МІНЕРАЛОГІЯ, ГЕОХІМІЯ ТА ПЕТРОГРАФІЯ

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GEOCHEMICAL CLASSIFICATION AND CHARACTERIZATION OF THE BEACH SANDS OF ABU DHABI, UNITED ARAB EMIRATES: A COMBINATION OF CLUSTER AND DISCRIMINANT ANALYSIS

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Fifty seven beach sand samples were collected along the shoreline of Abu Dhabi, United Arab Emirates (UAE). The aim of the paper is to geochemically classify and characterize the beach sediments of Abu Dhabi. Their geochemical compositions were determined, using X-ray fluorescence analysis. A combination of cluster and discriminant analysis was applied to classify and characterize the beach sand. Cluster analysis produced a dendogram with two major beach sand types namely terrigenous and marine sand types. Each sand type were further subdivided into two and was characterized through discriminant. The terrigenous sand type was subdivided into allumino-silicate characterized by SiO_2, Al_2O_3, K_2O and TiO_2 and heavy mineral-rich allumino-silicate through high content of Fe_2O_3, Cr_2O_3, MgO and MnO, while the marine sand type was subdivided into biogenic marine carbonate with high content of CaO and LOI and halite-rich biogenic carbonate marine sand types with Na_2O in addition CaO and LOI. Through stepwise discriminant analysis it was possible to identify SiO_2 and Fe_2O_3 as best discriminating geochemical variable for the four sand types by 100%.

Keywords: beach sand, shoreline, geochemical compositions, X-ray analysis.

Introduction. The composition and geochemical variation of beach sediments is controlled by numerous components and processes, including source composition, sorting, climate, relief, long shore drift, and winnowing by wave action [1, 2, 3, 7, 8, 9, 10, 11, 13].

Beaches are exposed to different marine, fluvial, and eolian processes such as wave and tidal regimes, fluvial discharges and wind transport among others factors. Furthermore, these factors control the grain-size and sand composition of the beaches in terms of mineralogy and geochemistry.

In addition, geomorphological features in the coast may also have a control in the grain-size, composition and geochemistry of beaches [14]. For instance, some beaches in protected embayments may have coarse grain sizes as result of little energy and removal of finer sizes offshore [13]. Furthermore, provenance of coastal sands may be related to different tectonic settings, as it has been documented in several papers [4, 10, 12].

Beach sands are generally composed of quartz, feldspar, other silicates, lithic fragments, and biogenic material such as shells, and are products of weathering, fragmentation and degradation.

The present study examines the geochemistry of beach sand samples collected along the coastal area Abu Dhabi (Fig. 1). The objective of this study is to classify, characterize and to infer the provenance of the beach sand.

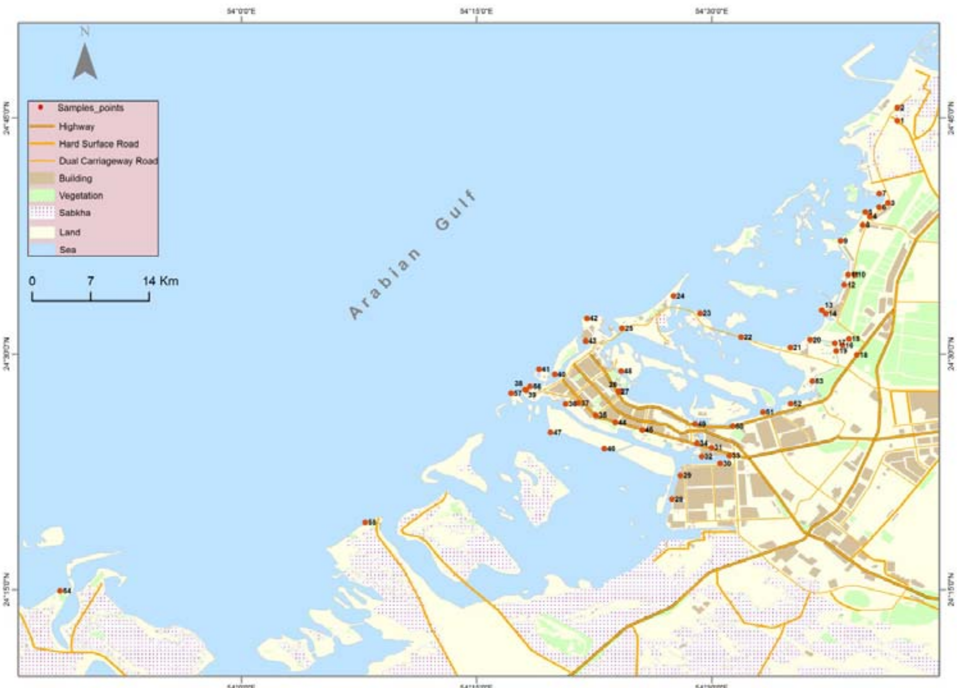

Fig. 1. Location map of sampling sites at the study area of Abu Dhabi, United Arab Emirates

1.1 Study area.

The study area is located in Abu Dhabi Emirate (state) which is the capital and the largest city in the United Arab Emirates. Abu Dhabi, accounts for 87 percent of the UAE's total area (67,340 km^2), with an estimated population of 896,751 in 2009. Abu Dhabi generated 56.7% of the GDP of the United Arab Emirates in 2008. The UAE is southwest Asia, boarding the Gulf of Oman and the Arabian Gulf, between Oman and Saudi Arabia. It is located along northern, approaching the Strait of Hormuz which is a central transit point for world crude oil. The UAE lies between 22°50′ and 26°00′ north and between 51°00′ and 56°25′ east. The climate in the UAE is hot and humid in the summer time, moderate with slight raining in the winter. The average temperature in the coastal site of Abu Dhabi Emirates is 43°C between May and September, and 14°C between October and April.

2. Material and Methods

2.1 Sampling and Analysis

2.1.1 Sampling. 57 beach sediment were collected from the study area (Fig. 1). Sampling was manually conducted from the coastal sites under the condition (10-15 cm in length and 5.5 cm in diameter). Handling the soil samples followed the 1981 EPA/CE-81-1 protocol [15]. The collected samples were taken in polyethylene bags and transported in sample container 3-4 hours after collection for various analyses.

Sample analyses were run out by the Acme Labs, Canada, and Central analytical Facilities, Stellenbosch University, South Africa.

2.1.2 XRF Analysis. Samples are crushed into a fine powder (particle size <70 μm) with a jaw crusher and milled in a tungstencarbideZibb mill prior to the preparation of a fused disc for major and trace elements analysis. The jaw crusher and mill are cleaned with clean uncontaminated quartz between 2 samples to avoid cross contamination. Glass disks were prepared for XRF analysis using 10 g of high purity trace element and Rare Earth Element-free flux ($LiBO_2$ = 32.83%, $Li_2B_4O_7$ = 66.67%, LiI = 0.50%) mixed with 1 g of the powder sample. Whole-rock major element compositions were determined by XRF spectrometry on a PANalyticalAxiosWavelength Dispersive spectrometer at the Central of Analytical Facilities, Stellenbosch University, South Africa. The spectrometer is fitted with an Rh tube and with the following ganalyzing crystals:LIF200, LIF220, PE 002, Ge 111 and PX1.

The instrument is fitted with a gas-flow proportional counter and a scintillation detector. The gas-flow proportional counter uses a 90% Argon-10% methane mixture of gas. Major elements were analyzed on a fused glass disk at 50 kV and 50 mA tube operating conditions. Matrix effects in the samples were corrected for by applying theoretical alpha factors and measured line overlap factors to the raw intensities measured with the SuperQP Analytical software. The concentration of the control standards that were used in the calibration procedures for major element analyses fit the range of concentration of the samples. Amongst these standards were NIM-G (Granite from the Council for Mineral Technology, South Africa) and BE-N (Basalt from the International Working Group).

2.1.3 Inductively Coupled Plasma (ICP) Analyses. Samples were prepared by digestion with a modified Aqua Regina solution of equal parts concentrated HCl, HNO_3, and DI H_2O, for one hour in a heating block of hot water bath. Samples were made up to volume with dilute HCl, then sample splits of 0.5 g, 15 g or 30 g were analyzed (Geochemical Aqua Regia Digestion). In addition (Lithogeochemical whole Rock Fusion) was applied to prepare sample by mixing with $LiBo_2/LiB_2O_7$ flux crucible are fused in a furnace, the cooled bead is dissolved in ACS grade nitric acid. Loss on ignition is determined by igniting a sample split then measuring the weight loss, total carbon and sulphur are determined by leco method (Group 2A). Sample analyses were run out by the Acme Labs, Canada.

Results and discussion.

Univariate statistics. The mean, standard deviation, minimum, maximum, values generated from the analysis of the 57 beach sand samples are presented in Table 1. Major elements are dominated by CaO and SiO_2 ranging between 22.81 to 50.97 and 2.66 to 48.35 in wt.%,respectively. The trace elements are dominated by Sr and Cr ranging between 560.90 to 7243.60 and 0.001 to 0.11%, respectively. The standard deviation of the beach sand geochemical composition showed that the sand in the beach area is not uniform.The variation could be attributed to difference in their sources.

Table 1

Beach sand samples from Abu Dhabi geochemical descriptive statistics

Variable	Mean	St.deviation	Minimum	Maximum
Al_2O_3	2.23	1.09	0.36	4.42
CaO	36.97	7.31	22.81	50.97
Fe_2O_3	0.89	0.42	0.22	2.15
K_2O	0.43	0.20	0.09	0.93
MgO	2.64	1.31	0.80	6.92
MnO	0.02	0.01	0.001	0.03
Na_2O	1.43	0.88	0.32	4.90
P_2O_5	0.05	0.01	0.03	0.09
SiO_2	21.23	11.09	2.66	48.36
TiO_2	0.13	0.06	0.03	0.27
L.O.I.	33.42	6.24	21.44	44.80
As	2.85	0.78	1.40	5.10
Ba	140.12	58.34	28.00	396.00
Co	4.31	2.05	0.40	12.90
Cr	272.48	182.17	0.001	752.62
Cu	4.04	1.72	1.80	13.50
Nb	2.99	1.20	0.70	6.10
Ni	29.94	22.80	3.50	118.20
Pb	2.26	1.56	0.90	10.40
Rb	14.88	5.13	3.00	24.20
Sr	2434.02	1563.41	560.90	7243.60
Th	1.37	0.50	0.20	2.50
U	2.34	0.84	1.30	4.60
V	29.05	9.53	9.00	47.00
Zn	9.00	5.79	2.00	35.00
Zr	91.14	61.86	11.60	300.10

Between the major elements significant positive correlation with Al_2O_3 was found for K_2O (0.93), MnO (0.90), SiO_2 (0.87) and TiO_2 (0.90), and significant negatively correlated with CaO (-0.88) and LOI (-0.88). CaOhass significant negative correlation with all major elements and significant positive correlation LOI.

Significant correlation was found among heavy metals, especially Ni/Co (r2=0.76), Co/Th (r2=0.61), Pb/Zn (r2=0.52), Cu/Zn (r2=0.65), Ni/Zn (r2=0.66), Th/V (r2=0.84), Nb/V (r2=0.81). Cr_2O_3 is mostly positively correlated with Fe_2O_3, MgO, Co, Nb, V, and Zr, indicating possible heavy mineral minerals and weathering of chromite enriched rocks (Table 2).

Table 2

Correlation coefficient matrix of different geochemical variables for the beach sands of Abu Dhabi

	Al_2O_3	CaO	Cr_2O_3	Fe_2O_3	K_2O	MgO	MnO	Na_2O	P_2O_5	SiO_2	TiO_2	LOI	As	Ba	Co	Cu	Nb	Ni	Pb	Rb	Sr	Th	U	V	Zn	Zr
Zr																										1
Zn																									1	0.10
V																								1	0.23	**0.55**
U																							1	**-0.40**	-0.35*	-0.22
Th																						1	**-0.44**	**0.84**	0.29*	**0.57**
Sr																					1	**-0.72**	**0.60**	**-0.70**	-0.22	-0.36*
Rb																				1	**-0.86**	**0.74**	**-0.64**	**0.73**	0.31*	0.34*
Pb																			1	0.10	-0.11	0.10	-0.20	0.02	0.52**	0.21
Ni																		1	**0.42**	0.29*	-0.18	0.17	-0.30*	0.23	**0.66**	0.03
Nb																	1	0.10	0.06	**0.69**	**-0.68**	**0.81**	**-0.42**	**0.81**	0.17	**0.72**
Cu																1	0.23	**0.58**	0.29*	0.37*	-0.28*	0.32*	-0.27*	0.31*	**0.65**	0.04
Co															1	**0.42**	**0.58**	**0.76**	0.33*	**0.59**	**-0.49**	**0.61**	**-0.47**	**0.64**	**0.47**	**0.44**
Ba														1	**0.52**	0.29*	**0.56**	0.28*	0.12	**0.82**	**-0.68**	**0.59**	**-0.59**	**0.53**	0.31*	0.29*
As													1	-0.27*	-0.22	-0.09	-0.09	-0.18	-0.18	-0.19	0.20	-0.01	0.36*	0.01	-0.17	-0.12
LOI												1	0.23	**-0.72**	**-0.46**	**-0.35**	**-0.59**	-0.21	-0.07	**-0.81**	**0.71**	**-0.61**	**0.53**	**-0.58**	0.08	**0.50**
TiO_2											1	**-0.78**	-0.03	**0.63**	**0.44**	0.17	**0.78**	-0.04	-0.08	**0.71**	**-0.71**	**0.80**	**-0.37**	**0.72**	0.08	**0.50**
SiO_2										1	**0.76**	**-0.96**	-0.19	**0.71**	**0.38**	0.31*	**0.55**	0.17	0.02	**0.80**	**-0.71**	**0.57**	**-0.54**	**0.54**	0.26	0.28*
P_2O_5									1	0.12	0.33*	-0.16	-0.30*	0.19	0.02	-0.02	0.27*	-0.26	0.03	0.16	-0.14	0.31*	-0.09	0.23	-0.03	0.22
Na_2O								1	-0.12	-0.01	0.10	0.10	0.27*	-0.02	-0.17	-0.12	-0.05	-0.22	-0.24	-0.04	0.05	0.003	0.22	0.06	-0.20	-0.16
MnO							1	0.07	0.19	**0.76**	**0.84**	**-0.81**	-0.09	**0.62**	**0.48**	0.24	**0.61**	0.11	-0.03	**0.69**	**0.60**	**0.65**	-0.31*	**0.61**	0.19	0.28*
MgO						1	**0.54**	0.01	-0.17	0.28*	0.26	**-0.36**	-0.07	0.28*	**0.55**	**0.36**	0.28*	**0.50**	0.24	0.28*	-0.19	0.20	-0.02	0.26	**0.41**	0.14
K_2O					1	0.19	**0.78**	0.22	0.16	**0.94**	**0.82**	**-0.90**	-0.08	**0.70**	0.31*	0.26	**0.54**	0.06	-0.06	**0.80**	**-0.70**	**0.62**	**-0.46**	**0.57**	0.19	0.22
Fe_2O_3				1	**0.56**	**0.82**	**0.82**	-0.09	0.03	**0.66**	**0.63**	**-0.72**	-0.14	**0.70**	0.31*	0.26	**0.54**	0.06	-0.06	**0.80**	**-0.70**	**0.62**	**-0.46**	**0.54**	0.19	0.22
Cr_2O_3			1	**0.72**	0.26	**0.59**	**0.48**	-0.27*	0.07	**0.44**	**0.48**	**-0.50**	-0.23	**0.35**	**0.65**	0.21	**0.58**	**0.39**	**0.41**	**0.38**	**-0.39**	**0.43**	-0.30*	**0.47**	0.22	**0.65**
CaO		1	**-0.46**	**-0.74**	**-0.93**	**-0.47**	**-0.81**	-0.20	-0.07	**-0.94**	**-0.78**	**0.92**	0.10	**-0.71**	**-0.46**	**-0.38**	**-0.55**	-0.26	-0.03	**-0.78**	**0.66**	**-0.59**	**0.44**	**-0.58**	-0.32*	-0.26
Al_2O_3	1	-0,88	0.31*	0.67	0.93	0.30*	**0.90**	0.16	0.23	**0.87**	**0.90**	**-0.88**	-0.05	**0.69**	**0.37**	0.27*	**0.63**	0.03	-0.09	**0.78**	**-0.71**	**0.70**	**-0.39**	**0.65**	0.16	0.22

CaO is positively correlated with LOI, Sr, U and As, while it is negatively correlated almost all the major, minor and trace elements, thus pointing that strontium, uranium and arsenic originate from the sea and not from the continent.

The combination of cluster and discriminant analysis was used in order to classify and characterise beach sand into geochemically homogenous groups. Cluster analysis was used to classify the beach sand, while discriminant analysis was used to characterise and differentiate the groups created through cluster analysis.

Cluster analysis (CA) was used to group the similar sampling sites (spatial variability) and to identify areas of similar geochemical composition or contamination [5, 6, 16, 18, 19, 20].

Hierarchical agglomerative cluster analysis was performed on major rock-forming elements using Ward's method with Euclidean distances as a measure of similarity. The results was presented as a dendrogram (Fig. 2) where all fifty-seven beach sand samples were grouped into four groups.

To geochemically characterise and differentiate the four beach sand groups created through hierarchical cluster analysis a linear discriminant analysis techniques was used. The maximum number of discriminant functions is either one less than the number of groups or equal to the number of the predictor variables. A three-group discriminant function was computed using the major rock-forming elements (Table 3 and 4).

As for the interpretation the combination Tables 3 and 4 were used to pinpoint geochemical elements that characterise each of the beach sand type. Function one, highly positive correlated with SiO_2, K_2O, Al_2O_3 and TiO_2 and negatively correlated with LOI and CaO, separated terrigenous from biogenic marine beach sand. Beach sand 4 and 1 are characterised by high SiO_2, K_2O, Al_2O_3 and TiO_2 indicating a terrigenous source, while beach sand 2 and 3 are enriched with LOI and CaO, identifying biogenic marine carbonate. Function two highly positively correlated with Fe_2O_3, Cr_2O_3, MgO and MnO, categorize sand type four for an ophiolite source for this sand type differentiate it from sand type two as silico-feldspathic group. Function three separate sand type three from the other three sand type as halite.

Table 3

Three discriminant group function Structure Matrix

	Function		
	1	2	3
SiO_2	.747*	.426	-.066
L.O.I	-.671*	-.102	.625
CaO	-.552*	-.038	-.044
K_2O	.492*	.342	.158
Al_2O_3	.405*	-.054	.038
TiO_2	.279*	-.218	.145
Fe_2O_3	.291	-.648*	-.039
Cr_2O_3	.139	-.493*	-.109
MgO	.100	-.457*	-.027
MnO	.302	-.306*	.057
P_2O_5	.010	.004	-.417*
Na_2O	.004	.162	.397*

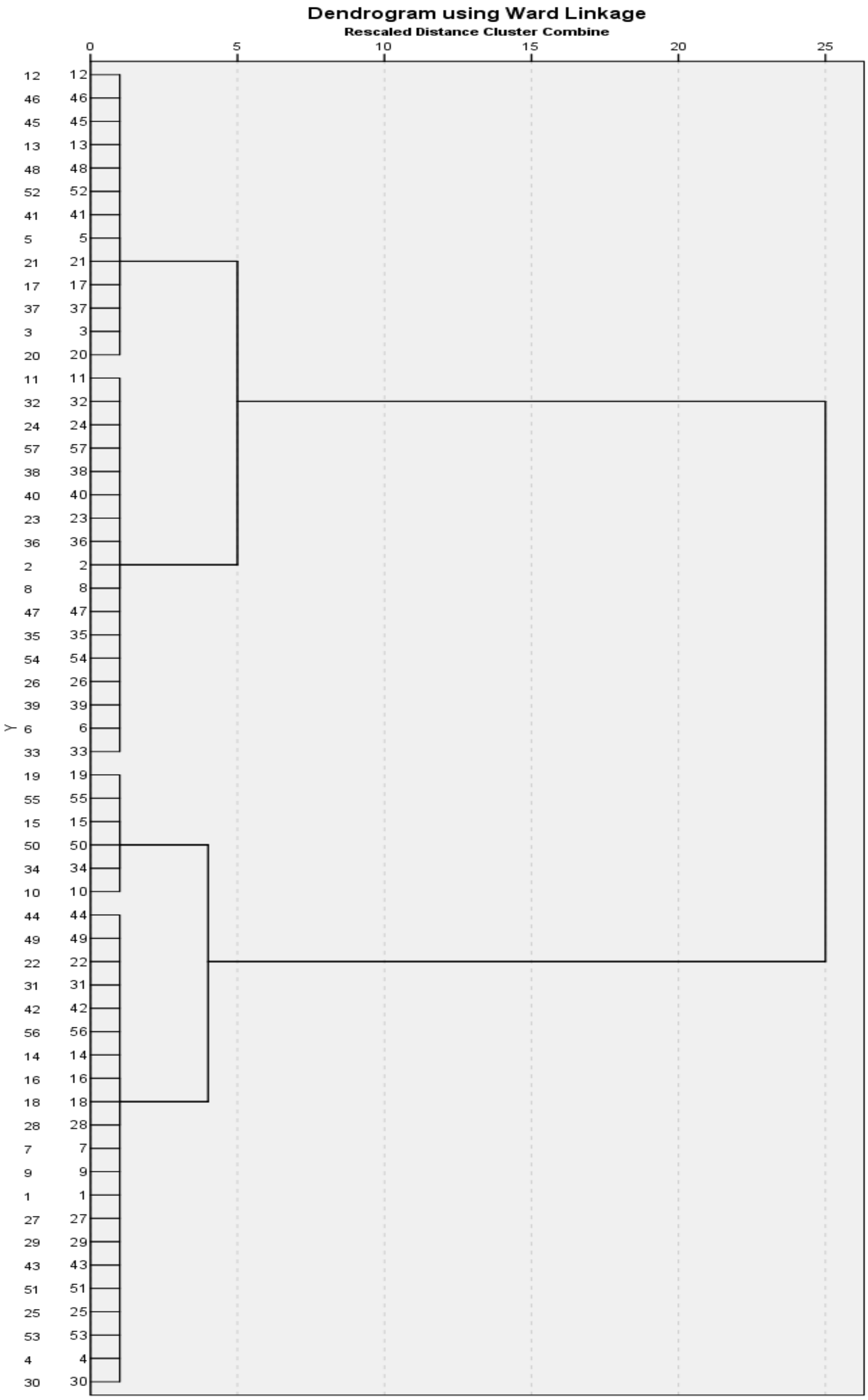

Fig. 2. Dendrogram showing cluster result for the beach sand of Abu Dhabi, United Arab Emirates

Table 4

Function at group centroid
Functions at Group Centroids

Beach sand types	Function			Name of the Sample
	1	2	3	
1	3.184	-.807	-.227	1, 4, 7, 9, 14, 16, 18, 22, 25, 27, 28, 29, 30, 31, 42, 43, 44, 49, 51, 53 and 56
2	-6.065	.406	-.321	2, 6, 11, 23, 24, 26, 32, 33, 35, 36, 38, 39, 40, 54 and 57
3	-1.189	-.123	.661	3, 5, 8, 12, 13, 17, 20, 21, 37, 41, 45, 46, 47, 48 and 52
4	6.991	2.115	-.053	10, 15, 19, 34, 50 and 55

The Table 5 provides element concentrations for the different sand types.

Beach sand groups classified through cluster analysis are correctly by 100%. Fig. 3 below is a discriminant plot representing the first two discriminant functions for the beach sand of Abu Dhabi. Unstandardized canonical discriminant functions evaluated at group means.

Since the direct discriminant function method does not show the importance of the individual geochemical variables for the description of classified groups, or their importance in the classification itself, a stepwise discriminant method should be considered [17]. In this method variables are selected through a statistical test to determine the order in which they are entered or removed into the analysis. At each step the element which yielded the best classification was entered.

In this SiO_2 and Fe_2O_3 were the best discriminating geochemical variables, separating the four beach sand up to 100% as shown Fig. 4

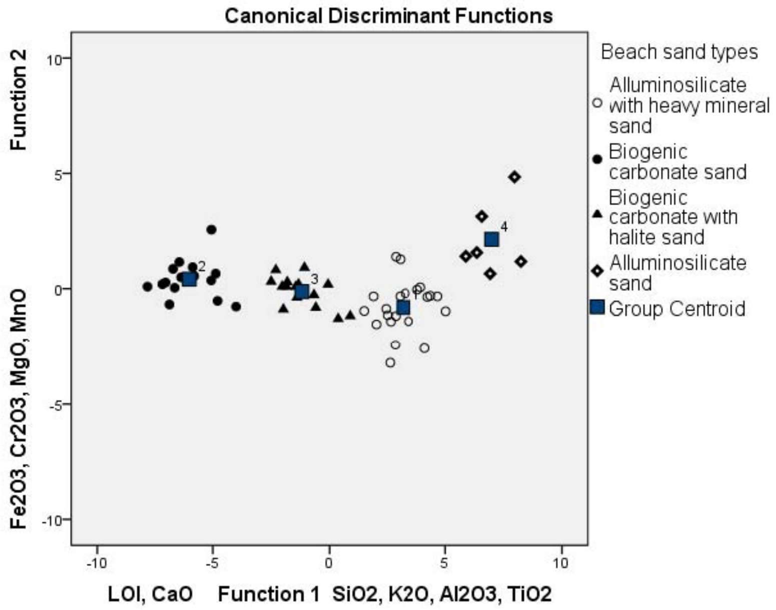

Fig. 3. Two-function discriminant plot showing the abundance of elements in each beach sand type

Table 5

The element concentrations for the different sand types .

	silico-feldspathic sand with heavy minerals (1)	Biogenic marine Carbonate sand (2)	Biogenic marine Carbonate with Halite sand (3)	silico-feldspathic sand (4)
Al_2O_3	2.94	0.90	1.99	3.68
CaO	32.16	46.18	38.74	25.94
Cr_2O_3	0.06	0.02	0.04	0.04
Fe_2O_3	1.24	0.41	0.81	1.05
K_2O	0.53	0.19	0.38	0.78
MgO	3.43	1.79	2.55	2.33
MnO	0.02	0.004	0.01	0.03
Na_2O	1.25	1.40	1.64	1.74
P_2O_5	0.05	0.05	0.05	0.05
SiO_2	27.84	7.33	18.06	40.98
TiO_2	0.17	0.07	0.12	0.18
L.O.I	29.02	41.08	35.87	23.52
Ba	163.57	86.64	132.60	220.33
Co	5.70	3.11	3.79	4.22
Nb	3.63	1.95	2.98	3.57
Rb	17.71	9.44	14.35	20.95
Sr	1621.29	3967.18	2449.83	924.80
Th	1.64	0.97	1.33	1.60
U	2.04	3.01	2.44	1.55
V	34.95	21.93	28.00	31.00
Zr	105.93	70.46	88.67	107.00
Y	7.65	4.28	6.47	7.62
Mo	0.94	0.87	0.82	0.50
Cu	4.92	3.35	3.62	3.97
Pb	2.80	2.27	1.69	1.97
Zn	10.91	6.93	8.40	9.50
Ni	39.20	24.29	25.17	27.03
As	2.74	2.99	3.11	2.45

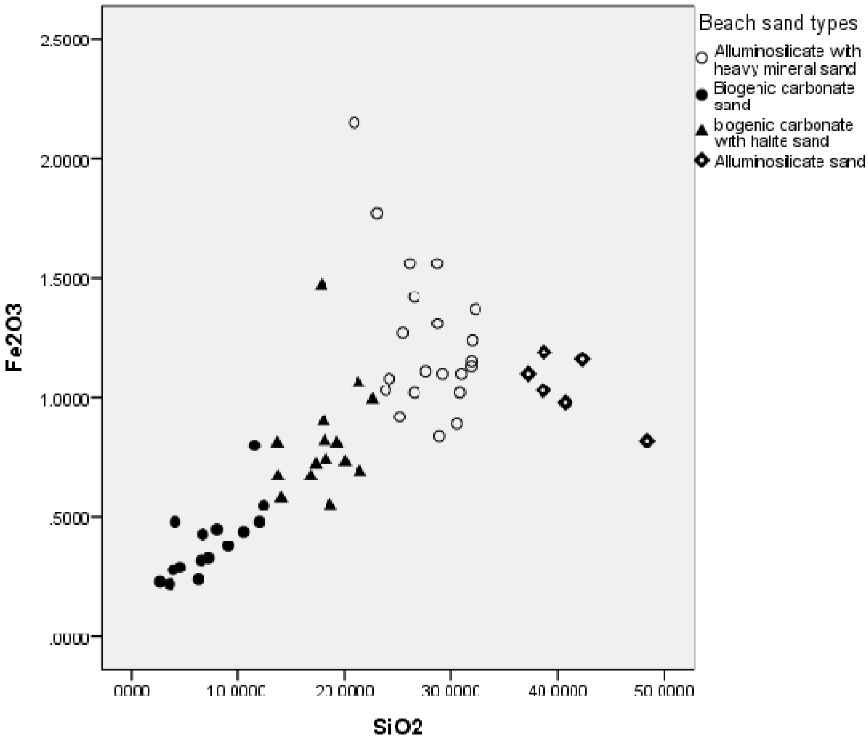

Fig. 4. Scatterplot of SiO_2 and Fe_2O_3

Conclusion. The determination of beach sand type of Abu Dhabi using combination of cluster and discriminant analysis shows that the beach sands are from either terrigenous or marine sources as indicated by dendogram produced cluster analysis. Each of the two sand types can be further classified into two. Linear discriminant analysis was used to geochemically characterise each of the four sand types. The terrigenous sand can be subdivided into allumino-silicate characterised by SiO_2, Al_2O_3, K_2O and TiO_2 and heavy mineral-rich allumino-silicate with high content of Fe_2O_3, Cr_2O_3, MgO and MnO. The biogenic marine beach sand can be subdivided into carbonate-rich identified with their high content of CAO and LOI, and halite-rich marine sand with high content of Na_2O.

Through stepwise discriminant analysis it was possible to identify that SiO_2 and Fe_2O_3 are best discriminating geochemical variables up to 100%. A scatterplot of these two variables was also produced.

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ГЕОХІМІЧНА КЛАСИФІКАЦІЯ ТА ХАРАКТЕРИСТИКА ПЛЯЖНИХ ПІСКІВ АБУ ДАБІ, ОБ'ЄДНАНІ АРАБСЬКІ ЕМІРАТИ: ПОЄДНАННЯ КЛАСТЕРНОГО ТА ДИСКРИМІНАНТНОГО АНАЛІЗІВ

Стаття присвячена аналізу хімічного складу піску на пляжах Абу-Дабі. В процесі роботи п'ятдесят сім зразків із піщаних пляжів було відібрано вздовж берегової лінії Абу-Дабі, Об'єднані Арабські Емірати (ОАЕ). Їхній геохімічний склад було визначено із використанням рентгенівського флуоресценцтного аналізу. Поєднання кластерного та дискримінантного аналізів було застосовано для класифікації та визначення характерних ознак піщаних пляжів. Кластерний аналіз проведено з використанням дендрограм, визначено два основні типии піщаних пляжів, а саме з теригенним і морським піском. Кожен тип піску було додатково поділено на два класи й охарактеризовано через дискримінанти. Теригенний тип піску поділено на алюмосилікат, який характеризується вмістом SiO_2, Al_2O_3, K_2O і TiO_2, і важкий пісок, багатий на мінерали силікату з високим вмістом Fe_2O_3, Cr_2O_3, MgO і MnO. Морський тип піску поділяється на біогенно-морський карбонатний з високим вмістом CaO і LOI, а також пісок, багатий на біогенні морські карбонати з Na_2O, на додачу до CaO і LOI. За допомогою ступінчастого дискримінантного аналізу визначено, що SiO_2 і Fe_2O_3 є основними геохімічними змінними для класифікації чотирьох типів піску.

Ключові слова: пляжні піски, узбережжя, геохімічний склад, рентгенівський аналіз

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ГЕОХИМИЧЕСКАЯ КЛАССИФИКАЦИЯ И ХАРАКТЕРИСТИКА ПЛЯЖНОГО ПЕСКА АБУ ДАБИ, ОБЪЕДИНЕННЫЕ АРАБСКИЕ ЭМИРАТЫ: СОЧЕТАНИЕ КЛАСТЕРНОГО И ДИСКРИМИНАНТНОГО АНАЛИЗА

Статья посвящена анализу химического состава песка на пляжах Абу-Даби. В процессе работы пятьдесят семь образцов были отобраны с песчаных пляжей вдоль береговой линии Абу-Даби, Объединенные Арабские Эмираты (ОАЭ). Их геохимический состав был определен с использованием рентгеновского флюоресценцтного анализа. Сочетание кластерного и дискриминантного анализа было применено для классификации и определения характерных черт песчаных пляжей. Кластерный анализ проведен с использованием дендрограмм, определены два основных типа песчаных пляжей, а именно с терригенным и морским песком. Каждый тип песка был дополнительно подразделен на два класса и охарактеризован посредством дискриминанты. Терригенный тип песка подразделяется на алюмосиликат, который характеризуется содержанием SiO_2, Al_2O_3, K_2O и TiO_2, и тяжелый песок, богатый силикатными минералами с высоким содержанием Fe_2O_3, Cr_2O_3, MgO и MnO. Морской тип песка подразделяется на биогенно-морской карбонатный с высоким содержанием CaO и LOI, а также песок, богатый биогенными морскими карбонатами с Na_2O, дополнительно к CaO и LOI. С помощью ступенчатого дискриминантного анализа определено, что SiO_2 и Fe_2O_3 являются основными геохимическими переменными для классификации четырех типов песка.

Ключевые слова: пляжные пески, побережье, геохимический состав, рентгеновский анализ.