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HYDROGRAPHY OF THE OSLOFJORD

Report

on

The Study Course in Chemical Oceanography

arranged in 1969 by ICES with support of UNESCO

by

T. Andersen, F. Beyer, and E. Föyn
Institute of Marine Biology, Depts. A & C,
University of Oslo

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INTRODUCTION

(T.Andersen)

The experience gained at the Intercalibration Meeting held in Copenhagen in 1966 revealed the desire of the ICES Working Group on Chemical Analysis of Sea-Water to arrange training courses in hydrochemical methods in order to achieve greater uniformity in analytical treatment of seawater samples. The courses were to be held for scientists and technicians in charge of chemical seawater research.

The Chairman of the Working Group, Dozent Dr. Klaus Grasshoff, Kiel, and Professor Dr. Ernst Föyn, Oslo, were requested to cooperate in the planning of such a course.

After several meetings the detailed plans were presented at the ICES Meeting in Copenhagen 1968.

According to these plans the Course was held at the University Biological Station, Dröbak at the Oslofjord, from 11 August to 6 September 1969, and it was attended by 15 participants from ICES member countries and 6 participants from UNESCO member countries.

During the first week lectures and discussions were held on the theoretical background of chemical oceanography. The manuscripts of the general lectures, which were collected by Dr. Rolf Lange, as well as a Manual in Analytical Methods, commonly applied by students in marine biology, are published by Universitetsforlaget, Oslo. The book, "Chemical Oceanography, an introduction," is in English.

The Norwegian R/V "G.O.Sars" was present at the beginning of the first week for demonstration of a sea-going research vessel.

During the second and third week practical laboratory work with different chemical methods was carried out. The results obtained were discussed and treated statistically.

The German R/V "Alkor" arrived at Dröbak on 26 August and remained for one week. Water samples were collected and analysed on daily cruises. Continuously recording analytical instruments were also demonstrated.

Two small Norwegian research vessels, "Gunnar Knudsen" and "Kristine Bonnevie", were available for the entire duration of the Course.

In order to give practical training, the hydrographical and chemical conditions in the Oslofjord were investigated by simultaneous observations carried out at different localities in the fjord in the course of one day.

During the last week the results of these observations were elaborated and discussed.

At the 57th Statutory Meeting of ICES in Dublin 1969 it was decided, on the recommandation of the Hydrography Committee, to publish a report dealing with the practical and theoretical results which were attained during the Course. This report follows.

DETAILED PROGRAMME and METHODS

(T. ANDERSEN)

Monday, 11 August

9.00 - 11.30	Registration at the biological station in Dröbak.
13.00 - 14.00	Introduction by Prof. J.T.Ruud, Vice-President of ICES, and Prof. E.Föyn, Superintendant of the Course.
14.00 - 17.00	The significance of chemical components in the marine environment (Prof. E.Föyn).

Tuesdag, 12 August

9.00 - 11.30	The significance of chemical components in the marine environment, cont. (Prof. E.Föyn).
13.00 - 17.00	Introduction to the topography and hydrography of the Oslofjord (Ass.Prof. F.Beyer).
19.00 - 22.00	Evening seminar: The theory of echo-sounding devices ("Simrad", Norway).

Wednesday, 13 August

9.00 - 17.00	Cruise on board the R/V "G.O.Sars". Demonstration of a sea-going research vessel. This involved demonstration and training of routine procedures for water sampling, as well as demonstration of the practical use of navigation systems (Decca) and different echo-sounding devices (Simrad).
17.00 - 19.00	Correction of temperature readings taken in connection with seawater sampling, by means of graphs and tables.

Thursday, 14 August

9.00 - 10.00	Stoichiometry and chemical equilibrium (Prof. D.Dyrssen).
10.00 - 11.30	The carbonate system (Prof. D.Dyrssen).
13.00 - 14.00	Marine biology and chemistry (Dr. R.Lange).
14.00 - 17.00	Sampling and sampling techniques (Dr. K.Grasshoff).

19.00 - 22.00	Demonstration of salinometers (Dr. K.Grasshoff), and subsequent determination of salinities of the seawater samples collected on the Wednesday's cruise.

Friday, 15 August

9.00 - 11.30	Short introduction to the methods for chemical analysis of seawater (Dr. S.Fonselius, Dr. F.Koroleff, and Dr. K.Grasshoff). Assignment of laboratory manuals.
13.00 - 14.00	The importance of intercalibration and statistics in marine analytical chemistry (K.Palmork).
14.00 - 16.00	Data logging and storage (Prof. O.Sælen).
19.00 - 21.00	Evening seminar: Demonstration of the "Olivetti" top desk computer.

Monday, 18 August

9.00 - 10.00	Introduction and orientation to laboratory facilities. Assignment of desks and work areas. Dividing the participants into ten groups.
10.00 - 11.30	General background and principles for the determination of salinity (Dr. K.Grasshoff).
13.00 - 15.00	Outline of methods for salinity determinations: The Mohr-Knudsen method, according to HERMANN *et al.* (1959). Potentiometric determination, according to HERMANN (1951). The direct gravimetric determination, according to MORRIS & RILEY (1964). Micro-chloride determination, according to GRASSHOFF (1968).
15.00 - 17.00	Practice of analytical methods in the laboratory.
19.00 - 22.00	Demonstrations of spectrophotometers (Perkin-Elmer, Zeiss and Unicam), gas chromatography (Perkin-Elmer) and atomic absorption (Perkin-Elmer).

Tuesday, 19 August

9.00 - 11.30	General background and principles for the determination of pH and alkalinity (Dr. K.Grasshoff and Dr. F.Koroleff). Outline of the method for pH determination according to GRASSHOFF (1968), and for alkalinity determination according to GRASSHOFF (1968) and KOROLEFF (1968).
13.00 - 17.00	Practice of analytical methods in the laboratory.
19.00 - 22.00	Evening seminar: Discussion on the third-decimal place in salinity determinations. The discussion was opened by Oscar Guillen, Peru, who had been asked to back the third-decimal place, and Eric Levy, Canada, who combatted it.

Wednesday, 20 August

9.00 - 11.30	General background and principles for the determination of oxygen and hydrogen sulphide (Dr. S.Fonselius). Outline of the Winkler method for oxygen determination according to GRASSHOFF (1968), and the methods for hydrogen sulphide determination according to FONSELIUS (1968) and ANDERSEN & FÖYN (1969).
13.00 - 17.00	Practice of analytical methods in the laboratoty.
19.00 - 22.00	Determination of salinity (by electrical conductivity) and chlorinity on one bulk sample of seawater. Conductivity and temperature were measured by means of a conductivity salinometer, and converted to salinity by means of the UNESCO International Oceanographic Tables. The chlorinity was determined according to HERMANN *et al.* (1959), and converted to salinity by the relationship $S = 1.80655\ Cl$ ‰. (See Table 1, p.12).

Thursdag, 21 August

9.00 - 10.00	The theory of spectrophotometry (Dr. K.Grasshoff).
10.00 - 11.30	General background and principles for the determination of phosphate and total phosphorus (Dr. F.Koroleff). Outline of the method for phosphate determination according to MURPHY & RILEY (1962), and of the method for determination of total phosphorus according to KOROLEFF (1968).
13.00 - 17.00	Practice of analytical methods in the laboratory.
19.00 - 22.00	Replicate determinations of oxygen in the same water sample. The samples differed between the different groups. (See Table 2, p.13).

Friday, 22 August

9.00 - 11.30	General background and principles for the determination of ammonia (Dr. F.Koroleff). Outline of the method for determination of ammonia according to KOROLEFF (1969), and for determination of ammonia and labile amino compounds according to ANDERSEN & FÖYN (1969).
13.00 - 17.00	Practice of analytical methods in the laboratory.
19.00 - 21.00	Checking of the solutions used for the pH-determinations (see Table 3, p.14).

Monday, 25 August

9.00 - 11.30	General background and principles for the determination of nitrite and silicate (Dr. K.Grasshoff). Outline of the method for nitrite determination according to BENSCHNEIDER & ROBINSON (1952), and for silicate determination according to STRICKLAND & PARSONS (1968).
13.00 - 17.00	Practice of analytical methods in the laboratory.
19.00 - 22.00	Demonstration of filtration equipment from "Sartorius".

Tuesday, 26 August

9.00 - 11.30	General background and principles for the determination of nitrate (Dr. K.Grasshoff). Outline of the method for determination of nitrate according to ANDERSEN & FÖYN (1969) and GRASSHOFF (1968).
13.00 - 17.00	Practice of analytical methods in the laboratory.
19.00 - 22.00	Evening seminar: Discussions concerning plans for different cruises, in particular the arrangement of the stations in the multi-ship survey of the Oslofjord.

Wednesday, 27 August

9.00 - 13.00	Group A: Cruise in Dramsfjord with R/V "Alkor". Water samples were collected for salinity, oxygen, hydrogen sulphide, and pH determinations. Group B: Cruise in inner Oslofjord with R/V "Gunnar Knudsen". Demonstration and practice with an oxymeter (FÖYN, 1965). Cruise in the Dröbak Sound with M/B "Bente". Demonstration and practice with a current-meter, the Bathyrheograph (BEYER *et al.* 1967).
14.00 - 17.00	Practice of analytical methods in the laboratory.
19.00 - 21.00	Evening seminar: Methods in use for the determination of primary production (Dr. E.Paasche).

Thursday, 28 August

9.00 - 13.00	The same cruise-program as the day before. (Group A and Group B changed programme).
14.00 - 17.00	Practice of analytical methods in the laboratory.
19.00 - 21.00	Preparation for the multi-ship cruise.

Friday, 29 August

9.00 - 16.00	Multi-ship cruise in the Oslofjord. Water samples were collected from R/V "Alkor" in the outer part of the fjord (stations 1-5), from R/V "Kristine

Bonnevie" in the Dröbak Sound area (stations 6-8), and from R/V "Gunnar Knudsen" in the inner fjord (stations 9-13).
During the period of sampling, i.e. 0900-1600, current measurements were run continuously at station A by means of the Bathyrheograph.
Locations of stations occupied are shown in Figure 1. Samples were taken with plastic-coated Nansen samplers (except on board "Kristine Bonnevie"), from depths chosen on the basis of a continuous recording (BT and/or oxymeter).
In addition to temperature determinations, subsamples for salinity, dissolved oxygen, phosphate, nitrate, nitrite, and ammonia were collected from each depth at all stations. Furthermore, subsamples for pH, alkalinity and reactive silicate were collected at stations 1-5.

18.00 - 22.00 Analyses of the seawater samples collected on the multi-ship cruise. Determination of phosphate (MURPHY & RILEY, 1962), nitrate (ANDERSEN & FÖYN, 1969), and pH (GRASSHOFF, 1968).

Saturday, 30 August

9.00 - 17.00 Analyses of the seawater samples collected on the multi-ship cruise. Determination of alkalinity (KOROLEFF, 1968), ammonia (KOROLEFF, 1969), silicate (STRICKLAND & PARSONS, 1968) and nitrite (BENSCHNEIDER & ROBINSON, 1952).

18.00 - 21.00 Determination of oxygen (GRASSHOFF, 1968) and salinity by an inductive salinometer.

Monday, 1 September

9.00 - 15.00 Cruise in the inner Oslofjord with R/V "Alkor". Demonstration and practice with a multi-channel "Technicon Autoanalyzer", "Hewlett-Packard C-N Analyzer" and "Oxygensonde" (GRASSHOFF, 1962).

Tuesdag, 2 September

9.00 - 17.00 Treatment of data accumulated.

19.00 - 22.00 Demonstration and practice with an atomic absorption spectrophotometer (Perkin-Elmer). Determination of copper and zinc in the seawater samples collected on the multi-ship cruise.

Wednesday, 3 September

9.00 - 11.30 Construction of isoplet (Ass. Prof. F. Beyer).

13.00 - 17.00 Treatment of data accumulated.

Thursday, 4 September

9.00 - 16.00 Discussion of results of the multi-ship cruise (Prof. E.Föyn).

Saturday, 6 September

Departure.

SOCIAL EVENTS:

Saturday, 30 August

19.00 - 22.00 Informal evening party onboard R/V "Alkor".

Monday, 1 September

18.00 - 20.00 Cocktail-party given by the German Embassy onboard R/V "Alkor".

Wednesdag, 3 September

19.30 - 24.00 Dinner given by the Norwegian Ministry of Fisheries.

Friday, 5 September

9.00 - 16.00 Sightseeing in Oslo, and visit to the University of Oslo, Blindern.

Table 1. Determination of salinity by conductivity and by chlorinity titration.

Group No.	Salinometer (S_s)	dev. from total mean	Cl-titration (S_{Cl})	dev. from total mean	$S_s - S_{Cl}$
1	33.737	0.042	33.60	- 0.08	0.14
2	33.723	0.028	33.70	0.02	0.02
3	33.760	0.065	33.76	0.08	0.00
4	33.676	-0.019	33.73	0.05	- 0.05
5	33.683	-0.012	33.73	0.05	- 0.05
6	33.702	0.007			
7	33.690	-0.005	33.60	- 0.08	0.09
8	33.680	-0.015	33.73	0.05	- 0.05
9	33.618	-0.077	33.69	0.01	- 0.07
10	33.680	-0.015	33.54	- 0.14	0.14
Total mean:	33.695		33.68		
Stand. dev:	± 0.039		± 0.076		

Table 2.

Oxygen content of the different samples in ml/1.

Group										Mean	St. dev.
1	6.06	6.04	6.07	6.09	6.06	6.07	5.97	6.07	6.02	6.05	± 0.034
2	5.30	5.30	5.32	5.31	5.30	5.30	5.31	5.31	5.29	5.30	± 0.012
3	5.98	6.04	6.07	5.98	6.10	6.04	6.02	6.03	6.05	6.03	± 0.039
4	7.03	7.04	6.99	7.00	7.09	7.01	7.08	7.01	7.06	7.03	± 0.036
5	6.97	7.09	7.10	6.93	6.96	6.93	7.06	6.99	7.00	7.03	± 0.065
6	6.99	7.04	7.01	6.84	6.98	6.98				6.97	± 0.069
7	6.24	6.08	6.31	6.23	6.09	5.99	6.27	6.25	6.26	6.19	± 0.109
8	6.03	6.09	6.05	6.01	6.06	6.09	6.11	6.06	5.96	6.06	± 0.047
9	6.32	6.21	6.10	6.78	6.19	6.27	6.05	6.15	6.24	6.20	± 0.259
10	5.08	5.03	5.02	5.02	4.99	4.99	5.05	4.99		5.02	± 0.032

Table 3.

Checking of the standards used for pH-determination

Group	phtalate std.	phosphate std.	$KH(IO_3)_2$	f/HCl	Control f/HCl
Check	4.008	6.867	0.0100	1.000	
1 + 2	4.016	6.874	0.0099	1.010	1.000
3	4.018	6.852	-	1.19	0.998
4	4.014	6.878	0.0101	1.002	1.000
5	4.013	6.881	0.0101	1.009	0.994
6	4.013	6.875	0.0099	-	0.994
7	4.029	6.871	0.0099	1.15	0.984
8	4.013	6.874	0.0099	1.02	0.998
9	4.014	6.673	0.0101	-	0.994
10	4.020	6.871	0.0097	0.945	0.994
Mean	4.016	6.872	0.0097	0.995	
St.dev.	± 0.005	± 0.008			

TOPOGRAPHY and STATIONS

(F.Beyer)

The Oslofjord (Fig. 1) can conveniently be divided into three major parts. The area from the fjord mouth by Ferder to the constriction between Horten and Moss is termed the o u t e r fjord. The part between this constriction and the shallow and narrow constriction at Dröbak is termed the m i d d l e fjord. This includes the wide area Breiangen, from which the Dramsfjord (to Drammen) branches off, and the narrow and straight part northwards to Dröbak. The waters inside Dröbak are called the i n n e r Oslofjord.

The dotted line in Figure 1 is drawn along the deepest groove in the Oslofjord from the fjord mouth eastward of Ferder to the head of the fjord, Bunnefjord. The triangles mark the locations of the hydrographic stations occupied on 29 August, 1969. Station 2 is not included in the present hydrographic sections (Figs. 2-12), because this station unfortunately was taken over the ridge westward of the deepest groove and for this reason gave records that do not fit well between the records from stations 1 and 3. Station 12 is also excluded from the sections because this station is located in a separate basin off the fjord axis.

Even from the survey chart presented in Figure 1, with the few selected isobaths, it appears that the topography of the Oslofjord is of a very complicated nature. Numerous islands, ridges, and bays are found nearly all along, and near the head the axis of the fjord bends 180°.

From the sections (Figs. 2-12) the deepest parts of the bottom also seem to be very rough, but this is due to the telescoped horizontal scale. In fact, the bottom of the various basins is covered with clay and is in most places smooth enough for commercial shrimp trawling. The ridges separating the basins are, however, indeed conspicuous features. Four major ridges can be distinguished.

1) The H v a l e r ridge crosses the fjord mouth between stations 1 and 3 from the Hvaler islands on the east to the Bolærne islands on the west. With a sill depth of approximately one hundred metres it separates the deep waters of the outer Oslofjord from the great Skagerak deep.

2) The second major ridge, the J e l ø y ridge, is found in the middle fjord, extending towards the northwest from the island Jeløy between stations 4 and 5. With a sill depth just exceeding 100 m it only mounts to half the distance between the maximum depth inside and the surface.

3) The most important of all the ridges is the D r ø b a k bar between stations 6 and 7, separating the middle and the inner fjord parts. The sill depth of only 19.5 m represents only 12% of the greatest depth (164 m) found inside. Moreover, there is only a narrow gap in this sill that is deeper than 15 m. The western half of the cross section of the sound in this area is even blocked by a jetty mounting to about 1 m below the sea surface.

4) The B y g d ø y ridge separating the Vestfjord from the Bunnefjord is broad and has a sill depth of about 55 m, whereas depths of approximately three times that much are found on both sides.

TIDES and CURRENTS

(F. Beyer)

Tides and currents were not really the subject of the present investigations. Since it had, however, previously been found by BEYER (not published) that the salinity at sub-surface levels in Breiangen south of Filtvet showed very considerable periodic changes, with a range of at least 2‰ at 10 to 30 m and maximum salinity corresponding, apparently, with high tide, it was felt highly desirable to provide some information on the actual tides during the present hydrographic cruise. Even with three vessels in action the difference in time between some of the stations would be about six hours. Thus horizontal gradients might appear that were not real but only represented different phases of the tide of other cyclic variation. To what extent the salinity oscillations found in the middle fjord propagate through the Dröbak Sound is not known.

Sea level records were obtained from Oslo harbour, and current profiles were recorded over the Dröbak sill by means of the Bathyrheograph. It was previously shown by BEYER *et al.* (1967) that currents measured at this point were in very good agreement with the sea level fluctuations recorded in the harbour of Oslo.

Water transport in the uppermost layers are governed by the following agents: (1) The tide, (2) The local wind, (3) The meteorological conditions and sea level in Skagerak, (4) The freshwater surplus.

Because of the oblong shape of the Oslofjord, water transports occur mainly as currents up or down the fjord. There are, however, some complications.

A northerly wind will carry surface water towards the head in the Bunnefjord and at the same time towards the sea in the Vestfjord.

Since by far the best possibility for water to cross the Dröbak bar is through the gap in the eastern half of the sound, where the current measurements were made (Fig. 1, Station A), some of the water crossing the sill at this point come from, or go to, the western side of the inner fjord. This explains the tendency of NW and SE current directions to prevail in the records. The proximity of the steep and crooked bottom ridge causes the flow to be very turbulent though (BEYER *et al.*, 1967).

The mighty flow of river water mixed with salt water coming out the Dramsfjord is thrown towards the east by the islands and shoals off Holmestrand. As a rule, it takes up a N-S path somewhere more or less due south of Filtvet, where a visible line of convergence can often be found.

On calm days, foam from the industrial waste waters of Glomma can be found right across the fjord mouth to the Ferder area. The surface salinity minimum found at Station 1 (Fig. 3) may well be the result of such a transport.

1. The tide

The sea level fluctuations recorded at Oslo are given in Figure 13, curve I. Sea level records obtained at Oscarsborg, which is very near the Dröbak sill, were on an earlier occasion found to be extremely similar to the Oslo records apart from a phase difference of 15 minutes with the Oslo records lagging behind.

The times of observations on the various hydrographic stations in the section were as follows:

Station No:

1	3	4	5	6	7	8	9	10	11	13
09^{02}	11^{10}	13^{59}	15^{43}	09^{10}	11^{30}	14^{15}	14^{20}	12^{40}	11^{55}	09^{10}

According to this table, the difference in time between the neighbour stations 6 and 5 was six and a half hours, which is ample time for cyclic variations to interfere.

According to NORGES GEOGRAFISKE OPPMÅLING (1951) the normal tidal range at Oslo is 24 cm and the spring tidal range is 32 cm. As the moon was full on 27 August, 1969, the recorded amplitude of about 27 cm (Fig. 13, curve I) did not differ much from what would be expected. The recorded high and low water tides also agreed well with the predicted hours. There were, however, very distinct secondary maxima and minima occurring about 3 hours prior to the predicted hours of tidal extremes.

The agreement between the record (curve I) and the tide tables (NORGES SJØKARTVERK) with respect to both low water and high water tides indicates that the resulting wave, although irregular in shape, includes a strong element of an astronomical tide in accordance with the predicted scheme. In order to check what other elements might be included, a regular smooth curve (II) corresponding to the predicted hours, but with allowance given for a falling mean sea level at a rate of 8 cm in 36 hours (straight sloping lines), has been subtracted from the recorded fluctuations. It appears that the recorded positive and negative deviations (III, plotted around the inserted 0-0 line) from the regular curve were very considerable and clearly of a complex nature. In Figure 14 this curve of disturbance is further graphically decomposed into the components (IV) and (V). The predominating element (IV), is a wave with the same frequency as the normal tide but 4 hours ahead in phase and with a somewhat reduced amplitude. The remaining oscillation (V) is a very distinct and almost perfectly regular wave with a frequency of 4 hours or a little more. This 4 hours wave seems to be superimposed on some long-term fluctuations, the most regular of which appears to be a wave with a double tide cycle (24-25 hours) being in phase with the afternoon highwater tides. This then would explain the alternation between comparatively great and comparatively small high tides (Fig. 13). The 4 hours wave (V) would be responsible for the small humps and depressions in the sea level record (I), and the wave (IV) with a cycle of a little more than 12 hours would be responsible for the dislocation towards the left of the entire tide gauge curve (I).

Although the above analysis should merely be considered a suggestion, the pronounced regularity of the elements, introduced and found, does support the idea of their existence. At any rate, the existence of a very significant 4 hours component cannot be queried.

An attempt to disregard the predicted phase (Fig. 13, II) and introduce a 12 hours wave in best possible agreement with the actual sea level record did give smaller deviations, but these were rather untidy, although, of course, including a 4 hours component.

The apparent disturbances all have a period of 4 hours or a multiple thereof. A cycle of 4 hours has previously (NORGES GEOGRAFISKE OPPMÅLING, 1951, BEYER *et al.*, 1967) been found to be one of the predominating constituents in the surface oscillations recorded at Oslo. It is assumed to be related to the special topography of the fjord.

From Figure 14 it appears that there was a good correspondence between the oscillations of the level of no current at Dröbak (cf. Fig. 15) and the suggested resultant disturbing wave (III). In view of the local influence of the bottom and the fact that the boundary was recorded at Dröbak whereas the sea level fluctuations were recorded at Oslo a perfect agreement could not be expected. This correspondence indicates that the irregularities of the sea level oscillations and the shifting of the current at sub-surface levels were both due to the same internal waves. The correspondence also seems to support the acceptability of the suggested waves (IV) and (V). The appearing cyclic irregularities of the tidal surface oscillations are thus representing weak reflections, in the range of one or two decimetres, of very much greater movements underneath.

The current boundary also corresponded to a distinct salinity discontinuity layer. During the current observation series D (Fig. 15), 26.42‰ and 30.91 ‰ of salt were recorded at 3 m and 4 m, respectively. Even with the smoothing effect of the long Nansen water bottles one metre apart this gives a $\Delta S/\Delta z$ = 4.49‰ per m.

The present current observations (Fig. 15) confirm the previously (BEYER *et al.*, 1967) found connection between a double-peaked tidal curve, internal waves, and what has been termed "sheet currents" (opposed currents at adjacent levels) in the Dröbak Sound. During the technical demonstration of the Bathyrheograph on 27 and 28 August "sheet currents" were also recorded, with a surface layer of varying thickness running out nearly all the time. The rate of ascent and descent of the current boundary surface found by BEYER *et al*. (1967) was equal to the rate appearing in Figure 14. It is noteworthy that surface water on 29 August was running out all the time. At about 14 hours, however, this transport was only weakly developed in the topmost layer. At this hour both the major suggested disturbing curves (IV and V, Fig. 14) showed minimum activity (crests). The concurrence of the crests of these two waves is probably responsible for the following remarkable observation. Between the current observation series D and E (Fig. 15) a very distinct front appeared extending in an east-west direction just south of our vessel, which was moored over the sill. The front was visible in two ways. On the northern side of the front the surface waves were smooth, indicating that water and air were moving in the same direction, which was, of course, also observed. On the southern side of the front the surface was rough, indicating opposed movements of the two elements. The front was also marked as a line of foam indicating water submergence along the front, as the rough surface water coming up the fjord on the southern side of the front was observed to carry scattered bubbles, which probably originated from the very considerable amounts of waste water from the cellulose industry in the middle fjord.

From a dinghy two salinity bottles were filled directly by hand with water from the very surface in two places a few metres apart, one on the northern and one on the southern side of the front (Fig. 15,+). The sample from the northern side gave a S = 23.28 ‰, and the sample from the southern side of the front gave a S = 25.93‰.

The same phenomenon was, indeed, observed in the same place the preceding day, when we did not have a dinghy from which good samples could be taken.

2. The local wind

Figure 16 gives the windway recorded at Fornebu (northernmost peninsula in the Vestfjord) in August 1969. Although the wind tends to follow the longitudinal direction of the fjord, considerable variations, both in speed and direction, occur within the area. Comparatively high wind velocities are often found in the Dröbak Sound because the landscape has the same effect as the constriction of an hour-glass.

During the summer season southerly wind components are predominating in the area (BRAARUD & RUUD, 1937). This was also true in 1969, but only to a small degree in August. The day preceding the cruise was fairly calm. On 27 August a gentle breeze from the north (Beaufort 3) was noted at Dröbak. The wind observed in the Dröbak Sound on the 29th (Fig. 13) did not seem to have any strong influence on the recorded water movements (Fig. 15), as the variations in the wind were not very well correlated with the variations in the surface water transport.

It follows that wind was not likely to have exerted more than a moderate influence on the distribution of properties in the present case. The hydrographic sections (Figs. 2-12) corroborate this conclusion. In July 1969 (not illustrated) winds from the south were far more predominating.

3. The mean sea level

The hydrographic observations were made during a period of low and falling mean sea level. Over a period of many years a total difference of 2.6 m (more than ten times the normal tidal range) between high and low water extremes has been recorded (NORGES GEOGRAFISKE OPPMÅLING, 1951). Compared to this the present mean sea level anomaly is small indeed. In August the mean sea level tends to be higher than for the year as a whole, corresponding on an average to about -8 cm on the present scale (Fig. 13), (cf. NORGES GEOGRAFISKE OPPMÅLING, 1951). In view of this and of Figure 16 and the July wind, we can assume that a net seaward transport of water had taken place during a period preceding the hydrographic cruise.

4. The freshwater surplus

Since the rivers discharging into the inner Oslofjord are small ones, a typical estuarine circulation is not well developed in this part of the fjord, and because of the large rivers discharging to the middle and outer fjord the estuarine circulation may even occasionally be inverted (GADE, 1967). At the time of the cruise, the mighty annual flood of the large rivers had ceased a long time ago. According to GADE (1968) the amount of freshwater discharged into the inner fjord during the summer barely exceeds surface evaporation. Through the Dröbak Sound only a small net seaward transport could therefore be attributed to the freshwater surplus during and prior to the cruise. This transport would represent an addition to the transport accounting for the mean sea level descent.

A seaward transport of surface water through the Dröbak Sound is likely to draw up water from deeper levels on the seaward side of the bar. It is possible that the hump appearing in the temperature and salinity sections (Figs. 2 & 3) is due to this effect. A comparison of the observation times given for the stations 5, 6, and 7 in the table on page 18, and the movements of the boundary shown in Figure 14 indicates that the hump appearing in the sections was not caused by the internal waves. In fact, it is more likely that the hump would have been more conspicuous if the stations were occupied simultaneously. Figure 3 agrees well with the typical salinity distribution during northerly winds in summer (GADE, 1968, Fig. 8). During periods of strong and lasting northerly winds and really low sea level the phenomenon is very much more clearly developed (cf. GRAN & GAARDER, 1918).

STRATIFICATION OF THE WATER MASSES

(F. Beyer)

The 7° isoline (Fig. 2) marks the boundary between a thermically uniform deep water and a transition layer with strongly increasing temperature towards the seasonally heated surface water. The slope of the 7° isoline (and the adjacent isolines) demonstrates the increasingly effective shelter of the encompassing land up the fjord. In the inner fjord, a pronounced thermocline is found at about 10 metres depth.

Reduced surface salinities are characteristic of the surface water of the entire area off the fjord mouth, this being mainly due to the influence of the Baltic current. In addition to that, the local discharge of freshwater in the Oslofjord is considerable, Glomma, discharging at Fredrikstad in the outer fjord, and Dramselv, discharging at Drammen with connection to the middle fjord, being numbers one and two respectively among Norwegian rivers as far as annual discharge is concerned. A number of smaller rivers are discharging into the inner fjord. This all leads to a marked salinity stratification all along the fjord (Fig. 3). The most pronounced vertical gradient, the halocline, is found at about 10 metres depth, which is the situation normally found during summer.

With the considerable salinity range in the discontinuity layer there was a corresponding density stratification, which must have exerted a substantial influence on the mixing processes and circulation in the fjord. It is therefore not surprising to find a considerable correspondence between the thermocline and the halocline. For the rest, however, the temperature and salinity isolines were definitely not parallel. As a result of reduced vertical mixing, water colder than 7°C was found much nearer the surface in the innermost part of the fjord than further out (P. 23), In spite of the reduced mixing, however, water with low salinity ($S < 33‰$) was found further down in the innermost fjord. This can be explained by the much greater accessibility of high salinity water in the outer fjord.

Since alkalinity and salinity are related properties it is quite reasonable that the alkalinity (recorded only at the stations 1-5 and not illustrated) showed great resemblance to the salinity in distribution.

The conspicuous vertical temperature and salinity gradients are due in the first place to the fact that both heating and dilution originate in the surface, secondly to the overwhelming influence of the dilution on the density, and hence the stability of the water, and thirdly to the fact that temperature and salinity at sub-surface and deeper levels are not influenced significantly by any processes other than mixing and transport.

The fact that no one of the remaining parameters showed anything like equally consistent horizontal stratification indicates that their distribution was strongly influenced by circumstances other than those governing temperature and salinity distribution.

The layering appearing in the pH section (Fig. 4) was due to local phenomena. The surface minimum at station 4 is based on one single observation only and may thus be erroneous or due to some local pollutant. The sub-surface maximum seems more significant. Corresponding with a maximum in oxygen saturation (Table 4) it may be related to photosynthetic activity. At any rate, the complete lack of correspondence between the density (salinity, Fig. 3) and oxygen distribution (Fig. 5) in the outer fjord indicates that oxygen production had taken place also below the density discontinuity layer (pycnocline), oxygen being consumed at all levels through respiration and decomposing processes. In the Oslo area of the fjord, however, the greater turbidity of the surface water, due partly to mass production of algae resulting from fertilization, significantly reduces the possibility (light) for photosynthesis to take place down below the pycnocline. A pronounced vertical oxygen gradient is therefore found in this sheltered and heavily polluted part of the fjord.

IMPORTANCE OF THE BARS

(F. Beyer)

If extensive vertical mixing takes place on both sides of a bar the significance of this bar as a hydrographic barrier is moderate, provided the exchange of water across the bar is considerable. In the Oslofjord, however, where vertical water exchange is strongly hampered by density stratification the blocking of advectional movements by transverse ridges may prove fatal.

1. The Hvaler ridge

Although temperature and salinity were very similar on the two sides of the Hvaler ridge the water definitely was not the same. The difference appears most clearly in the distribution of Si (Fig. 7). Also the concentrations of oxygen (Fig. 5) and nitrogen compounds (Figs.10, 9 & 8) differed significantly on the two sides of the ridge. It might be worth noting the influence of the Hvaler ridge as a barrier in connection with future pollution of the outer fjord.

2. The Jeløy ridge

Representing a comparatively small percentage depth reduction (P. 16) the Jeløy ridge is of subordinate importance to the circulation in the fjord.

3. The Dröbak bar

The great importance of the Dröbak bar for the conditions in the inner Oslofjord has been emphasized in various papers. At sill depth outside the bar very considerable variations in temperature and salinity occur which are partly seasonal and partly due to the actual meteorological conditions. The water with greatest density will fill the troughs on the inside and thereafter remain in the inner fjord deeps, being subject to very gradual dilution. Further communication with the middle fjord is prevented by the bar until eventually water of about equal or greater density appears over the sill, when another deepwater exchange takes place. Because of too high temperature and/or too low salinity at sill depth such deepwater exchanges cannot occur during the period June through October.

Being originally identical with the middle fjord water the water of the inner fjord basins soon develops a character of its own due to various processes or rates of processes that are characteristic of these basins.

In Figure 3 we can see that, because of the Dröbak bar, intermediate and deep waters of the middle and outer fjord, with a salinity of 34 ‰ or more does not at the moment, and did not recently, have access to the inner fjord.

Because of increased rate of oxygen consumption and reduced possibilities for reoxigenation from above through sub-surface production and mixing in the inner fjord (P. 25) the interruption of the advection brought about by the Dröbak bar is even of greater consequence to the oxygen distribution (Fig. 5).

One effect of the bar is to prevent substances like seawater salts and oxygen from penetrating into the inner fjord. Another equally evident effect is to hold back high concentrations of locally enriched substances like phosphates (Fig. 6) and nitrates (Fig. 8).

4. The Bygdøy ridge

Although comparatively deep, the Bygdøy ridge is of very great importance for the conditions in the Bunnefjord. The reason for this is the small capacity of the Dröbak Sound for deepwater influx, which is favoured by strong and continual northerly winds carrying surface water out of the fjord and causing upwelling immediately south of the Dröbak bar and a compensating current up the fjord. Because of the small cross section area over the Dröbak sill with depth greater than a few metres it takes a considerable period of time for the Vestfjord basins to get filled up with new, high density seawater, and if conditions do not prevail long enough for this process to be completed the Bygdøy ridge prevents the Bunnefjord deep from benefitting directly from the influx. It follows that a thorough deepwater exchange occurs less frequently in the Bunnefjord than in the Vestfjord, and the oxygen concentrations found in the Bunnefjord are therefore generally significantly lower (cf. Fig. 5). This difference may be tantamount to the difference between life and death for many organisms (cf. BEYER, 1968).

The comparatively great depth of the Bygdøy ridge does, however, permit extensive exchanges to take place at intermediate levels. The oxygen maximum at 60-100 m depth in the Bunnefjord (Fig. 5) and the corresponding minimum in dissolved phosphates (Fig. 6) give evidence that such an exchange had occurred some time ago. The fact that a corresponding minimum was not found in the distribution of nitrates may be explained through oxidation of other nitrogen compounds brought about by the increased concentration of oxygen.

EFFECTS OF POLLUTION

(E. Føyn)

When studying the hydrographical and chemical conditions in a fjord or nearshore waters, it is always necessary to consider the effect that human activities may have on the water masses. It is a question of the effect of waste from land, and the elimination of this effect by chemical, biological, and hydrographical processes. The surroundings of the Oslofjord are the most densely populated part of Norway, and it is to be expected that human influences on the water masses are considerable. This was the reason why various chemical parameters, which could be related to man-made pollution were determined during our investigations:
Cu, Zn, PO_4-P, NO_3-N, NO_2-N, NH_4-N, and O_2.

The analyses were carried out by the Course members except for the determination of copper and zinc, which was performed by means of atomic absorption measurements by one of the specialists on this type of analysis. The results are presented as isopleth diagrams in Figures 5, 6, 8, 9, 10, 11 and 12, and will be discussed below.

ZINC and COPPER

The distribution of ***zinc*** (Zn) does not seem to follow any special trend, neither horizontal nor vertical, and a very uniform distribution is observed all over the water system. An exception is the deep water in the inner basin station 13, where an intermediate maximum in the zinc concentration was observed in the depths around 100 metres, with a decrease in the concentration of zinc both towards the surface and the bottom. An explanation of this picture is difficult, but it may be noticed that this maximum is found exactly in depths where also other parameters, for instance the oxygen content, show variations.

The general picture of the variations in the concentration of ***copper*** (Cu) is a decrease according to the increasing distance from the harbour of Oslo. This fact indicates that the urban sewage is the dominating source of this pollutant. Contrary to other parameters, no regular variation towards the depth can be observed. The diagram shows a pronounced maximum around station 9 in 15 m depth. This maximum is, however, based on a single observation, and since a corresponding maximum was also found in the Zn distribution the most probable explanation seems to be contamination of the 10 m sample, possibly by paint from the ship's hull.

N, P and O_2

Nitrogen, phosphorous and oxygen show pronounced variations in the Oslofjord. These compounds are all related to the biosynthesis and the bio-degradation processes. Figure 9 gives the isopleths of NO_2-N. Ordinarily, NO_2-N only represents a small percentage of the total amount of bound nitrogen in seawater masses.

This was also found by these determinations. NO_2-N, being the intermediate compound between the most oxidized stages of nitrogen, NO_3-N, and the reduced stage, NH_4-N, is fairly unstable in the water masses, and is produced either by the oxidation of ammonia or by the reduction of nitrate.

The NO_2-N isolines show that the variation of nitrite in the fjord is very unsystematic. The intermediate maxima in 50 and 100 metres depth at station 1 are rather unexpected. The constructed isopleths around these maxima are, however, dependent on the measurements of the chemical conditions at station 1 only, and too, absolute conclusions should not be drawn. However, the NH_4-N values show a similar picture (Fig. 10) and the maximum of these two nitrogen compounds in the 100 meter depths must therefore be considered significant. Drainage from land or sub-surface currents from the sea outside are probably the cause of these nitrogen maxima, but it is also within the range of possibility that dumping of nitrite and/or ammonium-rich material may be responsible for the nitrogen distribution observed in 50-100 metres depth at station 1. Further observations from more distant stations are necessary. In our analyses, the ammonium determinations were carried out with the indophenol method after Koroleff, and this method gives a more selective measurement of the ammonium nitrogen than the method of Richards and Kletsch, which has been the recommended method till now. The registered amounts of ammonium nitrogen are therefore smaller than those that would be found by the Richards and Kletsch method. The distribution of the NH_4-N is fairly unsystematic and no general trend in the distribution of the compound, neither towards the depth nor with increased distance from harbour of Oslo, can be seen. The amount of NH_4-N certainly depends on the redox potential of the water but is, when oxygen is present generally, seen to be less than 10% of the NO_3-N content.

NO_3-N and PO_4-P

The content of NO_3-N and PO_4-P is shown in Figure 8 and Figure 6. When comparing the variations in the content of these two parameters it is seen that the picture of both parameters shows a similar trend. Very small concentrations in the surface layers are observed, and a general increase towards the depth is found, except for the inner stations 11-13. Here an intermediate maximum and minimum appear. The relative amounts of nitrate-nitrogen to that of phosphate-phosphorous is seen to be around 10 to 2.5 in the inner region of the fjord and 10 to 1 in the outer region. The reason of this is not clear. Precipitation and settling of phosphate-rich material in the inner fjord may be one reason. A broader discussion of the variations of the nitrate-nitrogen and the phosphate-phosphorous in the fjord in proportion to the oxygen variations is given below.

Both nitrogen and phosphorous are compounds that are generally considered important, because they are plant nutrients which influence the growth of phytoplankton in the sea. The main source of these compounds in the Oslofjord is the sewage from the town. The amounts released in the inner fjord are calculated by NIVA (Norwegian Institute of Water Research) and are given in Table 4.

Table 4.

Table 4. Calculated total discharge from sewage and from natural drainage to the inner part of the Oslofjord

Analytic component	Tons pr. year	% from sewage	% from rivers
Total P	600	79	21
PO_4-P	350	78	22
Total N	3 500	67	33
NO_3-N	580	66	34
Fe	680	11	89
BOD	14 600	79	21

During the photosynthetic productions the phosphorous and nitrogen compounds are partly bound as plant material and consequently removed from the watermasses. This process is dependent on light, taking place in the upper water layers only, while the bio-degradation of the organic material goes on in all depths. The amounts of nitrate-nitrogen and phosphate-phosphorous are generally found to accumulate in the deeper layers. The concentration of these compounds in the deep water will therefore appear as a semi-conservative property of the watermasses and be related to the water exchange processes. This explains the variations found in the deep layers in the inner fjord.

O_2, PO_4 and NO_3-N

The variation of oxygen content in the water can be seen from Figure 5. The horizontal variation of oxygen shows an increase according to the increasing distances from the head of the fjord. A decrease is generally found with increasing depth. Exactly the opposite picture is seen by the variation of the content of nitrate and phosphate, (Figs. 8 and 6). Here the concentration decreases with the increasing distances from the head, and an increasing concentration is observed with increasing depth. The horizontal variations are certainly caused by the exchange of water between the fjord and the sea outside. Tide and wind are among other agents active in this dilution process.

Vertical variation in both oxygen, phosphate-phosphorous, and nitrate-nitrogen shows, however, a more complex picture, especially at stations 11-13 (Fig. 17). At these stations different maxima and minima appear towards the depth, but also here the oxygen varies inversely to the phosphate, especially at the depth below 60 metres, where the water is more or less stagnant. Pronounced minimum in the phosphate-phosphorous can be observed, and at the same depth a maximum in the oxygen content is found. The depth above shows a maximum in the phosphate and a minimum in the oxygen content. The explanations of these maxima and minima are as follows: Sometimes the water outside Dröbak, above the thresholddeep in 19 metres, is so dense that an inflow of water from outside the threshold takes place. These watermasses find their way in the intermediate depth and fill up these layers of the inner fjord with water rich in oxygen and poor in phosphate and nitrogen. The old water of these layers are lifted up to the higher level. The result of these water movements are the maxima and minima in the oxygen and phosphate distributions as found at stations 11-13 (Figs. 5 and 6). This process seems, in our case, to have taken place some time ago, and stagnant conditions are probably again established at the time of the cruise.

The horizontal distribution of these three parameters points to the sewage of the city being the main source of the pollution of the fjord. The continuously decreasing values of the phosphates and nitrate concentration reaching even the outermost stations show that the pollution from Oslo is influencing the condition throughout the whole extent of the water system.

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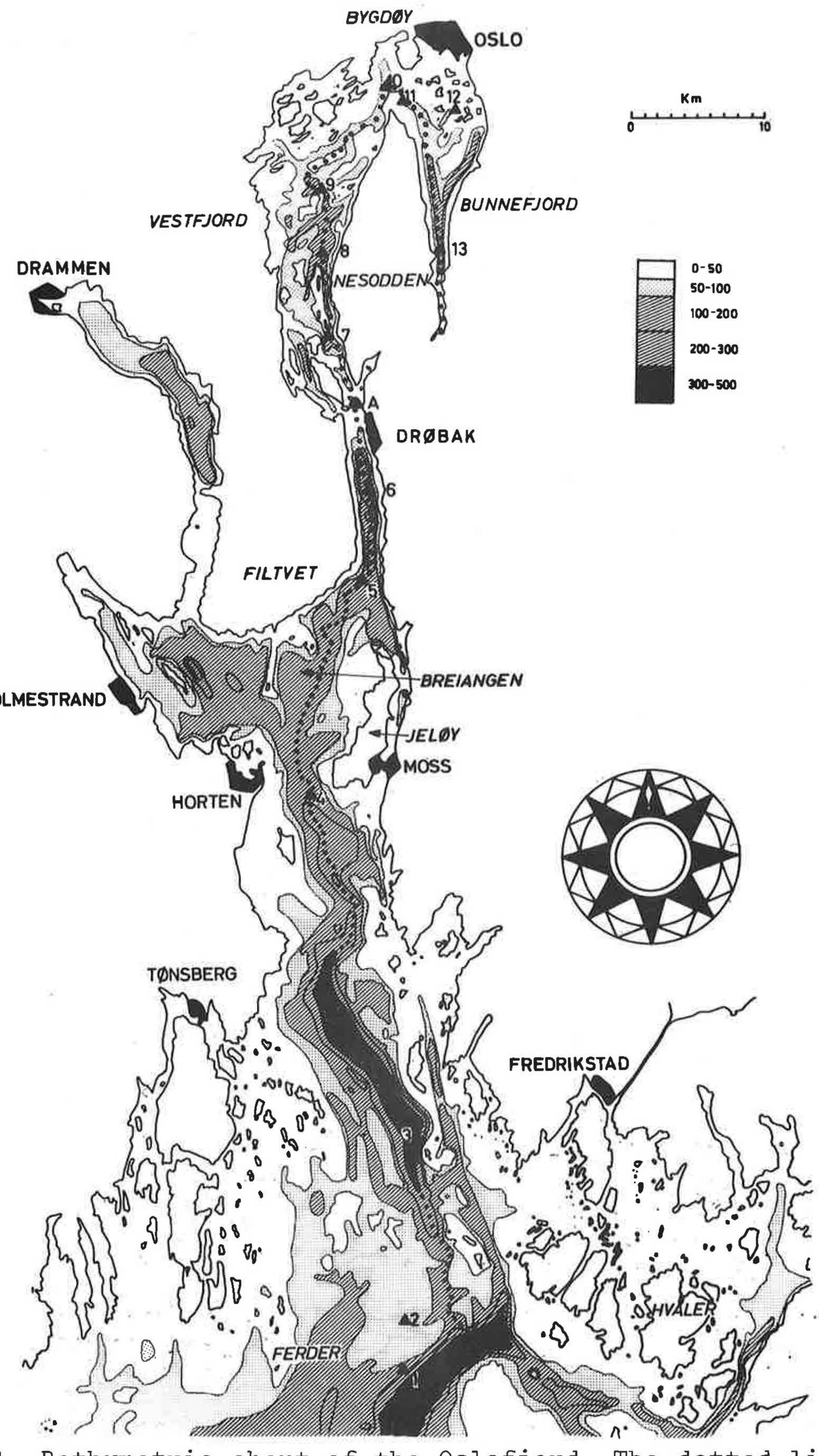

Figure 1. Bathymetric chart of the Oslofjord. The dotted line indicates the deepest approach from the mouth to the head of the fjord. Triangles mark the locations of the hydrographic stations occupied on 29 August 1969.

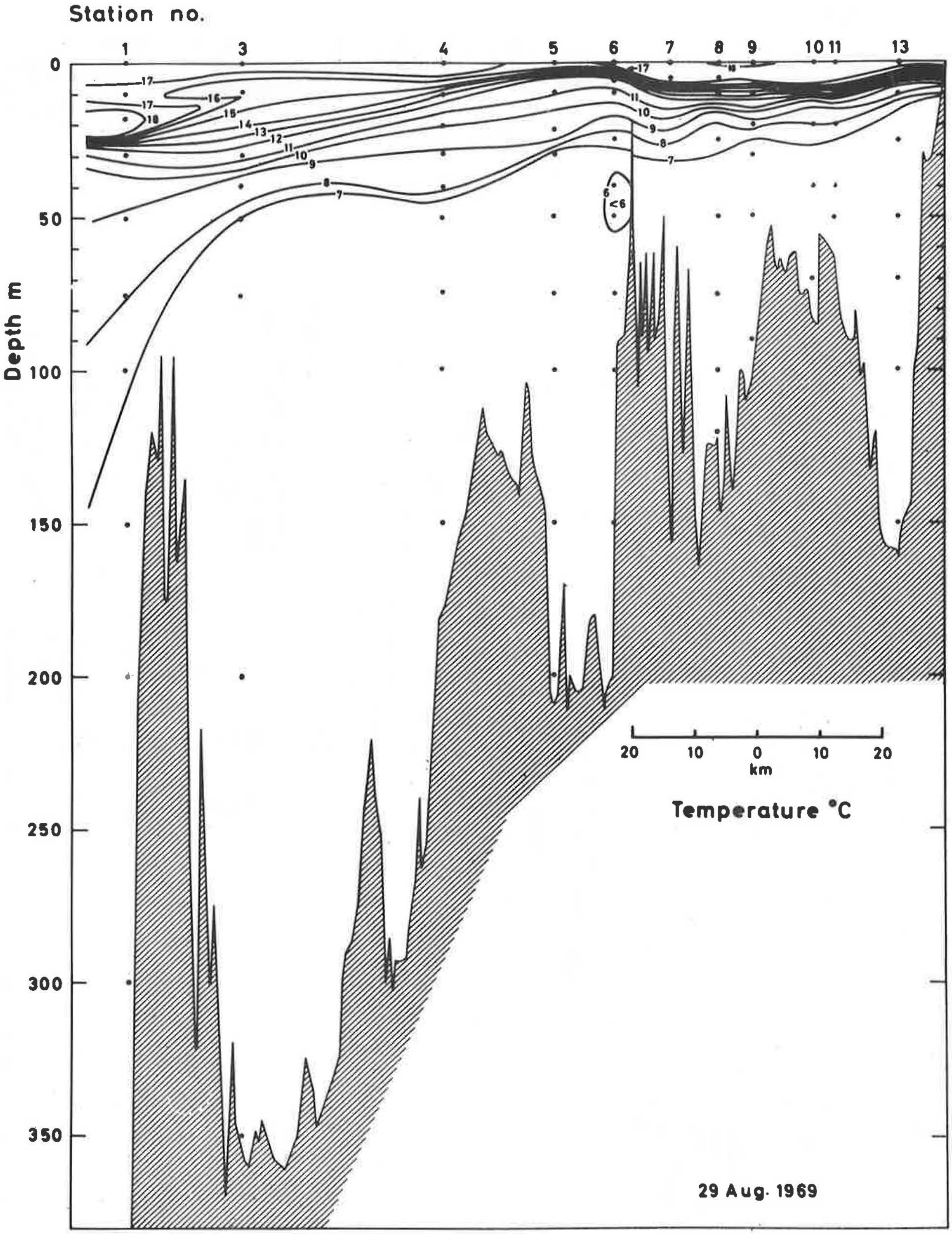

Figure 2. Longitudinal section from the mouth (left) to the head (rigth) of the Oslofjord. Dots mark depths of water bottle observations.

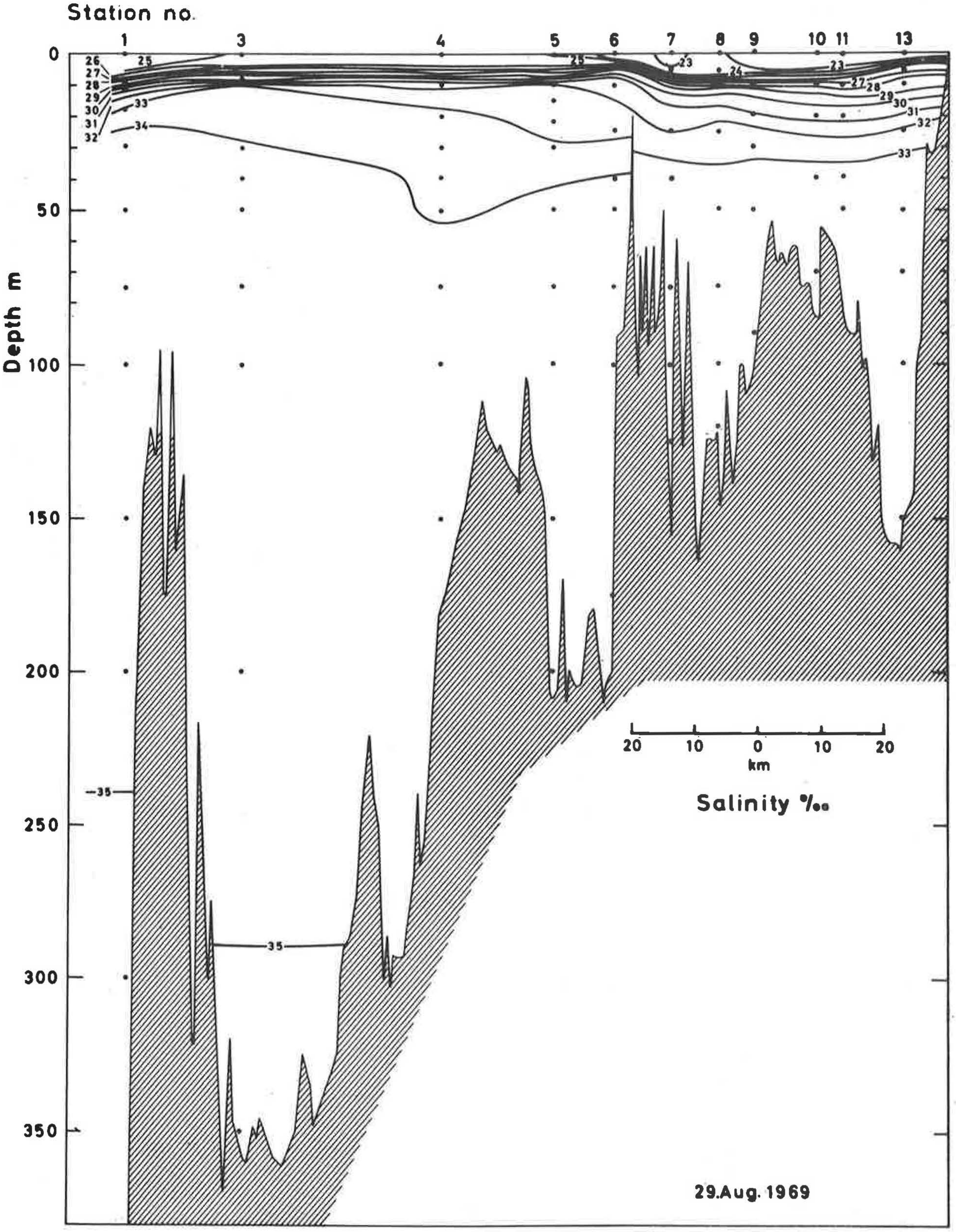

Figure 3. Longitudinal section from the mouth (left) to the head (right) of the Oslofjord. Dots mark depths of water bottle observations.

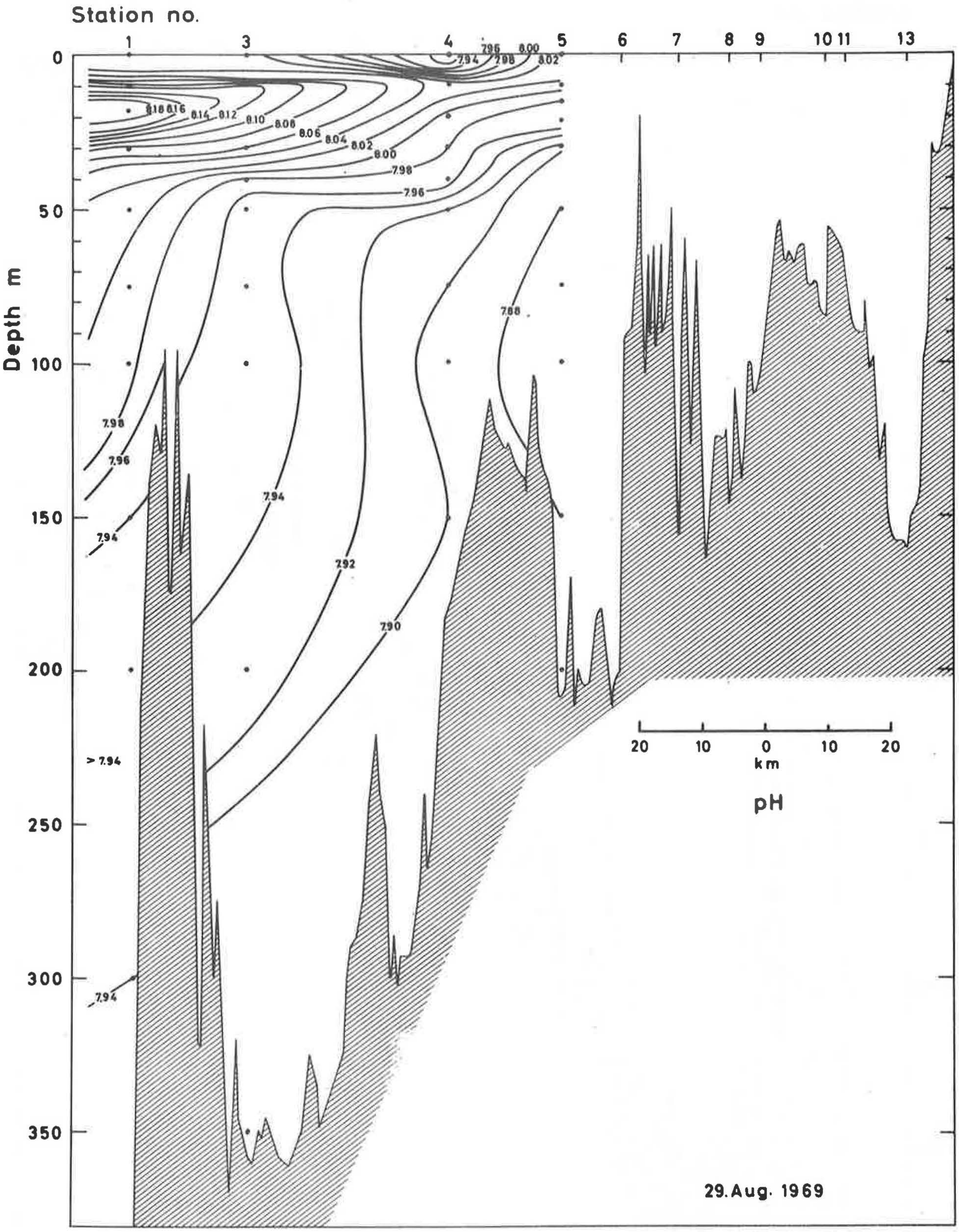

Figure 4. Longitudinal section from the mouth (left) to the head (right) of the Oslofjord. Dots mark depths of water bottle observations. pH was not measured on stations 6-13.

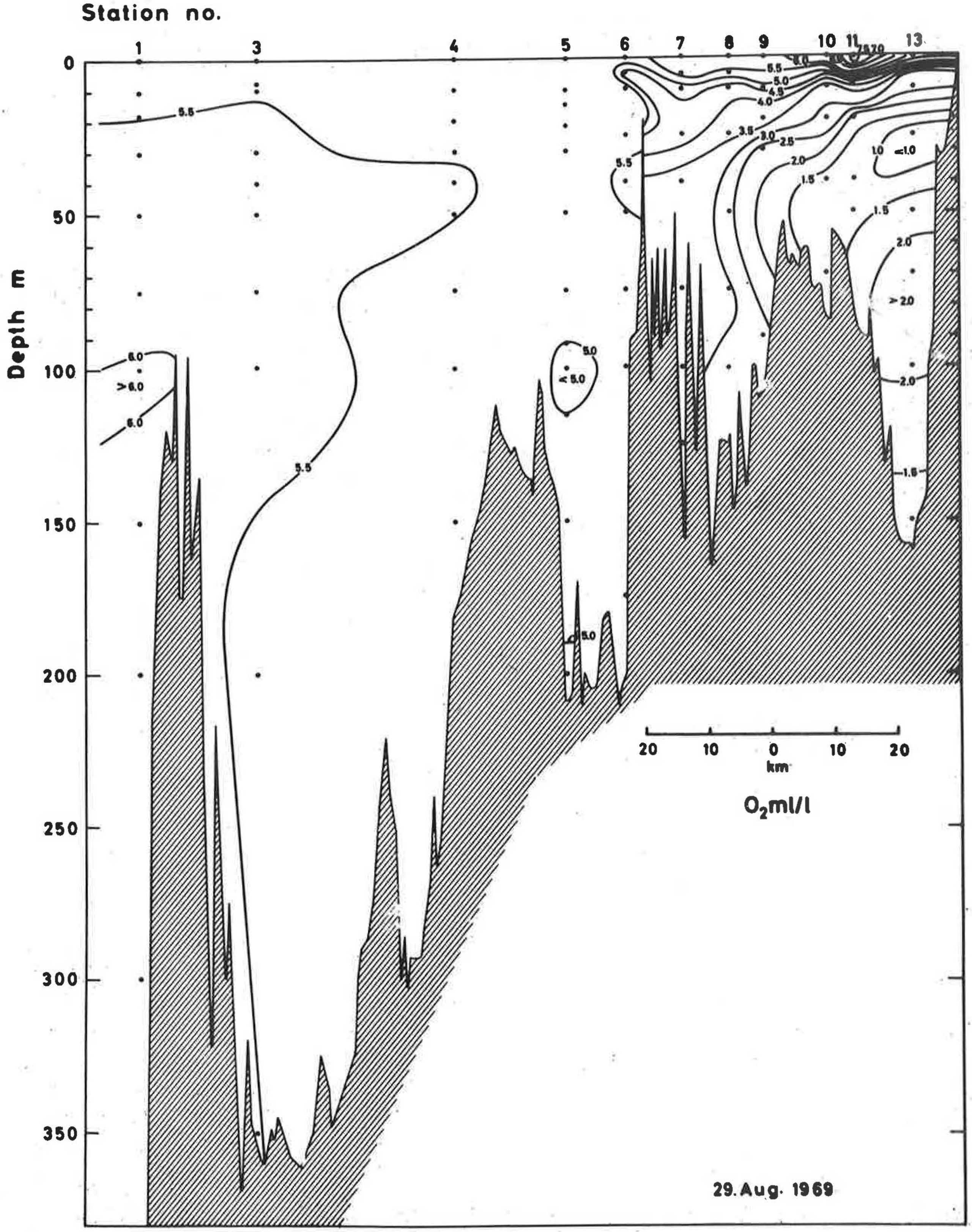

Figure 5. Longitudinal section from the mouth (left) to the head (right) of the Oslofjord. Dots mark depths of water bottle observations.

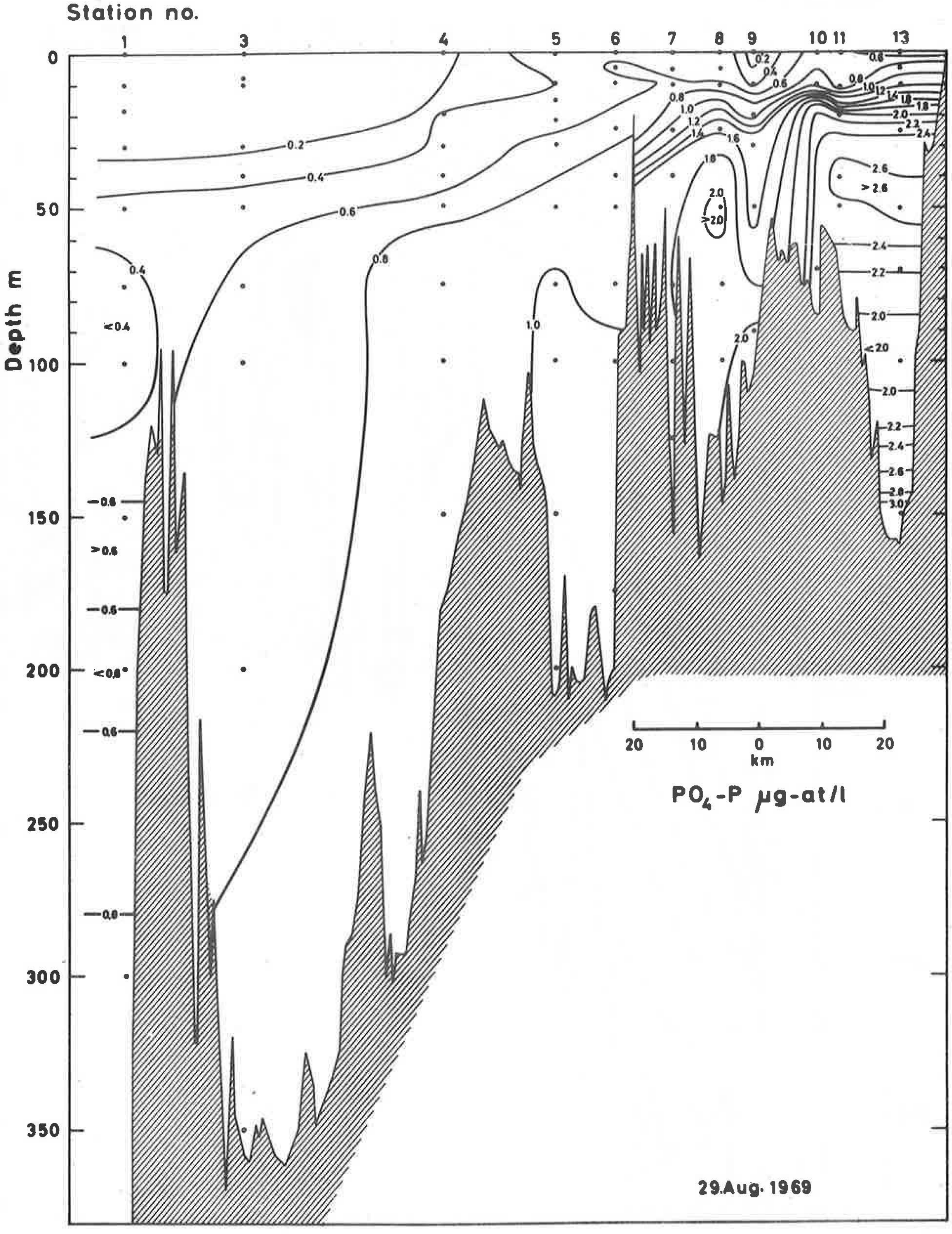

Figure 6. Longitudinal section from the mouth (left) to the head (rigth) of the Oslofjord. Dots mark depths of water bottle observations.

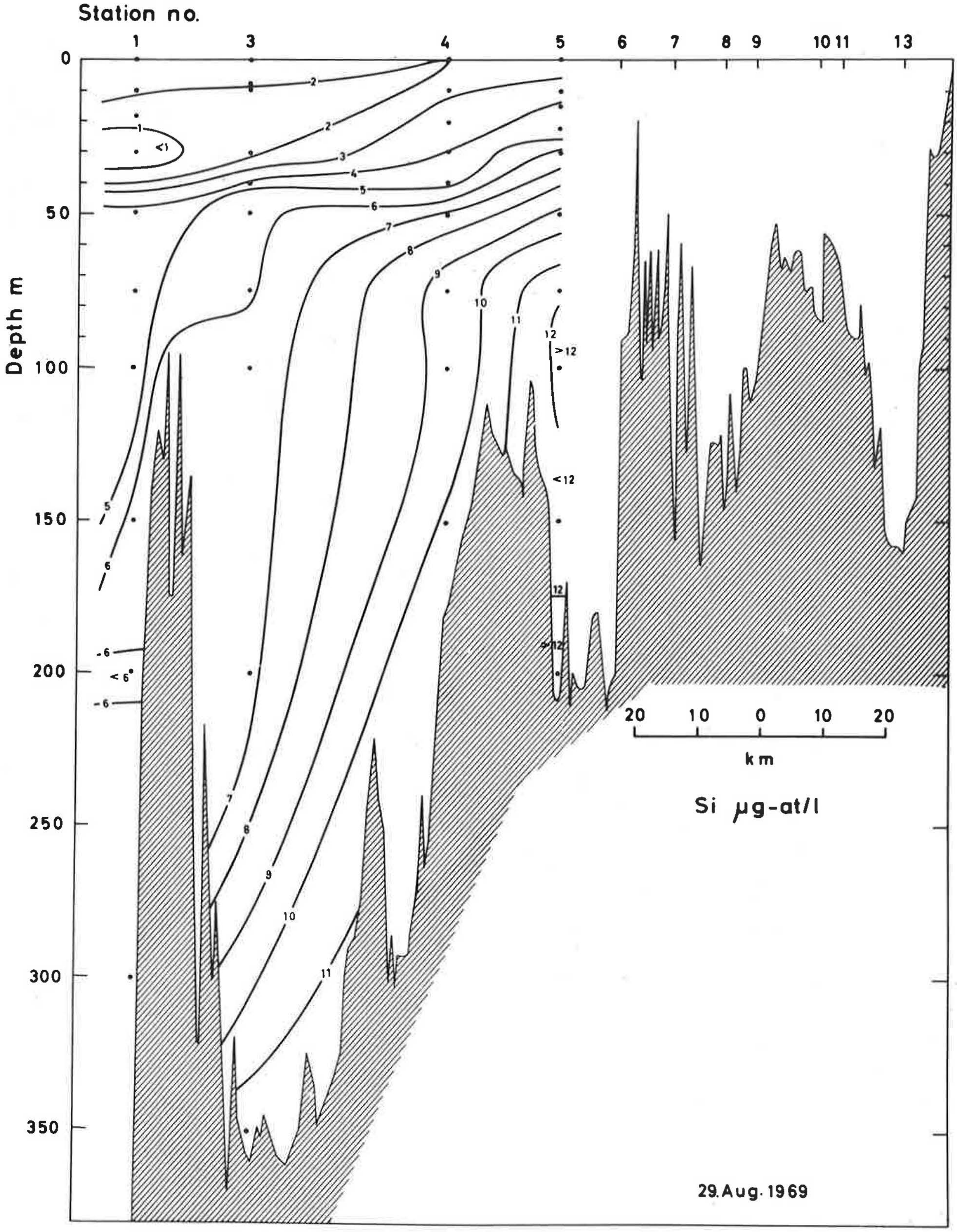

Figure 7. Longitudinal section from the mouth (left) to the head (right) of the Oslofjord. Dots mark depths of water bottle observations. Si content was not measured in the samples from stations 6-13.

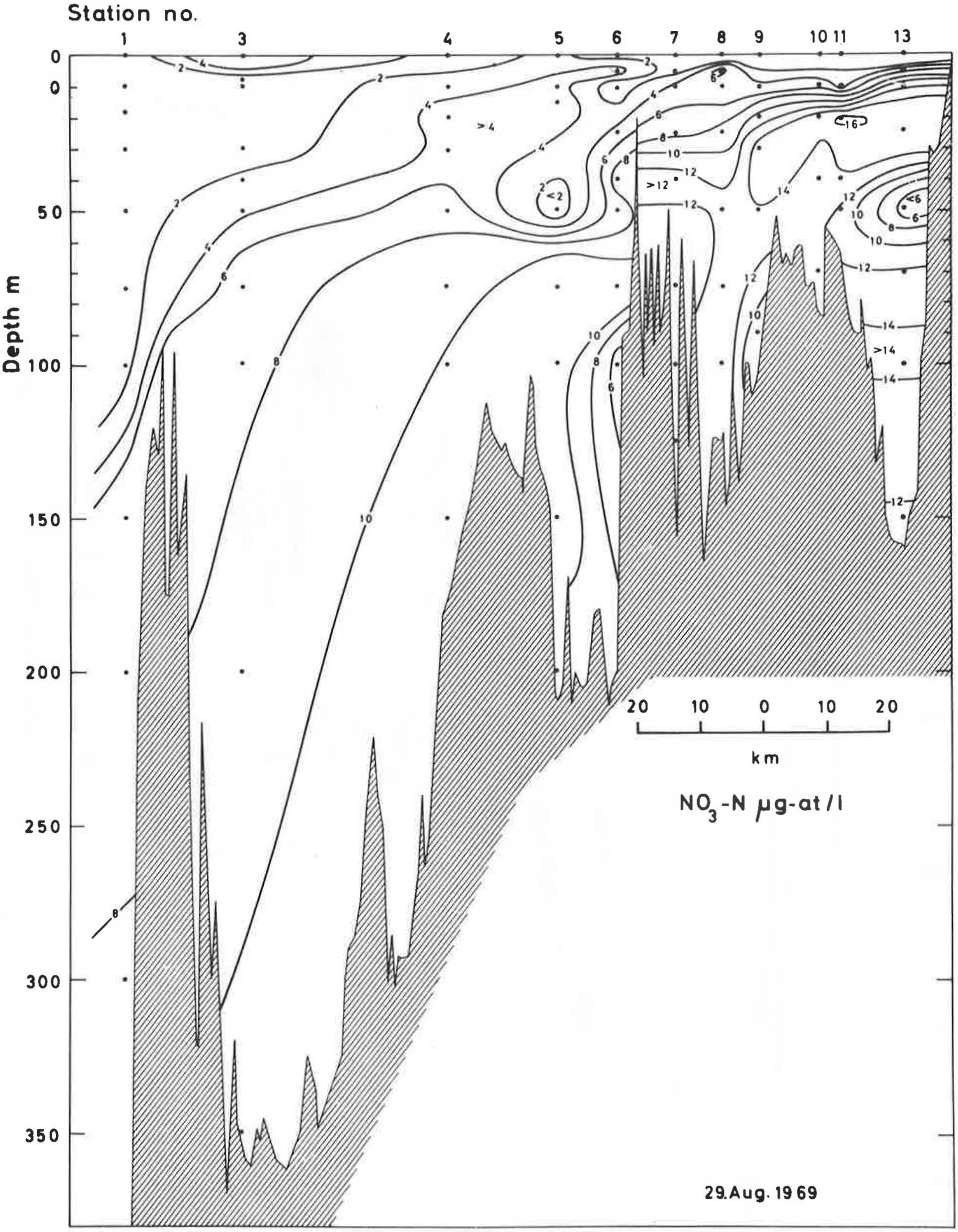

Figure 8. Longitudinal section from the mouth (left) to the head (right) of the Oslofjord. Dots mark depths of water bottle observations.

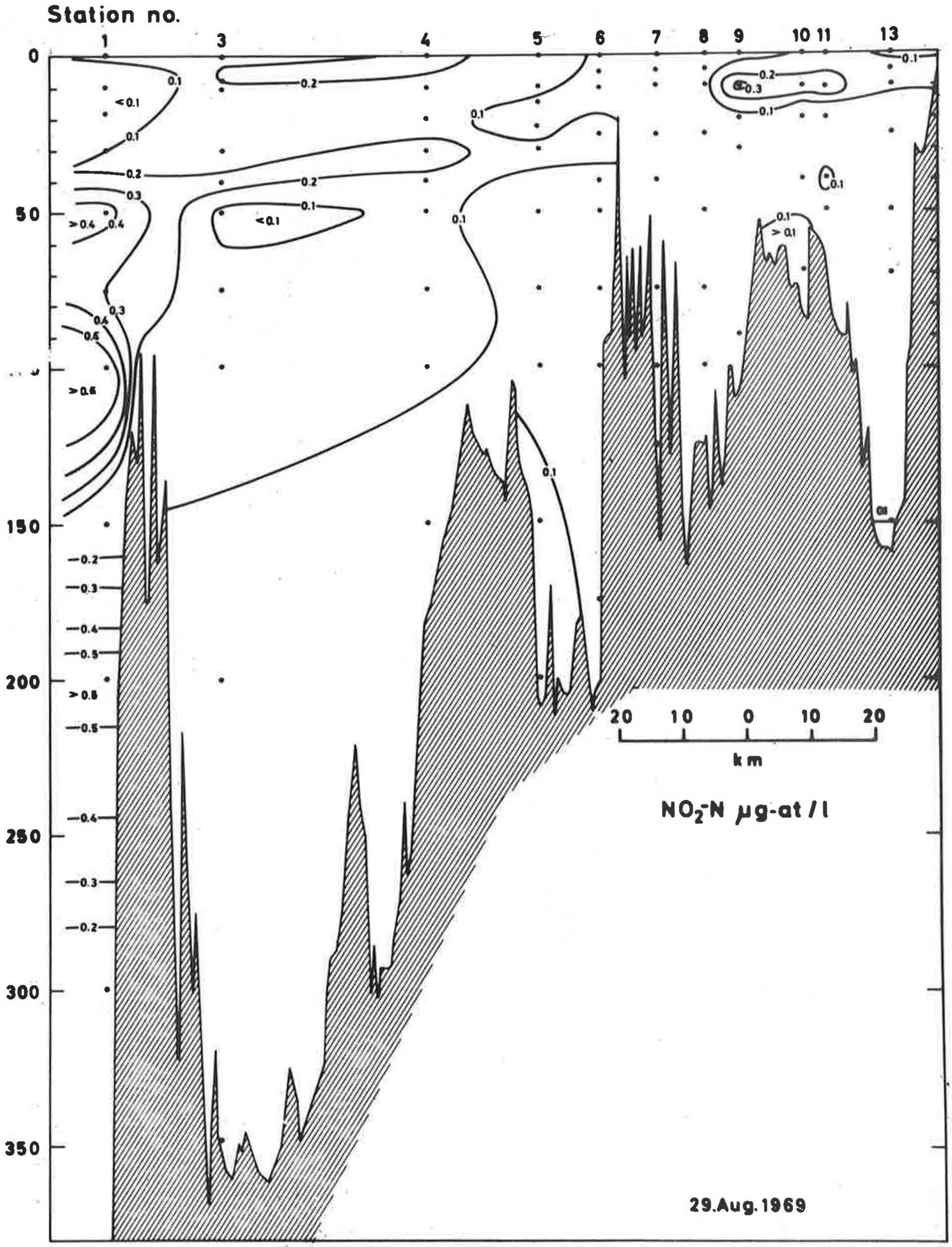

Figure 9. Longitudinal section from the mouth (left) to the head (right) of the Oslofjord. Dots mark depths of water bottle observations.

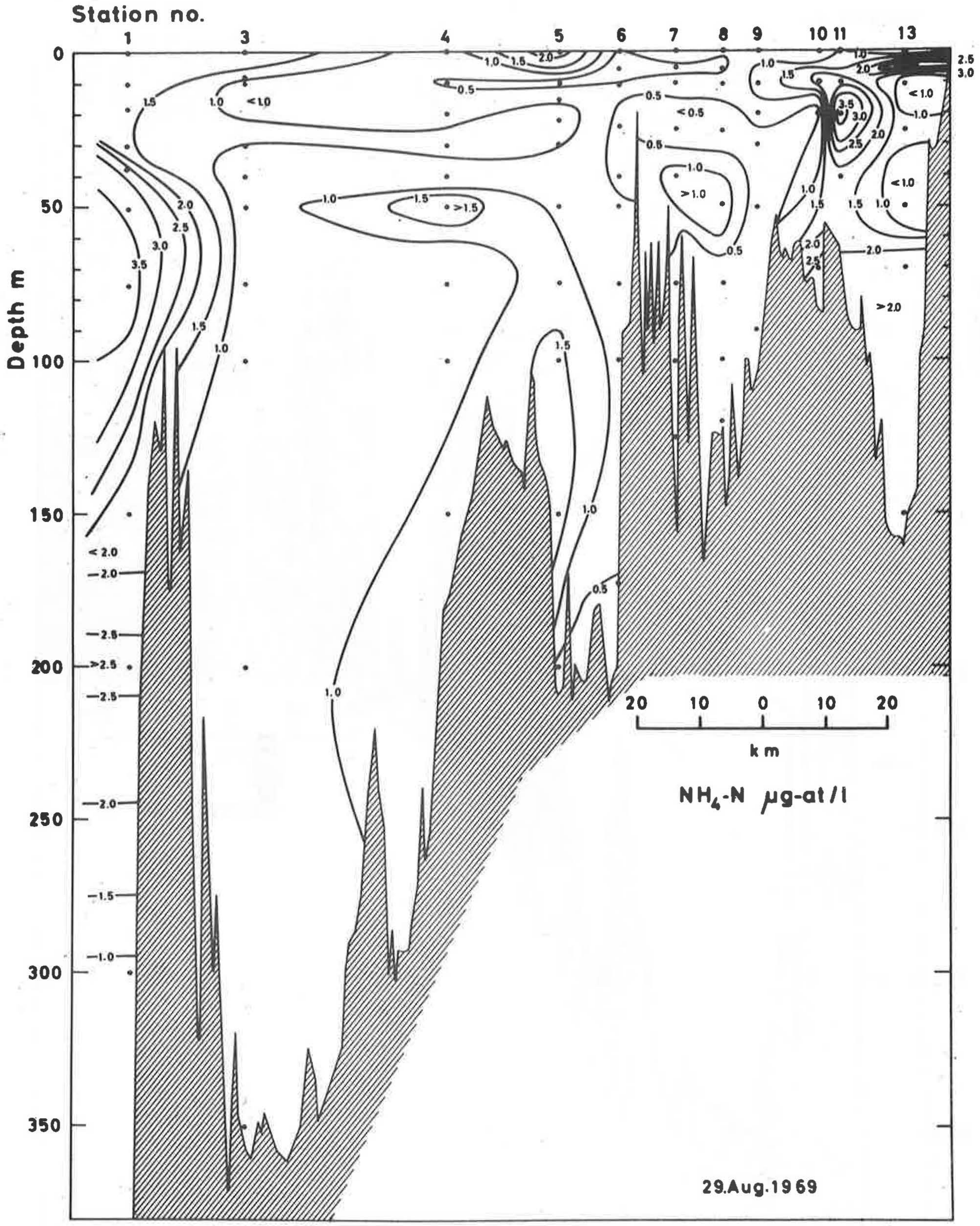

Figure 10. Longitudinal section from the mouth (left) to the head (right) of the Oslofjord. Dots mark depths of water bottle observations.

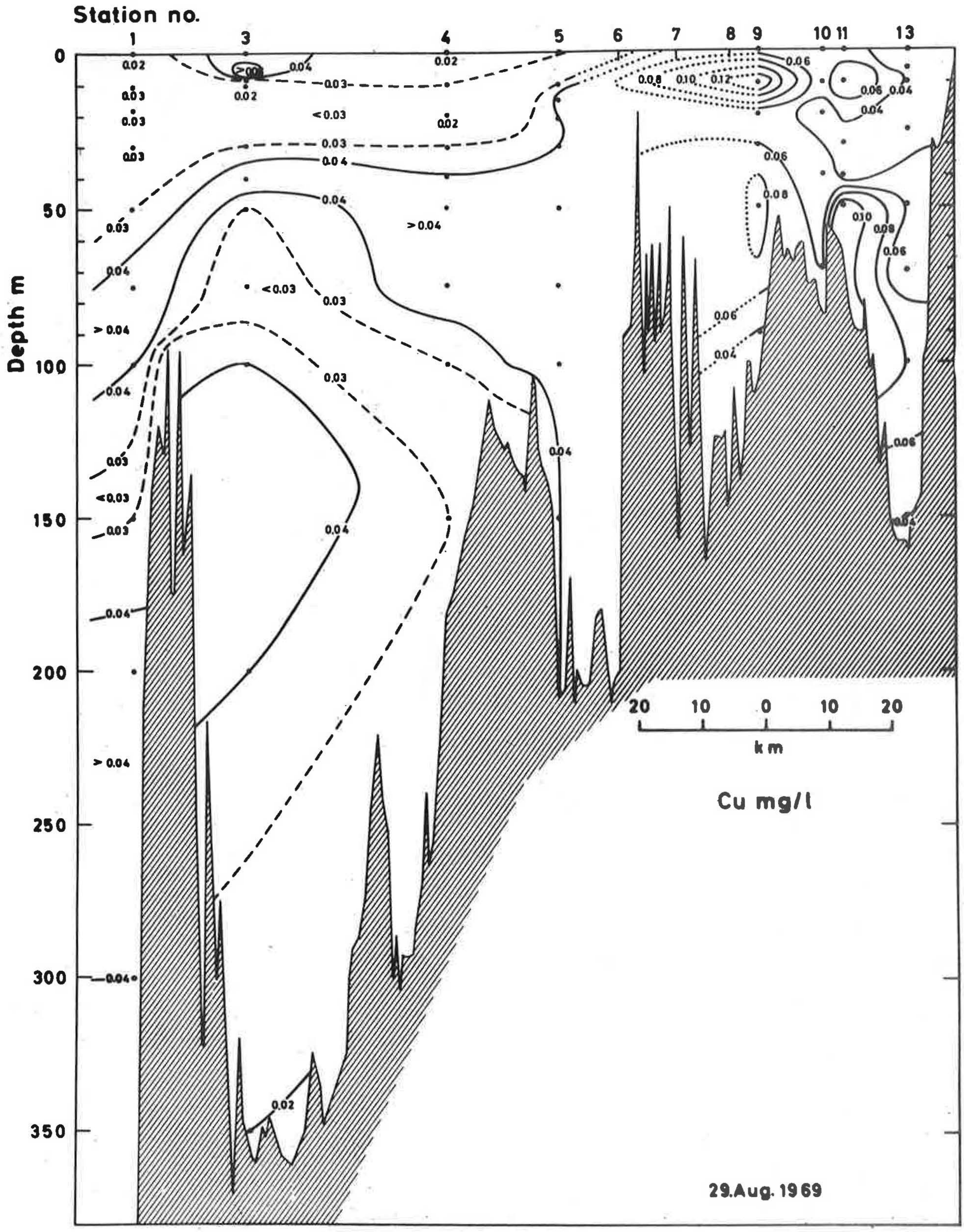

Figure 11. Longitudinal section from the mouth (left) to the head (right) of the Oslofjord. Dots mark depths of water bottle observations. No observations available from stations 6, 7, and 8.

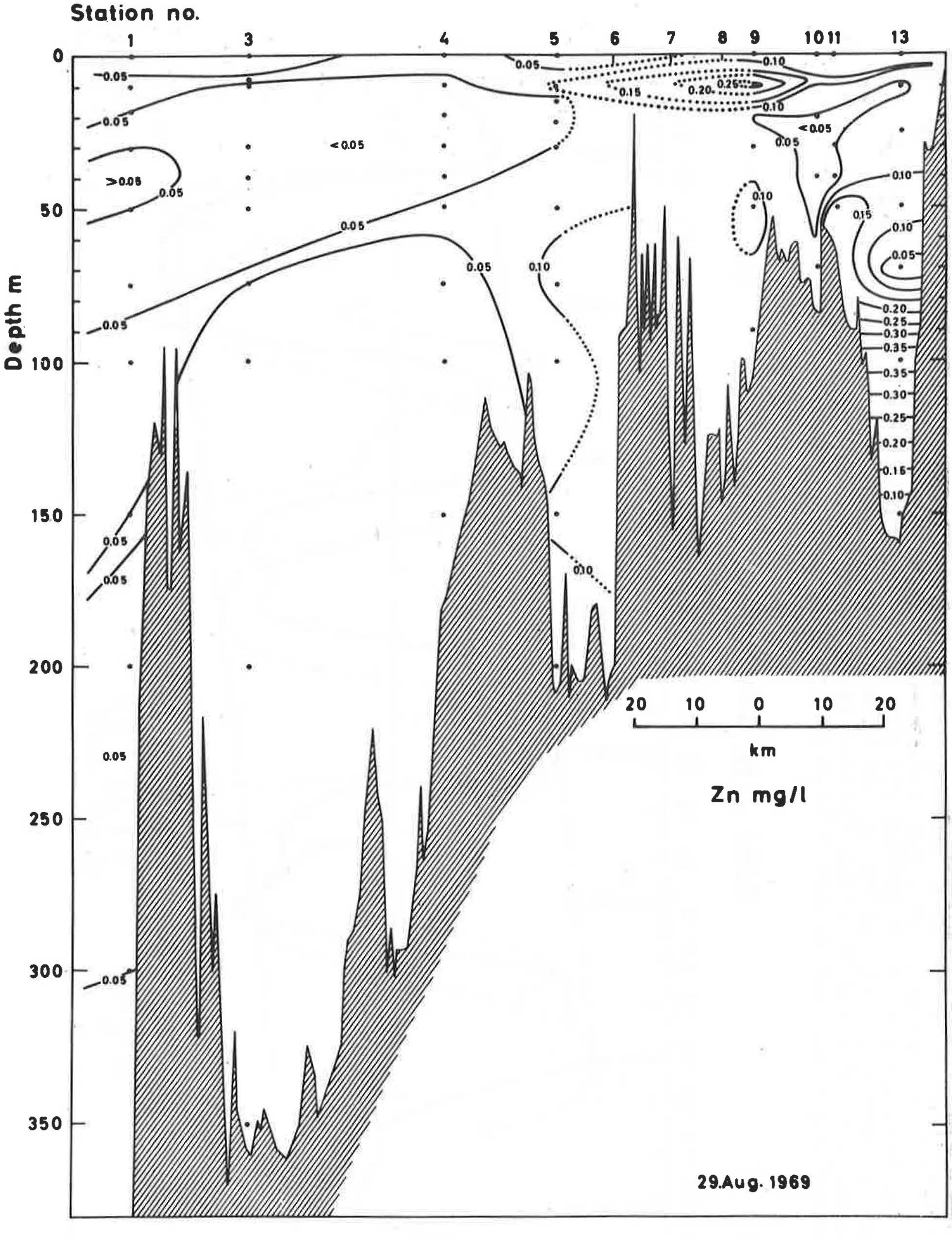

Figure 12. Longitudinal section from the mouth (left) to the head (right) of the Oslofjord. Dots mark depths of water bottle observations. No observations available from stations 6, 7, and 8.

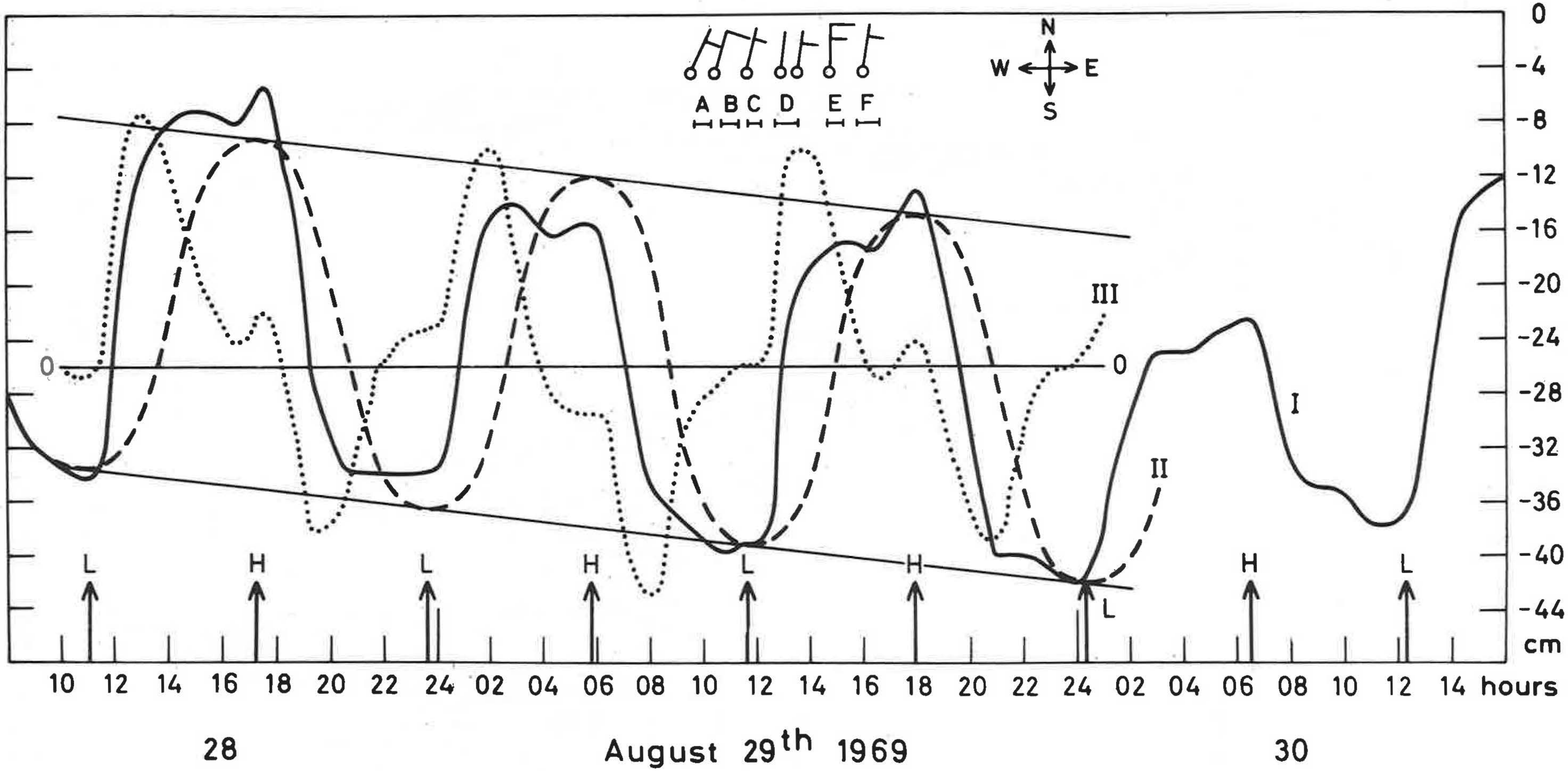

Figure 13. Curve I, sea level fluctuations traced from Oslo Havnevesen's small-scale tide gauge record, scale on the right, according to which the annual mean sea level should correspond to about - 14.5 cm. Curves II and III explained in the chapter on "Tides and Currents". Arrows indicate predicted hours of highwater and low water tides at Oslo. A, B, C etc. show the duration of the Bathyrheograph recording series, and over these letters directions and velocities of the local wind are given with velocities ranging from Beaufort 1 (D) to 4 (E).

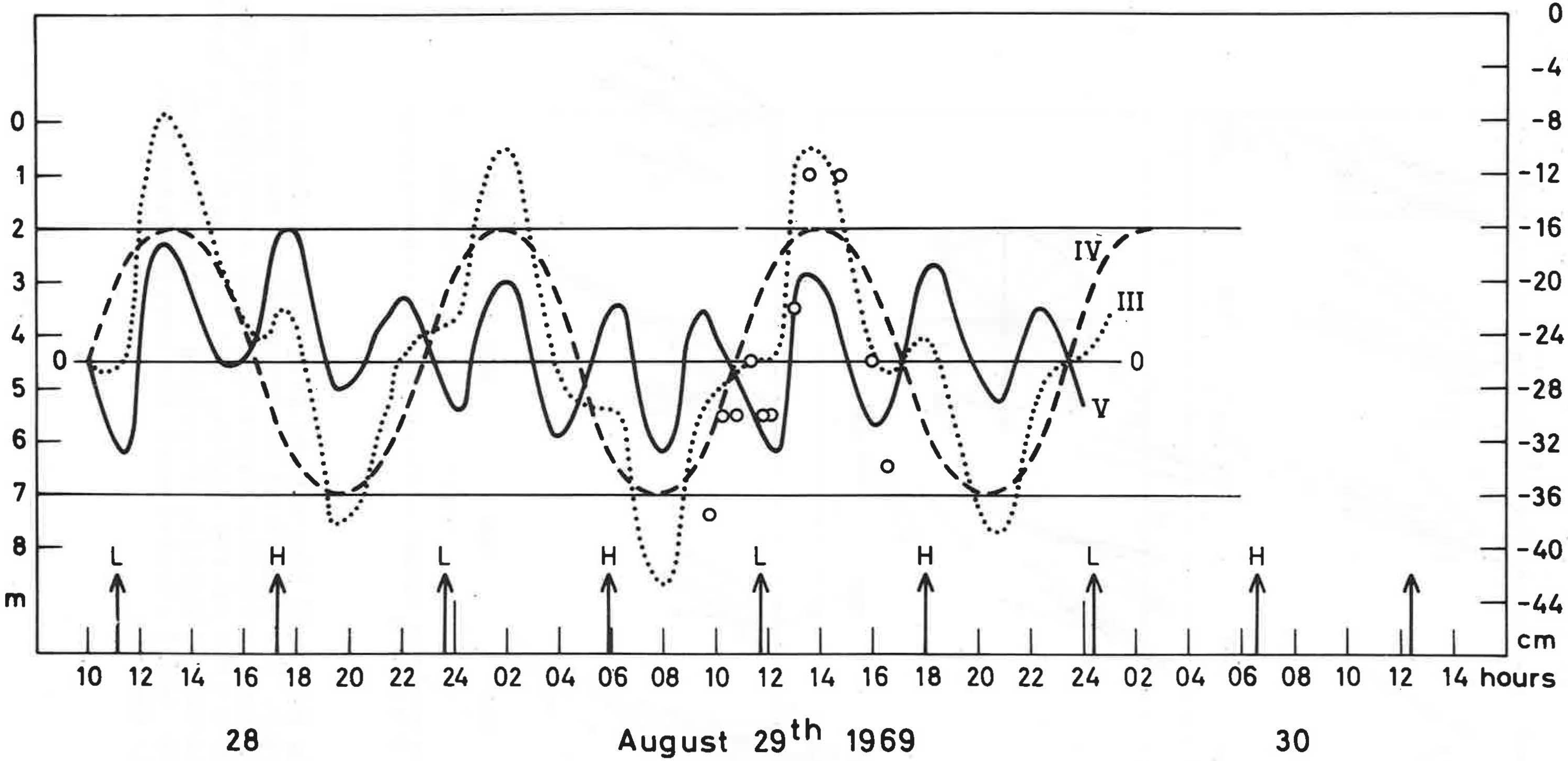

Figure 14. Disturbing wave (III) graphically decomposed into the waves (IV) and (V), right hand scale (cf.text in chapter on "Tides and Currents"). Small circles indicate the level of no current, left hand scale.

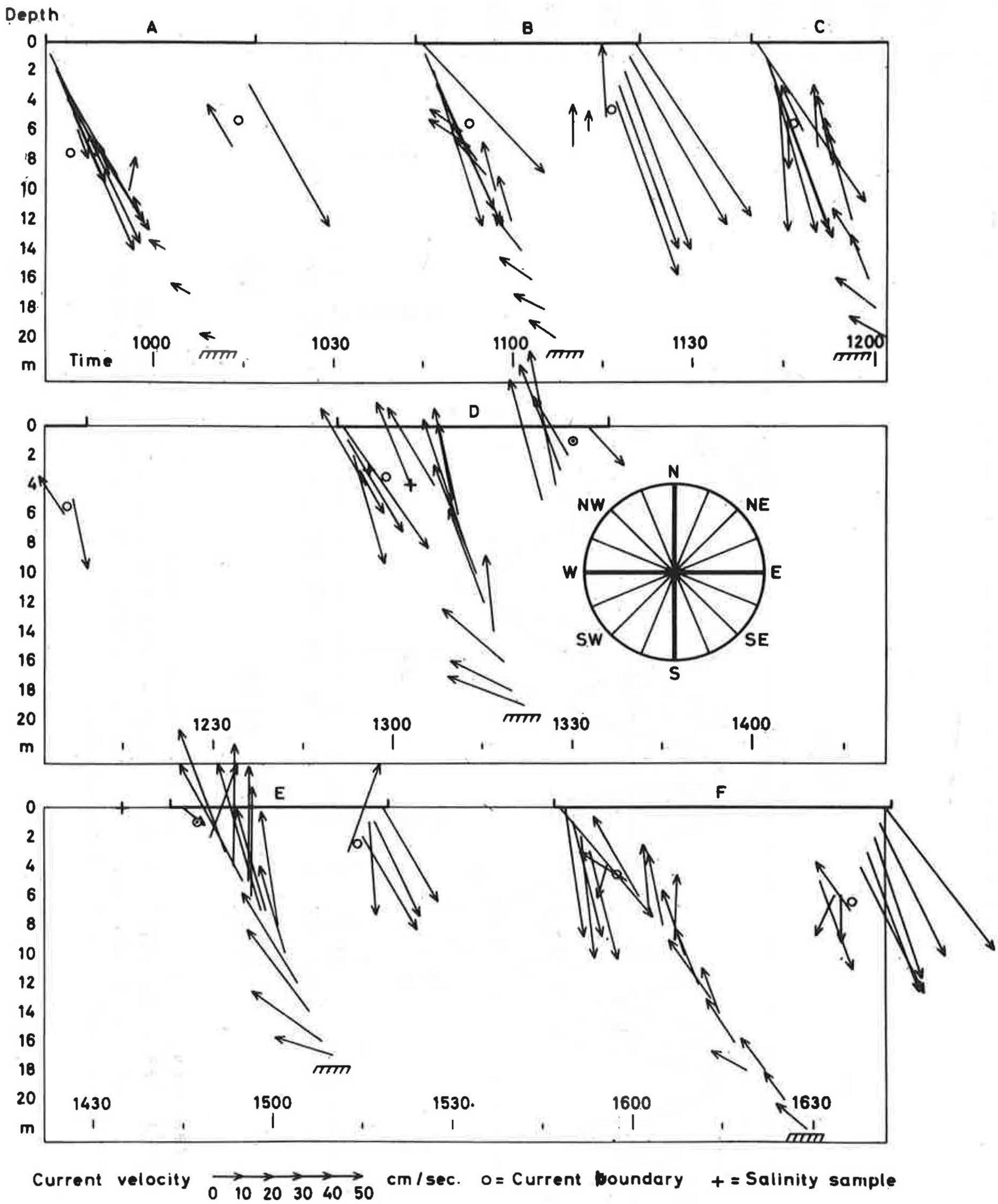

Figure 15. The starting point of the arrows gives the position of the Bathyrheograph. The length of an arrow gives the current velocity at that particular depth and time according to the scale at the bottom of the figure, and the angle of an arrow gives the current direction according to the inserted compass rose. Small circles mark the current boundary. + = salinity sample.

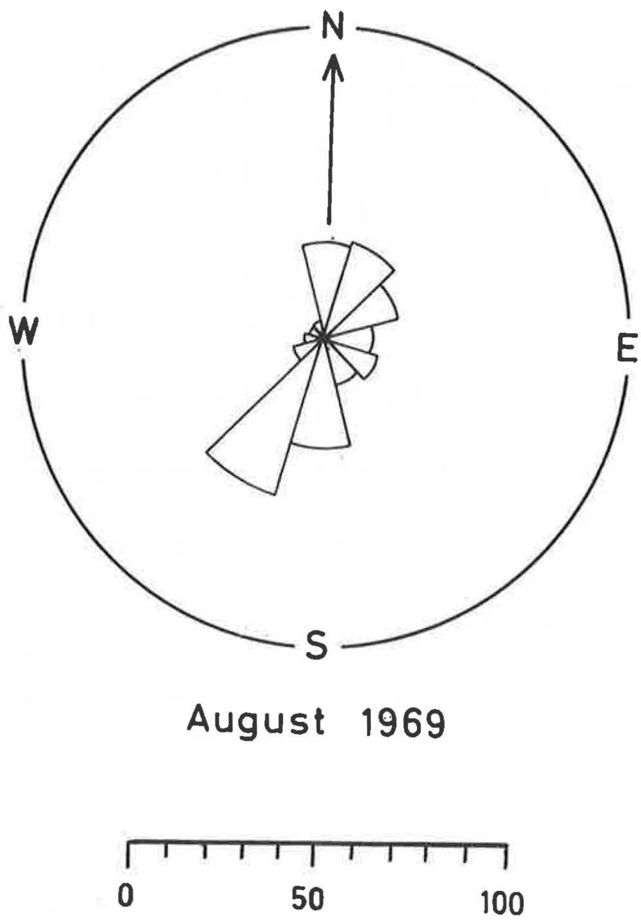

Figure 16. Windway, i.e. mean velocity given in Beaufort units times percentage frequency of the wind from the various sectors, according to the inserted scale. Based on observations three times a day at Fornebu, which is the northernmost peninsula in the Vestfjord. Data kindly supplied by the Meteorological Institute.

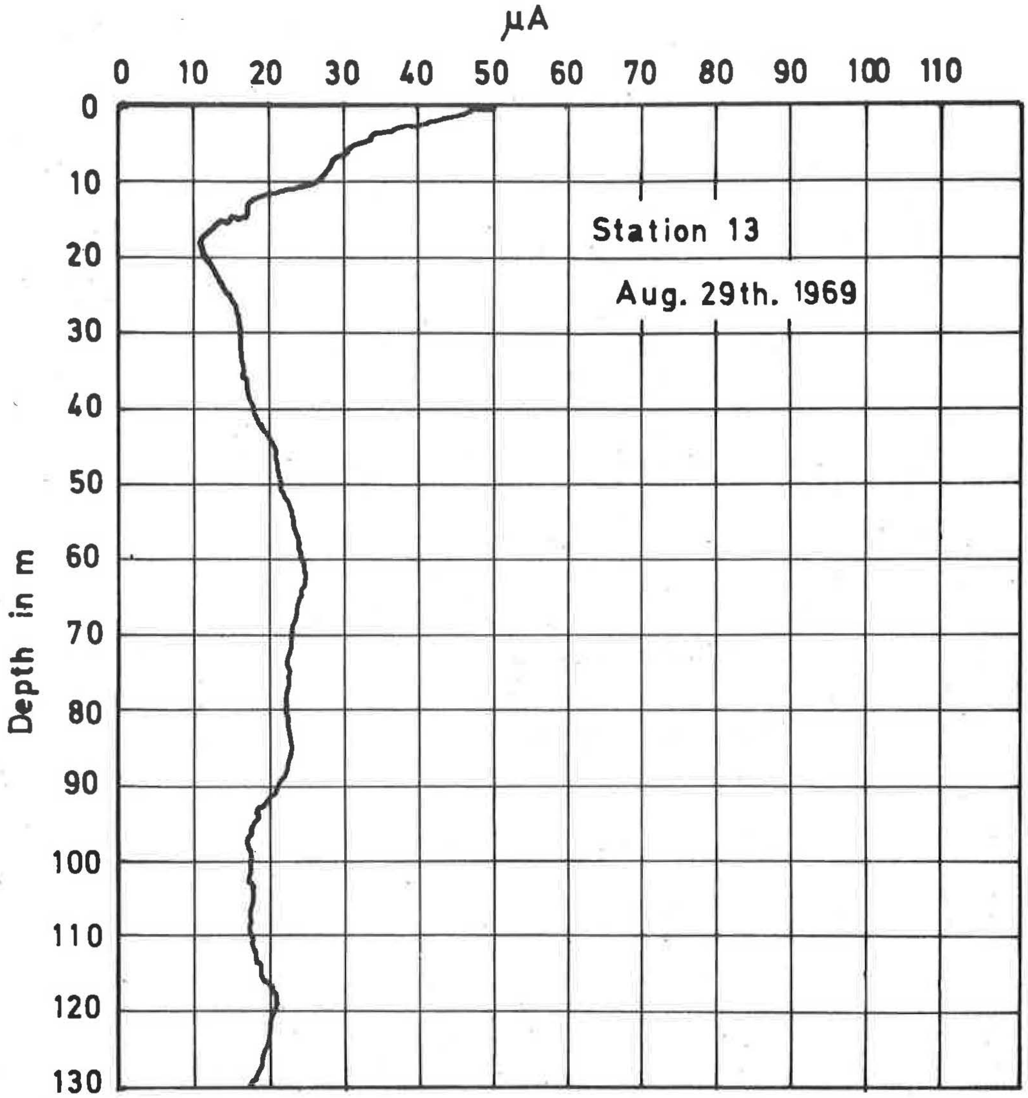

Figure 17. Oxygen curve taken with the Föyn oxymeter at station 13.

Table 5. The hydrographic conditions in Oslofjord 29 August 1969.

Stat. No.	Location	Time	Depth m.	Oxygen % Saturated	Alkalinity meq/l
1	59°01'N	0902	0	89.8	2.03
	10°42'E		10	91.0	2.26
			18	100.9	2.39
			30	97.7	2.43
			50	82.0	2.44
			75	86.3	2.44
			100	90.2	2.43
			150	82.5	2.44
			200	85.5	2.46
			300	85.0	2.44
2	59°3'N	1005	0	94.6	2.11
	10°40.5'E		5	95.0	2.23
			10	87.9	2.25
			15	104.6	2.40
			20	80.6	2.48
			30	81.0	2.42
			50	-	2.53
			75	85.7	2.48
			90	84.6	2.48
3	59°10.8'N	1110	0	88.0	2.03
	10°41.4'E		8	92.1	2.28
			10	96.2	2.47
			30	91.0	2.48
			40	84.5	2.46
			50	85.5	2.51
			75	82.4	2.51
			100	-	2.47
			200	76.9	2.53
			350	80.2	2.48

(continued)

(cont.)

The hydrographic conditions in Oslofjord 29 August 1969.

Stat. No.	Location	Time	Depth m.	Oxygen % Saturated	Alkalinity meq/l
4	59°24.8'N	1359	0	91.0	2.09
	10°34.1'E		10	85.5	2.39
			20	84.6	2.44
			30	83.2	2.48
			40	84.1	2.46
			50	79.6	2.48
			75	77.0	2.47
			100	78.0	2.51
			150	77.5	2.47
5	59°33.6'N	1543	0	90.0	2.01
	10°38.2'E		10	87.6	2.40
			15	79.2	2.42
			22	81.0	2.40
			30	75.6	2.42
			50	73.7	2.48
			75	77.8	2.48
			100	72.3	2.49
			150	74.8	2.48
			200	72.8	2.52
6	59°38.4'N	0910	0	92.0	
	10°38' E		5	70.0	
			10	80.4	
			25	73.2	
			40	83.5	
			50	76.5	
			75	73.7	
			100	72.8	
			175	74.6	

(continued)

(cont.)

The hydrographic conditions in Oslofjord 29 August 1969.

Stat. No.	Location	Time	Depth m.	Oxygen % Saturated	Alkalinity meq/l
7	59°42.9'N	1130	0	97.8	
	10°35.1'E		5	94.7	
			10	76.4	
			25	63.2	
			40	45.7	
			75	47.4	
			100	48.7	
			125	46.4	
8	59°46.6'N	1415	0	99.8	
	10°34'E		5	95.0	
			10	68.9	
			25	51.5	
			50	37.3	
			75	44.4	
			100	37.3	
			120	-	
9	59°49.0'N	1420	0	102.9	
	10°33.8'E		10	79.3	
			20	55.4	
			30	29.3	
			50	-	
			90	33.9	
10	59°52.8'N	1240	0	105.6	
	10°39.1'E		10	52.7	
			20	41.1	
			40	18.5	
			70	20.2	

(cont.)

The hydrographic conditions in Oslofjord 29 August 1969.

Stat. No.	Location	Time	Depth m.	Oxygen % Saturated	Alkalinity meq/l
11	59°53'N	1155	0	132.0	
	10°41'E		10	60.2	
			20	26.6	
			40	16.6	
			50	19.5	
12	59°52.1'N	1045	0	95.9	
	10°44.7'E		10	45.7	
			30	4.0	
			50	6.6	
			70	4.7	
13	59°47.0'N	0910	0	93.8	
	10°43.3'E		5	47.6	
			10	34.2	
			25	8.1	
			50	24.5	
			70	35.1	
			100	32.1	
			150	18.5	

LIST OF SPECIAL EQUIPMENT

1. Training and research vessels, fully equipped
   a) 171 ft. "G.O.Sars"
   b) 100 ft. "Alkor"
   c) 44 ft. "Gunnar Knudsen"
   d) 35 ft. "Kristine Bonnevie"
   e) 28 ft. "Bente"
2. Bathythermographs and readers (Brown Ltd.).
3. Atomic Absorption Spectrophotometer (Perkin-Elmer, 290).
4. Gas Chromatograph (Perkin-Elmer, 900).
5. Spectrophotometers.
   a) Zeiss, PMQ II
   b) Unicam SP 600
   c) Hitachi Perkin-Elmer 124 with recorder.
6. Dosimats (Metrohm).
7. Membranfilter equipment (Sartorius).
8. Desk computer (Olivetti).
9. Calculating machines (Olivetti divisumma 26, Facit CA 1-13).
10. pH-meters (Metrohm, Beckman).
11. Analytical balances (Mettler, Sauter, Sartorius).
12. Waterbath (Gerhardt)
13. Salinometers (C.S.I.R.O.).
14. Technicon Autoanalyzer.
15. Oxymeters
16. Oxygensonde
17. Bathyrheograph (Bergen Nautic).

LIST OF PARTICIPANTS

ARGENTINA

Mr. Jorge Pablo Castello
Instituto de Biologia Marina
Playa Grande
Mar del Plata CC 175
Argentina

CANADA

Dr. Eric Levy
Atlantic Oceanographic Laboratory
Bedford Institute
P.O.Box 1006
Dartmouth, N.S. Canada

Mr. Carl Cunningham
Fisheries Research Board of Canada
Marine Ecology Laboratory
Bedford Institute
Dartmouth, N.S. Canada

COLUMBIA

Mrs. Constanza van Hissenhoven
Facultad de Ciencias del Mar
Universidad Jorge Tadeo Locano
Calle 23 con Carrere 4^{e} A
Bogota, Colombia

EGYPT

Mr. Hosny Ibrahim Emera
Institute of Oceanography and Fisheries
Kaied Bay
Alexandria, Egypt

FRANCE

Mr. B. Voituriez
O.R.S.T.O.M.
24 Rue Bayard
Paris 8^{e}, France

GERMANY

Mr. Peter Fritsche
2305 Kiel-Heikendorf
Strandweg 44
Germany

Dr. Klaus Gumprecht
Deutsches Hydrographisches Institut
2000 Hamburg 4
Bernhard-Nocht-Strasse 78, Germany

IVORY COAST

Mr. Lionel Lemasson
Centre de Recherches Océanographiques
B.P. V 18 Abidjan
Côte d'Ivoire

MOZAMBIQUE

Miss Maria Beatriz Ruivo
Missão de Estudos Bioceanologicos e de Pescas de Mozambique
P.O. Box 1723, Lourenzo Marques
Mozambique

NETHERLANDS

Mr. Johannes W. Rommets
Netherlands Institute for Sea Research
Het Nieuve Diep 27
Den Helder, Holland

NORWAY

Mr. Kjell Seglem
Övre Kråkenesvei 20
Fana pr. Bergen
Norway

PERU

Mr. Oscar A. Guillen
Instituto del Mar
Esq. Gamarra y Gral. Valle
Callao, Peru

POLAND

Mrs. Zofia Zaborowska-Mlodzinska
Państwowy Instytut
Hyrologiczno-Meteorologiczny
Oddzial Morski
Gdynia, Polen

Mrs. Anna Martyniuk-Trzosinska
Państwowy Instytut
Hydrologiczno-Meteorologiczny
Oddzial Morski
Gdynia, Poland

Mr. Wojciech Kijowski
Sea Fisheries Institute
Aleja Zjednoczenia 1
Gdynia, Poland

SPAIN

Mr. Angelo Rodriquez de Leon
Instituto Español de Oceanografía
General Goded 63
Santa Cruz de Tenerife
Canary Islands, Spain

THAILAND

Miss Suchada Silpipat
496 Prakarn Road
Parknam
Samutprakarn, Thailand

Miss Chalanya Rattenasen
Marine Fisheries Laboratory
Department of Fisheries
89/1 Soi Sapan Pla
Yanawa District
Bangkok 12, Thailand

VENEZUELA

Mr. Benito Gamboa
Instituto Oceanografíco
Universidad de Oriente
Cumana-Edo, Sucre
Venezuela

YUGOSLAVIA

Mr. Ante Skrivanic
Centre for Marine Research of Institute "Rudjer Boskovic"
Rovinj, Yugoslavia

LIST OF TEACHERS

FINLAND

Dr. Folke Koroleff
Havsforskningsinstitutet
Observatoriegatan 2
Helsingfors

GERMANY

Privatdozent Dr.rer.nat. Klaus Grasshoff
Institut für Meereskunde an der Universität Kiel
Abt. Meereschemie
Niemannsweg 11
23 Kiel

NORWAY

Universitetslektor Fredrik Beyer
Institutt for Marin Biologi
Frederiksgt. 3
Oslo 1

Cand. real. A.T. Andersen
Institutt for Marin Biologi
Frederiksgt. 3
Oslo 1

Professor, dr.philos. Ernst Föyn
Institutt for Marin Biologi
Frederiksgt. 3
Oslo 1

Cand mag. Lars Föyn
Institutt for Marin Biologi
Frederiksgt. 3
Oslo 1

Dr.philos. Rolf Lange
Institutt for Marine Biologi
Frederiksgt. 3
Oslo 1

Dr.philos.Eystein Paasche
Institutt for Marin Biologi, avd.B.
Postboks 1069, Blindern
Oslo 3

Havforsker Karsten Palmork
Fiskeridirektoratets Havforskningsinstitutt
Nordnesparken 2
5000 - Bergen

Professor Dr.philos.Odd H. Sælen
Institutt for Geofysikk, avd.A.
Blindern
Oslo 3

SWEDEN

Professor, Dr. David Dyrssen
Institutionen för Analytisk Kemi, CTH/GU
Fack, 40220 Göteborg 5

Dr. Stig Fonselius
Fiskeristyrelsens Hydrografiska Avdeling
Box 4038
40040 Göteborg 4