Received: 14 April 2015 | Revised: 31 December 2016 | Accepted: 17 January 2017

DOI: 10.1111/iar.12206

WILEY Island Arc

RESEARCH ARTICLE

The Early Cretaceous coal-forming plants of southern part of East Siberia and Russian Far East

Eugenia V. Bugdaeva | Valentina S. Markevich

Laboratory of Paleobotany, Institute of Biology and Soil Science, Far Eastern Branch of Russian Academy of Sciences, Vladivostok 690022, Russia

Correspondence
Eugenia Vassilyevna Bugdaeva, Institute of Biology and Soil Science, Far Eastern Branch of Russian Academy of Sciences, 159 Prospect 100-letiya, Vladivostok 690022, Russia.
Email: bugdaeva@biosoil.ru

Abstract

For the first time the plants that gave rise to the Early Cretaceous coals of Transbaikalia (Khilok, Chita-Ingoda, Bukachacha, and Turga-Kharanor basins), Amur River region (Bureya Basin), and Primorye region (Razdolnaya River and Partizansk River basins) have been obtained. The plants that produced coals mainly belong to the ginkgoaleans (*Pseudotorellia*, *Sphenobaiera*, and *Baierella*), bennettites, and conifers having pinaceous, taxodiaceous, araucariaceous affinity, as well as extinct cheirolepidiaceous and miroviaceous plants. A parallel palynological study has identified a number of the same elements in addition to the cyatheaceous, gleicheniaceous, osmundaceous, and schizaeaceous ferns.

KEYWORDS

Amur River region, coal-forming plants, Cretaceous, Primorye region, Transbaikalia

1 | INTRODUCTION

The coal formation in the geological past was linked with the development of plant communities, which produced a large biomass at the same time possessed relatively simple structure. A considerable part of phytomass was removed from swamp ecosystems and became mortmass. The coal formation involving rapid burial of plant remains has paleoecological and taphonomical significance (e.g. Barbacka et al., 2015; Ferguson et al., 2010; Greb, Dimichele, & Gastaldo, 2006; Iannuzzi, 2010; Jasper, Hartkopf-Fröder, Flajs, & Littke, 2010; Michaelsen, 2002; Philippe et al., 2002; Steart, Collinson, Scott, Glasspool, & Hooker, 2007; Upchurch, 1995; Villalba-Breva, Martín-Closas, Marmi, Gomez, & Fernández-Marrón, 2012).

The coal seams are particularly the subject of paleobotanical research. The study of plant material has great importance for knowledge of the genesis of coal, its composition, and its quality.

Many elements of the coal-forming plant community can still be identified in the coal. At the time of the mire formation and growth, climatic conditions were not suitable for sediment transport into the basin particularly biogenic components, with almost complete absence of clastic sediments. Therefore, it is possible to assume that the plants that gave rise to the coal deposits were autochthonous and provided the first elements of peat accumulation. Since clastic deposits represent the material transported from the source area, phytofossil assemblages from the terrigenous deposits between the coal layers are often mixed, consisting of elements from both the slope and lowland communities.

In the present study, coal-bearing deposits of Transbaikalia (Chita-Ingoda, Khilok, Bukachacha, Turga-Kharanor basins), Amur River (Bureya Basin) and Primorye regions (Razdolnaya and Partizansk basins) were studied (Figure 1).

These deposits are of Tithonian–Valanginian, and Barremian-Albian stages of coal formation in these areas, of which, the Barremian–Albian stage occupied a large part (Figure 2). Coal accumulation was manifested on vast areas of Siberia and the Far East. During the Barremian–Aptian, the main coal-forming plants varied in composition depending on environments.

During this period, favorable conditions for the existence of mire vegetation occurred. The abundant plant material was feedstock for peat accumulation and coal origin. Coal-forming plants were buried in close proximity to their habitats. The extremely thin cuticles of ferns desintegrate after chemical maceration of coal, but their spores, having exine resistant to acids and alkali, provide evidence of the existence of ferns in mire vegetation (Taylor, Taylor, & Krings, 2009). Both palaeobotanical and palynological data reveal that these plants contributed to the coal formation. Usually coal and coaly rocks contain highly fragmented plant material as spores, pollen, and dispersed cuticles. The identifiable latter can be a very significant proxy for determination of taxonomical composition of coal-forming plants, paleoecological

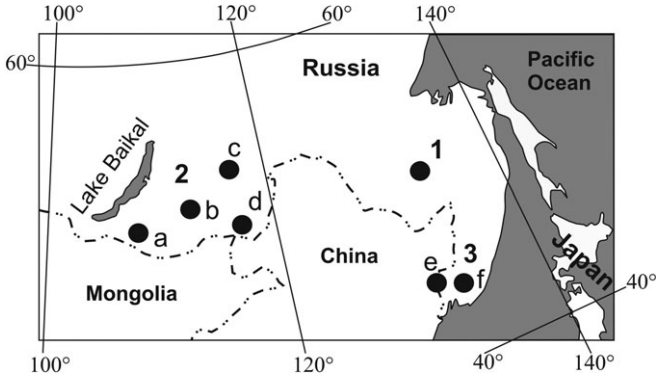

FIGURE 1 The studied Upper Jurassic–Lower Cretaceous coal basins. 1, Amur River region, Bureya Basin; 2, Transbaikalia; 3, Primorye region; a, Khilok Basin; b, Chita-Ingoda Basin; c, Bukachacha Basin; d, Turga-Kharanor Basin; e, Razdolnaya River Basin; f, Partizansk Basin

interpretation of living conditions of swamp plant communities, paleoenvironments, and stratigraphic correlation.

The study of dispersed cuticles began in the 20th Century and was linked to the study of coal geology and emphasized facies analysis and paleoecology (Kovach & Dilcher, 1984; Litke, 1966; Miner, 1935; Peters, 1963; Roselt & Schneider, 1969; Schneider, 1969; Upchurch, 1995; Upchurch & Askin, 1989). Special studies devote to plant cuticle structures and function (e.g. Barclay, McElwain, Dilcher, & Sageman, 2007; Cutler, 1982; Martin & Juniper, 1970; McElwain & Chaloner, 1996; Stace, 1965). The dispersed cuticles often having preserved systematic characters can be compared readily with the cuticular anatomy of megafossils.

Thereby, our main objective is a recovery of palynomorphs and dispersed cuticles from coals of the basins of the Transbaikalia, Amur River and Primorye regions, definition of their taxonomical composition, and after that to reveal a composition of coal-forming plants.

From the late Albian to the end of the Cretaceous peat accumulation was drastically reduced, especially in the south of Primorye region, where red-bed facies appeared for the first time (Khanchuk, Ratkin, Ryazantseva, Golozubov, & Gonokhova, 1995; Krassilov, 1985). These geological events may have been caused by climatic changes associated with a rainshadow effect of the rising volcanic ranges (Krassilov, 1967, 1985, 1992).

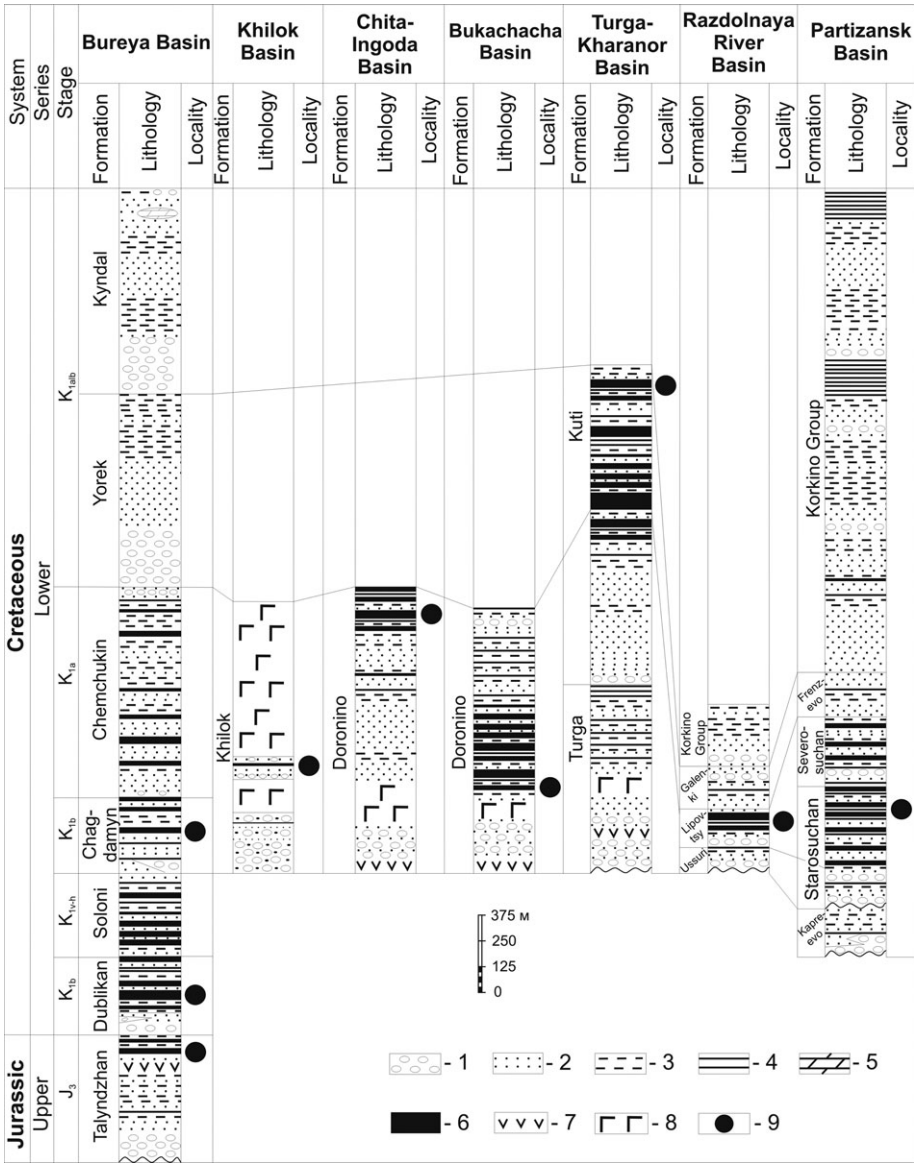

FIGURE 2 The sequences of coal-bearing basins of Amur River region, Transbaikalia, and Primorye region. 1, conglomerate; 2, sandstone; 3, siltstone; 4, mudstone; 5, marl; 6, coal; 7, basalt; 8, andesite; 9, place of coal sampling

The coals are often underlain by rooted tuffaceous sediments (Figure 3) and are overlain by tuffs (e.g. coals of the Talyndzhan Formation in the Bureya Basin and the Lipovtsy Formation in the Razdolnaya Basin; Figure 4). Peat growth was usually terminated by heavy ash falls that buried the swamps, preventing accumulation of thick coal seams (Kovaleva, Markevich, Bugdaeva, Volynets, & Afonin, 2016; Krassilov, 1992). The swamp plant communities and coal accumulation seem sensitive to major environmental crises.

2 | MATERIALS AND METHODS

Abundant plant material was collected from the Lower Cretaceous coal-bearing deposits of Transbaikalia (the Khilok Formation in the Khilok Basin, the Doronino Formation in the Chita-Ingoda and Bukachacha basins, the Kuti Formation in the Turga-Kharanor Basin), the Upper Jurassic–Lower Cretaceous coal-bearing deposits of the Amur River region (the Talyndzhan, Dublikan, Chagdamyn, and Chemchukin formations in the Bureya Basin), and from the Lower Cretaceous of Primorye region (the Lipovtsy Formation in the Razdolnaya Basin and the Starosuchan Formation in the Partizansk Basin).

Both plant megafossils and coals were collected to obtain dispersed cuticles of the coal-forming plants by bulk maceration. The coals were oxidized by concentrated nitric acid, washed with distilled water, then, treated with 10 % alkali (KOH) and rinsed. The cuticles were mounted on permanent slides for observation under a light microscope (LM) or were placed on standard stubs, splutter coated with gold for scanning electron microscope (SEM) studies. Photography was carried out using a Zeiss Axioscop 40 light microscope with camera Axiocam HRc and a Zeiss EVO-40 scanning electron microscope (IBSS FEB RAS).

FIGURE 3 The rooted tuffaceous sediments below the coal seam. Lipovtsy Formation, Porechye coal mine, Razdolnaya River Basin. The length of this steel head of the geological hammer is 14.5 cm

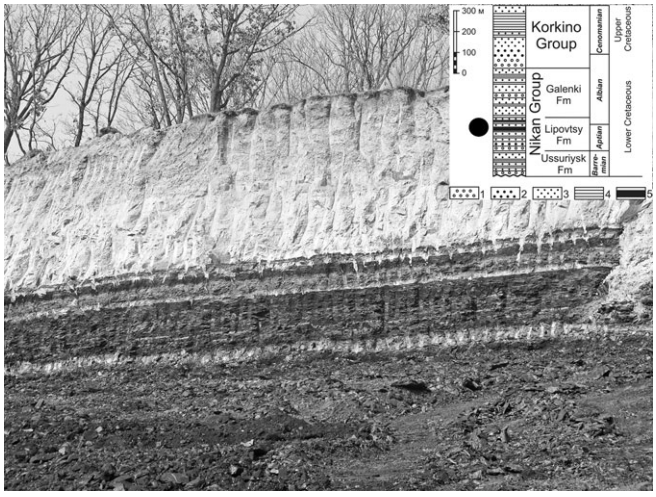

FIGURE 4 Tuff overlying the coal seam. Lipovtsy Formation, Porechye coal mine, Razdolnaya River Basin. Inset shows a schematic sequence of the Cretaceous deposits of the Razdolnaya River Basin. 1, conglomerate, gravelstone; 2, coarse-grained sandstone; 3, medium- and fine-grained sandstone; 4, siltstone; 5, coaly mudstone and coal. The black circle indicates the stratigraphic position of the outcrop

3 | RESULTS

3.1 | Amur River region

3.1.1 | Bureya Basin

The Bureya Basin is located in the upper part of the Bureya River (Figure 5) and has been the best subject for the study of the Upper Jurassic to Lower Cretaceous coal-bearing deposits, because the sequence of

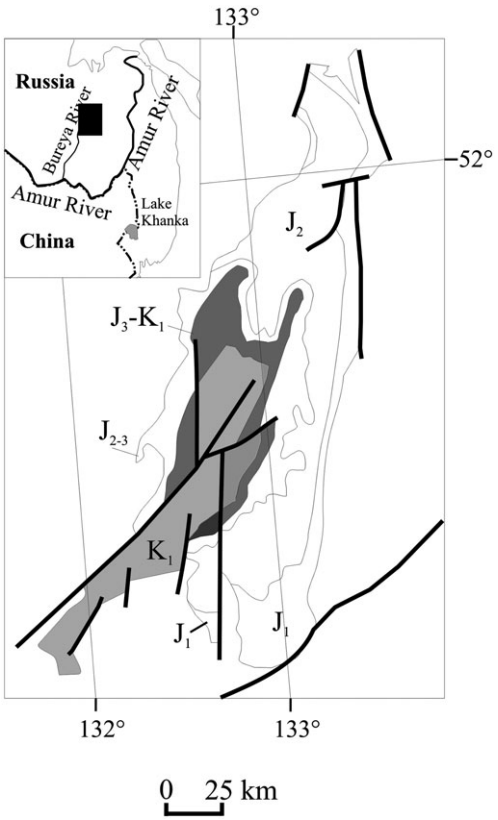

FIGURE 5 Schematic geological map of the Bureya Basin: J_1, J_2, $J_{2\text{-}3}$, marine deposits (white color); J_3-K_1, transitional brackish-terrestrial deposits with thin coal seams (grey color); K_1, terrestrial deposits with thick productive coal seams (light-grey color). Thick lines indicate faults

this tectonic structure includes productive coals of the Tithonian, Berriasian, Barremian, and Aptian ages (see Figure 2). The coals of other ages are thin and do not have commercial significance.

The Upper Jurassic strata were deposited in brackish coastal environments. The characteristic features of the Late Jurassic epoch are the homogeneous composition, not clearly defined differentiation, low diversity and smoothed zonation of vegetation. The main coal-forming plants were cyatheaceous ferns, ginkgoaleans, and conifers (Markevich & Bugdaeva, 2014). This is most conspicuous in the Bureya Basin. The coal-bearing Upper Jurassic (Talyndzhan Formation) to Lower Cretaceous (the Dublikan, Soloni, Chagdamyn, and Chemchuko formations) deposits have thickness of about 200–2000 m (see Figure 2).

The palynological assemblage of the Talyndzhan Formation is characterized by predominance of fern spores, mainly assigned to osmundaceous and cyatheaceous ferns, up to 90 % (Figure 6). The participation of diverse mosses is considerable. Gymnosperms are dominated by pollen closely affiliated to Pinaceae and *Ginkgocycadophytus* (Figure 7). The plant megafossils of this stratigraphic unit are represented by horsetails, bryophytes, ferns, cycadophytes, ginkgoaleans, czekanowskialeans, and conifers (Krassilov, 1972, 1973, 1978; Vakhrameev & Doludenko, 1961). The burials are dominated by ginkgoaleans and czekanowskialeans, the ferns and cycadophytes are highly represented. The representative of ginkgoaleans (*Pseudotorellia angustifolia* Doludenko) sometimes forms monospecific burials; their cuticle remains are common in coals (Figure 8). Perhaps, this arboreal plant prevailed in mire vegetation, osmundaceous and cyatheaceous ferns were in understory. Cycadophytes are often abundant in the clastic beds, but coals entirely lack remains of these plants. Consequently, cycadophytes were not constituent of mire vegetation.

The Lower Cretaceous (the Berriasian–Valanginian) strata are accumulated in vast swampy lowlands. The peculiarity of palynological assemblage from the Dublikan Formation (the Berriasian) is presence of considerable amount of cyatheaceous and lesser osmundaceous fern spores (up to 84 %). Among gymnosperms, *Classopollis* prevails parallel with conifers (see Figure 7). The floristic changes at the Jurassic–Cretaceous boundary are consistent in the

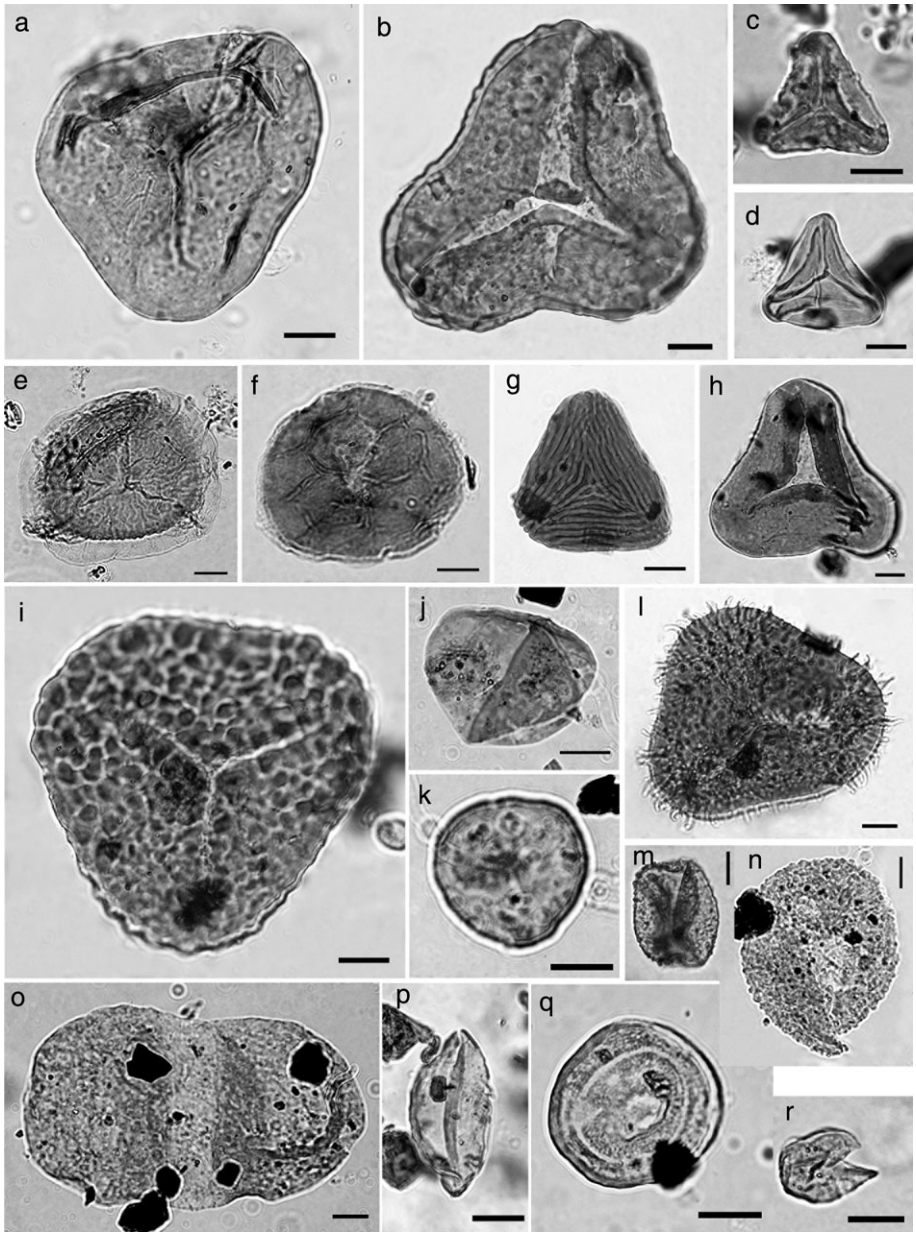

FIGURE 6 The typical spores and pollen of the Lower Cretaceous deposits of Transbaikalia, Amur River region, and Primorye region. Scale bars 10 μm. a, *Cyathidites australis* Coup.; b, *Impardecispora apiverrucata* (Coup.) Venkat. et Rasa; c, *Gleicheniidites laetus* (Bolch.) Bolch.; d, *Gleicheniidites senonicus* Ross; e, *Denzoisporites vellatus* Weyl. et Krieg.; f, *Rouseisporites reticulatus* Poc.; g, *Cicatricosisporites multicostatus* (Bolch.) Poc.; h, *Concavissimisporites asper* (Bolch.) Poc.; i, *Concavissimisporites variverrucatus* (Coup.) Singh; j, *Cyathidites minor* Coup.; k, *Stereisporites stereoides* (Wills. et Webst.) Dett.; l, *Pilosisporites echinaceus* Bolch.; m, *Osmundacidites nicanicus* (Verb.) E. Sem.; n, *Osmundacidites wellmanii* Coup.; o, *Alisporites bilateralis* Rouse; p, *Ginkgocycadophytus* sp.; q, *Classopollis classoides* Pfl. emend. Poc. et Jans.; r, *Taxodiaceaepollenites hiatus* (Pot.) Kremp

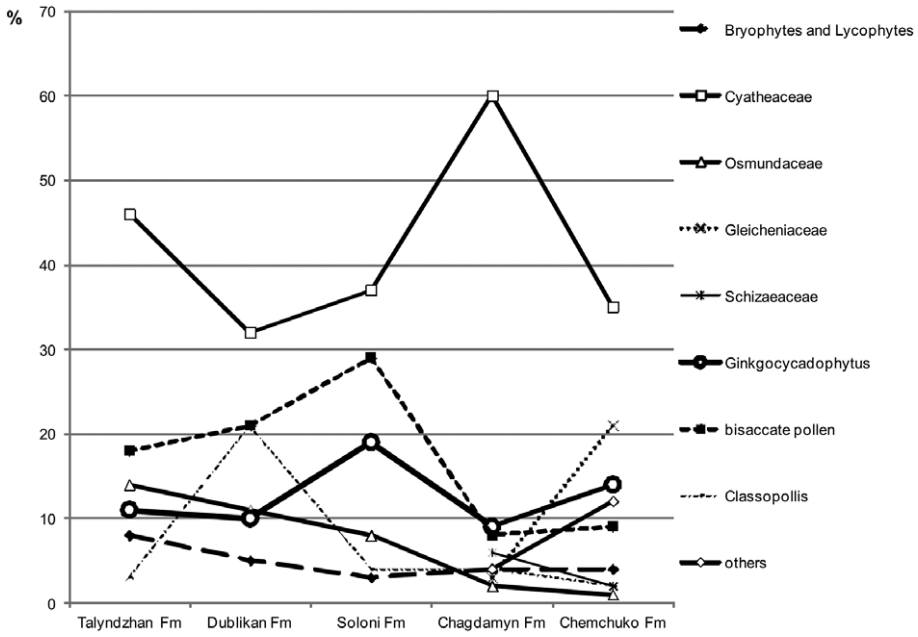

FIGURE 7 The relative abundances of major groups of spores and pollen in the coal-bearing deposits of the Bureya Basin

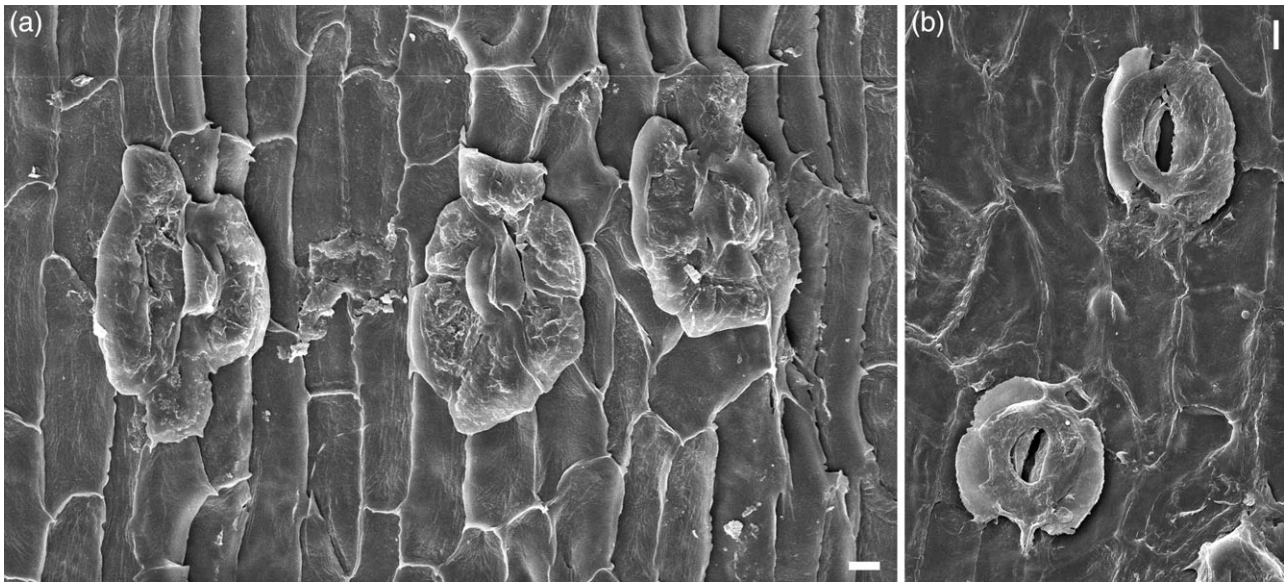

FIGURE 8 Cuticles of the coal-forming plants of the Bureya Basin. (a) *Bilsdalea* sp. (Dublikan Formation). (b) *Pseudotorellia angustifolia* Doludenko (Talyndzhan and Dublikan formations). Scale bars 10 μm

increase of ferns and cheirolepidiaceous gymnosperms, which might be related to the marginal uplift and drier climate (Markevich, 1981, 1995).

The coal-forming plants are represented by *Pseudotorellia angustifolia* and conifer of unknown affinity *Bilsdalea* Harris, 1952 (Figure 8).

Palynological assemblage of the Soloni Formation (the Valanginian) is dominated by conifers (up to 60 %) and *Ginkgocycadophytus* (Figure 6). Ferns reduce up to 50 %. The gleicheniaceous and schizaeaceous ferns have assumed great importance (see Figure 7).

In the Middle Cretaceous the sea retreated from this area and the coals are accumulated in the interior depressions. The palynoflora of the Chagdamyn Formation (the Barremian) is represented by mainly spores of *Cyathidites* (Figure 6). *Ginkgocycadophytus* and conifers prevail among gymnosperms. The diversity and amounts of ferns are high in the palynological assemblage of the Chemchuko Formation (the Aptian); they are represented by cyatheaceous, gleicheniaceous, and osmundaceous ferns. The Pinaceae and Taxodiaceae predominate among gymnosperms. The involvement of *Ginkgocycadophytus* remains rather high (see Figure 7).

Krassilov (1972, 1973) pointed out the coal-forming role of *Sphenobaiera* and *Pseudotorellia longifolia* Doludenko in the Early Cretaceous of the Bureya Basin. The osmundaceous ferns lost their significance, gleicheniaceous and schizaeaceous ferns replaced them. Essential features of these plant communities are inherited from the Jurassic vegetation.

Based on a number of criteria, such as the abundance of bryophytes, cycadophyte index and replacement of ecological dominance, Krassilov suggested a warming trend during the deposition of sediments of Talyndzhan, Dublikan, and Chemchuko, a cooling trend in

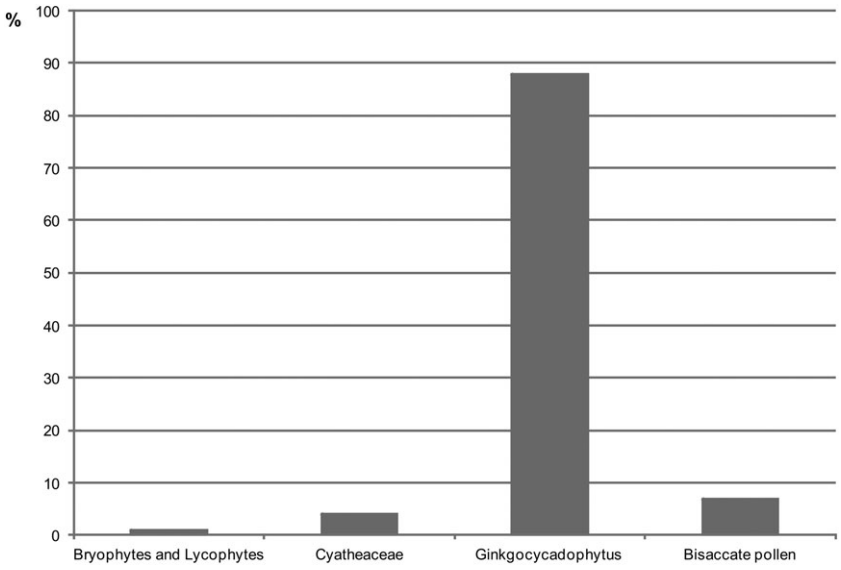

FIGURE 9 The relative abundances of major groups of spores and pollen in the coal seam of the Khilok Formation (Khilok Basin)

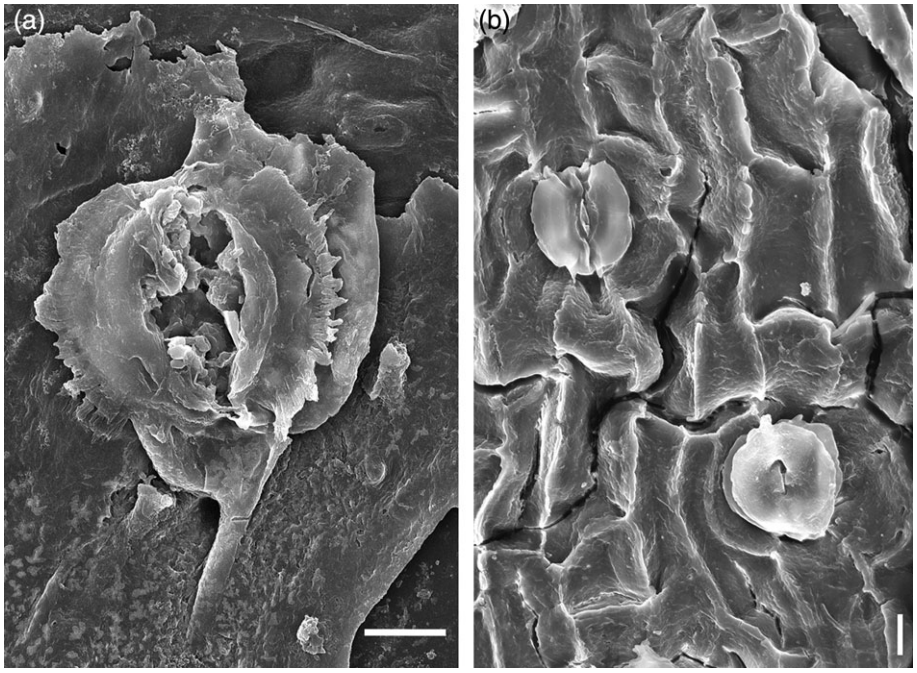

FIGURE 10 Cuticles of the coal-forming plants of the Doronino Formation (Chita-Ingoda Basin). (a) *Sphenobaiera starukhiniae* Bugdaeva. (b) *Pseudotorellia* sp. Scale bars 10 μm

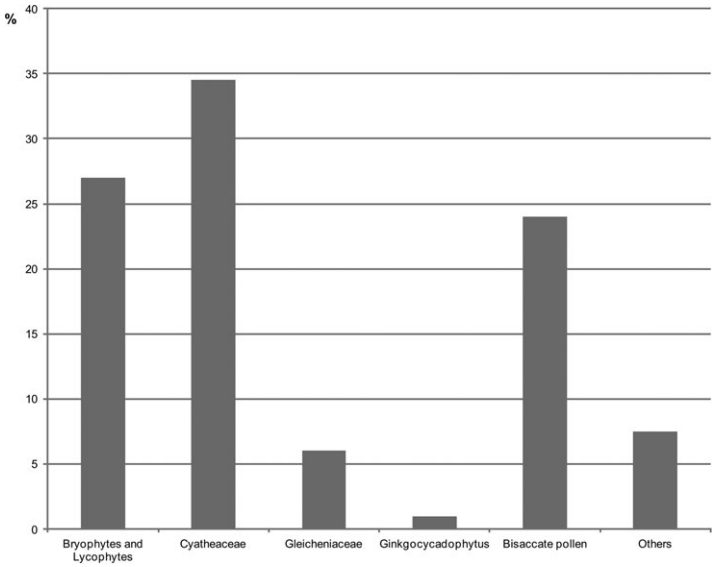

FIGURE 11 The relative abundances of major groups of spores and pollen in the coals of the Doronino Formation (Chita-Ingoda Basin)

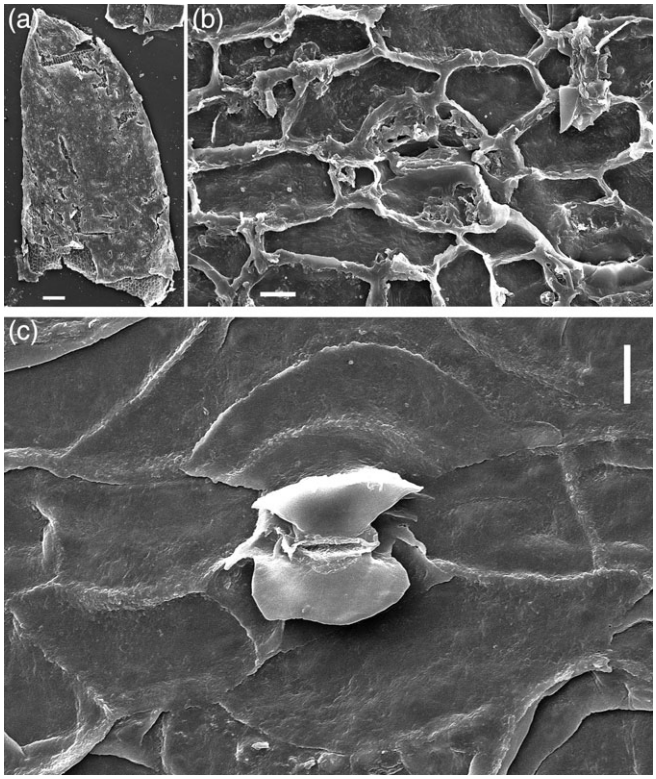

FIGURE 12 Cuticles of the coal-forming plants of the Doronino Formation (Bukachacha Basin) (a) Leaf of *Farndalea* sp., scale bar 200 μm. (b) Stoma of *Farndalea* sp., scale bar 10 μm. (c) *Pseudotorellia transbaikalica* Bugdaeva, scale bar 10 μm

Soloni and Chagdamyn deposition. The czekanowskialeans are reduced, whereas cheirolepidiaceous plants increased during the Chemchuko climatic warming (Krassilov, 1973).

The cyatheaceous ferns, conifers *Bilsdalea*, ginkgoaleans (*Pseudotorellia angustifolia*, *P. longifolia*, *Sphenobaiera urgalica* Krassilov, *S. ikorfatensis* (Seward) Florin) provided a basis for the Early Cretaceous mire plant communities.

3.2 | Transbaikalia

The Lower Cretaceous deposits fill numerous Transbaikalia intermontane rift basins. The strata are terrestrial, volcanogenic and coal-bearing (see Figure 2). The age of coal formation in this region was defined based on paleobotanical data (Bugdaeva, 1992, 1995; Bugdaeva & Markevich, 2012).

3.2.1 | Khilok Basin

The Khilok Formation (K_1hl) is represented by a sequence of trachyandesites, basalts, trachybasalts, their tuffs and tuffites with proluvial-lacustrine deposits (conglomerates, sandstones, and siltstones). Its geological age is the Barremian–Aptian (Gordienko, Bayanov, Klimuk, Ponomarchuk, & Travin, 1999).

In the sedimentary member of this sequence, E. V. Bugdaeva during the field expedition in 2002 found a thin coal seam (thickness is about 20 cm) consisting of very narrow dichotomously dissected leaves, later described as *Baierella averianovii* Bugdaeva. This representative of ginkgoaleans formed monospecific wetland plant communities and played coal-forming role during the Early Cretaceous (Bugdaeva & Markevich, 2007). The palynological spectrum from the coal seam is dominated by pollen *Ginkgocycadophytus* which was produced by ginkgoaleans (Figure 9).

3.2.2 | Chita-Ingoda Basin

In this basin the Barremian–Aptian Doronino Formation is widely distributed. This stratigraphic unit overlies with disconformity the Upper Jurassic strata and with conformity the Ulacha or Byrtsa formations. The Doronino Formation consists of mainly siltstones, mudstones, and sandstones, trachyandesites, basalts, trachybasalts, their tuffs and tuffites prevail, and thick productive coal seams in the upper part (see Figure 2). The thickness of this formation is 200–1600 m.

The fossil flora of the Doronino Formation in this basin is dominated by ferns, ginkgoaleans, and conifers. It was revealed that the coals of this stratigraphic unit were mainly composed of the

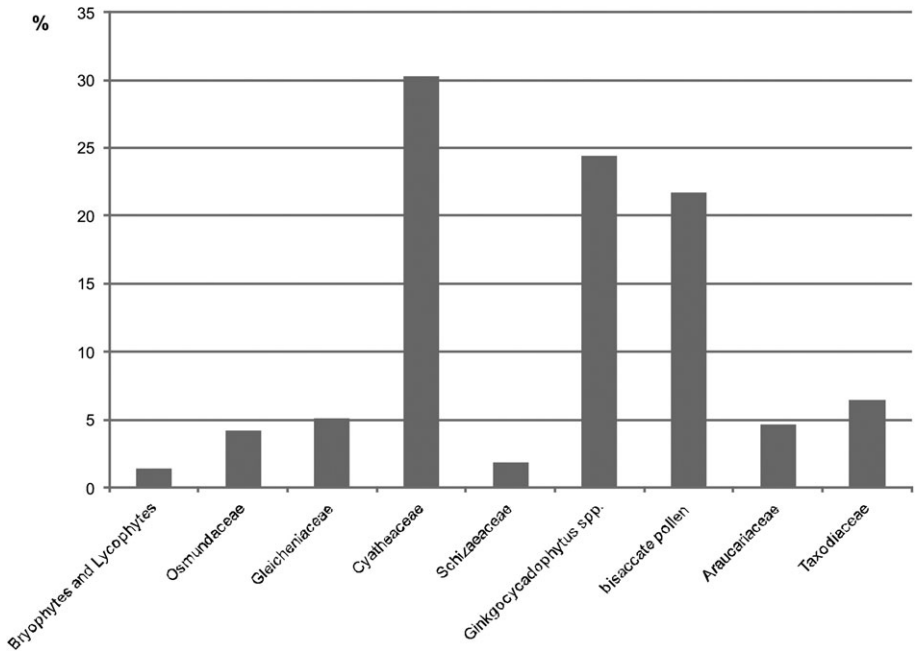

FIGURE 13 The relative abundances of major groups of spores and pollen in the coals of the Doronino Formation (Bukachacha Basin)

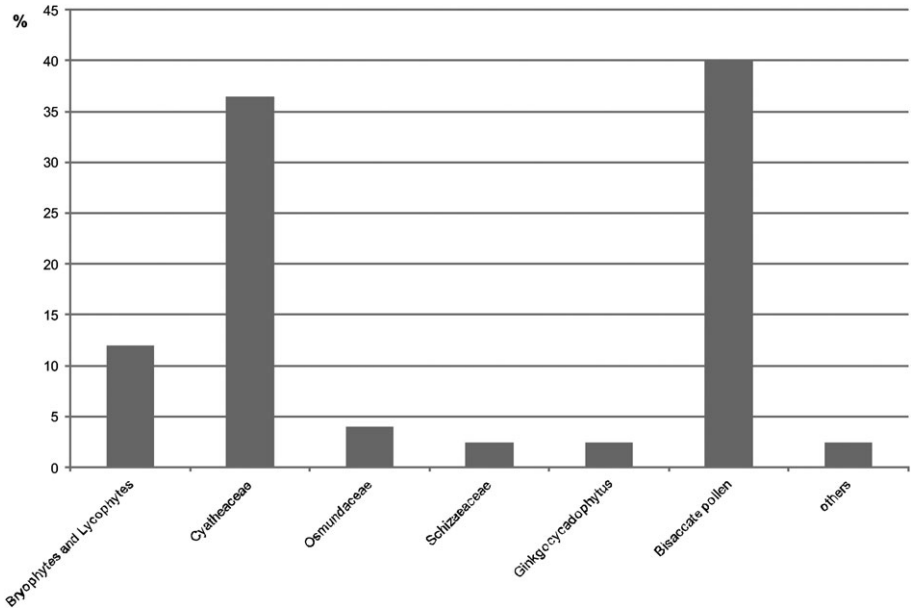

FIGURE 14 The relative abundances of major groups of spores and pollen in the coals of the Kuti Formation (Turga-Kharanor Basin)

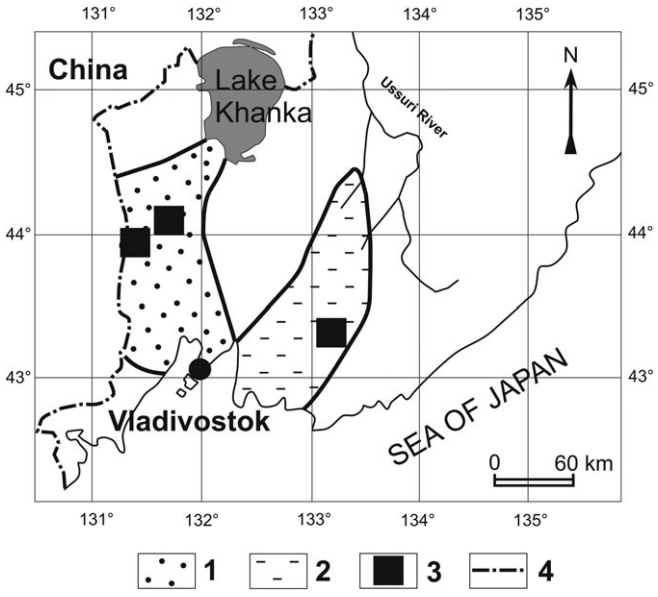

FIGURE 15 Study area in Primorye region. 1, Razdolnaya River Basin; 2, Partizansk Basin; 3, studied coal mines; 4, border between Russia and China

remains of ginkgoaleans, such as *Sphenobaiera starukhiniae* Bugdaeva (2010) and *Pseudotorellia* sp. (Figure 10a,b). The palynological spectra from coal seams are dominated by spores of bryophytes, lycophytes (Figure 6), and cyatheaceous ferns as well as by bisaccate pollen (Figure 11).

3.2.3 | Bukachacha Basin

The Doronino Formation in this basin is divided into two subformations. The lower subformation is represented by andesites, basalts, their lava breccias (150 m) and conglomerates, gravelstones, and coarse-grained sandstones (250 m). The upper subformation contains conglomerates, sandstones, mudstones, siltstones, and six productive coal seams, with a thickness of about 750 m (see Figure 2).

The fossil flora of coal-bearing deposits is dominated by conifers and ginkgoaleans, next in abundance–ferns and czekanowskialeans.

After bulk maceration of the coal from productive seam dispersed cuticles of *Farndalea* sp., belonging to conifers of araucariaceous affinity (Figure 12a,b), *Pityophyllum* sp. having pinaceous affinity, and ginkgoalean *Pseudotorellia transbaikalica* Bugdaeva (Figure 12c) were obtained.

The palynological spectrum of coal seam of the Doronino Formation in this basin is dominated by fern spores (more than 40 %), *Ginkgocycadophytus* sp. (more than 26 %) and bisaccate pollen having a pinaceous affinity (more than 22 %). The percentage of araucariaceous pollen is about 4.5 %, and that of taxodiaceous pollen 6.5 %. Among the ferns, the representatives of Cyatheaceae dominate, the percentage of gleicheniaceous and osmundaceous spores (Figure 6) reaches 5 % and 4 %, respectively (Figure 13).

The paleobotanical and palynological data revealed that the main coal-forming plants during the Doronino deposition in the Bukachacha Basin were cyatheaceous ferns, extinct ginkgoalean *Pseudotorellia* and diverse conifers.

3.2.4 | Turga-Kharanor Basin

The sequence of this basin is terminated by the Kuti Formation, represented by alluvial and lacustrine sedimentary rocks. In the upper part this stratigraphic unit has thick productive coal seams (see Figure 2). The thickness is up to 1500 m.

The fossil flora of coal-bearing deposits is represented by ferns, conifers, and ginkgoaleans.

The cuticle of ginkgoalean *Pseudotorellia kharanorica* Bugdaeva and cheirolepidiaceous plant *Pagiophyllum* sp. was revealed from coal of the Kuti Formation (Bugdaeva, 1995).

The palynological spectra of coals are dominated by cyatheaceous fern spores and pinaceous pollen, in a less degree by bryophytes and lycophytes (Figure 14).

The main coal-forming plants in this basin were cyatheaceous ferns, conifers, and ginkgoaleans, probably bryophytes and lycophytes.

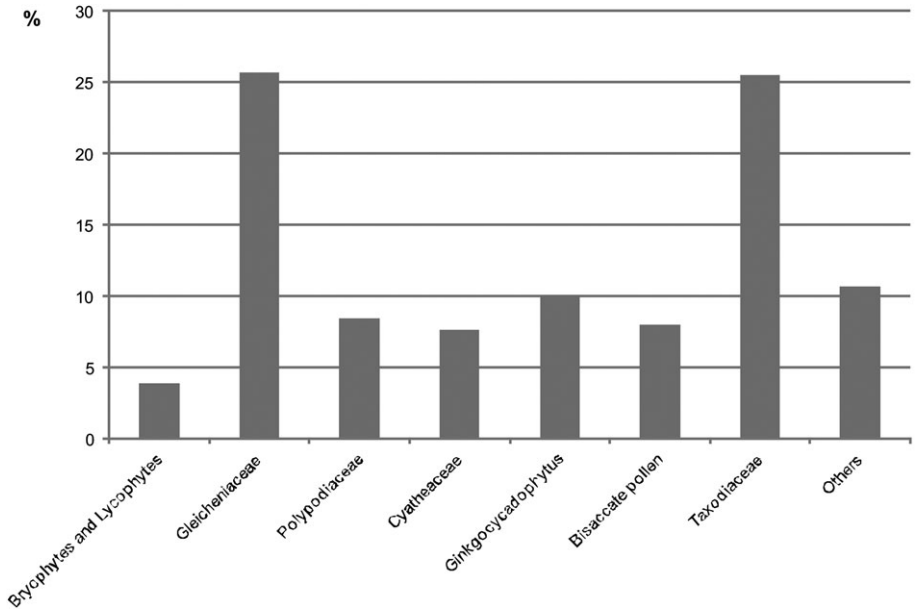

FIGURE 16 The relative abundances of major groups of spores and pollen in the coals of the Starosuchan Formation (Partizansk Basin)

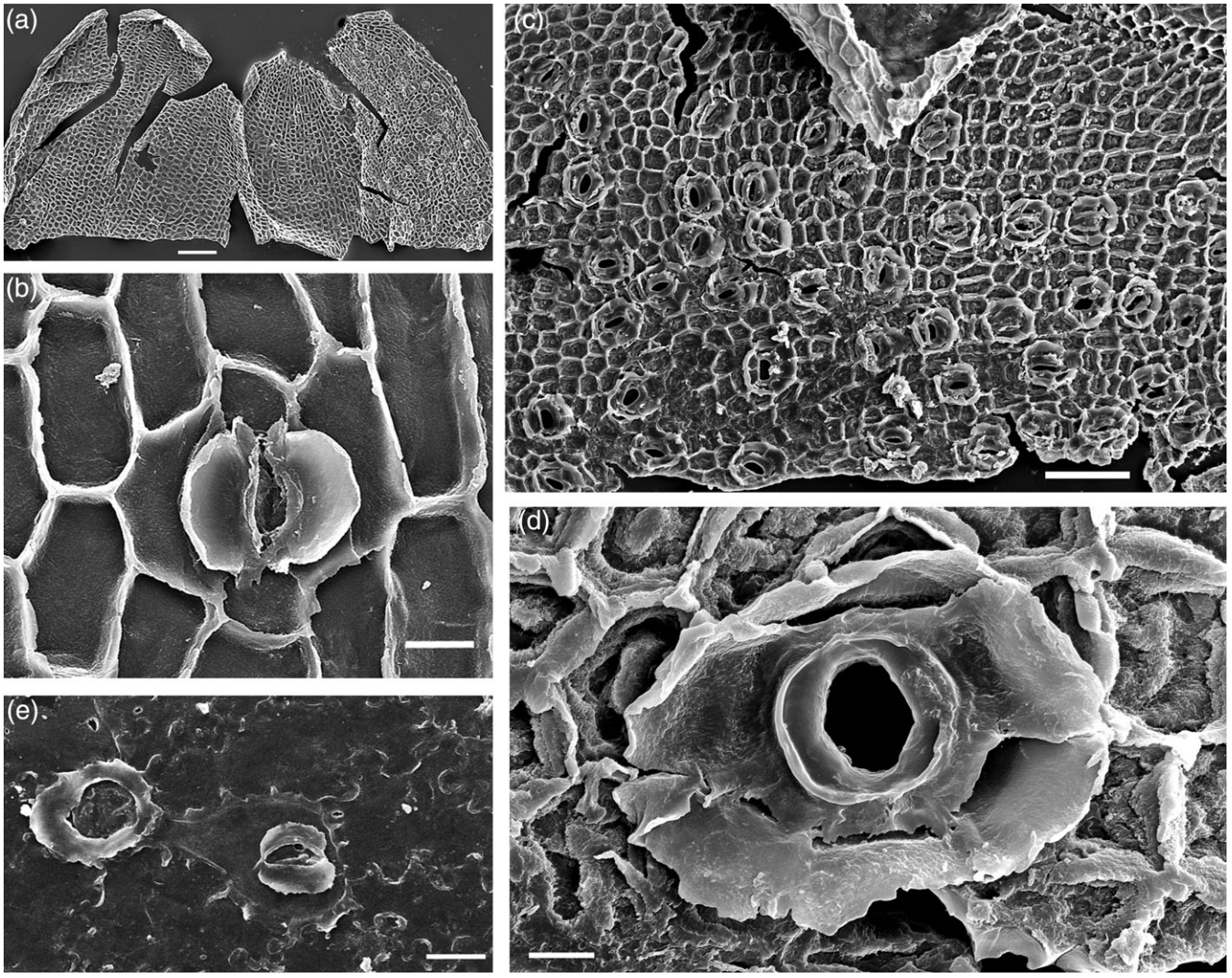

FIGURE 17 Cuticles of the coal-forming plants of the Lipovtsy Formation (Razdolnaya River Basin). (a) Upper part of leaf of *Mirovia orientalis* (Nosova) Nosova, scale bar 200 μm. (b) Stoma of *Mirovia orientalis*, scale bar 20 μm. (c) Stomatal and non-stomatal parts of *Athrotaxites orientalis* Deng et Chen, scale bar 100 μm. (d) Stoma of *Athrotaxites orientalis*, scale bar 10 μm. (e) Stoma and base of hair of *Nilssoniopteris rithidorachis* (Krysht.) Krassil., scale bar 20 μm

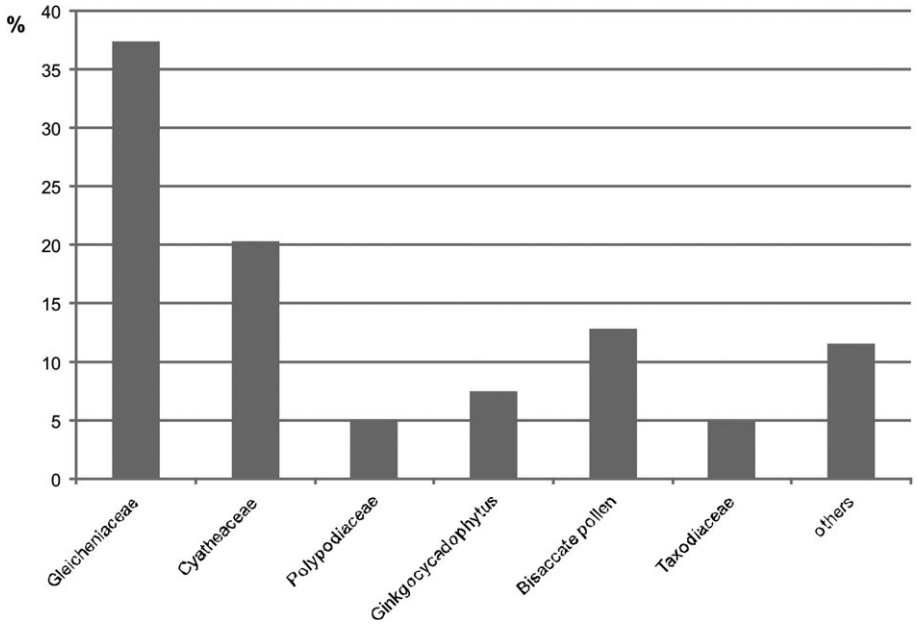

FIGURE 18 The relative abundances of major groups of spores and pollen in the coals of the Lipovtsy Formation (Razdolnaya River Basin)

3.3 | Primorye region

In the Primorye region two coal-bearing areas are widely distributed in the Partizansk and Razdolnaya basins (Figure 15).

3.3.1 | Partizansk Basin

The Starosuchan Formation of Aptian age was studied. The flora of this formation is dominated by the ferns and conifers. The coals of this stratigraphic unit are mostly composed of remains of taxodialean *Elatides asiatica* (Yok.) Krassil., subordinate Miroviaceae, rare ginkgoalean *Pseudotorellia* sp., and bennettite *Nilssoniopteris rithidorachis* (Krysht.) Krassil. (Bugdaeva, Markevich, & Volynets, 2014) The spores *Gleicheniidites* and pollen *Taxodiaceaepollenites* (Figure 6) are dominants in the palynospectra (Figure 16).

3.3.2 | Razdolnaya River Basin

The unique resinous coals (rhabdopissites) occur in the upper part of the Aptian Lipovtsy Formation (see Figure 2). The flora of this stratigraphic unit is very abundant and diverse. The plants that produced coals mainly belong to the Miroviaceae (*Mirovia orientalis* (Nosova) Nosova), ginkgoalean *Pseudotorellia krassilovii* Bugd., to a lesser degree these coals are composed of other groups of conifers (including scale-leaved *Athrotaxites orientalis* Deng et Chen) and bennettites *Nilssoniopteris rithidorachis*, *N. prynadae* Samyl., and *Anomozamites* sp. (Figure 17). The palynological data have revealed that cyatheaceous and gleicheniaceous ferns have played an important role (Figure 18) in the formation of coal in this basin (Bugdaeva & Markevich, 2009).

4 | CONCLUSIONS

The Early Cretaceous coal-forming plants comprise cyatheaceous, gleicheniaceous, osmundaceous, and schizaeaceous ferns, ginkgoaleans (*Pseudotorellia*, *Sphenobaiera* and *Baierella*), bennettites, and conifers having pinaceous, taxodiaceous, araucariaceous affinity, as well as extinct cheirolepidiaceous and miroviaceous plants.

It is well known that coal accumulation was controlled by tectonics, climatic conditions, and the structures of ecosystems that provided the organic material for the coal formation. The conservatism of taxonomic composition of mire plant communities is related to similar environments. The swamp plant communities and related coal accumulation seem to be sensitive to major environmental crises and these changes affect taxonomical composition of flora or extinction of swamp plants. A comparative account of the flora from different basins may substantiate the conclusions. Moreover palaeoecology of individual plant species may provide environmental inferences.

ACKNOWLEDGEMENTS

The authors thank the late V. A. Krassilov (Haifa University, Israel) for his advice, comments and fruitful discussions, N. G. Yadrishchenskaya, V. V. Golozubov, B. P. Nechaev for help during the field research, V. I. Podolyan for assistance with materials on coal geology, and E. B. Volynets for collaboration.

REFERENCES

Barbacka, M., Püspöki, Z., Bodor, E., Forgács, Z., Hámor-Vidó, M., Pacyna, G., & McIntosh, R. W. (2015). Palaeotopography related plant succession stages in a coal forming deltaic succession in early Jurassic in Hungary. *Palaeogeography, Palaeoclimatology, Palaeoecology*, *440*, 579–593.

Barclay, R., McElwain, J., Dilcher, D., & Sageman, B. (2007). The Cuticle Database: Developing an interactive tool for taxonomic and paleoenvironmental study of the fossil cuticle record. *Courier Forschungsinstitut Senckenberg*, *258*, 39–55.

Bugdaeva, E. V. (1992). The Early Cretaceous flora of Transbaikalia. In N. Mateer & P.-J. Chen (Eds.), *Aspects of non-marine Cretaceous geology*. Beijing, China: Ocean Press.

Bugdaeva, E. V. (1995). *Pseudotorellia* from the Lower Cretaceous coal-bearing deposits of Eastern Transbaikalia. *Paleontological Journal*, *29*, 182–184.

Bugdaeva, E. V. (2010). New species of *Sphenobaiera* Florin (Ginkgoales) from the Lower Cretaceous of Transbaikalia. *Paleontological Journal*, *44*, 1240–1251.

Bugdaeva, E. V., & Markevich, V. S. (2007). A new species of *Baierella* from the Krasnyi Yar locality, Early Cretaceous of Western Transbaikalia. *Paleontological Journal*, *41*, 1063–1067.

Bugdaeva, E. V., & Markevich, V. S. (2009). The coal-forming plants of Rhabdopissites in the Lipovtsy coal field (Lower Cretaceous of Southern Primorye). *Paleontological Journal*, *43*, 1217–1229.

Bugdaeva, E. V., & Markevich, V. S. (2012). The age of Lycoptera beds (Jehol biota) in Transbaikalia (Russia) and correlation with Mongolia and China. In P. Godefroit (Ed.), *Bernissart dinosaurs and Early Cretaceous terrestrial ecosystems* (pp. 452–464). Bloomington, IL: Indiana University Press.

Bugdaeva, E. V., Markevich, V. S., & Volynets, E. B. (2014). The coal-forming plants of the upper part of the Lower Cretaceous Starosuchan formation (Partizansk Basin, South Primorye Region). *Stratigraphy and Geological Correlation*, *22*, 256–268.

Cutler, D. F. (1982). Cuticular sculpturing and habitat in certain *Aloë* species (Liliaceae) from Southern Africa. In D. F. Cutler, K. L. Alvin, & C. E. Price (Eds.), *The plant cuticle* (pp. 425–444). London, England: The Linnean Society, Academic Press.

Ferguson, D. K., Lee, D. E., Bannister, J. M., Zetter, R., Jordan, G. J., Vavra, N., & Mildenhall, D. C. (2010). The taphonomy of a remarkable leaf bed assemblage from the Late Oligocene–Early Miocene Gore Lignite Measures, southern New Zealand. *International Journal of Coal Geology*, *83*, 173–181.

Gordienko, I. V., Bayanov, V. D., Klimuk, V. S., Ponomarchuk, V. A., & Travin, A. V. (1999). The composition and age ($^{39}Ar/^{40}Ar$) volcanogenic rocks of the Chikoi-Khilok taphrogenic trough in Transbaikalia. *Geology and Geophysics*, *40*, 583–591 (in Russian).

Greb, S. F., DiMichele, W. A., & Gastaldo, R. A. (2006). Evolution and importance of wetlands in earth history. In S. F. Greb & W. A. DiMichele (Eds.), *Wetlands through time*, Special Paper, 399. (1–40). Boulder, CO: Geological Society of America.

Iannuzzi, R. (2010). The Flora of Early Permian coal measures from the Paraná Basin in Brazil: A review. *International Journal of Coal Geology*, *83*, 229–247.

Jasper, K., Hartkopf-Fröder, C., Flajs, G., & Littke, R. (2010). Palaeoecological evolution of Duckmantian wetlands in the Ruhr Basin (Western Germany): A palynological and coal petrographical analysis. *Review of Palaeobotany and Palynology*, *162*, 123–145.

Khanchuk, A. I., Ratkin, V. V., Ryazantseva, M. D., Golozubov, V. V., & Gonokhova, N. G. (1995). *Geologiya I Poleznye Iskopaemye Primorskogo Kraya* [Geology and minerals of Primorye region]. Vladivostok, Russia: Dalnauka (in Russian).

Kovach, W. L., & Dilcher, D. L. (1984). Dispersed cuticles from the Eocene of North America. *Journal of the Linnean Society (Botany)*, *88*, 63–104.

Kovaleva, T. A., Markevich, V. S., Bugdaeva, E. V., Volynets, E. B., & Afonin, M. A. (2016). New data on Palynostratigraphy of the Lipovtsy formation in the Razdolnaya Coal Basin (southern Primorye). *Russian Journal of Pacific Geology*, *10*(1), 50–62.

Krassilov, V. A. (1967). *Rannemelovaya Flora Yuzhnogo Primorya I Eyo Znachenie Dlya Stratigraphii* [Early Cretaceous flora of Southern Primorye and its stratigraphic significance]. Moscow, Russia: Nauka (in Russian).

Krassilov, V. A. (1972). *Mezozoiskaya Flora Reki Burei (Ginkgoales i Czekanowskiales)* [Mesozoic flora of the Bureya River (Ginkgoales and Czekanowskiales)]. Moscow, Russia: Nauka (in Russian).

Krassilov, V. A. (1973). Materials on Stratigraphy and Paleofloristics of the coal-bearing strata of the Bureya Basin. In V. A. Krassilov (Ed.), *Iskopaemye Flory i Fitostratigrafiya Dal'Nego Vostoka* [The fossil floras and phytostratigraphy of the Far East] (pp. 28–51). Vladivostok, Russia: DVNC AN SSSR.

Krassilov, V. A. (1978). Mesozoic lycopods and ferns from the Bureja Basin. *Palaeontographica, Abteilung B*, *166*, 16–29.

Krassilov, V. A. (1985). *Melovoy period. Evolyutsiya Zemnoi Kory I Biosfery* [Cretaceous Period. Evolution of Earth crust and biosphere]. Moscow, Russia: Nauka (in Russian).

Krassilov, V. A. (1992). Coal-bearing deposits of the Soviet Far East. In P. J. McCabe & J. T. Parrish (Eds.), *Controls on the distribution and quality of Cretaceous coals*, Special Paper 267. Boulder, CO: Geological Society of America.

Litke, R. (1966). Kutikularanalytische Untersuchungen Im Niederlausitzer Unterflöz. *Paläontologische Abhandlungen, B II*, *2*, 327–426.

Markevich, V. S. (1981). New species of *Classopollis* from the Cretaceous deposits of the Sea of Japan seafloor. *Paleontologicheskii Zhurnal (Paleontological Journal)*, *1*, 129–133.

Markevich, V. S. (1995). *Melovaya Palynoflora Severa Vostochnoi Asii* [Cretaceous palynoflora of the northern East Asia]. Vladivostok: Dalnauka (in Russian).

Markevich, V. S., & Bugdaeva, E. V. (2014). Late Jurassic–Early Cretaceous coal-forming plants of the Bureya Basin, Russian Far East. *Stratigraphy and Geological Correlation*, *22*, 239–255.

Martin, J. T., & Juniper, B. E. (1970). *The cuticles of plants*. New York, NY: St. Martin'S Press.

McElwain, J., & Chaloner, W. G. (1996). The fossil cuticle as a skeleton record of environmental change. *PALAIOS*, *11*, 376–388.

Michaelsen, P. (2002). Mass extinction of peat-forming plants and the effect on fluvial styles across the Permian-Triassic boundary, northern Bowen Basin, Australia. *Palaeogeography, Palaeoclimatology, Palaeoecology*, *179*, 173–188.

Miner, E. L. (1935). Paleobotanical examinations of Cretaceous and Tertiary coals. I. Cretaceous coals from Greenland. *American Midland Naturalist*, *16*, 585–615.

Peters, I. (1963). Die Flora Der Oberpfälzer Braunkohlen und ihre stratigraphische Bedeutung. *Palaeontographica, Abteilung B*, *112*, 1–50.

Philippe, M., Méon, H., Lambert, G., Erdei, B., Thevenard, F., & Gomez, B. (2002). A palm-tree and *Sciadopitys* swamp-Forest from the Neogene of Bresse (eastern France). *Comptes Rendus Palevol*, *1*, 221–225.

Roselt, G., & Schneider, W. (1969). *Cuticulae Dispersae*, ihre Merkmale, Nomenklatur, und Klassifikation. *Paläontologische Abhandlungen, Series B*, *3*(1), 1–123.

Schneider, W. (1969). *Cuticulae Dispersae* Aus dem 2. Lausitzer Flöz (Miozän) und ihre fazielle Aussage. *Freiberger Forschungshefte, C*, *222*, 1–74.

Stace, C. A. (1965). Cuticular studies as an aid to taxonomy. *Bulletin of the British Museum (Natural History) Botany*, *4*(1), 1–78.

Steart, D. C., Collinson, M. E., Scott, A. C., Glasspool, I. J., & Hooker, J. J. (2007). The Cobham Lignite Bed: The palaeobotany of two petrographically contrasting lignites from either side of the Paleocene–Eocene carbon isotope excursion. *Acta Palaeobotanica*, *47*(1), 109–125.

Taylor, T. N., Taylor, E. L., & Krings, M. (2009). *Paleobotany. The biology and evolution of fossil plants* (2nd ed.). Burlington, IL: Academic Press.

Upchurch, G. R., Jr. (1995). Dispersed angiosperm cuticles: Their history, preparation and application to the rise of angiosperms in Cretaceous and Paleocene coals, southern Western interior of North America. *International Journal of Coal Geology*, *28*, 161–227.

Upchurch, G. R., Jr., & Askin, R. A. (1989). Latest Cretaceous and earliest Tertiary dispersed cuticles from Seymore Island, Antarctica. *Antarctic Journal of the United States*, *24*(5), 7–10.

Vakhrameev, V. A., & Doludenko, M. P. (1961). *Verkhneyurskaya i Nizhnemelovaya Flora Bureinskogo Basseina i ee Znachenie dlya Stratigrafii* [Late Jurassic and Early Cretaceous flora of the Bureya Basin and its stratigraphic significance]. Moscow, Russia: Izdatelstvo Akademii Nauk SSSR (in Russian).

Villalba-Breva, S., Martín-Closas, C., Marmi, J., Gomez, B., & Fernández-Marrón, M. T. (2012). Peat-forming plants in the Maastrichtian coals of the Eastern Pyrenees. *Geologica Acta*, *10*(2), 189–207.

How to cite this article: Bugdaeva EV, Markevich VS. The Early Cretaceous coal-forming plants of southern part of East Siberia and Russian Far East. *Island Arc*. 2017;26:e12206. https://doi.org/10.1111/iar.12206