Lithostratigraphy of the Miocene Iwaine Formation in the Yatsuo area, central Japan

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Abstract

We examined the Miocene Iwaine Formation formed in the margin of the Eurasian continent during the Japan Sea opening, of the Yatsuo Group in the Yatsuo area located in Toyama Prefecture, central Japan, on the basis of lithology and stratigraphy. The Iwaine Formation is composed mainly of monomictic autobreccia, polymictic volcanic breccia, pumice tuff and coherent andesites, with clastic rocks whose clasts were derived from the Iwaine Formation, in stratigraphically ascending order. Lithostratigraphy of the Iwaine Formation in the Yatsuo area will be of great significance to reveal the characteristics of volcanism during the Japan Sea opening.

Key words: Miocene, Iwaine Formation, Japan Sea opening, Yatsuo Group, lithostratigraphy.

Introduction

The Japan Sea opening which is the formation of a back-arc basin in the margin of the Eurasian continent is the most significant event in the Neogene of Japan (e.g., Yoshida, 2009). Kano et al. (2007) suggested that the earliest stage of the Japan Sea opening had already initiated in latest Eocene. The Japan arc was then separated from the continent due to rapid spreading of the Japan Sea in 20–15 Ma (substage IA; Nakajima et al., 2015), and deposits during this stage are widely distributed in the Neogene strata (Fig. 1). Toyama Prefecture is

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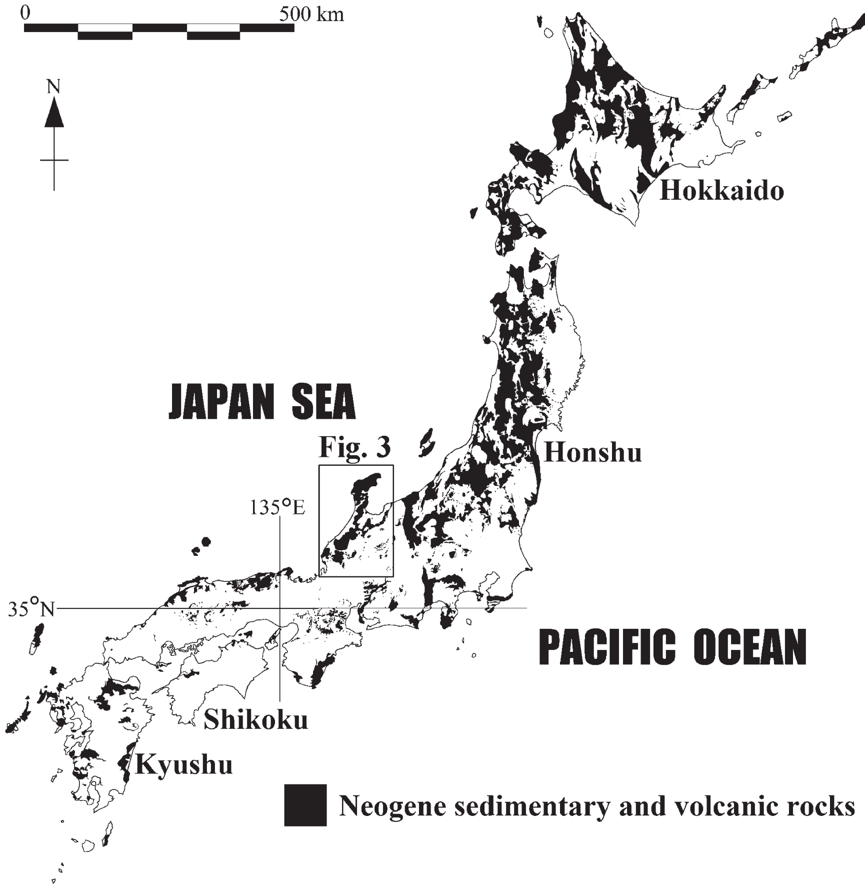


Fig. 1. Map showing the distribution of Neogene sedimentary and volcanic rocks in Japan. Modified from Seamless digital geological map of Japan 1: 200000, Geological Survey of Japan.

one of the most suitable places to study the Japan Sea opening, because the strata formed during this period are well preserved without large deformation.

In Toyama Prefecture, there are two successions that were formed during the Japan Sea opening: the upper Oligocene stratum (Tori Conglomerate and Usunaka Moonstone Rhyolite) and the lower to middle Miocene Yatsuo Group (Fig. 2). The Tori Conglomerate and the Usunaka Moonstone Rhyolite were formed in the early stage of the opening on the margin of the continent. Since sedimentary environment of the lower to middle Miocene Yatsuo Group changed gradually from non-marine or shallow marine to deep sea (Hayakawa and Takemura, 1987), it is expected to reflect the deepening of the Japan Sea.

The Iwaine Formation of the Yatsuo Group and equivalent beds, widely distributed in the Hokuriku Region, central Japan (Fig. 3), are composed mainly of andesites which erupted in the margin of the Eurasian continent in Early Miocene (Takahashi and Shuto, 1999). Petrological studies of the Iwaine Formation have been conducted by Ishiwatari and

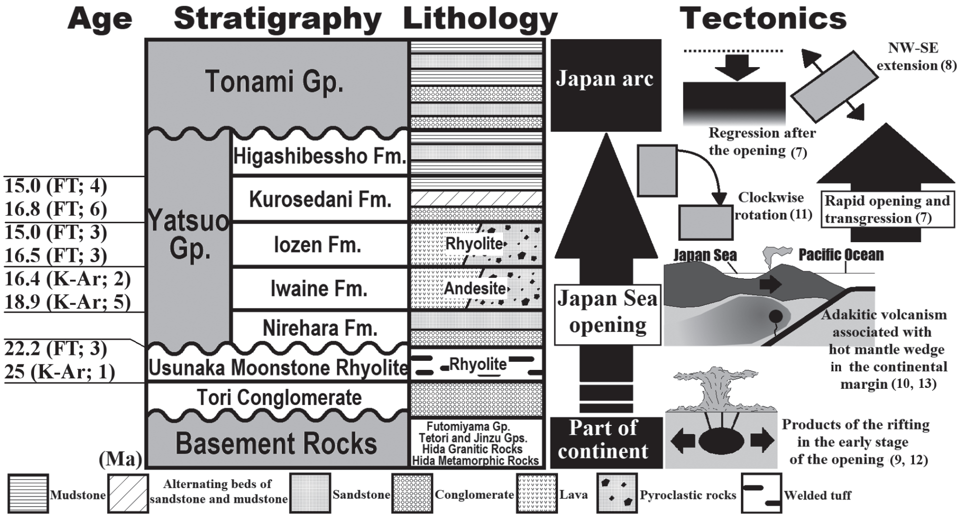


Fig. 2. Stratigraphy of strata associated with the Japan Sea opening in Toyama Prefecture (after Sudo (1979), and Hayakawa and Takemura (1987)). The youngest and oldest ages are showed as age data of each formation (1, Ueda and Aoki, 1970; 2, Shibata, 1973; 3, Ganzawa, 1983; 4, Nakajima and Mizushima, 1984; 5, Japan National Oil Corporation, 1985; 6, Hayakawa and Danhara, 1986). The tectonic interpretations associated with the Japan Sea opening are based on Hayakawa and Takemura (1987; 7), Fournier et al. (1994; 8), Ishida et al. (1998; 9), Takahashi and Shuto (1999; 10), Tamaki et al. (2006; 11), Ayalew and Ishiwatari (2011; 12), Sato et al. (2013; 13). K–Ar: K–Ar age. FT: zircon fission track age. Gp.: Group. Fm.: Formation.

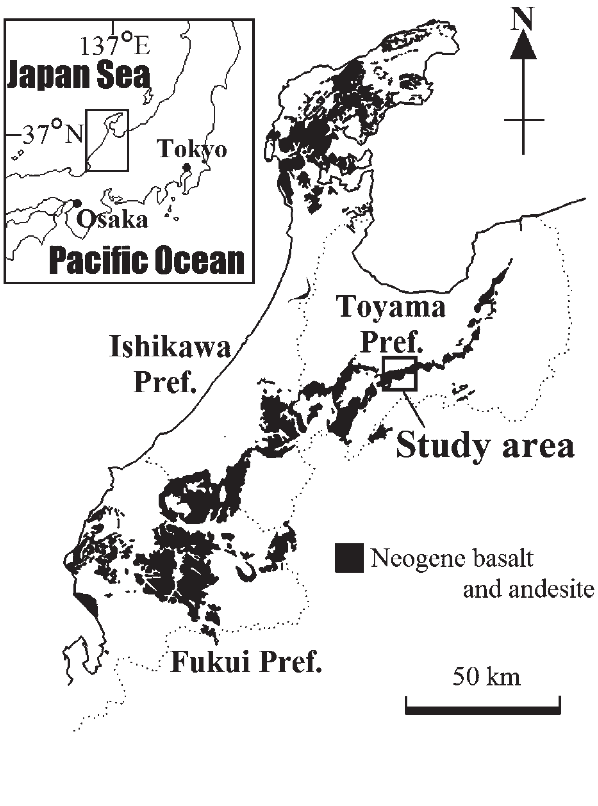


Fig. 3. Index map showing the distribution of Neogene basalts and andesites in Hokuriku Region (modified from Seamless digital geological map of Japan 1: 200,000, Geological Survey of Japan) and the study area. Pref.: Prefecture.

Ohama (1997), Takahashi and Shuto (1999), Tsuchihashi and Ishiwatari (2006), Ishiwatari et al. (2007), Sato et al. (2013), and Watanabe and Takahashi (2017). Most petrological studies concluded that the Iwaine Formation was formed by volcanic activities associated with hot mantle wedge in the margin of the Eurasian continent, in a subduction zone setting. However, this state differed from the present subduction and volcanic activities in the Japan arc. Although many researchers have referred to lithology and stratigraphy of the Iwaine Formation (e.g., Tsuda, 1953, 1955; Sakamoto and Nozawa, 1960; Hayakawa and Takemura, 1987), detailed studies on the lithostratigraphy of the Iwaine Formation are still not enough. Geology, including lithology and stratigraphy, should be as significant as petrology to reveal the characteristics of volcanism of the Iwaine Formation. Therefore, we examined lithology and stratigraphy of the Iwaine Formation in the Yatsuo area (Fig. 3), and accordingly we report the results of our field research and figure out some unsolved issues on stratigraphy of the Iwaine Formation.

Regional geology in the Yatsuo area

The stratigraphic division of the Neogene in the Yatsuo area was first founded by Makiyama (1930), and many other researchers have revised it (e.g., Imamura, 1936, 1937; Fujita and Nakagawa, 1948; Tsuda and Chiji, 1950; Tsuda, 1953; Nakaseko, 1953, 1954; Sakamoto et al., 1959; Sakamoto and Nozawa, 1960; Hayakawa and Takemura, 1987). Hayakawa and Takemura (1987) showed a stratigraphic division based on the correlation of key tuff beds and detailed columnar sections of the Miocene in the Yatsuo area. We think that their stratigraphic division is reasonable because they associated lithostratigraphy of Neogene strata in the Yatsuo area with the Japan Sea opening, and hence follow it in our study. However, type localities of some formations have already sunk into rivers due to construction of dams.

Mesozoic basement rocks are distributed in the southern part of the target area, and the Miocene Yatsuo Group overlies them (Fig. 4); the Miocene Yatsuo Group is composed of the Nirehara, Iwaine, Iozen, Kurosedani and Higashibessho formations, in stratigraphically ascending order (Fig. 5). The Yatsuo Group strikes ENE–WSW and dips 10–40° N (Fig. 4).

1. Basement rocks

The basement rocks of the Miocene in the Yatsuo area consist of the Hida Granitic Rocks (Kano, 1990), the Tetori and Jinzu groups (Matsukawa et al., 2014). The granite in this area is weathered and appears to be pale pink, consisting of potassium feldspar, plagioclase, quartz, biotite, and opaque minerals. The Tetori and Jinzu groups are in fault contact with the Hida Granitic Rocks (e.g., Sakamoto and Nozawa, 1960). The Tetori Group in the study area consists of upper Oxfordian marine sandstone and mudstone, whereas the Jinzu Group consists of Lower Cretaceous non-marine sandstone and mudstone (Matsukawa et al., 2014).

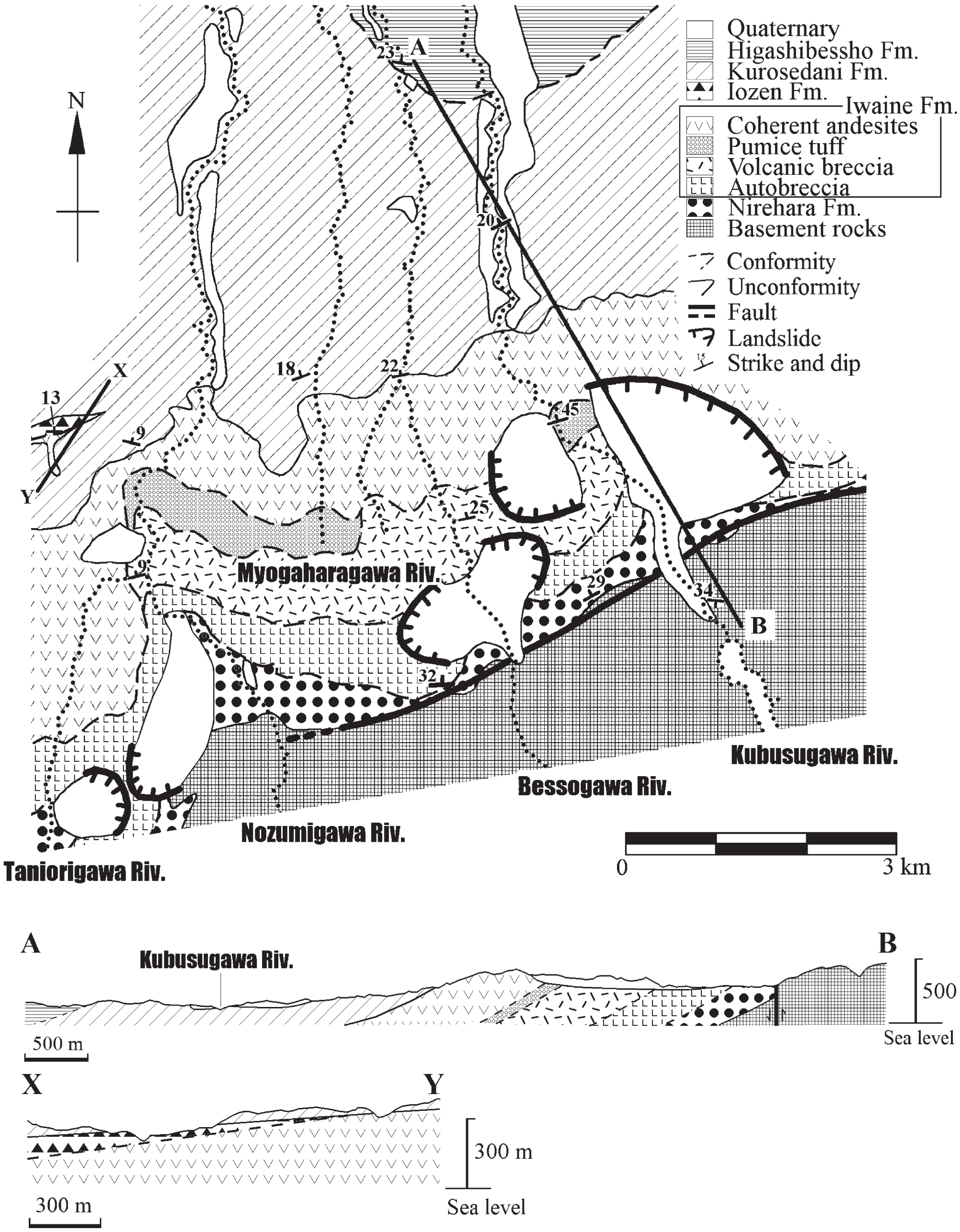


Fig. 4. Geological map and two cross sections of the Yatsuo area. Fm.: Formation.

2. Nirehara Formation

Name Named by Tsuda and Chiji (1950).

Type locality The bank of the Jinzugawa River in Nirehara, Toyama City, Toyama Prefecture (Hayakawa and Takemura, 1987).

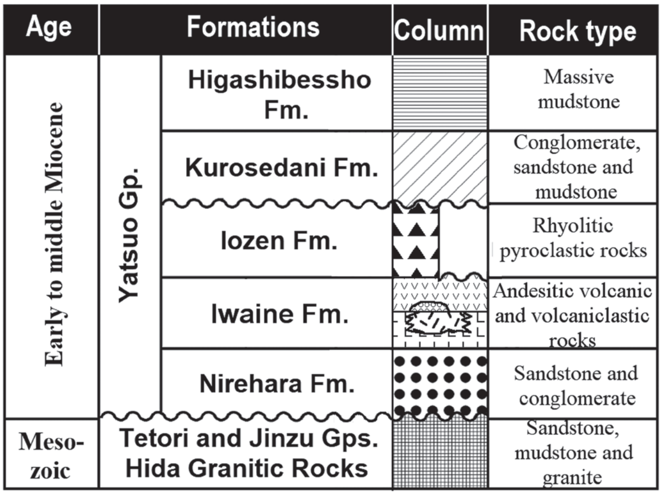


Fig. 5. Stratigraphy of the study area. The division of basement rocks is after Kano (1990) and Matsukawa et al. (2014). Gp.: Group. Fm.: Formation.

Distribution The Nirehara Formation is distributed narrowly between Taniori and Kiridani, southern part of the study area (Fig. 4).

Thickness 100–250 m.

Stratigraphic relationship The Nirehara Formation is in unconformable or fault contact with the basement rocks in the study area (Fig. 4).

Lithology The lower part of the Nirehara Formation is composed mainly of matrix-supported conglomerate containing rounded pebbles of granites and chert (approximately 10 cm in diameter). The conglomerate rarely shows imbricate structure and includes lenticular sandstone and mudstone. The upper part is composed of massive (rarely showing cross bedding) arkose sandstone and mudstone.

Fossil Tsuda (1953), Sakamoto and Nozawa (1960), and Hayakawa and Takemura (1987) reported unidentifiable fragments of plant fossils. Kashiwagi (2012) reported radiolarian fossils from chert gravels in the formation and concluded that the chert gravels were originated from the chert in the Tamba–Mino Belt or the chert gravels in the conglomerate beds of the Tetori Group.

3. Iwaine Formation

Name Named by Imamura (1937).

Type locality The bank of the Jinzu River in Iwaine, Toyama City, Toyama Prefecture (Hayakawa and Takemura, 1987).

Distribution The Iwaine Formation is distributed widely between Nunotani and Mt. Otakayama, the southern part of the study area (Fig. 4).

Thickness 600–1450 m.

Stratigraphic relationship The Iwaine Formation conformably covers the Nirehara Formation (Fig. 5).

Lithology The Iwaine Formation consists of coherent andesites, volcaniclastic and clastic rocks. Volcaniclastic and clastic rocks are predominant in the lower part of the formation, whereas coherent andesites are predominant in the upper part. Coherent andesites are generally massive but partly has joints. Thin beds of volcaniclastic or clastic rocks are intercalated often between coherent andesites. Volcaniclastic rocks in the Iwaine Formation are composed mainly of autobreccia, volcanic breccia and pumice tuff showing pale to dark green color.

Fossil Tsuda (1953) reported unidentifiable fragments of plant fossils. Sakamoto and Nozawa (1960) reported molluscan (e.g., *Soletollina* sp., *Calyptrea* sp. and *Nassarius* sp.) and plant (*Fagus antipofi*) fossils from mudstone in the formation. In this study, a gastropod molluscan shell of *Cerithideopsilla* sp. was found from siltstone in the upper part of the formation (Fig. 7).

Age K–Ar and FT (fission track) ages have been reported by Shibata (1973; K–Ar age; 13.6 ± 0.7, 15.9 ± 0.9, 16.0 ± 0.9 Ma), Japan National Oil Corporation (1985; K–Ar age; 15.8 ± 1.1, 18.9 ± 0.9 Ma), Kaneko (2001; K–Ar age; 16.3 ± 0.9, 16.5 ± 0.9 Ma), and Itoh and Watanabe (2006; FT age; 17.2 ± 0.9 Ma). Recently, Nakajima et al. (2015) reported the weighted average of ^{238}U–^{206}Pb ages of 17.6 ± 0.3 Ma from zircons in the welded tuff of the Iwaine Formation in the Kubusugawa basin.

4. Iozen Formation

Name Named by Fujita and Nakagawa (1948).

Type locality Mt. Iozen on the boundary between Nanto City, Toyama Prefecture and Kanazawa City, Ishikawa Prefecture (Hayakawa and Takemura, 1987).

Distribution The Iozen Formation is distributed narrowly around Yomedani, the westernmost part of the study area (Fig. 4).

Thickness Less than 50 m in this area.

Stratigraphic relationship The Iozen Formation conformably covers the Iwaine Formation (Fig. 5).

Lithology The Iozen Formation in the study area is composed of rhyolitic pumice tuff and lapilli tuff. The Iozen Formation can be distinguished from the Iwaine Formation by presence of rhyolitic rocks.

Age K–Ar and FT ages have been reported by Shibata (1973; K–Ar age; 14.1 ± 1.2 Ma), Ganzawa (1983; FT age; 15.0 ± 2.1, 16.5 ± 1.4 Ma) and Kaneko (2001; K–Ar age; 14.3 ± 0.3, 14.4 ± 0.3 Ma).

5. Kurosedani Formation

Name Named by Tsuda and Chiji (1950).

Type locality Area between Kakehata and Do, Toyama City, Toyama Prefecture (Hayakawa and Takemura, 1987).

Distribution The Kurosedani Formation is distributed widely between Do and Yomedani, the northern part of the study area (Fig. 4).

Thickness More than 900 m.

Stratigraphic relationship The Kurosedani Formation unconformably covers the Iozen and Iwaine formations (Fig. 5).

Lithology The lower part of the formation consists mainly of irregularly alternating beds of conglomerate, sandstone, and mudstone, whereas the upper part consists mainly of mudstone and alternating beds of sandstone and mudstone. Conglomerate contains rounded to sub-rounded pebbles of andesite. The lithofacies of the Kurosedani Formation changes gradually into the Higashibessho Formation.

Fossil The Kurosedani Formation is a Miocene fossiliferous formation in Japan. Various bivalve and gastropod fossils have been found including *Anadara kakehataensis, Cerithideopsilla* n. sp., *Vicarya yokoyamai*, and *Vicaryella ishiiana* var. (Tsuda, 1953, 1959). Tsuda (1953) also reported fossils of plants, Echinodermata, Crustacea, coral and shark teeth from the formation.

Age K–Ar and FT ages have been reported by Hayakawa (1983; FT age; 16.0 ± 2.4 Ma), Nakajima and Mizushima (1984; FT age; 15.0 ± 1.0 Ma), Hayakawa and Danhara (1986; FT age;16.8 ± 0.9 Ma), Kaneko (2001; K–Ar age;13.8 ± 0.4, 14.0 ± 0.4 Ma) from tuffs of the Kurosedani Formation. Yamada et al. (1998), Kaneko (2001), and Itoh and Watanabe (2006) reported 15.3–12.2 Ma of K–Ar and FT ages from volcanic rocks in the Fukuhira Formation, which is heterotopic with the Kurosedani Formation in the eastern part of Toyama Prefecture.

6. Higashibessho Formation

Name Named by Fujita and Nakagawa (1948).

Type locality Higashibessho, Tonami City, Toyama Prefecture (Hayakawa and Takemura, 1987).

Distribution The Higashibessho Formation is distributed around Kashio, the northern part of the study area (Fig. 4).

Thickness More than 500 m.

Stratigraphic relationship The Higashibessho Formation conformably covers the Kurosedani Formation in the study area (Fig. 5) and is unconformably covered by the Upper Miocene Otogawa Formation, the Tonami Group outside the study area (Hayakawa and Takemura, 1987).

Lithology The Higashibessho Formation is composed mainly of massive mudstone showing dark gray color. Thin conglomerate beds (2–10 cm thick) are intercalated in the formation and often include allochthonous bivalve and gastropod fossils.

Fossil The Higashibessho Formation abundantly yields fossils of mollusk, foraminifer, radiolarian and diatom (Hayakawa and Takemura, 1987).

Lithostratigraphy of the Iwaine Formation

We obtained columnar sections along fifteen routes in the Iwaine Formation (Fig. 6). We classify volcaniclastic rocks after the definition of Fisher (1961, 1966). Following the lithology and stratigraphy, the distribution of lithofacies can be classified into four parts (Fig. 7).

Monomictic variegated autobreccia (Fig. 8a), whose clasts are composed completely of amphibole-bearing andesite (Fig. 8b), without matrix occupies the lowest part of the Iwaine Formation (Fig. 7), and its maximum thickness reaches approximately 250 m. Coherent amphibole-bearing andesite sometimes occurs with the autobreccia.

Matrix supported volcanic breccia (Fig. 8c and d) composed of poorly sorted polymictic andesitic clasts overlie the autobreccia in many routes (Fig. 7). Generally, the volcanic breccia shows massive or reverse-grading structures (Fig. 8d). Its thickness indicates greatly lateral change. Clasts in the volcanic breccia consist of sub-angular to sub-rounded gravels (mainly 30–50 cm; maximum 100 cm in diameter) of various andesites. Conglomerate, sandstone and mudstone whose andesitic clasts derived from the Iwaine Formation overlie thickly the volcanic breccia in Routes 7 and 13 (Fig. 8e).

In some routes, poorly sorted massive pumice tuff (Fig. 8f) overlies the clastic rocks or the polymictic volcanic breccia (Fig. 7). The pumice tuff is composed of lithic clasts of andesites and pumice (approximately 5 cm in diameter), with tuffaceous matrix. The pumice

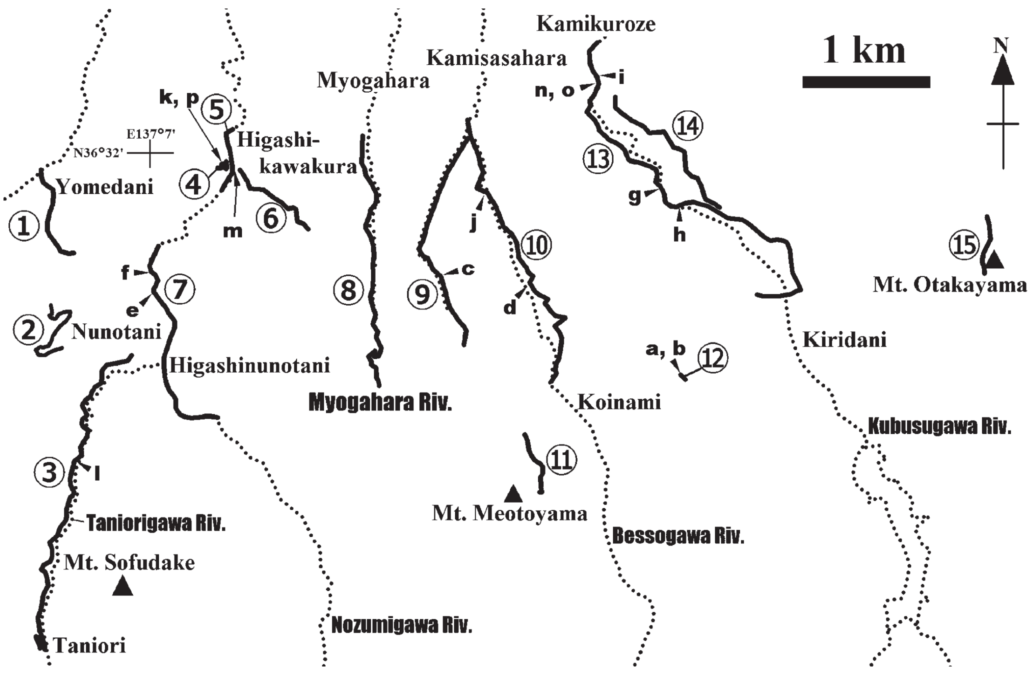


Fig. 6. Map showing place-names and routes along which columnar sections were obtained. Alphabets (a–p) with arrows indicate sampling points and locality of outcrops in Fig. 8. Riv.: River.

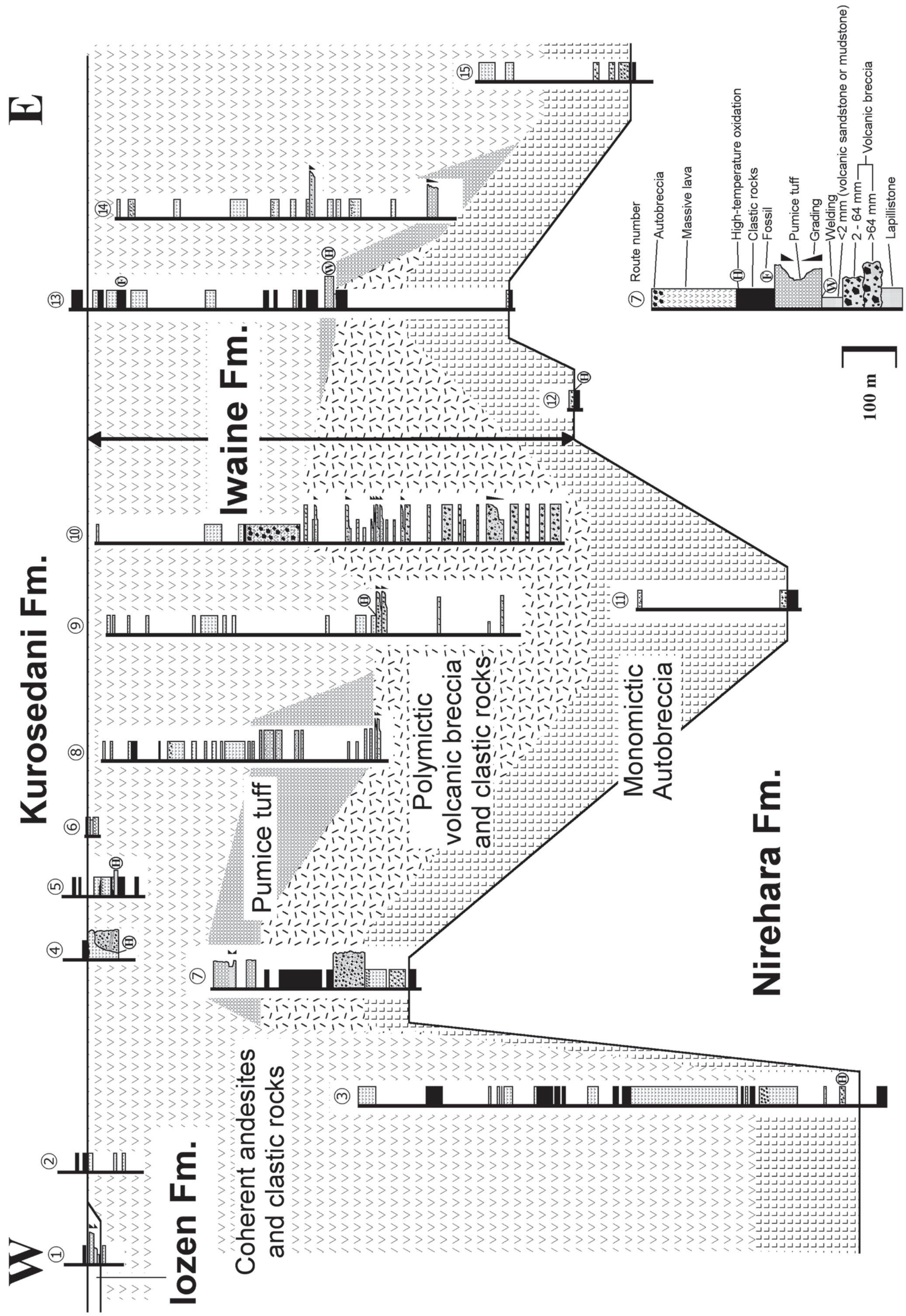


Fig. 7. Correlated columnar sections of the Iwaine Formation, the Yatsuo area and simplified distribution of rock types. Routes are shown in Fig. 6. Fm.: Formation.

tuff is partly welded in Route 13 (Fig. 8g and h). The content of lithic clasts and pumice changes with stratigraphic horizons and routes. In Route 8, the pumice tuff includes a lot of lithic clasts instead of pumice, while the pumice tuff in other routes includes much pumice rather than lithic clasts.

Coherent andesites (Fig. 8i–l) overlie thickly the pumice tuff or breccia (autobreccia and volcanic breccia) of the lower part. Pyroxene phenocrysts (two pyroxene, clinopyroxene or orthopyroxene; Fig. 8j) occur in coherent andesites of the upper part of the Iwaine Formation. Coherent andesites imply often columnar or platy joints (Fig. 8k). Coherent andesites change gradually to homogeneous autobreccia upward, which comprises reddish-brown colored angular blocks or vesicular scoriaceous clasts (Fig. 8l). Clastic rocks and polymictic volcanic breccia showing various lithofacies are intercalated usually between coherent andesites. A bed (10 m in thick) of very well sorted monomictic lapillistone occur in Route 5 (Fig. 8m). A gastropod molluscan shell of *Cerithideopsilla* sp. (Fig. 8n) was found from clastic rocks (Fig. 8o) of the uppermost Iwaine Formation, Route 13 in this study. The locality is probably the same as the locality where Sakamoto and Nozawa (1960) found some fossils including *Cerithidea miofluviatilis*. An outcrop, where a dike intrudes in volcanic breccia and partly shows red color, is exposed in Route 4 (Fig. 8p). The dike changes to effusive coherent andesite in the outcrop. Massive aphyric andesite is distributed successively in the top of the Iwaine Formation.

Implication

The Yatsuo Group is associated with the Japan Sea opening (Hayakawa and Takemura, 1987; Kaneko, 2001). Therefore, many experts have studied stratigraphy especially in the Yatsuo area, the central part of Toyama Prefecture, as already mentioned in the introduction. Following the stratigraphy in the Yatsuo area, some ones have studied in the eastern part (e.g., Nozawa and Sakamoto, 1960; Sumi and Nozawa, 1973; Kaneko, 2001) and the western part (e.g., Inoue et al., 1964; Sudo, 1979; Ganzawa, 1983) of Toyama Prefecture. Unfortunately, some formations which are not observed in the Yatsuo area occur in these areas (e.g., Fukuhira Formation in the eastern part; Tori Conglomerate and Usunaka Moonstone Rhyolite in the western part). In addition, the Neogene strata in some areas have been classified according to the division of the Hokuriku Group (Sakamoto et al., 1959), which had been widely accepted by geologists studying the Neogene in the Hokuriku Region until Hayakawa and Takemura (1987) proposed the division of the Yatsuo Group. As a result, the division and stratigraphy of the Yatsuo Group is waiting to be solved.

Sumi and Nozawa (1973) classified the Iwaine Formation in the Uozu area into three members. Although Kaneko (2001) correlated the Iwaine Formation in the Uozu area to the upper Iozen Formation, it includes both of andesites and rhyolites (Kaneko, 2001). Since the

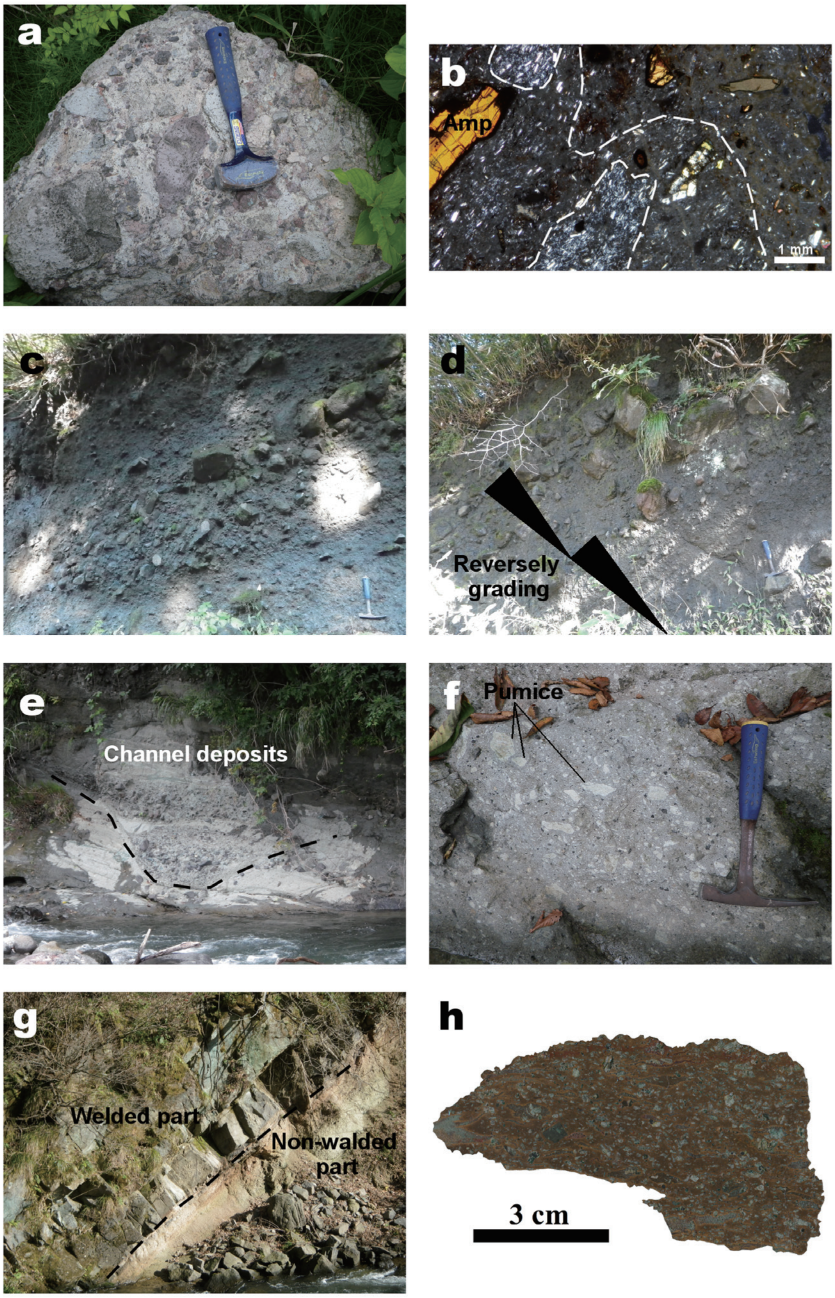
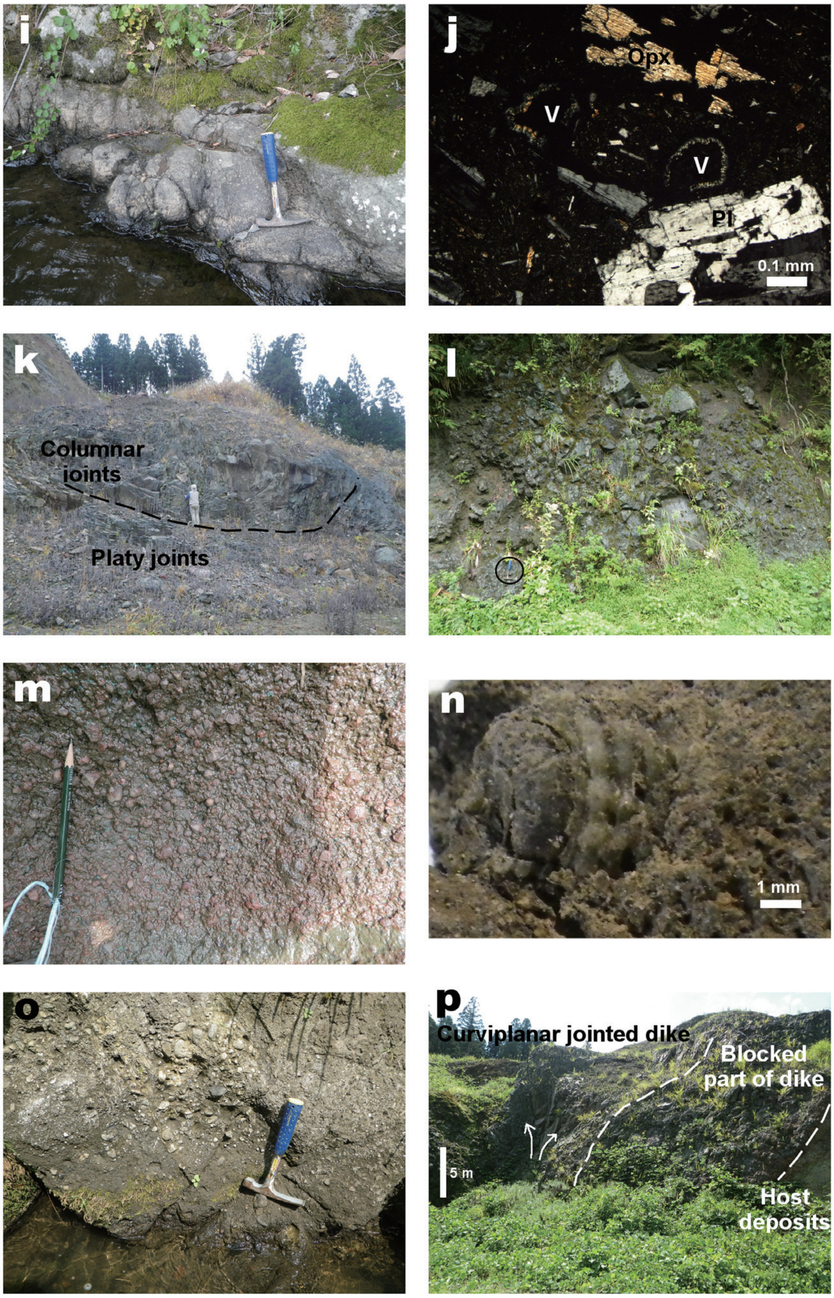


Fig. 8. Photographs of outcrops, a float, a hand specimen and thin sections (Pl: plagioclase, Opx: orthopyroxene, V: vesicle, Amp: amphibole). Localities of outcrops and sampling points are shown in Fig. 6. **a,** a float of monomictic autobreccia. **b,** a thin section of monomictic autobreccia. Broken lines indicate boundaries, which are unclear, of clasts. **c,** a cross section of polymictic volcanic breccia showing massive structure. Hammer for scale. **d,** a cross section of reverse-graded polymictic volcanic breccia. Hammer for scale. **e,** a cross section of clastic rocks whose all clasts are derived from the Iwaine Formation. **f,** a cross section of massive pumice tuff. **g,** a cross section of the contact between welded and non-welded parts of pumice tuff. **h,** a hand specimen of welded tuff. **i,** a cross section of massive coherent andesite. **j,** a thin



section of orthopyroxene-bearing andesite. **k,** a cross section of aphyric andesite showing columnar and platy joints. Parson for scale. **l,** a cross section of polymictic autobreccia consisting of andesitic coherent blocks. It would be clinker (flow breccia). Hammer (circle) for scale. **m,** a cross section of very well-sorted monomictic lapillistone. **n,** a photograph of a gastropod mollusk of *Cerithideopsilla* sp. obtained from clastic rocks (o), the uppermost Iwaine Formation. **o,** a cross section of fossiliferous clastic rocks, where a gastropod mollusk of *Cerithideopsilla* sp. was found (n). **p,** a cross section of a dike intruding host deposits (volcaniclastic rocks). The host deposits adjacent to the dike show red color by high-temperature oxidation.

Iwaine and Iozen formations comprise of andesites and rhyolites (e.g., Hayakawa and Takemura, 1987) respectively, it is difficult to judge which is correct. Nevertheless, Ganzawa (1983) and Takahashi and Shuto (1999) reported that amphibole-bearing andesites occur in the lowest part of the Iwaine Formation and that pyroxene-bearing andesites overlie them. The lithostratigraphy of the Iwaine Formation in the study area is consistent with their reports.

The stratigraphic division of volcanic rocks in the Yatsuo Group is very important to reveal the temporal change of characteristics of volcanism during the Japan Sea opening. Accordingly, lithostratigraphic evidence reported by this study will be significant to solve such issues. What we need to do is establishing formative history of the Iwaine Formation based on facies analysis, which is necessary to propose the stratigraphic division of this formation.

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*The title was translated by the authors.