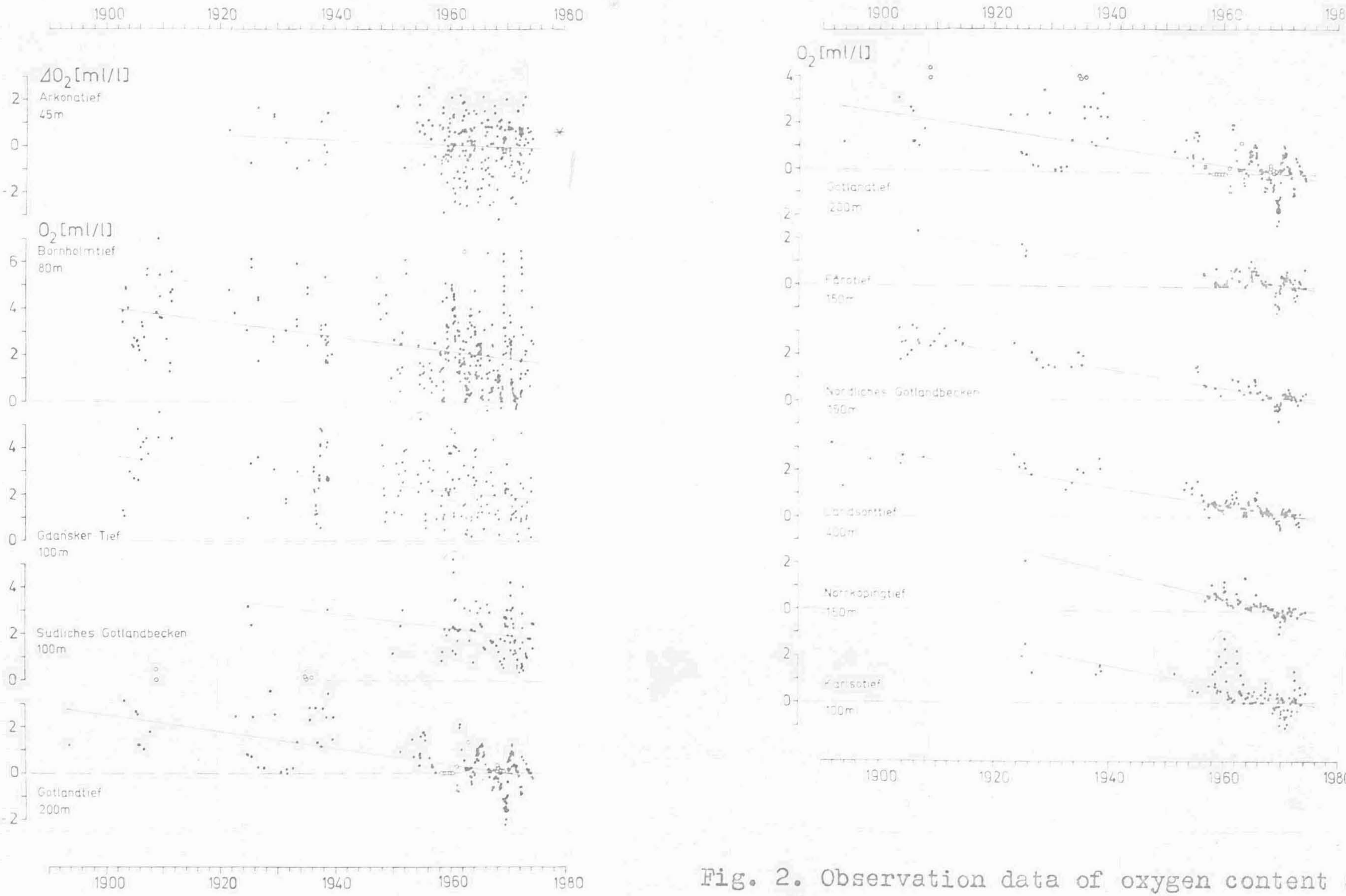

Fig. 2. Observation data of oxygen content and mean long-term variations in the near-bottom level of the stations

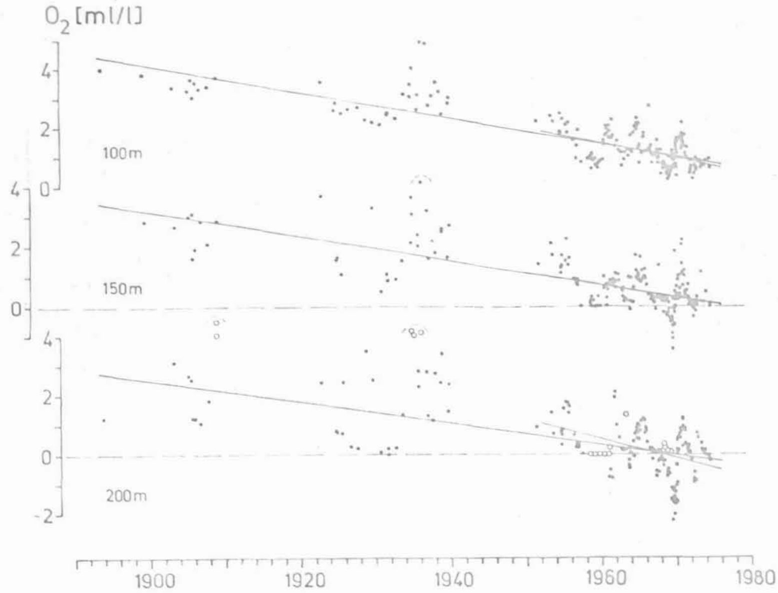

Fig. 3. Mean long-term variations of the oxygen content in selected levels of the deep water of the Gotland Deep

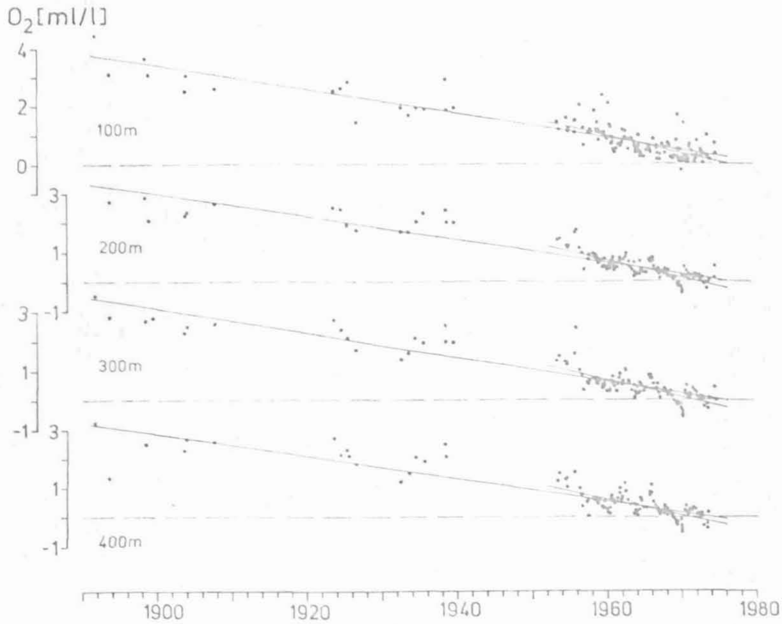

Fig. 4. Mean long-term variations of the oxygen content in selected levels of the deep water of the Landsort Deep

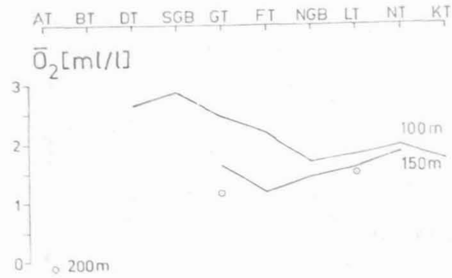

Fig. 5. Mean values of the oxygen content in the deep water of the Baltic proper within 1900 - 1975

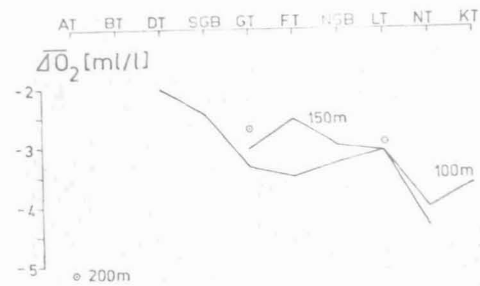

Fig. 6. Mean variation of the oxygen content in the deep water of the Baltic proper within 1900 - 1975

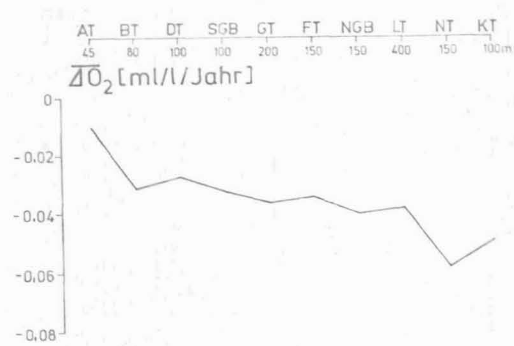

Fig. 7. Mean annual variation of the oxygen content in the near bottom level of the stations

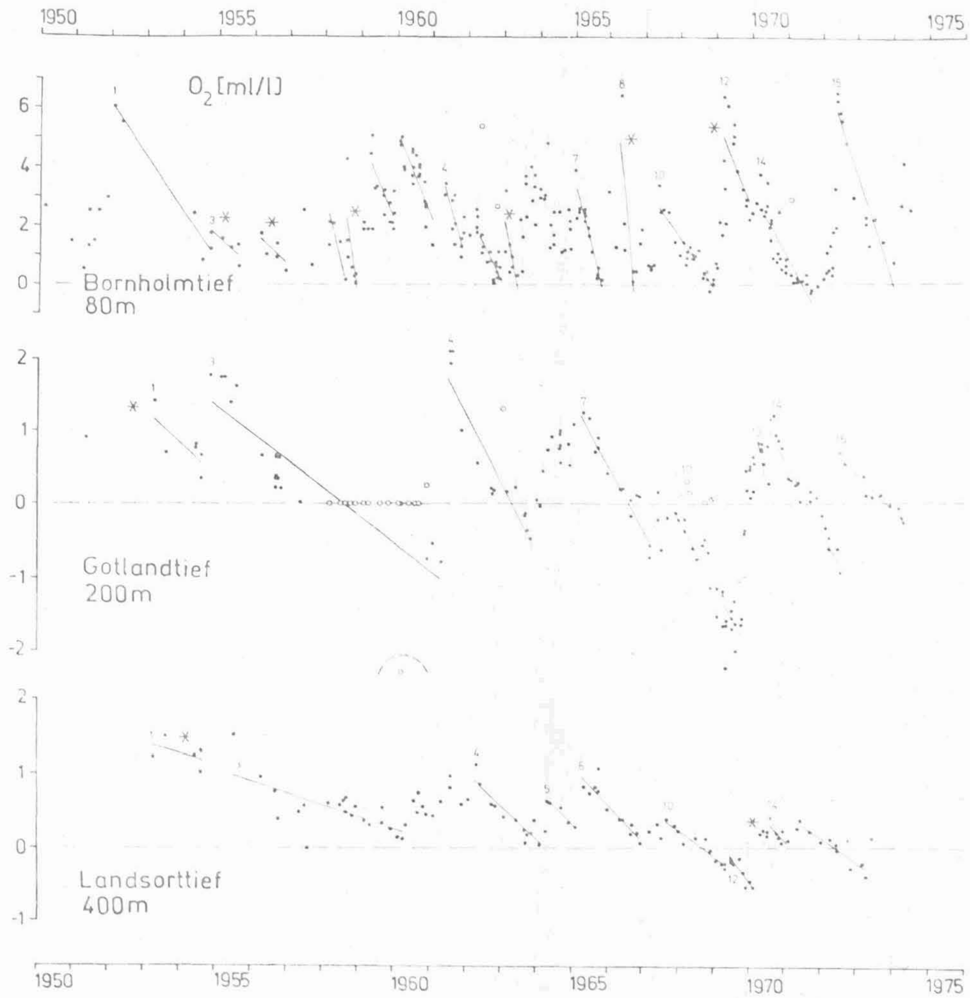

Fig. 8. Variations of oxygen content within the stagnation periods of the Bornholm-, Gotland- and Landsort Deeps

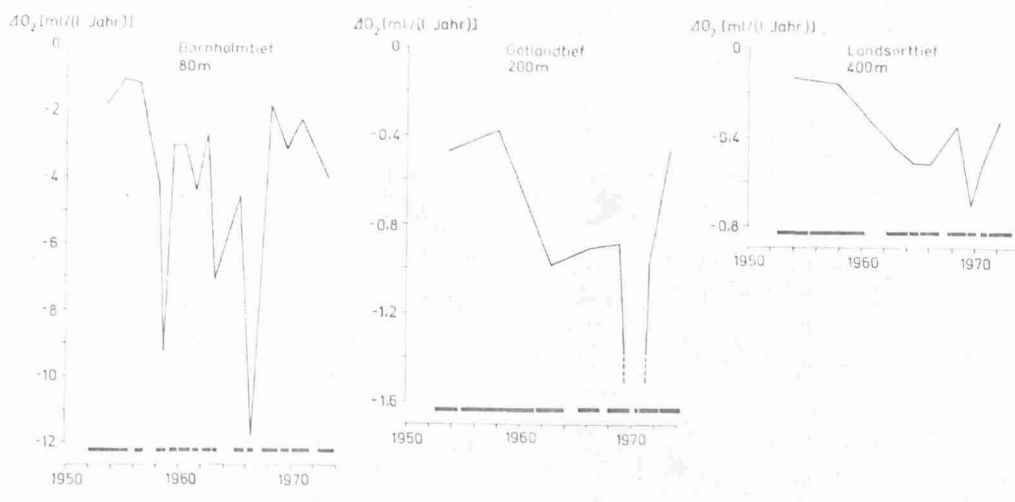

Fig. 9. Mean annual variations of the oxygen content within the stagnation periods of the Bornholm-, Gotland- and Landsort Deeps