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Article

Major and trace element compositions of sands from pocket beaches in western Yamaguchi Prefecture, Japan

Bah Mamadou Lamine Malick*, Erika Sano* and Hiroaki Ishiga*

Abstract

Beach sands were collected from ten beaches on the western coast of Yamaguchi Prefecture. The average length of the beaches was 1.13 km. Half of the beaches are less than 1 km in length, indicating the domination of pocket beaches in the area. X-ray fluorescence major and trace element analyses were made of 27 samples, to estimate the composition of the sands at each site. The sands can be divided into three types (silicate, carbonate and mixed sands), based on their geochemical composition. The silicate sands were rich in SiO_2, and consist mainly of quartz and feldspar, whereas carbonate sands had high CaO contents and LOI values due to significant contents of shell material. Compositions of mixed sands were intermediate between these two extremes, containing both silicate and carbonate sand.

Key words: Yamaguchi Prefecture, sand beach, silicate, carbonates

Introduction

Sandy beaches are regions of transition between the shore and the sea, and are subjected to significant influences from both ecosystems. These regions are exposed to sharp variations in the length of sun exposure, immersion and submersion, amount of rainfall and concentration of nutrients. The study of sand beach in Yamaguchi is pertinent due to extensive artificial coastline protection by seawalls, concrete tetrapods, and port constructions. Many such infrastructural elements are found around pocket beaches on the western shoreline of Yamaguchi Prefecture, where beaches may be only a few meters wide, and are delimited by bluffs, cliffs, roads, buildings, and other structures.

The object of this study is to characterize the major and trace element compositions of Yamaguchi beach sands, categorize the different types of beaches and sand present, and outline some of the relationships between abundances of elements in sand samples from the 27 sites investigated in this study.

Previous work on the composition of beach sands has been carried out at several sites around the San'in region, including the coastline of Tottori (Bah *et al.,* 2011; this volume) and in Shimane Prefecture. In the latter, Ishiga *et al.* (2010) examined characteristics of pocket beaches in the western San'in coast of southwest Japan, and evaluated the geochemical maturity of the beach sand.

Study Area and Geological Setting

Yamaguchi Prefecture is the westernmost prefecture on Honshu, and is one is of the principal parts of southwest Japan. It is surrounded on three sides by the sea. The Chogoku mountain range runs from east to west, separating the Seto Inland Sea from the Sea of Japan coast. Yamaguchi Prefecture enjoys a mild climate, and is not greatly affected by earthquake, flood and storm damage. The present study was conducted along the western part of the Japan Sea coast. This part of Yamaguchi Prefecture is situated between latitudes 34°21'19.11" North and 34°00'12.75" East, and longitude 130°50'39.45" East and 130°55'57.45" East (Fig. 1). The following descriptions of the Toyonishi and Kanmon Groups in these areas are based mainly on the compilations made by Hase (1960) and Matsumoto *et al*. (0982).

Toyonishi Group

In the north of Shimonoseki city at the western end of Chugoku, the Toyonishi Group is considered to range from uppermost Jurassic to lowermost Cretaceous in age (Hase, 1960). It lies on the Jurassic Utano Formation. The Toyonishi Group is essentially composed of clastic sedimentary rocks, including thick basalt conglomerates (200 m). It is divided into the lower Kiyosue Formation (200 m), which contains some plant fossils and rare molluscan fossils, and the upper Yoshimo Formation (500 m to 700 m), containing brackish or lacustrine molluscs. The Toyonishi Group contains a large amount of effusive volcanic material.

Kanmon Group

The Kanmon Group (Hase, 1958) is distributed in northern Kyushu and western Honshu (Fig. 1), and has been assigned to the late Valanginian to the early Albian, based on isotopic ages and paleomagnetic anomaly data of Mesozoic igneous rocks (Matsumoto *et al*., 1982; Sur *et al*., 2002). Although separated in many parts by overlying Tertiary and Quaternary deposits and Late Cretaceous granites, the Kanmon Group is distributed more extensively than the

* Department of Geoscience, Shimane University, Matsue 690-8504, Japan

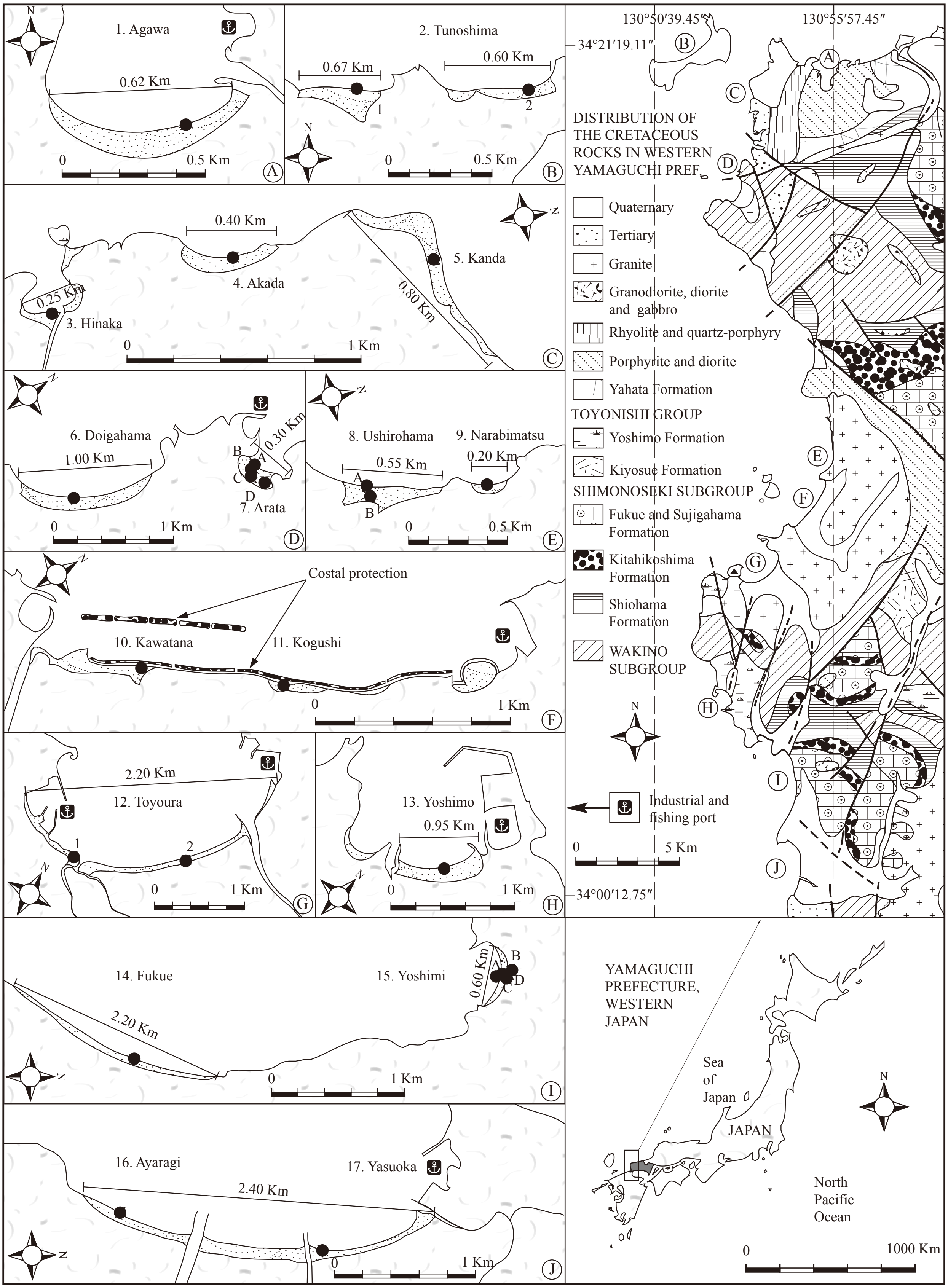

Fig. 1: Geological map of western Yamaguchi Prefecture showing the distribution of Cretaceous rocks, location of beaches sampled, and beach shapes and sample locations. Base geology from Hase (1958).

Toyonishi Group. The Kanmon group is divided into the lower Wakino Subgroup, consisting mainly of lacustrine clastic sediments, and the overlying Shimonoseki Subgroup, which contains a large volume of volcanic effusives.

The Wakino Subgroup reaches 1300 m in thickness, and has been correlated with the late Valanginian to Barremian, based on fossil data (Ota*,* 1960). It consists mainly of black shales with some conglomerates, red to purple shales, and acid tuffs, and contains abundant freshwater mollusk fossils, suggesting a lacustrine environment (Ota, 1960; Sur *et al*., 2002). The subgroup rests upon various Mesozoic and Paleozoic formations.

The Shimonoseki Subgroup is about 3,000 m thick, and disconformably overlies the Wakino Subgroup, while unconformably overlying older basement rocks. The Shimonoseki Subgroup is composed of conglomerates, sandstones, shales, tuffs, tuff breccias, and andesite, dacite, and rhyolite lavas (Horiuchi *et al.,* 2009). The Shimonoseki Subgroup is further subdivided into the Shiohama, Kitahikoshima, and Sujigahama Formations (from oldest to youngest), based on lithologic features and planes of disconformities (Ueda, 1957; Hase, 1960; Sur *et al*., 2002).

Beach profile

Beaches are environments where loose sediments such as sand, gravel and cobbles are regulated by oceanic processes. Beaches from western Yamaguchi exhibit a variety of characteristics. Fig. 2 shows a typical beach profile from shoreface to dune, although few beaches in the area have such complete profiles. The first part is the offshore bar, which protects beaches from erosion. Next is the foreshore, the part of the seashore which slopes from the low tide mark toward the crest of the berm. Finally, sand dunes may form in the backshore environment due to wind action.

Fields Sampling and Analytical Methods

Ten sand beaches were selected for sampling, based on accessibility and the character of the beach shape (Fig. 1). Selection of sampling sites was made using 1/25,000 topographic maps (Topographic map of Japan, revised edition, 1979). Each beach represented a different geomorphic setting, including sand grain size and beach slope. The coastline of western Yamaguchi Prefecture consists of granular material made up of fine rock particles and small remains of animals and plants (Fig. 3). In a few places like Kawatana and Kogushi (Fig. 1), the beaches are bounded by sea walls or other structures (coastal protection) meant to reduce erosion rates. Samples could not be taken at some of the intended sites due to the extent of artificial coastline protection in the area. Samples were collected from the shore surface, and the location from which the samples were obtained, date of collection and the type of sand (inshore, foreshore or backshore) recorded. Beach widths were measured using a linen tape, and beach slope measured with an inclinometer. In total 27 samples were collected on January 27th and 28th, 2011. The samples were stored in their natural state in the laboratory before further processing.

Approximately 50 g of each sample were placed in pyrex beakers and dried in an oven at 110°C for 24 hours. The dried samples were crushed using an automatic agate pestle and mortar system. The crushed samples were then used to make pressed pellets and fused glass discs for trace and major element analysis, respectively.

Pressed pellets were made from the powdered samples, using plastic rings (40 mm diameter) in an automatic pellet press by applying a force of 200 kN for about one minute.

For the preparation of the fused glass discs, about 10g of crushed sample was stored in glass vials and dried at 110°C for at least 24 hours before determining the loss on ignition (LOI). The LOI determinations were made by transferring about 5 g of dried sample to previously weighed porcelain crucibles, and the overall weight recorded. The samples were then ignited in a muffle furnace for two hours at 1050°C. The power of the furnace was then turned off to allow the crucibles to cool. The crucibles were held in desiccators until they were close to ambient temperature, and then reweighed. Total loss on ignition (total volatile loss, and weight gain by oxidation) was then calculated from the net weight loss.

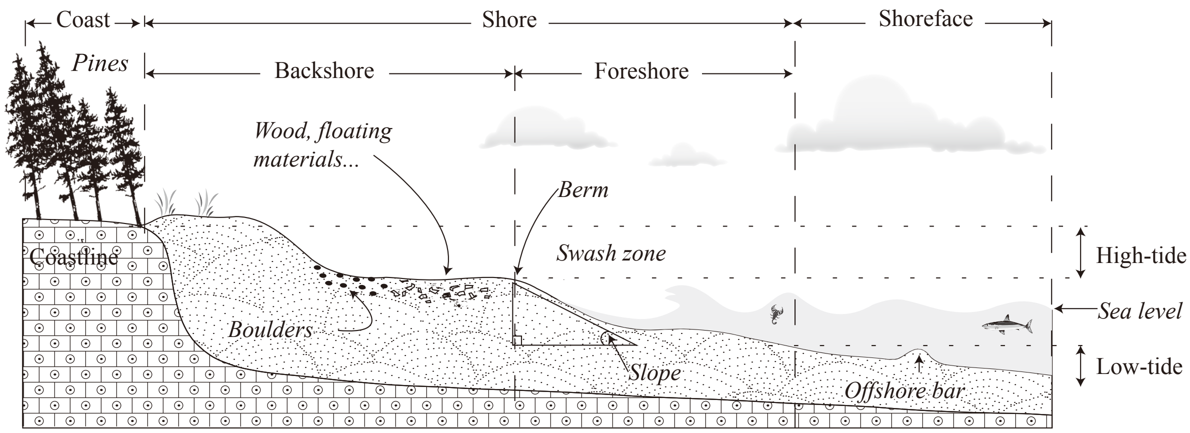

Fig. 2: Ideal beach profile (Emery, 1965).

The ignited materials were then manually disaggregated in an agate pestle and mortar, returned to glass vial, and returned to a 110°C oven for 24 hours. Fused glass discs were prepared using the 2:1 method (Kimura and Yamada, 1996). For fused glass disc preparation about 1.8g of sands sample and 3.6g of flux were put into an agate mortar. The mixture was thoroughly mixed, and then transferred to a platinum crucible for glass fusion bead preparation. The mixture was then fused using an automatic fusion machine with preset fusion parameters.

The XRF analyses were made at Shimane University using an automated RIX 2000 system (Rigaku Denki Co. Ltd.). The ten major elements (SiO_2, TiO_2, Al_2O_3, Fe_2O_3*, MnO, MgO, CaO, Na_2O, K_2O, and P_2O_5) were obtained by analysis of the fused glass discs, and eighteen trace elements (As, Pb, Zn, Cu, Ni, Cr, V, Sr, Y, Nb, Zr, Th, Sc, F, Br, I, Cl, and TS) were obtained by the pressed pellet method (Ogasawara, 1987).

Results and Discussion

Beach characteristics

The beaches investigated here can be classified into long, pocket, or convex beaches according to the characteristics of their shapes using the length (L), the arc length (ℓ), the radius of the approximated circle and radian (ℓ/r) of the beach. Radian values (arc length of the beach/radius; ℓ/r) more than one (> 1) characterize small and concave beaches (Ishiga *et al*., 2010). The average length of all the beaches investigated is 1.13 km, and eight have ℓ/r > 1 (Table 1). Generally, small-pocket beaches are formed between headlands, and are composed of sand and floating material such as algae, and provide isolated habitats for a variety of plants and animals.

Chemical composition

Major and trace element concentrations of sands from the sites investigated are listed in Table 2. These can be divided into three groups based on their composition, namely silicate sands, carbonate sands, and mixed sands.

Silicate sands

Sand samples from Toyoura, Kawatana, Kugushi, Ushirohama, Narabimatsu, Yasuoka, Ayaragi, Yoshimi and Fukue typically consist of silicate minerals such as quartz and feldspar (Fig. 3i, 3j, 3k, 3l, 3m, 3o, 3p, 3q, and 3r). The high SiO_2 contents of these samples (73.73-92.16 wt%; average 85.01 wt%, Table 2) are due to the abundance of quartz. Al_2O_3 abundances are also relatively high (9.50-2.27 wt%, average 5.83 wt%). CaO contents overall are significant (average 4.85 wt%) and show a considerable range, from 0.77 to 11.87 wt%. Similar average (4.05 wt%) and range (1.30-8.96 wt%) for LOI indicate the presence of significant $CaCO_3$ as shell material. K_2O and Na_2O, also likely to be contained within feldspar, are less abundant, averaging 2.43 and 1.17 wt%, respectively. Three major elements (Fe_2O_3, TiO_2 and MgO), are present only in minor amounts (average 1.14, 0.39 and 0.29 wt%, respectively), and P_2O_5 and MnO are present only in trace amounts (average 0.03 and 0.05 wt%, respectively).

Chlorine is the most abundant trace element in the silicate sands, averaging almost 6900 ppm, with a maximum of over 26000 ppm (Table 3). It is followed by total sulfur (TS), which averages 980 ppm (range 422-1577 ppm), and Sr (average 232 ppm, range 44-447 ppm). Average concentrations of all other trace elements except fluorine (129 ppm) are less than 100 ppm, reflecting the high SiO_2 contents and marked quartz dilution in this suite of sediments.

Fig. 4f and 4j respectively show high correlations between SiO_2/CaO and SiO_2/LOI. Silicate or siliciclastic sands are defined as sands consisting of grains that originated as clasts or fragments of silicate rocks. They thus typically consist of silicate minerals, such as quartz, feldspars and micas. The high SiO_2, and significant CaO, Na_2O and Al_2O_3 contents indicate that most of these constituents are quartz and plagioclase feldspar, although relatively high K_2O contents (Fig. 4h) also suggest the presence of significant contents of K-feldspar and K-bearing micas. According to correlation analysis, there is strong linear correlation between Nb and Zr, between Nb and TiO_2, between Cr and Fe_2O_3, and between Cr and Zr, respectively (Fig. 5b, 5d, 5g and 5h); these elements are thought to have the same origin.

Carbonate sands

Sand samples from Doigahama, Hinaka, and Akada consist of carbonate or biogenic sands, which are mainly composed of coral, algae, crustacean skeletons, and shells (Fig. 3d, 3e, and 3g). Foraminifer shells, coccoliths, pteropod shells, and corals consist of calcium carbonate ($CaCO_3$) or aragonite.

The XRF results show that the carbonate sands have high LOI values (Table 2), which reflect the amount of $CaCO_3$ present. The carbonate sand contains small amounts of SiO_2,

Table 1: Pocket beaches from western Yamaguchi Prefecture, Japan: shape and characteristics; length of the beach (L), radius (r) and arc length of the beach (ℓ).

Sites	L (km)	r (km)	ℓ (km)	ℓ/r
Toyoura	2.20	1.20	3.00	2.50
Ayaragi + Yasuoka	2.40	2.60	2.50	0.96
Yoshimi	0.60	0.25	0.50	2.00
Fukue	2.20	3.10	2.00	0.65
Doigahama	1.00	1.00	1.20	1.20
Hinaka	0.25	0.20	0.35	1.75
Akada	0.40	0.27	0.55	2.04
Tunoshima	0.67	0.72	0.72	1.00
Agawa	0.62	0.35	0.92	2.63
Yoshimo	0.95	0.52	0.62	1.19
Average	1.13	1.02	1.24	1.59

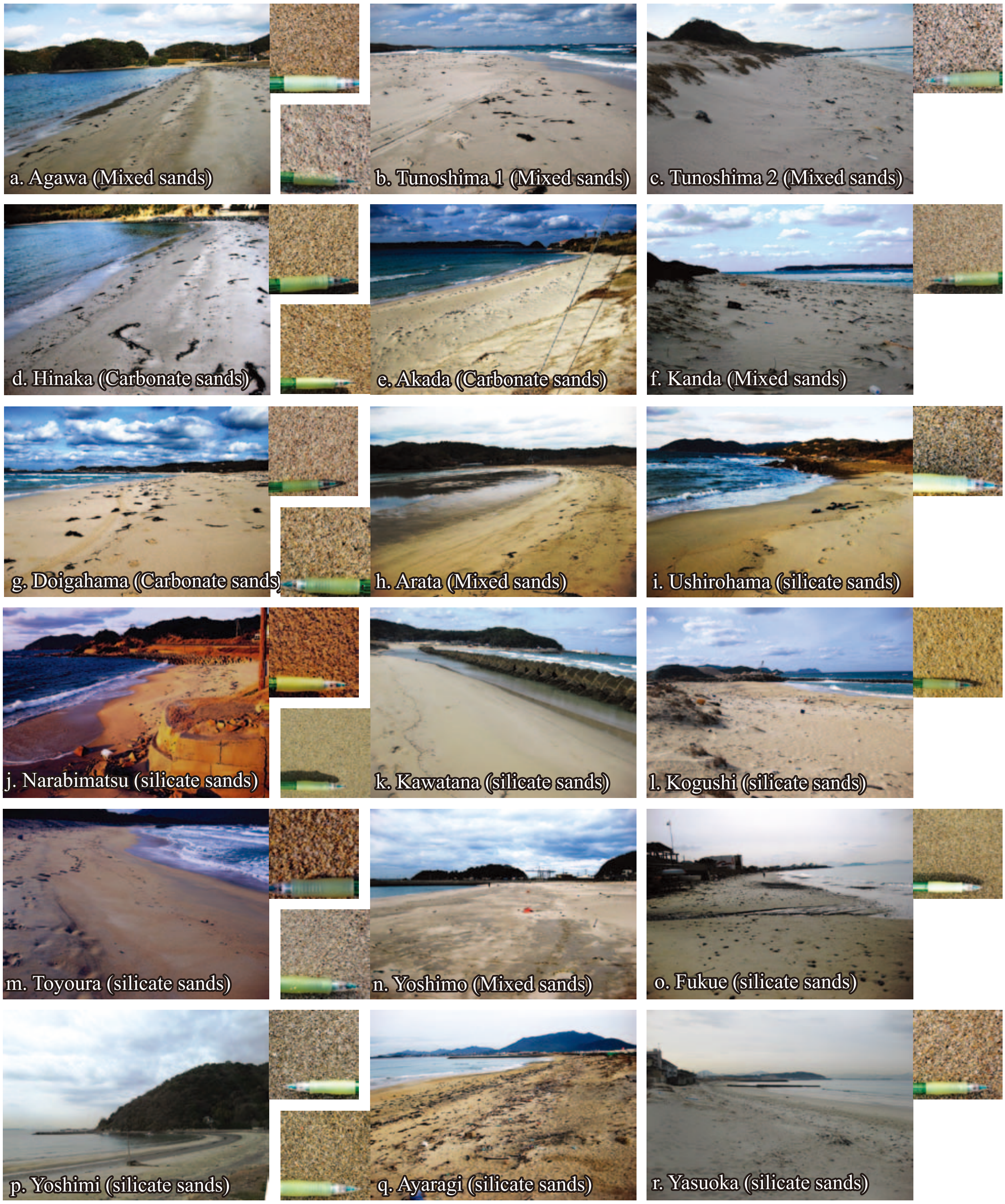

Fig. 3: Photographs of types of beaches found in the western part of Yamaguchi, Japan.

Table 2: X-ray fluorescence analyses of beach sands from western Yamaguchi Prefecture, Japan. Major elements (wt%), trace elements (ppm). Type of sand: (Blank) = Inshore, (*) = Foreshore and (**) = Backshore.

	Major elements (wt %)										wt%	wt%	Trace elements (ppm)																	
Sample	SiO_2	TiO_2	Al_2O_3	$Fe_2O_3^*$	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	Total	LOI	As	Pb	Zn	Cu	TS	Ni	Cr	V	Sr	Y	Nb	Zr	Th	Sc	F	Br	I	Cl
Silicate sand (*n* = 14)																														
Toyoura 1	84.52	0.05	6.84	0.52	0.01	0.21	3.04	1.51	3.27	0.02	99.99	2.80	7	17	12	2	745	6	18	–	155	18	1	55	3	1	–	11	32	3480
Toyoura 2	84.00	0.03	7.79	0.36	0.01	0.13	2.27	1.11	4.29	0.02	100.01	2.15	7	18	5	1	499	5	10	–	110	24	0	50	3	1	235	5	30	–
Kawatana	73.73	0.09	9.50	0.77	0.02	0.46	9.02	1.97	4.40	0.03	99.99	7.18	5	18	16	3	1113	1	11	–	386	23	2	73	5	8	–	11	21	4804
Kogushi	84.42	0.09	7.14	0.01	0.20	0.20	3.14	1.39	3.39	0.01	99.99	2.75	4	17	15	1	735	3	18	–	150	20	1	63	5	3	–	11	26	10049
Ushirohama A*	84.68	0.04	7.25	0.38	0.01	0.17	2.43	1.24	3.79	0.01	100.00	2.68	5	17	8	1	980	5	18	–	120	21	1	53	3	1	115	14	30	6568
Ushirohama B**	89.28	0.03	5.63	0.33	0.01	0.11	0.77	0.94	2.88	0.01	99.99	1.56	5	14	7	1	422	5	15	–	85	19	1	51	3	–	114	4	31	–
Narabimatsu	87.89	0.05	5.94	0.36	0.01	0.10	1.74	0.83	3.07	0.01	100.00	1.30	3	16	8	13	744	8	13	–	44	18	0	41	4	–	116	12	35	40
Yasuoka	81.64	0.22	4.85	1.25	0.02	0.60	8.16	1.44	1.78	0.05	100.01	6.52	7	14	32	5	1414	5	32	–	335	12	1	77	2	10	–	9	22	26640
Ayaragi	88.90	0.11	4.28	0.79	0.02	0.29	2.95	0.90	1.73	0.02	99.99	2.93	6	12	18	2	1010	9	19	–	142	11	1	55	2	4	–	14	36	7541
Yoshimi A	87.24	0.32	3.41	1.42	0.03	0.44	5.62	0.86	0.62	0.04	100.00	4.67	4	12	27	4	1061	8	40	3	255	7	2	79	2	6	76	12	27	6361
Yoshim B*	87.07	0.31	3.72	1.39	0.03	0.45	5.38	0.97	0.64	0.04	100.00	4.59	5	11	26	2	1031	9	37	3	258	8	2	78	2	8	137	11	28	5297
Yoshimi C*	80.54	0.90	4.49	2.66	0.04	0.66	8.86	0.94	0.85	0.05	99.99	6.79	6	11	34	5	1212	6	59	43	383	9	5	144	3	13	124	8	16	3748
Yoshimi D**	76.95	0.76	4.90	2.51	0.04	0.83	11.87	1.14	0.93	0.06	99.99	8.96	6	12	34	4	1577	7	50	28	477	10	4	103	2	14	11	11	19	6211
Fukue	92.16	0.38	2.27	1.61	0.03	0.29	2.60	0.30	0.34	0.02	100.00	1.86	4	11	15	3	561	5	32	14	97	6	2	73	2	1	128	5	34	–
Carbonate sand (*n* = 3)																														
Doigahama	4.72	0.06	0.65	0.45	0.03	4.93	87.37	1.31	0.35	0.12	99.99	41.12	1	7	1	4	5557	–	5	–	1348	7	–	–	–	39	62	15	–	18114
Hinaka	18.90	0.18	3.43	1.79	0.05	4.11	68.69	1.89	0.83	0.14	100.01	35.49	5	7	16	5	4023	–	8	–	1336	10	–	–	1	35	89	13	–	54231
Akada	21.36	0.11	2.62	0.98	0.03	3.50	68.71	1.69	0.85	0.14	99.99	35.01	4	8	6	4	4693	–	16	–	1358	8	–	–	–	38	96	15	–	180
Mixed sand (*n* = 10)																														
Arata	57.40	0.23	5.73	1.64	0.03	1.47	29.85	1.77	1.81	0.09	100.02	19.35	7	11	23	3	2517	–	10	–	954	12	–	–	1	24	78	14	–	11784
Arata A	32.29	0.18	3.90	1.66	0.04	3.14	55.41	1.94	1.33	0.13	100.02	29.15	6	10	20	6	4735	–	20	–	1197	13	–	–	2	37	274	12	–	9163
Arata B*	43.88	0.18	4.39	1.53	0.04	2.47	44.25	1.69	1.45	0.11	99.99	26.21	6	9	20	5	3917	–	12	–	1083	12	–	–	2	33	–	18	–	17912
Arata C*	28.29	0.16	3.71	1.69	0.04	3.59	59.23	1.99	1.16	0.14	100.00	32.35	6	9	20	6	4518	–	7	–	1238	12	–	–	2	37	89	20	–	46472
Arata D**	56.58	0.19	5.94	1.68	0.03	1.55	30.47	1.63	1.83	0.10	100.00	19.39	7	10	24	4	30	–	16	–	970	12	–	–	2	26	14	16	–	21873
Kanda	31.39	0.14	2.73	0.99	0.02	2.76	59.35	1.40	1.05	0.16	99.99	23.66	4	8	8	3	4106	–	10	–	1354	8	–	–	0	37	145	14	–	13222
Tunoshima 1	46.62	0.11	2.01	0.67	0.02	1.23	47.69	0.86	0.65	0.12	99.98	26.44	2	8	5	4	3817	–	8	–	1254	5	–	–	1	33	24	9	–	8941
Tunoshima 2	37.30	0.24	3.03	1.35	0.03	1.46	54.86	0.97	0.63	0.13	100.00	28.82	2	7	8	5	3645	–	13	–	1316	5	–	–	1	35	181	9	–	6715
Agawa	48.29	0.19	5.01	1.77	0.03	1.83	39.92	1.33	1.51	0.12	100.00	24.08	9	9	19	6	2789	–	9	–	1143	11	–	–	2	30	–	10	–	5094
Yoshimo	42.39	0.20	3.83	1.40	0.04	2.31	47.17	1.51	1.01	0.13	99.99	26.23	3	9	20	3	3652	6	16	–	1213	9	–	–	1	33	55	8	–	8016

Table 3: Summary statistics of major element abundances in the silica, carbonate, and mixed sands. STDEV = standard deviation.

	Anhydrous										Hydrous
	SiO_2	TiO_2	Al_2O_3	Fe_2O_3*	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI
Silicate sand (n = 14)											
Average	85.01	0.29	5.83	1.14	0.05	0.39	5.32	1.17	2.43	0.03	4.38
Maximun	92.16	0.90	9.50	2.66	0.20	0.83	11.87	1.97	4.40	0.06	8.96
Minimum	73.73	0.03	2.27	0.01	0.01	0.10	0.77	0.30	0.34	0.01	1.30
STDEV	4.99	0.28	1.96	0.82	0.05	0.23	3.38	0.39	1.46	0.02	2.43
Carbonate sand (n = 3)											
Average	14.21	0.12	2.16	1.09	0.04	4.19	76.17	1.62	0.64	0.13	37.55
Maximun	21.36	0.18	3.43	1.79	0.05	4.93	87.37	1.89	0.85	0.14	41.12
Minimum	4.72	0.06	0.65	0.45	0.03	3.50	68.69	1.31	0.35	0.12	35.01
STDEV	8.98	0.06	1.43	0.68	0.01	0.72	10.78	0.29	0.28	0.01	3.39
Mixed sand (n = 10)											
Average	42.51	0.18	4.02	1.40	0.03	2.22	46.45	1.49	1.24	0.12	25.61
Maximun	57.40	0.24	5.94	1.77	0.04	3.59	59.35	1.99	1.83	0.16	32.35
Minimum	28.29	0.11	2.01	0.67	0.02	1.23	29.85	0.86	0.63	0.09	19.35
STDEV	10.16	0.04	1.27	0.35	0.01	0.80	10.85	0.38	0.42	0.02	4.13

Table 4: Summary statistics of trace element abundances in the silica, carbonate, and mixed sands. STDEV = standard deviation.

	As	Pb	Zn	Cu	TS	Ni	Cr	V	Sr	Y	Nb	Zr	Th	Sc	F	Br	I	Cl
Silicate sand (n = 14)																		
Average	5	14	19	4	979	6	29	22	232	15	2	76	3	7	129	10	28	8948
Maximun	7	18	34	13	1577	9	59	43	477	24	5	144	5	14	235	14	36	26640
Minimum	3	11	5	1	422	1	10	3	44	6	0	41	2	1	11	4	16	40
STDEV	1	3	10	3	338	2	16	17	135	6	1	27	1	5	59	3	6	6888
Carbonate sand (n = 3)																		
Average	3	7	8	4	4771	–	10	–	1347	9	–	–	1	38	81	14	–	25387
Maximun	5	8	16	5	5557	–	16	–	1358	10	–	–	1	39	96	15	–	54231
Minimum	1	7	1	4	4023	–	5	–	1336	7	–	–	1	35	62	13	–	180
STDEV	2	1	8	1	769	–	6	–	11	2	–	–		2	18	1	–	27531
Mixed sand (n = 10)																		
Average	5	9	16	4	3208	6	12	–	1169	10	–	–	1	32	115	13	–	16730
Maximun	9	11	24	6	4735	6	20	–	1354	13	–	–	2	37	274	20	–	46472
Minimum	2	7	5	3	30	6	7	–	954	5	–	–	0	24	14	8	–	5094
STDEV	2	1	7	1	1358	–	4	–	135	3	–	–	1	5	88	4	–	12229

Al_2O_3, and Fe_2O_3, whereas CaO and LOI (hydrous) account for over 65% and 35% respectively. As the carbonate sands are characterized by high CaO contents (68.69-87.37 wt% on an anhydrous basis) and LOI values (35.01-41.12 wt%; hydrous basis), the abundances of SiO_2 are less than 22 wt%. Nevertheless, MgO contents of the carbonate sands are relatively high (3.50-4.93 wt%; average 4.19 wt%). Al_2O_3 contents are moderate (0.65-3.43 wt%; average 2.16 wt%). Among other elements, Na_2O is more abundant than K_2O, presumably because of the presence of marine NaCl.

Trace elements such as Ni, V, Nb, I, and Zr were not detected in this group (Table 4). Chlorine, TS and Sr are the most abundant trace elements, with averages of 24174, 4771 and 1347 ppm respectively.

Mixed sands

Sand samples from the beaches at Arata, Kanda, Tunoshima, Agawa and Yoshimo are mixtures of silica and carbonate grains (Fig. 3a, 3b, 3c, 3f, 3h, and 3n). The XRF results show that contents of SiO_2 (28.29-57.40 wt%) and CaO (29.85-59.35 wt%) are approximately equal overall (Table 3). Consequently, LOI values are moderate (average 25.57 wt%) compared to the carbonate sand. Al_2O_3 contents range from 2.01 to 5.90 wt%, and on average lie between those of the silica and carbonate sands. TiO_2, Fe_2O_3, MgO and Na_2O are present in small amounts.

As in the carbonate sands, Ni, V, Nb, I, and Zr were not detected in this group, and Cl and Sr are the most abundant trace elements (Table 4) with averages of 16730 and 1169 ppm respectively. Among the remainder TS (3208 ppm, range 30-4735 ppm), F (115 ppm, range 14-274 ppm), are the next most abundant on average. Scandium (average 32 ppm), Zn (average 16 ppm), Br (average 13 ppm), Cr (average 12 ppm) and Y (average 10 ppm) are present in small amounts, whereas Pb, Ni, As, Cu and Th (all averaging less than 10 ppm) are present only in trace amounts. In figure 5f, decrease of Sr with increased Al_2O_3 in the mixed sands suggests that Sr abundance is controlled by $CaCO_3$ content, rather than by feldspart.

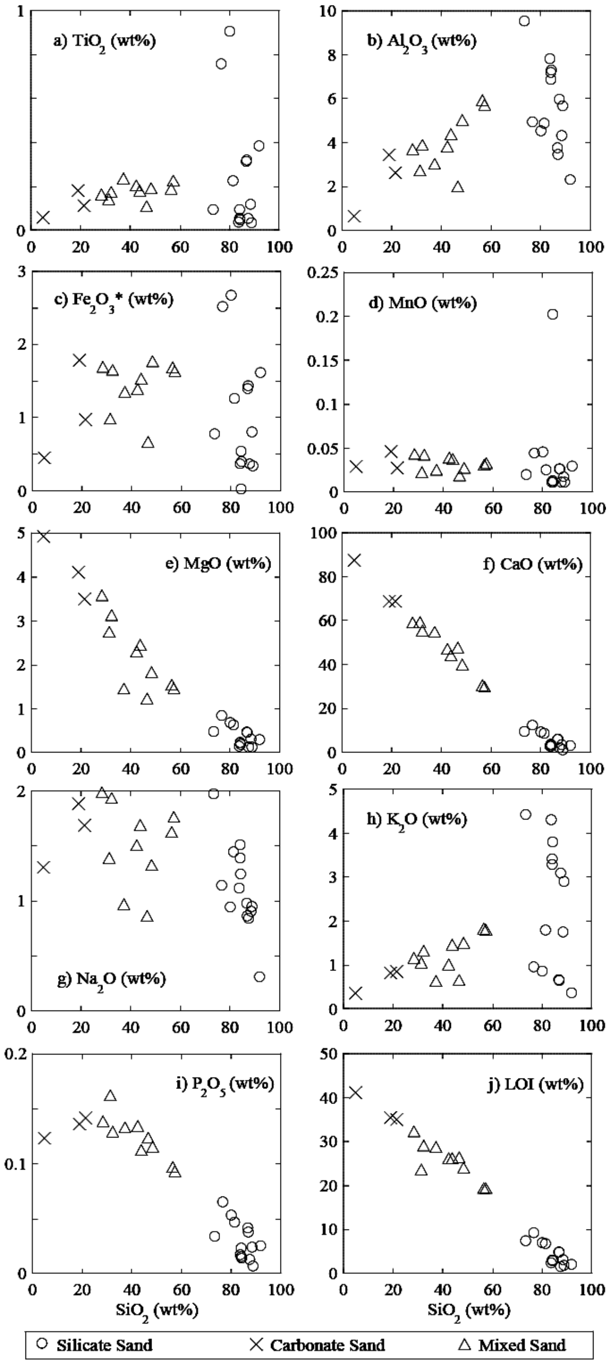

Fig. 4: Major element-SiO_2 variations in beach sand samples from western Yamaguchi Prefecture, Japan.

Conclusions

The 10 beaches investigated in western Yamaguchi prefecture are generally small pocket beaches formed between headlands, and have lengths of less than 1 km. Sands from these beaches can be classified according to their SiO_2 and CaO contents and their LOI values as silicate sands consisting of quartz and feldspar, carbonate sands derived from shell material, or as mixed sands containing both silicates and carbonate sands. With an average SiO_2 content of 85.01 wt%, the silicate sands constitute silica-rich sand sediments. The carbonate sands consist of the remains of marine plants or animals, and average 76.17 wt% CaO, and have consequently high LOI values. The mixed sands are mixtures of quartz, feldspar and shell material, and are thus chemically intermediate between these two extremes.

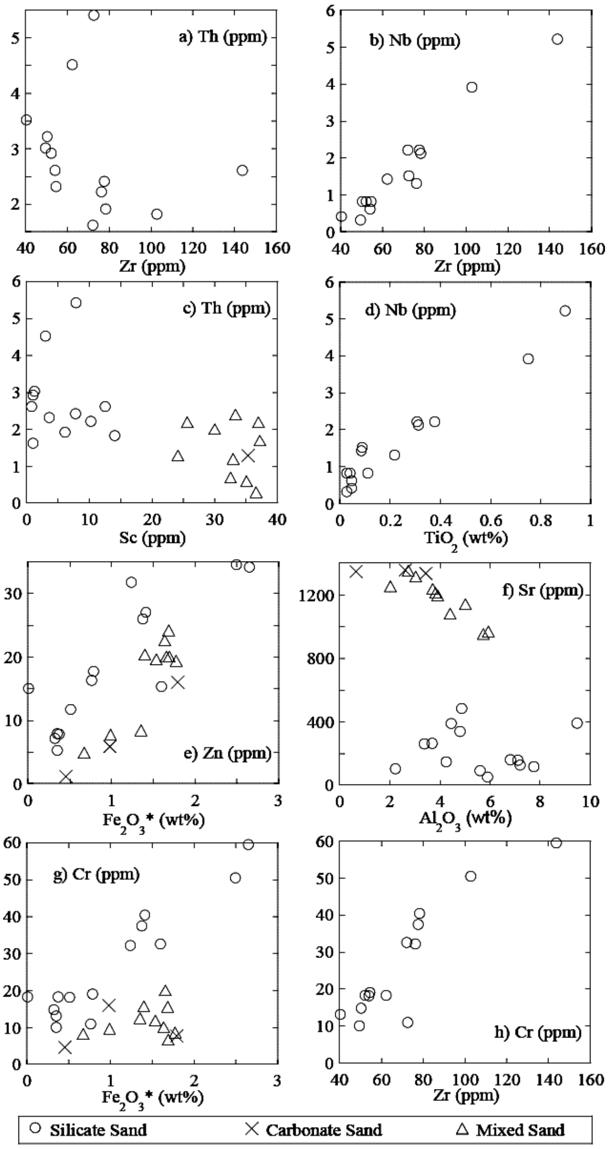

Fig. 5: Selected trace elements variations in beach sand samples from western Yamaguchi Prefecture, Japan.

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（要　旨）

Bah Mamadou Lamine Malick・佐野絵里香・石賀裕明，2011．山口県西部のポケットビーチにおける主元素と微量元素組成の検討．島根大学地球資源環境学研究報告，30，73-81．

山口県西部の 10 箇所の海浜において海浜砂試料を採取した．これらの海浜の長さの平均は 1.13km である．検討した海浜の半数が長さ 1km に満たないポケットビーチである．蛍光 X 線分析により 27 試料について主元素と微量元素の定量を行った．それらの地球化学組成からは分析値は 3 グループ（石英質，炭酸質とこの 2 者の混合）に区分される．石英質砂は SiO_2 に富んでおり石英と長石からなる．一方，炭酸塩質砂は CaO および LOI 値も高く，貝殻片に富む．混合した砂としたものはこの両者の中間的な組成を持ち石英質と炭酸塩物質を含む．