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GRAIN SIZE, TOTAL HEAVY MINERAL AND ELEMENT DISTRIBUTION AND CONTROL FACTORS OF CURRENT SEDIMENTS ON THE FLOOR OF HISARÖNÜ AND DATÇA BAYS

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ABSTRACT

This paper presents research results for Holocene sedimentary processes and controlling factors in Datça and Hisarönü Bays located in south west Turkey. For this purpose, we collected seafloor grab samples (upper 30 cm) from 71 stations and seismic profiles (only one sample is used to explain sedimentary process) from Hisarönü and Datça Bays with the MTA-SELEN research ship. According to the seismic profile, the continental self edge or threshold is found at depths of -90/-120 m and displays seismic facies parameters showing sea level variations from the Quaternary period. According to radiocarbon dating calculations, the sediment samples began to be deposited 2694-14700 years before present. The seafloor sediments comprise 1-18% gravel, 7-85% sand, 2-30% silt and 6-69% clay size clastic material. Although mud of mixed silt and sand composition is the most common sediment type, there are significant sand and gravel amounts. As well as discussing regional differences in grain size distribution, the presence of residual (relict) sediments is noted. The total amount of heavy mineral-rich black sand is mostly below 2%, reaching 13% in ophiolite- and chromite-rich central and eastern regions. Inorganic geochemistry of sediments includes relatively significant amounts of ophiolitic-sourced Mg, Cu, Ni and Fe. Regional variations in river drainage system, bay morphology, terrestrial source rock lithology and marine waves and currents affect not only sediment grain size distribution, but also total heavy mineral content and the main element composition.

1. Introduction

The study area incorporates Datça and Hisarönü Bays in the southwest of Turkey located with Datça Peninsula to the north, Marmaris to the east, and Simi (Sömbeki) island to the south between the Mediterranean and Aegean Seas with oceanographic characteristics of these seas (Figure 1). The studies and available data for the region are generally related to the general geology, with insufficient study on the seafloor sediments and their characteristics. This article, prepared to research the decomposition products of source rocks on Datça Peninsula and the offshore traces of heavy mineral placer sands deposited along the current coastline, comprises sedimentalogic and geochemical studies along with interpretations, partial seismic and C^{14} studies. As there is no previous data on studies of heavy mineral placers in the marine area south of Datça Peninsula, this study is considered to fill an important gap in the literature.

1.1. General Geology

The Aegean region is actively shaped by tectonic events (Figure 2). The region was the setting for the formation of the Aegean trench and is currently dominated by intense tectonic movements linked to subduction (Şengör and Yılmaz, 1981, Ersoy, 1991). The Upper Miocene was the period when N-S extension began in the Aegean region (Kurt, 1999). In this period the Aegean Sea, coastline and neighboring continents were one of the most seismically active regions in the world (Jackson and McKenzie, 1984; Taymaz et al., 1991; Dirik et al., 2003). Under the effect of these motions, the Aegean Sea was influenced by active extensional tectonics in the boundary system of plates around the Mediterranean (Mascle and Martin, 1990; Uluğ et al., 2005) and east-west striking grabens formed due to extensional tectonics (McKenzie, 1972, 1978; Dewey and Şengör, 1979; Angelier et al., 1981; Uluğ et al., 2005).

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The current setting of the Datça Peninsula is closely related to a range of geologic events such as the regional emplacement of the Likya Nappes and the formation of the Gökova, Datça and Hisarönü Bays. The Likya Nappes were formed by the thrusting of oceanic crust above the Anatolide-Tauride platform during subduction along the Izmir-Ankara suture belt in the Cretaceous and the shaping of this thrust and later material accreted by subduction during the continent-continent collision in the Upper Paleocene-Lower Eocene along with allocthonous units from the Western Taurus (Brunn et al., 1971, Şengör and Yılmaz, 1981, Ersoy, 1991, Uluğ, 2005). A NW-SE striking rift system including Middle-Upper Miocene units developing due to the effect of a compressional regime and later N-S oriented systems including Plio-Quaternary units occurring during the extensional regime appear to have been effective during the formation of Gökova Bay north of Datça Peninsula (Görür et al., 1995; Uluğ et al., 2005). With the effect of slab pull beginning in the Upper Miocene, the currently submarine Hisarönü Graben formed between the Datça and Bozburun Peninsulas (Ersoy, 1991). Gravity causing extensional forces on the Datça Peninsula produced structural elements like horst and graben due to a growth fault. The most typical examples are NE-trending faults bounding the north and south of Datça Graben. The faults of the Hisarönü and Gökova Grabens cut the faults of the Datça Graben obliquely. As a result the Datça Peninsula gained a horst structure together with the grabens between the Datça Graben (Ersoy, 1991).

Outcrop geology in the Datça Peninsula comprises the Triassic-Cretaceous age Likya Nappes including the Bodrum Nappe, Gülbahar Nappe and Marmaris Ophiolite and overlying Paleogene, Neogene and Quaternary units (Figure 3). The Bodrum Nappe comprises Middle Triassic-Upper Cretaceous dolomite, limestone, mudstone, claystone, siltstone and volcanics and represents bedrock. The Middle Triassic-Upper Cretaceous Gülbahar Nappe consisting of sandstone, mudstone, limestone and volcanic overlies these units (Şenel and Bilgin, 1997). The Jurassic-Upper Cretaceous Marmaris Ophiolite Nappe is located above the Gülbahar Nappe, and includes rock types such as limestone, cherty limestone, dolomite, radiolarite, chert and volcanics in sheared serpentinite mud with a chaotic structure. There is occasional harzburgite, dunite, gabbro, diabase and serpentinized harzburgite and dunite in the Kızılcadağ Melange and Olistostrome with harzburgite, occasionally serpentinized harzburgite and dunites and occasional small diabase and gabbro masses comprising the Marmaris Peridotites (Şenel and Bilgin, 1997). Paleogene clastic units are found over the Likya Nappes above an angular unconformity with Neogene clastics and carbonates continuing above an unconformity. Unconformably lying above all units are Quaternary-age clastic sediments (slope debris, alluvium) and volcanics (Şenel and Bilgin, 1997).

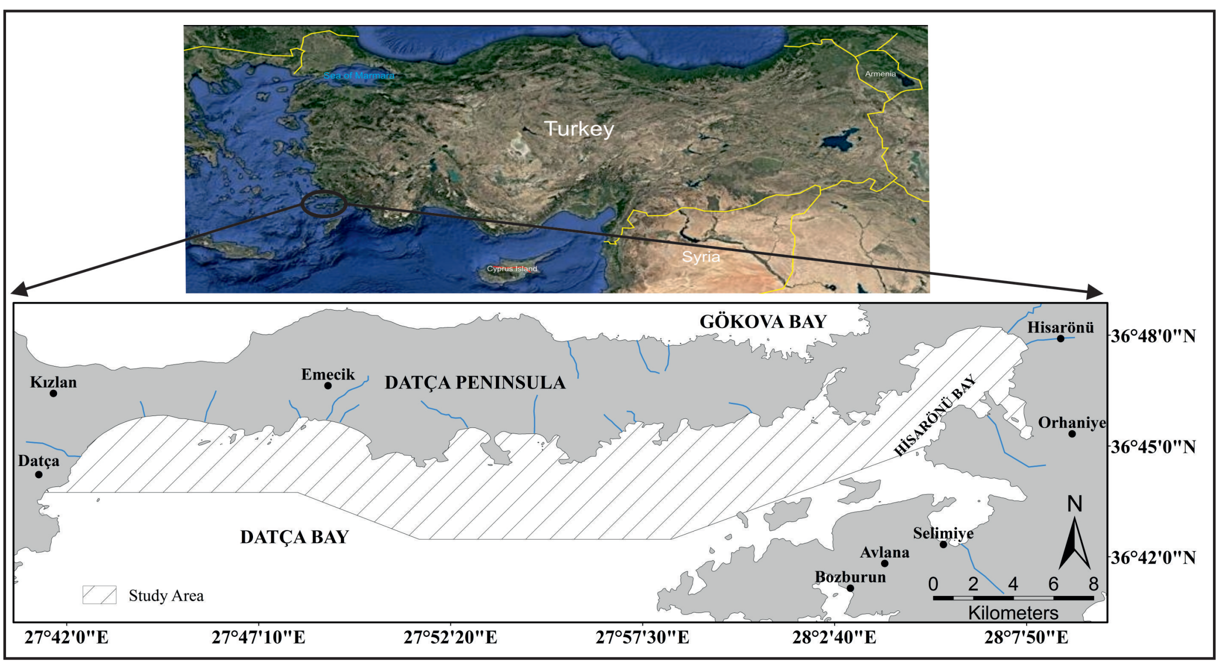

Figure 1- The study area of Datça and Hisarönü Bays and close surroundings.

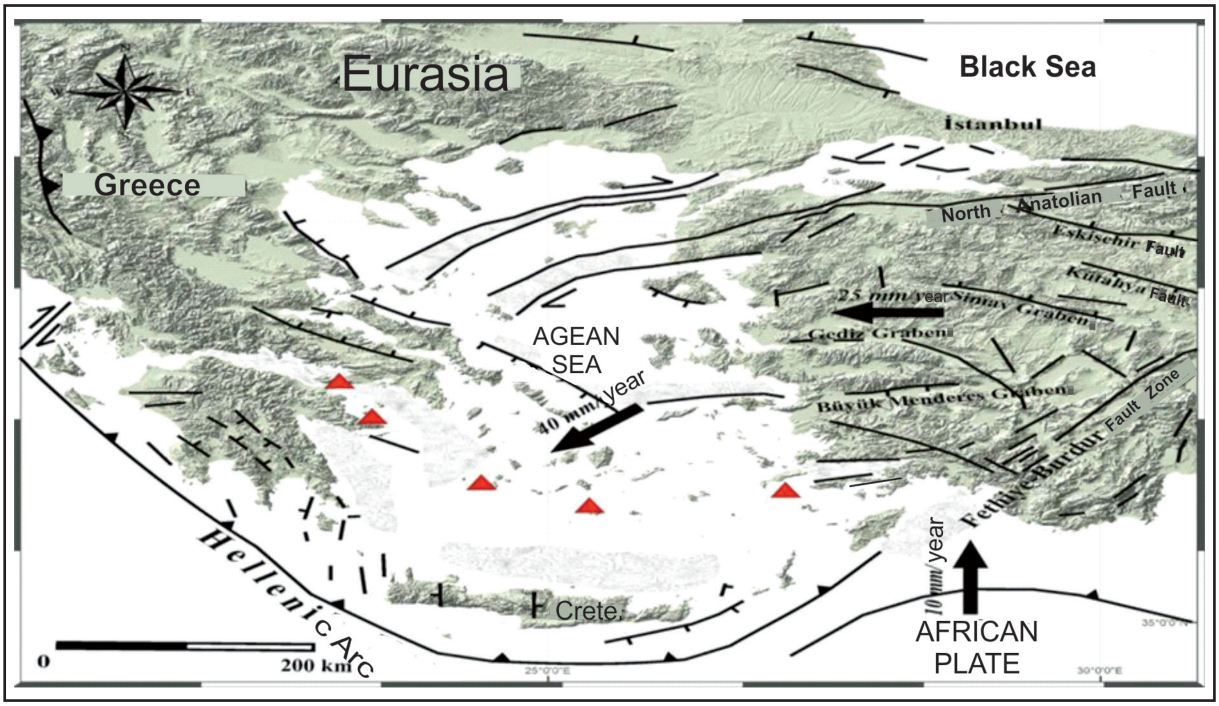

Figure 2- Tectonic map of Aegean Sea and surroundings (Large black arrows - plate movement directions, black lines - faults (Barka and Reillinger, 1997; from Kaşer, 2010, fault south of Datça Peninsula Ersoy, 1991), red triangles - volcanos (National Observatory of Athens, from Kaşer, 2010).

1.2. Morphology, Climate and Rivers

The coastline of the Datça Peninsula comprises mountainous morphology with generally narrow and short beaches, and small islands and submarine elevations extending from the coast into the sea (Figure 4). The highest points on the Datça Peninsula are from west to east; Yassıdağ (408 m); Karabalık Peak (455 m); Bozdağ (1163 m); Karmanbaşı Peak (747 m) and Mount Yağlıdağar (486 m). South of the peninsula the shelf area deepens from the coast to 200 m reaching broad extension in Hisarönü Bay of ~ 22 km, with a narrow shelf of ~ 5 to ~ 8 km in Datça Bay linked by a deepening section beginning from 200 m (Figure 4). The region has typical Mediterranean climate. Summers are hot and dry, while winters are mild and rainy. Mean annual temperature is 19.1 °C in Datça with the hottest month of July having mean temperature of 27.1 °C and the coldest month of January having mean temperature of 12.1 °C. Mean precipitation for Datça is 710.9 mm. Nearly all precipitation falls during the winter months (Taşlıgil, 2008).

Due to the steep morphology of the peninsula, it has many inclined short riverbeds with seasonal and irregularly flowing rivers and streams carrying material to the coast in the region represented by Küçükalataka Stream (1); Eksera Stream (2); Çakal Stream (3); Günuç Stream (4); Bakacak Stream (5); Alazeytin Stream (6); Akçabük Stream (7); Kızıl Stream (8); Karabük Stream (9); Koca Stream (10); Armutyanı Stream (11); İnceburun Stream (12); Zindan Stream (13); Uzunırmak Stream (14); Çakallıca Stream (15); Gökçe Stream (16); Havari Stream (17); Değirmen Stream (18); Bağlıca Stream (19); Cin Stream (20); Kurucaboğaz Stream (21); Kocaçığlı Stream (22); Karacalıbükü Stream (23); Dallı Stream (24); Kazan Stream (25); Hisarönü Stream (26); Değirmen Stream (27); and Çaykuyu Stream (28) (Figure 5). Apart from streams, the Datça Hot Spring collecting in a natural basin with temperature 27 °C is located 100 m inland west of Datça Pier (Taşlıgil, 2008).

2. Material and Method

On the General Directorate of Mineral Research and Exploration (MTA) research ship MTA Selen, the Datça Project voyage collected single channel shallow seismic reflection profiles, grab and core samples from Datça and Hisarönü Bays. For shallow seismic sections, a seismic profile perpendicular to the coast in accordance with the aims and scope of the

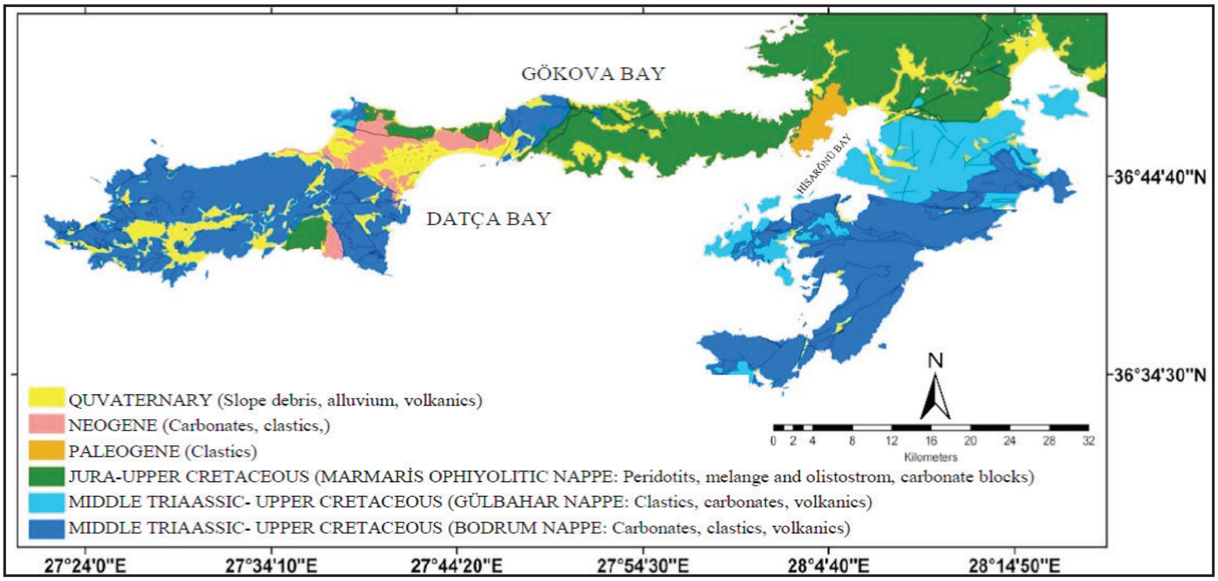

Figure 3- General geology map of Datça Peninsula and surroundings (adapted from Şenel and Bilgin, 1997).

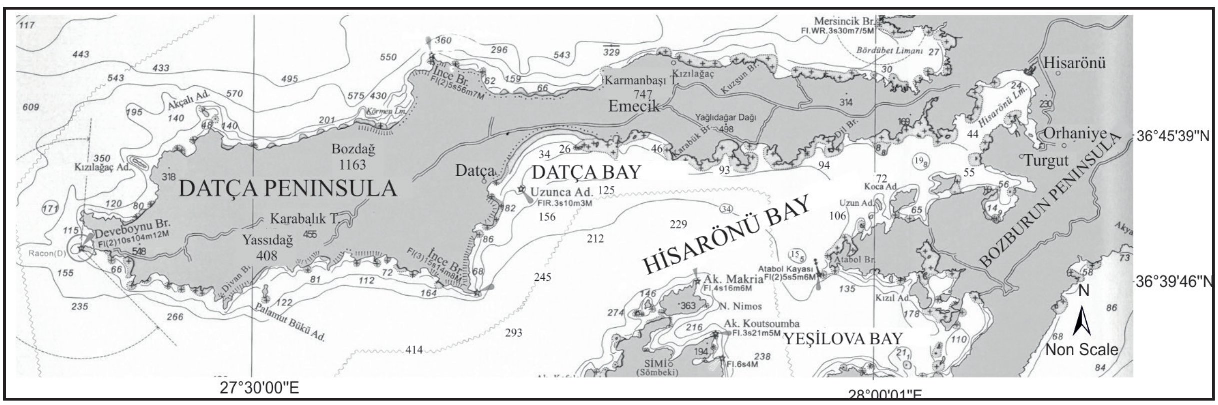

Figure 4- Underwater morphology map of bays north and south of Datça Peninsula (adapted from TR311 Navigation Map and www.hgk.gov.tr/sayisal-uygulamalar, no scale).

project was chosen (Figure 6). Single channel seismic data were collected using a high resolution shallow seismic system (Geoacoustics) with energy source of a 175 joule boomer, listen time of 500 ms and sampling interval of 40 μs. The data were processed with the system's Geo-Pro II data processing software to obtain seismic reflection profiles. For calculation of water and sediment depths from two way travel time (TWT) data, the acoustic wave speed was accepted as 1500 m/s. With the aim of explaining Quaternary geology, principles and methods stated in Mitchum et al. (1977) and Posamentier et al. (1988) were used for interpretation of facies analysis and parameters on seismic reflection profiles.

The study used 71 samples taken with a sediment scoop representing the top 30 cm of the seafloor (Figure 7). The majority of samples were analyzed in the MTA laboratories, with some completed in the Geological Engineering Department of Ankara University. The sediment sample points numbered 51, 52, 53, 54 and 55 were in close proximity to the region of the number 10 seismic profile (Figures 6 and 7).

For grain size analysis, the sediment samples were washed and after sea salt was removed, they were washed above a 0.0625 mm pore size sieve to separate the sand and gravel fractions. The remaining mud fraction was separated into silt and clay grain sizes with a Malyem Mastersizer 2000 device. The samples were later dried and passed through a 0.0625 mm sieve to separate 4 mm, 2 mm, 1 mm, 0.25 mm and 0.125 mm diameter grain sizes. Grain size classification was determined according to the Wentworth scale stated by Folk (1980).

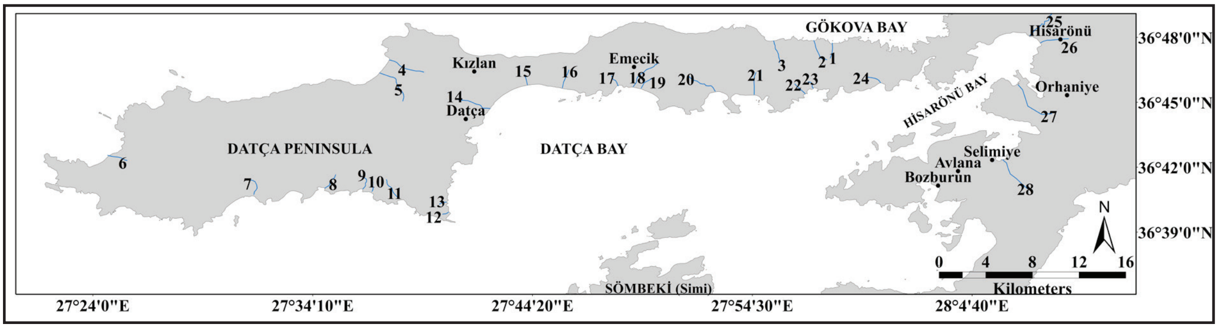

Figure 5- Irregular and seasonal streams on Datça Peninsula and surroundings (prepared from General Command of Mapping topographic maps and field observations).

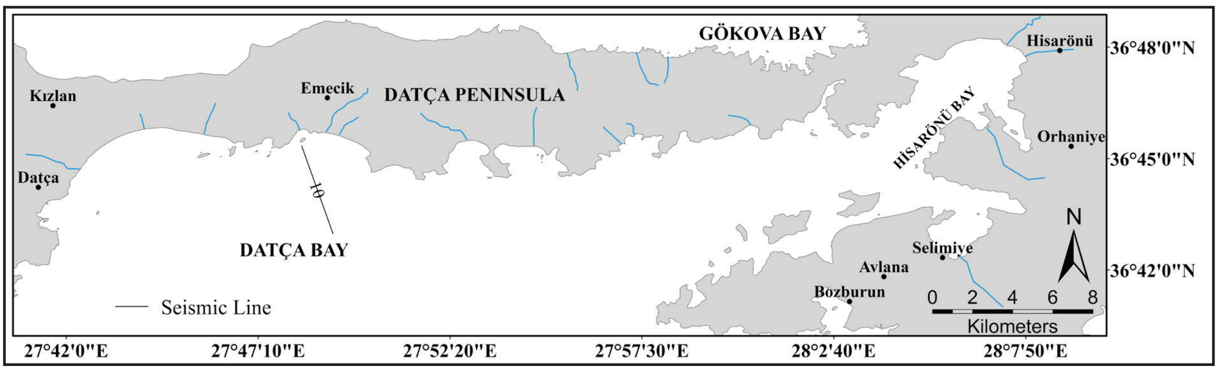

Figure 6- Location of no. 10 seismic section taken in Datça Bay.

To identify the ages of the sediments, sediment samples from the upper levels of cores obtained from 8 sample points (Figure 8) were sent to the ETH (Swiss Federal Institute of Technology of Zurich) laboratory and age dating was completed with convective radiocarbon methods with results given as C^{14} BP after C^{13} correction (BP – before present).

For total heavy mineral analyses, washed and dried sediment samples with grain size from 1 mm to 0.0625 mm were separated into heavy and light mineral fractions according to standard methods with bromoform liquid with density 2.89 g/ml (Müller, 1967; Lewis, 1984; Grosz et al., 1990).

Based on total heavy mineral analyses of scoop samples from Datça and Hisarönü Bays, 21 samples were chosen for geochemical analysis (Figure 9). The dried and ground sediment samples had main and trace elements measured with a Therma ARL XRF system (reference material UQ standart) in the Turkish Accreditation Agency-certified MTA General Directorate Laboratories for geochemical element analysis (Figure 9). Statistical methods like the Pearson correlation matrix were used to assess the analysis results.

3. Results

The assessment of data from sediment sample analyses and seismic section in Datça and Hisarönü Bays are given below.

3.1. Radiocarbon (C^{14}) Ages of Sediments

The ages of base levels of the sediments in the study (30 cm below the seafloor) were determined with calculation methods to have begun deposition 2694 years before present for station number 4 and 14,700 years before present for station number 3 with all ages obtained from the field between these values (Table 1). Calculations from other cores with 30 cm thickness found station no. 7 began deposition 11,424 years before present, station no. 8 began deposition 10,237 years before present with other stations beginning deposition between 2816 to 6112 years before present. The sediment deposition rates obtained from the ages of sediments was mean 6 cm/1000 years, with significant differences regionally (2-11 cm/1000 years) (Table 1). The highest values (10-11 cm/1000 years) were encountered in the concave, protected and relatively wide shelf at Datça Bay with fluvial inputs. The ages of scoop (surface) sediment samples in

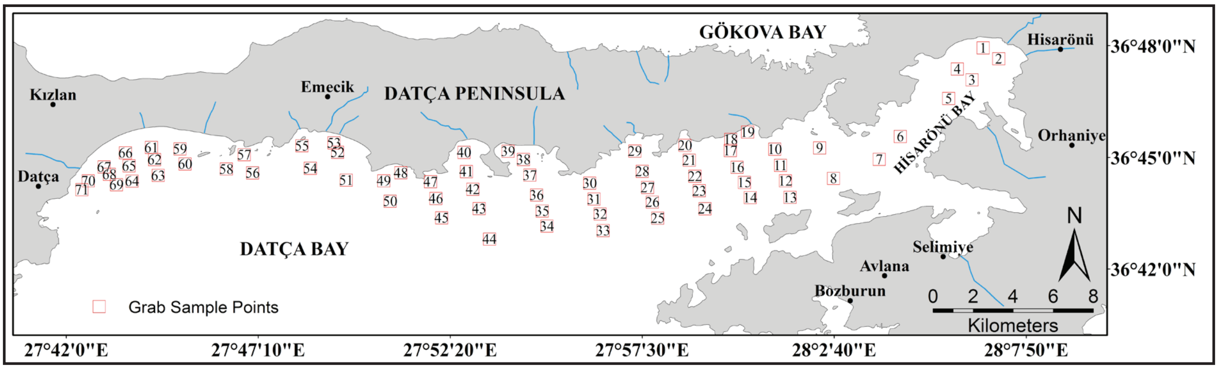

Figure 7- Surface sediment sampling stations in Datça and Hisarönü bays.

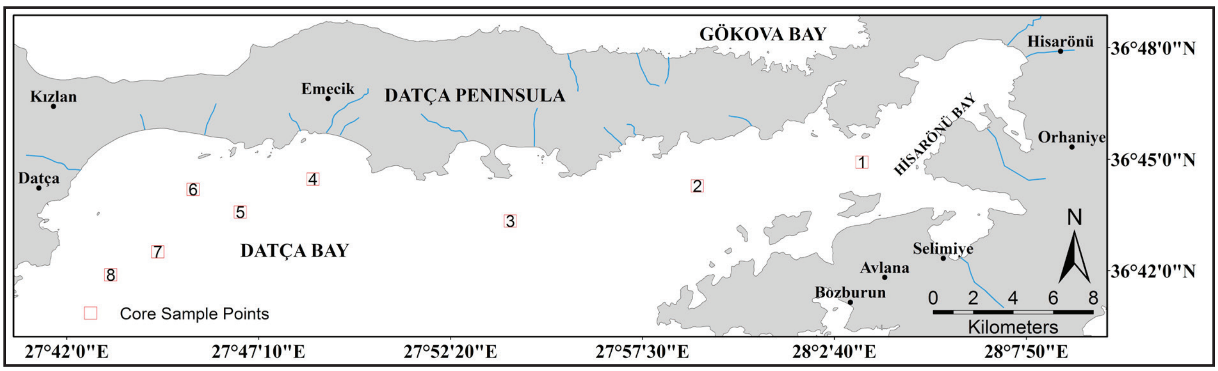

Figure 8- Core sample points chosen for radiocarbon age dating.

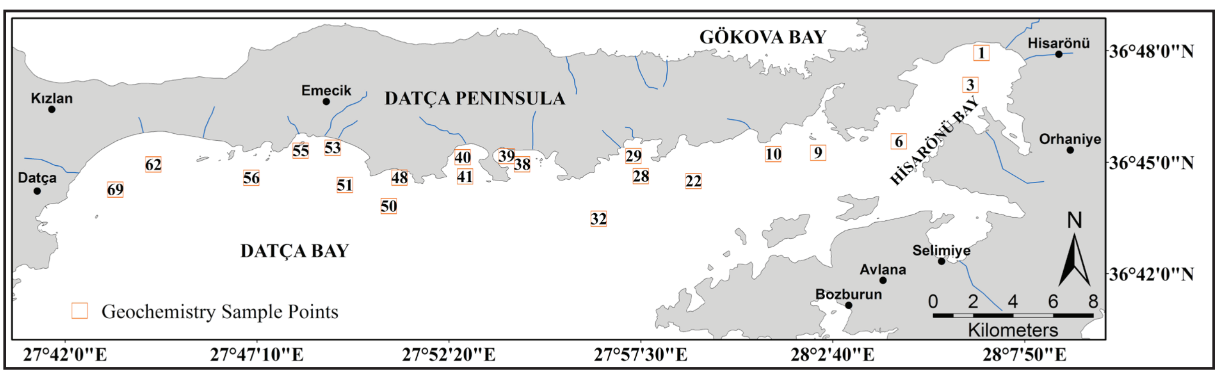

Figure 9- Grab sediment samples for geochemical analysis in Datça-Hisarönü bays.

Datça and Hisarönü Bays were assessed as varying from Upper Pleistocene to Holocene. For these bays, it was estimated that nearly 2 m of sediment may have accumulated from the beginning of the Last Glacial Maximum (LGM; 19,000 years BP, Hamann et al., 2008) and Holocene (11,700 year BP. IUGS ICS, 2016) to the present day (Table 1).

3.2. Seismic Facies Analysis

To make the seafloor, sea level changes and tectonics more comprehensible in the region, the no. 10 seismic reflection profile from east of Datça Bay was investigated (Figure 10). With approximately 410 ms listen time, no. 10 profile is equivalent to about 300 meters depth when seawater acoustic wave speed is taken as 1500 m/s. Beginning near the coast and in shallow water with 60 ms (45 m) water column depth, the section extends into open water with 270 ms (202 m) depth. The edge or threshold of the shelf is very clear on the profile at 160 ms (120 m) depth and is very much in accordance with the previously published Upper Pleistocene global sea level variation curves (Fairbanks, 1989; Siddall, 2003; Toucanne,

Table 1- Radiocarbon age (C^{14}) distribution of core samples from Datça and Hisarönü Bays and correlation to grab samples.

Core No	C^{14} Core Depth Grab Sample Depth Holocene (LGM) Depth (cm)	C^{13} Corrected C^{14}Age (BP)	Calculated sediment deposition rate (cm/1000 years)
1	40-41 30 78 (126)	6099 4517 11700 (19000)	6.64
2	40-41 30 89 (145)	5307 3931 11700 (19000)	7.63
3	29-30 30 24 (39)	14455 14700 11700 (19000)	2.04
4	34-35 30 130 (212)	3098 2694 11700 (19000)	11
5	40-41 30 57 (93)	8252 6112 11700 (19000)	4.9
6	26-28 30 125 (202)	2535 2816 11700 (19000)	10.65
7	25-26 30 31 (50)	9711 11424 11700 (19000)	2.62
8	30-31 30 50 (81)	10408 10237 11700 (19000)	2.93
Mean	30	7054	6

2012). Again on this profile, sediment or deposition depth on the inner shelf near the coast is 20 ms (15 m) reaching 60 ms (45 m) on the outer shelf and falling to 20 ms (15 m) again on the upper slopes. Seismic facies units with continuous regular high-amplitude reflections parallel to the slope with cover-like form pass to wavy, dome-like parallel moderate-high amplitude occasionally chaotic, irregular, lenslike and progressively clinoform units on the shelf. Especially at 160 ms depth (120 m) with clear progressive clinoforms, a sediment wedge similar to a low sea level delta and the ancient coastline from the Upper Pleistocene period shape the shelf in the study area. Investigation of available data shows that in the study area in Datça and Hisarönü Bays sea level variation and terrestrial clastic supply were among the important factors in the Upper Pleistocene and especially Holocene. The angled (normal, reverse) faults identified on the seismic profile show that the region was affected by active tectonics especially in the Miocene and later times (Figure 10).

Surface sediment samples obtained with a scoop (30 cm thick) are equivalent to 0.4 ms thickness on the seismic profile and as a result it is very difficult, if not impossible, to perform detailed seismic facies analysis with such low values (Figure 10).

3.3. Grain Size Distribution

The grain size distribution of sediment samples from 30 cm depth on the sea floor in Datça and Hisarönü Bays comprised 0-18% gravels, 7-85% sand, 2-30% silt and 6-69% clay (Figure 11). When the bays are compared, the sediments in Hisarönü Bay varied form 5-10% gravel, 25-50% sand, 10-30% silt and 25-69% clay. The sediments from Datça Bay meanwhile have distribution of 0-15% gravels, 25-85% sand, 0-30% silt and 0-69% clay (Figures 11 – 12 - 13 – 14 - 15).

According to this distribution the sediments in Datça Bay contained relatively high proportions of

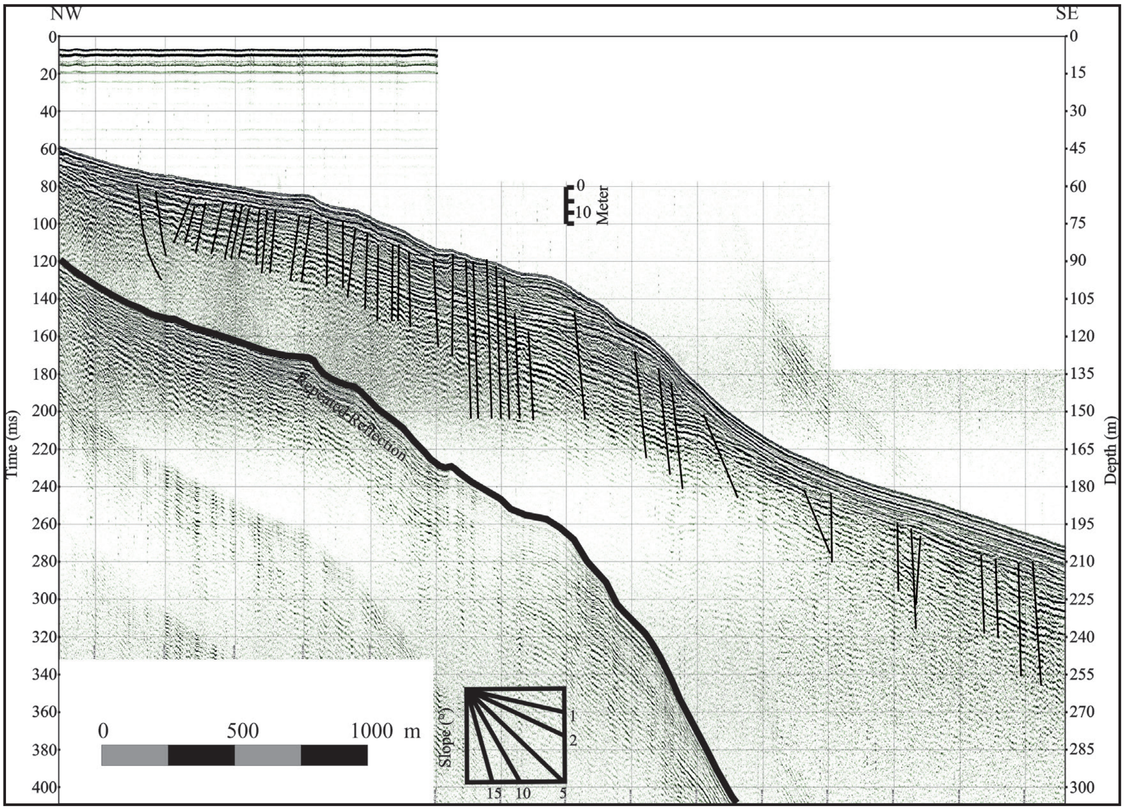

Figure 10- Seismic reflection profile no. 10 from east of Datça Bay. For section location see figure 6, interpretation in text.

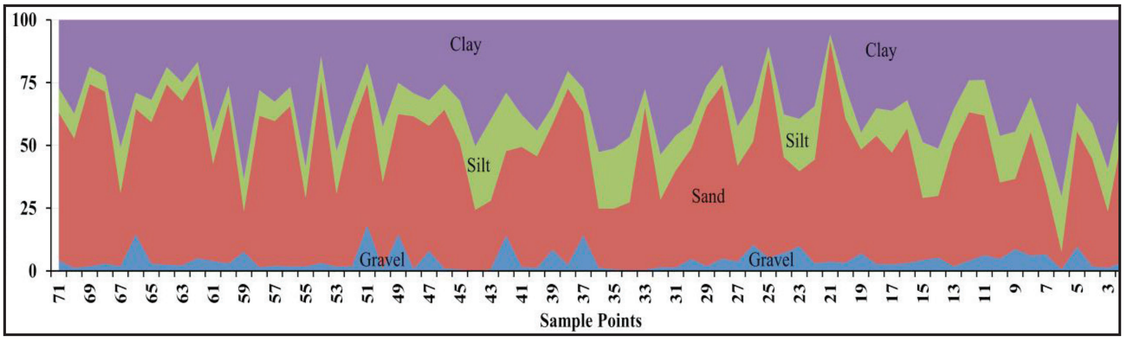

Figure 11- Grain size distribution of surface sediments in Datça and Hisarönü Bays.

sand and low proportions of clay. The relatively high gravel amounts in Datça Bay were found in the west, central and east sections in a regionally narrow area. Similarly the proportion of gravels in Hisarönü Bay has regional increases in the central and western sections. Generally the increase in gravels was encountered at the shelf edge and nearby, in front of rocky coasts and in relatively shallow waters (Figure 12). An increase in the proportion of gravels was only found near stream mouths in a few areas, with gravels in Datça Bay increasing from the interior to exterior.

Sand amounts may increase near the coast in the west and east of Datça Bay (50-85%) but also may increase in more distal areas (Figure 13). Silt proportions generally increase from the coast (<10%) toward open waters (shelf edge) (20-30%) (Figure 14). These increases appear to be more dominant in limited regions in the eastern portion of Datça Bay and the eastern, central and western protions of Hisarönü Bay.

Clay amounts vary in the western and eastern sections of Datça Bay. In the west in areas close to the coast 50-69% clay grain size material reduces toward open water to fall below 25% and in the east increases again to reach 69% occasionally on the shelf edge (Figure 15). In the protected and secluded Hisarönü Bay, the clay amount is generally high and values of

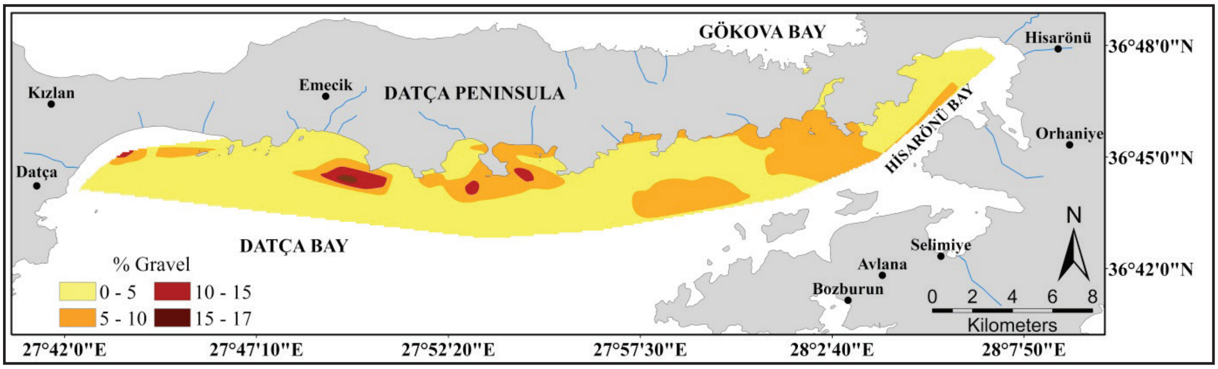

Figure 12- Distribution of gravel size material in surface sediments in Datça and Hisarönü Bays.

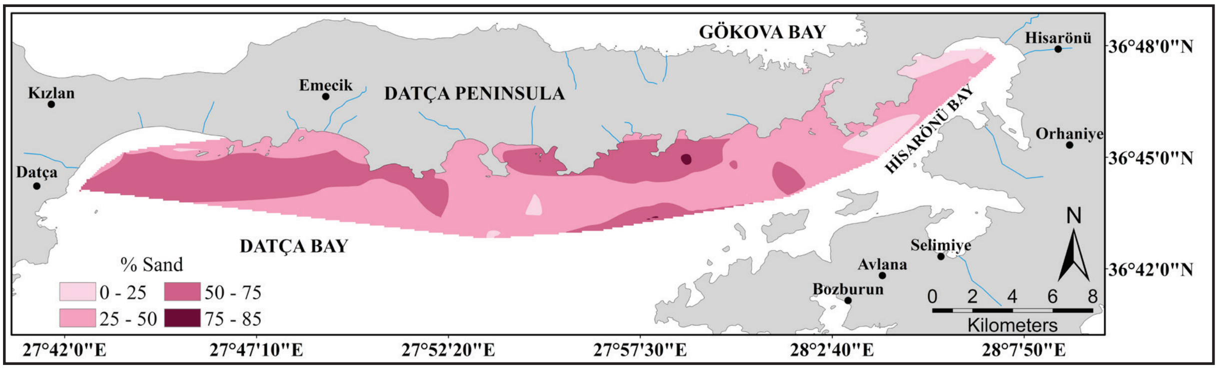

Figure 13- Distribution of sand size material in surface sediments in Datça and Hisarönü Bays.

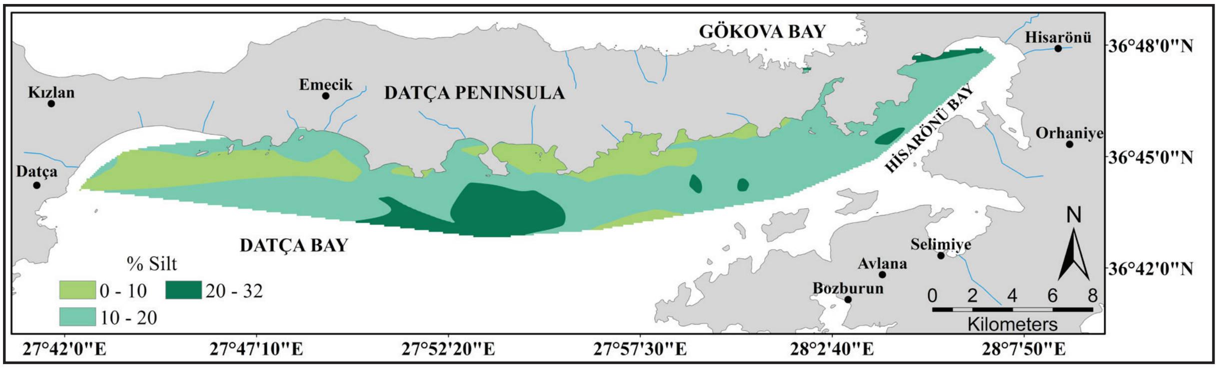

Figure 14- Distribution of silt size material in surface sediments in Datça and Hisarönü Bays.

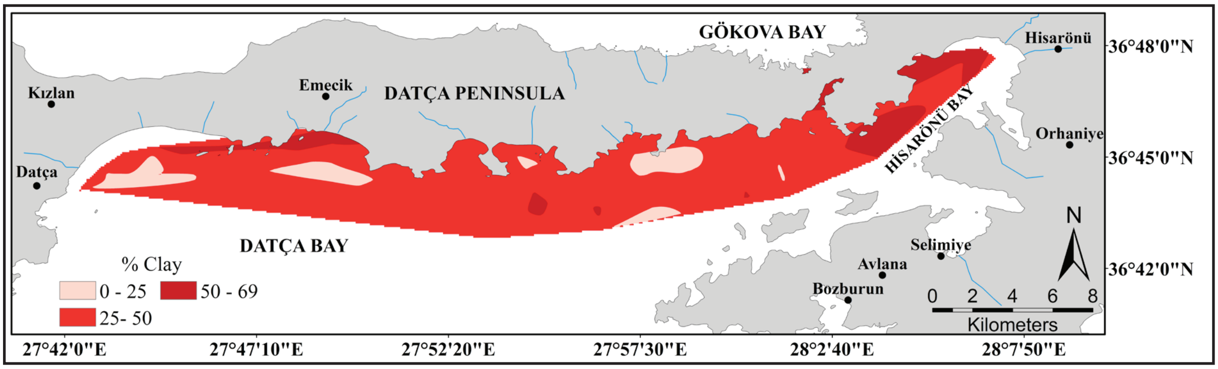

Figure 15- Distribution of clay size material in surface sediments in Datça and Hisarönü Bays.

50-69% are more common (Figure 15). Though high clay proportions are encountered near stream mouths, it appears difficult to apply this correlation to the whole study area. When sediment grain size distribution is classified according to the triangle diagram of Folk (1980) the bay sediments belong to slightly gravelly muddy sand "(g)mS", slightly gravelly sandy mud "(g) sM", gravelly muddy sand "gmS", slightly gravelly mud "(g)M", slightly gravelly sand "(g)S", gravelly mud "gM" and sandy mud "sM" with sand and mud proportions varying occasionally (Figures 16 - 17). In the field sandy and muddy units are the dominant two common sediment types and generally muddy units accumulate in Hisarönü Bay while sandy units generally accumulate in Datça Bay. In some regions and especially in the west, sediment types change from mud to sand from the coast to open water, while other regions display transition from sand to mud.

The graphic mean grain size of sediment samples varies from Ø 4.70 to Ø 8.14, with mean grain size of clay for a small area close to the coast in the interior of Hisarönü Bay, while the mean grain size for other areas of Hisarönü Bay and Datça Bay is mainly silt (Figure 18).

3.4. Total Heavy Mineral Distribution

The total heavy mineral (THM) amounts in surface sediments in Datça and Hisarönü Bays vary from <1 to 13% with values mainly lower than 2% (Figure 19). Relatively high THM amounts are encountered in the interior sections of Hisarönü Bay (10-15%) and in the tip area east of Datça Bay (5-10%) (Figure 20). Inland from the coast in the bays and especially in regions that may form source areas, it is previously known that there are ophiolitic rocks that may contain heavy minerals. In fact, ophiolitic rocks rich in heavy minerals are more common in Hisarönü Bay (Figure 3). When the total heavy mineral contents of samples are compared in terms of grain size, samples containing heavy minerals appear to have gravel percentages from 0-10% with sand 25-75%, silt 5-25% and clay 15-55% (Figure 21). Additionally it cannot be said that there was a strong direct positive correlation between total heavy mineral proportions and grain size distribution of sediments.

3.5. Element Geochemistry

The element analysis results obtained in the study (Figures 22-32, Table 2) were compared with mean values for continental crust, sedimentary (e.g., shale, sandstone, limestone) and basic-ultrabasic (e.g., dunite, harzburgite) rocks.

When the mean values for SiO_2, TiO_2, Al_2O_3, Fe_2O_3, MnO, MgO, CaO, Na_2O, K_2O, P_2O_5 and Cr_2O_3 in study area sediments are compared with mean sedimentary, magmatic and continental crust rock values, the majority had similarities identified. The source rocks found inland from the coasts are commonly observed, forming a wide range from dunite, harzburgite, basalt, sandstone, limestone and basic-ultrabasic rocks (Figure 3). Especially the relatively high Mg, Fe and Cr amounts may be considered decomposition products from the Marmaris Ophiolite. The distribution of some elements displays regional differences (Figures 22-32). In the outer portion of Hisarönü Bay in front of Dil Headland and from sample no. 28 at the shelf edge to Datça Bay in the west and Hisarönü Pier in the east, amounts of SiO_2, Al_2O_3, Fe_2O_3, and K_2O generally and clearly increase. The increasing trend toward the east is partially accompanied by TiO_2, MgO, Na_2O and P_2O_5. While MgO increases in the remaining area between the two bays (Figure 27), MnO values are high throughout all regions (Figure 26). CaO has an inverse distribution decreasing to the east and west from station no. 28 (Figure 28). Sampling station no. 28 is located in the region of the ~100 m depth contour in Datça and Hisarönü Bays and determines the bathymetric limit separating the bays (Figure 4). Datça Bay to the west of the sample point has a relatively narrow coast with steep slope linking 100 m to deeper areas, Hisarönü Bay to the east has a broader and relatively lower slope opening to deeper areas from 100 m (Figure 4).

Evaluation with a correlation matrix prepared from results of interelement correlations and dependence on other variables was completed taking account of correlations between elements and element associations and determined positive and high correlations for those with correlation coefficient +0.8 or more (Table 3). Accordingly SiO_2-TiO_2, SiO_2-Al_2O_3, SiO_2-Fe_2O_3, TiO_2-Al_2O_3 and Al_2O_3-K_2O have very high positive (+) correlations, with the majority of these elements directly or indirectly associated with or enriched in silicates and aluminosilicates. Coefficients varying from 0.66 to 0.91 for Cr_2O_3, MgO, Fe_2O_3 and total heavy mineral amounts may be linked to source rocks containing chromite and peridotite in the region. Generally the effect of total heavy mineral amounts on

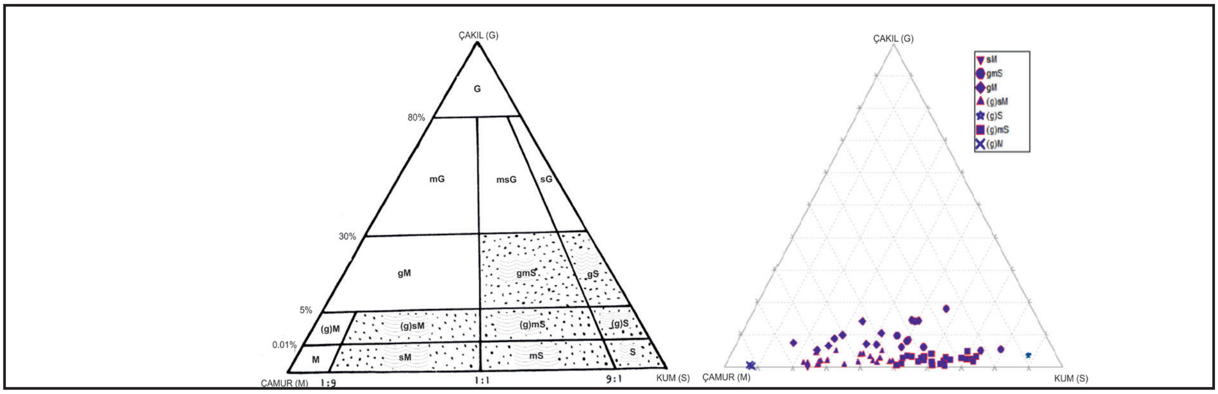

Figure 16- Classification of surface sediments in Datça and Hisarönü Bays according to Folk (1980).

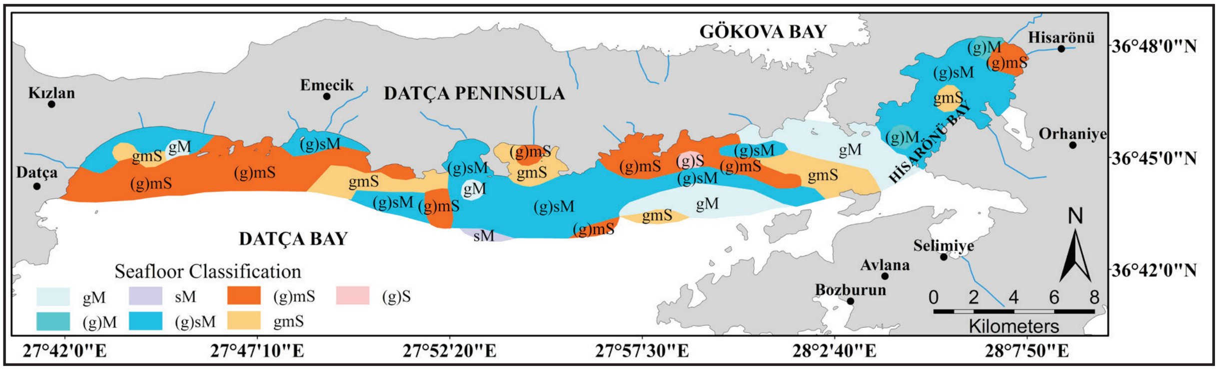

Figure 17- Distribution of surface sediments in Datça and Hisarönü Bays according to Folk's classification (1980).

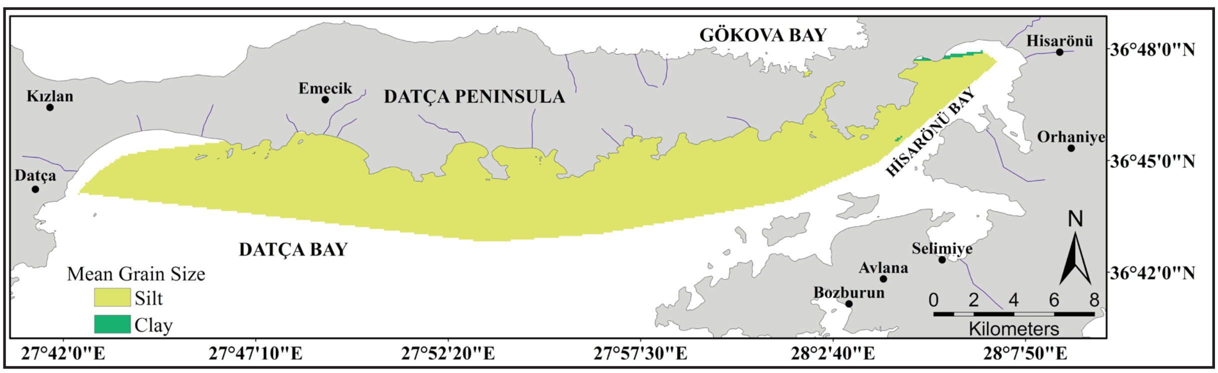

Figure 18- Mean grain size distribution of surface sediments in Datça and Hisarönü Bays.

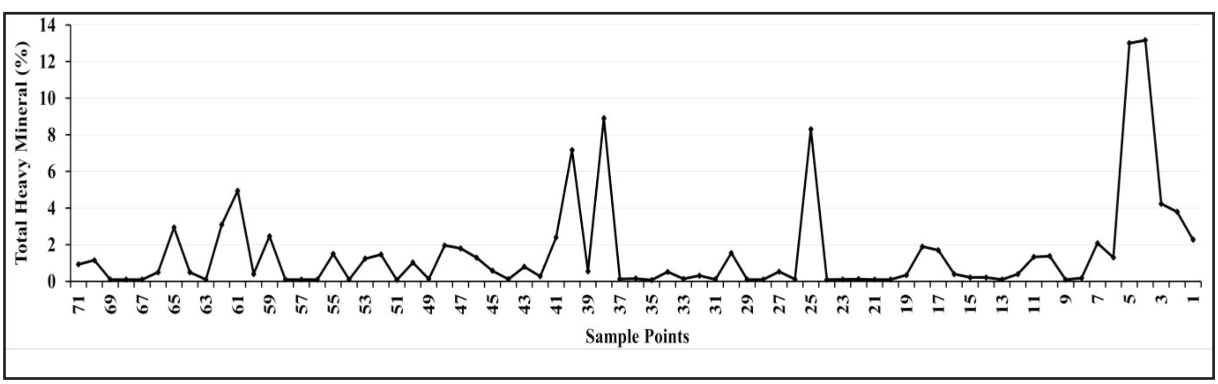

Figure 19- Total heavy mineral distribution in grab sediment samples from Datça and Hisarönü Bays.

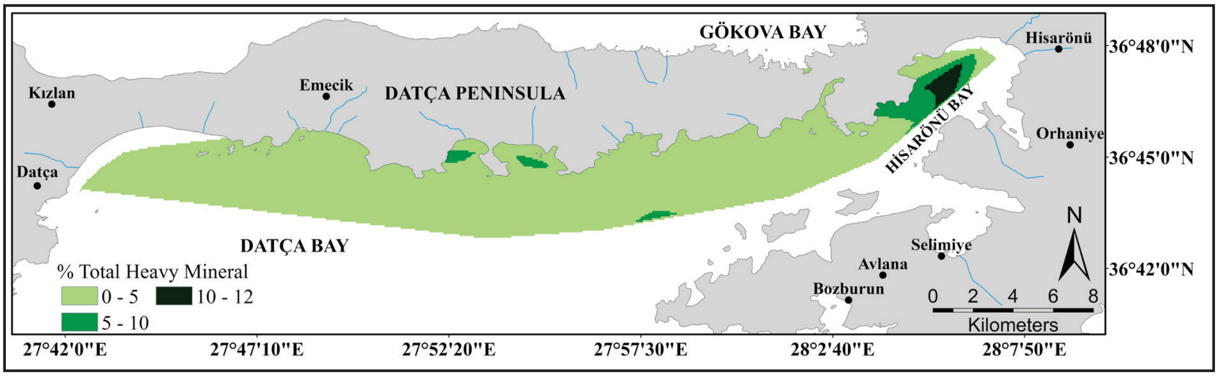

Figure 20- Total heavy mineral distribution in grab sediment samples from Datça and Hisarönü Bays.

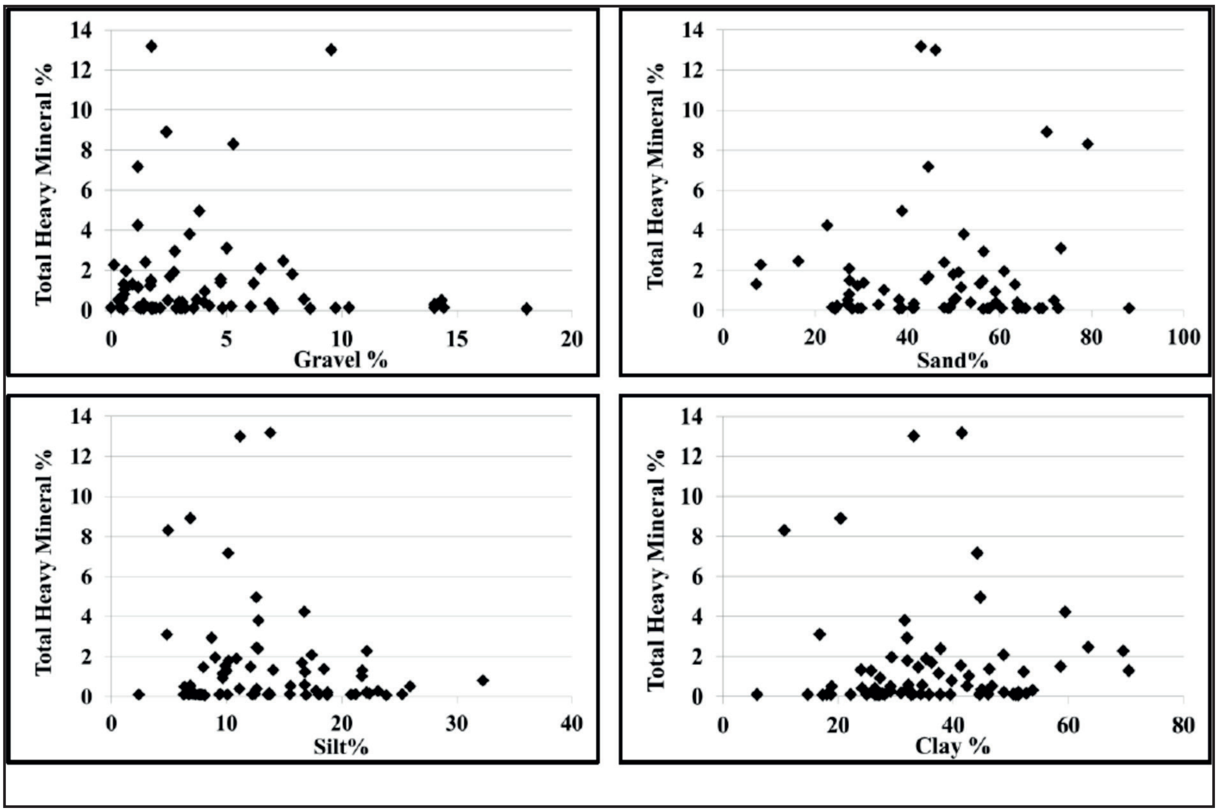

Figure 21- Correlation of total heavy minerals and grain size in samples from south of Datça Peninsula.

element distribution was very low (Table 3). No matter how sand size and clay size sediments appeared to have relatively high correlation coefficients, generally clay fractions were not enriched in elements (Table 3).

4. Discussion

Generally high resolution seismic reflection profiles provide important clues about the stages within a Quaternary-fill sedimentary basin including erosion, transportation and deposition conditions and texture and structure of accumulated sediment (Mitchum et al., 1977; Posamentier et al., 1988). These include, especially, environment and facies types linked to high and low sea levels developing in the Upper Pleistocene period (Ergin et al., 1992; Aksu et al., 1999; Çağatay et al., 2000; Boggs, 2006). Investigation of available seismic data show that sea level variation during the Upper Pleistocene-Holocene period and supply of terrestrial clasts were among the most important factors affecting the sea floor sediments in Datça and Hisarönü Bays. The fact that the surface sediments investigated had mean thickness of 30 cm made seismic facies analysis of the

Table 2- Comparison of continental crust, shale, basalt, sandstone, limestones, ultrabasics, dunite and harzburgite geochemistry with geochemical data of samples from Datça-Hisarönü Bays.

% Oxide	This study Min	This study Max	This Study Mean	Continental Crust (Rudnick, 2005)	Continental Crust (Gao et al., 1998)	Shale (Okunlola and Idowu 2012)	Basalt (Klein 2005)	Sandstone (Turekian and Wedepohl 1961)	Limestone (Turekian and Wedepohl 1961)	Harzburgite (Uysal 2007)	Dunite (Uysal 2007)	Ultrabasic (Turekian and Wedepohl 1961)
SiO2	7.80	49.00	23.96	60.60	64.20	61.26	50.01	78.71	5.13	43.64	41.48	43.85
TiO2	0.10	0.70	0.25	0.72	0.80	1.74	1.11	0.25	0.07	0.00	0.00	0.05
Al2O3	1.20	8.40	3.59	15.90	14.10	16.88	16.31	9.44	1.59	0.49	0.16	7.56
Fe2O3	2.10	10.50	5.20	6.71	6.80	3.75	9.73	2.80	1.09	8.87	8.83	26.96
MnO	<0.1	0.10	0.10	0.10	0.12	0.02	0.14	X0.1	0.14	0.11	0.11	0.21
MgO	3.90	18.40	7.90	4.66	3.50	0.16	8.67	1.16	7.79	45.24	47.83	33.82
CaO	5.50	41.10	27.37	6.41	4.90	0.05	11.75	5.47	42.29	0.66	0.27	3.50
Na2O	1.20	2.40	1.80	3.07	3.10	0.06	2.52	0.89	0.11	0.02	0.00	1.13
K2O	0.30	1.40	0.71	1.81	2.30	1.39	0.05	2.58	0.65	0.00	0.00	0.01
P2O5	<0.1	0.10	0.14	0.13	0.18	0.08	0.08	0.08	0.18	0.00	0.00	0.10
Cr2O3	0.04	0.52	0.16	0.01	0.01	0.01	0.03	0.01	0.00	0.14	0.05	0.47
X: Estimated value												

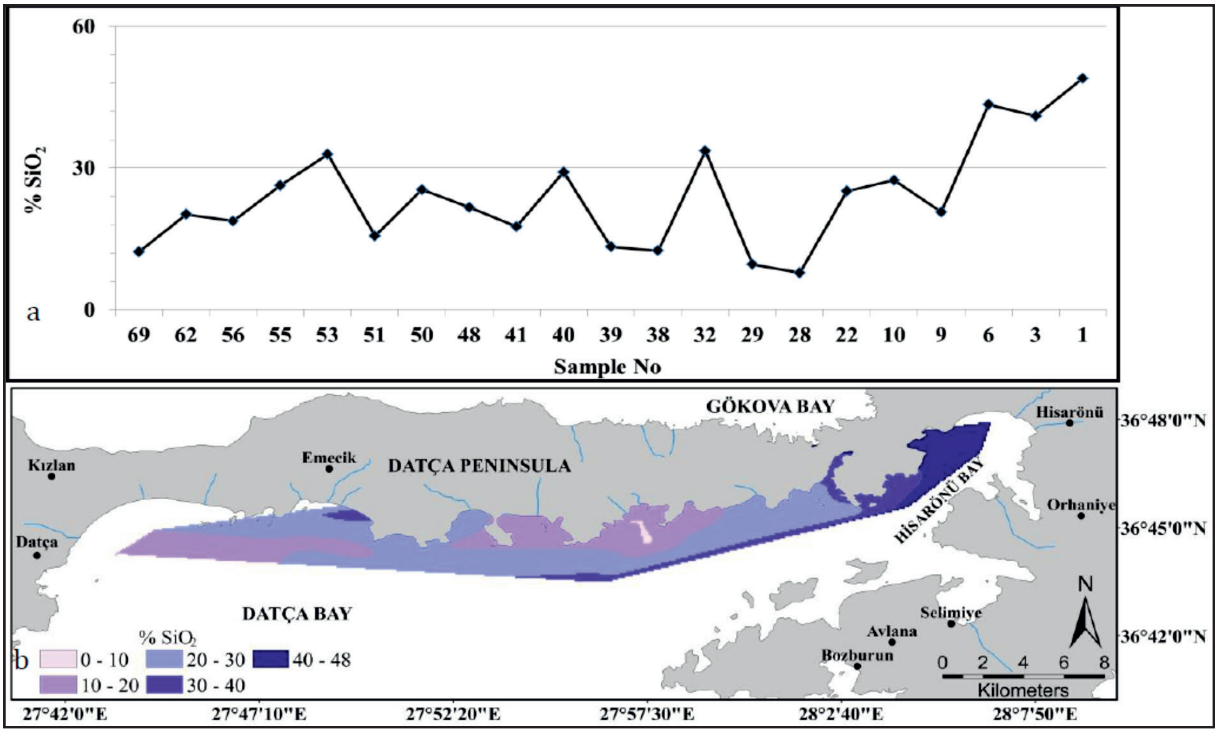

Figure 22- a) SiO_2 amounts and b) SiO_2 spatial distribution in surface sediments in Datça-Hisarönü Bays.

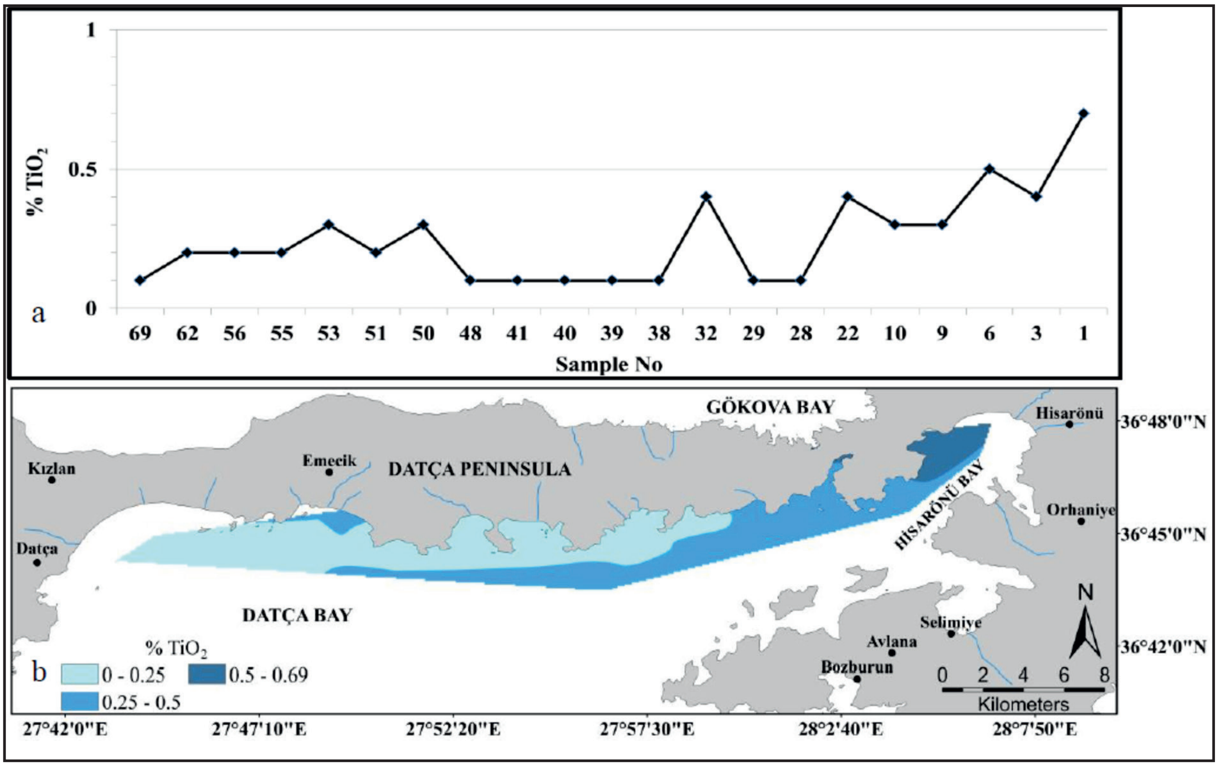

Figure 23- a) TiO_2 amounts and b) TiO_2 spatial distribution in surface sediments in Datça-Hisarönü Bays.

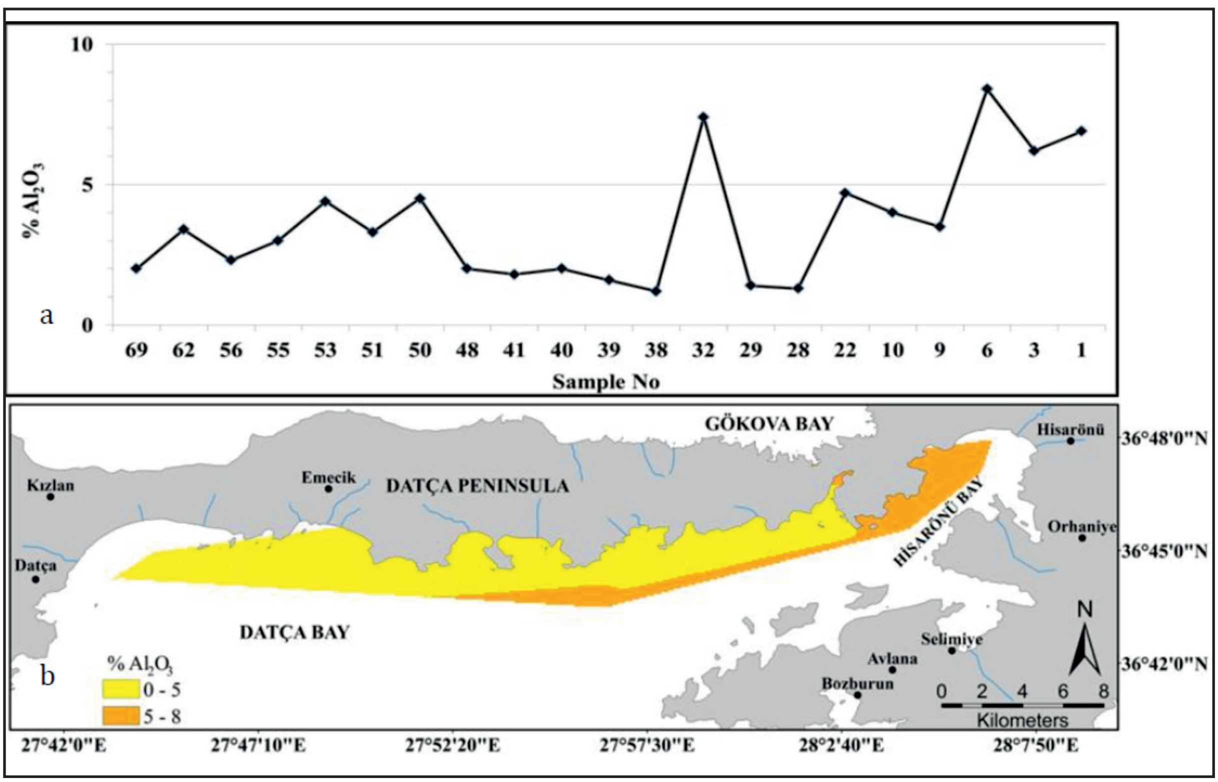

Figure 24- a) Al_2O_3 amounts and b) Al_2O_3 spatial distribution in surface sediments in Datça-Hisarönü Bays.

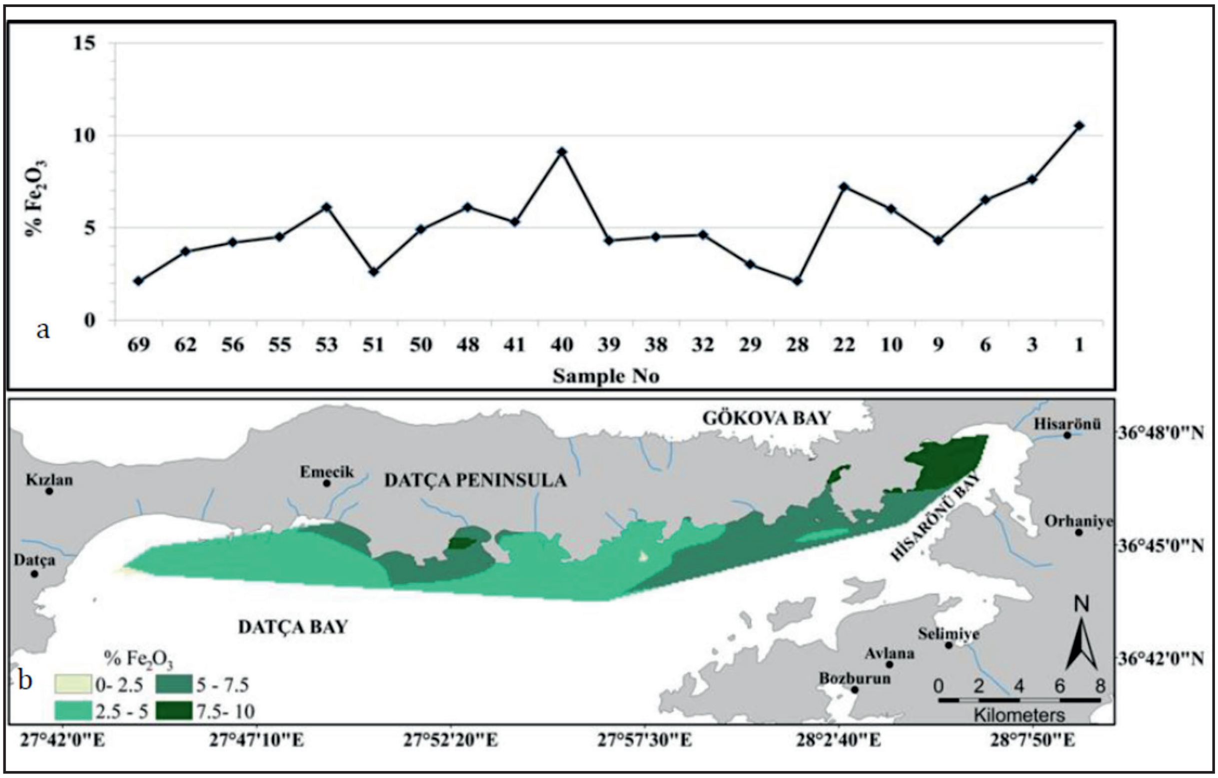

Figure 25- a) Fe_2O_3 amounts and b) Fe_2O_3 spatial distribution in surface sediments in Datça-Hisarönü Bays.

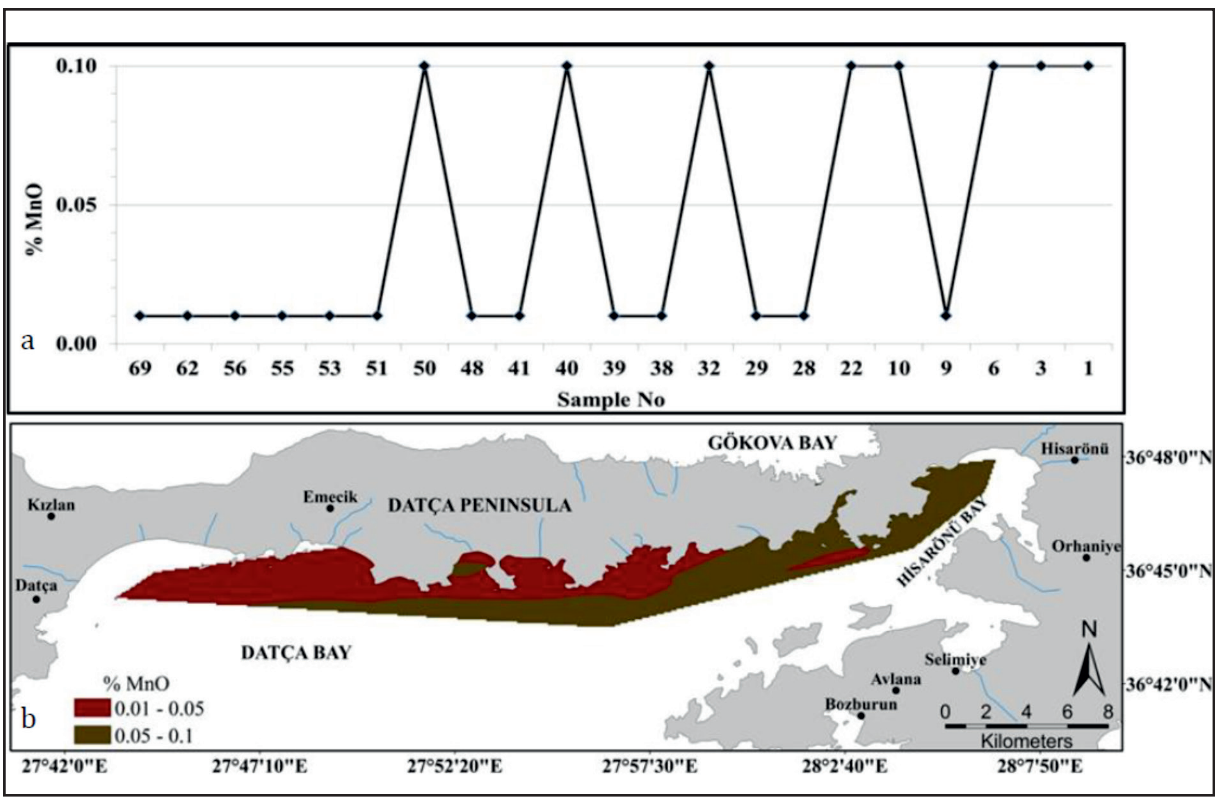

Figure 26- a) MnO amounts and b) MnO spatial distribution in surface sediments in Datça-Hisarönü Bays.

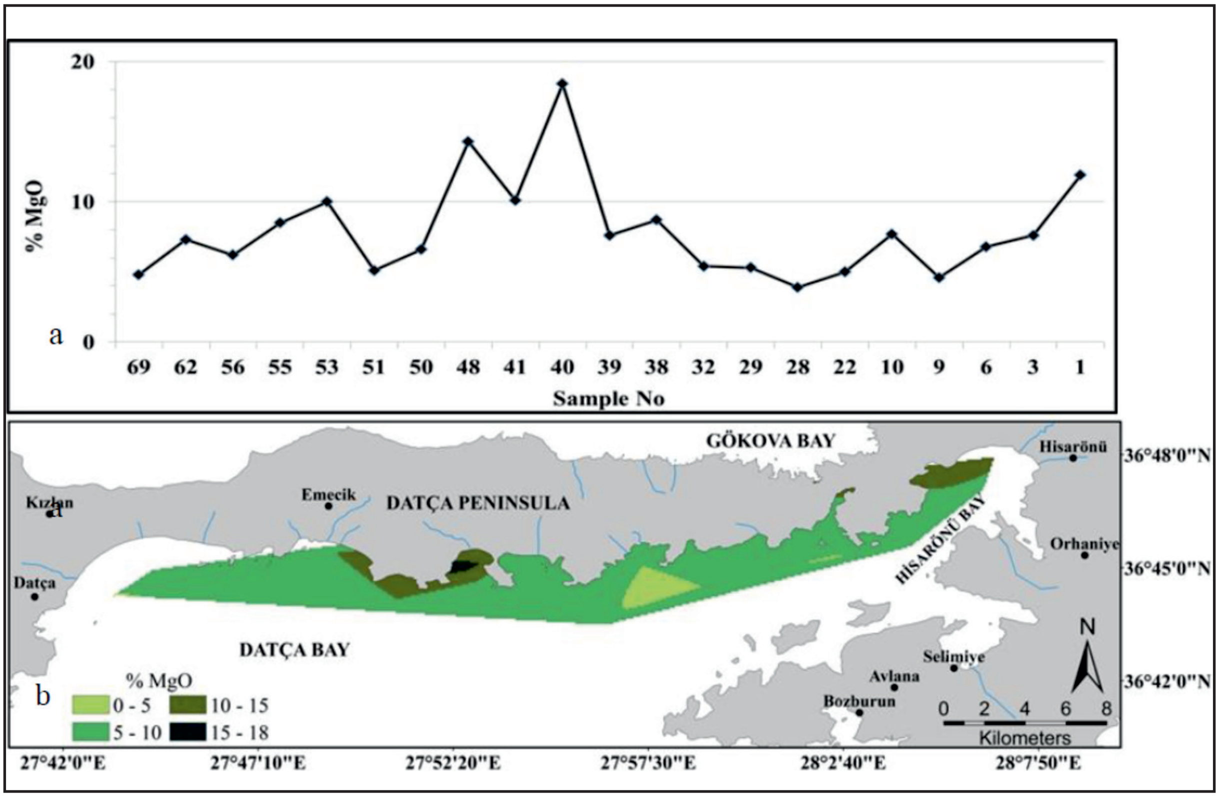

Figure 27- a) MgO amounts and b) MgO spatial distribution in surface sediments in Datça-Hisarönü Bays.

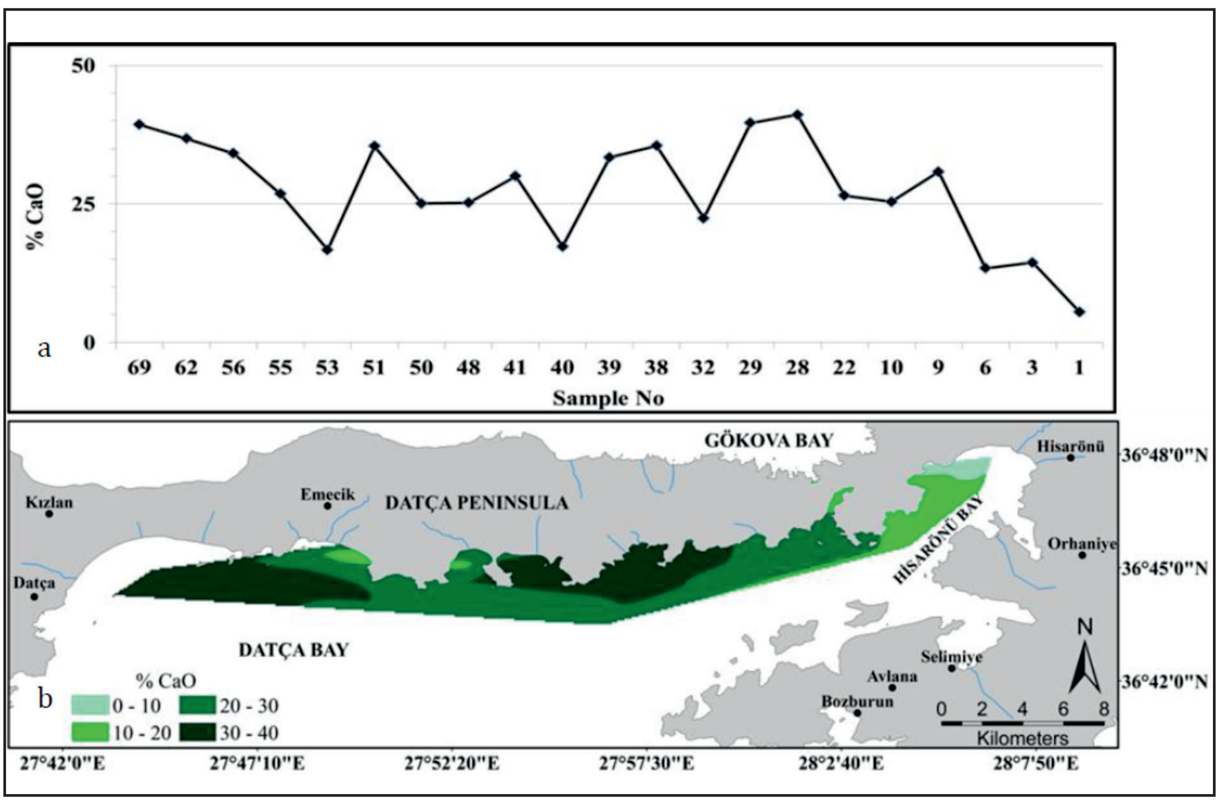

Figure 28- a) CaO amounts and b) CaO spatial distribution in surface sediments in Datça-Hisarönü Bays.

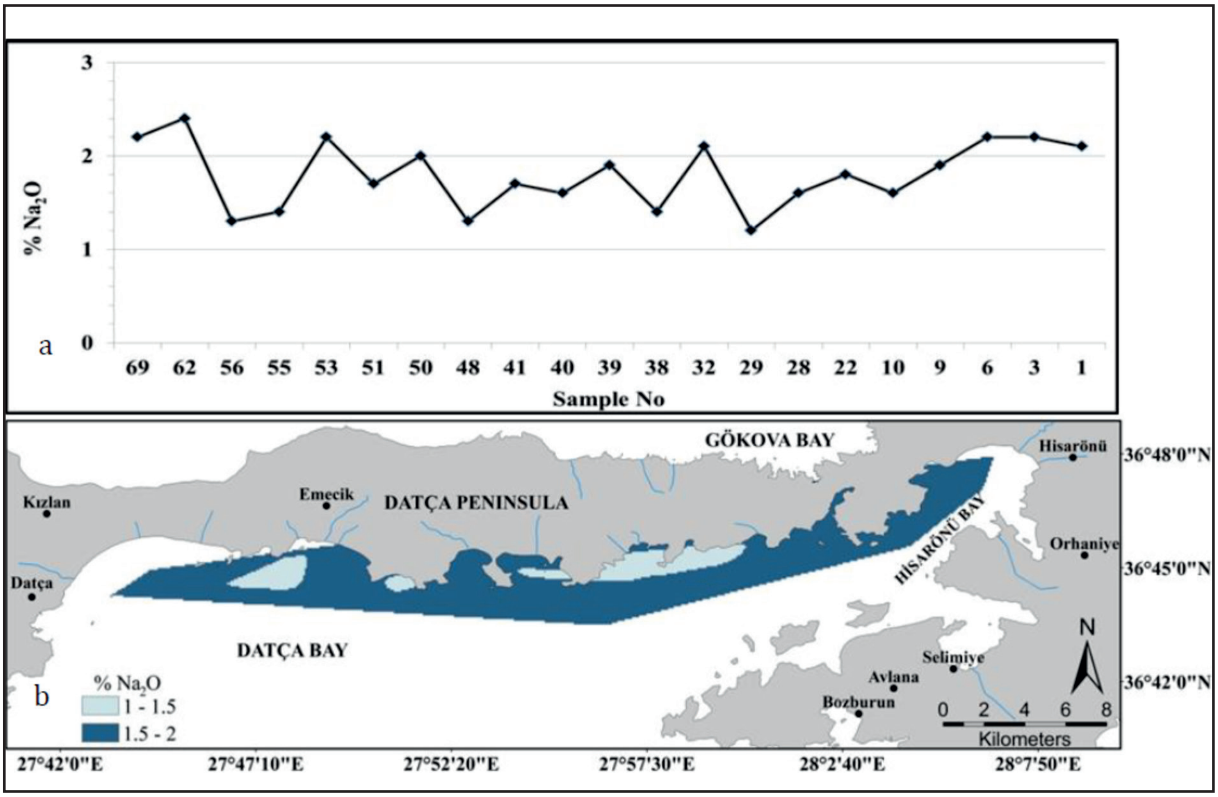

Figure 29- a) Na_2O amounts and b) Na_2O spatial distribution in surface sediments in Datça-Hisarönü Bays.

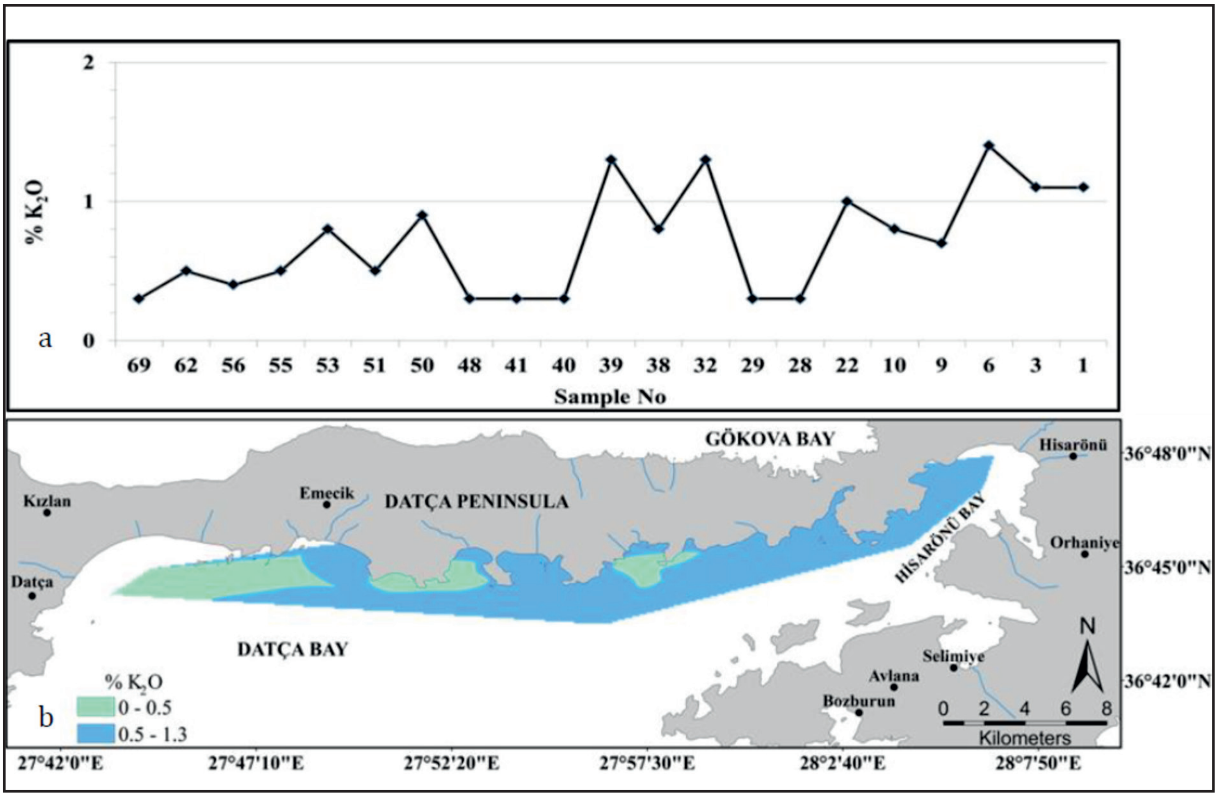

Figure 30- a) K_2O amounts and b) K_2O spatial distribution in surface sediments in Datça-Hisarönü Bays.

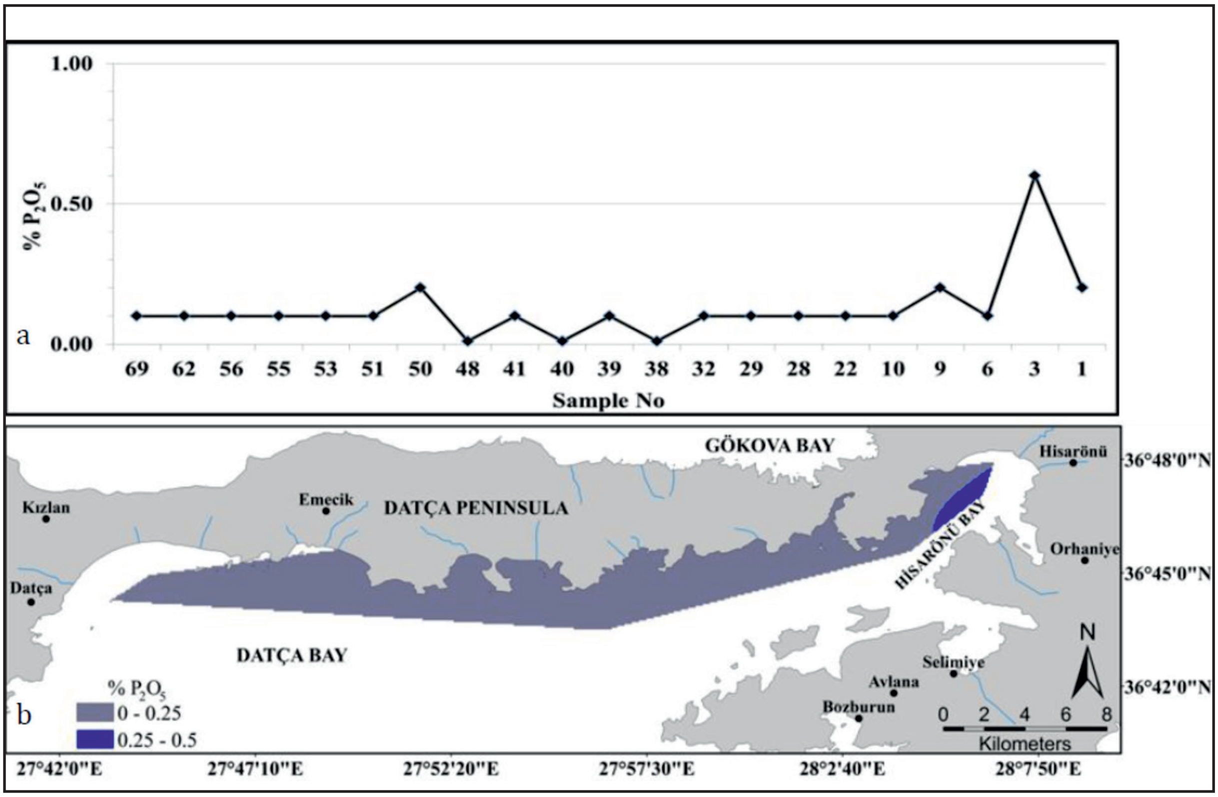

Figure 31- a) P_2O_5 amounts and b) P_2O_5 spatial distribution in surface sediments in Datça-Hisarönü Bays.

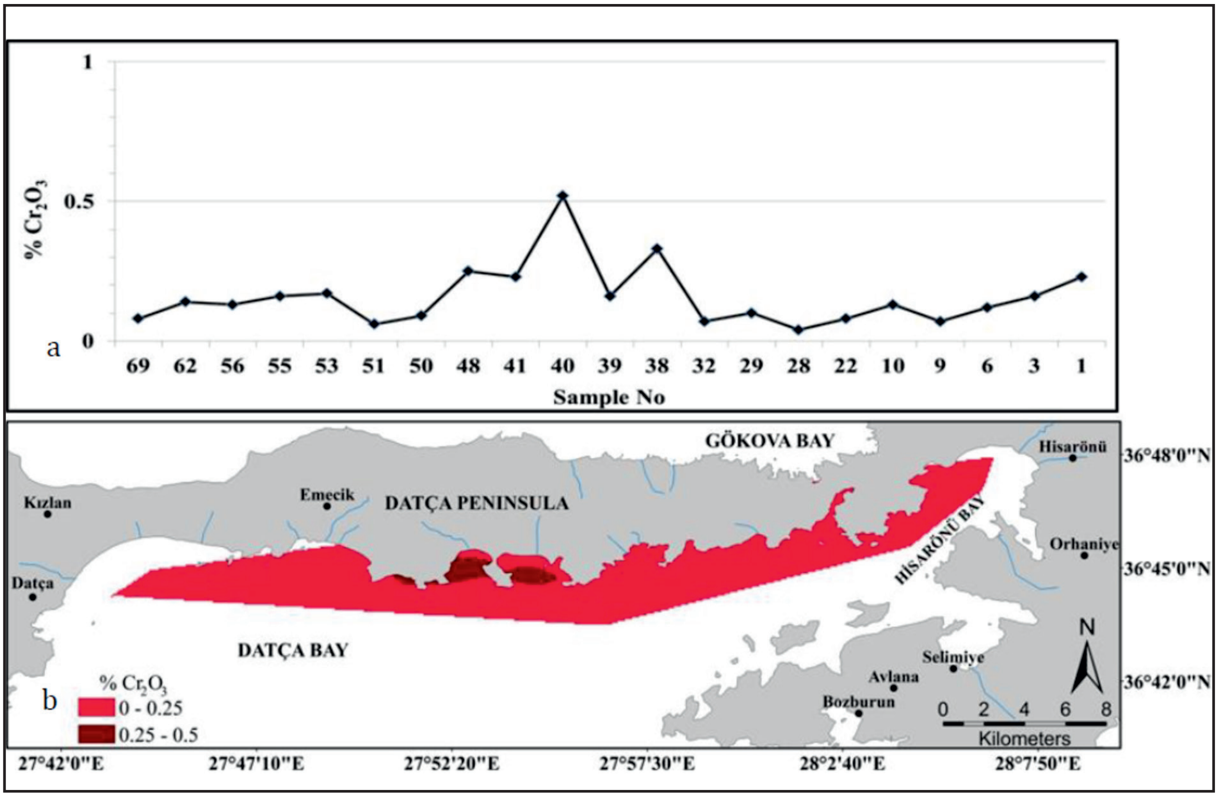

Figure 32- a) Cr_2O_3amounts and b) Cr_2O_3 spatial distribution in surface sediments in Datça-Hisarönü Bays.

Table 3- Correlation matrix for geochemical data, sand, clay and total heavy mineral amounts in surface sediments in Datça-Hisarönü Bays.

%	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	Cr_2O_3	Sand	Clay	Total Heavy Mineral
SiO_2	1.00	**0.87**	**0.86**	**0.80**	0.65	0.30	-0.95	0.42	0.68	0.37	0.17	-0.78	0.78	0.35
TiO_2		1.00	**0.90**	0.62	0.68	-0.07	-0.76	0.37	0.74	0.38	-0.17	-0.73	0.63	0.12
Al_2O_3			1.00	0.45	0.74	-0.15	-0.72	0.49	**0.82**	0.31	-0.25	-0.70	0.60	0.12
Fe_2O_3				1.00	0.52	0.66	-0.87	0.10	0.40	0.23	0.59	-0.58	0.64	0.51
MnO					1.00	0.03	-0.56	0.17	0.61	0.23	0.00	-0.49	0.38	0.14
MgO						1.00	-0.48	-0.12	-0.18	-0.17	**0.91**	-0.16	0.31	0.46
CaO							1.00	-0.41	-0.60	-0.30	-0.34	0.79	-0.81	-0.40
Na_2O								1.00	0.43	0.25	-0.17	-0.37	0.32	0.13
K_2O									1.00	0.27	-0.19	-0.63	0.55	0.16
P_2O_5										1.00	-0.20	-0.36	0.35	-0.02
Cr_2O_3											1.00	-0.01	0.17	0.65
Sand												1.00	-0.94	0.03
Clay													1.00	0.04
Total Heavy Mineral														1.00

uppermost section of the seismic profile used in this study very difficult.

According to radiocarbon age dating, the surface sediments of 30 cm thickness began to be deposited from 2694 to 14,700 years ago (BP) with sediment thicknesses from the Upper Pleistocene-Holocene boundary (11,700 BP) between 24 to 130 cm and from the Last Glacial Maximum (19,000 BP) from 39 to 212 cm in Datça and Hisarönü Bays. In other words, the scoop or surface sediment samples were generally Holocene in age. Regionally varying clastic supply, transportation and accumulation conditions are among important factors affecting deposition, ensuring sediment accumulation in different regions, at different times and thicknesses. However, it cannot be said that regional sediments are all current. The presence of different age sediments or older or relict sediments accumulating during the last glacial period and later may be interpreted.

In the study area of Datça and Hisarönü Bays with narrow and long morphology, the surface sediments covering the top 30 cm of the sea floor have grain size distribution from clay to gravel with relatively high proportions of clay and sand in sediments. Generally sand-rich areas at the coast become more clay-rich environments horizontally toward open water without clear transition. For example, regional increases in gravel and sand proportions not only occurred in high-energy shallow areas, but were found in areas close to the current shelf threshold parallel to the coast. These may be interpreted as relict deposits.

Near stream mouths in Datça Bay and in the interior section of Hisarönü Bay, the clay and silt proportions increase relatively, while increases in open water and shelf areas may indicate different sources or depositional environments. The current high clay, silt, sand and gravel proportions may indicate the presence of ancient stream channels and flood plains on the sea floor from the last glacial period. There are many factors affecting or controlling grain size of deposited clasts. Important factors controlling sediment types and distribution include varying regional climatic conditions and precipitation amounts, presence and abundance of transportation elements like rivers and ice/snow, distance from the coast and especially river mouths, morphologic properties of fluvial systems, topography of the coast and inland, underwater morphology and topography, and waves and currents along the shore and offshore (Reineck and Singh, 1975; Lewis, 1984; Leeder, 1988; Ergin et al., 1991; Ergin et al., 1998; Black and Oldman, 1999; Ergin and Bodur, 1999; Nichols, 1999; Çağatay et al., 2000; Hiscott et al., 2002; Boggs, 2006; Falco et al., 2015). Additionally there may be relict sediments carrying traces of previous deposition and last glacial/interglacial variations on the modern seafloor (Emery 1968; Falco et al., 2015). Marine regression during the last glacial period before the Holocene (19,000 years BP and up to -120 m globally) and large-grained sediments deposited in relative shallow waters are covered by fine-grained sediments belonging to the Holocene transgression (Ergin et al., 1992; 1999; Aksu et al., 1999; Algan et al., 2007). Currently in some shelf areas both large-grained (rich in sand and gravel) relicts and fine-grained (rich in clay and silt) current sediments are found together. In relatively high-energy coastal regions and river mouths, large-grained sediments like gravel and sand are deposited while in low-energy and open water areas silt and clay sediments commonly accumulate (Scruton, 1960; Kuehl et al., 1986; Jouanneau et al., 1989; Ergin et al., 1998; Owen, 2005). In short the study area does not just contain current sediments, but is covered by occasional relict sediments from the last glacial period. Another possibility affecting the grain size distribution in the study areas is the difference in rock types along the coast and inland in the region (Figure 3). South of Hisarönü Bay clastics, carbonates and volcanic are dominant, while ophiolites are more common in the north. While ophiolites have broad distribution in the east of Datça Peninsula, in the west clastics and carbonates are abundant. As fluvial systems in the area are short, high-energy with steep beds and seasonal-irregular flow, they may transport grains longer distances from the coast into open water.

The majority of sediments in the study area have total heavy mineral amounts below 2%, with relatively high values up to 13% common in Hisarönü Bay with heavy-mineral rich ophiolitic rocks along the coast. Between Datça and Hisarönü Bays and in the other two remaining coastal areas, total heavy minerals range from 5-10% which may be linked to previously-worked chrome mines inland and have been carried by streams. Beach sand rich in heavy minerals have been previously encountered along the south Mediterranean coasts (Ergin et al., 2013, Ergin, 2014). Generally, black sands containing varying proportions of chromite, magnetite and ilmenite forming heavy mineral placers are found on some sea coasts in the region and may even be worked as mines (Malik et al., 1987; Gujar et al., 2010).

In sediments accumulating distant from coasts, there are total heavy mineral amounts that are negligible which may indicate that sediments accumulating in the region are poor in heavy minerals and large grain sizes. Though there is generally no significant correlation between total heavy mineral amounts and grain size distribution in sediments, there is a relatively positive correlation between sediments with more than 2% total heavy mineral content and those rich in sand (Figure 21).

When the element geochemistry in study area sediments is compared with other geological reference data, the results indicate they are decomposition products of the rocks inland in the region (e.g., limestone, clay-mudstone, sandstone, peridotie, basalt, gabbro, serpentinite, radiolarite). Mean geochemistry for rocks forming the crust are given in works by Turekian and Wedepohl (1961), Gao et al. (1998), Klein (2005), Rudnick (2005) and Okunlola and Idowu (2012). Mean geochemical data for ophiolites near the study area indicated dunite and harzburgite in a doctoral study by Uysal (2007). These researchers' data and the values identified in this study are mainly in accordance, though amounts of elements like Fe, Mg and Cr are relatively high (Table 2). The presence of high concentrations of elements contained in ultramafic rocks like harzburgite and dunite support the values in this study.

5. Conclusion

Analyses completed on surface sediment samples collected with a scoop from the floors of Datça and Hisarönü Bays south of Datça Peninsula assessed the grain size distribution, geochemical components, total heavy mineral contents and seismic reflection profile in the region and the results are summarized below:

Datça Yarımadası güneyinde yer alan Datça ve Hisarönü Körfezlerinin tabanından kepçe ile alınan yüzeysel sediman örnekleri üzerinde gerçekleştirilen analizler ile bölgede elde edilen tane boyu dağılımları, jeokimyasal bileşimleri, toplam ağır mineral içerikleri ve sismik yansıma kesiti değerlendirilmiş ve elde edilen sonuçlar aşağıda özetlenmiştir:

The common sediment type in Datça and Hisarönü Bays is mud, with occasional contribution of sand and gravel. The age interval of sediment samples varies from 2694-14700 years (BP) and the sources are a variety of sedimentary and magmatic rocks outcropping along and behind the coasts indicating the Upper Pleistocene-Holocene period. The environmental characteristics developing linked to sea level changes during the last glacial and later period are very clear. Ancient coasts and shelf thresholds or edges are observed on the seismic profile at current water depths of -90/-120 m. Grain size distribution is significantly controlled by terrestrial and submarine morphology, fluvial drainage systems, geological source differences on land and wave and current variations. Generally low total mineral amounts of 2%, but reaching up to 13%, indicate the presence and significance of the Marmaris Ophiolite. The majority of the chemical element composition and statistical interpretation of sediments is in accordance with mean crustal rock values, with Fe, Mg and Cr amounts indicating the broad distribution of partially serpentinized peridotites. Element distribution also may be correlated with regional variations of source rocks.

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