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GEOPHYSICS

Heterogeneities in the Absorption Field of Short-Period *S* Waves in the Lithosphere of Tien Shan and Dzungaria with Their Relation to Seismicity

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The mapping for the absorption field of transversal waves in the lithosphere of Tien Shan and Dzungaria is carried out. The method based on analysis of the ratio between maximal values of amplitudes for *Sn* and *Pn* waves is used. Earthquake records obtained at distances of ~300–1300 km by the MKAR station were processed. It was found that *S* wave absorption in the lithosphere is significantly higher in the northwestern part of the area than in the southeastern one. It is shown that the source zones for strong earthquakes with $M \geq 7.0$ that occurred in 1978–1992 are characterized by a higher absorption. Areas of higher absorption, where there were no strong earthquakes for the last 130 years, are found. It is supposed that these areas are related to preparation of strong earthquakes.

It is shown in [1–3] that source zones of strong earthquakes in various regions of the world correspond to strong absorption anomalies for short-period transversal waves in the lower crust and upper mantle. It allows us to use methods of absorption field mapping for detection of source zones of strong earthquakes being prepared. In the present work, we examined characteristics of the absorption field for *S* waves in the areas of Tien Shan and Dzungaria for this purpose.

In the work, the method used is based on analysis of the ratios of maximal amplitudes for the *Sn* and *Pn* wave ($\log\frac{A_{\mathrm{Sn}}}{A_{\mathrm{Pn}}}$) parameter, which we will call *Sn*/*Pn*). It has been stated before that the *Sn* group is formed by transversal waves reflected from numerous subhorizontal boundaries in the upper mantle [4]. It had been shown through the analysis of records for *S* waves from near-field earthquakes that, in the Tien Shan area, the highest absorption of short-period *S* waves is usually observed in the lower crust and the upper mantle, in the layer located in the range of ~30–70 km depth [5] (average thickness of the crust in the Tien Shan area is ~50 km [5]). Estimates show that the deflection of rays in this layer for the *Sn* group, with respect to sources located at zero depth, is ~30–100 km. In this case, the main absorption of S waves is in the uppermost mantle. The *Sn*/*Pn* parameter was used for normalizing, because *Sn* and *Pn* waves are propagated in close paths. Absorption depends substantially on the frequency, so, narrow-band filtering was used in record analysis (namely, a filter with a central frequency of 1.25 Hz and bandpass of 2/3 octaves was used [6]).

Mapping of the absorption field in the studied area was carried out by records of local earthquakes, obtained at the MKAR station at epicentral distances of ~300–1300 km in, mostly, 2003–2009 (Fig. 1). In total, 450 records were processed for the earthquakes in the region within 39°–45° N and 70°–83° E.

In Fig. 2 there are examples of seismograms for earthquakes from various areas, obtained at approximately equal epicentral distances. It is seen that the shapes of the records are quite different. For the area of the Terskei-Alatau and Kokshaal ranges, the *Lg* group dominated, amplitudes for *Sn* waves are sufficiently higher than for the *Pn* group. In the eastern part of the Kyrgyz Ala Too range, the level of the *Pn* group is almost equal to the one of the *Lg* group. It should be noted that there is a rapid attenuation of amplitudes in the code of the *Pn* wave (contrary to two other records).

In Fig. 3, the dependence for the *Sn*/*Pn* parameter on the epicentral distance is presented. Every single point is the average value for a small area (having linear sizes, usually, of several tens of kilometers). Standard deviations σ for average values are varied from 0.02 to 0.39. Despite data averaging, there is a great dispersion for the *Sn*/*Pn* parameter values (from 0.96 to –0.23). In general, the *Sn*/*Pn* parameter values

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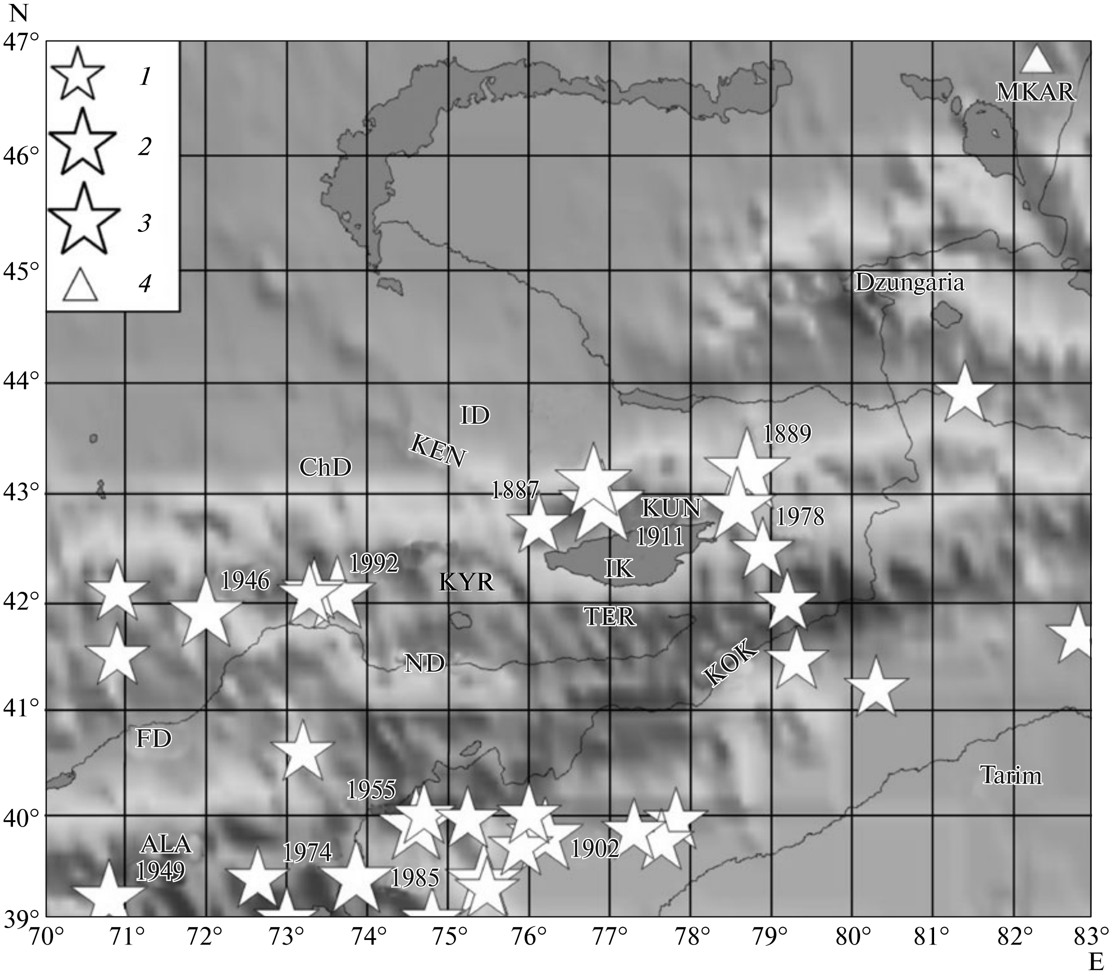

Fig. 1. The map for the study area. Epicenters of strong earthquakes (from 1887): (*1*) $6.5 \le M \le 6.9$; (*2*) $7.0 \le M \le 8.0$; (*3*) $M > 8.0$ (years of events with $M \le 7.0$ are displayed); (*4*) seismic station. The main depressions marked are Chuya (ChD), Ili (ID), Naryn (ND), Fergana (FD), and Issyk-Kul (IK); the main ranges marked are Kendyktas (KEN), Kyrgyz Ala Too (KYR), Kungei-Alatau (KUN), Terskei-Alatau (TER), Alai (ALA), and Kokshaal (KOK).

decrease at Δ distance. The equation for linear regression is

$$\mathrm{Sn/Pn} = 0.84\text{–}0.00067\Delta\ (\mathrm{km}). \qquad (1)$$

In Fig. 4, the map of the absorption field for *S* waves in the upper mantle of Tien Shan and Dzungaria is presented. In the map, the *Sn*/*Pn* parameter values, with correction for the epicentral distance taken into account differing from the average dependence (1), are presented. All the *Sn*/*Pn* parameter values were subdivided into three groups corresponding to lower ($Sn/Pn = 0.16$–0.53), intermediate ($-0.15 \le Sn/Pn \le 0.15$), and higher (*Sn*/*Pn* is from -0.53 to -0.16) absorption. It follows from the figure that the absorption field in the Tien Shan and Dzungaria areas is characterized by a great heterogeneity. In general, in the northwestern part of the studied area, absorption is substantially stronger than in the southeastern area. A distinctive anomaly is in the nearby Kyrgyz Ala Too range and adjacent parts of the Chuya and Ili depressions (between 73° and 76.5° E). Let us note that it corresponds to the space between source zones of the 1911 Kemin ($M = 8.2$) and 1992 Susamyr ($M = 7.3$) earthquakes. Smaller size anomalies are detected in the boundary of Dzungaria and the Ili depression (between 77° and 78° E), near the Kokshaal range (between 80° and 81° E), and in the boundary of South Tien Shan and Pamir (between 71.5° and 73° E) as well. Moreover, small areas of the *Sn*/*Pn* low values correspond to source zones of two strong earthquakes, namely, the 1978 Zhalanash–Tyup ($M = 7.0$) and Susamyr ones.

It should be noted that, in general, the zones of strong absorption form two discrete stripes: the one is wider and traced for ~800 km distance, from the Alai range to Dzungaria; the other is relatively narrow and of ~600 km length, oriented in the west-northwest direction, and traced from the Kokshaal range to the Ili depression. There are great gaps in the stripes: in the area of the Fergana and Naryn depressions in the first one; and gaps related to source zones of the 1887 Ver-

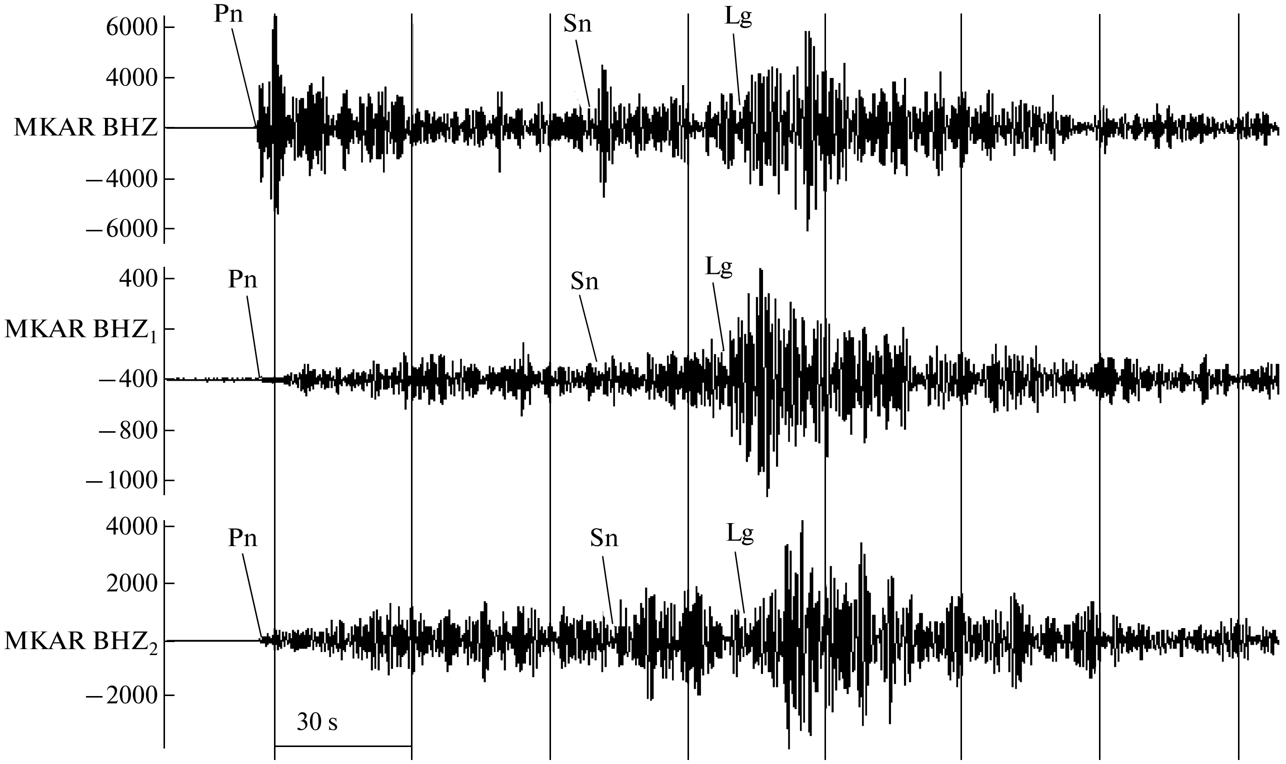

Fig. 2. Examples of earthquake seismograms. The upper path is 42.60° N, 75.40° E, $\Delta = 718$ km; the middle path is 41.75° N, 76.83° E, $\Delta = 710$ km; and the lower path is 40.88° N, 77.88° E, $\Delta = 747$ km. The MKAR station, channel 1.25 Hz, vertical component.

nyi ($M = 7.3$) and 1911 Kemin earthquakes and to the chain of sources, including the 1970 Sarykamysh earthquake ($M = 6.8$) and several weaker events ($M = 6.5$–6.7), in the second one (see Fig. 1). In the zones of these gaps, intermediate and lower absorption is observed. Intermediate absorption also corresponds to source zones of the following earthquakes: 1946 Chatkal ($M = 7.5$), 1949 Khait ($M = 7.4$), and 1985 Kashgar ($M = 7.0$). The greatest square anomaly of weak absorption is detected near the Kokshaal range, in the boundary with the Tarim Basin. It spatially corresponds to the source zones of three strong earthquakes, namely, 1902 Kashgar ($M = 7.8$), 1955 Ulugchat ($M = 7.1$), and 1974 Markansui ($M = 7.3$), as well as several events with $M = 6.5$–6.7 (Fig. 1).

In [7], the dependence of the *Sn*/*Pn* parameter on distance for the profile along the East Tien Shan, between ~80° and 91° E (by the data of the MKAR station located on the northwestern margin of Tien Shan). It follows from [7] that the *Sn*/*Pn* values in East Tien Shan are decreased, on average, by the values from ~0.75 at Δ ~800 km to ~0.3–0.4 at Δ ~1200–1300 km. Comparison to the data obtained in [7] shows that, in general, *S* wave absorption in the upper mantle in the East Tien Shan area is sufficiently higher than in the West Tien Shan area. Comparison to the region seismicity shows that source zones of earthquakes with $M \geq 7.0$, occurring in 1887–1974, and of the 1985 Kashgar earthquake as well, correspond to lower and intermediate absorption. In the zones of the Zhalanash–Tyup and Susamyr earthquakes, relatively

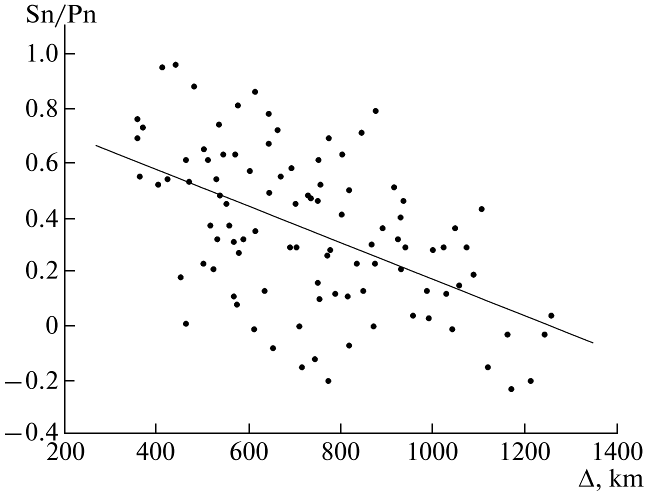

Fig. 3. Dependence of the *Sn*/*Pn* parameter on distance for the areas of Tien Shan and Dzungaria.

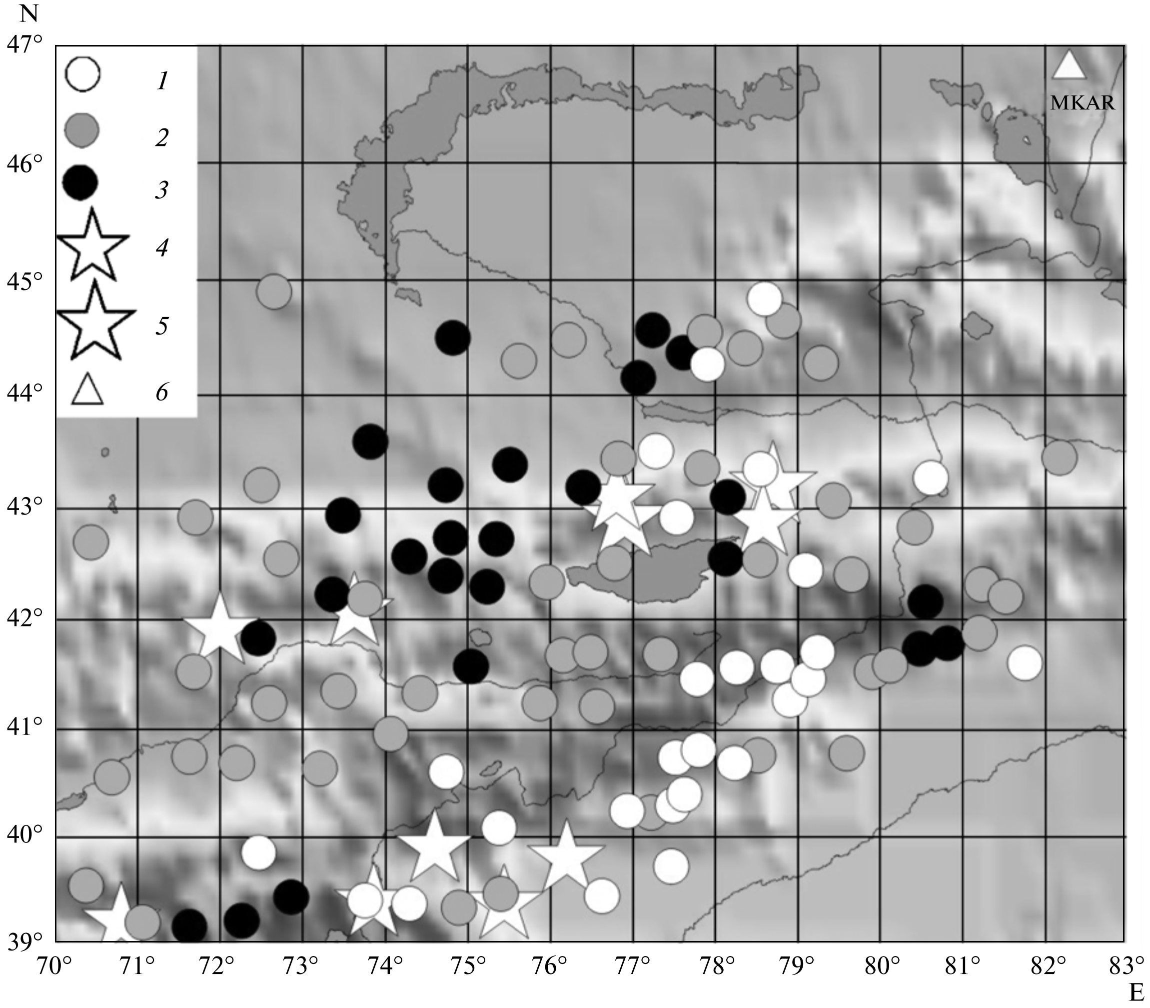

Fig. 4. Heterogeneities in the absorption field for *S* waves in the studied area. Absorption: (*1*) lower; (*2*) intermediate; (*3*) higher. Epicenters of strong earthquakes: (*4*) $7.0 \leq M < 8.0$; (*5*) $M > 8.0$; (*6*) seismic station.

higher absorption is observed approximately 10–30 years after these events. Let us note that, in general, in the southeastern part of the studied area, beginning from 1887, 8 events with $M \geq 7.0$ occurred, including the strongest ones in 1889 ($M = 8.3$), 1902, and 1911, while in the northwestern part only three such events ($M = 7.3$–3.5) occurred.

The obtained results agree with conclusions on the fact that uplift of fluids from the upper mantle to the Earth's crust takes place after sufficiently strong ($M \geq 7.0$) and shallow earthquakes. These conclusions are made on the basis of the seismic [2, 8, 9], geophysical [10], and geochemical [11] data analyzed. This process is implemented for several tens of years, which allows us to explain the existence of anomalies in the zones of the Zhalanash–Tyup and Susamyr earthquakes, and a less distinctive anomaly in the source zone of the 1985 Kashgar earthquake.

Concerning the causes why prolonged stripes have higher absorption and saturated with fluids, in the upper mantle, we propose the following hypothesis. In recent years, the data obtained are evidence for the fact that the fluid field can be substantially reorganized under the effect of shear stresses, and, as a result, the liquid phase, which was initially concentrated as isolated bubbles in corners of grains and forms connecting the network, which were distributed by the sides of grains [12]. This should lead to a gradual formation of fluid "domains," which are vertical channels saturated with liquids [13]. When a "domain" is sufficiently prolonged in the vertical, it can pierce the roof of a two-phase layer and gradually move upwards; first it concentrates in the upper mantle, and then it moves up to the lower crust [13]. The evidence for this hypothesis is that the location of stripes with higher absorption approximately corresponds to the orientation of maximal displacement stresses in the lithosphere of Tien Shan (as is known, this mountain region is under submeridional pressure [5]). Let us note that stripes of higher absorption, which are oriented in a similar way and with which sources of strong earthquakes are related, are found in the West Altai area, which is also a region of predominant submeridional pressure [3].

The appearance of gaps in the stripe of higher absorption in the areas of the Fergana and Naryn depressions can be explained by the relatively low content of free fluids in the lithosphere that disturbs "domain" formation [5, 14]. However, gaps in the second stripe of higher absorption are, probably, related to fluid uplift from the upper mantle resulting in a series of strong and very strong earthquakes at the end of the nineteenth century and in the twentieth century, as well as of some events with $M = 6.5–6.8$ (Fig. 1).

The anomalies of higher absorption, which are not related to the strong earthquakes that occurred in the last 100–300 years, are of the greatest interest. First of all, this concerns the vast zone of Sn/Pn low values in the Kyrgyz Ala Too range and adjacent parts of the Chuya and Ili depressions. Let us note that this zone of higher absorption was detected earlier by analysis of records from deep focus earthquakes in the Hindu Kush, obtained at several tens of seismic stations in the Tien Shan area [14]. Moreover, it reveals characteristics of the S code in records of local earthquakes [5]. The last strong event ($M \sim 6.5$) occurred in this zone (to the east of 74.5° E) in the fifteenth century [15]. All these facts are evidence for the preparation of a strong earthquake here, and this has been said before [14]. Judging by the residual anomalies of higher absorption, which correspond to zones of sufficiently strong earthquakes in the Altai [3] and Tien Shan, one can decide that an earthquake with $M \sim 7.0$ is preparing here. The smaller size of anomalies of higher absorption in the areas of the Kokshaal Range, to the south of Alay Range can also be evidence for the preparation of strong earthquakes. The constant monitoring of various geophysical and geochemical parameters should be made in the areas of the marked anomalies for the purpose of mid- and short-term prognosis of strong seismic events.

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