Finding of osumilite and andalusite from the Pliocene subaqueous ash layer in Niigata Prefecture, Central Japan

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Osumilite and andalusite phenocrysts are found from the silicic and peraluminous submarine volcanic ash layer in Niigata Prefecture, Central Japan. The ash is intercalated in the Pliocene marine mudstone and 2-6 cm thick. The osumilite grains are 0.1-0.4 mm in size, uniaxial positive and have low $Mg/(Mg+Fe+Mn)$ ratios (0.26-0.35). The andalusite occurs as fresh prismatic crystals of 0.1-0.3 mm long. Osumilite and andalusite coexisted with melt just before the eruption, and the P-T conditions are estimated at around 750°C and under less than 300 bar water pressure from the combined data for osumilite and andalusite stability fields.

Introduction

The association of osumilite and andalusite has not been reported from the volcanic ash to date. Osumilite was first reported by Miyashiro (1953) as a new mineral in the rhyodacite of the Osumi Province, Kyushu, Japan and thereafter it has been found from the druses and groundmass of rhyolitic and dacitic lavas, and also from the metamorphic rocks such as pyrometamorphosed rocks (Aramaki, 1961; Chinner and Dixon, 1973) and granulites (Berg and Wheeler, 1976), but its occurrence as phenocryst is not reported yet. Andalusite is common in low pressure metamorphic rocks and also found in pyrophyllite deposit (Kamitani, 1974), in the metasomatized rhyolite at Oketo, Hokkaido, Japan (Watanabe and Hasegawa, 1981), in the partly vesiculated pyrometamorphosed basement tuffs in the Sakurajima area, Kyushu, Japan (Ishihara and Kobayashi, 1988) and as xenocryst in the Kumano Acidic Rocks, Japan (Aramaki and Hada, 1965), but the occur-

rence of magmatic andalusite is restricted to some granites and pegmatites (Rose, 1957; Clarke *et al.*, 1976) and also to the glass pebbles in glacial and alluvial deposits in Peru (French and Meyer, 1970). This report aims to describe the localities and components of the osumilite and andalusite-bearing ash, occurrence and chemical compositions of the osumilite and andalusite, and to consider briefly on the paragenetic implications for the P-T conditions of the magma.

The osumilite andalusite-bearing ash

The osumilite and andalusite are found from the Pliocene Suganuma-a ash (Sawaguri and Kurokawa, 1986) intercalated in the marine mudstone (the Nishiyama and Suganuma Formations) in Niigata Prefecture. Loc. 1 is at Inagawa, Izumozaki Town, 15 km northwest of Nagaoka City, and Loc. 2 is along the Kunisawa river, Oguni Town, 13 km southeast of Kashiwazaki City (Fig. 1). Loc. 1 is situated at

Fig. 1. Localities of osumilite and andalusite-bearing Suganuma-a ash in Niigata Prefecture: Loc. 1 is at Inagawa, Izumozaki Town and Loc. 2 is at Takeishi, Oguni Town. Blank area is alluvial.

22 km north of Loc. 2.

The Suganuma-a ash is rhyolitic and vitric, and white in color. The total thickness of the ash is 2-3 cm at Loc. 1 and 3-6 cm at Loc. 2 (Fig. 2). At both localities, it is composed of more than two units. The basal unit (2-3 cm) is normally graded from medium sand-sized to silt-sized and the upper units are silt-sized.

Components of the ash in 68-125 μm fraction are 70-80% micropumice type glass shards, 10-20% plagioclase (andesine ~ labradorite) and 1% mafic minerals with a small amount of β -quartz. Some brownish glass shards and glassy volcanic fragments are also found. Accidental rock fragments are also accompanied up to 3%, among which blueschist fragments are notable (alkali amphibole is X' = pale blue, Z' = pale grayish violet).

Mafic mineral components are 30-50% biotite, 20-40% hornblende (X' = dark brown, Z' = dark greenish brown), 15-30% ferrosilite ($\gamma = 1.740$) ($\text{En}_{43}\text{Fs}_{55}\text{Wo}_2$ by XMA analysis), 1-3% cummingtonite (X' = pale brown, Z' = pale brownish green) and 1% almandine-spessartine garnet (pinkish orange), with a small amount of

Fig. 2. Field occurrence of the Suganuma-a ash along the Kunisawa river, Takeishi, Oguni Town. The ash is intercalated in the Pliocene mudstone of the Suganuma Formation and 6 cm in thickness.

augite, zircon, apatite, ilmenite, osumilite and andalusite. Osumilite content is 0.05% and andalusite is about 0.01% of the whole grains. Thus, the mineral paragenesis in the magma just before the eruption is plagioclase + β -quartz + osumilite + biotite + hornblende + cummingtonite + ferrosilite + augite + garnet + zircon + apatite + andalusite + ilmenite with liquid (glass) and vapor.

Osumilite and Andalusite

Osumilite grains are dark blue in color and 0.1–0.4 mm in size. They are mostly anhedral, but fragments of the euhedral grains, partly showing straight outlines are not uncommon (Fig. 3). The osumilite grains are optically uniaxial positive, showing dichroism with $\epsilon =$

colorless and $\omega =$ blue. Refractive indices determined by immersion method are $\omega = 1.549$, $\epsilon = 1.553$ (Loc. 1), and the lattice constants determined by electron diffraction analysis using aluminium standard are $a = 10.10 \text{ \AA}$, $c = 14.29 \text{ \AA}$ for a single specimen from Loc. 1. High-resolution [0001] image of the osumilite at Loc. 1 is shown in Fig. 4. Electron microscopy was performed with a JEM 200CX microscope operated at 200 kV.

XMA analyses of the osumilite were made at 15 kV and $0.02 \mu\text{A}$ specimen currents (Table 1). Their compositions are $\text{K} > \text{Na}$, $\text{Fe} > \text{Mg}$ in ionic base, and Si/Al ratio is less than 7, so they can be called osumilite after Bunch and Fuchs' (1969) classification. It is noteworthy that $\text{Mg}/(\text{Mg} + \text{Fe} + \text{Mn})$ ranges 0.26–0.35, which is the most (Fe + Mn)-rich among optically positive

Fig. 3. Osumilite and andalusite grains in the Suganuma-a ash. 1, osumilite from Loc. 1. A scale bar indicates 0.2 mm (same as in 2–4); 2, osumilite from Loc. 2; 3, andalusite from Loc. 1. An arrow shows the glass fringe around the andalusite grain; 4, andalusite from Loc. 2.

Table 1. Chemical compositions of the Suganuma-a osumilites (analyzed by XMA)

	Izumozaki			Oguni			
	1	2	3	4	5	6	7
SiO ₂	60.60	60.46	60.50	59.96	59.95	60.98	60.37
TiO ₂	0.02	0.03	0.01	0.00	0.07	0.00	0.00
Al ₂ O ₃	21.61	22.14	22.17	22.16	22.34	21.91	21.93
FeO*	9.37	9.99	9.91	10.01	9.88	9.82	9.90
MnO	1.02	1.52	1.54	1.34	1.41	1.33	1.49
MgO	3.13	2.32	2.70	2.52	2.35	2.52	2.39
CaO	0.10	0.00	0.02	0.01	0.03	0.00	0.00
Na ₂ O	0.85	0.79	0.72	0.80	0.62	0.46	0.71
K ₂ O	2.82	3.08	3.33	3.10	3.32	3.05	3.10
Total	99.52	100.33	100.90	99.90	99.97	100.07	99.89
O	30	30	30	30	30	30	30
Si	10.36	10.31	10.27	10.27	10.26	10.38	10.33
Al	1.64	1.69	1.73	1.73	1.74	1.62	1.67
Σ	12.00	12.00	12.00	12.00	12.00	12.00	12.00
Al	2.71	2.76	2.70	2.74	2.77	2.77	2.75
Ti	0.00	0.00	0.00	0.00	0.01	0.00	0.00
Fe ³⁺	0.29	0.24	0.30	0.26	0.22	0.23	0.25
Σ	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Fe ²⁺	1.05	1.19	1.10	1.17	1.19	1.17	1.17
Mg	0.80	0.59	0.68	0.64	0.60	0.64	0.61
Mn	0.15	0.22	0.22	0.19	0.21	0.19	0.22
Σ	2.00	2.00	2.00	2.00	2.00	2.00	2.00
K	0.61	0.67	0.72	0.67	0.72	0.66	0.67
Na	0.28	0.26	0.23	0.26	0.20	0.15	0.23
Ca	0.02	0.00	0.00	0.00	0.00	0.00	0.00
Σ	0.91	0.93	0.95	0.93	0.92	0.81	0.90
Mg/(Mg+Fe+Mn)	0.35	0.26	0.30	0.28	0.27	0.29	0.27
K/(K+Na+Ca)	0.67	0.72	0.76	0.72	0.78	0.81	0.74

* Total iron as FeO

1~3, from Loc. 1 (Inagawa, Izumozaki Town); 4~7, from Loc. 2 (Takeishi, Oguni Town). Fe²⁺ and Fe³⁺ are calculated based on stoichiometry.

osumilites so far reported (Deer *et al.*, 1982); as for the Japanese osumilites, it is 0.34–0.72 for the Haneyama rhyolite, Oita Prefecture (Aoki, 1954; Yokomizo and Miyachi, 1978), 0.36 in the Hayato rhyolite, Kagoshima Prefecture

(Kobayashi, 1978), 0.46 in the Sakkabira rhyodacite, Kagoshima Prefecture (Miyashiro, 1956), 0.55–0.64 in the Akagi dacite, Gunma Prefecture (Koga, 1981), 0.61 in the Iriki biotite dacite, Kagoshima Prefecture (Miyachi and

Fig. 4. High-resolution [0001] structure image of the osumilite from Loc. 1 and the corresponding [0001] zone axis diffraction pattern with Debye-Scherrer ring of Al.

Miyachi, 1978), and 0.68 in the rhyolite of the Rishiri Island, Hokkaido (Kobayashi, 1978). The $K/(K+Na+Ca)$ in C-site is in the range of 0.67–0.81, and Na_2O content (0.46–0.85%; 0.71% in average) is higher than that of the metamorphic osumilites (0.22–0.59%) (Deer *et al.*, 1982). The Fe population on the A octahedron is 0.53–0.60, which coincides with the relation between Fe population in A-site and refractive indices given by Armbruster and Oberhänsli (1988).

Andalusite grains are prismatic, mostly 0.1–0.3 mm in c-direction (Fig. 3). They are transparent with very pale pink tint, and optically length-fast, showing pleochroism with X =pale pink and $Y=Z$ =colorless. Alterations are not observed and mostly devoid of inclusions. Some grains have thin glass fringe (Fig. 3). This suggests that the andalusite is exclusive of xenocryst origin. Chemical composition of the andalusite by AEM analysis is listed in Table 2, using a JEM 200CX with EDS analyzer of TN2000 operated at 200 kV.

Table 2. Chemical composition (average of three grains) of the andalusite from Loc. 1 (analyzed by AEM)

SiO ₂	37.0
Al ₂ O ₃	61.9
Cr ₂ O ₃	0.1
FeO*	0.8
MnO	0.1
CaO	0.1
Total	100.0
<hr/>	
O	20
Si	4.01
Σ	4.01
Al	7.91
Cr	0.01
Fe ³⁺	0.07
Mn	0.01
Ca	0.01
Σ	8.01

*Total iron as FeO

Genetical Implications

Phenocryst mineral assemblage indicates that the magma was peraluminous. This observation is concordant with the crystallization of osumilite and andalusite. The P-T conditions of the magma just before the eruption would have been the experimental stability fields of both osumilite and andalusite.

In the hydrous system K_2O - MgO - Al_2O_3 - SiO_2 - H_2O , the stability field of osumilite is below 800 bar water pressure. It is between 765° and 800°C at 500 bar water pressure (Olesch and Seifert, 1981) (Fig. 5). As for Al_2SiO_5 polymorphs, the stability field of andalusite under hydrous conditions is less than 770°C, and this temperature decreases with increasing

Fig. 5. Stability limits of osumilite (solid line) (Olesch and Seifert, 1981) and andalusite (dot and line) (Holdaway, 1971) at $P(\text{total})=P(\text{H}_2\text{O})$. The overlapped stability field of osumilite and andalusite is shown as shadowed area. (Os, Osumilite; Cd, Cordierite; Kf, K-feldspar; Phl_{ss} = Phlogopite solid solution; Q, Quartz; L, Liquid; V, Vapor).

water pressure; at 500 bar and 730°C andalusite inverts to sillimanite (Holdaway, 1971) (Fig. 5). Thus, the P-T conditions of the magma just before the eruption are estimated to be around 750°C and less than 300 bar water pressure (Fig. 5). However, the stability field of osumilite coexisting with liquid under lower water pressures is not experimentally clarified. The eruption was probably phreatomagmatic, as deduced by the abundance of the micropumice type glass shards.

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新潟県の鮮新世水底堆積火山灰から大隅石と紅柱石の発見

黒川 勝己・小西 博巳・藤原 啓美

火山灰中から大隅石と紅柱石を発見した。この火山灰は新潟県の鮮新世の海成の泥岩中に挟在する菅沼ガラス質a火山灰で、発見地点1は出雲崎町稲川(層厚2-3cm)、地点2は小国町武石(国沢川)(層厚3-6cm)である。大隅石には破片状の自形結晶も認められ、また紅柱石は柱状の自形を示す。さらに両鉱物に変質は認められず、またしばしばガラスが付着していることから、両鉱物は噴火の直前には斑晶としてマグマ中に共存していたと考えられる。なお大隅石の $Mg/(Mg+Fe+Mn)$ は0.26-0.35であって、これまで知られている一軸性大隅石のうちでは最も低い値を示す。大隅石と紅柱石を晶出したマグマの組成は珪長質かつパーアルミナスであり、また噴火直前の温度・圧力条件は従来報告されている大隅石と紅柱石の安定領域の重複範囲から、温度750℃程度、水蒸気圧は300バール以下と推定される。