Clay Minerals, (2015) **50**, 233–248

Geochemical and mineralogical characteristics of beach sediments along the coast between Alanya and Silifke (southern Turkey)

M. G. YALCIN[1,*], M. SETTI[2], F. KARAKAYA[3], E. SACCHI[2] AND N. ILBEYLI[1]

[1] *Department of Geological Engineering, Akdeniz University, 07058 Antalya, Turkey,* [2] *Department of Earth and Environmental Sciences, University of Pavia, Via Ferrata 1, 27100 Pavia, Italy, and* [3] *Department of Geological Engineering, Nigde University, 51100 Nigde, Turkey*

(*Received 17 July 2014; revised 13 June 2015; Editor: G. Christidis*)

ABSTRACT: The aim of this work was to determine the distribution of trace metals in the coastal sediments from the area between Silifke and Alanya (Turkey) and to investigate the sources of these elements, based on their mineralogical, petrographical and geochemical characteristics. Forty three samples were analysed for the determination of their water content, grain-size distribution, petrographical features and their chemical and mineralogical compositions. The samples had low water content, in agreement with the large sand grain size.

The mineralogical composition reflects the complex geological setting of the area. The most abundant mineral phases are represented by calcite and dolomite, followed by quartz and mica. Chlorite, feldspar and other carbonates are present in lesser amounts, while kaolinite was detected in one sample only. All samples contain hematite, chromite, magnetite and goethite and one sample contained pyrite. Samples with high concentrations of trace metals, contained fragments of metamorphic rocks with pyroxene, amphibole, quartz and feldspar, whereas carbonates and opaque minerals were subordinate. Compared to literature data, the average concentrations of several elements and trace metals were great enough to be considered as possibly toxic, exceeding the Turkish higher acceptable limits. Geochemical data were treated statistically using Principal Component Analysis (PCA) to obtain evidence of their distribution and to identify any correlations.

Based on the distribution of mineral phases, the area investigated was divided into different provinces, each characterized by the abundance of one, or more, tracer minerals. In the westernmost areas, between Alanya and Demirtas, the sediments indicate a provenance from dolomites or marbles. In the area between Demirtas and Gazipasa the provenance was from quartzites, clastic and metamorphic rocks and in the sector between Guney and Anamur, the sediments were derived mostly from low-grade metamorphic rocks, in particular metaschists and metabasites. The sediments in the area between Anamur and Ovacik, display variable source rocks and those between Ovacik and Silifke, were derived from limestones and, subordinately, clastic rocks.

The trace-metal concentrations in beach sands appear to be related to the abundance of silicate minerals derived from weathering of the metamorphic-rock outcrops in the inland mountainous regions. In contrast, the trace-metal contents of the limestone- and dolomite-bearing beach sands were small.

* E-mail: gurhan46@gmail.com
DOI: 10.1180/claymin.2015.050.2.07

KEYWORDS: Alanya-Silifke, Turkey, beach sediment, trace metal, mineralogy, geochemistry, multivariate statistics.

Trace metals are among the more serious pollutants in our natural environment (Tam & Wong, 2000) and some coastal dunes contain large accumulations of them. These metals contaminate the marine environment and are concentrated in sediments and/or bio-accumulated in marine organisms (Rainbow, 1996). Previous studies investigated the trace-metal content of sediments, with a focus on their toxic effects and on natural and anthropogenic contaminations, using mineralogical, petrographical and geochemical data, with multivariate statistical methods, to reveal the origins of the trace metals (Rigler & Collins, 1984; Anfuso *et al.*, 1999; Hoffman *et al.*, 1999; Facchinelli *et al.*, 2001, 2005; Lakhan *et al.*, 2002; Liaghati *et al.*, 2003; Frihy & Dewidar, 2003; Setti *et al.*, 2004; Boruvka *et al.*, 2005).

Some Mediterranean coastal dunes are contaminated by trace metals due to anthropogenic and/or natural factors (Mulsow *et al.*, 2001; Rouibah, 2001; Yoshida *et al.*, 2004). In this study the sediments from the Mersin coast in southern Turkey were investigated. Previous work in the broader study area dealt with the biogeochemistry (Yilmaz, 2002), stratigraphy (Okyar, 1991; Okyar *et al.*, 2005); soil parameters (Everest & Seyhan, 2006); marine geology and geophysics (Ergin, 1989); tourism and urbanization in coastal settlements (Burak, 2004); the effects of sea water on the Mersin coast of the western Mediterranean (Demirel, 2004) and the regional geology (Ediger *et al.*, 2002; Ozer *et al.*, 2004) and geochemistry, including trace metal determination (Budimir & Makro, 1995; Narin & Soylak, 1999; Ngiam & Lim, 2001; Soylak *et al.*, 2001; Sutherland & Tack, 2003; Tuzen, 2003; Soylak *et al.*, 2004; Chun-gang *et al.*, 2004; Atlas & Buyukgungor, 2006; Yalcin & Ilhan, 2008; Yalcin, 2009). However, so far, data on trace-metal concentrations in coastal sands from the area between Silifke and Alanya are not available. Thus, the aim of this work was to determine the concentrations and spatial variability of trace metals in the coastal sediments of these areas and to investigate their sources based on their mineralogical, petrographical and geochemical characteristics.

REGIONAL GEOLOGY

The area studied is located in the Anatolide-Tauride platform which forms the bulk of southern Turkey (Fig. 1). The geological map of the area reports Quaternary deposits: alluvium; Miocene deposits: clastic sediments; Eocene deposits: Tauride carbonates and Palaeocene-Eocene deposits: flysch; Hadim nappe: peridotite, dolerite, radiolarian chert and limestone.

During the Late Cretaceous and Palaeocene, this area underwent strong deformation and metamorphism and a large ophiolite and ophiolitic mélange body was also emplaced (Machintosh & Robertson, 2012). The southern part of the central Tauride region consists of several units with different stratigraphic, lithologic, tectonic and metamorphic characteristics (Fig. 1) (Okyar, 1991; Ediger *et al.*, 2002; Ozer *et. al.*, 2004 and references therein). The autochthonous Geyikdagi unit (Ozgul, 1976) ranges in age from Infra-Cambrian (Dumont & Kerey, 1975) to Eocene (Ozgul, 1976; Monod, 1977). The Beydaglari autochthonous unit comprises platform carbonates of Jurassic to Miocene age (Poisson, 1977). The Antalya nappes, lying between these two autochthonous units, mostly comprise deep-sea sediments originating from a basin located between the two autochthonous units (Poisson *et al.*, 1984). The Antalya nappes exposed between the Geyikdagi unit and the Alanya metamorphic rocks, formed in a basin between the Lycian nappes and the Bozkir unit. The former was transported from NW to SE and emplaced in Miocene time (Poisson, 1977). The Bozkir unit-Beysehir Hoyran nappes are composed of Triassic-Cretaceous-aged pelagic limestones. The ophiolite nappes were emplaced on the partly metamorphic Bolkar unit comprising Devonian–Upper Cretaceous carbonates (Ozgul, 1976; Demirtasli, 1983; Ozgul, 1984; Tekeli *et al.*, 1984; Demirtasli *et al.*, 1984). The Bolkar Mountain, Aladag, Geyik Mountain and Alanya units were re-transported and emplaced on the Geyikdagi unit in Upper Lutetian–Lower Priabonian (Ozgul, 1976; Monod, 1977; Akay & Uysal, 1988). These four units contain mainly shelf carbonates and detrital rocks. The Bozkir and Alanya units contain shelf-rock blocks and also deep-sea sediments, basic volcanics and ophiolites (Ozgul, 1976).

https://doi.org/10.1180/claymin.2015.050.2.07 Published online by Cambridge University Press

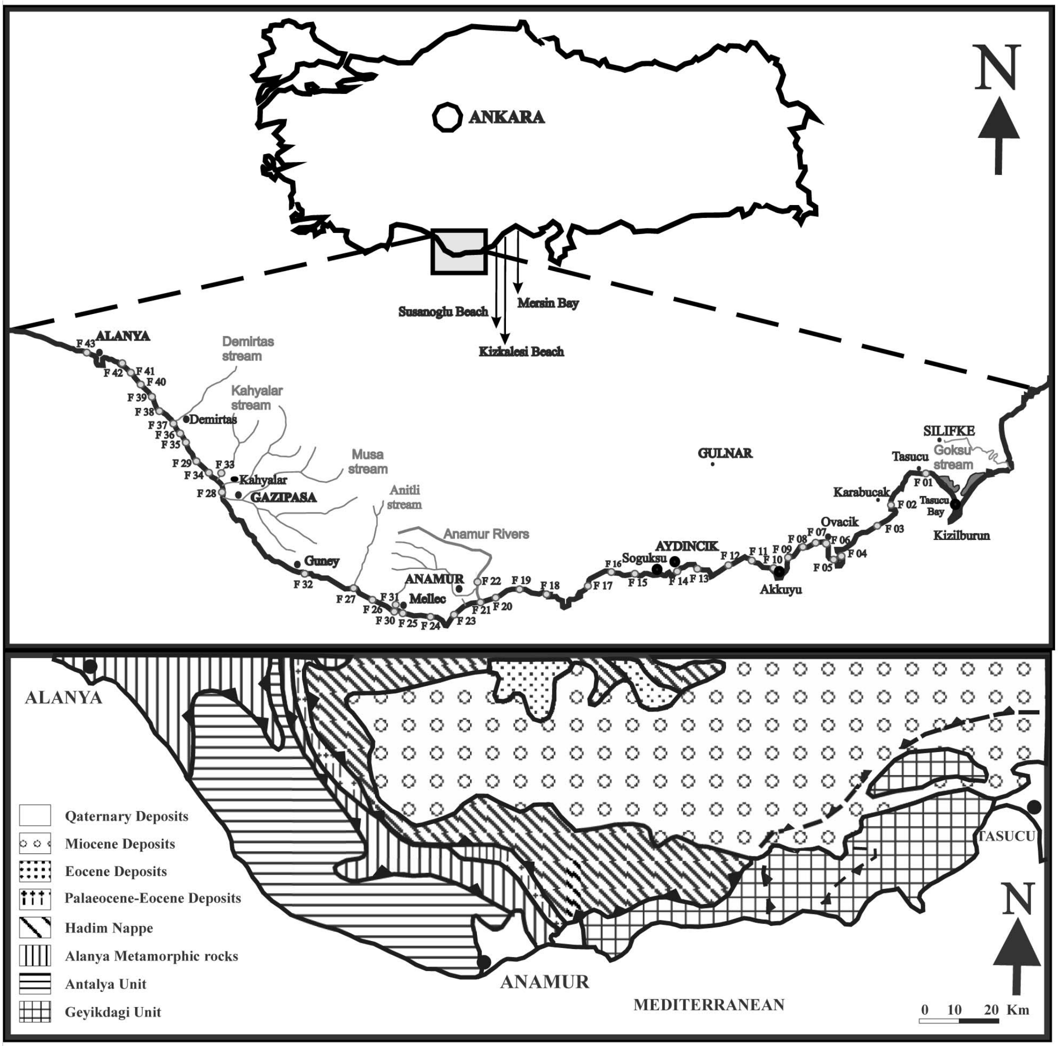

FIG. 1. Location (inset), sample locations and geological map (after Akay & Uysal, 1988) of the study area.

The study area

The area investigated was the coastal shore between Silifke (Mersin) and Alanya (Antalya) in southern Turkey (Fig. 1), extending for ~250 km. The region shows a complex geological setting with the outcroppings of several different lithologies, probably representing the sources of the coastal sediments (Akay & Uysal, 1988; Kozlu *et al.*, 2002; Isik & Tekeli, 1995; Ozsan & Karpuz, 1996; Okay, 2008).

In the hinterland of the eastern and central part of the research area, there are very large outcrops of limestone and marble, made of carbonate and clastic rocks. In particular, in the coastal area between Silifke and Kizilburun large outcrops of limestones of different ages were recorded, whereas between Soguksu and Kizilburun flysch, carbonate and clastic rocks are also present. Ophiolites crop out mostly in the hinterland of the easternmost area, near Silifke. Finally, in the coastal area between Alanya and Anamur, outcrops consist of limestones, metapelites, metabasites, marbles and quartzites (Isik & Tekeli, 1995; Ozsan & Karpuz, 1996), while near Guney outcrops of phyllites are common.

According to the petrographic features of the metamorphic rocks occurring between Alanya and Anamur, the dominant rock types are metapelites, followed by marbles, while metabasites and quartzites are inter-bedded in these rock types. The metapelitic rocks include phyllite and schists, which consist mainly of biotite and muscovite (20–50%), chlorite, quartz (10–35%) and plagioclase (15–40%), with accessory tourmaline and apatite. The metabasites consist of schists and amphibolites: the main minerals of the chlorite-actinolite schists are chlorite, plagioclase and actinolite, with accessory titanite, epidote and opaque minerals, while the main phases of the garnet-hornblende schists and amphibolites are biotite, quartz, garnet, plagioclase (10–35%) and hornblende. The marbles are composed almost exclusively of calcite, with small amounts of quartz and opaque minerals. Finally the quartzites are mostly composed of quartz and minor plagioclase (Isik & Tekeli, 1995).

In the area between Anamur and Silifke, there are outcrops of the Geyikdag unit, with a basement formed by low-grade metamorphic sediments intruded by mafic and felsic igneous rocks. The basement is overlain by Cambrian siliciclastic rocks and limestones (Kozlu *et al.*, 2002). The study area is also characterized by numerous mines or caves; dolomite mines are present near Anamur, Aydincik and Silifke, several marble mines also occur in the eastern and central part of the area, limestones and marbles are exploited at numerous locations near Alanya and Silifke and finally, quartz mines occur between Alanya and Gazipasa.

The terrigenous supply of sediments to the coast is by rivers and streams especially in the central and western parts of the area, while this source seems to be absent to the east. Four main rivers were observed (Table 1; Cevik & Yalcin, 2009). The Goksu River Basin has the largest drainage area. However the Ermenek Stream has the greatest flow rate and the largest load of transported sediments (Yalcin & Cevik, 2009; Yalcin *et al.*, 2013).

MATERIALS AND METHODS

Sand samples (2–5 kg) were obtained, using rubber gloves, from 10 cm deep holes, dug 5–20 m from the coastline, from 43 locations (stations) between Silifke and Alanya (Fig. 1). Stations F3, F13, F21, F27, F30 and F37 were in the river mouths; F22, F31 and F33 in the inland part of the river; F6, F27 and

TABLE 1. River characteristics between the Silifke and Alanya areas (Cevik & Yalcin, 2009).

Rivers (length)	Precipitation area (km^2)	Average sediment distribution (sand) (%)	Average sediment distribution (clay+silt) (%)	Flow rate (m^3/s)	Amount of transported sediment (ton/day)	Concentration of transported sediment (ppm)	Weight of sample (water+sed) (gr)	Weight of sample (clay+silt) (g)	Weight of sample (sand) (g)
Anamur Stream (35 km)	313.2	19.3	80.7	5.962	6.8	13.3	1660	0.002	0
Göksu River-Himmetli (260 km)	2597	37.9	62.1	13.21	30.9	27.1	1625	0.044	0
Göksu River-Kocahacili (260 km)	6907	53.3	46.7	24.58	170.3	80.2	1085	0.087	0
Göksu River-Bocak kisla (260 km)	2689	54	46.6	7.823	89.9	133.1	1676	0.058	0.165
Ermenek Stream (112 km)	3500	37.7	62.3	58.06	133.4	26.6	1542	0.041	0

F30 in small-boat harbours; F1, F2 and F28 in larger-ship harbours and F10 on the coast where a nuclear plant is planned. Coordinates were determined in the field with a GPS device (Garmin Colorado 300). For the determination of the water content, 100 g of the samples was dried at 105ºC for 24 h. Subsequently, the samples were sieved and the >4, 4.0–2.0, 2.0–1.0, 1.0–0.5, 0.5–0.25, 0.25–0.125, 0.125–0.0625 and <0.0625 mm fractions were obtained to determine the grain-size distribution. Heavy minerals were separated from a sample aliquot using bromoform: thin/polished sections were prepared and mineral determinations were performed with a Nikon Pol-400 polarizing microscope. A second sample aliquot was homogenized, using an agate mortar, for chemical analysis by inductively coupled plasma mass spectrometry (ICP-MS) (Acme Lab, Vancouver, Canada, 1EX method). Statistical analysis of the raw chemical data was performed with the *SPSS* 11.5 software.

Mineralogical analyses were performed by X-ray diffraction (XRD) on powders of the bulk sediment, using a Philips® PW 1800 diffractometer with CuKα radiation at the University of Pavia, Italy. For the semi-quantitative analyses of the bulk sample, the relative abundances of the minerals were estimated from the area of the main reflections. The XRD analyses were carried out following the method of Biscaye (1965). For the analyses of the bulk sediments, the relative abundance of each mineral was estimated from the height of the main peak. The following peaks were used for estimations: quartz (4.26 Å); alkali feldspar (3.24 Å); plagioclase (3.18 Å); mica (10 Å); chlorite (7 Å); kaolinite (peaks at 7 and 3.58 Å); amphibole (8.43 Å), low-Mg calcite (3.03 Å), high-Mg calcite (around 3.02 Å), dolomite (2.88 Å) and aragonite (3.40 Å).

RESULTS AND DISCUSSION

Water content and grain-size distribution

All samples, except for F15 and F32, showed limited weight loss upon heating at 105ºC. The water content was >1.42% in sample F24, >0.987% in F10, >0.66% in F1 and >0.3%, 0.41%, 0.529% and 0.561% in samples F3, F5, F17 and F25, respectively. The water content was <0.5% in the remaining samples.

The total amount of sample used to determine the grain-size distribution was 4298 g (43 × 100 g, with 2 g lost during handling). The particle size distribution of the final sample was: >4 mm (4.00%), 4.0–2.0 mm (7.14%), 2.0–1.0 mm (15.4%), 1.0–0.5 mm (24.04%), 0.5–0.25 mm (23.56%), 0.25–0.125 mm (23.10%), 0.125–0.0625 mm (0.52%) and <0.0625 mm (2.34%). Data for each sample have been deposited with the Principal Editor of the journal and are available at www.minersoc.org/pages/e_journals/dep_mat_cm.html

The raw data were used to calculate the percentage fractions and to elaborate histograms and cumulative graphics. The cumulative graphics were calculated using cumulative fraction values and the Φ values were determined, corresponding to the Q5, Q16, Q25, Q50, Q75, Q84 and Q95 parts of the cumulative graphics.

The Φ values were converted into mm values using the formula ($-\log_2(d) = \Phi$). Values (mm) were then used for the determination of parameters such as:

average grain size $\left(M_z = \dfrac{Q_{16} + Q_{50} + Q_{84}}{3}\right)$

gradation $\left(D = \dfrac{Q_{84} - Q_{16}}{4} + \dfrac{Q_{95} - Q_{5}+}{6.6}\right)$

skewness

$$\left(S = \frac{Q_{84} - Q_{16} - 2(Q_{50})}{2(Q_{84} - Q_{16})} + \frac{Q_{95} - Q_{5} - 2(Q_{50})}{2(Q_{95} - Q_{50})}\right)$$

and kurtosis $\left(K = \dfrac{Q_{95} - Q_{5}}{2.44(Q_{75} - Q_{25})}\right)$

The results of all the calculations for each sample are deposited as Appendix 1 and are available at www.minersoc.org/pages/e_journals/dep_mat_cm.html. Accordingly, the samples F5, F8, F22, F26, F31, F35 and F39 were classified as "medium sands" and the remaining samples were classified as "coarse sands". F31 is "well-sorted" and the remaining samples are "very well-sorted". Samples F8, F10, F17 display "positive skew", samples F6, F16, F22, F31 have "strong negative skew" and the remaining samples have "strong positive skew". Kurtosis values varied between "very platycurtic" and "quite leptokurtic".

Chemical composition and statistical analysis

The concentrations of major elements (%) and trace elements (ppm) have been deposited as

https://doi.org/10.1180/claymin.2015.050.2.07 Published online by Cambridge University Press

TABLE 2. Descriptive statistics computed from the chemical data. N = number of valid cases. Distribution: N = normal; LN = lognormal; BM = bimodal; MM = multimodal. When multiple modes exist, the smallest value is shown.

Element	N	Mean	Std. error of mean	Median	Mode	Std. deviation	Variance	Skewness	Std. error of skewness	Kurtosis	Std. error of kurtosis	Minimum	Maximum	Percentiles 10	25	75	90	Distribution
Ca%	43	14.10	1.36	12.01	13.79	8.893	79.079	0.667	0.361	−0.110	0.709	0.23	35.22	4.644	7.8	19.75	29.04	MM
Mg%	43	2.00	0.29	1.27	0.5	1.917	3.674	2.567	0.361	7.191	0.709	0.5	9.27	0.662	0.92	2.33	4.236	LN
Na%	43	162.0	78.10	0.442	0.072	512.1	262290	2.943	0.361	7.078	0.709	0.072	1913	0.212	0.327	0.716	909.4	BM
K%	43	0.57	0.06	0.45	0.14	0.382	0.146	0.864	0.361	−0.085	0.709	0.06	1.54	0.148	0.28	0.82	1.208	LN
Al%	43	2.10	0.21	1.8	0.57	1.380	1.905	0.782	0.361	−0.236	0.709	0.21	5.24	0.57	1.07	2.98	4.53	MM
Fe%	43	1.58	0.14	1.53	0.51	0.945	0.892	1.028	0.361	1.692	0.709	0.17	4.71	0.448	0.87	2.01	3.034	MM
Ti%	43	0.09	0.01	0.088	0.026	0.057	0.003	0.599	0.361	−0.496	0.709	0.015	0.214	0.025	0.052	0.126	0.198	MM
P%	43	0.03	0.00	0.026	0.016	0.022	0.000	2.396	0.361	8.121	0.709	0.008	0.129	0.011	0.016	0.037	0.055	LN
Sr	43	392.2	107.28	167	134	703.5	494919	4.666	0.361	24.71	0.709	54	4344	84.6	128	355	859.2	LN
Ba	43	140.0	15.92	108	27	104.4	10903	1.097	0.361	0.757	0.709	12	425	27.4	59	188	295.8	LN
Li	43	16.76	1.76	13.3	5.2	11.55	133.5	1.479	0.361	2.991	0.709	2.3	59	5.24	7.4	25	32.94	LN
Rb	43	25.35	2.69	20.8	9.2	17.62	310.6	0.898	0.361	0.027	0.709	2.4	66.9	6.3	10.8	35.5	54.62	MM
Mn	43	355.1	55.10	289	417	361.34	130567	4.647	0.361	25.917	0.709	49	2414	129.8	205	398	614	BM
V	43	28.02	2.63	22	18	17.26	297.8	1.381	0.361	1.613	0.709	7	78	12	16	37	53.6	BM
Cr	43	16.42	1.72	14	4	11.25	126.5	1.088	0.361	0.489	0.709	3	45	4	8	21	37.2	LN
Co	43	5.39	0.58	4.4	1	3.796	14.41	2.156	0.361	8.103	0.709	0.8	22.2	1.12	3.3	7.2	9.58	LN
Ni	43	15.48	1.45	13.5	4.4	9.519	90.61	1.462	0.361	3.456	0.709	3.7	51.2	4.4	9.9	19.5	28.44	LN
Cu	43	8.70	1.02	7.4	2.1	6.693	44.80	1.729	0.361	3.851	0.709	1.6	33.7	2.1	4.4	11.1	18.26	LN
Pb	43	9.06	0.90	7.8	3	5.871	34.47	1.514	0.361	2.304	0.709	2.6	26.8	3.04	4.9	11.8	17.64	LN
Zn	43	30.12	2.74	28	29	17.98	323.3	0.816	0.361	0.103	0.709	4	73	9.4	14	42	60	MM
Mo	43	0.53	0.03	0.5	0.4	0.211	0.044	0.860	0.361	0.721	0.709	0.2	1.1	0.3	0.4	0.7	0.8	BM
As	43	9.05	1.25	7	4	8.226	67.66	3.531	0.361	16.10	0.709	2	51	3	4	10	17	LN
Sb	41	1.61	1.09	0.3	0.2	6.986	48.80	5.994	0.369	36.95	0.724	0.1	44.2	0.1	0.2	0.4	0.68	LN
Sn	40	0.63	0.08	0.45	0.4	0.495	0.245	1.566	0.374	2.257	0.733	0.1	2.2	0.2	0.3	0.875	1.38	LN
Sc	42	3.95	0.40	3	3	2.613	6.827	1.364	0.365	1.639	0.717	1	12	1	2	5	8	N
Y	43	8.65	0.75	7.9	5.5	4.899	24.00	3.474	0.361	16.24	0.709	3.3	33.7	4.82	5.8	10.2	12.78	LN
Zr	43	9.41	0.87	7.6	5.9	5.730	32.83	2.970	0.361	12.926	0.709	3.2	37.4	4.74	6	12.2	14.9	LN
Nb	43	2.49	0.21	2.2	0.6	1.367	1.867	0.528	0.361	−0.757	0.709	0.6	5.6	0.9	1.3	3.7	4.66	BM
U	43	1.16	0.06	1.1	0.7	0.395	0.156	0.339	0.361	−0.285	0.709	0.4	2.2	0.7	0.8	1.5	1.7	BM
Th	43	3.28	0.31	2.9	2.5	2.036	4.145	1.016	0.361	0.706	0.709	0.4	8.6	0.94	1.8	4.3	6.68	LN
La	43	11.59	0.82	10.1	8.1	5.401	29.17	0.628	0.361	−0.272	0.709	3.4	24.3	4.88	8.1	14.9	20.8	LN
Ce	43	21.79	1.65	21	16	10.83	117.2	0.474	0.361	−0.512	0.709	5	47	8	14	29	38.8	BM
Hf	41	0.29	0.02	0.2	0.2	0.142	0.020	2.127	0.369	7.556	0.724	0.1	0.9	0.2	0.2	0.4	0.4	LN

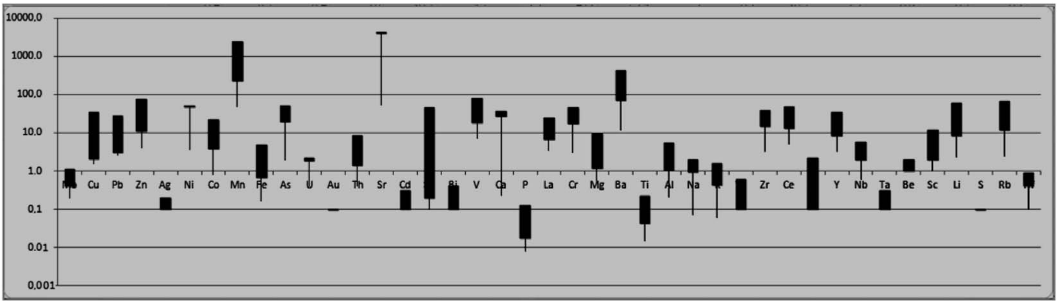

FIG. 2. Trace-element concentrations in the beach sediments (ppm).

Appendix 2 and are available at www.minersoc.org/pages/e_journals/dep_mat_cm.html. A simple statistical evaluation of the results is provided in Table 2. Greater values relative to the other stations were recorded at station, F1 for Sr and Ni, at F2 for Sr, at F3 for Mn, at F6 and F7 for Li, at F10 for Mg, at F15 and F29 for Pb, at F27 for Rb and Ti, at F32 for S and at F38 for Mn and As. In addition, station F30 gave relatively high values for Fe, Sn, Co, Cu, Zn, Al, Ba, Rb and Cr and station F25 gave high V, Cr, Ti, Ba, Al and Zn values compared to the other stations. A boxplot summarizing the concentrations of major and trace elements is reported in Fig. 2. Strontium, Mn and Ba were the predominant trace metals compared to the remaining elements.

The correlations between the various elements are reported in a correlation matrix (deposited as Appendix 3). Special attention was paid to the relationships between Al, Fe, Cu, Pb, Zn and Mn, which are potentially toxic. Accordingly, some elements show significant positive correlations indicating that they may have similar origins. Significant correlations (at the 0.01 level) are observed for Al *vs*. Na, Ca, Ce, Sn, Nb, Sc, Li and Rb; Fe *vs*. Th, V, P, La, Cr, Ba, Ti, Al, Na, K, Ce, Sn, Nb, Sc, Li and Rb; As *vs*. Y and Sc; Cu *vs*. Pb, Zn, Ni, Co, Fe, Th, V, P, La, Cr, Ba, Ti, Al, Na, K, Ce, Sn, Nb, Sc, Li and Rb; Pb *vs*. Zn, Co, Fe, Th, V, La, Ba, Ti, Al, K, Ce, Sn, Mb, Li and Rb; Zn *vs*. Ni, Co, Fe, Th, V, P, La, Cr, Ba, Ti, Al, Na, K, Ce, Sn, Nb, Sc, Li and Rb; Mn *vs*. As, Y and Sc. An additional significant correlation is recorded for Ca *vs*. La, Cr, Ba, Ti, Al, Na, K, Ce, Sn, Nb, Sc, Li and Rb.

Principal component analysis (PCA) was used to reduce the number of variables and also group those elements having similar characteristics. Eigenvalues >1 are displayed by the first seven factors extracted (Table 3). Nevertheless, a total variance of 69.55 is explained by the first three factors. The first factor (Factor 1) explains 49.91% of the total variance with a high eigenvalue of 16.47. This factor associates most of the analysed trace elements, namely Mo, Cu, Pb, Zn, Ni, Co, Fe, Th, V, La, Cr, Ba, Ti, Al, Na, K, Ce, Sn, Nb, Sc and Rb (deposited

TABLE 3. Explanation of total variance of the sediments with eigenvalues (PCA).

Component	—— Initial eigenvalues ——			Extraction sums of squared loadings		
	Total	% of Variance	Cumulative %	Total	% of variance	Cumulative %
1	16.469	49.905	49.905	16.469	49.905	49.905
2	3.342	10.128	60.033	3.342	10.128	60.033
3	3.140	9.515	69.548	3.140	9.515	69.548
4	2.150	6.516	76.064	2.150	6.516	76.064
5	1.509	4.571	80.635	1.509	4.571	80.635
6	1.385	4.196	84.831	1.385	4.196	84.831
7	1.039	3.150	87.981	1.039	3.150	87.981

Extraction method: principal component analysis.

https://doi.org/10.1180/claymin.2015.050.2.07 Published online by Cambridge University Press

as Appendix 4). The second factor (Factor 2) explains 10.13% of the total variance with an Eigenvalue of 3.34; it encompasses Mn, As, Sr, Ca, Li and Y. The third factor (Factor 3) explains 9.515% of the total variance with an eigenvalue of 3.140 and includes the elements P, Zr, Nb and Hf. Additional factors mostly account for an element each, namely Ni and part of Sr (Factor 4), Mg (Factor 5) and Sb (Factor 7).

A comparison of the arithmetical averages of some elements with literature data for the crust, sandstones, ultrabasic rocks, acceptable limit values in Turkey, Kizkalesi beach sands and Susanoglu beach sands is shown in Table 4. Comparison was made by calculating the ratio between the average concentration in the investigated area and the reference values. From the calculated ratios, the concentrations of: Ca, Ti, As, Ag and Sb are greater than in the Earth's crust (Krauskopf, 1979); Fe, Ca, Mg, Na, Mn, Ni, Co, Pb, Zn, Cd, As, Ag, Mo, Sb and V are greater than in sandstones (Turekian & Wedepohl, 1961); Al, Ca, Na, K, Ti, Pb, As, Ag, Mo, Sb and Sn are greater than in ultrabasic rocks (Turekian & Wedepohl, 1961); Na exceeds the acceptable limit values for Turkey (TKKY, 2005); Al, Na, K, Ti, Pb and Zn are greater than in the Kizkalesi Beach sands (Yalcin & Ilhan, 2008); Al, Fe, Mg, Na, Ti, Mn, Pb and Zn are greater than in the Susanoglu beach sands (Yalcin, 2009); Ca and Mg are greater than in the Mersin Bay beach sands (Yalcin *et al.*, 2013) (Table 4). Trace metals at these anomalous values could have toxicity effects in the region. Distribution maps displaying the trace-metal concentrations in the area studied have been deposited as Appendix 5.

Mineralogy

The semi-quantitative composition of the sediments, calculated using XRD, is reported in Table 5 and the XRD patterns of selected samples are given in Fig. 3. The main minerals are dolomite (abundance from 0–84%), calcite (0–67%), aragonite (0–37%), quartz (1–54%), plagioclase (0–24%), mica (0–55%) and chlorite (0–16%) (Table 5).

Five samples (F3, F4, F17, F25 and F30) were selected for their high-concentrations of Mo, Cu, Pb, Zn, Ni, Co, Mn, Fe, Cd, V, Cr, Sn and As for petrographic examination of thin and polished sections (Fig. 4). The metamorphic rocks (calc-schist, quartzschist, quartzite) consist of pyroxene, amphibole, quartz and feldspar; carbonates and opaque minerals were detected in small amounts. Quartz crystals were abundant in samples F3, F4, F17, F25 and F30. All samples contain hematite,

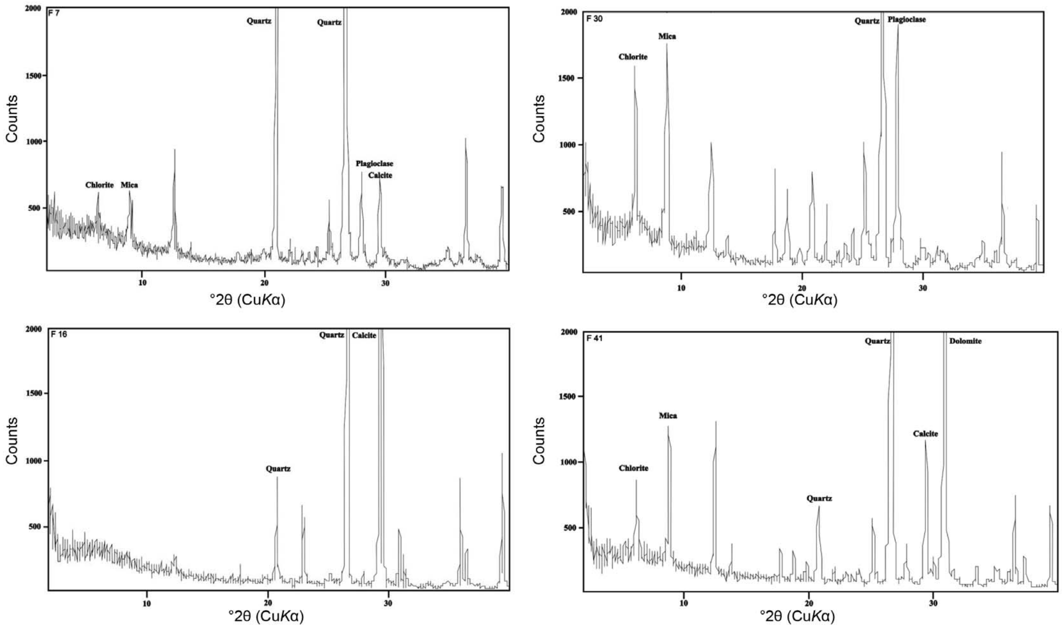

FIG. 3. Typical XRD patterns of the samples.

https://doi.org/10.1180/claymin.2015.050.2.07 Published online by Cambridge University Press

TABLE 4. Statistical summary in the Silifke-Alanya Beach and abundance of trace elements: Bold characters indicate anomaly values, Sediment (mg/kg, n = 22); Min: minimum; Max: maximum.

	Study area (Mean) (A)	Earth crust (Krauskopf, 1979) (B)	Variation of average concentra-tion in Earth crust (fold) (A/B)	Sandstone (Turekian & Wedepohl, 1961) (C)	Variation of average concentra-tion in sandstone (fold) (A/C)	Ultrabasic (Turekian & Wedepohl, 1961) (D)	Variation of average concentra-tion in ultrabasic (fold) (A/D)	Acceptable limit for Turkey (mg/kg) (TKKY, 2005) (E)	Variation of average concentra-tion (TKKY, 2005) (fold) (A/E)	Kizkalesi beach sediment mean (Yalcin & Ilhan, 2008) (F)	Variation of average concentra-tion in Kizkalesi beach sediment (fold) (A/F)	Susanoglu Beach sediment mean (Yalcin, 2009) (G)	Variation of average concentra-tion in Susanoglu (fold) (A/G)	Mersin Bay Beach sediment mean (Yalcin, 2009) (H)	Variation of average concentra-tion in Mersin Bay (fold) (A/H)
Al	20908	81000	0.26	25000	0.84	20000	**1.05**			8267.17	**2.53**	11924.24	**1.75**	30485	0.69
Fe	15751	54000	0.29	9800	**1.61**	94300	0.17			18803.63	0.84	13909.09	**1.13**	34078	0.46
Ca	141030	41000	**3.44**	39100	**3.61**	25000	**5.64**			233647.98	0.60	174745.45	0.81	42370	**3.33**
Mg	19998	23000	0.87	7000	**2.86**	204000	0.1			34993.03	0.57	15624.24	**1.28**	2772	**7.21**
Na	6008	24000	0.25	3300	**1.82**	4200	**1.43**	125	**48.06**	3385.59	**1.77**	3636.36	**1.65**	7666000	0.00
K	5749	21000	0.27	10700	0.54	40	**143.73**			1486.73	**3.87**	6560.61	0.88	15124100	0.00
Ti	947	5	**189.40**	1500	0.63	300	**3.16**			813.48	**1.16**	736.36	**1.29**	158517	0.01
Mn	355.12	1000	0.36	90	**3.95**	1620	0.22			585.99	0.61	333.85	**1.06**	2790920	0.00
Cr	16.42	100	0.16	35	0.47	1600	0.01	100	0.1642	553.84	0.03	428.06	0.04	281217	0.00
Cu	8.70	50	0.17	9	0.97	10	0.87	50−140	0.17−0.06	10.13	0.86	12.81	0.68	102300	0.00
Ni	15.48	75	0.21	2	**7.74**	2000	0.01	30−75	0.52−0.21	186.8	0.08	145.52	0.11	525500	0.00
Co	5.39	20	0.27	0.3	**17.95**	150	0.04	20	0.27	28.2	0.19	21.41	0.25	2127	0.00
Pb	9.06	12.5	0.73	7	**1.29**	1	**9.06**	50−300	0.18−0.03	4.55	**1.99**	5.51	**1.64**	88833	0.00
Zn	30.12	70	0.43	16	**1.88**	50	0.6	150−300	0.2−0.1	19.75	**1.52**	17.8	**1.69**		
Cd	0.14	0.15	0.93	0.09	**1.55**	0.9	0.16	1−3	0.14−0.04	4.21	0.03	4.32	0.03	4980	0.00
As	9.05	1.8	**5.03**	1	**9.05**	1	**9.05**	20	0.45	24.74	0.37	19.91	0.45	3433	0.00
Ag	0.10	0.07	**1.46**	0.09	**1.14**	0.06	**1.71**			4.13	0.02	4.12	0.02	8350	0.00
Mo	0.53	1.5	0.35	0.2	**2.64**	0.3	**1.76**	10	0.05	25.96	0.02	27	0.02	1141170	0.00
Sb	1.54	0.2	**7.70**	0.09	**17.11**	0.1	**15.4**			5.95	0.26	5.67	0.27	3116	0.00
Sn	0.59	2.5	0.24	0.9	0.66	0.5	**1.19**	20	0.03	8.17	0.07	7.83	0.08		
V	28.02	110	0.26	20	**1.40**	40	0.7			63.3	0.44	38.12	0.74		
W	0.23	1.2	0.192	1.6	0.14	0.77	0.3			7.61	0.03	6.58	0.04		

https://doi.org/10.1180/claymin.2015.050.2.07 Published online by Cambridge University Press

TABLE 5. Mineralogical compositions (%) of the beach sediments.

	Kaolin ite	Chlorite	Mica	Quartz	Alkali feldspar	Plagio-clase	Calcite	Aragon ite	Dolom ite	Mg-calcite	Total
F1	0	0	10	12	0	2	30	37	4	5	100
F2	0	0	0	1	0	1	59	23	3	13	100
F3	0	4	5	17	0	1	46	2	24	1	100
F4	0	0	0	6	0	1	63	7	15	8	100
F5	0	0	0	5	0	1	29	10	46	9	100
F6	0	5	17	34	0	2	35	0	4	3	100
F7	0	10	17	54	0	9	8	0	0	2	100
F8	0	4	5	42	8	3	21	2	13	2	100
F9	0	5	11	51	3	3	23	0	3	1	100
F10	0	0	0	5	0	0	5	0	84	6	100
F11	0	0	0	30	2	0	51	4	11	2	100
F12	0	0	0	31	0	2	62	0	4	1	100
F13	0	0	0	20	3	2	33	0	40	2	100
F14	0	0	0	20	0	0	24	0	54	2	100
F15	0	4	11	30	1	1	37	0	13	3	100
F16	0	4	5	14	0	1	67	0	7	2	100
F17	20	7	16	18	0	1	19	8	3	8	100
F18	0	4	5	20	0	2	38	7	15	9	100
F19	0	6	11	10	0	9	52	0	11	1	100
F20	0	4	20	8	1	6	9	0	52	0	100
F21	0	6	23	23	4	6	28	0	9	1	100
F22	0	7	28	8	2	6	15	0	33	1	100
F23	0	7	17	32	0	4	24	0	15	1	100
F24	0	10	31	16	3	12	5	0	22	1	100
F25	0	16	55	18	1	10	0	0	0	0	100
F26	0	8	23	37	3	6	14	0	8	1	100
F27	0	12	37	14	1	5	17	0	13	1	100
F28	0	7	20	35	2	7	22	0	6	1	100
F29	0	8	15	39	0	5	18	0	13	2	100
F30	0	13	52	18	3	11	1	0	2	0	100
F31	0	15	46	19	1	19	0	0	0	0	100
F32	0	12	32	15	2	11	14	0	13	1	100
F33	0	4	9	36	1	4	27	0	18	1	100
F34	0	4	10	32	1	5	27	0	18	3	100
F35	0	4	14	28	0	8	36	0	7	3	100
F36	0	3	8	24	1	5	12	0	45	2	100
F37	0	11	17	35	2	10	11	0	12	2	100
F38	0	3	20	10	2	24	4	0	28	9	100
F39	0	3	10	17	1	3	8	0	57	1	100
F40	0	3	9	19	7	7	10	0	44	1	100
F41	0	5	15	17	1	2	8	0	51	1	100
F42	0	6	17	24	0	2	8	0	42	1	100
F43	0	0	8	29	2	4	10	0	44	3	100

chromite, magnetite and goethite minerals. Pyrite was detected only in sample F30.

Mineral provenance and distribution

Dolomite is very abundant (>40%) in the westernmost sands, between Alanya and Demirtas and locally near Anamur and Aydincik, in the central sector. Its abundance is very low in the easternmost areas, near Silifke (<10%) and between Kahyalar and Aydincik (<10% or 10–20%). Calcite contents are low (<10%) in the western and western-central areas between Alanya and Kahyalar and between Guney and Anamur. They

https://doi.org/10.1180/claymin.2015.050.2.07 Published online by Cambridge University Press

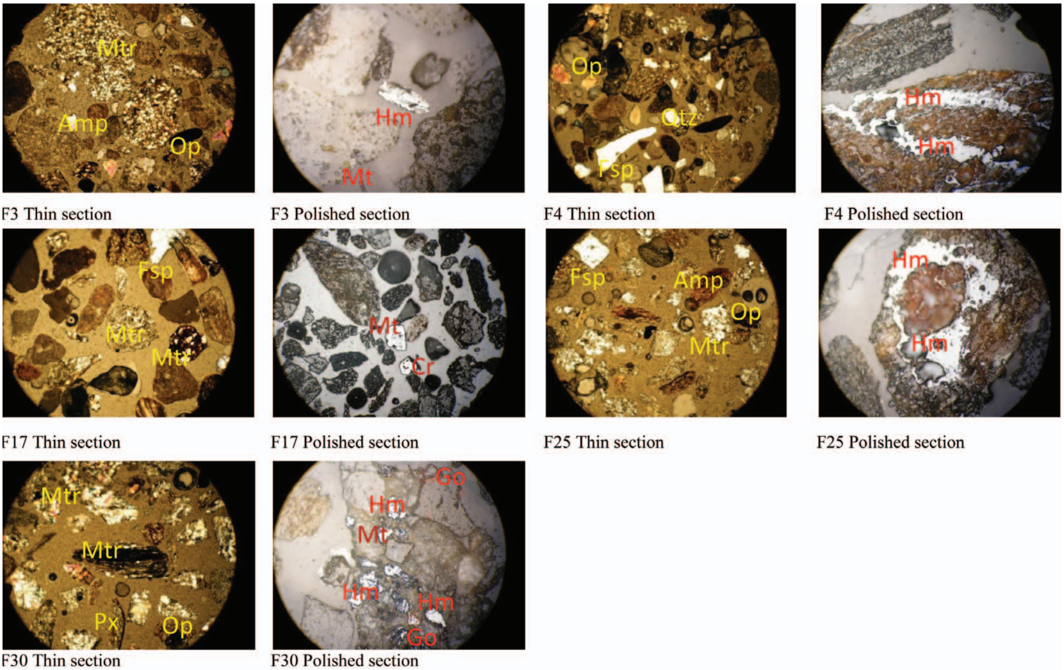

FIG. 4. Thin-section and polished-section images of the samples. Thin sections of samples F3, F4, F17, F25 and F30 are made up of metamorphic rocks (calcschist, quartzschist, quartzite) and fine-grained minerals (pyroxene, amphibole, quartz, feldspar). Polished sections (Opaque: Op) of the samples consist of hematite (Hm), chromite (Cr), magnetite (Mt) and goethite (Go).

are more abundant (25–40%) in the central part, especially between Anamur and Akkuyu and very abundant in the western areas (>40%), between Ovacik and Silifke. Mg-calcite is generally very low; larger amounts (<5%) can be found in the samples collected near Silifke. With the exception of the two most eastern samples near Silifke (content >20%), aragonite is generally very low or absent. Quartz is more abundant (25–35% or <35%) in the sectors between Demirtas and Gazipasa and between Aydincik and Ovacik and less abundant (<10%) in the westernmost (Alanya–Demirtas) and easternmost (Silifke-Ovacik) parts. The abundance of plagioclase is generally very low, but its content increases in the central sector between Gazipasa and Anamur, as is also observed for chlorite and mica. Also, plagioclase is more abundant, locally, at the outlet of the Demirtas stream, in the western part of the area investigated. The distribution of mica is roughly correlated with that of chlorite. The greatest contents (20–30% or even >30%) are found in the area between Gazipasa and Anamur, while in the other coastal areas, mica content is generally lower (10–20% or even <10%). In particular, mica is completely absent in the area between Akkuyu and Soguksu (samples F10–F15). Finally, the highest concentrations of chlorite are found in the area between Gazipasa and Mellec. Elsewhere, chlorite is generally low and is nearly absent in the easternmost areas (between Silifke and Ovacik and also between Akkuyu and Soguksu).

Based on the distribution of mineral phases, the investigated area can be divided into different provinces, each characterized by the abundance of one, or more, particular mineral (Fig. 5). The westernmost areas, between Alanya and Demirtas, are characterized by a very high content of dolomite, very low calcite, middle quartz, relatively low contents of chlorite and mica; this mineralogical association indicates a provenance from dolomites or marbles. The area between Demirtas and Gazipasa features a high quartz content, very low dolomite, variable mica and chlorite and higher calcite content. This association is clearly different from the previous one, therefore indicating a

https://doi.org/10.1180/claymin.2015.050.2.07 Published online by Cambridge University Press

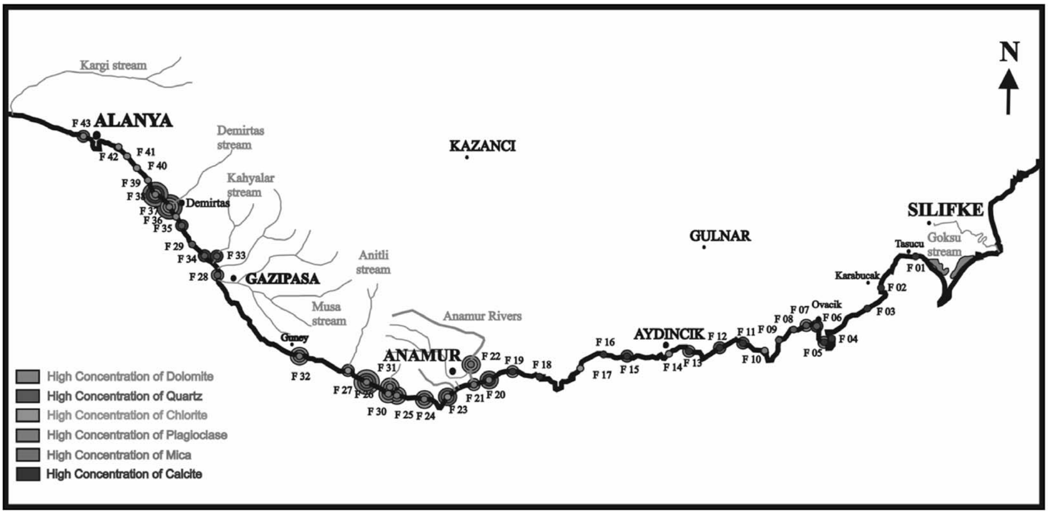

FIG. 5. Distribution map of the mineralogical composition of the samples.

different provenance with the source rocks represented by quartzites, clastic and metamorphic rocks.

The sector between Guney and Anamur is characterized by the largest mica content, relatively high chlorite and plagioclase and variable calcite, dolomite and quartz contents. This mineralogical association highlights a stronger input from the low-grade metamorphic rocks, in particular metaschists and metabasites, with a lower input from marbles and limestones.

In the area between Anamur and Ovacik no constant prevailing mineral phase is observed, but the abundance of each mineral is quite variable depending on the location. Quartz is very abundant in the area between samples F7 and F9; this quartz abundance indicates a strong supply from clastic rocks or quartzites. Also, the sector between Akkuyu and Soguksu (samples F10−F14) is completely devoid of mica and chlorite, while carbonates and quartz are abundant; probably as the source rocks are represented by limestones, marbles and clastic rocks, while metamorphic rocks are absent.

The most eastern part, between Ovacik and Silifke, is characterized by the greatest calcite content and variable amounts of the other detrital minerals. This composition clearly indicates a provenance from surrounding rocks, which consist mostly of limestones and, subordinately, clastic rocks. In addition, aragonite and high-Mg calcite are more abundant, probably due to a larger content of mollusc shells.

Correlation between mineralogical and geochemical composition

The mineralogical composition of the coastal sediments can be correlated with the abundances of some particular chemical elements (Fig. 6). For instance, Al is particularly abundant in the sediments in the sector between Guney and Anamur, because these sediments are rich in Al-bearing minerals like mica, chlorite and feldspar, but poor in carbonates. The presence of mica appears to correlate well with Al content (R^2 = 0.82). The sediments in the westernmost part, near Alanya, have abundant Mg as these sediments contain large amounts of dolomite; in fact the Mg contents are positively correlated with dolomite contents (R^2 = 0.75). In addition, Sr contents are particularly high in samples F1, F2 and F5 that also feature the greatest content of aragonite, as this mineral is an important carrier of Sr (Wedepohl, 1975).

Mica is positively correlated with K content (R^2 = 0.73) as this mineral contains K in its structure, and with Ba (R^2 = 0.70) and Rb (R^2 = 0.75) as these elements can occupy the Ca and K positions, respectively (Wedepohl, 1978). The total amount of phyllosilicates appears broadly positively correlated with some trace metals such as V (R^2 = 0.75), Cr (R^2 = 0.64) and Fe (R^2 = 0.68) because these elements are usually incorporated, or adsorbed on clay minerals (Wedepohl, 1978).

https://doi.org/10.1180/claymin.2015.050.2.07 Published online by Cambridge University Press

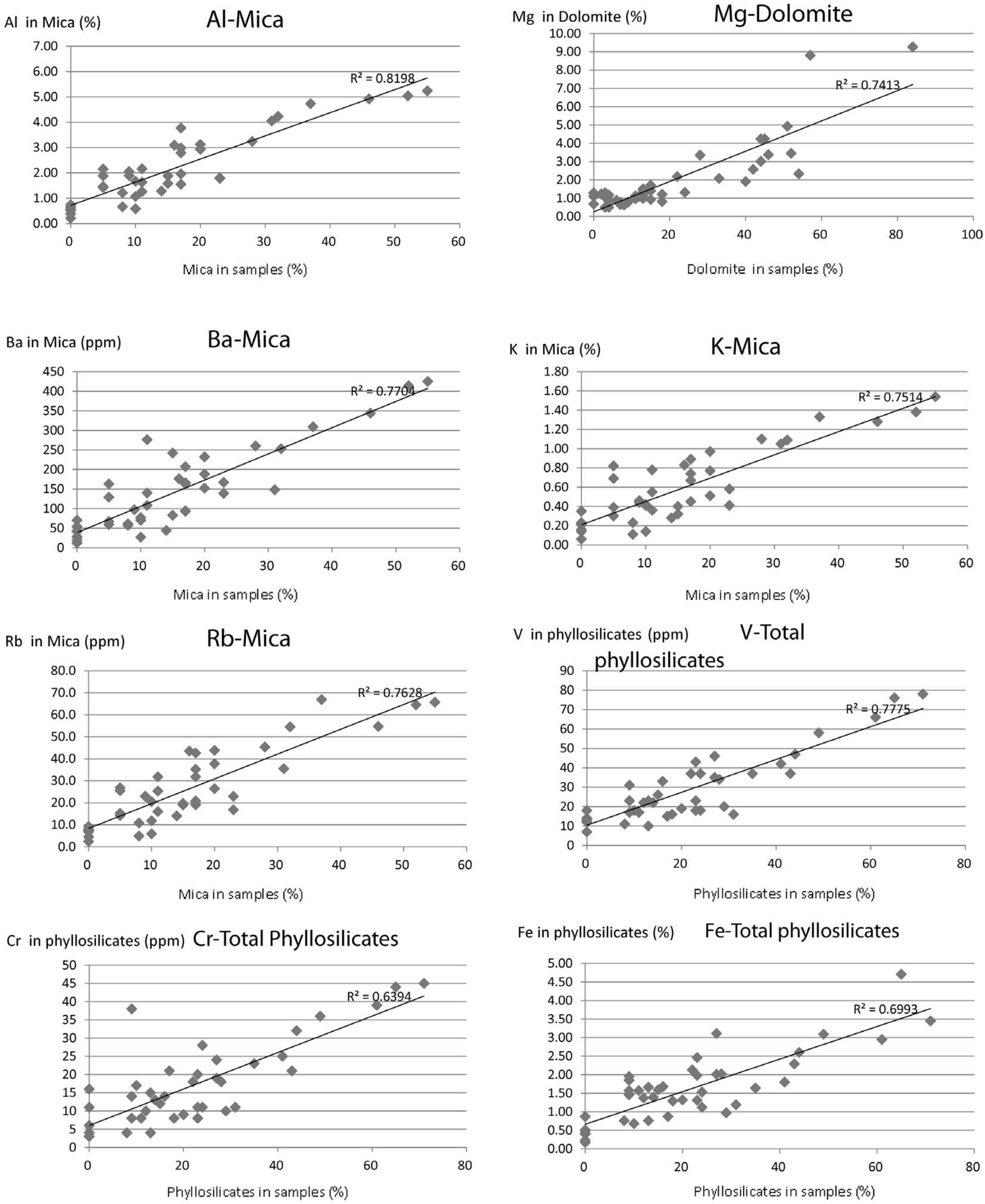

FIG. 6. Correlation between elements and minerals from the area studied.

In the light of the considerations above, the PCA results show that most trace metals are associated with Factor 1, also containing Al. Therefore the trace-metal concentrations in beach sands are related to the abundance of silicate minerals derived from the weathering of the metamorphic rocks outcropping in the inland mountainous regions. On the other hand, when limestones and dolomites are present, the trace-metal contents of the beach sands are low. Indeed, only Mn and As as trace metals are

https://doi.org/10.1180/claymin.2015.050.2.07 Published online by Cambridge University Press

associated with Ca and Sr in Factor 2 and no trace metal is associated with Mg in Factor 5.

CONCLUSIONS

The mineralogical compositions of the sediments show remarkable differences, which reflect the complex geological setting of the Silifke and Alanya areas. The most abundant mineral phases in the coastal sediments are carbonates (calcite and dolomite), followed by quartz, mica, chlorite, feldspar, other carbonates and kaolinite (trace amounts). Samples showing high concentrations of trace metals contained fragments of metamorphic rocks containing pyroxene, amphibole, quartz and feldspar, whereas carbonates and opaque minerals were only detected in small amounts. Every sample contained hematite, chromite, magnetite and goethite, with only one containing pyrite.

Based on the distribution of the mineral phases, the area investigated was divided into different provinces: in the westernmost areas, between Alanya and Demirtas, sediments indicate a provenance from dolomites or marbles; in the area between Demirtas and Gazipasa a provenance from clastic and metamorphic rocks; in the sector between Guney and Anamur, from low-grade metamorphic rocks, in particular metaschists and metabasites, with a lower input from marbles and limestones; in the area between Anamur and Ovacik, from various source rocks and between Ovacik and Silifke, from limestones and, to a lesser extent, clastic rocks.

The trace-metal concentrations in beach sands are related to the abundance of silicate minerals derived from the weathering of the metamorphic rocks outcropping in the inland mountainous regions. On the other hand, when limestones and dolomites are present, the trace-metal contents of the beach sands are low. Comparing the arithmetical averages of some elements with data from the literature, several elements and trace metals exceed the Turkish acceptable limit values, with potentially toxic effects. Geochemical data were treated statistically to determine the trace-element distributions and to identify correlations with the minerals present; PCA methods were also used for confirmation.

ACKNOWLEDGMENTS

This study was a part of the MSc Thesis prepared by Feridun Karakaya in the Department of Geological Engineering of Nigde University. The authors thank Luigi Marinoni for XRD analyses at the University of Pavia, Italy. The financial support of the Scientific Research Projects Unit of Akdeniz University is gratefully acknowledged. Dr M. Gurhan Yalcin thanks Dr George E. Christidis for editorial handling, review and editing of this article.

REFERENCES

Akay E. & Uysal S. (1988) Post-Eocene tectonics of the central Taurus mountains. *Bulletin of the Mineral Research and Exploration*, **108**, 23–34.

Anfuso G., Gracia F.J., Martinez-Del-Pozo J.A., Del Rio L., Andres J., Sanchez F. & Lopez-Aguayo F. (1999) Modelización del comportamiento morfodinámico de las playas mediante el estudio de la profundidad de removilización. *Estudios Geológicos*, **55**, 113–125.

Atlas L. & Buyukgungor H. (2007) Heavy metal pollution in the Black Sea shore and offshore of Turkey. *Environmental Geology*, **52**, 469–476; doi: 10.1007/s00254-006-0480-1.

Biscaye P.E. (1965) Mineralogy and sedimentation of recent deep-sea clay in the Atlantic Ocean and adjacent seas and oceans. *Geological Society of America Bulletin*, **76**, 803–832.

Boruvka L., Vacak O. & Jeilicka J. (2005) Principal component analysis as a tool to indicate the origin of potentially toxic elements in soil. *Geoderma*, **128**, 289–300.

Budimir S. & Makro B. (1995) Distribution of Cd, Pb, Cu and Zn in carbonate sediments from the Krka river estuary obtained by sequential extraction. *Science of the Total Environment*, **170**, 101–118.

Burak S., Dogan E. & Gazioglu C. (2004) Impact of urbanization and tourism on coastal environment. *Ocean & Coastal Management*, **47**, 515–527.

Cevik O. & Yalcin M.G. (2009) *Grain size, heavy mineral distribution in beach sediments and multivariate statistics to determine the origin of heavy metals from gulfs of Mersin, Eastern Mediterranean*. MSc Thesis, Nigde University, 102 pp.

Chun-gang Y., Jian-bo S., Bin H., Jing-fu L., Li-na L. & Gui-bin J. (2004) Speciation of heavy metals in marine sediments from the East China Sea by ICP-MS with sequential extraction. *Environment International*, **30**, 769–783.

Demirel Z. (2004) The history and evaluation of saltwater intrusion into a coastal aquifer in Mersin, Turkey. *Journal of Environmental Management*, **70**, 275–282.

Demirtasli E. (1983) Stratigraphy and tectonics of the area between Silifke and Anamur, Central Taurus Mountains. International Symposium: Geology of the Taurus Belt, 26–29 Sept., Ankara.

Demirtasli E., Turhan N., Bilgin A.Z. & Selim M.

(1984) Geology of the Bolkar Mountains. Pp. 125–141 in: *Geology of the Taurus Belt* (O. Tekeli & M.C. Goncuoglu, editors). Proceedings of the International Symposium on the Geology of the Taurus Belt, Institute of Mineral Research and Exploration, Ankara..

Dumont J.F. & Kerey E. (1975) Kirkkavak fault: a N-W strike-slip fault in the boundary of Western Taurids and Koprucay basins. *Türkiye Jeoloji Kurumu Bülteni*, **18**, 59–62 (in Turkish).

Ediger V., Velegrakis A.F. & Evans G. (2002) Upper slope sediment waves in the Cilician Basin, north-eastern Mediterranean. *Marine Geology*, **192**, 321–333.

Ergin M., Timur K., Okyar M., Bodur M.N. & Ediger V. (1989) *Marine geological and geophysical investigations related to construction of a landing place.* Technical Report of the Middle East Technical University, Institute of Marine Sciences, Erdemli, Mersin, 43 pp.

Everest A. & Seyhan L. (2006) Investigations of basic soil parameters in Mersin: Kozlar high plateau of south Turkey. *Building and Environment*, **4**, 837–841.

Facchinelli A., Sacchi E. & Mallen L. (2001) Multivariate statistical and GIS-based approach to identify metal sources in soils. *Environmental Pollution*, **114**, 313–324.

Facchinelli A., Magnoni M., Perrone U. & Sacchi E. (2005) Post-depositional processes in lake sediment traced by heavy metals and radionuclidies; a case study from lake Srio (Ivrea, northern Italy). 10th International Symposium on the Interactions between Sediments and Water IASWS2005, Bled, Slovenia, 28/08-2/09 2005, *Materials and Geoenvironment*, **52**, 31–33.

Frihy O.E. & Dewidar K.H. (2003) Patterns of erosion/sedimentation, heavy mineral concentration and grain size to interpret boundaries of littoral sub-cells of the Nile Delta. *Marine Geology*, **199**, 27–43.

Hoffmann J.A., Kafatos F.C., Janeway C.A. & Ezekowitz, R.A.B. (1999) Phylogenetic perspectives in innate immunity. *Science* **284** (5418), 1313–1318.

Isik V. & Tekeli O. (1995) New petrographical data at the eastern part of Alanya metamorphites (Anamur, S. Turkey). *Bulletin of the Mineral Research and Exploration (Turkey)*, **117**, 49–57.

Kozlu H., Göncüoğlu C.M., Sarmiento G.N. & Gul M.A. (2002) Mid-Ordovician (late Darriwilian) conodonts from the south-central Taurides, Turkey: Geological implications. *Turkish Journal of Earth Sciences*, **11**, 1–14.

Krauskopf K. (1979) *Introduction to Geochemistry*. McGraw-Hill, New York. 617 pp.

Lakhan V.C., Cabana K. & LaValle P.D. (2002) Heavy metal concentrations in surficial sediments from accreting and eroding areas along the coast of Guyana. *Environmental Geology*, **42**, 73–80.

Liaghati T., Preda M. & Cox M. (2003) Heavy metal distribution and controlling factors within coastal plain sediments Bells Creek catchment southeast Queensland Australia. *Environment International*, **29**, 935–948.

Mackintosh P.W. & Robertson A.H.F. (2012) Sedimentary and structural evidence for two-phase Upper Cretaceous and Eocene emplacement of the Tauride thrust sheets in central southern Turkey. Pp. 299–322 in *Geological Development of Anatolia and the Easternmost Mediterranean Region* (A.H.F. Robertson, O. Parlak and U.C. Ünlügenç). Geological Society of London, Special Publications, **372**. The Geological Society, London.

Monod O. (1977) *Recherches geologigues dans le Taurus occidental au sud de Beysehir (Turguie)*. PhD Thesis, Universite de Paris-Sud, Orsay, 442 pp.

Mulsow S., Povince P., Wyse E., Benmansour M., Sammir B. & Cahfik A. (2001) Trace elements, heavy metals and Pb isotopic ratios in marine sediments of the south Mediterranean Sea (Morroco). *Rapport Commission International Mer Méditerranee*, **36**, 147 pp.

Narin I. & Soylak M. (1999) Monitoring trace metal levels in Nigde, Turkey: nickel, copper, manganese, cadmium and cobalt contents of the street dust samples. *Trace Elements and Electroly*tes, **16**, 99–103.

Ngiam L.S. & Lim P.E. (2001) Speciation patterns of heavy metals in tropical estuarine anoxic and oxidized sediments by different sequential extraction schemes. *Science of the Total Environment*, **275**, 53–61.

Okyar M. (1991) *The Late-Quaternary Transgression and its associated submarine stratigraphy of Mersin Bay between the Goksu and the Seyhan Deltas: A geophysical approach*. PhD Thesis, Institute of Marine Sciences, Middle East Technical University, Erdemli, Mersin, 156 pp.

Okyar M., Ergin M. & Evans G. (2005) Seismic stratigraphy of Late Quaternary sediments of western Mersin Bay shelf, (NE Mediterranean Sea). *Marine Geology*, **220**, 113–130.

Okay A.I. (2008) Geology of Turkey: A synopsis. *Anschnitt*, **21**, 19–42.

Ozer E., Koc H. & Ozsayar T.Y. (2004) Stratigraphical evidence for the depression of the northern margin of the Menderes–Tauride Block (Turkey) during the late Cretaceous. *Journal of Asian Earth Sciences*, **22**, 401–412.

Ozgul N. (1976) Basic geologic characteristics of Taurides. *Turkiye Jeoloji Kurumu Bulteni*, **19**, 65–78.

Ozgul N. (1984) Stratigraphy and tectonic evolution of the central Taurides. Pp. 77–90 in: *Geology of the Taurus Belt* (O. Tekeli & M.C. Göncüoğlu, editors). Proceedings of the International Symposium on the Geology of the Taurus Belt, Institute of Mineral

Research and Exploration, Ankara.

Ozsan A. & Karpuz C. (1996) Geotechnical rock-mass evaluation of the Anamur dam site,Turkey. *Engineering Geology*, **42**, 65–70.

Poisson A. (1977) *Recherches geologiques dans les Taurides occidentales (Turquie)*. PhD Thesis, University of Paris-Sud, Orsay, 795 pp.

Poisson A., Akay E., Dumont J.F. & Uysal S. (1984) The Isparta Angle: a Mesozoic palaeorift in the western Taurides. Pp. 11–26 in: *Geology of the Taurus Belt* (O. Tekeli & M.C. Göncüoğlu, editors). Proceedings of the International Symposium on the Geology of the Taurus Belt, Institute of Mineral Research and Exploration, Ankara.

Rainbow P.S. (1996) Heavy metals in aquatic invertebrates. Pp. 405–425 in: *Environmental Contaminants in Wildlife: Interpreting Tissue Concentrations* (W.N. Beyer, G.A. Heinz & A.W. Redmon-Norwood, editors). Lewis Publishers, Boca Raton, Florida, USA.

Rigler J.K .& Collins M.B. (1984) Initial grain motion under oscillatory flow: a comparison of some threshold criteria. *Geo-Marine Letters*, **3**, 43–48.

Rouibah M. (2001) Etat de pollution par les métaux lourds dans le port de Djen-Djen et le port de Jijel (Algérie), *Rapport Commission International Mer Méditerranee.* **36**, 160 pp.

Setti M., Mari Noni L. & Pez-Galindo A.L. (2004) Mineralogical and geochemical characteristics (major, minor, trace elements and *REE*) of detrital and authigenic clay minerals in a Cenozoic sequence from Ross Sea, Antarctica. *Clay Minerals*, **39**, 405–421.

Soylak M., Akkaya Y. & Elci L. (2001) Monitoring trace metal levels in Yozgat-Turkey: determinations of some metal ions in roadside soils. *Trace Elements and Electrolytes*, **18**, 176–180.

Soylak M., Uzek U., Narin I., Tuzen M., Turkoglu O. & Elci L. (2004) Application of the sequential extraction procedure for dust samples from Kayseri-Turkey. *Fresenius Environmental Bulletin*, **13**, 454–457.

Sutherland R.A. & Tack F.M.G. (2003) Fractionation of Cu, Pb and Zn in certified reference soils SRM 2710 and SRM 2711 using the optimized BCR sequential extraction procedure. *Advances in Environmental Research*, **8**, 37–50.

Tam N.F.Y. & Wong Y.S. (2000) *Hong Kong Mangroves*, City University of Hong Kong Press, Hong Kong.

Tekeli O., Aksay A., Urgun M. B. & Isik A. (1984) Geology of the Aladag Mountains. Pp. 143–158 in: *Geology of the Taurus Belt* (O. Tekeli & M.C. Göncüoğlu, editors). Proceedings of the International Symposium on the Geology of the Taurus Belt, Institute of Mineral Research and Exploration, Ankara.

T.K.K.Y. (2005) Control regulation of soil pollution, I. Regulation No. 25831. *Official Gazette of the Republic of Turkey*.

Turekian K.K. & Wedepohl K.H. (1961) Distribution of the elements in some major units of the Earth's crust. *Geological Society of America Bulletin*, **72**, 175–192.

Tuzen M. (2003) Determination of trace metals in the River Yesilirmak sediments in Tokat, Turkey using sequential extraction procedure. *Microchemical Journal*, **74**, 105–110.

Yalcin M.G. & Ilhan S. (2008) Multivariate analyses to determine the origin of potentially harmful heavy metals in beach and dune sediments from Kizkalesi coast (Mersin), Turkey. *Bulletin of Environmental Contamination and Toxicology*, **81**, 57–68.

Yalcin M.G. (2009) Heavy mineral distribution as related to environmental conditions for modern beach sediments from the Susanoglu (Atakent, Mersin, Turkey). *Environmental Geology*, **58**, 119–129.

Yalcin M.G. & Cevik O. (2009) Accumulation rates of heavy metal in Mersin Bay beach sands. Abstracts Book of the 62nd Geological Congress, Ankara, pp. 538–539.

Yalcin M.G., Cevik O. & Karaman M.E. (2013) The use of multivariate statistics methods to determine grain size, heavy metal distribution and origins of heavy metals in Mersin Bay (Eastern Mediterranean) coastal sediments. *Asian Journal of Chemistry*, **25**, 2696–2702.

Yilmaz A. (2002) Biogeochemistry of the seas surrounding Turkey: cycling and distributions. *Turkish Journal of Engineering and Environmental Science*, **26**, 219–235.

Yoshida M., Hamdi H., Abdulnasser I. & Jedidi N. (2004) Contamination of potentially toxic elements (PTEs) in Bizerte lagoon bottom sediments, surface sediment and sediment repository. Pp. 31–54 in: *Study on Environmental Pollution of Bizerte Lagoon* (A. Ghrabi & M. Yoshida, editors). INRST-JICA Press, Tunis.

Wedepohl K.E.L (1975) The contribution of chemical data to assumption about the origin of magmas from the mantle. *Forschritte der Mineralogie*, **52**, 141–172.

Wedepohl K.H. (1978) *Handbook of Geochemistry*. Springer, New York, 364 pp.