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Deep Structure, Genesis, and Seismic Activation of the Bureya Orogen, Russian Far East

A. A. Stepashko* and T. V. Merkulova

*Kosygin Institute of Tectonics and Geophysics, Far East Branch, Russian Academy of Sciences,
ul. Kim Yu Chena 56, Khabarovsk, 680000 Russia*

**e-mail: stepashko@itig.as.khb.ru*

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Abstract—The Bureya orogen is a special object among the geodynamic factors determining the high seismicity of the Lower Amur region. Its location and deep structure are studied on the basis of comprehensive geophysical and tectonic data. This orogen is a low-density lithospheric domain expressed by an intensive negative gravity anomaly and Moho sunken down to 40 km depth. Within the limits of this lithospheric structure, contemporary uplifting takes place to form a meridional dome peaking at more than 2000 m altitude. The position of the orogen in the regional structure gives us grounds to think that the Bureya orogen formed in the Paleogene, at the finishing stage of tectonic block movement along the Pacific margin represented by the NE-trending strike-slip faults of the Tang Lu Fault Zone. Compression was concentrated at the triple junction between the Central Asian, Mongolian–Okhotian, and Sikhote Alin tectonic belts. The meridional orientation of the Bureya orogen is associated with the parallel elongated Cenozoic depressions in the region. The united morphotectonic system may have formed resulting from lithospheric folding under horizontal shortening in the Paleocene–Eocene. The wavelength of the Lower Amurian fold system is 250 km, which is consistent with the theoretical estimates and examples of lithospheric folds in other regions. The contemporary activation of the Bureya orogen began in the Miocene, under the effect of the Amurian Plate front moving in the northeastern direction. As a result of shortening, the meridional cluster of weak ($M \geq 2.0$) earthquakes formed along the western boundary of the orogenic dome. The most intensive deformations caused another type of seismicity associated with the activation-related uplift of the mentioned orogen. As a result, the so-called Bureya seismic zone formed above the apex of the dome, and it is here that the strongest regional earthquakes ($M \geq 4.5$) occur.

Keywords: deep structure, morphotectonics, seismicity, lithospheric folding, Amurian Plate, Tang Lu Fault Zone, Bureya orogen, Russian Far East

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INTRODUCTION

The most serious problems in understanding the nature of regional seismicity emerge when higher activity is observed in intracontinental areas which are located a priori far from lithospheric plate boundaries. In these regions, deformations often accumulate in multiple tectonic faults of different ranks and the lateral distribution of earthquake epicenters therefore becomes scattered, without any well-expressed spatiotemporal tendencies. This diffuse style of seismicity is observed in the Lower Amur region, Russian Far East (Fig. 1).

The character and genesis of the higher seismicity in the Lower Amur region has been discussed many times and from different, sometimes even opposite viewpoints [2, 3, 8, 9, 15, 17, 19–21, 26, 28, 31, 34, 35]. The main attention has traditionally been paid to analysis of the relationships between seismicity and fault structure and direct search for geological–geophysical peculiarities that may determine the spatial distribution and intensity of earthquakes. This problem has not been solved, suggesting a multifactor character of regional deformations. The diffuse epicentral field in the region likely reflects the aggregated pattern of events occurring under the effects of relatively independent tectonophysical mechanisms.

The only possible way to reveal the spatiotemporal regularities of seismicity in such a situation is to understand the geodynamic nature of the present-day deformations. Two major tectonic factors controlling the regional stress field in the Lower Amur region are well known. In the southern part of the region, the main structure is the Tang Lu Fault Zone (Fig. 1). The exact position of the Tang Lu Fault Zone in the territory of China is well mapped, whereas it is weakly traced and remains questionable within the Russian borders [3, 5, 13, 27, 49]. In our opinion, the most reliable markers of the position of the Tang Lu Fault Zone are the

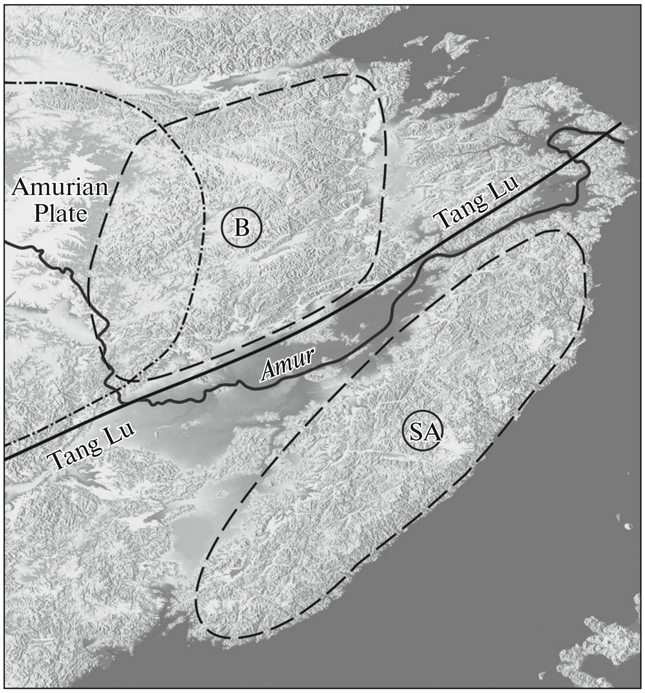

Fig. 1. Bureya (B) and Sikhote Alin (SA) orogens in the relief of the southern Russian Far East.

earthquakes with $M > 5.0$, the epicenters of which are concentrated along a band generally fitting the course of the Amur River down to the city of Nikolaevsk-na-Amure [36, 37]. The same band contains the epicenters of the two known strong earthquakes in the Lower Amur region: they occurred in 1500 and 1914 and both had magnitude of about 6.0. In the southern continuation of this band, Holocene seismogenic escarpments 70 and 20 km have long been documented, and the respective seismic events may exceed 7.0 in magnitude [59]. According to radiocarbon dating by Chinese seismologists, the most recent of these strongest earthquakes occurred 1730 ± 40 years ago [59].

The key to understanding of the regional seismic activation is the Amurian Plate (Fig. 1), which moves to the northeast at a rate of 1–1.3 km/yr [13]. In the initial geodynamic model [10], the boundaries of the Amurian Plate are drawn far to the east of those marked in Fig. 1; however, similar configurations of this plate are still used in reconstructions of the regional kinematics [42, 47, 52]. In this case, the Lower Amur region is located within the limits of the Amurian Plate, far from the tectonic boundaries, making it difficult to explain its higher seismic activity. However, comprehensive analysis of the deformations, supported by GPS geodetic data, suggests that the eastern boundary of the Amurian Plate is located far to the west [1, 13, 23, 49]. In this case, the area of the Amurian Plate is considerably reduced and its eastern boundary is along the Tang Lu Fault Zone [1, 5, 13, 36, 37]. This contemporary version places the Lower Amur region immediately at the front side of the Amurian Plate (Fig. 1) and the character of regional deformations is thus determined by westward shortening.

Contemporary geodynamic reconstructions should also take into account the following factor. The central object in the Lower Amur region is the contemporary Bureya orogen (Fig. 1) corresponding in relief to the Turana–Bureya–Badzhal mountain system [9, 12, 39, 41]. Along with the Sikhote Alin Range, this is one of two contemporary orogens in the southern Russian Far East. Notably, it is the Bureya orogen that seemingly demonstrates the most intensive deformations: there are fifteen peaks of more than 2000 m altitude, whereas only two peaks of this height are known in Sikhote Alin. Additionally, the seismic activity of the Bureya orogen is much more intensive compared that of Sikhote Alin (the latter is characteristic of rare and weak earthquakes). The main goals of the current work are to determine the features of the deep structure and tectonic genesis of the Bureya orogen and to clarify the character of its contemporary activity with respect to other geodynamic factors. The results obtained in this and subsequent articles will show that orogenesis in the Bureya orogen also directly affected the seismic activation of the Lower Amur region and determined the key tendencies of the spatiotemporal distribution of the earthquakes in the region.

POSITION OF BUREYA OROGEN IN THE REGIONAL STRUCTURE

Tectonic consolidation in the Lower Amur region completed by the Late Mesozoic; it resulted from a complex combination of accretionary processes of different time and direction that took place in the eastern margin of Asia (Fig. 2). The western part is composed of the ancient Bureya massif, which is a microcontinent of the Central Asian accretionary–fold belt formed upon closure of the paleoocean dividing the North China and Siberian continents in the Paleozoic. Here, the Amuria paleocontinent had formed by the early Mesozoic [33] and its collision with the Siberian continental margin had terminated by the Late Jurassic. Resulting from this, the second (Mongolian–Okhotian) accretionary belt had formed: its eastern segment determined the structure of the northern Lower Amur region (Fig. 2). Judging from the tectonic reconstructions supported by geophysical data, the boundary between the two regional tectonic belts is assumed to be a large divide between the plates. In the present-day structure, it is traced by the Paukan Fault (Fig. 2), where the probable Mongolian–Okhotian suture (remaining after the closure of the Mongolian–Okhotian Ocean) is located [24]. The evolution of the present-day Pacific Ocean began ca. 180 Ma ago; its effect on the Asian margin formed the accretionary Sikhote Alin sequences in the eastern Lower Amur

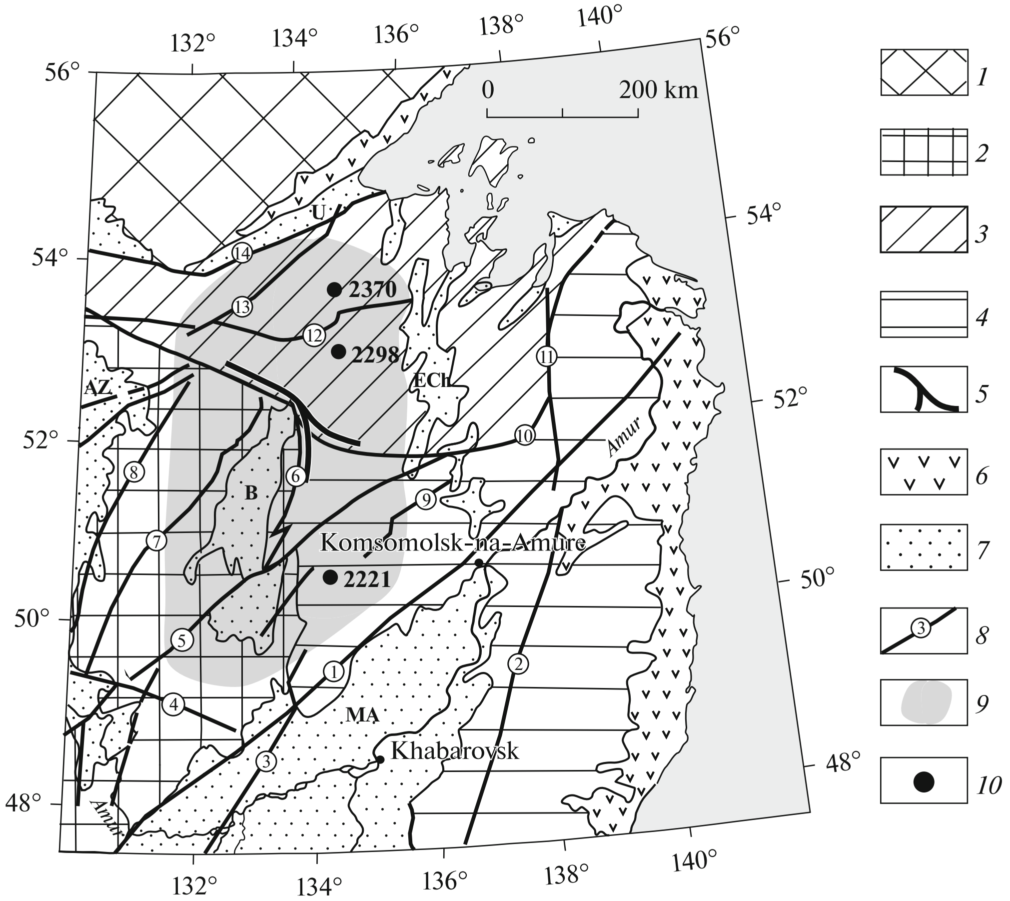

Fig. 2. Position of the Bureya orogen in the tectonic structure of the southern Russian Far East. Arbitrary notes: (*1*) Siberian Craton; (*2*)–(*4*) accretionary–fold belts: (*2*) Central Asian, (*3*) Mongolian–Okhotian, (*4*) Sikhote Alin; (*5*) triple junction of tectonic belts; (*6*) volcanic belts of the continental margin; (*7*) sedimentary basins surrounding the Bureya orogen: MA, Middle Amurian; ECh, Evoron–Chukchagir; U, Uda; AZ, Amur–Zeya; B, Bureya; (*8*) regional faults: 1, Tang Lu (Yilang–Yitong); 2, Central Sikhote Alin; 3, Kukan; 4, Xunhe–Bira; 5, Khingan; 6, Tastakh; 7, Mel'gin; 8, West Turana; 9, Duki; 10, Paukan; 11, Limurchan; 12, Tugur; 13, Uligdan; 14, North Tukuringra; (*9*) Bureya orogen; (*10*) main mountain peaks and their altitudes in meters.

region (Fig. 2). The meridional boundary between the Amuria continent and the Pacific Ocean runs along the eastern edge of the Bureya massif. Here, we can infer the presence of a second divide between the plates, superimposed by the Badzhal accretionary sequence of Jurassic–Cretaceous age [11].

Thus, the Lower Amur region is where the three major tectonic belts—Central Asian, Mongolian–Okhotian, and Pacific—join each other to form a unique lithospheric triple junction (Fig. 2). Relative to this structure formed in the Late Mesozoic, the present-day Bureya orogen is located in its logical position, "perched" on this triple junction. The triple junction structure in the center of the Lower Amur region became, most likely, a "focus" of the stress field where the most favorable conditions emerged for regional deformations to concentrate.

The most important role in the regional structure is played by tectonic faults of different ages, with the supposed deep continuation of the Yilan–Yitong segment of the Tang Lu Fault Zone playing a special role (Fig. 2). Importantly, many tectonic faults in the Lower Amur region are of the same (northeastern) or very similar trends: for example, the largest Khingan, Mel'gin, and West Turana faults (indicated with numerals 5, 7, and 8 in the circles in Fig. 2). This is obviously a unified supersystem of Mesozoic tectonic faults; this supersystem was formed by oblique subduction of the paleo-Pacific plates beneath the Asian continental margin. The position of the Bureya orogen is consistent with the locations of the faults in the Tang Lu Fault Zone; we can therefore infer their leading role in the formation of this orogen.

An important peculiarity of the tectonic structure of the Lower Amur region is the common distribution of continental sedimentary depressions surrounding the Bureya orogen (Fig. 2). Analogous riftogenic basins are well-known in East Asia; they are sometimes petroleum-bearing and their common character suggests that the continental margin evolved under conditions of long-term extension since the Late Mesozoic. Detailed studies of the North China basins [54] show that rifting gradually moved eastwards. Similar migration is demonstrated by the sedimentary basins of the Amur region. The Amur–Zeya and Uda basins to the west and north formed predominantly in the Jurassic–Cretaceous time, whereas Middle Amurian, Evoron–Chukchagir, and Lower Amurian basins to the east are of Cenozoic age. However, all of the mentioned basins are consistently located around the Bureya orogen (Fig. 2). This spatial consistency implies that downwarping of the sedimentary basins accompanied uplifting of the Bureya orogen probably during a common tectonic process.

MAIN STRUCTURAL PECULIARITIES OF THE BUREYA OROGEN

The data and results of the comprehensive regional geophysical studies of recent decades [7, 38] are of principal value for understanding the nature of the geodynamic processes in the Lower Amur region. At present, the entire area of the Lower Amur region is covered by middle-scale gravimetric and magnetometric surveys; we can thus specify the deep structural peculiarities of the Bureya orogen. Interpretation of the geophysical fields was carried out using the KOSKAD-3D software developed by A.V. Petrov for analyzing the digital geodata by probabilistic and statistical methods [32]. When interpreting the results, special emphasis was made on the procedure of separation of the geophysical fields into regional and local components by using 2D adaptive filtering.

The general lithospheric structure of the region is best demonstrated by seismic models; below we use the scheme of crustal thickness variations in the southern Russian Far East [7, 38] and the deep seismic cross section of the Lower Amur region along the Olekma River–Cape Nevelskoy profile, whose eastern part crosses the Lower Amur region in the sublatitudinal direction. The information on the lithosphere structure of the principal value is obtained by density simulation performed by V.Ya. Podgornyi [22].

Regional Position and Deep Structure of the Bureya Orogen from Geophysical Data

A known peculiarity of the gravity field in the Lower Amur region is a large negative anomaly, which is often considered as an element of the gravity step at the continental margin [7]. This anomaly spatially fits the Bureya orogen, and their relationship becomes obvious after application of the technique of field separation into regional and local components implemented in the KOSKAD-3D software. The obtained regional negative gravity anomaly (Fig. 3a) is isolated, and is seen to be dominant in the region. The outline of its central part is described well by the –4 mGal isoline and shows a clear meridional elongation. There are two minimums within the limits of the central contour, with the major one having a gravity intensity reaching –8 mGal. Within the limits of this anomaly, the gravity field is asymmetric in the west-to-east direction and the isolines are located closer to each other along the eastern boundary of the anomaly. The sedimentary basins surrounding the Bureya orogen are located in the periphery of the regional anomaly (Fig. 3a), which is particularly seen in the case of the Bureya and Evoron–Chukchagir basins. The position and outline of the regional gravity anomaly ideally fits the fanlike pattern of the regional NE-trending faults. This directly indicates the genetic relationship between both the Bureya orogen itself and the regional gravity anomaly marking the deep roots of this orogen, on the one hand, and the tectonics of Tang Lu Fault Zone, on the other hand.

The map showing the axes of the regional magnetic field anomalies in the Lower Amur region contains a great number of linear anomalies (Fig. 3b), both positive and negative, having different orientations. They probably mark the positions of multiple dikes of various compositions and ages, as well as the locations of vein and fractured zones saturated with hydrothermal fluids, thus reflecting in aggregate the complex deformation history of the region. A simple pattern is observed only in the southwest, where the axes of the magnetic anomalies are predominantly northeast-oriented. This relationship suggests the direct arrangement of small faults and fractured zones, which were filled by magmatic melts or fluids, along the vector of pressure that was translated on the strike-slip faults of the Tang Lu zone during a long time interval.

This pattern abruptly changes in the periphery of the density anomaly of the Bureya orogen (Fig. 3b), where the directions of the axes of the magnetic anomalies become variable. Nevertheless, it is seen in many cases that the linear anomalies are either parallel or orthogonal to the orientation of the orogen. In the center of the low-density domain pointed out by the gravity isoline of –5 mGal, the number of magnetic anomalies abruptly decreases. Everything indicates that the Bureya orogen considerably affects the deformation field and, ultimately, the pattern of dislocations in the upper crust.

The data on the anomalous lithospheric structure in the deepest parts of the Bureya orogen were obtained by density simulation along the Olekma River–Cape Nevelskoy profile [22] (Fig. 4a). In the eastern part of the cross section, a large archlike structure covering both the crust and the lithospheric mantle down to 70 km depth is seen. The asthenospheric top beneath the center of this structure is sunken; the calculated values of mantle density are minimal here (3.22 g/cm^3), but systematically grow in both directions from the center, reaching 3.31–3.37 g/cm^3 in the peripheral parts of the arch (Fig. 4a). The anomalous arch is located exactly where two large linear density inhomogeneities, probably reflecting the locations of the interpolated boundaries in the Lower Amur region, cross near the surface. The Bureya orogen is located above this arch and, thus, "caps" the low-density lithospheric domain of about 400 km in cross size identified along the cross section.

The more detailed crustal structure of the Bureya orogen is shown in the seismic cross section along the central CD segment of the Olekma River–Cape Nevelskoy profile (Fig. 4b). The Moho in this low-density domain is sunken down to 40 km depth, while the seismic boundaries in the upper crust of the orogen become archlike in appearance. The cross size of the anomalous domain in the seismic cross section is also 400–500 km. The distribution of seismicity along the profile seems to be nonrandom and is clearly related to the orogen position. The source depths of earthquakes with $M \geq 3.0$ recorded along the profile are greatest (~40 km) beneath the center of the anomalous domain, but drop to ~20 km towards its boundaries. This is evidence of the direct influence of the Bureya orogen on the seismodynamics of the Lower Amur region.

In the scheme of crustal thickness, the Bureya orogen is seen as a trough of the Moho surface with the crust thickening from ~36 to ~40 km (Fig. 4c). This trough is almost meridionally elongated and is surrounded by Moho surface rises (the crust thickness declines there to 34 km) on three sides. Based on the regional modeling data, the lithospheric mantle beneath the orogen contains many low-density domains. The thicker crust corresponding to the Bureya orogen is completely analogous to the thick crust of the Sikhote Alin orogen in terms of morphology and spatial characteristics (Fig. 4c). These are two major orogenic strictures in the southern Russian Far East, which demonstrate contemporary geodynamic activity.

Position of the Bureya Orogen in Morphotectonics of the Lower Amur Region

The position and structural features of the Bureya orogen are logically reflected in the regional relief where the Turana–Bureya–Badzhal mountain structure corresponds to it [6]. In terms of orography, it is subdivided into two parts. In the west, the large long mountain ranges of northeastern orientation dominate: Selemdzha, Turana, Bureya, and Badzhal (Fig. 5). The Turana, Bureya, and Badzhal ranges are subparallel to each other, and their orientations inherit the trends of the faults belonging to the Tang Lu zone. The short and low mountain ranges in the eastern part of the region (Magu, Chayatyn, and others) maintain the same northeastern orientation, emphasizing the key role the faults of the Tang Lu zone play in the neotectonics of the entire region.

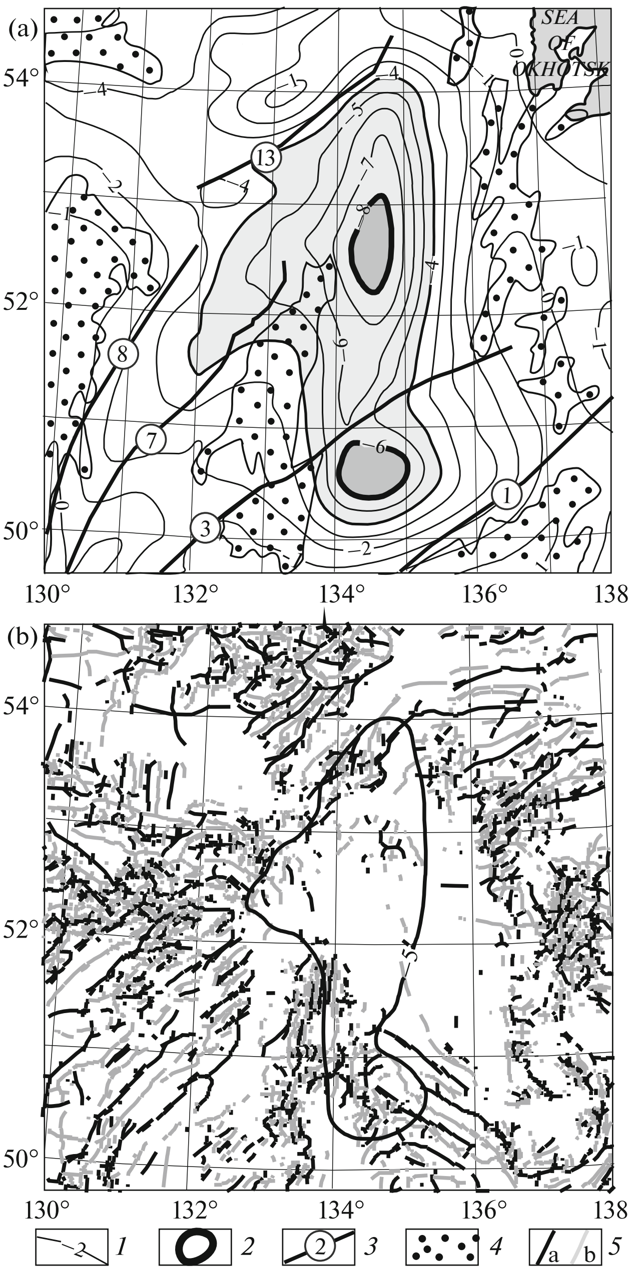

Fig. 3. Features of the Bureya orogen in gravity (a) and magnetic (b) field anomalies. Arbitrary notes: (*1*) isolines of the regional Bouguer gravity field (in mGal); (*2*) zones of minimal values of regional component (with the orogen core being marked gray); (*3*) main faults of the Tang Lu Fault Zone (numbers are as in Fig. 2); (*4*) sedimentary basins; (*5*) axes of positive (a) and negative (b) magnetic anomalies.

The character of the relief abruptly changes in the eastern Bureya orogen (Fig. 5). The Yam Alin, Dusse Alin, and Ezop mountain ranges located here can be characterized as high but short, with meridional and northwestern orientation. Together, they form the Yam Alin dome [40], which is oriented submeridionally, though transverse to the major regional struc-

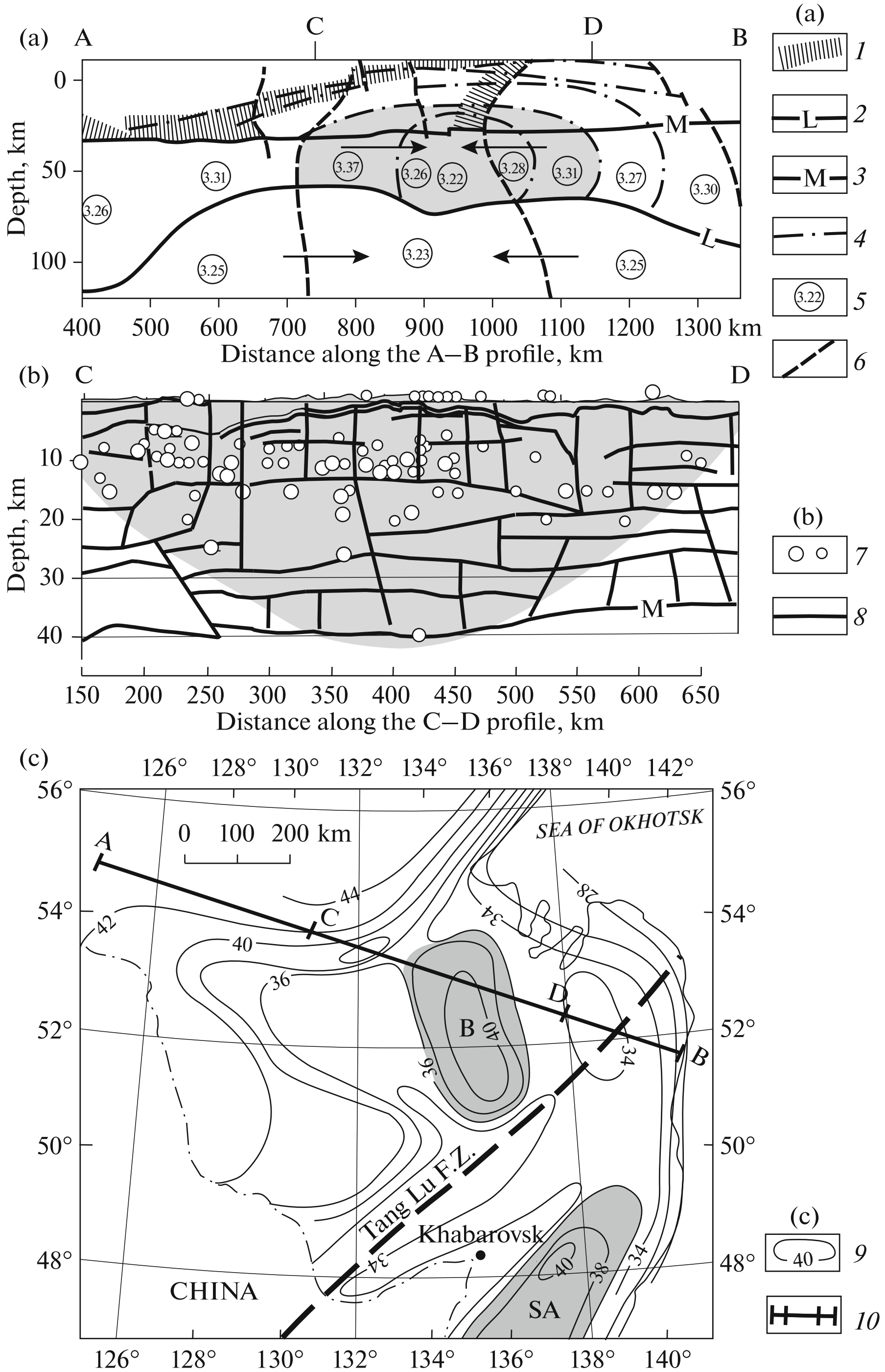

Fig. 4. Deep structure of the Bureya orogen. (a) Density model of the lithosphere along the AB profile (Olekma River–Cape Nevelskoy), simplified after Podgornyi [22]: (*1*) crustal density heterogeneities; (*2*) lithosphere base; (*3*) crustal base; (*4*) tops of density-inferred archlike structures; (*5*) calculated density (g/cm^3); (*6*) deep faults. Gray filling means the main structure of lithospheric low-density domain; arrows mark the directions of density decrease in the mantle. (b) Seismic cross section along the CD segment: (*7*) earthquakes with $M > 4.0$ and $3.0 < M < 4.0$, respectively, recorded within a ±100-km distance from the profile in 1960–2009; (*8*) seismic boundaries. Gray tone denotes the zone where earthquake hypocenters are concentrated. (c) In Moho depth in the Lower Amur region, after [38]: (*9*) crustal thickness isolines (km); (*10*) location of the deep-seismic-sounding profile (Olekma River–Cape Nevelskoy). Gray tone denotes the Bureya (B) and Sikhote Alin (SA) orogens.

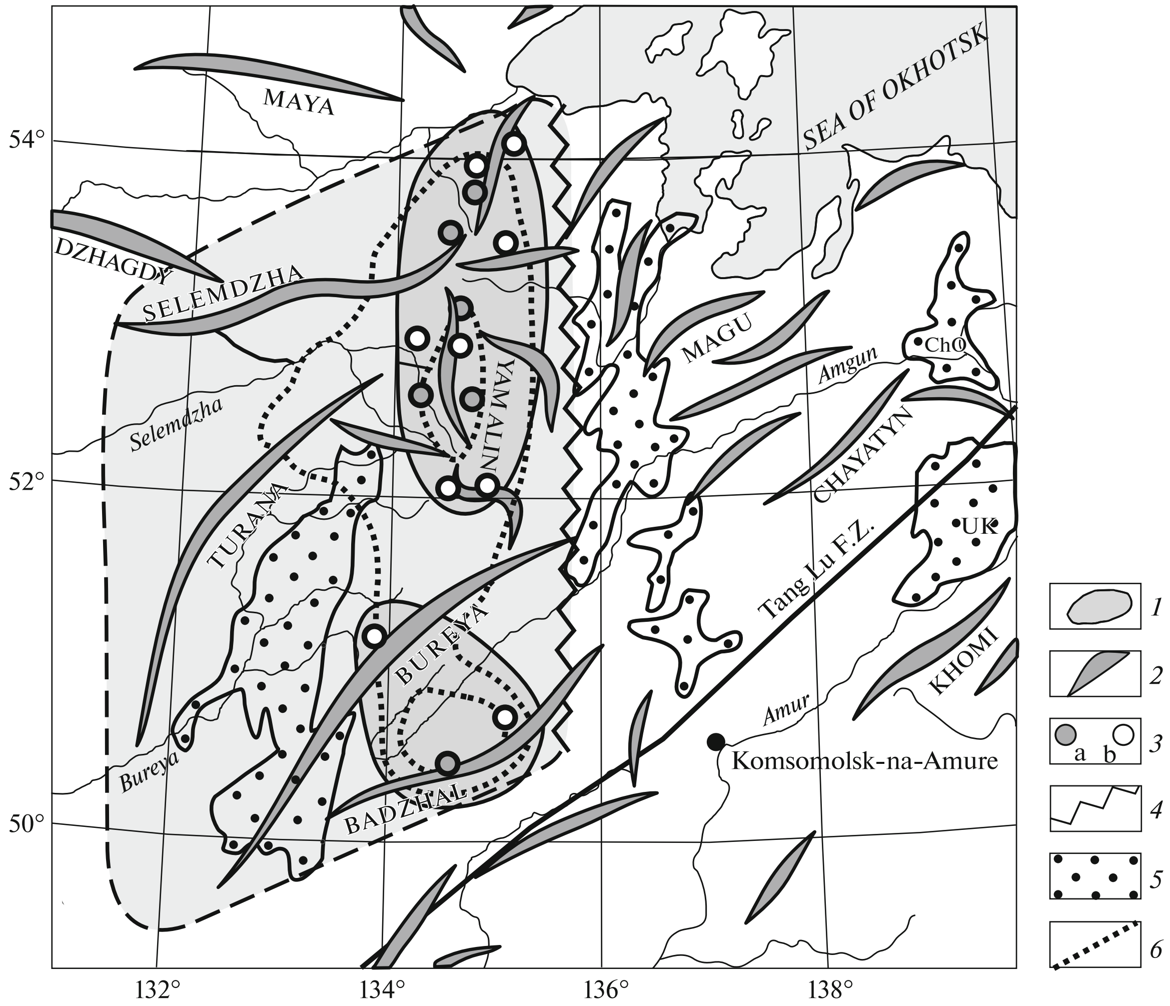

Fig. 5. Position of the Bureya orogen in morphostructure of the Lower Amur region. Arbitrary notes: (*1*) mountain structure of the orogen; (*2*) main ranges; (*3*) mountain peaks: (a) >2300 m high, (b) more than 2000 m high (two domes within the orogen limits are outlined); (*4*) Yam Alin tectonic scarp, after [40]; (*5*) system of Cenozoic depressions: UK, Udyl'–Kizi; ChO, Chlya–Orel' (others, see Fig. 2); (*6*) contour of the orogen center from gravity data (two maximum zones are marked).

tures of northeastern orientation. In terms of orography, this dome hosts 12 major mountain peaks higher than 2000 m in the Lower Amur region; five of these peaks are higher than 2300 m. It is this area that corresponds to the central part of the Bureya orogen, where uplifting is most intensive and contemporary geodynamic activity is concentrated. The position of the Yam Alin dome fits well the intensive gravity minimum (Fig. 3a), supporting the agreement between its deep structure and surface appearance.

The southern minimum of the gravity anomaly coincides with the central parts of the Bureya and Badzhal ranges. This is where three other peaks higher than 2000 m are located and another dome is identified in the central part of the orogen. A double regional rise is clearly expressed in the relief of the basis surface drawn on the minimal relief marks [40]. The eastern boundary of the orogenic rise is indicated by a submeridional tectonic scarp (Fig. 5) extending from the Uda Gulf in the north almost to the Amur River in the south [40]. In general, the morphotectonics demonstrates a clear asymmetry of the mountain structure, with a gentle western slope and high eastern dome (the latter is divided from the Tugur–Chikchagir–Evoron meridional system of depressions by a steep escarpment). The same west-to-east asymmetry is observed in terms of the distribution of gravity anomalies (Fig. 3a). In our opinion, this peculiarity is of principal value in understanding both the genesis and contemporary geodynamics of the Bureya orogen.

East of the meridional Tugur–Chikchagir–Evoron system of depressions, and at the same time parallel to it, the Lower Amur system of depressions extends, uniting the Chlya–Orel' and Udyl'–Kizi ones [40]. In the west, the elongated Bureya sedimentary basin has an analogous orientation. Although the main evolu-

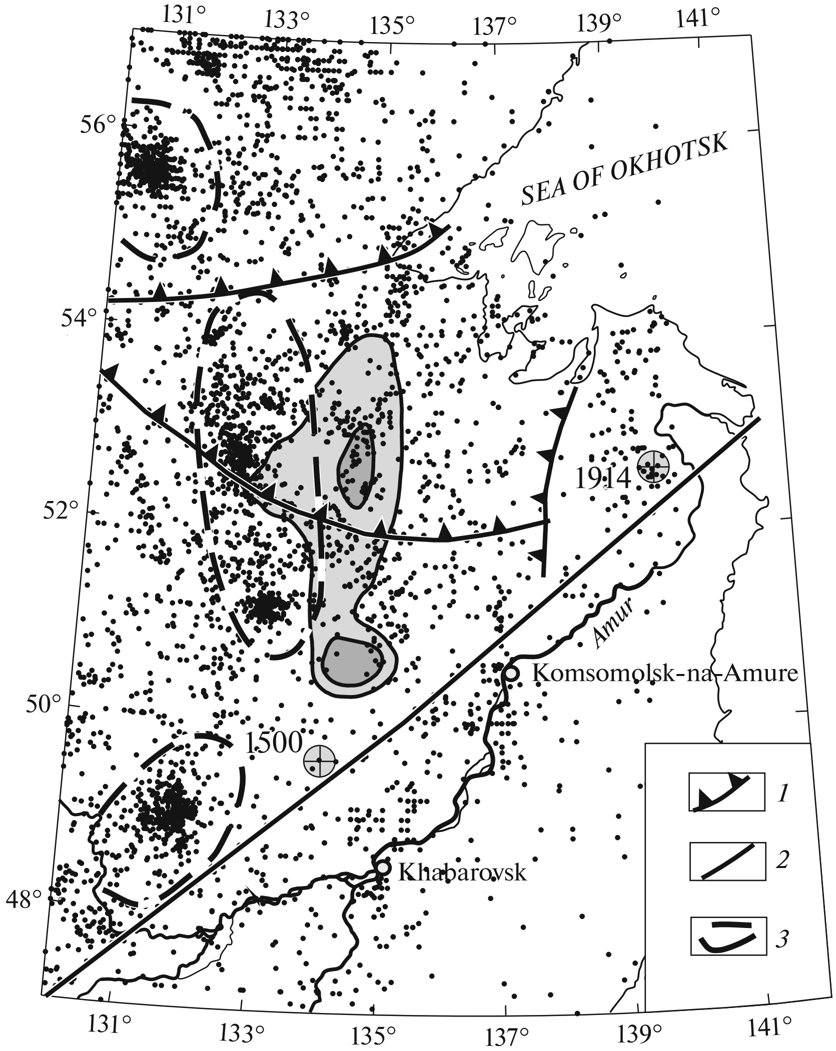

Fig. 6. Epicentral field of the Lower Amur region. Gray tone marks the gravity anomaly in the central Bureya orogen, in accordance with Fig. 3a. Dots denote epicenters of crustal earthquakes with $M \geq 2.0$ that occurred in 1940–2011; the strongest earthquakes of 1500 and 1914 are shown in particular. Arbitrary notes: (*1*) boundaries of the Siberian Craton and Mongolian–Okhotian tectonic belt; (*2*) Tang Lu Fault Zone; (*3*) clusters of earthquake epicenters.

tion stage of the Bureya basin occurred in the Jurassic–Cretaceous, wells drilled in its limits also reveal Miocene deposits [6]. Additionally, the meridional orientations of the Upper Bureya and Tyrma depressions which are located here emphasize the position of another Cenozoic rifting zone. The morphotectonics of the Lower Amur region generally demonstrate the regular alteration of negative and positive landforms: three parallel meridional depressions located at equal distances from each other are divided by two mountain rises, of which the western corresponds to the central part of the Bureya orogen and undoubtedly dominates in the morphotectonics of the entire Lower Amur region.

ROLE OF BUREYA OROGEN IN REGIONAL SEISMIC ACTIVATION

The earthquakes of the Lower Amur region are usually classified as weak and moderate ones. Over the short period of systematic observations since the late 19th century, only a few tens of quakes with $M \geq 4.5$ have been recorded in the region. The strongest earthquake in the last 100 years ($M = 6.0$) occurred on December 23, 1914 in the lower stream of Amur River (Fig. 6), near the city of Nikolaevsk-na-Amure. The epicenter of this earthquake was located in the zone of dynamic influence of the Tang Lu Fault Zone, as well as the epicenter of the previously known strong earthquake of 1500, which supposedly had magnitude $M \sim 6.5$. The high geodynamic activity of the Tang Lu

Fault Zone is verified by Chinese seismologists [59]: they found direct evidence of Holocene earthquakes with $M \geq 7.0$ along the Yilan–Yitong Fault.

Including the parameters of all of the available earthquakes, the epicentral field of the Lower Amur region demonstrates a clearly dispersed and irregular character (Fig. 6). Even the Tang Lu Fault Zone is not clearly reflected in the distribution of regional earthquakes. Likewise, seismicity does not mark the lithospheric boundaries between the Siberian Craton and Mongolian-Okhotian tectonic belt. The only important structural peculiarity of the epicentral field is the presence of three earthquake clusters in the western part of the region (Fig. 6). At a first approximation, these clusters can be united into a meridional, eastward bended zone. It was probably identified as a special lineament for the first time by V.E. Kuznetsov, who interpreted it as the shortening zone on the front side of the eastward-thrust lithospheric slab [17, 28]. According to K.G. Mackey and co-authors, it is this direction (instead of the commonly accepted one along the Amur River) that is the trend of the Tang Lu Fault Zone [49]. Recently, this zone of earthquake clusters has more often been attributed to the eastern boundary of the Amurian Plate [13, 14, 23]. The downside of these speculations is the absence of a real tectonic structure, whose activation might link the three clusters into a united seismogenic zone.

The occurrence and positions of these three earthquake clusters are caused, in our opinion, by the geodynamically active structures of the Lower Amur region (Fig. 6). The southern cluster (~49° N and ~132° E) is undoubtedly related to the Tang Lu Fault Zone. The central cluster, oriented submeridionally along ~133° E, is obviously located west of the central Bureya orogen. Moreover, this cluster contains two easily discernible subclusters corresponding to two centers of orogen shortening, which are in turn manifested in both relief and gravity anomalies. The third cluster is located within the limits of the Siberian Craton (~55.5° N and ~130.5° E); earthquakes here occur in the Stanovoy seismic belt. Both in the southern Lower Amur region (in the Tang Lu Fault Zone) and in its central part (near the Bureya orogen boundary), earthquake clusters are shifted west relative to the identified tectonic structures. This peculiarity evidently suggests that geodynamic and seismic activations in the Lower Amur region take place under the effect of the eastward-moving Amurian Plate.

The main regional zones concentrating the major amount of activation are well-identified in the zonal distribution of the strongest earthquakes with $M \geq 4.0$ (Fig. 7). In the southern Russian Far East there are four seismic zones, of which two are situated in the Lower Amur region. The first zone (called "Amurian" in [36, 37]) is well-known: it extends along the Tang Lu Fault Zone and is undoubtedly related to it genetically. The position of the second seismic zone in the Lower Amur region (let us call it "Bureya" for convenience) is obviously directly related to the main northern center of the orogen, where the most intensive uplifting takes place and the most intensive part of the regional negative gravity anomaly is identified. In terms of the number of earthquakes with $M \geq 4.0$ recorded in about the last 100 years, the Bureya zone is as active as the Amurian one. The Amurian and Bureya seismic zones correspond to the southern and central earthquake clusters, respectively (Fig. 7), supporting the united nature of seismic activity in the region. The same correspondence is characteristic of the third seismic zone located in the margin of the Siberian Craton. The mentioned peculiarities suggest that the strong earthquakes in the central Lower Amur region are caused by deformations emerging upon the uplift of the Bureya orogen. The same vertical movement likely causes the displacement of earthquake hypocenters from bottom to top, with the simultaneous decrease of their magnitudes, as was revealed by detailed seismic monitoring in the Lower Amur region in 1983–2002 [6].

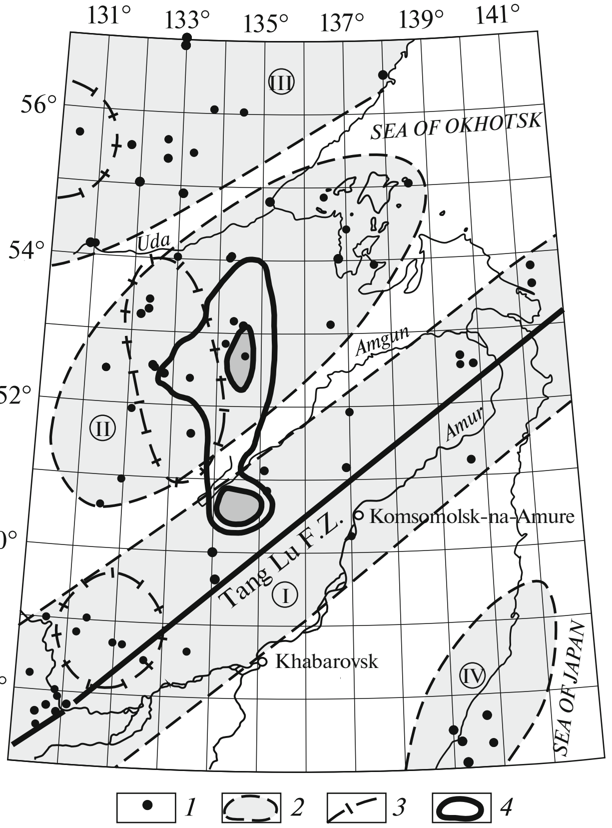

Fig. 7. Seismic zonality of Lower Amur region based on the analysis of earthquakes with $M \geq 4.5$ that occurred in 1888–2011. Arbitrary notes: (*1*) earthquake epicenters; (*2*) seismic zones: I, Amurian; II, Bureya; III, eastern Stanovoy belt; IV, Sovgavanskaya (Sovetskaya Gavan'); (*3*) earthquake clusters as in Fig. 6; (*4*) central Bureya orogen in gravity anomalies.

DISCUSSION

Two regional processes, supplementing each other and alternating in space and time, determined the tectonic evolution of Lower Amur region during the Late Mesozoic and Cenozoic. In the first half of the Cretaceous, accretion in the Sikhote Alin region ended and was replaced with final consolidation and gradual change to the intraplate evolution regime took place. By the beginning of the Cretaceous, the Mongolian–Okhotian Ocean disappeared and the last accretion episode in the region dated back to the Aptian–Early Albian [11] was completely caused by the effect of the Pacific lithosphere on the continental margin.

Simultaneously with accretionary consolidation of the eastern Eurasian Plate margin, the second common process—extension and oceanward moving of the eastern Asia margin—began to play a noticeable role by the end of the Jurassic; this process was manifested the most clearly in the formation of vast sedimentary basins in the continental margin [6, 46, 54]. This specific rifting developed in several stages and involved huge areas in the Asian margin, while gradually moving from west to east. Systematic migration of Jurassic–Cretaceous magmatism in the same direction, as is clearly documented in the territories of both Russia and China, shows that extension involved both the crust and lithospheric mantle beneath the continent. The vast fields of predominantly Neogene–Quaternary alkali and tholeiitic basalts commonly represented in the Sikhote Alin and Lower Amur regions reflect this terminal stage of rifting, which lasted from the end of the Mesozoic, gradually moving towards the Pacific.

Origin and Age of the Bureya Orogen

The regular position of the Bureya orogen at the junction of the main accretionary–fold belts and the obvious relationship of this orogen to the Tang Lu Fault Zone suggest that the orogen formed due to the final movements that ended the Pacific accretion period at the Asian continental margin. The most important element of the regional buildup was translation of the tectonic blocks along the Asian margin along the subparallel left-lateral strike-slips of the Tang Lu Fault Zone. The greatest displacements in the Tang Lu Fault Zone occurred in the Jurassic–Cretaceous under the effect of oblique subduction of the Pacific plates beneath the continental margin. The regular position of the Bureya orogen relative to the main faults of the Tang Lu Fault Zone—Khingan, Mel'gin, and West Turana—shows (Fig. 2) that it formed, most likely, as a shortening-related structure at the ending stage of regional tectonic movements.

The last period of clear left-lateral deformations in the central and northern Tang Lu Fault Zone dated back to the Paleocene–Eocene [18, 60]. Most probably, it was exactly this time when the zone of lithospheric shortening corresponding to the Bureya orogen formed under the intensified deformations in the Tang Lu Fault Zone. As shown by apatite thermochronology, in this period, ca. 67–47 Ma ago, rapid uplift and exhumation of the Greater Khingan Range occurred directly southwest of here [48]. The same orogenic phase was marked by the onset of uplift and erosion in the Sungliao sedimentary basin, which led to a considerable sedimentation hiatus in the local stratigraphic sequence [56].

Intensified shear movements in the beginning of the Cenozoic were accompanied by noticeable transverse extension. For example, the thickness of the Eocene–Oligocene deposits in the Yilan–Yitong graben is more than 3000 m [58]. Another comprehensively studied pull-apart object in the Tang Lu Fault Zone is the Fushun basin in Northeast China [50]. As was shown by pollen-spore analysis, its formation started in the Paleocene (59–65 Ma ago) and ended in the beginning of the Eocene (39–30 Ma ago). The sedimentation rate was greatest in the interval of ~45–39 Ma ago, and probably this period was marked by the highest intensity of northeast-directed motions in the Tang Lu Fault Zone. In the Middle Amurian depression joining the Bureya orogen in the south, multiple semigrabens with orientations fitting that of the Tang Lu Fault Zone formed under conditions of Eocene transtension [29]. East of the Bureya orogen, in parallel to the activation of left-lateral strike-slips, the foundation of the meridional depressions occurred in the beginning of the Cenozoic: the age of the basal deposits in these depressions is clearly older than Oligocene [18, 29].

Most likely, the Bureya orogen formed during the stage of intensive deformations in the beginning of the Cenozoic against the background of the completion of tectonic movements in the Tang Lu Fault Zone. By this time, the triple junction of the Mongolian–Okhotian, Central Asian, and Pacific main tectonic belts had already formed (Fig. 2). This anomalous structure appeared to be the most favorable location of concentrated deformations that were translated on the strike slips of the Tang Lu Fault Zone, acting as a focus of shortening in the regional lithosphere.

Model of Lithospheric Folding

The traditional approaches to understanding of the neotectonics in the Lower Amur region proceed from the dominant role of rifting processes in eastern Asia. In this context, the Cenozoic deformation structures of the region act as the key elements in the large rift system of the continental margin known in the literature as the "East Asian Graben Belt," the "Ussuri–Okhotian Rifting Zone," etc. [4, 16, 29, 30]. These ideas concentrate mainly on the groups of pull-apart basins in the Amur region, first of all the Evoron–Chukchagir and Lower Amurian–Udyl'–Kizi ones. However, the existence and tectonic genesis of the

Bureya orogen in terms of rifting ideas have not been considered.

However, the data given above on both the surface appearance and deep structure prove that it is the Bureya orogen that dominates in the region and its formation was the leading process in the Early Cenozoic tectonics of the region. Of course, we should not exclude the possibility of the independent occurrence of (a) horizontal shortening completing the Mesozoic–Cenozoic evolution of the Tang Lu Fault Zone and (b) riftogenic destruction of the continental margin. In this case, the Bureya orogen and Cenozoic riftogenic basins in the Lower Amur region formed independently and have different natures. However, the pull-apart basins and the Bureya orogen are both close in age and strictly parallel to each other. The distance between the Chlya–Orel'–Udyl'–Kizi and Evoron–Chukchagir systems of depressions is 240–250 km in latitude (Fig. 5). The meridional Bureya sedimentary basin, where Cenozoic sedimentation continued in the Tyrma and Upper Bureya depressions, is located at the same distance westwards. The meridionally elongated central part of the Bureya orogen is located at a distance of 120–130 km from the Evoron–Chukchagir basin, which is parallel to this part of the orogen. It is obvious that the riftogenic basins are spaced in a regular manner relative to the Bureya orogen (Fig. 8a), indicating that some common tectonophysical mechanism resulted in the formation of the system which united both the syncline and anticline structures of Lower Amur region.

Present-day theoretical and regional studies have revealed [43–45, 51, 55] that the tectonosphere structure is characterized by folds of 30–600 km long that are widely distributed and formed under horizontal shortening. A.M. Nikishin was probably the first who proposed the possible role of lithospheric folding in the morphotectonics of the southern Russian Far East [25]. We can assume that, as a result of horizontal shortening caused by final movements along the strike-slips in the Tang Lu Fault Zone, the system of lithospheric folds formed in the Lower Amur region, with the central meridional part of the Bureya orogen occupying its logical place (Fig. 8a). In this case, the Bureya sedimentary basin in its Cenozoic boundaries, the Evoron–Chukchagir, and the Lower Amurian–Udyl'–Kizi basins are syncompressional depressions. The wavelength in the Lower Amurian system of folds is about 240–250 km.

As was shown by theoretical simulation [43, 44], the wavelength of lithosphere folding directly depends on the thermotectonic age of the region, namely, when the lithosphere nucleated and was finally heated. In the Lower Amur region, a realistic estimate of this parameter can be assumed to be in the broad range of 140 to 40 Ma ago: the lithosphere of this region, most likely, nucleated and completed its formation in this period. The characteristics of lithosphere folding in the Lower Amur region are consistent (Fig. 8b) with both theoretical constructions and the folding parameters of other regions. The later rifting, whose gradually increasing influence has been being the main factor in the evolution of the eastern Asian continental margin since the end of the Eocene, was naturally inherited by downwarping and crustal thinning zones that appeared from lithosphere folding.

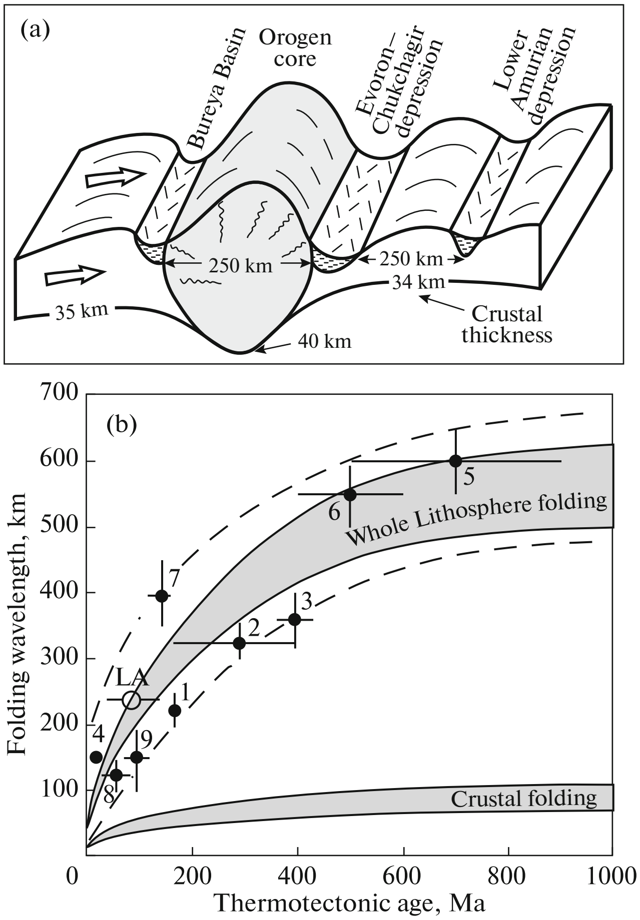

Fig. 8. Lower Amurian system of lithosphere folds: (a) model of spatial correlation between the Bureya orogen and regional sedimentary basins (large arrows denote horizontal shortening); (b) correlation between wavelength during lithosphere folding and thermotectonic age of the lithosphere. Gray zones are shown in accordance with theoretical estimates after [43]. Dots and circles mark lithosphere folding stages in different regions: circle (denoted LA) means Lower Amur; dots: 1, Tien Shan; 2, West Gobi; 3, Central Asia; 4, West Himalayas; 5, Central Australia; 6, East European Craton; 7, southern Caspian Basin; 8, eastern Black Sea; 9, western Black Sea. Regional folding parameters are after [44].

Late Cenozoic Activation of the Bureya Orogen

A predominant role in the long-term tectonic history of the Tang Lu Fault Zone has been played by left-lateral shear deformations related to oblique subduction of the Pacific slabs beneath the Asian continental margin. The left-lateral shear stress field also remained the main one in the region during the Paleocene–Eocene, when the Bureya orogen formed. This character of deformations is consistent with the northwest motion path of the Pacific plates in the late Cretaceous–early Cenozoic [53, 57]. A radical change in the kinematics of the Tang Lu Fault Zone occurred in the late Miocene when the stress field took on a right-lateral shear pattern [18, 29]. Probably, this was the time when the Lower Amur region began to be affected by westward shortening caused by the Amurian Plate motion in the northeast direction. Therefore, activation began in the region, and the main tectonophysical process was asymmetric uplift of the Bureya orogen. The location of the zone with strong earthquakes above the orogen center shows that this deep-seated structure transforms horizontal stress into vertical uplift. This is the way of "breaking" the crust, causing intensified seismic activity in the region.

CONCLUSIONS

Comprehensive analysis of the tectonic, geophysical, and geomorphic data has revealed the key role played by the Bureya orogen both in the structure of the Lower Amur region and in the contemporary regional activation. The results of seismic and density modeling show that there is a low-density anomaly in the lithosphere of the region, where the Moho is sunken down to 40 km depth. The position and contour of crustal thickening is consistent with the negative gravity anomaly and the location of the orogenic dome concentrating all of the mountain peaks higher than 2000 m. The Bureya orogen formed in the zone of concentrated deformations at the junction of three major tectonic belts in the Asian continental margin: the Mongolian–Ohkotian, Central Asian, and Sikhote Alin (Pacific). Horizontal shortening, which was related to the last Paleogene stage of movements along the Tang Lu system of NE-trending strike-slip faults, was translated to the triple junction of the lithospheric boundaries. The formation of meridional sedimentary basins in the Lower Amur region has become an important element of the assumed reconstruction. These basins spatially frame the Bureya orogen to form a united morphotectonic system of coeval units. This system of parallel depressions and rises may have formed under horizontal shortening during the process of folding of the whole lithosphere.

Activation in the Lower Amur region occurred in the Miocene under the effect of shortening on the Amurian Plate front; northeastward motion of this plate remains the leading factor determining the stress state of the region. The areal distribution of the strongest regional earthquakes with $M \geq 4.5$ demonstrates a clear structure with epicenters clustered in two activated NE-oriented zones. The first (Amurian) zone is located in the southern part of the region and extends along the main fault of the Tang Lu system. The central (Bureya) seismic zone is produced by activation of the orogen comprehensively characterized in the present article.

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REFERENCES

1. A. P. Ashurkov, V. A. San'kov, A. I. Miroshnichenko, A. V. Lukhnev, A. P. Sorokin, M. A. Serov, and L. M. Vyzov, "GPS geodetic constraints on the kinematics of the Amurian Plate," Russ. Geol. Geophys. **52** (2), 239–249 (2011).
2. V. A. Bormotov and A. A. Voitenok, "Tendencies in the earthquake migration in the Amur region," Tikhookean. Geol. **17** (2), 51–60 (1998).
3. V. A. Bormotov and T. V. Merkulova, "Cenozoic stage in the evolution of the northern branch of the Tan Lu–Okhotsk Rift System: deep structure and seismogeodynamics," Russ. J. Pac. Geol. **6** (1), 21–34 (2012).
4. V. G. Varnavskii and Yu. F. Malyshev, "East Asian graben belt," Tikhookean. Geol., No. 3, 3–12 (1986).
5. Yu. G. Gatinsky and D. V. Rundquist, "Geodynamics of Eurasia: plate tectonics and block tectonics," Geotectonics **38** (1), 1–16 (2004).
6. *Geodynamics, Magmatism, and Metallogeny of East Russia,* Ed. by A. I. Khanchuk (Dal'nauka, Vladivostok, 2006), vol. 1 [in Russian].
7. *Deep Structure and Metallogeny of East Asi*a, Ed. by A. N. Didenko, Yu. F. Malyshev, and B. G. Saksin (Dal'nauka, Vladivostok, 2010) [in Russian].
8. S. V. Gorkusha and A. O. Morin, "Seismicity, blocked structure, and tectonic stress of southern Far East," Tikhookean. Geol., No. 2, 42–50 (1998).
9. S. V. Gorkusha, F. S. Onukhov, and F. G. Korchagin, "Seismicity and neotectonics of the southern Far East," Tikhookean. Geol., No. 5, 61–68 (1999).
10. L.P. Zonenshain and L.A Savostin, *An Introduction to Geodynamics* (Nedra, Moscow, 1979) [in Russian].
11. S. V. Zyabrev, M. V. Martynyuk, and E. K. Shevelev, "Southwestern fragment of the Kiselevka-Manoma Acccretionary Complex. Sikhote-Alin: stratigraphy, subduction accretion, and post-accretion displacements," Tikhookean. Geol. **24** (1), 45–58 (2005).
12. Yu. K. Ivashinnikov, F. S. Onukhov, A. M. Sazykin, and V. N. Stavrov, "Seismological and neotectonic features of the northeastern flank of the Bureya Massif," Tikhookean. Geol. **17** (4), 42–49 (1998).
13. V. C. Imaev, L. P. Imaeva, B. M. Koz'min, V. V. Nikolaev, and R. M. Semenov, "Buffer seismogenic structures between Eurasian and Amur lithospheric plates in

South Siberia," Tikhookean. Geol. **22** (6), 55–61 (2003).

14. V. C. Imaev, L. P. Imaeva, and B. M. Koz'min, "Seismotectonics of the Olekma–Stanovoy seismic zone (South Yakutia)," Litosfera, No. 2, 21–40 (2005).
15. F. G. Korchagin and F. S. Onukhov, "Seismotectonic problems of the Amur region," in S*tructure and Evolution of East Asia. IInd Kosygin Readings, Khabarovsk, Russia, 1999* (Khabarovsk, 1999), p. 297–301 [in Russian].
16. L. I. Krasnyi, *Geology of the Baikal–Amur Railway Region* (Nedra, Moscow, 1980) [in Russian].
17. V. E. Kuznetsov, "Deep structure and modern geodynamics of the Amur region," Tikhookean. Geol. **17** (2), 61–67 (1998).
18. A. V. Kudymov, "Cenozoic stress fields in the Kiselevka Fault Zone, Lower Amur region," Russ. J. Pac. Geol. **4** (6), 495–501(2010).
19. B. V. Levin, Kim Chun Un, and T. V. Nagornykh, "Seismicity of Primorye and Amur region in 1888–2008," Vestn. Dal'nevost, Otd. Ross. Akad. Nauk, No. 6, 16–22 (2008).
20. N. A. Logachev, A. A. Vrublevskii, V. V. Nikolaev, and R. M. Semenov, "Seismotectonics of east Russia and seismicity of the Amur region," Vestn. Dal'nevost, Otd. Ross. Akad. Nauk, No. 3, 113–125 (1999).
21. Yu. F. Malyshev, "Deep structure, geodynamics, and seismicity in the junction zone of the Central Asian and Pacific mobile belts," Tikhookean. Geol. **17** (2), 18–27 (1998).
22. Yu. F. Malyshev, V. Ya. Podgornyi, B. F. Shevchenko, N. P. Romanovskii, V. B. Kaplun, and P. Yu. Gornov, "Deep structure of the Amur lithospheric plate border zone," Russ. J. Pac. Geol. **1** (2), 107–119 (2007).
23. A. I. Miroshnichenko, A. P. Sorokin, V. A. San'kov, A. V. Lukhnev, S. V. Ashurkov, A. T. Sorokina, N. I. Panfilov, M. A. Serov, and S. I. Sherman, "Space geodesy in geodynamic studies: recent movements in the Zeya–Bureya Basin," Russ. J. Pac. Geol. **2** (1), 64–71 (2008).
24. B. A. Natal'in and Ch. B. Borukaev, "Mesozoic sutures on the southern Soviet Far East," Geotektonika, No. 1, 84–97 (1991).
25. A. M. Nikishin, *Tectonic Settings. Within-Plate and Plate-Margin Processes* (MGU, Moscow, 2002) [in Russian].
26. A. V. Nikolaev, R. M. Semenov, and V. P. Solonenko, *Seismogeology of the Mongol-Okhotsk Lineament (Eastern Flank)* (Nauka, Novosibirsk, 1979) [in Russian].
27. V. V. Nikolaev, "Tan-Lu–Kur Fault: basement structure and seismicity," in *Tectonic Problems and Energetic and Mineral Resources of Northwestern Pacific* (DVO AN SSSR, Khabarovsk, 1992), pp. 81–91 [in Russian].
28. V. V. Nikolaev, A. A. Vrublevskii, V. A. Akhmadulin, and V. E. Kuznetsov, *Geodynamic and Seismic Zoning of the Continental Far East* (DVO RAN, Vladivostok, 2000) [in Russian].
29. A. N. Perestoronin and E. P. Razvozzhaeva, "The system of Cenozoic depressions in the Amur and Primorye regions: the structure, tectonic position, and geodynamic interpretation," Russ J. Pac. Geol. **5** (2), 139–154 (2011).
30. E. G. Peskov and I. M. Migovich, "Continental-margin rift system on northeastern Asia," Geol. Geofiz., No. 2 , 11–18 (1980).
31. A. M. Petrishchevskii, "The relation of seismicity to lithospheric density inhomogeneities in the Russian Far East," J. Volcanol. Seismol. **1** (6), 410–420 (2007).
32. A. V. Petrov, D. B. Yudin, and S. Khou, "Processing and interpretation of geophysical data using probabilistic–statistic approach with KOSKAD 3D computer technology," Vestn. KRAUNTs. Nauki O Zemle, No. 2, 126–132 (2010).
33. L. I. Popeko, *Carboniferous of the Mongol–Okhotsk Orogenic Belt* (Dal'nauka, Vladivostok, 2000) [in Russian].
34. *Seismotectonics and Seismic Zoning of the Amur Region*, Ed. by V. P. Solonenko (Nauka, Novosibirsk, 1989) [in Russian].
35. S. L. Solov'ev, "Main seismic zones of the Amur region and Primorye," Geol. Geofiz., No. 9, 9–19 (1980).
36. A. A. Stepashko, "Deep roots of seismotectonics in the Far East: the Sakhalin Zone," Russ. J. Pac. Geol. **4** (3), 228–241 (2010).
37. A. A. Stepashko, "Deep roots of seismotectonics of the Far East: the Amur River and Primorye zones," Russ. J. Pac. Geol. **5** (1), 1–12 (2011).
38. *Tectonics, Deep Structure, and Metallogeny of Junction Zone of the Central-Asian and Pacific Belts. Explanatory Note to the Tectonic Map on a Scale of 1 : 1500000* (DVO RAN, Vladivostok–Khabarovsk, 2005) [in Russian].
39. G. F. Ufimtsev, *Tectonic Analysis of Relief by the Example of the Soviet Far East* (Nauka, Novosibirsk, 1984) [in Russian].
40. G. F. Ufimtsev, S. N. Alekseenko, and F. S. Onukhov, "Morphotectonics of the Lower Amur region," Russ. J. Pac. Geol. **3** (6), 585–595 (2009).
41. G. I. Khudyakov, *Seismotectonics of the Southern Far East* (Nauka, Moscow, 1977) [in Russian].
42. A. Barth and F. Webzel, "New constraints on the intraplate stress field on the Amurian Plate deduced from light earthquake focal mechanisms," Tectonophysics **482**, 160–169 (2010).
43. S. Cloetingh, E. Burov, and A. Poliakov, Lithosphere folding: primary response to compression? (from Central Asia to Paris Basin), Tectonics **18** (6), 1064–1083 (1999).
44. S. Cloetingh and E. Burov, "Lithospheric folding and sedimentary basin evolution: a review and analysis of formation mechanisms," Basin Res. **23**, 257–290 (2011).
45. D. Delvaux, S. Cloetingh, F. Beekman, D. Sokoutis, E. Burov, M. M. Buslov, and K. E. Abdrakhmatov, "Basin evolution in a folding lithosphere: Altai-Sayan and Tien Shan belts in Central Asia," Tectonophysics **602**, 194–222 (2013).
46. S. A. Graham, T. Cope, C. L. Johnson, and B. Ritts, "Sedimentary basins of the Late Mesozoic extensional domain of China and Mongolia," in *Phanerozoic Rift Systems and Sedimentary Basins* (Elsevier, 2012), pp. 443–461 (2012).
47. K. Heki, S. Miyazaki, H. Takahashi, M. Kasahara, F. Kimata, S. Miura, N. F. Vasilenko, A. Ivashchenko,

and K.-D. An, "The Amurian plate motion and current plate kinematics in Eastern Asia," J. Geophys. Res. **104** (B12), 29147–29155 (1999).

48. X. Li, X. Yang, B. Xia, G. Gong, Y. Shan, Q. Zeng, W. Li, and W. Sun, "Exhumation of the Dahinggan Mountains, NE China from the Late Mesozoic to the Cenozoic: new evidence from fission-track thermochronology," J. Asian Earth Sci. **42**, 123–133 (2011).
49. K. G. Mackey, K. Fujita, L. V. Gounbina, B. M. Koz'min, V. S. Imaev, L. P. Imarva, and B. M. Sedov, "Explosion contamination of the Northeast Siberian seismicity catalog: implications for natural earthquake distributions and location of the Tan Lu Fault in Russia," Bull. Seismol. Soc. Am. **93** (2), 737–746 (2003).
50. Q. Meng, Z. Liu, A. A. Bruch, R. Liu, and F. Hu, "Paleoclimatic evolution during Eocene and its influence on oil shale mineralization, Fushun Basin. China," J. Asian Earth Sci. **45**, 95–105 (2012).
51. A. M. Nikishin, S. Cloetingh, L. I. Lobkovsky, E. B. Burov, and A. C. Lankreijer, "Continental lithosphere folding in Central Asia (P. 1): constraints from geological observations," Tectonophysics **226** (1–4), 59–72 (1993).
52. C. Petit and M. Fournier, "Present-day velocity and stress field of the Amurian Plate from thin-shell finite-element modelling," Geophys. J. Int. **160**, 357–369 (2005).
53. D. K. Rea and R. A. Duncan, "North Pacific Plate convergence: a quantitative record of the past 140 m.y.," Geology **14**, 373–376 (1986).
54. J. Ren, K. Tamaki, S. Li, and Z. Junxia, "Late Mesozoic and Cenozoic rifting and its dynamic setting in Eastern China and adjacent areas," Tectonophysics **344**, 175–205 (2002).
55. J. H. W. Smit, S. A. P. L. Cloetingh, E. Burov, M. Tesauro, D. Sokoutis, and M. Kaban, "Interference of lithospheric folding in western Central Asia by simultaneous Indian and Arabian plate indentation," Tectonophysics **602**, 176–193 (2013).
56. Y. Song, J. Ren, A. A. Stepashko, and J. Li, "Post-rift geodynamics of the Songliao Basin, NE China: origin and significance of T11 (Coniacian) unconformity," Tectonophysics **634**, 1–18 (2014).
57. Y. Song, A. A. Stepashko, and J. Ren, "The Cretaceous climax of compression in Eastern Asia: age 87–89 Ma (Late Turanian/ Coniacian), Pacific cause, continental consequences," Cretaceous Res. **55**, 262–284 (2015).
58. Z. Tian and Y. Du, "Formation and evolution of the Yilian-Yitong Graben," Tectonophysics **133**, 165–173 (1987).
59. M. Wei, Y. Liu, D. Jao, J. Shen, P. Xiaolong, "Evidence for Holocene activity of the Yilan-Yitong Fault, northeastern section of the Tan-Lu Fault Zone in northeast China," J. Asian Earth Sci. **67–68**, 207–216 (2013).
60. Z. Yu, S. Wu, D. Zou, D. Feng, and H. Zhao, "Seismic profiles across the middle Tan-Lu fault zone in Laizhou Bay, Bohai Sea, eastern China," J. Asian Earth Sci **33**, 383–394 (2008).

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