

GEOCHEMISTRY OF VOLCANIC GASES AND HOT SPRINGS AT SATSUMA-IWOJIMA VOLCANO, JAPAN

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Satsuma-Iwojima is one of the actively degassing volcano with many high-temperature fumaroles and hot springs (Fig. 1). An old literature of about 800 years ago already described the existence of fumarolic activity and sulfur mining on the Iwodake, a rhyolitic dome. Therefore the fumarolic activity at the summit area could have continued more than 1,000 years. A large amount of silicified rocks of up to >99 wt.% SiO₂ was distributed at the summit area, that also suggests a long-term acid leaching of the volcanic rocks by volcanic gas condensates.

High temperature fumaroles distribute at the summit area of Iwodake and several low-temperature fumaroles located along gullies on the flank. Although most fumarolic activity occurs on the Iwodake, a few weak fumaroles also exists along northwest part of the caldera rim. Presently a major gas discharges occurs from a degassing vent of 50 m diameter at the center of the

summit crater floor. The high-temperature fumaroles with temperature higher than 800°C distribute in the mainly along rim of the crater (Fig. 1b). The topographic map of Fig. 1b is taken from Saito (1997).

Three types of hot springs are recognized on the island; 1) Acid-type, 2) CO₂-rich type, and 3) Neutral pH-type (Kamada, 1964). All of the hot spring discharges occurs at almost the sea level. The acid-type locates only around the Iwodake, a presently degassing dome, whereas the CO₂-rich type are found around the Inamuradake, a basaltic cone. The neutral-pH type hot springs locate at outside of the caldera (Sakamoto) and at off-shore island, Showa-Iwojima, that formed by most recent eruption in 1934 (Ono et al., 1982). Submarine emission of bubbles were observed near the Higashi hot spring and Showa-Iwojima, where bubbling gas emission also occurs on the island.

Modern geochemical studies of the

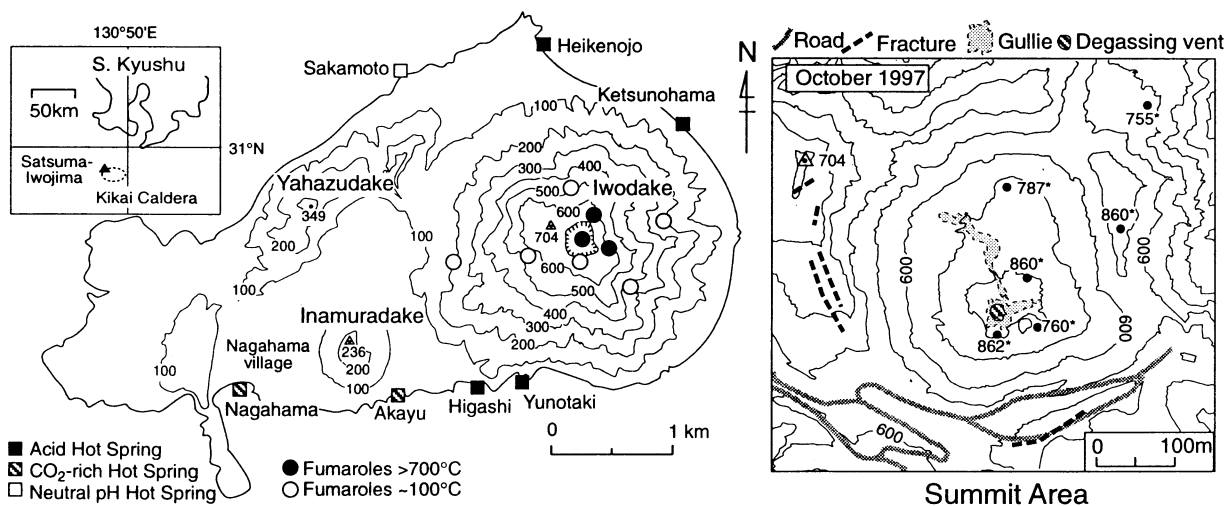


Figure 1 Distribution of fumaroles and hot springs on the Satsuma-Iwojima.

volcanic gases and hot spring waters started already in early 1960's, when maximum temperature of $>700^{\circ}\text{C}$ was measured (Kamada, 1964). The highest measured temperature is fairly constant close to 900°C for these 30 years (Fig. 2). The volcanic gas flux measured as SO_2 flux was also almost constant around 500 t/day. As this volcano provides an unique occasion to sample the high-temperature volcanic gases without any eruptive activities, many studies of the high-temperature gases have been conducted at this volcano (e.g., Matsuo, et al., 1974; Matsubaya et al., 1975; Kanzaki et al., 1979, Hedenquist et al., 1993; Shinohara et al., 1993).

Frequent survey of the summit area started in 1990. The degassing vent has not existed but the degassing has occurred from many fumaroles along the summit crater rim until 1991. The degassing vent formed during 1990's, in particular in 1997, while shallow earthquakes and ground deformation were also observed. Although temperature and SO_2 flux were almost

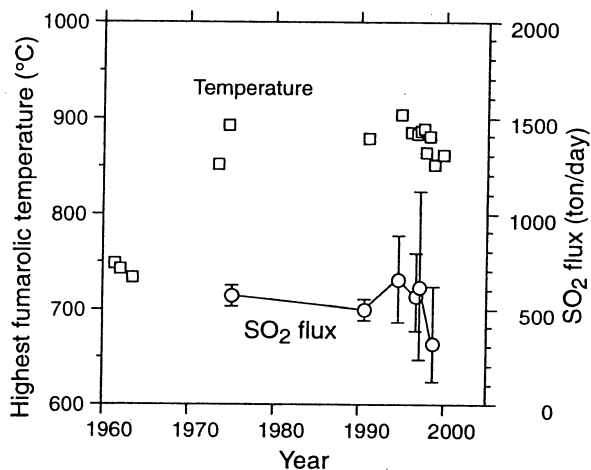


Fig. 2 Variation of maximum measured temperature and SO_2 flux measured by COSPEC.

constant for these 30 years, there is also a slight variation with a maximum in mid-1900's when the degassing vent formation, earthquakes and ground deformation were culminated. Chemical and isotopic compositions of the highest-temperature volcanic gases were also almost constant during this period (Table 1). However, the apparent equilibrium temperature for sulfur and carbon-bearing reactions (AET_s and AET_c) were also maximized in 1997 (Table 1 and Fig. 3). The AETs generally agree with fumarolic

Table 1 Composition of highest temperature fumarolic gases at Ohachi-oku, Iwodake cone, Satsuma-Iwojima volcano.

Date	Temp. °C	H_2O $\mu\text{mol/mol}$	CO_2	$\text{SO}_2^{\#}$	$\text{H}_2\text{S}^{\#}$	HCl	H_2	N_2	Ar	$\text{CO}^{\$}$	δD ‰	$\delta^{18}\text{O}$ ‰	$\delta^{13}\text{C}$ ‰	$\text{AET}_s^{\&}$ °C	$\text{AET}_c^{\&}$ °C
99.11.21	853	974 981	3 818	8 048	718	6 853	4 468	65	0.8	18	-29	6.3		840	824
98.11.7	840	973 024	3 808	8 756	971	6 783	5 593	92	1.0	23	-28	6.1		863	843
98.3.18	860	974 149	3 992	9 661	520	6 289	4 638	83	0.9	21	-31	6.0	-4.9	870	850
97.11.2	848	975 649	3 698	8 950	482	6 593	4 549	56	0.6	21	-28	6.4	-4.1	867	892
97.4.18	886	972 176	3 803	10 672	479	7 429	5 310	104	1.0	26	-26	6.4	-4.5	899	900
97.2.20	884	974 842	3 837	9 994	337	6 150	4 729	90	1.3	19				896	834
97.1.6	880	976 714	3 356	8 392	442	6 729	4 233	109	1.3	24	-29	6.4	-4.4	858	992
96.10.15	882	975 652	3 977	10 088	536	4 600	5 026	96	1.0	23	-28	6.2	-4.3	882	857
96.3.10	882	972 574	3 439	11 741	281	6 585	5 224	121	2.2	34	-28	6.1		929	1047
94.10.29	881	974 400	3 879	9 993	272	5 839	5 488	98	1.1	27	-28	8.4	-4.3	930	896
90.10.27*	877	974 798	3 758	9 181	656	6 767	4 740	82	0.7	11	-23	6.6	-5.0	860	(696)

-: not analyzed.

#: Calculated from a total sulfur content and an average oxidation states of sulfur species (Giggenbach and Goguel, 1989).

\$: Corrected for CO decrease during sample storage according to Giggenbach and Matsuo (1991).

&: Apparent equilibrium temperatures calculated with equations given by Ohba et al. (1994).

+: From Shinohara et al. (1993). Since a mistake in calibration for CO_2 analyses was found after the publication by the author, the results were recalculated considering the new calibration, that causes 20% increase in CO_2 contents.

Data from Shinohara et al. (2000)

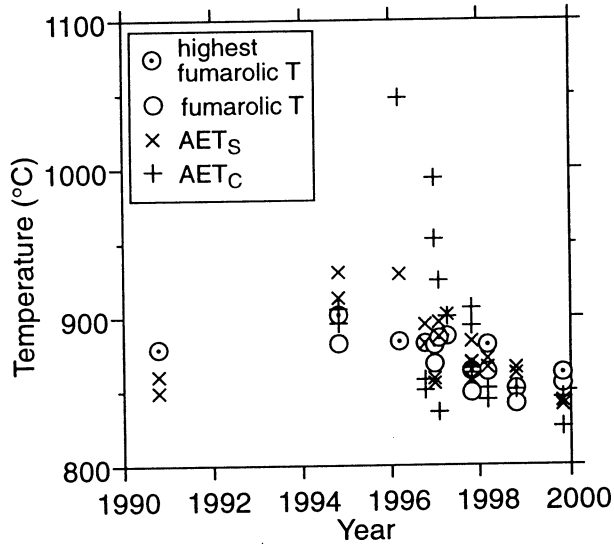
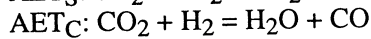
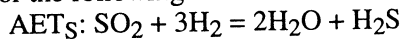


Fig. 3 Variation of fumarolic temperature and AET for the following reactions.



temperature, indicating that the reactions were in equilibrium just before the discharge from the fumarole.

Chemical and isotopic composition of the high-temperature gases are typical composition found at island-arc volcanoes, but is rather poor in CO_2 and rich in H_2O as such high temperature gases. As show in the agreement of the AETs and fumarole temperature, concentrations of H_2 and CO are controlled by the reaction equilibrium at high temperature. In contrast, concentration of CH_4 in the high temperature gases are quite variable and much higher than the equilibrium values, when it was measured. Therefore, the CH_4 is likely to be contaminated from a low-temperature hydrothermal envelop surrounding the fumarolic area. Isotopic composition of H_2O indicates that the low temperature gases emitted from the flank fumaroles are a mixture of meteoric water and the high-temperature gases.

Volatile compositions in melt inclusions of the most recently erupted magma (Showa-Iwojima) agree with that

of the high-temperature volcanic gases (Saito et al., in press.). They suggested that the agreement of these compositions indicate that separation of the volcanic gases from the magma should occur at a low pressure. The highest fumarolic temperature of 900°C is close to temperature of the magma estimated with the oxide and the pyroxene geothermometers. The agreement of the temperatures supports the idea of magma degassing near surface.

The large amount of magmatic gases were continuously emitted from the volcano for a long period, possibly for a thousand years long. As has been suggested for continuously degassing basaltic and andesitic volcanoes, convective magma transport from a deep chamber to near surface is likely to be responsible for the rapid supply of the huge amount of volatile components at the Iwodake (Kazahaya and Shinohara, in prep.). Although viscosity of the rhyolitic magma is much larger than that of a basaltic magma, the rapid transport of the magma is possible only if the conduit diameter is enough large as tens of meters.

Chemical and isotopic compositions of hot spring waters are common for all of the acid-type hot spring (Table 2). The anion and isotopic composition of water of the acid-type hot spring waters indicate that they formed from a mixture of the high-temperature volcanic gases and meteoric water. The cation composition shows that the cations are derived from volcanic rocks by acid leaching. The huge amount of the silicified rocks at the summit area might be the product of this acid leaching. The acid-type hot spring water also contains high concentration of silica, aluminum and iron, which is precipitated by mixing with seawater, that causes the discolored seawater distributing along the seashore (Nogami et al., 1993).

Table 2 Chemical and Isotopic composition of Hot spring waters from Satsuma-Iwojima

Location	Date	Temp	pH	Na	K	Mg	Ca	SO ₄	Cl	F	δD	$\delta^{18}O$
	dd/mm/yy	(°C)									(‰)	(‰)
Heikenojo	28.10.92	68	1.2	808	270	100	243	11920	2640	11	-21	-2.3
Ketsunohama	21.10.92	71	1.1	1060	296	225	315	14600	2960			
Yunotaki	28.10.92	60	1.6	603	166	58	314	7430	1847	10	-19	-0.2
Higashi	24.10.92	55	1.5	265	105	28	127	4710	1020	11	-30	-4.2
Sakamoto	23.10.92	57	6.0	2745	135	335	183	840	5430	0.3	-22	-3.6

Date from Hednquist et al. (1994)

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