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SESS.V

THE CHANGES OF THE HYDROGRAPHIC CONDITIONS IN THE BALTIC PROPER DUE TO 1993 MAJOR INFLOW TO THE BALTIC SEA

by

Hans Dahlin*, Stig Fonselius# and Björn Sjöberg#

*Swedish Meteorological and Hydrological Institute, S-60176 Norrköping
#Swedish Meteorological and Hydrological Institute, Oceanographical Laboratory, S-403 14, Göteborg

Abstract

The changes in salinity in the Arkona basin, the Bornholm basin and the Eastern Gotland basin caused by the 1993 major salt water inflow to the Baltic sea were studied during several expeditions with the R/V Argos between March and August and for shorter periods also with current meter moorings. It was found that the deep water in the Bornholm basin was exchanged in the beginning of March and that the old Bornholm Deep Water was flowing over the Slupsk Furrow into the large Baltic central basin. The water arrived into the Gotland Deep at the beginning of April. The average velocity of the inflowing water was estimated to be 9 cm/s. The changes in the Eastern Gotland basin were studied by help of diagrams showing the variations of salinity, oxygen/hydrogen sulphide, nitrate and phosphate in the water body at the Gotland Deep from 1990 to 1993. It was concluded that the inflow was not large enough to improve the oxygen conditions in the bottom water of the Easter Gotland basin for a longer time. The conditions in the southern Baltic proper have improved considerably. Opportunities for new inflows are good due to the still extremely low salinity of the bottom water. Because most of the hydrogen sulphide has now disappeared, such inflows will have good effects in the whole Baltic proper.

The salt water inflow in January 1993

In January 1993 a major inflow of salt water was recorded in the Öresund and in the Belt sea. The temperature of the inflowing salt water was below 5°C in contrast to the inflow in 1976-77 which brought unusually warm water into the Gotland Deep (>7°C). The size of the inflow was estimated to be about 300 km^3 (Matthäus 1993), (Håkansson et al. 1993). In the Gotland Deep the first signs of the inflow were observed the 1 of April. Thus it took a little more than 2 months for the water to reach the Gotland Deep. If we estimate the distance between the Darss sill and the Gotland Deep to be approximately 600 km going through the deepest connections, and estimate the time for the salt water to flow this way to be 75 days (15th January to 1st April) we get a mean water velocity of 9 cm/s which corresponds to about 1/2 - 1/3 of the velocity of a gravity current.

The effects in the Arkona basin and in the Bornholm basin

The "Argos" carried out an expedition in the southwestern Baltic sea the 2nd-5th of March in order to study the inflow in the Arkona basin and the Bornholm basin (Fig. 1). As an effect of the inflow new water had penetrated into the Arkona and Bornholm basins (Fig. 2). Remnants of the "old" bottom water in the Bornholm basin had been lifted up to the sill level (around 60 m) and was streaming in to the large central basin through the Slupsk furrow. The bottom salinities were the highest recorded since the inflow in 1976. The amount of "new" water in the Arkona basin was estimated to be approximately 25 km^3, with an average salinity of 22 psu.. The average salinity in the bottom water of the Bornholm basin (below 65 m) was a little above 18 psu and consisted partly of "old" water (14-15 psu) and "new" Arkona water (22-23 psu). This means that approximately 40-60 km^3 water had flown in to the Bornholm basin since the inflow in

January. Figs 3a and 3b show the salinity and temperature variations in the Bornholm basin in a section through the central part towards SE. We can see how water with high salinity is flowing over the Slupsk sill (3a). The temperature of this water(3b) is in the eastern part above 6-7 ^{o}C, indicating that this is "old" Bornholm basin bottom water, which is forced over the sill into the central basin. The "new" water had a temperature below 5 ^{o}C. This water is found at the bottom of the basin below the old water.

To be able to follow the new water filling the Bornholm Basin a transmitting buoy with salinity and temperature sensors on 50, 60, 70, 80 and 85 meters depth was deployed in the central Bornholm Basin (BY 5), fig. 4. However due to misjudgment of the velocity of the entering water, which was very high compared to earlier estimates and modelling calculations most of the bottom water was already exchanged when the buoy was on site. Fig. 5 shows the first week of salinity measurements, which demonstrate the new bottom water, the old bottom water around 70 meters, the old bottom water passing the depth of 60 meters and the low saline surface layer above.

April 21 three current meter moorings were placed in a cross section in the Stolpe Furrow. Each mooring had two Aanderaa RCM-7 current meters near and 5 meters above the bottom. The moorings were recovered in the beginning of September. Registrations of current, salinity and temperature from the period before the first change of memory are shown in fig. 6 and 7. The figures show that still during May high saline water, 12 - 14 psu was transported east through Stolpe Furrow.

The effects in the Eastern Gotland basin

Fig. 8 shows the salinity variations below 225 m in the Gotland Deep in the Eastern Gotland basin from 1963 to 1993. The salt water inflows in 1969, 1977, 1983 and 1993 can be seen. The 1983 inflow was not large enough to renew the old bottom water with oxygen containing water. It can also be seen that in spite of these inflows, the salinity of the bottom water is decreasing.

Fig. 9a shows the salinity variations at the station BY15, the Gotland Deep, from January 1990 to August 1993 and fig. 9b the oxygen/hydrogen sulphide variations during the same period. The first signs of the inflow were observed during the cruise of "Professor Albrecht Penck" from Warnemünde the 1st of April (Penck 1993a). The salinity at 236 m was reported to be 11.6 psu and thin layers with oxygen were observed in the hydrogen sulphide containing bottom water. The "Argos" visited the Gotland Deep two weeks earlier, the 15 of March and no signs of the inflow could be observed at that occasion. The salinity at 225 m was only 11 psu and the hydrogen sulphide values were extremely high in the stagnant water. Five weeks later, the 21 of April, when "Argos" returned to the Gotland Deep the bottom salinity had increased to 11.67, but there was still no signs of oxygen below 100 m. depth. The reason was probably that we took bottle samples and did not use a continuous oxygen recorder. The hydrogen sulphide concentration was very low close to the bottom and a maximum was found at 200 m, 4.8 ml/l, expressed as negative oxygen (Fonselius 1969). The next "Argos" expedition was the 4th of June. The bottom salinity was 11.70 and all hydrogen sulphide had disappeared from the water. Oxygen was present in the whole water column. In the deep water more than 1 ml/l oxygen was found from 175 m down to the bottom. Between 140 m and 160 m the oxygen values were below 1 ml/l indicating that the new water had penetrated below the old water lifting it up. The R/V Professor Albrecht Penck reported still Hydrogen sulphide between 130 and 195 m (Penck 1993b). We can also see that the salinity had increased to 11 at 175 m. Fig. 10 shows a map of the hydrogen sulphide distribution in the Gotland basin. We can see that hydrogen sulphide is present in some parts of the Eastern Gotland Basin and especially in the Fårö Deep north of the Gotland Deep. In July the salinity in the bottom water had decreased to 11.60 and the oxygen concentration had decreased to values below 1 ml/l at all depths below 125 m. Low concentrations of hydrogen sulphide were found at 150 m and 175 m (Fig. 11). The "Argos" again visited the Gotland Deep the 11 of

August. The salinity of the deep water was almost unchanged, the oxygen values of the deep water had decreased and the hydrogen sulphide values at 150 m and 175 m had increased. Obviously the inflow was not large enough to improve the oxygen conditions for a longer time.

Nutrient concentrations are also good indicators of salt water inflows. Stagnant hydrogen sulphide containing water does not contain nitrate and has high concentrations of phosphate. Nitrate and nitrite are in a reducing environment transformed into inorganic nitrogen gas and ammonia. Phosphate, which in oxygen containing water is coprecipitated together with ferri hydroxide, is in hydrogen sulphide containing water again dissolved, when the ferri-hydroxide is reduced to ferro ions and sulphide. When oxygen again appears in the water we immediately find nitrate and the phosphate concentration decreases.

Figs 12a and 12b show the nitrate and phosphate variations from 1990-1993. Since we have not seen the nutrient results of the "Penck", these are not included in the figures. From the nitrate diagram (8a) we can see that nitrate appeared in the Gotland Deep bottom water in June and that the values had increased in July and August. In July only traces of nitrate was found in the hydrogen sulphide containing water at 150 and 175 m. In August the nitrate had completely disappeared at these depths. The phosphate diagram (8b) shows a phosphate maximum of 6 µM in the old water at 200 m in April. In June and July all values in the deep water were low with minimivalues around 200 m. In July and August a maximum could be found around 150-175 m.

Conclusions

From these findings we may draw the conclusion that the inflow in January was not large enough to improve the conditions in the bottom water of the Eastern Gotland Basin for a longer time due to the large amounts of hydrogen sulphide present there, which react with the oxygen. Very soon we will again find hydrogen sulphide in this basin. Because of the small increase in salinity in the deep water there may, however, be good opportunities for new inflows in the near future. We have now got rid of most of the hydrogen sulphide and therefore even smaller new inflows may have positive effects on the oxygen conditions. The most positive effect of the inflow is that the oxygen conditions in the Baltic proper south of the Eastern Gotland basin have improved considerably. These areas are of great importance for the spawning of cod.

References

Fonselius, S. 1969. Hydrography of the Baltic Deep Basins III. Fishery Board of Sweden, Hydrography No. 23.

Håkansson, B., B. Broman and H. Dahlin 1993. The Flow of Water and Salt in the Sound During the Baltic Major Inflow Event in January 1993. ICES C.M. 1993/C:57

Matthäus, W. 1993. Salzwassereinbruch in die Ostsee. Geografie Aktuell. Forschungsberichte. Geografische Rundschau Jg. 45 (1993), H. 7/8.

Penck 1993a. Monitoring Cruise 02/93 20 March to 7 April 1993 Kiel Bight to northern Gotland Sea. Cruise report No. 3/93, R/V Prof.Albrecht Penck. Baltic Sea Research Institute, Warnemünde.

Penck 1993b. Monitoring Cruise 05/93 4 May to 26 May 1993 Kiel Bight to northern Gotland Basin. Cruise Report No. 4/93. Ibid.

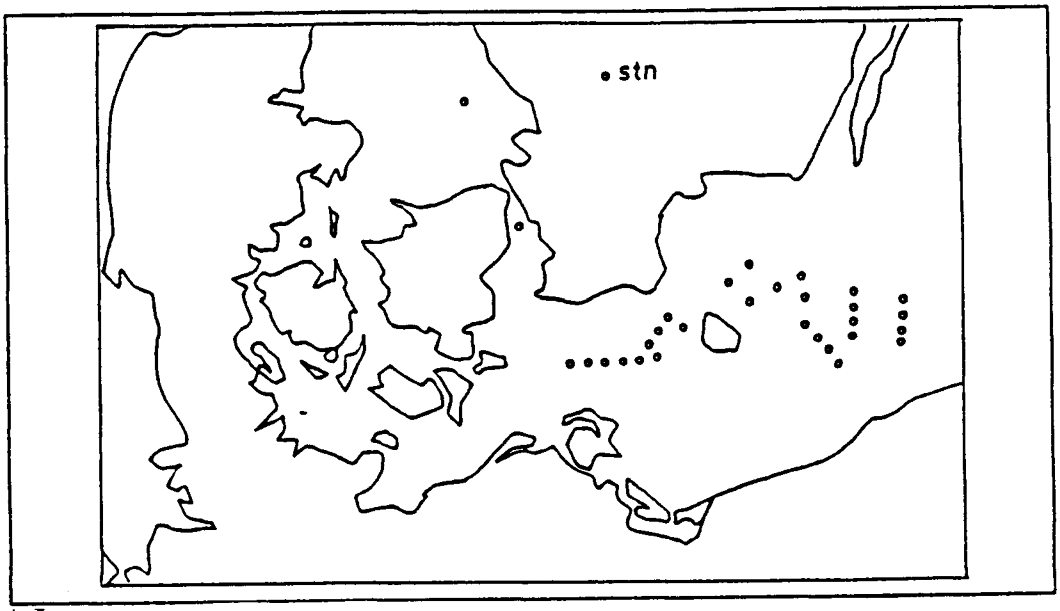


Fig. 1. Map showing the hydrographical stations visited during the expedition 2-5 of March.

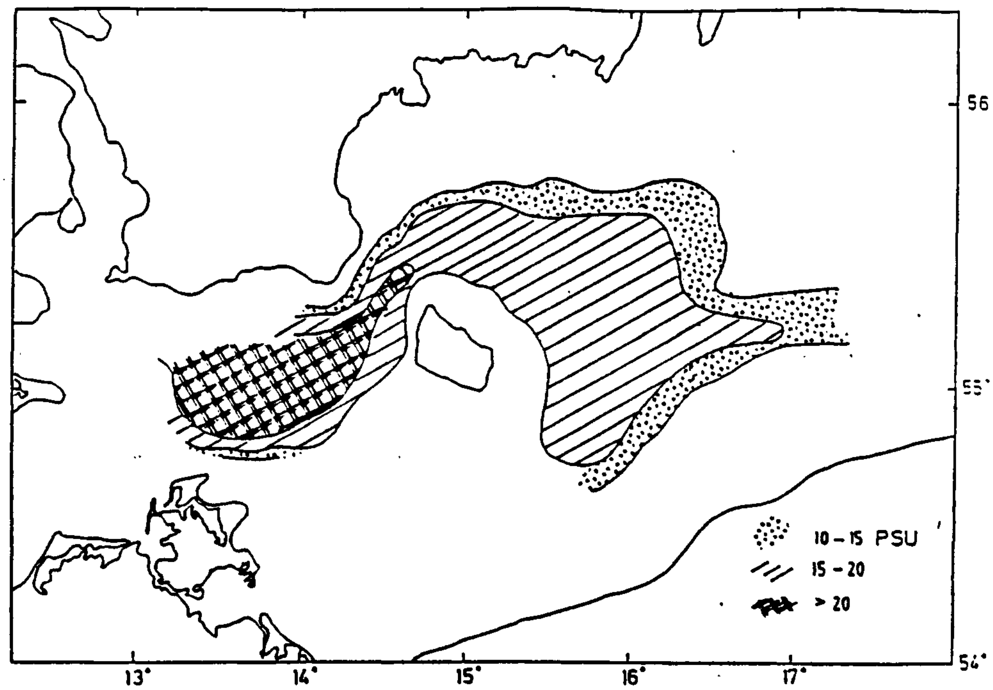


Fig. 2. The distribution of salinity close to the sea bed.

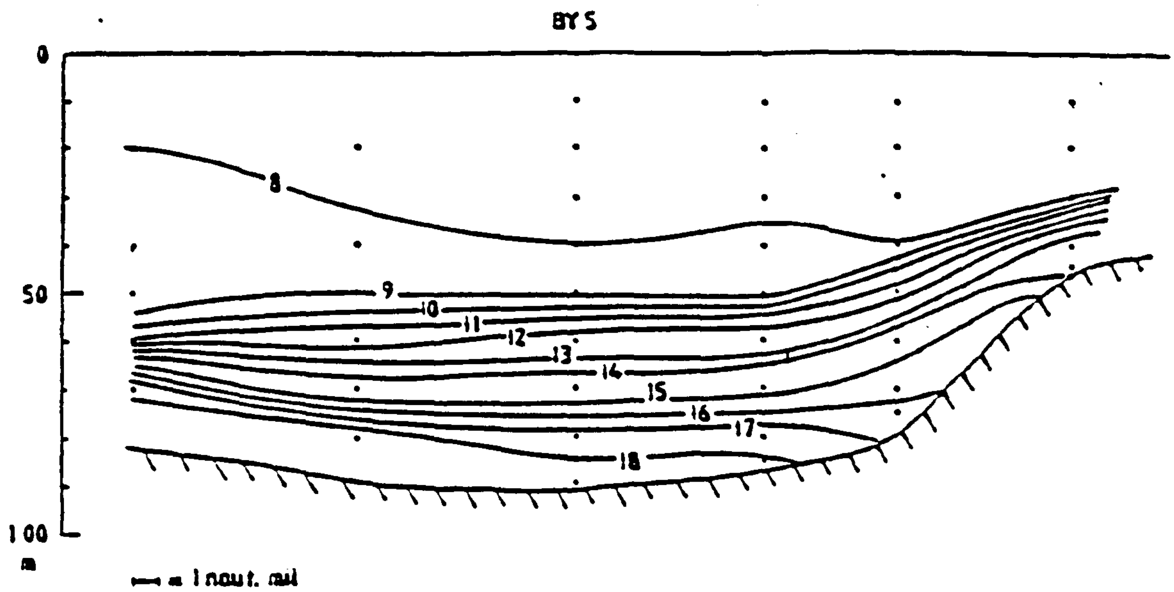


Fig. 3a. A salinity section from the central parts of the Bornholm basin towards SE.

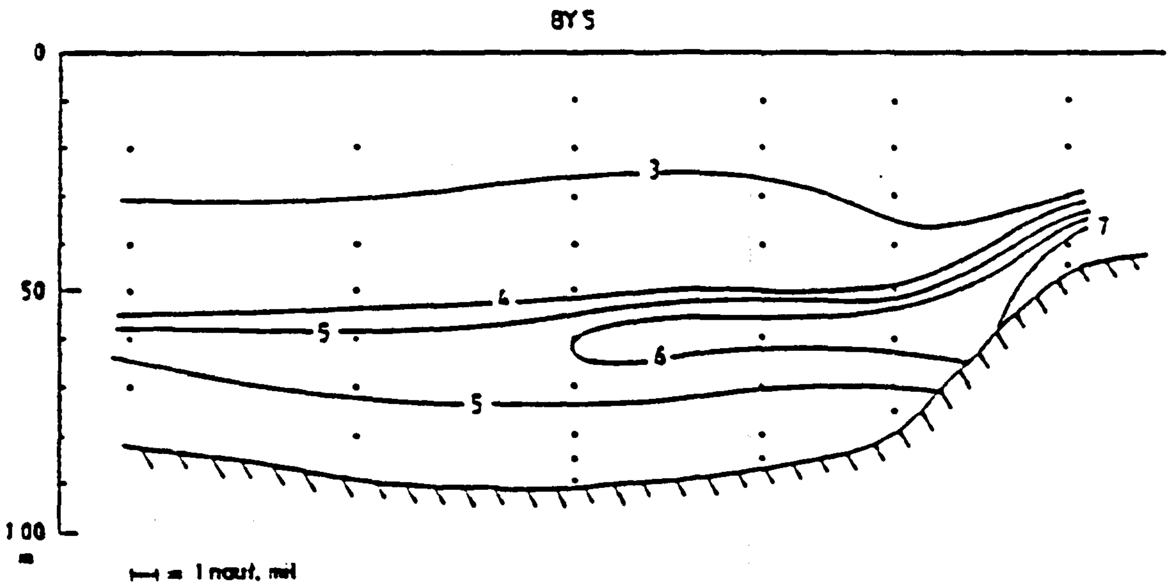


Fig 3b. The same section as in Fig. 3a showing temperature.

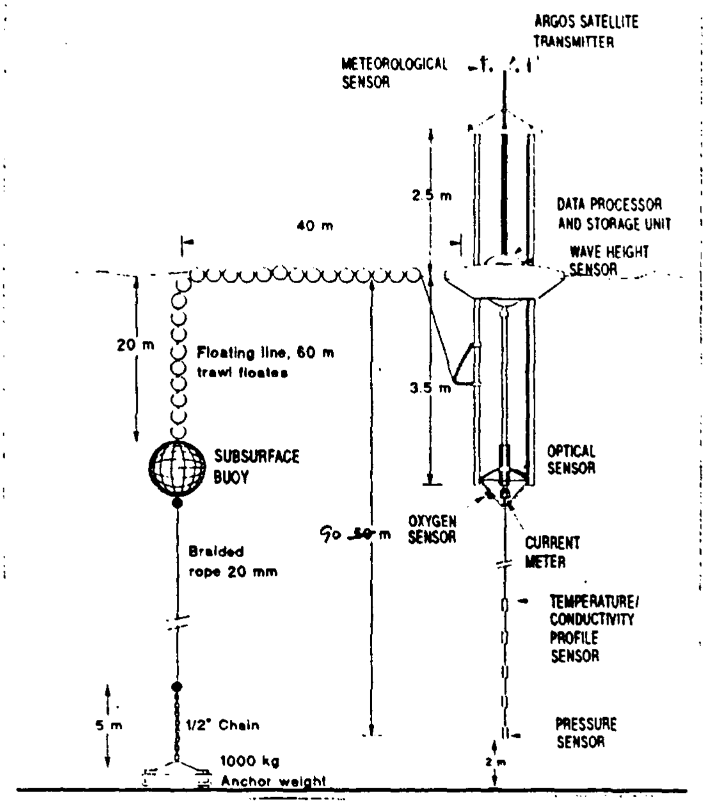


Fig. 4. Seawatch marine environmental data buoy (TOBIS)

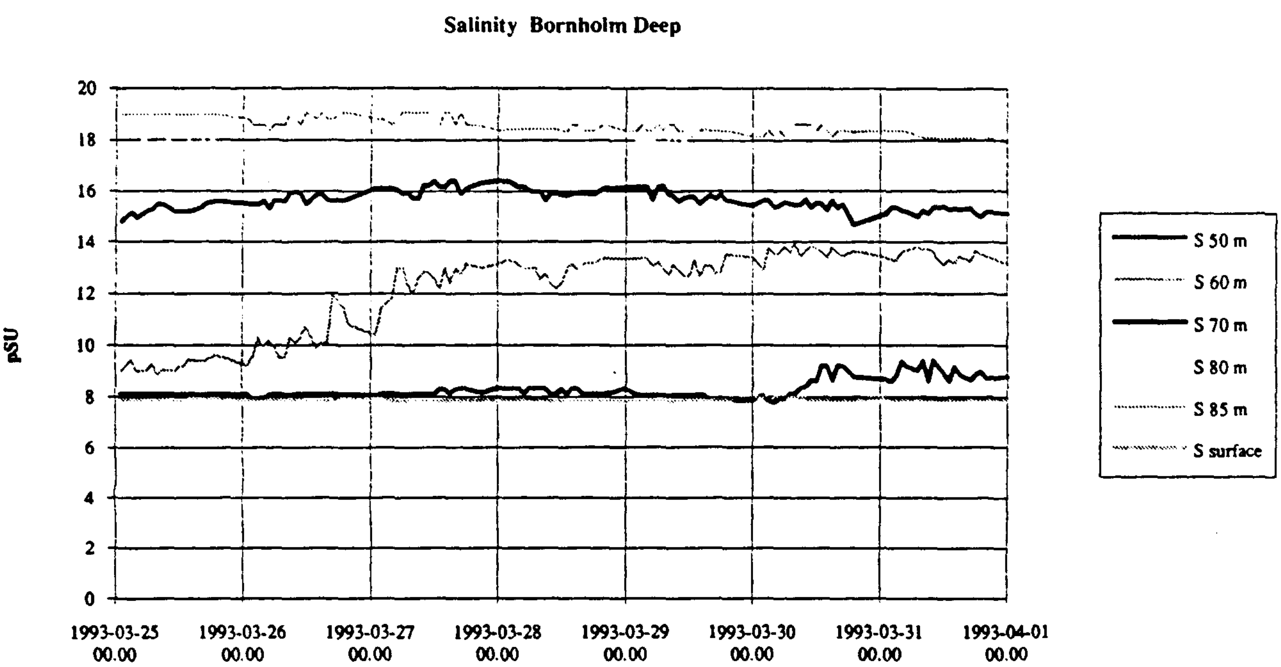


Fig. 5. Salinity, Bornholm Deep

Stolpe Furrow 69m Lat: 551315 Long:164689

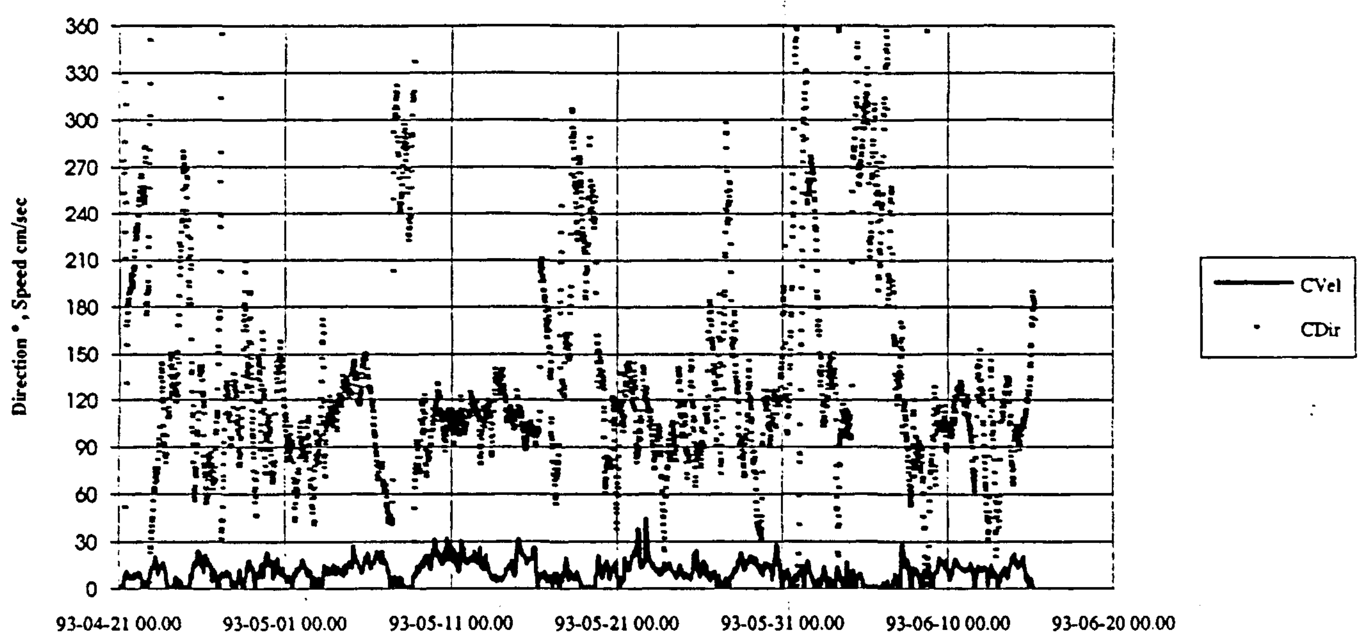


Fig. 6. Current, Stolpe Furrow

Stolpe Furrow 69m Lat: 551315 Long:164689

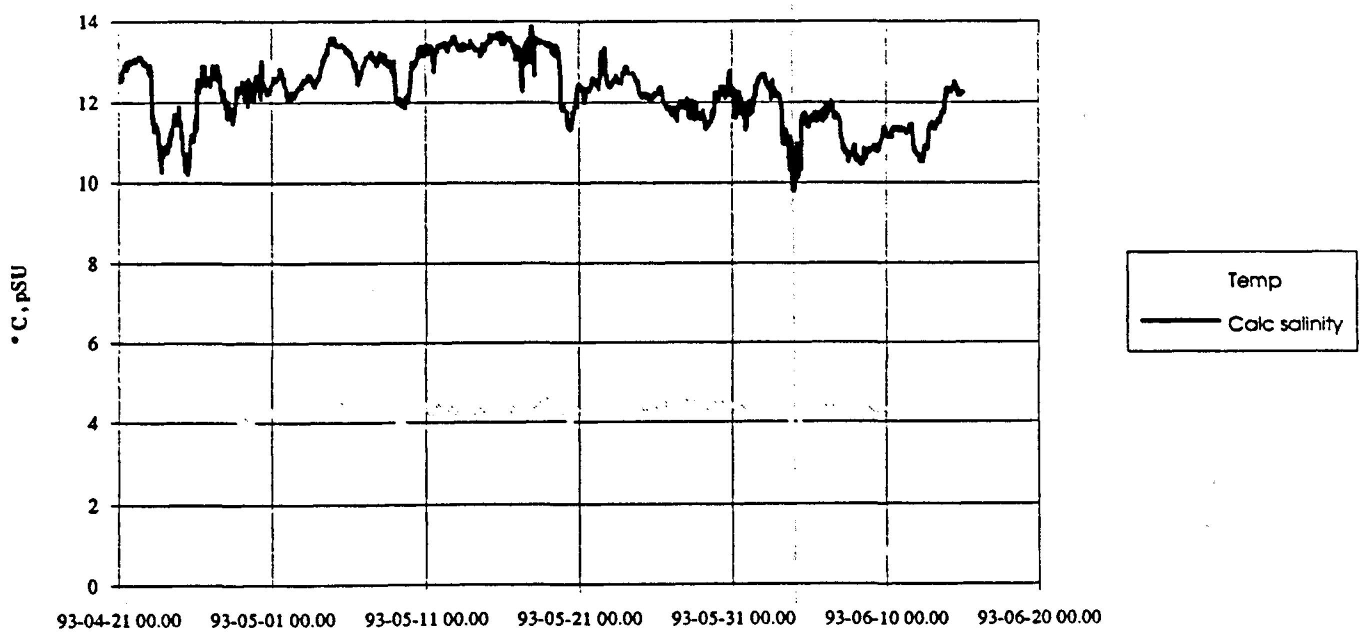


Fig. 7. Salinity and temperature, Stolpe Furrow

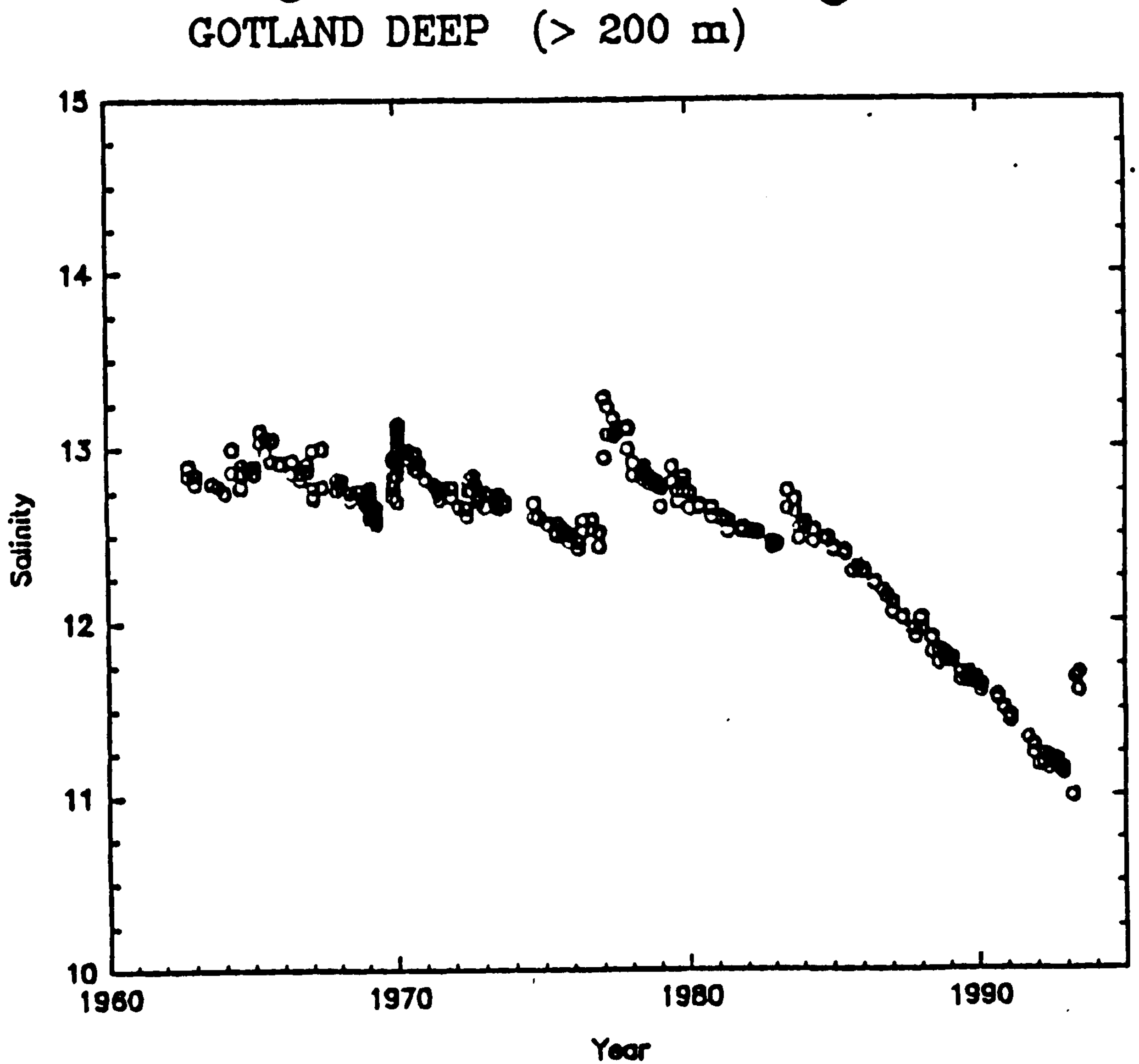
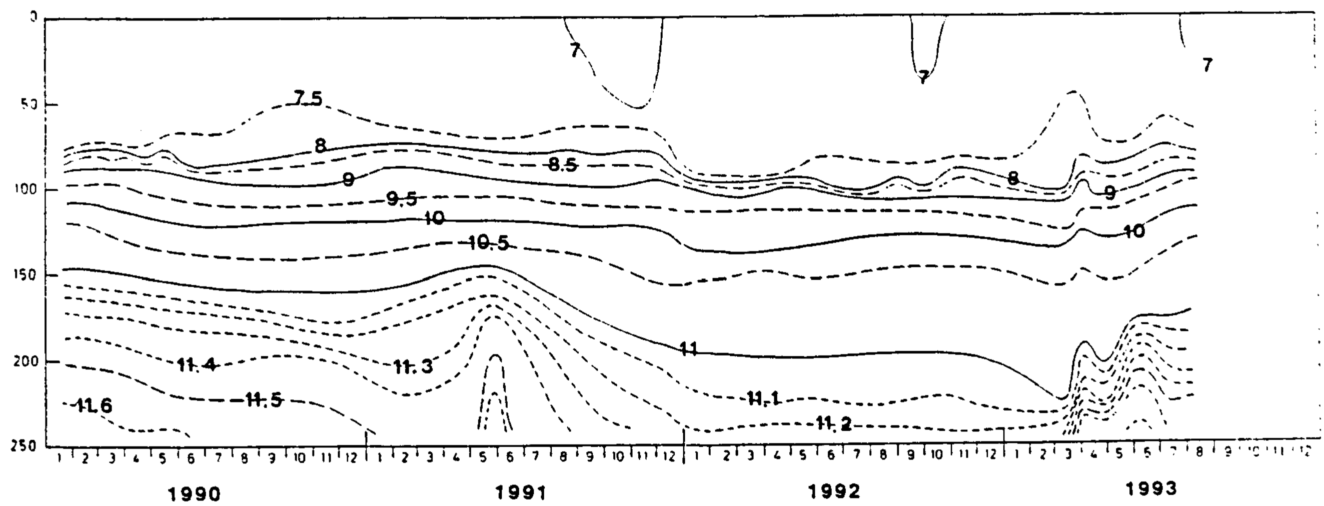


Fig. 8. The salinity below 225 m in the Gotland Deep 1963-1993.

BY 15 Salinity PSU



BY 15 Oxygen/Hydrogen Sulphide ml/l

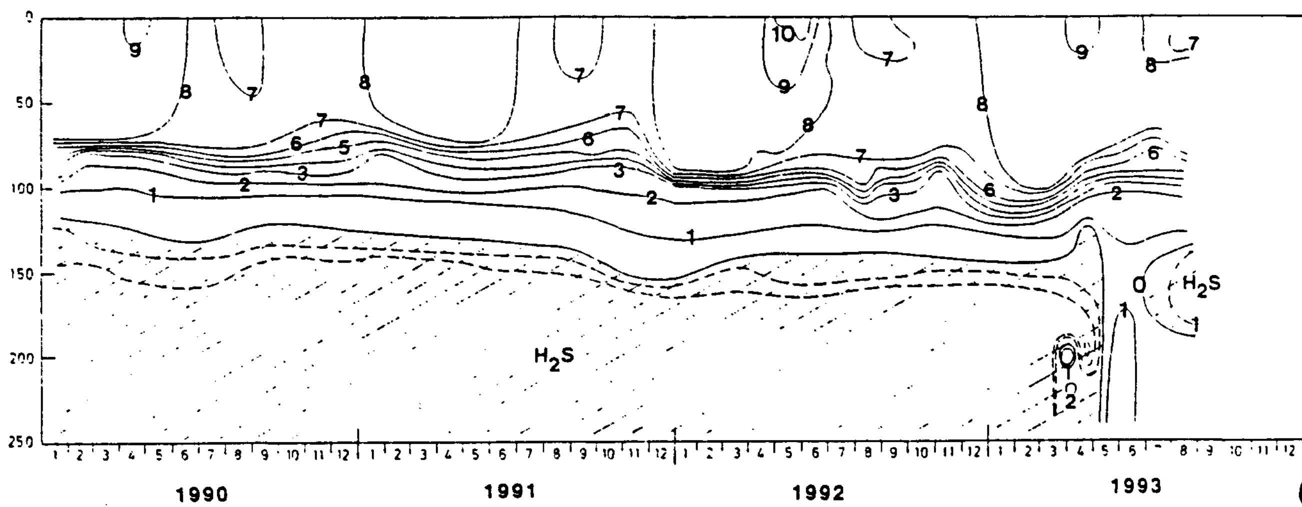


Fig. 9.
a. The salinity variations in the Gotland Deep 1990-1993.
b. The oxygen/hydrogen sulphide variations 1990-1993.

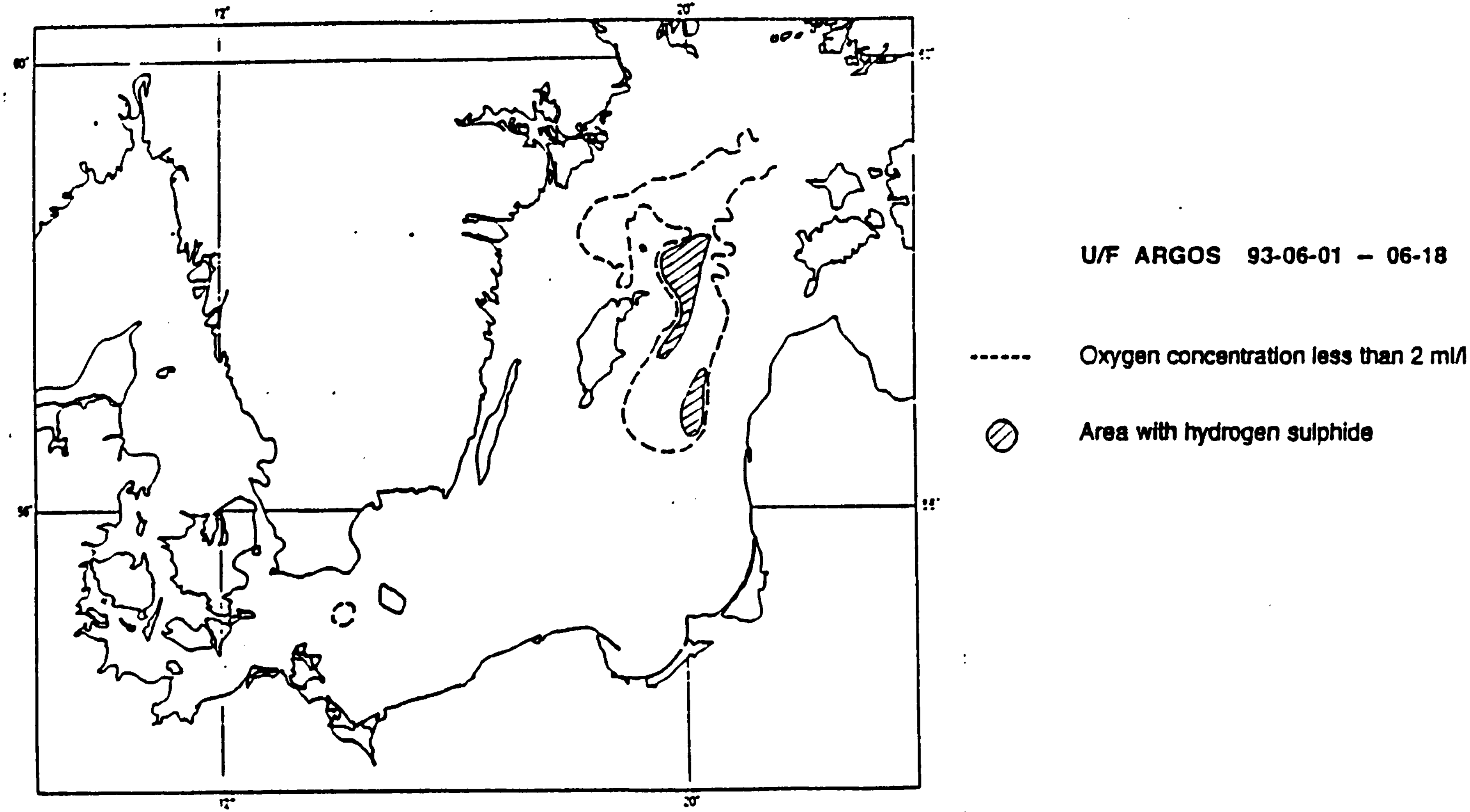


Fig. 10. The distribution of hydrogen sulphide in the bottom water in the Eastern Gotland Basin in June 1993.

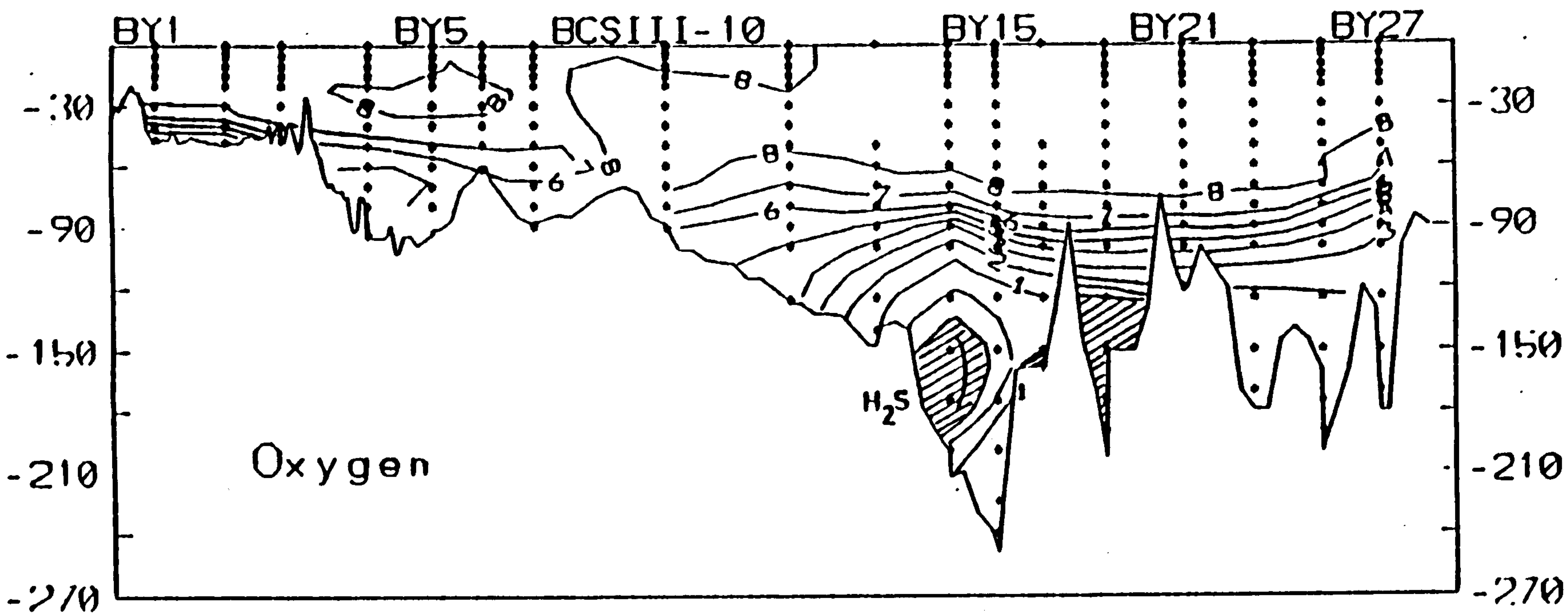
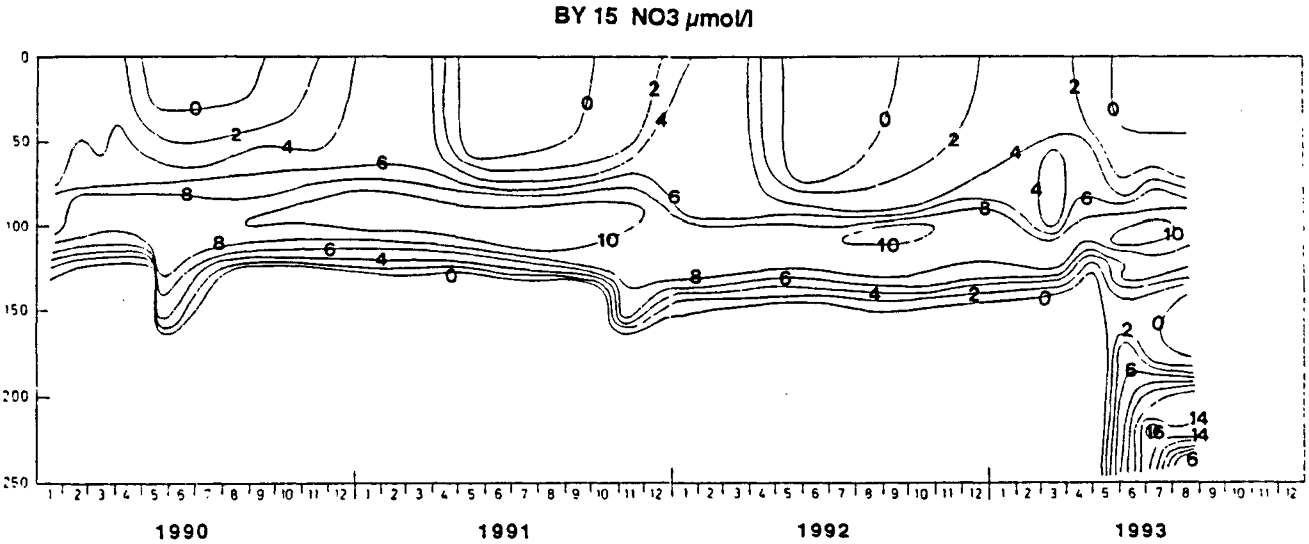


Fig. 11. The distribution of oxygen/hydrogen sulphide in the Baltic Proper. Isopleth interval is 1 ml/l.



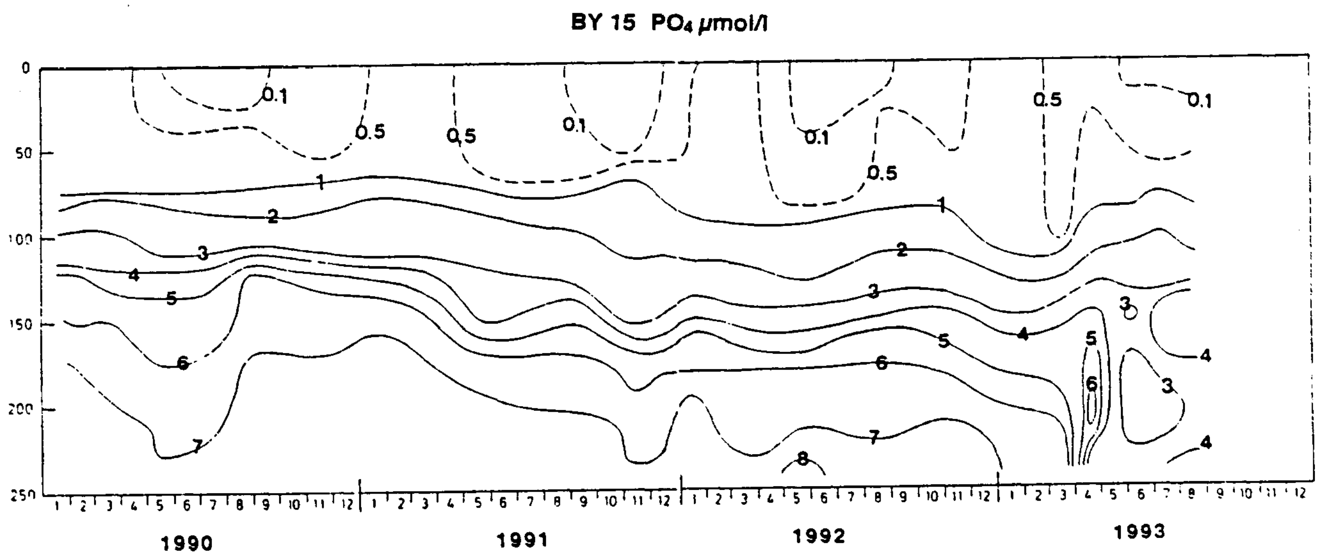


Fig. 12.
a. The nitrate variations in the Gotland Deep 1990-1993.
b. The phosphate variations 1990-1993.