Journal of Coastal Research	11	3	690–696	Fort Lauderdale, Florida	Summer 1995

Annual Sedimentation Rates and Role of the Resuspension Processes Along a Vertical Cliff (Ligurian Sea, Italy)

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ABSTRACT

BAVESTRELLO, G.; CATTANEO-VIETTI, R.; CERRANO, C.; DANOVARO, R., and FABIANO, M., 1994. Annual sedimentation rates and role of the resuspension processes along a vertical cliff (Ligurian Sea, Italy). *Journal of Coastal Research*, 11(3), 690–696. Fort Lauderdale (Florida), ISSN 0749-0208.

The annual sedimentation rates along a Portofino Promontory (Ligurian Sea, Mediterranean) cliff were studied using small sediment traps fixed directly to the rocks at 15, 20 and 25 m depth.

Monthly comparisons were made of organic and inorganic matter originating from biological production and cliff erosion in the upper water levels, with suspended matter collected in the water column close to the bottom. The highest quantity of coarse matter, related to the rainfall, was collected in the top trap. Fine sediments were due to the local sea conditions, *i.e.*, wave suspension, and increased from the shallow to the deepest trap. This suggests that resuspension of fine sediments from the sea floor may represent an important fraction of settling matter at lower levels of the submerged coastal cliff. TOM and TSM in the water column are well correlated both at the interface and 1 m above sea floor but not with the amounts of sedimented material. Their annual trends reflect rainfall values, suggesting an influence of the terrigenous outflows.

ADDITIONAL INDEX WORDS: *Sediment trap, cliff erosion, coastal sediments, suspended matter.*

INTRODUCTION

In recent years, several studies have been carried out on the coupling between pelagic primary production and the structure and functioning of the soft-bottom communities (HARGRAVE *et al.*, 1976; SMETACEK, 1980; TAGUCHI, 1983; BHOSLE *et al.*, 1989). Along coastal cliffs, little is known about this relationship (HEDGES *et al.*, 1988; EVANS *et al.*, 1980; GULLISKEN, 1982; BAVESTRELLO *et al.*, 1991) which appears to be affected not only by the pelagic primary production and local hydrographic regime (SMETACEK, 1980), but also by other factors, such as rainfall and wave action (BAVESTRELLO *et al.*, 1991). Only a small fraction of the primary production is used by hard bottom communities inhabiting the vertical cliff, while a large quantity of organic matter falls on the sea floor, playing an important role in the trophic chains of soft-bottom communities (ODUM and DE LA CRUZ, 1967; MANN, 1972; HEDGES, *et al.*, 1988; PELET, 1977; EVANS *et al.*, 1980). During rough sea periods, this sedimented matter is resuspended by wave action and contributes to the organic fraction of the water column (ZUNINI-SERTORIO and FABIANO, 1991).

In the present study, the nature and origin of the settling matter and its contribution to resuspended sediments were investigated using traps directly fixed at different depths along a high-energy cliff of Portofino Promontory (Ligurian Sea). In order to understand which factors influence the sedimentation processes, data collected from the traps were compared to the seasonal cycles of the total organic matter (TOM) and total suspended matter (TSM) collected at the water-sediment interface and, in the water column, 1 m above the bottom.

METHODS

Three sediment traps have been placed adherent to a vertical cliff near Punta del Faro (Por-

94013 received 28 January 1994; accepted in revision 10 May 1994.

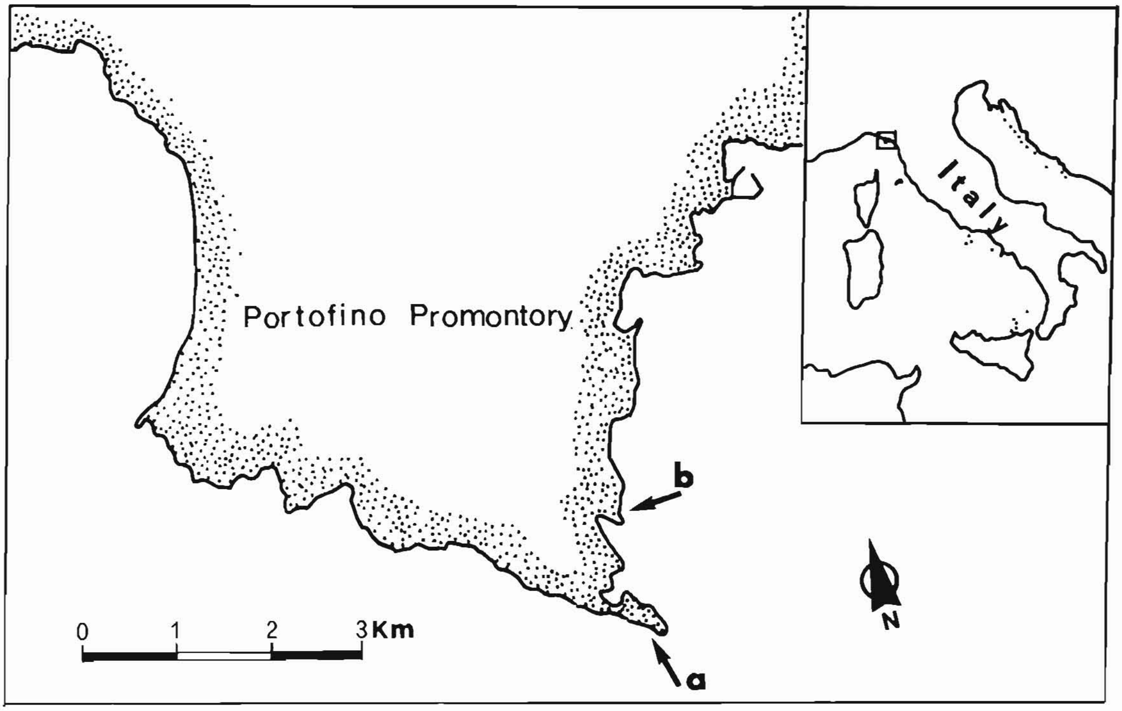

Figure 1. Sampling area at Portofino Promontory (Ligurian Sea): Punta del Faro (a). Paraggi Bay (b) is also marked.

tofino Promontory, Ligurian Sea, Mediterranean Sea, Figure 1). This kind of trap consists of a rectangular funnel with a mouth of 2 cm × 20 cm converging into a cylindrical collector 20 cm long (BAVESTRELLO *et al.*, 1991). The first trap was at 15 m depth, inside a pre-coralligenous community, characterized by the green alga *Halimeda tuna*; the second was located on a slightly over-

Table 1. *Meteorological data and sediment amount in traps and water column.*

	Average Wave Height	Average Rainfall (mm/	Trap 1 15 m ($g/m^2/day$)			Trap 2 20 m ($g/m^2/day$)			Trap 3 25 m ($g/m^2/day$)			TOM (mg/l)		TSM (mg/l)	
Date	(cm)	day)	cs	fs	ad	cs	fs	ad	cs	fs	ad	in	ab	in	ab
9.2.90	41.3	1.7	0.90	2.56	0.01	1.00	8.18	3.10	1.12	7.28	0.12	2.56	1.66	9.85	7.55
16.3.90	53.5	0.6	1.06	5.55	0.60	0.83	8.33	1.19	0.78	10.60	0.04	2.70	2.83	8.10	9.03
5.5.90	47.0	6.2	2.42	1.15	0.00	1.67	1.67	0.00	1.66	2.72	0.00	3.52	2.8	9.78	6.83
1.6.90	17.0	0.3	0.23	2.08	0.00	0.00	0.98	0.89	0.00	1.99	0.02	4.4	1.98	12.94	5.14
14.6.90	63.6	0.8	0.00	2.58	1.36	2.54	7.77	6.11	0.00	8.51	1.18	3.19	2.15	11.39	9.77
10.7.90	45.6	0.2	0.00	1.68	0.07	1.60	1.31	2.71	1.33	1.67	0.62	2.73	3.09	9.93	10.84
2.8.90	10.0	0.9	1.17	0.96	0.01	2.12	1.17	1.68	1.17	1.00	0.40	4.05	3.41	13.06	9.74
23.8.90	27.5	2.8	2.80	2.42	1.61	4.29	0.91	4.64	2.06	2.37	0.68	3.85	3.17	16.04	10.93
6.9.90	30.0	5.3	2.03	1.79	0.69	1.75	0.48	0.71	1.26	2.05	0.14	6.1	3.87	21.40	7.90
19.9.90	30.7	2.1	2.33	3.50	0.71	5.24	0.88	1.51	4.91	4.51	0.01	5.18	5.66	18.50	17.69
7.11.90	59.9	12.7	10.14	5.63	1.81	2.30	0.86	0.88	8.74	8.85	0.40	4.45	4.35	14.13	15.00
3.12.90	53.9	4.6	6.20	4.16	0.35	5.83	6.66	1.92	7.76	10.03	1.58	4.07	4.05	13.34	10.38
1.2.91	31.1	6.1	2.84	6.55	0.03	6.94	9.64	2.67	2.68	6.79	0.03	4.78	3.7	17.70	10.88

cs = coarse sediment; fs = fine sediment; ad = algal debris; in = interface; ab = 1 m above

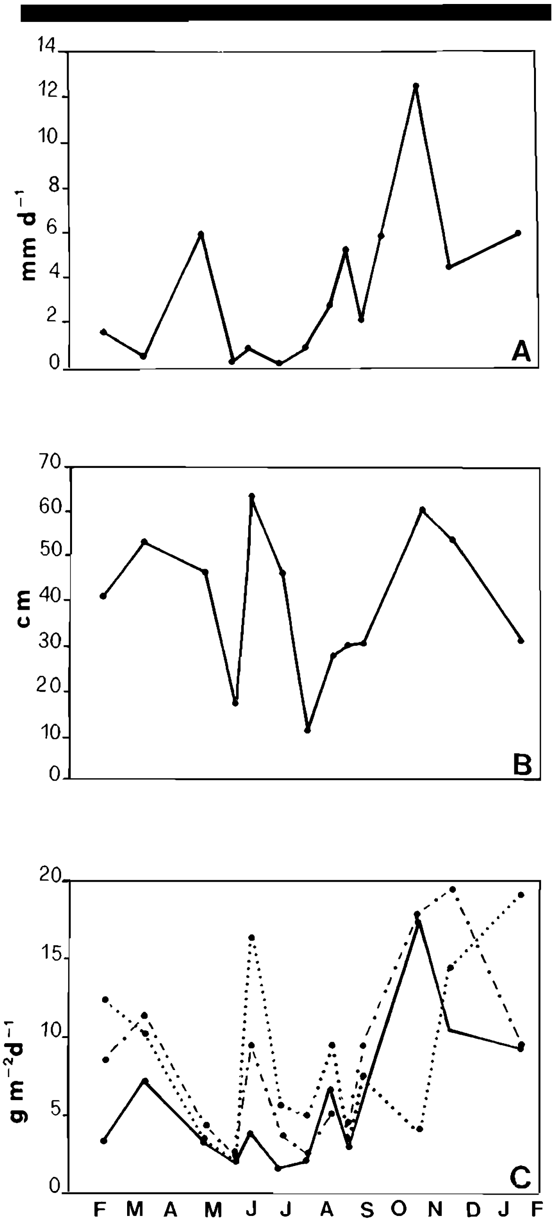

Figure 2. Annual trends of: rainfall (A); sea conditions as wave height (B); total collected sediments (C) at: 15 m depth (continuous line), 20 m depth (dotted line), 25 m depth (dashed line); traps 1, 2 and 3 respectively. All the data are reported as daily average of the considered period.

hanging wall inside a facies of the brown alga *Dictyota dichotoma*, at 20 m depth, and the third was placed within a *Corallium rubrum* facies, at 25 m depth. From January 1990 to February 1991, monthly observations were carried out and samples collected by SCUBA diving (Table 1).

Each trap was filled with 50 cc of chloroform to prevent bacterial decomposition of the collected matter and, after the collection, the samples were fixed in 4% formalin. The algal fragments were taken from the sediment, using a stereomicroscope and weighed separately. The sample was then dried at 60 °C (3 h) and weighed in two fractions, fine ($\phi > 0$, Wentworth scale) and coarse ($\phi < 0$). The organic matter content was calculated as the difference between the dry weight of the sediment and the residue left after combustion (ash-free dry weight) at 550 °C (4 h) (PARKER, 1983). At each sampling date (Table 1), 10 l of sea water was collected at the water-sediment interface and at 1 m above the bottom in order to analyze the total suspended matter (TSM), total organic matter (TOM). Water samples were filtered through Whatman GF/C 0.45 μm for TSM and TOM. The total suspended matter was analysed using the gravimetric method after drying (3 h at 60 °C), while the organic matter content was evaluated by the difference between the weight of the dry sediments and the residue left after combustion (550 °C, 4 h). Data on daily rainfall (mm d^{-1}) and sea conditions (measured as wave height) were kindly supplied by the Osservatorio Geofisico of the University of Genoa. Spearman-Rank correlations on non-transformed data were carried out using the programme STATGRAF.

RESULTS

This study was carried on along the cliff of Punta del Faro (Portofino Promontory) which is composed of an oligocenic conglomerate (GIANMARINO *et al.*, 1959). The studied cliff ends at 40 m depth on a detrital bottom (PANSINI and PRONZATO, 1975). The site shows a high level of hydrodynamism and it is not directly influenced by river and stream outflows.

Meteorological data, sedimented matter, TOM and TSM values from the water column are summarized in Table 1.

The amount of deposition shows a characteristic trend with wide variations during the year at all the considered depths (Figure 2). The average values range from 6 to 7 g m^{-2} d^{-1}. Highest values are recorded during the period between autumn and spring, with a strong decrease during the summer. At the beginning of this period, usually at 20 and 25 m depth, a strong peak can be

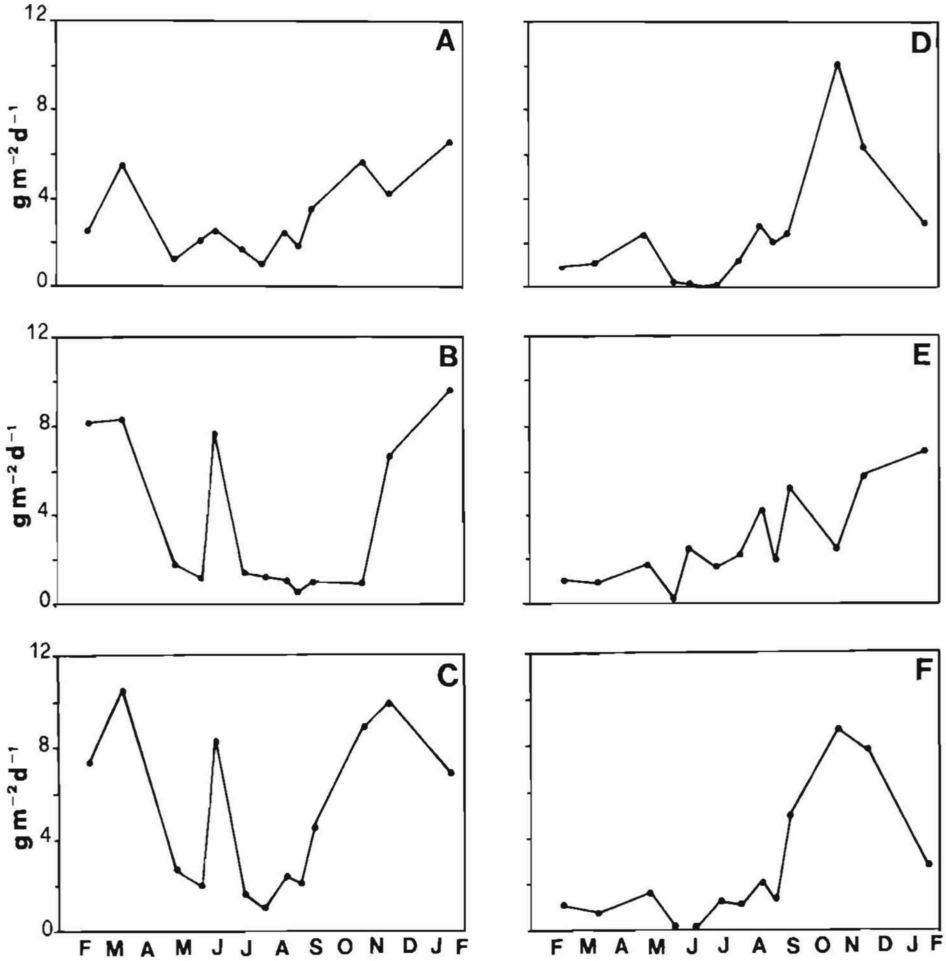

Figure 3. Annual trends of the collected sediments in the three traps. A, B, C: fine matter in traps 1, 2, 3, respectively. D, E, F: coarse matter in traps 1, 2, 3, respectively. The data are reported as daily average of the considered period.

observed, corresponding to heavy rainfall and rough sea periods.

Differences arise when studying separately the two granulometric fractions. The fine sediments collected by the superficial trap (Figure 3A) are abundant mainly in two distinct periods as follow: February–first half March (about 6 g m^{-2} d^{-1}) and from October to January (about 6–7 g m^{-2} d^{-1}) and are related to rainfall ($n = 13$; $p < 0.05$). In the second and third trap (Figure 3B and C), the fine sediments collected show a strong correlation with the average wave height ($n = 13$; $p < 0.05$ and $p < 0.001$ respectively) with three peaks in February–first half of March, June and October–January (about 8–10 g m^{-2} d^{-1}).

The coarse sediments are mainly composed of inorganic matter derived from the erosion of the cliff and animal debris (exuvias, serpulids tubes, shells). Most of this fraction was collected in the first trap (about 10 g m^{-2} d^{-1}) in October (Figure 3D), and its annual trend is again closely liked to the rainfall ($n = 13$; $p < 0.001$). Also the deepest trap (Figure 3F) shows a trend significantly correlated with rainfall ($n = 13$; $p < 0.001$), while no correlation can be found for trap 2, probably as a result of the particular slope of the cliff in this point. Algal debris has been collected mainly at 20 m depth (Table 1), inside the *Dictyota dichotoma* facies.

In the water column, the trends of TOM (Figure

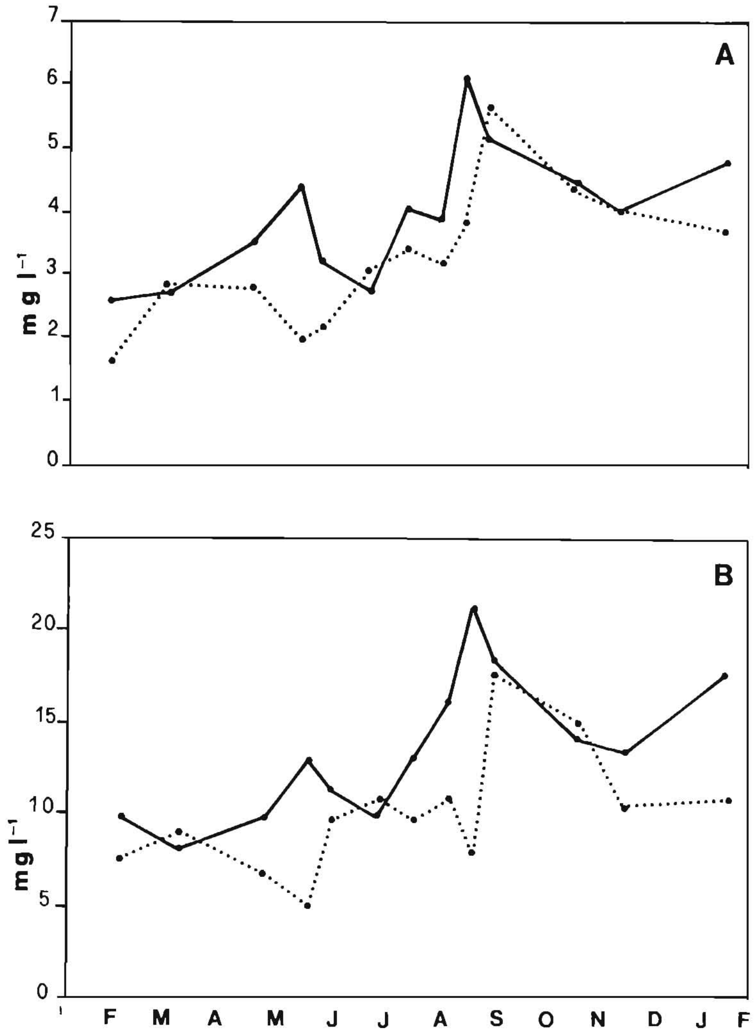

Figure 4. Annual trends of TOM (A) and TSM (B) in the water column at 1 m above the bottom (dotted line) and at the water-sediment interface (continuous line).

4A) and TSM (Figure 4B) are similar, and TSM values are at the interface level significally higher during the whole year ($p < 0.05$, Student t-test). Moreover, at both the depths at the beginning of the first September storms, an increase of all the considered parameters is evident, correlated with rainfall values ($n = 13$; $p < 0.01$).

DISCUSSION

The present investigation on trapped sediments has made evident the occurrence of a clear seasonality in sediment accumulation rate along a high-energy cliff, characterised by low values in summer-early autumn and high values in winter and spring. Similar patterns were found by BAVESTRELLO *et al.* (1991) in the Paraggi Bay (Ligurian Sea) and by ZEITZSCHEL (1965) and LUND-HANSEN (1991) in the Kiel Bay. The values of the sedimentation rates found in this study are comparable with those reported from northern European localities (SMETACEK, 1980; HARGRAVE and BURNS, 1976; WASSMANN, 1983, 1985).

The quantity and composition of sedimentation are clearly influenced by the local hydrodynamic conditions. This is well documented by the comparison between the present data and those collected by BAVESTRELLO *et al.* (1991) from Paraggi Bay, a locality very close to Punta del Faro (Figure 1), but much more sheltered from wave action with a seven times higher sedimentation rate. At Punta del Faro, in fact, the cliff is exposed to the main littoral ligurian current which flows from east to west and measures about 30 cm sec^{-1} (STOCCHINO and TESTONI, 1979). The Paraggi Bay, on the contrary, can be considered a decantation area, because a secondary branch of the main current slows down, flowing along the eastern coasts of the Portofino Promontory (SARA' *et al.*, 1978) forming the so-called "Gulf of Tigullio circuit". These different hydrodynamic conditions are not only at the basis of these quantitative differences, but also can define the qualitative composition of the settling matter. At Paraggi Bay, for instance, the fine sediment fraction, well represented during a large part of the year, is related to the coarse sediments owing to a reduced resuspension incidence. The opposite takes place at Punta del Faro, where the annual trends of the two fractions seem to be independent. Indeed, the fine sediment is more directly linked to wave action than the coarse one and is mainly controlled by the rainfall, which washes away the terrigenous detritus into the sea. Even if the organic fraction of the coarse sediment (animal debris) is quantitatively important, it is lighter than the inorganic one and consequently has a minor influence on the weight relationship. Obviously only the heavier fraction (gravel), originating from the erosion of the cliff, is linked to the rainfall. Along the Portofino Promontory cliff, the fine sedimented matter in agreement with GARDNER's (1977) results was related to the sea conditions, also determining an important resuspension. On average, fine sediments in the deepest trap constituted 66.6% of the total settling matter, and only 52.2 and 55.0% in the traps placed at 15 and 20 m depth. If we assume that the top trap was not significantly influenced by resuspended sediments, in the deepest trap a good fraction of fine sediments (12–15% of total sediment collected) could be related to the resuspension process.

Algal debris are also linked to the sea conditions. This fraction was mostly found in the traps during autumn, in connection with the end of the biological cycle of many macroalgae, but no direct relationship can be envisaged between the cycle of the algal debris and that of TSM and TOM in the water column. Algal debris before contributing to the particulate suspended matter undergo physical and biological processes, *i.e.*, dispersion, degradation, deposit-feeders ingestion, etc. These processes delay the presence of algal debris in the suspended particulate matter.

Finally, TOM and TSM, as expected, are well correlated both at the interface and 1 m above sea floor, but not with the amount of sedimented material. Their annual trends reflect rainfall values, suggesting a terrigenous origin of this kind of material.

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