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Newly Identified Oligocene Formation in the Sera Plateau, Hiroshima, SW Japan

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Abstract: This study aimed to show the presence of an Oligocene formation in the Sera Plateau, located in the eastern part of Hiroshima Prefecture, SW Japan, using field surveys, a petrological study, and fission-track dating. According to field surveys conducted between 1996 and 2002, and supplementally in 2017, rhyolitic pyroclastic rocks and conglomerate beds unconformably covered by the Quaternary sediments were identified along the bank of Mihara-gawa River at Kurohada in Sera Town. The rhyolitic pyroclastic rocks, tentatively called Kurohada Ryolite, were composed of welded tuff, coarse tuff, and tuff breccia, and were intercalated with conglomerate beds lithologically similar to the mountain gravels. The Kurohada Rhyolite and the conglomerate beds were either horizontal or dipped gently to the northwest, with a total thickness of about 5 m. Based on whole-rock chemical composition analysis by X-ray fluorescence (SiO_2: 72.39-75.82 wt %, K_2O+Na_2O: 5.78-7.80 wt %) the welded tuff was classified into rhyolite of sub-alkalic series. Under the microscope, the pyroclastic rocks were composed of crystal fragments of plagioclase and quartz, and lithic fragments in glassy matrix, and signs of thermal alteration could not be confirmed. On the other hand, one of the lithic fragments of rhyolite contained biotite fine crystals as thermal metamorphic products. Thus, the Kurohada Rhyolite was distinguished from the Mesozoic Takada Rhyolites distributed widely in Hiroshima Prefecture depending on the presence of thermal metamorphism. Fission track ages of zircons from the welded tuff were 30.4 ± 1.6 Ma and 30.9 ± 1.5 Ma. This result shows that the geologic age of Kurohada Rhyolite and associated conglomerate beds in the study area is constrained to the early Oligocene and suggests the possibility that the mountain gravels distributed in the eastern part of Hiroshima Prefecture are Paleogenic.

Key words: Oligocene formation, fission-track dating, mountain gravels, Sera Plateau, Hiroshima Prefecture

1. Introduction

The transition between the Paleogene and Neogene is a very dynamic period in the geological history of the Japanese Islands, during which time the region changed from a continental arc to an island arc. To assemble a picture of this transitional period, it is necessary to know the geological features of the Paleogene and Neogene formations in and around the Japanese Islands. Some papers have reviewed the stratigraphic and sedimentary features of Neogene formations distributed in the area of the Chugoku District (Takayasu et al., 1992; Seto et al., 2000).

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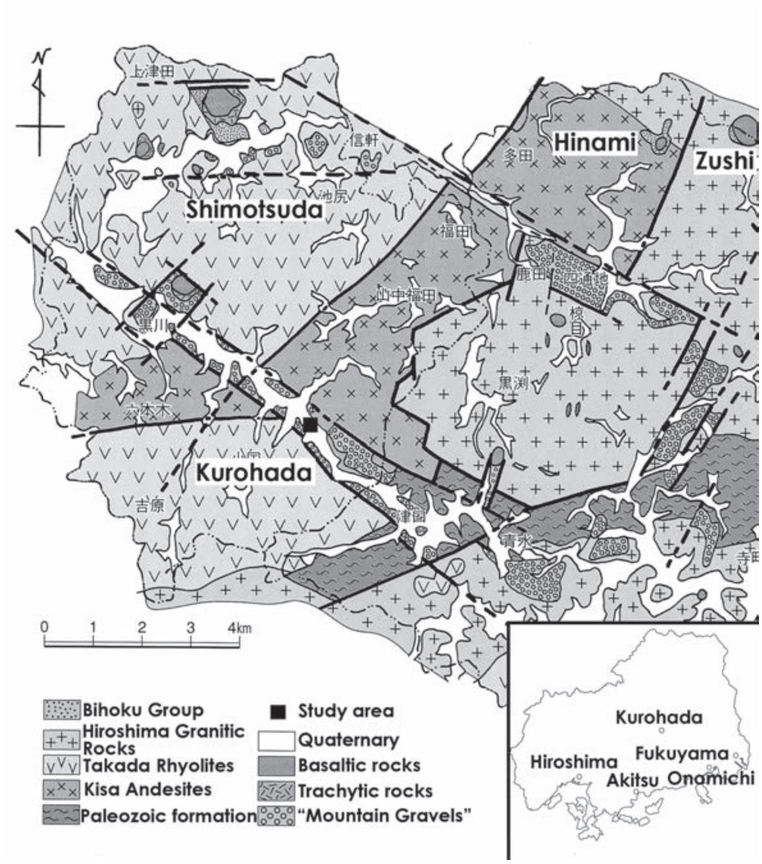

Fig. 1. Geological map of the western part of Sera Town (modified from Suga and Yoshimura, 2001), showing the location of study area.

In recent years, the geologic age of the formations has been reexamined (e.g. Matsubara, 2009). Previously, most of the Paleogene volcanics and sedimentary rocks in the Hiroshima Prefecture have been recognized as belonging to the formations of the Paleocene Sakugi cauldron defined by Murakami and Komuro (1993). Recently, however, reexaminations of the geologic chronology have shown that Paleogene formations are associated with the southeastern part of the Hiroshima Prefecture. A fission-track age of zircons from the tuff intercalated with clastic rocks, previously referred to Miocene in Akitsu, have shown that the formation was in fact early to Middle Paleogene (Matsuura, 2001). "Mountain gravels" of unknown geologic age distributed in Onomichi and Fukuyama were estimated to be Eocene to Oligocene, respectively, based on fission-track ages and the lithologically similar characteristics of coarse clastic sediments (Matsuura et al., 2002).

This study aimed to show the presence of Oligocene formation from the Sera Plateau, in the eastern part of Hiroshima Prefecture, SW Japan, by means of field surveys, a petrological study, and fission-track dating. The field survey was mostly conducted between 1996 and 2002, and supplementally in 2017.

2. Geologic setting

The Neogene marine sediments, volcanic rocks, and mountain gravels sporadically cover the pre-Cenozoic basement with an unconformable relationship in Sera Town, which occupies a major part of the Sera Plateau (Fig. 1). The basement rock consists of Paleozoic formations, which belong to a Jurassic accretionary complex (Yamada et al., 1985; Suzuki, 2001a), and Mesozoic igneous rocks, which are divided into the Kisa Andesites, Takada Rhyolites, and Hiroshima Granitic Rocks (Yamada et al., 1985; Hayashi, 2001). The Kisa Andesites, which are composed of andesite and dacite lavas and pyroclastics ranging from andesite to dacite in composition, are thermally altered as a whole. The Takada Ryolites are mostly made up of rhyolitic welded tuffs with a glassy matrix, and contain volcanic breccia in some locations. The glassy matrix has some thermal metamorphic products such as fine crystals of biotite. The Hiroshima Granitic Rocks are composed chiefly of medium-grained granite and are accompanied by granodiorite.

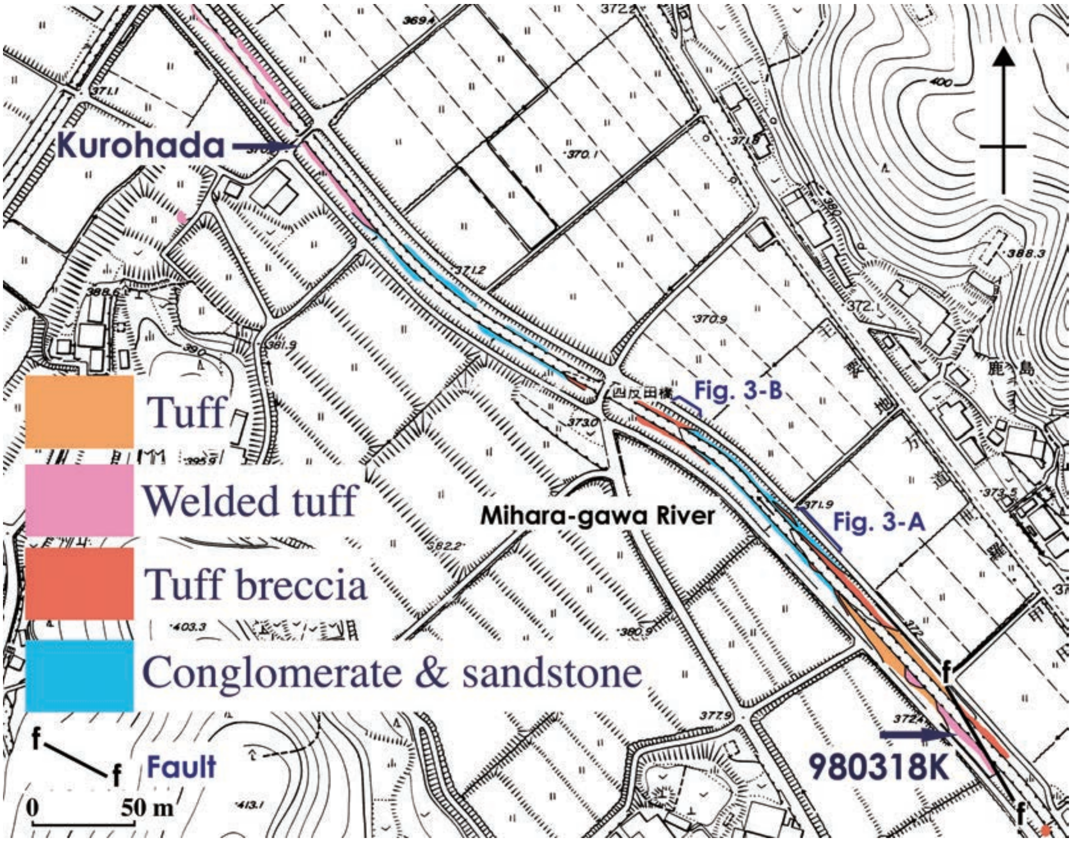

Fig. 2. Rout map of the Kurohada section along the river bank of Mihara-gawa River showing the sample localities for fission-track dating (980318K, Kurohada) and the locations of Figs. 3-A and B.

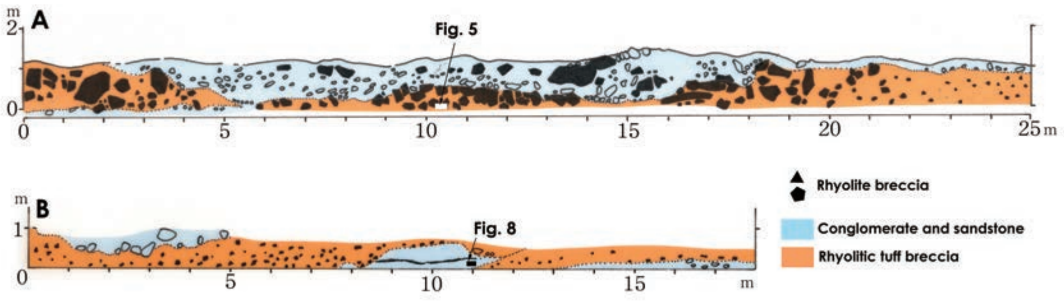

Fig. 3. Outcrop sketches showing the stratigraphic relations between the tuff breccia of Kurohada Rhyolite and the conglomerate and sandstone of conglomerate beds and the locations of Figs. 5 and 8. A: Conglomerate beds with intercalations of rhyolitic tuff breccia contain large rhyolite breccia. B: A rhyolitic tuff breccia with intercalation of conglomerate and stratified sandstone.

The Neogene marine sediments have limited distributions in Shimotsuda, Hinami, and Zushi in Sera Town. On the basis of similar lithological characteristics and the occurrence of *Crassostrea* sp., which were frequently found in the Bihoku Group, and *Operculina* sp., a Miocene index fossil, these sediments are closely correlated with the Miocene Bihoku Group, distributed widely in the area adjacent to the north of Sera Town (Suga and Yoshimura, 2001).

The so-called "Mountain Gravels" in Sera Town are fully weathered, and consist mostly of ill-sorted conglomerates (Suga and Yoshimura, 2001). They are predominantly composed of boulder gravels that are rounded to sub-angular in shape, often associated with boulders of diameters over 1 m, and intercalated with relatively thin sandstone beds. The "Mountain Gravels" have weakly stratified units up to 2 m thick and lithofacies that change laterally. The "Mountain Gravels" unconformably cover the Paleozoic formations and the Mesozoic rocks, and are intruded by the Late Miocene basaltic rocks (mentioned later). However, the stratigraphic relation between the "Mountain Gravels" and the Neogene marine sediments is unknown. These data suggest that the geologic age of the "Mountain Gravels" is roughly confined to between the Paleogene and Middle Miocene.

The Neogene volcanic rocks are divided into trachytic rocks and basaltic rocks (Uto, 1989; Harada, 1998; Suzuki, 2001b). The trachytic rocks consist of trachyte and trachyandesite. Their distributional areas are limited to Mts. Tsudamyojin, Inari, and Kurokawamyojin in the western part of Sera Town. These rocks unconformably overlie the Neogene marine sediments. Based on the stratigraphic relation and a K-Ar dating result (12.8 ± 0.5 Ma), the trachytic rocks erupted in the late Middle Miocene (Suzuki, 2001b). The basaltic rocks are made up of basaltic trachyandesite, trachybasalt, and alkali basalt, and are scattered across the town over a small area. The period of volcanic activity associated with the basaltic rocks is estimated to occur in the Late Miocene, based on K-Ar dating data (12-8 Ma) (Uto, 1989; Suzuki, 2001b).

3. The Kurohada section

The Kurohada section is a 500-m zone along the bank of Mihara-gawa River, running from southeast to northwest at Kurohada (Fig. 1). In this section (Fig. 2), pyroclastic rocks tentatively called the Kurohada Rhyolite (Harada, 1998; Suzuki, 2001b) show intercalation of conglomerate beds at the middle and upper horizons (Fig. 3). They are either horizontal or dip gently to the north, and are unconformably overlain by unconsolidated horizontal Quaternary terrace deposits (Yamasaki et al., 2000). The lower limit of these beds is unknown at the section, but the total thickness is estimated to be at least 5 m (Fig. 4).

The Kurohada Rhyolite is composed of coarse tuff and tuff breccia accompanied partially with welded tuff (Fig. 4). The coarse tuff is greyish white in color and displays thin stratification. It contains plant fragments at several horizons. The tuff breccia consists of angular fragments of rhyolite which vary in size from large boulders to granules. It shows a lithology that is somewhat similar to autobrecciated lava or hyaloclastite (Fig. 5). The welded tuff predominantly consists of coarse tuff with lithic fragments. Under the microscope, it contains crystal fragments of plagioclase and quartz, and lithic fragments in glassy matrix, in which signs of thermal alteration cannot be confirmed. On the other hand, one of lithic fragments of rhyolite contains biotite fine crystals as thermal metamorphic products (Fig. 6). The whole-rock chemical composition was analyzed by X-ray fluorescence and shows SiO_2 and K_2O+Na_2O contents of 72.39-75.82 (wt%) and 5.78-7.80 (wt%), respectively (Harada, 1998). The welded tuff was classified into rhyolite of sub-alkali series (Fig. 7).

The conglomerate beds consist of sandstone showing cross-stratification and graded bedding, and clast-supported conglomerate containing well-rounded gravels ranging in size from boulders to cobbles (Fig. 8). Most gravels are not weathered but some large boulders are unusually weathered.

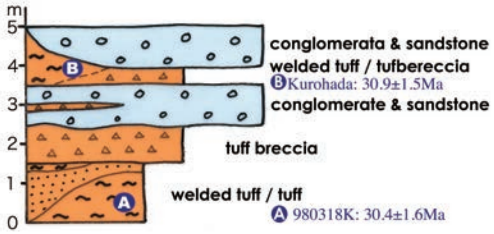

Fig. 4. Columnar section measured along the Kurohada section showing the stratigraphy and the lithology of Kurohada Rhyolite and intercalated conglomerate beds. A and B indicate the horizons of welded tuff for fission-track dating.

Fig. 5. Close-up photograph of tuff breccia of the Kurohada Rhyolite showing a lithology that is somewhat similar to autobrecciated lava or hyaloclastite. The ballpoint pen for scale is 0.15 m long.

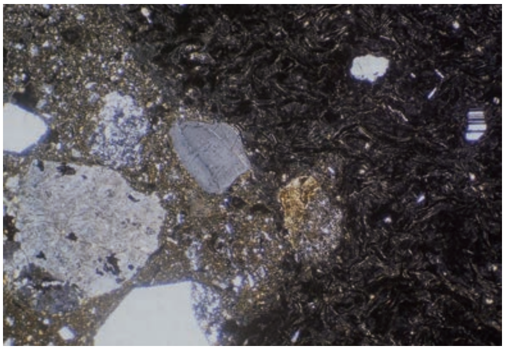

Fig. 6. Photomicrograph of the Kurohada Rhyolite showing biotite fine crystals in a lithic fragment as thermal metamorphic products (modified from Suzuki, 2001b). The photo is 3 mm wide.

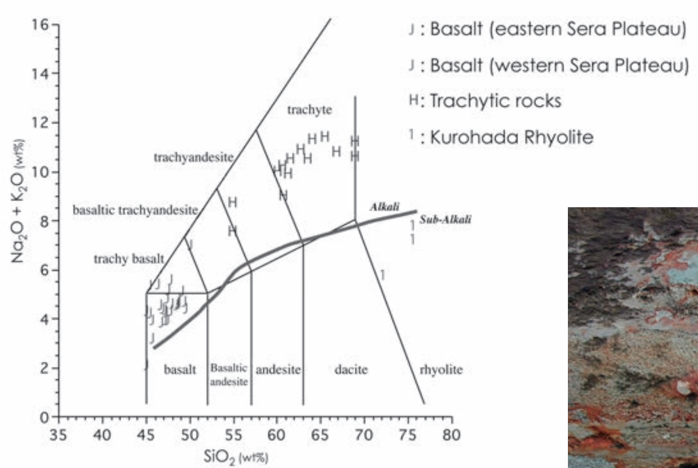

Fig. 7. $Na_2O + K_2O$ - SiO_2 diagram for volcanic rocks from the Sera Plateau (modified from Harada, 1998).

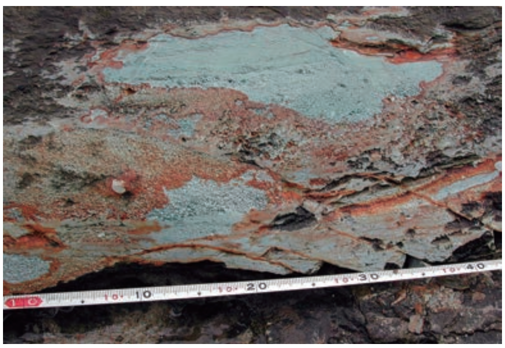

Fig. 8. Close-up photograph of intercalating sandstones in the conglomerate beds showing sedimentary structures such as graded bedding and cross bedding.

Table1. Zircon fission-track data of 980318K and Kurohada from Kurohada rhyolitic rock.

Sample	No. of crystals	Spontaneous $\rho s[cm^{-2}]$	(Ns)	Induced $\rho i[cm^{-2}]$	(Ni)	$P(\chi^2)$ [%]	Dosimeter $\rho d[cm^{-2}]$	(Nd)	r	U content [ppm]	Age($\pm 1\sigma$) [Ma]
980318K	30	1.48×10^6	(966)	1.45×10^6	(950)	77	8.06×10^4	(2476)	0.832	140	30.4±1.6
Kurohada	30	1.43×10^6	(946)	1.59×10^6	(1054)	26	10.38×10^4	(2656)	0.578	150	30.9±1.5

ρ and N are the density and the total number of fission tracks counted, respectively. Analyses were made by the external detector method using geometery factors of 1 for 2π/2π(ED2). Age was calculated using a dosimeter glass SRM612 and age calibration factor ζ(ED2)=372±5(Danhara et al., 1991) for Sample 980318K and ζ(ED2)=332±3(Danhara et al., 2001) for Sample Kurohada. P(χ2) is the probability of obtaining the χ2 -value for v degrees of freedom(where v= number of crystals-1). r is the correlation coefficient between ρs and ρi. Samples 980318K and Kurohada were irradiated using TRIGA MARK II nuclear reactor of St. Paul's University (Rikkyo Daigaku), Japan and JRR4 nuclear reactor of Japan Atomic Energy Research Institute, respectively.

4. Fission-track dating

Two samples (980318K, Kurohada) of rhyolitic welded tuff were collected from the Kurohada Rhyolite in the Kurohada section for fission-track dating (Figs. 2 and 4). Zircon fission-track dating was carried out by the Kyoto Fission Track Co., Ltd. The analyses were conducted using the external detector method (ED2 method: Danhara et al., 1991). The zircon crystals of Sample 980318K and Sample Kurohada were irradiated using the TRIGA MARK II nuclear reactor at St. Paul's University (Rikkyo Daigaku), Japan, and the JRR4 nuclear reactor at the Japan Atomic Energy Research Institute, respectively. Ages were calculated using a dosimeter glass SRM612 and an age calibration factor ζ (ED2) of 372 ± 5 (Danhara et al., 1991) for Sample 980318K and of 332 ± 3 (Danhara et al., 2001) for Sample Kurohada.

Thirty randomly selected zircon grains from each sample were analyzed and these data passed a χ^2 test (Galbraith, 1981) (Table 1). The age of Sample 980318K was 30.4 ± 1.6 Ma and that of Sample Kurohada was 30.9 ± 1.5 Ma. Therefore the calculated ages from each sample are almost identical. It follows from the zircon fission-track dating result that the Kurohada Rhyolite is early Oligocene in age.

5. Oligocene volcanic activity and formations around the Sera Plateau

The Kurohada Rhyolite is the first Oligocene volcanic product found in the northern and eastern parts of Hiroshima Prefecture. Previously, two types of volcanic rocks had been identified around the study area, one being the Mesozoic volcanic rocks and the other belonging to the late Miocene period (Fig. 1). Though the newly identified Kurohada Rhyolite has some lithological features similar to those of the Mesozoic Takada Rhyolites, the Kurohada Rhyolite is distinguished from the Takada Rhyolites by the absence of thermal metamorphism. In addition, the calc-alkaline Kurohada Rhyolite is geochemically different from the alkaline Late Miocene volcanic rocks (Fig. 7). It also seems clear that the Kurohada Rhyolite is distinguished by the chronological data.

The thickness of the volcanic products is very low at the Kurohada section (only about 5 m), and most of the volcanic activity associated with the Kurohada Rhyolite eruption is presumed to have occurred outside the study area. Though the distribution area of the Kurohada Rhyolite is uncertain, the location of the Eocene-Oligocene magmatic front, graphically demonstrated by Imaoka et al. (2011), suggests that it is more likely that the main volcanic activity occurred to the north of the study area.

Based on the result of field observations of the stratigraphic relationship between the Kurohada Rhyolite and the conglomerate beds (Figs. 2 and 3), these formations are estimated to be contemporaneous and are likely to have piled up in very close contact with each other. Therefore, the conglomerate beds are estimated to be of Oligocene age. On the other hand, the "Mountain Gravels" are also distributed over a small area on the flatland at the skirt of the mountain around the Kurohada section (Fig. 1). The conglomerate beds and the "Mountain Gravels" are closely situated in the Kurohada area and their lithofacies are very similar. These observations suggest that the conglomerate beds of the Kurohada section are part of the "Mountain Gravels". As mentioned above, the geologic age of the "Mountain Gravels" is roughly confined between the Paleogene and Middle Miocene. This estimation of the stratigraphic relationship in the study area is consistent with the geologic age of these formations. However, they differ in appearance, which depends on the severity of weathering. While most of the "Mountain Gravels" exposed on the outcrop are intensely weathered by the surface process, the un-weathered part of the "Moutain Gravels" is exposed at the Kurohada section. This dependence of the appearance on the weathering level is also documented in the mountain gravels of the Kibi Group (Suzuki et al., 2003).

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