Δελτίο της Ελληνικής Γεωλογικής Εταιρίας τομ. XXXII/2, 183-191, 1998
Πρακτικά 8ου Διεθνούς Συνεδρίου, Πάτρα Μάιος 1998

Bulletin of the Geological Society of Greece vol. XXXII/2, 183-191, 1998
Proceedings of the 8th International Congress, Patras, May 1998

STUDY OF THE LAKKI BAY SURFACE SEDIMENTS, LEROS ISLAND, SE AEGEAN SEA. SEDIMENTOLOGY, MINERALOGY AND GEOCHEMISTRY

SIOULAS A.[1], ANAGNOSTOU CH.[2], KARAGEORGIS A.[2], AND GEROLYMATOS I.[3]

ABSTRACT

A set of 18 surface sediments form the Lakki bay were collected and analysed for sedimentological properties, mineralogical composition and the geochemical properties of the fine pelitic fraction. The sediments are sandy, with high carbonate and organic carbon contents. The minerals identified are: quartz, feldspars, amphiboles, clay and carbonate minerals. The major and trace elements were grouped according to their geochemical similarity and distribution: i) Si, Al, K, Ti, Rb are related with detrital aluminosilicates; ii) Ca, Sr, Ni, biogenic group; iii) Fe, Mn, Zr, and V, related with the erosion of post-alpine formations with Fe-minerals and iv) Cu, Pb and Zn, related with human activities. The computation of I_{geo} index, revealed the enrichment of the eastern, southeastern part of the bay in Pb, Zn, possibly due to the past and present port activities.

ΠΕΡΙΛΗΨΗ

Ο όρμος Λακκί βρίσκεται στα ΝΔ της νήσου Λέρου και είναι το κύριο και ασφαλές λιμάνι του νησιού. Η τοπογραφία του πυθμένα παρουσιάζει σχετικά μεγάλες κλίσεις κατά μήκος της ακτογραμμής, ενώ στο εσωτερικό το ανάγλυφο είναι πιό ομαλό. Το μέγιστο βάθος είναι περίπου 75μ., κοντά στη στενή είσοδο του όρμου.

Μια σειρά 18 επιφανειακών δειγμάτων συλλέχθηκε και αναλύθηκε για το μέγεθος των κόκκων, την περιεκτικότητα σε ανθρακικά και οργανικό άνθρακα, την ορυκτολογική σύσταση και τέλος, για τα επίπεδα των κυρίων στοιχείων και ιχνοστοιχείων στη λεπτόκοκκη πηλιτικό κλάσμα.

Τα ιζήματα είναι κυρίως αμμώδους σύστασης, με μεγάλη περιεκτικότητα σε ανθρακικά. Τα μεγαλύτερα ποσοστά της κλάσης της άμμου παρατηρούνται κατά μήκος των ακτών και επίσης στο ΝΔ τμήμα του όρμου, ενώ το ΒΑ άκρο, άν και ρηχότερο, καλύπτεται από πιο λεπτόκοκκα ιζήματα. Η κατανομή των ανθρακικών είναι παρόμοια. Η γεωγραφική διανομή των παραμέτρων αυτών σχετίζεται με το ενεργειακό καθεστώς του όρμου, που είναι χαμηλότερο στο ΒΑ άκρο και αντίστοιχα πιό ισχυρό στα ΝΔ. Τα ιζήματα αποτελούνται κυρίως από χαλαζία, άστριους, αμφιβόλους, αργιλικά ορυκτά [1]και ανθρακικά ορυκτά.

Τα κύρια στοιχεία και τα ιχνοστοιχεία που προσδιορίστηκαν στην πηλιτική φάση, σε συνδυασμό με τον υπολογισμό των συντελεστών συσχέτισης και τη γεωγραφική κατανομή των χημικών στοιχείων, διαμόρφωσαν τις παρακάτω ομάδες χημικών στοιχείων i) Si, Al, K, Ti, Rb, σχετίζονται με τα χερσογενή αργιλιοπυριτικά, ii) Ca, Sr, Ni, βιογενής ομάδα, iii) Fe, Mn, Zr, V, προέρχονται από την αποσάθρωση μεταλπικών πετρωμάτων με Fe-ούχες ενώσεις και iv) Cu, Pb, Zn, στοιχεία που σχετίζονται με ανθρωπογενείς δραστηριότητες. Η χρήση του δείκτη γεωσυσσώρευσης επισήμανε την επιβάρυνση της νότιας περιοχής του όρμου σε Pb και λιγότερο σε Cu, Zn, πιθανό αποτέλεσμα της χρήσης του στο

1 Hydrobiological Station of Rodos, Ko str., 85 100 Rodos, Greece
2 National Centre for Marine Research, Agios Kosmas, 166 04 Elliniko, Athens, Greece
3 Institute of Geology and Mineral Exploration, Mesogeion 80, Ampelokipoi, Athens, Greece

παρελθόν σαν ναυτικής βάσης ή και εξαιτίας των εγκαταστάσεων φόρτωσης καυσίμων, που υπάρχουν στο νότιο τμήμα του.

KEY WORDS: sediment; mineralogy; geochemistry; geoaccumulation index; Leros island; Aegean sea; Greece.

1. INTRODUCTION

Leros island belongs to the Dodekanisa island complex, located between the Patmos and Kalymnos islands, in the SE Aegean sea. The island is covering an area of 53km^2, the total coastline is 71km long and the population is about 8.000 inhabitants. The area under investigation concerns the Lakki bay (Fig. 1a), located in the SW part of the island. The Lakki bay is a semi-enclosed marine area, with a very narrow entrance of approximately 400m.. It is the major port of the island and one of the safest ports of the Mediterranean, also used as a naval base during the 2nd world war. The city of Lakki has a population of 2.400 inhabitants.

The present study aims at giving information upon the oceanographic status of the Lakki bay, as far as it concerns the bottom topography and the quality of the surface sediments, represented by their sedimentological properties, their mineralogical and geochemical composition. The latter parameter, will also reveal possible human impact in the area, taking into account the levels of the heavy metals in the surface sediments.

Geological setting

Leros island lies in the eastern part of the intermediate metamorphic field of "Hellenides" and the geodynamic evolution of the formations is similar to those of Kyklades islands.

The part of the island within the watershed of the Lakki bay (Fig. 1a) is composed by non metamorphic post-alpine and metamorphic alpine and variscan formations. The main types of the post-alpine formations are loose detrital sediments, occurring mainly in the valleys and the coastal areas, and molassic sediments with clastic rocks and marly limestones. The latter, are characterised by the presence of fine Fe compounds in oxidised form.

The basement of the post-alpine rocks is represented by alpine and variscan metamorphic formations. The alpine formations comprise the mesozoic cover and its underlying polymorphic clastic rocks, with carbonate lenses and metavolcanites of intermediate basicity. Compact and dispersed Fe compounds, both in reduced and oxidised forms, are observed in tectonic zones of the latter rock types. The variscan rocks are composed of different types of schists with amphibolitic bodies and small marble lenses.

The creation of the bays of Leros island is due to intensive movements, in an extensive field, vertical to the long axis of the island and related with the exhumation of metamorphic formations of the "Hellenides" intermediate metamorphic field.

2. MATERIALS AND METHODS

The field work was carried out during a cruise of R/V Aegaeo in the Dodekanisa area. A set of 18 surface sediment samples was collected with a Reineck stainless steel grab. The sampling stations location is illustrated in Figure 1b. Bathymetric measurements were performed along tracks, with a narrow beam echosounder (Furuno FE-824). The Integrated Navigation System of R/V Aegaeo (GPS, gyro compass, speedlog) was used for the positioning during both the sampling and the bathymetry.

The samples were treated with H_2O_2 10% solution, in order to remove the organic matter and passed through a 63μm sieve (Folk, 1974). The fine fraction was analysed in a Sedigraph (Micromeritics 5100) grain size analyzer, to determine the silt and clay content. The determination of the total carbonate content was performed with the 'carbonate bombe' (Müller and Gastner, 1971) and the total organic carbon (TOC) by the Walkley & Black method (Williams, 1977).

The mineralogy of the bulk sediment was determined by X-Ray Diffraction (Rigaku D/Max B system).

The diffractometer employed CuKa radiation, graphite monochromator, whilst the powdered samples were scanned in the range 2°-50° 2q. The scanning conditions were: scan speed 1°/min, voltage 40kV and current 20mA.

The geochemical analyses were performed in the pelitic (<6μm) fraction of the sediment, which was separated in settling tubes. The major and trace elements were determined by the Energy Dispersive X-Ray Fluoresence method (Tracor TX 5000 system), in the laboratories of Technische Universitδt Hamburg-Harburg. The accuracy of the measurements was 15% for Cr, 20% for Cu and between 5-10% for the other elements, checked by a set of international reference materials (NBS 1646 'Estuarine Sediment', NIES No. 2 'Pond Sediment', BCR 277 'Estuare Sediment', BCR 280 'Lake Sediment', BCR 320 'River Sediment').

The comparison of the present heavy metal levels with background values, not affected by human activities, was performed with the "Index of Geoaccumulation", introduced by Müller (1979):

$$I_{geo}=\log_2 \frac{C_n}{1.5*B_n}$$

Cn is the measured concentration of the element "n" in the clay sediment fraction (∅<2μm) and Bn represents the geochemical background concentration of element "n" for the "average shale" referenced from Turekian and Wedepohl (1961). The factor 1.5 is introduced to include possible variations of the background values due to lithogenic effects. Igeo value is a measure of heavy metal contamination and it is defined in the following scale:

I_{geo}	I_{geo} class	Designation of sediment quality
>5	6	Extremely contaminated
4-5	5	Strongly to extremely strongly contaminated
3-4	4	Strongly contaminated
2-3	3	Moderately to strongly contaminated
1-2	2	Moderately contaminated
0-1	1	Uncontaminated to moderately contaminated
<0	0	Uncontaminated

The method can be applied also in the fraction ∅<6μm, if the content of the ∅<2μm particles in the samples is very low (Karageorgis *et al.*, 1997a). The methods' performance is not altered significantly, because the clay minerals (major carriers of the trace elements) are the major component of the ∅<6μm fraction as well. The I_{geo} index has been determined for the sediments of various sites of the Hellenic territory, providing useful information about the sediments quality (Anagnostou *et al.*, 1996; Anagnostou *et al.*, 1997; Karageorgis *et al.*, 1997a; Karageorgis *et al.*, 1997b). The relationships between the chemical elements were studied by the use of summary statistics and the correlation coefficients matrix, calculated by the software package Statgraphics Plus (Statistical Graphics Corporation, 1994).

3. RESULTS AND DISCUSSION

Bottom topography

The Lakki bay bathymetric map is illustrated in Fig. 1b. The general bottom topography is characterised by steep slopes along the northern and the southwestern coast and smoother NE and SE parts. The inner bay is more flat (depths between 30 and 50m). The deepest part of the bay is the SW, max. depth around 75m close to the the narrow entrance.

Grain-size properties

The surface sediments grain-size properties are presented in Table 1. The sediments are consisted mostly of sand (25.7-85.8%) and silt (9.3-62.7%), while the clay content is a minor component (0-20.9%). According to Folk (1974), the sediments are muddy sands and silty sands. The spatial distribution of the

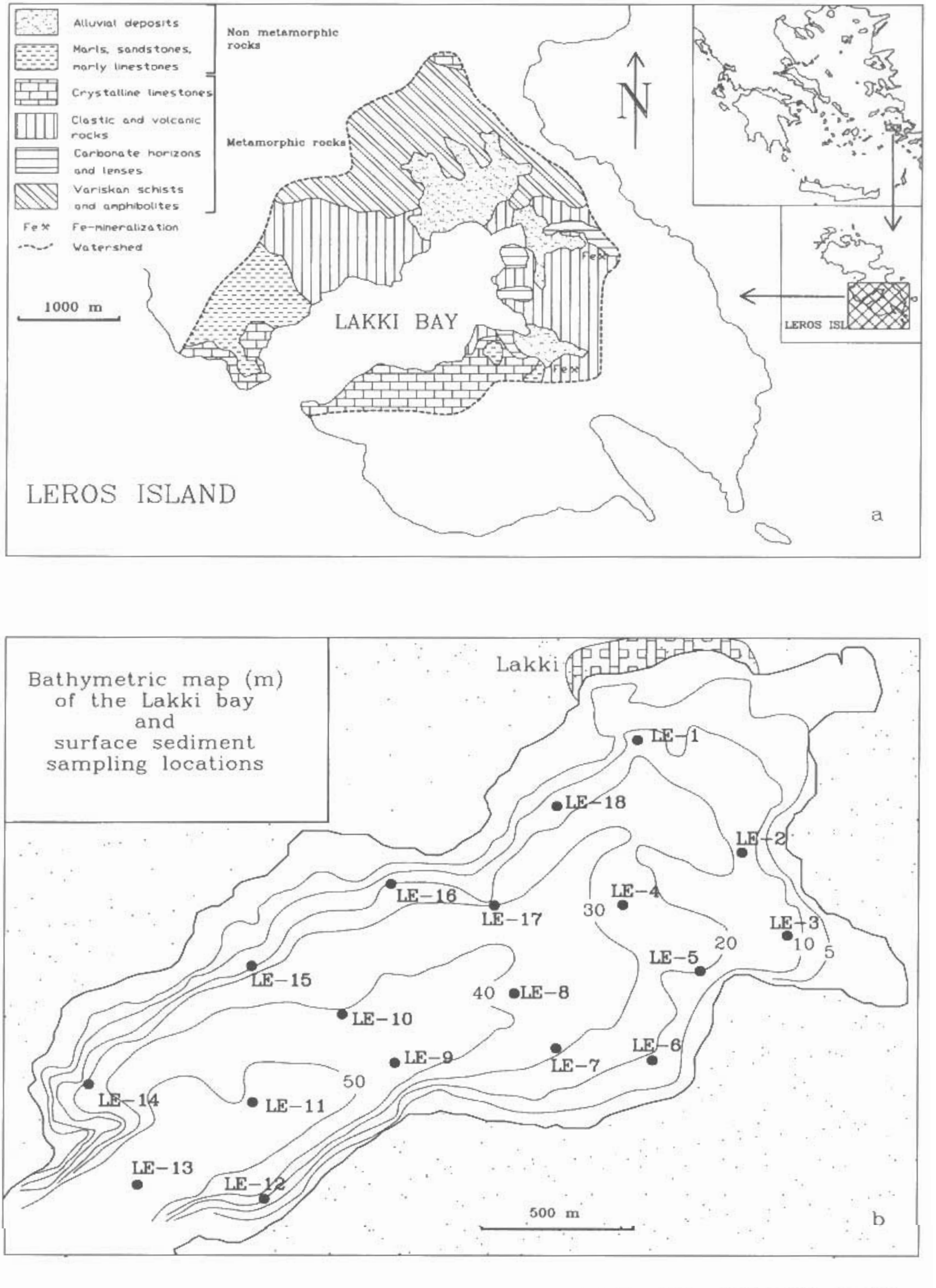

Figure 1. (a)Rock formations within the Lakki bay drainage basin (Stavropoulos and Gerolymatos, 1995), (b)Bathymetric map of the Lakki bay, depth contours in meters. Sampling stations location for samples LE-1 to LE-18.

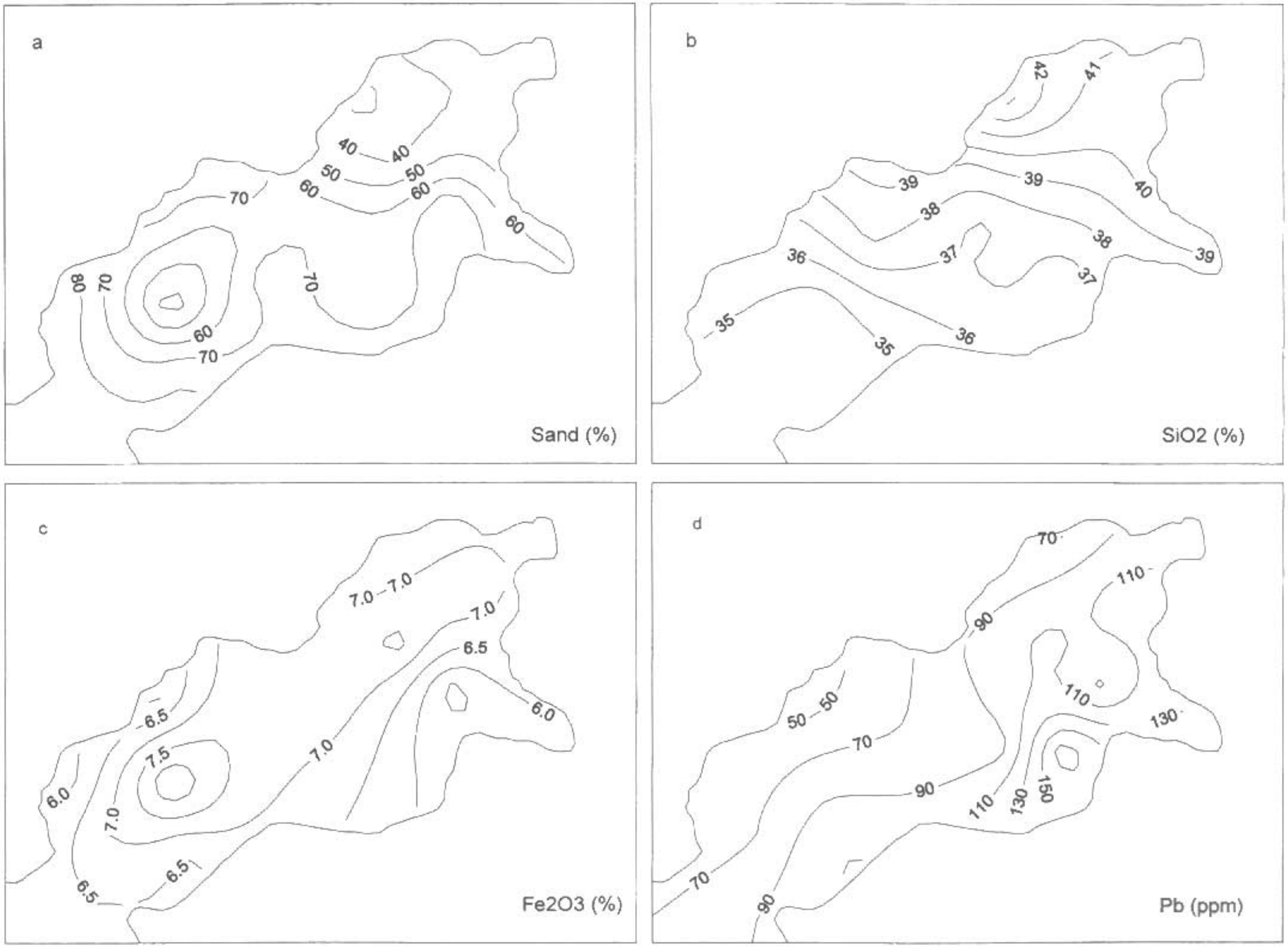

Figure 2. Spatial distribution for sand (a), SiO2 (b), Fe2O3 (c) and Pb (d)

more coarse sand fraction (>63μm), shows that sediments are less sandy in the NE part of the bay, whilst higher percentages are observed along the northern coast, up to the bay entrance (Fig. 2a). In the inner SW part, the sand content is significantly smaller (station LE-11).

In general, the grain-size distribution is reversibly proportional to the depth, that is coarse sediments appear in the shallow water and fine grained sediments in the deeper parts, as a function of the hydrodynamic conditions. In the case of the Lakki bay this rule is not exactly applicable, since the lower sand content is covering the shallow NE part of the bay and higher values appear in the deeper SW area. It seems that the hydrodynamic status in the NE part is lower and fine grained sediments dominate this relatively calm environment. On the contrary, the sedimentation in the SW is regulated by the sharp coastal morphology and is also is affected by stronger coastal currents, resulting to higher sand content (stations LE-12, 13, 14). The inner SW part (LE-11) is dominated by finer sediments due to the significant increase of the depth (>50m) and hence, the hydrodynamically more calm environment.

Table 1.Grain-size, carbonates, organic carbon and major elements (<6μm), of the Lakki bay surface sediments.

Sample	Sand %	Silt %	Clay %	Carbo- nate %	Org. carb.%	SiO_2 %	Al_2O_3 %	Fe_2O_3 %	CaO %	K_2O %	TiO_2 %
LE 1	42.4	57.6	0.0	47.4	3.78	41.22	17.80	6.73	8.71	2.97	0.88
LE 2	41.7	51.9	6.3	44.7	3.00	40.28	16.63	7.25	9.04	2.94	0.89
LE 3	48.6	47.6	3.8	52.6	2.52	40.38	17.76	6.35	8.30	3.28	0.82
LE 4	40.4	53.4	6.2	53.9	2.06	39.52	15.46	7.65	10.48	2.76	0.86
LE 5	81.6	18.4	0.0	85.5	1.68	38.51	14.10	5.31	10.64	2.51	0.65
LE 6	69.3	28.8	1.9	63.2	3.10	36.55	13.45	6.00	11.36	2.38	0.69
LE 7	62.2	34.8	3.1	64.5	0.83	37.43	14.14	6.80	12.37	2.43	0.82
LE 8	69.8	9.3	20.9	59.2	0.83	36.76	14.75	7.22	11.52	2.51	0.84
LE 9	73.6	23.4	3.0	57.9	0.81	36.81	14.66	7.21	12.15	2.46	0.82
LE 10	52.3	44.7	3.0	65.8	0.87	38.00	14.67	7.42	12.35	2.39	0.84
LE 11	32.7	56.8	10.5	50.0	1.42	34.32	13.25	8.54	12.75	2.28	0.70
LE 12	78.5	19.5	2.0	69.7	1.08	34.08	13.58	6.51	12.92	2.28	0.69
LE 13	76.1	19.9	4.0	65.8	1.25	34.79	14.04	6.98	12.54	2.35	0.73
LE 14	85.8	12.6	1.6	86.8	1.42	35.20	13.04	5.84	13.62	2.05	0.65
LE 15	72.1	28.0	0.0	75.0	1.39	37.06	14.02	5.87	13.26	2.24	0.67
LE 16	79.7	20.3	0.0	47.4	0.70	39.80	14.60	7.40	11.14	2.21	0.78
LE 17	49.3	44.7	6.0	59.2	1.13	38.61	16.16	7.35	11.05	2.71	0.87
LE 18	25.7	62.7	11.6	42.1	2.78	43.45	17.80	6.62	8.69	2.84	0.80

Carbonate content

The carbonate content is generally high, varying between 42.1% and 86.8% (Table 1). Principal source of the carbonate material is the various marine organisms, which use calcium carbonate to build their shells. The distribution patterns are similar to the sand fraction, denoting the presence of carbonates preferably in the coarser part of the sediment.

Organic carbon

The total organic carbon varies between 0.70 and 3.78% (Table 1) and it is considered as high. Especially the northwestern area is carrying most of the organic load. Nevertheless, this phenomenon is due to the decomposition of sea- weed, rather than human impact.

Mineralogy

The mineralogical composition is following the typical characteristics of the coastal sediments. The minerals identified were: quartz, feldspars (plagioclase), amphiboles, clay minerals (illite, chlorite and smectite) and carbonate minerals (calcite, Mg-calcite, aragonite). The samples with strong peaks of carbonate minerals are nicely correlated with the sand distribution patterns (and apparently the total carbonate content distribution), indicating that these minerals appear mostly in the coarse fractions.

Table 2. Trace elements and Igeo index, of the Lakki bay surface sediments (<6μm).

Sample	Mn ppm	Igeo class	Cu ppm	Igeo class	Pb ppm	Igeo class	Zn ppm	Igeo class	Cr ppm	Igeo class	Ni ppm	Igeo class	Sr ppm	Rb ppm	Zr ppm	V ppm
LE 1	322	0	81	1	68	2	168	1	148	1	68	0	450	125	162	176
LE 2	347	0	85	1	120	3	257	1	144	1	65	0	471	125	184	204
LE 3	256	0	83	1	117	2	204	1	128	0	57	0	428	124	177	171
LE 4	366	0	90	1	116	2	235	1	133	0	74	0	517	119	205	208
LE 5	248	0	67	0	85	2	162	1	116	0	63	0	532	94	134	169
LE 6	289	0	89	1	182	3	260	1	141	1	77	0	608	101	152	173
LE 7	385	0	74	1	81	2	178	1	127	0	77	0	573	107	184	154
LE 8	376	0	92	1	89	2	174	1	143	1	73	0	559	115	188	156
LE 9	379	0	69	1	74	2	177	1	140	1	79	0	558	108	183	197
LE 10	418	0	72	1	66	2	164	1	132	0	78	0	540	104	203	199
LE 11	414	0	71	1	84	2	196	1	126	0	81	0	587	98	175	208
LE 12	322	0	121	1	109	2	304	2	123	0	73	0	629	102	144	179
LE 13	353	0	85	1	68	2	160	1	123	0	77	0	605	104	167	172
LE 14	318	0	57	0	57	1	125	0	138	1	77	0	615	93	175	155
LE 15	331	0	58	0	40	1	125	0	137	1	81	0	553	96	153	150
LE 16	373	0	74	1	63	2	154	1	134	0	76	0	420	99	190	190
LE 17	344	0	86	1	93	2	187	1	138	1	77	0	508	112	167	177
LE 18	308	0	70	1	80	2	152	1	127	0	70	0	392	114	141	183

Geochemistry of the pelitic fraction

The results of the geochemical analyses of the pelitic fraction (<6μm) for major and trace elements are presented in Tables 1 and 2. The correlation coefficients matrix is presented in Table 3.

The fine pelitic fraction is mostly composed of aluminosilicates, hence Si and Al are the dominant chemical elements, exceeding the 60% of the total concentration (Table 2). Si, Al, K and Ti show high inter-correlations (Table 3, Si-Al:0.87, K-Al:0.92, Ti-Al:0.72, K-Si:0.74, etc.), denoting their common geochemical behaviour. These elements are forming the group of detrital origin elements, related with the aluminosilicates. Rb and the organic carbon go with this group as well. The spatial distribution of the aforementioned elements is very similar (the representative distribution of SiO_2 is illustrated in Fig. 2b). The general pattern is an increasing trend of the concentrations in the direction SW-NE, indicating that the major source of the aluminosilicates in located in the NE part of the bay.

CaO and Sr from the minor elements are forming the biogenic group. They show negative correlations with the detrital origin group (Table 3, Ca-Al:-0.91, Sr-Si:-0.94, Ca-Sr:0.84) and positive correlations with the carbonates and the sand content. Likewise, Ni is attracted to this group (Ni-Ca:0.80). These elements illustrate also an opposite aerial distribution, that is, an increase from the NE towards the SW.

Studying the correlation coefficients matrix, as well as the spatial distribution of the trace elements, we recognised a group of elements with similar properties. Fe is not related to the land derived aluminosilicates, but seems to form another group together with Mn, Zr and V (Fe-Mn:0.81, Fe-Zr:0.65, Fe-V:0.70), partly with Ti (Fe-Ti:0.53) and also positively related with the silt and clay fractions. Their spatial distribution is quite similar (Fig. 2c). The maximum concentrations appear in the deepest SW part of the bay and the NE area. This is probably a group related with the erosion of Fe compounds in the post-alpine formations occurring in the western side of the drainage basin of the bay. Another potential source is the majority of the metamorphic rocks of the area and specifically an existing Fe mineralization zone (Fig. 1a) comprised of magnetite, hematite, hy[illegible] 1995).

Table 3. Correlation coefficients matrix of the major and minor elements, the grain-size, the carbonate and the organic carbon results. (n=18, significance level 0.05).

	SiO_2	Al_2O_3	Fe_2O_3	CaO	K_2O	TiO_2	Mn	Cu	Pb	Zn	Cr	Ni	Sr	Rb	Zr	V	Sand	Silt	Clay	Carb.
SiO_2	1.00																			
Al_2O_3	0.87																			
Fe_2O_3	-0.04	0.08																		
CaO	-0.87	-0.91	0.01																	
K_2O	0.74	0.92	0.05	-0.91																
TiO_2	0.59	0.72	0.53	-0.58	0.67															
Mn	-0.28	-0.27	0.81	0.44	-0.36	0.34														
Cu	-0.16	0.08	0.18	-0.13	0.21	0.21	-0.05													
Pb	0.03	0.07	-0.04	-0.33	0.33	0.08	-0.33	0.57												
Zn	-0.14	0.00	0.16	-0.16	0.23	0.12	-0.09	0.83	0.80											
Cr	0.20	0.26	0.14	-0.17	0.17	0.47	0.18	-0.04	0.09	-0.01										
Ni	-0.56	-0.64	0.34	0.80	-0.77	-0.24	0.68	-0.20	-0.30	-0.21	0.13									
Sr	-0.94	-0.85	-0.10	0.84	-0.69	-0.56	0.20	0.16	0.08	0.19	-0.15	0.55								
Rb	0.63	0.85	0.29	-0.79	0.90	0.85	-0.05	0.36	0.29	0.30	0.42	-0.56	-0.58							
Zr	0.01	0.02	0.65	0.07	0.04	0.57	0.69	-0.04	-0.08	-0.03	0.33	0.21	-0.06	0.30						
V	0.18	0.18	0.70	-0.24	0.20	0.38	0.41	0.16	0.22	0.39	0.01	0.02	-0.24	0.26	0.39					
Sand	-0.56	-0.66	-0.52	0.60	-0.65	-0.58	-0.17	-0.03	-0.18	-0.16	-0.12	0.21	0.53	-0.64	-0.16	-0.52				
Silt	0.59	0.67	0.42	-0.60	0.65	0.52	0.09	-0.03	0.16	0.15	0.09	-0.23	-0.56	0.59	0.11	0.54	-0.96			
Clay	0.04	0.16	0.46	-0.13	0.18	0.32	0.31	0.20	0.11	0.04	0.12	0.00	-0.06	0.33	0.21	0.08	-0.39	0.11		
Car.	-0.57	-0.66	-0.64	0.64	-0.58	-0.69	-0.27	-0.22	-0.21	-0.23	-0.31	0.19	0.66	-0.70	-0.29	-0.57	0.73	-0.68	-0.37	
Org car.	0.55	0.60	-0.23	-0.73	0.64	0.19	-0.53	0.08	0.46	0.26	0.32	-0.54	-0.42	0.54	-0.31	0.12	-0.51	0.58	-0.09	-0.39

The elements Cu, Pb and Zn form another group (Cu-Zn:0.83, Pb-Zn:0.80, Cu-Pb:0.57). The distribution of Pb is nicely representing this group (Fig. 2d). The general trend is an increase of the concentrations from NW to SE, parallel to the axis of the bay. The elements are not correlated with the detrital groups and seem to have another source. The calculation of the I_{geo} index (Table 3), shows that the Lakki bay is enriched in Pb, reaching the class 'Moderately to strongly contaminated', in the eastern, south-eastern area (see also Fig. 2d). I_{geo} values for Cu and Zn are significantly lower, but still they reach the class 'Uncontaminated to moderately contaminated'. This could be related with human activities which took place during the past, since Lakki served as an Italian naval base during the 2nd world war, but also the present activities of fuel storage and loading facilities, located along the southern coast.

4. CONCLUSIONS

The Lakki bay is a semi-enclosed marine area, with steep slopes along the north coastline and southwestern coastline and a smoother inner and NE part. The surface sediments are classified in general as muddy sands and silty sands. They have high carbonate (biogenic origin) and organic content, the latter due to the decomposition of sea-weed.

The mineralogical composition comprises quartz, feldspars (plagioclase), amphiboles, clay minerals (illite, chlorite and smectite) and carbonate minerals (calcite, Mg-calcite, aragonite).

The geochemistry of the fine pelitic fraction (<6μm) and the further statistical analysis revealed four groups of major and trace elements:

i) *Si, Al, K, Ti, Rb, which are related with detrital aluminosilicates.*

ii) Ca, Sr, Ni, which form the biogenic origin group.

iii) Fe, Mn, Zr, and V, related with the erosion of Fe compounds of the post-alpine formations located mainly in the western part of the drainage basin.

iv) Cu, Pb and Zn, elements related with human activities during the past (naval base during the 2nd world war), or the present (activities of fuel storage and loading).

REFERENCES

ANAGNOSTOU, CH., KABERI, H. AND KARAGEORGIS A., 1996. The effects of domestic and industrial discharges on the seabed quality of Thessaloniki bay and gulf. Proceedings of the 3rd International Conference on Environmental Pollution, Thessaloniki, Greece, 227-233, (in Greek).

ANAGNOSTOU, CH., SIOULAS, A. AND KARAGEORGIS A., 1997. The "Geoaccumulation Index" in the surficial sediments of Pagassitikos gulf. 5th Hel. Symp. Oceanogr. & Fish., Kavala, Greece, 97-100.

FOLK R.L., 1974. Petrology of sedimentary rocks. Hemphil Publ. Co., Austin-Texas.

KARAGEORGIS , A., ANAGNOSTOU, CH., SIOULAS, A., CHRONIS, G. & PAPATHANASSIOU, E., 1997A. Sediment geochemistry and mineralogy in Milos bay, SW Kyklades, Aegean Sea-Greece. Journal of Marine Systems, in press.

KARAGEORGIS, A., ANAGNOSTOU, CH., SIOULAS, A., KASSOLI-FOURNARAKI A. AND ELEFTHERIADIS G., 1997B. Sedimentology and geochemistry of surface sediments in a semi-enclosed marine area. Central Aegean - Greece. Oceanologica Acta, 20, No. 3, 513-520.

MÜLLER, G., 1979. Schwermetalle in den Sedimenten des Rheins-Verδnderungen seit 1971. Umschau, 79: 778-783.

MÜLLER, G. AND GASTNER, M., 1971. The carbonate bomb, a simple device for the determination of the carbonate content in sediments, soils and other materials. N. Jahrb. Mineral, 10: 466-469.

STATISTICAL GRAPHICS CORPORATION, 1994. Statgraphics Plus, Version 1. Manugistics, Inc., U.S.A..

STAVROPOULOS, I. AND GEROLYMATOS, I., 1995. Geological map of Leros-Levitha-Kinaros islands, scale 1:50.000. Institute of Geology and Mineral Exploration, (in press).

TUREKIAN, K.K. AND WEDEPOHL, K.H., 1961. Distribution of the elements in some major units of the earth's crust. Bull. Geol. Soc. Am., 72: 175-192.

WILLIAMS, P.J., 1977. Analysis of organic matter. In: Practical Estuarine Chemistry, P.C. Head (ed), pp. 160-190, Cambridge University Press.