Early Cretaceous plant assemblages from the Tetori Group in central Japan and their paleoclimatic implications

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Contents

Abstract

The Early Cretaceous floras of East Asia have been divided into three types, the Tetori-, Ryoseki- and Mixed-type. The Tetori-type Flora, distributed in the Inner Zone of southwest Japan, Siberia and northeast China, flourished under warm-temperate and humid climate conditions. The Ryoseki-type Flora, distributed in the Outer Zone of southwest Japan and southern China, flourished under tropical to subtropical climate conditions with a seasonal aridity. The composition of the Tetori- and Ryoseki-type floras was completely different with no species in common. The Mixed-type Flora was distributed in between the Tetori- and Ryoseki-type floristic provinces.

This study discusses the Early Cretaceous climate on the eastern margin of Asia, target at the Barremian to Albian non-marine deposits of the Tetori Group. First, the stratigraphy of the Tetori Group in the Kuzuryu area of Fukui Prefecture, which is the type area of the Tetori Group, was reexamined. The group in the area is divided into Yambara, Ashidani, Obuchi, Itsuki and Nochino formations, in stratigraphic ascending order. The plant assemblage from the Ashidani Formation has no Ryoseki-type floral element, whereas the assemblages from the Itsuki and Nochino formations have some Ryoseki-type floral elements such as microphyllous conifers.

Second, the stratigraphy of the Tetori Group in the Shiramine area of Ishikawa Prefecture and the Takinamigawa area of Fukui Prefecture was reexamined. The group in the area is divided into Gomijima, Kuwajima, Akaiwa and Kitadani formations, in stratigraphic ascending order. Plant assemblage from the Akaiwa Formation around Mt. Oarashiyama in the Shiramine area includes 18 genera and 23 species typified by the abundant of the Tetori-type floral elements including ferns, ginkgoaleans and conifers, associated with macrophyllous bennettitalean (or cycadalean) and microphyllous coniferous foliages represented by *Brachyphyllum* which favored climate with drying season(s). It had been presumed that the occurrence of the Ryoseki-type floral elements is consistent with floral change and a warming and drying climate trend during the

deposition time of the Kitadani Formation. However, this study suggests that such a trend started from the deposition time of the Akaiwa Formation earlier than previously thought.

Finally, the stratigraphy of the Oguchi area of the Ishikawa Prefecture was reexamined. The group in the area is divided into the Gomijima and Kuwajima formations, in stratigraphic ascending order. The plant assemblage of the Kuwajima Formation collected from the Onabara section includes 18 genera and 26 species. This study describes the co-occurrence of plant fossils in 10 plant fossil-bearing beds. It is considered that these fossil occurrences are allochthonous. This study described the co-occurrence of plant fossils in these plant fossil-bearing beds. It is likely that the occurrence of *Podozamites* is not influenced by depositional environment. In contrast, it is obvious that the occurrence of ferns is varied by depositional environment. The difference of taphonomic process and sedimentary environment probably become a factor for this trend. This study provides clues for understanding the local floral compositional change and reveals the details of the regional vegetation difference and floral succession in the Tetori Group.

The Ryoseki-type floral elements occur at the Nochino, Akaiwa and Kitadani formations. The floral element analysis infers a warming and drying climate trend between the Itsuki Formation and the Nochino Formation and between the Kuwajima Formation and the Akaiwa Formation. The trend suggests that the floral composition of the Tetori Group changed from the Tetori-type to the Mixed-type. Therefore, the drying on the Tetori basin has started much earlier than previously thought.

The floral composition of the Tetori Group changed from the Tetori-type to the Mixed-type because the climate condition around the Tetori basin became warmer and more arid in the Aptian. The warming and drying trend in the Tetori Group probably expresses the potential links with the Lower Cretaceous climate transition in the mid-latitudes in the Northern Hemisphere. Thermophilic reptiles such as crocodilians also have been discovered in the uppermost part of the Tetori Group, and they unequivocally indicate warmer environments around the Tetori basin.

East Asia on Early Cretaceous was divided into some basins by mountain range. The coastal area was under humid climate, and the inland area was under dry climate at that time. It remains even now doubt on the differences of fauna in the basins of the Tetori and Jehol groups, which were located at the same latitude in the same age. The cmparison of floral succession between inland (Jehol) and the coastral (Tetori) basins revealed that successive climate change recorded in the Tetori Group is representing the moving northward process of the Ryoseki-type Flora along the coastal area on East Asia. Thus, the Tetori basin, which was located in the eastern margin of Asia, is an important area that leads to the elucidation of the establishing process of the terrestrial ecosystem in East Asia.

Part 1

Introduction

1.1. Introduction

The Cretaceous is the best examples of greenhouse climates in Earth history (Takashima et al., 2006; Wang et al., 2014; Takahashi and Nishi, 2017). As the greenhouse climate reached its summit in the mid-Cretaceous, the Earth was characterized by equably distributed warmth with mean annual polar temperatures exceeding 14°C (Tarduno et al., 1998). There were no permanent polar ice sheets (Frakes et al., 1992), and sea levels were 100–200 m higher than those of today (Haq et al., 1987).

The Cretaceous was not only a long greenhouse episode, but several unusual geological phenomena occurred: the Oceanic Anoxic Events (OAEs) (Schlanger and Jenkyns, 1976; Wang et al., 2005) and the K–T boundary catastrophe (KTB) (Alvarez et al., 1980). The unusual geological phenomena triggered rapid environmental and climate changes and had profound impacts on the biosphere (McElwain et al., 2005; Royer et al., 2007; Davis et al., 2009). Most of the reported studies of the Cretaceous paleoclimate are based upon marine sedimentary records. The most dramatic environmental changes during the Cretaceous concerned the oxidation state of the ocean, recognized as the "Oceanic Anoxic Events" (OAEs). OAEs were first described by Schlanger and Jenkyns (1976) as global-scale transient periods of marine anoxia, accompanied by the widespread deposition of organic carbon-rich sediments, occurring at the Aptian–Albian and Cenomanian–Turonian boundaries. The major anoxic intervals were the Weissert OAE in the late Valanginian, the early Aptian Selli event (OAE1a), at the Cenomanian–Turonian boundary (OAE2, Bonarelli event), and the Coniacian–Santonian event (OAE3) (Leckie et al., 2002; Erba, 2004). They are represented by organic-rich sediments ("black shales") and were often accompanied by biotic extinctions (Leckie et al., 2002).

The author studies Early Cretaceous plant assemblages from the Tetori Group in central Japan and their paleoclimatic implications. This part shows outline and aim of the doctoral study after explaining Early Cretaceous plant assemblages from the Tetori

Group.

1.2. Early Cretaceous topographic data in East Asia

The mid-Cretaceous phytogeographic world map obtained by megafossil and pollen analysis research is divided into four zones: tropical, peri-tropical, peri-temperate and temperate region (Saward, 1992). According to recent palaeotopographic data, the terrestrial basins of East Asia were divided into some basins by mountain range during the Early Cretaceous (e. g., Philippe et al., 2014; Liu et al., 2015; Cao, 2018). In response to this, recent Early Cretaceous phytogeographic map in East Asia is based on the discussion of the palaeotopographic model. Amiot et al. (2015) estimated that each mosaic-like environment of tropical and peri-tropical, cold temperate and different climatic zones from wet to dry existed, and showed that the coastal area was humid condition, the inland area was dry condition. Fang et al. (2015) had identified seven climatic zones based on the distribution of the association of climate-indicative sediments and the influences of paleotopography. However, it is still not understood how climatic zones in each area change on the East Asia including Japan and North China (Figs. 1-1, 1-2). It is necessary for the Early Cretaceous phytogeographic map in North China and Japan to revise based on the recent palaeotopographic model.

1.3. Tetori Group

The Lower Cretaceous deposits in East Asia are dominated by non-marine successions, thus the palaeoclimatic reconstruction for this time interval largely depends on the terrestrial proxies. The Japanese Mesozoic sequences consist of alternating beds of marine and non-marine deposits and contain many marine fossil assemblages. Recently, it has been recognized that the Tetori Group is composed of non-marine beds with intercalations of marine beds (Sato and Yamada, 2005; Goto, 2007; Matsukawa et al., 2007; Matsukawa and Fukui, 2009; Sano et al., 2013, 2015; Kashiwagi et al. 2016;

Haggart and Matsukawa, 2020; Sano, 2020).

The Tetori Group (Oishi, 1933; Yamada and Sano, 2018) is a Lower Cretaceous sequence distributed in the Inner Zone of southwest Japan, on the eastern margin of Asia (Maeda, 1961; Kusuhashi et al., 2002; Matsukawa et al., 2006; Sano, 2015) (Fig. 1-1, 1-2). The group is composed mainly of non-marine deposits, which were often correlated with non-marine Lower Cretaceous strata in northeastern China (Li and Matsuoka, 2015; Sano and Yabe, 2017; Cao, 2018; Xi et al., 2019).

The standard stratigraphic section of the Tetori Group is exposed in the area along the Itoshiro River (Yamada and Sano, 2018). In the section, effective key bed and index fossil have not been discovered until now. Therefore, there are the several disagreements for the opinions about stratigraphic correlation (Maeda, 1961; Kusuhashi et al., 2002; Fujita, 2003; Matsukawa et al., 2006, 2008; Sano et al., 2008; Matsukawa et al., 2014; Sano, 2015; Yamada, 2017; Nagata et al., 2018). Recently, some zircon U–Pb age data has been reported from the group (Kusuhashi et al., 2006; Kawagoe et al., 2012; Nagata et al., 2018, 2019, 2020; Sakai et al., 2019b, 2021).

The author discusses floral change on the age range from the Early Cretaceous (Barremian to Albian). The depositional time of the upper part of the Tetori Group corresponds this range. The Early Cretaceous floral change on the Tetori Group gives the important clue about the historical transition of climate on the eastern margin of Asia.

1.4. Paleobotanical note

Comparison of the plant assemblages with those of coeval strata in Japan, Korea and northeast China reveals that similar climate conditions are recognized in East Asia. However, it is difficult to the correlate widespread terrestrial deposits in China and Korea with a succession of marine–continental transitional strata of the Tetori Group.

Kimura (1987) classified the Late Jurassic and Early Cretaceous floras of East Asia into three types, the Tetori-, Ryoseki- and Mixed-type (Fig. 1-3-1). The Tetori-type

Flora, distributed in the Inner Zone of southwest Japan and northern China, flourished under warm-temperate and humid climate conditions (Kimura, 1987; Vakhrameev, 1991). The Ryoseki-type Flora, distributed in the Outer Zone of southwest Japan and southern China, flourished under tropical to subtropical climate conditions with an arid seasonality (Kimura, 1987). The Mixed-type Flora was distributed in between the Tetori- and the Ryoseki-type floristic provinces (Kimura, 1987). The composition of the Tetori- and Ryoseki-type floras was completely different with no species in common. They were relatively uniform throughout the Late Jurassic to the Early Cretaceous (Kimura, 1987).

Saiki and Wang (2003) reviewed the distribution of Early Cretaceous plants from China. The Early Cretaceous flora of China has been divided into two floristic provinces. The Northern type flora flourished under a warm-temperate and humid climate while the Southern type flora flourished under a tropical–subtropical and rather arid climate (Fig. 1-3-2). The area of the Mixed Zone of Sun et al. (1995) is narrower than the Mixed-type Flora of Ohana and Kimura (1995).

On the contrary, Yamada (2009) suggested that the floral conflict has caused until the Barremian time (Fig. 1-4) and the Ryoseki-type Flora became expanded to the Oshana Inner Zone of Japan. This was explained by northward expansion of the Ryoseki-type Flora in the Aptian (Yamada et al., 2018). They also claimed that there is no difference the Inner Zone and Outer Zone of Japan in the Albian.

1.4.1. Tetori Flora

The stratigraphic occurrence of fossil plants in the Tetori Group has been discussed by Oishi (1933), Omura (1974), Kimura (1975, 1987) and Sakai et al. (2018, 2020c). In recent decades, some fossil plant taxa which likely favor warm and dry conditions (i.e., the Ryoseki-type floral elements) have been reported from the group (Yabe et al., 2003; Yabe and Kubota, 2004; Yabe and Shibata, 2011; Terada and Yabe, 2011; Sakai et al., 2018, 2021c). It is likely that the climate change has been reflected by this floral evolution across the deposition times of the Tetori Group (Yabe et al., 2003).

Fossil plants from the Tetori Group are known as the Tetori Flora (Tateiwa, 1925). Many fossil plants were reported from the upper part of the Tetori Group. Since Geyler (1877) first reported fossil plants from the Tetori Group, many palaeobotanical studies have been conducted (e.g., Yokoyama, 1889; Oishi, 1940; Ogura et al., 1951; Kimura, 1958, 1959, 1975; Kimura and Sekido, 1972, 1976a, 1976b, 1978; Kimura et al., 1978; Matsuo and Omura, 1968; Kimura and Horiuchi, 1979; Tsunada and Yamazaki, 1987; Yabe and Kubota, 2004; Yabe and Shibata, 2011; Terada and Yabe, 2011; Yukawa and Yabe, 2019; Sakai, 2020; Sakai et al., 2018; 2020c). Plant assemblages from the Tetori Group include osmundaceous and dicksoniaceous ferns, and several taxa of *Podozamites* and Ginkgoaleans which are classified as Tetori-type (or Siberian) elements, which flourished under a humid warm-temperate climate (Kimura, 1987; Vakhrameev, 1991).

The Early Cretaceous Tetori Flora is subdivided into three stratofloras (Kimura, 1975), including Oguchi Flora (Kimura et al., 1978; Yabe et al., 2003), Akaiwa Flora (Kimura and Sekido, 1976a, 1978; Yabe et al., 2003), and “Tamodani Flora” (Kimura, 1975; Yabe et al., 2003) (Fig. 1-6).

The Oguchi Flora was established based on fossil plants from the Kuwajima Kaseki-kabe and Mekkodani in the Shiramine area and Ogamigo in the Shokawa area (Kimura et al., 1978). According to Kimura (1987), this flora comprises 39 genera and 82 species. The flora is composed of ferns, bennettitaleans such as *Neozamites* and *Dictyozamites*, cycadaleans such as *Ctenis*, *Nilssonia* and *Tetoria*, Ginkgoaleans, several taxa of *Podozamites* and conifers.

The Akaiwa Flora comprises 26 genera and 41 species. The flora is composed of ferns, cycadaleans such as *Nilssonia*, Ginkgoaleans, several taxa of *Podozamites* and conifers such as *Elatocladus*. The flora was established based on fossil plants from Bettodani and Osugidani in the Shiramine area and Tamodani in the Kuzuryu area (Kimura, 1975; Kimura and Sekido, 1976a, 1978). It includes the Ryoseki-type floral elements, *Nilssonia* sp. cf. *Nil. schaumburgensis* (Dunker) Nathorst from the

Minamimatadani conglomerate and Wasabu alternation members in Toyama Prefecture (Omura, 1974; Toyama Dinosaur Research Group, 2002), *Ptilophyllum pectin*? (Phillips) Morris from Yunotani in the Shiramine area (Matsuo and Higashino, 1979).

The "Tamodani Flora" comprises 17 genera and 19 species. The flora is composed of ferns, cycadaleans, Ginkgoaleans and conifers. The flora was established based on fossil plants from Tamodani and Chinaboradani in the Kuzuryu area (Kimura, 1975; Kimura and Horiuchi, 1979). It includes the Ryoseki-type floral elements, "*Zamiophyllum*" sp. in the Shiramine area (Omura, 1966). Recently, *Brachyphyllum obesum* Heer (Yabe et al., 2003; Yabe and Kubota, 2004), *Brachyphyllum* sp. (Yabe and Shibata, 2011), *Ptilophyllum* sp. (Yabe and Shibata, 2011) and *Podocarpoxylon* sp. (Terada and Yabe, 2011) were reported from the Kitadani Formation of the Tetori Group in the Takinamigawa area. Sano (2015) and Sano and Yabe (2017) focused on some differences between the typical Tetori Flora and the assemblage from the Kitadani Formation, and proposed the Kitadani Flora instead of the "Tamodani Flora" (Fig. 1-6).

Palynoflora from the Tetori Group were studied by Umetsu and Matsuoka (2003) and Legrand et al. (2013, 2019, 2021). Fossil spores and pollen were obtained from the Tetori Group in the Kuzuryu area (Umetsu and Matsuoka, 2003). Legrand et al. (2013) reported spores and gymnosperm pollen grains from the Kitadani Formation of the Tetori Group in the Takinamigawa area. They indicate a warm temperate and humid climate, with locally drier conditions. Recently, Legrand et al. (2019) reported angiosperm pollen grains from the Kitadani Formation in the Takinamigawa area.

1.4.2. Tetori- and Ryoseki-type floras

The Tetori-type floral elements are characterized by the predominance of osmundaceous and dicksoniaceous ferns, bennettitaleans such as *Neozamites* and *Dictyozamites*, cycadaleans such as *Ctenis*, *Nilssonia* and *Tetoria*, ginkgoaleans, czekanowskialeans, and several taxa of *Podozamites* and conifers with needle-like leaves (Ohana and Kimura, 1995) (Fig. 1-5). The Ryoseki-type floral elements are characterized by the predominance of gleicheniaceous and matoniaceous ferns, *Zamites* [including "*Zamiophyllum*"] and *Ptilophyllum* which are macrophyllous bennettitaleans, and *Brachyphyllum*, *Cupressinocladus*, *Frenelopsis*, *Pagiophyllum* and *Pseudofrenelopsis* which are microphyllous coniferous foliages (Ohana and Kimura, 1995) (Fig. 1-5). Macrophyllous bennettitaleans and microphyllous coniferous foliages is minor under humid climate, and indicates a climate with drying season(s) (Rees et al., 2000). Ohara and Kimura (1995) stresses that they are not contained in plant assemblages of the Tetori Group.

In recent decades, some climate-indicator plants (such as thermophilic taxa) have been reported from the middle to late Early Cretaceous strata in Northeast China (Sun et al., 2001) and the Inner zone of southwest Japan (Yabe et al., 2003). The occurrence of the Ryoseki-type floral elements is considered the best indicator of floral and climatic change. Some thermophilic plants were previously documented from the Lower Cretaceous Tetori Group (Kawai, 1961; Matsuo and Omura, 1966; Omura, 1973, 1974; Matsuo and Higashino, 1979; Toyama Dinosaur Research Group, 2002; Yabe et al., 2003; Yabe and Kubota, 2004; Yabe and Shibata, 2011; Terada and Yabe, 2011; Sakai et al., 2018; Sakai et al., 2020c).

However, the stratigraphic occurrence and diversity characters of these microphyllous conifers are still not clear in the Tetori Group, which may impede our comprehensive understanding towards the climatic switch pattern during the Early Cretaceous episode. In addition, it is necessary to obtain more fossil plants from the upper part of the Tetori Group so as to reveal the continuous floral change between the lower and upper part of the group.

1.5. Outline and aim of the doctoral study

The author reveals floristic diversity of the Tetori Group (Sakai et al., 2012, 2014, 2018, 2019a, 2020a, 2020c; Sakai, 2020) (Fig. 1-1). This study focuses on fossil plants from the Kuzuryu area of Fukui Prefecture which is the type area of the Tetori Group in

Part 2, the Shiramine and Takinamigawa areas which is the border area between Ishikawa and Fukui prefectures in Part 3, and the Oguchi area of Ishikawa Prefecture in Part 4. All plant-bearing horizons is located in correct stratigraphic levels because fossil plants were collected from outcrops in this study. In Part 5, the author discusses the historical transition of climate on the eastern margin of Asia, target at the Tetori Group based on floral change of the Tetori Group (Fig. 1-7).

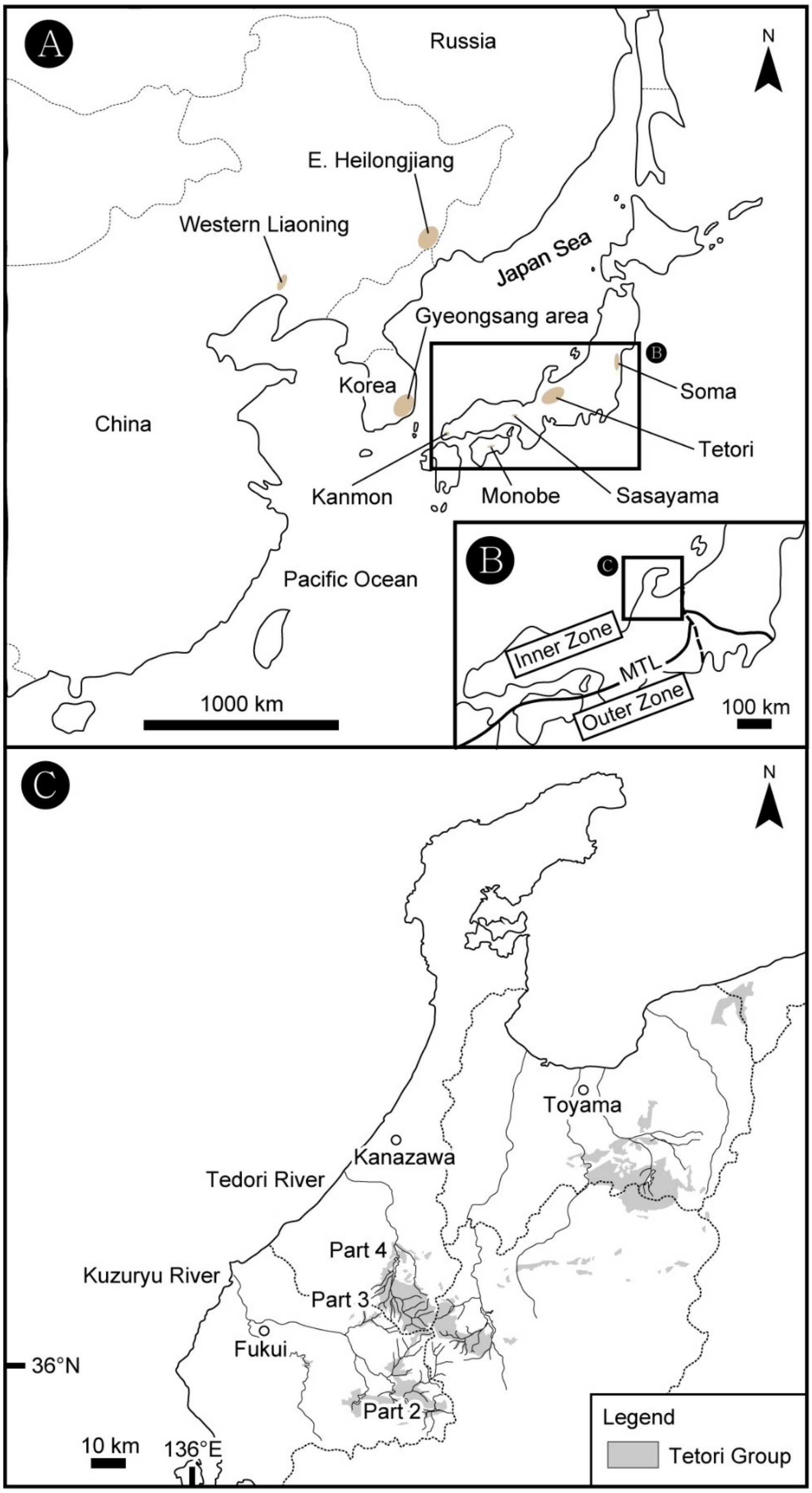


Fig. 1-1. Distribution of the Tetori Group in central Japan (Maeda, 1961). MTL: Median Tectonic Line.

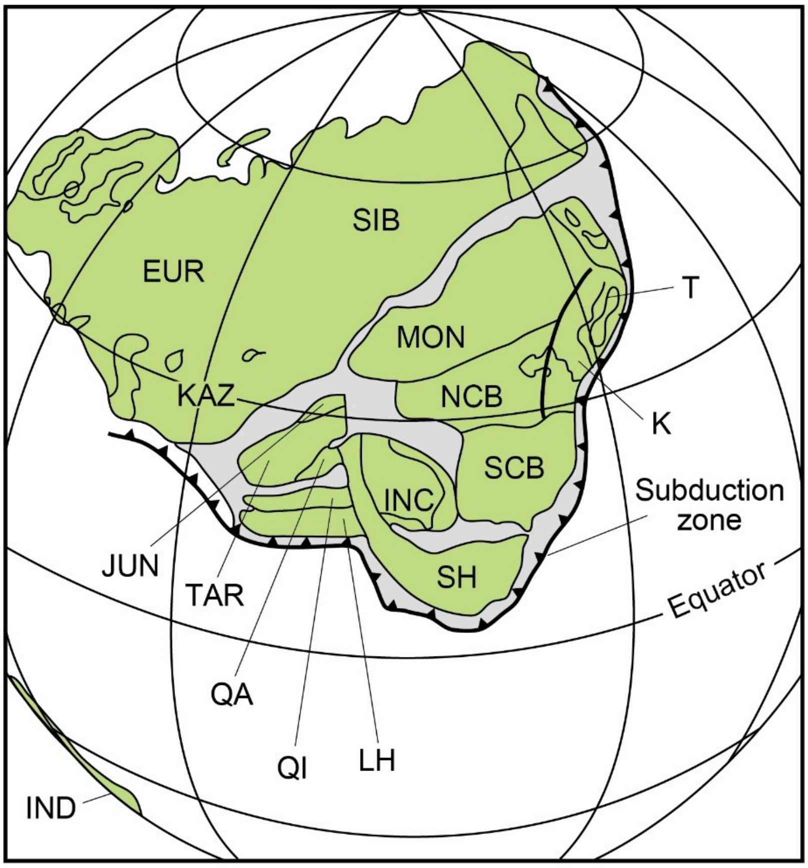


Fig. 1-2. Palaeogeographic map of eastern Asia in the Lower Cretaceous, showing major regional tectonic features (modified from Enkin et al., 1992). Abbreviations: EUR, Europe; INC, Indo-China; IND, India; T, Tetori (Japan); JUN, Junggar; K, Korea; KAZ, Kazakhstan; LH, Lhassa; MON, Mongolian; NCB, North China; QI, Qiangtang; SCB, South China; SH, Shan Thai; SIB, Siberian; TAR, Tarim.

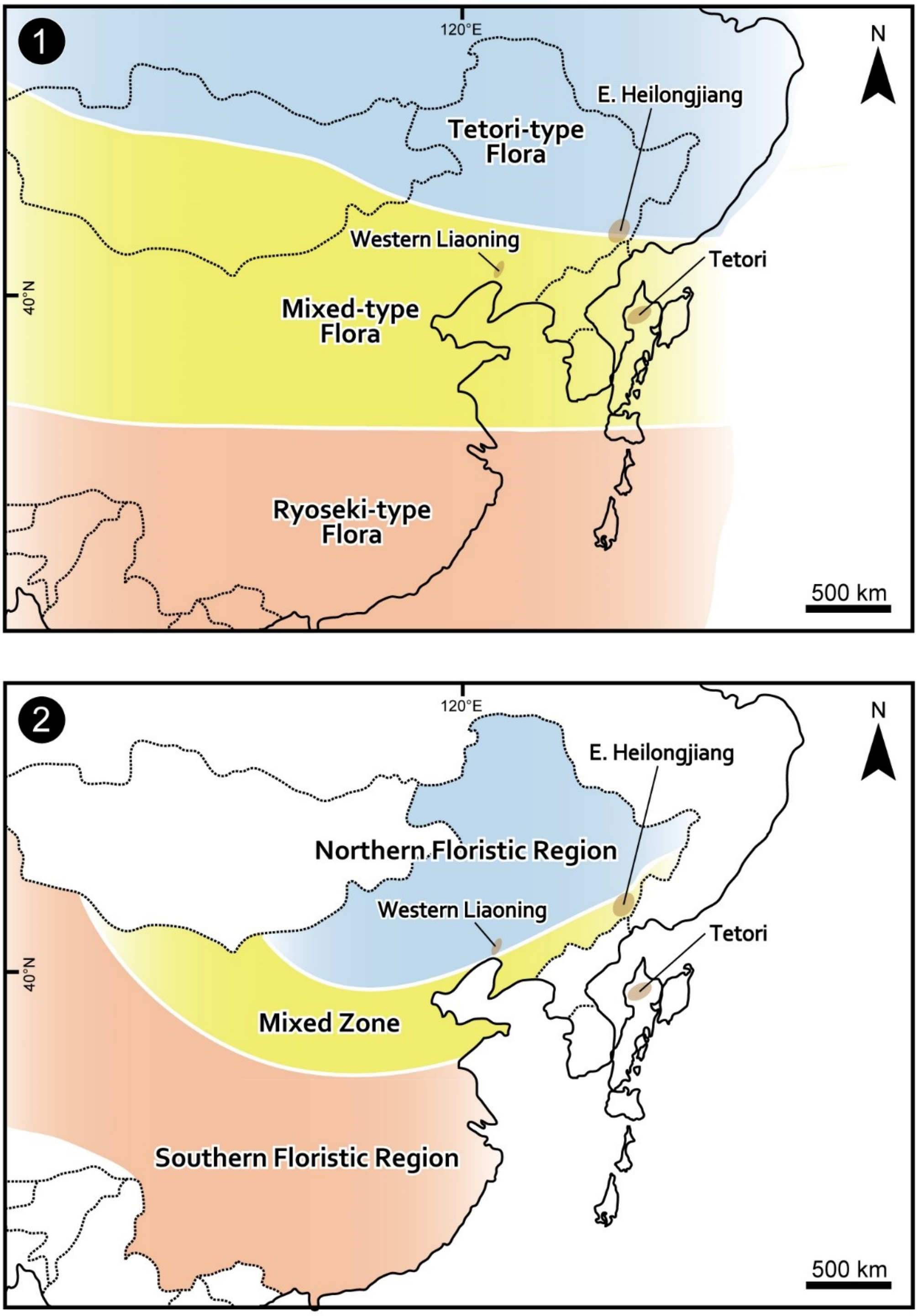


Fig. 1-3. Early Cretaceous paleophytogeography in East Asia (paleogeographic map, modified from Yamakita and Otoh, 2000). 1: Paleophytogeography map of East Asia (modified from Ohana and Kimura, 1995). 2: Paleophytogeography map of China (modified from Sun et al., 1995).

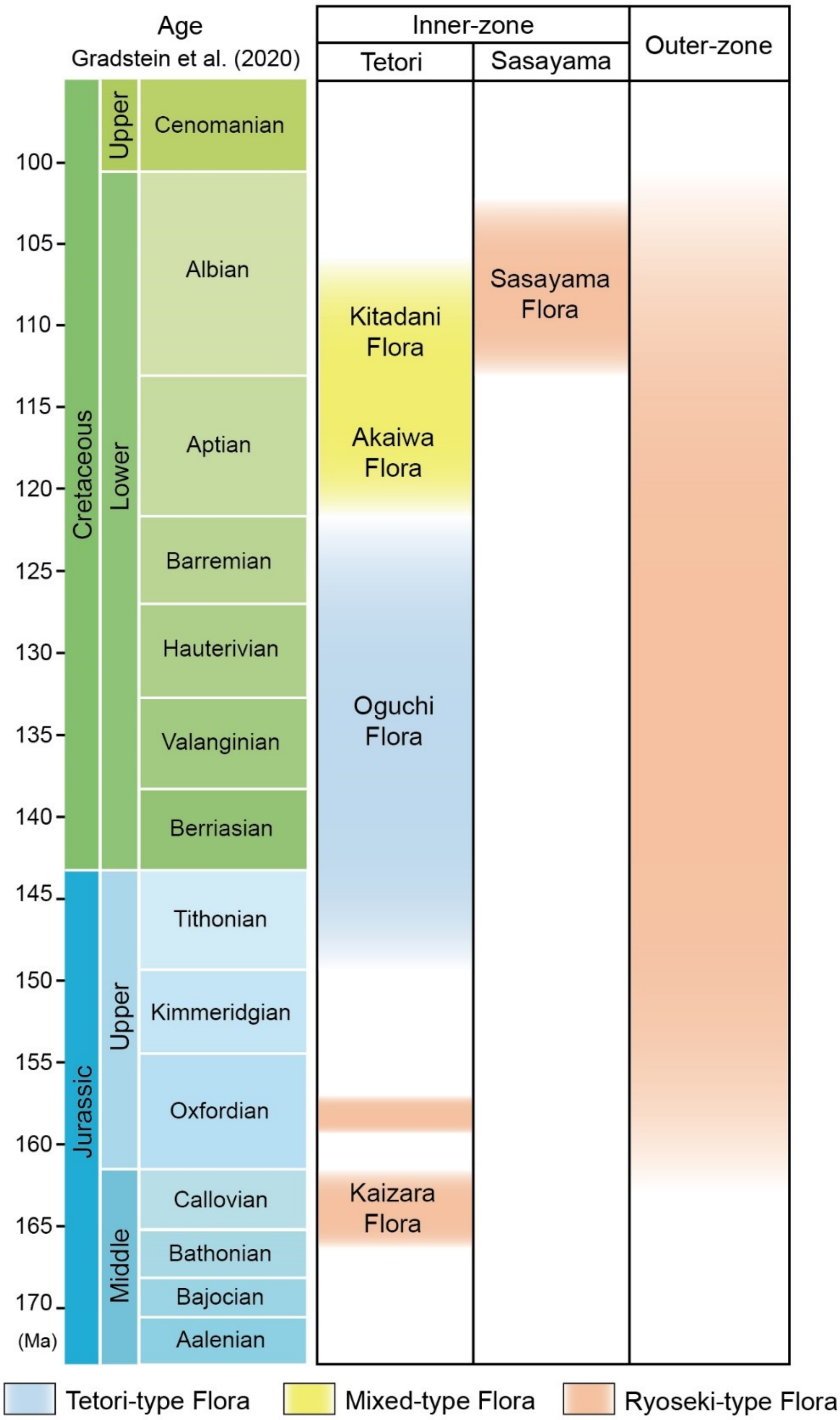


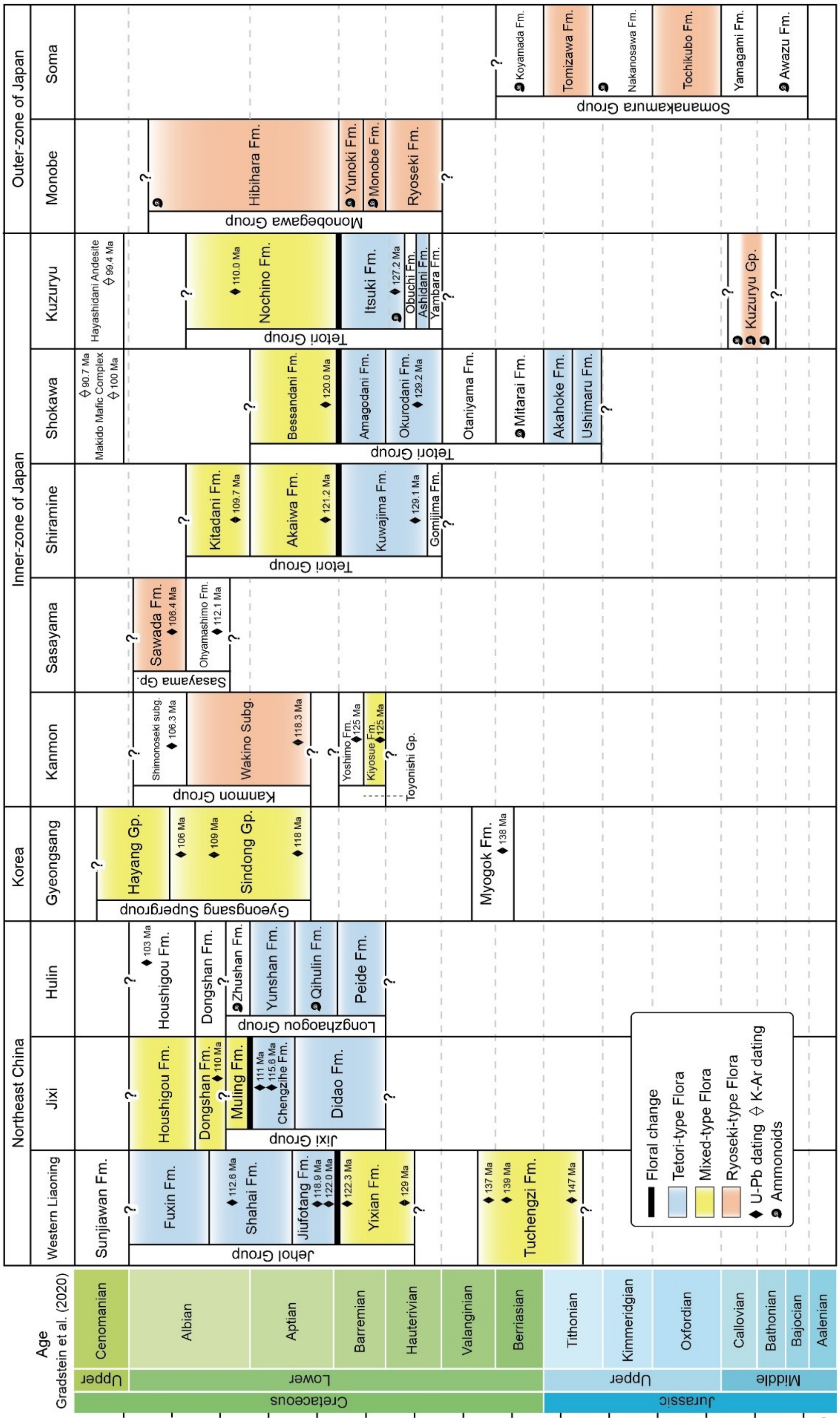
Fig. 1-4. The Late Jurassic and Early Cretaceous floras in Japan (modified from Yamada, 2009; Yamada, 2018; Yamada et al., 2018).

Fossil plant taxa		Tetori-type	Ryoseki-type
Filicales	*Raphaelia*	Abundant	None
	Birisia	Abundant	None
	Coniopteris	Abundant	Very rare
	Eboracia	Abundant	Very rare
	Dicksonia	Varied and abundant	Very rare or none
	Matonidium	None	Varied and abundant
	Weichselia	None	Varied and abundant
Bennettitales	*Zamites*	None	Abundant
	Ptilophyllum	None	Varied and abundant
	Nipponoptilophyllum	None	Abundant
	Williamsonia	None	Abundant
	Neozamites	Abundant	None
	Dictyozamites	Varied and abundant	None
Cycadales	*Ctenis*	Abundant	None
	Tetoria	Abundant	None
	Nilssonia lobatidentata-type	Abundant	None
	N. shaumburgensis-type	None	Abundant
	N. densinervis-type	None	Abundant
Ginkgoales	*Ginkgoites*	Varied and abundant	None
	Ginkgoidium	Abundant	None
	Eretomophyllum	Abundant	None
	Baiera	Abundant	None
	Pseudotorellia	Abundant	None
	Sphenobaiera	Abundant	None
Czekanowskiales	*Czekanowskia*	Abundant	None
	Leptostrobus	Abundant	None
	Arctobaiera	Abundant	None
	Phoenicopsis	Abundant	None
Coniferales	*Podozamites*	Varied and abundant	None
	Lindleycladus	Abundant	None
	Pseudofrenelopsis	None	Abundant
	Cupressinocladus	None	Varied and abundant
	Brachyphyllum	None	Varied and abundant
	Frenelopsis	None	Varied and abundant

Fig. 1-5. Comparison of the floristic composition between the Tetori-type and Ryoseki-type floras in East Asia (Ohana and Kimura, 1995; Oh et al., 2011).

<table>
<tr><th colspan="2">Kuzuryu</th><th colspan="2">Shiramine</th><th>Tetori Flora</th></tr>
<tr><td rowspan="6">Tetori Group</td><td></td><td rowspan="6">Tetori Group</td><td>Kitadani Fm.</td><td>Kitadani</td></tr>
<tr><td>Nochino Fm.</td><td>Akaiwa Fm.</td><td>Akaiwa</td></tr>
<tr><td>Itsuki Fm.</td><td>Kuwajima Fm.</td><td rowspan="4">Oguchi</td></tr>
<tr><td>Obuchi Fm.</td><td>Gomijima Fm.</td></tr>
<tr><td>Ashidani Fm.</td><td rowspan="2"></td></tr>
<tr><td>Yambara Fm.</td></tr>
</table>

Fig. 1-6. Stratigraphic correlation of the Lower Cretaceous Tetori Group, showing stratigraphic positions of plant fossil assemblages; the Oguchi Flora (Kimura, 1975), the Akaiwa Flora (Kimura, 1975) and the Kitadani Flora (Sano and Yabe, 2017).



Age
Gradstein et al. (2020)
Cretaceous
Jurassic
Upper
Lower
Middle
Cenomanian
Albian
Aptian
Barremian
Hauterivian
Valanginian
Berriasian
Tithonian
Kimmeridgian
Oxfordian
Callovian
Bathonian
Bajocian
Aalenian
100
105
110
115
120
125
130
135
140
145
150
155
160
165
170
(Ma)
Northeast China
Western Liaoning
Jixi
Hulin
Korea
Gyeongsang
Inner-zone of Japan
Kanmon
Sasayama
Shiramine
Shokawa
Kuzuryu
Outer-zone of Japan
Monobe
Soma
Sunjiawan Fm.
Fuxin Fm.
Shahai Fm.
112.6 Ma
Jiufotang Fm.
118.9 Ma
122.0 Ma
122.3 Ma
Yixian Fm.
129 Ma
Jehol Group
Tuchengzi Fm.
137 Ma
139 Ma
147 Ma
Houshigou Fm.
Dongshan Fm.
110 Ma
Muling Fm.
111 Ma
115.6 Ma
Chengzihe Fm.
Didao Fm.
Jixi Group
103 Ma
Houshigou Fm.
Dongshan Fm.
Zhushan Fm.
Yunshan Fm.
Qihulin Fm.
Peide Fm.
Longzhaogou Group
Hayang Gp.
106 Ma
109 Ma
Sindong Gp.
118 Ma
Gyeongsang Supergroup
Myogok Fm.
138 Ma
Shimonoseki subg.
106.3 Ma
Wakino Subg.
118.3 Ma
Kanmon Group
Yoshimo Fm.
125 Ma
Kiyosue Fm.
125 Ma
Toyonishi Gp.
Sawada Fm.
106.4 Ma
Ohyamashimo Fm.
112.1 Ma
Sasayama Gp.
Kitadani Fm.
109.7 Ma
Akaiwa Fm.
121.2 Ma
Kuwajima Fm.
129.1 Ma
Gomijima Fm.
Tetori Group
90.7 Ma
Makido Mafic Complex
100 Ma
Bessandani Fm.
120.0 Ma
Amagodani Fm.
Okurodani Fm.
129.2 Ma
Otaniyama Fm.
Mitarai Fm.
Akahoke Fm.
Ushimaru Fm.
Tetori Group
Hayashidani Andesite
99.4 Ma
Nochino Fm.
110.0 Ma
Itsuki Fm.
127.2 Ma
Obuchi Fm.
Ashidani Fm.
Yambara Fm.
Tetori Group
Kuzuryu Gp.
Hibihara Fm.
Yunoki Fm.
Monobe Fm.
Ryoseki Fm.
Monobegawa Group
Koyamada Fm.
Tomizawa Fm.
Nakanosawa Fm.
Tochikubo Fm.
Yamagami Fm.
Awazu Fm.
Somanakamura Group
Floral change
Tetori-type Flora
Mixed-type Flora
Ryoseki-type Flora
U-Pb dating
K-Ar dating
Ammonoids

Fig. 1-7. Middle Jurassic to Lower Cretaceous sequences in East Asia, showing age and floral composition. Western Liaoning (Chen et al., 1988; Chen, 1999; Sun et al., 2001; Sha et al., 2012; Li and Matsuoka, 2015; Yu et al., 2021; Xu et al., 2022), Jixi (Yang, 2003; Sha, 2007; Sha and Hirano, 2012; Sha et al., 2012; Li and Bengtson, 2018), Hulin (Cao, 1983a, b; Sha, 2007; Sha and Hirano, 2012; Sha et al., 2012; Li and Bengtson, 2018), Gyeongsang (Kimura, 2000; Seo and Kim, 2009: Lee et al., 2010; Kim et al., 2012), Kanmon (Kimura et al., 1992; Yamada and Ohno, 2005; Aoki et al., 2014; Miyazaki et al., 2019), Sasayama (Kusuhashi et al., 2013; Hayashi et al., 2017; Yamada et al., 2018), Shiramine (Kimura et al., 1978; Sakai et al., 2018, 2019b, 2021; Nagata et al., 2019), Shokawa (Kunimitsu and Nakashima, 1987; Gifu-ken Dinosaur Research Committee, 1993; Shibata and Uchiumi, 1995; Sato et al., 2008; Sakai et al., 2014; Nagata et al., 2019; Haggart and Matsukawa, 2020), Kuzuryu (Sato and Westermann, 1991; Tanase et al., 1994; Goto, 2007; Yamada and Uemura, 2008; Kawagoe et al., 2012; Handa et al., 2014; Nagata et al., 2020; Sakai et al., 2020c; Goto and Sakai, 2021), Monobe (Oishi, 1940; Kozai et al., 2005; Matsukawa and Obata, 2015), Soma (Sato, 1962; Kimura and Ohana, 1988a, b; Sato and Taketani, 2008).

Part 2

Early Cretaceous plants from the Lower Cretaceous Tetori Group in the Kuzuryu area, Fukui Prefecture

2.1. Introduction

Previously, a few plant fossils have been reported from the Ashidani, Itsuki and Nochino formations of the Tetori Group in the Kuzuryu area in Ono City, Fukui Prefecture, central Japan (e.g., Oishi, 1933; Maeda, 1952, 1957; Kawai et al., 1957; Fujita, 2002). However, the floristic compositions in these formations have not been well known until now. Sakai et al. (2020c) reported the plant assemblages from the Tetori Group in the Kuzuryu area. As a result, this study suggests that the Early Cretaceous plant assemblages from the Tetori Group bears some microphyllous conifers. In the Kuzuryu area, the author reveals the microphyllous conifers that first occurred in the uppermost part of the Itsuki Formation based on our review of their stratigraphic occurrences between the Itsuki and Nochino formations. This provides evidence for palaeoclimate implication in the Early Cretaceous in East Asia.

2.2. Geological setting

The Kuzuryu area is located throughout the upper reaches of the Kuzuryu River which occupies the southeastern part of Fukui Prefecture in central Japan (Fig. 2-1). The basement rocks in this region are represented by metamorphic rocks of the Hida Terrane (Kawai et al., 1957). The Tetori Group unconformably overlies the Kuzuryu Group. The Kuzuryu Group in fault contact with Hida Terrane. There is an inferred fault along Taniyamadani. The strata of the Tetori Group strike northwest and dip 30° to 80° NE (Fig. 2-1). There is synclinal structure between Nochino and Maesakadani, between Taniyamadani and Nagakuradani because the strata of that around Maesakadani and Nagakuradani strike southwest and gradual dip (Fig. 2-1). The Tetori Group is overlain by the Hayashidani Andesite or Upper Cretaceous acid igneous rocks.

The Tetori Group is composed of the Yambara, Ashidani, Obuchi, Itsuki and Nochino formations in ascending order (Fig. 2-1). The age of some formations of the Tetori Group has been identified mainly by biostratigraphic correlation. Goto (2007) reported the occurrence of the Late Hauterivian ammonoid *Pseudothurmannia* sp. from the Itsuki Formation of the Tetori Group in the Uchinamigawa area. The brackish bivalve *Myopholas tanakai* Tashiro was reported from the Itsuki Formation exposed in the eastern part of the Kuzuryu area (Fujita, 2002; Sano et al., 2013), this bivalve has been known from the Hauterivian formations in the Outer Zone of Southwest Japan (Tashiro, 1994). Umetsu and Matsuoka (2003) reported palynomorphs from the Tetori Group in the Kuzuryu area. The spore and pollen assemblage from the Nochino Formation of the Tetori Group can be correlated with Hauterivian to Aptian assemblages from the Songliao Basin of China. The youngest zircon grain from the sandstone of the Itsuki Formation has a concordant age of 127.2±2.5 Ma assignable to the Barremian (129.4–125.0 Ma) (Kawagoe et al., 2012). Based on zircon U–Pb dating, the zircon grains from the tuff of the Akaiwa Formation of the Tetori Group in the Shiramine area which are correlated with the Nochino Formation has an age of 121.2±1.1 Ma (Sakai et al., 2019b). The K－Ar dating of the lower part of the Hayashidani Andesite indicates 99.7±5.0 Ma (Tanase et al., 1994). Therefore, the age of the Itsuki Formation is considered as Hauterivian－Barremian, and that of the Nochino Formation is Aptian.

2.3. Lithostratigraphy

Sakai et al. (2020c) survived 32 routes in the Kuzuryu area (Fig. 2-2). The area along the Itoshiro River includes the type section of the Tetori Group (Oishi, 1933; Yamada and Sano, 2018). The Tetori Group in this area consists of the Yambara, Ashidani, Obuchi, Itsuki and Nochino formations in ascending order.

2.3.1. Yambara Formation

[Nomenclature] The formation is named by Maeda (1952).

[Type section] Yambara along the Itoshiro River (Maeda, 1952).

[Distribution] The Itoshiro River (Fig. 2-2-13) and ridgeline route (Fig. 2-2-12).

[Thickness] The formation is about 100 m thick in the Itoshiro River.
[Relationship with the lower formation] The formation overlies the Yambarazaka Formation of the Kuzuryu Group unconformably (Maeda, 1952).
[Lithology] The formation is composed of massive conglomerates which are poorly-sorted and clast-supported. Clasts are rounded and are characterized mainly by crystalline limestone, gneiss and granite (Maeda, 1952; Kamata, 2017). The greatest dimension of clast size is about 25 cm, and average dimension is about 5 cm.

2.3.2. Ashidani Formation

[Nomenclature] The formation is named by Maeda (1952).
[Type section] Itoshiro River (Maeda, 1952).
[Distribution] Itoshiro River (Fig. 2-2-13) and ridgeline route (Fig. 2-2-12).
[Thickness] The formation is about 260 m thick in ridgeline route.
[Relationship with the lower formation] The formation overlies the Yambara Formation conformably.
[Lithology] The formation is composed mainly of alternating beds of sandstone and mudstone, medium to coarse-grained sandstone and conglomerate. The alternating beds are composed of medium-grained sandstone, gray mudstone, gray sandy mudstone, gray fine-grained sandstone and coal bed. Some sandstone and mudstone beds are laminated. Rootlets are recognized in sandstone and mudstone beds. Plant fossils occur in the alternating bed of mudstone and sandstone. Conglomerate beds of the formation are poorly-sorted and matrix-supported. Clasts are rounded and are characterized mainly by orthoquartzite and granite. Coarse-grained sandstone beds are poorly sorted and include many quartzes sub-rounded pebbles and mudstone clasts.
[Fossils] Plant and Ostreidae bivalve fossils have been reported from the formation (Maeda, 1952; Sakai et al., 2020c).

2.3.3. Obuchi Formation

[Nomenclature] The formation is named by Maeda (1952).

[Type section] The Itoshiro River (Maeda, 1952).

[Distribution] Taniyamadani (Fig. 2-2-4, 5) and ridgeline route (Fig. 2-2-12).

[Thickness] The formation is about 330 m thick in ridgeline route.

[Relationship with the lower formation] The formation overlies the Ashidani Formation conformably.

[Lithology] The formation is composed of coarse-grained sandstone and conglomerate. Massive conglomerates are poorly-sorted and matrix-supported. The matrix is coarse-grained sandstone. Clasts are rounded and are characterized by orthoquartzite and granite. The greatest dimension of clast size is about 15 cm, and average dimension is about 5 cm. Medium to coarse-grained sandstone and conglomerate include plant fragments and mudstone clasts.

2.3.4. Itsuki Formation

[Nomenclature] The formation is named by Maeda (1952).

[Type section] The Itoshiro River (Maeda, 1952).

[Distribution] Itsuki (Fig. 2-2-16, 17, 18), Itoshiro River (Fig. 2-2-18), ridgeline route (Fig. 2-2-12), Taniyamadani (Fig. 2-2-6, 8) and Yugami (Fig. 2-2-1, 2). The most continuous section is exposed in Taniyamadani.

[Thickness] The formation is about 740 m thick in the Itoshiro River.

[Relationship with the lower formation] The formation overlies the Obuchi Formation conformably in Taniyamadani.

[Lithology] The formation consists of alternating beds of mudstone and sandstone, medium to coarse-grained sandstone and conglomerate. The alternating beds are composed of medium-grained sandstone, gray mudstone, gray sandy mudstone and gray fine-grained sandstone. The lateral variation of these beds is often changed. Sandstone and mudstone are laminated. Rootlets are recognized in sandstone and mudstone beds.

Plant and molluscan fossils occur in the alternating bed of mudstone and sandstone. A thick conglomerate layer including chert clasts is present in the lower part of the Itsuki Formation (Ito et al., 2015). The matrix is medium to coarse-grained sandstone. Clasts are sub-rounded and are characterized mainly by chart, siliceous mudstone and orthoquartzite. The greatest dimension of clast size is about 2 cm, and average dimension is about 1 cm. Medium to coarse-grained sandstone and conglomerate include plant fragments and mudstone clasts. A tuff bed is 0.5 m thick and is intercalated in the alternating bed of mudstone and sandstone in Taniyamadani.
[Fossils] Plant, mollusk and vertebrate fossils occur commonly in the sandstone and mudstone beds of the formation (Tsukiji et al., 2019; Hirayama et al., 2020; Sakai et al., 2020b, 2020c). Brackish and freshwater molluscan fossils such as *Myrene tetoriensis* Kobayashi and Suzuki, *Tetoria yokoyamai* Kobayashi and Suzuki, Ostreidae gen. et sp. indet., "*Unio*"? sp., *Megasphaerioides* sp., *Nippononaia tetoriensis* Maeda, *Melanoides vulgaris* Kobayashi and Suzuki and *Viviparus onogoensis* Kobayashi and Suzuki have been reported from the formation (e.g., Kobayashi and Suzuki, 1937; Matsukawa and Ido, 1993; Koarai and Matsukawa, 2016; Sakai, 2019; Sakai et al., 2020b).

2.3.5. Nochino Formation

[Nomenclature] The formation is named by Maeda (1957).
[Type section] Nochino in the Itoshiro River.
[Distribution] Itoshiro River (Fig. 2-2-18, 30, 31, 32), Chinaboradani (Fig. 2-2-19, 20, 21, 22, 23, 24, 25), Taniyamadani (Fig. 2-2-8), ridgeline route (Fig. 2-2-12), Yugami (Fig. 2-2-1, 2), Nagakuradani (Fig. 2-2-9) and Maesakadani (Fig. 2-2-11). The most continuous section is exposed in the Itoshiro River.
[Thickness] The formation is about 780 m thick in the Itoshiro River.
[Relationship with the lower formation] The formation overlies the Itsuki Formation unconformably in Taniyamadani, Yambara and the Itoshiro River.
[Lithology] The formation consists of medium to coarse-grained sandstone,

conglomerate and alternating beds of mudstone and sandstone. Conglomerate beds of the formation are poorly-sorted and matrix-supported. Clasts are rounded and are characterized mainly by orthoquartzite. Coarse-grained sandstone beds are poorly sorted and include many quartz sub-rounded pebbles and mudstone clasts. The alternating beds are composed of mudstone, sandy mudstone, fine-grained sandstone, medium-grained sandstone and green mudstone. The lateral variation of these beds is often changed. Sandstone and mudstone are laminated. Rootlets are recognized in sandstone and mudstone beds. The uppermost part of the formation contains calcareous nodules and red mudstone and sandstone beds. Fossil plants occur commonly in the alternating beds.

[Fossils] The formation yields molluscan, plant fossils. Mollskcan fossils were reported from Maesakadani (Maeda, 1957). Plant fossils were reported from the Itoshiro River and Chinaboradani (Maeda, 1952, 1957; Sakai et al., 2020c). Dinosaur footprint fossils were reported from the Itoshiro River and Nagakuradani (Tsukiji et al., 2019).

2.4. Material

Sakai et al. (2020c) surveyed 32 sections in the Kuzuryu area (Figs. 2-2, 2-3). Diverse and rich plant fossils have been recently collected and investigated from the Ashidani, Itsuki and Nochino formations of the Tetori Group in this area (Table 2-1), including 64 localities (Figs. 2-2, 2-3). These plant fossils are systematically identified and the representative specimens are selected, digital photographed and illustrated in Figs. 2-4, 2-5, 2-6. All specimens are cataloged and are stored in Izumi local History Museum, Fukui Prefecture, Japan (OMFJ).

2.5. Floristic composition

Fossil plants of the Ashidani Formation of the Tetori Group were collected from 3 localities in ridgeline route (Fig. 2-2-12) and the Itoshiro River (Fig. 2-2-18). The plant assemblage includes 7 genera and 8 species, including *Cladophlebis hukuiensis* Oishi, *Cladophlebis* sp., *Gleichenites nipponensis* Oishi, *Onychiopsis elongata* (Geyler) Yokoyama, *Sphenopteris* sp., *Nilssonia nipponensis* Yokoyama, *Ginkgoites digitata* Brongniart and *Podozamites lanceolatus* (Lindley and Hutton) Braun. This assemblage is characterized by gleicheniaceous ferns, *Nilssonia*, ginkgoaleans and *Podozamites*. No Ryoseki-type floral element has been reported from this formation.

Fossil plants of the Itsuki Formation were collected from 22 localities in Yugami (Fig. 2-2-1, 2, 3), Taniyamadani (Fig. 2-2-6), ridgeline route (Fig. 2-2-12) and the Itoshiro River (Fig. 2-2-18). The plant assemblage includes 24 genera and 31 species (Table 2-1), including *Thallites yabei* (Kryshtofovich) Harris, *Equisetites ushimarensis* (Yokoyama) Oishi, *Adiantopteris* sp., *Birisia onychioides* (Vassilevskaja and Kara-Mursa) Samylina, *Cladophlebis denticulata* (Brongniart) Fontaine, *Cladophlebis* cf. *C. williamsoni* (Brongniart) Brongniart, *Coniopteris burejensis* (Zalesskey) Seward, *Eboracia nipponica* Kimura and Sekido, *Onychiopsis elongata*, *Osmundopsis distans* (Heer) Kimura and Sekido, *Sphenopteris* sp., *Sagenopteris* sp., *Nilssonia kotoi* (Yokoyama) Oishi, *Nil. nipponensis*, *Nilssonia* sp., *Dictyozamites kawasakii* Tateiwa, *Dictyozamites* sp., *Neozamites elongates* Kimura and Sekido, *Otozamites* sp., *Baiera furcata* (Lindley and Hutton) Braun, *Ginkgoidium nathorsti* Yokoyama, *Ginkgoites digitata*, *Pagiophyllum* sp., *Pityophyllum* sp., *Podozamites lanceolatus*, *Po. reinii* Geyler, *Protodammara* sp., *Schizolepis* sp. and *Taeniopteris emarginata* Oishi. This assemblage is characterized by osmundaceous and dicksoniaceous ferns, *Neozamites*, *Dictyozamites*, *Nilssonia*, ginkgoaleans, *Podozamites* and conifers with needle-like leaves. However, the assemblage of the uppermost part of the formation is characterized by osmundaceous and dicksoniaceous ferns, ginkgoaleans, *Dictyozamites*, *Nilssonia*, *Podozamites* and microphyllous conifers, such as *Pagiophyllum*. It is thus considered to be a Mixed-type Flora (Kimura, 1987) including the Ryoseki-type floral elements.

Fossil plants of the Nochino Formation were collected from 38 localities in Nagakuradani (Fig. 2-2-9), Maesakadani (Fig. 2-2-10, 11), Chinaboradani (Fig. 2-2-19, 20, 21, 22, 23, 24, 25) and the Itoshiro River (Fig. 2-2-18, 30, 31, 32). The plant assemblage includes 18 genera and 24 species (Table 2-1), including *Equisetites* *ushimarensis*, *Cladophlebis denticulata*, *Cl. hukuiensis*, *Cladophlebis* sp., *Coniopteris burejensis*, *Gleichenites nipponensis*, *Gl. porsildi* Seward, *Gl. yamazakii* Kimura and Sekido, *Onychiopsis elongata*, *Sphenopteris* sp. *Sagenopteris* sp., *Pterophyllum* sp., *Ginkgoites digitata*, *Ginkgoidium nathorsti*, *Sphenobaiera* sp., *Czekanowskia* sp., *Cephalotaxopsis* sp., *Elatocladus* sp., *Geinitzia* sp., *Pagiophyllum* sp., *Podozamites lanceolatus*, *Po. reinii* and *Taeniopteris emarginata*. This assemblage is characterized by gleicheniaceous ferns, ginkgoaleans, czekanowskialeans, *Podozamites* and microphyllous conifers such as *Pagiophyllum*, and is considered to be a Mixed-type Flora (Kimura, 1987) with the Ryoseki-type floral elements. Based on Harris (1979), *Pagiophyllum*-like coniferous foliage from the Nochino Formation is identical to *Geinitzia*. Conifers are more diverse in the Nochino Formation than in the Itsuki Formation as the number of species changes from four of the Itsuki Formation to eight of the Nochino Formation.

Based on detailed field survey and fossil collections from the Ashidani, Itsuki and Nochino formations of the Tetori Group, Sakai et al. (2020c) provide further insights into the Ryoseki-type floral element-bearing horizons in the Kuzuryu area (Fig. 2-7). As previously noted, the plant assemblage from the Itsuki Formation is characterized by osmundaceous and dicksoniaceous ferns, *Neozamites*, *Dictyozamites*, several species of *Nilssonia*, ginkgoaleans, some taxa of *Podozamites* as well as conifers with needle-like leaves. Our comparison demonstrates that the floristic composition of the Itsuki Formation corresponds to that of the Tetori-type Flora (Kimura, 1987). On the other hand, the fossil plant assemblage from the Nochino Formation is characterized by gleicheniaceous ferns, ginkgoaleans, several species of *Podozamites*, *Elatocladus* and *Geinitzia* as well as microphyllous conifers such as *Pagiophyllum*, and is the Mixed-type Flora (Kimura, 1987).

Throughout the Itsuki and Nochino formations, the lowest horizon of Ryoseki-type floral elements occurs at the uppermost part of the Itsuki Formation (Fig. 2-7). Therefore, the floral element analysis infers a major change in conifers between the Itsuki and Nochino formations. Furthermore, the assemblage from the Nochino

Formation is characterized by no occurrence of *Dictyozamites* and *Nilssonia*, whereas they are highly diverse within the Itsuki Formation. It is thus assumed that a distinct floral change event can be recognized across the boundary between the Itsuki and Nochino formations.

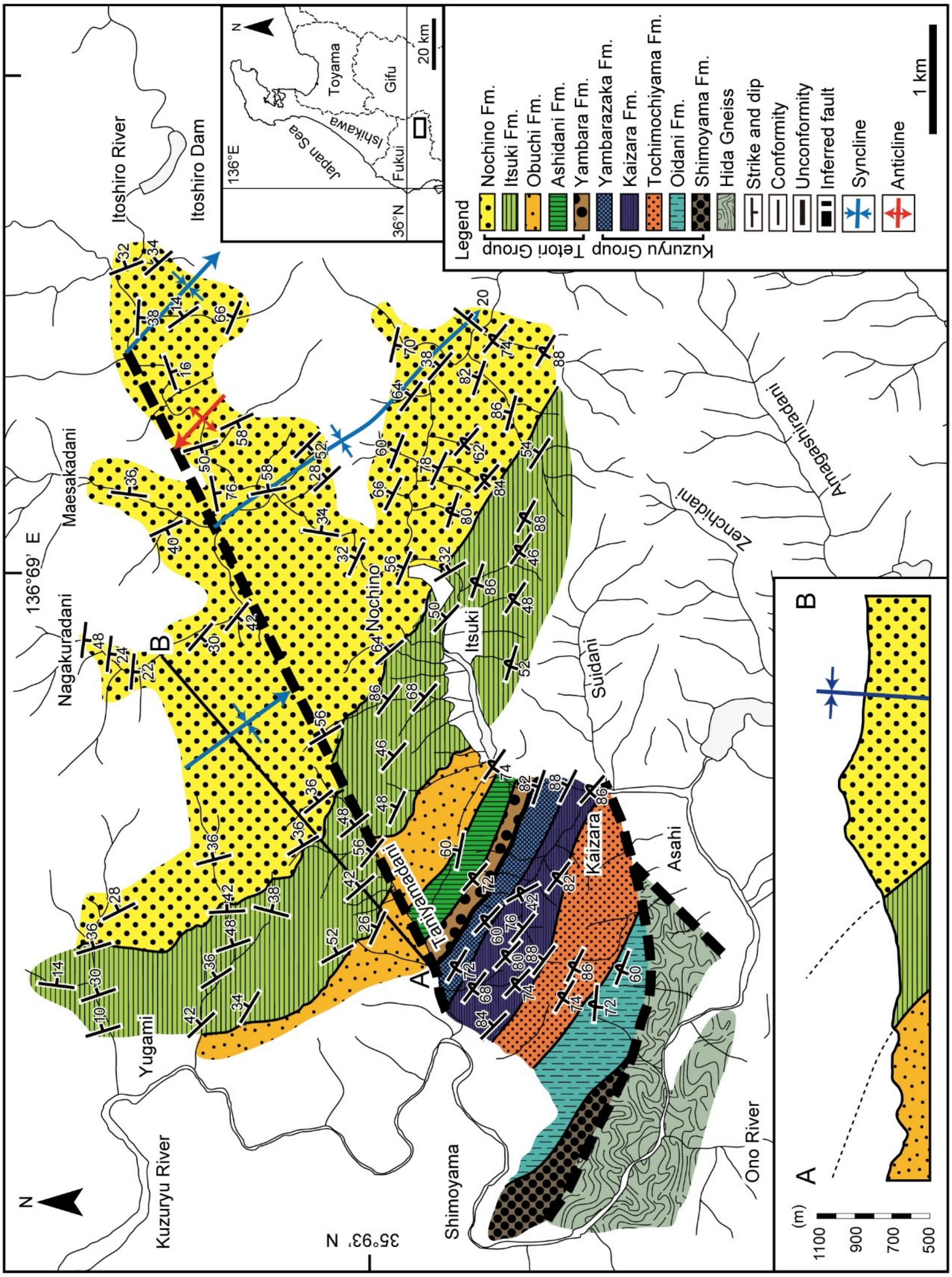


Fig. 2-1. Geological map of the upper reaches of the Itoshiro River. A-B indicates a cross section of the Obuchi, Itsuki and Nochino formations.

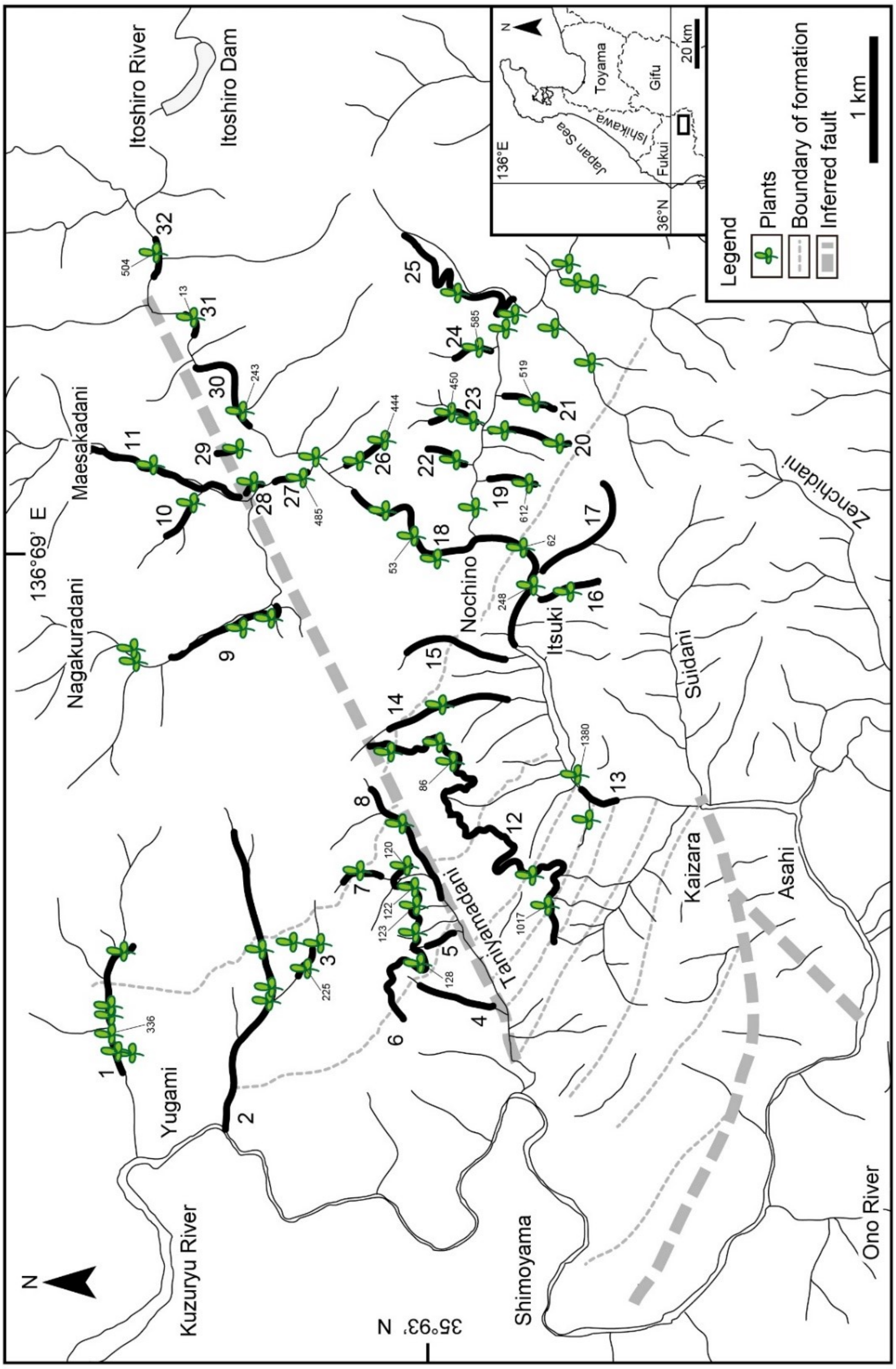


Fig. 2-2. Map showing the field study routes and fossil localities in the Kuzuryu area marked with numbers. Small numbers represent the plant fossil localities.

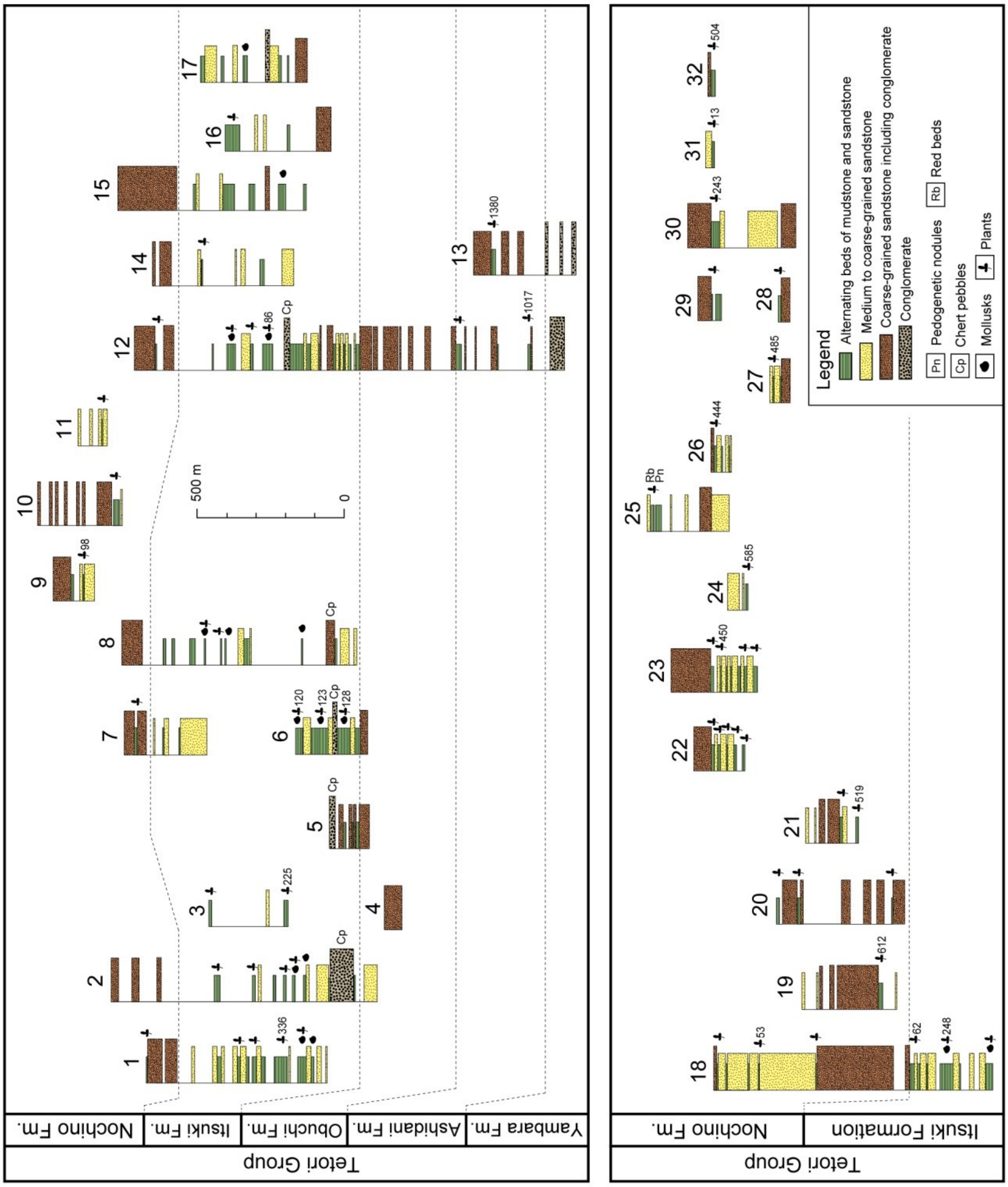


Fig. 2-3. Columnar sections of the Tetori Group in the Kuzuryu area. Locations of number are shown in Fig. 2-2.

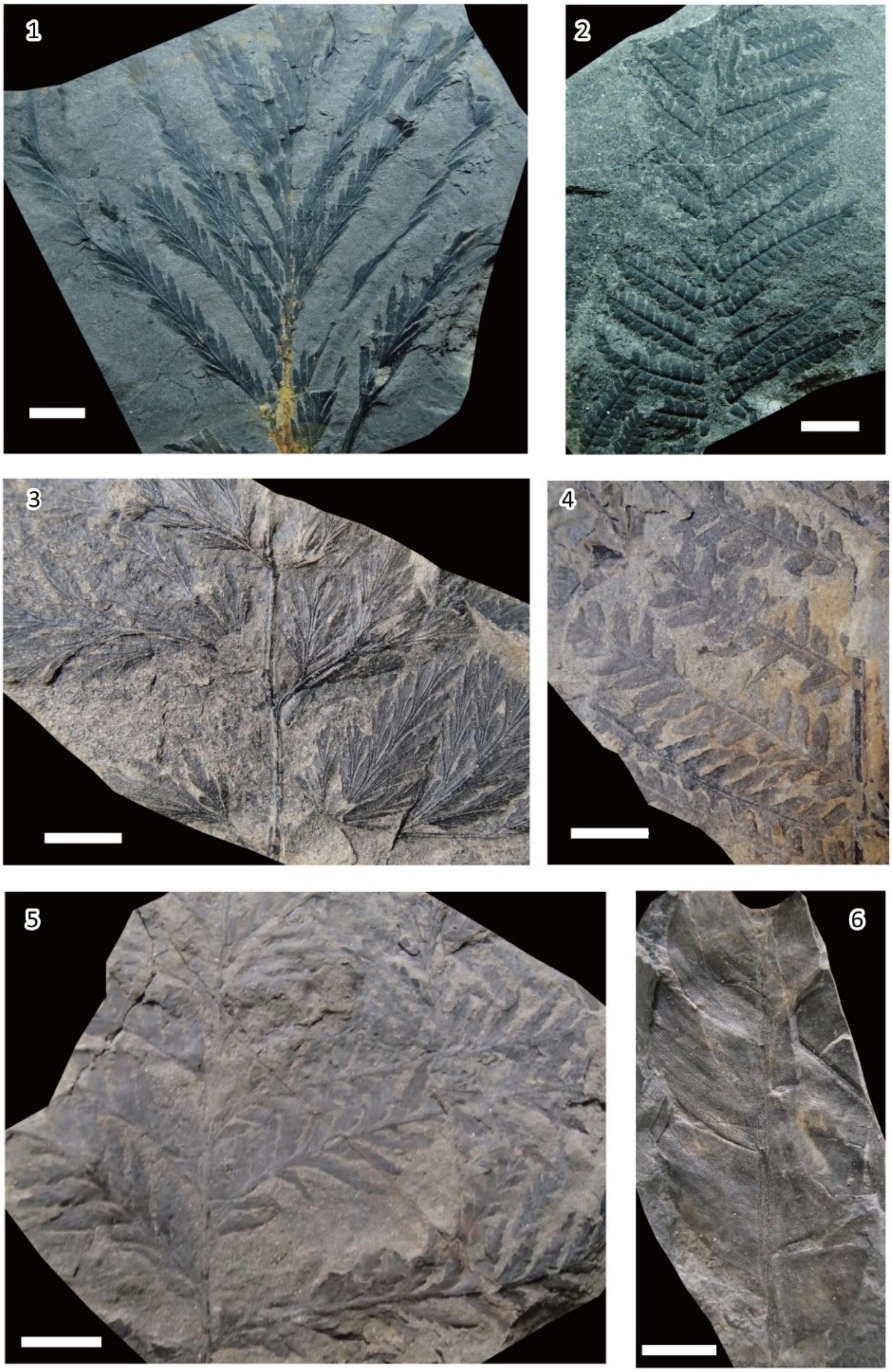

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Fig. 2-4. Fossil plants from the Tetori Group in the Kuzuryu area. The localities of plant-bearing beds and stratigraphic horizons are indicated in Figs. 2-2, 2-3, respectively.1: *Onychiopsis elongata* (Geyler) Yokoyama from Loc. 243 in the Nochino Formation, OMFJ P-229, 2: *Gleichenites nipponensis* Oishi from Loc. 243 in the Nochino Formation, OMFJ P-244, 3: *Sphenopteris* sp. from Loc. 504 in the Nochino Formation, OMFJ P-574, 4: *Cladophlebis* sp. from Loc. 612 in the Nochino Formation, OMFJ P-614, 5: *Coniopteris burejensis* (Zalesskey) Seward from Loc. 225 in the Itsuki Formation, OMFJ P-275, 6: *Nilssonia nipponensis* Yokoyama from Loc. 336 in the Itsuki Formation, OMFJ P- 420. The Tetori-type floral elements (5, 6). All scale bars are 10 mm.

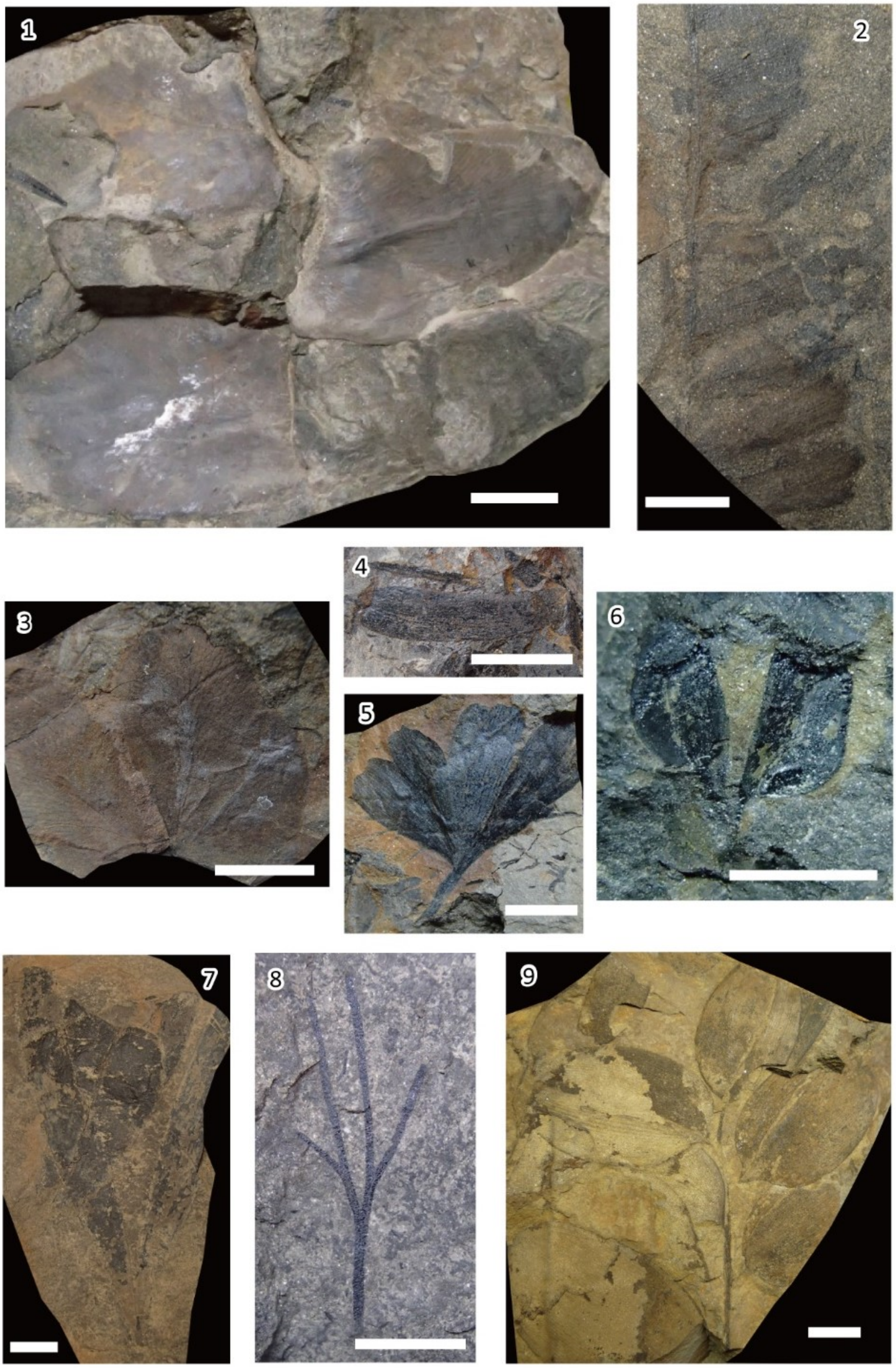
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Fig. 2-5. Fossil plants from the Tetori Group in the Kuzuryu area. The localities of plant-bearing beds and stratigraphic horizons are indicated in Figs. 2-2, 2-3, respectively. 1: *Dictyozamites kawasakii* Tateiwa from Loc. 128 in the Itsuki Formation, OMFJ P-100, 2: *Neozamites elongatus* Kimura and Sekido from Loc. 128 in the Itsuki Formation, OMFJ P-143, 3: *Sagenopteris* sp. from Loc. 128 in the Itsuki Formation, OMFJ P-151, 4: *Dictyozamites* sp. from Loc. 128 in the Itsuki Formation, OMFJ P-104, 5: *Ginkgoites digitata* Brongniart from Loc. 128 in the Itsuki Formation, OMFJ P-107, 6: *Schizolepis* sp. from Loc. 128 in the Itsuki Formation, OMFJ P-135, 7: *Sphenobaiera* sp. from Loc. 13 in the Nochino Formation, OMFJ P-173, 8: *Baiera furcata* (Lindley and Hutton) Braun from Loc. 86 in the Itsuki Formation, OMFJ P-197, 9: *Podozamites reinii* Geyler from Loc. 123 in the Itsuki Formation, OMFJ P-84. The Tetori-type floral elements (1, 2, 4, 5, 7, 8, 9). Scale bars- 5 mm (6), 10 mm (1-5, 7-9).

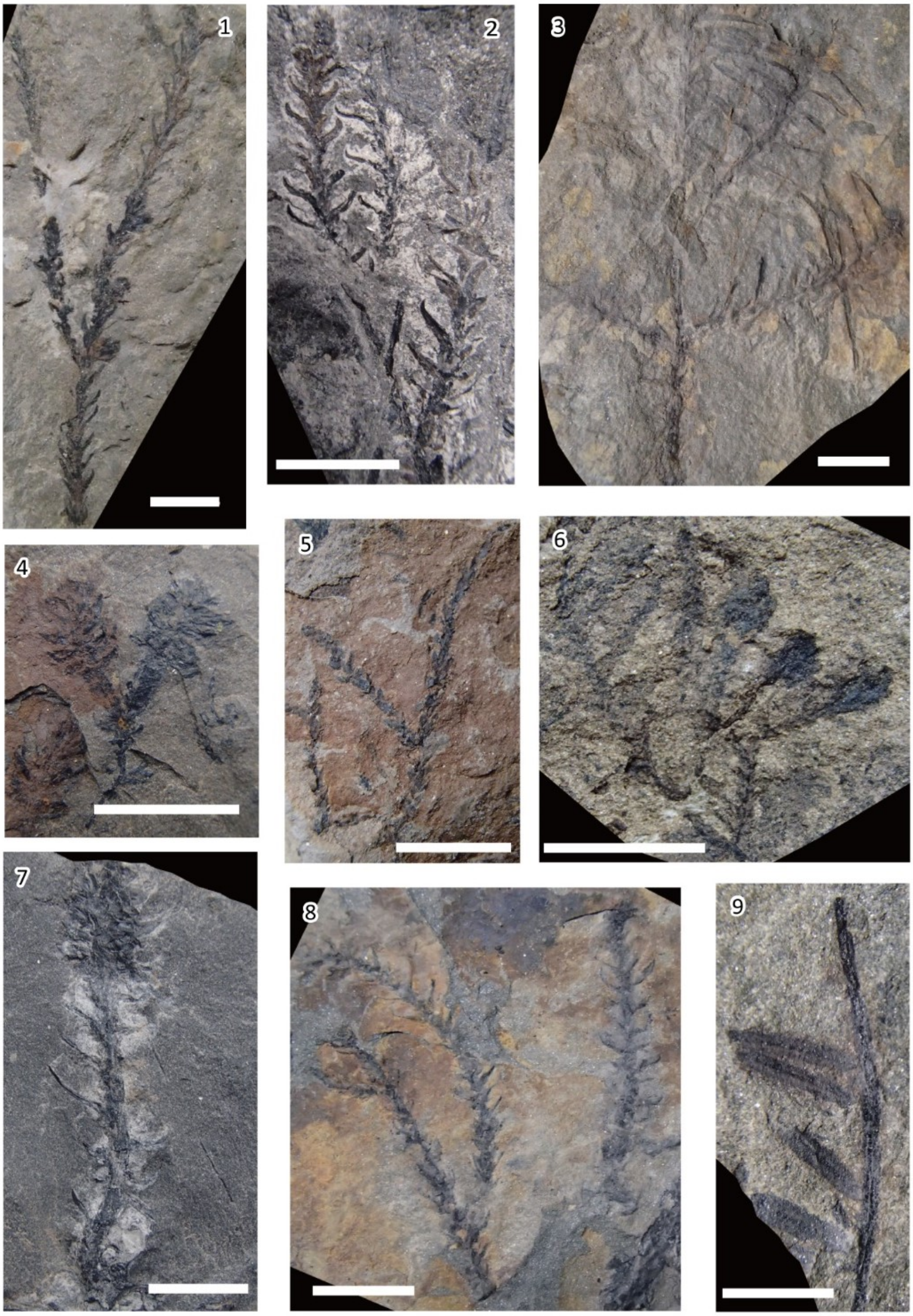
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Fig. 2-6. Fossil plants from the Tetori Group in the Kuzuryu area. The localities of plant-bearing beds and stratigraphic horizons are indicated in Figs, 2-2, 2-3, respectively. 1: *Geinitzia* sp. from Loc. 612 in the Nochino Formation, OMFJ P-623, 2: *Pagiophyllum* sp. from Loc. 444 in the Nochino Formation, OMFJ P-508, 3: *Cephalotaxopsis* sp. from Loc. 519 in the Nochino Formation, OMFJ P-596, 4: Cone of *Pagiophyllum* sp. from Loc. 62 in the Itsuki Formation, OMFJ P-923, 5: *Pagiophyllum* sp. from Loc. 485 in the Nochino Formation, OMFJ P-538, 6; Cone of *Pagiophyllum* sp. from Loc. 485 in the Nochino Formation, OMFJ P-549, 7: *Geinitzia* sp. from Loc. 450 in the Nochino Formation, OMFJ P-517, 8: *Geinitzia* sp. from Loc. 519 in the Nochino Formation, OMFJ P-596, 9: *Elatocladus* sp. from Loc. 485 in the Nochino Formation, OMFJ P-561. The Ryoseki-type floral elements (2, 4, 5, 6). All scale bars are 10 mm.

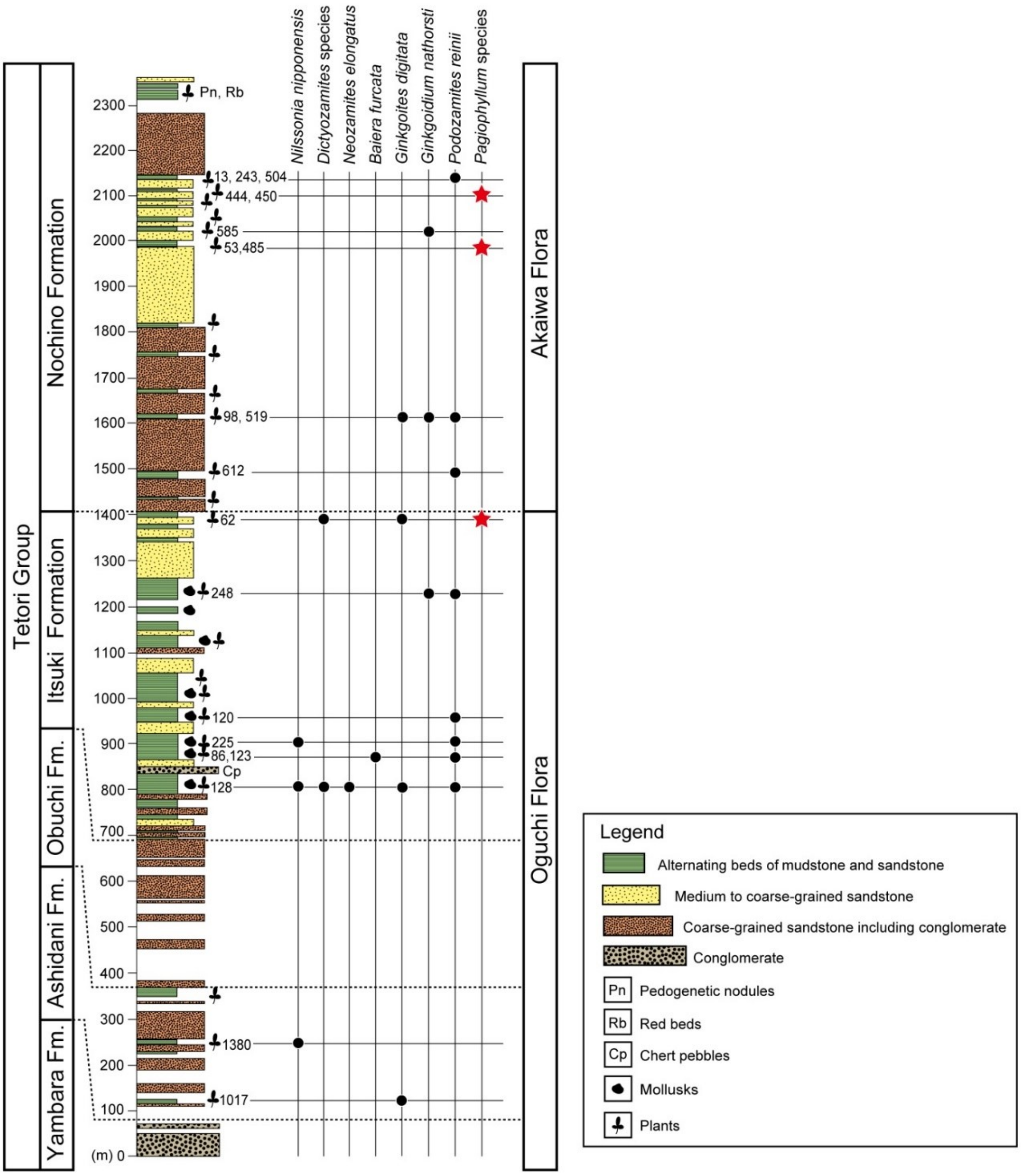

Fig. 2-7. Generalized columnar section in the study area, showing the stratigraphic occurrence of fossil plants. The localities of plant-bearing beds and stratigraphic horizons are indicated in Figs. 2-2, 2-3, respectively. ●: the Tetori-type floral elements, ★: the Ryoseki-type floral elements. The line chart shows the transition process of plant biofacies.

Table 2-1. List of fossil plants from the Itsuki and Nochino formations in the study area. The localities and stratigraphic horizons are indicated in Figs. 2-2, 2-3, 2-7, respectively.

Localities	Itsuki Formation									Nochino Formation										
Species	62	86	120	122	123	128	225	248	336	13	53	98	243	444	450	485	504	519	585	612
Bryophyta																				
Thallites yabei (Kryshtofovich) Harris				○	○															
Sphenopsida																				
Equisetites ushimarensis (Yokoyama) Oishi		○	○	○	○	○														
Ferns																				
Adiantopteris sp.				○		○														
Birisia onychioides (Vassilevskaja and Kara-Mursa) Samylina				○																
Cladophlebis denticulata (Brongniart) Fontaine						○										○		○		
Cladophlebis hukuiensis Oishi											○		○							
Cladophlebis cf. *C. williamsoni* (Brongniart) Brongniart						○														
Cladophlebis spp.				○		○						○			○					○
Coniopteris burejensis (Zalesskey) Seward				○	○		○						○							
Eboracia nipponica Kimura and Sekido	○					○										○				
Gleichenites nipponensis Oishi													○			○	○	○		
Gleichenites porsildi Seward															○		○			
Gleichenites yamazakii Kimura and Sekido										○										
Onychiopsis elongata (Geyler) Yokoyama	○	○	○	○	○	○	○	○		○	○	○	○		○	○		○	○	
Osmundopsis distans (Heer) Kimura and Sekido	○					○														
Sphenopteris sp.				○		○						○	○				○			
Seed ferns																				
Sagenopteris sp.						○									○	○				
Cycadaleans																				
Nilssonia kotoi (Yokoyama) Oishi						○														
Nilssonia nipponensis Yokoyama						○	○		○											
Nilssonia spp.	○					○														
Bennettitaleans																				
Dictyozamites kawasakii Tateiwa						○														
Dictyozamites sp.	○					○														
Neozamites elongatus Kimura and Sekido						○														
Otozamites sp.						○														
Pterophyllum sp.															○					
Ptilophyllum ? sp.																○				
Ginkgoaleans																				
Baiera furcata (Lindley and Hutton) Braun		○			○															
Ginkgoidium nathorsti Yokoyama								○				○							○	
Ginkgoites digitata Brongniart	○					○						○								
Sphenobaiera sp.										○										

Table 2-1. (Continued)

Czekanowskialeans																				
Czekanowskia sp.																	○			
Conifers																				
Cephalotaxopsis sp.																	○			
Elatocladus sp.																○				
Geinitzia sp.															○			○		○
Pagiophyllum sp.	○													○	○	○				
Pityophyllum lindstroemi Nathorst						○														
Podozamites lanceolatus (Lindley and Hutton) Braun	○		○	○						○			○				○			
Podozamites reinii Geyler			○	○	○	○	○	○	○	○			○					○		○
Protodammara sp.				○																
Schizolepis sp.						○														
Systematic position unknown																				
Taeniopteris emarginata Oishi						○	○					○								

Part 3

Early Cretaceous plants from the Lower Cretaceous Tetori Group in the border area between Ishikawa and Fukui prefectures

3.1. Introduction

The stratigraphic relation of plant fossil-bearing beds of the Tetori Group had been discussed by Oishi (1933), Omura (1973) and Kimura (1975, 1987). However, the comparison of plant fossil-bearing beds has not been successful in the Tetori Group because the lithological classifications of each region are different among researchers. And it is further necessary to collect plant fossil from the Akaiwa and Kitadani formations which fossil record is poor for understanding floral change from the Kuwajima Formation to the Kitadani Formation continuously. Therefore, the author studies the stratigraphical change of plant assemblages in the Shiramine area, Hakusan City, Ishikawa Prefecture.

Sakai et al. (2018) carried out a detailed field survey in the Shiramine and Takinamigawa areas. They verified that the uppermost formation in the Takinamigawa area is correlated with the uppermost formation in the Shiramine area, and showed the common stratigraphic classification on both areas. Furthermore, as a result of reexamining the stratigraphic horizon of the plant fossil-bearing beds in this study area together with the data of the previous works, the assemblage, characterized by taxa preferring a dry climate such as macrophyllous bennettitaleans and microphyllous coniferous foliages, was clarified that the assemblages started to appear from the lower part of the Akaiwa Formation.

3.2. Geological setting

The Shiramine area is located throughout the upper reaches of the Tedori River which occupies the southern part of Ishikawa Prefecture (Fig. 3-1). The Takinamigawa area is located throughout the Takinami River which is a tributary of the Kuzuryu River. The strata in both areas are metamorphic rocks of the Hida Terrane, the Lower Cretaceous Tetori Group, the Upper Cretaceous Asuwa Group, the Upper Cretaceous to Paleogene Nohi Rhyolites and Neogene to Quaternary Andesites, in ascending order

(Fukui Pref., 2010) (Fig. 3-1). The Tetori Group contacts metamorphic rocks of the Hida Terrane throughout a fault between Nishijima Pass and Oarashidani (Fig. 3-1). The Tetori Group is composed of the Gomijima, Kuwajima, Akaiwa and Kitadani formations, in ascending order (Fig. 3-2). The molluscan fossils from the Kuwajima Formation are can be correlated with Valanginian to Hauterivian (Isaji et al., 2005). Recently, the U–Pb age of the lower part of the Kuwajima Formation indicates 129.1±1.5 Ma (Nagata et al., 2019). Sakai et al. (2019b) reported that a new U–Pb age of the lower part of the Akaiwa Formation indicates 121.2 ± 1.1 Ma. The continuous of the Tetori Group in boarder area between the Shiramine and Takinamigawa areas is untraceable because the Tetori Group is overlain by the younger volcanic rocks in Tani Pass between Fukui and Ishikawa prefectures. The Tetori Group is overlain by the Upper Cretaceous to Paleogene Nohi Rhyolites and Neogene to Quaternary Andesites.

The strata of the Tetori Group in the Shiramine area strike southwest and gradual dip (Fig. 3-1). There is synclinal structure between Mt. Nishiyama and Myodani because the strata of that around Mt. Nishiyama strike northeast and gradual dip. In the Takinamigawa area, there is synclinal structure between Kougo and Tani because the strata of that in the Suguyama River strike southeast and gradual dip, and the strata of that in Kinehashi and Ohara strike northwest and gradual dip (Fig. 3-1). The geological structure of the Tetori Group in Otadani of the Shiramine area is similar to that of the group in Tani of the Takinamigawa area. The Tetori Group is overlain by the Omichidani Formation, the Upper Cretaceous to Paleogene Nohi Rhyolites and Neogene to Quaternary Andesites.

3.3. Lithostratigraphy

Sakai et al. (2018) surveyed 24 routes in the Shiramine area and 13 routes in the Takinamigawa area (Fig. 3-3). The Tetori Group is composed of the Gomijima, Kuwajima, Akaiwa and Kitadani formations, in ascending order.

3.3.1. Gomijima Formation

[Nomenclature] The formation is named by Oishi (1933).
[Type section] Gomijima (Maeda, 1958).
[Distribution] Togadani (Fig. 3-3-17).
[Thickness] The formation is estimated to be about 20 m thick in Togadani (Fig 3-3-17).
[Relationship with the lower formation] The formation overlies the Hida Terrane which is basement rocks unconformably in Gomijima.
[Lithology] The formation is composed of massive conglomerates which are poorly-sorted and clast-supported. The matrix is coarse-grained sandstone. Clasts are rounded and are characterized mainly by crystalline limestone, gneiss, and granite.

3.3.2. Kuwajima Formation

[Nomenclature] The formation is named by Oishi (1933).
[Type section] Around the Kaseki-kabe (Maeda, 1958).
[Distribution] Tochigamiya (Fig. 3-3-3), Akadani River (Fig. 3-3-14), Togadani (Fig. 3-3-17), Kaseki-kabe (Fig. 3-3-36) and Nishijima Pass (Fig. 3-3-37). The most continuous section is exposed in Togadani.
[Thickness] The formation is estimated to be about 950 m thick in Togadani.
[Relationship with the lower formation] The formation overlies the Gomijima Formation unconformably in Togadani.
[Lithology] The formation consists mainly of alternating beds of sandstone and mudstone, medium to coarse-grained sandstone. The alternating beds are composed in dark gray mudstone and fine-grained sandstone. Sandstone and mudstone are laminated. Rootlets are recognized in sandstone and mudstone beds. Molluscan and plant fossils occur from the alternating beds in Togadani and Kaseki-kabe. The course-grained sandstone includes sometimes orthoquartzite pebbles and mudstone clasts.

［**Fossils**］ The formation yields molluscan, plant and vertebrate fossils. The lower part of the formation in Togadani includes *Myrene tetoriensis*. The upper part of the formation in Nishijima Pass includes *My. tetoriensis* and “*Ostrea*” sp. The upper part of the formation in Kaseki-kabe includes “*Unio*” *ogamigoensis* Kobayashi and Suzuki and “*Viviparus*” *onogoensis*. The upper part of the formation in Tochigamiya includes *My. tetoriensis* (Tsukano, 1969), “*Unio*”? sp. and “*Viviparus*” sp. Vertebrate fossils were reported from Kaseki-kabe (Matsuoka, 2000; Isaji et al., 2005; Sano and Yabe, 2017).

3.3.3. Akaiwa Formation

[Nomenclature] The formation is named by Maeda (1958).
[Type section] Kazarashi, Akaiwa and Ichinose along the Tedori River.
[Distribution] Tochigamiya (Fig.3-3-2, 3), Sugiyama River (Fig. 3-3-4), Ohara (Fig. 3-3-9), Akadani River (Fig. 3-3-14), Shimotahara River (Fig. 3-3-17), Myodani (Fig. 3-3-27), Byakodan (Fig. 3-3-31), Oarashiyama (Fig. 3-3-33, 34) and Nishijima Pass (Fig. 9-37). The most continuous section is exposed in Oarashiyama, the Shimotawara River and the Akadani River.
[Thickness] The formation is estimated to be about 760 m thick in the Akadani River, about 740 m thick in the Takinami River and about 1400 m thick in the Shimotahara River.
[Relationship with the lower formation] The formation overlies the Kuwajima Formation unconformably in the Akadani River.
[Lithology] The formation consists of medium to coarse-grained sandstone, conglomerate, sandstone-dominated alternating bed of sandstone and mudstone. Conglomerate beds are poorly-sorted and matrix-supported. The matrix is medium to coarse-grained sandstone. Clasts are rounded and are characterized mainly by orthoquartzite, granite and siliceous tuff. The greatest dimension of clast size is about 30 cm, and average dimension is about 3 to 5 cm. Medium to coarse-grained sandstone and conglomerate include plant fragments and mudstone clasts. Clast-supported

conglomerate beds are exposed in Byakodan and Oarashiyama. Matrix-supported conglomerate beds are exposed in Ohara and the Sugiyama River. Bedding conglomerate beds in the Akadani River are considered as cross bedding. The alternating beds are composed of fine to medium-grained sandstone, gray fine-grained sandstone, gray sandy mudstone, gray mudstone and green gray mudstone (green mudstone). Sandstone and mudstone are laminated. The lateral variation of these beds is often changed. Calcareous nodules were reported from green mudstone beds in Oarashiyama (Fujita, 1998). Rootlets are recognized in sandstone and mudstone beds. Plant fossils occur from the alternating beds of mudstone and sandstone.

[Fossils] The formation yields molluscan, plant and vertebrate fossils. "*Unio*"? sp. was obtained from Byakodan (Sakai et al., 2018). Turtle fossils were reported from Oarashiyama (Hirayama et al., 2012).

3.3.4. Kitadani Formation

[Nomenclature] The formation is named by Maeda (1958).

[Type section] Sugiyama River.

[Distribution] Sugiyama River (Fig. 3-3-4), Kougo (Fig. 3-3-3), Kinehashi (Fig. 3-3-8), Tani (Fig. 3-3-10, 11, 12, 13), Akadani River (Fig. 3-3-14, 15), Nishiyama (Fig. 3-3-20, 21), Otadani (Fig. 3-3-22, 23) and Myodani (Fig. 3-3-27). The most continuous section is exposed in the Takinami River.

[Thickness] The formation is estimated to be about 670 m thick in the Akadani River and about 600 m thick in the Takinami River.

[Relationship with the lower formation] The formation overlies the Akaiwa Formation unconformably in the Akadani River, Myodani and the Sugiyama River.

[Lithology] The formation consists of sandstone-dominated alternating bed of sandstone and mudstone, medium to coarse-grained sandstone and conglomerate. The alternating beds are composed of medium-grained sandstone, gray mudstone, gray sandy mudstone, gray fine-grained sandstone and green mudstone. Sandstone and mudstone are laminated. The lateral variation of these beds is often changed. Calcareous nodules were reported from green mudstone beds (Morikiyo and Sato, 2002; Kubota, 2003; Yabe and Shibata, 2011). Rootlets are recognized in sandstone and mudstone beds. Plant and molluscan fossils occur in the alternating bed of mudstone and sandstone. Conglomerate beds are poorly-sorted and matrix-supported. The matrix is medium to coarse-grained sandstone. Clasts are rounded and are characterized mainly by orthoquartzite. Medium to coarse-grained sandstone and conglomerate include plant fragments and mudstone clasts. A tuff bed is 1.0 m thick and is intercalated in the alternating bed of mudstone and sandstone in Nishiyama (Fig. 3-3-20). A tuff bed is 0.5 m thick and is intercalated in the alternating bed of mudstone and sandstone along the Omichidani River (Fig. 3-3-25). Red mudstone bed is about 1.0 m thick and is discovered from Nishiyama (Fig. 3-3-21).

[Fossils] The formation yields molluscan, plant and vertebrate fossils. *Plicatounio nakutongensis* Kobayashi and Suzuki, *Nagdongia soni* Yang, *Trigonioides tetoriensis* Maeda, *Nippononaia ryosekiana*, *Nippononaia tetoriensis* Maeda, *Pseudophria matsumotoi* Yang and “*Viviparus*” sp. were reported from Kinehashi along the Sugiyama River, and Otadani (Maeda, 1958, 1962, 1963; Tamura, 1990; Isaji, 1993; Matsukawa et al., 2003a). *Pl. nakutongensis*, *Na. soni*, *Nip. ryosekiana* and *Ps. matsumotoi* are discovered from the upper reaches of the Akadani River, and *Pl. akutongensis*, *Na. soni*, *Tr. tetoriensis* are discovered from the Omichidani River (Sakai et al., 2018). Charophyte gyrogonites (Kubota, 2005) and palynoflora (Legrand et al., 2013, 2019) from the Sugiyama River. Vertebrate fossils were reported from the Sugiyama River (e.g., Hirayama, 2002a; Azuma, 2003; Shibata and Goto, 2008) and Otadani (Hirayama, 2002b).

3.4. Stratigraphy in the Tetori Group in the Shiramine and Takinamigawa areas

The stratigraphic correlation of the Tetori Group between the Shiramine and Takinamigawa areas was discussed by previous works (Maeda, 1958; Ishikawa Pref.

Board of Education, 1978; Matsukawa et al., 2003b). Maeda (1958) proposed that the Kitadani Formation which this type section is the Takinami River regarded as the uppermost part of the Tetori Group, and showed the distribution of the formation in the Shiramine area. In contrast, there are opinion that the Kitadani Formation in the Takinamigawa area is correlated with the Kuwajima Formation in the Shiramine area (Kawai, 1961; Tamura, 1990), and opinion that it is contemporaneous heterotopic facies of the Kuwajima Formation (Matsukawa et al., 2003b). The author proposes about the comparison with the uppermost formation in both areas, based on the lithological and lithostratigraphic similarity of distributed in the Shiramine and Takinamigawa areas, the existence of green mudstone beds and pedogenetic nodules, and the occurrence of a bivalve assemblage mentioned later as the TPN fauna.

As described above, the Tetori Group in the Shiramine area is composed of 1) the Gomijima Formation composed mainly of conglomerate, 2) the Kuwajima Formation composed mainly of dark gray mudstone-dominated alternating bed of sandstone and mudstone, 3) the Akaiwa Formation composed mainly of massive conglomerate, 4) the Kitadani Formation composed mainly of green mudstone-dominated alternating bed of sandstone and mudstone. This study clarifies that the Tetori Group in the Takinamigawa area is also composed of formation composed mainly of dark gray mudstone-dominated alternating bed of sandstone and mudstone, formation composed mainly of massive conglomerates, formation composed mainly of green mudstone-dominated alternating bed of sandstone and mudstone, in ascending order, and consider that each formation is corresponded to the Kuwajima, Akaiwa and Kitadani formations in the Shiramine area.

Next, the author offers about the stratigraphical position of green mudstone bed, alternating bed of sandstone and mudstone including green mudstone bed and thin layer of green mudstone bed are distinguished on Oarashiyama, Byakodan, upper reach of the Akadani River, the Myodani River, the Omichidani River, Nishiyama and the Otadani River in the Shiramine area, and the Sugiyama River, Kougo, Kinehashi and Tani in the Takinamigawa area. These horizons belong to the Akaiwa Formation or the Kitadani Formation in this study. Therefore, the existence of green mudstone beds is effective for understanding the Akaiwa and Kitadani formations.

Moreover, pedogenetic nodule were discovered in Oarashiyama, the Omichidani River and the Otadani River in the Shiramine area, the Sugiyama River in the Takinamigawa area (Figs. 3-4, 3-7), These horizons belong to the Akaiwa Formation or the Kitadani Formation in this study. Therefore, the existence of pedogenetic nodules is also effective for understanding the Akaiwa and Kitadani formations.

The difference of bivalve fauna between the Kuwajima Formation in the Shiramine area and the Kitadani Formation in the Takinamigawa area have been often suggested (Maeda, 1958, 1962, 1963; Tamura, 1990; Isaji, 1993; Matsukawa et al., 2003a). For example, the Kuwajima Formation contains brackish water bivalve fossils such as *Myrene* and *Tetoria*, whereas they are not recognized in the Akaiwa and Kitadani formations (Maeda, 1958; Tamura, 1990) (Table 3-1). Maeda (1958) reported freshwater bivalve fossils such as "*Unio*" and *Nippononaia* [Maeda (1962) described as *Nip. tetoriensis*] from the Kuwajima Formation. He focused on the occurrence of *Trigonioides* and *Plicatounio* from the Kitadani Formation, which is no occurrence from the Kuwajima Formation, and called bivalve assemblages in the Kitadani Formation as the "Kitadani fauna". The TPN fauna which is bivalve assemblage including *Trigonioides*, *Plicatounio*, *Nippononaia* occurred the Sugiyama River in the Takinamigawa area, where is the type locality of the Kitadani Formation. Therefore, the assemblage is characteristics of the Kitadani Formation (Maeda, 1958, 1962, 1963; Tamura, 1990; Isaji, 1993; Matsukawa et al. 2003a). In the Shiramine area, though the occurrence of *Nip. ryosekiana* from the Otadani River was reported by Isaji (1993), are limited this occurrence horizon. The author obtained newly *Plicatounio* and *Nip. ryosekiana* from the upper reach of the Akadani River, and *Trigonioides* and *Plicatounio* from the Omichidani River (Fig. 3-4, Table 3-1). After consideration about these occurrence horizons of the TPN fauna, in case of applying stratigraphic classification in this study, except for *Nip. tetoriensis* from the Kuwajima Formation and Okurodani formations in the Shokawa area, all horizons containing *Trigonioides*, *Plicatounio* and *Nip. ryosekiana* belong to the Kitadani Formation (Fig. 3-7). Therefore, the occurrence of the TPN fauna is effective for understanding the Kitadani Formation.

As above, in addition to the lithological and lithostratigraphic similarity of distributed in the Shiramine and Takinamigawa areas, the existence of green mudstone beds and pedogenetic nodules, and the occurrence of the TPN fauna suggests that the upper formations in both areas are comparable, Maeda (1958)'s opinion which the Kitadani Formation distribute in both areas is supported.

By the way, the distribution of the Kitadani Formation in the Shiramine area varies greatly depending on previous work (Maeda, 1958; Ishikawa Pref. Board of Education, 1978; Matsukawa et al., 2003b). The distribution area of the Kitadani Formation in this study is the same as that of Ishikawa Pref. Board of Education (1978), the distribution of the locality of the TPN fauna also supports this opinion.

3.5. Material

Plant fossils have been collected from the Kuwajima, Akaiwa and Kitadani formations. List of plant fossils is shown in Table 3-2, 3-3. Plant fossils of these formations were collected from 30 localities. The number of specimens from the Kuwajima Formation is 54, that of the Akaiwa Formation is 130 and that of the Kitadani Formation is 74.

3.6. Floristic composition

Fossil plants of the Kuwajima Formation were collected from Togadani, Kaseki-kabe, the Shimotawara River and the Nishijima Pass. The plant assemblage of the formation includes 25 genera and 38 species (Table 3-2). The lower part of the formation distributed in Togadani contains *Cladophlebis exiliformis* (Geyler) Oishi, *Nilssonia nipponensis*, *Dictyozamites imamurae* Oishi, *Podozamites lanceolatus*, *Taeniopteris emarginata* and *Ta. vittata* Brongniart, which is called the Togadani Flora (Matsuo and Omura, 1968). The middle part of the formation distributed in Kaseki-kabe contains *Thallites yabei*, *Osmudopsis distans*, *Birisia onychioides*, *Coniopteris burejensis*, *Eboracia nipponica*, *Gleichenites nipponensis*, *Onychiopsis elongata*, *Sphenopteris* sp., *Ctenis nipponica* Kimura and Sekido, *Cycadites* sp., *Nil. nipponensis*, *Tetoria endoi*, *Dictyozamites tetoriensis* Kimura and Sekido, *Neozamites* sp., *Ginkgoidium nathorsti*, *Ginkgoites digitata*, *Czekanowskia* sp., *Phoenicopsis* sp., *Elatocladus* sp., *Pityophyllum* sp., *Po. reinii* and *Ta. emarginata* (Oishi, 1940: Kimura et al., 1978; Matsuoka, 2000). No Ryoseki-type floral element has been found from the formation. The plant assemblage in the formation is characterized by osmundaceous and dicksoniaceous ferns, *Neozamites*, *Dictyozamites*, several kinds of *Nilssonia*, ginkgoaleans, several taxa of *Podozamites* and conifers with needle-like leaves and is considered to be the Tetori-type Flora.

Fossil plants of the Akaiwa Formation were collected from Byakodan and Oarashiyama. The plant assemblage of the formation includes 18 genera and 23 species (Table 3-2). The formation distributed in Oarashiyama includes *Thallites* sp., *Eboracia nipponica*, *Raphaelia diamensis* Seward, *Gleichenites nipponensis*, *Onychiopsis elongata*, *Sphenopteris* sp., *Zamites* sp. (or *Pseudoctenis* sp.), *Ginkgoidium nathorsti*, *Ginkgoites digitata*, *Brachyphyllum*? sp., *Elatocladus* sp., *Pityophyllum* sp., *Podozamites lanceolatus*, *Po. reinii*, *Taeniopteris emarginata* and *Ta. vittata*. The formation distributed in Byakodan contains *Nilssonia nipponensis*, *Dictyozamites* sp., *Ginkgoidium nathorsti* and *Ta. emarginata*. In addition, Omura (1966) reported *Cladophlebis* sp. and *Po. lanceolatus* from Byakodan. *Zamites* and *Brachyphyllum* species are the Ryoseki-type floral elements (Ohana and Kimura, 1995). The plant assemblage of the formation is characterized by gleicheniaceous ferns, ginkgoaleans, several taxa of *Podozamites* and conifers with scale-like leaves, such as *Brachyphyllum*, and is considered to be the Mixed-type Flora including some Ryoseki-type floral elements.

Fossil plants of the Kitadani Formation were collected from 13 localities. The plant assemblage of the formation includes 19 genera and 21 species (Table 3-2). The formation distributed in Sugiyama River contains *Adiantopteris* sp., *Onychiopsis* *elongata*, *Gleichenites nipponensis*, *Ptilophyllum* sp., *Podozamites lanceolatus*, *Brachyphyllum obesum* Heer and *Pityophyllum* sp. (Yabe et al., 2003; Yabe and Kubota, 2004; Yabe and Shibata, 2011). In addition, the author collected *Gl. nipponensis*, *On. elongata*, *Zamites* sp. (or *Pseudoctenis* sp.) and *Taeniopteris vittata* from the river. The formation distributed in Tani includes *Po. lanceolatus* and *Nilssonia* sp. The formation distributed in Karadani contains *Dictyozamites kawasakii*, *Elatocladus* sp. and *Po. lanceolatus*. The formation distributed in the Akadani River contains *On. elongata* and *Po. lanceolatus*. The formation distributed in Nishiyama contains *Cladophlebis* sp., *Coniopteris* sp. and *Ctezozamites* sp. The formation distributed in the Otadani River contains *On. elongata*. Omura (1966), Matsuo and Omura (1966) reported *Cladophlebis* sp., *On. elongata*, "*Zamiophyllum*" sp., *Po. lanceolatus* and *Sequoia* sp. from the Myodani River. Omura (1966) reported *Cladophlebis* sp., *On. elongata* and *Po. lanceolatus* from the Otadani River. The plant assemblage of the formation is characterized by gleicheniaceous ferns, *Po. lanceolatus* and conifers with scale-like leaves, such as *Brachyphyllum*, and is considered to be the Mixed-type Flora including some Ryoseki-type floral elements. Conifers contained in the formation have a higher diversity than that of the Akaiwa Formation.

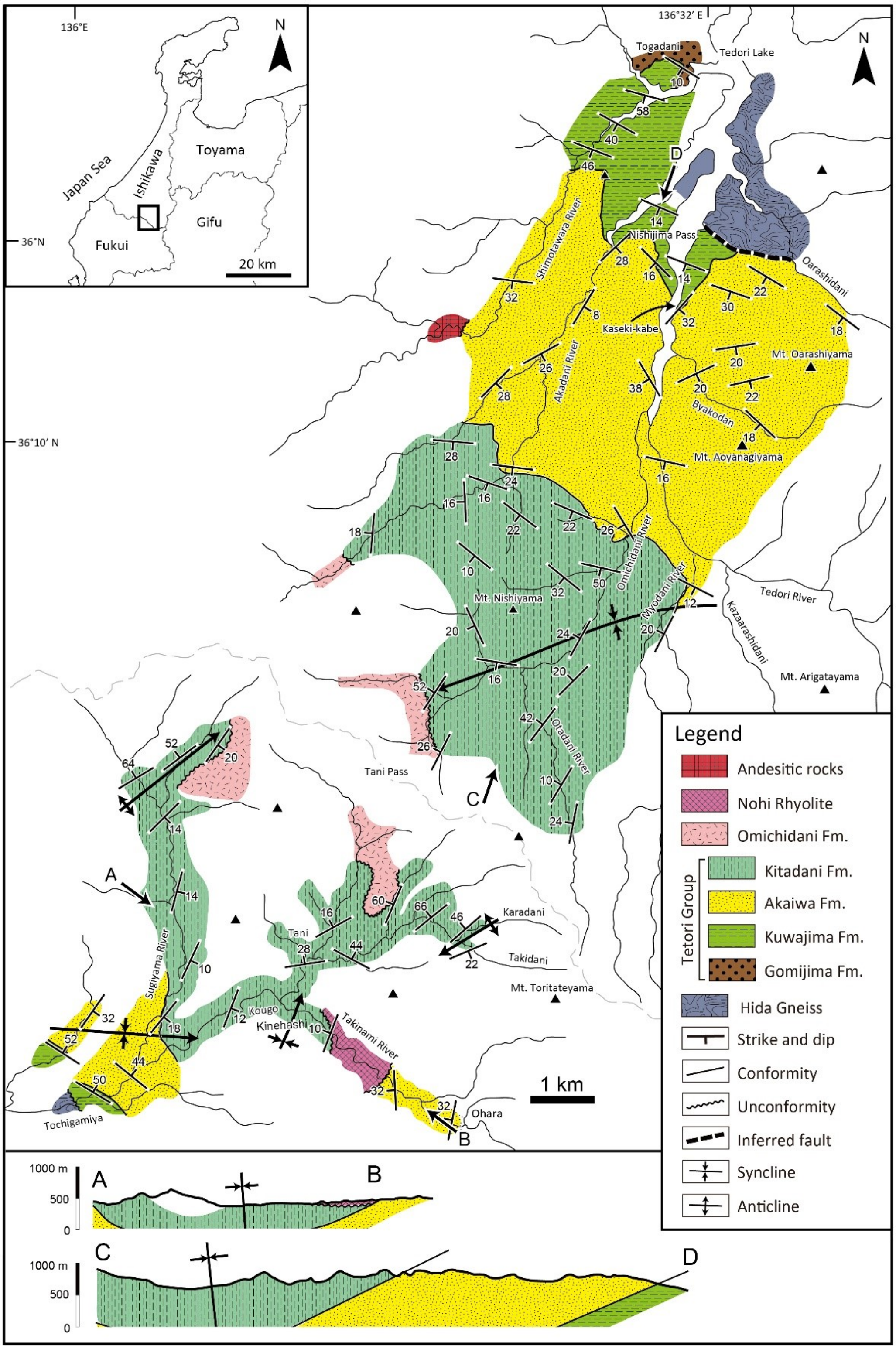

Fig. 3-1. Geological map and cross sections (modified from Sakai et al., 2018). The inserted map indicates the distributions of the Tetori Group in central Japan (from Maeda, 1961).

Oishi (1933)	Maeda (1958)	Kawai (1961)		Omura (1966)	IPBE (1978)	Matsukawa et al. (2003b)	Sakai et al. (2018)
	Kitadani Formation	Myogatani Formation		Myodani Formation	Myodani Formation	Bessandani Formation	Kitadani Formation
Akaiwa sandstone	Akaiwa Formation upper	Akaiwa Formation		Akaiwa Formation	Akaiwa Fm. sandstone member	Okura Formation	Akaiwa Formation
	Akaiwa Formation lower				Akaiwa Fm. alternation member	Amagodani Formation	
Kuwajima Formation	Kuwajima Formation	Oguchi Formation	Kuwajima Member	Kuwajima Formation	Kuwajima Formation	Kuwajima / Okurodani Formation	Kuwajima Formation
Gomishima conglomerate	Gomishima Formation		Gomishima Member	Gomijima Formation	Gomijima Formation	Otaniyama Formation; Gomijima Member	Gomijima Formation

Fig. 3-2. Lithostratigraphic divisions in the Shiramine and Takinamigawa areas in previous works. IPBE: Ishikawa Prefecture Board of Education.

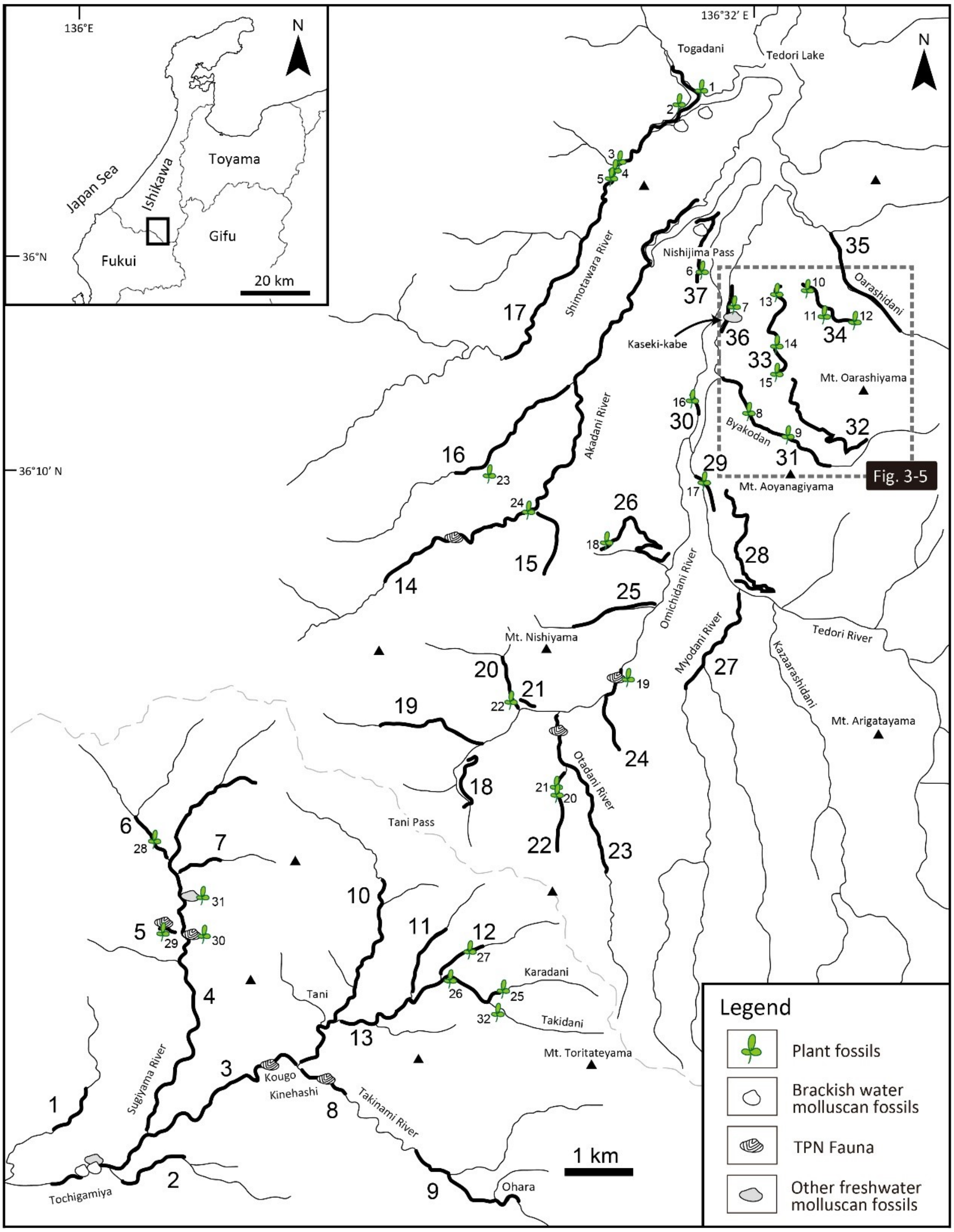

Fig. 3-3. Map showing the study routes and fossil localities (modified from Sakai et al., 2018). The bivalve assemblages including *Trigonioides*, *Plicatounio* and *Nippononaia* are called as TPN fauna (Tamura, 1990).

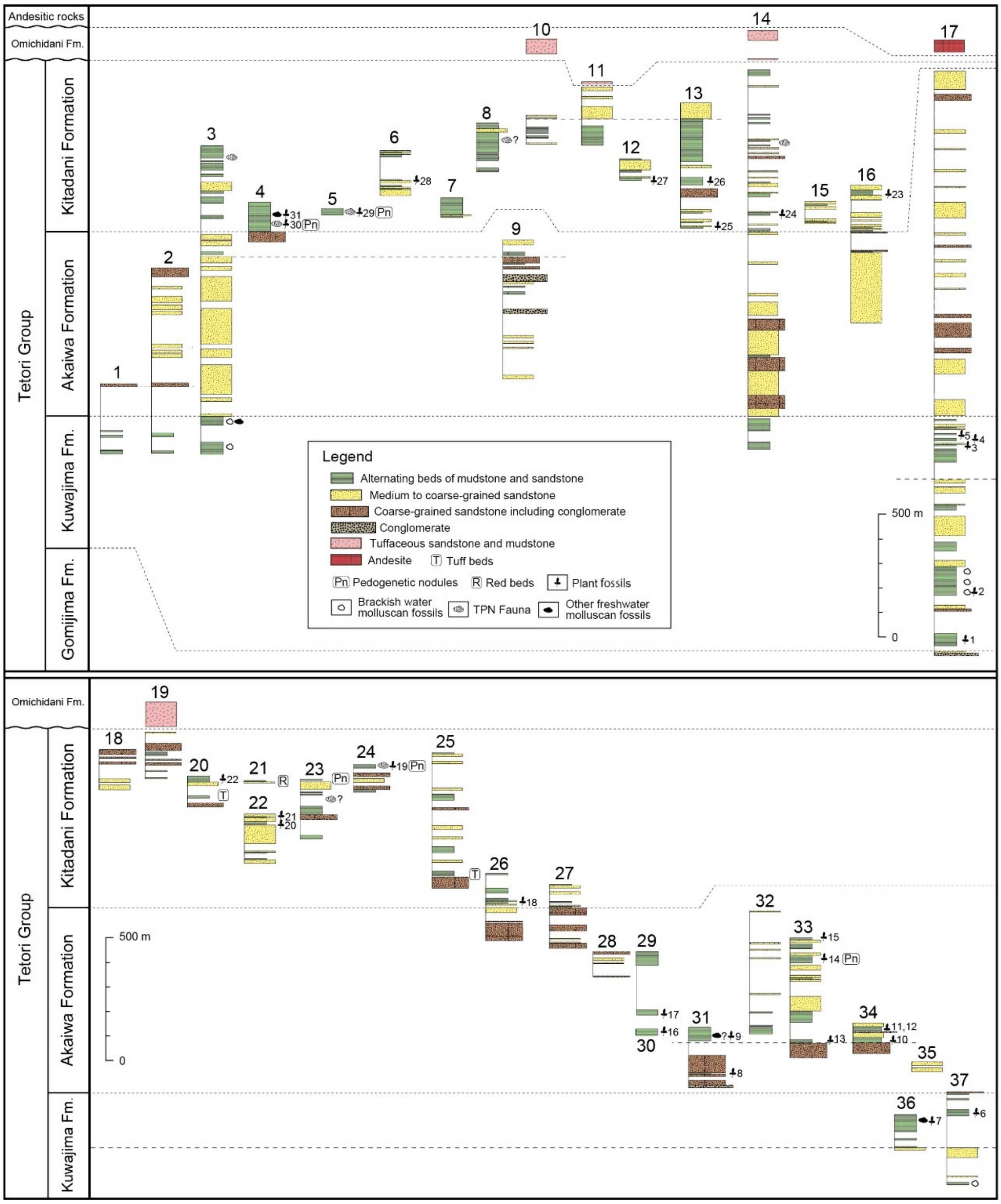

Fig. 3-4. Columnar sections of the Tetori Group in the study area (modified from Sakai et al., 2018). Locations of number are shown in Fig. 3-3.

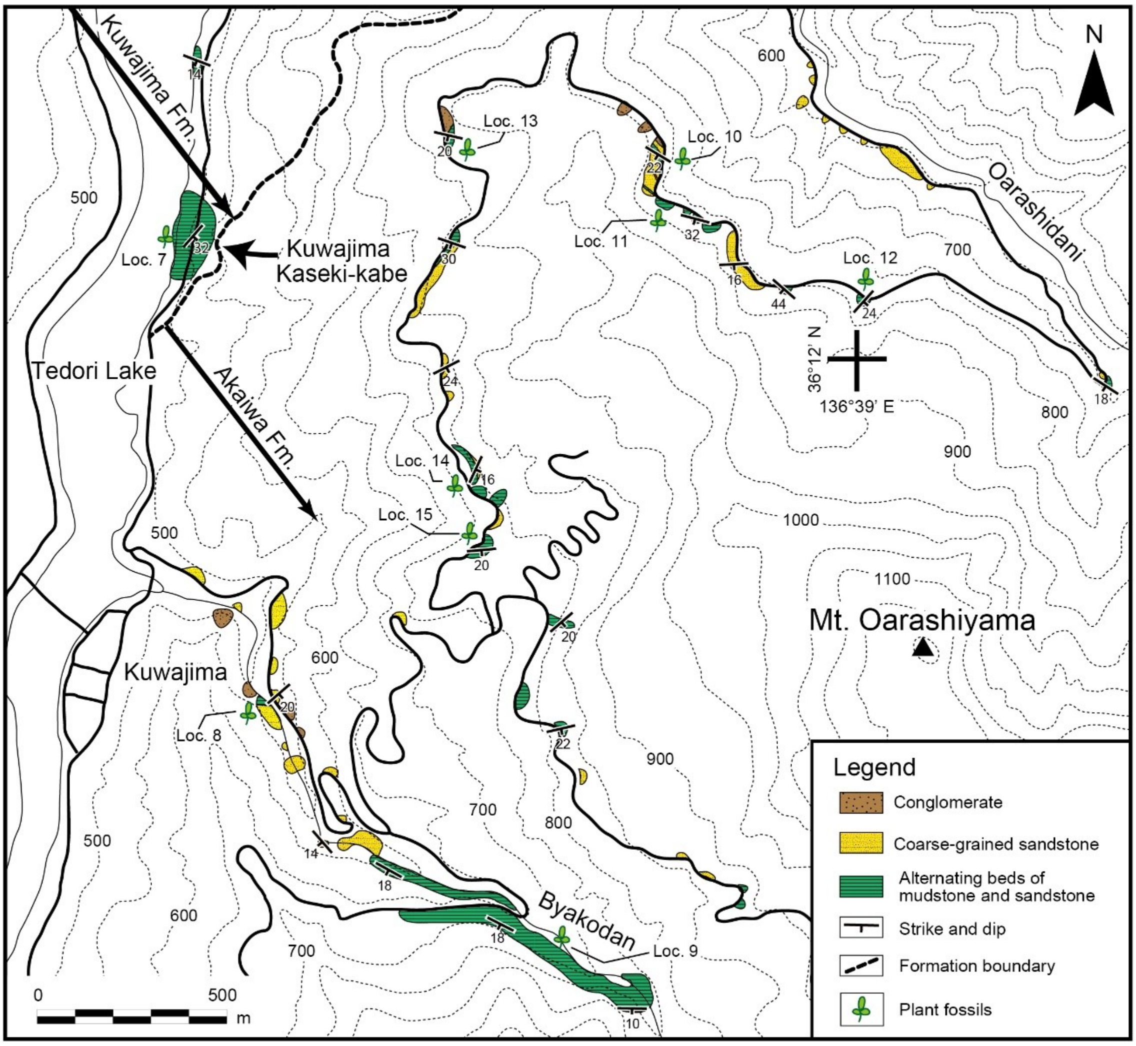

Fig. 3-5. Route map around Mt. Oarashiyama. This mapped area is indicated in Fig. 3-3 as a square with broken lines.

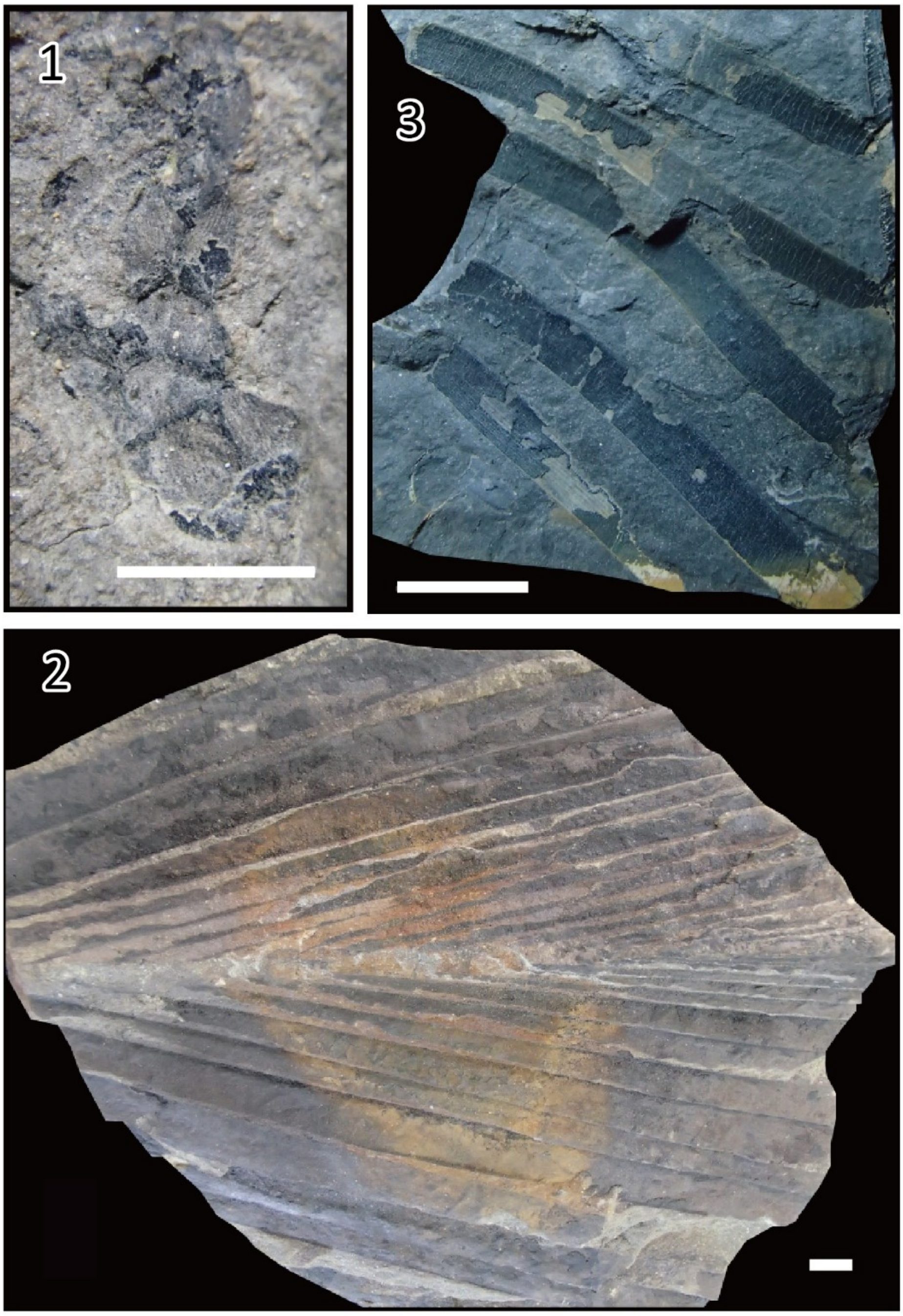

Fig 3-6. Plant fossils from the Tetori Group in the Shiramine and Takinamigawa areas. 1: *Brachyphyllum*? sp. from Loc. 14 in the Akaiwa Formation in the Shiramine area, SBEI P-3043, 2: *Zamites* sp. (or *Pseudoctenis* sp.) from Loc. 12 in the Akaiwa Formation in the Shiramine area, SBEI P-3003, 3: *Zamites* sp. (or *Pseudoctenis* sp.) from Loc. 31 in the Kitadani Formation in the Takinamigawa area, FPDM-P-1358. Scale bars- 5 mm (1), 10 mm (2, 3).

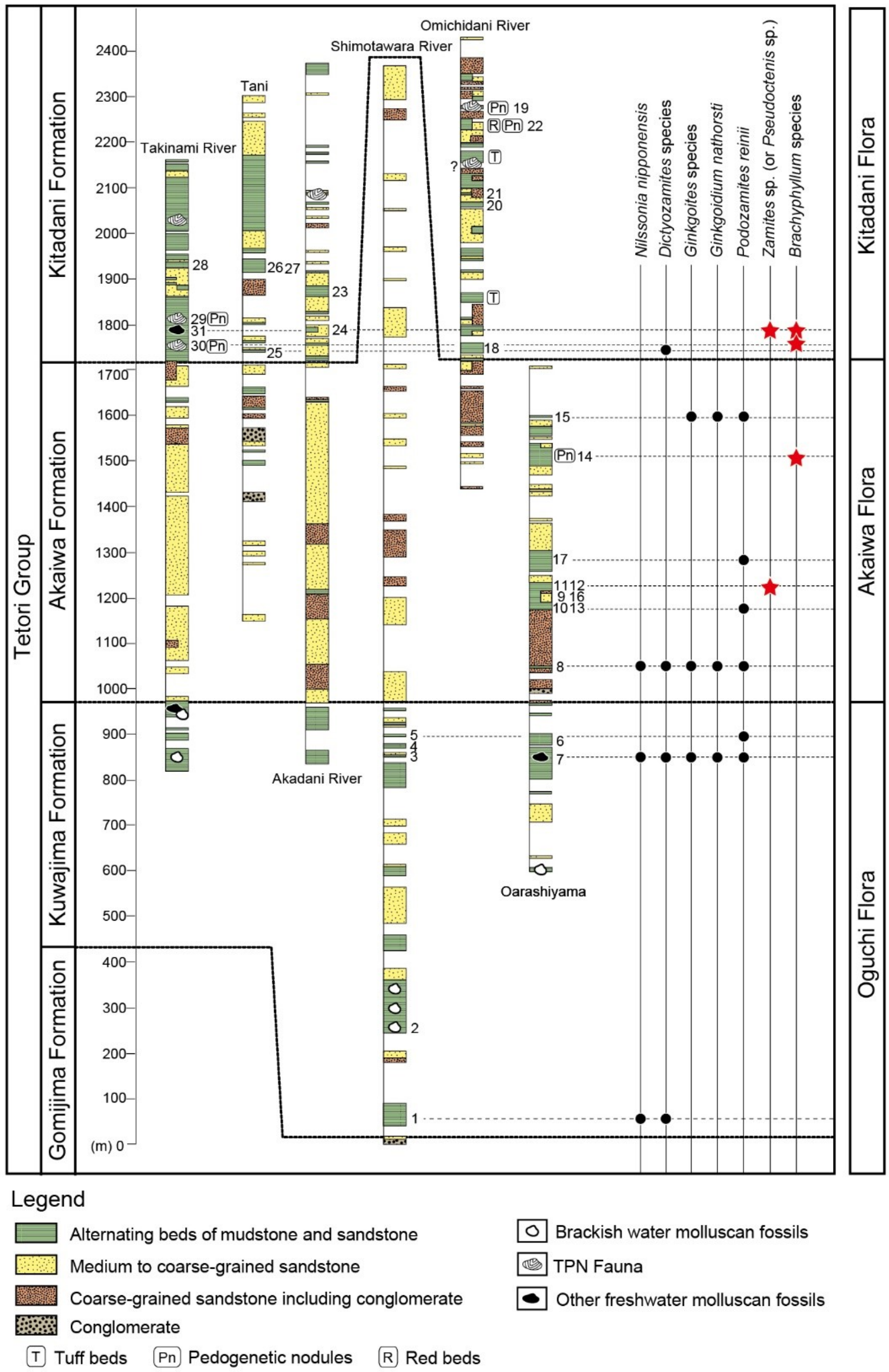

Fig. 3-7. Generalized columnar sections of the Tetori Group in the study area, showing the stratigraphic occurrences of selected plant fossils (modified from Sakai et al., 2018). Small numbers represent the plant fossil localities. ●: Tetori-type floral elements, ★: Ryoseki-type floral elements.

Table 3-1. Records of molluscan fossils from the Tetori Group in the Shiramine and Takinamigawa areas.

Localities	Strata	Species	Occurrence reports
Togadani (Fig. 3-3-17)	Kuwajima Fm.	*Myrene tetoriensis*	Maeda (1958)
Nishijima Pass (Fig. 3-3-37)	Kuwajima Fm.	*Myrene tetoriensis* , “*Ostrea*” sp.	Okazaki and Isaji (2008)
Tochigamiya (Fig. 3-3-3)	Kuwajima Fm.	*Myrene tetoriensis*	Tsukano (1969)
Kaseki-kabe (Fig. 3-3-36)	Kuwajima Fm.	“*Unio*” *ogamigoensis* , “*Viviparus*” *onogoensis*	Tamura (1990)
Byakodan (Fig. 3-3-31)	Akaiwa Fm.	“*Unio*”? sp.	Sakai et al. (2018)
Akadani River (Fig. 3-3-14)	Kitadani Fm.	*Nagdongia soni* , *Nippononaia ryosekiana* , *Plicatounio naktongensis* , *Pseudohyria matsumotoi*	Sakai et al. (2018)
Omichidani River (Fig. 3-3-24)	Kitadani Fm.	*Nagdongia soni* , *Plicatounio naktongensis* , *Trigonioides tetoriensis*	Sakai et al. (2018)
Otadani River (Fig. 3-3-23)	Kitadani Fm.	*Nagdongia soni* , *Nippononaia ryosekiana* , *Nippononaia* sp., *Plicatounio naktongensis* , *Pseudohyria matsumotoi* , “*Viviparus*” sp.	Tamura (1990), Isaji (1993)
Sugiyama River (Fig. 3-3-4, 5)	Kitadani Fm.	*Nagdongia soni* , *Nippononaia ryosekiana* , *Nippononaia tetoriensis* , *Plicatounio naktongensis* , *Pseudohyria matsumotoi* , *Trigonioides tetoriensis* , “*Viviparus*” sp.	Maeda (1958, 1962, 1963), Tamura (1990), Isaji (1993), Matsukawa et al. (2003a)
Kougo (Fig. 3-3-3)	Kitadani Fm.	*Nippononaia tetoriensis* , *Trigonioides* sp., “*Viviparus*” sp.	Sakai et al. (2018)
Kinehashi (Fig. 3-3-8)	Kitadani Fm.	*Plicatounio naktongensis* , *Pseudohyria matsumotoi*	Tamura (1990)

Table 3-2. List of plant fossils from the Kuwajima, Akaiwa and Kitadani formations of the Tetori Group. The stratigraphic horizons and localities are indicated in Figs. 3-3, 3-4, respectively. ○: from outcrop, ●: from float.

Localities	Kuwajima Formation							Akaiwa Formation										Kitadani Formation															
Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
Bryophyta																																
Thallites yabei (Kryshtofovich) Harris							○																									
Thallites sp.												○																				
Sphenopsida																																
Equisetites ushimarensis (Yokoyama) Oishi			○				○																									
Equisetites sp.																			○				○									
Ferns																																
Adiantopteris ginkgoifolia Kimura and Sekido								○																								
Adiantopteris sewardi (Yabe) Vassilevskaja							○																									
Adiantopteris sp.	○																													○		
Birisia alata (Prynada) Samylina							○																									
Birisia onychioides (Vassilevskaja and Kara-Mursa) Samylina							○																									
Cladophlebis exiliformis (Geyler) Oishi	○																													○		
Cladophlebis denticulata (Brongniart) Fontaine		○					○																									
Cladophlebis spp.				○								○		●			●					○										
Coniopteris burejensis (Zalesskey) Seward							○																									
Coniopteris sp.																						○										
Eboracia nipponica Kimura and Sekido							○					○																				
Eboracia sp.																														○		
Gleichenites nipponensis Oishi							○		●			○							○										○	○	○	
Gleichenites porsildii Seward							○																									
Marsileaceae? gen. et sp. indet.																														○		
Onychiopsis elongata (Geyler) Yokoyama	○			○		○	○	○	●			○	○	○	○	○	●	○			○		○	○						○	○	
Osmundopsis distans (Heer) Kimura and Sekido	○						○						○					○														
Raphaelia diamensis Seward															○																	
Ruffordia goepperti (Dunker) Seward							○																							○		
Sphenopteris sp.										○																	○					
Seed ferns																																
Ctenozamites sp.																						○								○		
Cycadaleans																																
Ctenis nipponica Kimura and Sekido							○																									
Cycadites sp.							○																									
Nilssonia kotoi (Yokoyama) Oishi	○						○																									
Nilssonia nipponensis Yokoyama	○						○	○																								
Nilssonia orientalis Heer	○																															
Nilssonia spp.																				○						○	○					
Tetoria endoi Kimura and Sekido							○																									
Bennettitaleans																																
Dictyozamites falcatus (Morris) Oldham	○																															
Dictyozamites imamurae Oishi	○																															
Dictyozamites kawasakii Tateiwa							○																		○							
Dictyozamites reniformis Oishi							○																									
Dictyozamites tetoriensis Kimura and Sekido							○																									
Dictyozamites sp.								○																								
Neozamites sp.							○																									
Pelourdea ? sp.																														○		

Table 3-2. (Continued)

Ptilophyllum spp.																													○		
Zamites sp. (or *Pseudoctenis* sp.)											○																			○	
Ginkgoaleans																															
Ginkgoidium nathorsti Yokoyama						○	○							○																	
Ginkgoites digitata Brongniart						○								○																	
Ginkgoites huttonii (Sternberg) Black						○								○																	
Ginkgoites sp.							○																								
Czekanowskialeans																															
Czekanowskia sp.						○																									
Phoenicopsis sp.						○																									
Conifers																															
Brachyphyllum obesum Heer																														○	
Brachyphyllum sp.																													○		
Brachyphyllum ? sp.													●																		
Elatocladus cf. *manchurica* (Yokoyama) Yabe																													○		
Elatocladus spp.						○					○			○															○		
Pagiophyllum sp.																								○							
Pityophyllum sp.					○		○						○		○															○		
Podocarpites sp.																													○		
Podozamites lanceolatus (Lindley and Hutton) Braun	○			○			○				○						○							○	○	○	○			○		○
Podozamites reinii Geyler		○			○		○	○					○		○		○														
Systematic position unknown																															
Taeniopteris emarginata Oishi	○						○	○					○		○																
Taeniopteris vittata Brongniart	○											○																○			

Table 3-3. Records of plant fossils from the Tetori Group in the Shiramine and Takinamigawa areas.

Localities	Strata	Species	Occurrence reports
Togadani (Fig. 3-3, Loc. 1)	Kuwajima Fm.	*Adiantopteris* sp., *Cladophlebis exiliformis* , *Onychiopsis elongata* , *Osmundopsis distans* , *Nilssonia kotoi* , *Nilssonia nipponensis* , *Nilssonia orientalis* , *Dictyozamites falcatus* , *Dictyozamites imamurae* , *Podozamites lanceolatus* , *Taeniopteris emarginata* , *Taeniopteris vittata*	Matsuo and Omura (1966, 1968)
Togadani (Fig. 3-3, Loc. 2)	Kuwajima Fm.	*Cladophlebis* sp., *Podozamites reinii* , silicified woods	Sakai et al. (2018)
Shimotawara River (Fig. 3, Locs. 3, 4, 5)	Kuwajima Fm.	*Equisetites ushimarensis* , *Cladophlebis* sp., *Onychiopsis elongata* , *Pityophyllum* sp., *Podozamites lanceolatus* , *Podozamites reinii*	Sakai et al. (2018)
Nishijima Pass (Fig. 3-3, Loc. 6)	Kuwajima Fm.	*Onychiopsis elongata*	Sakai et al. (2018)
Kaseki-kabe (Fig. 3-3, Loc. 7)	Kuwajima Fm.	*Thallites yabei* , *Equisetites ushimarensis* , *Adiantopteris sewardi* , *Birisia alata* , *Birisia onychioides* , *Cladophlebis denticulata* , *Coniopteris burejensis* , *Eboracia nipponica* , *Gleichenites nipponensis* , *Gleichenites porsildii* , *Onychiopsis elongata* , *Osmundopsis distans,* *Sphenopteris goepperti* , *Ctenis nipponica* , *Cycadites* sp., *Nilssonia kotoi* , *Nilssonia nipponensis* , *Tetoria endoi* , *Dictyozamites kawasakii* , *Dictyozamites reniformis* , *Dictyozamites tetoriensis* , *Neozamites* sp., *Ginkgoidium nathorsti* , *Ginkgoites digitata* , *Ginkgoites huttonii* , *Czekanowskia* sp., *Phoenicopsis* sp., *Elatocladus* sp., *Pityophyllum* sp., *Podozamites lanceolatus* , *Podozamites reinii* , *Taeniopteris emarginata*	Oishi (1940), Kimura et al. (1978), Matsuo and Sekido (2000)
Kaseki-kabe (Fig. 3-3, Loc. 7)	Kuwajima Fm.	*Xenoxylon latiporosum*	Ogura et al. (1951), Yamazaki et al. (1984)
Byakodan (Fig. 3-3, Locs. 8, 9)	Akaiwa Fm.	*Adiantopteris ginkgoifolia* , *Gleichenites nipponensis* , *Onychiopsis elongata* , *Nilssonia nipponensis* , *Dictyozamites* sp., *Ginkgoidium nathorsti* , *Ginkgoites* sp., *Podozamites reinii* , *Taeniopteris emarginata*	Sakai et al. (2018)
Byakodan	Akaiwa Fm.	*Cladophlebis* sp., *Podozamites lanceolatus*	Omura (1966)*
Byakodan	Akaiwa Fm.	*Xenoxylon latiporosum*	Suzuki and Terada (1992)
Oarashiyama (Fig. 3-3, Locs. 10, 11, 12, 13, 14, 15)	Akaiwa Fm.	*Thallites* sp., *Cladophlebis* sp., *Eboracia nipponica* , *Gleichenites nipponensis* , *Onychiopsis elongata* , *Osmundopsis distans* , *Raphaelia diamensis* , *Sphenopteris* sp., *Zamites* sp. (or *Pseudoctenis* sp.), *Ginkgoidium nathorsti* , *Ginkgoites digitata* , *Ginkgoites huttonii* , *Brachyphyllum* ? sp., *Elatocladus* sp., *Pityophyllum* sp., *Podozamites lanceolatus* , *Podozamites reinii* , *Taeniopteris emarginata* , *Taeniopteris vittata*	Sakai et al. (2018)

Table 3-3. (Continued)

Tedori River (Fig. 3-3, Locs. 16, 17)	Akaiwa Fm.	*Onychiopsis elongata, Cladophlebis* sp., *Podozamites lanceolatus* , *Podozamites reinii*	Sakai et al. (2018)
Omichidani River (Fig. 3-3, Locs. 18, 19)	Kitadani Fm.	*Equisetites* sp., *Gleichenites nipponensis, Onychiopsis elongata* , *Osmundopsis distans*	Sakai et al. (2018)
Otadani River (Fig. 3-3, Locs. 20, 21)	Kitadani Fm.	*Onychiopsis elongata* , *Nilssonia* sp.	Sakai et al. (2018)
Otadani River	Kitadani Fm.	*Cladophlebis* sp., *Onychiopsis elongata, Podozamites lanceolatus*	Omura (1966)*
Myodani River	Kitadani Fm.	*Cladophlebis* sp., *Onychiopsis elongata* , "*Zamiophyllum* " sp., *Podozamites lanceolatus* , *Sequoia* sp.	Omura (1966)*, Matsuo and Omura (1966)*
Nishiyama (Fig. 3-3, Loc. 22)	Kitadani Fm.	*Cladophlebis* sp., *Coniopteris* sp., *Ctenozamites* sp.	Sakai et al. (2018)
Akadani River (Fig. 3-3, Locs. 23, 24)	Kitadani Fm.	*Equisetites* sp., *Onychiopsis elongata* , *Podozamites lanceolatus* , Silicified woods	Sakai et al. (2018)
Karadani (Fig. 3-3, Loc. 25)	Kitadani Fm.	*Dictyozamites kawasakii* , *Pagiophyllum* sp., *Podozamites lanceolatus*	Sakai et al. (2018)
Tani (Fig. 3-3. Locs. 26, 27)	Kitadani Fm.	*Sphenopteris* sp., *Nilssonia* sp., *Podozamites lanceolatus*	Sakai et al. (2018)
Sugiyama River (Fig. 3-3, Locs. 28, 29)	Kitadani Fm.	*Gleichenites nipponensis* , *Taeniopteris vittata*	Sakai et al. (2018)
Sugiyama River (Fig. 3-3, Loc. 30)	Kitadani Fm.	*Adiantopteris* sp., *Cladophlebis exiliformis* , *Eboracia* sp., *Onychiopsis elongata* , *Gleichenites nipponensis* , Marsileaceae? gen. et sp. indet., *Ruffordia goepperti* , *Ctenozamites* sp., *Pelourdea* ? sp., *Ptilophyllum* spp., *Elatocladus* cf. *manchurica* , *Elatocladus* sp., *Brachyphyllum* sp., *Pityophyllum* sp., *Podocarpites* sp., *Podozamites lanceolatus* , *Conites* sp.	Yabe and Shibata (2011), Yabe et al. (2012), Sano and Yabe (2017)
Sugiyama River (Fig. 3-3, Loc. 31)	Kitadani Fm.	*Gleichenites nipponensis* , *Onychiopsis elongata* , *Zamites* sp. (or *Pseudoctenis* sp.), *Brachyphyllum obesum*	Yabe et al. (2003), Yabe and Kubota (2004), Sakai et al. (2018)
Takidani (Fig. 3-3, Loc. 32)	Kitadani Fm.	*Podozamites lanceolatus*	Sakai et al. (2018)
Sugiyama River	Kitadani Fm.	*Podocarpoxylon* sp., *Xenoxylon latiporosum*	Terada and Yabe (2011)
Takinami River	Kitadani Fm.	*Gleichenites nipponensis* , *Onychiopsis elongata* , *Cladophlebis exiliformis* , *Ginkgoites digitata* , *Podozamites lanceolatus* , *Podozamites reinii*	Tsukano (1969)*

* only list

Part 4

Early Cretaceous plants from the Lower Cretaceous Tetori Group in the Oguchi area, Ishikawa Prefecture

4.1. Introduction

Plant fossils are useful for the reconstruction of environmental terrestrial ecosystem. It is necessary to understand detailed floral compositional change with lithofacies. Vast plant fossil specimens collected from the Tetori Group are stored in many institutes in Japan. Most of them are collected from well-known plant fossil localities, including Kaseki-kabe and Mekkodani (Kimura et al., 1978), in the Shiramine area, Hakusan City, Ishikawa Prefecture. Two plant fossil localities are essential for vegetation reconstruction because they indicate the highest diversity in the Tetori Group. However, the relation of each fossil-bearing horizons is mostly unknown because many paleobotanists have been collected plant fossil specimens without attention to check where is these fossils obtained. The author assume that the specimens were not directly picked out from an outcrop in these fossil localities which is a precipice, in addition, strata containing plant fossils is hard for using hummer.

The author discovered a new plant fossil locality containing plant assemblages with higher diversity from the Tetori Group in Onabara of the Oguchi area, Hakusan City, Ishikawa Prefecture. In the locality, it is possible for us to directly pick out various plant fossils from each plant-bearing bed in the outcrop. This paper reported about the characteristic of floral compositional change and relation to lithofacies in the locality.

4.2. Geological setting

The Oguchi area is located throughout the upper reaches of the Tedori River which occupies the southern part of Ishikawa Prefecture (Fig. 4-1), and is located in the north of the Shiramine area considered by represent lithostratigraphy of the Tetori Group. The strata in this area are metamorphic rocks of the Hida Terrane, the Lower Cretaceous Tetori Group, the Upper Cretaceous to Paleogene Nohi Rhyolites and Neogene to Quaternary Andesites, in ascending order. The Tetori Group in the Oguchi area is composed of the Gomijima and Kuwajima formations, in ascending order. Recently, marine mollusks, fossilized limuloids tracks, radiolarians and belemnite were reported from the lower part of the Kuwajima Formation in the Oguchi area (Tamura, 1990; Matsuoka et al., 2009; Kashiwagi et al., 2016). The report implies that marine beds are intercalated with the formation. The upper part of the formation contains plant fossils.

The marine transgression in the lower part of the Kuwajima Formation probably indicates Hauterivian age. Nagata et al. (2019) obtained a zircon U–Pb age of 129.1±1.5 Ma from a tuff bed of the lower part of the formation in the Oguchi area. Therefore, the Kuwajima Formation can be roughly correlated with the Late Hauterivian to Early Aptian.

The continuity between the Oguchi and Shiramine areas has not been understood because stratigraphic correlations between both areas have not been successfully made due to the presence of several faults. There are some inferred faults in the east-west direction and the north-south direction in the Oguchi area (Fig. 4-1). The Tetori Group unconformably overlies or in fault contact with the Hida metamorphic rocks (Maeda, 1958). There is synclinal structure between Seto and Onabara (Figs. 4-1, 4-2). The Tetori Group is overlain by the Upper Cretaceous to Paleogene Nohi Rhyolites and Neogene to Quaternary Andesites.

4.3. Lithostratigraphy

The author surveyed 25 sections in the Oguchi area (Figs. 4-3, 4-4). The Tetori Group in this area consists of the Gomijima and Kuwajima formations, in ascending order.

4.3.1. Gomijima Formation

[Nomenclature] The formation is named by Oishi (1933).
[Type section] Gomijima (Maeda, 1958).
[Distribution] Ozo River (Fig. 4-3-21, 22), Akagodani (Fig. 4-3-20) and Onabara (Fig.

4-3-23, 24). The most continuous section is exposed in Onabara.

[Thickness] The formation is estimated to be about 130 m thick in Onabara (Fig. 4-3-23).

[Relationship with the lower formation] The formation overlies the Hida Terrane which is basement rocks unconformably in Gomijima and the Ozo River.

[Lithology] The formation is composed of massive conglomerates which are poorly-sorted and clast-supported. The matrix is very-coarse-grained sandstone. Conglomerate beds are clast-supported. Clasts are rounded and are characterized mainly by crystalline limestone, gneiss and granite (Maeda, 1958). The greatest dimension of clast size is about 40 cm, and average dimension is about 5 cm in Onabara.

4.3.2. Kuwajima Formation

[Nomenclature] The formation is named by Oishi (1933).

[Type section] Around Kaseki-kabe (Maeda, 1958).

[Distribution] Setono (Fig. 4-3-6, 7), Seto (Fig. 4-3-10, 11, 12, 13, 14, 15, 16), Onabara (Fig. 4-3-17, 19), Kinamerishin (Fig. 4-3-8, 9) and Higashinikuchi (Fig. 4-3-1, 2, 3, 4). The most continuous section is exposed in Kinamerishin.

[Thickness] The formation is estimated to be about 200 m thick in Seto.

[Relationship with the lower formation] The formation overlies the Gomijima Formation unconformably.

[Lithology] The formation consists of alternating beds of sandstone and mudstone, medium to coarse-grained sandstone and conglomerate. The alternating beds are composed in mudstone, sandy mudstone and fine-grained sandstone. Sandstone and mudstone are laminated. Molluscan and plant fossils occur in the alternating bed of mudstone and sandstone. Ripple marks are observed in Setono. A tuff bed is about 0.4 m thick and is intercalated in the alternating bed of mudstone and sandstone in Setono. Conglomerate beds are poorly-sorted and matrix-supported. The matrix is Medium to coarse-grained sandstone. Clasts are sub-rounded to rounded and are characterized mainly by crystalline limestone, gneiss and granite, andesite, rhyolite, quartz and mudstone. The greatest dimension of clast size is about 15 cm, and average dimension is about 2 cm. Conglomerate beds in the Ozo River include bivalve fossils together with pebbles. Conglomerate beds of upper part of the formation are poorly-sorted and matrix-supported. The matrix is medium to coarse-grained sandstone. Clasts are rounded and are characterized mainly by orthoquartzite and granites. The greatest dimension of clast size is about 10 cm, and average dimension is about 1 cm.

[Fossils] The formation yields molluscan and plant fossils. Many molluscan fossils are reported in the Ozo River, Setono and Onabara (Oishi, 1933; Maeda, 1958; Tamura, 1990; Matsukawa et al. 2003a). *Myrene tetoriensis*, *Tetoria yokoyamai,* Ostreidae gen. et sp. indet., *Megasphaerioides* sp. and *Melanoides vulgaris* were obtained from the lower part of the formation in the Ozo River, Setono, Seto, Onabara and Higashinikuchi in this study. Horseshoe crab track fossils were reported from the lower part of the formation in Setono (Matsuoka et al., 2009). Radiolarian fossils were reported from the lower part of the formation in Setono (Kashiwagi et al., 2016). Plant assemblage was obtained from the upper part of the formation in Onabara in this study.

4.4. Materials

The author collected plant remains from alternating beds of sandstone and mudstone in the upper part of the Kuwajima Formation at one locality in Onabara of the Oguchi area (Fig. 4-6). This study measured a columnar section which is about 7.5 m thick at the locality. Lithostratigraphy of the section is presented in Fig. 4-7. These specimens are stored in the Shiramine Institute of Paleontology, Hakusan City, Ishikawa Prefecture, Japan (SBEI).

4.5. Occurrence of plant fossils at Onabara

The Onabara section is composed of alternating beds of fine- to medium-grained sandstone and mudstone. Fining-upward cycles are repeated in the section. Parallel laminations are observed in the plant fossil-bearing beds. This study described the co-occurrence of plant fossils in 10 beds (Fig. 4-7). It is considered that these fossil occurrences are allochthonous.

Bed P-1 is composed of mudstone. It contains *Podozamites reinii*. Leaves of *Po. reinii* and plant fragments closely occur in the mudstone on horizontal layer.

Bed P-2 is composed of well-laminated mudstone. It contains *Birisia onychioides*, *Coniopteris burejensis*, *Sphenopteris goepperti*, *Dictyozamites* sp., *Nilssonia nipponensis*, *Nilssonia* sp., *Ginkgoites digitata*, *Podozamites lanceolatus* and *Carpolithes* sp. Ferns and *P. reinii* are abundant. *Co. burejensis* and *Sphenopteris goepperti* are dominant. These ferns co-occur with *Birisia onychioides*, *Dictyozamites* sp. and *Carpolithes* sp. Leaf of *Po. reinii* is abundant, and leafy twig of that is rare. Leaf of *Po. lanceolatus* is common. Overlapping leaves of *Po. reinii* and *Po. lanceolatus* are mixed and are piled with minor *Ginkgoites digitata, Nil. nipponensis* and *Nilssonia* sp.

Bed P-3 is composed of fine-grained sandstone. It contains *Gleichenites* sp., *Osmundopsis distans*, *Nilssonia nipponensis*, *Podozamites reinii*, *Po. lanceolatus*. The lower horizon contains abundant leafy twig of *Po. lanceolatus*. The middle one contains abundant leaves of *Po. reinii*. A few ill-preserved *Coniopteris burejensis, Nil. nipponensis*, *Gleichenites* sp. and *Os. distans* yielded in the upper horizon. The co-occurrence of them is unknown.

Bed P-4 is composed of mudstone observed parallel laminations partially. It contains *Podozamites reinii*. Leaves of *Po. reinii* and plant fragments closely occur in the mudstone on the same horizontal layer.

Bed P-5 is composed of well-laminated sandy mudstone. It contains *Cladophlebis laxipinnata*, *Cladophlebis* sp., *Gleichenites* spp., *Raphaelia diamensis*, *Raphaelia* sp., *Sphenopteris* sp., *Todites nipponicum*, *Nilssonia nipponensis*, *Ginkgoidium nathorsti*, *Ginkgoites digitata*, *Podozamites reinii*, *Po. lanceolatus*, *Elatocladus* sp., *Taeniopteris emarginata*, *Ta. vittata*, *Carpolithes* sp. The composition of plant fossils is changed by lateral transition. The lower horizon contains abundant ferns: *R. diamensis*, *Cladophlebis* sp., *To. nipponicum* and *Gleichenites* sp. B, a few *Sphenopteris* sp., *Raphaelia* sp. and pinnae fragment of *Cladophlebis laxipinnata*. The upper horizon contains Coniferales, Ginkgoaleans, Cycadaleans, *Taeniopteris* and seeds. Overlapping leaves of *Po. reinii* and *Po. lanceolatus*, *Ginkgoidium nathorsti*, a few *Ginkgoites digitata* closely occur on horizontal layer. They co-occur on same horizontal layers. But on the other hand, abundant *Ta. vittata* closely occur, *Nil. nipponensis* and fragments of *Elatocladus* sp. occur rarely. The co-occurrence of *Ginkgoites digitata*, *Ta. emarginata*, *Ta. vittata*, *Nil. nipponensis* and *Elatocladus* sp. is uncertain.

Bed P-6 is composed of sandy mudstone. It contains abundant plant fragments and *Ginkgoites huttonii*.

Bed P-7 is composed of laminated mudstone. The author obtained *Gleichenites hakusanensis*.

Bed P-8 is composed of well-laminated mudstone. It contains *Podozamites reinii* and *Po. lanceolatus*. Leafy twig of *Po. reinii* and *Po. lanceolatus* co-occur on different horizontal layers.

Bed P-9 is composed of well-laminated sandy mudstone. It contains *Nilssonia kotoi*, *Nil. nipponensis*, *Podozamites reinii* and *Taeniopteris vittata*. *Po. reinii*, *Nil. kotoi*, *Nil. nipponensis* co-occur and are piled on same horizontal layers. *Ta. vittata* is abundant in other horizontal layers. *Ta. vittata* from this horizon is the biggest leaf size.

Bed P-10 is composed of well-laminated sandy mudstone. It contains *Osmundopsis distans, Nilssonia kotoi*, *Ginkgoites digitata*, *Elatocladus* sp. *Podozamites reinii*, *Taeniopteris emarginata* and *Stenorachis* sp. on same horizontal layers. *Ginkgoites digitata* is most abundant, *Elatocladus* sp. and *Stenorachis* sp. are rare.

4.5. Floristic composition

The plant assemblage of the Kuwajima Formation collected from the Onabara section includes 18 genera and 26 species (Fig. 4-7). The plant assemblage in the formation is characterized by dicksoniaceous ferns, *Dictyozamites*, several kinds of

Nilssonia, ginkgoaleans, several taxa of *Podozamites* is considered to be the Tetori-type Flora. The existence of *Co. burejensis*, *R. diamensis*, *Nil. kotoi*, *Ginkgoidium nathorsti* and *Ta. emarginata* suggests that the floral composition of Onabara is comparable with those reported from Bettokuzure (Kimura and Sekido, 1976a, 1978) and Kaseki-kabe (e.g., Kimura et al., 1978; Matsuo and Sekido, 2000) (Table 4-1).

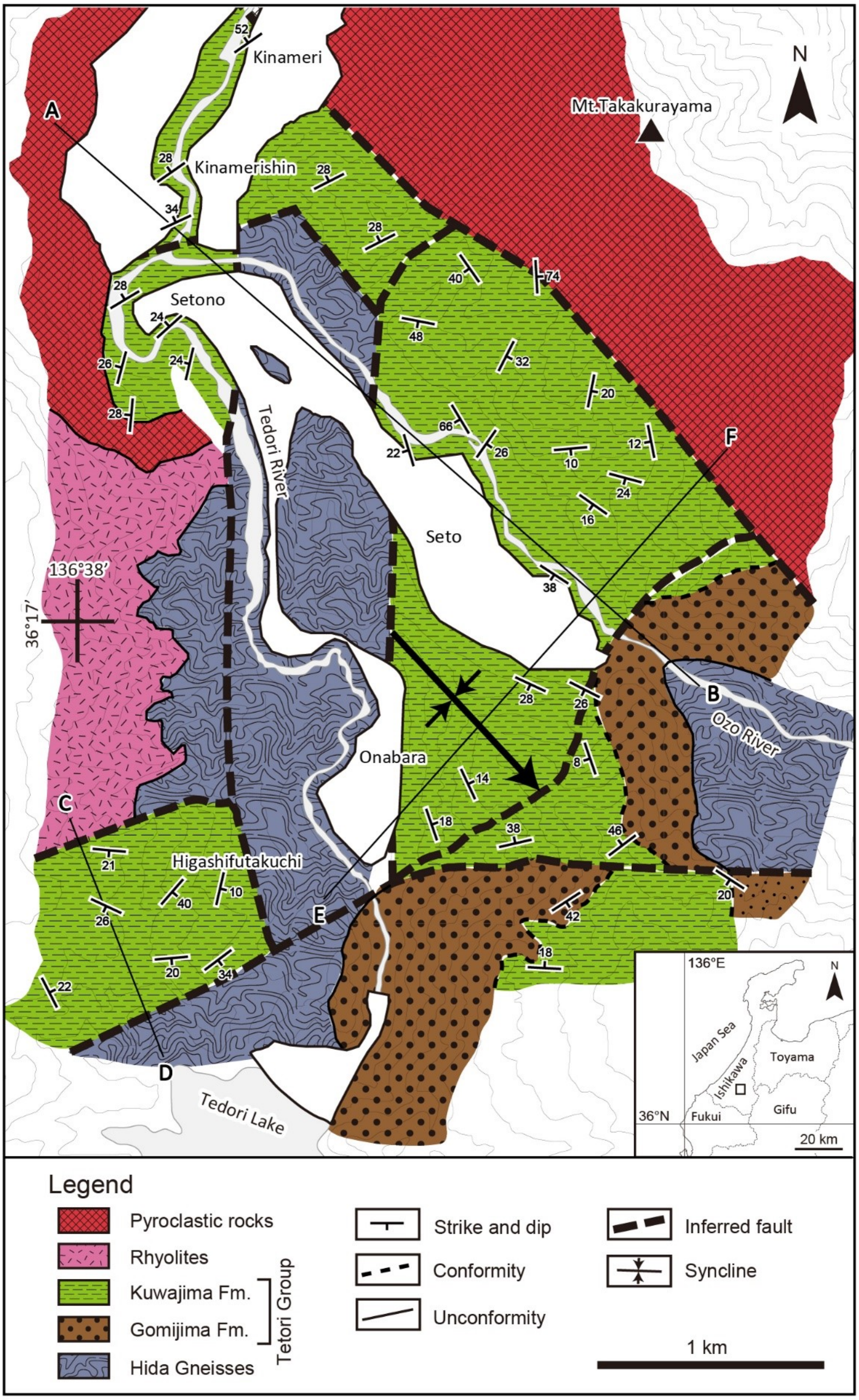

Fig. 4-1. Geological map and cross sections.

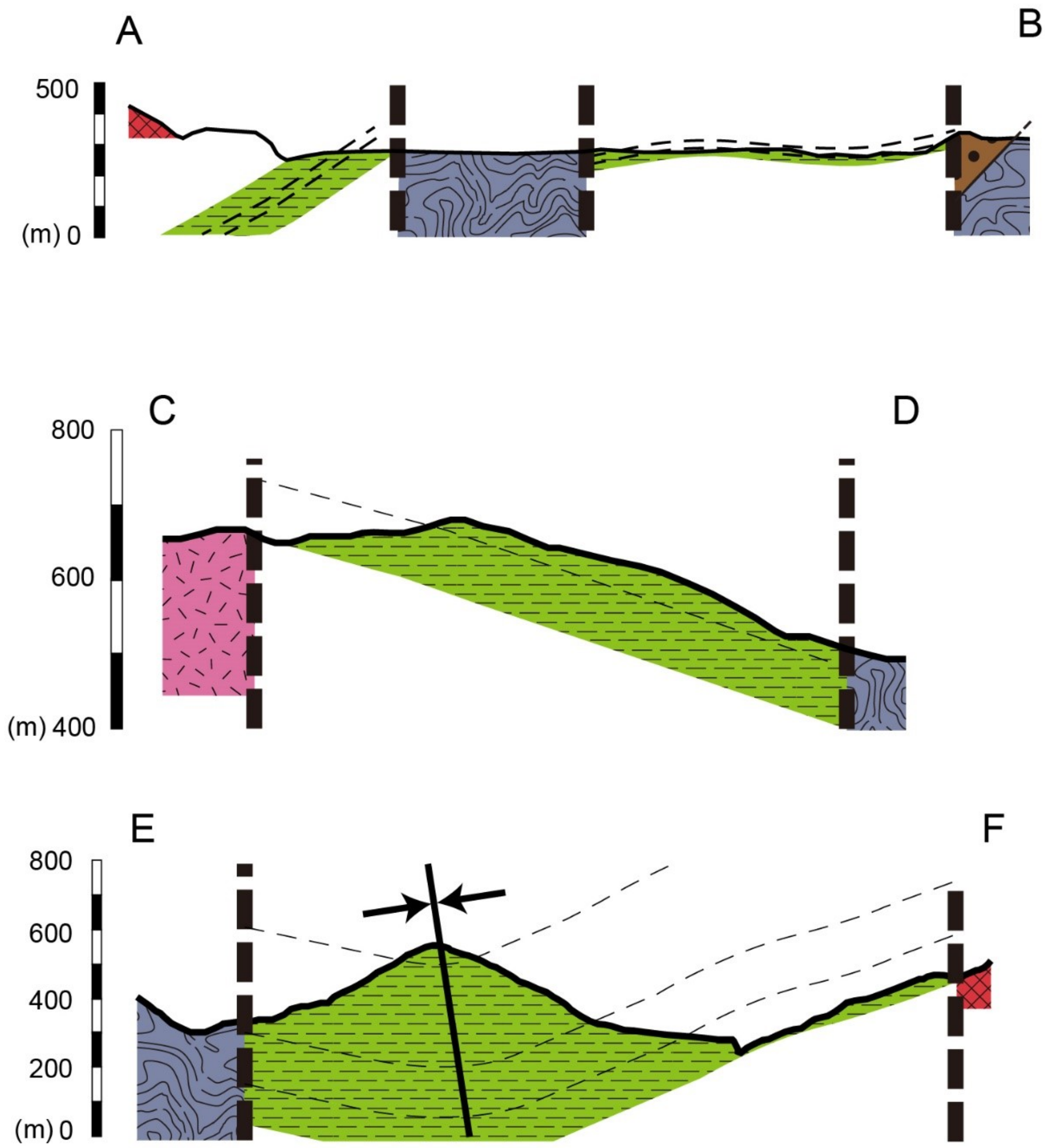

Fig. 4-2. Cross sections shown in Fig. 4-1.

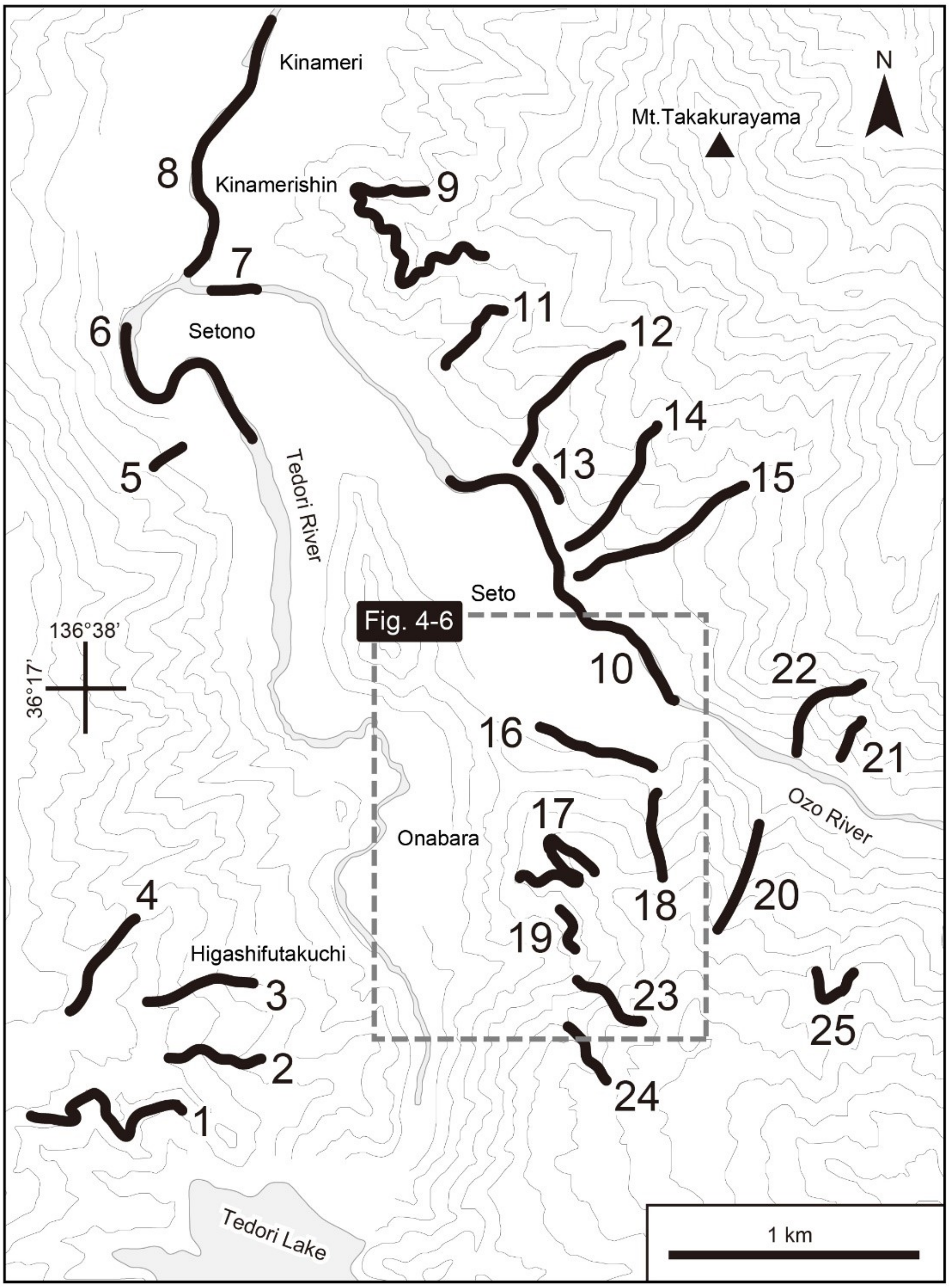

Fig. 4-3. Map showing the study routes in the Oguchi area.

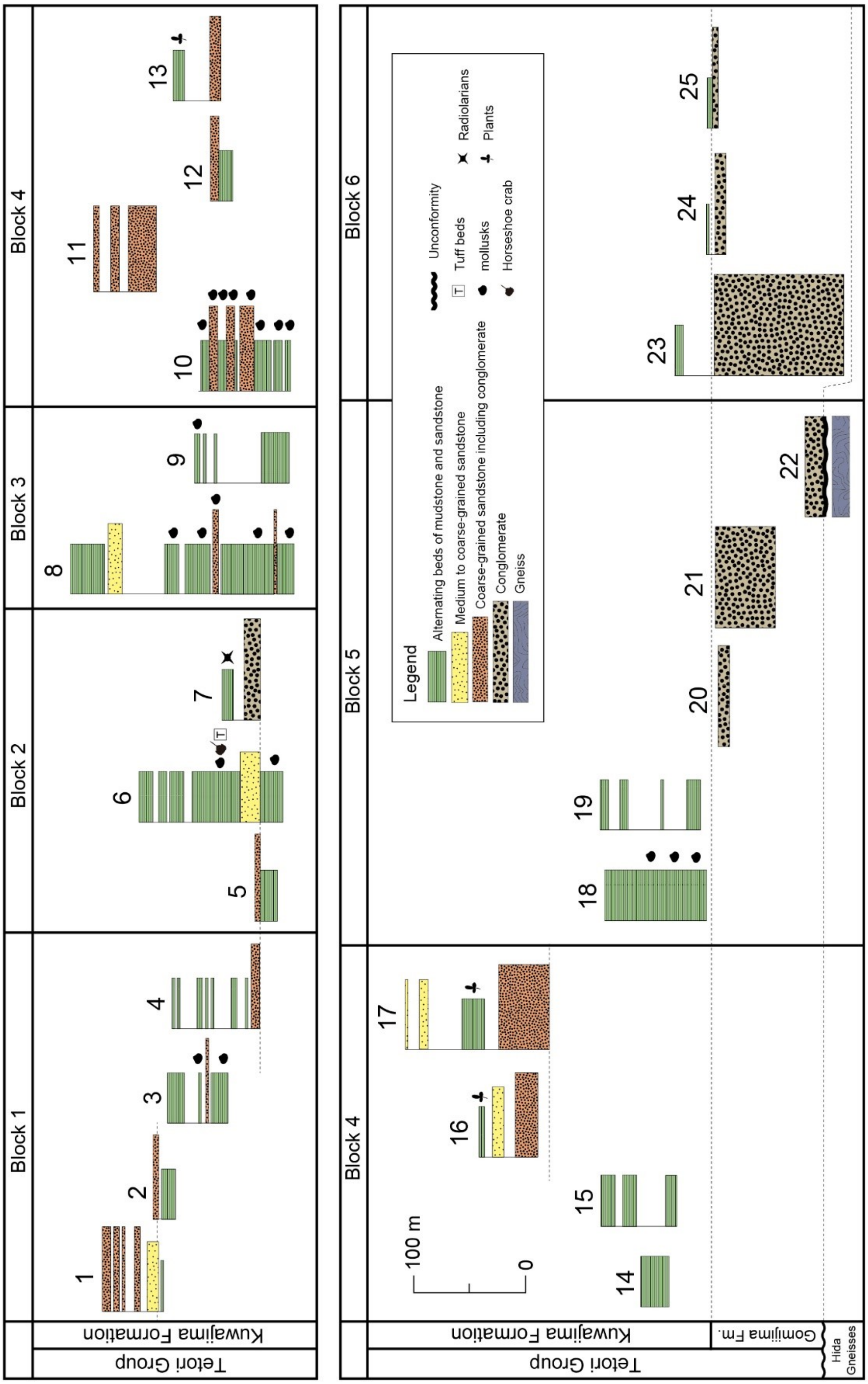

Fig. 4-4. Columnar sections of the Tetori Group in the Oguchi area. Locations of number are shown in Fig. 4-3.

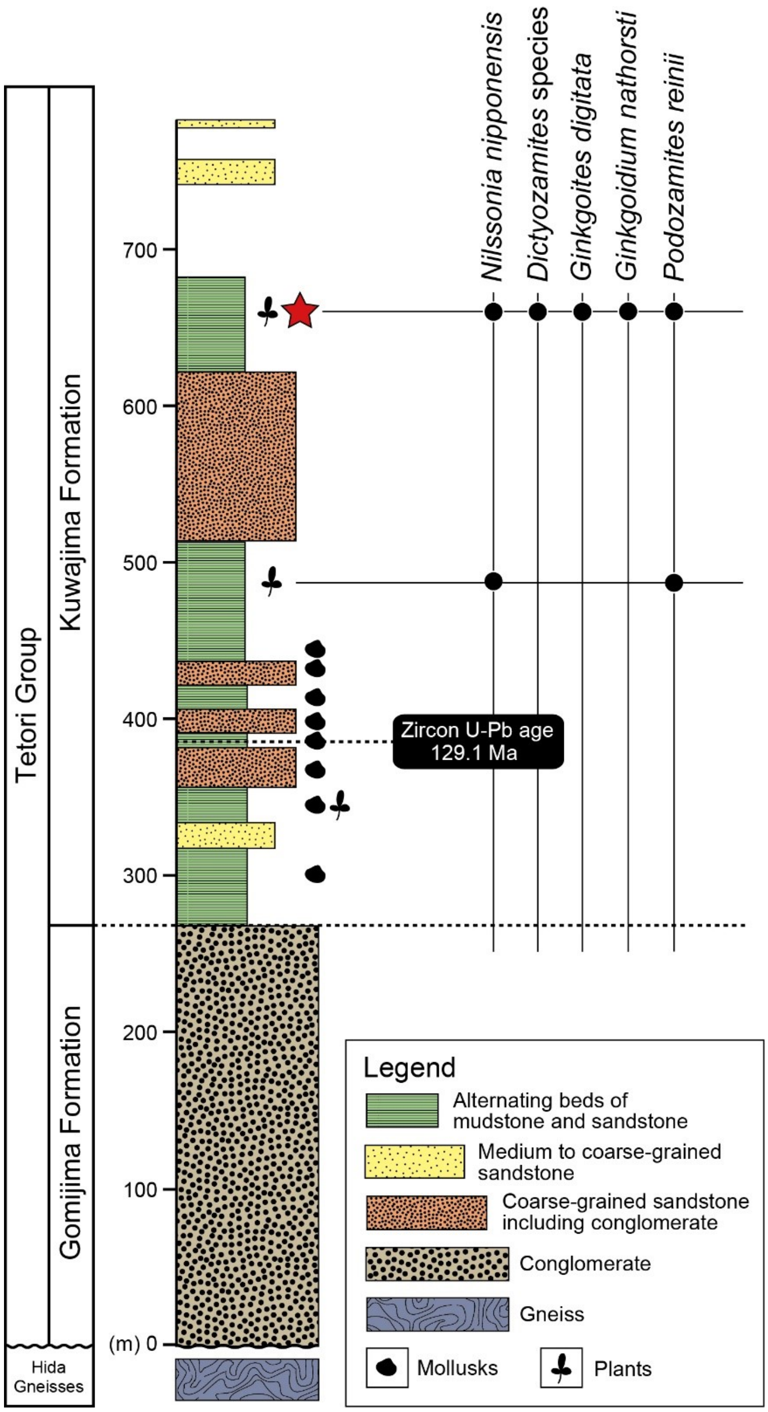

Fig. 4-5. The stratigraphic column and fossil horizon of the Tetori Group in the Oguchi area.

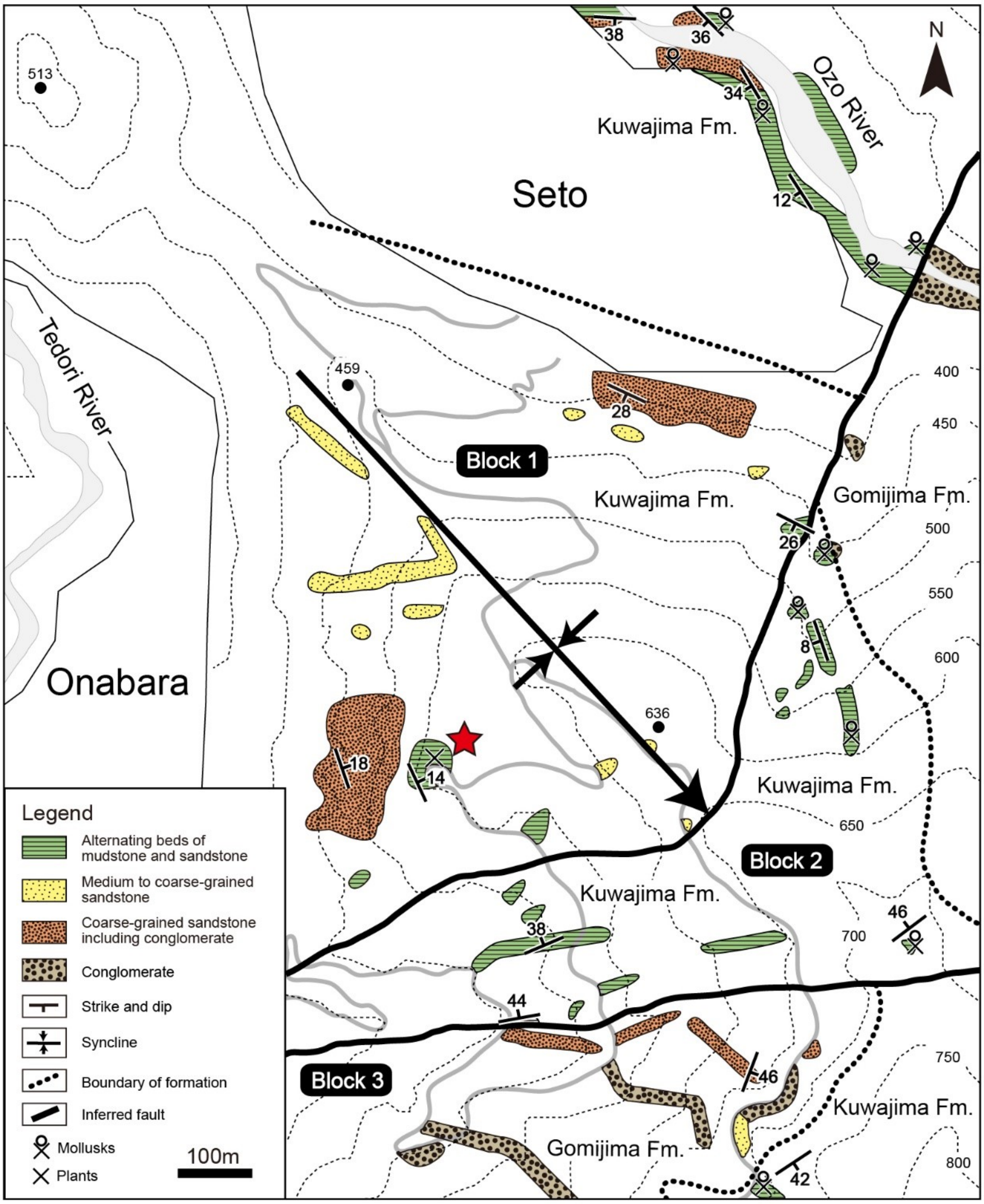

Fig. 4-6. Route map of Seto and Onabara in the Oguchi area.

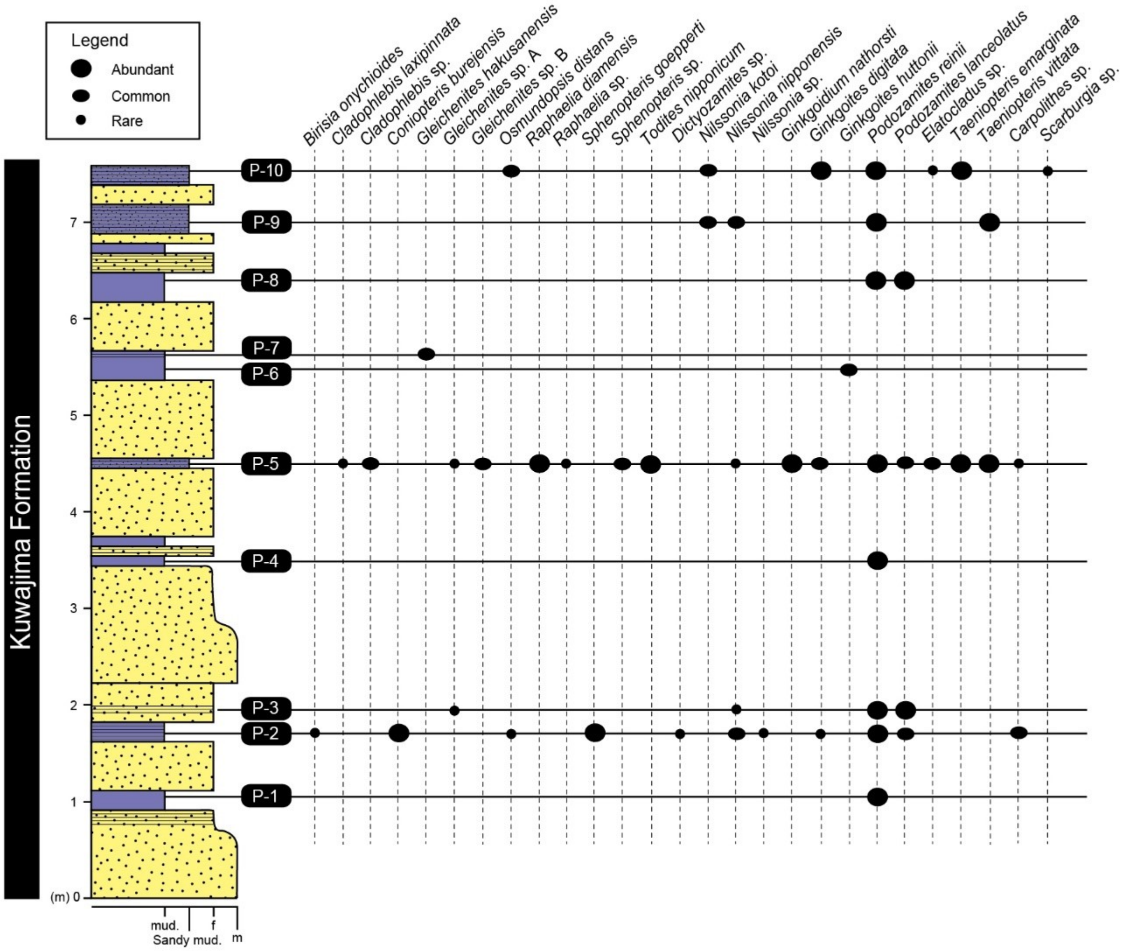

Fig. 4-7. Columnar section showing lithology and plant fossil-bearing beds. ms: mudstone, f: fine-grained sandstone, m: medium-grained sandstone.

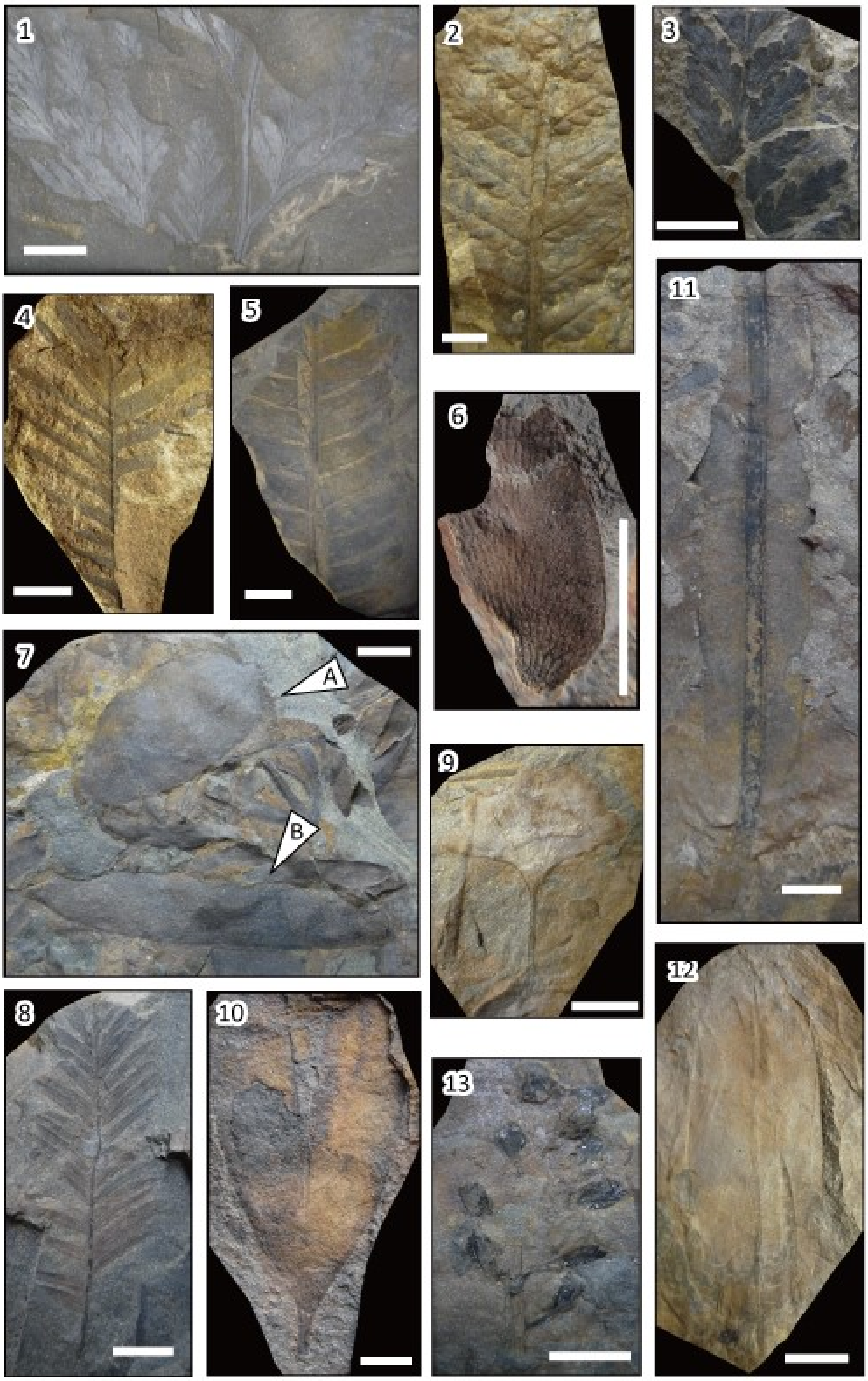
1
2
3
4
5
6
7
A
B
8
9
10
11
12
13

Fig. 4-8. Plant fossils from the Tetori Group in the Oguchi area. Scale bars are 10 mm. 1: *Coniopteris burejensis* (Zalesskey) Seward from Bed P-2 (SBEI P-3420), 2: *Raphaelia diamensis* Seward from Bed P-5 (SBEI P-3655), 3: *Sphenopteris goepperti* Dunker from Bed P-2 (SBEI P-3391), 4: *Nilssonia kotoi* (Yokoyama) Oishi from Bed P-9 (SBEI P-3738), 5: *Nilssonia nipponensis* Yokoyama from Bed P-2 (SBEI P-3547), 6: *Dictyozamites* sp. from Bed P-2 (SBEI P-3561), 7: (A) *Podozamites reinii* Geyler and (B) *Podozamites lanceolatus* (Lindley and Hutton) Braun from Bed P-2 (SBEI P-3537), 8: *Elatocladus* sp. (SBEI P-3739) from Bed P-10, 9: *Ginkgoites digitata* Brongniart (SBEI P-3723) from Bed P-10, 10: *Ginkgoidium nathorsti* Yokoyama from Bed P-5 (SBEI P-3602), 11: *Taeniopteris vittata* Brongniart (SBEI P-3688) from Bed P-5, 12: *Taeniopteris emarginata* Oishi from Bed P-10 (SBEI P-3725), 13: *Scarburgia* sp. from Bed P-10 (SBEI P-3740).

Table 4-1. List of plant fossils from Onabara, Bettokuzure and Kaseki-kabe (Kimura and Sekido, 1976a, 1978; Kimura et al., 1978; Matsuo and Sekido, 2000).

Species	Onabara	Bettokuzure	Kaseki-kabe
Bryophyta			
Thallites yabei (Kryshtofovich) Harris			●
Sphenopsida			
Equisetites ushimarensis (Yokoyama) Oishi			●
Equisetites spp.		●	
Ferns			
Adiantopteris sewardi (Yabe) Vassilevskaja		●	●
Adiantopteris toyoraensis (Oishi) Vassilevskaja		●	
Adiantopteris spp.		●	
Birisia alata (Prynada) Samylina			●
Birisia onychioides (Vassilevskaja and Kara-Mursa) Samylina	●		●
Cladophlebis denticulata (Brongniart) Fontaine		●	●
Cladophlebis laxipinnata Prynada	●		
Cladophlebis williamsoni (Brongniart) Brongniart		●	
Cladophlebis sp.	●	●	
Coniopteris burejensis (Zalesskey) Seward	●		●
Coniopteris saportana (Heer) Vachrameev		●	
Coniopteris sp. cfr. *C. arctica* (Prynada) Samylina		●	
Eboracia nipponica Kimura and Sekido			●
Gleichenites hakusanensis (Kimura and Sekido) Kimura and Sekido	●		
Gleichenites nipponensis Oishi		●	●
Gleichenites porsildii Seward		●	●
Gleichenites spp.	●		
Onychiopsis elongata (Geyler) Yokoyama		●	●
Osmundopsis distans (Heer) Kimura and Sekido	●	●	●
Raphaelia diamensis Seward	●	●	
Raphaelia sp.	●	●	
Sphenopteris goepperti Dunker	●	●	●
Sphenopteris kochibeana (Yokoyama) Oishi		●	
Sphenopteris sp.	●		
Todites nipponicus Kimura and Sekido	●		
Cycadaleans			
Ctenis nipponica Kimura and Sekido			●
Cycadites sp.			●
Nilssonia kotoi (Yokoyama) Oishi	●	●	●
Nilssonia lobatidentata Vassilevskaja		●	
Nilssonia nipponensis Yokoyama	●	●	●
Nilssonia schmidtii (Heer) Seward		●	
Nilssonia sp.	●		
Tetoria endoi Kimura and Sekido		●	●
Bennettitaleans			
Dictyozamites kawasakii Tateiwa			●
Dictyozamites reniformis Oishi			●
Dictyozamites tetoriensis Kimura and Sekido			●
Dictyozamites sp. cf. *D. cordatus* (Kryshtofovich) Prynada		●	
Dictyozamites sp. cf. *D. obliquus* Samylina		●	
Dictyozamites sp.	●		
Neozamites sp.			●

Table 4-1. (Continued)

Ginkgoaleans			
Butefia ? sp.		●	
Ginkgoidium nathorsti Yokoyama	●	●	●
Ginkgoites digitata Brongniart	●	●	●
Ginkgoites huttonii (Stemberg) Black	●	●	●
Ginkgoites paradiantoides (Samylina) Kimura and Sekido		●	
Ginkgoites sibirica Heer		●	
Pseudotorellia sp.		●	
Czekanowskialeans			
Arctobaiera ? sp.		●	
Czekanowskia sp.		●	●
Leptostrobus sp.		●	
Phoenicopsis sp.			●
Conifers			
Elatocladus spp.	●	●	●
Pityophyllum lindstroemi Nathorst		●	
Pityophyllum sp.			●
Podozamites angustifolius (Eichwald) Heer		●	
Podozamites lanceolatus (Lindley and Hutton) Braun	●	●	●
Podozamites reinii Geyler	●	●	●
Protodammara sp.		●	
Xenoxylon latiporosum (Cramer) Gothan		●	●
Systematic position unknown			
Carpolithus sp.	●	●	
Scarburgia sp.	●		
Taeniopteris emarginata Oishi	●		●
Taeniopteris vittata Brongniart	●		

Part 5

Discussion

5.1. Relation between floral composition and lithofacies

The reconstruction of depositional environment and paleovegetation have been discussed in various cases on the basis of detailed observation of plant fossil occurrence and sedimentary facies (e.g., Matsuo, 1977; Yabe and Shibata, 2011; Yukawa et al., 2012). The floral composition is varied by depositional environment. There are three lithofacies such as mudstone, sandy mudstone, fine-grained sandstone beds on the Onabara section. The composition in sandy mudstone beds is the highest diversity of the floral assemblage, while the composition in fine-grained sandstone beds is low diversity remarkably (Fig. 4-7). Most of plant fossil-bearing beds in the Onabara section include *Podozamites reinii.* In Bed P-2, *Coniopteris burejensis, Sphenopteris goepperti* and *Nilssonia nipponensis* are abundant, and *Ginkgoites digitata*, *Osmundopsis distans* and *Birisia onychioides* are rare. *Co. burejensis* and *B. onychioides* are absent in the upper horizons. In Bed P-3, *Gleichenites* sp. A first appears. In Bed P-5, *Raphaelia diamensis*, *Todites nipponicum*, *Cladophlebis* sp., *Gleichenites* sp. B, *Ginkgoidium nathorsti*, *Elatocladus* sp., *Taeniopteris emarginata* and *Ta. vittata* are first appear. *R. diamensis*, *To. nipponicum*, *Cladophlebis* sp., *Gleichenites* sp. B, *Sphenopteris* sp. and *Ginkgoidium nathorsti* are absent in the upper horizons. In Bed P-6, *Gleichenites hakusanensis* first appears and are absent in the upper horizons. *Po. reinii*, *Os. distans*, *Nil. kotoi*, *Ginkgoites digitata*, *Elatocladus* sp. and *Ta. emarginata* continue to occur until Bed P-10. The dominant species of these plant fossil-bearing beds are different. Bed P-2 is represented by *Co. burejensis* and *Sp. goepperti*. Bed P-5 is represented by *R. diamensis* and *To. nipponicum*. Bed P-10 is represented by *Os. distans*.

Podozamites is abundant in mudstone, sandy mudstone, and fine-grained sandstone beds. It is likely that the occurrence of *Podozamites* is not influenced by lithofacies. *Ginkgoites digitata* is abundant in sandy mudstone bed, and is rare in mudstone bed, and is absent in fine-grained sandstone bed. *Ginkgoidium nathorsti* and *Elatocladus* sp., *Taeniopteris emarginata* and *Ta. vittata* are abundant in sandy mudstone bed and are absent in and mudstone and fine-grained sandstone beds. *Nilssonia nipponensis* is abundant in mudstone and sandy mudstone beds and is absent in fine-grained sandstone bed. In summary, these leaves except for *Ginkgoidium nathorsti* co-occur in the same horizon. Composition of fern shows leaves relationship with lithofacies. Mudstone bed contains *Coniopteris burejensis* and *Sphenopteris goepperti*. Sandy mudstone beds contain *Osmundopsis distans*, *Raphaelia diamensis*, *Sphenopteris* sp. and *Todites nipponicum*, however *Os. distans* rarely occur with other species in some horizon.

The remarkable floral composition change is considered between Bed P-3 and P-5 based on the appearance of *R. diamensis*, *To. nipponicum*, *Cladophlebis* sp., *Gleichenites* sp. B, *Ginkgoidium nathorsti*, *Elatocladus* sp., *Ta. emarginata* and *Ta. vittata*. Dominant fern species change *Co. burejensis* and *Sp. goepperti* assemblage, *To. nipponicum* and *R. diamensis* assemblage, and *Os. distans*, in ascending order.

This result provides clues for understanding local floral compositional change and reveals the details of regional vegetation difference and floral succession in the Tetori Group. It is probably likely to the occurrence of *Podozamites* is not influenced by depositional environment. In contrast, it is obvious that the occurrence of ferns is varied by depositional environment. The difference of taphonomic process and sedimentary environment probably become a factor for this trend. In the future, if the author discovers plant fossil localities containing rich various genus and species which are possible for us to pick out specimens directly from an outcrop, the author expects to lead to further reveal vegetation distribution in the Tetori Group during the Early Cretaceous time.

5.2. Stratigraphic implication of plant assemblages in the Tetori Group

The recognition of the Mixed-type Flora which has the Ryoseki-type floral elements is important for understanding the climate change during the Early Cretaceous (Yabe et al., 2003). Among these, the occurrence of "*Zamiophyllum*" and *Brachyphyllum* is recorded in the Tetori Group in Fukui and Ishikawa prefectures until now, the stratigraphic relationship of each fossil locality is not discussed yet. Kawai

(1961) have shown the occurrence record of "*Zamiophyllum*" in his list, and Matsuo and Omura (1966) have shown that from the Myodani River in the Shiramine area in their list. Kimura and Sekido (1963) reported "*Zamiophyllum*" *buchianum* (Ettingshausen) Seward Irabara in the Shiramine area. And Oishi (1940) reported this specie from Mochiana in the Kuzuryu area as *Ptilophyllum pachyrachis* Oishi. However, genus "*Zamiophyllum*" is included in genus *Zamites* now (Watson and Sincock,1992). And there is an opinion that "*Zamiophyllum*" *buchianum* discovered in Japan is regard as *Zamites choshiensis* Kimura and Ohana (Kimura and Ohana,1985). On the other hand, as the occurrence record of *Brachyphyllum*, Kawai (1961) reported that obtained from Miyadani and Yunotani in the Shiramine area, Yabe and Kubota (2004) described *B. obesum* from the Sugiyama River in the Takinamigawa area.

Recently, Yabe and Kubota (2004) and Yabe and Shibata (2011) reported the Ryoseki-type floral elements from the Kitadani Formation, it points out that the climate may have become dry at the end of deposition of the Tetori Group. However, there are no specific data on when the drying began, and how the composition of plant assemblages has changed is not fully understood. The reason is that the plant fossils-bearing beds cannot be compared between fossil localities, because the stratigraphy of the Tetori Group is not unified. The author reconfirmed the lithological formation, and examined plant fossils collected in the Kuwajima, Akaiwa and Kitadani formations. As a result, this study was able to capture the changes of plant assemblages although it is a limited and continuous area.

Sakai et al. (2018) obtained *Zamites* sp. (or *Pseudoctenis* sp.) and *Brachyphyllum*? sp. which are the Ryoseki-type floral elements from the Akaiwa Formation, and the typical elements of the Ryoseki-type Flora. The occurrence of macrophyllous bennettitaleans and microphyllous coniferous foliages suggests it is possibly that drier climate spreaded more than climate flourished under the typical Tetori-type Flora during the depositional time of the Akaiwa Formation. Therefore, the drying recognized within the Tetori Group start from the depositional time of the Akaiwa Formation.

Plant assemblages of the Kuwajima Formation is the typical Tetori-type Flora, containing the Tetori-type floral elements as *Nilssonia nipponensis*, *Dictyozamites*, *Ginkgoites* and *Ginkgoidium*, *Podozamites reinii*. There are two horizons within the Akaiwa Formation containing some taxa preferring a dry climate, and the Tetori-type floral elements is abundant in another horizons (Figs. 3-7, 5-1). Plant assemblages of the Akaiwa Formation is recognized as the Mixed-type Flora (Kimura, 1987) mixed the Tetori-type floral elements and *Zamites* (or *Pseudoctenis*) and *Brachyphyllum* which is the Ryoseki-type floral elements. And some taxa preferring a dry climate such as *Zamites* (or *Pseudocteni*s) and *Brachyphyllum* were reported in the Kitadani Formation (Yabe and Shibata, 2011; Sano and Yabe, 2017) (Table 3-3). On the other hand, the Tetori-type floral elements are recognized only *Dictyozamites* from the lower part of the Kitadani Formation (Figs. 3-7, 5-1). Plant assemblages of the Akaiwa and Kitadani formations contains some taxa preferring a dry climate, and the Tetori- and the Ryoseki-type floral elements are mixed, both assemblages are considered as the Mixed-type Flora (Figs. 1-7, 3-7, 5-1). To focus on the stratigraphical distribution of the Tetori-type floral elements and taxa preferring a dry climate, it is presumed that the influence of drying was gradually strengthened during the depositional time of the Akaiwa and Kitadani formations. This estimate is harmonious with that the Akaiwa and Kitadani formations in the Shiramine and Takinamigawa areas contain pedogenic carbonates (Lee and Hisada, 1999) indicating the warming and drying (Fujita, 1998; Kubota, 2003; Yabe and Shibata, 2011). And Shigeno et al. (2004) suggests that there is a warming and drying trend to upward, based on a result of the paleosol analysis in the Tetori Group in the Kamiichi–Tateyama area, Toyama Prefecture. The result suggests it is possibly that the drying was progressing on the Tetori basin during the depositional time of the Akaiwa Formation.

5.3. The Early Cretaceous floral change in East Asia

Based on leaf morphologies, the occurrence of such microphyllous conifers represented by *Pseudofrenelopsis*, *Pagiophyllum*, *Cupressinocladus*, *Brachyphyllum* and *Frenelopsis* is considered the best indicator of floral and climate change (Rees et al., 2000). The assemblage from the Nochino Formation has some Ryoseki-type floral elements including *Pagiophyllum*, thus indicating a dry climate condition. The occurrence of such Ryoseki-type floral elements is consistent with the floral change and the warming and drying trend from the Itsuki Formation to the Nochino Formation, thus corresponding a warming climate change event (Figs. 1-7, 2-7, 5-1). The climate change event from the Hauterivian to the Barremian was also reported by Golovneva (1998), who dealt with floras distributed in the northeastern Russia and Northeast China. Sun et al. (1995) suggested the occurrence of a warm and arid climate during the late Early Cretaceous of Heilongjiang Province in China based on the occurrence of the Ryoseki-type floral elements. The assemblage from the Muling Formation also has the Ryoseki-type floral elements including *Pagiophyllum* (Yang, 2003). The occurrence of such Ryoseki-type floral elements is consistent with the floral change and the warming and drying trend from the Chengzihe Formation to the Muling Formation (Fig. 1-7). Krassilov (1973) suggested the warming trend from Barremian to Aptian in East Asia based on the flora compositional change. Consequently, it is likely that warming and drying trend recognized in the Tetori Flora reflect the extension occurrence of a warm and arid climate in East Asia from the Barremian to the Aptian.

It is worth noting that pedogenetic nodules have been reported from the upper part of the Tetori Group (Sakai et al., 2018). Interestingly, the similar pedogenetic nodules and red beds are also found in the uppermost part of the Nochino Formation (Figs. 2-7, 5-1), suggesting higher temperatures and arid conditions. It is thus indicated that the climate condition became warmer and more arid during the sedimentation of the upper part of the Tetori Group (Shigeno et al., 2004). In addition, thermophilic reptiles such as crocodilians also have been discovered in the uppermost part of the Tetori Group (Azuma, 2003) (Fig. 5-1), and they unequivocally indicate warmer environments (Amiot et al., 2011). The warming and drying trend responded by fossil plants in the Lower Cretaceous Tetori Group of Japan probably expresses the potential links with the paleoclimate transition in the mid-latitudes in the Northern Hemisphere (Hasegawa et al., 2012).

5.4. Moving northward process of the Ryoseki-type Flora on the eastern margin of Asia

This study creates the phytogeographic maps in the late Early Cretaceous time (Barremian, Aptian and Albian), discuss about moving northward process of the Ryoseki-type Flora on the eastern margin of Asia (Fig. 5-2). Successive climate change recorded in the Tetori Group shows a trend of the warming and drying during the Aptian to Albian time, which is representing the moving northward process of the Ryoseki-type Flora along the coastal area, and climate change on East Asia in the midlatitudes in the Early Cretaceous, based on zircon U–Pb age reported by Nagata et al. (2019, 2020) and Sakai et al. (2019b, 2021) (Fig. 5-1). Sakai et al. (2018, 2020c) clarified floral change on the Tetori Group, and the sedimentation of the group was continuing until Albian. In the Barremian time, the Tetori basin is located near sea, the Tetori-type Flora distributed there.

As mentioned in Part 1, Philippe et al. (2014) and Amiot et al. (2015) suggests that mountain range existed between the coastal and inland areas of East Asia, therefore, the elevation difference estimation is essential for comparing both basins (Fig. 5-2). The coastal area is under harsh environment for plants; wind from sea and splashing salt, and it trends that environmental condition is relieved toward the inland area. Whereas most of fossil woods reported from the Tetori Group is *Xenoxylon latiporosum* (Cramer) Gothan which is the Tetori-type wood, and the wood diversity is low (Terada et al., 2004; Terada, 2008; Terada et al., 2011), the wood diversity in the inland area was increasing (Oh et al., 2011; Ding et al., 2016). After Aptian, the Tetori basin gradually move away the sea, because the warming and drying proceed, the Ryoseki-type Flora moved northward, and *Podocarpoxylon* sp. of the Ryoseki-type wood appeared on the Tetori basin in the Albian time (Terada and Yabe, 2011). Namely, floral change was obvious in the coastal area including Tetori and Heilongjiang basins, the flora transferred the Mixed-type Flora in the Albian time. There were a mountain range between Heilongjiang and Western Liaoning basins (e.g., Philippe et al., 2014; Liu et al., 2015; Cao, 2018). Therefore, the flora of the inland area including Western Liaoning basin is the Tetori-type or Mixed-type Flora, maybe its change is less than the coastal area. It doubts remain even now about the differences of fauna in the basins of the Tetori and Jehol groups, which were located at the same latitude in same age (Zhou et al., 2003; Sano and Yabe, 2017). The depositional environment of the Barremian Yixian Formation is represented mainly by lacustrine environment (Jiang, and Sha, 2007). The multi-evaluation without the Tetori- and Ryoseki-type floral elements as index is necessary for further verification. For example, recent report on the Tetori Group of the existence of *Manchurochelys* which is representative turtle of the Jehol Group is paid attention now (Hirayama et al., 2020).

Recently, some researchers are studying age spectra of zircon for sandstone sample from the Tetori Group. Their opinion that the group is a series of sediments on the basin. (Maeda, 1961; Matsukawa et al., 2014; Sano, 2015) have being reviewed (Otoh et al., 2018). The floral comparison between the Itoshirogawa area (the type area) and the Shiramine and Takinamigawa areas in this study, appearing the Ryoseki-type floral elements is different. It suggests a possibility that the floral compositional changes in the Tetori basin by difference elevation (Fig. 5-1). Accumulating data of flora comparison in each distribution area of the Tetori Group and age spectra of zircon for sandstone sample is being important for understanding the vegetation distribution into the Tetori basin.

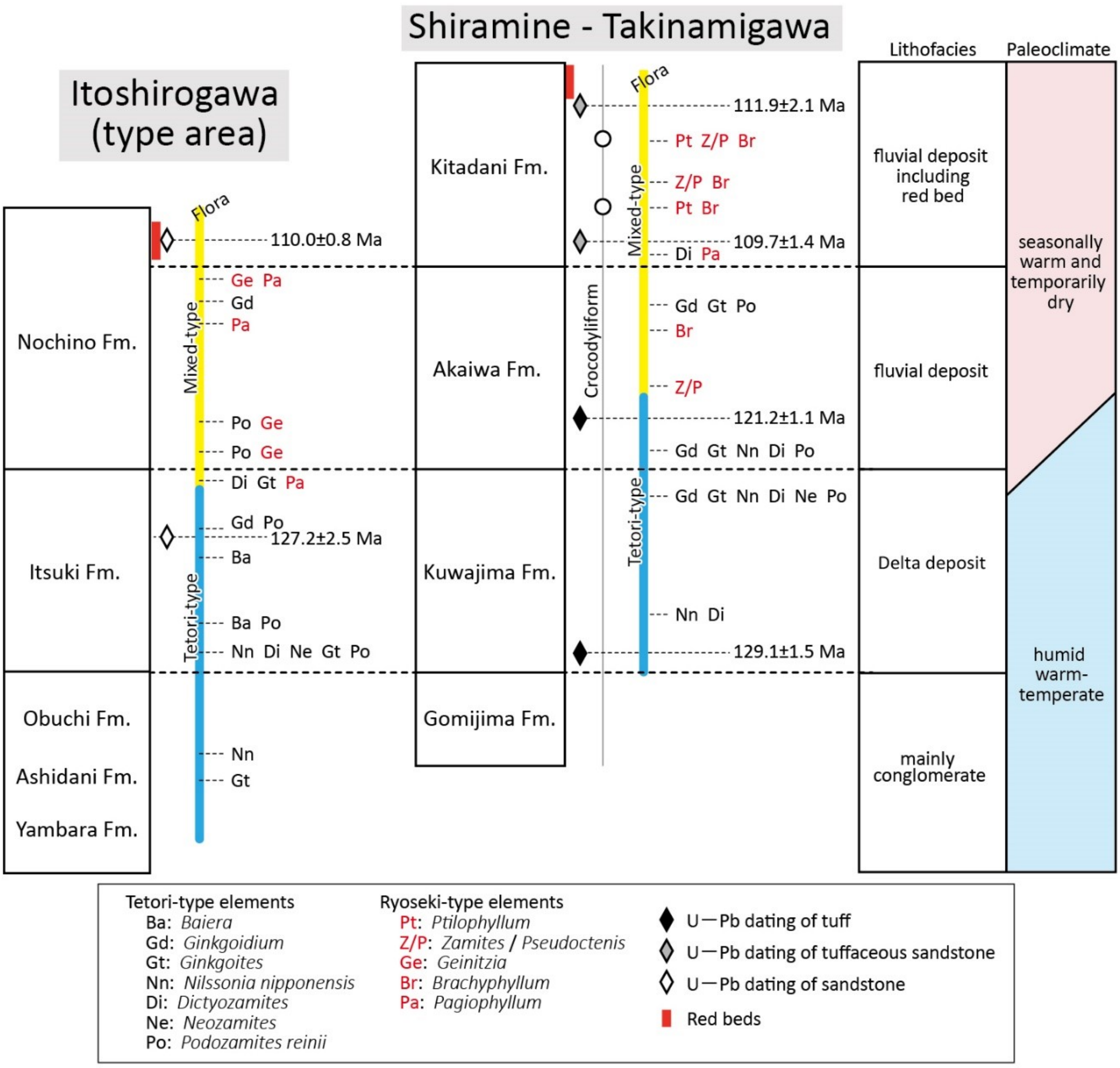

Fig. 5-1. The appearance and transition of biota in the Tetori Group during the Early Cretaceous time.

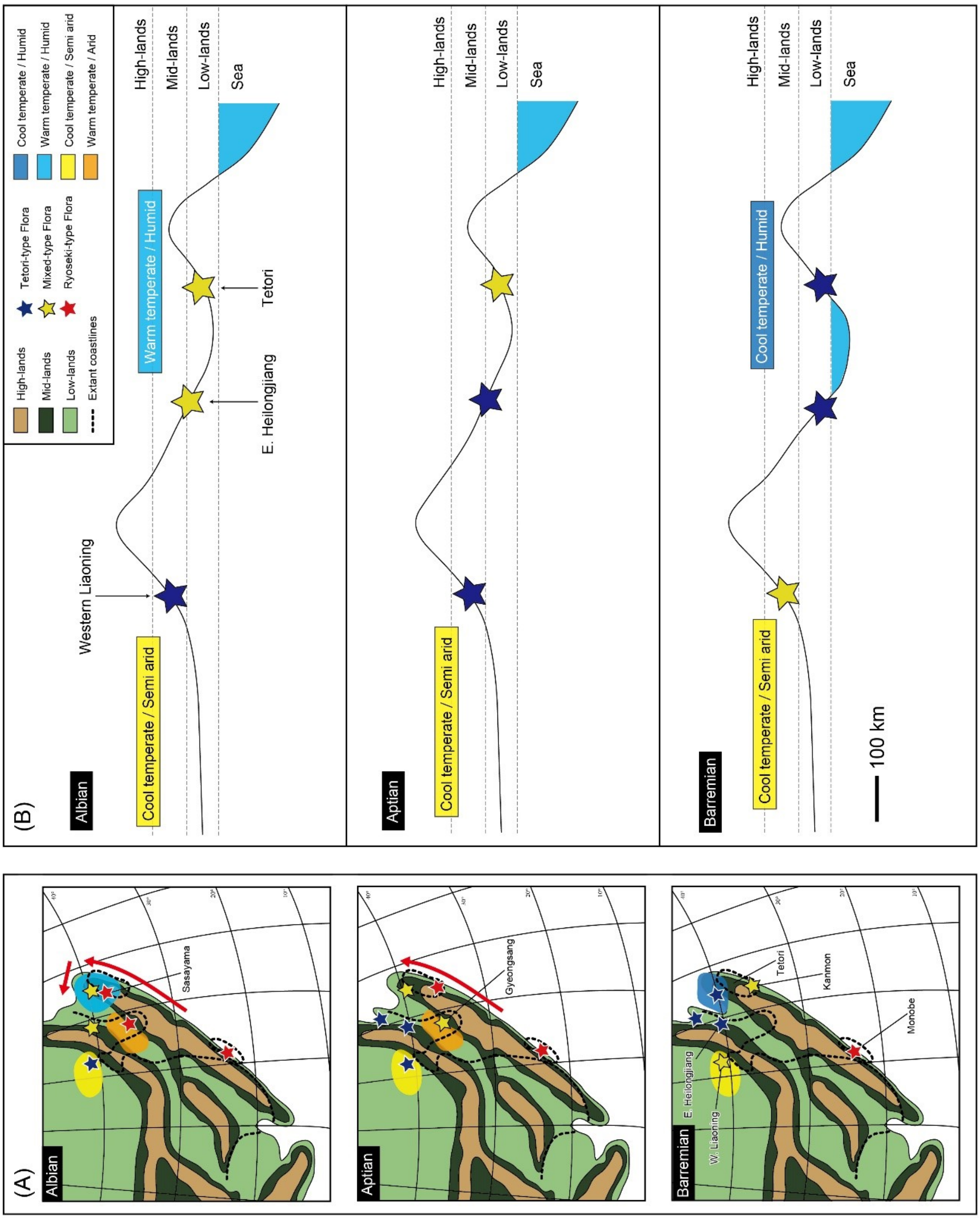

Fig. 5-2. A: Paleogeographic map of East Asia based on Matsukawa and Fukui (2009), Philippe et al. (2014), Cao (2018), Yamada et al. (2018) and Sakai et al. (2020c). B: topographic cross sections on the 40 degrees north latitude. The red arrows show the moving northward process of the Ryoseki-type Flora along the coastal area.

Conclusion

1. The Tetori Group in the Kuzuryu area of Fukui Prefecture, which is the type area of the Tetori Group is divided into the Yambara, Ashidani, Obuchi, Itsuki and Nochino formations, in stratigraphic ascending order. The group in the Shiramine area of Ishikawa Prefecture and the Takinamigawa area of Fukui Prefecture is divided into the Gomijima, Kuwajima, Akaiwa and Kitadani formations, in stratigraphic ascending order. The Ryoseki-type floral elements occur at the Nochino, Akaiwa and Kitadani formations of the Tetori Group. The floral element analysis infers a warming and drying climate trend between the Itsuki Formation and the Nochino Formation and between the Kuwajima Formation and the Akaiwa Formation. The trend suggests that the floral composition of the Tetori Group changed from the Tetori-type to the Mixed-type. Therefore, the drying on the Tetori basin started much earlier than previously thought.

2. The Tetori Group in the Oguchi area of the Ishikawa Prefecture is divided into the Gomijima and Kuwajima formations, in stratigraphic ascending order. The plant assemblage of the Kuwajima Formation collected from the Onabara section includes 18 genera and 26 species. This study describes the co-occurrence of plant fossils in 10 plant fossil-bearing beds. These are considered as allochthonous based on the occurrence of plant fossils. This study described the co-occurrence of plant fossils in these plant fossil-bearing beds. It is likely that the occurrence of *Podozamites* is not influenced by depositional environment. In contrast, it is obvious that the occurrence of ferns is varied by depositional environment. The difference of taphonomic process and sedimentary environment probably become a factor for this trend.

3. The floral composition of the Tetori Group changed from the Tetori-type to the Mixed-type because the climate condition around the Tetori basin became warmer

and more arid in the Aptian. The warming and drying trend in the Tetori Group probably expresses the potential links with the Lower Cretaceous climate transition in the mid-latitudes in the Northern Hemisphere. Thermophilic reptiles such as crocodilians also have been discovered in the uppermost part of the Tetori Group, and they unequivocally indicate warmer environments around the Tetori basin.

4. East Asia on Early Cretaceous was divided into some basins by mountain range. The coastal area was under humid climate, and the inland area was under dry climate at that time. The floral change of the inland area maybe is lesser than that seen in the coastal area. The comparison of floral succession between inland and the coastral basins revealed that successive climate change recorded in the Tetori Group is representing the moving northward process of the Ryoseki-type Flora along the coastal area on East Asia.

Acknowledgments

The author gratefully thanks Prof. Atsushi Matsuoka, my supervisor in Niigata University for his supports in Japan. I thank Emeritus Prof. Jun-ichi Tazawa, Emeritus Prof. Yoshiyuki Hasegawa, Dr. Isao Niikawa, Dr. Toshiyuki Kurihara, Dr. Hayato Ueda, Dr. Yuta Shiino, and members of the Historical Earth Science Seminar of Niigata University for helpful discussions, Prof. Yongdong Wang (Nanjing Institute of Geology and Palaeontology, China), Mr. Shinji Sekido (Komatsu City Museum, Japan), Dr. Atsushi Yabe (National Museum of Nature and Science, Japan) and Prof. Toshihiro Yamada (Osaka City University, Japan) for their paleobotanical comments, Dr. Shinji Isaji (Natural History Museum and Institute, Chiba, Japan), Mr. Masatoshi Okura (Konan City, Aichi Prefecture, Japan), Dr. Teppei Sonoda (Fukui Prefectural Dinosaur Museum, Japan), Mr. Kento Otsuka (Shiramine Institute of Paleontology, Hakusan City, Japan), Mr. Tsuyoshi Hibino (Hakusan City, Ishikawa Prefecture, Japan), Dr. Mitsuhiro Nagata (Japan Atomic Energy Agency, Japan), Dr. Shin-ichi Sano (University of Toyama, Japan), Dr. Tsuyoshi Ito, Dr. Yukiyasu Tsutsumi (Nat. Mus. Nat. Sci., Japan), Dr. Nao Kusuhashi (Ehime University, Japan), Dr. Michiharu Goto (Fukui Pref. Dinosaur Mus., Japan), Dr. Kazuo Terada (Fukui Pref. Dinosaur Mus., Japan), Dr. Masato Fijita (Toyama Science Museum, Japan) and Dr. Naoto Handa (Tokyo City University, Japan) for their guidance, advice and discussion for this study. I'm grateful to Prof. Yongdong Wang, Prof. Gang Li (Nanjing Institute of Geology and Palaeontology, China) and Prof. Shenghui Deng (Research Institute of Petroleum Exploration and Development, China) for his kind instruction and supporting my study in China. The author thanks the Ono City Board of Education for granting the opportunity for this doctoral program and the permission for field work.

This research was financially supported by the Japan Society for the Promotion of Science KAKENHI (grant numbers 15K05329 and 15H02142) to AM. This study was jointly supported by the Strategic Priority Research Program (B) of the Chinese

Academy of Sciences (Grant No. XDB18000000), the National Natural Science Foundation of China (Grant Nos. 41790454, 41688103), State Key Programme of Basic Research of Ministry of Science and Technology, China (Grant No. 2012CB822003) and the Team Program of Scientific Innovation and Interdisciplinary Cooperation of CAS to YDW.

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