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Cretaceous tectonics and geological environments in East Russia

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Abstract

By the Late Jurassic, the northern part of the East Asian continental margin was diversified. Principal structural constituents were the Siberian (or North Asian) craton bounded on the east by a miogeosynclinal fold belt, a system of smaller ancient blocks, and a collage of terranes that had been attached to the craton from the east and southeast at different times. Such a diverse structural environment caused variability of Cretaceous landscapes and related sedimentary systems. Global processes of lithospheric plate interaction and related regional tectonic processes played a leading role in Cretaceous environmental changes in the continental margin of East Russia.

During the Early Cretaceous, the oblique plate convergence produced a transform continental margin over a long period of time. During the Middle Albian, a collage of terranes were attached to the continental margin of East Russia. Then during the Late Albian period, the angle of convergence increased, subduction resumed, and a giant East Asian volcanic belt formed along the continental margin. This belt was morphologically represented by a chain of mountain ridges (up to 3000 m), thus creating a sublongitudinal tectonic and climatic zonation. The active continental margin with a typical environmental arrangement of marginal seas–island arcs–the open sea, persisted until the end of the Cretaceous. The Late Maastrichtian tectonics was mostly characterized by overall uplift of the region.

Keywords: Cretaceous tectonics; Sedimentation; Stratigraphic levels

1. Introduction

At present, the investigation of the Cretaceous system in East Russia is being conducted within the framework of IGCP 434 ‘Land–ocean interactions of carbon cycle and bio-diversity change during the Cretaceous in Asia’.

Cretaceous deposits of East Russia occupy a broad area extending from Chukotka to Primorye, with a distance of more than 4500 km in between. The Cretaceous environment was diversified and inherited its main features from the Late Jurassic. Principal structural constituents in the present structural pattern (Fig. 1) are the Siberian (or North Asian) craton bounded on the east by the Verkhoyansk miogeosynclinal fold belt, a system of smaller ancient blocks (the Stanovoy, Bureya, Khanka blocks), and a collage of different terranes that attached to the craton from the east and southeast at different times (Parfenov et al., 1993; Khanchuk, 1993; Nokleberg et al., 1994; Sengor and Natal’in, 1996; and others). This diverse structural environment caused variability in the Cretaceous landscapes and related sedimentary systems (Fig. 2). Coastal lowlands with well-developed river networks, oxbow-lakes, lakes and swamps adjoined the paralic basins, which existed throughout the Cretaceous and migrated mostly eastward. At certain periods during the Cretaceous, these lowlands were covered with a shallow sea with numerous islands. In the hinterland of uplifted areas and plains, continental coal-bearing deposits accumulated in isolated basins. During the Cretaceous, terrigenous sedimentation, together with a volcanogenic admixture, predominated. Siliceous and siliceous-clayey deposits typical of a back-arc basin and ocean are limited in distribution. Limestones in the form of individual lenses and nodules are found but rarely (Kirillova, 2000; Kirillova et al., 2000; Markevitch et al., 2000).

Throughout the Cretaceous, latitudinal climatic zonality prevailed, while longitudinal zonality was manifested along the continent-ocean boundary.

The events causing substantial changes in environments were mainly tectonic. We will therefore preferentially

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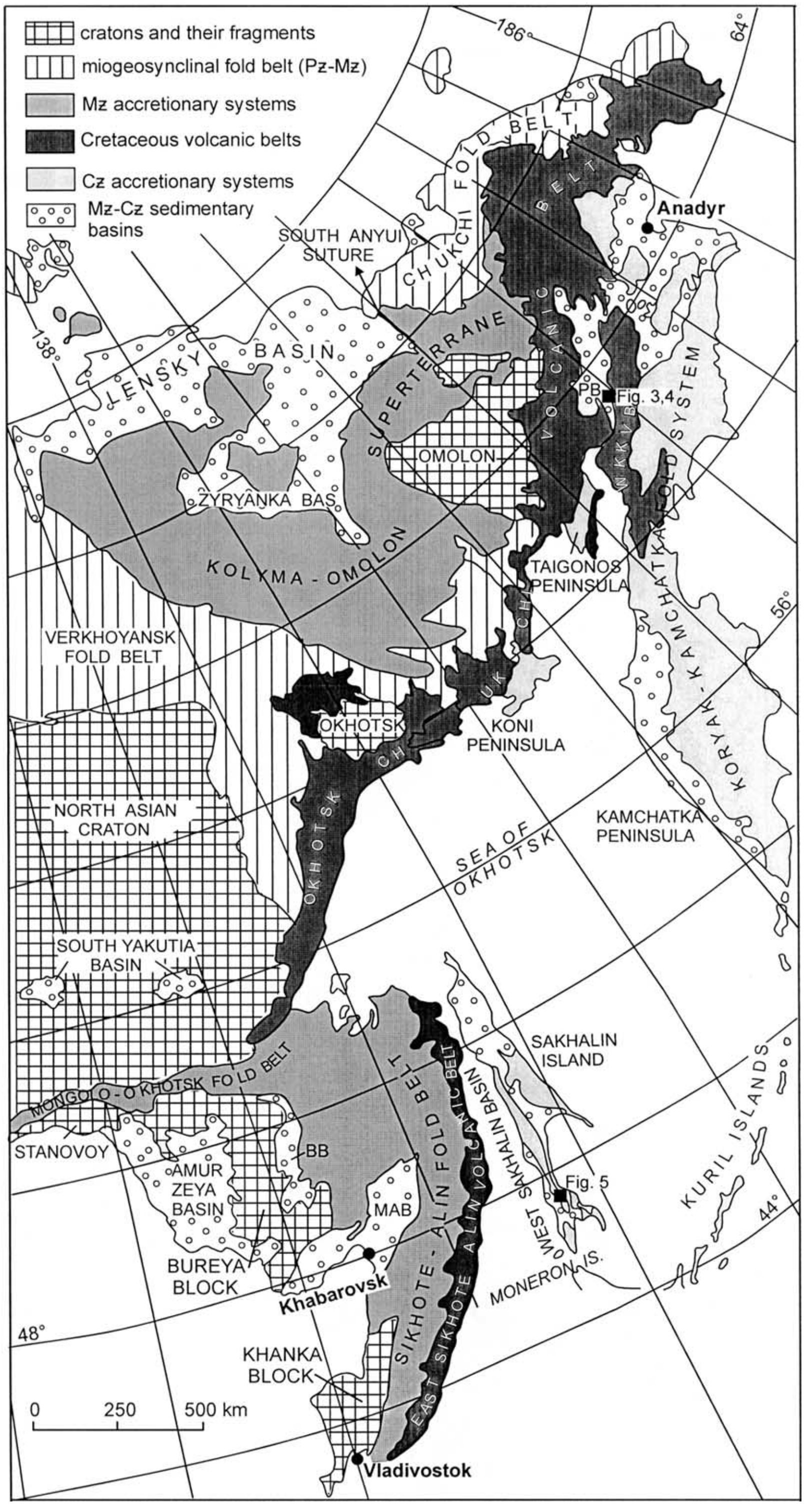

Fig. 1. The scheme of the principal structural elements of East Asia. 1: Cratons and their fragments; 2: miogesyclinal fold belts; 3: Mesozoic accretionary systems; 4: Cretaceous volcanic belts; 5: Cenzoic accretionary systems; 6: Mesozoic–Cenzoic basins; 7: location of Figs. 3–5. BB: Bureya basin; MAB: Middle Amur basin; PB: Penzhina basin; WKKVB: West Koryak–Kamchatka volcanic belt.

focus on the role of tectonics in producing environmental changes.

The Cretaceous deposits of East Russia have traditionally been assigned into four regions, each of which is characterized by different tectonic regimes and sedimentation conditions (Krasny and Putintsev, 1984): East Siberian, Northeastern, Far Eastern and Pacific coastal regions (Fig. 2).

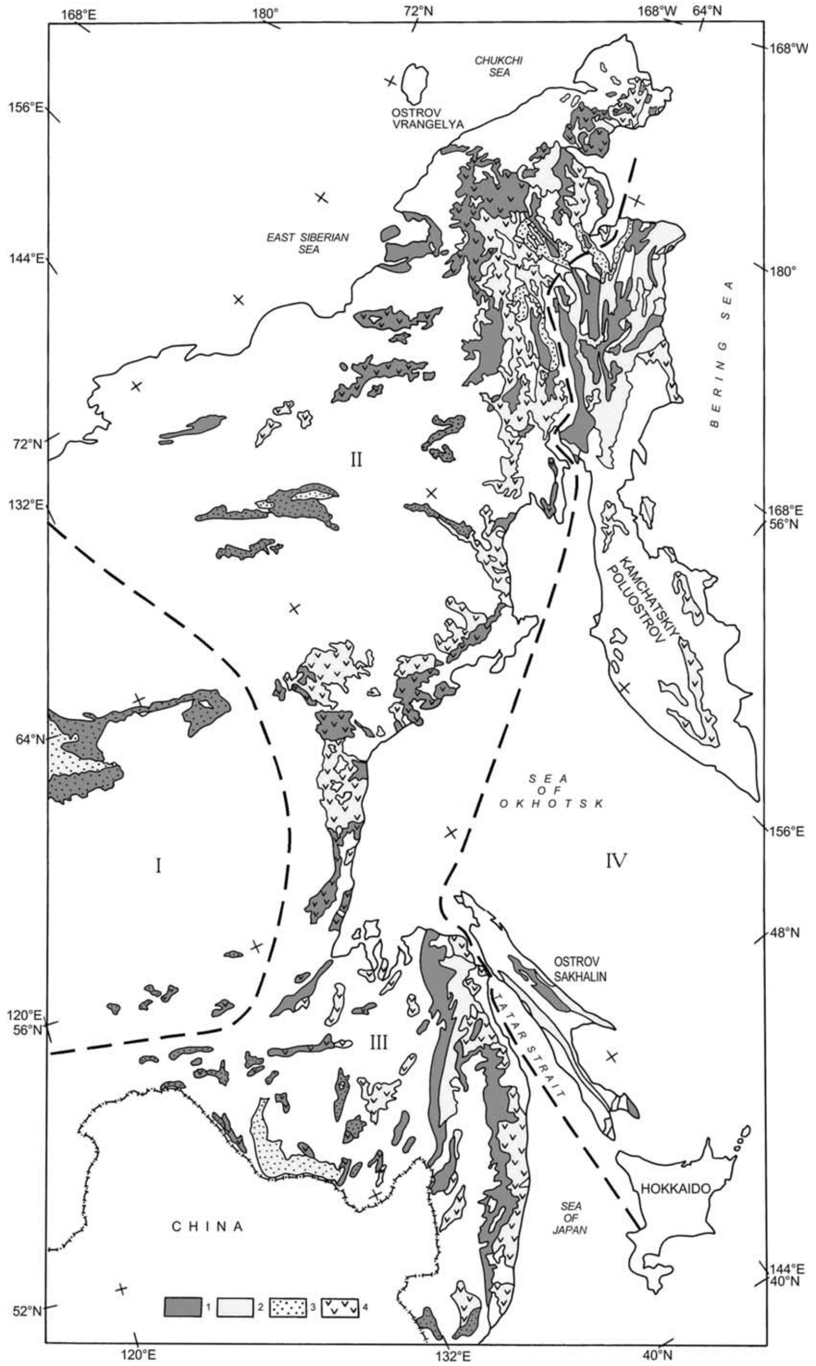

Fig. 2. Distribution of Cretaceous deposits in East Russia. 1,2: marine: 1, Lower Cretaceous; 2, Upper Cretaceous. 3,4: continental: 3, terrigenous coal-bearing; 4, volcanogenic. Regions: I: East Siberian; II: North Eastern; III: Far Eastern; IV: Pacific coastal.

2. Early Cretaceous

The Lower Cretaceous deposits of East Russia are divided rather distinctly into pre-Hauterivian and post-Hauterivian stages. During the Hauterivian, a Kolymian orogenic phase occurred throughout East Russia and left-lateral strike–slip movements were activated. In places, these movements are represented only by the change of the sedimentation pattern, while in other places they caused the formation of basal conglomerates or a hiatus in sedimentation.

2.1. Pre-Hauterivian stage

The Early Cretaceous history of East Russia closely follows that of the Late Jurassic. The coastline of the *East Siberian region* migrated north- and eastward by hundreds of kilometers during the Berriasian and a huge coastal plain separated from the east by low hills was thus created. Under these continental conditions in the Lensky and South Yakutiya basins (Fig. 2), there accumulated terrigenous coal-bearing formations about 1500 m thick, one of the greatest of all geological epochs in the Earth. Volcanogenic sedimentary formations about 600 m thick were developed in the southern part of the region.

The Northeastern region is characterized by a complex evolutionary history that determined the diversity of geological environments. In the southwestern part of the region, continental coal-bearing terrigenous formations (about 1500 m) accumulated in two large lowland areas, the Zyryanskaya and Priokhotsky that were separated by low hills. In addition, Berriasian–Hauterivian intermediate–basic volcanics, tuffs, and volcanogenic-sedimentary rocks were deposited in Priokhotie.

The northeastern part of the region appears to have been a marine basin with archipelagoes, extending to the southeast. Terrigenous sediments about 2000 m thick occur there.

One of the geodynamic interpretations of pre-Hauterivian development of the Northeastern region is proposed by Parfenov (1996). Compositionally and genetically different terranes were amalgamated to form a superterrane at the Middle–Upper Jurassic boundary, prior to its accretion to the North Asian craton, which occurred in the Late Jurassic. Due to the opening of the South Anyui basin during the Late Jurassic to Neocomian, collision occurred between the Kolyma–Omolon superterrane and the North Asian craton (Parfenov, 1996). All of these terranes are overlain unconformably by Upper Jurassic through Cretaceous volcano-sedimentary rocks. Along the northern margin of the Kolyma–Omolon superterrane, the Oloy–Svyatonossky volcanic arc, composed of calc-alkaline volcanics, is distinguished. Fore-arc turbidites are known from the South Anyui terrane. South of the Kolyma–Omolon superterrane, the Koni-Murgalsky Triassic-Neocomian island arc terrane is distinguished. Post-accretion formations are represented by the Jurassic-Neocomian volcano-sedimentary deposits of the Udsky segment of the southern Okhotsk–Chukchi belt. It is a marginal-continental Andian type magmatic arc, which is the southwestern extension of the Udsky–Murgalsky island arc.

The style of sedimentation in *the Far Eastern region* during the Early Cretaceous closely follows that of the Late Jurassic. Three basin types are distinguished for the Early Cretaceous. The Lower Amur and Sikhote-Alin basins, located at the eastern part, are regarded as the first type. They appear to have been rather deep seas where stable downwarping resulted in accumulation of mostly Berriasian to Valanginian turbidites about 6000 m thick (Krasny and Putintsev, 1984; Markevitch and Konovalov, 1999; Likht, 1999) with a subordinate amount of cherty-volcanic rocks and limestones. Horizons associated with olistostromes containing diverse Paleozoic to Mesozoic clasts are often observed near the continental boundary (Natal'in, 1993; Kirillova, 1995b; Kirillova et al., 1997). Some investigators suggest the existence of an Early Cretaceous oceanic basin with deposits of jasper, cherts and mudstones associated with alkaline basalts described in the Kiselyovka–Manoma terrane (Zyabrev, 1996; Popova et al., 1999; Markevitch et al., 2000).

Basins located along the margin of the pre-Jurassic continental structures (Krasny and Putintsev, 1984; Likht, 1999 and others) comprise the second type. They are represented by epicontinental seas with rich benthos where terrigenous material of diversified facies, including products of terrestrial volcanism, accumulated during the Berriasian to Early Hauterivian. Here epochs of intensive downwarping were repeatedly superseded by phases of uplifting, erosion and continental sedimentation including coal formation. The thickness of the deposits ranges from 2000 to 4000 m. The third basin type comprises intracontinental rift and postcollision basins separated by low mountains (the Amur-Zeya, Pre-Dzhugdzhursky) in which continental coal-bearing volcanogenic-terrigenous deposits about 1000 m thick accumulated during the Berriasian–Hauterivian. Acid to intermediate volcanics accumulated along the basin margins. According to geodynamic reconstructions (Natal'in, 1994; Khanchuk, 1993; Nechaev et al., 1999), the Khingan–Okhotsk active continental margin existed in the Early Cretaceous, bounded by the Amur suture on the east. It comprised a magmatic arc marked by a chain of volcanic areas extending from the Lesser Khingan to the Sea of Okhotsk, along with an accretionary complex made up mainly of turbidites. Olistostrome horizons found at different stratigraphic levels during the Early Cretaceous are confined to zones of the largest bed-by-bed disintegrations. As a result of the oblique subduction of the Izanagi plate, the Valanginian sinistral margin-slip movements initiated along the East Asian margin (Morin, 1995; Nechaev et al., 1999) and the transform continental margin began to form (Liu et al., 1999). In the eastern part of the region, the Anyui microcontinent accreted (Natal'in and Faure, 1994). These movements accompanied by local collision events became more intensive during the Hauterivian and caused uplifting of large blocks, hiatuses in sedimentation and considerable changes in the coastline.

The Pacific coastal region borders the Koryak Upland, the Kamchatka Peninsula and Sakhalin Island (Fig. 2). Here Lower Cretaceous rocks have much in common with those of the Upper Jurassic that formed during subsidence, resulting in accumulation of thick volcanogenic-cherty-terrigenous marine deposits poor in organic material. The following three Neocomian zones are recognized within the regions: the Sakhalin, Taigonos-Anadyr and Talov-Mainitskaya (Krasny and Putintsev, 1984; Pokhialainen, 1994).

In Sakhalin, up to 4000 m of Upper Jurassic–Lower Cretaceous deposits occur mostly in the eastern part of the island. The lower part is composed mainly of volcanogenic-cherty rocks, in which Early Cretaceous radiolarians (Kazintsova and Rozhdestvensky, 1982) and occasional limestone lenses with corals and foraminifers (Poyarkova, 1987) have been discovered. The upper part is dominated by terrigenous deposits with subordinate amount of volcanogenic-cherty rocks. This rock unit is well correlated with the Sorachi and Lower Yezo Groups on Hokkaido Island. They are approximately dated as Berriasian to Barremian (Hirano et al., 1992). Sediments of the Sorachi Group accumulated in the oceanic basin, whereas those of the whole Yezo Supergroup were concentrated in the fore-arc basin (Okada, 1983). However, the outlook on the onset of the terrigenous sedimentation, both in Sakhalin and Hokkaido, still remains in dispute. On Moneron Island, a Lower Cretaceous volcanogenic-sedimentary formation related to the Rebun-Kabato volcanic arc was penetrated by boreholes, and is presumably linked to the Samarga arc located to the north (Rozhdestvensky, 1994).

The Taigonos-Anadyr zone is located between the Verkhoyansk–Kolyma and Koryak–Kamchatka fold systems, providing diverse sections. A typical section of the deposits distributed in the northwestern part of the Taigonos Peninsula has been studied on the western coast. It is represented by an Upper Volgian–Valanginian series of coastal-marine and continental deposits about 5000 m thick, composed of andesite, basalts, ignimbrites, rhyolites (lavas and tuffs) of common volcanic arc facies. Another typical section of the Volgian–Valanginian sequence has been described in the southeastern Taigonos Peninsula and in the Penzhina river basin (Fig. 3). The lower part consists of spilites, diabases, cherty-clayey shales and turbidites, while the upper part includes turbidites with horizons of olistostromes with ultramafic olistoliths. A total thickness of the section reaches 5000–6000 m (Krasny and Putintsev, 1984; Pokhialainen, 1994).

The Koryak–Kamchatka zone is characterized by about 2500 m of Upper Jurassic (Volgian), Berriasian and Valanginian marine deposits that occur unconformably on older deposits. Two section types are known; one mostly terrigenous with siltstones containing *Buchia* sp., and the other consisting of radiolarian cherty-volcanogenic rocks with interbedded limestones. They are interpreted as subduction-accretionary complexes, magmatic arcs and fore-arc basins (Sengor and Natal'in, 1996). In the present-day structural pattern, these sequences are composed of narrow slabs and sheets superposed along overthrusts and strike–slip faults.

2.2. Hauterivian–Albian stage

During the Hauterivian–Albian stage, the Lena and South Yakutiya coal fields continued to form in the *East Siberian region*, where about 1500 m of terrigenous coal-bearing formations were deposited. In the southern part of the region, volcanogenic sedimentary deposits about 500 m thick continued to accumulate, being interrupted by hiatuses within a restricted area.

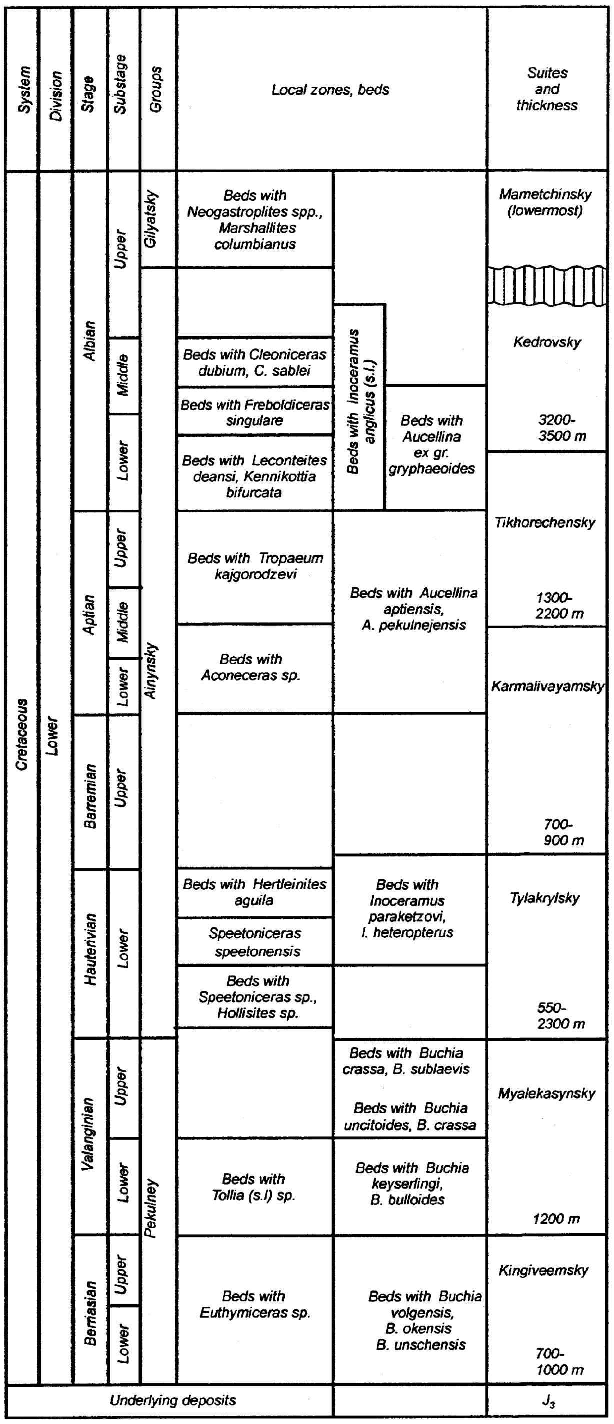

Fig. 3. Stratigraphic column of the Lower Cretaceous deposits in the Penzhina basin (after Terekhova and Dundo (1987)). For location see Fig. 1.

Two principal zones of sedimentation persisted in the *Northeastern region* in spite of the Hauterivian regression. In the central part of the region, the Momo-Zyryanka and Sugoisky basins, bordered by mountains, developed throughout the Middle Albian and were filled with terrigenous coal-bearing deposits about 7000 m thick. East of the Early Neocomian seas, gulf sediments about 2000 m thick accumulated from the Hauterivian to Aptian only in the Anyui sea. These sediments included sandstones, siltstones, conglomerates with lenses of coals and andesitic tuffs.

The Albian deposits are represented by continental facies. The Aptian–Albian boundary is identified by a change from marine to continental deposits. The Lower Albian deposits contain sandstones, conglomerates and siltstones about 1200 m thick. The upper part is dominated by volcanics about 900 m thick unconformably resting on the lower section.

According to the geodynamic reconstructions made by Parfenov (1996), the closure of the South Anyui basin was caused by the opening of the Canadian basin, during which time the Chukchi terrane, previously situated along the northern margin of North America, accreted to Siberia in pre-Albian time. The Koni–Murgal arc was also accreted at that time. As suggested earlier, terranes were believed to have migrated from the southeast, from the Pacific. However, based on the latest paleomagnetic data derived from different parts of the Koni–Murgal arc (Alexyutin and Sokolov, 2000), the Middle Jurassic–Cretaceous tectonics of Northeastern Russia was explained in terms of Eurasian and North American plate interaction. When the Atlantic ocean was opening, terranes may have passed through the North Pole during the Jurassic and moved southwards during post Middle Jurassic time.

In the *Far Eastern region*, marine Hauterivian deposits are known only in the southeastern Primorye, where a continuous Berriasian–Albian section has been described. No deposits are observed in the rest of the region.

With regard to Barremian to Middle Albian times, the following four areas of sedimentation can be distinguished: West Sikhote-Alin, East Sikhote-Alin, marginal-continental, and intracontinental basin areas.

The West Sikhote-Alin basin is viewed as a pull-apart basin filled with Late Hauterivian to Barremian turbidites. In the eastern part of the basin, during the Aptian–Early Albian the Samarga and Udyl island arcs were generated and the basin assumed the features of a back-arc basin. Among the terrigenous material, volcanogenic sandstones, tuffs and tuffaceous siltstones are predominant. Judging from the thickness of the deposits, the rate of sedimentation abruptly increased after the Aptian when volcanic arcs grew larger. The thickness of Upper Hauterivian–Middle Albian deposits reaches 5500 m.

The East Sikhote-Alin basin is interpreted as a pull-apart basin filled with terrigenous turbidites during the Hauteivian to Barremian. At the beginning of Aptian time, volcanic material was deposited as turbidites and the rate of sedimentation increased sharply. Since that time, the basin was a fore-arc basin where sedimentation continued until the Middle Albian. The deposits were about 9000 m thick (Nechaev et al., 1999; Markevitch et al., 2000).

The marginal-continental basin area includes the Udsky, Toromsky, Bureya, Razdolnensky, and Partizansky basins. Terrigenous continental deposits about 1500 m thick were predominant. The deposits of the first two basins consist mostly of conglomerates and sandstones of diversified facies (about 600 m) containing volcanic material, indicating proximity to the volcanic arcs. In the Late Aptian to Middle Albian, the Okhotsk–Chukchi volcanic belt began to form along the basin margins. Rhyolites and dacites were the first volcanics to appear.

During the Hauterivian to Middle Albian, the Bureya, Razdolnensky and Partizansk basins were coastal-marine marsh plains. Cyclic terrigenous coal formations 1500 m thick accumulated there. The Razdolnensky and Partizansk basins are regarded as pull-apart basins because their formation during the Hauterivian was associated with intensive left-lateral strike–slip faulting (Golozubov and Lee, 1999). During the Middle Albian transgression, the sea penetrated the Bureya and Partizansky basins for a short period, as confirmed by beds with marine *Trigonia* and foraminifers. From Late Albian time, however, sedimentation in the Partizansk and Razdolnensky basins changed sharply. After a short hiatus, Upper Albian–Cenomanian continental volcanic and terrigenous sediments about 3500 m thick were deposited (Turbin, 1994).

The Amur–Zeya basin (Fig. 1) is related to the intracontinental basin area that expanded substantially during the Hauterivian to Early Albian, thus marking a post-rift subsidence stage of development (Kirillova, 1995a). During this time, terrigenous coal-bearing deposits up to 1200 m thick accumulated. Along the faults on the intracontinental uplifts, acid to intermediate volcanics erupted.

The presence of Tethyan fauna in Neocomian deposits in Priokhotie and Primorye (Sey and Kalacheva, 1997) suggests that Early Cretaceous sedimentation occurred close to the equator (Sengor and Natal'in, 1996). During the Albian, the Khabarovsk, Amursky and Kiselyovka–Manoma subduction-accretionary complexes of the Khingan–Okhotsk active continental margin were attached to the pre-Cretaceous continent along sinistral faults. Other reconstructions suggest the displacements were not considerable (Nechaev et al., 1999; Utkin, 1999) and the events developed in different modes. It is certain that the environment changed abruptly from the Middle Albian. After collision of a number of terranes, most of the Far Eastern territory experienced uplift and extensive volcanism. Only a narrow sea inlet remained along what is today the Amur River valley.

During the Hauterivian, *the Pacific coastal* sea basins remained in the regions of stable downwarping. Terrigenous marine deposits mostly accumulated along with a subordinate quantity of volcanics and occasional continental intercalations. The most typical section has been described in the Penzhina river basin (Fig. 3). It should be noted that the most complete Cretaceous section about 13,000 m thick has been described there. Hauterivian–Lower Barremian deposits comformably overlying the Valanginian complexes consist of sandstones, turbidites with conglomerate beds, volcanoclastics and basalts. In the Barremian–Lower Aptian deposits, mixing of a volcanogenic component with the terrigenous deposits indicate volcanic arc activity. Tuffstones, tuffites, intermediate to acid tuffs, including beds of tuff breccia, and tuff conglomerates are predominant. Upper Aptian deposits are represented by very thick turbidites. Albian deposits are also dominated by turbidites interbedded with tuffs, conglomerates, and limestones.

The stratigraphy and thickness of post-Hauterivian sequences in other parts of the Pacific coastal region are different. For example, Barremian to Middle Albian deposits in the western Kamchatka are represented only by volcanogenic terrigenous complexes about 500 m thick. In Sakhalin, there is a thick sequence of deep-water volcanogenic-cherty-terrigenous deposits containing few organic remains. Jurassic–Early Cretaceous radiolarians are recognized at the base of the section, whereas Albian–Cenomanian radiolarians are discovered in the upper part. This part of the section is most likely correlatable with the lower Middle Yezo Group in Hokkaido.

All over the Pacific coastal region, Lower to Middle Albian deposits are dominated by turbidites. Upper Albian deposits in most sections occur unconformably with basal conglomerates, indicating a significant change in the tectonic regional framework.

According to tectonic and geodynamic interpretations (Sokolov, 1992; Parfenov et al., 1993; Sengor and Natal'in, 1996, and others), an Early Cretaceous accretionary wedge formed primarily along the Udsk–Murgal and afterwards along the Okhotsk–Chukchi (Middle Albian only) magmatic arcs. Subduction-accretionary island–arc complexes and fore-arc basin complexes successively accreted to the East Asian craton. By the Middle Albian, the Ganychalan–Ust–Belsky subduction-accretionary complex, contiguous to the Penzhina fore-arc basin, was formed and accreted. In West Kamchatka, the Omgon subduction-accretionary complex and a magmatic arc formed. Dextral displacement and compression followed oblique subduction during the Late Jurassic–Early Cretaceous (Bondarenko and Sokolov, 1996). Accretion of the Chukchi–Alaska block to the East Asian craton occurred concurrently with gabbro-plagiogranite and diorite–granodiorite emplacement.

The formation of the extensive Okhotsk–Chukchi magmatic arc (or volcanic belt) began during the Middle Albian (Belyi, 1994; Filatova, 1995) and was the most remarkable event at the Early/Late Cretaceous transition. The East Sikhote-Alin belt, which also originated during the Middle Albian, represented the southern extension of the Okhotsk–Chukchi belt.

3. Late Cretaceous

Since the Middle Albian, the seas retreated eastward beyond the volcanic arcs. Along the Siberian craton margin in the *East Siberian region*, Late Cretaceous cross-bedded sandstones about 800 m thick and pebble-conglomerates interbedded with lignite continued to accumulate. To the south, volcanics were being deposited. Acid volcanics (about 200 m thick) dominated the Early Cenomanian. During Upper Cenomanian–Turonian times, intermediate and basic volcanics of the same thickness accumulated.

In *the Northeastern region*, the extensive Okhotsk–Chukchi arc or belt continued to form in the Late Cretaceous. Its emergence was associated with the subduction of the Kula plate under the continental margin of Asia, which superseded the Middle Albian collisional regime. The belt overlapped the thrust-fold structures of the Verkhoyansk–Chukchi tectonic area, Koryak–Kamchatka orogenic belt and collisional sedimentary basins. Within the belt, a 200–5000 m thick basalt–andesite–dacite–rhyolite association of calc-alkaline series was deposited (Belyi, 1994; Filatova, 1995).

Behind the Okhotsk–Chukchi belt, there was a system of arc-like mountain ranges, the Okhotsk–Chukchi mountain belt, subjected to erosion. In its valleys, continental volcanogenic-terrigenous sediments accumulated, often with coal-bearing deposits. Further west, continental sedimentation and synchronous volcanism persisted in several basins, namely: (1) the Ukveemsky basin, from which Cenomanian ignimbrites and dacite tuffs 600 m thick are known, (2) the Momo-Zyryanka basin containing 600 m of Turonian terrigenous deposits that accumulated after a hiatus, and (3) the Sugoisky basin where 3500 m of Cenomanian volcanogenic sediments occur, of which andesites, rhyolites and their tuffs are predominant.

During the Late Cretaceous in the *Far Eastern region*, eastern and western deposional areas existed. The western continental area was locally characterized by the accumulation of Cenomanian–Turonian acid to intermediate volcanics. A hiatus is observed between the Upper Albian and Turonian deposits in the Amur–Zeya basin. During the Turonian to Senonian, extensive 300 m thick lacustrine sandstones, siltstones and gravelstones, including fresh water fauna, were deposited. Along the basin margins, conglomerates occur with deposits that reach 800 m in thickness. Maastrichtian–Danian cyclical sandstones, sands, gravels, and claystones (about 450 m thick) are widespread along with dinosaur remains intercalated in Middle Maastrichtian beds.

In the eastern area, the formation of the Late Cretaceous East Sikhote-Alin volcanic belt took place in the coastal area of the continent. It consists of an alternating series of lavas and acid to intermediate tuffs about 1500 m total thickness. During the Late Cretaceous, the West Sikhote-Alin belt, consisting of an 1800 m thick series of alternating lavas and intermediate to acid tuffs, continued to form. Volcanic arcs were topographic highs that probably had an impact on local climatic conditions and hence sedimentary regimes. Within the back arc basins, Cenomanian–Turonian continental variegated volcanogenic-sedimentary deposits up to 3000 m thick were generated, suggesting an initial high rate of volcanic arc denudation. Fore-arc troughs with terrigenous marine sediments formed within the frontal part of the system.

During the Late Cretaceous, most of the Far Eastern region was land. A marine embayment persisted only in the northeastern part, along the present-day Amur River valley. It represented a back-arc basin where about 4000 m of coarse sandstones, siltstones, and mudstones mixed with tuffaceous material were deposited during the Cenomanian–Turonian. Basal conglomerates occur at the base of the sequence. At the end of the Turonian, the sea retreated from the region. Afterwards, until the latest Cretaceous, andesites and rhyolite volcanics up to 1000 m thick formed. The sea retreated to the eastern margin of the East Sikhote-Alin belt.

The *Pacific coastal region* of Russia is also divided into western and eastern areas for the Late Cretaceous. Coastal-marine, shelf, lagoon sandy-argillaceous deposits, including paralic coal-bearing strata of the marginal continental basins are developed in the *western area*. The most complete and representative section has been studied in the Penzhina river basin (Fig. 4). The Aptian–Late Cretaceous sedimentation history in this area is distinguished by flysch and molasse stages. The former is of Aptian–Cenomanian age, and the latter is Turonian–Maastrichtian in age. The second stage is subdivided into three sedimentary cycles with transgressions in the Early Turonian, Late Santonian–Early Campanian, and Late Campanian–Early Maastrichtian. Regression and nonmarine sedimentation took place during the Coniacian–Early Santonian, Middle Campanian and Late Maastrichtian (Rozhdestvensky, 1987; Salnikov et al., 1990). The Valizhgensky suite is a typical example of the continental coal-bearing sediments alternating with offshore deposits (Terekhova and Dundo, 1987).

In the *eastern sedimentary area* of the Pacific coastal region, Upper Cretaceous marine deposits are widespread, but in general contain few organic remains except for southwestern Sakhalin. There, the most complete Upper Cretaceous section for East Russia has been described along the Naiba river (Fig. 5). The section is characterized by the occurrence of ammonites, inoceramids, foraminifers, radiolarians, and other organic remains (Poyarkova, 1987). The Late Cretaceous first order cycle is subdivided into smaller second and third order cycles. The cyclicity is defined by the alternation of relatively deep offshore marine, shallow marine and shoreface facies. The transgression period correlates well with the peak of the global Cenomanian–Turonian transgression (Graciansky et al., 1998).

In East Sakhalin, a Turonian–Maastrichtian series (6000 m thick) of deep-water volcanogenic-cherty-terrigenous deposits has been recorded. The upper part contains turbidites with olistostrome horizons. In addition, island-arc trachyandesites are found in southeastern Sakhalin. It is there that a Campanian–Danian complex of coastal-marine

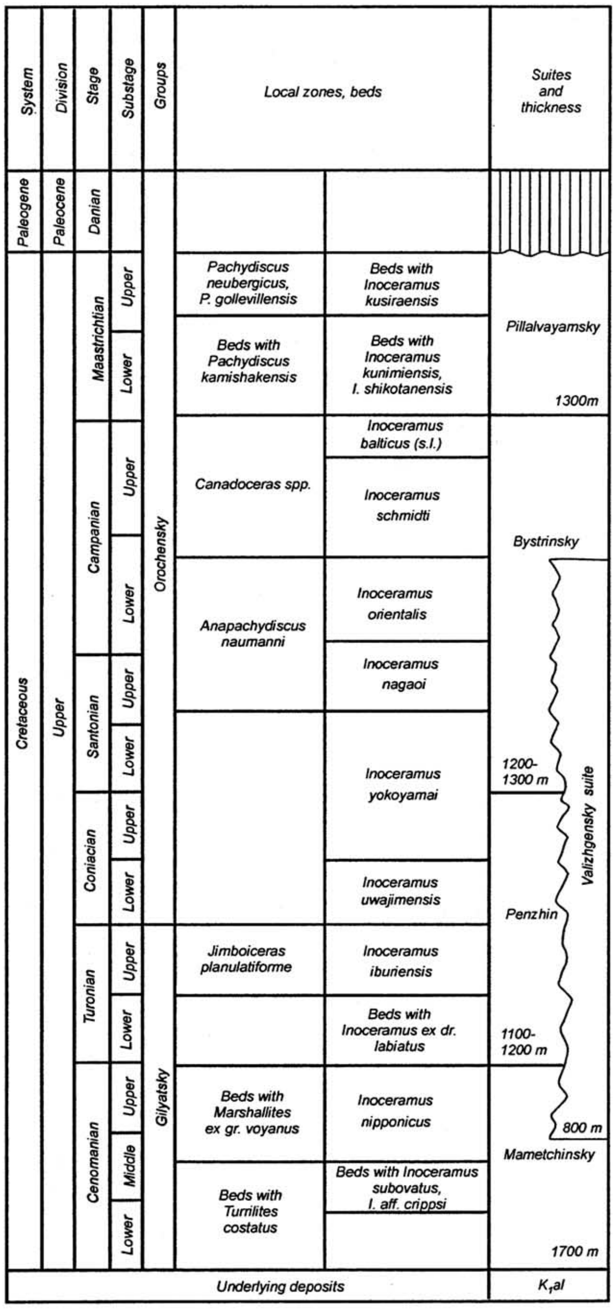

Fig. 4. Stratigraphic column of the Upper Cretaceous deposits in the Penzhina basin (after Terekhova and Dundo (1987)). For location see Fig. 1.

and continental terrigenous deposits with coal interbeds is developed. A similar change in deposits can be observed on Hokkaido Island (Campanian to Maastrichtian Hakobuchi Group).

Over the last decade, data on detailed stratigraphic, structural and paleomagnetic studies for the Cretaceous of NE Russia have been obtained and analyzed (Sokolov, 1992; Parfenov et al., 1993; Pushcharovsky, 1993; Nokleberg et al., 1994; Vishnevskaya and Filatova, 1994; Shapiro, 1995; Zinkevich and Tsukanov, 1996; Kovalenko, 1996; Filatova, 1996; Sengor and Natal'in, 1996; Vishnevskaya,

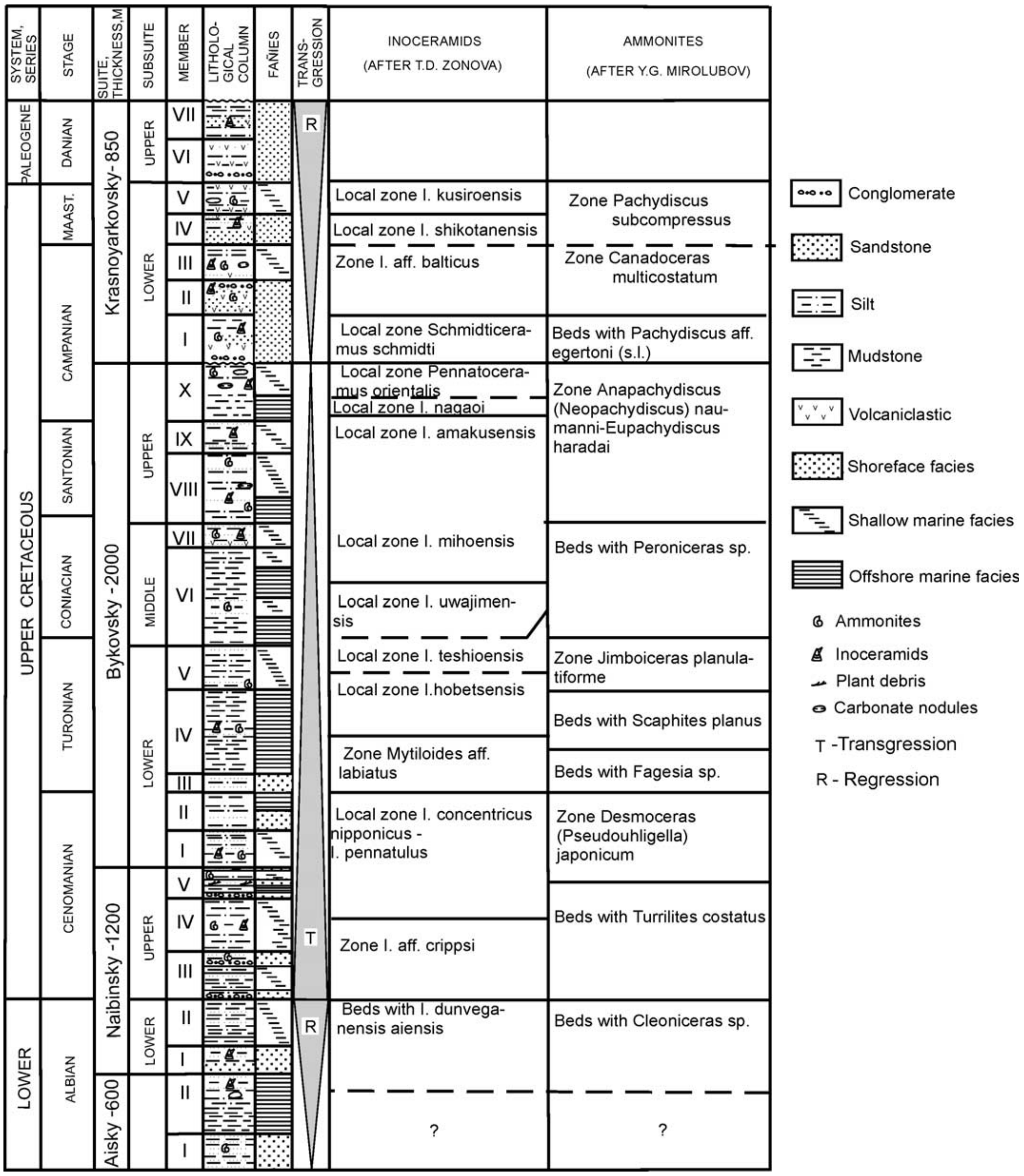

Fig. 5. Lithological–stratigraphical column of the Cretaceous deposits in the Western Sakhalin basin, the Naiba section (after Poyarkova (1987) with the author's additions). For location see Fig. 1.

1996; Bondarenko and Didenko, 1997; Levashova et al., 1997; Alexyutin et al., 2000; Khanchuk, 2000; Bogdanov and Filatova, 2000 and others). These investigations resulted in considerable change to previous concepts.

According to tectonic and paleogeodynamic reconstructions, Middle Albian deformation created a new structural pattern characterized by its lateral environmental range and corresponding sedimentary complexes (from west to east): volcanogenic-sedimentary complex of the Okhotsk–Chukchi volcanic belt, terrigenous shelf deposits, continental slope and bottom deposits, volcanic-tuffaceous and hyaloclastic–basaltic island–arc series, jasper–basalt and volcanic-tuffaceous-cherty oceanic formations (Sokolov, 1992).

The growth of the Late Cretaceous accretionary wedge outboard the Okhotsk–Chukchi arc ceased during the Late Cretaceous in response to the collision of the continental margin with the Okhotsk Sea microcontinent located in the central segment of the Okhotsk Sea (Sengor and Natal'in, 1996). Part of the microcontinent can be observed in southwestern Kamchatka. Eastward, fragments of another Late Cretaceous subduction-accretionary complex and Turonian–Maastrichtian magmatic arc had formed. These complexes constitute the base of the Kamchatka Cenozoic volcanic arcs (Tsukanov and Zinkevitch, 1987). The subduction-accretionary complex consists of ophiolites, pelagic sediments and turbidites that represent a packet of slabs with southeastern vergence. Shapiro (1995) and Kovalenko (1996) established that during the Late Cretaceous, the Achaivaam–Valaginsky Campanian–Maastrichtian intraoceanic arc was located at 50°N. It accreted to the continent during the Early Paleocene. As far as the Okhotsk–Chukchi belt is concerned, the paleomagnetic data showed that it remained at the same location during the Late Cretaceous.

Another NW–SE Late Cretaceous island–arc system persisted west of the Okhotsk Sea microcontinent. It is represented by the Late Albian to Paleogene East Sikhote-Alin volcanic belt and the subduction-accretionary complex in the fore-arc trough that crops out in Sakhalin. The Shmidt complex, containing ophiolites and shales (Rozhdestvensky, 1987, 1994), appears to be the suture along which the Okhotsk Sea microcontinent accreted to Sakhalin during the Early Paleocene.

A Late Cretaceous island-arc system of NE extension existed along the southern margin of the Okhotsk Sea microcontinent (Kiminami et al., 1992; Rozhdestvensky, 1987, 1994). Fragments of volcanic arc and accretionary prism within the fore-arc trough are known in southwestern Sakhalin, southeastern Hokkaido Island (Nemuro Group) and on the islands of the Lesser Kuril Range. According to geodynamic reconstructions, this system was located at approximately 50°N during the Late Cretaceous and achieved its current position by meridional dextral displacements during the Late Cenozoic (Kiminami et al., 1992; Hirano et al., 1992).

4. Summary

Global processes of lithospheric plate interaction and related regional tectonics played a leading role in Cretaceous environmental changes along the continental margin of East Russia.

Multi-disciplinary investigations and stratigraphic correlations carried out by Russian researchers of different specialities permitted identification of the synchroneity and interaction of various geological and biological events. These investigations allowed reconstruction of the consecutive changes in climatic, biological and physical–geographical environments that took place in East Russia during the Cretaceous. The results obtained have been synthesized in a number of papers (Kirillova, 2000; Kirillova et al., 2000; Markevitch et al., 2000 and others).

During the Early Cretaceous, oblique plate convergence activated a transform continental margin over a long period of time. During the Middle Albian, a collage of terranes accreted to the continental margin of East Russia. During the Late Albian period, the angle of convergence increased, subduction recommenced and a giant East Asian volcanic belt began to form along the continental margin. This belt was morphologically represented by a chain of mountain ridges (up to 3000 m), thus creating a sublongitudinal tectonic and climatic zonation. The active continental margin, with typical marginal seas–island arcs–open sea environments, persisted until the end of the Cretaceous.

The Late Maastrichtian was characterized by overall uplift of the region.

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