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# The composition and age of the Ul'ya flora (Okhotsk-Chukotka volcanic belt, North-East of Russia): paleobotanical and geochronological constraints

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ABSTRACT. The Ul'ya flora comes from the Amka Formation of the Ul'ya Depression, located in the Okhotsk–Chukotka volcanic belt (North-East Russia). This flora includes ~50 species, among which conifers predominate. Ferns and angiosperms are also diverse. The Ul'ya flora is characterized by high endemism and by the presence of numerous Early Cretaceous relicts (*Hausmannia*, *Podozamites*, *Phoenicopsis*, *Baiera*, *Sphenobaiera*). Four new endemic species of conifers from the Ul'ya flora are described: *Elatocladus amkensis* Golovneva, sp. nov., *Araucarites sheikashoviae* Golovneva, sp. nov., *Elatocladus gyrbykensis* Golovneva, sp. nov. and *Pagiophyllum umitbaevii* Golovneva, sp. nov. Two-lobed leaves of *Sphenobaiera* are assigned to *S. biloba* Prynada based on their epidermal structure. Because of its systematic composition the Ul'ya flora is correlated with the Coniacian Chaun flora of Central Chukotka, with the Coniacian Aliki flora from the Viliga–Tumany interfluve area, and with the Coniacian Kholchan flora of the Magadan Region. The U-Pb age of zircon (ID-TIMS method) from plant-bearing tuffites within the Amka Formation at the Uenma River is 86.1 ± 0.3 Ma. Thus, Coniacian age (most likely the end of the Coniacian, near the Coniacian/Santonian boundary) is assigned to the Ul'ya flora and plant-bearing pyroclastic deposits of the Amka Formation on the basis of paleobotanical and isotopic data.

KEYWORDS: Late Cretaceous flora, U-Pb geochronology, Okhotsk–Chukotka volcanic belt

## INTRODUCTION

The Okhotsk–Chukotka volcanic belt (OCVB) is one of the largest Andian-type volcanic provinces related to continental margin subduction. It extends for more than 3200 km along the Sea of Okhotsk and the Bering Sea coasts from the Uda River in the Khabarovsk Region to Chaplino village in East Chukotka (Belyi 1977, Akinin & Miller 2011, Tikhomirov et al. 2012). The total thickness of the volcanic deposits ranges between one and two kilometers, and the total volume of the erupted material in the OCVB has been estimated at more than one million km$^3$ (Akinin & Miller 2011).

The deposits of the OCVB comprise lavas (basalts, andesites, rhyolites, and ignimbrites with a high proportion of felsic rock) and pyroclastic interlayers, which contain numerous burials of fossil plants, reflecting mountain vegetation. Due to its negligible post-magmatic deformation, the OCVB is a unique object for basic studies in the fields of petrology,

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volcanology, hydrothermal ore-forming processes and paleobotany.

The stratigraphy of the OCVB has been studied by E.K. Ustiev, V.F. Belyi, E.L. Lebedev, V.A. Samylina, N.I. Filatova and many other researchers (Samylina 1974, Belyi 1977, Lebedev 1987, Filatova 1988, Kotlyar & Rusakova 2004). Until the end of the 20th century, age determination of volcanic rocks was based on analyses of plant fossils distributions and on K-Ar and Rb-Sr isotopic dating. The results of these methods were imprecise and often contradictory. The Cretaceous floras of the OCVB significantly differ from the contemporaneous floras of adjacent coastal lowlands along the eastern margin of the volcanic belt (Philippova & Abramova 1993, Shczepetov & Golovneva 2010, Herman 2013). The OCVB floras were formed in montane environments and are marked by high endemism, predominance of ferns and conifers, a minor share of angiosperms, and considerable numbers of Early Cretaceous relicts in all plant groups. Lithological correlation was also hampered by significant variability within the volcanic successions preserved in different parts of the OCVB.

Updated isotopic techniques (U-Pb, $^{40}Ar/^{39}Ar$) developed during recent decades produce more reliable and precise geochronological data (Kelley et al. 1999, Ispolatov et al. 2004, Hourigan & Akinin 2004, Akinin & Khanchuk 2005, Tikhomirov et al. 2006, 2012, Akinin & Miller 2011). On the whole, the OCVB is characterized by discontinuous magmatic activity ranging in age from the mid-Albian up to the mid-Campanian (106–76 Ma). There are several peaks of volcanism defined with modes at approximately 105, 100, 96, 92.5, 87, 82 and 77 Ma (Akinin & Miller 2011). The formation of the OCVB was completed by effusion of the plateau-basalts, which are considered to have been deposited at 80–76 Ma (Akinin et al. 2014).

A recent systematic study of plant fossils and a comparison of the floristic assemblages of the OCVB with well-dated floras of the coastal lowlands have also allowed more accurate age determination (Herman 2013). On the basis of both paleobotanical and isotopic data (Kelley et al. 1999, Spicer et al. 2002, Akinin & Miller 2011, Herman et al. 2016), the ages of the Chaun flora from Central Chukotka, the Arman flora from the Magadan Region and the Grebenka flora from the Anadyr River were revised (Fig. 1).

This paper deals with age determination of a floristic assemblage from the Amka Formation, distributed in the Ul'ya River basin (Ul'ya Depression) in the southern part of the OCVB (Fig. 1), on the basis of floristic analysis and U-Pb ID-TIMS zircon dating.

## MATERIAL AND METHODS

Volcanic rocks for isotopic dating were sampled by L.B. Golovneva and S.V. Shczepetov in the Ul'ya Depression area in 2013. Rock thin-sections were examined under a microscope and analyzed for their major and trace elements by X-ray fluorescence at the Analytical Center of NEISRI FEB RAS, Magadan. The standard procedure of zircon extraction from tuffites, tuffs and ignimbrites (samples 5–15 $cm^3$) included crushing, separation in heavy liquids, electromagnetic separation and then selection under a binocular microscope. Separated zircons from two preferred samples (1-2a from Amka Formation, Uenma River; 7-3 from Urak Formation, Gyrbykan River) were processed for study and isotopic measurements.

The U-Pb geochronological analyses (ID-TIMS) of zircons from these two samples were carried out at the Institute of Precambrian Geology and Geochronology, Saint Petersburg. Selected zircon crystals were subjected to stepwise removal of their surface impurities using acetone, alcohol and 1*M* $HNO_3$. Zircon grains (or their fragments) were washed in high-pure water at each stage of processing. A modified version of Krogh's (1973) method was used to chemically decompose zircon in Teflon microcapsules placed in a Parr system decomposition vessel, with $^{235}U/^{202}Pb$ tracer added immediately before starting the decomposition process. A Triton TI mass spectrometer was used for U-Pb isotopic measurements, to accuracy of ~0.5% relative to standards. Procedure-related contamination was less than 1–2 pg for lead and less than 0.2 pg for uranium. The measured isotopic data were processed using the PbDAT (Ludwig 1991) and the "ISOPLOT" (Lugwig 2012) programs. Conventional values of uranium decay constants were used to calculate the ages (Steiger & Jager 1977). The common lead correction was applied according to the model of Stacey and Kramers (1975). All errors are given at 2σ level.

Our general description of the floristic assemblage from the Amka Formation is based on previous collections of E.L. Lebedev and V.G. Korol'kov, as well as on new collections gathered by Golovneva and Shczepetov during summer 2013. Lebedev's collections are housed at the Geological Institute of the Russian Academy of Sciences in Moscow (prefix GIN in specimen numbers). The collections of Golovneva and Shczepetov are kept at the Komarov Botanical Institute of the Russian Academy of Sciences in St. Petersburg (prefix BIN). The small collection gathered by geologist Korol'kov in the Gyrbykan River basin in 1966 is stored at the Geological Museum of the Magadan Branch of the Far East Federal District Territorial Fund of Geological Information in Magadan (prefix TFI).

Most plant fossils are preserved as impressions, yielding almost no structurally preserved material.

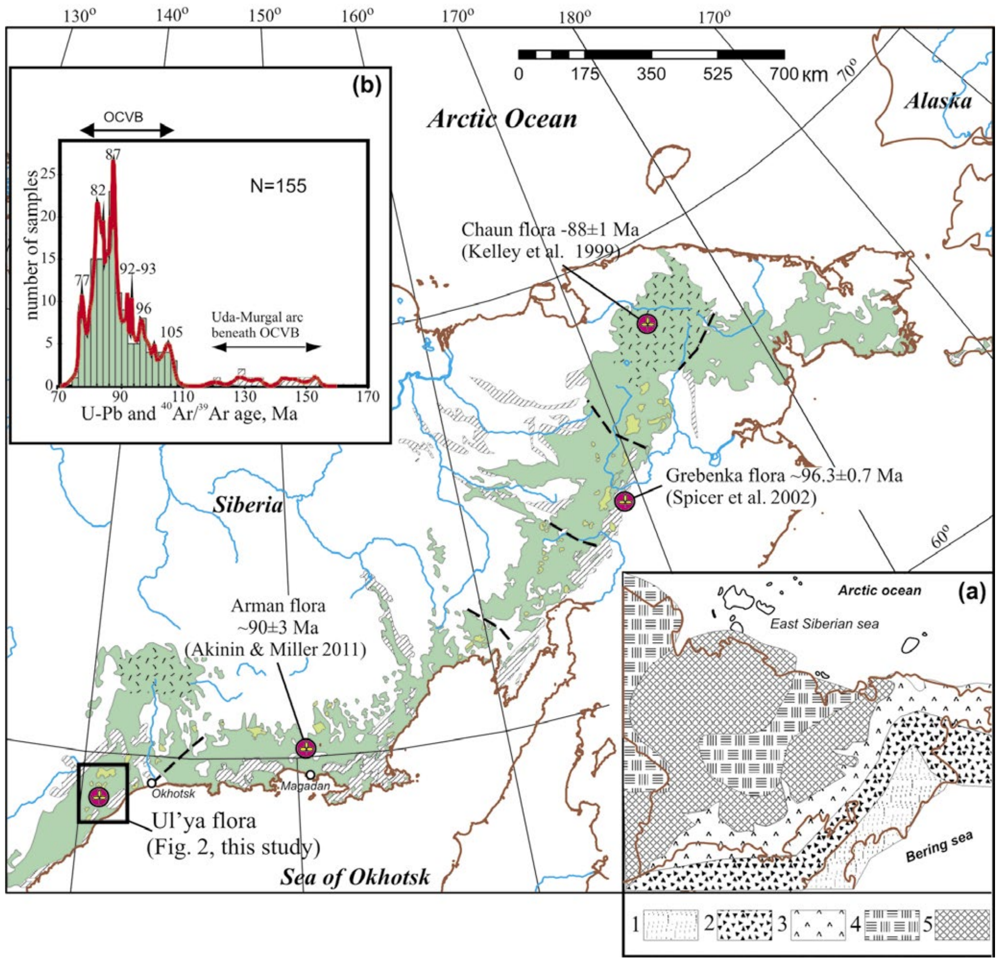


**Fig. 1**. The Okhotsk–Chukotka volcanic belt (OCVB) extends along the continental margin of North-east Asia (Akinin & Miller 2011). Its major Albian–Campanian calc-alkalic magmas are shown in green (major catastrophic eruptions of felsic magmas in the Pegtymel Depression in Chukotka and in the Kuidusun Area near the Ul'ya Depression are shown by patterns), and the final Campanian basalts are shown in light green (Khakarin, Mygdykit, Enmyvaam and other formations). The "pre-belt" island-arc volcanic-sedimentary successions are indicated by slanted hatching. Red dots with leaves show the main localities of fossil floras having $^{40}$Ar /$^{39}$Ar and U-Pb age determination

Inset map (a) – paleogeographic environments in the Albian–Maastrichtian (Herman 2011, revised). 1 – steady sea conditions, 2 – repeatedly sea-flooded coastal lowlands, 3 – volcanic highlands, 4 – non-flooded plains, 5 – uplands.

Inset map (b) – histogram of the ages of volcanic rocks from the OCVB and its basement structures according to $^{40}$Ar /$^{39}$Ar and U–Pb SHRIMP dating (Akinin & Miller 2011). Thick curve approximates the relative probability density of the isotopic ages.

They were studied under a Zeiss Stemi 2000-C binocular microscope. The specimens were photographed using a Nikon Coolpix P7700 camera at low-angle illumination. Some specimens were photographed in water to increase contrast.

Cuticles of *Shenobaiera* leaves were prepared according to the standard procedures outlined by Kerp (1990). The preparations were examined and photographed using a Carl Zeiss Axio Scope.A1 and a Jeol JSM–6390LA scanning electron microscope (SEM).

## STRATIGRAPHY

The Ul'ya Depression (the Ul'ya Trough) stretches from the town of Okhotsk in the north-east to Ayan village in the south-west, and from the Sea of Okhotsk coast in the south to the Maya and Yudoma river basins in the north (Figs 1, 2). The initial stratigraphic investigations were summarized by G.N. Chertovskikh (1964) and T.V. Sheikashova (1964). According to these authors, the volcanic succession of the Ul'ya Depression is divisible into the Uchulikan, Amka, Khetana, Urak and Khakarin formations (Tab. 1). They overlie a ravinement surface of pre-Upper Jurassic deposits (Precambrian, Paleozoic, lower Mesozoic) or lie on highly dislocated Early Cretaceous basic effusive rocks, sometimes including sedimentary layers.

The Uchulikan Formation is exposed in the north-western part of the Ul'ya Depression in the lower part of the Ul'ya River basin (Fig. 2). There are polymictic conglomerates with sandstone interbeds ~300 m thick in the

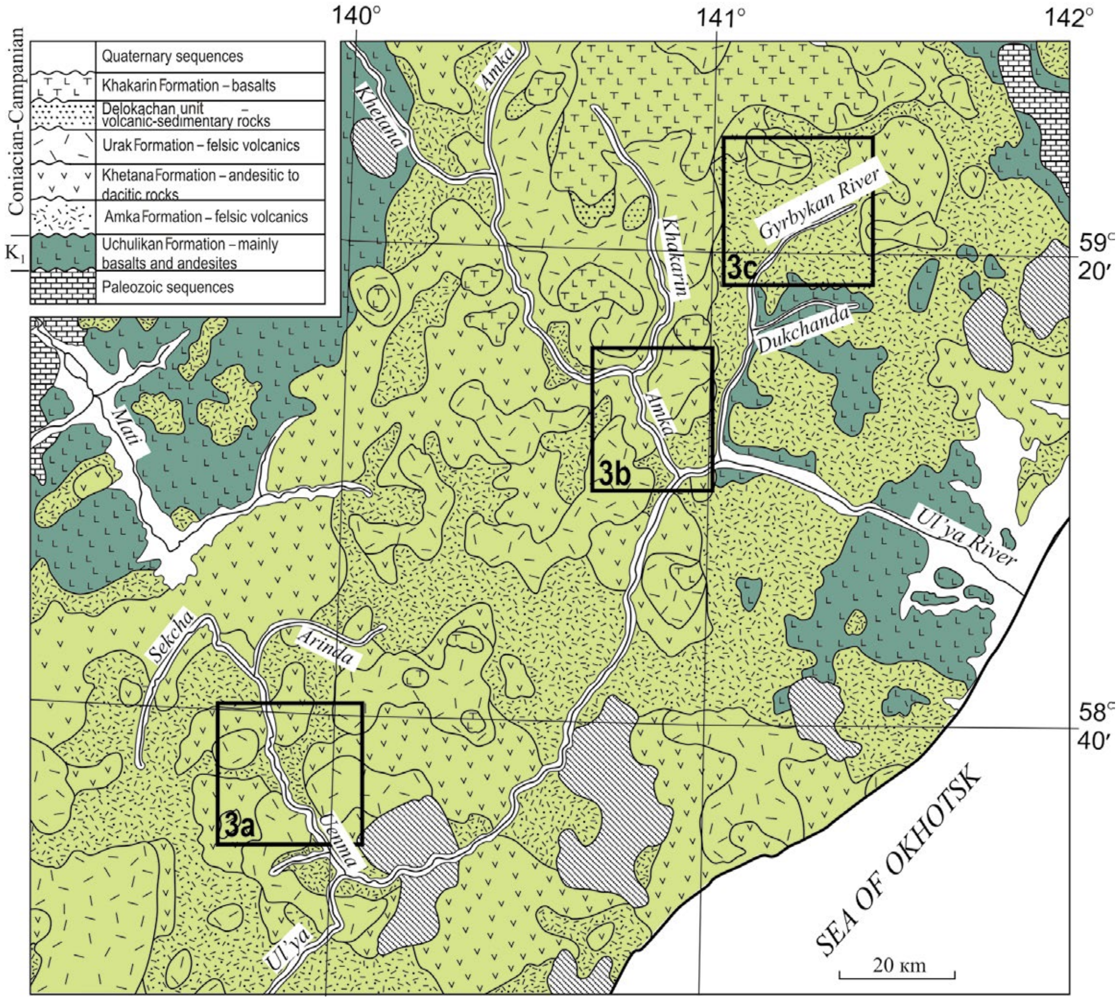


**Fig. 2**. Geological map of the Ul'ya Depression with study areas (numbers indicate maps in Fig. 3, intrusions shown by slanted hatching). Constructed using Federal geological maps, scale 1:200 000 (Korol'kov 1973, Umitbaev et al. 1975, Filichev et al. 1978)

bottom of the section. The upper part (~700 m thick) mainly consists of altered andesitic and basaltic lava flows. This formation was first described by Chertovskikh along the Uchulikan River (Urak River basin). In that area the Uchulikan Formation conformably overlies sandstones of the Dalninskaya Formation, yielding sparse Lower Cretaceous plant fossils.

The Amka Formation, ~600 m thick, unconformably overlies the Uchulikan Formation or different Mesozoic and Paleozoic rocks. It is composed of felsic and medium-felsic volcanic and volcano-sedimentary rock yielding abundant plant fossils. The Amka Formation is widely distributed in the central part of the Ul'ya Depression (Fig. 2). Sheikashova (1964) described its stratotype, located near the mouth of the Amka River, a tributary of the Ul'ya River. Later the Amka Formation was studied in detail during geological mapping done by the North-East Territorial Geological Survey (Korol'kov 1973, Umitbaev et al. 1975, Filichev et al. 1978). The formation is characterized by significant facies variability. Unstratified felsic lavas with white tuff intercalations prevail in the upper reaches of the Devoksha and Arinda rivers, on the left side of the Ul'ya River. This lava field is surrounded by ignimbrites, coarse tuffs and tuff-breccia rocks. In more distal areas the Amka Formation is represented by volcaniclastic deposits consisting of tuffaceous sandstones, tuffaceous siltstones and coaly mudstones. These deposits contain abundant plant fossils.

The Khetana Formation conformably overlies the Amka Formation and consists of two-pyroxene andesites and basaltic andesites with admixture of tuffs. The formation is 150–800 m thick. There are no plant fossils in these deposits.

The Urak Formation is ~600 m thick and comprises welded ignimbrites, rhyolitic lavas and tuffs. It unconformably overlaps the

**Table 1**. The volcanic succession of the Ul'ya Depression, Okhotsk-Chukotka volcanic belt

| System | Series | Lithology | Formation | Synonyms in Gromov & Lebedev 1978a, Lebedev 1987 |
|---|---|---|---|---|
| Cretaceous | Upper | olivine basalts | Khakarin | |
| | | ignimbrites, tuffs, rhyolite lavas | Urak | |
| | | two-pyroxene andesites and basaltic andesites with admixture of tuffs | Khetana | Ust'-Khetana |
| | | ignimbrites, rhyolite lavas and volcano-sedimentary rocks | Amka | Emanra, Magey |
| | | | | |
| | Lower | andesitic and basaltic lavas, tuffs | Uchulikan | |

andesites of the Khetana Formation or the deposits of the Amka Formation. Sparse plant fossils were reported from the Urak River basin (Chertovskikh 1964).

The Khakarin Formation is 500–600 m thick and conformably overlies the Urak Formation. It consists mainly of olivine basalts, more rarely pyroxene andesites and basaltic andesites. These rocks form the plateau in the Khakarin River headwaters area and do not yield plant fossils.

The Delokachan Unit and the Emanra Formation were additionally established in the Ul'ya River area. The Delokachan Unit underlies the Khakarin basalts and consists of felsic tuffaceous-sedimentary rocks distributed in a small area in the Khakarin River headwaters (Gromov & Lebedev 1978a, Gromov et al. 1980). The Emanra Formation was established by V.V. Gromov and E.L. Lebedev in the lower part of the Khetana River basin (Gromov & Lebedev 1978b, Gromov et al. 1980). It overlies the Uchulikan Formation and consists of felsic lava flows and tuffs in the lower part and andesitic lava flows in the upper part. This succession was previously assigned by Sheikashova (1964) to the Amka and Khetana formations. However, Lebedev believed that the plant fossils from the lower part of the Emanra Formation are older than those from the stratotype of the Amka Formation. First, the deposits from the Khetana River were assigned to the Magey Formation. The upper andesites were included in this formation as the separate Ust'–Khetana Unit (Gromov & Lebedev 1978a), but the Magey Formation was earlier described from the Fore-Djugdjur Depression, and the use of that name for deposits from the Ul'ya Depression is incorrect. Therefore, the volcano-sedimentary deposits from the Khetana River basin were named the Emanra Formation (Gromov & Lebedev 1978b, Gromov et al. 1980).

During a geological survey done by the Aerogeologia Company in the Ul'ya Depression, the Magey, Emanra, Amka and Urak formations were mapped. The relationships of these deposits to the andesites of the Khetana Formation were interpreted quite arbitrarily. These decisions gave rise to much confusion in Ul'ya Depression stratigraphy. Later, all deposits lying between the Emanra and the Khakarin formations were considered as the Ul'ya Series in order to eliminate any discrepancy between the mapped stratigraphic subdivisions and the ages of the floristic assemblages. According to Lebedev (1987), this series yielded andesite lenses of different ages.

The results of our field studies are in compliance with the stratigraphic scheme developed by Chertovskikh (1964) and Sheikashova (1964), which is used in this paper. Later we discuss why the Emanra Formation cannot be distinguished on paleobotanical grounds.

The age of volcanic deposits from the Ul'ya Depression was initially estimated from paleobotanic data, mostly from plant fossils of the Amka Formation, since plant remains from other stratigraphic units were not necessarily representative. However, it should be also noted here that these plants previously have not been identified to species level, so these estimates were approximate and based rather on ideas about floral development in neighboring regions than on specified stratigraphic distributions of plant fossils. As a result, the ages of the floristic assemblages determined by different authors vary greatly.

The first collection of plant fossils from the Amka River's lower reaches was gathered by G.I. Stalnov in 1926. It was examined by A.N. Kryshtofovich (1937), who determined the age of the fossils in general as Late Cretaceous.

Collections gathered by geologists through the middle of the 20$^{th}$ century were analyzed by A.F. Efimova, a paleontologist from the

North-East Territorial Department, who estimated the age of the Uchulikan Formation as Cenomanian–Turonian, the age of the Amka Formation as Senonian, and the age of the Urak and Khakarin formations as early Paleogene (Chertovskikh 1964). These estimates were adopted in the stratigraphic scheme of Chertovskikh and Sheikashova, who considered the Ul'ya Depression section as comparable with a section of volcanic deposits in the middle part of the OCVB, in the Magadan city area.

Through the 1970s and 1980s, plant fossils from the Ul'ya Depression were studied by Lebedev. The age determinations vary somewhat in his different papers. On the whole, he considered that the floristic assemblages were much older, based on V.A. Samylina's (1974) view on floral development in North-East of Russia. Lebedev (1987) dated the Uchulikan Formation as Berriassian–Valanginian, the Emanra Formation as early–middle Albian, the Delokachan Unit as Turonian or Campanian, and the Khakarin Formation as Danian. Lebedev assigned deposits corresponding to the Amka Formation (lower felsic succession) to either the Emanra Formation or the Ul'ya Series. Plant fossils from the Amka Formation were assigned to several floristic assemblages of different ages from the Albian to Coniacian.

The modern isotopic geochronology data were obtained just for a few sites in the Ul'ya Depression (Mishin et al. 2008, Akinin & Miller 2011). The upper volcanic unit (Khakarin Formation from the Khakarin Plateau) yielded an age of 76–78 Ma, corresponding in age and composition to the Mygdykit Formation which occurs in the central part of the OCVB. The Urak rhyolites, which immediately underlie the Khakarin basalts in the mid-reaches area of the Urak River, range in age from 84 Ma to 80 ± 1 Ma. According to $^{40}Ar/^{39}Ar$ and U-Pb age data, the Uchulikan basalts occurring in the Urak River area are older than 120 Ma. These data disagree with the age of the Uchulikan Formation in the Ul'ya River area, where its age was determined on the basis of plant fossils. This floristic assemblage was dominated by Taxodiaceae associated with angiosperms, which implies a Late Cretaceous age (Chertovskikh 1964). The age and distribution area of the Uchulikan Formation obviously requires further investigation.

We determined the age of the Amka Formation using two independent methods: isotopic and paleobotanical. The plant fossils were gathered in the basins of the Uenma, Amka and Gyrbykan rivers flowing into the Ul'ya River (Fig. 2). Localities are described in detail further in this text.

### AREA 1 (UENMA RIVER BASIN)

In the Uenma River basin the plant fossils were found at two sites: one located in the middle part of the Uenma River and the other in its lower part, downstream from the Dyulbaky River mouth (Fig. 3a). The first site corresponds to Site 20 of Lebedev (1987), and the second one to Site 28.

At the first site the main river bluff extends for ~200 m and reaches ~60 m in height (Pl. 1, fig. 2). It exposes a thick volcano-sedimentary succession crumpled into gentle folds and sometimes broken by faults with very slight displacement. The concordant gentle bedding is quite obvious and dips SE (strike 120–140°, dip 15–20°). Plant fossils were sampled from gray-yellowish volcaniclastic sandstones and tuffites with rare thin coalified layers and from tuffs consisting of mostly felsic volcanics. Also, large tree stems up to 1 m high and 30–40 cm in diameter were found buried in a vertical position, but their roots are not in palaeosol. These trunks could have been rafted, as is common in volcaniclastic debris flows (Fritz & Harrison 1985, Spicer 1989). There is a significant similarity of rock composition, rock bedding and interbedding patterns between this bluff and the Amka Formation stratotype at the Amka River.

A thin section of tuffite and welded tephra with dated zircons (sample 1-2a) contains a large amount of poorly rounded fragmentary crystals of feldspar and biotite, and a smaller amount of quartz in a fine-grained silt and ash matrix (Fig. 4a). This teffra is rhyolitic, based on its chemical composition ($SiO_2$ = 72.8 wt %, $Na_2O + K_2O$ = 8.7 wt %).

### AREA 2 (AMKA RIVER BASIN)

Plant fossils were sampled from the stratotype section of the Amka Formation. Here, bluffs up to 100–200 m high are exposed near the Amka River mouth for ~7 km (Pl. 1, fig. 1). The succession consists of alternating tuffs of different thickness and composition, with rhyolitic to dacitic lava flows. Sometimes interbeds of tuff conglomerates, tuff sandstones and tuffites occur. Sheikashova (1964) gave a detailed description of this section, which is ~220 m thick. Plant fossils occur through the entire succession, mostly in tuffites in the upper and lower portions of the section. The underlying rocks are not exposed in the Amka River mouth area. The rocks unconformably overlying the Amka Formation consist of vitreous lilac-white rhyolites of the Urak Formation and coeval subvolcanic light-brown trachytes (Fig. 3b). Upward, along the Amka River and in the Khetana River Basin, the Amka Formation is conformably overlain by intermediate and basic effusive rocks of the Khetana Formation.

A petrographic description of pyroclastic rocks (Fig. 4b) and the results of U-Pb SHRIMP-dating of zircons from this section were published earlier (Akinin et al. 2016).

### AREA 3 (GYRBYKAN RIVER BASIN)

The Amka Formation is widely distributed in the Gyrbykan River Basin (Fig. 3c). It is composed of rhyolitic ignimbrites and tuffs with tuffaceous-sedimentary intercalations in the lower part of the section; the tuffaceous-sedimentary rocks occur to a much greater extent in the upper portion of the section. The most productive plant fossil localities occur in the Gyrbykan and Dukchanda headwaters. The relationships between the Amka Formation and the underlying Uchulikan and overlying Khetana formations can be easily traced

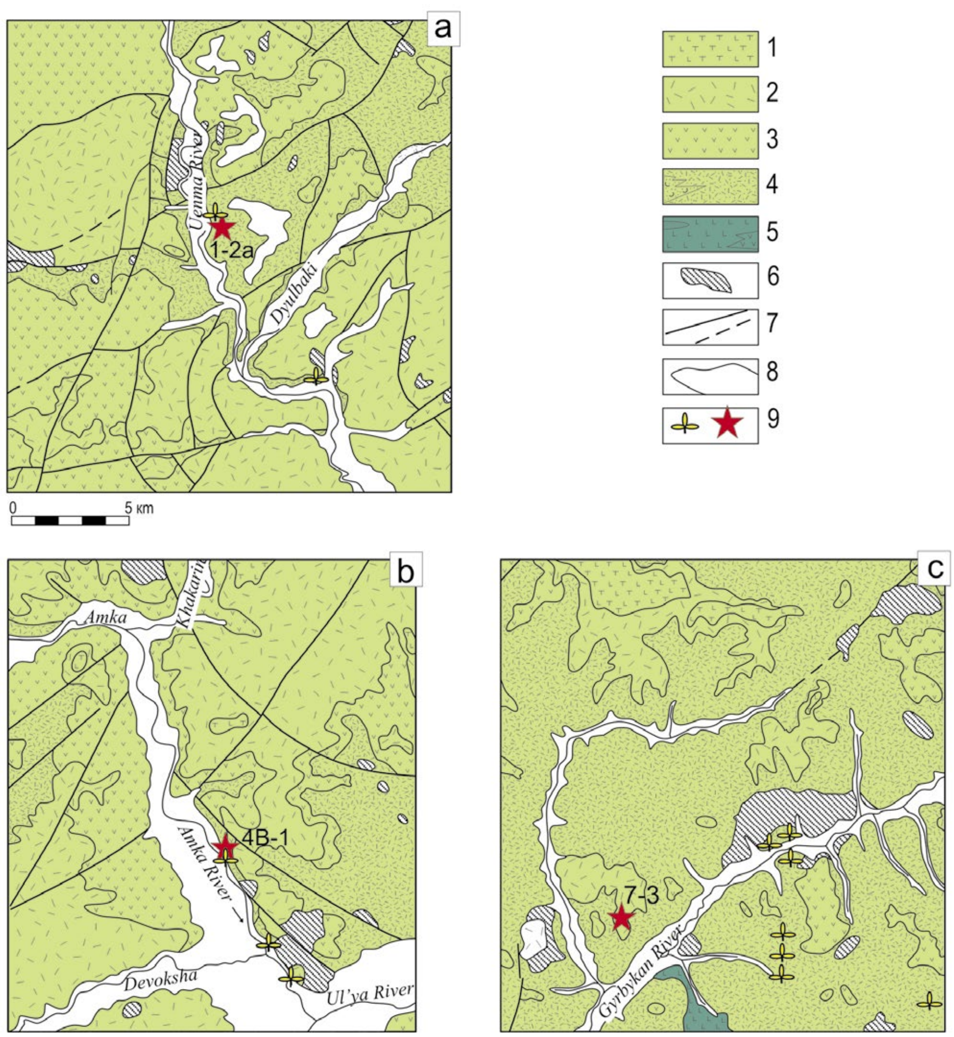


**Fig. 3**. Geological maps of studied areas, based on Federal geological maps, scale 1:200 000: **a** – Uenma River basin; **b** – Amka River basin; **c** – Gyrbykan River basin. Map explanations: **1** – Khakarin Formation dominated by basalt and trachybasalt lava flows; **2** – Urak Formation dominated by rhyolitic strongly welded ignimbrites, dacites and their tuffs; **3** – Khetana Formation dominated by andesitic and basaltic andesite lavas; **4** – Amka Formation dominated by tuffs and tuffites of felsic composition, with less frequent lavas and ignimbrites of felsic composition; **5** – Uchulikan Formation dominated by andesite and basaltic andesite lava flows; **6** – granitoid and subvolcanic rhyolite to trachyte intrusions of the Upper Cretaceous; **7** – mapped and assumed faults; **8** – geological boundaries; **9** – plant fossils and geochronology sample localities (see the text)


**Plate 1**. **1**. Stratotype section of the Amka Formation near the Amka River mouth. **2**. Deposits of the Amka Formation in the middle part of the Uenma River

over the hill slopes by observing rock colors, landforms and vegetation, due to the almost horizontal bedding pattern of volcanics without any significant tectonic dislocation. Outcrops of the Amka Formation extend along the right side of the Gyrbykan River for ~4 km. The section is ~70 m thick, with plant fossils occurring throughout. There are also some small fossil-bearing exposures on the other side of the river. Sites 151 and 153, described by Lebedev (1987), also occur in this area.

The Urak Formation, consisting of lavas and rhyolite ignimbrites, overlies the Khetana Formation in this area and unconformably overlies the Amka Formation in some places. Thin sections of the Urak rocks demonstrate predominance of fresh fluid lava flows, as well as welded ignimbrites with phenocrysts of sanidine, biotite and quartz (Fig. 4c). In order to constrain the upper limit of the Amka Formation age, we determined the age of rhyolites from sample 7-3, collected from the lower part of the Urak Formation, 50 m above its boundary with the Amka Formation.

## COMPOSITION OF THE UL'YA FLORA

Plant fossils from the Amka Formation have been gathered many times, but these collections were never monographically described or accurately determined. Only tentative

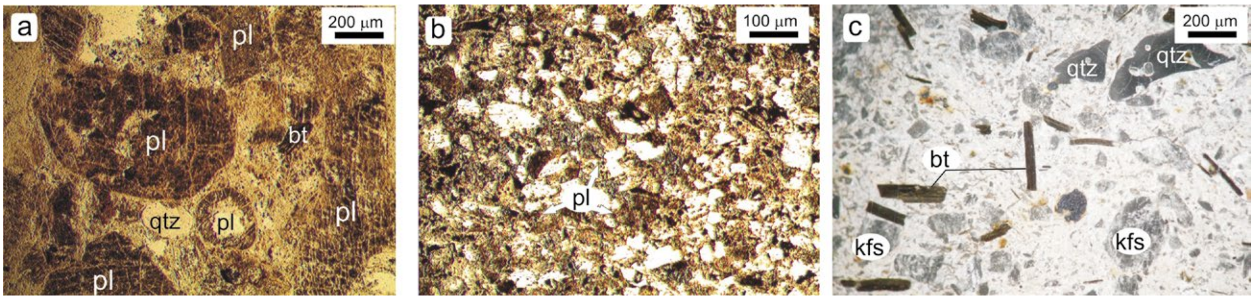


**Fig. 4**. Thin sections of samples used for U-Pb isotopic dating: **a** – felsic tuffite from the Amka Formation, crystals of feldspar, biotite and quartz are rounded to various extents and cemented by ash and clay matrix (sample 1-2a), photo in transmitted light; **b** – intermediate tuffite from the Amka Formation dominated by poorly rounded feldspar crystals (sample 4B-1), photo in transmitted light; **c** – rhyolite ignimbrite from the Urak Formation, quartz, biotite and sanidine phenocrysts occurring in strongly welded glassy matrix (sample 7-3), photo in slanted reflected light. Mineral abbreviations: **pl** – plagioclase, **qtz** – quartz, **kfs** – sanidine, **bt** – biotite

determinations, mostly at generic level, are available.

Lebedev (1987) subdivided plant fossils from the deposits we assigned to the Amka Formation into six floristic assemblages: the Emanra, Arinda, Uenma, Gyrbykan, Ust'–Amka and Dukchanda: in his opinion, they display an evolutionary sequence from the early Albian to the Turonian. Each assemblage contains plant fossils from one or seldom from two or three localities. An analysis of our more comprehensive collections together with Lebedev's collections shows that the floristic assemblages from all localities are very similar in their systematic composition. Therefore, all plant fossils from the Amka Formation were combined into a joint assemblage, which was named the Ul'ya flora (Golovneva 2013). Some minor compositional differences between the florulae from the different sites are due to facies and taphonomical factors which will be discussed below.

The Ul'ya flora is characterized by high species endemism, with most genera composed of new species. Not all of them have been described. This paper describes four new conifer species whose shoots occur frequently in many localities. The remains of gymnosperms usually lack cuticle, so they were assigned to form taxa or determined to generic level.

On the whole, the Ul'ya flora includes ~40–50 species, among which gymnosperms (mostly conifers) predominate. Ferns and flowering plants are rather diverse but their remains are less frequent than the remains of gymnosperms.

Remains of horsetails (*Equisetum* sp.) were found in all localities and are represented by subsurface tuberous shoots, which were numerous in immature palaeosols. The occurrence of the enigmatic water plant *Lokyma onkilonica* (Kryshtofovich) Samylina, with a putative lycopsid affinity (Pl. 2, fig. 6), is of a particular research interest. It was previously reported only from the Ola, Mygdykit and Arkagala formations of Santonian–Campanian age (Samylina 1988).

Ferns are represented by the families Dipteridaceae (*Hausmannia*), Aspleniaceae (*Asplenium*) and Dicksoniaceae (*Tchaunia*). The genera *Arctopteris* and *Kolymella* are thought to belong to the family Pteridaceae. Pinnae of *Arctopteris* and the form genus *Cladophlebis* occur most often in the Ul'ya localities. Among ferns, the species *Tchaunia lobifolia* Philippova, *Kolymella raevskii* Samylina et Philippova (Pl. 2, fig. 5, Pl. 3, fig. 3) and *Arctopteris ilirnensis* Golovneva (Pl. 2, fig. 2) occur in common with the Coniacian Chaun flora, and are widely distributed in the northern part of the OCVB (Golovneva 2018). *Hausmannia bipartita* Samylina et Shczepetov (Pl. 2, fig. 7, Pl. 3, fig. 6) and *Asplenium dicksonianum* Heer were widespread in the Late Cretaceous floras of Northern Asia.

The gymnosperms of the Ul'ya flora are highly diverse and include seed ferns, cycadophytes, czekanowskialeans, ginkgoaleans and conifers.

Seed ferns are represented by the order Caytoniales. They include the cosmopolitan species *Sagenopteris variabilis* (Velenovsky) Velenovsky. Remains of cycadophytes are rare and represented by leaves of *Taeniopteris* sp. (Pl. 2, fig. 1).

Ginkgoaleans are diverse and represented by three genera: *Ginkgo*, *Baiera* and *Sphenobaiera*. Almost all remains are assigned to form species because of the absence of phytoleims. The genus *Ginkgo* includes two species: *G.* ex gr. *adiantoides* (Unger) Heer with bilobate or

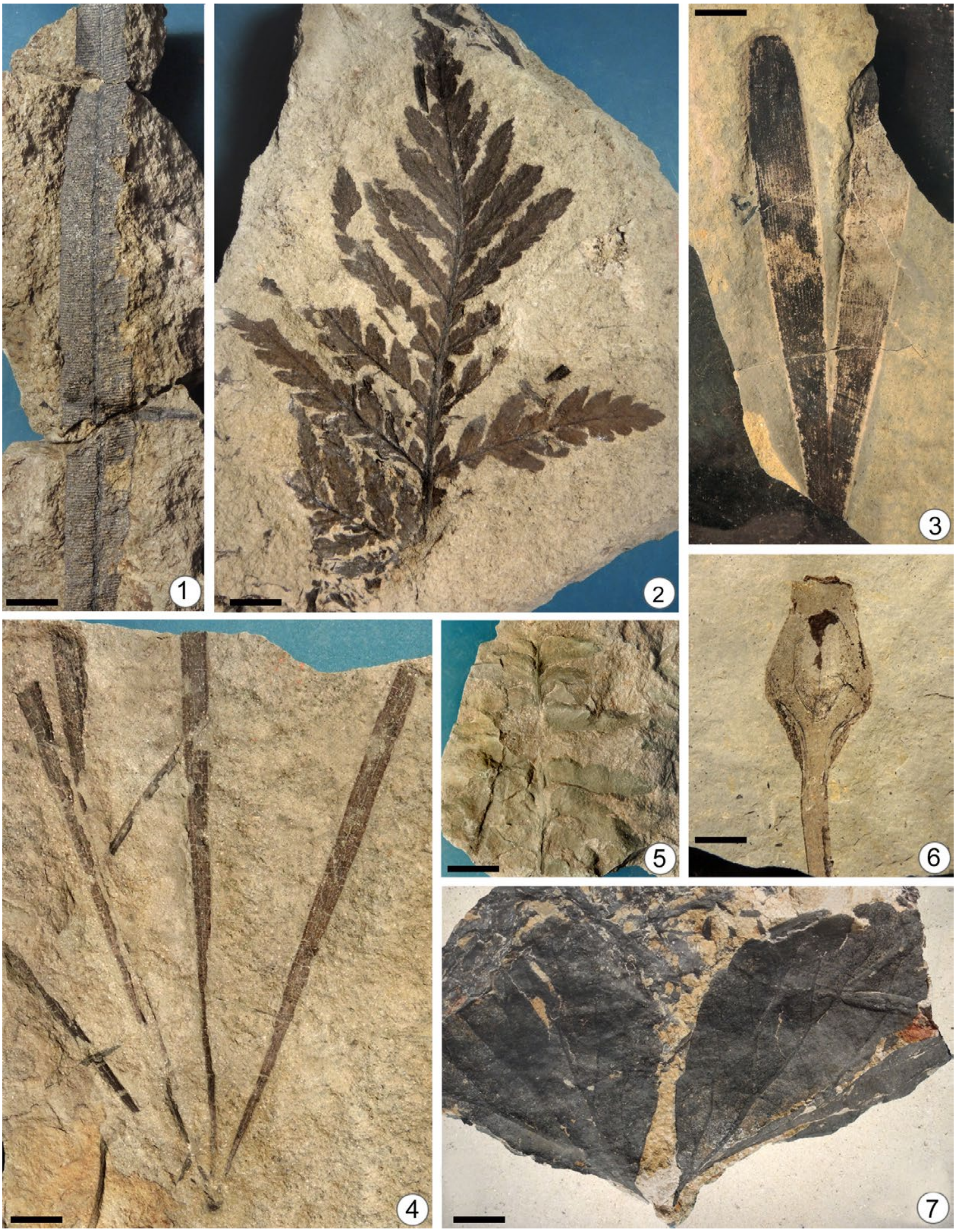

**Plate 2**. **1**. *Taeniopteris* sp., spec. GIN 3381/124-3; **2**. *Arctopteris ilirnensis* Golovneva, spec. GIN 3369/33-416; **3**. *Sphenobaiera biloba* Prynada, spec. BIN 1578/93; **4**. *Phoenicopsis* ex. gr. *angustifolia* Heer, spec. GIN 3389/168-15; **5**. *Tchaunia lobifolia* Philippova, spec. GIN 3389/168-16; **6**. *Lokyma onkilonica* (Kryshtofovich) Samylina, spec. GIN 3389/153-17; **7**. *Hausmannia bipartita* Samylina et Shczepetov, spec. GIN 3381/4. Khabarovsk Region, Ul'ya Depression, Amka Formation, Coniacian. Scale bars = 1 cm

entire leaves, and *G.* ex gr. *sibirica* Heer (Pl. 3, fig. 1) with deeply dissected leaves. The last species is the most common among ginkgoaleans. This species is known from many Early Cretaceous floras of Siberia, and the species *G.* ex gr. *adiantoides* was widespread mostly in Late Cretaceous and Paleogene floras of Eurasia.

The genus *Sphenobaiera* also consists of two species: *S.* ex gr. *longifolia* (Pomel) Florin (Pl. 3, fig. 9) with 4–8 leaf lobes, and *S. biloba*

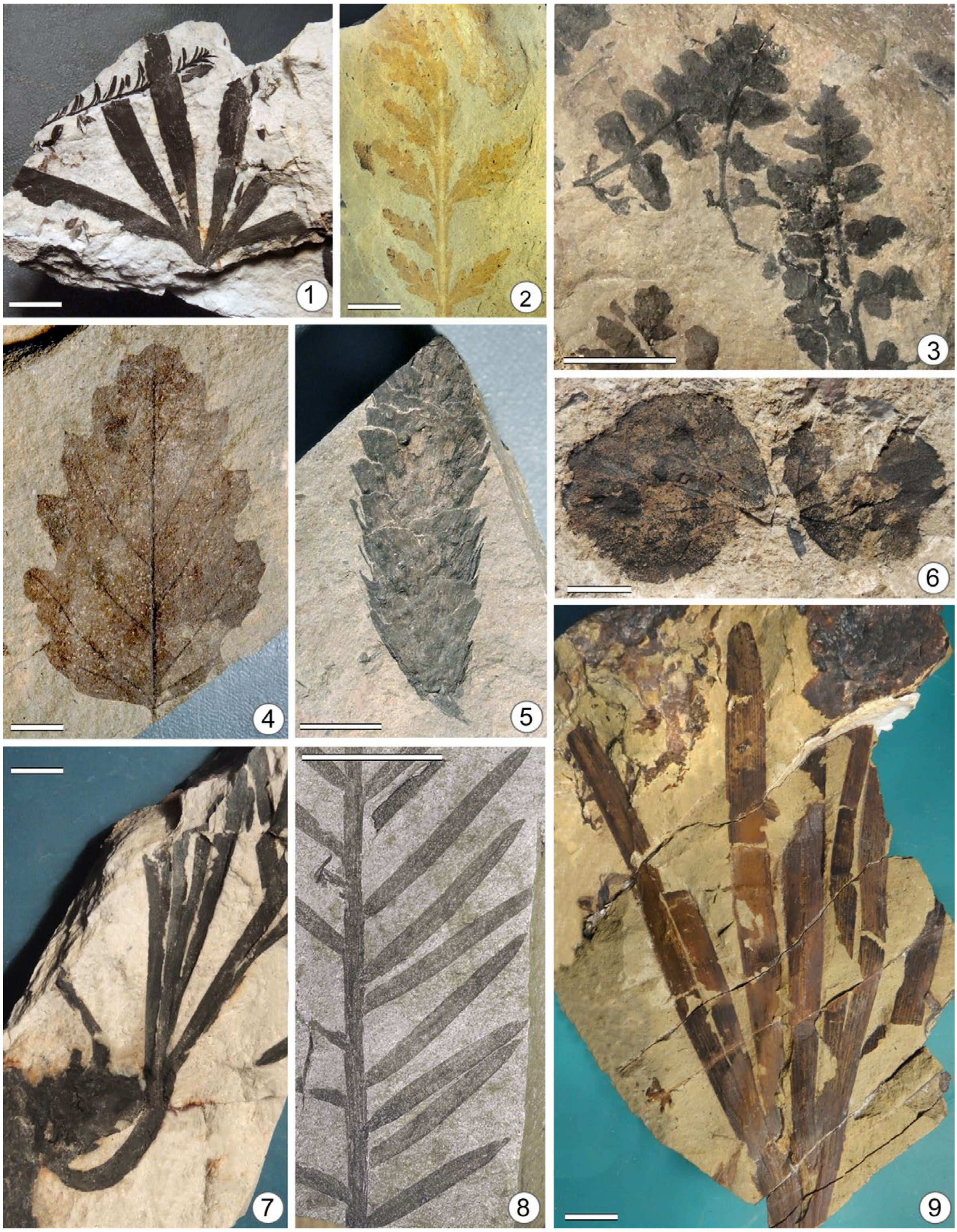

**Plate 3**. **1**. *Ginkgo* ex gr. *sibirica* Heer, spec. GIN 3369/20-45; **2**. *Ditaxocladus* sp., spec. BIN 1578/81; **3**. *Kolymella raevskii* Samylina et Philippova, spec. GIN 3389/162-9a; **4**. *Dalembia bolschakovae* E. Lebedev et Herman, spec. GIN 3389/153-2; **5**. *Pityostrobus* sp., spec. GIN 3389/153-14; **6**. *Hausmannia bipartita* Samylina et Shczepetov, spec. GIN 3381/120-120; **7**. *Baiera lebedevii* Golovneva, spec. GIN 3393/326-31b; **8**. *Taxodium amguemensis* (Efimova) Golovneva, spec. BIN 1578/28; **9**. *Sphenobaiera* ex gr. *longifolia* (Pomel) Florin, spec. GIN 3369/28-4. Khabarovsk Region, Ul'ya Depression, Amka Formation, Coniacian. Scale bars = 1 cm

Prynada (Pl. 2, fig. 3, Pl. 4, fig. 1) with two leaf lobes. *S. biloba* has preserved cuticle (Pl. 4, figs 2–12). As well as from the Amka Formation, this species was reported from the lower–middle Albian Buor–Kemyus Formation of the Kolyma River basin and the upper Albian–lower Turonian Krivorechenskaya Formation of the Anadyr River basin (Prynada 1938, Samylina 1967, Nosova & Golovneva 2018). Leaves of *S.* ex gr. *longifolia* are large,

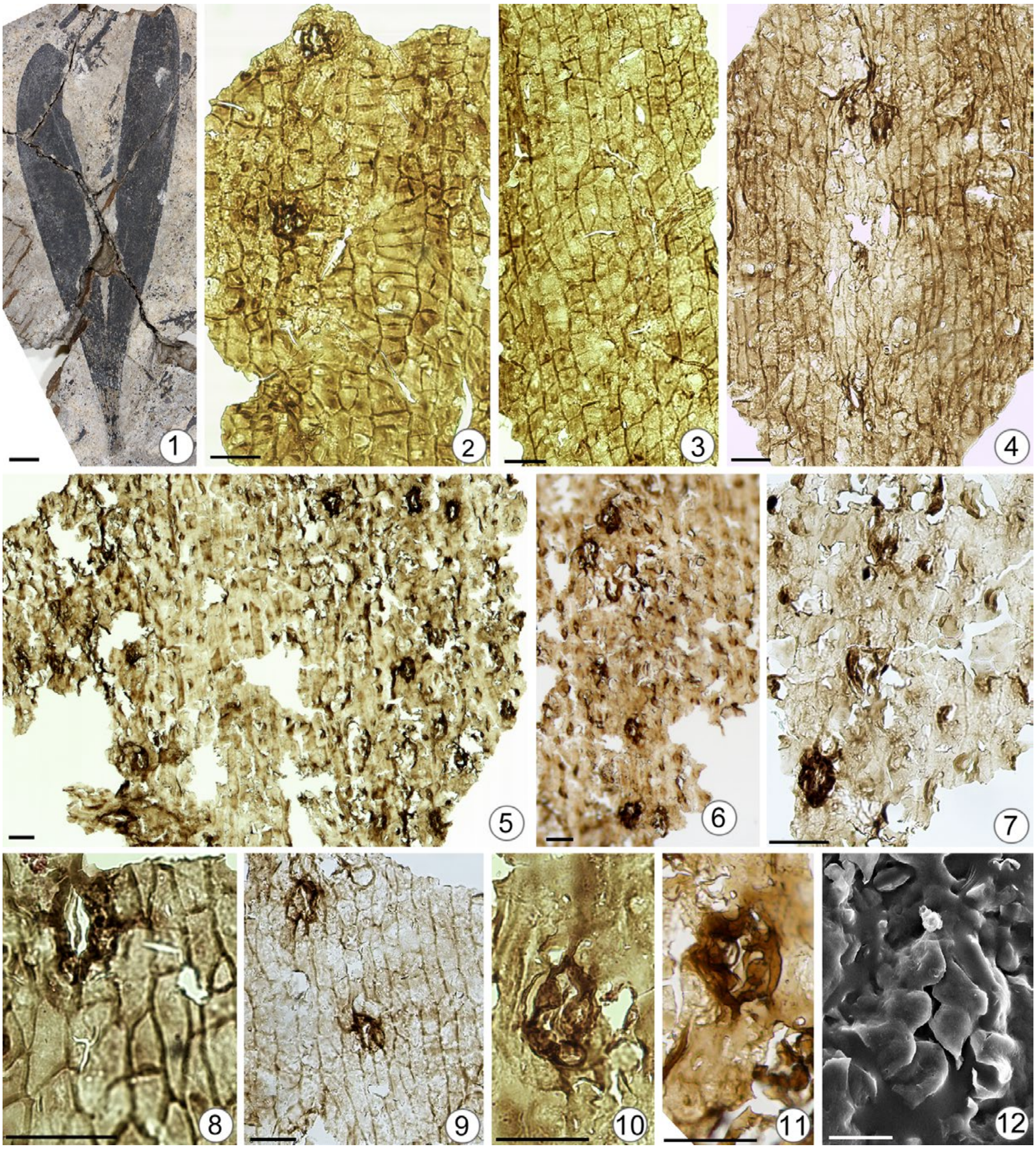


**Plate 4**. **1–12**. *Sphenobaiera biloba* Prynada, spec. GIN 3389/154-82, Khabarovsk Region, Ul'ya Depression, Amka Formation, Coniacian: **1 –** Leaf; **2**, **3 –** Adaxial leaf surface; **4**, **8**, **9 –** Abaxial leaf surface with solitary stomata near base; **5**, **6 –** Abaxial leaf surface with stomatal bands; **7**, **10**, **11 –** Stomata; **12 –** Stoma, SEM, external view. Scale bars: 1 = 1 cm; 2–11 = 50 µm; 12 = µm

up to 10–15 cm in length. Similar leaves are found in the Late Cretaceous Karamken, Aliki and Chaun floras of the OCVB (Shczepetov & Golovneva 2010, Golovneva & Shczepetov 2011). The genus *Baiera* is represented by the endemic species *B*. *lebedevii* Golovneva (Pl. 3, fig. 7, Pl. 5, fig. 1), possessing very large leaves 25–30 cm in length (Golovneva 2016).

Similar diversity of ginkgoaleans was recorded only in the Turonian–Coniacian Arman flora from middle part of the Okhotsk–Chukotka volcanogenic belt (Herman et al. 2016), but occurrences of ginkgoaleans are rather rare in the Arman Formation.

Czekanowskialeans are represented by the form species *Phoenicopsis* ex. gr. *angustifolia* Heer (Pl. 2, fig. 4), with relatively large, broad leaves. Brachyblasts with bundles of linear leaves and dispersed leaves of *Phoenicopsis* are very common in the various Upper Cretaceous deposits of the OCVB (Philippova & Abramova 1993, Herman 2011). In the Amka Formation these leaves are relatively scarce and never form leaf mats.


**Plate 5**. **1**. *Baiera lebedevii* Golovneva, spec. GIN 3393/326-30; **2**. *Trochodendroides gromovii* (E. Lebedev) Golovneva, spec. GIN 3393/7; **3**. *Taxodium amguemensis* (Efimova) Golovneva, spec. 3389/153-18; **4**. *Arthollia* sp., spec. GIN 3389/154-19. Khabarovsk Region, Ul'ya Depression, Amka Formation, Coniacian. Scale bars = 1 cm

Conifers of the Ul'ya flora are represented by *Podozamites*, Cupressaceae, Pinaceae and genera of uncertain taxonomic affinity.

Dispersed and attached leaves of *Podozamites* sp. (Pl. 6, fig. 8) show considerable variability in size and shape. They occur rarely but in almost all localities. This genus is usually characteristic for the Early Cretaceous and is considered as relict in the Ul'ya flora.

The family Cupressaceae includes the genera *Sequoia* (Pl. 6, fig. 7), *Metasequoia* (Pl. 6, fig. 5), *Taxodium* (Pl. 3, fig. 8, Pl. 5, fig. 3),


**Plate 6**. **1**. *Quereuxia angulata* (Newberry) Kryshtofovich ex Baikovskaya, spec. GIN 3389/153-20; **2–4**. *Araucarites sheikashoviae* Golovneva: **2** – Spec. GIN 3389/163-21; **3** – Spec. TFI 86/1501-1; **4** – Spec. TFI 86/1501-4; **5**. *Metasequoia* sp., spec. GIN 3389/153-22; **6**. *Trochodendroides deminii* Yudova et Golovneva, spec. GIN 3389/153-5; **7**. *Sequoia ochotica* Yudova et Golovneva, spec. GIN 3393/328-37; **8**. *Podozamites* sp., spec. GIN 3389/153-23. Khabarovsk Region, Ul'ya Depression, Amka Formation, Coniacian. Scale bars = 1 cm

*Ditaxocladus* (Pl. 3, fig. 2) and *Cupressinocladus*. The first three genera are widely distributed in the Late Cretaceous floras of the OCVB. Shoots and cones of *Sequoia ochotica* Yudova et Golovneva and *Metasequoia* sp. are the most frequent species in localities. Shoots of *Taxodium amguemensis* (Efimova) Golovneva are also rather abundant. Remains of *Ditaxocladus* sp. and *Cupressinocladus* sp. occur sparsely and are usually fragmented. The first genus is represented by oppositely branched sprays with cladode-like foliage,


**Plate 7**. **1**, **2**, **4**. *Elatocladus gyrbykensis* Golovneva, sp. nov.: **1** – Spec. BIN 1578/1b; **2** – Spec. BIN 1578/51; **4** – Spec. BIN 1578/1a, holotype; **3**. *Araucarites sheikashoviae* Golovneva, sp. nov., spec. GIN 3389/153-24, holotype; **5**. *Elatocladus amkensis* Golovneva, sp. nov., spec. BIN 1575/1, holotype. Khabarovsk Region, Ul'ya Depression, Amka Formation, Coniacian. Scale bars = 1 cm

and the second is represented by alternately branched leafy sprays.

The family Pinaceae is represented by cones, dispersed scales and leaves, identified as the form genera *Pityophyllum*, *Pityostrobus* (Pl. 3, fig. 5) and *Pityolepsis*. Shoots of *Pityocladus* with long linear leaves on brachyblasts also occur.

Genera of uncertain taxonomic affinity are diverse and represent the most conspicuous and exotic constituent of the Ul'ya flora. These are shoots with evergreen scale-like, hook-shaped

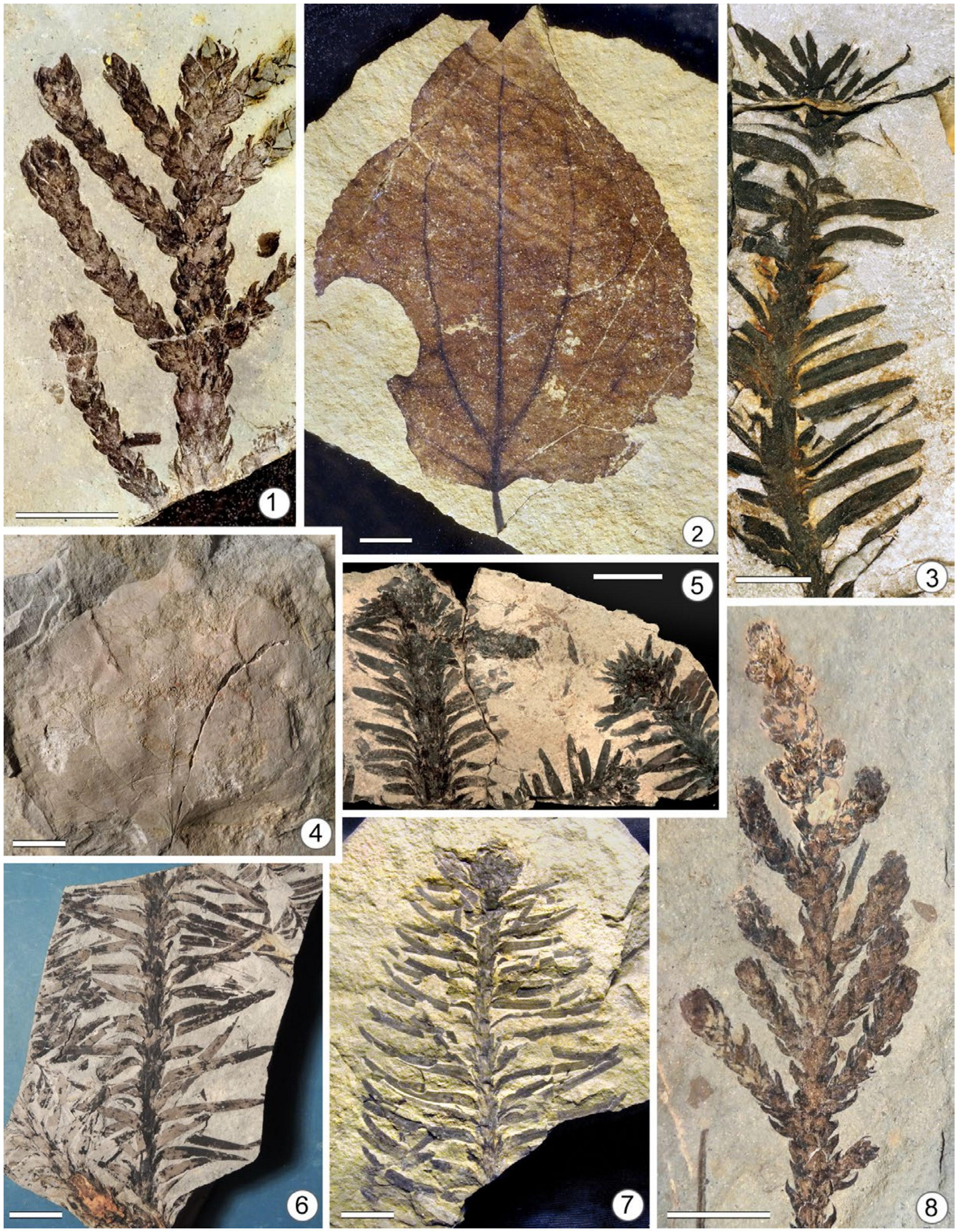

**Plate 8**. **1**, **8**. *Pagiophyllum umitbaevii* Golovneva, sp. nov.: **1** – Spec. BIN 1578/35b, holotype; **8** – Spec. BIN 1578/16-1; **2**. *Trochodendroides microdentata* Golovneva, Ge Sun et Bugdaeva, spec. BIN 1578/102a; **3**, **5**. *Elatocladus amkensis* Golovneva, sp. nov.: **3** – Spec. BIN 1575/2; **5** – BIN 1577/20; **4**. *Zizyphoides flabella* (Newberry) Crane, Manchester et Dilcher, spec. GIN 3389/151-25; **6**, **7**. *Elatocladus gyrbykensis* Golovneva, sp. nov.: **6** – spec. GIN 3381/132-4; **7** – spec. GIN 3389/153-26. Khabarovsk Region, Ul'ya Depression, Amka Formation, Coniacian. Scale bars = 1 cm

or linear leaves, which are assigned to the form genera *Araucarites*, *Elatocladus* and *Pagiophyllum*. The species *Elatocladus amkensis* Golovneva, sp. nov. (Pl. 7, fig. 5, Pl. 8, figs. 3, 5) is the most typical element of the Ul'ya flora. Its shoots occur almost as frequently as shoots of *Sequoia*. Shoots of *Araucarites sheikashoviae* Golovneva, sp. nov. (Pl. 6, figs. 2–4, Pl. 7, fig. 3), *Elatocladus gyrbykensis* Golovneva, sp. nov. (Pl. 7, figs. 1, 2, 4, Pl. 8, figs.

6, 7) and *Pagiophyllum umitbaevii* Golovneva, sp. nov. (Pl. 8, figs. 1, 8) are less frequent but also locally abundant.

Angiosperms are relatively diverse in comparison with other OCVB floras. Representatives of the families Platanaceae and Cercidiphyllaceae predominate. The genus *Trochodendroides* from the family Cercidiphyllaceae is represented by three species (Golovneva et al. 2017): *T. deminii* Yudova et Golovneva (Pl. 6, fig. 6), *T. microdentata* Golovneva, Ge Sun et Bugdaeva (Pl. 8, fig. 2) and *T. gromovii* (E. Lebedev) Golovneva (Pl. 5, fig. 2). The last species is endemic to the Ul'ya flora. The remains of Platanaceae are not well studied yet. Only the genus *Arthollia* was determined (Pl. 5, fig. 4). The family Trochodendraceae is represented by *Zizyphoides flabella* (Newberry) Crane, Manchester et Dilcher (Pl. 8, fig. 4). This is the oldest occurrence of this species, which was widespread in Paleogene floras.

The systematic affinity of other angiosperms remains unclear. Only two species were determined: *Dalembia bolschakovae* E. Lebedev et Herman (Pl. 2, fig. 4) and the water plant *Quereuxia angulata* (Newberry) Kryshtofovich ex Baikovskaya (Pl. 6, fig. 1). Other flowering plants require further investigation.

The floristic assemblages from the various localities of the Amka Formation differ slightly in their composition and abundance of remains. These differences appear to be due to taphonomic factors. The predominance of *Sequoia* shoots and ferns, and the presence of cycadophytes and angiosperms along with a small number of endemic conifers in the Dulbaki and Khetana localities suggest that they were formed in broad river valleys. This is supported by the composition of the plant-bearing rocks, which usually consist of highly reworked sediments such as tuffaceous sandstones, tuffaceous siltstones and coaly shale. The localities on the Uenma River and the Amka stratotype section are characterized by the prevalence of slope facies which are represented by effusive rocks, coarse tuffs and tuffites. These localities are dominated by shoots of different endemic conifers, whereas ferns, cycadophytes and flowering plants are less numerous.

Lebedev (1987) maintained that the assemblages from the various localities of the Amka Formation represent vegetation of different ages. He believed that the localities containing the cycadophyte genera (*Taeniopteris* and *Neozamites*) are older and that the localities containing diverse angiosperms are younger. However, the Dukchanda locality contains both a variety of angiosperms and *Taeniopteris*. On the whole, *Taeniopteris* was widely distributed in North-East of Russia throughout the Late Cretaceous up to the Santonian–Campanian (Herman 2011). The other genus reported by Lebedev, *Neozamites*, is still not identified in other Late Cretaceous floras of North-East of Russia. Its presence in the Ul'ya flora needs to be confirmed by new findings, since Lebedev's specimens are not preserved. Overall, it should be noted that different relict cycadophytes are typical for the Late Cretaceous floras of the OCVB, and the occurrence of one additional genus in an assemblage should not be the basis for significantly increasing its age.

The floristic assemblage from the Gyrbykan River is the most diverse among all the other localities. It contains ferns, cycadophytes, ginkgoaleans, czekanowskialeans as well as angiosperms and diverse conifers. The co-occurrence in one locality of practically all species of the Ul'ya flora is evidence of its unity.

## SYSTEMATIC DESCRIPTIONS

### Class: Ginkgoopsida

### Genus: *Sphenobaiera* Florin 1936

#### ***Sphenobaiera biloba*** Prynada

Pl. 2, fig. 3, Pl. 4, figs 1–12

1938 *Sphenobaiera biloba* Prynada: 47; pl. V, fig. 1.
1967 *Sphenobaiera biloba* – Samylina: 143; pl. VIII, figs. 5, 6, 7a, pl. IX, figs 8, 9.
1979 *Sphenobaiera biloba* – Philippova: 113; pl. XXII, figs 6, 7.
2016 *Sphenobaiera* ex gr. *biloba* – Golovneva: 83; pl. II, fig. 2, pl. III, fig. 6.

Holotype. The Central Scientific-Research Geological Exploration Museum, St. Petersburg, spec. CNIGRM 51/5350, North-East of Russia, Kolyma River basin, Zyryanka River, Buor–Kemyus Formation, early–middle Albian; Prynada, 1938, pl. V, fig. 1.

Material studied. Coll. GIN 3389, spec. 82, coll. BIN 1578, spec. 93.

Stratigraphic horizon and occurrence. North-East of Russia, Khabarovsk Region, Ul'ya River basin, Amka Formation, Coniacian; Kolyma River basin, Zyryanka River, Buor–Kemyus Formation, early–middle Albian; Anadyr River basin, Grebenka River, Krivorechenskaya Formation, late Albian–early Turonian.

D e s c r i p t i o n. The leaves are wedge-shaped, the lamina bifurcating into lanceolate lobes. The lobe apices are obtuse. Only two leaves have preserved details of the epidermal structure. One leaf from the Gyrbyrkan River (spec. BIN 1578/93) is more than 90 mm long, with an incision to 70 mm, 25 mm wide in the widest part, the lobes up to 20 mm wide (Pl. 2, fig. 3). The second leaf from the Dukchanda River (spec. GIN 3389/154-82) is 4 mm wide near the base and up to 60 mm in the widest part, >165 mm long, with an incision to 125 mm, the lobes up to 20 mm wide (Pl. 4, fig. 1). Vein density for all studied leaves is ~15–18 veins/cm.

The leaves are hypostomatic, but solitary stomata occur on the adaxial side near the leaf base (Pl. 4, fig. 2). The cells of the adaxial side are short, rarely elongate, rectangular to rhombic, forming rows (Pl. 4, figs 2, 3). The anticlinal cell walls are straight; the periclinal walls are with small, flattened to hollow papillae. Ordinary epidermal cells in the costal zones of the abaxial surface are predominantly elongate, tetragonal. Most of the cells have papillae. The intercostal zones correspond to the stomatal bands. There are 2–4 stomata per width of the stomatal band (Pl. 4, figs 5, 6). The stomata are oriented longitudinally. Ordinary epidermal cells in the stomatal bands are variably elongate to short, with hollow papillae (Pl. 4, figs 5–7). The periclinal cell walls are often smooth near the leaf base (Pl. 4, figs 4, 8, 9). The anticlinal cell walls are straight.

The stomatal complexes are with 5–7 subsidiary cells. Most of the subsidiary cells bear proximal papillae (Pl. 4, figs 10–12) but in some cases the subsidiary cells lack papillae and their aperture walls are thickened to form a cuticular rim around the aperture (Pl. 4, figs 8, 9).

D i s c u s s i o n. Prynada (1938) established the species *Sphenobaiera biloba* based on morphology only. Later, Samylina (1967) briefly described the epidermal structure of the adaxial leaf surface based on additional material from the type locality (Zyryanka River, Buor–Kemyus Formation). We re-investigated all material of *S. biloba* from the Zyryanka River and studied the epidermal structure of both the adaxial and abaxial leaf surfaces for the first time (Nosova & Golovneva 2018).

Our investigation of the morphological and epidermal features of the leaves from the Dukchanda River shows that they are identical to those of *S. biloba* from the Zyryanka River; therefore we determine them as this species.

Class: Pinopsida *incertae sedis*

Genus: *Araucarites* C. Presl. 1838

***Araucarites sheikashoviae***
Golovneva, sp. nov.
Pl. 6, figs 2–4, Pl. 7, fig. 3

E t y m o l o g y. Named after the geologist V.T. Sheikashova, in recognition of her great contributions to the study of Ul'ya Depression stratigraphy.

H o l o t y p e. Vegetative shoot, spec. GIN 3389/153-24, Khabarovsk Region, Ul'ya River basin, Gyrbykan River, Amka Formation, Coniacian. – Pl. 7, fig. 3.

M a t e r i a l s t u d i e d. Coll. GIN 3389, spec. 153-24, 163-21, coll. TFI 86, spec. 1501-1, 1501-4.

S t r a t i g r a p h i c h o r i z o n a n d o c c u r r e n c e. North-East of Russia, Khabarovsk Region, Ul'ya River basin, Amka Formation, Coniacian.

D i a g n o s i s. Leafy shoots straight; leaves spirally disposed, widely spaced, subulate, falcate, with acute apices, 4-sided in cross section, with prominent keels, 8–10 mm long and 1–1.5 mm wide, spreading from axis at 40–50° angle.

D e s c r i p t i o n. The largest shoot fragments reach 10 cm in length. The shoot axes are rather thick, 1.5–2 mm in diameter, and straight. The leaves are spirally disposed, subulate, falcate, 8–10 mm long and 1–1.5 mm wide, spreading from the axis at a 40–50° angle. They have tapering upward-curved acute apices and slightly widened decurrent sessile bases. In the middle part the leaves are 4-sided in cross section, with prominent keels. The leaves are disposed on the shoot ±sparsely, so that their apices overlap only the bases of the overlying leaves.

C o m p a r i s o n. The species *Araucarites anadyrensis* Kryshtofovich (1958) from the Krivorechenkaya Formation of the Anadyr

River basin is distinguished by thicker stems (2–3 mm in diameter) and larger, more closely spaced leaves extending from the axis at an almost right angle, while in *A. sheikashoviae* the leaves are smaller, extending from the axis at an acute angle (40–50°) and gradually bending upwards.

In *A. ochotensis* Golovneva et Shczepetov from the Turonian–Coniacian Parnino Formation of the northern Okhotsk region (Shczepetov & Golovneva 2014), the shoots are thin and the leaves are smaller (6–8 mm in length), S-like curved, and extend from the shoot at a more acute angle (30–50°).

The new species differs from *A. subacutensis* Philippova from the Coniacian Voronya Formation of Central Chukotka (Philippova 1972, Philippova & Abramova 1993) in the shape and size of the leaves. The leaves of the Chukotka species are larger (8–13 mm in length), slightly curved or straight, and have rounded ribs and narrowed, not decurrent bases.

The shoots of *A. orientalis* Philippova from the Santonian-Campanian Ola Formation of the Magadan Region (Philippova 1980, Philippova & Abramova 1993) are characterized by more frequent branching and a more dense leaf arrangement than shoots of *A. sheikashoviae*. The leaves of this species are more strongly flattened, not tetragonal, and are significantly overlapping.

Genus: *Elatocladus* Halle 1913

***Elatocladus amkensis*** Golovneva, sp. nov.

Pl. 7, fig. 5, Pl. 8, figs 3, 5

Etymology. After the Amka Formation.

Holotype. Vegetative shoot, spec. BIN 1575/1, Khabarovsk Region, Ulya River basin, Uenma River, Amka Formation, Coniacian. – Pl. 7, fig. 5.

Material studied. Coll. BIN 1575, spec. 1, 2, 4, 15, 42, 55, coll. BIN 1577, spec. 20.

Stratigraphic horizon and occurrence. North-East of Russia, Khabarovsk Region, Ul'ya River basin, Amka Formation, Coniacian.

Diagnosis. Ultimate leafy shoots 4–10 cm long and 2–2.5 cm in diameter, extending from axis at 30–45° angle. Branching alternate; axes straight, thick, 2–5 mm in diameter; leaf arrangement spiral and dense. Leaves with one vein, flattened, leathery, linear-lanceolate, with acute apices, slightly narrowed at base, sessile, decurrent to shoot, 12–17 mm long and 2–2.5 mm wide, extending from axis at 60°–80° angle.

Description. The largest fragments of shoots reach 40 cm in length and have alternate branching. The shoot axes are straight, thick, up to 4–6 mm in diameter on the perennial shoots and ~2–5 mm in diameter on the ultimate shoots. Ultimate leafy shoots 4–10 cm long and 2–2.5 cm in diameter, extending from the axis at a 30–45° angle The leaf arrangement is spiral. The leaves are densely spaced, flattened, leathery, with one vein, linear-lanceolate in shape, with acute apices, slightly narrowed at the base, sessile, decurrent to the shoot, 12–17 mm long and 2–2.5 mm wide, extending from the axis at a 60°–80° angle. In the upper part of the shoots there are several shorter, tightly spaced leaves that surround the buds. The leaves on the perennial shoots are rarer and extend from the axis at a more open angle.

Comparison. These shoots are most similar in morphology to shoots of *E. smittiana* (Heer) Seward, which is widespread in the Late Cretaceous floras of the Northern Hemisphere, but differ from them in having larger leaves (12–17 mm in length in *E. amkensis*, and 10–17 mm in *E. smittiana*) and thicker axes. Shoots of *E. cunningamioides* Sveshnikova et Budantsev from the Lower Cretaceous of Franz-Joseph Land (Sveshnikova & Budantsev 1969) are also very similar to our material in leaf shape and arrangement. However, this species differs in having smaller leaves and a tendency to display a two-ranked leaf arrangement.

***Elatocladus gyrbykensis***

Golovneva, sp. nov.

Pl. 7, figs 1, 2, 4, Pl. 8, figs 6, 7

Etymology. After the Gyrbykan River.

Holotype. Vegetative shoot, spec. BIN 1578/1a, Khabarovsk Region, Ul'ya River basin, Gyrbykan River, Amka Formation, Coniacian. – Pl. 7, fig. 4.

Material studied. Coll. BIN 1578, spec. 1a-e, 51, coll. GIN 3381, spec. 132-4, coll. GIN 3389, spec. 153-26.

Stratigraphic horizon and occurrence. North-East of Russia, Khabarovsk

Region, Ul'ya River basin, Amka Formation, Coniacian.

Diagnosis. Ultimate leafy shoots 5–11 cm long and 2–3.5 cm in diameter, branching alternate. Axes straight, thick, 2–3.5 mm in diameter; leaf arrangement spiral and dense. Leaves flat, leathery, with one vein, almost linear, gradually tapering to acute apices, sessile, decurrent, 9–22 mm long and 1.5–2.5 mm wide, extending from axis at 80–90° angle.

Description. This species displays large leafy shoots branching alternately at an acute angle. The ultimate shoots are 5–11 cm long and 2–3.5 cm in diameter. The shoot axes are straight and thick, 2–3.5 mm in diameter. The leaf arrangement is spiral and dense; the leaves tend to be arranged in one plane. The leaves are flat, leathery, with one vein, almost linear, gradually tapering to the acute apices, sessile, decurrent, 9–22 mm long and 1.5–2.5 mm wide, extending from the axis at a 80–90° angle.

Comparison. The new species differs from *E. amkensis* in having longer leaves, in a more dense arrangement, and in departing from the shoot at an angle close to 90°. Leaf shape in *E. amkensis* is linear-lanceolate, while in *E. gyrbykensis* it is almost linear, gradually tapering to the apex.

Genus: *Pagiophyllum* Heer 1881

***Pagiophyllum umitbaevii***
Golovneva, sp. nov.
Pl. 8, figs 1, 8

Etymology. Named after the geologist R.B. Umitbaev, in recognition of his contributions to the study of Ul'ya Depression stratigraphy.

Holotype. Vegetative shoot, spec. BIN 1578/35b, Khabarovsk Region, Ul'ya River basin, Gyrbykan River, Amka Formation, Coniacian. – Pl. 8, fig. 1.

Material studied. Coll. BIN 1578, spec. 16-1 and 35b.

Stratigraphic horizon and occurrence. North-East of Russia, Khabarovsk Region, Ul'ya River basin, Amka Formation, Coniacian.

Diagnosis. Shoots branching off at 40–50°, with spirally disposed, scale-like, densely spaced imbricate leaves. Leaves sessile, with decurrent wide bases and acute incurved apices, falcate in side view and romboidal or ovate in plan view, with slight abaxial keel; 2–3 mm long and ~1.5 mm wide in ultimate shoots, and 4–4.5 mm long and ~2 mm wide in second-year shoots.

Description. The shoot axes are straight and thick, covered by sessile leaves, with decurrent wide bases and acute incurved apices, falcate in side view and romboidal or ovate in plan view, with a small abaxial keel. The leaves are 2–3 mm long and ~1.5 mm wide in ultimate shoots, and 4–4.5 mm long and ~2 mm wide in second-year shoots.

Comparison. These shoots are most similar to shoots of *Pagiophyllum zhuravlevii* Golovneva from the Coniacian Chaun Group of Central Chukotka (Golovneva 2018). The ultimate shoots in *P. umitbaevii* are larger (1–6 cm in length and 4–8 mm in diameter) and the leaves are thicker and wider at the base, with a more prominent abaxial keel. The leaves of the perennial shoots are larger, up to 5–7 mm in length, are more widely spaced, and spread from the axis at a 40–50° angle.

*P. triangulare* Prynada from the Buor–Kemyus Formation of the Kolyma River basin (Prynada 1938, Samylina 1967) is characterized by small, narrow (4–5 mm in diameter), frequently branching shoots, and has widely spaced and laterally flattened leaves. The shoots in *P. umitbaevii* are larger and have dorsiventrally flattened, imbricate overlapping leaves.

## U-PB GEOCHRONOLOGY OF ZIRCONS

About 150 grains of accessory zircon were separated from the tuffite sample 1-2a, taken from the Amka Formation at the Uenma River. The zircon consists of idiomorphic short-prismatic and prismatic, transparent, light yellow crystals, 60 to 200 μm in size (length/width ratio 1.5–2.0). The crystals are prism-shaped {100} and dipyramid-shaped {101}, {111}, {211} (Fig. 5A, I–III). The internal structure of the zircon reveals a fine and well-expressed zoning and sector pattern (Fig. 5A, IV, V). Some crystals contain inherited core relicts (Fig. 5A, VI). We selected two microsamples (15 grains, 12 grains) of transparent and homogeneous zircons for our U-Pb isotope measurements (No 1

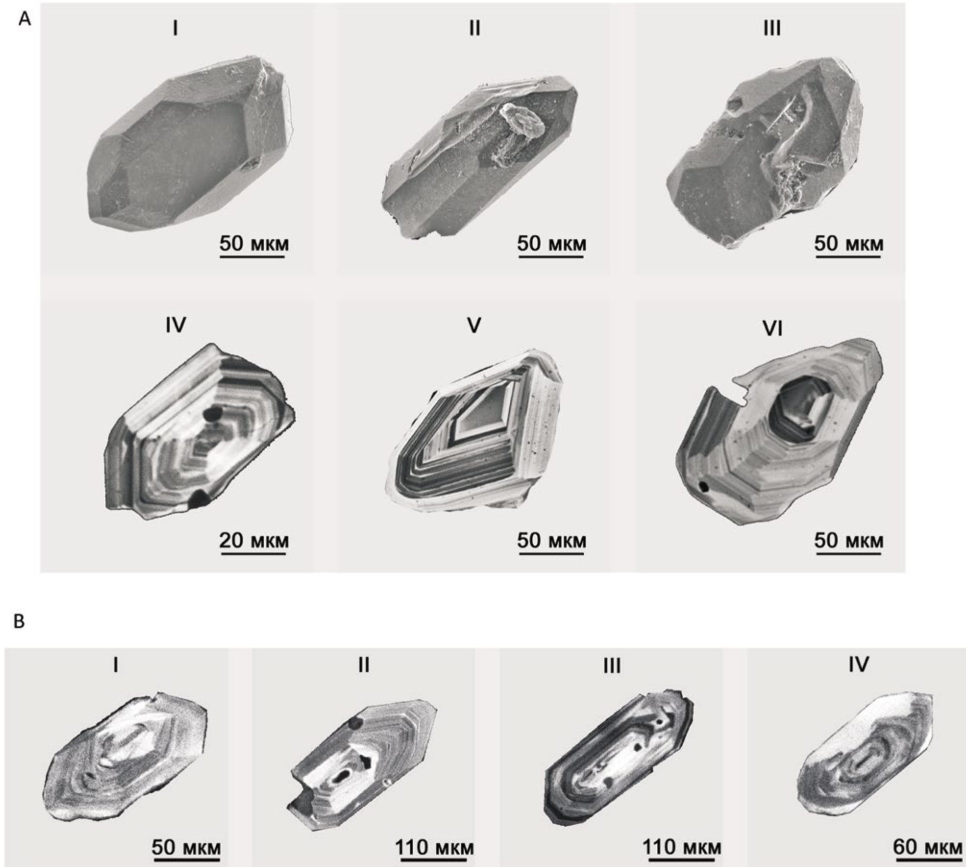


**Fig. 5**. Images of dated zircon crystals from samples 1-2a (A) and 7-3 (B) under VEGA3 TE SCAN scanning electron microscope: I–III (A) – secondary electron images; IV–VI (A) and I–IV (B) – cathodoluminescence images

and 2, Tab. 2). As shown in Table 2 and Figure 6, the zircon isotopic ratios reveal a concordant age of 86.1 ± 0.3 Ma (MSWD=0.43, probability of concordance = 0.51). The morphology of the zircons indicates their magmatic character, so the obtained age dating can be used to estimate the ages of the tuffs and teffroid rocks from the plant-bearing successions of the Amka Formation and, correspondingly, of the Ul'ya flora.

About 100 zircon grains were separated from the ignimbrite sample 7-3 taken from the Urak Formation at the Gyrbykan River above pyroclastic rocks of the Amka Formation. The zircon crystals are idiomorphic, transparent, or less frequently semi-transparent, colorless and prism-shaped, and 60 to 300 µm in size (length/width ratio 2.0–3.0). The zircon has thin oscillatory zonation (Fig. 5B) and contains gas-liquid microinclusions. The cleanest zircon

**Table 2**. Results of U-Pb TIMS isotopic dating of zircons from volcanic rocks of the Ul'ya Depression, the Okhotsk-Chukotka volcanic belt

| Fraction number | Size (mm), and number of zircons in fraction | U/Pb | Isotopic ratio | | | | | Rho | Age (Ma) ± error | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $^{206}Pb/^{204}Pb$ | $^{207}Pb/^{206}Pb^a$ | $^{208}Pb/^{206}Pb^a$ | $^{207}Pb/^{235}U$ | $^{206}Pb/^{238}U$ | | $^{207}Pb/^{235}U$ | $^{206}Pb/^{238}U$ | $^{207}Pb/^{206}Pb$ |
| Sample 1-2a (58°36.287′N 139°48.832′E, left bank of Uenma River) | | | | | | | | | | | |
| 1 | 50–100, 13 grains | 50.1 | 155 | 0.0476 ± 4 | 0.3549 ± 4 | 0.0878 ± 9 | 0.0134 ± 1 | 0.43 | 85.4 ± 0.8 | 85.7 ± 0.3 | 80 ± 20 |
| 2 | 100–150, 12 grains | 50.2 | 267 | 0.0476 ± 2 | 0.3289 ± 1 | 0.0887 ± 5 | 0.0135 ± 1 | 0.45 | 86.1 ± 0.4 | 86.2 ± 0.2 | 80 ± 11 |
| Sample 7-3 (59°20.247′N 141°09.963′E, right bank of Gyrbykan River) | | | | | | | | | | | |
| 3 | 100–150, 3 grains | 58.9 | 453 | 0.0477 ± 2 | 0.3636 ± 2 | 0.0872 ± 4 | 0.0133 ± 1 | 0.56 | 84.9 ± 0.3 | 84.9 ± 0.2 | 84 ± 8 |
| 4 | 100–150, 7 grains | 57.0 | 359 | 0.0479 ± 3 | 0.3318 ± 2 | 0.0877 ± 5 | 0.0133 ± 1 | 0.44 | 85.3 ± 0.5 | 85.0 ± 0.2 | 95 ± 13 |

Note: [a] – isotopic ratio corrected for blank and common Pb; Rho – error correlation coefficient for $^{207}Pb/^{235}U$ – $^{206}Pb/^{238}U$ ratios; Error values (2σ) correspond to the last non-zero digits

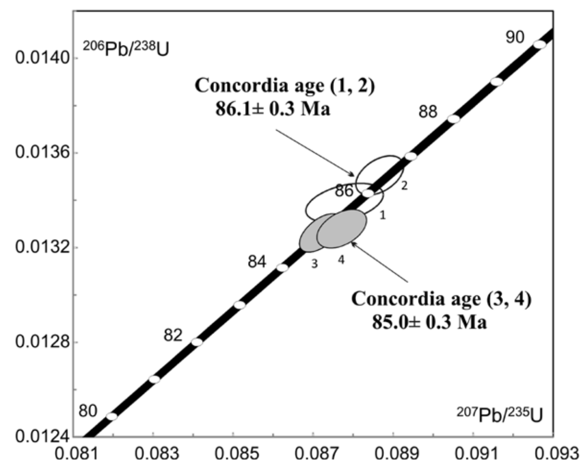


**Fig. 6**. ID-TIMS results of U-Pb zircon dating for samples 1-2a and 7-3. Thick black line represents the Wetherill concordia. Error ellipses are shown at 2 σ uncertainty. Point numbers 1–4 correspond to ordinal numbers in Table 1

crystals were selected for U-Pb dating (No 3 and 4, Tab. 2). Their concordant age yields 85.0 ± 0.3 Ma (MSWD=0.33, probability of concordance = 0.57, Fig. 6). This constrains the upper age limit of the Ul'ya flora.

The SHRIMP-based U-Pb age of the zircons of ~85.5 ± 2 Ma (the Santonian), which we obtained earlier for the tephroid sample 4B-1 from the Amka stratotype at the Amka River (Akinin et al. 2016), is in a general agreement with this new dating.

## DISCUSSION

Originally, the age of the Amka Formation was estimated by A.F. Efimova as Senonian (Sheikashova 1964). In the opinion of Lebedev (1987), the floristic assemblages from different localities of the Amka Formation are of different ages. He dated the Arinda and Emanra assemblages, characterized by fewer conifers and angiosperms and an abundance of ferns and cycadophytes, as being middle and late Albian. The Uenma, Ust'–Amka and Gyrbykan assemblages were combined in the Amka flora and this was correlated with the Arkagala flora of the Magadan Region (Samylina 1974, 1988) on the basis of predominance of conifers. The Arkagala flora was dated as Cenomanian at that time (Samylina 1988), but now the combination of floristic and isotope geochronology data indicate Santonian–Campanian age for this flora (Herman & Shczepetov 1997, Markevich 1989, Akinin & Miller 2011). The floristic assemblages from the Dukchanda and the Gyrbykan rivers with abundant angiosperms were determined to be Turonian in age.

We suggest that the floristic assemblages from all localities of the Amka Formation can be integrated into an aggregate Ul'ya flora. Its age can be estimated on the basis of new data obtained in recent years during studies of other floras of the Okhotsk–Chukotka volcanic belt. Among numerous floristic assemblages of the OCVB, the Arman and Ola floras from the Magadan Region and the Chaun flora from Central Chukotka are the most diverse and the best-studied (Philippova & Abramova 1993, Herman & Shczepetov 1997, Herman 2013, Herman et al. 2012, 2016, Philippova 2009, Golovneva & Shczepetov 2018). These floras are most reliably dated by both paleobotanical and isotopic data (Kelley et al. 1999, Akinin & Miller 2011). In the last few years, new paleobotanical data were published also for the Aliki, Chingandzha, Kholochovchan, Yana, Zarya, Ust'–Emuneret and Kholchan floristic assemblages (Shczepetov & Golovneva 2010, Golovneva et al. 2011, Golovneva & Shczepetov 2011, 2014, Moiseeva 2014).

The Ul'ya flora is characterized by predominance of conifers, subsidiary angiosperms, high endemism, and the presence of Early Cretaceous relicts (*Hausmannia*, *Sagenopteris*, *Podozamites*, *Phoenicopsis*, *Baiera*, *Sphenobaiera*). These features indicate that it is a typical flora of the Okhotsk–Chukotka volcanic belt. Since all floras of the OCVB are characterized by high endemism, age determination by direct comparison is complicated. In addition, the Ul'ya flora contains a large number of new undescribed taxa. Nevertheless, we will try to estimate the age of this flora based on floristic comparisons.

The Arman flora comes from the Arman and Narauli formations that occur at the base of the volcanic succession of the OCVB, and appears to be one of the oldest in the belt (Tab. 3, Fig. 1). It is currently dated as Turonian–Coniacian (Herman et al. 2016). The most typical species of the Arman flora are *Birisia ochotica* Samylina, *Nilssonia pilifera* Samylina, *Phoenicopsis* ex. gr. *angustifolia*, *Ginkgo* ex. gr. *sibirica*, *Podozamites* sp., *Sequoia ochotica* Yudova et Golovneva and different endemic angiosperms. Among them, *Birisia ochotica* and *Podozamites* do not occur in younger floras of the OCVB. Only solitary findings of *Podozamites* have been reported in

**Table 3**. Correlation of the Late Cretaceous floras of the Okhotsk–Chukotka volcanic belt (after Golovneva 2018)

| Age | Northern part of the OCVB (Central and Eastern Chukotka, Anadyr sector) | Middle part of the OCVB (Arman and Ola rivers and Viliga-Tumany interfluve) | Southern part of the OCVB (Ul'ya Depression) |
|---|---|---|---|
| Campanian | Enmyvaam floristic assemblage | Ola and Arkagala floras | Delokachan floristic assemblage |
| Santonian | Ust'Emuneret and Amguema floras | | |
| Coniacian | Chaun flora, Aunei floristic assemblage | Aliki and Kholchan floras | Ul'ya flora |
| Turonian | | Arman flora | |

the Aunei floristic assemblage from the Anadyr River headwaters (Golovneva & Shczepetov 2013). The Aunei floristic assemblage belongs to the Chaun regional flora, the age of which is determined as Coniacian on the basis of both paleobotanical and isotopic data (Kelley et al. 1999, Golovneva 2018). In the Amka Formation, leaves of *Podozamites* are quite common but do not form leaf mats as they do in the deposits of the Arman Formation. Leaves of *Birisia ochotica* were not found in the Amka Formation.

However, such taxa as *Metasequoia* and *Quereuxia angulata* have not yet been found in the Arman Formation. They first appear in the younger floras of the OCVB, dated as Coniacian, for example in the Aliki and Chaun floras (Shczepetov & Golovneva 2010, Golovneva 2018).

The ferns *Tchaunia lobifolia*, *Kolymella raevskii* and *Arctopteris ilirnensis* were earlier considered to be endemic elements of the Coniacian Chaun flora (Golovneva 2018). The occurrence of these species in the Amka Formation suggests Coniacian age for the Ul'ya flora.

Up to now, remains of *Lokyma onkilonica* were found only in the Santonian–Campanian floras of the OCVB (Samylina 1988, Herman 2011). However, such a young age for the Ul'ya flora is unlikely. It lacks many recent conifer genera typical for the Santonian–Campanian Ola flora, including *Cryptomeria cretacea* Samylina, *Cunninghamia orientalis* (Philippova) Samylina and *Taiwania cretacea* Samylina.

Based on the co-occurrence of such taxa as *Podozamites*, *Metasequoia*, *Quereuxia*, *Tchaunia lobifolia*, *Kolymella raevskii* and *Arctopteris ilirnensis*, the age of the Ul'ya flora can be determined as Coniacian. The U-Pb isotope data indicate the age of the Amka Formation as being near the Coniacian/Santonian boundary.

The stratigraphic equivalent of the Amka Formation in the Magadan Region is the Kholchan Formation, which overlies the Arman Formation and underlies the Ulyn and Ola formations. Plant fossils from the Kholchan Formation were assigned to the Kholchan flora (Golovneva & Shczepetov 2014). This flora includes *Cladophlebis* sp., *Heilungia* sp., *Phoenicopsis* ex gr. *angustifolia*, *Sphenobaiera* ex gr. *longifolia*, *Ginkgo* ex gr. *adiantoides*, *Podozamites* sp., *Araucarites* sp., *Taxodium amguemensis*, *Metasequoia* sp., *Sequoia ochotica*, *Pagiophyllum* sp., *Pityophyllum* sp., *Trochodendroides* sp. and *Quereuxia angulata*. All genera except *Heilungia* are common to the Ul'ya flora. Based on the stratigraphic position of the Kholchan Formation (between the Turonian–Coniacian Arman Formation and the Santonian–Campanian Ola Formation) and the presence of *Podozamites*, *Metasequoia* and *Quereuxia*, the age of the Kholchan flora is determined as Coniacian.

Thus, the Ul'ya flora can be correlated with other Coniacian floras of Okhotsk–Chukotka volcanic belt: the Chaun flora of the Central Chukotka, the Aliki flora from the Viliga–Tumany interfluve area, and the Kholchan flora of the Magadan Region. The Coniacian age of the Chaun flora has been determined on the basis of $^{40}Ar/^{39}Ar$ data (Kelley et al. 1999).

The new U-Pb zircon isotopic age obtained here for the Amka Formation indicates a position near the Coniacian/Santonian boundary [U-Pb ID-TIMS age is $86.1 \pm 0.3$ Ma for the Uenma locality, and U-Pb SHRIMP age of $85.5 \pm 2$ Ma obtained earlier for the Amka stratotype at the Amka River (Akinin et al. 2016)]. These ages coincide with one of the main peaks of volcanism within the OCVB, as can be seen from the compilation of geochronology data (Fig. 1b). The two most pronounced peaks of volcanism occur at around $87 \pm 1$ and $82 \pm 2$ Ma throughout all parts of the OCVB, and correspond to the most voluminous stages of the middle to late cycles of felsic volcanism (Akinin & Miller 2011, Tikhomirov et al. 2012). Moreover, isotopic dating of the major plant-bearing volcanics and volcano-sedimentary rocks coincides with the main peaks of OCVB volcanism (Fig. 1b).

It is worth noting that we obtained similar U-Pb zircon ages from three different plant-bearing localities of the Ul'ya Depression along the Uenma, Amka and Gyrbykan rivers. This finding strongly supports our suggestion all floristic assemblages from the Amka Formation can be merged into a single Ul'ya flora, in contrast to Lebedev's opinion that these assemblages differ in age.

## CONCLUSIONS

1. The U-Pb-based (ID-TIMS method) concordant age of the zircons obtained from plant-bearing pyroclastic rocks of the Amka Formation at the Uenma River is $86.1 \pm 0.3$ Ma, which corresponds to the Coniacian/Santonian boundary interval. The age of the zircons from overlying ignimbrite rocks of the Urak Formation is Santonian ($85.0 \pm 0.3$ Ma).

2. The Ul'ya flora is correlated in its systematic composition with the following Coniacian floras of the OCVB: the Chaun flora of Central Chukotka, the Aliki flora from the Viliga–Tumany interfluve area, and the Kholchan flora of the Magadan Region.

3. The age of the Ul'ya flora and plant-bearing rocks of the Amka Formation is determined as Coniacian (most likely the end of the Coniacian, near the Coniacian/Santonian boundary) by two independent methods.

4. Four new endemic species of conifers from the Ul'ya flora are described: *Elatocladus amkensis* Golovneva, sp. nov., *Araucarites sheikashoviae* Golovneva, sp. nov., *Elatocladus gyrbykensis* Golovneva, sp. nov. and *Pagiophyllum umitbaevii* Golovneva, sp. nov. Two-lobed leaves of *Sphenobaiera* are assigned to *S. biloba* Prynada based on their epidermal structure.

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