Petrographic Properties of Visible Tephra Layers in SG93 and SG06 Drill Core Samples from Lake Suigetsu, Central Japan

Seiji MARUYAMA*, **, Keiji TAKEMURA***, Takafumi HIRATA****, Tohru YAMASHITA* and Tohru DANHARA*

[Received 11 September, 2018; Accepted 17 April, 2019]

Abstract

In this paper, we report the petrographic properties of visible tephra layers sampled from two drill cores (SG93 and SG06) from Lake Suigetsu, central Japan, because no fundamental petrographic data including the refractive indices of minerals and volcanic glass shards, the shapes of volcanic glasses, and mineral compositions of the Suigetsu tephra samples have been reported. The Suigetsu tephra layers can be broadly classified into those derived from calderas on Kyushu Island (e.g., Aso, Ata, and Aira) and those that derive from Daisen and Sambe volcanoes in the Chugoku district of southwest Japan. The tephra layers correlated with the Ulleung–Oki tephra from Ulleung Island on Japan Sea, the Sakate tephra which has a close relationship with the Sambe–Ukinuno tephra, and the scoria layer from an unknown source volcano were also found in the Suigetsu core samples. The Suigetsu tephra layer correlated with the San’in 1 tephra found in the drill core bored from Japan Sea can be also correlated with the Kuju-1 tephra which erupted from the Kuju caldera on Kyushu Island, based on the petrographic properties. The petrographic characteristics provide important constraints on the correlation and identification of tephras, which cannot be obtained by only the major element compositions of volcanic glass shards. However, the correlation of some tephra layers remains ambiguous. Therefore, additional geochemical data from volcanic glass shards including the concentrations of various trace elements are also necessary for a more rigorous identification and correlation of the Suigetsu tephra.

Key words: Lake Suigetsu, drill core, tephra, volcanic glass shards, petrographic properties

I. Introduction

Lake Suigetsu is located in the central region of Wakasa Bay, central Japan, and is one of the Five Lakes of Mikata (Fig. 1). These lakes and neighboring areas (e.g., the Kurota lowland; Takemura et al., 1994) are important for several aspects of Quaternary research, including the calibration and modeling of terrestrial 14C dating, paleoclimatology, and tephrochronology, as they may preserve a more-or-less continuous record of late Quaternary deposition, including
pollen and tephra (e.g., Yasuda, 1982; Takemura et al., 1994; Nakagawa et al., 2003). Of the Five Lakes of Mikata, Lake Suigetsu has been regarded as the most suitable for these lines of research, as there is almost no evidence for significant inflow or outflow of water (e.g., Nakagawa, 2015). As shown in Fig. 1c, the number of rivers flowing into Lake Suigetsu is far fewer than those flowing into Lake Mikata. Moreover, the surrounding mountains shelter the lakes from winds which can disturb lake sediments, and sediments at the bottom of Lake Suigetsu could escape bioturbation (e.g., Nakagawa, 2015).

Following the drilling of some shorter sediment cores, a longer 75-m-long core, SG93, was drilled close to the center of Lake Suigetsu in 1993 (Fig. 1c). Takemura et al. (1994) correlated the tephra layers found within the SG93 core with tephra marker horizons throughout Japan. In 2006, the SG06 sediment core, which was composed of four separate boreholes, was recovered. Nakagawa et al. (2012) detailed the relationships of the visible tephra layers of core SG06 with those within core SG93. Smith et al. (2013) correlated some of the visible tephra layers obtained from core SG06 with tephra marker horizons found in Japan based on the major element compositions of volcanic glass shards. Moreover, McLean et al. (2016) found a signature of the deposition (i.e., a cryptotehra layer) of the Baegdusan-Tomakomai (B-Tm) tephra (e.g., Machida and Arai, 2011) within the SG06 core samples, which was erupted from the Baegdusan volcano on the Eurasian continent (Fig. 1a). The $^{14}$C data obtained from the SG06 varved sediments was adopted by IntCal13, and the SG06 core samples are cur-
rently regarded as a world standard age calibration up to 50,000 cal yr BP (e.g., Nakagawa, 2015).

Paleoclimatology and tephrochronology research on the Lake Suigetsu sediments has generally used the most recent samples from core SG14 drilled in 2014 (Fig. 1c), and is focused mainly on the identification of cryptotephra (or invisible tephra) layers within the upper (younger) part of the core (McLean et al., 2016, 2018). However, there are almost no published data detailing the petrographic properties of the visible tephra layers within cores SG93 and SG06. Nakagawa et al. (2012) correlated the Suigetsu tephra layers based on their petrographic properties but provided no detailed information. Smith et al. (2013) reported the major element compositions of volcanic glass shards from core SG06, but also did not detail the petrographic properties of the individual tephra layers. The observations of the petrographic properties such as the refractive indices of heavy minerals (orthopyroxene and amphibole) and volcanic glass shards, the shapes of volcanic glass shards, the size distribution of minerals/volcanic glasses, and the mineral composition of the tephra have been established as fundamental information for researches on tephrochronology in Japan (e.g., Machida and Arai, 2011). As with the major compositions of volcanic glass shards, the above-mentioned petrographic properties are essential for correlations of tephras. Nevertheless, the petrographic properties such as the refractive indices of minerals/glasses of the tephra layers of the Suigetsu core samples have not been reported at all, although the data set of the major element compositions of the volcanic glass shards of them has been published (Smith et al., 2013). Therefore, it has been highly problematic to correlate the Suigetsu tephra layers with other widespread tephras, because of the absence of the common basis for the correlation.

In this paper, we present the petrographic properties of the visible tephra layer samples within the SG93 and SG06 drill cores, including the refractive index values of the heavy minerals (i.e., orthopyroxene and amphibole) and volcanic glass shards. We also attempt to correlate the tephra layers from Lake Suigetsu based on their petrographic properties.

II. Samples and analytical methods

The abbreviations for the tephra layers referred to in this study are based on the work of Machida and Arai (2011). As mentioned above, the SG06 tephra samples were obtained from a total of four separate boreholes (A, B, C, and D; Nakagawa et al., 2012; Smith et al., 2013), and the first letter of each sample name represents the borehole from which it was obtained. A detailed overview of the SG06 core samples was provided by Nakagawa et al. (2012), Smith et al. (2013), and Schlolaut et al. (2014). The sediment profile of the SG93 tephra samples was briefly summarized by Takemura et al. (1994) and Kitagawa et al. (1995).

The refractive index values of orthopyroxene, amphibole, and volcanic glass shards from a total of 25 tephra samples from the SG93 core and 32 tephra samples from the SG06 cores were determined using a refractive index measurement system (RIMS; Kyoto Fission-Track Co., Ltd.) refractometer (Danbara et al., 1992).

The petrographic properties, including the refractive index values of volcanic glass shards in the SG93 tephra samples, are summarized in Fig. 2 and Table 1. The petrographic properties of the SG06 tephra layers are summarized in Fig. 3 and Table 2, and the refractive index values of orthopyroxene, amphibole, and volcanic glass shards are summarized in Table 3. The correspondence between the SG06 tephra samples from this study and those described by Smith et al. (2013) is summarized in Table 2. The correspondence between individual tephra samples from the SG93 and SG06 cores are shown in Tables 1 and 2. To avoid confusion, the names of the tephra samples from the SG93 core used in the previous studies (e.g., Takemura et al., 1994) were renamed, partly according to the method of Smith et al. (2013). For example, SG93-59 of this study corresponds
to SG59 of the previous studies.

The shapes and degrees of hydration of the volcanic glass shards are summarized in Tables 1 and 3. In this study, classification of the shapes of the volcanic glass shards are based on the method proposed by Yoshikawa (1976), which is a popular method among Japanese tephrochronology researchers (e.g., Ikehara et al., 2004; Ikuta et al., 2016). Yoshikawa (1976) has broadly divided the shapes of volcanic glass shards into the following three types: a bubble wall type (abbreviated to bw in the Figures and Tables), corresponding to the Henpei (or tabular) type of Yoshikawa (1976); a pumiceous type (pm), corresponding to a Takoushitsu (or porous) type; an intermediate (Chukan types of Yoshikawa, 1976) type intermediate (im) between bw and pm types; and an irregularly shaped type (irr) different to the other types. Excluding the irregularly shaped glass (irr), these classifications are further subdivided as follows: bwα = tabular glass with no ridge; bwβ = tabular glass with few ridges; imα = tabular glass with curved ridges; imβ = tabular glass with linear ridges; pmα = porous and polygonal glass with abundant curved ridges; pmβ = porous and fibrous glass with abundant linear ridges (Yoshikawa, 1976; Ikuta et al., 2016; Figs. 2 and 3).

In Table 2, the ages from D-03-05 to A-19-07 are the 14C ages calibrated using IntCal13 reported as “IntCal13 BP” by Albert et al. (2019). The 14C ages of A-07-16, B-20-α and B-20-07 were reported by Smith et al. (2013). The ages of the tephra layer samples lower than B-20-07 are those of the correlated tephras with the Suigetsu tephra layer samples (Table 2).

III. Results and discussion

In this study, based on the petrographic properties including refractive index values of heavy minerals and volcanic glass shards, the tephra layers from the SG93 and SG06 cores are correlated with widespread tephra marker horizons that are distributed in and around the Japanese Islands (Figs. 2 and 3). The volcanic glass shards within the SG93 and SG06 cores are silicic, except for A-07-16 and B-18-03 (i.e., SG93-15 and SG93-38 of the SG93 core, respectively). In many cases, the rock fragments in the Suigetsu Lake tephra layers are glassy, rich in microlites, and contain Fe–Ti oxides, such as magnetite and ilmenite. The proposed source volcanoes of the tephra layers within the SG06 and SG93 cores are mainly calderas on Kyushu Island (i.e., the calderas of Aso, Aira, Ata, Kikai, and Kujū) or the Daisen and Sambe volcanoes in the Chugoku district (Fig. 1b).

Correlations based on the petrographic properties (Tables 1 and 2) are generally consistent with those of Smith et al. (2013) based on the major element compositions of volcanic glass shards. In the following sections, except for sample SG93-72 from the SG93 core, the descriptions mainly focus on tephra from SG06 core samples, because correlations and petrographic properties of tephra samples in the SG93 core are consistent with those in the SG06 (Tables 1 and 2). The lowermost tephra layers from SG93-69U to SG93-72 have not been clearly correlated with tephra marker horizons (Fig. 2; Table 1) in the analyses of samples from SG93. However, these layers were partly correlated with possible marker horizons by analysis of the SG06 core samples (Fig. 3; Table 2).

1) Tephra layer D-03-05

The D-03-05 [depth of base (dob) = 5.88 m] tephra layer corresponds to layer SG93-7 of the SG93 core. The volcanic glass shards in layer D-03-05 are mainly irregular in shape and microlite-rich. The volcanic glasses within tephra from layers SG93-7 and D-03-05 appear to be fragments of the matrix rather than separate glass shards, and many of them are incompletely hydrated or unhydrated (Tables 1 and 2). Plagioclase and quartz are the main light minerals, and greenish amphibole, biotite, and opaque minerals are the dominant heavy minerals. The rock fragments are glassy and microlite-rich. Layer D-03-05 may be correlated with one of the tephra layers erupted from Sambe volcano in Shimane Prefecture, in the Chugoku district of Honshu Island (Fig. 1b).
Fig. 2 Analytical results for samples from visible tephra layers within the SG93 core. The grain size distributions are also shown. The classification of the shapes of volcanic glass shards is based on Yoshikawa (1976). The abbreviations of the heavy minerals are described in Table 1.
2) Tephra layer A-04-13

The A-04-13 (dob = 7.76 m) tephra layer corresponds to layer SG93-9. McLean et al. (2018) described this layer as correlating with sample SG14-0781 (T. Nakagawa, pers. comm.), although Smith et al. (2013) made no mention of it. The thickness of layer A-04-13 is 3 mm (T. Nakagawa, pers. comm.), within which the volcanic glass shards are irregular in shape and microlite-rich. As with the glasses in SG93-7 and D-03-05, those in SG93-9 and A-04-13 have the appearance of incompletely hydrated matrix fragments (Tables 1 and 2). The uppermost two tephra layers from both SG93 and SG06 are sufficiently young that there may have been almost no time for them to be hydrated after deposition. Layer A-04-13 may be correlated with the Sambe-Oohirayama (SOh) tephra layer (Miura and Hayashi, 1991; Kusano and Nakayama, 1999; Fukuoka and Matsui, 2002).

3) Tephra layer B-05-04

The B-05-04 (dob = 9.67 m) tephra layer corresponds to layer SG93-11 (dob = 9.3 m; Takeamura et al., 1994). The volcanic glass shards occupy 95% of layer B-05-04 (Table 2) and 99% of layer SG93-11 (Table 1). The volcanic glass shards within layer B-05-04 are mainly classified as bubble wall type, although rare glass shards have a tortoise shell-like appearance. Plagioclase is the dominant light mineral, and pyroxene, opaque minerals, and apatite are the dominant heavy minerals (Table 2). The rock fragments are glassy, brownish, and

---

**Table 1** Summary of petrographic properties of tephra samples from core SG93.

| Tephra sample | Mineral composition (%) | Heavy mineral composition (%) |
|---------------|-------------------------|-------------------------------|
|               | Gl Lm Hm Rf Others | Ol Opx Cpx BAmpl GAmpl Opq Cum Zrn Bt Ap |
| SG93-7        | tr 39.0 7.0 54.0 0.0 | 0.0 2.0 0.0 2.0 81.5 8.0 0.5 0.0 3.0 3.0 |
| SG93-9        | 1.0 38.5 10.5 50.0 0.0 | 0.0 0.0 0.0 2.0 73.0 7.5 0.0 0.0 16.0 1.5 |
| SG93-11       | 99.0 1.0 tr 0.0 0.0 | 0.0 tr tr 0.0 0.0 tr 0.0 0.0 0.0 tr |
| SG93-15       | 70.0 19.0 1.5 9.5 0.0 | 0.0 1.4 8.3 16.7 8.3 5.6 0.0 0.0 47.2 12.5 |
| SG93-22       | 22.0 42.5 10.0 24.0 1.5 | 0.0 2.0 0.0 3.0 55.5 5.5 0.5 0.0 29.5 4.0 |
| SG93-28U      | 39.0 30.0 11.5 19.5 0.0 | 0.0 19.5 0.0 0.0 56.0 7.5 1.0 0.5 14.5 1.0 |
| SG93-28M+     | 8.0 41.0 7.0 37.0 7.0 | 0.0 27.5 0.0 5.0 46.5 11.0 0.0 0.0 7.5 2.5 |
| SG93-28L      | 18.0 34.0 8.0 40.0 0.0 | 0.0 22.0 0.0 1.0 61.0 8.0 0.0 0.0 7.0 1.0 |
| SG93-29       | 93.5 5.5 tr 1.0 0.0 | 0.0 tr tr 0.0 tr 0.0 0.0 0.0 0.0 tr |
| SG93-29base   | 89.5 10.0 tr 0.5 0.0 | 0.0 tr tr 0.0 tr 0.0 0.0 0.0 0.0 tr |
| SG93-38       | 2.0 8.5 0.5 89.0 0.0 | 0.0 7.7 21.2 21.2 0.0 0.0 0.0 0.0 0.0 0.0 |
| SG93-40       | 16.0 55.0 7.5 18.5 0.0 | 0.0 0.0 0.0 0.0 43.0 4.5 0.0 0.0 46.0 6.5 |
| SG93-43       | 4.0 36.0 6.0 54.0 0.0 | 0.0 2.5 0.0 1.0 56.0 3.5 0.0 0.5 34.5 2.0 |
| SG93-46U      | 77.5 19.0 1.5 1.0 1.0 | 0.0 0.7 0.0 0.0 11.8 4.2 0.0 0.0 81.9 1.4 |
| SG93-46L      | 62.5 23.0 13.5 1.0 0.0 | 0.0 10.5 0.5 0.5 79.5 4.0 0.0 0.0 3.0 2.0 |
| SG93-47       | 35.0 29.5 17.5 11.0 7.0 | 0.0 4.5 2.0 1.5 82.0 3.0 0.0 0.5 5.5 1.0 |
| SG93-48       | 18.5 37.5 43.0 1.0 0.0 | 0.0 13.8 0.0 0.0 48.1 37.5 0.0 0.0 0.3 0.3 |
| SG93-55       | 95.0 2.5 0.5 2.0 0.0 | 0.0 tr tr 0.0 0.0 tr 0.0 0.0 0.0 0.0 tr |
| SG93-57       | 89.5 9.5 1.0 tr 0.0 | 0.0 tr tr 0.0 tr 0.0 0.0 0.0 tr |
| SG93-59       | 88.0 9.0 1.0 2.0 0.0 | 0.0 tr tr 0.0 0.0 0.0 tr 0.0 0.0 tr |
| SG93-69U      | 49.6 39.6 2.4 8.4 0.0 | 0.0 tr tr 0.0 0.0 tr 0.0 0.0 tr |
| SG93-69L      | 81.5 16.0 0.5 2.0 0.0 | 0.0 tr 0.0 0.0 tr tr 0.0 0.0 tr 0.0 |
| SG93-70       | 19.0 24.5 13.5 43.0 0.0 | 0.0 7.0 0.0 0.5 76.5 4.0 3.5 0.0 5.5 3.0 |
| SG93-71       | 59.5 33.5 2.5 4.0 0.5 | 0.0 0.0 0.0 0.0 tr 0.0 0.0 0.0 0.0 tr |
| SG93-72       | 73.0 20.5 5.0 1.5 0.0 | 0.0 12.5 0.5 0.0 80.5 5.5 0.0 0.0 0.5 0.5 |
microlite-rich. Based on refractive index values and the shapes of the volcanic glass shards, layer B-05-04 can be correlated with the Kikai-Akahoya (K-Ah) tephra layer (e.g., Machida and Arai, 2011) that was erupted from the Kikai caldera in south Kyushu (Fig. 1b).

4) Tephra layer A-07-16

The A-07-16 (dob = 12.86 m) tephra layer corresponds to layer SG93-15 (dob = 12.4 m; Takemura et al., 1994). The volcanic glass shards are pumiceous, and have high refractive index values (1.521–1.525; Table 3) suggesting alkalic compositions. The light minerals are...
Fig. 3 Analytical results for samples from visible tephra layers within the SG06 core. The distributions of the refractive index values of orthopyroxene and amphibole are also shown; the grain size distributions of minerals and glasses were not measured. The classification of the shapes of volcanic glass shards is based on Yoshikawa (1976). The abbreviations of the heavy minerals are described in Table 1.
Fig. 3 (continued)
mainly alkali feldspar with minor plagioclase. Biotite, clinopyroxene, apatite, brownish amphibole, and opaque minerals are the dominant heavy minerals (Table 2). The rock fragments are glassy and may have been derived from pyroclastic materials. Layer A-07-16 can be correlated with the Ulleung–Oki (U-Oki) tephra layer (Machida et al., 1984; Machida and Arai, 2011) that was erupted from Ulleung Island (Ulleungdo; Fig. 1b) in the Japan Sea.

Smith et al. (2013) described the presence of the SG06-1293 (A-07-17; dob = 12.93 m) tephra layer just beneath layer A-07-16, although the former has not been correlated with any tephra layer based on the major element components of the glass shards. As a sample of A-07-17 has
Notes: Gl = glass; Lm = light minerals; Hm = heavy minerals; Rf = rock fragments; Ol = olivine; Opx = orthopyroxene; Cpx = clinopyroxene; BAMP = brownish amphibole; GAmp = greenish amphibole; Opq = opaque minerals; Cum = cummingtonite; Zrn = zircon; Bt = biotite; Ap = apatite. tr = trace.

The ages from D-03-05 (SG06-0588) to A-19-04 (SG06-3668) are the $^{14}$C ages calibrated using IntCal13 (cal BP; all errors are 2σ) reported by Albert et al. (2019) except for that of A-07-02 (Smith et al., 2013). The ages of B-20-a and B-20-07 are the $^{14}$C ages (cal BP) reported by Smith et al. (2013). The radiocarbon detection limit is ca. 50 ka BP (e.g., Nakagawa et al., 2012). The ages of the tephras lower than B-20-07 are those of the correlated tephras with the Suigetsu tephras.

Sample number described in Albert et al. (2019). This layer was not mentioned in Smith et al. (2013).

$^{14}$C ages described in Smith et al. (2013) (cal BP; errors are 2σ).

$^{14}$C age of SG06-2534 (Albert et al., 2019). The age of SG06-2535 was estimated to be 28,895 ± 72 ka BP (Albert et al., 2019).

$^{14}$C age of SG06-2601 (Albert et al., 2019). The age of SG06-2602 was estimated to be 29,837 ± 96 ka BP (Albert et al., 2019).

| Tephra sample | Sample No. of Smith et al. (2013) (SG06-) | Correlated tephra | Age$^a$ | Corresponding tephra sample of SG93 |
|---------------|------------------------------------------|-------------------|---------|-----------------------------------|
| D-03-05       | 0588                                     | Sambe Group       | 4,036 ± 32 | SG93-7               |
| A-04-13       | 0775$^b$                                 | SOh               | 5,501 ± 20 | SG93-9               |
| B-05-04       | 0967                                     | K-Ah              | 7,253 ± 46 | SG93-11              |
| A-07-16       | 1288                                     | U-Oki             | 10,177-10,255$^c$ | SG93-15           |
| A-11-00       | 1965                                     | Sakate            | 19,551 ± 80 | SG93-22              |
| A-13-07       | 2504                                     | DMS               | 28,449 ± 78 | –                   |
| A-13-08       | 2534, 2535                              | DHg               | 28,888 ± 72$^d$ | SG93-28U          |
| B-13-06       | 2601, 2602                              | DSs               | 29,830 ± 96$^e$ | SG93-28M+, 28L     |
| B-13-Bottom   | 2650                                     | AT                | 30,078 ± 96 | SG93-29              |
| B-14-Top      | 2650                                     | AT (A-Os)         | 30,078 ± 96 | SG93-29base         |
| B-18-03       | 3485                                     | Scoria layer      | 43,713 ± 300 | SG93-38            |
| A-19-04       | 3668                                     | SI                | 46,295 ± 418 | SG93-40            |
| B-20-a        | 3912                                     | Aso-K?            | 49,974 ± 337$^f$ | –                 |
| B-20-07       | 3974                                     | Sambe-Koyahara?   | 50,929 ± 378$^g$ | SG93-43           |
| B-21-03       | 4124                                     | SUN               | 50 ka      | SG93-46U            |
| B-21-04       | 4141                                     | SAN1 or Kj-P1     | 55-53 ka (SAN1) | SG93-46L          |
| B-22-01       | 4281                                     | DKP               | 55 ka      | SG93-47             |
| C-18-04       | 4281                                     |                   | –         | SG93-48             |
| B-22-03       | 4318                                     | DSP               | 80-55 ka   | SG93-48             |
| C-19-03       | 4963                                     | Aso-4             | 87.3-86.8 ka | SG93-55            |
| C-19-04       | 4979                                     |                   | –         | SG93-55             |
| B-29-04       | 5181                                     | K-Tz              | 95 ka      | SG93-57             |
| C-21-01       | 5287                                     | Aso-ABCD          | 105-100 ka | –                   |
| A-30-02       | 5353                                     | Ata               | 105 ka     | SG93-59             |
| A-30-03       | 5385                                     | Aso-4/3?          | (not estimated) | –               |
| B-32-10-34 cm | –                                       | SK?               | 100 ± 20 ka | –                   |
| A-37-01to     | 6344                                     | Aso-4/3?          | (not estimated) | SG93-69U         |
| A-37-07       | 6412                                     | Aso-3             | 133 ka     | SG93-69L            |
| A-38-24.1 cm  | 6454                                     |                   | 140 ± 50 ka (DHP) | SG93-70         |
| B-38-07       | 6547                                     | DHP or DMP?       | 180 ± 60 ka (DMP) | SG93-70         |
| A-38-b 81.1 cm| 6510                                     |                   | –         | –                   |
| A-40-02       | 6634                                     |                   | –         | SG93-71             |
not been made available to us, we have no information on this tephra layer.

5) **Tephra layer A-11-00**

The A-11-00 \((\text{dob} = 19.65\, \text{m})\) tephra layer corresponds to layer SG93-22 \((\text{dob} = 18.7\, \text{m};\) Takemura \textit{et al.}, 1994\)\). The volcanic glass shards are classified as pumiceous and irregular types. Plagioclase and quartz form the light minerals, and greenish amphibole and apatite are the dominant heavy minerals, alongside minor cummingtonite and opaque minerals. The rock fragments are glassy, and may have been derived from pyroclastic materials. Layer A-11-00 can be correlated with the Sakate tephra found in Nara Prefecture, Kinki district (Azuma \textit{et al.}, 1983; Yoshikawa \textit{et al.}, 1986). The Sakate layer has been correlated with the Sambe–Ukinuno (SUk) tephra layer (e.g.,

---

---
Refractive index values of greenish amphiboles, although brownish amphiboles in A-07-16.

Index values of volcanic glass shards were measured on hydrated parts. Tephra sample = \( \alpha \), ACH = (unknown).  

| Tephra sample | Refractive index of volcanic glass | Shape of volcanic glass\(^a\) | Degree of hydration\(^b\) |
|---------------|----------------------------------|-------------------------------|--------------------------|
| D-03-05       | 1.4925–1.5024                    | 1.499–1.500                   | 1.4976                   |
| A-04-13       | 1.4937–1.4989                    | 1.496–1.497                   | 1.4967                   |
| B-05-04       | 1.5095–1.5162                    | 1.511                        | 1.5120                   |
| A-07-16       | 1.5205–1.5252                    | 1.523                        | 1.5226                   |
| A-11-00       | 1.4974–1.5012                    | 1.499                        | 1.4990                   |
| A-13-07       | 1.4991–1.5053                    | 1.502                        | 1.5019                   |
| A-13-08       | 1.5009–1.5046                    | 1.503                        | 1.5028                   |
| B-13-06       | 1.5018–1.5054                    | 1.504                        | 1.5038                   |
| B-13-Bottom   | 1.4978–1.5010                    | 1.500                        | 1.4998                   |
| B-14-Top      | 1.4970–1.5011                    | 1.500                        | 1.4997                   |
| B-18-03       | 1.5727                           | 1.5727                      |                         |
| A-19-04       | 1.4985–1.5022                    | 1.500                        | 1.5002                   |
| B-20-α        | 1.5061–1.5116                    | 1.510                        | 1.5095                   |
| B-20-07       | 1.4947–1.5000                    | 1.496                        | 1.4968                   |
| B-21-03       | 1.4941–1.4978                    | 1.496                        | 1.4961                   |
| B-21-04       | 1.4989–1.5021                    | 1.501                        | 1.5005                   |
| B-22-01       | 1.4973–1.5117                    | 1.503–1.508                  | 1.5057                   |
| C-18-04       | 1.4990–1.5118                    | 1.505–1.509                  | 1.5062                   |
| B-23-03       | 1.5058–1.5207                    | 1.514–1.517                  | 1.5129                   |
| C-19-03       | 1.5078–1.5131                    | 1.509, 1.512                 | 1.5105                   |
| C-19-04       | 1.5074–1.5128                    | 1.509, 1.512                 | 1.5098                   |
| B-29-04       | 1.4984–1.5009                    | 1.500                        | 1.4997                   |
| C-21-01       | 1.5147–1.5262                    | 1.516                        | 1.5172                   |
| A-30-02       | 1.5102–1.5128                    | 1.511                        | 1.5108                   |
| A-30-03       | 1.5255–1.5448                    | 1.497                        | 1.4971                   |
| B-32-10 ~ 34 cm | 1.4959–1.4986                    | 1.497                        | 1.4971                   |
| A-37-01to     | 1.5182–1.5309                    | 1.523–1.527                  | 1.5244                   |
| A-37-07       | 1.5155–1.5176                    | 1.517                        | 1.5166                   |
| A-38-24.1 cm  | 1.4981–1.5065                    | 1.503                        | 1.5016                   |
| B-38-07       | 1.5002–1.5032                    | 1.502                        | 1.5021                   |
| A-38-β 81.1 cm | 1.5273–1.5368                    | 1.534–1.535                  | 1.5340                   |
| A-40-02       | 1.5023–1.5214                    | 1.506                        | 1.5088                   |

\(^{a}\) Number of measurements.  
\(^{b}\) Refractive index values of greenish amphiboles, although brownish amphiboles in A-07-16.  
\(^{c}\) Classification of the shape of volcanic glass shards is based on Yoshikawa (1976): bw = bubble wall type, im = intermediate type, pm = pumice type, and irr = irregularly shaped type.  
\(^{d}\) IH = Incompletely hydrated (thickness of hydrated rims of glass shards is shown in parentheses), ACH = almost completely hydrated (i.e., hydrated glass shards have tiny unhydrated cores), CH = completely hydrated. The refractive index values of volcanic glass shards were measured on hydrated parts.
Machida and Arai, 2011), which has not been identified within the Suigetsu core samples. However, the refractive index of the volcanic glass shards of the Sakate tephra (1.498–1.500; Katoh et al., 2007), which is consistent with that of layers SG93-22 and A-11-00 (1.497–1.501; Tables 1 and 3), is distinguishable from that of the SUk tephra (1.505–1.507; Machida and Arai, 2011). This implies that the Sakate tephra should not be directly correlated with the SUk tephra, although these tephras certainly have a close relationship.

6) Tephra layer A-13-07
The A-13-07 (dob = 25.03 m) tephra layer has no corresponding layer within the SG93 core. The volcanic glass shards are mostly pumiceous or irregular in shape. Plagioclase and quartz are the main light minerals. The rock fragments are glassy and microlite-rich. Layer A-13-07 may be correlated with the Daisen–Misen (DMs) tephra or, more specifically, the Daisen–Kusadanihara pumice (Tsukui, 1984; Miura and Hayashi, 1991; Domitsu et al., 2002), which erupted from Daisen volcano, Tottori Prefecture, Chugoku district (Fig. 1b).

7) Tephra layer A-13-08
The A-13-08 (dob = 25.34 m) tephra layer corresponds to layer SG93-28U (dob = 24.0 m; Takemura et al., 1994). The volcanic glass shards are pumiceous or irregular in shape. The irregularly shaped glass shards are dusty and blocky. Plagioclase and quartz dominate the light minerals, and greenish amphibole, orthopyroxene, and opaque minerals form the main heavy minerals. The refractive index of cummingtonite in A-13-08 is 1.659–1.664, with a mode and mean of 1.661–1.662 and 1.661, respectively. The rock fragments are glassy and derived from pyroclastic materials. Layer A-13-08 can be correlated with the Daisen–Higashidaisen (DHg) tephra (Tsukui, 1984; Miura and Hayashi, 1991).

8) Tephra layer B-13-06
The B-13-06 (dob = 26.01 m) tephra layer corresponds to layers SG93-28M+ and 28L (dob = 24.7 m). The volcanic glass shards are pumiceous or irregular in shape. The irregularly shaped glass shards are dusty and blocky. The light minerals are mainly plagioclase and quartz. Greenish amphibole, orthopyroxene, and opaque phases are the dominant heavy minerals, along with minor brownish amphibole and cummingtonite. The rock fragments are glassy and microlite-rich. Layer B-13-06 can be correlated with the Daisen–Sasaganaru (DSs) tephra (Tsukui, 1984; Miura and Hayashi, 1991).

9) Tephra layers B-13-Bottom and B-14-Top
The B-13-Bottom (dob = 26.18 m) tephra layer corresponds to layer SG93-29 (dob = 25.0 m; Takemura et al., 1994). Volcanic glass shards volumetrically dominate tephra samples within both the SG06 (72.5% of B-13-Bottom; Table 2) and SG93 cores (93.5% of SG93-29; Table 1). Secondary sedimentary minerals occupy almost a quarter of the B-13-Bottom layer (Table 2). Plagioclase is the dominant light mineral, and the rare heavy minerals comprise orthopyroxene, greenish amphibole, opaque minerals, biotite, and apatite (Table 2). The volcanic glass shards are mainly classified into bubble wall or pumiceous types. The B-13-Bottom layer can be correlated with the Aira-Tn (AT) tephra (e.g., Machida and Arai, 2011).

The B-14-Top tephra layer corresponds to SG93-29base. This tephra layer sample is included in SG06-2650 of Smith et al. (2013). As with the B-13-Bottom and SG93-29 layers, the B-14-Top and SG93-29base layers contain large amounts of volcanic glass shards (88.0% in B-14-Top, Table 2; 89.5% in SG93-29base, Table 1). The volcanic glass shards are bubble wall or pumiceous types. The volcanic glass shards have incompletely hydrated rims (~10 μm in width), and some have a tortoise shell-like appearance. Plagioclase and quartz are the dominant light minerals. The B-14-Top and SG93-29base layers contain very small quantities of heavy minerals (Tables 1 and 2). Biotite crystals within the volcanic glass shards may have crystallized together with the glass shards. The rock fragments are glassy and microlite-rich. The B-14-Top layer can be correlated with
AT, or more specifically, the Aira–Ohsumi pumice fall deposit (e.g., Kobayashi et al., 1983), which erupted from the Aso caldera during the first stage of the widespread ash-fall eruption of AT (Machida and Arai, 2011).

10) **Tephra layer B-18-03**

The B-18-03 (dob = 34.85 m) tephra layer is a scoria layer corresponding to layer SG93-38. The volcanic glass shards are brownish in color and show an irregularly shaped appearance. The volcanic glass shards can be categorized into those normally occurring in scoria. A small amount of pumiceous silicic glass shards have also been found, although these may be exotic contaminants. Plagioclase is the only light mineral, and orthopyroxene, clinopyroxene, olivine, and opaque minerals are the dominant heavy minerals. The rock fragments are glassy and brown in color. The source volcano of this scoria layer is currently unknown, but may be from the Kannabe monogenetic volcano group (e.g., Furuyama, 1973, 1976; Kawamoto, 1990), which is ~120 km west of Lake Suigetsu (Fig. 1b), or even Mt. Fuji (e.g., Takahashi et al., 2003).

11) **Tephra layer A-19-04**

The A-19-04 (dob = 36.68 m) tephra layer corresponds to layer SG93-40. The volcanic glass shards are pumiceous or irregular in shape. The irregularly shaped glass shards are dusty and partly pumice-like in appearance. The light minerals are plagioclase and quartz, and biotite and greenish amphibole are the dominant heavy minerals, along with minor apatite, opaque minerals, and cummingtonite. Both glassy and lithic rock fragments occur in layer A-19-04, which may be correlated with the Sambe-Ikeda (SI) tephra (Matsu and Inoue, 1971; Miura and Hayashi, 1991; Fukuoka and Matsui, 2002).

12) **Tephra layer B-20-α**

The B-20-α (dob = 39.12 m) tephra layer has no corresponding layer in the SG93 core. The volcanic glass shards are mainly pumiceous, with a small amount of scoria glass additionally present. The light minerals are mainly alkali feldspar, plagioclase, and quartz. Biotite, greenish amphibole, opaque minerals, and orthopyroxene are the dominant heavy minerals, along with minor apatite and clinopyroxene. The rock fragments are a mixture of glass and lithic fragments. Layer B-20-α contains weathered particles (1.5%; Table 2). The Aso-Kusasenrigahama (Aso-K) tephra (Ono and Watanabe, 1985; Takada, 1989), which erupted from the Aso caldera (Fig. 1b), may be correlated with the B-20-α layer based on the stratigraphic sequence.

13) **Tephra layer B-20-07**

The B-20-07 (dob = 39.74 m) tephra layer corresponds to layer SG93-43. Irregularly shaped volcanic glass shards dominate over pumiceous examples. The irregularly shaped glass shards are flakey or pumice-like, and include large quantities of microlite and vesicles. The light minerals are mostly plagioclase with minor quartz. Greenish amphibole and biotite are the dominant heavy minerals, along with minor cummingtonite (1.0%; Table 2) that has a refractive index of 1.661–1.663. The rock fragments are glassy and microlite-rich. Layer B-20-07 may be correlated with the Sambe–Koyahara ash fall deposits (Matsu and Inoue, 1971).

14) **Tephra layer B-21-03**

The B-21-03 (dob = 41.24 m) tephra layer corresponds to layer SG93-46U. The volcanic glass shards are mainly pumiceous and irregular in shape. The irregularly shaped glasses shards are dusty and blocky. Plagioclase and quartz are the main light minerals. Most of the heavy minerals (greenish amphibole and biotite) are included within the glass shards, or have fragment of glass attached to them. The rock fragments are glassy and microlite-rich. Layer B-21-03 may be correlated with the Sambe–Unnan (SUn) tephra layer (Miura and Hayashi, 1991). Shitaoka et al. (2009) estimated the TL age of SUn at 72 ± 13 ka, whereas Machida and Arai (2011) proposed 50 ka as the age of SUn. Considering the stratigraphic relationships, the latter age may be more reasonable for layer B-21-03.

15) **Tephra layer B-21-04**

The B-21-04 (dob = 41.40 m) tephra layer
corresponds to layer SG93-46L. The volcanic glass shards are mainly pumiceous. Plagioclase and quartz are the main light minerals, and greenish amphibole is the dominant heavy mineral (85.0% for B-21-04, Table 2; 79.5% for SG93-46L, Table 1). The rock fragments are glassy and microlite-rich. Layer B-21-04 may be correlated with the San’in 1 (SAN1) tephra (e.g., Nakajima et al., 1996; Ikehara et al., 2004; Nagahashi et al., 2016) whose source volcano is unknown (Yamamoto, 2017b), or the Kuju-1 (Kj-P1) tephra (Machida and Arai, 2011), which erupted from the Kuju caldera (Fig. 1b) based on petrographic similarities. Ikehara et al. (2004) estimated the $^{14}$C age of SAN1 at 55–53 ka, and Okuno et al. (1998) estimated the eruption age of Kj-P1 at 51–49 ka based on its stratigraphic position. Considering the stratigraphic relationships, it appears that the 55–53 ka estimate is a more likely age for layer B-21-04.

The petrographic properties of layer B-21-04 and correlation with SAN1 and Kj-P1 suggest that SAN1 may be correlated with Kj-P1. This implies that the source volcano may be the Kuju caldera, although Nagahashi et al. (2016) suggested Daisen volcano as the source of SAN1 tephra. Discriminating between these possibilities requires chemical analyses of the volcanic glass shards.

16) Tephra layers B-22-01 and C-18-04

The B-22-01 (dob = 42.81 m) tephra layer corresponds to layer SG93-47 (dob = 41.3 m; Takemura et al., 1994). The volcanic glass shards are mainly pumiceous. The irregularly shaped glass shards are flakey or blocky. The light minerals are mainly plagioclase and quartz. The heavy minerals mostly comprise greenish amphibole, orthopyroxene, and opaque minerals, with minor cummingtonite and apatite (Table 2). Zircon is also present in the SG93-47 layer (0.5%; Table 1). The rock fragments are glassy and microlite-rich. Layer B-22-01 can be correlated with the Daisen–Kurayoshi pumice (DKP; Machida and Arai, 1979; Miura and Hayashi, 1991). Machida and Arai (2011) suggested ~55 ka as the age of DKP based on its stratigraphic position and $^{14}$C dating (e.g., Machida and Arai, 1979; Takemoto et al., 1987; Togashi et al., 1999).

The C-18-04 (dob = 42.81 m) tephra layer, which was obtained from borehole C, is the same as layer B-22-01 from borehole B. The petrographic properties (Table 2) and refractive index values of the heavy minerals and volcanic glass shards (Table 3) are generally similar to those in layer B-22-01.

17) Tephra layer B-22-03

The B-22-03 (dob = 43.18 m) tephra layer corresponds to layer SG93-48. The volcanic glass shards are mainly pumiceous. In many cases, the volcanic glass shards occur as inclusions within, or fragments attached to, the pheocrysts. Plagioclase and quartz are the main light minerals, whereas greenish amphibole and orthopyroxene are the dominant heavy minerals. The rock fragments are glassy and microlite-rich. Layer B-22-03 can be correlated with the Daisen–Sekigane pumice (DSP; Machida and Arai, 1979). Suto et al. (2007) estimated the age of DSP at 80–55 ka from its stratigraphic position.

18) Tephra layers C-19-03 and C-19-04

The C-19-03 (dob = 49.63 m) tephra layer corresponds to layer SG93-55 (dob = 48.5 m; Takemura et al., 1994). The volcanic glass shards are mostly bubble wall or pumiceous types. Some glass shards have a deep brownish color, and a small amount of scoria glass is also present. Plagioclase and quartz are the main light minerals. Orthopyroxene, greenish amphibole, apatite, and opaque minerals are the main heavy minerals. The rock fragments are glassy, brownish, and microlite-rich. The refractive index of orthopyroxene and occurrence of greenish brown amphibole (Table 2) suggest that layer C-19-03 can be correlated with the Aso-4 tephra (Machida et al., 1985). Aoki (2008) estimated the eruptive age of Aso-4 to be 87.3–86.8 ka based on the oxygen isotopic stratigraphy of core samples from central Japan.

The C-19-04 (dob = 49.79 m) tephra layer corresponds to layer SG93-55. SG93-55 has
been identified as the single tephra layer that is correlated with Aso-4 in the SG93 core, whereas two discrete tephra layers (i.e., C-19-03 and 04) occur within the SG06 core. The single tephra layer that is correlated with Aso-4 was identified from boreholes A and B of the SG06 core, and the discrete Aso-4 layers are found only in borehole C of the SG06 core (T. Nakagawa, pers. comm.). The petrographic properties of C-19-04 are generally similar to those of C-19-03 (Fig. 3; Tables 2 and 3).

19) Tephra layer B-29-04

The B-29-04 (dob = 51.81 m) tephra layer corresponds to layer SG93-57 (dob = 50.3 m; Takemura et al., 1994). The volcanic glass shards occupy ~ 90% of SG93-57 (Table 1) and B-29-04 (Table 2). The volcanic glass shards are mostly bubble wall or pumiceous types. The light minerals are quartz and plagioclase; β-quartz (i.e., high-temperature quartz) is also present. Layer B-29-04 contains small quantities of heavy minerals (0.5%; Table 2). The volcanic glass fragments are in contact with grains of orthopyroxene, greenish amphibole, andapatite. No rock fragments have been found. Layer B-29-04 can be correlated with the Kikai–Tozurahara (K-Tz) tephra (e.g., Machida and Arai, 2011), which erupted from the Kikai caldera (Fig. 1b). Machida and Arai (2011) estimated the eruption age of K-Tz at 95 ka from the fission-track (FT) age (98 ± 26 ka; Danhara, 1995) and stratigraphic sequence (e.g., Takemoto et al., 1987).

20) Tephra layer C-21-01

The C-21-01 (dob = 52.87 m) tephra layer has no corresponding layer in the SG93 core. The volcanic glass shards are mostly pumiceous. Some bubble-wall-shaped glass shards contain tiny vesicles. Plagioclase and quartz are the main light minerals. The heavy minerals include apatite, orthopyroxene, and opaque minerals, which are mostly included within the volcanic glass shards. The rock fragments are glassy and microlite-rich. Layer C-21-01 can be correlated with the Aso-ABCD tephra layer (e.g., Machida and Arai, 2011), which erupted from the Aso caldera (Fig. 1b). Machida and Arai (2011) proposed an age of 105–100 ka for the Aso-ABCD layer.

21) Tephra layer A-30-02

The A-30-02 (dob = 53.51 m) tephra layer corresponds to layer SG93-59 (dob = 51.8 m; Takemura et al., 1994). The volcanic glass shards are mainly a bubble wall type. Rare volcanic glass shards are super-hydrated (e.g., Steen-McIntyre, 1975), and vesicles within the volcanic glasses are filled with water. Corroded plagioclase grains are included within 2–3% of the volcanic glasses. A single glass shard is brownish in color and had a tortoise shell-like appearance. Plagioclase is the dominant light mineral. Heavy minerals are minor components of A-30-02 (1.5%; Table 2), and comprise orthopyroxene, greenish amphibole, opaque minerals, andapatite. The rock fragments are glassy. Layer A-30-02 can be correlated with the Ata tephra (Machida and Arai, 2011), which erupted from the Ata caldera (Fig. 1b). Machida and Arai (2011) estimated the eruption age of Ata at 105 ka based on the FT age (100 ± 27 ka; Danhara, 1995) and K–Ar age (108 ± 3 ka; Matsumoto and Ui, 1997).

22) Tephra layer A-30-03

The A-30-03 (dob = 53.84 m) tephra layer has no equivalent horizon within the SG93 core. The volcanic glass shards are relatively fine-grained and mainly pumiceous. Plagioclase and quartz are the main light minerals. Minor heavy minerals (0.5%; Table 2) comprise greenish amphibole, opaque minerals, orthopyroxene, apatite, and clinopyroxene. The rock fragments are glassy. Judging from the presence of apatite and the relatively high refractive index of the volcanic glass shards (Table 2), layer A-30-03 may belong to the Aso-4/3 tephra (Ono et al., 1977; Hoshizumi, 1990; Hoshizumi et al., 2017) from the Aso caldera. The Aso-4/3 tephra was produced by at least 40 eruption cycles (Hoshizumi, 1990).

23) Tephra layer B-32-10 ~ 34 cm

The B-32-10 ~ 34 cm (dob = 56.08 m) tephra layer was not mentioned by Smith et al. (2013), and no corresponding tephra has been obtained from the SG93 core. However, this tephra layer
was apparently shown in figure 10 of Naka-
gawa et al. (2012) as a gray and bold line on
column C representing the SG06 visible tephra
layers. The tephra components, such as vol-
canic glass shards, are scattered within core
sample B-32. However, as no varved sediment
was found at this depth, it is difficult to identi-
fy any discrete tephra layer within this sample
(T. Nakagawa, pers. comm.). Therefore, the
thickness of the B-32-10 ~ 34 cm layer was not
clearly determined.

The volcanic glass shards are mostly clas-
sified into pumiceous or bubble wall types.
Plagioclase and quartz are the dominant light
minerals. Heavy minerals are trace components
in B-32-10 ~ 34 cm, and comprise orthopyrox-
ene, greenish amphibole, opaque minerals, and
brownish amphibole. The secondary minerals
(39%; Table 2) are mainly composed of vivi-
anite. There are no rock fragments in sample
B-32-10 ~ 34 cm. Judging from the refractive
index of the volcanic glass shards and strati-
graphic sequence, sample B-32-10 ~ 34 cm may
be correlated with the Sambe-Kisuki (SK)
tephra (e.g., Matsui and Inoue, 1971; Miura
and Hayashi, 1991; Machida and Arai, 2011)
whose FT age is estimated to be 100 ± 20 ka
(Kimura et al., 1999). However, this correla-
tion needs to be verified using chemical data.

24) Tephra layer A-37-01t

The A-37-01t (dob = 63.44 m) tephra layer
 corresponds to layer SG93-69U. The volcanic
glass shards are mainly pumiceous and micro-
lite-bearing. Almost half of the pumiceous glass
shards are colorless or pale brownish in color,
and the other half are dark brownish. Two-
thirds of the irregularly shaped volcanic glass
shards are dusty or flakey, and pumice-like,
and a third are scoria glass. The light mineral
is plagioclase. The heavy minerals are ortho-
pyroxyene, opaque minerals, clinopyroxene, and
apatite. The rock fragments are glassy and mi-
crolite-rich. Layer A-37-01t may be correlated
with the tephra layer Aso-4/3 (Ono et al., 1977;
Hoshizumi, 1990; Hoshizumi et al., 2017), con-
sidering the presence of apatite and relatively
high refractive index of the volcanic glass
shards (Table 2).

25) Tephra layer A-37-07

The A-37-07 (dob = 64.12 m) tephra layer
 corresponds to layer SG93-69L. The volcanic
glass shards occupy more than 95% of layer
A-37-07 (Table 2). The volcanic glass shards
are fine-grained and mainly pumiceous. Pla-
gioclase and quartz are the dominant light
minerals. The heavy minerals comprise apatite
as inclusions within the volcanic glass shards,
along with opaque minerals, orthopyroxene,
clinopyroxene, and greenish amphibole. The
rock fragments are glassy. Microfossils are
present in both layers A-37-07 and SG93-69L.
Layer A-37-07 can be correlated with the Aso-3
tephra (Machida and Arai, 2011). Nagahashi
et al. (2007) estimated the age of Aso-3 at 133
ka based on the age-depth relationships of the
marker tephras in cores through the Takano
Formation, central Japan.

26) Tephra layers A-38-24.1 cm and B-38-
07

The A-38-24.1 cm (dob = 64.54 m) tephra
layer corresponds to layer SG93-70. The volca-
nic glass shards comprise a minor component
of layer A-38-24.1 cm (0.5%; Table 2), and may
represent redeposited components. The volcanic
glass shards are mostly irregular in shape or
pumiceous. The light minerals are plagioclase
and quartz. The heavy minerals are composed
of opaque minerals and greenish amphibole.
Opaque minerals in layer A-38-24.1 cm may
be sedimentary pyrite, judging from their dark
color and spherical form. Most rock fragments
are lithic. Layer A-38-24.1 cm contains micro-
fossils such as diatoms (8.5%; Table 2).

The B-38-07 (64.57 m) tephra layer also cor-
responds to layer SG93-70. Layers A-38-24.1
cm and B-38-07 are the upper and lower parts
of the single SG93-70 tephra horizon, respec-
tively. The volcanic glass shards (24.5%; Table
2) are also irregular in shape or pumiceous.
The irregularly shaped glass shards are blocky
or pumice-like, and may contain inclusions. The
light minerals comprise plagioclase and quartz.
The heavy minerals are composed of greenish
amphibole, orthopyroxene, and cummingtonite,
along with biotite, brownish amphibole, and opaque minerals. Some biotite phenocrysts are included within the glass shards. The refractive index of cummingtonite is 1.702–1.707 (mode and mean are both 1.705). The rock fragments are glassy and microlite-rich. Unlike layer A-38-24.1 cm, layer B-38-07 contains no microfossils.

Layers A-38-24.1 cm and B-38-07 (i.e., SG93-A-38-24.1 cm) may be correlated with the Daisen–Hiruzenbara pumice (DHP) or Daisen–Matsue pumice (DMP) (Machida and Arai, 1979; Tsukui, 1984; Miura and Hayashi, 1991), considering the eruption sequence of Daisen volcano. The FT age of DHP and DMP are estimated to be 140 ± 50 and 180 ± 60 ka, respectively (Kimura et al., 1999); these ages are consistent with the stratigraphic sequence (Machida and Arai, 1979).

Importantly, Machida and Arai (1979) and Tsukui (1984) noted an absence of orthopyroxene in DHP and DMP. In addition, Machida and Arai (1979) suggested the presence of cummingtonite as one of the characteristics of DMP. Orthopyroxene and cummingtonite were not found in layer A-38-24.1 cm, whereas layers B-38-07 and SG93-70 contain both minerals (Tables 1 and 2). Furthermore, Machida and Arai (1979, 2011) and Yamamoto (2017a) suggested the ash fall deposit of DMP is distributed throughout the western area of Daisen volcano. In other words, DMP could never reach to Lake Suigetsu at all. Therefore, DHP may have partly reached to Lake Suigetsu. The correlation of these samples remains ambiguous.

27) Tephra layer A-38-β 81.1 cm

The A-38-β 81.1 cm (dob = 65.10 m) tephra layer has no corresponding layer within the SG93 core. The refractive index of the volcanic glass shards in layer A-38-β 81.1 cm is relatively high (1.527–1.537; Fig. 3; Table 3); such a tephra layer was not found in the lower part of the SG93 core beneath SG93-69L (Fig. 2; Table 1). The volcanic glass shards are pumiceous or irregular in shape. The pumiceous glass shards are slightly brownish, and the irregularly shaped shards are pumice-like and microlite-rich. Plagioclase and quartz are the dominant light minerals. Small amounts of heavy minerals (0.5%; Table 2) comprise greenish amphibole, opaque minerals, and apatite. The rock fragments (40.0%; Table 2) are a mixture of glassy and lithic fragments. Layer A-38-β 81.1 cm contains 2.5% microfossils and weathered particles. No tephra has yet been correlated with layer A-38-β 81.1 cm.

28) Tephra layer A-40-02

The A-40-02 (dob = 66.34 m) tephra layer corresponds to SG93-71. The volcanic glass shards are fine-grained and mainly pumiceous. The light minerals are plagioclase and quartz. The heavy minerals comprise mainly opaque minerals, apatite, greenish amphibole, and orthopyroxene. Most phenocrysts are included within the glass shards. The rock fragments are glassy and microlite-rich. No other component is present within A-40-02, although microfossils are present within layer SG93-71 (0.5%; Table 1). No tephra has yet been correlated with layer A-40-02.

29) Tephra layer SG93-72 within the SG93 core

The SG93-72 tephra layer was only identified within the SG93 core. Unfortunately, the depth and thickness of this layer are unknown. However, the depth of this layer may be ~ 65 m, if the lowest tephra layer shown in figure 10 of Nakagawa et al. (2012) is layer SG93-72. The volcanic glass shards are mainly pumiceous. Plagioclase is the dominant light mineral. Greenish amphibole, orthopyroxene, and opaque minerals are the main heavy minerals, along with small amounts of clinopyroxene, apatite, and biotite (Table 1). The rock fragments are glassy and lithic. No tephra has yet been correlated with layer SG93-72.

IV. Conclusions

The petrographic properties of the visible tephra layers within the SG06 and SG93 Suigetsu cores were analyzed, and the layers
**Fig. 4** Summary of the stratigraphy of visible tephra layers in the SG09 and SG06 drill cores. The horizontal dotted line represents the limit of 
$^{14}$C dating (~ 50 ka cal BP). The tephra layers shown in red, blue, and green represent those correlated with tephra layers from the Kyushu calderas, Daisen volcano, and Sambe volcano, respectively. The orange tephra layers are those from the other source volcanoes, and the uncorrelated tephra layers are shown in black. The ages of the tephra layers shown in this figure are the same as those summarized in Table 2. Layer SG06-1293 (A-07-17) from SG06 described in Smith *et al.* (2013) has not been analyzed here, nor correlated with any tephra.
were correlated with widespread tephra marker horizons based on their petrographic properties. The stratigraphy of the visible tephra layers obtained from the SG93 and SG06 cores is summarized in Fig. 4. The Suigetsu tephra layers trace the activity of various volcanoes up to ~0.2 Ma, in particular the Daisen and Sanbe volcanoes and Aso caldera. Layer B-32-10 ~ 34 cm has been tentatively correlated with SK based on its petrographic properties and the stratigraphic sequence. However, an analysis of the chemical composition of the volcanic glass shards is required for more rigorous identification and correlation of this tephra sample.

Mizuno (2018) suggested that the trace element compositions of volcanic glass shards can play a significant role in the correlation of tephra layers, in addition to their major element compositions. However, the petrographic properties of tephra layers provide essential additional information. The correlation of the Suigetsu tephra layers based on the major and trace element concentrations of volcanic glass shards (e.g., Maruyama et al., 2016, 2017) are required to establish their source volcanoes.

Acknowledgments

The SG93 core was drilled with the support of a Grant-in-Aid for Scientific Research on Priority Areas (04212114 to S. Itoh) from Ministry of Education, Culture, Sports, Science and Technology (MEXT), Japan. The SG06 core samples were bored by T. Nakagawa of the University of Newcastle, UK (now Ritsumeikan University, Japan) with the support of the UK Natural Environment Research Council (NERC) (grant NE/D000289/1 to TN). T. Nakagawa provided the visible tephra samples of the SG06 for us in 2007 for petrographic analyses. This study was partly supported by a Grant-in-Aid for Scientific Research (17K05720 to S. Maruyama) from the MEXT, Japan.

References

Albert, P.G., Smith, V.C., Suzuki, T., McLean, D., Tomlinson, E.L., Miyabuchi, Y., Kitaba, I., Mark, D.F., Moriwaki, H., SG06 Project Members and Nakagawa, T. (2019): Geochemical characterisation of the Late Quaternary widespread Japanese tephrostratigraphic markers and correlations to the Lake Suigetsu sedimentary archive (SG06 core), Quaternary Geochronology, 52, 103–131, doi:10.1016/j.quageo.2019.01.005.

Aoki, K. (2008): Revised age and distribution of ca. 87 ka Aso-4 tephra based on new evidence from the northwest Pacific Ocean. Quaternary International, 178, 100–118, doi:10.1016/j.quaint.2007.02.005.

Azuma, U., Okuda, H., Yoshikawa, S., Hara, H. and Shimakuma, M. (1983): Report of Archaeological Researches of Sakate, Tawaramoto-cho, Shiki-gun (Shiki-gun Tawaramoto-cho Sakate Iseki Hakutsu Chousa Houkoku). Kashihiara Archaeological Institute, Nara Prefecture, 159–183. (in Japanese) *

Danbara, T. (1995): Towards precise measurement of zircon and glass fission-track geochronology for Quaternary tephras. Quaternary Research (Daiyonki-Kenkyu), 34, 221–237, doi:10.4116/jaqua.34.221. (in Japanese with English abstract)

Danbara, T., Yamashita, T., Iwano, H. and Kasuya, M. (1992): An improved system for measuring refractive index using the thermal immersion method. Quaternary International, 13/14, 89–91, doi:10.1016/1040-6182(92)90013-R.

Domitsu, H., Shiihara, M., Torii, M., Tsukawaki, S. and Oda, M. (2002): Tephrostratigraphy of the piston cored sediment KT96-17 P-2 in the southern Japan Sea—The eruption age of Daisen–Kusadanihiara Pumice (Kp). Journal of the Geological Society of Japan, 108, 545–556, doi:10.5575/geosoc.108.545. (in Japanese with English abstract and captions)

Fukuoka, T. and Matsui, S. (2002): Stratigraphy of pyroclastic deposits post-dating the AT tephra, Sanbe Volcano. Earth Science (Chikyu Kagaku), 56, 105–122, doi:10.15080/agechikyukagaku56.2_105. (in Japanese with English abstract and captions)

Furuyama, K. (1973): Volcanostratigraphy of the Kannabe volcano group. Journal of the Geological Society of Japan, 79, 399–406, doi:10.5575/geosoc.79.399. (in Japanese with English abstract)

Furuyama, K. (1976): Petrology of the Kannabe volcano group. Journal of the Geological Society of Japan, 82, 327–336, doi:10.5575/geosoc.82.327. (in Japanese with English abstract and captions)

Hoshizumi, H. (1990): Aso-4/3 fallout tephra: Activity of Aso Volcano before Aso-4 eruption. Programme and Abstracts the Volcanological Society of Japan, 1990, H32-14, doi:10.18940/vsj.1990.1.0_92. (in Japanese)

Hoshizumi, H., Miyabuchi, Y. and Miyagi, I. (2017): Stratigraphy and whole-rock chemical composition of Aso-4/3 tephra, Aso volcano, Japan. Programme and Abstracts the Volcanological Society of Japan, 2017, P001, doi:10.18940/vsj.2017.0_121. (in Japanese)

Ikehara, K., Kikkawa, K. and Chun, J-H. (2004):
Origin and correlation of three tephras that erupted during oxygen isotope stage 3 found in cores from the Yamato Basin, central Japan Sea. *Quaternary Research (Daiyonki-Kenkyu)*, 43, 201–212, doi: 10.4116/jaqua.43.201. (in Japanese with English abstract and captions)

Ikuta, M., Niwa, M., Danhara, T., Yamashita, T., Maruyama, S., Kamataki, T., Kobayashi, T., Kurosawa, H., Saito-Kokubu, Y. and Hirata, T. (2016): Identification of pumice derived from historic eruption in the same volcano: Case study for the Sakurajima–Bunmei tephra in the Miyazaki Plain. *Journal of the Geological Society of Japan*, 122, 89–107, doi:10.5575/geosoc.2016.0003. (in Japanese with English abstract and captions)

Katoh, S., Handa, K., Hyodo, M., Sato, H., Nakamura, M., Takemura, K., Hayashida, A. and Yasuda, Y. (2016): Preliminary report on depositional processes of block-and-ash flow deposits at Sambae volcano, southwest Japan. *Bulletin of the Volcanological Society of Japan*, 41, 145–155, doi:10.4116/jaqua.38.145. (in Japanese with English abstract and captions)

Katoh, S., Handa, K., Hyodo, M., Sato, H., Nakamura, M., Takemura, K., Hayashida, A. and Yasuda, Y. (2016): Preliminary report on depositional processes of block-and-ash flow deposits at Sambae volcano, southwest Japan. *Bulletin of the Volcanological Society of Japan*, 41, 145–155, doi:10.4116/jaqua.38.145. (in Japanese with English abstract and captions)

Kawamoto, T. (1990): Geology of the Kannebo monogenetic volcano area, southwest Japan. *Bulletin of the Volcanological Society of Japan*, 35, 41–56, doi:10.18940/kazanc.35.1.41. (in Japanese with English abstract and captions)

Kimura, J., Okada, S., Nakayama, K., Umeda, K., Kusano, T., Asahara, Y., Tatoeno, M. and Danhara, T. (1999): Fission track ages of tephras from Daisen and Sambe volcanoes and their volcanicological implications. *Quaternary Research (Daiyonki-Kenkyu)*, 38, 145–155, doi:10.4116/jaqua.38.145. (in Japanese with English abstract and captions)

Kitagawa, H., Fukuzawa, H., Nakamura, T., Okamura, M., Takemura, K., Hayashida, A. and Yasuda, Y. (1995): AMS 14C dating of varved sediments from Lake Suigetsu, central Japan and atmospheric 14C change during the late Pleistocene. *Radiocarbon*, 37, 371–378, doi:10.1017/S0033822200030848.

Kobayashi, T., Hayakawa, Y., and Aramaki, S. (1983): Thickness and grain-size distribution of the Osumi pumice fall deposit from the Aira caldera. *Bulletin of the Volcanological Society of Japan*, 28, 129–139, doi:10.18940/kazanc.28.2.129.

Kusano, T. and Nakayama, K. (1999): Preliminary report on depositional processes of block-and-ash flow deposits: An example from the Taheizan pyroclastic flow deposits at Sambae volcano, southwest Japan. *Bulletin of the Volcanological Society of Japan*, 44, 143–156, doi:10.18940/kazanz.44.3.143. (in Japanese with English abstract and captions)

Machida, H. and Arai, F. (1979): Daisen Kurayoshi Pumice: Stratigraphy, chronology, distribution and implication to late Pleistocene events in central Japan. *Journal of Geography (Chigaku Zasshi)*, 88, 313–330, doi:10.5026/igeography.88.5.313. (in Japanese with English abstract)

Machida, H. and Arai, F. (2011): *Atlas of Tephra in and around Japan (Second Edition)*. University of Tokyo Press. (in Japanese)

Machida, H., Arai, F., Lee, B.-S., Moriwaki, H. and Furuta, T. (1984): Late Quaternary tephras in Ulleung-do Island, Korea. *Journal of Geography (Chigaku Zasshi)*, 93, 1–14, doi:10.5026/geography.93.1. (in Japanese with English abstract and captions)

Machida, H., Arai, F. and Momose, M. (1985): Aso-4 ash: A widespread tephra and its implications to the events of late Pleistocene in and around Japan. *Bulletin of the Volcanological Society of Japan*, 30, 49–70, doi:10.18940/kazan.30.2.49. (in Japanese with English abstract and captions)

Maruyama, Y., Hattori, K., Hirata, T. and Danhara, T. (2016): A proposed methodology for analyses of wide-ranged elements in volcanic glass shards in widespread Quaternary tephras. *Quaternary International*, 397, 267–280, doi:10.1016/j.quaint.2015.06.020.

Maruyama, S., Danhara, T. and Hirata, T. (2017): Re-identification of Shishimuta-Pink tephra samples from the Japanese Islands based on simultaneous major- and trace-element analyses of volcanic glasses. *Quaternary International*, 456, 180–194, doi:10.1016/j.quaint.2017.02.024.

Matsui, S. and Inoue, T. (1971): Pyroclastics and their stratigraphy from Volc. Sambe. *Earth Science (Chikyu Kagaku)*, 25, 147–163, doi:10.15080/agej.chikyukagaku.25.4.147. (in Japanese with English abstract)

Matsumoto, A. and Ui, T. (1997): K–Ar age of Ata pyroclastic flow deposit, southern Kyushu, Japan. *Bulletin of the Volcanological Society of Japan*, 42, 223–225, doi:10.18940/kazan.42.3.223. (in Japanese with English captions)

McLean, D., Albert, P.G., Nakagawa, T., Suzuki, T., Suzuki, T., Suigetsu 2006 Project Members and Staff, R.A. (2016): Identification of Shishimuta-Pink tephra samples from the Japanese Islands based on simultaneous major- and trace-element analyses of volcanic glasses. *Quaternary International*, 456, 180–194, doi:10.1016/j.quaint.2017.02.024.

McLean, D., Albert, P.G., Nakagawa, T., Staff, R.A., Suzuki, T., Suigetsu 2006 Project Members and Staff, R.A. (2016): Identification of Shishimuta-Pink tephra samples from the Japanese Islands based on simultaneous major- and trace-element analyses of volcanic glasses. *Quaternary International*, 456, 180–194, doi:10.1016/j.quaint.2017.02.024.

Miura, K. and Hayashi, M. (1991): Quaternary tephra studies in the Chugoku and Shikoku districts. *Quaternary Research (Daiyonki-Kenkyu)*, 30, 339–
Nakajima, T., Kikkawa, K., Ikehara, K., Katayama, Nagahashi, Y., Fukaya, M., Kimura, J., Qing, C., Sannakawa, T., Gotanda, K., Haraguchi, T., Danhara, Nakagawa, T., Nagahashi, Y., Sato, T., Takeshita, Y., Tawara, T. Mizuno, K. (2018): Stratigraphy and chronology of widespread tephra beds intercalated in the TKN-2004 core sediment obtained from the Takano formation, central Japan. Quaternary Research (Daiyonki-Kenkyu), 46, 305–325, doi:10.4116/jaqu.46.305. (in Japanese with English abstract and captions)

Nagahashi, Y., Sato, T., Takeshita, Y., Tawara, T. Mizuno, K. (2018): Stratigraphy and age of the Daisen-Kurayoshi Pumice (DKP) and San’in 1 (SAN1) tephra beds: Examination of off-Wakasa bay sediment cores and Lake Suigetsu SG06 core. Annual Meeting of the Geological Society of Japan, 123, R21-O-4, doi:10.14863/geosocabst.2016.0_301. (in Japanese)

Nakagawa, T. (2015): A Lake that Records Time (Toki Wo Kizamu Mizumu). Iwanami Shoten. (in Japanese)

Nakagawa, T., Kitagawa, H., Yasuda, Y., Tarasov, P.E., Nishida, K., Gotanda, K., Sawai, Y. and Yangtze River Civilization Program Members (2016): Stratigraphy and age of the Daisen-Kurayoshi Pumice (DKP) and San’in 1 (SAN1) tephra beds: Examination of off-Wakasa bay sediment cores and Lake Suigetsu SG06 core. Annual Meeting of the Geological Society of Japan, 123, R21-O-4, doi:10.14863/geosocabst.2016.0_301. (in Japanese)

Nakagawa, T., Gotanda, K., Haraguchi, T., Danhara, T., Yonenobu, H., Brauer, A. Yokoyama, Y., Tada, R., Takemura, K., Staff, R.A., Payne, R., Bronk Ramsey, C., Bryant, C., Brock, F., Schlolaut, G., Marshall, M., Tarasov, P., Lamb, H. and Suigetsu 2006 Project Members (2012): SG06, a fully continuous and varved sediment core from Lake Suigetsu, Japan: Stratigraphy and potential for improving the radiocarbon calibration model and understanding of late Quaternary climate changes. Quaternary Science Reviews, 36, 164–176, doi:10.1016/j.quascirev.2010.12.013.

Nakajima, T., Kikkawa, K., Ikehara, K., Katayama, H., Kikawa, E., Yoshima, M. and Seto, K. (1996): Marine sediments and late Quaternary stratigraphy in the southeastern part of the Japan Sea—Concerning the timing of dark layer deposition. Journal of the Geological Society of Japan, 102, 125–138, doi:10.5575/geosoc.102.125. (in Japanese with English abstract and captions)

Okuno, M., Nakamura, T., Kamata, H., Ono, K. and Hoshizumi, H. (1998): AMS 14C age of the Handa pyroclastic-flow deposit from Kuju volcano, Japan. Bulletin of the Volcanological Society of Japan, 43, 75–79, doi:10.18940/kazan.43.2_75. (in Japanese with English captions)

Ono, K. and Watanabe, K. (1985): Geological map of Aso Volcano. Geological Map of Volcanoes 4, 1:50,000. Geological Survey of Japan, AIST. (in Japanese with English abstract)

Ono, K., Matsumoto, Y., Miyahisa M., Teraoka, Y. and Kambe, N. (1977): Geology of the Takeda district. Quadrangle Series, Scale 1:50,000. Geological Survey of Japan, AIST. (in Japanese with English abstract)

Schlolaut, G., Brauer, A., Marshall, M.H., Nakagawa, T., Staff, R.A., Bronk Ramsey, C., Lamb, H.F., Bryant, C.L., Naumann, R., Dulski, P., Brock, F., Yokoyama, Y., Tada, R., Haraguchi, T. and Suigetsu 2006 Project Members (2014): Event layers in the Japanese Lake Suigetsu ‘SG06’ sediment core: Description, interpretation and climatic implications. Quaternary Science Reviews, 83, 157–170, doi:10.1016/j.quascirev.2013.10.026.

Shitaoka, Y., Fukuoka, T., Hasegawa, A., Kusano, T. and Nagatomo, T. (2009): Thermoluminescence dating of the pyroclastic deposits of the Sanbe Volcano. Bulletin of the Shimane Nature Museum of Mt. Sanbe (Shahime), 7, 15–24. (in Japanese)

Smith, V.C., Staff, R.A., Blockley, S.P.E., Bronk Ramsey, C., Nakagawa, T., Mark, D.F., Takemura, K., Danhara, T. and Suigetsu 2006 Project Members (2013): Identification and correlation of visible tephras in the Lake Suigetsu SG06 sedimentary archive, Japan: Chronostratigraphic markers for synchronising of east Asian/west Pacific palaeoclimatic records across the last 150 ka. Quaternary Science Reviews, 67, 121–137, doi:10.1016/j.quascirev.2013.01.026.

Steen-McIntyre, V. (1975): Hydration and superhydration of tephra glass—A potential tool for estimating age of Holocene and Pleistocene ash beds. in Quaternary Studies edited by Suggate, R.P. and Cresswell, M.W., Royal Society of New Zealand, 271–278.

Suto, S., Inomata, T., Sasaki, H. and Mukoyama, S. (2007): Data base of the volcanic ash fall distribution map of Japan. Bulletin of the Geological Survey of Japan, 58, 261–321, doi:10.9795/bullgsj.58.261. (in Japanese with English abstract and captions)

Takada, H. (1989): Summary report of tephras from Aso central volcanic cones. Kumamoto Chigaku Kaishi, 90, 8–11. (in Japanese)*

Takahashi, M., Kominiami, M., Nemoto, Y., Hasegawa, Y., Nagai, T., Tanaka, H., Nishi, N. and Yasui, M. (2003): Whole-rock chemistry for eruptive products of Fuji volcano, central Japan: Summary of analytical data of 847 samples. Proceedings of the Institute of Natural Sciences, Nihon University, 38, 117–166.
Takemoto, H., Momose, M., Hirabayashi, K. and Kobayashi, T. (1987): Stratigraphy and correlation of the Younger Ontake tephra group—An implication to the Late Pleistocene chronology in central Japan. Quaternary Research (Daiyonki-Kenkyu), 25, 337–352, doi:10.4116/jaqua.25.337. (in Japanese with English abstract)

Takemura, K., Kitagawa, H., Hayashida, A. and Yasuda, Y. (1994): Sedimentary facies and chronology of core samples from Lake Mikata, Lake Suigetsu and Kurota lowland, central Japan—Sedimentary environment in Mikata lowland since the last interglacial time. Journal of Geography (Chigaku Zasshi), 103, 233–242, doi:10.5026/geography.103.233. (in Japanese with English abstract and captions)

Togashi, H., Sakai, J., Kumon, F. and Kobayashi, M. (1999): Sakasayachi peat bed on the southeastern foot of Iizuna volcano, central Japan. Bulletin of Nagano Nature Conservation Research Institute, 2, 33–41. (in Japanese with English abstract and captions)

Tsukui, M. (1984): Geology of Daisen Volcano. Journal of the Geological Society of Japan, 90, 643–658, doi:10.5575/geosoc.90.643. (in Japanese with English abstract and captions)

Yamamoto, T. (2017a): Quantitative eruption history of Pleistocene Daisen Volcano, SW Japan. Bulletin of the Geological Survey of Japan, 68, 1–16, doi:10.9795/bullgsj.68.1. (in Japanese with English abstract and captions)

Yamamoto, T. (2017b): Stratigraphic positions of the Daisen–Kurayoshi and San-in 1 tephra fallouts in NE Japan. Bulletin of the Geological Survey of Japan, 68, 223–235, doi:10.9795/bullgsj.68.223. (in Japanese with English abstract and captions)

Yasuda, Y. (1982): Pollen analytical study of the sediment from the Lake Mikata in Fukui Prefecture, central Japan—Especially on the fluctuation of precipitation since the last glacial age on the side of Sea of Japan. Quaternary Research (Daiyonki-Kenkyu), 21, 255–271, doi:10.4116/jaqua.21.255. (in Japanese with English abstract and captions)

Yoshikawa, S. (1976): The volcanic ash layers of the Osaka Group. Journal of the Geological Society of Japan, 82, 497–515. (in Japanese with English abstract)

Yoshikawa, S., Nasu, T., Taruno, H. and Furutani, M. (1986): Late Pleistocene to Holocene volcanic ash layers in central Kinki district, Japan. Earth Science (Chikyu Kagaku), 40, 18–38, doi:10.15080/agcjchikyukagaku.40.1_18. (in Japanese with English abstract)

* Title etc. translated by S.M.
水月湖から掘削された SG93 および SG06 コア試料中の可視テフラ層の岩石学的特性

丸山誠史*,**, 竹村恵二***, 平田岳史****
山下透*, 檜原徹*

本論文では、水月湖から掘削された 2 つのコア試料（SG93 および SG06）に含まれる可視テフラ層の、岩石学的特性に関して報告する。水月湖のテフラ層に含まれる鉱物や火山ガラスの屈折率、火山ガラスの形状、鉱物構成のよう、基本的かつ重要な岩石学的特性は、これまで公表されてこなかった。水月湖コア試料のテフラ層は、九州のカルデラ（例えば阿蘇、阿多、姶良）を起源とするもの、西南日本の中中国地方に存在する大山および三瓶火山を起源とするもの、それに大別することができる。水月湖コア試料には、日本海上的鬱陵島を起源とする鬱陵−隠岐テフラ、三瓶浮布テフラと密接な関係がある飯手テフラ、そして給源火山が不明なスコリア層も存在していた。日本海で掘削されたコア試料から見いだされた山陰 1 テフラに対比された、水月湖コア試料のテフラ層は、岩石学的特性に基づくと、九州の九重カルデラから噴出した九重第 1 テフラとも対比可能である。岩石学的特性の記載はテフラ層の識別・対比に関して、火山ガラスの主要元素組成だけでは得ることのできない重要な制約条件を与える。しかしながら、いくつかのテフラ層の対比はいまだ曖昧さを残しており、種々の微量元素組成も含む火山ガラスの地球化学的データも、識別・対比をより厳密に行うために必要である。

キーワード：水月湖、ドリルコア、テフラ、火山ガラス、岩石学的特性

* 株式会社京都フィッション・トラック
** 同志社大学文化遺産情報科学調査研究センター
*** 京都大学地球熱学研究施設
**** 東京大学理学部地殻化学実験施設