ISSN 1028-334X, Doklady Earth Sciences, 2008, Vol. 423, No. 8, pp. 1257–1261. © Pleiades Publishing, Ltd., 2008.
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GEOPHYSICS

Characteristics of the Seismicity and Absorption Field of *S*-Waves in the Source Region of the Sumatra Earthquake of December 26, 2004

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Presented by Academician V.N. Strakhov March 17, 2008

Received March 18, 2008

DOI: 10.1134/S1028334X08080163

Characteristics of the seismicity and absorption field of short-period transversal waves are studied in the source region of the Sumatra earthquake of December 26, 2004 ($M_w = 9.0$). A ring structure was distinguished west of Sumatra Island, which was formed by the epicenters of shallow earthquakes with $M \geq 5.5$ that occurred in the period from January 1, 1969, to December 25, 2004, in the region between 1° and 7° N. The majority of relatively strong ($M \geq 5.5$) deep aftershocks of the Sumatra earthquake was confined to the boundaries of this structure. Mapping of the absorption field in the source zone and nearby vicinities was made on the basis of records at the PSI station at epicentral distances ~250–700 km. We used the method based on the analysis of the attenuation rate of the early coda Sn and Lg. This method allows us to distinguish horizontal inhomogeneities of the absorption field in the upper mantle. Two linear bands of increased absorption are confined to the eastern part of the ring structure. Low and moderate absorptions are observed within the structure. The absence of modern volcanism in the region of the ring structure indicates that the revealed effects are related to the high content of free fluids in the mantle cline and descending plate. This conclusion agrees with the fluid ascent from the upper parts of the mantle after strong and very strong earthquakes, which was found earlier.

It is known that before many strong earthquakes seismic rings are formed in different regions of the world, which surround regions of relative calmness [1–3]. Research into the fine structure of the Earth's crust and upper parts of the mantle is important for investigation into the nature of such rings in the regions where they appear. First of all, it is important to distinguish zones with a relatively high fluid content. (According to data collected in the last years, free fluids in the Earth's crust and upper mantle play an important role in the period before strong earthquakes [4–6].) One of the most important parameters, which allows us to distinguish the zones saturated with fluids, is absorption of transversal waves that are sensitive to the presence of the liquid phase [7, 8]. In this work, we compare the characteristics of seismicity and inhomogeneities of the absorption field of *S*-waves in the southern part of the source zone of the Sumatra earthquake on December 26, 2004 ($M_w = 9.0$), which caused a strong tsunami in the Indian Ocean.

Figure 1 shows the epicenters of shallow ($h \leq 33$ km), relatively strong ($M \geq 5.5$) earthquakes, which occurred in the study region during the period from January 1, 1969, to December 25, 2004. It is seen that, in the region between 1° and 7° N, the epicenters form a ring structure extended in the northwesterly direction with a large axis ~700 km long. The epicenter of the Sumatra earthquake was located near the eastern edge of the ring. It is important that the dominating part of relatively weak ($M \geq 5.5$) aftershocks of this event is located at the boundary of this ring structure (Fig. 1). The depths of these aftershocks recorded before March 28, 2005, when another strong earthquake with $M_w = 8.3$ occurred, are 34–60 km.

We used a method based on analysis of the attenuation rate of amplitudes in early coda Sn and Lg [8] to study the inhomogeneities of the absorption field of *S*-waves in the upper parts of the mantle in the study region. Previously, it has been shown that coda Sn and

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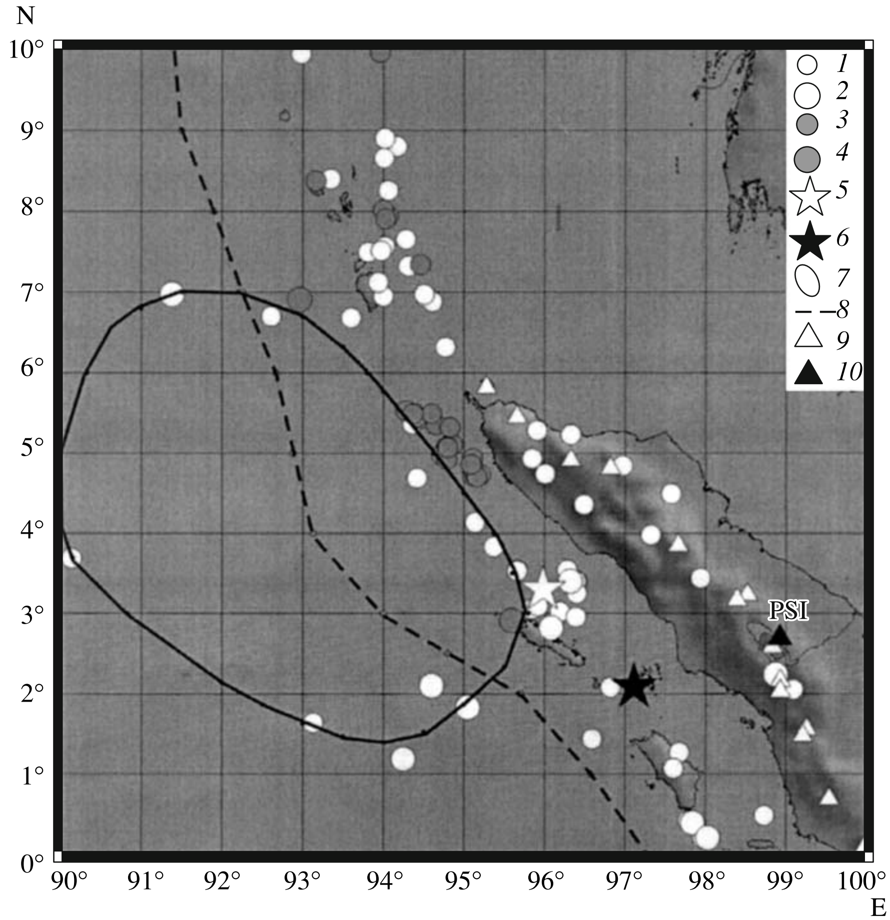

Fig. 1. Characteristics of seismicity in the source region of the Sumatra earthquake. (*1*, *2*) earthquakes in the period from January 1, 1969, to December 25, 2004; depths 0–33 km; (*3*, *4*) earthquakes in the period from December 26, 2004, to March 27, 2005; depths 34–60. (*1*, *3*) $5.5 \le M < 6.5$; (*2, 4*) $M > 6.5$; (*5, 6*) epicenters of earthquakes on December 26, 2004, and March 28, 2005 ($M_w = 8.3$); (*7*) seismic ring before Sumatra earthquake on December 26, 2004; (*8*) axis of the deep trench; (*9*) volcanoes; (*10*) seismic station.

Lg at frequencies close to 1 Hz is formed mainly by transversal waves reflected from numerous subhorizontal boundaries in the upper mantle [7, 9]. When time t from the beginning of wave emission increases, the waves in the coda cross the upper parts of the mantle in the source region ever more steeply. Horizontal inhomogeneities of the absorption field in the upper mantle at depths approximately up to 200 km can be distinguished from the attenuation rate of amplitudes in the early coda [8]. We also determined the efficient Q-factor in the interval with a duration of 70 s immediately after the Lg group. We used the relation

$$A_c(t) \sim \exp\left(-\frac{\pi t}{Q_s T}\right)\frac{1}{t},$$

where T is the period of oscillations. Narrow band frequency filtration was used in the analysis of the records (we used a filter with a central frequency of 1.25 Hz and a band-pass with a width of 2/3 of an octave [7, 8]).

We analyzed records of shallow earthquakes ($h \le 30$ km) obtained at station PSI (mainly in 2004–2006) at epicentral distances ~250–700 km. (We note that the thickness of the continental crust in the region of Sumatra Island is approximately 30 km [10].) A total of more than 200 records of events with magnitudes $M \le 5.5$ were processed.

Figure 2 shows examples of common envelope curves for different regions of the source zone and its vicinities (for the profile crossing the trench and volcanic front). It is seen that the rate of amplitude attenuation in the early coda varies strongly. In this case a flat slope in the initial part of the coda corresponds to the regions of the deep trench and regions located east of the volcanic front. A much steeper slope is observed in the volcanic region. It is worth noting that the strongest attenuation of the coda amplitudes for the profile corresponds to the region west of Sumatra Island at distances ~180 km from the trench.

Figure 3 shows a chart of the absorption field in the study region. The entire range of Q_s variation is divided into three levels corresponding to high (Q_s = 150–220), intermediate (230–330), and low (370–1000) absorption. Each sign is related to the center of a small zone (with a size usually of a few tens of kilometers) in which envelope coda curves were plotted; hence, averaging of data was performed. It is seen that two linear bands of strong absorption extending in the northwesterly and north-northeasterly directions are distinguished in the region between the trench and Sumatra Island. The epicenter of the Sumatra earthquake is located in the region where these bands cross. It is worth noting that the eastern part of the ring of shallow seismicity is confined to the northwestern and southwestern regions of these bands. It is interesting that the southwestern edge of the southern band of strong absorption crosses the trench. Absorption sharply decreases in the northwesterly direction from this edge. Low and intermediate absorption is generally observed within the seismic ring. A narrow zone of intermediate values of Q_s is distinguished at the western boundary of Sumatra Island. East of this zone, in the volcanic region, the absorption field is strongly inhomogeneous. We note that low absorption is observed in the region of the northernmost Pleistocene volcano Pulu-Veh, while strong and partly intermediate absorption corresponds to the young southern volcanoes Selavaikh Agam, Geredong, and Peetsagu, which erupted in the 19th and 20th centuries. The values of Q_s sharply increase east of the volcanic front (between 97° and 98° E).

Figure 4 shows the dependence of the effective Q-factor on the distance for the profile normal to the trench (Fig. 3). The values of Q_s generally decrease from the trench to the volcanic front. A clearly seen anomaly of Q_s located at the crossing of the strong absorption band (at distances of ~130–200 km from the trench) is distinguished over this background. On average, the values of Q_s are generally even lower here than in the volcanic region.

The data evidence that high absorption of S-waves in the upper parts of the mantle corresponds to the eastern and southeastern boundaries of the seismic ring, which was pronounced before the Sumatra earthquake. The absence of modern volcanism in this region evidences that this effect is related to the high content of free fluids in the mantle cline and descending plate. This conclusion is confirmed by the fact that the majority of strong and relatively deep aftershocks are confined to the seismic ring formed before the Sumatra earthquake. There are grounds to consider that they are related to the brittle behavior of the upper mantle material as a result of dehydration processes [5, 6].

Previously, it was shown that ascent of mantle fluids into the Earth's crust is observed after strong and very strong earthquakes in different regions of the Earth. The intensity of this process depends strongly on the source mechanism [8, 11]. We can assume that this effect, along with the high content of mantle fluids in the seismic ring before the Sumatra earthquake revealed in this

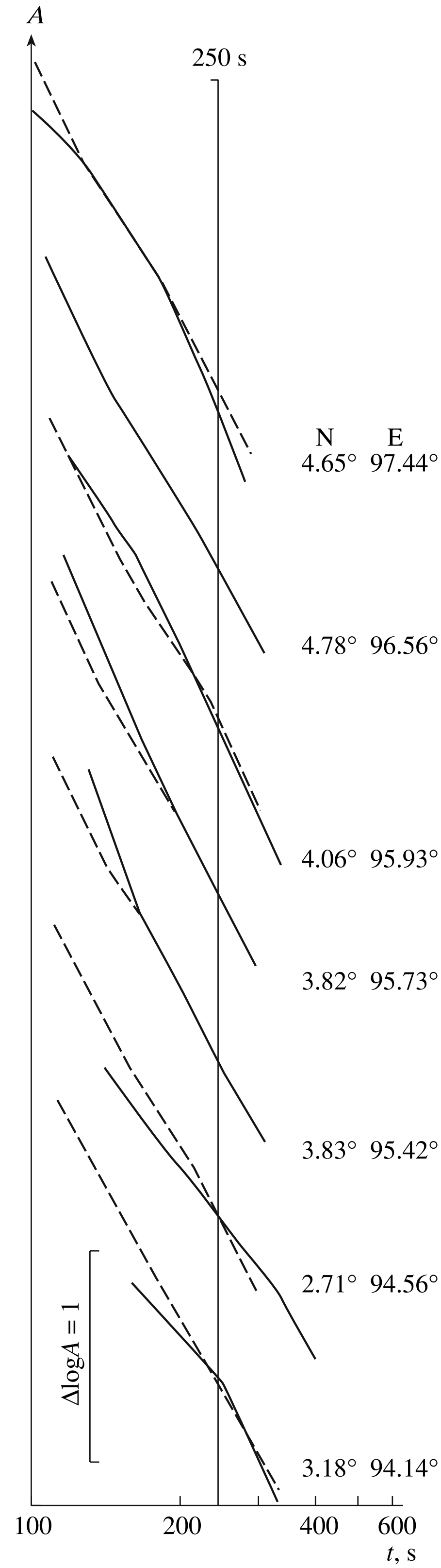

Fig. 2. Envelope codas for different regions of the source zone and its close vicinities. The coordinates of centers of regions are given for which common envelope curves were plotted. The dashed line shows the envelope curve for the region of the volcanic front.

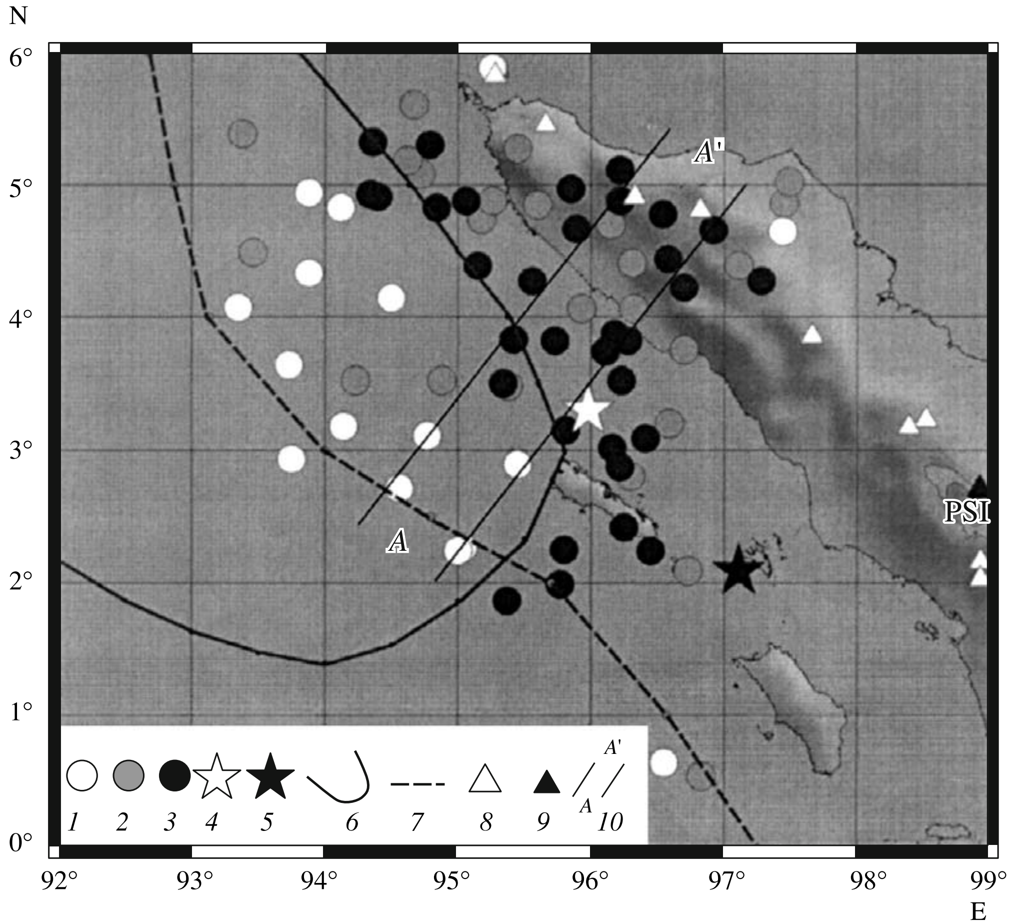

Fig. 3. Inhomogeneities in the absorption field of transversal waves in the source region of the Sumatra earthquake. Absorption: (*1*) low; (*2*) intermediate; (*3*) high; (*4, 5*) epicenters of earthquakes on December 26, 2004, and March 28, 2005, respectively; (*6*) seismic ring before the earthquake on December 26, 2004; (*7*) axis of the deep trench; (*8*) volcanoes; (*9*) seismic station; (*10*) profile up to which we consider the dependence of the effective *Q*-factor as a function to the trench.

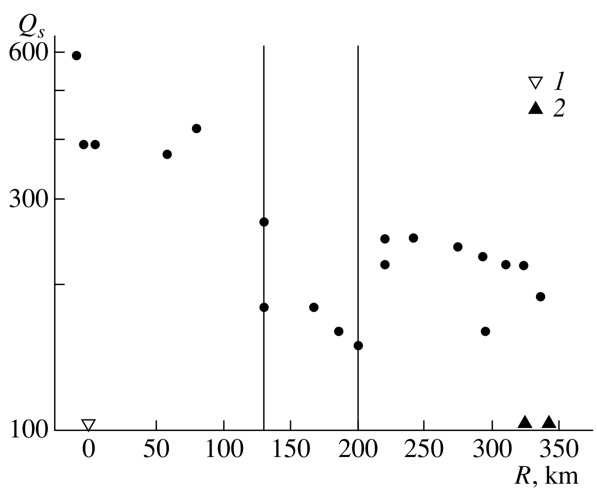

Fig. 4. Dependence of Q_s on the distance to the trench for profile *A–A'* (Fig. 3); (*1*) axis of the deep trench; (*2*) volcanoes; vertical lines denote the border of the strong absorption band.

research, is a reflection of self-organization of geodynamic processes [12] in the Earth's crust and upper mantle, which finally lead to a decrease in the potential energy of the Earth.

ACKNOWLEDGMENTS

The authors thank IRIS DMC for the digital data of the PSI station [13].

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