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Cicada Fossil from Nasushiobara City, Tochigi Prefecture

Eri NAKANO[*1], Yui TAKAHASHI[*2], Hiroaki AIBA[*3] and Tamaki SATO[*1]

Department of Astronomy and Earth Sciences

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Abstract

The Shiobara Group in Nasushiobara City, Tochigi Prefecture, represents the middle Pleistocene (300 Ka) deposits of a caldera lake, and numerous well-preserved fossils have been yielded for many years. We describe a fossil specimen of the cicada *Terpnosia nigricosta* recently found from this group and estimated the paleotemperature of Shiobara. The paleotemperature between May to July in this area of 300 Ka is estimated to be within the range of 10.4-22.3 degrees Celsius based on the distribution of the adult individuals of living *T. nigricosta*. It is expected that an application of this method to other insect fossils from the Shiobara Group will refine the paleotemperature estimate.

Keywords: insect fossils, Pleistocene, paleotemperature estimate

Department of Astronomy and Earth Sciences, Tokyo Gakugei University, 4-1-1 Nukuikita-machi, Koganei-shi, Tokyo 184-8501, Japan

*1 Tokyo Gakugei University (4-1-1 Nukuikita-machi, Koganei-shi, Tokyo, 184-8501, Japan)
*2 Muroto Geopark Promotion Committee (1810-2 Murotomisaki-cho, Muroto-shi, Kochi, 781-7101, Japan)
*3 Keio Yochisha Elementary School (2-35-1 Ebisu, Shibuya-ku, Tokyo, 150-0013, Japan)

1. Introduction

The middle Pleistocene Shiobara Group in Nasushiobara City, Tochigi Prefecture, is a Lagerstätte which yields well-preserved fossils of plants, vertebrates and insects, and has been a subject to scientific researches since the early 20th century (e.g. Yabe 1929, Shikama 1955, Fujiyama 1969, Tsujino et al. 2009, Aiba 2015, Takahashi et al. 2017). In addition to their significance in geological and paleontological studies, the fossils from the group have a great potential as educational material, and Aiba (2015) proposed several teaching materials for classroom use to introduce the reconstruction of paleoenvironment.

Insects are expected to indicate paleoclimates and environments, but there are only a few such studies based on the fossil insects from the Shiobara Group (Fujiyama 1969 and 1979, Aiba 2015). In fact, academic publications on insect fossils from the group are few and sporadic after a series of works by Fujiyama (1968, 1969, 1979, 1983), despite their remarkable taxonomic diversity known to public by popular books and museum exhibits (e.g. Aoshima et al. 2014, Aiba 2015). In this study, we describe a single hindwing fossil of cicada from Shiobara and propose a new method to estimate paleotemperatures based on the current distribution of the species.

2. Materials and methods

The insect fossil described here was collected by one of us (YT) from the quarry of Konoha Fossil Museum in Nasushiobara City (Fig. 1A, B), and belongs to the museum with a specimen number of SFMA0379; "SFMA" stands for Shiobara Fossil Museum Arthropod. The specimen represents a single insect hindwing preserved in finely laminated diatomaceous siltstone. At Tokyo Gakugei University, it is further prepared physically under a microscope (Leica DMS-1000), using an insect pin held at the tip of a chopstick and supported with adhesive tapes. This specimen was observed and photographed using the same digital microscope. This image was processed with Leica Application Suite Ver. 4.8 (Leica Microsystems) and Adobe Photoshop CS6 Ver.13.0x32 (Adobe Systems Inc.).

3. Geological Setting

The specimen came from the middle Pleistocene Miyajima Formation of the Shiobara Group (Tsujino and Maeda 1999). The group is distributed in the central part of the Shiobara Basin which is exposed in the northern slope of the Quaternary Takahara Volcano in Tochigi Prefecture (Fig. 1A, B). According to Onoe (1989), this group unconformably covers the basement-rocks, and is overlain by terrace gravels, loam and talus deposits.

Onoe (1989) suggested that the group represents lacustrine deposits based on observations of the lateral lithological variation. Tsujino and Maeda (1999) followed the interpretation of Onoe (1989) and divided the Shiobara Group into the Miyajima and Kamishiobara Formations, representing contemporaneous heterotopic facies as the central and the marginal deposit of the lake, respectively. The former is mainly composed of laminated mudstone and siltstone, and the latter consists of conglomerate and

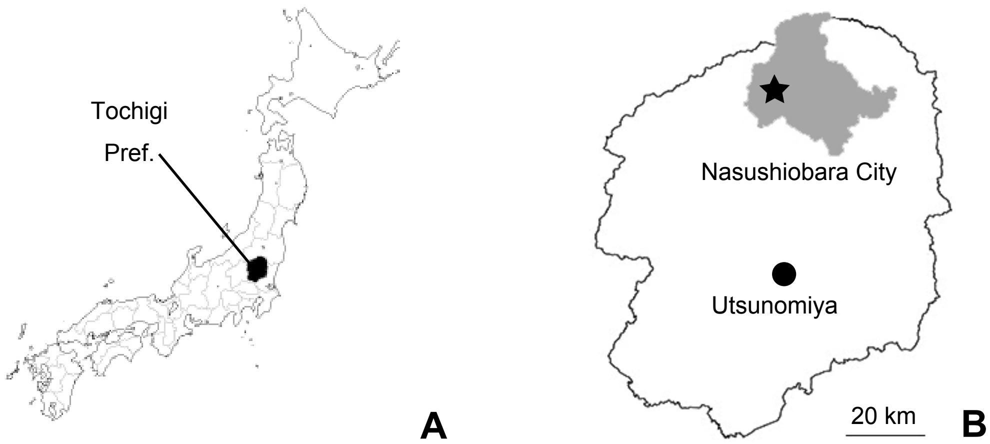

Fig. 1. Maps showing the location of Tochigi Prefecture (A), Nasushiobara City and fossil locality (star, Konoha Fossil Museum) (B).

sandstone. The grains coarsen and terrestrial substances increase towards the margin, as in typical lake deposits (Tsujino and Maeda 1999). Gohara et al. (1952) noted that the absence of marine fossils also supports the lake origin of the fossil-bearing strata.

Onoe (1989) interpreted the "Shiobara Lake" as a caldera lake based on the presence of the large amount of pumice flow and subsurface distribution of the base rocks of the volcano, and his view has been accepted widely (e.g. Itaya et al. 1989, Tsujino and Maeda 1999). This caldera lake must have been formed by the eruption of the "Paleo-Takahara Volcano". Thereafter, volcanic activity occurred at the southern edge of the caldera, and modern Takahara Volcano was formed (Onoe 1989). Associated flows of lava poured into the southern part of "Shiobara Lake", which gives approximately 300 Ka by K-Ar dating (Itaya et al., 1989).

4. Systematic Paleontology

Class **Insecta** Linnaeus 1758
Order **Hemiptera** Linnaeus 1758
Family **Cicadidae** Latreille 1802
Subfamily **Cicadinae** Latreille 1802
Tribe **Cicadini** Latreille 1802
Genus ***Terpnosia*** Distant 1892

Terpnosia nigricosta (Motschulsky 1866)
(Fig. 2)

Cicada nigrocosta Motschulsky 1866
Terpnosia nigricosta (Motschulsky) Distant 1892

Material. A hind wing (SFMA0379)

Description. A large and short wing is characterized by the uniform winged mass, heavy and firm venation and presence of six apical cells (ac). The wing is hyaline bearing no infuscations. Anal lobe folded up inwards only represents a part of wing margin. The lobe is relatively wide and bears thin arched margin. Radial cross vein (r) is almost straight and sharply angled to both ambient vein (av) and radial posterior veins (RP), and the r meets RA near the branching point from Sub costa (Sc) + RA. RP and median veins (M) fused at the base of the wing. Long and slightly concave av and RP which curves forward forms slowly arched first apical cell. Each apical cell is elongated, and the sixth cell is strongly projected posteriorly.

Measurements. Due to the incomplete specimen, we estimated the entire length of the wing based on the preserved part. The length from the base of the wing to tip of the first apical cell represents 16.6 mm suggesting the entire length 18.5 mm.

Remarks. The uniform winged mass, heavy and firm venation, and six apical cells of the fossil characterize a hindwing of Cicadidae. In the family, 35 species of 15 genera belonging to 8 tribes live in Japan today. The hyaline hindwing without infuscations is the original feature of the specimen, because color patterns of insect wings are commonly preserved in the Miyajima Formation (e.g. Aiba 2015). This character easily excludes some tribes such as Platypleurini, Polyneurini, Oncotympanini and Cicadettinae, and most species of Cryptotympanini do not correspond with the character. The size and morphology of the anal lobe also supports this view and further expects Cryptotympanini. Furthermore, collaborations of almost straight r vein sharply angled to both av and RP veins, and slowly arched and elongated first apical cell distinguish the

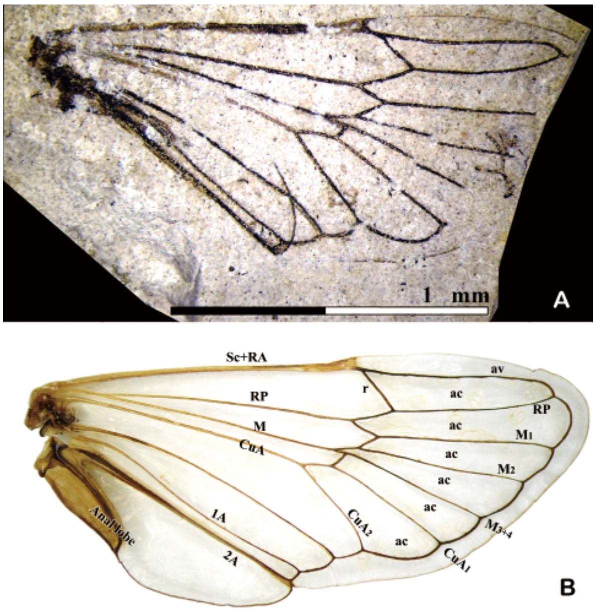

Fig. 2. Hindwing of the described fossil SFMA0379 (A) and a modern specimen (B) of *Terpnosia nigricosta* (Motschulsky 1866). Modern specimen captured in Yamane Town of Kuji City, Iwate Prefecture on June 16, 2003. Scale bar: 10 mm.

specimen from Cicadatrini and Prasiini. Most members of Cicadini share above characteristics. Addition to these, strongly posteriorly projected sixth apical cell is only applicable to *Terpnosia nigricosta*.

Three specimens of cicadas have been reported from the Shiobara Group: one specimen of *Tibicen* (=*Lyristes*) *bihamatus* and two specimens of *Terpnosia nigricosta* reported by Fujiyama (1969, 1979) and Aiba (2015). SMFA0379 is the third specimen of *T. nigricosta*, and the first documented occurrence of the cicada hindwing.

5. Discussion

Recent *Terpnosia nigricosta* live in the mountain region with elevation 700-1500 m in the west of central Japan during the summer season (May to July) where beeches and oaks are common (Hayashi and Saisho 2015). In this section, we attempted to estimate the paleotemperature range at the time of "Shiobara Lake" based on the distribution of *T. nigricosta* today.

Previous paleotemperature estimates resulted in conflicting views. Endo (1935) noted that the Shiobara flora correspond with the lowland of the central Hokkaido and estimated that average annual paleotemperature was lower than that of the present by 5-5.5 degrees Celsius. Fujiyama (1969), who described a fossil *Terpnosia nigricosta* supported Endo (1935), because this species lives in higher altitudes in nearby Nasu area today, suggesting a cooler paleotemperature. On the other hands, Ozaki (1982) calculated the paleo-altitude based on the ratio of evergreens in broad-leaved trees, and he concluded that average annual paleotemperature was almost the same as that of today. Onoe (1989) noted the Shiobara flora includes the elements of hemitemperate forests and suggested that the annual temperature was slightly (+1 degree) higher than that of today.

We estimated the summer temperature of Shiobara in the middle Pleistocene based on the current temperature ranges in May to July during which adult individuals of *T. nigricosta* appear (Hayashi 2009). According to Biodiversity Center of Japan (2002), adult individuals of *T. nigricosta* (up to the 1998 survey) were observed from Hokkaido to Kyushu. There are few records of the temperatures at the exact spots where *T. nigricosta* was observed, so data at the weather stations closest to the *T. nigricosta* were employed and the effect of altitude to the temperature was estimated.

The highest temperature at the station near the *T. nigricosta* spots is observed is 22.3 degrees Celsius (Maebara in Fukuoka Prefecture) and the lowest is 10.4 degrees (Chippomanai in Hokkaido), according to Biodiversity Center of Japan (2002) and Japan Meteorological Agency (2017). Therefore, the estimated range of the temperatures in habitats of *T. nigricosta* in Japan is 10.4-22.3 degrees Celsius.

Next, based on the altitude and temperature data provided by Geospatial Information Authority of Japan (2018) and Japan Meteorological Agency (2018), the present temperature at the fossil collection site (Konoha Fossil Museum, approximately 570 meters above sea level) is estimated based on the record at Nasukogen (749 m above sea level), the closest weather station. The average temperature from May to July is 15.9 degrees Celsius in Nasukogen. To compensate the higher altitude of the museum, the lapse rate (temperature decreases 0.55 degrees every time the altitude rises 100 meters) is applied, and the calculated average temperature at the museum from May to July today is 16.9 degrees. Presence of the *T. nigricosta* fossils at the museum indicates that the average paleotemperature of these months in 300 Ka could have been lower by 6.5 degrees or higher by 5.4 degrees than today.

The previous studies mentioned earlier estimated the annual, not summer, temperature, so their results are not directly comparable to our result. However, the wide temperature range in the current habitats of *T. nigricosta* includes the average summer temperature in this area today, suggesting that the presence of this species does not necessary indicate a cooler climate (contra Fujiyama, 1979).

The seasonal presence of *T. nigricosta* adults allows an estimate of temperature range for particular months, but the range is too wide for a practical comparison. If more insect fossils, preferably those of stenothermal taxa which live in similar season(s), are identified scientifically, the estimation can be narrowed down both in the range and months.

Records of body and trace fossils of the Cicadoidea can be traced back to the Mesozoic (see Krause et al. 2008, Smith and Hasiotis 2008). Known Japanese fossil cicadas are from the Miocene to Pleistocene, and are affiliated with living species (e.g., Fujiyama 1969, 1979, 1982, Kinugasa and Miyatake 1976, this study), suggesting that the new method employed in our study for the estimation of paleotemperature is promising.

6. Conclusion

An insect fossil from the middle Pleistocene Shiobara Group in Nasushiobara City, Tochigi Prefecture, is identified as the cicada *Terpnosia nigricosta*. Fossils of cicada are rare, and the described specimen is the third occurrence of this species and the first occurrence of the hindwing of a cicada. Based on the range of temperatures for adult individuals of this species today, it is estimated that the average paleotemperature from May to July at the Shiobara in 300 Ka was within the range of 10.4-22.3 degrees Celsius. Application of this method to multiple species with similar seasonal appearances will improve the precision of the paleotemperature estimate for a particular season.

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栃木県那須塩原市で発見されたセミ化石について

中野　絵理[*1]・高橋　唯[*2]・相場　博明[*3]・佐藤　たまき[*1]

宇宙地球科学分野

要　旨

栃木県那須塩原市の塩原層群は中期更新世のカルデラ湖の堆積物から構成されており，保存状態の良い化石が数多く見つかっている。本論文では，最近見つかったエゾハルゼミ *Terpnosia nigricosta* の化石を記載した。また，現生の同種成虫の分布データから当時の夏（5月～7月）の古気温は10.4℃から22.3℃であったことが推定できる。同様の手法を同層から産出する他の昆虫化石に適用することで，更に精度の高い古気温推定が可能になると考えられる。

キーワード:　昆虫化石，更新世，古気温推定

＊1　東京学芸大学 広域自然科学講座 宇宙地球科学分野（184-8501　小金井市貫井北町 4-1-1）
＊2　室戸ユネスコ世界ジオパーク（781-7101　室戸市室戸岬町 1810-2）
＊3　慶応義塾幼稚舎（150-0013　渋谷区恵比寿 2-35-1）