Journal of Geosciences, Osaka City University
Vol. 49, Art. 7, p. 119-135, March, 2006

# Volcanic Stratigraphy in Western Oita, Kyushu, Japan - Part 1: The Tsuetate Area

Masahiro DAISHI[1] and Michinori INOUE[2]

[1] Geochronology Japan Inc., Osaka 540-0012, Japan
[2] INA Corporation, Fukuoka 816-0964, Japan

**Abstract**

The volcanic stratigraphy of Western Oita, Japan is clarified through detailed geological field work, petrographic study and age determination. The oldest volcanic activity is identified as that responsible for the Yoshinomoto Andesite (2.8 - 2.4 Ma), followed by that for the Matsubara Andesite (2.4 - 2.1 Ma). The Kamitarumizu Andesite, Fukuro Andesite and Kusu Group make up a succession from 1.7 to 1.3 Ma, and is followed by the Yamakogawa Rhyolite activity (1.3 - 1.0 Ma) and subsequent formation of the Yabakei Pyroclastic Flow Deposit. Volcanic activity related to deposition of the Tsuetate Formation, Iketsuru Pyroclastic Rock, Kan'non'iwa Andesite and Kan'non'iwa Pyroclastic Flow Deposit is inferred to have occurred at approximately 0.7 Ma, succeeded by the activity related to the Haneyama Rhyolite and Kameishiyama-Yoshitakeyama Dacite.

**Key-words** : Volcanic stratigraphy, Tsuetate, Oita Prefecture, Pliocene-Pleistocene volcanic rocks

## 1. Introduction

The Amagase - Oyama - Tsuetate area extends from the west of Oita Prefecture to the north of Kumamoto Prefecture in Kyushu, Japan (Fig. 1). This area forms a part of the northern margin of the Beppu-Shimabara graben (Matsumoto, 1979) with Pliocene to Pleistocene volcanic products distributed extensively throughout.

Although many stratigraphic reports have been published for this area (e.g., Daishi et al., 1981; Hase et al., 1993; Hayashi et al., 1982; Hayashi and Watanabe, 1987; Iso and Ikeda, 1979; Iwauchi and Hase, 1989; Kamata, 1985a, 1985b, 1997; Kido, 1981; Kido et al., 1987; Matsumoto et al., 1977; NEDO, 1990; Sudo, 1985a, 1985b; Tamanyu and Kasuya, 1983; Uemura, 1985; Uto and Sudo, 1985; Watanabe and Hayashi, 1983; Watanabe et al., 1987), there remain many inconsistencies. In this study, we performed age determinations, detailed geological field survey work and petrographic studies for many volcanic rocks in this area as an adjunct to previous reported data (Daishi et al., 2003) to clarify the volcanic stratigraphy of this region. This article presents the volcanic stratigraphy of the Tsuetate area as the first report in this series.

## 2. Geographical setting

The study area is located on a pyroclastic flow plateau that spreads to the north from the Aso caldera, bounded to the east by the Kuju volcano and to the west by the Chikuhi Mountains. A mountainous region consisting of peaks 500 - 700 m in height extends into the area, with Mt. Kameishiyama (942.6m a.s.l.) in the north as its highest point. Mt. Yoshitakeyama (926.5m a.s.l.) lies to the east of Mt. Kameishiyama, and relatively high peaks run in an east/west manner to the north of the area.

The Tsuetategawa River flows in the central part of the area from south to north with a westerly deviation in its northern part. The Oyamagawa River flows from the south to the north in the western part of the study area and joins the Tsuetategawa River as it flows from the east in the vicinity of Matsubara. These rivers flow from 300 - 250 m in altitude and have banks presenting steep geographical

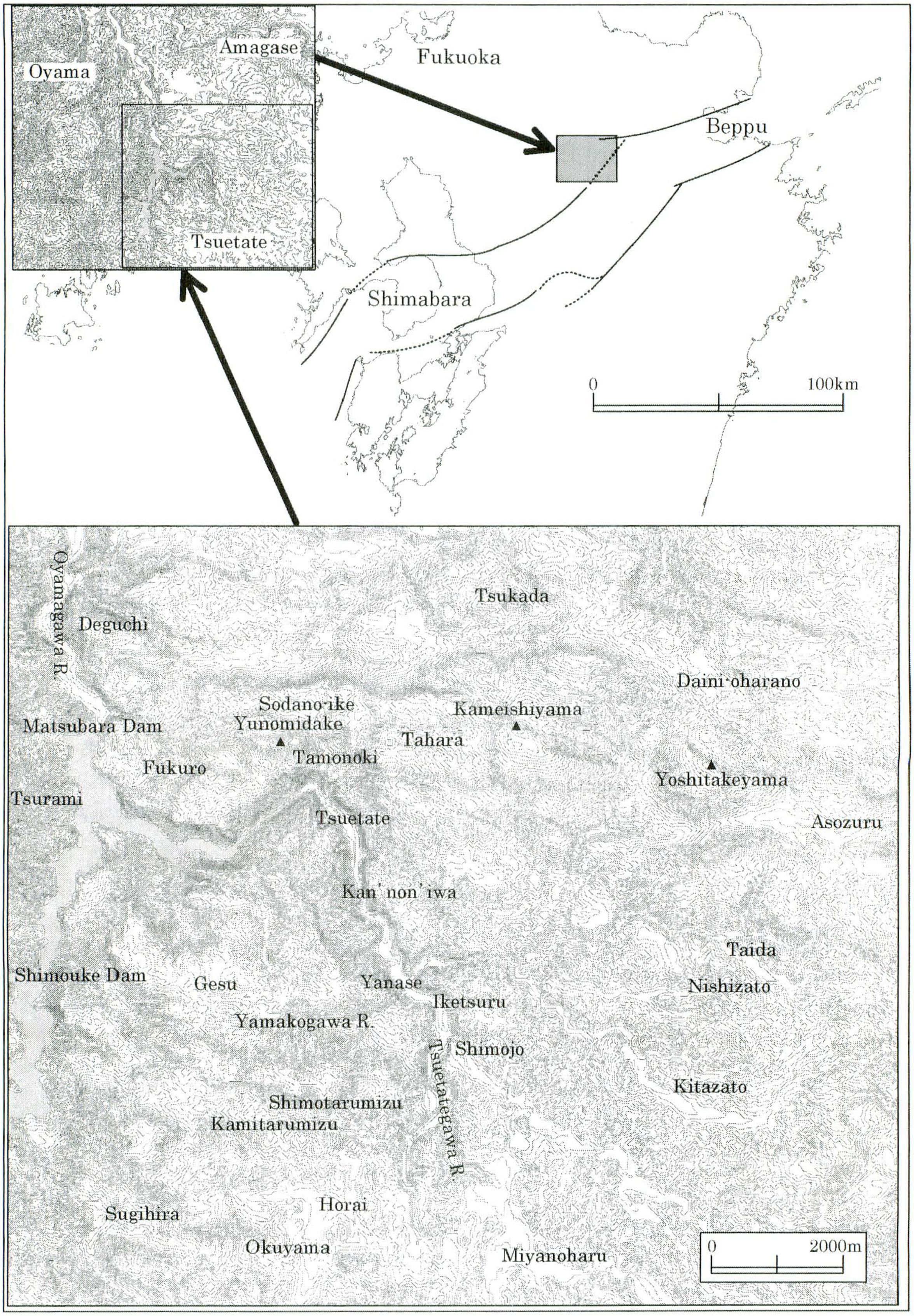



Fig. 1 Index Map.
The bolder lines show the Beppu - Shimabara graben (Matsumoto, 1979)

features.

## 3. Volcanic Stratigraphy

The geologic map of the Tsuetate area is shown in Fig. 3, and the volcanic stratigraphy is shown in Fig. 2. The area hosts the Yoshinomoto Andesite, Matsubara Andesite, Fukuro Andesite, Kamitarumizu Andesite, Kusu Group, Yamakogawa Rhyolite, Yabakei Pyroclastic Flow Deposit, Kan'non'iwa Lahar Deposit, Tsuetate Formation, Iketsuru Pyroclastic Rock, Haneyama Rhyolite, Shimojo Andesite, Kan'non'iwa Andesite, Kan'non'iwa Pyroclastic Flow Deposit, Sugihira Pyroclastic Flow Deposit, Kameishiyama-Yoshitakeyama Dacite, Yamakawa Debris Avalanche Deposit, Pre-Aso 4 Pyroclastics, Aso Pyroclastic Flow Deposit, terrace deposit, rock avalanche deposit and talus deposit in ascending order.

### (1) Late Pliocene

#### a. Yoshinomoto Andesite

The Yoshinomoto Andesite (NEDO, 1990) is formed by two-pyroxene hornblende andesite lava flows and a small amount of pyroclastic rocks, and is distributed throughout Sugihira, Okuyama, and in the downstream area of the Mitakawauchigawa River in the southwest.

The rock contains phenocrysts of plagioclase mega-crystals (maximum 15mm in size), hornblende, clinopyroxene and orthopyroxene, and occasionally contains hornblende mega-crystals (maximum 12mm in size).

The Yoshinomoto Andesite is the lowermost stratum in this area and is overlain by two-pyroxene andesite of the Kamitarumizu Andesite in the vicinity of the Mitakawauchigawa River, northeast of the Shimouke Dam, and by the Sugihira Pyroclastic Flow Deposit and the Aso Pyroclastic Flow Deposit to the east of Sugihira. The total thickness of the Yoshinomoto Andesite exceeds 250 m.

Although the volcanic activity of the Yoshinomoto Andesite is reported to be 3.7 - 0.6 Ma in age (Kamata, 1985a; MITI, 1980, 1981, 1984; NEDO, 1990; Tamanyu and Kasuya, 1983), careful examination of the results with respect to the measurement technique and sample condition suggests that the ages are concentrated around 2.8 - 2.4 Ma. The activity of the Yoshinomoto Andesite thus appears to have occurred in the Late Pliocene.

#### b. Matsubara Andesite

The Matsubara Andesite (redefine) consists of two-pyroxene andesite lava flows and pyroclastic rocks, distributed in the vicinity of Matsubara, the Tsuetate-ohashi Bridge and Tsurami in the northwest part of the area.

The Matsubara Andesite is re-defined from the Matsubara Formation and the Tsurami Lava (Oita Pre., 1972), where the Matsubara Andesite and Takakurayama Andesite (MITI, 1984) have been merged.

The rock contains phenocrysts of plagioclase, clinopyroxene and orthopyroxene.

The Matsubara Andesite is covered by the Yamakogawa Rhyolite to the southeast of the Tsuetate-ohashi Bridge and is overlain by the Aso Pyroclastic Flow Deposit on the east side of the Shin'tsuegawa-hashi Bridge. This andesite is also overlain by the Fukuro Andesite along the right bank of the Tsuetategawa River at Fukuro. The stratigraphical relationship between the Matsubara Andesite and the Yoshinomoto Andesite has not been reported. The total thickness of the Matsubara Andesite is more than 100m, where the lower part consists chiefly of pyroclastic rock and the upper part consists mainly of lava flow.

Although the radiometric age of the Matsubara Andesite has been reported to be between 2.5 to 1.9 Ma (Kamata, 1985b; MITI, 1984; Sudo, 1985b), the largest constituent is concentrated in the range 2.4 - 2.1 Ma. It is thus concluded that the volcanic activity of the Matsubara Andesite occurred in the Late Pliocene.

#### c. Fukuro Andesite

The Fukuro Andesite, which has been re-named for this study, is composed of two-pyroxene hornblende andesite to dacite lava flows and pyroclastic rocks. These rocks are distributed throughout Fukuro and the Tsuetate-ohashi Bridge area in the northwest of the study area.

Although the Fukuro Andesite corresponds to the Hyugami Lava (Oita Pre., 1972) and/or the Kameishiyama -Yoshitakeyama Dacite (NEDO, 1990), it is given a new name here due to the difference in rock type and activity.

The rock contains phenocrysts of plagioclase, hornblende, clinopyroxene and orthopyroxene.

The Fukuro Andesite is overlain by the Kusu Group near the ridge on the right side of the Tsuetate River in Fukuro, and directly covers the Matsubara Andesite near the south of Fukuro. The total thickness of the Fukuro Andesite is more than 100m.

The radiometric age of the Fukuro Andesite has not been reported. However the ages of the underlying Matsubara Andesite (2.4 - 2.1 Ma) and overlaying Kusu Group (1.5Ma; Daishi et al., 2003) suggest that the Fukuro Andesite is formed in the period 2.0 - 1.5 Ma, which corresponds to the Late Pliocene and Early Pleistocene.

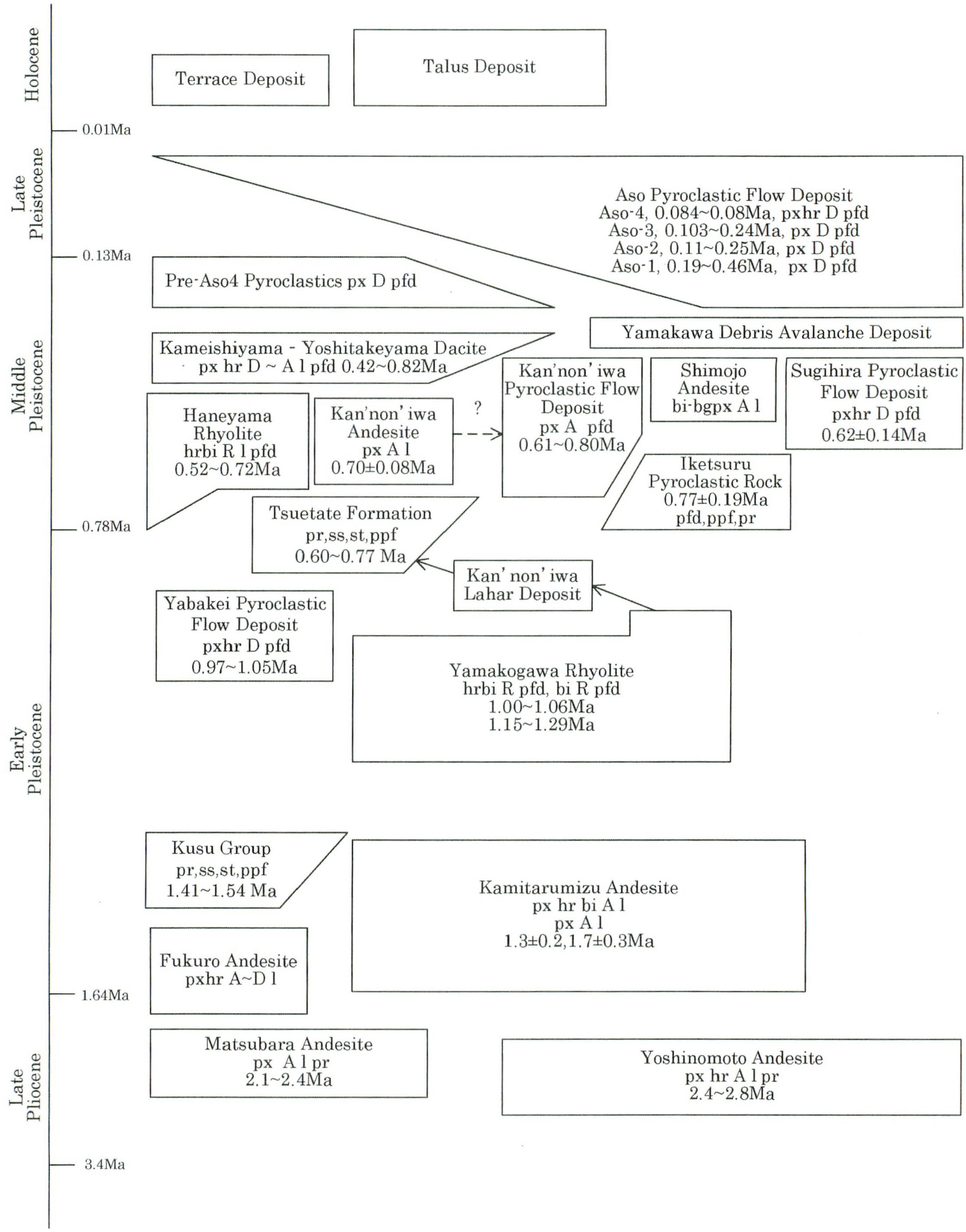



Fig. 2 Volcanic Sequence of the Tsuetate Area.
Abbreviation: A = Andesite, D = Dacite, R = Rhyolite, bi = biotite, hr = hornblende, px = pyroxene, l = lava, pr = pyroclastic rock, pfd = pyroclastic flow deposit, ppf = pumice flow deposit, ss = sandsotone, st = silt stone.

### (2) Early Pleistocene

#### a. Kamitarumizu Andesite

The Kamitarumizu Andesite (Kamata, 1985a; NEDO, 1990) is mainly composed of two-pyroxene andesite lava flows, which are widely distributed to the north of the Tsuetate, Yanase, Shimotarumizu, Kamitarumizu and Shimouke villages.

The rocks contain phenocrysts of plagioclase, clinopyroxene and orthopyroxene with less frequent quartz, biotite, hornblende and olivine phenocrysts.

The Kamitarumizu Andesite is directly covered by the Yamakogawa Rhyolite at the vicinity of the Shimojo Elementary School and overlies the two-pyroxene hornblende andesite lava of the Yoshinomoto Andesite at the Mitakawauchigawa River northeast of the Shimouke Dam. The total thickness of the Kamitarumizu Andesite exceeds 200 m.

The reported radiometric ages of the Kamitarumizu Andesite are 1.7 and 1.3 Ma (Kamata, 1985a), indicating Early Pleistocene activity. However, the Kamitarumizu Andesite also includes many two-pyroxene andesite rocks without hornblende or biotite (Kamata, 1985a; NEDO, 1990), which may be of a different age.

#### b. Kusu Group

The Kusu Group (NEDO, 1990) mainly consists of biotite hornblende dacitic pumice flow deposits with siltstone. This group is distributed around the Gesu Ranch in the vicinity of the Tsuetate-ohashi Bridge.

The NEDO definition the Kusu Group (NEDO, 1990) includes pyroclastic rocks distributed in the Tsuetate region. Here, however, the rocks distributed in the vicinity of the Tsuetate-ohashi Bridge are reclassified due to a difference in the inferred age of activity.

The rocks contain phenocrysts of plagioclase, biotite and hornblende with occasional clinopyroxene and orthopyroxene.

The Kusu Group is covered by the Yamakogawa Rhyolite and overlays the Fukuro Andesite at the ridge on the right side of the Tsuetategawa River at Fukuro. The total thickness of the Kusu Group is in excess of 50 m.

The reported radiometric age of the Kusu Group is 1.41 - 1.54 Ma, corresponding to the Early Pleistocene (Daishi et al., 2003). Volcanic rocks with similar radiometric ages are found in the Oyama and Amagase area (Daishi et al., 2003) to the north, suggesting that volcanic activity occurred contemporaneously over a wide area in this period.

#### c. Yamakogawa Rhyolite

The Yamakogawa Rhyolite (NEDO, 1990) is mainly composed of hornblende-free or hornblende biotite rhyolite pyroclastic flow deposits and lava flows, distributed in Yamakogawa, the Gesu Ranch and Yunomidake. The $SiO_2$ content of these deposits is 69.23 - 74.74 wt% (Table 1).

Kamata (1985a) named the rhyolite lava in the Yamakogawa valley as the Yamakogawa Lava, which had previously been included with the Haneyama Lava of Oita Prefecture (1972), based on differences in the ages of volcanic activity. Aso and Watanabe (1985) suggested that the rhyolites distributed in the vicinity of the Yamakogawa River are in fact pyroclastic flow deposits. NEDO (1990) renamed that rhyolite as the Yamakogawa Rhyolite, since most of the product was associated with pyroclastic flows. Kamata (1997) further re-defined the Yamakogawa Rhyolite as a unit composed mainly of lava flows, with non-welded pyroclastic flow deposit distributed in the lower section of the unit. This study considers the Yamakogawa Rhyolite to consist mainly of pyroclastic flow deposits with little lava flows.

The Yamakogawa Rhyolite is covered by the Kan'non'iwa Lahar Deposit in the vicinity of the Shin-Kan'non'iwa-hashi Bridge, and by the Kan'non'iwa Andesite in the adit south of the Shin-Kan'non'iwa-hashi Bridge. The Yamakogawa Rhyolite directly covers the Kamitarumizu Andesite on the left bank of the Tsuetategawa River near the Shimojo Elementary School.

The biotite dacite non-welded pyroclastic flow deposit covering the Kamitarumizu Andesite on the right bank of the Mitakawauchigawa River was previously considered to be a part of the Yamakogawa Rhyolite. However, the rock faces suggests that this deposit may belong to another geologic unit (e.g. the Kusu Group). Further petrologic study is therefore required to assign this deposit to the proper unit.

The lightfaces of the Yamakogawa Rhyolite are variable. Although apparent linear structures on the biotite rhyolite lava resemble the generally known flow structure of viscous lava flows, the intermittent features of the structure show that the material had been derived from the flattened pumice of pyroclastic flow deposits. In addition, part of the thick pyroclastic flow deposit near the Tsuetategawa River in Yanase is welded and parallels a non-welded pyroclastic flow deposit that changes in part to that of a welded layer. The lightfaces of the non-welded pyroclastic flow deposit change from pumice flow deposit, consisting almost entirely of pumice, to a Merapi-type pyroclastic flow deposit and/or a debris avalanche deposit. The Yamakogawa Rhyolite also includes a densely welded to weakly and/or non-welded section that is clearly revealed by erosion at the Yamakogawa River and Yunohira. A rhyolite pyroclastic flow deposit with

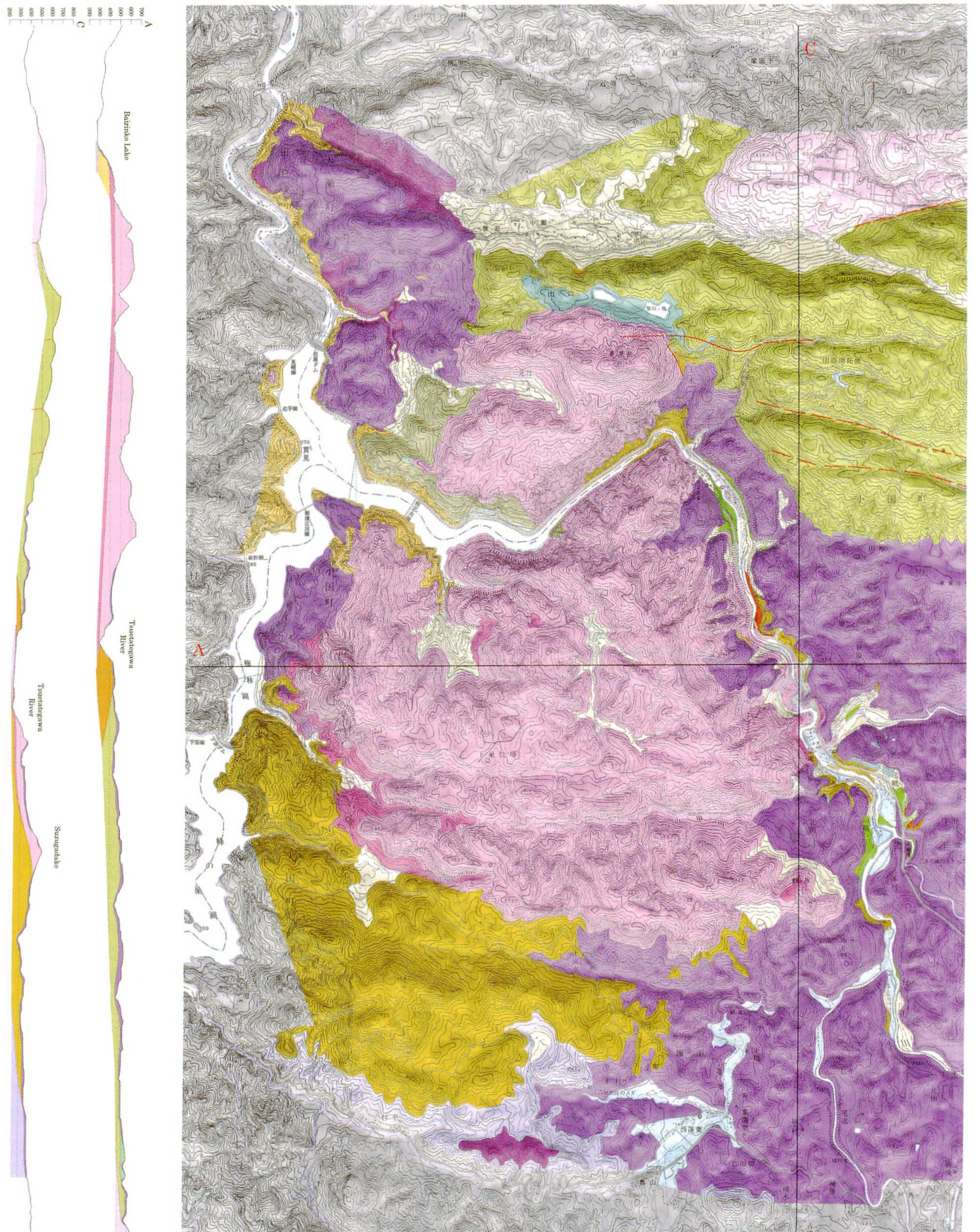
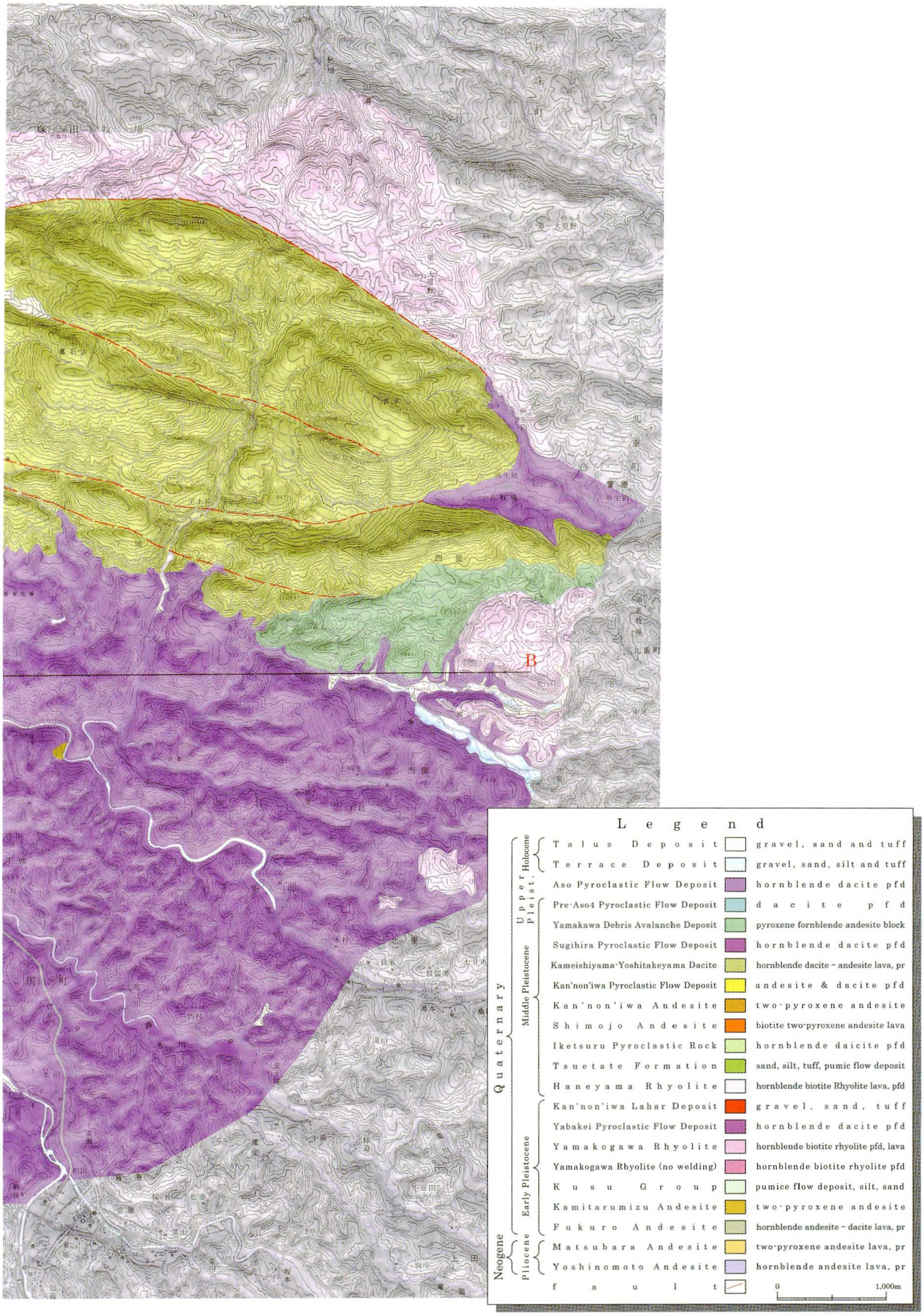



Fig. 3 Geologic Map of the Tsuetate Area.
1:25,000 A Topographic Map (Bungo Ono, Tsuetate, Taio, Miyahara), published by the Geographical Survey Institute, Ministry of Land, Infrastructure and Transport of Japan.


B
Legend
Quaternary
Holocene
Upper Pleist.
Middle Pleistocene
Early Pleistocene
Neogene
Pliocene
Talus Deposit — gravel, sand and tuff
Terrace Deposit — gravel, sand, silt and tuff
Aso Pyroclastic Flow Deposit — hornblende dacite pfd
Pre-Aso4 Pyroclastic Flow Deposit — dacite pfd
Yamakawa Debris Avalanche Deposit — pyroxene fornblende andesite block
Sugihira Pyroclastic Flow Deposit — hornblende dacite pfd
Kameishiyama-Yoshitakeyama Dacite — hornblende dacite – andesite lava, pr
Kan'non'iwa Pyroclastic Flow Deposit — andesite & dacite pfd
Kan'non'iwa Andesite — two-pyroxene andesite
Shimojo Andesite — biotite two-pyroxene andesite lava
Iketsuru Pyroclastic Rock — hornblende daicite pfd
Tsuetate Formation — sand, silt, tuff, pumic flow deposit
Haneyama Rhyolite — hornblende biotite Rhyolite lava, pfd
Kan'non'iwa Lahar Deposit — gravel, sand, tuff
Yabakei Pyroclastic Flow Deposit — hornblende dacite pfd
Yamakogawa Rhyolite — hornblende biotite rhyolite pfd, lava
Yamakogawa Rhyolite (no welding) — hornblende biotite rhyolite pfd
Kusu Group — pumice flow deposit, silt, sand
Kamitarumizu Andesite — two-pyroxene andesite
Fukuro Andesite — hornblende andesite – dacite lava, pr
Matsubara Andesite — two-pyroxene andesite lava, pr
Yoshinomoto Andesite — hornblende andesite lava, pr
fault
0
1,000m

strongly welded character changes to the east and west, demonstrating the typical structure of a pyroclastic flow deposit, in the vicinity southwest of the Gesu Ranch.

The Yamakogawa Rhyolite reaches 400 m or more in thickness from the vicinity of the Tsuetategawa River bed (about 300 m a.s.l.) to a triangulation point (697.1m a.s.l.) on the left bank of the Tsuetategawa River, and is further distributed up to about 270 m a.s.l. in the vicinity of the Tsuetategawa River in Yunomidake (740.3m a.s.l.) in the north of Tsuetate. Several plateau features are exposed on the left bank of the Tsuetategawa River in Tsuetate, which may have been formed by the flow unit and/or the cooling unit of the pyroclastic flow deposit. The lack of a plateau on the right bank of the Tsuetategawa River hints to a difference in geologic structure. NEDO (1990) supports the gravity observations of a fault structure in this area. A fault with a sheared zone oriented in the same direction can also be seen near the first Yanase tunnel, and a NNW - SSE fault outcrops in the Yamakogawa Rhyolite along a forest road in Yunohira.

The rock has hornblende or hornblende free biotite rhyolite pyroclastic flow deposits and clinopyroxene orthopyroxene biotite hornblende rhyolite pyroclastic flow deposits near the triangulation point (697.1m a.s.l.) on the left bank of the Tsuetategawa River.

The reported radiometric ages of the Yamakogawa Rhyolite are in the range 1.3 - 0.9 Ma (Daishi et al., 2003; Kamata, 1985a, 1986, 1997), indicating the Early Pleistocene activity. Daishi et al. (2003) also reported that the Yamakogawa Rhyolite can be further divided into a 1.3 Ma - 1.2 Ma unit and a 1 Ma unit.

**d. Yabakei Pyroclastic Flow Deposit**

The Yabakei Pyroclastic Flow Deposit (Ishii et al., 1956) consists of a orthopyroxene hornblende dacite pyroclastic flow deposit with occasional pyroxene andesite xenoliths and black glass lenses. It is distributed in Deguchi in the northwest of the study area. The dacite pyroclastic flow deposit distributed in the vicinity of the 613 m peak between Sugihira and Okuyama has previously been included in the Yabakei Pyroclastic Flow Deposit (e.g. Kamata, 1997). However, radiometric dating clearly shows that flow to be related to different activity to that responsible for the Yabakei Pyroclastic Flow Deposit.

The Yabakei Pyroclastic Flow Deposit is covered by the Aso Pyroclastic Flow Deposit in the vicinity of Deguchi, and overlies the Matsubara Andesite near Deguchi. The total thickness of the Yabakei Pyroclastic Flow Deposit exceeds 50m.

The reported fission track ages of the Yabakei Pyroclastic Flow Deposit are 0.40 Ma (Matsumoto et al., 1977) and 0.32 Ma (Tamanyu and Kasuya, 1983), while the K-Ar ages are in the range 0.96 - 1.03 Ma (Uto and Sudo, 1985; NEDO, 1990). Kamata (1997) concluded that the peak activity of the Yabakei Pyroclastic Flow Deposit occurred at about 1 Ma. Although previous reports have indicated the widespread distribution of the Yabakei Pyroclastic Flow Deposit in the study area, the present radiometric ages indicate that the previous dates on which these conclusions were based may be incorrect, leading to the inconsistency in formation definitions. In this report, the age of activity corresponding to the Yabakei Pyroclastic Flow Deposit is considered to be 1 Ma. Similar pyroclastic flows with ages of 1.2, 1.0, 0.8, 0.6 and 0.3 Ma have also been identified in the study (Daishi et al., 2003).

**e. Kan'non'iwa Lahar Deposit**

The Kan'non'iwa Lahar Deposit (new name) is comprised of volcanic mud flow deposits that include volcanic boulder gravel and river sediment (pebble gravel to fine grain sand). This deposit is distributed within a limitedly range along the right bank of the Tsuetategawa River downstream of the Shin-Kan'non'iwa-hashi Bridge.

At least part of the Kan'non'iwa Lahar deposit continues to the Merapi-type pyroclastic flow deposit or debris avalanche of the non-welded pyroclastic flow deposit belonging to the Yamakogawa Rhyolite, which is distributed at upper levels near the Shin-Kan'non'iwa-hashi Bridge. This deposit changes continuously to the lower stratum of the Tsuetate Formation of the Tsuetategawa River.

The total thickness of the Kan'non'iwa Lahar Deposit exceeds 20 m.

Although the radiometric age of the Kan'non'iwa Lahar Deposit has not been reported, the age is inferred to be similar to that of the Yamakogawa Rhyolite based on geological information.

**(3) Middle Pleistocene**

**a. Tsuetate Formation**

The redefined Tsuetate Formation is composed of pyroclastic rocks (including pyroclastic flow deposit), pumice flow deposits, bedded sandstone and mudstone, lappili tuff and siltstone with diatomite. It is distributed in the vicinity of the Tsuetate Hot Spring, along the Kitazatogawa River in Yanase and in Mukaizuru.

The pumice flow deposit has a hornblende clinopyroxene orthopyroxene dacite assemblage with or without biotite, and a $SiO_2$ content in the range 64.61 - 66.74 wt% (Table 1).

The Tsuetate Formation is directly covered by the Aso

Table 1 Chemical Composition of volcanic rocks from the Tsuetate Area.

| | Geol. | Yamakogawa R. | | | Yamakogawa R.nw | | | | Tsuetate F. | | | Iketsuru P.R. | | | | | | | K. A | Kan'non'iwa P.F.D. | | | | | | Pre-Aso4 Pyroclastics | | | Aso-4 P.F.D. | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Element | Units | 50011 | 50020 | 50061 | 50010 | 50100 | 50110 | 50415 | 50090 | 50150 | 60130 | 50140-100 | 50140-30 | 50140-40 | 50140-50 | 50140-70 | 50140-80 | 50140-90 | 50070 | 50030a | 50030b | 50040a | 50040b | 50050a | 50050b | 50450 | 50460 | 50470 | 50710 | 50730 | 50740 | 50760 | 50780 | 60710 |
| SiO2* | % | 74.21 | 72.17 | 71.12 | 71.84 | 69.23 | 74.74 | 71.77 | 66.74 | 66.57 | 64.61 | 41.75 | 40.88 | 43.88 | 41.73 | 38.47 | 40.15 | 43.22 | 58.25 | 71.49 | 57.10 | 63.99 | 57.76 | 48.28 | 57.15 | 45.98 | 37.55 | 44.93 | 67.38 | 64.01 | 64.77 | 63.87 | 67.15 | 67.49 |
| TiO2* | % | 0.18 | 0.30 | 0.32 | 0.23 | 0.32 | 0.16 | 0.22 | 0.48 | 0.53 | 0.55 | 1.13 | 1.07 | 1.08 | 1.05 | 1.56 | 1.16 | 1.17 | 0.91 | 0.34 | 1.11 | 0.73 | 0.90 | 1.28 | 1.13 | 1.22 | 1.08 | 1.37 | 0.59 | 0.54 | 0.61 | 0.61 | 0.56 | 0.53 |
| Al2O3* | % | 13.91 | 14.86 | 14.80 | 16.05 | 15.15 | 14.07 | 17.73 | 15.31 | 14.60 | 16.24 | 25.56 | 30.03 | 29.13 | 30.29 | 23.92 | 25.77 | 27.99 | 18.86 | 15.15 | 17.22 | 14.92 | 17.11 | 22.90 | 16.74 | 21.90 | 20.92 | 26.10 | 16.17 | 17.60 | 16.43 | 16.69 | 16.53 | 16.15 |
| Fe2O3* | % | 1.45 | 2.22 | 2.50 | 1.79 | 2.37 | 1.37 | 0.53 | 2.62 | 2.89 | 3.06 | 6.20 | 6.13 | 6.44 | 5.34 | 14.33 | 10.95 | 6.57 | 5.52 | 2.48 | 8.77 | 3.99 | 7.66 | 8.44 | 8.75 | 8.52 | 15.37 | 7.18 | 3.92 | 3.26 | 3.59 | 3.93 | 3.19 | 3.22 |
| MnO* | % | 0.08 | 0.08 | 0.13 | 0.09 | 0.08 | 0.09 | 0.01 | 0.08 | 0.09 | 0.09 | 0.03 | 0.16 | 0.10 | 0.08 | 0.16 | 0.04 | 0.07 | 0.10 | 0.09 | 0.14 | 0.11 | 0.14 | 0.18 | 0.13 | 0.27 | 0.05 | 0.23 | 0.13 | 0.12 | 0.13 | 0.13 | 0.13 | 0.13 |
| MgO* | % | 0.17 | 0.31 | 0.38 | 0.12 | 0.53 | 0.07 | 0.05 | 0.53 | 0.65 | 0.62 | 0.29 | 0.28 | 0.46 | 0.40 | 2.20 | 0.29 | 0.18 | 1.45 | 0.42 | 2.10 | 0.88 | 2.08 | 1.03 | 1.86 | 1.32 | 0.81 | 0.73 | 0.94 | 0.99 | 0.95 | 0.95 | 0.82 | 0.80 |
| CaO* | % | 0.74 | 2.28 | 2.38 | 0.50 | 2.39 | 0.71 | 0.09 | 2.37 | 2.54 | 2.67 | 0.65 | 0.58 | 1.27 | 1.70 | 2.04 | 0.46 | 0.31 | 6.57 | 2.35 | 5.53 | 2.26 | 5.85 | 2.77 | 5.10 | 2.06 | 0.72 | 1.84 | 2.77 | 3.49 | 2.81 | 2.84 | 2.49 | 2.36 |
| Na2O* | % | 3.45 | 4.13 | 4.06 | 2.58 | 3.88 | 3.44 | 0.52 | 3.13 | 3.30 | 3.03 | 0.54 | 0.26 | 0.74 | 0.72 | 0.20 | 0.15 | 0.37 | 3.35 | 4.06 | 3.67 | 4.40 | 3.50 | 1.80 | 3.74 | 1.23 | 0.47 | 1.22 | 4.75 | 5.04 | 4.37 | 4.27 | 5.05 | 4.93 |
| K2O* | % | 4.19 | 3.70 | 3.67 | 4.01 | 3.58 | 4.41 | 1.03 | 4.13 | 3.74 | 3.53 | 0.75 | 0.34 | 0.34 | 0.40 | 0.34 | 0.41 | 0.78 | 2.73 | 3.48 | 2.84 | 4.19 | 2.63 | 1.58 | 2.83 | 1.16 | 1.04 | 0.87 | 3.63 | 3.13 | 3.37 | 3.19 | 3.73 | 3.81 |
| P2O5* | % | 0.03 | 0.08 | 0.09 | 0.04 | 0.07 | 0.02 | 0.05 | 0.10 | 0.10 | 0.11 | 0.32 | 0.06 | 0.05 | 0.11 | 0.30 | 0.05 | 0.05 | 0.31 | 0.08 | 0.37 | 0.16 | 0.42 | 0.17 | 0.40 | 0.26 | 0.46 | 0.15 | 0.14 | 0.12 | 0.14 | 0.14 | 0.11 | 0.12 |
| LOI | % | 2.11 | 0.51 | 1.02 | 3.62 | 3.21 | 1.43 | 8.81 | 5.19 | 4.53 | 5.70 | 21.85 | 19.90 | 15.82 | 17.52 | 16.67 | 19.32 | 17.85 | 1.83 | 0.87 | 1.40 | 4.21 | 1.27 | 11.34 | 1.76 | 16.35 | 21.07 | 14.25 | 0.29 | 2.64 | 2.44 | 2.83 | 0.94 | 1.18 |
| total | % | 100.52 | 100.64 | 100.45 | 100.86 | 100.81 | 100.51 | 100.80 | 100.67 | 99.55 | 100.20 | 99.06 | 99.70 | 99.32 | 99.33 | 100.19 | 98.75 | 99.56 | 99.86 | 100.81 | 100.24 | 99.82 | 99.30 | 99.77 | 99.59 | 100.28 | 99.52 | 99.87 | 100.70 | 100.94 | 99.58 | 99.44 | 100.71 | 100.72 |
| Ag*** | ppm | <0.4 | 0.5 | <0.4 | 0.7 | 0.6 | <0.4 | <0.4 | <0.4 | <0.4 | <0.4 | <0.4 | <0.4 | <0.4 | <0.4 | 0.6 | <0.4 | <0.4 | <0.4 | <0.4 | <0.4 | 0.4 | 0.5 | <0.4 | <0.4 | <0.4 | <0.4 | <0.4 | <0.4 | <0.4 | <0.4 | <0.4 | <0.4 | <0.4 |
| As** | ppm | 2 | 1 | 1 | 1 | 2 | <1 | 3 | 3 | 2 | 2 | 5 | 5 | 1 | 1 | <1 | 1 | 1 | 2 | 1 | 6 | 9 | 5 | 4 | 4 | 14 | 12 | 2 | 8 | 5 | 8 | 7 | 7 | 8 |
| Au** | ppb | <2 | <2 | <2 | <2 | <2 | <2 | <2 | <2 | <2 | <2 | <2 | <2 | <2 | <2 | 7 | <2 | <2 | <2 | <2 | 3 | <2 | <2 | <2 | 3 | <2 | 2 | <2 | 3 | <2 | <2 | <2 | <2 | 5 |
| Ba* | ppm | 1018 | 786 | 817 | 969 | 752 | 898 | 556 | 936 | 802 | 850 | 1099 | 2039 | 1185 | 1918 | 902 | 920 | 1001 | 599 | 779 | 595 | 769 | 532 | 901 | 609 | 704 | 842 | 954 | 686 | 650 | 694 | 668 | 746 | 825 |
| Be* | ppm | 2 | 2 | 2 | 2 | 2 | 2 | <1 | 2 | 2 | 2 | 5 | 3 | 3 | 3 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 3 | 3 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| Bi*** | ppm | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 |
| Br** | ppm | 0.5 | <0.5 | <0.5 | <0.5 | 2.3 | <0.5 | <0.5 | 3.3 | 2.0 | 2.8 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | 1.6 | <0.5 | <0.5 | 2.8 | <0.5 | <0.5 | <0.5 | 4.0 | 1.0 | <0.5 | 2.1 | 4.2 | <0.5 | 1.0 | 1.6 | 2.2 |
| Cd*** | ppm | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | 0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 |
| Ce** | ppm | 74 | 61 | 69 | 84 | 66 | 79 | 76 | 82 | 76 | 80 | 87 | 109 | 110 | 145 | 76 | 80 | 107 | 60 | 66 | 61 | 75 | 58 | 100 | 60 | 88 | 56 | 146 | 67 | 61 | 67 | 64 | 71 | 69 |
| Co** | ppm | 1.6 | 2.1 | 2.1 | 1.4 | 2.1 | 1.0 | 1.0 | 3.0 | 3.7 | 3.1 | 3.5 | 7.0 | 8.5 | 8.4 | 30.6 | 14.4 | 10.3 | 8.3 | 3.2 | 18.0 | 4.6 | 13.6 | 13.8 | 16.3 | 15.9 | 14.0 | 7.8 | 5.2 | 4.6 | 4.5 | 4.6 | 4.2 | 3.2 |
| Cr** | ppm | 9.9 | 8.0 | 18.9 | <0.5 | 6.4 | <0.5 | 6.0 | 5.1 | 4.0 | 3.7 | 8.7 | 6.0 | 9.8 | 2.5 | 30.5 | 7.1 | <0.5 | 14.2 | 20.9 | 7.2 | 26.4 | 8.5 | 6.2 | 4.6 | 18.0 | 28.1 | 4.4 | 5.3 | 3.4 | 6.1 | 3.1 | 5.6 | 5.2 |
| Cs** | ppm | 2.6 | 2.0 | 3.0 | 2.9 | 4.6 | 2.8 | 1.0 | 4.8 | 4.6 | 5.0 | 3.3 | 2.7 | 3.4 | 1.6 | 2.4 | 2.6 | 2.4 | 3.0 | 2.8 | 4.5 | 7.6 | 4.8 | 4.6 | 3.7 | 6.5 | 10.6 | 11.1 | 6.1 | 5.9 | 5.8 | 5.7 | 5.9 | 6.8 |
| Cu*** | ppm | 2 | 6 | 5 | 2 | 3 | 2 | 3 | 4 | 5 | 5 | 12 | 15 | 14 | 8 | 37 | 48 | 11 | 16 | 6 | 81 | 9 | 23 | 36 | 44 | 16 | 58 | 13 | 7 | 5 | 8 | 8 | 6 | 5 |
| Eu** | ppm | 1.03 | 1.06 | 1.12 | 1.02 | 1.19 | 1.03 | 0.80 | 1.59 | 1.55 | 1.41 | 3.40 | 1.98 | 2.90 | 2.75 | 2.10 | 2.36 | 2.93 | 1.58 | 1.15 | 1.62 | 1.60 | 1.57 | 2.12 | 1.82 | 2.02 | 2.29 | 2.60 | 1.55 | 1.65 | 1.61 | 1.58 | 1.68 | 1.55 |
| Ga**** | ppm | 16 | 17 | 15 | 19 | 17 | 17 | 20 | 16 | 18 | 18 | 17 | 35 | 34 | 36 | 33 | 29 | 31 | 21 | 18 | 20 | 13 | 18 | 25 | 21 | 26 | 23 | 30 | 16 | 19 | 19 | 15 | 19 | 15 |
| Hf** | ppm | 5.1 | 5.3 | 5.6 | 5.9 | 5.2 | 4.4 | 6.1 | 6.9 | 6.1 | 7.0 | 9.0 | 12.0 | 10.8 | 12.5 | 4.9 | 5.2 | 7.7 | 4.8 | 5.9 | 4.8 | 7.3 | 4.7 | 8.6 | 5.2 | 6.9 | 5.3 | 10.3 | 5.7 | 5.1 | 5.6 | 5.4 | 5.7 | 6.0 |
| Hg** | ppm | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 |
| Ir** | ppb | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 |
| La** | ppm | 43.4 | 31.1 | 33.5 | 40.4 | 33.4 | 41.1 | 110.0 | 38.3 | 34.4 | 34.4 | 63.5 | 68.2 | 62.2 | 51.8 | 32.3 | 42.1 | 63.2 | 28.7 | 32.1 | 28.5 | 35.3 | 26.8 | 35.0 | 33.4 | 31.8 | 38.3 | 51.5 | 33.4 | 27.6 | 30.8 | 29.9 | 35.1 | 32.4 |
| Lu** | ppm | 0.48 | 0.43 | 0.45 | 0.60 | 0.45 | 0.51 | 0.85 | 0.47 | 0.46 | 0.46 | 1.30 | 0.61 | 0.80 | 0.95 | 0.58 | 0.63 | 0.70 | 0.39 | 0.43 | 0.46 | 0.58 | 0.44 | 0.63 | 0.50 | 0.60 | 0.66 | 0.85 | 0.50 | 0.43 | 0.56 | 0.47 | 0.59 | 0.54 |
| Mo** | ppm | <2 | <2 | <2 | <2 | 4 | <2 | 17 | <2 | 4 | 4 | <2 | <2 | 2 | 3 | <2 | <2 | <2 | 4 | 4 | 3 | <2 | 5 | 5 | 2 | 4 | 4 | 3 | <2 | <2 | 3 | 3 | 2 | 3 |
| Nd** | ppm | 32 | 23 | 27 | 33 | 27 | 33 | 58 | 33 | 34 | 32 | 75 | 46 | 62 | 59 | 40 | 44 | 66 | 27 | 28 | 30 | 36 | 27 | 38 | 34 | 33 | 41 | 55 | 31 | 26 | 30 | 32 | 38 | 33 |
| Nd**** | ppm | 15 | 13 | 12 | 16 | 13 | 14 | 24 | 16 | 15 | 17 | 23 | 33 | 27 | 31 | 11 | 11 | 19 | 14 | 11 | 10 | 15 | 9 | 17 | 11 | 15 | 12 | 23 | 12 | 10 | 11 | 11 | 13 | 12 |
| Ni*** | ppm | 4 | 3 | 5 | 2 | 3 | 2 | 2 | 2 | 5 | 5 | 3 | 3 | 5 | 3 | 11 | 8 | 2 | 10 | 7 | 9 | 9 | 5 | 5 | 3 | 7 | 15 | 3 | 3 | 2 | 4 | 3 | 3 | 2 |
| Pb*** | ppm | 21 | 18 | 20 | 24 | 19 | 20 | 23 | 19 | 17 | 19 | 25 | 38 | 33 | 38 | 7 | 18 | 29 | 15 | 18 | 19 | 24 | 13 | 22 | 15 | 21 | 22 | 31 | 17 | 13 | 22 | 18 | 13 | 20 |
| Pb**** | ppm | 20 | 16 | 13 | 21 | 13 | 19 | 21 | 15 | 15 | 19 | 26 | 36 | 27 | 28 | 15 | 15 | 18 | 14 | 18 | 12 | 19 | 12 | 21 | 19 | 22 | 17 | 31 | 19 | 15 | 20 | 15 | 14 | 17 |
| Rb** | ppm | 118 | 83 | 111 | 126 | 89 | 118 | 33 | 118 | 110 | 98 | 33 | <10 | <10 | 27 | 17 | 23 | 49 | 73 | 96 | 75 | 138 | 92 | 63 | 71 | 57 | 93 | 76 | 117 | 91 | 111 | 114 | 123 | 125 |
| Rb**** | ppm | 138 | 111 | 116 | 128 | 114 | 146 | 36 | 128 | 126 | 122 | 31 | 18 | 18 | 23 | 20 | 28 | 39 | 78 | 116 | 90 | 149 | 93 | 67 | 83 | 72 | 79 | 77 | 118 | 110 | 120 | 119 | 120 | 124 |
| S**** | ppm | <50 | <50 | 140 | 70 | <50 | 50 | 90 | 105 | 185 | 120 | <50 | 875 | 270 | 115 | 100 | <50 | 60 | 365 | <50 | 250 | 85 | 395 | 205 | 270 | 120 | 165 | 70 | 120 | 1160 | 160 | 110 | <50 | 300 |
| Sb** | ppm | 0.3 | 0.1 | 0.2 | 0.2 | 0.2 | 0.2 | 0.4 | 0.3 | 0.3 | 0.3 | 0.4 | 0.4 | 0.3 | 0.3 | <0.1 | 0.2 | 0.2 | 0.3 | 0.1 | 0.4 | 0.8 | 0.5 | 0.5 | 0.5 | 0.9 | 1.0 | 0.8 | 0.8 | 0.5 | 0.9 | 0.8 | 0.8 | 0.7 |
| Sc** | ppm | 2.5 | 2.9 | 3.5 | 3.7 | 3.3 | 2.5 | 2.7 | 8.4 | 8.6 | 8.9 | 18.3 | 17.5 | 19.2 | 17.4 | 42.4 | 31.7 | 18.6 | 12.5 | 3.6 | 18.0 | 12.3 | 17.5 | 22.7 | 19.5 | 20.9 | 24.3 | 21.8 | 8.3 | 7.3 | 9.1 | 9.0 | 7.7 | 7.5 |
| Se** | ppm | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | 1.9 | 1.1 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | 1.2 | 1.0 | <0.5 | <0.5 |
| Sm** | ppm | 5.48 | 4.47 | 4.97 | 6.09 | 4.87 | 6.09 | 9.51 | 6.74 | 6.55 | 6.22 | 14.10 | 8.21 | 12.10 | 11.60 | 7.88 | 8.45 | 12.40 | 5.73 | 4.67 | 6.37 | 7.46 | 6.14 | 8.59 | 7.56 | 7.26 | 8.89 | 11.30 | 5.74 | 5.07 | 6.30 | 6.10 | 6.60 | 5.90 |
| Sn**** | ppm | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 |
| Sr* | ppm | 124 | 280 | 289 | 102 | 288 | 121 | 19 | 303 | 317 | 325 | 131 | 192 | 226 | 295 | 140 | 103 | 82 | 586 | 288 | 504 | 281 | 517 | 378 | 479 | 263 | 140 | 310 | 391 | 578 | 419 | 433 | 394 | 372 |
| Ta** | ppm | 1.4 | 0.8 | 0.7 | 1.2 | 1.2 | 0.4 | 1.5 | 0.9 | 1.3 | 0.7 | 1.2 | 1.5 | 1.7 | 2.1 | 0.7 | <0.3 | 1.3 | 0.9 | 0.8 | 1.1 | <0.3 | 0.9 | 0.9 | 0.9 | 1.0 | 0.5 | 1.6 | 0.8 | 0.7 | <0.3 | 0.6 | 1.1 | 0.7 |
| Tb** | ppm | 0.7 | 0.6 | 0.6 | 0.8 | 0.7 | 0.8 | 1.2 | 0.8 | 0.9 | 0.8 | 2.0 | 1.2 | 1.4 | 1.6 | 1.4 | 1.2 | 1.6 | 0.7 | 0.6 | 0.8 | 1.0 | 0.9 | 1.1 | 0.9 | 0.9 | 1.2 | 1.5 | 0.9 | 0.7 | 0.9 | 0.8 | 0.9 | 0.8 |
| Th** | ppm | 13.0 | 9.7 | 10.4 | 14.2 | 9.3 | 12.5 | 18.8 | 12.5 | 10.6 | 12.1 | 16.1 | 23.1 | 19.6 | 22.1 | 7.9 | 8.6 | 12.8 | 7.2 | 9.8 | 8.5 | 14.3 | 8.6 | 16.3 | 9.5 | 12.8 | 9.7 | 19.8 | 10.9 | 9.7 | 9.6 | 10.2 | 11.6 | 12.5 |
| U** | ppm | 2.5 | 2.1 | 2.3 | 2.9 | 2.1 | 2.5 | 4.2 | 2.6 | 2.7 | 2.1 | 4.6 | 4.1 | 2.6 | 3.3 | 1.2 | 2.0 | 4.5 | 1.6 | 2.1 | 2.4 | 4.5 | 2.6 | 4.0 | 2.3 | 4.6 | 3.1 | 4.9 | 2.7 | 1.9 | 3.8 | 2.9 | 2.6 | 3.0 |
| V* | ppm | 6 | 20 | 23 | 7 | 21 | 6 | <5 | 35 | 40 | 42 | 75 | 52 | 77 | 44 | 326 | 127 | 68 | 105 | 27 | 212 | 48 | 156 | 103 | 204 | 168 | 289 | 59 | 51 | 45 | 51 | 52 | 40 | 40 |
| W** | ppm | <1 | <1 | <1 | 2 | <1 | <1 | 2 | <1 | 2 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | <1 | 4 | 2 | <1 | <1 | <1 | <1 | <1 | 2 | <1 |
| Y* | ppm | 29 | 25 | 25 | 34 | 26 | 31 | 60 | 30 | 31 | 28 | 83 | 39 | 54 | 53 | 36 | 45 | 46 | 25 | 25 | 29 | 32 | 27 | 36 | 33 | 32 | 43 | 48 | 29 | 24 | 30 | 29 | 32 | 30 |
| Yb** | ppm | 3.27 | 2.92 | 3.09 | 4.07 | 3.09 | 3.75 | 5.84 | 3.29 | 3.29 | 3.24 | 8.86 | 4.12 | 5.73 | 6.55 | 3.93 | 4.31 | 4.87 | 2.66 | 2.89 | 3.18 | 3.88 | 3.03 | 4.42 | 3.20 | 4.07 | 4.55 | 5.96 | 3.26 | 2.78 | 3.65 | 3.39 | 3.86 | 3.42 |
| Zn*** | ppm | 42 | 42 | 51 | 48 | 49 | 34 | 22 | 47 | 50 | 69 | 84 | 108 | 97 | 100 | 133 | 112 | 95 | 73 | 48 | 86 | 73 | 84 | 98 | 88 | 92 | 98 | 121 | 71 | 67 | 81 | 66 | 61 | 63 |
| Zr* | ppm | 164 | 205 | 299 | 195 | 207 | 154 | 201 | 256 | 240 | 264 | 346 | 493 | 414 | 487 | 183 | 193 | 290 | 182 | 212 | 192 | 253 | 173 | 320 | 200 | 267 | 208 | 401 | 208 | 174 | 204 | 203 | 210 | 216 |

K.A : Kan'non'iwa Andesite, analyzed by *: ICP-OES, **: INAA, ***: ICP-MS, ****: XRF

Pyroclastic Flow Deposit in the vicinity of the Tsuetate Hot Spring and Mukaizuru. The total thickness of the Tsuetate Formation is grater than 50 m.

The previous definition of the Tsuetate Formation included the pyroclastic rocks, stratified and mud stone, lapilli tuff, and diatomite siltstone distributed in the vicinity of the Tsuetate Hot Spring (Iwauchi and Hase, 1989). In this study, the Tsuetate Formation is redefined to consist of the pyroclastic rocks (mainly pyroclastic flow deposits) and the siltstone and/or sandstone distributed near the Tsuetate Hot Spring with intercalated pyroclastic surge deposits.

The radiometric age of the Tsuetate Formation has been reported to be 0.77 - 0.60 Ma (Daishi et al., 2003; Iwauchi and Hase, 1989), corresponding to the Middle Pleistocene.

**b. Iketsuru Pyroclastics Rock**

The newly named Iketsuru Pyroclastic Rock has a clinopyroxene orthopyroxene hornblende dacite assemblage and consists of pyroclastic flow deposits with pumice, surge deposits and fallout tuff. It is distributed in the vicinity of Iketsuru. The $SiO_2$ content is 38.47 - 43.88 wt% (Table 1), indicating that decreased a part of chemical composition by the leaching.

The Iketsuru Pyroclastic Rock is directly covered by the Shimojo Andesite to the north of the Shimojo-taki Waterfall and overlies the Tsuetate Formation in the vicinity of Iketsuru. The total thickness of the Iketsuru Pyroclastic Rocks is more than 15m.

The reported FT age of the Iketsuru Pyroclastic Rock is 0.77 Ma (Daishi et al., 2003), corresponding to the boundary between the Lower and Middle Pleistocene. The age of the Iketsuru Pyroclastic Rock is suggested to be similar to that of the Tsuetate Formation, although it is thought that the two units are the products of different volcanic events based on the differences in rock facies and chemical composition.

**c. Haneyama Rhyolite**

The Haneyama Rhyolite (NEDO, 1990) consists of biotite rhyolite lava with some pyroclastic flow deposits. The rhyolite is distributed in the vicinity of the Tsukada Ranch, Daini-oharano, Nishizato and Taida.

This unit contains phenocrysts of plagioclase, hornblende and biotite, with occasional clinopyroxene and orthopyroxene.

The Haneyama Rhyolite is covered by the Kameishiyama-Yoshitakeyama Dacite in the vicinity of the Tsukada Ranch and Asozuru, by the Yamakawa Debris Avalanche Deposit in Nishizato, and the Aso Pyroclastic Flow Deposit in the vicinity of Asozuru. Although the subordinate strata of the Haneyama Rhyolite dose not outcrop in the study area, the rhyolite covers the andesite to the north of Mt. Haneyama (NEDO, 1990). The total thickness of the Haneyama Rhyolite exceeds 50 m.

The radiometric ages of the Haneyama Rhyolite fall in range 1.06 - 0.47 Ma (Daishi et al., 2003; Iso and Ikeda, 1979; Kamata and Muraoka, 1982; MITI, 1979; Sudo, 1985b; Uto and Sudo, 1985), corresponding to the Early to Middle Pleistocene. However, the ages become concentrated in the range 0.72 - 0.52 Ma when measurement techniques and sample conditions are considered.

**d. Shimojo Andesite**

The newly named Shimojo Andesite is composed of biotite-bearing two-pyroxene andesite lava distributed to the north of the Shimojo-taki Waterfall. It is covered by the Aso Pyroclastic Flow Deposit in the vicinity of Shimojo and Iketsuru, and overlies the Iketsuru Pyroclastic Rock to the north of the Shimojo-taki Waterfall. The total thickness of the Shimojo Andesite is greater than 30 m.

The Shimojo Andesite was included in the Kamitarumizu Andesite in previous reports (e.g., Kamata, 1997). However, the latter resides on an evidently lower horizon than the former, necessitating redefinition of the former as the Shimojo Andesite.

The radiometric age of the Shimojo Andesite has not been reported. The geological succession, however, suggests that the age is similar to that of the Kan'non'iwa Andesite.

**e. Kan'non'iwa Andesite**

The newly named Kan'non'iwa Andesite consists of two-pyroxene andesite lava with 58.25 wt% of $SiO_2$ (Table 1) distributed in the vicinity of Kan'non'iwa, Tamanoki and the northern slope of the Deguchi-Sodano-ike Pond.

The Kan'non'iwa Andesite is overlain by the Pre-Aso 4 Pyroclastics at the north of the Tsubakinoto-hashi Bridge, covers the Yamakogawa Rhyolite to the south of the Shin-Kan'non'iwa-hashi Bridge, and is bounded by a fault against the Kamitarumizu Andesite in the vicinity of Tamanoki. The total thickness of the Kan'non'iwa Andesite is greater than 50 m.

The Kan'non'iwa Andesite was previously included in the Kamitarumizu Andesite. However, as it directly covers the Yamakogawa Rhyolite and the reported K-Ar age is 0.70 Ma (Daishi, et al., 2003), a re-definition as the Middle Pleistocene Kan'non'iwa Andesite was warranted.

**f. Kan'non'iwa Pyroclastic Flow Deposit**

The newly named Kan'non'iwa Pyroclastic Flow Deposit contains both acidic and basic pyroclastic flow deposits with a limited distribution in the adit of the left bank of the Tsuetategawa River south of the Shin-kan'non'iwa-hashi Bridge.

The deposit contains both acidic (hornblende clinopyroxene orthopyroxene rhyolite, 71-72 wt% $SiO_2$) and basic (clinopyroxene orthopyroxene andesite, 57-58 wt% $SiO_2$) bombs with similar abundances.

The Kan'non'iwa Pyroclastic Flow Deposit is covered by the Aso Pyroclastic Flow Deposit, and is overlain by the Yamakogawa Rhyolite in the adit. The total thickness of the Kan'non'iwa Pyroclastic Flow Deposit exceeds 10 m.

The FT ages of the deposit range from 0.80 to 0.61 Ma (Daishi, et. al., 2003), corresponding to the boundary between the Early and Middle Pleistocene. This deposit may be related to the volcanic activity responsible for the Kan'non'iwa Andesite considering the spatial distribution, age, and composition.

**g. Sugihira Pyroclastic Flow Deposit**

The newly named Sugihira Pyroclastic Flow Deposit, distributed in the vicinity of Sugihira, has an orthopyroxene clinopyroxene hornblende dacite assemblage with occasional pyroxene andesite xenolith and black glass lenses.

The Sugihira Pyroclastic Flow Deposit covers the Yoshinomoto Andesite. It was previously considered to belong to the Yabakei Pyroclastic Flow Deposit (Kamata, 1997), but subsequent radiometric dating of the deposit (Daishi et. al., 2003) suggests an age that differs from that of the Yabakei Pyroclastic Flow Deposit, warranting its new name. The total thickness of the Sugihira Pyroclastic Flow Deposit is 30 m or more.

The FT age of the Sugihira Pyroclastic Flow Deposit is 0.62 Ma (Daishi, et al., 2003), corresponding to the Middle Pleistocene. Coincidentally, a deposit exhibiting a similar age is distributed in the Oyama area (Daishi, et al., 2003).

**h. Kameishiyama-Yoshitakeyama Dacite**

The Kameishiyama-Yoshitakeyama Dacite (NEDO, 1990) is mainly composed of hornblende dacite to andesite lava with pyroclastic flow deposits. It is widely distributed in the vicinity of Deguchi, Mt. Kameishiyama and Mt. Yoshitakeyama.

The rock is biotite-bearing clinopyroxene orthopyroxene hornblende dacite to andesite.

The Kameishiyama-Yoshitakeyama Dacite is covered by the Pre-Aso 4 Pyroclastics in the vicinity of the Sodanoike Pond and is overlain by the Aso Pyroclastic Flow Deposit near Tahara and Asozuru. The Kameishiyama- Yoshitakeyama Dacite covers the Kan'non'iwa Andesite in Tamanoki, and is bounded by a fault against the Yamakogawa Rhyolite in the vicinity of Deguchi. The total thickness of the Sugihira Pyroclastic Flow Deposit exceeds 100 m.

The radiometric ages of the Kameishiyama-Yoshitakeyama Dacite fall in the range 0.82 - 0.42 Ma (MITI, 1979; Tamanyu and Kasuya, 1983; Watanabe and Hayashi, 1983), corresponding to the Middle Pleistocene.

**i. Yamakawa Debris Avalanche Deposit**

The Yamakawa Debris Avalanche Deposit (Kamata et al., 1988), composed of enormous blocks of andesite lava and fine fragments of andesite, is distributed in the vicinity of Nishizato in the east of the study area. These blocks have a clinopyroxene orthopyroxene hornblende andesite assemblage.

The Yamakawa Debris Avalanche Deposit is covered by the Aso Pyroclastic Flow Deposit in Taida, and overlies the Haneyama Rhyolite and the Kameishiyama-Yoshitakeyama Dacite in that area. The total thickness of the Yamakawa Debris Avalanche Deposit is greater than 50 m.

The reported K-Ar age of andesite blocks in the deposit is 0.58 Ma (Uto and Sudo, 1985). As the K-Ar age indicates the eruption age of the andesite, it can be deduced that the Yamakawa Debris Avalanche Deposit is younger. The Yamakawa Debris Avalanche Deposit is covered by the Waitasan Andesite (0.45 Ma; Kamata, 1997), suggesting an age of ca. 0.5 Ma.

**j. Pre-Aso 4 Pyroclastics**

The newly named Pre-Aso 4 Pyroclastics are mainly composed of dacite and andesite air-fall tuff, pyroclastic flow deposits, surge deposits and secondary deposits, and is distributed in the vicinity of Iketsuru and the Sodanoike Pond. The source or sources of the volcanic deposit remain unclear. The subordinate stratum underlying the Aso 4 Pyroclastic Flow Deposit is categorized as a single unit called the Pre-Aso 4 Pyroclastics.

The Pre-Aso 4 Pyroclastics are directly covered by the Aso 4 Pyroclastic Flow Deposit in the vicinity of the Yanase-daiichi-zuido Tunnel. The total thickness of the Pre-Aso 4 Pyroclastics is approximately 10 m.

The age of the Pre-Aso 4 Pyroclastics is presumed as 0.5 - 0.1 Ma based on the ages of the stratum and the Aso 4 Pyroclastic Flow Deposit.

**(4) Late Pleistocene**

**a. Aso Pyroclastic Flow Deposit**

The Aso Pyroclastic Flow Deposit is composed of hornblende-free or hornblende two-pyroxene dacite pyroclastic flow deposits and is found in the vicinity of Deguchi, and on the plateau on both sides of the Tsuetategawa River (more predominantly on the right bank), and in Asozuru. The distribution is generally below 500 m in altitude, but reaches 700 m in the vicinity of Asozuru.

The pyroclastic flow deposit is generally dense welded, with non-welded to weakly welded parts in the upper and lower area of the flow unit. It occasionally exhibits a basal conglomerate.

At least 3 flow units can be recognized in the Aso Pyroclastic Flow Deposit in the study area, with the upper unit being the most widely distributed of the trio. The upper unit contains hornblende characteristic of the Aso 4 Pyroclastic Flow Deposit, whereas the lower two units includes a small amount of hornblende that correlates more closely with the Aso-2A Pyroclastic Flow Deposit (NEDO, 1990), which also contains a small amount of crystalline hornblende. The total thickness of the Aso Pyroclastic Flow Deposit is greater than 50 m.

Data concerning the activity of the Aso Pyroclastic Flow Deposits, 0.19 - 0.46 Ma for Aso-1, 0.11 - 0.25 Ma for Aso-2, 0.10 - 0.24 Ma for Aso-3, and 0.08 - 0.084 Ma for Aso-4, have been reported by NEDO (1990).

**(5) Holocene**

**a. Terrace Deposit**

The Terrace Deposit is distributed in the vicinity of the Shimojo Elementary School, Iketsuru, Nishihorai and Taida.

The deposit is composed of andesite and rhyolite gravel with a tuff matrix, and is unconsolidated. The total thickness of the Terrace Deposit is approximately 10 m.

**b. Talus Deposit**

The Talus Deposit is unconsolidated and is distributed on the plateau slope and basal part of the Tsuetategawa River on both banks to the north of Kameishiyama. It consists of lava gravel with a tuff matrix. The maximum thickness of the Talus Deposit is 20 m.

## 4. Results

The volcanic stratigraphy of the study area is elucidated based on detailed filed work and determinations of petrography and age.

The oldest volcanic activity is the Yoshinomoto Andesite (2.8 - 2.4 Ma), followed by the Matsubara Andesite (2.4 - 2.1Ma). The Fukuro Andesite, Kamitarumizu Andesite and Kusu Group have ages in the range 1.7 - 1.3 Ma, and activity responsible for the Yamakogawa Rhyolite has been dated at 1.3 - 1.0 Ma. The Yabakei Pyroclastic Flow Deposit is inferred to have been lain near the end of the period of the Yamakogawa Rhyolite deposition.

A concentration of volcanic activity appears to have occurred at approximately 0.7 Ma, resulting in formation of the Kan'non'iwa Lahar Deposit, Tsuetate Formation, Iketsuru Pyroclastic Rock, Kan'non'iwa Andesite, Kan'non'iwa Pyroclastic Flow Deposit, Shimojo Andesite and Sugihira Pyroclastic Flow Deposit. This period was succeeded by deposition of the Haneyama Rhyolite, Kameishiyama-Yoshitakeyama Dacite, and Yamakawa Debris Avalanche Deposit.

## Acknowledgments

We thank Prof. K. Furuyama, Osaka City University, for reading an earlier manuscript. The manuscript was reconstructed based on his critical comments. We thank Prof. Y. Hase, Kumamoto University for their constructive comments and discussions.

## References

Aso, H. and Watanabe, K. (1985) About so-called Haneyama Lava of the pyroclastic flow origin distributed in northwestern part of Oguni. *Rep. Geol. Kumamoto*, 79, 6-10.(in Japanese)

Daishi, M., Hayashi, M. and Ishibashi, K. (1981) So-called "Setouchi volcanic rock kind" Ooita Prefecture distribute. *Abstracts of 1981 Joint Annual Meeting of Soc. Res. Geol. Japan. Japan Assoc. Min. Petr. Econ. Geol. and Mineral. Soc. Japan*, 100. (in Japanese)

Daishi, M., Inoue, M. and Furuyama, K. (2003) Radiometric Ages of Late Cenozoic Volcanic Rocks and Implications for Volcanic Activity in Western Area of Oita, Kyushu, Japan. *Jour. Geosciences, Osaka City Univ.* 46, Art. 3, 25-45.

Hase, Y., Iwauchi, A., Danhara, T. and Yamashita, T. (1993) Fission track ages of volcanic rocks and refractive index of volcanic glass in non-welded pyroclastic flow deposits of Late Cenozoic Era in central Kyushu, Japan, *Memoirs of the Faculty of General Education Kumamoto University, Natural Sciences*, 28, 71-83. (in Japanese with English abstract)

Hayashi, M., Taguchi, S. and Matsumoto, Y. (1982) The radiometric age of the volcanic rocks, distributed in central part Kyushu. The basement and collapse structure of synthetic research Kyushu, 1, 31-34. (in Japanese)

Hayashi, M. and Watanabe, K. (1987) Radiometric ages for Neogene and Quaternary igneous rocks in Kyushu. *Assoc. Geol. Coll. Japan, Monograph* 33, 295-311. (in Japanese with English abstract)

Ishii K., Tanida K. and Aoki K. (1956) Concerning the Yabake welded tuff (forecast). *Jour. Japan Assoc. Min. Petro.Econ. Geol.*, 40, 131-136. (in Japanese with English abstract)

Iso, N. and Ikeda, Y. (1979) A Fission Track Age of Haneyama Lavas near Mt. Haneyama, Central Kyushu, Japan. *Quaternary Res.*, 18, 165-168. (in Japanese with English abstract)

Iwauchi, A. and Hase, Y. (1989) Late Cenozoic vegetation and paleoenvironment of northern and central Kyushu, Japan - Part 4 Oyama - Tsuetate area (Lower Pleistocene) -. *Jour. Geol. Soc. Japan*, 95, 63-75. (in Japanese with English abstract)

Kamata, H. (1985a) Stratigraphy and eruption age of the volcanic rocks in the west of Miyanohara area, Kumamoto Prefecture - Age and distribution of the volcanic activity of central-north Kyushu, Japan. *Jour. Geol. Soc. Japan*, 91, 289-303. (in Japanese with English abstract)

Kamata, H. (1985b) The change of the volcanic activity and geology structure in the middle northern part of Kyushu. *Rept. Geol. Surv. Japan*, 264, 33-64. (in Japanese)

Kamata, H. (1986) Time change of the quantity of the volcanic rock ejection and chemical composition in the geothermal filed in the central Kyushu, Showa 59.60th , The Sun Shine Project research-and-development result interim report, Research about country geothermal resources evaluation technology, *Geol. Surv. Japan*, 113-124. (in Japanese)

Kamata, H. (1989) Shishimuta caldera, the buried source of the Yabakei pyroclastic flow in the Hohi volcanic zone, Japan. *Bull. Volcanol.*, 51, 41-50.

Kamata, H. (1997) Geology of the Miyahara district. With Geologiacl Sheet Map at 1:50,000, *Geol. Surv. Japan*, 1-127. (in Japanese with English abstract)

Kamata, H. and Muraoka, H. (1982) K-Ar ages of the volcanic rocks in the central part of Oita Prefecture, southwestern Japan. *Bull. Geol. Surv. Japan*, 33, 561-567. (in Japanese with English abstract)

Kido, M. (1981) Geology and geological structure of Tsue mountain, Central Kyushu. *Earth Science*, 35, 115-134. (in Japanese with English abstract)

Kido, M. and Hikosan Collaborative Reserch Group (1987) Tectonic movement and volcanism of Miocene and Pliocene ages in the Hiokosan and Tsue areas, Northern and Central Kyushu, Japan. *Assoc. Geol. Coll. Japan, Monograph* 33, 107-126. (in Japanese with English abstract)

Matsumoto, Y. (1979) Some Problems on Volcanic Activities and Depression Structures in Kyushu, Japan. *Assoc. Geol. Coll. Japan, Monograph* 16, 127-139. (in Japanese)

Matsumoto, Y., Nishimura, S. and Tajima, T. (1977) Fission-track ages of some igneous rocks in Kyushu. *Bull. Fac. Lib. Arts, Nagasaki Univ. Nat. Sci.*, 17, 63-75. (in Japanese with English abstract)

Ministry of International Trade and Industry (1979) Large-scale deep geothermal power station place environmental preservation proof investigation (Hohi Area) in the Showa 53th. *Electric Power Dev.*, 1-118. (in Japanese)

Ministry of International Trade and Industry (1980) Large-scale deep geothermal power station place environmental preservation actual proof investigation (Hohi Area) in the Showa 54th. *Electric Power Dev.*, 1-62. (in Japanese)

Ministry of International Trade and Industry (1981) Large-scale deep geothermal power station place environmental preservation actual proof inspection slip (Hohi Area) in the Showa 55th (late term) exploration well logging (DY-1 pit), *Electric Power Dev.*, 1-131. (in Japanese)

Ministry of International Trade and Industry (1984) The large-scale depths geothermal power plant environmental-preservation actual proof investigation report document (Hohi area) geology structure in the Showa 58th and volcanic rock heat source investigation. *Electric Power Dev.*, 1-191. (in Japanese)

NEDO (1990) Heisei 1st whole country subterranean heat resources synthetic investigation (the 3rd) wide area heat water flowing investigation, volcanic heat water convection area type 3, Tsurumidake area volcanic geology map (1:50,000) and Tsurumidake area subterranean heat geology compilation map (1:100,000) and report. 1-88. (in Japanese)

Oita Prefecture (1972) Geologic Map of Oita (1:200,000). (in Japanese)

Sudo, S. (1985a) The K-Ar age and paleomagnetism of the volcanic rock from Hohi geothermal area. *Bull. Geol. Surv. Japan*, 36, 119-136. (in Japanese with English abstract)

Sudo, S. (1985b) The K-Ar age and paleomagnetism of the volcanic rock from Hohi geothermal area (Part 2). *Rept. Geol. Surv. Japan*, 264, 87-112. (in Japanese)

Tamanyu, S. and Kasuya, M. (1983) Fission-track ages of the boring core from Hohi geothermal field. *Bull. Geol. Surv. Japan*, 34, 455-469. (in Japanese with English abstract)

Uemura, F. (1985) The stratigraphy and K-Ar ages of the Nakatsue group, distributed in the west shore of Shimouke lake, Kumamoto Prefecture. *Rept. Geol. Surv. Japan*, 264, 143-150. (in Japanese)

Uto, K. and Sudo, S. (1985) K-Ar ages of the volcanic rocks from Hohi geothremal area. *Rept. Geol. Surv. Japan*, 264, 165-183. (in Japanese)

Watanabe, K. and Hayashi, M. (1983) Fission track ages of the Hyugami Lava from central Kyushu. *Jour. Japan Assoc. Min. Petr. Econ. Geol.*, 78, 65-69. (in Japanese with English abstract)

Watanabe, K., Hayashi, M., Fujii, M. and Kido, M. (1987) Fission track ages of Neogene volcanic rocks from Tsue region, Central Kyushu, Japan. *Assoc. Geol. Coll. Japan, Monograph* 33, 137-148. (in Japanese with English abstract)

*Manuscript received September 8, 2005.*
*Revised manuscript accepted December 26, 2005.*

**Plate 1**

Yamakogawa Rhyolite
Flow texture of pyroclastic flow deposit at Gesu

**Plate 2**

Yamakogawa Rhyolite
non-welded pyroclastic flow deposit is covered by glassy welded pyroclastic flow deposit at Suzugadake


**Plate 3**

Boundary between the Yamakogawa Rhyolite and the Kan'non'iwa Andesite at Tamanoki

**Plate 4**

Laminated silt and tuff of the Tsuetate Formation at Mukaizuru

**Plate 5**

Kan'non'iwa Pyroclastic Flow deposit in the adit at Kan'non'iwa

**Plate 6**

A lava flow of the Kameishiyama - Yoshitakeyama Dacite at the north of the Kameishiyama sumit