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SOME SEDIMENTOLOGICAL AND CHEMICAL FEATURES OF THE SEAFLOOR IN FRONT OF THE TIBER RIVER (1)

ABSTRACT: G. BORTOLUZZI, F. FRASCARI, S. GUERZONI, N. INCREMONA, M. RAVAIOLI & G. ROVATTI, *Some sedimentological and chemical features of the seafloor in front of the Tiber River*). (IT ISSN 0084-8948, 1982).

26 sediment samples, collected Oct 3d-4th, 1978 off the Tiber River mouth (Tyrrhenian Sea) were analyzed for grain size parameters, nutrients (inorganic and extractable P, NH_3, extractable Si) and organic matter (org C, N, P) in order to study the influence of the biogeochemical cycles on global ecological processes. Three depositional facies were recognized from grain size and Geomorphology of the submersed delta: *a*) nearshore sands area, with nearly constant high energy; *b*) delta front with prevailing sands and silty clays deposited directly off the river mouth (flocculation area); *c*) prodelta slope, with prevailing silty clays and presence of mass movement processes.

The comparison with other coastal areas of the Mediterranean Sea and the study of the linear correlation coefficients among all parameters indicate: *a*) the organic matter content, mostly of fluvial origin, is higher in the finest grained sediments; good correlation was found between this group and phosphorus compounds, whose organic fraction is also strongly correlated with silt; *b*) pH and redox, directly correlated with the coarser fraction, are very useful for contouring reducing areas with conditions for the mineralization of org N and a likely increase in phosphate release from sediments; *c*) ammonia is totally independent from any other parameter. Its areal distribution shows direct influence from fresh water input rather than "in situ" biochemical transformation mechanism. A preliminary conclusion emphasizes the delta front as the best target area for the study of the influence of sediments on the coastal water quality.

RIASSUNTO: G. BORTOLUZZI, F. FRASCARI, S. GUERZONI, N. INCREMONA, M. RAVAIOLI & G. ROVATTI, *Alcune caratteristiche sedimentologiche e chimiche dei fondali antistanti il Fiume Tevere*). (IT ISSN 0084-8948, 1982).

Su 26 campioni di sedimento superficiale, raccolti nell'Ottobre 1978 nell'area marina antistante il delta del Tevere, sono state eseguite analisi granulometriche e chimiche (per le sostanze nutrienti: P inorg., P estr., NH_3, e per la materia organica: C org., N org., P org.) al fine di contribuire allo studio dell'influenza dei cicli biogeochimici sui processi ecologici globali dell'area.

Lo studio geomorfologico e sedimentologico del delta sommerso ha portato alla individuazione di tre facies deposizionali: *a*) la zona delle sabbie costiere, ad energia media abbastanza elevata; *b*) il fronte deltizio, con prevalenza di sabbie siltose e depositi di silt-argilloso di fronte alle bocche del fiume (area di flocculazione); *c*) la scarpata di prodelta, con prevalenti argille siltose ed evidenti processi di frane sottomarine in atto.

Il confronto con altre zone marine del Mediterraneo e lo studio delle correlazioni esistenti fra tutti i parametri indicano che: *a*) il contenuto di materia organica, per la maggior parte di origine fluviale, è più alto nei sedimenti a grana fine ed esiste una buona correlazione fra i costituenti citati ed i composti del fosforo, la cui frazione organica è fortemente correlata con la frazione siltosa; *b*) il pH ed il potenziale redox, direttamente correlati con la frazione grossolana del sedimento, sono utili per individuare le aree in condizioni riducenti, favorevoli per la mineralizzazione dell'azoto organico e per fenomeni di rilascio di fosforo dal sedimento; *c*) l'ammoniaca è totalmente scorrelata da ogni altro parametro e la sua distribuzione areale sembra essere legata più all'apporto diretto del fiume che non a trasformazioni biogeochimiche « in situ ».

TERMINI-CHIAVE: sedimentazione deltizia; granulometria; analisi multivariata; prevenzione d'inquinamento, eutrofizzazione.

INTRODUCTION

This study is part of an interdisciplinary research program, promoted by IRSA of Rome (Water Research Inst. - National Research Council) together with other national research institutions, on the evaluation of the quality of the Tiber River water (IRSA, 1978) and its influence on the marine water body.

The investigated zone (fig. 1) is part of a well defined physiographic unit, the Tiber delta: its study from the environmental point of view (platform management, control of pollution) is relevant because the river, just before reaching the sea, crosses Rome and receives its industrial and sewage discarges (ann. av.: 230 m^3/s, IRSA, 1978).

The study, started in 1971, includes hydrodynamic researches in the coastal area (GIULIANELLI & *alii*, 1978) studies on the distribution of nutrients and pollutants

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(PAGNOTTA & PUDDU, 1978; BLUNDO & *alii*, 1980; LA NOCE & *alii*, 1980; PUCCETTI & LEONI, 1980) and on the Microbiology (LA NOCE & *alii*, 1980) in fresh and marine waters; researches were also carried out on the benthonic biocenoses of bottom sediments (DELLA SETA & *alii*, 1977).

Our experimental investigation of marine sediments aims at better understanding their relevance to the global ecological processes in the area. We also attempt to

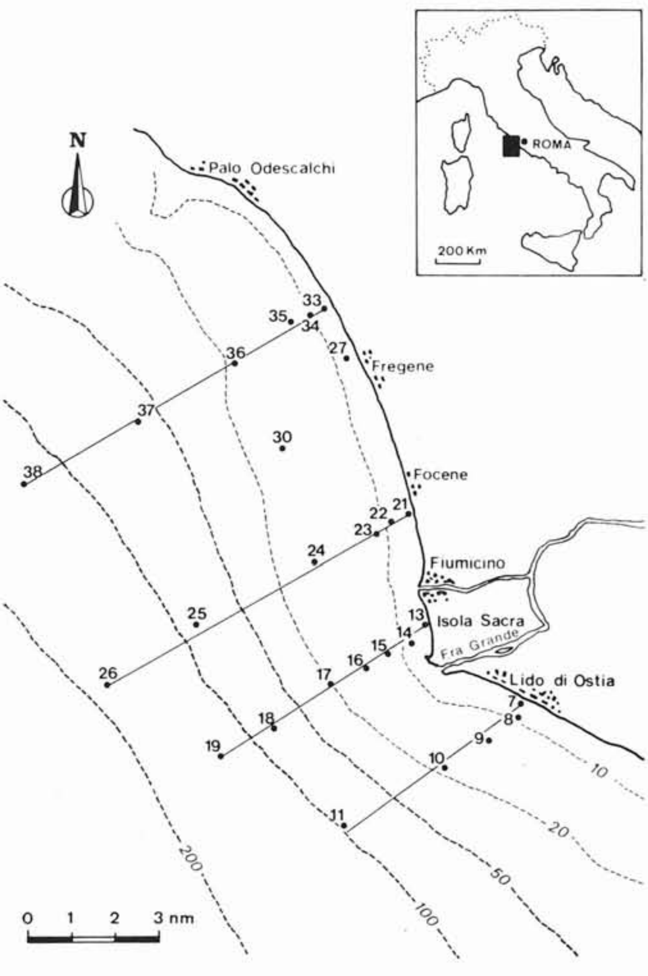

FIG. 1 - Location map for sediment samples.

evaluate the sediment influence on water quality. The mechanism recognized from shallower coastal waters of northern Adriatic Sea investigated at our Institute (AA.VV., 1978; ANGELONI & *alii*, 1979; FRASCARI & *alii*, 1979) could considerably change in deeper waters, directly affected by only one river.

Information on exchange processes of pollutants and nutrients between suspended and deposited solid materials and waters can be used as input for modeling the coastal ecosystem. A rational study to get this information deals with:

1) the distributary channels and the river mouth;

2) the marine water body;

3) the sediments of the sea floor.

Research should deal with hydrodynamic, chemical, geomorphologic and sedimentologic studies, verifying directly:

a) quality and quantity of solid loads and pollutants transported by the river (upstream of salt wedge);

b) the transformation processes of the transported materials due to the mixing of fresh with salt water;

c) which environments control deposition and dispersion processes, sedimentation rates and exchange potentials with waters.

Type *a*) and *b*) studies are profitable when a good knowledge of sea-river hydrodynamics will be available. Type *c*) studies are immediately profitable, yielding a great amount of information about the ecosystem. The evaluation of pollutants content in the surface sediments outlines the pollution "stress" of the sea bed and a possible (and inferred) drainage network of the river. Geomorphologic and sedimentologic features of the submersed body bring up more information on the drainage basin and on the seasonal average levels at the sea floor. Correlations between chemical and sedimentologic features of the sediments point out the role of grain size during exchange processes. The study of sediment cores allows to establish the temporal evolution of the depositional environments and of the degree pollution. It also offers an opportunity to evaluate the natural (base) levels of the examined substances and the long period sedimentation rate.

This paper presents a preliminary characterization of the coastal sediments (nutrients and sedimentology) from samples collected during a test cruise (Oct. 3d-4th, 1978).

MATERIALS AND METHODS

SAMPLING

Sediments were sampled from 26 stations around the Tiber River mouth, using a VanVeen grab (fig. 1); bottom water was also sampled for nutrients and salinity measurements. Determination of T, pH and Eh were made on shipboard immediately after collection of the surface samples (upper 3 cm); three subsamples were split and stored at 5° C for grain size analysis and frozen at —15° C for chemical analysis.

ELECTROCHEMICAL MEASUREMENTS

The pH was measured using an Orion combination electrode standardized against pH 6 and 8 buffers; redox potential was measured by means of a platinum electrode (values, referred to hydrogen electrode, are expressed as "Eh") standardized against a Zobell solution (ZOBELL, 1946). Redox and pH measurements, together with sediment hydration (calculated by drying sediments at 110° C overnight) can be used for a cursory empirical environmental characterization related to biochemical activity of the bottom sediments (BAAS BECKING & *alii*, 1960; WHITFIELD, 1969).

BATHYMETRY

Four bathymetric profiles (fig. 1) from 4-5 m nearshore to 200 m have been executed by an echosounding system Atlas Krupp Deso 10 and by a radiopositioning system Loran C. The profiles have been chosen along paths likely to yield maximum information during the test survey. Three of them are located off the principal

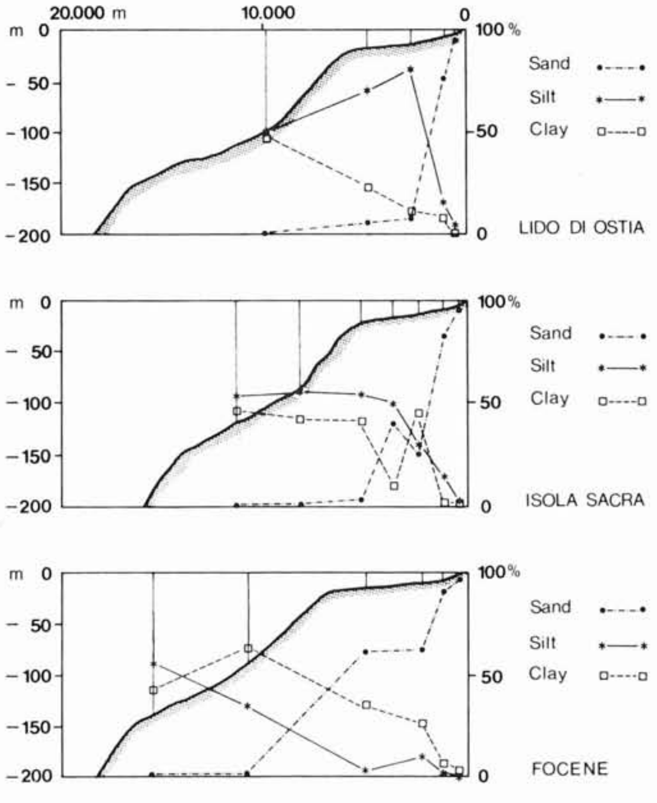

FIG. 2 - Bathymetric cross-profiles and salt-silt-clay % distribution.

mouth, covering the area of highest impact of transported and dispersed materials; the fourth profile is located to the North across the prevalent direction of the plume (GIULIANELLI & *alii*, 1978) and the dispersion area of the distributary channel of Fiumicino.

GRAIN SIZE ANALYSIS

After a preliminary treatment, for extraction of salt and of organic matter, sands (>62 μ) were separated from pelites by sieves (GALLIGNANI & *alii*, 1972). Analyses of sands were made by a sedimentation balance (BRAMBATI, 1971) with size class interval of 1/2 phi; pelites were analyzed with the pipette method after a dispersion treatment (GALLIGNANI & *alii*, 1972) with a 1 phi size class interval (4 phi to 9 phi), the remaining clay fraction was calculated.

CHEMICAL ANALYSIS

Samples for chemical analysis were frozen and stored at —15 °C immediatly after collection and freeze-dried at the laboratory until analysis. Total organic and inorganic phosphorus were determined according to known procedures (ANDERSEN, 1976; ASPILA & *alii*, 1976; STRICKLAND & PARSONS, 1972) modified for the extractable P and Si by shaking for two hours in artificial sea water. Ammonia represents exchangeable NH_4^+ and was analyzed

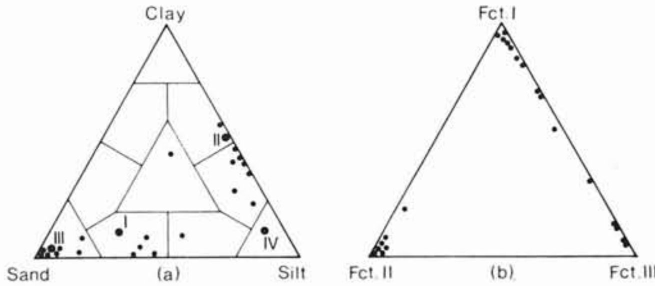

FIG. 3 - Samples composition: *a*) sand-silt-clay % (SHEPARD, 1954): I, II, III, IV are the "end-members" (see text); *b*) factor I, II, III % (after 'Q'-F.A. on grain-size data).

on wet sample (STRICKLAND & PARSONS, 1972). Finally, in order to complete the organic cycles, organic N and C were run with CHN analyzer, after dissolution of carbonates (ANGELONI & *alii*, 1979). Bottom water analyses were run by IRSA on filtered samples, following Strickland and Parsons method (BLUNDO & *alii*, 1980).

RESULTS AND DISCUSSION

GEOMORPHOLOGY

The studied part of the Tiber River delta is formed by two distributary channels: the natural influent stream at Fiumara Grande and the artificial channel at Fiumicino (fig. 1). The latter was constructed by the Romans in Imperial period for controlling the rates of flow of the river and for navigational and commercial use. The submersed delta is built on the continental platform, about 100 m deep, as it can be seen 4-6 nautical miles off the coast.

Preliminary bathymetric investigations show morphologic discontinuities from shore to offshore. The Isola Sacra profile (fig. 2) shows the most ample variations: the delta front (mean inclination 2 ‰), the prodelta slope, the continental platform margin, the continental slope. The profile of the prodelta indicates the most recent mass movement structures (SEGRE, 1967; WRIGHT, 1978).

Texture

Samples have been classified according to Shepard (1954) as sand, silt, clay percentages. Fig. 3 outlines a predominance of sands, silty sands and clayey silts. Few samples can be defined sandy silts, silts or loams. In order to obtain a less schematic, closer to natural conditions, classification, data have been processed with a "Q" type factor analysis (Klovan, 1966; Davis, 1973; Klovan, 1975; Ciabatti & *alii*, 1974). This also allowed to relate the provisional granulometric facies to the depositional hydrodynamic conditions.

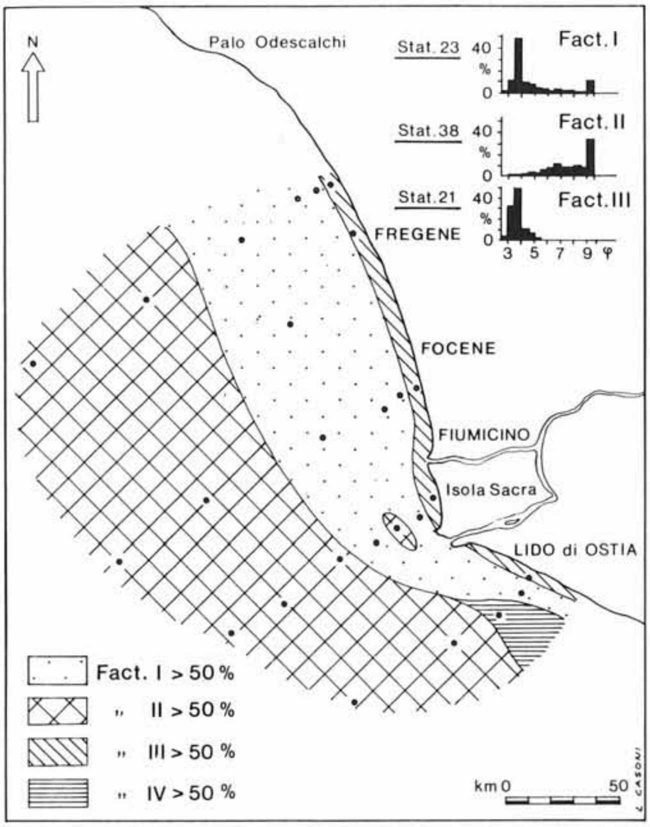

Fig. 4 - Distribution of principal grain-size 'factors': the hystograms show the "end-member" composition.

The results point out three factors, corresponding to the principal "facies". Their compositions are well represented by samples 23 (Factor I), 38 (Factor II), 21 (Factor III), that can be assumed as "end members" (see histograms and classification according to Shepard in figs. 3 and 4).

Sample 23 is a fine grained sand with fine silt, sample 38 is a very silty clay, sample 21 is a fine grained sand. Table 1 lists the statistical parameters according to Folk & Ward (1957). Fig. 4 shows the distribution pattern of the principal facies in a highly schematic sketch, as it reports the prevailing distribution of all the Factors extracted by the Factor Analysis. The depositional "facies" related to Factor III indicates nearly constant high energy above the sea floor: its area of predominance lies alongshore, energy is due to wave motion. The facies related to Factor I is typical of a high mean energy domain, due to wave motion and/or to currents. Periods of calm allow deposition of fine grained silts; it is distributed in the delta front, 10-15 m deep. The facies related to Factor II lie in a low mean energy domain: gravity deposition of the finest particles occurs. This facies is extended seaward, on the prodelta and out seaward, and in a little region 1-2 km offshore in front of the river mouth. The temporal and spatial persistency of the "facies" of this area may be less stable than it is seaward. Actually, during periods of calm and low rate of flow, gravity deposition of the fine particles transported by the river might occur with sedimentation rates exceeding resuspension processes during periods of highly disturbed water body. Fig. 4 illustrates a late summer-fall situation (Klovan, 1966; Visher, 1968). In conclusion, the composition of almost all the samples can be represented either by the "end members" defined above, on by a proportioned mixture of them. Sample composition according to this classification are found in fig. 3: most samples are of intermediate composition between Factors I and III.

TABLE 1

Statistical parameters of end members according to Folk & Ward.

sample n.	Mz	σ_I	SK_I	K_G
23	4.47	1.43	0.74	2.59
38	7.89	1.31	-.31	0.69
21	3.10	0.45	0.03	1.16

A detailed discussion of F.A. results reveals the presence of a secondary facies (Factor IV), that probably corresponds to a depositional environment different from the principal ones. This secondary facies has not been clearly defined because of the limited number of samples; it seems to interfere with the other main facies as a group of samples, located South, and it is enriched in silts. The distribution of sand, silt, clay percentages over three transepts (fig. 2) add detail to the discussion.

The clay fraction along Isola Sacra has a peak connected with the fine grained depositional area off the principal outlet, that can probably be related to flocculation phenomena of clay minerals at the fresh water/salt water mixing layer (Biggs, 1978).

Physical and chemical features

Table 2 shows mean values and ranges of the analyzed parameters; table 3 shows nutrients concentration and salinity of bottom waters and a tentative concentration Factor (K) for N—NH_4^+, P—PO_4, Si—SiO_2; table 4 gives a comparison of the concentrations of the elements with samples from the Northern Adriatic Sea analyzed at this Institute. As concentration of organic matter and of some nutrients in sediments may vary considerably with sediment texture (AA.VV., 1978; Frascari & *alii*, 1979; Angeloni & *alii*, 1979), the good likeness of these coastal areas is favorable for comparison with known data (tab. 4):

TABLE 2

MEAN AND RANGE FOR CHEMICAL PARAMETERS (SEDIMENTS).

	inP (a)	orgP (a)	extP (a)	Si (a)	$N-NH_4$ (a)	orgN %	orgC %	pH	Eh mV
mean	500.5	203.8	9.5	36.2	3.44	0.05	0.46	7.49	+123
max	706.9	763.6	18.7	96.3	9.24	0.107	1.00	7.93	+318
min	225.1	7.3	4.1	15.3	0.78	0.011	0.08	7.11	-039
cv %	21.3	82.8	41.1	59.2	69.7	70.4	65.1	2.9	47.2
s	106.5	168.7	3.9	21.4	2.40	0.035	0.30	0.22	105

(a) concentration expressed as mg/kg dry weight.

TABLE 3

NUTRIENTS AND SALINITY OF BOTTOM WATERS AND CONCENTRATION FACTOR (K).

	sal. ‰	$N-(NO_2+NO_3)$ (b)	$N-NH_4$ (b)	$P-PO_4$ (b)	$Si-SiO_2$ (b)
mean	-	12.6	23.1	5.56	134
max	38.1	39.0	48.5	30.66	261
min	36.9	2.2	6.0	0.66	69
cv	-	67.0	49.8	168.0	37.6
s	-	8.4	11.5	6.0	50.2

(b) concentration expressed as mg/m^3 dry-weight

K = concentration factor = [ ] sed* / [ ] water.

$N-NH_4$ 10.09×10^3 / 23.10 = 437

$P-PO_4$ 27.86×10^3 / 3.56 = 7826

$Si-SiO_2$ 106.20×10^3 / 134.00 = 792

$$^{*}C_1 = \frac{(100-a) \cdot C_2 \cdot sw}{a}$$

C_1 ppm in the interstitial water of sediment

C_2 ppm in sediment, dry weight

a % of water in sediment

sw specific weight (1.6 with 40% of sand)

a) nitrogen compound values are low (mean $N-NH_4$: 3.4 ppm; org N: 0.05 %);

b) organic phosphorus values are high (mean: 203 ppm);

c) all other parameters fall within the normal ranges: e.g. inorganic compound of phosphorus (mean inorg P : 500 ppm; extr P : 9.5 ppm); organic carbon (mean: 0.46 %) and extractable silica (mean: 39 ppm).

A matrix of the linear correlation coefficient "r" was calculated (tab. 5) and a Cluster analysis was performed (DAVIS, 1973) for all samples. The dendogram of fig. 5 gives a tentative evaluation of multiple correlations between variables and the relationship between three groups of elements well correlated to each other. Only ammonia cannot be correlated to any other parameter: the probable cause is the direct influence of fresh water inputs (LA NOCE & *alii*, 1980). This hypothesis is supported by the distribution pattern of the high values, all from delta front samples, off both river mouths (nearshore mean: 5.2 ppm; offshore mean: 1.9 ppm); the distribution is more similar to that found in the overlying water body than dependent on the physical settling mechanism of the suspended organic matter (BILLEN, 1975). Three correlated groups are formed by:

1) org C, org N and precentage of water (hydration) coefficient are strongly correlated (r = 0.8-0.9) to each other and to the finest grained parcticles (<2 μ);

2) phosphorus compounds and extractable silica are well correlated to each other and to silt (2-62 μ);

3) pH and redox potential are strongly correlated (r = 0.7-0.8) with the coarse grained fraction (>62 μ) and, as group, negatively correlated with groups 1 and 2.

The strong positive linear correlation coefficient among org C, org N, hydration coefficient, depth and clay percentage and negative with pH (fig. 6) considered together with the areal distribution of the parameters (fig. 7), supports traditional ideas that:

TABLE 4

COMPARISON OF PRESENT WORK DATA WITH OTHER COASTAL AREAS OF MEDITERRANEAN SEA.

	inP mg/kg	orgP mg/kg	extP mg/kg	Si mg/kg	NH3 mg/kg	orgN %	orgC %
present work (26)	500 226-707	204 8-764	9.5 4-19	36 15-96	3.4 0.8-9.2	0.05 0.01-0.11	0.46 0.08-1.00
Po River delta (63)[a]	485 330-749	120 1-233	14.7 5-26	73 6-184	6.4 0.7-19.0	0.09 0.02-0.28	0.64 0.08-1.86
N Adr.Sea (64)[b], summer	481 224-860	74 8-263	6.1 4-19	38 7-136	5.1 0.4-40.0	- -	0.44 0.08-1.30
N Adr.Sea (38)[c], winter	532 278-1152	75 2-209	9.3 2-28	43 9-97	4.5 0.4-23.0	- -	0.41 0.07-1.30

Number of samples in parenthesis; range under mean for all variables. a) Frascari & alii, 1979; b) AA.VV., 1978; c) Angeloni & alii, 1979.

TABLE 5

LINEAR CORRELATION COEFFICIENT MATRIX.

	inP	orgP	extP	Si	NH_3	orgC	H_2O	orgN	pH	Eh	depth	sand	silt	clay
inP	1.000													
orgP	0.201	1.000												
extP	0.477	0.474	1.000											
Si	0.321	0.524	0.608	1.000										
NH3	0.117	0.062	0.206	-.142	1.000									
orgC	0.256	0.367	0.612	0.228	-.049	1.000								
H2O	0.399	0.387	0.504	0.221	-.274	0.835	1.000							
orgN	0.445	0.452	0.613	0.338	-.136	0.849	0.925	1.000						
pH	-.486	-.308	-.503	-.091	-.232	-.716	-.639	-.746	1.000					
Eh	-.491	-.331	-.373	-.086	-.392	-.481	-.390	-.492	0.750	1.000				
depth	0.330	0.266	0.411	0.088	-.269	0.767	0.933	0.796	-.526	-.241	1.000			
sand	-.666	-.405	-.602	-.345	-.060	-.670	-.769	-.846	0.804	0.610	-.673	1.000		
silt	0.708	0.335	0.572	0.384	0.186	0.335	0.413	0.519	-.633	-.527	0.342	-.872	1.000	
clay	0.408	0.357	0.450	0.188	-.095	0.841	0.932	0.952	-.742	-.514	0.837	-.825	0.443	1.000

For N = 26: r • 0.49 significant at 99.0% confidence level; r • 0.60 significant at 99.9% confidence level.

a) the organic matter content, mostly affected by river input, is higher in the finest grained sediments (DE GROOT & *alii*, 1976; CAHET & GADEL, 1976);

b) the organic substances are dissolved in the so called "polywater" (HALLBERG & *alii*, 1973; HORN & *alii*, 1968);

c) the pH of the sediments generally decreases with increasing concentration of decaying organic matter (KRAUSKOPF, 1979).

This group is also correlated, although at a lower confidence level (r = 0.5), with organic phosphorus, thus completing the organic matter cycles. The probable fluvial origin of the organic material is also confirmed by C/N/P ratios in the sediments: the C/N values are higher than the "typical" marine value (106/16) and N/P values are generally much lower than (16/1) (REDFIELD & *alii*, 1963).

This could be due to the relatively low content of organic nitrogen and high content of organic phosphorus in the sediments. The second group of strongly correlated parameters (r = 0.7) includes pH, redox potential and sands (>62 μ): we can particularly note the strong correlation between pH and sand percentages (fig. 8) due to the influence of sudden changes in salinity and oxigen content of bottom water, related to fresh water inputs and/or to high wave energy (BAGANDER & NIEMSTO, 1979). Both pH and Eh present a distribution pattern with the lowest values (mean pH = 7.34; eH = +55) in the prodelta and seaward of it; the highest values (mean pH = 7.62; Eh = +180) are found at the delta

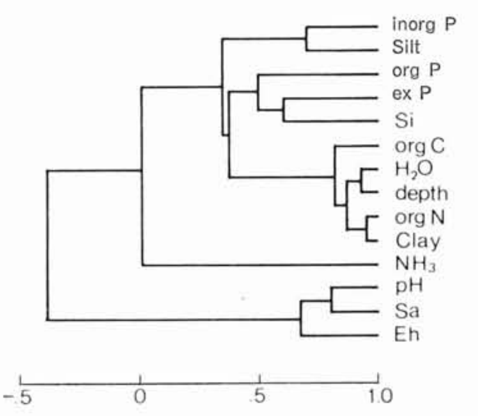

FIG. 5 - Correlation coefficients dendrogram (after Cluster An. of all variables).

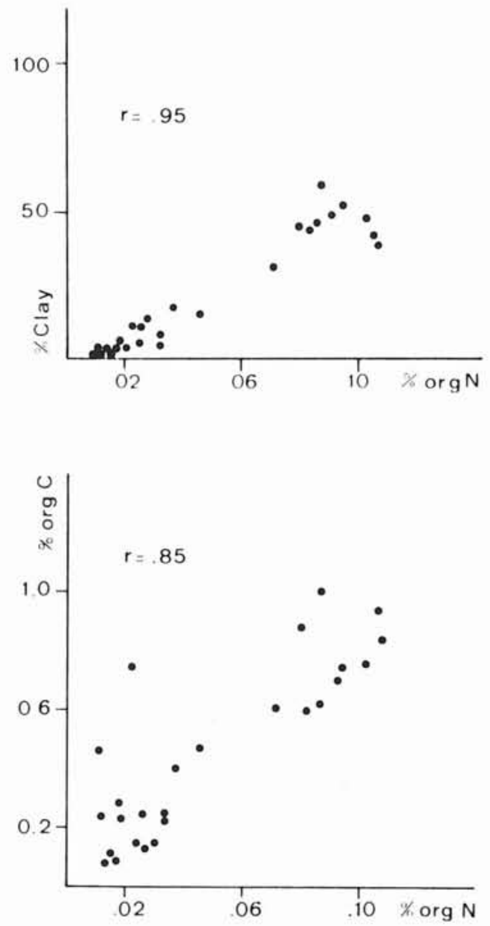

FIG. 6 - Plot of org C, org N and clay % in surface sediments.

front with the exception of areas directly affected by flocculation of fluvial pelites rich in organic matter (figs. 8 and 9).

Redox contour lines lower than +100 mV (fig. 9) show reducing areas with conditions for the mineralization of organic nitrogen and a marked increase in extractable phosphorus (HALLBERG, 1973; PATRICK & *alii*, 1977). The interpretation of the third group; including some P compounds, extractable Si and the silt fraction (2-62 μ) is difficult because of the interactions of different biochemical and physical processes, i.e.:

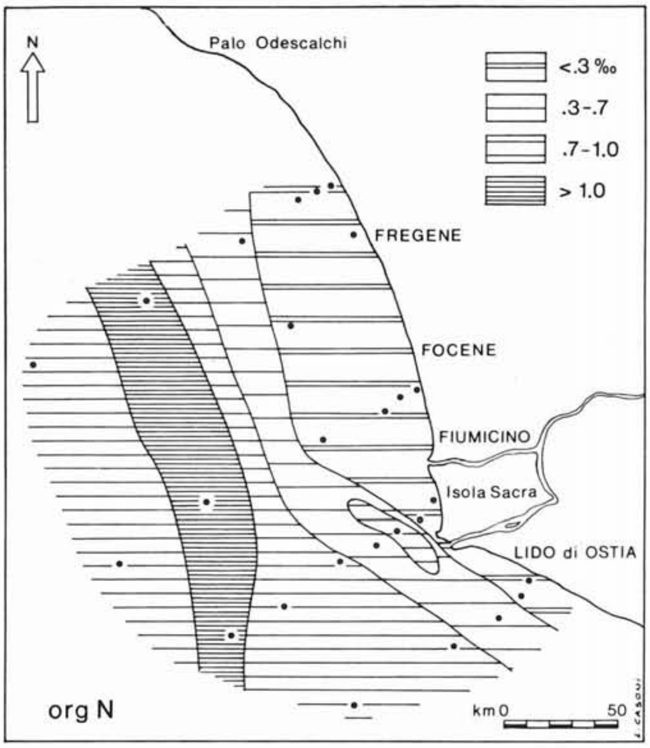

FIG. 7 - Distribution of organic nitrogen (mg/g, dry weight) in surface sediments.

a) the tendency of phosphorus to co-precipitate with iron oxide in the sediments on the surface of silt (see also plot of fig. 10) parcticles (PATRICK, 1964; PATRICK & DELAUNE, 1977);

b) the organic phosphorus mineralization (SHIPPEL & *alii*, 1973);

c) the exchange mechanism between phosphates within the sediments and in the overlying waters (PATRICK, 1964);

d) the influence of phytoplancton on the P and Si contents in the sediments (BLUNDO & *alii*, 1980). The third group shows, therefore, a correlation at a low confidence level (r = 0.5) with group 1.

A comparison between nutrients in sediments and in the overlying bottom waters show different K (concentration factors), ranging from 150 for $N—NH_4^+$ to 2650 for $P—PO_4$. The distribution of K highest values is principally between 5 and 15 m depth (expecially for $N—NH_4^+$ and $P—PO_4$), while the $Si—SiO_2$ values show a random distribution.

CONCLUSIONS

The present work give a preliminary description of the geomorphology of the Tiber delta and of the grain-size patterns of surficial sediments; moreover the comparison of nutrients with other coastal areas of the Mediterranean and with bottom waters at the same stations stresses:

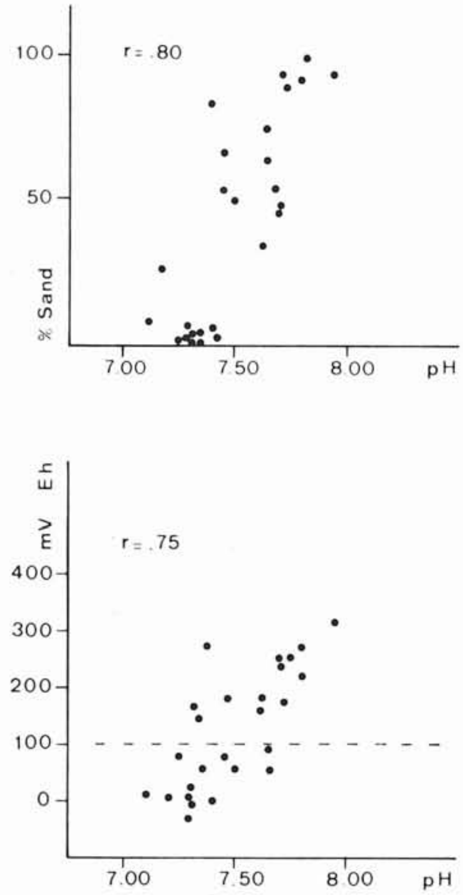

FIG. 8 - Plot of Ph, redox and sand % in surface sediments.

a) the distribution patterns of organic an inorganic compounds in sediments, related with the finer grained fractions (clay and silt respectively);

b) the high correlations between the electrochemical parameters (pH and Eh), the coarser sediment (directly) and the organic matter (negatively).

The preliminary results indicate also the "delta front" as the best target area to study thoroughly the influence of sediments on the coastal water quality (as for nutrients) of the ecosystem around the Tiber delta: shallow water (5 to 15 m depth), the complexity of physical and chemical phenomena (due to mixing mechanisms and flocculations), the alternate occurence of reducing conditions (and the highest "K" for N—NH_4^+ and P—PO_4) can cause strong seasonal interactions between the upper portion of the sedimentary bed and the overlying water body.

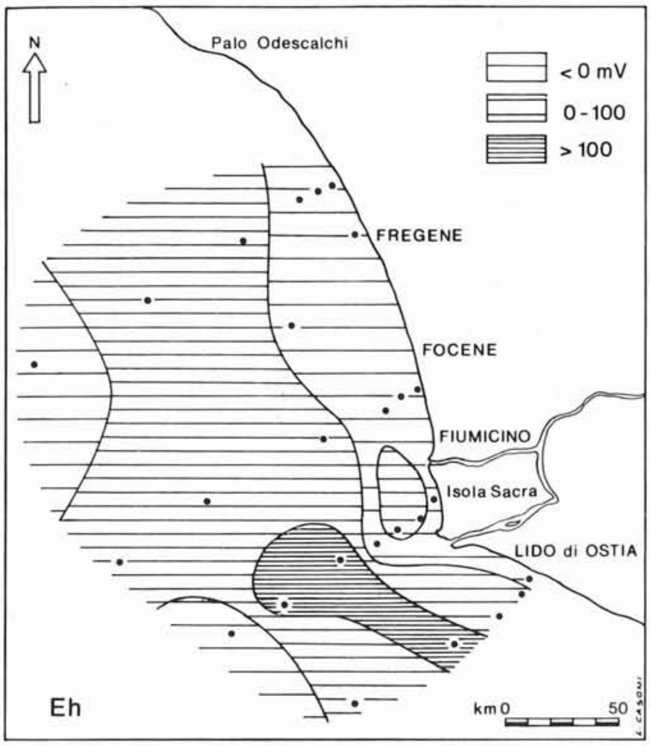

FIG. 9 - Contours of redox values (expressed in mV) in surface sediments.

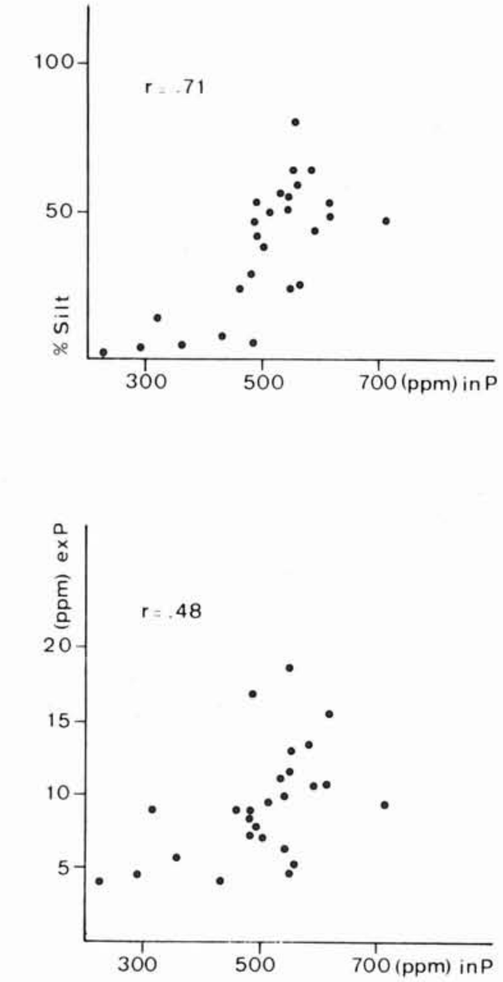

FIG. 10 - Plot of inorg P, extr P and silt content in surface sediments.

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