



Full length article

New fossil genus and species of carrion beetle (Coleoptera, Silphidae) from the Lower Cretaceous Jinju Formation, South Korea

Jae-Cheon Sohn^{*}, Gi Soo Nam

Department of Science Education, Gongju National University of Education, Gongju, Chungnam, Republic of Korea

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ABSTRACT

A new fossil genus of Silphidae, *Cretosaja* gen. nov., is described, based on a new fossil species, *Cretosaja jinjuensis* sp. nov. from the Lower Cretaceous Jinju Formation in South Korea. The association of *Cretosaja* with Nicrophorinae is discussed on the basis of morphological evidence. Diagnostic differences of the fossil and extant genera of Nicrophorinae are provided. Primitive characteristics presented in Mesozoic silphids are discussed.

Introduction

Silphidae, commonly known as carrion beetles, are an iconic insect group that recycles organic matter in terrestrial ecosystems (Peck, 1990; Wolf and Gibbs, 2004; Jakubec and Ruzicka, 2015). The larvae of silphids are primarily necrophagous, but a few species are detritivorous, predatory, or even phytophagous. Ikeda et al. (2008) suggested that the ancestors of Silphidae were necrophagous, and the other feeding modes in the lineage were derived from them.

The monophyly of Silphidae as currently defined, has been well supported in previous morphological (e.g., Lawrence and Newton, 1982; Grebennikov and Newton, 2012) and molecular studies (e.g., Dobler and Müller, 2000; McKenna et al., 2015). On the other hand, there is increasing evidence showing that Silphidae are paraphyletic to the mega-diverse Staphylinidae (e.g., Hansen, 1997; McKenna et al., 2015). The systematic status of Silphidae within Staphyliformia may require further attention. The members of Silphidae exhibit two synapomorphies (Grebennikov and Newton, 2012): the larval head almost as wide as the prothorax and the proximal antennomere in the adult antenna different from other antennomeres in the club section, lacking most of the pubescence. The division of silphids into two well-defined sub-families, Silphinae and Nicrophorinae, has been broadly accepted by researchers (Newton, 1991; also see a review by Sikes, 2005).

Nicrophorines share two apomorphies: the presence of a transverse frontoclypeal suture and the paired stridulatory files on the tergite V (Sikes, 2005; Cai et al., 2014). The extant Nicrophorinae comprise 72

species in three genera (Sikes et al., 2002, 2008). These beetles are distributed mostly in the temperate Northern Hemisphere. Sikes (2008) suggested that Nicrophorinae are less tolerant to warmer climates than Silphinae. The elaborate social behaviors of Nicrophorinae, notably *Nicrophorus*, have been studied extensively (Eggert and Müller, 1997).

The fossil record of Nicrophorinae is poor and consist of six fossils and subfossils (Miller and Peck, 1979; Sikes et al., 2002). Cai et al. (2014) reported eleven fossils of Nicrophorinae from the Lower Cretaceous Yixian Formation and the Mid-Cretaceous Burmese ambers, but they did not describe the specimens. The evidence suggests that Nicrophorinae may have existed around the beginning of the Cretaceous period. In a recent molecular study (Toussaint and Condamine, 2016), the origin of Silphidae and *Nicrophorus* was estimated to be in the Early Jurassic period and the end of the Early Cretaceous period, respectively.

The aims of this study are to describe a new genus and species of Nicrophorinae from the Lower Cretaceous Jinju Formation and to discuss the characteristics of the new fossil species regarding the Mesozoic and extant relatives.

Materials and methods

The specimen examined here was one of the fossils from the Jinju Formation located in the Jeongchon Section of Jinju City, Gyeongsangnamdo Province, South Korea (35°07'45"N, 128°06'02"E). The age of this fossil stratum was estimated as the Early Cretaceous, contentiously ranging from Hauterivian to Albian (Chang, 1975; Lee et al.,

^{*} Corresponding author at: Department of Science Education, Gongju National University of Education, Woongjinro 27, Gongju, Chungnam 32553, Republic of Korea.

E-mail address: jsohn74@gju.ac.kr (J.-C. Sohn).

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2010). Detailed geological setting of the Jinju Formation can be found in Sohn et al. (2019). The fossil was discovered from an exposed outcrop comprising black shale. The rock fragment including the fossil was trimmed with a small hammer and further processed in the laboratory.

The processed specimen was examined using a dissecting microscope (Leica EZ4) and as necessary photographed using a digital camera (Nikon D40) in an all-purpose light box in the Gongju National University of Education or a photographing system comprising a Canon EOS-1 Dx digital camera with a 100 mm EF macro lens in the Department of Paleobiology, the United States National Museum of Natural History, Washington DC. The type specimen has been deposited in the Paleontology collection of the Gongju National University of Education, Gongju, South Korea (GNUE).

We adopt Sikes (2005) for the classification system of Silphidae. Morphological terms and measurement definitions follow Lawrence et al. (2011) and Chang et al. (2007), respectively.

Systematic accounts

Order

Family
Subfamily

Cretosaja gen. nov.

Type species: *Cretosaja jinjuensis* sp. nov., by monotypy.

Diagnoses. This genus is similar to the extant genus, *Ptomascopus* Kraatz, 1876 (3 spp.) in the weakly-capituted antennae, but differs from the latter in the arched anterior margin of the clypeus (transverse in *Ptomascopus*), the posteriorly converging frontal sutures, and the orbicular pronotum. *Cretosaja* is distinguished from an Oligocene fossil genus, *Palaeosilpha* Flach, 1890 (type species: *Palaeosilpha fraasii* Flach, 1890 [Calyux in France]) in having the orbicular pronotum and the broadly-round outer-lateral margin of elytron. *Cretosaja* is similar to *Nicrophorus* Fabricius, 1775 (61 spp.: Sikes et al. 2002) in the shape of the clypeus but differs from the latter in having the weakly-capituted antennae. *Cretosaja* also differs from a monobasic genus, *Eonecrophorus* Kurosawa, 1985 (type species: *Eonecrophorus tenuicornis* Kurosawa, 1985 [Nepal]) in having the apical four antennomeres overlapping each other (lax in *Eonecrophorus*).

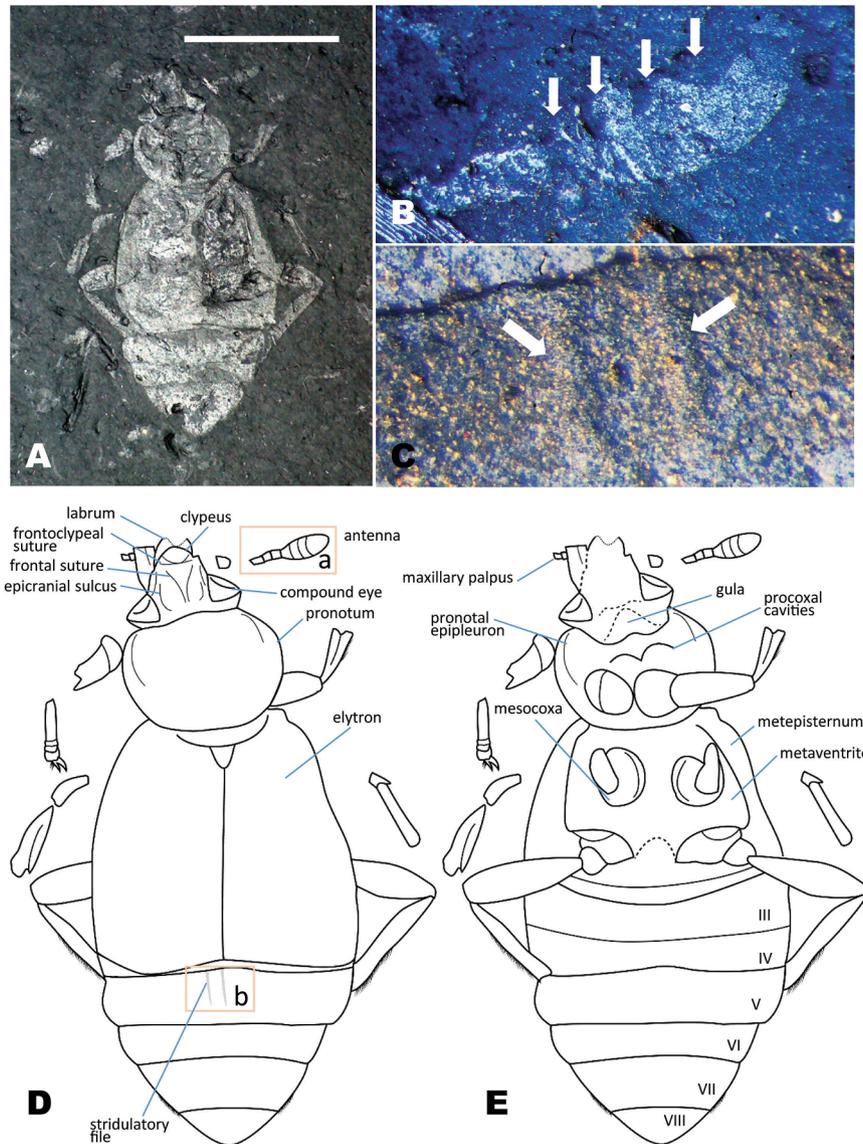


Fig. 1. *Cretosaja jinjuensis* gen. et sp. nov., holotype. A. whole body (scale bar = 5 mm); B. enlarged view of right antenna, corresponding the 'a' box in figure D (arrows = four segments of antennal club); C. tergite V, corresponding the 'b' box in figure D (arrows = stridulatory files); D–E. drawing and anatomical interpretations of figure A (D: dorsal elements, E: ventral elements).

Description. This genus is characterized by a combination of the following characters: the presence of i) the curved epicranial sulci (Fig. 1D); ii) the orbicular pronotum; iii) the broadly-round outer-lateral margins of the elytra; and iv) a pair of metacoxae separated from each other in distance (Fig. 1E). Interpretation of the last character may need caution, as it is possibly due to postmortem alteration during fossilization.

Remarks. The association of *Cretosaja* with Silphidae is substantiated by the general habitus and the presence of the clubbed antennae, a large mesoscutellum, truncate elytra, and well-separated mesocoxae. Cai et al. (2014) used these characteristics to associate their specimens with Silphidae. Moreover, *Cretosaja* can be assigned to Nicrophorinae by having two synapomorphies for the subfamily: the presence of a straight frontoclypeal suture and the stridulatory files on the tergite V.

Etymology. The generic name is derived from a combination of the Latin ‘creta’, where the ‘Cretaceous’ stems from, and the Korean ‘saja’, meaning “netherworld emissary.”

***Cretosaja jinjuensis* sp. nov.** (Fig. 1)

Type. Holotype: GNUE-I-2013003.

Preservation. The matrix of the specimen was a ca. 30 × 50 mm near-rectangular black-shale block with an oblique margin. The beetle specimen was located on approximately 2/3 of the long side of the block. Other than the beetle, there were fragments of culicid larvae and other debris together on the matrix. The beetle fossil showed near-perfect preservation for the head, thorax, and abdomen. Axillary structures, such as the mandible, maxillary palpus, antenna, and legs, were fragmented and partly preserved in the fossil specimen. The dorsal and ventral elements of the fossil body exhibited mismatch in some parts, possibly due to fossilization.

Diagnoses. Same as generic diagnoses.

Description. Head nearly triangular; frons and occiput slightly protruding; ridge present on lateral area of frons, near antennal socket; frons campanulate; frontal suture present, closely converging posteriorly; epicranial sulcus arched, not reaching frontoclypeal suture. Mandible stout, with ridged groove dorsally. Labrum emarginated medially. Clypeus narrowly-round apically; clypeal membrane fusiform, laterally closed by clypeus. Frontoclypeal suture transverse. Apical four segments of antenna (Fig. 1B) abruptly clubbed, overlapping with each other. Socket of compound eye triangular in remaining, with transverse ridge medially.

Thorax with pronotum orbicular, slightly concave anteriorly. Pronotal epipleuron narrow. Procoxal cavity bi-arched, on anterior 2/5 of pronotal disc. Scutellum subtriangular. Elytron broadly-round out-erlaterally, truncate posteriorly, 2 times as long as metasternum, finely punctuate. Protibia with apical carina dorsally, longitudinal ridge laterally, and stiff-setae dorsally. Mesotibia with longitudinal ridge. Metatrochanter small; metafemur slightly broadened, as long as metatibia; metatibia of even width except basal 1/6, with stiff-setae dorsally on posterior 2/3.

Abdomen broadly round laterally, widest on sternite IV; abdominal segment V–VIII exposed. Mesosternum small. Mesocoxal cavities open beyond posterior margin of mesoventrite. Metaventrite trapezoidal, convex posteromedially. Metacoxal cavities shallowly emarginated. Sternite II visible between metacoxae. Sternite IV concave posteromedially. Sternite V with a pair of stridulatory files (Fig. 1C). Sternite VII broader than sternite VI, with stiff-setae along lateral margins. Sternite VIII broad, subtriangular.

Measurements (in millimeters). Body length: 14; maximum body width: 6.1; head length: 1.8; maximum head width: 2.9; maximum pronotum length: 2.6; maximum pronotum width: 3.9; elytron length: 5.5; maximum elytron width 3; profemur length: 2; mesotibia length: 2.5; metafemur length 3; metatibia length 2.9.

Etymology. This species is named after Jinju, the type locality.

Remarks. *Cretosaja jinjuensis* is the first record of Silphidae from the Jinju Formation and the Cretaceous fossil strata in Korea.

Discussion

The silphid specimen from the Jinju Formation was similar to the fossils of Nicrophorinae from the Cretaceous Yixian Formation of Northeast China, which were illustrated by Cai et al. (2014). These Yixian silphids were associated with the extant genus *Ptomascopus* by the authors, despite the lack of detailed descriptions and proper generic assignments for them. The current silphid fossil clearly showed some differences from *Ptomascopus*, meriting a new genus. Some, if not all, of the Yixian Silphidae likely belong to *Cretosaja* as well. *Cretosaja* exhibits closer affinity with the *Ptomascopus*-lineage than with the *Nicrophorus*-lineage in terms of the shapes of the antennae and pronotum.

Cai et al. (2014) proposed that the *Ptomascopus*-lineage was more primitive than the *Nicrophorus*-lineage in social behavior, but there was no phylogenetic assessment of the inter-relationships among the four genera of Nicrophorinae. Those two lineages may have coexisted in the Early Cretaceous period, given the fossil occurrence of *Nicrophorus* from the mid-Cretaceous Burmese amber (Cai et al., 2014). The shapes of the body and the antennae in *Cretosaja* and the Yixian silphids are similar to their Jurassic relatives from the Daohugou Formation, Inner Mongolia, China (Cai et al., 2014). This indicates a long stasis of *Ptomascopus*-like characteristics through the evolution of Nicrophorinae. All Mesozoic silphids exhibit truncate elytra. These characteristics are considered to be primitive in Staphyloidea (Lawrence and Newton, 1982).

Cretosaja and some Cretaceous nicrophorines possess the stridulatory files on the fifth tergite (Fig. 1C). The same characteristic can be observed from the extant members of the subfamily producing sound for acoustic aposematism, courtship calling, or socialism in various degrees (Hall et al., 2013). This suggests that *Cretosaja* produced sound using the files and the elytra like the extant nicrophorines. Cai et al. (2014) suggested that the Cretaceous nicrophorines were scavengers of the carcasses of rodents and small birds. Traces of small vertebrates, such as small hopping mammals, avian theropods, lizards, and frogs, were discovered from the Jinju Formation (Kim et al., 2019).

Conclusion

A fossil specimen of Silphidae was found from the Early Cretaceous Jinju Formation, South Korea. This fossil was attributed to Nicrophorinae, based on the presence of two synapomorphies for the subfamily, a straight frontoclypeal suture on the head and a pair of stridulatory files on the tergite V. Compared to the previously-known fossils in the family, this represents a new genus and species, *Cretosaja jinjuensis* gen. et sp. nov. Given the morphological affinities, *Cretosaja* and the Early Cretaceous silphids from the Yixian Formation, China appear to belong to the same lineage. The lineage exhibits a closer affinity to *Ptomascopus* than to *Nicrophorus* in the shape of antennae. This suggests that *Cretosaja* and the Yixian nicrophorines may represent the primitive *Ptomascopus*-lineage. This finding buttresses the Early Cretaceous origin of sound production in the evolution of carrion beetles.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence

the work reported in this paper.

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References

- Cai, C.-Y., Thayer, M.K., Engel, M.S., Newton, A.F., Ortega-Blanco, J., Wang, B., Wang, X.-D., Huang, D.-Y., 2014. Early origin of parental care in Mesozoic carrion beetles. *Proc. Natl. Acad. Sci. U.S.A.* 111, 14170–14174.
- Chang, K.H., 1975. Cretaceous stratigraphy of southeast Korea. *J. Geol. Soc. Korea* 11, 1–23.
- Chang, H., Ren, D., Shih, C., 2007. New fossil elaterid (Coleoptera: Polyphaga: Elateridae) from Yixian Formation of western Liaoning, China. *Pro. Nat. Sci.* 17, 1244–1249.
- Dobler, S., Müller, J.K., 2000. Resolving phylogeny at the family level by mitochondrial cytochrome oxidase sequences: phylogeny of carrion beetles (Coleoptera, Silphidae). *Mol. Phylogenet. Evol.* 15, 390–402.
- Eggert, A.-K., Müller, J.K., 1997. Biparental care and social evolution in burying beetles: lessons from the larder. In: Choe, J.C., Crespi, B.J. (Eds.), *The Evolution of Social Behavior in Insects and Arachnids*. Cambridge University Press, Cambridge, pp. 216–236.
- Fabricius, J.C., 1775. *Systema entomologiae, sistens insectorum classes, ordines, genera, species, adiectis synonymis, locis, descriptionibus, observationibus*. Libraria Kortii, Flensburgi et Lipsiae. 832 p.
- Flach, C., 1890. Ueber zwei fossile Silphiden (Coleoptera) aus den Phosphoriten von Caylux. *Dtsch. Entomol. Z.* 1890, 105–109.
- Grebennikov, V.V., Newton, A.F., 2012. Detecting the basal dichotomies in the monophylum of carrion and rove beetles (Insecta: Coleoptera: Silphidae and Staphylinidae) with emphasis on the Oxytelinae group of subfamilies. *Arthropod Syst. Phylo.* 70, 133–165.
- Hall, C.L., Mason, A.C., Howard, D.R., Padhi, A., Smith, R.J., 2013. Description of acoustic characters and stridulatory *pars stridens* of *Nicrophorus* (Coleoptera: Silphidae): A comparison of eight North American species. *Ann. Entomol. Soc. Am.* 106, 661–669.
- Hansen, M., 1997. Phylogeny and classification of the staphyliniform beetle families (Coleoptera). *Biol. Skr.* 48, 1–339.
- Jakubec, P., Ruzicka, J., 2015. Is the type of soil an important factor determining the local abundance of carrion beetles (Coleoptera: Silphidae). *Eur. J. Entomol.* 112 (4), 747–754.
- Kim, K.S., Lim, J.D., Lockley, M.G., Kim, D.H., Pinuela, L., Yoo, J.S., 2019. Largest Cretaceous lizard track assemblage, new morphotypes and longest trackways comprise diverse components of an exceptional Korean Konservat-Lagerstätten ichnofauna. *Sci. Rep.* 9, 13278.
- Kraatz, G., 1876. Uebersicht über die südamerikanischen Arten der Silphiden-Gattung *Hyponecrodes* Kraatz. *Dtsch. Entomol. Z.* 20, 375–376.
- Kurosawa, Y., 1985. A new silphid genus and species (Coleoptera, Silphidae) from Nepal. *Bull. Natl. Sci. Mus. Tokyo, Ser. A* 11, 45–48.
- Lawrence, J.F., Newton, A.F., 1982. Evolution and classification of beetles. *Annu. Rev. Ecol. Evol. Syst.* 13 (1), 261–290.
- Lawrence, J.F., Ślipiński, A., Seago, A.E., Thayer, M.K., Newton, A.F., Marvaldi, A.E., 2011. Phylogeny of the Coleoptera based on morphological characters of adults and larvae. *Ann. Zool.* 61, 1–217.
- Lee, T.H., Park, K.H., Chun, J.H., Yi, H.W., 2010. SHRIMP U-Pb zircon ages of the Jinju Formation and Silla conglomerate, Gyeongsang Basin. *J. Petrol. Soc. Korea* 19, 89–101.
- McKenna, D.D., Wild, A.L., Kanda, K., Bellamy, C.L., Beutel, R.G., Caterino, M.S., Farnum, C.W., Hawks, D.C., Ivie, M.A., Jameson, M.L., Leschen, R.A.B., Newton, A. F., Robertson, J.A., Thayer, M.K., Whiting, M.F., Lawrence, J.F., Ślipiński, A., Maddison, D.R., Farrell, B.D., 2015. The beetle tree of life reveals that Coleoptera survived end-Permian mass extinction to diversity during the Cretaceous terrestrial revolution. *Syst. Entomol.* 40, 835–880.
- Miller, S.E., Peck, S.B., 1979. Fossil carrion beetles of Pleistocene California asphalt deposits, with a synopsis of Holocene California Silphidae (Insecta: Coleoptera: Silphidae). *Trans. San Diego Soc. Nat. Hist.* 19, 85–106.
- Newton, A.F.Jr., 1991. Silphidae (Staphylinioidea). In: Stehr, W. (Ed.), *Immature Insects, Vol. 2*. Kendall/Hunt Publishing Co., Dubuque, Iowa. pp. 339–341.
- Peck, S.B., 1990. Insecta: Coleoptera: Silphidae and the associated families Agyrtidae and Leiodidae. In: Dindal, D. (Ed.), *Soil Biology Guide*. John Wiley and Sons, New York, pp. 1113–1136.
- Sikes, D.S., 2005. Silphidae Latreille, 1807. In: Beutel, R.G., Leschen, R.A.B. (Eds.), *Coleoptera, Beetles Volume 1: Morphology and Systematics (Archostemata, Adephaga, Myxophaga, Polyphaga partim)*. Handbook of Zoology Volume IV Arthropoda: Insecta, Part 38. Walter de Gruyter, Berlin/New York. pp. 288–296.
- Sikes, D.S., Madge, R.B., Newton, A.F., 2002. A catalog of the Nicrophorinae (Coleoptera: Silphidae) of the world. *Zootaxa* 65, 1–304.
- Sikes, D.S., Vamosi, S.M., Trumbo, S.T., Ricketts, M., Venables, C., 2008. Molecular systematics and biogeography of *Nicrophorus* in part-The *investigator* species group (Coleoptera: Silphidae) using mixture model MCMC. *Mol. Phylogenet. Evol.* 48, 646–666.
- Sohn, J.-C., Nam, G.S., Choi, S.-W., Ren, D., Robillard, T., 2019. New fossils of Elateridae (Insecta, Coleoptera) from Early Cretaceous Jinju Formation (South Korea) with their implications to evolutionary diversity of extinct Protagrypninae. *PLoS ONE* 14, e0225502.
- Toussaint, E.F.A., Condamine, F.L., 2016. To what extent do new fossil discoveries change our understanding of clade evolution? A cautionary tale from burying beetles (Coleoptera: *Nicrophorus*). *Biol. J. Linn. Soc.* 117, 686–704.
- Wolf, J.M., Gibbs, J.P., 2004. Silphids in urban forests: Diversity and function. *Urban Ecosyst.* 7, 371–384.