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Stratigraphic Correlation of the Upper Mesozoic–Cenozoic Sequences of the Middle Amur (Sanjiang) Sedimentary Basin

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A stratigraphic correlation of the Upper Mesozoic–Cenozoic sequences of the Middle Amur (Sanjiang) sedimentary basin as a single structure, the northeastern part of which lies in Russia, and the southwestern, in China, has been carried out. Dependence of the structure and composition of the Late Mesozoic sequences on the nature of the basement is demonstrated: the western sector rests upon the Jiamusi–Bureya block; the eastern, on the Nadanhada-Sikhote Alin accretionary fold system. Various parts of the basin obviously differ in the degree of stratigraphic subdivision. Correlation of the main phases of volcanic activity and coal accumulation has become possible. The scope of problems requiring further deeper investigation both in Russia and in China is outlined. The stratigraphic correlation data provide a basis for new paleogeographic and paleogeodynamic reconstructions enabling re-evaluation of the petroleum potential of the Middle Amur basin.

INTRODUCTION

The Middle Amur (Sanjiang) sedimentary basin lies in Russia (northeastern sector) and the Heilongjiang Province of China (southwestern sector). Within the framework of the Russian–Chinese cooperation, an opportunity has arisen to study the boundary structures as a whole and to finally reveal the main regularities of their inception and evolution. The succession of geodynamic events in the Middle Amur sedimentary basin, reconstructed on the basis of comparative analysis of geologic and geophysical data will be described in a series of articles aimed at re-estimating its petroleum potential in the light of new lithologic, paleogeographic, and geodynamic concepts.

Naturally, it is necessary to begin with the examining and correlation of the stratigraphic schemes of the adjacent regions. It should be noted that until recently the Middle Amur basin was interpreted as a Cenozoic basin [4], [5], [6], [7], [8]. During the last decade, however, when deep wells were drilled in both Russian and Chinese sectors of the basin, mostly Cretaceous and in some cases presumably Upper Jurassic deposits were penetrated.

Therefore a necessity arose to correlate the Cretaceous sequences in well sections with those mapped on the rims of the basin and in the inner highs. Two main stratigraphic documents were taken as the basis or standard for correlation. For the Russian territory, the regional stratigraphic schemes adopted in 1990 at the IV Joint Stratigraphic Conference [18] were applied; for the Chinese, the stratigraphic schemes prepared during the compilation of the geological map of the Heilongjiang Province at a scale of 1:1 000 000 and published in the explanatory text [8]. In some cases, the ages of stratigraphic units were corrected and changed according to new data.

THE TECTONIC POSITION AND THE MAIN STRUCTURAL FEATURES OF THE MIDDLE AMUR SEDIMENTARY BASIN

The Middle Amur sedimentary basin lies at the junction between the Jiamusi–Bureya block (with its Paleozoic and Mesozoic foredeeps) and the Sikhote Alin–Nadanhada accretionary fold system (Fig. 1) including a wedge of the Khanka block extending from the south. The boundary between the Urmi trough of the Bureya block and the structures of the Sikhote Alin system runs along the Kukan wrench fault [6]. Such geologic and structural position accounts for the diversity of Cretaceous sequences formed in various parts of the Middle Amur basin.

The Middle Amur sedimentary is presently a system of grabens and horsts. In the southwestern sector of the basin (Sanjiang depression), the first-order structures are (eastward) the Jia–Yi graben, Suebing deep, Fujing high, and Qianjin deep. In the northeastern sector, the first-order structures are the Birofeld–Kur–Urmi graben system, the Pereyaslavka graben, and a series of highs, the largest of which are the Uldura–Churka, Vandan–Gorbylyak, and Khekhtzir highs [4]. Thus far there is no agreement as to the age of the folded basement in the eastern sector of the Middle Amur basin. This problem is comprehensively studied in a highly informative article by B.A. Natalyin and S.G. Chernysh [16], and the authors conclude that the whole Lower Cretaceous complex is part of the basement. But then they were not aware of the latest data on the lithostratigraphy and depositional environments of the sequence penetrated by deep wells in the eastern sector of the Middle Amur basin, the Pereyaslavka graben. In addition, they did

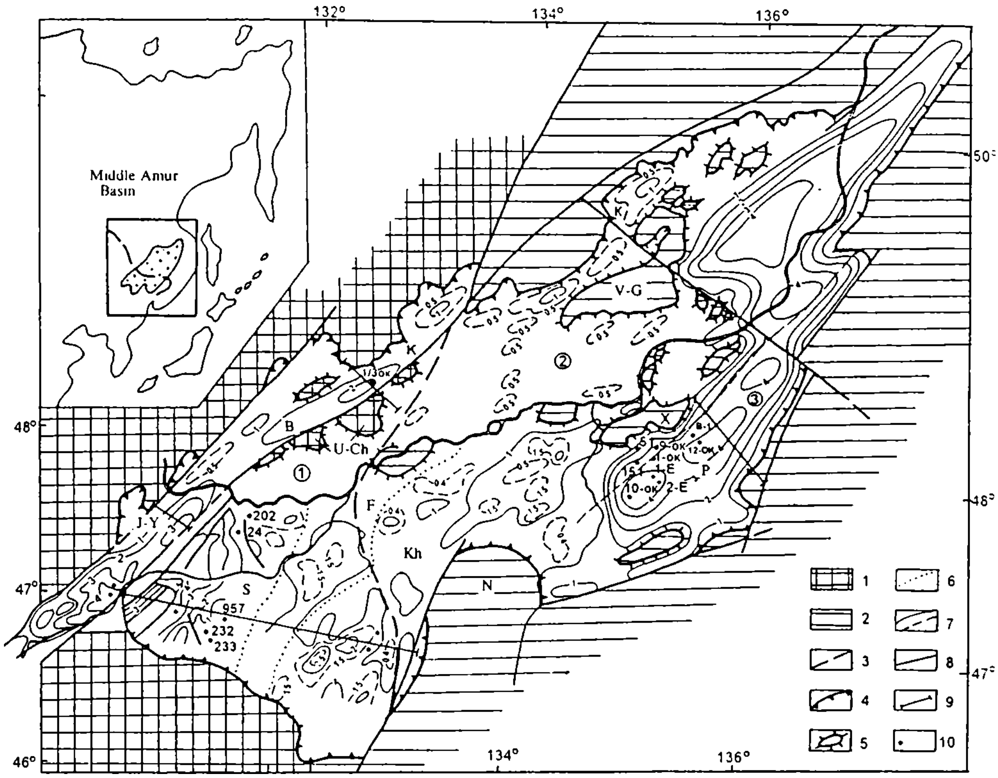


Fig. 1 Tectonic position and major structures of the Middle Amur (Sanjiang) basin. 1 - Bureya block; 2 - Sikhote Alin fold system and Nadanhada terrane (N); 3 - zonal boundaries: Bira-Beloyan (1), Gori (2), West Sikhote Alin (3); 4 - basin boundaries; 5 - structural highs; 6 - limits of the buried Fujin high; 7 - sediment isopachs; 8 - major faults; 9 - section lines; 10 - deepest wells. Grabens: J-Y - Jia-Yi; B - Birofeld; K - Kur-Urmi; P - Pereyaslavka; sags: S - Suibin, Q - Quanjin; highs: F - Fujin, U-Ch - Uldura-Churka; V-G - Vandan-Gorbylyakh; Kh - Khekhtsir.

not take into account the structural zoning of the Cretaceous deposits proposed at the last stratigraphic conference [18] in which the western sector of the Middle Amur basin was classified as the Bira-Beloyan zone of continental Cretaceous strata; the central part, as the Gorin zone (with predominantly marine sequence); and the eastern, as the West Sikhote Alin zone with a coastal marine, transitional to continental volcaniclastic sequence. The Bira-Beloyan zone lies on the margin of the Bureya block, and the Gorin and West Sikhote Alin zones are superimposed upon the Sikhote Alin fold system.

THE STRATIGRAPHIC SUBDIVISION OF THE CRETACEOUS DEPOSITS

The southwestern sector of the Middle Amur sedimentary basin

The Cretaceous deposits of the Sanjiang depression (southwestern Middle Amur basin) are unevenly studied. On the geological map and in the explanatory text [8], they are subdivided into the Lower and Upper Cretaceous with a further subdivision into formations (Fm). Sometimes, correlating the formations with those of the Songliao basin where chronostratigraphy is much better known [25], the recognized formations are dated by certain stages.

In Chinese literature [8], the Cretaceous deposits of the Sanjiang depression are ascribed to the Jiamusi-Wangda Shan zone, although a large lineament subdivides this territory into the proper Jiamusi-Wangda Shan and the Nadanhada terrane.

The Cretaceous sequence of the Jiamusi-Wangda Shan zone appears as follows [8]:

Bomi He Fm. Mostly intermediate lavas and tuffs. Thickness 275 m. K-Ar age 137.5 Ma.

Dongtaling Fm. Acid tuffs, lavas (with perlite beds), and sandstones interbedded with mudstones. Thickness 669 m; carries *Sphaerium jeholense*. K-Ar age 118 Ma.

Chengzi He Fm. Predominant are light-gray medium-coarse sandstones interbedded with siltstones and coal with conglomerate lenses at the base. The 527 m-thick formation carries *Onychiopsis elongata* and *Acanthopteris gothani;* in the lower part, a *Ferganoconcha* was identified, probably correlated with the *Eosestheria-Ephemeropsis-Lycoptera* horizon, whereas the upper part lies below the *Ruffordia* horizon.

Mulin Fm., Xiacengzi Fm. The Mulin Fm. consists of siltstones and fine sandstones with tuffstone, mudstone, and coal beds. Thickness 861 m. The sequence carries *Ruffordia goepperti*; in the upper part, also *Neozamites*. The Xiacengzi Fm. is an equivalent of the Mulin Fm., locally developed in the southern part of the zone. The lagoonal and continental deposits consist of siltstones, sandstones, and mudstones with tuffaceous admixture; thickness is 700 m; the rocks carry *Trigonioides* and *Plicatounio* sp.

Dunshan Fm. consists of intermediate volcanic breccias and agglomerates interbedded with sandstones and mudstones. Thickness is 672 m. From this formation, *Manchurichthys uwatokoi* were identified.

Houshigo Fm. The lower part is composed of conglomerates interbedded with sandstones grading into sandstone and siltstone facies. The upper part consists of sandstones, siltstones, and mudstones. Total thickness is more than 2000 m. The rocks carry the *Platanus* imprints.

Hailang Fm. consists of purple-yellow and brown gravelly gritstones interbedded with silty pelites, fine tuffstones, and tuffaceous siltstones. Thickness is 1404 m. The sequence carries *Estherites mitsuishii* and *E. yui* correlating the host rocks with the Nenjian

Formation of the Songliao basin. Below the fossiliferous horizon, the rocks are extremely thick. In terms of lithofacies and metamorphism, the Hailang Formation as a whole correlates with the Chuantuo-Nenjian formations of the Songliao basin (late Aptian-Coniacian).

Qixing He Fm. consists of purple-gray, green mudstones interbedded with siltstones and conglomerates with a thickness of 309 m, carrying spores and pollen similar to those in the Sifangtai Formation of the Songliao basin (early Maastrichtian).

Yanwo Fm. consists of purple-gray, green sandstones and sandy conglomerates interbedded with mudstones and silty mudstones with a total thickness of 297.5 m and carries a spore and pollen assemblage corresponding to that in the Minsui Fm. of the Songliao basin (late Maastrichtian).

The Cretaceous biota was dominated by diversified abundant continental forms. During the Early Cretaceous, the *Lycoptera-Eosestheria-Ephemeropsis* fauna widely developed in the western sector of the region, whereas the eastern Rao He zone was dominated by the marine *Buchia*. In the Xiacengzi district of the Mulin province, the *Trigonioides* fauna was predominant. The plants flourished in the east and were depleted in the west; they correspond to the middle-late phase of the *Ruffordia-Onychiopsis* assemblage. The late phase of the assemblage contains protoangiosperms.

The Upper Cretaceous carries abundant ostracods, estherias, and charophytes.

This stratigraphic scheme was corrected and somewhat amended in the areas covered by detailed stratigraphic surveys and drilling.

During the last decade, following a revision of the age of some fossil groups, some formations in northeastern China were reclassified from Upper Jurassic to Lower Cretaceous [20], [26], [27], [33], [36], [37], etc. Particularly great changes affected the Lunzhaogou and Jixi groups containing a number of coaliferous formations in the eastern Heilongjiang. Formerly they were dated as Middle-Late Jurassic, but after the revision of fossil flora and fauna (for instance, some buchias are presently interpreted as aucellines) most of workers classify these formations as Early Cretaceous [26], [28], [33], [34], [35], [36], [37], [38], etc. In addition, the Barremian ammonites were identified in the rocks of the Qihuling Fm. of the Lunzhaogou Group [24], [31]. Nevertheless, not all problems are finally solved. For instance, views differ as to the position of the Jurassic/Cretaceous boundary in marine and non-marine sequences [23], [26], [27], [34].

Particularly intense were the studies of the Nadanhada terrane undertaken by geologists from various countries. Mizutani [32] first proposed in 1987 that the Mino terrane in central Japan, Nadanhada in northeast China, and west Sikhote Alin are parts of a formerly single Mesozoic superterrane. At present, after numerous corrections, the sequence appears as follows [38]. The Middle-Upper Triassic-Lower Jurassic succession consists of red, green, and gray cherts and cherty shales with occasional limestone lenses carrying conodonts. Above is sedimentary melange with exotic (up to 300 m) blocks of Carboniferous-Permian limestones (carrying fusulinids, crinoids, and corals) and

Mesozoic cherts. The limestones are supposedly deposited on the ancient East Tethyan oceanic plateaus. The silty-muddy matrix of the melange carries the Middle Jurassic radiolarians. Collision of the superterrane with the continental margin took place late in the Middle Jurassic [38], i.e. almost simultaneously with the collision of the Samarka terrane with the continental margin and the Siberian block with Bureya. After that, the amalgamated terranes and blocks were buried beneath the Upper Jurassic–Lower Cretaceous clastic deposits (mudstones, siltstones, sandstones, and conglomerates) carrying ammonites and bivalves characteristic of a neritic depositional environment. At the base of the latter sequence are basal conglomerates carrying the Middle Triassic–Middle Jurassic radiolarians in the clasts. Above are the basalts widespread in the eastern Heilongjiang Province and dated in the interval of 111.3–97.9 Ma [30].

The eastern Nadanhada terrane extends into the Russian territory and is bounded to northeast by the Dunhua-Mishan fault and its northeastern extension. The sedimentary melange or mixtites were first recognized by S.Yu. Belyaev [2] in a section along the Amur River near Khabarovsk; later, the problem of mixtites in the Amur region was thoroughly studied by E.K. Shevelev [15], [21]. As a result, much of the Paleozoic, Triassic, and Jurassic sequences and formations previously recognized on the margins of the Bureya massif were found to be merely blocks and olistoliths floating in the Lower Cretaceous matrix. The Khabarovsk sequence was studied later by many workers. The principal structural features of this sequence and the relevant problems were repeatedly discussed by Natalyin [16], etc. The matrix is differently dated by various scientists. Matsuoka and Zyabrev report (personal communication) about the finds of poorly preserved late Tithonian–Valanginian radiolarians in the matrix – that is the youngest possible age of the matrix. However, this report requires a detailed examination.

In the Russian territory, the Jurassic/Cretaceous boundary was long studied by I.I. Sei, E.D. Kalacheva, and E.P. Brudnitskaya [19], etc. This boundary is best studied in the Western Okhotsk region and South Primorie.

Table 1 shows the position of the Jurassic/Cretaceous boundary based on buchias and the subdivision of the Cretaceous based on buchias and aucellines; you may see that the Russian and Chinese subdivisions are not quite identical, and the discrepancies are yet to be worked on.

Another problem is the age of the Chengzi He coaliferous formation of the Jixi Group. Formerly it was dated as Jurassic. Several years ago, a brackish-water mollusk, *Tetoria yokoyamai* (Ko. et Suz.) typical of the Berriasian in Japan [20], was identified from this formation in the eastern Heilongjiang. In the northern and southern Suebin deep, this formation was penetrated by wells and subdivided into four members with a total thickness of 850 m (Fig. 2). Its spore and pollen age was identified as Hauterivian–Barremian [28]. In addition, marine beds with the Valanginian–Hauterivian dinophlagellates were recently identified from the lower Chengzi He Formation in the eastern Heilongjiang Province [35]. In the upper parts of the formations, the authors describe the earliest angiosperms.

In general, the authors give the formation a wide age range, Berriasian-Hauterivian (or up to early Barremian). It should be noted that the earliest appearance of Late Hauterivian angiosperms in Primorie was reported in the Staryi Suchan coaliferous formation [11]. In addition, the Chengzi He Formation in the Suebin deep of the Sanjiang depression is underlain by the Dongrung Formation (Fig. 2) whose spore and pollen age is established as Berriasian-Valanginian [28]. It is interesting that the dinophlagellates were identified in well 202 at a depth of 328 m (Chengzi He Fm., Hauterivian-Barremian) and 603 m (Dongrung Fm., Berriasian-Valanginian). Therefore the latter version of subdivision suggested by Li Wen-ben [28] is probably the most reliable.

Table 1

System	Series	Stage	Substage	Nadanhada Terrane		Sikhote Alin Fold System
				Sun Ge et al. 1992 [35]	Sha Jin-geng 1992 [33]	Decision of the IV Stratigraphic Conference [18]
K	Lower	Albian				Quadratatrigonia fudsensis-Actaeonella dolium Quadratatrigonia (Transitrigonia) fudsinensis Mirol., Pterotrigonia pocilliformis (Yok.), P. hokkaidoana (Yeh.) Ussuritrigonia ussurica Konov., Inoceramus salomoni Orb., I. concentricus Park., Panope gurgitis (Brongn.), P. kissoumi (Mlag.), Thracia sanctae-crucis Pictet et Camp., Callista pseudoplana Yabe et Nagao, Actaeonella dolium Roem., A. orientalis Pcel.
		Albian / Aptian				Aucellina caucasica (Buch); Aucellina aptiensis Pomp.
		Aptian			A.cf.caucasica A.cf.aptiensis A. jeletzkii A. aptiensis A.caucasica	
		Barremian			?	Inoceramus colonicus Inoceramus colonicus Anders., I. ex gr. paraketzovi Efim.
		Hauterivian				
		Valanginian		B.pacifica		Buchia solida Buchia solida (Lah.), B. crassicollis (Keys.), B. tisangensis (Sok.), B. sublaevis (Keys.)
				B.volgensis B.cf.okensis B.cf.subokensis B.unschensis	B.pacifica	Buchia inflata: Buchia pacifica Jeletzky, B. inflata (Toula), B. keyserlingi (Lah.), B. crassicolis (Keys.), B. solida (Lah.), B. billoides (Lah.), B. sibirica (Sok.), B. nikitini (Sok.), B. uncitoides (Pavl.), B. volgensis (Lah.), B. surranensis (Pavl.)
						Buchia pacifica: Buchia uncitoides (Pavl.), B. volgensis (Lah.), B. terebratuloides (Lah.), B. sibirica (Sok.), B. inflata (Toula), B. keyserlingi (Lah.), B. billoides (Lah.), B. pacifica Jeletzky
		Berriasian (Ryazanian)			B.volgensis B. okensis B. subokensis	Buchia uncitoides Buchia uncitoides (Pavl.), B. volgensis (Lah.), B. terebratuloides (Lah.), B. keyserlingi (Lah.), B. cf. inflata (Toula)
						Buchia volgensis-B.okensis Buchia volgensis (Lah.), B. okensis (Pavl.), B. fischeriana (Orb.), B. terebratuloides (Lah.)
J	Upper	Volgian	U	B.fischeriana- B.unschensis	B.fischeriana B.unschensis	Buchia piochii (Gabb.), B. piochii f. tenuicollis (Pavl.), B. fischeriana f. andersoni (Pavl.), B. trigonoides (Lah.)
			M	B.russensis- B.fischeriana	B.russensis- B.fischeriana	Buchia piochii (Gabb.), B. fischeriana (Orb.), B. mosquensis f. orbicularis (Hyatt), B. trigonoides (Lah.) B. terebratuloides (Lah.), B. cf. circula (Pavl.), Mytiloceramus ex gr. retrorsus (Keys.)
			L			Buchia mosquensis (Buch.), B. mosquensis f. rugosa (Fisch.), Myophorella aff. orientalis Kob. et Mori, Lotrigonia kraatschini (Vor.), Pinna subradiata Pcel., Camptonectes lens Sow., Mytiloceramus ex gr. retrorsus (Keys.)

Considering the above data, we have made an attempt to compile a generalized sequence of the Cretaceous in the Suebin deep subdivided by stage (Fig. 3). The

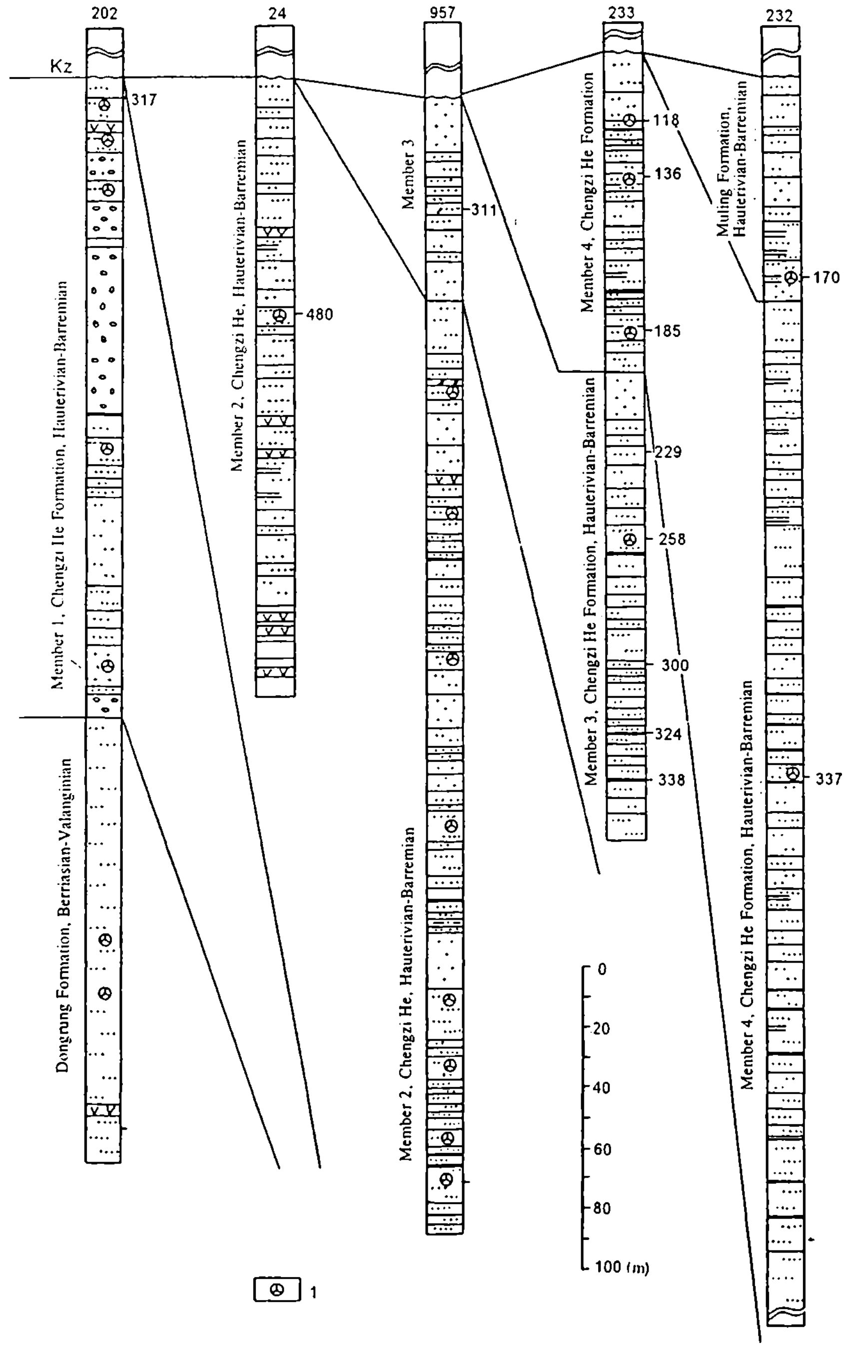


Fig. 2 Correlation of well sections in the Suibin sag [28]. 1 – localities of samples with spore and pollen spectra.

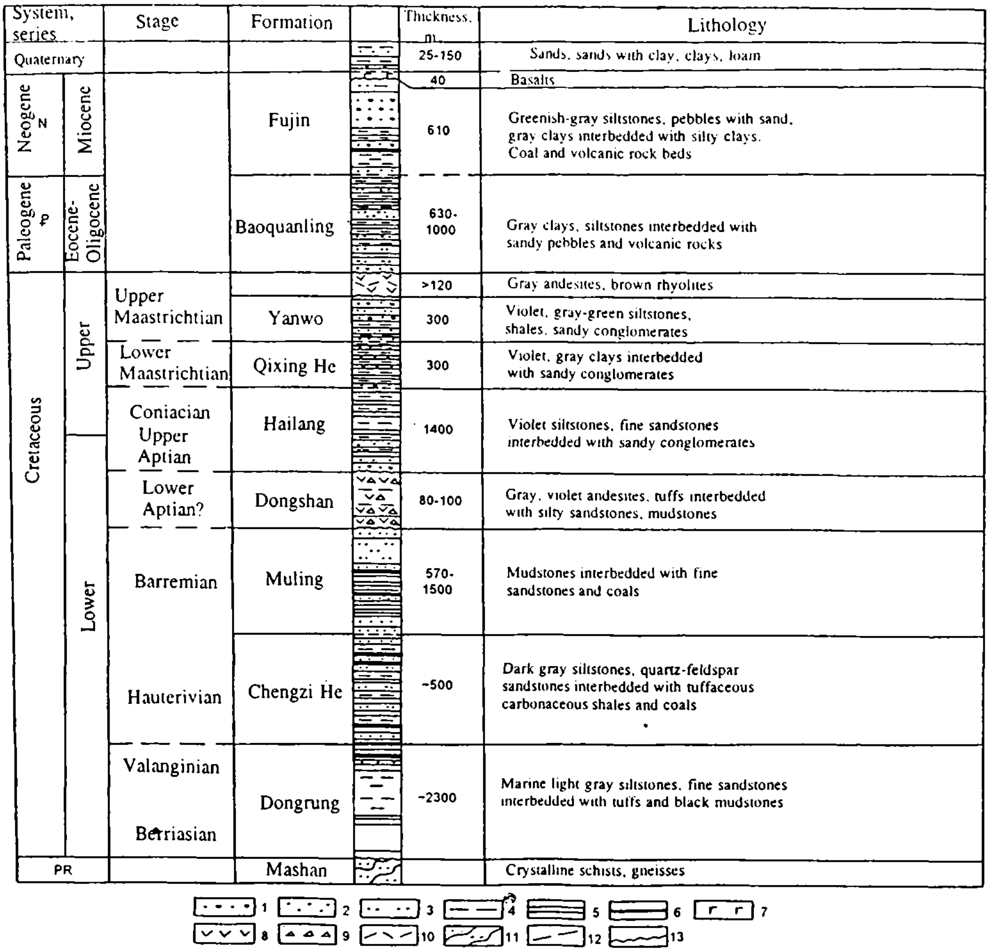


Fig. 3 Well section in the Suibin sag. 1 - pebbles with sand, sandy conglomerates; 2 - inequigranular sands; 3 - fine sands and sandstones; 4 - siltstones; 5 - shales; 6 - coals; 7 - basalts; 8 - andesites; 9 - andesite tuffs; 10 - rhyolites; 11 - crystalline basement; 12 - conformable contact; 13 - unconformable contact.

schematic cross-section of the southern Sanjiang depression clearly shows alternating horsts and grabens of various size and with various Cretaceous thicknesses (Fig. 4).

The northeastern sector of the Middle Amur sedimentary basin

As the southwestern, the northeastern sector of the Middle Amur basin is a system of grabens and horsts. Within the latter, Cretaceous and older deposits are exposed. Three zones are recognized from W to E: Bira-Beloyan, Gorin, and West Sikhote Alin, differing in sequence lithology.

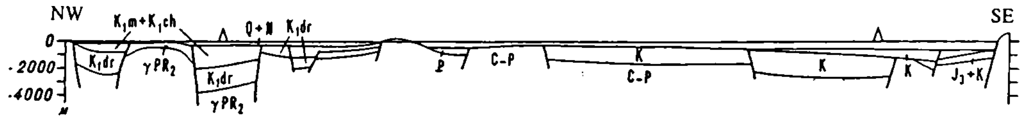


Fig. 4 Schematic geologic cross-section of the southern Sanjiang depression. See Fig. 1 for section line location. K_1dr - Dongrung Formation; K_1ch - Chegzi He Formation; K_1m - Muling Formation; γPR_2 - Proterozoic granites.

The Cretaceous sequence of the Bira-Beloyan zone located on the margin of the Bureya block is composed of interbedded continental, terrigenous, and volcanic strata resting upon the Early Paleozoic granites and Early Proterozoic rocks (Table 2). Also, Devonian, Upper Permian, and Triassic strata are exposed on the southeastern flank of the Birofeld graben within the Uldura-Churka high.

It should be noted that during the 1970s vast fields of the Jurassic coal-bearing clastics with a total thickness about 2000 m (Langari, Katon, Budukan formations) were mapped in the Bira-Beloyan zone. The Jurassic age of these deposits was poorly substantiated. In the light of Kiryanova's data, the phytostratigraphy of the Cretaceous deposits in the neighboring Lesser Khingan zone farther west, where a complete Cretaceous sequence from the Berriasian to Maastrichtian has been identified, suggests a possibility to date some of the Jurassic strata as Cretaceous, but this requires additional investigations. As it is, only the Middle Cretaceous rocks are established in the Bira-Beloyan zone.

The Gorin zone of the Sikhote Alin fold system extends northeastward from Khabarovsk to the lower reaches of the Amur River. Here, the Cretaceous sequence is fairly complete; the recognized formations, correlations between them, thicknesses, and fossil fauna and flora assemblages are given in Table 3. The necessity to additionally study the stratotypes of the formations recognized in the Komsomolsk Group more than 30 years ago and revise the necessity to subdivide the Gorin zone into two subzones, Vandan and Chayatyn, was pointed out at the IV Stratigraphic Conference [18] and should be agreed with. The suggested sequence of the Gorin zone does not show the olistostrome sequence widespread in the southern sector of the zone. The age of the matrix of that sequence is interpreted differently, from the Upper Jurassic to Hauterivian. This problem requires further investigations.

The Cretaceous sequence of the West Sikhote Alin zone is somewhat different (Table 4). During the last decade, the southeastern termination of the Middle Amur basin in the Bikin drainage area was covered by geologic mapping and special surveys, which led to the compilation of a new stratigraphic scheme for that area [9], [10], [12], [13], [17]. The abundant fossil fauna finds enabled the dating of inception of volcanic activity in that zone

Table 2

System	Series	Stage	Substage	Bureya Block / Bira-Beloyan Zone / 1
Cretaceous	Upper	Maastrich	Upper	
			Lower	
		Campan	Upper	
			Lower	
		Santonian	Upper	
			Lower	
		Coniacian	Upper	
			Middle	
			Lower	
		Turonian	Upper	
			Middle	
			Lower	**Nabatov Sequence** Andesites, their tuffs and lava brecciasl. Equisetum sp., Pinus sp., Taxodiaceae sp., Vitis sp.
		Cenomanian	Upper	
			Middle	280-600м
			Lower	? **Bira Sequence** Sandstones, siltstones, and their tuffaceous varieties; acid tuffs; tuffites Asplenium cf.dicksonianum Heer, Gleichenia sachalinensis Krysht., Ginkgo sibirica Heer, Cephalotaxopsis brevifolia Font., C.acuminata Krysht. et Pryn., Sequoia cf. fastigiata (Stern.) Heer
	Lower	Albian	Upper	
			Middle	
			Lower	75-100м
		Aptian	Upper	? **Shuki-Poktoi Sequence** Rhyolites, dacites, acid tuffs and volcanic breccias 400-500м
			Middle	? **Bolshaya Churka Sequence**
			Lower	Andesites and andesitic lava breccias 200-250м
		Barremian	Upper	Sandstones, siltstones, mudstones, conglomerates, coals Onychiopsis mantelii Brongn., O.cf.elongata (Geyl.) Yok., Coniopteris hymenophylloides (Brongn.) Sew., C.orientalis (Shenk.) Pryn., Cladophlebis nebbensis (Brongn.) Nath., C.haiburnensis (L. et H.) Brongn., Sphenopteris naktongensis Yabe, Podozamites lanceolatus (L. et H.) Braun, Ginkgo sibirica Heer, G.digitata (Brongn.) Heer, Nilssonia cf.schmidtii (Heer) Sew.
			Lower	700-750м
		Hauteriv	Upper	
			Lower	
		Valangin	Upper	
			Lower	
		Berriasian	Upper	
			Lower	

PR_1 γPZ_1

Table 3

System	Series	Stage	Substage	Sikhote Alin Fold System — Gori Zone — 2
Cretaceous	Upper	Maastrichtian	Upper	Tuffstones, tuffaceous siltstones and conglomerates, brown coal beds, rhyolite tuffs
			Lower	? Onoclea sensibilis L., Trochodendroides ex gr.arctica (Heer) Berry, Mognolia sp. 170м
		Campanian	Upper	
			Lower	Tatarka Formation
		Santonian	Upper	Dacites, dacite tuffs and ignimbrites, rhyolites, tuffites, tuffstones, tuffaceous conglomerates, tuff breccias Cephalotaxopsis heterophylla Holl., C. intermedia (Holl.), Glyptostrobus europaeus Heer, Metasequoia disticha (Heer) Miki, Taiwania sp., Dicotyledones sp.
			Lower	500м ?
		Coniacian	Upper	Bolbin Formation
			Middle	Andesites, andesite lava breccias and tuffs, basalts, basaltic andesites, lava-conglomerates, tuffstones, tuffaceous siltstones, dacites Cladophlebis frigida (Heer) Sew., Asplenium dicksonianum Heer, Gleichenia gracilis Heer, Metasequoia sp., Cephalotaxopsis intermedia (Holl.), C. heterophylla
			Lower	(Holl.), Platanus cf.cuneifolia (Bronn.) Vachr., Trochodendroides ex gr.arctica (Heer) Berry, Credneria inordinata Holl.
		Turonian	Upper	
			Middle	950м
			Lower	? Utitsa Formation Upper member Tuffstones, tuffaceous siltstones, basaltic andesites, andesites, andesite tuffs 500м
		Cenomanian	Upper	Lower member Sandstones, tuffstones, andesites, and the associated tuffs. *Inoceramus* cf. *nipponicus* Nag. et Mat. 450-600м
			Middle	Silasi Formation 'A Upper member. Siltstones, mudstones, tuffstones about 400м
			Lower	Lower member. Siltstones, mudstones, silicified tuffs Inoceramus sf.beringensis Perg., I.ginterensis Perg., I. aff.tenuistriatus Nag. et Mat., I. sichotealinensis Zon., I.pressulus Zon., I. cf.nipponicus (Nag. et Mat.), J. ex gr.concentricus Park.
			Upper	500м

Table 3 (continued).

Series	Stage	Substage		
Lower	Albian	Upper	Sitogi Formation Top: sandstones, members of rhythmically interbedded sandstones and siltstones Bottom: sandstones, siltstone beds, conglomerates. Boulders in the conglomerates contain goudryceras (Eogoudryceras) shimizui menneri Avdeiko, Anagaudriceras aurarium (And.) Inoceramus concentricus Park. Aucellina pekulnejensis Ver., A. cf.caucasica Buch, Eo-	600-800м 700-800м
		Middle	?	
		Lower	Gornaya Protoka Formation Sandstones, siltstones, members of rhythmically interbedded sandstones and siltstones; tuffstones; gritstones; conglomerates; cherts with radiolarians; spilites Inoceramus anglica Wood	Siltstones, mudstones, cherts and cherty mudstones, spilites
	Aptian	Upper		
		Middle	Aucella sp.	
		Lower		
	Barremian	Upper	Inoceramus sp.	Alievium cf.helenae Schaaf,Crolanium triquetrum Pessagno, Xitus olievi (Foreman), X.spicularius (Aliev), Thanaria conica (Aliev), Holocryptocanium aff. barbui Dumitrica
		Lower	до 1450м	more than 300м
	Hauterivian	Upper		?
		Lower		
	Valanginian	Upper	Komsomolsk Group Livan Formation Sandstones, siltstones, rhythmically interbedded sandstones and siltstones, gritstones, sedimentary breccias, conglomerates Buchia aff.keyserlingi (Lah.), B. inflata (Toula), B. inflata f.crassa (Pavl.), B.cf.uncitoides (Pavl.), B.fischeriana (Orb.) Onychiopsis elongata (Geyl.) Uok., Kilianella sp. 1400-1600м	
		Lower		
	Berriasian	Upper	Pionersk Formation Siltstones, mudstones, sandstones Buchia bulloides (Lah.), B.inflata (Toula), B.inflata f.wollassowitschi (Sok.), B.uncitoides (Pavl.), B.sibirica (Sok.), B. cf.keyserlingi (Lah.), B.ex gr.fischeriana (Orb.), B.terebratulbides (Lah.), Lima consobrina (Orb.), Inoceramus wollossowitschi Sok., I.vereshagini Poch., I. (Anopaea) cf.sphenoides Geras.; Jakutiella? amurensis (Nov.) Sam., Coniopteris cf.angustiloba Brick., Cladophledis orientalis Pryn., Nikania? aff.pectinata Pryn., Podozamites cf.angustifolius (Eichw.) Heer 2000м	
		Lower	Gori Formation Sandstones, siltstones, rhythmically interbedded sandstones and siltstones, mudstones, gritstones, limestone lenses, cherts Buchia ex gr.uncitoides (Pavl.), B.volgensis (Lah.), B.okensis (Pavl.) 1300-1700м	
			J_3vg	?

Table 4

System	Series	Stage	Substage	Sikhote Alin Fold Zone		
				West Sikhote Alin Zone A		
				Rivers Bikin (lower course), Podkhorenok, Vtoraya Sedmaya, Matai, Si, Nempta, Durmin, Alchan, Ulitka; Strelnikov Ridge		
				3		
Cretaceous	Upper	Maastrichtian	Upper	Rhyolites and the associated tuffs 700м		Ash tuffites, siltstones, coals. Spores and pollen: dominant flowering plants; typical forms are Orbiculapollis lucidus Chlon., O. globosus (Chlon.), O. reticulatus Markev., Fibulapollis mirificus (Chlon.) Chlon., Aquilapollenites spinulosus Sriv., A.minutulus Stanl., Tricolpites microscabratus Nort., Triporopollenites plectosus Anders., Triatriopollenites aroboratus Pfl. up to 400м
			Lower	Andesites, andesite tuffs and tuffolavas Cephalotaxopsis intermedia (Holl.), E.gracillima (Holl.), Taxodium cf.dubium (Sternb.) Heer, Sequoia ambiqua Heer, Platanus cuneifolia (Bronn.) Vachr. 500м		Severyanka Sequence. Andesites, basaltic andesites, and the associated tuffs; conglomerates Sequoia minuta Sveshn., Glyptostrobus vachrameevii Svechn., Menispermites cf.nelumbites Budants., Trochodendroides arctica (Heer) Berry etc. up to 450м
		Campanian	Upper			
			Lower			Zalomi Sequence. Conglomerates, gritstones, sandstones, mudstones, coals. Asplenium dicksonianum Heer, Sphenopteris stricta (Newb.) Bell., Araucarites longifolia Dorf., Menispermites kujiensis Tanai, Macclintockia spp. etc. Spores and pollen: dominant flowering plants, typical forms are Tricolpites mataurensis Coup., T. lilei Coup., T. gracilis Bratz., T.varius Norr., T. sagax Norr., Aquilapollenites asper N.Mtch., A.cruciformis N.Mtch., A.reticulatus (N.Mtch.) Thudy et Leopold., A.trialatus Rouse., Orbiculapollis globosus (Chlon.) Chlon., O. lucidus (Chlon.) Chlon., Proteacidites thalmanii Anders. up to 350м
		Santonian	Upper			
			Lower			
		Coniacian	Upper			
			Middle	?		?
			Lower			
		Turonian	Upper			
			Middle			
			Lower			
		Cenomanian	Upper			...ovka Sequence. Conglomerates, sandstones, siltstones. Paleoleptesteria favosa Oleyn., Bairdesteria abbreviata Oleyn., Onychiopsis psilotoides (Stokes et Webb.) Ward., Nilssonia yukonensis Holl., Cephalotaxopsis heterophylla Holl., Araliaephyllum sp., Protophyllum sp. etc. Spores and pollen: dominant Taxodiaceae, typical forms are Taxodiumpollenites hiatus (Pot.) Kremp., Foveosporites cenomanicus (Chlon.) Schwetz., F. canalis Balme., Selaginella kemensis Chlon., Lobatia involucrata (Chlon.) Chlon., Flowering Tricolpites micromunus (Groot et Penny) Singh., Polyporites clarus N.Mtch. up to 450м
			Middle			
			Lower	Basalts, conglomerates, tuffaceous siltstones, литы, туфопес-tuffstones Excentropylomma cenomana Dumit., Holocryptocanium barbui Dumit., Obesacapsula cf.somphedia (Foram.) about 600м	? Eoqu...marites?, Neogastroplites ?	Alchan Formation. Dacite, rhyolite, andesite tuffs and lavas; tuffaceous siltstones, tuffstones, conglomerates. Upper part: Birisia onychioides (Vassil. et K.-M.) Samyl., Athrotaxopsis expansa Font., Sapindopsis variabilis Font., Laurophyllum lower part: Limnocyrena andersoni (Grub.), L. cyclica Yakush., Viviparus sp.; Cladophlebis frigida Heer, Nilssonia densinervis (Font.) Berry, Ginkgo ex gr.adiantoides (Ung.) Heer, Athrotaxites berry Bell. Spores and pollen: dominant Taxodiaciae, typical forms are Taxodiumpollenites hiatus (Pot.) Kremp., Gnetaceaepollenites mitucustatus (Brenn. et Norr.) Verb., Lophotriletes babsae (Brenn.) Singh., Acquitriradites verrucosus Cook. et Dett., цветковые Retitricolpites georgensis Brenn., R.vulgaris Pierce, Fraxinopollenites constrictus Stanl. up to 1800м
	Lower	Albian	Upper	Strelnikov Formation. Upper member. Sandstones, conglomerates, siltstones Ussuritrigonia ussurica Konov., Grantziceras sp., Grycia ex gr.pereziana (Whit.) 1500м		
			Middle	Strelnikov Formation. Lower member. Sandstones, conglomerates, siltstones Astarte ex gr.portana McLearn, Pleuromya skilani McLearn, Lythoceras sp., Grycia ex gr.pereziana (Whit.) 900м		

Table 4 (continued).

Series	Stage	Substage	Section
Lower	Albian	Middle	
		Lower	Assikai Formation. Upper member. Sandstones, siltstones, conglomerates, dacite tuffs. Entolium utukokense Imlay, Aucellina caucasica (Buch), Thracia cf. kissoumi McLearn, Pleuromya kelleri Imlay, Ruffordia goepperti (Dunk.) Sew., Coniopteris nympharum (Heer) Vachr., Cladophlebis novopokrovskii Pryn., Ahrotaxopsis expansa Font. etc. 700–800м. Middle member. Siltstones, sandstones, rhythmically interbedded siltstones and sandstones in the upper part, andesites and the associated tuffs. Entolium utukokense Imlay, Inoceramus anglicus Woods, Aucellina caucasica (Buch), A. aptiensis Pomp., Eogaudryceras (Eogaudryceras) shimizui menneri Avd., Anagaudryceras Aurarium (And.), Puzosia sp., Kennicottia sp. 710м
	Aptian	Upper	Lower member. Sandstones, siltstones, carbonaceous mudstones. Entolium utukokense Imlay, Tetragonites duvalianus Orb.; Sagenopteris mantellii (Dunk.) Schenk, Torreya nicanica Krassil., Polypodites verestchagini Krassil. etc. 750м
		Middle	
		Lower	
	Barremian	Upper	
		Lower	
	Hauterivian	Upper	
		Lower	
	Valanginian	Upper	Sandstones, siltstones. more than 500м
		Lower	Sandstones, siltstones. Buchia uncitoides (Pavl.), B. pacifica Jeletzky, B. fischeriana (Orb.), B. ex gr. keyserlingi (Lah.) more than 900м ?
	Berriasian	Upper	?
		Lower	?
			T-J; T_3, $T-J_1$, J_3vg

(middle Assikaevo Formation, early-middle Albian). The sequence exhibits a close similarity with those of deep wells (V-1, E-1, E-2) recently drilled in Pereyaslavka graben (Fig. 1), where a relatively thick Cretaceous sequence was for the first time penetrated.

Correlation of the well sections with the known Cretaceous members and formations and analysis of the stratigraphic order and fauna assemblages were not given due attention, so we shall dwell upon these problems in more detail. The deepest (3200 m) and best studied is well V-1. Let us discuss the Cretaceous part of the well section. Tale 5 shows the intervals from which the richest foram (identified by T.V. Turenko) and bivalve (identified by N.V. Salnikova) assemblages were obtained and the stratigraphic range of their possible occurrence. Salnikova concluded that the fauna assemblage from the lowermost interval, 2770–2781 m, consists of brackish and freshwater mollusk forms; the rest of the fauna up the sequence are inhabitants of a shallow, fairly warm sea with normal or somewhat low salinity. Salnikova indicates the poor preservation of the fauna, but nevertheless she believes that the whole fauna assemblage from the well section and its distribution by depth resembles the fauna assemblage and its distribution by sequence in the Staryi Suchan and Severnyi Suchan formations in Primorie and their equivalents in Russia's Far East. The age of these formations was established as late Hauterivian–earliest late Albian by the IV Stratigraphic Conference [18]. Examining the equivalents from nearer territories, quite obvious is the similarity with the Assikaevo and Stolbovka formations of the West Sikhote Alin zone. Well section V-1 does not contain volcanic rocks, but they were encountered by the neighboring E-1 and E-2 wells (Fig. 1), in whose sections the Albian bivalves were also identified.

In well V-1, agglutinated benthic forams were also identified (Table 5). Micropaleontologist Turenko indicates the poor preservation of the forams and tentatively estimates the age of the interval 1490–2430 m as middle Aptian–Albian, and the interval 1310–1432 m, as Aptian–Campanian. Besides, forams of wide stratigraphic occurrence were encountered in the interval 380–1113 m. In the opinion of Turenko, they indicate a shallow marine depositional environment. These data, however, contradict other facts. It is well known [7], [18] that the latest marine sediments in this zone are Turonian. Later, the predominant environment was continental. The geologists who studied well section V-1 believe that the sequence above 1250 m is Cenozoic.

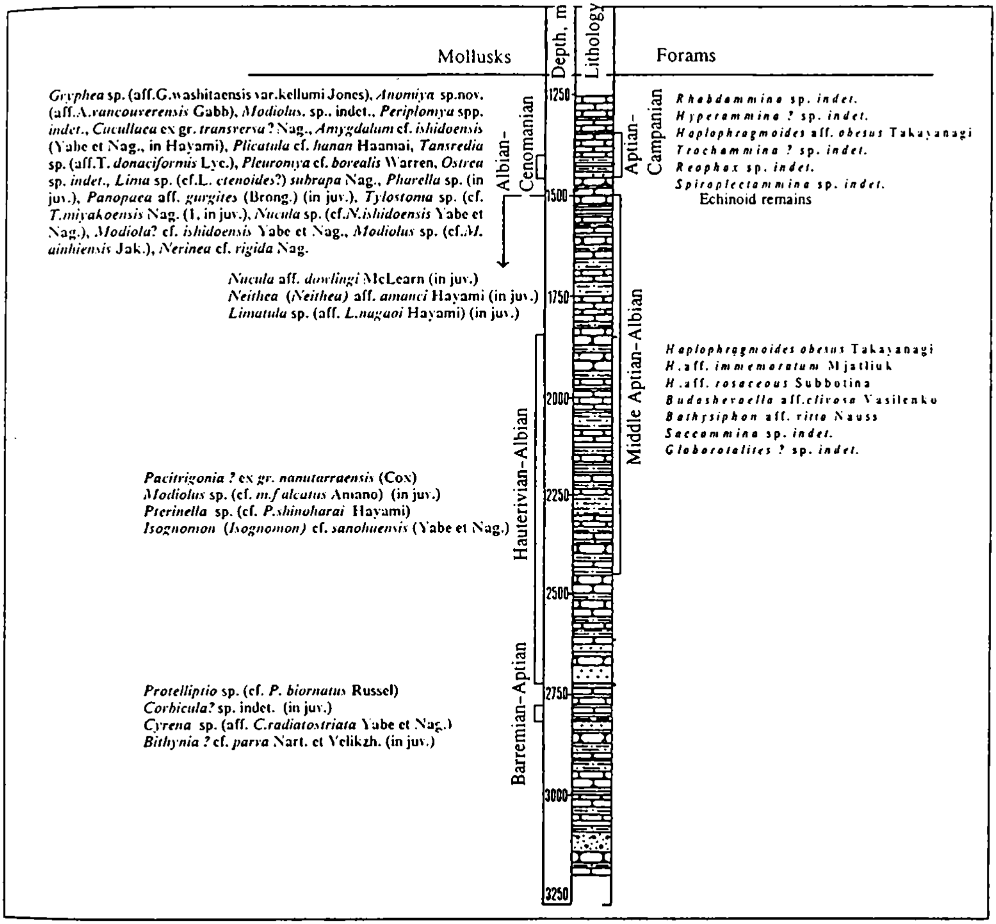
The general structure of the Pereyaslavka graben is illustrated by a schematic cross-section compiled before drilling (Fig. 5).

THE CENOZOIC

The southwestern sector of the Middle Amur sedimentary basin

In northeast China, the Paleocene–Eocene deposits unconformably rest upon the underlying strata and are of limited occurrence confined to the near-fault Heilongjiang, Yilan-Shulan, and Dunhua-Mishan depressions [8]. They consist of three formations: Wuyun Fm. (Paleocene) with a thickness of 700 m; Dalian He Fm., and Huanghua Fm. (Paleocene-Eocene) with a thickness up to 2000 m. Their composition is fairly uniform. The lower and upper parts of the formations are dominated by sands and sandstone pebbles; the middle, by sand, shale, and coal. Thick shale beds were reported only in the upper part of the Dalian He Fm.

Table 5 Fauna distribution by V-1 well section.



The subdivision of the Late Cretaceous-Cenozoic deposits based on spore and pollen assemblages was carried out by Liu Muling [29]. He has recognized 12 spore and pollen assemblages, five of which are Late Cretaceous; three, Paleocene; four, Eocene; three, Oligocene; and five, Neogene. This author suggests that the Cretaceous/Paleogene boundary should be drawn between the lower and upper members of the Furao Formation, and not between the Furao and Wuyun formations as it was previously done.

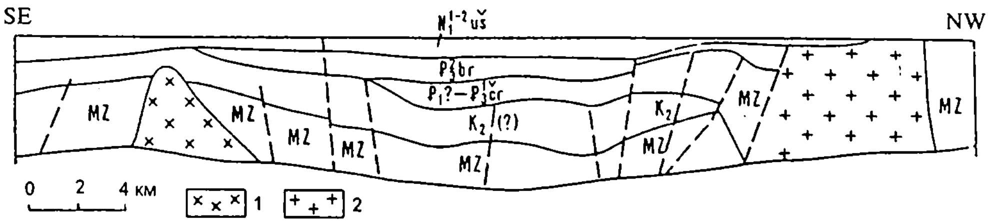


Fig. 5 Schematic geologic cross-section of the Oboro–Ussuri segment of the Pereyaslavka graben [22]. Legend: 1 – Late Cretaceous diorites; 2 – Late Cretaceous granodiorites; Mz – inferred basement of the basin; K_2(?) – inferred Late Cretaceous sedimentary cover; Ꝑ$_1$?–Ꝑ$_3^1$čr – Chernaya River Formation; Ꝑ$_3^2$br – Birofeld Formation; N_1^{1-2}uš – Ushumun Formation.

In the Sanjiang depression, the Cenozoic sequence begins with the Eocene–early Oligocene Baoquanling Formation [8], [29] with a thickness up to 1300 m. As a rule, the lower part of this formation is composed of sandy pebbles; the middle, of fine sands, clays, coal, and oil shales; and the upper, of sands and sandy pebbles. The spore and pollen assemblages are dominated by angiosperms; sometimes, the Cretaceous relics are present. The Eocene–Oligocene sediments are the thickest in the Jia–Yi graben (Figs 6, 7), but the well sections are not always subdivided by formation; nevertheless, the composition is described in detail. In some sections, volcanic rock beds are reported.

Above is the Miocene Fujin Formation with a thickness of 100 to 600 m. It usually consists of sands and shales with coal lenses in the lower part and sandy pebbles, in the upper. Sometimes, basalt sheets with a thickness up to 40 m are found in the upper part (Fig. 3). In the eastern sector of the depression, according to shallow well sections [8], the Miocene beds rest immediately upon the Cretaceous (Fig. 4).

The northeastern sector of the Middle Amur sedimentary basin

Over much of the study area, a significant tectonic restructuring with predominantly ascending movements accompanied by volcanic eruptions took place between the Cretaceous and Paleocene. The presumably Paleocene deposits are known east of the Middle Amur basin in small fault-line depressions along the Central Sikhote Alin fault. They are recognized as the Kandakhe Formation composed of andesites, tuffaceous conglomerates, conglomerates, graywacke sandstones, tuffites, tuffstones, and andesite tuffs. Its thickness ranges from 200 to 600 m. Based on flora remains including *Taxodium dubium* (Sternb.) Heer, *Metasequoia disticha* (Heer) Miki, *Trochodendroides* cf. *arctica*

(Heer) Berry, *T.* sp., *Acer arcticum* Heer, and *Phyllites* sp., the age of the formation is determined as Danian. In addition, Upper Paleocene–Lower Eocene deposits were recently penetrated by wells near the Bikin brown coal deposit [3]. They are composed of clays with sand and pebble beds at the base, with a total thickness not more than 80 m. The dating is supported by a reliable spore and pollen spectrum.

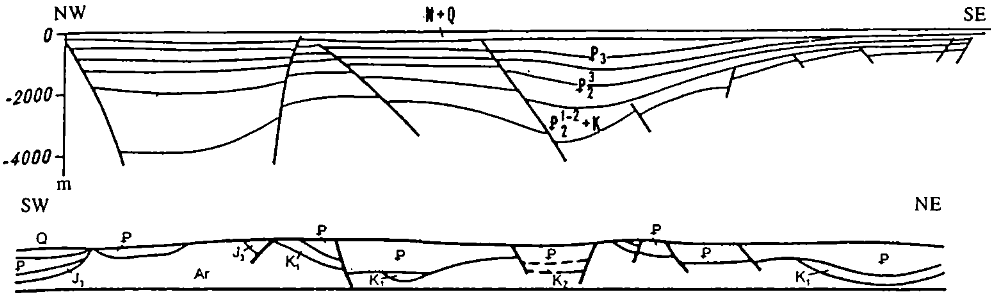


Fig. 6 Lengthwise (SW–NE) and transverse (NW–SE) cross-sections of the northern Jia–Yi graben (after Jing Huilin, 1994 from [41]).

The base of the Cenozoic well sections of the proper Middle Amur basin is usually composed of Eocene–Oligocene deposits (Table 6), whereas the Paleocene is absent, probably reflecting a non-deposition period. However, the Paleocene andesites, dacitic andesites, and the associated tuffs were encountered in a number of well sections and on the rim of the Middle Amur basin (Table 6).

The Cenozoic deposits of the grabens within the Middle Amur basin were well studied by drilling and described in the previous years in connection with brown coal prospecting [1], [4], [5], [7], etc. The past stratigraphic scheme did not undergo any significant changes. Its latest version is given in Table 6 [18].

The thickest and the most complete Cenozoic sequence is found in the Birofeld and Pereyaslavka grabens. The sequence of the asymmetrical Birofeld graben with a steep eastern and a more gentle western flank is given in Fig. 8. In the central part, the deepest well has been drilled (Fig. 9). Here, the Chernaya River Formation is the thickest and its occurrence is the deepest. Considering that the dating of the formation was revised after drilling, it should be adjusted to the latest data (Table 6), i.e. the Chernaya River Formation should be dated as Eocene–Middle Oligocene; the Birofeld, as Late Oligocene; and the Ushumun, as Early–Middle Miocene.

The structure and composition of the Cenozoic sequence in the Pereyaslavka graben are demonstrated by well sections drilled in the central part of the graben (Fig. 10 [4]). The Chernaya River Formation was penetrated only by the deepest wells. Its composition is variable, grading from essentially muddy in the central part of the graben to sands and sandy pebbles on the flanks. The thickest sequence of this formation was penetrated by well I-V (860–1250 m). Usually, it is subdivided into two members (Table 6). S.P. Kuzmenko [14], who studied the Cenozoic deposits of the Middle Amur Basin during 1970–80s, suggests that the lower member of the Chernaya River Formation should be recognized as the Oborsk Formation.

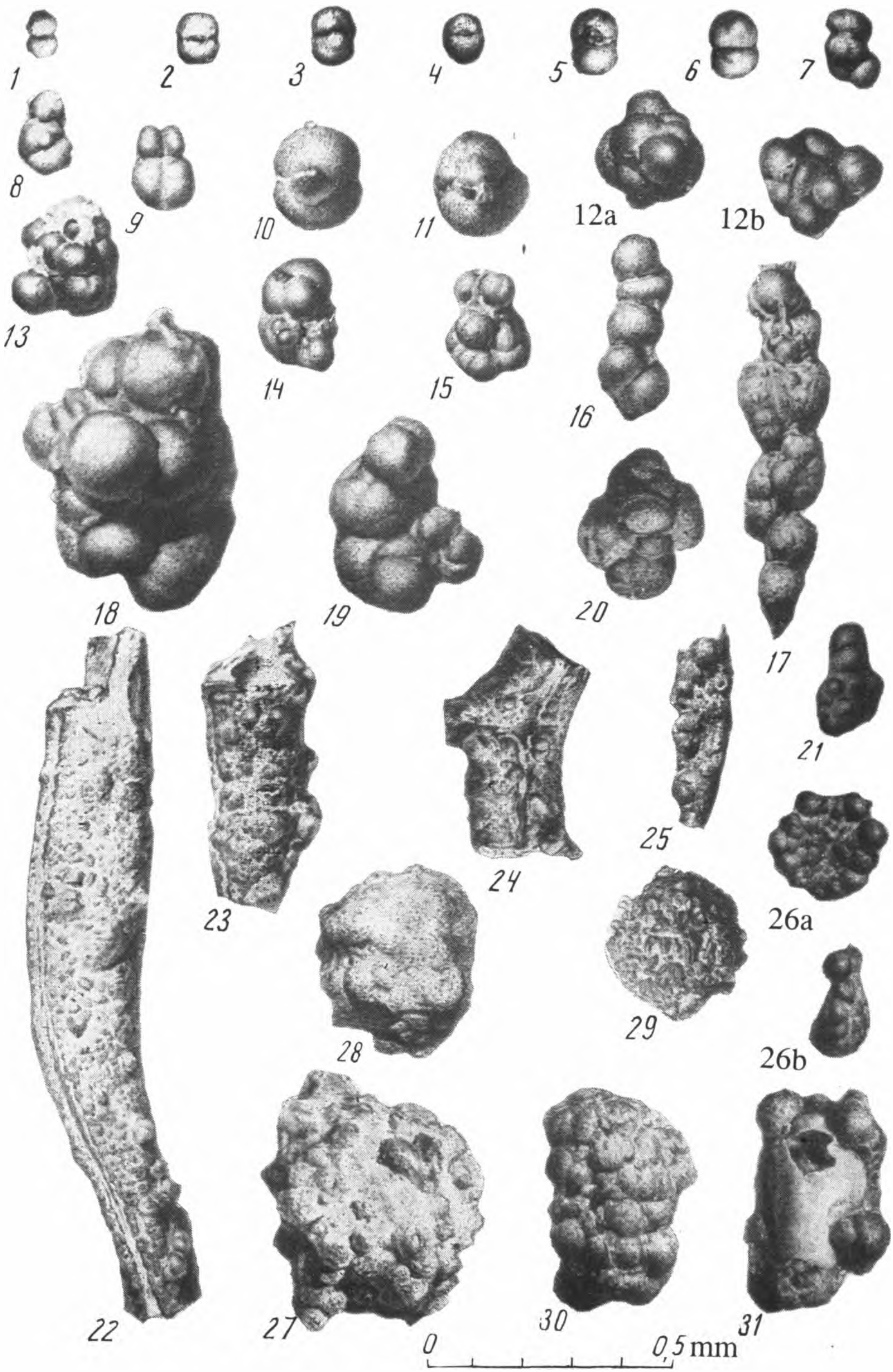
System	Series			Thickness, m	Lithology
Quaternary				150	Variegated sands, pebbly sands
Neogene	Miocene			100	White sandy pebbles, yellowish-gray sands, siltstones, two basalt beds
Paleogene	Oligocene			250	Dark-gray clays, silty clays interbedded with coal. Variegated sandy pebbles at the base
	Eocene	Upper		650	Upper part: gray, dark-gray clays, silty clays, siltstones, fine sands interbedded with thin coaly beds. Lower part: black, gray clays interbedded with silty clays
		Middle		110	Sandy pebbles, sands, clays, coal beds
				400	Dark-gray, black shales, sands, sandy pebbles
				390	Sands, sandy pebbles interbedded with coal beds
		Lower		390	Sands, sandy pebbles interbedded with clays
Cretaceous				210	Sandya pebbles, sands, coarse sands, clays
PR	Lower				Crystalline schists

Fig. 7 Well section in the Jia–Yi graben. See Fig. 3 for the legend.

The Birofeld Formation rests conformably upon the Chernaya River Formation. The most typical sequence was penetrated by well 5-OK (Fig. 10) where it consists of

Table 6

System	Series	Middle Amur Depression	
Pliocene		Sovgavan Formation (lower part) Basalts up to 100 м	Priamur Formation Sand, gravel, pebble, shales, siltstones Spores and pollen: dominant: *Betula, Alnus*, Cyperaceae, Polypodiaceae; subdominant: *Sphagnum, Pinus* s/n Haploxylon, Gramineae, *Juglans, Quercus, Ulmus*, Ranunculaceae, Rosaceae, Ericaceae, *Carpinus, Ilex, Tilia, Picea, Larix, Tsuga*, Taxodiaceae, *Corylus* 190 м
Miocene	Upper Middle	Golovin Formation Inequigranular sands, gravel and pebble lenses, silt, brown coal lenses Spores and pollen: dominant: *Picea, Betula, Alnus;* subdominant: Polypodiaceae, *Pinus, Tsuga, Ulmus;* associate: *Sphagnum*, Taxodiaceae, *Carya, Juglans, Corylus, Quercus, Ilex, Tilia*, Gramineae, Cyperaceae, Rosaceae up to 165 м	
Miocene	Middle Lower	Ushumun Formation. Siltstones, shales, sands, brown clays, carbonaceous shales Flora: *Osmunda schalinensis* Krysht., *Ginkgo adiantoides* Uung) Heer, *Glyptostrobus europacus* (Brongn) Heer, *Salix varians* Goepp., *Papulus* cf. *balsamoides* Goepp., *Pterocarya* cf. *asymmetrosa* Konno, *Ulmus drepandonta* Grub., *Zelkova ungeri* Kov., *Dalbergia ussuriensis* Baik., *Phellodendron granulifera* Iljinsk., *Atangium tiliaefolium* (At.Br.) Krysht. Spores and pollen. Assemblage 1. Dominant: *Picea, Alnus, Ulmus* Subdominant: Polypodiaceae, *Pinus, Betula, Juglans* Associate: *Sphagnum, Tsuga*, Taxodiacea, *Carya, Corylus, Carpinus, Quercus, Fagus, Liquidambar, Ilex, Tilia*, Ranunculaceae, Carpifoliaceae, Rosaceae Diatoms: *Melosira praegranulata* Jouse, *M. praeislandica* Jouse, *M. scabrosa* Quests., *Tetracydus ellipticus* (Ehr) Grum. var. *ellipticus* et var. *lanceca* Hust., *Eunotia nokolskiae* Jouse, *E. veneris* var. *nipponica* Skv., *Achnanthes pinnata* cf. *robusta* Moiss. Assemblage 2 Dominant: Polypodiaceae, *Picea, Pinus, Alnus;* Subdominant: *Betula, Tsuga*, Taxodiaceae, *Juglans;* Associate: *Sphagnum, Osmunda, Myrica, Carya, Corylus*	Kizi Formation Basalts, basaltic andesites, tuffites, tuff Flora: *Metasequoia disticha* (Heer) Mikj., *Phragmites alskana* Heer, Thypha latissima Al.Br., *Betula prisca* Ett., *Alnus* cf. *kefersteinii* (Goepp.) Ung., *Corylus nacquartii* (Forgels) Heer, *Castanea atavia* Ung., *Ulmus* cf. *protojaponica* Tanai et Onoe; *Platanus aceroides latifolia* Knewit, *Alangium tiliaefolium* (Al.Br.) Krysht., *Sophora schmidtiana* Heer Diatoms: *Melosira jouseana* Moiss., *M. praegranulata* Jonse, *Tetracyclus ellipticus* (Ehr) Grum. var. *ellipticus Eunatia japonica* Pant., *Gomphocymbella miocenica* Jouse, *Didymasphenia geminata* var. *curvata* Skv. et Mever 100-480 м Absolute age 15.2-17.5 Ma
Oligocene	Upper	Birofeld Formation. Tuffaceous shaleds, siltstones, tuffites, ash tuffs, coals, conglomerates Flora: *Pinus, Glyptostrobus europaeus* (Br.) Heer, *Metasequoia disticha* (Heer) Miki, *Salix varians* Goepp, *Carpinus grandis* (Ung) Heer, *Castanea atavia* Ung., *Quercus* sp., *Ulmus drepanodonta* Grub., *Zelkova ungeri* Kov., *Alangium tiliaefolium* (Al.Br.) Krysht. Spores and pollen: dominant: *Polypodiaceae, Picea, Taxodiaceae* Subdominant: *Pinus, Alnus, Ulmus* Associate: *Sphagnum, Podocarpus, Tsuga, Myrica, Juglans, Corylus, Quercus, Q. conferta* Boitz., *Liquidambar, Eucommia, Rhus, Acer, Tilia, Nyssa, Engelhardtia, Elytranthe striatus* Conper, *Diervilla* Forams: *Kiina, Pseudocaspirella* sp., *Khabarovella* sp., *Glabigarisiphon* sp., *Detritella, Pinus* 74-500 м	
Oligocene Eocene	Lower-Middle Upper	Chernaya River Formation Upper member Siltstones, shales, brown coals, inequigranular sands Spores and pollen: dominant: Taxodiacea, *Picea, Polypodiaceae;* Subdominant: *Pinus, Juglans, Alnus;* Associate: *Osmunda, Podocarpus, Tsuga, Myrica, Carya, Betula, Corylus, Fagus, Castanea, Quercus conferta* Boitz., *Q. graciliformis* Boitz., *Ulmus, Liquidambar, Engelhardtia*, Moraceae, *Platanus, Steculia*, Hamamelidaceae, *Tricolpites, Tricolporopollenites* up to 265 м	
Eocene	Upper Middle Lower	Chernaya River Formation Lower member Unsorted shale-sand-rubble deposits, inequigranular sandstones, gravel, pebble, silt, shale. Brown coal lenses in the lower part Flora: *Osmunda sachalinensis* Krysht, *Taxodium dubium* (Sternb.) Heer, *T. tinajorum* Heer, *Metasequoia disticha* (Heer) Miki, *Glyptostrobus europaeus* (Brongn.) Heer, *Zelkova* sp., *Trochodendroides arctica* (Heer) Berry, *Corylopsis orientalis* Bors., *Zizyphus sachalinensis* Krysht., *Pterospermites* sp., *Alangium tiliaefolium* (Al.Br.) Krysht Spores and pollen: dominant: Taxodiaceae; Subdominant: *Picea, Carya, Alnus, Quercus, Fagus, Ulmus, Liquidambar;* Associate: *Podocarpus, Pinus, Myrica, Comptonia, Juglans, Pterocarya, Betula, Carpinus, Quercus graciliformis* Boitz., *Q. forestdalensis, Castanea*, Hamamelidaceae, *Trochodendron, Tricolporopollenites cingulum* (R.Pot) Th. et Pfl., *Ulmoideipites, Moraceae, Loranthus, Platanus* 840 м	Kuznetsovka Formation Basaltic andesites, augite basalts, andesites, and the associated tuffs 300-1000 м Trachyandesites, rhyolites, andesites, and the associated tuffs; dacites; conglomerates K-Ar age 45 Ma 150-200 м
Paleocene	Upper Lower	?	Andesites, dacitic andesites, and the associated tuffs.
		? Pz, Mz	


1
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21
22
23
24
25
26a
26b
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28
29
30
31
0
0,5 mm

interbedded silt-shale and sand beds. The age of the Cenozoic formations was identified by spore and pollen assemblages, sometimes by macrofauna. However, as far back as 1961 V.A. Markov collected microfauna from the Birofeld Formation sequences in wells 51-OK, 5-OK, and 1-OK. In the opinion of V.P. Alimarina and N.A. Gorbachik, paleontologists from the Moscow University, this microfauna resembles forams. In Table 6 [4], [18], this microfauna is also given as forams. More accurate and comprehensive study of the discovered fossils was further continued by senior researcher N.K. Bykova from the All-Union Oil and Gas Exploration Research Institute (VNIGRI) who suggested to classify them as a new group of colonial organisms tentatively termed as *Semibryozoa* (Table 7). This group was first discovered by Bykova in the Cenozoic deposits of Mangyshlak Peninsula in 1960. Its forms were also identified in the sequences of West Siberia, Yakutia, Sakhalin, Mexico, and US. In the opinion of Bykova, this group of organisms can be used for stratigraphic reconstructions, because their occurrence is confined to certain sequences. Unfortunately, Bykova says nothing about the habitat of this microfauna. If these organisms, like forams, are marine organisms (which is supported by their presence of the marine Oligocene deposits of Mangyshlak), then their presence in the Upper Oligocene beds may be indicative of a brief marine transgression episode. Simultaneously, i.e. in the Late Oligocene, traces of marine transgression have been identified in the lower member of the Shaheze Formation in the Bohaiwan basin [39], where glauconite and marine fossils have been found. This fact is very interesting and important for the paleogeographic reconstructions.

Plate 1 Semibryozoa forms identified by Bykova [4]: figs 1-6 - *Embrionellina* sp. gen n. (South Mangyshlak). Upper(?) Oligocene; figs 7-9 - Colony of *Embrionellina* sp. gen. n. (South Mangyshlak). Upper(?) Oligocene; figs 10-11 - *Kiina* sp. (Pereyaslavka graben, well. 51-OPK, interval 816-821 m) Upper Oligocene-Lower Miocene; figs 12a, 12b - *Caspirella drusa* N. Bykl, colony of *Embrionellina* sp. gen. n. (Mangyshlak. Middle(?) Oligocene; figs 13-15 - *Caspirella drusa* N.Byk., colonies of *Embrionellina* sp. gen. n. (South Mangyshlak). Upper(?) Oligocene; fig. 16 - *Caspirellina mangischlakensis* (N.Byk.) gen. n., colony of *Embrionellina* sp. gen. n. (South Mangyshlak). Upper(?) Oligocene; fig. 17 - *Caspirellina* (?) sp. gen. n. (South Mangyshlak). Upper Oligocene; figs 18-20 - *Pseudocaspirella* sp. gen. n., drusy colonies of *Kiina* sp. (Pereyaslavka graben, well 51-OK, interval 816-821 m) Upper Paleogene-Lower Neogene; fig. 21 - *Caspirella drusa* N.Byk. (South Mangyshlak. Upper (?) Oligocene; figs 22-24 - *Globigerisiphon* sp. gen. n. (Pereyaslavka graben, well 51-OK, interval 748-764 m). Upper Paleogene-Lower Neogene. Magnification 33x; fig. 25 - Rod-like colony of *Kiina* sp. (?) gen. n. (without a coelom) (northern Emba region) Pliocene (?). Magnification 33x; figs 26a, 26b - Crust-like colony of *Kiina* sp. (?) gen. n. (northern Emba region). Pliocene(?). Magnification 33x; figs 27-28 - *Pseudotrochosodon* sp. gen. n. Globular colony of *Kiina* sp. (?) gen. n. (Pereyaslavka graben, well 51-OK, interval 685-890 m). Upper Paleogene-Lower Neogene. Magnification 47x; fig. 29 - Colony of *Detritella* sp. gen. n., globular (Pereyaslavka graben, well 51-OK, interval 685-690 m. Upper Paleogene-Lower Neogene (?). Magnification 47x; figs 30-31 - Crust-like colony of *Kiina* sp. (?) gen. n. Ostracoda (northern Emba region). Magnification 47x.

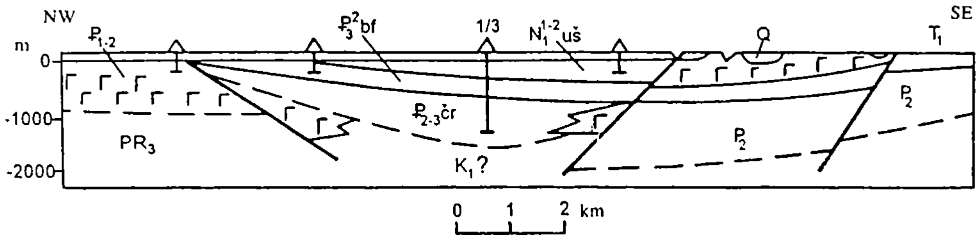

Fig. 8 Cross-section of the Birofeld graben. Chronostratigraphy: PR_3 - Late Proterozoic; P_2 - Late Permian; T_1 - Early Triassic; K_1? - presumably Early Cretaceous; $₽_{1-2}$ - Paleocene–Eocene basalts. See Fig. 5 for formation indices.

The Ushumun Formation rests unconformably upon the Birofeld Formation. It was penetrated by all wells, and the most complete and typical sequence was penetrated by well 12-OK (Fig. 10). In some sequences, this formation is subdivided into the lower coal-bearing and the upper barren members [4]; its maximum thickness is about 700 m. In the southwestern part of the Pereyaslavka graben, the rocks of the Ushumun Formation are replaced by basalts, basaltic andesites, tuffites, and tuffs of the Kizi Formation carrying fossil flora and diatom remains (Table 6).

The Ushumun Formation is unconformably overlain by the Middle–Upper Miocene Golovin Formation (Table 6). On the margins of the grabens, it is exposed on the surface. The sequence is characterized by predominantly cherty pebbles and kaolinite clays which enables the scientists to interpret this formation as residue [14]. Residue has been also identified upon the basalts of the Kizi Formation.

The Cenozoic sequence is crowned by sands and gravel of the Priamur Formation of Pliocene age grading eastward into the Pliocene-Quaternary basalts of the Sovgavan Formation.

CONCLUSION

The performed correlation of the Cretaceous and Cenozoic stratigraphic sequences in various parts of the Middle Amur (Sanjiang) sedimentary basin enabled us to examine the accuracy of subdivision of various stratigraphic units in different parts of the basin, the completeness of sequences, and in some cases, to correlate timing of the main phases of volcanic activity and coal accumulation, and at the same time to outline the problems requiring a further detailed investigation both in Russia and China. The most important of them are the following:

(1) Compilation of a correliable subdivision scheme for all structures of the Middle Amur basin, detailed by stage for the Cretaceous and by subseries for the Cenozoic.

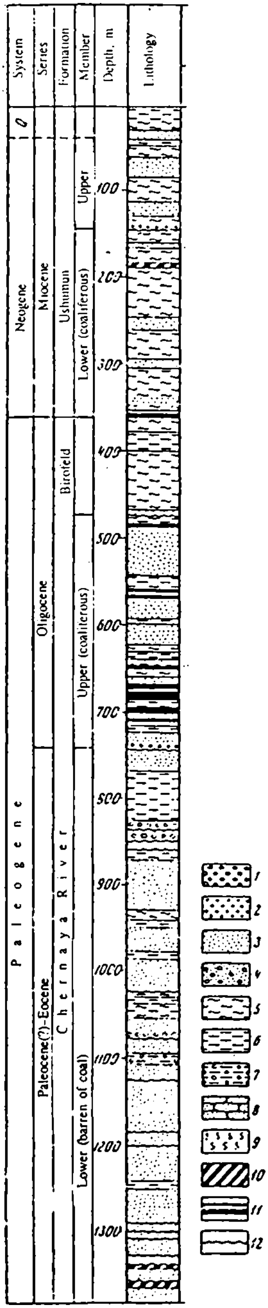

Fig. 9 Well section 1/3-OK in the Birofeld graben [4]. 1 - pebble, conglomerate; 2 - gravel, gritstone; 3 - sand, sandstone; 4 - pebbly sand; 5 - silt; 6 - clay; 7 - pebbly clay; 8 - loosely cemented sandstone; 9 - diatomite; 10 - carbonaceous shale; 11 - coal; 12 - erosional unconformity.

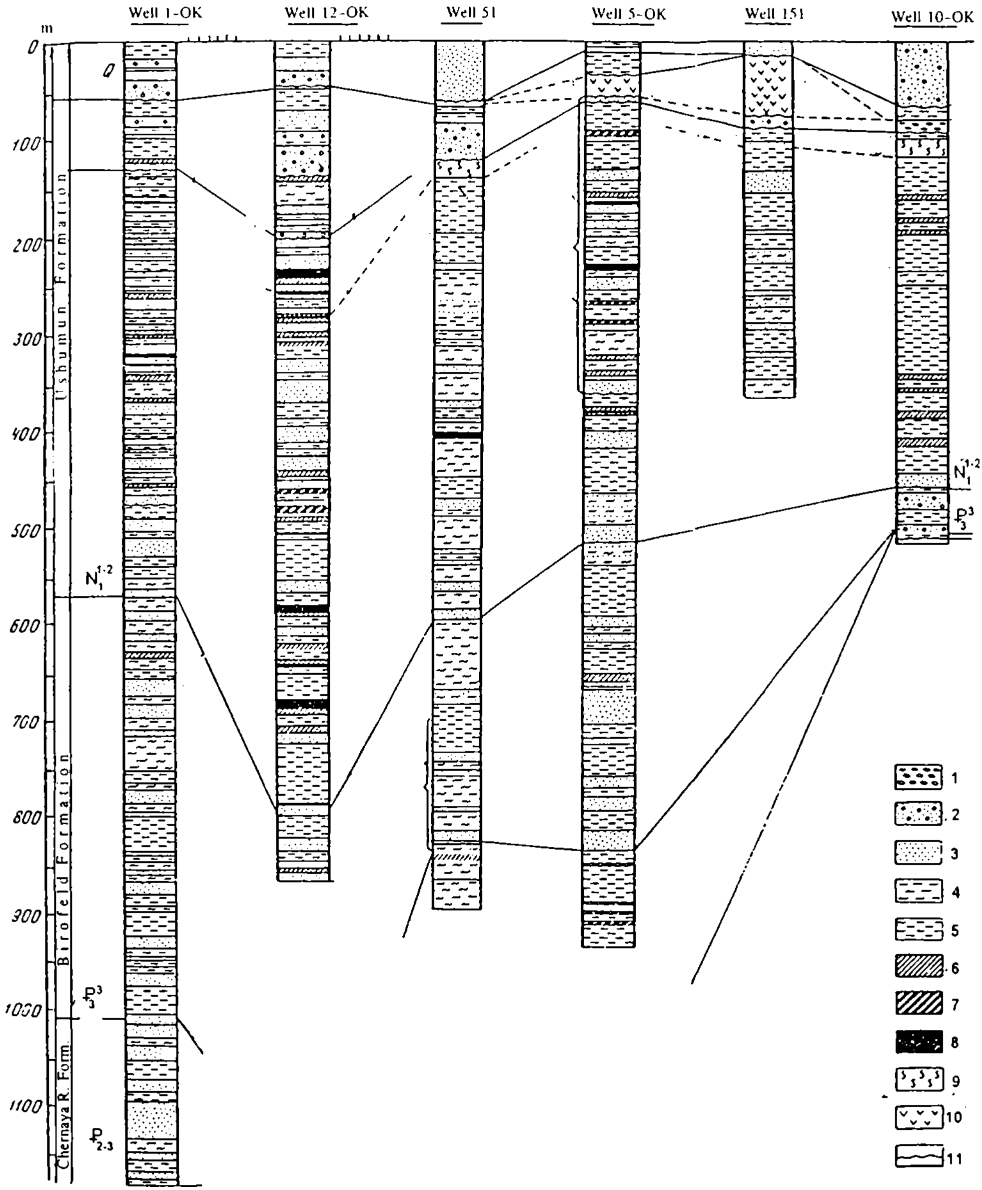

Fig. 10 Correlation of Cenozoic sequences in the most important well sections of the Pereyaslavka graben [4], [5]. 1 - pebbles; 2 - pebbly sands; 3 - sands; 4 - silt; 5 - clay; 6 - brown and dark-brown clays of stagnant lake facies; 7 - carbonaceous shales; 8 - brown coal; 9 - diatomites; 10 - basalts; 11 - erosional unconformity.

(2) Adjustment of the Jurassic-Cretaceous boundary in the Russian and Chinese sequences;

(3) Performance of additional investigations to more accurately determine the age of the matrix of the olistostrome sequences;

(4) More accurate determination of the stratigraphic range of the aucellines in the Chinese and Russian sequences;

(5) Adjustment of the volume, nomenclature, and paleontologic substantiation of the Hauterivian-Cenomanian deposits in the Gorin and West Sikhote Alin zones;

(6) Determination of the ecological characteristics of the Semibryozoa.

The obtained stratigraphic correlation data will serve as the basis for paleogeographic and paleogeodynamic reconstructions at the present phase of studies of the Middle Amur sedimentary basin, and finally enable a revision of the petroleum potential of this basin.

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