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GEOPHYSICS

Ring Seismicity in Different Depth Ranges before Large and Great Earthquakes in Subduction Zones

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Characteristics of seismicity before eight strong and very strong shallow earthquakes in the subduction regions (in Sumatra, New Britannia, Mexico, Hokkaido, and Peru) are studied. The data on earthquakes are considered in two depth ranges: 0–33 and 34–70 km. It was found that ring structures of seismicity were formed in both ranges before large earthquakes. The epicenters of the main events were located near the regions of crossing or maximum closeness of shallow and deep rings. An interpretation of the revealed effects is offered related to the migration of deep fluids.

Ring seismicity structures appear frequently before many large earthquakes in different regions of the world [1, 2]. It is worth noting that usually no depth differentiation of seismicity was performed in the analysis of ring structures in the subduction zones so far (for example the author of [1] considered all earthquakes with depths up to 80 km). In this work, we present a detailed study of ring seismicity in the source regions of strong and great earthquakes in the subduction zones with hypocenter depths shallower than 40 km (Table 1).

We considered seismicity characteristics for different intervals of Benioff zones in the depth ranges of 0–33 and 34–70 km. We analyzed the data of earthquakes that occurred in the vicinity of future source zones with magnitudes $M \geq M_{n1}$ and $M \geq M_{n2}$, where M_{n1} varied from 5.0 to 5.5 for the first depth ranges and M_{n2} varied from 4.5 to 5.5 for the second depth ranges (Table 1). We selected the time interval usually from January 1, 1973, to the day prior to the main event. We processed the data on seismicity before eight strong and great earthquakes with M_w = 7.6–9.0 in the regions of Sumatra, New Britannia, Mexico, Hokkaido, and Peru (Table 1).

The maximum amount of data was obtained in the Sumatra region. Figure 1 presents seismicity maps in the source region of the Sumatra earthquake of June 4, 2000. We selected the earthquakes in the period from January 1, 1973, to June 3, 2000. One can see that shal-

Characteristics of ring seismicity before large earthquakes

Date	Coordinates		h, km	M_w	L, km	M_{n1}	l, km	M_{n2}	Region
June 4, 2000	4.72° S	102.09° E	7	7.9	150	5.5	60	5.5	Sumatra
November 17, 2000	5.50 S	151.78 E	37	7.8	110	5.5	45	5.5	New Britannia
January 22, 2003	18.77 N	104.10 W	9	7.6	200	5.0	110	4.5	Mexico
September 25, 2003	41.82 N	143.91 E	13	8.3	85	5.0	40	5.0	Hokkaido
December 26, 2004	3.30 N	95.98 E	30	9.0	700	5.5	200	5.5	Sumatra
March 28, 2005	2.09 N	97.11 E	21	8.6	190	5.0	190	5.0	Sumatra
August 15, 2007	13.39 S	76.60 W	39	8.0	170	5.0	65	5.0	Peru
September 12, 2007	4.44 S	101.37 E	34	8.5	290	5.0	100	5.0	Sumatra

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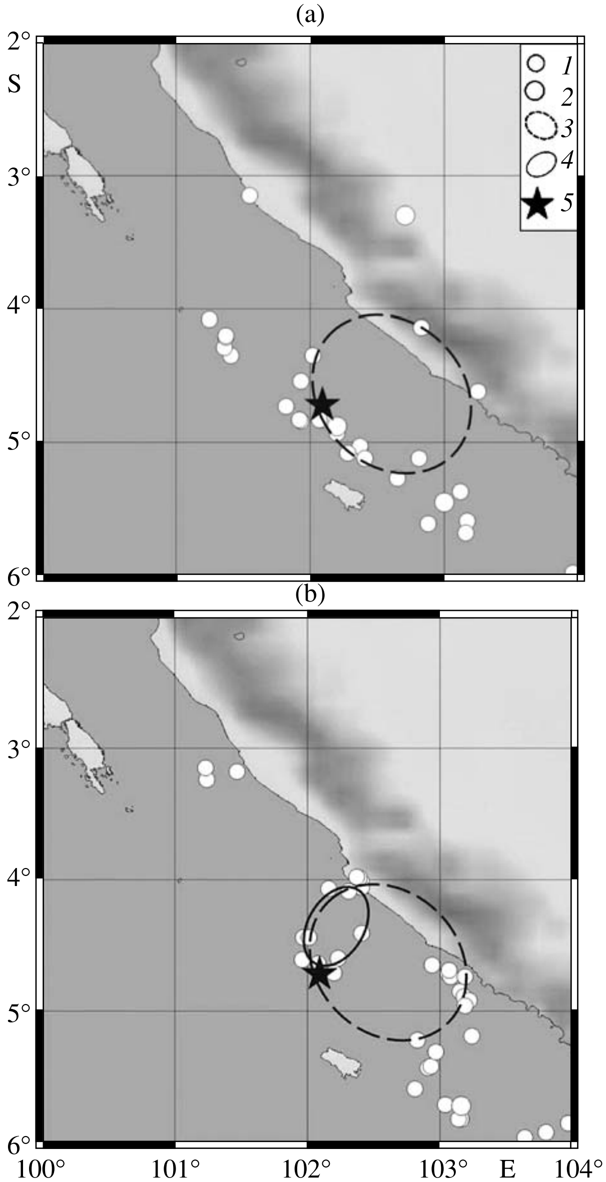

Fig. 1. Ring seismicity before the Sumatra earthquake of June 4, 2000. Here and in Fig. 2, (a) depths 0–33 km; (b) depths 34–70 km; (*1, 2*) epicenters of large earthquakes with $5.5 \le M < 6.5$ (*1*) and $M \ge 6.5$ (*2*); (*3*) shallow ring; (*4*) deep ring; (*5*) epicenters of earthquakes on June 4, 2000 (Fig. 1), and November 17, 2000 (Fig. 2).

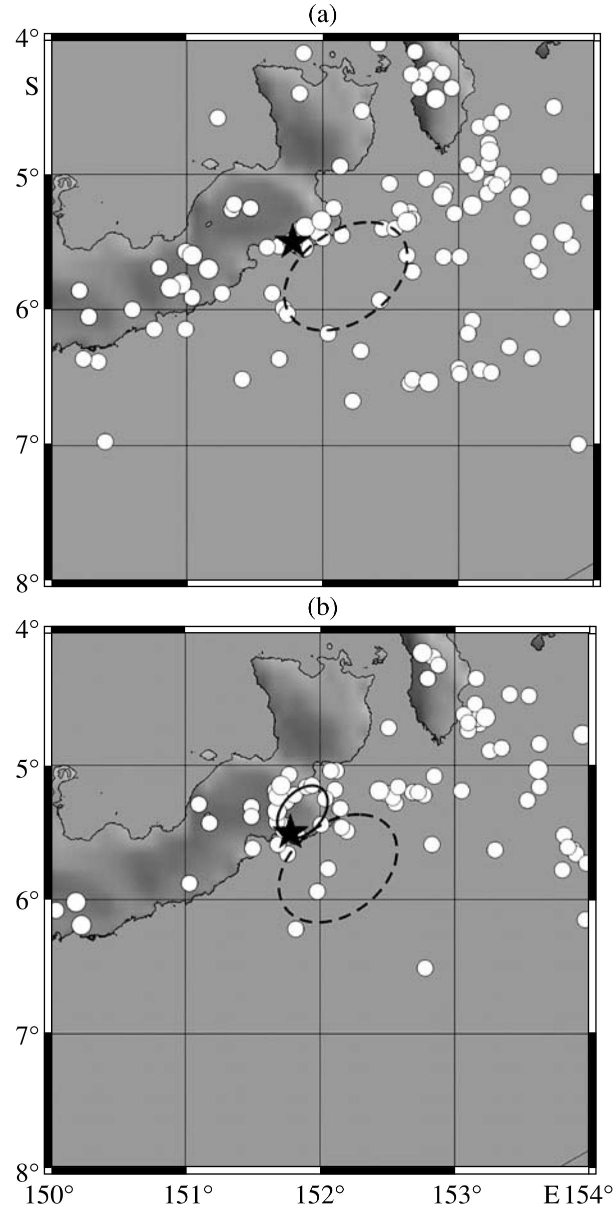

Fig. 2. Ring seismicity before the earthquake in the region of New Britannia on November 17, 2000.

low events ($h \le 33$ km) formed a ring structure with the length of a large axis $L \sim 150$ km extended along the coastline. Earthquakes with source depths h = 34–70 km formed a ring of a smaller size ($l \sim 60$ km) located in the northwestern margin of the shallow ring. We note that the epicenter of the main event was located at a distance of about 10 km from the southern region of the intersection of the ring structures. For convenience, we shall call the rings of the first type shallow rings and the rings of the second type deep rings.

The earthquake of November 17, 2000, occurred south of New Britannia Island. Seismicity analysis shows that in the period from January 1, 1973, to November 16, 2000, earthquakes with $M \ge 5.5$ formed a shallow and a deep ring in this region with the sizes of the larger axes ~110 and 45 km, respectively (Fig. 2). In this case, the deep ring was located to the northwest of the shallow one, while the epicenter of the strong earthquake of November 17, 2000, was located near the region of the contact between the two rings.

Shallow and deep seismicity rings were also formed in the source regions of the other six large earthquakes (Table 1), which intersect or almost contact each other (the distances between nonintersecting rings did not exceed 10–15 km). It is interesting that in some cases, shallow rings (first of all related to the earthquake of

December 26, 2004) crossed the deep trenches, while the deep rings were always located between the trenches and volcano chains. It is important to note that, in all cases, the epicenters of the main events were located near the intersection regions or maximum closeness of the seismicity rings. Table 1 summarizes the data on the sizes of shallow and deep rings in the regions considered. It is seen that the values of L vary from 85 to 700 km, while the values of l vary within 40–200 km. The ratios $\frac{L}{l}$ vary in the range from 1.0 to 3.5. On average, $\frac{L}{l} \sim 2.4$.

The data indicate that ring seismicity structures are formed in the subduction zones over a few decades before large and great shallow earthquakes. It is significant that such structures are formed in two depth ranges. In the regions considered here, the thickness of the continental crust is, on average, about 30 km [3, 4]; therefore, in the first approximation we can consider that shallow rings are formed in the crust, while the deep ones are formed in the uppermost mantle (mainly in the mantle wedge).

The authors of [5, 6] demonstrated that contours of shallow rings correspond to high attenuation of short-period shear waves, while relatively low attenuation is observed inside the rings. Lack of modern volcanism in the regions of rings indicates that they are not related to the presence of partially melted rocks. Thus, the most natural explanation of the revealed effects is related to the migration of deep fluids. It is likely that shallow rings surround relatively rigid blocks and ascent of fluids occurs at their boundaries [5, 6]. One can suppose that a similar situation takes place also in the regions of deep rings. Most likely, seismicity at the contours of deep rings is caused by the fact that the rocks of the oceanic crust and uppermost mantle become more brittle as a result of dehydration processes [7, 8].

It was shown earlier that in the case of the existence of a two-phase layer with the related network of cracks and pores filled with fluid, concentration of stresses is observed at the roof of the layer [9]. The value of excessive stresses increases with the thickness of the layer. In the cases considered here, the maximum stresses should be observed also in the areas of the boundaries between the fluid networks corresponding to the shallow and deep rings and the maximum thickness of the two-phase layer is observed here. This makes possible to explain why the epicenters of the strongest earthquakes are confined to the intersection regions or maximum closeness between the shallow and deep rings. In the cases when the rings do not intersect, fluid networks can merge in the lower crust, which in seismically active regions is usually characterized by high electric conductivity and strong attenuation of shear waves related to the presence of fluids [10, 11]. The new data also agree with the earlier found effect of mantle fluid ascent to the Earth's crust after large and great earthquakes [12–14].

The new results are important to solve the problems of seismic zoning and middle-term earthquake forecasting. In future research and detection of the ring structures in the regions of earthquake preparation, it is reasonable to use characteristics of the attenuation field of short-period shear waves, which are most sensitive to the presence of the liquid phase [5, 6]. This will allow us to map the seismically active regions more reliably because use of only the seismicity data can result in distinguishing false ring structures as well as false quitness zones [15].

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