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## EARLY CRETACEOUS BIRDS AND PTEROSAURS FROM THE SINUJU SERIES, AND GEOGRAPHIC EXTENSION OF THE JEHOL BIOTA INTO THE KOREAN PENINSULA

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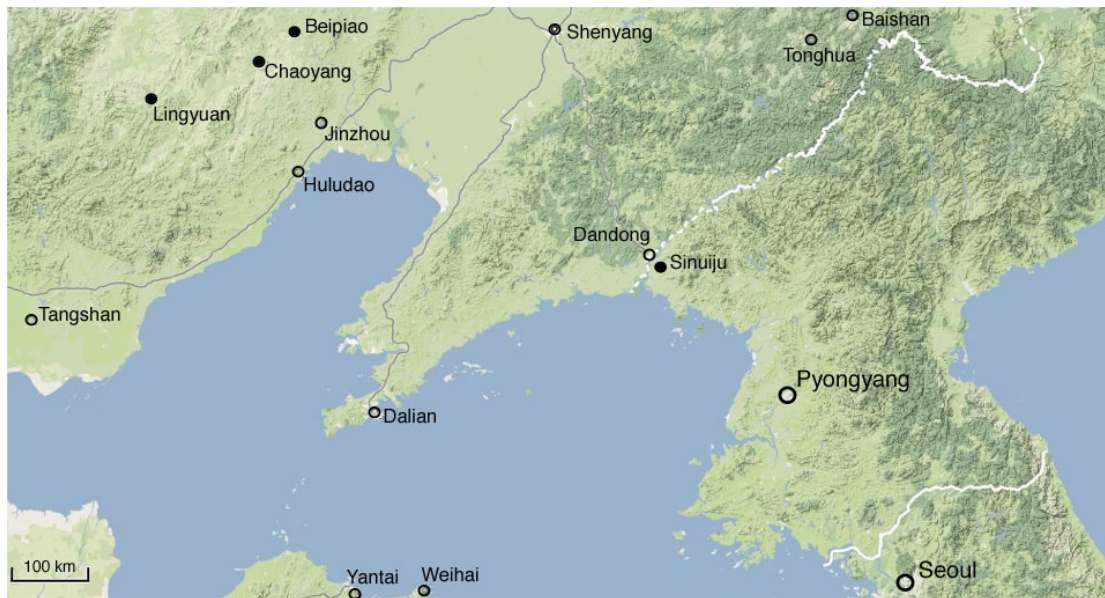
**Abstract:** The Lower Cretaceous Sinuiju Series of the Jasong Supergroup (=Jasong System of Pak and Kim, 1996) developed in the Amnok River Basin, North Korea, has yielded a potentially important vertebrate fauna, the taxonomic components of which are closely similar to those of the Jehol Biota best known from the Yixian and Chiufotang (=Jiufotang) formations in western Liaoning province, China (Chang *et al.*, 2003; Zhou *et al.*, 2003). The fossil-bearing beds of the Sinuiju Series consist of lacustrine fine-grained sandstones, mudstones, tuffaceous shales and andesites with a total thickness of over 2500 meters (Pak and Kim, 1996). Stratigraphically, the Sinuiju Series rests unconformably on top of Paleo-proterozoic metamorphic rocks, and underlies the Cretaceous Taobo Supergroup and Palaeogene strata. The age of the Sinuiju Series was thought to be Late Jurassic (Pak and Kim, 1996), but the strata contain the characteristic *Eosestheria-Ephemeropsis-Lycoptera* complex of the Jehol Biota, supporting an Early Cretaceous age of the Series (see also Lee *et al.*, 2001). Accordingly, the Sinuiju fauna signifies the geographic extension of the Jehol Biota from northeast China into the Korean Peninsula. Vertebrate fossils were found at a road-cut approximately six kilometers south of the city of Sinuiju (Figure 1). The fossil specimens already excavated from this site include *Lycoptera* and sturgeon fishes, anuran amphibians, several birds, possible theropod dinosaurs, and pterosaurs; none of these have been described in scientific publication, and the taxonomic status has remained uncertain ever since their discovery. Most of the fossils are preserved as dorso-ventral compressions as commonly seen in the Liaoning beds, but occur in dark shales that denote a slightly different depositional environment than the Yixian and Chiufotang formations in western Liaoning, China.

### Fossil birds:

Of the fossil birds known from the Sinuiju site, probably the most famed and also the most dubious is the “*Archaeopteryx* of Korea,” found from “the third bed of the series” (Pak and Kim, 1996). This important fossil discovery was publicized in a news report in 1993 but the fossil has never been scientifically described. The high expectation but lack of information on its anatomical details cast enormous doubt but heightened speculation on this conceivably important fossil bird. Until now, this Korean bird has been known from two incomplete specimens, both have wing digits preserved that show taxonomically significant features. The first specimen, illustrated in a photo image in a 1993 newspaper report, consists of a nearly complete wing-supporting skeleton; the second specimen is also a partial wing skeleton, comparable in size and structure to the first one (Figure 2). Close examination of these specimens in a recent study has come to the conclusion that the so-called “*Archaeopteryx* of Korea” is actually a confuciusornithid (Li and Gao, 2007). As clearly shown in these specimens, this fossil bird is characterized by having: a strongly widened and subquadrangular deltopectoral crest of the humerus; a phalangeal formula 2-3-4-x-x; the major and minor metacarpals equal in length; the proximal phalanx of

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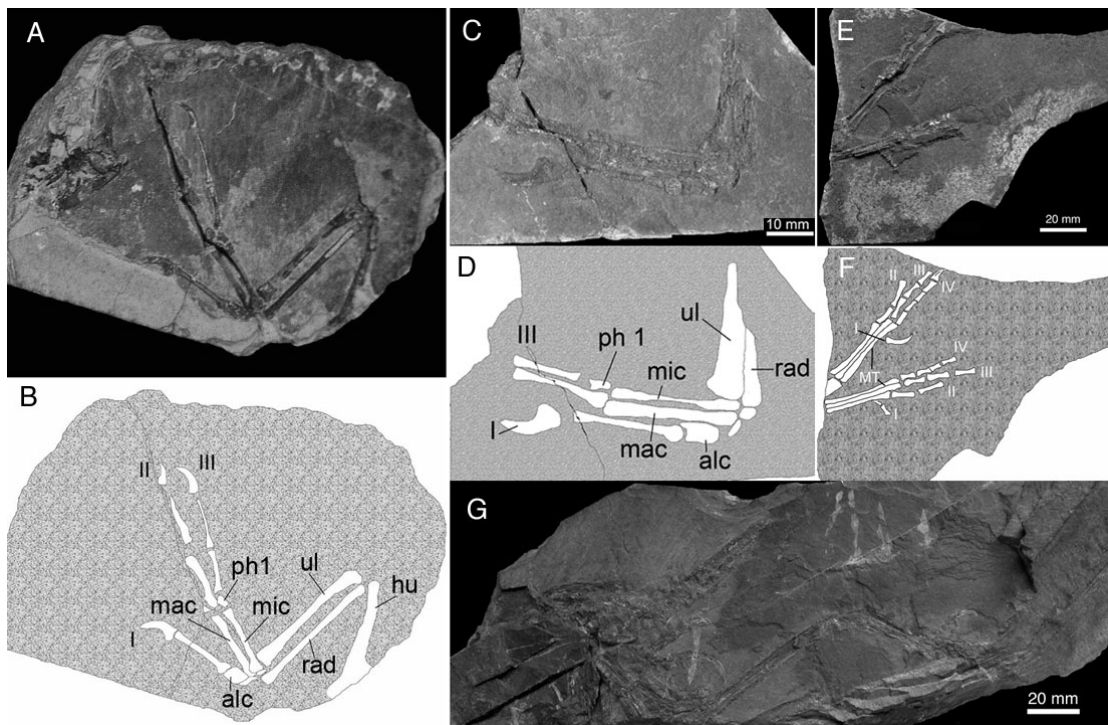
**Fig. 1.** Map showing the geographic location of the Sinuiju (solid dot) in relation to Beipiao and other major fossil sites (solid dots) in western Liaoning province, China.

minor digit (III) extremely short; and a semilunate bone free from the major metacarpal (Figure 2). All of these are diagnostic features of the family Confuciusornithidae (Chiappe, 2002), and their occurrence in the Korean fossil form indicates its affiliation with this family. Phylogenetically, the Confuciusornithidae (*Confuciusornis* + *Changchengornis*) are more derived than *Archaeopteryx*, and they were the first beaked birds with the tail vertebrae fused into a true pygostyle. Confuciusornithids were previously only known from the Lower Cretaceous Yixian and Chiufotang formations in western Liaoning province, China, but now it is clear that the biogeographic distribution of the family extended into the Korean Peninsula, although the lower level taxonomy (at the generic and species level) of the Korean fossil bird is still uncertain.

Other fossil birds from the Sinuiju Series are known from several specimens that give evidence of the occurrence of enantiornithine and even more advanced ornithurine birds in the Cretaceous System of the Korean Peninsula. One of these specimens has both left and right feet well preserved, and shows taxonomically significant features including: three unfused metatarsals; MT III-IV equal in length; and MT II significantly shorter than MT III-IV. The combination of these features indicates the possible enantiornithine affiliation of this bird. Enantiornithines are a diverse group of extinct birds primitively retaining teeth, and are commonly known from Mesozoic deposits worldwide. Another specimen represents a large bird with a tibia approximately 5.0 cm long. The specimen shows a partly preserved wing digit with a very large claw in the hand, and has a robust and elongated pygostyle of more than 3.5 cm in length. Without more detailed information on its anatomy, however, the taxonomic affinity of this large bird cannot be ascertained until more complete material becomes available.

### **Pterosaurs:**

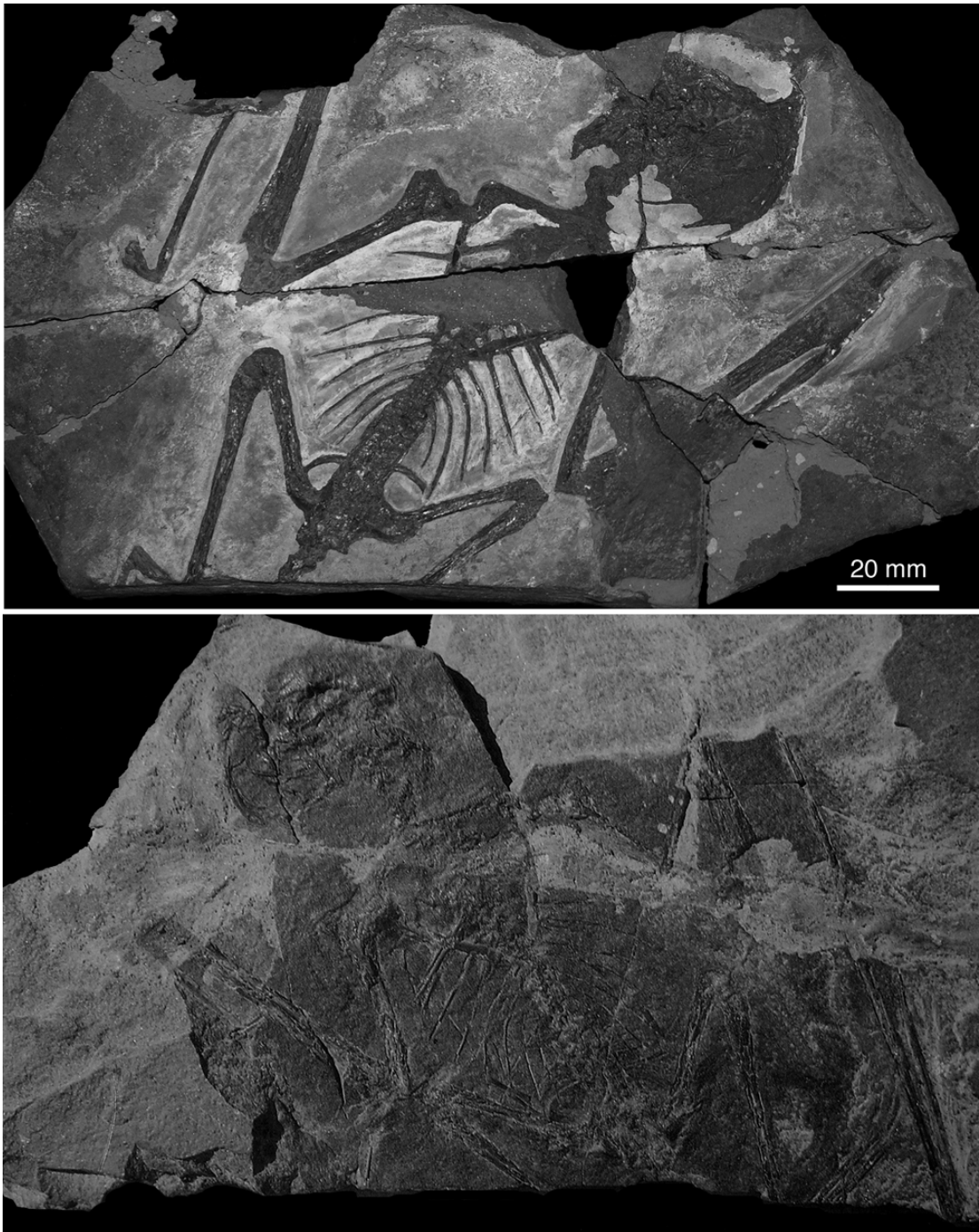
Besides the above-mentioned bird fossils, the best-preserved material so far collected from the Sinuiju Series is the skeleton of a pigeon-sized pterosaur (Figure 3). The specimen is approximately 25 cm long from the tip of the snout to the end of the tail, and probably had a wingspan of more than 80 cm. The skull is bilaterally compressed, but the postcranial skeleton is dorso-ventrally compressed as preserved. The skull is short and deep, and the neck is evidently shorter than the trunk. The pectoral girdle has the



**Fig. 2.** Representative bird fossils from Sinuiju, North Korea: **A-B**, wing skeleton and claws of a confuciusornithid (specimen of the “*Archaeopteryx* of Korea”); **C-D**, partial forelimb of a confuciusornithid; **E-F**, feet and the claws of an enantiornithine; **G**, a large specimen with a long pygostyle. Abbreviations used in this figure: alc, alular metacarpal; hu, humerus; mac, major metacarpal; mic, minor metacarpal; MT, metatarsal; ph, phalanx; rad, radius; ul, ulna;

scapula and coracoid fused, and the rod-like coracoids meet posteromedially at an acute angle to form a V-shaped structure. The tail, although incompletely preserved, is probably greatly reduced to a short stump similar to the pygostyle in advanced birds. All of these characters suggest that the Korean pterosaur can be confidently recognized as a member of the family Anurognathidae. As a family classified within the suborder Rhamphorhynchiodea (Wellnhofer, 1978; Unwin, 2006), the Anurognathidae include the type genus *Anurognathus* and *Batrachognathus*; both were small to medium-sized pterosaurs (wingspan ~50 cm) known from the Upper Jurassic Solnhofen lithographic limestones and the Upper Jurassic Karatau, Kazakhstan. More recent discovery of *Jeholopterus* from the Daohugou beds, Inner Mongolia, China, has extended the stratigraphic range of the family to the Middle Jurassic as the fossil beds have been independently dated at 164-165 Ma (Chen *et al.*, 2004; Yang and Li, 2004; Liu *et al.*, 2006; Gao and Ren, 2006; contra Wang *et al.*, 2002: Lower Cretaceous Yixian Formation); and now the new fossil discovery from North Korea may well provide the evidence for a geologically younger range extension of the family into the Upper Cretaceous.

Compared to *Jeholopterus* from China, the immediate differences that can be recognized in the Korean form are: ten rib-bearing trunk vertebrae (vs. 12-13); synsacrum formed by fusion of at least seven sacral vertebrae (vs. by three); scapula and coracoid roughly equal in length (vs. coracoid about half length of the scapula); and greater elongation of the ulna/radius segment to twice the length of the humerus. Although it can be recognized as a member in the family Anurognathidae, the taxonomy of this Korean pterosaur at the generic and species level cannot be determined before a thorough study of the available specimens.



**Fig. 3.** Part and counter-part skeleton of an anurognathid pterosaur from the Sinuiju Series.

In general, several bird fossils from the Sinuiju Series, North Korea, document the occurrence of confuciusornithid and enantiornithine birds in the Upper Cretaceous of the Korean Peninsula, and may include some other forms that have not been previously recognized in the fossil record. The pterosaur, known from a single specimen, can be referred to the family Anurognathidae. Although not yet formally

named and described, this fossil extends the stratigraphic range of the family into the Upper Cretaceous in the Korean Peninsula. The Sinuiju fossils provide arguably the most significant evidence for a geographical extension of the Jehol Biota from northeastern China into the Korean Peninsula, and forthcoming scientific study of these specimens will undoubtedly provide a significant source of information for a better understanding of the evolution of the Jehol Biota.

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