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MINERALOGY, CHEMISTRY AND GRAIN SIZE COMPOSITION OF THE BOTTOM SEDIMENTS IN THE ELBA-ARGENTARIO BASIN (SOUTHERN TUSCANY, ITALY): CONTRIBUTION TO THE ASSESSMENT OF SEDIMENT SOURCES AND DYNAMICS (**)

Abstract - In the frame of a research program on the environmental quality of Tuscany's continental shelf, the textural, mineralogical, and chemical characteristics of the bottom sediments in the Elba-Argentario basin have been analyzed. Mineralogical and grain size data have been applied to the assessment of sediment sources and movement patterns.
The greatest part of the basin area is occupied by clays and silty clays, mostly contributed by the Ombrone River. These sediments are dominated by illite (> 50% of the non-carbonate fraction), to which minor amounts of chlorite, kaolinite, and smectite (all in the range of 5-15% of the non-carbonate fraction) are associated. A contribution to the clay sedimentation from allochtonous sources has been appreciated in some peripheral areas such as the Elba Ridge (wind-blown kaolinite and chlorite) and the southern zone of the basin (smectite from the Latium rivers). But the Elba Ridge shallow sea-bed appears mostly affected by the sedimentation of bioclastic carbonate sands, which make up the dominant sediments (though mixed with an important terrigenous component) also in the current-swept Piombino Channel.
As to the agents of transport, littoral drift carries the coarse grades of the Ombrone River sediment load both northward and southward from the river mouth; these sediments blanket the shallow belt (< 10 m deep) bordering Italy's mainland. The fine-grained sediments are transported by a northward-flowing current, which interacts with an irregular coastal and bottom topography to set up a slow circular movement of water similar to an anti-clockwise small-scale gyre. This explains the distribution of the fine-grade sedimentary facies in concentric belts around the basin's central trough.

Key words - Marine sediments, Mineralogy, Chemistry, Grain size, Continental shelf, Elba-Argentario basin, Southern Tuscany, Italy.

Riassunto - *Composizione granulometrica, chimica e mineralogica dei sedimenti di fondo del bacino Elba-Argentario (Toscana meridionale, Italia): contributo allo studio dell' origine e del trasporto del materiale sedimentario.* Nell'ambito di un programma di ricerca sulla qualità dell'ambiente nella zona della piattaforma costiera toscana sono state studiate le caratteristiche mineralogiche, chimiche e granulometriche dei sedimenti di fondo del bacino compreso fra l'isola d'Elba ed il promontorio dell'Argentario. I dati raccolti sono stati utilizzati per individuare le più importanti sorgenti del materiale sedimentario e per determinare i principali meccanismi di distribuzione di tale materiale.
La maggior parte del fondo del bacino è occupata da argille e da argille limose, per lo più riferibili al carico di torbida del fiume Ombrone. Questi sedimenti sono costituiti in prevalenza da illite (> 50% della frazione non-carbonatica), a cui si accompagnano quantità minori di clorite, caolinite e smectite (ciascuna compresa nell'intervallo 5-15% della frazione non-carbonatica). È stato evidenziato un contributo alla sedimentazione argillosa riferibile a sorgenti esterne al bacino solo in alcune zone periferiche, quali la Dorsale dell'Elba (caolinite e clorite di apporto eolico) e la zona più meridionale del bacino (smectite proveniente dai fiumi laziali). Il fondo marino in corrispondenza della Dorsale dell'Elba è però in prevalenza ricoperto di sedimenti sabbiosi bioclastici; lo stesso è stato osservato nel Canale di Piombino, dove la frazione bioclastica è comunque accompagnata anche da un'importante frazione terrigena grossolana.
Per quanto riguarda i principali meccanismi di trasporto e di distribuzione del materiale sedimentario, è stato confermato che le frazioni grossolane del carico di torbida dell'Ombrone vengono trasportate sia verso nord che verso sud (a partire dalla foce del fiume) da parte del *drift* costiero, che le disperde su una stretta fascia, poco profonda (< 10 m), lungo la linea di costa della penisola italiana. I sedimenti fini appaiono invece trasportati da una corrente che fluisce prevalentemente verso nord, ma che, interagendo con le irregolarità della costa e del fondo, forma ampi vortici caratterizzati da un movimento rotatorio in senso anti-orario. Questo schema di movimento delle acque spiega la distribuzione dei sedimenti limo-argillosi, che risultano deposti in fasce concentriche rispetto alla depressione centrale del bacino e che sono caratterizzati da granulometrie progressivamente più fini dall'esterno verso l'interno di tale zona.

Parole chiave - Sedimenti marini, Mineralogia, Chimica, Granulometria, Piattaforma continentale, Bacino Elba-Argentario, Toscana meridionale, Italia.

Introduction

Knowledge of the mineralogical, chemical (major elements) and textural composition of the sediments

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deposited in a marine basin is a key condition for the identification of their sources and the assessment of their transport-dispersion patterns. It is very important also for every environmental study requiring discrimination between natural and anthropogenic contributions of particulate materials and the trace elements associated with them; in particular, this knowledge is essential in the analysis of heavy metal distribution. For these reasons the studies recently carried out on the heavy metal distribution and accumulation in the bottom sediments of Tuscany's coastal basins (Leoni *et al.*, 1991b; 1995; Leoni and Sartori, 1996) have always been complemented with investigations on the grain size, mineralogy and major element chemistry of sedimentary materials (Leoni *et al.*, 1991a; 1992). The work presented here encompasses the study of sediment composition in the Tuscany's shelf southernmost basin, which stretches from the Elba Island to the Argentario Promontory. It is mostly aimed to expand the available data base on the basin's dynamics and to provide a detailed mineralogical-geochemical framework for assessing the sources and mechanism of heavy metal input, enrichment, and distribution (Leoni and Sartori, 1997).

Geographic and oceanographic setting

The investigated zone is an approximately circular basin with a diameter of about 85 km and an area of 5600 km^2 (Fig. 1). It is a semienclosed basin confined in the east and north-east by the mainland of Italy, in the north by the Elba island and the Piombino Channel's sill, in the west by the Elba Ridge. At the southern side the basin is open toward the southern Tyrrhenian Sea, the study area being confined here by an ideal line linking the M. Argentario Promontory to the Giglio and Montecristo islands. The basin corresponds to a block-faulted region limited in the west by a long, submerged anticlinal arch (Elba Ridge), locally rising above sea level (the Pianosa island and the Scoglio d'Africa reef). The sea bed of the peripheral parts is mostly a relatively shallow plain (depth < 200 m); the basin's center is occupied by a wide, sub-rounded depression progressively deepening southward. This trough represents a graben structure, which reaches its maximum depth just south of the Montecristo and Giglio islands (500-600 m) (Wezel *et al.*, 1981).
Italy's mainland has a morphologically variable coast. The rocky cliffed headlands of Piombino and Punta Ala enclose the wide pocket beach of Follonica. From Punta Ala, a low-lying sandy coast stretches about 30 km to the south up to the coastline of the Uccellina Mountains, where there are again hard-rock cliffs. These extend over a short distance, being followed southward by a low-lying sandy shore up to the Argentario Promontory.
This headland has a high, rocky coast. High cliffs also ring all the isles, being interrupted only on the Elba and Giglio islands by some small pocket beaches.
The sediments are delivered from a watershed characterized by a great variety of mainly sedimentary rocks, ranging from carbonatic via marly-clayey to arenaceous. These rocks are related both to sedimentary complexes involved in the Apennines orogenesis (Ligurids and Tuscan nappe) and to post-orogenic (or neo-autochthonous) sedimentary sequences. Magmatic rocks are not uncommon; they mostly consist of intrusive, sub-intrusive or volcanic acid rocks from the Tertiary and Quaternary post-orogenic magmatism of Tuscany. Less important outcrops are the ophiolitic rocks belonging to the Ligurid nappes. Within the studied area there are some of the most important mineralizations of Tuscany; among them the eastern Elba iron ores, the Campiglia Marittima and Boccheggiano (Cu - Pb - Zn) sulfide deposits, the Gavorrano and Niccioleta pyrite mineralizations, the Sb and Hg ores of Manciano and Monte Amiata.
The Ombrone River is by far the most important stream delivering sediments; its drainage basin covers an area of about 3500 km^2. At about 5 km downstream from the confluence with the last important tributary (Orcia R.), the average flow values are around 27 m^3/sec, but they may show minimum values as low as 4 m^3/sec in summer months and maximum values of 48 m^3/sec in winter (MM. LL. PP., Servizio Idrografico, 1973). The Cornia, Bruna and Albegna rivers are small streams of essentially seasonal flow; their sediment contribution to the marine basin is almost negligible.
Information on the basin water circulation pattern is detailed for littoral drifts (Aiello *et al.*, 1975; D'Alessandro *et al.*, 1979), while for offshore currents there are only fragmentary data restricted to particular areas or time periods or general investigations concerning the whole Tyrrhenian-Ligurian Sea basin (Elliott, 1979). From the Piombino Promontory to the Ombrone River mouth the dominant littoral drift direction is northwestward, with an anti-clockwise circular motion set up within the Follonica Gulf. This dominant direction may be seasonally or occasionally reversed over short distances. From the Ombrone mouth to the Argentario Promontory the longshore movement of material is most commonly from northwest to southeast; here, too, restricted parts of the coast show a reversal of the movement depending on the season and the distance from the shore. The coarse grades of Ombrone River sediment load are therefore dispersed along shore both northward and southward. As to the offshore currents there is agreement over a general surface water-current system flowing northward (Elliott, 1979); the main branch moves approximately parallel to the Italy mainland's coast, while a minor branch flows toward the Ligurian Sea (north of the studied area) through the Corsica Channel (westernmost part of the mapped area of Fig. 1).

Materials and methods

Sampling was carried out with the Bannock oceanographic ship on twelve traverses roughly perpendicular to the coastline so as to uniformly cover most

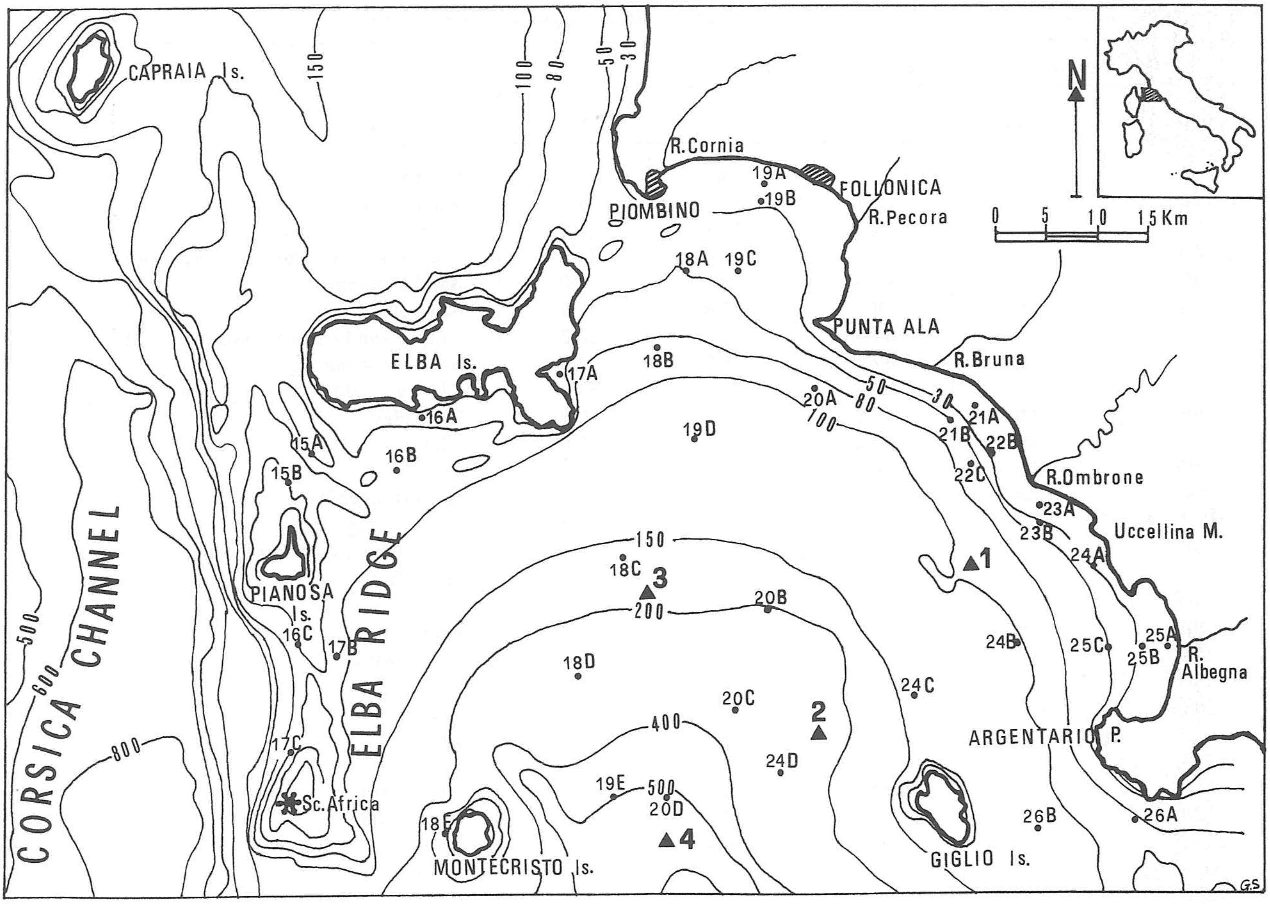

Fig. 1 - Geographic setting and location of sampling sites. Surface sediment and core sampling sites are marked by dots and triangles, respectively.

of the basin area. In nearshore zones, particularly near the Ombrone and the Albegna rivers' mouths, a more close sampling was performed.

Thirty-seven surficial sediments, sampled with a Shipeck grab (which scrapes about 2-4 cm of sediment from the sea floor), and four short cores (30 to 40 cm long), collected with a Reineck corer, were selected for this study. Locations of the grab samples (solid dots) and the cores (solid triangles) are shown in Figure 1.

The bulk samples were analyzed for grain size, mineralogy, and major element contents.

The grain size composition was determined by a combination of wet sieving (for fractions coarser than 63 µm) and sedimentation analysis with a sedigraph 5000 procedure. Bioclastics were not removed.

X-ray fluorescence spectrometry on the bulk sample was used to analyze the major elements (Franzini *et al.*,1975; Leoni and Saitta, 1976). Volatile components (H_2O, CO_2 and organic matter) were collectively determined as ignition loss (IL) at 850°C; a separate CO_2 determination by gasometric method was also performed (Leone *et al.*, 1988). The qualitative mineralogical composition of bulk samples and clay fractions was studied by X-ray diffraction analysis (XRD). Quantitative estimations of the crystalline components were made through a method that combines chemical and diffractometric data (Leoni *et al.*, 1988). In a first step, non-clay minerals were determined by X-ray diffractometry using an external standard technique (Klug and Alexander, 1974) on the bulk sample. On the basis of the chemical composition of the whole sample the results were corrected for absorption effects. The difference of total non-clay minerals from 100 was entirely assigned to clay minerals. The relative proportion of the latter were semiquantitatively estimated on the less than 4 µm fraction with the Biscaye (1965) technique. The final assessment of all mineral phase proportions was realized through a computer program (Leoni *et al.*, 1988) that combines the XRD initial data with bulk sample chemical composition.

RESULTS AND DISCUSSION

Sedimentological analysis

The grain size composition of the surficial sediments is reported in Table 1. Sedimentological analysis

Tab. 1 - Grain size composition of the bottom sediments in the Elba - Argentario basin (weight %).

Main grain size grades (Wentworth scale)					
Sample	Gravel	Sand	Silt	Clay	Classification
15A	4.6	78.3	3.8	13.3	Sand (biogenic)
15B	14.6	77.7	2.5	5.2	Sand (biogenic)
16A	2.5	49.9	23.1	24.5	Loam
16B	0.2	63.2	8.4	28.2	Clayey sand (mainly biogenic sand)
16C	5.6	90.6	0.8	3.0	Sand (biogenic)
17A	0.0	0.8	27.8	71.4	Silty clay
17B	4.4	64.3	9.1	22.2	Clayey sand (mainly biogenic sand)
17C	6.5	89.5	1.7	2.3	Sand (biogenic)
18A	0.3	53.4	12.7	33.6	Clayey sand (sand terrig. and biogenic)
18B	0.0	0.8	28.3	70.9	Silty clay
18C	0.0	0.2	22.2	77.6	Clay
18D	0.0	1.0	19.8	79.2	Clay
18E	2.0	85.8	2.6	9.6	Sand (biogenic)
19A	12.7	83.5	0.8	3.0	Sand (terrig.)
19B	1.4	22.3	17.5	58.8	Sandy clay (sand terrig. and biogenic)
19C	0.0	3.1	32.0	64.9	Silty clay
19D	0.0	2.6	22.2	75.2	Clay
19E	0.0	0.8	20.8	78.4	Clay
20A	0.0	3.3	27.7	69.0	Silty clay
20B	0.0	1.1	23.7	75.2	Clay
20C	0.0	0.0	22.0	78.0	Clay
20D	0.0	0.9	23.8	75.3	Clay
21A	1.4	54.7	23.3	20.6	Loam
21B	0.0	0.4	52.8	46.8	Clayey silt
22B	0.0	0.8	57.5	41.7	Clayey silt
22C	0.0	0.3	40.4	59.3	Silty clay
23A	0.2	45.2	31.1	23.5	Loam
23B	0.0	13.5	46.3	40.2	Clayey silt
24A	0.2	7.9	49.6	42.3	Clayey silt
24B	0.0	0.3	26.9	72.8	Silty clay
24C	0.0	0.7	25.8	73.5	Silty clay
24D	0.0	1.1	24.7	74.2	Silty clay
25A	1.8	3.8	33.5	60.9	Silty clay
25B	0.1	2.1	49.9	47.9	Clayey silt
25C	0.0	0.5	35.6	63.9	Silty clay
26A	8.8	32.5	23.0	35.7	Loam
26B	0.0	1.2	25.7	73.1	Silty clay

data have been simplified by reporting only the main Wentworth scale grades (gravel, sand, silt, and clay). The spatial distribution of sedimentary facies is illustrated in Figure 2, where the pattern of clay content (weight percent) in sediments is shown through «iso-clay» lines.

The facies distribution appears to be closely related to bathymetry, distance from the main sources of terrigenous materials, and transport dynamics. The clays and silty clays dominate most of the study area, covering the central part of the basin. They are commonly located at depths greater than 60-70 m, but in some restricted areas they are also present at much lower depths. This occurs where seagrass prairies provide a low-energy environment that trap fine-sized particles (Follonica Gulf) or close to river mouths, where important flocculation phenomena are present (Ombrone and Albegna mouths). Sandy clays, loams and clayey silts are distributed in a narrow, concentric belt all around the central portion of the basin; this zone is characterized by water depths ranging from 10 to 70 m (most commonly < 30 m). Coarse-grained sediments are distributed in a near-shore belt, which commonly is less than 10 m deep, along the Italian mainland coast. Such sediments, made up of terrigenous sands delivered by the Ombrone River and the minor streams flowing into the basin, have been sampled in only one station (19A). In the west, the biogenic sands which lie atop the Elba Ridge and the Montecristo Island platform are the result of the zone little depth and isolation from the Italian mainland, which cause both a little influx of terrigenous sediment and a high biologic productivity. They tipically show a bimodal distribution with a domi-

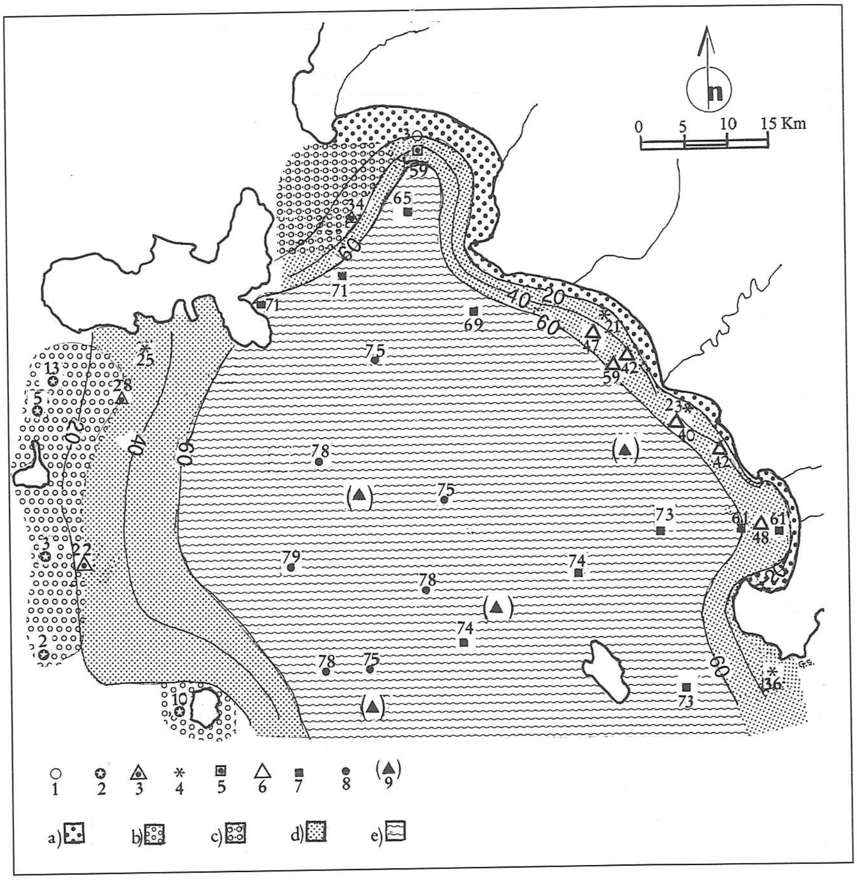

Fig. 2 - Sedimentary facies in the Elba-Argentario basin. Graphic symbols for point distribution: 1 = sand (terrigenous); 2 = sand (biogenic); 3 = clayey sand; 4 = loam; 5 = sandy clay; 6 = clayey silt; 7 = silty clay; 8 = clay; 9 = top core sediment with undetermined grain-size composition. Graphic symbols for areal distribution: a = terrigenous sand; b = biogenic sand and clayey sand; c = terrigenous and biogenic sand and clayey sand; d = loam, clayey silt and sandy clay; e = clay and silty clay. Values show the sediment clay content (weight%).

nant bioclastic sandy fraction (65 to 90 percent) and a minor amount of very fine clay fraction. The Piombino Channel is blanketed by mixed biogenic-terrigenous sands (Leoni *et al.*, 1991a). In spite of the proximity of the continent, the terrigenous fraction is not dominant and restricted to the coarser grades because of the currents that sweep the shallow sill within the channel. A clear increasing trend of the clay fraction with distance from the sill is observed between Elba and the Follonica Gulf (station 18A).

Mineralogical analysis

Quantitative mineralogical compositions of the surficial and core sediments are shown in Table 2. Correlation coefficients of minerals with major chemical elements and grain size grades are reported in Table 3. The areal distributions of minerals within the basin are mapped in Figures 3-6; only those more useful to highlight the source-transport-sedimentation sequences and the depositional environments are reported.

Total carbonate fraction (calcite + aragonite + dolomite) distribution is illustrated in Figure 3, whose values represent weight percents of the bulk samples. Since the carbonate fraction is often very abundant and may be to a large extent of biogenic origin, it acts as a diluent of terrigenous minerals, thus preventing a clear exhibition of their distribution patterns. For this reason the non-carbonate mineral distributions illustrated in Figures 4-6 are based on data recalculated on a carbonate-free basis.

Carbonates

Carbonate minerals are abundant in all samples. In a wide belt bordering Italy's mainland coast, up to 30-35 Km offshore, the sediments have carbonate contents ranging from 15 to 20 percent. Mineralogy and geochemistry indicate that these carbonates are mostly terrigenous in origin, largely contributed by the Ombrone River and, to a much lesser extent, by the minor tributary streams. According to Gandolfi and Paganelli (1975) the Ombrone sediment load contains up to 26 percent of carbonates, while the minor stream sediments have carbonate contents ranging from 10 to 30 percent.

In the central basin the carbonate content increases with the organogenic fraction. Very high carbonate contents (> 60 percent) are apparent on the Elba Ridge and in the Piombino Channel; most of them are from organic origin, as indicated by the frequent shell debris and the abundant aragonite and magnesian calcite. As pointed out, these are zones of high bio-

Tab. 2 - Mineralogical composition of the bottom and core sediments in the Elba - Argentario basin (weight%)[a].

	Cc	Ar	Do	Qz	Pg	K-f	Ill	Ka	Ch	Sm
Bottom sediments										
15A*	65	20	2	5	2	1	8	2	3	2 ■
15B*	71	20	-	2	1	tr	3	1	1	1 ■
16A*	30	17	-	15	5	2	19	3	4	5
16B*	34	15	-	10	4	2	19	4	5	7
16C*	62	29	-	2	1	tr	3	1	1	1 ■
17A	15	-	1	14	4	2	39	8	13	4
17B*	45	24	-	5	2	1	13	3	4	3 ■
17C*	76	17	-	2	1	tr	2	tr	1	1 ■
18A	20	6	2	30	5	2	23	3	5	4
18B	15	-	2	15	4	1	40	8	11	4
18C	17	-	2	13	3	1	38	10	7	9
18D	22	-	2	12	3	1	37	9	6	8
18E*	50	25	-	4	2	tr	12	2	2	3
19A*	11	8	1	58	9	5	3	2	2	1
19B*	15	17	1	12	4	2	32	6	6	5 ■
19C	15	-	2	18	5	2	37	9	8	4
19D	15	-	2	14	3	1	40	8	10	7
19E	26	-	2	10	3	1	35	7	6	10
20A	15	-	2	17	4	2	39	8	8	5
20B	19	-	2	12	3	1	38	9	7	9
20C	24	-	2	11	3	1	35	8	7	9
20D	25	-	2	10	3	1	35	7	7	10
21A	20	-	3	27	8	3	25	6	5	3
21B	15	-	2	19	5	2	37	8	8	4
22B	16	-	2	20	5	2	36	8	7	4
22C	14	-	1	17	4	2	39	9	9	5
23A	19	-	1	26	7	3	26	7	5	6
23B	17	-	3	24	6	3	28	8	5	6
24A	16	-	3	23	6	3	28	9	5	7
24B	13	-	1	13	5	2	39	8	6	13 ■
24C	17	-	1	10	4	2	38	8	7	13 ■
24D	23	-	2	10	3	1	34	7	7	13
25A*	11	5	1	17	5	2	37	8	9	5
25B	14	-	2	19	5	2	37	9	7	5
25C	13	-	2	16	4	2	39	10	8	6
26A*	17	4	1	18	4	2	33	6	8	7
26B	19	-	1	12	4	2	32	6	10	14
Core sediments[b]										
1-01	14	-	1	13	6	3	37	8	7	11
1-02	14	-	1	14	6	3	38	7	7	10
1-04	14	-	1	14	6	3	37	7	7	11
1-06	14	-	1	13	6	3	38	7	8	10
1-08	14	-	1	14	6	3	38	7	7	10
1-10	14	-	1	14	6	3	36	8	8	10
1-15	14	-	1	14	6	3	37	8	7	10
1-20	14	-	1	14	6	3	37	7	8	10
1-25	14	-	1	14	6	3	37	8	7	10
1-30	14	-	1	14	6	3	37	7	8	10
2-01	21	-	1	11	3	1	37	7	7	12
2-04	21	-	1	11	3	1	37	7	7	12
2-06	21	-	1	11	3	1	37	7	7	12
2-09	21	-	1	11	3	1	37	7	7	12
2-13	21	-	1	11	3	1	37	7	7	12
2-17	21	-	1	11	3	1	37	7	7	12

Segue

Segue Tab. 2

	Cc	Ar	Do	Qz	Pg	K-f	Ill	Ka	Ch	Sm
2-23	22	-	1	11	3	1	37	6	7	12
2-29	22	-	1	11	3	1	38	6	7	11
2-41	23	-	1	10	3	1	38	6	7	11
3-01	17	-	2	13	4	2	37	9	7	9
3-02	17	-	2	15	4	2	36	8	6	10
3-04	17	-	2	13	4	2	37	9	7	9
3-06	17	-	2	14	4	2	36	9	7	9
3-08	17	-	2	14	4	2	37	8	7	9
3-10	18	-	2	15	4	2	36	9	6	8
3-15	17	-	2	14	4	2	37	9	7	8
3-20	18	-	2	15	4	2	36	8	6	9
3-25	18	-	2	15	4	2	35	9	7	8
3-30	19	-	2	15	4	2	35	8	7	8
4-01	27	-	1	9	3	1	36	7	5	11
4-04	27	-	1	9	3	1	36	7	5	11
4-06	26	-	1	9	3	1	36	7	5	12
4-09	26	-	1	9	3	1	36	7	5	12
4-13	26	-	1	9	3	1	36	7	5	12
4-17	28	-	1	8	3	1	36	7	5	11
4-21	28	-	1	8	3	1	36	7	5	11
4-30	28	-	1	8	3	1	36	7	5	11
4-41	26	-	1	8	3	1	37	7	5	12

a) Cc = calcite; Ar = aragonite; Do = dolomite; Qz = quartz; Pg = plagioclase; K-f = K-feldspar; Ill = illite (and muscovite); Ka = kaolinite; Ch = chlorite; Sm = smectite.
tr = trace; - = not detected.
* The samples contain significant amounts of Mg-rich calcite.
■ These samples contain high amounts of organic matter
b) The numbers following the core identifier give sub-sample depth from the top of the core (in cm).

logical productivity coupled with little terrigenous influx (Elba Ridge) or with a regime of strong currents sweeping the finer terrigenous material (Piombino Channel).

Quartz and feldspars
These components are highly correlated in abundance (Tab. 3). The overall trend shows a gradually decreasing content with decreasing grain size and increasing distance offshore. In the nearshore zone quartz+feldspars make up 35-45 percent of the non-carbonate fraction, while in the central and the westernmost parts of the basin these components only contribute to 15-20 percent of the same fraction.
This indicates that these components occur mostly in the terrigenous coarser fraction. Seemingly, the observation is not supported by the correlation matrix data (Tab. 3), which show an inverse correlation between quartz+feldspars and sand. The discrepancy is only apparent, being due to the peculiar composition of the sandy sediments sampled in the present study; in fact they are all bioclastic sands (except sample 19A) and then predominantly carbonatic sands. The main sources of quartz and feldspars can be traced back to the Ombrone River and to the minor tributaries. Their sediment loads are invariably quartz- and feldspar-rich, as shown by Gandolfi and Paganelli (1975); for the Ombrone sand these authors report quartz and feldspar contents of 32 and 11 percent, respectively.

Phyllosilicates
Mica, chlorite, kaolinite, and smectite are the dominant sheet-silicates of the bulk sediments; as shown by correlation coefficients (Tab. 3) they are mostly contained in the fine-size grades (clay and, to a lesser extent, silt).
Mica (represented mostly by illite and subordinately by muscovite) dominates (> 50 percent) the clay mineral assemblage; its areal distribution closely reflects that of the clay fraction (Fig. 2). This distribution is characterized by a uniform zone of maximum contents covering all the basin's central section; such a pattern reflects the general hydrodynamic conditions of the Elba-Argentario basin, which favour the settling of clays in the centre of the area.
Kaolinite is a minor component of the non-carbonate fraction; its low content, commonly in the range of 5-12 percent, reflects that of the tributaries's sediment loads, which all contain small amounts of kandite minerals (Quakernaat, 1968). The distribution (Fig. 4) is rather uniform all over the basin. Equal

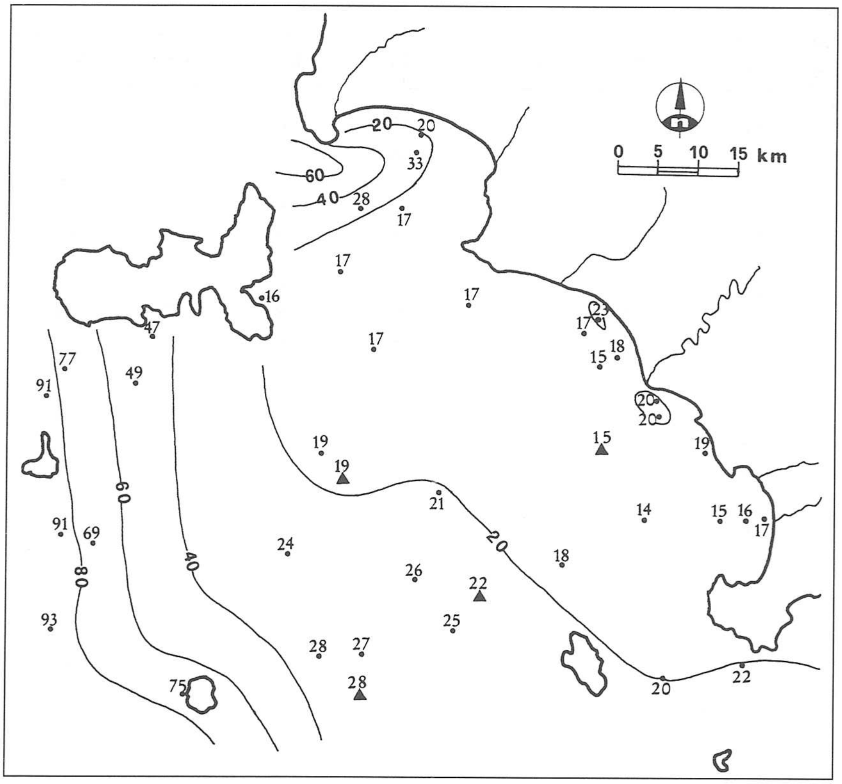

Fig. 3 - Carbonate (calcite + aragonite + dolomite) distribution in the Elba-Argentario basin (weight % of the bulk sample).

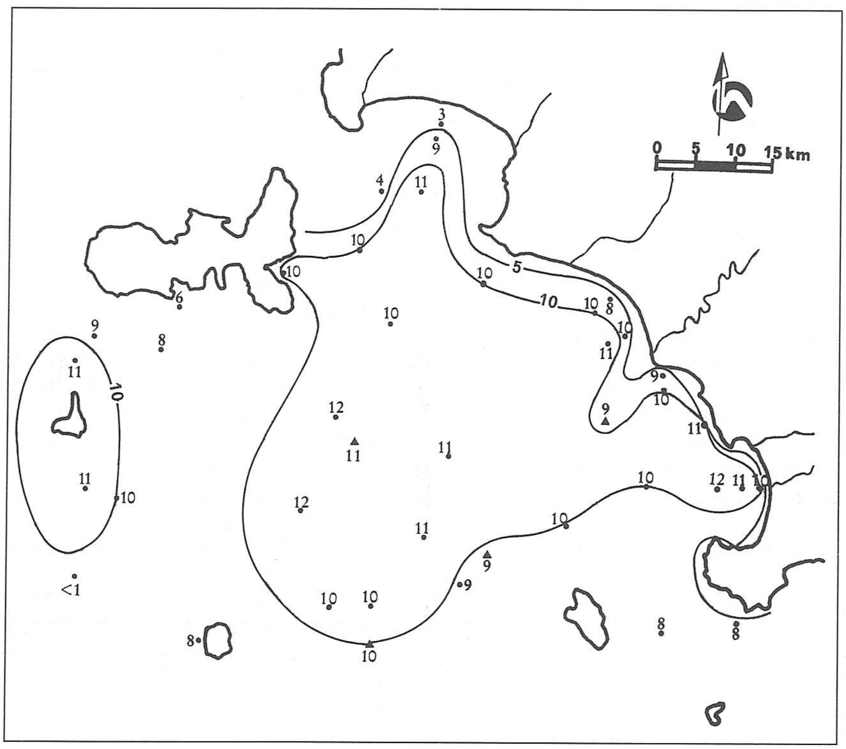

Fig. 4 - Kaolinite distribution in the Elba-Argentario basin (weight % of the non-carbonate fraction)

Tab. 3 - Correlation coefficients of major chemical elements with minerals and grain size grades[a].

	H_2O	CO_2	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	K_2O	CaO	TiO_2	MnO	Fe_2O_3	Cc	Ar	Qz	Pg	K-f	Ill	Ka	Ch	Sm	GR	SA	SI
CO_2	-0.34																							
Na_2O	-0.27	-0.68																						
MgO	0.15	0.30	-0.57																					
Al_2O_3	0.53	-0.92	0.41	0.02																				
SiO_2	0.08	-0.95	0.84	-0.48	0.75																			
P_2O_5	0.41	-0.68	0.17	0.14	0.85	0.48																		
K_2O	0.47	-0.95	0.47	-0.07	0.99	0.81	0.83																	
CaO	-0.33	0.99	-0.68	0.27	-0.92	-0.95	-0.68	-0.95																
TiO_2	0.49	-0.91	0.42	0.05	0.99	0.75	0.85	0.98	-0.92															
MnO	0.47	-0.32	-0.16	0.19	0.46	0.16	0.52	0.44	-0.32	0.43														
Fe_2O_3	0.45	-0.81	0.29	0.10	0.93	0.63	0.90	0.93	-0.82	0.93	0.43													
Cc	-0.34	0.98	-0.70	0.39	-0.87	-0.94	-0.64	-0.91	0.97	-0.86	-0.24	-0.78												
Ar	-0.05	0.73	-0.62	0.41	-0.61	-0.73	-0.04	-0.66	0.73	-0.59	0.01	-0.37	0.58											
Qz	-0.37	-0.57	0.88	-0.71	0.21	0.80	-0.06	0.31	-0.57	0.21	-0.21	0.09	-0.60	-0.60										
Pg	-0.57	-0.44	0.98	-0.48	0.01	0.75	-0.30	0.07	-0.44	0.04	-0.46	-0.15	-0.51	-0.50	0.87									
K-f	-0.75	-0.12	0.88	-0.71	-0.57	0.75	-0.61	-0.54	-0.12	-0.50	-0.62	-0.55	-0.29	-0.32	0.86	0.92								
Ill	0.61	-0.86	0.27	0.10	0.98	0.65	0.87	0.96	0.86	0.98	0.50	0.94	-0.80	-0.51	0.08	-0.18	-0.70							
Ka	0.49	-0.84	0.28	0.28	0.95	0.64	0.81	0.92	0.84	0.96	0.44	0.86	-0.77	-0.53	0.09	-0.02	-0.40	0.93						
Ch	0.54	-0.77	0.21	0.12	0.87	0.58	0.70	0.87	-0.77	0.86	0.34	0.90	-0.72	-0.62	0.10	-0.18	-0.49	0.88	0.76					
Sm	0.55	-0.51	0.05	0.03	0.63	0.34	0.64	0.61	0.50	0.60	0.74	0.54	-0.45	-0.40	-0.13	-0.30	-0.50	0.63	0.54	0.38				
GR	-0.19	0.39	-0.25	-0.04	-0.58	-0.24	-0.73	-0.51	0.39	-0.60	-0.66	-0.72	0.40	-0.02	0.05	0.17	0.18	-0.61	-0.55	-0.49	-0.60			
SA	-0.61	0.82	-0.23	-0.15	-0.95	-0.63	-0.81	-0.92	0.83	-0.95	-0.53	-0.88	0.76	0.52	-0.07	0.16	0.15	-0.96	-0.94	-0.83	-0.64	0.50		
SI	0.18	-0.71	0.48	0.07	0.76	0.63	0.66	0.73	-0.72	0.79	0.02	0.68	-0.67	-0.49	0.27	0.27	0.04	0.71	0.76	0.59	0.27	-0.55	-0.76	
CL	0.73	-0.71	0.03	0.18	0.86	0.48	0.76	0.84	-0.71	0.85	0.73	0.83	-0.65	-0.44	-0.09	-0.41	-0.80	0.91	0.82	0.79	0.74	-0.57	-0.92	0.45

[a] GR = gravel; SA = sand; SI = silt; CL = clay; H_2O see footnote in Table 4.
Mineral symbols as in Table 2.

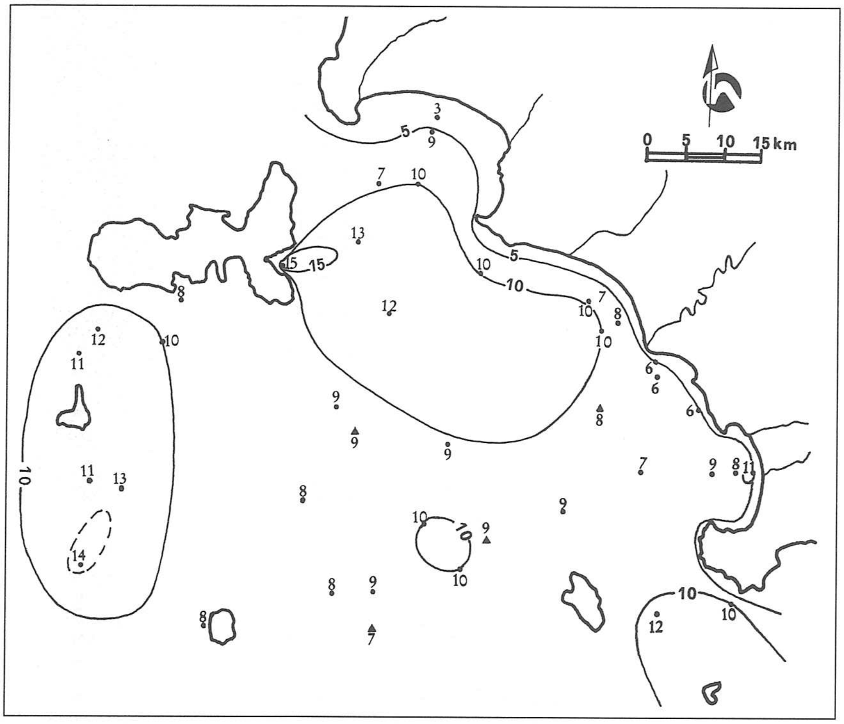

Fig. 5 - Chlorite distribution in the Elba-Argentario basin (weight % of the non-carbonate fraction).

to illite, the kaolinite distribution closely matches the distribution of the clay fraction, except for the south-eastern zone, where clay is significantly richer in smectite than in kaolinite.

A zone of slight kaolinite enrichment is located on the Elba Ridge; this feature is common to some restricted, outer areas of Tuscany's central (Leoni *et al.*, 1991a) and northern (Leoni *et al.*, 1992) basins, where a minimum influx of terrigenous material from the mainland through marine currents is present. For these zones it is inferred that aeolian input significantly contributes to the accumulation of sediment, as demonstrated by Tomadin (1981) for the southern Tyrrhenian Sea. Southern winds from Africa supply the greatest amount of dust to the Western Mediterranean basins. Measurements performed on Corsican «red rain» sediments lead Loyle-Pilot *et al.* (1986) to envisage that this amount could be of the same order of magnitude as sediments delivered by the Rhone river ($4x10^{16}$ tons/year). This African dust contains kaolinite, poorly-organized illite, and quartz as main components.

Chlorite is a component of the non-carbonate fraction with approximately the same quantitative importance as kaolinite and smectite (5-15 percent). On the basis of Quakernaat data (1968), it is reasonable to infer that this mineral is supplied to the basin mostly by the Ombrone river and, subordinately, by nearly all the minor streams. Chlorite is evenly distributed over most of the basin (Fig. 5) except for two main zones of slightly higher concentrations. The larger one covers a wide area between Elba Island and Italy's mainland. This enrichment could be related to the hydrodynamic conditions of that zone, which favour a local settling of chlorite particles delivered by the Ombrone River, but could also reflect an important supply of chlorite from the metamorphic rocks of eastern Elba. This hypothesis seems to be supported by the location of the maximum enrichment, which is very close to that part of the Elban coast where the Capo Calamita schists crop out. The western area of chlorite enrichment is located on the Elba Ridge, in the same zone where a kaolinite enrichment has been observed. The most likely cause is an important aeolian supply. Tomadin *et al.* (1984) showed that northerly winds, blowing from the European continent, carry abundant well-organized illite and high amounts of chlorite (and serpentine) over the central-western Mediterranean; these minerals most likely derive from rocks and soils of the Alpine region.

Smectite is present only in very small concentrations in the sediment load of the basin's tributaries (Quakernaat, 1968), while it is rather abundant in the sediments of the streams draining the Latium region (just south of the study area) and particularly abundant in the sediments of the great Tiber river. This is in agreement with the nature of rock outcrops (volcanites and pyroclastites) in this region and with their most frequent processes of weathering, which are known to produce abundant smectite. The distribution of the mineral over the Elba-Argentario basin (Fig. 6), with concentrations progressively increasing southeastward, clearly reflects an important influx of allochthonous material from southern sources. Transportation would have been provided by the general current of the Tyrrhenian Sea, which flows

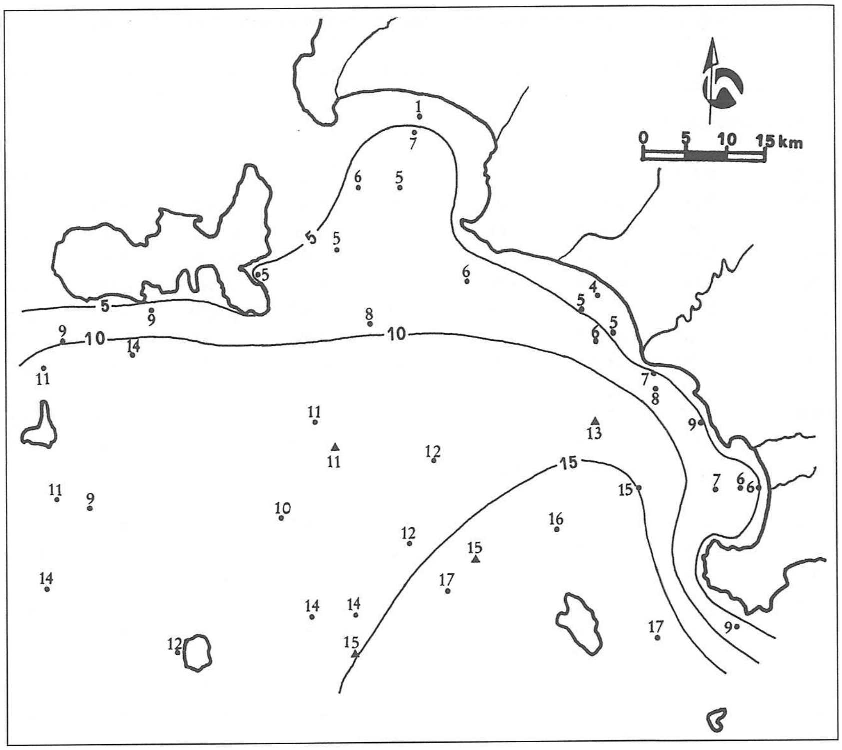

Fig. 6 - Smectite distribution in the Elba-Argentario basin (weight % of the non-carbonate fraction).

northward along Italy's mainland coast (Elliott, 1979). The mineralogical composition of the core samples (Table 2) shows a substantial uniformity all through the columns, suggesting an essentially constant sedimentary regime for the sampling area.

Chemical analysis

The major element contents in surficial and core sediments of the Elba-Argentario basin are reported in Table 4.
As expected, the distribution of the major elements is mostly dependent on the grain size and the mineralogical composition of the sediments; the main correlations are shown by the highest coefficient values of Table 3.
Al, P, K, Ti, and Fe are mainly correlated with the two finest grain size classes (clay and, to a lesser degree, silt); in fact, all of them are chiefly associated with the clay-(and silt-) forming mineral phases (sheet-silicates) (Tab. 3). Mn is mostly correlated with clay. Sodium appears significantly correlated with quartz, K-feldspar and plagioclase. Due to a multiple mineralogical control magnesium shows poor correlations with every mineral; this element is in fact a common component both of the phyllosilicate minerals (chlorite) and of the carbonate fraction (dolomite and, more frequently, magnesian calcite). Calcium appears strongly and exclusively correlated with carbonates; it results mostly concentrated in the coarser grades, in agreement with the composition of the basin's sands, which nearly all are bioclastic carbonate sediments.
The major chemistry of core sediments is substantially uniform all over the columns; only Mn appears strongly enriched in the upper column layers (Tab. 4), following a distribution pattern clearly related to the well-known processes of solubilization and migration of the element under reducing conditions and its precipitation at the water-sediment interface, where more oxiding conditions prevail (Wedepohl, 1978a and 1978b). The thickness of the Mn-enriched layer commonly ranges from 2 to 4 cm; only in core 4 this layer is 6 cm thick, probably as a consequence of a fair bioturbation affecting the sediments of this sampling area.

CONCLUSIONS

The sedimentological and mineralogical analyses of the bottom sediments provide a valuable way for improving the knowledge of the prevailing hydrodynamic conditions and for assessing the sediment source-transport-deposition sequences in the Elba-Argentario basin. The current flowing up along Italy's western coast penetrates into the basin from the wide southern entrance, but inside the basin its movement is complicated by the interaction with an irregular coastal and bottom topography. The sedimentary facies distribution suggests that only the surficial layer of this current of southern origin passes the shallow sill within the Piombino Channell (< 50 m deep), while

Tab. 4 - Chemical composition (major elements) of the bottom and core sediments in the Elba - Argentario basin (weight%)[a].

	H_2O	CO_2	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	K_2O	CaO	TiO_2	MnO	Fe_2O_3
Bottom sediments												
15A	4.83	33.89	0.24	2.85	4.03	11.32	0.06	0.53	40.23	0.14	0.07	1.81
15B	3.04	40.34	0.08	4.10	1.55	4.05	0.05	0.19	45.67	0.05	0.06	0.82
16A	2.61	20.44	0.66	3.18	9.36	33.22	0.10	1.57	23.85	0.42	0.08	4.59
16B	3.98	21.37	0.50	3.30	10.03	30.08	0.11	1.47	24.38	0.37	0.10	4.31
16C	3.00	40.05	0.08	3.47	1.29	3.84	0.06	0.18	46.67	0.05	0.08	1.23
17A	5.39	7.29	0.50	3.75	17.00	45.59	0.15	2.52	6.97	0.75	0.21	9.88
17B	8.26	29.13	0.30	2.86	5.92	15.73	0.09	0.75	34.26	0.21	0.10	2.39
17C	2.79	41.65	0.09	4.53	0.82	2.16	0.05	0.09	47.31	0.03	0.03	0.45
18A	3.06	12.15	0.65	2.59	10.53	50.05	0.11	1.72	13.86	0.44	0.10	4.74
18B	5.75	7.53	0.55	3.48	16.53	46.43	0.15	2.50	8.34	0.77	0.14	7.83
18C	7.65	8.34	0.51	3.29	16.43	44.22	0.16	2.39	9.23	0.72	0.43	6.66
18D	5.34	10.61	0.42	3.36	15.51	42.23	0.16	2.30	12.41	0.70	0.50	6.46
18E	1.46	33.18	0.24	2.48	4.13	13.20	0.16	0.79	39.33	0.16	0.08	4.79
19A	0.65	8.70	1.17	0.89	4.81	70.99	0.02	1.16	10.38	0.16	0.03	1.04
19B	13.46	0.50	2.84	12.90	35.48	0.11	1.89	15.93	0.55	0.08	5.24	11.02
19C	5.46	7.87	0.65	3.33	15.64	48.57	0.15	2.35	8.51	0.72	0.09	6.66
19D	7.52	7.51	0.40	3.25	17.03	45.82	0.16	2.50	7.63	0.75	0.35	7.08
19E	5.44	13.49	0.42	3.35	14.50	39.32	0.14	2.15	14.28	0.65	0.32	5.94
20A	5.91	7.41	0.63	3.24	16.31	48.37	0.14	2.42	7.70	0.76	0.13	6.98
20B	7.32	9.01	0.43	3.27	16.12	43.47	0.15	2.34	10.24	0.71	0.33	6.61
20C	7.17	11.25	0.45	3.27	14.82	40.52	0.15	2.16	13.08	0.66	0.45	6.02
20D	6.72	11.97	0.46	3.32	14.66	40.01	0.14	2.14	13.77	0.63	0.32	5.86
21A	1.66	10.43	1.07	2.96	12.70	52.24	0.13	1.86	10.96	0.61	0.13	5.25
21B	5.40	7.20	0.71	3.26	15.96	49.62	0.15	2.31	8.12	0.72	0.09	6.46
22B	4.45	8.11	0.74	3.21	15.68	49.44	0.15	2.27	8.93	0.71	0.10	6.21
22C	6.13	6.94	0.51	3.20	16.64	48.76	0.16	2.46	7.36	0.79	0.10	6.95
23A	2.36	9.02	1.07	2.90	12.95	52.63	0.13	1.92	11.17	0.59	0.11	5.14
23B	2.96	9.28	0.78	3.05	14.50	51.48	0.15	2.07	9.17	0.65	0.09	5.82
24A	2.70	8.68	0.76	3.13	14.95	51.40	0.15	2.15	9.10	0.71	0.10	6.17
24B	8.06	6.30	0.61	2.79	16.77	47.84	0.16	2.40	7.29	0.77	0.17	6.84
24C	7.98	8.01	0.53	3.13	16.39	44.18	0.16	2.33	9.57	0.73	0.40	6.60
24D	7.24	11.11	0.42	3.20	14.94	40.98	0.15	2.14	12.76	0.66	0.41	5.99
25A	6.58	7.77	0.59	2.82	16.26	47.94	0.12	2.30	8.46	0.74	0.09	6.33
25B	5.60	7.20	0.67	2.98	16.03	50.11	0.14	2.24	7.93	0.74	0.08	6.28
25C	6.98	6.48	0.55	3.10	17.06	48.51	0.14	2.42	7.04	0.77	0.10	6.65
26A	5.49	9.71	0.53	2.64	14.66	46.69	0.13	2.39	11.50	0.61	0.09	5.56
26B	7.57	8.48	0.50	3.10	16.24	43.96	0.16	2.29	10.20	0.72	0.30	6.47
Core sediments[b]												
1-01	8.02	6.15	0.97	2.95	16.25	47.09	0.13	2.45	7.91	0.79	0.21	7.07
1 02	6.61	6.21	0.95	3.04	16.55	47.71	0.13	2.54	8.04	0.82	0.16	7.24
1-04	7.41	6.54	0.91	2.85	15.92	47.63	0.13	2.44	8.19	0.79	0.15	7.06
1-06	6.18	6.22	0.83	2.94	16.84	47.88	0.14	2.61	8.04	0.83	0.13	7.37
1-08	5.74	6.19	0.98	3.02	17.18	48.05	0.14	2.68	7.81	0.83	0.11	7.28
1-10	6.61	6.34	0.84	2.97	16.78	47.55	0.14	2.65	7.91	0.83	0.11	7.27
1-15	6.68	6.27	0.87	3.07	16.98	47.17	0.13	2.65	8.10	0.81	0.11	7.16
1-20	6.55	6.43	0.92	3.15	16.91	47.02	0.13	2.70	8.10	0.82	0.11	7.15
1-25	6.50	6.20	0.84	3.23	17.04	47.41	0.13	2.74	7.93	0.83	0.11	7.04
1-30	6.04	6.26	0.97	3.23	16.95	47.50	0.13	2.76	8.03	0.83	0.11	7.18
2-01	7.83	9.41	0.41	3.24	15.55	42.43	0.15	2.31	11.16	0.70	0.34	6.47
2-04	6.84	9.82	0.39	3.30	15.77	43.00	0.16	2.37	11.04	0.72	0.14	6.45
2-06	6.85	9.69	0.42	3.34	15.77	43.03	0.16	2.40	11.04	0.72	0.13	6.54
2-09	6.38	9.84	0.39	3.39	15.74	43.32	0.16	2.42	11.07	0.71	0.12	6.46
2-13	6.99	9.98	0.36	3.37	15.45	43.00	0.16	2.35	11.27	0.70	0.12	6.25
2-17	7.15	10.18	0.40	3.39	15.07	42.51	0.15	2.36	11.71	0.70	0.11	6.27

Segue

Segue Tab. 4

	H_2O	CO_2	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	K_2O	CaO	TiO_2	MnO	Fe_2O_3
2-23	6.48	10.09	0.48	3.37	15.39	42.80	0.17	2.41	11.71	0.70	0.12	6.28
2-29	7.54	9.93	0.48	3.26	15.29	42.20	0.16	2.37	11.71	0.68	0.11	6.27
2-41	6.32	10.60	0.40	3.27	15.24	41.78	0.17	2.37	12.45	0.72	0.12	6.56
3-01	7.29	8.03	0.74	3.14	15.86	43.69	0.14	2.48	10.16	0.77	0.55	7.15
3-02	7.55	7.95	0.68	3.15	15.81	43.68	0.13	2.47	10.20	0.77	0.49	7.10
3-04	6.45	8.22	0.79	3.20	16.00	43.97	0.14	2.52	10.43	0.78	0.27	7.23
3-06	6.83	8.17	0.83	3.23	15.92	43.79	0.14	2.56	10.36	0.77	0.18	7.23
3-08	7.39	8.11	0.75	3.26	15.89	43.60	0.14	2.53	10.30	0.76	0.17	7.10
3-10	5.45	8.61	0.70	3.30	15.91	44.25	0.14	2.62	10.84	0.79	0.17	7.23
3-15	6.40	7.89	0.81	3.31	15.95	44.22	0.14	2.61	10.16	0.78	0.16	7.12
3-20	6.16	8.33	0.83	3.33	15.85	44.19	0.14	2.61	10.57	0.78	0.15	7.06
3-25	6.59	8.34	0.92	3.36	15.66	44.19	0.14	2.60	10.65	0.77	0.14	6.64
3-30	6.48	8.59	0.94	3.35	15.55	43.79	0.14	2.59	10.84	0.76	0.14	6.83
4-02	6.22	12.74	0.45	3.30	14.13	39.20	0.15	2.18	14.64	0.66	0.30	6.03
4-04	6.33	12.04	0.45	3.35	14.46	39.94	0.14	2.21	14.05	0.65	0.41	5.97
4-06	6.68	11.87	0.46	3.34	14.45	39.90	0.14	2.21	13.71	0.66	0.65	5.94
4-09	6.32	11.91	0.45	3.35	14.48	40.19	0.15	2.25	13.99	0.65	0.16	6.09
4-13	6.24	11.98	0.47	3.30	14.46	40.11	0.15	2.25	14.08	0.65	0.15	6.18
4-17	5.98	12.98	0.46	3.21	14.16	38.86	0.16	2.20	15.06	0.63	0.14	6.15
4-21	6.23	12.69	0.47	3.19	14.12	39.19	0.16	2.17	15.00	0.64	0.12	6.04
4-30	5.75	13.13	0.45	3.23	14.18	38.98	0.16	2.13	15.19	0.64	0.11	6.04
4-41	6.40	12.08	0.45	3.30	14.91	39.47	0.17	2.27	13.98	0.65	0.12	6.21

a) Fe_2O_3 = total iron as Fe_2O_3; H_2O = water + organic matter (commonly present in minor amounts, except for samples marked with full squares in Table 2). It has been derived from ignition loss (I.L.) through deduction of CO_2 content.
b) The numbers following the core identifier give sub-sample depth from the top of the core (in cm).

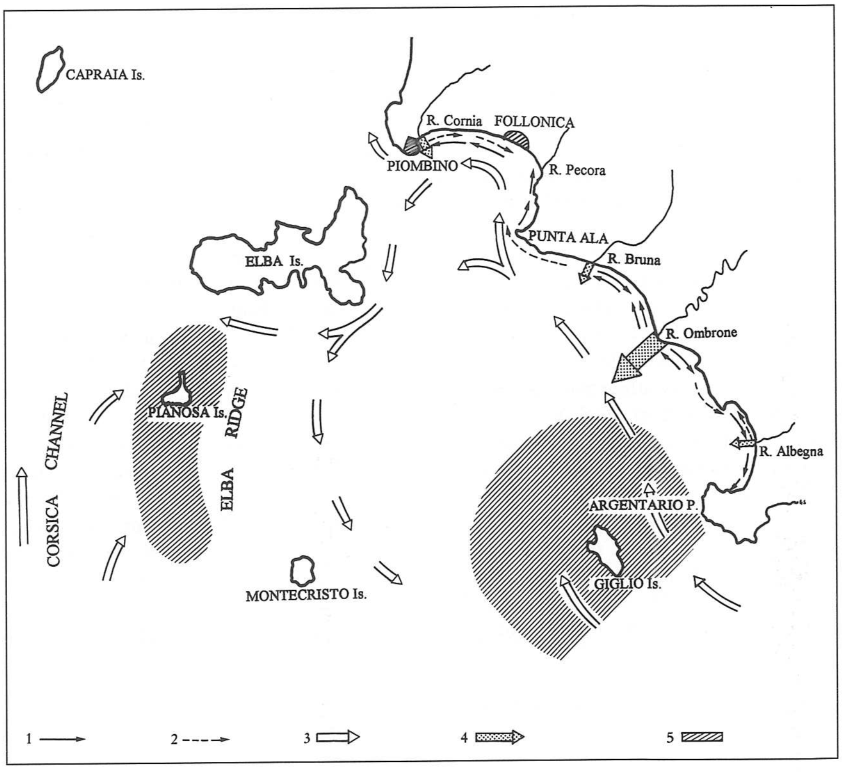

Fig. 7 - Sediment sources and transport-dispersal pattern in Elba-Argentario basin: 1 = main coastal drift directions; 2 = occasional or seasonal coastal drift directions; 3 = main currents; 4 = main terrigenous imputs; 5 = areas affected by a marked (Elba Ridge) or appreciable (south-eastern sector) influx of allogenic sediments.

the greatest and deepest part turns to west, flowing along the Elba coast, and then returns to south along the inner margin of the Elba Ridge. This slow circular movement of water, which is like an anti-clockwise small-scale gyre, is the main agent of transport and distribution of the finest sediment particles delivered by the tributary streams (essentially by the Ombrone River). The centre of the gyre corresponds to a low-energy zone in the basin, which favours sinking of the finest-sized particulates (Fig. 7).

The composition of the basin's clays is dominated by the clay mineral assemblage of the Ombrone River sediment load. Only in few marginal areas (Elba Ridge, Cornia mouth, Giglio-Argentario zone) the sedimentation of the finest grades is significantly affected by the influx of markedly different materials. In some of these areas an appreciable difference (mostly negative) in trace element concentrations from the background content reflects this sedimentation of allochtonous materials (Leoni and Sartori, 1997).

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