Two new species of fossil *Eomerope* (Mecoptera: Eomeropidae) from the Ypresian Okanagan Highlands, far-western North America, and Eocene Holarctic dispersal of the genus

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Abstract—Two new species of Eocene *Eomerope* Cockerell (Mecoptera: Eomeropidae) are described from the Ypresian Okanagan Highlands deposits of British Columbia, Canada: *Eomerope simpkinsae* **new species** from the Allenby Formation near the town of Princeton, and *Eomerope eonearctica* **new species** from the McAbee locality near the towns of Cache Creek and Ashcroft. *Eomerope eonearctica* is very close to the coeval *Eomerope asiatica* Ponomarenko from Primorskiy Kray in Pacific-coastal Russia, consistent with Eocene intercontinental dispersal, which is well documented in numerous plant and animal taxa.

Introduction

Today, the family Eomeropidae (Mecoptera) consists of a single species, *Notiothauma reedi* MacLachlan, which inhabits the Valdivian southern beech (*Nothofagus* Blume, Nothofagaceae) forests of central Chile. It has a cockroach-like form and habits, active nocturnally on the forest floor in the leaf litter, where it apparently feeds on plant material (Peña 1968; Penny 1975; and see review by Archibald *et al*. 2005).

Soszyńska-Maj *et al*. (2016) recently reviewed the fossil record of the family and provided a genus-level phylogenetic analysis and a discussion of the evolution of key wing characters. Its oldest known member is the Early Jurassic *Jurachorista bashkuevi* Soszyńska-Maj *et al*. from the United Kingdom, followed by the Middle Jurassic Chinese *Tsuchingothauma shihi* Ren and Shih and *Jurathauma simplex* Zhang *et al*., and two Cretaceous species, *Typhothauma yixianensis* Ren and Shih and *Typhothauma excelsa* Zhang *et al*., also from China (Ren and Shih 2005; Zhang *et al*. 2011, 2012; Soszyńska-Maj *et al*. 2016).

Four species are known in the Cenozoic, all belonging to the genus *Eomerope* Cockerell. *Eomerope macabeensis* Archibald *et al*. from the McAbee locality of the Okanagan Highlands in British Columbia, Canada, and *E. asiatica* Ponomarenko from the Tadushi Formation in Primorye (Primorskiy Kray), Russia are both Ypresian. *Eomerope tortriciformis* Cockerell from Florissant, Colorado, United States of America is Priabonian, and *E. pacifica* Ponomarenko from the Amgu locality in Primorye, is also Priabonian, or perhaps Rupelian (Cockerell 1909; Ponomarenko and Rasnitsyn 1974; Archibald *et al*. 2005). Archibald *et al*. (2005) discussed the biogeography and ecology of the family in the Cenozoic.

Here, we describe two new species of *Eomerope* from the Ypresian Okanagan Highlands series in British Columbia, Canada: one from the Allenby Formation near the town of Princeton

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in southern-most British Columbia, and the second from the McAbee locality in south-central British Columbia near the towns of Cache Creek and Ashcroft.

Materials and methods

We examined three new fossils in Okanagan Highlands laminated lacustrine shale, two from the McAbee locality in south-central British Columbia in the collections of Thompson Rivers University (Kamloops, British Columbia, Canada), and the third from the Vermilion Bluffs Shale unit of the Allenby Formation near Princeton, British Columbia in the Royal British Columbia Museum (Victoria, British Columbia, Canada). We also examined specimens of *E. asiatica* from the Tadushi Formation of Primorye in Pacific-coastal Russia, housed in the collections of the A.A. Borissiak Paleontological Institute, Russian Academy of Sciences (Moscow, Russia). Line drawings were made of these specimens from new photographs.

While the specific Allenby Formation locality where the specimen examined here was recovered has not been dated, an age of 52.08 ± 0.12 million years old was estimated by U-Pb analysis of zircons for an exposure of the Vermilion Bluffs Shale at nearby Hospital Hill in Princeton (Moss *et al.* 2005). McAbee has been dated as 52.90 ± 0.83 million years old by $^{40}Ar/^{39}Ar$ decay (Archibald *et al.* 2010). There is no precise age estimate for the Tadushi Formation in Primorye, but it is also Ypresian by stratigraphy (Popov and Grebennikov 2001, not late Paleocene as in Archibald *et al.* 2005).

Abbreviations: PIN, the A.A. Borissiak Paleontological Institute, Russian Academy of Sciences, Moscow, Russia; PDM, Princeton and District Museum and Archives, Princeton, British Columbia, Canada; RBCM, Royal British Columbia Museum, Victoria, British Columbia, Canada; TRU, Thompson Rivers University, Kamloops, British Columbia, Canada. Terminology of wing venation follows that of Willmann (1989) as employed by Archibald *et al.* (2005) and by Soszyńska-Maj *et al.* (2016), in which Rs includes MA sensu Ponomarenko and Rasnitsyn (1974).

Eomerope simpkinsae Archibald and Rasnitsyn, new species

Fig. 1.

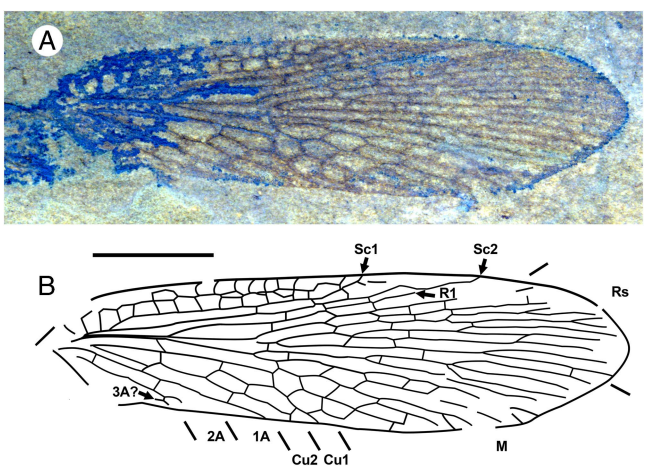
Etymology

The specific epithet is formed from the surname of Kathy Simpkins, collections manager of fossils at the PDM, who found and donated the holotype specimen.

Type specimen

Holotype RBCM.EH2017.003.0001.001, part, no counterpart, a single forewing, mostly rather

Fig. 1. *Eomerope simpkinsae* **new species**, holotype forewing. **A**, Photograph, wetted with ethanol; **B**, drawing. Scale bar = 5 mm, both to scale.



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well preserved. Housed in the collections of the RBCM.

Locality and age

An exposure of the Vermilion Bluffs Shale unit of the Allenby Formation on Black Mine Road, near the town of Princeton, British Columbia, Ypresian.

Diagnosis

Easily separated from other species of *Eomerope* by its narrow forewing, width to length ratio 1:3.7 (*E. macabeensis*, 1:2.8; *E. eonearctica*, 1:2.6–2.8; *E. pacifica*, 1:2.3; *E. tortriciformis* and *E. asiatica* forewings incomplete, but preserved portions indicate similar shape to *E. macabeensis* and *E. eonearctica*, *i.e.*, not narrow); also by combination of the following: 1A, 2A rather straight (*E. macabeensis*, zigzagged); two rows of cells with occasional third cell between C, Sc1 (*E. asiatica* and *E. macabeensis*, two rows (some variation in *E. asiatica*, see Fig. 5); *E. tortriciformis*, three rows in much of this space; *E. pacifica*, three rows in distal half of space).

Description

Forewing as in diagnosis, and: length 24.0 mm, width 6.5 mm, broad costal space, apparently (as preserved) bowed out from base, *i.e.*, without narrow basal-most portion (compare with *E. pacifica*, *E. torticiformis*); veins thickened in approximately basal half, then narrower; no colouration detected; costal space mostly with double-cell row but also a few cells between these to make three cells deep, ending with Sc1 just over half wing length; Sc with two branches, forking about one-eighth the wing length; R forks at basal one-fourths; R1 rather straight (somewhat zigzagged by crossveins in places), apical quarter not preserved; Rs with at least 11 branches (indistinctly preserved near apex); base of M close to R, M with 12 branches as preserved; Cu branched immediately basad branching of Sc; Cu1 and Cu2 apparently simple, both zigzagged by crossveins, Cu1 bent sharply posteriad approximately two-thirds length; Cu2 not sharply bent; 1A, 2A mostly preserved, straight; small portion of 3A preserved. Crossveins numerous, stronger basally, faintly preserved apically, creating irregular cells between branches of Cu; crossvein connecting two crossveins that join Cu1 and Cu2 creates two cells between Cu1 and Cu2 at maximum width, *i.e.*, area of sharp bend of Cu1 ("third position" of Fig. 5, red).

Discussion

The narrow shape of the wing is surely not due to plastic deformation of the rock. While some small amount of distortion is at times seen in Allenby Formation fossils, it is never seen to the extent that would be required to transform a forewing shaped like those of all other *Eomerope* species to the shape of the *E. simpkinsae* forewing. Some slight deformation can be seen in the McAbee specimen F-780 (note minor difference between left and right wings in Figs. 2–3, 5), and some specimens of *E. asiatica* show more extreme distortion (Figs. 5–6, and see Ponomarenko and Rasnitsyn 1974, fig. 7), but again, never near the extent necessary to transform one to this shape.

We assign the new species to *Eomerope* primarily by venation of the anterior portion of the wing. All *Eomerope* species have between two and three rows of cells in the C-Sc1 space and a few crossveins in the Sc1-Sc2 space, as in *Eomerope simpkinsae* (two rows of cells with occasional cells between C and Rs1). This excludes it from *Notiothauma* MacLachlan (many rows between C and Sc, Sc simple) and the Mesozoic genera *Tsuchingothauma* Ren and Shih (five rows between C and Sc2), and *Jurathauma* Zhang *et al*. (one row between C and Sc1 and a few crossveins between Sc1 and Sc2). Only *Typhothauma* Ren and Shih has a configuration in this space like that found in *Eomerope*, with two rows of cells between C and Rs1, and an Rs1-Rs2 space with a few crossveins. *Eomerope* is distinct from *Typhothauma*, however, by the branching of Cu1 in the forewing: three branches in the holotype of *T. yixianensis*, and four as preserved in the holotype of *T. excelsa*. Cu1 is simple where it is known in *Eomerope*, although this is unknown by preservation in the type species of the genus, *E. tortiriciformis*.

Eomerope eonearctica Archibald and Rasnitsyn, new species

Figs. 2–6

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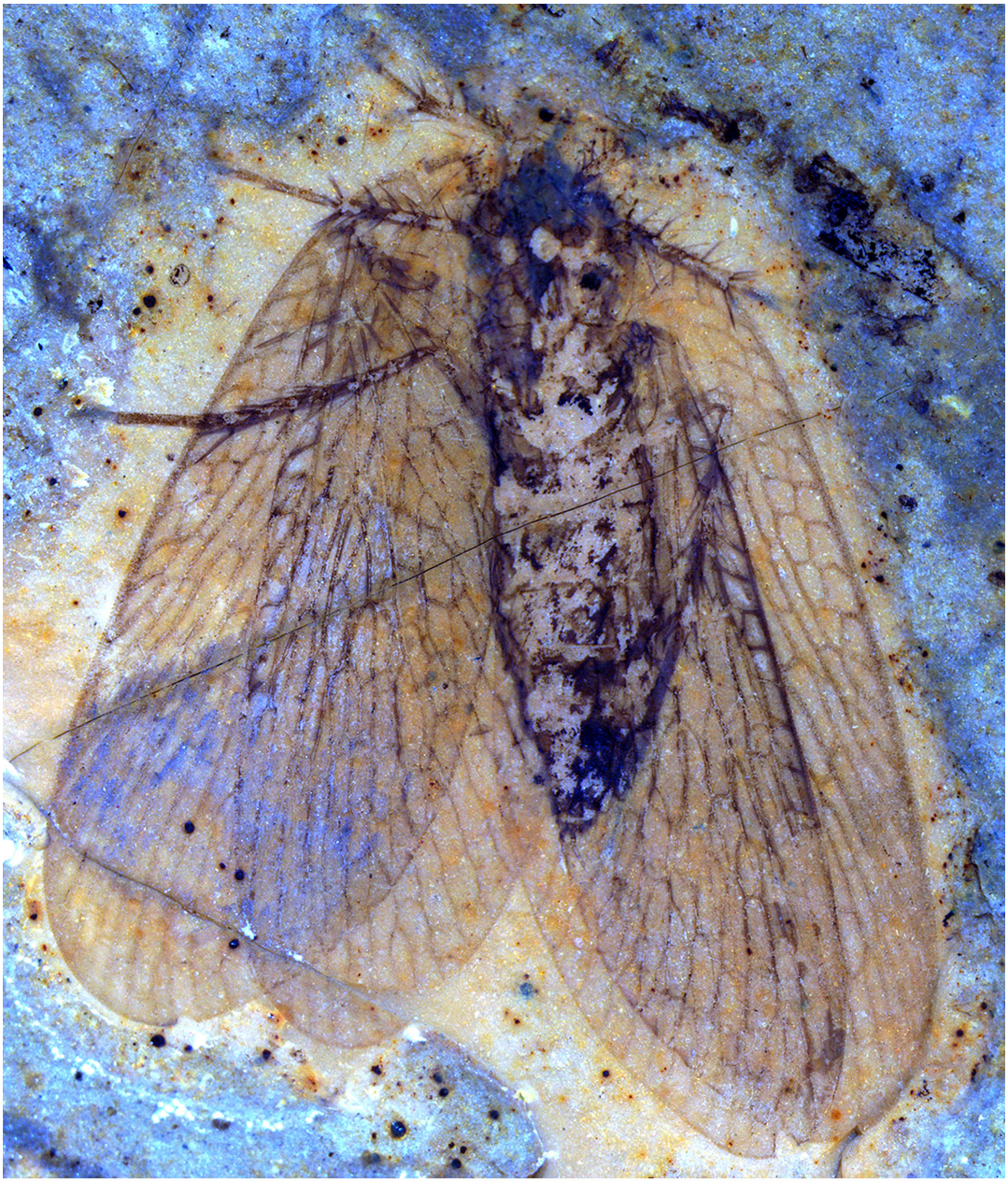
Fig. 2. *Eomerope eonearctica* **new species**, holotype (F-780). Photograph of the specimen wetted with ethanol. Scale bar = 5 mm.



Etymology

The specific epithet combines *Eo*-, Greek for "dawn", from Eocene, and Nearctic, alluding to the very similar *E. asiatica* and to the intercontinental dispersal of plants and animals around this time. The name should be treated as an adjective in the nominative singular.

Type specimens

Holotype TRU F-780 (Figs. 2–3, 5–6), a complete specimen, female, preserved in ventral aspect, with forewings partly overlapping hind wings. Paratype TRU F-781 (Fig. 3, 5–6), a well-preserved forewing. Both collected by unknown persons at the McAbee site, housed in the collections of TRU.

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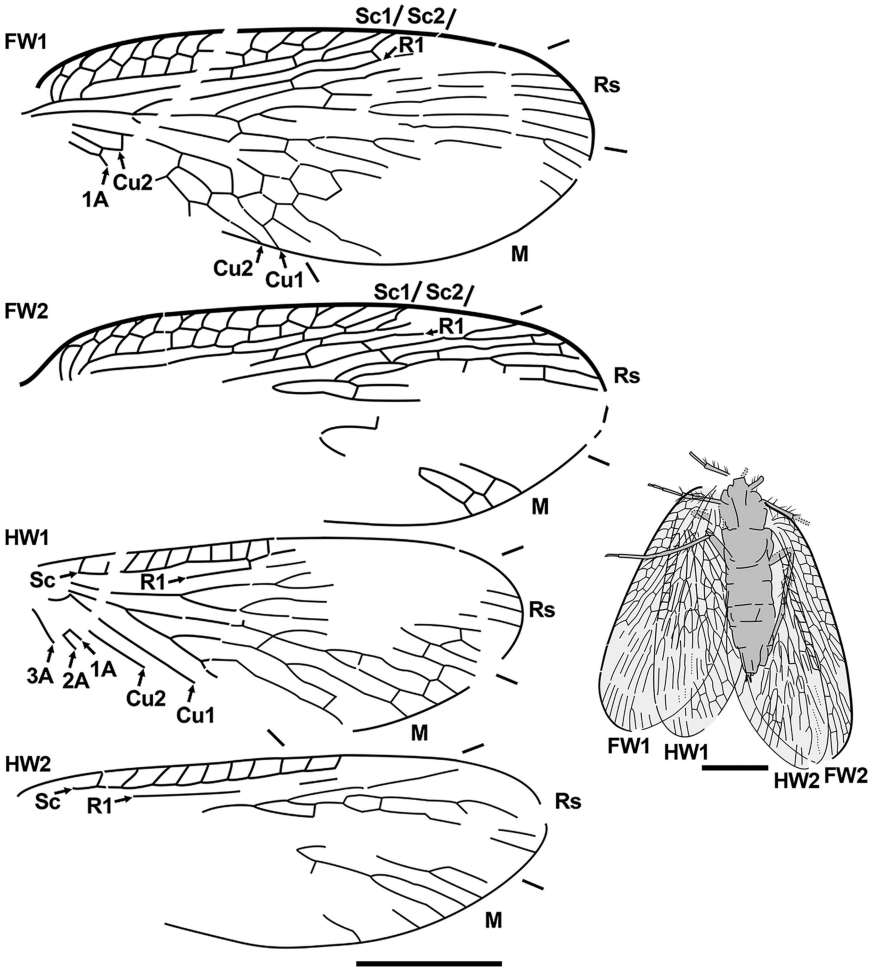
Fig. 3. *Eomerope eonearctica* **new species**, holotype (F-780). Drawings of the wings (colouration omitted and veins in overlapping portions of wings that cannot be confidently assigned to either are omitted) and positions of the wings indicated by a drawing of the complete specimen. Scale bars = 5 mm.



Locality and age

McAbee, British Columbia, Ypresian.

Diagnosis

Forewing is distinguished from those of other species of *Eomerope* most easily by the following: from *E. tortriciformis* and *E. pacifica* by two rows of cells in the C-Sc1 space (*E. tortriciformis*, three in part; *E. pacifica*, three in part); further from *E. pacifica* by elongate shape, width:length ratio of 1:2.6–2.8 (*E. pacifica*, 1:2.3); from *E. macabeensis* by third Cu1-Cu2 cell divided (*E. macabeensis*, not so divided: Fig. 5, red); from *E. asiatica* by infuscation throughout wing (*E. asiatica*, membrane hyaline except for pterostigma), by ranging to larger size (see discussion below); from *E. simpkinsae* by shape as in its diagnosis, above.

Description

Holotype TRU F-780 (Figs. 2, 4–6). Female. Body dark in colouration, length 14.8 mm. Head. Indistinctly preserved. Legs. As in *E. macabeensis*, with many thick, long setae on tibiae. Thorax, abdomen difficult to interpret as preserved, but apparently generalised as in other Cenozoic female Eomeropidae. Abdomen tapers caudad. Wing membrane, veins infuscate throughout. Right forewing (FW1 of Figs. 3, 5). Length ~ 20.0 mm, width ~ 8.0 mm (width:length,

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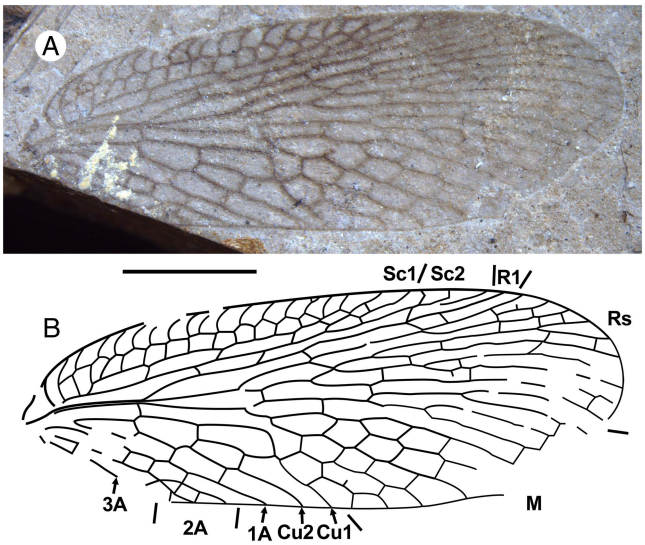
Fig. 4. *Eomerope eonearctica* **new species**, paratype forewing (F-781). **A**, Photograph; **B**, drawing (colouration omitted). Scale bar = 5 mm, both to scale.



1:2.6), expanded costal space; veins thicker basally; C bowed outward basally, then rather straight to apical quarter; costal space with regular double-cell row ending about 2/3 wing length; Sc with two branches, forking one-eighths wing length; R forks at basal quarter; R1 slightly zigzagged, apical portion not preserved; Rs with at least eight branches (indistinctly preserved in part); base of M not preserved; apical region of M not clearly preserved; Cu: Cu1 and Cu2 apparently simple, Cu1 strongly bent posteriad approximately two-thirds length; Cu2 zigzagged, not sharply bent; small portion of 1A preserved; crossveins numerous; many between branches of Rs and M, stronger basally, a few preserved apically; crossvein connecting two crossveins that join Cu1 and Cu2 creates two cells between Cu1 and Cu2 at maximum width, *i.e.*, area of sharp bend of Cu1 (Fig. 5, red). Left forewing (FW2 of Figs. 3, 5) most clearly preserved in anterior region, more in mid wing. Length ~ 20.0 mm, width ~ 7.5 mm (width:length, 1:2.7). All preserved parts agree with right wing as above, with minor differences in crossveins. Right hind wing (HW1 of Figs. 3, 5). Length ~ 16.9 mm, width ~ 6.6 mm as preserved (basal-most portion not clear). C not bowed out, anterior margin rather straight to apical quarter; Sc not branched, with one row of cells in C-Sc space, not preserved apically; R1 not preserved (but space present where it should be); Rs branches about basal third wing length, with four branches preserved, apical region of Rs not preserved; M with at least six branches preserved. Portions of presumably Cu1 and Cu2 preserved, straight. Small portions of presumably 1A, 2A, 3A preserved. Left hind wing (HW2 of Figs. 3, 5) ~ 18.0 mm, width ~ 6.5 mm as preserved. Much of Sc and single cell row in C-Sc1 space preserved, extending at least three-quarters the wing length, then not preserved. Some apical branching of Rs and portions of distal branches of M preserved.

Paratype

F-781 (Figs. 4–6). Forewing. Length 22.5 mm, width 8.0 mm, broad (width:length, 1:2.8), veins thickened in approximately basal half, narrower apically; membrane infuscate; wide costal space apparently without narrow basal-most portion; C-Sc1 space with regular double-cell row ending after middle of wing length; Sc with two branches, forking one-eighth the wing length; R forks at basal quarter; R1 rather straight to anterior margin; Rs with at least 10 branches (indistinctly preserved near apex); base of M very close to R, straight or only slightly bent at forking of R1 and Rs; irregularly branched to approximately nine at margin; Cu branched immediately basad branching of Sc; both Cu1 and Cu2 apparently simple,

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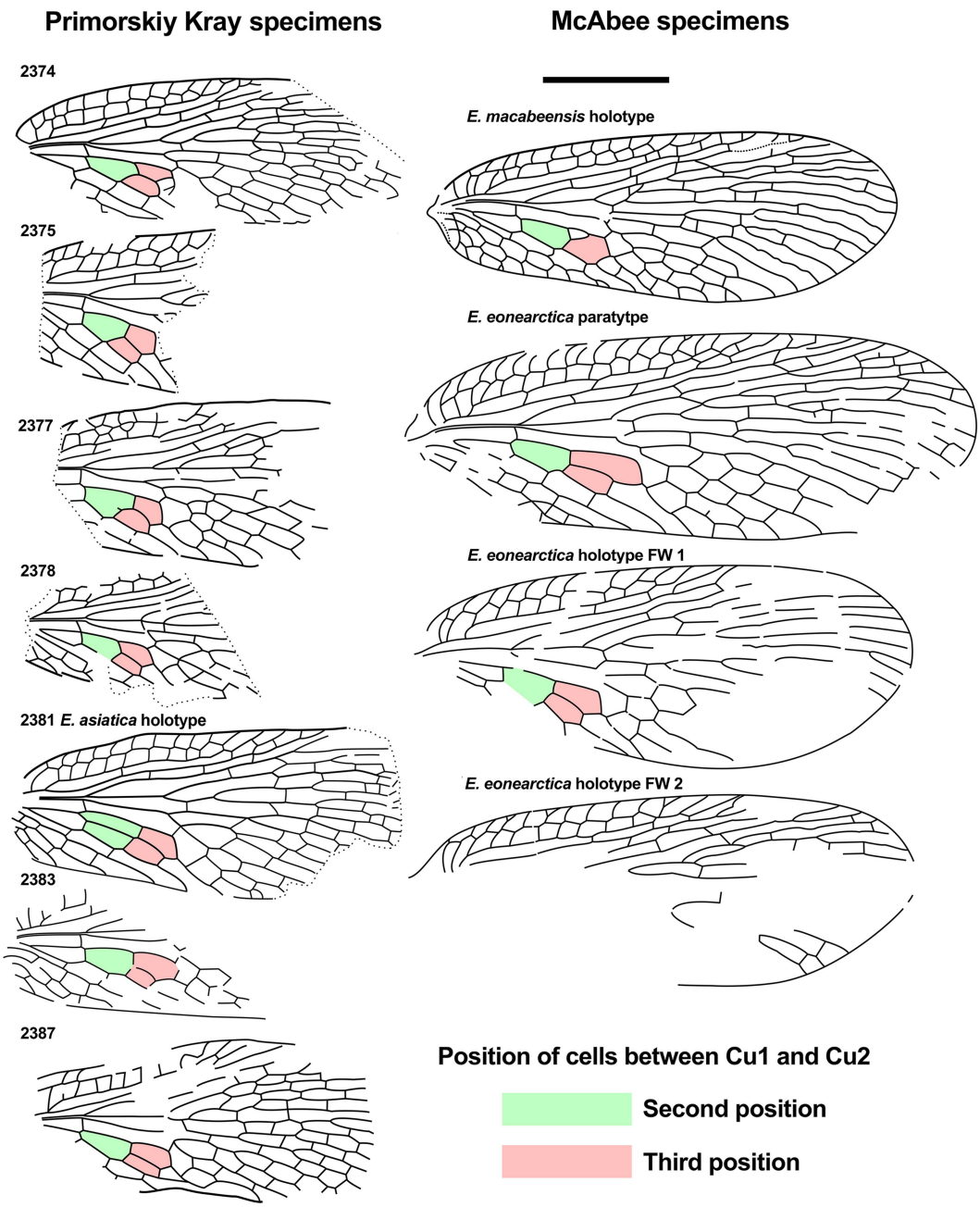
Fig. 5. Drawings of the forewings of *Eomerope asiatica* from Primorye, Russia (except specimen 2383, see text) based on combined morphology preserved on the part and counterpart (where available) compared with those of the McAbee *E. eonearctica* (F-780 and F-781) and *E. macabeensis*. Scale bar = 5 mm, all to scale. Wing colouration omitted.



Cu1 strongly zigzagged by crossveins, bent sharply posteriad approximately two-thirds length; Cu2 not sharply bent, rather straight (some zigzag); three anal veins preserved, 1A and 2A, rather straight (some zigzag), 3A straight where partially preserved; crossveins numerous; many between branches of Rs and M, stronger basally, not preserved in most of apical portion;

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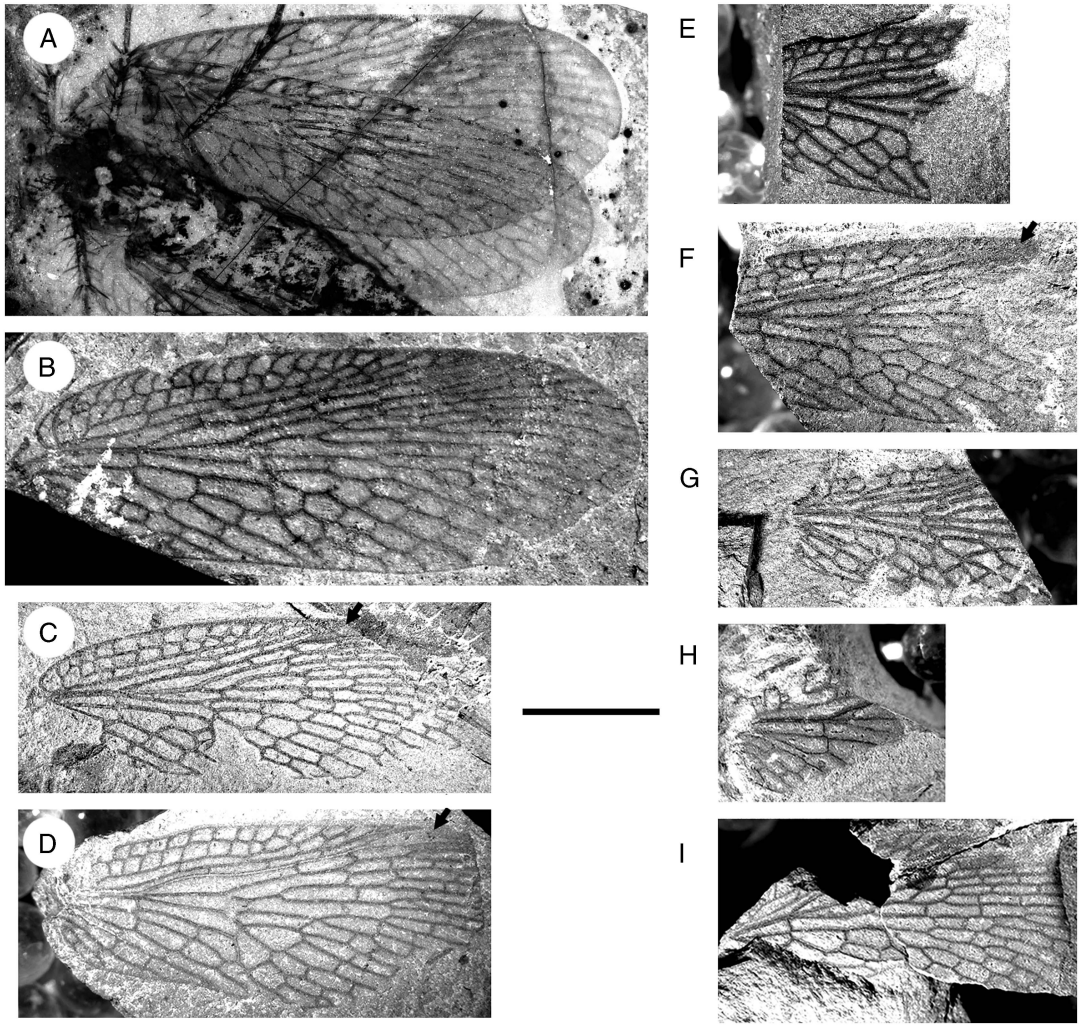
Fig. 6. Primorye and *Eomerope eonearctica* forewings in greyscale with increased contrast to show infuscate membrane in *E. eonearctica* forewings and Primorye specimen 2383 (*Eomerope* (?) indeterminate, see text), and hyaline membrane (except for the pterostigma, see arrows) in *E. asiatica*. **A**, *Eomerope eonearctica* holotype (F-780); **B**, *E. eonearctica* paratype (F-781); **C**, *E. asiatica* paratype (2374); **D**, *E. asiatica* (2381); **E**, *E. asiatica* (2375); **F**, *E. asiatica* (2377); **G**, *E. asiatica* (2378); **H**, *Eomerope* (?) indeterminate (2383); **I**, *E. asiatica* (2387). Some differ from their drawings in Fig. 5, as those combine morphology from both the part and counterpart. Scale bar = 5 mm, all to scale.



crossvein connect two other crossveins that join Cu1 and Cu2 creating two cells between Cu1 and Cu2 at maximum width, *i.e.*, area of sharp bend of Cu1 (Fig. 5, red).

Discussion

The new species is assigned to *Eomerope* by the same reasons as discussed under *E. simpkinsae*, above. The forewings of the McAbee specimens F-780 and F-781 are very similar to those of *E. asiatica* (Fig. 5). Ponomarenko and Rasnitsyn (1974) examined 12 specimens of the species, which showed extensive variability, particularly in the radial sector. We examined 10 of these in the PIN collections: numbers 2374 (paratype), 2375, 2376, 2377, 2378, 2380, 2381 (holotype), 2383 (paratype), 2384, and 2387. Specimen 2384 is quite compressed, incomplete, and the remaining

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specimens are fragmentary and/or distorted, and these were excluded as not informative here. Specimens 2376 and 2380 are hind wings, which are quite damaged and fragmentary, and not usefully comparable with the hind wings of F-780. We compared the remaining seven with the McAbee specimens (Figs. 5–6).

Other venational characters vary in this collection. Specimen 2377 shows two cells separating the regular cell rows between C and Sc1, creating an occasional three cells width, as does 2372 (a fragmentary specimen not examined by us, but illustrated by Ponomarenko and Rasnitsyn 1974, fig. 7d). The holotype has two cells wide separating Cu1 and Cu2 between the basal-most cell and two wide separating these veins at the bend in Cu1 ("second position" of Fig. 5, green). All other specimens that we examined had a single cell in this position, although 2377 bears a vein stub in this position (Fig. 5), further supporting the notion of plasticity of this character state within the species rather than separating 2381 as a distinct species from others with a single cell in this position. There are numerous minor differences in the positioning of crossveins.

The wing membrane of the holotype of *E. asiatica* (2381) is hyaline except for the pterostigma (Fig. 6). This is consistent with five of the other six specimens examined (Fig. 6). Colouration of the pterostigma in specimens where this region is preserved supports the notion that if the wing membrane was infuscate throughout in these as in *E. eonearctica*, this would be preserved. We consider this to separate *E. asiatica* from *E. eonearctica*. Wing colouration is consistent in specimens examined of the nearest living relative, *N. reedi*, in the Museum of Comparative Zoology, Harvard University (Cambridge, Massachusetts, United States of America). Only in specimen 2383 (designated as a paratype of *E. asiatica*) is the preserved portion of the wing membrane generally infuscate. We treat this specimen as "*Eomerope* (?) indeterminate", also hesitating to firmly assign it to genus by its fragmentary nature.

Although the *E. asiatica* forewings in the sample examined are incomplete, their preserved portions indicate a variation in size with 2378 about 70% as large as 2381. *Eomerope eonearctica* appears to have a similar size range, with F-780 about 75% the size of F-781 supporting the supposition that these specimens are conspecific (Fig. 5).

The existence of closely related species of *Eomerope* in Primorye, Russia and British Columbia, Canada, in the Ypresian is consistent with described dispersals across the Bering Land Bridge between Asia and North America preceding and during the Ypresian, well documented in plants and vertebrates (*e.g.*, Woodburne and Swisher 1995; Beard and Dawson 1999; Manchester 1999; Tiffney 2000; Manchester and Tiffney 2001; Tiffney and Manchester 2001; Bowen *et al.* 2002; Manchester *et al.* 2009; Brikiatis 2014). Plant taxa commonly found at McAbee that only persist in eastern Asia today include, *e.g.*, Ginkgo (*Ginkgo* Linnaeus, Ginkgoaceae), Katsura (*Cercidiphyllum* Siebold and Zuccarini, Cercidiphyllaceae), dawn redwood (*Metasequoia* Miki, Cupressaceae), and Chinese golden larch (*Pseudolarix* Gordon, Pinaceae) (Greenwood *et al.* 2005; Moss *et al.* 2005). Ypresian forests grew in the Arctic above 72°N (Suan *et al.* 2017). The Dinopanorpidae (Mecoptera) is only known from Okanagan Highlands sites, including McAbee, and Primorye, at the Amgu locality of the Khutsin Formation and from the Tadushi Formation (Cockerell 1924; Zherikhin 1978; Archibald 2005). The myrmeciine ant genus *Ypresiomyrma* Archibald *et al.* (Hymenoptera: Formicidae) was distributed widely across the Holarctic in the Eocene, in the Ypresian at McAbee (Archibald *et al.* 2006) and in Denmark (Rust and Andersen 1999), and in the Priabonian of Primorye (Dlussky *et al.* 2015).

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