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Title: Petrographic characteristics in the pumice clast deposited along the Gulf of Thailand, drifted from Fukutoku-Oka-no-Ba

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Keywords: pumice rafts; Fukutoku-Oka-no-Ba; Izu-Ogasawara arc; Gulf of Thailand, South China Sea

Abstract

The 2021 eruption of Fukutoku-Oka-no-Ba (FOB) in the northwest Pacific on 13 August 2021 produced a large volume of pumice that drifted westward for ~1300 km to the Nansei Islands, Japan, and some extent. In February 2022, pumice with similar characteristics to the FOB pumice was deposited along along the Gulf of Thailand. The pumice clasts deposited in Songkhla Province, Thailand, were <4 cm in length and rounded. Most of the clasts consisted of clinopyroxene, plagioclase (andesine), and olivine phenocrysts in a vesiculated grey groundmass, with black-coloured spots exhibiting signatures of a basaltic magma. The whole-rock compositions of the pumice are trachytic, with 61 mass% SiO_2 and 9 mass% total alkali (Na_2O + K_2O). The overall characteristics in the pumice from Thailand are similar to those in FOB pumice. These pumice in Thailand were from the 2021 FOB eruption, and drifted >2800 km south-westward across the South China Sea.

Keywords

pumice rafts; Fukutoku-Oka-no-Ba; Izu-Ogasawara arc; Gulf of Thailand, South China

Sea

Introduction

Fukutoku-Oka-no-Ba (FOB) is a submarine volcano in the NW Pacific located at 24° 17.1′ N/141° 28.9′ E, ~5 km northeast of Minami-Iōtō Island and ~1300 km south of mainland Japan (Fig. 1a). The 2021 eruption occurred on the early morning of 13 August (Japan Standard Time) and produced a large amount of pumice that formed rafts drifting to the west by the Kuroshio Counter-current, and drifting to many places in Japan, Taiwan, and Philippines until December (Yoshida et al., 2022). On 9 February 2022, a considerable amount of pumice was deposited on the beaches of Songkhla province in southern Thailand and subsequently at Chumphon and Rayong provinces in the north of the Gulf of Thailand (Fig. 1a, b). This pumice strongly resembles the 2021 FOB pumice collected in Japan. The westward drifting of the FOB pumice was also observed in 1986 eruption at ~200 km off the coast of Vietnam (16° 28.2′ N, 110° 24′ E) on 28 August 1986 (Fig. 1a; Smithsonian Institution, 1986). This paper aims at briefly describing the petrographic and geochemical characteristics of the pumice collected in Thailand, comparing them with other FOB pumice collected in Japan, and documenting the pumice raft dispersal.

Methods

Whole-rock compositions of representative pumice clasts were determined by X-ray fluorescence (XRF) spectrometry (Rigaku ZSX Primus II) at the Japan Agency for Marine-Earth Science and Technology (JAMSTEC), Yokosuka, Japan. Mineral and glass compositions were determined using a field emission gun electron microprobe (EMP) analyzer with five wavelength-dispersive X-ray detectors (JEOL, JXA-8500F) at JAMSTEC. Details of the analytical procedure followed Yoshida et al. (2022).

Petrography and Mineralogy

The pumice clasts investigated in this study were collected from Thung Yai (7° 9.8′ N, 100° 35.9′ E) and Samila (7° 12.6′ N, 100° 37.4′ E) beaches in Songkhla Province, Thailand, on 10 February 2022. The clasts are rounded compared to those collected in the Nansei Islands and are <4 cm in length. Most clasts are monotonously grey in color, although one clast is a mixture of black and grey parts (Fig. 1c). Goose barnacles of <2 cm are often found on the clasts (Fig. 1c). The whole-rock compositions of the representative grey pumice clasts from the two localities are listed in Table S1.

The pumice clasts consist of plagioclase (Pl), clinopyroxene (Cpx), and olivine (Ol) phenocrysts in a vesiculated groundmass of volcanic glass, with a small amount of apatite and opaque minerals (Fig. 2a). In addition, poorly vesiculated black enclaves were identified (Fig. 2b). Representative mineral and glass compositions are listed in Tables S1 and S2, respectively.

The whole-rock compositions yield SiO_2 contents of 61.6 and 61.8 mass% and total alkali (K_2O + Na_2O) contents of 9.2 and 9.1 mass%, respectively, on an anhydrous basis. These are almost identical to the FOB trachyte samples from the 2021 and earlier eruptions (Fig. 2c). EMP analyses of the vesiculated glass in the grey groundmass yield higher SiO_2 (65-66 mass%) and total alkali (10-10.6 mass%), while the interstice of the type-1 black enclaves yield slightly lower SiO_2 (~64 mass%) and higher FeO* (~4.4 mass%).

Plagioclase in the groundmass has X_{An} (=Ca/[Ca+Na+K]) values of 0.41 and 0.32 in the core and rim, respectively. Glass associated with or included as melt inclusions in coarse-grained plagioclase is brown and yields a similar composition to the colourless groundmass glass (Table S1). Clinopyroxene in the groundmass is augite, with Mg# (=Mg/[Mg+Fe] × 100) of 76. Olivine in the groundmass yields Mg# of 65. High-Mg (Mg# ~90) olivine crystals occur in the mixed black and grey pumice clast (SM-01) and are associated with brown glass (Table S2).

The black enclaves consist of clinopyroxene and plagioclase phenocrysts in a poorly vesiculated groundmass with abundant clinopyroxene, plagioclase, and magnetite microlites of <100 μm in length (Fig. 2b). Olivine microlites are possibly also present, although individual analyses could not be carried out due to their small size. Plagioclase phenocrysts in the black enclave have X_{An} values of 0.95, and contain basaltic melt inclusions with SiO_2 contents of 47 mass%. The interstitial glass in the black enclave yields trachytic composition (Table S1). These characteristics are the similar to those of the type-1 black enclave found in the grey FOB pumice (Yoshida et al., 2022)

Implications

The petrographic and geochemical characteristics of the pumice clasts in the raft that arrived in Thailand are similar to those of the FOB pumice observed on the coast of Japan (Yoshida et al., 2022). In particular, the poorly vesiculated black enclaves in the pumice from Thailand are similar to the type-1 black enclaves reported in the FOB pumice. These observations suggest that the pumice raft from the 2021 FOB eruption drifted another ~2800 km from Luzon Strait to Thailand in ~ 80 days (Fig. 1a). The South China Sea (SCS) lies in the monsoon regime, and strong northeast winds prevail over the region during winter (~9 m/s on average; Hu et al., 2000), which enabled the pumice raft to be transported over the SCS.

The areal extent of the raft dispersal would provide a better understanding of pumice rafting and related disaster prevention. Records of the locations and arrival times of pumice rafts are crucial for disaster prevention in the Circum-Pacific belt. An international pumice monitoring network might be required for future large eruptions.

Acknowledgements

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Figure legends

Figure 1 (a) Summary of the arrival dates of drifting pumice modified after Yoshida et al. (2022). Yellow star indicates the raft recognition in 1986 (Smithsonian Institution, 1986). (b) Dark grey pumice deposit at Thung Yai beach in Songkhla Province, Thailand, on 10 February 2022. (c) Grey pumice clasts collected on Samila beach in Songkhla Province, Thailand, with black spots and often with attached goose barnacles. One clast contained a black pumice band.

Figure 2 (a) Photomicrograph of a pumice clast collected from Thung Yai beach (sample TY-1) in Songkhla Province. Plagioclase (Pl), clinopyroxene (Cpx), and olivine (Ol) phenocrysts were observed. The glass adhering to, and as melt inclusions in, Pl phenocrysts is brown, whereas the groundmass glass is colourless. “Vac” indicates a vesicle. (b) Backscattered electron image of the black enclave in TY-1. Anorthite-rich Pl and diopsidic Cpx with an augitic rim occur in the poorly vesiculated groundmass of the black enclave that contained ubiquitous magnetite. (c) Total alkali (Na_2O + K_2O) versus SiO_2 diagram for the classification of volcanic rocks, showing the whole-rock and glass compositions of pumice clasts from Thailand. Previously reported data for pumice rafts from the 2021 eruption of FOB are also shown (Yoshida et al., 2022).

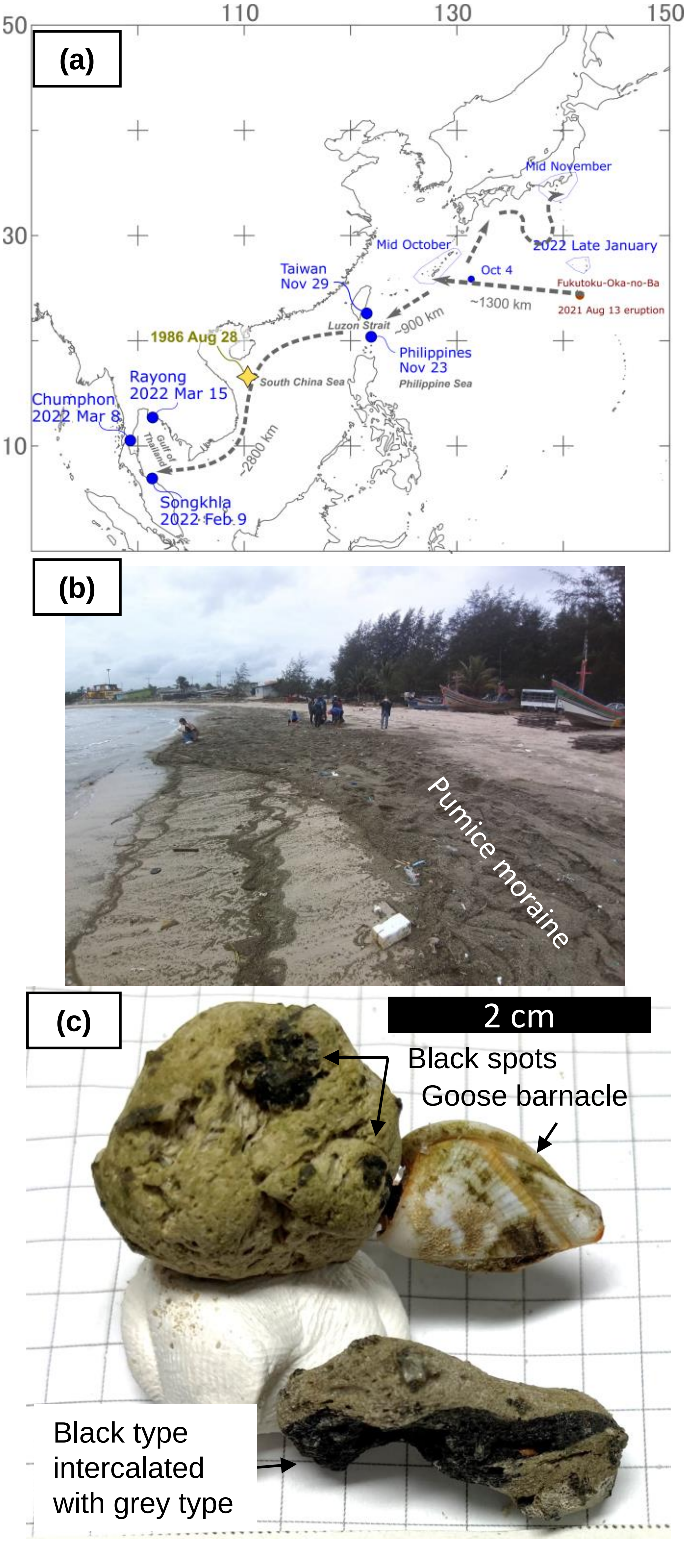
Table S1. Whole rock and groundmass glass compositions of the pumice.

Footnote: FeO*, total iron as FeO. n.a., not analysed.

Table S2. Representative mineral compositions.

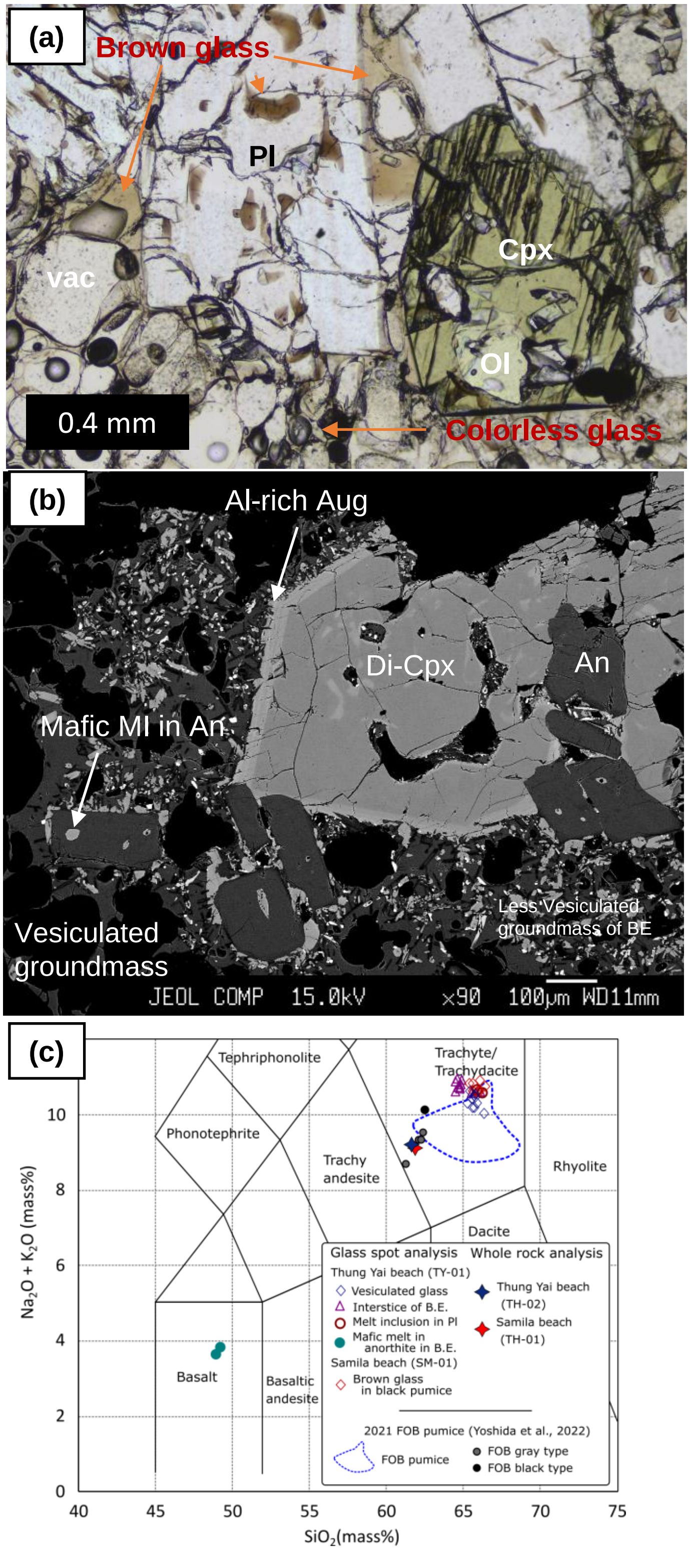
Footnote: FeO*, total iron as FeO. Fe^{3+}/Fe^{2+} was determined as follows: total cation =4 (clinopyroxene), (Fe^{2+} + Mg + Mn) = 1 (magnetite).

Figure 1



(a)
110
130
150
50
30
10
Mid November
Mid October
2022 Late January
Oct 4
Taiwan
Nov 29
Fukutoku-Oka-no-Ba
~1300 km
2021 Aug 13 eruption
Luzon Strait
~900 km
1986 Aug 28
Philippines
Nov 23
South China Sea
Philippine Sea
Rayong
2022 Mar 15
Chumphon
2022 Mar 8
Gulf of Thailand
~2800 km
Songkhla
2022 Feb 9
(b)
Pumice moraine
(c)
2 cm
Black spots
Goose barnacle
Black type
intercalated
with grey type

Figure 2



(a)
Brown glass
Pl
Cpx
vac
Ol
0.4 mm
Colorless glass
(b)
Al-rich Aug
Di-Cpx
An
Mafic MI in An
Vesiculated groundmass
Less Vesiculated groundmass of BE
JEOL COMP 15.0kV ×90 100μm WD11mm
(c)
Tephriphonolite
Trachyte/Trachydacite
Phonotephrite
Trachy andesite
Rhyolite
Dacite
Basalt
Basaltic andesite
Glass spot analysis
Whole rock analysis
Thung Yai beach (TY-01)
Vesiculated glass
Interstice of B.E.
Melt inclusion in Pl
Mafic melt in anorthite in B.E.
Samila beach (SM-01)
Brown glass in black pumice
Thung Yai beach (TH-02)
Samila beach (TH-01)
2021 FOB pumice (Yoshida et al., 2022)
FOB pumice
FOB gray type
FOB black type
$Na_2O + K_2O$ (mass%)
SiO_2(mass%)
0
2
4
6
8
10
40
45
50
55
60
65
70
75

Table S1

	XRF whole rock analysis		EMP spot analysis				
Sample No.	TH-01	TH-02	TY-01				SM-01
locality	Samila beach	Thung Yai beach	Thung Yai beach				Samila beach
			Gray pumice		Black enclave in gray pumice		Black pumice
occurrence			groundmass	melt inclusion in plagioclase	interstice in black enclaves	melt inclusion in anorthite	brown glass
n=			10	10	10	2	8
SiO2	60.748	60.497	65.07	64.94	64.29	46.95	65.35
TiO2	0.567	0.584	0.51	0.48	0.42	0.86	0.48
Al2O3	15.971	16.031	16.22	16.16	16.37	11.33	16.17
Cr2O3	n.a.	n.a.	0.00	0.01	0.03	0.01	0.03
FeO*	5.447	5.589	3.95	3.41	4.41	13.29	3.71
MnO	0.17	0.171	0.17	0.12	0.14	0.22	0.11
MgO	2.51	2.516	1.08	0.75	0.99	8.52	0.82
CaO	4.189	4.094	1.79	1.69	1.70	10.97	1.91
Na2O	4.53	4.602	5.02	5.15	5.23	2.23	5.29
K2O	4.42	4.435	5.22	5.24	5.42	1.35	5.31
P2O5	0.23	0.232	0.16	0.16	0.24	0.16	0.19
F	n.a.	n.a.	0.12	0.12	0.12	0.27	0.09
Cl	n.a.	n.a.	0.29	0.32	0.36	0.12	0.32
total	98.782	98.751	99.60	98.56	99.72	96.27	99.79
LOI	0.64	0.64					

Table S2

Sample	TY-01											SM-01
occurrenc	Gray pumice, phenocryst					Black enclave, phenocryst			Black enclave, microlite			with brown glass
	Pl, core	Pl, rim	Cpx	Ol	Mag	Pl	Cpx, core	Cpx, rim	Pl	Cpx	Mag	Ol
SiO2	57.88	59.88	53.13	37.56	0.12	44.40	50.35	46.268	56.851	44.774	0.268	41.05
TiO2	0.02	0.03	0.29	0.00	10.47	0.00	0.38	0.888	0.139	0.977	7.527	0.01
Al2O3	25.86	24.16	1.55	0.02	2.98	34.40	4.46	8.605	26.035	10.234	3.673	0.02
Cr2O3	0.00	0.04	0.05	0.00	0.01	0.02	0.00	0	0.01	0.02	0.069	0.04
FeO*	0.57	0.47	9.32	30.84	77.97	0.92	6.38	9.272	0.948	10.653	77.843	9.87
MnO	0.03	0.08	0.75	1.87	1.07	0.03	0.20	0.095	0.012	0.146	0.539	0.19
MgO	0.00	0.05	15.26	31.91	2.94	0.10	15.22	12.578	0.121	12.017	2.805	49.10
CaO	8.67	6.72	19.85	0.41	0.06	19.13	22.92	22.064	9.437	20.917	0.115	0.26
Na2O	6.36	7.13	0.40	0.03	0.00	0.57	0.14	0.207	5.602	0.263	0	0.00
K2O	0.79	1.10	0.02	0.00	0.02	0.04	0.01	0.017	0.88	0.042	0.08	0.01
total	100.19	99.66	100.63	102.64	95.62	99.62	100.06	99.99	100.04	100.04	92.92	100.53
O=	8	8	6	4	3	8	6	6	8	6	3	4
Si	2.60	2.69	1.96	1.00	0.00	2.07	1.85	1.72	2.57	1.66	0.01	1.00
Ti	0.00	0.00	0.01	0.00	0.22	0.00	0.01	0.02	0.00	0.03	0.16	0.00
Al	1.37	1.28	0.07	0.00	0.10	1.89	0.19	0.38	1.39	0.45	0.12	0.00
Cr	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fe3+			0.03		0.94		0.10	0.14		0.20	0.98	
Fe2+	0.02	0.02	0.26	0.69	0.85	0.04	0.10	0.14	0.04	0.13	0.87	0.20
Mn	0.00	0.00	0.02	0.04	0.02	0.00	0.01	0.00	0.00	0.00	0.01	0.00
Mg	0.00	0.00	0.84	1.26	0.12	0.01	0.83	0.70	0.01	0.67	0.12	1.78
Ca	0.42	0.32	0.78	0.01	0.00	0.95	0.90	0.88	0.46	0.83	0.00	0.01
Na	0.55	0.62	0.03	0.00	0.00	0.05	0.01	0.01	0.49	0.02	0.00	0.00
K	0.05	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00
XAn	0.41	0.32				0.95			0.46			
XAb	0.54	0.62				0.05			0.49			
Xor	0.04	0.06				0.00			0.05			
Mg#			76	65			89	83		83		