Chapter

Tentative Intracontinental Seismic Activity in South Siberia and Russian Far East

Yuriy Gatinsky and Tatiana Prokhorova

Abstract

Overwhelming majority of minor, strong and major earthquakes in south Siberia and Russian Far East coincide with relatively narrow intracontinental zones on the boundaries of blocks and lithosphere plates. The geodynamic activity of these zones connects, besides the plate interaction, with deep lithosphere structure and anomalies of the different geophysical fields as well as with blocks' kinematics. Authors' located areas of the seismic centers origin and the possible manifestations of the high seismicity based on the distribution of the maximal volumes of releasing seismic energy. We established these areas, with certain care, in the northeast Altai and adjacent part of the west Sayany, in the west of the east Sayany, around the Baikal Lake and in northwest Transbaikalia, in the east of Transbaikalia between the Vitim River and upper stream of the Aldan River, and in the north of the Sakhalin Island. The majority of minor and strong, rarely major, earthquakes took place in these areas. Deep and near surface structural peculiarities influence on these areas' geodynamics and allow establishing possible levels of seismic energy releasing. We draw areas of intensive seismic energy releasing with its calculating for each from investigated regions. They gravitate towards interblock zones, which separate crust blocks and the North Eurasian Lithosphere Plate. The fulfilled investigation allows establishing specific areas of the increased seismicity in south Siberia, Russian Far East and adjacent territories.

Keywords: seismic active zone, strong and major earthquakes, seismic energy, area of origin of seismic centers, active fault, block, interblock zone, lithosphere plate, deep structure, geophysical field

1. Introduction

In 2013–2018, authors analyzed at the relatively small scale the structure and seismicity of intracontinental interblock zones within the Asiatic part of Russia and adjacent countries together with calculation of the releasing seismic energy and construction of their dissipation graphs as well as the deep seismic sections [1, 2]. The results of this analyzing allowed selecting the most active seismic zones, including overwhelming majority of minor and strong earthquakes' epicenters, and examined in detail the lithosphere deep structure under them and not far of them with establishing the possible connection of these zones with the geodynamic activity and anomalies of different geophysical fields. With special attention, we considered kinematics of blocks and main lithosphere plates as well as the connection with them active processes in interblock zones. All blocks considered in our paper are delineated by active

faults, data on which we taken from the works of [3, 4], including results of author's field investigations in Transbaikalia in 2008 [5]. The modern block structure of central Asia was considered and validated in some previous author's works [1, 6–8].

In 2018–2020, we investigated in the more large scale the influence of the deep and near surface lithosphere structure on the interblock zones geodynamic activity with possible levels of seismic energy releasing. Within the most active from these zones, we established areas with seismic energy maximal releasing. They situate in the northwest Altai together with the adjacent part of the west Sayany, in the west of the east Sayany, around the Baikal Lake and in northwest Transbaikalia, in the east of Transbaikalia between the Vitim River and upper stream of the Aldan River and in the north of the Sakhalin Island.

2. Areas of seismic centers origin in South Siberia and Russian Far East

Based on the earthquake epicenters distribution and maximal volumes of seismic energy releasing we located, with certain care, five specific areas of origin of seismic centers (OSC) with seismic energy volumes calculation in them. Active faults limit the majority of these areas. The fulfilled investigation of these intracontinental areas allows showing increased seismicity distribution in south Siberia, Far East and adjacent territories. Below we consider geodynamics and seismicity of each from five selected OSC areas.

3. OSC area in the Altai

The area includes seismic active zones selecting the Altai Block from the North Eurasian Plate (NEP), West Mongolia and Sayany blocks within the south part of the Altai Republic, west part of the Tuva Republic in Russia and adjacent territory of northwest Mongolia (**Figure 1**). Its length is 356 km, width – 87-243 km and the total seismic energy volume achieves $1.70833 \cdot 10^{16}$J (here and below we calculate cumulative energy volume during the course of 1966–2017 using for its calculation data from NEIC2019 catalog). Left- and right-lateral northwest slips with compression component predominate within the area as well as near latitudinal and northwest thrusts to the north and northwest. Maximal magnitudes (M) of earthquakes reach 5–8. The greatest seismic activity coincides with the boundary of the Altai Block and NEP, where the energy releasing increases up to 10^{11}J. According to seismic cross section [1] right-lateral slips and thrusts to the northeast develop here in the depth 10-34 km. East on the boundary between West Mongolia and Sayany blocks left-lateral slips predominate in the depth of 8-32 km. Tectonic strain axis's have the northeast direction.

The heat flow (HF) value changes from 25 to 28 $\mu W/m^{-2}$ within NEP near Novosibirsk, up to 55–96 to the south in the Altai Mountains [10]. Within the Mining Altai in east Kazakhstan HF is equal 29-61 $\mu W/m^{-2}$. East on the boundary between West Mongolia and Sayany blocks HF value increases up to 80 $\mu W/m^{-2}$ and larger. The International Terrestrial Reference Frame (ITRF2014) vectors of horizontal displacement have mainly east and southeast direction in stations near Novosibirsk (88.7–92.2°) with velocities 23.9–27.1 mm/y. However, the Altai Station north of Ust-Kamenogorsk fixes the displacement to 350° NW with the velocity 50 mm/y. The large gradient in the crust structure takes place at the boundary between Altai and Junggar blocks south from investigated region, where crust thickness decreases southeast from 55 to 60 down to 35-40 km [11]. Data on HF and the Global Navigation Satellite System (GNSS) velocities as well on S-wave velocities below give the representation of the crust and lithosphere activity, which can have the indirect connection with the seismicity level.

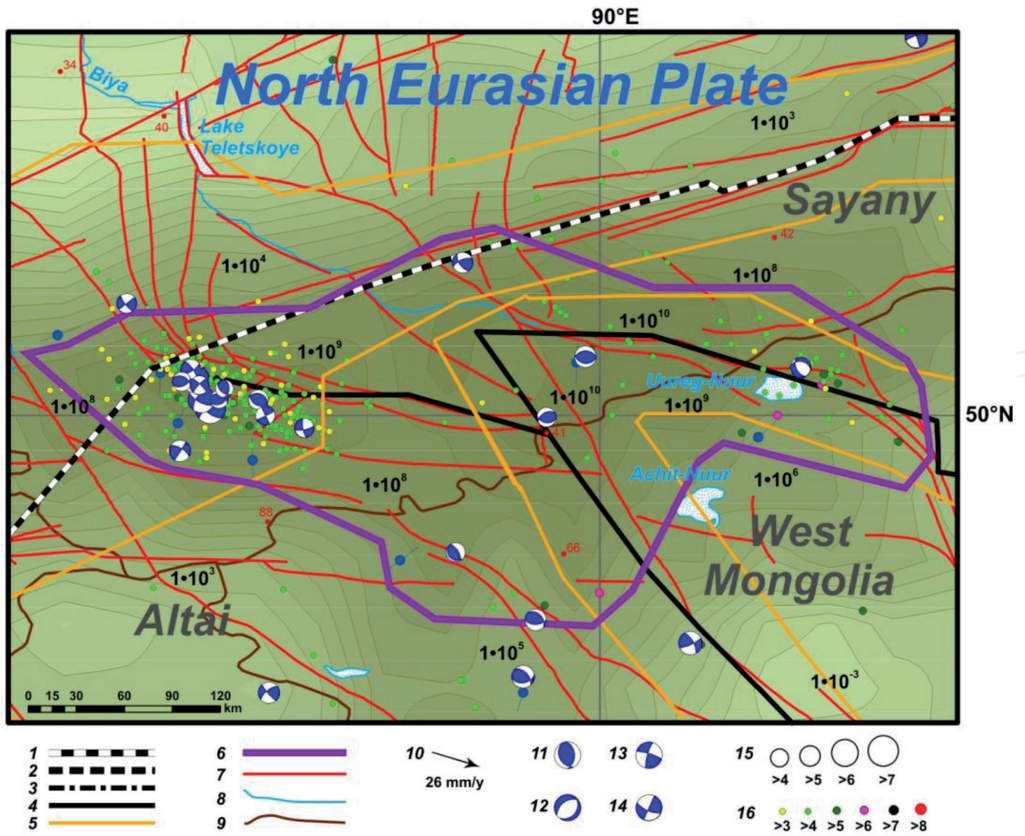

Figure 1.
The OSC area situated in the northeast altai and west Sayany within seismic active zones selects the Altai block from NEP, Sayany and West Mongolia blocks. The summary legend for ***Figures 1****,* ***2*** *and* ***3-5*** *includes boundaries of: 1 – Lithosphere plate, 2 – The same supposed, 3 – Transitional zone, 4 – Block, 5 – Interblock zone, 6 – OSC area (see the part 2). Other symbols: 7 – Active fault, 8 – River, 9 – State frontier, 10 – ITRF2014 (see the part 3) vectors of horizontal displacement, 11–14 – Mechanism in hypocenters after the centroid moment tensor (CMT2019) according to NEIC2018 seismological data (11 – Compression, 12 – Extension, 13 – Left-lateral slip, 14 – Right-lateral slip; the predominant orientation of segments in mechanism corresponds to a displacement direction), 15 – The magnitude scale of earthquake epicenters by CMT, 16 – The magnitude scale of earthquake epicenters, for which CMT2019 data are absent (according to NEIC seismological data). Thin lines with dark-blue circles correspond to tectonic stress axis's [9]. Green color fields, divided by isohypsis, show volumes of seismic energy releasing. Increasing color intensity corresponds to increasing energy volume on* 10^{1}*J or* 10^{-1} *J. the minimal value is* 10^{-7}*J, the maximal –* 10^{14}*J. The black numerals in the scheme correspond to energy volume values in joules. Dotes with red figures near them correspond to values of the heat flow in* $\mu W/m^{-2}$*. The total extensions of studied blocks see in the* ***Figure 6****. The authors of the chapter constructed this scheme as all others.*

The geodynamic and seismicity data analysis allow supposing future earthquakes intensity within the Altai OSC area. Events with M7–8 are possible in the west quarter of this area within the Mountain Altai at the left bank of the Argug River, which is the Biya River left source, southwest from the Belyashi settlement. The hypocenters' predominant depth is there about 10-20 km that allows waiting mainly destructive events in this part of the area. Earthquakes with M5–6 are more probable in future within the rest territory of the OSC area.

4. OSC area in the East Sayany

This area embraces seismic active interblock zones separating the Sayany Block from NEP and from the Hangay Block in the east part of the Tuva Republic, southwest of Buryat Republic and adjacent part of north Mongolia (**Figure 2**). Its length is 350 km, width – 100-216 km and the total seismic energy volume achieves $1.805.11{\cdot}10^{16}$J. The most intensive seismic energy releasing up to 10^{9-11}J characterizes

the left bank of the Ka-Hem River in the upper stream and south from it in both sides of the Russia and Mongolia Frontier. The majority of epicenters correspond to events with M3–6 and M of some of them in the Mongolia territory increase up to 7–9.

In the OSC area's north parts near latitudinal thrusts to the north predominate with the left-lateral slip component. The stead left-lateral slips take place south between Sayany and Hangay blocks. Transverse north – northeast subsidiary faults develop inside the Sayany Block. The majority of tectonic stress axis's have the strike changing from near longitudinal in the west up to northeast in the east. The transition from transpression to transtension conditions takes place in south Siberia from west to east within interblock zones separating NEP from blocks, which situate south. Thrusts predominate on Altai and west Sayany, where instrumentally measuring crust shortening reaches 2-4 mm/y [12]. They changes on slips with the thrust component in the east Sayany and further east on left-lateral slips with the extension component in the Tunka depression approaching to the Lake Baikal. More easts within the Baikal Rift System the extension completely predominates. The tectonic stress tensors' analysis confirms this changing as well as our field investigation together with V.A. San'kov near the Lake Baikal and in Transbaikalia [5, 13].

The steady NEP displacement east characterizes regarded territory with velocities 25-26 mm/y and the azimuth 89° NE on the Novosibirsk Station and 104.5° SE on the Badary Station north of the east Sayany. Permanent azimuth deflections east and southeast correspond to the plate small clockwise rotation. The maximal difference between measuring and a model vector of horizontal displacement reaches 68° in the NEP – Sayany interblock zone, where active slips predominate. The Novosibirsk Station records the uplift at 8.0 mm/y. The lesser uplift with velocities 2.0–2.5 mm/y characterizes the east Sayany. High magnetic anomalies up to +50 - +100*n* coincide with interblock zones between NEP, Altai and Sayany blocks as well as with faults within them (*http://projects.gtk.fi/WDMAM/project/perugia/index.html*).

The negative gravitational anomalies at the Bouguer Reduction up to –50 – -150mGal, characterize the great part of central Asia, including Hangay and Sayany

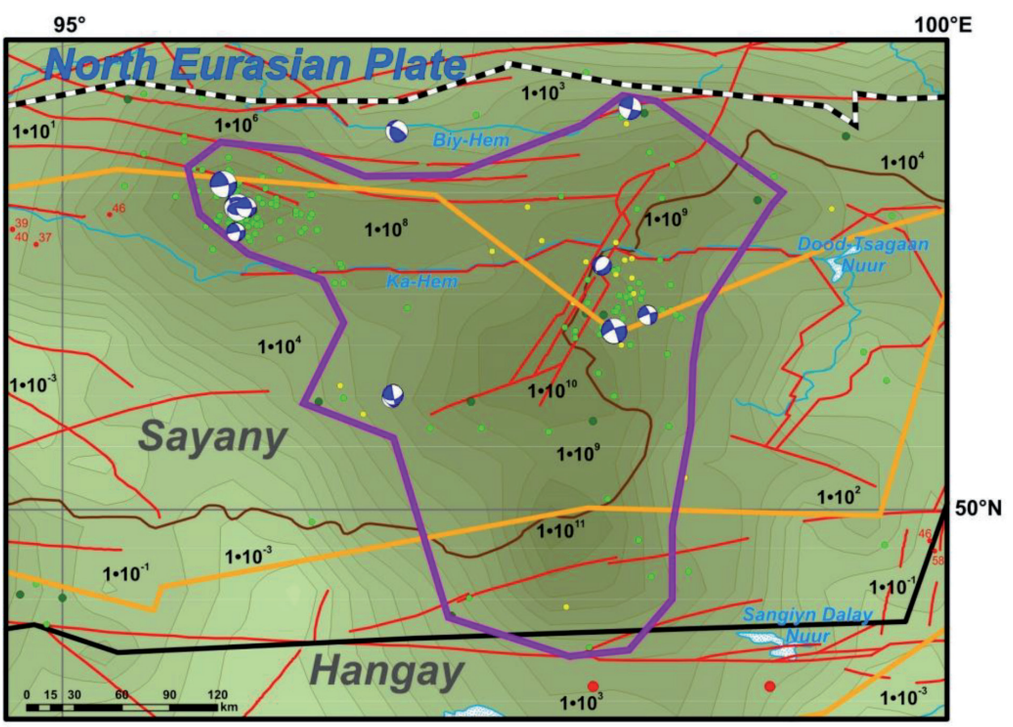

Figure 2.
The OSC area in east Sayany takes place within seismic active zones separating the Sayany block from NEP and the Hangay block. See the summary legend for the ***Figure 1****.*

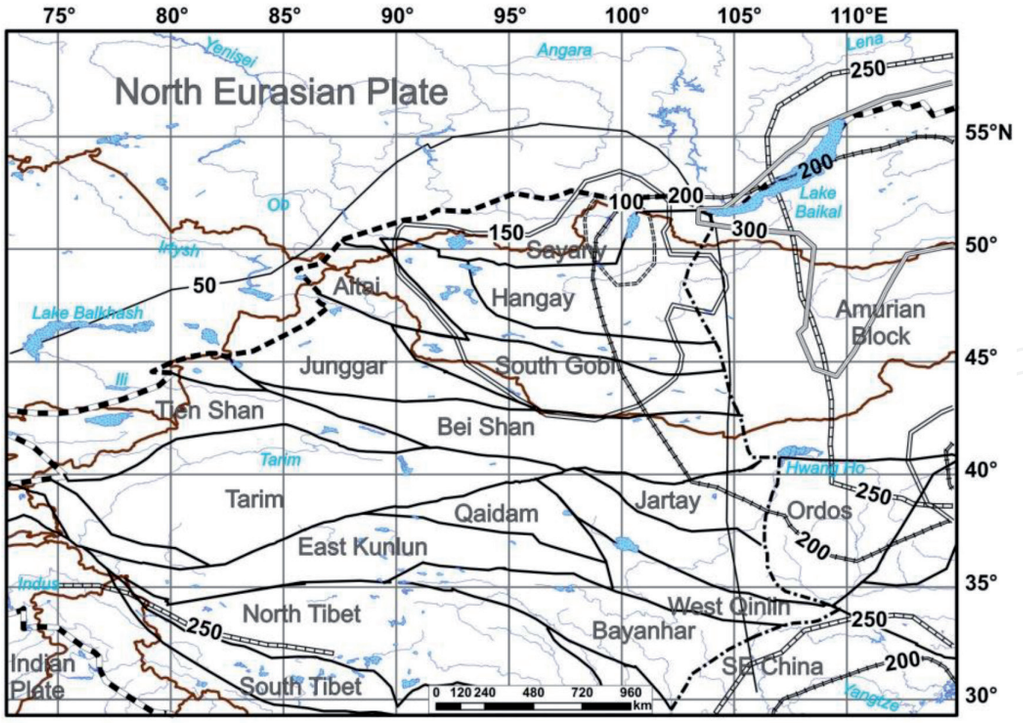

Figure 3.
Central Asian mantle anomalies. For block, transitional zone and plate boundaries see summary legend for the ***Figure 1****. Gray lines of different types limit projections of S-waves' velocity slowing-down up to ≤4.2–4.25 km/sec−1 on 50, 100, 150, 200, 250, and 300 km depth levels after seismic tomography data. Authors of the paper drew these lines after data contained in the work [16]. Note that both parts of OSC areas with possible earthquakes' M to 7–9 (see* ***Figures 1****,* ***2****) coincide with near isometric outline (counter), under which S-wave velocities slow down at the depth 150 km. That allows supposing the connection of the increase seismicity there with the possible mantle plume rising.*

blocks. In the Junggar–Altai interblock zone they reach even −200mGal [14]. High negative values of these anomalies correspond to significant increasing of the crust thickness within the above-mentioned blocks. HF values increase in the interblock zone between Sayany – NEP up to 47-150 μW/m^{-2} and between Hangay – Sayany blocks within the Hubsugul Rift up to 80–140. The increasing HF values often coincide with areas, which situate above supposed mantle plumes [15]. One of those plumes can situate after seismic tomography data at the boundary between Hangay and Sayany blocks in east Tuva in depth 100-150 km (see **Figure 3**). There the lithosphere thickness decreases down to 70-50 km and the temperature at the depth 50 km can reach 1000–1200° C after relation of isotopes 3He/4He [17].

The increased level of seismicity can characterize in the future two parts of the OSC area with possible earthquakes M to 7–9. The first of them takes place on the left bank of the Ka-Hem River in its upper stream between the Lake Tere-Hol in the west and the Russia – Mongolia frontier in the east (see **Figure 2**). The second part situates south from it in both sides of the Russia and Mongolia Frontier. The hypocenters' concentration takes places at the depth 9-1 km, so we can wait mainly destructive events in this part of the area. Earthquakes with M4.99–5.99 are more probable in future within the rest territory of the OSC area.

5. The OSC area in the Baikal system and northwest Transbaikalia

The OSC area includes territory between NEP and the Amurian Block (or the small plate in other interpretation [18]) within the Baikal Rift System and its northeast continuation (**Figure 4**). The area length is 950 km, its width – 11-230 km

and the total releasing energy volume reaches $1.79362 \cdot 10^{15}$J. Normal northeast faults predominate there with the left-lateral slip component. Tectonic stress axis's have stead northeast direction. The releasing energy level oscillates from 10^4 to 10^{12}J, M changes from 3 to 6 reaching 6–7 for some certain events. The zone of active extension stands out within all Baikal Rift System after mechanism earthquake solutions. Releasing energy maximal volumes coincides with this zone. The extension processes do not get out from the crust (10-33 km) according to analysis of the hypocenters development after CMT2017 data. Separate faults in adjacent parts of the Amurian Block are left-lateral slips, rarely thrusts to southwest.

Normal faults and left-lateral slips with extension component prevail near southwest ending the Baikal Rift System at the depth of 10-16 km within the interblock zone dividing NEP and the Amurian Block. Yu. Gatinsky and G. Vladova together with V. San'kov discovered during 2008 field itineraries in the Barguzin Depression distinct changing slips, causing seismic dislocations, by later normal faults [5]. These faults cross from the Paleozoic granite to the yang alluvium corresponding to the time progress of the transtension process. The maximal increasing the seismic energy dissipation up to $1.4 \cdot 10^{15}$J occurs above normal faults restricting the Baikal Trough in southwest [1]. Just there near the Kultuk settlement the earthquake with M6.3 took place in 2008. The earthquake near destroyed the settlement and some communication ways. West we observed the displacement of modern streamlets' thalwegs along NW slips with amplitudes up to 10 m. NEP displaces on 105.6° SE with the velocity 25.9 mm/y according to measuring in the Irkutsk Station into absolute coordinates of ITRF2014. Vectors within the Amurian Block have azimuths of 106.9° -108.0° SE on the Ulan-Bator Station with the velocity 31.2 mm/y and up to 121° SE and more on some Chinese stations with velocities 26-35 mm/y. HF values reach 96-140 $\mu W/m^{-2}$ in the Lake Baikal Trough in comparison with 36–79 at its sides within NEP and the Amurian Block.

Note, that in the east part of Central Asia horizontal displacements predominate into transtension conditions with opening numerous rifts in the Baikal System,

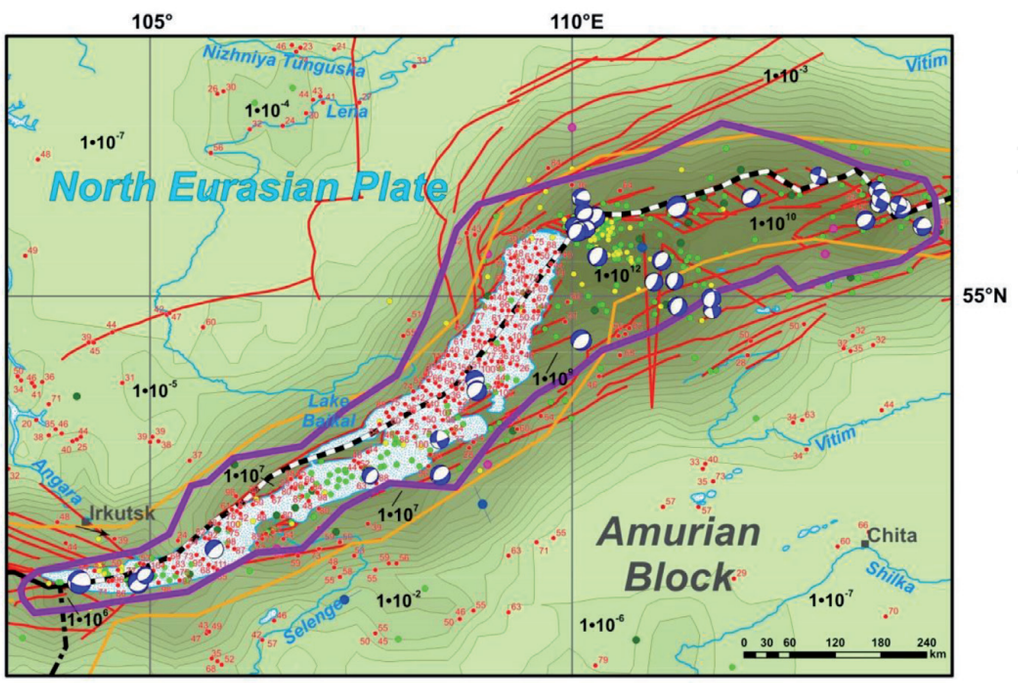

Figure 4.
The OSC area within the Lake Baikal and northwest Transbaikalia takes place in seismic active zones separating NEP and the Amurian block. See summary legend for the ***Figure 1****.*

around the Ordos Block and in boundaries of some other blocks. The development of those extension processes has different interpretation: squeezing out east some blocks including the Amurian Block under the influence of the Hindustan – Asia collision [12], or the upper mantle flow generated by the deep submergence of the Pacific slab under Asia [19–21]; mantle plume raising under north Mongolia and the Baikal region (see **Figure 3**) resulted in the crust extension and rift formation [7, 17]. The increase anisotropy exists in the majority regions of central Asia with coinciding north-northeast direction of splitting *Pn*-waves high velocities with the axes of maximal compression and GPS vectors [22], that shows the complete deformation coupling within crust and lithosphere mantle. The authors of paper [23] arrived at the same conclusion for the region of Baikal, west and central Mongolia.

Data on geodynamics and seismicity of the regarded OSC area allow predicting maximal intensive seismic events with M up to 7–9 within northwest third of the area territory: to the north in the Stanovoi Upland at both banks of the Upper Angara River and farther south east of the Lake Baikal in the north part of the Barguzin Range. New earthquakes with M up to 6–7 can be in the other part of the OSC area. The main hypocenters concentrations of preceding events were at the depth 10-16 km, so within regarded area disastrous earthquakes will be the most probably, most likely as near Kultuk in 2008.

6. The OSC area in the northeast Transbaikalia

The area situates in the territory of Zabaikalian Krai, south Yakutsk, and northwest of the Amurian District between the Vitim River and upper stream of the Aldan River (**Figure 5**). Its length is 464 km, width – 64-108 km, and the total seismic energy reaches $4.64153 \cdot 10^{16}$J, that is nearly equally to the energy of the OSC area of the north Pamir - $4.50343 \cdot 10^{16}$J [24]. The energy level oscillates on the regarded area between 10^4 - 10^{12}J and M in epicenters changes from 3 up to 6. M of separate events reaches 6–7. Northeast normal faults with the left-lateral slip component predominate in the west of the OSC area and northwest left-lateral slips develop in the east. Tectonic stress axis's have the stead northeast direction.

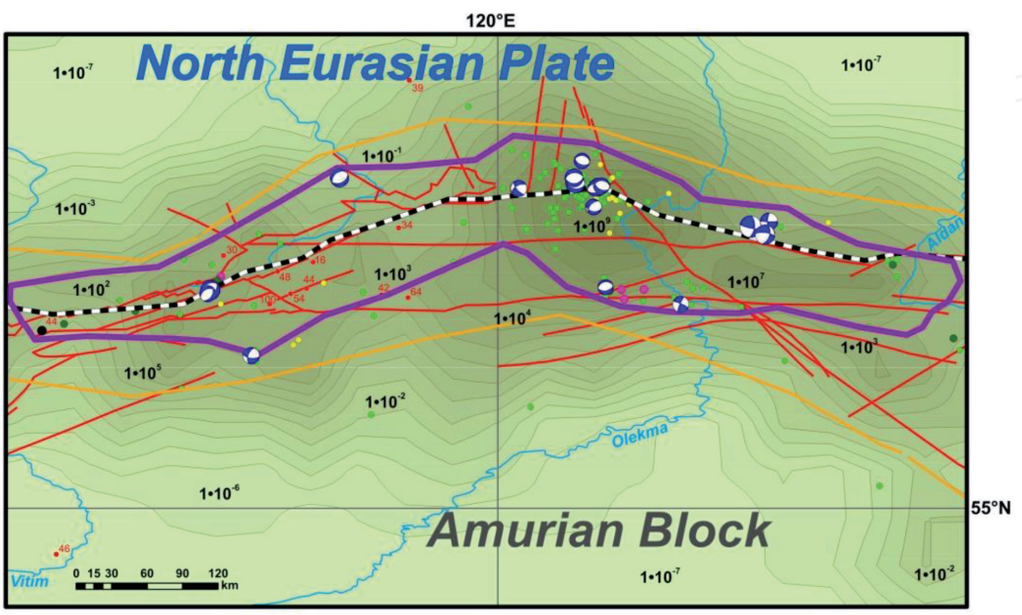

Figure 5.
The OSC area in northeast Transbaikalia settles down within the seismic active interblock zone between NEP and the Amurian block. See summary legend for the ***Figure 1****.*

According measuring at the Yakutsk Station NEP moves on 121° SE with velocity 20.0 mm/y, but simultaneously displaces south relatively the stable Eurasia in the NNR_NUVEL_1A System. Azimuths of the vast Amurian Block change from 106° SE on the Ulan-Bator Station up to 110° near Beijing with velocities 29-32 mm/y. This block turns counter-clockwise after SLR and GPS data 2000–2008 coinciding with right-lateral displacing along the large-scale Tanlu Slip System on the block east boundary. The same turn fixed by results of the Belgic-Russia tidal gravitation profile along 50° N latitude [25, 26]. The alternation of wide northeast strips with +100 - -100*n* takes place in the magnetic field above the Amurian Block. They apparently can reflect the early Precambrian block fundament structures strike. After seismic tomographic data, the reduced lithosphere thickness characterizes the north part of the block (100-105 km in comparison with 200 km under NEP) [27]. The low values of the rock density and electric resistance apparently correspond to lithosphere deep stratification on boundaries of 10, 20, 40 and 70-90 km [28].

Low *Pn*-waves velocities characterize the upper mantle under the transitional zone between continent and ocean under Amurian and neighboring Japanese-Korean blocks [22]. Some researches suppose existing of the strong upper mantle substance flow on the southeast direction based on the analysis of lengthening deformation axis's and anisotropy in border fields of NEP and Amurian Block. This deep flow causes the NEP clockwise turn confirmed by ITRF2014 vectors [23]. The above-mentioned simultaneous counter-clockwise turn of the Amurian Block apparently results in opening the Baikal Rift. At the same time, we cannot exclude the influence of plume tectonic processes on geodynamics of the Amurian Block – NEP zone. After seismic tomography data isometric counters of S-waves' velocity slowing-down projections (see **Figure 3**) up to ≤4.2–4.25 km/sec^{-1} take places on 50, 100, 150, 200, 250, and 300 km depth levels [16]. Note that the majority of the high heat-flow meanings up to 64-100 μW/m^{-2} coincide with S-waves velocity slowing-down projections [8]. These data allow supposing ascent of heating and non-consolidated mantle material to the earth's surface with increasing seismicity level.

Speaking on the future seismic events it is needed to distinguished the east part of the regarded OSC area on Olekma River booth banks in the region of BAM railway stations of Khani and Yuktali as well as east up to left bank of the Upper Aldan River. There it is possible to wait for new earthquakes with M up to 7–8. In the other area territory M most likely will be not higher than 6. The light hypocenters concentrations coincide with depths of 10–11 and 21-26 km.

7. The OSC area in the north half of the Sakhalin Island

We select this area within the interblock zone dividing Japanese-Korean and Okhotsk blocks (**Figure 6**). Its length is 530 km, width – 154 km, the total seismic energy releasing after instrumental measuring data (NEIC2017) reaches 1.15535·10^{16}J. The energy level in the central part of the area is about 10^{11}J. Epicenters with M4–5 are numerous, with 6–8 are only single. This interblock zone stretches through all island, but in its south half is "absorbed" by the Pacific subduction zone dipping under Eurasia [1].

Longitudinal right-lateral slips with north-northeast thrust component predominate in the up-to-date structure of the north Sakhalin. Hypocenters in the crust (10-40 km) correspond to the dip slip in the island east and to thrusts in the west. The intensive earthquakes with M7.2 in Moneron (1971) and Neftegorsk (1995) occurred in northeast Sakhalin within its coastal part. Their hypocenters depth reaches 30-60 km. North Sakhalin GPS vectors direction is about 130° SE with

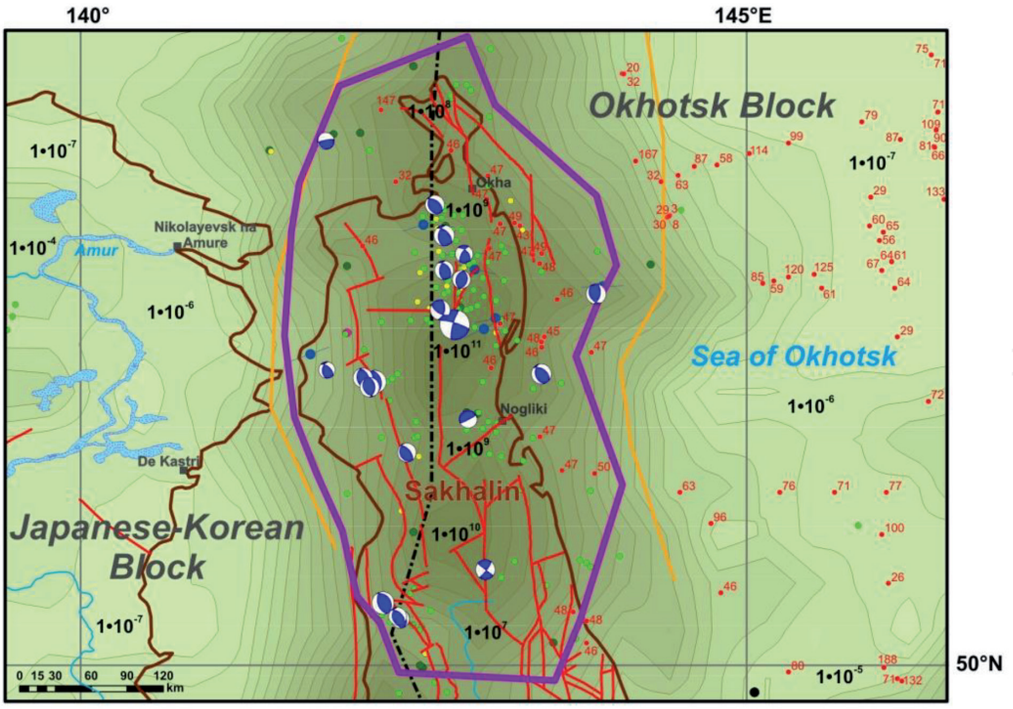

Figure 6.
The OSC area in the north half of the Sakhalin Island situates within the seismic active interblock zone dividing Japanese-Korean and Okhotsk blocks. See summary legend for ***Figure 1****.*

velocities 18.1–22.1 mm/y. After measuring in the ITRF2014 System on Khabarovsk and Seoul stations the Japanese-Korean Block moves on 115–120° SE with velocities 22-25 mm/y. This block also turns clockwise to southeast with the velocity of 0.9–1.5 mm/y according with measuring in the Sikhote-Alin geodynamic net [29]. This turn can evoke up-to-date extension and crust non-consolidation in northeast China within the Songliao Depression [30] differ from main lithosphere plates displacing by their kinematics. The Okhotsk Block displaces on 149° SE with the velocity 22.9 mm/y, North Japanese – on 132° SE with the velocity 25.0 mm/y. In the central part of the Honshu Island, the uplift fixes with the velocity 3.7 mm/y after ITRF2014. The Pacific Plate moves relatively Eurasia on 288°NW with the velocity 75 mm/y in the NNR_NUVEL_1A System.

The HF average value in Sakhalin Island is 76 μW/m^{-2} increasing within adjacent aqyatories up to 123-200 μW/m^{-2} [31, 32]. After the same authors magnetic field anomalies within island do not exceed 0-200*n* sharply increase in the Okhotsk Sea up to 1000-1200*n*. Gravitational anomalies on Sakhalin in the Bouguer reduction come to −30 - +50mGal [15]. The crust thickness under island reaches 30-35 km, the lithosphere thickness – 52 km [31]. Completing the examination of the north Sakhalin OSC area we can expect the probably origin of earthquakes with M up to 7–8 in the center of the island north part within the Neftegorsk Region, as well as west and southwest from it. For the more south regions of OSC area and the extreme north of the island we can, with certain care, suppose, that M of future seismic events will be not higher than 5–6. Hypocenters concentrations situate at the depth 5-55 km.

8. Conclusion

We selected five OSC areas in intracontinental interblock zones, in which the most intensive seismic events can take place. The OSC areas with maximal seismic activity divide the Altai Block and NEP, Hangay and Sayany blocks,

Amurian Block and NEP within republic's Altai, Tuva, Buryat, Irkutsk District and Mongolia. Volumes of releasing seismic energy reach in them 10^{7-12}J, earthquakes with M4–6 are frequent, some infrequent events have M up to 7–9. The seismicity intensity is a little weaker within OSC areas dividing the Amurian Block and NEP in Transbaikalia Krai, Amurian District, Mongolia, and northeast China, as well as Japanese and Okhotsk blocks in Sakhalin, where seismic energy volumes reach 10^{6-10}J, earthquakes with M5–7 are frequent, infrequent events have M up to 8.

We excluded from our analysis continental margin zones, dividing Japanese-Korean and North Japan, Kuril-Kamchatka and Okhotsk blocks because they situate in connection with west Pacific subduction zones as distinguished from investigated above intracontinental OSC areas. These continental margin zones represent subjects of the special investigation and partly were examined in some earlier papers of Yu. Gatinsky and G. Vladova [33, 34].

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Author details

Yuriy Gatinsky* and Tatiana Prokhorova
Institute of Earthquake Prediction Theory and Mathematical Geophysics, Russian Academy of Sciences, Moscow, Russia

*Address all correspondence to: gatinsky@gmail.com

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