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DISCUSSIONS

Composition and Age of the Ayanka Flora (Late Cretaceous, Santonian–Campanian) of the Okhotsk–Chukotka Volcanogenic Belt: Response to the Criticism

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Abstract—The main critical remarks to the paper by M.G. Moiseeva, A.B. Herman, and A.B. Sokolova entitled "On the Stratigraphic Setting and Composition of the Ayanka Flora from the Upper Cretaceous of Okhotsk–Chukotka Volcanogenic Belt, Northeastern Russia" (*Stratigraphy and Geological Correlation*, 2022, vol. 30, no. 4, pp. 250–272), stated by S.V. Shczepetov in his article "On the Ayanka Flora from the Upper Cretaceous of Northeastern Russia" (*Stratigraphy and Geological Correlation*, 2022, vol. 30, no. 6, pp. 578–585), are considered. Additional arguments are given to confirm the conclusions we have previously made: (1) all three taphofloras from the Obryvistaya River basin came from the same stratigraphic unit, which, however, is called differently in separate sheets of the 1 : 200000 State Geological Map of the Russian Federation: Auney Member on the northern sheet and Makkoveem Formation on the southern one; (2) according to the composition of the plants of these taphofloras, all of them are approximately coeval and can be considered as a unified Ayanka flora; (3) the most probable age of the Ayanka Flora is Santonian–Campanian, since it is undoubtedly the most similar to the Santonian–Campanian floras of Northeastern Russia and Northern Alaska.

Keywords: paleobotany, stratigraphy, Santonian, Campanian, floristic assemblage, Northeast Asia, Chukotka

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Because of the complexity of the geological structure of natural stratigraphic objects, statements about them are usually more or less probabilistic. Therefore, the task facing a stratigrapher is to come to conclusions that are most consistent with the observed facts, with a minimum of a priori assumptions. Recently, we published an article devoted to the systematic composition and age of the Late Cretaceous Ayanka flora of the Okhotsk–Chukotka Volcanogenic Belt (OCVB) (Moiseeva et al., 2022), and Shczepetov (2022) published a critical note on this article. Considering the above, let us try to understand this criticism.

S.V. Shczepetov questions three main statements of our paper: (1) taphofloras from three localities in the Obryvistaya River basin (Bolshaya Ayanka River basin) come from the same stratigraphic unit; (2) these taphofloras are coeval on the scale of geological time and can be considered as a single fossil flora; (3) it is most likely that the flora called the Ayanka one is Santonian–Campanian in age. Let us consider Shczepetov's criticism of our statements in order.

(1) There is a certain difficulty in the interpretation of the stratigraphic position of plant-bearing beds related to the fact that the localities of fossil plants are located on two adjacent sheets of the 1 : 200000 State Geological Map of the Russian Federation (GGK-200): locality (site) 700 is on the southern sheet Q-58-XXXIV, and localities (sites) 701 and 702 are on the northern sheet Q-58-XXVIII. The geological survey of these sheets was carried out by two different parties of different organizations: Aerogeologiya and SVPGO Sevvostgeologiya, respectively (Moiseeva et al., 2022, Fig. 1a). In the process, the geologists of these crews used different stratigraphic schemes and nomenclature of the mapped stratigraphic units: within the southern sheet, plant fossils were collected from felsic and mafic rocks of the Makkoveem Formation; within the northern sheet, from felsic volcanics of the Auney Member. Along the boundaries of the map sheets, outcrops of the Auney Member, which enclose beds of localities 701 and 702, are adjacent to those of the Makkoveem Formation, which encloses locality 700. The same is observed for the Atvuveem Formation (in the south) and Tuvyi Formation (in the north), which overlap a plant-bearing member: the fields of their distribution adjoin each other at the boundary between sheets of GGK-200 and their southern boundaries coincide. Accordingly, we believe that plant-bearing

deposits belong to the same stratigraphic unit, named differently on the southern and northern map sheets, and the fossil plant-bearing beds of this unit are approximately of the same age. It goes without saying that this unit should be named the same on both the north and south sheets of GGK-200. However, we believe that geologists who are planning to conduct a geological survey here should name this unit.

However, S.V. Shczepetov believes that the studied taphofloras are essentially different-aged. For this reason, he appeals to the supposed fault, which is traced, in his opinion, between sites 700 and 701: "... if we extend the faults shown on the map with point 700 to the maps with points 701 and 702 (the relief very well allows this), the locations would be quite convincingly separated from each other by faults" (Shczepetov, 2022, p. 581). However, the submeridional fault, which is "passing from the south to the area of point 701," in the opinion of Shczepetov (2022, p. 581), in reality it does not trace to the area of this site at all. It is shown only on the southern sheet of GGK-200, being traced only to the map sheet boundary. Shczepetov (2022, p. 581) drew the supposed continuation of the fault zone between localities 700 and 701 by the results of map interpretation (probably, following the relief shown on the topographic base of geological maps?) at his own discretion considering that "the relief very well allows this." It is likely that Shczepetov needed this hypothetical fault very much to argue his point of view.

It is known that faults in the OCVB are poorly and ambiguously mapped in general, and the fact that the above fault ends at the boundary of the map sheets allows us to doubt its existence. Otherwise, why did the geologists of SVPGO Sevvostgeologiya, who mapped the northern sheet, not notice it? For this reason, we did not draw this fault, along which no stratigraphic boundaries are displaced, on the schematic geological map of the area (Moiseeva et al., 2022, fig. 1). In Herman's opinion, who took part in the collection of plant fossils in the Obryvistaya River basin during the 1985 field season, a well-grounded mapping of faults here is hardly possible, because this area is occupied by dense tundra and taiga vegetation. However, the supposed fault, which never observed in the field, is used by S.V. Shczepetov as the main geological evidence that the taphofloras of locality 700 and those of localities 701 and 702 are confined to significantly different-age stratigraphic units. We cannot agree with this argument and, as before, we believe that the beds of all three fossil plant assemblages belong to a single unit and they are approximately of the same age.

(2) It is difficult to understand why Shczepetov (2022, p. 581) believes that "an undoubted merit of this chapter in the work..., is that the composition of the 'flora' is given little attention, while the compositions of specific localities are described in detail." We assume that the list of plants of the Ayanka flora and the distribution of 60 fossil plant taxa at sites 700, 701, and 702 given in Table 1 of our article and the corresponding places in the text providing the information on quantity of ancient plant taxa give rather full information about the flora as a whole (1) and show that three taphofloras in the Obryvistaya River basin, ***judging by composition of plants included in them***, most likely existed simultaneously on the geological time scale (2). It is this conclusion that allows us to consider them as a single paleofloristic assemblage (the Ayanka flora). However, let us expand on the validation of this conclusion.

The floristic assemblage of **locality 700** is the most diverse and includes 41 species of fossil plants. This assemblage is described and depicted in detail (Moiseeva et al., 2022, p. 253, Plates I–III). Therefore, we recap briefly on some of the highlights important for its comparison with other taphofloras and age determination. In this assemblage, liverworts with rather large thalli were identified; one of them, *Thallites* sp. 1 (Moiseeva et al., 2022, Plate I, figs. 1, 2), is the most similar to a liverwort from Santonian–Campanian Ust-Emuneret flora of Central Chukotka. Ferns are represented by *Arctopteris* sp. 1–2 and *Coniopteris tschuktschorum* (Kryshtofovich) Samylina. In addition, we have identified ginkgoaleans with non-dissected leaf blade (*Ginkgodium* (?) sp.), as well as those with weakly and highly dissected blades (*Ginkgo* ex gr. *adiantoides* Heer and *Ginkgo* ex gr. *digitata* Brongniart, respectively). Conifers are rather diverse: there are shoots of *Ditaxocladus* sp. and *Metasequoia* sp. (two species), large-leaved shoots of *Taxites* sp., and also several types of male and female cones or macro- and microstrobili of family Cupressaceae and diverse representatives of family Pinacea. Among the conifers from this assemblage, shoots of *Parataxodium* cf. *wigginsii* Arnold et Lowther (Moiseeva et al., 2022, p. 259, Plate II, figs. 1, 2, 8), a species typical of Santonian–Maastrichtian floras of the Early and Late Kogosukruk of Northern Alaska (Arnold and Lowther, 1955; Rothwell et al., 2020), should be noted first. Angiosperm remains are the most abundant and diverse in locality 700. The presence of species such as "*Vitis*" *penzhinica* Herman, "*Macclintockia*" *ochotica* Vachrameev et Herman, and *Trochodendroides notabilis* Herman, which were identified in early Campanian Barykov and Upper Bystraya floras (Herman and Lebedev, 1991; Moiseeva and Sokolova, 2011), is of importance for age dating. In addition, when collecting plant fossils at this site in 1985, leaf impressions of *Barykovia tchucotica* (Abramova) Moiseeva (previously described as *Quercus tchucotica* Abramova)—a specific species of Santonian–Campanian floras of the region under study—were noted in a field diary of A.B. Herman. Unfortunately, these specimens were subsequently lost. Therefore, we have no opportunity to provide actual (photographic) evidence of the presence of this species and can only refer to its identifi-

cation by E.L. Lebedev and A.B. Herman in the field. In addition, there are impressions of another species *Trochodendroides* sp. 1, most likely new, in this locality (Moiseeva et al., 2022, Plate III, fig. 3). It is most similar to the species from the Ust-Emuneret flora (previously defined as *Macclintockia* sp. (Moiseeva and Sokolova, 2014, p. 277, text-figs. 4i, 4j, Plate II, figs. 10, 11)).

The floristic assemblage from **locality 702** is also dominated by angiosperm leaf remains. The flora diversity is low, numbering only 15 species. This is explained by the fact plant fossils were collected from a small lens, whereas in locality 700 they were collected from several beds in two outcrops. Of 15 species, only seven species, i.e., almost half of the total amount also occurs in the taphoflora from locality 700. It is important to note the findings of "*Macclintockia*" *ochotica* and a new species *Trochodendroides* sp. 1 which characterised by small leaves with flat large teeth or sometimes with undulate entire margin, as well as small peltate leaves of *Menispermites* sp., similar to specimens from the Ust-Emuneret flora. Of conifers, as in locality 700, several impressions of *Parataxodium* cf. *wigginsii* and *Metasequoia* sp. were found. Despite the low diversity, this floristic assemblage from all other Late Cretaceous taphofloras of Northeast Asia is the most similar, in our opinion, in composition to the assemblage from locality 700, as well as to the Ust-Emuneret floristic assemblage of Chukotka.

The floristic assemblage from **locality 701** is the most problematic in terms of comparison. It is characterized by a rather low diversity (22 species) with predominance of conifer remains, most of which occur in many Late Cretaceous floras. According to this feature, this assemblage is similar to Campanian Ola flora (Samylina, 1988; Filippova and Abramova, 1993; Herman, 2011; Shczepetov et al., 2019), in which angiosperm remains are also very rare. As in locality 700, ferns are represented by *Coniopteris tschuktschorum* and, apparently, a new species *Arctopteris* sp. 2 represented by fertile and sterile leaves with small pinnules (Moiseeva et al., 2022, p. 263, Plate IV, figs. 5, 13, 15). Similar *Arctopteris* specimens are present in locality 700. In addition, they were identified in the Barykov flora (Moiseeva and Sokolova, 2011, p. 65, Plate I, fig. 8). Besides, we identified the same two *Ginkgo* species as at site 700: one with a weakly dissected lamina and the other with a strongly dissected lamina. Conifers are dominated by polymorphic shoots of "*Sequoia*" sp. (Moiseeva et al., 2022, Plate IV, fig. 1; Plate V, figs. 1, 2). Female cones of the sequoia (?) type (Moiseeva et al., 2022, Plate IV, figs. 11, 12), as well as a shoot with male cones, probably belong to the same plant (Moiseeva et al., 2022, Plate V, fig. 3). Such shoots were found in the Ust-Emuneret and Barykov floras and identified as *Glyptostrobus comoxensis* Bell (Moiseeva and Sokolova, 2011, 2014). Moreover, as at site 700, shoots of *Metasequoia* sp. 1 and *Pityocladus* sp. were identified. Angiosperms in locality 701 occur rarely and fragmentarily. They are represented by leaf impressions of the aquatic plant *Quereuxia angulata* (Newberry) Kryshtofovich and a few specimens of "*Macclintockia*" *ochotica*, a characteristic species, which was found in all three localities of the Ayanka flora, as well as *Dicotylophyllum* sp. 4 and small fruits of *Nyssidium* sp. and *Carpolithes* sp.

Regarding the composition of fossil plants from locality 701, Shczepetov (2022, p. 581) states that, of all these species, only "*Macclintockia*" *ochotica* Vachr. et Herman can be attributed to the young forms of plants characteristic of the late stage of the Okhotsk-Chukotka belt (Santonian–Campanian). This species, however, is represented by "leaf fragments of poor preservation" (Moiseeva et al., 2022, p. 258). Having been found "without context," these fragments might have been identified as *Trochodendroides* sp." Unfortunately, Shczepetov gave no arguments why this species would necessarily be assigned to the genus *Trochodendroides* (we, as a matter of course, do not think so). In addition, he should have clarified what "context" he referred to. There is probably no point in discussing the cited quotation without appropriate explanations. By the way, findings of a representative of the *Macclintockia* (but not of the Ayanka species, but *M. beringiana* Herman) were considered by Herman and Shczepetov (1997) as evidence of the presumably Campanian rather than more ancient age of the Ola Formation in the Magadan region.

Thus, if consider the floristic assemblage from locality 701 separately, it is not easy to determine its age. Many ferns and conifers show a wide range of distribution occurring both in more ancient (Turonian–Coniacian) and in the Santonian–Campanian floras. Angiosperms are not very well preserved, but they are definitely similar to those identified in Ola and Ust-Emuneret floras. It should be noted that no fossil plant species characteristic only of the Turonian–Coniacian flora were found in this 2 represented by fertile and sterile leaves or in the taphofloras from localities 700 and 702; i.e., its composition, as a minimum, does not contradict the Santonian–Campanian age of the taphoflora from locality 701.

The Ayanka flora as a paleobotanical object is of interest because the three floristic assemblages of this flora are not fully identical in composition, but the presence of common taxa, in our opinion, indicates their floristic similarity. Of course, this conclusion would not cause a protest from our opponent if the systematic composition of all taphofloras was the same. This happens, but not often, because vegetation, both ancient and modern, is usually irregular in area and represented by different plant communities. This could easily be verified by simply walking in a modern coniferous forest, birch forest, meadow, or shrubbery along a river.

(3) As was shown above and discussed in much more detail in our article (the section "Correlation

with Other Late Cretaceous Floras and the Age of the Ayanka Flora"), floristic assemblages from three localities in the Obryvistaya River basin (Ayanka flora) are the most similar namely to Santonian–Campanian floras of Northeastern Russia and Northern Alaska: Barykov, Upper Bystraya, and Ust-Emuneret floras, to a lesser extent to Ola and Early Kogosukruk. In contrast to the Turonian–Coniacian and more ancient floras of the North Pacific, there are no characteristic forms in the Ayanka flora among ferns (genera *Tchaunia*, *Kolymella*, *Lobifolia*, *Birisia*, *Sagenopteris*, *Hausmania*). In addition, there are no relict ginkgoaleans (*Sphenobaiera*), leptostrobaleans (*Czekanowskia*, *Phoenicopsis*, *Leptostrobus*), cycadophytes (*Nilssonia*), and Bennettitales (*Pterophyllum*). No relict genera, such as *Podozamites*, or the taxa typical of Turonian–Coniacian and more ancient floras, such as *Araucarites* and *Elatocladus zheltovskii*, were identified among conifers of the Ayanka flora. Angiosperms show only a slight resemblance to pre-Santonian floras only at the generic level; platanoids, which dominate in Turonian–Coniacian floras, are practically absent; there are no representatives of genera *Araliephyllum*, *Dalembia*, *Terechovia*, and other taxa typical of Turonian–Coniacian and more ancient floras of the North Pacific.

Our study of the Ayanka flora is based, first of all, on a detailed analysis of the morphology of fossil plants and their comparison with plants of other ancient floras. Only such very laborious studies allow us to judge confidently the composition and age of the fossil floras. Therefore, the statement of Shczepetov (2022, p. 582) does not seem to us very reasonable: "I managed to have a glimpse of some part of the collection of the "Ayanka flora." From everything I had seen before, it seemed to me most similar to the Ulya flora."

Shczepetov believes that the most acceptable approach to determine the age of plant-bearing (and not only) deposits of the OCVB is to determine their position in the sequence of five contrast units which are widespread throughout a large part of the volcanogenic belt. It is assumed implicitly that (1) this sequence of members is distributed without significant regional variations and missing of some strata throughout the entire or at least over most of the vast territory of the OCVB, and (2) the age of these members is the same. Following this approach, S.V. Shczepetov states that "the taphoflora of point 700 and points 701 and 702 are, respectively, related to the fourth and second strata of the contrast sequence of volcanism of this structure" and that "they should be dated differently, to the Santonian–Campanian and Turonian–Coniacian, respectively" (Shczepetov, 2022, p. 584).

Of course, this approach is redeeming because it is easy to apply. However, how substantiated is it? Not being experts on volcanogenic deposits, we will not engage in polemics with our opponent and only refer to the opinion of the famous paleovolcanologist V.V. Akinin (written communication, 2022) concerning the mapping of units of the OChVB. He considers that "volcanic strata are not consistent in composition and, in many cases, the age of the same-type rocks in adjacent volcanic structures, and even more in the belt segments, differs significantly (the difference may be up to 5–10 m.y.)." In addition, the volcanologist A.Yu. Ozerov (oral communication, 2022) drew our attention to the fact that lateral instability in composition of products of volcanic eruptions is well illustrated by modern volcanism of Kamchatka. For example, the products of eruptions of the Klyuchevskoi volcano are high-Mg basalts, and those of the nearby Bezymyannyi volcano are dacites. Therefore, it seems to us that radioisotopic and paleobotanical methods of dating are most applicable for determining the age of volcanogenic sequences of the OCVB. In this case, considerations concerning the position of volcanogenic strata in the "standard" sequence can be used only as supplementary ones.

In conclusion, we may say that we continue to defend the main conclusions drawn in our article (Moiseeva et al., 2022): all three taphofloras from the Obryvistaya River basin came from the same stratigraphic unit. Judging from the composition of the plants of these taphofloras, they are approximately of the same age and can be considered as a single Ayanka flora; comparison of this flora with other fossil flora has shown its undeniable similarities to the Santonian–Campanian floras of Northeastern Russia and Northern Alaska. It follows that Santonian–Campanian age of the Ayanka flora is the most probable.

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CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

Reviewer E.Yu. Baraboshkin

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