Nature and sedimentation of suspended particulate matter during density stratification in shallow coastal waters (Gulf of Trieste, northern Adriatic)

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ABSTRACT: Suspended particulate matter in the Gulf of Trieste (northern Adriatic) during seawater density stratification in summertime consists of about 5% total hydrolyzable carbohydrates, 2% proteins and 1.0% lipids. The bulk of particulate organic matter (POM) remains uncharacterized and is probably composed mainly of terrigenous refractory material, evidenced by more negative total POM $\delta^{13}C$ values (ca $-24.5‰$) and a somewhat higher C/N atomic ratio (6.5). The composition of diatomaceous macroaggregations observed in the whole northern Adriatic in the summers of 1988 and 1989 (containing 12 to 34% total hydrolyzable carbohydrates, 0.3 to 1.4% proteins, ca 0.08% lipids, and a high C/N ratio) differed from that of summer POM. The predominance of glucose (ca 60% of total hydrolyzable carbohydrates), and $\delta^{13}C$ values typical of cultured diatoms (-17 to $-19‰$), suggested that the bulk of macroaggregate organic matter was composed of algal structural products, possibly glucans. Amino acid composition was dominated by glycine, aspartic acid, alanine and glutamic acid and was similar to common summer POM. Sedimented POM, measured by moored sediment traps, was depleted of proteins and water-soluble carbohydrates by 80 to 85% and of lipids by 74% with respect to summer POM composition. Rapid sedimentation of macroaggregates in mid-August 1989 scavenged the POM from the water column during disruption of density stratification. Sedimentation was reflected in higher total sedimented organic matter (ca 25%) but lower protein, water-soluble carbohydrate and lipid contents.

INTRODUCTION

Suspended particulate matter (SPM) in seawater is composed of mineral and organic fractions (Sackett 1978). The organic fraction or particulate organic matter (POM) is predominantly composed of detritus, except during phytoplankton blooms when living organic matter predominates.

POM in ocean waters originates almost entirely from biological (mostly phytoplankton) production, while in coastal waters terrigenous input could be an important source of POM (Degens & Ittekkot 1985). A somewhat curious type of POM in seawater is represented by large organic macroaggregates between 1 mm and several meters in size (Alldredge 1979), which are thought to be the products of decomposition of phyto- and zooplankters (Smetacek 1985, Alldredge & Gotschalk 1989).

Macroaggregates represent an important site of accumulation and degradation of organic matter in the seawater column, contributing to the patchiness of POM distribution in seawater. The regular occurrence of macroaggregates in summertime in the Mediterranean (Heusner et al. 1987) and in the northern Adriatic (Herndl & Peduzzi 1988) is well documented. In summer 1988 and 1989 great quantities of macroaggregates appeared in the whole northern Adriatic (Brambati et al. 1988, Degobbis 1989), due to diatomaceous blooms (Fanuko & Turk 1990); these macroaggregates were composed of entrapped phytoplankters, microzooplankters, bacteria and mineral particles (Stachowitsch et al. 1990).

POM, produced in the euphotic part of the water column, degrades into nitrogen- and phosphorus-depleted organic matter when sedimenting, due to the lower energies of C-N and C-P bonds in comparison to

C-C and C-H bonds (Toth & Lerman 1977). This degradation also leads to the formation of refractory organic compounds resistant to subsequent microbial degradation. Many transformations of POM occurring in the water column are similar to those in recent sediment (Lee & Wakeham 1989, Wakeham & Lee 1989). Only larger particles such as faecal pellets (Small et al. 1987), phytodetritus (Billett et al. 1983), or macroaggregates (Fowler & Knauer 1986, Alldredge & Silver 1988) could reach the sediment with unaltered or relatively little-altered chemical composition. Smaller particles represent food for zooplankters and are thus involved in rapid transport by zooplankton vertical migration, or could be incorporated into larger faecal pellets through zooplankton coprophagy (Turner & Ferrante 1979).

In shallow coastal waters, where biological production and degradation occur together throughout the water column, most of the POM degradation and mineralization processes occur at the sediment-water interface. These benthic processes, consuming dissolved oxygen in bottom water layers, are important sources of nutrients for benthic primary production. Benthic organic matter also contributes to sedimented POM by resuspension and hence the net distinction between pelagic and benthic origins is usually difficult. Analyses of biochemical markers (Cowie & Hedges 1984, Ittekkot et al. 1984), and contents of stable isotopes of C and N (Fry & Sherr 1984, Altabet 1989) are currently applied with some success, though not without uncertainties, including multiple sources of organic matter and isotopic changes during decomposition (Fry & Sherr 1984).

The aim of the present work was to study the origin and variations in chemical composition of POM in the water column of the Gulf of Trieste (northern Adriatic) during the period of density stratification, in terms of particulate organic carbon (POC), particulate nitrogen (PN), particulate proteins, amino acids, carbohydrates and lipids. A comparison was made with the annual variations of POM composition in this area in previous years (1980 to 1983), which apparently were not affected by any planktonic blooms. Special attention was paid to determining the composition, origin, and transformation during sedimentation of macroaggregates produced by diatomaceous blooms in the summers of 1988 and 1989.

MATERIALS AND METHODS

Samples. Samples for analysis of POM were taken weekly at a fixed sampling point (MA) located in the SE part of the Gulf of Trieste (Fig. 1) at a depth of 17 m, from July to September 1989, during thermal and density stratification in the water column (Fig. 2). Samples for POM, POC, PON, particulate proteins, carbohydrates and lipids were collected from the surface (0.3 m) and bottom (16 m) layers using 5 l Niskin samplers. During the period 1980 to 1983 samples were collected monthly at the sampling points MA and K-1 (Fig. 1) at depths of 0.5, 5, 10, 16 m. Macroaggregates forming a 'creamy surface layer' (Stachowitsch et al. 1990) were collected in the Bay of Piran (Fig. 1) in July 1988 and July 1989 at the sea
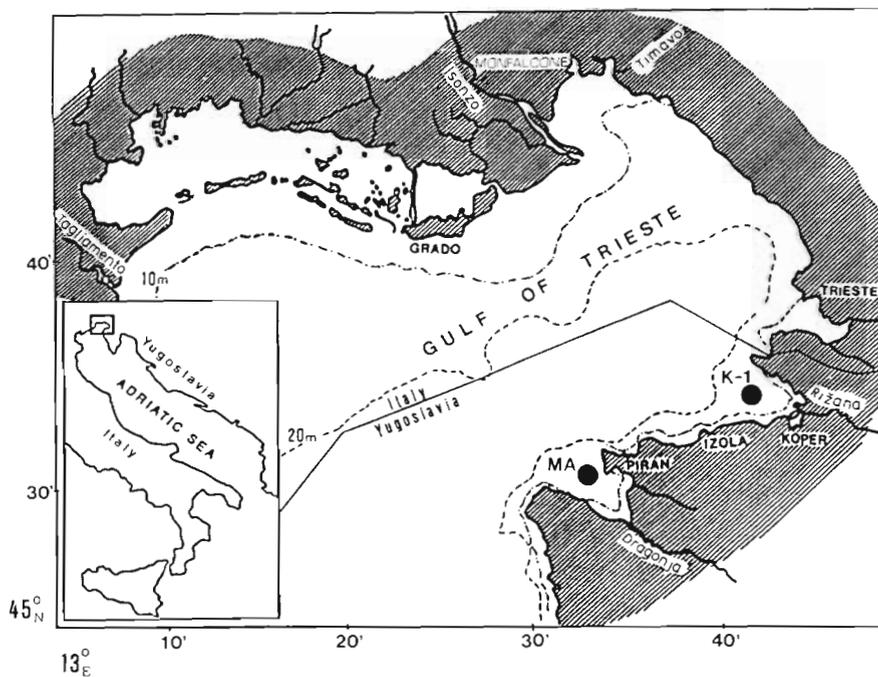

Fig. 1. Location of sampling points K-1 and MA in the Gulf of Trieste (northern Adriatic)
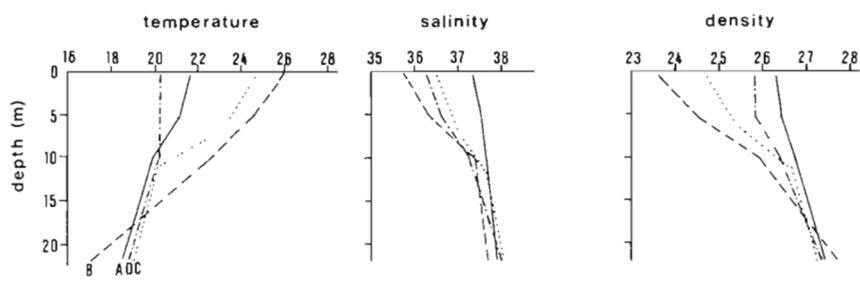
Fig. 2. Vertical profiles of temperature (°C), salinity (‰) and density in the water column in the southern part of the Gulf of Trieste on (A) 5 July, (B) 25 July, (C) 24 August and (D) 6 September 1989. Data from the Marine Biological Station Piran

surface and bottom by SCUBA, using polyethylene bottles.

The sedimentation rate of POM was measured from July to September 1989 at point MA (Fig. 1) with a moored sediment trap, similar to that described by Blomqvist & Kofoed (1981). The trap was situated ca 1 m above the bottom to reduce the influence of sediment resuspension. The trap was designed to collect 4 samples simultaneously and consisted of 4 plastic cylinders, each 80 cm^2 in area. The height/width ratio of the cylinders was ca 5. The amount of POM was measured over a period of 24 h once a week.

Samples of particulate matter (2 l), macroaggregates (1 l) and sedimented particulate matter were filtered through Whatman GF/F glass-fiber filters pre-ignited for 3 h at 480 °C to eliminate organic contaminants. The material collected on the filters was rinsed several times with distilled water to remove salts. All samples were dried at 60 °C overnight and weighed. Dried samples were used for analysis of C, H, and N content, ^{13}C content of organic matter, and protein, amino acid, total and water-soluble carbohydrate, and lipid contents.

Analyses. Total particulate and sedimented particulate matter was determined gravimetrically, and the organic fraction was measured as the difference between the total and that remaining after combustion at 500 °C. C, H and N content was determined with a commercial CHN analyzer (Coleman). Analysis of ^{13}C isotopic fractionation in the CO$_2$ produced was performed with a Varian MAT 250 mass spectrometer and the results expressed as per mil (‰) deviations from the ^{13}C/^{12}C ratio of the Chicago PDB standard (δ^{13}C).

Protein contents in samples were determined in aqueous homogenates (Packard & Dortch 1975) colorimetrically, using a slightly modified Coomassie Brilliant Blue protein assay (Bio Rad or Pierce, USA) method of Setchell (1981) with casein as a standard (Mayer et al. 1986). Casein seems to be an appropriate standard for this protein assay in plankton generally. The commonly used bovine serum albumin (BSA) standard in the protein assay with the Coomassie Brilliant Blue method (Kochert 1978) gives low results in plank-

ton analyses, since the response of various proteins is not uniform. Bovine γ-globulin, ovalbumin and casein give approximately identical results (Setchell 1981, Faganeli et al. 1989). The Coomassie Brilliant Blue protein assay (Pierce reagent) was tested for interferences from other natural polymeric products in the marine environment, i.e. humates and lignin. The aqueous solutions of wood ligninsulphonate and purified fulvic acid, isolated from coastal marine sediment (west coast of Sweden), gave no response in the range 5 to 800 μg ml^{-1}. A purified humic acid, isolated from the same marine environment, exhibited an absorbance of about 1/3 that of casein in the same concentration range. It seems possible that the humic acid tested consists of some larger polypeptide residues adsorbed or bonded onto the structure of humic acid (Domagalski et al. 1989).

Amino acid composition was determined by hydrolysis of samples in 6 N HCl in sealed evacuated ampoules at 110 °C for 20 h and by subsequent analysis using a Beckman 118 CL amino acid analyzer. Total carbohydrate contents were determined colorimetrically using the phenol-sulphuric acid method of Dubois et al. (1956) with D-glucose as a standard after hydrolysis of samples in sealed ampoules in 1 M H$_2$SO$_4$ at 100 °C for 4 h (Mopper 1977). Monosaccharides were determined by thin-layer chromatography (TLC) on Kieselgel 60 WRF 254 S plates (Merck) using a mobile phase composed of acetonitrile : phosphate buffer (pH = 5.5) : methanol in the proportions 179:39:0.2. Detection of monosaccharides was performed visually using a mixture of diphenylamine, aniline and phosphoric acid (20 % in methanol), comparing with standards.

Water-soluble carbohydrate contents of samples were analyzed in water homogenates (Packard & Dortch 1975) using the phenol-sulphuric acid method of Dubois et al. (1956) with D-glucose as a standard. Lipid content was determined by extraction with a mixture of chloroform and methanol (2:1) and subsequent colorimetric detection using the sulphophospho-vanillin method of Zöllner & Kirsch (1962) and cholesterol as a standard.

The composition of the mineral fraction was determined by X-ray diffraction analysis.

RESULTS

Composition and sedimentation of SPM

Temporal variations in the composition of POM from July to September 1989 are depicted in Fig. 3. Concentrations of protein varied in the range 20 to 40 μg l^{-1}, these of water-soluble carbohydrates between 10 and 40 μg l^{-1} and of lipids between 0 and 200 μg l^{-1} in the surface and bottom layers. The lowest concentrations of all particulate constituents were detected in mid-August 1989 in both layers. The temporal variations in both layers were similar, except that higher concentrations were observed at the bottom. The sum of analyzed constituents varied widely and represented between 2 and 28 % of the total particulate matter and between 6 and 84 % of POM (Fig. 4).

Sedimentation rates of particulate matter, POM, particulate proteins, water-soluble carbohydrates and lipids ranged from 8.6 to 106 g, 3 to 12 g, 50 to 540 mg, 40 to 170 mg and 0 to 420 mg m^{-2}d^{-1}, respectively (Fig. 3). The temporal variations in sedimentation rates of particulate components during collection followed the variations in concentration of particulate substances in the water column. The highest sedimentation rate of POM but the lowest of particulate proteins, water-soluble carbohydrates and lipids was observed in mid-August 1989, in parallel with the lowest concentrations of these particulate substances in the water column. The content of sedimented POM decreased during the following 2 wk with increasing content of other sedimented particulate substances.

Lipids, proteins and water-soluble carbohydrates represented respectively between 0 and 1.3, 0.20 and 1.85, and 0.08 and 0.40 % of sedimented matter, and together represented about 10 % of the total sedimented POM and between 1.5 and 4.5 % of the total sedimented matter (Fig. 5). All of the organic constituents analyzed comprised only ca 25 % of the sedimented POM and 6.5 % of total sedimented matter The major part (75 to 85 %) of the total sedimented matter was composed of an inorganic fraction with the following minerals: calcite (28 %), illite (21 %), quartz (19 %), chlorite (15 %), plagioclase (6 %), dolomite (6 %), microcline (4 %) and pyrite (2 %) (Fig. 5).

Concentrations of the particulate constituents between 1980 and 1983 (Fig. 6A) exhibited intensive temporal fluctuations without statistically significant correlation (paired t-test, p < 0.01) between particulate constituents or between them and phytoplankton biomass (based on chlorophyll a concentration). The differences between sampling points and depths were not significant (t-test, p < 0.01). However, the total particulate carbohydrate concentration maxima observed in the period May–June coincided with low nitrate in seawater (Fig. 6B).
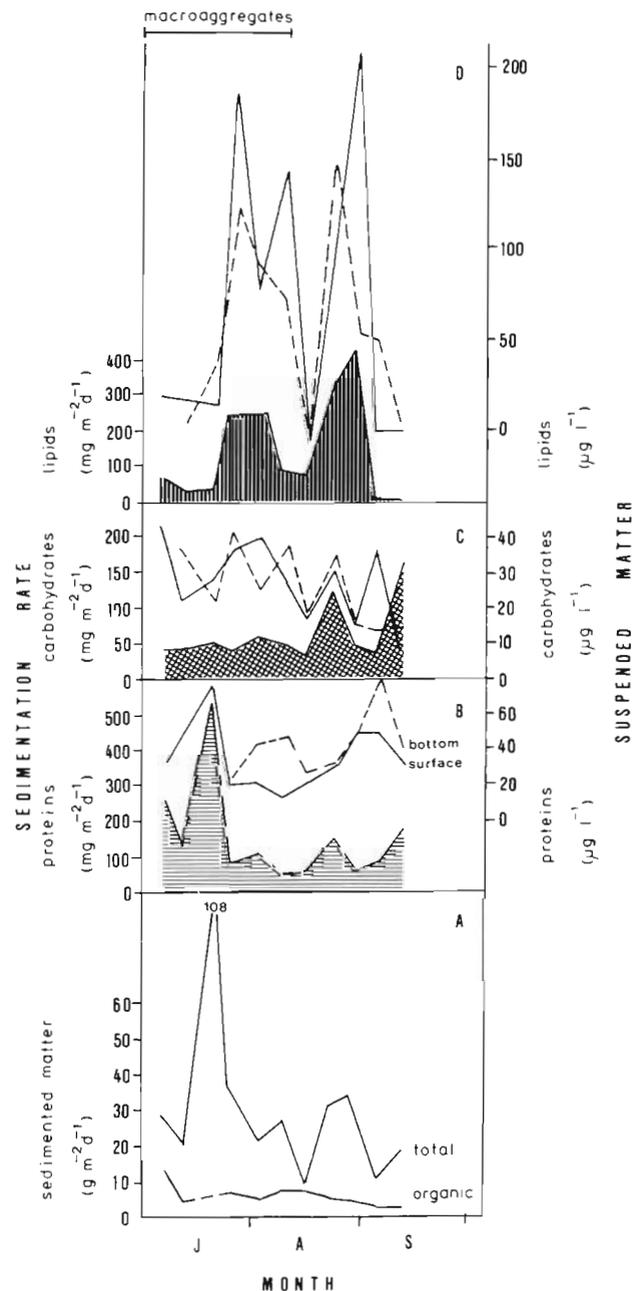

Fig. 3. (A) Sedimentation rate of total and organic suspended matter; and sedimentation rate and concentration variations of (B) particulate proteins, (C) water-soluble particulate carbohydrates, and (D) particulate lipids, in the surface (0.5 m: continuous line) and bottom (15 m; dashed line) layers at sampling point MA from July to September 1989. Horizontal line at top indicates occurrence of macroaggregates

Composition of macroaggregates

The chemical and ^{13}C isotopic composition of macroaggregates in July 1988 and July 1989 is reported in
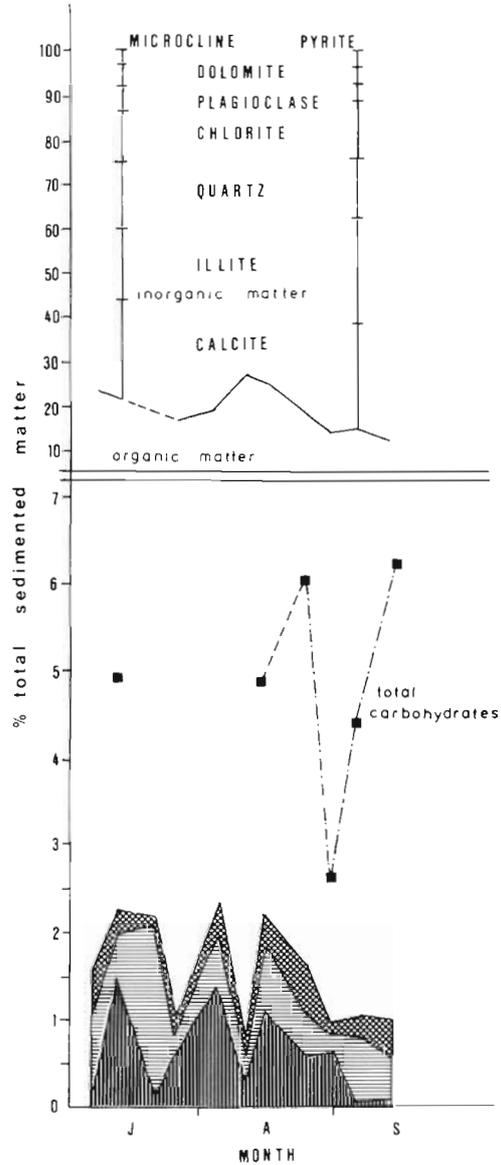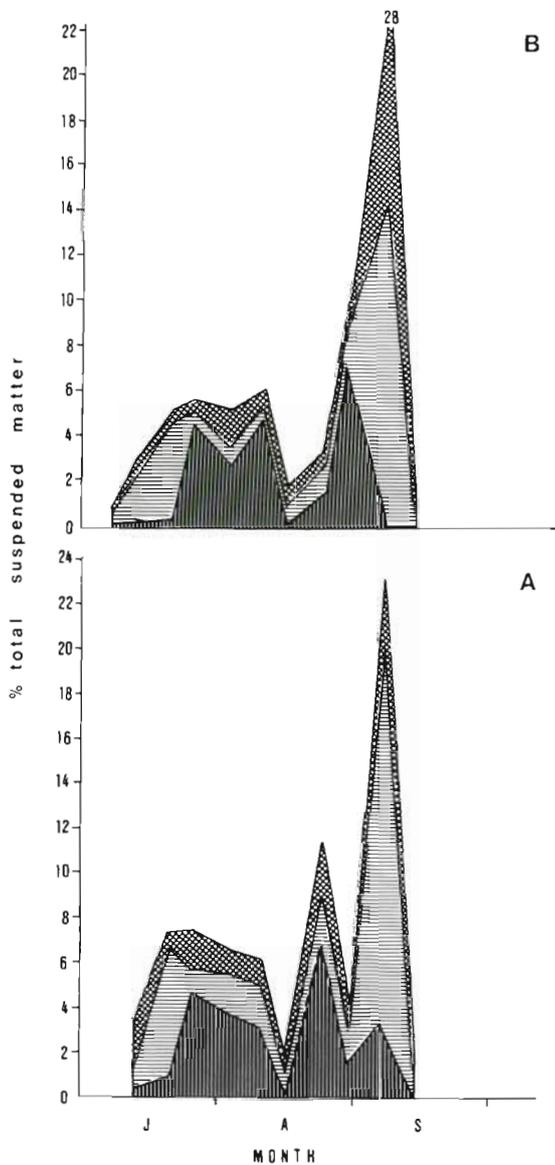
Fig. 4. Variation in composition of suspended matter in the (A) bottom and (B) surface layers at sampling point MA from July to September 1989. Patterns for components in Fig. 3

Fig. 5. Variations in composition of sedimented matter at sampling point MA from July to September 1989. Patterns for components as in Fig. 3

Table 1. Content of organic matter varied between 35 and 57 % and that of organic C between 10 and 25 %, with an organic matter:organic C ratio between 2 and 3.6. The total N content of surface macroaggregates was low, with a higher value (3.4 %) in sedimented macroaggregates in July 1988. The C/N atomic ratio of surface macroaggregates was high (15 to 29), but a lower C/N ratio was found in sedimented macroaggregates.

Total carbohydrates were the major component com-prising total matter (11.6 to 33.5 %), and glucose comprised up to 60 % of the total carbohydrates. On the other hand, water-soluble carbohydrate contents ranged between 11 and 15 % of total hydrolyzable carbohydrates. Protein content was low, comprising only about 68 % of total hydrolyzable amino acid. The amino acid spectrum of macroaggregates (Table 2) was similar to that of typical summer POM in the Gulf of Trieste. The most abundant amino acids were glycine,
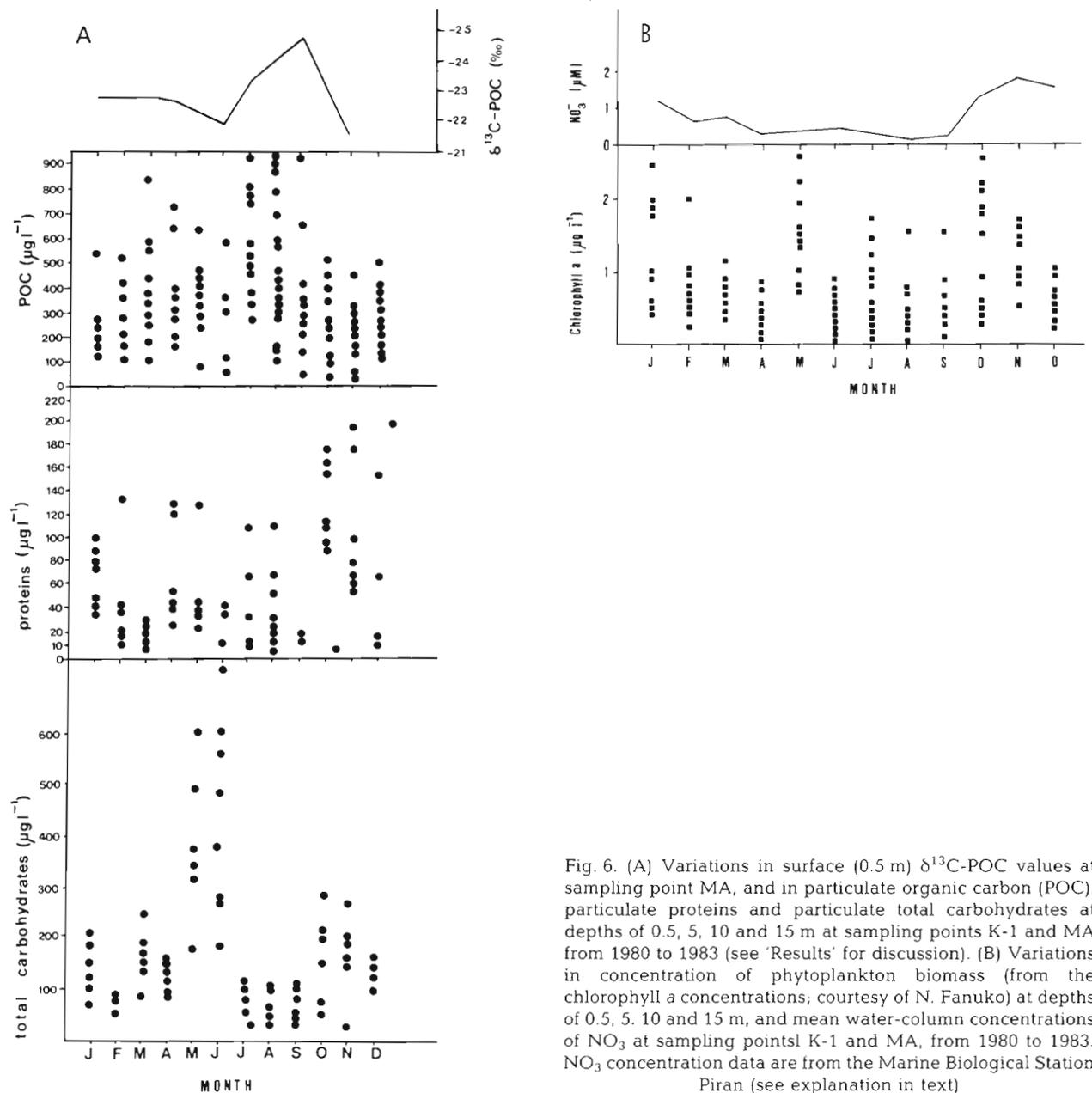
Fig. 6. (A) Variations in surface (0.5 m) δ^{13}C-POC values at sampling point MA, and in particulate organic carbon (POC), particulate proteins and particulate total carbohydrates at depths of 0.5, 5, 10 and 15 m at sampling points K-1 and MA from 1980 to 1983 (see 'Results' for discussion). (B) Variations in concentration of phytoplankton biomass (from the chlorophyll a concentrations; courtesy of N. Fanuko) at depths of 0.5, 5, 10 and 15 m, and mean water-column concentrations of NO₃ at sampling pointsl K-1 and MA, from 1980 to 1983. NO₃ concentration data are from the Marine Biological Station Piran (see explanation in text)

aspartic acid, alanine and glutamic acid in both materials. The sum of all analyzed constituents accounted for 23 to 100 % of the total organic matter content.

DISCUSSION

Composition of SPM

The annual variation in particulate substances was apparently unaffected by the appearance of macro-aggregates, displaying little synchronization with phy-

toplankton biomass (based on chlorophyll a) and a marked occurrence of high total particulate carbohydrate content in the period May–June. This phenomenon coincided with lower seawater nitrate concentrations, similar to the observations reported by Haug et al. (1973), indicating the prevalent synthesis of carbohydrates in phytoplankton during depletion of nitrate in the surrounding water. The high summer POC concentrations were most likely a result of a higher contribution of allochthonous POC, as illustrated by more negative δ^{13}C-POC values (Faganeli et al. 1988). The scattered PN data on the POC vs PN plot

Table 1. Composition of macroaggregates in the SE part of the Gulf of Triste (% of dry weight)

Component	1989 (surface)	1988 (surface)	1988 (bottom)
Organic matter	57.3	35.3	47.4
C	17.73	9.77	24.94
H	2.12	2.08	3.85
N	0.72	0.84	3.37
C/N (atomic)	28.7	15.3	8.6
Total carbohydrates	11.48	33.53	–
Water-soluble carbohydrates	1.23	1.89	–
Proteins	0.34	1.36	–
Total amino acids	1.57	2.19	–
Lipids	0.09	0.07	–
Carbohydrates + total amino acids + lipids	13.1	35.8	–
$\delta^{13}C$ (‰)	−18.9	−17.0	−21.3

Table 2. Amino acid composition (mol %) of macroaggregates and suspended matter in the SW Gulf of Trieste

Amino acid	Macroaggregates 1988	1989	Suspended matter 1983
Ala	12.0	11.2	10.7
Arg	1.4	3.4	3.5
Asp	13.9	9.8	13.7
Glu	10.3	12.1	12.5
Gly	17.2	11.2	12.0
His	0.8	1.9	1.9
Ile	4.2	6.4	4.0
Leu	6.0	8.8	6.9
Lys	3.1	6.4	5.1
Met	0	0	Traces
Phe	3.0	4.6	4.0
Pro	8.2	–	3.8
Ser	6.7	6.3	8.3
Thr	5.1	8.2	6.7
Tyr	1.0	1.4	0
Val	6.3	8.3	6.9

($r^2 = 0.64$, $p < 0.01$; Fig. 7) are probably a consequence of the fact that a substantial part of PN consists of dissolved N adsorbed onto particles or inorganically bonded, since the POC vs PN regression line (POC = 3.3PN + 114.2; n = 150) indicates that not all N is organically bound. Up to 20 % of total N in surficial sediment of the Gulf of Trieste was found to consist of inorganic N, i.e. the sum of fixed ammonium and exchangeable ammonium, nitrate and nitrite ions (Faganeli et al. 1991). This statement is supported by the data on particulate protein and amino acids, consisting of a yearly average of ca 16 and 30 %, respectively, of PN in the Gulf (Faganeli 1989). This also in part explains the unusually low mean C/N ratio of particulate matter in the Gulf.

Floristic analysis of macroaggregates showed that they were composed of live and dead diatoms, especially of the genus Nitzschia, as well as of microflagel-

lates and bacteria (Fanuko & Turk 1990, Stachowitsch et al. 1990). Analysis of chemical composition revealed that carbohydrates were the principal constituent of macroaggregates, with glucose being the most abundant monosaccharide in acid hydrolyzates, and a low content of the water-soluble carbohydrates. This suggests that the principal components were structural glucans of the diatom cell wall, since storage polysaccharides are water-soluble (Handa & Yanagi 1969). The carbohydrates of diatoms are generally divided into storage (reserve) polysaccharides principally composed of glucose (Handa & Yanagi 1969, Haug & Myklestad 1976), structural cell-wall polysaccharides consisting of rhamnose, fucose, ribose, arabinose, xylose, mannose, galactose and glucose (Handa & Yanagi 1969, Haug & Myklestad 1976) bonded with amino acids to silicate in frustula (Hecky et al. 1973), and extracellular polysaccharides composed principally of rhamnose, fucose and galactose, with a minor contribution of xylose, mannose and galactose (Haug & Myklestad 1976, Percival et al. 1980). The monosaccharide composition of diatomaceous mucus, according to Ittekkot et al. (1982). is similar to that of the frustula. In our sample pretreatment these monosaccharides were probably lost by vacuum filtration, as reported by Ittekkot et al. (1984) and Liebezeit (1987). The high reserve polysaccharide content in diatom spores was suggested by Liebezeit (1987) to be important to diatom survival strategy (Smetacek 1985) in 3 ways: the increasing amount of reserve polysaccharide, probably glucans, increases the density of the spore and thus the sinking velocity, the high content of reserve polysaccharides serves as an energy store and prolongs survival time, and the degradation of reserve glucans decreases cell density and thus facilitates optimal growth conditions.

Our statement that the majority of carbohydrates originates from structural polysaccharides does not agree with the observation of Liebezeit (1987) but does, on the other hand, agree with that of Tanoue & Handa
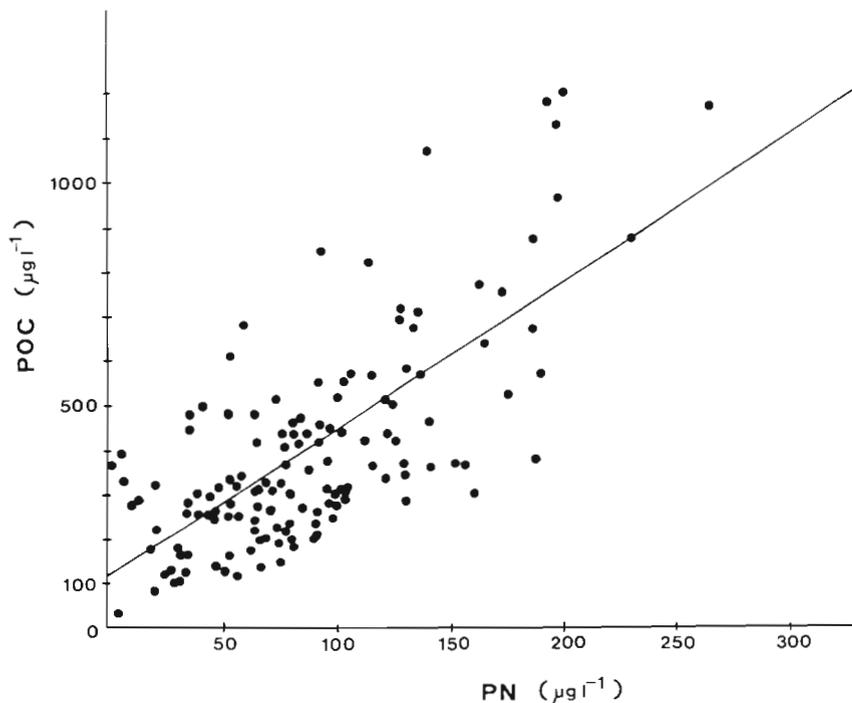
Fig. 7. Relationship between particulate organic carbon (POC) and particulate nitrogen (PN) at sampling points K-1 and MA in the southern part of the Gulf of Trieste from 1980 to 1983. The regression line is described by the equation: POC = 3.3PN + 114.2; r^2 = 0.64, n = 150

(1987). Thus, the ratio of glucose to galactose, proposed as an index of predominance of storage or structural polysaccharides in diatoms (Ittekkot et al. 1982), seems not to be applicable in this case.

The amino acid composition of macroaggregates suggests that they were mostly not bonded to the silicate frustula, since in general it shows no marked enrichment of glycine, serine and threonine and a decrease of acidic, sulphur-containing and aromatic acids (Hecky et al. 1973) relative to the amino acid composition of summer POM (Table 2). Low lipid concentrations of macroaggregates were also reported by Degobbis (1989) along the western Istrian coast.

The source of macroaggregates could be deduced using their $\delta^{13}C$ values and their position on a graph of the $\delta^{13}C$ values vs C/N ratios of different classes of organic matter in the Gulf of Trieste (Faganeli et al. 1988). The $\delta^{13}C$ values of surface macroaggregates were similar to those of batch-cultured diatoms (*Chaetoceros affinis, Nitzschia closterium*), isolated from the Gulf of Trieste, in the stationary phase of growth (Faganeli et al. 1989). The C/N ratio was high due to the strong predominance of carbohydrates and depletion of organic nitrogen compounds. Thus, these macroaggregates could be classified as predominantly of pelagic origin.

The composition of summer POM in the Gulf of Trieste differed from that of macroaggregates. The summer POM in the surface and bottom layers contained higher quantities of proteins, lipids and water-soluble carbohydrates; this is in accordance with the

observation of Alldredge (1979) for the waters of southern California. A comparison of the mean C and N contents of POM (Faganeli 1989) with those of macroaggregates revealed higher C and lower N in the latter, with a consequently higher C/N ratio. This higher C/N ratio is partially attributed to the intense degradation processes occurring within the dense macroaggregates (Alldredge 1989). The $\delta^{13}C$ values of macroaggregates are more positive than those of the summer POC values, the latter probably being affected by the presence of allochthonous organic matter.

Sedimentation of SPM

The summer temporal fluctuations in particulate protein, water-soluble carbohydrate and lipid concentrations in surface and bottom layers, and those of sedimented particulate constituents, showed some dissimilarities. A likely explanation may be that the composition of rapidly sinking matter, such as zooplankton faecal pellets (Downs & Lorenzen 1985, Altabet 1989) and the larger macroaggregates described above, differs from that of suspended POM, and that there is an intense degradation of smaller, slowly sinking particles accumulating at the pycnocline (Herndl 1989) in a summer density-stratified water column. These statements are illustrated by the compositional difference between suspended particulates and sedimental particles: the decrease amounted to ca 74 % for lipids and 83 to 85% for water-soluble carbohydrates and pro-

teins. A similar percentage (ca 80 %) of particulate amino acid loss during sedimentation was previously described for summer and winter periods in the water column of the Gulf of Trieste (Faganeli 1989).

The rapid sedimentation of macroaggregates in mid-August 1989 on the occasion of an abrupt wind disruption of the pycnocline was reflected in a higher sedimentation rate of total organic matter but a lower sedimentation rate of proteins, lipids and water-soluble carbohydrates. The protein content of sedimented matter was similar to that of macroaggregates, with lipids somewhat higher but water-soluble carbohydrates much lower, due to the degradation of reserve glucans and dissolution into the surrounding water (Ittekkot et al. 1982, Tanoue & Handa 1987), and their use in phytoplankton respiration (Handa & Yanagi 1969). More stable and water-insoluble structural (cell-wall) polysaccharides are thus the most important source of carbohydrates in sedimented matter and marine sediments. A more negative $\delta^{13}C$ value of sedimented macroaggregates in July 1988 relative to that of the surface layer most likely indicates mixing with other plankters and POM, generally with more negative $\delta^{13}C$ values (Faganeli et al. 1988), or selective degradation of more labile components, such as amino acids and carbohydrates (Wefer et al. 1982). It is well known that the $\delta^{13}C$ values of planktonic lipids are 8 to 10 ‰ more negative than those of more degradable proteins and carbohydrates (Degens et al. 1968). On the other hand, only 4 ‰ more negative $\delta^{13}C$ values were found after anaerobic degradation of algal organic matter (Spiker & Hatcher 1984). Moreover, practically no fractionation was observed under oxic degradation of planktonic material (Gearing et al. 1984). The lower C/N ratio of sedimented macroaggregates also suggests intense bacterial degradation, or adsorption of dissolved nitrogen compounds.

A comparison of the composition of sedimented POM in the Gulf of Trieste with that of hydrologically and biologically different marine environments seems interesting, bearing in mind the different analytical methods used. Assuming a POM:POC ratio of 2 (Riley 1970), the percentage of protein in sedimented POC was similar to that in the Kiel Bight (up to 15 %; Liebezeit et al. 1985), but lower than that observed in some deep-sea environments, e.g. the Panama basin (15 to 35 %; Lee et al. 1983), offshore of Peru, and the equatorial Atlantic (20 to 30 %; Liebezeit & von Bodungen 1987). The total carbohydrate content of sedimented POM in the Gulf of Trieste was higher than in Dabob Bay (9 %; Hedges et al. 1988), ocean environments off Antarctica (10 to 15 %; Liebezeit & von Bodungen 1987), and the northern North Pacific (8 to 10 %; Tanoue & Handa 1987), but the lipid content was lower, i.e. 5 to 10 % of sedimented POM in the Panama

basin (Lee et al. 1983). The striking characteristic of sedimented as well as suspended POM in the Gulf of Trieste appears to be a relatively high carbohydrate content, probably in part land-derived (of vascular plant origin), although cellulose and its monomer glucose are highly degradable in the water column (Hedges et al. 1988).

The sum of analyzed chemical constituents represented only a minor fraction of the sedimented, as well as summer suspended, POM in the Gulf of Trieste, in accordance with various reports from different marine environments, e.g. Dabob Bay, USA (Hedges et al. 1988), the Sargasso Sea (Ittekkot et al. 1984) and the South Atlantic (Wefer et al. 1982). The bulk of sedimented and suspended POM in the Gulf is thus probably present in other chemical forms, such as humates (Degens 1970), hydrocarbons (Bates et al. 1984), lignin (Hedges et al. 1988) and probably other land-derived organic matter, indicated by more negative summer $\delta^{13}C$-POC values in the Gulf. Some, probably a minor, part of the difference could arise from the not completely specific analytical methods or standards applied. Thus, protein determination in the NaOH extracts (Rausch 1981) from cultured phytoplankters gave 2- to 3-fold higher yields than in aqueous extracts (Faganeli et al. 1989). However, a comparison of our protein measurements with published amino acid sedimentation data (Faganeli 1989) revealed very similar rates, suggesting that the great majority of sedimented amino acids were bound to proteins.

The major fraction of the total sedimented matter in summer was inorganic, with a composition similar to that of the surficial sediment in this area of the Gulf of Trieste (Ogorelec et al. 1991). The presence of the authigenic mineral pyrite, occurring regularly in the surficial sediment a few millimeters below the sediment-water interface, in the sedimented matter in September 1989 is an indication of resuspension of bottom sediment. Following the method of Gasith (1975), which calculates the degree of resuspension from the known composition (pyrite content) of sedimented particulate matter and surficial marine sediment (Ogorelec et al. 1991), it was found that resuspension accounted for ca 2/3 or sedimented matter in that period.

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