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REVIEW

NEW VIEW OF THE STRATIGRAPHY OF THE TETORI GROUP IN CENTRAL JAPAN

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ABSTRACT

The stratigraphy of the Tetori Group (*sensu lato*) and other Early Cretaceous strata in the Hakusan Region in the Hida Belt, northern Central Japan, is reviewed based on recent advances in ammonoid biostratigraphy, U-Pb age determination of zircons using inductively coupled plasma-mass spectrometry with laser ablation sampling (LA-ICPMS), recognition of marine influence, and climatic change inferred from the occurrences of thermophilic plants and pedogenetic calcareous nodules. Four depositional stages (DS) are recognized: DS1 (Late Bathonian–Middle Oxfordian)—mainly marine strata characterized by the occurrences of ammonoids; DS2 (Berriasian–Late Hauterivian)—mainly brackish strata characterized by the occurrences of *Myrene* (*Mesocorbicula*) *tetoriensis* and *Tetoria yokoyamai*; DS3 (Barremian–Aptian)—fluvial strata characterized by the occurrence of abundant quartzose gravels and freshwater molluscs, such as *Trigonioides*, *Plicatounio* and *Nippononaia*; DS4 (Albian–Cenomanian)—volcanic/plutonic rocks which unconformably covered or intruded into the Tetori Group. I here propose new interpretation that 1) the Tetori Group (*s.l.*) in the Hakusan Region in the Hida Belt is divided into Middle–Late Jurassic Kuzuryu Group (corresponding to DS1) and unconformably overlying Early Cretaceous Tetori Group (*sensu stricto*) (corresponding to DS2–3); and 2) the Tetori Group (*s.l.*) in other areas is separated from the Tetori Group (*s.s.*), and divided into the Late Jurassic strata of the Kuzuryu Group (corresponding to the upper part of the same group in the Hakusan Region) and the Early Cretaceous Jinzu Group in the Jinzu Region in the Hida Belt, and the Late Jurassic–Early Cretaceous Managawa Group in the Hida Gaien Belt.

Key words：Tetori Group, Kuzuryu Group, Jurassic, Early Cretaceous, Hakusan Region, Central Japan

佐野晋一（2015）手取層群の新しい見方—時代論の見直しと再定義の提案—．福井県立恐竜博物館紀要 14：25–61.

白山区の飛騨帯上に分布する手取層群（広義）からの，アンモノイドの時代論，ジルコン粒子を用いたLA-ICPMS年代測定，軟体動物化石などによる海水の影響，好熱性植物と土壌性炭酸塩ノジュールの存在に基づく気候変動などの新知見をレビューした結果，本地域のジュラ～下部白亜系を４堆積ステージに区分する．すなわち，主に海成層からなるステージ１（後期バトニアン～中期オックスフォーディアン），主に汽水成層からなるステージ２（ベリアシアン～後期オーテリビアン），豊富な石英質砂岩礫と淡水棲二枚貝化石の産出で特徴づけられるステージ３（バレミアン～アプチアン），主に火成・深成岩からなるステージ４（アルビアン～セノマニアン）である．また，手取層群（広義）は地域によって層序や時代が異なっており，白山区の中部～上部ジュラ系九頭竜層群（堆積ステージ１相当）と下部白亜系手取層群（狭義）（堆積ステージ２と３相当），神通区の上部ジュラ系九頭竜層群と下部白亜系神通層群，飛騨外縁帯の上部ジュラ系～下部白亜系真名川層群に区分することを提案する．

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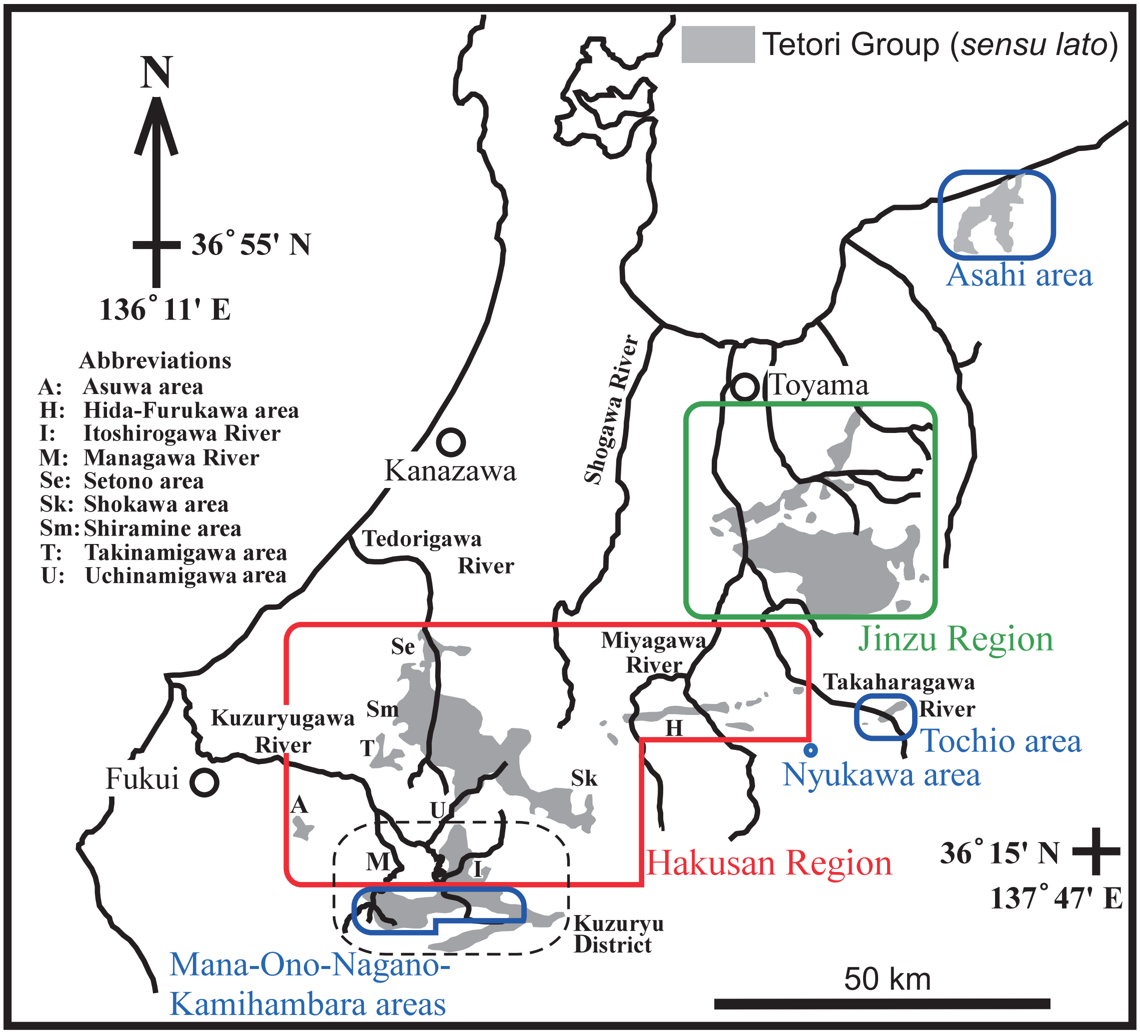

FIGURE 1. Index map showing the distribution of the Tetori Group (*sensu lato*) (modified from Maeda (1961d) and Fujita (2003)). As for subdivision of the Kuzuryu District, see Sano et al. (2013).

INTRODUCTION

The Middle Jurassic–Early Cretaceous Tetori (or Tedori) Group is thick marine to non-marine siliciclastic sequence, and is sporadically distributed in northern Central Japan (Maeda, 1961d; Yamada, 1988; Kusuhashi et al., 2002; Fujita, 2003; Matsukawa et al., 2006, 2014a; Takeuchi et al., 2015a, b) (Fig. 1). It is one of the most important targets to better understand Cretaceous tectonic events and the evolution of terrestrial ecosystem in East Asia (e.g., Manabe et al., 2000; Matsuoka et al., 2002; Hirano et al., 2003; Matsukawa et al., 2006). However, contrary to the Jurassic, generally marine, Kuzuryu Subgroup (lower part of the Tetori Group), the age and stratigraphy of the generally non-marine Itoshiro and Akaiwa subgroups (middle and upper part of the Tetori Group, respectively) are still debatable, because of the scarcity of good index fossils and volcanic rocks suitable to numerical age analysis, and also distinct lateral change of lithofacies (e.g., Yamada et al., 1989; Sano et al., 2008; Matsukawa et al., 2008a; Yamada and Uemura, 2008).

During the last three decades, marine strata have been recognized in the Itoshiro Subgroup, and some of them are tuned by the finding of age-diagnostic ammonoid specimens (Tamura, 1990; Fujita et al., 1998; Kumon and Umezawa, 2001; Sato et al., 2003, 2008; Sato and Yamada, 2005; Goto, 2007; Matsukawa et al., 2007; Yamada and Uemura, 2008; Matsukawa and Fukui, 2009; Matsukawa and Asahara, 2010; Kashiwagi, 2014; Kashiwagi et al., 2014). Recently, U-Pb age determination of zircons using inductively coupled plasma-mass spectrometry with laser ablation sampling (LA-ICPMS) is also applied to the Tetori Group (Kusuhashi et al., 2006; Kawagoe et al., 2012, 2014; Takeuchi et al., 2015a). These data strongly require the complete revision of the age and stratigraphy of the Tetori Group.

Furthermore, the discoveries of the lapilli tuff of 124.6 ± 2.3 Ma (late Barremian–early Aptian: ICS, 2015) LA-ICPMS U-Pb zircon age (Kawagoe et al., 2012), and a Tithonian ammonoid (Sano et al., 2013) from the putative Kuzuryu Subgroup in the Ono area of the southern Kuzuryu District suggested the difference of the age and stratigraphy between the Tetori Group in the Hida Belt (a continental block/fragment, which is mainly composed of Hida Metamorphic Rocks, Permian to Middle Triassic meta-granitoids, and Early Jurassic granitoids (e.g., Kunugiza et al., 2010)) and that in the Hida Gaien Belt (a narrow tectonized zone, which is composed of Middle to early Late Triassic shallow marine formations including their metamorphosed facies (Tsukada et al., 2004; Kawagoe et al., 2013)). Thus it is indicated that the stratigraphy of the Tetori Group in each belt should be discussed separately (Sano et al., 2013). In addition, there are recent proposals to distinguish the Cretaceous strata of the "Tetori Group" in the Jinzu Region and also some formations of the "Tetori Group" in the Asahi (or Tomari) area from the Tetori Group in the Hakusan Region (Matsukawa et al., 2014a; Takeuchi et al., 2015a).

In this paper, the age and correlation of the Tetori Group in all important distributional areas in the Hakusan Region in the Hida Belt are reviewed, mainly focusing on the recent findings of the age-diagnostic ammonoids, detrital zircon U-Pb dating and the presence or absence of marine and brackish molluscs. Historical review of the studies of the Tetori Group is beyond the scope of this paper. Other articles have already described this topic in detail (e.g., Maeda, 1961c, d; Matsuo and Omura, 1966; Kusuhashi et al., 2002; Fujita, 2003; Matsukawa et al., 2003a, 2006, 2014a; Takeuchi et al., 2015a). New view of the stratigraphy of the Tetori Group is proposed here to contribute to future studies of Cretaceous tectonic events and the evolution of terrestrial ecosystem in East Asia.

STUDY AREAS

The Tetori Group is distributed in two regions: the western Hakusan Region and the eastern Jinzu Region (Maeda, 1961a) (Fig. 1). Mainly discussed in this paper are the Tetori Group in the Itoshiro, Uchinamigawa, Shokawa, Hida-Furukawa, Setono, Shiramine and Takinamigawa areas in the Hakusan Region in the Hida Belt (Fig. 1). The Tetori Group in the Hida Gaien Belt, such as that in the Mana–Ono–Nagano–Kamihambara areas in the Kuzuryu District, is excluded here.

The name "Tetori Series" was proposed in Yokoyama (1894, p. 212) for all those strata containing Middle Jurassic plants, which are distributed only in the inner side of Japan, from the name of the valley of the "Tetori" river (= Tedorigawa River or Tedori River) in Kaga (former name of southern part of Ishikawa Prefecture), where these fossils were first discovered (Geyler, 1877; Yokoyama, 1889). Later, Oishi (1933a, b) re-defined the "Tetori Series" as the whole Late Jurassic strata with both marine and terrestrial environments, which are distributed in the Inner and Outer zones of Southwest Japan, and even in Northeast Japan (Oishi, 1933b, p. 693), and called the Late Jurassic (= Tetori Series) non-marine strata in Central Honshu Island (= Central Japan) as the Tetori Group. He also mentioned that the Tetori Series is "relatively typically" developed in the upper reaches of the Tedorigawa River (the area along the Ushikubigawa River and southern foot of Mt. Hakusan) in Ishikawa Prefecture, and its stratigraphy provides the standard for the comparison with those of the coeval strata in other areas (Oishi, 1933a, p. 619). It is reasonably considered that the "type locality/area" of the Tetori Group is probably located in the area along the Tedorigawa River, namely in the Shiramine area in this paper. In the case of three-fold division of the Tetori Group, i.e., the Kuzuryu, Itoshiro and Akaiwa subgroups, in ascending order (Maeda, 1961d; Yamada, 1988; Kusuhashi et al., 2002)*[1], type localities of the Kuzuryu and Itoshiro subgroups are located in the Itoshiro area, and that of the Akaiwa Subgroup is in the Shiramine area (Maeda, 1952a, 1961c, d).

METHODS

Stratigraphic interpretation and geological maps of the Tetori Group in each distributional area are considerably different among studies. Their detailed reviews are beyond the scope of this paper. Here, marine influence, bio- and magnetostratigraphy, and numerical age data are focused on, because they are important to discuss the age of the Tetori Group and the change of sedimentary environments in the Tetori Group. They are reported on the basis of the general idea of the stratigraphy in each area.

1 Marine influence

Presence or absence of marine and brackish molluscs in each area is used to recognize marine influence and correlation of strata among depositional areas. Occurrences of freshwater molluscs are also mentioned in some cases, to recognize the absence of marine influence.

2 Bio- and magnetostratigraphy

Stratigraphic ranges of ammonoids are mainly taken into consideration. Age assignment using the composition of radiolarian assemblage is also discussed. Charophyte biostratigraphy and magnetostratigraphy are referred to in the Takinamigawa and Shiramine areas, respectively. In some cases, biostratigraphic values of bivalves and ostracods are also mentioned.

3 Numerical age data

Only the LA-ICPMS U-Pb ages of zircons are used for the discussion. Fission Track (FT) dating method has been applied to

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*[1]
The Tetori Group consists of three subgroups and the latest Cretaceous Omichidani Formation according to Maeda (1961c, d). However, it has almost always been cited that Maeda (1961c, d) subdivided the Tetori Group into three subgroups. This is inconsistent with Maeda's original definition in terms of exclusion of the Omichidani Formation. In this paper, the Omichidani Formation is discussed separately from the Tetori Group following Yamada (1988) and Kusuhashi et al. (2002).

the studies of the Tetori Group (e.g., Gifu-ken Dinosaur Research Committee, 1993). However, recent zircon U-Pb dating of tuffaceous rocks in the Tetori Group revealed that zircon grains of Precambrian and Paleozoic age are very abundant in some samples (Kusuhashi et al., 2006; Kawagoe et al., 2012), and thus the reliability of the FT age data, which require a group of ages of many zircon grains, needs very careful review (e.g., Matsukawa et al., 2014a). Furthermore, FT age can be relatively easily affected by secondary heating (e.g., Seike et al., 2013). Since the reliability of the FT age data of the Tetori Group in most literature seems low, I do not use them here.

On the other hand, K-Ar age data of volcanic/plutonic rocks, which cover or intrude into the Tetori Group, are mentioned to define the upper limit of the age of the Tetori Group.

AGE AND STRATIGRAPHIC DISTRIBUTION OF MARINE/ BRACKISH HORIZONS OF THE TETORI GROUP

In this paper, the stratigraphic scheme is mainly based on Maeda (1961d) and Kusuhashi et al. (2002), because the occurrences of molluscs were mentioned in these papers in detail. In Figure 2, names of subgroups and formations are usually not mentioned to avoid confusion, because the names of formations and their inclusion to each subgroup are different among studies.

1 Kuzuryu District

The Kuzuryu District (or Kuzuryugawa area/Region) is one of the classic and important localities for discussion of the stratigraphy of the Tetori Group (e.g., Yokoyama, 1889, 1904; Oishi, 1933a; Maeda, 1961d; Yamada, 1988; Kusuhashi et al., 2002; Matsukawa et al., 2003c, 2006). The Tetori Group is widely distributed in this district. Recently, Sano et al. (2013) proposed the idea that the Tetori Group in this district can be divided into three parts (Northern, Middle and Southern rows), which are bounded by east-trending faults and contain different stratigraphy of the Jurassic to Cretaceous strata in each part. The Northern Row is located in the Hida Belt and other two rows in the Hida Gaien Belt. In this chapter, the Tetori Group in the Itoshiro and Uchinamigawa areas, which belong to the Northern Row of the Tetori Group in this district, is discussed.

It should be noted that, in case that the records in previous studies are referred to, not only the formation names but also the locality names in these studies must be reviewed. For example, Nagano, a classic Oxfordian ammonoid locality, is located in the Middle Row of the Tetori Group in this district, and is probably not assigned to the Yambarazaka Formation, contrary to the interpretations in previous studies (see Sato, 2008 and references therein) (Sano et al., 2013). Type locality of *Vaugonia* (*Vaugonia*) *fukuiensis* of Maeda (1962d) is Aradani, south of Kurotodo in the Middle Row, and should not be assigned to the Yambarazaka Formation, contrary to the original paper.

1) Itoshiro area (Fig. 2A)

Maeda (1952b, 1957) first established the stratigraphic framework of the Tetori Group in this area, and divided it into 11 formations: the Shimoyama, Oidani, Tochimochiyama, Kaizara, Yambarazaka, Yambara, Ashidani, Obuchi, Itsuki (or Izuki), Nochino and Chinaboradani formations, in ascending order. Among them, the Chinaboradani Formation is distributed only in a small area, near the boundary between the Northern and Middle rows of the Tetori Group (Sano et al., 2013), and is not discussed in this paper.

The Kuzuryu Subgroup consists of lower five formations, and is overlain by the Yambara Formation with the Umagatani Unconformity (Maeda, 1952b). The Itoshiro Subgroup is composed of Yambara to Itsuki formations, and the Akaiwa Subgroup consists of only the Nochino Formation.

Marine/brackish horizons—Marine molluscs, such as ammonoids, belemnites, and "inoceramid" and trigoniid bivalves, have been recovered from the Oidani, Tochimochiyama, Kaizara, Yambarazaka, and Yambara formations (e.g., Yokoyama, 1904; Kobayashi, 1947, 1956, 1957a; Maeda, 1952b, 1962d, 1963a; Sato, 1962; Matsukawa et al., 2003c, 2006; Sano et al., 2010, 2011; Handa et al., 2014; Goto and Handa, 2014). Hasegawa et al. (2010) confirmed the marine or brackish condition of the Kaizara Formation based on a geochemical study using the ratio of total sulfur (TS) to total organic carbon (TOC) of the sedimentary rocks. On the other hand, brackish molluscs, such as oysters and corbiculoids, are known from the Ashidani and Itsuki formations (Kobayashi and Suzuki, 1937; Maeda, 1952b; Matsukawa and Ido, 1993; Matsukawa et al., 2003c; Nishida et al., 2013). Freshwater molluscs were also recovered from the Itsuki Formation (Kobayashi and Suzuki, 1937; Maeda, 1957; Matsukawa and Ido, 1993; Matsukawa et al., 2003c), and possibly co-occur with brackish bivalves in some horizons of this formation (Kobayashi and Suzuki, 1937; Matsukawa et al., 2003c).

Biostratigraphic age data—Sato and Westermann (1991) established three ammonoid zones of the upper Bathonian to lower Callovian in the Kaizara Formation. Handa et al. (2014) confirmed this ammonoid zonation and discussed the Bathonian/ Callovian boundary in the Kaizara Formation. Sano and Kashiwagi (2014) and Kashiwagi and Hirasawa (2015: this issue) reported a radiolarian fauna from the Kaizara Formation and assigned its age to the late Bathonian–early Callovian.

Sato and Westermann (1991) established Oxfordian ammonoid zonation in the Yambarazaka Formation. This proposal is mainly based on the ammonoid records from Nagano. Sano et al. (2013) pointed out Nagano belongs to the Middle Row of the Tetori Group, and in fact the Yambarazaka Formation is not distributed there. However, some Oxfordian ammonoids were recovered from the exact Yambarazaka Formation, and the Oxfordian age assignment to the Yambarazaka Formation is probably still valid, though Oxfordian ammonoid zone in the Yambarazaka Formation is dubious (see the discussion in Sano et al. (2013)).

The occurrence of terrestrial palynomorphs, such as fern spores: *Appendicisporites*, *Cicatricosisporites*, *Cyathidites*, *Osmundacidites* and *Schizaeoisporites*, and a gymnosperm pollen:

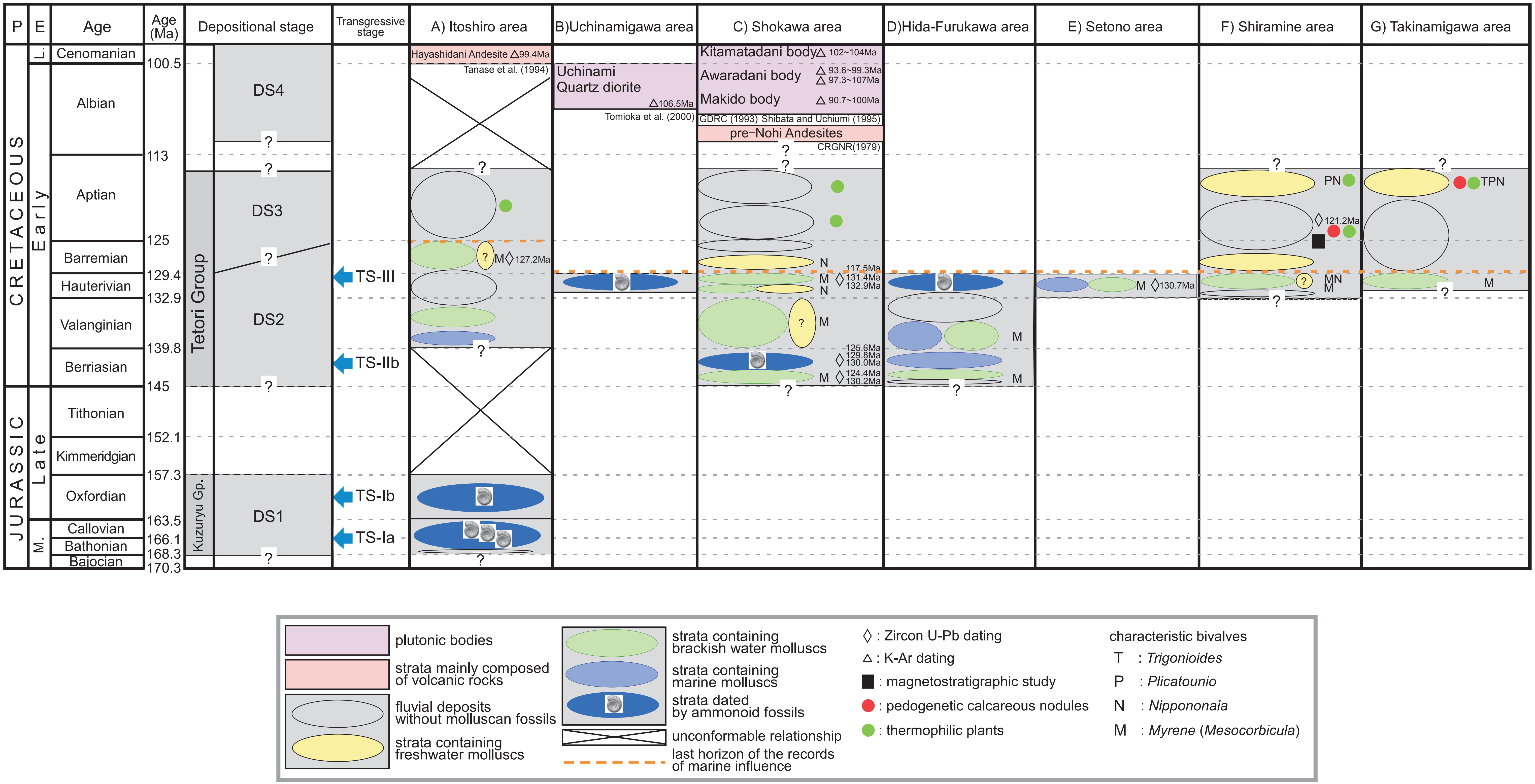

FIGURE 2. Stratigraphic distribution of marine and brackish horizons of the Kuzuryu and Tetori (*sensu stricto*) groups in each important distributional area in the Hakusan Region in the Hida Belt, and their possible correlation. Stratigraphic distribution of marine (e.g., ammonoids), brackish (e.g., *Myrene*) and freshwater (e.g., *Trigonioides, Plicatounio* and *Nippononaia*) molluscs, and climatic indicators (pedogenetic calcareous nodules and thermophilic plants) is shown. Numerical age data and the horizon of magnetostratigraphic study in the Tetori Group and Albian–Cenomanian volcanic/plutonic rocks, Transgressive stages (TS(s)) of Sano et al. (2013) in the Tetori Group (*sensu lato*), and Depositional stages (DS(s): proposed here) are also mentioned. See the text for details. The numerical ages are based on ICS (2015). Abbreviation: GDRC—Gifu-ken Dinosaur Research Committee; CRGNR—Collaborative Research Group for the Nohi Rhyolite.

Classopollis, from the uppermost part of the Tetori Group in this area were reported, and its Hauterivian–Aptian age was suggested (Umetsu and Matsuoka, 2003; Umetsu and Sato, 2007).

Numerical age data—Kawagoe et al. (2012) obtained LA-ICPMS U-Pb ages of detrital zircons in sandstone recovered from about 100 m above the base of the Itsuki Formation along the Itoshirogawa River, and revealed that its youngest zircon has the concordant age of 127.2 ± 2.5 Ma (2 SD). The depositional age of the Itsuki Formation is Barremian or younger (International Commission on Stratigraphy (ICS), 2015). The Hayashidani Andesite of 99.4 ± 5 Ma K-Ar cooling age (Tanase et al., 1994) unconformably covers the Tetori Group in this area, and defines the age of the upper limit of the Tetori Group in this area.

2) Uchinamigawa area (Fig. 2B)

Stratigraphy of the Tetori Group in this area is still debated, and there is no consensus on its stratigraphy and correlation with that of the Itoshiro area (Maeda, 1957; Kawai et al., 1957; Goto, 2007; Matsukawa and Asahara, 2010). In this paper, only the Early Cretaceous ammonoid record reported by Goto (2007) is focused, and mentioned in Figure 2.

Marine/brackish horizons—Goto (2007) reported the occurrence of an ammonoid from the Tetori Group at Ikegahara along Taniyamagawa River. In addition, several horizons of brackish molluscs are recognized in this area (e.g., Matsukawa and Asahara, 2010). However, it is difficult to correlate them, or compare their stratigraphic position with ammonoid-bearing horizon.

Biostratigraphic age data—Goto (2007) described an ammonoid *Pseudothurmannia* sp. and considered its age as late Hauterivian to Early Barremian. Later Matsukawa and Asahara (2010) discussed the stratigraphic distribution of the species of this genus more strictly, and assigned the age of this ammonoid to the late Hauterivian.

2 Shokawa area (Fig. 2C)

Maeda (1952a) divided the succession of the Tetori Group in the Shokawa (or Shiokawa) area into eight formations: Ushimaru, Akahoke, Mitarai (or Mitarashi), Otaniyama, Okurodani, Amagodani, Okura, Bessandani (or Betsuzandani) formations, in ascending order. Although he considered that the Okura Formation overlies the Amagodani Formation with unconformity, subsequent studies revised its relationship as conformity (e.g., Umezawa, 1997; Matsukawa and Nakada, 1999).

Marine/brackish horizons—Diversified marine invertebrates, such as bivalves, ammonoids, a belemnite, a glypheid lobster, scalpellomorph barnacles, a crinoid, were described or reported from the Mitarai Formation (Hayami, 1959a, b, 1960; Sato and Kanie, 1963; Ito et al., 1999; Komatsu et al., 2001; Sato et al., 2003, 2008; Kato and Karasawa 2006; Nomura and Shimizu, 2008; Hunter et al., 2011; Yano, 2012; Sha and Hirano, 2012; Sano et al., 2015). Kumon and Umezawa (2001) first recognized the marine bed in the lower part of the Otaniyama Formation from the discovery of belemnite specimens. Yamashita et al. (2011, fig. 3) reported the marine horizon also occurs in the upper part of the Otaniyama Formation. Hasegawa et al. (2010) confirmed the marine or brackish condition of the Mitarai Formation and some horizons of the lower part of the Otaniyama Formation based on geochemical studies.

Maeda (1952a) reported the brackish bivalves from the Ushimaru, Akahoke, Otaniyama and Okurodani formations. Komatsu et al. (2002) described new oyster species *Crassostrea tetoriensis* from the Ushimaru Formation. Brackish and freshwater bivalves occur alternatingly in the Otaniyama and Okurodani formations, indicating the frequent environmental changes in this stratigraphic sequence (Gifu-ken Dinosaur Research Committee, 1993; Matsukawa and Nakada, 1999; Matsukawa et al., 2006; Yamashita et al., 2011). On the contrary, only the freshwater molluscs have been recovered in the uppermost part of the Okurodani Formation, and no brackish molluscs have been recognized in younger Cretaceous strata in this area (Matsukawa and Nakada, 1999; Yamashita et al., 2011).

Biostratigraphic age data—Sato et al. (2003, 2008) assigned the Mitarai Formation to the Berriasian based on the discovery of *Neocosmoceras* sp. On the other hand, Sha and Hirano (2012) pointed out that four bivalves of the Mitarai Formation occur also in the Barremian–Aptian Qihulin and Yunshan formations of the Longzhaogou Group in eastern Heilongjiang Region, Northeast China. Combining these occurrences with the numerical age data mentioned below, they assigned the Mitarai Formation to the Barremian–Aptian age. However, it should be noted that the marine bivalve fauna of the late Hauterivian Inagoe Formation (see the section of Hida-Furukawa area below) is very similar to that of Yunshan Formation (Matsukawa and Fukui, 2009). Since ammonoid assemblages of the Mitarai and Inagoe formations are distinct, different ages are indicated for these two formations, though some similarity of the bivalve fauna is recognized. Thus the hypothesis of age assignment of the Mitarai Formation using these bivalves is not adopted here, and the similarity of bivalves may be explained by another interpretation: for example, these fore-mentioned taxa are long ranging species at least from the Berriasian to Barremian–Aptian. A belemnite, *Cylindroteuthis* aff. *knoxvillensis* was recently described from the Mitarai and possibly Otaniyama formations (Sano et al., 2015). Since the upper limit of stratigraphic range of the genus *Cylindroteuthis* (*sensu* Dzyuba (2011)) is Valanginian (e.g., Doyle and Kelly, 1988; Dzyuba, 2005), this belemnite record probably supports the age assignment (Berriasian) by ammonoids.

Komatsu et al. (2003) described a charophyte gyrogonite: *Mesochara* sp. from the Okurodani Formation for the first time in Japan, though more materials are necessary to discuss the charophyte biostratigraphy in this area.

Numerical age data—Kusuhashi et al. (2006) first reported the zircon LA-ICPMS U-Pb age of tuffs of the Tetori Group in this area: 130.2 ± 1.7 Ma (errors of Kusuhashi et al. (2006) represent 2 SE) for the Ushimaru Formation; 130.0 ± 1.7 Ma and 129.8 ± 1.0 Ma for the Mitarai Formation; 132.9 ± 0.9 Ma, 131.4 ± 0.9 Ma and 117.5 ± 0.7 Ma for the Okurodani Formation, excluding less reliable data. They chose the youngest age data of each formation for the age assignment, and concluded that maximum ages of the Ushimaru, Mitarai and Okurodani formations are late Hauterivian to Barremian, late Hauterivian to Barremian and Barremian to Aptian, respectively (using the time scale of Gradstein et al. (2004)).

The Tetori Group in this area was intruded by several mid-Cretaceous plutonic bodies, such as Kitamatadani Diorite: K-Ar cooling age 102~104 Ma (71.6 Ma of their data is dubious) (Shibata and Uchiumi, 1995), Awaradani Granodiorite: K-Ar age 93.6~99.3 Ma (Shibata and Uchiumi, 1995) and 97.3~107 Ma (84.9 Ma of their data is dubious) (Gifu-ken Dinosaur Research Committee, 1993), and Makido Mafic Complex: K-Ar age 90.7~100 Ma (125 Ma of their data is dubious) (Shibata and Uchiumi, 1995) (e.g., Kamiya and Harayama, 1982; Tanase et al., 2005). In addition, the "pre-Nohi Andesites (Collaborative Research Group for the Nohi Rhyolite, 1979)", which was also intruded by the Kitamatadani Diorite, is distributed in this area, and is correlated with the Hayashidani Andesite (ca. 100 Ma) in the Kuzuryu District (Tanase et al., 2005). These data probably define the upper limit of the age of the Tetori Group in this area.

Remarks—There is a large discrepancy between the ammonoid biostratigraphic and numerical age data of the Mitarai Formation. *Neocosmoceras* is recovered also from the earliest Cretaceous strata in the South Kitakami Region in Northeast Japan (e.g., Sato et al., 2011). Similarity of ammonoid assemblages among coeval strata in the Tetori and South Kitakami regions suggests the validity of the age assignment of the Mitarai Formation using ammonoids. On the contrary, it is a bit dubious that very similar numerical age data (ca. 130 Ma) were obtained from different formations of the Tetori Group in this area, and different age data (OK3: 117.5 ± 0.7 Ma and OK4: 132.9 ± 0.9 Ma) were recorded in almost the same horizons (OK3 is only several meters below OK4) (Kusuhashi et al., 2006). Further numerical dating studies are necessary to confirm the validity of these data.

3 Hida-Furukawa area (Fig. 2D)

The Tetori Group in this area is divided into the Tanemura, Numamachi, Sugizaki, Taie, Inagoe formations in ascending order (Matsukawa et al., 2007). The Tochio Formation (Maeda, 1958a) in the Fukuji area is excluded from this study, because it belongs to the Hida Gaien Belt (e.g., Otoh et al., 2003; Nakama et al., 2010).

Marine/brackish horizons— Matsukawa et al. (2007) and Matsukawa and Fukui (2009) reported the occurrences of marine molluscs from Sugizaki, Taie and Inagoe formations, and those of brackish water molluscs from Numamachi and Taie formations. In addition, some species of marine bivalves (inoceramid and trigoniid) were described from this area (Hayami, 1960; Maeda, 1962b).

Biostratigraphic age data—Matsukawa and Fukui (2009) described ammonoids, *Phyllopachyceras infundibulum*, *Pseudothurmannia* aff. *baleare* and *Acrioceras* (*Paraspinoceras*) sp. from the Inagoe Formation, and assigned its age to the Hauterivian–Barremian. This idea is re-mentioned in detail in Matsukawa and Asahara (2010). These three species were recovered from two very nearby horizons (WT-03, 4) in the same route (columnar section 7 in Matsukawa et al., 2007). Stratigraphic ranges of *Ph. infundibulum* and *Acrioceras* (*Paraspinoceras*) sp. are Hauterivian to Barremian. Matsukawa and Fukui (2009) mentioned *Pa. jourdani* as the related species of the Hida-Furukawa *Acrioceras* (*Paraspinoceras*) sp. The former is recovered from very nearby horizons in the Hauterivian succession in Southwest Romania with *Ph. infundibulum* and *Pseudothurmannia* spp. (Avram, 1994), In addition, *Pseudothurmannia* clearly indicates the late Hauterivian age (Matsukawa and Asahara, 2010). Thus the age of the Inagoe Formation can be discussed more precisely, as around the Hauterivian–Barremian boundary, or possibly the late Hauterivian, on the basis of these ammonoid records.

4 Setono area (Fig. 2E)

Distribution of the Tetori Group in this area is divided into many fault bounded blocks, and its stratigraphy, especially the correlation with that of the Shiramine area, is still uncertain (Matsuoka et al., 2009; Sakai and Matsuoka, 2011). Thus only the marine stratum near the confluence of the Tedorigawa River and the Ozogawa River is focused on in this paper, because Matsuoka et al. (2009) reported the occurrence of limuloid tracks (*Kouphichnium* isp.) there, and shows the distribution of relatively thick marine strata in geological map and columnar section.

Marine/brackish horizons—Maeda (1958b) mentioned several localities of brackish bivalves. Tamura (1990) first reported the occurrence of a marine bivalve, *Isognomon*, with other brackish bivalves from Setono (the place between Seto and Setono in Tamura (1990, table 1)), though its exact locality is not mentioned. Matsuoka et al. (2009) recognized relatively thick marine strata near the confluence of the Tedorigawa River and the Ozogawa River. Recently, Kashiwagi et al. (2014) reported the occurrence of sponge spicules and radiolarian tests from mudstone rich alternating beds of sandstone and mudstone in this locality. They also reported the occurrence of a belemnite specimen in a sandstone float along the Ozogawa River, which was discovered in upstream from the sponge and radiolarian locality discussed here, and suggested the possible presence of another marine horizon in the Setono area, though its stratigraphic relationship with above-mentioned marine strata is still ambiguous.

Biostratigraphic age data—Marine horizon is recognized, but no age-diagnostic fossil has been reported.

Numerical age data—Matsumoto et al. (2006) obtained a LA-ICPMS U-Pb zircon age of 130.7 ± 0.8 Ma (2 SE) from a tuff bed covering the limuloid tracks bed, and indicated that the marine stratum is Hauterivian in age (ICS, 2015).

5 Shiramine area (Fig. 2F)

The "type locality/area" of the Tetori Series (Yokoyama, 1894) and also the Tetori Group (Oishi, 1933a, b) is probably located in this area, as mentioned above. Maeda (1958b, 1961d) divided the succession of the Tetori Group in this area into four formations: the Gomishima (or Gomijima), Kuwajima (or Kuwashima), Akaiwa and Kitadani formations, in ascending order. One of the famous dinosaur localities of the Tetori Group (Kaseki-kabe (or Kasekiheki)) is assigned to the upper part of the Kuwajima Formation (e.g., Matsuoka, 2000; Matsuoka et al., 2002; Isaji et al., 2005). Its age assignment was discussed in detail in Kusuhashi (2008: p. 380–381), and is basically followed in this paper. Since the correlation between the stratigraphy of the Shiramine area and that of the Setono area is uncertain, the stratigraphy of both areas are discussed here separately.

Brackish horizons—Brackish bivalves, *Myrene* (*Mesocorbicula*) *tetoriensis* and ostreoid are recovered only from the lower part of the Kuwajima Formation (Maeda, 1958b; Okazaki and Isaji, 2008). Freshwater molluscs have been known from the upper part of the Kuwajima Formation and the Kitadani Formation (Matsuo et al., 1976; Isaji, 1993, 2010).

It should be noted that at Yanagidani, east of Ichinose, brackish and freshwater bivalves, such as *Myrene* and *Nippononaia*, co-occur in the same beds (Maeda, 1958b; Matsuura, 2001). The assignment of this fossil-bearing stratum to either the Kuwajima (or Okurodani) Formation or the Akaiwa Formation has been debated for a long time, and is still ambiguous (e.g., Maeda, 1958b; Matsukawa et al., 2000, 2003a; Matsuura, 2001; Hachiya, 2011). Choristoderan remains, which have been known from the Kuwajima Formation and not from the strata above the Kuwajima Formation (Matsumoto et al., 2015), occur in the same outcrop (Matsuura, 2001), and may indicate the possible correlation between this stratum and the Kuwajima Formation. Further studies are clearly required to solve this problem, and to reveal the paleoenvironmental significances of this record.

Biostratigraphic age data—Marine horizon is not recognized in this area. Isaji (1993) reported the occurrence of *Nippononaia ryosekiana* and *Plicatounio* sp. from the Kitadani Formation in this area (see the discussion in the Takinamigawa area below).

Magnetostratigraphic age data—Geomagnetic study suggested that the deposition of the Akaiwa Formation did not occur during the period of the Cretaceous Normal Polarity Superchron (early Aptian to Santonian), because twice changes of the magnetic polarities were recognized in the outcrop at Yunotani (Kunugiza et al. 2002a). The age of the Akaiwa Formation in this locality can be considered as the pre-Aptian time.

Numerical age data—Sakai et al. (2015) obtained LA-ICPMS U-Pb zircon age of 121.2 ± 1.1 Ma (95% confidence interval, CI) (Aptian; ICS, 2015) from the tuff of the Akaiwa Formation in Osugidani.

Remarks—Age assignment of the Akaiwa Formation (pre-Aptian) by the magnetostratigraphic data is considerably different from recent numerical age datum (Aptian). Although precise stratigraphic relationship between two outcrops where these data were obtained is uncertain, it is clearly indicated that the upperlimit of the age of the Akaiwa Formation is extended to the Aptian, and this formation can be tentatively considered as the Barremian–Aptian age.

6 Takinamigawa area (Fig. 2G)

The formation names, which were used to describe the stratigraphy of the Tetori Group in this area, are variable among papers, because of the different interpretation of the correlation with that of the Shiramine area (e.g., Maeda, 1958b; Tsukano, 1969; Omura, 1973; Tamura, 1990; Matsukawa et al., 2003a, 2006; Molnar et al., 2009; Nichols et al., 2010). However, their recognition of lithological changes of the Tetori Group in this area is usually identical. Sano et al. (2008) divided the Tetori Group in this area into four lithostratigraphic units (Unit A to D in ascending order), and this unit division is used here. Unit C and D correspond to the Kitadani Formation of Maeda (1958b). One of the famous dinosaur localities of the Tetori Group, the Kitadani Dinosaur Quarry (Azuma, 2003), is assigned to Unit C.

Brackish horizon—A brackish bivalve, *Myrene* sp. occurs in the lowermost part of Unit A (Tsukano, 1969; Sano et al., 2008).

Biostratigraphic age data—Since marine horizon is not recognized in this area, the age assignment of the Tetori Group in this area should be discussed based on non-marine fossil biostratigraphy. Various freshwater molluscs including *Trigonioides*, *Plicatounio* and *Nippononaia* occur in Unit C (e.g., Maeda, 1962e, 1963b, Tamura, 1990; Matsukawa and Ido, 1993). Isaji (1993) discussed the age of Unit C as Late Barremian–Early Aptian, according to the occurrence of a freshwater bivalve *Nippononaia ryosekiana*, which is known from the Sebayashi Formation in the Sanchu area, Kanto Mountains, in the Outer Zone of Southwest Japan. This information has been used as the grounds for the age of the Kitadani Formation. However, *N. ryosekiana*-bearing horizon of the Sanchu area is now considered as the Barremian in age (Terabe and Matsuoka, 2009; Matsukawa and Tomishima, 2009). On the contrary, the age of Nakdong Formation in Korea, where *N. ryosekiana* occurs (Yang, 1978), is re-assigned to the late Aptian (118 Ma) or younger, based on LA-ICPMS U-Pb dating of detrital zircons (Lee et al., 2010). Thus stratigraphic range of *N. ryosekiana* should be revised as Barremian–Upper Aptian (or above).

On the other hand, according to recent summary of stratigraphic range of Early Cretaceous non-marine bivalves in East Asia, the stratigraphic range of *Plicatounio* is usually considered as the Aptian–Albian (Sha et al., 2012), though the age of the Monomiyama Formation in South Kitakami Region in Northeast Japan, where *Plicatounio* was reported, can be considered as pre-Aptian (Ogasawara, 1988), and the stratigraphic range of this genus needs further confirmation.

Kubota (2005) described 5 species of charophyte gyrogonites: *Clavator harrisii* var. *reyi*, *Mesochara harrisi* and *Mesochara stipitata*, *Mesochara* sp. and *Stellatochara* sp. from Unit C, and assigned its age to Barremian according to the co-ocurrence of *C. harrisii* var. *reyi*, *M. harrisi* and *M. stipitata*. Among them, stratigraphic range of *C. harrisii* var. *reyi* is usually considered as the Barremian–Early Aptian (Kubota, 2005; Vicente and Martín-Closas, 2013). It was also reported from the Nakdong Formation in Korea of the Late Aptian or younger age (Choi, 1989; Kubota, 2005; Lee et al., 2010). *M. harrisi* and *M. stipitata* show relatively long stratigraphic ranges from the Kimmeridgian and Berriasian, respectively, and their youngest records were recognized in the Barremian deposits (Kubota, 2005). In Europe, *M. harrisi* occurs also in the *Ascidiella cruciate–Pseudoglobator paucibracteatus* charophyte biozone of the Late Barremian–Early Aptian age with *C. harrisii* var. *reyi* (Martín-Closas et al., 2009; Vicente and Martín-Closas, 2013). *M. stipitata* was known from the upper part of the Jiufotang Formation to the Fuxin Formation (Wang et al., 2003). These formations were recently assigned to the Aptian (Sha et al., 2012). Thus the co-ocurrence of these three species probably indicates the Barremian to Aptian in age instead of the Barremian.

Legrand et al. (2013) described rich palynoflora from Unit C, but they concluded that the assignation of an accurate age to it was difficult. Recently, Legrand et al. (2015) reported the occurrence of an angiosperm pollen *Clavatipollenites hughesii* from Unit C, suggesting the possibility of future biostratigraphic study using angiosperm pollen from the Kitadani Formation.

Cao (1996) described four ostracod species: *Cypridea angusticaudata*, *C.* (*Morinia*) *monosulcata zhejiangensis*, *C.* (*Bisulcocypridea*) sp. and *Timiriasevia* sp. from Unit C, and suggest its close similarity to that of the Guantou Formation in Southeast China. The age of Guantou Formation is now considered as Aptian based on SHRIMP (sensitive high-resolution ion-microprobe) zircon dating (Zhang et al., 2014). Wang et al. (2012) discussed the age of *Cypridea* (*Morinina*)–*Bisulcocypridea–Mongolocypris* assemblage is mainly Aptian–Albian.

Numerical age data—Arakawa et al. (2005) applied detrital zircon SHRIMP dating to Unit C, and mentioned that youngest detrital zircon from the Kitadani Formation is Hauterivian in age, and Unit C is assigned to Hauterivian or later. However, their discussion is based on the datum of only a single grain of zircon, and the detailed evaluation of the datum is not provided. The reliability of this datum needs further confirmation.

Remarks—The age of the Kitadani Formation had been sometimes mentioned as the Aptian–Albian in literature. This age assignment is probably based on the figure showing the correlation of the Tetori Group in various localities published in Maeda (1961d, table 1). However, the age of Kitadani Formation was described as Lower Cretaceous or "Eo-Cretaceous" in the subsequent papers (e.g., Maeda, 1962e, 1963b), and thus the supposed Aptian–Albian age of the Kitadani Formation is probably misinterpretation of the figures of Maeda (1961c, d). Based on the above mentioned data, the age of Unit C (and also the Kitadani Formation) can be considered as the Aptian at this moment, though some discrepancies still exist among the age assignment on each biota. Furthermore, the upper limit of the age of the Kitadani Formation is still ambiguous.

Maeda (1958b) defined "the Kitadani alternation of sandstone, shale and tuff", which is characterized by the presence of "reddish or greenish tuffaceous rock facies" and also the occurrences of non-marine molluscs, such as *Trigonioides* and *Plicatounio*. Putative greenish tuffaceous rocks are in fact paleosol (e.g., Kubota, 2003), and unambiguous tuffaceous rocks are probably absent in the Kitadani Formation, causing the difficulty of numerical dating study of this formation.

7 Asuwa area

Since purported occurrence of ammonoid from the Asuwa area was reported, the presence of the Kuzuryu Subgroup in this area has been supposed (e.g., Maeda, 1961b). The presence of marine strata in this area is now questioned (Yamada and Uemura, 2008; Yamada et al., 2008). Since age indicating data have not been obtained, the stratigraphy of the Tetori Group in this area is not discussed in this paper.

CORRELATION BETWEEN THE STRATA IN EACH DISTRIBUTIONAL AREA

1 Marine horizons in the Tetori Group

Alternating changes of marine and non-marine depositional environments are recognized in the lower and middle part of the Tetori Group. "Three" marine transgression stages in the Tetori Group were recognized in Matsukawa et al. (2007), and slightly revised in Sano et al. (2013). Marine strata can be used as key horizons for correlation in the Tetori Group. Stratigraphic distributions of marine strata in the studied areas, which are reviewed in detail in previous chapter, are summarized as follows.

Bathonian–Callovian (transgression stage (TS)-Ia of Sano et al. (2013), the same reference for TS hereafter) and Oxfordian (TS-Ib) marine strata occur only in the Itoshiro area. Tithonian (TS-IIa) one has not been recognized in any part of the studied areas.

Berriasian (TS-IIb) one is recognized in the Shokawa area. The marine Sugizaki Formation in the Hida-Furukawa area can be considered as the older transgression than that of the late Hauterivian Inagoe Formation, and to be correlated with the Mitarai Formation and lower part of the Otaniyama Formation, because of the occurrences of *Inoceramus maedae* and belemnite specimens, and similar changes of depositional environments (Matsukawa et al., 2007). Thus TS-IIb transgression possibly occurred also in the Hida-Furukawa area.

Occurrence of *Vaugonia* (*Vaugonia*) *yambarensis* from the Yambara Formation suggests the marine influence on the lowermost pat of the Itoshiro Subgroup in the Itoshiro area (Maeda, 1952a; Kobayashi, 1956). Age assignment of this horizon is debatable (see discussion in Kawagoe et al. (2012) and Sano et al. (2013)). It is possible that this marine horizon is directly correlated with Mitarai Formation (corresponding to TS-IIb) in the Shokawa area, because it is probably the last transgression below the Barremian Itsuki Formation, though the lithologies of the Mitarai and Yambara formations are different. However, it should be noted that only a single specimen of *V.* (*V.*) *yambarensis* was recovered, and this species was considered as the youngest record of this genus in Japan (Kobayashi et al., 1959). Thus it is necessary to review the possibility that this specimen was reworked from the lower strata such as the Yambarazaka Formation, where abundant trigoniid specimens including *Vaugonia kuzuryuensis* occur (Kobayashi, 1957a; Maeda, 1963a). On the other hand, *Inoceramus*-bearing boulder in the Yambara Formation suggests the deposition and subsequent erosion of *Inoceramus*-bearing marine stratum occurred in this area. *Inoceramus* is very abundant in the Mitarai Formation (e.g., Hayami, 1960; Komatsu et al., 2001). If this eroded marine stratum is correlated with the Mitarai Formation, the age of the Yambara Formation can be considered younger than that of the Mitarai Formation. Another candidate of the *Inoceramus*-bearing marine stratum is the Tithonian Kamihambara Formation (corresponding to TS-IIa) in the Kamihambara area of the Middle Row of the Tetori Group in the Kuzuryu District. However, in this case, there is another discrepancy that marine horizon of TS-IIb (corresponding to the Mitarai Formation) cannot be recognized in the Itoshiro area. Furthermore, marine horizon of TS-IIa is not recognized in any other part of studied areas in the Hida Belt. Thus the second hypothesis that the Yambara Formation is younger than the Mitarai Formation is preferred, though further dating studies of the Yambara Formation is required.

Late Hauterivian (TS-III) marine strata are recognized in the Uchinamigawa, Hida-Furukawa and Setono areas. The former two records are based on ammonoids, and the last one is dated by zircon U-Pb dating.

2 Disappearance of marine influence on the Tetori Group

Brackish environment characterized by the occurrences of *Myrene* (*Mesocorbicula*) *tetoriensis* and *Tetoria yokoyamai*, is prevailed widely in the middle part of the Tetori Group (Maeda, 1955; Kondo et al., 2006; Nishida et al., 2013), though marine horizons are limited to only a few horizons (Fig. 2). Kondo et al. (2006) supposed the presence of a huge brackish lake in the Tetori Region. Nishida et al. (2013) recognized the Tetori Region is one of the important areas to consider the evolution of brackish bivalve corbiculoids.

On the other hand, freshwater molluscs, such as *Nippononaia*, were reported only from the upper formations of the Tetori Group: the Kuwajima Formation in the Shiramine area, the Okurodani Formation in the Shokawa area, and the Kitadani Formation in the Takinamigawa area (e.g., Kobayashi and Suzuki, 1937; Maeda, 1952a, b, 1955; 1958b, 1961d, 1962a, e, 1963b; Matsuo et al., 1976; Tamura, 1990, Matsukawa and Ido, 1993; Isaji, 1993, 2010; Matsukawa and Nakada, 1999; Matsukawa et al., 2003b, 2006; Komatsu et al., 2003; Goto, 2010; Kikuchi, 2011; Hachiya, 2011), except for the Otaniyama Formation in the Shokawa area, where the marine/brackish environments were predominant (Matsukawa et al., 1998; Matsukawa and Nakada, 1999; Yamashita et al., 2011) (Fig. 2).

The faunal change from the lower brackish fauna to upper freshwater fauna in the Kuwajima Formation and in the Shokawa area was mentioned in Tamura (1990), though he discussed the strata in the Shiramine and Setono areas together, contrary to the description in this paper. Quartzose gravel rich conglomerates are very dominant in the upper part of the Tetori Group, and a fluvial environment prevails in these strata (e.g., Maeda, 1961d; Taira and Matsuo, 1983, Masuda et al., 1991; Fujita, 2002; Yamagami et al., 2003; Kim et al., 2007; Sano et al., 2008; Okazaki and Isaji, 2008). Thus the distinct change of depositional environments from brackish to fluvial probably occurred in the Tetori Region and its hinterland during the time of deposition of the middle to upper part of the Tetori Group. The similar idea was already proposed by Matsukawa et al. (1997a).

If the same or related tectonic event(s) caused these environmental changes in the whole Tetori Region, the transition from the marine/brackish to freshwater environments in each distributional area possibly occurs at almost same time or short time interval, and can be used as the approximate correlation tool in the middle and upper part of the Tetori Group. The last marine strata of the Tetori Group (TS-III) are late Hauterivian based on ammonoids and zircon U-Pb dating. On the other hand, last appearance of brackish fossils in the Tetori Group are recognized in the lowermost part of the Tetori Group in the Takimanigawa area, within the Kuwajima Formation in the Shiramine area, within the Okurodani Formation in the Shokawa area, and in the Itsuki Formation in the Itoshiro area (Fig. 2). Among them, the numerical age of the Itsuki Formation is 127.2 ± 2.5 Ma (Barremian) or younger. Those of the Okurodani Formation are Hauterivian to Aptian (132.9 ± 0.9 Ma, 131.4 ± 0.9 Ma and 117.5 ± 0.7 Ma), though the validity of these numerical age data was questioned, as mentioned above. In the Shiramine area, paleomagnetic study and recent numerical age datum (121.2 ± 1.1 Ma) of the Akaiwa Formation revealed that the Kuwajima Formation is probably older than Aptian. Charophytes, freshwater molluscs and ostracods indicate the Aptian age for the uppermost part of the Tetori Group in the Takinamigawa area. Thus the disappearance of marine influence in the whole Tetori Region is supposed to occur within the Barremian stage, and used as approximate correlation tool in this paper.

Matsukawa et al. (1997a) already proposed the hypothesis that the tectonic duplication of Jurassic–early Early Cretaceous accretionary complexes in the Hauterivian caused the upheaval of the hinterland and the change of depositional environments of the Tetori Group at that time. However, their recent studies (e.g, Matsukawa et al., 2006, 2007; Matsukawa and Fukui, 2009) interpreted the significant hiatus (Berriasian–Valanginian) between the Itsuki and Nochino formations in the Itoshiro area, because they considered the age of Itsuki Formation as the Tithonian, and thus did not used the transition of depositional environment as the correlation tool in the whole Hakusan Region.

Compared with eustatic sea level curve (Haq, 2014), TS-IIb (Berriasian) and TS-III (late Hauterivian) probably correspond to the duration of relatively high sea level in the early to middle Early Cretaceous. Although much higher sea level in global scale is recorded in the Aptian–Albian time, transgressive stage corresponding to it is not recognized in the Tetori Group. A possible explanation is that the change of depositional environment from the huge brackish lake to the fluvial environment occurred in the Barremian, and then the marine influence had not been recognized in the Tetori Group after that time.

3 Appearance of relatively warmer and dryer climate indicators in the Tetori Group

The plant fossils of the Tetori Group (the Tetori Flora) represent the Tetori-type flora, which flourished in the Tetori Region, north China and Russia, where the temperate and moderate humid climatic condition prevailed (e.g., Kimura, 1987; Ohana and Kimura, 1995). Yabe et al. (2003) pointed out the presence of thermophilic plant species, which characterize the Ryoseki-type flora of Kimura (1987), and/or pedogenetic calcareous nodules from the upper formations of the Tetori Group in the Takinamigawa, Shiramine, and possibly Shokawa areas (Fig. 2). The Ryoseki-type flora was mainly distributed in the Outer Zone of Southwest Japan, south China and Southeast Asia, and has been interpreted to represent subtropical climatic condition with continuous dry season (e.g., Ohana and Kimura, 1995; Yabe et al., 2003). Kubota (2003) described the paleosol in the Kitadani Formation, focusing on the characters of pedogenetic calcareous nodules, and discussed the depositional environments of the Kitadani Formation and paleoclimatic (relatively dry) condition at that time. Subsequently, Yabe and Kubota (2004) described *Brachyphyllum*, a typical thermophilic species, from the Kitadani Formation in the Takinamigawa area. Terada and Yabe (2011) reported the silicified wood specimens of *Xenoxylon latiporosum* and *Podocarpoxylon* sp. from the Kitadani Formation. The latter also indicates that the climate with dry season occurred at that time. Recently, Sakai et al. (2014a, b) and Sakai (2014) confirmed the presence of thermophilic plant species from the upper formations of the Tetori Group in the Shokawa, Shiramine and also Itoshiro areas (Fig. 2). In addition, Yabe and Shibata (2011) discussed the paleoecology of *Brachyphyllum* from the Kitadani Formation, and the difference of climatic conditions between the Oguchi Flora of the Kuwajima Formation and the flora of the Kitadani Formation (warmer and dryer in the latter). This idea is clearly supported by the fact that some typical elements of the Oguchi Flora, for example, *Nilssonia*, *Otozamites*, *Podozamites reinii*, ginkgos and czekanowskias, which characterize the Tetori-type flora, have not been found in the Kitadani Formation (Yabe et al., 2012). At this moment, neither thermophilic species nor pedogenetic calcareous nodule is reported from the lower and middle parts of the Tetori Group. Thus the presence of these climatic indicators (and possibly absence of typical elements of the Oguchi Flora) in upper stratigraphic sequence can be considered as the useful tool to recognize climatic change in the Early Cretaceous.

Recently Matsumoto et al. (2015) discussed a climatic barrier may have separated the distribution of choristoderes (North) and crocodyliforms (South) in Asia during the Early Cretaceous, and the faunal change from choristoderan occurrences without crocodilyforms in the Okurodani and Kuwajima formations to crocodilyform occurrence without choristoderes in the Kitadani Formation is concordant with climatic change from cool to hot, which is recognized based on floral change in Yabe et al. (2003).

Since such climatic changes probably affected the whole Tetori Region at almost the same time, the presence of these climatic indicators in upper stratigraphic sequence can be used to divide the upper part of the Tetori Group prevailing warmer and dryer climate from its other parts.

4 About 100 Ma volcanic/plutonic activities

About 100 Ma or Albian–Cenomanian volcanic/pultonic rocks, such as the Hayashidani Andesite in the Itoshiro area, the Uchinami Quartzdiorite in the Uchinamigawa area (Tomioka et al., 2000), and the Kitamatadani Diorite, the Awaradani Granodiorite, the Makido Mafic Complex and the pre-Nohi Andesites in the Shokawa area, unconformably covered or intruded into the Tetori Group in the Hakusan Region. Volcanic/pultonic rocks of similar age are sporadically but widely distributed in the northern Central Japan, and can be correlated with the volcanic episodes recorded in the Kwanmon (or Kanmon) and Sasayama groups in the Inner Zone of Southwest Japan (Tanase et al., 1994; Yamada et al., 2001; Yamada, 2005 and references therein). These volcanic episodes in the Hakusan Region are important not only for defining the upper limit of the age of the Tetori Group, but also for the possible correlation with those recorded in other regions in Southwest Japan, or even in East Asia.

SUMMARY OF NEW STRATIGRAPHIC SCHEME

Three subgroup division of the Tetori Group (*sensu lato*) (e.g., Maeda, 1961d; Yamada, 1988; Kusuhashi et al., 2002) has been generally used to discuss its correlation and change of depositional environments, though such a scheme has recently been challenged (e.g., Matsukawa et al. 2006, 2007; Matsukawa and Asahara, 2010). As discussed above, the timing of change of depositional environment is not concordant with subgroup and/or formation boundaries (Fig. 2), and thus the subgroup division is not appropriate to discuss the correlation and environmental changes, as suggested by Matsukawa et al. (2003b, 2006).

Middle–Late Jurassic strata (lower part of the Tetori Group (*s.l.*)) are distributed only in the Itoshiro area, whereas those of the Early Cretaceous (middle to upper part of the Tetori Group (*s.l.*)) are widely distributed in the Hakusan Region. The latter overlies the former with unconformity. Since the age of the former is at least late Bathonian to middle Oxfordian, the Kimmeridgian–Tithonian strata is probably absent. Thus the Jurassic strata (**Kuzuryu Group** of Maeda (1952a) = Kuzuryu Subgroup of Maeda (1961d)) should be separated from the Early Cretaceous ones (**Tetori Group** (*sensu stricto*))*2.

Oishi (1933a, b) probably used the term "Tetori Group" for the first time. He clearly separated ammonoid-bearing formation (Kaizara Formation) in the Kuzuryu District from the "Tetori

*2
In this paper, the term "Tetori Group" is revised from the previous general usage for the Middle Jurassic–Early Cretaceous stratum (e.g., Maeda, 1961d; Yamada, 1988; Kusuhashi et al., 2002) to that for the Early Cretaceous stratum. In case of the necessity of the distinction of two usage, the "Tetori Group (*sensu lato*, or *s.l.*)" is used for the former case, and the "Tetori Group (*sensu stricto*, or *s.s.*)" for the latter case. From this chapter, the "Tetori Group" means the Tetori Group (*s.s.*).

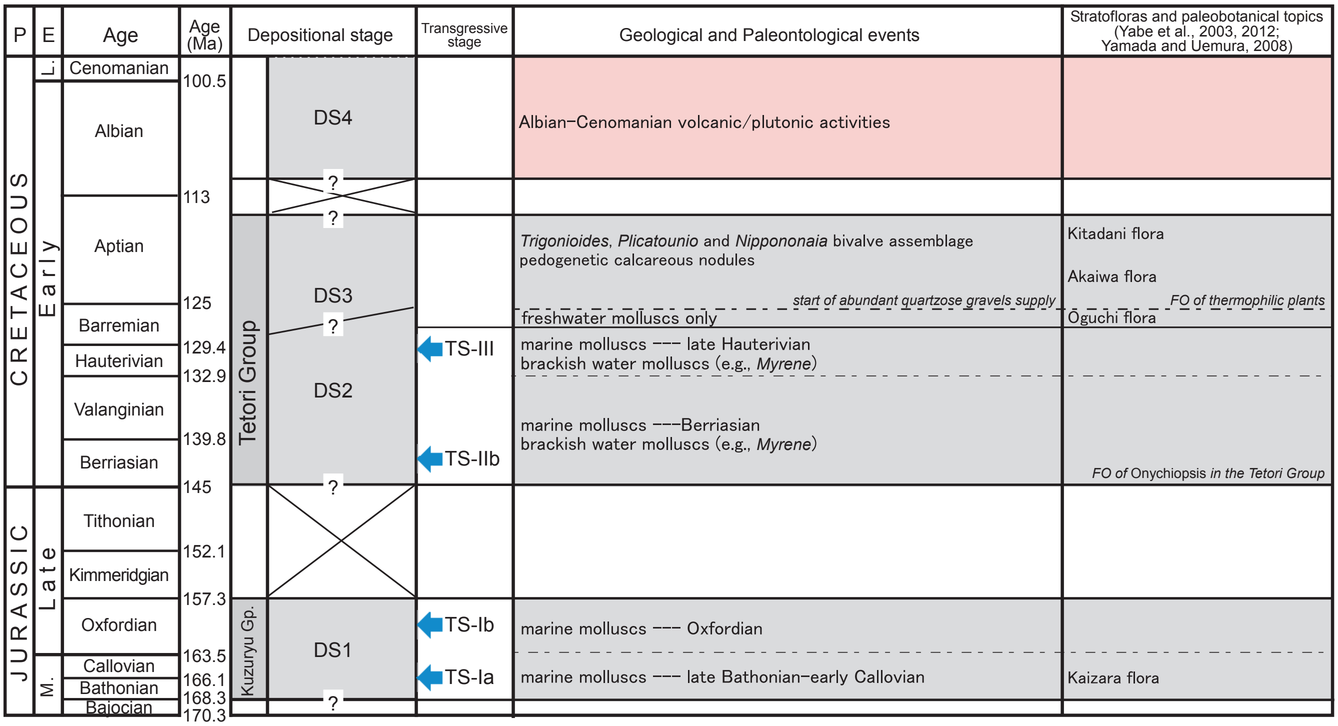

FIGURE 3. Summary of the Depositional stages (DS(s)) in the Hakusan Region in the Hida Belt. Transgressive stages (TS(s)), geological and paleontological events, and stratofloras and paleobotanical topics in the Middle Jurassic to Early Cretaceous strata are shown. Abbreviation: FO—First occurrence. The numerical ages are based on ICS (2015).

Group", though he considered both of the "Tetori Group" and the Kaizara Formation are almost coeval, and belong to the Tetori Series (Late Jurassic). The usage of the Tetori Group (*s.s.*) in this paper is almost identical to the original usage in Oishi (1933a, b). Omura (1973) and Kumon (1995) used the both terms of the Kuzuryu and Tetori groups, and similar usage was also seen in Tashiro (2000) and Kunugiza et al. (2002b). Following the usage of the Kuzuryu Subgroup in Maeda (1961d), the Kuzuryu Group, re-proposed in this paper, includes Oxfordian marine strata in the Jinzu Region.

The idea of depositional stage (DS) is introduced here for the discussion of the paleoenvironmental changes in the Jurassic–Early Cretaceous strata in the Hakusan Region in the Hida Belt (Fig. 3). The Kuzuryu Group covers the basement in the Hida Belt, such as the Hida Metamorphic Rocks, and represents the first depositional stage (DS1) of the Mesozoic non-metamorphic strata in the Hida Belt. The Tetori Group covers the Kuzuryu Group in the Itoshiro area. In other areas, it unconformably overlies, or in fault contact with the constituents of the Hida Belt (e.g., Maeda, 1961d; Matsukawa and Nakada, 1999; Matsukawa et al., 2003a, 2007). It is almost continuous sequence, and no large time gap is known during its depositional time, though the depositional environmental change from brackish lake to fluvial environment is recognized. DS2 and DS3 are proposed here for the lower brackish dominant part and the upper fluvial part of the Tetori Group, respectively (see Fig. 3). Since TS-IIb and TS-III are recognized in DS2, DS2 ranged at least from Berriasian to Late Hauterivian, indicating the presence of significant stratigraphic gap between the Kuzuryu and Tetori groups (see discussion in Sano et al., 2013). The Tetori Group showed much wider distribution at the period of TS-III than that of TS-IIb, especially in northwestern part of the Hakusan Region, and such wider distribution continues to DS3. The transition from DS2 to DS3 probably occurred within the Barremian stage. DS3 represents the stratigraphc range from the Barremian to Aptian, though its upper limit is still ambiguous.

After the deposition of the Tetori Group, about 100 Ma or Albian–Cenomanian volcanic/pultonic rocks unconformably covered or intruded into the Tetori Group in the Hakusan Region. These volcanic/plutonic rocks can be considered as DS4 in this paper for the comparison with other Albian strata in Southwest Japan, such as the Kwanmon and Sasayama groups (e.g., Kusuhashi et al., 2013; Aoki et al., 2014), or even in East Asia.

1 Comparison with previous stratigraphic schemes

The new stratigraphic scheme, here proposed, seems to be basically similar to the classic scheme of Maeda (1961d), Yamada (1988) and Kusuhashi et al. (2002). However, the accumulation of recent age data revealed that marine strata is not limited to the Kuzuryu Group, contrary to the Maeda's supposition, and a large time gap between the Kuzuryu and Tetori groups is supposed in this paper. In addition, the transition from DS2 to DS3, here proposed focusing on the disappearance of marine influence, is not concordant with the boundary between the Itoshiro and Akaiwa subgroups of Maeda (1961d). The upper limit of the age of the Tetori Group is still uncertain. Instead of Maastrichtian Omichidani (or Omitidani) Formation, DS4 is proposed above the Tetori Group in this paper, and probably can be used to be correlated with Albian strata in the Inner Zone of Southwest Japan.

The stratigraphic scheme in this paper is generally similar also to that of Fujita (2003). However, he used the FT data for the age assignment of each area, and interpreted that the base of the Tetori Group in most distributional areas is tentatively assigned to the base of Hauterivian (= the base of the Early Cretaceous strata in the Outer Zone of Southwest Japan), because Berriasian ammonoids had not been known from the Tetori Group at that time. After recent accumulation of ammonoid data and U-Pb dating in the Tetori Group, the age assignment of this group and correlation among each distributional area in Fujita (2003) are completely revised in this paper.

Omura (1973) proposed the complete different idea of the stratigraphy that "the formations" of the Tetori Group represent different lithofacies of the same age. However, recent age data mentioned in this paper revealed that different ages are usually suggested for the formations in each area.

Matsukawa and his colleagues' scheme (see Matsukawa and Asahara (2010) and Matsukawa et al. (2014a, fig. 7) for recent concept) is significantly different in the correlations of the selected formations/horizons in each distributional area and thus in their age assignment from the new scheme here proposed: for example, the correlation of the Itsuki Formation in the Itoshiro area and the Tithonian ammonoid-bearing horizon in the Kamihambara area; that of Late Hauterivian ammonoid-bearing horizon in the Uchinamigawa area to the Amagodani Formation in the Shokawa area; that between the Okurodani Formation in the Shokawa area and the Kitadani Formation in the Takinamigawa area. Such ideas of correlation are not supported by the recent age data, or contradict those discussed in this chapter, and cannot be adopted here.

IMPLICATION FOR THE AGES OF VERTEBRATE FAUNAS AND FLORAS OF THE TETORI GROUP

1 Age of vertebrate fossil-bearing formations

In the Tetori Region, several important vertebrate fossil localities are known. Their age assignment is still controversial, and discussed here based on new stratigraphic scheme of the Tetori Group. The fossil-bearing stratum at Locality KO-2 in the Shokawa area is the lowermost part of the Okurodani Formation (e.g., Hasegawa et al., 1995; Cook et al., 1998, Evans et al., 1998), and thus is assigned to Late Hauterivian or earlier, because this horizon is lower than last brackish horizon (but later than Berriasian, which is the age of the underlying Mitarai Formation). At Kaseki-kabe in the Shiramine area, a vertebrate fossil-bearing stratum is in the upper part of the Kuwajima Formation, and is assigned to Barremian, because it is younger than the age of brackish horizon, and earlier than Barremian–Aptian Akaiwa Formation. A vertebrate fossil-bearing stratum at the Kitadani Dinosaur Quarry in the Kitadani Formation can be considered as Aptian, because it is younger than the age of the last brackish horizon in this area (Unit A of Sano et al. (2008)), and overlies also the thick sandstone dominant unit (Unit B of Sano et al. (2008)), which is probably corresponding to the Barremian–Aptian Akaiwa Formation in the Shiramine area. These ages of vertebrate fossil-bearing formations are well concordant with the recent turtle evolutionary hypothesis/biostratigraphy, namely Okurodani, Kuwajima, Akaiwa and Kitadani turtle faunas in ascending order (Hirayama, 2007, 2010; Hirayama et al., 2013).

2 Age of plant fossil-bearing formations and climatic change

Yabe et al. (2003) reviewed the floral composition of the Oguchi, Akaiwa and Tamodani floras, in ascending order, and discussed the change of climatic conditions recorded in the Tetori Group. Tamodani, a "type locality" of the Tamodani Flora, is located in the Kamihambara area in the Middle Row of the Tetori Group (*s.l.*) in the Kuzuryu District, and thus its stratigraphy and possibly its age also need revision. It is better to use the name of the Kitadani Flora (Yabe et al., 2012) instead of the Tamodani Flora for the youngest stratoflora in the Tetori Group. Characters of the youngest stratoflora discussed in Yabe et al. (2003) do not change though the exclusion of the floral composition of the Tamodani locality from the Kitadani Flora (A. Yabe personal communication, 2014. February). The Oguchi Flora is recovered from the upper part of the Kuwajima Formation, and is assigned to Barremian, as discussed in previous chapter. The Akaiwa Flora is recovered from the Barremian–Aptian Akaiwa Formation, and the Kitadani Flora from the Aptian Kitadani Formation. Thus climatic change (warmer and dryer) recognized in Yabe et al. (2003) probably occurred around the period of the Barremian–Aptian boundary.

COMPARISON WITH CRETACEOUS STRATA FORMERLY ASSIGNED TO THE TETORI GROUP (*SENSU LATO*) IN OTHER REGIONS

The Tetori Group (*s.l.*) is sporadically but widely distributed in northern Central Japan (e.g., Maeda, 1961d; Yamada, 1988) (Fig. 1). The attribution of Late Mesozoic strata in most of these areas to the Tetori Group (*s.l.*) is challenged recently (e.g., Sano et al., 2013; Matsukawa et al., 2014a; Takeuchi et al., 2015a). In this chapter, Late Mesozoic strata in the Jinzu Region in the Hida Belt, and the Mana–Ono–Nagano–Kamihambara areas of the Kuzuryu District, Tochio, Asahi (or Tomari) and Nyukawa areas in the Hida Gaien Belt are focused on. Furthermore, the possible Early Cretaceous stratum in the Katashina area of the Joetsu Belt, which has been considered as the correlative of the Tetori Group (*s.l.*), is also briefly mentioned. Marine influence, biostratigraphy, and numerical age data (mainly LA-ICPMS U-Pb zircon age data) are

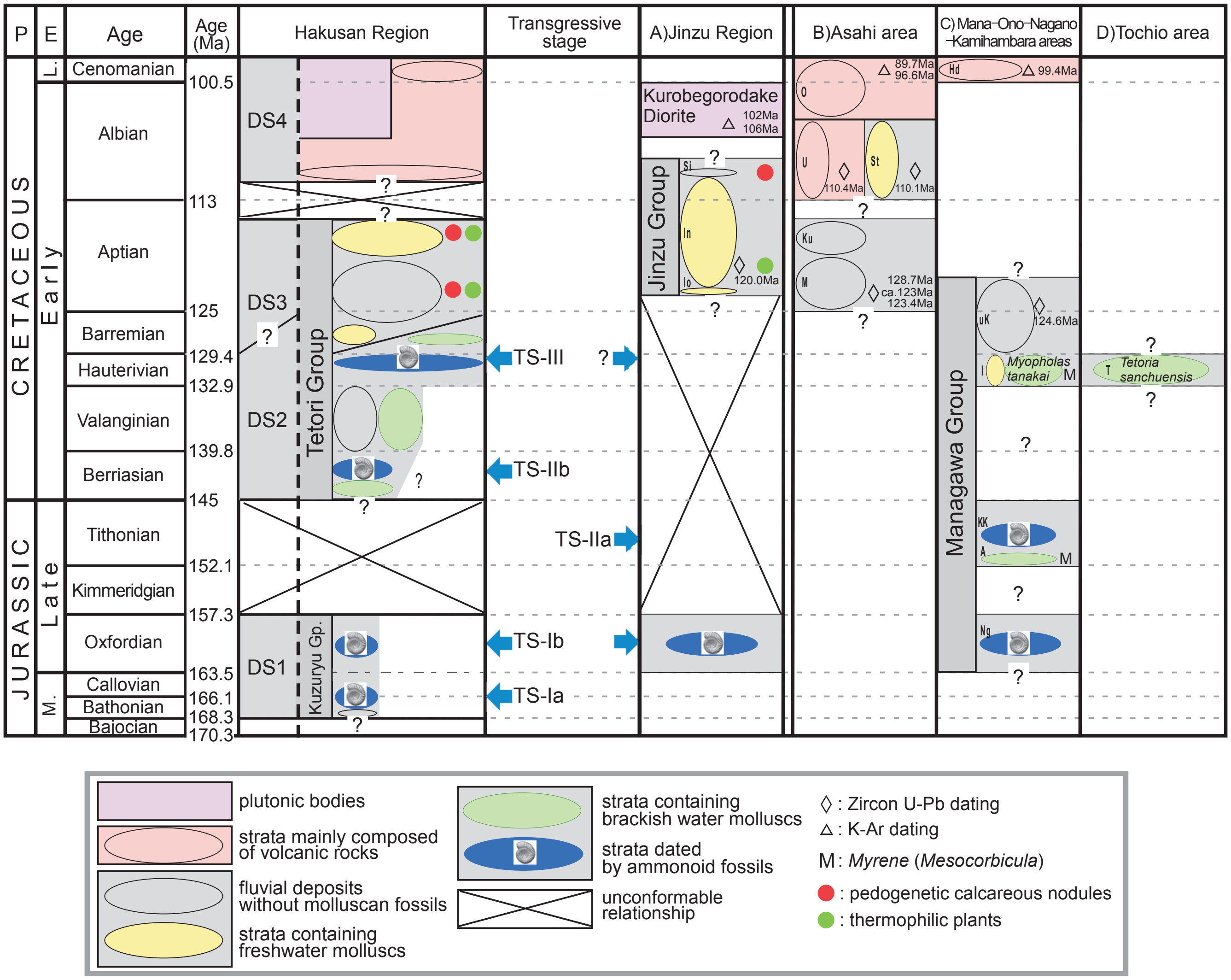

FIGURE 4. Comparison of stratigraphy, horizons of marine, brackish and freshwater molluscs and climatic indicators (pedogenetic calcareous nodules and thermophilic plants), numerical age data, and depositional and transgressive stages (DS(s) and TS(s)) of the Middle Jurassic to Early Cretaceous strata in the each regions/areas in northern Central Japan. *Myopholas tanakai* and *Tetoria sanchuensis* are typical Hauterivian brackish bivalves in the Outer Zone of Southwest Japan. These strata except Albian volcanic/plutonic rocks were previously called as the Tetori Group (*s.l.*), but are divided into four different groups: the Kuzuryu, Tetori (*s.s.*), Jinzu and Managawa groups in this paper. See the text for details. Abbreviation: Io—Ioridanitoge Formation, In—Inotani Formation, Si—Shiroiwagawa Formation for the Jinzu Group in the Jinzu Region (Matsukawa et al., 2014a); M—Mizukamidani Formation, Ku—Kurobishiyama Formation, U—Uchiyama Formation, St—Shiritakayama Formation, O—Oyashirazu Formation for the Asahi area (Takeuchi et al., 2015a); Ng—"Nagano Shale", A—"Ashidani Formation in the Kamihambara area (Fujita, 2002)", KK—Kurotodo and Kamihambara formations, I—"Itsuki Formation in the Kamihambara area (Fujita, 2002)", uK—"Upper Formation of the Kuzuryu Subgroup (Yamada et al., 1989)", Hd—Hayashidani Andesite for the Mana–Ono–Nagano–Kamihambara areas in the Kuzuryu District (Tanase et al., 1994; Sano et al., 2013); T—Tochio Formation for the Tochio area (Maeda, 1958a). The numerical ages are based on ICS (2015).

reviewed in each area, and compared with those of the Kuzuryu and Tetori groups (Fig. 4).

1 Jinzu Region in the Hida Belt (Fig. 4A)

Upper Mesozoic strata (= The Tetori Group (*s.l.*)) in the Jinzu Region is divided into two parts: lower marine sequence and upper non-marine sequence (e.g., Maeda, 1961d; Hirasawa et al., 2010; Matsukawa et al., 2014a). The lower sequence is now in fault contact with, but originally unconformably overlies the constituent rocks of the Hida Belt, such as Hida Metamorphic Rocks and granitoids (e.g., Matsukawa et al., 2014a). The upper sequence unconformably overlies the lower sequence or the constituents of the Hida Belt (e.g., Kashiwagi and Hirasawa, 2010; Matsukawa et al., 2014a).

The stratigraphy, correlation and age assignment of the upper non-marine sequence (= Jinzu Group of Matsukawa et al. (2014a)) is still debatable (e.g., Maeda, 1961d; Omura, 1973, 1974; Matsukawa et al., 1997b, 2014a; Board of Education of Toyama Prefecture, 2003; Hirasawa et al,, 2010), because of the absence of marine index fossils and key beds/horizons. In this paper, the names of the strata of the upper non-marine sequence basically follow those of Matsukawa et al. (2014a): the Ioridanitoge, Inotani and Shiroiwagawa formations, in ascending order.

Marine/brackish horizons—The lower marine sequence contains abundant marine ammonoids, other molluscs and trace fossils (e.g., Kobayashi, 1956, 1957b; Sato, 1962, 2008; Maeda, 1962c; Maeda and Kawabe, 1963, 1966; Matsukawa et al., 2008b; Hirasawa and Kashiwagi, 2010; Hirasawa et al., 2010; Hirasawa, 2012a, b, 2015; Sato et al., 2012; Sato and Yamada, 2014). Abundant radiolarians and other microfossils were also recently reported from this sequence (Kashiwagi and Hirasawa, 2010, Hirasawa et al., 2010). It should be noted that marine influence was supposed by the geochemical study in the Shiroiwagawa Formation (Hasegawa et al., 2010), though further studies are necessary to clarify this possible marine record. On the contrary, rare occurrences of possible freshwater bivalves are recently reported from the Ioridanitoge and Inotani formations (Shigeno, 2003; Fujita, 2014; Matsukawa et al., 2014a, b).

Biostratigraphic age data—The lower marine sequence is assigned to the Oxfordian age by the ammonoid biostratigraphy (e.g., Sato, 1962, 2008; Matsukawa et al., 2008b; Sato et al., 2012; Sato and Yamada, 2014). Such age assignment has been confirmed recently by the radiolarian biostratigraphy (Kashiwagi and Hirasawa, 2010; Hirasawa et al., 2010).

Chemostratigraphy—Hasegawa and Hibino (2006) already published the preliminary result of organic carbon isotope study from the upper non-marine sequence. If reliable datum planes can be established, carbon-isotope stratigraphy probably provides a powerful tool for the correlation between the non-marine and marine strata (e.g., Hasegawa, 2003; Hasegawa and Hibino, 2006; Weissert et al., 2008). Attention should be paid to the application of this method to the stratigraphic study of Mesozoic non-marine strata in future.

Numerical age data—Kawagoe et al. (2014) reported 120.0 ± 1.2 Ma (2 SD) LA-ICPMS U-Pb zircon age for the tuff bed possibly from the upper part of the Inotani Formation. Matsukawa et al. (2014a) discussed the age of non-marine sequence as Aptian–Albian based on their own new FT dating with best-fit peak ages (112.5 (-11.0, +11.7) Ma, 102.6 (-6.1, +6.5) Ma, 121.0 (-12.1, +11.7) Ma, 111.6 (-6.2, +6.6) Ma, in ascending order) of the tuffaceous sandstone in the Inotani Formation. On the other hand, Harayama et al. (1991) reported K-Ar age of 106 ± 5 Ma and 102 ± 2 Ma from the Kurobegorodake Diorite, which intruded the Jinzu Group in the easternmost part of its distribution. These data probably represent the upper limit of the depositional age of the Jinzu Group. In addition, such plutonic activities possibly caused the thermal effects to the FT age data of the Jinzu Group. Thus the age of the Jinzu Group is considered as the Aptian–early? Albian in this paper, and significant hiatus (at least from the Kimmeridgian to Barremian) is supposed to occur between the lower marine and upper non-marine sequences.

Correlation—The Oxfordian marine sequence corresponds to TS-Ib represented by the Yambarazaka Formation in the Hakusan Region. The lower marine sequence is redefined as the the Kuzuryu Group in this paper, as mentioned before, though the strata correlated with the middle to lower part of the Kuzuryu Group (Kaizara Formation (corresponding to TS-1a) or lower formations) in the Hakusan Region have not been recognized in the Jinzu Region (Fig. 4).

Matsukawa et al. (2014a) considered their FT age data are significantly younger than the age of the Tetori Group, and thus proposed new name: the Jinzu Group for the upper non-marine sequence of the Mesozoic strata in the Jinzu Region. However, since DS3 in the Hakusan Region is assigned to the Barremian–Aptian as discussed above, the uppermost part of the Tetori Group can be considered as the age equivalent to at least some part of the Jinzu Group. The absence of DS2 equivalent in the Jinzu Region suggest the difference of the geological histories of the Cretaceous basins between the Hakusan and Jinzu regions, and support the idea of the separation of the Jinzu Group from the Tetori Group. Difference of the river systems between the two groups has already been pointed out by the detrital zircon geochronology (Kawagoe et al., 2014), and probably support that idea.

On the other hand, the Albian part of the Jinzu Group can be correlated with DS4 in the Hakusan Region. Occurrence of thermophilic plant species probably from the the Inotani Formation (Yabe et al., 2003), and the presence of the red beds with abundant pedogenetic calcareous nodules in the Shiroiwagawa Formation (Shigeno et al., 2004; Matsukawa et al., 2014b) indicate that the warmer and dryer climatic conditions, which are comparable to those of the upper part of DS3 in the Hakusan Region (e.g., Yabe et al., 2003) or much younger (Albian) strata, such as the Kwanmon and Sasayama groups (e.g., Yamada, 2009; Horiuchi et al., 2009), prevailed there.

2 Hida Gaien Belt

1) Kuzuryu District (Fig. 4C)

The Tetori Group (*s.l.*) in this district is divided into three fault-bounded parts (Northern, Middle and Southern rows): the Northern Row in the Hida Belt and the Middle and Southern rows in the Hida Gaien Belt (Sano et al., 2013). Boundary between the Northern and Middle rows is marked by the fault running southern margin of the Hida Metamorphic Rocks, that of the Middle and Southern rows by the Ono Thrust. Stratigraphy and age data of the Tetori Group (*s.l.*) in the Middle and Southern rows were recently reviewed in Sano et al. (2013), and now it is clear that they are probably different from those of the Tetori Group (*s.s.*) in the Itoshiro area in the Northern Row. Thus the Managawa Group, named in Kobayashi (1954), is used here for the Late Mesozoic strata in the Mana–Ono–Nagano–Kamihambara areas in the Middle Row to avoid confusion with the Tetori Group (*s.s.*). In this chapter, Late Mesozoic strata in the Middle Row are mainly focused on, and those in the Southern Row is briefly mentioned in the Remarks section. The Managawa Group unconformably overlies, or is in fault contact with the Carboniferous Fujikuradani Formation, a constituent rock of the Hida Gaien Belt, in the Mana–Ono areas (e.g., Maeda, 1961a; Yamada, 1967; Fukahori et al., 1983). At present the stratigraphy of the Mesozoic strata in the Middle Row await its complete revision (Sano et al., 2013). Since the names of formations of the Tetori Group (*s.s.*) in the Itoshiro area in the Northern Row had been usually applied to the succession in the Middle Row, the names of the formations of the Managawa Group are not fully established yet.

Marine/brackish horizons—Many ammonoids, belemnites and bivalves have been described or reported from the Managawa Group in the Mana–Ono–Nagano–Kamihambara areas (Kobayashi, 1954; Hayami, 1960; Maeda, 1961a, 1962d; Sato, 1962, 2008; Yamada et al., 1989; Fujita et al., 1998; Fujita, 2002; Matsukawa et al., 2003c; Sato and Yamada, 2005; Yamada and Uemura, 2008; Sano et al., 2013). Marine strata are called differently in each area, such as the Kurotodo Formation in the Mana–Ono areas, the "Nagano Shale" in the Nagano area (see Sano et al., 2013), and the Kamihambara Formation in the Kamihambara area (Fujita, 2002). At least two marine strata, corresponding to TS-Ib (Oxfordian) and TS-IIa (Tithonian), are supposed to be there, though the distribution of each stratum and their stratigraphic relationship are still ambiguous (Sano et al., 2013).

Brackish bivalves occur in several horizons in the Kamihambara area (Fujita, 2002). For examples, *Myrene* (*Mesocorbicula*) were known from the horizons above and below the Kamihambara Formation (TS-IIa) ("Itsuki and Ashidani formations", respectively; Fig. 4). Another brackish bivalve *Myopholas tanakai* and freshwater molluscs were also reported from the horizon above the Kamihambara Formation (= "Itsuki Formation" of Fujita (2002); Fig. 4) (Fujita, 2002; Sano et al., 2013). Although the occurrences of brackish and freshwater molluscs were also reported from the southern part of the Mana area (e.g., Kobayashi, 1954; Maeda, 1961a; Yamada et al., 1989), their stratigraphic position in the Managawa Group are uncertain.

Hasegawa et al. (2010) confirmed the marine or brackish condition of the middle part of the Managawa Group in the Kamihambara area (= "Itoshiro and Akaiwa subgroups" in the Izumi Section (east) in Hasegawa et al. (2010)) based on geochemical studies.

Biostratigraphic age data—Sato and Westermann (1991) established the Oxfordian ammonoid zonation in the Tetori Group (*s.l.*) mainly based on the ammonoid records from Nagano. This ammonoid-bearing stratum was assigned to the "Nagano Shale" in the Nagano area (Sano et al., 2013). An Oxfordian ammonoid specimen from the Mana area was also figured in Sato (1962). A Tithonian ammonoid *Parapallasiceras* has been described or reported from the Mana, Ono and Kamihambara areas (Sato and Yamada, 2005; Yamada and Uemura, 2008; Sano et al., 2013).

A brackish bivalve *Myopholas tanakai* has been known from the Hauterivian formations in the Outer Zone of Southwest Japan (Tashiro, 1994). Its occurrence from the horizon above the Tithonian Kamihambara Formation possibly contributes its age assignment (Fujita, 2002; Sano et al., 2013).

Rare fern spores were reported from the Kamihambara area, though age assignment based on these fossils is probably difficult (Umetsu and Matsuoka, 2003; Umetsu and Sato, 2007).

Numerical age data—Lapilli tuff from the upper part of the Managawa Group in the Mana area ("Upper Formation of the Kuzuryu Subgroup"; Fig. 4) has 124.6 ± 2.3 Ma (2 SD) LA-ICPMS U-Pb zircon age (Kawagoe et al., 2012). The Hayashidani Andesite of ca. 100 Ma, representing DS4 in the Hakusan Region, directly covers also the Managawa Group in the Kamihambara area with unconformity (Tanase et al., 1994). It means that the Tetori Group in the Hida Belt and the Managawa Group in the Hida Gaien Belt had juxtaposed before DS4.

Correlation—Marine strata corresponding to TS-Ib and TS-IIa have been recognized in the Managawa Group (e.g., Sato, 1962; Sato and Yamada, 2005; Sano et al., 2013), though their stratigraphic relationship (belonging to a same formation or two different formations) are still uncertain. It should be noted that TS-IIa is known only in the Managawa Group, but not in the Tetori Group.

The Managawa Group has the stratigraphic range at least from the Oxfordian to early Aptian, and corresponding to the upper part of the Kuzuryu Group and the Tetori Group. No large time gap has been known during its depositional time at this moment. Even during the time of possible hiatus between the Kuzuryu and Tetori groups, the Kamihambara and Kurotodo formations representing TS-IIa, which has not been known in the Mesozoic strata in the Hida Belt, were deposited. However, since the change of depositional system in the sedimentary basin was supposed to occur at the time between the Kurotodo Formation and overlying non-marine strata (possibly during the time between Tithonian and Hauterivian) in the Mana–Ono areas (Yamada et al., 1989; Sano et al., 2013), stratigraphic gap in this horizon can be expected in future studies.

Remarks—In the Southern Row of the Tetori Group (*s.l.*) in the Kuzuryu District, its northernmost part contains possible Tithonian–Berriasian ammonoids and inoceramids, which is equivalent in its age and fauna to the Managawa or Tetori (*s.s.*) Group, whereas the age of its most part is still uncertain (Sano et al., 2013). The occurrence of *Hausmannia* (Maeda, 1961a), usually recovered from Late Triassic to Early Jurassic strata, from this latter part indicates that this undated stratigraphic sequence may be correlated with the Early Jurassic Kuruma Group or its equivalents, which is distributed in the Asahi area in the Hida Gaien Belt (T. Yamada written communication, 2013. August). Attention should be paid to that the gravels of serpentine and crystalline schist have been reported from this sequence (Sohma et al., 1983, fig. 4; Sohma and Maruyama, 1989, fig. 4, 5), as with the Kuruma Group (Kobayashi et al., 1957; Kumazaki and Kojima, 1996; Takeuchi et al., 2006). Furthermore, Northeast–Southwest directed lenticular distribution of the Tetori Group (*s.l.*) in the Southern Row indicates that these Mesozoic strata possibly formed a dextral strike-slip duplex with the Permian–Triassic formations (including the Motodo Formation, which had been considered as a part of the Tetori Group (*s.l.*) (see Kawagoe et al. (2013) for the discussion of its attribution)) of the Hida Gaien

Belt after its deposition (Sano et al., 2013). In this case, their age defines the lower limit of the dextral movement, and they possibly deposited faraway place (in the East) from the Managawa Group and even from the Tetori Group (*s.s*) (Sano et al., 2013). Further studies are necessary to confirm these hypotheses.

2) Tochio area (Fig. 4D)

Maeda (1958a) established the Tochio Formation in the Tetori Group (*s.l.*) in the Tochio area. Matsukawa et al. (2007) considered the Tochio Formation is a time equivalent to the Sugizaki Formation, both of which were possibly deposited in the same or nearby basin(s). However, since the differences between the Tetori Group in the Hida Belt and Late Mesozoic strata in the Hida Gaien Belt were pointed out in the Kuzuryu District (Sano et al., 2013), the Tochio Formation in the Hida Gaien Belt is separately discussed from the Tetori Group in the Hida-Furukawa area in the Hida Belt in this paper. The Tochio Formation is in fault contact with the constituent rocks of the Hida Gaien Belt (Harayama, 1990; Otoh et al., 2003). Otoh et al. (2003) pointed out that the age of the Tochio Formation provides the clues to revealing the formation of the Hida Gaien Belt, constraining the timing of the sinistral shearing there.

Biostratigraphic age data—Maeda (1959) paid attention to the occurrences of two brackish bivalves from the Tochio Formation: *Polymesoda* (*Isodomella*) *kobayashii* sp. nov. and *Polymesoda* (*Paracorbicula*) *sanchuensis*, which are different from brackish molluscs in other areas of the Tetori Group (*s.l.*), but probably similar to those of Lower Cretaceous in the Outer Zone of Southwest Japan and the Yoshimo Formation of the Toyonishi Group in the Inner Zone of Southwest Japan, and named the Kamitakara Fauna for them (Maeda, 1958a). Later Hayami (1975) assigned these species to *Crenotrapezium*? *kobayashii* and *Tetoria sanchuensis*, respectively. In addition, Matsukawa et al. (2007) figured *Crenotrapezium kobayashii* and *Tetoria yokoyamai* from this formation.

Tetoria sanchuensis has been recovered from the Hauterivian strata (Kondo et al., 2006) or Hauterivian–Early Aptian strata (Kozai and Ishida, 2003; Kozai et al., 2005, 2012; Nishida et al., 2013) in the Outer Zone of Southwest Japan. *T. yokoyamai* has been only known from DS2 in the Hakusan Region, and assigned to Berriasian–Late Hauterivian. Thus the age of the Tochio Formation is supposed to be the Hauterivian based on these bivalves.

Correlation—On the basis of the supposed Hauterivian age of the Tochio Formation, it can be correlated at least partly to the Early Cretaceous strata of the Managawa Group. Furthermore, occurrences of Hauterivian (possibly corresponding to TS-III) brackish bivalves, which have been known only from the Outer Zone of Southwest Japan, in the Managawa Group in the Kuzuryu District and the Tochio Formation may suggest possible similarity of tectonic or paleoenvironmental settings between the two strata. The Tochio Formation is tentatively included in the Managawa Group in the following discussion.

Remarks—Although numerical age data have not been obtained directly from the Tochio Formation, sandstone samples from the putative Ordvician Hitoegane Formation in the Fukuji area in the Hida Gaien Belt, which is adjacent to the Tochio area, contain detrital zircon of the Cretaceous or Paleocene LA-ICPMS U-Pb age (the youngest age is 123.2 Ma for NK-12, 59.7 Ma for NK-22) (Nakama et al., 2010). The former age is almost coeval with the upper part of the Managawa Group in the Mana area. Thus the distribution of Cretaceous strata in the Tochio–Fukuji areas is possibly much wider than previously thought. It should be noted that conspicuous shear zone runs along the southern boundary of the Tochio Formation (Otoh et al., 2003), and complex geological structure is suggested for these areas. Stratigraphic relationship among the Early Cretaceous Tochio Formation, the Maastrichtian Oamamiyama Group (Kasahara, 1979; Takahashi and Shimono, 1982), and newly-recognized Cretaceous–Paleocene strata in the Fukuji area remain unsolved, and further studies are awaited.

3) Asahi area (Fig. 4B)

Although non-marine strata covering the Kuruma Group in the Asahi area in the Hida Gaien Belt (e.g., Mizukamidani, Kurobishiyama and Shiritakayama formations) have been considered as the Tetori Group (*s.l.*) (e.g., Chihara et al., 1979; see Takeuchi et al., 2015a for historical review), their age assignment has been controversial for a long time, because of the lack of index fossils. In this paper, the stratigraphy of Cretaceous non-marine strata in this area are basically based on Takeuchi et al. (2015a).

Biostratigraphic age data—Marine or brackish horizon is not recognized in this area. Sakai et al. (2013) recently reported the occurrence of possible freshwater molluscs from the Shiritakayama Formation of the Takeuchi et al. (2015a, b), which was originally reported from the Mizukamidani Formation in Sakai et al. (2012).

Numerical age data—Takeuchi et al. (2015a) applied the LA-ICPMS U-Pb zircon dating to these strata and related rocks, and revealed that the youngest age of detrital zircon from the Mizukamidani Formation is ca. 123 Ma; the age of a dacite dyke intruding the Mizukamidani and overlying Kurobishiyama formations is ca. 109 Ma; the youngest age of detrital zircon from the Uchiyama Formation, which possibly covers the Kurobishiyama Formation with unconformity, is ca. 110 Ma. Thus the Mizukamidani and Kurobishiyama formations can be assigned to the Aptian (–early Albian) (ICS, 2015).

On the other hand, both the Shiritakayama and Uchiyama formations underlain the Oyashirazu Formation, where K-Ar ages of 96.6 ± 4.8 Ma and 89.7 ± 4.5 Ma were reported (Yamada et al., 2001). The youngest age of detrital zircon from the Shiritakayama Formation is also ca. 110 Ma, though the reliability of this datum needs further confirmation (Takeuchi et al., 2015a, b). Both the Shiritakayama and Uchiyama formations show almost same age: Albian (–early Cenomanian) (ICS, 2015), and can be considered that they are composed of contemporaneous heterotopic facies (the Uchiyama Formation contains thick rhyolitic or andesitic lavas/volcanic rocks) (Takeuchi et al., 2015a).

Correlation—Aptian strata are distributed more widely in the Hida and Hida Gaien belts than pre-Aptian strata. The Mizukamidani and Kurobishiyama formations can be correlated with the upper part of the Managawa Group or the lower part of the Jinzu Group, or the uppermost part of the Tetori Group or DS3 in the Hakusan Region. The Uchiyama and Shiritakayama formations are correlated with DS4 in the Hakusan Region, or possibly to the upper part of the Jinzu Group, or even to the Kwanmon and Sasayama groups.

Tomita et al. (2007) and Takeuchi et al. (2015b) recognized the similarity of the characters of composition of clastics, their stratigraphic change, and the occurrences of Permian and Triassic radiolarian fossils in the gravels between the Mizukamidani and Kurobishiyama formations and the Jinzu Group. On the other hand, Takeuchi et al. (2015a, b) pointed out the difference of the published depositional age between these strata, and also the necessity of the application of U-Pb zircon dating to the Jinzu Group to reconfirm their possible correlation. As discussed above, the Mizukamidani and Kurobishiyama formations can be correlated with at least some part of the Jinzu Group. Thus the Early Cretaceous strata in the Asahi area is most likely correlated in age and clastic composition with the Jinzu Group. Since the Uchiyama Formation overlies not only the Kurobishiyama Formation but also the granite in the Hida Belt (Takeuchi et al., 2015a), it is indicated that the Hida Belt and Hida Gaien Belt in this area had been juxtaposed before the deposition of this formation (probably Albian) at the latest, and possibly in the Aptian, and thus similar lithofacies (e.g., the Jinzu Group) probably deposited in both belts.

4) Nyukawa area

The "Yokoo Conglomerate Formation (Kasahara, 1979)", or "Yokoo Conglomerate (Kojima, 1986)" in the Nyukawa area has been assigned to the Tetori Group (*s.l.*) (e.g., Nozawa et al., 1975; Otoh et al., 2003). Matsukawa et al. (2007) included it in the Tanemura Formation of the Tetori Group (*s.s.*) in the Hida-Furukawa area. However, it is distributed near the boundary between the Hida Gaien Belt (North) and the correlative of the Ultra-Tamba Belt (South) (Kojima, 1986; Niwa et al., 2002), and probably separated from the Tetori Group (*s.s.*). Although the stratigraphic position and age of this stratum is still uncertain, by the presence of reddish brown to yellowish brown tuffaceous rocks (Kojima, 1986), it can be correlated with Albian volcanic strata, such as the Hayashidani Andesite in the Kuzuryu District or the Uchiyama Formation in the Asahi area both in the Hida Gaien Belt.

3 Joetsu Belt

Very narrow distribution of the possible Early Cretaceous shallow marine to non-marine stratum has been known in the Katashina area in the Joetsu Belt, which located about 140 km east from the Asahi area (Hayashi et al., 1965; Toya et al., 1965; Hayama et al., 1969; Sudo, 1976). The occurrences of *Myrene* (*Mesocorbicula*) *tetoriensis*, which characterizes the Early Cretaceous Tetori Group (*s.l.*), and plant fossils similar to the Tetori-type flora were reported from the Tokurazawa (or Tokurasawa) Formation (Hayashi et al., 1965; Kimura et al., 1979; Matsukawa et al., 2015). On the basis of these data, the Tokurazawa Formation has been assigned to, or correlative with the Tetori Group (*s.l.*) (Hayashi et al., 1965; Toya et al., 1965; Kimura et al., 1979; Takenouchi and Takahashi, 2002; Matsukawa et al., 2015).

Marine/brackish horizons—The Tokurazawa Formation consists of the Lower, Middle and Upper members (Toya et al., 1965; Kimura et al., 1979). Marine belemnites were recovered from the Lower Member, and a brackish bivalve *Myrene* and plant fossils from the Upper Member (Hayashi et al., 1965; Toya et al., 1965; Kimura et al., 1979; Matsukawa et al., 2015). The Middle Member is composed of an arkose and partly conglomeratic sandstone (Toya et al., 1965; Matsukawa et al., 2015), and possibly indicates the freshwater or terrestrial depositional environment.

Biostratigraphic age data—No good age-diagnostic fossil has been reported at present. Thus the Tokurazawa Formation is not shown in Figure 4.

Correlation—The Joetsu Belt is characterized by low-grade schists indicating high-pressure type metamorphism, metabasic rocks, ultrabasic rocks, Permian accretionary complex, and Permian, Late Triassic, Early Jurassic and possible Early Cretaceous shallow marine to brackish strata (the Oze-Takinosawa Formation, the Okutone Group, the Iwamuro Formation, the Tokurazawa Formation, respectively), and located in the inner side of the Jurassic accretionary complex (Ashio Belt) (Takenouchi and Takahashi, 2002). The Tokurazawa Formation is surrounded by, and in fault contact with the Tokura Metabasic rocks (e.g., Takenouchi, 1988; Takenouchi and Takahashi, 2002). Such constituent rocks of the Katashina area are similar to those in the Asahi area and the Southern Row of the Kuzuryu District, both in the Hida Gaien Belt. *Myrene*, belemnites and plant fossils similar to the Tetori-type flora were known not only from the Tetori Group (*s.s.*), but also from the Managawa Group (for example, the succession from the Kamihambara to the "Itsuki" formations of Fujita (2002) in the Kamihambara area) (e.g., Maeda, 1961a; Kimura, 1975; Fujita, 2002; Sano et al., 2013). Thus the Tokurazawa Formation is possibly correlated with the Managawa Group, and not to the Tetori Group (*s.s.*). In this case, the marine and brackish horizons of the Managawa Group and its correlatives can be traced to the Katashina area, far east from the Tochio area.

4 Summary of the division of the Tetori Group (*sensu lato*)

The Tetori Group (*s.l.*) in northern Central Japan can be divided into four different groups at this moment: Middle–Late Jurassic (Bathonian–Oxfordian) Kuzuryu Group distributed in the Hakusan Region in the Hida Belt, and only its Late Jurassic strata in the Jinzu Region in the Hida Belt; Early Cretaceous (Berriasian–Aptian) Tetori Group (*s.s.*) only in the Hakusan Region in the Hida Belt; Early Cretaceous (Aptian–early? Albian) Jinzu Group in the Jinzu Region and its possible correlatives in the Asahi area in the Hida Gaien Belt; Late Jurassic–Early Cretaceous (Oxfordian–

early Aptian) Managawa Group in the Kuzuryu District and the Tochio area both in the Hida Gaien Belt (Fig. 4).

The Kuzuryu Group shows only narrow distribution. At the period of TS-Ia, it is distributed only in the Itoshiro area of the Hakusan Region, whereas, at the period of TS-Ib, it is distributed not only in the Itoshiro area, but also in very narrow areas in the Jinzu Region. On the contrary, the Tetori Group is widely distributed in the Hakusan Region, indicating the possible difference of the mode of development and size of the sedimentary basins and/or tectonic setting between the periods of deposition of the Kuzuryu and Tetori groups. The size of basin(s) probably became wider in the Hauterivian (before the period of TS-III at the latest). Sedimentation continued in most parts of the Hakusan Region to the period of DS3, but ceased before the period of DS4.

The Managawa Group is characterized by the occurrence of rich Oxfordian ammonoid fauna representing the *Kranaosphinctes matsushimai* assemblage zone of Sato and Westermann (1991), which is corresponded to TS-Ib; the presence of marine strata corresponding to TS-IIa and the possible absence of marine strata corresponding to TS-IIb; the occurrences of the possible Hauterivian brackish bivalves usually found in the Outer Zone of Southwest Japan with typical brackish bivalves of the Tetori Group; a clear evidence of volcanic activity of the age close to the Barremian–Aptian boundary, which has not been known in the Tetori Group, but possibly in the Jinzu Group (Fig. 4). Further studies are necessary to reveal the stratigraphy of the Managawa Group, and to clarify its difference from and/or similarity with the Tetori Group.

The Aptian–early? Albian Jinzu Group is composed of the lithofacies reflecting alluvial fan, fluvial and flood-plain environments (e.g., Matsukawa et al., 2014b), and deposited in the period after the transition from DS2 to DS3 in the Hakusan Region (Fig. 4). It is indicated that sedimentary basin(s) showed much wider distribution at that time than previous period in the Hida Belt and possibly even in the Hida Gaien Belt. The presence of Albian volcanic rocks, and red beds with abundant pedogenetic calcareous nodules are characteristic lithofacies of the upper part of the Jinzu Group and its possible correlatives in the Asahi area. They can be compared in age and lithofacies to DS4 in the Hakusan Region, possibly to the "Yokoo Conglomerate Formation" in the Nyukawa area, and to the Kwanmon and Sasayama groups, indicating that the warmer and dryer climate and also volcanic activities prevailed in the Inner Zone of Southwest Japan at that time.

Omura (1973) already proposed the four-fold division of the Mesozoic strata in the northern Central Japan: the Kuzuryu, Tetori, Arimine and Asuwa groups. The Asuwa Group of Omura (1973) includes the Omichidani Formation and its coeval strata in the Hakusan Region. Matsukawa et al. (2014a, p. 156) named the Jinzu Group for almost same stratigraphic unit with the Arimine Group to avoid the duplication of the group name and formation name in the same region. Thus, in terms of the group division, the proposal of this paper is similar to that of Omura (1973), though the correlation of the strata within the groups are completely different, and DS4 is newly recognized in the time between the Tetori and Asuwa groups in this paper.

5 Comments on the group divisions of the strata of the Tetori Group (*sensu lato*) where radioralia-bearing gravels were recovered

Radiolarian records from the gravels in the Tetori Group (*s.l.*) attracted much attention for last three decades, because they represent the clues to revealing the exhumation and denudation process of the Jurassic accretionary complexes, such as those of the Mino Belt, and also the juxtaposing of the Hida, Hida Gaien and Mino belts (Kojima, 1986; Saida, 1987; Takeuchi et al., 1991; Matsukawa and Takahashi, 1999; Tomita et al., 2007; Ito et al., 2012, 2014a, 2015; Takeuchi et al., 2015b). The Itoshiro and Akaiwa subgroups of the Tetori Group (*s.l.*) in Maeda (1961d) have been used to describe geological setting in all these studies (e.g., Ito et al., 2012, table 1). As discussed above, recent age data indicate that such subgroup division cannot be applied to the Cretaceous strata in the Hida Gaien Belt and the Jinzu Region in the Hida Belt. The group divisions of the strata, where radioralia-bearing gravels were recovered, are briefly mentioned here based on the proposal of group division in this paper.

The radiolarian records from the gravels in the Tetori Group (*s.s.*) were reported from the Otaniyama Formation in the Shokawa area (Matsukawa and Takahashi, 1999) and the Itsuki Formation in the Itoshiro area (Ito et al., 2015). The radiolarian records from the gravels in the Kurobegawa area (Takeuchi et al., 1991) represent the only record from the Jinzu Group in the Hida Belt. The Mizukamidani and the Kurobishiyama formations in the Asahi area in the Hida Gaien Belt contains the radiolaria-bearing gravels (Tomita et al., 2007; Takeuchi et al., 2015b), and are probably correlable to the Aptian part of the Jinzu Group. Ito et al. (2012, 2014a) also reported the radiolaria-bearing gravels in the Cretaceous stratum in the Asahi area. Although they considered this stratum was the Mizukamidani Formation, it was re-assigned to the Albian Shiritakayama Formation in Takeuchi et al. (2015a, b).

Another record of radioralia-bearing gravels was reported from the "Yokoo Conglomerate" in the Nyukawa area (Kojima, 1986), which is possibly correlated with Albian volcanic strata, such as the Hayashidani Andesite in the Kuzuryu District or the Uchiyama Formation in the Asahi area both in the Hida Gaien Belt.

The records in the Kamihambara area (Saida, 1987) are those of the Managawa Group in the Hida Gaien Belt. It should be noted that the studied conglomerate is found in the lower horizon in the stratigraphic sequence (= "Ashidani Formation") than the Tithonian Kamihambara Formation (e.g., Fujita, 2002), and its pre-Tithonian age can be considered as the earliest record indicating the exhumation and denudation process of the Jurassic accretionary complex (Ito et al., 2014b). On the other hand, Ito et al. (2014b) still questioned the stratigraphic position of radiolarian-bearing gravels and also their age assignment.

The exhumation and denudation process of the Jurassic accretionary complexes should be discussed in future research, considering the paleogeographic relationships among the sedimentary basins of each Early Cretaceous stratum in northern Central Japan.

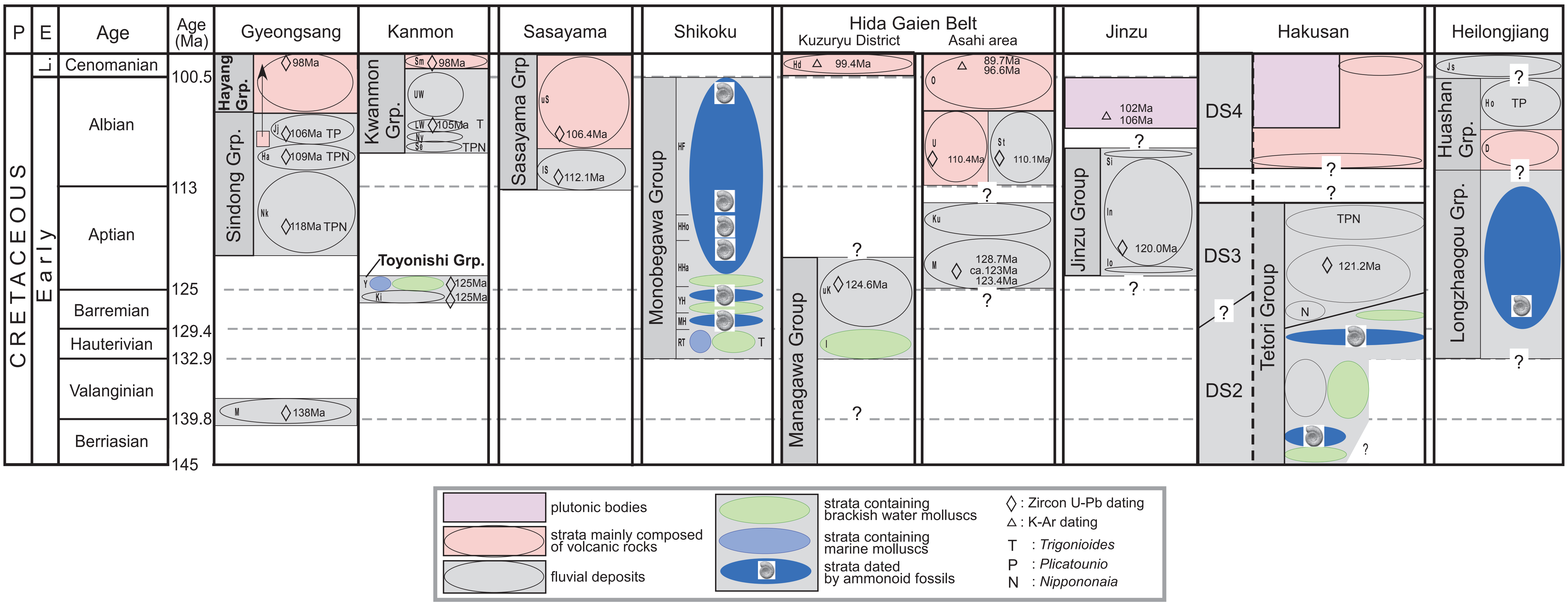

FIGURE 5. Comparison of stratigraphy, marine and brackish horizons, volcanic/plutonic strata/rocks, numerical age data, and the occurrences of selected freshwater bivalves of the Early Cretaceous strata in the Inner Zone of Southwest Japan and adjacent regions. Data are based on the following studies: Gyeongsang Region in South Korea—Chang and Park, 2003; Jwa et al., 2009; Lee et al., 2010, Kanmon Region in the Inner Zone of Southwest Japan—Shiraishi and Yoshidomi, 2005; Kozai et al., 2005; Aoki et al., 2014, Sasayama Region in the Inner Zone of Southwest Japan—Yoshikawa, 1993; Hayashi et al., 2010; Kusuhashi et al., 2013, Shikoku Region in the Outer Zone of Southwest Japan—Kozai et al., 2005; Matsukawa and Obata, 2015, Heilongjiang Region in Northeast China—Sha, 2007; Sha et al., 2012. Note that about 97 Ma tuff bed of the Hayang Group in the Gyeongsang Region contains some accidental zircons of 107.9 Ma, which indicate the presence of Albian volcanic activity there (Jwa et al., 2009). Abbreviation: M—Myogok Formation, Nk—Nakdong Formation, Ha—Hasandong Formation, Jj—Jinju Formation for the Gyeongsang Region (Lee et al., 2010); Ki—Kiyosue Formation, Y—Yoshimo Formation, Se—Sengoku Formation, Ny—Nyoraida Formation, LW—Lower Wakamiya Formation, UW—Upper Wakamiya Formation, Sm—Shimonoseki Subgroup for the Kanmon Region (Kozai et al., 2005; Aoki et al., 2014); lS—"Lower Formation" of the Sasayama Group, uS—"Upper Formation" of the Sasayama Group for Sasayama Region (Kusuhashi et al., 2013); RT—Ryoseki and Tatsukawa formations, MH—Monobe and Lower Hanoura formations, YH—Yunoki Formation and Hiura Facies, HHa—Lowermost part of Hibihara Formation and Upper Hanoura Formation, HHo—Lower part of Hibihara Formation and Hoji Formation, HF—Upper part of Hibihara Formation and Fujikawa Formation for the Shikoku Region (Kozai et al., 2005); D—Dongshan Formation, Ho—Houshigou Formation, Js—Jinsha Formation for the Heilongjiang Region (Sha, 2007; Sha et al., 2012); See abbreviation in Figure 4 for other regions. The numerical ages are based on ICS (2015).

COMPARISON OF GEOLOGICAL EVENTS OF THE TETORI GROUP WITH THOSE OF EARLY CRETACEOUS STRATA IN THE INNER ZONE OF SOUTHWEST JAPAN AND ADJACENT REGIONS

1 Correlation of geological events

Generally non-marine Early Cretaceous strata are sporadically but widely distributed in the Inner Zone of Southwest Japan and adjacent regions, and their correlation with the Tetori Group has been discussed frequently (e.g., Yang, 1979; Matsumoto et al., 1982; Tamura, 1990; Matsukawa and Obata, 1992; Chang and Park, 2003; Kozai et al., 2005; Sha et al., 2012). Depositional ages and marine/brackish horizons of these Early Cretaceous strata are summarized in Figure 5, mainly based on the recent age data of zircon U-Pb dating, and also age assignment using marine fossils in the Shikoku and Heilongjiang regions. Occurrences of some freshwater bivalves, *Trigonioides*, *Plicatounio* and *Nippononaia*, which are typical to Early Cretaceous East Asia, are also shown in Figure 5, according to Sha et al. (2012) and Kozai et al. (2005), to indicate the horizons of freshwater environments. In this chapter, geological events recorded in the Tetori and Jinzu groups and other Early Cretaceous strata/rocks in the Tetori Region are tentatively compared with those in other regions for future research.

The marine/brackish strata of the Berriasian age are only distributed in the Hakusan Region, though the early Valanginian Myogok Formation with freshwater molluscs has been known in the Gyeongsang (or Kyongsang) Region. The development of sedimentary basins of the Monobegawa Group in the Shikoku Region and the Longzhaogou Group in the Heilongjiang Region started in the Hauterivian, almost concurrently with the widening of sedimentary basin in the Hakusan Region. Possible causal relationship of basin development in these regions in the Hauterivian was already pointed out (e.g., Tashiro and Okuhira, 1993; Matsukawa et al., 1997a), and was ascribed to the tectonic duplication of Jurassic–early Early Cretaceous accretionary complexes at that time, proposed by Matsukawa et al. (1997a) (Matsukawa et al., 2007; 2008a; Matsukawa and Fukui, 2009). However, its mechanism and timing should be reconfirmed and re-discussed in future studies, considering the presence of subsequent other geological events discussed below.

The marine/brackish strata of the Hauterivian–Barremian age are known mainly in the Kanmon and Hakusan regions in the Inner Zone of Southwest Japan. Drastic change of the depositional environment from the brackish lake (DS2) to fluvial environment (DS3) possibly started at the early Barremian (after TS-III) and probably completed within the Barremian in the Hakusan Region. The youngest marine/brackish strata in the Kanmon Region is the Yoshimo Formation of the Toyonishi Group, and was recently assigned to the age around Barremian–Aptian boundary by zircon U-Pb dating (Aoki et al., 2014), though such age is comparatively younger than previous age assignment (Hauterivian) based on molluscs (e.g., Kozai et al., 2005). Considering that the Sindong and Hayang groups in the Gyeongsang Region were deposited in the same or related basins with the Kwanmon Group (e.g., Okada and Sakai, 2000), similar change of depositional environments with the Hakusan Region possibly occurred in the Early Aptian after the end of the deposition of the Toyonishi Group, but before the start of the deposition of the Sindong Group. Thus the disappearance of marine influence, or distinct change of depositional environments from shallow marine/brackish lake to fluvial environments occurred in the Barremian–Early Aptian in the Hakusan and Kanmon regions or in the whole intracontinental basins in East Asia. Subsequently, no marine/brackish stratum of the Early Cretaceous age has been known there except for Shikoku and Heilongjiang regions, though sedimentation usually continued to the Albian in almost all regions. It should be noted that almost at the same time (early Aptian), new sedimentary basins started to develop in the Gyeongsang Region, the Jinzu Region, and the Asahi area, and the deepening of the depositional environment (= absence of brackish strata) is also recognized in the Monobegawa Group. It is speculated that some causal relationship might exist among also these geological events in the Barremian–Early Aptian: the disappearance of marine influence, and the development of sedimentary basins in East Asia, in addition to above-mentioned Hauterivian events.

The Albian time is characterized by the widespread andesitic volcanic/plutonic activities across almost all regions (e.g., DS4 in the Hakusan Region), now including the Sasayama Region and excluding the Shikoku Region. Such activities possibly extended to the Heilongjiang Region. These Albian volcanic strata/rocks are probably related to the development of huge volcanic belt along the continental margin of East Asia at that time (e.g., Takahashi, 1983).

These Albian volcanic episodes in a continental arc were recently interpreted as the final stage of slab rollback after the flat-slab subduction during the Jurassic in East Asia (e.g., Kiminami and Imaoka, 2013; Imaoka et al., 2014). Furthermore, a series of geological episodes, such as the basin development, uplift and volcanism, in the continental margin of western North America at the Paleogene (e.g., Smith et al., 2014) and of southeastern China at the early to mid-Jurassic (e.g., Li and Li, 2007), were recently recognized, and are ascribed to the flat-slab rollback. It is supposed that the series of above-mentioned geological events in Southwest Japan and adjacent regions in the Early Cretaceous (for example, the lithofacies change from (at least the upper part of) DS2 to DS4 through DS3 in the Hakusan Region) can be explained by the similar mechanism of the flat-slab rollback.

On the other hand, a series of Jurassic–earliest Cretaceous accretionary complexes is widely exposed in the Inner Zone of Southwest Japan (e.g., Wakita, 1988; Nakae, 2000). It contains abundant Carboniferous–Jurassic oceanic plate material/rocks, such as bedded chert, basalts and limestones, which clearly indicates very old (more than 100 million years) oceanic plate(s) subducted along the eastern margin of the Asian Continent at that time (e.g., Sano and Kojima, 2000; Imaoka et al., 2014). According to the comparative studies of subduction zones (e.g., Uyeda, 1983), an old oceanic plate slab generally subducts at a steep angle, and an accretionary prism is not fully developed in

TABLE 1. Comparisons of Hauterivian freshwater and brackish bivalves among the Monobegawa, Managawa and Tetori groups. Occurrence of *Trigonioides* (*Wakinoa*) *tetoriensis* from the Tetori Group is not based on the records from the Okurodani Formation, but the Aptian Kitadani Formation.

	Monobegawa Group	Managawa Group	Tetori Group
	Tatsukawa Formation	Tochio Formation; "Itsuki Formation" in the Kamihambara area	Okurodani Formation (*Kitadani Formation)
	Kozai et al. (2005, 2012)	Maeda (1959), Hayami (1975) Tashiro (1994), Fujita (2002), Matsukawa et al. (2007)	Kozai et al. (2005, 2012)
Freshwater bivalves	*Unio? ogamigoensis*		*Unio? ogamigoensis*
	Megasphaerioides okurodaniensis		*Megasphaerioides okurodaniensis*
	Batissa? antiqua		*Batissa? antiqua*
	Trigonioides (Wakinoa) tetoriensis		*Trigonioides (Wakinoa) tetoriensis**
		Sphaerium sp.	*Sphaerium coreanicum*
			Nagdongia soni
			Nippononaia tetoriensis
Brackish bivalves	*Myrene (Mesocorbicula) tetoriensis*	*Myrene (Mesocorbicula) tetoriensis*	*Myrene (Mesocorbicula) tetoriensis*
		Tetoria yokoyamai	*Tetoria yokoyamai*
	Crenotrapezium kitakamiense	*Crenotrapezium? kobayashii*	
	Tetoria sanchuensis	*Tetoria sanchuensis*	
	Myopholas tanakai	*Myopholas tanakai*	
	Protocardia ibukii		
	Costocyrena otsukai		
	Hayamina naumanni		
	Isodomella shiroiensis		
	Pulsidis antiqua		

the subduction zone. Such a general idea is not concordant with the Late Jurassic–Early Cretaceous case in East Asia, where the flat-slab or shallow angle subduction was supposed, and huge accretionary complexes were developed, as discussed above. Further detailed studies are required to reconstruct the tectonic model to explain Early Cretaceous geologic events in East Asia.

2 Comparison of the brackish bivalve fauna of the Managawa Group with those of the Tetori and Monobegawa groups

Occurrence of the possible Hauterivian brackish bivalves, usually found in the Outer Zone of Southwest Japan, is one of important characters of the Managawa Group. The comparison among almost coeval faunas from the Managawa and Tetori groups in the Inner Zone of Southwest Japan, and the Monobegawa Group in the Outer Zone of Southwest Japan is briefly discussed here (Table 1).

Five brackish bivalve species have been described or reported from the Managawa Group (Maeda, 1959; Tashiro, 1994; Matsukawa et al., 2007). Among them, *Tetoria sanchuensis* and *Myopholas tanakai* are known also from the Tatsukawa Formation of the Monobegawa Group, but not from the Tetori Group. *Polymesoda* (*Isodomella*) *kobayashii* Maeda, 1959 is now considered to belong to *Crenotrapezium*, and this genus is also known from the Tatsukawa Formation. On the other hand, the bivalve assemblage of the Tatsukawa Formation is characterized by the typical Early Cretaceous brackish genera in East Asia, namely *Hayamina*, *Isodomella* and *Pulsidis* (Kozai et al., 2012), and thus distinct difference and slight similarity exists between the brackish bivalve faunas of the Managawa and Monobegawa groups. On the other hand, the occurrences of typical brackish bivalves of the Tetori Group: *Myrene* (*Mesocorbicula*) *tetoriensis* and *Tetoria yokoyamai* (e.g., Kondo et al., 2006; Nishida et al., 2013), are recently recognized in the Managawa Group (Fujita, 2002; Matsukawa et al., 2007). Thus the similarity of the brackish bivalve faunas between the Managawa and Tetori groups is also strongly suggested. Occurrence of *Sphaerium* sp. from the Kamihambara area in the Kuzuryu District (Fujita, 2002) may suggest the presence of the typical freshwater bivalves of the Tetori Group in the Managawa Group.

Freshwater bivalves are usually not recovered in the Monobegawa Group (Tashiro and Okuhira, 1993), but several species have been known from the Tatsukawa Formation (e.g., Kozai and Ishida, 2003; Shinomiya, 2011; Kozai et al., 2012). Freshwater bivalve fauna of the Tatsukawa Formation is usually common with that of the Tetori Group, though some elements of the Tetori Group have not been known in the Tatsukawa Formation (Table 1). Even in the brackish bivalves, *Myrene* (*Mesocorbicula*) *tetoriensis* was also common element between the Tetori and Monobegawa groups (e.g., Kozai and Ishida, 2003; Kozai et al., 2012).

In summary, some common bivalves are recognized among two or three groups, and brackish bivalve fauna of the Managawa Group represents intermediate composition between those of the

Tetori and Monobegawa groups (Table 1). It is supposed that some geographical and/or environmental barrier(s) separated the composition of brackish faunas between the Monobegawa and Tetori groups. Such geographical and/or environmental conditions in the depositional area of the Managawa Group were possibly intermediate between those of the Monobegawa and Tetori groups, and may cause the intermediate composition of brackish bivalve fauna of the Managawa Group.

Recently, it is revealed that the bivalve faunas of the late Hauterivian Inagoe Formation in the Hida-Furukawa area and the Berriasian Mitarai Formation in the Shokawa area, both of which belong to the Tetori Group, are similar to that of the Barremian–Aptian Qihulin and Yunshan formations of the Longzhaogou Group in the Heilongjiang Region, Northeast China (Matsukawa et al., 2007; Matsukawa and Fukui, 2009; Sha and Hirano, 2012). Thus the northern current probably influenced the Tetori Basin, where the Tetori Group deposited, at that time.

On the contrary, shallow marine limestones containing hermatypic fossils occur in the Early Barremian Lower Hanoura and Monobe formations of the Monobegawa Group (e.g., Iba and Sano, 2007; Iba et al., 2011), and thus tropical/subtropical marine condition are indicated for the depositional area of the Monobegawa Group. Different environmental conditions, such as, temperature, salinity, oceanic current system, etc. (see the discussion in Kozai et al., 2012) are inferred to exist between the depositional areas of the Tetori and Monobegawa groups. Such ideas may provide the clues to revealing the differences and similarities of the Hauterivian brackish faunas of the Tetori, Managawa and Monobegawa groups, or even those of marine environmental conditions in the Hida Belt, the Hida Gaien Belt, and the Outer Zone of Southwest Japan in the Early Cretaceous.

New view of the Tetori Group and related strata possibly provides the basic standpoint to future studies of the interregional correlation among the Early Cretaceous strata, paleogeographical and paleoenviromental reconstruction, and also the evolution of Late Mesozoic terrestrial ecosystem in East Asia.

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* : in Japanese
** : in Japanese with English abstract
*** : in Russian with English summary

<　地名・地層名　>

Akahoke Formation ……… 赤歩危層
Akaiwa ……… 赤岩
Akaiwa Formation ……… 赤岩層
Akaiwa Subgroup ……… 赤岩亜層群
Amagodani Formation … アマゴ谷層
Aradani ……… 荒谷
Arimine Group ……… 有峰層群
Asahi ……… 朝日
Ashidani Formation ……… 葦谷層
Ashio Belt ……… 足尾帯
Asuwa ……… 足羽
Asuwa Group ……… 足羽層群
Awaradani Granodiorite ……… アワラ谷花崗閃緑岩
Bessandani (or Betsuzandani) Formation ……… 別山谷層
Chinaboradani Formation ……… 知那洞谷層
Dongshan Formation ……… 東山層
Fujikawa Formation ……… 藤川層
Fujikuradani Formation …… 藤倉谷層
Fukui ……… 福井
Fukuji ……… 福地
Fuxin Formation ……… 阜新層
Gifu-ken (= Gifu Prefecture) … 岐阜県
Gomishima (or Gomijima) Formation ……… 五味島層
Guantou Formation ……… 馆头層
Gyeonsang (or Kyongsang) Region ……… 慶尚区
Hakusan Region ……… 白山区
Hasandong Formation …… 霞山洞層
Hayang Group ……… 河陽層群
Hayashidani Andesite …… 林谷安山岩
Heilongjiang ……… 黒竜江
Heilongjiang Region ……… 黒竜江区
Hibihara Formation ……… 日比原層
Hida Belt ……… 飛騨帯
Hida-Furukawa ……… 飛騨古川
Hida Gaien Belt ……… 飛騨外縁帯
Hida Metamorphic Rocks ……… 飛騨変成岩類
Hitoegane Formation …… 一重ヶ根層
Hiura Facies ……… 日浦相
Hoji Formation ……… 傍示層
Honshu Island ……… 本州
Houshigou Formation ……… 猴石沟層
Huashan Group ……… 桦山層群
Ichinose ……… 市ノ瀬
Ikegahara ……… 池ケ原
Inagoe Formation ……… 稲越層
Inotani Formation ……… 猪谷層
Ioridanitoge Formation …… 庵谷峠層
Ishikawa Prefecture ……… 石川県
Itoshiro ……… 石徹白
Itoshiro Subgroup …… 石徹白亜層群
Itoshirogawa River ……… 石徹白川
Itsuki (or Izuki) Formation …… 伊月層
Iwamuro Formation ……… 岩室層
Izumi ……… 和泉
Jinju Formation ……… 晋州層
Jinsha Formation ……… 金沙層
Jinzu Group ……… 神通層群
Jinzu Region ……… 神通区
Jiufotang Formation ……… 九佛堂層
Joetsu Belt ……… 上越帯
Kaga ……… 加賀
Kaizara Formation ……… 貝皿層
Kamihambara ……… 上半原
Kamihambara Formation … 上半原層
Kamitakara ……… 上宝
Kanazawa ……… 金沢
Kanmon Region ……… 関門区
Kanto Mountains ……… 関東山地
Kaseki-kabe (or Kasekiheki) … 化石壁
Katashina ……… 片品
Kitadani ……… 北谷
Kitadani alternation of sandstone, shale and tuff … 北谷砂岩頁岩凝灰岩互層
Kitadani Formation ……… 北谷層
Kitamatadani Diorite … 北俣谷閃緑岩
Kiyosue Formation ……… 清末層
Kurobegawa ……… 黒部川
Kurobegorodake Diorite ……… 黒部五郎岳閃緑岩
Kurobishiyama Formation … 黒菱山層
Kurotodo ……… 黒当戸
Kurotodo Formation ……… 黒当戸層
Kuruma Group ……… 来馬層群
Kuwajima (or Kuwashima) Formation ……… 桑島層
Kuzuryu District (or Kuzuryugawa area/ Region) ……… 九頭竜地区
Kuzuryu Group ……… 九頭竜層群
Kuzuryu Subgroup …… 九頭竜亜層群
Kuzuryugawa River ……… 九頭竜川
Kwanmon (or Kanmon) Group ……… 関門層群
Longzhaogou Group …… 龍爪溝層群
Lower Hanoura Formation ……… 下部羽ノ浦層
Lower Wakamiya Formation ……… 下部若宮層
Makido Mafic Complex ……… 牧戸苦鉄質複合岩体
Mana ……… 真名
Managawa Group ……… 真名川層群
Managawa River ……… 真名川
Mino Belt ……… 美濃帯
Mitarai (or Mitarashi) Formation ……… 御手洗層
Miyagawa River ……… 宮川
Mizukamidani Formation … 水上谷層
Monobe Formation ……… 物部層
Monobegawa Group …… 物部川層群
Monomiyama Formation … 物見山層
Motodo Formation ……… 本戸層
Mt. Hakusan ……… 白山
Myogok Formation ……… 卯谷層
Nagano ……… 長野
Nagano Shale ……… 長野頁岩層
Nakdong Formation ……… 洛東層
Nochino Formation ……… 後野層
Nohi Rhyolite ……… 濃飛流紋岩
Numamachi Formation ……… 沼町層
Nyoraida Formation ……… 如来田層
Nyukawa ……… 丹生川
Oamamiyama Group … 大雨見山層群
Obuchi Formation ……… 大淵層
Oguchi ……… 尾口
Oidani Formation ……… 大井谷層
Okura Formation ……… 大倉層
Okurodani Formation ……… 大黒谷層
Okutone Group ……… 奥利根層群
Omichidani (or Omitidani) Formation ……… 大道谷層
Ono ……… 大納
Ono Thrust ……… 大納衝上断層
Osugidani ……… 大杉谷
Otaniyama Formation …… 大谷山層
Oyashirazu Formation …… 親不知層
Oze-Takinosawa Formation ……… 尾瀬滝ノ沢層
Ozogawa River ……… 尾添川
Pre-Nohi Andesite …… 先濃飛安山岩
Qihulin Formation ……… 七虎林層
Ryoseki ……… 領石
Ryoseki Formation ……… 領石層
Sanchu ……… 山中
Sasayama Group ……… 篠山層群
Sasayama Region ……… 篠山区
Sebayashi Formation ……… 瀬林層
Sengoku Formation ……… 千石層
Seto ……… 瀬戸
Setono ……… 瀬戸野
Shikoku Region ……… 四国区
Shimonoseki Subgroup … 下関亜層群
Shimoyama Formation ……… 下山層
Shiramine ……… 白峰

Shiritakayama Formation ··· 尻高山層
Shiroiwagawa Formation ··· 白岩川層
Shogawa River ····················· 庄川
Shokawa (or Shiokawa) ············ 荘川
Sindong Group ··············· 新洞層群
South Kitakami Region ··· 南部北上区
Sugizaki Formation ············ 杉崎層
Taie Formation ·················· 太江層
Takaharagawa River ············ 高原川
Takinamigawa ·················· 滝波川
Tamodani ························ 田茂谷
Tanemura Formation ············ 種村層
Taniyamagawa River ············ 谷山川
Tatsukawa Formation ············ 立川層
Tedorigawa (or Tedori/Tetori) River
······································ 手取川
Tetori ································· 手取
Tetori (or Tedori) Group ··· 手取層群
Tetori Region ····················· 手取区
Tetori Series ····················· 手取統
Tochimochiyama Formation ··· 栃餅山層
Tochio ································· 栃尾
Tochio Formation ··············· 栃尾層
Tokura Metabasic rocks
····················· 戸倉変塩基性岩類
Tokurazawa (or Tokurasawa) Formation
································· 戸倉沢層
Tomari ································· 泊
Toyama ······························ 富山
Toyama Prefecture ··············· 富山県
Toyonishi Group ············ 豊西層群
Uchinami Quartzdiorite
························ 打波石英閃緑岩
Uchinamigawa ·················· 打波川
Uchiyama Formation ············ 内山層
Ultra-Tamba Belt ············ 超丹波帯
Umagatani Unconformity
······ 馬ガ谷（または馬ヶ谷）不整合
Upper Hanoura Formation
··························· 上部羽ノ浦層
Upper Wakamiya Formation
······························ 上部若宮層
Ushikubigawa River ············ 牛首川
Ushimaru Formation ············ 牛丸層
Yambara Formation ············ 山原層
Yambarazaka Formation ······ 山原坂層
Yanagidani ··························· 柳谷
Yokoo Conglomerate ········· 横尾礫岩
Yokoo Conglomerate Formation
······························ 横尾礫岩層
Yoshimo Formation ············ 吉母層
Yunoki Formation ············ 柚ノ木層
Yunotani ························ 湯ノ谷
Yunshan Formation ············ 云山層