AMS RADIOCARBON DATING OF HOLOCENE TEPHRA LAYERS ON ULLEUNG ISLAND, SOUTH KOREA

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ABSTRACT. Ulleung Island, a large stratovolcano, is located in the western part of the Japan Sea (East Sea), 130 km off the eastern coast of the Korean Peninsula. The Ulleung-Oki (U-Oki) is a widely distributed tephra in and around the Japan Sea, and has an age of 10.7 cal ka BP obtained from the Lake Suigetsu data set (central Japan). Of the 7 tephra layers (U-7 to -1) on the island, the pumiceous U-4, U-3, and U-2 tephra layers are petrochemically and petrographically similar to the U-Oki tephra. To determine the eruption ages of 3 tephra layers on Ulleung Island, we conducted radiocarbon dating for 5 soil and 2 charcoal samples. Although the soil samples have the C/N ratios from 5 to 10, the obtained ^{14}C dates are still consistent with the tephra stratigraphy of the island. The calibrated ^{14}C dates for the U-4, U-3, and U-2 tephras are 11 cal ka BP, 8.3 or 9 cal ka BP, and 5.6 cal ka BP, respectively, indicating that the explosive eruptions occurred in the island with a time interval of 2000 to 3000 yr during the period of the early to middle Holocene. Based on our chronology, the U-4 tephra is most likely correlated with the U-Oki tephra.

INTRODUCTION

Ulleung Island (37°30′N, 130°52′E), a large Quaternary stratovolcano, is situated in the west Japan Sea (East Sea), 130 km off the eastern coast of the Korean Peninsula (Figure 1). The Ulleung-Oki tephra (U-Oki) erupted from the Nari caldera of the island and distributed in and around the Japan Sea, occurs between the Aira-Tn (AT) and Kikai-Akahoya (K-Ah) tephras (Machida 1999; Machida and Arai 1983, 2003). These widespread tephra layers are a useful tool for a providing chronological marker to paleoenvironmental changes in the Japan Sea (Bahk et al. 2004; Domitsu and Oda 2006). Age determination using accelerator mass spectrometry (AMS) radiocarbon dating (Park et al. 2006) and characterization of tephra layers (Park et al. 2003, 2007) have been performed for cored marine sediments around the island. Previous ^{14}C dates of organic material indicate its eruption age to be about 9.3 ka BP (Machida et al. 1981; Arai et al. 1981). On the other hand, AMS ^{14}C data sets of cored samples in Lake Suigetsu (Figure 1) have revealed calendar ages of these tephras as 29 cal ka BP for the AT tephra (Kitagawa and van der Plicht 1998), 10.7 cal ka BP for the U-Oki tephra, and 7.3 cal ka BP for the K-Ah tephra (Kitagawa et al. 1995).

Machida et al. (1984) described 7 tephra layers, U-1 to U-7 in descending order, which are composed mainly of pumice fall deposits in the island. Among them, the U-4, U-3, and U-2 tephras seem to occur between the AT and K-Ah tephras. Although it is difficult to correlate the U-Oki tephra with tephra deposits on the island by petrographic characteristics, the U-2 tephra might be the first candidate based on its distribution, volume, and stratigraphic position (Machida et al. 1984). In order to refine the chronology of the U-4, U-3, and U-2 tephras, we conducted a detailed field survey on the island, then performed ^{14}C dating with AMS. In this paper, we present the ^{14}C dating results for these tephras and discuss the eruption ages.

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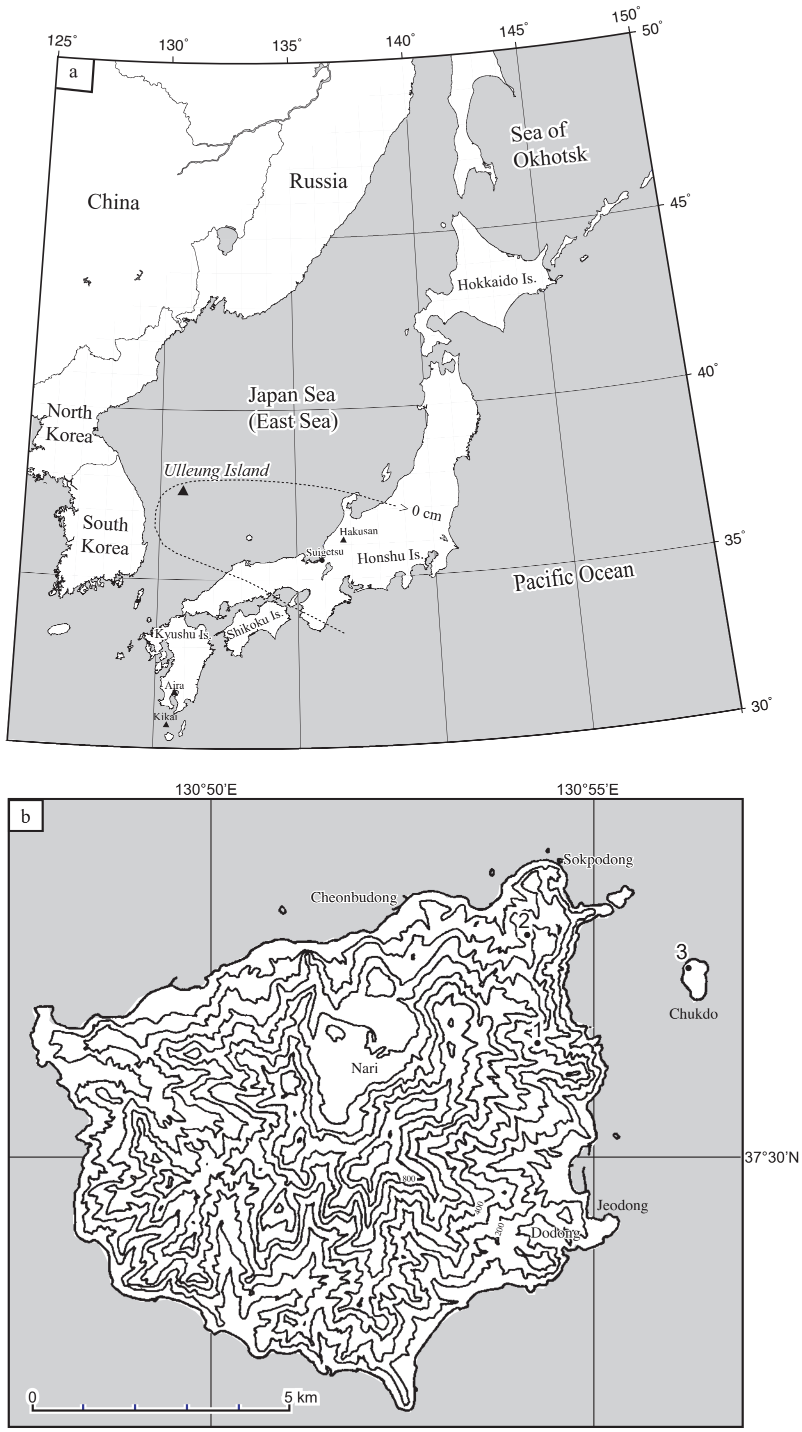

Figure 1 a) Location of Ulleung Island and the minimum limitation of the U-Oki tephra (Machida and Arai 2003; Park et al. 2003). Triangles indicate the location of volcanoes referred to in the text. Black dot indicates location of Lake Suigetsu. b) Topographic map of Ulleung Island. Contour intervals are 100 m. Dots numbered 1 to 3 indicate location of outcrops.

STRATIGRAPHY OF PUMICE FALL DEPOSITS ON ULLEUNG ISLAND

We conducted a field survey to confirm the stratigraphic relationship of the U-2, U-3, U-4 tephra deposits on Ulleung Island. Representative columnar sections and their localities in the island are shown in Figures 1b and 2, respectively.

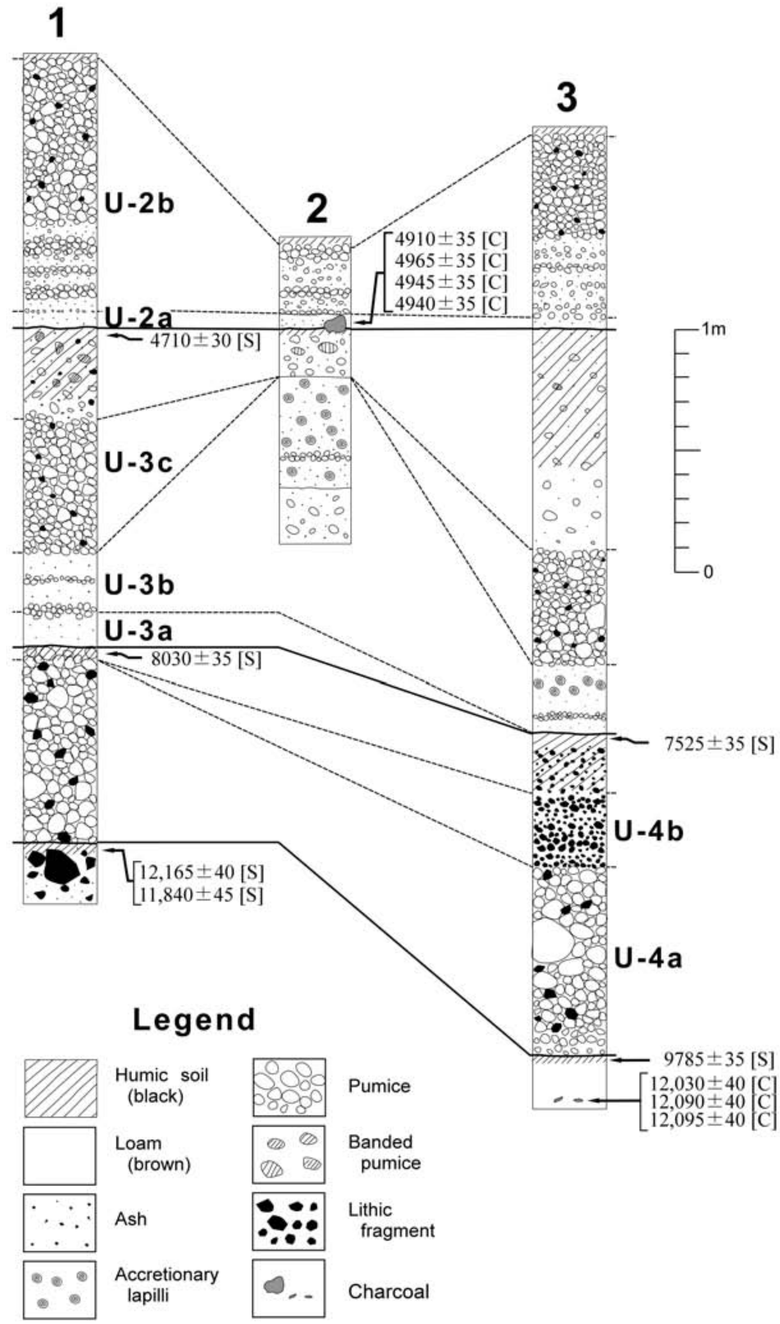

Figure 2 Columnar sections for the Holocene tephra layers of Ulleung Island. [C]: charcoal fragment, [S]: soil sample.

The U-4 tephra overlies light-colored loams. It can be divided into 2 lithologic units, Unit U-4a and 4b at Locality 3. U-4a is a normally graded, grayish white deposit of pumice lapilli and lithic fragments as thick as 70 cm, and directly overlain by U-4b. It is a single bed, gray deposit composed of lithic and scoria lapilli with a maximum thickness of 30 cm. The soil layer between the U-4 and U-3 tephras is brown to black and has thickness of up to 25 cm. The U-3 tephra can be divided into 3 units (Unit U-3a, 3b, and 3c) at Locality 1. Unit U-3a is a grayish brown to white deposit consisting of ash and small pumice as thick as 12 cm. Unit U-3b, characterized by the presence of accretionary lapilli, is a grayish white deposit consisting of ash and pumice up to 20 cm thick. Unit U-3c is a single bed, normally graded, gray to white deposit of pumice lapilli and lithic fragments up to 50 cm thick. The soil layer between the U-3 and U-2 tephras is brown to black and as thick as 90 cm. The U-2 tephra can be divided into 2 units, Units U-2a and 2b at Locality 1. U-2a is a single bed, grayish yellow to white deposit of ash and accretionary lapilli and measures 8 cm. The U-2b is composed of at least 3 beds of normally graded gray to white deposits of pumice lapilli and lithic fragments up to 100 cm thick, and overlain by a black soil. The lithology of these sections is almost in accordance with that presented in Machida et al. (1984).

MATERIALS AND METHODS

We collected buried soil (2 cm thick) and charred wood trunks in and below the U-2, U-3, and U-4 tephras from Localities 1 to 3 (Figure 2). Charred wood fragments were found in the U-2a tephra and in loam (10 cm below the U-4 tephra).

For soil samples, a humin fraction was separated by acid-alkali-acid (AAA) treatments (Okuno et al. 2001). The organic carbon and nitrogen contents were measured for each humic fraction using a CN coder (MT-700, Yanaco). The charcoal sample was also cleaned by AAA treatment. The pretreated material was oxidized by heating at 900 °C for 2 hr in a sealed Vycor® tube together with CuO. The produced CO_2 was reduced catalytically to graphite on Fe powder with hydrogen gas in a sealed Vycor tube (Kitagawa et al. 1993).

We used a HVEE Tandetron AMS system at Nagoya University to make ^{14}C measurements of graphite targets with NIST oxalic acid (HoxII) as standards (Nakamura et al. 2000). We corrected for carbon isotopic fractionation using the ^{13}C / ^{12}C ratio ($\delta^{13}C_{PDB}$). To estimate the ^{14}C background level, the ^{14}C age of commercial graphite powder (dead carbon) was also measured in the same sequence of sample measurements. ^{14}C ages were calculated by subtracting the ^{14}C concentration of the background sample. These ^{14}C dates were calibrated to the calendar years range by the calibration data set IntCal04 (Reimer et al. 2004) using the CALIB 5.0 program (Stuiver and Reimer 1993).

RESULTS AND DISCUSSION

The results of AMS ^{14}C dating and their calibration are shown in Table 1. The obtained ^{14}C dates are 9785 ± 35 to 12,165 ± 40 BP for the U-4 tephra, 7525 ± 35 and 8030 ± 35 BP for the U-3 tephra, and 4710 ± 30 to 4965 ± 35 BP for the U-2 tephra. The C/N ratio of soil samples ranges from 5 to 10, which indicates that organic materials contained in these samples have been considerably decomposed (Okuno et al. 1997, 2001; Okuno and Nakamura 2003). It seems that a humin fraction whose C/N ratio is close to 10 may produce a ^{14}C date younger than expected from its stratigraphic position. However, the results that we obtained are still reliable since the ^{14}C dates are consistent with the stratigraphy (Figure 2). The ^{14}C age of the paleosol just below a tephra represents the time when the tephra layer covered the soil, thus giving its eruption age (Okuno et al. 1997, 2001; Okuno and Nakamura 2003). The ^{14}C dates for both charcoal and soil are almost identical within the measurement errors, with the exception of the U-4 tephra. For estimating the eruption ages, we used a modal part of the calibrated age range; 14 or 11 cal ka BP for U-4, 8.3 or 9 cal ka BP for U-3, 5.6 cal ka BP for U-2. Because the C/N ratio of soil samples is a useful indicator for detecting possible contamination from allochthonous organic materials, the older ^{14}C dates close to 12 ka BP may be applied for the U-4 tephra. However, charcoal samples may often introduce uncertainties to the eruption age because the trees were growing before the eruption and are resistant to weathering. We also have to take into account the old wood effect. Thus, 11 cal ka BP is tentatively adopted for the U-4 tephra in this study. This age agrees well with the age of 10.7 cal ka BP obtained from the Lake Suigetsu data for the U-Oki tephra. The eruption age of 8.3 or 9 cal ka BP for the U-3 tephra also correlates well with an alkaline tephra, Hm-2 (Higashino et al. 2005), which occurs as an intercalated tephra with peat layers on the slope of Hakusan Volcano (Figure 1), central Japan. Therefore, pumice eruptions in the island have occurred at intervals of 2000 to 3000 yr during the early Holocene.

Table 1 Results of AMS ^{14}C dating.

Locality	Stratigraphic position	Material	C (%)	N (%)	C/N ratio	$\delta^{13}C_{(PDB)}$	^{14}C date (BP)	Lab nr (NUTA2-)	Age range (cal BP) (2 σ, probability %)
2	In U-2	Charcoal	—	—	—	–25.4	4910 ± 35	5494	5590–5666 (85.39)
									5671–5714 (14.61)
						–25.5	4965 ± 35	5495	5604–5749 (97.01)
									5829–5844 (2.63)
									5848–5852 (0.36)
						–23.9	4945 ± 35	5496	5602–5738 (100)
						–23.8	4940 ± 35	5497	5600–5734 (100)
1	Below U-2	Soil	0.3	n.d.	—	–27.0	4710 ± 30	7730	5323–5417 (52.11)
									5442–5484 (22.19)
									5517–5522 (0.90)
									5527–5580 (24.80)
3	Below U-3	Soil	1.21	0.11	10.71	–28.1	7525 ± 35	6755	8213–8145 (6.58)
									8247–8257 (1.28)
									8301–8405 (92.14)
1	Below U-3	Soil	0.33	0.04	8.64	–25.7	8030 ± 35	6756	8774–8842 (29.07)
									8846–9017 (70.93)
3	Below U-4	Soil	0.54	0.06	9.12	–27.5	9785 ± 35	6752	11,177–11,126 (100)
1	Below U-4	Soil	0.14	0.03	5.17	–24.5	12,165 ± 40	6754	13,890–14,141 (100)
						–27.5	11,840 ± 45	7309	13,581–13,816 (100)
3	Below U-4	Charcoal	—	—	—	–27.0	12,030 ± 40	6764	13,781–13,996 (100)
						–26.5	12,090 ± 40	6765	13,819–14,051 (100)
						–26.5	12,095 ± 40	6766	13,822–14,056 (100)

CONCLUSIONS

The obtained ^{14}C ages are consistent with the stratigraphy on the island. Calibrated ^{14}C dates for Ulleung tephras revealed eruption ages of 11 cal ka BP for the U-4 tephra, 8.3 or 9 cal ka BP for the U-3 tephra, and 5.6 cal ka BP for the U-2 tephra. The results also suggest that the explosive eruptions in the island occurred at intervals of 2000 to 3000 yr in the early Holocene period.

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REFERENCES

Arai F, Oba T, Kitazato H, Horibe Y, Machida H. 1981. Late Quaternary tephrochronology and paleo-oceanography of the sediments of the Japan Sea. *Daiyonki-Kenkyu* 20:209–30. In Japanese with English abstract.

Bahk JJ, Ham S-J, Khim B-K. 2004. Variations of terrigenous sediment supply to the southern slope of the Ulleung Basin, East/Japan Sea since the Last Glacial Maximum. *Geosciences Journal* 8(4):381–90.

Domitsu H, Oda M. 2006. Linkages between surface and deep circulations in the southern Japan Sea during the last 27,000 years: evidence from planktic foraminiferal assemblages and stable isotope records. *Marine Micropaleontology* 61(4):155–70.

Higashino T, Tsujimori T, Itaya T. 2005. An alkaline tephra found at Midagahara, Mt. Hakusan. *Annual Report of the Hakusan Nature Conservation Center* 32: 1–7. In Japanese.

Kitagawa H, van der Plicht J. 1998. A 40,000-year varve chronology from Lake Suigetsu, Japan: extension of the ^{14}C calibration curve. *Radiocarbon* 40(2):505–15.

Kitagawa H, Masuzawa T, Nakamura T, Matsumoto E. 1993. A batch preparation method for graphite targets with low background for AMS ^{14}C measurements. *Radiocarbon* 35(2):295–300.

Kitagawa H, Fukuzawa H, Nakamura T, Okamura M, Takemura K, Hayashida A, Yasuda Y. 1995. AMS ^{14}C dating of varved sediments from Lake Suigetsu, central Japan and atmospheric ^{14}C change during the late Pleistocene. *Radiocarbon* 37(2):371–8.

Machida H. 1999. The stratigraphy, chronology and distribution of distal marker-tephras in and around Japan. *Global and Planetary Change* 21(1–3):71–94.

Machida H, Arai F. 1983. Extensive ash falls in and around the Sea of Japan from large late Quaternary eruptions. *Journal of Volcanology and Geothermal Research* 18(1–4):151–64.

Machida H, Arai F. 2003. *Atlas of Tephra in and around Japan*. Revised edition. Tokyo: University of Tokyo Press. 336 p. In Japanese.

Machida H, Arai F, Moriwaki H. 1981. Two Korean tephras, Holocene markers in the Sea of Japan and the Japanese Islands. *Kagaku* 51:562–9. In Japanese.

Machida H, Arai F, Lee B, Moriwaki H, Furuta T. 1984. Late Quaternary tephras in Ulleung-do Island, Korea. *Chigaku-Zasshi* 93:1–14. In Japanese with English abstract.

Nakamura T, Niu E, Oda H, Ikeda A, Minami M, Takahashi H, Adachi M, Pals L, Gottdang A, Suya N. 2000. The HVEE Tandetron AMS system at Nagoya University. *Nuclear Instruments and Methods in Physics Research B* 172(1–4):52–7.

Okuno M, Nakamura T. 2003. Radiocarbon dating of tephra layers: recent progress in Japan. *Quaternary International* 105(1):49–56.

Okuno M, Nakamura T, Moriwaki H, Kobayashi T. 1997. AMS radiocarbon dating of the Sakurajima tephra group, southern Kyushu, Japan. *Nuclear Instruments and Methods in Physics Research B* 123(1–4): 470–4.

Okuno M, Nakamura T, Kamata H, Kobayashi T. 2001. Radiocarbon dating of paleosol intercalated with tephra layers in Japan. In: Juvigné E, Raynal JP, editors. *Tephras, Chronology and Archaeology.* Les Dossiers de l'Archeo-Logis Volume 1. Clermont-Ferrand: CRDP. p 67–71.

Park M-H, Kim I-S, Shin J-B. 2003. Characteristics of the late Quaternary tephra layers in the East/Japan Sea and their new occurrences in western Ulleung Basin sediments. *Marine Geology* 202(3–4):135–42.

Park M-H, Kim J-H, Ryu B-J, Kim I-S, Chang H-W. 2006. AMS radiocarbon dating of the marine late Pleistocene-Holocene sediment cores from the western Ulleung Basin, East/Japan Sea. *Nuclear Instruments and Methods in Physics Research B* 243(1): 211–5.

Park M-H, Kim J-H, Kil Y-W. 2007. Identification of the late Quaternary tephra layers in the Ulleung Basin of the East Sea using geochemical and statistical methods. *Marine Geology* 244(1–4):196–208.

Reimer PJ, Baillie MGL, Bard E, Bayliss A, Beck JW, Bertrand CJH, Blackwell PG, Buck CE, Burr GS, Cutler KB, Damon PE, Edwards RL, Fairbanks RG, Friendrich M, Guilderson TP, Hogg AG, Hughen KA, Kromer B, McCormac G, Manning S, Bronk Ramsey C, Reimer RW, Remmele S, Southon JR, Stuiver M, Talamo S, Taylor FW, van der Plicht J, Weyhenmeyer CE. 2004. IntCal04 terrestrial radiocarbon age calibration, 0–26 cal kyr BP. *Radiocarbon* 46(3):1029–58.

Stuiver M, Reimer PJ. 1993. Extended ^{14}C data base and revised CALIB 3.0 ^{14}C age calibration program. *Radiocarbon* 35(1):215–30.