Sedimentology and geochemistry of beach sediments along Sardinia's eastern coast: the Gulf of Orosei

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Abstract. Relations between textural and compositional characteristics of the sediments of the small beaches situated in the Gulf of Orosei (east-central Sardinia) are discussed. Beaches to the north are characterized by unimodal sandy sediments, while those to the south are made up of polymodal gravels. The former contain a prevalent siliciclastic component not to be found in the beaches to the south, which are composed of carbonatic sediments. Analyses of the major and, most of all, of the trace elements show not only a clear differentiation between beach components, but also between the single lithologies.

1. Introduction

Recent sandy sediments taken from the beaches of the Gulf of Orosei (east-central Sardinia) (Fig. 1) are examined. This is the continuation of a research project that has recently been extended to the entire southern sector of the east coast to identify sources of recent deposits (Cristini et al., 1981, 1989, 1992). Since sedimentological parameters, certain geochemical relationships and the content of trace elements have been found to be useful in distinguishing the lithologies of the basins from which they come, the purpose of our study is not only to verify this in a particular depositional environment, but also to see if longshore drift alters beach composition by introducing extraneous sediments. The stretch of coast sampled, which is 30 km long, extends from the inhabited area of Cala Gonone to the cape of Monte Santo. Sampling was performed on 14 beaches, going from north to south. Considering the limited extent of the beaches, each sampling point corresponds to a single beach. Samples were taken at the waterline, with the exception of sample no. 12, which was taken below the waterline. The area's geological lineaments are determined by the presence of a Paleozoic crystalline basement on which marine sediments, volcanic rocks and continental sediments, dating from the Mesozoic and Quaternary, lie unconfor-

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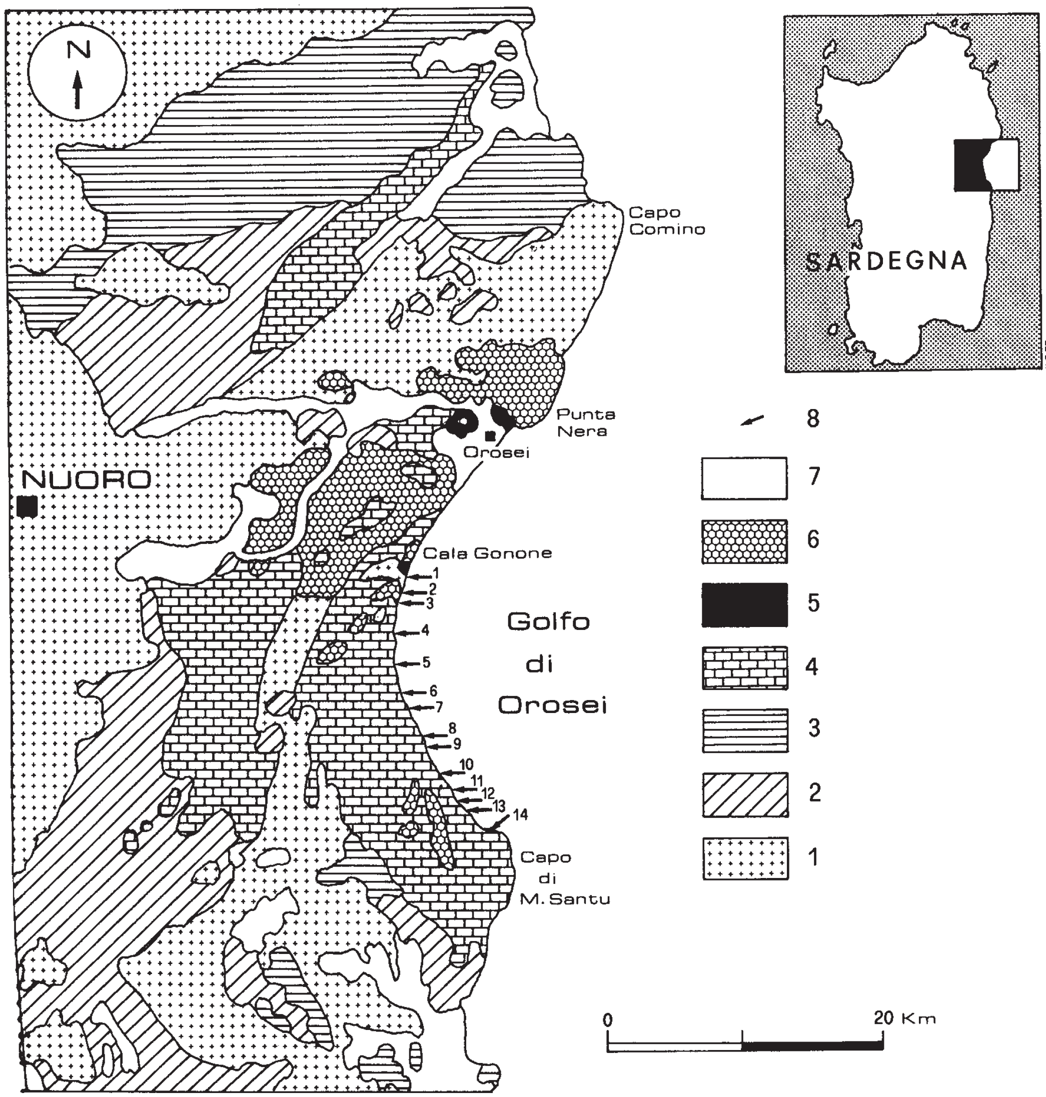


Fig. 1 - Geolithological map of the area examined.
1, 2, 3 - Metamorphic and granitic rocks (Paleozoic);
4 - Limestones and dolomitic limestones (Jurassic-Cretaceous);
5 - Conglomerates and marls (Neoge);
6 - Basalts (Plioce);
7 - Modern sediments and talus cone;
8 - Sampling points.

mably. Carbonatic Mesozoic lithologies of a chemical and organogenic nature make up the coast along which the sampled beaches are found. Some of these beaches are situated at the mouths of karst valleys, while others are at the base of active or dead cliffs; sediments of the former are of a siliciclastic nature, since they derive from the erosion of the granitic and metamorphic rocks and dikes of the basement, as well as from the erosion of the Pliocene basalts outcropping along the coast, while detritus from the cliffs are the source of the latter. To the north, and close to one

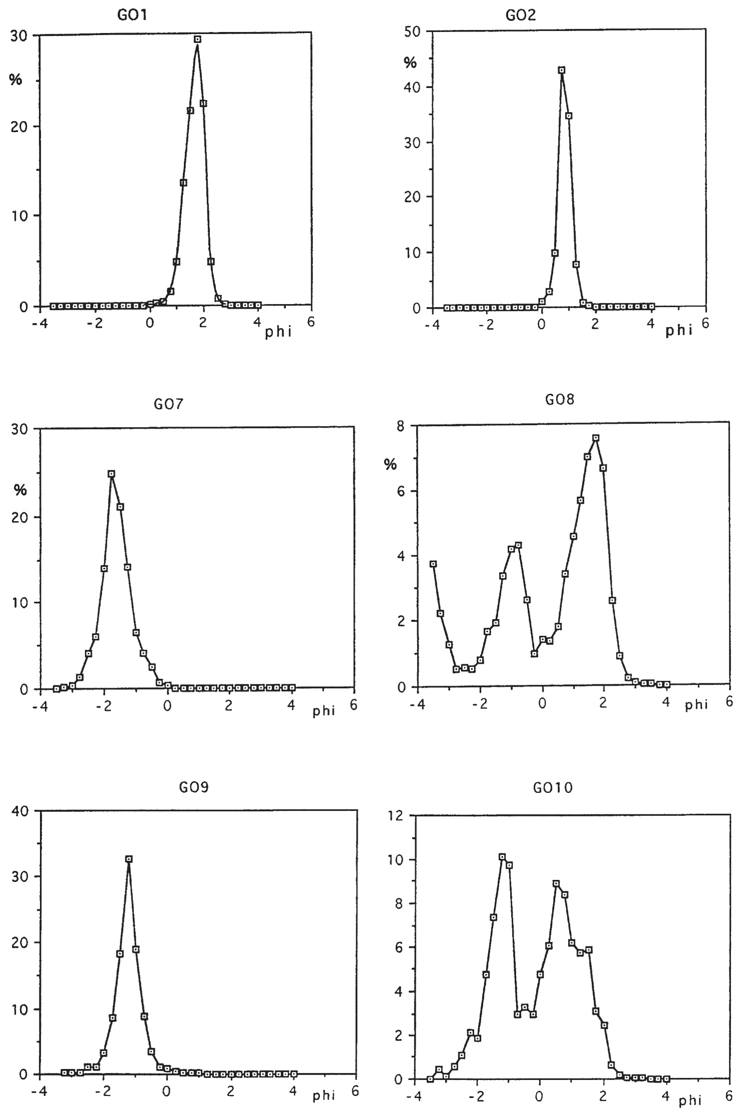


Fig. 2 - Grain-size distribution of various kinds of sediments present on the beaches sampled from N to S.

of the sampling points, one finds periglacial Pleistocene deposits (éboulis ordonnés) of a certain extension, for the most part made up of carbonatic detritus (Di Simplicio et al., 1974; Beccaluva et al., 1977; Ulzega et al., 1980; Ghezzo and Orsini; 1982, Dieni and Massari, 1985).

2. Methods of analysis

The texture of samples was determined with the customary sedimentological methods (Folk and Ward, 1957), while mineralogical composition was found by means of microscopy and X-ray powder diffraction. Chemical analyses for major (Al, Si, Ti, Mn, Fe, Na, K, Ca, Mg) and

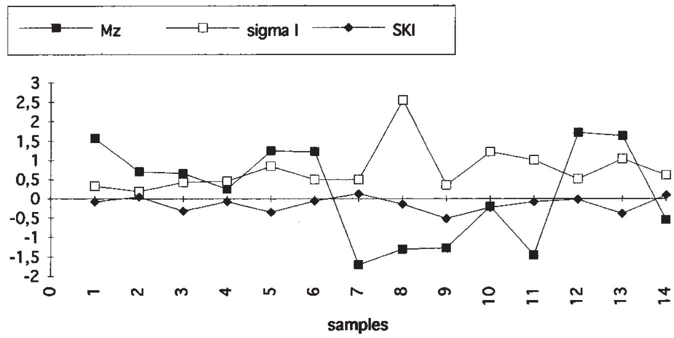


Fig. 3 - Range and trend of grain-size parameters from N to S.

trace elements (Nb, Zr, Y, Sr, Rb, Pb, Zn, Cd) were performed by X-ray fluorescence, while Cd was determined by means of Zeeman-effect AA flameless spectrophotometry after solubilizing with aqua regia.

3. Results and discussion

3.1. Textural and mineralogical characteristics

The most significant grain size distribution curves (Fig. 2) and textural parameters (Mz, Skl, σl) (Fig. 3) allowed sediment characterization. Overall, the values of these parameters indicate sediments whose mean diameter is between granules and medium sands ($-1.70\ \Phi < Mz < +1.72\ \Phi$) with sorting between good and poor ($0.19 < \sigma < 2.55$) and distribution curves that tend to be strongly and negatively asymmetrical ($Skl = -0.51$) and leptokurtic ($K_G = 2$). Along the beaches of the Gulf, going from north to south, one notes a differentiation in textural characteristics. Prevalently sandy sediments (Fig. 2) characterize sampling points from 1 to 6 and from 12 to 14 (Fig. 1), while gravelly sediments (Fig. 2) prevail at points from 7 to 11 and 13 (Fig. 1). Sandy sediments are mostly unimodal, very well sorted, almost symmetric and slightly leptokurtic, with tails of granules. Conversely, the gravelly sediments are strongly polymodal, poorly sorted, strongly and negatively asymmetrical and show distribution curves from platikurtic to leptokurtic owing to the mixing of different grain-size components. These textural differences are to be attributed to a different mineralogical composition of the modes. Observation by optical microscope evidenced two fundamental components characterizing the modes: a siliciclastic and a carbonatic component. The siliciclastic component is made up of angular quartz clasts, feldspars, micas, magnetites and lithic fragments (metamorphic, granitic rocks, volcanites), transported to the beaches by the watercourses; the carbonatic component is composed of well-rounded clasts from the erosion of the carbonatic complex. In the unimodal sediments, the mode is composed of medium sand, for the most part quartzose-feldspar, characterized by the presence of biotite and magnetite; the coarse tails of these sediments instead are made up of granitic and metamorphic elements, and sometimes of carbonatic pebbles. In the polymodal samples, the modes

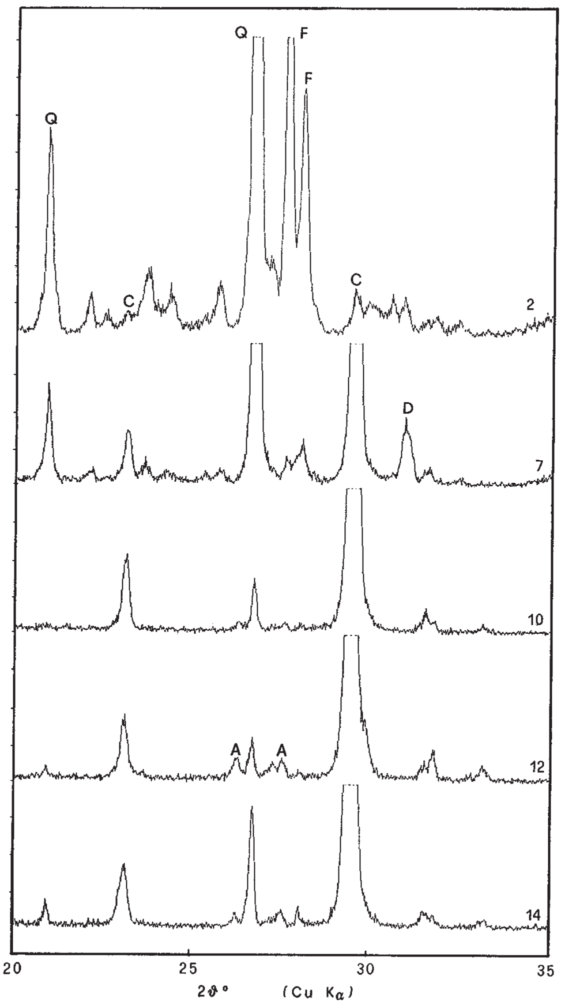


Fig. 4 - X-ray patterns of the series of samples 2, 7, 10, 12 and 14, in which it is seen that as calcite increases (from north to south) quartz decreases; in sample 7, in particular, besides calcite, dolomite also appears, while in samples 10, 12 and 14 aragonite is present.
A=Aragonite; C=Calcite; D=Dolomite; F=Na feldspar; Q=Quartz.

are made up of carbonatic sediments, also with the presence of an angular quartzose component in the fine tails. The points of demarcation between the two areas are sampling points 7 and 8 (Fig. 2), which show coarse carbonatic modes to which have been added a component of medium sand made up of lithic fragments and a fine sandy quartzose-biotitic component.

The mineralogical composition of the individual beaches correlates both with that of watercourses and with that of the lithologies (limestones, dolomites, basalts, Quaternary deposits) present along the coast. In the watercourses feeding the northern sector of the gulf (Codula de Luna, Codula de Sisine, Codula de Fuili) the basement lithologies entirely constitute the highest part of the Codula de Luna watershed, and partially outcrop in the innermost part of Codula de Sisine. Sediments at sampling points 2, 3 and 4, fed by Codula de Luna, are almost entirely made up of

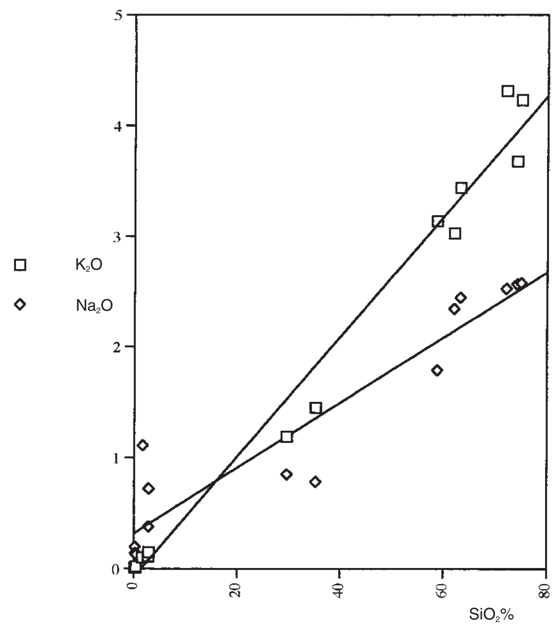


Fig. 5 - Correlation of K_2O and Na_2O with SiO_2.

quartz (Table 1), feldspars, biotites and granitic and metamorphic lithic fragments. In the sediments at sampling points 7 and 8, fed by the Sisine, the siliciclastic component is partly made up of volcanite clasts and olivines and pyroxenes from erosion of the basalts. At sampling point 1, sediment composition is influenced by the Quaternary deposits present at that point along the coast. The carbonatic component, which is present in all sediments, is composed of calcite with a low magnesium content, dolomite and aragonite. Calcitic clasts predominate and are rounded on all beaches examined; aragonite clasts are jagged shell-like fragments of modern origin and are not especially abundant in the sediments examined.

In Fig. 4 can be seen the X-ray patterns of 5 samples (2, 7, 10, 12, 14) representative of the two kinds of beaches, which confirm observations made previously. On examining the angular interval between 15 and 35° 2ϑ it was found that while observing from north to south, the peaks characteristic of quartz (20.88°; 26.68° 2ϑ) and feldspars, especially albite (27.56°; 28.00° 2ϑ), decrease in intensity, while those of calcite (23.05°; 29.42° 2ϑ), which becomes the predominant mineralogical phase, increase. Furthermore, in sample 7 dolomite is present (30.8° 2ϑ), while in samples 10, 12 and 14 small quantities of aragonite are evident (26.18°; 27.20° 2ϑ). The quartzose component reappears in the final terms of the series.

3.2. Geochemical characteristics

Table 1 shows the chemical analyses of the major elements, as highlighted by the mineralogical composition. Two families of sediments are observed, one to the south with a prevalent car-

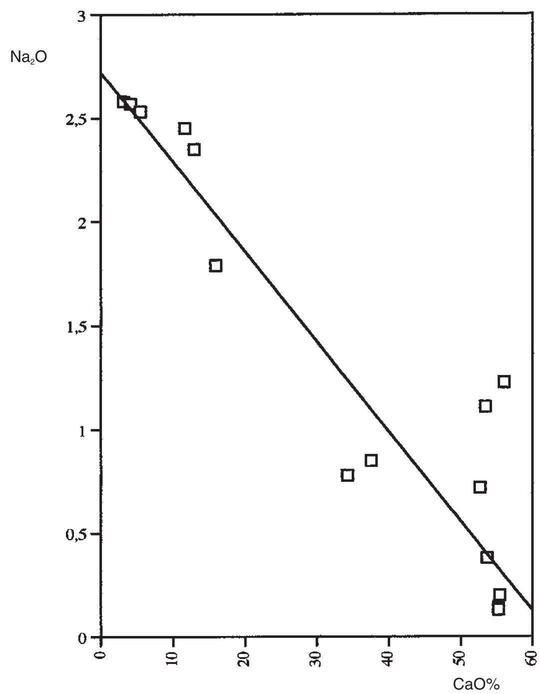


Fig. 6 - Inverse correlation of Na_2O with CaO.

bonatic component, the other in the northern area with a prevalently siliciclastic component (samples 1 to 6), where volcanic, metamorphic and granitic elements predominate. Indicative of volcanic feed, we find silicon, iron and manganese, which, having similar trends, most likely come from the same source; the high average values of aluminum denote the influence of metamorphic feeds, which are also clearly highlighted by the titanium values, and in part by those for

Table 1 - Major elements.

sample	SiO_2%	TiO_2%	Al_2O_3%	Fe_2O_3%	MnO%	MgO%	CaO%	Na_2O%	K_2O%	LOI%
GO 1	62,00	0,08	8,18	0,60	0,02	0,89	12,89	2,35	3,03	9,91
GO 2	75,00	0,07	10,88	0,61	0,01	0,46	3,15	2,58	4,23	2,96
GO 3	74,17	0,07	10,20	0,69	0,02	0,74	4,08	2,57	3,68	3,72
GO 4	72,07	0,09	10,71	0,71	0,02	0,63	5,44	2,53	4,31	3,45
GO 5	58,69	0,08	7,99	0,63	0,02	0,44	15,91	1,79	3,14	11,25
GO 6	63,22	0,07	8,66	0,59	0,02	0,73	11,60	2,45	3,44	9,20
GO 7	29,60	0,07	3,53	0,80	0,02	1,19	37,58	0,85	1,19	25,14
GO 8	35,19	0,07	3,66	0,86	0,02	0,88	34,27	0,78	1,45	22,80
GO 9	0,43	0,00	0,09	0,03	0,00	0,41	55,27	0,13	0,02	43,58
GO 10	1,67	0,00	0,24	0,06	0,01	0,54	53,44	1,11	0,10	42,80
GO 11	0,30	0,00	0,07	0,02	0,01	0,40	55,24	0,14	0,01	43,79
GO 12	2,88	0,01	0,30	0,05	0,01	0,82	52,67	0,72	0,15	42,39
GO 13	0,20	0,00	0,05	0,02	0,00	0,39	55,44	0,20	0,01	43,68
GO 14	2,84	0,00	0,25	0,03	0,01	0,50	53,69	0,38	0,11	42,18

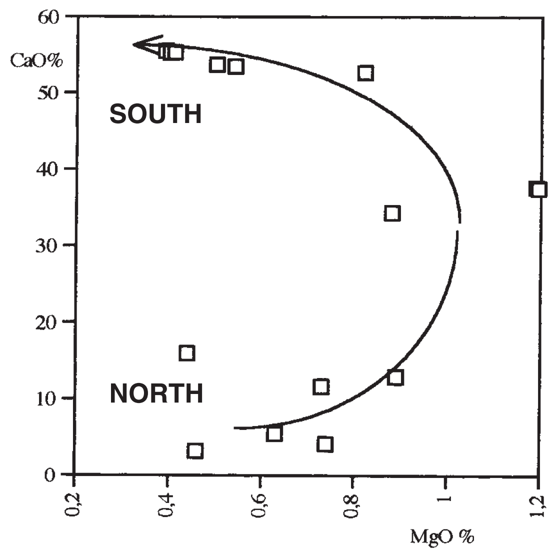
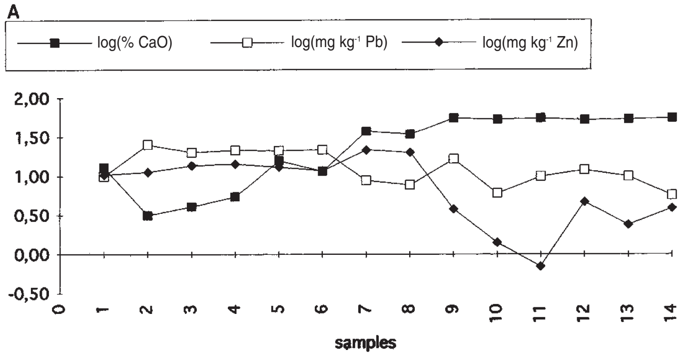


Fig. 7 - Correlation between CaO and MgO. An increase in magnesium with respect to calcium is noted from south to north.

magnesium. Granitic feeds are indicated by the sodium and potassium contents, which decrease until they disappear altogether. Then the carbonatic component (samples 9 to 14), to which must also be attributed the calcium content of all sediments, predominates over the other components. Figs. 5 and 6 show the relations between Na, K, Ca and Si. The Na and K trends reflect the distribution of Na and K feldspars; their constant relationship with Si indicates their origin in the intrusive magmatic component. In samples 7 and 8, the sedimentary siliciclastic and carbonatic components are equal, thus identifying an area of intermediate values, while the Mg content, the highest of the series, is to be attributed partly to the dolomitic phase (Fig. 4) and partly, as has already been indicated, to the ferro-magnesium minerals. This behaviour of magnesium is shown in Fig. 7.

Table 2 presents the values of trace elements, which allow us to confirm provenance, since some of them distinguish between different types of sediment sources (Cristini et al., 1992). Strontium is present, with constant mean values, in all sediments; in fact, its presence is indicative not only of feldspars, but also of calcite, and sometimes recent aragonite phases, which make up the sands of the beaches sampled; since its linear trend does not distinguish the original lithologies, this element cannot be used as a possible marker in this sedimentary environment. In samples 10, 12 and 14, the higher strontium contents are related to the aragonite phases (Fig. 4), present together with those of calcite, thus indicating that this element differentiates only the different phases of the carbonatic sediments. This is especially evident in sample 7, where the lower amount of Sr is related to the dolomitization that leads to the depletion of this element (Bustillo et al., 1992). In these sediments, Zr, Y and Rb, which are present in different amounts and correlated one to the other, are considered as markers, since they allow a clear distinction between the siliciclastic (Zr=39 mg kg^{-1}; Y=5 mg kg^{-1}; Rb=110 mg kg^{-1}) and the carbonatic (Zr=8 mg kg^{-1};



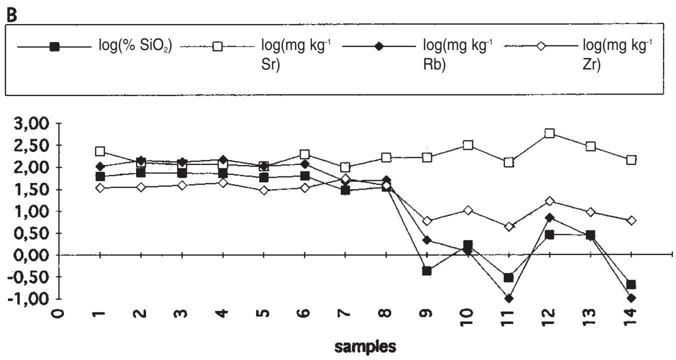


Fig. 8 - Trend of Pb and Zn with respect to the carbonatic phases from north to south (a). Trend of Sr, Rb and Zr with respect to the siliciclastic compont from north to south (b).

Table 2 - Trace elements.

sample	Rb mg kg^{-1}	Sr mg kg^{-1}	Pb mg kg^{-1}	Y mg kg^{-1}	Zr mg kg^{-1}	Zn mg kg^{-1}	Cd μg kg^{-1}
GO 1	105,4	225,7	12,5	3,5	34,3	10,4	nd
GO 2	141,1	126,2	25,4	3,4	35,7	11,3	nd
GO 3	130,2	114,6	20,1	6,8	39,1	13,8	25
GO 4	147,7	115,6	21,5	4,8	44,2	14,4	nd
GO 5	106,8	103,8	21,3	4,6	29,9	13,1	80
GO 6	116,7	194,4	21,8	3,4	33,9	11,8	nd
GO 7	47,3	97,6	8,9	9,1	54,9	21,7	140
GO 8	50,9	160,4	7,8	3,5	38,0	20,1	nd
GO 9	2,2	162,1	16,5	0,0	6,0	3,8	120
GO 10	1,2	306,5	6,1	0,0	10,4	0,0	230
GO 11	0,0	123,6	0,0	0,0	4,4	0,7	nd
GO 12	7,0	571,1	12,0	0,0	16,3	4,7	190
GO 13	0,0	138,2	5,7	0,0	6,0	3,9	160
GO 14	2,6	283,0	0,0	0,0	9,3	2,4	nd

nd = not determined.

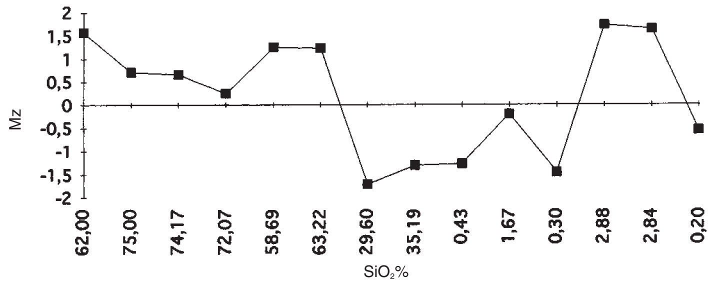


Fig. 9 - Correlation between grain-sizes and chemical characteristics in the siliciclastic compont from north to south.

Y=0 mg kg^{-1}; Rb=2 mg kg^{-1}) components. Within the siliciclastic component, at sampling points from 1 to 6, the granitic feed is prevalent: the mean value found in the sediments was Zr=31 mg kg^{-1}; Y=4 mg kg^{-1}; Rb=114 mg kg^{-1} and was similar to that found in beach sediments of the same nature (Cristini et al., 1992: Zr=32 mg kg^{-1}; Y=3 mg kg^{-1}; Rb=96 mg kg^{-1}). On the contrary, the volcanic and metamorphic feeds are more relevant at sampling points 7 and 8: values found in the sediments (Zr=47 mg kg^{-1}; Y=6 mg kg^{-1}; Rb=49 mg kg^{-1}) are within the average range of beach sediments having a similar composition (Zr=90 mg kg^{-1}; Y=10 mg kg^{-1}; Rb=70 mg kg^{-1}) (Cristini et al., 1992). The higher Zn and Fe contents found in the sediments of beaches 7 and 8 indicate an enrichment caused by dolomitization; one notes at the same time, in the same sediments and for the very same phenomenon, a decrease in the content of Pb (Bustillo et al., 1992), an element that increases in samples in which aragonite is present. The Zn and Pb contents of all other samples reflect the Sardinian background (Cristini et al., 1992). The carbonatic component (samples 7 to 14), on the other hand, shows a higher cadmium content: this metal is correlated both with calcium and with ignition weight loss (LOI), which reflects the content of organic matter (Aizawa and Akaiwa, 1992).

Fig. 8 illustrates the considerations given above, while Fig. 9 shows the correlation between textural characteristics (Mz) and elements; it shows the close correlation to be found in the analysed sediments between the compositional and grain-size characteristics as they were inherited from the parent rocks.

4. Conclusions

From north to south, the sedimentological, mineropetrographic and geochemical characteristics of sediments making up the individual beaches of the Gulf of Orosei in east central Sardinia are described. There are correlations between sedimentological characteristics and elements, with the latter considered as tracers, since they indicate provenance from mixed (granitic, metamorphic, carbonatic) or exclusively carbonatic petrographic provinces. It is shown that the beaches are mainly fed by carbonatic clasts from the Mesozoic reefs and watercourses. This is especially true of samples from the northern part of the gulf, starting from the beach of Cala Sisine.

To the north of Cala Sisine, beaches are composed of medium coarse, unimodal and well sorted sands. These characteristics are analogous to those of the other siliciclastic beaches along the eastern coast.

To the south, where the carbonatic component prevails, feed comes mostly from detritic contributions from the cliffs; we thus have a prevalence of somewhat poorly sorted polymodal gravels due to mixing of the different grain-size components.

Within the siliciclastic component, the constant ratios of K, Na, Rb and Zr to $Si0_2$ that were found in the sediments reflect the preponderance of granite as compared to metamorphic and volcanic contributions.

As concerns the carbonatic component, it was seen that the distribution of Sr, Mg, Zn and Pb was influenced by the mineralogic phases.

The distribution of Sr and Mg is constant in all sediments, since these elements come from different lithologies.

In each of the components, we found a different content of trace elements, which allowed discrimination of the sediments. Within each component, each lithology was identified by geochemical markers (Rb, Zr, Y and Cd), which showed that coastal processes do not influence the original composition of the sediments, which depends essentially on the characteristics of the sources.

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