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GEOLOGICAL AGE AND CORRELATION OF THE VERTEBRATE-BEARING HORIZONS IN THE TETORI GROUP

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ABSTRACT

Correlation and age of the vertebrate-bearing horizons in the Tetori Group, which is representative sedimentary succession of the Middle Jurassic to Early Cretaceous in the Inner Zone of the Southwest Japan, have been reexamined with new data. The Tetori Group is divided into the Kuzuryu, Itoshiro, and Akaiwa subgroups in ascending order. The Kuzuryu Subgroup referred to Middle to Late Jurassic on the basis of marine molluscan fossils. The Itoshiro Subgroup contains Late Hauterivian to Early Barremian ammonite, and the upper part of the subgroup yields non-marine molluscan fossils (Tatsukawa type Fauna) indicating Hauterivian. The Akaiwa Subgroup conformably overlies the Itoshiro Subgroup and its upper part yields the Late Barremian non-marine fauna (Sebayashi type Fauna). Molluscan assemblages and zircon fission track dating of tuff indicate that terrestrial and freshwater vertebrate fossils including dinosaurs of the Tetori Group are found in the Hauterivian, Late Barremian, and Aptian to Early Albian strata.

Key words: Tetori Group, Jurassic, Lower Cretaceous, stratigraphy, fission track dating, dinosaur

藤田将人（2003）手取層群の脊椎動物化石産出層の地質年代と対比について．福井県立恐竜博物館紀要 2：3–14．

西南日本内帯の代表的中部ジュラ―下部白亜系である手取層群の対比および時代論について，近年発表されているデータを加えて再検討を行った．手取層群は下位から九頭竜，石徹白，赤岩亜層群からなる．最下部の九頭竜亜層群は海棲軟体動物化石によりジュラ紀中期～後期とされている．石徹白亜層群は Hauterivian 後期～Barremian 前期のアンモナイトを含み，その上部は Hauterivian の非海生軟体動物化石（立川型ファウナ）を産出する．赤岩亜層群は石徹白亜層群を整合に覆い，その上部層から Barremian 後期の瀬林型ファウナを産出する．軟体動物化石群および凝灰岩中ジルコンのフィッション・トラック年代測定により，手取層群の恐竜化石を含む陸上・淡水生脊椎動物化石は Hauterivian，Barremian 後期および Aptian～Albian 前期の地層から産出している．

INTRODUCTION

The Tetori Group of the Inner Zone of the Southwest Japan records a terrestrial ecosystem of Lower Cretaceous and attracts worldwide attention (e.g. Azuma and Tomida, 1995; Evans et al., 1998; Manabe et al., 2000a; Matsuoka et al., 2002). It is still difficult to correlate among sedimentary basins and to determine precise geological age, because of scattered distribution of basins and scarcity of key beds and index fossils.

Recently, the occurrence of dinosaur remains and footprints from the Tetori Group was reported (e.g. Azuma et al., 1992; Hasegawa et al., 1995; Matsukawa et al., 1997b; Azuma and Currie, 2000) and dinosaur excavations have been carried out (e.g. Dinosaur Excavation Party of the Fukui Prefectural Museum, 1991; Gifu-ken Dinosaur Research Committee, 1993; Manabe and Barrett, 2000; Toyama Dinosaur Research Group, 2002). However, the stratigraphical correlation and geological age among vertebrate fossil-bearing horizons have not been clarified.

The purpose of this paper is to discuss the stratigraphy and geological age of the Tetori Group, particularly of vertebrate fossil-bearing horizons, and to contribute toward the future study.

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STRATIGRAPHY OF THE TETORI GROUP

The Middle Jurassic to Early Cretaceous Tetori Group is distributed in the Hakusan and Jinzu Regions in Hokuriku, Central Japan (Maeda, 1961a). The Tetori Group is divided into the Kuzuryu, Itoshiro, and Akaiwa subgroups in ascending order. Although the Omichidani Formation was originally included in the Tetori Group (Maeda, 1961a), Tsukano (1969) distinguished the formation from the Tetori Group as the Asuwa Group. This paper follows his opinion.

Stratigraphy and correlation of the Tetori Group between districts are shown in the Fig. 1, mainly based on Maeda (1961a) and Yamada (1988). Recently Kusuhashi et al. (2002) reviewed the stratigraphy of the Tetori Group in the Hakusan Region. New stratigraphic data are also shown and correlations among the basins are slightly modified from Maeda (1961a), based on these new data.

GEOLOGICAL AGE AND CORRELATION OF THE TETORI GROUP

The age and correlation of the Tetori Group are discussed with new data in this chapter. Proposed correlation among the selected districts is summarized in Fig. 2.

Kuzuryu Subgroup

The age of the Kuzuryu Subgroup has not been revised since the 1970's. The Kuzuryu Subgroup is composed of marine and non-marine deposits. The lower part of this subgroup is non-marine origin in some districts (Fig. 1-B, F, J). The precise age of start of deposition of the Tetori Group is difficult to determine due to lack of index fossils from the lower part. Marine molluscan fossils, reliable for dating, are found in the upper part of this subgroup. The Kaizara Formation (Fig. 1-A) is correlated with the lower part of the Mitarai Formation in Shokawa district (Fig. 1-F) yielding ammonites (Sato et al., 1963; Sato and Kanie, 1963) which indicate Callovian in age. The Yambarazaka Formation (Fig. 1-A) and Kiritani alternation (Fig. 1-L) yield Oxfordian ammonites (Maeda, 1952a; Maeda, 1961a; Sato et al., 1963). Maeda (1962c) reported *Nipponitrigonia sagawai* from the Kiritani alternation, which is also obtained from the Middle to Upper Jurassic in the Sakawa district, Kochi Prefecture (Kobayashi, 1957b). As Hayami (1960) pointed out that the upper part of the Mitarai Formation is younger than the Kaizara Formation and could be correlated with the Oxfordian Yambarazaka Formation (Fig. 1-A) based on bivalve fossils. The Sugisaki Formation in Furukawa district (Fig. 1-J) yields *Inoceramus furukawensis* which closely resembles *I. maedae* from the Mitarai Formation in Shokawa district, and is considered as Oxfordian in age (Maeda, 1962b). Therefore, the Yambarazaka Formation, upper part of the Mitarai Formation, Sugisaki Formation, Kiritani alternation, and Arimine shale (Fig. 1-M) might be coeval. However, *Inoceramus* sp. cf. *I. maedae* was found in the Itoshiro Subgroup in the east of Izumi (Fujita et al., 1998) (Fig. 1-D). There is a possibility that the range of *I. maedae* could be longer than previously thought. It needs further consideration to discuss the geological age of the Kuzuryu Subgroup with *Inoceramus*. The age of the upper limit of the Kuzuryu Subgroup is not clarified in detail.

Itoshiro Subgroup

Because the Itoshiro Subgroup consists mainly of non-marine deposits with few index fossils, it is difficult to correlate the formations. The lowest part of the Itoshiro Subgroup yields marine molluscan fossils at the Itoshiro River (*Vaugonia yambarensis*; Fig. 1-A) (Kobayashi, 1956) and Shokawa (belemnite; Fig. 1-F) districts (Kumon and Umezawa, 2001). Recently, *Inoceramus* sp. cf. *I. maedae*, hitherto described as Jurassic species, was collected from the Kamihambara Formation in the east of Izumi (Fig. 1-D) (Fujita et al., 1998). Goto (2001) reported Late Hauterivian to Early Barremian ammonoid from the Itoshiro Subgroup in the Uchinami district (Fig. 1-C). The formation yielding the ammonoid would correspond to the Kamihambara Formation. The lower part of the Kuwajima Formation (Fig. 1-H) yields brackish to marine molluscan fossils such as *Crassostrea* sp., *Isognomon* sp., and *Tetoria yokoyamai* (Tamura, 1990). A dentary of fish (Pachycormidae) (Yabumoto, 2000) and limuloid tracks (*Kouphichnium* isp.) (Matsuoka et al., 2001a), which indicate influences of marine conditions, are reported from the Kuwajima Formation (Fig. 1-H). This marine influenced horizon could be correlated widely within the Itoshiro Subgroup as maximum transgressive phase (Kamihambara stage). The upper part of the Kuwajima Formation yields freshwater molluscan fossils as *Nippononaia tetoriensis*, *Nagdongia soni* (Maeda, 1958a, 1962d; Tamura, 1990). *Myopholas* sp. cf. *M. semicostata* is collected from a float of the Itsuki Formation (Fig. 1-D) (Fujita, 2002), which has been reported from the Ryoseki Formation of the Monobegawa Group and its correlatives (Tashiro, 1994). The Itsuki (Fig. 1-A, C, D), Kuwajima, and upper part of the Okurodani Formations are correlated with the Hauterivian Ryoseki Formation of the Monobegawa Group in the Outer Zone of Southwest Japan on the basis of the bivalve fauna (Tatsukawa type fauna) which is characterized by *Hayamina naumani–Unio ogamigoensis* Assemblage (Kozai et al., 2002).

Tochio Formation in the Tochio district (Fig. 1-K) yields non-marine molluscan fossils (*Isodomella shiroiensis*, *Paracorbicula sanchuensis*), which represent the "Ryoseki Fauna" in the Outer Zone of Southwest Japan (Maeda, 1958b, 1959; Matsumoto et al., 1982). It should be correlated with the Hauterivian Ryoseki Formation. This fauna is not found in other parts of the Tetori Group.

Zircon fission-track (FT) data was reported as 135±7 Ma for the crystal tuff of the Okurodani Formation (Fig. 1-F) (Gifu-ken Dinosaur Research Committee, 1993) and 128±8 Ma for tuffaceous sandstone of the Nakanomatanokkoshi sandstone in the Kamioka district (Fig. 1-N) (Gifu-ken Dinosaur Fossil Excavation Party, 1998).

The Itoshiro Subgroup overlies the Kuzuryu Subgroup unconformably in the areas, such as Itoshiro and Mana River, Uchinami River, Jinzu River, and Arimine districts (Fig. 1), while sedimentation succeeded from Middle Jurassic to Early Cretaceous without unconformity in the Shokawa district. Thus the age of the lower part of the Itoshiro Subgroup might be different in each district (Fig. 2). In the case of unconformable contact, the base of the Itoshiro Subgroup it is assigned tentatively to the base of the Ryoseki Formation, as suggested by Tashiro and Okuhira (1993).

Akaiwa Subgroup

The Akaiwa Subgroup overlies the Itoshiro Subgroup conformably in all districts (Fig. 1).

The lower part of the Akaiwa Subgroup is barren of fossils except for some dinosaur footprints. The Kitadani Formation (Fig. 1-H, I) of the uppermost part of the Akaiwa Subgroup yields some non-marine molluscan fossils reliable for determining geological age. The Kitadani non-marine fauna has an affinity with that of the Lower Cretaceous Naktong–Wakino series which is distributed in South Korea and North Kyushu (Maeda, 1962a). The non-marine molluscan fossils include so-called TPN elements such as *Trigonioides* (*Wakinoa*) *tetoriensis*, *Plicatounio naktongensis*, *Nagdongia soni*, *Pseudohyria matsumotoi*, and *Nippononaia tetoriensis* (Tamura, 1990). Tashiro and Okuhira (1993) reported *Trigonioides* (*Wakinoa*) *tetoriensis*, which is characteristic species of the TPN fauna, from the upper part of the Tatsukawa Formation of the Monobegawa Group, and suggested that TPN fauna be found in Late Hauterivian to Barremian (Fig. 2). Isaji (1993) reported *Nippononaia ryosekiana*, which indicates Late Barremian to Early Aptian in age, from the Kitadani Formation. *N. ryosekiana* is a characteristic species of the Late Barremian Sebayashi type fauna of the Monobegawa Group in the Outer Zone of Southwest Japan (Kozai et al., 2002). Thus it is likely that the Kitadani Formation could be assigned to Barremian in age on the basis of occurrences of *N. ryosekiana* and TPN fauna.

In recent years, absolute age of tuffaceous rock has been determined in several districts. Zircon FT ages were obtained as 127±8 Ma and 106±7 Ma for tuffaceous rocks of the Bessandani Formation (Fig. 1-F) (Gifu-ken Dinosaur Research Committee, 1993). FT data, which was measured on zircon crystals separated from tuffaceous sandstone of the Wasabu alternation in the Kamioka district (Fig. 1-N), indicates 119±6 Ma (Gifu-ken Dinosaur Fossil Excavation Party, 1996) and 125±10 Ma (Gifu-ken Dinosaur Fossil Excavation Party, 1997). Board of Education of Toyama Prefecture (2003) reported a fission track age of 113±6 Ma (Aptian–Early Albian) for greenish tuff which covers the footprint horizon at the dinosaur footprint site of the Jinzu River district in Ohyama Town (Fig. 1-L). The upper part of the Akaiwa Subgroup is characterized by intercalation of the same kind of greenish tuff in the Hakusan and Jinzu regions. Therefore, the strata yielding footprints would correspond to the Upper Akaiwa Subgroup both chronologically and lithologicaly, though Matsukawa et al. (1997b) regarded the same strata as the Itoshiro Subgroup (Inotani alternation of the Nagatogawa Formation). The Shiroiwagawa Formation also contains reddish or greenish tuff in the Kamiichi River district (Fig. 1-O). The dinosaur track site in Ohyama is regarded tentatively as the Wasabu alternation in this paper, in spite of that there is no strata corresponding to the Shiroiwagawa Formation in the Jinzu River district.

Recently carbon-isotope stratigraphy was applied to the study of the Tetori Group (Hasegawa and Yoshida, 1999). According to them, the Minamimatadani conglomerate and lower part of the Wasabu alternation in the Kamiichi River district are Kimmeridgian to early Tithonian in age, and the middle part of the Wasabu alternation is younger than Berriassian. These data is not concordant with the age obtained from other methods.

The Tetori Group is overlain or intruded by around 100 Ma volcanic or plutonic rocks (Gifu-ken Dinosaur Research Committee, 1993; Tanase et al., 1994; Shibata and Uchiumi, 1995; Gifu-ken Dinosaur Fossil Excavation Party, 1997; Tomioka et al., 2000; Yamada et al., 2001).

AGE OF VERTEBRATE FOSSIL-BEARING HORIZONS OF THE TETORI GROUP

Kuzuryu Subgroup

A reptile skeleton (*Tedorosaurus asuwaensis*) was found from the Sakaidera Formation in the Asuwa district (Fig. 1-B) (Shikama, 1969). The Sakaidera Formation is correlated with the Callovian Kaizara Formation of the Kuzuryu Subgroup (Maeda, 1961a). This is only record of terrestrial vertebrate from the Kuzuryu Subgroup. Recently, marine plesiosaur(?) tooth was reported from the Kiritani alternation, which is assigned to the Oxfordian, in the Jinzu River district (Fig. 1-L) (Board of Education of Toyama Prefecture, 2003).

Itoshiro Subgroup

The oldest bird tracks (*Aquatilavipes izumiensis*) in Asia were collected from the Itsuki Formation (Fig. 1-A) (Azuma et al., 2002). Manabe (1999) reported a tyrannosaurid tooth from the same formation (Fig. 1-D).

Abundant vertebrate remains including dinosaur were

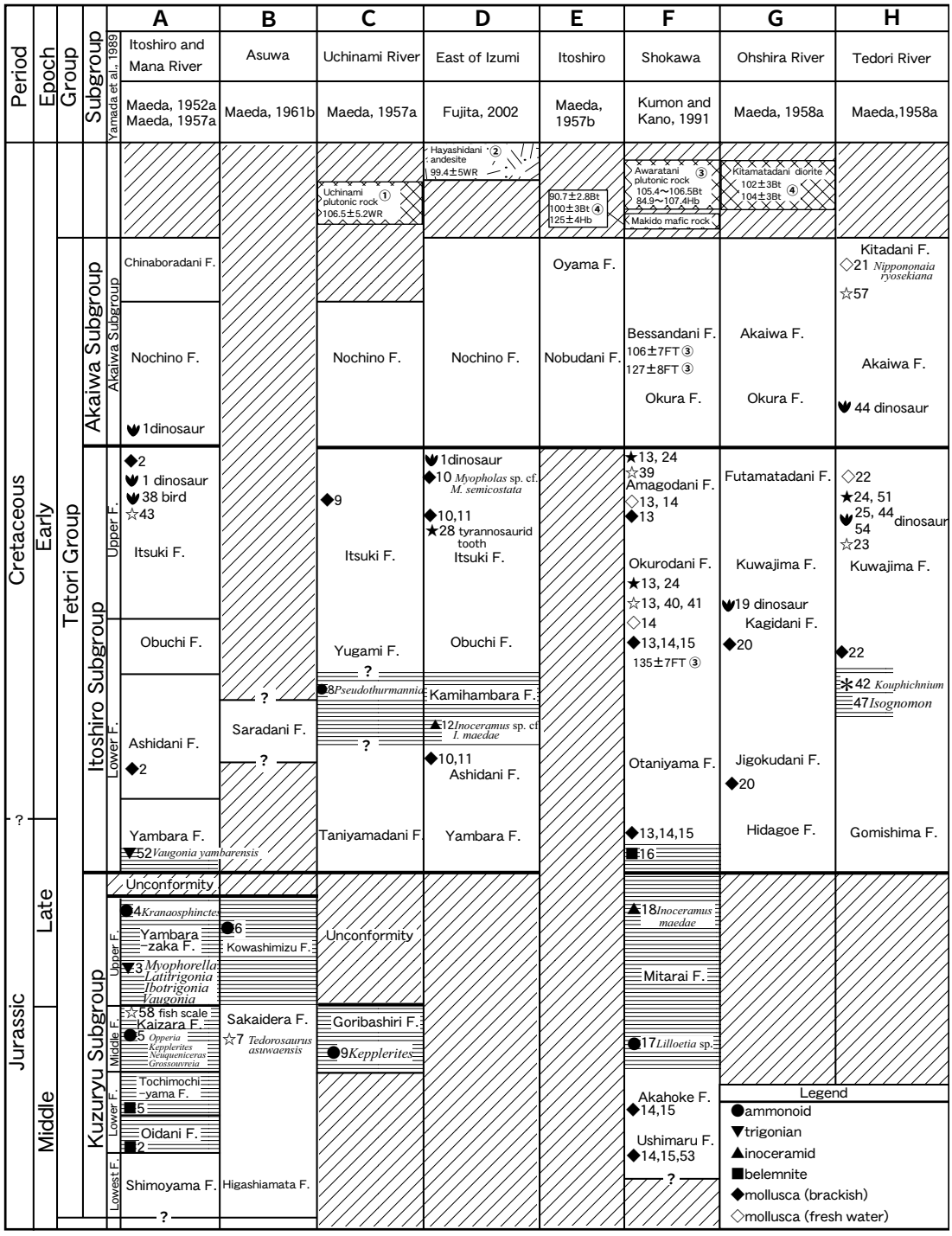
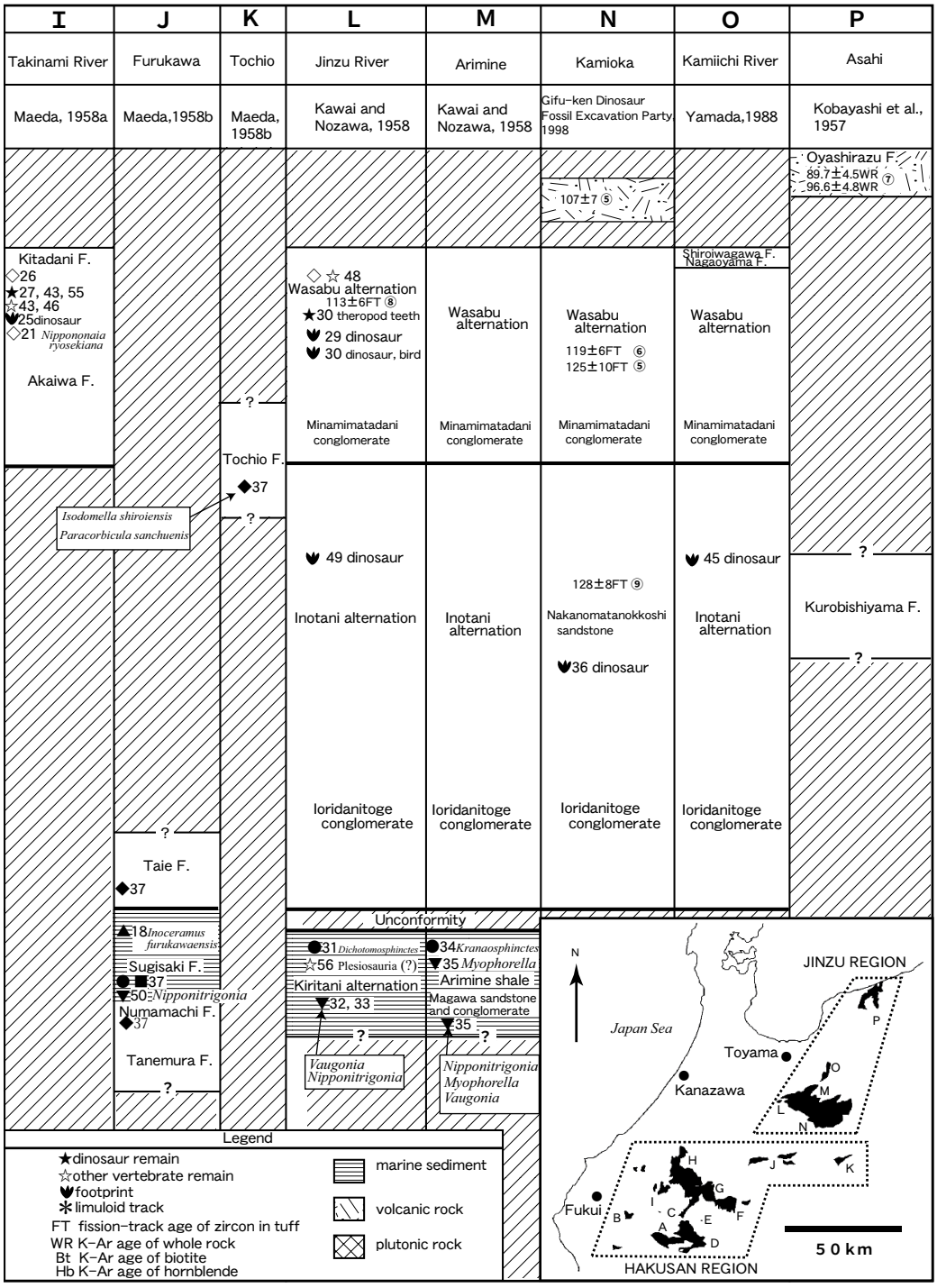


FIGURE 1. Stratigraphy and correlation of the Tetori Group. The references are given below.
1: Azuma et al. (1992), 2: Maeda (1952a), 3: Kobayashi (1957a, b), Maeda (1963a), 4: Maeda (1952a), Sato et al. (1963), 5: Sato et al. (1963), 6: Maeda and Hori (1950), 7: Shikama (1969), 8: Goto (2001), 9: Maeda (1957a), 10: Fujita (2002), 11: Maeda (1957c), 12: Fujita et al. (1998), 13: Gifu-ken Dinosaur Research Committee (1993), 14: Matsukawa and Nakada (1999), 15: Maeda (1952b), 16: Kumon and Umezawa (2001), 17: Sato and Kanie (1963), 18: Hayami (1960), 19: Kunimitsu et al. (1990), Shikano et al. (2001), 20: Maeda (1958a), 21: Isaji (1993), 22: Maeda (1958a), 23: Evans and Manabe (2000), Hirayama (2000), Manabe et al. (2000), Matsuoka (2000), 24: Hasegawa et al. (1995), 25: Azuma and Takeyama (1991), 26: Maeda (1962a; 1963b), 27: Azuma and Currie (2000), 28: Manabe (1999), 29: Matsukawa et al. (1997), 30: Toyama Dinosaur Research Group (2002), 31: Maeda (1958c), 32: Kobayashi (1957b), 33: Maeda (1962c), 34: Maeda and Takenami (1957), 35: Maeda (1966), 36: The Gifu-ken Dinosaur Fossil Excavation Party (1999), 37: Maeda (1958b), 38: Azuma et al. (2002), 39: Unwin et al. (1996),



40: Evans and Manabe (1999), 41: Cook et al. (1998), 42: Matsuoka et al. (2001a), 43: Azuma and Tomida (1995), 44: Azuma et al. (1991), 45: Goto (1993), 46: Kobayashi (1998), 47: Tamura (1990), 48: Shigeno (in press), 49: Matsukawa et al. (2002), 50: Maeda (1962b), 51: Manabe et al. (2000a), Barrett et al. (2002), 52: Maeda (1963a), 53: Komatsu et al. (2002), 54: Matsuoka et al. (2001b), 55: Kobayashi and Azuma (2003), 56: Board of Education of Toyama Prefecture (2003), 57: Hirayama (2002b), Yabumoto (2002), 58: Yasuno (1994).
① Tomioka et al. (2000), ② Tanase et al. (1994), ③ Gifu-ken Dinosaur Research Committee (1993), ④ Shibata and Uchiumi (1995), ⑤ Gifu-ken Dinosaur Fossil Excavation Party (1997), ⑥ Gifu-ken Dinosaur Fossil Excavation Party (1996), ⑦ Yamada et al. (2001), ⑧ Board of Education of Toyama Prefecture (2003), ⑨ Gifu-ken Dinosaur Fossil Excavation Party (1998)

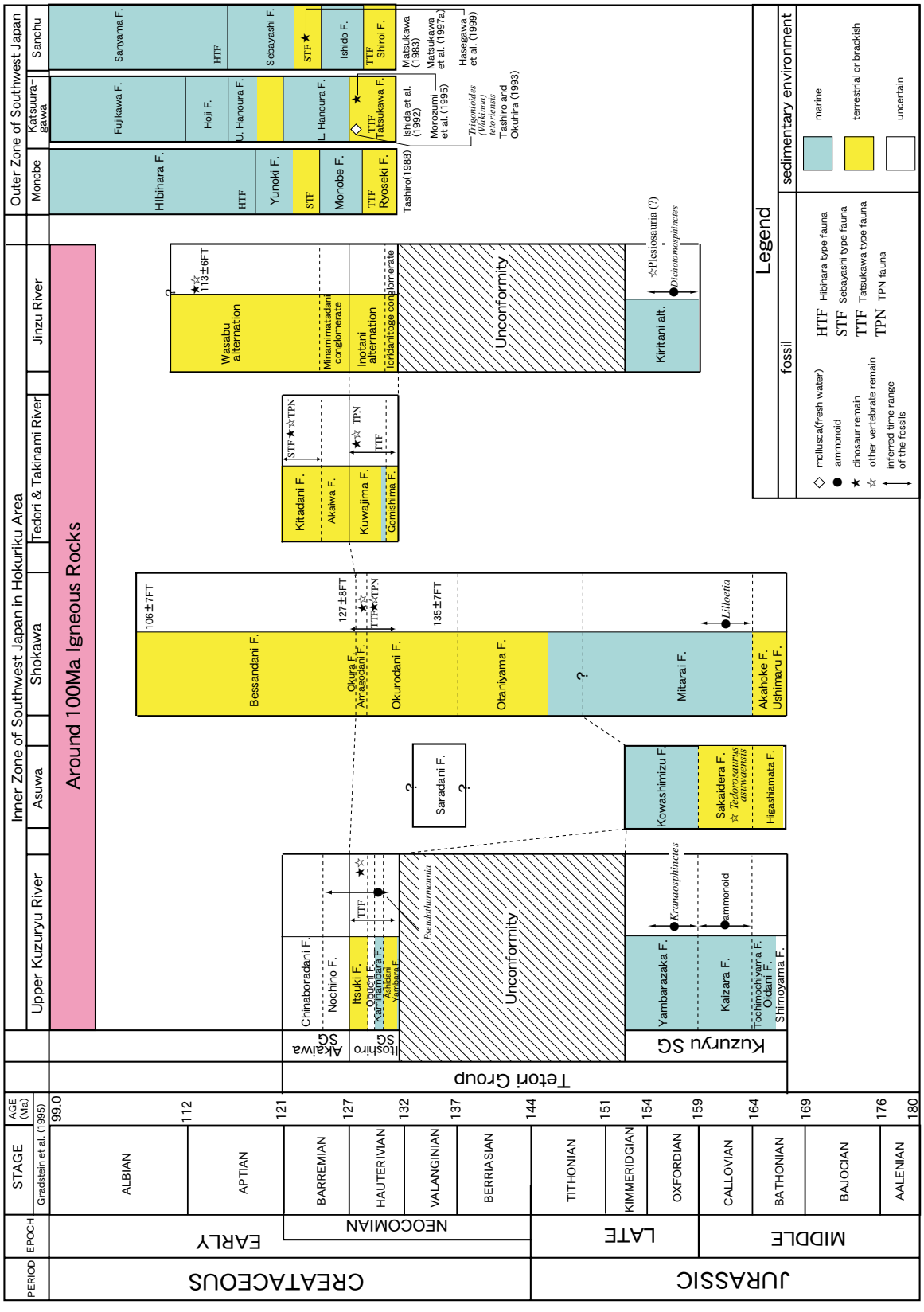


FIGURE 2. Tentative geological age and correlation of the Tetori Group, compared with the strata of the Outer Zone of Southwest Japan.

discovered from the Okurodani Formation (Fig. 1-F) (Gifu-ken Dinosaur Research Group, 1992; Gifu-ken Dinosaur Research Committee, 1993; Hasegawa et al., 1995; Evans et al., 1998; Evans and Manabe, 1999) and Amagodani Formation (Fig. 1-F) (Gifu-ken Dinosaur Research Group, 1992; Gifu-ken Dinosaur Research Committee, 1993; Unwin et al., 1996).

The Kuwajima Formation (Fig. 1-H) also yields various vertebrate remains (birds, dinosaurs, pterosaurs, mammal-like reptiles, mammals, lizards, turtles, amphibians, and fishes) (Hasegawa et al., 1995; Evans and Manabe, 2000; Hirayama, 2000; Manabe et al., 2000a; Manabe et al., 2000b, Matsuoka, 2000; Unwin and Matsuoka, 2000; Yabumoto, 2000; Matsuoka et al., 2002；Barrett et al., 2002) and dinosaur footprints (Azuma and Takeyama, 1991; Azuma et al., 1991; Matsuoka et al., 2001b).

Shikano et al. (2001) reported dinosaur footprints, which are identified as ornithopods, from the Kagidani Formation in Shirakawa Village (Fig. 1-G). Dinosaur footprints were discovered from the Inotani alternation in the Joganji River district (Fig. 1-O) (Goto, 1993), Kamioka (Fig. 1-N) (Gifu-ken Dinosaur Fossil Excavation Party, 1999), and Hosoiri (Fig. 1-L) (Matsukawa et al., 2002).

Akaiwa Subgroup

Dinosaur footprints were found in the Nochino formation (Fig. 1-A) (Azuma et al., 1992) and Akaiwa Formation (Fig. 1-H) (Azuma et al., 1991).

Abundant vertebrate remains (plesiosaurs, turtles, crocodiles, dinosaurs, and fishes) were obtained from the Kitadani Formation (Fig. 1-H, I) (Azuma and Tomida, 1995; Azuma and Currie, 2000; Goto et al., 2002; Hirayama, 2002a, b; Yabumoto, 2002, Kobayashi and Azuma, 2003).

Dinosaur and/or bird footprints and theropod teeth were discovered at the Ohyama Town (Fig. 1-L) (Matsukawa et al., 1997b; Toyama Dinosaur Research Group, 2002). As mentioned above, the strata may correspond to the Upper Akaiwa Subgroup. Turtle carapaces and fish scales were obtained from the Wasabu alternation of this district (Shigeno, in press).

Azuma (1991) proposed the Tetori dinosaur fauna, which consists of the Shiramine dinosaur fauna from the Itoshiro Subgroup and the Katsuyama dinosaur fauna from the Akaiwa Subgroup. There are at least two horizons yielding dinosaur remains in the Tetori Group as well as the Lower Cretaceous in the Outer Zone of Southwest Japan during Hauterivian to Barremian (Fig. 2). Dinosaur fossil found in the Wasabu alternation in Ohyama Town (Fig. 1-L) may be younger than those of the Kitadani Formation, based on the absolute age (113±6 Ma) (Board of Education of Toyama Prefecture, 2003) (Fig. 2). If it is true, this indicates third horizon containing dinosaur materials in the Tetori Group, which may be time-equivalent to the Miyako Group (late Aptian–early Albian), northeast Japan (Hasegawa et al., 1991).

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* : in Japanese with English abstract

** : in Japanese

＜ 地 名 ＞

Akahoke ……赤歩危
Akaiwa ……赤岩
Amagodani……アマゴ谷
Arimine ……有峰
Asahi ……朝日
Ashidani ……葦谷
Asuwa ……足羽
Bessandani ……別山谷
Chinaboradani ……智那洞谷
Furukawa……古川
Futamatadani ……二又谷
Gomishima ……五味島
Goribashiri ……ゴリバシリ
Hakusan ……白山
Hidagoe ……飛騨越
Inotani ……猪谷
Ioridanitoge……庵谷峠
Itoshiro ……石徹白
Itsuki ……伊月
Izumi ……和泉
Jigokudani ……地獄谷
Jinzu River ……神通川
Joganji River ……常願寺川
Kagidani ……カギ谷
Kaizara ……貝皿
Kamihambara ……上半原
Kamioka ……神岡
Katsuyama ……勝山
Kiritani ……桐谷
Kitadani……北谷
Kuwajima ……桑島
Kuzuryu ……九頭竜
Mana River ……真名川
Minamimatadani ……南俣谷
Mitarai ……御手洗
Monobegawa ……物部川
Myodani ……明谷
Nagaoyama……長尾山
Nakanomatanokkoshi ……中俣乗越
Naktong ……洛東
Nochino ……後野
Numamachi ……沼町
Obuchi ……大淵
Oidani……大井谷
Okura ……大倉
Oshira River ……大白川
Ryoseki ……領石
Sakawa ……佐川
Sebayashi ……瀬林
Shokawa ……荘川
Sugisaki ……杉崎
Taie ……太江
Takinami River ……滝波川
Tanemura ……種村
Taniyamadani ……谷山谷
Tatsukawa ……立川
Tedori River ……手取川
Tochimochiyama ……栃餅山
Tochio……栃尾
Uchinami River ……打波川
Ushimaru ……牛丸
Yambara ……山原
Yambarazaka ……山原坂
Yugami ……湯上
Wasabu ……和佐府
Wakino ……脇野