J. Paleont. Soc. Korea. Vol. 22, No. 1, (2006) : p. 119-132

EARLY CRETACEOUS FRESHWATER FISHES FROM JAPAN AND KOREA

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Abstract: The Early Cretaceous freshwater fish assemblages found in the Wakino Subgroup in northern Kyushu, Japan and the Nagdong Subgroup in southern Korea are the same in age, but different in depositional environment, because there is a common species, *Wakinoichthys aokii*, but other fishes differ. The Nagdong Subgroup was probably deposited near the sea, because of the existence of elopiform and albuiform fishes. The age of both subgroups may be slightly older than that of the localities of the *Mesoclupea-Paralycoptera* assemblage in southern China. The fish fossils from the Tetori Group are unique, somewhat earlier, and may support the gradual Jurassic-Cretaceous faunal transition hypothesized from the reptilian fossils, although evidence from these fish fossils is insufficient to confirm or deny the hypothesis.

Key words: Early Cretaceous, freshwater fishes, Japan, Korea

INTRODUCTION

Early Cretaceous freshwater fishes have been found from many localities in East Asia. Chang and Jin (1996) divided Early Cretaceous Chinese fishes into four groups: *Siyuichthys* fauna from Xinjiang; *Lycoptera* fauna from northern China, southeastern Mongolia and the Transbaikalian region of Russia; *Mesoclupea* fauna from southeastern China; and faunally grouped fish remains from Southwest China. Chang and Miao (2004) later included with the *Mesoclupea* fauna of Chang and Jin (1996) the fish remains from Southwest China, southern Korea and northern Kyushu, Japan in the *Mesoclupea-Paraclupea* assemblage.

Three freshwater fish assemblages have been found, the Wakino fish fauna and fishes from the Tetori Group, both in Japan, and one from the southern part of Korea (Fig. 1). In this study we describe these freshwater fish assemblages from Japan and Korea and their research status, and we discuss them in comparison to the Chinese fish fossil assemblages.

Institutional abbreviation – **DESRI**, Daegu Education and Science Research Institution; **KMNH VP,** Kitakyushu Museum of Natural History and Human History, Department of Vertebrate Paleontology; **KPE**, Earth Science Department of Kyungpook National University; **SBEI**, Museum of the Shiramine Board of Education, Shiramine, Japan.

COMPOSITION OF EARLY CRETACEOUS FRESHWATER FISH FAUNAS FROM JAPAN AND KOREA

WAKINO FISH FAUNA

The first record of Early Cretaceous freshwater fish from Japan (Ota, 1955), was from the Dobaru

Formation, Wakino Subgroup, Kanmon Group in southern Kokura, Kitakyushu City, Fukuoka. Ota (1957) further reported that fish fossils were abundant in the uppermost formation (Kumagai Formation) at Kokura.

In 1975, more fragments of fish fossils were found in the Kumagai Formation, and this led to two excavations by a team of geologists and paleontologists sponsored by Kitakyushu City in 1976 and 1977.

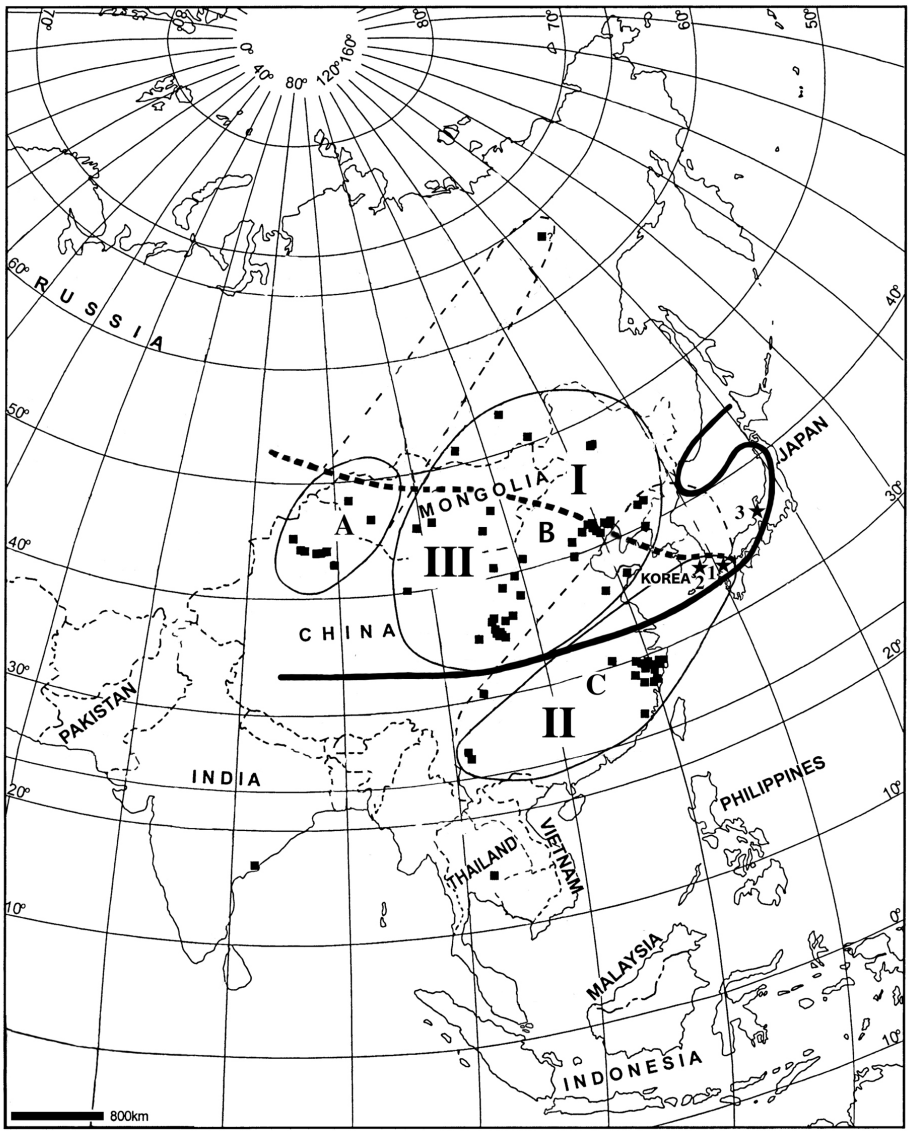

Fig. 1. Localities of the Early Cretaceous freshwater fishes in East Asia and areas of distribution of fish assemblages and flora types. Solid squares indicate fish localities. A, assemblage in Xinjiang, northwestern China and western Mogolia; B, The *Lycoptera-Peipiaosteus* Fauna or the "Jehol Fauna" C, *Mesoclupea-Paraclupea* assemblage. Continuous thin lines encircle the areas of distribution of fish assemblages, broken lines encircle possible additional portion of areas A and C (from Chang and Miao, 2004); broken and solid thick line denote floral regions, I, Tetori Type Flora; II, Ryoseki-Type Flora; III, Mix-Type Flora (from Kimura and Ohana, 1992). 1, locality of the Wakino fish fauna from the Wakino Subgroup in the Kanmon Group; 2, locality of the Nagdong Subgroup in the Geongsang Group; 3, locality of the Itoshiro Subgroup in the Tetori Group.

On the basis of the specimens from these excavations, two species of the genus *Diplomystus*, *D. primotinus* and *D. kokuraensis* were described by Uyeno (1979). In 1989, another fish fossil site, which belongs to the Dobaru Formation was found at Tokuriki, Kokuraminamiku, Kitakyushu City by Tateyu Aoki and Masahiro Sato. Naoki Kikuchi collected some specimens from another site in the same city, but belonging to the Gamo Formation. Thus fish fossils from Kitakyushu City have been found in three formations: (Dobaru, Gamo, and the Kumagai formations), from which twenty-one species, 8 genera and 6 families have been recognized (Yabumoto, 1994).

The Wakino Subgroup is divided into four formations (Ota, 1953). The names of the formations of the Wakino Subgroup in Kitakyushu follow those of Nakae *et al*. (1988): the Dobaru Formation was called the lower formation (Ota, 1955, 1957), W_1 (Ota, 1960) or the First Formation (Matsushita, 1968; Ota *et al*., 1979); Takatsuo Formation called the middle formation (Ota, 1955, 1957), W_2 (Ota, 1960) or the Second Formation (Matsushita, 1968; Ota *et al*., 1979); Gamo Formation called the upper formation (Ota, 1955; 1957), W_3 (Ota, 1960) or the Third Formation (Matsushita, 1968; Ota *et al*., 1979); and Kumagai Formation called the uppermost formation (Ota, 1955, 1957), W_4 (Ota, 1960) or the Fourth Formation (Matsushita, 1968; Ota *et al*., 1979). The age of the Sengoku Formation, which is a lateral equivalent to the Dobaru Formation is considered to be Hauterivian to Barremian (Ota, 1981).

The Wakino fish fauna consists of three assemblages: the *Nipponamia-Aokiichthys*, *Paraleptolepis – Wakinoichthys*, and *Diplomystus – Wakinoichthys* (Fig. 2). The *Nipponamia-Aokiichthys* fauna have been found in the Dobaru Formation. This fauna consists of *Lepidotes macropterus* (Semionotiformes),

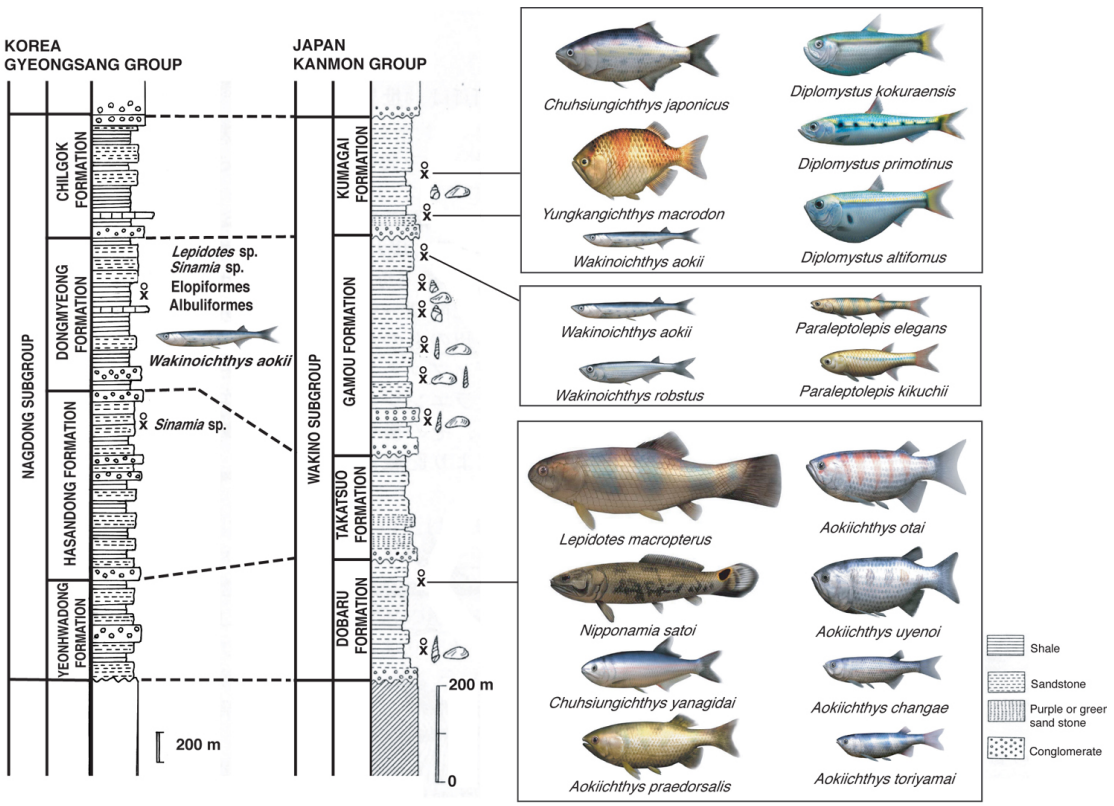

Fig. 2. Stratigraphic section of the Wakino Subgroup in Kitakyushu and the Nagdong Subgroup in southern Korea, the horizons of fish fossils, and reconstructions of some representative species.

Nipponamia satoi (Amiiformes), *Chuhsiungichthys yanagidai (*Ichthyodectiformes), and *Aokiichthys toriyamai*, *A. changae*, *A. otai*, *A. uyenoi, A. praedorsalis*, and *A.* sp. (Osteoglossiformes). Among these, fishes of the genus *Aokiichthys*, having the smallest number of vertebra among the Osteoglossomorpha, are the most abundant in numbers of species and individuals (Fig. 3B). *N. satoi* is the only Mesozoic species of the family Amiidae in East Asia (Fig. 3A).

The *Paraleptolepis-Wakinoichthys* fauna has been found in the Gamo Formation. This fauna is com-

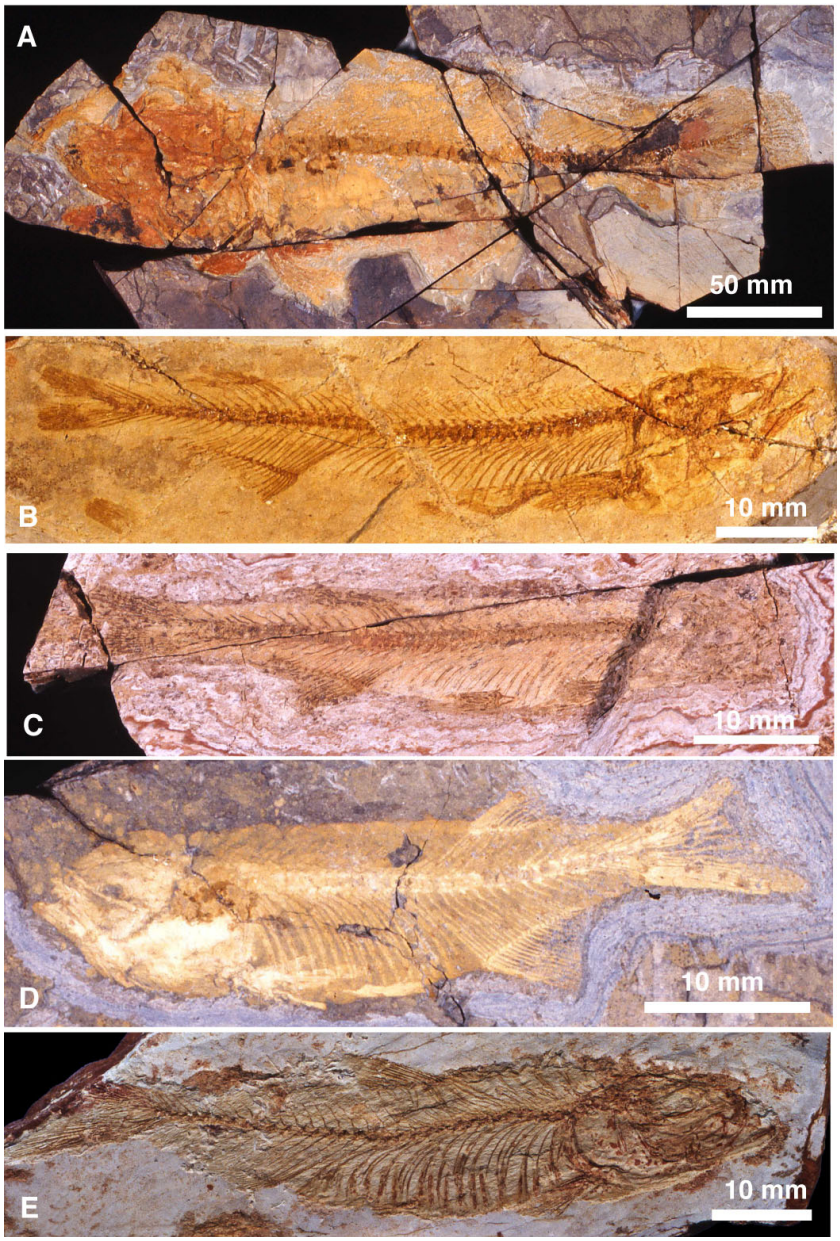

Fig. 3. Early Cretaceous freshwater fishes of the Wakino fish fauna from the Wakino Subgroup in northern Kyushu, Japan. A, *Nipponamia satoi* B, *Wakinoichthys aokii* C, *Paraleptolepis elegans*, D, *Aokiichthys toriyamai* E, *Diplomystus primotinus*.

posed of *Paraleptolepis kikuchii* and *P. elegans* (order and family *incertae sedis*), *Chuhsiungichthys* sp. (Ichthyodectiformes), and *Wakinoichthys aokii* and *W. robustus* (Osteoglossomorpha). Fishes of the genera *Paraleptolepis* and *Wakinoichthys* are the most abundant (Fig. 3C and D).

The *Diplomystus-Wakinoichthys* fauna has been found in the Kumagai Formation. It is composed of *Chuhsiungichthys japonicus* (Ichthyodectiformes), *Yungkangichthys macrodon* and *W. aokii* (Osteoglossomorpha), and *Diplomystus primotinus*, *D. kokuraensis, D. altisomus* and *D.* sp. (Clupeiformes), with the genus *Diplomystus* being most abundant (Fig. 3E). No fish fossils have been found from the Takastuo Formation (Fig. 2).

Based on this evidence, it is believed that the *Nipponamia-Aokiichthys* fauna became extinct by the end of Dobaru Formation time or the beginning of Takastuo Formation time. There is a strong possibility that the clupeiform fishes of the Dobaru Formation entered the lake from the sea at the beginning of this period, and took its place as the most abundant fish, *Paraleptolepis*, of the *Paraleptolepis-Wakinoichthys* fauna (Yabumoto, 1994).

FISHES FROM THE TETORI GROUP

The Tetori Group, widely distributed in central Japan, is divided into three subgroups: the Kuzuryu, Itoshiro and Akaiwa subgroups in ascending order (Maeda, 1961). The Itoshiro Subgroup distributed in Shokawa, Takayama City in Gifu Prefecture consists of the Otani, Ookurodani, and Amagodani Formations (Maeda, 1952). The Itoshiro Subgroup in southern Ishikawa Prefectuer is composed of the Gomijima and Kuwajima Formations (Oishi, 1933, Maeda, 1961). Many isolated fish fossil bones and scales have been found from the Ookurodani Formation in Shokawa and the Kuwajima Formation in Kuwajima, Hakusan City in Ishikawa. The Kuwajima Formation is a lateral equivalent of the Okurodani Formation, which stratigraphic, biostratigraphic and radiometric data show that the age is the basal Cretaceous (Valanginian or Hauterivian) (Evans *et al*., 1998).

The first fish fossil, a left lower jaw, was recovered from Kuwajima in 1987 (Fig. 4B), and together with a few ganoid scales was reported by Azuma and Hasegawa (1989) as Semionotiformes, Hoslostei, Osteichthyes, but according to Yabumoto (2005a) these should be assigned to *Sinamia*, Sinamiidae, Amiiformes.

From Kuwajima Formation, many isolated bones and scales of *Sinamia*, two isolated sacales of *Lepidotes* (Semionotidae, Semionotiformes), a dentary of Pachycormidae, and disarticulated skull bones, centra and scales of Osteoglossiformes have been found in Kuwajima by the fossil research project there since 1997 (Yabumoto, 2005a).

Olsen and McCune (1991) restricted the family Semionotidae to two genera, *Lepidotes* and *Semionotus*, based on the presence of dorsal ridge scales and a large, posteriorly directed process on the epiotic. *Lepidotes* is distinguished from *Semionotus* by having two or more suborbitals. Althougth the presence of these characters cannot be determined in the specimens of *Lepidotes* from the Kuwajima Formation, the specimens were assigned to the genus because the thick ganoin covering and the dorsal and anterior processes in the overlapped area of the scales are very similar to those of the genus *Lepidotes* (Fig. 4A)(Yabumoto, 2005a).

The best specimen of *Sinamia* is a skull associated with some ganoin scales and centra was recovered from Shokawa, but unfortunately it belongs to a private collection. The parietal is absent in this specimen, but the posterior margin of the frontals infer the presence of a single parietal which is one of the characteristics of *Sinamia*, although some individuals of the only extant species of Amiiformes, *Amia calva* have a single median parietal rather than paired parietals (Grande and Bemis, 1998). Three specimens of maxilla, two dentaries and gular plates, a hyomandibular, a frontal, two infraorbital bones, a preopercle, two cleithra, four supracleithra, and many ganoin scales of *Sinamia* have been described in de-

tail (Yabumoto, 2005a). The dorsal arm of the cleithrum is covered with ridged ornamentation (Fig. 4E), which is similar to *Amia* (Amiidae), but the shape of the bone is different. *Sinamia* has a crescent-shaped cleithrum and *Amia* has an L-shaped one with a longer ventral arm (Yabumoto, 2005b). At least two species of the genus were recognized on the basis of two types of gular plates and supracleithra from Kuwajima (Fig. 4C, D, F, and G). Scales having a long overlapped area and no process were assigned to *Sinamia*, as were those having smooth surfaces and posterior margins.

Pachycorumids had been reported only from marine sediments, therefore the pachycormid dentary

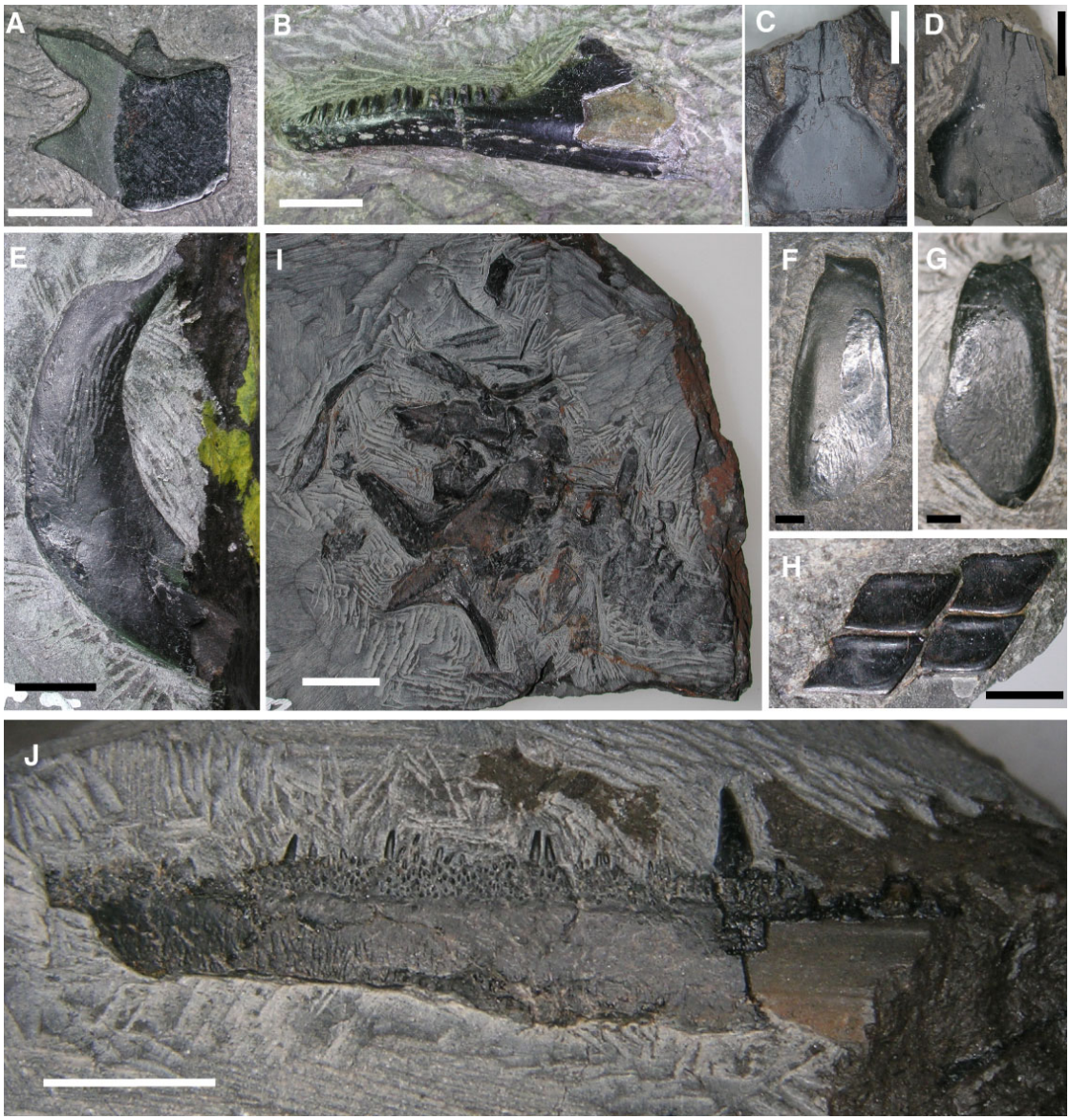

Fig. 4. Early Cretaceous freshwater fishes from the Itoshiro Subgroup of the Tetori Group in Kuwajima, Hakusan, Ishikawa, Japan. A, *Lepidotes* sp.; B-H, *Sinamia* sp., B, left dentary, SBEI-014 C, gular plate, SBEI-300 D, gular plate, SBEI-1208 E, right cleithrum, SBEI-316; F, left supracleithrum, SBEI-301; G, right supracleithrum, SBEI315; H, ganoin scales, SBEI-297; I, Osteoglossiform fish, SBEI-1489a J, Dentary of the family Pachycormidae, SBEI-826.

from the Kuwajima Formation represents the first report of the group from non-marine strata (Fig. 4J) (Yabumoto, 2005a). This suggests that the depositional environment of the Kuwajima Formation was probably near the sea and had some intrusions of marine water. Based on analysis of polycyclic aromatic hydrocarbons of the sediments, Hasegawa *et al*. (2002) suggested that the Kuwajima Formation was deposited in a salt water lake having occasional marine water intrusions as well as briefly being filled with fresh water.

The osteoglossiform fish from the Kuwajima Formation (Fig. 4I), probably belonging to the family Osteoglossidae, is the best preserved fish from the Tetori Group collected so far. It is the oldest record of the family, and is significant for understanding the origin of osteoglossids (Yabumoto, 2005a).

FISHES FROM KOREA

Since 1977, cooperative research between Korea and Japan has been carried out to uncover fish fossils at several localities of the Nagdong Subgroup of the Gyeongsang Group in the southern part of Korea (Yang *et al*., 2003). The Nagdong Subgroup is divided into four formations: the Yeonhwadong (Nagdong), Hasandong, Dongmyeong (Jinju), and Chilgok Formations (Lee *et al*., 2001). *Lepidotes* sp., *Sinamia* sp., some species of Albuliformes and Elopiformes, and *Wakinoichthys aokii* have been found from the Dongmyeong Formation. *Sinamia* sp. has been foundfrom the Hasandong Formation.

The specimen of *Lepidotes* sp., missing the anterior portion of the head, is the largest specimen. Its estimated total length is 40 cm, and maximum body depth, 96.2 mm (Fig. 5A). Dorsal ridge scales are present (Fig. 5B). The number of suborbitals cannot be determined.

Specimens belonging to the genus *Sinamia* have been found from the Dongmyeong and Hasandong

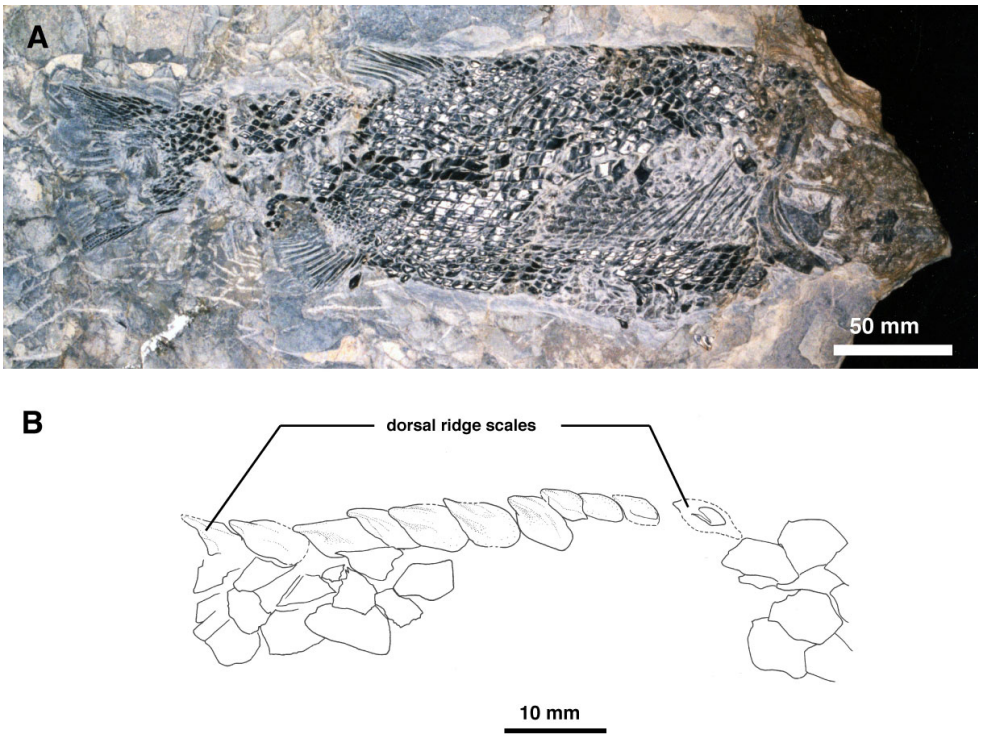

Fig. 5. A, *Lepidotes* sp. (KPE 90201) from the Dongmyong Formation of the Nagdong Subgroup in Korea, B, Dorsal ridge scales of KPE 90201.

Formations. The specimen from the Dongmyeong Formation consists of the caudal portion of the body with the caudal fin and some unidentified disarticulated bones. Each scale has a smooth posterior margin and surface (Fig. 6A and B). The material from the Hasandong Formation consists of weathered articulated vertebrae and ganoin scales having serrated posterior margins (Fig. 7 A and B).

The elopiform fish is small with a total length of about 30 mm. Its dorsal fin and pelvic fin are located in the middle of the body, and the anal fin, under the posterior end of the dorsal fin base. Infraorbital bones with a tubercular surface behind the orbit are large. Scales are relatively large. The mouth is large, and both upper and lower jaws have teeth. It has a deeply forked caudal fin. (Fig. 8A).

The albuliform fish from the Dongmyeong Formation (Fig. 8B) differs from other members of the order in having the following combination of characters: no teeth on the maxilla, dorsal fin origin just behind the pelvic insertion, anal fin nearer to the pelvic fin than the caudal peduncle, a long, strong first pectoral fin ray and 35 to 37 vertebrae, the fewest in number in the order (Lee, 1999).

It is interesting that many film-like preserved specimens found from the Dongmyeong Formation are considered to be juvenile elopiform or Albuliform fishes just after metamorphosis from the leptocephali (Fig. 8C).

Many specimens of *W. aokii*, originally described from the Wakino Subgroup in Kitakyushu, Japan (Yabumoto, 1994), have also been found from the Dongmyeong Formation in Chinju (Yabumoto and Yang, 2000) and several other fossil sites in Korea (Fig. 9).

CONCLUDING REMARKS

Chang and Jin (1996) recognized about 36 genera and 57 species, and divided these into four fauna: *Siyuichthys* fauna from Xinjiang; *Lycoptera* fauna from northern China, southeastern Mongolia and the Transbaikalian region of Russia; *Mesoclupea* fauna from southeastern China; and fish remains in Southwest China in Late Jurassic to/or Early Cretaceous Chinese fishes. Chang and Miao (2004) distinguished three fauna or assemblages among the Early Cretaceous freshwater fishes: the assemblage

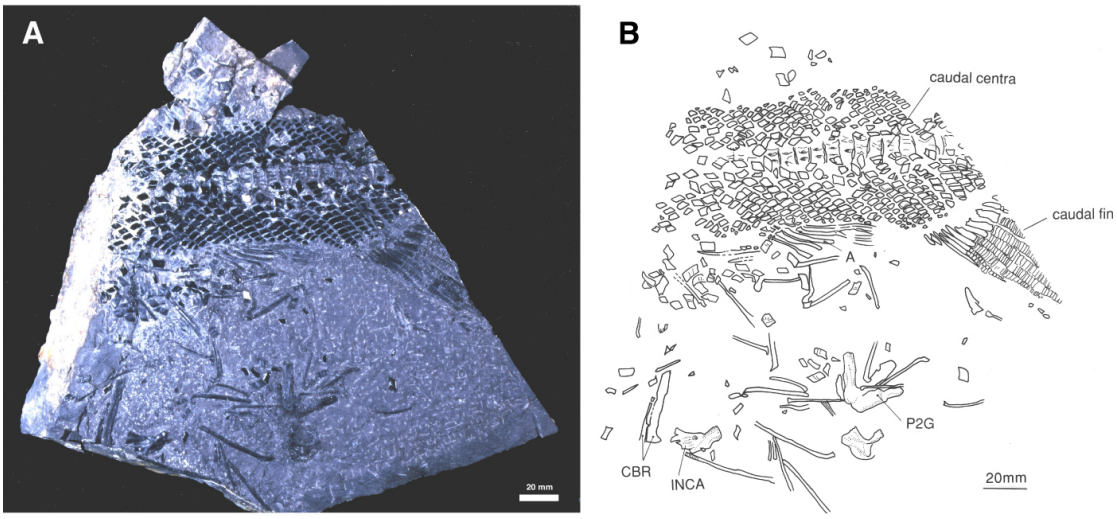

Fig. 6. *Sinamia* sp. from the Dongmyeong Formation of the Nagdong Subgroup in Korea. KMNH VP 100,256.

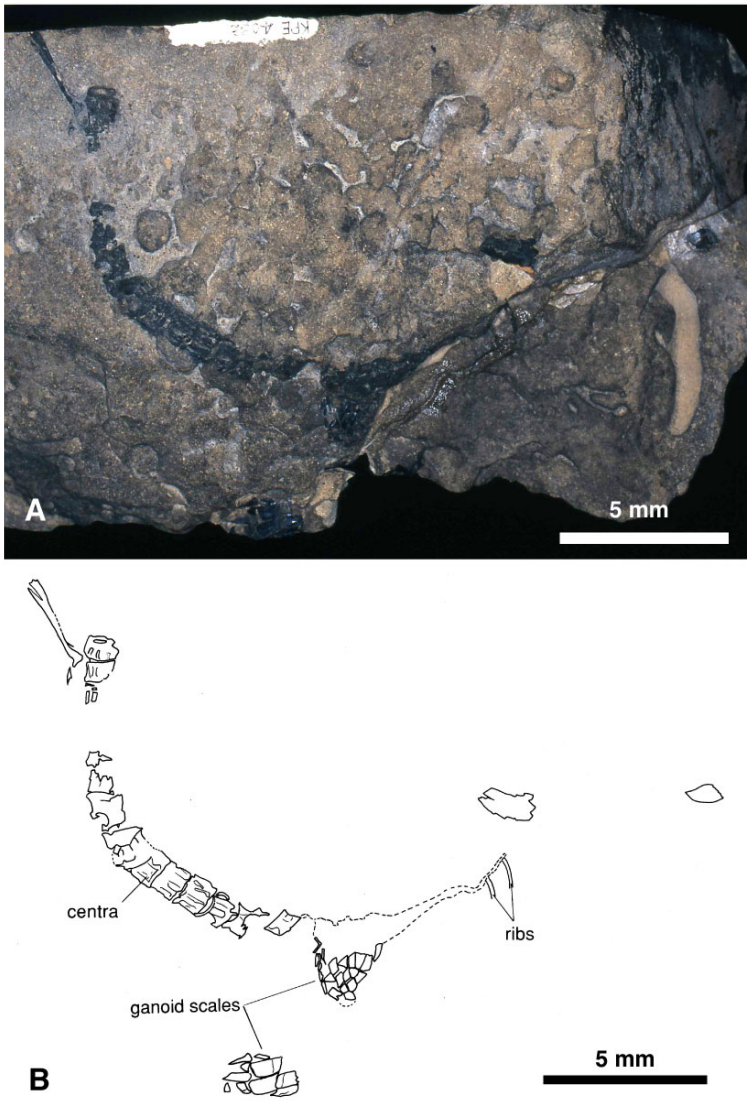

Fig. 7. *Sinamia* sp. from the Hasandong Formation of the Nagdonng Subgroup in Korea. KPE 4032.

distributed in Xinjiang, northwestern China and western Mongolia which includes the *Siyuichthys* fauna of Chang and Jin (1996); the *Lycoptera-Peipiaosteus* fauna or the "Jehol Fauna" which is the same as the *Lycoptera* fauna; and the *Mesoclupea-Paraclupea* assemblage, which includes the *Mesocupea* fauna and fish remains in Southwest China of Chang and Jin (1996), fishes from southern Korea and those from northern Kyushu, Japan (Fig. 1).

The Wakino Subgroup and the Nagdong Subgroup are probably the same age because the common species, *W. aokii*, has been found in both sediments, but the depositional environments are different because of the different composition of other fishes. The Nagdong Subgroup was probably deposited near the sea because most extant elopiform and albuliform fishes are mainly marine, rarely brackish and freshwater, and yielded specimens considered to be just post-metamorphosis (from leptocephali) elopiform or albuliform fishes (Fig. 8C).

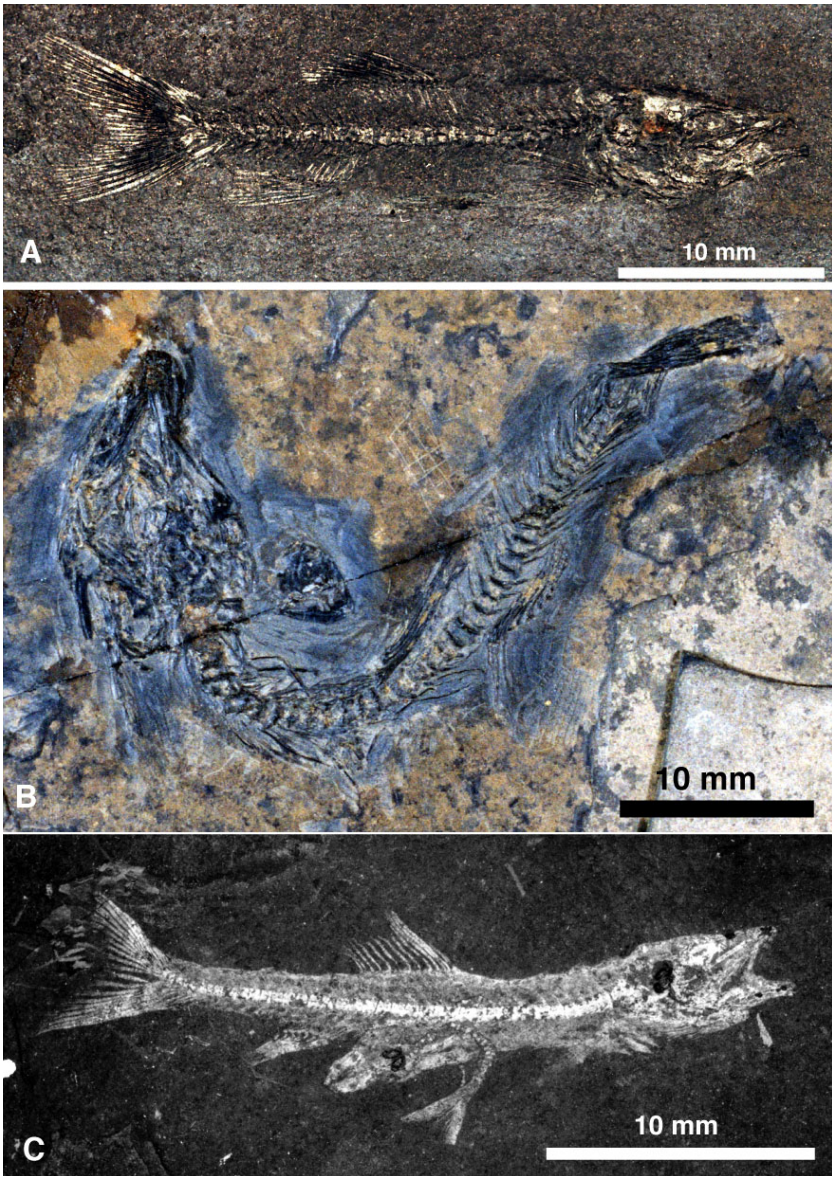

Fig. 8. Early Cretaceous freshwater fishes from the Dongmyeong Formation of the Nagdong Subgroup in Korea. A, Elopiform fish, DESRI, 2050780; B, albuliform fish, KPE, 90002; C, a film-like preserved specimen, considered to be a juvenile just after metamorphosis from a leptocephalous of an elopiform or albuliform fish, KPE, 90206.

The vegetative (or floristic) character of the Wakino Subgroup is considered to be Ryoseki- or possibly mixed-type (Kimura *et al*., 1992). Flora of the Nagdong Subgroup is regarded as mixed-type (Kimura and Ohana, 1992).

The composition of the Wakino fish fauna is similar to that of the *Mesoclupea-Paralycoptera* assemblage (Yabumoto, 1994; Chang and Miao, 2004). *Aokiichthys* of the Wakino Subgroup is comparable to *Paralycoptera*, but the number of vertebrae (34 to 36) is fewer than that of *Paralycoptera*. This number is the fewest in the Osteoglossomorpha. *Diplomystus primotinus*, *D. kokuraensis* and *D. altisomus* of the Wakino fish fauna are closely related to *Paraclupea chetungensis* of the *Mesoclupea-Paraclupea* assem-

blage in having similar ridged ornamentaion of the dorsal scutes (Yabumoto, 1995; Chang and Grande, 1997), but the species of the Wakino fish fauna can be considered more primitive than *P. chetungensis* because *P. chetungensis* has derived characters such as stout ventral and dorsal scutes and a deep body with a dorsal margin of the anterior body that abruptly ascends to the dorsal origin.

The Wakino fish fauna and the *Mesoclupea-Paralycoptera* assemblage have two common genera, *Yunchangichthys* and *Chuhsungichthys*, but other genera and species differ.

Probably there are geographical and chronological differences between the *Mesoclupea-Paraclupea* assemblage and the Wakino fish fauna. Although the age and horizon of localities of the *Mesoclupea-Paralycoptera* assemblage are difficult to compare with each other, probably the Wakino fish fauna can be considered to be slightly older than the *Mesoclupea-Paralycoptera* assemblage because the species of *Diplomystus* of the Wakino fish fauna are more primitive than *P. chetungensi*. Further, the Wakino Subgroup is regarded as of the Ryoseki or possibly of mixed-type vegetative character (Kimura *et al*., 1992), but that of the *Mesoclupea-Paralycoptera* assemblage is of the Ryoseki type (Kimura and Ohana, 1992).

While many fragments of *Sinamia,* which evolved and had relatively wide geographical and chronological distribution in East Asia, have been found from the Tetori Group, the fish assemblage from Kuwajima is unique in East Asia because of the existence of both a pachycormid and the oldest osteoglossid.

The fossil reptiles from the Kuwajima Formation and its lateral equivalents in the Itoshiro subroup suggest that Middle or Late Jurassic and late Early Cretaceous taxa existed together in the Early Cretaceous, which indicates a gradual Jurassic-Cretaceous faunal transition aswith the fauna of the Late

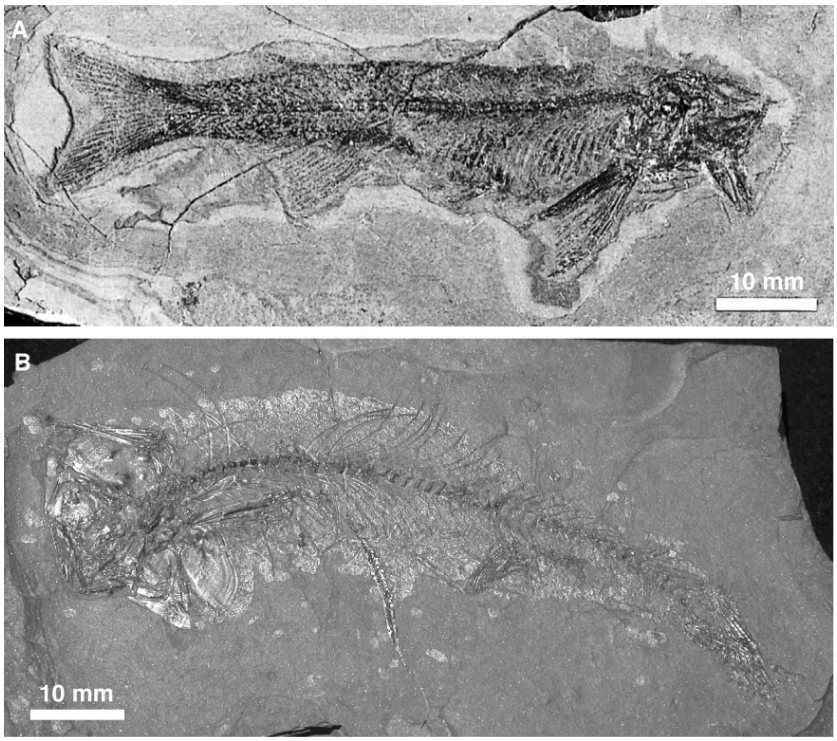

Fig. 9. *Wakinoichthys aokii* from the Dongmyeong Formation of the Nagdong Subgroup in Korea. A, KMNH VP 100,242; B, KPE 90204.

Jurassic Morrison Formation of North America, and several dinosaur clades (such as tyrannosaurids and psittacosaurids) which might have originated and diversified in eastern Asia while a number of other lineages (tritylodontid synapsids, compsognathid dinosaurs and 'rhamphorhynchoid' pterosaurs) persisted in this region (Manabe *et al*., 2000). The fossil fishes of the Kuwajima Formation may thus support this hypothesis from the reptilian fossils, although the fish fossils from the Kuwajima Formation and its lateral equivalents are insufficient to make a definite conclusion. The dentary of the pachycormid fish from the Kuwajima Formation is more similar to that of the Late Jurassic *Hypsocormus macrodon* from Solnhofen, Germany (Yabumoto, 2005a) than the Early Cretaceous pachycorumid *Protosphyraena*. The osteoglossid fish from the Kuwajima Formation is the oldest in the family (25 million years older than the previous oldest record, *Laeliichthys ancestralis* Silva Santos, 1985 from the Aptian, Brazil) (Yabumoto, 2005).

The age of the Kuwajima Formation is almost the same as that of the Wakino Subgroup or slightly older. The Kuwajima Formation is considered as Valanginian or Hauterivian (Evans *et al*., 1998), and the Dobaru Formation (the lowest formation) of the Wakino Subgroup, to be Hauterivian to Barremian (Ota, 1981), but the composition of fish fossils and the flora are different. The flora of the Wakino Subgroup is considered to be Ryoseki- or mixed-type (Kimura *et al*., 1992), while the Kuwajima Formation has Tetori-type flora (Kimura and Ohana, 1992).

ACKNOWLEDGMENTS

We express our sincere gratitude to Teruya Uyeno of the National Science Museum, Tokyo for his critical reading of the manuscript and valuable advice, and also Neal M. Teitler for editing the manuscript. We thank Gi Bon Kim of the Seongsan High School, Daegu, Korea for his help for our research in Korea and donation of his specimen, and Masafumi Kurokawa for donation of his specimen. The study of the fish fossils from the Tetori Group by the first author was supported by a Grant-in-Aid for Scientific Research (B), No. 15340179 to Makoto Manabe from the Japan Society for the Promotion of Science (JSPS).

한국과 일본의 전기 백악기 민물 물고기화석

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요 약: 일본 북 Kyushu의 Wakino Subgroup과 한국의 Nagdong Subgroup에서 발견된 전기 백악기 민물 물고기 화석군은 같은 시기이지만 퇴적환경은 다르다. 왜냐하면 *Wakinoichthys aokii*가 공통종으로 산출되지만 다른 종들은 서로 다르기 때문이다. Nagdong Subgroup은 elopiform과 albuiform 물고기들이 산출되기 때문에 바다 근처에서 퇴적된 것으로 추정된다. 두 subgroup의 시대는 남중국의 *Mesoclupea-Paralycoptera* 화석군의 산지보다 약간 오래된 것으로 보인다. Tetori Group의 물고기 화석은 독특하며 다소 시기가 오래되어 이들 물고기 화석 자체만으로는 증거가 불충분하지만 파충류화석으로부터 추정된 점진적인 쥐라기-백악기 변이를 지지할 수도 있다.

주요어: 전기 백악기, 민물물고기, 일본, 한국

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