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КОНТИНЕНТАЛЬНЫЙ РИФТОГЕНЕЗ, СОПУТСТВУЮЩИЕ ПРОЦЕССЫ

Материалы Второго Всероссийского симпозиума
с международным участием и молодежной научной школы,
посвященных памяти академиков Н.А. Логачева и Е.Е. Милановского
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Том 1

CONTINENTAL RIFTING, ACCOMPANYING PROCESSES

Proceedings of the Second All-Russia symposium with international
participation and training school for young scientists,
dedicated to the memory of academicians N.A. Logatchev and E.E. Milanovsky
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Континентальный рифтогенез, сопутствующие процессы: Материалы Второго Всероссийского симпозиума с международным участием и молодежной научной школы, посвященных памяти академиков Н.А. Логачева и Е.Е. Милановского / Под редакцией С.В. Рассказова, А.М. Никишина, С.П. Приминой. Иркутск: Институт земной коры СО РАН, 2013. – В 2-х томах. – Т. 1. – 250 с.

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В сборнике рассматриваются вопросы эволюции процессов, сопутствующих континентальному рифтогенезу в истории Земли, результаты мониторинга современных процессов в областях континентального рифтогенеза для целей прогноза геологических катастроф, обсуждаются проблемы стратиграфии, литологии и геохронологии осадочных и вулканогенно-осадочных толщ континентальных рифтов, выделяются структурные, геофизические и магматические критерии рифтогенеза, закономерности строения мантии и коры рифтовых зон, приводятся геодинамические реконструкции, выявляются особенности формирования месторождений углеводородов и других полезных ископаемых в рифтовых структурах.

Материалы сборника могут быть использованы в дальнейшем развитии общей теории континентального рифтогенеза и ее отдельных аспектов, при чтении специализированных курсов в вузах и при разработке научных основ оценки опасности современных геологических процессов.

Симпозиум и молодежная школа проводятся при финансовой поддержке РФФИ (проект № 13-05-06106) и Программы стратегического развития ФГБОУ ВПО «ИГУ» на 2012–2016 гг. (проект Р132–ОУ–002)

Текст материалов конференции на английском языке публикуется в авторской редакции.
На обложке использованы рисунки из работ Н.А. Логачева (1974) и Е.Е. Милановского (1999)

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миграции очагов землетрясений являются в большей степени характерным свойством именно земной коры и верхней мантии, нежели более глубоких ее слоев.

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MIGRATION WAVES OF THE EARTHQUAKE FOCI AND STRUCTURE OF THE UPPER MANTLE

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Introduction. For several years the authors study spatio-temporal the patterns of earthquke distribution. For this purpose the electronic seismic catalog, which contains information about the earthquakes that occurred in the world over the last 4.1 million years, was compiled (Vikulin, 2012a). The patterns of distribution of seismic events in depth are studied on the example of three of the most seismically active regions in the world, within which more than 90% of all earthquakes are recorded: the Pacific margin (PM), the Alpine-Himalayan belt (AH), the Mid-Atlantic Ridge (MAR).

The source data. The seismic electronic catalog, compiled by authors, contains information about: 7819 earthquakes within the Pacific Ocean with a magnitude of $6 \le M \le 9.5$ and the depth of the hypocenter $0 \le H \le 690$ km; 1540 events within the Alpine-Himalayan belt with a magnitude of $6 \le M \le 8.3$ and hypocenter depths $0 \le H \le 720$ km; 1042 events of the Mid-Atlantic Ridge with magnitudes $5.5 \le M \le 7.6$ and the depth of the hypocenter $0 \le H \le 308$ km. For each region the frequency plots were constructed, their slope coefficients are found to be –0.9, –0.7 and –1.2, respectively.

Study of the earthquakes distribution by depth showed that more than 80 % of all events contained in the catalog, have a depth of up to 100 km. Given the uncertainties in the hypocenter parameters such events can be attributed to a group of crustal earthquakes. The distribution of such earthquakes within the crust for all the regions under study is uneven and has local maxima at depths of 10 and 40 km.

Analysis of the earthquakes distribution at depths of more than 100 km showed that these seismic events are distributed unevenly along the considered zone. Thus, within the Mid-Atlantic Ridge the entire deep earthquakes are located near the South Sandwich Islands.

Within the Alpine-Himalayan belt and the Pacific margin deep earthquakes are distributed along the zones unequally – there are extensive areas where such earthquakes are not observed (for example, the coast of North America to the Pacific Ocean and part of the territory of Central Asia in the AH zone).

The distribution of deep earthquakes by depth is also uneven. Thus, within the Pacific margin three peaks at depths 150, 400 and 600 km are allocated. Hypocenters of these events are within the upper mantle, seismic boundary at a depth of 670 km is considered to be its lower limit (Pushcharovsky D.Yu., Pushcharovsky Yu.M., 1998). Within the Alpine-Himalayan belt local maxima of the number of earthquakes are distinguished at depths of 150 and 600 km.

Research method. The study of migration phenomenon, that is, the patterns of distribution of earthquakes in space and time within the above three regions is carried out in accordance with the method described in (Vikulin, 2012c). After the transition from two-dimensional coordinate system (geographic latitude-longitude of the earthquake epicenter) to the one-dimensional (distance along the line *l*) sequences of events naturally occurring in space and time sequence of events (the migration chains of earthquakes) are detected.

The algorithm for allocation of migration chains of seismic events within each zone is to find in the catalog for each *i*-th event with L_i coordinate and t_i time such (*i*+1)-th event which coordinate and a time will satisfy the conditions: $L_{i+1} \geq L_i$, $t_{i+1} \geq t_i$. The study of earthquakes migration is carried out within the range of different magnitudes.

Each identified migration chain is characterized by the duration, extent and migration velocity that characterizes the linear relationship between the dates of earthquakes in the chain and their distance along the line.

After the formation of an array of migration chains their statistical analysis is carried out, which resulted in the analysis of the relationship between velocity *V* and magnitude $M \geq M_0$ (energy) characteristics of earthquakes. The values of coefficient of the $\mathrm{Lg}V(M_0)$ slope are of greatest interest in this study because they allow to quantify the wave processes occurring in the regions under study .

According to the task to study the migration of seismic activity in different layers of the crust and upper mantle the above-described basic method was used for the analysis of the initial sets of seismic events that have occurred at different depths. A prerequisite for this study was the completeness of the analyzed sample, which would make it possible for different ranges of the magnitude to identify quite a number of long enough migration chains. Thereby samples were formed around the detected local maxima of number of earthquake, so that all events in catalog eventually were selected.

Discussion of results. Previously, the authors have studied in detail and described the phenomenon of earthquakes migration with $H \leq 100$ km (Vikulin, 2012b). It has been shown that the process of foci migration of such earthquakes is statistically significant and it can be considered a characteristic feature of Earth's seismic activity. The existence of well-defined changes in migration velocity where shown, the values of such changes are proportional to the values of M_0 considered set of events. For each region with the method of least squares relationships between the logarithm of the migration velocity $\mathrm{Lg}V$ of seismic events and magnitudes M_0 (Fig.) are defined:

$$M_{PM} \approx (7.6 \pm 1.0)\mathrm{Lg}V; \quad M_{AH} \approx (6.7 \pm 0.5)\mathrm{Lg}V; \quad M_{MAR} \approx (-4.9 \pm 0.2)\mathrm{Lg}V$$

The important fact is that the identified relationships between speed and power characteristics of seismic events have different angles of inclination. For the Pacific margin and the Alpine-Himalayan belt (areas of mainly compression) relationships $M_{PM}(V)$ and $M_{AH}(V)$ have a "positive" inclinations, that is, with an increase in the magnitude the velocity of migration increases. For the Mid-Atlantic Ridge (area of mainly stretching) the dependence $M_{MAR}(V)$ has a negative slope, that is, with increasing earthquake magnitude their rate of

migration reduces. Thus, the slopes of the curve defining the relationship between the velocity of earthquakes migration, are "sensitive" to the tectonic condition in region. This result allows the wave (in fact) seismic migration process to consider as a display of uniform wave geodynamic processes taking place within the Earth's crust in the active regions of the Earth (Akmanova et al., 2013).

The authors studied the phenomenon of earthquakes migration in different depth ranges, both within the Earth's crust and upper mantle. The phenomenon of crustal earthquakes migration was investigated on samples of seismic events with a focal depth up to 20 km, 50 km and 70 km. For all the depth sections it was found that migration is a characteristic property of the seismic activity with roughly equal "angles" between the velocities of earthquakes migration and their magnitudes (Table).

The values of the slopes of Lg$V(M_0)$ curves for earthquake foci at different depth

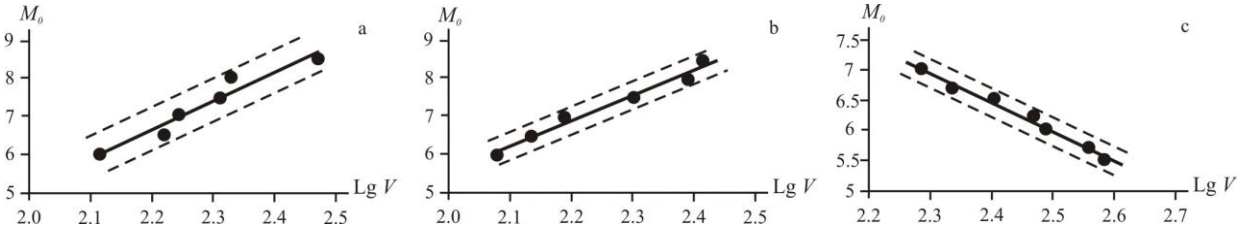
Region / Depth	The Pacific margin	The Alpine-Himalayan belt	The Mid-Atlantic Ridge
$0 \le H \le 20$	6.9 ± 0.3	4.9 ± 0.6	–5.0 ± 0.5
$0 \le H \le 50$	7.7 ± 1.5	6.7 ± 1.4	–5.1 ± 0.5
$0 \le H \le 70$	7.6 ± 1.3	6.2 ± 0.9	–4.7 ± 0.3
$0 \le H \le 100$	7.6 ± 1.0	6.7 ± 0.5	–4.9 ± 0.2
$100 < H \le 300$	7.7 ± 1.3	7.5 ± 1.5	—
$300 < H \le 500$	8.5 ± 1.3	—	—
$500 < H \le 700$	4.2 ± 0.1	—	—
$100 < H \le 700$	5.7 ± 1.0	5.4 ± 1.4	—

It is important to note that the numerical value of the slope of the Lg$V(M_0)$ dependences considering errors of their determination are proved to be close to the above values for the migration of earthquakes with depths up to 100 km (Table). The data obtained suggest that the earthquakes migration is a characteristic feature not only of the individual layers of the crust and the *earth's crust as a whole*, but also of the part of the upper mantle.

As mentioned above, within the Mid-Atlantic Ridge earthquake foci with $H>100$ km are located only in the South Sandwich Islands. Thus, the study of the migration of deep earthquakes in the entire Mid-Atlantic Ridge is impossible because the available data are not representative of the entire catalog of this region.

Despite some incompleteness of catalogues of deep earthquakes of the Alpine-Himalayan belt and the Pacific margin the available statistics data allows to identify a sufficient number of migration chains in various ranges of the magnitude.

To investigate the spatial and temporal patterns of seismicity of the Pacific Ocean below 100 km the samples of events were formed considering mentioned above maxima of number of such earthquakes. In all the samples sufficiently large number of migration chains was revealed. Depths limits for each sample and the coefficients of relationships between migration velocities and magnitudes of events are shown in the table. It is important to note, that Lg$V(M_0)$ relationships for various depths "sections" within the upper mantle are significantly different. In this case, less profound event (with depths of up to 300 km) have a slope that is very close to the obtained value for the crustal seismicity, which may correspond to the inner seismic section of the upper mantle at a depth of 410 km (Pushcharovsky D.Yu., Pushcharovsky Yu.M., 1998). For deeper events, the hypocenters of which are below the current section, the values of the slopes Lg$V(M_0)$ considering the error of their determination not overlap with "crustal" slopes.



Migration velocity V of earthquakes versus magnitude M_0 of the events: *a* – the Pacific margin; *b* – the Alpine-Himalayan belt; *c* – the Mid-Atlantic Ridge.

The study of migration of deep earthquakes the Alpine-Himalayan belt was investigated only at depths of 100 to 300 km and for all deep events, because the catalog of AH earthquakes corresponding to the second mentioned above maximum at depth of 600 km, does not contain a sufficient number of data to analyze. For these sets of events the phenomenon earthquakes migration was confirmed also confirmed, and the velocity characteristics of migration chains were also dependent on the magnitude of events. The results are shown in the table 1. It is clear that, considering the errors in determining the coefficients Lg$V(M_0)$ revealed dependences for the mantle (up to 410 km section) and crustal earthquakes are very similar in nature, as well as such dependences for the Pacific margin earthquakes.

Based on the foregoing, we conclude that relative to the wave geodynamic processes, which reflection is the process of earthquakes migration studied by authors, the earth's crust is quite uniform over the whole of its thickness, in contrast to the layers of the mantle. Thus, the waves of earthquakes migration are characteristic feature more for the Earth's crust and upper mantle, rather than its deeper layers.

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