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Geochemical maturity of pocket beach sands from the San'in region of southwest Japan

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Abstract

Major and trace elements of ninety-two coastal beach sands samples, collected along the San'in region of southwest Japan, were determined by X-ray fluorescence to define their geochemical characteristics. These included Yamaguchi (n=27), Shimane (n=50), and Tottori (n=15) beach sands samples. Data of beach sands from Shimane and Tottori normalised averages show approaching patterns relative to the upper crust of the Japan arc UCJAN, and upper continental crust UCCN, reflecting the composition of the source rocks that dominate their watersheds. In contrast the normalised patterns for most elements of Yamaguchi beach sands samples are less than 1 except for CaO, Sr, and Th. The primary component of beach sands from Shimane is quartz, or silica (SiO_2), Sands from Tottori are composed essentially of weathered particles of feldspar, and in contrast components of biogenic and quartz-rich sands from Yamaguchi are primarily shell fragments, quartz, and igneous rock.

Keywords: geochemistry, San'in coast, maturity, beach sands, pocket beach

1. Introduction

1.1 Background and Objectives

The Japanese Islands have complex coastal landforms, where mountains and hills meet the sea in composite geometries; the total length of Japan's coastline is roughly 35,000 kilometres. The southwestern region of Japan, which includes western Honshu (Chūgoku), as well as Shikoku and northern Kyushu, is divided into two distinguishing domain separated by the Median Tectonic Line-MTL (Ito et al., 2010): comprising the Inner and the Outer Zones. The Inner Zone is predominantly composed of Mesozoic granites and rocks of Paleozoic age (250 to 459 million years). Our study suggests that pocket beaches are common on the coastline of the Inner Zone of southwest Japan, which generally coincides with the southwestern Mountain arc, and the inclusive trend of highlands and lowlands roughly convex toward the Sea of Japan, this is clear contrast to those on the Outer Zone of Southwest Japan. The Sea of Japan, one of the largest marginal seas of the Western Pacific Ocean, is located along the edge of the Eurasian continent and partially separated from the open ocean by Japan islands (Gamo & Horibe, 1983; Danchenkov et al., 2006; Talley et al., 2006; Inoue et al., 2007). It is connected to the open Pacific Ocean through the Tsushima in the south, Tsugaru, Soya and Mamiya Straits in the North. The warm Tsushima Current is thought to be composed of three branch currents. One of these, the Tsushima Coastal Branch Current enters the Sea of Japan through the Eastern Channel of the Tsushima Strait and moves northeast along the San'in Coast (Inoue et al., 2007). The Tsushima current supplies a large quantity of heat and nutrient and transports marine organisms in the Sea of Japan as well. Thus, the current has presumably had a deep impact on the Quaternary paleoclimate, paleoenvironment and ecosystem within and around the Sea of Japan (Akihisa et al., 1997).

The coastal area is a singular space where people reside and undertake a variety of social and economic activities unlike anywhere else on the planet. Numerous components and processes, including source composition, sorting, climate, relief, long shore drift, and winnowing by wave action, influence its sediments. Among other factors, beaches are also subject to local processes such as wave and tidal regimes, fluvial discharges, and wind transport (Carranza-Edwards et al., 2009).

The current study is a compilation of works on the composition of beach sands, which were carried out at several sites along the San'in coast of Southwest Japan, involving the coastline of Yamaguchi, Shimane and Tottori District. Work on sound producing sand in Japan by Igarashi et al., 2007, revealed that beach sand from Tottori coast contains more than 60 wt% SiO_2 and are predominantly composed of quartz and k-feldspar. More recently Yasumoto et al., 2007, investigated beach erosion of the Tottori coast. However, both of these studies were based on sand samples collected from single beaches or within restricted geographic areas. In this study, however, the geochemical composition as well as the maturity of pocket beach sands from the San'in coast, Southwest Japan was determined. The San'in coast was chosen due to its importance from the geological point of view since it is likely the sand sediments were supplied through major river systems (Takasu, Gono Hii, Hino, Tenjin, and Sendai, Rivers) from the Chūgoku Mountains to the shoreline.

The objective of this study is to conduct a systematic evaluation of geochemical composition of sand sediments collected from the San'in coast and outline some of the relationships between abundances of elements in sand samples from the 92 sites investigated in this study. In addition, interpret the maturity of beach sands from the region in terns of geochemistry compared with geochemical composition of 15 local river sediments from AIST & GSJ, 2013a, 15 near-shore marine sediments along the San'in district from AIST & GSJ, 2013b, average Upper crust of the Japanese archipelago, according to (Togashi et al., 2000), and average Upper Continental Crust (UCC) (Rudnick & Gao, 2003).

1.2 Geology of Study Area and Contributing Watersheds

The study area is located in the coastal zone of the San'in coast of Southwest Japan. Sampling was carried out on the coastline of Yamaguchi, Shimane and Tottori District. Samples were taken in pocket beaches where sand is derived from erosion of upland and supplied by major river systems running from the Chūgoku Mountains. These major river systems include the Hii, Gonokawa, and Takasu River in Shimane district as well as the Sendai and Tenjin River in Tottori district (Figure 1). However, fluvial input to pocket beach system in Yamaguchi is limited as a result of the smallness of rivers in the area. The Hii, Gonokawa, and Takasu rivers flow down northwards from the Chugoku Mountains. The Sendai River flows through the eastern part of Tottori District. It has the largest watershed in the region, and is the second longest river in the West after Hino River. The river rises on Mt. Okinoyama, then flows to the North and is joined by several tributary rivers, runs across the central part of the Tottori Plain, and finally enters the Sea of Japan. The Tottori sand dunes are located at the coasts near the mouth of the Sendai River. The Tottori sand dunes are Japan's largest, covering an area of about 30 km2. The tallest dunes reach an altitude of about 90 meters above sea level, and slopes reach 40 degrees in some places. The Tenjin River is located in central Tottori District, between the Sendai River in the East and Yumigahama Peninsula in the West (Figure 1). The Takeda River, a tributary in the upper part of the Tenjin River, runs through a region of granitic rocks. The Ogamo River, one of the main tributaries of the Tenjin River, flows along a dissected valley on the flanks of the Mt. Daisen volcano.

2. Materials and Methods

Approximately 350 to 400 g of sands sample was collected at the uppermost centimetres from the beach using a stainless steel scoop. Selection of sampling sites was made using Google Earth (2010-2011). Sampling was carried out at moderate to low tides when the weather was fine based on tidal information available from the Japan Meteorological Agency. In total ninety samples were collected during fieldwork at Yamaguchi district (January 2011), Shimane district (March and April 2010) and Tottori district (November 2010). Approximately one-third of each sample was transferred to Pyrex beakers in their natural state (wet sand from seawater), covered with aluminum foil to allow air circulation, and dried in an oven at 110°C for 24 hours. Once dried, sub-samples of the sediments were crushed in an automatic agate mortar and pestle grinder to produce a powder suitable for analysis. Fused glass and discs pressed powder pellets were prepared from the crushed samples for major oxide and trace element analysis, respectively. Loss on Ignition (LOI) determinations were made by transferring about 5.000g±0.001 g of dried powder sample to previously weighed porcelain crucibles, and the overall weight recorded. The samples were then ignited in a muffle furnace for at least 2 h at 1050°C. The weight differential was calculated and reported as a percent loss. The ignited material was then manually disaggregated and recrushed in an agate pestle and mortar, and returned to an 110C oven for at least 24hours. The fused glass discs were prepared in an NT-2000 automatic bead sampler using the ignited material in addition to an alkali flux comprising 80% lithium tetraborate and 20% lithium metaborate, with a sample to flux ratio of 1:2. Analytical methods, instrumental conditions and calibration follow those described by Kimura & Yamada,

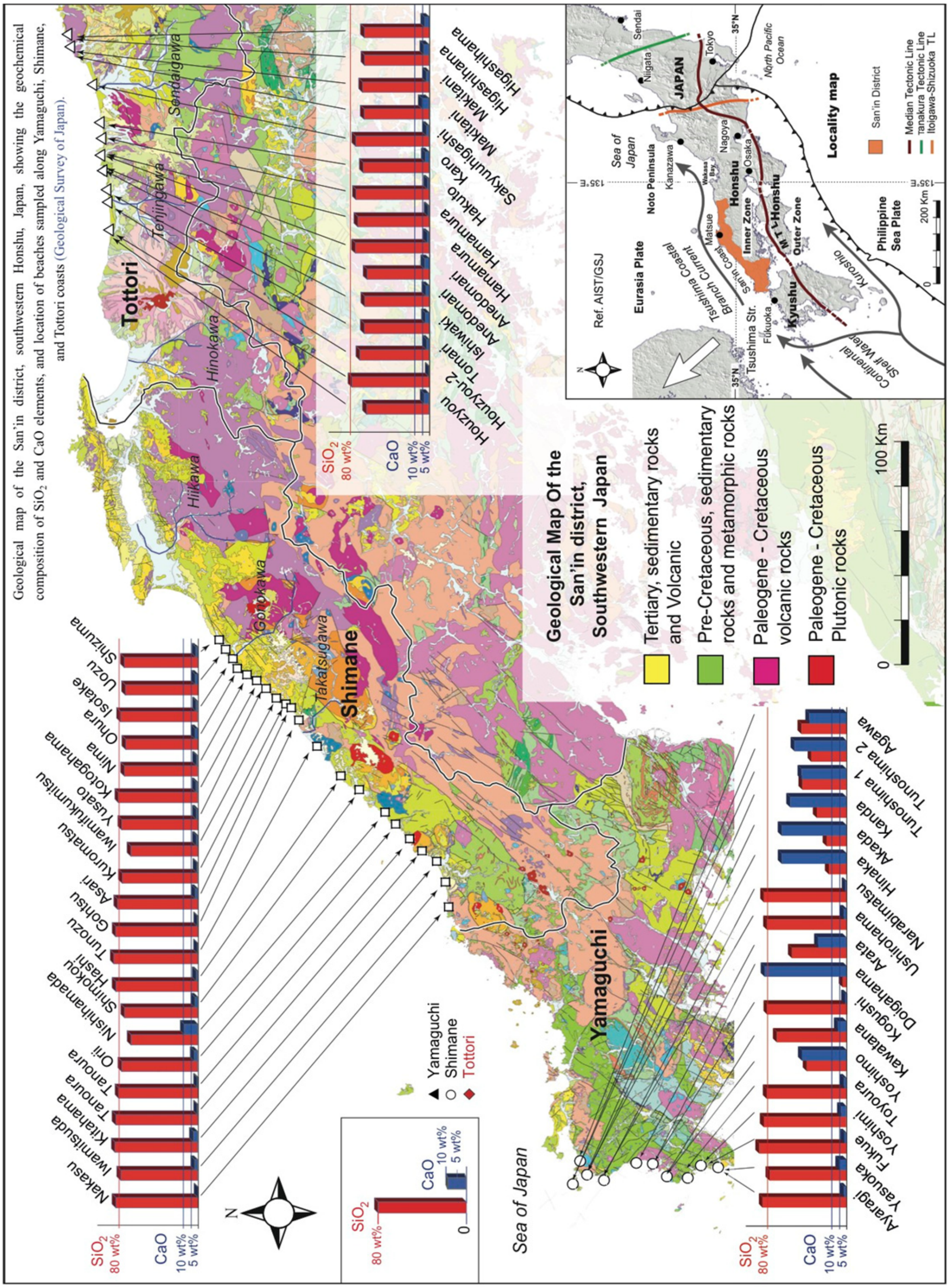

Figure 1. Geological map of the San'in region, southwest Japan, showing the geochemical composition of SiO_2 and CaO elements, and location of beaches sampled along Yamaguchi, Shimane, and Tottori coasts. Locality map showing of the San'in district showing water circulation systems of the Sea of Japan, and geotectonic subdivision of the Japanese Island. Modified from, (AIST/GSJ, 2013; Yukio, et al., 2010; Inoue & Tanaka, 2007)

1996. The pressed powder pellets were prepared by pressing the powdered samples into 40 mm diameter plastic rings, using a force of 200 kN for about 60 s in an automatic pellet press (E-30 T.M Maekawa) following the (Ogasawara, 1987) method. Major elements expressed as oxides (SiO_2, TiO_2, Al_2O_3, Fe_2O_3*, MnO, MgO, CaO, Na_2O, K_2O, and P_2O_5) and 18 trace elements (As, Pb, Zn, Cu, TS, Ni, Cr, V, Sr, Y, Nb, Zr, Th, Sc, F, Br, I, and Cl) were obtained using an automated RIX 2000 system (Rigaku Denki Co. Ltd.) at Shimane University.

3. Results and Discussion

3.1 Major and Trace Elements

Table 1 summarises results of major and trace element compositions of the analysed sand samples from Yamaguchi, Shimane and Tottori, accompanied by data of local river sediments and near-shore marine sediments AIST & GSJ, 2013, San'in region of southwest Japan. The corresponding LOI values are included in Table 1 for each location.

Yamaguchi coastal beach sands samples have low to high SiO_2 contents, with abundances ranging from 4.72 wt% to 92.16 wt%, and averaging 60.32 wt%. These high values reflect their quartz content. The next most abundant element in average CaO (29.27 wt%) ranges from 0.77 wt% to 87.37 wt%. For low CaO values correspond to high SiO_2 contents vice versa. While high values of CaO suggest presence of a significant biogenic $CaCO_3$ component in this case, the low values reflect low shell contents. Al_2O_3 is the next abundant element with (4.66 wt%) average and ranges from 0.65 wt% to 9.50 wt%. Among the remaining major elements, K_2O (average 1.76 wt%, range 0.34- 4.40 wt%), MgO (average 1.53 wt%, range 0.10-4.93 wt%), Na_2O (average 1.30 wt%, range 0.30-1.99 wt%), and Fe_2O_3 (1.20 wt%, range 0.01-2.66 wt%) are the next most abundant. Other major elements (TiO_2, P_2O_5, and MnO) are less abundant. Yamaguchi coastal beach sands samples revealed low to high LOI contents relatively with CaO contents, (averaging 16.08 wt%, ranging 1.30-41.12 wt%). Among the analysed trace elements, Cl has the highest content as a result of contaminations from seawater, averaging 13720 ppm, and ranging from 40 ppm to 54231 ppm, followed by total sulfur (TS) averaging 2300 ppm, with range from 30 ppm to 5557 ppm. Sr contents are significant, averaging 695 ppm and ranging from 44 ppm to 1358 ppm, whereas F contents vary from 11 ppm to 274 ppm, averaging 111 ppm. Zr contents range from 41 ppm to 144 ppm and V from 3 ppm to 43 ppm. The average content of I and Sc are 27 ppm and 20 ppm, respectively. Concentrations of other trace elements are less than 20 ppm on average.

As expected, SiO_2 is the most abundant from Shimane coastal beach sands samples, averaging 81.82 wt%, with a range of 54.38-89.50 wt%, followed by Al_2O_3 (average 8.85 wt%, range 4.54-16.46 wt%), (Table 1). Among the remainder CaO (3.36 wt%, range 0.45-35.35 wt%), K_2O (2.18 wt%, range 0.88-4.44 wt%), Fe_2O_3 (1.67 wt%, range 0.42-3.14 wt%), Na_2O (1.66 wt%, range 0.87-2.97 wt%), are the next most abundant on average. MgO (average 0.49 wt%) and TiO_2 (average 0.24 wt%) are present in small amounts, whereas MnO and P_2O_5 (both averaging 0.04 wt%) are present only in trace amounts. In these samples overall, LOI contents range from 0.42-22.59 wt%, averaging 2.59 wt%. Cl is the most abundant trace element as a result of contaminations from seawater, with an average value of 3138 ppm, and a maximum of 9959 ppm. Total sulfur (TS) values are also significant, ranging from 275 ppm to 3398 ppm, with a mean value of 674 ppm. Sr is the next most abundant, with a maximum of 1126 ppm, a minimum of 77 ppm, and an average value of 226 ppm. Among the remaining trace elements, only F, Zr, Zn, Cr, V, As, and I contents are present in moderate concentrations, other trace elements, Pb, Cu, Ni, Y, Nb, Th, Sc and Br showed very low concentrations.

Coastal beach sands samples from Tottori typically consist of silicate minerals such as quartz and feldspar. The high SiO_2 contents of these samples (66.30-82.23 wt%; average 72.30 wt%, (Table 1) are due to the abundance of quartz. Al_2O_3 abundances are also relatively high (10.05-17.35 wt%, average 14.59 wt%). CaO contents overall are significant (average 3.66 wt%) and show a considerable range, from 0.84 to 7.49 wt%. Similar average (1.95 wt%) and range (0.50-5.50 wt%) for LOI indicate the presence of significant $CaCO_3$ as shell material. Na_2O and K_2O, also likely to be contained within feldspar, are less abundant, averaging 2.88 and 2.63 wt%, respectively. Three major elements (Fe_2O_3*, MgO and TiO_2), are present only in minor amounts (average 2.47, 1.03 wt%, and 0.27 respectively), and P_2O_5 and MnO are present only in trace amounts (both averaging 0.05 wt%. Iodine (I) is the most abundant trace element averaging 3722 ppm, with a maximum of 7394 ppm. It is followed by total Chlorine (Cl), which averages 589 ppm (range 342-1007 ppm), and Sr (average 384 ppm, range 131-598 ppm). Average concentrations of all other trace elements except TS (158 ppm) are less than 100 ppm, reflecting the high SiO_2 contents and marked quartz dilution in this suite of sediments.

Summary of geochemical composition of beach sands samples from the San'in district are illustrated in Figure 2. The highest concentrations of MgO, SiO_2, CaO, P_2O_5, LOI, and Sr were noted in the Yamaguchi beach sands. Concentrations of major elements for Yamaguchi beach sands samples was similar to that of Tottori beach sands samples although the median values differs for major elements, whereas contents of the Yamaguchi coastal beach sands ranged widely in the overall analysed major elements. TiO_2 and MnO however varied with similar ranges.

Table 1. Summary statistics of major and trace element abundances in sands samples from Yamaguchi, Shimane and Tottori, and comparative averages for local river sediments and near-shore marine sediments AIST/GSJ, 2013 from San'in district, southwest Japan

	Major elements (wt%)										wt%
	SiO_2	TiO_2	Al_2O_3	$Fe_2O_3^*$	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI
	Yamaguchi coastal beach sands (N=27)										
Max	92.16	0.9	9.5	2.66	0.2	4.93	87.37	1.99	4.4	0.16	41.12
Min	4.72	0.03	0.65	0.01	0.01	0.1	0.77	0.3	0.34	0.01	1.3
Average	60.32	0.22	4.66	1.2	0.04	1.53	29.27	1.3	1.76	0.08	16.08
	Shimane coastal beach sands (N=60)										
Max	89.5	0.7	16.46	3.14	0.13	1.57	35.35	2.97	4.44	0.11	22.59
Min	54.38	0.05	4.54	0.42	0.01	0.1	0.45	0.87	0.88	0.01	0.42
Average	81.82	0.24	8.85	1.67	0.04	0.49	3.36	1.66	2.18	0.04	2.59
	Tottori coastal beach sands (N=15)										
Max	82.23	0.48	17.35	3.91	0.08	1.98	7.49	3.5	3.77	0.07	5.5
Min	66.2	0.11	10.05	0.89	0.02	0.24	0.84	1.83	1.6	0.02	0.5
Average	72.3	0.27	14.59	2.47	0.05	1.03	3.89	2.88	2.63	0.05	1.95
	Local river sediment data, AIST 2013 a, b. (N=15)										
Max	79.78	1.14	16.46	6.48	0.36	2.5	4.71	3.48	3.79	0.19	-
Min	69.49	0.31	8.76	2.2	0.06	0.37	0.47	1.45	1.15	0.05	-
Average	74.71	0.63	11.8	4.77	0.14	1.57	1.88	2.42	2.14	0.13	-
	Marine sediment data, AIST 2013 a, b. (N=15)										
Max	80.18	0.57	12.17	5.65	0.11	2.74	22.36	6.53	2.74	0.19	-
Min	64.28	0.12	3.1	1.28	0.03	0.88	2.52	1.09	0.74	0.05	-
Average	73.54	0.3	8.31	3.21	0.06	1.97	8.58	2.59	1.78	0.09	-

	Trace elements (ppm)																	
	As	Pb	Zn	Cu	Ni	Cr	V	Sr	Y	Nb	Zr	Th	Sc	TS	F	Br	I	Cl
	Yamaguchi coastal beach sands (N=28)																	
Max	9	18	34	13	9	59	43	1358	24	5	144	5	39	5557	274	20	36	54231
Min	1	7	1	1	1	5	3	44	5	1	41	1	1	30	11	4	16	40
Average	5	12	17	4	6	20	19	695	12	2	74	2	20	2300	111	11	27	13720
	Shimane coastal beach sands (N=61)																	
Max	23	54	85	12	15	46	103	1126	22	6	98	7	20	3398	283	14	37	9959
Min	3	8	8	2	3	11	1	77	8	1	55	1	1	275	3	3	5	11
Average	13	17	35	5	8	24	27	226	16	3	74	4	5	674	117	8	27	3128
	Tottori coastal beach sands (N=16)																	
Max	21	15	41	6	14	36	49	598	20	4	89	4	15	350	14	31	7394	1007
Min	6	11	9	1	4	18	3	131	12	1	59	2	2	37	3	10	293	342
Average	15	13	28	4	9	26	21	384	16	2	74	3	8	158	8	22	3722	589
	Local river sediment data, AIST 2013 a, b. (N=16)																	
Max	124	305	162	38	93	138	587	28	13	86	15	11	-	-	-	-	-	-
Min	12	78	16	7	20	34	41	6	4	34	3	4	-	-	-	-	-	-
Average	52	174	49	18	45	89	217	15	8	53	7	8	-	-	-	-	-	-
	Marine sediment data, AIST 2013 a, b. (N=16)																	
Max	40	131	31	18	43	70	1209	13	6	43	14	10	-	-	-	-	-	-
Min	10	26	4	3	7	16	178	6	2	14	3	1	-	-	-	-	-	-
Average	23	73	11	12	27	43	519	9	4	30	6	6	-	-	-	-	-	-

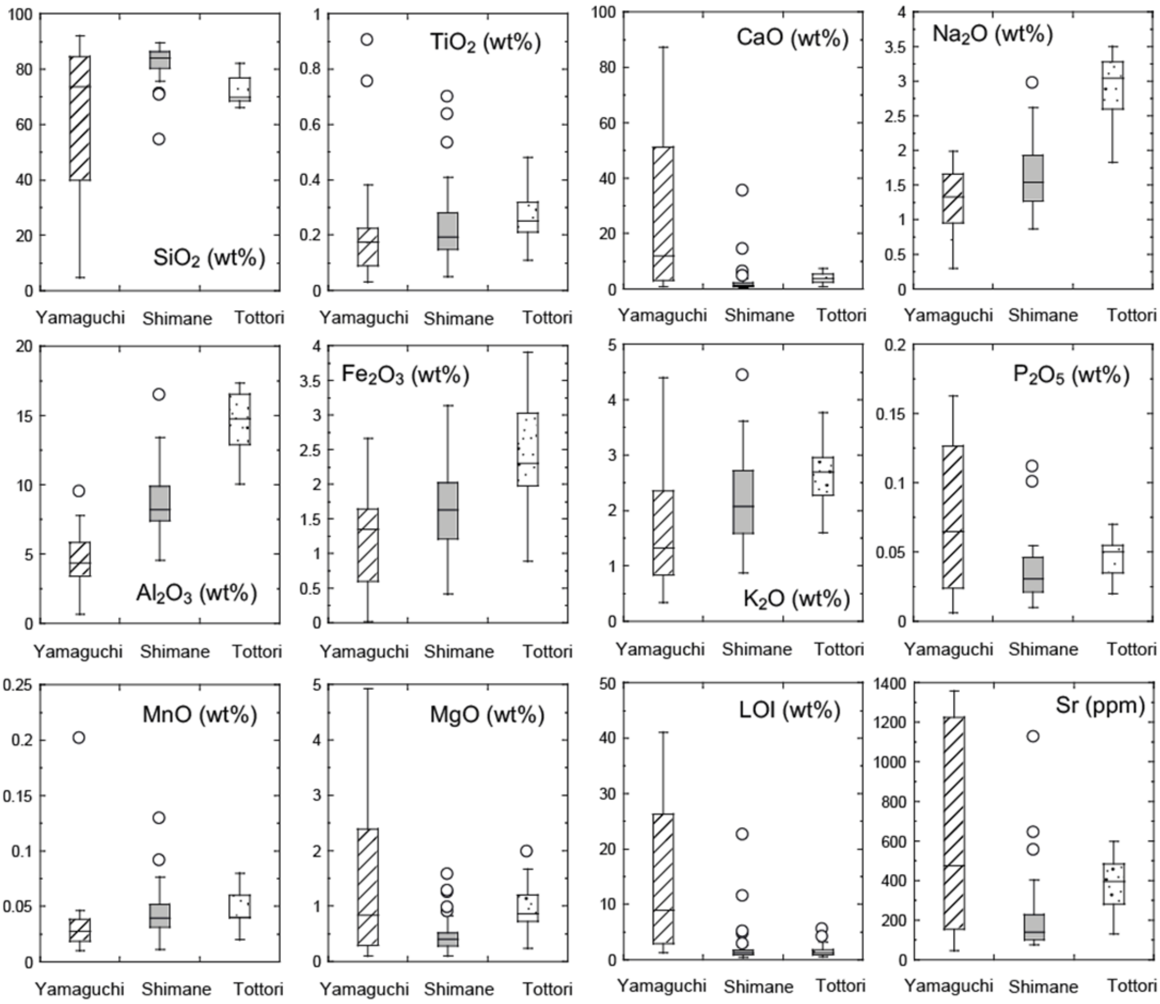

Figure 2. Box-plots showing the summary of geochemical compositions of beach sands samples from the San'in district, covering Yamaguchi, Shimane and Tottori, southwest Japan. Vertical lines give the range, excluding outliers (circles); boxes enclose 50% of the data and illustrate the 25% quartile, median (horizontal bar), and 75% quartile. Outliers are defined as the upper or lower quartile ±1.5 times the interquartile difference

3.2 Inter-Element Relationship

Harker variation diagrams of selected elements in the beach sand samples are shown in Figure 3. Contents of major elements are plotted against SiO_2 contents for all samples. The increase of SiO_2 reflects a greater geochemical maturity. All of the major elements plotted show broad trends of decreasing abundance with increasing silica content. The significant SiO_2, Al_2O_3 and Na_2O contents of Shimane and Tottori sand samples indicate that quartz and feldspar are the main constituents. Overall depletion of CaO and MgO suggests that the carbonate content of the beach sand sediments is generally low, except in a few samples. CaO shows a well-defined decrease with increasing SiO_2, except for higher values in a small group of Yamaguchi sand samples with lower SiO_2 contents. These samples also have higher LOI values, and hence are likely to contain a biogenic $CaCO_3$ component such as shell material. These samples consist of carbonate or biogenic sands, which are mainly composed of coral, algae, crustacean skeletons, and shells. Foraminifer shells, coccoliths, pteropod shells, and corals consist of calcium carbonate ($CaCO_3$) or aragonite. Carbonate sands consist of the remains of either marine plant or animals. Carbonate sands found in the coastal zone and shallow water consist of porous or hollow particles with rough texture of mainly remains of corals, shells of molluscs and algae. Foraminifer shells, coccoliths, pteropode shells, and corals are the principal constituents of the calcium carbonate (calcite or aragonite, $CaCO_3$) of the sand (Khaled, & Stephanie, 2007).

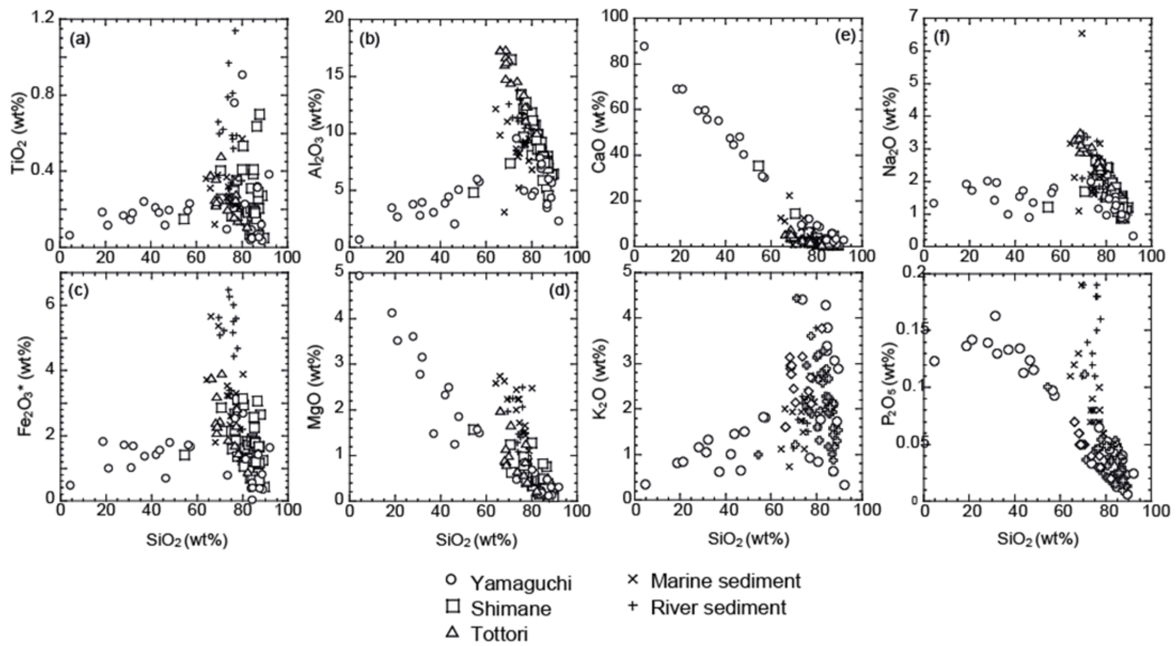

Figure 3. Cross-plots of selected elements showing the geochemical variations of beach sands samples from Yamaguchi, Shimane and Tottori, compared to average local river sediments and near-shore marine sediments AIST/GSJ, 2013 from San'in district, southwest Japan

3.3 UCJA and UCC -Normalised

Data of sands samples from Yamaguchi, Shimane and Tottori were compared by normalisation with average Upper Crust of the Japanese Archipelago UCJAN, (Togashi et al., 2000) in Figure 4a; And average Upper Continental Crust UCC with normalising values from (Rudnick & Gao, 2003) Figure 4b. As reported by (Togashi et al., 2000), the upper crust of the Japan arc is similar to the averaged upper continental crust data reported by (Rudnick & Gao, 2003). In the Yamaguchi beach sands samples, the UCJAN as well the UCCN ratio for most of major and trace elements is less than 1 (Figure 4a and 4b). Exemptions to this trend are CaO, Sr, and Th, which have UCJAN and UCCN greater than 1. Shimane and Tottori normalised averages show approaching patterns in the UCJAN likewise in the UCCN diagram (Figure 4a and 4b). Normalised pattern for Shimane coastal beach sands are depleted except for Arsenic relative to the UCCN, and it is possible that the geochemical variations are mostly controlled by local geology.

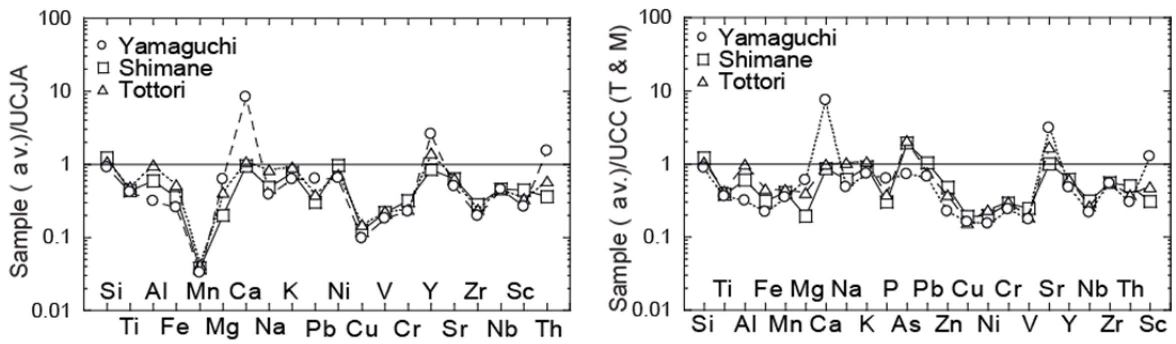

Figure 4. Average UCC-Normalised major and trace elements plots of beach sands samples from Yamaguchi, Shimane and Tottori, in contrast to local river sediments and near-shore marine sediments AIST & GSJ, 2013 from San'in district, southwest Japan. a) Samples normalized to average Upper Crust of the Japanese archipelago (UCJAN) according to Togashi et al., 2000. b) Average UCC-normalised (UCCN), normalizing values from Rudnick & Gao, 2003. The major element values were normalised as wt% and trace elements as ppm

3.4 Chemical Maturity

Chemical maturity is a compositional state of a clastic sedimentary body wherein there is a dominance of quartz and an absence or minority of less resistant particles such as feldspars, detrital carbonates or lithic fragments (Blatt et al., 2004). The distribution of the investigated sand sediments on the three areas are elucidated on a ternary plot containing mixtures of terrigenous detritus (expressed by Al_2O_3 and SiO_2) and biogenous material (expressed by CaO and SiO_2), Al_2O_3*5–SiO_2–CaO*2 (Brumsack, 1989) Figure 5. The three axes Al_2O_3, SiO_2, and CaO represent clays, quartz and/or biogenic silica, and calcium carbonate respectively. Sand samples from Yamaguchi generally rich in carbonate plot close to the CaO and SiO_2 line, showing varying contents of carbonate in addition to quartz and biogenic silica. Shimane and Tottori Sand samples however, plot on a mixing trend shifting toward SiO_2. Shimane samples are particularly mixture of sand and mud making up the sedimentary layers and probably, deposited by both tides and rivers on the area. Sand from Shimane and Tottori are generally lower in carbonate, and the shifting toward the SiO_2 edge indicate higher surplus of silica content. This surplus of silica may reflect the abundance of coarse grains of quartz-rich sand rather than biogenic silica that categorise most of the Yamaguchi samples.

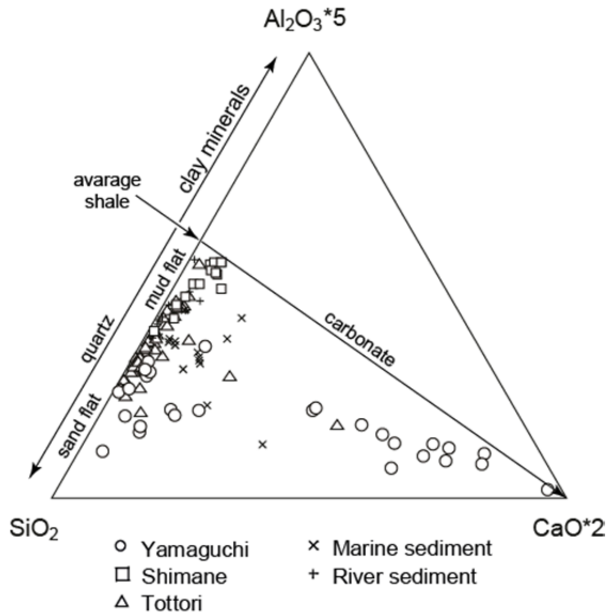

Figure 5. Ternary plot Al_2O_3*5–SiO_2–CaO*2 (Brumsack, 1989), of beach sands samples from Yamaguchi, Shimane and Tottori, compared to average local river sediments and near-shore marine sediments AIST/ GSJ, 2013 from San'in district, southwest Japan

In Figure 6a, the plot of SiO_2 (reflective of quartz content) versus $K_2O+Na_2O+Al_2O_3$ (reflective of feldspar content) in beach sands samples from Shimane and quartz-rich sands from Yamaguchi shows high degrees of maturity, which probably indicate rich chemical weathering in source areas.

In contrast, sands samples from Tottori show lesser degrees of chemical maturity. In the binary plot of Na_2O/K_2O (Crook, 1974), Figure 6b, sands samples from Shimane and quartz-rich sands from Yamaguchi scheme on the quartz-rich field. However, sand sample from Tottori in addition to biogenic silica and calcium carbonate sands from Yamaguchi are plotted on the quartz-intermediate domain.

The composition of beach sands is highly variable, depending on the local rock sources and conditions. While the primary component of beach sands from Shimane is quartz, or silica (SiO_2), the distributions of sand sediment along these beach areas are substantially regulated by the influence of sand sediments derived from the Chūgoku Mountains. Since most of rivers basin is underlain by easily weathered granite, large volume of sediment is provided from the upstream basin areas (Somura et al., 2012.).

Sands from Tottori are composed essentially of weathered particles of quartz and feldspar, its sediments are influence by fluvial systems otherwise by erosion of older materials underlying the inner shelf and probably, eroded by longshore currents and other coastal processes like winnowing and reworking of the beach. Admitting that sediments from Tottori sand dunes are formed from sediments derived from the nearby Chugoku Mountains and transported by the Sendai River to the ocean.

In contrast components of biogenic sands from Yamaguchi are primarily shell fragments, quartz, and igneous rock (Figure 7). As follows Yamaguchi coast is invaded by the warm Tsushima Strait, which probably causes the biogenic productivity in the region.

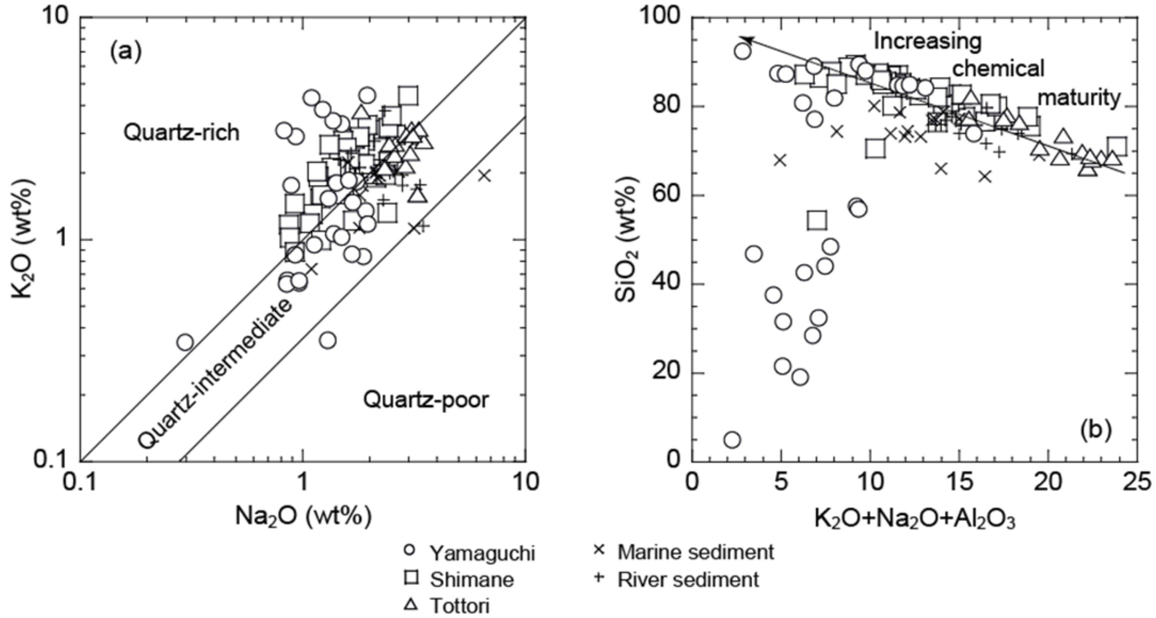

Figure 6. a) Plot of SiO_2 (reflective of quartz content) versus $K_2O+Na_2O+Al_2O_3$ (reflective of feldspar content) in beach sands samples from Yamaguchi, Shimane and Tottori, in contrast to local river sediments and near-shore marine sediments AIST/GSJ, 2013 from the San'in district, southwest Japan. b) Plot of Na_2O versus K_2O (Crook, 1974)

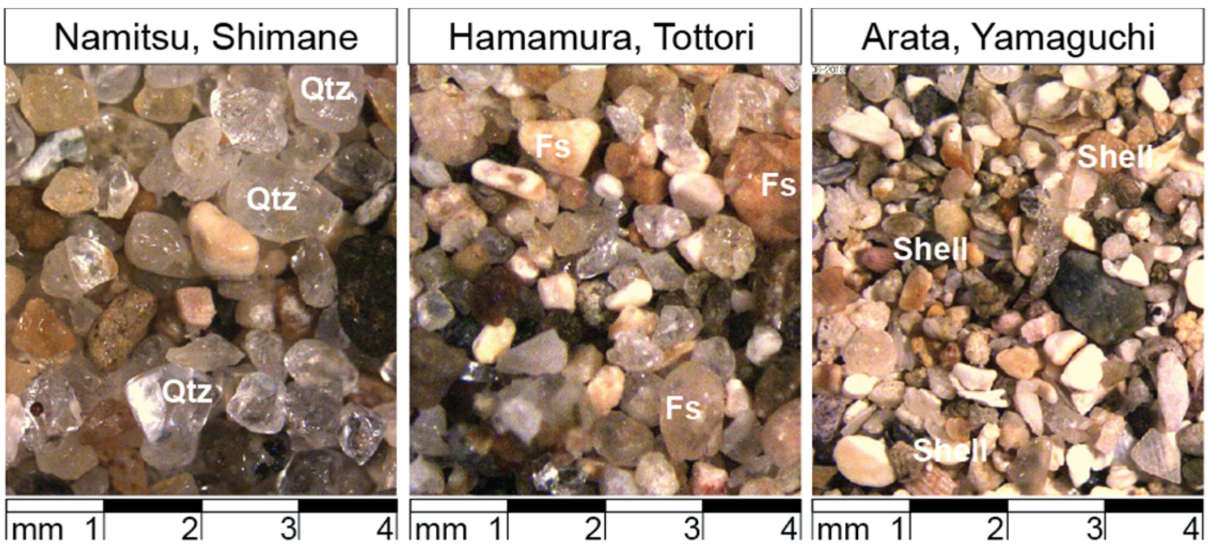

Figure 7. Selected microscopic photographs of silica rich sand from Namitsu Beach, feldspathic sand from Hamamura Beach, and biogenic sand from Arata Beach from respectively, Shimane, Tottori and Yamaguchi from the San'in district, southwest Japan

4. Summary and Conclusions

Geochemically, pocket beach sands from the San'in region of southwest Japan are composed of terrigenous detritus and biogenic material. The result of this study shows that the primary component of matured beach sands from Shimane is quartz, or silica (SiO_2), derived from already-matured source rock supplied through major river systems from the Chūgoku Mountains to the shoreline. Sands from Tottori are composed essentially of weathered particles of quartz and feldspar; in contrast components of biogenic and quartz-rich sands from Yamaguchi are primarily shell fragments, and quartz.

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