ON THE QUESTION OF THE NATURE OF DEEP EARTHQUAKES

GEOPHYSICS

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Figure 1

Figure 1: Figure 1

Abstract

Full Text

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GEOPHYSICS

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ON THE QUESTION OF THE NATURE OF DEEP EARTHQUAKES

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Gutenberg and Richter' s data for all seismoactive zones of the globe ([1]) were used to calculate the seismic energy released at different depths in the Earth' s crust and mantle. The transition from magnitude to energy, taking into account the results of work ([2]), was made as follows: for normal earthquakes ($h < 70$ km), according to the formula $\lg E$ (erg) $= 12 + 1.5M$; for deep earthquakes ($h \geqslant 70$ km), $\lg E = 12.5 + 1.5M$.

In contrast to other works devoted to the quantitative comparison of the seismicity of different regions of the globe (see, for example, ([3])),

Fig. 1. Distribution of the active volumes of the seismoactive zones of the globe with depth.
I –maxima of the specific seismic power $\bar{\varepsilon}(h)$, **II** –minima $\bar{\varepsilon}(h)$, **III** –absence of earthquakes. Regions of existence of groups of earthquakes: **H** –normal, **VG** –upper-deep, **SG** –intermediate-deep, **NG** –lower-deep. Seismoactive zones (according to ([1])): **1** –Aleutians–Alaska, **2** –Alaska–British Columbia, **3** –California, **4** –Gulf of California, **5** –Mexico, **6** –Central America, **7** –Caribbean Sea, **8** –South America north of 37° S, **9** –South America south of 37° S, **10** –South Antilles Ridge, **11** –New Zealand, **12** –Kermadec–Tonga, **13** –Fiji, **14** –New Hebrides, **15** –Solomon Islands, **16** –New Guinea, **17** –Caroline Islands, **18** –Mariana Islands, Bonin, **19a** –Japan, **19b** –Kamchatka, **20** –Ryukyu Islands, **21** –Taiwan, **22** –Philippine Islands, **23** –Celebes, **24** –Sunda Arc, **25–28, 47, 48** –Himalayas–Hindu Kush–Central Asia, **29–31, 36, 51** –Alpine Belt (west), **32, 33, 37, 40, 43–45** –oceanic ridges and rift zone, **46** –Kamchatka, deep-focus earthquakes, **misc.** –others.

in the present work the total value of the seismic energy was related to the active volumes of the seismoactive zones, i.e., to the minimal compact convex regions that included all known earthquake foci of the given zone within a specified depth interval:

$$\varepsilon = \sum E_i / V_s t,$$

Table 1

Specific seismic power of seismoactive zones at different depth levels

Region	No. according to (1)	Observation period, years	Normal: V_s, 10^{24} cm^3	Normal: $\sum E_i/t$, 10^{21} erg/year	Normal: $\bar{\varepsilon}$	Upper deep: V_s	Upper deep: $\sum E_i/t$	Upper deep: $\bar{\varepsilon}$	Intermediate deep: V_s	Intermediate deep: $\sum E_i/t$	Intermediate deep: $\bar{\varepsilon}$	Lower deep: V_s	Lower deep: $\sum E_i/t$	Lower deep: $\bar{\varepsilon}$
Aleutian Islands	1	47	0,019	0,180	9,5	0,029	0,097	3,3		0			0	
Alaska	2	41	0,022	0,042	1,9		0			0			0	
California	3	46	0,040	0,082	2,1		0			0			0	
Gulf of California	4	41	0,0075	0,0079	1,05		0			0			0	
Mexico	5	43	0,011	0,190	17,0	0,033	0,106	3,2		0			0	
Central America	6	46	0,018	0,058	3,2	0,019	0,052	2,7		0			0	
Caribbean Sea	7	46	0,025	0,060	2,4	0,010	0,037	3,7		0			0	
South America north of 37° S	8	46	0,060	0,510	8,5	0,186	0,280	1,5		0		0,056	0,104	1,9
South America south of 37° S	9	31	0,005	0,042	8,4	(0,008)	(0,012)	(1,5)		0			0	

Region	No. according to (1)	Observation period, years	Normal: V_s, 10^{24} erg/year	Normal: $\sum E_i/t$, 10^{21} erg/cm³	Normal: $\bar{e}$	Upper deep: V_s	Upper deep: $\sum E_i/t\bar{e}$	Upper deep:	Intermediate deep: V_s	Intermediate deep: $\sum E_i/t\bar{e}$	Intermediate deep:	Lower deep: V_s	Lower deep: $\sum E_i/t\bar{e}$	Lower deep:
South Antilles Ridge	10	40	0,050	0,040	0,8	0,004	0,013	3,2		0			0	
New Zealand	11	37	0,022	0,073	3,3	0,005	0,054	1,1	?*	0,0003	?		0	
Kermadec — Tonga	12	39	0,025	0,220	8,8	0,066	0,162	2,5	0,036	0,076	2,2	0,052	0,137	2,6
Fiji	13	26	0,010	0,0043	0,43		0			0			0	
New Hebrides	14	43	0,015	0,142	9,5	0,071	0,380	5,4	?	0,0005	?		0	
Solomon Islands	15	42	0,019	0,200	10,5	0,024	0,046	1,9	0,014	0,013	0,9	?	0,0005	?
New Guinea	16	44	0,031	0,143	4,6	0,025	0,045	1,8		0			0	
Caroline Islands	17	34	0,019	0,040	2,1		0			0			0	
Mariana Islands	18	43	0,027	0,036	1,3	0,054	0,182	3,4	0,032	0,036	1,1		**	
Japan — Kamchatka	19+46	48	0,028	0,630	22,5	0,044	0,160	3,6	0,054	0,138	2,5	0,033	0,049	1,5
Ryukyu, Taiwan	20+21	47	0,018	0,147	8,2	0,036	0,240	6,7		0			0	
Philippines	22	45	0,026	0,263	10,1	0,037	0,046	1,2	0,002	0,0023	1,1	0,021	0,014	0,7
Sulawesi (Celebes)	23	40	0,018	0,119	6,6	0,051	0,170	3,3		0			0	
Sunda Arc	24	45	0,050	0,134	2,7	0,084	0,193	2,3	0,007	0,005	0,7	0,029	0,018	0,6
Burma	25	38	0,033	0,062	1,9	0,018	{0,004	0,7		0			0	
Tibet	26	47	0,096	0,320	3,3		{0,008}			0			0	
North China	27	29	0,052	0,260	5,0	0,0008	0,0021	2,6		0			0	

Region	No. according to (1)	Observation period, years	Normal: V_s, 10^{24} erg/year	Normal: $\sum E_i/N$, 10^{21}	Normal:	Upper deep: V_s	Upper deep: $\sum E_i/t\bar{e}$	Upper deep:	Intermediate deep: V_s	Intermediate deep: $\sum E_i/t\bar{e}$	Intermediate deep:	Lower deep: V_s	Lower deep: $\sum E_i/t\bar{e}$	Lower deep:
Tien Shan – Baikal	28	36	0,066	0,310	4,7		0			0			0	
Iran	29	39	0,092	0,078	0,85	0,0025	0,0064	2,6		0			0	
Eastern Mediterranean	30	44	0,045	0,057	1,3	0,032	0,067	2,1		0		?	0,001	?
Western Mediterranean	31	43	0,040	0,075	1,9	0,006	0,002	0,3		0			0	
Atlantic Ocean	32	32	0,120	0,032	0,27		0			0			0	
Indian Ocean	33	47	0,150	0,047	0,31		0			0			0	
North America	34	27	0,062	0,038	0,61		0			0			0	
Western Europe	36	35	0,030	0,0003	0,01		0			0			0	
Africa	37	46	0,065	0,0057	0,09		0			0			0	
Australia	38	40	0,070	0,011	0,16		0			0			0	
Hawaiian Islands	39	22	0,001	0,0031	3,1		0			0			0	
Arctic	40	37	0,035	0,0021	0,06		0			0			0	
Chukotka – North Canada	42	27	0,015	0,0057	0,38		0			0			0	
Southwest Pacific Ocean	43	38	0,120	0,010	0,08		0			0			0	
East Pacific Ocean	44	24	0,060	0,0012	0,02		0			0			0	

Region	No. according to (1)	Observation period, years	Normal: V_s, 10^{24} cm^3	Normal: $\sum E_i/t$, 10^{21} erg/year	Normal: $\bar{\varepsilon}$	Upper deep: V_s	Upper deep: $\sum E_i/t$	Upper deep: $\bar{\varepsilon}$	Intermediate deep: V_s	Intermediate deep: $\sum E_i/t$	Intermediate deep: $\bar{\varepsilon}$	Lower deep: V_s	Lower deep: $\sum E_i/t$	Lower deep: $\bar{\varepsilon}$
Southeast Indian Ocean	45	30	0,022	0,0057	0,26		0			0			0	
Beludzhistan	47	31	0,010	0,014	1,4	?	0,00002	?		0			0	
Central Asia	48	39	0,015	0,041	2,7	0,0065	0,155	24,0		0			0	
Carpathians	51	40		0		0,0008	0,0126	16,0		0			0	

* From a single earthquake it is impossible to estimate the magnitude of the active volume.
** Earthquakes at this depth form a single inclined active volume with protruding foci.

where ε is the specific seismic power in erg/cm^3 · yr; E_i is the seismic energy of individual earthquakes in ergs; V_s is the active volume in cubic centimeters; t is the observation time in years.

A preliminary analysis of the material showed (Fig. 1) that the traditional division of all earthquakes into normal ($h < 70$ km), intermediate ($70 \leq h < 300$ km), and deep proper ($h \geq 300$ km) earthquakes is inadequate. Both in the number of earthquakes and in the total seismic energy, minima are clearly traced that make it possible to divide earthquakes by depth into 4 groups: normal (with foci above the roof of the low-velocity layer, on average $h < 70$ km), upper-deep ($70 \leq h < 280 \div 300$ km), middle-deep ($280 \div 300 < h < 450$ km), and lower-deep ($h \geq 450$ km).

The active volumes in seismic zones were distinguished separately for each of these groups (of course, when earthquakes of the corresponding groups were observed in the given zone). The error in estimating the specific power ε does not exceed 20–30% (this does not include the possible constant, identical for all zones, error in the conversion from magnitude M to energy). The results are presented in Table 1.

As was to be expected, the value of the specific seismic power for normal earthquakes varies greatly from zone to zone, which characterizes differences both in the mechanical properties of the rocks and in the intensity of tectonic processes in the Earth' s crust and adjacent mantle layers (above the asthenosphere). Apparently, comparison of the three-dimensional distribution of $\bar{\varepsilon}$ in the Earth' s crust with geological data may be a useful tool for seismo-tectonic investigations.

In contrast to this, the specific seismic power of the active volumes of deep earthquakes proved to be very stable and independent either of the dimensions of the active volumes or of the energy of the largest earthquakes (Fig. 2). Taking into account the low accuracy of determining $\bar{\varepsilon}$ and, chiefly, the relatively short observation period (30–40 years), one may consider that the value $\bar{\varepsilon} \approx 2$ erg/cm^3 · yr (within the limits from 0.7 to 5 erg/cm^3 · yr) is a specific constant that determines the ability of the mantle to generate deep earthquakes.

Fig. 2. Distribution diagrams of the specific seismic power by active volume of the zones. The designations are the same as in Fig. 1.

Let us suppose that the mechanism of all deep earthquakes is the same and that an equal fraction of the stored potential energy of the medium E_{0i} passes, at the moment of the earthquake, into the elastic form $E_i = kE_{0i}$. Then it may be asserted that if an amount of energy less than $\varepsilon_0 V/k$ enters a given mantle volume V per year, deep earthquakes do not arise in that volume, and the incoming energy is completely relaxed. When a threshold value ε_0 is reached in some volume, deep earthquakes appear there; however, the value $\bar{\varepsilon}$ cannot exceed a certain upper limit, and with further growth in the amount of incoming energy the active volume of the zone begins to increase.

These features and, in particular, the "dropping out" of whole groups of earthquakes despite the undoubted unity of the seismogenic process along the vertical –

…(for example, the absence of intermediate-depth earthquakes in South America, Fig. 1) can be explained only by the predominance of plastic processes in the transfer of seismotectonic energy.

An exception to the picture considered, which is valid for 20 zones of deep earthquakes, is constituted by the local focal zones of deep earthquakes in the Carpathians and the Hindu Kush. Here, in an extremely limited volume, an anomalously large amount of seismic energy is released, so that $\bar{\varepsilon}$ for these zones is comparable with $\bar{\varepsilon}$ for the most active regions of the Earth' s crust. Thus, the deep earthquakes of the Carpathians and the Hindu Kush cannot be regarded as analogues of the deep earthquakes of the Pacific belt.

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Note: Figure translations are in progress. See original paper for figures.