SUSPENDED MATTER BETWEEN NORWAY AND SHETLAND AND IN THE SOGNEFJORD

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by

D. EISMA AND J. KALF

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SUMMARY

Between Norway and Shetland and at stations in the Sognefjord and in Sognesjöen particle size, total content, ashweight and organic content of suspended matter were determined as well as salinity. The inflowing ocean water has the same content of inorganic suspended material as the outflowing North Sea water. This agrees with a preliminary estimate that more than 90% of the suspended matter supplied to the North Sea by rivers, through erosion of cliffs and the seafloor, inflow from the Baltic and the atmosphere and from organic production is deposited within the North Sea. The data for the Sognefjord suggest that suspended material from the North Sea is deposited in the fjord and that inside the fjord organic material is

being accumulated. For the surface water the data on particle size, total content and organic content of the suspended material are complicated by the presence of living plankton.

I. INTRODUCTION

The general circulation in the North Sea is rather well known, although there is still considerable discussion about the quantities involved. Atlantic Ocean water enters the North Sea through the Channel and the Straits of Dover-Calais, around Scotland and around Shetland (LEE 1970, DOOLEY 1974, OTTO 1976). Fresh water comes in from rivers, from the Baltic and from precipitation. Yearly evaporation is about equal to the yearly precipitation (OTTO 1976). The resulting North Sea water flows out into the northern Atlantic Ocean along the coast of Norway.

The mean turn-over time is less than one year but there are large seasonal and year-to-year variations and one year is not sufficient to obtain complete mixing of the North Sea, indicating that in different sections of the North Sea the turn-over times are not the same.

Suspended matter in the North Sea comes from various sources in roughly the following quantities (MCCAVE 1973, EISMA 1977):

	million ton/year
rivers	4.6
cliff erosion	0.7
seafloor erosion	≈ 5 (?)
inflow through the Channel	7
inflow around Scotland and Shetland	9.7
inflow from the Baltic	0.5
organic production	small (≈1 ?)
from the atmosphere	1.6
total	>24.7

Preliminary budget calculations have shown that at least 90% of the suspended matter supplied by rivers, through erosion of cliffs and the seafloor, through inflow from the Baltic, by organic production and from the atmosphere is deposited within the North Sea. However, only few data are available on suspended matter in the North Sea north of Dogger Bank, in the Norwegian Channel and in the Skagerrak, as well as on recent sedimentation rates in the areas where suspended material is being deposited. The offer of joining a bottom sediment sampling program in May 1977 with the R/V H.U. SVERDRUP, covering the area between Norway and Shetland and the adjacent continental slope, provided a welcome opportunity for obtaining data on suspended matter in this region: it would be possible to sample the inflow from the Atlantic Ocean and the outflow from the North Sea as well as the western-most part of the Sognefjord.

A complication, however, would be the presence of living plankton in the surface water as this cannot be quantitatively separated from the non-living suspended material in suspension except by a laborious counting method (EISMA & GIESKES 1977). However, it would be possible to determine the content of inorganic material in suspension (ash-weight) for all samples which is the most important fraction to compare with bottom deposits in the North Sea as the latter contain seldom more than 5% organic matter. Moreover it would be possible to determine total content of suspended matter without interferences from plankton below ca. 100 m depth.

The sampling was carried out in the period 2-11 May 1977 on the stations indicated in Fig. 1. Also two stations were made in Sognefjord and Sognesjöen respectively. Salinity, total dry-weight of suspended matter, particle size, organic content and

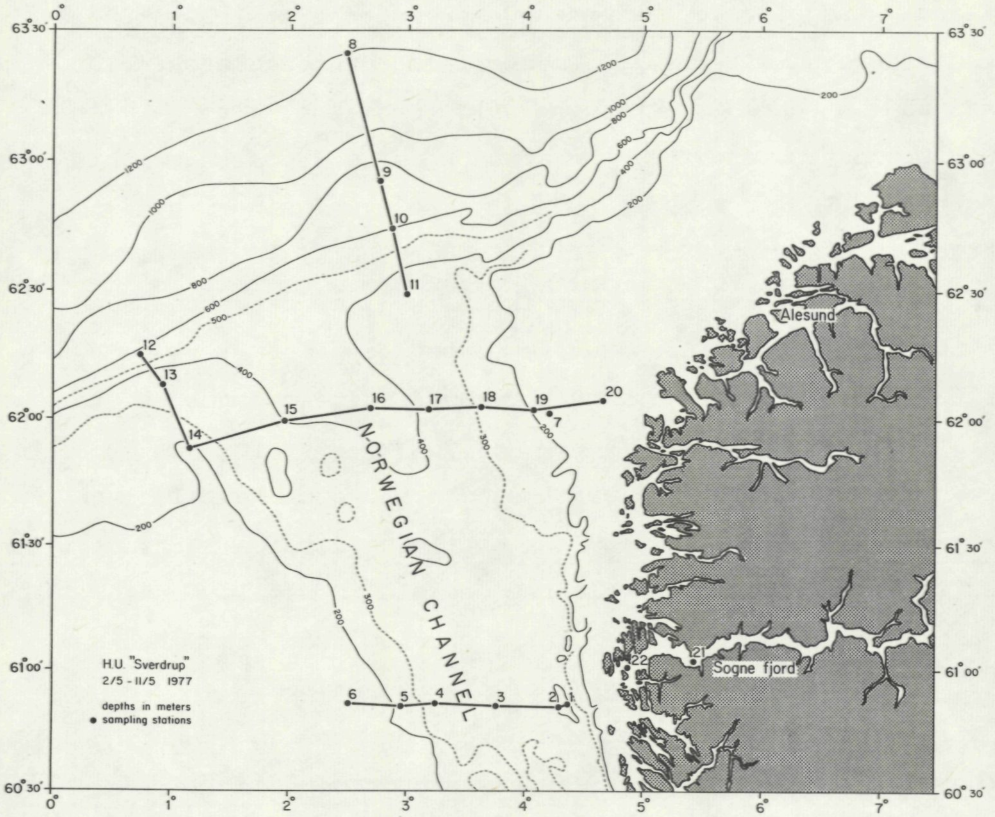


Fig. 1. Stations sampled in May 1977.

ash-weight of the suspended material were determined. Because of the weather not all data could be collected at all stations but a sufficient number of data could be obtained to characterize in- and outflow during that period.

We are much indebted to Prof. Hans Holtedahl who invited us to join the program and to Dr. Inge Aarseth whose pleasant company made a delightful trip and whose coöperation on board was a great help. We also like to thank Captain Olav Nordhus and the crew of the H.U. SVERDRUP without whose assistance our work would not have been possible. We very much appreciated the R/V H.U. SVERDRUP which proved a very workable ship even in force 8 winds.

II. METHODS

The samples were collected with 1.1 l Nansen bottles and 30 l bottles. At stations 12 to 20 heavy seas prevented the use of the plastic 30 l bottles as they were damaged against the ship's side so that only the 1.1 l steel bottles were used. At these stations only samples for determination of particle size and salinity were collected. Salinity was determined on board with an Autolab salinometer and some control determinations were made later in the laboratory at Texel. For the determination of suspended matter up to 5 liters (depending on the concentration of suspended matter) were filtered through a 0.45 µm millipore filter and up to 1 liter through a 0.4 µm Nuclepore filter. Subsequently the filters were washed thoroughly with distilled water. Both filters had been weighed before and were weighed again after filtration and after drying at 105° C. After determining the total weight of suspended material the millipore filters were ashed in a Tracerlab low temperature asher. The remaining inorganic material was resuspended in distilled water and filtered over a pre-weighted 0.4 µm Nuclepore filter. Weighing was done down to 0.01 mg. Trials with known quantities and blanco determinations indicated that the concentrations thus obtained can be considered accurate at least down to 0.05 mg/l and in most cases to 0.02 mg/l.

Particle size was determined in a Coulter Counter Model B. The method has been described by SHELDON & PARSONS (1967). Mainly a 50 µm tube was used as only rarely particles larger than 12.6 µm and only once larger than 15.9 µm were found. In some surface or near-surface samples large planktonic organisms (mainly Copepods) of several mm length were found on the filter.

The particle size determinations were done as much as possible directly on board after sampling but most of the time weather conditions and the resulting ship movement prevented this because the mercury column started to swing. Therefore most samples were measured inshore in quiet water within ca. 35 hours. Trials made in the Southern Bight of the North Sea, where suspended matter concentrations are much higher, have shown that this can be safely done without changes in the original size composition. To the samples JKJ was added to prevent plankton growth and bacterial activity.

The amounts of material on the filters proved too small for mineralogical analysis. The material on the Nuclepore filters was stored for elementary analysis. Two samples (the surface samples from stations 1 and 9), which contained relatively large amounts of living plankton, could not be ashed completely. A thin, white, brittle film was found which proved resistant against further oxydation and could not be removed with 1 N NCl. On adding water the film broke into a number of flakes which could not be removed quantitatively. Also in other instances it has been found that sometimes not all organic material was removed by ashing at low temperature so that the percentages giving here for organic content should be regarded as minimum values.

III. THE NORWEGIAN CHANNEL AND THE ADJACENT OCEAN

a. Salinity

The salinity data for the stations along the sections indicated in Fig. 1 are given in Table I. The distribution of salinity along the four sections during the period of sampling (fig. 2-5) is largely similar to the distribution given by

Table I
Suspended matter, salinity and depth at the sampling stations.

Station nr	Depth m	Salinity (°/ooS)	Total suspended matter (mg/l)	Total suspended matter (mm^3/l)	Inorganic susp. matter (mg/l)	Organic susp. matter (% of total)
1 (1)	1	32.48	0.70	0.645	-	-
	100	34.58	0.31	0.124	0.25	37
	200	35.09	0.24	-	0.23	4
	350	35.20	0.22	0.213	0.20	9
	450	35.23	0.13	0.050	0.13	0
2 (2)	1	32.93	0.48	0.264	0.10	79
	100	34.75	0.14	0.078	0.11	22
	200	35.03	0.07	0.036	0.06	14
	300	35.13	<0.02	0.023	-	-
	400	35.18	0.13	0.047	0.10	23
3 (3)	1	33.35	0.15	0.197	0.05	66
	100	34.74	0.24	0.052	0.04	83
	200	35.08	0.18	0.055	0.15	17
	320	35.21	0.07	0.047	0.07	0
4 (4)	1	33.81	0.69	0.170	0.20	71
	100	34.92	0.18	0.070	0.07	61
	200	35.22	0.04	0.050	-	-
	330	35.32	0.03	0.050	-	-
5 (5)	1	35.04	0.43	0.109	0.20	53
	100	35.25	0.11	0.087	0.10	9
	220	35.31	0.12	0.142	0.08	33
6 (6)	1	34.61	0.04	0.147	0.13	68
	100	35.26	0.08	0.101	0.04	50
7 (9)	1	34.22	0.12?	0.645	<0.02	>83
	135	34.77	0.08	0.069	0.06	25
8 (16)	1	35.03	0.27		0.23	17
	200	35.15	0.21		0.15	30
	400	35.14	0.13		0.07	46
	600	35.06	0.17		0.04	77
	1000	34.98	<0.02		-	-
	1200	34.97	0.02		<0.02	-
9 (18)	1	35.16	1.21		-	-
	200	35.09	0.14		0.03	79
	400	34.96	0.02		0.03	-
	600	34.97	0.10		0.02	80
	800	34.97	0.15		0.09	40
10 (19)	1	35.03	1.12		0.06	95
	200	35.19	-		-	-
	400	35.10	0.10	0.038	<0.02	>80
	600	34.98	0.18	0.033	0.03	83

Table I continued

Suspended matter, salinity and depth at the sampling stations.

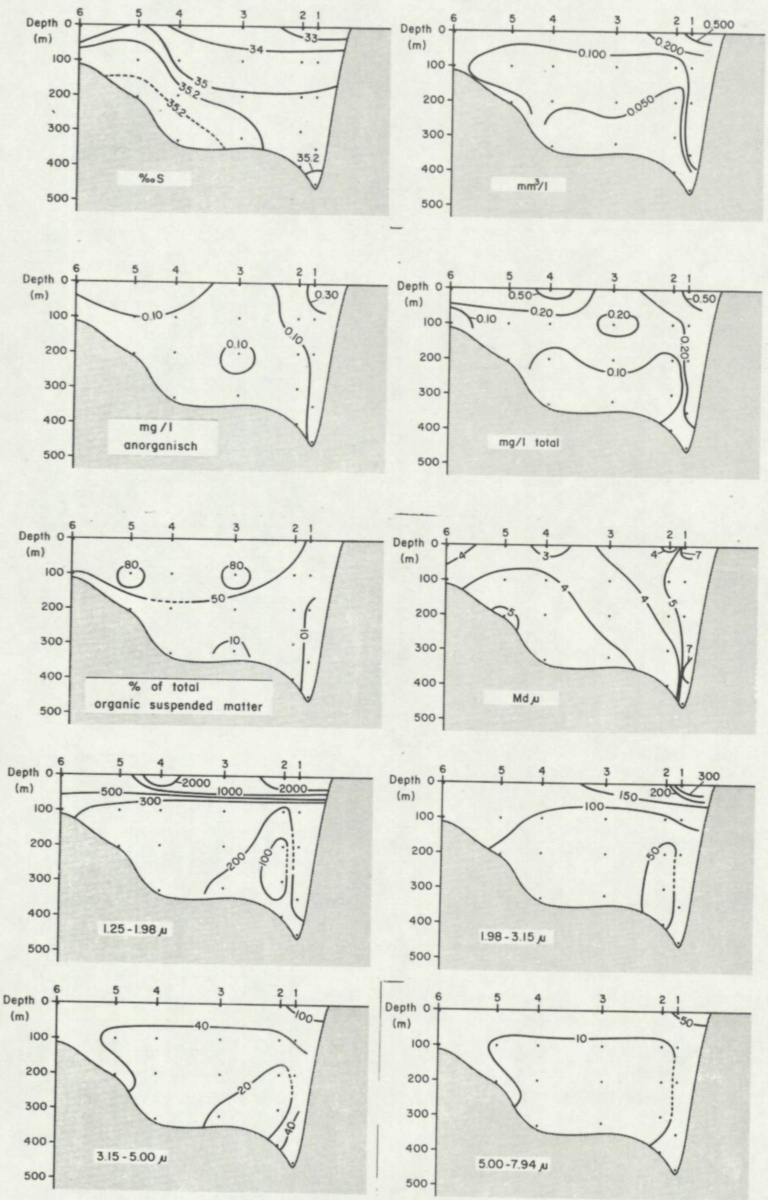
Station nr	Depth m	Salinity (°/ooS)	Total suspended matter (mg/l)	Total suspended matter (mm^3/l)	Inorganic susp. matter (mg/l)	Organic susp. matter (% of total)
11 (20)	1	34.27	1.02	0.620	0.15	85
	100	35.28	0.19	0.118	0.06	68
	200	35.28	0.18	0.115	0.07	61
	360	35.22	0.10	0.069	0.04	60
12 (30)	1	35.28		0.183		
	200	35.16		0.081		
	400	35.07		0.059		
	600	34.98		0.147		
13 (31)	1	35.28		0.184		
	100	35.30		0.036		
	200	35.30		0.045		
	300	35.32		0.041		
	400	35.15		0.087		
14 (32)	1	35.28		0.225		
	100	35.29		0.057		
	200	35.26		0.061		
15 (33)	1	35.00		0.582		
	75	35.18		0.144		
	150	35.26		0.050		
	250	35.18		0.052		
	350	35.08		0.039		
16 (34)	1	33.66		0.215		
	100	35.15		0.132		
	200	35.22		0.057		
	300	35.20		0.086		
	400	35.01		0.071		
17 (35)	1	33.74		0.464		
	100	35.10		0.088		
	200	35.25		0.083		
	300	35.21		0.067		
	375	35.14		0.078		
18 (36)	1	33.24		0.390		
	75	34.62		0.133		
	150	35.12		0.040		
	250	35.18		0.095		
19 (37)	1	33.04		0.240		
	100	34.44		0.072		
	175	35.13		0.062		
20 (38)	1	33.82		0.492		
	100	35.13		0.074		
	220	35.04		0.079		

Table I continued
Suspended matter, salinity and depth at the sampling stations.

Station nr	Depth m	Salinity (°/ooS)	Total suspended matter (mg/l)	Total suspended matter (mm3/l)	Inorganic susp. matter (mg/l)	Organic susp. matter (% of total)
21 (48)	1	32.69	0.71	0.512	0.11	84
	10	32.68	1.42	0.637	0.07	95
	20	32.77	0.92	0.452	0.05	94
	50	33.97	0.28	0.209	0.03	89
	100	34.82	0.20	0.105	0.05	75
	120	34.89	0.28	0.080	0.03	89
	135	34.93	0.23	0.063	0.03	87
	200	34.96	0.18	0.086	0.05	72
	400	35.04	0.17	0.059	0.06	65
	600	35.03	0.25	0.070	0.02	92
	900	35.26	0.20	0.057	0.04	80
	1210	35.37	0.32	0.059	0.05	84
22 (49)	1	32.01	0.79	0.651	0.06	92
	10	32.85	0.80	0.402	<0.02	>97
	20	32.77	0.24	0.218	0.05	79
	50	33.66	0.56	0.148	0.07	88
	100	34.73	0.19	0.106	0.03	84
	200	34.92	0.14	0.057	0.07	50
	475	35.24	0.18	0.100	0.12	33

(in brackets: station numbers of the Geological Institute, Bergen)

HELLAND-HANSEN (1934) for May-June 1925-1929, by SAELEN (1959) for July 1951 and found during the Coastal Current Project in May/June 1975 (Report 1/76), and is in agreement with the data given by HELLAND-HANSEN (1905) and ROBERTSON (1909, 1913) for this area. The inflowing ocean water, coming around Shetland, is concentrated along the western side of the Norwegian Channel and forms also most of the deeper water in the Channel. The outflow from the North Sea (the Norwegian coastal current) has a lower salinity due to the admixture of river water, Baltic outflow and runoff from Norway. This flow is concentrated along the eastern margin of the Norwegian Channel and spreads over the surface. The two watermasses are conventionally separated



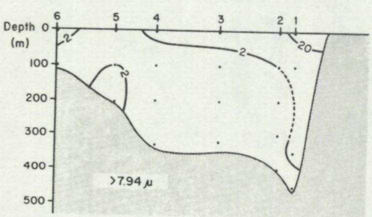


Fig. 2. Salinity, suspended matter data and number of particles per size fraction for stations 1 to 6.

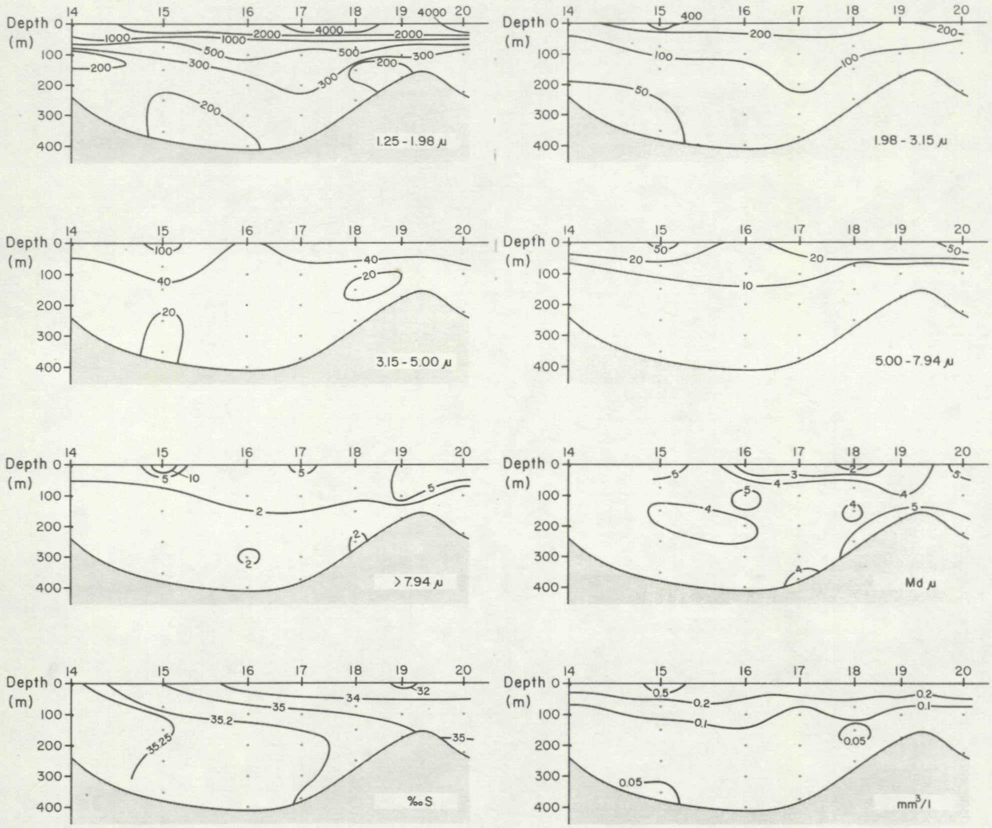


Fig. 3. Salinity, suspended matter data and number of particles per size fraction for stations 14 to 20.

by the 35 $^{o}/oo$ isohaline (HELLAND-HANSEN and NANSEN 1909, SAELEN 1959, Coastal Current Project Report 1/76). The core of the inflowing ocean water has a salinity >35.2 $^{o}/oo$ (the maximum found in May 1977, was 35.32 $^{o}/oo$): the salinity of the coastal current is usually much lower than 35 $^{o}/oo$.

b. Particle size

The particle size distribution are given in Tabel II. Maximum particle size is between 10 and 20 µm (apart from some larger plankton organisms of up to several mm length) and the highest

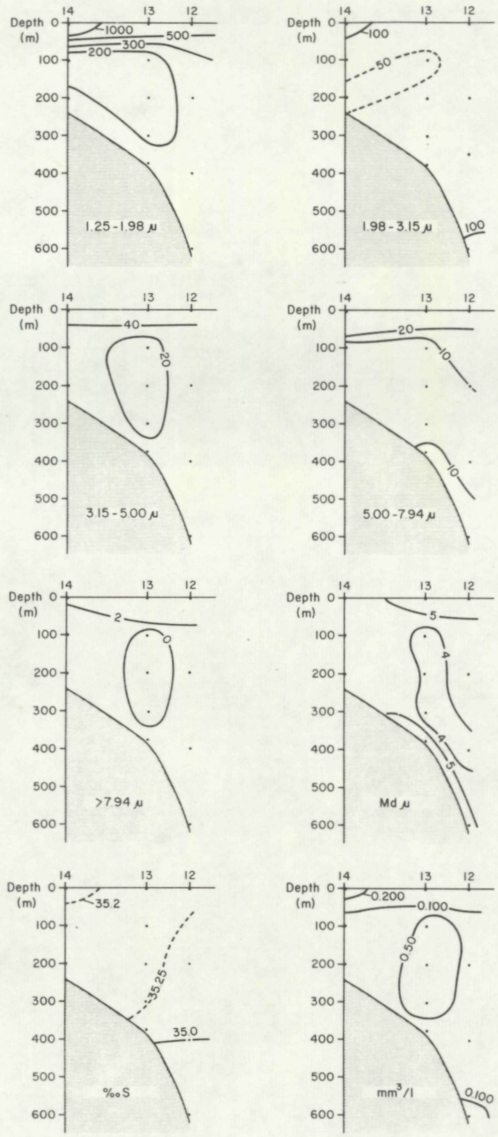


Fig. 4. Salinity, suspended matter data and number of particles per size fraction for stations 12 to 14.

number of particles occurs in the finest size fractions Fig. 6. The relation between the logarithm of the particle diameter and the logarithm of particle number is a straight line (Fig.7).This is also true for a sample from the Channel which is given for

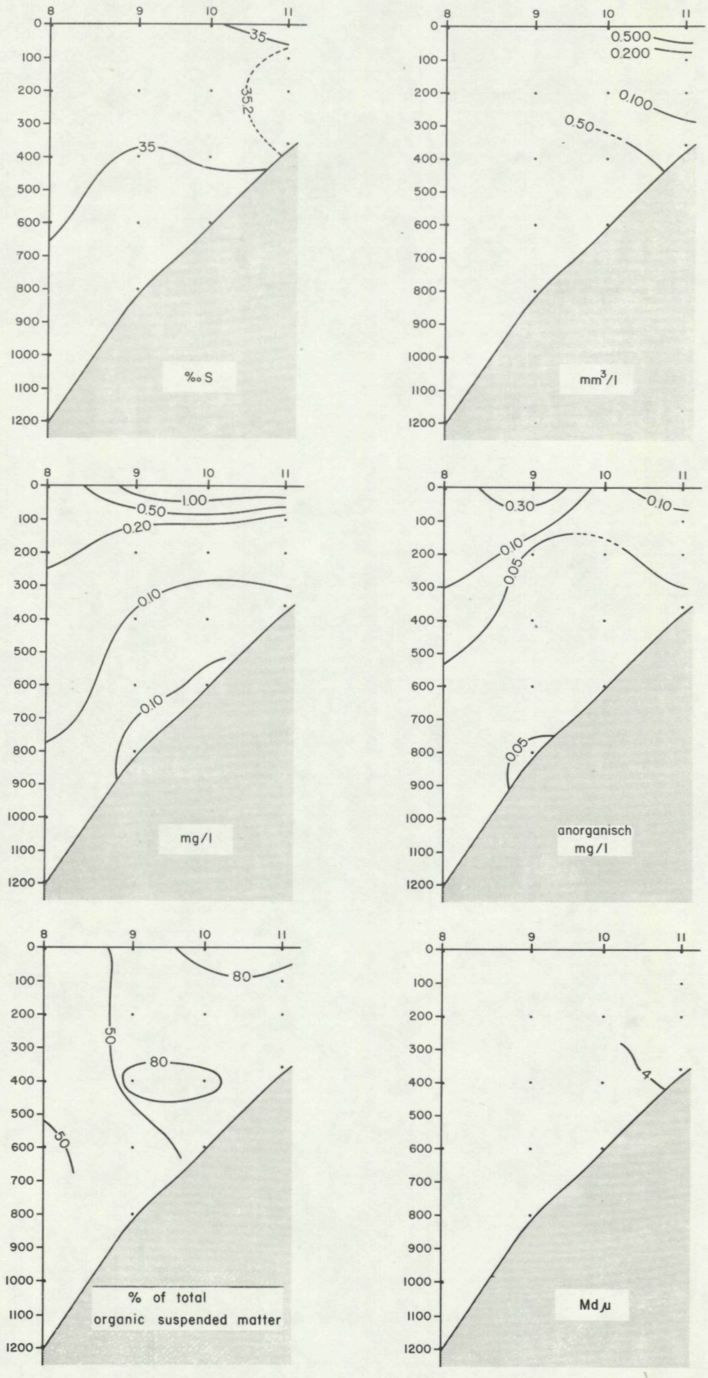


Fig. 5. Salinity and suspended matter data for stations 8 to 11.

Table II

Suspended particles per size class, counts per 0.05 ml.

Stà. nr.	Depth m	1.25 to 1.57 µm	1.57 to 1.98 µm	1.98 to 2.50 µm	2.50 to 3.15 µm	3.15 to 3.97 µm	3.97 to 5.00 µm	5.00 to 6.30 µm	6.30 to 7.94 µm	7.94 to 10.00 µm	10.00 to 12.60 µm	12.60 to 15.87 µm	15.87 to 20.00 µm
1	1	1343	798	208	122	77	50	39	32	18	4	1	0
	100	201	84	64	55	25	19	8	5	2	1	0	0
	200	-	-	-	-	-	-	-	-	-	-	-	-
	350	139	78	60	35	32	15	13	7	3	2	1	0.5
	450	80	41	27	18	12	5	8	2	1	0	0	0
2	1	2388	315	95	87	50	22	12	5	2	1	1	0
	100	122	70	38	23	18	9	5	3	1	1	0	0
	200	54	31	24	16	12	6	4	2	0	0	0	0
	300	63	35	21	17	8	3	3	0.5	0	0.5	0	0
	400	102	44	29	19	23	11	3	2	0	0	0	0
3	1	1363	306	112	51	23	22	7	9	4	0.5	0	0
	100	190	107	63	25	20	7	3	1	0	0	0	0
	200	181	88	50	30	18	9	5	1	0	0	0	0
	320	94	60	38	27	8	5	5	2	0.5	0	0	0
4	1	1932	320	87	40	25	18	7	4	3	0	0	0
	100	153	90	54	36	20	10	6	3	0.5	0	0	0
	200	137	70	44	28	8	6	5	2	0.5	0	0	0
	330	171	72	45	21	11	11	4	2	0	0	0	0
5	1	369	181	90	42	29	20	12	3	0	0	0	0
	100	172	117	63	46	23	11	5	2	2	0	0	0
	220	186	110	57	41	35	16	11	3	2	2	0.5	0
6	1	450	259	88	50	38	21	10	3	2	1	0	0
	100	242	115	92	50	34	17	10	3	0.5	0	0	0
7	1	2980	1062	405	83	58	53	33	28	18	2	0.5	0
	135	203	122	64	37	19	7	7	3	0	0	0	0
10	1	-	-	-	-	-	-	-	-	-	-	-	-
	200	-	-	-	-	-	-	-	-	-	-	-	-
	400	117	77	45	19	13	7	2	1	0	0	0	0
	600	91	58	41	22	15	8	1	0	0	0	0	0
11	1	3488	1514	232	116	76	64	51	26	10	0.5	0	0
	100	296	182	87	50	32	20	8	5	1	0	0	0
	200	185	88	53	59	30	22	10	5	2	0	0	0
	360	147	70	46	28	21	8	4	5	0.5	0	0	0
12	1	532	130	62	30	28	30	15	10	3	1	0	0
	200	176	113	57	30	19	14	7	3	1	0	0	0
	400	138	78	41	34	22	10	5	2	0.5	0	0	0
	600	206	118	66	42	32	18	8	6	4	1	0	0

Table II continued

Suspended particles per size class, counts per 0.05 ml.

Sta. nr.	Depth m	1.25 to 1.57 µm	1.57 to 1.98 µm	1.98 to 2.50 µm	2.50 to 3.15 µm	3.15 to 3.97 µm	3.97 to 5.00 µm	5.00 to 6.30 µm	6.30 to 7.94 µm	7.94 to 10.00 µm	10.00 to 12.60 µm	12.60 to 15.87 µm	15.87 to 20.00 µm
13	1	544	148	51	36	26	29	17	9	4	0.5	0	0
	100	124	55	27	22	14	5	3	1	0	0	0	0
	200	135	66	33	22	11	9	3	3	0	0	0	0
	300	125	52	31	24	11	5	3	2	0	0	0	0
	400	201	77	48	23	17	8	6	6	2	0	0	0
14	1	1073	427	77	41	31	25	20	13	3	0	0	0
	100	141	57	42	18	10	10	4	3	1	0	0	0
	200	148	68	30	19	14	8	5	4	2	0	0	0
15	1	1685	738	284	125	93	63	40	19	7	4	2	0
	75	279	182	90	53	37	22	14	5	1	0.5	0	0
	150	140	68	55	28	17	10	2	2	0	0	0	0
	250	126	55	33	18	13	6	3	3	1	0	0	0
	350	80	53	28	17	15	5	2	3	0	0	0	0
16	1	1710	1129	173	40	21	16	9	5	2	0	0	0
	100	321	186	66	46	22	10	9	7	2	1	0	0
	200	170	69	54	28	15	6	3	3	0.5	0	0	0
	300	165	93	43	30	20	14	3	3	4	0	0	0
	400	125	69	40	28	20	12	4	5	2	0	0	0
17	1	4323	1717	241	51	28	25	18	9	4	3	0.5	0
	100	209	127	65	38	15	9	10	2	3	0	0	0
	200	235	104	71	41	22	12	8	2	1	0	0	0
	300	145	82	38	18	20	9	7	4	0.5	0	0	0
	375	238	118	59	39	24	10	5	4	1	0	0	0
18	1	3761	1479	208	84	38	29	18	12	4	0	0	0
	75	473	199	105	57	18	15	5	5	2	1	0	0
	150	110	55	49	17	10	5	3	2	0	0	0	0
	250	129	90	52	30	17	7	8	3	3	0.5	0	0
19	1	1782	536	127	54	23	23	17	13	5	0	0	0
	100	243	117	64	35	13	7	7	2	4	0	0	0
	175	104	52	37	23	13	8	3	4	0.5	0.5	0	0
20	1	3522	516	197	89	50	37	40	25	6	3	0	0
	100	160	104	52	25	18	9	8	2	0.5	0.5	0	0
	220	140	72	45	25	13	10	6	4	2	0.5	0	0
21	1	3254	1084	336	145	97	83	15	8	5	2	1	0
	10	3802	1536	563	219	112	47	30	15	6	2	2	0
	20	3902	625	196	81	44	40	17	14	7	2	1	0
	50	370	179	93	65	44	27	16	6	4	2	0	0
	100	169	86	56	35	27	13	9	4	2	0.5	0	0
	120	154	95	57	38	17	9	7	3	2	0	0	0

Table II continued

Suspended particles per size class, counts per 0.05 ml.

Sta. nr.	Depth m	1.25 to 1.57 µm	1.57 to 1.98 µm	1.98 to 2.50 µm	2.50 to 3.15 µm	3.15 to 3.97 µm	3.97 to 5.00 µm	5.00 to 6.30 µm	6.30 to 7.94 µm	7.94 to 10.00 µm	10.00 to 12.60 µm	12.60 to 15.87 µm	15.87 to 20.00 µm
	135	152	87	61	28	13	11	6	1	1	0	0	0
	200	170	91	69	34	29	13	6	2	1	0	0	0
	400	127	75	42	31	16	9	5	1	1	0	0	0
	600	93	56	33	26	10	7	2	4	1	1	0	0
	900	119	62	39	25	12	6	5	2	2	0	0	0
	1210	129	65	57	40	20	6	5	3	0	0	0	0
22	1	1299	657	325	147	87	56	26	34	28	2	0	0
	10	2535	1141	375	114	51	42	18	16	2	1	0	0
	20	772	330	159	82	49	32	13	8	2	2	0.5	0
	50	570	228	102	62	24	18	13	4	3	0.5	0	0
	100	163	100	59	32	16	10	5	4	1	2	0.5	0
	200	146	82	54	32	18	11	7	0.5	0	0	0	0
	475	186	108	67	42	32	14	8	3	1	0.5	0	0

comparison, although the number of particles is about two orders of magnitude higher. The maximum diameter is 40 to 50 µm. As the Coulter Counter actually measures volume, the Coulter Counter data have been calculated into mm^3 : the volumes can be compared to weights, and size frequency distributions were calculated on the basis of the volumes. Some size distributions are given in Fig. 8. The peaks usually lie between 4 and 10 µm. The distribution of the median diameter along the sections indicated in Fig. 1 is given in Fig. 2-5. The surface water is characterized by median diameters of 1.5 - 7 µm except at station 1 where median values of up to 9 µm were found.

In Fig. 2-5 also the distribution of the number of particles in five fractions (1.25-1.98 µm, 1.98-3.15 µm, 3.15-5.00 µm, 5.00-7.94 µm and >7.94 µm) along the sections I - IV is given. The highest particle numbers occur in the

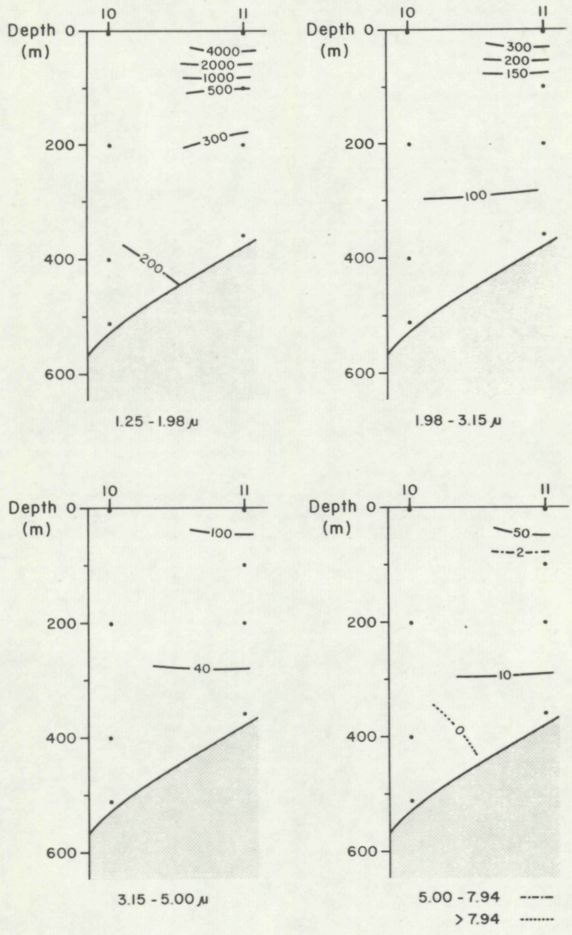


Fig. 6. Number of particles per size fraction for stations 10 and 11.

surface water. Inspection by microscope as well as the green colour of the suspended material on the filters indicated that this is due to the presence of living plankton. Below 100 m depth no living plankton was seen under the microscope and the colour of the material on the filters was brownish or beige. In the deeper water the distribution of particle number is rather uniform except at the eastern side of the most southern section (station 1-6) where locally very low particle numbers were found, especially at station 2.

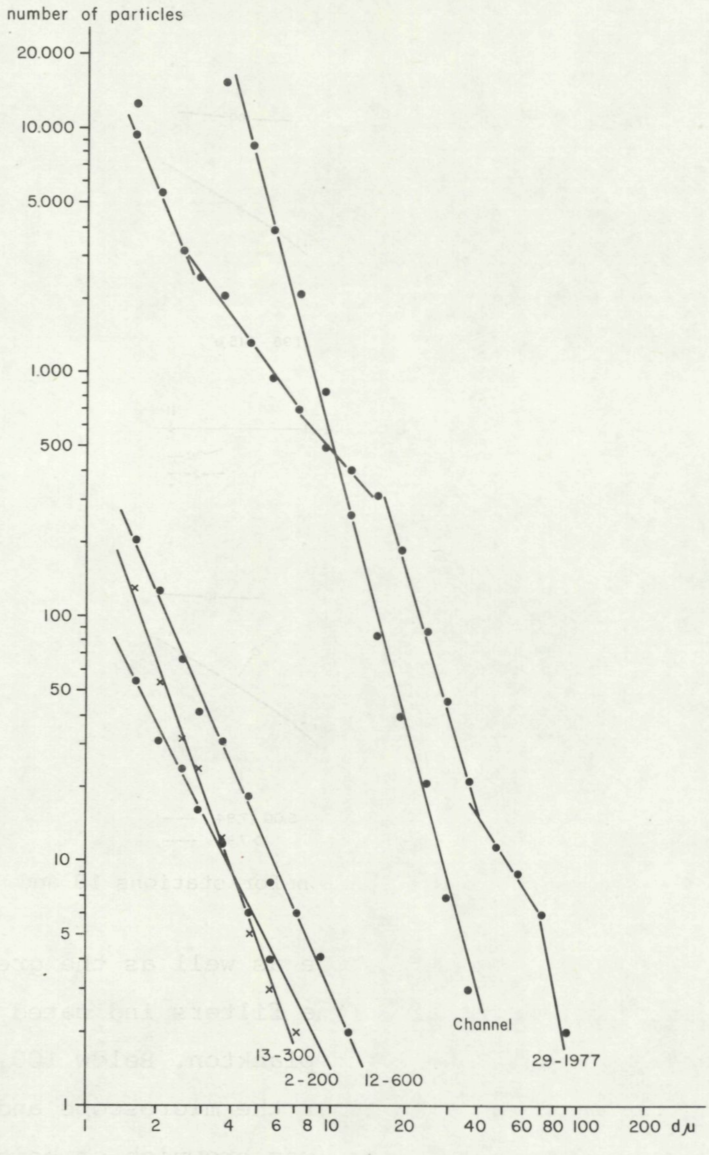


Fig. 7. Relation between log d (particle diameter) and log N (particle number).

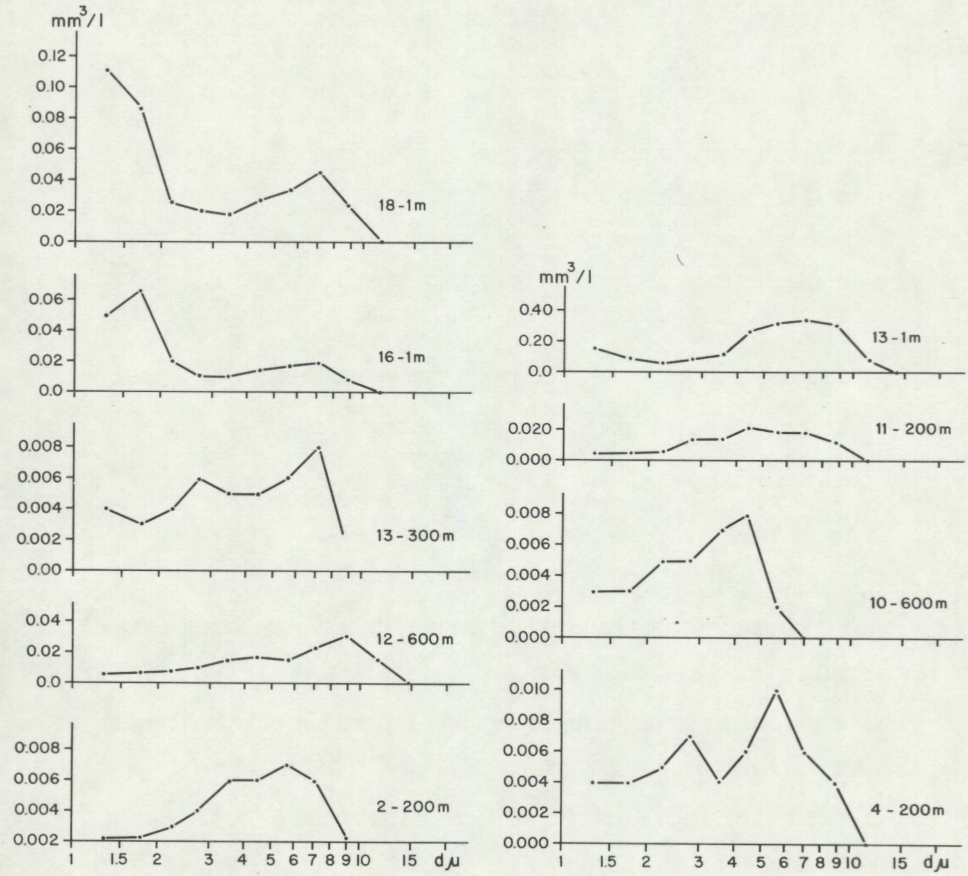


Fig. 8. Size distributions, based on volume, of some samples.

c. Content of total suspended matter, ashweight and organic content

The total content of suspended matter (Table I) is low compared to e.g. the Southern North Sea and the western Channel. The highest concentrations (which are found in the surface water) are 1.00-1.21 mg/l (dry-weight) which includes a certain amount of living plankton. At 100 m depth and deeper the total weight concentrations vary between 0.02 and 0.24 mg/l whereas in the Southern North Sea and the eastern Channel the lowest concentrations (found during the winter of 1976 and 1977 in the absence of living plankton) were 2.60-2.70 mg/l. In Fig. 9 the relation between the total volume of all particles >1.25 μm (in mm^3/l), calculated from the Coulter Counter data and the total weight (in mg/l) of the suspended material >0.4 μm is given. Assuming the inorganic particles to have a density of about 2.65 and the organic material a density near to 1 the points should fall between the lines x=y and x= 2.65 y, as suspended material is a mixture of both. Also there should be some displacements towards higher densities as total weight covers a larger size fraction than total volume. Some points, mainly at low values, fall outside these lines but this deviation is largely within the limits of error of determining total volume and total weight. Most points indicate a specific gravity between 2.65 and 1 which is in accordance with the presence of aggregates of inorganic and organic material and (in the surface samples) living plankton. In the case of aggregates the Coulter Counter probably also measures a certain volume of water, resulting in a relatively large volume and a low s.g. The percentage of organic material in the suspended matter in the deeper water, below 100 m, is in the most southern section (stations 1-6) 0 - 33 % (resulting in s.g. of 2.65 - 2.15) and reaches 80 % in the surface water (lowering the s.g. to 1.33). At stations 8 - 11, which are situated in Atlantic Ocean water, the percentage of organic matter reaches 80 % in the deeper water and 95 % at the surface (which lowers the s.g. to 1.08). The s.g. however, as determined from the weight (with an error of 0.02 to 0.05 mg/l) and the volume (with an error of 10 to 20 %) varies between wide limits which makes it very unreliable as an indicator of organic content. Moreover, it is not clear what the volume, as measured with a Coulter Counter, exactly means when the particles consists of loose aggregates of variable shape.

The concentration of inorganic material (ashweight) in suspension is 0.02 - 0.23 mg/l below 100 m depth and reaches 0.55 mg/l in the surface water.

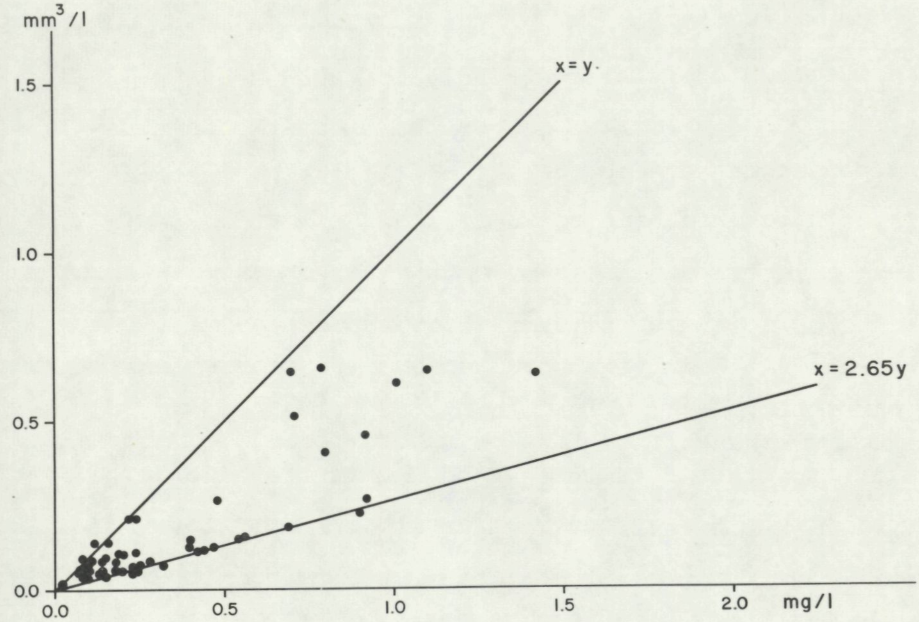


Fig. 9. Relation between weight and volume of suspended material.

d. Discussion

The inflowing ocean water is characterized by a low content of suspended matter (0.02-0.24 mg/l), which has a maximum size of 10 to 20 µm and a diameter of 3-6 µm. When stations 12-14, 8-11, 14-17 and 3-6 are compared there is no indication that bottom material is being picked up into suspension when the ocean water, flowing around Shetland, enters the Norwegian Channel. There is some indication for a change in organic content : comparing stations 3-6 with stations 8-11 the content of organic material tends to be lower at stations 3-6 although the total concentration of suspended material and particle size are very similar. The error at the lowest concentrations involved, however, is relatively large (up to 50-100 %) so that it is uncertain whether this decrease is significant.

The outflowing North Sea water is more difficult to characterize as to its particle content because it mainly formes the surface water which is also strongly influenced by primary production. Thus the surface water has the highest concentrations of suspended matter (up to 1.21 mg/l), the highest contents of organic material (up to 95 %) and the most variable median diameter (1.5 - 7 µm). The content of inorganic material (ashweight) however, is the same as in the deeper water, indicating that inflow and outflow have the same concentrations of inorganic particles.

There are no other data on suspended matter available for the area between Norway and Shetland but a comparison can be made with data for the North Atlantic Ocean and the Northern North Sea. JACOB & EWING (1969) give for the North Atlantic Ocean below a layer of 180 m, which is influenced by primary production, concentrations of suspended matter ranging from 0. 1 to 49.5 mg/100 l or 0.0005 - 0.25 mg/l, i.e. the same range as found in the ocean water flowing into the Norwegian Channel. For the surface water in the North Atlantic Ocean SVIRENKO (1970) gives 0.2 - 1.6 mg/l (total content) and LISITZIN (1972) 0.5 - 1.5 mg/l in spring and $<$ 0.5 mg/l in winter.

Table III

Suspended matter in surface waters of the North Sea according to various authors.

Hagmeier (1960, in Krey 1961)	0.49 - 3.20 mg/l	(Fladen Ground, upper 50 m)
Hagmeier (1960, in Krey 1961)	0.03 - 0.59 mg/l	(Norwegian Channel, upper 50 m)
Hagmeier (1961b) "	0.10 - 2.1 mg/l	(Northern North Sea, surface)
Krey (1961)	0.1 - 0.6 mg/l	(Fladen Ground, surface)
Svirenko (1970)	0.4 - 3.9 mg/l	(Northern North Sea, surface, winter)
Lisitzin (ed. 1975)	0.5 - 1.0 mg/l	(Northern North Sea)

For the Northern North Sea only data for the surface water are available. These are probably not wholly comparable to those of the area between Norway and Shetland because of the slower currents and the somewhat larger residence time of the water in the Northern North Sea (DOOLEY 1974, MAIER-REIMER 1977). Table III shows that the maximum concentrations of suspended material in this area are somewhat higher than those in the surface ocean water or in the area between Norway and Shetland, (where concentrations go up to 1.21 mg/l). As all these data are influenced to a variable degree by the admixture of living plankton KREY (1961) and HAGMEIER (1961a) estimated the total of dead (organic and inorganic) material in suspension by subtracting from the total a certain value calculated from plankton counts. In this way they found concentrations of non-living suspended material of 0.03 - 0.53 mg/l and 0.10 - 1.60 mg/l respectively. This is much higher than the concentrations found in the deeper water of the Norwegian Channel. As HAGMEIER (1961a) found a positive relation between the plankton and concentration of the content of non-living suspended material, it can be assumed that these high concentrations are due (apart from the error in the determination) to the admixture of organic or inorganic plankton debris.

On the basis of the data obtained here for the inflow from the Atlantic Ocean and the outflow from the North Sea, it can be concluded that the same amount of suspended material leaves the North Sea along the Norwegian coast as has entered the North Sea around Shetland and between Orkney and Shetland. It is assumed then that the inflow between Orkney and Shetland (which is only ca. 20% of the inflow through the Norwegian Channel) has the same suspended matter content as the North Atlantic Ocean water and the inflow around Shetland. This conclusion agrees with the preliminary estimate that more than 90 % of the suspended material supplied to the North Sea by rivers, through erosion of cliffs and the seafloor, inflow from the Baltic and the atmosphere and from organic production is deposited within the North Sea. If less than 10 %, i.e. less than 2.5 million ton, leaves the North Sea by way of the coastal current, this gives, at a flow of ca. 55.000 km3/year (OTTO 1976), an average concentration of at most 0.045 mg/l which is very near to the error of determination. However, in order to reach a more accurate result, a second series of samples should be collected between Shetland and Norway, as well as between Orkney and Shetland, during the winter when living plankton is absent so that more precise data can be obtained for the surface water.

IV. SOGNEFJORD AND SOGNESJÖEN

The salinity distributions at the stations in the Sognefjord and in Sognesjöen are given in Fig.10. The halocline was situated between ca. 25 and 100 m depth. In Table IV the data on suspended matter for the Sognefjord, Sognesjöen and the adjacent Norwegian Channel (stations 1-3) are summarized. Below the halocline the total contents of suspended matter tends to

Table IV

Suspended matter in Sognefjord,Sognesjöen and the Norwegian Channel

	mg/l	mm^3/l	Md µm	Ash weight mg/l	Organic content %
Surface water					
Sognefjord	0.28-1.42	0.209-0.637	2.5-6.5	0.03-0.11	84-95
Sognesjöen	0.24-0.80	0.148-0.651	2.5-8.0	<0.02-0.7	79->97
Norw. Channel	0.14-0.70	0.052-0.645	3-7	0.05-0.20	22-83
Below halocline					
Sognefjord	0.17-0.32	0.057-0.209	3-5	0.02-0.06	65-92
Sognesjöen	0.14-0.19	0.057-0.106	3-6.3	0.03-0.12	33-84
Norw. Channel	<0.02-0.24	0.023-0.213	3-10	0.06-0.23	0-23

be higher in the Sognefjord and in Sognesjöen than in the Norwegian Channel, whereas the median diameter tends to be smaller. The concentration of inorganic suspended matter (ash-weight) however is much smaller, especially in the Sognefjord where the organic content is high. Assuming a slow inflow of seawater from the North Sea into the fjord below the halocline (SAELEN 1967) these data suggest a gradual settling of particles in the fjord with at the same time addition of organic particles from the surface layers. In the surface water the differences in concentration between the fjord and the Norwegian Channel are hardly significant but the organic content is,

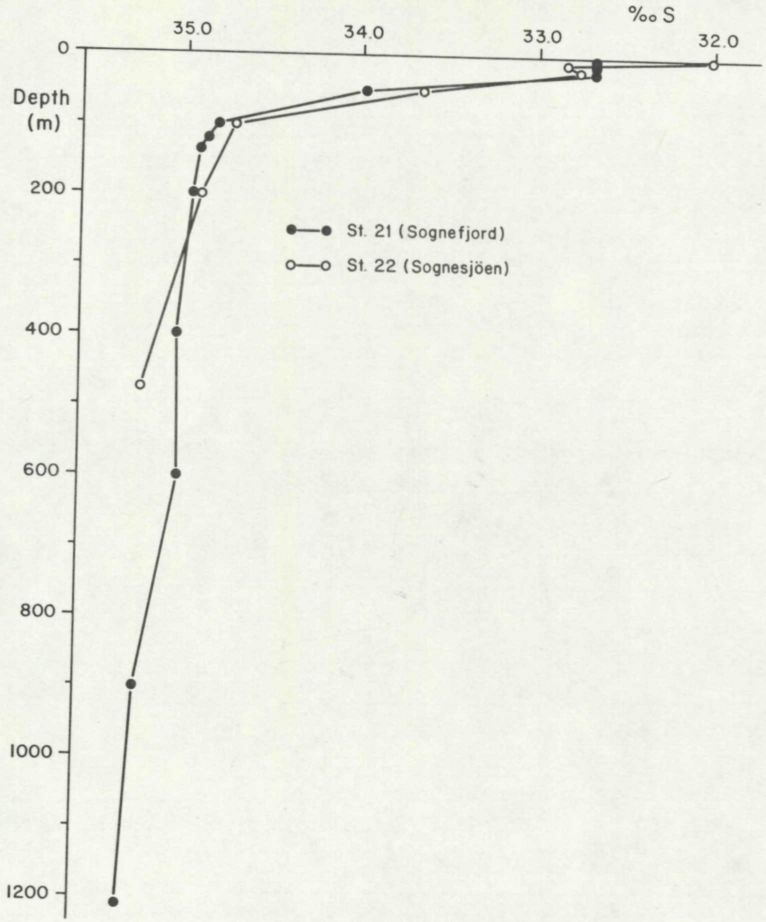


Fig. 10. Salinity distribution at the two Sognefjord stations.

again, much higher. There is no indication for a significant outflow of suspended material from the fjord into the North Sea during the period of sampling,but this should be measured in the summer when fresh-water runoff is at a maximum. During that season the density stratification is strongest and, according to PRICE and SKEI (1975),it is an effective barrier to particle settling.

The high organic content of the suspended matter in the fjord suggests an accumulation of organic matter in the fjord sediments but data on this are very scarce. OLAUSSON (1975) gives some data for a fjord north of Göteborg where the organic carbon content of bottom deposits is 1.8 - 3.9 %. In the adjacent Skagerrak it is 0.2 - 2.2 %. Elsewhere in the Skagerrak (presumably in fine grained sediments) the organic carbon content increases to 3.0 %. This would indicate that there is only a slight accumulation, if any, of organic material inside the fjord, which would imply a strong mineralization. However, conditions in the small fjord north of Göteborg may not be the same as in the Sognefjord.

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