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The compression mating fossil of sciarid fly (Diptera: Sciaridae) from Shiobara, Tochigi Prefecture, Japan

YUI TAKAHASHI\textsuperscript{1}, MITSUAKI SUTOU\textsuperscript{2} AND SHŪHEI YAMAMOTO\textsuperscript{3,4}

\textsuperscript{1}Graduate School of Life and Environmental Sciences, University of Tsukuba, 1-1-1 Tenoudai, Tsukuba, Ibaraki 305-0001, Japan

E-mail: wqvqzggp@geol.tsukuba.ac.jp

\textsuperscript{2} Department of General Systems Studies, Graduate School of Arts and Sciences, University of Tokyo, Komaba 3-8-1, Tokyo 153-8902, Japan

\textsuperscript{3} Entomological Laboratory, Graduate School of Bioresource and Bioenvironmental Sciences, Kyushu University, Hakozaki 6-10-1, Fukuoka 812-8581, Japan

\textsuperscript{4} Japan Society for the Promotion of Science Research Fellow (DC), Japan

Corresponding author:

Yui Takahashi (mail and e-mail addresses same as “1” above)

Phone: 029-853-6138, Fax: 029-853-7887

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The compression mating fossil of sciarid fly (Diptera: Sciaridae) from Shiobara, Tochigi Prefecture, Japan

YUI TAKAHASHI¹, MITSUAKI SUTOU² AND SHÛHEI YAMAMOTO³,⁴

¹ Graduate School of Life and Environmental Sciences, University of Tsukuba, 1-1-1 Tenoudai, Tsukuba, Ibaraki 305-0001, Japan

² Department of General Systems Studies, Graduate School of Arts and Sciences, University of Tokyo, Komaba 3-8-1, Tokyo 153-8902, Japan

³ Entomological Laboratory, Graduate School of Bioresource and Bioenvironmental Sciences, Kyushu University, Hakozaki 6-10-1, Fukuoka 812-8581, Japan

⁴ Japan Society for the Promotion of Science Research Fellow (DC), Japan

Key words: copulating fossils, insect fossil, Pleistocene, Sciaridae, Shiobara
Abstract

Preservations illustrating insect reproductive behaviors are much rarer in compression fossils than in amber. We discovered a copulating compression fossil of the sciarid flies from the Pleistocene Shiobara Group, Tochigi Prefecture, Japan, which is briefly described herein. The specimen represents one of the rare examples of a compression fossil showing mating dipteran insects. This finding implies that the small bodies of sciarid flies which readily fall onto the water surface may have contributed to the preservation of our copulating fossil. Moreover, the depositional environment of the paleo-Shiobara Lake was the main factor that served to preserve this specimen.

Introduction

Preserved fossils occasionally show not only the remains of an organism but also the past “behavior” of an organism, with this behavior sometimes having evolutionary implications (e.g. Wang et al., 2015). Determining the behavior of a fossil animal in comparison with that of modern related taxa is an integral part of paleoethology. The preservation of mating behavior within a fossil is one of the most obvious forms of evidence for direct intraspecific interactions between male and female (Penny and Jepson, 2014). Because of the paucity of examples of mating behavior in insect fossils, studies of their mating behavior are preliminary. At present, examples of fossils showing mating
behavior have been reported in four orders of insects, spanning twenty-four families (Boucot and Poinar, 2011; Li et al., 2013). Most of these specimens have been preserved in amber, representing approximately forty examples; however, examples of preserved compression fossils are dramatically fewer. In fact, Boucot and Poinar (2011) and Li et al. (2013) listed only eight compression fossil specimens of insects showing the process of mating, representing four known families and two undetermined families in four orders. In Diptera, fossils representing eleven families showing mating behavior are listed (Boucot and Poinar, 2011), and only five compression specimens are known from the two families, Bibionidae (Fujiyama and Iwao, 1974) and Chironomidae (Heer, 1850; Abel, 1935; Müller, 1957, 1979), among them. However, some examples of chironomid compression specimens showing mating are in fact from amber specimens (Abel, 1935; Müller, 1957, 1979), and no more than two dipteran compression specimens belonging to Bibionidae (Fujiyama and Iwao, 1974) and Chironomidae (Heer, 1850) have ever been recognized. In this study, we report on a new dipteran compression fossil showing mating behavior. We describe this specimen briefly based on a single specimen collected from the quarry of the Konoha Fossil Museum in Nasushiobara City, Tochigi Prefecture, central Japan.

As many as one hundred forty two species in fourteen genera of the sciarid fossils
have been reported globally, spanning the Cretaceous to Quaternary age, with most being found on European continent (Evenhuis, 1994, updated online in 1996). However, there have been few previous reports of sciarid fossils from Japan. Fujiyama and Iwao (1975) described three species of sciarid flies as *Sciara?* sp. A, B, and Sciaridae gen. et sp. indet. from the Middle-Late Pliocene or Early Pleistocene Tôgô Formation, Tôgô, Kagoshima Prefecture. In addition, *Sciara* sp. has been reported from the Early Miocene Masaragawa Formation, Sado Island, Niigata Prefecture, central Japan. (Fujiyama, 1985). Recently, six species of Sciaridae gen. et sp. A–F from Shiobara have been briefly described by Aiba (2015).

**Geological Setting**

Shiobara Basin is a caldera basin located on the northern slope of the Quaternary Takahara Volcano situated along the Hoki River (Figure 1). The caldera had a lake (paleo-Shiobara Lake in Tsujino and Maeda, 1999), the deposits of which have been assigned to the Middle Pleistocene Shiobara Group. The age of deposits was determined from the correlation of fossil flora (Onoe, 1989) and tephrochronology (Suzuki *et al*., 1998). The group adjoins and unconformably covers the Miocene volcanic and sedimentary rocks on
the west, north, and east sides, and the lavas of the Takahara Volcano intercalate on the south side. In some places, the group is overlain by terrace deposits and altered volcanic ash layers. The Shiobara Group includes a series consisting of sandstone, taffleaceous mudstone, diatomaceous laminated mudstone, and conglomerate. The group shows lateral lithological variation and is composed of two formations (the Kamishiobara and Miyajima Formations), which represent contemporaneous heterotopic facies. The Kamishiobara Formation represents a terrigenous marginal facies and includes coarse sediments. The Miyajima Formation, distributed in the center of the basin, shows profound facies of the paleo-Shiobara Lake and is composed mainly of diatomaceous laminated mudstones. This formation is exposed in the Konoha Fossil Museum, and a number of exceptionally well-preserved fossils, including leaves (e.g. Nathorst, 1883; Endo, 1931; Onoe, 1989), insects (e.g. Fujiyama, 1968, 1969, 1979, 1983; Aiba, 2015), and vertebrates (e.g. Shikama, 1955; Hasegawa and Aoshima, 1988) have been discovered. Because of the remarkable preservation, the locality has recently been described as a conservation Lagerstätten (Allison et al., 2008), and new specimens are being obtained from the quarry in the museum. The fossil bearing rock comprises whitish
laminites, which consist of rhythmic alternations of gray and white thin parallel laminae. Allison et al. (2008) observed that the former gray laminae are clastic layers and the latter are white cemented laminae of porcelaneous opaline silica. These liminae may be regarded as annual rhythmites (Akutsu, 1964; Aiba, 2015). The specimen occurred at the boundary of these laminae and it was parallel to bedding.

**Systematic Paleontology**

Order Diptera Linnaeus, 1758

Family Sciaridae Billberg, 1820

Sciaridae gen. et sp. indet.

Figure 2

Referred specimen - EES-TY-0001a, b; they are counterparts of one another. They show two individual flies: one male and one female. The studied specimens are deposited at the Graduate School of Life and Environmental Sciences, University of Tsukuba, the Ibaraki Prefecture, Japan. The prefix EES represents the abbreviation of Earth Evolutionary Science University of Tsukuba.

Remarks - Two individual flies were identified from the fossil. They were identified as a male and female based on their traced genital organs (Figure 2D-2). In Figure 2A, the
abdomen of the left individual is slightly larger than that of the right individual. This
difference of abdominal size also suggests that the left individual is female and the right
is male. The wing shape and venation of the female individual are partly observed and
are traced here (Figure 2C-2). The following wing veins are clearly visible in this example
(please see the caption of Figure 2 for abbreviations): R, R1, R5, Rs, r-m, M1, M2, CuA1,
and CuA2. Based on the arrangement of these wing veins, this fossil fly can be identified
as a member of the family Sciaridae (black fungus gnat). In particular, the branching at
the base of the wing veins CuA1 and CuA2 are characteristic of fungus gnats of this
family. For the genus- and species-level identification of the sciarid flies, examination of
the detailed structures of the antenna, maxillary palpus, inner apex of foretibia, and male
genitalia is necessary. Unfortunately, these characteristics are not preserved or clearly
visible in the fossil flies reported here. Although examination of the detailed structures of
the genitalia of the two flies identified in this fossil is difficult, the outlines of the apices
of the abdomens are traceable, and we show the attenuated female terminalia and the
caspers of the male genitalia called the gonostylus (Figure 2D-2). Posterior parts of the
abdomens of these two flies are closely contiguous with each other; therefore, they could
represent a female and a male sciarid fly in the process of copulation. Generally during
copulation of sciarid flies, a line forms connecting genitalia of both flies (Mohrig et al.,
Copulating postures are often disturbed in fossils showing copulating insects. The line connections are preserved in more or less V shape with fulcrums of their connecting points found in both amber and compression fossils (e.g. Penny and Jepson, 2014; Boucot and Poinar, 2011; Fujiyama and Iwao, 1974 and also see Figure 2E). Some line connections have strongly curved postures (see figure 183 on page 157 in Penny and Jepson, 2014 and Figure 2E). Therefore, we interpret that the copulatory position of these two sciarid flies was also probably disturbed during their transportation and deposition probably because of the collision to the water surface and water current, and eventually the connection was loosely broken.

**Discussion**

Although insect fossils demonstrating mating behavior are rare, these fossils are relatively well recognized in midges (Chironomidae and Ceratopogonidae), scavenger flies (Scatopsidae), and sciarid flies (Sciaridae). These taxa demonstrate comparatively long-lasting copulation times, and their mating pairs are thought to be more easily preserved as fossils than those of other groups of insects (Boucot and Poinar, 2011). Most sciarid flies inhabit forests and water sides, and they fly during the initial stage of their copulation. Their small bodies may be easily blown off on a windy day. These facts indicate that they tend to fall onto the surface of water while remaining in the coupling.
162 posture. Experimental verification has shown that soft tissue preservation is closely
163 related to the intensity and duration of the transportation of water current and the degree
164 of decay of the bodies of animals (Spicer, 1981; Allison, 1986). Fossils with well-
165 preserved soft tissue are thought to be deposited in a short period without extensive
166 transportation or decay. Martínez-Delclòs and Martinell (1993) have suggested that small
167 insects can be trapped on the water surface by surface tension for several days; however,
168 physical factors such as weak waves produced by wind and rain readily facilitate their
169 sinking to the bottom. The fact that the two flies of our specimen remained is in a mating
170 posture with little disturbance confirms that the specimen was rapidly buried. Fossil
171 animals are mostly limited in laminite in Shiobara lacustrine deposits and rapid burying
172 and anoxia probably protected them from scavenging (Allison et al., 2008; TuZino et al.,
173 2009). Soft tissue preservation requires fast diagenesis (Briggs, 2003). Lepispheres of
174 opal-CT derived from diatomaceous opal-A are recognized in this formation and the early
175 diagenetic mineral associated with soft tissue preservation is silica in Shiobara (Allison
176 et al., 2008). The phase change of silica may stabilize the biotic remains and contribute
177 to the preservation of soft tissue (TuZino et al., 2009). In addition, diatomaceous mud
178 works like a microbial mat, which plays a role in early mineralization and prevention of
179 scavenging (Seilacher et al., 1985; Harding and Chant, 2000). Hence, the characteristics
of the mating behavior of fungus gnats and the sedimentary environment of the paleo-
Shiobara Lake facilitated the preservation of the specimen described here. The Shiobara
lacustrine deposits have yielded many macrofossils, and this discovery serves as a
reminder of the importance of this deposit. Further discoveries of ethology-indicative
insect fossils, such as those that show predatory behaviors (which are more frequently
seen than copulation) are prospective.

Conclusion

The specimen described here represents one of the rare examples of dipteran
compression fossil showing mating behavior of sciarid flies. The mating behavior of the
sciarid fly and the particularly depositional environment of the paleo-Shiobara Lake were
factors that facilitated the preservation of this specimen. This discovery reiterates the
importance of the Shiobara lacustrine deposit. Further discoveries of fossils indicative of
the ethology of insects are expected.

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**Figure captions**

**Figure 1.** The schematic map at the upper left shows a location of Shiobara, Tochigi Prefecture, Japan (after TuZino and Maeda, 2009). The lower is the simplified local
geological map of Shiobara. The star represents the locality, Konoha Fossil Museum, which is located on the Miyajima Formation.

Figure 2. A, EESUT-TY01-0001a; B, EESUT-TY01-0001b, counter part of A; C, wings of the female; C-1, macrophotograph of C; C-2, interpretation of C-1. R for radius; R₁ for anterior branch of radius; R₅ for posterior branch of radius; Rs for radial sector; r-m for crossvein; M₁ for anterior branch of media; M₂ for posterior branch of media; CuA₁ for first branch of anterior branch of cubitus; CuA₂ for second branch of anterior branch of cubitus; D, distal parts of the abdomen; D-1, macrophotograph of D; D-2, interpretation of D-1. Ov for ovipositor of the female; gs, gonostylus of the male genitalia; E, mating pair of chironomid flies in Eocene Baltic amber. The right individual having longer antenna is male, and left one with shorter antenna is female. The photo is reprinted by courtesy of M. Veta.