Particulate Matter in Icelandic Surface Waters

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ABSTRACT

In May-June 1974 and 1976 eighty eight surface samples were collected in Icelandic waters for investigating particular matter. In nearshore areas considerably affected by freshwater afflux ($12.6‰ \leq S \leq 33.75‰$) total suspended matter (TSM) ranged from 0.280 to 50.5 mg/L, particulate aluminium 16–6169 μg/L, and particulate iron 21–8827 μg/L. In offshore areas ($33.82‰ \leq S \leq 35.15‰$) TSM ranged from 0.310 to 1.070 mg/L, particulate aluminium 1.1–18.9 μg/L, particulate iron 1.0–17.0 μg/L, and particulate organic carbon (POC) 29–420 μg/L, constituting about 30% of the TSM. With one exception „soluble“ iron ranged from undetectible to 1.80 μg/L, with significantly higher concentrations in Atlantic water than in Arctic water.

In nearshore areas where the predominant freshwater system is typically of glacial origin with high ratio between coarse silt and clay, the TSM/salinity relationship tends to be irregular, whereas in coastal waters diluted by rivers with low silt/clay ratio, a linear TSM/salinity relationship is indicated. In all regions a close correlation existed between particulate aluminium, particulate iron and TSM. However, the fraction of particulate aluminium and iron in the TSM was not constant, but increased with increasing TSM. On the whole, the average composition of TSM in nearshore areas with respect to aluminium and iron resembled closely that of the basaltic rocks constituting the main fraction of the particulate material of the predominant rivers.

In areas outside appreciable coastal influence there was as expected a correlation between primary production and TSM, primary production and POC and between chlorophyll a and POC. In May-June 1976 the chlorophyll a/POC ratio ranged from 0.8×10^{-3} to 31×10^{-3}. This ratio appears to increase with increasing primary production. It was found that high ratios generally coincided with great phytoplankton bloom irrespective of the zooplankton volume, presumably because the phytoplankton becomes the predominant part of the living matter whenever the plant production rate is high. On the other hand, the lowest ratios were generally found when relatively large zooplankton volumes coincided with small productivity. Where both phytoplankton and zooplankton densities were low, the ratios were intermediate.

INTRODUCTION

In the past numerous research efforts have been devoted to investigations of suspended material in various parts of the world ocean. These studies, utilizing optical methods, direct gravimetric determinations and chemical analyses, have included i. a. measurements of the size distribution of particles, the total weight, the particulate organic fractions, calcium carbonate, silica, iron and aluminium, besides a number of trace metals (see e. g. Armstrong 1958, Joyner 1964, Jacobs and Ewing 1969, Chester and Stoner 1974, Kullenberg 1974, Brewer et al. 1976 and Krishnaswami and Sarin 1976). These and various other investigations have revealed that the suspended matter in the sea consists of particles derived mainly from four sources:

a) terrigenous material, mostly inorganic, carried to the sea as the suspended load of rivers, brought by air currents or resulting from coastal erosion.
b) organic particles formed through biological processes in the sea, as well as inorganic remains of marine organisms.
c) inorganic precipitation in the sea, e. g. in estuaries or at the deep sea floor.
d) inorganic debris resulting from volcanic activities, in particular submarine eruptions.

The prevailing type of particulate material as well as the total amount per unit volume of seawater will depend on a number of factors, such as the proximity of the coast, the nature of the runoff from land, the fertility of the ocean area in question, the season etc. In some regions the distribution of a specific particulate component has proved to be a most sensitive indicator of the presence of continental runoff water (e. g. Joyner 1964). Furthermore, the chemical as well as the minerological composition of terrigenous particulate matter may provide information on the origin of the freshwater system by which a particular suspended load was carried to the sea, and thus make it possible, at least theoretically, to differentiate between suspended matter from different sources. Conversely, in offshore areas outside the coastal influence, it would be expected that the particulate matter is principally of organic origin, in which case the total suspended matter as well as its major components should be a measure of the biomass and the distribution might reflect variations in primary production.

The objectives of the present investigations were: a) to obtain basic information on the nature and the distribution of particulate matter in Icelandic waters, b) to study the total suspended matter, as well as particulate aluminium and iron as a function of freshwater admixture due to runoff from glacial rivers, and c) to study in areas outside the coastal water the concentration of total suspended matter and particulate organic carbon in relation to primary production and clorophyll a.

MATERIAL AND METHODS

During May-June 1974 and 1976 samples were collected at various localities in Icelandic waters, from river estuaries to regions beyond the continental shelf. This time of the year was selected since it roughly coincides with the maximum runoff from several major rivers and coincides with or follows the maximum plant production. In 1974 37 sta-

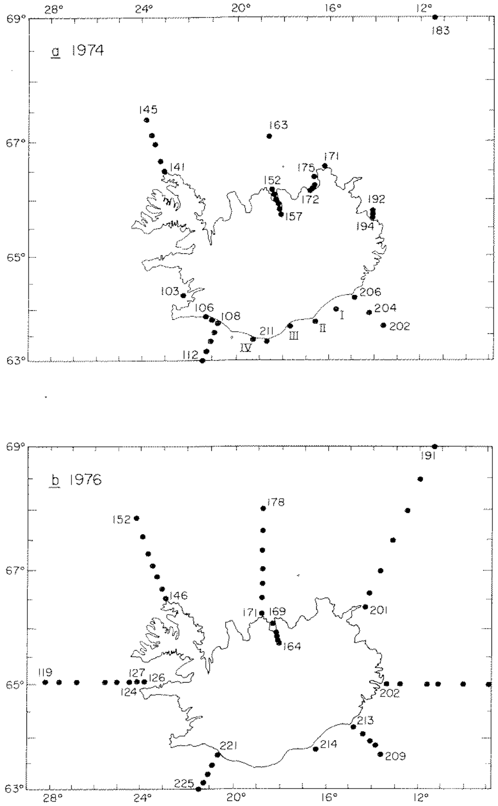

Fig. 1. Stations where surface samples were taken for analyzing suspended matter: a) May 21 — June 8 1974, b) May 28 — June 15 1976.

tions and in 1976 51 stations were occupied (Fig. 1). The samples were collected at the surface only. They were taken, using an all-plastic bucket with an attached nylon rope, from the hydrographic platform at a distance of 2–3 meters from the side of the ship. Upon collection the water was filtered by vacuum (30–40 cm Hg). Preweighed glass fiber filters (GF/C 1.2 μ) were used to determine the total suspended matter and particulate organic carbon, whereas Millipore filters (0.45 μ) were used for determining particulate aluminium and iron. In areas where the water was highly turbid, e. g. in i river estuaries, only 0.5 to 2 liters could be filtered through either type of filters. In clear offshore water 4–5 liters were filtered, except at a few stations where dense phytoplankton made it impossible to filter more than 1–3 liters. Following filtration the filters were carefully washed with distilled water, folded and air-dried. The glass fiber filters were subsequently dried at 60°C in a drying oven until constant weight was reached. The standard deviation due to uncertainty in weighing before and after filtration was found to be about 0.06 mg. This implies that for the offshore samples the weighing error alone in the determination of the total suspended matter may be from 3–6% (in one instance up to 12%), while in the nearshore areas where the concentration of suspended matter is high, this error will be negligible (< 1%).

Particulate carbon was estimated by oxidation with dichromate as described by Strickland and Parsons (1968).

Following ignition and Na_2CO_3 fusion particulate aluminium and iron were determined spectrophotometrically according to the method of Joyner (1964) as modified by Amieil (1968). Using silver crucibles simultaneous determinations of a rock standard (British Chemical Standard, GES9) gave 99–100% recovery of iron and 90–91% recovery of aluminium. „Soluble" iron was determined according to Strickland and Parsons (1968) with the modification that the coloured ferrous complex was extracted from 300 ml. of Millipore-filtered seawater (which had been acidified with HCl to pH=2) into redistilled reagent grade isoamyl alcohol and the volume of the extract adjusted to 25 ml. Duplicate analyses were made on 46 of the 51 samples taken. The precision, estimated to be twice the standard deviation computed from these duplicate analyses, was 0.55 µg/L. The standard deviation of the blank was determined from several sets of blank determinations. The detection limit taken as 3 times this standard deviation, was found to be 0.51 µg/L.

Besides the analyses described above, routine measurements were made of the seawater samples, viz. of temperature, salinity, dissolved oxygen, nutrients, primary productivity, chlorophyll a and zooplankton density.

RESULTS

The concentrations of the various fractions of particulate matter as well as salinity are given in Tables 1 and 2. In addition, Table 2 includes concentrations of "soluble" iron, determined in 1976.

The stations occupied can be divided into two groups: a) nearshore stations where the influence of freshwater afflux was considerable and consequently relatively large concentrations of terrigenous suspended materials, and b) offshore stations where such influence was relatively small. In the former group the salinity ranged from 12.65‰ to 33.75‰, and the total suspended matter (TSM) from 0.28 mg/L to 50.53 mg/L. In the latter group the salinity ranged from 33.82‰ to 35.15‰ and TSM from 0.31 to 1.07 mg/L, with an average of 0.57 mg/L.

At the inshore stations the concentrations of particulate aluminium and iron were highly variable (Fe: 21–8827 µg/L, Al: 16–6169 µg/L) depending upon TSM. At offshore stations the particulate aluminium concentrations ranged from 1.1 to 18.9 µg/L (mean value 6.1 µg/L) and those of iron from 1.0–17.0 µg/L (mean value 6.2 ug/L). The ranges as well as the mean values were similar for 1974 and 1976. These mean concentrations of TSM, particulate aluminium and particulate iron are about an order of magnitude higher than those recently reported for the surface layers of the deep Atlantic (Brewer et al. 1976, Krishnaswami and Sarin 1976) where terrigenous effects are much smaller and productivity generally less than at those stations considered to be "offshore" in the present study.

With the exception of one sample taken in brackish water near to town of Akureyri, where the average concentration of "soluble" iron was found to be as high as 4.83 µg/L, the "soluble" iron concentrations ranged from 0 to 1.98 µg/L (Table 2) with an average of 0.64 µg/L.

Particulate organic carbon (POC) ranged from 29 to 420 µg/L, with an average of 170 µg/L. Values of TSM for offshore stations were available only for 1974, while determinations of POC were made only in 1976. Thus the two sets of

TABLE 1

Particulate matter in Icelandic surface waters

May – June 1974

St. No.	Position		Salinity ‰	TSM mg/L	Particulate Aluminium µg/L	Particulate Iron µg/L	Fe/Al
	N	W					
103	66°14′	22°13′	33.966	0.371	—	5.34	—
106	63°51′	21°12′	31.060	12.493	—	457.4	—
107	63°46′	20°49′	32.642	14.456	—	434.4	—
108	63°41′	20°40′	33.533	4.223	—	246.0	—
109	63°29′	20°54′	35.075	0.374	7.01	5.63	0.80
110	63°19′	21°07′	35.109	0.624	5.48	2.19	0.40
111	63°09′	21°18′	35.114	0.736	1.15	1.74	1.51
112	63°00′	21°28′	35.114	0.517	1.72	1.02	0.59
141	66°30′	23°00′	34.213	0.403	9.86	6.88	0.70
142	66°41′	23°09′	34.593	0.664	4.68	6.53	1.39
143	66°56′	23°22′	35.040	0.775	2.34	2.22	0.95
144	67°05′	23°28′	33.822	0.447	3.31	2.52	0.76
145	67°21′	23°41′	33.381	0.563	(9.17)	(64.0)	—
152	66°09′	18°32′	33.976	0.775	14.0	13.1	0.94
153	66°05′	18°27′	33.410	0.275	—	—	—
154	65°59′	18°18′	33.282	0.580	15.6	21.0	1.35
155	65°55′	18°14′	30.018	0.733	37.5	58.6	1.56
156	65°50′	18°09′	28.764	1.055	56.1	75.8	1.35
157	65°41′	18°04′	22.155	2.100	105.2	179.2	1.69
163	67°05′	18°43′	34.862	0.853	—	8.04	—
171	66°34′	16°15′	34.093	0.351	6.57	12.2	1.86
172	66°09′	16°45′	32.754	28.540	(25.3)	457.3	—
173	66°11′	16°50′	33.300	5.578	(82.0)	311.4	—
174	66°16′	16°43′	33.104	1.629	42.8	67.9	1.59
175	66°25′	16°46′	33.716	0.562	20.5	43.8	2.14
183	69°00′	11°27′	34.784	0.474	5.39	7.84	1.45
192	65°48′	14°10′	33.751	1.660	27.6	49.1	1.79
193	65°43′	14°11′	33.721	5.315	249.5	284.2	1.14
194	65°40′	14°12′	12.646	50.533	6169	8827	1.43
202	63°40′	13°40′	35.161	0.307	3.12	6.43	2.06
204	63°52′	14°08′	34.984	0.720	5.93	7.68	1.30
206	64°12′	14°50′	34.724	1.067	14.2	17.0	1.19
I	64°00′	15°42′	34.334	1.507	28.7	46.6	1.61
II	63°47′	16°38′	28.873	5.630	370.8	485.8	1.31
III	63°40′	17°46′	25.661	13.218	748.4	991.6	1.32
211	63°22′	18°47′	32.723	2.247	144.3	183.6	1.27
IV	63°27′	19°23′	32.804	4.012	134.9	120.6	0.89

TABLE 2

Particulate matter in Icelandic surface waters
May – June 1976

St. No.	Position		Salinity ‰	TSM mg/L	POC µg/L	Particulate Aluminium µg/L	Particulate Iron µg/L	Fe/Al	"Soluble" Iron	
	N	W							I µg/L	II µg/L
119	65°03′	28°11′	34.992	—	163	—	—	—	—	1.34
120	65°03′	27°35′	34.986	—	144	—	—	—	—	1.20
121	65°03′	26°43′	34.965	—	151	—	—	—	1.15	0.92
122	65°03′	25°30′	34.943	—	259	—	—	—	1.15	0.88
123	65°03′	25°02′	34.663	—	211	—	—	—	0.60	0.46
124	65°03′	24°34′	34.637	—	146	4.86	5.25	1.08	0.69	0.46
126	65°03′	23°50′	33.977	—	110	—	—	—	0.74	0.51
127	65°03′	24°10′	34.091	—	66	—	—	—	0.65	0.32
146	66°30′	23°00′	34.012	—	190	7.01	6.00	0.86	0.55	0.65
147	66°41′	23°09′	34.607	—	420	10.79	4.25	0.39	0.65	0.69
148	66°53′	23°19′	34.800	—	379	—	—	—	0.65	0.88
149	67°05′	23°28′	34.929	—	196	—	—	—	0.23	0.55
150	67°19′	23°40′	34.875	—	164	—	—	—	0.09	0.69
151	67°32′	23°55′	34.381	—	169	—	—	—	0.00	(1.01)
152	67°50′	24°10′	34.294	—	29	—	1.83	—	0.00	0.18
164	65°42′	18°04′	—	18.110	137	1311	1335	1.02	4.66	4.98
165	65°46′	18°07′	16.593	5.110	191	—	—	—	0.65	0.46
166	65°50′	18°09′	18.776	2.960	105	241.5	184.9	0.77	0.42	0.51
167	65°55′	18°14′	26.653	2.390	104	135.8	146.6	1.08	0.05	0.37
169	66°06′	18°23′	30.471	1.330	112	64.7	80.0	1.24	0.32	0.23
171	66°16′	18°50′	34.264	—	232	—	—	—	0.14	0.69
173	66°32′	18°50′	34.476	—	115	11.87	12.70	1.07	0.69	0.60
174	66°44′	18°50′	34.751	—	359	17.12	12.40	0.72	0.65	—
175	67°00′	18°50′	34.679	—	269	18.88	9.50	0.50	0.60	0.65
176	67°20′	18°50′	34.668	—	302	—	—	—	0.65	—
177	67°40′	18°50′	34.725	—	259	—	—	—	0.28	0.42
178	68°00′	18°50′	34.722	—	336	—	—	—	0.51	0.55
184	66°37′	14°16′	34.442	—	92	—	—	—	0.18	0.65
185	67°00′	13°51′	34.457	—	147	—	—	—	0.14	0.65
187	67°30′	13°16′	34.644	—	—	—	—	—	1.15	1.20
189	68°00′	12°38′	34.701	—	118	1.21	3.00	2.48	0.32	0.55
190	68°30′	12°03′	34.717	—	228	6.88	4.00	0.58	0.32	0.37
191	69°00′	11°27′	34.746	—	133	5.93	4.75	0.80	0.69	0.65
201	66°22′	14°22′	34.575	—	134	3.51	4.50	1.28	0.83	0.88
202	65°00′	13°30′	34.387	—	71	8.99	13.33	1.48	0.18	0.92
203	65°00′	12°49′	34.404	—	196	5.39	6.00	1.11	0.69	1.11
204	65°00′	11°40′	34.535	—	126	3.24	3.00	0.93	0.09	0.55
205	65°00′	11°17′	34.541	—	92	2.56	6.25	2.44	0.37	0.69

TABLE 2 cont

St. No.	Position N	Position W	Saninity ‰	TSM mg/L	POC µg/L	Particulate Aluminium µg/L	Particulate Iron µg/L	Fe/Al	"Soluble" Iron I µg/L	"Soluble" Iron II µg/L
206	65°00′	10°07′	35.052	—	99	1.73	4.08	2.36	0.74	1.20
207	65°00′	9°00′	34.721	—	123	2.43	5.20	2.14	0.37	0.37
209	63°40′	13°40′	35.119	—	133	—	2.50	—	0.46	0.74
210	63°48′	13°58′	35.119	—	79	—	1.95	—	0.46	0.60
211	63°52′	14°08′	34.904	—	163	2.45	4.25	1.73	0.42	0.51
212	64°02′	14°28′	34.765	—	149	5.39	6.80	1.26	0.55	0.55
213	64°12′	14°50′	34.624	—	164	—	—	—	0.65	0.92
214	63°46′	16°36′	34.374	—	270	—	—	—	0.65	0.78
221	63°41′	20°41′	33.003	3.850	—	186.0	297.1	1.60	1.15	1.98
222	63°29′	20°54′	34.999	—	83	24.8	—	—	0.78	1.57
223	63°19′	21°07′	35.039	—	117	4.25	—	—	0.37	1.11
224	63°09′	21°18′	35°043	—	89	2.50	—	—	0.42	1.25
225	63°00′	21°28′	35.044	—	170	2.50	—	—	—	1.52

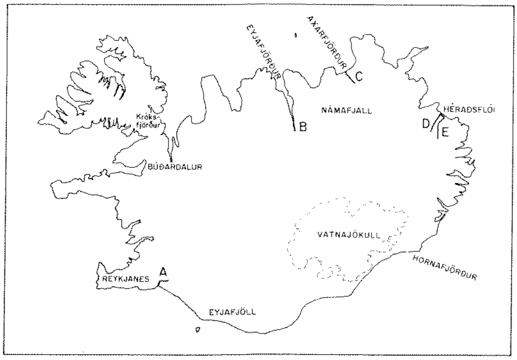

Fig. 2. Localities and rivers referred to in the text. A: Ölfusá, B: Eyjafjarðará, C: Jökulsá á Fjöllum, D: Jökulsá á Brú, E: Jökulsá í Fljótsdal.

determinations were not from the same samples and therefore are not strictly comparable. However, the mean values for the offshore stations would be expected to be similar in the two years (POC ≈ 170 µg/L, TSM ≈ 574 µg/L) as were the mean offshore values for particulate aluminium and iron. Consequently, the mean POC in offshore waters around Iceland in May-June probably amounts to about 30% of the TSM. This is within the range given by Strickland (1965) and in good agreement with the percentage (33%) found by Montegut and Montegut (1972) for the Northeast Atlantic and Krishnaswami and Lal (1977) for the major part of the Atlantic. In nearshore waters the organic fraction will of course be much smaller as indicated by Table 2.

DISCUSSION

TSM and Particulate Aluminium and Iron

Due to the suspended load of rivers, in particular glacial streams, the TSM normally increases with decreasing salinity (Table 1 and 2). However, most oft-

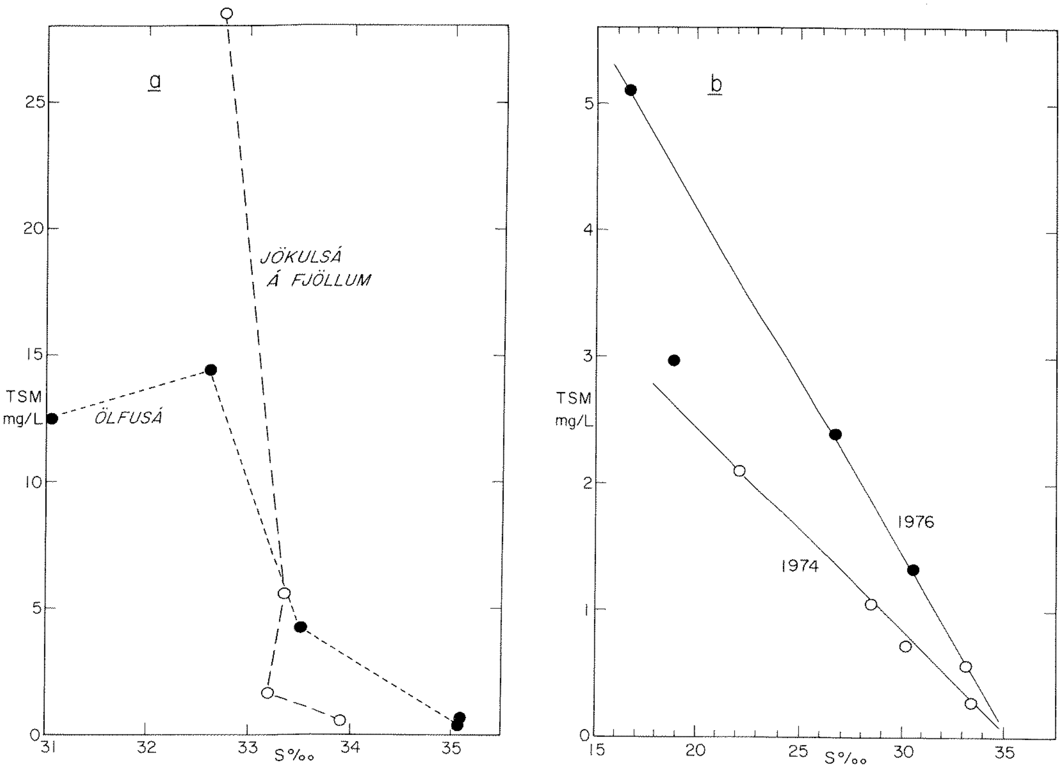

Fig. 3. Total suspended matter (TSM) (mg/L) as a function of salinity. a) Outside the river mouths of Ölfusá and Jökulsá á Fjöllum in May 1974, b) In Eyjafjörður in late May 1974 (open circles) and in early June 1976 (filled-in circles).

en this relationship is irregular and highly variable, depending upon the freshwater system in question.

In rivers from the neovolcanic zone, such as Jökulsá á Fjöllum and many of the south coast rivers (Fig. 2), the ratio between coarse silt and clay tends to be high (10–24), while in rivers from the tertiary basalt region this ratio is much smaller (≤ 1) and the suspended particles consequently finer (Haukur Tómasson, National Energy Authority, personal communications). It is, therefore, in agreement with expectation to find that in the typical glacial rivers (Fig. 3a) the relationship between TSM and salinity is somewhat irregular and that in the surface layer the rate of change of TSM with salinity generally decreases markedly as the salinity increases. This is no doubt because of sinking of the relatively coarse particles which constitute a large percentage of the suspended load of these rivers.

In the Eyjafjarðará, a river draining into the head of the large fjord Eyjafjörður (Fig. 2) the suspended matter of glacial origin is relatively small. According to Haukur Tómasson (personal communication) the coarse silt/clay ratio of

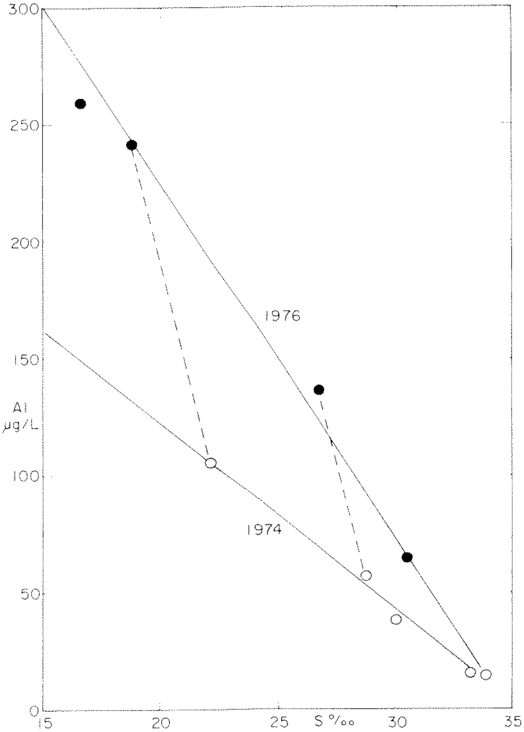

Fig. 4. Particulate aluminium as a function of salinity in Eyjafjörður in 1974 (open circles) and in 1976 (filled-in circles). Values for the same localities in the two years are joined with broken lines.

this river is presumably low. Here an almost linear TSM/salinity relationship is indicated (Fig. 3b), suggesting that very little settling out of particles is taking place.

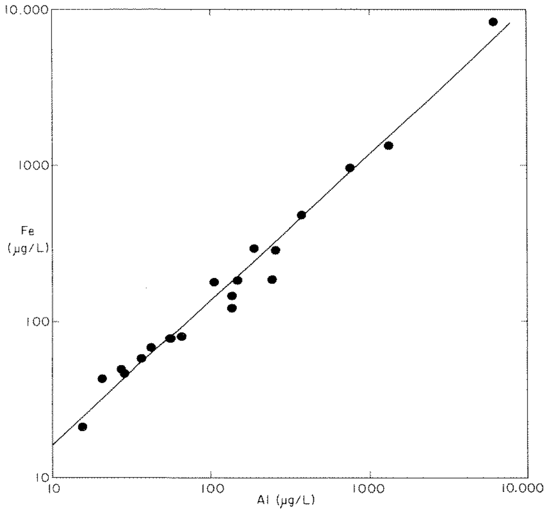

Fig. 5. Particulate iron (µg/L) plotted as a function of particulate aluminium (µg/L) for nearshore stations.

There is a clear indication of seasonal variations in the TSM of the glacial rivers. Late March is the time of the year when the glacial runoff normally approaches minimum, and in that month both in 1976 and 1979 the TSM of the river Ölfusá was found to be only about 5 mg/L (unpubl.). Also, the TSM of the diluted seawater just outside the estuary, was almost an order of magnitude smaller than at comparable salinities in late May 1974. Thus near the runoff peak (which normally is in May-June) the suspended matter transported by the rivers will be much greater than in winter, not only because of greater freshwater afflux, but also because the increased runoff causes more effective stirring-up of solid material which in turn leads to greater concentration of suspended matter per unit volume of freshwater. Consequently, at times of great floods which are known to occur occasionally due to volcanic activities under glaciers, tremendous quantities of solid matter will probably be carried out to sea.

This effect of greater concentration of TSM associated with greater runoff is also revealed by data from the Eyjafjörður region. Here markedly greater concentrations of TSM for a given salinity

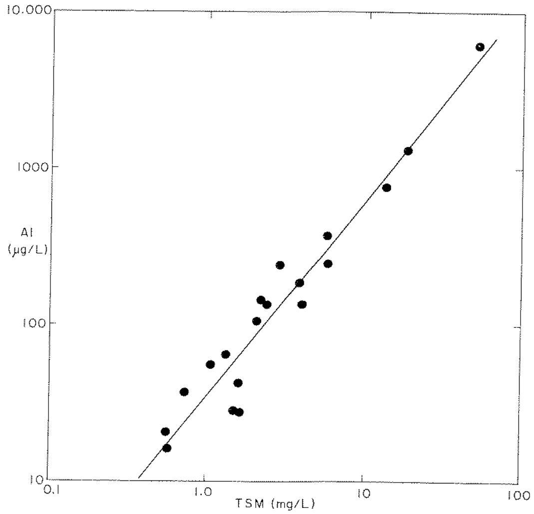

Fig. 6. Particulate aluminium (µg/L) as a function of TSM (mg/L) for nearshore stations.

(Fig. 3b) coincided with lower salinities and thus greater freshwater admixture in early June 1976 than at the end of May 1974. The relatively high surface salinities found in Eyjafjörður in late May 1974 as compared to early June 1976 conform with meteorological data which showed that the May precipitation in the former year was about 95% of the 1931/60 mean, while in the latter year it was 225%. This marked difference between the years 1974 and 1976 is further illustrated by the relationship between particulate aluminium and salinity (Fig. 4). It will be seen that not only is the concentration of particulate aluminium greater at any given locality in 1976 than in 1974, but it is also greater in 1976 for a given salinity. Again, the linear relationship between particulate aluminium and salinity is an evidence for a small particle size of the suspended matter.

At the 19 nearshore stations ($S < 33.82$‰) the correlation between iron and aluminium (Fig. 5) was found to be very close ($r = 0.998$). As would be expected, a strong association also existed between iron and TSM ($r = 0.974$) and aluminium and TSM ($r = 0.966$) (Fig. 6). In the offshore area the correlation between particulate iron and aluminium was also found to be significant ($r = 0.74$, $n = 32$), although much less close than for the nearshore samples. However, a closer examination reveals that the fraction of particulate iron and aluminium respectively of the TSM is not constant, but tends to increase with increasing concentrations of TSM. For the offshore stations, where the terrigenous component must be relatively small, the mean percentages of particulate aluminium and iron (expressed as Al_2O_3 and Fe_2O_3) of TSM were 2.1% and 1.8% respectively. These results compare quite well with those of Montegut and Montegut (1972) for the Northeast Atlantic (Al_2O_3: 2.4%, Fe_2O_3: 1.6%). At those of the inshore stations where TSM has a relatively small value (< 2 mg/L) and consequently the particulate organic matter resulting mainly from primary production constitutes a significant fraction, the percentages ranged from 3–9%, with an average value of only 6.6% for both Al_2O_3 and Fe_2O_3. For the highest concentrations of TSM (> 5 mg/L), consisting almost entirely of terrigenous material, the average percentages were 13.8% for Al_2O_3 and 13.4% for Fe_2O_3. It is of interest to consider how these values compare with the composition of the rock material from which the rivers derive their suspended matter.

From Jakobsson's survey of the chemistry and distribution pattern of basaltic rocks in Iceland (1972) it appears that in the drainage area of the south coast rivers the dominating rock type is olivine tholeiite with some transitional alkali basalt in the Eyjafjöll region[1]) In the zone extending from Vatnajökull to Axarfjörður quartz tholeiite constitutes the major fraction. According to Jakobsson (1972) the mean chemical composition of these rocks with respect to aluminium and iron is as follows:

	Olivine tholeiite	*Transit. alk. basalt*	*Quartz tholeiite*
Al_2O_3	14.09%	13.84%	13.52%
Fe_2O_3	13.87%	16.83%	16.57%

Slightly lower average values were obtained by Kristmannsdóttir (1971) who analyzed 20 basaltic rock samples from drill holes on the Reykjanes peninsula (Al_2O_3: 11.42%, Fe_2O_3: 10.87%).

Thus with respect to particulate aluminium and iron the average composition of the TSM at inshore stations closely resembles that of basaltic rocks which presumably constitute the main fraction of the suspended materials carried by the south coast rivers as well as the north coast river Jökulsá á Fjöllum.

In Jökulsá í Fjótsdal which together with Jökulsá á Brú drains into Héraðsflói, up to 30% of the suspended load consist of clay minerals (Haukur Tómasson, personal communication), and because of their small particle size they are likely to constitute a relatively large fraction of the TSM out at sea. The same might also apply to the TSM derived from other rivers even though their original suspended load contained only a small quantity of clay. Chemical analyses of a variety of Icelandic clays were carried out by Magnússon et al. (1973). Clay minerals derived from shallow water sediments in Hornafjörður, Southeast Iceland, contained on the average 14.31% Al_2O_3 and 13.52% Fe_2O_3, while for similar clays in West Iceland (Króksfjörður, Búðardalur) the averages were 15.71% Al_2O_3 and 13.22% Fe_2O_3. This composition does not differ much from that of basaltic glass. However, clay minerals formed in geothermal areas may have a highly variable composition. Frequently the percentages of Al_2O_3 and/or Fe_2O_3 of such clays may reach high values (Magnússon et al. 1973, Kristmannsdóttir 1975). Thus a sample from Bjarnarflag, Námafjall, Northeast Iceland, contained 22.75% Al_2O_3 and 23.8% Fe_2O_3. These values are very similar to those found in the suspended matter in the Héraðsflói estuary (S = 12.65 ‰, TSM = 50.53 mg/L, Al_2O_3 = 23%, Fe_2O_3 = 25%) in early June 1974.

The Fe/Al ratio of the 19 inshore samples ranged between 0.77 and 2.14. The mean value was found to be 1.34 (± 0.07). This is a somewhat higher value than that found by Joyner (1964) for the Northeast Pacific (1.12), by Montegut and Montegut (1972) for the Northeast Atlantic (0.89), by Price and Calvert (1973) for Loch Etive on the

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[1]) For this and other place names see Fig. 2.

west coast of Scotland (1.06) and by Price and Skei (1975) for the Hardanger Fjord, Norway (1.16). It is, however, almost identical to that (1.35) found by Krishnaswami and Sarin (1976), based on analyses of the suspended phases collected from several tons of Atlantic surface water. For the 32 offshore stations the average Fe/Al ratio was 1.22 (± 0.11).

Soluble Versus Particulate Iron

For the 21 offshore samples where both "soluble" and particulate iron was determined (Table 2), the soluble fraction ranged from about 5% to 27% of the total iron, with an average of about 11%. This is a lower value than has been reported for other regions (e. g. Brewer 1975). However, the ratio between "soluble" and particulate iron is likely to be considerably lower in Icelandic waters than in the oceanic regions of the Atlantic which, as stated before, are less affected by terrestrial aggregates.

Table 3 gives the "soluble" iron concentrations for different water masses around Iceland. In making the calculations all the values were used rather than the averages of each pair of duplicate samples. This was done in order not to underestimate the analytical uncertainty. A student t-test was applied to investigate whether there existed a real difference between the "soluble" iron concentrations of the two water masses having the most different temperature-salinity characteristics, viz. Atlantic water and Arctic water. The result indica-

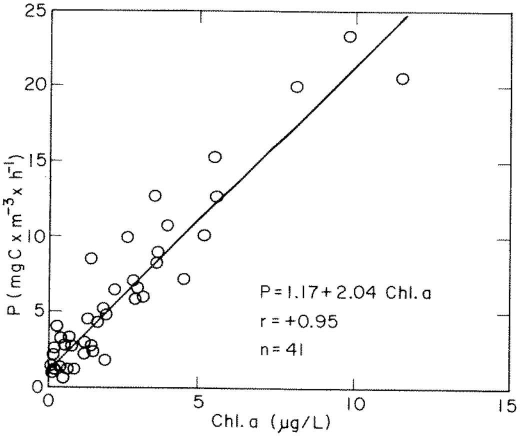

Fig. 7. Relationship between primary production and chlorophyll a, May — June 1976.

TABLE 3

Concentrations of "soluble" iron of different water masses around Iceland

(The one sample with exceptionally high concentration (4.83µg/L) taken near Akureyri is omitted)

Water Mass	No. of analyses	Temp. Range	Salinity Range	"Soluble" Iron (µg/L)		
				Range	Mean	St. Dev. of Mean
Atlantic Water	21	6.40−9.27	34.90−35.12	0.37−1.52	0.89	0.08
Artic Water	20	−1.22−3.59	34.29−34.75	0.00−1.20	0.49	0.08
Mixed Water	34	4.12−8.43	34.09−34.92	0.09−1.11	0.58	0.04
Coastal Water	20	2.35−10.10	16.59−34.57	0.05−1.98	0.61	0.10
Total Mean	95	−1.22−10.10	16.59−35.12	0.00−1.98	0.64	0.04

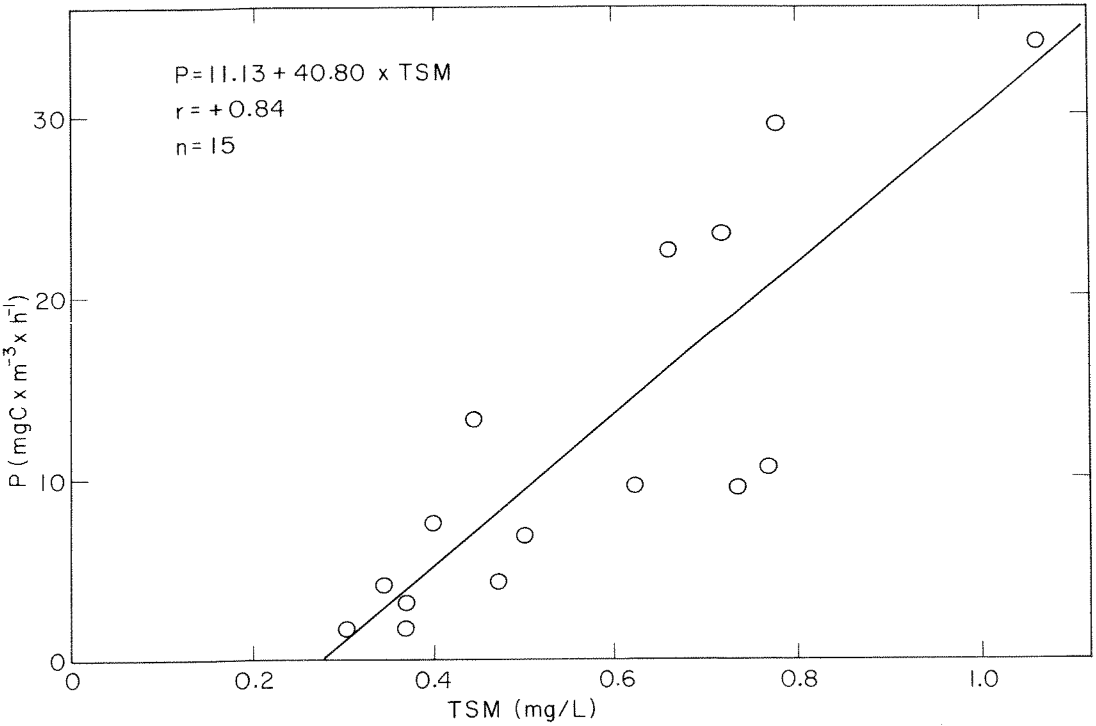

Fig. 8. Relationship between primary production and TSM, May — June 1974.

ted that the difference between the two means, i. e. 0.89 µg/L for Atlantic water and 0.49 µg/L for the Arctic water, is significant at the 0.2% level and almost significant at the 0.1% level.

TSM and POC in Relation to Productivity

Determinations of chlorophyll a are often used for estimating the plant biomass in the sea. For the offshore surface samples considered in the present study a close correlation was found to be between primary production and chlorophyll a (Fig. 7). At the time of the spring bloom, when phytoplankton constitutes a significant fraction of the TSM in regions outside appreciable coastal influence, an association would also be surmised between TSM or POC and primary production and between POC and chlorophyll a. As revealed by Figs. 8—10 such relationships apply to our study area. Although these correlations are highly significant, they are considerably weaker than the one found between primary production and chlorophyll a. Probably this discrepancy arises primarily from variable composition of the TSM. Thus the TSM may, in addition to phytoplankton, contain variable amounts of detritus. The total POC will include particulate carbon derived from living materials other than phytoplankton, and these will not be accounted for by the chlorophyll a determination.

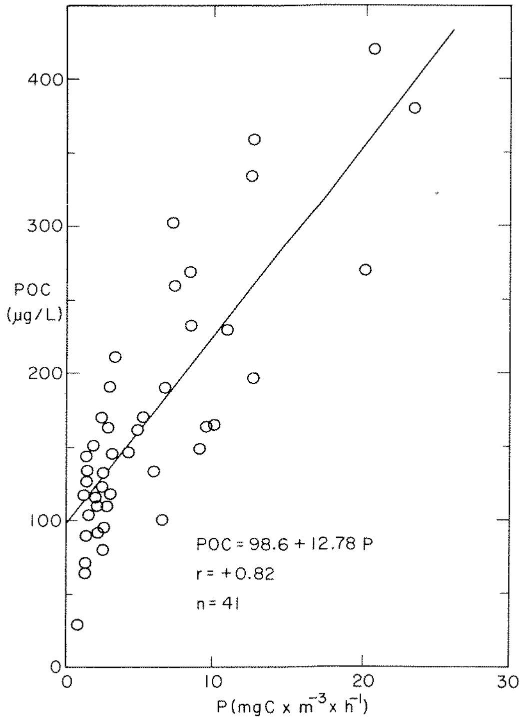

Fig. 9. Relationship between particulate organic carbon (POC) and primary production, May — June 1976.

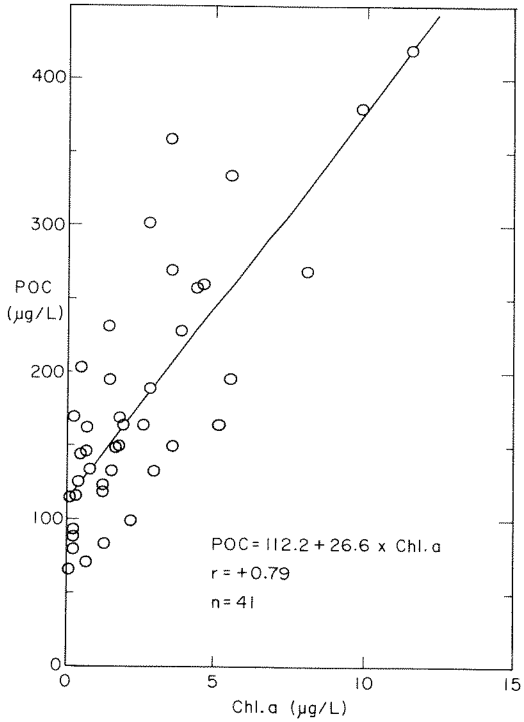

Fig. 10. Relationship between POC and Chlorophyll a, May — June 1976.

The ratio between chlorophyll a and particulate carbon has been found to vary within a wide range (Parsons 1975). Thus the results of seasonal investigations by Steele and Baird (1962) in Loch Nevis on the west coast of Scotland and Fladen Ground in the North Sea showed that this ratio decreased from 43×10^{-3} during a period of favourable growth to about 4×10^{-3} in late summer. The results of the present study represent regional variations in the period May-June 1976. Whithin this period the spring bloom of phytoplankton reached its maximum in some parts of the area, but in other parts it was over. However, large variations are found in the primary production both with regard to time and space, depending upon depth, wind conditions, water masses, development of stratification and other variables (Thórdardóttir 1976, Thórdardóttir and Stefánsson 1977). Table 4 shows that in Icelandic waters during May-June 1976 the chlorophyll a/POC ratio ranged from 0.9×10^{-3} to 31×10^{-3}. It will also be seen (Fig. 11) that in spite of a great scatter there appears to be a relationship between the chlorophyll a/POC ratio and the primary production in such a way that the ratio increases with increased productivity.

Differences in the chlorophyll a/POC ratio have been attributed to variations

TABLE 4

The ratio between chlorophyll a (Chl.a) and particulate organic carbon (POC) in relation to productivity, nitrate concentration and zooplankton displacement volumes in May–June 1976. H 50–0: Hensen net hauled vertically from 50 m to the surface. IHSS: Icelandic high-speed sampler, towed horizontally at 3–5 m depth for 1.5 miles following station.

St. No.	Productivity (mgC × m^{-3} × h^{-1})	Chl.a (µg/L)	POC (µg/L)	NO$_3$–N (µg–at/L)	Chl.a/POC $\times 10^3$	H 50–0 (ml)	IHSS (ml)
119	2.8	(0.6)	163	12.0	3.98	3	3
120	1.3	0.5	144	12.0	3.26	5	3
121	1.8	1.8	151	9.6	11.79	20	4
122	7.2	4.5	259	0.6	17.37	9	17
123	3.2	0.4	211	0.8	2.09	10	22
124	3.2	0.7	146	1.7	4.73	13	13
126	2.7	0.4	110	0.6	3.82	52	2
127	1.1	0.1	66	0.7	0.76	25	2
146	6.6	2.9	190	0.7	15.21	3	—
147	20.6	11.5	420	0.6	27.40	3	5
148	23.4	9.8	379	3.5	25.99	2	7
149	12.7	5.5	196	8.5	28.01	2	3
150	10.0	2.6	164	9.9	16.04	2	3
151	5.2	1.8	169	7.2	10.59	3	4
152	0.8	0.5	29	9.7	18.62	8	10
171	8.5	1.4	232	0.1	5.99	3	2
173	2.0	0.3	115	0.1	2.43	12	—
174	12.7	3.5	359	3.6	9.69	3	3
175	8.3	3.6	269	1.1	13.23	2	<1
176	7.1	2.8	302	1.1	9.14	4	1
177	—	4.7	259	4.5	17.99	4	2
178	12.7	5.5	336	1.7	16.43	7	3
185	4.3	1.6	147	1.5	11.16	4	2
189	2.9	1.2	118	6.5	10.25	25	78
190	10.9	3.9	228	2.3	17.15	60	30
191	5.9	2.9	133	6.6	21.80	18	2
201	1.2	0.8	134	10.1	5.67	8	—
202	1.3	0.6	71	6.5	9.01	1	—
203	2.9	1.4	196	—	7.40	2	4
204	1.2	0.3	126	0.4	2.62	12	66
205	2.1	0.2	92	0.1	2.61	9	45
206	6.5	2.2	99	4.7	22.12	5	1
207	2.4	1.2	123	0.2	9.92	2	1
209	2.4	1.5	133	6.1	11.58	8	7
210	2.5	0.4	79	7.1	5.32	10	6
211	4.9	2.0	163	2.3	12.02	19	13
212	9.0	3.6	149	1.8	24.16	10	7

TABLE 4 cont.

St. No.	Productivity (mgC × m^{-3} × h^{-1})	Chl.a (μg/L)	POC (μg/L)	NO_3–N (μg–at/L)	Chl.a/POC × 10^3	H 50–0 (ml)	IHSS (ml)
213	10.0	(5.1)	164	1.9	31.34	11	9
214	20.0	8.0	270	1.4	29.67	15	2
222	—	1.3	83	4.5	16.14	70	56
223	1.1	0.1	117	6.2	0.85	58	39
224	1.3	0.2	89	6.0	2.25	26	30
225	1.3	0.2	170	5.7	1.41	15	12

in species composition, nutrient availability and light conditions (Riley and Chester 1971, Chapter 8, Fogg 1975). It is suggested here that besides these variables zooplankton density may also affect this ratio. Normally, the animals and detritus of animal origin will constitute only a small fraction of the particulate carbon present in the water column. However, in regions where phytoplankton density is maintained quite small because of grazing, and there are high densities of zooplankton, the animal fraction of the POC may no longer be small. The results listed in Table 4 suggest that such conditions may have been prevailing at some of the stations occupied in May-June 1976.

It should be noted that the zooplankton displacement volumes given in Table 4 do not strictly refer to the surface layer, but rather to the depth interval 3–5 meters (Icelandic high-speed sampler) and the uppermost 50 meters (Hensen net). However, it is presumed that there is an association between these zooplankton volumes, in particular those found in the 3–5 meter interval, and those within the uppermost 1 meter. There does not appear to be a correlation between the chlorophyll a/POC ratio and the nutrient concentrations (column 8, Table 4). However, it will be seen that high ratios generally coincide with great phytoplankton bloom, irrespective of the zooplankton volume. This is presumably so, because the phytoplankton becomes the predominant part of the living matter, whenever the plant production rate is high. On the other hand, the lowest ratios are generally

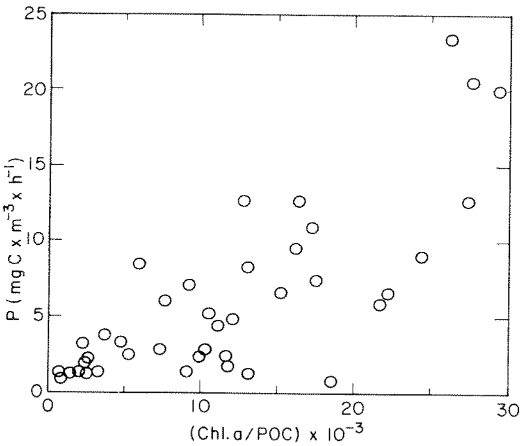

Fig. 11. Relationship between primary production and the ratio between chlorophyll a and particulate organic carbon, May — June 1976.

found when relatively large zooplankton volumes coincide with small productivity. This applies e. g. to stations 123–127, 173, 205 and 223–225. Where both phytoplankton and zooplankton densities are low, the ratio is intermediate, e. g. at stations 202 and 207.

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