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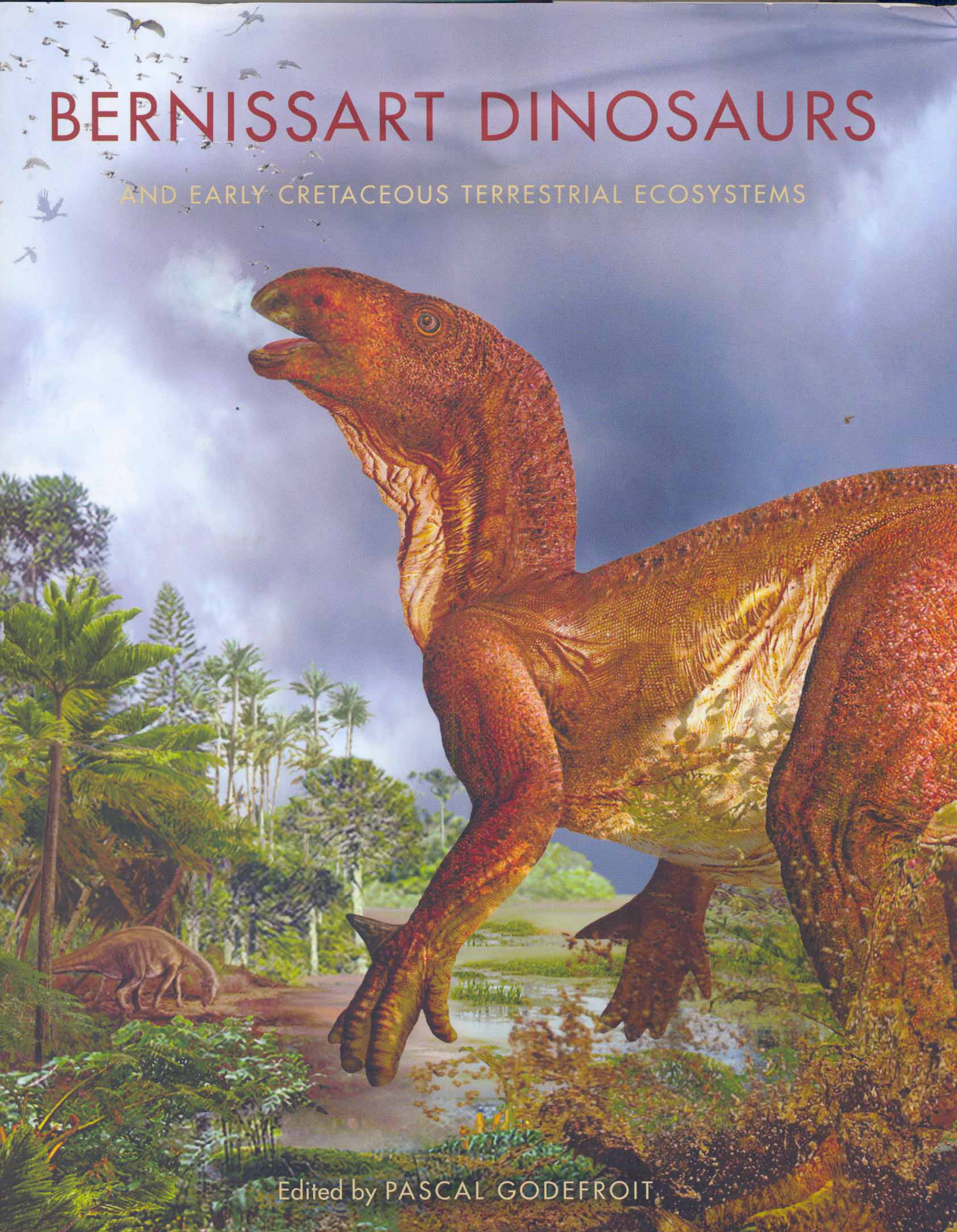

Edited by PASCAL GODEFROIT

This book is a publication of

Indiana University Press
601 North Morton Street
Bloomington, Indiana 47404-3797 USA

iupress.indiana.edu

Telephone orders 800-842-6796
Fax orders 812-855-7931

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Manufactured in the United States of America

Library of Congress Cataloging-in-Publication Data

Bernissart dinosaurs and early Cretaceous terrestrial ecosystems / edited by Pascal Godefroit.
p. cm. — (Life of the past)
Includes bibliographical references and index.
ISBN 978-0-253-35721-2 (cloth : alk. paper) — ISBN 978-0-253-00570-0 (e-book) 1. Iguanodon—Belgium—Bernissart. 2. Paleontology—Belgium—Bernissart. 3. Paleoecology—Cretaceous. I. Godefroit, Pascal, [date]
QE862.O65B485 2012
567.914—dc23
2011049613

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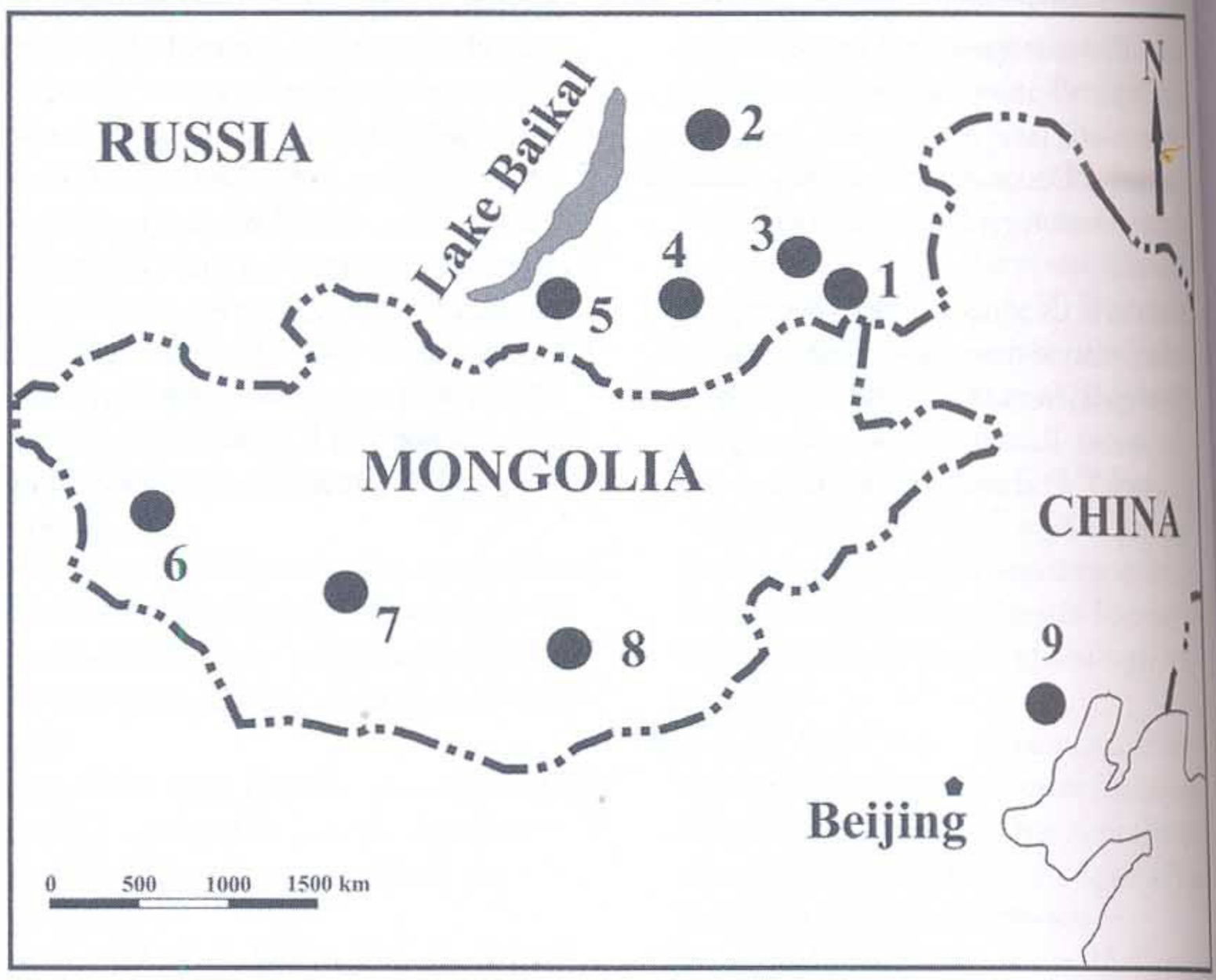
25.1. Map showing the distribution of localities of *Lycoptera* beds. 1, Middendorf's outcrop; 2, Baisa; 3, Shiviya; 4, Semion; 5, Gusinoe Ozero; 6, Gurvan-Eren; 7, Bon-Tsagan; 8, Manlaj; 9, main localities of Yixian Formation.



The Age of *Lycoptera* Beds (Jehol Biota) in Transbaikalia (Russia) and Correlation with Mongolia and China

25

Evgenia V. Bugdaeva* and Valentina S. Markevich

Volcanogenic sedimentary deposits, which contain abundant fossils of lacustrine fauna and flora, are widespread in the territory of Transbaikalia (Russia), Mongolia, and northeastern China. These fossil ecosystems are known as the Jehol Biota. The Jehol Biota of the Yixian Formation in western Liaoning province (China) are particularly famous because of the discovery, from 1996, of feathered dinosaurs and of the earliest angiosperms. However, the age of the Yixian Formation is still the object of discussions. The possibilities of correlation of the fossil flora of *Lycoptera* beds of Transbaikalia with potential coeval floras of Yakutia, Mongolia, and northeastern China are considered. Comparison with the Transbaikalia flora allows us dating the beds with Jehol Biota, including the Yixian Formation, as Barremian to Aptian.

Introduction

The volcanogenic sedimentary deposits, which contain abundant remains of lacustrine ecosystems, are widespread in the territory of Transbaikalia (Russia), Mongolia, and northeastern China. In the nineteenth century, A. P. Gerassimov was the first to discover fossils from the Jehol Biota in so-called fish shales, outcropping in the basin of the Turga and Byrka rivers. Gerassimov transmitted his findings to A. Th. Middendorf, who accomplished a journey through Siberia between 1842 and 1845. It is possible to say that the history of paleontology of the region began from that time. The outcrop in the bank of the Turga River (Figs. 25.1 and 25.2) is often called Middendorf's outcrop, although it was the less famous local, Gerassimov, who discovered and collected fossils. Also in Alexander Theodore Middendorf's honor are the name of the fish from these layers, *Lycoptera middendorfii* Müller (Fig. 25.3), and the representative of the conchostracans, *Bairdestheria middendorfii* Jones.

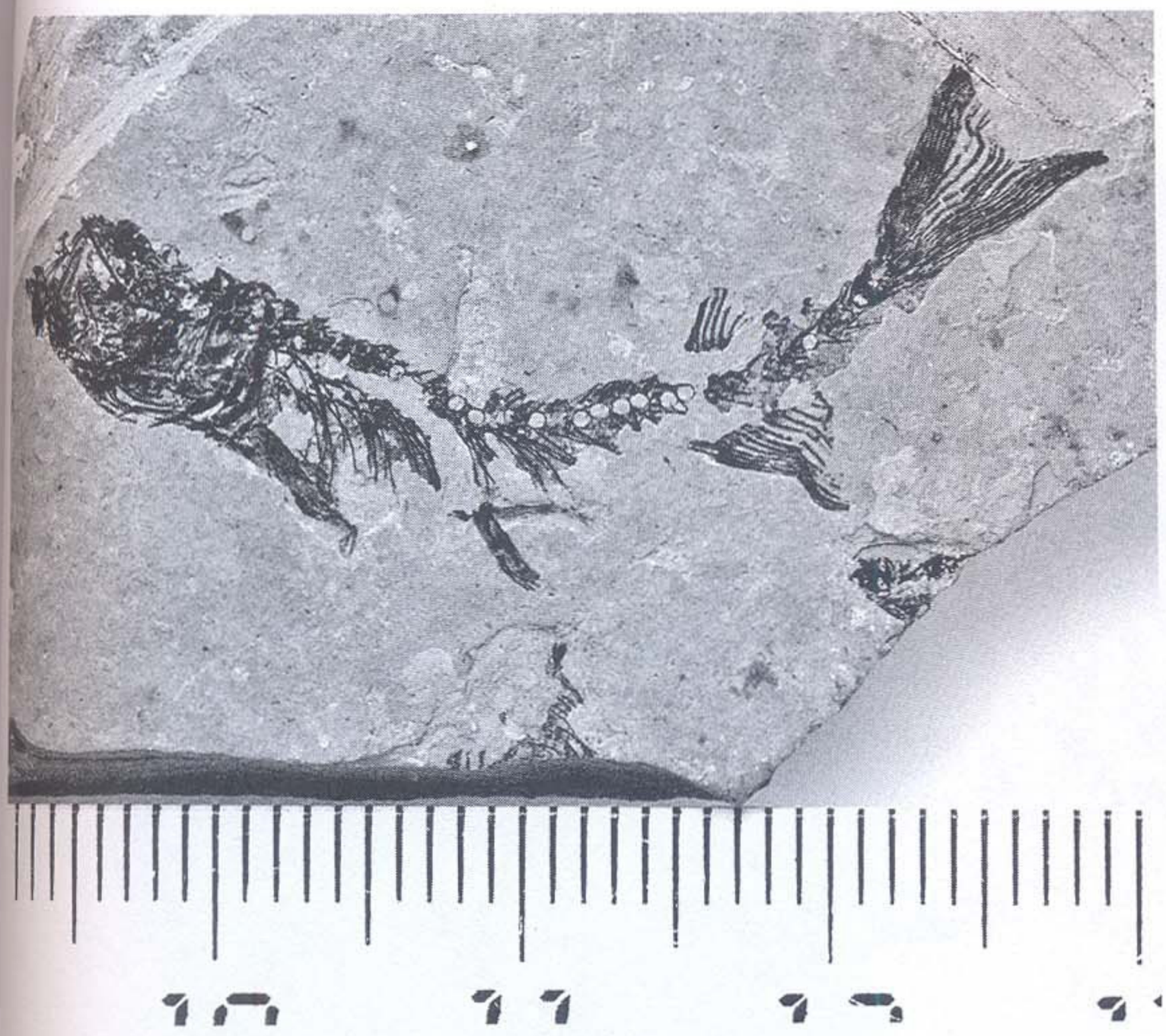
The fossiliferous layers in this locality are dominated by diverse insects, the most abundant of which is *Ephemeropsis trisetalis* (Fig. 25.4). Subsequently, Reis (1909) published a description of new animal and plant taxa from the fish shales in the basins of the Turga and Vitim rivers from materials collected during Middendorf's expedition. The author noted the scarcity and fragmentary nature of the plant remains. He came to the conclusion that these sediments were Late Jurassic to Early Cretaceous in age. This dating of fossil-bearing strata was the first in a chain of opinions of researchers. Stratigraphic correlation of the Upper Mesozoic deposits was hampered by complicated tectonics of Transbaikalia, facies diversity, and

25.2. The Middendorf's outcrop locality (Transbaikalia, Russia).

Photo by R. Korostovsky.

high endemism of the biota. Curiously, the high diversity of animals and plants at numerous sites did not facilitate the age determination of the layers containing organic remains, but resulted in a debate among specialists about the dating and position of beds in the sequence. Paradoxically, some paleontologists who studied the flora or the same groups of faunas came to diametrically opposite conclusions.

A more complete study of fossil plants of Transbaikalia was undertaken by Prynada (1950, 1962). He regarded the Turga Formation as the horizon of the same name and considered it as facies of coal-bearing formation completing the sequence of the continental Mesozoic in the isolated basins of Transbaikalia. The localities cropping out on the banks of the Turga and Vitim rivers, and near Shivia town (Fig. 25.1), were included by Prynada in the Turga facies. In his conclusion, "there are no plants in the Turga flora, which can be considered as guide fossils for a certain time," so he considered the age of the coal-bearing formation to be the Late Jurassic or Early Cretaceous (Prynada, 1962, 15). In the assemblage of the Turga Formation, Prynada included fossil plants from Bukachacha, Holbon, Chernovskoe, Duroi, Kharanor, Tarbagatai, Tugnui, Gusino-Uda, and Bayangol coal mines, as well as from deposits outcropping in the basins of Alyangui, Bukukun, and Chikoi rivers. Martinson (1961) substantiated a different age for the above-mentioned localities. He thought that the Turga–Vitim Formation, set up by him, was Early Cretaceous in age. However, Kolesnikov



25.3. *Lycoptera middendorfii* Müller, actinopterygian fish, Transbaikalia, Middendorf's outcrop, Turga Formation, Barremian–Aptian, ZBT531/3-5522, IBSS FEB RAS.

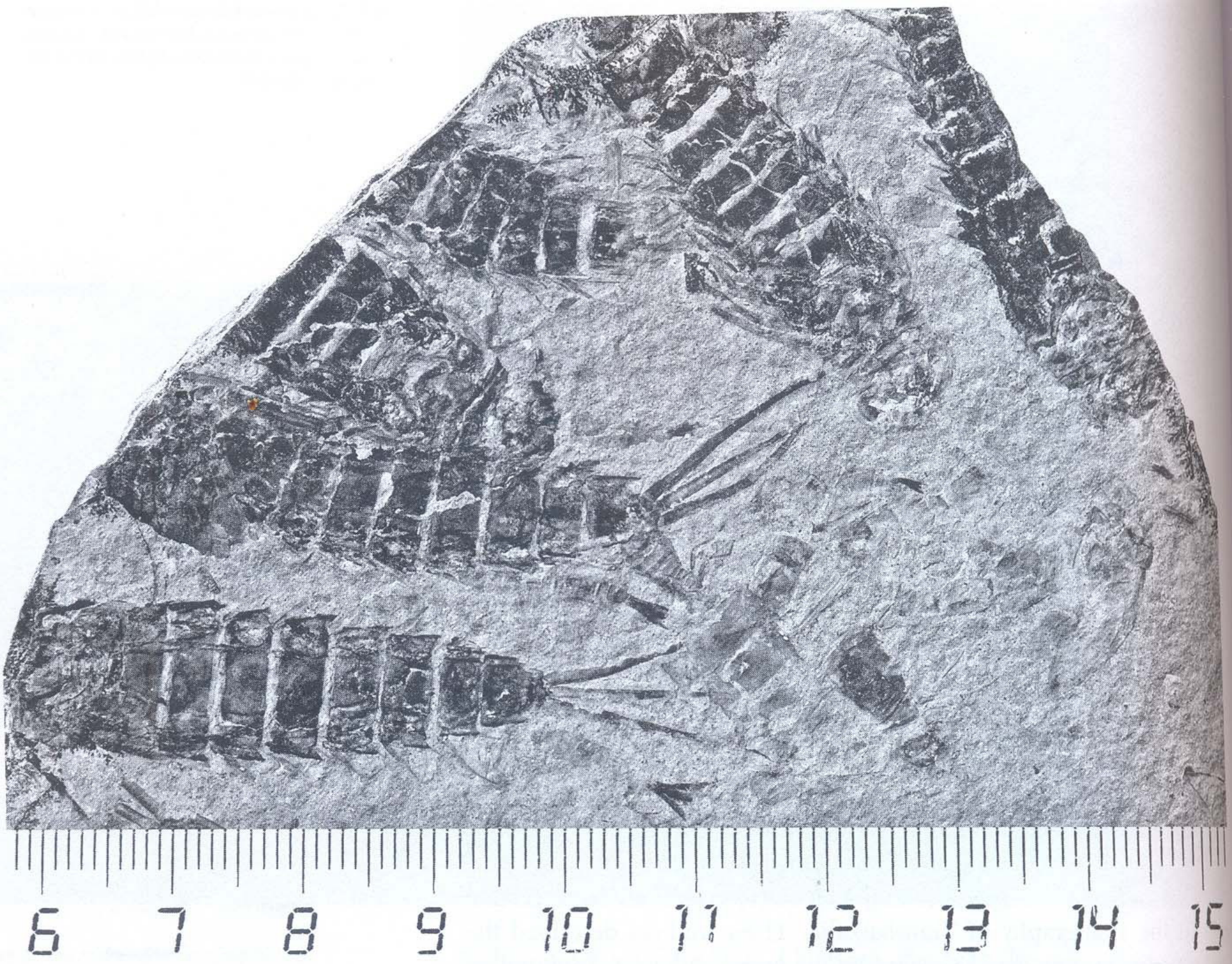
(1964) recognized four correlative biostratigraphic horizons in Transbaikalia and considered that the Turga horizon was Late Jurassic in age. Perhaps his opinion had a major impact on the development during the 1950s and 1960s of the Mesozoic stratigraphy in northeastern China. Many Chinese researchers still consider the fish shales to be Late Jurassic in age.

The studies of Vachrameev and Kotova (1977) played an important role in the stratigraphy of Transbaikalia. These authors described the earliest angiosperms (leaf *Dicotylophyllum pussilum* Vachr., fruit, pollen *Asteropollis asteroides* Hedl. et Norris) from Baisa locality (Zaza Formation; Fig. 25.1) and substantiated the late Neocomian–Aptian age for the plant-bearing deposits (Vachrameev and Kotova, 1977). On the basis of their results, it became possible to date the flora from the Turga Formation, which closely resembles the flora from the Zaza Formation. In addition, Kotova (1964, 1968) substantiated the Early Cretaceous age of coal-bearing deposits from Gusinoe Ozero and Bukachacha basins (Fig. 25.1), shattering the positions of Martinson (1961) and Kolesnikov (1964), who considered a Late Jurassic age.

Institutional abbreviation. IBSS FEB RAS, Institute of Biology and Soil Science, Far East Branch of Russian Academy of Sciences, Vladivostok, Russia.

Correlation of *Lycoptera* Beds in Transbaikalia and Mongolia

During the Early Cretaceous, the Transbaikalia and Mongolia area was a vast ecotone between the temperate and subtropical zones (Krassilov, 1981, 1982). Transbaikalia then was part of the Amur province of the Siberian–Canadian realm and was enriched by elements from the Euro-Sinian realm (Vachrameev, 1964; Vachrameev et al., 1970; Bugdaeva, 1989). On the one hand, the Turga flora included representatives of the flora from the Siberian–Canadian realm such as *Gleichenia lobata* Vachr. (Fig. 25.5),

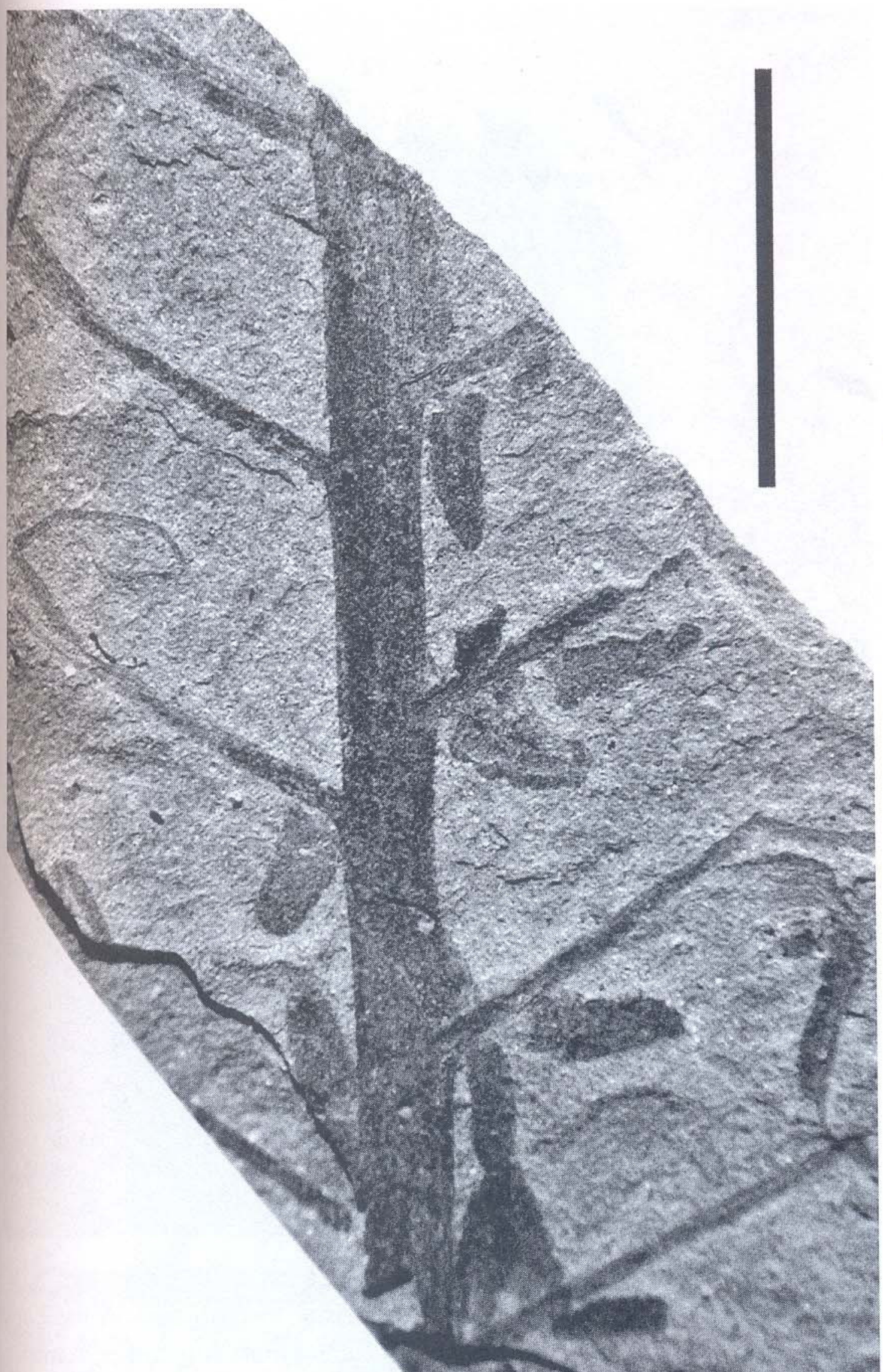


25.4. The burial of *Ephemeropsis trisetalis,* mayflies, Transbaikalia, Baisa locality, Zaza Formation, Barremian–Aptian, ZBB15–01, IBSS FEB RAS.

Czekanowskia, *Phoenicopsis*, *Coniopteris setacea* (Pryn.) Vachr., *Neozamites verchojanensis* Vachr. (Fig. 25.6), and *Pityolepis oblonga* Samyl. (Fig. 25.7). On the other hand, representatives of the Euro-Sinian realm (*Otozamites*, *Cladophlebidium*, *Onychiopsis*) occur in this flora. All the material figured in this chapter is deposited at the Institute of Biology and Soil Science, Far East Branch of Russian Academy of Sciences, Vladivostok, Russia.

The transitional location of the Transbaikalian flora during the Early Cretaceous provides an excellent opportunity to carry out its correlation with the floras from both the temperate and subtropical zones. When compared with synchronous paleofloras, the flora from the Turga Formation shows distinctive features (Bugdaeva, 1989).

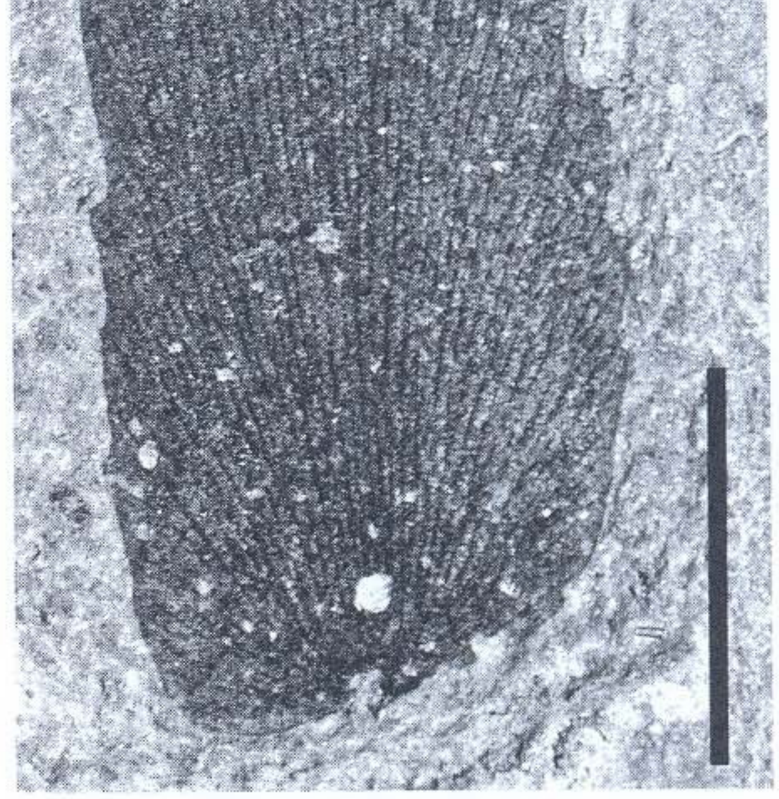
The paleoflora from the Lena Basin is one of the best-studied Early Cretaceous floras from temperate regions. Kiritchkova (1985) singled out four stages in the evolution of the Early Cretaceous flora: Batylykh, Eksenyakh, Khatyrykh, and Agrafenovo. These stages correspond to horizons established on a paleobotanic basis traceable from south to north over almost 200 km from the lower reaches of the Aldan River to the delta of the Lena River (Vachrameev, 1991). The Eksenyakh horizon is of Aptian age; in the south, it encompasses the Eksenyakh Formation from Vilyui Syneclise, whereas it encompasses the upper parts of the Chonkogor, Bulun, and



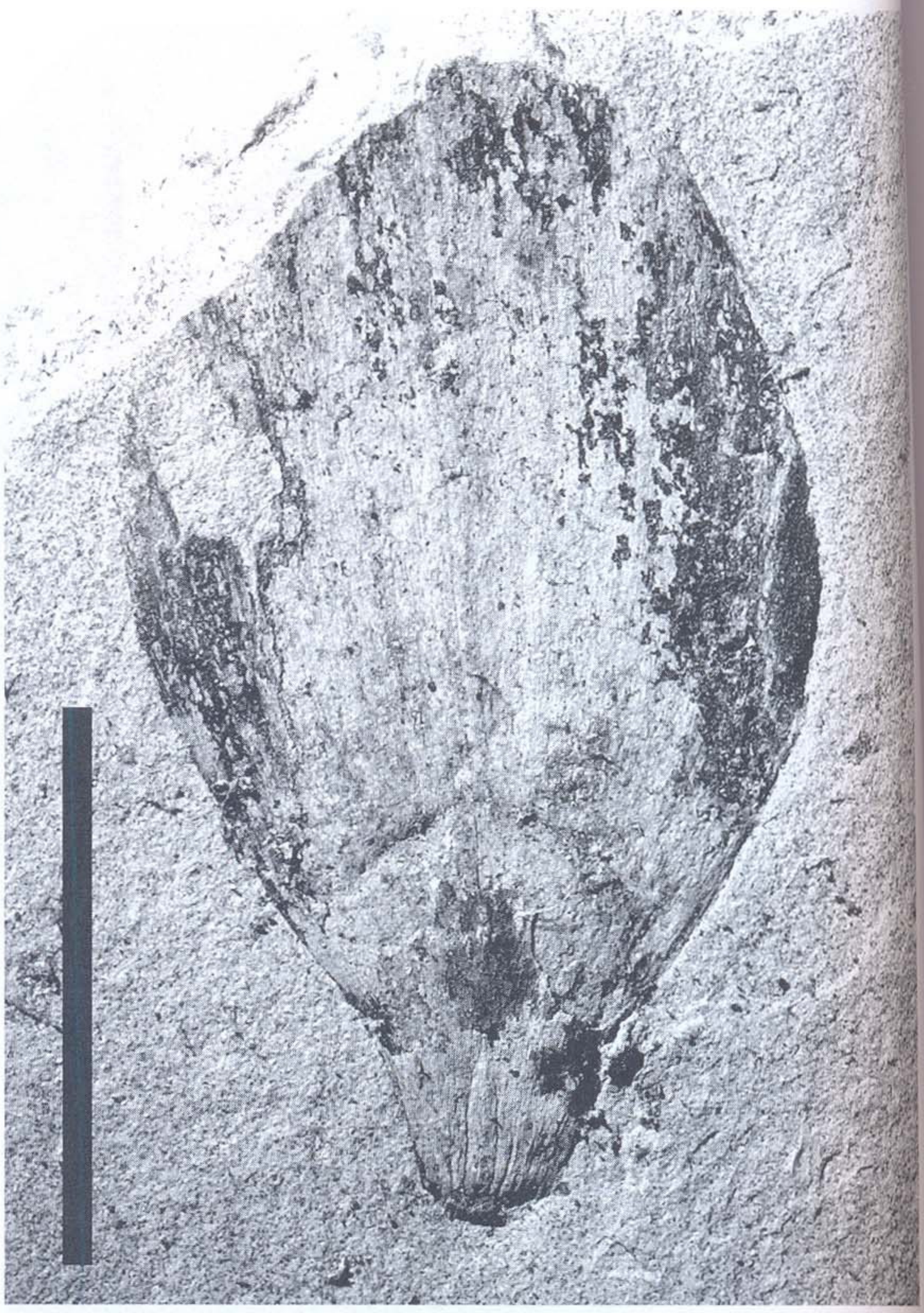
25.5. *Gleichenia lobata* Vachr., Gleicheniaceae, Transbaikalia, Semion locality, Semion unit, Barremian–Aptian, ZB325/I-01, IBSS FEB RAS; scale bar = 1 cm.

Bakh formations in the middle and northern parts of the region. The upper part of this horizon is characterized by the occurrence of the bennettite *Neozamites verchojanensis*, whose remains were found in the Transbaikalian localities of Baisa and Semion. The fern *Gleichenia lobata*, found in the Semion locality in the Chita-Ingoda Basin, is also typical for the Eksenyakh horizon.

Common or similar species are found in floristic assemblages from the Barremian–Aptian Chegdomyn and Chemchukin formations in the Bureya Basin (Vachrameev and Doludenko, 1961; Krassilov, 1973), from the Ussuri (Barremian) and Lipovtsy (Aptian) formations in the Razdolnoe Basin, and from the Starosuchan (Barremian) and Severosuchan (Aptian) formations in the Partizan Basin of South Primorye (Krassilov, 1967).



25.6. *Neozamites verchojanensis* Vachr., Bennettitales, Transbaikalia, Semion locality, Semion unit, Barremian–Aptian, ZB325/III-3033, IBSS FEB RAS; scale bar = 1 cm.



25.7. *Pityolepis oblonga* Samyl., Pinaceae, Transbaikalia, Baisa locality, Zaza Formation, Barremian–Aptian, ZB31/87, IBSS FEB RAS; scale bar = 1 cm.

Krassilov (1982) defined four paleofloristic assemblages in the Early Cretaceous of Mongolia: (1) a zone with *Baiera manchurica* (Berriasian?), (2) a zone with *Otozamites lacustris–Pseudolarix erensis* (Barremian–Aptian), (3) a zone with *Baierella hastata–Araucaria mongolica* (Aptian), and (4) a zone with *Limnothetis–Limnoniobe* (Aptian, and perhaps Early Albian).

Study of the Early Cretaceous flora of Mongolia has revealed its undoubted affinities with the Transbaikalian flora (Krassilov, 1982; Bugdaeva, 1989). In the localities of Middendorf's outcrop and Semion, besides *Pseudolarix*, remains of the bennettite *Otozamites lacustris* Krassil. have been found (Fig. 25.8). Both morphological and epidermal studies showed absolute identity of the Mongolian and Transbaikalian *O. lacustris*. These plants allowed correlation of the Turga flora with an assemblage from the second zone defined in the Early Cretaceous flora of Mongolia, which includes plants from the Bon-Tsagan, Manlaj, and Gurvan-Eren localities (Fig. 25.1).

25.8. *Otozamites lacustris* Krassil., Bennettitales,Transbaikalia, Baisa locality, Zaza Formation, Barremian–Aptian, ZB31/173, IBSS FEB RAS; scale bar = 5 mm.

In the Baisa locality, the remains of *Samaropsis aurita* Krassil. (Fig. 9) are abundant. This plant is peculiar to the Early Cretaceous Mongolian localities Bon-Tsagan, Holbotu-Gol, Shin-Khuduk, and Manlaj.

Thus, the correlation of the Turga flora with the Barremian–Aptian flora of Mongolia confirms its age.

Correlation of Jehol Biota in Northeastern China

In the second half of the twentieth century, intensive geological research began to be carried out in China. In the Mesozoic sediments of northeastern China, abundant fossil remains were revealed. In the mass burials, diverse fishes, insects, mollusks, vertebrates, and plants were discovered. This biota, which undoubtedly had a high level of endemism, was named Jehol Biota.

25.9. *Samaropsis aurita* Krassil., Coniferales, Transbaikalia, Baisa locality, Zaza Formation, Barremian–Aptian, ZB31/476, IBSS FEB RAS; scale bar = 5 mm.

The Jehol Biota has attracted the attention of the world science community since 1996, when the discoveries of feathered dinosaurs from sediments of the Yixian Formation (Liaoning province) were published. Later, exquisitely preserved fossils of pterosaurs, birds, mammals, and plants (including earliest angiosperms) were also described (e.g., Cao et al., 1998; Gibbons, 1998; Sun et al., 1998, 2001; Swisher et al., 1999; Unwin, 1998). The amazing findings and their unique preservation contributed to detailed studies of these extraordinary animals and plants, which answered many questions about the evolution of the Cretaceous biota and allowed reconstructions of the ecosystem. However, the fundamental question—what is the age of the fossil-bearing beds?—remained unsolved.

According to Chinese stratigraphers, the age of the Yixian Formation is Late Jurassic (Cao et al., 1998; Chen and Chang, 1994; Lo et al., 1999; Sun et al., 1998, 2001), although some paleontologists advocate for an Early Cretaceous age (Li and Liu, 1994, 1999; Mao et al., 1990; Pu and Wu, 1992; Swisher et al., 1999). The most detailed biostratigraphic analysis of the Yixian Formation was undertaken by Smith et al. (2001, 559), who presented an overview of all faunistic and floristic groups found in this stratigraphic unit and concluded that "biostratigraphy is a poor means by which to determine the age of the Yixian Formation." The most reliable are radiometric dates consistently given late Early Cretaceous ages. $^{40}Ar/^{39}Ar$ analyses of volcanic rocks from the Yixian Formation give ages ranging from 121.1 ± 0.2 to 122.9 ± 0.3 Ma (Smith et al., 1995) and 124.6 ± 0.3 Ma (Swisher et

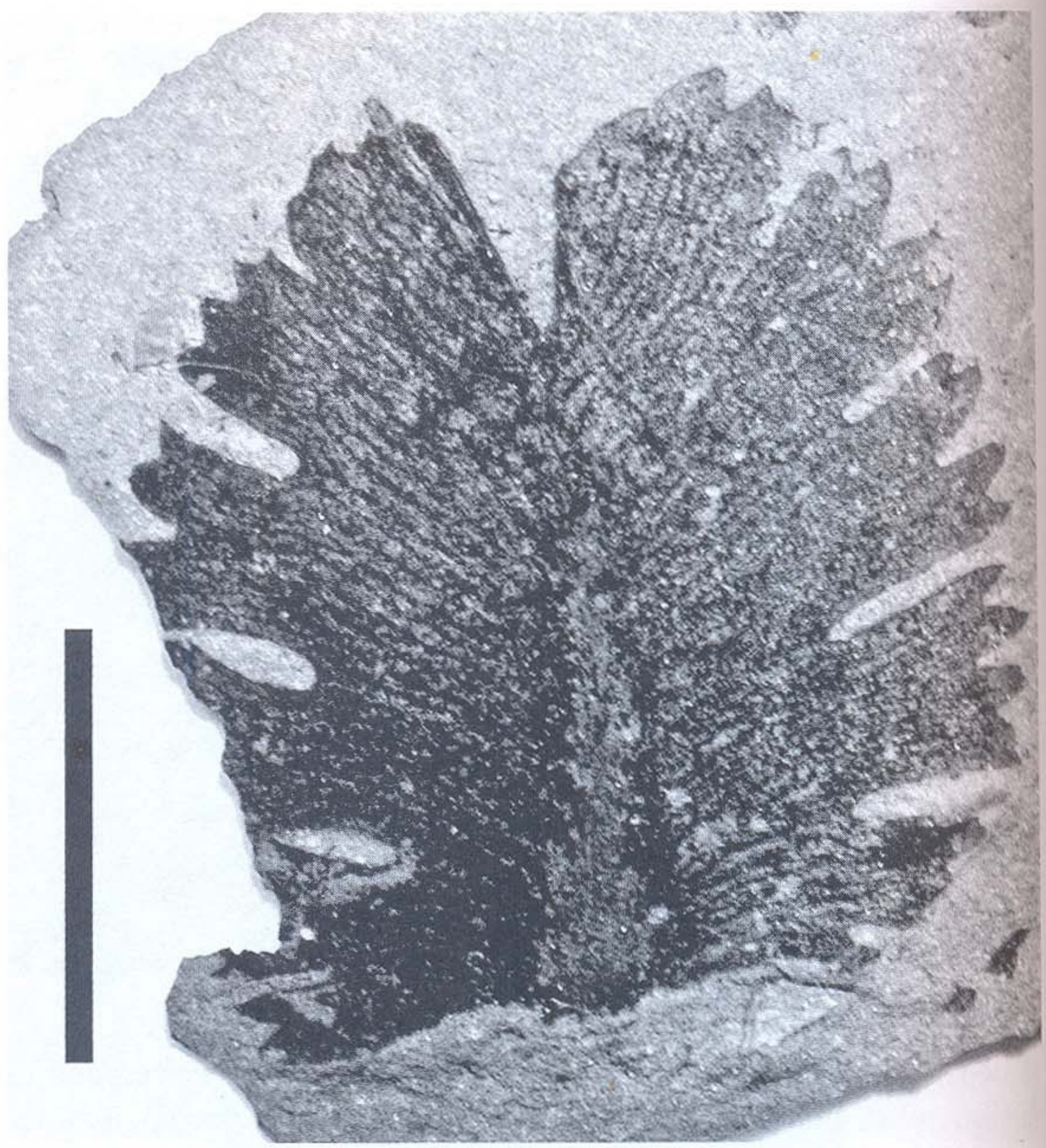
25.10. *Baisia hirsuta* Krassil., Proangiospermae, Transbaikalia, Baisa locality, Zaza Formation, Barremian–Aptian, ZB31/209, IBSS FEB RAS; scale bar = 5 mm.

al., 1999). According to these authors, the age estimations correspond to the Barremian, although according to the Gradstein et al. (2004), it rather corresponds to the Aptian. Recently Chang et al. (2009) obtained an age of 129.7 ± 0.5 Ma for a basaltic lava from the bottom of the Yixian Formation and an age of 122.1 ± 0.3 Ma for a tuff from the lowermost part of the overlying Jiufotang Formation. Their age results provide an age calibration of the whole Yixian Formation and show that the whole formation was deposited during the Early Cretaceous, from the Barremian to the Early Aptian, within an interval of ~7 Ma.

Fossils of flowering plants and plants having affinities with angiosperms were found in Early Cretaceous deposits from Transbaikalia, Mongolia, and northeastern China (Vachrameev and Kotova, 1977; Krassilov, 1982, 1986; Krassilov and Bugdaeva, 1982, 2000). Krassilov called the latter plants proangiosperms. In proangiosperms, the features typical for flowering plants are not yet fully developed but appear discretely, not forming stable combinations. According to his opinion, angiospermization was expressed in whole plant communities. It can only be assumed that it was the response of biota to some external influence.

In June 2006, E. V. Bugdaeva visited the main localities in the Yixian Formation in Liaoning and Hebei provinces and collected plant remains (Fig. 25.1). She was particularly attentive to plants regarded as guide fossils for the Turga assemblage of Transbaikalia.

The most important plant is *Baisia hirsuta* Krassil., which belongs to proangiospermous plants with bennettitalean affinities (Krassilov and Bugdaeva, 1982). This plant consists of dispersed cupulate ovules, which occupy an apical position on a short rounded to triangular receptacle that is persistent in disseminules and bears minute bracts and tufts of long bristles



25.11. *Baikalophyllum lobatum* Bugd., Cycadales, Transbaikalia, Semion locality, Semion unit, Barremian–Aptian, ZB325/III-2880, IBSS FEB RAS; scale bar = 1 cm.

(Fig. 25.10). In Transbaikalia, this species has been found in abundance in the Middendorf's outcrop, Baisa, Semion (Elizavetino Basin) and Shiviya (Unda-Daya Basin) localities.

We visited the Museum of Natural History in Beijing and the Museum of National Geopark around Sihetun locality in Chaoyang city (Liaoning province). In the exhibition halls of these museums, cycad leaves are displayed. The label on the specimens from the Sihetun locality provides the name *Pityolepis larixiformis*, which is clearly erroneous. This species was described from the Semion locality in Transbaikalia as *Baikalophyllum lobatum* Bugd. (Bugdaeva, 1983). The Yixian flora has also yielded the conifer *Nageiopsis transbaikalica* Srebr., originally described on the basis of material from the Semion locality (Srebrodolskaya, 1983) and also present in the Baisa locality in Transbaikalia, but Chinese paleobotanists referred it to as *Podocarpidites reheensis* (Wu) Sun et Zheng (Sun et al., 2001) (Figs. 25.11 and 25.12). *Botrychites reheensis* Wu, *Neozamites verchojanensis* Vachr., *Pityolepis pseudotsugaoides* Sun et Zheng, *Brachyphyllum longispicum* Sun, Zheng, et Mei, *Scarburgia hilii* Harris, *Ephedrites chenii* (Cao et Wu) Guo et Wu X.W., *Carpolithus multiseminalis* Sun et Zheng, and *C. pachythelis* Sun et Zheng are present both in the Turga and in the Yixian floras.

In addition, the endemic plant *Gurvanella* occurs in the Yixian flora (Sun et al., 2001). This genus was found in the Early Cretaceous Gurvan-Eren locality in Mongolia (Krassilov, 1982). *Gurvanella* has not been discovered in Transbaikalia yet, but floras of the Gurvan-Eren, Manlaj, and

25.12. *Nageiopsis transbaikalica* Srebr., Coniferales, Transbaikalia, Semion locality, Semion unit, Barremian–Aptian, ZB31/341, IBSS FEB RAS; scale bar = 1 cm.

Bon-Tsagan localities are similar with the Turga flora of Transbaikalia (Bugdaeva, 1989).

Conclusions

Paleofloras from the Yixian Formation in northeastern China and from the Turga Formation in Transbaikalia have the same age. During the Barremian–Aptian, a high level of endemism characterized the biota over a vast area that included the modern territories of Transbaikalia, Mongolia, and northeastern China. Floras from these regions were similar and included elements from temperate and subtropical floras, which allow for broad cross-regional correlations. Therefore, paleobotanical data support a Barremian–Aptian age for the Yixian Formation and the Jehol Biota, as also indicated by $^{40}Ar/^{39}Ar$ analyses.

Acknowledgments

Our research was supported by the Presidium of the Far Eastern Branch of the Russian Academy of Sciences and the Presidium of the Russian Academy of Sciences (grant 09-I-P15-02). We are grateful to Sun Ge, D. Dilcher, P. Grote, M. Nelson, R. Korostovsky, L. Starukhina, V. Scoblo, N. Lyamina, A. Averianov, and N. Yadrishchenskaya. Thanks to V. Krassilov and H. Pfefferkorn for useful comments and to P. Godefroit for his support.

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