# AN INTEGRATED STRATIGRAPHY AROUND THE PLIO-PLEISTOCENE BOUNDARY IN THE CHIKURA GROUP, THE BOSO PENINSULA, CENTRAL JAPAN, BASED ON DATA FROM PALEOMAGNETIC, OXYGEN ISOTOPIC AND WIDESPREAD TEPHRA CORRELATION

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*Abstract* As widespread tephra is considered to have been deposited widely in an extremely short time after volcanic eruption, it has an important role as a useful geological time index. To improve the accuracy of tephrochronology, we propose a widespread tephra correlation based on various characteristics of the tephra layers for the middle section of the Chikura Group from the southernmost part of the Boso Peninsula, Japan, with a refined chronorostratigraphy based on magnetostratigraphy and oxygen isotopic stratigraphic analysis of benthic foraminifers. Around the Plio-Pleistocene boundary, we were able to compare seven tephra layers with the other tephra layers in Plio-Pleistocene strata in central Japan, and were able to obtain a detailed tephrochronology. The improved accuracy of the integrated tephrochronology is expected to contribute to the understanding of environmental changes over time.

**Key words:** widespread tephra correlation, tephrochronology, integrated stratigraphy, Chikura Group, Plio-Pleistocene

## 1. Introduction

The Japan arc is located along a subduction zone of the Pacific and Philippines Sea Plates with the Eurasian Plate. Numerous volcanoes are associated with these plate boundaries and many tephra layers exist in the Plio-Pleistocene strata of the Japanese Islands. Studies of tephrochronology in Japan have revealed a detailed time and space diagram of widespread marker tephra layers for the past 1 Ma (e.g. Machida and Arai 2003). These tephra layers have greatly contributed to the reconstruction of palaeoenvironments and tectonic events in the Japanese Islands. Since the middle 1970s many tephra correlation data have been accumulated for older (early Pleistocene and Pliocene) strata in central Japan. Many widespread tephra layers of early Pleistocene and Pliocene age have been identified (e.g. Kurokawa and Tomita 2000; Tamura and Yamazaki 2004; Tamura *et al*. 2008). However, compared with the late Pleistocene tephra layers,

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the accuracy of the early Pleistocene and Pliocene tephra layers' age remains low. Improving the accuracy of the older tephra layers' chronology remains an important issue.

In this research, the age of the early Pleistocene and Pliocene widespread tephra layers was decided based on a chronostratigraphy for the middle section of the Chikura Group, from the southernmost part of the Boso Peninsula, Japan, based on magnetostratigraphy and oxygen isotopic stratigraphic analysis of benthic foraminifers. We were therefore able to identify with high accuracy the ages of seven tephra layers.

## 2. General Geology of the Study Area

The Chikura Group, in the southernmost part of the Boso Peninsula, Japan, are composed of the Shirahama Formation, the Shiramazu Formation, the Mera Formation, the Minamiasai Formation and the Hata Formation (Kotake *et al*. 1995). The Chikura Group produces a lot of well-preserved micro fossils, and shows a strongly stable paleomagnetism signal. Furthermore, abundant tephra layers are present in these strata (Kotake *et al*. 1995).

Okada *et al.* (2012) reported a detailed route map in the Mera F. -the Mianamiasai F. exposed along the path of the Oikura in the Chikura-cho, Southboso City, Chiba Prefecture. Okada *et al.* (2012) named this range an Oikura section, over 500 m in thickness of the layer of the stratum. In this section, the paleomagnetism samples were collected at about 10–25 m intervals, and the sample of the benthic foraminifers for the oxygen isotopic stratigraphic analyses was gathered at intervals of about 3 m. The oxygen isotope curve reported by Okada *et al.* (2012) is concordant with LR04 (Lisiecki and Raymo 2005) widely used as an oxygen isotope standard curve in Plio-Pleistocene series. Based on this, it became possible to construct an integrated stratigraphy in the Chikura Group by paleomagnetism-oxygen isotopic analyses (Figs. 1 and 2).

## 3. Tephra Samples and the Laboratory Methods

Abundant tephra layers are recognized in the Oikura section. The lithofacies description and the sample collection were done for fine grain vitric tephras with high possibility of the widespread tephra among these. We newly named fine grain vitric tephra layers as Oikura1 (Okr1) to Oikura15 (Okr15) in ascending order (Fig. 2). The tephra description by the previous work is only of YK tephra of Kawakami and Shishikura (2006). The YK tephra is a combination tephra of three tephra layers. The lower layer is a black and white pumicious tephra layer, the middle one is scoria tephra and the upper layer is a fine vitric tephra layer. The number in tephra name considering the sequence was adopted in examining the hierarchical relationship to other vitreous tephras in this research, and the most significant vitreous tephra of the YK marker bed was assumed to be Okr5. In this research, a vitric fine tephra of the upper layer of the YK tephra was named to be Okr5.

The tephra samples were washed and dried, then, we did a petrographic description, the refractive-index measurement and the major and trace element chemical analysis of the volcanic glass shards. The refractive-index measurement was determined with a refractometer called RIMS2000 (Kyoto Fission Track Co., Ltd.). Details of the refractive index measurement accuracy etc. of the volcanic glass are shown in Danhara (1991). The chemical analysis on the volcanic glass was done by the ICP AES analysis at the laboratory of Mitsubishi materials, natural

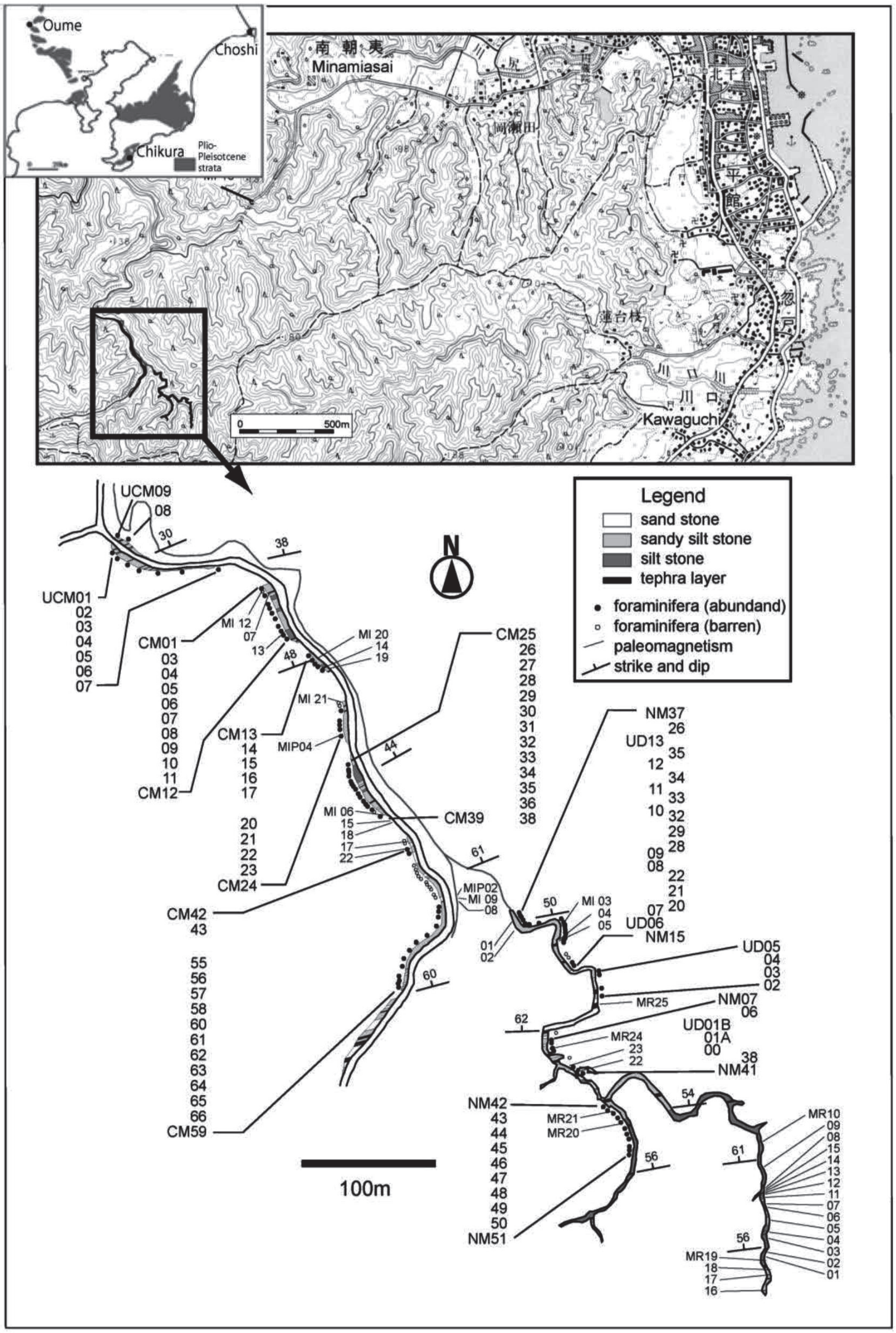


**Fig. 1** Lithology and sampling sites within the study area partly added after Okada *et al*. (2012). The topographic map is after Chikura 1: 25,000 map published by Geospatial Information Authority of Japan (GSI) in 1992.

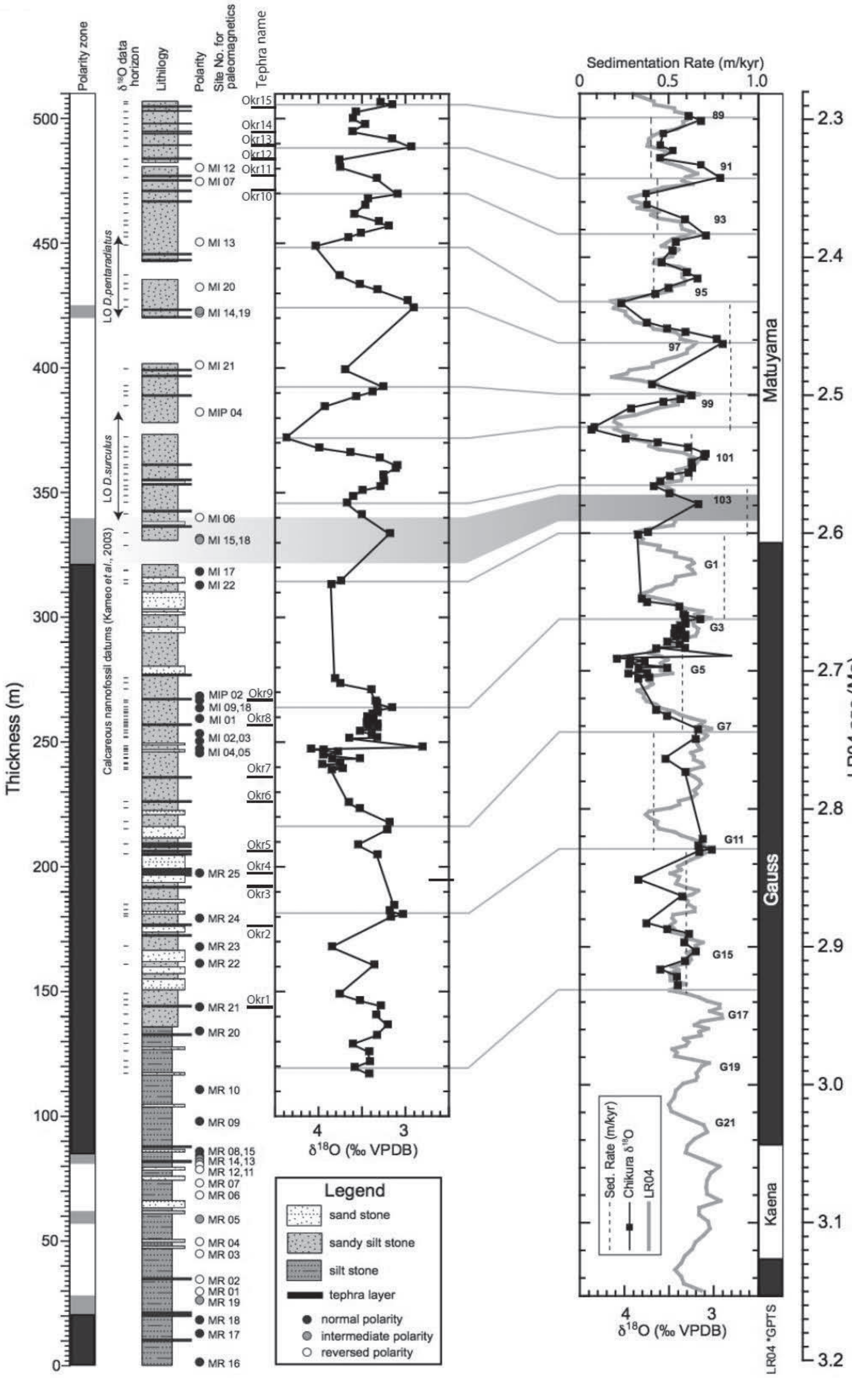


**Fig. 2** Integrated stratigraphy and an age model of the Oikura section of the Chikura Group partly added after Okada *et al*. (2012).

Resources Development Corp. The analytical condition and the standard sample analysis result, etc. are shown in Tamura *et al.* (2008).

## 4. Description of the Tephra Layers at the Oikura Section in the Chikura Group

Description of the outcrop, petrological features, and the major and trace element analyses data of the volcanic glass are indicated by the subordinate position of tephra layers (Okr1, Okr4, Okr6, Okr7, Okr10, Okr12 and Okr14). These tephra layers are compared with the widespread tephra in this research (Tables 1 and 2).

Okr1 is very fine vitric ash layer and white colored. The thickness of this tephra is 15 cm. This tephra mainly consists of thin glass shards of bubble-wall type with small amount of orthopyroxene and hornblende phenocrysts. Okr4 can be seen 54 m above Okr1. Okr4 consists of medium sand grain size and vitric white colored layer. The thickness of this tephra is 22 cm, and it is overlain by a reworked tuffaceous sand with a thickness of >3 m. This tephra mainly consists of glass shards of tube-like straight type and a small amount of thick bubble-wall type with biotite and small amount of orthopyroxene and hornblende phenocrysts. Okr6 can be found 27.5 m above Okr4. Okr6 consists of fine vitric ash layer and is pale pink colored. The thickness of this tephra is 17 cm. This tephra mainly consists of thin glass shards of bubble-wall and straight type with orthopyroxene phenocrysts. Okr7 can be seen 13 m above Okr6. Okr6 is very fine grain sized and appears as a vitric white colored layer. The thickness of this tephra is 3 cm. This tephra mainly consists of glass shards of bubble-wall type with orthopyroxene and small amount of clinopyroxene and hornblende phenocrysts. The volcanic glass shards are rich in Sr (>150 ppm), which markedly differs from other tephra beds of the Oikura section. Okr10 can be seen 228 m above Okr7. Okr10 is very fine grain size and vitric white colored layer. The thickness of this tephra is 80 cm. This tephra mainly consists of glass shards of bubble-wall and straight types with clinopyroxene, orthopyroxene and small amount of hornblende phenocrysts. Okr12 can be seen 10 m above Okr10. Okr12 is fine vitric ash layer and white grey colored. The thickness of this tephra is 30 cm. This tephra mainly consists of glass shards of straight type with biotite, hornblende and orthopyroxene phenocrysts. Okr14 can be seen 5 m above Okr12. Okr14 is fine vitric ash layer and white beige colored. The thickness of this tephra is 5 cm. This tephra mainly consists of glass shards of straight type and small amount of thick bubble wall type with biotite, hornblende and orthopyroxene phenocrysts.

## 5. Correlation of the Plio-Pleistocene Tephra Layers of the Oikura Section in the Chikura Group and Detection of the Plio-Pleistocene Tephra Layers

The Okr1–Okr9 are positioning in the upper Gauss chronozone (C2An.1n: 3.052–2.581 Ma) and the Okr10–Okr15 in the lower Matsuyama chronozone (C2r.2r: 2.581–2.229 Ma) on magnetostratigraphy. We examined the comparison with the detection of the Plio-Pleistocene tephra layers at about 3–2 Ma to be Okr1–Okr15 tephra layers based on the mineral assemblage and the refractive index of glass shards, major and trace element chemical compositions of the volcanic glass. Seven tephra layers of the Oikura section are widely correlated with the other

**Table 1** Petrographic properties of tephra layers in the Oikura section and widespread tephra layer

| tephra name(1) | | locality | grain size | color | thickness(cm) | phenoclist minerals(2) | volcanic glass shade(3) | refractive index gl (n) | tephra correlation |
|---|---|---|---|---|---|---|---|---|---|
| Oikura 15 | Okr15 | Chikura | fine ash | white | 24 | opx, cpx, ho | bw | 1.501-1.503 | |
| Oikura 14 | Okr14 | Chikura | f.-m. ash | beige-wh. | 5 | bio, ho, opx | str > bw | 1.498-1.500 | Tng-Tsp |
| Oikura 13 | Okr13 | Chikura | f.-m. ash | white | 2 | ho = opx >> cpx | sb,bw | 1.507-1.509 | |
| Oikura 12 | Okr12 | Chikura | f.-m. ash | grey-wh | 30 | bio, ho, opx | str > sb | 1.502-1.505 | Jwg4 |
| Oikura 11 | Okr11 | Chikura | very fine ash | white | 7 | ho >> opx | bw, str | 1.503-1.506 | |
| Oikura 10 | Okr10 | Chikura | very fine ash | white | 80 | cpx, opx, +ho | bw, str | 1.500-1.502 | Jwg3 |
| Oikura 9 | Okr9 | Chikura | very fine ash | white | 1 | opx > cpx | str, sb, bw | 1.500-1.504 | |
| Oikura 8 | Okr8 | Chikura | very fine ash | pink-wh | 5 | opx | str, sb, bw | 1.502-1.503 | |
| Oikura 7 | Okr7 | Chikura | very fine ash | white | 3 | opx >> cpx > ho | bw > str | 1.509-1.512 | Znp I |
| Oikura 6 | Okr6 | Chikura | very fine ash | pink-wh | 17 | opx | bw > str | 1.508-1.511 | Cgs6 |
| Oikura 5 | Okr5 | Chikura | very fine ash | white | 25 | ho > opx, cpx | bw, str | 1.503-1.506 | |
| Oikura 4 | Okr4 | Chikura | f.-m. ash | white | > 200 | bio, opx, +ho | str > bw | 1.498-1.500 | MD2, Cgs2 |
| Oikura 3 | Okr3 | Chikura | f.-m. ash | grey-wh | 8 | opx > cpx | bw > str | 1.502-1.505 | |
| Oikura 2 | Okr2 | Chikura | f.-m. ash | white | 25 | opx, cpx | str > sb, bw | 1.508-1.510 | |
| Oikura 1 | Okr1 | Chikura | very fine ash | white | 15 | poor (opx, ho) | bw > str | 1.499-1.501 | Hbt1, Cgs1 |
| Tsp[(a)] | Tsp | Nigata Nagaoka | medium. ash | white | 40 | bio, opx, ho | str > bw | 1.498-1.500 | Taniguchi |
| Jwg4[(a)] | Jwg4 | Nigata Nagaoka | fine ash | white | 10 | bio, ho | str, sb | 1.501-1.505 | |
| Jwg3[(a)] | Jwg3 | Nigata Nagaoka | fine ash | white | | — | bw, str | | |
| Zenpukuji I[(b)] | Znpk1 | Shiga Koka | fine ash | white | 30 | opx > cpx | bw, str | 1.505-1.511 | |
| Chigase 6[(c)] | Cgs6 | Tokyo Oume | fine ash | pink-wh | 20 | opx, cpx | bw > str | 1.507-1.509* | |
| Chigase 2[(c)] | Cgs2 | Tokyo Oume | f.-m. ash | white | 100 | qt, bi: (opx, ho) | str > bw | 1.498-1.500 | MD2* |
| Chigase 1[(c)] | Cgs1 | Tokyo Oume | very fine ash | ye-wh | 10 | qt: ho, opx, cpx | bw >> str | 1.500-1.501 | Hbt1* |

(1) tephra name by (a) : Kurokawa *et al*. (1999), (b) : Yoshikawa (1984), (c) : Shoda *et al*. (2005),
(2) qt : quartz, bio : biotite, opx : orthopyroxene, cpx : clinoopyroxene, ho : hornblende, gar : garnet, cum : cummingtonite
(3) glass type by Kishi and Miyawaki (1996). ＊: Shoda *et al*. (2005)

**Table 2** Major and trace element composition of volcanic glass

| Tephra name | area | $TiO_2$ | $Al_2O_3$ | $Fe_2O_3$T | MnO | MgO | CaO | $Na_2O$ | $K_2O$ | $P_2O_5$ | Σ Oxide | Fe-Mgmol | Ba/La | La/Y | Ba | La | Sr | Y |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Okr14** | Chikura | 0.06 | 10.72 | 1.09 | 0.05 | 0.04 | 0.69 | 3.38 | 3.86 | 0.01 | 19.90 | 93.22 | 21.04 | 1.59 | 568 | 27 | 72 | 17 |
| Taniguchi | Toyama | 0.07 | 10.99 | 1.11 | 0.06 | 0.03 | 0.74 | 3.36 | 4.15 | 0.03 | 20.54 | 94.92 | 19.59 | 1.68 | 627 | 32 | 80 | 19 |
| In11* | Chiba Choshi | 0.07 | 11.26 | 1.1 | 0.05 | 0.07 | 0.73 | 3.37 | 4.2 | 0.01 | 20.86 | 88.81 | 22.33 | 1.50 | 603 | 27 | 77 | 18 |
| **Okr12** | Chikura | 0.1 | 12.15 | 1.74 | 0.06 | 0.04 | 0.93 | 4.02 | 3.76 | <0.01 | 22.80 | 95.64 | 20.34 | 1.13 | 712 | 35 | 93 | 31 |
| Jwg-4 | Nigata Izumozaki | 0.11 | 12.59 | 1.93 | 0.04 | 0.01 | 0.91 | 3.68 | 4.18 | 0.02 | 23.47 | 99.00 | 19.70 | 1.17 | 690 | 35 | 92 | 30 |
| **Okr10** | Chikura | 0.08 | 11.63 | 1.18 | 0.04 | 0.05 | 0.77 | 3.48 | 3.94 | 0.02 | 21.19 | 92.26 | 21.60 | 1.36 | 648 | 30 | 82 | 22 |
| Jwg-3 | Nigata Izumozaki | 0.09 | 12.1 | 1.24 | 0.03 | 0.04 | 0.86 | 3.3 | 3.86 | 0.02 | 21.54 | 94.00 | 21.40 | 1.48 | 662 | 31 | 103 | 21 |
| **Okr7** | Chikura | 0.41 | 12.55 | 1.94 | 0.07 | 0.39 | 1.57 | 3.75 | 3.14 | 0.07 | 23.89 | 71.52 | 21.48 | 0.70 | 494 | 23 | 170 | 33 |
| Znpk I | Shiga Koka | 0.40 | 11.80 | 2.10 | 0.05 | 0.34 | 1.71 | 3.71 | 3.05 | 0.07 | 23.29 | 75.7 | 25.04 | 0.74 | 576 | 23 | 162 | 31 |
| **Okr6** | Chikura | 0.4 | 13.6 | 1.8 | 0.1 | 0.3 | 1.5 | 4.2 | 3.6 | (EDS) | | | | | | | | |
| Cgs6 | Tokyo Oume | 0.29 | 12.73 | 2.08 | 0.04 | 0.22 | 1.40 | 3.56 | 4.23 | 0.06 | 24.61 | 82.7 | 19.9 | 1.29 | 716 | 36 | 146 | 28 |
| **Okr4** | Chikura | 0.05 | 11.45 | 1.06 | 0.06 | 0.04 | 0.7 | 3.76 | 4.5 | 0.02 | 21.64 | 93.04 | 23.37 | 1.17 | 631 | 27 | 79 | 23 |
| Cgs2 | Tokyo Oume | 0.06 | 10.39 | 0.95 | 0.06 | 0.02 | 0.7 | 3.2 | 3.9 | 0.01 | 19.26 | 96.00 | 27.04 | 1.10 | 622 | 23 | 76 | 21 |
| Hzn2 | Shiga Koka | 0.06 | 10.38 | 0.94 | 0.06 | 0.02 | 0.7 | 2.87 | 4.3 | 0.01 | 19.32 | 95.96 | 29.57 | 1.05 | 621 | 21 | 73 | 20 |
| **Okr1** | Chikura | 0.2 | 10.91 | 1.12 | 0.03 | 0.12 | 0.99 | 3.34 | 3.67 | 0.02 | 20.40 | 82.49 | 25.00 | 1.00 | 525 | 21 | 95 | 21 |
| Hbt1** | Okasa Sennan | 0.24 | 11.53 | 1.28 | 0.04 | 0.14 | 0.98 | 3.17 | 3.56 | 0.03 | | 82 | 27.36 | 1 | 594 | 25 | 97 | 25 |
| Cgs1 | Tokyo Oume | 0.2 | 11.4 | *0.87* | 0.04 | 0.14 | 0.77 | 3.56 | 3.82 | 0.02 | 20.82 | 75.83 | 23.15 | 1.3 | 602 | 26 | 96 | 20 |

*: Tamura *et al*. (2010), **: Yoshikawa *et al*. (2000)

$TiO_2$-$P_2O_5$ in % and Ba-Y in ppm. $Fe_2O_3$ T means total Fe as $Fe_2O_3$.

tephras intercalated in Plio-Pleistocene sediments in central Japan. A list of these widespread tephra layers is given in Table 1, and these are described below in detail. Table 2 presents the major and trace element data for these tephras. Fig. 3 presents the time and space diagram of Plio-Pleistocene widespread tephras in central Japan.

**Correlation Okr1 and Habitaki1-MT2 tephra (Hbt1-MT2)**

Hbt1-MT2 is found in many sedimentary basins in central Japan (Tomita and Kurokawa 1999; Mizuno 2000; Shoda *et al*. 2005). This tephra mainly consists of volcanic glass of bubble-wall type with small amount of orthopyroxene and hornblende phenocrysts. The chemical composition of glass shards is lower in $K_2O$ (<4%) than those in other Pliocene tephras, and La/Y is about 1.0 (Table 2; Tamura *et al*. 2008). Biostratigraphically, this tephra is situated between the rapid increase of *N.Koizumii* and the last occurrence of *N.kamitschatica* (Watanabe 2002). The age of this tephra is thus estimated at about 2.8–2.9 Ma (Watanabe 2002). Features of Okr1 are similar to those of Hbt1-MT2, and they are comparable, so that they are correlated.

**Correlation Okr4 and UN-MD2 tephra (UN-MD2)**

This tephra is found with Hbt1-MT2 in many sedimentary basins in central Japan (Kurokawa and Tomita 2000; Watanabe 2002; Shoda *et al*. 2005). This tephra mainly consists of volcanic glass of tube-like straight type with biotite phenocrysts. The chemical composition of glass shards is higher in $K_2O$ (about 4%) and lower in CaO (<0.8%) than those of Hbt1-MT2 (Table 2; Tamura *et al*. 2008). The age of this tephra is estimated at about 2.6–2.7 Ma (Kurokawa and Tomita 2000; Watanabe 2002). Features of Okr4 are similar to those of UN-MD2, and they are comparable, so that they are correlated.

**Correlation Okr6 and Chigase6 tephra (Cgs6)**

Cgs6 is found in above Chigase2 tephra (Cgs2) which is correlated with UN-MD2 (Shoda *et al.* 2005; Fig. 3). Cgs6 can be seen 2.5 m above Cgs2. Cgs6 is very fine grain size and vitric pale pink colored layer. The thickness of this tephra is 20 cm. This tephra mainly consists of glass shards of bubble-wall and straight types with orthopyroxene, and small amount of clinopyroxene phenocrysts. The chemical composition of glass shards is higher in $Fe_2O_3$ (2%) and CaO (1.3%) than Cgs2 (Table 2). Features of Okr6 are similar to those of Cgs6, and they are comparable, so they are correlated.

**Correlation Okr7 and Zenpukuji1 tephra (Znpk1)**

Znpk1 is found in the Koka Formation of Kobiwako Group, Plio-Pleistocene sedimentary basin in central Japan (Yoshikawa 1984) and upper Hozoin2 tephra (Hzn2) which is correlated with UN-MD2 (Mizuno 2000). Znpk1 is very fine grain size and vitric white colored layer. The thickness of this tephra is 30 cm. This tephra mainly consists of glass shards of bubble-wall and straight types with orthopyroxene, and a small amount of hornblende and clinopyroxene phenocrysts. The chemical composition of glass shards is higher in $Fe_2O_3$ (2.1%) and CaO (1.7%) and lower in La/Y (0.7) than Cgs2 (Table 2). Features of Okr7 are similar to those of Znpk1 well, and is comparable, so they are correlated.

**Correlation Okr10, Okr12, Okr14 and Jwg3, Jwg4, Tsp tephras**

Jwg3, Jwg4, Tsp tephras (Kurokawa *et al.* 1999) are found in the Nishiyama Formation of

Plio-Pleistocene sedimentary basin at the Jyorakuji-route in Izumozaki City, Niigata Prefecture. The age of these tephras are estimated at about 2.4–2.3 Ma based on magnetostratigraphy and microfossil biostratigraphy (Kishi and Miyawaki 1996).

Jwg3 is found in the middle part of the Nishiyama Formation. This is fine grain size and vitric white colored layer. The thickness of this tephra is 3 cm. This tephra mainly consists of glass shards of bubble-wall and straight types. The chemical composition of glass shards is poor in CaO (0.9%) (Table 2). Jwg4 can be seen 4.5 m above Jwg3. Jwg4 is very fine grain size and vitric pale blue white colored layer. The thickness of this tephra is 10 cm. This tephra mainly consists of glass shards of bubble-wall and straight types with small amount of biotite and orthopyroxene phenocrysts. The chemical composition of glass shards is rich in $Fe_2O_3$ (1.9%) and $K_2O$ (4.2%), and poor in CaO (0.9%) (Table 2). Tsp can be seen 5 m above Jwg4. Tsp is medium grain size and vitric white colored layer. The thickness of this tephra is 40 cm. This tephra mainly consists of glass shards of straight type and small amount of thick bubble-wall type with biotite and small amount of orthopyroxene and hornblende phenocrysts. The chemical composition of glass shards is poor in CaO (0.8%) and rich in $K_2O$ (4.2%). Tsp is correlated with Taniguchi tephra (Tng: Machida and Arai 2003). Tng is found in many Plio-Pleistocene sedimentary beds in the Hokuriku, Kanto, Nagano and Niigata (Fig. 3). The age of this is estimated to be 2.2–2.3 Ma (Machida and Arai 2003).

As the above-mentioned, the three tephra layers of Okr10, Okr12, and Okr14 are correlated with Jwg3, Jwg4, and Tsp respectively based on petrography features and the chronological age.

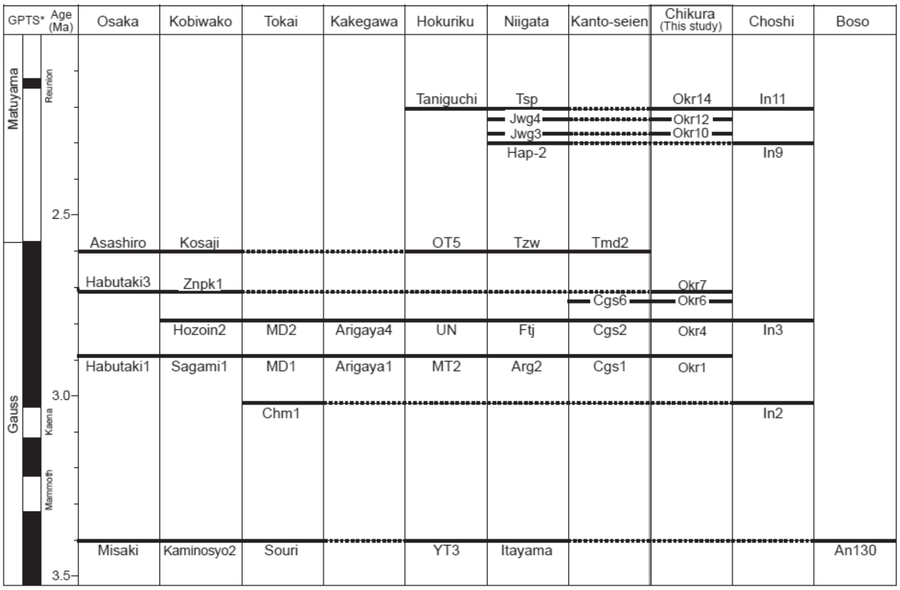


**Fig. 3** Time and space diagram of Plio-Pleistocene marker tephras partly added after Tamura *et al*. (2010).

## The ages of the widespread tephra at the Oikura section

In the Oikura section, the ages of seven marker tephra layers were acquired (Table 3). The age of Okr1 (Hbt1-MT2) is estimated at about 2.89 Ma, during G14 and G15 of oxygen isotopic stage, Okr4 (UN-MD2) is 2.79 Ma at about G9 and Okr14 (Tng-Tsp) is 2.33 Ma at about MIS 90. They almost agree with the age obtained for previous research of these ages.

**Table 3** Ages of major tephra layers around the Plio-Pleistocene boundary

| tephra | widespread tephra<br>other area tephra | age (Ma) | oxygen isotope<br>stage |
|---|---|---|---|
| Okr14 | Tng-Tsp | 2.33 | MIS90 |
| Okr12 | Jwg4 | 2.35 | MIS92 |
| Okr10 | Jwg3 | 2.38 | MIS93 |
| Okr7 | Znpk1 | 2.71 | G6 |
| Okr6 | Cgs6 | 2.73 | G6 / G7 |
| Okr4 | UN-MD2 | 2.79 | G9 |
| Okr1 | Hbt1-MT2 | 2.89 | G14 / G15 |

## 6. Conclusion

In order to provide highly accurate tephrochronology of the early Pleistocene and Pliocene age, 15 tephra layers that existed in an integrated stratigraphy in the Chikura Group were described, and compared with widespread tephra layers in Plio-Pleistocene sedimentary beds in central Japan. The seven widespread tephra layers distributed in central Japan were discovered, and the ages in the oxygen isotope stage were identified. This result will contribute specifically by assigning a certain chronological value to widespread tephra layers and will provide a time marker of various environmental changes based on tephrochronology.

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## References

Danhara, T. 1991. Measurement of refractive index by RIMS and its application. *Chikyu Monthly*

*(Gekkan Chikyu)* **13**: 193–200.*
Kawakami, S. and Shishikura, M. 2006. *Geology of the Tateyama District. Quadrangle Series.* 1 : 50,000. Geological Survey of Japan, AIST.**
Kishi, K. and Miyawaki, R. 1996. Plio-Pleistocene Fold development in the Kashiwazaki Plain and vicinity, Niigata Prefecture. *Journal of Geography (Chigaku Zasshi)* **105**: 88–112.**
Kotake, N., Koyama, M. and Kameo K. 1995. Magnetostratigraohy andbiostratigraphy of the Plio-Pleistocene Chikura and Toyofusa Group, southernmost part of the Boso Peninsula, central Japan. *Journal of the Geological Society of Japan* **101**: 515–531**.
Kurokawa, K. and Tomita, Y. 2000. The UN-MD2 Ash: a late Pliocene widespread tephra deposit in central Japan. *Earth Sci*ence *(Chikyu Kagaku)* **54**: 337–341.*
Kurokawa, K., Tomita, Y., Aoki, T., Sawaguri, T. and Maruyama, E. 1999. Volcanic ash layers in the Nishiyama Formation along the Jorakuji route, Niigata, central Japan with special reference to the correlation of the Jjj and Sig ash layers. *Memoirs of the Faculty of Education and Human Sciences. Natural sciences* **1**: 63–101.**
Lisiecki, L.E. and Raymo, M.E. 2005. A Pliocene-Pleistocene stack of 57 globally distributed benthic $\delta^{18}O$ records. *Paleoceanography* **20**: PA1003. doi:10.1029/2004PA001071.
Machida, H. and Arai, F. 2003. Atlas of Tephra in and around Japan [revised edition], Tokyo: University Tokyo press.*
Mizuno, K. 2000. Geohistory of the Pliocene sedimentary basins in the Kinki and Tokai districts based on the correlation of some volcanic ashes. *Abstracts, the 107th annual meeting of the Geological Society of Japan*: 77.*
Okada, M., Tokoro, Y., Uchida, Y., Arai, Y. and Saito, K. 2012. An integrated stratigraphy around the Plio-Pleistocene boundary interval in the Chikura Group, southernmost part of the Boso peninsula, central Japan, besed on data from paleomagnetic and oxygen isotopic analyses. *Journal of the Geological Society of Japan* **118**: 97–108.**
Shoda, K., Kikuchi, T., Suzuki, T., Takegoshi, S. and Research Group for Geology of the Western Hills of the Kanto Plain. 2005. Tephrostratigraphy of the lower part of the Hannou Gravel, western part of the Kanto Plain, central Japan, and correlation with some wide-spread tephras. *Earth Science (Chikyu Kagaku)* **59**: 339–356.**
Tamura, I. and Yamazaki, H. 2004. Tephrochronological study of the Hokuriku Group – the age of the Hokuriku Group by tephra stratigraphy and correlation to the widespread tephra layers. *Journal of the Geological Society of Japan* **110**: 411–436.**
Tamura, I., Yamazaki, H. and Mizuno, K. 2008. Characteristics for the recognition of Pliocene and Pleistocene marker tephras in central Japan. *Quaternary International* **178**: 85–99.
Tamura, I., Takagi, H. and Yamazaki, H. 2010. The Tanzawa-garnet pumice: widely distributed 2.5 Ma tephra in the southern Kanto area, Japan. *Journal of the Geological Society of Japan* **116**: 360–373.**
Tomita, Y. and Kurokawa, K. 1999. A widespread volcanic ash layer of about 2.7Ma in central Japan; correlation of the Habutaki 1 (Osaka Group), the MT2 (Himi Group) and the Arg-2 (Nishiyama Formation) ash layers. *Journal of the Geological Society of Japan* **105**: 63–71.**
Watanabe, M. 2002. Revised diatom biostratigraphy and chronostratigraphy of the Pliocene sequence in the Himi-Nadaura area, Toyama prefecture central Japan. *Journal of the Geological Society of Japan* **108**: 499–509.**
Yoshikawa, S. 1984. Volcanic ash layers in the Osaka and Kobiwako Groups, Kinki district, Japan. *Journal of Geosciences Osaka City University* **27**: 1–40.**

Yoshikawa, S., Mizuno, K., Katoh, S., Satoguchi, Y., Miyakawa, C., Kinugawa, Y., Mitamura, M. and Nakagawa, K. 2000. Stratigraphy and correlation of the Plio-Pleistocene volcanic ash layers from a 1700 m core taken from Higashinada, Kobe City, Southwestern Japan. *The Quaternary Research (Daiyonki Kenkyu)* **39**: 505–520.**

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