Letter

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On the Eruption Age of the Hijiori Caldera, Based on More Accurate and Reliable Radiocarbon Data

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Eight ^{14}C ages of the Hijiori pyroclastic flow deposit (stage 1 and 4, Kawaguchi and Murakami , 1994) are reported. Calibrated ^{14}C ages of the stage 1 pyroclastics fall in a relatively narrow range, while those stage 4 are more fluctuated. The larger fluctuation may be attributed to nature of samples collected (lower organic carbon concentration and poor state of sample preservation relative to the stage 1). No significant difference in the ^{14}C age is recognized between the stage 1 and stage 4. It is concluded that the eruptive activities of Hijiori volcano reached its peak shortly after the outbreak at about 12,000 y.B.P. (calendar age).
Key words: caldera, Hijiori, hot dry rock, ^{14}C, radiocarbon

1. Introduction

Hijiori caldera (Sugimura, 1953) is located in the Northeastern Japan arc at about 15 km NE from the Gassan volcano (Fig. 1). This area is about 40 km back arc side from the volcanic front of NE Japan arc (the Moriyoshi volcanic zone, Nakagawa *et al.,* 1986). Pyroclastic flow deposits of the Hijiori dacite with 64± 2 wt.% SiO_2 (Ui, 1971; Kawaguchi and Murakami, 1994; Murakami and Kawaguchi, 1994) covered the area of about 10 km from the caldera center with estimated maximum thickness of about 150 m. The estimated total volume of pyroclastic flow deposit, about 1.4 km^2 (Sugimura, 1953) is comparable with the volume of depression, 0.8 km^3 (Sugimura, 1953)∼1.2 km^3 (Ui, 1971). Coincident pumice falls are distributed toward the east. At a location 50 km away from the caldera, total thickness of the pumice falls is about 20 cm (Miyagi in preparation, thicker than previous reports by Yonechi and Kikuchi, 1966 and Machida and Arai, 1992).

Present activity of the Hijiori caldera is as hot springs. Although there is no high temperature volcanic steams, nor active fumaroles, the caldera lake deposits have undergone remarkable hydrothermal alteration. A Japanese administrative organization NEDO, New Energy and Industrial Technology Development Organization, conducted a series of experiments (a long term flow test for two years) on geothermal electricity power plant that will make use of hot dry rock as a heat source (e.g., Sato and Okabe, 2001).

The Hijiori caldera is one of a "new active volcano" of Japan, because CCPVE (Coordinating Committee for Prediction of Volcanic Eruption, JMA/MLIT) reorganized definition of "Active volcano", on 21 January 2003. Now the definition includes those volcanoes erupted in the last 10 thousand years (Ui *et al.,* 2002). The Hijiori volcano is watched not only by the nations as a new active volcano but also by archaeologists since the coincident pumice fall can be used as a time marker.

Ages of the Hijiori pyroclastic flow were reported to be around 10 thousand years (10,740–9,780 y.B.P. ^{14}C, Ui *et al.,* 1973; 8800±1800 years, Fukuoka and Kigoshi, 1971).

Recent develops in radio carbon dating techniques have greatly improved the accuracy and reliability. In those days, ideal conditions were assumed for the ^{14}C dating that ^{14}C concentration in the atmosphere to be constant through the past until the present, and that the ^{14}C concentration in all parts of the living plants to be constant. However, production rate of ^{14}C in the high atmosphere varies with time, also, ^{14}C concentration in biosphere can be modified by isotopic fractionation through biochemical reactions. Radiocarbon dating nowadays is able to calibrate the temporal change of ^{14}C concentration using a measured $^{14}C/^{12}C$ ratio in tree rings of known age, and the modern datings correct the carbon isotopic fractionation using $^{13}C/^{12}C$ ratios of each sample (Stuiver and Reimer, 1993; Stuvier *et al.,* 1998).

To obtain up-to-date age of the Hijiori pyroclastic flow, radiocarbon specimens should be re-measured, rather than re-calibrated, because the correction for isotopic fractionation requires $^{13}C/^{12}C$ analysis for the same sample that analyzed the $^{14}C/^{12}C$ ratios.

An essential benefit of re-measureing is that a more detailed stratification of the pyroclastic flow deposit

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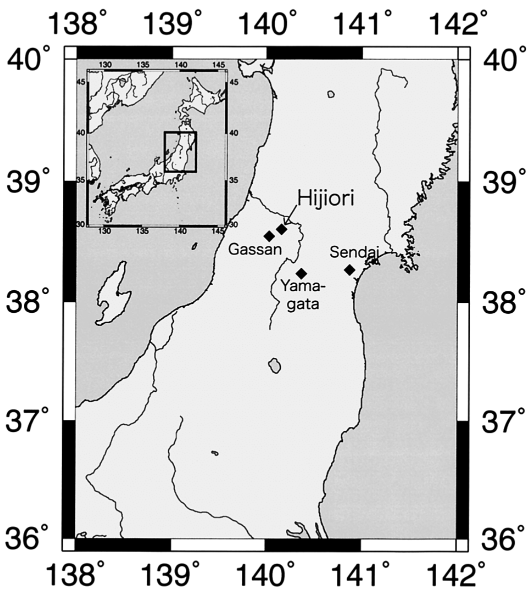

Fig. 1. Map showing the location of Hijiori caldera, includes neighboring major towns (Sendai, Yamagata) and a volcano (Gassan).

(Kawaguchi and Murakami, 1994) is now available. The volcanic activity of Hijiori caldera is subdivided into five stages; 1) pyroclastic flow without welding, 2) pyroclastic flow with welded base, 3) lava dome, 4) pyroclastic flow of the maximal, 5) local and small scale tephric deposit that covers the lake deposits (Kawaguchi and Murakami, 1994).

2. Samples and methods

Samples for radiocarbon dating (charred woods, woods, peat, plant material and organic sediments) were collected from the body of pyroclastic flow deposit or from a carbon rich horizon directly covered by the pyroclastics. Locality of the outcrops (latitude and longitude) is reported in a geodetic frame of the Tokyo Datum. Samples collected in this report will represent the age of the first eruptive stage 1, and the most prominent stage 4. After preparations, ^{14}C concentration of the samples was measured with beta-ray counting using liquid scintillation counter in case that a plenty amount of carbon were available, otherwise ^{14}C, ^{13}C, and ^{12}C were measured with AMS. All the analyzer in this report is BETA ANALYTIC INC. (4895 SW 74 Court, Miami, FL, U.S.A. 33155). The author collected all the samples.

3. Result

In the following descriptions, "measured ^{14}C age" stands for a calculated age using $^{14}C/^{12}C$ ratio of the sample and a constant half-life of 5568 years (so called Libby half-life). "Calibrated ^{14}C age" as well as "conventional ^{14}C age" means a corrected ^{14}C age for the effect of carbon isotopic fractionation in ^{14}C and ^{12}C. The correction depends on measured $^{13}C/^{12}C$ ratios of each sample. "Calendar age" includes both the carbon isotopic fractionation effect and the ^{14}C production rate change using the calibration data by Talma and Vogel (1993).

The measured ^{14}C age, calibrated ^{14}C age, and the calendar age are expressed in y.B.P. (year Before Present, AD 1950).

No. 1.
Measured ^{14}C age: 10,250±60 y.B.P., $\delta^{13}C = -25.9‰$
Calibrated ^{14}C age: 10,240±60 y.B.P.
Calendar age: 12,360−11,680 (2σ) y.B.P.,
12,330−11,830 (1σ) y.B.P.
Intercept age: 11,950 y.B.P.
Analysis (preparation) method: Beta counting (acid/alkali/acid)
Analyzed material: Charred wood bulk
Sampling date: 3 Aug. 2001
Sample number: IM20010803J (Beta-163454)
Location: N38°34′56.85″, E140°08′50.00″
(1.7 km south from the Hijiori caldera center)
Occurrence: Charred woods are accumlated near the bottom of the Hijiori pumice flow deposit in stage 1. Analyzed sample is a piece of charred wood the diameter of which is about 15 cm.

No. 2.
Measured ^{14}C age: 10,360±100 y.B.P., $\delta^{13}C = -24.8‰$
Calibrated ^{14}C age: 10,370±100 y.B.P.
Calendar age: 12,840−11840 (2σ) y.B.P.,
12,790−11,920 (1σ) y.B.P.
Intercept age: 12,320 y.B.P.
Analysis (preparation) method: Beta counting (acid/alkali/acid)
Analyzed material: Charred wood bulk
Sampling date: 2 Aug. 2001
Sample number: IM20010802B (Beta-163453)
Location: N38°37′04.75″, E140°14′01.49″
(6.6 km ENE from the caldera center)
Occurrence: This outcrop comprises layers of stage 1 to 4. No charred material was found except the stage 1. The charred wood from the Hijiori stage 1 layer analyzed is about 10 cm in diameter.

No. 3.
Measured ^{14}C age: 10,330±50 y.B.P., $\delta^{13}C = -28.1‰$
Calibrated ^{14}C age: 10,280±50 y.B.P.
Calendar age: 12,580−12,520 (2σ)
12,370−11,830 (2σ), 12,350−11,900 (1σ) y.B.P.
Intercept age: 12,100, 12,010, 11,970 y.B.P.

Analysis (preparation) method: AMS (acid/alkali/acid)
Analyzed material: Wood
Sampling date: 3 Aug. 2001
Sample number: IM20010803G (Beta-163444)
Location: N38°34′57.10″, E140°08′49.53″
(2.8 km SSW from the caldera center)
Occurrence: The sample was collected from an organic material-rich layer with good continuity and 5–10 cm in thickness, which is sandwiched between reddish Tertiary silt and Hijiori pumice flow deposit in stage 1.

No. 4.
Measured ^{14}C age: 10,330±50 y.B.P., δ^{13}C=−28.0‰
Calibrated ^{14}C age: 10,280±50 y.B.P.
Calendar age: 12,580−12,520 (2σ),
12,370−11,830 (2σ), 12,350−11,900 (1σ) y.B.P.
Intercept age: 12,100, 12,010, 11,970 y.B.P.
Analysis (preparation) method: AMS (acid/alkali/acid)
Analyzed material: Wood
Sampling date: 14 Sep. 2001
Sample number: IM20010914B (Beta-163451)
Location: N38°33′45.78″, E140°10′53.58″
(5.3 km SSE from the caldera center)
Occurrence: Analyzed sample was collected from the layer (1 cm in thickness) of organic carbon rich material, which layer is sandwiched between a Tertiary silty basement and the Hijiori pumice flow deposit (stage 4) with pale blue sandy basal part of about 5 cm thickness.

No. 5.
Measured ^{14}C age: 10310±50 y.B.P., δ^{13}C=−29.2‰
Calibrated ^{14}C age: 10,240±50 y.B.P.
Calendar age: 12,350−11,710 (2σ),
12,330−11,810 (1σ) y.B.P.
Intercept age: 11,950 y.B.P.
Analysis (preparation) method: AMS (acid/alkali/acid)
Analyzed material: Peat
Sampling date: 13 Sep. 2001
Sample number: IM20010913FB (Beta-163449)
Location: N38°39′07.64″, E140°10′07.71″
(3.1 km NNE from the caldera center)
Occurrence: Analyzed sample was a black peat layer with about 1 cm in thickness which is sandwiched between the Tertiary purplish silt and Hijiori pumice flow deposit in stage 4.

No. 6.
Measured ^{14}C age: 9,810±50 y.B.P., δ^{13}C=−29.1‰
Calibrated ^{14}C age: 9,740±50 y.B.P.
Calendar age: 11,210−11,110 (2σ),
11,190−11,160 (1σ) y.B.P.
Intercept age: 11,180 y.B.P.
Analysis (preparation) method: AMS (acid/alkali/acid)
Analyzed material: Plant material
Sampling date: 14 Sep. 2001
Sample number: IM20010914A (Beta-163450)
Location: N38°33′45.78″, E140°10′53.58″
Occurrence: Location of this outcrop is the same as the No. 4. Analyzed organic particles were less than 1 mm in size and dispersed in pale blue sandy ash covered by the pumice flow deposit in stage 4.

No. 7.
Measured ^{14}C age: 11850±50 y.B.P., δ^{13}C=−26.4‰
Calibrated ^{14}C age: 11,830±50 y.B.P.
Calendar age: 14,070−13,540 (2σ),
14,040−13,630 (1σ) y.B.P.
Intercept age: 13,830 y.B.P.
Analysis (preparation) method: AMS (acid washes)
Analyzed material: Organic sediment (silt)
Sampling date: 12 Sep. 2001
Sample number: IM20010912U (Beta-163446)
Location: N38°40′21.15″, E140°09′47.93″
(7.3 km N from the caldera center)
Occurrence: The sample was collected from an organic material-rich layer with poor continuity and less than 1 cm in thickness. This layer is on reddish or purplish Tertiary silt, and is covered by the Hijiori pumice flow deposit in stage 4.

No. 8.
Measured ^{14}C age: 7,830±50 y.B.P., δ^{13}C=−24.7‰
Calibrated ^{14}C age: 7,830±50 y.B.P.
Calendar age: 8,740−8,460 (2σ),
8,630−8,560 (1σ) y.B.P.
Intercept age: 8,600 y.B.P.
Analysis (preparation) method: AMS (acid washes)
Analyzed material: Organic sediment without charcoal, plant
Sampling date: 4 Aug. 2001
Sample number: IM20010804D (Beta-163445)
Location: N38°38′47.37″, E140°11′38.56″
(5.4 km NE from the caldera center)
Occurrence: The sample analyzed is an organic material-rich layer with good continuity and 1–2 mm in thickness, which covers Tertiary orange silt. About 10 cm from the top of the silt is more reddish in color, probably representing an oxidation by heating with the overlying Hijiori stage 4 pumice flow deposit.

4. Discussions and summary

In spite of smaller analytical errors (±50–100 years, while ±180–340 years by Ui *et al.,* 1973), total range of the measured ^{14}C ages in this report was wider (11,830 – 7,830 y.B.P.) relative to the range 10,740–9,780 y.B.P. by Ui *et al.* (1973). However, weeding out three samples, No. 6, 7, and 8 will reduce the fluctuation. All the three dropped samples correspond to those put in parenthesis in Fig. 2, indicating that the thickness of organic carbon rich layer is less than 1 cm. Because they have relatively lower carbon concentration and smaller (silty sediment except No. 6) organic carbon particles, it is rational to remove them. The author supposes the lesser carbon concentration in the dropped samples from the stage 4 to be related with a possible damage in ecological system due to the forerunning stage 1 activities.

Measured ^{14}C ages of qualified samples (No. 1–5) fall in a narrow range between 10,360 and 10,250 y.B.P., with good agreement with 10,740–9,780 y.B.P. by Ui *et al.* (1973). However, the "Measured ^{14}C ages" do not represent true eruptive ages because they still need to be calibrated as mentioned earlier.

After the corrections for both the carbon isotopic fractionation effect and the ^{14}C production rate change, "Calendar ages" become available. All the intercept ages of the screened samples fairly focus around 12,055 y.B.P. (arithmetical mean) and fall within an over wrapped 1σ probability range from 12,330 to 11,920 y. B.P. (Fig. 2). Thus no significant difference is recognized in the formation age between the stage 1 and stage 4 of the Hijiori pumice flow deposits. To summarize, the eruptive activities of Hijiori volcano reached its peak shortly after the outbreak at about 12,000 y.B.P. (calendar age). The coincident air fall pumice layers can be used as a good time marker in archaeological studies.

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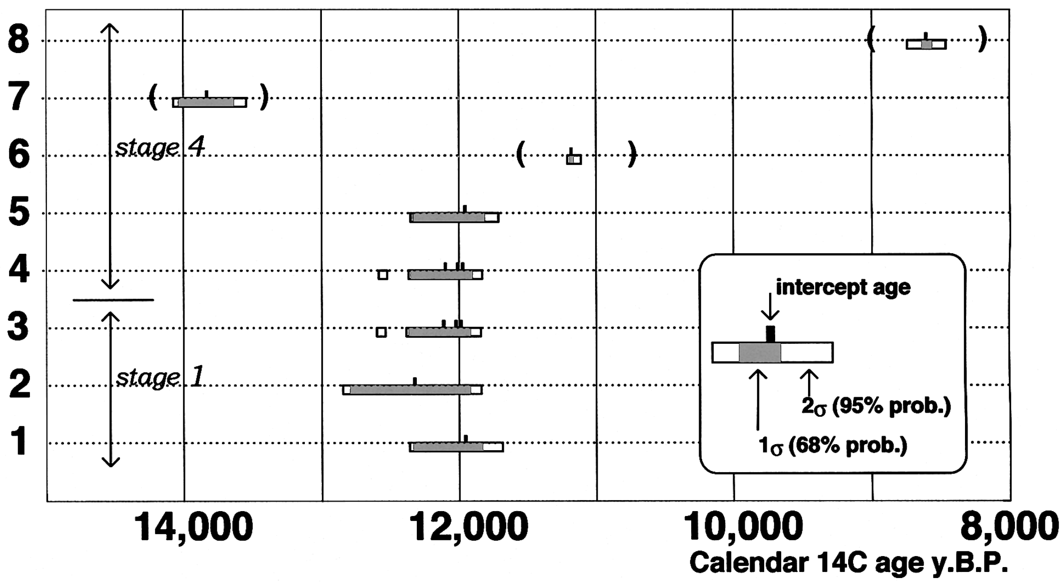

Fig. 2. Distribution of calendar ages for the Hijiori pyroclastic deposits. Parenthesis means that the thickness of the layer from which organic carbon was collected is less than 1 cm.

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(Editorial handling Masao Ban)

高精度放射性炭素年代測定にもとづく肘折カルデラの噴火年代

宮城磯治

肘折火砕流 (ステージ 1 と 4; 村上・川口，1994) の放射性炭素年代測定値を 8 つ報告する．ステージ 1 火砕流堆積物の年代値 (同位体分別補正済) は比較的まとまる一方，ステージ 4 ではばらつきが大きい．ステージ 4 試料にみられた年代の大きなばらつきの原因は，得られた試料の性質 (保存状態が悪く炭素含有量も少ない) に起因すると考えられる．ステージ 1 と 4 の年代値には，明らかな違いが認められない．肘折火山は約 12,000 年前 (歴年代) に噴火活動を開始後，短時間で活動のピークを迎えたと考えられる．