Sound-Producing Sand in Japan: Major Element Composition and Its Minerals Determined by X-ray Diffraction and X-ray Fluorescence

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The major element composition, including two kinds of clay minerals and moisture content of sound-producing sand are reported for the first time. Sand from 33 beaches in Japan has been found to make sound. Ten sound-producing beaches were selected to compare with silent beach sand. Both sound-producing sand and silent beach sand are mostly composed of quartz and feldspar. The range of SiO₂ content of sound-producing sand is not different from silent sand samples. This indicates that a high quartz content is not necessary to produce sound, although more than 60 weight percent of quartz is necessary. One silent sand recovered its sound after a 3.5 percent HNO₃ treatment. Also, a small portion of clay minerals was found. A clean grain surface is a necessary factor for sand to produce sound. Illite was found in all silent sand samples.

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Introduction

The sound producing-sand has been well known as musical sand, or booming sand, for thousands of years. They are distinguished in two types—booming and squeaking sand. “Booming sand” especially occurs in dune and desert regions. It produces a low-frequency sound during avalanching. “Squeaking sand” is often found on beaches, which shows a high-pitched note. The sound is produced when walking across dried beach sand. It occurs on the seacoast of every continent,¹⁻³ island and along lakeshores.⁴ Japan is one of the islands surrounded by ocean, and the sound-producing sand is more common and widespread in occurrence.^{3,5-9} Most of the sound-producing sand beaches are found in a crescent-shape between low cliffs, and are isolated from frequency access. In a rare phenomenon, some sand forms dunes along the coast. There are many sound-producing sand beaches in Japan, but only 30 singing beaches were reported in 1997.¹⁰ The sounding mechanism and physical characteristics of the singing sand have been researched by many scientists.^{1-3,5-9,11,12} The mechanism of sound-producing sand has been under a veil for some time. An early hypothesis suggested that the sound is produced by a piezoelectric effect, the production of electrical currents by quartz grains under mechanical stress.¹³ Finally, Miwa and Hidaka¹⁴ stated that sound is produced when the grains create friction to vibrate each other. For sand to create sound, a few conditions are necessary: 1) more than 90% of quartz grains, 2) the sand must be dry, 3) clean surface and well washed, well rounded and highly spherical, 4) smooth surface, and 5) well sorted.

This paper explains the bulk chemical composition and mineralogy of sound-producing sands. The characteristics of

sound producing sand and silent sand were investigated.

Analytical Procedure

All of the beach sand samples presently studied were located in Cretaceous granitic regions (Fig. 1). Samples were collected from two main regions of Japan: the Miyagi area in the Northern main land (Honshu) and the Tottori area in western Honshu. Three samples were collected from each beach surface.

Fig. 1 Map showing the location of sound-producing sand (1–7) and silent sand beaches (8–12) sampled in Japan. The numbers correspond to the entries listed in Table 1.

Table 1 Major element composition of each beach sand in weight percent

	SiO ₂	TiO ₂	Al ₂ O ₃	FeO	MnO	MgO	CaO	Na ₂ O	K ₂ O	P ₂ O ₅	LOI	Total
Sound producing sand												
1. Kugunarihama (Oshima)	94.82	0.07	2.12	0.38	0.01	0.00	0.12	0.21	0.76	0.21	0.38	99.09
2. Kukunakihama	97.70	0.97	1.31	0.17	0.02	0.00	0.04	0.01	0.41	0.00	0.24	100.87
3. Natsuhama	99.19	0.09	4.15	0.42	0.03	0.00	0.19	0.76	1.41	0.00	0.42	106.64
4. Takehama	61.35	0.36	17.93	5.32	0.23	2.54	6.03	4.57	0.17	0.04	0.24	98.79
5. Murohama	62.62	0.22	19.82	2.70	0.09	1.12	6.38	5.09	0.23	0.03	0.19	98.49
6. Idegahama	68.57	0.21	16.50	2.24	0.04	0.94	4.09	4.04	2.61	0.06	0.22	99.51
7. Aoya beach	67.28	0.25	17.73	2.49	0.05	1.23	4.42	4.15	2.00	0.04	0.54	100.17
Silent sand												
8. Shirahama	94.71	0.10	2.79	0.61	0.03	0.10	0.38	0.41	0.70	0.00	0.31	100.13
9. Kugunarihama	89.17	0.58	3.94	2.49	0.08	0.74	0.88	0.33	0.58	0.01	0.44	99.24
10. Ohama	69.44	0.22	15.29	3.05	0.10	1.05	4.49	3.75	0.56	0.04	0.57	98.57
11. Tsukihama	66.83	0.26	17.37	2.96	0.07	0.93	5.19	4.16	0.70	0.04	0.93	99.43
12. Otomehama	64.03	0.29	19.00	2.86	0.08	0.93	5.81	4.63	0.61	0.03	1.60	99.87
Albite	64.65	0.00	19.43	0.04	0.00	0.03	0.38	3.71	10.97	0.00		
Anorthite	43.79	0.00	35.79	0.43	0.00	0.33	18.69	0.42	0.03	0.00		
Quartz	99.53	0.00	0.02	0.10	0.00	0.00	0.00	0.00	0.00	0.00		
Illite	49.84	0.03	30.98	7.79	0.00	0.00	1.17	10.02	0.00			
Montmorillonite	69.39	0.10	20.53	1.47	0.08	0.00	5.75	2.96	0.17	0.00		
fresh granite/Kitakami	64.92	0.56	15.18	5.39	0.11	1.99	4.24	3.20	2.61	0.11		
fresh granite/Sanin	72.39	0.24	14.01	2.49	0.05	0.44	2.40	3.86	3.00	0.05		

X-ray fluorescence (XRF)

Each sample was washed with 3.5% HNO₃ to rid of its carbonates, dried at room temperature for about 24 h, then milled and powdered with an automatic pot mill for about 15 min to determine any loss of ignition (LOI). The powdered samples were completely dried for 24 h at 900°C in a muffle oven. Samples were prepared for major-element analysis using fused lithium tetraborate glass disks. Pt-Au crucibles were used for the fusion, then melted in air at 1100°C for ~10 min with constant agitation to ensure thorough mixing, and then cooled. A wavelength-dispersive X-ray spectrometer (Rigaku), equipped with Rh-anode X-ray tubes, was used to determine the major element abundances in the samples. The spectrometer was calibrated using well-analyzed standard JG-2 and JB-1b of the Geological survey of Japan.

X-ray powder diffraction

The samples were air dried and milled for X-ray powder diffraction method. The mineral compositions of sands were determined by an X-ray powder diffraction (Rigaku) method in the range 4 – 60°C with Cu K α under 50 kV and 60 mA.

The sticking complements on grains were also measured by powder X-ray diffraction. To see the properties of beach sand, some experiments were reinforced. Five mixtures, bentonite (Junsei Chemical Co., Ltd.), which is mostly composed of very fine-grained montmorillonite and Illite, Iron(III) hydroxide (Junsei Chemical Co., Ltd.), loam (red soil), silent sand and calcite were added to sound-producing sand up to several percent by weight.

Results

The yielded weight percentages of each averaged major component for the different beach samples are given in Table 1. All sound-producing sand contained more than 50% of SiO₂. Only one silent sand, *Shirahama* in Miyagi, produced sound after washing with HNO₃ acid.

Because the beach sand is a product of the breakdown of

coarse-grained source rocks, granite and granitic sandstone supplied mostly quartz and feldspar (Table 1). The sticking materials are given in Table 2. Each type of beach sand contains mostly quartz and clay minerals on its surface.

The addition of more than 0.1% of the sample weight of the first three mixtures destroyed the sound. More than 0.4% of silent sand and calcite made a feeble sound (Table 3). Next, 1 weight% of the moisture of distilled water was added to the each sound-producing sand. It made a feeble sound. Less than 1% of moisture made the sound clearly.

Discussion

The major element composition of sound-producing sand determined in this study are compared to the composition of selected silent sand in Table 2 and three graphs in Fig. 2. In general, the composition of sound-producing sand shows a high concentration of SiO₂, more than 90 weight%. Our samples showed more than 61 weight% of SiO₂ concentration in sound-producing sand, as did the silent sand. The concentration of SiO₂ in silent sand ranged from 66.8 to 94.7 weight%. The relatively high SiO₂, Al₂O₃ and Na₂O composites were quartz and feldspar.

A plot of Al₂O₃ vs. SiO₂, Al₂O₃ vs. CaO and Al₂O₃ vs. Na₂O (Fig. 2) reveals important characteristics of beach sands. The sands in this figure are divided into two classes with respect to their SiO₂ and Al₂O₃ composition. A negative correlation of Al₂O₃ vs. SiO₂ indicates that the beach sand is composed of mainly quartz and feldspar, and a positive correlation between Na₂O and Al₂O₃ is due to the Na-feldspar content.

A high quartz/feldspar ratio automatically suggests that almost all of the unstable minerals had been removed by chemical weathering, erosion or transportation by river water. The ratio cannot tell much about the original source rock composition if the sand derived from it is all quartz, because there is a limit as to how closely quartz varieties correspond to rock compositions. It is difficult to distinguish that these quartz grains were not derived by erosion of an older granite exposed at the surface.

Table 2 Major minerals and wrapping clay minerals of the sound-producing sand and the silent sand

Location	Major minerals		Wrapping clay minerals				
	Quartz	Feldspar	Illite	Hornblen	Chamosite	Biotite	Muscovite
Sound producing sand beach							
1. Kugunarihama (Oshima)	rich	poor	○		△	△	
2. Kukunakihama	rich	poor	○		△	△	
3. Natsuhama	rich	poor				△	△
4. Takehama	poor					△	
5. Murohama	poor			△			
Sound reproducing sand							
8. Shirahama	rich	poor	○	△	△	△	
Silent sand beach							
9. Kugunarihama(Oshika peninsula)	rich	poor	○	△	△		
10. Tsukihama	poor	rich	○				
11. Ohama	poor	rich	○				
12. Otomehama	rich	rich	○				

The open circle indicates a remarkable mineral and the triangle is a second remarkable mineral.

Table 3 Five different samples are added to sound-producing sand

Sample	Amount added/gram					
	0.01	0.02	0.03	0.04	0.05	0.06
Bentnite	○	×	×	×	×	×
FeO(OH)	×	×	×	×	×	×
Silent sand	○	○	○	△	×	×
Calcite	○	○	○	△	×	×
Loam	△	×	×	×	×	×

A small grain, such as bentnite, FeO(OH) or soil destroyed the sound; even 0.1% was added by weight (indicated with ×). The open circle indicates the sound and the triangle indicates a feeble sound.

The importance of cleanness of the grain surface has been noticed by many researchers.^{2,4,12} There are some sticking minerals, including clay minerals, found in each of the beach sands (Table 2). The cleanness of the grain surface is an important factor for sand to make sound; however, it seems that a small portion of any contamination on the surface does not affect the sound process. The results of solid experiments (Table 3) also provide that a few, less than 0.1% by weight, surface contaminations do not influence the sand to produce sound.

A very dry condition is required for the sounding process. Our experiments found that as a unique consequence, a drop of moisture, less than 0.1 weight%, creates the friction between grains to vibrate each other, thus creating sound (Table 4). The sound-producing mechanism of beach sand is effective under 0.1% wet by weight or dry conditions, but much more effective when the sand is dry.

Conclusions

Our study on sound-producing sand in Japan indicates that at least 60 weight% of quartz grains are necessary for sand to produce sounds. XRD and XRF analyses indicate that major minerals are quartz and feldspar for both sound-producing sand and silent sand. Small amounts of clay minerals are present in both sound-producing sand and silent sand. Illite is found in the

Fig. 2 Three different chemical compositions normalized to the Al_2O_3 values of each sample. A) SiO_2 vs. Al_2O_3 for the sound-producing sand and silent sand. B) Na_2O vs. SiO_2 . C) CaO vs. Al_2O_3 . Each symbols correspond to the entries listing in Table 1.

surface of all silent sand samples. 0.1 weight% of contamination, such as clay minerals, iron hydroxide and soil, destroyed the sound. 0.4 weight% of silent sand and calcite

Table 4 Ten different values of water are added to each 10 g of 7 sound producing sand samples

Amount added/ml	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	1.00
Sound producing sand										
1. Kugunarihama(Oshima)	○	○	○	○	○	○	○	△	△	×
2. Kukunakihama	○	○	○	○	○	○	○	△	△	×
3. Natsuhama	○	○	○	○	○	○	△	△	×	×
4. Takehama	○	○	○	○	○	○	○	△	△	×
5. Murohama	○	○	○	○	○	○	△	△	×	×
6. Idegahama	○	○	○	○	○	○	△	△	×	×
7. Aoya beach	○	○	○	○	○	○	△	△	×	×

1 weight % of water/moisture made a feeble sound (×). Clear sound is indicated by an open circle, and a feeble sound by a triangle.

made a feeble sound. The sound-producing beach sand produces sound under 0.1% wet or dry conditions, although it is much more effective when the sand is dry.

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