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A revised Barremian–Aptian age for the Mitarai Formation (lower Tetori Group, Makito area of central Japan), previously considered Middle Jurassic–earliest Cretaceous

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The Tetori Group of central Japan, dated in the past as Middle Jurassic–Early Cretaceous, has been widely used in correlation and even for dating Asian non-marine Late Mesozoic strata, because it is composed of marine and non-marine deposits, containing marine molluscs and various non-marine fossils. However, when comparing the marine bivalve faunas, four out of 11 species previously recorded from the Mitarai Formation (a critical formation in determining the age of the Tetori Group) of the lower Tetori Group in the Makito/Shokawa area of northern Gifu Prefecture, central Japan (i.e., Palaeonucula makitoensis (Hayami) Entolium inequivalve Hayami, Thracia shokawensis Hayami, and Pleuromya hidensis Hayami) could be recognized from the Barremian–Aptian Qihulin and Yunshan formations of the Longzhaogou Group in the Yunshan area of eastern Heilongjiang, NE China. These formations yield Barremian ammonites and the global late Barremian–middle Albian (mainly Aptian) index Aucellina caucasica–Aucellina aptiensis assemblage, suggesting that the Japanese Mitarai Formation is late Early Cretaceous (Barremian–Aptian, mainly Barremian) rather than Middle Jurassic or Late Jurassic–earliest Cretaceous in age, and implying that the basal formation of the Tetori Group, the Ushimaru Formation, conformably overlain by the Mitarai Formation, is likely to be no older than Hauterivian.

Introduction

The Tetori Group is widely distributed in the regions of Hakusan and Jinzu in the Inner Zone of Southwest Japan (e.g., Maeda, 1952, 1961; Hayami and Yoshida, 1991a, b; Kusuhashi et al., 2002, 2006; Fujita, 2003 and references therein; Matsukawa et al., 2006; Matsukawa and Fukui, 2009). It consists, in ascending order, of the

Kuzuryu Subgroup/lower Tetori Group, Itoshiro Subgroup/middle Tetori Group, and Akaiwa Subgroup/upper Tetori Group, and formerly was dated as the Bathonian (Middle Jurassic) (e.g., Hayami and Yoshida, 1991a), Bajocian (Matsukawa and Ido, 1993)–Early Cretaceous Aptian (e.g., Hayami and Yoshida, 1991b; Fujita, 2003), and even as young as Albian (e.g., Matsukawa et al., 2006) in age. It has been widely used in correlation of Upper Mesozoic strata across parts of Asia, particularly in correlating and dating the non-marine Late Mesozoic strata, because it is composed of marine and non-marine deposits and yields both marine fossils including ammonites (e.g., Sato and Kanie, 1963; Sato et al., 2003, 2008), brachiopods, and bivalves, as well as various non-marine macro- and microfossils, including dinosaurs, molluscs, insects, plants, charophytes, and sporopollen (e.g., Maeda, 1952, 1961, 1962; Hayami, 1959a, b, 1960, 1975; Matsukawa and Nakada, 1999; Kusuhashi et al., 2002; Fujita, 2003; Umetsu and Matsuoka, 2003; Matsukawa et al., 2003, 2006; Sano et al., 2008; Yamada and Uemura, 2008; Matsukawa and Fukui, 2009), particularly trigonoidid bivalves, which are widely distributed in Asia and parts of Europe (Sha, 2007a, 2010).

The depositional history of the group varies across the basins/areas. In the Makito (= Makido)/Shokawa area of northern Gifu Prefecture, located in the eastern part of the Hakusan Region (Fig. 1 A, C; fig. 1 F in Fujita, 2003), the Tetori Group unconformably rests on basement rocks consisting of the Hida Metagranites older than 200 Ma, and underlies the Nohi Rhyolite, which is less than 100 Ma old (Kusuhashi et al., 2006). There are different subdivision schemes of the Tetori Group for the numerous small sedimentary basins (e.g., Matsukawa and Nakada, 1999; Matsukawa et al., 2003; Kusuhashi et al., 2006; Sano et al., 2008). All the formations have conformable contacts except the Okura Formation of the Akaiwa Subgroup, which unconformably, disconformably or conformably overlies the Amagodani Formation (Kusuhashi et al., 2002) (Fig. 1 C).

The Mitarai Formation, the upper formation of the Kuzuryu Subgroup, is composed of fine-grained sandstones, black arenaceous shales, and a layer of acidic tuffaceous siltstones, presumably deposited in a calm inland sea of moderate depth (Hayami, 1959a). It yields ammonites (e.g., Sato and Kanie, 1963; Sato et al., 2003, 2008) and marine bivalves (e.g., Hayami, 1959a, b, 1960, 1975; Matsukawa and Nakada, 1999). The Mitarai Formation is therefore a critical unit for dating the Tetori Group.

Figure 1. Correlated areas (marked by three five-pointed stars in (A) and litho- and biostratigraphy of the Longzhaogou Group in the Yunshan area and the Jixi Group in the Jixi Basin of eastern Heilongjiang Province, NE China (B), and of the Tetori Group in the Makito/Shokawa area of northern Gifu Prefecture, central Japan (C).

The deposits below and above the Mitarai Formation all contain marine to brackish-water and/or non-marine (brackish-, freshwater, and terrestrial) fossils. The Ushimaru Formation, the basal formation of the Tetori Group, and the Otaniyama and Okurodani formations of the Itoshiro Subgroup/middle Tetori Group all contain a marine to brackish-water bivalve assemblage with *Myrene* (*Mesocorbula*) *tetoriensis* (Kobayashi et Suzuki) and *Tetoria* (*Tetoria*) *yokoyamai* (Kobayashi et Suzuki). The Okurodani Formation of the upper middle

Tetori Group yields a non-marine assemblage with the bivalves *Unio?* *ogamigoensis* (Kobayashi et Suzuki), *Nakamuraia chingshanensis* (Grabau) (= *Nagdongia soni* Yang), *Nippononai tetoriensis* Maeda, and *Sphaerium coreanicum* Kobayashi et Suzuki, and the gastropod *Viviparus onogoensis* Kobayashi et Suzuki, which are widely distributed in Asia, especially in East Asia. However, the Akaiwa Subgroup/upper Tetori Group only contains a few plant fossils (e.g., Maeda, 1962; Kushuhashi, et al., 2002; Matsukawa et al., 2003).

Sato and Kanie (1963) described the Callovian ammonite *Lilloetia* sp. from the Mitarai Formation. The bivalve fauna from the formation was suggested to be Late Jurassic in age by Hayami in 1959a, b and 1960, and then Callovian in 1975. Thus, the Mitarai Formation and the Kuzuryu Subgroup/lower Tetori Group were confirmed and widely accepted by geoscientists as being Middle–Late Jurassic in age (e.g., Hayami and Yoshida, 1991a; Fujita, 2003). However, 40 years later, when a larger collection of ammonites became available, Sato et al. (2003) revised the ammonite fauna to represent the topmost Jurassic–basal Cretaceous and dated the Mitarai Formation as latest Tithonian–earliest Berriasian (spanning the Jurassic–Cretaceous boundary). This view was followed by some palaeontologists (e.g., Matsukawa et al., 2006; Matsukawa and Fukui, 2009). In 2008, Sato et al. discovered the ammonite *Neocosmoceras* sp. (cf. *N. hunevciense*) from Mitarai (Gifu Prefecture), and assigned the ammonite-bearing strata of the Mitarai Formation to the Berriasian.

The present authors suggested a Barremian–Aptian age for the bivalve fauna of the Mitarai Formation of the Makito/Shokawa area while studying the bivalve collections kept in the Tokyo University Museum in 2007 (manuscript by Sha and Hirano), and Professor Hayami (pers. comm., 2007) thought the age should be changed from the Callovian to the earliest Cretaceous. We compared the bivalve specimens from the Mitarai Formation, kept in the Tokyo University Museum, with those collected from the Longzhaogou and Jixi groups of eastern Heilongjiang Province, northeastern China

(Fig. 1 A, B) and figured by Gu et al. (1997). Four species of the Mitarai Formation bivalve fauna from the Mitarai Formation could be recognized from the Barremian–Aptian Qihulin and Yunshan formations of the Longzhaogou Group of the Yunshan area, eastern Heilongjiang Province, NE China. They suggest that the Mitarai Formation is Barremian–Aptian, younger than Hauterivian, in age, and imply that the Tetori Group is unlikely to be older than Hauterivian in the Makito/Shokawa area.

Comparison of the bivalve faunas between the Mitarai Formation of Central Japan and the Qihulin and Yunshan formations of NE China

Although the bivalve fauna from the Mitarai Formation of Central Japan comprises 20 taxa, only 11 of them could be identified at the species level (Hayami, 1959a, b, 1960, 1975). Among them, the following four species, which are briefly described and discussed below, could be easily recognized also from the Qihulin and Yunshan formations of the Longzhaogou Group of the Yunshan area, eastern Heilongjiang, NE China, though they were figured as different species (Fig. 2).

Palaeonucula makitoensis (Hayami) (Fig. 2a–d)

This species was established by Hayami in 1959a (pp. 143–145, pl. 12, figs. 4–6) based on specimens from the Mitarai Formation of the Makito/Shokawa area, northern Gifu Prefecture. It is characterized by its small size, inequilateral but equivalve shell, rounded subtriangular outline and smooth (except for fine commarginal growth lines) (e.g., Fig. 2c, d). This species was referred to the genus *Nuculopsis* by Hayami in 1959a, and named both as *mitaraiensis* (p. 143) and as *makitoensis* (explanation of plate 12, figs. 4–6). However, in 1975 (p. 20), Hayami chose *makitoensis* rather than *mitaraiensis* because he thought the latter was erroneously spelled, which is accepted in the present article.

The specimens referred to *Palaeonucula* cf. *makitoensis* (Hayami) from the Qihulin and Yunshan formations of the Longzhaogou Group of Yunshan area, eastern Heilongjiang (Gu et al., 1997, pp. 7–8, pl. 1, figs. 8–12, synonyms of Late Mesozoic bivalves from eastern Heilongjiang listed on p. 7), are very similar to the Japanese ones in all aspects of size, outline, and ornamentation (Fig. 2a, b).

Entolium inequivalve Hayami (Fig. 2e–h)

The Japanese specimens of *Entolium inequivalve* are medium-sized for the genus *Entolium*, inequivalve but subequilateral, and suborbicular in outline. It is characterized by concentric grooves and numerous feeble commarginal growth lines between grooves on the right, but only commarginal growth lines on the left shell surface (e.g., Fig. 2g, h). The species comes from the Mitarai Formation (Hayami, 1959b, pp. 154–156, pl. 13, figs. 3–8; 1975, p. 72, pl. 3, fig. 2) and probably extends upwards into the Otaniyama Formation of the Itoshiro Subgroup/middle Tetori Group (Matsukawa and Nakada, 1999).

Compared with the Japanese species, the concentric grooves and commarginal growth lines of *Entolium extensum* Li et Yu figured by Gu et al. (1997, pp. 78–80, pl. 9, figs. 14–19, pl. 10, figs. 1–9) from the Qihulin and Yunshan formations are weaker (e.g., Fig. 2e, f). However, such a difference falls most likely within intraspecific variation. The Chinese taxon is, therefore, regarded as conspecific with Japanese *Entolium inequivalve* Hayami (Fig. 2g, h).

Thracia shokawensis Hayami (Fig. 2i–l)

This taxon was established by Hayami in 1959b (pp. 162–163,

pl. 13, figs. 17–19) based on fossils from the Mitarai Formation. It is medium- to small-sized for the genus *Thracia*, much longer than high, inequilateral, and subrectangular in outline with a slightly rostrate posterior margin. The left valve is slightly larger than the right one, the shell surface is marked with numerous fine commarginal growth lines and irregular commarginal undulations are impressed on the inner surface (Fig. 2k, l).

The specimens of *Thracia yunshanensis* Yu et Li and *Thracia* cf. *phillipsi* Römer figured by Gu et al. (1997, pp. 237–238, pl. 37, figs. 4–10; pp. 240–241, pl. 38, figs. 10–18) from the Qihulin and Yunshan formations (Fig. 2i, j) are identical to those of *Thracia shokawensis* from Japan (Fig. 2k, l).

Pleuromya hidensis Hayami (Fig. 2m–p)

According to Hayami (1959b, pp. 158–159, pl. 13, figs. 12, 13), this taxon is medium- to small-sized for the genus *Pleuromya*, with an equivalve but inequilateral shell, ca. 1.5 times longer than high, and subrounded subtrapezoidal in outline. The posterodorsal margin is distinctly subtruncated, the umbones are placed at one-quarter to two-sevenths of shell length from the anterior end, and the shell is very thin. The shell surface is smooth except for several irregularly-spaced commarginal folds and numerous faint commarginal growth lines (Fig. 2o, p).

Pleuromya sp. nov.? 2 figured by Gu et al. (1997, pp. 235–236, pl. 38, figs. 8, 9) from the Yunshan Formation is identical to *Pleuromya hidensis* except that in the former the commarginal growth folds are stronger than in the latter. Such a distinction is most probably a preservation feature and/or represents intraspecific variation.

Stratigraphic significance

From a biostratigraphic point of view, the Mitarai Formation of the lower Tetori Group of the Makito/Shokawa area could be correlated with the Qihulin and Yunshan formations of the Longzhaogou Group of the Yunshan area, eastern Heilongjiang Province, judging from the four species described above, which are common to both areas.

In eastern Heilongjiang, the Longzhaogou Group in the Yunshan area is correlated with the Jixi Group, which consists of coal measures intercalated with marine deposits in the Jixi Basin (Fig. 1 A, B). It is composed of alternating marine and non-marine coal-bearing strata yielding various marine and non-marine macro- and microfossils, unconformably overlying Permian strata or older granitic basement rocks, and disconformably overlain by the Huashan Group containing the Albian bivalves *Trigonioides* (*T.*) *heilongjiangensis* Sha et Gu and *Sphaerium coreanicum* Kobayashi et Suzuki. In ascending order, this group comprises the Peide, Qihulin, Yunshan and Zhushan formations (Fig. 1 B). The Peide Formation consists of non-marine deposits with peats and coals; the Qihulin Formation is mainly composed of littoral and sub-littoral rocks with coals; the Yunshan Formation comprises marine and non-marine strata with coals; and the Zhushan Formation consists of interbedded non-marine and marine deposits, yielding coals (e.g., Sha, 1990, 1991, 2007b; Sha et al., 1994, 2002, 2007, 2008).

The Qihulin Formation has been assigned a Barremian age based on the presence of the Barremian–Aptian ammonites *Pseudohaploceras* and *Silisites* group (Sha et al., 1994), *Phyllopachyceras* sp., and *Pseudohaploceras* cf. *liptoviense* (Zeuschner) (Futakami et al., 1995), and the bivalves *Filosina subovalis* Yao, J. Chen et Gu

Figure 2. Bivalve species common to the Qihulin and Yunshan formations of the Longzhaogou Group of Yunshan area, eastern Heilongjiang Province, NE China (a, b, e, f, i, j, m, n) and the Mitarai Formation of the lower Tetori Group of Makito/Shokawa, northern Gifu Prefecture, central Japan (c, d, g, h, k, l, o, p). Repositories: Specimens from China: Collection Department of the Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences (NIGPAS); Shenyang Institute of Geology and Mineral Resources of the Chinese Academy of Geological Sciences (BH); Japanese specimens: Tokyo University Museum (MM). Scale bar = 10 mm.

a–d: *Palaeonucula makitoensis* (Hayami). a: right internal mould, NIGPAS 81336; b: left composite mould, BH1176. They were described as *Palaeonucula* cf. *makitoensis* Hayami by Gu et al. (1997). c: right valve, MM3142 (paratype, figured by Hayami, 1959a, pl. 12, fig. 6a–b); d: left internal mould, MM3141 (holotype, figured by Hayami, 1959a, pl. 12, fig. 4).

e–h: *Entolium inequivalve* Hayami. e: right external mould, BH1062–2; f: right internal mould, BH1050–2. They were described as *Entolium extensum* Yu et Li by Gu et al. (1997). g: right external mould, MM3166 (holotype, figured by Hayami, 1959b, pl. 13, fig. 8); h: right internal mould, MM3168 (figured by Hayami 1959b, pl. 13, fig. 3).

i–l: *Thracia shokawensis* Hayami. i: right internal mould, BH0239; j: left valve, BH0724. These two specimens were described as *Thracia* cf. *phillipsi* Römer, and *Thracia yunshanensis* Yu et Li, respectively by Gu et al. (1997). k: steinkern, right side view, MM3188 (holotype, figured by Hayami, 1959b, pl. 13, fig. 17a–b); l: steinkern, left side view, MM3191 (paratype, figured by Hayami, 1959b, pl. 13, fig. 19).

m–p: *Pleuromya hidensis* Hayami. m: eroded left valve, NIGPAS82058; n: right internal mould, NIGPAS82060. They were described as *Pleuromya* sp. nov.? 2 by Gu et al. (1997). o, p: steinkern, o: left side view, p: right side view, MM3179 (holotype, figured by Hayami, 1959b, pl. 13, fig. 12a–b).

and *Thracia rotundata* (J. de C. Sowerby) (Sha et al., 2002, 2003; Sha, 2007b). Furthermore, it contains a dinocyst assemblage consisting of *Oligosphaeridium* spp., *Odontochitina operculata* (Wetzel), *Gardodinium trabeculosum* (Gocht) and *Palaeoperidinium cretaceum* (Pocock), which cannot be older than middle Barremian or younger than Aptian (Sha et al., 2003; Sha, 2007b).

The Yunshan Formation yields the *Aucellina* (A.) *caucasica*–A. (A.) *aptiensis*–*Filosina subovalis*–*Thracia rotundata* bivalve assemblage and the *Odontochitina operculata*–*Vesperopsis didaoensis* dinocyst assemblage (Sha, 1990, 1991, 1992a, b, 2002, 2007b; Sha and Fürsich, 1993, 1994; Sha et al., 1994, 2002, 2003, 2007, 2008, 2009). The *Aucellina* (A.) *caucasica*–A. (A.) *aptiensis* assemblage was widely distributed in the northern and southern hemispheres during the latest middle/late Barremian–middle Albian, but particularly in Aptian strata (Sha, 2012). The age of the concurrent-range-zone of *Aucellina*, *Filosina subovalis* (which extends downwards into the Qihulin Formation), *Thracia rotundata*, and *Odontochitina operculata* is Aptian (Sha and Fürsich, 1993; Sha et al., 1994, 2002, 2003, 2007, 2009; Sha, 2002, 2007b).

In summary, on the basis of the marine bivalve assemblage, the Qihulin and Yunshan formations range from the Barremian to Aptian (Sha, 1990, 1991, 1992a, b, 2002, 2007b; Sha and Fürsich, 1993, 1994; Sha et al., 1994, 2002, 2003, 2007, 2008, 2009), the corresponding Mitarai Formation is, therefore, most probably also Barremian–Aptian in age, even most probably mainly Barremian judging from the 129.8 ± 1.0 Ma U–Pb age measured from the zircon in the formation (Fig. 1 C) by Kusuhashi et al. (2006), but definitely not Callovian or Middle–Late Jurassic (e.g., Maeda, 1952, 1961; Hayami, 1959a, b, 1975; Sato and Kanie, 1963; Hayami and Yoshida, 1991a; Fujita, 2003; Matsukawa and Nakada, 1999) nor Tithonian–earliest Berriasian or Berriasian (e.g., Sato et al., 2003, 2008; Matsukawa et al., 2006; Matsukawa and Fukui, 2009).

The age of the strata/fossils below and above the Mitarai Formation, in fact the age of the whole Tetori Group in the Makito/Shokawa area, can be constrained by the Barremian–Aptian (mainly Barremian) age of the Mitarai Formation, as discussed below.

- (1) The basal strata of the Tetori Group, the Ushimaru Formation, conformably overlain by the Mitarai Formation and unconformably overlying basement rocks older than 200 Ma (Fig. 1, C) (Kusuhashi et al., 2006), is most likely not older than Hauterivian rather than Jurassic as previously proposed (e.g., Hayami, 1975; Hayami and Yoshida, 1991a; Matsukawa and Nakada, 1999; Fujita, 2003; Matsukawa et al., 2006; Matsukawa and Fukui, 2009), which has been confirmed by the 130.2 ± 1.7 Ma zircon U–Pb age measured from the tuff beds of the formation (Kusuhashi et al., 2006).
- (2) The Otaniyama Formation, the lower formation of the Itoshiro Subgroup/middle Tetori Group, conformably overlies the Mitarai Formation (Fig. 1 C). It is probably Barremian–Aptian age too, as it yields the typical marine bivalve *Entolium inequivalve* Hayami (Matsukawa and Nakada, 1999), extended from the underlying Mitarai Formation. Although there is no typical marine fossil in the Okurodani Formation, the upper formation of the Itoshiro Subgroup conformably overlies the Otaniyama Formation (Fig. 1 C). However, the 117.5 ± 0.7 Ma U–Pb age of the zircon in the formation indicates an Aptian age, and thus definitely younger than Barremian, rather than early or mainly early Early Cretaceous as proposed earlier (e.g., Fujita, 2003; Matsukawa et al., 2006; Matsukawa and Fukui, 2009).
- (3) Consequently, the Akaiwa Subgroup/upper Tetori Group, conformably overlying the Itoshiro Subgroup/middle Tetori Group, is likely Albian in age, and probably even extends upwards into the early Late Cretaceous, since it is sandwiched between the underlying Aptian Okurodani Formation and the overlying Nohi Rhyolite younger than 100 Ma (Fig. 1 C) (Kusuhashi et al., 2006).
- (4) The marine–brackish-water *Myrene* (*Mesocorbula*) *tetoriensis* and *Tetoria* (*Tetoria*) *yokoyamai* bivalve assemblage occurring in the Ushimaru, Otaniyama, and Okurodani formations of the lower and middle Tetori group has a fairly long range (Hauterivian–Aptian), but does not extend back to the Late Jurassic (as proposed earlier, e.g., Hayami, 1975). The non-marine molluscan assemblage of the bivalves *Unio?* *ogamigoensis*, *Nakamuranaia chingshanensis* (= *Nagdongia soni*), *Nippononaia tetoriensis* and *Sphaerium coreanicum*, and the gastropod *Viviparus onogoensis* appearing in the Okurodani Formation of the upper middle Tetori Group should be assigned an Aptian–Albian (mainly Aptian) age, definitely younger than Barremian, and thus could not be as early as latest Jurassic (as proposed earlier, e.g., Maeda, 1962).
- (5) As a result, the plant remains of the Akaiwa Subgroup/upper Tetori Group unconformably overlain by rhyolite younger than 100 Ma are presumably Albian or might be early Late Cretaceous.

Conclusion

To sum up, in the Makito/Shokawa area, the Mitarai Formation/upper lower Tetori Group is here referred to the Barremian–Aptian (mainly Barremian), the Otaniyama and Okurodani formations of the Itoshiro Subgroup/middle Tetori Group to the Barremian–Aptian and Aptian, respectively, and the Tetori Group to the Hauterivian–Albian, corresponding to the Longzhaogou Group. This Group is correlated with the Jixi Group of eastern Heilongjiang and the Jehol Group yielding the Jehol Biota of western Liaoning, NE China (Sha, 1990, 1991, 2002, 2007b; Sha and Fürsich, 1993; Sha et al., 2002, 2003, 2007), and the non-marine *Unio?* *ogamigoensis*, *Nakamuranaia chingshanensis* (= *Nagdongia soni*), *Nippononaia tetoriensis*, *Sphaerium coreanicum*, and *Viviparus onogoensis* molluscan assemblage, widely distributed in East Asia, is assigned an Aptian–Albian (mainly Aptian) age. These conclusions are backed by the zircon U–Pb ages measured by Kusuhashi et al. (2006) for the Ushimaru Formation (130.2 ± 1.7 Ma), the lowest formation of the Tetori Group, corresponding to late Hauterivian. The radiometric age of the Mitarai Formation is 129.8 ± 1.0 Ma, corresponding to the Barremian; and Okurodani Formation is 117.5 ± 0.7 Ma, corresponding to the Aptian.

Although these revised ages are mainly based on a comparison of marine bivalve faunas of the Mitarai Formation and the Qihulin and Yunshan formations, they will contribute to revising the correlation of strata, determining the age of non-marine beds, and particularly will contribute to a better palaeogeographical reconstruction and to understanding the evolution of Late Mesozoic sedimentary basins of Asia.

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