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CHARACTERISTICS OF DRIFT PUMICE CLASTS ALONG THE COAST OF THE JAPANESE ISLANDS: THE AT TEPHRA, REPRESENTATIVE SOURCE OF DRIFT PUMICE CLASTS

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Abstract We analyzed the major element composition of volcanic glass shards in drift pumice clasts sampled from the Japanese coast before the 2021 eruption of Fukutoku-Oka-no-Ba (FOB). Consequently, it has been explained that the source volcanoes of some drift pumice clasts are Shikotsu, Toya, Towada, Hakone, Aso, Aira, Ata, Baegdusan volcanoes, and submarine volcanoes FOB and NNE of Iriomotejima (SVI). In particular, drift pumice clasts estimated from the Aira volcano were found in broad areas from the Amami-Oshima to the Shimokita Peninsula, the southern and northern limits of our sampling sites, respectively. Furthermore, the Aira-Tn tephra, erupted from Aira volcano, forming a wide pyroclastic flow plateau in the southern part of Kyushu Island. Therefore, we interpreted that the reworking process of pyroclastic flow deposits is one of the major mechanisms of the continuous supply of pumice clasts into the sea, regardless of whether volcanic activity continues. In addition, the presence of drift pumice clasts from the FOB and SVI suggests that pumice clasts from a single submarine volcanic eruption can remain on the coast for at least several tens to a hundred years.

Keywords: Marine debris, drift pumice, volcanic glass, glass chemistry

1. Introduction

Pumice included in tephra (e.g., ash fall deposits, pumice fall deposits, and pyroclastic flow deposits), referring to products of volcanic eruptions, is commonly porous and can float on the water in the case where the specific gravity is below 1. Thus, once pumice clasts float on the water in the sea, they continue to drift in the area. On the other hands, they stop drifting when they are washed up on the coast or sink to the seafloor due to the filling of the pores by water or biofouling (e.g., Kato 2009). It has been pointed out that the ocean currents at the time of the eruption can be reconstructed by identifying pumice clasts and their sources at many marine sediment cores because pumice are transported by ocean currents (Aoki and Arai 2000). However, because large-scale pumice drift directly caused by volcanic eruption is a less-frequent geological event (Bryan *et al.* 2012), the studies on drift pumice primarily focus on a single drifting event or limited sampling sites in one area (e.g., Sawada *et al.* 2003; Jutzeler *et al.* 2014). More fundamental research is therefore needed as follows: how to produce drift pumice (production process), route and duration of drifting (transport process), and depositional conditions (depositional process).

On August 13, 2021, Fukutoku-Oka-no-Ba (FOB), a submarine volcano in the Ogasawara Islands (Bonin Islands), erupted, and numerous pumice clasts were supplied to the sea. Consequently, clasts were washed up on coasts all over the Japanese Islands and some countries in Southeast Asia (Yoshida *et al.* 2022). However, no volcanic eruptions that potentially supply large amounts of pumice clasts into the sea occurred around Japan for about 35 years between the 1986 FOB eruption (Kato 1988) and the 2021 FOB eruption. Here, to preliminary discuss the production process of drift pumice clasts during the absence of volcanic eruptions, we attempted to identify source volcanoes by analyzing the major element composition of volcanic glass shards in drift pumice clasts sampled from the coast of the Japanese Islands before the 2021 FOB eruption.

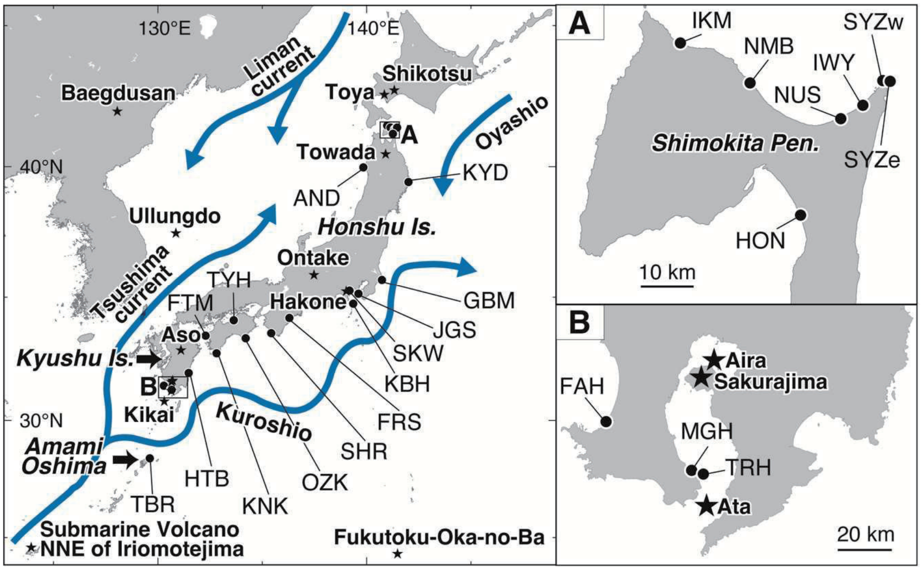

Fig. 1 Location map of sampling sites, estimated source volcanoes of drift pumice clasts, and main ocean currents surrounding the Japanese Islands. See Table 1 and Supplement 2 for more information on locations sampled drift pumice clasts.

2. Methodology

Sampling and classification of drift pumice clasts

We used GSI Maps provided by Geospatial Information Authority of Japan and Google Maps of aerial photographs, and Google Street View to confirm coastal topography, beach conditions, and the presence or absence of drifted objects to choose favorable sampling sites for drift pumice clast collection. Drift pumice clasts were found on most of the Japanese coasts. However, if pyroclastic deposits were exposed behind the coast, it was challenging to distinguish them from drift pumice. Thus, such sites were avoided. This study sampled drift pumice clasts at 22 sites between March 2018 and December 2019, before the 2021 FOB eruption (Fig. 1, Table 1). The time for sampling and description was about 1 h per beach for a person. We sampled as many drift pumice clasts as possible over 1 cm in diameter as sufficient samples were needed for the analysis. In the laboratory, their color, degree of porosity, heavy mineral content, and shape were first

Table 1 Sampling locations of drift pumice clasts

No.	Location name	Sampling date	Latitude	Longitude	Number of pumice clasts analysed (Sample name)
1	Ikokuma, Kazamaura-mura, Aomori (IKM)	29/Jul/2018	41°29'31.1"N	140°59'28.7"E	4 (IKM-1, 2, 3, 4)
2	Nimaibashi, Mutsu-shi, Aomori (NMB)	27/Jul/2018	41°25'26.14"N	141°08'58.85"E	8 (NMB-1, 2, 3, 4, 5, 6, 7, 8)
3	Noushi, Higashidori-mura, Aomori (NUS)	28/Jul/2018	41°21'45.39"N	141°21'19.76"E	4 (NUS-1, 2, 3, 4)
4	Iwaya, Higashidori-mura, Aomori (IWY)	28/Jul/2018	41°23'08.6"N	141°24'21.2"E	3(IWY-1, 2, 3)
5	West side of Shiriyazaki, Higashidori-mura, Aomori (SYZw)	29/Jul/2018	41°25'31.92"N	141°27'27.16"E	2 (SYZw-1, 2)
6	East side of Shiriyazaki, Higashidori-mura, Aomori (SYZe)	29/Jul/2018	41°25'40.33"N	141°27'49.61"E	4 (SYZe-1, 2, 3, 4)
7	Hamaokunai, Mutsu-shi, Aomori (HON)	28/Jul/2018	41°11'53.91"N	141°15'50.96"E	4 (HON-1, 2, 3, 4)
8	Anden coast, Oga-shi, Akita (AND)	29/Sep/2018	39°58'24.89"N	139°51'00.76"E	4 (AND-1, 2, 3, 4)
9	Koyadori, Yamada-machi, Iwate (KYD)	13/Apr/2018	39°25'46.76"N	142°00'36.04"E	3 (KYD-1, 2, 3)
10	Gyobu-misaki, asahi-shi, Chiba (GBM)	26/Aug/2019	35°41'33.82"N	140°44'22.54"E	4 (GBM-1, 2, 3, 4)
11	Jogashima, Miura-shi, Kanagawa (JGS)	18/Nov/2018	35°08'04.24"N	139°36'35.28"E	6 (JGS-1, 2, 3, 4, 5, 6)
12	Sakawa coast, Odawara-shi, Kanagawa (SKW)	17/Feb/2019	35°15'45.39"N	139°11'12.43"E	3 (SKW-1, 2, 3)
13	Kobohama, Oshima-machi, Tokyo (KBH)	3/Nov/2018	34°44'31.96"N	139°21'25.72"E	5 (KBH-1, 2, 3, 4, 5)
14	Furusato beach, Kihoku-cho, Mie (FRS)	15/Jun/2019	34°10'51.90"N	136°18'23.15"E	3 (FRS-1, 2, 3)
15	Shihara coast, Shirahama-cho, Wakayama (SHR)	15/Jun/2019	33°34'12.54"N	135°25'52.87"E	5 (SHR-1, 2, 3, 4, 5)
16	Toyohama, Kanonji-shi, Kagawa (TYH)	11-12/Aug/2018	34°05'06.10"N	133°38'10.91"E	7 (TYH-1, 2, 3, 4, 5, 6, 7)
17	Ozaki, Muroto-shi, Kochi (OZK)	25/Dec/2019	33°22'08.27"N	134°12'19.25"E	2 (OZK-1, 2)
18	Kainokawa, Tosashimizu-shi, Kochi (KNK)	19/Aug/2019	32°45'41.57"N	132°48'53.01"E	2 (KNK-1, 2)
19	Futami, Ikata-cho, Ehime (FTM)	19/Aug/2019	33°27'52.77"N	132°17'22.19"E	3 (FTM-1,2, 3)
20	Hitotsuba coast, Miyazaki-shi, Miyazaki (HTB)	21/Sep/2018	31°57'15.09"N	131°28'30.19"E	5 (HTB-1, 2, 3, 4, 5)
21	Fukiagehama, Minamisatsuma-shi, Kagoshima (FAH)	19/Aug/2018	31°26'29.25"N	130°16'59.46"E	8 (FAH-1, 2, 3, 4, 5, 6, 7, 8)
22	Miyagahama, Ibusuki-shi, Kagoshima (MGH)	15/Mar/2018	31°16'44.50"N	130°37'08.46"E	6 (MGH-1, 2, 3, 4, 5, 6)
23	Tarahama, Ibusuki-shi, Kagoshima (TRH)	15/Mar/2018	31°15'58.95"N	130°39'52.50"E	3 (TRH-1,2, 3)
24	Tebiro coast, Tatsugo-chi, Kagoshima (TBR)	4/Mar/2019	28°24'13.72"N	129°37'11.94"E	4 (TBR-1, 2, 3, 4)

described. Then, they were divided into several groups, and a few pumice clasts per group were selected for the analysis described in the next section. Additional information on individual characteristics (size, color, and shape) of the analyzed drift pumice clasts are presented in Supplement 1.

Major element composition of volcanic glass shards (EPMA analysis)

Volcanic glass shards in drift pumice clasts were analyzed using a wavelength dispersive electron probe microanalyzer (EPMA). In addition, 20 tephra samples were analyzed using EPMA as the reference and compared with the EPMA analysis of drift pumice clasts. The following tephra for the type tephra samples was used in this study. If no reference was noted, the eruption age was based on Machida and Arai (2003). We used the Shikotsu-Daiichi Ignimbrite (Spfl: 42–44 ka), Shikotsu-Daiichi Pumice (Spfa-1: 42–44 ka), Toya tephra (Toya: 112–115 ka), Ontake-Daiichi Pumice (On-Pm1: 100 ka), Towada-Ofudo tephra (To-Of: ≥32 ka), Towada-Hachinohe tephra (To-H: 15 ka), Towada-Chuseri tephra (To-Cu: 6 ka), Towada-a tephra (To-a: AD 915), Hakone-Tokyo tephra (Hk-TP: 60–65 ka), Aso-4 tephra (Aso-4: 85–90 ka), Ata tephra (Ata: 105–110 ka), Aira-Tn tephra (AT: 30 ka; Albert *at al.* 2019), Sakurajima-Taisho tephra (Sz-Ts: AD 1914), Kikai-Tozurahara tephra (K-Tz: 95 ka), Kikai-Akahoya tephra (K-Ah: 7.3 ka), 1986 FOB pumice (1986 FOB: AD 1986; Tsuchide and Sato 1986), 1924 Submarine Volcano NNE of Iriomotejima pumice (1924 SVI: AD 1924; Seki 1927), Baegdusan-Tomakomai tephra (B-Tm: 1 ka), Ulleung-Oki tephra (U-Oki: 11 ka; Okuno *et al*. 2010), and U-2 tephra (U-2: 5.6 ka; Okuno *et al.* 2010). Details of the type tephra samples are presented in Supplement 2.

Pumice clasts were crushed one by one using mortar and pestle and then washed through ultrasonic bath. The samples were sieved using disposable nylon mesh into three fractions: less than 62 μm, 62–120 μm, and more than 120 μm. Volcanic glass shards in the 62–120-μm size fraction were used for the EPMA analysis at the Center for Advanced Marine Core Research, Kochi University. The EPMA was operated at 15 kV using a 10 nA beam current, a 10 μm beam diameter, and counting times of 10 s at peak and 5 s at the background according to Aoki and Machida (2006). At the beginning and end of the analysis, we analyzed the AT (Machida and Arai 2003) sampled at Chigaki, Tateyama Town, Toyama Prefecture and the obsidian sampled at Wadatoge, Nagano Prefecture. The AT was used as a working standard and the obsidian was used to check the stability of the analyzer and the reproducibility of the measurements.

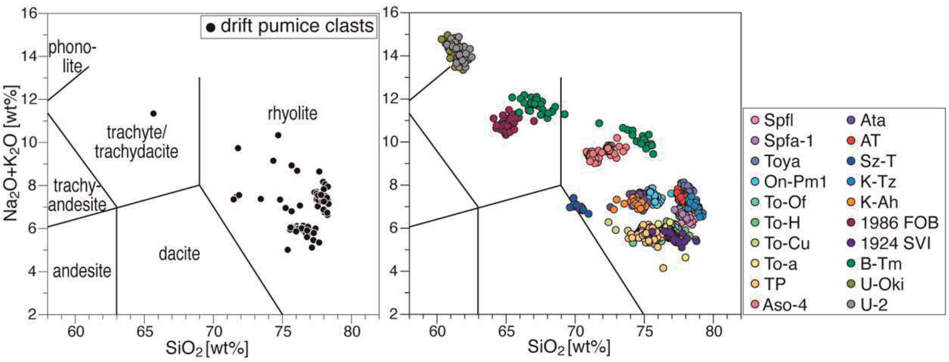

Fig. 2 Characteristics of the major element composition of volcanic glass shards in type tephra samples and drift pumice clasts. Rock types are classified based on Le Bas *et al.* (1986). The average chemical compositions are plotted in the left figure, and the individual chemical composition values are plotted in the right figure.

3. Result and Discussion

Figure 2 presents the total alkali-silica (TAS) diagram created by Le Bas *et al.* (1986), which is used to classify volcanic rocks. For U-Oki, U-2, and B-Tm, which erupted from the volcano on the back arc side, the major element composition of volcanic glass shards (Table 2) is notably high in alkaline elements (Na_2O+K_2O), and U-Oki and U-2 are mainly plotted in the phonolite area. B-Tm shows the bimodal distribution or wide range of SiO_2 with 65–70 wt.% and 73–76 wt.% and is plotted in the trachyte/trachydacite to rhyolite areas. The 1986 FOB pumice also exhibits high alkali and low SiO_2 composition and is plotted in the trachyte/trachydacite area. Sz-Ts is composed of 4.06 wt.% FeO* and 3.06 wt.% CaO. It is characteristically rich in mafic components plotted in the dacite to rhyolite areas. Other type tephra samples are plotted in the rhyolite area. However, the major element composition of volcanic glass shards in drift pumice clasts (Supplement 3) is plotted in the area of trachyte/trachydacite for only one sample on the TAS diagram. Contrarily, the other 101 samples are plotted in the area of rhyolite.

The drift pumice clasts were identified as follows based on the major element composition of volcanic glass shards in type tephra samples: 48 samples (sampling site: IKM, NMB, SYZw, SYZe, GBM, JGS, KBH, FRS, SHR, TYH, OZK, KNK, FTM, HTB, FAH, MGH, TRH, TBR; Fig. 1) are AT from Aira volcano; 17 samples (IKM, NMB, NUS, IWY, SYZe, HON, AND, KYD, TBR) are To-Of, To-H, To-Cu, and To-a from Towada volcano; 4 samples (IKM, JGS, OZK) are 1924 SVI pumice from SVI; 3 samples (NUS, SYZe) are Toya from Toya volcano; 3 samples (SKW) are TP from Hakone volcano; 1 sample (HON) is Spfa-1 and Spfl from Shikotsu volcano; 1 sample (KBH) is Aso-4 from Aso volcano; 1 sample (MGH) is Ata from Ata volcano; 1 sample (TBR) is 1986 FOB pumice from FOB; and 1 sample (TYH) is B-Tm from Baegdusan volcano

Table 2 Major element composition of volcanic glass shards in type tephra samples

Sample	Spfl		Spfa-1		Toya		On-Pm1		To-Of		To-H		To-Cu		To-a		TP (upper)		TP (middle)		TP (lower)	
(wt %)	ave.	std.	ave.	std.	ave.	std.	ave.	std.	ave.	std.	ave.	std.	ave.	std.	ave.	std.	ave.	std.	ave.	std.	ave.	std.
SiO_2	78.12	0.3	77.68	0.2	78.09	0.2	75.73	0.3	77.06	0.5	76.29	1.0	74.72	0.7	76.95	0.3	75.27	0.5	75.00	0.3	75.28	0.5
TiO_2	0.15	0.0	0.14	0.1	0.05	0.0	0.13	0.0	0.32	0.0	0.35	0.1	0.44	0.0	0.36	0.1	0.49	0.1	0.47	0.1	0.45	0.1
Al_2O_3	12.30	0.2	12.30	0.1	12.52	0.1	13.74	0.2	12.48	0.2	13.00	0.5	13.43	0.5	12.59	0.2	12.82	0.3	13.03	0.2	12.99	0.4
FeO*	1.26	0.2	1.49	0.1	0.96	0.1	1.11	0.1	1.75	0.2	1.86	0.2	2.38	0.1	1.76	0.1	2.61	0.2	2.55	0.1	2.49	0.1
MnO	0.05	0.0	0.05	0.0	0.09	0.0	0.10	0.0	0.09	0.0	0.09	0.0	0.10	0.0	0.10	0.0	0.10	0.0	0.10	0.0	0.11	0.0
MgO	0.16	0.0	0.16	0.0	0.04	0.0	0.23	0.0	0.38	0.1	0.47	0.1	0.57	0.1	0.41	0.0	0.52	0.1	0.55	0.0	0.54	0.1
CaO	1.37	0.1	1.44	0.1	0.38	0.0	1.50	0.1	1.98	0.2	2.27	0.3	2.65	0.2	2.01	0.1	2.43	0.1	2.53	0.1	2.44	0.2
Na_2O	3.83	0.1	4.05	0.1	4.75	0.1	3.77	0.1	4.56	0.1	4.37	0.2	4.38	0.2	4.35	0.3	4.53	0.1	4.51	0.4	4.50	0.2
K_2O	2.74	0.1	2.68	0.1	3.12	0.1	3.69	0.1	1.38	0.1	1.31	0.1	1.32	0.1	1.46	0.1	1.23	0.1	1.26	0.1	1.20	0.1
Total**	97.36	1.4	95.37	0.8	95.12	0.8	94.39	0.7	97.74	1.4	96.27	1.5	98.69	1.6	98.52	1.9	98.32	1.0	97.44	0.9	97.25	1.6
n	49		33		29		43		37		35		26		33		28		28		24	
Sample	Aso-4		Ata		AT		Sz-Ts		K-Tz		K-Ah		1986 FOB		1924 SVI		B-Tm		U-Oki		U-2	
(wt %)	ave.	std.	ave.	std.	ave.	std.	ave.	std.	ave.	std.	ave.	std.	ave.	std.	ave.	std.	ave.	std.	ave.	std.	ave.	std.
SiO_2	72.04	0.7	74.80	0.9	77.90	0.3	70.19	0.4	78.62	0.3	74.37	0.5	65.14	0.5	77.15	0.5	70.33	3.8	61.25	0.5	61.55	0.4
TiO_2	0.42	0.1	0.47	0.1	0.12	0.0	0.74	0.1	0.23	0.0	0.54	0.1	0.53	0.1	0.14	0.0	0.32	0.1	0.50	0.1	0.45	0.1
Al_2O_3	14.72	0.4	13.02	0.3	12.12	0.2	13.98	0.2	11.68	0.1	12.90	0.2	16.14	0.3	12.49	0.3	13.02	2.1	19.08	0.2	19.14	0.2
FeO*	1.66	0.2	2.08	0.3	1.24	0.1	4.06	0.2	1.13	0.1	2.53	0.2	3.93	0.2	2.46	0.2	4.34	0.4	2.98	0.3	2.85	0.2
MnO	0.11	0.0	0.10	0.0	0.05	0.0	0.10	0.0	0.05	0.0	0.08	0.0	0.17	0.0	0.11	0.0	0.11	0.0	0.15	0.0	0.15	0.0
MgO	0.37	0.1	0.43	0.1	0.13	0.0	0.88	0.0	0.19	0.0	0.47	0.1	0.98	0.1	0.09	0.0	0.08	0.1	0.29	0.1	0.24	0.0
CaO	1.17	0.2	1.79	0.2	1.10	0.1	3.06	0.1	1.04	0.1	1.96	0.2	2.28	0.2	1.98	0.1	0.78	0.5	1.50	0.2	1.40	0.1
Na_2O	4.73	0.2	4.24	0.2	3.75	0.1	4.20	0.1	3.59	0.2	4.16	0.2	5.17	0.2	4.39	0.2	5.56	0.4	6.73	0.5	6.92	0.3
K_2O	4.78	0.3	3.08	0.2	3.60	0.1	2.78	0.1	3.48	0.1	2.98	0.1	5.67	0.2	1.19	0.1	5.47	0.5	7.52	0.3	7.30	0.3
Total**	97.53	1.4	95.80	1.8	95.99	1.3	97.15	2.1	94.47	0.5	97.32	1.8	98.83	1.4	98.7	2	98.43	1.8	98.75	1.2	98.5	2
n	48		36		134		16		42		27		52		38		48		40		34	

Average composition (wt%) and standard deviation are shown in the ave. column and the std. column. *: total iron oxide as FeO. **: raw data before recalculations to 100 % on a water-free basis. See Supplement 1 for more information about the analyzed tephras as reference.

In this study, we focused on the drift pumice clasts from Aira volcano, which is the most widely distributed, and conducted preliminary discussions about their production processes. Drift pumice clasts estimated from Aira volcano were found in broad areas, from the Amami-Oshima (TBR) to the Shimokita Peninsula (IKM, NMB, SYZw, SYZe), the southern and northern limits of our sampling sites, respectively. The AT eruption erupted from Aira volcano at 30 ka (Albert *et al.* 2019) is one of the most significant eruptions in the Japanese Islands. The AT is the generic name including pumice fall deposits (e.g., Osumi pumice fall (A-Os) deposit), pyroclastic flow deposits (e.g., Tsumaya pyroclastic flow deposit, Ito Ignimbrite deposit), and ash fall deposits (e.g., Aira-Tn ash fall deposit) from the AT eruption (Machida and Arai 2003). Drift pumice clasts from the AT eruption drifting to the present coasts may have entered the sea at the time of the eruption or have been transported to the sea by mass movement after the eruption. It is difficult to assume that drift pumice clasts that flowed into the sea immediately after the eruption would have kept on drifting for about 30,000 years and existed on the present coasts. The Ito ignimbrite, on the other hands, formed a wide pyroclastic flow plateau called "Shirasu Daichi" in the southern part of Kyushu Island and is widely exposed along the rivers and coasts around the source (Machida and Arai 2003; Takarada *et al.* 2022). Thus, pumice clasts from pyroclastic flow deposits are reworked by recent mass movement and are thought to be distributed on the present coast.

Then, we focus on the volume of the AT eruption. The original volume at the time of eruption of the Ito ignimbrite was 500–600 km^3, and that of the Aira-Tn ash fall, which is co-ignimbrite ash of the Ito ignimbrite, was calculated to be about 300 km^3. Therefore, the total volume of the Ito ignimbrite and Aira-Tn ash fall is estimated to be 800–900 km^3 (Takarada *et al.* 2022), which means that the Volcanic Explosivity Index (VEI) of the AT eruption is calculated to be 7. VEI 7 eruptions (volume of erupted tephra: 100–1000 km^3) occurred only nine times in the past 125,000 years (Machida and Arai 2003). Consequently, the Ito ignimbrite deposits are one of Japan's

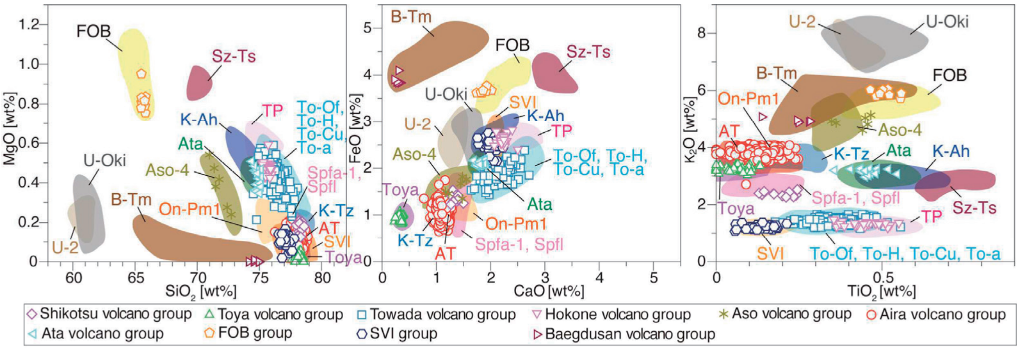

Fig. 3 Major element composition of volcanic glass shards by EPMA. Shikotsu volcano group (HON-4), Toya volcano group (NUS-1, 2, SYZe-4), Towada volcano group (IKM-1, NMB-4~6, NUS-3, 4, IWY-2, SYZe-2, HON-3, AND-1~4, KYD-1~3, TBR-1), Hakone volcano group (SKW-1~3), Aso volcano group (KBH-5), Ata volcano group (MGH-3), Aira volcano group (IKM-3, NMB-1, SYZw-2, SYZe-1, GBM-1~4, JGS-1, 2, 6, KBH-1~4, FRS-1, SHR-1~4, TYH-1, 5, OZK-1, KNK-1, 2, FTM-1~3, HTB-1~5, FAH-1~8, MGH-1, 2, 4, 6, TRH-2, 3, TBR-2), Baegdusan volcano group (TYH-7), FOB group (TBR-3), SVI group (IKM-4, JGS-3, 4, OZK-2).

largest pyroclastic flow deposits. The present volume of the Ito ignimbrite deposit is 71.7 km^3, and the current distribution area is calculated to be 2.62×10^9 km^2 (Takarada *et al.* 2022). Because the Ito ignimbrite deposits are widespread on terrestrial areas, it is expected that pumice from the AT eruption will continue to flow into the sea and produce drift pumice clasts. Besides Aira volcano, pyroclastic flow deposits are widely distributed around Shikotsu, Toya, Towada, Aso, and Ata volcanoes (Machida and Arai 2003), suggesting that drift pumice clasts from these volcanoes, as well as these from Aira volcano, are likely to be reworks of pyroclastic flow deposits. For these reasons, we speculate that the reworking process of pyroclastic flow deposits and pumice fall deposits widely distributed on land is one of the major mechanisms of the continuous supply of pumice clasts into the sea, regardless of whether volcanic activity continues or not.

Meanwhile, some drift pumice clasts from Aira volcano exhibit low in FeO* (Fig. 2, Supplement 3), and there are no significant differences in chemical composition other than FeO*. According to Tsukui and Aramaki (1990), the compositions of whole rock chemistry and phenocryst minerals in the series of the AT eruption are uniform, and no systematic changes are observed, except for slight differences. However, they said that the middle and lowermost parts of A-Os, the earliest product of the AT eruption, are slightly rich in SiO_2, K_2O, and Rb and poor in FeO*, MgO, and Sr. Moreover, Nagahashi *et al.* (2022) reported the presence of the Aira-Tn ash fall and A-Os in the marine sediment core from off Wakasa Bay, central Japan Sea. Although the deposits' chemical composition of volcanic glass shards is similar, A-Os is slightly rich in SiO_2 and slightly lower in FeO*. Thus, even if the pumice is from a series of the same eruption, the chemical composition may vary from unit to unit. Therefore, to identify the source tephra of drift pumice clasts, it would be ideal to analyze multiple pumice clasts from all members of the eruption and make type sample data of each member.

FOB and SVI recently provided pumice clasts into the sea during submarine eruptions. Therefore, pumice clasts from those two volcanoes were supplied into the sea immediately after the FOB eruption in AD 1986 (Tsuchide and Sato 1986) and the SVI eruption in AD 1924 (Seki 1927), which provided a large number of pumice clasts into the sea and caused pumice rafts. For this reason, it was interpreted that the pumice clasts from those two volcanoes were supplied into the sea immediately after the eruption and have persisted along the coast thereafter. Consequently, the presence of drift pumice clasts from these two submarine volcanoes suggests that a large amount of drift pumice from a single submarine volcanic eruption will continue to exist on the coast for at least several tens to a hundred years.

In the Japanese Islands, where pyroclastic deposits are partly distributed, drift pumice clasts are found on most coasts. In addition, the sources of many drift pumice clasts are still unknown. In some cases, their sources may be terrestrial volcanoes out of the Japanese Islands and/or unknown submarine volcanoes. Furthermore, it is necessary to analyze more samples of drift pumice clasts collected from several coasts in the future to precisely identify or detect the sources of drift pumice clasts. Therefore, the spatial distribution of drift pumice clasts is one of the most critical information for studying the production, transport, and depositional processes of drift pumice.

4. Conclusions

In this study, to elucidate the characteristics of drift pumice clasts, we analyzed 102 drift pumice clasts sampled from 22 sites before the 2021 FOB eruption using EPMA. Consequently, it was found that the source volcanoes of some drift pumice clasts were Shikotsu, Toya, Towada, Hakone, Aso, Aira, Ata, Baegdusan volcanoes, and submarine volcanoes FOB, and SVI. Particularly, drift pumice clasts originated or derived from Aira volcano and were found in wide areas from the Amami-Oshima to the Shimokita Peninsula. In addition, Shikotsu, Toya, Towada, Aso, Aira, and Ata volcanoes, where pyroclastic flow deposits are widely distributed, are likely to continuously provide pumice clasts into the sea by reworking the pyroclastic flow deposits. However, drift pumice clasts from the 1986 FOB eruption and 1924 SVI eruption were identified, indicating that drift pumice clasts may continue to exist on the coast for at least several tens to a hundred years after a single submarine volcanic eruption.

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