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Tectonophysics

RECENT STRONG EARTHQUAKES IN CENTRAL ASIA: REGULAR TECTONOPHYSICAL FEATURES OF LOCATIONS IN THE STRUCTURE AND GEODYNAMICS OF THE LITHOSPHERE. PART 1. MAIN GEODYNAMIC FACTORS PREDETERMINING LOCATIONS OF STRONG EARTHQUAKES IN THE STRUCTURE OF THE LITHOSPHERE IN CENTRAL ASIA

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Abstract: Studying locations of strong earthquakes (M≥8) in space and time in Central Asia has been among top problems for many years and still remains challenging for international research teams. The authors propose a new approach that requires changing the paradigm of earthquake focus – solid rock relations, while this paradigm is a basis for practically all known physical models of earthquake foci. This paper describes the first step towards developing a new concept of the seismic process, including generation of strong earthquakes, with reference to specific geodynamic features of the part of the study region wherein strong earthquakes were recorded in the past two centuries.

Our analysis of the locations of M≥8 earthquakes shows that in the past two centuries such earthquakes took place in areas of the dynamic influence of large deep faults in the western regions of Central Asia.

In the continental Asia, there is a clear submeridional structural boundary (95–105°E) between the western and eastern regions, and this is a factor controlling localization of strong seismic events in the western regions. Obviously, the Indostan plate's pressure from the south is an energy source for such events. The strong earthquakes are located in a relatively small part of the territory of Central Asia (i.e. the western regions), which is significantly different from its neighbouring areas at the north, east and west, as evidenced by its specific geodynamic parameters. (1) The crust is twice as thick in the western regions than in the eastern regions. (2) In the western regions, the block structures resulting from the crust destruction, which are mainly represented by lense-shaped forms elongated in the submeridional direction, tend to dominate. (3) Active faults bordering large block structures are characterized by significant slip velocities that reach maximum values in the central part of the Tibetan plateau. Further northward, slip velocities decrease gradually, yet do not disappear. (4) In the western regions of Central Asia, the recurrence time of strong earthquakes is about 25 years. It correlates with the regular activation of the seismic process in Asia which is manifested in almost the same time intervals; a recurrence time of a strong earthquake controlled by a specific active fault exceeds seems 100–250 years. (5) Mechanisms of all the strong earthquakes contain a slip component that is often accompanied by a compression component. The slip component corresponds to shearing along the faults revealed by geological methods, i.e. correlates with rock mass displacements in the near-fault medium. (6) GPS geodetic measurements show that shearing develops in the NW direction in the Tibet. Further northward, the direction changes to the sublatitudinal one. At the boundary of ~105°E, southward of 30°N, the slip vectors attain the SE direction. Further southward of 20°N, at the eastern edge of the Himalayan thrust, the slip vectors again attain the sublatitudinal direction. High velocities/rates of recent crust movements are typical of the Tibet region. (7) The NW direction is typical of the opposite vectors related to the Pacific subduction zone. The resultant of the NE and NW vectors provides for the right-lateral displacement of the rocks in the submeridional border zone. (8) The geodynamic zones around the central zone (wherein the strong earthquakes are located) are significantly less geodynamically active and thus facilitate the accumulation of compression stresses in the central zone, providing for the transition of rocks to the quazi-plastic state and even flow. This is the principal feature distinguishing the region, wherein the strong earthquakes are located, from its neighboring areas.

In Central Asia, the structural positions of recent strong earthquakes are determined with respect to the following factors: (1) the western regions separated in the studied territory; (2) the larger thickness of the crust in the western regions; (3) strong submeridional compression of the crust and upper lithosphere in combination with shear stresses; (4) high rates of recent crustal movements; and (5) the rheological characteristics of the crust.

Key words: seismicity; strong earthquake; earthquake foci; magnitude; focal mechanism; fault; crustal thickness; crustal movement; recurrence time; block; shear/slip amplitude; rheology

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Современные сильные землетрясения Центральной Азии: тектонофизические закономерности локализации в структуре и геодинамике литосферы. Часть 1. Главные геодинамические факторы локализации сильных землетрясений в структуре литосферы Центральной Азии

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Аннотация: Изучение пространственно-временной локализации сильных (M≥8) землетрясений Центральной Азии – актуальная современная задача. Над ее решением в течение многих лет работают группы специалистов ряда стран. Принятый авторами подход требует изменения парадигмы о связи очагов землетрясений с очень прочным составом пород. На этот тезис опираются практически все известные физические модели очагов землетрясений. В статье изложен новый подход к пониманию сейсмического процесса, при котором генерируются сильные землетрясения. Он базируется на акцентировании специфики геодинамики части региона, в которой зафиксированы сильные землетрясения двух последних столетий.

Локализация землетрясений с M≥8 за последние два столетия показывает их приуроченность к областям динамического влияния крупных глубинных разломов только западной части Центральной Азии. Наличие четкой субмеридиональной структурной границы, проходящей примерно по 95–105° в.д. и разделяющей континентальную Азию на западную и восточную части, предопределяет локализацию сильных событий в западной части. Их энергетическим источником является давление с юга Индостанской плиты. Это факт, не подлежащий сомнению. Важную роль в локализации сильных событий в относительно небольшой по площади центральной части Центральной Азии играют окружающие территории. Установлены специфические геодинамические параметры, отличающие регион от сопредельных территорий с севера, востока и запада, к которым относятся следующие. 1. Толщина земной коры в два раза больше. 2. Большая ранговая раздробленность блоковых структур с тенденцией к превалированию линзовидных обтекаемых форм, вытянутых в субширотном направлении. 3. Активные разломы, ограничивающие крупные блоковые структуры, характеризуются существенными сдвиговыми скоростями, достигающими максимальных значений в центральном части Тибетского плато. Севернее скорости постепенно снижаются до минимальных значений. 4. Рекуррентное время сильных землетрясений в целом для территории западной части Центральной Азии составляет около 25 лет. Численно оно совпадает с периодической активизацией сейсмического процесса, которая происходит в Азии примерно с таким же временн***ы***м интервалом; рекуррентное время для сильных событий в зоне влияния одного разлома составляет 100–250 лет и более. 5. Механизмы очагов всех сильных землетрясений содержат сдвиговую компоненту, чаще всего сочетающуюся с компонентой сжатия. Она корреспондирует со смещениями по разломам, установленными геологическими методами, то есть с движениями масс горных пород в околоразломной среде. 6. Современные данные по движениям земной коры методом GPS-геодезии показывают их векторную направленность в СВ направлении в Тибете, севернее направление меняется на субширотное, а на границе ~105°в.д. и южнее 30° с.ш. векторы приобретают ЮВ направление; южнее 20° с.ш., в области выступа на восток Гималайского надвига, векторы вновь приобретают субширотное направление. Высокие скорости современных движений характерны для Тибета. 7. Встречные векторы, связанные с тихоокеанской зоной субдукции, характеризуются северо-западным направлением. Равнодействующая северо-восточных и северо-западных векторов способствует правостороннему сдвижению горных масс в субмеридиональной пограничной зоне. 8. Геодинамические зоны, окружающие центральную зону с локализацией сильных землетрясений, характеризуются несравненно более низкой геодинамической активностью. Они способствуют накоплению напряжений сжатия в центральной геодинамической зоне, в которой происходит переход пород в квазипластическое состояние и даже течение. Это обстоятельство принципиально выделяет регион локализации сильных землетрясений из окружающего пространства.

Структурная позиция современных сильных землетрясений континентальной Центральной Азии ограничивается: (1) территориальным вычленением только западной части названной территории; (2) увеличенной мощностью коры в ней; (3) сильным субмеридиональным сжатием коры и верхней части литосферы в сочетании со сдвиговыми напряжениями; (4) высокими скоростями современных движений земной коры и (5) ее реологическими характеристиками.

Ключевые слова: сейсмичность; сильное землетрясение; очаг землетрясения; магнитуда; механизм очага; разлом; толщина земной коры; движение земной коры; рекуррентное время; блок; амплитуда смещения; реология

1. INTRODUCTION

Problems of determining locations of earthquakes in space and time and earthquake forecasting are among top priorities in the modern studies of seismicity. Actually, much effort has been already invested to study the seismic process as an integral part of the recent geodynamics, and many of its aspects are known. All the identified seismic belts and seismic zones of the Earth have been mapped, and the maps show a variety of details of the areas wherein the earthquakes were recorded. Concepts of relations between specific geodynamic settings and the occurrence of earthquakes have been proposed. Fault-block tectonics, detailed characteristics of crustal movements, stresses and other parameters that are specific of the active tectonics (mainly, of the Holocene) have been described. Seismic zoning maps are available for many regions; theoretical problems of the seismic process, seismic regimes and migration of seismicity have been studied; earthquake mechanisms have been described; and over 200 indicators/precursors that are useful for earthquake forecasting have been revealed. Nonetheless, in view of a broad range of seismic safety issues, prediction of times and locations of seismic events is still a major challenge. The great Tohoku earthquake (11 March 2011, Japan) is another reminder of the fact that the current earthquake prediction system remains deficient and has many shortcomings. A post factum approach is most typical – after an earthquake took place, its causes and some precursors suggesting its location and timing are typically revealed by the analysis of the past seismic events. Out of more than 200 known precursors of earthquakes, none ever occur jointly. Besides, it is quite often discovered that that precursors recorded prior to an earthquake were be unambiguously interpreted and thus not properly taken into account. Obviously, problems with interpreting the precursors are due to the fact that the preparation and occurrence of an earthquake in nature are complicated processes. The higher is the earthquake magnitude, the more complex is the history prior to the earthquake occurrence, and the more factors are integrated in the natural setting before such an earthquake. In-depth analyses of strong earthquakes that occur rarely are hindered by the very fact of their rarity. An earthquake focus or a hypocentre of an earthquake is a major manifestation in a seismic zone. Foci of strong earthquakes as rare events should be studied in detail, and precursors and potential triggering mechanisms need to be discovered and understood.

Location and time are two indisputable characteristics of the past strong earthquakes. In terms of geology and geophysics, it can be stated that earthquakes typically occur in zones of large faults. Outside the zones of the dynamic impact of large faults, there are no records of any earthquakes with M≥5.5. An earthquake time is a parameter that is registered only post factum. Timelines of potential earthquakes can be assessed, but may not always be useful with regard to a broad range of seismic safety issues. There have been numerous attempts at predicting strong earthquakes on the basis of precursors with account of the leading factors preceding an earthquake, rather than the number of such factors. The majority of the attempts were unsuccessful, which is an evidence of the fact that the precursors have not been properly studied yet.

While being well aware of the fact that the seismic process is very complex, we support with the scientific certainty the concept that the majority of natural phenomena, especially those of the endogenic origin, reflect the sequential development of endogenic processses and are thus predictable. It is not always easy to distinguish a stage of the endogenic process within which an event has occurred, or determine whether a combination of additional factors or any special trigger was involved in the process when the event took place. Important factors that need to be studied in detail to understand the origin of the earthquake and its occurrence are the physical and structural status of the endogenic medium of the crust/lithosphere in the region wherein a strong earthquake took place, and trends in the development of the medium.

Based on the above concepts, the authors have analysed strong earthquakes (M≥8) registered in Central Asia, the largest continental territory of the Earth, in terms of the first main obvious criteria, including locations (at active faults and in areas of the dynamic influence of the faults), conditions of short-term activation, thickness, state of stresses, and vector mobility of the crust. The analysed earthquake data set covers the period from 1900 to 2014. The objective of our study is in compliance with the tectonophysical concept of the seismic process [*Sherman*, *2014*] and does not contradict the ideas on the block/fault-block structure of the basement in seismic zones discussed in many publications, including those by colleagues from China. Central Asia provides abundant opportunities for such studies – strong earthquakes in the continental lithosphere of Central Asia are well recorded, and earthquake prediction is among the priority social problems in this region. In our study, Central Asia includes the seismic zone of the Pribaikalie, seismic zones of Mongolia and the continental China.

2. Geodynamics of the crust and lithosphere in Central Asia

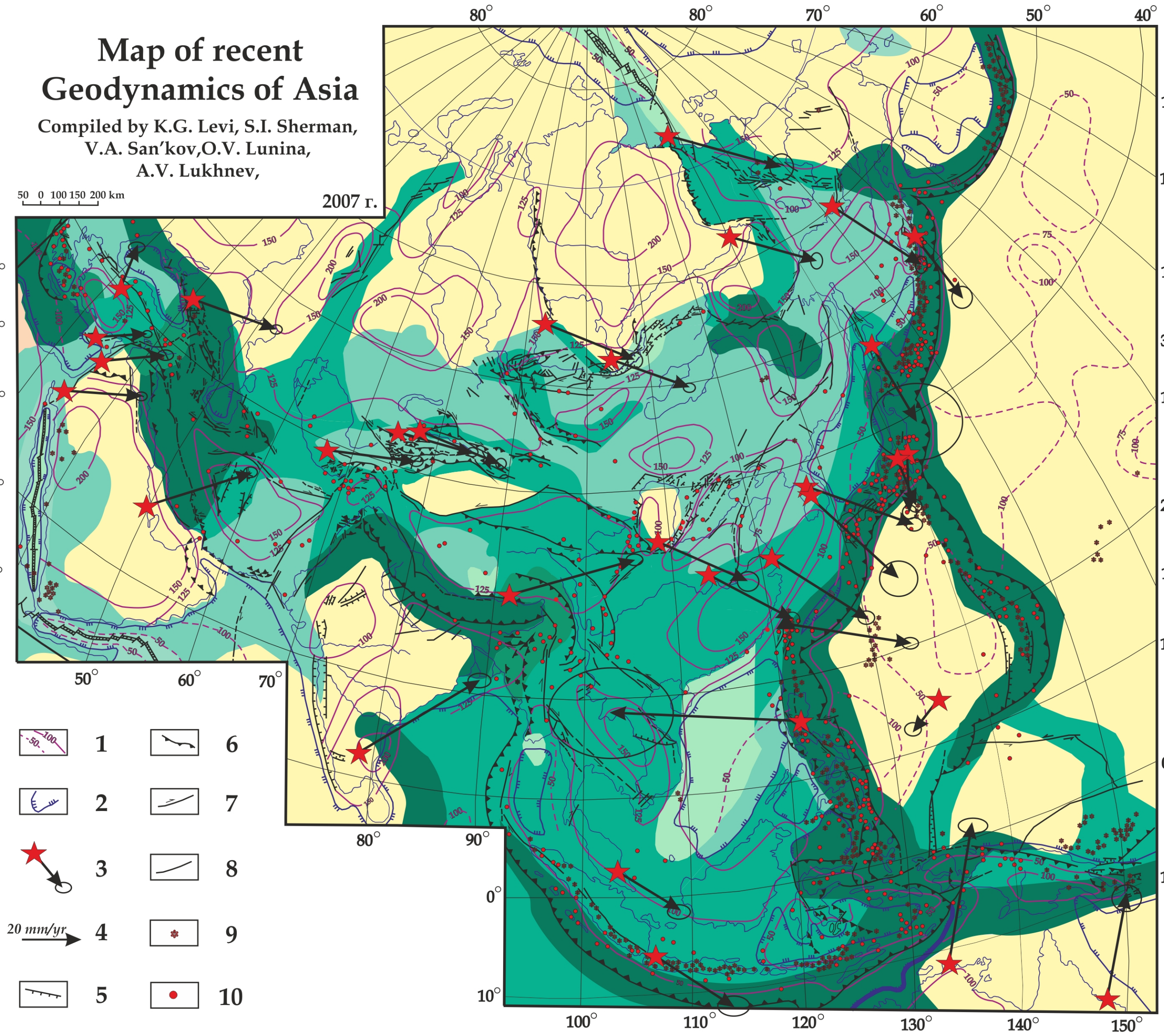
Central Asia is the main component of the transregional Alpine-Himalayan (Mediterranean-Transasian) sublatitudinal seismic belt stretching from the European Alps across the Carpathians, Caucasus, Tien Shan, Pamirs and Himalayas. It is the largest global intra-continental seismic belt (see Fig. 1 in [*Sherman, Zlogodukhova*, *2011*]). In Central Asia, the belt is expanded, and near the boundary at 85–90°E in the sublatitudinal direction in Altai region, which changes to the north-eastern direction in Pribaikalie, it has a narrow branch, the Baikal seismic zone that is locally extended along the Stanovoy zone to the Pacific coast. The main branch of the belt, that is weakly manifested from the Pamirs, goes to the east across the territory of China and joint the West Pacific seismic belt that is genetically related to the subduction zone.

Geological, structural, geomorphological, geophysical and other criteria of the studied territory are highly variable. Actually, seismicity is one the most clearly manifested criteria of the recent activity of Central Asia. Based this criterion, two segments are clearly distinguished to comprise the western and eastern regions. The boundary zone between the two segments is narrow in the Pribaikalie at ~105°E and gradually widens southwards to the Burma mountains (i.e. the western Himalayas) to become almost 500 km wide. The boundary separates the western edge comprising an independent structure of the Birma mountains with active ongoing subduction and the seismic focal plane that is steeply dipping underneath the Southern China plate [*Komarov et al., 1978; Ma Xingyuan et al.,1987; Ma Xingyuan, 1990; Grachev et al., 1993; Trifonov, 1983, 1999; Burtman, 2012a, 2012b; Gatinsky, Rundquist, 2004; Gatinsky et al., 2005a, 2005b, 2011; Sherman, 1978, 2014; Kuchai, Bushenkova, 2009; Kuchai, Kozina, 2015*; etc.]. However, variations in the recent seismic process and other geological and geophysical characteristics, such as earthquake intensity, distribution of strong earthquakes, recent crustal movements etc., are only a reflection of geodynamics factors predetermining the major manifestations of seismicity, i.e. strong earthquakes. In this respect, main parameters of the lithosphere structure are briefly reviewed below with a focus on the parameters that predetermine the occurrence of strong seismic events. The review is based on the commonly accepted scheme of the occurrence of seismicity in the mobile fault-block structure of the basement.

Foci of large earthquakes occur in faults separating the blocks when such blocks are displaced [*Sadovsky et al., 1987; Sadovsky, Pisarenko, 1991; Sobolev, 1993, 2011; Sobolev, Ponomarev, 2003; Goldin, 2004; Gol'din et al., 2003, 2004; Kocharyan, Spivak, 2003; Trifonov, Karakhanyan, 2004; Gatinsky et al., 2008; Kuzmin, 2002, 2004; Kuzmin, Zhukov, 2004; Sherman, 2014*; etc.]. Blocks may be displaced due to a variety of causes, primarily endogenic ones. Below we provide a detailed overview of the recent geodynamic activity in the studied region.

In Central Asia, seismic activity is high, the state of stresses is complex (see Fig. 1 in [*Sherman, Zlogodukhova*, *2011*]), the crust thickness is variable, crustal movements and other geological and geophysical parameters of the crust are diverse [*Trifonov*, *1999*; *Burtman, 1990, 2012a; Makarov, 1977; Grachev et al., 1993*; etc.]. The available data are consolidated in the map of the recent geodynamics of Asia (Fig. 1) [*Levi et al., 2005, 2009*] which is based on a number of general and specific geodynamic parameters. The map shows that the lithosphere thickness is slightly variable across the mapped territory. The lithosphere top is near the ground surface in the Baikal and Shansi rift systems. A more detailed scheme of the lithosphere thickness of the Mongolia-Siberian mountainous region and neighbouring territories is given in [*Zorin et al*., *1989*], and it does not show any significant variations of the lithosphere thickness in this region.

It should be noted that the most recent studiesprovided new data on variations in the lithosphere thickness and relations between the lithosphere thickness and strong earthquakes in Central Asia [*Gatinsky et al*., *2009*]. The lithosphere is 200 km thick in Southern Kazakhstan and the Tarim massif; the thickness decreases to 80–90 km in Tien Shan located between the above-mentioned regions [*Bao et al*., *2011*]. From East Tibet to the Sichuan basin, the thickness changes from 100–120 km to 130–170 km [*Hu et al*., *2012*]. Moreover, the boundary between Tibet and the southeastern China is distinguished by both the thickness and properties of the lithosphere. In Tibet, the lithosphere is layered and contains semi-plastic layers [*Gatinsky et al*., *2009*] as shown by electric sounding and geological survey data [*Burtman*, *2012a*], while in the south-



Types of the state of stress of the lithosphere and relationship between vertical σ_z, maximum σ_x and minimum σ_y of horizontal stresses

Exstension areas, $\sigma_z > \sigma_x > \sigma_y$	*Extension with strike-slip areas,* $\sigma_z = \sigma_x >> \sigma_y$	*Strike-slip areas,* $\sigma_x > \sigma_z > \sigma_y$	*Compression with strike-slip areas,* $\sigma_x >> \sigma_y = \sigma_z$	*Compression areas,* $\sigma_x > \sigma_y > \sigma_z$	*Areas with tectonically neutral state of stress,* $\sigma_z > \sigma_x = \sigma_y$

Fig. 1. The map of recent geodynamics of Asia [*Levi et al., 2009*].

Structure of the lithosphere: *1* – lithosphere thickness isolines, km; *2* – boundaries between oceanic lithosphere and continental lithosphere. Movements, active faults, seismicity and volcanism: *3* – vectors of recent horizontal block movement velocities with confidence ellipses (by GPS data); *4* – scale of recent horizontal movement velocities; *5* – normal faults; *6* – reverse faults and thrusts; *7* – strike-slip faults; *8* – faults of undetermined kinematics; *9* – active volcanoes; *10* – epicenters of earthquakes with M≥6.

Рис. 1. Карта современной геодинамики Азии [*Levi et al., 2009*].

Структура литосферы: *1* – изолинии толщины литосферы, км; *2* – границы между океанской и континентальной литосферой. Движения, активные разломы, сейсмичность и вулканизм: *3* – векторы скоростей современных горизонтальных движений литосферных блоков с эллипсами ошибок (по данным GPS); *4* – масштаб векторов скоростей современных горизонтальных движений; *5* – сбросы; *6* – взбросы и надвиги; *7* – сдвиги; *8* – разломы с неустановленным типом смещений; *9* – действующие вулканы; *10* – эпицентры землетрясений M≥6.

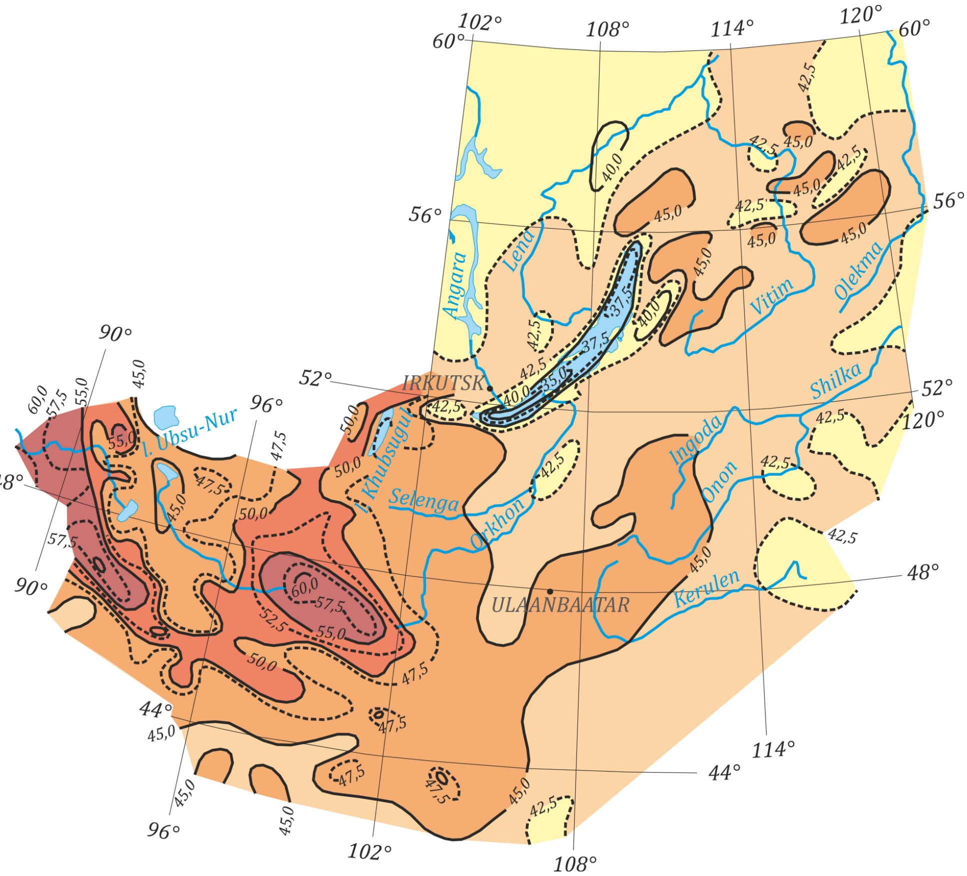


Fig. 2. Thickness of the crust in the Mongolia-Siberia mountain region. In this scheme, isolines are spaced by 5 km (amended from [*Zorin et al., 1990*]).

Рис. 2. Схема толщины земной коры Монголо-Сибирской горной страны. Сплошные изолинии проведены через 5 км (по [*Zorin et al., 1990*], с изменениями).

western China, the lithosphere is cold and rigid [*Gatinsky et al., 2009*].

The boundary at ~105°Eis clearly noted in many studies of the crustalthickness variations.

The map showing thickness of the crust is available in [*Zorin et al., 1990*] for the territory of Pribaikalie and Mongolia, i.e. the northern regions of the territory in our study (Fig. 2). The distance between isolines is 50km. The map shows that the thinner crust segment (up to 35 km thick) stretches in the Baikal rift zone from the southern termination of Lake Baikal further to the south in the meridional direction and at 106–107°E goes across Mongolia to the border with China. A thicker segment of the crust (up to 57 km) is located in the Altai-Gobi zone.

Variations of the crust thickness are considerably different in the territory southward of Gobi. In the map in [*Li et al., 2006*] (Fig. 3),the two areas differ in strikes of isopachs and crust thickness values. In the eastern area, the strike of local structures is submeridional, and the crust thickness varies from 30 to 42 km. Only at the south termination of this area (i.e. at the edge of the Himalayan thrust and the Burma mountains), the strike of the structures changes to latitudinal, and the crust thickness is up to 32 km. In the western area, the crust thickness varies in the sublatitudinal direction from 70+ to 40 km. According to the map, the crust thickness gradually decreases from the south to the north. The thickness of the crust has maximum values (over 70 km) at the Tibetan Plateau and minimum values (around 44 km or less) at the Tarim block. The crust thickness variation gradients reflect the zones of dynamic influence of deep faults that predetermine subhorizontally striking forms of the block divisibility of the crust and lithosphere, as well as locations of strong earthquakes in the regions wherein the crust thickness is more than 45 km. A meridional zone that is clearly distinguishable in the map [*Li et al., 2006*] is the boundary between the western and eastern areas of the territory of Central Asia. Its width is variable. Values of the crust thickness in this zone are persistent, about 42–44 km. In the north, a similar boundary zone can be observed in the map in [*Zorin et al., 1990*]. In the south, it is blocked by the sublatitudinal thinning of the

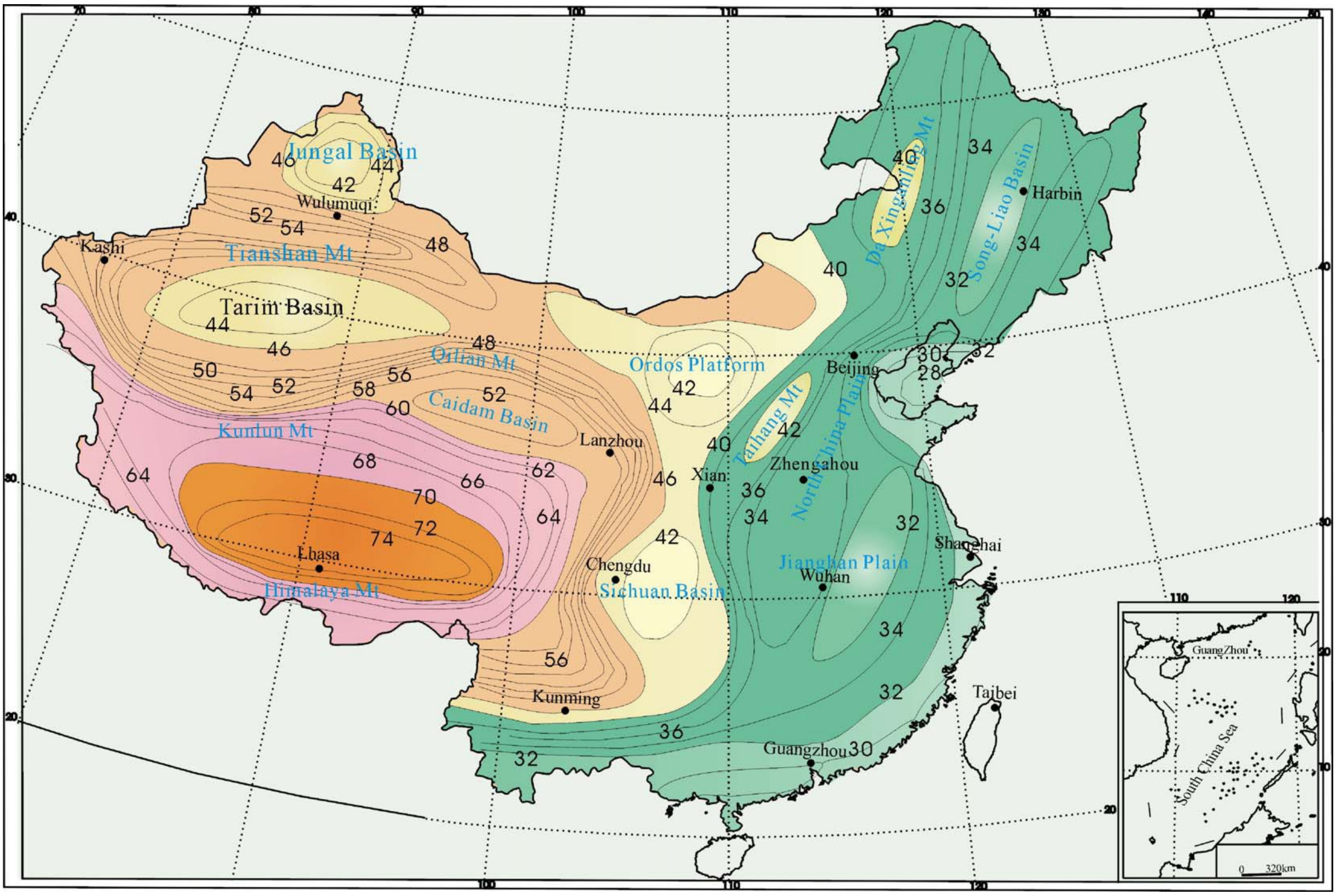


Fig. 3. Contour map of crustal thickness obtained from profile data (contour interval is 2 km).

Crustal thickness ranges from 28 to 46 km in the eastern China, and from 42 to 74 in the western China. The margins of the Tibetan plateau are marked by a steep gradient in crustal thickness [*Li et al., 2006*].

Рис. 3. Схема толщины земной коры, построенная по профилям, изопахиты проведены через 2 км.

Толщина коры изменяется от 28 до 46 км в Восточном Китае и от 42 до 74 км в Западном Китае. Граница Тибетского плато выделяется крутым градиентом толщины земной коры [*Li et al., 2006*].

crust. According to the intensity of isopachs (gapped by 2 km), the western boundary of the meridional marginal area seems to be steeply dipping westwards, while the eastern boundary is gently dipping eastwards. It is noteworthy that the submeridional boundary identified by variations of the crust thickness is reflected in the fault-block structure of Central Asia as shown the atlas of the territory of China and neighbouring countries in [*Ma Xingyuan et al., 1987*] and in the map in [*Ma Xingyuan, 1990*].

Tomographic data published by the Russian and Chinese scientists show that the submeridional boundary is also traceable at the deeper horizons.

In [*Yanovskaya, Kozhevnikov, 2003*; *Kozhevnikov et al., 2014*], 3D models of S-wave velocities in Central Asia are proposed for depths from 50 to 700 m. The two above-mentioned publications cover a significant part of the Asian continent between 25° and 65°N and 80° and 155°E. At depths of 50 km between 25° and 45°N (at the north, up to the southern termination of Lake Baikal) along the meridian at ~105°, a clear boundary is traceable between areas wherein S-waves are significantly different – the velocities are low in the western area, and high in the eastern area (Fig. 4). An average S-wave velocity is 4.46 km/sec. The low velocities refer to the thick, and relatively strongly disturbed crust under the Pamirs. The Southern China block is located eastward of this boundary. Its bottom seems to be located at a depth of about 100 km as the relevant profile shows a low-velocity mantle underneath the block at this depth. Quite an opposite setting is revealed for a depth of 300 km – from 25°N to 55°N and also along ~105°E there is a continuous boundary between the low-velocity mantle in the east and the

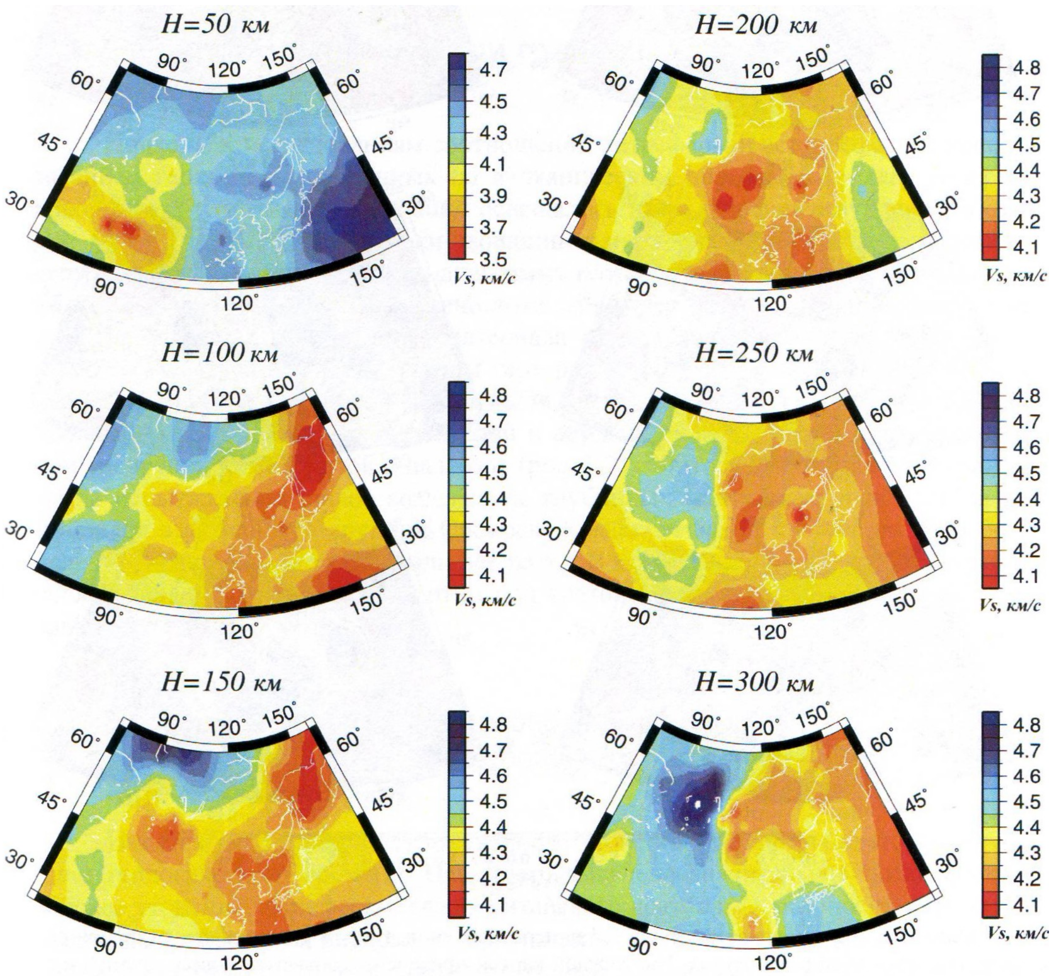


Fig. 4. Maps of variations of transverse wave velocities [*Kozhevnikov et al.*, *2014*].

Numbers at isolines show percentage values of variations of transverse wave velocities. Under each map, a corresponding depth and an average velocity is shown ($V_{S\ average}$).

Рис. 4. Карты вариаций скоростей поперечных волн [*Kozhevnikov et al.*, *2014*].

Цифры у изолиний – вариации скоростей поперечных волн в процентах. Над каждой картой приведены соответствующие глубины и средняя скорость ($V_{S\ ср.}$).

high-velocity mantle in the west. The boundary is partially traceable at a depth of 250 km between 35°и 60°N [*Kozhevnikov et al.*, *2014*]. At depths of 400 and 600 km, the setting is more complicated. At the depth of 400 km, the boundary is traceable along 105°E. The ratio of variations in S-wave velocities ($dV_s/V_{s\ average}$, %) is higher in the western area than in the eastern [*Yanovskaya, Kozhevnikov*, *2003*]. Other profiles show less unambiguous settings.

Based on the interpretation of the deep seismic profiles, there are grounds to distinguish between the two areas in Central Asia which are significantly different in terms of recent seismic activity and separated by the transregional meridional boundary that is manifested by differences in the physical fields. The transregional boundary may penetrate to a depth of around 600 km.

According to the map in Fig. 9 in [*Priestley, McKenzie*, *2006*], this boundary is located in the segment between 25 and ~40°N along the meridian at ~106–108°E. It reflects a 100-km difference between depths of the lithosphere in the eastern and western areas (~180 km and ~280 km, respectively). In nature, this is the region of the boundary between the Tibet and the Southern China block.

In [*Priestley et al.*, *2006*], the scheme of East Asia shows the lithosphere thickness and earthquake epicentres (M≥5). It is obvious from the above-mentioned scheme that the earthquakes are generally associated with the relatively thick lithosphere of the Tibet, Pamir and Tien Shan, as well as to the transitional-thickness lithosphere of the Gobi-Altai zone (*S.Sh.* – the recent lithosphere destruction zone) of the NW strike, linear zones of the NE strike in Pribaikalie and the latitudinal zone of the Stanovoy ridge. It can be concluded that earthquakes tend to occur in relatively thick segments of the lithosphere, and earthquake magnitudes of correlate with the lithosphere thickness values and the state of stresses (in the above-mentioned case, stresses of compression or shear) in the lithosphere [*Sherman, Zlogodukhova*, *2011*].

Fault-block structures and faults in the lithosphere can be viewed as geological objects that directly control epi- and hypocentral fields of earthquakes.

3. Active deep faults and fault-block structures as objects of the direct structural control over strong earthquakes

The notion of 'active fault' is broad in terms of genetic criteria of factors that trigger activation. It is also broad, considering the duration of the active process, which depends on triggers'/excitation sources [*Sherman et al., 2005*]. For the purpose of analysis of relationships between the seismic process and faults, it is reasonable to consider that a fault is active in the recent geodynamic stage if earthquake foci were registered in the zone of its dynamic influence [*Sherman et al.*, *1983*] within the past 100 years. This criterion is important for the short-term period when earthquake foci are registered by instrumental methods. In studies of fault activation, the research method using the software [*Sherman et al., 2005*; *Sherman*, *2014*] allows a researcher to reduce an interval to one year and process fault databases in order to identify individual faults in fault sets and conclude that such faults manifested short-term activation in specified years. When studying the seismic process in a group of faults in any territory, it is possible to identify faults that were activated many times and those not involved in the seismic process for many years.

In our study, the above-mentioned method providing for the assessment of short-term activation of large seismically active faults [*Sherman et al., 2005*; *Sherman*, *2014*] is applied to analyse strong earthquakes. For the purposes of our study, a fault is considered active if earthquakes of M≥8 were recorded in the zone of its dynamic influence in the specified time interval. Data on active faults with seismic events of M≥8 are selected from the earthquake catalogue published in China and kindly provided by Acad. Ma Jin who consolidated the data in Table 1. With reference to the short-term activation criterion (Fig. 5), the faults are classified into two groups: (1) recently activated faults (with earthquake foci in the period from 1900 to 2014), and (2) faults of more ancient activation (with earthquake foci in the period from 1800 to 1900). The latter group also includes the largest historical earthquakes known for the studied area. In the studied territory of Central Asia within the specified period (from 1900), the activation of large inter-block faults has been observed only within the western region of Central Asia. Earthquakes of M≥8 did not take place anywhere in the eastern regions in the past 100 years. Moreover, cases of two seismic events of equal magnitudes were very rare in the zones of dynamics influence of large faults. An exceptionally rare phenomenon is repeated activation of the same large faults and the stimulation of the occurrence of strong earthquake foci in the zones of dynamics influence of large faults with the interval of less than 100 years. Therefore, the genetic origin of activation of large faults in the lithosphere, which can stimulate seismic events with M≥8, is related to one or several geologo-geophysical criteria that rarely occur during the process of the recent geodynamic development of the territory.

In the publication on long-term seismicity and strong earthquakes in the eastern regions in the Mediterranean [*Trifonov, Karakhanyan*, *2004*], E.R. Sen'ko and colleagues distinguish between three stages of seismic activation which last for 200÷300 years with the recurrence period of 1300-1700 years. Within each stage, there are two periods of peak activity. The stages and activity peaks differ in the size of involved territories. In the summary of results of seismic activity studies in the central part of the Alpine-Himalayan collisional belt, V.G. Trifonov and A.S. Karakhanyan (p. 201) [*2004*] emphasise that “activation period of 200÷250 years are typical of some zones, and such periods correspond to seismic cycles defined by S.A. Fedotov”. Our conclusions on the studied territory of central Asia are in agreement with the ideas of the above-mentioned authors, though admit shorter periods of seismic activation of the faults in case of control over earthquakes of maximum magnitudes. This may be related to a specific position of the studied territory of Central Asia which is described below.

As shown in Fig. 5, block structures are bordered by large active faults that were activated recently and subject to ancient short-term activations. The inter-block boundaries are controlled by faults that occurred in the Paleozoic; seismic events with M≥8 took place in the zones of dynamic influence of the faults. The blocks of the Tibetan Plateau, Tarin, Altai-Sayan and smaller block structures are identified in the western regions. The interplate boundary, i.e. the western margin of the huge Amur plate, is located at ~105°E. In the western regions, the blocks have irregular shapes, and most of them are lense-shaped and elongated in the sublatitudinal directions.

In the eastern regions, the blocks are rectangular and often isometric. The South China, Ordoss, North China, East China, Mongolia and Tranbaikalia blocks are distinguished in the eastern regions [*Zhang et al.*, *2003*; *Sherman, Levi*, *1978*].

Table 1. **Strong earthquakes of Central Asia, according to historical data and recent records (1900 to 2014) (compiled by Ma Jin after [*Song Zhiping et al., 2011; China…, 2015*])**

Таблица 1. **Сильные землетрясения Центральной Азии за историческое и современное (1900–2014 гг.) время (составлено Ма Цзинь по данным [*Song Zhiping et al., 2011; China…, 2015*])**

Year	Month	Day	Latitude	Longitude	Magnitude
1303	9	25	36.3	111.7	8
1411	10	8	30.1	90.5	8
1505	6	6	29.5	83	8.2
1556	2	2	34.5	109.7	8.25
1654	7	21	34.3	105.5	8
1668	7	25	34.8	118.5	8.5
1669	6	4	33.4	73.3	8
1679	9	2	40	117	8
1725	2	1	56.5	118.5	8.2
1739	1	3	38.8	106.5	8
1761	12	9	50	90	8.3
1803	9	1	31	79	8.1
1812	3	8	43.7	83.5	8
1833	8	26	28.3	85.5	8
1833	9	6	25	103	8
1879	7	1	33.2	104.7	8
1889	7	11	43.2	78.7	8.3
1897	6	12	26	91	8.7
1902	8	22	39.9	76.2	8.25
1905	7	9	49	99	8.4
1905	7	23	49	98	8.4
1920	12	16	36.7	104.9	8.5
1927	5	22	37.7	102.2	8
1931	8	10	47.1	89.8	8
1934	1	15	26.5	86.5	8.1
1935	5	30	28.894	66.176	8.1
1950	8	15	28.5	96.5	8.6
1951	11	18	31.1	91.4	8
1957	12	4	45.153	99.206	8.1
2001	11	14	35.918	90.543	8.1
2008	5	12	30.95	103.4	8

It is noteworthy that when Academician Ma Xingyuan analysed the geodynamics of the lithosphere in China [*Ma Xingyuan*, *1990*; *Ma Xingyuan et al*., *1987*], he focused on subplates and tectonic block bordered by active faults or graben zones. In the territory of China and the neighbouring regions, he distinguished eight active subplates and 18 tectonic blocks. The Tibet plate was viewed as an active subplate of the low integrity, i.e. relatively low quasi viscosity of the medium. The highly intensive seismicity to depths more than 120 km suggest that the crust is highly disturbed and very mobile, and its quasi viscosity is low, which predetermine the recent seismicity of various magnitudes in a wide range of depths. The maximum number of the recent strong earthquakes took place at the large faults that border the Tibetan Plateau and at its inter-block large faults.

In [*Gatinsky et al*., *2009*] the same ides is highlighted with account of the most recent data, and it is concluded that, generally, boundaries of the blocks are seismically active, earthquake epicentres tend to occur in narrow zones between the blocks, and such zones are typically 50–100 km wide. In view of lengths of the faults separating the blocks, the width of 50–100 km refers to areas of dynamic influence of the faults [*Sherman et al., 1983*]. According to [*Gatinsky et al.*, *2009*], in the inter-block zones, rocks are strongly crushed and the accumulated seismic energy is high, and seismic hazard in such zones is thus high. Hypocentres occur at depths of 20–40 km in the inter-block zones in Tibet. Earthquake foci at depths from 80 to 240+ km are recorded rarely in areas southward and westward of Tiber, in the region neighbouring Himalayas, at Hindukuch, Pamir, and Birma mountains.

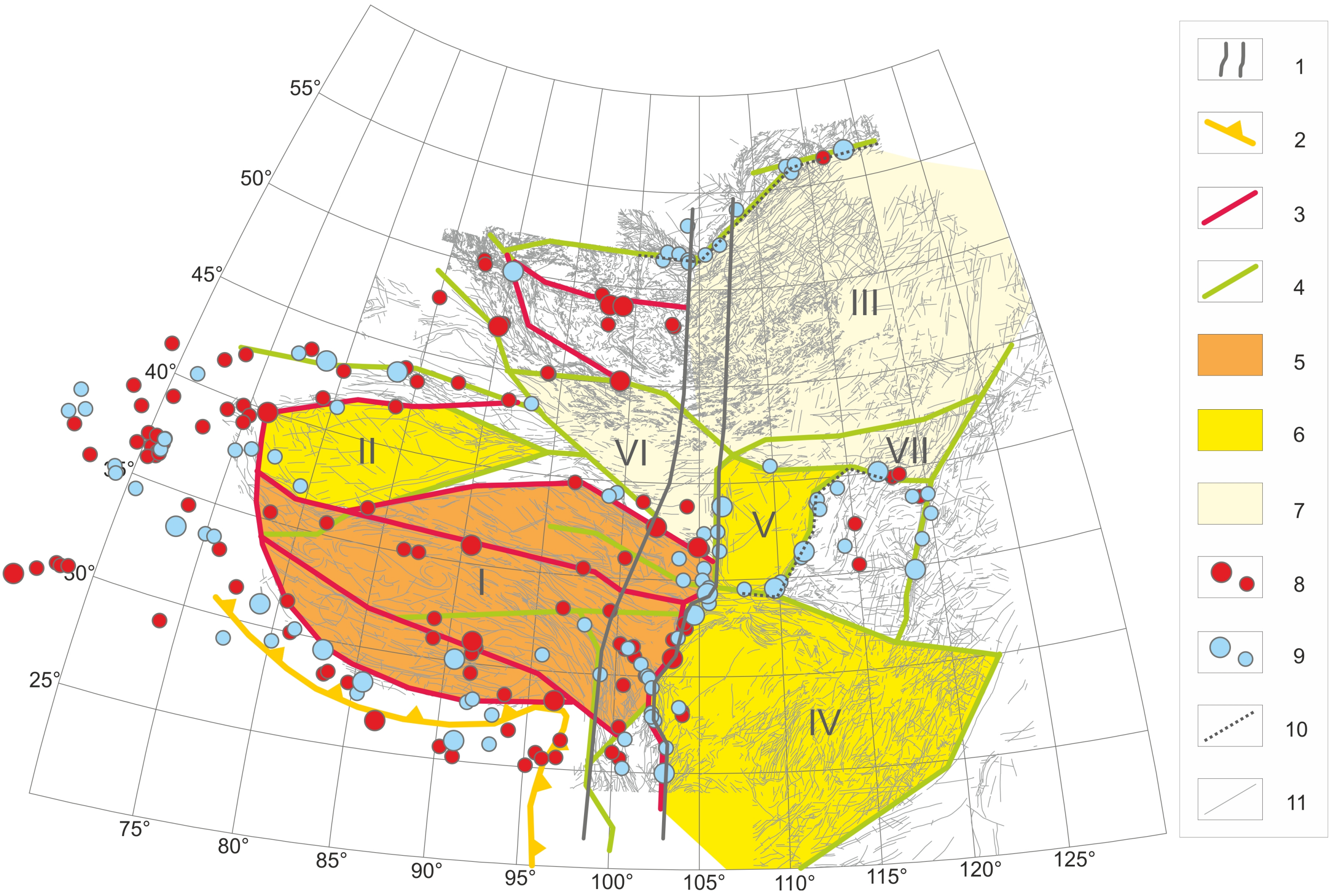


Fig. 5. Map of active major (deep) faults and blocks of Central Asia which control recent strong earthquakes and historic seismic events (M≥8 and 8>M≥7).

1 – global transregional boundary structure separating the areas of recent high (western regions) and medium (eastern regions) seismic activity (VEBIRS zone [*Komarov et al.*, 1978]); *2* – Himalayan thrust; *3* – active major faults (earthquakes M≥8 which occurred after 1900 in zones of dynamic influence of these faults); *4* – active faults (earthquakes 8>M≥7 are in zones of their dynamic influence); *5* – uplifted block (thicker lithosphere); *6* – active blocks (35–40 km thick lithosphere); *7* – blocks of low, scattered seismic activity; *8* – earthquakes M≥8 and 8>M≥7, respectively, which occurred in the period from 1900 to 2014; *9* – earthquakes M≥8 and 8>M≥7, respectively, which occurred in the period from 1800 to 1900; *10* – axes of local crust extension zones (Baikal and Fen Wei rift systems); *11* – local faults. I – Tibet; II – Tarim block; III – western segment of the Amur plate; IV – South China block; V – Ordoss block; VI – Gobi block; VII – North China block.

Рис. 5. Карта активных генеральных (глубинных) разломов и блоков Центральной Азии, контролирующих сильные современные и исторические землетрясения с M≥8 и 8>M≥7.

1 – глобальная трансрегиональная пограничная структура, разделяющая области высокой (западная часть) и средней (восточная часть) современной сейсмической активности (зона ВЕБИРС [*Komarov et al., 1978*]); *2* – Гималайский надвиг; *3* – активные генеральные разломы, в границы динамического влияния которых входят сейсмические события, контролирующие землетрясения с M≥8, произошедшие после 1900 г.; *4* – активные разломы, в области динамического влияния которых включены сейсмические события с 8>M≥7; *5* – высокоподнятый блок с утолщенной литосферой; *6* – активные блоки с толщиной литосферы 35–40 км; *7* – слабоактивные блоки с рассеянной сейсмичностью; *8* – землетрясения с магнитудами M≥8 и 8>M≥7, соответственно произошедшие в последнее столетие (1900–2014 г.); *9* – землетрясения с магнитудами M≥8 и 8>M≥7, соответственно произошедшие в предшествующее столетие (1800–1900 г.); *10* – оси зон с локальным растяжением земной коры (рифтовые системы Байкальская и Фэн-Вей); *11* – локальные разломы. Римскими цифрами обозначены: I – Тибет; II – Таримский блок; III – западная часть Амурского блока; IV – Южно-Китайский блок; V – Ордосский блок; VI – Гобийский блок; VII – Северо-Китайский блок.

A sharp increase of the seismic energy release in the inter-block fault zonesis closely related to mobility of the blocks and variations in the lithosphere thickness. The conclusions by Yu.G. Gatinsky and his colleagues are very important – our attention is focused on three conditions charactering locations of strong earthquakes: (1) block structure of the crust; (2) thicker crust, (3) high mobility of the crustal blocks.

The conclusions concerning mobility of the blocks and their impact on seismic potentials of generated earthquakes are based on calculations by the abovementioned authors under the concept of seismic intensity inside transit zones (S.Sh. – areas of dynamic influence of faults separating the blocks). The block tectonics, active faults and seismicity, horizontal slip vectors measured from space geodesy data on the Central Asian transit zone are analyzed in [*Gatinsky et al., 2005b, Gatinsky et al., 2008, Gatinsky, Prokhorova, 2014*], and it is established that the quantity of seismic energy reduces with a distance inland from the collisional suture between Indostand and Eurasia. It is noted that the energy dissipation correlates with reducing values of moduli of horizontal slip rates. The high mobility of the blocks is thus associated with the horizontal displacement vector, which is the major component of mobility and potential seismicity of the rocks.

A more detailed division of the territory of China into blocks of various ranks is described in [*Wang et al*., *2011*]. They distinguish 26 blocks of different sizes and estimate Euler rotation poles and clockwise/counterclockwise angles of block rotation. They believe that both shear/slip displacements of blocks along the faults bordering such blocks and rotation of the block structures are possible. For the purpose of our paper, we specially note slip rates along the main faults in the studied territory, especially those which zones of dynamic influence contain foci of strong earthquakes. The large faults are reasonably termed as 'seismic belts' (Fig. 6), and average rates of slip along such faults are calculated (Table 2). It is revealed that average slip rates and magnitudes of the strong earthquakes do not correlate with each other.This means that the well-known dependence between slip rates, faults lengths and earthquake magnitudes [*Anderson et al*., *1996*] is not applicable to systems of shear faults which are integrated into local seismic belts. Conclusions stated in [*Wang et al*., *2011*] support our opinion that the majority of the strong earthquakes in the continental lithosphere are associated with the systems of shear faults or large individual shear faults.

The intensity of block divisibility is variable as evidenced by average sizes of the blocks and dominant forms of the blocks located westwards and eastwards of the submeridional marginal zones. The Tarim, South China and Tibetan Plateau blocks as well as other local block structures are significantly different in this respect. The Tibetan Plateau is the largest geomorphologically manifested upland that can be viewed as a specific subplate that is separated from the Tarim block by Altyn Tagh, Qilian и Haiyuan faults. The Tibetan Plateau is composed of smaller blocks and more fractured at the southern and south-western margins, i.e. in the zone of its junction with the Himalayan thrust. The high intensity of 'crushing' in the Tibetan Plateau is correlated with the high thickness of the crust in this region and a specific sequence of thrusting of the large blocks over each other [*Burtman*, *2012a*].

Lense-shaped and latitudinally elongated structures are dominant in the western regions of Central Asia, while isometric and mainly four-sided forms are prevailing in the eastern regions.

In our study, the block structures of the lithosphere are classified into recently kinematically active/mobile blocks and passive blocks. This classification is based on the occurrence of strong earthquakes in time. At the recent stage of development, the Tibet block is considered as the most active one. It is intensely crushed and, in terms of geomorphology, represented by the Tibet upland. It contains three sublatitudinally oriented blocks separated by faults that control one/two recent earthquakes with M≥8. The Tarim and Orodoss blocks are smaller in size; they are also active and mobile. The activity of the Tarim and Orodoss blocks is determined by kinematic slip along seismically active faults (with dominant earthquakes of 8≥M≥7) which border these blocks.

The South China, North-east China and Transbaikalia (i.e. Amur block which western segment includes North-East Mongolia and Transbaikalie, Russia) blocks are relatively passive and characterized by scattered weak seismicity.

The faults and zones of dynamic influence of faults can be classified by activity with respect to locations of strong earthquakes (M≥8 and 8>M≥6.9) which took place in the period from 1900 to 2015 and in the past (see Fig. 5 and 6).

This method allows us to identify active major faults and take areas of dynamic influence of such faults (marked by thick red lines) into account in the analysis of seismicity. Local seismic belts with the higher recent activity (including those with earthquakes of M≥8 which took place after 1900) are located within the limit of the zones of dynamic influence of faults: 8 – South Tien Shan; 6 and 3 – Kunlun; 5 – Haiyuan-Qilian; 2 – Karakorum; 1 – Himalayan; 15–16 – Meridional (Anninghe-Xiaojiang and MinShan-Longmen Shan) seismic belts.

The second objective is to identify active major fault and areas of dynamic influence of such faults (see Fig. 5 and 6), within the limits of which there are highly active local seismic belts that control seismic events with 8≥M≥7 and rare earthquakes of M≥8 which took place

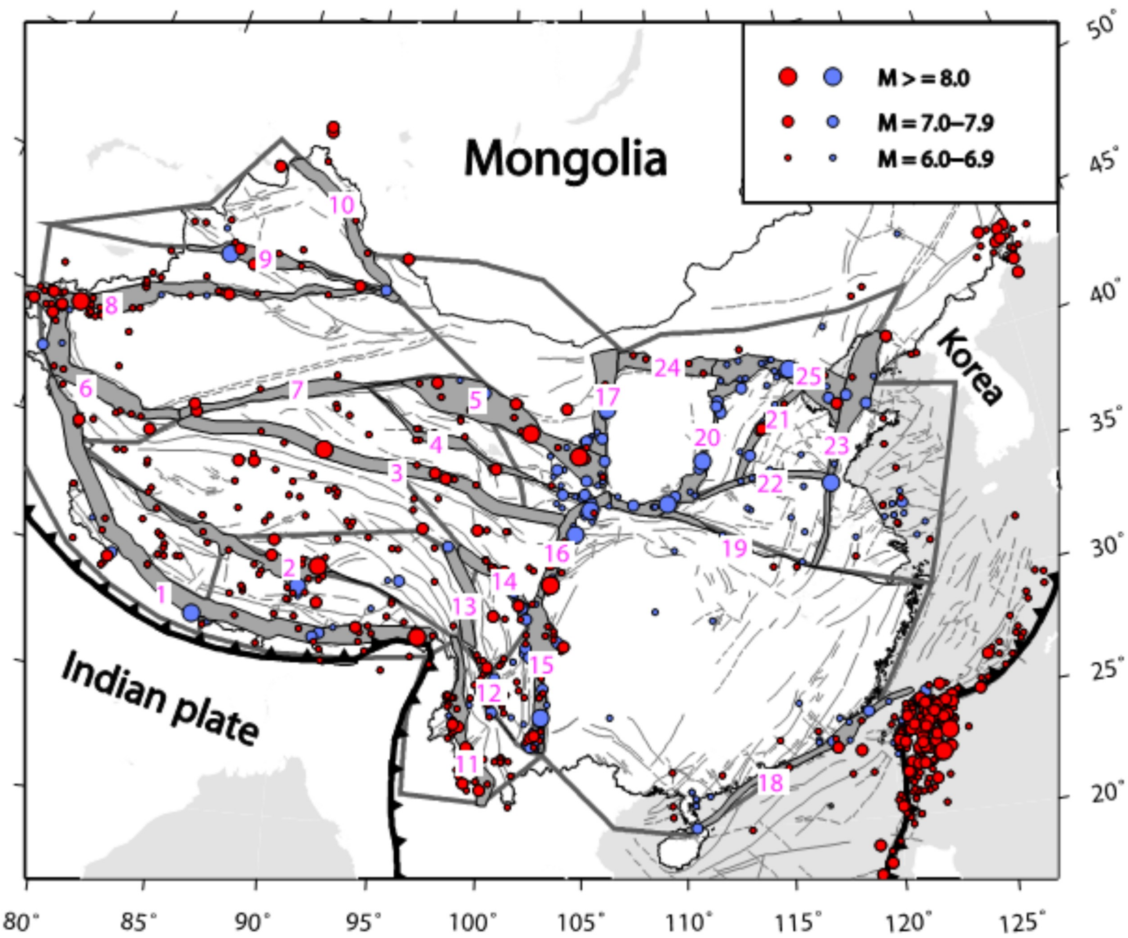


Fig. 6. Major seismic belts in mainland China.

Blue dots indicate epicenters of historic earthquakes before 1900; red dots indicate earthquakes during 1900–2010 (mostly instrumental records). Number shows the seismic belts listed in Table 2 [*Wang et al., 2011*].

Рис. 6. Основные сейсмические пояса континентального Китая.

Голубыми точками обозначены землетрясения по историческим данным до 1900 г.; красными точками показаны землетрясения за период 1900–2010 гг. (большинство из которых были зарегистрированы инструментальными методами). Цифра соответствует номеру сейсмического пояса в таблице 2 [*Wang et al., 2011*].

before 1900: 9 – North Tien Shan; 3 – North Kunlun; 12–13 – Red River and Sanjiang; 24–25 – Yan Shan-Bohai; 23 – Tanlu; 4–19 – West Qinling-QinlingDabie; 10 – Altai; 17 – West Ordoss; 20 – East Ordoss seismic belts.

The active faults and the areas of dynamic influence of such faults control the local seismic belts which are highly active in the past 200 years. No catastrophic events (M≥8) were recorded in the eastern regions of the studied territory wherein seismicity is associated with faults bordering the Ordoss block.

Thus, a general scheme of the fault-block tectonics is now available. It shows locations of the strong earthquakes that occurred in the past 200 years and a few earlier seismic events. Below we discuss the mechanisms of strong earthquake foci in close relation to the fault-block tectonics.

4. Mechanisms of strong earthquake foci

An earthquake focal mechanism reflects an 'instantaneous' release of stresses in a focal area of an earthquake and its surrounding area. The mechanism may suggest potential directions of displacements of wings of seismically active faults.

Record of 31 strong earthquakes (M≥8) are available for the studied territory. A detailed analysis of parameters of mechanisms of crustal and deep-foci earthquakes in [*Kuchai, Bushenkova*, *2009*] coversregions in Central Asia, including Tien Shan, Tarim, Tibet, Pamir-Karakorum, Kunlun, Altai and Sayan mountains. Data on earthquakes in Pribaikalie and Mongolia are analysed in [*Melnikova, Radziminovich*, *2007*].

Earthquakes with foci at depths of 200-300 km are typical of the southern areas in Central Asia (Pamir and

Table 2. **Seismic belts of Central Asia, which are controlled by areas of dynamic influence of large faults [*Sherman et al., 1983*], and mean slip rates (an incomplete list from [*Wang et al., 2011*])**

Таблица 2. **Сейсмические пояса Центральной Азии, контролируемые областями динамического влияния крупных разломов [*Sherman et al., 1983*], и средние скорости смещений в них ([*Wang et al., 2011*] с сокращениями)**

№ [a]	Seismic belt	Slip rate [b] (mm/yr)
1	Himalayan	15.6 ± 3.3
2	Karakorum-Jiali	12.9 ± 3.3
3	East Kunlun	11.2 ± 1.8
4	West Qinling-Delingha	3.7 ± 1.8
5	Haiyuan-Qilian	8.2 ± 1.3
6	West Kunlun	9.7 ± 2.1
7	Altyn Tagh	8.3 ± 1.7
8	South Tian Shan	5.3 ± 1.1
9	North Tian Shan	2.9 ± 1.3
10	Altai	8.0 ± 1.1
11	Lancang River	10.0 ± 1.8
12	Red River	8.2 ± 1.3
13	Sanjiang	1.6 ± 1.7
14	Xianshuihe	18.1 ± 1.3
15	Anninghe-Xiaojiang	12.7 ± 0.9
16	Min Shan-Longmen Shan	2.8 ± 0.8
17	Yinchuan graben	3.0 ± 0.7
18	Southeast China coastal zone	4.9 ± 0.6
19	Qinling-Dabie	1.5 ± 0.6
20	Fenhe-Weihe	1.2 ± 0.6
21	Hebei Plain	0.5 ± 0.7
22	Anyang-Heze-Linyi	0.4 ± 0.9
23	Tanlu	0.9 ± 0.8
24	Yin Shan	0.9 ± 0.7
25	Yan Shan-Bohai	1.5 ± 0.7

Note. a – numbers of seismic belts correspond to those in Fig 6; b – slip rates are mean values for the seismic belts.

Примечание. a – цифры у названия пояса соответствуют номерам на рис. 7; b – скорости смещений отражают среднее значение для сейсмического пояса.

Hindukush). In the area of the edge of the Indostan plate (Burmamountains), earthquake foci may occur at depths of 160 km. These two seismic zones are gradually sinking in the westward direction. The strongest seismic events took place in the Hindukush at depths of 80–120 and 180–230 km, and maximum depths were recorded in the narrow area between 70–71°E and 35.5–36.5°N [*Kuchai, Bushenkova*, *2009*]. By depths, focal mechanisms are distinguished as follows: thrust, shear and normal-shear types are typical of depths from 80 to 150 km, and the thrust type is typical only of depths from 180 to 260 km. The distribution of focal mechanisms is different at the edge of the Indostan plate – shear and normal-shear slip dominate at depths from 45 to 110 km, thrusting (!) is noted in the eastern part of the edge (S.Sh. – this important concussion is stated by O.A. Kuchai and N.I. Bushenkova). The thrust-type mechanism at depths exceeding 110 km is also observed in the northern area of the Burmamountains [*Kuchai, Bushenkova*, *2009*].

Additional arguments in support of the above-mentioned data are presented in [*Kuchai, Kozina*, *2015*]. With the reference to the focal mechanisms, we have calculated vectors of seismotectonic deformation of the crust volumes in the geographic system of coordinates and revealed specific features of vectors of shortening and extension of the crust volumes in Central Asia (Fig. 7). In the western regions of Central Asia, the crust volumes are mainly subject to shortening in the meridional direction and extension in the latitudinal direction, while the SE part (i.e. Amur plate) is subject to extension in the meridional direction and shortening in the latitudinal direction. Shortening zones are typical of the areas near the Himalayan thrust zone. Maximum vertical movements are typical of the entire Tibet uplift and reflect tension combined with sublatitudinal movements. Compression of the crust volumes is recorded in the zone of the submeridional margin.

In [*Gatinsky, Prokhorova*, *2015*], based on analyses of CMT2015 data, it is concluded that compression is dominant at depths from 10 to 250 km in the Southern Pamir, right-lateral shear dominates at depth from 28 to 56 km in the Northern Pamir, thrusting takes place northward in the Southern Tien Shan at the boundary

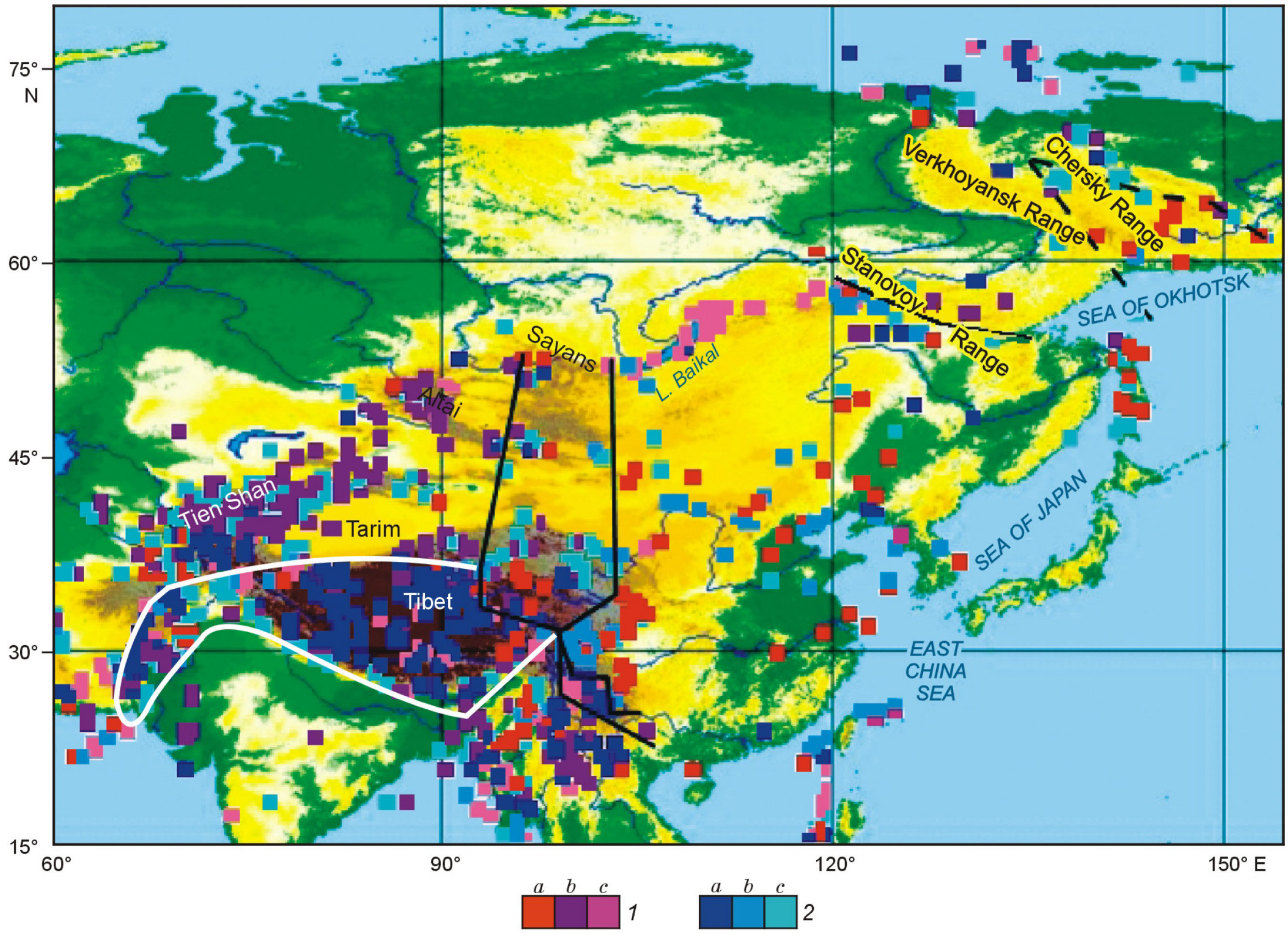


Fig. 7. The map of maximum magnitudes of one of the three linear components of the seismotectonic strain tensor in the geographical coordinates [*Kuchai, Kozina, 2015*].

Maximum negative magnitudes are marked by pink and red (1a – Exx, 1b – Eyy, 1c – Ezz); maximum positive magnitudes – light blue and dark blue (2a – Exx, 2b – Eyy, 2c – Ezz). The black line shows the regions of maximum latitudinal and vertical extension.

Рис. 7. Карта максимальных значений (по абсолютной величине) одной из трех линейных компонент тензора сейсмотектонических деформаций, полученных в географической системе координат [*Kuchai, Kozina, 2015*].

Розово-красные цвета соответствуют максимальным отрицательным значениям – сжатию (1a – Exx, 1b – Eyy, 1c – Ezz), сине-голубые цвета – максимальным положительным значениям – растяжению (2a – Exx, 2b – Eyy, 2c – Ezz). Черной линией оконтурены области максимального широтного и вертикального удлинения.

with the Tarim massif at depth from 7 to 14 km; besides, left-lateral shears are located in the same region at depth of 20–35 km and 50–70 km. The available magnetotelluric sounding data on Tien Shan give evidence that its lithosphere is layered [*Rybin, 2011*].

Compression with shear is dominant in the West Sayan region. In Pribaikalie, the southern areas are subject to extension, and compression is recorded in the northern areas. In the Baikal rift system, extension is typical of the central part, and left-lateral shearing takes place at the flanks [*Sherman, Dneprovsky, 1989*].

The territory of Mongolia is subject to seismotectonic deformation whichvariable values are well recorded in the Gobi-Altai seismic zones.

Generally, subvertical compression and subhorizontal extension of the crust is typical of Central Asia as suggested by our analysis of the focal mechanisms and the vectors of seismotectonic deformation caused by the strong earthquakes. The NE compression replaced by the sublatitudinal compression in the east is typical of the North Tibet. The Tien Shan is subject to submeridional compression. In the Altai-Sayan and Mongolian Altai, submeridional compression is present only generally; in this territory, directions of subhorizontal compression axes vary from NW in the west to NE in the east. Left-lateral shearing and corresponding foci are recordedat the Tunka fault [*Sherman, 1977*; *Parfeevets, San'kov, 2006; Mel'nikova, Radziminovich,* *2007*]. Left-lateral components are also noted in earthquake foci in North Pribaikalie.

Figure 8 shows selected seismic events and focal mechanisms according to [*Feng et al., 2007; Gao et al., 2010*]. The map shows slip vectors of wings of the large faults and focal mechanisms of the earthquakes of various magnitudes. All the large deep faults strike sublatitudinally and have a shear component; the left-lateral shear/slip dominates in the northern area, while the right-lateral shear/slip is dominant in the southern area. The left-lateral shear/slip is typical of the Gobi-Altai fault in Mongolia and the Main Sayan fault in the East Sayan region. Below we discuss data on several faults that control seismic events with M≥8 and a few one with M~7.

At the latitudinal Khangai fault in Mongolia, two strong seismic events took place, Bolnai (July 1905, M=8.2) and Mogod (January 1964, M=7.8) earthquakes. The latter was recorded at the eastern termination of the fault, in its submeridional feathering structures. According to [*Gao et al., 2010; Atlas…, 2013*], the Khangai fault is characterized by left-lateral slip with an average rate of 2.6 mm per year. The focal mechanism of the Bolnai earthquake is shearing, and that of the Mogod earthquake is right-lateral shearing andslip (among the two, the slip component is most important).

The western dichotomic termination of the Khangai fault is limited by the NW termination of the Gobi-Altai fault system, and a complex junction zone comprising the NW, NNE and latitudinal fault zones is formed. In the western part of the Gobi-Altai fault system, inside the area of its dynamic influence, the Chuya (Altai) earthquake took place in September 2003 (coordinates of the epicentre: – 50°08′N, 87°48′E), M=7.5 with a hypocentre at a depth of about 15 km. According to [*Gol'din et al.*, *2004*], the focal mechanism was shear. It should be noted that the Chuya earthquake (M≈6) occurred in the same region in 1923, but any detail description of this event is not available.

In the SE part of the Gobi-Altai fault system, the Gobi-Altai earthquake took place in 1957 (coordinates of the epicentre: 45.1°N, 99.4°E.), M=8.1 [*Florensov, Solonenko*, *1963*]. The left-lateral slip occurs at the rate of 1.2 mm per year. The focal mechanism is compression with shear.

The catastrophic Sichuan earthquake (China) of 12 May 2008 deserves special attention. It was associated with the Longman fault of the NE strike which determines the Himalayan folding of the Tibetan Plateau from the South China block. This thrust fault is among the numerous faults in the VEBRIS submeridional transregional zone. The earthquake focus was in the thrust zone combined with the right-lateral component [*Zheng et al.*, *2009*]. The earthquake magnitude is specified as M_w=8 in the data from the China Seismological Bureau, and M_w=7.9 in the catalogue of the USA Geological Survey. The earthquake hypocentre is located at a depth of about 19 km. The fact that the earthquake focus is located in the VEBRIS submeridional transregional zone and, at the same time, in the area of dynamic influence of the Himalayan thrust, predetermines its high seismic potential. The crustal movements take place in the SE directions towards the South China block and are related to compression of the crust due to the impact of the Himalayan thrust. Another opinion is described in [*Li et al.*, *2010*] – the Sychuang earthquake might have been triggered by infilling the water reservoir; obviously, infilling the water reserve increased stresses in this region. Anyway, it is more significant that the earthquake focus is associated with two fault structures, the transregional boundary between the active seismic zone and the very passive, practically aseismic zone (which reflects the state of high stresses) and the thrust (that is also characterised by high stresses). It is most probable that an important trigger was an additional pressure caused by the water column.

The Karakorum fault zone is located in the direct vicinity to the Himalayan thrust and goes almost parallel to its strike. Its area of dynamic influence controls the Karakorum seismic belt. The Karakorum earthquake (M=8) took place in November 1951, and its focus was located at a depth of about 30 km(according to USGS data, http://earthquake.usgs.gov).

More northward, there is the Kunlun fault, the largest in Central Asia, which controls the Kunlun seismic belt. The Kunlun earthquake (M_s=8.1) took place on 14 November 2001 (coordinates of the epicentre: 36.1°N, and 90.9°E).

In [*Wen et al.*, *2009*], concerning the growth of the major fault associated with the Kunlun earthquake, it is shown that its hypocentre was relatively shallow (about 15 km), and its aftershocks were scatted at depths from 10 to 35 km. The fault zone was activated minimum to the level of the specified maximum depth. When the seismic event took place, left-lateral slip was recorded with amplitudes gradually increasing from the epicentre along the fault strike in the eastward direction. The slip values ranged from about 4 m in the epicentre to 16 m at a distance of 270 km along the fault strike to the east. The above information corresponds well to the data in [*Kim, Choi*, *2007*]; this paper also provide data on maximum displacement along this seismogenic fault, which occurred kilometres away from the fault.

A specific feature of the strong Kunlun earthquake is noted by Yu.F. Kopnichev and I.N. Sokolova [*2010*] – prior to this catastrophic seismic event, within several dozens of years, epicentres of relatively weak earthquakes formed ring-shaped structures in this area. Such ring-shaped structures are marked by the relatively high absorption of S-waves in comparison with

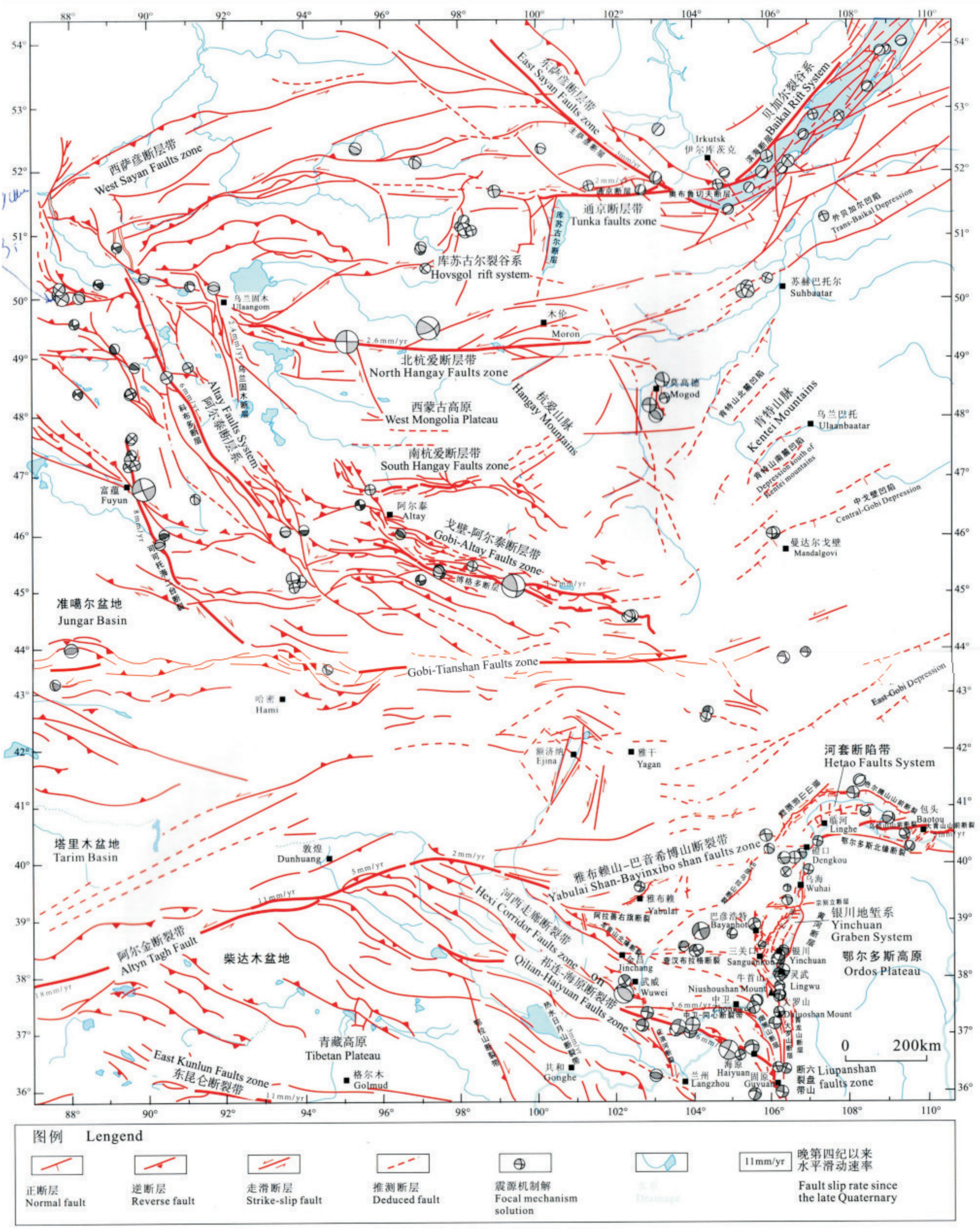


Fig. 8. Seismotectonics of the north segment of the eastern boundary of the strong earthquake domain in Central Asia (map II-12, by Huang Xiongnan, Liu Fenga, Feng Ju [*Atlas…, 2013*]).

Рис. 8. Сейсмотектоника северной части восточной границы района сильных землетрясений в Центральной Азии (карта II-12, авторы: Huang Xiongnan, Liu Fenga, Feng Ju [*Atlas…, 2013*]).

that in the areas inside the 'rings'. According to [*Kopnichev, Sokolova*, *2010*], this effect is related to the high content of free fluids in the upper mantle. It is know that the absorption of short-term transverse waves can be high if partially melted materials or fluids are present in significant amounts. In case of the Kunlun earthquake, recent volcanism is absent in the area wherein the 'seismicity rings' are located, which suggests the presence of fluids in significant amounts [*Kopnichev, Sokolova*, *2010*]. The accumulation of fluids to a certain amount might have been the trigger in this case.

The Haiyuan-Qilian deep fault and the area of its dynamic influence control the seismic belt of the same name. Two strong events took place at this fault – M_s=8 on 22 May 1927 (coordinates of the epicentre: 102.2°E and 37.7°N; focal depth depth 15 km, according to data from USGS, http://earthquake.usgs.gov), and M_s=8.5 on 16 December 1920 (36.7 N, and 104.9 E; focal depth 15 km, according to data from USGS, http://earthquake.usgs.gov). The foci were associated with the thrust segments of the SE dichotomic termination of the Altyn Tagh fault, the largest in Asia. According to [*Shen Jun et al*., *2013*], the focal mechanisms are shear-thrust with the left-lateral slip. It should be noted that the seismic event of 1920 occurred in the zone of influence of the VEBIRS submeridional structure, and its location was controlled by a specific cross-section of the faults.

At the recent stage of its development, the entire territory of Central Asia, except its northernmost segment (partially Pribaikalie), can be viewed as the area of high seismicity with typical medium- and deep-foci earthquakes that took place everywhere across the profile of the crust and, partially, lithosphere. The deep-foci earthquakes are most typical of the southern regions of the studied territory and recorded at the margin of the Indostan plate, in the Pamirs and Hindukush mountains, as well as at the eastern edge of the plate near the VEBIRS meridional boundary.

Northwards, in Mongolia and Pribaikalie, focal depth are smaller and classified as those in the crust.

The review of the state of stresses in the crust and lithosphere from the focal mechanisms gives grounds for the following conclusions: (1) The strong earthquakes tend to occur in areas wherein the crust is more than 45 km thick, and the hypocentres are recorded at depths to 190 km. (2) The focal mechanisms of all the strong earthquakes contain a shear/slip component. (3) The shear/slip component corresponds to shearing along faults revealed by geological methods, i.e. correlates with rock mass displacements in the near-fault medium.

Based on the analysis of the stress orientations in the foci of the strong earthquakes and the foci locations (especially, in the VEBIRS zone) in the territory southward of Mongolia, it is possible to reveal the deep structure of the transregional zone and suggest that it is slightly tilted and dips underneath the high mountains in Asia, and underthrusting takes place.

Below we review our general calculations of recurrence periods of the strong earthquakes.

5. Recurrence periods of the strong earthquakes

The above-mentioned meridional zone is also a boundary between some parameters that refers only to the strong earthquakes, including the number of the registered strong earthquakes. There were more recent events with M≥7 in the eastern regions than in the western regions (Table 3). In the past 100 years, all the strong seismic events in these regions were recorded. A reasonable observation is that the intensity of activation of the large deep faults that control the strong earthquakes was different in the western and eastern regions separated by the meridional zone. It can be reliably stated that the geodynamic differences of the western and eastern regions of Central Asia were the main cause predetermining the lack of strong seismic events in the eastern regions of Central Asia through the past 100 years. The strong earthquakes that took place in the eastern regions over 200 years ago are an evidence of a high seismic activity of the faults in the eastern regions, but not in the recent development stage. With account of the fact that the studied territory has been seismically active through thousands of years, it is reasonable to suggest that the above-mentioned difference between the western and eastern regions is due to deep processes and structures involved in such processes.

A similar observation concerns seismic events of 8≥M≥7 which are irregularly scattered across the studied territory. The majority of earthquakes with 8≥M≥7 occurred in the western regions. Therefore, the VEBIRS zone plays an important role in differences (as a minimum) in the manifestation of intensity of seismic events across the territory of Central Asia. In view of the above, it is challenging to precisely calculate the recurrence time. Nonetheless, we have attempted such calculations and analysis to determine, in general, the recurrence time/ periods between the strong earthquakes across the entire territory and at its large faults. At the recent development stage, each of the large deep faults shown in Fig. 6 controls one seismic event with M≥8 (Table 3). The Jiaii и Haiyuan faults located in the southern and eastern segments of the Tibetan Plateau, respectively, and the sublatitudinal Khangai fault in Mongolia may be excluded.

According to [*Trifonov, Karakhanyan*, *2004*], ancient cycles of seismic activation of different duration were manifested in the Middle and Late Holocene in the

T a b l e 3. **Historical and recent strong earthquakes: quantity distribution across the territory of Central Asia**

Т а б л и ц а 3. **Количественное распределение исторических и современных сильных землетрясений на территории Центральной Азии**

Years	Entire territory	Western regions	Eastern regions
M≥8			
1800–2008	20	20	0
1800–1899	7	7	0
1900–2008	13	13	0
8≥M≥7			
1800–2015*	147	139	8
1800–1899	28	26	2
1900–2015*	119	113	6

N o t e. * – The data as of April 2015.

П р и м е ч а н и е. * – Данные по состоянию на апрель 2015 г.

central segment of the Alpine-Himalayan collisional belt. Considering the entire region, the cycles are smoothed and reflected in seismic activity recurrence periods of 200÷300 years.

In our calculations, the recurrence time between the strong seismic events at one and the same fault is evidently more than 100 years, which generally correlates with the data in [*Trifonov, Karakhanyan*, *2004*].

For the western regions of the studied territory, calculations regardless of the locations of the seismic events in the fault zones show that the recurrence time between the earthquakes with M≥8 is 24.9 years (Table 4). With account of the 200-years monitoring period of the earthquakes with M≥8, we receive a close estimation of the recurrence time for the entire territory, 23.5 years. The recurrence time of the seismic events with 8≥M≥7 does not differ a lot for the entire territory and its western regions – the difference in only 1.2 fold. The recurrence time of the seismic events with M≥8 is by a factor of 2.1 longer than that of the events with 8≥M≥7. The above may suggest identical, but asynchronous triggers or other mechanisms that lead to the occurrence of seismic events of different strength at different times in the fault-block medium of the crust and, probably, lithosphere under the state of stresses. Calculating the recurrence time for the eastern regions is problematic. Only the general regular feature is confirmed– seismic activity is lower in the eastern regions.

Based on the above, it can be generally concluded that strong earthquakes in Central Asia take place in the inter-block seismic belts.

1. For the fault zones in the western regions of the studied territory, the recurrence time of the seismic events with M≥8 is by a factor of 2.1 longer than that of the events with 8≥M≥7. Considering seismic events in the seismic belts determined by the areas of dynamic influence of the large faults, it can be suggested that identical, but asynchronous triggers or other mechanisms lead to the occurrence of seismic events of different strength at different times in the fault-block medium of the lithosphere under the state of stresses. In further studies, it seems most reasonable to focus on the wave mechanism, as well as on the origin of movements of large rock massifs in the western regions. Besides, it is important to study the physical features of the meridional zone that goes across the significant portion of the continental Asia and to clarify its geodynamic indicators. It may be possible that one of such indicators may be a cause of the differences in the manifestation of seismic activity in the studied regions. It is obviously required to conduct additional studies of this zone in terms of geology and structure primarily in the recent geodynamic development stage.

2. The main causes of strong earthquakes at large faults in the western regions of Central Asia include the following: (a) high mobility of the blocks due to their depths and impacts of convection in the astheno-

T a b l e 4. **Recurrence time (years) between earthquakes (M≥8; 8 ≥M≥7) in Central Asia**

Т а б л и ц а 4. **Рекуррентное время (в годах) между землетрясениями M≥8 и 8 ≥M≥7 в Центральной Азии**

	Entire territory	Western regions	Eastern regions
M≥8	23.5	24.9	105.5
8≥M≥7	9.8	11.8	94.9

sphere; such impacts may explain the asynchronous activation of the blocks and rare seismic events in specific blocks; (b) impact of the strong pressure from the Himalayan transregional thrust belt.The latter causes directional quasi-plastic slip of the rock mass, compression and shearing in the large fault zones, and the strongest displacements of the fault wings (i.e. blocks) are followed by strong earthquakes.

A common criterion of the above-mentioned causes is displacements of wings of large faults due to impacts of various sources.

6. Recent movements of the Earth's surface: GPS geodesy results

Using data from the Global Positioning System (GPS) is one of the most efficient and informative techniques applied to study movements of the crust, especially when medium- and small-scale works are conducted. GPS data are used in many studies of recent geodynamics in Central Asia [*San'kov et al., 2011; Ashurkov et al., 2011; Burtman, Molnar, 1993; Calais et al., 2003; Royden, 1993; Lombardi, Marzocchi, 2007; Chéry et al., 2001*].

Based on the GPS data, recent movements of the crust were studied in short-term time intervals, and the general map of such movements in the fault zones was compiled by the scientists from China (Fig. 8). In general, the crustal movements in Central Asia tend to go from SW to NE, and the vectors are rotated eastwards and even south-eastwards and gradually 'cease'. The significant amplitudes of the movements are reduced towards the meridional boundary at ~105°E. A considerable reduction of the absolute values of the vectors is noted, which corresponds to a lower level of the recent kinematic activity of the blocks and other structures, as well as a lower rheological flow of the crust.

GPS data were used to determine vectors of crustal movement rates/velocities and to construct Map II-1 by Gao Xianglinin in [*Atlas…, 2013*] for Central Asia and the neighbouring territories (Fig. 9). High rates above 30 mm per year are typical of the Tibet; the vector is SE. The rates are reducednorthwards and change the direction. The NW and WNW vectors are typical of the Altai and Sayan regions. The vectors of all the directions are replaced by sublatitudinal ones at the submeridional boundary at ~105°E and acquire the SE direction southward of 30°N. Southward of 20°N, in the area of the Himalayan thrust edge, the vectors again acquire the sublatitudinal direction to the west. Quite characteristically, the vectors of slip rates in the neighbouring territories confirm the exceptionally high compression of the studied territory. From the south, the huge Indostan plate produces high stresses in the NNE direction towards the Tibet. The impacts of such stresses cease near 45°N and are replaced by shearing. Near 120°E, vectors of slip rates of the crust at the entire eastern boundary are neutralized by the vectors of the opposite direction which reflect the 'ceasing' forces caused by the West Pacific subduction.

More detail patterns of recent slip rates in Central Asia, Mongolia ad Pribaikalie are shown in Fig. 10 [*Gan Weijiun, Xiao Genru*, *2013*; *Niu*, *2014*]. The map clearly shows that the recent slip rates are gradually reduced from 40 mm per year in the Himalayas and Pamirs to 20 m per year in the Gobi-Altai mountain region and to lower values in Pribaikalie and the East Sayan region. The position of the transmeridional boundary of Asia is more clearly specified. This boundary hinders the propagation of deformation to the east and makes them 'rotate' to the meridional direction. It should be noted that a similar rotation can be revealed from the GPS data published in [*Li Yanxing et al*., *2001*]. The above conclusions are fully supported by slip rate values and vectors published by other authors.

The following is confirmed: (1) variability of the slip vectors of the crust in the contemporaneous period; (2) abrupt changeability of the slip rate vectors or reduction to 'extinction' from the southern regions of Asia to the north; (3) strong resistance of large blocks of the lithosphere from the east which is supported by vectors of the 'opposite' crustal movements in the NW direction. The boundary between the areas with slip vectors of the opposite directions goes along the VEBIRS submeridional zone. With reference to the variations of crust deformation, variations of the state of stresses which are revealed from the earthquake focal mechanisms and GPS data, it is reasonable to increase the width of the transregional meridional boundary up to 95°E. It is clearly observed that this zone becomes wider from the north to the south, and its control over the contemporaneous processes is also increasing.

Thus, in the past 100 years, the differentiation of the areas wherein the strong earthquakes occurred was significantly influenced by the recent velocities of displacements of the large massifs of the crust. Together with the slip along the large faults, which reflects displacements in the earthquake foci, the recent velocities of displacements predetermine the generation of strong earthquake foci.

7. Conclusion

Our analysis of the locations of M≥8 earthquakes shows that in the past two centuries such earthquakes took place in areas of the dynamic influence of large deep faults in the western regions of Central Asia. The western regions are characterized by specific parameters that are significantly different from those of the background geodynamic setting:

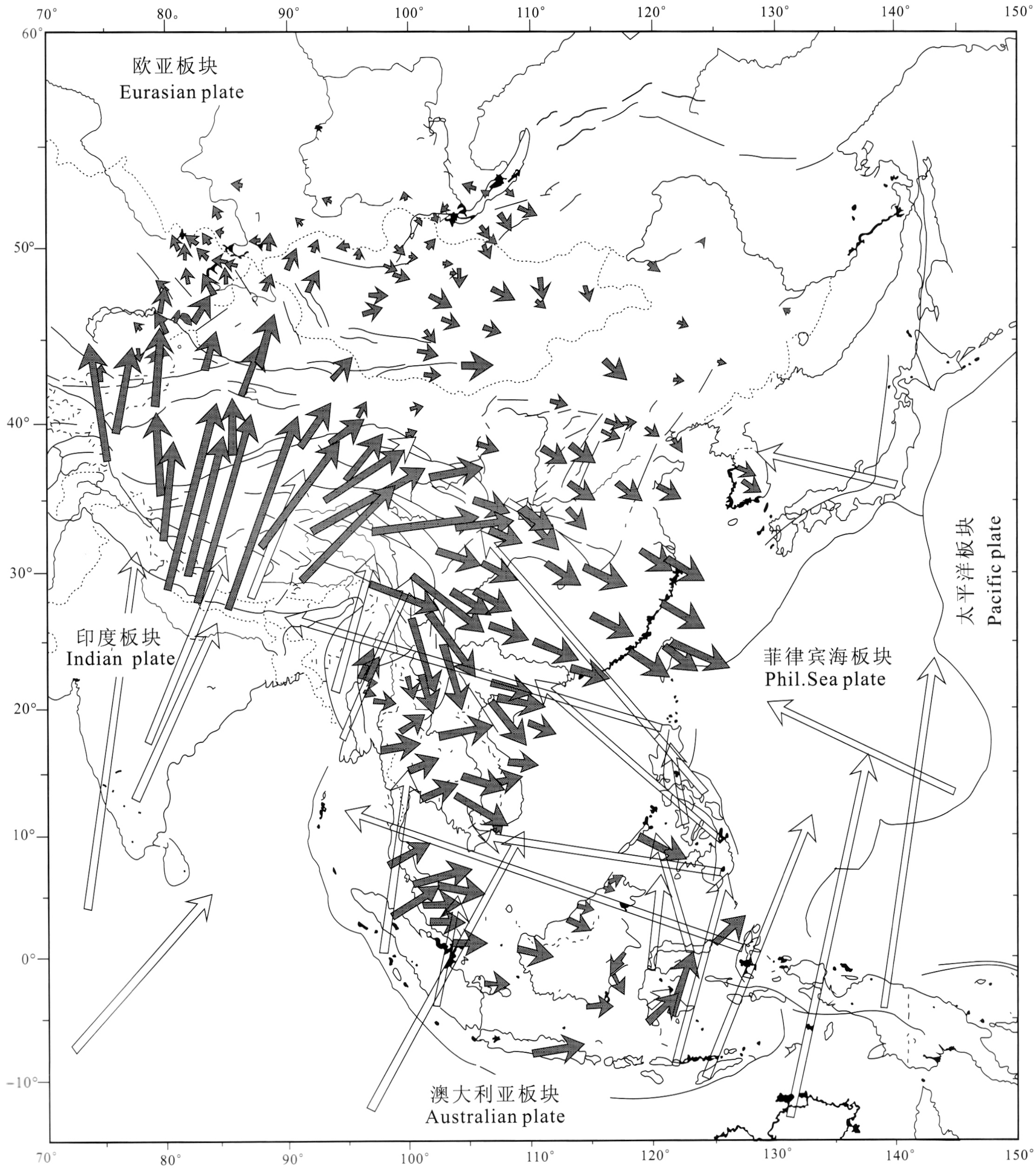


Fig. 9. Velocities of recent crustal movements in Asia and neighboring territories (map II-1, by Gao Xianglin [*Atlas…, 2013*]).

Рис. 9. Скорости современных движений земной коры Азии и окружающих территорий (карта II-1, автор: Gao Xianglin [*Atlas…, 2013*]).

1. In the continental Asia, there is a clear submeridional structural boundary (95–105°E) between the western and eastern regions which geological, structural and geophysical parameters are considerably different.

2. The crust is twice as thick in the western regions than in the eastern region (maximum 74 km to minimum 42 km versus maximum 40 km to 32 km).

3. In the western regions, the block structures resulting from the crust destruction, which are mainly represented by lense-shaped forms elongated in the submeridional direction, tend to dominate. In the

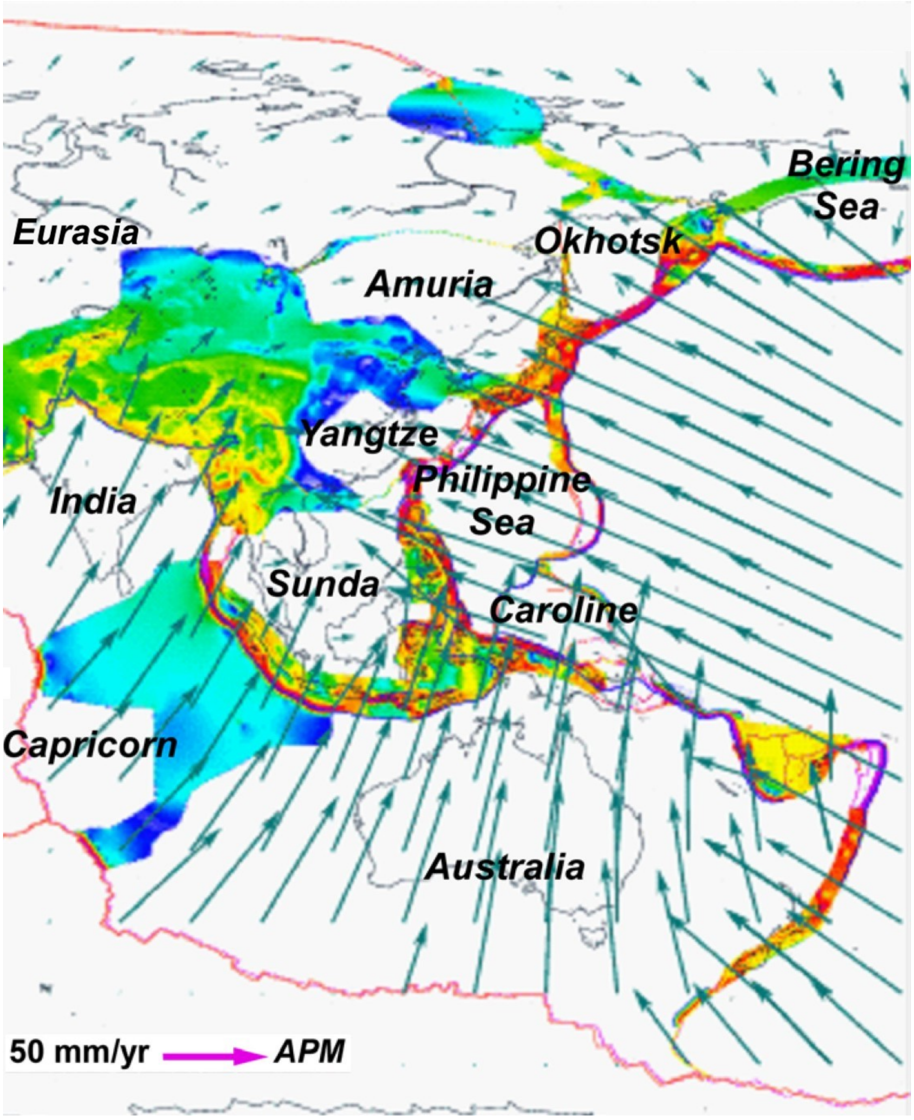


Fig. 10. Standard plate boundaries and the present-day plate motion vectors using the "sub-asthenosphere" reference frame (a partial representation from [*Niu*, *2014*]).

Рис. 10. Границы плит и векторы современных движений плит, установленные относительно «под-астеносферы» (по [*Niu*, *2014*], представлена частично).

eastern regions, large blocks (most of which are square-shaped) are dominant.

4. The large fault structures are bordered by the active faults. In the western regions, the faults separating the blocks control the earthquakes with M≥8, which were recorded from 1900 to 2014. The faults are characterized by shear/slip displacements which amplitudes increase from the south to the north and reach maximum values in the central part of the Tibetan Plateau and the Gobi-Altai fault system. Further northward, the shear/slip amplitudes decrease gradually, yet do not disappear. In many cases, shearing is right-lateral in the southern regions and left-lateral in the northern regions.

Earthquakes of M≥8 did not take place anywhere in the eastern regions of the continental Central Asia in the past 100 years.

5. Generally, in the western regions of Central Asia, the recurrence time of strong earthquakes is about 25 years. It correlates with the activation of the seismic process in Asia which is manifested in almost the same time intervals [*Trifonov, Karakhanyan, 2004; Sherman, 2014*]. Due to the lack of records, it is now impossible to determine a recurrence time of a strong earthquake controlled by a specific active fault. However, it seems to be more than 100 years, if we take into account the information collected through the monitoring period and refer to the data published in [*Trifonov, Karakhanyan, 2004*; *Wang, Zhang, 2004*].

6. Mechanisms of all the strong earthquakes contain

a slip component that is often accompanied by a compression component. The shear/slip component corresponds to shearing along faults revealed by geological methods, i.e. correlates with rock mass displacements in the near-fault medium.

Based on the analysis of the stress orientations in the foci of the strong earthquakes and the foci locations (especially, in the VEBIRS zone) in the territory southward of Mongolia, it is possible to reveal the deep structure of the transregional zone and suggest that it is slightly tilted and dips underneath the high mountains in Asia, and underthrusting takes place.

7. GPS geodetic measurements show that shearing develops in the NW direction in the Tibet. Further northward, the direction changes to the sublatitudinal one. At the boundary of ~105°E, southward of 30°N, the slip vectors attain the SE direction. Further southward of 20°N, at the eastern edge of the Himalayan thrust, the slip vectors again attain the sublatitudinal direction. High velocities/rates of recent crust movements are typical of the Tibet region.

In the eastern regions of Central Asia, vectors of movements of the lithospheric blocks are directed to the north-east and limited by the VEBIRS submeridional zone that facilitates the complete decay of the impacts of the Pacific zone of subduction to the Central Asia continent. It should be noted that in [*Ma Xingyuan, 1990*], the junction of the western and eastern regions is shown as the fault striking from the Southern Baikal (~48°N) to ~20°N, i.e. the fault structure with the right-lateral slip, which is fully correlated with the VEBIRS zone. Along with other observations, this information provides for a better understanding of the tectonic features of the large transregional zone of the Continental Asia.

The transitional territory is a marginal zone wherein the crustal thickness is about 42 km. This zone has not been the subject of special studies yet, but a variety of its definitions can be found in many publications. It is manifested by dominating submeridional faults, mainly of shear, shear with normal component, and reverse-thrust types. Three recent earthquakes with M≥8, including the Sichuan earthquake, were recorded within this zone. The reverse-thrust fault controlled the Sichuan earthquake and is the major structural reflection of the entire marginal zone.

There is no doubt that the strong earthquakes that occurred in the western regions of the Continental Central Asia in the past century, were controlled by the large active faults with the well manifested slip component, which border the longitudinally elongated lense-shaped blocks of the lithosphere and/or the crust. These faults are involved in the overall recent movements of the crust, primarily in the NE and latitudinal directions. The high vector velocitiesare limited by the submeridional transregional boundary. At the boundary, the direction of the vectors changes to the southern one, and becomes latitudinal in the southernmost area of the studied territory. The slip vectors associated with the Pacific subduction zone have the NW direction. It may be suggested that the turn of the vectors evidenced by the GPS data is related to the submeridional boundary and the NW pressure applied to the Amur plate. The resultant of the two vectors facilitates the right-lateral slip of the rock masses in the VEBIRS zone.

Thus, structural positions of recent strong earthquakes in the continental Central Asia are controlled by the following factors: (1) the western regions separated in the studied territory; (2) the larger thickness of the crust in the western regions; (3) strong submeridional compression of the crust and upper lithosphere in combination with shear stresses; (4) high rates of recent crustal movements.

In view of the above, the geodynamics of the studies territory should be reviewed with the focus on the origin of the factors predetermining locations of strong earthquakes. We continue our studies and aim at developing a model showing locations of strong earthquakes with account of all the above-mentioned factors.

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9. References

Anderson J.G., Wesnousky S.G., Stirling M.W., 1996. Earthquake size as a function of fault slip rate. *Bulletin of the Seismological Society of America* 86 (3), 683–690.

Ashurkov S.V., San'kov V.A., Miroshnichenko A.I., Lukhnev A.V., Sorokin A.P., Serov M.A., Byzov L.M., 2011. GPS geodetic constraints on the kinematics of the Amurian Plate. *Russian Geology and Geophysics* 52 (2), 239–249. http://dx.doi.org/10.1016/j.rgg.2010.12.017.

Atlas of Seismotectonics in Central Asia, 2013. Beijing, 129 p.

Bao X., Xu M., Wang L., Mi N., Yu D., Li H., 2011. Lithospheric structure of the Ordos Block and its boundary areas inferred from Rayleigh wave dispersion. *Tectonophysics* 499 (1), 132–141. http://dx.doi.org/10.1016/j.tecto.2011.01.002.

Burtman V.S., 1990. Tectonic flow processes in the Alpine belt. *Izvestiya AN SSSR. Seriya Geologicheskaya* (6), 30–39 (in Russian) [*Буртман В.С.* Процессы тектонического течения в Альпийском поясе // *Известия АН СССР. Серия геологическая*. 1990. № 6. С. 30–39].

Burtman V.S., 2012a. Geodymanics of Tibet, Tarim, and the Tien Shan in the Late Cenozoic. *Geotectonics* 46 (3), 185–211. http://dx.doi.org/10.1134/S0016852112030028.

Burtman V.S., 2012b. Tian Shan and High Asia: Geodynamics in the Cenozoic. GEOS, Moscow, 188 p. (in Russian) [*Буртман В.С.* Тянь-Шань и Высокая Азия: Геодинамика в кайнозое. М.: ГЕОС, 2012б. 188 с.].

Burtman V.S., Molnar P., 1993. Geological and geophysical evidence for deep subduction of continental crust beneath the Pamir. *Geological Society of America Special Papers*, v. 281, p. 1–76. http://dx.doi.org/10.1130/SPE281-p1.

Calais E., Vergnolle M., San'kov V., Lukhnev A., Miroshnitchenko A., Amarjargal S., Déverchère J., 2003. GPS measurements of crustal deformation in the Baikal-Mongolia area (1994–2002): Implications for current kinematics of Asia. *Journal of Geophysical Research: Solid Earth* 108 (B10), 2501. http://dx.doi.org/10.1029/2002JB002373.

Chéry J., Carretier S., Ritz J.F., 2001. Postseismic stress transfer explains time clustering of large earthquakes in Mongolia. *Earth and Planetary Science Letters* 194 (1), 277–286. http://dx.doi.org/10.1016/S0012-821X(01)00552-0.

China Earthquake Network Center, 2015. Available from: http://www.csndmc.ac.cn/newweb/index.jsp (last accessed December 4, 2015) (in Chinese).

Feng R., Ma Z., Fang J., Wu X., 2007. A developing plate boundary: Tianshan-Baikal active tectonic belt. *Earth Science Frontiers* 14 (4), 1–17. http://dx.doi.org/10.1016/S1872-5791(07)60027-X.

Florensov N.A., Solonenko V.P., 1963. The Goby-Altai Earthquake. Publishing House of the USSR Acad. Sci., Moscow, 392 p. (in Russian) [Гоби-Алтайское землетрясение / Ред. Н.А. Флоренсов, В.П. Солоненко. М.: Изд-во АН СССР, 1963. 392 с.].

Gan Weijiun, Xiao Genru, 2013. Present-day crustal motion GPS velocity field of Central Asia. In: Atlas of seismotectonics in Central Asia. Beijing, p. 41–43.

Gao X.-L., Ma X.-J., Li X.-L., 2010. A surrounding and deep dynamic context of the great triangle-shaped seismic region in the eastern Asia continent. *Earth Science Frontiers* 17 (4), 33–42.

Gatinsky Y.G., Prokhorova T.V., 2014. Superficial and deep structure of Central Asia as example of continental lithosphere heterogeneity. *Universal Journal of Geoscience* 2 (2), 43–52. http://dx.doi.org/10.13189/ujg.2014.020202.

Gatinsky Y.G., Prokhorova T.V., 2015. Seismic active zones in South Siberia, Russian Far East, and adjacent countries. *Russian Journal of Earth Sciences* 15 (3), ES3003. http://dx.doi.org/10.2205/2015ES000554.

Gatinsky Y.G., Prokhorova T.V., Rundquist D.V., Vladova G.L., 2009. Zones of Catastrophic Earthquakes of Central Asia: Geodynamics and Seismic Energy. *Russian Journal of Earth Sciences* 11 (1), ES1001. http://dx.doi.org/10.2205/2009ES000326.

Gatinsky Y.G., Rundquist D.V., 2004. Geodynamics of Eurasia: Plate tectonics and block tectonics. *Geotectonics* 38 (1), 1–16.

Gatinsky Y.G., Rundquist D.V., Cherkasov S.V., 2005a. Geological discontinuity at 102–103° in the Eastern Asia: geological and metallogenic indicators. In: Tectonics of the Earth's Crust and Mantle. Tectonic Regularities in the Distribution of Mineral Resources. Proceedings of the 28th Tectonic Meeting. GEOS, Moscow, p. 127–130 (in Russian) [*Гатинский Ю.Г., Рундквист Д.В., Черкасов С.В.* Гераздел 102–103° на Востоке Азии: геологические и металлогенические признаки // Тектоника земной коры и мантии. Тектонические закономерности размещения полезных ископаемых: Материалы 28-го Тектонического совещания. М.: ГЕОС, 2005. С. 127–130].

Gatinsky Y.G., Rundquist D.V., Tyupkin Y.S., 2005b. Block structures and kinematics of Eastern and Central Asia from GPS data. *Geotectonics* 39 (5), 333–348.

*Gatinsky Y.G., Rundquist D.V., Vladova G.L., Prokhorova T.V., Romanyuk T.*V., 2008. Block structure and geodynamics of the continental lithosphere at plate margins. *Bulletin of Kamchatka Regional Association"Educational-Scientific Center". Earth Sciences Series* (1), 32–47 (in Russian) [*Гатинский Ю.Г., Рундквист Д.В., Владова Г.Л., Прохорова Т.В., Романюк Т.В.* Блоковая структура и геодинамика континентальной литосферы на границах плит // *Вестник КРАУНЦ. Серия «Науки о Земле»*. 2008. № 1. С. 32–47].

Gatinsky Y.G., Vladova G.L., Prokhorova T.V., Rundquist D.V., 2011. Geodynamics of Central Asia and prediction of catastrophic earthquakes. *Prostranstvo i Vremya* (*Space and Time*) 3 (5), 124–134 (in Russian) [*Гатинский Ю.Г., Владова Г.Л., Прохорова Т.В., Рундквист Д.В.* Геодинамика Центральной Азии и прогноз катастрофических землетрясений // *Пространство и время*. 2011. Т. 3. № 5. С. 124–134].

Goldin S.V., 2004. Dilatancy, repacking, and earthquakes. *Izvestiya, Physics of the Solid Earth* 40 (10), 817–832.

Gol'din S.V., Seleznev V.S., Emanov A.F., Filina A.G., Emanov A.A., Novikov I.S., Gibsher A.S., Vysotskiy E.M., Agatova A.R., Dyadkov P.G., Fateev A.V., Kashun V.N., Podkorytova V.G., Leskova E.V., Yankaitis V.V., Yarygina M.A., 2003. The Chuya earthquake of 2003 (M=7.5). *Vestnik. Earth Sciences Division RAS* 1 (21) (in Russian) [*Гольдин С.В., Селезнёв В.С., Еманов А.Ф., Филина А.Г., Еманов А.А., Новиков И.С., Гибшер А.С., Высоцкий Е.М., Агатова А.Р., Дядьков П.Г., Фатеев А.В., Кашун В.Н., Подкорытова В.Г., Лескова Е.В., Янкайтис В.В., Ярыгина М.А.* Чуйское землетрясение 2003 года (M=7.5) // *Вестник Отделения наук о Земле РАН.* 2003. № 1 (21)].

Gol'din S.V., Seleznev V.S., Emanov A.F., Filina A.G., Emanov A.A., Novikov I.S., Vysotskii E.M., Fateev A.V., Kolesnikov Yu.I., Podkorytova V.G., Leskova E.V., Yarygina M.A., 2004. The Chuya earthquake and its aftershocks. *Doklady Earth Sciences* 395 (3), 394–396.

Grachev A.F., Kalashnikova I.V., Magnitsky V.A., 1993.Contemporary and recent geodynamics and seismicity of China. *Fizika Zemli* (10), 3–13 (in Russian) [*Грачев А.Ф., Калашникова И.В., Магницкий В.А*. Современная и новейшая геодинамика и сейсмичность Китая // *Физика Земли.* 1993. № 10. С. 3–13].

Hu J., Yang H., Xu X., Wen L., Li G., 2012. Lithospheric structure and crust–mantle decoupling in the southeast edge of the Tibetan Plateau. *Gondwana Research* 22 (3–4), 1060–1067. http://dx.doi.org/10.1016/j.gr.2012.01.003.

Kim Y.-S., Choi J.-H., 2007. Fault propagation, displacement and damage zones. In: D. Ankhtsetseg, K.G. Levi, A. Schlupp, M. Ulziibat (Eds), Proceedings of the Conference commemorating the 50th anniversary of the 1957 Gobi-Altay earthquake. Ulaanbaatar, p. 81–86.

Kocharyan G.G., Spivak A.A., 2003. Deformation Dynamics of Block-Shaped Rock Massifs. Akademkniga, Moscow, 423 p. (in Russian) [*Кочарян Г.Г., Спивак А.А*. Динамика деформирования блочных массивов горных пород. М.: ИКЦ «Академкнига», 2003. 423 с.].

Komarov Yu.V., Belichenko V.G., Misharina L.A., Petrov P.A., 1978. The Verkhoyano-Birmanskaya junction zone of Central and East-Asian structures (VEBIRS zone). In: VEBIRS Trans-Asian Continental Zone. East Siberian Division of the Siberian Branch, USSR Acad. Sci., Irkutsk, p. 5–24 (in Russian) [*Комаров Ю.В., Беличенко В.Г., Мишарина Л.А., Петров П.А*. Верхояно-Бирманская зона сочленения центрально- и восточноазиатских структур (зона ВЕБИРС) // Трансазиатская континентальная зона ВЕБИРС (оперативная информация). Иркутск: Восточно-Сибирский филиал СО АН СССР, 1978. С. 5–24].

Kopnichev Y.F., Sokolova I.N., 2010. On the correlation between seismicity characteristics and S-wave attenuation in the ring structures that appear before large earthquakes. *Journal of Volcanology and Seismology* 4 (6), 396–411. http://dx.doi.org/10.1134/S0742046310060047.

Kozhevnikov V.M., Seredkina A.I., Solovei O.A., 2014. 3D mantle structure of Central Asia from Rayleigh wave group velocity dispersion. *Russian Geology and Geophysics* 55 (10), 1239–1247. http://dx.doi.org/10.1016/j.rgg.2014.09.010.

Kuchai O.A., Bushenkova N.A., 2009. Earthquake focal mechanisms in Central Asia. *Fizicheskaya Mezomekhanika* (*Physical Mesomechanics*) 12 (1), 17–24 (in Russian) [*Кучай О.А., Бушенкова Н.А.* Механизмы очагов землетрясений Центральной Азии // *Физическая мезомеханика.* 2009. Т. 12. № 1. С. 17–24].

Kuchai O.A., Kozina M.E., 2015. Regional features of seismotectonic deformations in East Asia based on earthquake focal mechanisms and their use for geodynamic zoning. *Russian Geology and Geophysics* 56 (10), 1491–1499. http://dx.doi.org/10.1016/j.rgg.2015.09.011.

Kuzmin Yu.O., 2002. Contemporary anomalous geodynamics of aseismic fault zones. *Vestnik. Earth Sciences Division RAS* 1 (20), 27 p. (in Russian) [*Кузьмин Ю.О.* Современная аномальная геодинамика асейсмичных разломных зон // *Вестник отделения наук о Земле РАН.* 2002. № 1 (20). 27 с.].

Kuzmin Yu.O., 2004. Recent Geodynamics of Fault Zones. *Izvestiya, Physics of the Solid Earth* 40 (10), 868–882.

Kuzmin Yu.O., Zhukov V.S., 2004. Recent Geodynamics and Variations of Physical Properties of Rocks. Publishing House of the Moscow State Mining University, Moscow, 262 p. (in Russian) [*Кузьмин Ю.О., Жуков В.С.* Современная геодинамика и вариации физических свойств горных пород. М.: Изд-во Московского государственного горного университета, 2004. 262 с.].

Levi K.G., Sherman S.I., San'kov V.A., 2005. Recent geodynamics of Asia. In: K.G. Levi, S.I. Sherman (Eds.), Topical issues of recent geodynamics of Central Asia. Publishing House of SB RAS, Novosibirsk, p. 253–267 (in Russian) [*Леви К.Г., Шерман С.И., Саньков В.А*. Современная геодинамика Азии // Актуальные вопросы современной геодинамики Азии / Ред. К.Г. Леви, С.И. Шерман. Новосибирск: Изд-во СО РАН, 2005. С. 253–267].

Levi K.G., Sherman S.I., San'kov V.A., 2009. Recent geodynamics of Asia: Map, principles of its compilation, and geodynamic analysis. *Geotectonics* 43 (2), 152–165. http://dx.doi.org/10.1134/S001685210902006X.

Li C.Y., Wei Z.Y., Ye J.Q., Han Y.B., Zheng W.J., 2010. Amounts and styles of coseismic deformation along the northern segment of surface rupture, of the 2008 Wenchuan Mw 7.9 earthquake, China. *Tectonophysics* 491 (1), 35–58. http://dx.doi.org/10.1016/j.tecto.2009.09.023.

Li S., Mooney W.D., Fan J., 2006. Crustal structure of mainland China from deep seismic sounding data. *Tectonophysics* 420 (1–2), 239–252. http://dx.doi.org/10.1016/j.tecto.2006.01.026.

Li Yanxing, Hu Xikang, Shui Ping, Ge Liangquan, Hudng Cheng, Zhu Wenyao, Hu Xiaogong, 2001. The current crust strain fields in the continent of China and its adjacent areas from GPS measurement results. In: Huang Cheng, Qian Zhihan (Eds), Asia-Pacific space geodynamics program: Proceedings of the fourth workshop (14–19 May, 2001). Shanghai Scientific and Technical Publishers, Shanghai, p. 113–123.

Lombardi A.M., Marzocchi W., 2007. Evidence of clustering and nonstationarity in the time distribution of large worldwide earthquakes. *Journal of Geophysical Research* 112 (B2), B02303. http://dx.doi.org/10.1029/2006JB004568.

Ma Xingyuan, 1990. Tectonic processes shown in the lithosphere dynamics map of China. In: N.A. Logachev (Ed.), Geodynamics of Intracontinental Mountainous Regions. Nauka, Novosibirsk, p. 341–351 (in Russian) [*Ма Си Юань*. Тектонические процессы, отраженные на карте динамики литосферы Китая // Геодинамика внутриконтинентальных горных областей / Ред. Н.А. Логачев. Новосибирск: Наука. СО РАН, 1990. С. 341–351].

Ma Xingyuan et al., 1987. 1:1000000 Scale Lithospheric Dynamics Map of China and Adjacent Seas and Explanatory Notes to supplement Map. Geological Publishing House, Beijing.

Makarov V.I., 1977. Recent Tectonic Structure of Central Tien Shan. Nauka, Moscow, 172 p. (in Russian) [*Макаров В.И.* Новейшая тектоническая структура Центрального Тянь-Шаня. М.: Наука, 1977. 172 с.]

Mel'nikova V.I., Radziminovich N.A., 2007. Parameters of seismotectonic deformations of the Earth's crust in the Baikal Rift Zone based on seismological data. *Doklady Earth Sciences* 416 (1), 1137–1139. http://dx.doi.org/10.1134/S1028334X07070355.

Niu Y., 2014. Geological understanding of plate tectonics: Basic concepts, illustrations, examples and new perspectives. *Global Tectonics and Metallogeny* 10 (1), 23–46. http://dx.doi.org/10.1127/gtm/2014/0009.

Parfeevets A.V., San'kov V.A., 2006. Stress State of the Earth's Crust and Geodynamics of the Southwestern Part of the Baikal Rift System. Geo Academic Publishing House, Novosibirsk, 151 p. (in Russian) [*Парфеевец А.В., Саньков В.А.* Напряженное состояние земной коры и геодинамика юго-западной части Байкальской рифтовой системы. Новосибирск: Академическое изд-во «Гео», 2006. 151 с.].

Priestley K., Debayle E., McKenzie D., Pilidou S., 2006. Upper mantle structure of eastern Asia from multimode surface waveform tomography. *Journal of Geophysical Research* 111 (B10), B10304. http://dx.doi.org/10.1029/2005JB004082.

Priestley K., McKenzie D., 2006. The thermal structure of the lithosphere from shear wave velocities. *Earth and Planetary Science Letters* 244 (1), 285–301. http://dx.doi.org/10.1016/j.epsl.2006.01.008.

Royden L.H., 1993. The tectonic expression slab pull at continental convergent boundaries. *Tectonics* 12 (2), 303–325. http://dx.doi.org/10.1029/92TC02248.

Rybin A.K., 2011. Deep Structure and Recent Geodynamics of Central Tien Shan from Magnetotelluric Sounding Results. Nauchnaya Mysl, Moscow, 272 p. (in Russian) [*Рыбин А.К.* Глубинная структура и современная геодинамика Центрального Тянь-Шаня по результатам магнитнотеллурического зондирования. М.: Научная мысль, 2011. 272 с.].

Sadovsky M.A., Bolkhovitinov L.G., Pisarenko V.F., 1987. Deformation of Geophysical Medium and Seismic Process. Nauka, Moscow, 100 p. (in Russian) [*Садовский М.А., Болховитинов Л.Г., Писаренко В.Ф.* Деформирование геофизической среды и сейсмический процесс. М.: Наука, 1987. 100 с.].

Sadovsky M.A., Pisarenko V.F., 1991. Seismic Process in Block Medium. Nauka, Moscow, 96 p. (in Russian) [*Садовский М.А., Писаренко В.Ф.* Сейсмический процесс в блоковой среде. М.: Наука, 1991. 96 с.].

San'kov V.A., Parfeevets A.V., Lukhnev A.V., Miroshnichenko A.I., Ashurkov S.V., 2011. Late Cenozoic geodynamics and mechanical coupling of crustal and upper mantle deformations in the Mongolia–Siberia mobile area. *Geotectonics* 45 (5), 378–393. http://dx.doi.org/10.1134/S0016852111050049.

Shen Jun, Bai Meixiang, Shi Guangling, 2013. Seismotectonics of the northwestern boundary of strong earthquake concentration in central Asia. In: Atlas of seismotectonics in Central Asia. Beijining, p. 70–71.

Sherman S.I., 1977. Physical Regularities of Faulting in the Earth's Crust. Nauka, Novosibirsk. Наука, 1977, 102 p. (in Russian) [*Шерман С.И.* Физические закономерности развития разломов земной коры. Новосибирск: Наука, 1977. 102 с.].

Sherman S.I., 1978. On VEBIRS meridional zone in the Asian continent and its identification criteria. In: VEBIRS Trans-Asian Continental Zone. East Siberian Division of the Siberian Branch, USSR Acad. Sci., Irkutsk, p. 31–35 (in Russian) [*Шерман С.И.* О меридиональной зоне ВЕБИРС на Азиатском континенте и критериях ее выделения // Трансазиатская континентальная зона ВЕБИРС (оперативная информация). Иркутск: Восточно-Сибирский филиал СО АН СССР, 1978. С. 31–35].

Sherman S.I., 2014. Seismic Process and the Forecast of Earthquakes: Tectonophysical Conception. Academic Publishing House "Geo", Novosibirsk, 359 p. (in Russian) [*Шерман С.И.* Сейсмический процесс и прогноз землетрясений: тектонофизическая концепция. Новосибирск: Академическое издательство «Гео», 2014. 359 с.].

Sherman S.I., Bornyakov S.A., Buddo V.Yu., 1983. Areas of Dynamic Influence of Faults (Modelling Results). Nauka, Novosibirsk, 110 p. (in Russian) [*Шерман С.И., Борняков С.А., Буддо В.Ю.* Области динамического влияния разломов (результаты моделирования). Новосибирск: Наука. СО АН СССР, 1983. 110 с.].

Sherman S.I., Dneprovsky Yu.I., 1989. Crustal Stress Fields and Geological and Structural Methods of Studies. Nauka, Novosibirsk, 157 p. (in Russian) [*Шерман С.И., Днепровский Ю.И.* Поля напряжений земной коры и геолого-структурные методы их изучения. Новосибирск: Наука, 1989. 157 с.].

Sherman S.I., Levi K.G., 1978. Transform faults of the Baikal rift zone and seismicity of its flanks. In: N.A. Logachev (Ed.), Tectonics and Seismicity of Continental Rift Zones. Nauka, Moscow, p. 7–18 (in Russian) [*Шерман С.И., Леви К.Г.* Трансформные разломы Байкальской рифтовой зоны и сейсмичность ее флангов // Тектоника и сейсмичность континентальных рифтовых зон / Ред. Н.А. Логачев. М.: Наука, 1978. С. 7–18].

Sherman S.I., Sorokin A.P., Savitskii V.A., 2005. New methods for the classification of seismoactive lithospheric faults based on the index of seismicity. *Doklady Earth Sciences* 401 (3), 413–416.

Sherman S.I., Zlogodukhova O.G., 2011. Seismic belts and zones of the Earth: formalization of notions, positions in the lithosphere, and structural control. *Geodynamics & Tectonophysics* 2 (1), 1–34 (in Russian) [*Шерман С.И., Злогодухова О.Г.* Сейсмические пояса и зоны Земли: формализация понятий, положение в литосфере и структурный контроль // *Геодинамика и тектонофизика*. 2011. Т. 2. № 1. С. 1–34]. http://dx.doi.org/10.5800/GT-2011-2-1-0031.

Sobolev G.A., 1993. Foundations of Earthquake Prediction. M.: Nauka, Moscow, 314 p. (in Russian) [*Соболев Г.А.* Основы прогноза землетрясений. М.: Наука, 1993. 314 с.].

Sobolev G.A., 2011. The Earthquake Predictability Concept Based on Seismicity Dynamics under Triggering Impact. IPERAS, Moscow, 56 p. (in Russian) [*Соболев Г.А*. Концепция предсказуемости землетрясений на основе динамики сейсмичности при триггерном воздействии. М.: ИФЗ РАН, 2011. 56 с.].

Sobolev G.A., Ponomarev V.A., 2003. Physics of Earthquakes and Precursors. Nauka, Moscow, 270 p. (in Russian) [*Соболев Г.А., Пономарев А.В.* Физика землетрясений и предвестники. М.: Наука, 2003. 270 с.].

Song Zhiping, Zhang Guoming, Liu Jie et al., 2011. Global Earthquake Catalog (9999 BC – 1963 AD, 1964 AD – 2010 AD, M≥6.0). Seismological Press, Beijing, 450 p. (in Chinese).

Trifonov V.G., 1983. Late Quaternary Tectogenesis. Nauka, Moscow, 224 p. (in Russian) [*Трифонов В.Г.* Позднечетвертичный тектогенез. М.: Наука, 1983. 224 с.].

Trifonov V.G., 1999. Neotectonics of Eurasia. Nauchny Mir, Moscow, 252 p. (in Russian) [*Трифонов В.Г.* Неотектоника Евразии. М.: Научный мир, 1999. 252 с.].

Trifonov V.G., Karakhanyan A.S., 2004. Geodynamics and History of Civilizations. Nauka, Moscow, 668 p. (in Russian) [*Трифонов В.Г., Караханян А.С.* Геодинамика и история цивилизаций. М.: Наука, 2004. 668 с.].

Wang H., Liu M., Cao J., Shen X., Zhang G., 2011. Slip rates and seismic moment deficits on major active faults in mainland China. *Journal of Geophysical Research* 116 (B2), B02405. http://dx.doi.org/10.1029/2010JB007821.

Wang S.-Z., Zhang Z.-C., 2004. Plastic-flow waves ("slow waves") and seismic activity in central-eastern Asia. *Dizhen Dizhi* 26 (1), 91–101 (in Chinese).

Wen Y.Y., Ma K.F., Song T.R.A., Mooney W.D., 2009. Validation of the rupture properties of the 2001 Kunlun, China (Ms=8.1), earthquake from seismological and geological observations. *Geophysical Journal International* 177 (2), 555–570. http://dx.doi.org/10.1111/j.1365-246X.2008.04063.x.

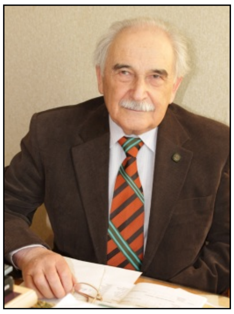
Yanovskaya T.B., Kozhevnikov V.M., 2003. 3D S-wave velocity pattern in the upper mantle beneath the continent of Asia from Rayleigh wave data. *Physics of the Earth and Planetary Interiors* 138 (3–4), 263–278. http://dx.doi.org/10.1016/S0031-9201(03)00154-7.

Zhang P., Deng Q., Zhang G., Ma J., Gan W., Min W., Mao F., Wang Q., 2003. Active tectonic blocks and strong earthquakes in the continent of China. *Science in China Series D: Earth Sciences* 46 (2), 13–24. http://dx.doi.org/10.1360/03dz0002.

Zheng Y., Ma H., Lü J., Ni S., Li Y., Wei S., 2009. Source mechanism of strong aftershocks (Ms⩾5.6) of the 2008/05/12 Wenchuan earthquake and the implication for seismotectonics. *Science in China Series D: Earth Sciences* 52 (6), 739–753. http://dx.doi.org/10.1007/s11430-009-0074-3.

Zorin Y.A., Kozhevnikov V.M., Novoselova M.R., Turutanov E.K., 1989. Thickness of the lithosphere beneath the Baikal rift zone and adjacent regions. *Tectonophysics* 168 (4), 327–337. http://dx.doi.org/10.1016/0040-1951(89)90226-6.

Zorin Yu.A., Novoselova M.R., Turutanov E.Kh., Kozhevnikov V.M., 1990. The lithosphere structure of the Mongolia-Siberian mountainous region. In: N.A. Logachev (Ed.), Geodynamics of Intracontinental Mountainous Regions. Nauka, Novosibirsk, p. 143–154. (in Russian) [*Зорин Ю.А., Новоселова М.Р., Турутанов Е.Х., Кожевников В.М.* Строение литосферы Монголо-Сибирской горной страны // Геодинамика внутриконтинентальных горных областей / Ред. Н.А. Логачев. Новосибирск: Наука. СО РАН, 1990. С. 143–154].



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