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Petrologic characteristics of the newest stage in Azuma volcano group, Northeast Japan

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ABSTRACT

Basic petrologic properties of the eruptive products of the newest stage of Azuma volcano group were examined. These are calc-alkaline andesite–dacite, possessing petrographic evidence of magma mixing events. The linear whole rock trends indicate the mixing events were between mafic and felsic end-members. Goshikidake (*ca.* 6.5 to 6 ka) and Oana (AD 1331) units show higher than Kofuji (*ca.* 6 to 5 ka) and Issaikyo (*ca.* 5 to 4 ka) units in mafic part of the MgO, MnO, Ni, and Cr diagrams, while the trends converge in the felsic part. During the newest stage the dacitic (64-65 wt% SiO_2) magma reservoir have been stored at shallow crustal level. At the beginning (Goshikidake unit) and the recent (Oana unit) of the newest stage the least differentiated mafic magmas infused into the reservoir which resulted in the eruptions. Whereas, in the middle term (Kofuji and Issaikyo units), the mafic magma would differentiate to some extent before the infusion.

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1. Introduction

In the case of volcanoes of NE Japan, outlines of petrologic features of eruption products were revealed by early studies in 1960s (*e.g.* [1]), and in 1980s, the genesis of basaltic magmas were the main target of volcanic petrology, based on the accumulated data from many volcanoes. After 1990, by the progress of analytical methods, it has become possible to analyze chemical compositions of many rock samples in a shorter time. The information from such many analytical data allow us to reveal sub-volcanic crustal magmatic processes [2-7]. Among these, detailed petrologic studies on the calc-alkaline andesites in northeast Japan have shown that these were derived from magma mixing between mafic and felsic end-members. Further, such studies have become to focus on identical activity of active volcanoes, these are effective to reveal crustal magmatic processes and magma evolution in detail [8-10]. The results of this type of study are also useful to predict future eruption of the studied volcanoes. Such petrologic studies on active volcanoes, however, have not been performed enough in the case of northeast Japan. First of all, it is important to produce enough basic data on the targeted activity of the volcano and characterize these.

In this paper, we show petrologic features of the newest stage in Azuma volcano group, where the eruption history has been already revealed [11].

2. Geological descriptions of the newest stage of Azuma volcano

In NE Japan (Fig. 1), the volcanic front is situated ca. 100 km above the seismic plane of the Pacific Plate, which is subducting at an angle of about 30^{o} westward beneath the North American Plate. The volume distribution of volcanic materials, excluding caldera-related felsic rocks, clearly reveals the existence of two volcanic chains: the frontal row (Nasu volcanic zone) and the back arc row (Chokai volcanic zone) (*e.g.* [1, 12]). These chains are also geochemically distinct, such as lower K_2O and large lithophile elements in the frontal raw (*e.g.* [1]). These across-arc features are observed in many subduction zones [12].

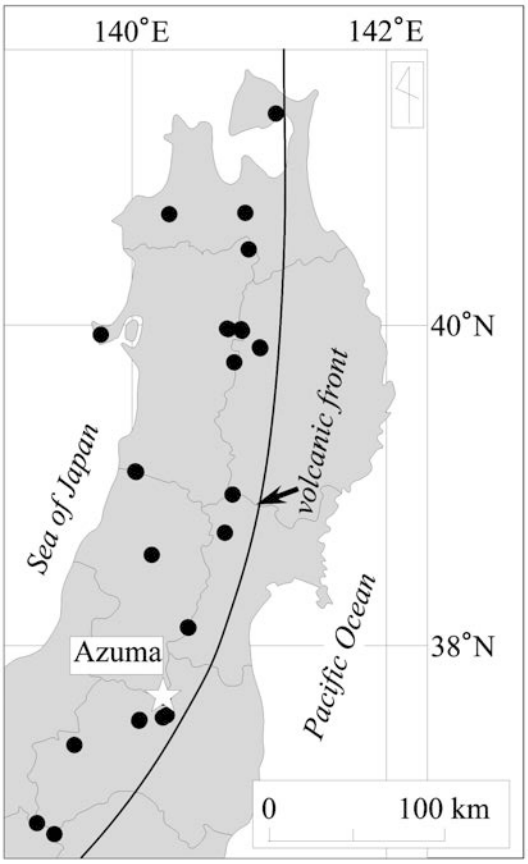

Fig. 1 Locality map of Azuma volcano

The eruption products of the Azuma volcano cover an area of *ca*. 25 km x 15 km. The Azuma volcano is not a typical single stratovolcano but a volcano group comprising many small-sized stratovolcanoes [13]. Many peaks are mainly the result of migration of the eruption center temporally and spatially. The main peaks are Iegatayama (1877 m), Issaikyo (1948.8 m), Higashi-Azumayama (1974.7 m), Kofuji (1704.6 m), and Kohyama (1804.8 m) in the eastern part; Shogensan (1892.6 m), Higashidaiten (1927.9 m), Mamamori (1910.2 m), and Naka-Azumayama (1930.6 m) in the middle part; and Tohjyuhryoh (1860 m), Nakadaiten (1963.6 m), and Nishi-Azumayama (2035 m), Nishidaiten (1981.8 m) in the western part (Fig. 2).

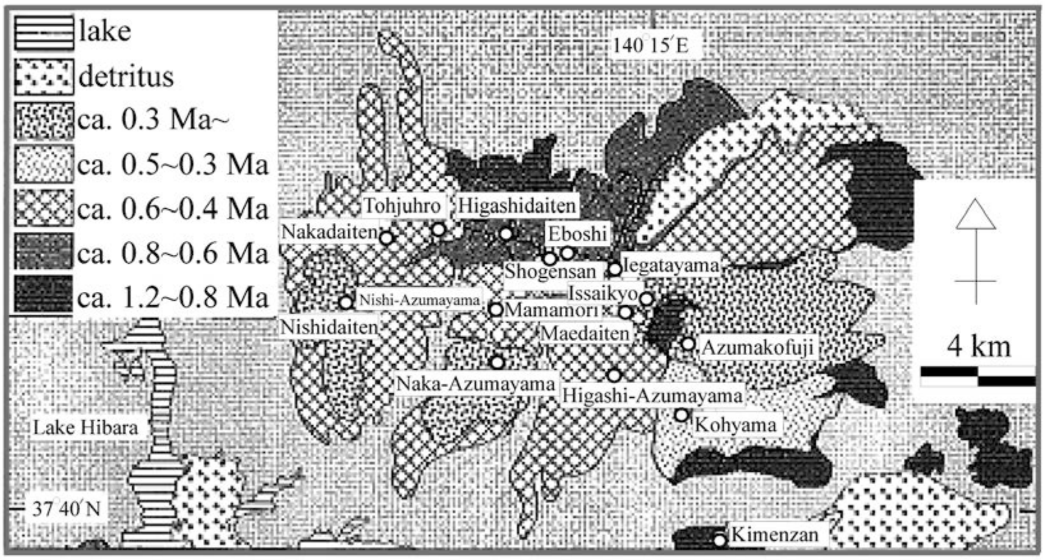

Fig. 2 Geologic outline of Azuma volcano [14]. The ages are estimated based on the data from [15].

Kawano *et al.* [1] and Kuno [16] revealed geologic and petrologic outline of the Azuma volcano. NEDO [15] reported geologic, petrologic, and K-Ar age data on the whole area of the Azuma volcano. Based on the K-Ar data by [15], the volcanic activity can be divided into five periods: 1.2 to 0.8 Ma, 0.8 to 0.6 Ma, 0.6 to 0.4 Ma, 0.5 to 0.3 Ma, and less than 0.3 Ma (Fig. 2). Most of the products are andesitic lava flow, but in the later part of each period, a lava dome or pyroclastic cone tends to be formed in the summit area. Except for the period of 0.5 to 0.3 Ma, the eruption products are distributed widely in the area of the Azuma volcano.

The available K-Ar age data for ca. 0.3 Ma~ period products other than Holocene products distributing around Issaikyo and Kofuji show around 0.3 Ma. Thus it may be *ca*. 300 ky time gap between the most of the ca. 0.3 Ma~ period products and Holocene products. Yamamoto [11] defined the newest stage as the periods of the formation of the Holocene products.

The newest stage is restricted to the area around Issaikyo. According to Yamamoto [11], the eruptions occurred form Goshikinuma crater, Issaikyo-minami craters chain, Oana crater, Tsubakurosawa craters chain, Iwodaira-minami craters chain, Kofuji crater, and

Okenuma crater, which are arranging from northwest to southeast (Fig. 3). Yamamoto [11] revealed the eruption history of the youngest activity based on tephra stratigraphy. The activity began at about 7 ka. The eruption products are composed of pyroclastic fall deposits and lava flows. The former are divided into twelve units. Five of these include Vulcanian fall deposits and the other seven are composed of phreatic eruption fall deposits.

Figure 3 shows the columnar section of a representative outcrop by [11]. The magmatic phases are the Okenuma (*ca.* 7 to 6.5 ka, *ca.* 2 x 10-3 DRE km^3), Goshikidake (*ca.* 6.5 to 6 ka, *ca*. 8 x 10-4 DRE km^3), Kofuji (*ca.* 6 to 5 ka, ca. 4.4 x 10-1 DRE km^3), Issaikyo (*ca*. 5 to 4 ka, *ca*. 5 x 10-4 DRE km^3), and Oana (AD 1331, *ca.* 3 x 10-4 DRE km^3) ones [11]. Pyroclastic cones were formed around the Okenuma and Kofuji crater, but the thickness of the eruption products around the other craters are rather thin. Many lava lobes were flowed from Kofuji crater.

A horse-toe-shaped caldera can be observed in the eastward area of Issaikyo. The age of the formation is not well restricted, but some time between 0.28 and 0.1 Ma [17], when the main edifice composed of some small stratovolcanoes in the eastern part of the Azuma volcano had formed.

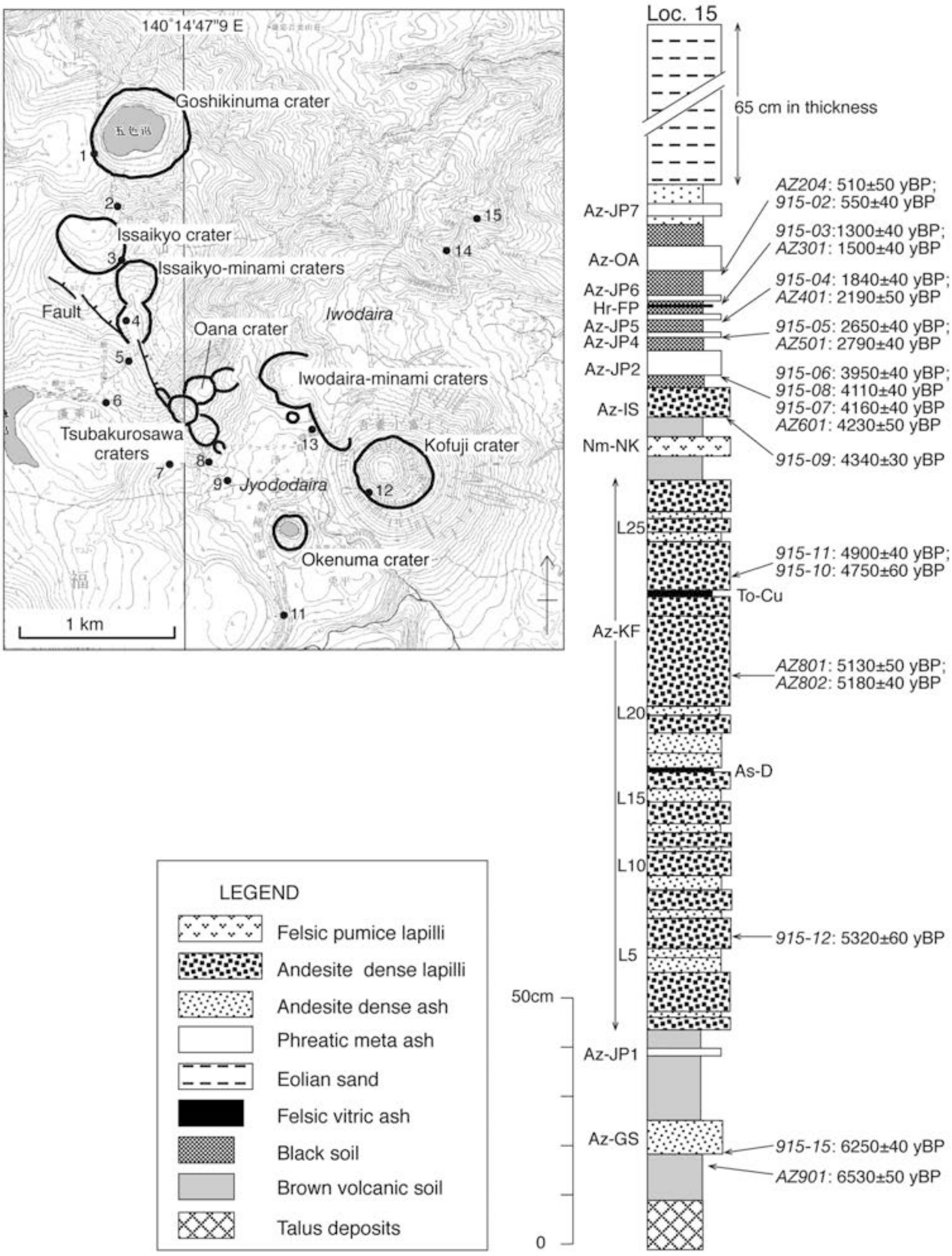

Fig. 3 Locality of craters and columnar section of the representative outcrop [11].

3. Petrographical descriptions of eruption rocks of the newest stage of Azuma volcano

Most of the rocks from the Azuma volcano belong to medium-K calc-alkaline andesite, having phenocrysts of plagioclase and two pyroxene with or without olivine and quartz (e.g., [15]), but tholeiitic rocks are rarely observed [18].

The petrographical features of rocks by magmatic eruptions of the newest stage were reported [11]. With additional information, we will summarize the features below. Also, we show the modal compositions of representative rocks in Table 1. We note that rocks of Okenuma unit are usually weathered, thus these samples are not included in this study.

Table 1 Petrographic characteristics of host rocks and mafic inclusions from the Shirataka volcano

Geologic	Sample name	Phenocryst assemblages	plg A-type	plg B-type	plg C-type	cpx	opx	olv	ox	gm
Oana	OA-mi-H-0510-2		5.8	10.0	2.3	4.5	3.8	1.2	1.2	71.2
	OA-An-1	olv, cpx, opx, plg, ox	6.1	9.9	6.7	3.8	4.5	2.5	1.0	65.5
	OA-GrayDa-2	olv, cpx, opx, plg, ox	5.6	8.3	7.1	4.3	3.8	0.2	1.6	69.1
	OA-Da-1	olv, cpx, opx, plg, ox	6.8	11.3	8.2	4.5	6.2	0.4	0.8	61.8
	OA-I-H-0510-2	olv, cpx, opx, plg, ox	6.7	12.5	5.3	5.6	6.6	2.3	1.3	59.7
	OA-Mi-0510-1(m.i.)	olv, cpx, opx, plg, ox	8.4	10.2	7.8	3.6	2.6	2.3	1.2	63.9
	OA-Mi-0510-2(m.i.)	olv, cpx, opx, plg, ox	11.4	13.1	6.2	7.5	6.3	1.8	0.4	53.3
Issaikyo	IS-An-1	olv, cpx, opx, plg, ox	6.5	7.1	4.4	3.6	3.9	0.2	0.4	73.9
	IS-Da-1	olv, cpx, opx, plg, ox	6.3	10.9	6.8	5.7	6.1	0.2	1.5	62.5
	IS-Sc-1	olv, cpx, opx, plg, ox	2.2	8.2	2.3	2.5	3.3	0.4	4.6	76.5
	IS-baSc-1(black)	cpx, opx, plg, ox	1.7	14.1	1.0	4.3	5.2	-	1.0	72.7
	IS-baSc-1(white)	olv, cpx, opx, plg, ox	1.9	12.7	2.8	4.5	5.3	0.1	0.5	72.2
Kofuji	Loc.15-1	cpx, opx, plg, ox	5.4	12.5	9.5	5.6	4.6	-	1.2	61.2
	KF-resAn-1	olv, cpx, opx, plg, ox	8.9	11.2	8.9	5.0	5.6	0.2	1.0	59.2
	KF-An0606	olv, cpx, opx, plg, ox	3.9	10.1	4.1	3.6	6.0	1.2	0.6	70.5
	KF-GrayDa-1	cpx, opx, plg, ox	1.3	6.0	3.5	3.5	3.0	-	1.0	81.7
	KF-res(pumice)-1	cpx, opx, plg	0.1	4.7	0.5	1.7	3.7	-	-	89.3
Goshiki -numa	GS-An3	olv, cpx, opx, plg, ox	4.3	14.2	2.9	4.8	7.1	1.5	1.9	63.3
	GS-An5	olv, cpx, opx, plg, ox	2.2	12.7	4.2	6.7	6.0	1.0	0.5	66.7
	GS-An6	olv, cpx, opx, plg, ox	1.1	17.5	3.8	3.7	3.6	0.7	0.6	69.0
	GS-An8(Sc)	olv, cpx, opx, plg, ox	2.0	12.3	6.9	3.4	6.3	1.9	0.9	66.3
	GS-An9(Pan)	olv, cpx, opx, plg, ox	1.6	16.8	3.3	2.4	4.4	1.3	0.6	69.6

m.i., mafic inclusion; olv, olivine; qtz, quartz; cpx, clinopyroxene; opx, orthopyroxene; plg, plagioclase; ox, Fe-Ti oxides; gm, groundmass -, not observed

The juvenile fragments in the vulcanian fall deposits are usually poorly vesiculated black colored andesite to poorly to highly vesiculated gray colored dacite with 20 to 40% phenocrysts in hyalo-ophitic textures groundmass. Phenocrysts are plagioclase, orthopyroxene, clinopyroxene, and Fe-Ti oxides. Olivines are usually included in andesites and sometimes in dacites. The banded structure constituted of black andesite and gray dacite parts are sometimes observed, especially in the Issaikyo unit. Exceptionally, white pumice with dacitic composition can be observed in one layer of the Kofuji unit.

Plagioclase phenocrysts (<5 mm) usually have oscillatory or patchy zoning [19] or sieved textures (Fig. 4) [20]; unzoned phenocrysts are rarely found. Here, we named the clear plagioclase as type-A, dusty zoned one as type-B, and honey-comb one as type-C. Total amounts of plagioclase phenocryst are around 20% except for the white pumice, which includes ca. 5%. The type-B is the common in most of samples.

Clinopyroxene and Orthopyroxene phenocrysts (<4 mm) are usually subhedral to euhedral in shape and occasionally have glass inclusions in core. Some of pyroxene phenocrysts have Mg-rich zone ~100 μm inside from the rim (Fig. 5).

In andesites of Oana unit, mafic inclusions are sometimes observed. These are subspherical in shape, up to a few centimeters in diameter and have igneous texture characterized by abundant, elongated, euhedral crystals in residual glass, indicative of rapid cooling. These correspond to the features of mafic magmatic inclusions [21, 22], and are different from those of magmatic cumulate rocks. Other than these, large up to *ca*. 2 cm crystal clots are sometimes observed. We note the size of the microlites is less than 0.2 mm and that of phenocrysts is more than 0.2 mm.

In addition, fragments of basement rocks, such as shale or older lavas are sometimes observed in large bombs of Oana unit.

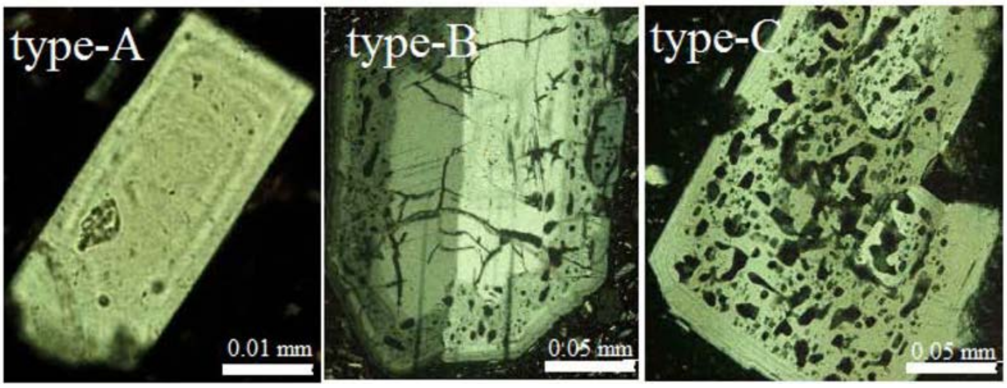

Fig. 4　Photo microscope images of three types of pla-gioclase phenocryst.

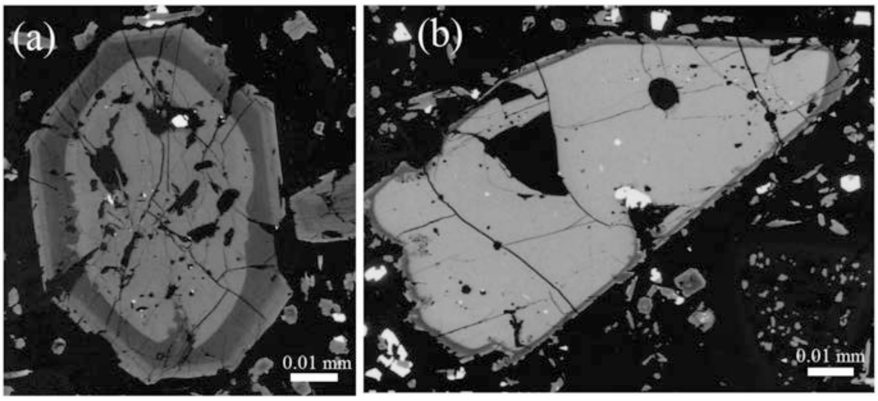

Fig. 5　Back scattered electron images of clinopyrox-ene (a) and orthopyroxene (b) phenocrysts.

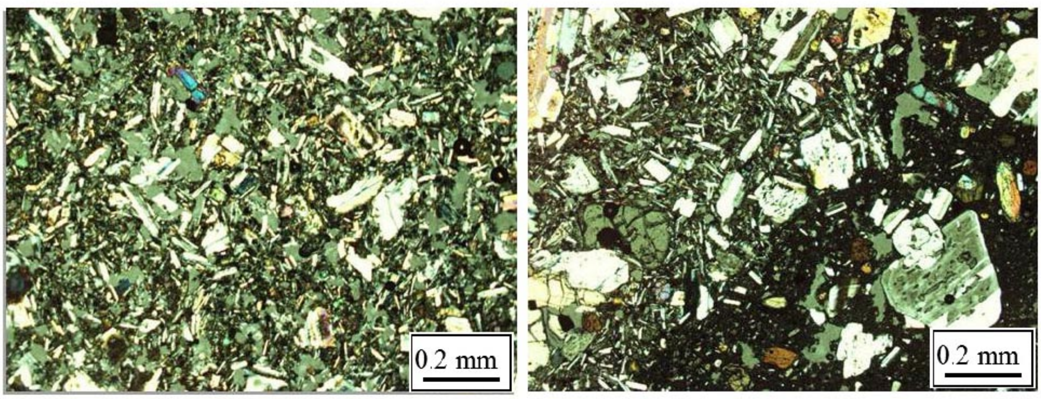

Fig. 6　Photo microscope images of mafic inclusions. Diktytaxtic textured mafic inclusion (left) and the boundary between the inclusion and the host (right)

4. Analytical procedure

Whole-rock major element and trace element (Rb, Sr, Ba, Zr, Y, Nb, and V) concentrations were determined by X-ray fluorescence analysis with a Rigaku RIX2000 analyzer at Yamagata University. Operating conditions were 50 kV accelerating voltage and 50 mA current using a Rh anode tube. The preparation method of the glass disks and the calibration method for major and trace elements followed Yamada *et al.* [23]. The matrix effect for trace elements was corrected by using the so-called Ip/Ib (net over background intensity) method. For a detailed explanation of this method, see [23, 24]. The standards used in the analyses are the Geological Survey of Japan (GSJ) igneous rocks series. Analytical uncertainties for XRF trace elements are <5% for Nb, Zr, Y, Sr, Rb and Ni; <10% for V and Cr; 5–15% for Ba. The range of uncertainties for a single element is based on the concentration range observed in standards.

5. Whole rock chemistry

Major and trace element analyses of representative rocks are listed in Table 2. For major elements, volatile-free compositions normalized to 100% were used in the following diagrams [7]. All rocks but white pumice samples (>SiO_2=65%) are plotted on same linear trend in each diagram. The white pumice samples are plotted on higher parts than the trends in TiO_2, FeO*, MgO, and MnO, while lower in Al_2O_3 and Na_2O diagrams.

5.1. Major elements

Rocks of the newest stage of Azuma volcano belong to the medium-K calc-alkaline series including the mafic inclusions (Fig. 7).

As a whole, with increasing SiO_2 content, MgO, Al_2O_3, CaO, TiO_2, MnO and FeO* contents decrease, whereas Na_2O and K_2O contents gradually increase, and P_2O_5 shows a flat pattern (Fig. 8). These trends are similar to those of the other frontal calc-alkaline volcanoes in northeast Japan (*e.g.* [7, 8]). The white pumice samples (>SiO_2=65%) are plotted on higher parts than the trends in TiO_2, FeO*, MgO, and MnO, while lower in Al_2O_3 and Na_2O diagrams.

Looking at in detail, samples from the Goshikidake and Oana units are plotted on higher parts than those from Kofuji and Issaikyo units in MgO diagram at silica poor part.

Table 2 Whole rock chemical compositions of rocks from the newest stage of Azuma volcano

		wt%										ppm									
Geologic unit	Sample name	SiO_2	TiO_2	Al_2O_3	FeO*	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	Ba	Cr	Nb	Ni	Rb	Sr	V	Y	Zn	Zr
Oana	OA-Mj-1	62.67	0.66	15.20	6.42	0.12	3.57	6.58	2.80	1.90	0.08	403	49	5.3	20	61	205	181	28	68	146
	OA-Mj-2	61.96	0.67	15.38	6.66	0.12	3.77	6.96	2.63	1.76	0.08	364	66	5.0	20	57	210	191	27	71	138
	OA-An-1	61.77	0.66	15.45	6.69	0.12	3.79	6.82	2.82	1.79	0.08	381	61	5.0	23	57	211	176	28	69	141
	OA-Da-1	60.99	0.64	15.88	6.57	0.12	4.11	7.28	2.68	1.65	0.07	357	74	5.0	28	52	221	179	26	69	131
	OA-Mi-0510-1 (m.i.)	54.30	0.67	16.75	8.50	0.15	7.02	9.48	2.22	0.85	0.07	184	132	2.9	67	25	241	237	19	79	73
	OA-Mi-H-0510-1	61.79	0.67	15.42	6.75	0.12	3.77	6.90	2.72	1.78	0.08	379	68	4.8	21	58	209	184	26	71	139
	OA-I-0510-2 (m.i.)	55.08	0.66	15.56	8.53	0.15	7.71	9.17	2.17	0.89	0.07	207	196	3.1	82	28	227	231	20	78	79
	OA-I-H-0510-2	60.59	0.67	15.45	7.15	0.13	4.39	7.30	2.66	1.58	0.08	346	81	4.4	29	51	214	192	25	73	129
	OA-Mi-0606-1 (m.i.)	58.84	0.73	16.63	7.98	0.16	4.62	7.36	2.60	0.99	0.09	330	62	4.2	20	26	250	208	23	80	109
	OA-Mi-H-0606-1	58.24	0.70	15.64	7.83	0.14	5.64	7.95	2.49	1.30	0.08	313	123	4.6	55	40	221	212	23	75	110
	OA-Mi-0606-1・2 (m.i.)	58.72	0.72	16.83	7.88	0.16	4.58	7.47	2.56	0.99	0.09	310	66	3.8	21	25	251	200	22	78	108
	OA-Mi-H-0606-1・2	58.76	0.69	16.03	7.49	0.13	4.99	7.94	2.54	1.34	0.08	313	104	4.1	40	42	227	208	23	72	116
	OA-Mi-0606-2 (m.i.)	54.46	0.73	16.66	8.86	0.16	6.49	9.51	2.22	0.83	0.07	197	117	2.5	47	23	243	261	20	85	77
	OA-Mi-H-0606-2	62.15	0.65	15.49	6.47	0.12	3.74	6.72	2.79	1.80	0.07	402	60	5.0	24	59	210	177	27	67	143
	OA-Shale-H	61.79	0.68	15.20	6.89	0.13	3.94	6.83	2.74	1.74	0.08	373	67	4.8	22	68	205	185	26	71	138
	OA-GrayDa-1	62.43	0.65	15.50	6.45	0.12	3.65	6.66	2.64	1.82	0.08	390	55	5.2	19	61	208	174	27	70	143
	OA-GrayDa-2	62.33	0.64	15.41	6.44	0.12	3.78	6.55	2.78	1.87	0.07	391	53	4.9	25	59	209	174	27	66	145
	OA-Mi-0607030 (m.i.)	56.70	0.79	16.68	8.32	0.17	5.95	7.85	2.40	1.01	0.13	297	128	4.2	46	28	280	210	26	74	100
	OA-Mi-H-060730	58.84	0.77	15.77	8.48	0.15	4.74	7.04	2.65	1.42	0.14	361	98	5.4	36	42	268	199	30	73	128
Issaikyo	IS-An-1	58.53	0.73	15.93	8.01	0.14	4.73	8.05	2.65	1.14	0.09	270	66	4.3	32	32	231	230	24	82	103
	IS-Da-1	61.72	0.69	15.65	6.85	0.12	3.72	6.66	2.78	1.74	0.07	375	45	5.2	16	53	212	186	26	70	141
	IS-Sc-1	57.49	0.73	16.73	8.07	0.15	4.99	8.04	2.60	1.11	0.09	259	69	5.4	33	33	228	231	25	80	111
	IS-Sc-2	57.66	0.75	16.42	8.32	0.15	5.01	7.87	2.60	1.12	0.09	261	67	4.3	34	32	222	234	24	78	106
	IS-baSc-1(black)	57.72	0.72	16.56	8.11	0.15	5.00	7.94	2.59	1.13	0.09	270	69	4.5	35	32	223	220	24	78	104
	IS-baSc-1(white)	64.05	0.58	15.99	5.59	0.11	2.75	5.85	2.97	2.08	0.04	432	30	5.2	11	65	204	140	28	62	156
	IS-baSc-2(black)	57.76	0.73	16.28	8.28	0.15	5.04	7.89	2.63	1.15	0.09	267	66	4.0	33	32	222	217	25	80	104
	IS-baSc-2(white)	64.46	0.61	15.60	5.73	0.11	2.76	5.53	2.98	2.19	0.04	465	29	5.6	9	70	198	147	29	64	159
Kofuji	LOC.15-1	62.11	0.68	15.42	6.69	0.12	3.66	6.69	2.79	1.76	0.08	385	41	5.0	17	56	207	200	28	72	143
	LOC15.1-2	62.68	0.67	15.50	6.47	0.12	3.41	6.31	2.87	1.88	0.08	403	38	7.2	14	60	206	173	27	72	164
	LOC.15.1-3	57.91	0.72	16.51	7.88	0.14	4.76	8.24	2.52	1.22	0.09	293	69	4.1	22	37	246	231	24	77	108
	KF-res(pumice)-1	67.86	0.89	11.76	6.43	0.14	4.02	3.89	2.47	2.46	0.08	478	37	7.5	13	76	118	126	34	75	205
	KF-resAn-1	58.75	0.70	16.59	7.92	0.13	4.30	7.85	2.41	1.28	0.08	285	59	4.0	21	39	232	224	24	79	111
	KF-GrayDa-1	60.57	0.68	16.15	7.08	0.12	3.82	7.34	2.53	1.62	0.08	344	46	4.9	16	50	224	202	26	72	127
	KF-An0606	57.74	0.73	16.96	8.31	0.14	4.39	8.27	2.30	1.09	0.08	239	59	3.5	21	30	215	218	21	76	93
	Kf-resPumice2	67.08	0.84	12.50	6.46	0.14	3.93	4.26	2.41	2.29	0.08	474	34	7.0	13	73	129	119	31	74	192
Goshiki -numa	GS-An1	59.37	0.69	15.52	7.95	0.14	4.79	7.61	2.47	1.38	0.08	295	110	4.3	39	43	214	211	25	74	113
	GS-An2	58.20	0.70	15.89	8.24	0.14	5.08	8.07	2.39	1.21	0.09	266	118	3.7	40	38	221	231	23	79	104
	GS-An3	59.52	0.69	15.39	8.06	0.14	4.76	7.41	2.49	1.45	0.08	305	100	4.1	39	46	209	198	25	73	117
	GS-An4(A)	58.84	0.71	15.34	8.27	0.14	5.24	7.67	2.41	1.31	0.07	294	121	4.3	46	40	208	209	24	76	109
	GS-An4(B)	58.86	0.69	15.64	8.09	0.14	5.00	7.75	2.43	1.32	0.07	295	112	4.3	42	41	212	216	24	75	109
	GS-An5	58.60	0.70	15.89	8.20	0.14	4.96	7.79	2.40	1.25	0.09	282	110	3.9	40	38	221	207	23	77	107
	GS-An6	57.28	0.85	17.90	7.96	0.15	4.86	7.20	2.47	1.24	0.09	343	84	4.2	35	36	295	233	24	90	106
	GS-An7(Black)	58.89	0.74	15.80	8.61	0.14	4.92	7.02	2.39	1.39	0.09	334	116	4.3	32	43	198	227	24	79	116
	GS-An7(White)	61.56	0.72	15.69	7.62	0.12	3.70	6.11	2.63	1.79	0.07	386	81	5.3	20	56	196	189	26	71	141
	GS-An8(Sc)	58.95	0.69	15.93	7.78	0.13	4.89	7.77	2.45	1.34	0.07	288	111	4.3	36	43	214	208	24	76	112
	GS-An9(Pan)	58.31	0.68	16.06	7.98	0.14	5.15	8.00	2.41	1.21	0.07	267	119	4.1	41	38	221	219	23	75	103

FeO*, total iron calculated as FeO; m. i., mafic inclusion

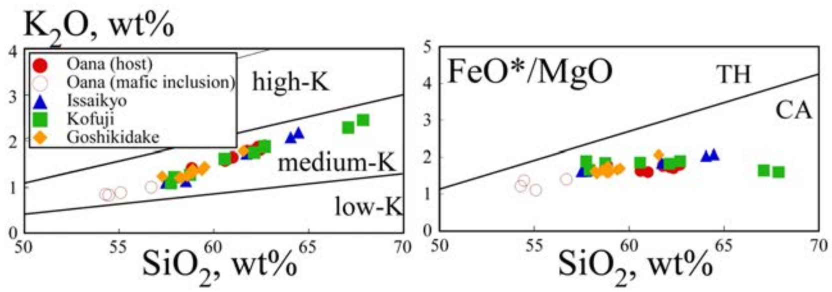

Fig. 7 K_2O vs SiO_2 and FeO*/MgO vs SiO_2 diagrams of rocks from the newest stage of Azuma volcano. The boundaries defining the low-K and medium-K fields in K_2O vs SiO_2 diagram are from [25], and that between TH (tholeiitic) and CA (calc-alkalic) fields in the FeO*/MgO vs SiO_2 diagram is from [26].

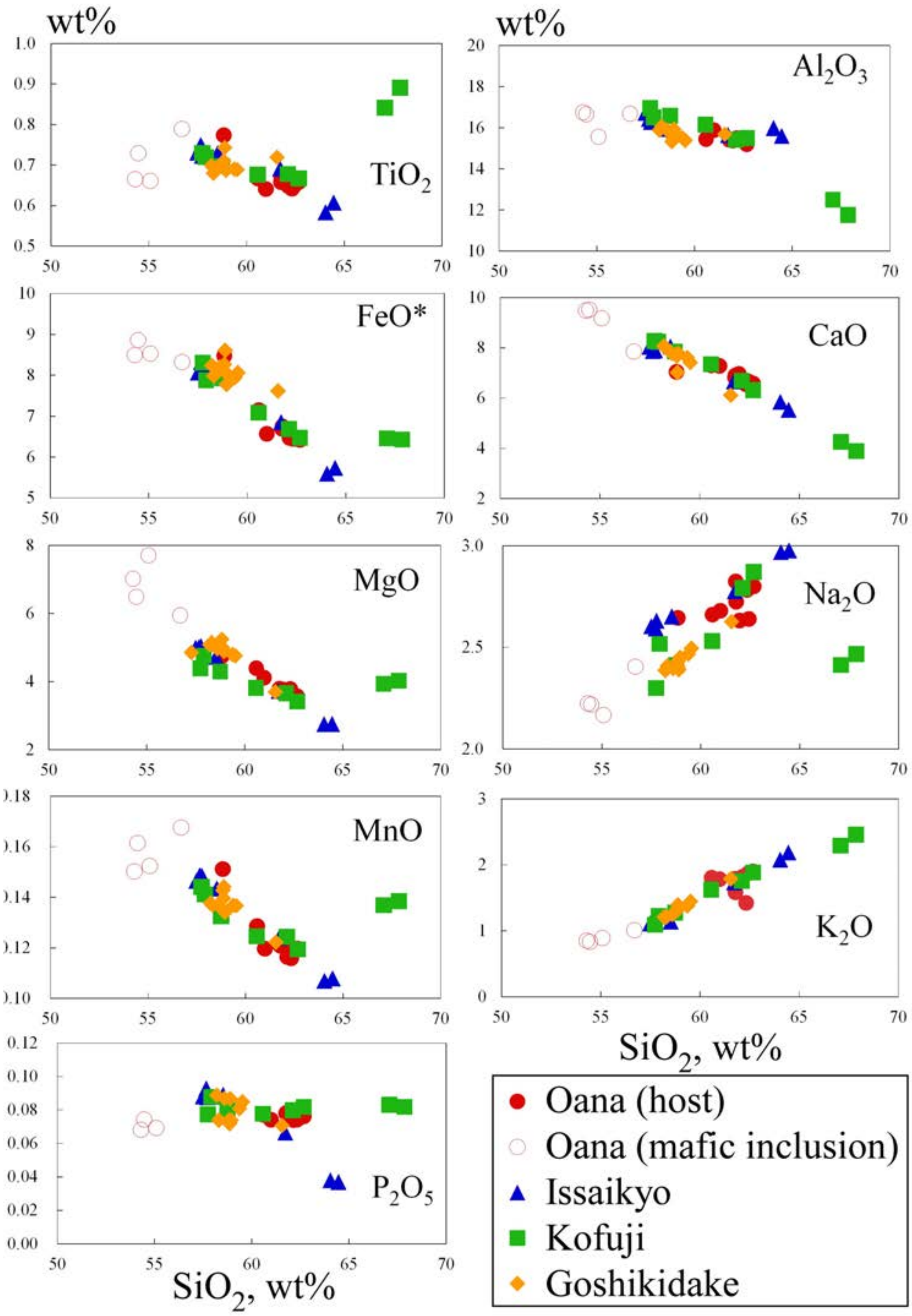

Fig. 8 SiO_2 variation diagrams showing abundances of major oxides for rocks from the newest stage of Azuma volcano.

5.2. Trace elements (V, Cr, Ni, Rb, Sr, Zr, Nb, Ba and Y)

Figure 9 shows covariant diagrams between several selected trace elements and SiO_2 concentrations. Rb, Ba, Zr, Nb and Y gradually increase with increasing SiO_2, Sr content gradually decreases. All rocks but white pumice are plotted on same linear trend in each diagram. The white pumice samples are plotted on lower parts than the trends in Ba and Sr diagrams.

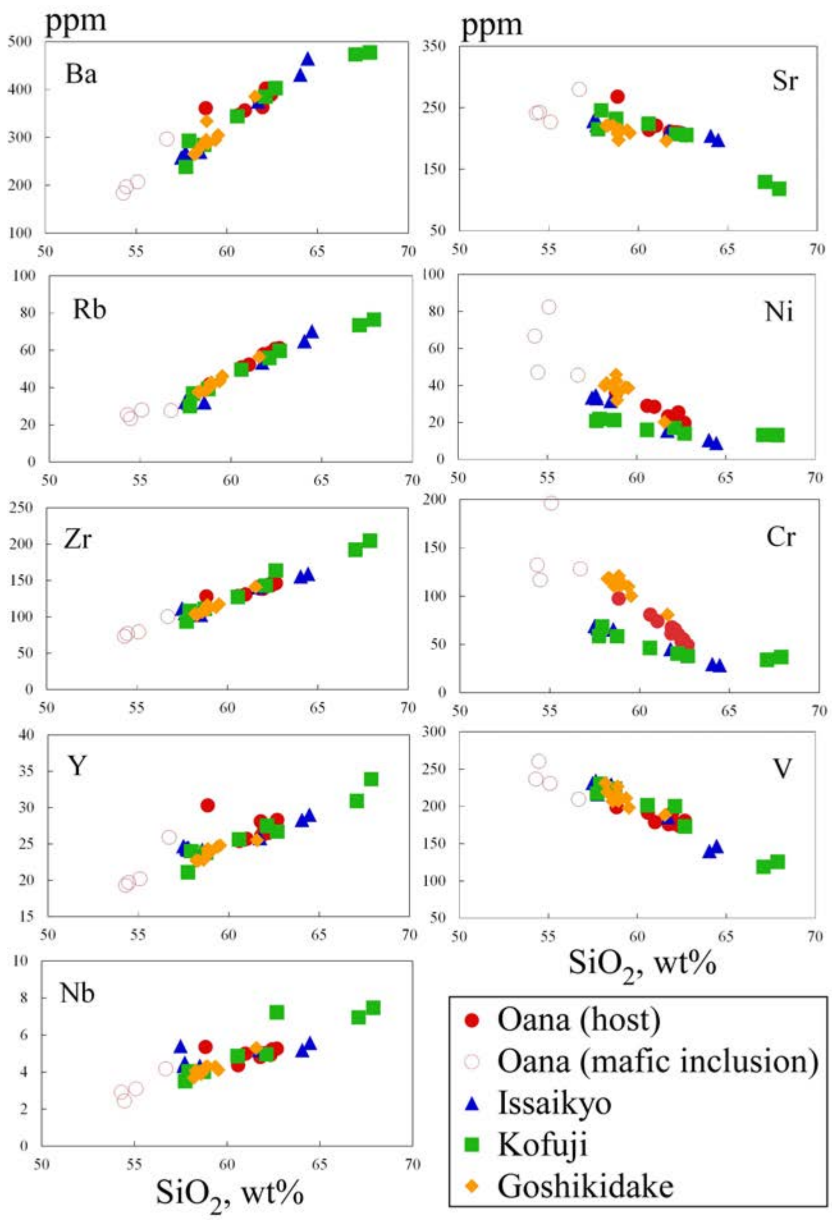

Fig. 9 SiO_2 variation diagrams showing abundances of trace elements for rocks from the newest stage of Azuma volcano.

Compatible element contents (V, Cr, Ni) of early stage rocks show linear trends that decrease with increasing SiO_2 contents. Further, in the silica poor parts of Ni and Cr diagrams, samples from the trends of the Goshikidake and Oana units are higher than those from Kofuji and Issaikyo units, while in the V diagram, formers are lower than the latters.

6. Temporal variation of whole rock compositions of eruption rocks in the newest stage of Azuma volcano

Rocks of the Goshikidake (*ca*. 6.5 to 6 ka) and Oana (AD 1331) are similar in whole rock compositional characteristics, while those of the Kofuji (*ca*. 6 to 5 ka), Issaikyo (*ca*. 5 to 4 ka) are similar as well. All of the trends are rather linear, but the formers show higher than the latters in mafic part of the MgO, Ni, and Cr diagrams, while the trends converge in the felsic part.

Many petrographic characteristics, such as existence of the mafic inclusion, the banding structure, Mg-rich zones in pyroxene phenocrysts, and dissolution textures in plagioclase phenocrysts, suggest that the rocks were formed through magma mixing events. The linear trends shown by whole rock compositions indicate the mixing events were between mafic and felsic end-members.

Consequently, the difference in compositional trends between Goshikidake and Oana units vs. Kofuji and Issaikyo units is attributed to that of mafic end-member magma (Fig. 10). In addition, the felsic end-member would have been similar in composition. The compositional trends converge at ca. 64 to 65 wt% SiO_2, which would be the composition of the felsic end-member. Mg-richer characters of the mafic end-members for Goshikidake and Oana units indicate these are sort of parental magmas for the mafic end-members of Kofuji and Issaikyo units. The mafic end-member magnas of Kofuji and Issaikyo units would be formed from that of Goshikidake and Oana units through fractional crystallization olivine crystals with Cr-spinel inclusions.

During the newest stage, the dacitic (64-65 wt% SiO_2) magma reservoir would have been stored at shallow crustal level. At the beginning (Goshikidake unit) and the recent (Oana unit) of the newest stage, the least differentiated mafic magmas infused into the reservoir which resulted in the eruptions. Whereas, in the middle term (Kofuji and Issaikyo units) of the newest stage, the mafic magma would differentiate to some extent before the infusion. It is probable that the difference of these two cases would be attributed to the amount of the upwelled least differentiated magma.

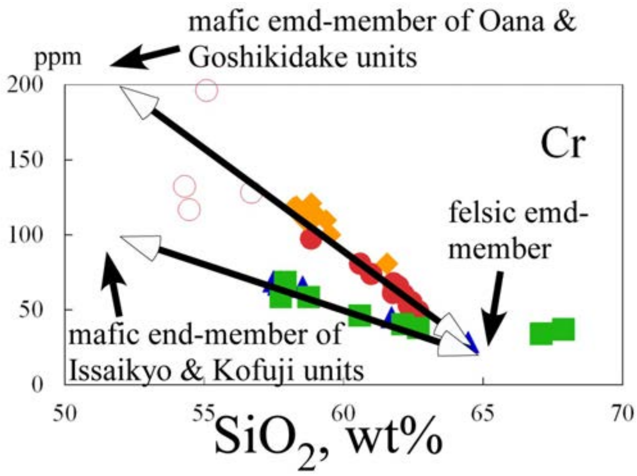

Fig. 10 Cr vs SiO_2 diagram of rocks from Azuma newest stage. Mafic end-members of Oana and Goshikidake units have higher Cr contents than those of Issaikyo and Kofuji units. Whereas felsic end-members have similar composition among these four units.

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