Reports

Helium-3 Emission Related to Volcanic Activity

Abstract. *The helium-3/helium-4 ratio in bubbling gases from ten hot springs located around Mount Ontake, an active volcano in central Japan, ranges from 1.71* R_{atm} *(1.71 times the atmospheric ratio of* 1.40×10^{-6}*) to 6.15* R_{atm}*. The value of the ratio decreases with distance from the central cone of the volcano. Such a tendency may be a characteristic of helium-3 emission in volcanic areas and suggests more primitive helium-3 is carried with fluid flowing through a conduit during volcanic activity.*

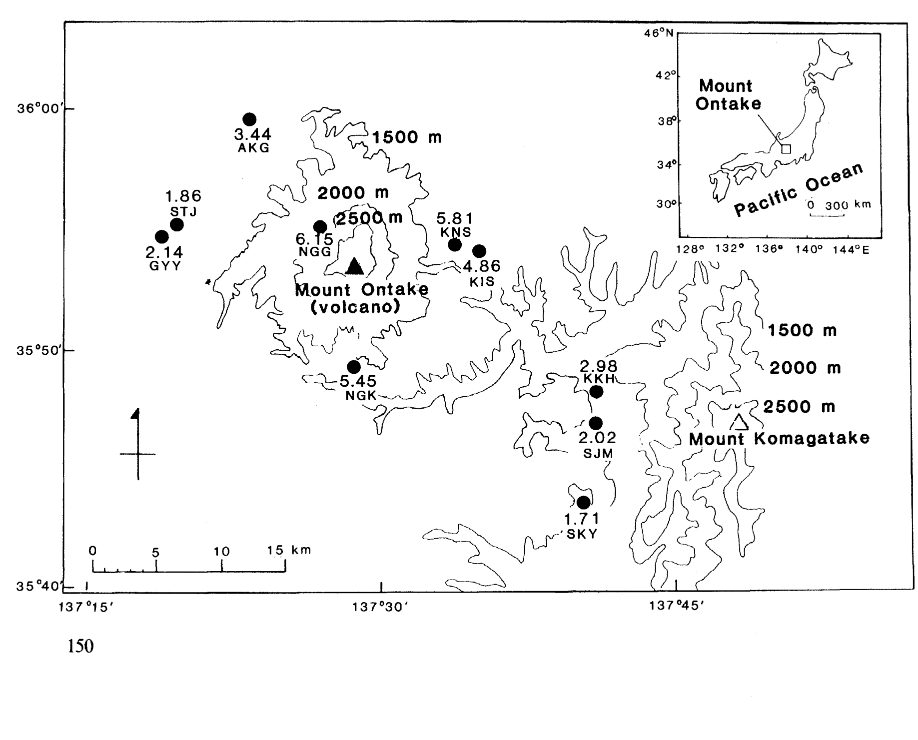
Mount Ontake, an isolated stratovolcano (elevation 3063 m), is located in central Honshu, Japan (35° 54′N, 137° 29′E). The first historic eruption of this volcano took place on 28 October 1979, forming several new craters and ejecting large amounts of volcanic ash and steam. (The last eruptive activity is estimated to have occurred about 23,000 years ago.) The volcano had been believed to be dormant, but weak fumarolic activity was observed at the southwestern flank of the central cone. The main rock type is pyroxene andesite (*1*). There is no other active volcano within a radius of about 40 km of Mount Ontake.

We have surveyed ^3He emission in the vicinity of the volcano. Bubbling gases were collected from ten hot springs at various distances from the central cone. Sampling sites located within a radius of 25 km of the volcano are shown in Fig. 1. The bubbling gases were introduced by water displacement into lead-glass containers equipped with vacuum stopcocks. After the containters had been brought back to the laboratory, the $^3He/^4He$ and $^4He/^{20}Ne$ ratios in these gaseous samples were measured with a 15.2-cm magnetic-deflection mass spectrometer. A resolving power of about 600 was achieved for the complete separation of $^3He^+$ beams from those of H_3^+ and HD^+ (*2*). The instrument used in this study

Table 1. Observed $^3He/^4He$ and $^4He/^{20}Ne$ ratios and N_2, CH_4, CO_2, and helium contents of bubbling gases obtained from ten hot springs near Mount Ontake Volcano.

No.	Code	Name	Distance (km)	Elevation (m)	$^3He/^4He$ ($\times 10^{-6}$)	$^3He/^4He$ (R/R_{atm})	$^4He/^{20}Ne$	N_2 (%)	CH_4 (%)	CO_2 (%)	He (ppm)
1	NGG	Nigorigo	4.2	1850	8.61 ± 0.11	6.15	32	40.1	0.33	58.8	97
2	NGK	Nigorikawa	7.6	1700	7.63 ± 0.18	5.45	4.3	6.6	< 0.01	91.6	5.1
3	KNS	Kanose	8.0	1350	8.13 ± 0.27	5.81	83	1.1	< 0.01	98.9	4.6
4	KIS	Kiso	9.6	1500	6.30 ± 0.07	4.86	150	6.5	0.11	93.2	55
5	AKG	Akigami	14.0	1150	4.81 ± 0.18	3.44	2.5	5.4	3.8	90.3	1.6
6	STJ	Shitajima	14.2	750	2.60 ± 0.16	1.86	0.77	6.0	0.03	90.7	1.6
7	GYY	Yuya	15.0	800	3.00 ± 0.15	2.14	37	16.5	3.18	80.0	91
8	KKH	Kakehashi	21.0	800	4.17 ± 0.06	2.98	23	2.3	1.07	96.6	15
9	SJM	Shojima	22.2	750	2.83 ± 0.10	2.02	17	0.4	0.09	99.5	8.5
10	SKY	Shikanoyu	25.4	800	2.39 ± 0.04	1.71	71	2.4	0.87	96.5	3.3
		Air			1.40*	1.00	0.317	78.1	< 0.01	0.03	5.2

*From Mamyrin *et al.* (*5*).



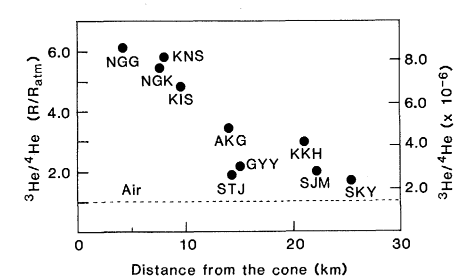


Fig. 1 (left). Locations of sampling sites around Mount Ontake. The observed $^3He/^4He$ ratios are expressed in terms of (R/R_{atm}), where $R_{atm} = 1.40 \times 10^{-6}$. Fig. 2 (right). The relation between the distance of the sampling site from the central cone of Mount Ontake and the $^3He/^4He$ ratio.

was limited to the analysis of terrestrial samples in order to avoid possible contamination from extraterrestrial samples, which usually cause a memory effect for ^{3}He. The chemical compositions of gaseous samples were measured by gas chromatography.

The observed $^3He/^4He$ and $^4He/^{20}Ne$ ratios are listed in Table 1 together with the measured concentrations of N_2, CH_4, CO_2, and helium. The elevations of the sampling sites and their distances from the central cone of the volcano are also listed. Except for samples 2 and 6, the oxygen contents of the samples were less than 0.2 percent. Thus the direct contamination of atmospheric air during sampling was negligibly small. The major chemical constituent in most samples was CO_2; sample 1 was composed of N_2 and CO_2.

The observed $^3He/^4He$ ratios are in good agreement with the magmatic $^3He/^4He$ ratios observed in subduction zones (*3*). The highest $^3He/^4He$ ratio of 8.61×10^{-6} (6.15 R_{atm}, where R_{atm} is the atmospheric $^3He/^4He$ ratio, 1.40×10^{-6}) was observed for the gas sample from Nigorigo hot spring, the sampling site closest (4.2 km) to the central cone. This value is identical to the value (6.14 R_{atm}) observed in the central region of Hakone Volcano (*4*). The $^3He/^4He$ ratios decrease with distance from the cone. The ratio (1.71 R_{atm}) at Shikanoyu hot spring (25.4 km away from the cone) was the lowest of all the samples but was higher than R_{atm}, thus suggesting the addition of ^{3}He originating in the mantle.

Figure 2 indicates the correlation between the $^3He/^4He$ ratio (R/R_{atm}) and the distance of the sampling site from the cone. No simple correlation was observed between the $^4He/^{20}Ne$ ratio and the distance. If the decrease in the $^3He/^4He$ ratio is attributed to mixing with atmospheric helium, the observed $^4He/^{20}Ne$ ratio should decrease as the $^3He/^4He$ ratio decreases. In the present case, however, there is no correlation between the $^3He/^4He$ ratio and the $^4He/^{20}Ne$ ratio. Accordingly, the observed $^3He/^4He$ variation may be ascribed to dilution of magmatic helium by radiogenic helium derived from the basement rock.

A contribution of about 10 percent mantle-derived helium can be observed about 25 km away from the cone. The effective range of ^{3}He leakage for an independent volcano of a size similar to Mount Ontake may be some 30 km, based on the $^3He/^4He$ ratio measurement. The radius of 30 km is significantly larger than the topographic feature of the volcanic edifice, about 5 km.

During volcanic activity, appreciable amounts of magmatic gases are released from deep in the earth into the atmosphere. Most of the gases derived from the magma reservoir are emitted from the central cone of a volcano through conduits, or they may be partially derived from basalts. Some of the gases are also released to the atmosphere through fissures or any permeable channels. There exists a kind of fluid flow, which may act as a carrier for primordial helium.

The $^3He/^4He$ ratio is decreased by dilution with radiogenic helium, as the gas has passed through the crustal rock region where radiogenic helium is enriched. The contribution of radiogenic to primordial helium varies, depending upon the velocity and volume of the ascending fluid flow. The decreasing trend of the $^3He/^4He$ ratio with increasing distance from the cone may be attributed to the change in the mixing ratio of a more primitive helium in the fluid flow and a more radiogenic helium from the crustal rock.

YUJI SANO, YUJI NAKAMURA, HIROSHI WAKITA
Laboratory for Earthquake Chemistry, University of Tokyo, Bunkyo-ku, Tokyo, Japan
AKIKO URABE, TAKESHI TOMINAGA
Department of Chemistry, University of Tokyo

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Early Eocene Vertebrates from Baja California: Evidence for Intracontinental Age Correlations

Abstract. *Newly discovered fossils support a Wasatchian (early Eocene) age for the Punta Prieta vertebrate fauna of Baja California and reveal the utility of land mammal ages on a continental scale. Dispersal scenarios for late Paleocene and early Eocene vertebrates usually invoke heterochrony for similar, but geographically separated, faunas or taxa. Such heterochrony is not supported by independent geochronologies or adequate geographic samples.*

The provincial land mammal ages for North America proposed by Wood *et al.* (*1*) in 1941, although subject to continued refinement, are widely recognized by vertebrate paleontologists. Several investigators (*2, 3*) have now suggested that geographically separated faunas of similar taxonomic composition assigned to the same provincial age are not always time-equivalent or that faunas thought to represent successive ages may overlap temporally. To what extent, then, are North American land mammal ages useful in geochronology? More precisely, can such time units be applied on a regional, continental, or even intercontinental scale?

The establishment and refinement of the Clarkforkian (latest Paleocene–earliest Eocene) and Wasatchian (early Eocene) Land Mammal ages (*4, 5*) derive from faunas restricted to depositional basins of the Rocky Mountain region of the western United States (Fig. 1). The discovery of new vertebrate fossils from Baja California provides a rare test for the discrimination of these ages on a broader geographic scale. Information on this fauna is also relevant to diverse theories for mammalian dispersal during the Early Tertiary.

The fossil locality is a limited area of badlands surrounding the prominent Lomas las Tetas de Cabra ("Occidental Buttes" of Gastil) (*6*). The area is approximately 25 km south of the town of Punta Prieta, Baja California Norte, Mexico. Fossils occur in terrestrial, variegated sands and siltstones that belong to an unnamed formation (*6, 7*). To the west, these strata intertongue with fossiliferous shallow and deep water marine units (*6*).

The mammals originally collected from the Punta Prieta region (*7*) include *Hyracotherium seekinsi*, *Esthonyx* sp., a barylambdid pantodont (new taxon, similar to *Barylambda*), and a juvenile creodont (Table 1). This small assemblage was tentatively assigned a Clarkforkian age, with the qualification that the fauna could range from Tiffanian (late Paleocene) to Wasatchian in age (*7*).

Vertebrate fossils collected from this