Original Scientific Paper

Benthic bionomy of the North Aegean Sea. I. Physico-chemical characteristics of the Strymonikos Gulf

Ath. Koukouras, E. Voultsiadou-Koukouras, and M. Kattoulas

Laboratory of Zoology, University of Thessaloniki, Thessaloniki, Greece

February 16, 1982

Seventy sampling stations were selected for the study of the Strymonikos Gulf, that covers an area of 540 km². In every one of these stations, besides the faunal samples, samples of the water near the bottom and the sediment were taken in order to collect data on the salinity, temperature, sulphates, sulphites, sulphides, bicarbonates, oil, organic carbon and the granulometric composition. The variations of some of these parameters through the year were observed in two groups of stations. The first group was selected in the estuarine region of the Strymonas river which is located in the northern part of the gulf, and the second far from the estuary in the southern coastal region of the gulf. The information collected is analyzed and discussed.

INTRODUCTION

The Strymonikos Gulf is one of the more poorly studied regions of the Aegean Sea in spite of its great importance for the fisheries. The only biological, hydrographical and sedimentological information existing is given by the bionomic study of the mediolittoral zone of this gulf made by Koukouras[1].

In the present paper the data collected on some physico-chemical parameters of the water and the substratum of the gulf are given, as a part of a more comprehensive research on the bionomic study of its benthic fauna.

The gulf is situated NE of the Chalkidiki Peninsula, it covers an area of 540 km² and it opens to the east (Fig. 5). Its coasts have a length of about 70 km and are limited between 24°04'00" E — 40°43'08" N and 23°53'00" E — 40°33' 39" N.

In the northern part of the gulf, the Strymonas River discharges its waters and it is the only important source of pollution for the gulf, because it carries agricultural and domestic sewage as well as effluents from the industrial estates that are located along its banks, in Greece as well as in Bulgaria. According to Koukouras[1], in 1973 this river had an annual discharge of 90.60 m³/sec (monthly mean maximum 209.84 m³/sec; monthly mean minimum 30.38 m³/sec) and in 1974 an annual discharge of 99.97 m³/sec (monthly mean maximum 228.86 m³/sec; monthly mean minimum

28.46 m^3/sec). The greatest amount of the river waters turns to the east, possibly because of the geostrophic current, the existence of which has been reported by Athanassopoulos[2] and Golemes[3]. There are no other important streams that can have an influence, even a seasonal one.

According to Variagin[4, 5], the tide, in the adjacent of the gulf areas, is mixed with the dominance of the semi-diurnal type. The mean tidal amplitude is 18 cm, the maximum amplitude is 96 cm and the minimum one is 1 cm.

Koukouras[1] gave information on the mediolittoral zone of the gulf, concerning the benthic fauna of this zone and the values of some physico-chemical parameters of the water and the sediment.

MATERIALS AND METHODS

The sampling stations

The 70 sampling stations (Fig. 5) are grouped in two categories.

The first one includes the stations that are located along two transects (SA, SB)). One of these transects (SA) was selected on the southern side of the gulf, far from the estuary, and the second one (SB) in front of the river mouth, in order to determine the influence limits of the fresh water.

Transect SA (Fig. 1, I) includes stations 100 to 104 (or SA_1 to SA_5). The distances of stations SA_1, SA_2, SA_3, SA_4 and SA_5 from the shore are 10 m, 250 m, 500 m, 1000 m and 2000 m, and the depths of each one of them 2 m, 10 m, 27 m, 34 m and 40 m correspondingly.

Transect SB (Fig. 2, I) includes stations 115 to 119 (or SB_1 to SB_5). Station SB_1 is located in the middle of the river mouth (at a depth of 2.6 m) and the other four of them have a distance from station SB_1 of 300 m, 500 m, 1000 m and 1700 m, and a depth of 3.4 m, 2.1 m, 3.4 m and 24.4 m correspondingly. The stations along the transects were sampled at approximately 3-month intervals.

The second category includes the remaining 60 stations, that are dispersed all over the gulf (Fig. 5). The exact situation of each of them is given in Table I. In every one of these stations only one sampling was made from October 31, to November 2, 1976. When it was necessary, besides these stations some supplementary samplings were made.

Collection of data and methods

In everyone of the stations, on the transects, sediment and water samples (20 cm over the bottom) were taken. When the sediment carried on the deck its temperature was measured in a depth of 5 m. The water samples were taken in reversing Nansen bottles supplied with reversing thermometers. The sediment samples were separated with a corer from the content of the van Veen sampler which was used for taking the biological samples. In all the stations of the second category no water sampling was made.

The determination of sulphates, sulphites and sulphides was made by the test kits of HACH, models SF-1, SU-5 and HS-6 correspondingly. The organic carbon in the water and the salinity were determined according to Strickland and Parsons[6] while the determination of organic carbon in the sediment and the particle size analysis were made according to Buchanan[7]. The bicarbonates of the sediment were determined according to Alexiades[8]. The determination of oil in seawater samples, was made by the Organic Chemistry Laboratory of the University of Thessaloniki.

The whole of the measurements and the analysis of results are given in Table I.

Table I. Physico-chemical characteristics of the sediment and bottom water.

Station number	Geographical longitude – latidude	Depth (m)	Sea water					Sediment										Date
			Salin. ‰	Temp. °C	Oil ppm	Organic Carbon mg/z	$SO_4^{=}$ ppm	Temp. °C	Organic Carbon %	HCO_3^- mg/100g	$SO_4^{=}$ ppm	$SO_3^{=}$ ppm	H_2S ppm	Md µm	QD phi	Sk$_g$ phi	
69	23°55'10"–40°32'09"	55.8	–	–	–	–	–	11.8	1.93	91.26	400	25	2.5	4	–	–	31.10.76
70	23°55'38"–40°32'48"	70.2	–	–	–	–	–	13.4	1.01	76.05	420	28	6.0	<4	–	–	"
71	23°56'44"–40°33'52"	73.8	–	–	–	–	–	14.2	1.22	60.89	560	60	6.5	<4	–	–	"
72	23°58'46"–40°36'04"	81.0	–	–	–	–	–	13.6	0.83	74.87	340	48	6.0	<4	–	–	"
73	24°00'00"–40°38'12"	81.0	–	–	–	–	–	13.6	1.06	76.83	360	50	7.0	5	–	–	"
74	24°02'13"–40°39'50"	86.4	–	–	–	–	–	13.5	1.03	76.11	380	38	8.0	18	1.25	0.30	"
75	24°01'19"–40°41'46"	84.6	–	–	–	–	–	13.9	0.60	91.23	400	27	7.0	<4	–	–	"
76	24°02'08"–40°42'33"	66.6	–	–	–	–	–	14.0	1.19	61.00	410	33	4.5	<4	–	–	"
77	24°00'00"–40°43'06"	7.2	–	–	–	–	–	11.5	0.05	60.99	130	16	<1	384	0.30	0.02	"
78	24°00'17"–40°43'36"	6.5	–	–	–	–	–	10.9	0.06	60.60	150	17	<1	482	0.34	-0.01	"
79	24°00'06"–40°41'58"	79.2	–	–	–	–	–	13.0	0.79	60.82	500	28	5.5	10	0.77	0.01	"
80	23°58'42"–40°39'38"	82.8	–	–	–	–	–	13.8	1.04	91.38	370	45	6.0	<4	–	–	"
81	23°58'51"–40°37'53"	83.0	–	–	–	–	–	13.7	0.98	91.23	440	35	7.0	<4	–	–	"
82	23°56'10"–40°36'06"	79.2	–	–	–	–	–	13.8	0.71	84.73	340	48	6.5	9	0.73	-0.13	"
83	23°54'20"–40°34'20"	70.2	–	–	–	–	–	13.8	1.13	86.68	410	32	5.5	<4	–	–	"
84	23°54'00"–40°32'54"	54.0	–	–	–	–	–	12.0	2.37	136.89	500	25	3.5	8	–	–	"
85	23°52'52"–40°33'23"	27.0	–	–	–	–	–	10.8	0.94	74.87	540	55	<1	120	0.94	-0.01	"
86	23°51'34"–40°33'43"	25.2	–	–	–	–	–	11.0	2.49	91.09	410	35	<1	41	2.34	0.94	"
87	23°50'04"–40°33'53"	27.0	–	–	–	–	–	11.9	1.24	60.97	530	58	<1	66	0.79	0.39	"
88	23°50'57"–40°34'34"	50.4	–	–	–	–	–	13.1	1.69	60.89	400	43	4.0	<4	–	–	1.11.76
89	23°52'37"–40°36'00"	66.6	–	–	–	–	–	14.6	1.29	91.43	380	42	5.0	5	–	–	"
90	23°54'20"–40°37'34"	72.0	–	–	–	–	–	14.3	0.71	76.22	350	45	6.0	<4	–	–	"
91	23°55'36"–40°37'50"	78.2	–	–	–	–	–	14.2	0.72	76.25	360	43	7.0	<4	–	–	"
92	23°57'40"–40°40'55"	72.3	–	–	–	–	–	13.9	0.69	76.30	370	44	5.5	<4	–	–	"
93	23°58'30"–40°43'33"	37.8	–	–	–	–	–	12.1	0.88	55.73	420	31	4.0	16	–	–	"
94	23°58'34"–40°44'20"	8.5	–	–	–	–	–	15.5	0.08	60.80	140	16	<1	398	0.35	0.02	"
95	23°56'28"–40°42'34"	68.4	–	–	–	–	–	14.4	1.19	59.98	410	30	6.5	10	0.65	0.05	"
96	23°54'08"–40°41'33"	57.6	–	–	–	–	–	14.7	0.42	75.04	570	63	6.0	143	2.16	1.31	"
97	23°54'14"–40°38'05"	71.0	–	–	–	–	–	14.6	0.71	76.30	350	44	6.0	<4	–	–	"
98	23°51'37"–40°37'30"	63.0	–	–	–	–	–	14.9	1.17	85.13	430	40	5.5	<4	–	–	"
99	23°50'38"–40°35'59"	54.0	–	–	–	–	–	15.5	1.46	91.18	400	30	4.0	<4	–	–	"
100 (SA1)	23°48'29 40°34'56"	2.0	29.8	17.1	0.9	84.1	2800	17.9	0.24	43.96	250	133	<1	176	0.49	-0.19	"
101 (SA2)	23°48'33 – 40°35'03"	20.0	36.8	18.5	1.2	61.8	3350	17.7	0.28	84.40	320	60	1.1	812	0.44	0.04	"
102 (SA3)	23°48'39"–40°35'09"	27.0	37.1	18.2	2.1	80.2	3450	17.6	0.96	72.31	380	46	2.1	66	0.82	0.37	"
103 (SA4)	23°48'48"–40°35'24"	34.0	39.7	18.6	1.6	107.4	3600	17.3	1.18	88.93	390	42	3.0	35	2.05	0.90	"
104 (SA5)	23°49'07"–40°35'53"	40.0	40.4	18.0	1.1	78.3	3300	17.1	1.20	117.85	600	56	5.5	25	–	–	"
105	23°49'43"–40°36'45"	50.1	–	–	–	–	–	16.3	1.02	118.60	350	25	4.0	15	–	–	"
106	23°51'06"–40°38'26"	56.2	–	–	–	–	–	15.3	0.14	92.04	420	50	<1	153	1.92	1.37	"
107	23°47'06"–40°36'05"	10.2	–	–	–	–	–	18.8	0.64	30.59	170	58	4.0	707	0.63	0.12	"
108	23°48'02"–40°37'43"	34.2	–	–	–	–	–	17.4	1.84	90.11	380	58	<1	329	1.40	0.85	"
109	23°49'26"–40°39'42"	51.0	–	–	–	–	–	15.7	2.01	74.25	390	50	6.0	159	1.03	0.49	"
110	23°51'49"–40°42'07"	52.2	–	–	–	–	–	15.2	1.22	75.69	540	54	1.5	203	1.36	0.54	"
111	23°52'32"–40°43'45"	66.6	–	–	–	–	–	14.9	0.82	60.71	430	38	5.0	<4	–	–	"
112	23°54'08"–40°44'40"	50.4	–	–	–	–	–	15.7	1.24	60.56	420	35	3.5	<4	–	–	"
113	23°53'21"–40°45'44"	18.0	–	–	–	–	–	18.0	0.90	89.71	450	38	3.0	44	2.11	1.26	"
114	23°51'58"–40°46'30"	16.2	–	–	–	–	–	18.9	1.51	91.08	440	40	2.5	8	–	–	"
115 (SB1)	23°50'55"–40°47'18"	2.6	0.3	15.1	4.9	41.5	150	15.2	1.60	115.30	580	67	5.0	5	–	–	2.11.76
116 (SB2)	23°50'51"–40°47'08"	3.4	6.5	15.8	1.8	35.3	170	16.8	1.51	89.53	450	105	6.0	204	0.30	0.01	"
117 (SB3)	23°50'47"–40°47'03"	2.1	36.5	18.8	1.5	79.6	3200	18.5	1.56	89.53	410	125	6.0	250	0.56	0.16	"
118 (SB4)	23°50'40"–40°46'49"	3.4	37.5	18.8	1.1	86.9	2900	18.8	1.78	86.04	480	67	5.0	82	0.46	0.04	"
119 (SB5)	23°50'28"–40°46'24"	24.4	38.1	18.8	0.9	129.4	3400	18.5	0.19	89.69	430	33	7.0	6	–	–	"
120	23°49'31"–40°46'31"	8.5	–	–	–	–	–	19.0	2.11	120.80	710	<1	6.5	27	0.72	0.01	"
121	23°48'43"–40°46'26"	8.5	–	–	–	–	–	19.1	2.57	62.00	390	108	6.0	77	0.62	0.17	"
122	23°49'31"–40°45'46"	51.0	–	–	–	–	–	15.8	1.20	119.90	400	33	3.0	<4	–	–	"
123	23°51'14"–40°45'24"	52.2	–	–	–	–	–	16.2	0.62	74.07	430	30	3.5	13	2.12	-1.05	"
124	23°49'52"–40°44'02"	64.8	–	–	–	–	–	14.8	2.02	67.27	530	58	5.5	<4	–	–	"
125	23°47'58"–40°43'06"	59.5	–	–	–	–	–	14.9	1.08	120.75	470	33	6.0	<4	–	–	"
126	23°47'28"–40°45'21"	56.1	–	–	–	–	–	15.1	1.28	119.37	560	<1	6.5	<4	–	–	"
127	23°46'34"–40°45'49"	8.5	–	–	–	–	–	19.0	1.60	91.87	210	133	6.0	149	0.39	0.01	"
128	23°43'55"–40°44'49"	8.5	–	–	–	–	–	19.0	1.12	85.30	300	54	7.0	145	0.74	0.17	"
129	23°45'06"–40°43'23"	57.8	–	–	–	–	–	14.9	1.33	118.53	540	<1	4.0	<4	–	–	"
130	23°49'26"–40°40'54"	52.2	–	–	–	–	–	14.9	0.30	89.21	460	48	5.0	154	0.97	0.22	"
131	23°42'32"–40°42'59"	29.0	–	–	–	–	–	19.1	1.39	175.93	310	<1	6.0	25	–	–	"
132	23°43'33"–40°42'33"	52.2	–	–	–	–	–	15.8	1.61	168.30	560	<1	6.0	<4	–	–	"
133	23°45'04"–40°42'23"	57.8	–	–	–	–	–	15.4	1.45	115.20	620	<1	6.0	<4	–	–	"
134	23°46'53"–40°39'36"	40.0	–	–	–	–	–	17.0	1.27	159.80	660	83	5.5	12	1.06	-0.14	"
135	23°45'28"–40°38'32"	8.5	–	–	–	–	–	19.0	0.78	93.45	250	<1	3.0	467	0.25	-0.04	"
136	23°44'00"–40°39'48"	3.4	–	–	–	–	–	19.1	0.25	90.97	320	83	<1	268	0.36	0.05	"
137	23°42'58"–40°40'54"	47.6	–	–	–	–	–	16.5	1.62	109.38	750	<1	6.5	<4	–	–	"
138	23°41'57"–40°41'07"	18.7	–	–	–	–	–	18.9	1.08	85.00	330	42	5.0	82	0.98	0.55	"
SA1	—	2.0	29.8	10.5	1.2	73.4	2800	–	0.56	45.50	250	101	–	392	2.67	-1.26	4.2.77
SA2	—	20.0	36.9	12.3	–	68.3	3200	–	0.54	90.86	350	40	–	829	0.77	0.28	"
SA3	—	27.0	37.2	12.0	0.2	67.8	3250	–	1.18	75.69	410	33	–	58	0.68	0.17	"
SA4	—	34.0	39.7	12.5	0.5	90.6	3500	–	1.11	91.33	330	43	–	36	0.97	0.03	"
SA5	—	40.0	40.1	12.9	0.7	75.1	3200	–	1.75	76.20	320	45	–	14	2.03	-0.90	"
SB1	—	2.6	0.3	7.0	–	43.2	250	8.7	1.58	103.50	560	61	–	220	1.40	0.70	5.2.77
SB2	—	3.4	6.4	7.3	–	37.5	280	7.8	0.07	58.85	140	19	–	5	–	–	"
SB3	—	2.1	36.5	7.0	–	74.6	3300	8.9	0.08	29.31	130	17	–	159	1.70	0.55	"
SB4	—	3.4	37.4	11.5	1.5	83.1	2900	10.8	0.54	90.33	350	50	–	88	1.40	0.90	"
SB5	—	24.4	38.2	12.5	–	85.8	3350	12.8	0.23	89.10	420	30	–	4	–	–	"
SA1	—	2.0	32.1	19.5	–	70.4	2800	–	0.60	48.10	260	85	–	287	0.86	0.02	16.5.77
SA2	—	20.0	36.8	16.5	–	65.8	3100	–	0.59	95.30	340	48	–	586	1.55	0.83	"
SA3	—	27.0	37.2	14.2	1.1	64.2	3250	–	1.03	78.60	400	35	–	51	1.80	0.90	"
SA4	—	34.0	39.7	14.5	0.5	70.3	3550	–	1.05	90.40	350	45	–	51	–	–	"
SA5	—	40.0	39.9	15.5	0.5	72.4	3250	–	1.81	70.70	340	40	–	9	–	–	"
SB1	—	2.5	0.3	20.0	–	44.4	200	20.1	1.61	98.04	540	60	–	164	2.40	2.00	"
SB2	—	3.5	0.6	20.0	0.7	38.5	250	20.0	0.09	54.50	200	25	–	210	0.30	0.00	"
SB3	—	2.1	36.2	19.5	0.7	74.7	3150	19.5	0.08	29.40	210	19	–	21	0.78	-0.03	"
SB4	—	3.4	37.3	17.4	0.9	80.3	2950	17.1	0.48	85.10	300	45	–	35	1.92	1.01	"
SB5	—	24.4	38.1	14.1	0.9	88.0	3400	14.9	0.28	75.70	410	25	–	5	–	–	"
SA1	—	2.0	33.9	25.5	0.9	71.8	2590	–	0.57	49.34	270	88	–	153	0.50	-0.10	24.7.77
SA2	—	20.0	38.3	20.2	–	64.0	2850	–	0.86	91.39	380	51	–	616	0.35	-0.05	"
SA3	—	27.0	40.1	18.0	1.2	61.7	2950	–	1.17	76.22	410	40	–	51	0.85	0.25	"
SA4	—	34.0	40.0	18.4	0.9	68.7	3350	–	1.12	83.67	360	48	–	86	2.72	1.25	"
SA5	—	40.0	40.3	16.5	0.2	70.1	3300	–	1.82	75.07	360	47	–	32	–	–	"
SB1	—	2.5	32.0	25.0	1.1	56.7	2590	25.0	1.53	85.94	570	72	–	148	1.47	1.03	"
SB2	—	3.5	34.0	24.8	1.0	43.6	2450	24.9	0.05	46.60	250	25	–	25	1.25	-0.13	"
SB3	—	2.1	36.7	24.8	1.2	74.9	3100	23.9	0.10	46.32	265	20	–	27	2.00	0.30	"
SB4	—	3.4	37.5	24.8	1.2	85.4	2900	23.8	0.55	76.02	320	47	–	66	0.58	0.03	"
SB5	—	24.4	38.4	16.5	1.1	88.3	3300	23.7	0.31	75.40	440	30	–	4	–	–	"

RESULTS

Seawater

Stations along transects

As it can be seen on the profile of transect SA (Fig. 1,I), the bottom slope is steeper enough in the first 1,000 m off the coast than it is in the next 1,000 m were the bottom tends to be horizontal. On the contrary, in the estuarine region, along transect SB (Fig. 2,I), the bottom slope in the first 1,000 m (that is, from station SB_1 on the river mouth to the station SB_4) is nearly even and the depth is between 2.1 m and 3.4 m while in

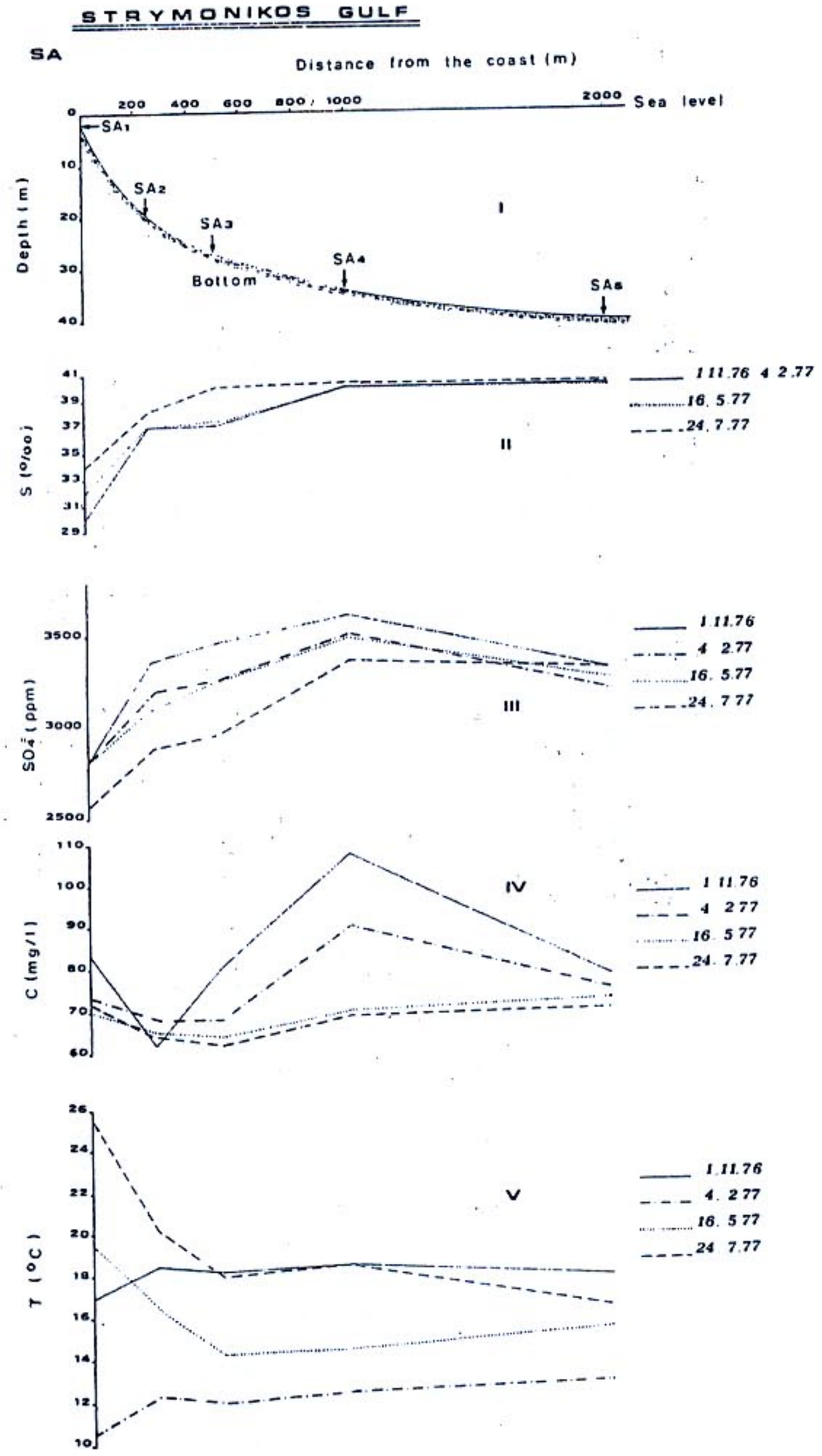


Fig. 1. (Continued).

the next 1,000 m the slope becomes much more steeper and the depth at station SB_5 is 24.4 m.

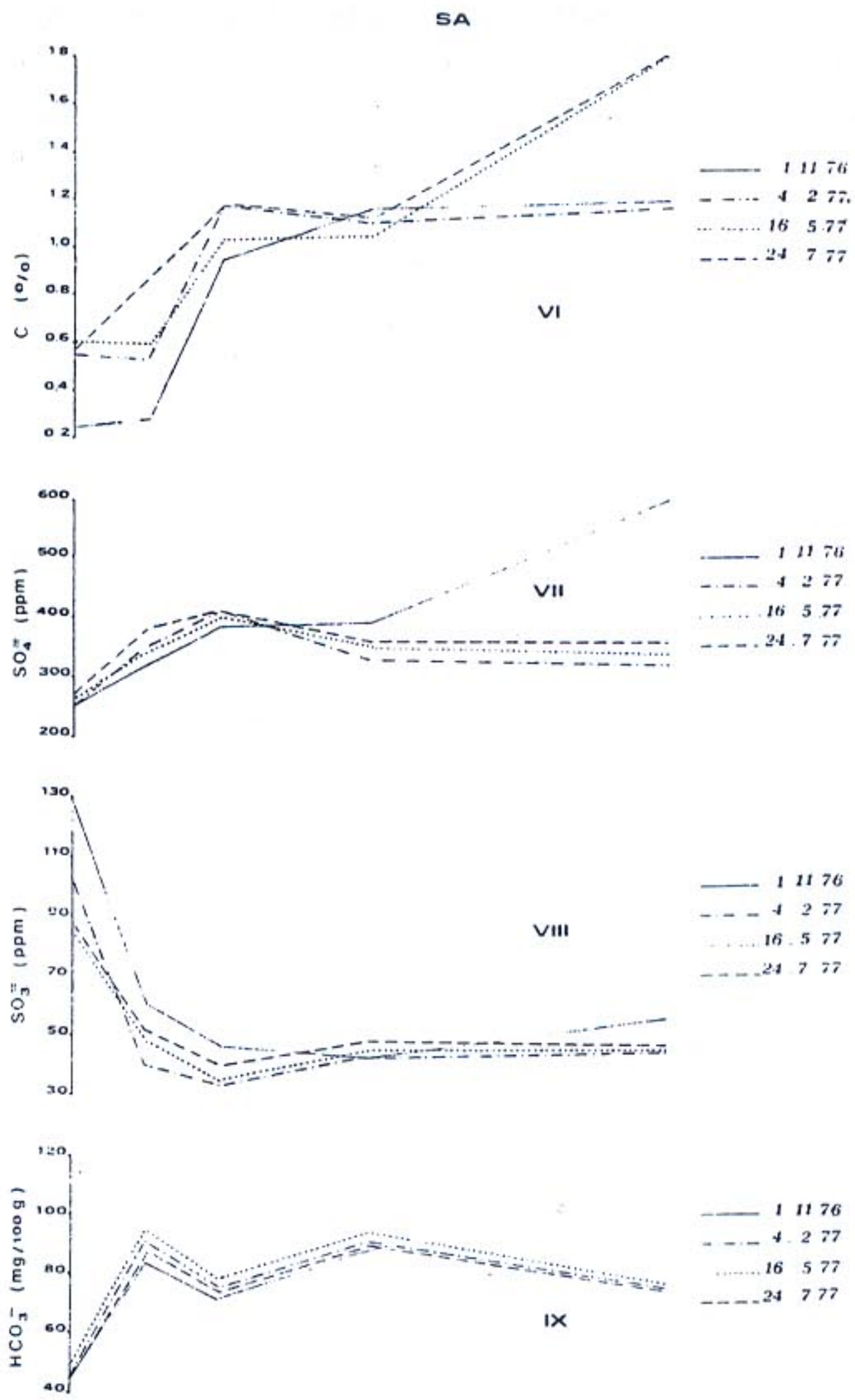


Fig. 1. Diagrams showing the profile and the seasonal variations of the physico-chemical parameters along transcet SA. — I. Bottom profile indicating the sampling stations. — II. Salinity of the water near the bottom. — III. Sulphates of the water. — IV. Organic carbon of the water. — V. Temperature of the water. — VI. Organic carbon of the sediment. — VII. Sulphates of the sediment. — VIII. Sulphites of the sediment. — IX. Bicaronates of the sediment.

Salinity

Along transect SA, in every season, the salinity increased with the depth and the distance from the coast (Fig. 1,II). In the first three stations (SA_1, SA_2, SA_3) the seasonal variations were considerably greater than they were in stations SA_4 and SA_5 that are located in depths of 34 m and 40 m correspondingly. From winter to summertime the salinities were gradually increased. The lowest salinity (29.8‰) was observed at station SA_1 on November 1, 1976 and the highest one (40.3‰) at station SA_5 on July 24, 1977.

The salinity along transect SB (Fig. 2,II) was changing in the same way (as it was on transect SA), but at stations SB_1 and SB_2 the seasonal variations (that depend mainly on the river discharge) were greater than they were at the corresponding stations of transect SA. At the other stations the variations were also very limited. The lowest salinity (0.3‰) was measured at station SB_1 (river mouth) on November 2, 1976, February 5, 1977 and May 16, 1977, and the highest one (38.4‰) at station SB_5 on July 24, 1977. At station SB_1 on July 24, 1977, salinity during the flood, and at a very low river discharge was 32.0‰.

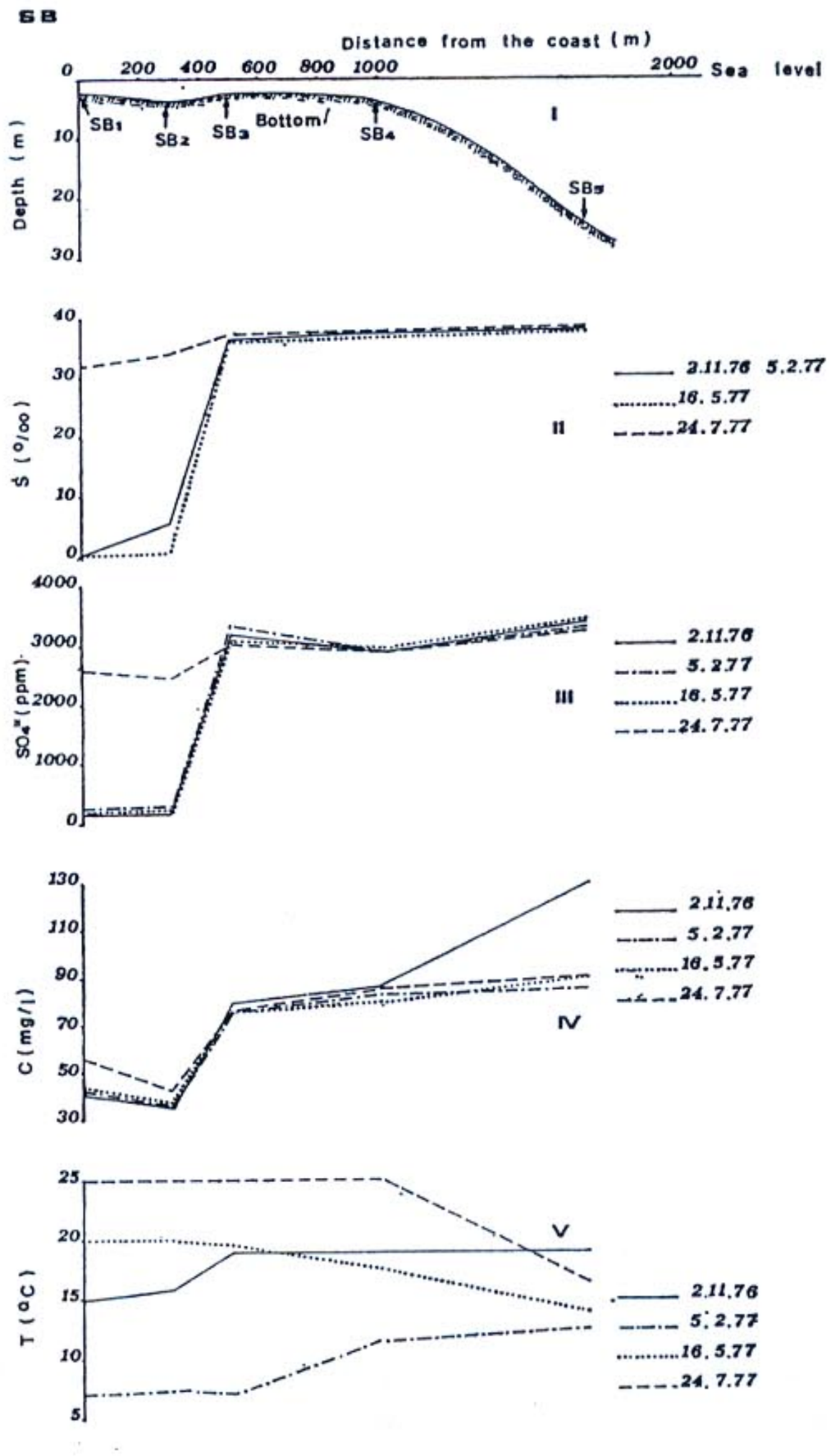


Fig. 2. (Continued).

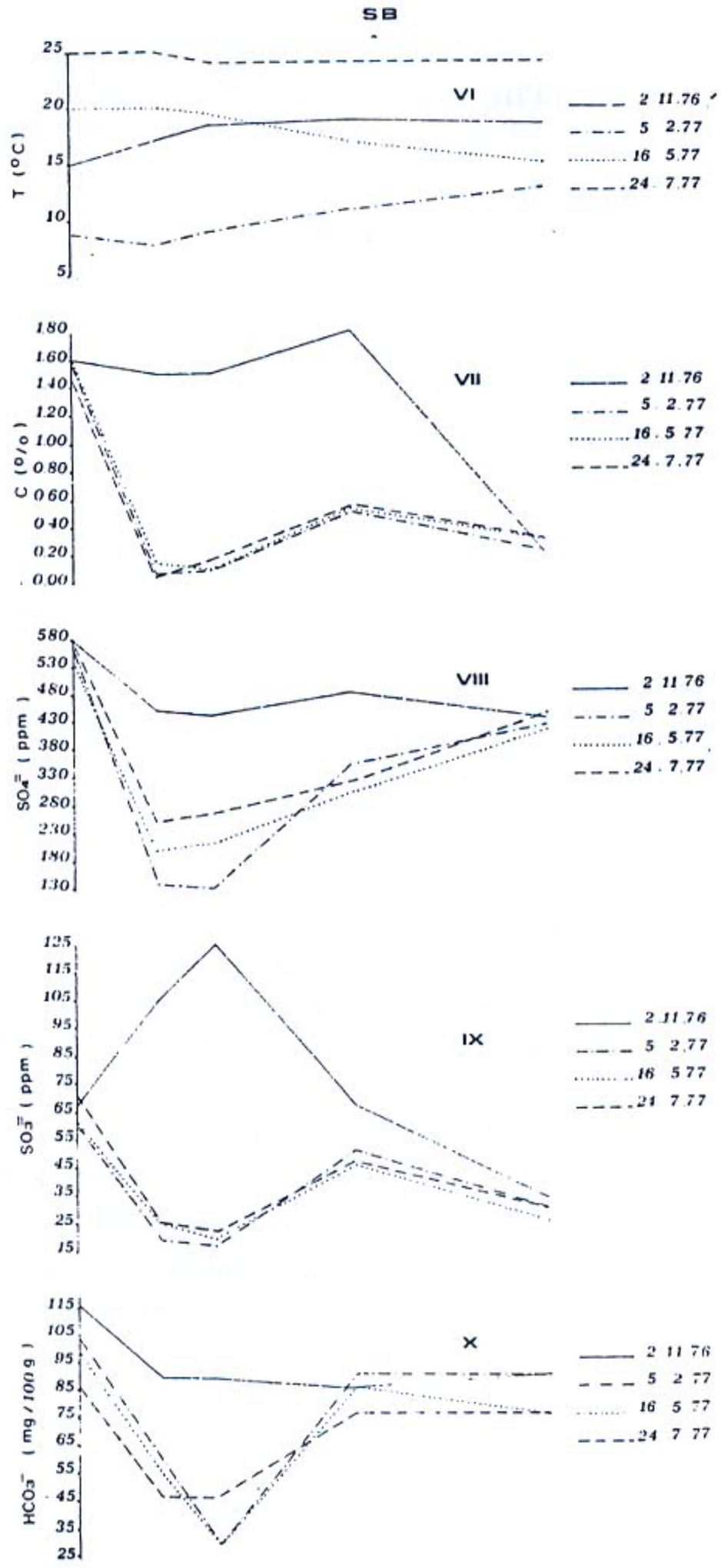


Fig. 2. Diagrams showing the profile and the seasonal variations of the physico-chemical parameters along transcet SB. — I. Bottom profile indicating the sampling stations. — II. Salinity of the water near the bottom. — III. Sulphates of the water. — IV. Organic carbon of the water. — V. Temperature of the water. — VI. Temperature of the sediment. — VII. Organic carbon of the sediment. — VIII. Sulphates of the sediment. — IX. Sulphites of the sediment. — X. Bicarbonates of the sediment.

Temperature

On transect SA (Fig. 1,V) on November 1, 1976 and February 4, 1977 the temperatures at station SA_1 were lower than they were at the other stations of this transect. On the contrary, on May 16, 1977 and July 24, 1977 at stations SA_1 and SA_2 they were very higher. Generally, the sea-

sonal variations at the stations near the coast (small depth) were higher than they were at the stations that are located at a greater distance from the coast (greater depth). The highest temperature (25.5 °C) was observed at station SA_1 on July 24, 1977 and the lowest one (10.5 °C) at the same station on February 4, 1977.

The temperatures along transect SB (Fig. 2,V) on November 2, 1976 and February 5, 1977 were increasing with the depth and the distance from the river mouth. The opposite was observed on May 16, 1977 and on July 24, 1977. At station SB_5 the seasonal variations were much lower than they were in every other station. The lowest temperature (7.0 °C) was observed on February 5, 1977 at stations SB_1 and SB_3 and the highest one (25.0 °C) at station SB_1 on July 24, 1977.

Oil

The oil values on transect SA as well as on transect SB (Table I) did not seem to change in a certain way. On transect SA there was a variation between 0.2 ppm and 2.1 ppm and on transect SB between 0.7 ppm and 1.8 ppm.

Organic carbon

On transect SA (Fig. 1,IV) the values were especially high at station SA_4, on November 1, 1976 (107.4 mg/l) and on February 4, 1977 (90.6 mg/l). At the other stations the values varied seasonally between 61.7 mg/l and 84.1 mg/l. A general fall was also observed in the values from November, 1976 to July, 1977.

On transect SB (Fig. 2,IV) the organic carbon was especially high (129.4 mg/l) at station SB_5 on November 2, 1976. At the rest of the stations the values varied between 35.3 mg/l and 88.3 mg/l.

In both transects, in spite of the deviations, a general increase was observed in the values of the organic carbon, following the increase of the depth.

Sulphates

Along transect SA (Fig. 1,III) the values were increasing from station SA_1 to SA_4, while at station SA_5 they were decreasing. At station SA_5 the seasonal variation was also lower than it was in the other stations. At stations SA_1, SA_2 and SA_3 the sulphate values were higher on November 1, 1976 and lower on July 24, 1977. The highest value (3,600 ppm) was observed at station SA_4 on November 1, 1976 and the lowest one (2,590 ppm) at station SA_1 on July 24, 1977.

Along transect SB (Fig. 2,III), the values at all the stations varied slightly seasonally. An exception were the values of July at stations SB_1 and SB_2 that were higher (2,590 ppm and 2,450 ppm correspondingly) than the values of the other seasons that varied around 200 ppm. Generally, in all seasons, the values increased with the distance from the mouth of the river.

Sediments

Stations along transects

Temperature

The seasonal variation of the temperature along transect SB (Fig. 2,VI) were higher at the stations near the river mouth. Generally, the values on November 2, 1976 and February 5, 1977 increased with the distance from the mouth of the river, while on May 16, 1977 and July 24, 1977 the opposite was observed. The highest temperature (25.0 °C) was taken at station SB_1 on July 24, 1977 and the lowest one (7.8 °C) at station SB_2 on February 5, 1977.

Organic carbon

The organic carbon of the sediment, along transect SA, in spite of the variations, increased with the distance from the coast (Fig. 1, VI). The highest value (1.82‰) was observed at station SA_5 on July 24, 1977 and the lowest one (0.24‰) at station SA_1 on November 1, 1976. At station SA_4 the seasonal variation was lower than that at the other stations.

The organic carbon along transect SB varied slightly seasonally with the exception of November 2, 1976 when the values at stations SB_2, SB_3 and SB_4 were especially high (Fig. 2, VII). Generally, the values were much higher near the mouth of the river. The highest value (1.78‰) was observed at station SB_4 on November 2, 1976 and the lowest one (0.05‰) at station SB_2 on July 24, 1977.

Bicarbonates

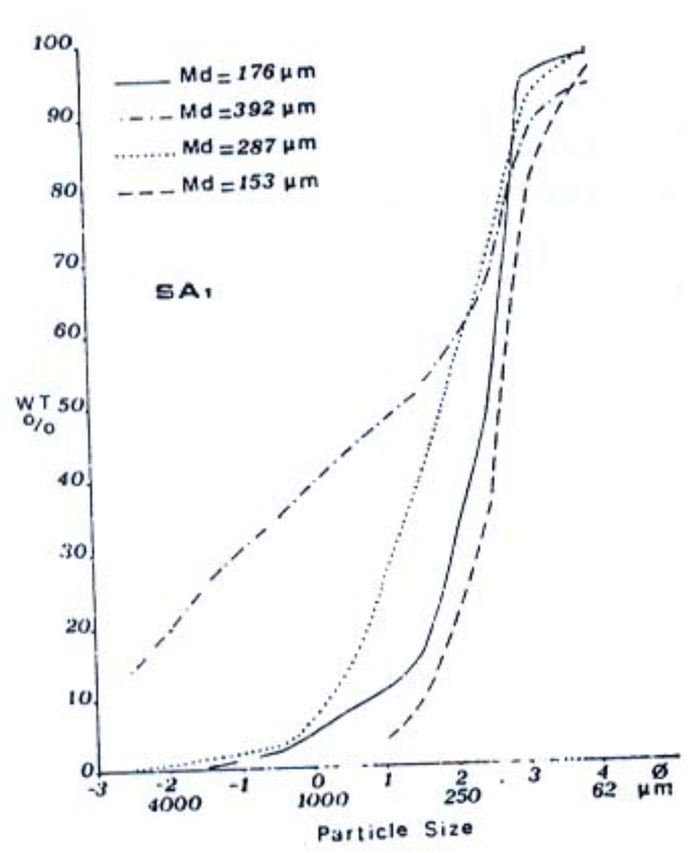
On transect SA, the seasonal variation of the bicarbonates at all the stations (Fig. 1, IX) was low with the exception of station SA_5 where the highest value (117.85 mg/100 g) was observed on November 1, 1976. The lowest values were observed at station SA_1.

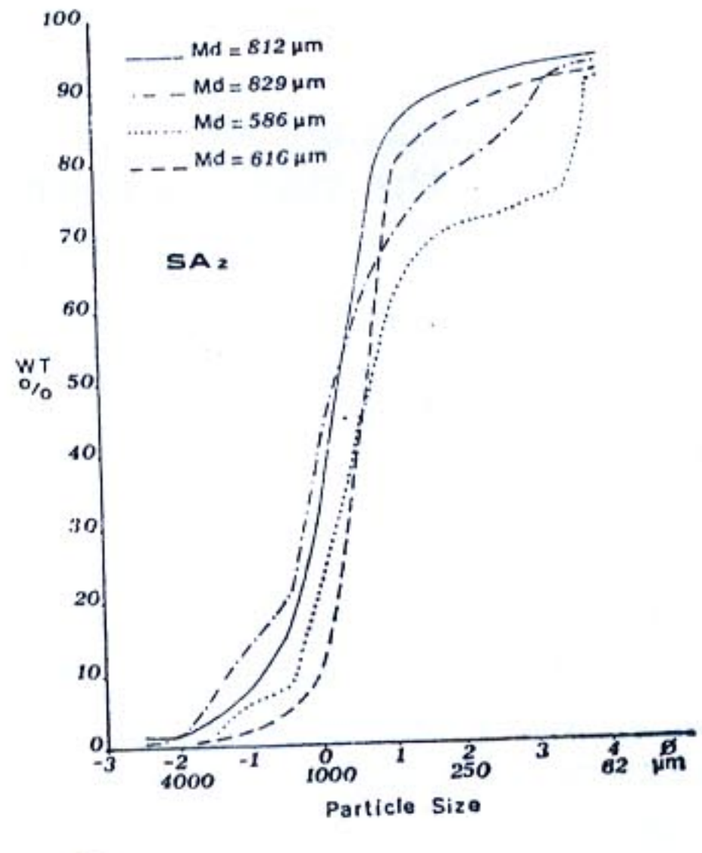
At stations SB_2 and SB_3, on transect SB (Fig. 2, X), the values were lower than they were at the other stations of the transect, except on November 2, 1976 when the values were similar. The lowest value (29.31 mg/100 g) was observed at station SB_3 on February 5, 1977 and the highest one (115.30 mg/100 g) at station SB_1 on November 2, 1977.

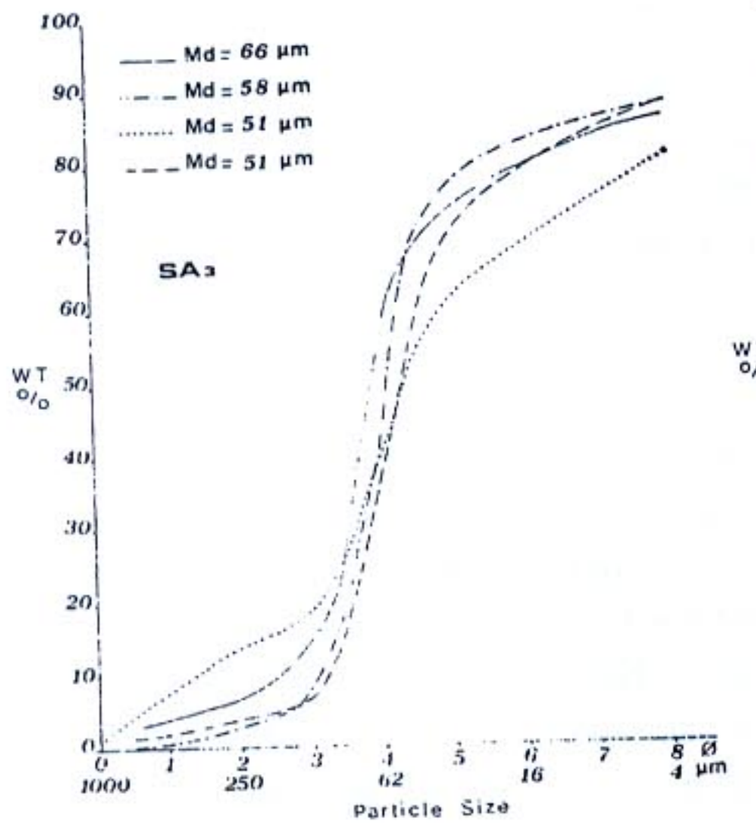
Sulphates

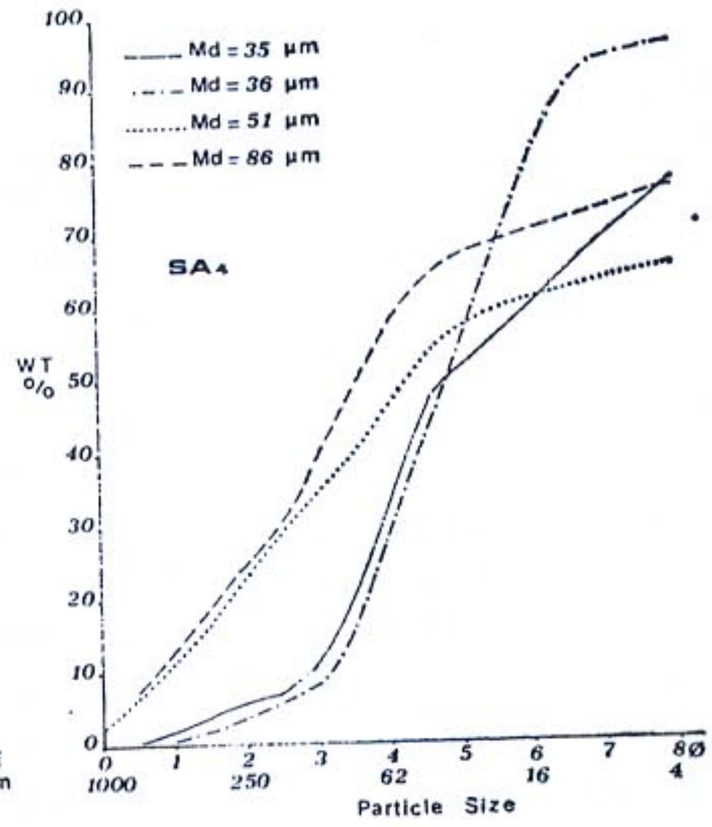
The seasonal variation of the sulphates at all the stations of transect SA was low (Fig. 1, VII) except for station SA_5. At this station, on November 1, 1976, the highest value was observed (600 ppm). This value is much higher than are the values in all the other stations. The lowest values (250 ppm) were observed at station SA_1 on November 2, 1976 and February 4, 1977.

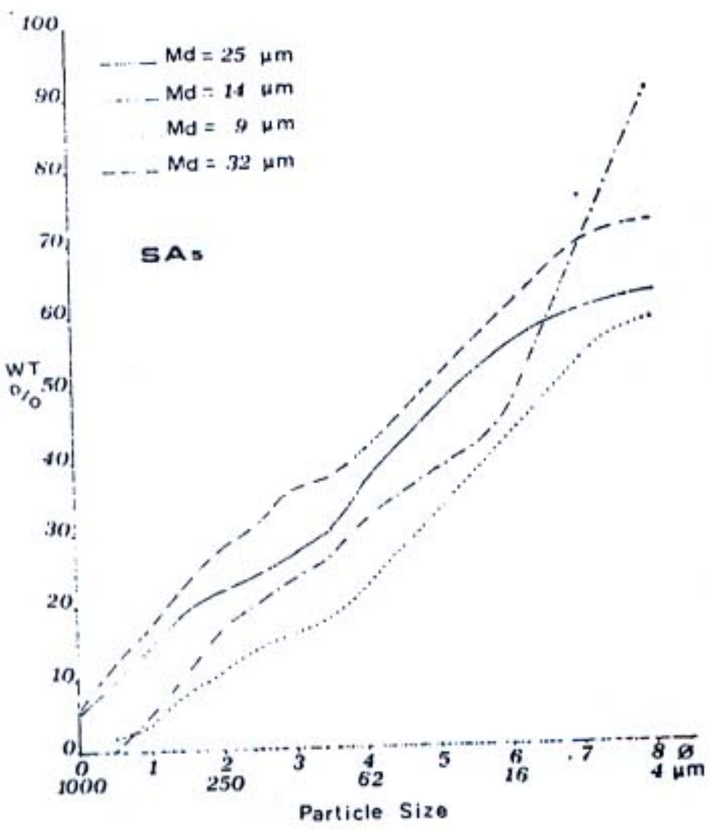
At stations SB_2, SB_3 and SB_4, on transect SB (Fig. 2, VIII), the sulphate values, on November 2, 1976, were much higher than they were in different dates of sampling at the same stations. At stations SB_1 and SB_5 the seasonal variation of the values was lower than it was in the other stations. At station SB_1 the highest values were observed (the highest one was 580 ppm, on November 2, 1976). The lawest value (130 ppm) was observed at station SB_3 on February 5, 1977.











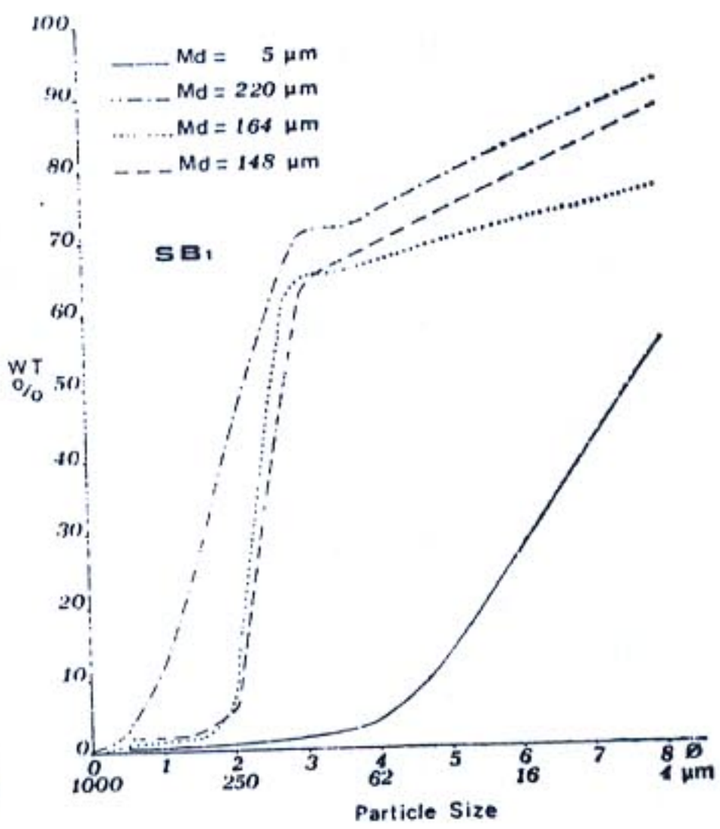


Fig. 3. (Continued).

Sulphites

On transect SA (Fig. 1, VIII) the seasonal variation of the sulphites was generally low. At station SA_1 the values were generally higher than they were at the other stations. The highest walue (133 ppm) was observed at station SA_1 on November 1, 1976 and the lowest one (33 ppm) at station SA_3 on February 4, 1977.

At stations SB_2 and SB_3 of transect SB (Fig. 2, IX) much higher values were observed on November 2, 1976 than on any other date. With this exception, the seasonal variation of the sulphites at all the stations was low. The highest value (125 ppm) was measured on November 2, 1976 at station SB_3 and the lowest one (17 ppm) on February 5, 1977 at the same station.

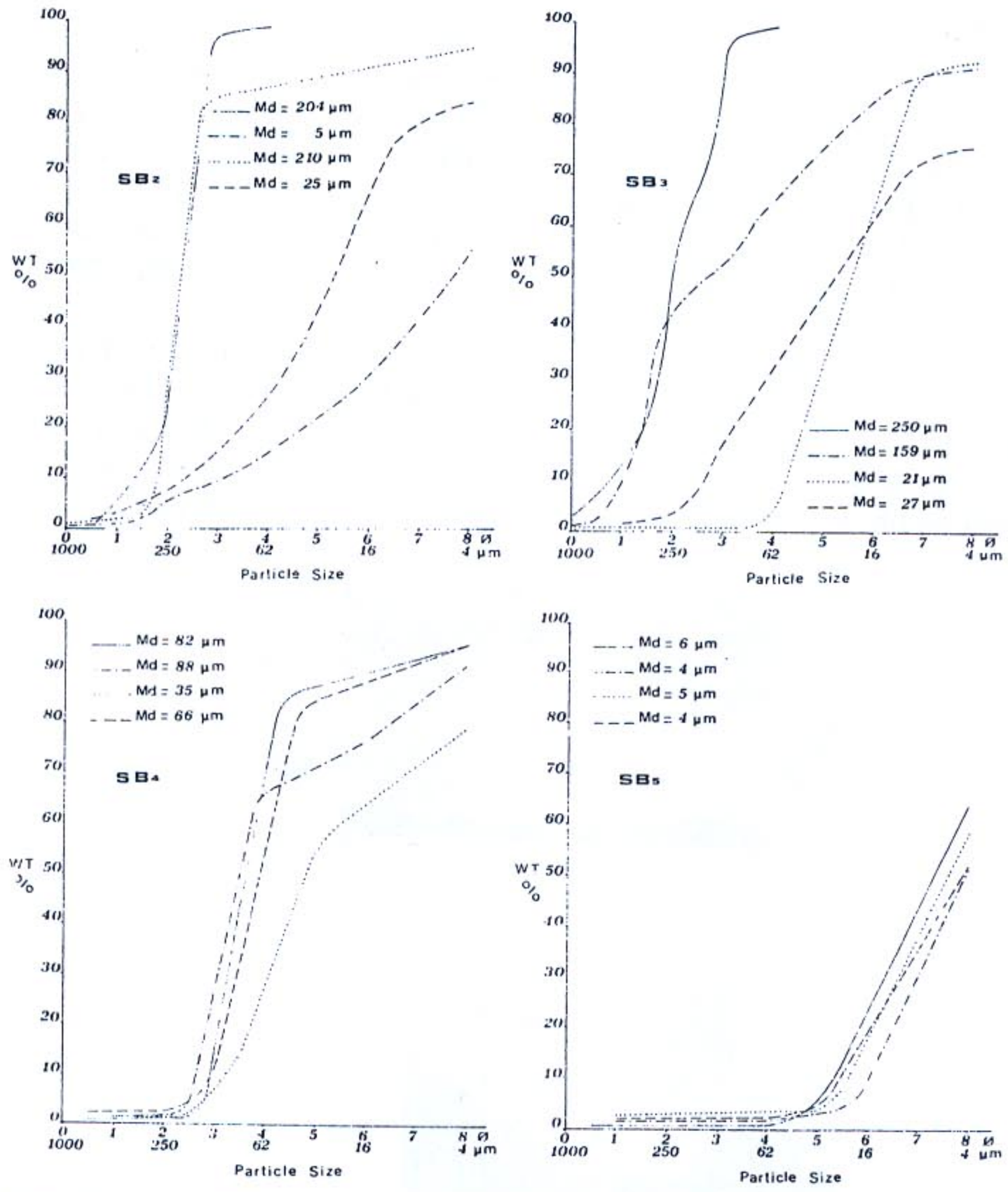


Fig. 3. Cumulative grain-size curves of the sediments for the sampling stations along transects SA (SA_1 to SA_5) and SB (SB_1 to SB_5), for the four sampling dates (———, November 1976; —.—., February 1977; . . . . ., May 1977; — — —, July 1977).

Granulometric composition

On Table I, the values of median diameter (Md), phi quartile deviation (QDϕ) and phi quartile skewness (Skqϕ) are given for all the sediment samples. The cumulative grain-size surves for the sediments of all the stations of transects SA and SB and for all the sampling dates are given in Fig. 3.

It is obvious from the corresponding curves, that at station SA_2, the substrate is coarser than it is at station SA_1, inspite the fact that the former is located in a greater depth than the latter. However, from station SA_2 to station SA_5, the sediment becomes and remains (as we should expect) finer with the increase of the depth. The seasonal variation of the median diameter is considerable. At station SA_1 it varies between 153 μm and 392 μm, at SA_2 between 586 μm and 829 μm, at SA_3 from 51 μm to 66 μm, at SA_4 from 35 μm to 86 μm and at SA_5 from 9 μm to 32 μm.

At stations SB_1, SB_2 and SB_3 of transect SB, the seasonal variation of the median diameter was very intensive, while at station SB_4 (which is located at a distance of 1000 m from the mouth of the river) much lower. At station SB_5, which is at a greater depth (about 25 m) than all the other stations are, the seasonal variation of the median diameter is very low and the sediment much more fine (Fig. 3). The Md of the sediment at station SB_1 varied from 5 μm to 220 μm, at station SB_2 from 5 μm to 204 μm, at SB_3 from 21 μm to 250 μm, at SB_4 from 35 μm to 88 μm and at SB_5 from 4 μm to 6 μm.

In Fig. 4, where the distribution of gravel, sand, silt and clay fractions of sediment along transects SA and SB is given, for the 4th and 5th of February 1977 correspondingly, the differences in the granulometric composition of the sediment in these two diferent sites, are obvious. The differences between the stations of the same transect are also obvious.

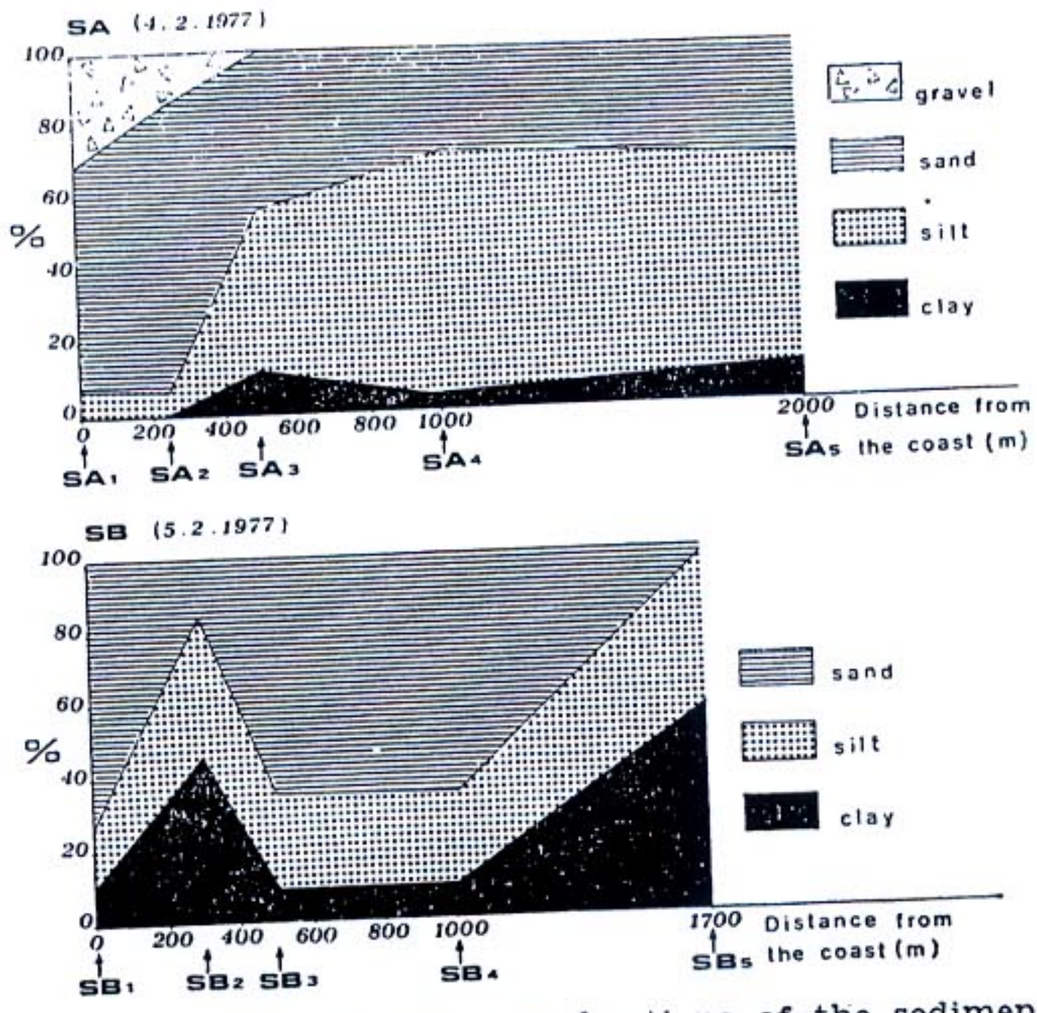


Fig. 4. Distribution of gravel, sand, silt and clay fractions of the sediment, along transects SA and SB, on February 4 and February 5, correspondingly.

The other stations

The stations of this second category are distributed all over the area of the gulf and their depths are from 3.4 m (st. 136) to 86.4 m (st. 74).

Temperature

The distribution of the sediment temperatures during the sempling period (from October 31, 1976 to November 2, 1976) is given in Fig. 5. Having in mind the depths crossed by the various isotherm curves, it becomes obvious that the greater the depth is, the lower the temperature of the sediment is. In this general pattern, except for small variations, there are three considerable ones. The first one concerns the region off the mouth of the river, where the isotherm curves of 17 °C, 18 °C and 19° C especially are moved slightly to the south. The two other exceptions

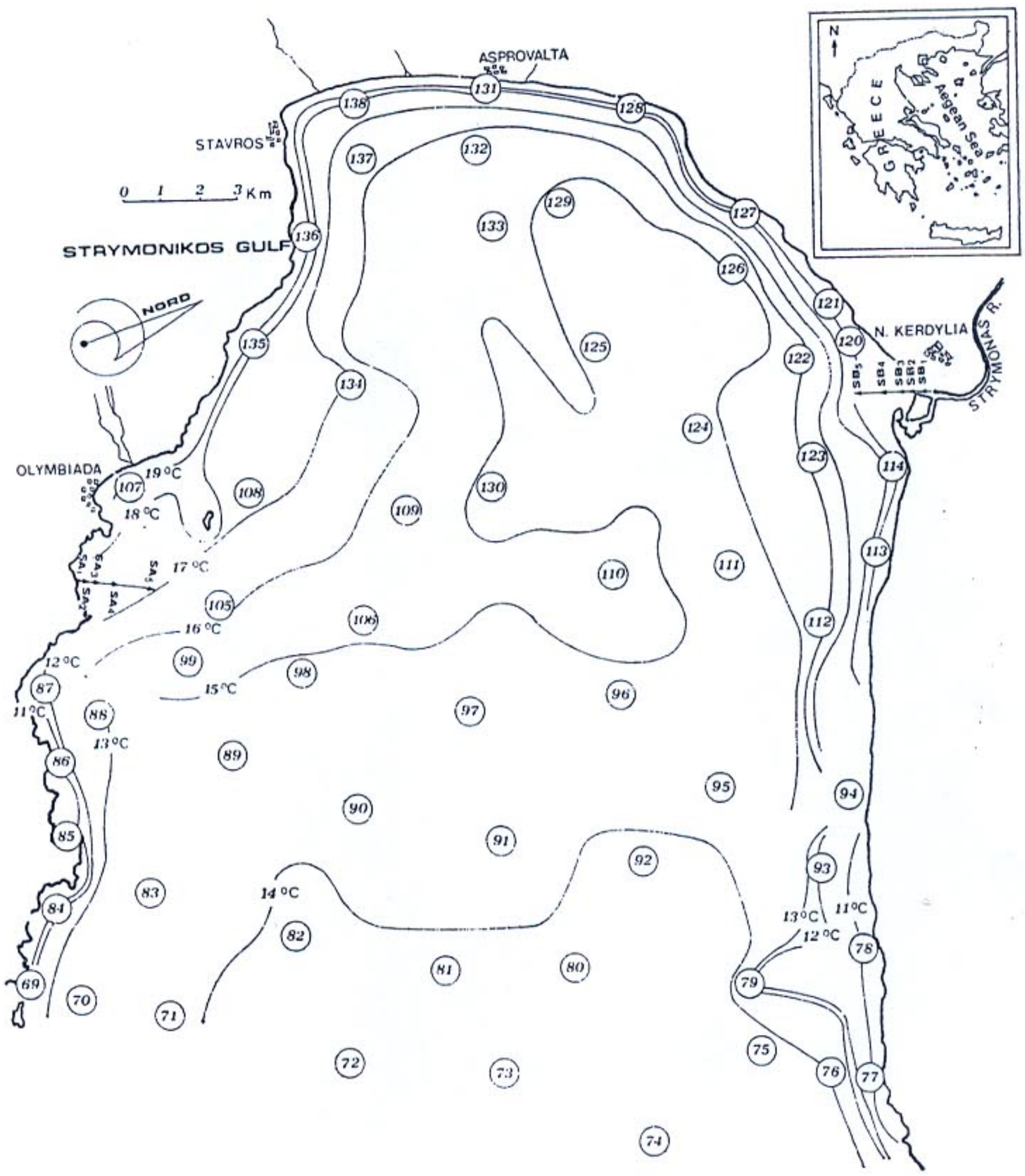


Fig. 5. Map showing the 70 sampling stations (the stations of the two transects SA and SB, are included), as well as the regional distribution of the sediment temperatures in the Strymonikos Gulf, for the sampling period. △, stations along transects; ○, the other stations.

concern the NE and SE regions of gulf. In these two regions, the sediment temperatures near the coast are lower than they are in greater distances from the coast. That is, the sediment temperature increases gradually from the coast to the open sea and from the 11 °C near the coast, it reaches the 14 °C on the corresponding isotherm curve.

The highest temperature (19.1 °C) was observed at stations 121, 131 and 136 and the lowest one (10.8 °C) at station 85 (see Table I).

Organic carbon

The organic carbon of the sediment varied from 0.05% (st. 77) to 2.57% (st. 121). The regional distribution of organic carbon is given in Fig. 6. In the greatest part of the gulf the organic carbon varied from 1.0% to 1.5%. In a more limited area, the organic carbon was <1%. Much

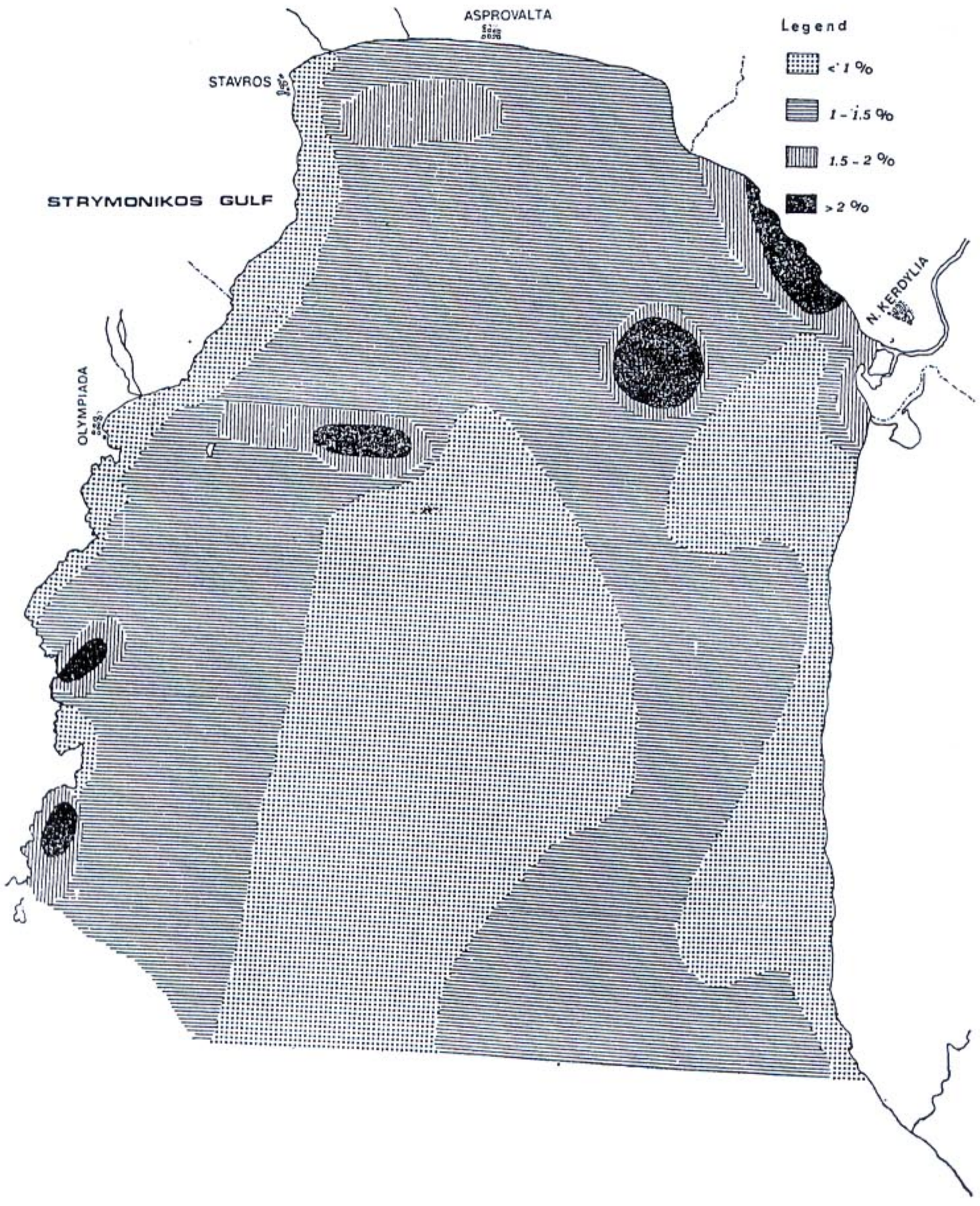


Fig. 6. Regional distribution of percent organic carbon in Strymonikos Gulf sediments.

more limited were the areas with values of 1.5—2.0‰ and >2.0‰. The areas with values >2.0‰ are located in five different places, one of which is in the west side of the estuary, that is, in the area where the river water is diverted by the geostrophic current.

Bicarbonates

The bicarbonates varied from 30.59 mg/100 g (st. 107) to 175.93 mg/100 g (st. 131), but usually their value was limited between 70 mg/100 g and 90 mg/100 g (Table I).

Sulphates

The lowest value (130 ppm) was measured at station 77 and the highest one (750 ppm) at station 137, but the usual range was between

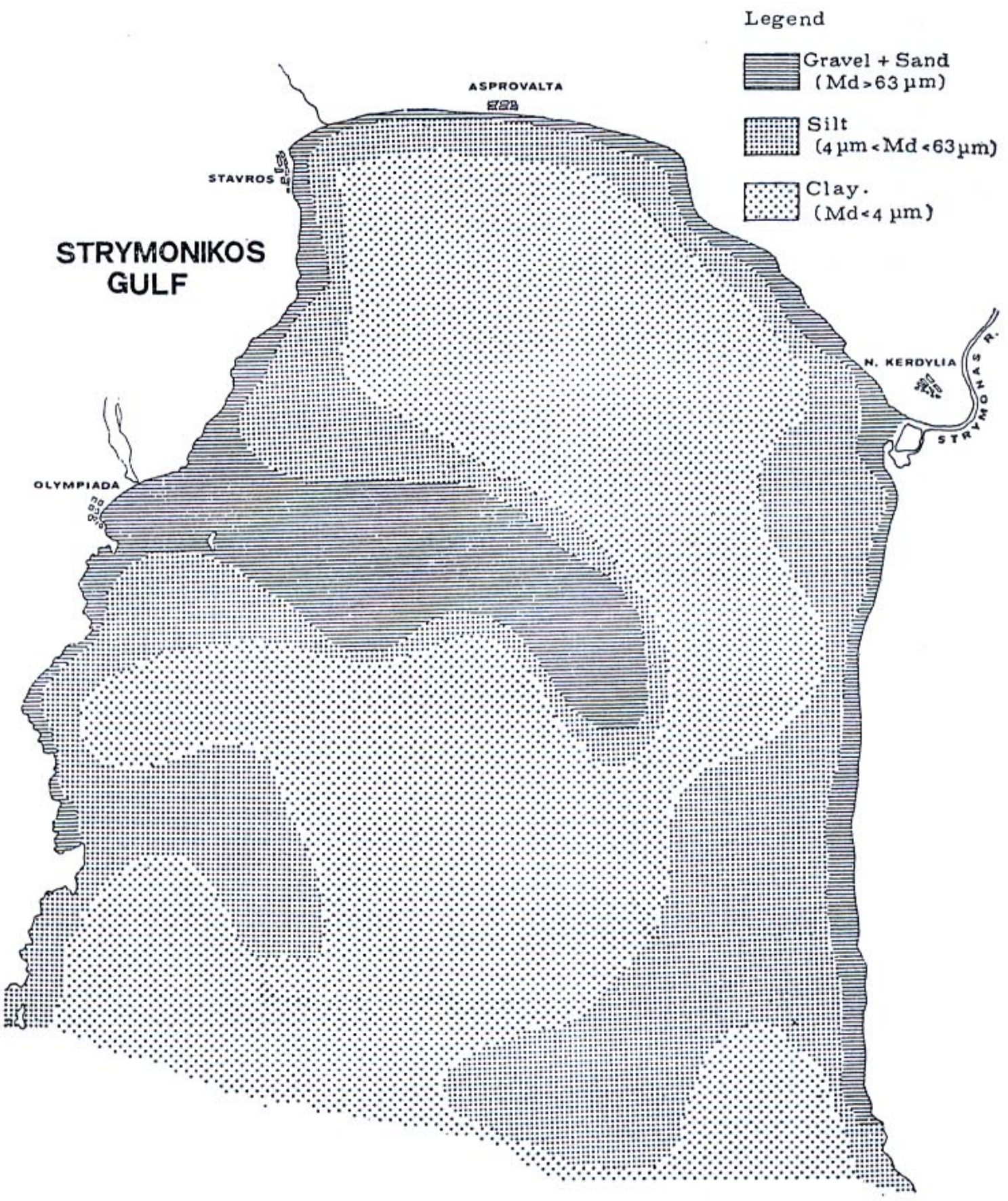


Fig. 7. Distribution of surface sediments in the Strymonikos Gulf.

300 ppm and 500 ppm. From Table I it is obvious that at stations with small depths the values are much lower than they are at stations with greater depths.

Sulphites

The values varied from <1 ppm (stations 120, 126, 129, 131, 132, 133, 135 and 137) to 133 ppm (st. 127) but they were usually between 20 ppm and 50 ppm (Table I).

Sulphides

In nine stations the values (Table I) were <1 ppm. The greatest value (8.0 ppm) was observed at station 74, and is located at a greater depth than all the other stations.

Granulometric composition

The sediment analysis of the samples showed that the median diameter varied from 707 μm (st. 107) to less than 4 μm (in 25 stations). In Table I, the values of Md, QDϕ and Skqϕ are given, for all the sediment samples. In Fig. 7, the distribution of the various types of sediments is given, based on the Md values. From Table I, it is obvious that generally the Md decreases when the depth increases. This general pattern, however, shows some considerable deviations.

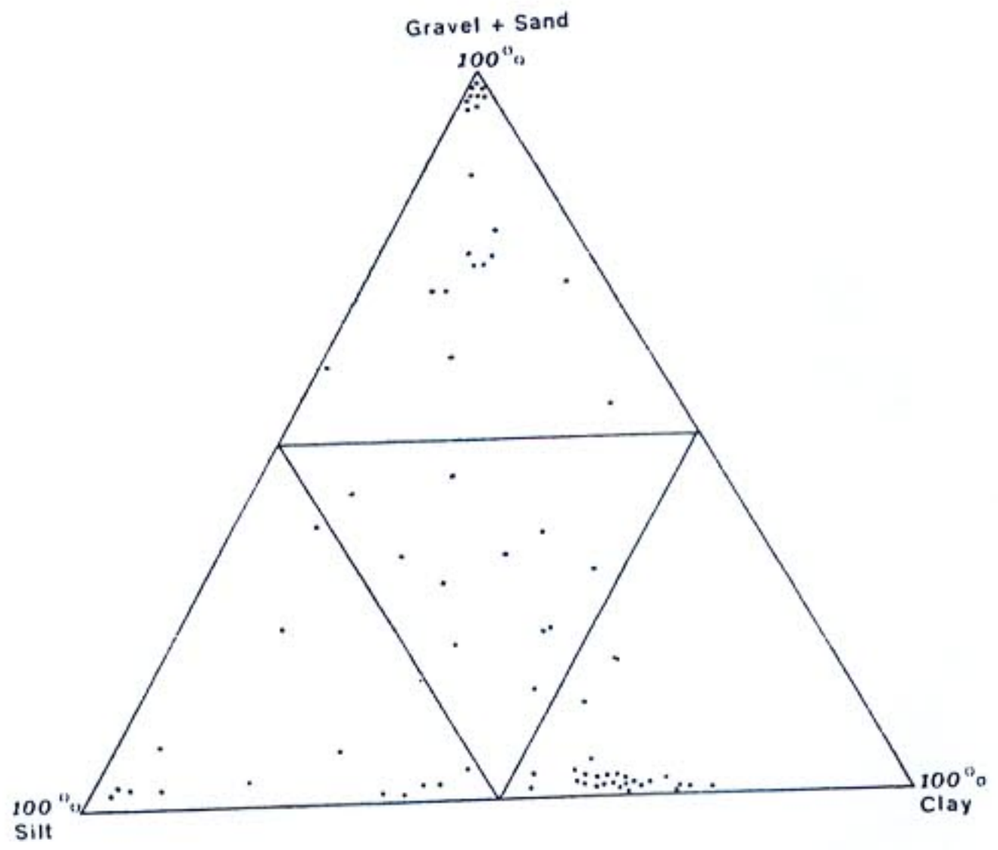


Fig. 8. Variations of the granulometric composition of the sediments, in all the stations of the Strymonikos Gulf.

According to the diagram in Fig. 8, that was constructed according to Buchanan[7], if we consider as sand the gravel+sand fraction (because of the small amount of gravels), the sediments of the gulf can be placed in the following subdivisions: silty clay, in 27 stations (38.6%); clayey silt, in 6 stations (8.6%); silt, in 6 stations (8.6%); sandy silt, in 2 stations (2.8%); silty sand, in 4 stations (5.7%); sand, in 13 stations (18.6%); clayey sand, in 3 stations (4.3%); and sand-silt-clay, in 9 stations (12.8%).

DISCUSSION AND CONCLUSIONS

During an attempt to study the bionomy of the benthic fauna of the Strymonikos Gulf, a number of parameters of sediment and water of the Gulf were examined, in order to find their spatial or seasonal variation.

The salinity, near the bottom and in areas not influenced by the waters of the Strymonas River, in every season, increased gradually with the depth and the distance from the coast. In a depth of 40 m it was stabilized at a value of 40‰, in all seasons. Near the coast (at a depth of about 2 m) in autumn and winter the salinity is lower than it is in spring and especially in summer and its seasonal variation is about 4‰. In the mediolittoral zone, salinity in summer varies spatially from 22‰ to 31‰ according to Koukouras[1]. The lower values of salinity near the coast are due to the smaller depth as well as to the submarine outflow of fresh water that is more plentiful in steep rocky shores. This outflow is more plentiful in autumn and winter and its influence enfeebles with the distance from the coast and the depth.

In the estuarine region and especially in the river mouth, the seasonal variation of the salinity is much higher and it is of course in connection with the river discharge. Due to the low discharge and the stratification, the salinity near the bottom is considerably influenced at a distance up to 500 m from the river mouth. At a distance of 2000 m from the river mouth, at a depth of about 25 m, salinity has almost the same value (about 38‰) throughout the year. On the contrary, in the river mouth, where the depth is about 2.5 m, salinity is about 0.3‰ when the river discharge is great, while in summer, when the discharge is much reduced, salinity reaches 32.0‰ during the high tide. In the mediolittoral zone, salinity is affected only in the west part of the estuary due to the geostrophic current, according to Koukouras[6].

The values of the dissolved oxygen, in the mediolittoral zone, usually ranges between 7 ml/l and 8 ml/l in the summer, as reported by Koukouras[1].

Temperature that is, of course, controlled by the local conditions, is generally increased from the coast to greater depths, during the cold period of the year, and by summer this condition is gradually reversed. In this general pattern there are deviations, first in the estuarine region, where the temperature is reduced due to the colder water of the river (when the discharge is high) and secondly at the two ends of the gulf, with the steep rocky shores, where there is plentiful submarine freshwater outflow, that influences localy the temperature. In these rocky shores, in November the temperature was reduced to 11 °C, while at the same depths in other regions it was 19 °C. Furthermore, in the mediolittoral zone of the small sheltered and shallow bays, in the summer, during the day, the temperature often reaches the 30 °C or even higher according to Koukouras[1]. We may notice that in the estuarine region, due to the interference of many factors and mainly to the sampling method, it was not possible to investigate the changes and the relations of the temperatures of water and sediment.

We must consider that the pattern of distribution of the organic carbon in the gulf is a result of the type and the location of the existing biocoenoses, of the quantities of the deposited organic detritus and the

way they enter the gulf, and finally of the circulation of the water mass by the currents. Although a mathematic relationship between the content of organic carbon in the sediment and its granulometric composition can not be proved, as it was made, for example, for the Gulf of St. Lawrence by Loring and Nota[9], it seems that in the coastal regions where the sediments are coarser, the organic carbon content is generally lower than it is in the finer sediments, in greater depths. An exception is a large area in the central part of the gulf where, although the sediments are fine and the depth great, the organic carbon content is equally low as that of the coastal regions. At the west of the estuarine region the organic carbon content is high perhaps due to the deposition of organic detritus carried by the waters of the river, as they turn to this direction. The seasonal fluctuations of the organic carbon contents, in the water and in the sediment of the estuarine region, must also be attributed to the deposited organic detritus. The organic carbon content of the sediment reported from the mediolittoral zone of the gulf, ranges between 0.02% and 0.20%, according to Koukouras[1].

The values of bicarbonates in the sediments of the gulf varied between 30 mg/100 g and 176 mg/100 g. The lowest values given by Koukouras[1], for the mediolittoral zone during the summer are similar to our lowest values, while his highest values are lower than the ones we measured. Generally, it seems that the values of bicarbonates can vary more or less, seasonally and locally.

The sulphates of the sediment varied between 130 ppm and 750 ppm and it is obvious that their values are generally lower in shallow waters than in deeper ones. The seasonal variation of the values seems to be limited, with the exception of the estuarine region where it is considerably greater and seems to be connected to the discharge of the river. In the mediolittoral sediments, the values, in summer, range from 1 ppm to 230 ppm as reported by Koukouras[1].

Near the river mouth, the sulphates of the water are much lower (when, of coarse, the discharge is important) than they are in the water of the other regions of the gulf and in the sediment of the estuarine region. Comparing the curves of salinity (Fig. 2, II) and sulphates (Fig. 2, III), we can also observe an increase of sulphates with the increase of salinity. Similar correlations have been reported and discussed by Culkin[10]. The sulphites in the sediment, although along the transects seem to be higher near the coast, in the rest of the gulf do not seem to have the same or another pattern of distribution. Also there is no obvious interdependence with the sulphates. The seasonal variations of the sulphites usually seem to be low but sometimes they become remarkably higher. The values given by Koukouras[1] for the mediolittoral sediments range between 1 ppm and 230 ppm.

The sulphide values, as we should expect, are generally higher in areas with finer sediment and greater depth, although there are exceptions. In the mediolittoral sediments the values are always lower than 1 ppm, during the summer, according to Koukouras[1].

Generally, the granulometric composition of the sediment varies in inverse ratio to the depth. The coarser sediments that are located near

the coast, had a median diameter up to 707 μm, while the finer ones were located in the deeper parts of the gulf, and their median diameter was less than 4 μm. The local deviations in this general pattern, must be attributed mainly to the presence of the plentiful organic detritus. In the mediolittoral sediments the median diameter of the particles ranges between 217 μm and 707μm in the estuarine region, while in the rest of the gulf between 406 μm and 2143 μm, according to Koukouras[1].

The sediment near the shore consists almost exclusively of sand and small quantities of gravels. The greatest part of the gravels is granules. The silt and clay fractions increase gradually with the depth and they are the most prevailing in the greater depths. In the deepest parts of the gulf the clay percentage is greater than 50%. In some places the substrate of the gulf consists of great amounts of the three main fractions of the sediment (gravels-sand, silt, clay).

In the south and west coastal regions that are more exposed, the former because of the N and NW winds and the latter because of the great fetch, the hydrodynamism is greater, resulting in greater seasonal changes of the granulometric composition of the sediment in these regions than in the northern regions of the gulf.

Although the exposure of the estuarine region is very restricted, the seasonal changes of the granulometric composition of the substrate are especially intensive and they can be attributed mainly to the combined depositing and erosive action of the river waters, whose intensity changes seasonally and depends on the discharge of the river.

REFERENCES

1. A. Koukouras, Bionomic study of the macrofauna of the mediolittoral soft substratum in Strymonikos and Thermaikos Gulfs (in greek), *Sci. Annals Fac. Phys. & Mathem. Univ. Thessaloniki* **19** (1979) 1—283.
2. G. D. Athanassopoulos (ed.), Rapport presenté par le comité thalassographique hellenique a la commission internationale pour l' exploration scientifique de la mer Mediterranée, *Bull. com. thalassogr. Hellen.* 4 (1921) 1—19.
3. A. Golemes, Contribution to the study of the water circulation in the Mediterranean Sea and especilally in the greek seas (in greek), *Bull. com. thalassogr. Hellen.* **1** (1936) 1—36.
4. M. Variagin, Tides and tide values of the greek bays (in greek), *Oceanogr. center Navy hydrogr. serv. Oceanogr. study* **9** (1972) 1—117.
5. M. Variagin, Contribution to the analysis and forecast of tides in the greek bays (in greek), *Ph. D. Thesis,* Univ. Athens, 1975, 232 p.
6. J. D. H. Strickland and T. R. Parsons, A practical handbook of seawater analysis, *Bull. Fish. Res. Bd. Can.* **167** (1968) 311.
7. J. B. Buchanan, Measuremends of the physical and chemical environment sediments. Sediments, Ch. 3 in N. A. Holme and A. D. McIntyre (eds.), *Methods for the Study of Marine Benthos,* I. B. P. Handbook No 16, Oxford, 1971, 30—52.
8. D. K. Alexiades, Physical and chemical analysis of soil (in greek), Univ. Thess., Thessaloniki, 1972, 383 p.
9. D. H. Loring and D. J. Nota, Morphology and sediments of the gulf of St. Lawrence, *Bull. Fish. Res. Bd. Can.* **182** (1973) 147.
10. F. Culkin, The major constituents of sea water, Ch. 4 in J. P. Riley and G. Skirrow (eds.), *Chemical Ocenanography,* Vol. I, Academic Press, London, 1965, 121—161.

IZVOD

Bionomija bentosa sjevernog Egejskog mora. I. Fizičko-kemijske karakteristike zaljeva Strymonikos

Ath. Koukouras, E. Voultsiadou-Koukouras i *M. Kattoulas*

Za ispitivanje zaljeva Strymonikos, čije područje pokriva 540 m², odabrano je 70 postaja za uzorkovanje. Na svakoj od tih postaja uzeti su osim uzoraka za faunu i uzorci pridnene vode i sedimenta da bi se prikupili podaci o salinitetu, temperaturi, sulfatima, sulfitima, sulfidima, bikarbonatima, nafti, organskom ugljiku i granulometrijskom sastavu.

Godišnje promjene nekih od tih parametara promatrane su na dvije grupe postaja. Prva grupa postaja određena je u području ušća rijeke Strymonas koja je smještena u sjevernom dijelu zaljeva, a druga grupa postaja daleko od ušća u južnom dijelu obalnog područja zaljeva. Sakupljene informacije analizirane su i diskutirane.