УДК 550.23 DOI: 10.21440/0536-1028-2019-1-42-51

Seismotectonics of the Urals

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Abstract

Introduction. *The earth's crust of the Urals, having experienced the epoch of geosynclinal development with active tectonic and volcano-magmatic processes in the pre-Paleozoic and Paleozoic time, in the Mesozoic-Cenozoic time experienced the epoch of platform development, which in the period of the recent tectonic activation resulted in the formation of the recent Uralian epiplatform orogen, which generated in the western part of the Uralian Paleozoic orogen destroyed by the processes of denudation. The recent Uralian orogen inherits the main features of the Paleozoic orogen structure. At the modern stage within the boundaries and in the vicinity of the recent Ural mountain belt rare sensible earthquakes with intensity from 3–4 to 5–6 on the MSK-64 scale are recorded, as well as rock bumps and natural-technogenic earthquakes at mining enterprises exploiting mineral deposits by means of underground mine workings.*

Research aims *to estimate the connection between the manifestations of recent seismicity and tectonics of different age in the Ural region.*

Research methodology *involved the estimation of sensible earthquakes position relative to the geological-tectonic structures of the contemporary, Paleozoic, and pre-Paleozoic age, as well as relative to the elements of the earth's crust recent vertical movements field morphology.*

Results. Conclusion has been made, that the earth's crust of the middle Urals is characterized by the greatest seismic activity in the area of the submeridional Ural mountain belt interference and the zone of recent submersions of the earth's surface with relatively increased velocities, having the north-western direction corresponding to the direction of the pre-Riphean basement structures.

Results application area. *The results of the given work can be of help in the course of seismic zoning of the Ural territory, as well as when planning accommodation and when designing engineering facilities within the Ural region.*

Key words: *recent orogen; mountain belt; sensible earthquakes; rock bumps; seismicity; pre-Riphean basement; seismodomen; seismic zoning.*

Introduction. The Urals earth's crust, according to [1], experienced the Late-Precambrian-Cambrian and Ordovician-Late-Paleozoic megacycles of geosynclinal development, when tectonic and volcano-magmatic processes were active in the region, having led to the generation of the Uralian orogen in the ending, in the Late Paleozoic of the Paleozoic (in the Hercynian time). The final stage of the Hercynian orogeny and the initial stage of the Uralian earth's crust platform development (Triassic-Early-Middle-Jurassic time) were characterized by the development of the rift grabens of Chelyabinsk type accompanied with the effusions of volcanites of the basic, average, and acid composition, petrochemically similar to volcanic trappean formation of the Siberian platform [1, 2]. In Mesozoic-Cenozoic time the earth's crust of the Ural region experienced the period of relatively calm platform development characterized by slow epeirogenic low-amplitude vertical crustal movements and the destruction of the Uralian orogenic belt [1] originated in the Late Paleozoic time by the processes

of denudation. In the period of the recent tectonic activation (for about the last 30 million years) in the western part of the Paleozoic (Hercynian) Uralian orogenic belt appeared the recent Uralian orogen which inherited, according to [1], the main features of the Paleozoic (Hercynian) orogen. The amplitude of deformations (the recent uplifts) of the earth's crust within the boundaries of the Uralian orogenic belt and the adjacent territories in the contemporary history is rated from 150–400 [3] to 500–700 m in the Middle Urals [1]. According to [4], the period of the recent orogeny in the Urals is rated as the one shorter, "than it has been generally believed, and it corresponds to the Pliocene-Quaternary Period", and the depth of denudation within the boundaries of the contemporary Uralian orogen "are not the hundreds of meters from the middle of the Mesozoic, but 1.5–2.0 km and more after the Eocene, at least, in the axial area of the Urals". Based on the foregoing, the average velocities of the Uralian crustal deformations during the contemporary history can be estimated as hundredths-thousandths of a millimeter per year. This degree of the Uralian crustal deformation velocities allows to consider them as low ones [5]. The recent vertical movements of the Uralian earth's surface occur with higher velocities – up to several millimeters per year [6]. At that, at the modern stage, the earth's surface of the Urals and the adjacent territories experiences general submersion relative to the level measuring points on the sea shores with the velocities from 1–4 to 6–10 mm per year *(A Map of Recent Vertical Crustal Movements According to Geodetic Data at the Territory of the USSR (RVCM). Scale 1 : 5 000 000. GUGK Publ., 1989. Edited by L. A. Kashin)*.

At the modern stage, tectonic activity of the Uralian earth's crust is low, of platform type. Sensible earthquakes with intensity from 3–4 to 5–6 on the MSK-64 scale are nevertheless recorded in the region, described in [7] as "posthumous crustal quakes being the aftereffects of the former colossal breaks", occurring in the Paleozoic and pre-Paleozoic time when the Ural earth's crust experienced geosynclinal stages of development.

The frequency of earthquakes in the Urals at the modern stage according to the data in [10] is rated as follows:

a) earthquakes with intensity 6 on the MSK-64 scale – once in 100–120 years;

b) earthquakes with intensity 5–6 and magnitude 4.0–4.5 – once in 50–60 years;

c) earthquakes with intensity 4–5 and magnitude 3.0–4.0 – once in 30–40 years; rare earthquakes of such intensity are not hazardous for engineering structures and human life.

Research aims to estimate the spatial position of epicentral zones of the recent sensible Uralian earthquakes relative to the Uralian tectonic structures of different age.

Research methodology involved the Uralian earthquakes sensible epicentral zones position comparison relative to the Uralian tectonic structures, both pre-Paleozoic, Paleozoic, and recent ones and the Uralian recent vertical crustal movements (RVCM) velocities field morphology elements.

Results. The analysis fulfilled testifies to the fact that the epicenters of the rare sensible earthquakes in the Urals are centered primarily within the boundaries of the Middle Urals and the adjacent parts of the South and North Urals and form the Middle Ural seismodomen [11]. The focuses of the earthquakes, according to [8, 9], are located in the rocks of the pre-Riphean basement at the depth of 20–25 km. According the schemes in [11], it can be concluded that the Middle Ural seismodomen is situated within the interference area of the submeridian recent Uralian orogen and the regional zone of the recent submersions of the earth's surface with the velocities of 1–4 mm per year possessing north-western direction along the approximate azimuth of 315°, which corresponds to the zone of geodynamic influence of the north-western boundary of the Russian Plate of the East European Platform (EEP). The same direction within the boundaries of the region under consideration possess the structures of the pre-Riphean

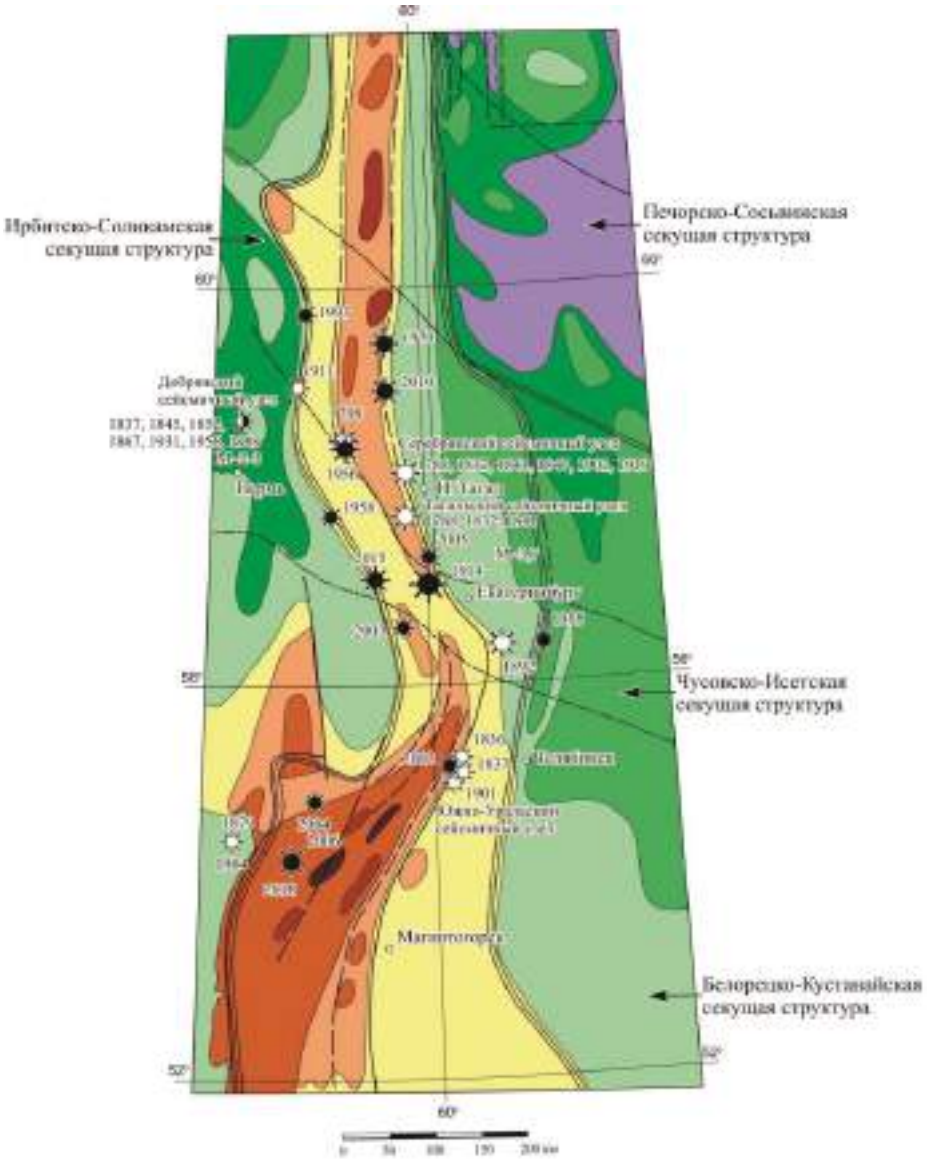


Fig. 1. The scheme of the recent tectonics of the Urals (according to Trifonov V. P., 1969) with the epicenters of sensible earthquakes (according to Guliaev A. N., 2018):
1 – the border between the orogen area of the Urals and the Russian plate (in the west) and the West Siberian Platform (in the east); *2* – recent and revived tectonic faults (established and assumed); *3* – the borders of the main through (cross) structures

Рис. 1. Схема новейшей тектоники Урала (по Трифонову В. П., 1969 г.) с вынесенными эпицентрами ощутимых землетрясений (по А. Н. Гуляеву, 2018 г.):
1 – граница между орогенической областью Урала и Русской платформой (на западе) и Западно-Сибирской плитой (на востоке); *2* – новейшие или омоложенные тектонические разрывы (установленные и предполагаемые); *3* – границы главнейших сквозных (секущих) структур

basement forming the azimuthal unconformity with submeridional Paleozoic geological-tectonic structures [4, 12]. The concurrence of the direction of the earth's surface recent submersion regional zone and the extent of the pre-Riphean basement structures can testify to the fact that recent tectonic processes in ancient horizons develop inheriting the structures of the "pre-Urals" cycle of development [1].

In the velocities field of the recent vertical crustal movements (RVCM), the region of the Middle Ural seismodomen is characterized by relatively increased velocities of the earth's surface submersion from 4–6 to 8–10 mm per year amid the field of lower submersion velocities of the earth's surface from 1–2 to 3–4 mm per year in the remaining part of the Urals and the adjacent parts of the East European Platform and the West Siberian Plate [11]. The existence of the above-mentioned zones of recent crustal submersions with relatively increased velocities can testify to the presence of the zones of recent subhorizontal stretching underneath them within the deep horizons of the earth's crust of the Middle Urals. The schemes of similar setting are represented in [13]. Crustal deformation as a result of the subhorizontal stretching within deep horizons and the submersion of the earth's surface accompanied by the processes of subsoil degassing can be the reason for sensible earthquakes in the Middle Urals. The research [14] reports the significant role of the process of subsoil degassing in natural seismic phenomena.

Within the structures of the recent Uralian orogen the epicenters of the sensible earthquakes are timed to the western and eastern periphery of its most uplifted part – the axial zone (fig. 1) which corresponds to the area of the Riphean-Vendian Central-Uralian uplift. At that, the major part of the Middle Ural seismodomen sensible earthquakes epicenters is timed to the Middle Ural section of the submeridian Paleozoic Main Uralian Deep Fault (MUDF) which divides the Riphean-Vendian Central-Uralian uplift area situated west of it, composed of metamorphic rocks of the pre-Paleozoic age and Tagil-Magnitogorsk trough situated east of it, composed of volcanogenic and volcanogenic sedimentary rocks of the early and middle Paleozoic age (fig. 2). To the axial zone of the Middle Ural section of MUDF and to the zone of its geodynamic influence the epicenters of the following earthquakes are timed (citation from the south to the north):

– earthquakes of the South Uralian (Zlatoust-Miass-Kyshtym) seismic knot in the region of the cities of Miass and Zlatoust in 1836–1837, 1901, 2002; magnitude is rated from 2.5 to 3.5 [8];

– earthquakes of Bilimbai seismic knot in the region of the cities of Pervouralsk and Revda in 1914, 2005, 2015; magnitudes are rated from 3.5 to 4.5–5.0 of Bilimbai earthquake on the 17th August, 1914, which has been the strongest earthquake in the Urals [8];

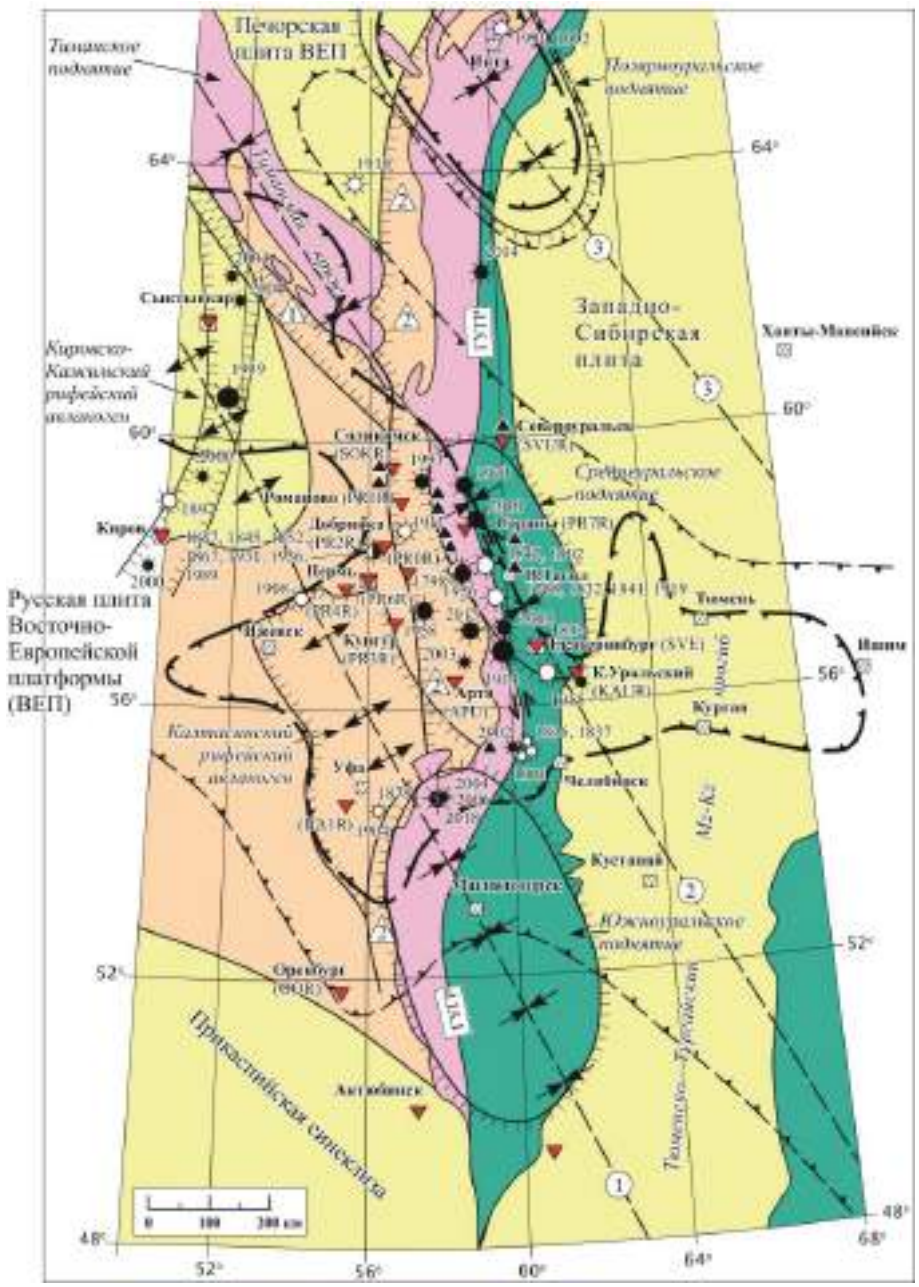
– earthquakes in the region of Tagil seismic knot in 1788, 1832, 1841, 1919 in the vicinity of Nizhny Tagil city; magnitude is rated from 3.0 to 4.0 [8];

– earthquakes in the region of Serebryanka seismic knot in the region of Kushva town and in valley of the Serebryanka river in 1847, 1902; magnitude is rated from 3.5 to 4.5 [8];

– Katchkanar earthquake in 2010 in the region of Katchkanar town, magnitude of which is rated as 4.7 [15];

– earthquake of 1970 in the region of Pavda settlement, magnitude of which is rated as 4.0 [8].

The Middle Ural fault of MUDF can be an element of the axial zone and the zone of geodynamic influence of Timan-Kokshetau trans-orogen structure of the pre-Riphean basement [20] possessing the character of a linear uplift, to the axial zone of which Timan and Middle Ural local Paleozoic uplifts are timed (fig. 2). There is a possibility that in the Paleozoic Era shear crustal deformations could occur in the Middle Ural



① The axis of Bashkiro-Ulutavsky trans-orogen structure

② The axis of Timan-Kokshetau trans-orogen structure

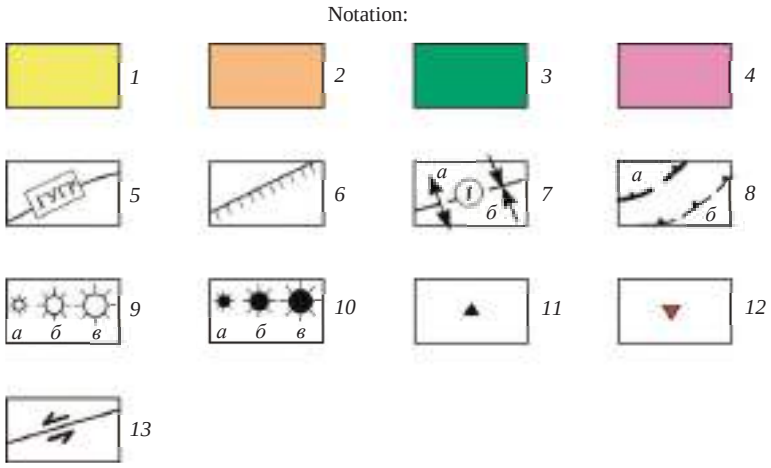
③ The axis of Intinsky trans-orogen structure

△1 The zone of the Late Vendian pre-Timan trough

△2 The zone of the Late Paleozoic pre-Uralian trough

Fig. 2. The scheme of seismotectonics of the Urals (prepared by Guliaev A.N., the Institute of Geophysics UB RAS, 2018, computer graphics by Arzamastseva N. V.)

Рис. 2. Схема сейсмотектоники Урала (составил А. Н. Гуляев, Институт геофизики УрО РАН, 2018 г., компьютерная графика Н. В. Арзамасцевой)



1 – the areas of developing sedimentary mantle of the Mesozoic-Cenozoic age within the boundaries of EEP and West Siberian Platform; *2* – areas of developing Paleozoic deposits of the platform mantle of the East European Platform; *3* – areas of outcrops of Paleozoic-aged dislocated rocks of the Uralian-Siberian Paleozoic geosyncline to the earth's surface; *4* – areas of developing dislocated rocks of Paleozoic and pre-Paleozoic age and the pre-Riphean basement of the eastern part of EEP; *5* – axial zone of the Main Uralian Deep Fault; *6* – the borders of the assumed local uplifts of the surface of pre-Paleozoic rocks (ripples outwards), Riphean aulacogens, and submontane troughs (ripples inwards); *7* – the axes of the assumed trans-orogen zones of subhorizontal stretching (*а*) and contraction (*б*) in the earth's surface; *8* – the outlines of the area of recent submersions of the earth's surface with the relatively increased velocities from 4–6 to 8–10 mm per year (a) and the outlines of the local zone of recent submersions of the earth's surface with the velocities of 1–4 mm per year (*б*); *9* – the epicenters of natural earthquakes by macroseismic descriptions in the materials of archive documents with magnitude 2.0–2.,5 (*а*); 3.0–3.5 (*б*); from 4.0–4.5 to 5.0 (*в*); *10* – the epicenters of natural earthquakes according to the data from the seismic monitoring stations with magnitude 2.0–2.5 (*а*); 3.0–3.5 (*б*); from 4.0–4.5 to 5.0 (*в*); *11* – the sites of strong rock bumps and natural-technogenic earthquakes; *12* – seismological stations of the Ural seismological network; *13* – the zone of assumed Paleozoic shearing deformations at the Middle Ural section of MUDF

1 – области развития чехла отложений мезозойско-кайнозойского возраста в пределах ВЕП и Западно-Сибирской плиты; *2* – области развития палеозойских отложений платформенного чехла Восточно-Европейской платформы; *3* – области выходов на земную поверхность дислоцированных пород палеозойского возраста Урало-Сибирской палеозойской геосинклинали; *4* – области развития дислоцированных пород палеозойского и допалеозойского возраста и дорифейского фундамента восточной части ВЕП; *5* – осевая зона Главного Уральского глубинного разлома; *6* – границы предполагаемых локальных поднятий поверхности допалеозойских пород (зубчики наружу контура), рифейских авлакогенов и предгорных прогибов (зубчики внутрь контура); *7* – оси предполагаемых трансорогенных зон субгоризонтального растяжения (*а*) и сжатия (*б*) в земной коре; *8* – контуры области современных погружений земной поверхности с относительно увеличенными скоростями от 4–6 до 8–10 мм в год (*а*) и контуры региональной зоны современных погружений земной поверхности со скоростями 1–4 мм в год (*б*); *9* – эпицентры природных землетрясений по макросейсмическим описаниям в материалах архивных документов с магнитудой событий 2,0–2,5 (*а*); 3,0–3,5 (*б*); от 4,0–4,5 до 5,0 (*в*); *10* – эпицентры природных землетрясений по данным станций сейсмического мониторинга с магнитудой событий 2,0–2,5 (*а*); 3,0–3,5 (*б*); от 4,0–4.5 до 5,0 (*в*); *11* – места сильных горных ударов и природно-техногенных землетрясений; *12* – сейсмологические станции Уральской сейсмологической сети; *13* – зона предполагаемых палеозойских сдвиговых деформаций на Среднеуральском участке ГУГРа

fault of MUDF [17]. It is possible that the above-mentioned deformations could be caused by the interaction between the Russian Plate of EEP and the Uralian orogen [10]. It can be assumed that these tectonic processes happened in the contemporary history and continue at the modern stage but with considerably lower velocities causing small rare sensible earthquakes.

In the region west of the Urals the epicenters of sensible earthquakes are timed to Perm arch (high) of the East European Platform (EEP) basement, as well as to the Middle Ural parts of the Late Paleozoic pre-Uralian trough and Paleozoic West Uralian zone of orogeny and overthrusts (fig. 2).

The sensible earthquakes of Dobryanka seismic knot in 1837, 1845, 1852, 1867, 1908, 1911, 1931, 1956, and 1989 are timed to Perm arch (high) of EEP basement [8]. Magnitude are rated as 2.0–3.0, the intensity of shakes from 3.0 to 5.0 on the MSK-64 scale. Karst-depression nature of these earthquakes is not excluded [9].

To the Middle Uralian part of the Paleozoic pre-Uralian trough and to the West Uralian zone of orogeny and overthrusts the following natural seismic events are timed (citation from the south to the north):

– earthquakes of 1879 and 1904 with the epicenters situated approximately within 20–30 km southwest of Ufa, quakes intensity about 3 on the MSK-64 scale, magnitude is rated as 2.5 [8]; the nature of these earthquakes may be of karst-depression [9];

– earthquakes of 2004 in the region of Katav-Ivanovsk town; quakes intensity 3–4 on the MSK-64 scale, magnitude is rated as 2.1–2.8 [18];

– earthquake of 2003 within the boundaries of Sabarsky Uval, with the epicenter situated approximately within 20 km north of Arti settlement, magnitude is rated as 2.0–2.5, quakes intensity 2.5 on the MSK-64 scale [18];

– earthquake of 2015 in the vicinity of the railway stations of Sabik and Sarga, magnitude is rated as 4.0 (from 3.5 according to the data from the geophysical observatory Arti of the Institute of Geophysics UB RAS to 4.7 according to the data from the Institute of Mining UB RAS), quake intensity in the epicenter – 5 on the MSK-64 scale [19];

– earthquake of 1798 г., an epicenter could presumably be situated in the vicinity of Kyn settlement on the river Chusovaya, quakes intensity is rated as 4.5 on the MSK-64 scale [8];

– earthquakes of 1911 with epicenters in the vicinity of Tihaya village, Milkova village on the river Kosva, magnitude 3.0, quakes intensity is rated as 5 [8]; karst-depression nature of these events is possible;

– earthquake of 1993 with an epicenter in the vicinity of Berezniki town, magnitude 3.2, quake intensity 4, presumably of natural-technogenic nature [8].

Apart from the natural earthquakes, the Urals experiences sensible seismic events of natural-technogenic character, namely, rock bumps in mines carrying out the exploitation of mineral deposits using underground mine workings, and natural-technogenic earthquakes occurring as a result of geodynamic events in underground mine workings (rockfalls, depressions, fractures) [20, 21]. Due to the relatively shallow depth of the focuses of seismic events of natural-technogenic character (about dozens and hundreds of meters), they are hazardous mainly for underground mining workings of a functioning mining enterprise and its personnel, but not for the neighboring settlements. In this regard they are similar to karst-depression earthquakes. In general, rare small Uralian natural earthquakes are not hazardous for mine workings of mining enterprises.

Results application area. The results of the given work can be of help in the course of seismic zoning of the Ural territory, as well as when planning accommodation and when designing engineering facilities within the Ural region.

Conclusions. Geological-tectonic crustal and subsoil activity in the Urals at the modern stage is low and of platform type. It manifests itself in rare and weak seismicity

of the region, and low amplitude recent vertical crustal movements. Due to rare and weak seismicity of the Urals, local sensitive earthquakes are not hazardous for engineering structures and human life.

Uralian sensible earthquakes epicenters concentration area, the Middle Ural seismodomen, is timed to the knot of intersection (interference) of submeridian recent Uralian orogen and the local zone of recent submersions of the earth's surface of the north-western direction which can be the manifestation of a large zone of subhorizontal crustal stretching within it deeper horizons.

The epicenters of sensible earthquakes of the Middle Ural seismodomen are timed to the south-western and western periphery of the Middle Ural section of the Late Vendian Central-Uralian uplift. In the area of the south-western periphery of this structure they are timed to the zone of pre-Uralian trough and West-Uralian zone of orogeny and overthrusts, and in the area of the eastern periphery – to the axial zone and to the zone of geodynamic influence of the Middle Ural section of submeridian Paleozoic Main Uralian Deep Fault.

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Received 28th June, 2018

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DOI: 10.21440/0536-1028-2019-1-42-51

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Реферат

Введение. *Земная кора Урала, пережившая в допалеозойское и палеозойское время эпоху геосинклинального развития с активно протекавшими тектоническими и вулкано-магматическими процессами, в мезозойско-кайнозойское время пережила эпоху платформенного развития, завершившегося в период новейшей тектонической активизации формированием новейшего Уральского эпиплатформенного орогена, возникшего в западной части разрушенного процессами денудации Уральского палеозойского горно-складчатого сооружения. Новейший Уральский ороген наследует основные черты строения палеозойского горно-складчатого сооружения. На современном этапе в пределах и в окрестностях новейшего Уральского горного пояса отмечаются редко происходящие ощутимые землетрясения силой от 3–4 до 5–6 баллов по шкале MSK-64, а также горные удары и природно-техногенные землетрясения на горнорудных предприятиях, ведущих отработку месторождений полезных ископаемых подземными горными выработками.*

Целью работы *является оценка связи проявлений современной сейсмичности и разновозрастной тектоники Уральского региона.*

Методика исследования *заключалась в оценке положения эпицентров ощутимых землетрясений относительно геолого-тектонических структур новейшего, палеозойского и допалеозойского возраста, а также относительно элементов морфологии поля современных вертикальных движений земной коры.*

Результаты. *Сделано заключение, что наибольшей сейсмической активностью характеризуется земная кора Среднего Урала в области интерференции субмеридионального Уральского горного пояса и зоны современных погружений земной поверхности с относительно увеличенными скоростями, имеющей северо-западное направление, соответствующее направлению структур дорифейского фундамента.*

Область применения результатов. *Результаты данной работы могут быть полезны при выполнении работ по сейсмическому районированию территории Урала, при планировании размещения и при проектировании в пределах Уральского региона инженерных объектов.*

Ключевые слова: *новейший ороген; горный пояс; ощутимые землетрясения; горные удары; сейсмичность; дорифейский фундамент; сейсмодомен; сейсморайонирование.*

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Поступила в редакцию 28 июня 2018 года

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Для цитирования: Гуляев А. Н. Сейсмотектоника Урала // Известия вузов. Горный журнал. 2019. № 1. С. 42–51.
For citation: Guliaev A. N. Seismotectonics of the Urals. *Izvestiya vysshikh uchebnykh zavedenii. Gornyi zhurnal = News of the Higher Institutions. Mining Journal*. 2019; 1: 42–51.