STRATIGRAPHY AND OLIGOCENE-MIOCENE MAMMALIAN BIOCHRONOLOGY OF THE AKTAU MOUNTAINS, DZHUNGARIAN ALATAU RANGE, KAZAKHSTAN

by

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ABSTRACT

Stratigraphic studies in the Aktau Mountains bordering the Dzhungarian Alatau Range in southeastern Kazakhstan have included mapping of Tertiary lithostratigraphic units, documentation of fossiliferous deposits, correlation of sections, etc. These investigations have led in turn to revised interpretation of the Tertiary geology of the area. The Tertiary sequence in the Aktau Mountains is represented by three lithostratigraphic units (in ascending order): (1) the middle Eocene Akbulak Formation; (2) the Oligocene Aktau Formation with a lower member including white quartz sands that contain fossil mammals, and an upper member including red-colored clays and sandstones, brick red clays, an anhydrite and gypsum clayey horizon, and bright brown-red clays; and (3) the upper Oligocene-Miocene Chul'adyr Formation with a lower member of greenish and yellowish conglomerates and gritstones, a middle member including grayish and yellowish sands and gritstones, and an upper member including brown and red clays and carbonate- and anhydrite-rich clays. The Aktau and Chul'adyr Formations represent separate cycles of sedimentation. Mammalian biostratigraphy and biochronology of the three vertebrate faunas in Aktau Mountains are reviewed. The mammalian fauna from white sands of the lower Aktau Formation is small but includes *Ardynia* and is thought to be early Oligocene in age. The mammalian fauna from conglomerates and gritstones of the lower member of the Chul'adyr Formation is also small but includes *Paraceratherium* and is thought to be late Oligocene in age. The mammalian fauna from sands of the middle member of the Chul'adyr Formation is extensive, with micro- and macrofauna attributed to Neogene mammal zones MN4 to MN6, indicating a latest early Miocene to earliest middle Miocene age (Orleanian-Astaracian). Most genera of middle Chul'adyr mammals are known from the middle Miocene Shanwang faunas of China and from the Castelnau-d'Arbieu faunal assemblage (MN4-MN6) of southwestern France.

RESUME

Les études stratigraphiques dans les Montagnes de l'Aktau qui bordent la chaine de l'Alatau Dzhungarien au sud-est du Kazakhstan ont inclu la cartographie des unités lithostratigraphiques tertiaires,

la documentation des dépôts fossilifères, la corrélation des sections, etc. Ces investigations ont conduit à réviser l'interprétation de la géologie du Tertiaire de la région. La séquence tertiaire des Montagnes de l'Aktau est représentée par trois ensembles lithostratigraphiques (en ordre ascendant): (1) la formation éocène supérieure Akbulak; (2) la formation oligocène Aktau, avec un membre inférieur incluant des sables à quartz blancs qui renferment des mammifères fossiles, et un membre supérieur inclazuant des argiles et grès rouges, des argiles rouges brique, un horizon argileux à anhydrite et gypse, et des argiles rouges-brunes foncées; et (3) la formation oligocène supérieure-miocène Chul'adyr, avec un membre inférieur de conglomérats et gritstones verts et jaunes, un membre intermédiaire incluant des sables et des gritstones gris et jaunes, et membre supérieur comprenant des argiles brunes et rouges, et des argiles riches en carbonates et anhydrites. Les formations Aktau et Chul'adyr représentent des cycles sédimentaires distincts. La biostratigraphie et la biochronologie mammalienne des trois faunes de vertébrés des Monts Aktau sont revues. La faune de mammifères des sables blancs de la formation inférieure Aktau est pauvre mais elle inclut *Ardynia*, et elle est considérée comme d'âge Oligocène inférieur. La faune des conglomérats et gritstones du membre inférieur de la formation Chul'adyr est également réduite, mais elle comporte *Paraceratherium*, et elle est considérée comme Oligocène supérieur. La faune des sables du membre intermédiaire de la formation Chul'adyr est importante, avec des petits et des grands mammifères attribués aux zones à mammifères néogènes MN4 à MN6, correspondant à la période allant du sommet du Miocène inférieur au début du Miocène moyen (Orléanien-Astaracien). La plupart des genres de mammifères de cette formation Chul'adyr moyenne sont connues dans les faunes du Miocène moyen de Shanwang en Chine et dans l'assemblage faunique de Castelnau-d'Arbieu dans le sud-ouest de la France (MN4-MN6).

INTRODUCTION

The most complete stratigraphic section of the Cenozoic in southeastern Kazakhstan, containing fossiliferous strata of different ages, is in the Aktau Mountains (Aktau means white in Kazakh). Extensive middle Cenozoic nonmarine deposits are exposed in there from 43°59'-44°06'N to 79°10'-79°25'E (Fig. 1). These strata form the southern slopes of the mountains, which have a shallowly-domed anticlinal structure. The longer axis of this structure is elongated to the northeast (40°) and a southern wing is complicated by faults of different sizes, with northeastern and northwestern extension (Fig. 3). The Aktau Mountains represent a large complexly-shaped graben, restricted by a system of dislocations. The Aktau Mountains have extensive arid piedmont badlands with steep (to 40-80°) slopes and deeply eroded valleys that sometimes make excavation and collection of fossils difficult.

Paleontological investigation of the Aktau Mountains was first carried out in the 1950s before there was any real understanding of the stratigraphy of the fossiliferous deposits (see Bazhanov & Kostenko 1961a, b). Then for a long time preliminary lists of fossils were repeated in one synopsis after another (Geologiya SSSR 1971, Belyayeva *et al.* 1974, Russell & Zhai 1987, etc.). Paleontological investigations were not based on detailed stratigraphy, and fossil mammals were collected only from one ravine

Figure 1.— Location map of the investigated area.

(Aktau I in our terminology). In the late 1980s we continued to study the paleontology and stratigraphy of Tertiary deposits producing fossils in the Aktau Mountains (Kordikova 1993, Kordikova & Mavrin 1996, Kordikova in press).

Numerous stratigraphic schemes were made as a result of different investigations, but there has been little agreement about the names and ages of lithostratigraphic units (Fig. 2). Stratigraphic schemes available previously were sometimes very controversial and heterogeneous, and the same investigators have sometimes changed their points of view (compare, for example, Bazhanov & Kostenko 1961a, 1961b, Kostenko 1964, and Kostenko *et al.* 1977). The stratigraphic scheme accepted by the Republic Interdepartmental Commission in 1986, in our opinion, also conflicts with paleontological and geological observations in the field. Thus there is a need for revision of interpretation of the Tertiary geology of the Aktau Mountains area.

The purpose of this study is to clarify the lithostratigraphic and biostratigraphic relations of middle Cenozoic fossiliferous deposits in the Aktau Mountains bordering the Dzhungarian Alatau Range. Our research focuses on the geology and biostratigraphy of fossiliferous deposits in relation to underlying and overlying strata, as well as on the available faunal lists. This contribution is also directed toward developing a well documented set of data for the Tertiary formations to be used later in recording the history of vertebrates and understanding the evolution and ecology of Tertiary vertebrate faunas in the Dzhungarian Alatau region.

Our investigations involved interpretation of aerial photographs at scales of 1:33000, 1:25000, and 1:10000, and mapping on topographic maps at scales of 1:50000 and 1:25000.

PREVIOUS STUDIES

The region under study is situated on the northern boarder of the Ili Basin in the southern Dzhungarian Alatau Range area of southeastern Kazakhstan. Annexation of the Semirech'ye ("seven of rivers") area to Russia led to geological exploration of the southern Dzhungarian Alatau region. Since the 19th century several great Russian scientists (e.g., Semenov-Tien-Shanski, Mushketov, Obruchev, and Kassin) were the first to investigate this region. Systematic geological study of the area was conducted since 1933 by Sokolov *et al.* (1944), Shlygin *et al.* (1952), Petrushevskiy (1955), Bazhanov & Kostenko (1961a, b), Chakabayev (1960), Kostenko (1964), Ivkin & Sokolov (1966), Ivkin *et al.* (1969), Ivkin (1969), Sokolov & Ivkin (1971), Li (1975), Kostenko *et al.* (1977), Azbel' *et al.* (1978), Dmitriyeva & Nesmeyanov (1982), Lavrov & Rayushkina (1983), Rayushkina (1988, 1993), and others (Fig. 2).

The presence of Eocene strata in the Ili Basin first was recognized by Sokolov, Eryomenko, and Palenova (1944). They distinguished Kaychinsk and Aktau cycles of sedimentogenesis, and described two stratigraphic intervals within the Kaychinsk cycle and seven intervals within the Aktau cycle (Fig. 2). In 1952 Shlygin and others divided Tertiary strata into three lithostratigraphic units thought to represent cycles. In 1955 Petrushevskiy proposed Usun and Karluk as distinct series within the Ili Basin.

In 1957 general geological mapping on a scale of 1:50000 was initiated in this region. Geochemical metallometric investigations on this scale were carried out under the leadership of Sakovkin. In 1960-62 the Katutau Group of South Kazakhstan Geological Department carried out prospecting investigations in South Dzhungarian Alatau under the leadership of Fremd. In 1971 V. Sokolov of Kazakh State University prospected on a scale of 1:25000 in the Aktau Mountains to locate salt-bearing clays as a potential agricultural resource (Sokolov & Ivkin 1971). In 1974 Ignatyk carried out an aeromagnetic survey of scale of 1:50000 in this region. In the first half of 1970s Azbel' and Borukayeva revised geological mapping on a scale of 1:50000 in accordance with modern requirements for a geological survey on this scale. As a result geological maps of scale 1:50000 became available.

In 1961 the lower red-colored part of the exposed section was referred to the Aktau Svita (Bazhanov & Kostenko 1961a, b). Later mining activity in the southern piedmont of the Aktau Mountains led to recognition of bluish-brown clays of Eocene age. These were joined to the white quartz sands in an Akbulak Svita, decreasing the earlier content of the Aktau Svita. Kostenko and others (Kostenko 1964, Bazhanov *et al.* 1971, Nesmeyanov 1967, and others) also proposed recognition of Chul'adyr and Santash Svitas of the Tekess Basin Group in stratigraphic sections of the Ili Basin. But the union of the Eocene and Oligocene deposits into the same svitas is not advantageous because the latter are not lithostratigraphic units.

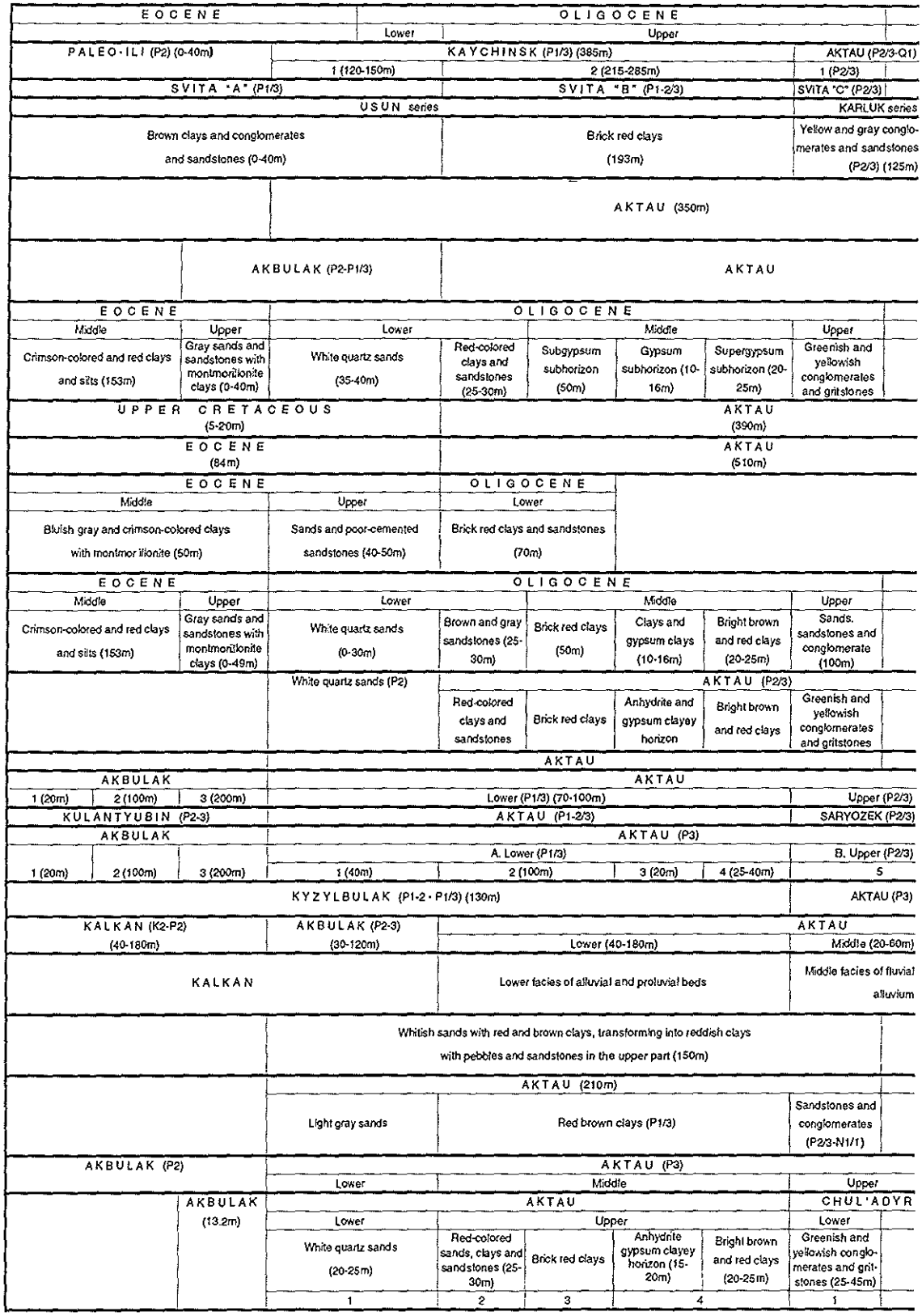

Figure 2.— History of nomenclature of the Tertiary stratigraphic units.

OLIGOCENE		MIOCENE			DIVISIONS
Upper		Lower	Middle-Upper		Subdivisions
KAYCHINSK (P1/3) (385m)		AKTAU (P2/3-Q1) (1362m)			Sokolov 1944
2 (215-285m)	1 (P2/3)	2 (N1/1)	3 (N2/1)	4 (N3/1)	
SVITA "B" (P1-2/3)	SVITA "C" (P2/3)	I cycle	II cycle	III cycle (N1/1)	Shlygin & Kazanli 1952
USUN series	KARLUK series (N3/1 - N1/2)				Petrushevskiy 1952
Brick red clays (193m)	Yellow and gray conglomerates and sandstones (P2/3) (125m)	Brown and red clays (N1/1) (85m)	Blue-colored clays and marls (450m)		Ivkin 1958
AKTAU (350m)			Salt-bearing bed (160m)	Gray plastered clays and siltstones (175m)	Bazhanov & Kostenko 1961a, b
AKTAU			Gray and green gypsum clays (N1/1)		Kostenko 1964

OLIGOCENE			MIOCENE			Ivkin & Sokolov 1966
Middle		Upper	Lower			
Gypsum subhorizon (10-16m)	Supergypsum subhorizon (20-25m)	Greenish and yellowish conglomerates and gritstones	Subgypsum subhorizon (60-70m)	Gypsum subhorizon (35-45m)	Supergypsum subhorizon (300m)	
AKTAU (390m)				SARYOZEK (335m)	PAVLODAR (125m)	Chabdarov *et al.* 1967
AKTAU (510m)				ARAL (186m)	PAVLODAR (144m)	Men'shikov 1968
						Ivkin 1969

OLIGOCENE			MIOCENE			Ivkin *et al.* 1969
Middle		Upper	Lower			
Clays and gypsum clays (10-16m)	Bright brown and red clays (20-25m)	Sands, sandstones and conglomerate (100m)	Brown and red clays (65-70m)	Carbonate and angydrite clays (35-45m)	Bluish gray hydromicaceous clays (370m)	

AKTAU (P2/3)				ARAL (N1-2/1)		Ivkin & Sokolov 1971
Anhydrite and gypsum clayey horizon	Bright brown and red clays	Greenish and yellowish conglomerates and gritstones	Grayish and yellowish sands and gritstones	Brown and red clays	Carbonate and anhydrite clays	Blue-colored clays and dolomites

AKTAU	CHUL'ADYR		Li 1975
AKTAU		Gray and green gypsum clays (N1/1)	Kostenko *et al.* 1977
Lower (P1/3) (70-100m)	Upper (P2/3) (35m)		
AKTAU (P1-2/3)	SARYOZEK (P2/3)	CHUL'ADYR (N1)	Azbel' *et al.* 1978
AKTAU (P3)		CHUL'ADYR (N1)	Dmitriyeva & Nesmeyanov 1982
A. Lower (P1/3)	B. Upper (P2/3)		
3 (20m) / 4 (25-40m)	5	6	7

KYZYLBULAK (P1-2-P1/3)	AKTAU (P3) (120m)	CHUL'ADYR (N1/1) (120m)	AYGYRZHOL' (N1-2/1) (60m)	Lavrov & Rayushkina 1983
AKTAU			SANTASH	Stratigraphic Meeting 1986
Lower (40-180m)	Middle (20-60m)	Upper (60-200m)	(0-200m)	
Lower facies of alluvial and proluvial beds	Middle facies of fluvial alluvium	Upper facies of piedmont alluvium and proluvium		Avdeyev *et al.* 1986
Whitish sands with red and brown clays, transforming into reddish clays with pebbles and sandstones in the upper part (150m)	Reddish sands with pebbles and lenses of gray silty clays (150m)	Salt-bearing bed (150m)	Mottled silts, marls and limestones (400m)	Rayushkina 1988, 1993

AKTAU (210m)	CHUL'ADYR (N2/1)			Abdrakhmanova *et al.* 1988
Red brown clays (P1/3)	Sandstones and conglomerates (P2/3-N1/1)	Pebbles with lenses of gray clays	Red and brown clays	

AKTAU (P3)		CHUL'ADYR		Tsirel'son *et al.* 1990
Middle	Upper	Lower (N1)	Upper (N2)	

AKTAU	CHUL'ADYR				Kordikova & Mavrin this paper
Upper	Lower	Middle	Upper		
Anhydrite gypsum clayey horizon (15-20m) / Bright brown and red clays (20-25m)	Greenish and yellowish conglomerates and gritstones (25-45m)	Grayish and yellowish sands and gritstones (58-75m)	Brown and red clays (60-75m)	Carbonate and anhydrite clays (35-45m)	Blue-colored clays and dolomites
4	1	2	3	4	

Figure 2 (continued).— History of nomenclature of the Tertiary stratigraphic units.

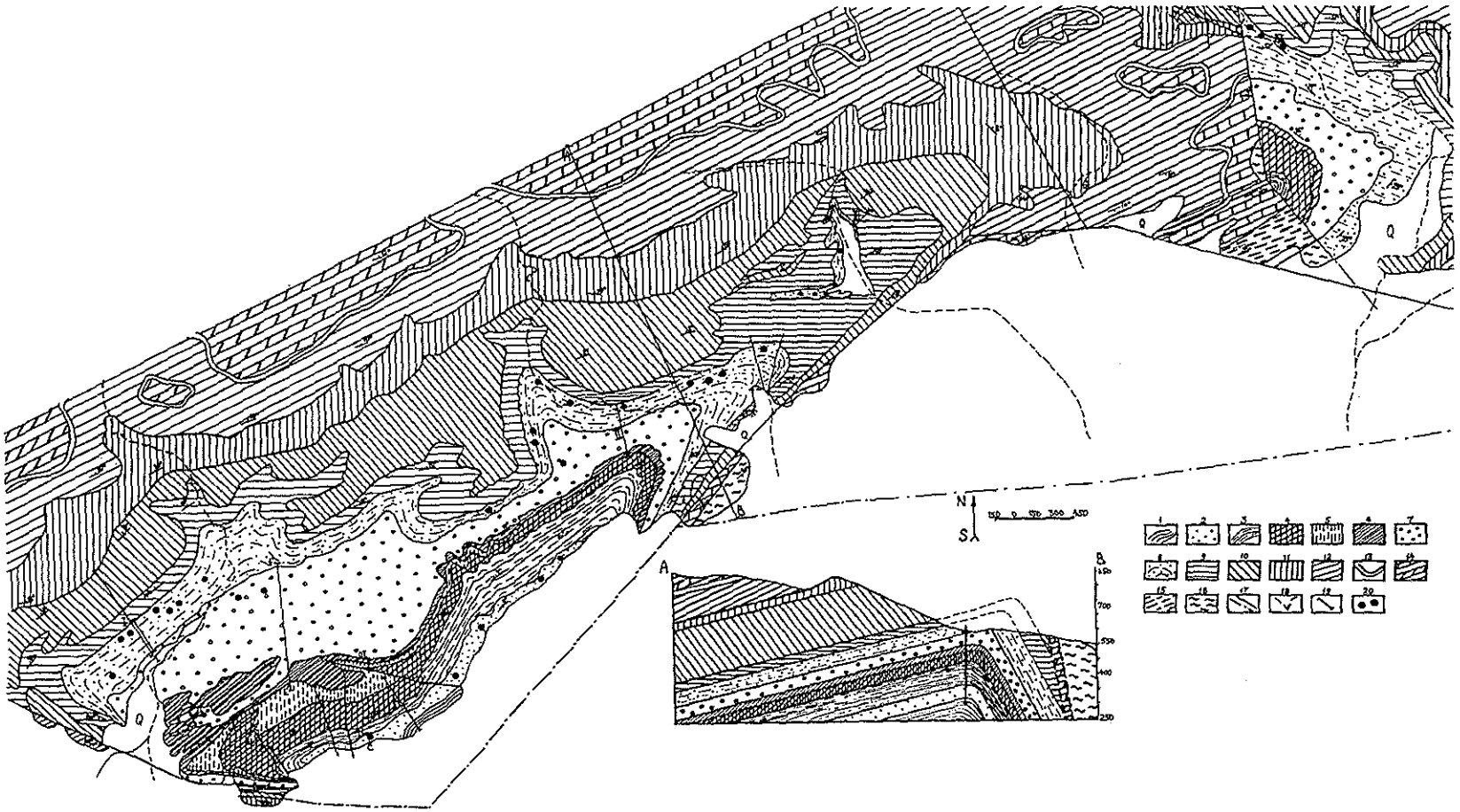

Figure 3.— Geological map of the southern Aktau Mountains, showing fossil localities, measured sections, and cross-section A-B (see Fig. 4 for others; modified from Kordikova 1991). Key to mapping units and symbols: 1, red-colored clays and silts and grey sandstones; 2, white quartz sands; 3, red-colored clays and sandstones; 4, brick red clays; 5, anhydrite and gypsum clayey horizon; 6, bright brown and red clays; 7, grayish and yellowish sands and gritstones; 8, greenish and yellowish conglomerates and gritstones; 9, brown and red clays; 10, carbonate and anhydrite clays; 11, blue-colored clays and dolomites; 12, blue-colored clays; 13, red-colored horizon; 14, white-colored clays; 15, brown-colored clays; 16, yellowish grey clays; 17, dislocations; 18, gullies; 19, measured sections; 20, fossil localities. Roman numerals are particular stratigraphic sections described in the Appendix and illustrated in Fig. 5.

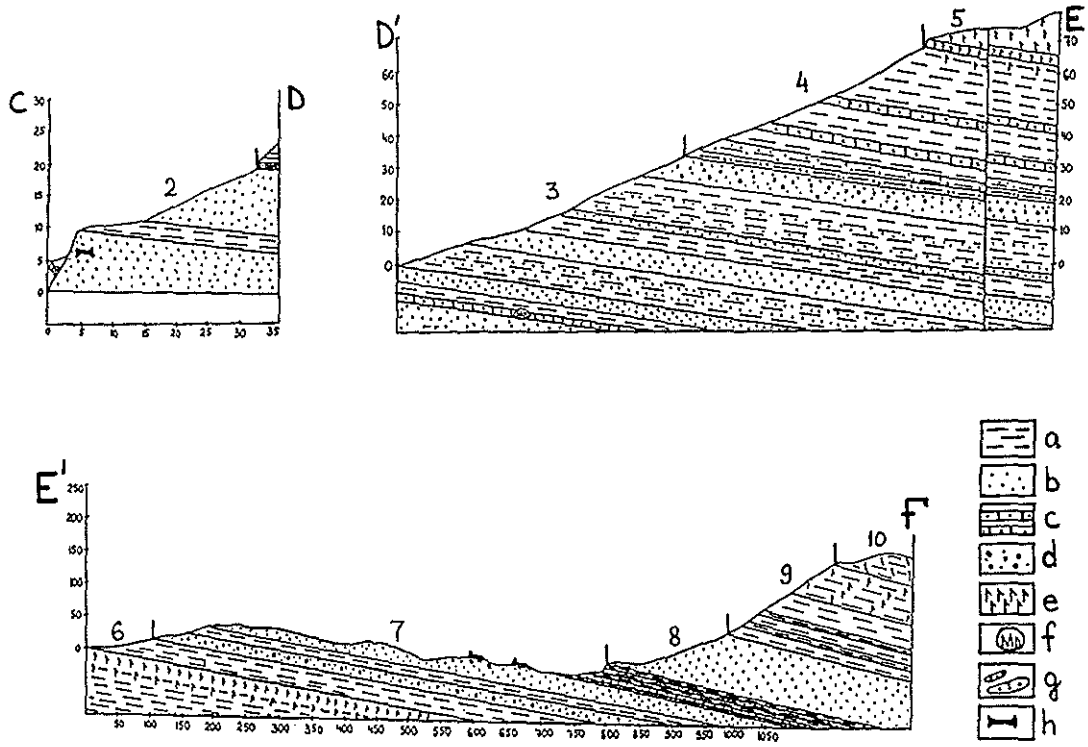

Figure 4.— Cross-sections C-D, D'-E, E'-F in the southern Aktau Mountains (see map in Fig. 3). Modified from Kordikova 1991. Key to lithologies and symbols: a, clays; b, sands; c, sandstones; d, gritstones, pebbles, conglomerates; e, gypsums; f, Fe, Mn concretions; g, lenses of siderites and leptochlorites; h, fossils.

Nesmeyanov (1977) described two sedimentary cycles beginning with coarse clastic sediments in the previously known Oligocene deposits and referred them to Akbulak (lower cycle) and Aktau (upper cycle) svitas. Later Kostenko restricted the Akbulak svita to unexposed Eocene strata and restored all exposed Oligocene beds to the Aktau svita, thus restoring its earlier meaning. Kostenko *et al.* (1977) also recognized the above-mentioned sedimentary cycles of Nesmeyanov by making adequate subdivision of the Aktau svita.

Paleontological study in the Aktau Mountains started in 1950 when Kazanli and Bazhanov discovered a vertebrate fauna, leading to the first interpretation of Aktau Mountain stratigraphy based on fossil vertebrates (Bazhanov & Kostenko 1961a,b). Since then many paleontologists and geologists, among them co-workers from the Laboratory of Paleozoology of the Institute of Zoology, Kazakh Academy of Sciences (Almaty), have collected fossil vertebrates. In 1979 a fossil plant locality was discovered by Lavrov, and from 1981 to 1993 Rayushkina collected and studied fossil plants.

In 1986 the Republic Interdepartmental Stratigraphic Commission of the 3rd Stratigraphic Meeting in Almaty accepted the following scheme of Tertiary lithostratigraphic units: (1) Kalkan (K2-P2kk); (2) Akbulak = Kulaktyubin (P3/2-

P1/3kt); and (3) Aktau (P3-N1ak) with lower, middle and upper subdivisions. In 1988 a special excursion for correlation of Mesozoic and Cenozoic deposits in intermontane basins of southeastern Kazakhstan was organized by the Institute of Geological Sciences and Institute of Zoology of the Kazakh Academy of Sciences (see Fig. 2).

From the 1980s to the present, we have systematically studied the paleontology and stratigraphy of fossil-producing middle Cenozoic deposits of the Aktau Mountains (Kordikova 1991, 1993, Kordikova & Mavrin 1996, Kordikova in press), leading to discovery of a large number of fossil vertebrate localities in the Aktau and Chul'adyr Formations of the southern and eastern parts of the mountains.

LITHOSTRATIGRAPHY

The Aktau Mountains stratigraphic sequence does not include Cretaceous deposits with a bone horizon as Lavrov and Rayushkina (1983) believed. Their stratigraphic column for the Ili Basin is rather generalized and contains bones of dinosaurs and trionychids (see Efremov 1944) correlated from Upper Cretaceous deposits at Kalkany situated on the north bank of the Ili River. Palynological remains in bore holes penetrating Paleocene and Eocene deposits here were first attributed to the Cretaceous by Bazhanov *et al.*(1971).

Most researchers interpret the middle Cenozoic sections in the Aktau Mountains as being continental deposits. However, Chabatayev (1960) reported finding marine Paleogene Foraminifera during stratigraphic reference drilling in the Ili Basin and suggested marine transgression into Fergana, the Aral Sea region, and other areas of Central Asia, with a marine introgression into the Ili Basin too. Kostenko (1964) rejected this hypothesis because he interpreted the foraminifera-bearing deposits as being reworked and redeposited. Nevertheless, there are some geochemical data suggesting subaqueous manganese accumulation here in part of an Eocene delta of a river flowing into a shallow marine Ili Basin (Ivkin 1969). Besides, foraminiferans typical of Miocene marine saline basins were also found in the adjacent Kegen' and Karkarin basins of southeastern Kazakhstan (Ivkin 1969). Crocodilian and trionychid fossils of estuarine type also suggest the nearby presence of a marine basin.

Tertiary strata are exposed only along the southern and southeastern flank of the Aktau Mountains, in the core of the anticline. Here we recognize three lithostratigraphic units (formations) of middle Cenozoic age (in ascending order): (1) the Akbulak Formation of middle to late Eocene age; (2); the Aktau Formation of late Eocene to late Oligocene age; and (3) the lower part of the Chul'adyr Formation of late Oligocene to Miocene age. These units in Kazakhstan are usually termed svitas, an important local stratigraphic subdivision characterized by specific facies and lithological characteristics as well as paleontological distinctiveness, with isochronous boundaries that represent a particular cycle or phase of deposition (Stratigraphic code of the USSR 1977). However, the three units recognized here are mappable and can be distinguished solely on lithologic criteria, so they can also be referred to as formations. The Aktau and Chul'adyr formations reflect two distinct cycles of sedimentogenesis, each beginning

with coarse clastics and having sediment grain size fining from the base to the top of the unit.

MIDDLE - UPPER EOCENE AKBULAK FORMATION

The lowermost sequence of Paleogene strata exposed in the Aktau Mountains area is placed in the Akbulak Formation. It is exposed at the south end of the Aktau Mountains in the core of anticline (Fig. 3, Pl. 1). The exposed thickness is about 13.2 m. In this region strata of the formation disconformably overlie upper Paleozoic extrusives (Kostenko *et al.* 1977). As exposed, the Akbulak Formation consists of grey and yellowish-grey quartz and feldspar sands of varying grain size, sandstones with layers of bright red hydromicaceous and montmorillonite clays, and conglomerates (see section Aktau 0 in the Appendix). No fossil vertebrates are known from the Akbulak Formation in the study area, but a palynological assemblage was extracted by Baybulatova from grey-brown to green argillites (Kostenko 1964).

UPPER EOCENE - OLIGOCENE AKTAU FORMATION

The Aktau Formation conformably overlies the Akbulak Formation and, according to mining sources, disconformably overlies Paleozoic rocks. It is also in turn disconformably overlain by the Chul'adyr Formation (Figs. 3-5). Most of the Aktau Formation is red-colored clays and sands. It is divided into two members, including five distinctive intervals: a lower member with (1) white quartz sands, containing a late Eocene to early Oligocene mammalian fauna; and an upper member with (2) red-colored clays and sandstones, (3) brick red clays, (4) an anhydrite and gypsum-rich clayey interval, and (5) bright brown-red clays. The brick red clays, beds of clays and gypsum clays, as well as brown red clays are thought to have been formed in the deepest parts of the Ili Basin (Ivkin *et al.* 1969). They appear to represent the shallow phase of a regressive sea and represent a complete facies assemblage of hydrochemical sediments. Calcareous clays are overlain by gypsiferous clays and anhydrites, and the latter are overlain by high-salinity brown and red clays (galopelites).

Lower Member

White quartz sands

This interval is represented by cross-bedded white quartz sands and weakly-cemented sandstones passing upward to white medium- and coarse-grained feldspar-rich quartz sandstones with manganese and calcite cements and lenses of manganese-rich calcite (Pl. 1). The sediments are interpreted as representing an alluvial river bed facies. The interval ranges from 20 to 25 m in thickness. Fine-grained sands, including ferruginous cross-bedded sands producing poorly preserved fossil mammals, turtles, and crocodiles (Table 1) indicate on the presence of a humid subtropical climate. Accumulation of quartz and feldspar sands of varying grain size, with lenses and layers of clays, silts, and gritstones, probably took place in continental conditions (see above).

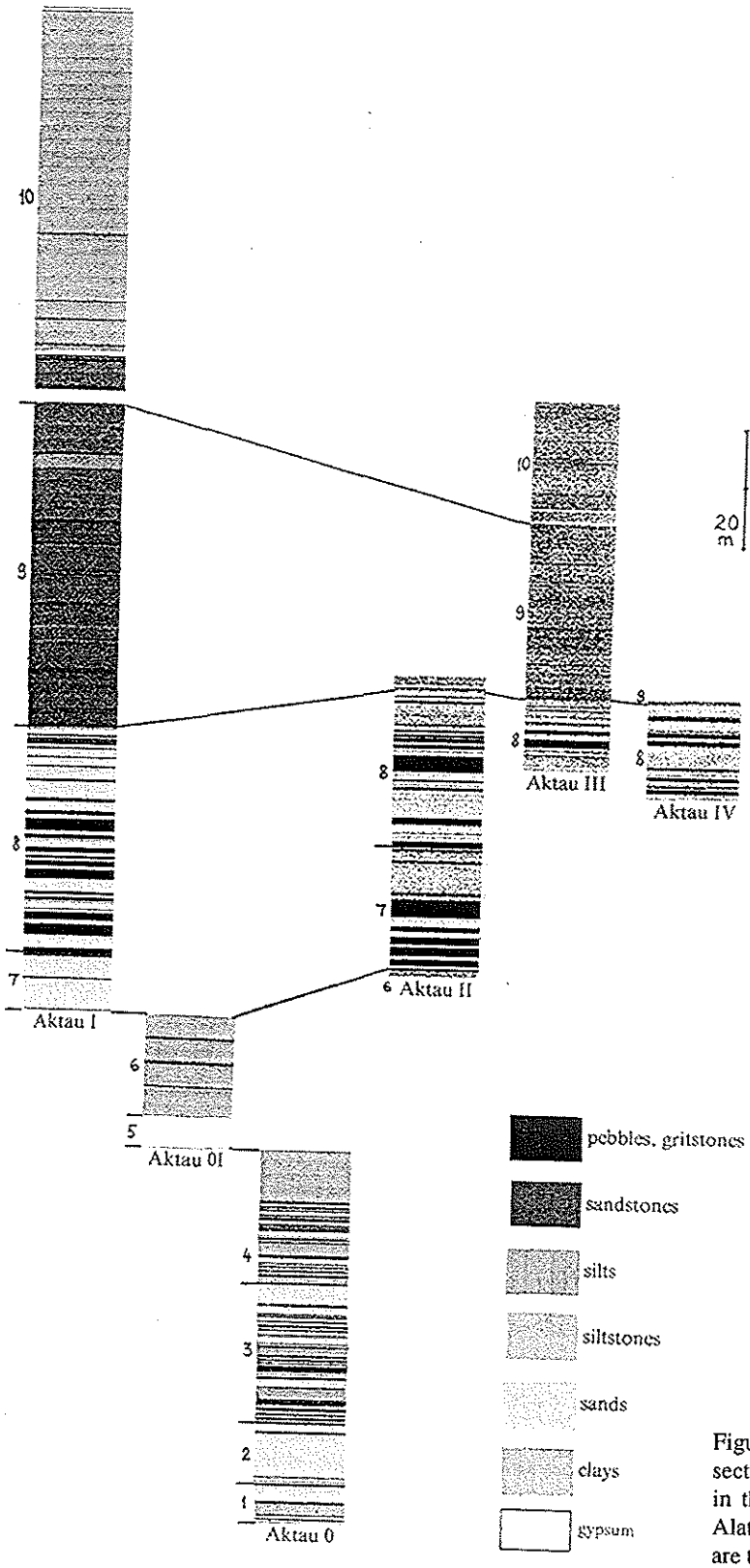

Figure 5.— Correlation of stratigraphic sections of middle Cenozoic deposits in the Aktau Mountains, Dzhungarian Alatau. Numbers of lithological units are the same as those in Fig. 3.

Upper Member

Red-colored clays and sandstones

This is an interval of red and brown to greenish grey course- and medium-grained poorly-sorted clayey sandstones with calcite or barite cement (Pl. 1). Sandstones are interbedded with traces of calcareous montmorillonite and hydromicaceous clays. The interval ranges from 25 to 30 m in thickness.

Brick red clays

This is an interval of brick red, very finely-layered argillaceous, calcareous montmorillonite, palygorskite, and hydromicaceous clays, with rare thin layers of brownish-red fine- and medium-grained sandstones having basal calcite and hydromicaceous cements (Pl. 1). The interval is about 70 m in thickness. Baybulatova extracted an Oligocene palynological assemblages in the middle part of the interval (Kostenko *et al.* 1977).

Anhydrite and gypsum clayey horizon

This is a conspicuous, well marked interval of light green clays and gypsum clays with individual layers and lenses of anhydrite reaching 4 m in thickness (Pl. 1). Clays are palygorskite, montmorillonite, and hydromicaceous clays. The interval ranges from 15 to 20 m in thickness.

Bright brown and red clays

This interval is represented by bright brown and red salt-rich clays (halopelites) that are argillaceous, cracked with polygonal cleavage, and slicken-sided with 0.2-0.5 m layers of blue marls and medium-grained poorly-sorted sandstones containing neogenic rhodusite, albite, glauconite, and barite (Pl. 1). Clays are montmorillonite, halloysite, and hydromicaceous clays. This interval ranges from 20 to 25 m in thickness. The color of the clays is very characteristic in resembling sealing wax.

UPPER OLIGOCENE - MIOCENE CHUL'ADYR FORMATION

The Chul'adyr Formation unconformity overlies the Aktau Formation (Figs. 3-5). Lowermost beds show red-colored erosional traces that overlie red deposits of the Aktau Formation. The Chul'adyr Formation is the beginning of the next cycle of sedimentation. Its composition has been changed during our stratigraphic studies (Fig. 2). At present the Chul'adyr Formation includes three members and four beds: (1) greenish and yellowish conglomerates and gritstones of the lower member, with a late Oligocene mammalian fauna; (2) grayish and yellowish sands and gritstones of the middle member, containing an early-middle Miocene mammalian fauna; and (3) brown and red clays, and (4) carbonate and anhydrite clays of the upper member. It is interpreted as a continental lacustrine and alluvial facies.

Lower Member

Greenish and yellowish conglomerates and gritstones

This interval is predominantly greenish and yellowish conglomerates and gritstones as well as slightly cemented medium- and coarse-grained cross-bedded sandstones with layers of red clays (Pl. 1). At the base of the interval there are fine conglomerates and gritstones. Sands and sandstones are found in the upper part. Clays of the middle part of the measured sections are lenses and layers up to 0.5 m thick of clayey siderites and leptochlorites. The interval ranges from 25 to 45 m in thickness. This interval is the beginning of the next cycle of sedimentation, which includes the other overlying members of the Chul'adyr Formation. Mammalian fossils are found in brownish, ocherous, alluvial sands, and in small-pebble conglomerates with rare lenses of ferruginous sandstones. Fossils were evidently buried in coarser clastic deposits on underwater deltaic fans building into lakes. The very large indricotheriid *Paraceratherium* is characteristic of this interval.

Middle Member

Grayish and yellowish sands and gritstones

Sands, silts and clays of this interval overlie the conglomerate interval with a vaguely erosional contact. This interval contains greenish grey medium-grained poorly-sorted sandstones, with layers and lenses of silty clays (Pl. 1). The thickness of the interval ranges from 25 to 75 m. The principal bone concentration formed in lenses of very coarse-grained cross-bedded sands and gritstones interpreted, again, as having been deposited underwater on a lacustrine delta.

Upper Member

Brown and red clays

This interval includes carbonate-rich brown and red palygorskite, montmorillonite, and hydromicaceous thick- and thin-layered argillite-rich clays (Pl. 1). In the southeastern part of the Aktau Mountains it is possible to trace up to five layers of blue marls, ranging from 0.5 to 2 m thick, that contain authigenic rhodusite, albite, and hydrochlorite. The thickness of this interval ranges from 60 to 75 m.

Carbonate and anhydrite clays

The overlying deposit is composed of a salt-rich interval with greyish-green gypsiferous clays (Pl. 1) and thin interbeds of brownish-red and bluish-green grey argillite, chalky palygorskite, and hydromicaceous clays, gypsum-rich clays, and dolomitic marls. The thickness of this interval ranges from 35 to 45 m. The greyish-green gypsum-rich clays have been dated by many freshwater mollusks as being Miocene in age (Bazhanov & Kostenko 1961a, b). Dmitriyeva and Nesmeyanov (1982), however, referred it to the middle Pliocene.

Blue colored clays and dolomites

Blue and green laminated argillite, carbonate-rich palygorskite, montmorillonite, and hydromicaceous clays that are chalky in the lower part of the interval and salt-rich in the upper part (Pl. 1). They contain layers of blue platy dolomite marls, anhydrites, and glauberite dolomites. In some places there are lenses up to 0.5 m thick of clayey magnesite, rock salt, and thenardite. Glauberite and anhydrite compose up to 30% of the total volume of the matrix.

LITHOLOGICAL CORRELATION

Our research indicates the feasibility of lithologic correlation between different exposures in the Aktau Mountains that are located relatively short distances apart (Fig. 5). Their lithologies can be precisely correlated over approximately 10 km direct distance between the most widely separated outcrops. The present study has demonstrated the wide lateral extent of many beds: some of these are distinctive marker strata.

AKBULAK FORMATION

The Akbulak Formation is exposed only for a hundred meters or so in the core of the Aktau Mountain anticline, where it contains a distinctive horizon of grey sandstones. This lithological unit is analogous to one in the Kokturlak, Chonkurchak, and Suluterek Svitas of more southern and western Asian regions (Dmitriyeva & Nesmeyanov 1982). Shlygin *et al.* (1952) correlated Svita "A", including the Akbulak Formation (Fig. 2), with the upper horizon of the marine Chegan Formation in the Aral Sea region and Turgai.

AKTAU FORMATION

Lower and upper members of the Aktau Formation are widely exposed in the south and south-eastern part of the Aktau Mountains and in other parts of the southern Dzhungarian Alatau Range. The lower part of the formation with the white quartz sands is easily to map, and its age, judging from the vertebrate fauna, is early Oligocene. On the basis of detailed lithological and geochemical analyses, as well as correlation to the middle Cenozoic sections of Ili Basin and Aral Sea region, Ivkin (1969) considered the interval of white quartz sands to be late Eocene.

The upper member of the Aktau Formation contains two well marked intervals, one of anhydrite and gypsum-rich clays and the other of bright brown and red clays (Pl. 1). The anhydrite and gypsum-rich clayey interval crops out to the north-east side of the mountains. The brick red and dense gypsiferous clays resemble the Massaget Formation in the Fergana Depression (Dmitriyeva & Nesmeyanov 1982). Bright red-colored

deposits of the upper member of the Aktau Formation, here lacking fossil vertebrates, are characteristic of the indricothere interval in the interregional stratigraphic scheme. The interval of bright brown and red clays can be correlated with the Betpakdala Formation (P2/3) of central Kazakhstan.

CHUL'ADYR FORMATION

Lower Member

The conglomerate interval contains well marked lenses and layers up to 0.5 m thick of clayey siderites and leptochlorites (Pl. 1). The thickness of the layer increases to the northeast of the Aktau Mountains. Proceeding from lithological criteria, the interval can be formally correlated with conglomerate and sandy strata of the Askazansor Formation. Dmitriyeva and Nesmeyanov (1982) joined the first three intervals of the formation (in our understanding), and also correlated these with the conglomerate interval of Askazansor.

Middle Member

Strata of this member can be compared to those of the sandstone and silt-rich Sarybulak Formation in the Zaysan Basin of eastern Kazakhstan. It contains numerous fossils.

REPTILIA
- Crocodylia
  - Crocodylidae
    - Crocodylidae indet. [Efimov's and Kordikova's determination]
- Testudinata
  - Trionychidae
    - *Paraplastomenus* cf. *mlynarskii* CHKHIKVADZE, 1973 [= *Trionyx* sp.: Bazhanov & Kostenko, 1961a, b; Kordikova's determination]
  - Emydidae
    - Emydidae indet. [Kordikova's determination]

MAMMALIA
- Creodonta
  - Creodonta indet. [Bazhanov & Kostenko 1961a, b]
- Perissodactyla
  - Ceratomorpha
    - Hyracodontidae
      - *Ardynia kazachstanensis* [Gromova 1960]
      - Ceratomorpha indet. [Bazhanov & Kostenko 1961a, b]
- Artiodactyla
  - Suiformes
    - Suiformes indet. [Bazhanov & Kostenko 1961a, b]

Table 1.— Updated faunal list of vertebrates from the white quartz sand of the Aktau Formation, Aktau Mountains, Dzhungarian Alatau Range, compiled from various sources. Fauna is here interpreted as early Oligocene in age.

Upper Member

The interval of brown and red clays appear to be correlated with the upper part of the red-colored molasse (Massaget) of Tien-Shan (Resolutions of All-Union excursion, 1988).

MAMMALIAN BIOCHRONOLOGY

Fossil remains are known from many fossiliferous horizons in the Aktau Mountains in sands, gritstones, clays, and other deposits spanning the upper Eocene through middle Miocene. The largest bone concentrations are found in lenses of very coarse-grained, cross-bedded sandstones and conglomerates of the middle member of the Chul'adyr Formation. Our main discoveries can be referred to one of three faunas of vertebrates (Tables 1-3) from the lower member of the Aktau Formation, and from the lower and middle members of the Chul'adyr Formation.

AKTAU FAUNA

Since the first mention of mammals from this formation, paleontologists have recognized that the fauna was early Oligocene (Bazhanov & Kostenko 1961a, b; Russell & Zhai 1987; and others). Recovery of the ceratomorph *Ardynia kazakhstanensis* provides evidence of age, but *Ardynia kazakhstanensis* occurs in the large faunas of Myneskesuyek and Chelkar-Teniz, which suggests an age at the end of the early Oligocene or beginning of the late Oligocene (Kordikova 1990, 1994).

As for lower vertebrates, trionychids resemble those from the upper Eocene of southeastern and eastern Kazakhstan (Kordikova 1993). Dmitriyeva and Nesmeyanov (1982) correlated the Aktau fauna with the Indricothere Svita, which was followed by Russell and Zhai (1987). Our analysis of paleontological and stratigraphic data of the Aktau Mountains indicates that vertebrates from the interval of white quartz sands (Table 1) are early Oligocene in age (possibly with a suggestion from trionychids that the fauna may be older).

CHUL'ADYR FAUNA

At first Bazhanov and Kostenko (1961a, b) listed the Chul'adyr faunas as coming from the conglomerate and sandy interval of the upper part of the Aktau Formation. They mixed material from the interval of greenish and yellowish conglomerates and gritstones and from the interval of grayish and yellowish sands and gritstones (in our terminology). Few bones were found in place but rather from the surface of sediments forming steep and strongly dissected slopes with canyons and fissures. Most bones found by early collectors have no precise stratigraphic information. Further, early reports and preliminary lists were largely based on vertebrates represented by poorly-

diagnostic postcranial material. These mixed lists of an Aktau Mountain fauna have been republished in many different works (Geologiya SSSR 1971, Belyayeva *et al.* 1974, Russell & Zhai 1987, etc.). In general, a middle Oligocene age was proposed for the upper fossiliferous levels on the basis of a different appreciation of correlative relationships of the vertebrate assemblages. Dmitriyeva and Nesmeyanov (1982) compared the mixed faunal assemblage with one from Askazansor. The stratigraphic relations of these fauna have not been well understood by any previous authors.

Lower Member

For this level the presence of *Paraceratherium* is characteristic. Taking *Paraceratherium* into account, the fauna can be correlated with faunas of the localities of Akespe (western Kazakhstan, north Aral Sea region) and Kyzylzhar (southeastern Kazakhstan; Abdrakhmanova *et al.* 1988, Tleuberdina *et al.* 1993). *Paraceratherium* usually indicates a late Oligocene age (see also Lucas *et al.* in press). However, Savinov (Savinov 1963, Kostenko *et al.* 1977) believed that giant indricotheres from the Aktau Mountains are more archaic in comparison with *Paraceratherium prochorovi* known from the Akespe fauna. Later Bayshashov referred bone remnants to Aral species based on general resemblances (Abdrakhmanova *et al.* 1988). Finding of the Oligocene genus *Schizotherium*, known from the beginning of the late Eocene in China

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REPTILIA
- Testudinata
  - Trionychidae
    - Trionychidae indet. [Bazhanov & Kostenko 1961a, b; Kordikova's determination]
  - Emydidae
    - Emydidae indet. [Kordikova's determination]
  - Testudinidae
    - Testudinidae indet. [Kordikova's determination]

MAMMALIA
- Creodonta
  - Creodonta indet. [Bazhanov & Kostenko 1961a, b]
- Perissodactyla
  - Hippomorpha
    - Chalicotheriidae
      - *Schizotherium* sp. [Bazhanov & Kostenko 1961a, b]
  - Ceratomorpha
    - Indricotheriidae
      - *Paraceratherium* sp. [Savinov 1963]
      - Indricotheriidae indet. [Kordikova's determination]
      - Ceratomorpha indet. [Bazhanov & Kostenko 1961a, b]
- Artiodactyla
  - Suiformes
    - Suiformes indet. [Bazhanov & Kostenko 1961a, b]

Table 2.— Updated faunal list of vertebrates from the lower member of the Chul'adyr Formation of the Aktau Mountains, Dzhungarian Alatau Range, compiled from various sources. Fauna is here interpreted as late Oligocene in age.

(Belyayeva *et al.* 1974) unfortunately does not help precise an age. The lithology of this member resembles that of the Askazansor Formation. But it is known that the Askazansor fauna is younger than the Akespe fauna. We hope that new discoveries will help to advance our understanding of this fauna.

Large testudinids also occur in the lower part of the Chul'adyr Formation. The age of this fauna is considered to be late Oligocene.

Middle Member

At present the fauna of the middle member of the Chul'adyr Formation is comparatively well studied (Table 3). The micromammal assemblage consists of insectivores, rodents, and a lagomorph (Kordikova & Mavrin 1996, Kordikova in press). It suggests an end of early Miocene to beginning of middle Miocene age.

Rodents from the middle member of the Chul'adyr Formation include castorids and cricetids. The castorids are represented by *Asiacastor* cf. *A. baschanovi* LYCHEV, 1971, described from the middle Miocene of the Semipalatinsk area (Ayaguz; Lychev & Aubekerova 1971). Species of this Asian genus are also known from Karashigar and Kalkaman in the Pavlodar Irtysh River region, and from Kentyubek in the Turgai region (Lychev & Aubekerova 1971, Lychev 1982, Bendukidze 1993, Tleuberdina *et al.* 1993b).

Discovery of *Democricetodon* appears to indicate a middle Miocene age. In Europe this genus ranges in age from MN4 to MN9 (Bruijn *et al.* 1992). It is also known from the Miocene of China.

The synolagomyine is represented by *Bellatona* cf. *B. kazakhstanica* ERBAYEVA, 1988. This species is known from the middle Miocene of the Semipalatinsk area (Ayaguz) and from the early and middle Miocene of the Zaysan Basin (Akzhar and Sarybulak Svitas) (Erbayeva 1988, 1994).

Macromammals are relatively well documented. Amphicyonids of the middle member of the Chul'adyr Formation are more progressive in comparison with those of Askazansor in Betpakdala (unpublished data).

The rhinocerotid *Brachypotherium aurelianense* is known from the lower Miocene of Kushuk in the Turgai region (Borissyak 1927) and from Les Beilleaux in France (Ginsburg *et al.* 1981). *Brachypotherium* ranges in age from the upper part of zone MN4 to MN7+8 (Bruijn *et al.* 1992).

The Aktau Mountains middle Chul'adyr fauna is characterized by a diversity of artiodactyls, including suids, cervid lagomerycines and muntiacines, and bovids, as well as palaeomerycids and giraffids. *Lagomeryx colberti* CHOW & SHIH, 1978 (= *Lagomeryx simpsoni* TEILHARD, 1939) was described originally from the middle Miocene of Shantung. Specimens earlier referred to *Lagomeryx vallesensis* CRUSAF. & VILL., 1955 (Tleuberdina *et al.* 1993) from the middle member of the Chul'adyr formation appear to belong to *Lagomeryx colberti*. *Lagomeryx* is also known from the European Neogene (Bulot *et al.* 1992) and it ranges in age from MN3 to MN6 (Bruijn *et al.* 1992).

Procervulus gracilis VISLOBOKOVA, 1983 is known from the Oshin Formation of

REPTILIA
- Testudinata
  - Trionychidae
    - *Pelodiscus jakhimovitchae* CHKHIKVADZE, 1989 [= *Trionyx* sp.: Bazhanov & Kostenko 1961a, b]
  - Emydidae
    - *Ocadia iliensis* (KHOZATSKIY & KUZNETSOV, 1971) [= *Clemmys iliensis*: Khozatskiy & Kuznetsov 1971; = *Mauremys iliensis*: Chkhikvadze 1973, Kuznetsov 1978, 1984; = *Melanochelys fontinalis* CHKHIKVADZE, 1973; Kuznetsov 1978, 1984]

MAMMALIA
- Insectivora
  - Talpidae
    - Talpidae indet. [Kordikova & Mavrin 1996]
    - Insectivora indet. [Kordikova & Mavrin 1996]
- Rodentia
  - Castoridae
    - *Asiacastor* cf. *baschanovi* LYCHEV, 1971 [Kordikova & Mavrin 1996]
  - Cricetidae
    - *Democricetodon* sp. [Kordikova & Mavrin 1996]
- Lagomorpha
  - Ochotonidae
    - *Bellatona* sp. [Kordikova & Mavrin 1996]
- Carnivora
  - Amphicyonidae
    - Amphicyonidae new taxon [Kordikova & Mavrin 1996]
- Perissodactyla
  - Rhinocerotidae
    - *Brachypotherium aurelianense* [Tleuberdina *et al.* 1993, Kordikova & Mavrin 1996]
- Artiodactyla
  - Suiformes
    - Suidae indet. [Bazhanov & Kostenko 1961a, b, Kordikova & Mavrin 1996]
  - Ruminantia
    - Cervidae
      - *Lagomeryx vallesensis* CRUSAF. & VILL., 1955 [= *Lagomeryx triacuminatus*: Abdrakhmanova *et al.* 1989; = *Gazella longicornis*: Abdrakhmanova *et al.* 1989] [Tleuberdina *et al.* 1993]
      - *Lagomeryx* sp. [Tleuberdina *et al.* 1993]
      - *Lagomeryx* cf. *colberti* CHOW & SHIH, 1978 [Kordikova & Mavrin 1996]
      - *Procervulus gracilis* VISLOBOKOVA, 1983 [= *Eostyloceros actauensis*: Abdrakhmanova *et al.* 1989; = *Euprox margaritae*: Abdrakhmanova *et al.* 1989] [Tleuberdina *et al.* 1993]
      - *Stephanocemas aralensis* BELYAYEVA, 1974 [= *Stephanocemas brevistephanos*: Abdrakhmanova *et al.* 1989, p. 77] [Tleuberdina *et al.* 1993]
      - *Stephanocemas actauensis* ABDRACHMANOVA, 1993 [Tleuberdina *et al.* 1993]
    - Bovidae
      - *Gazella* sp. [Kordikova & Mavrin 1996]
      - Tragocerini indet. [Kordikova & Mavrin 1996]
    - Giraffidae
      - *Praepalaeotragus actauensis* GODINA, VISLOBOKOVA & ABDRAKHMANOVA, 1993
    - Palaeomerycidae
      - *Palaeomeryx* sp. [Kordikova & Mavrin 1996]
- Proboscidea
  - Gomphotheriidae
    - *Gomphotherium angustidens* CUVIER [Tleuberdina *et al.* 1993, Kordikova & Mavrin 1996]

the lower Miocene of Mongolia. It ranges in age from MN3 to the lower part of zone MN5 (Bruijn *et al.* 1992).

The muntiacine *Stephanocemas aralensis* BELYAYEVA, 1974, is known from Bishtobe in northeastern Ustyurt. *Stephanocemas* is also represented in the middle Miocene Shanwang faunas of China (Qiu & Qiu 1995) and from European Neogene faunas attributed to zones MN5 to MN7+8 (Bruijn *et al.* 1992).

Early bovids, represented by tragocerinines, are known beginning from MN4 (Bruijn *et al.* 1992). The presence of bovids in the Chul'adyr fauna is interesting for understanding the early evolution and ecology of the group.

Discovery of an archaic giraffid, *Praepalaeotragus actauensis* GODINA, VISLOBOKOVA & ABDRAKHMANOVA, 1993, also provides evidence of a middle Miocene age. *Palaeotragus* is present at Akkemer in the Turgai region (Bendukidze 1985).

Palaeomerycids of the genus *Palaeomeryx* are known from the beginning of the middle Miocene at Shanwang in Shandong, China (Qiu Zhanxiang *et al.* 1985) and from the early-middle Miocene at Ulan-Tologoy in western Mongolia (Godina 1994). This genus lived in Europe during the Neogene. It ranges in age from MN3 to MN10 (Bulot *et al.* 1992, Bruijn *et al.* 1992).

The gomphotheriid *Gomphotherium angustidens* (CUVIER, 1806) provides evidence of the early evolution of the group in Asia. This genus is also found at Akkemer in the Turgai Basin (Bendukidze 1985). It ranges in age from MN4 to MN7+8 (Bruijn *et al.* 1992).

Discovery of turtles *Pelodiscus jakhimovitchae* (CHKHIK.), known from early and middle Miocene of Zaysan Basin (localities of Akzhar and Sarybulak Svitas), eastern Kazakhstan, and *Ocadia iliensis* (KHOZ. & KUZ.), probably from the middle Miocene of Kalkaman in the Pavlodar Irtysh River region, suggest correlation of these fossiliferous deposits dating to the end of the early Miocene and the middle Miocene.

The macrofauna from the middle Chul'adyr Formation in the Aktau Mountains can be also compared with the Kushuk and Akkemer faunas of the Turgai region and with Bishtobe in northeastern Ustyurt (Table 4). According to Vislobokova (1990), the Akkemer fauna is referable to MN4 and the Bishtobe fauna belongs to MN4 (Bruijn *et al.* 1992). However, the taxonomic diversity of the Aktau fauna is higher and it is distinguished by the presence of numerous artiodactyls, proboscideans, and turtles. Diversification of artiodactyls in the Ili Basin is parallelled by a relatively high diversity of Salicaceae and Fabaceae, the familial diversities of which are very high (see Rayushkina 1993).

Many genera and some species such as *Democricetodon*, *Brachypotherium*, *Lagomeryx*, *Procervulus*, *Palaeomeryx*, and *Gomphotherium angustidens* are represented in the fauna of Castelnau-d'Arbieu in southwestern France, which is

Table 3.— Updated faunal list of vertebrates from the middle member of the Chul'adyr Formation of the Aktau Mountains, Dzhungarian Alatau Range, compiled from various sources. Fauna is here interpreted as late early Miocene to early middle Miocene in age (MN4-MN6 on a European faunal scale).

	1	2	3	4	5	6	7	8	9	10	11
REPTILIA											
Testudinata											
Trionychidae											
Pelodiscus jakhimovitchae	-	-	+	+	-	-	+	+	-	-	-
Emydidae											
Ocadia iliensis	-	-	+	+	-	-	-	-	-	-	-
Ocadia cf. *iliensis*	-	-	-	-	-	+	-	-	-	-	-
Ocadia sp.											
MAMMALIA											
Rodentia											
Cricetidae											
Democricetodon sp.	-	-	+	-	-	-	-	-	-	-	-
Castoridae											
Asiacastor baschanovi	-	-	-	-	-	+	-	-	-	-	+
Asiacastor cf. *baschanovi*	-	-	+	-	-	-	-	-	-	-	+
Asiacastor major	-	-	-	-	-	+	+	-	-	-	-
Asiacastor aff. *major*	-	-	-	-	-	-	-	-	-	+	-
Asiacastor orientalis	-	-	-	-	-	-	-	+	-	-	-
Asiacastor antecedens	-	-	-	-	+	-	-	-	-	-	-
Lagomorpha											
Ochotonidae											
Bellatona kazakhstanica	-	-	-	-	-	-	-	+	-	-	-
Bellatona ex gr. *kazakhstanica*	-	-	-	-	-	-	-	+	-	-	-
Bellatona cf. *kazakhstanica*	-	-	+	-	-	-	-	-	+	-	-
Bellatona sp.	-	-	-	-	-	-	-	-	+	-	-
Perissodactyla											

Table 4.— Distribution of vertebrates found in the middle Chul'adyr Formation of the Aktau Mountains (column 3) with early to middle Miocene faunas found elsewhere in Kazakhstan.

attributed to zones MN4-MN6 (Bulot *et al.* 1992). Many genera and some species are also characteristic of the middle Miocene Shanwang fauna of China (Qiu & Qiu 1995).

The presence of such archaic taxa as *Gomphotherium angustidens*, *Stephanocemas actauensis*, *Propalaeotragus actauensis*, *Palaeomeryx* sp., and some bovids, is the distinguishing feature of the middle Chul'adyr mammalian fauna of the Aktau Mountains. This is similar to middle Miocene faunas of north Ustyurt in China, of Mongolia, and of southwestern France. In fact, most genera of middle Chul'adyr mammals are known from the middle Miocene Shanwang faunas of China and from the faunal assemblage of Castelnau-d'Arbieu (MN4-MN6) of southwestern France. Thus, the mammalian fauna of the middle member of the Chul'adyr Formation is attributed to zones MN4 and MN6 and indicates an end of the early Miocene and beginning of the middle Miocene age (Orleanian-Astaracian).

CONCLUSIONS

The principal results of this study are documentation of the fossiliferous deposits, mapping of the Tertiary and some other lithostratigraphic units, and lithological correlation of stratigraphic sections. During our investigation a synopsis of previous geological and paleontological study of the region was made, and the mammalian biostratigraphy and biochronology of three vertebrate faunas are here correlated by using the biochronological zonation of the continental Neogene of Europe and Central Asia.

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APPENDIX — MEASURED STRATIGRAPHIC SECTIONS

Lithological units (Arabic numerals) in the measured sections of Fig. 3 and Fig. 5 are described here. Colors are those of Goddard *et al.* (1984).

Unit	Lithology	Thickness (m)

AKTAU I

The section begins at 4436026E, 4871944N. Dip of strata is 10°. This section section is for Lower, Middle and Upper Members of Chul'adyr Formation represented by bed of greenish and yellowish conglomerates and gritstones, bed of grayish and yellowish sands and gritstones, bed of brown and red clays, and bed of carbonate and anhydrite clays.

Chul'adyr Formation

(12) Blue colored clays and dolomites		
174.	Bluish and greenish laminated argillite, strongly carbonate palygorskite, montmorillonite and hydromicaceous clays that are chalky in the lower part of the layer	
(11) Carbonate and anhydrite clays (Slope angle is 32°)		
173.	Gypsum pale brown (5YR5/2) to dark reddish brown (10R3/4)	0.54
172.	Clays; light olive gray (5Y6/1) with numerous gypsum streaks from 1 mm to 5 cm	39.4
171.	Clays; pale olive (10Y6/2) to light greenish clay (5GY8/1); with thin layers of pale reddish brown (10R5/4) to moderate reddish brown (10R4/6) clays and thick gypsum streaks (up to 20 cm)	11.9
170.	Clays; moderate brown (5YR4/4); very chalky	3.3
169.	Clays; pale olive (10Y6/2); with numerous gypsum streaks	4.4
168.	Clays; moderate brown (5YR4/4); with gypsum streaks	1.1
167.	Gypsum; impure greenish gray (5GY6/1) clays	0.83
166.	Clays; moderate brown (5YR4/4); chalky	0.83
165.	Clays; pale olive (10Y6/2) to greenish gray (5GY6/1); very chalky	2.2
164.	Clays; pale yellowish brown (10YR6/2) to moderate brown (5YR4/4); chalky	3.9
163.	Gypsum; impure of pale olive (10Y6/2) to greenish gray (5GY6/1) clays	2.6
162.	Clays; pale yellowish brown (10YR6/2) to moderate brown (5YR4/4); very chalky. Gypsum is either monolithic or streaky from 1 mm to 2-3 cm	11.1
161.	Clays; grayish red (10R4/2); with gypsum layers	12.35
160.	Gypsum	0.13
159.	Siltstones; greenish gray (5GY6/1) to dark greenish gray (5GY4/1) with 3 cm gypsum layers	3.25
(9) Brown and red clays (it starts at 44359190E, 4872051N)		
158.	Clays; moderate brown (5YR4/4, 5YR3/4)	11.1
157.	Clays; pale olive (10Y6/2)	0.33
156.	Clays; same colors and lithologies as unit 158	4.55
155.	Clays; greenish gray (5GY6/1) to light olive gray (5Y6/1)	0.13
154.	Clays; pale yellowish brown (10YR6/2) to moderate brown (5YR4/4)	5.85
153.	Clays; same colors and lithologies as unit 155	0.65
152.	Clays; same colors and lithologies as unit 154	6.5
151.	Clays; same colors and lithologies as unit 155	0.2
150.	Clays; pale brown (5YR5/2) to moderate brown (5YR4/4)	4.55
149.	Clays; greenish gray (5GY6/1)	2.6
148.	Clays; same colors and lithologies as unit 154	6.5
147.	Clays; same colors and lithologies as unit 149	0.65
146.	Clays; same colors and lithologies as unit 154	7.8
145.	Clays; same colors and lithologies as unit 149	0.65
144.	Clays; same colors and lithologies as unit 154	3.25
143.	Clays; same colors and lithologies as unit 149	0.65
142.	Clays; moderate brown (5YR4/4) to light brown (5YR6/4); with spots of grayish yellow green (5GY7/2) to greenish gray (5GY6/1) clays	16.3
(8) Grayish and yellowish sands and gritstones (azimuth of dip is NW355°; dip is 15°)		
141.	Sands; greenish gray (5GY6/1) to yellowish gray (5Y8/1); fine-grained; slightly cemented; highly cemented on the place of contact with above-lying pale red (10R6/2) to dusky yellow (5Y6/4) clays	1.5
140.	Gritstones; yellowish gray (5Y8/1); cemented with debris of clays	0.2
139.	Sands; yellowish gray (5Y8/1) to light olive gray (5Y6/1); fine- and medium-grained; slightly cemented	0.5
138.	Sands; greenish gray (5GY6/1) to yellowish gray (5Y8/1); fine-grained; with cross-bedding of greenish gray (5GY6/1) and pale reddish brown (10R5/4) clays and gypsum-rich beds; with plates of Trionychinae	0.7
137.	Clayey sands; moderate reddish brown	0.15
136.	Silts; dusky yellow (5Y6/40; micaceous	1.5

135. Sands; grayish yellow (5Y8/4); coarse-grained; cross-bedding with debris of dusky yellow (5Y6/4) to light olive brown (5Y5/6) clays and lenses of cross-bedding light brown (5YR5/6) to moderate brown (5YR3/4) gritstones 1.5
134. Sands; dark yellowish orange (10YR6/6) to dusky yellow (5Y6/4); fine-grained; slightly cemented 3.0
133. Sands; light olive brown (5Y5/6); medium- and coarse-grained; cross-bedded 3.0
132. Sands same colors and lithologies as unit 134 4.25
131. Sands; moderate yellowish brown (10YR5/4) to dark yellowish orange (10YR6/6); coarse-grained; in the base lumps of pale blue green (5BG7/2) clays and clayey filler 0.6
130. Sands; moderate yellowish brown (10YR5/4) 5.75
129. Gritstones; moderate yellowish brown (10YR5/4) to dusky yellow (5Y6/4); size 1-8 mm; slightly cemented, with lumps of pale blue green (5BG7/2) clays (5-20 cm) and ferrous nodules; with plates of turtles 1.1
128. Sands; dusky yellow (5Y6/4) to grayish orange (10YR7/4); fine- and medium-grained; cross-bedding of medium- and coarse-grained sands and clayey and pale blue green (5BG7/2) sandy layers; slightly cemented 3.0
127. Gritstones; grayish orange (10YR7/4) to moderate yellowish brown (10YR5/4); with plates of turtles 1.25
126. Sands; dusky yellow (5Y6/4) to grayish orange (10YR7/4); fine- and medium-grained with small-sized inserting lenses of gritstones; bones of vertebrates 1.5
125. Gritstones; same colors and lithologies as unit 127; with bones of vertebrates 3.7
124. Sands; same colors and lithologies as unit 126; with thin-layer lenses (from 1-2 up to 5 cm) of gritstones; in the base layer- bones of vertebrates 1.5
123. Gritstones; moderate yellowish brown (10YR5/4); with lenses of ferrous sandstones in the base layer. Debris material: 70%, clayey and sandy binder; the size of debris is 5-10 mm 1.0
122. Clays; light brown (5YR5/6) to dark yellowish orange (10YR6/6) with spots of yellowish (5Y7/2) clays 0.2
121. Clays; light olive gray (5Y6/1) to grayish orange (10YR7/4); slightly ferrous; with debris of ferrous scales 0.75
120. Sands; grayish orange (10YR7/4); quartz arenite; micaceous with lenses of gritstones extended to 3-4 m, connected with the lower gritstone layer 2.15
119. Gritstones; moderate yellowish brown (10YR5/4); 70% of debris in size of 3-10 mm; with clayey and sandy filler 0.3
118. Sands; pale yellowish brown (5YR6/2) to moderate yellowish brown (10YR5/4); fine- and medium-grained; micaceous; with lumps (up to 0.15 m) of light olive brown (5Y5/6) to moderate reddish brown (10R4/6) clays, extended to 1.5-2 m; with bones of Mastodontoidea 1.25
117. Gritstones; dusky yellow (5Y6/4) 1.25
116. Sands; yellowish gray (5Y7/2); fine- and medium-grained; micaceous; with grits 0.7
115. Gritstones; dusky yellow (5Y6/4) 0.7
114. Sands; same colors and lithologies as unit 116 0.6
113. Gritstones and sandstones 1.25
112. Sands; grayish yellow (5Y8/4) to moderate yellow (5Y7/6); micaceous very fine-grained 1.1
111. Sandstones and gritstones; with lenses clayey fine-grained micaceous sands 3.0
110. Sands clayey; grayish yellow (5Y8/4); with micaceous 3.0
109. Sands; dark yellowish orange (10YR6/6); fine- and medium-grained with 5-10 cm layers of gritstone; painted by Mn compounds 1.5
108. Gritstones; dark yellowish orange (10YR6/6) to moderate yellowish brown (10YR5/4) 0.75
107. Sands; light olive gray (5Y6/1) to dark yellowish orange (10YR6/6); fine-grained with gritstone layers (up to 1-2 cm) 1.2
106. Gritstones; moderate brown (5YR3/4) 0.7
105. Sands; dark yellowish orange (10YR6/6); fine-grained with lumps of pale blue green (5BG7/2) clays 0.65
104. Sands; moderate yellow (5Y7/6); fine-grained; with spots of Mn compounds 2.5
103. Sands; moderate reddish orange (10R6/6) to moderate reddish brown (10R4/6); fine- and medium-grained 0.6
102. Grit; size of debris up to 2-3 cm 0.3
101. Sands; moderate reddish orange (10R6/6) to dark yellowish orange (10YR6/6); fine-grained; slightly cemented 0.3
100. Gritstones; pale reddish brown (10R5/4) to moderate reddish brown (10R4/6) 0.75
99. Gritstones; yellowish gray (5Y7/2); size of debris: 1-30 mm; slightly cemented; in the base layer ferrous sandstones 1.3
98. Sands; grayish yellow (5Y8/4) to yellowish gray (5Y7/2); quartz arenite; micaceous; fine-grained 1.5
97. Gritstones; brownish gray (5YR4/1) to dark gray (N3) interbedding of quartz arenite micaceous fine-grained yellowish gray (5Y7/2) sands 3.5
96. Sands; dark yellowish orange (5YR6/6); fine-grained 4.5
95. Conglomerates, sandy and pebble gritstones; moderate brown (5YR3/4) to grayish brown (5YR3/2); cemented; in the roof not cemented gritstones and pebbles; size of debris: 1-40 mm, prevailing size of debris: 10-20 mm; ferrous and manganic on the place of contact with lower-lying clays 1.5

(7) Greenish and yellowish conglomerates and gritstones

94. Clays; moderate reddish brown (10R4/6) to grayish red (10R4/2); with spots of pale olive (10Y6/2) clays 0.3
93. Clays; dark yellowish brown (10YR4/2) to moderate yellowish brown (10YR5/4); manganic parts range from pale green(5G7/2) and dusky yellow green (5GY5/2) to grayish red (10R4/6) and pale red (10R6/2); with numerous ferrous nodules; sporadic cemented (cemented ferrous and manganic sandstones are formed in other parts of the Aktau Mts.); with gritstones 0.4
92. Clays; moderate reddish brown (10R4/6) 2.3
91. Sands; yellowish gray (5Y7/2); quartz arenite fine-grained; with pebbles and gritstones 2.5
90. Sands; dark yellowish orange (10YR6/6); fine-grained; quartz arenite; with bones of Indricotheriidae 7.25
89. Sands; dark yellowish orange (10YR6/6) with layers (up to 1.5 m) of pebbles or sandstones of effusive rocks of olive gray (5Y4/1) color, less commonly quartz, with sands as a filler 10.0

AKTAU 0 I

Offset on 40 m on South-West. South wing of brachianticline; lock. Dip of strata is 65°. It ends at 44359686E, 4871122N. This section for Upper Member of Ktua Formation, anhydrite gypsum clayey horizon and bed of bright brown and red clays.

Aktau Formation

(6) Bright brown and red clays

88.	Clays; moderate reddish brown (10R4/6) to moderate brown (5YR4/4)7.5	
87.	Sandstones; yellowish gray (5Y7/2); fine- and medium-grained slightly cemented	0.2
86.	Clays; same colors as unit 88	7.25
85.	Sands; yellowish gray (5Y8/1); with varying grain size with 5-10 cm layers of moderate reddish brown (10R4/6) to moderate brown (5YR4/4)	0.4
84.	Sandstones; yellowish gray (5Y8/1) to pale yellowish brown (10YR6/2); medium-grained, of different composition; slightly cemented by greenish gray (5GY6/1)	0.4
83.	Clays; moderate brown (5YR4/4) with few vertical cracks filled by gypsums; lumped, greenish gray (5GY6/1) in the upper part of layer	7.25

(5) Anhydrite gypsum clayey horizon

82.	Clays; grayish yellow green (5GY7/2), very chalky, interbedded with slightly chalky clays	10.0
81.	Gypsums; very pale orange (10YR8/2) to pale olive (10Y6/2) and yellowish gray (5Y8/1)	10.0

AKTAU 0

Start at 44361271E, 4871563N. Azimuth of direction is SW50°. Dip of strata is 11°.

(4) Brick red clays

80.	Clays; dark reddish brown (10R3/4)	17.5
79.	Clays; moderate green (5G5/6) to dark yellowish green (10GY4/4)	0.4
78.	Clays; grayish red (10R4/2) to moderate brown (5YR4/4)	1.4
77.	Clays; same colors and lithologies as unit 79	0.3
76.	Clays; same colors and lithologies as unit 78	0.9
75.	Clays; same colors and lithologies as unit 79	0.2
74.	Sands; grayish yellow green (5GY7/2); fine-grained	1.45
73.	Clays; moderate brown (5YR4/4)	0.2
72.	Clays; same colors and lithologies as unit 79	0.8
71.	Clays sandy; dark reddish brown (10R3/4)	0.5
70.	Sands; grayish yellow green (5GY7/2); slightly cemented	0.3
69.	Sands; yellowish gray (5Y8/1); medium- and coarse-grained with spots of moderate brown (5YR3/4) clays	1.3
68.	Sands clayey; grayish orange (10YR7/4) to moderate yellowish brown (10YR5/4) with gritstone layers	2.2
67.	Sands; very light gray (N8); fine- and middledle-grained	1.9
66.	Sands; grayish orange (10YR7/4) to moderate yellowish brown (10YR5/4)	0.7
65.	Sands; light olive gray (5Y6/1)	0.3
64.	Clays; light brown (5YR5/6)	1.0
63.	Sandy clays; pale yellowish brown (10YR6/2); in the base without sands	4.5
62.	Sands; yellowish gray (5Y8/1); fine-grained	0.4
61.	Clays; grayish orange (10YR7/4) to moderate yellowish brown (10YR5/4); with sands	0.3
60.	Sands; very light gray (N8); fine-grained; with layers (0.2 m) of light brown (5YR6/4) to moderate yellowish brown (10YR5/4)	2.0
59.	Clays; yellowish gray (5Y7/2) to dusky yellow (5Y6/4); with moderate reddish orange (10R6/6), pale pink (5RP8/2) and grayish orange pink (5YR7/2) clayey and sandy layers	1.1
58.	Clays; light brown (5YR5/6)	1.5
57.	Clays; same colors and lithologies as unit 58	1.5
56.	Sands; with∂‰_r-with‰‡,‰; slightly cemented	0.2
55.	Clays; same colors and lithologies as unit 58	2.8
54.	Clayey sands; light brown (5YR6/4)	6.9
53.	Clays; moderate yellowish brown (10YR5/4)	0.7
52.	Clayey sands; pale yellowish brown (10YR6/2) to moderate yellowish brown (10YR5/4)	2.8
51.	Clays; light brown (5YR5/6)	0.9
50.	Sands; same colors and lithologies as unit 51	1.5
49.	Sands; yellowish gray (5Y8/1); coarse-grained	0.1
48.	Sands; very light gray (N8); fine- and medium-grained	1.3
47.	Sandstones; very light gray (N8); medium- and coarse-grained; cemented	0.1-0.2
46.	Clays; moderate yellowish brown (10YR5/4)	1.5
45.	Clayey sands; fine- and medium-grained	1.2
44.	Sands; yellowish gray (5Y8/1); middle and coarse-grained	0.7
43.	Silty sands; grayish orange pink (5YR7/2) to pale yellowish brown (10YR6/2); with layers of grayish red (10R4/2) clays	2.3
42.	Clays; pale reddish brown (10R5/4) to moderate reddish brown (10R4/6)	1.2
41.	Sands; with layers of red-brown clays	3.7
40.	Sandstones; very light gray (N8); coarse-grained	0.2

(3) Red-colored sands, clays and sandstones

39. Clays; reddish brown (10R4/6) 2.8
38. Silts; pinkish gray (5YR8/1) to grayish yellow (5Y8/4) 0.5
37. Clays; moderate reddish brown (10R4/6) 0.9
36. Sandstones; very pale orange (10YR8/2); cemented 0.3
35. Clays same colors and lithologies as unit 37 with sands 0.9
34. Silts; yellowish gray (5Y8/1) 0.1
33. Clays; same colors and lithologies as unit 37 1.1
32. Sandstones; very light gray (N8); interbedding of light brown (5YR6/4) and pale olive (10Y6/2) clays 1.1
31. Clays moderate reddish brown (10R4/6) with 10% of sands 0.5
30. Silts; pinkish gray (5YR8/1) 0.1
29. Clays; light brown (5YR5/6); with a lots of sandy material; with spots of pinkish gray (5YR8/1) clays and lumps (up to 3-5 cm) of cemented sands 1.1
28. Sands; moderate yellowish brown (10YR5/4); fine- and medium-grained 0.8
27. Gritstones; light brown (5YR5/6) and moderate yellowish brown (10YR5/4) in size from 1-2 up to 7 mm 0.4
26. Sands; light brown (5YR5/6); fine- and medium-grained; slightly cemented 0.2
25. Sands; light brown (5YR6/4); medium- and coarse-grained quartz-and-feldspar arenite; with gradual transition into Öœ‡œÇ clayey and sandy, medium-grained mass; slightly cemented; clayey and fine-grained sands dominate in the roof of layer 2.9
24. Clays; moderate reddish brown (10R4/6) to moderate brown (5YR4/4); with layers of light brown (5YR5/6) silts (up to 0.1 m); cemented 4.3
23. Clays; very pale orange (10YR8/2); with spots of moderate reddish orange (10R6/6) clays 0.2
22. Clays; pale reddish brown (10R5/4); calcareous, chalky, with spots of grayish orange pink (5YR7/2) clays 0.5
21. Sandstones; pale yellowish brown (10YR6/2); consist of pinkish gray (5YR8/1) sands and siltstones fine- to coarse-grained 0.7
20. Clays; same colors and lithologies as unit 22 1.5
19. Sandstones; same colors and lithologies as unit 21 0.6
18. Clays same colors and lithologies as unit 22 1.4
17. Clays; grayish orange (10YR7/4), lumped, laminated 0.2
16. Clays; same colors and lithologies as unit 22 1.2
15. Sandstones; light gray (N7); cemented; with Mn dendrites 0.2
14. Clays; moderate reddish brown (10R4/6); kaolinitic; calcareous 1.3

(2) White quartz sands

13. Sands; dusky yellowish brown (10YR2/2); quartz arenite; micaceous; slightly cemented 0.3
12. Sands; grayish orange (10YR7/4); fine-grained; quartz arenite; micaceous 2.8
11. Gritstones; dusky yellow (5Y6/4); in size of 5-15 mm with sands as a filler; among of them lumps of dusky yellow (5Y6/4) clays Ör_r_-rÎr "∂‰_ in size of 1-3 cm with bones [Akt0] are met 0.3
10. Sands; yellowish gray (5Y8/1); medium-grained; quartz arenite; micaceous; slightly limonitic; with layers of gritstones ranged from 5 to 20-25 cm; cross-bedded, with vertical cracks, filled by cemented sands 15.0
9. Siltstones; grayish orange (10YR7/4) to dusky yellow (5Y6/4) 1.7
8. Sands; yellowish gray (5Y8/1); fine-grained; quartz arenite; micaceous 0.7

Akbulak Formation

7. Sandstones; dark yellowish brown (10YR4/2); quartz arenite; micaceous; cemented; slightly limonitic 0.3
6. Sands; yellowish gray (5Y8/1); fine- and medium-grained; quartz arenite; micaceous 5.8
5. Sandstones; very light gray (N8); laminated (marked horizon) 0.5
4. Clays; light brown(5YR5/6) with spots and 0.1 m layers of yellowish gray (5Y8/1) clays; cemented; lumped 4.3
3. Sands; moderate yellowish brown (10YR5/4); laminated; cemented 1.2
2. Clays moderate brown (5YR4/4); lamellar 0.2
1. Sands; yellowish gray (5Y8/1); fine-grained; slightly micaceous; slightly cemented 0.9

AKTAU II

South of second gully. The section ends at 44363149E, 4873984N.

Chul'adyr Formation

(9) Brown and red clays

66. Clays; pale olive (10Y6/2) to greenish gray (5GY6/1)

(8) Grayish and yellowish sands and sandstones

65. Sands; yellowish gray (5Y8/1) to light olive gray (5Y6/1); micaceous 1.75
64. Sands; yellowish gray (5Y8/1) to light olive gray (5Y6/1); coarse-grained 1.0
63. Clays; pale yellowish brown (10YR6/2) to light brown (5YR5/6) 1.0
62. Sands; yellowish gray (5Y8/1) to light olive gray (5Y6/1); fine-grained; micaceous 2.0
61. Gritstones; with greenish gray (5GY6/1) and pale reddish brown (10R5/4) clays 0.2
60. Sands same colors and lithologies as unit 62 1.5
59. Silts; yellowish gray (5Y7/2) to dusky yellow (5Y6/4) 0.6
58. Sands; same colors and lithologies as unit 62 4.25
57. Sands; limonitic dark yellowish orange (10YR6/6) to pale yellowish brown (10YR6/2); coarse-grained; with pebbles 2.5

56. Sands; same colors and lithologies as unit 62 0.75
55. Gritstones; with debris of pale olive (10Y6/2) clays 0.3
54. Sands same colors and lithologies as unit 62 0.65
53. Sands; yellowish gray (5Y8/1); coarse-grained; with pebbles and lumps of pale olive (10Y6/2); with bones of vertebrates 1.0
52. Clays; pale olive (10Y6/2); with spots of moderate red (5R4/6) to grayish red (10R4/2) clays; with bones of vertebrates in roof of layer 0.15
51. Sands; light greenish gray (5GY8/1); fine-grained; micaceous 0.1
50. Gritstones; with bones of vertebrates 0.4
49. Sands; same colors and lithologies as unit 51 0.8
48. Gritstones with plates of turtles and bones of ruminants 0.75
47. Sands; same colors and lithologies as unit 51 0.5
46. Gritstones; with bones of vertebrates; with pale olive (10Y6/2) clays in the base of the layer 1.25
45. Sands same colors and lithologies as unit 62 1.25
44. Nodules ferrous with gritstones and pebbles; dark yellowish orange (10YR6/6) to pale reddish brown (10R5/4); with lumps of yellowish gray (5Y7/2) clays with bones of vertebrates [AktII-1] 1.0
43. Sands; dark yellowish orange (10YR6/6); middledle-grained; with gritstones having 30 % of total volume 1.0
42. Sands; yellowish gray (5Y7/2); fine- and medium-grained micaceous 1.5
41. Gritstones; yellowish gray (5Y7/2); with rare debris of pale olive (10Y6/2) clays 0.7
40. Nodules ferrous; moderate yellowish brown (10YR5/4) to grayish orange (10YR7/4); cemented by clays 0.4
39. Gritstones; same colors and lithologies as unit 41 4.5
38. Sands; yellowish gray (5Y8/1); fine-grained; with cross-bedded of pebbles and gritstones; with bones of vertebrates [AktII-0] 3.0
37. Gritstones with big debris of pale olive (10Y6/2) and moderate yellowish brown (10YR5/4) clays 0.3
36. Sands same colors and lithologies as unit 38 1.5
35. Sands ferrous; dark yellowish orange (10YR6/6) 0.75
34. Gritstones and pebbles; limonitic dusky yellow (5Y6/4) to moderate yellowish brown (10YR5/4); with sands as a filler 0.75
33. Sands clayey; dusky yellow (5Y6/4) to grayish orange (10YR7/4); very fine-grained 0.3
32. Silty sands; grayish yellow (5Y8/4) 3.0
31. Sands; fine-grained; micaceous; debris of yellowish gray (5Y7/2) to dusky yellow (5Y6/4) limonitic nodules and pale olive (10Y6/2) in the base layer 6.5
30. Gritstones; light olive brown (5Y5/6) to dusky yellow (5Y6/4); slightly limonitic 2.25
29. Sands; grayish orange (10YR7/4); fine-grained; quartz arenite; micaceous; ferrous sands in the base of the layer pass into yellowish gray (5Y8/1); a bed of ferrous sandstones up to 0.1 m is in 1 m from a roof of layer 3.0
28. Sands; yellowish gray (5Y7/2); medium-grained; with gritstones and pebbles having 40% content of total volume 1.5
27. Sands ferrous; dusky yellow (5Y6/4); fine- and medium-grained 1.5
26. Ì‡ ∂_c-r-pebbles; slightly cemented; in the base layer bigger ferrous debris are met 2.0
25. Sands; grayish yellow (5Y8/4); medium-grained 0.75
24. Sandstones; yellowish gray (5Y8/1); cemented by the calcite and gypsum 0.1

(7) Grayish and yellowish conglomerates and gritstones

23. Clays; light brownish gray (5YR6/1) 0.2
22. Clays; light brown (5YR5/6) to pinkish gray (5YR8/1) with spots of clays; with a large number of sand and rock debris 0.2
21. Clays; light brown (5YR5/6) to moderate brown (5YR4/4); forming manganic and ferrous sandstones; sporadically cemented into pancakes 0.4
20. Sands; dusky yellow (5Y6/4) to grayish orange (10YR7/4); fine-grained; slightly cemented; with gritstone and pebble layers 3.0
19. Gritstones and pebbles; dusky yellow (5Y6/4); with sands as a filler; the size of gritstones and pebbles is about 1-2 cm 0.75
18. Sands; dark yellowish orange (10YR6/6); fine-grained; micaceous; slightly cemented; with rare layers of pebbles up to 5 cm; with bones of vertebrates in the upper part, in 2.25 m from the roof of the layer 10.0
17. Gritstones and pebbles; moderate yellowish brown (10YR5/4) to grayish orange (10YR7/4); with sandy filler. Sands medium- and coarse-grained, having 10% content of total volume; the size of pebbles and gritstones is from 0.5 to 3-4 cm 0.2
16. Sands fine- and medium-grained with‰‡r∂ _r-l‰_¸‰; cross-bedding of coarse-grained sands and pebbles 0.4
15. Gritstones and pebbles same colors and lithologies as unit 17 0.5
14. Sands; same colors and lithologies as unit 16 1.5
13. Gritstones and pebbles; yellowish gray (5Y7/2); with sandy filler, forming lenses up to 20 cm extended to 20-30 cm; the size of pebbles having 40-50% content of total volume, is 1-3 cm; the size of gritstones having 10% content of total volume is to 7-8 cm 6.0
12. Sands; yellowish gray (5Y7/2); fine- and medium-grained cross-bedding of coarse-grained sands and moderate reddish brown (10R4/6) to moderate brown (5YR4/4); in the upper part bigger debris of ferrous nodules are met; bones of Indricotheriidae are in 0.75 m of the roof layer 3.5
11. Gritstones and pebbles; same colors and lithologies as unit 13 1.5
10. Sands; yellowish gray (5Y7/2); cross-bedding of pebbles having 40% content of total volume 2.0
9. Pebbles; pale yellowish brown (10YR6/2) to grayish orange (10YR7/4); the size of pebbles is from 0.5 to 1-2 cm 1.0
8. Gritstones and pebbles; pale yellowish brown (10YR6/2) to grayish orange (10YR7/4); with sandy filler having 20% content of total volume; the size of debris material is 1-8 cm; with sporadic lenses (up to 0.5 m) of gritstones and pebbles; cemented by Fe and Mn compounds 1.5
7. Sands; yellowish gray (5Y7/2); fine-grained; with pebbles having 30% content of total volume; the size

	of pebbles is to 2-3 cm	1.0
6.	Gritstones and pebbles; pale yellowish brown (10YR6/2) to grayish orange (10YR7/4); with sandy filler; bulk; the size of debris material is from 0.5 to 5-6 cm; sand and gritstone-pebble ratio is 1:1	3.0
5.	Sands; yellowish gray (5Y8/1); medium-grained; cross-bedding of coarse-grained sands; slightly cemented	1.35
4.	Gritstones and pebbles with sandy filler	2.0

Middle part of gully. Offset on 100 m to the north.

3.	Sands fine- and medium-grained with gritstones and pebbles having 20-30% content of total volume; the lower layer sands having lenses-formed structure	1.1
2.	Grits and pebbles; grayish orange pink (5YR7/2) to pale yellowish brown (10YR6/2); with sandy and clayey filler	0.5

Aktau Formation

(6) Bright brown and red clays

1.	Clays moderate reddish brown (10R4/6) to dark reddish brown (10R3/4)	>2.0

AKTAU III

Chul'adyr Formation

(10) Carbonate and anhydrite clays

66.	Clays; light olive gray (5Y6/1); highly chalky	1.0
65.	Siltstones; light gray (N7)	0.5
64.	Clays; greenish gray (5GY6/1); with rare layers of moderate brown (5YR4/4) clays (up to 10-15 cm)	12.0
63.	Clays; greenish gray (5GY6/1); thin 20-cm-interbedding of greenish gray (5GY6/1) and moderate brown (5YR4/4) clays	6.0
62.	Siltstones same colors and lithologies as unit 65	0.3
61.	Clays; yellowish gray (5Y8/1)	0.25
60.	Clays Öœ‡‚‰; pale brown (5YR5/2); slightly chalky with gypsum streaks	0.7
59.	Clays; greenish gray (5GY6/1)	10.5
58.	Clays; greenish gray (5GY6/1); with spots of moderate brown (5YR4/4); very chalky	3.0
57.	Clays moderate brown (5YR4/4) with layers of greenish gray (5GY6/1); chalky	2.25
56.	Gypsum; white (N9) and very light gray (N8)	0.75
55.	Clays; moderate brown (5YR4/4); very chalky; gypsum is in the form of frequent sporadic streaks	1.5
54.	Clays; grayish yellow green (5GY7/2); very chalky, with numerous streaks	1.25
53.	Clays; greenish gray (5GY6/1)	0.75
52.	Gypsum; very light gray (N8)	0.75

(9) Brown and red clays

51.	Clays; greenish gray (5GY6/1) with layers of pale yellowish brown (10YR6/2) to grayish orange pink (5YR7/2)	0.5
50.	Clays; pale yellowish brown (10YR6/2) to grayish orange pink (5YR7/2)	0.75
49.	Clays; moderate brown (5YR4/4)	12.0
48.	Clays; same colors as unit 53	0.5
47.	Clays; same colors as unit 49	6.0
46.	Clays ¤‰_‰-‚‰; cracks filled by gypsum	1.25
45.	Clays; same colors as unit 49	4.0
44.	Clays; same colors as unit 53	0.75
43.	Clays; same colors as unit 49	5.5
42.	Clays; same colors as unit 53	0.75
41.	Clays; same colors as unit 49	1.0
40.	Clays; same colors as unit 53	0.2
39.	Clays; pale yellowish brown (10YR6/2) to moderate brown (5YR4/4)	2.5
38.	Clays; light olive gray (5Y6/1); with layers (up to 5-10 cm) very light gray (N8) dense clays	3.0
37.	Clays; pale red (10R6/2) to pale yellowish brown (10YR6/2); slightly contaminated with sand	2.75
36.	Clays; same colors as unit 53	0.5
35.	Clays; pale red (10R6/2) to pale yellowish brown (10YR6/2)	3.5
34.	Sands clayey; grayish orange pink (5YR7/2)	0.1
33.	Clays; same colors as unit 49	1.75
32.	Clays; same colors as unit 53	0.5
31.	Clays; pale yellowish brown (10YR6/2) to grayish orange pink (5YR7/2)	3.0
30.	Clays; same colors as unit 53	0.75
29.	Clays; grayish orange pink (5YR7/2)	1.5
28.	Clays; pale yellowish brown (10YR6/2)	0.75
27.	Clays same colors and lithologies as unit 29	2.0
26.	Clays; pale yellowish brown (10YR6/2) to grayish orange pink (5YR7/2); with spots of grayish yellow green (5GY7/2) clays	1.25
25.	Clays; pale olive (10Y6/2) to yellowish gray (5Y7/2); dusky yellow (5Y6/4) to yellowish gray (5Y8/1) clays predominate	1.0
24.	Clays; light bluish gray (5B7/1) to grayish pink (5R8/2)	0.65
23.	Clays; moderate brown (5YR4/4)	0.35
22.	Clays; yellowish gray (5Y7/2)	0.5

(8) Grayish and yellowish sands and gritstones

21. Silty sands; yellowish gray (5Y8/1); quartz arenite; micaceous 2.0
20. Clays; light brown (5YR6/4) 0.1
19. Sands; same colors and lithologies as unit 21 1.25
18. Clays grayish orange (10YR7/4) 0.1
17. Sands fine-grained; quartz arenite; micaceous; slightly cemented 2.0
16. Clays; same colors and lithologies as unit 18 0.1
15. Silty and clayey sands; very light gray (N8); quartz arenite; micaceous 2.0
14. Gritstones; with numerous of debris of pale olive (10Y6/2) and moderate yellowish brown (10YR5/4) clays with bones of vertebrates [AktIII-4] 0.25
13. Sands; fine- and medium-grained; slightly cemented 0.5
12. Gritstones; with debris of pale brown (5YR5/2) and pale olive (10Y6/2) clays 0.15
11. Sands; yellowish gray (5Y8/1); fine- and medium-grained; with thin (up to 1-2 cm) layers of lumps of clays and medium-grained sands 1.75
10. Gritstones; interbedding of medium- and coarse-grained sands; slightly cemented; with numerous debris of pale olive (10Y6/2) and dark yellowish orange (10YR6/6) clays with bones of vertebrates 1.25
9. Sands; grayish orange (10YR7/4); fine- and medium-grained; cross-bedding of fine- and medium-grained sands; slightly cemented 2.0
8. Gritstones; light brown (5YR5/6); with sandy and clayey filler; cross-bedded; with lenses of very fine-grained clayey sands; with bones of vertebrates 2.5
7. Sands clayey; micaceous; ¿r‡__-‰∂ _r-l‰_,‰; slightly cemented 1.5
6. Sands; same colors and lithologies as unit 7; not cemented 1.5
5. Gritstones; with plates of turtles [AktIII-3] 0.1
4. Sands fine- and medium-grained ¿r‡__-‰∂ _r-with‰‡,‰; loose and bulk ; with gritstone layers -r↓-rwith_1Ç up to 5 cm 0.75
3. Sands; yellowish gray (5Y7/2); fine- and medium-grained; slightly cemented [AktIII-2] 2.25
2. Gritstones with lumps of pale olive (10Y6/2) and moderate yellowish brown (10YR5/4) clays (up to 10 cm); the size of debris material is from 1-2 to 6 cm [AktIII-1] 0.1
1. Sands; yellowish gray (5Y7/2); medium-grained; slightly cemented >1.5

AKTAU IV

Chul'adyr Formation

(9) Brown and red clays

24. Clays; moderate brown (5YR4/4)

(8) Grayish and yellowish sands and gritstones

23. Sands; yellowish gray (5Y8/1) to light greenish gray (5GY8/1); fine- and medium-grained 1.5
22. Sands; yellowish gray (5Y8/1); fine-grained; micaceous 2.0
21. Sands; yellowish gray (5Y7/2); middledle-grained 0.5
20. Silts; grayish yellow green (5GY7/2); micaceous 1.5
19. Sands; grayish orange pink (5YR7/2); fine-grained 3.0
18. Silty clays; grayish yellow green (5GY7/2) 1.25
17. Gritstones; yellowish gray (5Y7/2) to dusky yellow (5Y6/4); with debris of clays; with bones of vertebrates 1.25
16. Sands; yellowish gray (5Y7/2); fine-grained; micaceous 1.25
15. Gritstones; dark yellowish orange (10YR6/6) to pale reddish brown (10R5/4); with numerous small lumps of yellowish gray (5Y7/2) clays; with bones of vertebrates 1.5
14. Cross-bedding of sands; yellowish gray (5Y7/2); ranged from coarse- to fine-grained of thickness 0.2 m 1.5
13. Sands; grayish orange (10YR7/4) to grayish orange pink (5YR7/2); medium- and coarse-grained 4.5
12. Sands; yellowish gray (5Y7/2); fine-grained; micaceous cross-bedded 1.25
11. Gritstones; grayish orange (10YR7/4) to moderate yellowish brown (10YR5/4); with bones of vertebrates 0.8
10. Sands; yellowish gray (5Y7/2) to light greenish gray (5G8/1); middledle- and coarse-grained; cross-bedding of gritstones 1.25
9. Sands; yellowish gray (5Y8/1); micaceous; fine-grained 1.25
8. Gritstones; same colors as unit 11; with bones of vertebrates [AktIV-1] 1.0
7. Sands; yellowish gray (5Y7/2); fine-grained; with lumps of ¤‰_‰-„ clays; cross-bedded; in the roof part: bones of vertebrates 0.75
6. Sands; dusky yellow (5Y6/4); coarse-grained; with pebbles 0.75
5. Clays; pale olive (10Y6/2) to moderate reddish orange (10R6/6); mottled; with debris of pebbles, gritstones and sands 0.5
4. Sands; yellowish gray (5Y7/2) ; micaceous; fine-grained 1.0
3. Gritstones; same colors as unit 11; with lumps of pale reddish brown (10R5/4) and pale olive (10Y6/2) clays 1.25
2. Sands; yellowish gray (5PY8/1); fine-grained; quartz arenite; slightly micaceous 1.5

Quaternary sediments

1. Gritstones and pebbles

LEGEND OF THE PLATE

PLATE 1

Exposed Paleogene-Lower Neogene outcrops of Aktau Mountains, South Dzhungarian Alatau.

A. Aktau 0; Akbulak and Aktau Formations.

B. Aktau I; Chul'adyr Formation.

C. Aktau I; Chul'adyr Formation, lens of greenish gray clays with fossils (lithological unit N8).

D. Aktau I, "Yurta" Hill; Chul'adyr Formation.

E. Aktau II; Upper Member of Aktau Formation, and Chul'adyr Formation.

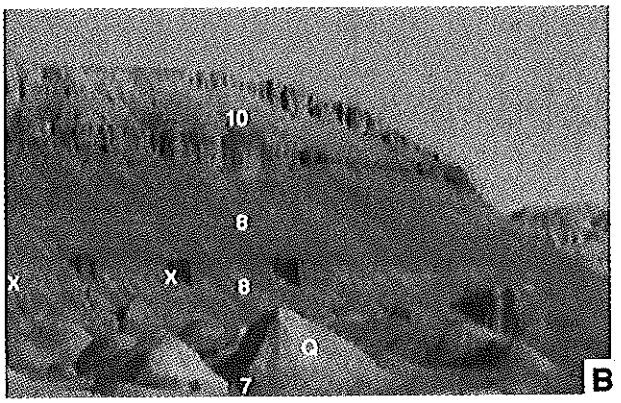
F. Aktau II, south part of gally; Middle and Upper Members of Chul'adyr Formation.

G. Aktau II, north part of gally; Middle and Upper Members of Chul'adyr Formation.

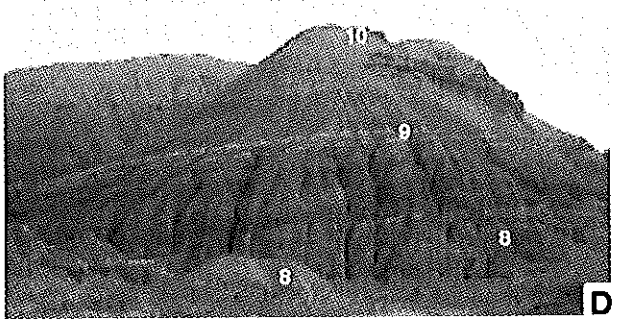
H. Aktau IV; Chul'adyr Formation.

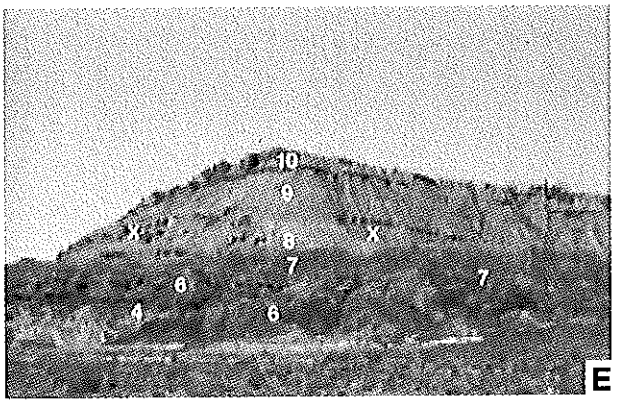
Fossil sites are indicated by cross. Numbers of lithological units are the same as those in Fig. 3.

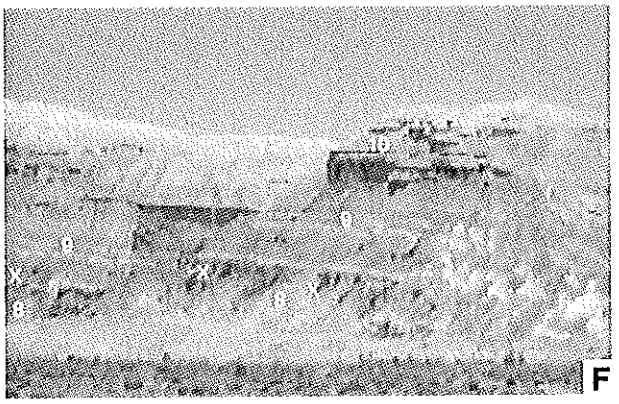

6
5
4
3
2
1
X
X
A

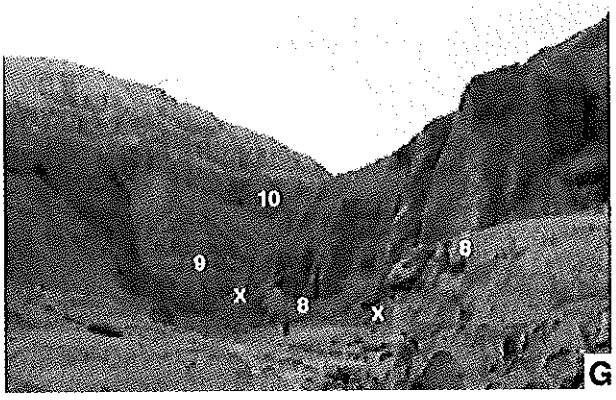

10
8
X
X
8
Q
7
B

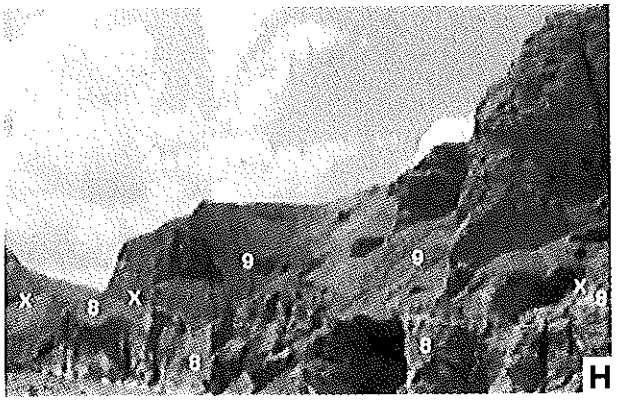

10
9
C


10
9
8
8
D


10
9
X
X
6
7
6
7
4
6
E


10
9
9
X
X
8
8
F


10
9
8
X
8
X
G


9
9
X
8
X
8
8
H