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Late Mesozoic–Cenozoic sedimentary basins of active continental margin of Southeast Russia: paleogeography, tectonics, and coal–oil–gas presence

Galina L. Kirillova*

Institute of Tectonics and Geophysics, Far Eastern Branch, Russian Academy of Sciences, 65, Kim Yu Chen Str., Khabarovsk 680000, Russian Federation

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Abstract

Various settings took place during the Late Mesozoic: divergent, convergent, collisional, and transform. After mid-Jurassic collision of the Siberian and Chinese cratons, a latitudinal system of post-collision troughs developed along the Mongol-Okhotsk suture (the Uda, Torom basins and others), filled with terrigenous coal-bearing molasse.

The dispersion of Pangea, creation of oceans during the Late Jurassic are correlated to the emergence of the East Asian submeridional rift system with volcano-terrigenous coal-bearing deposits (the Amur-Zeya basin). At that time, to the east there existed an Andean-type continental margin. Foreland (Upper Bureya, Partizansk, and Razdolny) and flexural (Sangjiang-Middle Amur) basins were formed along the margin of the rigid massifs during the Late Jurassic to Berriasian.

During the Valanginian-mid-Albian an oblique subduction of the Izanagi plate beneath the Asian continent occurred, producing a transform margin type, considerable sinistral strike slip displacements, and formation of pull-apart basins filled with turbidites (the Sangjiang-Middle Amur basin).

The Aptian is characterized by plate reorganization and formation of epioceanic island arcs, fore-arc and back-arc basins in Sakhalin and the Sikhote-Alin (the Alchan and Sangjiang-Middle Amur basins), filled with volcanoclastics.

During the mid-Albian a series of terranes accreted to the Asian continental margin. By the end of the Albian, the East Asian marginal volcanic belt began to form due to the subduction of the Kula plate beneath the Asian continent. During the Cenomanian–Coniacian shallow marine coarse clastics accumulated in the fore-arc basins, which were followed by continental deposits in the Santonian–Campanian. From the Coniacian to the Maastrichtian, a thermal subsidence started in rift basins, and continental oil-bearing clastics accumulated (the Amur-Zeya basin).

Widespread elevation and denudation were dominant during the Maastrichtian. This is evidenced by thick sediments accumulated in the Western Sakhalin fore-arc basin.

During the Cenozoic, an extensive rift belt rmade up of a system of grabens, which were filled with lacustrine–alluvial coal–and oil-bearing deposits, developed along the East Asian margin.

Keywords: Sedimentary basins; Continental margin; Cretaceous; Southeast Russia

1. Introduction

Sedimentary basins of Southeast Russia have still remained poorly investigated. In the earlier time their classification and typification were conducted within a geosynclinal concept (Voronkov, 1987). Under the progress of the plate tectonics in the Far East there have appeared geodynamic reconstructions proposed by a number of authors (Khanchuk, Golozubov, Martynov, & Simanenko, 1997; Natal'in, 1994; Parfenov, 1983).

During the 1980s great interest has been expressed in multidisciplinary researches of the sedimentary basins as reservoirs of various mineral deposits including oil, gas and coal. At the same time, the journal 'Basin Research' began to be issued, and a series of text-books devoted to different aspects of the study of the sedimentary basins has been published (Allen & Allen, 1990; Dickinson, 1976; Hsü,

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* Fax: +7-(4212)-22-76-84.
E-mail address: kirillova@itig.as.khb.ru (G.L. Kirillova).

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1989; Ingersoll, 1988; Miall, 1984). New classifications of the sedimentary basins based on the actualistic model have been proposed by Bally (1975), Bally and Snelson (1980), Dickinson (1974), Ingersoll (1988), and Kingston, Dishroon and Williams (1983), and others. In oil industry a classification by Halbouty (1980) is used, which was further developed by Fischer (1975), and Klemme (1980). Hydrocarbon potential of the basins is estimated regarding their type of basin classification.

Dickinson (1974, 1976) determined the type of the sedimentary basins based on the nature of the earth crust, such as locations of the basins in plate margins (divergent, convergent, and transform), recognizing five major basin types: (1) oceanic; (2) basins of rift continental margins; (3) basins related to suture belts; (4) arc-trench system basins and (5) intracontinental basins. More recently, on this basis more detailed classification of the sedimentary basins was proposed by Busby and Ingersoll (1995).

It has now become quite obvious that basins should be classified in accordance with the geodynamic setting that existed during a definite stratigraphic interval. Dickinson (1974, p. 1) says that subsequently, evolution of the sedimentary basin could be considered as a result of successive discrete change of plate tectonic setting and plate interaction. Hence, there exists a basin-forming and basin-transforming tectonics that appears to be a leading factor in the basin formation and evolution. It should be added that the global plate tectonics should be correlated with regional tectonics producing main faults which form spaces for sediment accommodation as well as uplifts and island-arcs exerting a direct influence over the supply of clastic material and its rate, and sediment thicknesses.

The second important factor providing spaces for sediment accommodation is sea level fluctuations of the world ocean. The global scale of eustatic fluctuations of the world ocean (Graciansky, Hardenbol, Jacquin, & Vail, 1998; Haq, Hardenbol, & Vail, 1987) is the base for correlation with regional settings.

Combination of tectonics and eustasy permits discrimination of the sequence stratigraphic units of different ranks. Stratigraphic fill of every megasequence is controlled by interaction of the tectonic setting, rate of sedimentation and sea level changes.

Thus, fundamental knowledges obtained from the basins well studied by different geological and geophysical techniques and drillings, have allowed to attempt a new classification and typification of sedimentary basins of Southeast Russia. For this aim, global geodynamic reconstructions of plate movements along the East Asian margin (Maruyama & Seno, 1986), the global curve of eustatic fluctuations of the world ocean (Graciansky et al., 1998; Haq, Hardenbol, & Vail, 1988), and regional information on the location of major fault systems, island-arcs, and data on stratigraphy, paleogeography and sedimentology have been used intergrally. A synthesis of these data has enabled to obtain only preliminary judgement regarding basin types and main stages of their evolution.

2. Correlation of the Late Jurassic regional events in Southeast Russia with the global events

2.1. Late Jurassic–Berriasian

Cretaceous history of the region is in close relation to the Late Jurassic. After Middle Jurassic collision of the North Asian craton against the Chinese craton, a sublatitudinal system of post-collision Late Jurassic-Cretaceous basins (e.g. the Uda and Torom basins) was generated along the Mongol-Okhotsk suture (Figs. 1 and 2). These basins were filled with terrigenous coal-bearing molasse. The Faralon plate was slowly spreading at that time toward the northeast with the rate of 10.7 cm/y (Maruyama & Seno, 1986). Formation of the East Asian submeridional rift system with subalkaline volcanism is most likely connected with these movements (Kirillova, 1994, 1999). Mantle plumes are believed to have played a certain role in rifting and in forming related sedimentary basins (Songliao, Amur-Zeya), as deduced from a thinned continental crust under these basins (Hsü, 1989).

A system of large submeridional faults was evidence of the extension of the Late Jurassic continental margin (Figs. 1 and 2). Along the margin of the Bureya massif, there was formed the Late Jurassic Upper Bureya foreland basin, filling with terrigenous coal-bearing deposits. Basins similar to that (Partizansk, Razdolny) were formed along the Khanka massif margin. Late Jurassic to Berriasian terrigenous sediments accumulated in the coastal-marine environment. Sedimentation occurred during the time of global transgression, which reached maximum in the Middle Tithonian, and was later followed by regression (Haq et al., 1987).

To the east of the submeridional margin there was a vast sea basin inhabited by a variety of both Boreal and Tethyan biota: buchias, ammonites, radiolarians. The rate of the terrigenous sedimentation in this basin was 140–250 m/my. Subduction and the related accretion were practically over by the Late Jurassic, that is fixed by the change from a volcano–siliceous accretionary complex to a terrigenous one. In the Berriasian slow oblique subduction of the Izanagi plate re-emerged with the rate of 5.3 cm/y (Maruyama & Seno, 1986).

The type of the Sanjiang-Middle Amur basin at this stage is not sufficiently clear. It was probably a flexural basin of a passive continental margin. In its western part Late Jurassic–Early Cretaceous sediments are represented by a coal-bearing continental clastic formation. In the vicinity of the town of Khabarovsk there are olistostrome assemblages with clayey Late Jurassic matrix, and so far to the east a marine clayey hemipelagic (?) formation is developed.

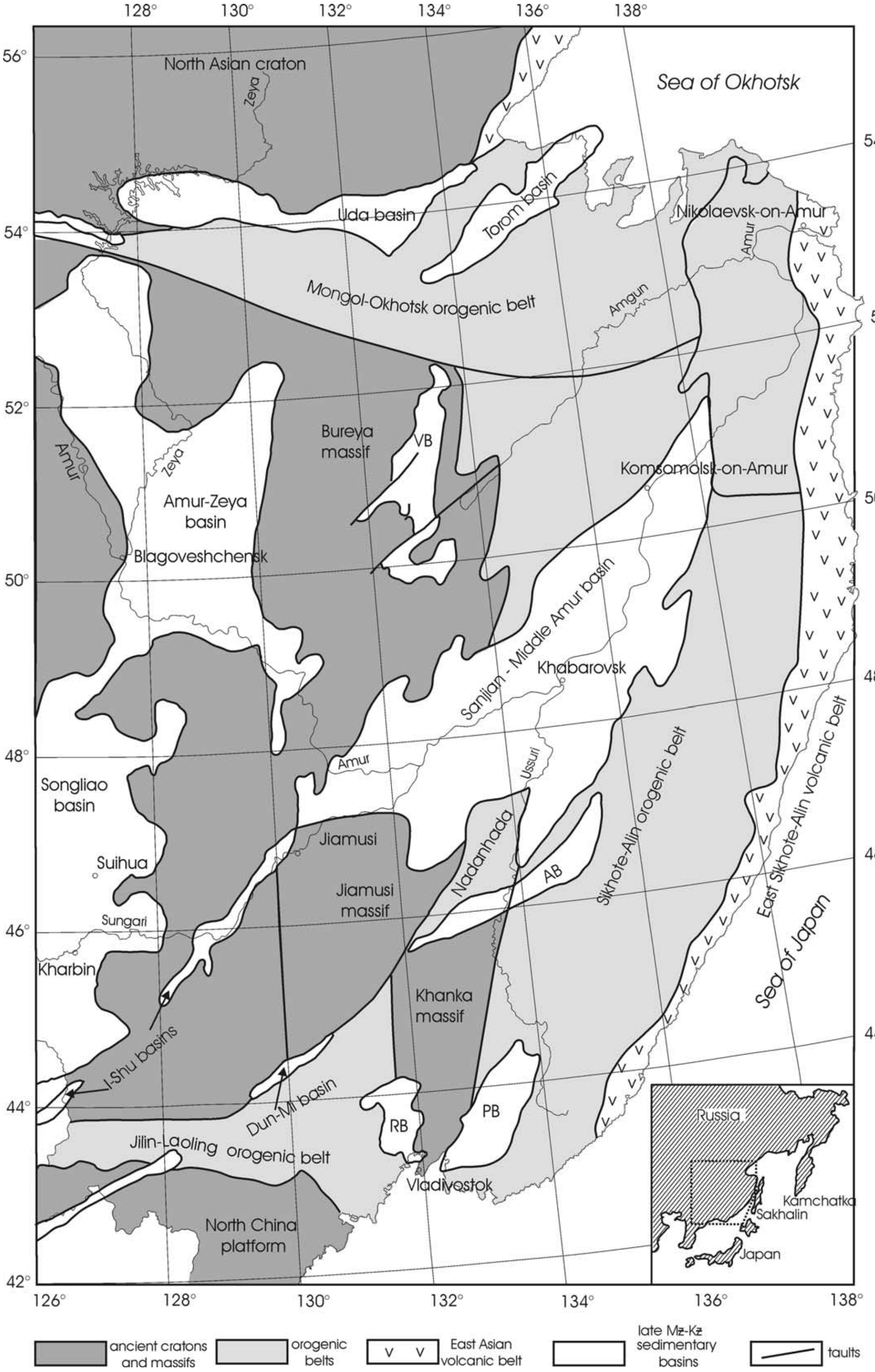

Fig. 1. Location of the principal structures and sedimentary basins in Southeast Russia and adjacent regions. AB—Alchan basin; PB—Partizansk basin; RB—Razdolny basin; VB—Upper Bureya basin.

2.2. Valanginian

The oblique sliding of the Izanagi plate accelerated up to 30 cm/y providing formation of the transform-type margin. Left-lateral strike-slip northeastward movements dissected the former submeridional margin (Fig. 2). Due to the folded and strike-slip movements, a chain of uplifts resembling a non-volcanic island-arc arose and formed the eastern flank of the Sanjiang-Middle Amur basin. At this stage a transtensional pull-apart basin was filled with clastic turbidities at the rate of 300–600 m/my.

General patterns of the sea basin, biogeographic distributions in East Russia during the Valanginian are shown in Fig. 3. At that time the Tethyan zoogeographic realm was linked with the Boreal realm. Sediments of mostly terrigenous rudaceous composition are a manifestation of the global regression in Southeast Russia in the Valanginian (Haq et al., 1987).

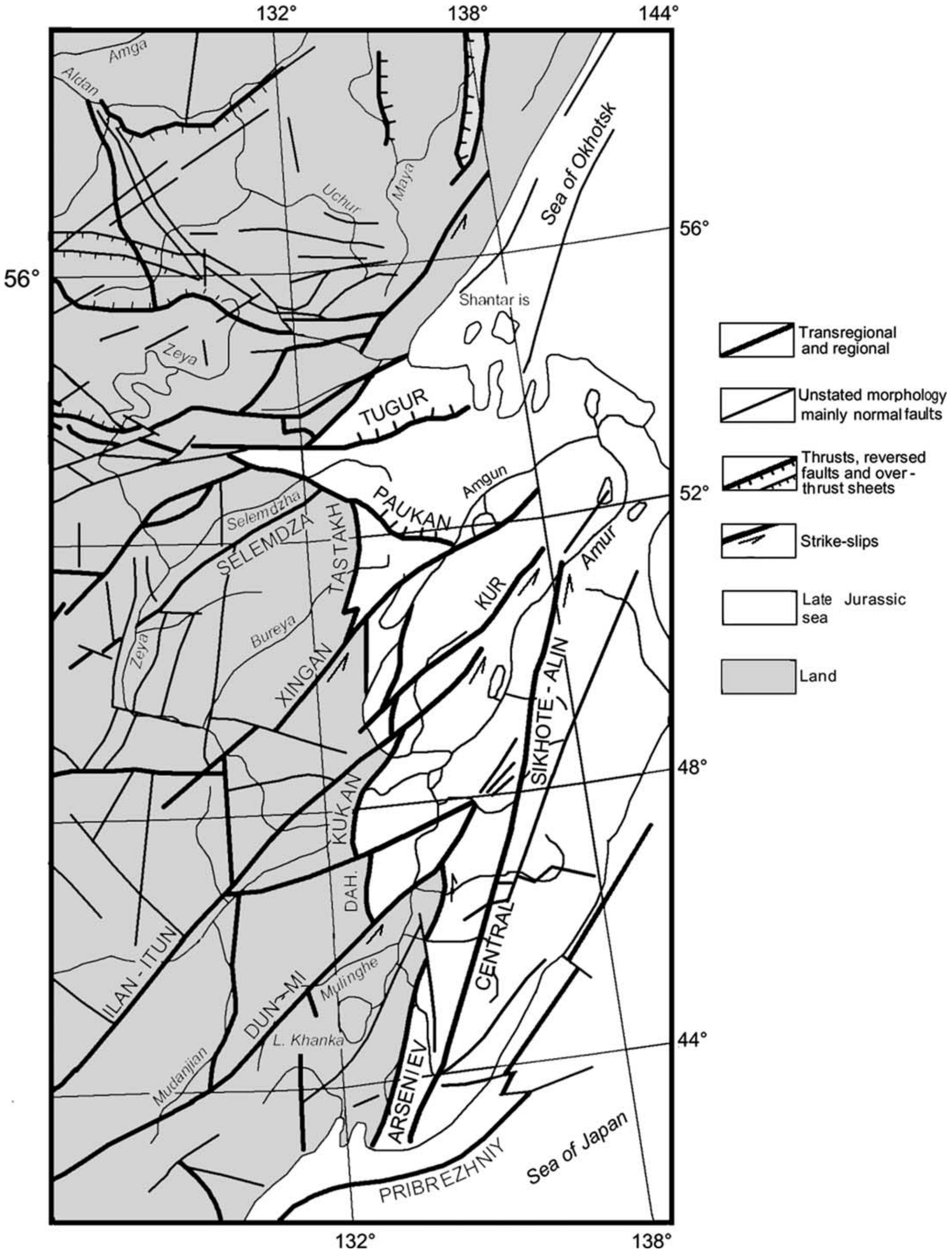

Fig. 2. Scheme showing the location of the major faults (after Krasny et al. (1999)).

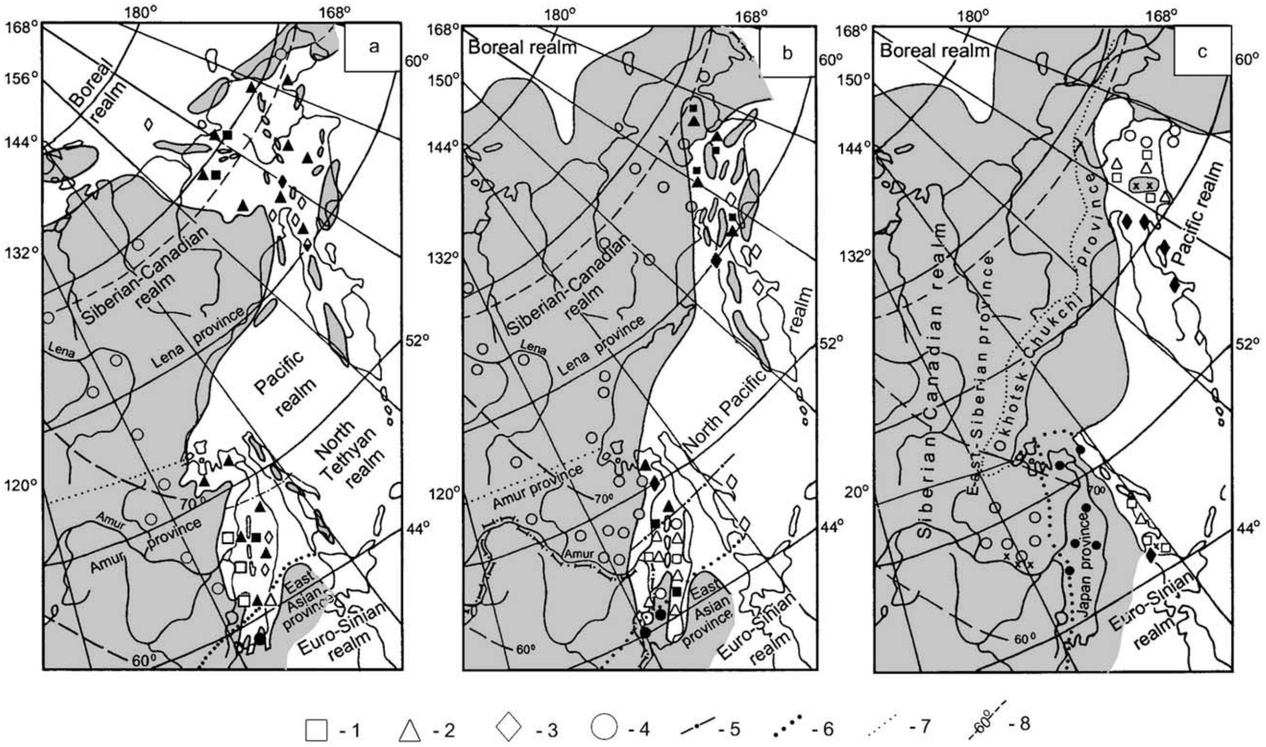

Fig. 3. Paleogeography of East Russia in three different ages: (a) Valanginian, (b) Albian, (c)-Maastrichtian Kirillova et al. (2000). 1—ammonite; 2—bivalves; 3—radiolarians: open symbols—Tethyan realm (a, b), Pacific realm (c); shaded symbols—Boreal realm (a, c), North Pacific (b); 4—paleoflora: open circles—Siberian—Canadian realm; shaded circles—Euro-Sinian realm; 5—realm boundary from ammonites; 6—phytogeographic realm boundary; 7—phytogeographic province boundary; 8—paleolatitudes.

In the west, intraplate volcanism in the Amur-Zeya basin continued to the Valanginian. In the Uda basin in the Early Cretaceous (Berriasian–Valanginian) a thick unit of conglomerates (700 m thick) was deposited. It is notable that pebbles of gneiss, granites, migmatites, amphibolites, and gabbro are predominant. This gives evidence of an abrupt upheaval of the Stanovoy ridge at that time and of the predominance of the northern provenance. Consequently, after collision the region remained tectonically active.

2.3. Hauterivian–Barremian

Transform marginal setting as a whole persisted till the mid-Albian (Fig. 3). At that time a strait connecting the Boreal and Tethyan realms closed, as evidenced by the absence of the Boreal fauna (Kirillova, Markevitch, & Belyi, 2000; Pokhialainen, 1994). In the Hauterivian left-lateral strike-slip displacements along the NE faults of the Tan-Lu system became active (Utkin, 1989; Xu Jiawei, 1993). The Selemdza, Xingan, Kur, Ilan-Itun, and Dun-Mi faults refer to this system (Fig. 2).

The global transgression, which commenced in the Late Hauterivian (Haq et al., 1987; Pokhialainen, 1994), coincided with the Simbirskitian transgression in Northeast Russia. In Southeast Russia, however, regression was dominant probably due to uplifting along the strike-slips. Hauterivian deposits were described only in East Sikhote-Alin (Markevitch, Konovalov, Malinovsky, & Filippov, 2000; Sokolov, 1987; Turbin, 1994).

In the Amur-Zeya basin hiatus in sedimentation lasted from the Hauterivian till the Late Barremian, and intraplate volcanism occurred at that time. Hiatuses of shorter duration were also identified in the Partizansk and Sanjiang-Middle Amur basins.

2.4. Aptian

Aptian time is characterized by global-scale volcanic activity, particularly in the western Pacific, as on the Darwin Rise. Recent researches suggest that this event seems to have been associated with a mantle plume rising from the core-mantle boundary beneath the Central Pacific and rapidly moving (<3 m y) to the surface (Larson, Fischer, Erba, & Premoli Silva, 1993; Maruyama & Seno, 1986). In Southeast Russia intraplate volcanism was active at that time within the Amur-Zeya basin, whereas an epioceanic Udyl volcanic island-arc of submeridional extension began to form in the east (Markevitch et al., 2000). Along the northeastern margin of the Sanjiang-Middle Amur basin, the Samarga-Moneron volcanic arc was generated in the Aptian to mid-Albian. A small West Sikhote–Alin epicontinental volcanic island arc stretched along the northeastern margin of the Alchan basin. From that time the Sanjiang-Middle Amur and the newly formed Alchan basins might be considered as back-arc basins. The sediments of the basins contained substantial volcaniclastic admixture, and the rate of sedimentation was 200–400 m/my.

Though the global regression was typical of the Aptian, an extensive mantle plume in the western Pacific caused the transgression on the continental margin. This is evidenced by the penetration of the sea into the Upper Bureya and Alchan basins during the Aptian.

There are some differences of opinion concerning the plate movements at that time. Maruyama and Seno (1986) suggest that in the interval of 127–119 Ma the Izanagi plate was moving northwestwards at the rate of 21.1 cm/y. However, the data obtained from the 144 ODP cruise show that basalts from the basement of the Seiko and Mitt guyots are of the Aptian age, and as it is evident from the paleomagnetic data, the Pacific plate was moving in a zigzag mode, but predominantly southwards in the Aptian (Arnaud-Vanneau et al., 1993). This event coincides with the onset of volcanism and an extensional regime in East Russia (Kirillova, 1994, 1999).

Regional data indicate that the transform margin regime remained through the Aptian with a substantial extensional component. This is supported by the formation of the Alchan pull-apart basin along the Dun-Mi fault system (Fig. 2). An Aptian to Cenomanian sedimentary sequence of the Upper Bureya basin was also formed in the regime of the NE pull-apart extensional basin (Fig. 1), that is at an angle to the previous extension of the basin.

According to the global curve (Larson et al., 1993), the Aptian was marked by the warming regime. In southeastern Russia a climatic optimum was also noticeable which was expressed in the change of vegetation and intense coal formation in the Upper Bureya, Razdolny and Partisansk basins (Fig. 4).

2.5. Albian

The Albian time was extremely rich in geologic events. First of all, at the beginnning of the Albian the largest global transgression was triggered. In southeastern Russia two large bays seperated by uplifts (Fig. 3b) were formed. The presence of mixed fauna suggests free relations between the North Pacific and Tethyan zoogeographic realms (Kirillova et al., 2000). The sea water as narrow sea inlets (not shown in Fig. 3) penetrated rather deeply into the continent. This is confirmed by the beds with marine *Trigonia* faunas in the continental section of the Partizansk basin, beds with foraminifers and brachiodontes in the Upper Bureya basin, and occurrences of marine fish remains in the Lesser Xingan.

However, this transgression appeared to have been rather short in duration in the south of the Partizansk area, where after thin marine beds were deposited, continental sedimentation was resumed. This event was related with large-scale compressional processes over entire East Asia. A series of terranes attached to the continental margin, and complex packets of covers were formed, and large granite and monzonite bodies were intruded (Natal'in, 1994).

In the opinion of Khanchuk (Khanchuk et al., 1997), in Southeastern Russia collisional processes expanded laterally from the west to the east and from the south to the north and hence on different areas of the Sikhote-Alin folding and collisional granite intrusions are dated in different ways; nevertheless, as a whole as Middle to early Late Cretaceous in age.

During the Late Albian an oblique subduction of the Izanagi plate was resumed at the rate of 23.5 cm/y and in the consequence, the extensive East Sikhote-Alin marginal-continental volcanic belt began to form. Within the belt, a thick calc–alkaline basalt–andesite–dacite–rhyolite association was deposited.

Beginning in the Aptian and mostly in the Albian through Cenomanian, products of the volcanic activity are found in the sediments of all basins. In the Amur-Zeya continental basin, sedimentation recommenced in the grabens, and along the flanks of the grabens volcanic eruptions took place. The Upper Bureya basin entered a final phase of its development, and the area of sedimentation was reduced. The depocenter was shifting toward the west due to the pressure from the east. The Sanjiang-Middle Amur and Alchan basins can be considered as back-arc basins where turbidites continued to accumulate until the mid-Albian. After a short interval in the mid-Albian the type of sedimentation changed and coastal-marine coarse clastic sediments with a considerable mixture of volcanics were accumulated.

2.6. Cenomanian–Coniacian

The Izanagi plate was moving in the NW direction (Fig. 4). Intense volcanism along the East Sikhote-Alin belt continued. Cenomanian-Turonian volcanics are represented mainly by tuffaceous conglomerates, tuffites, tuffs and andesite-basalt, and andesite lavas with occasional basalts. After a short interval in the mid-Turonian, Turonian-Campanian tuff and rhyolite ignimbrites related to the diorite–granite intrusion were formed.

Despite the global transgression reached its peak in the Cenomanian and Turonian (Graciansky et al., 1998; Haq et al., 1987), a ridge like a volcanic belt and a general elevation of the region caused by the Albian collision closed the way to the sea waters. Cenomanian to Lower Turonian coastal-marine sediments accumulated only in the Sanjiang-Middle Amur and Upper Bureya basins. Thereafter, the sea retreated from the region, and marine sedimentation continued only in the frontal part of the volcanic belt in the West Sakhalin forearc basin.

In the Partizansk basin terrigenous red beds with a considerable mixture of volcaniclasts were deposited. The rate of sedimetation in the Partizansk basin was rather high probably due to the proximity of the degrading East Sikhote-Alin volcanic arc. Presence of the red beds suggests

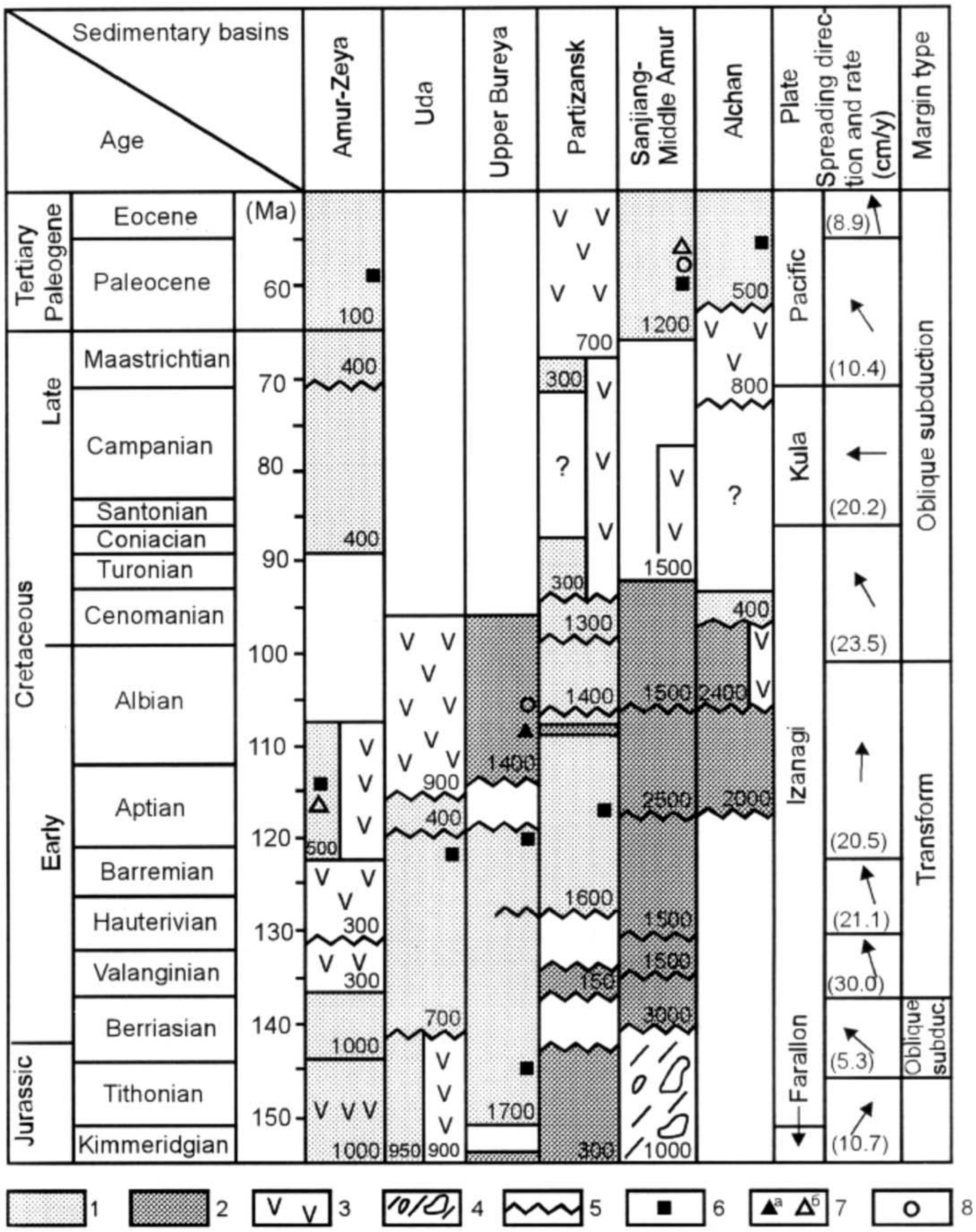

Fig. 4. Stratigraphy and lithology of the main basins. (Direction and velocity of the plate motions after Maruyama and Seno (1986)). 1—continental facies; 2—marine facies; 3—volcanics; 4—olistostrome assemblage; 5—unconformity; 6—coal deposit; 7—gas deposit (a), gas manifestation (b); 8—oil show.

that the climate in the back of the volcanic belt, which formed a rather high edifice and closed the way to humid winds, was dry and hot. The nature of the vegetation during the Late Cretaceous is evidence of this inference (Volynets, 1998). In the Late Turonian to Coniacian terrigenous thin coal-bearing sediments accumulated on the restricted area. In the Alchan basin during the Cenomanian thin alluvial-lacustrine sediments accumulated, but red beds were rare (Amel'chenko, Golozubov, Volynets, & Markevitch, 2001).

In the Amur-Zeya basin, after a substantial hiatus in the early Coniacian fine lacustrine sediments with abundant fresh-water fauna were deposited. At this stage the rifting regime was replaced by a post-rift subsidence regime of the basin (Kirillova, 1995).

2.7. Santonian–Campanian

In the Santonian to Campanian, rapid subduction of the Kula plate beneath the Asian continental margin was predominant. Intense volcanism and considerable upheaval of the territory were supposedly caused by this subduction. Sedimentation in the lacustrine-alluvial environment

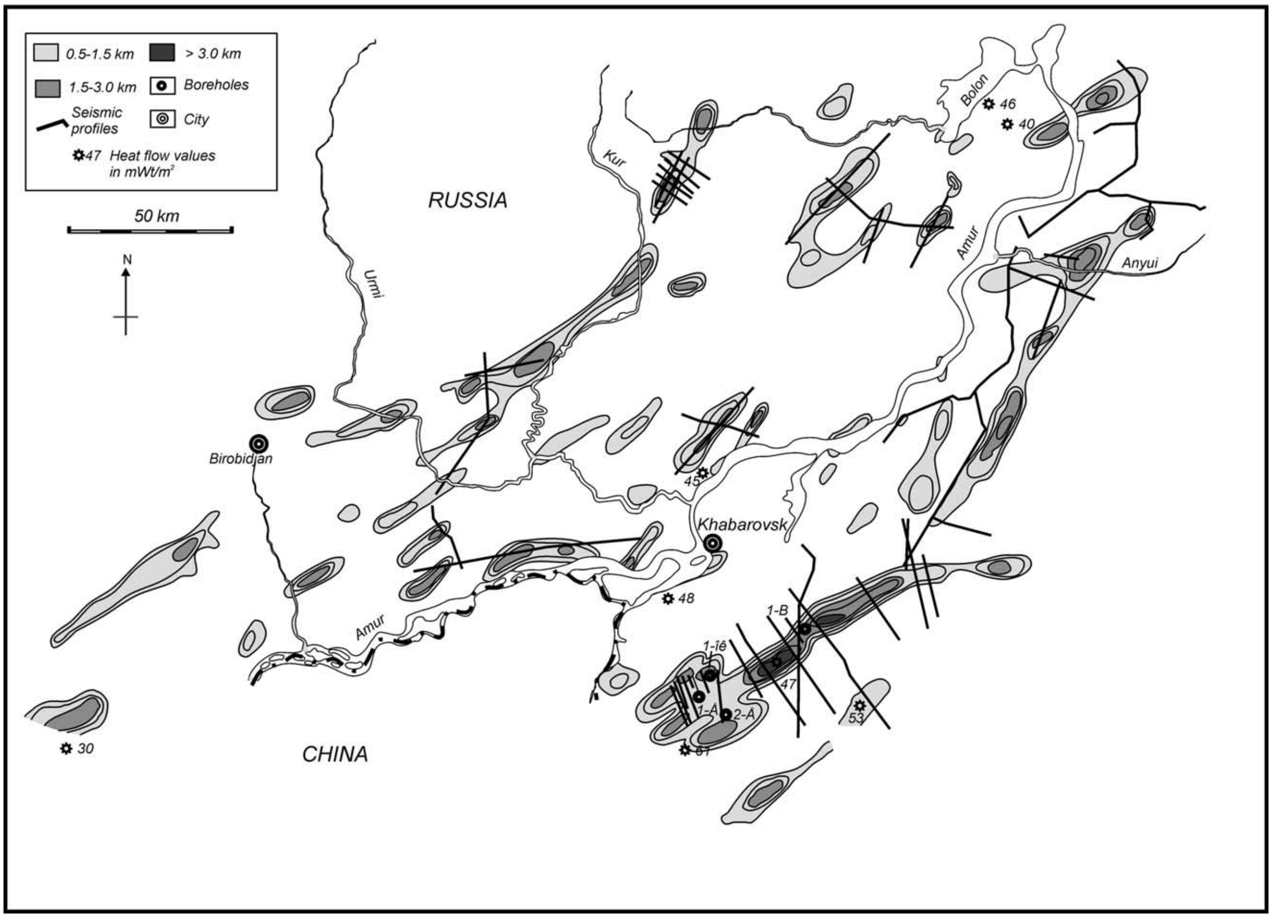

Fig. 5. Cenozoic grabens in the Sanjiang-Middle Amur basin.

continued only in the Amur-Zeya basin. Thin alluvial sediments also accumulated in the northwestern margin of the Partizansk basin.

2.8. Maastrichtian

In the Maastrichtian, reconstruction of the lithospheric plate kinematics occurred, and thereafter the Pacific plate shifted northwestward with a low rate (10.4 cm/y). In Southeast Russia volcanism continued. As a whole, during the Maastrichtian East Russia was a landmass (Fig. 3). Only in the Amur-Zeya basin cyclically alternating alluvial sediments, mostly coarse-grained, were deposited after a short hiatus.

At the Cretaceous/Cenozoic boundary uplifts and intensive erosion occurred almost throughout the territory, except for the Amur-Zeya basin, where continental sedimentation continued. Cenozoic sediments appeared to be of small thickness but spatially widespread.

In the east, from the Khanka Lake on the south to the western coast of the Sea of Okhotsk on the north, along the NE faults, an extensive rift belt made up of a system of asymmetric grabens developed (Fig. 5), which was filled with lacustrine-alluvial coal- and oil-bearing sediments (Kirillova, Liu, Simin, Varnavsky, & Krapiventseva, 1997; Krasny et al., 1999). The Pacific plate moved northwestward in the Cenozoic. Formation of the rift belt is most likely connected with extensive mantle plume activity.

3. Basin types and stages of their evolution

Analysis of the results of the correlation of the regional events in Southeast Russia with global events permits determination of the basin types, stages of their evolution, and sedimentary systems characterizing these stages.

3.1. Amur-Zeya basin

By analogy with the Songliao basin in China (Hsü, 1989), this basin is considered as an intracratonic basin of the combination type. The basin evolution is distinguished by three major stages: rifting (Late Jurassic-early Albian), when volcanogenic-terrigenous formations accumulated with a total thickness of 3100 m; a post-rifting stage (Coniacian to Campanian) characterized by the expansion of the sedimentation area and accumulation of lacustrine-alluvial deposits (clays, siltstones, sandstones with rich lacustrine fauna), 400 m thick, and a compressional stage (Maastrichtian to Cenozoic) distinctive for formation of the lacustrine-alluvial coal-bearing deposits, about 600 m thick (Kirillova, 1995).

In general terms, according to Klemme (1980), the North Sea and the West Siberian basins are of a similar type. From Busby and Ingersoll (1995) standpoint, the Paleozoic Michigan basin is a typical ancient intracratonic basin, whereas the Chad basin in Africa might be interpreted as a modern analogue. Okada (2000) believes that mantle plumes played a substantial role in the formation of such basins at the initial stages.

3.2. Uda basin

This basin is in general characterized by a convergent setting. It is considered as a peripheral post-collisional foreland basin. Its southern flank adjacent to the Mongol-Okhotsk orogenic belt appears to be steeper, and sediments here are more dislocated, as compared to the gentle northern flank adjacent to the North Asian craton. After the Middle Jurassic collision, Late Jurassic coastal marine clastic sediments accumulated on the northern margin of the Mongol-Okhotsk orogene in the presumably residual basin. The North Asian craton became active and sharply upheaved at the beginning of the Berriasian, because of rather thick Berriasian–early Hauterivian conglomerates and sandstones containing abundant pebbles of Precambrian rocks. Terrigenous continental sediments continued to accumulate till the mid-Aptian, with a short hiatus in the Late Barremian. Thereupon volcanism became active in the eastern part of the basin. A total thickness of the sediments attains about 2000 m.

3.3. Upper Bureya basin

It is located on the eastern margin of the Bureya massif and shows a submeridional extension as a whole. The basin is best investigated because of the coal fields prospected (Davydova & Goldshtein, 1949; Krapiventseva, 1979; Voronkov, 1987; Shcherbakov, 1967; Varnavsky & Krapiventseva, 1995). Nevertheless, geodynamic history of the basin has not hitherto been presented. The basement of the basin is composed of Precambrian complexes of the Bureya massif and Paleozoic granites. The history of the basin is rather complex and dates back to the Early Jurassic (Sinemurian). The Sinemurian to early Bajocian sequence of the coastal-marine shelf terrigenous sediments accumulated in the passive continental margin along the Bureya massif. The thickness of the deposits increases from the west to the east, ranging from 1000 to 4600 m. Coarse sediments are commonly changed upwards into fine sediments (siltstones, mudstones). Terrigenous material is substantially quartz-feldspathic in composition.

Collision of the North Asian and China cratons in the Middle Jurassic caused elevation, dislocation, and strong catagenetic rock changes in the eastern part of the basin. The depocenter of the basin shifted westward. Unconformities and conglomerate strata are observed at the base of the Middle Bathonian–Middle Oxfordian sequence. At that time the basin continued to be filled rapidly with terrigenous sediments. Sedimentation cycles begin with the accumulation of sandstones, about 1500 m thick, then being alternated by about 800 m thick sand, silt and mudstones. These series accumulated in the coastal-marine environment. The latter, the third member in this cycle indicates a gradual change of the coastal-marine conditions by deltaic, lacustrine and river environments from the south to the north. Polymictic sandstones in this sequence indicate the supply of the sediments from the east.

The second half of the Oxfordian and Kimmeridgian is marked by a non-depositional hiatus probably related to block movements during the Late Jurassic rifting. The sedimentation area was significantly reduced in size, but the location of the depocenter did not substantially change. During the Volginian–Middle Aptian interval a rather monotonous sequence of alternating sandstones, siltstones, and coals accumulated. The basal beds of the sequence are composed of conglomerates. The basic coal reserves in the basin are associated with these units. The top of the sequence is marked by Barremian tuff interbeds exhibiting the onset of volcanism in the east. In this interval sedimentation was significantly affected by left-lateral strike-slip movements along the northeastern displacement system (Fig. 2). Sediments extended in this direction. Thus, at this stage the basin can be interpreted as a pull-apart basin.

In the Middle Aptian a short non-depositional hiatus is observed, whereupon sea waters along narrow sea inlets penetrated into a narrow graben from the northeast. In the coastal-marine, lagoon environment a series of terrigenous rocks, about 1400 m thick, was deposited there. Collisional processes in the east stipulated the compressional regime, formation of submeridional overthrusts, and cessation of sedimentation in the basin.

3.4. Partizansk basin

The basin is located in the southeastern margin of the Khanka massif (Fig. 1). According to Golozubov and Lee (1999), it is an epicontinental basin. This interpretation seems to be very simplified, and the basin should be referred to as a hybrid basin (Busby & Ingersoll, 1995) with several stages of its development. During the Late Jurassic a submeridional flexure emerged here along the Arseniev fault (Fig. 2) and coastal-marine sediments accumulated, the thickness of which increased from the west to the east attaining about 300 m in average. After a short Berriasian hiatus, which might have been caused by the global regression, sedimentation recommenced in the Valanginian in the northeastern part of the basin under condition of a river valley (continental sediments), and then submerged beneath the shallow sea, in which rhythmically bedded sediments, ranging from 150 m in the west to 1000 m in the east, accumulated (Golozubov & Lee, 1999). Since Valanginian to mid-Albian the basin formation seems to have been led by the Arseniev and Central Sikhote-Alin left-lateral strike-slip movements, and the basin can be considered as a pull-apart basin. From the southwest to the northeast river valley facies are replaced by cyclical swamped deltaic facies with thick coal seams and finally by shelf deposits (Golozubov & Lee, 1999). In response to accretion, the basin underwent compression in the mid-Albian, and the depocenter shifted somewhat northward. Formation and rapid destruction of the Sikhote-Alin volcanic belt controlled a high rate of sedimentation and abundance of volcaniclastics in a cyclic series of terrigenous lacustrine-alluvial variegated sediments. At this stage the Partizansk basin can be interpreted as a back-arc basin. During the Late Turonian the depocenter spread toward the west, and the Turonian-Coniacian terrigenous coal-bearing deposits, about 300 m thick, accumulated on the extremely limited area.

3.5. Sanjiang-Middle Amur basin

The basin is located between the Bureya, Jiamusi and Khanka massifs in the west and in the south and Sikhote-Alin orogenic belt in the east. Such a geostructural location predetermined different types of the Cretaceous sections, which formed in different parts of the basin. Geographically, the southwestern part of the basin belongs to China, and the northeastern part to Russia. The Cenozoic part of its cover was studied 30 years ago for search and prospecting of coal, whereas the Cretaceous sequence has not been completely understood, but a total of three holes have been drilled to a Cretaceous complex.

Sanjiang-Middle Amur basin (SMAB) was originated on the heterogenous basement, the western and southern parts of which are made up of the Precambrian massifs, and Riphean-Middle Triassic shallow sea carbonate-terrigenous formations overlap them. As for the eastern part, there is still a great deal to clarify. Natal'in and Chernysh (1994) regard the whole Lower Cretaceous complex as an accretionary prism.

Mizutani (1987) assumed that the Mino terrane in Central Japan, the Nadanhada in Northeastern China and the Western Sikhote-Alin terrane are parts of once existed Mesozoic superterrane. At present, after numerous corrections of different parts, the section of the superterrane is as follows (Yang, Mizutani, & Nagai, 1993). The Middle-Upper Triassic-Lower Jurassic sequence consists of red, green, gray cherts, and siliceous shales with occasional lenses of limestones and conodonts. Then follows a sedimentary melange with exotic (about 300 m in size) blocks of Carboniferous-Permian limestones (with fusulinids, crinoids, and corals) and Mesozoic cherts. It is suggested that the limestones were formed on the ancient oceanic plateau of East Tethys. Silty argillaceous matrix of the melange contains Middle Jurassic radiolarians. Collision of the superterrane with the continental margin took place in the Late Middle Jurassic (Yang et al., 1993), that is, nearly simultaneously with the collision of the Samarka terrane with the continental margin (Khanchuk et al., 1997) and the North Asian craton with the Chinese craton.

Thereafter, above the attached terranes and blocks, the Upper Jurassic-Lower Cretaceous clastic deposits (siltstones, mudstones, sandstones, and conglomerates) containing ammonite and bivalve fauna indicating a neritic environment accumulated. At the base of the terrigenous unit, basal conglomerates containing Middle Triassic to Middle Jurassic radiolarians in the fragments occur.

Summarizing, it is logical to suggest that after the Middle Jurassic collision along the margin of the Bureya-Jiamusi-Khanka ancient Precambrian massifs there existed a regime of passive continental margin complicated by submeridional Late Jurassic rifts, where the SMAB was formed.

Under conditions of the Late Jurassic–Berriasian regression, in the western part of the basin Late Jurassic–Early Cretaceous terrigenous coal-bearing sediments, about 1000 m thick, accumulated, and to the east beds containing dinoflagellates (Kirillova et al., 1997). In the eastern flank of the basin and within isolated horsts (in the vicinity of the town of Khabarovsk, in particular) the Late Jurassic–early Valanginian sequence consists of cherty siltstones, silty mudstones, and turbidites about 1500 m in thickness. Horizons of olistostromes are observed at the base of the section, in which a clayey matrix is dated as the Late Jurassic (A. Matsuoka, personal communication), whereas chert, basalt, sandstone, and limestone fragments and blocks are of different age (Fig. 4).

Starting with the Late Valanginian, in the environment of the commencing transgression, a transformed continental margin was formed, and left-lateral strike-slip faults became active. As a result, along the displacements uplifts bounding the basin from the east were generated, and formed a bay facing northeastwards. Coarse clasts are dominant at the base of the sequence, and higher up the section turbidities prevail. A total thickness of the Valanginian sequence attains 1500 m.

After a hiatus in the early Hauterivian the mode of the sedimentation changed but unsubstantially. During the Hauterivian–early Aptian turbidities, 1500 m thick, were dominant. In the western part of the basin during the Berriasian–Hauterivian a terrigenous continental coal-bearing formation accumulated, which was marked by coastal-marine beds with dinoflagellates, but not frequently.

The Aptian is noted for some shallowings of the basin, and in the Aptian to Middle Albian coastal-marine sediments were deposited, though turbidities were in a lesser amount. As pointed out above, during the Aptian a volcanic arc emerged in the east, and thus SMAB became a back-arc basin. The rate of sedimentation increased significantly. A mixture of volcanic material appeared in the sediments. The Aptian-mid-Albian sequence ranges up to 2500 m in thickness.

Owing to the Middle Albian collision processes, the sedimentation area got narrower, essentially retaining a general NE trend. The mid-Albian–Cenomanian sequence is represented mostly by conglomerates, sandstones, and siltstones, about 1500 m thick, which accumulated in the shallow sea.

During the Cenozoic a new stage of rifting began on the East Asian margin. A system of asymmetric half-grabens with gently northwestern and steeply sloping southeastern flanks was formed. Some of them were developed along the Cretaceous displacements of the Tan-Lu system: a chain of grabens I-Shu and Dun-Mi (Fig. 1). Part of them was newly formed grabens and half-grabens. During the Cenozoic SMAB got the features of a basin and ridge structure. The Cenozoic stage of the basin evolution was discussed by Varnavsky (1971).

Within SMAB geophysical investigations revealed more than 30 grabens from 1 to 4.5 km deep (Fig. 5). Sediments of the I-Shu graben system reach as much as 7000 m in thickness. Grabens are filled with lacustrine-alluvial terrigenous coal-bearing sediments, and oil–gas-bearing sediments in some grabens (Kirillova et al., 1997).

3.6. Alchan basin

This basin is located at the boundary between the Khanka massif and the Sikhote-Alin orogenic belt (Fig. 1). On both sides it is bounded by NE strike-slips which played a key role in the basin formation (Amel'chenko et al., 2001).

Left-lateral strike-slip displacements along the northeastern faults as well as Aptian transgression caused sedimentation in the pull-apart basin. Basal conglomerates occur unconformably on various Permian and Triassic horizons. During the Late Aptian–Middle Albian a sequence of alternating continental and coastal-marine facies accumulated with a total thickness of about 2000 m. Presence of volcaniclastics in the sediments is evident of the proximity of the volcanic arc located from the east. With respect to this arc, the basin can be regarded as a back-arc basin.

At the beginning of the Middle Albian the sea persisted only in the central part of the basin, retreating northeastwards by the Late Albian. At the end of the Middle to Late Albian, sedimentation took place against the background of intense superficial volcanism, particularly active in the eastern part of the basin. In the western part of the basin lacustrine sediments with abundant fauna accumulated at that time.

By the end of the Albian active compressional processes led to the basin reduction. In the Cenomanian, sedimentation occurred within the alluvial plain and saucer lakes in the environment of arid climate. The sediments did not exceed 400 m in thickness.

After a prolonged hiatus, along the margins of the basin and along the same faults, continental coal-bearing sediments, about 400 m thick, accumulated in the grabens.

4. Coal, oil and gas presence

Early Cretaceous coals are common throughout intracontinental and marginal-continental basins, although the deposits are being developed only in the Upper Bureya and Partizansk basins (Fig. 4). Brown coal deposits are being exploited in the Amur-Zeya, Sanjiang-Middle Amur, and Alchan basins.

Perspectives for oil and gas presence in the basins still remain unclear because of shortage of investigation. A comparative analysis of the intracratonic rift basins of Amur-Zeya and Songliao was made (Kirillova, 1995), the latter of which is known for rich oil deposits, evidencing similar deposits in the Amur-Zeya basin.

A gas field and many prospective structures were discovered in the Upper Bureya basin in 1989.

In the Sanjiang-Middle Amur basin, two oil- and gas-bearing systems are expected: Late Jurassic-Cretaceous and Cenozoic ones. The Late Jurassic-Cretaceous Systems are as yet poorly investigated, although a high potential of hydrocarbons in the turbidite systems established in the last few years gives good ground to hope for success. In the Cenozoic System in China two medium-sized gas deposits in the I-Shu graben system are known. On the territory of Russia only oil and gas shows appear to be common.

In the Uda, Alchan, and Partizansk basins prospects are unclear. Coaly gas might be supposed in the Partizansk basin.

5. Conclusion

Based on the analysis of the global and regional Late Mesozoic–Cenozoic geological events in the southeastern continental margin of Russia, as well as fundamental knowledges obtained by diverse geological–geophysical methods and drillings in world basins, a new classification and typification of the sedimentary basins of Southeastern Russia have been suggested. The author has not followed any one of the existing classifications of the sedimentary basins, but has attempted to obtain the most essential regional parameters and features from each of the classifications. It is important to determine which between global and related regional events provide the space for sediment accommodation at one or other stages of the basin evolution. Although it remains unclear and unsufficiently substantiated, the author believes that the material collected and synthesized will undoubtedly promote further research of the basins in Southeastern Russia and their potential for oil and gas.

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