Journal of Palaeogeography, 2025, 14(3): 100244

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Research article

# The Lower Miocene Askazansor Formation in Central Kazakhstan: Paleontological characteristics, biostratigraphy and paleogeographical conditions

*Saida Nigmatova* *, *Bolat Bayshashov*, *Ilnura Madiyarova*, *Arman Seidali*, *Balzhan Kalibek*

*K.I. Satpayev Institute of Geological Sciences, Laboratory of Mesozoic and Cenozoic Geology, Kazakh National Research Technical University, 69 Kabanbai Batyr St., Almaty, 050010, Republic of Kazakhstan*

**Abstract** This manuscript provides valuable insight into the geological evolution of Central Kazakhstan during the Cenozoic and serves as a key tool for understanding the paleogeographic evolution of the surrounding regions. Based on the literature and the results of our own research, data on the Oligocene-Early Miocene fauna of the Askazansor site, located in the southern part of Central Kazakhstan, were analyzed and summarized. The stratigraphy was examined, the history of the research was studied, and an attempt was made to synchronize the paleofauna with other localities in Kazakhstan and Eurasia. The article presents descriptions of bone remains of previously unknown equids from here. The age of the deposits is considered to be the Early Miocene. Based on the study of mammals and the lithofacial analysis of sediments, conclusions were drawn about the paleoecological situation of this time.

**Keywords** Central Kazakhstan, Askazansor, Cenozoic, Miocene, Paleofauna, Paleoclimate, Biostratigraphy



Received 13 March 2024; revised 30 June 2024; accepted 26 November 2024; available online 15 March 2025

## 1. Introduction

Issues of improving the stratigraphic charts of the Cenozoic of Kazakhstan do not lose their relevance. Continental strata require special studies, which, unlike marine sediments, often do not preserve sufficiently reliable and abundant materials for a biostratigraphic substantiation of the age of sediments. In this regard, the study of each locality of fossil flora and fauna of the Cenozoic becomes of great importance.

The diversity of Cenozoic continental environments is clearly represented in the territory of Central

* Corresponding author.
E-mail address: nigmatova@mail.ru (S. Nigmatova).

Peer review under responsibility of China University of Petroleum (Beijing).
https://doi.org/10.1016/j.jop.2024.09.005

Kazakhstan, and the rich paleontological materials deposited in this area allow to establish the age of these deposits according to biostratigraphic analyses and to conduct the reconstruction of paleogeographical environment.

The purpose of our research is to discuss the climate change and geological environment during the Paleogene and Neogene of Central Kazakhstan based on the study of fossil fauna. The development of the organic world is determined by many factors, among which the climate stands out. The climate changes in the geological history of the planet actively influenced the development of marine fauna and were less pronounced in the deep continental areas of the Earth. We can definitely recognize the relative synchronicity in the development of terrestrial and aquatic faunas and floras, if they were influenced by the climate change directly or indirectly through the evolution of ecosystems.

The importance of this work is reinforced by the fact that over the past 25 years, the study of the Cenozoic deposits of Kazakhstan has not received due attention, and the analysis of new data combined with old data allows obtaining new materials for improving the research on stratigraphy and paleobiogeography of the region.

## 2. Materials and methods

Based on numerous paleontological materials obtained in the mid-20$^{th}$ century, the large scale of paleontological material collections by Bolat Bayshashov (Bayshashov B.) in year 2001, and the repeated collection work in years 2022—2023, resulted in obtaining of the most complete materials on the fauna of the Askazansor site.

Paleontological materials collected over different years are stored in the Institute of Zoology at the Ministry of Education and Science of the Republic of Kazakhstan, and the most important specimens, skeleton of *Borissiakia betpakdalensis* (Flerov), 1938 and other finds, are kept in the Paleontological Museum named after Orlov Yu.A. in Moscow, Russia.

For paleontological study, the taxonomic affiliation of the materials was determined by measuring bone remains and comparing distinctive features with previously described reference samples. Dental abbreviations: i/I, lower/upper incisor p/P, lower/upper premolar; m/M, lower/upper molar.

Based on adaptive characteristics and features, the landscape and climatic conditions of their habitat were reconstructed. Paleoclimatic findings will be proposed for use in the search for minerals in practical geology.

As a method, we can recommend the routing of the 2022 field studies with layer-by-layer description and sampling of the reference section of Paleogene—Neogene deposits of the Aryskum—Betpakdala district for studying the sections of the Askazansor and Betpakdala formations.

## 3. Results

Within the Betpakdala district of the southern part of Central Kazakhstan, three reference sections, Kyzylkiya, Kyzylkak, and Askazansor sections, which are abundantly saturated with organic remains, have been studied. They correlate and complement each other well, and represent, in essence, a “single” section of Paleogene and Neogene deposits.

The most complete section of Paleogene deposits is presented along the Kyzylkiya ridge, where an interlayer of 0.5 m—0.8 m thick containing light-gray and greenish fine-grained sandstones, lies on the eroded surface of a layer of greenish-gray clay sediments of the marine Eocene, with interlayers of greenish-gray plastic clays of the base of the Betpakdala Formation.

Above that, where lies a layer consisting of brick-red and red-brown clays and highly dense lumpy sandy carbonate sediments with inclusions of calcareous lime nodules and gypsum crystals. Similar clays are widespread within the region under consideration. They completely represent the section of the Kyzylkak depression, the middle part of which is associated with the burial of vertebrate fauna. The thickness of the clayey section of the Betpakdala Formation is 15 m.

The section is crowned by a pack of reddish-brown variegated clays with light gray spots and stains, and contains brownish-green and green lumpy carbonate with interlayers of siltstone on carbonate—clay cement. The thickness of this part is 6 m. The bone-bearing horizon at the Kyzylkak locality is represented by light clayey sands enclosed between a layer of cemented pebbles (at the top) and dense gypsum-bearing clays of the middle slope ledge (at a height of 8 m—10 m above the bottom of the depression).

Here this study collected and identified: the rare scattered fish vertebrae — *Esox aralensis* Sytch.; turtle scutes — *Ocadia turgaica* Kuzn. & Ckhikv., *Trionyx ninae* Ckhikv., *Planiplastron tatarinovi* Ckhikv.; remains of birds — Podicipediformes, *Aquilavus* sp., Gruidae, Ottidae; teeth and bones of mammals — *Tsaganomys altaicus* Matth. & Grang., *Woodomys chelkaris* Shev., *Cricetops dormitor* Matth. & Grang., *Cricetops aenus*, *Eomys* sp., *Karakaromys arcanus* (*K. chelkaris*), *Eoemys deploratus* Shev., *Prosciurus arboraptus* Shev., *Parasmintus parvulus* Bohlin., *Eucricetodon caducus* Shev., *Terraboreus arcanus* Shev., *Plesiosminthus quartus* Shev., *Pseudocylindrodon piruzae* Benduk., *Capalanca kazakhstanicus*, *Ansomys arboraptus*, *Propaleocastor kazachstanicus* BorisogL, *Steneofiber* (-*Agnotocastor*) *aubekerovi Lytsch.*, *Hyaenodon aymardi FiL*, *Schizotherium turgaicum Borissiak*, *Paraceratherium* (-*Indricotherium*) *transouralicum* PavL, *Ardynia kazachstanica* (Grom.), *Allocerops* sp., and *Entelodon* sp., especially *Lophiomeryx turgaicus Her.* Shevyreva (1976) noted the discovery of Eomys teeth in Karakoin and Kyzyl-Kak, which are indicated for the upper level of the San Jacques site in Central Asia in the end of the Early Oligocene.

The fossil fauna was found in the deposits of the Askazansor site. The deposits of the Askazansor Formation named after the Askazansor salt marsh were deeply eroded on the Betpakdala Formation, and are composed mainly of inequigranular quartz and polymict sands with gravel and small pebbles, colored by iron hydroxides in ocher-yellow and reddish-brown colors. In places, the section is dominated by fine-grained micaceous sands, silts and clays variegated in gray—green, bright green, blue, ocher-yellow, pink and brown colors; and siliceous—ferruginous solutions in places cemented the clastic material with strong cement to sandstones and reddish-black conglomerates. The thickness varies widely from 15 m—20 m (visible part) to 70 m—80 m (as per borehole data).

During the Late Paleogene and Early Neogene, lakes became widespread in low areas of Central Kazakhstan. Gypsum-bearing clays, marls, and siltstones were deposited there; salts of halite, glauberite, mirabilite, and thenardite accumulated in some lakes.

Bone remains are often cemented with siliceous—ferruginous strong cement; in places the section is dominated by fine-grained micaceous sands, silts, and mottled clays. Sediments of the Askazansor Formation are well exposed throughout the ridge. The main accumulation of vertebrate remains is located on the southern shore of the large Askazansor salt marsh (>150 $m^2$). There are especially large accumulations of bones in the middle part of the ridge at the southern end of this salt marsh. Here, the side of the hill is cut by high narrow ravines, separating an almost isolated round height of about 0.25 ha; its top is made of sandstone, which protects the underlying layers from being blown away by the wind, and in the middle there is a layer of cemented yellow gravel. There and apparently above, is the bulk of the well-preserved bones.

### *3.1. A brief history of the research of the Askazansor paleofauna*

The Askazansor site was discovered in 1929 by Yakovlev D.M. (Central Geological Institute for Exploration and Research, Russian Ministry of Geology, Moscow). The site is located in the Betpakdala desert, 150 km north of the village Suzak, on the southern shore of the Askazansor salt marsh. In 1934, here, the bones were collected by Selevin V.A. (Betpakdala complex expedition of the Central Asian State University, Tashkent), and the first major excavations were carried out in 1936 by employees of the Paleontological Institute (Moscow) under the leadership of Orlova Yu.A. The next field works of the scale were carried out here in 1958—1959 by employees of the paleobiology laboratory of the Institute of Zoology (Almaty, Kazakhstan). In addition, in different years, small expeditions were carried out here by geologists and paleontologists.

The site is distinguished by the abundance of chalicotheri bones. Based on materials of Yakovlev D.M. and Selevin V.A., the first remains of chalicotheri were described by Flerov K.K. in 1938 as *Moropus betpakdalensis* Flerov (1938). *Hemimeryx, Brachyodus, Aceratherium, Indricotherium* have also been identified. According to collections by Orlov Yu.A. in 1941, rhinoceroses (*Ceratotherium tagicus*, *Brachypotherium* sp.), artiodactyls (*Hemimeryx, Antracotherium*), predators (Amphicyon, Machairodontinae) were identified here.

The bones of a large equid animal, chalicotheri, were studied in detail and redefined by Borissiak A.A (Borissiak, 1940, 1946). as *Phyllotillon betpakdalensis* (*Flerov*) Borissiak (1938). In 1965, Butler P.M. assigned it to a new genus *Borissiakia* Butler, 1965; Butler (1965). In addition, a new species of pig-like *Conohyus* was described here as *betpakdalensis* (Trofimov, 1949). Nikiforova K.I. described the bone-bearing deposits at this site as the Askazansor Formation (Nikiforova, 1960).

The age of the deposits was determined to be Upper Oligocene (Flerov and Yanovskaya, 1971; Kostenko *et al.*, 1977) and Lower Miocene (Trofimov, 1949; Devyatkin, 1981).

In 2001, as a result of excavations guided by Bayshashov B (Bayshashov *et al.*, 2002), rich lens with bones of ancient vertebrates were discovered on the western slope of the elevation of the Askazansor site (45°05′66″N; 68°02′25″E) (Figs. 1—3).

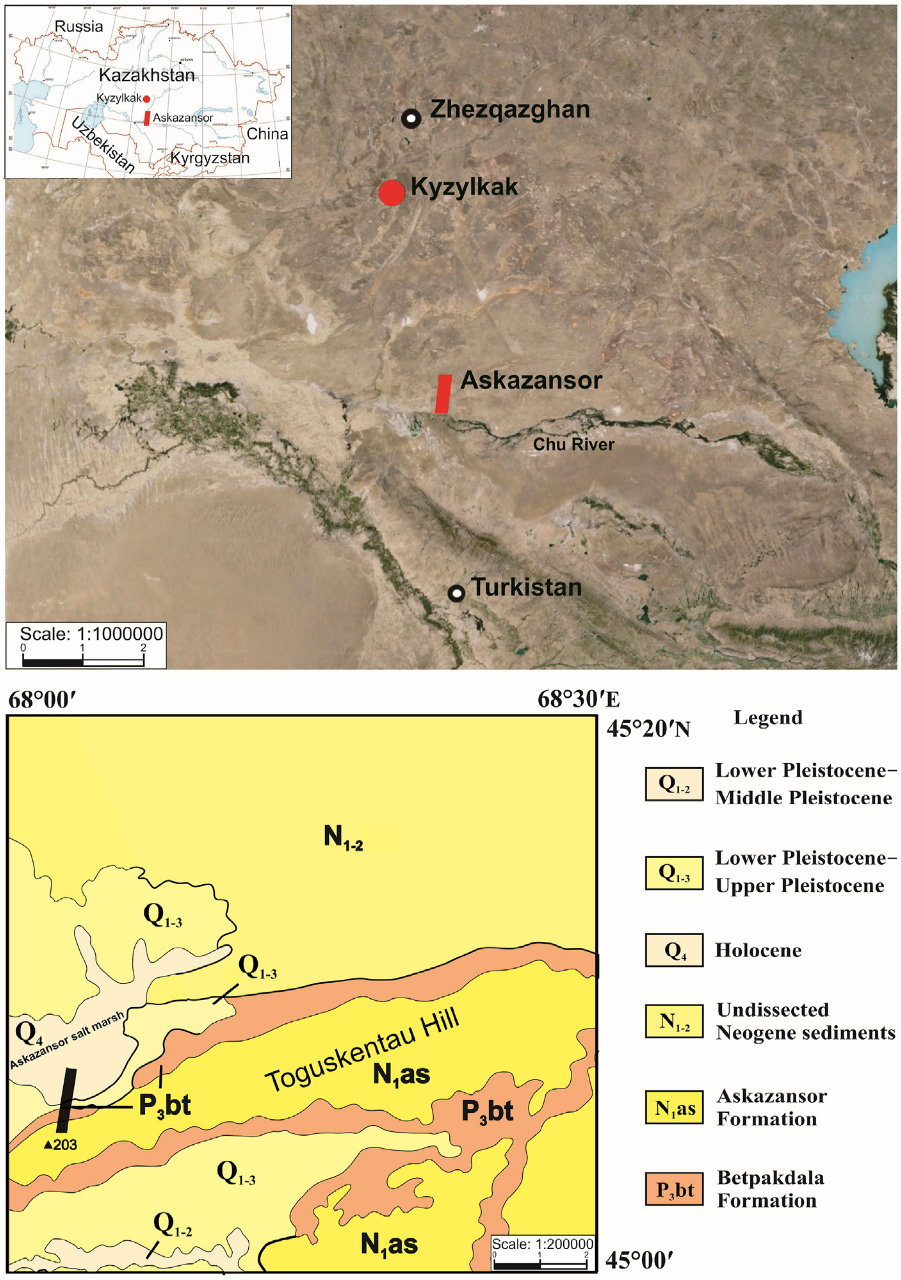


**Fig. 1** Overview and geological map of the Askazansor section in Central Kazakhstan.

### *3.2. Analysis and description of the fauna*

The general composition of the Askazansor fauna is currently represented by: 1) Reptilia, such as *Clemmys kazachstanica*, *Melanochelys kazachstanica* (Khoz.), *Melanochelys betpakdalensis* (Khoz.); 2) Carnivora, such as *Amphicyon* sp., *Machairodus* sp.; 3) Perissodactyla, such as *Borissiakia* (*Phyllotillon*) *betpakdalensis* (Flerov), 1938 (Fig. 4), *Protaceratherium betpakdalense* (Borissiak), 1938 (= *Dicerorhinus tagicus* var. *betpakdalensis* Borissiak, 1938), *Protaceratherium cf. kazakhstanensis* Bayshashov (1989), *Diaceratherium askazansorense* (Beliajeva), 1964 (= *Brachipotherium* sp.), *Aprotodon ayakozensis* Bayshashov (2001) (= *Aceratherium aralense*), *Dicerorhinus minutus*; 4) Artiodactyla, such as *Conohyus betpakdalensis* (Trofimov, 1949), *Hemimeryx turgaicus*, *Antracotherium*, *Brachyodus*, *Lophiomeryx turgaicus*, *Prodremotherium* sp.; 5) Lagomorpha, such as *Sinolagomys cf. minor*; 6) Rodentia, such as Tachyoryctoididae Indet (Bayshashov *et al.*, 2002).

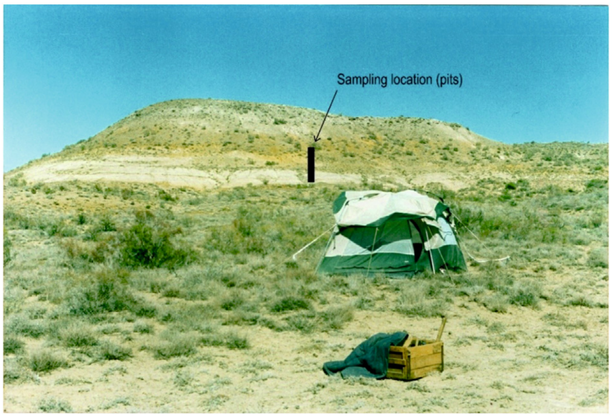


**Fig. 2** Outcrop photograph for showing the western side of the Askazansor site in Central Kazakhstan (photo by Bayshashov B. in 2001).

**Fig. 3** Excavations at the Askazansor site in Central Kazakhstan (photo by Bayshashov B., the central figure on the picture, 2001).

**Fig. 4** Skeleton of the chalicotheri *Borissiakia* (*Phyllotillon*) *betpakdalensis* (Flerov), 1938, presented at the Orlov Yu.A. Paleontological Museum in Moscow, Russia.

Below are descriptions of some equid bones first identified at the Askazansor site in Central Kazakhstan.

### *3.2.1.* Protaceratherium cf. kazakhstanensis *(Figs. 5 and 6)*

**Family**: Rhinocerotidae Owen, 1845.

**Subfamily**: Menoceratina e Prothero, Manning, Hanson, 1986.

**Genus**: *Protaceratherium* Abel, 1910;

*Protaceratherium kazakhstanensis* Bayshashov (1989).

**Material**: The material from the collections of the Institute of Zoology at the Ministry of Education and Science of the Republic of Kazakhstan, Askazansor site, Kazakhstan; Lower Miocene, Askazansor Formation (Figs. 5 and 6). No. Ac-01/552 — Upper incisor (I/1); No. Ac-01/553 — Upper molar (M/1); No. Ac-01/554 — Upper milk tooth (DP/4); No. Ac-01/555 — Fragment of the lower jaw with teeth (P/3—P/4).

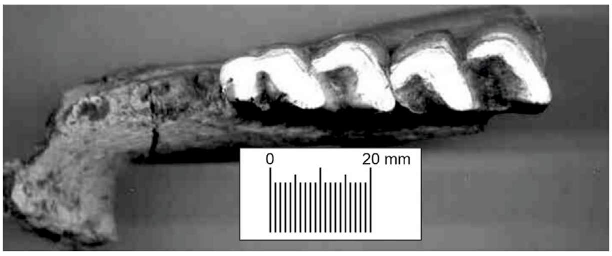


**Fig. 5** *Protaceratherium cf. kazakhstanensis*, No. Ac-01/555, fragment of the lower jaw with teeth (P/3—P/4) (view with chewing surface).

**Description**: Fragment of the anterior part of the lower jaw with teeth (P/3—P/4). The symphyseal section is narrow, the horizontal branch is not high. The height in front of P/2 is 34 mm, also in the rear of P/4 is 48 mm, thickness there is 18 mm. P/1 and P/2 are broken off, only roots preserved. R/3: The tooth is long, there is a small valley in front of the paraconid. The paraconid at the lingual end does not narrow and

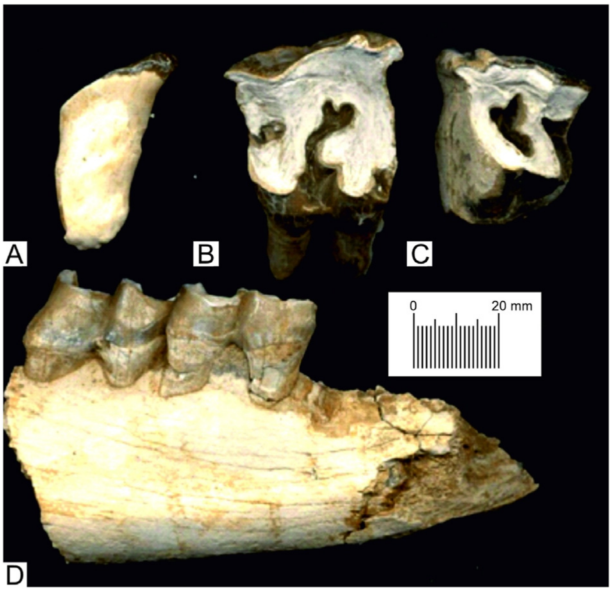


**Fig. 6** *Protaceratherium cf. kazakhstanensis* Bayshashov (1989), Askazansor site, Central Kazakhstan, Lower Miocene: A — No. Ac-01/552 — Upper incisor (I/1); B – No. Ac-01/553 — Upper molar (M/1); C – No. Ac-01/554 — Upper milk tooth (DP/4); D — No. Ac-01/555 — Fragment of the lower jaw with teeth (P/3—P/4).

reaches the inner edge of the tooth. The anterior internal valley (antesinus) is narrow. The metaconid is wide, lingually extended posteriorly. The hypoconid is narrow in front and adjoins the posterior wall of the metaconid in the middle part. The posterior internal valley (postsinus) is wide and triangular in shape. The lingual edge of the entoconid is rounded. The length of the longest tooth is 34 mm, and its width is 15 mm. R/4: The anterior end of the paraconid is adjacent to the middle of the posterior wall of P/3 and forms a rectangle with the metaconid. The hypoconid in front is narrow, small and does not reach the posterior wall of the metaconid on the chewing surface. The inner lobes are wide. The length of the longest tooth is 32 mm, and the width is 16 mm. Upper incisor (I/1): The incisor is heavily worn, the tooth enamel is preserved only in the front part. The chewing surface is flat, oblong-elongated. The greatest width in the middle is 12 mm. The anteroposterior diameter is 31 mm. Length from the root to chewing surface is 36 mm. Upper molar (M/1): The ectoloph is not smooth, the parastyle and parastyle fold are well defined. The middle valley is lingually open. There is a small crista. The antecrochet is thick and protrudes significantly into the valley. The posterior valley is round in shape, covered at the back by a bridge. The protocone is well expressed, but the hypocone is not expressed. The length of the tooth according to the ectoloph is 42 mm. Maximum width (front) is 45 mm. Height along the ectoloph is 21 mm. The protocone and hypocone are not expressed. The lingual side of the tooth bears a solid, thick collar (cingulum). The length of the tooth according to the ectoloph is 36 mm. Upper milk tooth (DP/4): The parastyle and parastyle fold are well defined. The anterior internal valley is lingually closed by a bridge, and the posterior one is open at the back. The greatest width along the proto-lobe, without collar, is 38 mm. Height at ectoloph is 33 mm.

**Differences and comparison**: *Protaceratherium cf. kazakhstanensis* from Askazansor differs from all other species in the presence of an anterior valley in front of the paraconid on P/3. In terms of dimensions and shape of the upper incisor (I/1), it is close to similar incisors of the Upper Oligocene Zhairem location *Protaceratherium kazakhstanensis* Bayshashov (1989), but differs in smaller size and features of the internal formation of the molars (possibly some differences are due to different wear of the teeth). *Protaceratherium minutum* (Cuvier), 1822 (Ginsburg *et al.*, 1981) is distinguished by larger teeth, a well-defined parastyle and a weak collar on the molars.

### *3.2.2.* Protaceratherium betpakdalense *(Fig. 7)*

**Family**: Rhinocerotidae Owen, 1845.

**Subfamily**: Menoceratina e Prothero, Manning, Hanson, 1986.

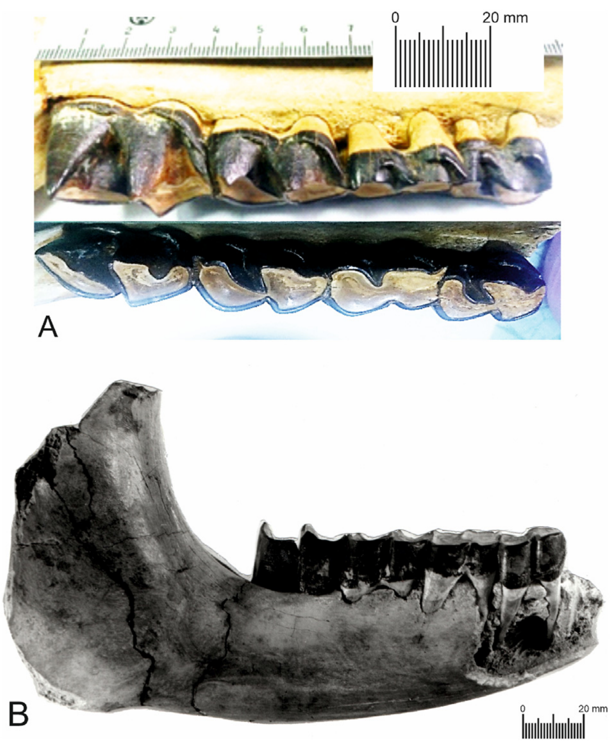


**Fig. 7** *Protaceratherium betpakdalense*, Askazansor site, South-east Betpakdala, Central Kazakhstan, Lower Miocene. **A**) View from the lingual chewing surface; **B**) View from the labial side of the jaw.

**Genus**: *Protaceratherium* Abel, 1910;

*Dicerorhinus tagicus* var. *betpakdalensis* Borissiak, 1938;

*Protaceratherium betpakdalense* (Borissiak) Bonis et al., 1997.

**Material**: The material from the Collections of the Institute of Zoology at the Ministry of Education and Science of the Republic of Kazakhstan (Almaty, Kazakhstan), Askazansor site, Southeast Betpakdala, Central Kazakhstan; Lower Miocene. No. 3905/53-Bet. — Fragment of the upper jaw with teeth (P/3—M/3); No. (Ac-58) 29/98 — Fragment of the upper jaw with teeth (R/3); No. Ac-01/556 — Fragment of the upper jaw with teeth (R/4-M/3); No. (Ac-58) 12/98 — Upper molar (M/3); No. (Ac-58) 65/98 — Fragment of the lower jaw with teeth (P/4—M/3).

**Description**: Fragment of the upper jaw with teeth (P/3) is very short, the parastyle does not stand out forward, and the parastyle fold is expressed as a barely noticeable bend. The protocone is not isolated, its anterior-internal angle is rectangular. The hypocone is more prominent lingually. The length of the tooth is 36 mm, the width is 21 mm, and the height along the ectoloph is 28 mm. R/4: The parastyle is not expressed due to the absence of a parastyle fold. The protocone is also not pronounced, but the lingual part of the protoloph is wider than that of the metaloph and is bordered in front by a low collar. The length is 27 mm, the width is 36 mm, and the height is 14 mm. M/1: Heavily erased. The parastyle is prominent labially, but the parastyle fold is not noticeable. The length is 35 mm, the width is 38 mm, and the height is 13 mm. M/2: The parastyle of M/2 is the same as that of M/1, but projects more forward. The middle valley is open lingually, and the posterior valley is also open posteriorly. The antecrochet is expressed by a small bump. The protocone and hypocone are weakly separated. The length is 45 mm, the width is 47 mm, and the height is 22 mm. M/3: M/3 is triangular in shape. The parastyle is narrow and long. The parastyle fold is not distinct. The antecrochet is not prominent, only a slight thickening is noticeable on the inner side of the protoloph. The spur on the posterior wall of the ectoloph is small and low. There is a small collar on the front wall of the tooth. The length on the lingual side of the tooth is 31 mm, the width along the protoloph is 36 mm, and the height along the ectoloph is 25 mm. The lower jaw is not high, its height in front of M/1 is 40 mm, and the height behind M/3 is 48 mm. The molars are small and relatively high. The internal valleys are small, and therefore they quickly shorten and then disappear. The outer vertical groove is deep. The paraconid is curved lingually. Antesinus tapers conically forward. In connection with this, the metaconid thickens as it wears off. The posterior wall of the entoconid is straight. The hypoconid is small as it is erased, merging with the metaconid and disappearing.

**Differences and comparison**: Rhinoceroses are small. On the anterior roots the parastyle is weakly expressed. The outer vertical grooves of the lower molars are more oblique and deeper.

### *3.2.3.* Diaceratherium askazansorense *(Figs. 8 and 9)*

**Family**: Rhinocerotidae Owen, 1845.

**Subfamily**: Rhinocerotinae Owen, 1845

**Genus**: *Diaceratherium* Dietrich, 1931;

*Brachypotherium* sp. Flerov (1938);

*Brachypotherium askazansorense* Belyaeva (1964);

*Diaceratherium* sp. Bonis et al. (1997);

*Diaceratherium* (*Brachypotherium*) *askazansorense* (Belyaeva) 1964 Kordikova (2001).

**Material:** The material from the Collections of the Institute of Zoology at the Ministry of Education and Science of the Republic of Kazakhstan, Askazansor site, Southeast Betpakdala, Central Kazakhstan; Lower Miocene. No. Ac-01/651 (holotype) — Posterior teeth (M/1—M/2); No. 1/3Ac — Fragment of the lower jaw with teeth (P/3—M/3); No. 552/Mp-61 — Lower radicals (M/2—M/3).

**Description:** M/1: The antesinus is small, visible as a fold, so the paraconid is not expressed. Postsinus is extended to the middle of the tooth. Tooth length is


**Fig. 8** *Diaceratherium askazansorense* (Belyaeva), 1964, No. Ac-01/651 (holotype), posterior teeth, M/1—M/2, Askazansor site, Southeast Betpakdala, Central Kazakhstan.


**Fig. 9** *Diaceratherium askazansorense* (Belyaeva), 1964, No. 1/3Ac, fragment of the lower jaw with teeth, P/3—M/3, Askazansor site, Southeast Betpakdala, Central Kazakhstan. **A)** View from the lateral side; **B**) View from the chewing surface of the teeth.

37 mm, width is 24 mm. M/2: The antesinus is small, and the postsinus is extended by 2/3 of the width of the tooth. The outer vertical groove, as on M/1, is well defined. Tooth length is 40 mm, width is 27 mm. The mandibular branch is high and thick. The lower edges of the ramus from the symphysis to the maxillary angle are noticeably rounded. The posterior edges of the symphyseal notch are located at the level of the anterior part of P/3. Jaw height in front of P/2 is 59 mm, in front of M/1 is 87 mm, and in back of M/3 is 107 mm. The teeth on the jaw are much worn. The anterior internal valley, with the exception of M/3, is absent (erased). On isolated, slightly worn teeth, it is clear that the anterior-internal valley on the molars is small and narrow. As they are erased, they quickly disappear. Although the posterior valley is wide and deep, its inner wall is cone-shaped, which also quickly decreases when abraded. The outer vertical valley on unworn teeth is well defined.

**Differences and comparison**: In terms of the structure and expression of the lower molars, the described tooth is almost completely similar to the known *Diaceratherium aurelianense* of Europe (Ginsburg *et al.*, 1981; Cerdeno, 1993). The differences include the fact that rhinoceroses are relatively small in size, the external vertical groove is deep, the antesinus is much smaller than the postsinus, and on M/1, the external vertical groove and the small size of the teeth are almost not expressed. Perhaps these features make the Askazansor species an earlier stage of evolutionary development.

### *3.2.4.* Aprotodon ayakozensis *(Fig. 10)*

**Family**: Rhinocerotidae Owen, 1845.
**Subfamily**: Rhinocerotinae Owen, 1845.
**Genus**: *Aprotodon* Forster Cooper, 1915.
*Chilotherium cf. schlosseri* Vorobeychik (1958).
*Aceratherium aralense* Kochenov (1983).
*Plesiaceratherim commune* Kordikova (2001).
*Aprotodon ayakozensis* Bayshashov (2001).

**Material:** The material from the Collections of the Institute of Zoology at the Ministry of Education and Science of the Republic of Kazakhstan, Askazansor site, Southeast Betpakdala, Central Kazakhstan; Lower Miocene. No. (Ac-58) 3/98 (cutter) — Upper incisor (I/2); No. (Ac-58) 8/98 — Upper premolar (P/4) (Kochenov, 1983); No. 543/Mp-61 — Upper molar (M/1); No. 1/99-Ac — Upper molar (M/3).

**Description:** The incisor is short, sharply narrows towards the end and has a triangular outline. The cutting surface is somewhat concave in the middle, and slightly curved upward and inward at the end. The inner edges of the incisor are strongly pointed, the

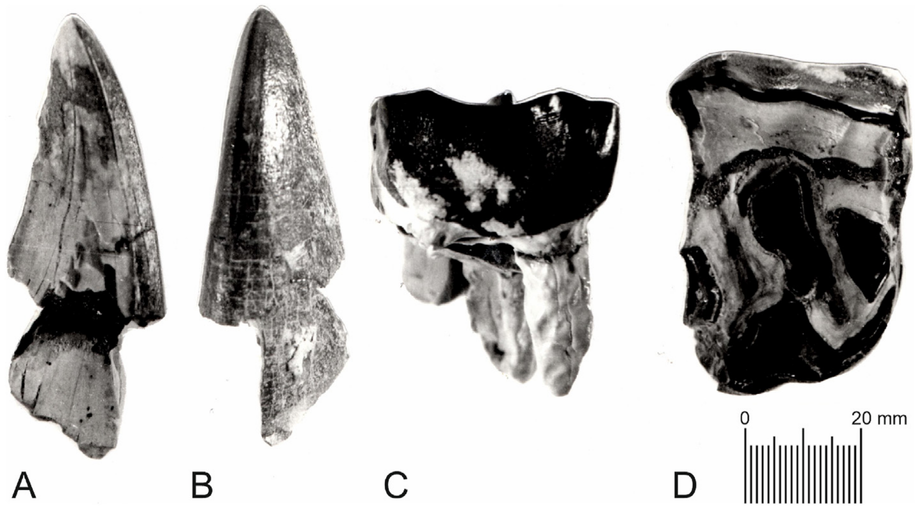


**Fig. 10** *Aprotodon ayakozensis*. **A**—**B**) Incisor; **C**) Upper molar from the side view; **D**) Upper molar from the chewing surface view.

outer edges are rectangular at the end up to 25 mm, and then rounded towards the base. The length of the cutting part of the incisor is about 55 mm, its width closer to the base is 26 mm, and it is pointed at the end. The outer wall of the cutter is vertical. The lower corner, shifted to the outer edge from an acute angle (in front) passes to a rounded one at the back. P/4: The parastyle and parastyle fold are very weak. The protocone is large, but the hypocone is not isolated. The middle and posterior valleys are closed. Apparently, they can be open, respectively lingually and posteriorly, only on unworn teeth. The depression between the protocone and hypocone is covered lingually by the collar. The length is 42 mm, the width is 59 mm, and the height is 23 mm. The posterior roots are weakly worn out and probably not completely erupted. A collar borders the anterior and lingual sides of the teeth. M/1: The parastyle is narrow and long. The parastyle fold is deep and has a sharply projecting ridge behind it. The crochet is small; the antecrochet becomes more prominent as it wears off, and it is located closer to the lingual end of the protoloph. The protocone is also more isolated with greater tooth wear. The anterior and posterior valleys are wide and deep, respectively, and open lingually towards the posterior side. Due to the thickened lower part, the width of the teeth in protolophus on heavily tooth wear becomes wider than in metalophus. The length is 42 mm, the width along the protoloph on the chewing surface is 26 mm, and the width at the base of the tooth is 50 mm. According to the metaloph, the length is 45 mm and the width is 25 mm. According to the ectoloph, the height is 47 mm. M/3: The parastyle does not project forward much. The tubercle of the parastyle fold has the same size as the parastyle. The protocone is isolated, and the hypocone is not developed. Antecrochet stands out when the tooth is severely worn, and with a very small crumble and slight abrasion, the set disappears. The talonid, on the posterior wall of the ectoloph, is wide and triangular in shape. The length along the lingual side of the tooth is 46 mm, the width along the chewing surface is 32 mm, and the width at the base of the tooth is 55 mm. The height is 43 mm.

**Differences and comparison**: The short, cutting part of the incisor and its symmetrically triangular outline, unlike *Aprotodon smith-woodwardi* (Cooper), 1915 and *Aprotodon borissiaki* (Belyaeva, 1954; Bayshashov, 1994), show similarities with *Aprotodon ayakozensis* (Bayshashov, 2001). It is also distinguished by the larger size of the molars, better defined internal valleys and a well-separated protocone.

Thus, a thorough study of vertebrate remains from the Askazansor site shows the presence of four species of rhinoceros, two of them belonging to Protaceratherium. One species of the rhinoceros here is larger and significantly different from the previously known species of the genus. This form is close to the Late Oligocene Kazakhstan species of *Protaceratherium cf. kazakhstanensis*, described previously from the Upper Oligocene deposits of the Zhairem locality (Bayshashov, 1989). One species of the rhinoceros is smaller in size and similar to that described by Borissiak A.A. as *Dicerorhinus tagicus* var. *betpakdalensis* Borissiak (1938) and later classified as a member of the genus Protaceratherium with the species name of *Protaceratherium betpakdalense* (Bonis et al., 1997). Another species of the rhinoceros, medium in size, is not much different in dental characteristics from *Diaceratherium (Brachypotherium) askazansorense*. It was previously described as *Brachypotherium* sp. (Flerov, 1938), then Belyaeva (1964) listed the fauna as a new species *Brachypotherium askazansorense*, later it was carried to *Diaceratherium* sp. (Bonis et al., 1997) and *Diaceratherium askazansorense* sp. nov (Kordikova, 2001). Also, bones of a larger and more peculiar rhinoceros were found here than other forms known from here. It was previously described as *Aceratherium aralense* (Kochenov, 1983) and *Plesiaceratherium commune* n. sp. (Kordikova, 2001). A study of the materials in the collections shows that it belongs to *Aprotodon ayakozensis* described from the same locality of Ayakoz, northeast of Betpakdala (Bayshashov, 2001).

### 3.3. Ecology of fossil fauna

Based on the morphofunctional characteristics of the animals found here, it can be judged that their main habitat was the coastal areas of numerous rivers and lakes remained after the retreat of the sea basin. These were predominantly floodplain forests with abundance of shrubs and low trees.

The structure of the skeleton and teeth of *Chalicotherium—Borissiakia* indicates that their main foods were leaves of woody plants, young shoots and possibly tree bark. Long front legs with elongated claws might be used for bending branches and stripping tree bark.

Of the rhinoceroses, *Protaceratherium* with weakly molarized teeth were probably fed mainly on woody foods in the form of shrubs. *Aprotodon*, with a scoop-shaped symphyseal part of the lower jaw and elongated incisive fangs, adapted to being fed on aquatic plants, like the *Chilotherium*.

## 4. Biostratigraphic discussions

The area under consideration covers most of the southern, rather gentle and stepped slope of the Kazakh Shield and the elevated Betpakdala Plateau. The structural position of the area and the repeated occurrence of neotectonic movements determined the lithological—facies features of the continental formations and their erosion in most of the studied territory. They were preserved only in troughs, in relief depressions and in areas of ancient valleys.

The analysis of the vertebrate fauna from these burial areas indicates proximity to the Akespe fauna in northern Aral region, confined to the lower Aral Formation. The complexes of these burials overwhelmingly consist of genera known from deposits of the Late Oligocene—Early Miocene.

The age of the Askazansor fauna earlier was considered by various researchers to be Late Oligocene—Early Miocene based on its comparison with a number of similar forms such as the Late Oligocene fauna of Benara from Georgia and the Late Oligocene—Early Miocene fauna of the northern Aral region from Akespe.

Considering the stratigraphic distribution of taxa of the Askazansor fauna, it should be noted that at the genus level, some of them rooted in the Oligocene, had a wide time interval of distribution: *Protaceratherium* was known in the Oligocene—Miocene of Western Europe; *Amphicyon* was from the Upper Oligocene to the Lower Pliocene.

The presence of the most abundant species *Borissiakia betpakdalensis* fauna of Askazansor could be compared with the fauna of the Harrison beds of North America (Coombs and Coombs, 1997; Coombs, 2009), also with the predominant presence of remains of Early Miocene *Moropus*. Therefore, this fauna was known as the phylotilon complex (Bazhanov, Kostenko, 1964). The main accumulation of vertebrate remains was associated with coarse-grained ferruginous sandstone, from which new materials were collected with a predominance of remains of *Borissakia betpakdalensis* Boris., *Diaceratherium*, and *Protaceratherium*.

Bonis et al. (1997) identified two bone-bearing horizons in the Askazansor Formation: 1) the lower bone-bearing horizon, named Boktykaryn, was established on the left bank of the river Boktykaryn, from which identified the chalicotheri forms of Chalicotheriidae indet., *Chrysemys cf. lavrovi* Kuzn. & Ckhikv., *Indricotherium cf. transouralicum* Pavl., *Ocadia cf. turgaica* Kuzn. & Ckhikv., *Paraceratherium* sp., Pisces indet., Rhinocerotoidea indet., Rodentia indet., *Schizotherium cf. turgaicum*, Testudinidae indet., Tragulidae indet., and *Ulutrionyx cf. turgaicus* Kuzn. & Ckhikv. Based on the presence of chalicotheri forms of turtles, rhinoceroses, tragulids and their comparison with the known Oligocene forms, the age of the lower bone-bearing horizon was determined to be the Late Oligocene; 2) the upper bone-bearing horizon, which was isolated from the upper Askazansor Formation in the southern part of the Askazansor salt lake, consisted of Aceratheriini indet., Antracotheriidae indet., *Borissiakia betpakdalensis* (Boris.), *Brachyodus trofimovi* Bonis, *Brachypotherium* sp., Carnivora indet., Cervoidea indet., *Diaceratherium* sp., *Melanochelys betpakdalensis* (Choz.), *Melanochelys kazachstanica* (Khoz.), Menoceratini indet., *Mesaceratherium* sp., *Protaceratherium betpakdalensis* (Boris.), Teleoceratini indet., and *Ysengrinia* sp., and *Borissiakia betpakdalensis* (Boris.) made up most of the finds.

Since the sediments of the Askazansor Formation with deep erosion overlay the sediments of the Betpakdala Formation, the composition of Late Oligocene vertebrates could be assumed and identified by these sediments on the River Boktykaryn, the lower bone-bearing horizon, most likely came from the lower part of the Askazansor Formation, corresponding to the Paleogene mammal zones of MP 28—30. Vertebrates of the Askazansor Formation by Mein zone (MN) occupied intervals from MN 1 to MN 8 and mainly correspond to MN 3—5 (burdigal) (Fig. 11), including the *Protaceratherium* in MN 1—4, *Diaceratherium* in MN 1—4, *Aprotodon* in MN 1—4, *Brachyodus* in MN 3—4, *Conohyus* in MN 5—8, as well as *Amphicyon* in MN 1—10.

The previous studies by Flerov (1938) and Orlov (1941) suggested that the fauna of the Askazansor Formation was "mixed", and the remains of *Indricotherium* came from the sediments underlying the Askazansor Formation. In this case, we can assume most likely that the remains of bone finds from the lower and upper parts of the Askazansor Formation were mixed.

Remains of *Sinolagomys*, including *Sinolagomys cf. gracilis* (Shokysu, Akotau, Zhilansai, Sayaken) and *Sinolagomys cf. kansuensis* (second pack Sayaken), were known from the Early Miocene localities of the Northern Aral Sea region and are close in age to Askazansor (Bendukidze, 1993). Directly the residues of *Sinolagomys cf. minor* were described from the Early Miocene deposits Ayakoz (Erbaeva, 1982). Remains of Tachyoryctoididae both in Kazakhstan and in China were characteristic of the Lower Miocene layers (Vorontsov, 1963; Li and Qiu, 1980; Bendukidze, 1993). Thus, according to the biochronological zones of Mein, most of the species identified from here corresponded to the Early Miocene. This opinion is confirmed by the absence of bones of giant rhinoceroses, widespread in the Oligocene of this region.

## 5. Paleogeography

At the beginning of the Cenozoic, the northern water bodies of the Tethys Ocean occupied the majority of the territory of Kazakhstan. During the first half of the Cenozoic, the sea basin in question underwent a significant and repeated regression, gradually retreating in a westward direction. The freed lands


**Fig. 11** Stratigraphic section of the Paleogene and Neogene sediments of the Askazansor, northern slope of Toguzken. The mammal zone is a series of fossil mammalian assemblages from single localities placed in chronological sequence on the basis of stage-in-evolution, entries by migration and exits by extinction of specific taxa; and MP stands for the mammal zone of the Paleogene, MN stands for the mammal zone of the Neogene.

were subsequently colonized by evergreen tropical and subtropical flora of the Paleogene (Poltava flora).

In the Early Oligocene, the sea flooded the western margins of the Turgai Depression, reaching the Mugodzhars and the eastern slope of the Southern Urals, and extending beyond the Ishim River. Since the Middle Oligocene, due to the transgression of the Chegan Sea, uplifts had occurred in the region of the Southern Urals, Mugodzhars, Kustanai Shaft and the Kazakh Highlands. In the Middle Oligocene, tectonic activity began to revive, the Turgai Strait continued to dry up, and the entire Northern Aral Sea region and the basins of the Chegan Sea and the Irgiz River were dried up. The climate of the Aral-Turgai plains during this time was humid, with pronounced seasonality in precipitation. The Late Oligocene period was characterized by a widespread increase in climate continentality, with cooling in the south and increasing dryness, which affected the change of flora and vegetation cover. As the climate continued to become more continental in the second half of the Paleogene, floras of the Turgai ecological type, which were characterized by a prevalence of moderately heat-loving plants, began to emerge in the vast, levelled territory of Central Kazakhstan.

Paleoclimatic and paleogeographic shifts resulted in significant alterations to the fauna, including changes in its composition, the evolution of vertebrates, and the number of mammals, which constituted the most notable difference between the Oligocene and subsequent periods. In Asia, including Kazakhstan, a number of different types of mammals became widespread, including brontotherians, chalicotherians, aminodonts, tapiroids, gyracodontids, giant rhinoceroses and true rhinoceroses. During the Oligocene period, some primitive carnivores, the creodonts, continued to evolve. Among the pairs of ungulates, two groups of extinct animals were known, the entelodonts and anthracotherians, which resemble pigs; and the tragulids and eumerixes, which resemble deers.

The Oligocene marked the Indricotherium fauna, which included a diverse array of animals, including insectivores, rodents, creodonts, chalicotherians, tapiriforms, gyracodonts, aminodonts, rhinoceroses, entelodonts, tragulids, some birds and turtles. Among the most notable mammals were the giant, hornless rhinoceroses, Indricotherium, which reached the heights of up to 6—8 m. Another noteworthy group was the massive, sedentary aminodonts, and the ancient pig-like entelodonts, which reached sizes of up to 1.5 m in height and 3 m in length. A considerable variety of ancient rodents (more than 15 species) emerged during this period.

At the beginning of the Miocene, the general uplift of the mountain ranges of the Himalayas, Tibet and Tian Shan intensified, which resulted in the blocking of the circulation of moist air masses from the oceans across the territory of Central Asia. This, in turn, led to the intensification of aridisation arid climate processes.

The composition of the vegetation also underwent a change. The deciduous warm-moderate flora of the Turgai ecological profile was replaced in Burdigal by the "Mediterranean" one. Sparse forests were concentrated around drying water bodies and rivers, and large areas of watersheds and hills were gradually occupied by steppe herbaceous and shrub vegetation. At this juncture, savanna-type landscapes began to emerge on the watersheds. The climate was evidently characterized by a temperate to subtropical Mediterranean climate. The landscape and climate of the region were conducive to the survival of animals adapted to these conditions. As the land was developed, representatives of both Asian and European paleofauna migrated to the area. During the initial phase of the Miocene epoch, extensive lakes were formed across the vast sea, and strongly denuded the territory of Kazakhstan, in addition to adjacent regions of Western Siberia. The previously monotonous landscape of the plain, now elevated to a highland, and became more diverse in its colorations. In addition to the upland areas, there were also instances where Neogene sediments were deposited in the form of depressions. During the Neogene period, the contrast in climate between Kazakhstan and the surrounding areas increased significantly.

During the Early Neogene epoch under consideration, the last representatives of the family of giant rhinoceros Indricotheriidae and their numerous archaic companions, especially those associated with humid forests and swampy areas, became extinct. At the same time, mastodons, including *Gomphotherium* and *Serridentinus,* as well as rhinoceroses with long legs, such as *Aceratherium,* hippopotamus-like *Brachypotherium, Anthrocotherium, Anchytherium*, rodents, and turtles, entered the territory of Kazakhstan from the southwest. The first horned muntjac deer, which inhabited bushland, appeared. The presence of this fauna was indicative of the progressive development of open spaces, climate cooling and aridisation. This was further corroborated by the abundance of terrestrial turtles, which was accompanied by a sharp decrease in the number and diversity of inhabitants of clear freshwater bodies, especially freshwater turtles (trionyxes).

## 6. Conclusions

A paleontological and lithological—stratigraphic study of sections of the Askazansor Formation established the age of the deposits as the Early Miocene (Burdigalian). This was determined by examining the fauna of terrestrial vertebrates. The faunal complex of Askazansor demonstrated a notable degree of continuity with the Oligocene complexes.

The faunal composition of Askansor is close to the composition of the Akespe reference section in the Northern Aral Sea region and the fauna of the Harrison beds in North America.

The fauna was comprised of animals that inhabited sparse valley forests, with a diet of woody foods, primarily including young shoots, tree bark, and shrubs.

The faunal assemblage from the Askazansor site was one of the most representative for the Lower Miocene of the southern part of Central Kazakhstan, and was of significant importance for the understanding of regionally geological and biotic processes.

## CRediT authorship contribution statement

**Saida Nigmatova:** Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Visualization, Writing — review & editing. **Bolat Bayshashov:** Formal analysis, Investigation, Methodology, Resources, Supervision. **Ilnura Madiyarova:** Conceptualization, Formal analysis, Methodology, Project administration, Visualization, Writing — review & editing. **Arman Seidali:** Methodology, Resources, Software, Visualization. **Balzhan Kalibek:** Methodology, Resources, Software, Visualization.

## Availability of data and materials

Data supporting the findings of this research are available upon request from the corresponding author.

## Funding

This research was prepared as a part of the grant project AR 14871967 “Geological—paleontological and paleoclimatic studies of Cenozoic deposits of Central Kazakhstan as a basis for predicting mineral deposits” of the Ministry of Science and Higher Education of the Republic of Kazakhstan.

### Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Acknowledgements

Other authors want to express deep gratitude to the author Bayshashov B. for valuable assistance and professional help in writing this article. Without his expert contribution and insightful recommendations, the author team could not have achieved such results.

## References

Bayshashov, B.U., 1989. Finds of rhinoceros bones of the genus Protaceratherium in Kazakhstan. *Paleontological Journal, Moscow*, 2, 116—118.
Bayshashov, B.U., 1994. The first discovery of a rhinoceros skull of the genus Aprotodon. *News of the National Academy of Sciences of the Republic of Kazakhstan Biological Series*, 2, 54—57.
Bayshashov, B.U., 2001. New data on ancient ungulates from the Ayakoz locality and their biostratigraphy. *Geology of Kazakhstan*, 5—6, 140—147.
Bayshashov, B.U., Tyutkova, L.A., Lucas, S.G., Emry, R.J., 2002. New mammal finds and the Early Miocene age of the Askazansor locality, Kazakhstan. *Journal of Vertebrate Paleontology*, 22(3), 34.
Belyaeva, E.I., 1954. New materials on Tertiary Rhinoceroses of Kazakhstan. *Tertiary Mammals*, 47(2), 24—54.
Belyaeva, E.I., 1964. Some results of the study of Tertiary faunas of terrestrial mammals of the Soviet Union. Tertiary Mammals. *Reports of the Geological Congress 22 Session* 14—26.
Bendukidze, O.G., 1993. *Small mammals of the Miocene of South—Western Kazakhstan and Turgai*. Metsniereba Publishing House, Tbilisi, pp. 1—144.
Bonis, L., Brunet, M., Kodrdikova, E., Mavrin, A., 1997. *Oligocene—Miocene sequence stratigraphy and vertebrate paleontology of Western and Southern Betpakdala Steppe, South Kazakhstan*. Biochrom’97, Abstracts, Montpellier, p. 34.
Borissiak, A.A., 1938. On the phylogeny of Dicerorhinae. *Reports of the Academy of Sciences of the Soviet Union*, 19(9), 762—770.

Borissiak, A.A., 1940. *Phillotillon? betpakdalensis* (Flerov). *Reports of the Academy of Sciences of the Soviet Union*, 26(8), 841—844.

Borissiak, A.A., 1946. A new representative of chalicotheriums from tertiary deposits of Kazakhstan. *Proceedings of the Paleontological Institute*, 13(3), 3—134.

Butler, P.M., 1965. Fossil mammals of Africa. *Bulletin of the British Museum (Natural History) Geology*, 10, 165—237.

Cerdeno, E., 1993. Etude sur Diaceratherium aurelianense et Brachypotherium brachypus (Rhinocerotidae, Mammalia) du Miocene moyen de France. *Bulletin Museum History Natural, Paris*, 4(Ser.15), 25—77.

Coombs, C.M., 2009. The Chalicothere *Metaschizotherium bavaricum* (Perissodactyla, Chalicotheriidae, Schizotheriinae) from the Miocene (MN5) Lagerstatte of Sandelzhausen (Germany): Description, comparison, and paleoecological significance. *Paläontologische Zeitschrift*, 83(1), 85—129.

Coombs, M.C., Coombs, W.P., 1997. Analysis of the geology, fauna, and taphonomy of Morava Ranch Quarry, Early Miocene of Northwest Nebraska. *Palaios*, 12(2), 165—187.

Devyatkin, E.V., 1981. *Cenozoic of Inner Asia: Stratigraphy, Geochronology, Correlation*. Nauka, Moscow, pp. 1—196.

Erbaeva, M.A., 1982. *Cenozoic lagomorphs of Kazakhstan. Materials on the history of fauna and flora of Kazakhstan*, 8. Almaty, Nauka, pp. 25—38.

Flerov, K.K., 1938. On the remains of Ungulate from Betpakdala. *Reports of the Academy of Sciences of the Soviet Union*, 21(3), 94—96.

Flerov, K.K., Yanovskaya, R.M., 1971. Ecological complexes of mammals of the Oligocene of Asia and their zoogeographical characteristics: Modern problems of paleontology. *Proceedings of Paleontological Institute*, 130, 7—31.

Ginsburg, L., Huin, J., Locher, J.P., 1981. The Rhinocerotidae of the Lower Miocene of the Beilleaux at Savigne-Sur-Latan. *Bulletin Museum Natural History Nature*, 3(4), 345—361.

Kochenov, V.G., 1983. The first find of the oldest representative of Aseratherium in the Paleogene Betpakdala. *Izvestia of the Academy of Sciences of the Kazakhstan*, 1, 41—45.

Kordikova, E.G., 2001. Remarks on the Oligocene—Miocene mammal paleontology and sequence stratigraphy of South-Western Betpakdala Steppe, South Kazakhstan. *Neues Jahrbuch für Geologie und Paläontologie*, 221(1), 35—79.

Kostenko, N.N., Biryukov, M.D., Lychev, G.F., Savinov, P.F., 1977. Oligocene continental deposits of Southern Kazakhstan. Problems of geology and hydrogeology of Kazakhstan. *Alma-Ata*, 7, 101—123.

Li, C.K., Qiu, Z., 1980. Early Miocene mammalian fossils of Xining Basin, Qinghai. *Vertebrata Palasiatica*, 3, 198—215.

Nikiforova, K.V., 1960. *Cenozoic hungry steppe of Central Kazakhstan*. Science, Moscow, pp. 1—253.

Orlov, Yu.A., 1941. Paleontological expedition of 1936 to Betpakdala. *Proceedings of the Paleontological Institute*, 8(3), 87—98.

Shevyreva, N.S., 1976. *Paleogene rodents of Asia*. Science, Moscow, pp. 1—116.

Trofimov, B.A., 1949. The oldest representative of primitive pigs in Asia. *Reports of the Academy of Sciences of the Soviet Union*, 67, 145—148.

Vorobeychik, A.A., 1958. Remains of mammals from the deposits of the Aral Formation on the river Ayaguz. *Materials on the history of fauna and flora of Kazakhstan, Nauka, Almaty*, 2, 28—33.

Vorontsov, N.N., 1963. *Aralomys glikmani* — A new species of hamster-like animals. *Palaeontological Journal*, 2, 151—154.