Acta Palaeobot. 41(2): 141–146, 2001

Structure of the Turgayan flora in the Oligocene and Miocene and its palaeoclimatic features*

SERGEY G. ZHILIN

Komarov Botanical Institute, Russian Academy of Sciences, 2 Popov Street, St. Petersburg 197376, Russia,
e-mail: zhilin@AH1553.spb.edu

Received 15 December 1999; accepted for publication 5 February 2001

ABSTRACT. Five phases should be distinguished in the evolution and development of the Turgayan flora in Kazakhstan and the south of Western Siberia, namely: **1**. **The end of the Late Eocene.** Involvement of the temperate nucleus in a subtropical flora of a Drevlyanian type, representing the Poltavian flora sensu Krishtofovich. **2**. **The beginning of the Early Oligocene.** Transformation of the subtropical Drevlyanian flora into the warm temperate Turgayan flora. **3**. **The end of the Early Oligocene.** The origin of the warm temperate Turgayan flora, retaining a noticeable portion of a subtropical relictual elements (in separate local floras it comprises one tenth to one third of the total). The Turgayan flora of the third phase is typical predominantly of central and western parts of Kazakhstan. The systematic composition of the flora at this phase is rather unusual due to an appreciable fraction of the subtropical inherited from the previous flora of Drevlyanian type. **4**. **The Late Oligocene – Early Miocene (the Aquitanian**). The flora characteristic of this phase is practically devoid of a Subtropical element and is extensively distributed far beyond the Kazakhstan limits. In Kazakhstan this is a phase of a typical Turgayan flora. A small portion of Eocene relict plants retained in the flora was sufficiently adapted to new climatic conditions. This flora occurs in the Central and Western Kazakhstan, it is also well-developed in eastern part of Kazakhstan and the south of Western Siberia and in the Southern Urals. Most general notions on the ecological type of the Turgayan flora that can be found in the palaeobotanical literature are based on this particular phase in the history of the Tertiary floras from Kazakhstan and Western Siberia. **5**. **The end of the Early Miocene (the Burdigalian).** The proper Turgayan flora starts to decline in Kazakhstan and its numerous derivatives begin to form in other regions. In my opinion, palaeofloras of Mamontova Gora (Mamontova Mountain) are referred, for example, to such derivatives, their most probable age is Middle Miocene.

KEY WORDS: Drevlyanian, Turgayan flora, thermophilic element, initial Turgayan (mesophilous) element, palaeoflora, Oligocene, Miocene

The Turgayan flora is a temperate flora that originated in Asia during the mid-Tertiary. Any research worker who has studied Tertiary floras would most probably agree with this definition of the Turgayan flora. Krishtofovich modified this determination in his numerous papers dealing with Tertiary floras and suggested this term in 1928. In his first paper Krishtofovich (1928) introduced a number of new names of palaeophytochoria but without providing their distinct differentiation in time and space. However, over the years and from subsequent studies of Tertiary palaeofloras Krishtofovich (1928, 1929a, 1929b, 1933, 1955, Krishtofovich et al. 1956) originated new phytogeographical concepts and facts in respect to the Greenlandian and Turgayan floras, as well as several other past floras.

Among hypotheses on the origin and spread of great past floras there naturally prevailed hypotheses focussing on migration. Some biologists disagree with the application of the term "migration" for plants and they prefer to use it only in respect to the cyclic migrations of animals. But the use of the term "spread of plants" instead of "plant migration" would not

* The present study, supported by RFFR grant No. 00-04-48543, was presented at the Workshop of NECLIME: Neogene Climate Evolution in Eurasia. 9.05. – 12.05. 1999. Institute and Museum of Geology and Paleontology, University of Tübingen, Germany.

clarify this notion and therefore a change in terminology is unnecessary. Some neobotanists are inclined to think that settlement of plants in a territory is possible only in cases when the area was previously completely devoid of vegetation, but these concepts are not supported by observations. Changes occur in modern floras over the life span even of one generation of researchers and show that both individual species and whole plant communities are gradually conquering territories that they previously did not inhabit.

In terms of geological history in any time-period (of hundred thousands to millions of years) there were unlimited possibilities for a given flora to establish itself in neighbouring regions.

Krishtofovich's assumption of the origin of the Turgayan flora in northeast Asia during the Late Cretaceous was one of his pioneering ideas on plant migration. According to Krishtofovich the primary nucleus (Late Cretaceous) of the Turgayan flora migrated from the northeast in western and southwestern direction.

There were only a few grounds for Krishtofovich's selection of the word "Turgayan" as part of the term, because when he proposed this concept only two small floras were known to him from the Turgay itself. But this name was a happy choice: over a hundred palaeofloras of this particular Turgayan type were subsequently discovered in the Turgay region, and many of these between 1940–1960. If the Turgayan flora is treated in a narrow sense, then it would be inherent only to Oligocene and Early Miocene floras from Kazakhstan and partly the southern portion of West Siberia. For the most part these floras were investigated in great detail and moreover they were precisely dated (Zhilin 1974, 1989).

Five phases should be distinguished in the evolution and development of the Turgayan flora in this region, they are:

1. **The end of the Late Eocene.** Inclusion of a temperate nucleus in a subtropical flora of the Drevlyanian type (Zhilin 1989, p. 220–224). This is the Poltavian flora in the sense meant by Krishtofovich who clearly characterized floras of this type (Krishtofovich 1928, 1929a, 1929b, 1933, 1955, Krishtofovich et al. 1956). Fossil remains of floras from Kazakhstan of the Drevlyanian type have been previously described by Makulbekov (1972, 1997).

Renaming of this type flora is due to the fact that the stratigraphic division "the Poltavian Formation" (located in the Ukraine) is of Miocene age, while "the flora of Poltavian type" is dated as Eocene. Reasons for the change of the name from "Poltavian flora" to Drevlyanian are described in detail by Zhilin (1989 p. 213–227). The Drevlyanian flora ranges from the Middle to Late Eocene.

2. **The beginning of the Early Oligocene.** Transformation of the subtropical Drevlyanian flora into the warm temperate Turgayan flora. Phases 1 and 2 are known from fossil plant collections from the Southern Urals (Orenburg District of Russia).

3. **The end of the Early Oligocene.** The early warm temperate Turgayan flora retains a noticeable portion of a subtropical relictual elements (in separate local floras it comprises one tenth to one third of the total). The Turgayan flora of the third phase is typical of the central and western parts of Kazakhstan. The systematic composition of the flora, at this phase, is rather unusual due to an appreciable fraction of subtropical elements from the previous Drevlyanian-type flora.

4. **The Late Oligocene – Early Miocene (the Aquitanian**). The flora characteristic of this phase is practically devoid of a subtropical element and is extensively distributed far beyond the geographical limits of Kazakhstan. In Kazakhstan this is a phase of typically Turgayan floras. Small portions of Eocene relict plants retained in the flora were sufficiently adapted to new climatic conditions. This flora occurs in Central and Western Kazakhstan, it is also well developed in the eastern part of Kazakhstan, south of Western Siberia, and in the Southern Urals. Most general notions on the ecological type of the Turgayan flora that can be found in the palaeobotanical literature are based on this particular phase in the history of the Tertiary floras from Kazakhstan and Western Siberia.

5. **The end of the Early Miocene (the Burdigalian).** The proper Turgayan flora starts to decline in Kazakhstan and its numerous derivatives begin to arise in other regions. In my opinion, palaeofloras of Mamontova Gora (Mamontova Mountain, Il'inskaya et al. 1976, Nikitin 1976) are referred, for example, to such derivatives; their most probable age is the Middle Miocene.

The fourth phase is most useful for proper understanding of the process how the tem-

perate flora of a modern type was formed. The flora of this particular type was most widely distributed throughout the Northern Hemisphere. Its rather depauperate derivatives exist even today.

In an assessment of the affinity of these palaeofloras much depends on the criteria selected and aims to be achieved. If a flora is assessed by ecological criteria, then all the palaeofloras of a temperate type in the Northern Hemisphere, which do not involve a thermophilic element, can and should be considered to be Turgayan floras. The flora from Kazakhstan and south of Western Siberia, belonging to the fourth phase, was analyzed at the level of species (Zhilin 1989) and the analysis clearly revealed that this flora was from various adjacent local floras of Eastern Siberia (Mamontova Mountain, Middle Miocene) and Kamchatka (Krutogorova River, Late Oligocene–Early Miocene). A flora of Krutogorova River (Chelebaeva 1988) is not distinguished from typical Turgayan floras of Kazakhstan by the generic composition of dicotyledons (*Fagus, Alnus, Betula, Corylus, Pterocarya, Rumex, Populus, Salix, Actinidia, Clethra, Diospyros, Sorbaria, Acer*) and is comprised of exclusively local species that may be endemics. None of the species of the flora from the Krutogorova River are regarded by Chelebaeva (1988) to be identical to proper Turgayan species. Actually, Chelebaeva did not apply the name Turgayan to the Krutogorova flora, but due to ecological similarity and complete coincidence of its generic composition, this flora can be considered to be a flora of the Turgayan ecological type.

However, many palaeobotanists have applied the term "Turgayan" to temperate floras from Eastern and Central Europe of the Oligocene and Miocene (sometimes even the Pliocene). Another version of the term can sometimes be found in the literature – "Turgayan flora of the European type". But detailed investigations and establishment of links between floras at the specific level have led to a new designation of the former "Turgayan flora of European type". Negru (1986) suggested calling this flora "Cleomean flora" (from name of genus *Cleome*). Negru also believes that a term "flora of *Hipparion* epoch" is a synonym of the "Cleomean flora". This existed until the end of the Middle Miocene – Pliocene.

Kvaček (1996a, 1996b) raised the question about the homogeneity of the Turgayan flora and gave a negative answer. However, Kvaček considered the similarity of the floras of the Turgayan type in a broad sense, namely at the generic level and in an ecological aspect. His treatment the Turgayan flora is as including a zonal type flora and vegetation extending from Central Europe to the Asian Far East, from west to east North America, throughout the Oligocene and Neogene. This concept is very interesting and I fully support it although I have one comment. When Kvaček objects to Krishtofovich's statement about "exhaustingly monotonous Turgayan flora" it should be noted that Krishtofovich had another aim in mind. When our predecessor noted a slight floristic similarity he wished to emphasize it in every publication.

It should also be borne in mind that in those days, temperate floras of the Oligocene and Miocene from vast expanses of Eurasia were systematically poorly studied. Many palaeobotanists of that time worked on of geological surveys and made superficial examinations of collections. They identified specimens (and then species), which could be most easily related to known taxa. The situation changed when Krishtofovich and his colleagues (Krishtofovich et al. 1956) completed the monograph on "Oligocene flora of Ashutas Mount in Kazakhstan": it was an excellent handbook both for researchers and students.

Tracing the floras of Turgayan type "along the vertical line" to clarify the differences which occurred with age changes, produced new names "pre-Turgayan" and "post-Turgayan". Some difficulties arise in establishing the predecessors of the Turgayan flora in various regions.

It is most tempting to establish how the rather monolithic (similar in specific composition) Turgayan flora was developed from pre-Turgayan floras of different compositions (Zhilin 1989). It is natural to suppose that a complex process of mixing of heterogeneous elements of floras was necessarily involved. And any form of "mixing" could not occur without movement and spread. In other words, migration of these elements is needed. When a new type of a flora is created, the process involves a great number of various factors: abiotic and biotic.

During the early phases of the formation of

the temperate flora, which was called Turgayan (the end of Late Eocene – the beginning of Early Oligocene), the Turgayan flora was certainly heterogeneous (various compositions in various regions). Besides, it consisted of elements that were hardly compatible in ecological respects. However, then came the time of relative stability and homogenization of this plant assemblage during the Late Oligocene – the beginning of Early Miocene. There are significant differences in the systematic composition of local palaeofloras from different areas even within the limits of, for example, Kazakhstan where homogeneity of the Turgayan flora during the Late Oligocene and the Early Miocene was most pronounced. One should naturally compare those floras, which are established by homogenous fossil material that is separately established based upon fossil leaves, fruits and seeds, pollen, woods, etc. If similarity of palaeofloras is assessed at the level of genus, then there arises similarity between the Turgayan and modern floras, for example, those of Southern Europe and south-eastern Canada. In the instance of southern Europe I follow Krishtofovich in naming *Betula, Alnus, Carpinus, Ulmus, Acer, Castanea* and *Platanus* among extant genera, in the case of south-eastern Canada these genera are *Comptonia, Carya* and *Sassafras*.

This similarity to modern taxa is clearly seen in a group of four genera of Taxodiaceae: *Sequoia, Metasequoia, Taxodium* and *Glyptostrobus*. During the Tertiary all four genera were common floristic members of the Holarctic. A climatic cataclysm of the Quaternary left different genera from this group still living in different parts of the Northern Hemisphere (Zhilin 1989 p. 285–286). But their disjunction (North America – Asia) began as early as the Pliocene.

All of them were members of the Turgayan flora in a narrow sense, that is in Kazakhstan and south of Western Siberia during the Oligocene – Early Miocene. Now oceans isolate them. For this reason, no matter how great the estimated percentage of genera common to the Turgayan flora of the past exists in any modern flora, we have no right to apply the word “Turgayan” to such a modern flora: it is only a derivative of the Turgayan flora.

But if in a modern flora we see traces of the climatic cataclysm everywhere – refugia of past Turgayan vegetation, but only in fragments: on the east of North America, in Colchis, Japan and China, it means that there should have also existed a Tertiary temperate flora (which is Turgayan in the broadest sense) during the Oligocene-Miocene of North America.

Thus, the Turgayan flora as an ecological type had existed very extensively since the Oligocene, throughout the Northern Hemisphere. It originated in Asia, most likely in Kazakhstan. A probable explanation is that Kazakhstan is much better studied and a wealth of material has been accumulated of the Kazakhstan floras, while in other places only fragments of this floristic history are known.

It is reliably established that, during the Oligocene-Miocene of Kazakhstan, plants migrated both eastwards and westwards. According to my data westward migrations were more intensive. Apparently, provincial floras which originated on routes of migration had appeared later than floras at locations of their primary formation. Therefore the later history of Turgayan ecological type flora has specific features at every location.

We should also touch upon the concept of “Arcto-Tertiary” flora. Unfortunately the term “Arcto-Tertiary” is in disrepute due to its misuse by phytogeographers of several generations. The term in its modified version can and should be applied to an Ancient Arctic flora, a flora of the Early and Middle Palaeogene, but in no case a flora of the Oligocene-Miocene. The use of Turgayan and Arcto-Tertiary floras as synonyms is erroneous (for example, Krishtofovich 1933). It may be preferable to reject the term “Arcto-Tertiary” flora.

However, history of the ancient arctic floras is very engaging and it is interwoven with the history of the Turgayan flora itself and history of the origin and migration of an initial Turgayan element.

The initial Turgayan (or temperate) element appeared in the Senonian of Kazakhstan but then with climate warming it disappeared from the Kazakhstan floras. At last, during the Palaeocene and Eocene the temperate element was practically absent in Central and Western Kazakhstan. It emerged here again at the end of the Late Eocene, but of course, it was represented by younger species of the same genera (Zhilin 1997, 1999).

It is natural to suppose that the temperate element was in some refugia, but I felt the necessity to prove its existence. It became

possible only after my visit to the Institute of Botany in Beijing in May 1998.

Investigation of the Palaeocene collection from Wu Yun (right bank of Amur River) showed traces of the temperate flora which had vanished in Kazakhstan by the Palaeocene. These are, first of all, representatives of the family Betulaceae (*Corylus, Alnus,* etc.). I call them an initial element of a future Turgayan flora (the Oligocene-Early Miocene of Kazakhstan). The Palaeocene flora of Wu Yun was previously considered to be Late Cretaceous (Tao & Xiong 1986). During our work on the collection in the Institute of Botany in Beijing we discovered not only the initial Turgayan element first recorded in the Senonian of Kazakhstan but we also found some species (for example, *Rhus turcomanica*) which hardly had been traceable earlier and which had appeared to be species native to Eocene floras of Turkmenia and Southern Kazakhstan. The collection of Wu Yun also contains a number of mesophilous monocotyledons (e.g. *Nitophyllites* and *Strelitzia*). Consideration of the composition of the Palaeocene flora of Wu Yun throws light on history of dispersal of different ecological groups during the Palaeogene. To illustrate this, xerophilous element of the Middle Eocene flora of Badkhyz (Turkmenia) existed in northeastern China at the beginning of the Palaeocene, moreover, it was present within the Wu Yun flora which was for the most part mesophilous.

History of the origin of the temperate flora in extra-tropical part of the Northern Hemisphere, which is often called “Turgayan flora”, or Turgayan Geoflora is rather complicated. The interest for this history lies primarily in the observation that a relatively homogenous (at a generic level) flora covering a vast territory (covering extra-tropical part of Northern Hemisphere) was formed during the Oligocene recognized on the basis of heterogeneous local (provincial) floras. This existed for approximately thirty millions years and today exist in numerous refugia, producing a large number of derivative floras.

Modern floras of the holarctic or the boreal Realm are obviously successors from the temperate flora of the geological past, namely of the flora which began to form in the Late Eocene – Early Oligocene.

In the paper I am not concerned with a very interesting situation with the floristic interchange between continents during the Tertiary that is described in detail by Manchester (1999). However, among my investigations I have one work (Zhilin 2000) dedicated to the links in the part of family *Rosaceae* between the Turgayan floras (end the Late Eocene – Early Miocene) and the Eocene floras of North America. I think, the continuation of investigations on fossil *Rosaceae* will be a future research area for myself.

I am very much grateful to Prof. David Dilcher for his notes on the text of this paper.

REFERENCES

CHELEBAEVA A.I. 1988. Pozdneoligotsenovaya – rannemiotsenovaya flora Kamchatki (Late Oligocene – Early Miocene flora of Kamchatka): 25–68. In: Pushcharovsky Yu.M. (ed.) Ocherki po geologii Kamchatki i Koryakskogo nagor'ya (Outline on geology of Kamchatka and Koryak Range). Nauka, Moscow. (in Russian).

IL'INSKAYA I.A., PNEVA G.P. & SCHVAREVA N.Ya. 1976. Flora Mamontovoy Gory po otpechatkam list'ev (The Mamontova Gora flora through leaf impressions). Trudy Instituta geologii i geofiziki Sibirskovo otdeleniya Akademii Nauk SSSR (Trans. Inst. Geol. Geophys. Siberian Branch Acad. Sci. USSR), 233: 66–130. (in Russian).

KRISHTOFOVICH A.N. 1928. Grenlandskaya tretichnaya flora na Severnom Urale i botaniko-geograficheskie provintsii tretichnovo perioda (Greenlandian Tertiary flora on the North Ural and botanical geographical provinces of the Tertiary time). Priroda, 5: 499–502. (in Russian).

KRISHTOFOVICH A.N. 1929a. Evolution of the Tertiary flora in Asia. New Phytol., 28(4): 303–312.

KRISHTOFOVICH A.N. 1929b. Principal features of evolution of the flora in Asia in the Tertiary period. Proc. 4th Pacific Sci. Congr. Java, 1929. Batavia: 253–263.

KRISHTOFOVICH A.N. 1933. Angarskaya svita. Baikail'skii otdel (summary: Baikal Formation of the Angara Group). Trudy Vsesoyuznovo Geologo-Razvedochnovo Ob'edineniya NKPT SSSR (Transactions of the United Geological and Prospecting Service of U.S.S.R.), 326: 1–136.

KRISHTOFOVICH A.N. 1955. Razvitie botaniko-geograficheskikh oblastei severnovo polushariya s nachala tretichnovo perioda (Development of botanical geographical regions of Northern Hemisphere from the beginning of Tertiary). Voprosy geologii Azii (Problems of Asian geology), 2: 825–844. (in Russian).

KRISHTOFOVICH A.N., PALIBIN I.V., SHAPARENKO K.K., YARMOLENKO A.V., BAYKOVSKAYA T.N., GRUBOV V.I. & IL'INSKAYA I.A. 1956. Oligotsenovaya flora gory Ashutas v Kazakhstane (Oligocene flora of Ashutas Mount in Kazakhstan). Bot. Inst. Komarova Akad. Nauk SSSR,

Trudy, ser. 8, Palaeobotanica, 1: 1–241. (in Russian).

KVAČEK Z. 1996a. Are the Turgayan floras homogenous? The 5th Quadrennial Conference of the International Organisation of Palaeobotany, University of California, Santa Barbara, 1996. Abstracts: 56.

KVAČEK Z. 1996b. Are the Turgayan floras homogenous? Chtenya pamyati Vsevoloda Andreevicha Vakhrameeva. Sbornik tezisov i dokladov. 13–14 noyabrya 1996 g. (Memorial Conference dedicated to Vsevolod Andreevich Vakhrameev, November 13–14, 1996, Moscow). Abstract and Proceedings: 29–33.

MAKULBEKOV N.M. 1972. Eotsenovaya flora Severnovo Kazakhstana (Eocene flora of the North Kazakhstan). Alma–Ata. (in Russian).

MAKULBEKOV N.M. 1997. Paleotsenovye i eotsenovye flory Tsentral'noy Evrazii (Palaeocene and Eocene floras of Central Eurasia). PhD Theses, Abstract. (in Russian).

MANCHESTER S.R. 1999. Biogeographical relationships of North American Tertiary floras. Ann. Missouri Bot. Gard., 86: 472–522.

NEGRU A.G. 1986. Meoticheskaya flora severo-zapadnovo Prichernomor'ya (Meotian flora of North-Western Black Sea Region). Kishinev. (in Russian).

NIKITIN V.P. 1976. Flora Mamontovoy Gory po semenam i plodam (Seeds and fruits in paleoflora of the Mamontova Gora). Trans. Inst. Geol. Geophys. Siberian Branch Acad. Sci. USSR. Moscow, 233: 131–194. (in Russian).

TAO J. & XIONG X. 1986. The Latest Cretaceous flora of Heilongjiang Province and the floristic relationship between East Asia and North America. Acta Phytotaxon. Sinica, 24(1,2): 1–15, 121–135.

ZHILIN S.G. 1974. Tretichnye flory Ust'yurta (The Tertiary floras of the Plateau Ustjurt (Transcaspia)). Nauka, Leningrad. (in Russian).

ZHILIN S.G. 1989. History of the development of the temperate forest flora in Kazakhstan, U.S.S.R. from the Oligocene to the Early Miocene. Bot. Rev., 55(4): 205–330.

ZHILIN S.G. 1997. K istorii predstavleniy o turgayskoy flore (summary: On the history of idea of the "Turgayan flora"). Toporkovskiye chteniya (Toporkov Lecture Series, Rudny, Kazakhstan), 3: 209–215, 272–273. (in Russian).

ZHILIN S.G. 1999. Struktura turgayskoy flory v oligotsene i miotsene Kazakhstana (summary: Structure of the Turgayan flora in Kazakhstan (Oligocene and Miocene)). Toporkovskiye chteniya (Toporkov Lecture Series, Rudny, Kazakhstan), 4: 458–466. (in Russian).

ZHILIN S.G. 2000. Links in the family Rosaceae between the floras of North America and Central Asia during the Eocene–Miocene. The 6th Conference of International Organization of Palaeobotany, July 31 August 3, 2000, Qinhuangdao, China. Abstracts: 156–157.