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GEOPHYSICS

Depth Distribution of Earthquakes through Latitudinal Belts of the Pacific Region: General Trends

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The geological sciences have recently demonstrated a tendency to move away from considering the Earth as an immobile system and from explaining global seismic processes only by endogenic interrelationships. Nowadays, some geologists take into consideration external forces and irregularities in the orbital parameters of the Earth in the Earth–Sun–Moon system when analyzing seismic processes [2].

The study of global regularities in the latitudinal distribution of earthquake foci revealed their distinct irregularity. It has been shown [3, 4, 6] that seismic activity is practically absent at polar and near-polar latitudes and rapidly increases in the middle latitudes to reach a maximum at 40°–50° N and 20°–30° S with a stable local minimum along the equator. The quantitative distribution of seismic events through different latitudes with account for hypocenter depths at four depths intervals is considered in [7], although its authors performed no quantitative analysis of their two-dimensional distribution (through depths and latitudes) and two-dimensional distribution of released energy.

The purpose of this work is to reveal statistically substantiated regularities in the depth distribution of seismic events for different latitudinal belts and energy levels.

The Pacific region, where over 80% of all the world seismic events occur, was selected as the object for this study. The region comprises the ocean with island arcs, marginal seas, and land areas above subduction zones. The events with a magnitude M_b at least 4.0 high that occurred in the period from 1964 to 2004 [8] were used for the analysis. The data from the catalog were subjected to preliminary processing to standardize magnitudes and remove aftershocks. In total, approximately 200 000 earthquakes were subjected to such processing.

Inasmuch as different-energy events may differ in the depth distribution patterns, their distributions are considered independently for six magnitude ranges (MR): $4.0 \le M_b < 4.5$, $4.5 \le M_b < 5.0$, $5.0 \le M_b < 5.5$, $5.5 \le M_b < 6.0$, $6.0 \le M_b < 6.5$, $M_b \ge 6.5$.

The Pacific region was subdivided into 18 latitudinal belts each 10° wide. In the analysis, an irregular depth scale was used: $H = \{0, 20, 40, 60, 80, 100, 120, 160, 200, 240, 300, 350, 400, 450, 500, 600, 700, 800 \text{ km}\}$.

The earthquakes that happened in the western and eastern parts of the Pacific region (west and east of 145° W) were analyzed separately. The quantitative distribution of events through all the selected depth intervals and their percentage were considered for each latitudinal belt. The data were normalized to the integral quantity of events in the assigned latitudinal belt.

Figure 1 shows the depth distribution of events for latitudinal belts located between 60° S and 60° N in the eastern part of the Pacific region. Nine plots located successively one after another demonstrate the depth distribution of earthquakes for each latitudinal belt located between these latitudes. Arrows indicate the corresponding belt. The number of earthquakes in the particular latitudinal belt is shown in the upper right corner of each plot. When neighboring belts are characterized by a similar distribution, the single plot is indicated by several arrows with indication of different latitudinal belts and several values corresponding to the quantity of events in the latter. The plots demonstrate the distributions for average values of normalized events available for all the magnitude ranges in each latitudinal belt.

Figure 2 presents the results derived from the analysis of the depth distribution of earthquakes for the same latitudinal belts of the western Pacific region. Figures 1 and 2 are both lacking data on the distribution of events in near-polar latitudes (60°–70°, 70°–80°, and 80°–90° of the Northern and Southern hemispheres). The sources of all events in these latitudinal belts are located at

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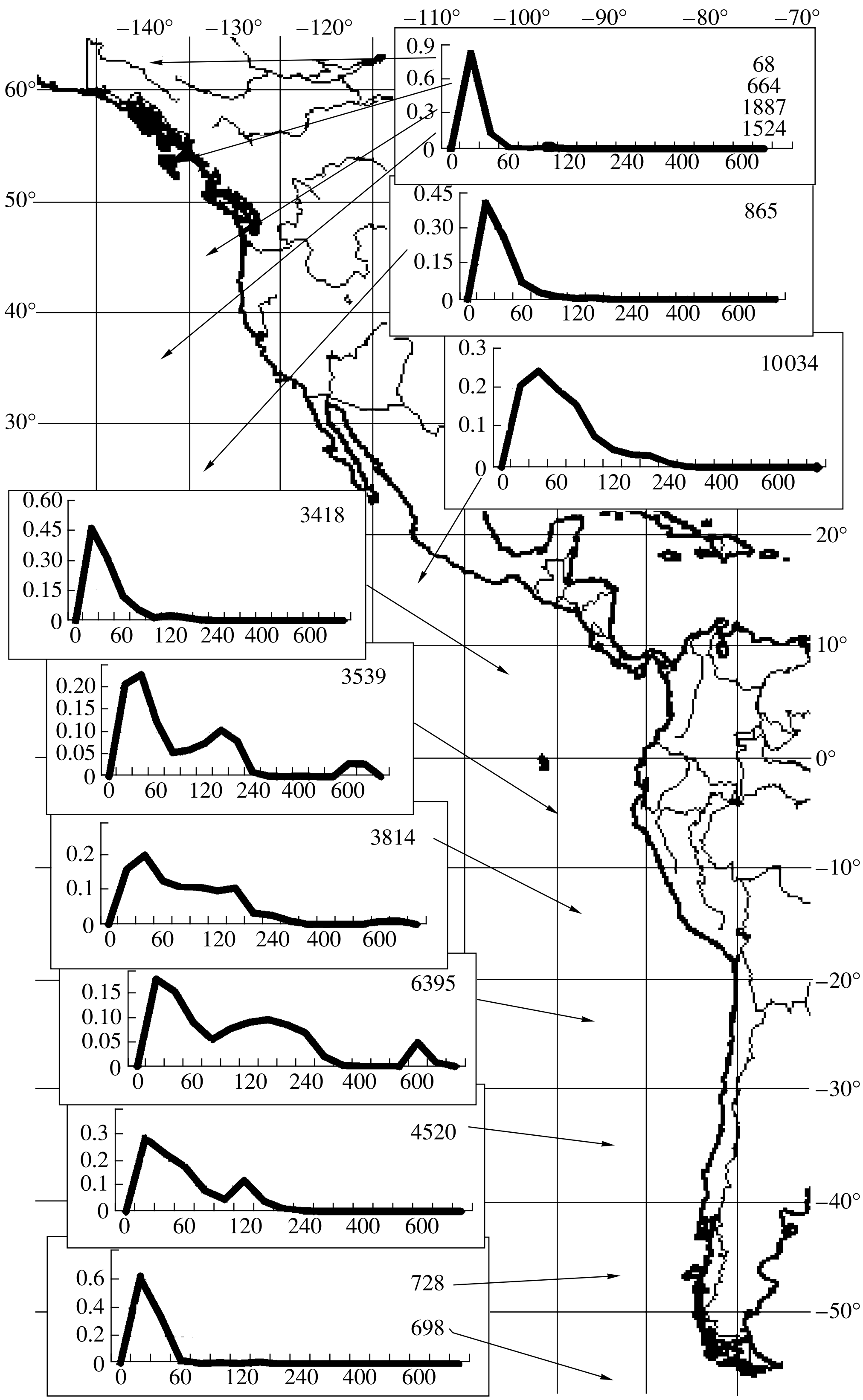

Fig. 1. Depth distribution of the relative share of earthquakes for latitudes between 70° N and 60° S in the eastern Pacific region. Nine successive plots demonstrate the depth distribution of earthquakes for each latitudinal belt with depths of earthquake foci (km) and relative share of earthquakes (normalized to the total quantity of seismic events in the corresponding latitudinal belt) shown along the abscissa and ordinate, respectively. The total number of seismic events in the corresponding latitudinal belt is shown in the upper right corner of each plot.

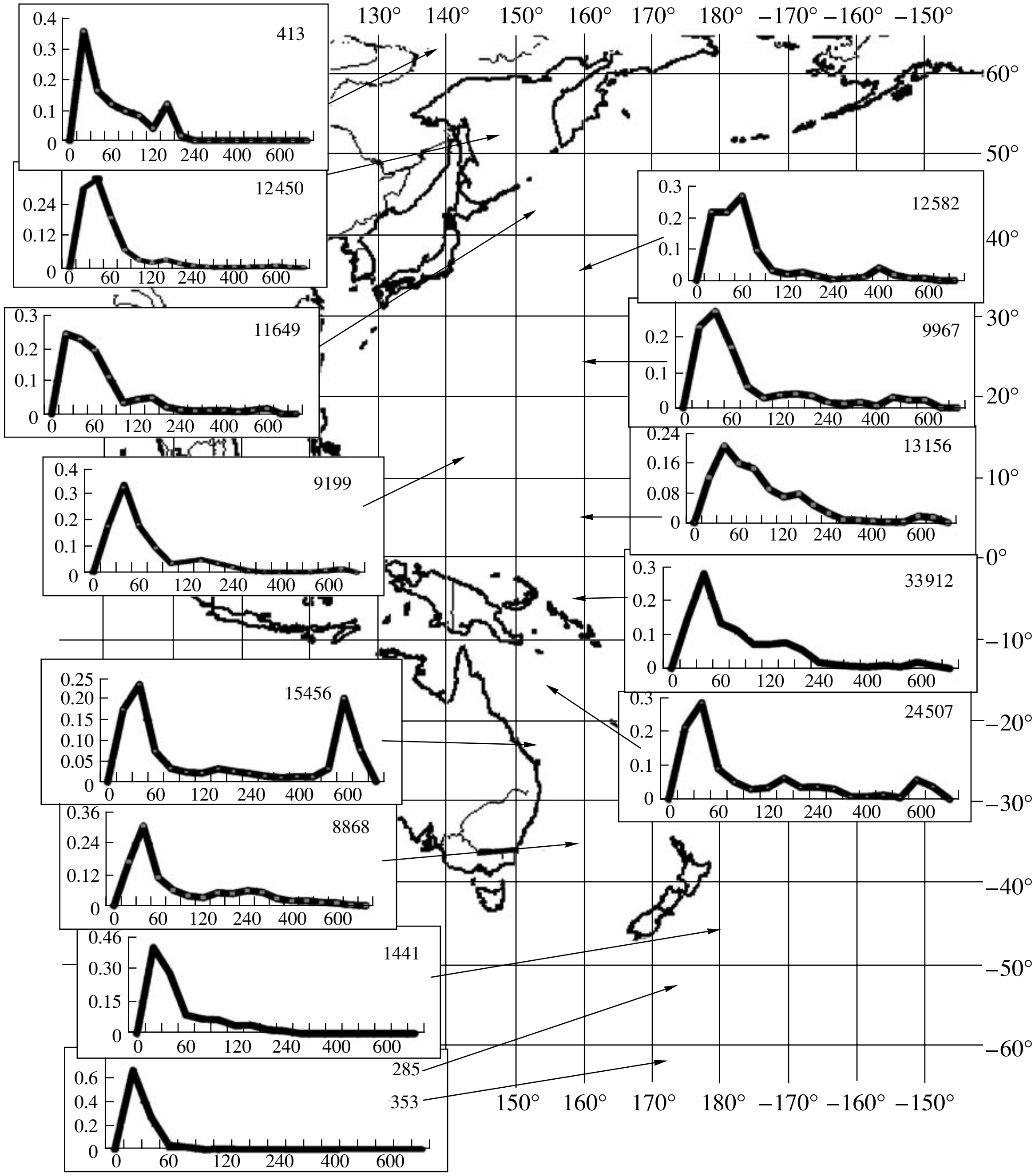

Fig. 2. Depth distribution of the relative share of earthquakes for latitudes between 70° N and 70° S in the western Pacific region. The solid line shows contours of continents and island arcs. Plots demonstrating the distribution of earthquakes are arranged similarly to their counterparts in Fig. 1.

depths $H \leq 10$ km, and their number is insignificant (up to 25 events in each of these latitudinal belts).

The depth distribution of the earthquake foci in all the latitudinal belts is compiled for six magnitude ranges. In high and middle latitudes, the distribution compiled for all the magnitude ranges is practically similar. In latitudinal belts located between 30° S and 30° N, their depth distribution demonstrates insignificant variations for some magnitude ranges, although its patterns remain unchanged.

The analysis of the presented data shows that the foci of practically all the earthquakes (up to 90%) in the high latitudes are localized at depths $H \leq 20$ km. Toward the middle latitudes, the share of events concentrated at depths of 20 km < $H \leq 60$ km increases. In the latitudinal belts located close to the equator (30° S to 30° N), earthquake foci are frequently located at

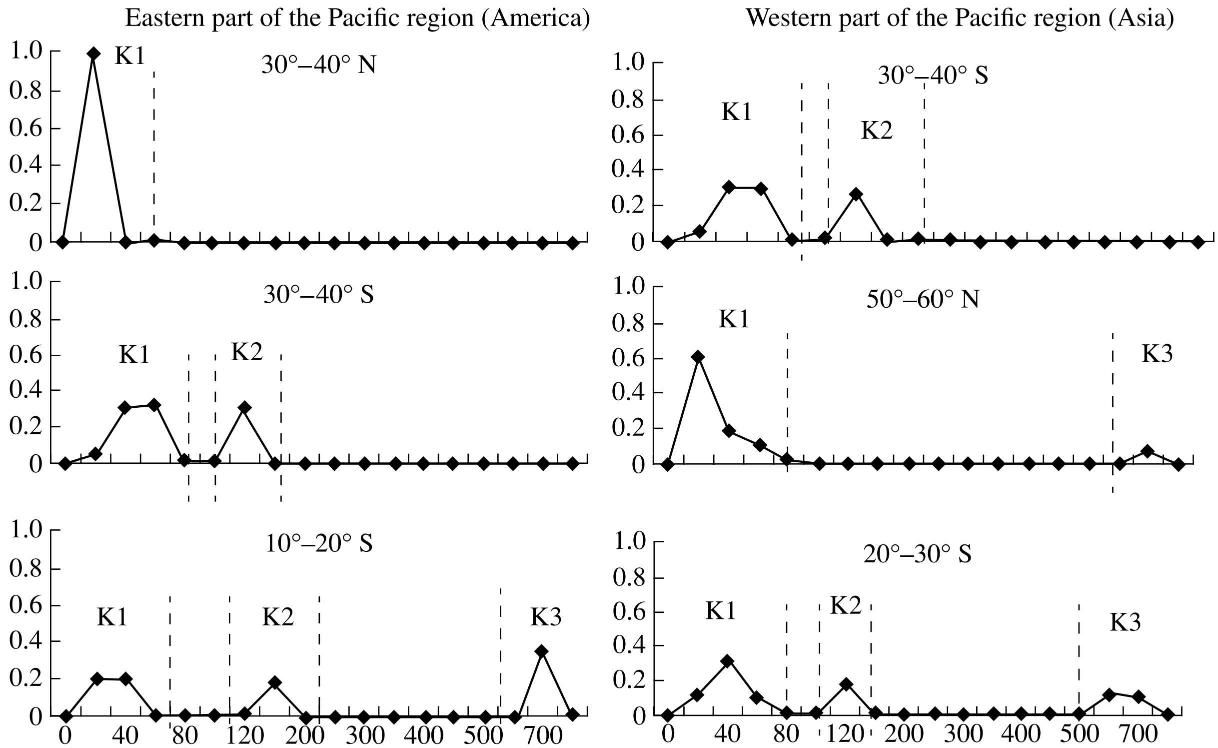

Fig. 3. Depth distribution of energy released by earthquakes in six latitudinal belts. Depths (km) and normalized energy values are shown along the abscissa and ordinate, respectively. Each plot also shows defined clusters and their boundaries.

depths of 100 km < $H \leq 240$ km or, at some latitudes, $H \geq 500$ km. The maximal number of events with foci at $H \geq 500$ km is characteristic of the latitudinal belt between 30° and 20° S both in the western and eastern parts of the Pacific region.

For each latitudinal belt, energy released during earthquakes was also determined with the simultaneous analysis of its depth distribution in every latitudinal belt under consideration. The vertical energy distribution was normalized in each belt to the sum energy released in the particular belt.

It appeared that the entire study depth interval comprises three groups (clusters) of events with relatively distinct boundaries. The first (K1), second (K2), and third (K3) clusters unite events with foci located at depths of 0–80, 120–240, and 500–700 km, respectively. Figure 3 demonstrates examples of the vertical energy distribution with defined clusters.

The table presents the data on the successive vertical energy distribution for all the latitudinal belts in the western and eastern parts of the Pacific region. The 5th and 9th columns show the threshold depth, below which only 5% of earthquake foci are registered in each latitudinal belt. It is seen that in high and middle latitudes (between 90° and 50°), all energy in both the Northern and Southern hemispheres is released by earthquakes of the first cluster (K1). Beginning from latitudes of 30°–40°, the share of deeper events belonging to the second cluster (K2) increases to yield up to 30% of the energy released in this belt, while the relative share of energy released by earthquakes belonging to the first cluster (K1) decreases. At latitudes between 20° and 30°, the role of events belonging to the third cluster (K3) becomes notable. They yield usually approximately 10–12% of released energy in this belt. The latitudinal belts between 10° and 30° in both hemispheres are marked by a jump in the relative share of energy released by these earthquakes up to 41%. It is remarkable that the cluster K1 in high latitudes is characteristic of depths of 0–20 km. In sum, events of all the clusters yield >95% of energy released in the belt under consideration (98.6% on average), while other earthquakes release an insignificant share of energy averaging 1.4%.

It should be remembered that the percentages indicated the table characterize particular latitudinal belts. The global energy distribution through latitudinal belts (as well as the normalized distribution of the number of seismic events) is characterized by distinct bimodal patterns with close-to-zero values at near-polar latitudes, maximums between 30° and 50°, and a local minimum near the equator. Therefore, the sum energy released even at latitudes between 60° and 70° is 3–4 orders of magnitude lower as compared with that released at latitudes of 10°–20°.

Thus, the analysis of the depth distribution of earthquakes and their energy performed for 18 latitudinal

The depth distribution of released energy (relative to the sum energy released in the particular latitudinal belt) in 18 latitudinal belts of the Pacific region obtained for depths: 10–80 km (K1), 120–240 km (K2), and 500–700 km (K3)

Latitudinal belt	Western part of the Pacific region (Asia)				Eastern part of the Pacific region (America)			
	energy distribution, %			threshold depth, km	energy distribution, %			threshold depth, km
	K1	K2	K3		K1	K2	K3	
1	2	3	4	5	6	7	8	9
80°–90° S	–	–	–	20	–	–	–	–
70°–80° S	100	–	–	40	99.63***	–	–	40
60°–70° S	99.7	–	–	40	99.96***	–	–	40
50°–60° S	99.9	–	–	40	99.99	–	–	40
40°–50° S	99	–	–	160	99.29	–	–	60
30°–40° S	67	30.8*	–	450	68.6	31.0	–	160
20°–30° S	55	19.0*	22.6	700	56.2	27.4	14	240
10°–20° S	67	21.2	10	700	42.9	21	35.9	200
0°–10° S	79.8	15.0	1	300	11.0	47.3	41.4	200
0°–10° N	68	27.7*	0.8	300	99.2	–	–	120
10°–20° N	96	2.8	1	240	34.6	64.8	–	160
20°–30° N	84	13.4	–	450	98.7	–	–	80
30°–40° N	85	–	12.4**	400	99.9***	–	–	40
40°–50° N	82.7	6.25*	10.5	300	53.1	46.2	–	40
50°–60° N	91	–	7.6	160	99.9***	–	–	40
60°–70° N	97.8	–	–	160	99.9***	–	–	40
70°–80° N	100	–	–	40	–	–	–	–
80°–90° N	100	–	–	20	–	–	–	–

Note: (–) indicates the absence of the corresponding cluster. The 5th and 9th columns show the boundary depth for each latitudinal belt, below which seismic events constitute 5% (or lower) of their sum quantity in the particular latitudinal belt. (*) and (**) indicate that cluster K2 in the latitudinal belt under consideration characterizes depths of 120–160 and 400–500 km, respectively; (***) means that cluster K1 corresponds to depths of 0–40 km in the latitudinal belt under consideration.

belts of the Pacific region revealed a global regularity in the vertical–latitudinal distribution of earthquake foci.

Of interest is the geophysical aspect of the empirically defined regularity (latitudinal dependence of the number of earthquakes, their sum energy, and threshold hypocenter depths). As is known, the earthquake epicenters are largely located along boundaries between lithospheric plates. Some researchers identify these boundaries with surface boundaries between neighboring convective cells. The contribution of tidal processes in the formation of such boundaries, in addition to convective processes, cannot be ruled out as well. The energy maximums of the tidal effect are located in middle latitudes (±45°). These latitudes correspond to defined belts with local maximums of seismic activity for shallow (crustal) earthquakes. In addition, according to the theory of the Earth's figure, zones with maximal values of the inertia moment gradient along the latitude are located at 30°–35° in each hemisphere. These zones coincide to deep zones of seismic activity, which allow the inference that convective and tidal processes play an important role in the formation of crustal earthquakes and the probable contribution of the Earth's rotation to deep seismicity.

The established trend of variations in the depth distribution of seismic events and their energy in different latitudinal belts provides a basis for the future study of the earthquake generation mechanism. It is clear that nonlinear effects related to the rotation of the Earth as a viscous-elastic body [1] and detailed analysis of tidal processes [5] may yield new data for explaining the established regularities.

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