

First report of Cixiidae insect fossils from the Miocene of the northeastern Tibetan Plateau and their palaeoenvironmental implications

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A new insect species, *Cixius discretus* (Hemiptera, Fulgoromorpha), from the Lower Miocene Garang Formation of Zeku County, Qinghai Province (northeastern Tibetan Plateau) is described. This species can be assigned to Cixiidae and represents the first fossil representative of this family from Qinghai Province. Based on the recent single-origin hypothesis and the distribution of tectonic plates in the Cretaceous, we consider that ancient *Cixius* had dispersed globally prior to the Cretaceous. Through analysis of the habitats of extant *Cixius*, the palaeoclimate and fossil flora of the Zeku area during the Miocene, we interpret the climate of Zeku in the early Miocene to have been warm-temperate and mildly arid. The new species constitutes evidence of wooded and shrubby habitats in Zeku during the Miocene.

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CIXIIDAE is regarded as the most primitive family of Fulgoroidea and has a cosmopolitan distribution (Fennah 1987, Larivière 1999, Holzinger *et al.* 2002). Cixiidae includes three subfamilies: Bothriocerinae Muir, 1923, Borystheninae Emeljanov, 1989 and Cixiinae Spinola, 1839 (Emeljanov 2002, Szwedo 2004). Of these subfamilies, Cixiinae, which contains 15 tribes, is the most abundant (Szwedo 2004). *Cixius* is an important genus in the tribe Cixiini. Extant species of *Cixius* have a wide distribution (Zhang 1989), occurring in Asia, North America, South America, Africa and Europe (China 1942, Kramer 1981, Van Stalle 1984, Nickel & Remane 2002, Zhang & Chen 2008), and even in Oceania (Myers 1927). The adults feed on various shrubs, bushes and trees (China 1942). The nymphs are root feeders, especially on grasses, and live in crevices in the ground (China 1942).

Twelve species with equivocal relationships have been assigned to *Cixius*: *Cixius vitreus*, *C. fraternus*, *C. gracilis*, *C. insignis*, *C. longirostris*, *C. sieboldtii*, *C. succineus*, *C. testudinarius* and *C. loculatus* Germar & Berendt, 1856 from the Baltic Sea, *C. petrinus* Fennah, 1961 from the UK, and *C. proavus* and *C. hesperidium* Scudder, 1890 from the USA. However, Szwedo *et al.* (2004) argued that only two species (*C. petrinus* Fennah,

1961 and *C. vitreus* Germar & Berendt, 1856) were tentatively attributable to *Cixius*. In addition, Szwedo *et al.* (2004) considered that two undescribed specimens reported from the upper Oligocene of Germany (Statz 1950) could also be placed tentatively in *Cixius*.

The fossil specimens described herein were collected from the Guide Group at Caergen Village, Duohemao Town, Zeku County, eastern Qinghai Province, Northwest China (34°56'N, 101°48'E, 3700 m a.s.l.; Fig. 1), which constitutes a lacustrine–fluvial sedimentary succession. The Guide Group crops out mainly in the Xining–Minhe, Guide–Hualong, Tongde and Caergen basins of eastern Qinghai Province (Guo 1980, Fang *et al.* 2005), and has been subdivided into five formations: the Guidemen Formation (19–20.8 Ma), the Garang Formation (<16–19 Ma), the Ashigong Formation (7.8 to >11.5 Ma), the Herjia Formation (3.6–7.8 Ma) and the Ganjia Formation (2.6–3.6 Ma; Fang *et al.* 2005). The exposed oil shale beds of the section belonging to the Garang Formation yield abundant, exquisitely preserved fossil plants (Guo 1980). Recently, we collected insect fossils from the Garang Formation, including Diptera, Hymenoptera, Neuroptera, Mecoptera, Odonata and Hemiptera. This material included five well-preserved fossil specimens of Cixiidae, which represent a new species of *Cixius* (Fulgoromorpha: Cixiidae).

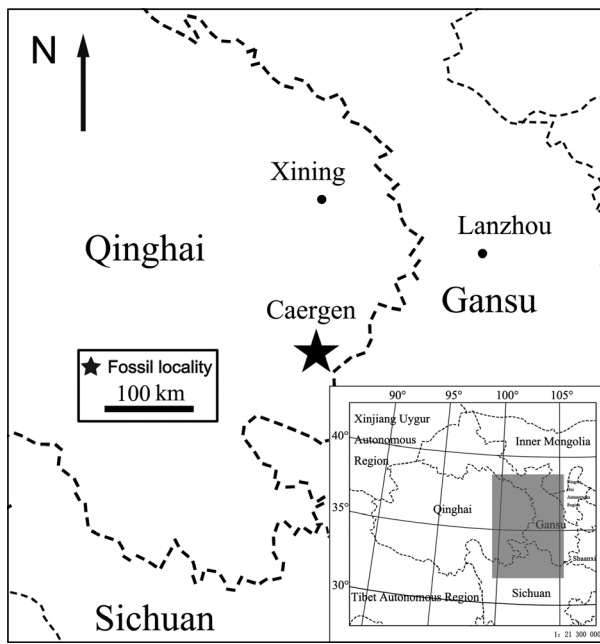


Fig. 1. Map showing the location of the fossil site near Caergen Village.

Materials and methods

All the type specimens are housed in the fossil insect collection of the Key Laboratory of Insect Evolution & Environmental Changes, College of Life Sciences, Capital Normal University, Beijing, China (Capital Normal University (CNU); Dong Ren, Curator). The specimens were examined using Leica M165C microscopes and photographs taken with a Leica DFC 500 digital camera. Line drawings were prepared with Adobe Photoshop Elements 5.0 graphics software. The wing venation nomenclature used in this paper is based on the interpretations and system proposed by Bourgoïn *et al.* (2015).

Systematic palaeontology

Order HEMIPTERA Linnaeus, 1758
 Suborder FULGOROMORPHA Evans, 1946
 Superfamily FULGOROIDEA Latreille, 1807
 Family CIXIIDAE Spinola, 1839
 Subfamily CIXIINAE Spinola, 1839
 Tribe CIXIINI Spinola, 1839

Cixius Latreille, 1804 emend

Subgenus **Cixius** Wagner, 1939

Revised diagnosis. Frons flat and wide, its width longer than its length. Median carina of frons nonbranched. Clypeus in lateral view elevated. Head narrower than pronotum. Forewing lacking basicostal field. In forewing, ScP, R and M from basal cell. ScP+R and MP fused in a short stem. Vein A1 not strongly curved and elevated. Veins covered with chaetae. In hind wing, MP and CuA₁ partly or completely fused.

Type species. *Cicada nervosa* (Linnaeus, 1758).

Included fossil species. *Cixius discretus* Li, Liu, Ren, Li & Yao sp. nov. and *C. petrinus* Fennah, 1961.

Cixius discretus Li, Liu, Ren, Li & Yao sp. nov. (Figs 2, 3, 4)

Etymology. The specific name is derived from Latin *discretus* ('discrete'), referring to the pterostigma separating from the veins.

Material examined. Holotype ♀, No. CNU-HEM-QZ2015001 (Figs 2A–B, 4B), in ventral view, with relatively complete wings, but body is broken. Paratypes ♀, No. CNU-HEM-QZ2015003 (Fig. 2C–D) and CNU-HEM-QZ2015005 p/c (Fig. 3C–D). Gender unknown, No. CNU-HEM-QZ2015002 (Figs 3A, 4A) and CNU-HEM-QZ2015004 (Fig. 3B). Deposited at the Key Lab of Insect Evolution & Environmental Changes, the College of Life Sciences, CNU, Beijing, China.

Unit, age and locality. Garang Formation; early Miocene; Caergen Village, Zeku County, Qinghai Province, China.

Diagnosis. In forewings, pterostigma separated from veins. ScP+R forking at 0.33–0.37 of tegmen length. Cell between RP branches present. MP forking at about 0.59 of tegmen length. CuA bifurcation slightly basad of fork of ScP+R. Two crossveins *m-cu*, one crossvein *icua* and one crossvein *icu* present. Claval veins Pcu+A1 entering the commissure close to the apex. Tegmen without any markings or bands.

Description. Holotype. Body length 4.52 mm; width 2.03 mm.

Forewings. Tegmen surpassing the abdomen moderately. Pterostigma conspicuous and triangular. Costal margin mildly curved at base, without basicostal field, almost straight in median portion, rounded-angular in apical portion of tegmen, with no projecting apex. Crossveins in costal area and postcostal cell absent. ScP not reaching pterostigma and RA monobranched. RP forking at apical portion in four branches to the tegmen margin. Fork of MP apicad of forks of ScP+R and CuA, with five branches. Nodal line absent. Crossveins including two *ir*, two *r-m*, two *im* and two *m-cu* visible. Apical crossveins irregular, not forming distinct line. Veins covered with chaetae.

Hind wing. ScP+RA finishing distinctly above apex of hind wing. RP₁ and RP₂ connected with margin at apex of hind wing. MA with two branches, MP monobranched and CuA with two branches. Crossvein *r-m* long, placed basal of M branches. Crossvein *m-cu* relatively short.

Abdomen. Abdomen conical, with eight visible segments. Connexivums not preserved.

Paratype CNU-HEM-QZ2015002. Tegmen 5.13 mm long, 2.15 mm wide at widest point. Pterostigma

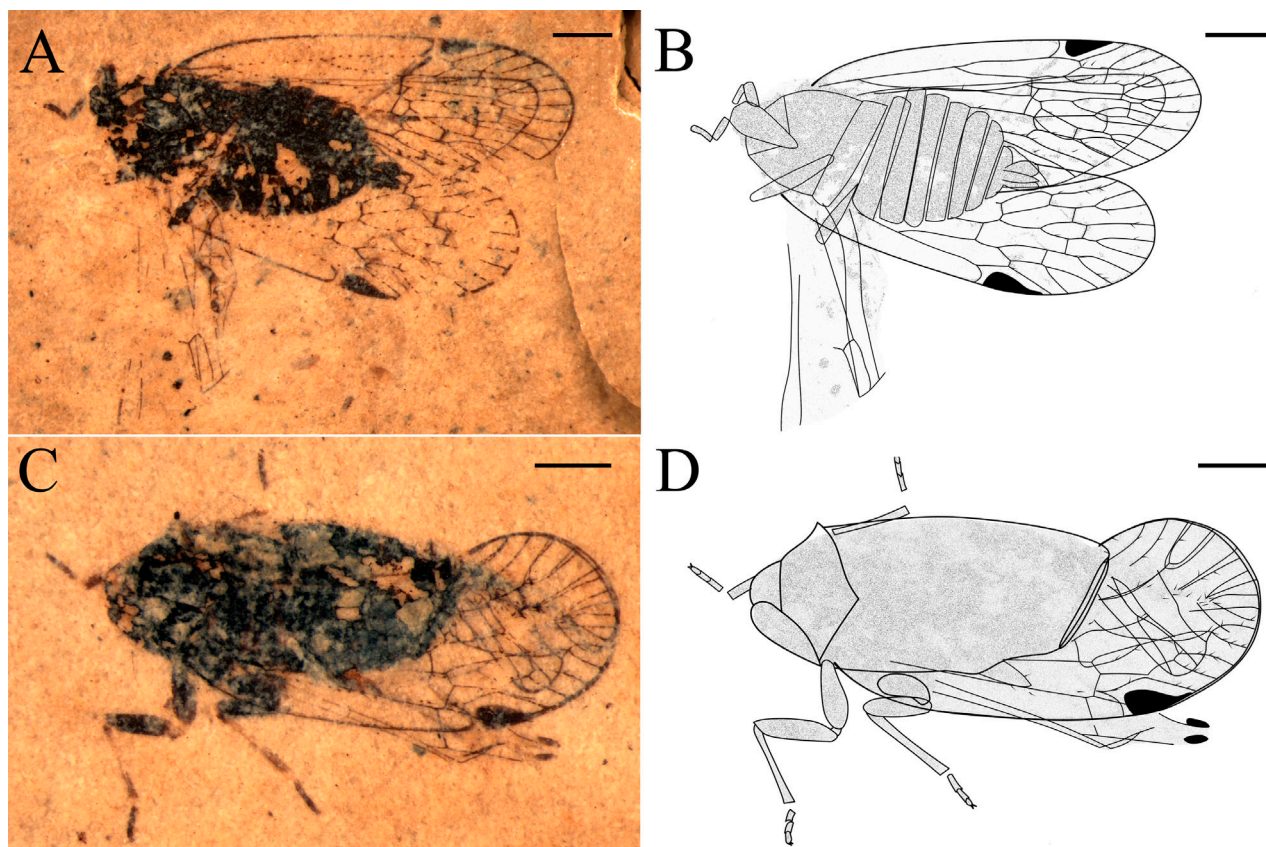


Fig. 2. *Cixius discretus* sp. nov. A, B, Holotype, CNU-HEM-QZ2015001: A, Photograph, under alcohol; B, Interpretative drawing of A. C, D, Paratype, CNU-HEM-QZ2015003: C, Photograph, under alcohol; D, Interpretative drawing of C. Scale bars = 1 mm.

conspicuous and triangular. Costal margin mildly curved at base, without basicostal field, almost straight in median portion, rounded-angular in apical portion of tegmen, with no projecting apex. Crossveins in costal area and postcostal cell absent. Basal cell triangular and truncated distally, about three times longer than its widest part. ScP+R and MP with a short common stem after the basal cell. ScP not reaching pterostigma and RA monobranched. RP separating in four branches. MP simple at base, forking apicad of forks of ScP+R and CuA, with five branches. CuA bifurcation slightly basad of fork of ScP+R, CuA₁ branch distinctly arcuate. Nodal line absent. Crossveins include two *ir*, two *r-m*, two *im*, two *m-cu*, one *icua* and one *icu*. Two crossveins *r-m* enclosing C2. Apical crossveins irregular, not forming distinct line. Clavus very long, with apex reaching half of tegmen length. Claval veins Pcu and A1 fused at about half of clavus length. Common claval vein entering commissure before claval apex. Veins covered with chaetae.

Paratype CNU-HEM-QZ2015003. Head: vertex flattened; postclypeus visible. Thoracic legs: fore coxae long; fore and middle tibiae widening toward apex; tarsi with three tarsomeres; basitarsi longer than mesotarsi and pretarsi, with claws. Wings not well preserved.

Paratype CNU-HEM-QZ2015005 p/c. Head: vertex flattened; median carina of frons distinct; postclypeus visible. Thoracic legs: fore femora visible.

Paratype CNU-HEM-QZ2015004. Not well preserved.

Measurements (mm). Body length 4.01–5.13, maximal width of body 1.75–2.15. Middle leg: 3.04; coxa 0.82; femur 0.94; tibia 0.90; tarsi 0.38. Hind leg: tibia 1.02; tarsi 0.48. Forewing: length 5.13–5.71, width 1.99–2.15.

Remarks. The new species is recognized as being most similar to *Cixius nervosus*, but differs in the position of the pterostigma, the numbers of RP branches, the number of *ir*, the cell between RP branches, C4, C5, the apical cell of MP₁, the distance between the apex of Pcu+A1 and the claval apex, the lack of markings on the forewings, and curvature of CA in the hind wing.

Discussion

We can not fully compare with other species assigned tentatively to *Cixius* because their descriptions were not exhaustive and the illustrations were not comprehensive. However, *Cixius petrinus* Fennah, 1961 is an exception. According to the original authors, *C. petrinus* has the following characters: forewing lacking basicostal field; in forewing, ScP, R and M derive from basal cell; vein A1 not strongly curved and elevated; in hind wing, MP and CuA₁ partly or completely fused. These are the

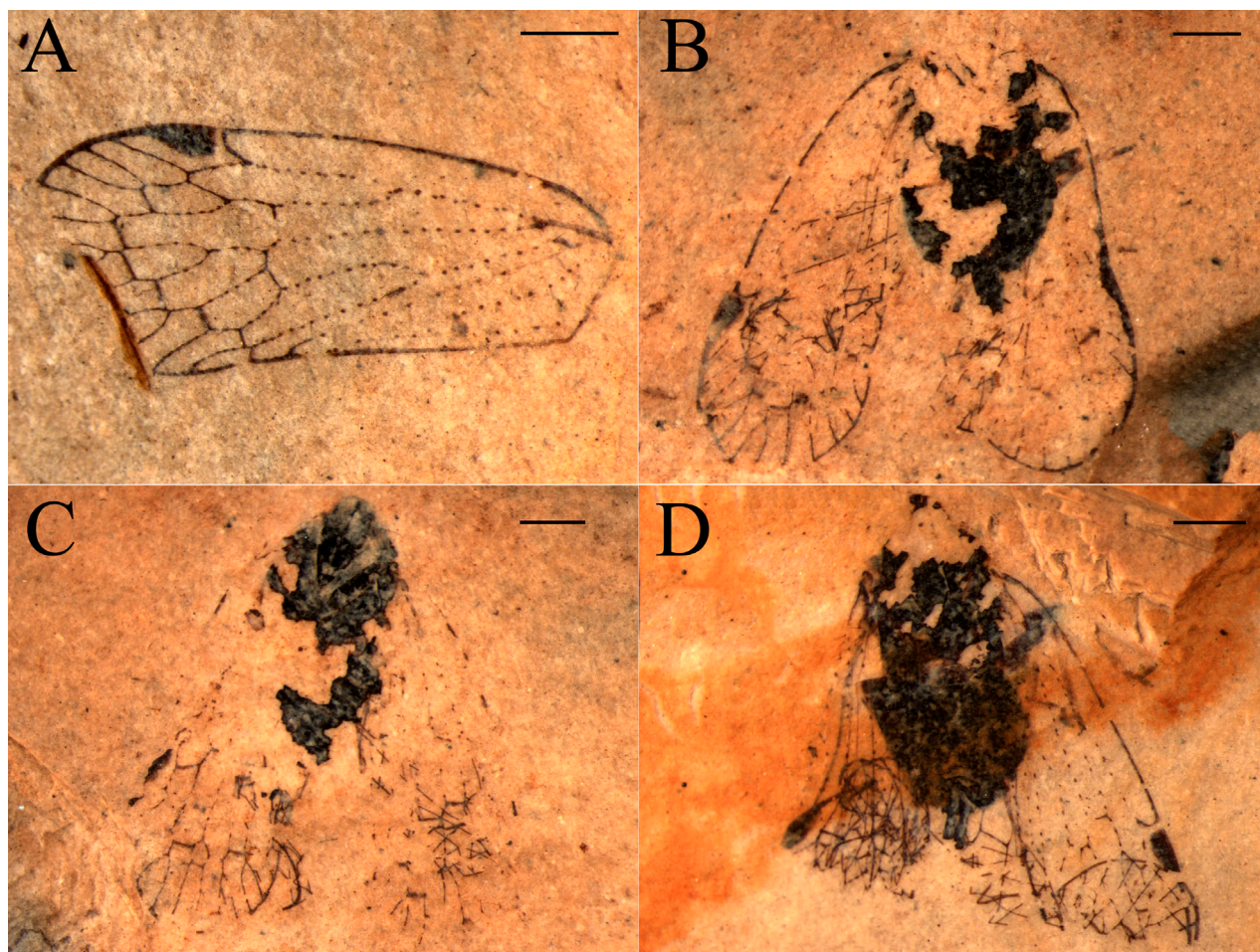


Fig. 3. *Cixius discretus* sp. nov. A–D, Photographs of paratypes, under alcohol: A, CNU-HEM-QZ2015002; B, CNU-HEM-QZ2015004; C, Part of CNU-HEM-QZ2015005; D, Counterpart of CNU-HEM-QZ2015005. Scale bars = 1 mm.

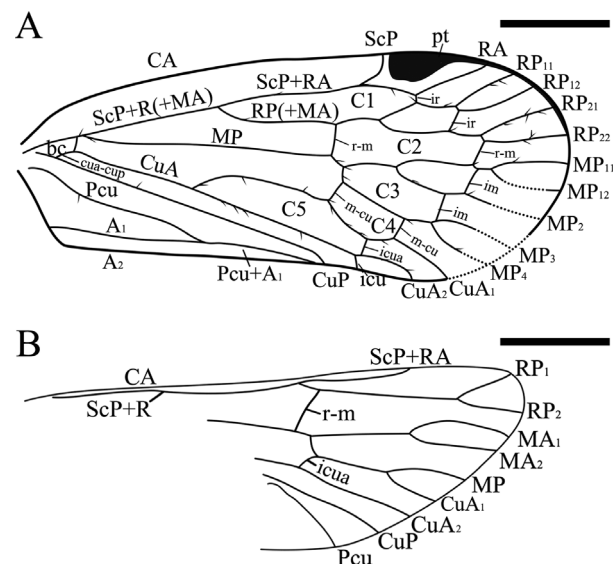


Fig. 4. Line drawing of wings of *Cixius discretus* sp. nov. A, Forewing of CNU-HEM-QZ2015002; B, hind wing of CNU-HEM-QZ2015001; bc, basal cell; pt, pterostigma. Scale bars = 1 mm.

main diagnostic features of the genus. Although we did not examine this fossil specimen, based on the available evidence, we consider it representative of *Cixius*.

The fossil species confidently attributable to *Cixius* are, thus, only: *C. petrinus* Fennah, 1961 from the Early Cretaceous of the UK and *Cixius discretus* sp. nov. from the Early Miocene of Qinghai (Fig. 5). However, extant *Cixius* is distributed in most areas of the world (Fig. 5). During the Cretaceous, North America was isolated (Jia 1994) and Australia only connected to Antarctica. If *Cixius* had a single origin and was unable to overcome marine barriers, we consider that the genus must have dispersed globally prior to the Cretaceous.

Extant *Cixius* is most common throughout the United States and Europe (Kramer 1981, Nickel & Remane 2002, Holzinger & Kunz 2006, Demir 2008, Trivellone 2010, Bowser 2014). Extant species of *Cixius* also occur in Russia, South China, Japan, Borneo, parts of Western Asia, Nigeria, southern Australia, New Zealand and Mexico (Distant 1907, Fennah 1956, Kramer 1981, Van Stalle 1984, Liang & Suwa 1998, Larivière 1999, Dmitriev 2002, Vadell & Hoch 2009). Extant *Cixius* is adapted to tropical rainy, tropical savanna, tropical monsoon, subtropical monsoon, Mediterranean, middle-latitude monsoon, temperate continental and temperate maritime climates. Guo (1980) suggested that the climate in Zeku during the Miocene was temperate or warm-temperate

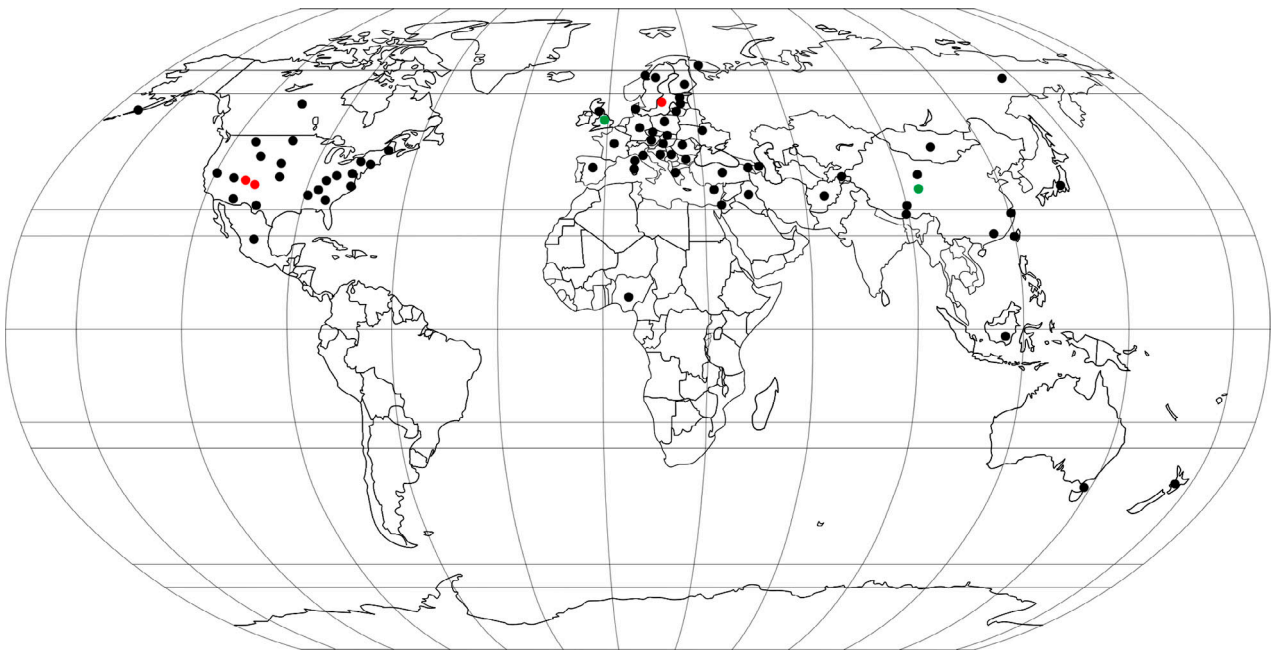


Fig. 5. Distribution of *Cixius*. The black spots represent the distribution of extant *Cixius*, the red spots represent the distribution of doubtful fossil *Cixius*, and the green spots represent the distribution of valid fossil *Cixius*.

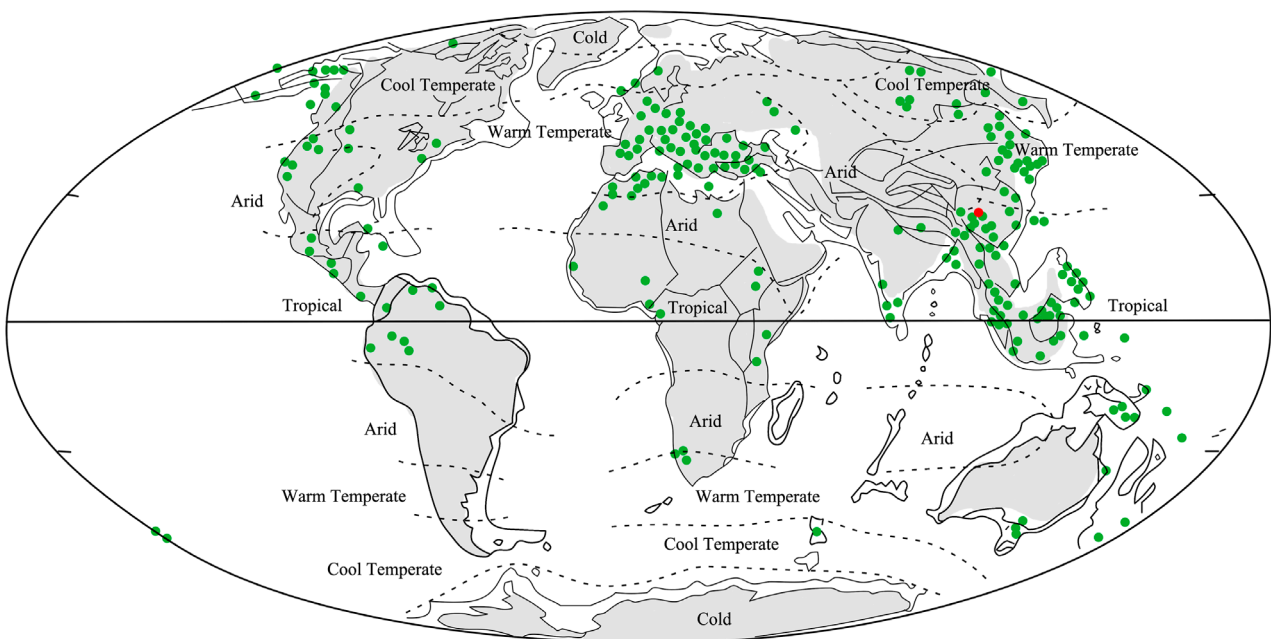


Fig. 6. Map of Miocene climate (from Scotese 2000). The green spots represent the distribution of coal, and the red spots represent the collection site of the new species.

and arid, based on plant fossils. Furthermore, considering the overall Miocene palaeoclimate (Scotese 2000), the collection site of the new species was located in the transitional zone between warm and hot areas and the junction between arid and humid areas (Fig. 6). Hence, we speculate that the fossil species originally lived in a warm-temperate and mildly arid climate.

Some extant species of *Cixius* live on tall trees, such as spruce, fir, hickory, aspen, poplar and pine, and

medium-sized trees, such as willow (Kramer 1981). *Cixius discretus* might have fed and lived on similar types of coexisting plants in the Miocene. The Garang Formation in Zeku is reported to preserve fossils of diverse shrubs and trees, including fir, willow and legumes (Guo 1980). In addition, the new fossil *Cixius* constitutes indirect evidence that the environment of Zeku in the Miocene was wooded and shrubby, which differs from the present typical plateau meadow.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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